Section V.

Global Locations And Networking

AUTOMATIC PHOTOMETRIC TELESCOPE SERVICE: AN INDIAN PERSPECTIVE

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INTRODUCTION:

Modern astronomy in India, has been primarily instituted around 1972, with the introduction of the 1.0m class telescope of Carl Zeiss Jena, in Nainital in north India and subsequently in Kavlur, in south India. Most of the professional astronomy has been conducted with these work-horses for the last two or three decades. The concept of a 2.0m class telescope began only in the early eighties, and by the year 1985, the telescope saw the first starlight through it; and at this point of time the idea of "automation" began. And now we have the largest telescope in the country named after its mentor "Vainu Pappy Telescope (VBT)."

The concept of automation began only around the eighties. However the progress was slow due to non-availability of good optical encoders or shaft angle encoders. The effort of automation of telescopes at the commercial level at present does not exist.

The imported telescope is still beyond the reach of amateur astronomers and students. Very few universities and colleges have telescopes, and the ones which are available are either in dilapidated condition or have been left unused for a long time.

At present, there are only three major observatories in the country having telescopes of 0.75m, 1.0m, 1.2m, and 2.34m. These telescopes are at Uttar Pradesh State Observatory (UPSO), in Nainital, the Vainu Pappy Observatory (VBO) in Kavalur, and the Japal-Rangapur Observatory (JRO) in Hyderabad. There has been growing interest in the field of amateur astronomy, primarily due to the growing number of planetaria and the amateur astronomers' associations in various parts of the country.

Automatic Photoelectric Telescopes or (APT) (Genet 1986, Boyd, Genet, and Hall 1986) are the pioneering examples of an APT. The important character of these APT's, is that they make photometric observations completely unattended by human operators. One of the telescopes has been operated in the fully-automatic mode for over three years, and over 500,000 observations have been made in this period and many publications have resulted and a number of new variable stars have been discovered (Boyd, Genet, and Hall 1985 (a) (b). Hall, Kirkpatrick, and Seufert 1986, Hall et al. 1986).

And now another novel concept has originated as Remote-Access Automatic Photometry (RAAP) (Haynes, Genet, Boyd, and Crawford 1986) *i.e.*, the telescope would still operate in the fully automatic mode, and what would be different is that the new observing program for the telescope could be entered by the observer by direct communication with a Remote Access Control Computer (RACC); this in turn would schedule the RAAP to open observing slots for the observer, and keep the data available for the observer by morning and then again by direct communication with RACC down load the data for the observer; which not only reduces considerable cost, but makes the telescope more cost effective and efficient.

The "observer" using RAAP could be located at any distance from the telescope. The observing program for the night would be determined before the night began.

The first effort of automation began at the Nehru Planetarium (NP) with making an indigenous effort for the Nehru Planetarium - Solar Telescope (NP-ST) in 1982. The solar observation of the full solar disc has been conducted since then. The proper motion of the sunspots were also studied and the plans for solar seismograph for use in the global network.

NEHRU PLANETARIUM - SOLAR TELESCOPE (NP-ST):

This is primarily a two mirror coelostat; the primary mirror is on the yoke mounting. The mirror diameter is 12.5" and has been ground to about one fourth of the wavelength of visible light.

The primary mirror is driven by a 14" gear with a stepper motor of 3 kg./cm^2. The drive system for this mirror is 200 steps/second and the motion is very smooth.

The secondary mirror has primarily two motions (i.e. east/west and north/south motion). Both of these motions are possible again by using the gear train and stepper motors. Both of these motors are controlled with same console which also drives the primary mirror. It is also possible to link this control-console to a microcomputer.

For east/west, or the rising/setting of the sun, the primary mirror can be moved to either position depending on the azimuth of the sun. The secondary mirror is on a permanent pier, and it is able to move the secondary to take care of the daily motion of the sun (or the sun's declination).

Adur, B. and Paramsivam, S. (1987) have also discussed the usefulness of using a fiberglass dome along with this solar telescope and have compared the results of conventional onion-shell domes to the fiberglass ones, and have further determined the solar seeing to dome seeing.

Another important feature of the present dome is its stepper motor drive system, which is likely to be linked up to a microcomputer. The general house-keeping like managing the stepper motors of the telescope, as well as the dome, and relieving the observer from the travails of telescope guiding, will be controlled by the microcomputer.

The stepper motor drive system was developed with active collaboration of APLAB Company, and hence this coelostat is able to track the solar, lunar, and other bright stars.

It is proposed to have a still video camera for monitoring of solar images in white light as well as with filters. One of the important aspects is to observe high resolution features in solar plages in a Calcium II filter and the Ha filter. It is also proposed to use the same telescope for the lunar occultation and regular photometry of the bright stars.

In view of growing needs of observational astronomy and also to enthuse young students in the modern observational techniques amongst serious amateurs, school/college teachers and for educators in astronomy.

BADLAPUR OBSERVATORY (BO):

The Badlapur Observatory (BO) is to be situated at a distance of about 83 kilometers from Bombay on the east mainland. This is one of the good locations with dark sky conditions and with a low clear horizon.

Except for the monsoon season (i.e. June-August), the site has good clear nights during the year. The best observing conditions prevail during November-January.

The main instrument of the Badlapur Observatory is to have the 30" diameter mirror of f/4 and it could be used either as a Newtonian or Cassegrain/coude.

It is to be yoke mounted with an open serrier truss tube design and would have a detachable spider ring at the top end of the telescope, making it easy to shift the secondary mirror or the prime focus camera.

Both the R.A. and the declination are to be controlled from a remote panel or on a hand control. The R.A. drive would have a drive corrector and is a must for long photographic exposures and useful for centering of the photometer diaphragm.

A 3" f/11.7 refractor is already acquired and is to be used as finder and guidescope.

The focal plane instrumentation and auxiliaries would be like Solid State Photometer (SSP-5) with standard UBVRI filters, fast photon counting devices, Charge Coupled Devices (CCD), and Reticon of 1024 element diode coupled CCD.

The integral part of the Automatic Photometric Telescope (APT) is the emergence of low priced microcomputers, display devices with large memory storage banks, good astronomical databases, and not so expensive, powerful, astronomical data reduction packages. However, not forgetting "handshake" devices like bus linking the telescope to the microcomputers and the observers.

The Telescope Control System would consist of an AT computer (80mb hard disk and 1.2mb floppy drive), custom telescope control card, clock card, math coprocessor card, microstep driver, manual control pad and software written in Turbo Pascal. One of the important aspects is a continuous, surge free, quiet and reliable power supply. The main power supply would be complimented by the total solar backup. Solar voltaic cells would deliver current which will be stored in 1000 amp/hr batteries and inverted through a series of 2000 watt inverters. One of the inverters would service the telescopes, computers, dome rotation, and also lighting, etc.

Badlapur Observatory would be probably the first APT Observatory in the country. The site development is already on and building work should be ready by March '91. A 20-foot dome of masonite and fiberglass would be set up with a stepper motor drive system of its own.

The Observatory would be primarily interested in the following observing programs:

- Automated Supernova Search
- Activity of Cool Stars
- Precision Photometry of Bright stars 12 south to 45 south
- RS Canis Venaticorum stars
- Be (emission) stars
- Algol binaries
- Monitoring the Flare stars and many more

ESTIMATED BUDGET:

a) Land development, building, Telescope pier, Dome		$20,000
b) Telescope:		
i) Optics	$6,000	
ii) Mounting and Drive System	$8,000	
iii) Focal-plane instrumentation	$10,000	$24,000
c) computers, image Display Devices bulk memory banks, Printers/plotters		$10,000
	GRAND TOTAL	$54,000

Capital:

1)	Donations, grants for purchase of Telescope Drive systems, and focal plane instrumentation.	$24,000
2)	Personal funds for building, land development, telescope pier, and the fiberglass dome	$20,000
3)	Donation of computer system from computer company	$10,000

Recurring Grant: For the upkeep of the observatory $5,000 per annum.

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GLOBAL NETWORK OF AUTOMATIC TELESCOPES (THE "LIBERTY NETWORK"): ITS PHILOSOPHY AND F.A. HAYEK'S VIEW OF ECONOMICS

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INTRODUCTION

The Global Network of Automatic Telescopes (GNAT, or, the "Liberty Network") is envisioned as a cooperating system of photometric observing stations located all over the world (Baliunas, Cornell, and Genet 1988; Crawford, Genet, and Hayes 1988). We propose that the system of telescopes be organized in a "hub and spoke" manner. Telescopes could either be devoted primarily to collaborative research programs ("hub") or occasionally involved with collaborative observations ("spoke"). The component stations of both systems can be linked together in any combination desired. The emphasis of GNAT is on high-quality photometric data that can be exchanged between stations which can be networked in a variety of ways so that the maximum scientific freedom, creativity and productivity of individual researchers is possible.

The ability to link telescopes together in a network provides a powerful research tool which has previously been extremely difficult or impossible to construct. The economic and political ideas developed by F.A. Hayek (Nobel laureate in economics) provide a good foundation for the philosophy of the GNAT. The following is a discussion of the philosophy of the GNAT, using the Hayek model for establishing and operating the GNAT.

ORIGIN OF THE HUB AND SPOKE SYSTEM OF GNAT

The access to high-quality photometric data through inexpensive, standardized technology has led to the possibility that a world-wide network of telescopes can be formed. To this end, the concept of the Global Network of Automatic Telescopes (GNAT) has been discussed over the previous year. An initial mailing discussing the concept in January, 1989, produced over 100 interested participants. A study of the various responses from professional and volunteer astronomers revealed a wide range of possible programs. This survey guided our thinking of the next step: defining the global network in more detail.

The GNAT is planned to be a world-wide linking of telescopic observations which are comparable. Because of the development of inexpensive automatic telescopes which use off-the-shelf technology, many interested participants plan to have nearly identical telescopes and instrumentation. A common design for the building-block of a GNAT station might be an automatic telescope similar to that of the 0.75 Automatic Photoelectric Telescope (APT) in operation at the Smithsonian Astrophysical Observatory's F.L. Whipple Observatory in southern Arizona (see Figure 1). The similarity of the instruments in the GNAT would help efforts to establish comparable photometric data.

On the other hand, several survey respondents reported that they are already retrofitting existing telescopes for automatic or semi-automatic operations. Those activities gave rise to the notion that such retrofitted telescopes, and manual ones as well, could join the network as long as their instrumentation can produce data compatible with the standards of the GNAT.

Thus, the concept of the GNAT is formed by two complementary structures: either a copy of the APT or a device which produces compatible data. These two fundamental building blocks of the GNAT are called the "hub" and the "spoke systems.

NATURE OF THE HUB SYSTEM

The hub is defined as a network of approximately one dozen sites located world wide. Perhaps funded under one blanket source, the hub of the GNAT would consist of one dozen robotic telescope systems that would be constructed in assembly-line fashion and hence be virtually identical. Participants in the hub of the GNAT would be joint collaborators on a large proposal, international in scope. David Crawford of NOAO has issued the call to begin the hub system (see accompanying paper, "GNAT: A Global Network of Automatic Telescopes" by Crawford and Baliunas).

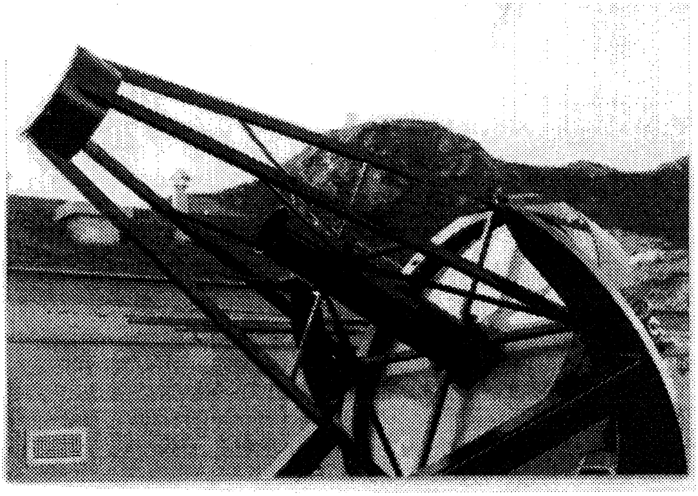

Figure 1. *The Smithsonian 0.75-m Automatic Photoelectric Telescope which is now operating full-time at the F.L. Whipple Observatory in southern Arizona. The SAO 0.75-m APT is an example of the type of robotic telescope that could be used for the GNAT. This telescope, originally constructed in 1917, was retrofitted for semi-automatic operation in the early 1980's.*

One advantage of the hub system is that less-experienced partners could be helped by the more experienced ones in the system. In addition, virtually identical devices would be installed; this is a large step toward ensuring compatibility of photometric data.

NATURE OF THE SPOKE SYSTEM

One disadvantage of a hub system with such a large number of components is that some experiments might require observations from only two or three stations instead of all stations in the hub. In that case, the hub system is ineffective and even burdensomely complex. We must try to ensure the flexibility of using the GNAT by making access to and operations of many or a few telescopes as convenient and efficient as possible.

It was obvious from the diversity of responses to the initial global-network mailing that many astronomers and institutions were interested in participating in the GNAT, but only occasionally, not on a full-time or majority-time basis. The concept of the "spokes" of the GNAT sprung from the desire of part-time participation in network research.

Several advantages of the spoke system deserve consideration. First, the telescope of the spoke system of the GNAT could contribute very cost-effectively to those of the hub with additional, global coverage of observations. Second, the spokes need not be identical to the APT's of the hub. The spokes would need only to make observations meeting the standards of the GNAT, but such measurements need not be obtained with APT's. Compatible observations could indeed be made with existing manual telescopes -- the data need only meet the requirements of the GNAT. The expansion of the GNAT to include many different telescopes means a wider participation in GNAT. Moreover, spoke stations of the network might indeed be copies of the hub stations. In that case, individuals may have decided to purchase a hub system, but primarily for their own scientific pursuits, and perhaps secondarily as a system which is compatible with the hub. Third, the spoke stations are individually funded, owned, operated, and managed, so the direction of each spoke stations is independent of any other. Individual management means no massive planning system will be required to oversee such diverse systems. The flexibility of spoke stations makes projects requiring a few stations easy to organize.

The disadvantage of the hub system is that tough problems, introduced by the diversity of equipment, must be solved to ensure high standards of data quality and compatibility.

THE COMBINED HUB AND SPOKE SYSTEM: THE LIBERTY NETWORK

The major advantage of the spoke stations is that a minimum amount of centralized direction and coordination is needed to keep them operating. The disadvantage of the spoke system is that somewhat more flexibility and individuality remains in the system than may be desirable to accomplish large projects involving many stations. The hub system offers the advantage of similar equipment, assembly-line manufacturing for cost savings, and an organized system of technical expertise and communication. However, the hub may at times be too cumbersome for some observing programs which are simply done with fewer stations.

A blend of both hub and spoke stations will enable the GNAT to undertake a wide range of research programs in an efficient way. In addition, we believe that the flexibility introduced by the hub-and-spoke system will serve many of the diverse programs of its participants. Finally, the goal of GNAT is to make access (through either the hub or spoke stations) to it extremely easy. Coordinated, easy access would ensure that those lacking telescopes but brimming with ideas could successfully participate. We call the philosophy of the combined hub-and-spoke system of the GNAT the Liberty Network.

HAYEK'S *The Road To Serfdom*

The philosophy of the Liberty Network is, we believe, embodied in Hayek's 1944 masterpiece, *The Road to Serfdom.* Hayek's political and economic thoughts in this treatise was derived from a view of Germany through the 19th and early 20th centuries. Hayek left Austria prior to the outbreak of World War II in Europe, and wrote while in England. Hayek considered the evolution of the German political and economic systems and their similarity to some developing characteristics of the British systems. The treatise provides clear thoughts on the dangers of the centralized government in light of the National Socialists' seizure of power in Germany. Moreover, Hayek posits that the dangers are not the result of an unexpected or accidental aberration, but a consequence that begins with the inception of strong, centralized planning. This is the road to serfdom. In Hayek's words:

> *...[T]he unforeseen but inevitable consequences of socialist planning create a state of affairs in which, if the policy is to be pursued, totalitarian forces will get the upper hand* (p. xvii).
>
> *Few are ready to recognize that the rise in fascism and Naziism was not a reaction against the socialist trends of the preceding period but a necessary outcome of those tendencies* (pp. 3-4).

In this work, Hayek does not address science directly, but the lessons of centralized planning of national economies are also applicable to scientific research. In order to conduct science, each investigator must be free to choose his course and methods. A centrally-planned system cannot be intelligent enough to foresee and accommodate all possible creative ideas of all scientists. In order to do so, a central planning authority would have to be omniscient. In the case of science (or government), this is clearly impossible. A centrally-planned economic system, argues Hayek, must evolve to totalitarianism, because, "Collectivist planning cannot tolerate many opportunities for people to do with them as they wish (p. 52)."

Moreover, Hayek contends that even abstract science will be affected by central-planning governments:

> *Facts and theories must thus become no less the object of an official doctrine than views about values. And the whole apparatus for spreading knowledge will be used exclusively to spread those views which, whether true or false, will strengthen the belief in the rightness of the decisions taken by the authority...*(p. 160).

The lesson is that in science, as in economies, central planning will stifle creativity because the planning authority must make decisions for all individuals. Because a central authority is unable to have all knowledge in order to make those decisions, centralized planning will devolve into a rigid system that allows no individual choice. This is just as dangerous in science as it is in political governance.

On the other hand, "dogmatic laissez-faire," as Hayek describes the counterpoint to centralized planning, must also be avoided. Instead, we can choose to make intelligent decisions about potential opportunities. For the system to work, there must be a covenant -- the *Rule of Law* -- which guarantees that the government "will be bound by rules fixed and announced beforehand -- rules which make it possible to foresee with fair certainty how the authority will use its coercive powers in given circumstances and to plan one's individual affairs on the basis of this knowledge (p. 52)."

Such a "carefully thought-out legal framework" is necessary to ensure the greatest freedom which is derived from decision-making at an individual level. Authority should not enforce a "blueprint" but rather should provide a backdrop of conditions that allow individuals to best choose their directions and to foster maximum scientific freedom of opportunity. This is the philosophical underpinning of the Liberty Network.

FOUNDATION OF GNAT PRINCIPLES

Learning from Hayek's arguments, we wish to establish and nurture a research program based upon a network of telescopes that will be scientifically productive, creative and efficient.

First, we must establish a "rule of law," that is, common principles to which all participants agree to adhere, and we must also establish a process to effect changes in the basic principles when necessary.

We suggest the formation of working groups who will adopt an initial set of criteria for the foundation of the networks. All participants will be asked to approve the draft criteria, in preparation of finalizing them. Here are the working group tasks:

1. Define the GNAT concept and proposal -- The nature of GNAT is two, complementary structures that will be linked in a variety of ways:

    a. "Hub" concept and proposal -- D. Crawford, S. Baliunas and interested participants.

    b. "Spoke" concept -- S. Baliunas, D. Crawford and interested participants.

2. Establish a communication system -- such as a central, electronic billboard that can be accessed from computer networks or modem.

3. Set standard of instructions for automatic telescopes, such as ATIS (Automatic Telescope Instruction Set), developed for the APT's. This system would allow easy scheduling of systems of the hub, and other spoke systems using ATIS. Mis-communication of observing instructions could be kept to a minimum with a standardized instruction set.

4. Set standards for data reduction routines -- for intercomparison of data from different telescopes.

5. Set standards for quality control -- For example, all GNAT participants would be required to observe from a list of standard stars for a few nights per quarter. In addition, we will also monitor systems, filters, sites, etc. These processes would help ensure that data are comparable between stations.

6. Establish an archive -- The wisdom of the AAVSO (American Association of Variable Star Observers) in obtaining, overseeing and maintaining an archive of photometric data over nearly eight decades should be incorporated in the establishment of the GNAT archive. In addition, the experience of the National Space Science Data Center, Strassbourg and other astronomical data base facilities will also be of great value.

7. Set rules for exchanging telescope time -- The fair exchange of telescope time on the network must be carefully and thoughtfully established. In the case of differential photometry, time could be exchanged on a star-by-star basis (or, more correctly, group-by-group).* For observations in the hub system, the telescopes are similar devices which means that an exchange of the observations of a group would essentially be equivalent to an exchange on the basis of time. For observations from the spoke system, the differences between instruments, procedures and amount of observing time needed to complete a measurement may be vast. Again, the unit of exchange perhaps could be the measurement of a group, which would correct for differences in weather and speed of equipment. Similar exchange rates could be set up for different kinds of measurements.

   It is useful to note that the observations made by the GNAT have some value in the real world exclusive of telescope time. That is, time from the GNAT may be purchased or traded. Because it has some worth, we call the value of GNAT observations the "GNAT currency." We believe that the value of GNAT currency should be determined by individual owners or operators, who can best judge the worth of GNAT currency according to local criteria. We can imagine some unusual cases wherein GNAT observations might be traded in unconventional ways. In those instances, GNAT scientists might choose exchange GNAT observations for cash, time on other telescope facilities, engineering services, equipment, or any other item valued by the seller and agreed upon by the buyer.

   As we have learned from *The Road to Serfdom,* no fixed exchange rate should be attempted by any central authority, because no one can foresee the value of GNAT currency under such widely different conditions or in the

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* A *group* is the complete sequence of observations of a variable star, including the background sky, comparison and check star measurements necessary to obtain the final differential magnitude.

future. The penalty for decreeing the value of GNAT currency is a rigid system which ultimately restricts the freedom of scientific investigation.

8. Rules for Adjudication -- we should also agree to the means of resolving disputes. For example, a committee of three GNAT station representatives, which serve fixed terms, could decide arguments. Representation on the committee could be rotated between stations. In addition, we would be willing to serve as ombudsmen who try to resolve a case between individuals before asking for dispute resolution.

All are invited to participate in the GNAT, especially at these early stages of planning. Please contact us to express the nature of your interests and contributions.

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GNAT: A GLOBAL NETWORK OF AUTOMATIC TELESCOPES

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ABSTRACT

We discuss again the concept of a global network of automatic telescopes and its value to the astronomical community, and we propose here a method of developing a formal proposal for funding the basic part of that network. The idea is to form a consortium of many potential users and jointly develop and submit the proposal to funding organizations that have a potential interest in astronomical research, science education, and that have a global rather than a national view of such.

I. INTRODUCTION

The GNAT we are proposing is an international network of small optical telescopes linked together by common interests and common algorithms. The concept and extensive discussion about what it may consist of, how it would operate, justifications on the basis of research and of education are contained in a number of references: see Crawford, Genet, and Hayes (1989), Baliunas, Cornell, and Genet (1989), and Genet and Hayes (1989), as well as the references given in these two papers and the Robotic Observatories book. There are a number of other papers included in the current meeting program that discuss some aspects of a GNAT or similar technology, including another by us discussing one aspect of the GNAT operation.

We are suggesting here that a formal proposal for a minimum of six GNAT observing sites (plus a Home Base) be developed and submitted to a number of funding sources by a consortium of many (40 or more) organizations and users. These organizations and users will cover a gamut of global locations, sizes, and other characteristics, and will include universities, observatories, amateur clubs, schools, and perhaps even individuals. [Consortium: a partnership or association; alliance of two or more firms in a common venture; an international agreement or association.]

Each consortium member will list briefly (but with clarity and excitement) the most interesting research programs they would plan to do and their expected use of the facility for science education. This input will be the core of proposal. Included also will be a description of the facility, its value to the astronomical community and beyond, a discussion of small science and the importance of Value/$ as a major factor in support of the proposal, a budget, and a management plan for implementation and operation.

II. GENERAL DISCUSSION ABOUT THE NEED FOR A GNAT

Is there a need for such a facility? Yes !! The articles referenced above address the question, but let us discuss it here as well.

For Research: There are many "have nots," and it is a fact that these include many very good and creative people, as well as young people who have not yet been able to enter the world of 10-meter telescopes or of expensive observatories in space. The GNAT can and will be of great value to them (and their students), and it will be a proving ground leading some of them into 'big science.'

Existing facilities, both large and small, that are located at good observing sites are greatly oversubscribed for observing time. Many creative and productive observers are not able to get enough observing time. The situation is getting worse. The addition of a few large telescopes will not help, as these will offer only a small amount of time to such observers. It is hard for newcomers, even the best, to break into big science. To make matters worse, the number of small telescopes with easy access is actually declining at this time.

A relatively small telescope is a powerful instrument in astronomy, quite capable of frontier research. For example, a telescope with a one-meter primary mirror can do wide band (BVRI) photometry to fainter than 20-magnitude in less than 20 minutes using a relatively inexpensive CCD imaging photometer. This is about as good as the 200-inch telescope, the world's largest, was able to do only a few decades ago. The advances in detectors and instrumentation recently mean that small telescopes have become large, for many programs. Such small telescopes are an excellent complement to the large existing and planned telescopes as well as to facilities in space. We need it all, and the small telescopes are by far the least expensive part of the system. The value per dollar is excellent. GNAT is a prime example of quality small science. Small science is needed, not just big science. Big science will struggle and suffer without the backup and support of small science. The past and some of the present difficulties with big science show this fact well. We need big science, but we also need cost effective small science, for both research and for science education. In astronomy, small science is still effective frontier science and frontier technology.

These small telescopes are essential for many programs: monitoring of a wide variety of objects, surveys of all sorts, variable star photometry and spectrophotometry, cluster photometry, spectroscopy and photometry of brighter objects of all sorts, and astronomy and science education. The paragraphs in the proposal written by members of the consortia will prove this statement without a doubt.

In additional to being able to do frontier research, the modern small telescopes are also examples of frontier technology in their own right. They use computers for all their operation and control. The data handling and transfer and archiving are similar to that on large telescopes and on space facilities. It is also similar to the data handling needed for many other aspects of science, and even for non-science subjects. Any remote control or remote access to data bases is similar. The GNAT will be an excellent training ground for anyone, not just astronomers.

Furthermore, the detectors and instrumentation used by the GNAT telescopes are similar to those used on larger telescopes. Any GNAT user is getting great training for efficient observing on the larger, much more expensive facilities, on the ground and in space.

Cost aspects are most powerful arguments for the value of small telescopes. Much more research can be done with small telescopes, many more users can be served, and many more papers will result than from the dollar equivalent amount of larger telescopes (See the scaling arguments given in an addendum to this report.).

Note that the GNAT sites are all excellent ones for observing. There is no requirement that a new generation small telescope (NGST) be located near the observer, whose home base is generally at a rather poor observing location. The resultant quality and quantity of data will be much improved over previous generation small telescopes. Value per $ is excellent: GNAT will be extremely cost effective, to build and to operate. There can be other telescopes linked into a GNAT, of course, some of these even being at not so good sites. Their value will be increased, though, even at a poor site, because they will be able to take advantage of the standardizations and algorithms developed and used by the GNAT telescopes. Such additional telescopes will be a valuable secondary network, complementing the GNAT telescopes very well.

For Education: Students and all other users would be working with real data from telescopes at excellent sites. The GNAT facility can in principle be accessible to all, those from large or small universities, from high schools even, from amateur clubs and societies, from individuals anywhere. There is no geographical restriction: third world countries, eastern Europe, potential observers anywhere can and will be linked in. The only requirement is that the user have a computer that can access the GNAT Home Base computer system; a PC with a modem is adequate. Users, including students, will prepare their programs on the computer, send the information to GNAT, and receive the data back via the same route. Certainly, the observing proposal first has to be accepted by GNAT, based on scientific merit and on the ability to follow the GNAT guidelines as to the use of GNAT. But access is not limited to Who You Are, or Where You Are.

III. INTRODUCTION TO THE NETWORK PHILOSOPHY

We quote here (in many cases, quite paraphrased) from a upcoming paper by Russ Genet based on extensive discussion between us and others about conclusions that can be drawn with respect to automatic observatories.

1. The telescopes must be placed at existing installations so that construction and site costs are minimized. In case of problems, items can be conveniently replaced, thus avoiding expensive redundancy and other costs associated with inaccessible or "remote" telescopes.

2. A number of identical telescopes must be placed together at each site to reduce the cost per telescope. Sharing of the building, of computers, of weather sensors, and of spares is both possible and essential. N telescopes sharing fixed costs is a most viable approach.

3. The telescopes must be kept simple (but excellent). They should be built in batches, of identical design.

4. Standardized, relatively simple instruments that do not push the state of the art must be used. Leave most new development to others. Small telescopes can be excellent test beds for using instrumentation and for developing understanding about remote and automatic operation of telescopes and of instrumentation.

5. The instruments are mounted permanently on the telescope: no instrument changes, with the resultant problems and down time. Generally, there will be only one or two instruments per telescope, all of these standardized. For example, a small chip CCD imaging camera plus a conventional photomultiplier photometer.

6. The telescopes will not be designed for direct human interface; there will be no eyepieces, for example. All normal operations, including even focus, alignment, and calibration must be done remotely.

7. Users should make up their own observing requests and their own observing programs in detail and send them to the GNAT via modem.

8. Users should retrieve, reduce, and analyze their own data. GNAT will monitor standard stars, systems, sky quality, and telescope and instrument

status and performance. GNAT will produce extensive tutorials on How To ….. , of course.

9. The GNAT Home Base will be responsible for coordinating telescope usage and monitoring the overall quality of the data and of telescope and instrumentation performance. GNAT will act in the role of a PA, as defined by Genet and by Seeds, and also develop many tutorials about the effective use of GNAT and NGST's.

10. Communications between users and GNAT and between GNAT or users and the telescopes must be by uniform and agreed on standard protocols, rather like that of the ATIS developed by Genet and others.

11. Buildup of staff and overhead must be minimized. Operating budgets should reflect only the basic needs. Users must be involved, and sharing is critical to keeping costs low. The GNAT staff will be there to insure standards, to be a viable and effective catalyst, and to be the communication link between users and observing sites. As such, GNAT is different than the APTS described by Genet. In APTS there is a direct link between user and the user owned telescope. There is not a network of telescopes. The PA in APTS handles all the telescope users, and he is the link between them and the telescope: multiple users, one telescope. GNAT will have both multiple users and multiple telescopes, and it is therefore a natural extension of the APTS ideas.

12. Frequent coordination between the users will be vital. This will allow the sharing to occur in an effective way. Such coordination will occur via E-mail, other ordinary routes (regular mail, phone, visits, ...) and by meetings of those involved, at general astronomical meetings, local, national, and international. Special GNAT meetings will occur at least once a year, generally in conjunction with another meeting held at the same time (such as one of the annual APTS meetings, at an IAU General Assembly, or at an IAU Symposium or Colloquium held on topics of interest to many of the GNAT users).

IV. GNAT SITES

We propose, for the initial GNAT network, six observing sites having GNAT owned telescopes. (See the discussion in the references mentioned in the Introduction for additional details.) Each of these sites can and probably will have other AT's (automatic telescopes) owned by others, some of them perhaps operating as part of the GNAT network. Other sites with non-GNAT owned automatic telescopes could be linked to the GNAT, some of the telescopes operating some of the time as part of the system.

It is essential that GNAT itself own and operate a basic network of well located telescopes. Six is the minimum number of locations to have adequate global coverage, and two telescopes per site is the minimum to have adequate cost savings (more sites and more telescopes per site would increase the value and effectiveness of GNAT, of course). Non-GNAT telescopes at GNAT sites could easily join in the philosophy of cost sharing of buildings and other support facilities with GNAT.

In the first year of the proposal, we would select the actual sites, based on local interest and support, the existence of currently operating or planned AT's, and cost aspects. All sites considered would be of excellent (and known) observing quality. Examples of sites to be considered include: Arizona (several possible locations, almost certainly there will also be non-GNAT sites in Arizona with AT's linked to GNAT), Canary Islands, Sicily, India, Hawaii, California, Chile (again, several possible locations), Australia, South Africa. It is easy to expand the list of excellent sites and easy to include many non-GNAT sites (both those with excellent nighttime skies and those which can be secondary sites linked to GNAT). A number of these sites already have, or will have soon, one or more AT's in operation similar to those proposed by GNAT.

We imagine that there would be a gradual (maybe rapid) enlargement of the number of telescopes and sites linked to GNAT. We also imagine that a number of medium sized telescopes would be developed by others, incorporating many of the aspects of GNAT, but offering higher spectral resolution instruments to user. It would make a great deal of sense to have these at the same locations as the GNAT telescopes, perhaps even operated out of the same GNAT Home Base.

V. PRELIMINARY BUDGET

A. *Initial Capital Costs:* Before submission of the proposal, a firm budget will be developed, of course. We expect the time between now and when a proposal is finished to be no more than one year. Any longer would not be in the spirit of the Value/$ goals of a GNAT. Small telescopes can and must have fast turnaround, for proposals, for design, for construction, and for improvements. We would expect the telescopes to be ordered and obtained in less than two years after a successful proposal funding. Operation would begin soon thereafter and gain in efficiency as operating software development continued.

Here is a rough estimate of a budget for the minimum facility:

1. Ten one-meter (approximately) telescopes, at $350K each, installed at six GNAT sites. We assume that two telescopes will be funded by others, but that they will be part of the GNAT network. At least two telescope companies are currently making automatic telescopes of this size and in this price range. This price also includes a CCD imaging photometer and an Optec SSP-5 for each telescope, as well as all other associated equipment. This instrumentation is standard and easily obtained. We imagine also a fiber feed port for some or all of the telescopes, and perhaps a "TV"camera for local use to see images and/or for acquisition and guiding, if the CCD photometer is not used for this. Each site would have one building to house the telescopes, built initially large enough to hold from six to ten telescopes

eventually. Even at this stage, we would explore cost sharing with those who already are planning an AT at the chosen sites. Total: $3500K.

2. We assume donated office space. Other home base initial costs: Office equipment $100K, computer system $100K, other necessary tools and equipment and supplies $100K. Total: $300K

3. In addition, one will need funding for travel and other costs during the definition year of site selection and of document preparation. We estimate $200K for these efforts. About 1/2 FTE time for an astronomer is included.

4. Total initial costs: $4000K.

B. Operating Costs Per Year (the final proposal will have specific details of each item):

1. Staff (astronomers, technical, administrative), including overhead: $650
2. Travel: $50K
3. Supplies, postage, phone: $125K
4. Publication costs, consulting, meeting costs: $50K
5. New equipment: $75K
6. Miscellaneous (dues, subscriptions, professional fees, freight, etc): $50K
7. Maintenance & Power: $100K (Shared with local hosts?)
8. Post-Doc and Summer Student Programs: $100K
9. Total annual operating costs: $1200K

Item #8 can be a shared cost, of course, and could be expanded by future grants.

C. Charges for Telescope Time: It is expected that GNAT will charge most users for telescope time, with perhaps some fraction (25 percent or more, depending on the endowment raised to support the operation) of the telescope time being awarded free for the truly "ave-nots."

For example: For CCD images, two effective frames per hour, twenty per night, 200 nights. At $30 per frame, a GNAT would generate $100K per year per telescope. With twelve telescopes operating: $1200K. If we allow for 30 percent non-charged time on the telescopes for "have-nots," then the cash flow to GNAT is $840K per year. This is 70 percent of the annual operating costs. The proposal will be submitted so as to include an endowment ($4000K, equal to the capital cost) sufficient to cover the other 30 percent of the annual operating costs. This type funding assures stability, but also efficiency. The GNAT can grow (more telescopes) as additional funding comes, from any source.

Sample program: pen or globular cluster. 4 filters, 4 exposures areas per cluster, 5 exposures per color. Hence a total of 80 frames. Cost to user: about $2400. Very cost effective small science! [Note that 12 x 240 clear nights = 2880 usable. 4 per user, say, leads to 720 users per year. This is considerably more than the annual total of users of KPNO, before telescope closures, and KPNO's operating budget is twenty times that of GNAT's.]

Sample program: Variable star. 4 colors, 20 exposures in each color. 80 total. $2400. Again, very cost effective research. If one did the variable star with the conventional photometer, at a cost of $10 per exposure, then the total cost would be $800. Even more cost effective, for those programs that could benefit from this type of photometry.

VI. SUMMARY

Most all astronomers are suffering for lack of telescope time, and it is getting worse. Access to telescopes by students and "have-nots" is especially tough. It is a world-wide phenomena, and it is especially bad for those creative people who live in the third world or any location without good access to modern telescope facilities.

One can do frontier research with a new generation one-meter telescope equipped with excellent, but inexpensive, instrumentation. Such a facility is also at or near the frontier in the use of technology, and it provides a learning process for all users. Many will then be able to become effective large telescope users or users of space facilities. Modern small telescopes are relatively inexpensive and can serve many users. Many papers and much good research will result: excellent small science, really a nearly perfect example of such.

NGST's and GNAT can and must be a vital part of a balanced astronomy program, worldwide. They can and will be a leader in many aspects of development, of research, and of education. They will be an excellent complement to the research done on larger telescopes and in space research. Furthermore, a GNAT can easily grow with time, thus serving even more astronomers. The incremental costs are relatively low.

The impact on science education may well be even larger than the impact on research. It is training by doing and is all real research using modern, first rate equipment accessed remotely by computer. Many published student papers would result, of course. Professors and students anywhere can benefit, both those with and those without current observing facilities.

VII. IMPLEMENTING THIS SPECIFIC PROPOSAL

A draft of a "Survey and Poll' is attached. It is designed to assess interest, to develop additional ideas and input, and to test the viability of the concept of such a proposal. You can help greatly by thinking carefully about GNAT itself and about the proposal concept. Then fill out a copy of the Survey and Poll, add as much text as you like, and return it promptly to DLC.

If interest is high and the support for such a proposal is there, a small working group will develop a draft of such a proposal. Material in the responses to the Survey and Poll will be used. The responses will also be used to develop the initial consortium of potential users and the working groups. After detailed but rapid review and approval by the consortium, it will be submitted to potential funding sources, those interested in both research and in science education, especially those with a global outlook. Your input and help at every stage of this process is critical.

Let's get a network established and get a GNAT funded and operating. The proposal idea suggested here may be an effective way to do it. The time is ripe. The advantages are great. We can and should do it. Let's get on with it!

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Astro-economics: The Use of Scaling Laws
Addendum to the GNAT Discussion

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Number of Users

Abt did an earlier study of the number of users, papers, and citations as a function of telescope aperture. We extend that here by more recent data and by the use of data for the 4-meter telescope at KPNO.

Abt found that the number of users and the number of papers scaled close to the first power of the aperture and the SCI counts scaled with the 1.5 power of the aperture (more citations per paper for larger telescopes).

Let us set the zero point for the number of users to be 30 on a one-meter aperture telescope, the average of Abt's values for the 0.9 and the 1.3 meter telescopes. Then we find:

Ngts in Run		16x	100x	If A0.5	Ngts in Run
1m serves	30 users	11		40	8
4m serves	120 users	2.7	480	80	4
10m serves	300 users	1.1	3000	125	2.8

The column headed Ngts in Run indicates how many nights each user would be scheduled assuming 320 nights per year for each telescope. Actually, the smaller telescope may well have less down time for repairs or scheduled maintenance than the larger ones.

The columns headed 16x and 100x are the number of users that would result from having 16 or 100 one-meter telescopes, the equivalent amount of aperture to the larger telescopes. The efficiency of small telescopes to serve a large number of users is clear.

The column headed A0.5 is the result of my update of Abt's study. I used the 1987 schedules for the telescopes at KPNO and counted the number of users (Details will be published elsewhere). The result is that the number scales more closely with the 0.5 power than with the 1.0 power. I also increased the number of users on the one-meter to 40, as that is the average of users on the #1 and #2 0.9-meter telescopes that year. I did not update the number of papers study, and one might well expect the number of papers per user to be larger for the large telescopes than for the small ones. Likewise, I did not update the SCI study, and one might expect that the citations per paper will be larger per paper for the large telescopes.

Number of citations (using a 1.5 exponent in the scaling law):

		16x	100x
1m yields	40 citations		
4m yields	320 citations	640	
10m yields	1280 citations		4000

Here the differences are not as large as in the number of users, but still the small telescopes show remarkable efficiency and power. These efficiencies result, of course, because the number of photons (or the area) goes with the 2.0 power while the number of users, papers, and citations goes with less than the 2.0 power. There appears to be no way to rationalize scaling any of these three items with powers much higher than those used above. Remember too that studies show that the cost of the telescope scales with a power of 2.7 and it appears very difficult to get this exponent below 2.5 for any comparable telescopes (one must compare new generation small telescopes with new generation large telescopes, of course).

Telescope Costs, via Scaling Law Estimates

A	A2	A2.6	$	A0.5	A0.8	A1.5
0.5	0.25	0.16	85 K	0.7	0.6	0.4
0.75	0.56	0.47	150 K	0.9	0.8	0.6
1.0	1.0	1.00	225 K	1.0	1.0	1.0
2.0	4	6.06	1.4 M	1.4	1.7	2.8
4.0	16	36.8	8.1 M	2.0	3.0	8.0
6.0	36	105	23 M	2.4	4.2	15
8.0	64	223	49 M	2.8	5.3	23
10.0	100	398	88 M	3.2	6.3	32
16.0	256	1351	300 M	4.0	9.2	64
100 x 1m	100	23 M	100	100	100	.pm 0.2"

"A" is the telescope aperture and we use a two term scaling law for cost of Cost = 0.050 + 0.22 x A2.6, the results of which appear to fit well to existing costs of the present generation NGT's. The cost includes a basic set of instrumentation. More details will be published separately.

We add columns with exponents that fit well with the number of users, papers, and citations for these size telescopes. One should multiple each by about 40 to give actual expected values (see the text above). The line beginning "100 x 1m" shows that for the same $23M as a 6m costs one collects about three times as many photons and serves about 40 times the number of users, who produce about 25 times the number of papers (different topics, to be sure).

Small telescopes produce a great bang for the buck. They stimulate creativity and are great for educational use as well. They are the only hope for an adequate amount of observing time for most users. A realistic goal is to have enough time available to insure that risky and innovative ideas can be tried, and that long term programs requiring a great number of observing hours can be accommodated.

PROSPECTS FOR ROBOTIC OBSERVATORIES AND STELLAR SEISMOLOGY IN LATIN AMERICA

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INTRODUCTION:

Twelve years ago, when I was working at Serra da Piedade Observatory (operated by Universidade Federal de Minas Gerais, Brazil), we begun with the automated data acquisition from a telescope (photometric information). We also used tele-transmission for processing the information at a very distant computer, located at the University building -- 28 miles away.

Our experience at that time was very useful for the development of a system composed by the following set of tasks:

1. To construct and program the microprocessors for the data acquisition from the stellar photoelectric photometer. This task includes hardware and software development.

2. To program the interfaces between the analog photometer output and the digital signal transfer between the observatory site and the university building. This task deals with digital electronics, microprocessors and software developing.

3. To program the communication software for enabling the data transferring, both at the microprocessor and at the minicomputer.

4. To program the software for real-time data analysis and the generation of adequate mandatory instructions for the system at the telescope. These instructions were only messages for the operator, as there was no automatic operation system at the Piedade's telescope.

The system saw the light in 1981. During one year of continuous observations, it was devoted to a couple of works: dwarf cepheids (the δ Sct and SX Phe types of variable stars as we known at present) and eclipsing binaries (specially the close binary systems and RS CVn type). The system worked very well until my return, in 1982, to the Instituto Copernico. Unfortunately, as far as I know, the project did not continue.

By this time, Mr. Russell Genet and I became in contact, because the IAPPP was founded and I was invited to be a Charter Member of this pioneer institution.

A few years ago, we became interested in the installation of an observatory for automated photoelectric photometry, and we tasted the possibility of making our own APT.

From that time, we were working on a project that I will intend to explain to you during the next few minutes, if you are patient enough.

LATIN AMERICAN SOUTHERN REGIONAL PROJECTS

Two years ago, in a Regional Encounter (Brazil, Argentina, Uruguay and Paraguay) of educators, amateur astronomers and a few professional astronomers, we idealized the possibility of building a regional observatory, devoted to scientific, educational and popularization of works. During the earliest discussions, we chose the Campinas Observatory (near Campinas city, Sao Paulo, Brazil) operated under a contract between three Brazilian Universities (UNICAMP, PUCAMP and Federal University of Rio de Janeiro), the municipal government of Campinas, the Federal Ministry of Education and Culture, and the amateur institution Observatorio do Capricornio.

We plan to begin with the installation of a photoelectrical photometer at the Campinas 0.6 m reflector, but the economic troubles of Brazil and Argentina made it impossible until now. Another problem was that some of the astronomers present at the regional meeting, spent some days at Campinas and did not agree that the local weather conditions where good enough to justify the choice of Campinas as the better site.

The observing conditions at Campinas are quite good in terms of image stability, transparency, humidity, and altitude (over 1000 meters), etc. Nevertheless, the total number of clear nights per year are very tiny, about 120.

Recently, the Uruguayan National Committee of Astronomy devoted new resources for the installation of an observatory near the city of Montevideo. This event opens new perspectives for the materialization of the projected regional observatory. During some talks between the Directors of both, the Department of Astronomy of the University of the Republica (Uruguay) and the Instituto Copernico (Argentina), the possibility of mounting a Robotic Observatory at this site becomes feasible.

The observing conditions at this site are quite different than those at Campinas. The total number of clear nights oscillates between 150 and 170, but the wind during these nights is variable in strength and direction. Also, the transparency and altitude (about 100 meters) are not as good as at Campinas. The image stability is comparatively good at both places. However, the economical possibilities make it a viable prospect.

Finally, besides the regional observatory, another possible project is to place a robotic observatory at the best site in Argentina, El Leoncito, San Juan, where two observatories are actually under operation. The Felix Aguilar Observatory operates an astrometric telescope (installed by Yale-Columbia Universities) and a 70 cm reflector. On the other hand, the CASLEO operates a 2.15 m reflector. The site is very interesting because of the nice atmospheric conditions, and its general characteristics. The problem is the extremely hard economical and financial situation for the science in Argentina, however it seems to be a very interesting project for the Argentine astronomical community, and also for the Uruguayan.

STELLAR SEISMOLOGY

During the last decade helioseismology, the study of the interior structure of the sun by the analysis of its surface oscillations, has blossomed. Their spectacular successes impulsed the desire to apply the theory developed for the sun to other stars.

A conspicuous group of nondegenerate pulsating stars is the δ Scuti type of variable stars in the galaxy. They are population I, A and F main sequence and giant stars which show light variations with amplitudes ranged from a few millimagnitudes up to many tenths of a magnitude, over periods ranging 28 minutes up to many hours. Some of these stars are singly or doubly periodic radial pulsators, but there is a group of multiperiodic ones that pulsate in a mixture of radial and non-radial modes.

Many reviews of these stars have been written during the last two decades. The most extensive are those of Fitch (1976), Breger (1979), Eggen (1979) and Wolf (1983). Shorter reviews are those of Kurtz (1986) and Shibahashi (1987). Lists and catalogues for these stars can be found in Breger (1979), Eggen (1979), Halprin and Moon (1983) and Garcia et al. (1988).

The astroseismologist should see the δ Scuti stars as a gold mine: many of them are naked-eye stars and very easy to observe, they are common, many pulsate in non-radial modes and some pulsate in many non-radial modes simultaneously. The latter characteristic is most important since it is the variety of spherical-harmonic modes which gives us the ability to resolve the interior structure of a pulsating star, as emphasize Kurtz (1988), in a recent paper about this matter.

The complete set of characteristics of these stars imply an adequate observational program for monitoring:

i) The star magnitude that varies during the photometric integrations. This implies that shorter integration is the best.

ii) The star colors, which also vary during the photometric integrations. This implies: no standard colors but differential photometry under the best chosen filter.

iii) The smaller known amplitude. This implies: the most careful measurement of the sky background.

iv) The variation of periods from cycle to cycle. This implies: the longer time of continuous observation, the better period determination.

Therefore, the continuous monitoring of these stars is a good challenge for a network of observatories around the world. But the best choice is a network of robotic ones, because the global monitoring task is coordinated by a rigorous computer program instead of the arbitrary time assignment done by the observatory staff committee.

The increasing accuracy of the observational methods by means of the robotic observatories, let us to encourage the application of these techniques to the observation of the δ Scuti stars. By now, precisions of the order of 1 millimag may be achieved in differential photometry, as demonstrated in a recent paper due to Young et al. (1990a & b). This is enough precision for stellar seismology. Nevertheless, as E. Nather pointed out early in this Symposium, there is a problem with the needing of simultaneous measurements of the sky, the comparison star and the variable.

CONCLUSIONS

We think that δ Scuti stars in the southern hemisphere are not adequately monitored due to the lack of observatories as well as astronomers devoted to this field of the astrophysical knowledge.

We also believe that the study and the continuous monitoring of these stars may enlighten something about the internal constitution and the structure of the stars.

Perhaps, these tasks would have been very difficult a decade ago. But at the present time, it is impossible to achieve a good result without the collaboration of the inhabitants of the whole hemisphere, prevailing the good agree with the foundations of the network of observatories all around the world.

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THE SUTHERLAND (SAAO) AUTOMATIC PHOTOELECTRIC TELESCOPE

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I. INTRODUCTION

The Automatic Photoelectric Telescope (APT) planned for the Sutherland site of the South African Astronomical Observatory is being jointly funded by the SAAO, the Universities of Cape Town (UCT) and South Africa (UNISA) and the Foundation for Research Development (FRD). This short paper describes the planned APT and reports on progress made to date.

II. HOUSING

Since this is a single APT (and it was not known if there would be more) it was decided to construct a conventional building/dome structure. A small building has been erected on the Sutherland site and a dome purchased from Ash Dome - this was chosen because the rack-and-pinion drive should allow easy digitized control although the 'roll-over' shutter might be less convenient than sideways opening shutters when observations need to be made near the zenith (the version with an extra 5° of roll-over was purchased). It was felt that a dome would give better protection from wind effects and possibly stray light. If it proves possible to build more APT's or if we agreed to host APT's for other institutes, then it would be necessary to look very carefully at roll-off sheds or roll-off roof types of housing.

III. TELESCOPES

We have adopted the basic AutoScope design (see, for example, Genet et al. 1989) for a telescope with a 0.75m diameter primary mirror; the telescope will effectively be built under licence from AutoScope. A mirror system has been ordered from the Production Technology division of the Council for Scientific and Industrial Research (CSIR); one reason for doing this is to encourage development of local expertise in reflective optics for telescopes, in the hope that mirror systems for future APT's and other instruments can be produced quickly and cheaply. The technology for producing blanks of the required size does not yet exist in S. Africa so it is our intention to purchase a blank from Hextek in the U.S.A. C.S.I.R. will also produce a focal reducer to provide a suitable field for the field identification/offset guider CCD system.

IV. PHOTOMETER AND CCD

A fairly conventional photometer is envisaged for the Sutherland APT. Filters and apertures will need to be computer controlled but almost all software necessary for this exists and is used in photometry with our existing instruments. It is intended to use a cooled GaAs photomultiplier to enable UBVRI, uvby, etc. with a single channel.

An integral part of the photometer will be a CCD system for field acquisition and off-set guiding (should this be required for "continuous" monitoring, for example). For the present, we have avoided using an astronomical quality CCD to do the actual photometry because of the cost, to simplify the data handling and to avoid the necessity of liquid Nitrogen cooling in the APT set up. It is intended to use an EEV (578x386) chip in frame transfer mode with transputer controlling electronics designed by Royal Greenwich observatory. Peltier cooling of the CCD is expected to achieve -55°C which would make dark current negligible over the short integration times envisaged for field acquisition; readout noise will probably be ~50 electrons/pixel. In white light, the system will produce ~1500 electrons/sec for the full image of a star with V ~15.5 mag. Brighter than this, there are ~300 stars per square degree at the galactic poles (Allen 1973) so that the CCD, which will have an effective size of ~6x8 arcmin at a focal reduction of 2:1, should average ~5 stars per field even in the "worst" case, enough for the field recognition algorithm to operate. The code for this has been kindly supplied to us by Butler Hine and Ed Nather of the University of Texas at Austin and operates by summing positional information (r,Θ) so that star brightnesses are not important and small field distortions will not be serious - hence it should be possible to construct "artificial" finding charts (though using the CCD to take actual frames might be easier) which can be stored as a list of positions, not a whole frame of data.

V. COMPUTER SYSTEMS

Three IBM compatible AT personal computers with 1Mb memories and 30Mb hard disks have been purchased; two will be used to control the APT, the third is a spare. The intention is to use one in much the same way that human observers use our current PC-controlled photometers. The second PC will then function as the "observer." The system can be sketched as follows:

PC1	PC2
Telescope Control	Photometer Control and data acquisition
Dome/Shutter control	
Focus Control	Wind speed and direction
monitor --> CCD control; field acquisition	Time & display --> monitor
Serial Link -->	<-- Serial Link
⇓	
"Remote"	

Input to the system will be from our existing time service, dome and focus encoders, wind speed and direction data and of course the CCD and photomultiplier output. Temporary monitors will be available to check the CCD output and the photometry in real time and provision is to be made for a manual control paddle for setting up and testing operations. It is planned to have a "remote" terminal in one human controlled dome, although it is intended that the system be fully automatic, the fact that there are always observers on site can be made of us. The remote terminal could, for example be used to override start-up or to restart the system if the weather improves after a close-down. Perhaps more importantly, a number of simple error messages (several are already included in the basic photometry program) could be sent to a human observer in the event of a breakdown. A technician could then be called to investigate the fault very quickly.

Telescope focussing will either be by measurement from the CCD or from scanning across a photometer aperture. Either test will give a measure of the seeing disk and enable the "correct" aperture to be selected. The program star database can include a maximum permissible aperture for each star (for crowded fields) and an offset to a suitable "sky" position.

Although the first Sutherland APT will probably be used in "all sky" mode, we intend to build in everything necessary for continuous monitoring so that future APT's can be directly copied from the first and individual units will be essentially interchangeable.

VI. "SMART OPERATION OF THE APT

Since the Sutherland APT will have to serve three different institutes and (probably) many different observing programmes, some kind of automatic or semi-automatic selection process will be necessary. As noted above, it is almost certain that the APT will operate mainly in the "all sky" mode, observing many stars per night with a different frequency of observation for each star. As examples, long-period variables (symbiotics, Miras, etc) might need to be observed with UBVRI once a month, other stars might be monitored with only a quick V measure until a specific "spectacular" event (say a CV outburst or RCB deep minimum) when some kind of "alert" might be made by a direct message via the remote terminal and/or the telescope could switch to a different mode of operation for that particular object, measuring perhaps UBVRI every hour or whatever is required. In order to do this the programme star database will include a mean magnitude which can be checked against the current observation; it may also be desirable to have a database of recent observations of all the programme stars on one of the hard disks.

Individual stars will be assigned a priority rating, initially perhaps on an integer scale of 1 to n, where n is the number of days between required observations. Each night that a star is not observed, the priority will decrease by one, negative values being allowed, until that star is observed, whereupon the priority rating will return to the original assigned value. Giving a star a high negative priority will assure that it is observed on every clear night. Obviously it will be necessary to check that the observing programme is full but not too full or the low priority stars will not get observed with any useful frequency. Tests are currently being carried out with artificial observing programmes and using real weather records to try to establish reasonable programme densities. Undoubtedly the system will need adjustment in actual operation!

The observing program can calculate ephemerides for the Sun and Moon (see also Warner 1990). Times of nautical and astronomical twilight can be calculated so that bright standard stars can be observed between these times. The position and phase of the Moon will be known so that stars are not observed too close to the Moon and faint stars are not observed too close to Moonrise/set. Account will be taken of the seeing conditions and the position and phase of the Moon in determining whether the system observes the brighter or fainter stars in the programme.

Although the usual procedure to observe stars near to the meridian (to minimize airmass) will be followed, it is planned that the program will arrange observations to minimize wind interference by facing the dome downwind as much as possible.

Subsidiary observing programmes will be provided so that different integration times, filter sequences and different modes of operation can be altered for.

VII. TIMESCALE

Some of the above comments are only at the "idea" stage, however, we hope to complete the telescope and photometer/CCD on a timescale of $\sim$1 year. Undoubtedly there will be a fair amount of testing, setting up and fine tuning of the system but I believe it will be a fascinating learning process for those involved. For the future, there is certainly interest in another APT or "high speed" operation (continuous monitoring of selected stars) and we shall also be giving some consideration to "networking" possibilities.

ACKNOWLEDGEMENTS

I would like to thank Darragh O'Donoghue, Digby Ellis, Angela Jones and Guy Woodhouse - all working on the Sutherland APT project - for discussions contributing to this paper.

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RETROFITTING TELESCOPES TO THE GLOBAL NETWORK

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I. INTRODUCTION

This paper is aimed at persons that I suspect are a great and underutilized resource for astronomy in this country. They include the "A" in IAPPP, the "climatically underprivileged" of Fernie, and the astronomy instructors at "comprehensive universities." Many people in these groups find themselves in the enviable position of having telescopes which are undersubscribed. Amateurs have full-time jobs which proscribe all-night observations and the affected faculty have higher than average teaching loads. Those in poor climatic areas likely miss partial nights, particularly if the clearing occurs after midnight. Can something be done to tap these resources to the betterment of the science? The answer can be yes if proper organization is achieved. The well-documented funding shortfalls for Astronomy at NSF and the uncertain near future of NASA should encourage us to explore means of organizing these undersubscribed resources. As the title of this paper suggests, I believe that telescope networks are the wave of the future, but that these networks may take several forms. Elsewhere in this book Baliunas and Crawford discuss the possible currency of telescope networks, or what's in it for me. I wish to discuss hardware limitations to networking which must also be addressed.

II. THE TRADITIONAL TELESCOPE

By the traditional telescope I mean one with a heavy mount and telescope tube, motorized manual motion control (hand paddle), manually operated instrumentation, and a manually controlled housing (dome or slide off roof). This was the typical situation at all but the largest observatories 10-15 years ago. Can such a facility possibly be involved in a telescope network?

Historically, astronomers have been quite willing to participate in international campaigns (e.g., the β Lyrae or ε Aurigae campaigns) or targets of opportunity (Pallas occultation or SN 1987a). Generally, the model of the international campaign is more applicable here, although features of both need inclusion. The campaigns are notable for their organization, standardized observing bandpasses and sequences, and finite commitment. This last point is important since it is not practical to change human nature. The usual objection to using results from different sites and telescopes is the difficulty in standardizing the data. Even if we consider broadband UBV photometry, how well matched is the data collection system (telescope, filters, photomultiplier, and site) to H. L. Johnson's standard? Observers that fall into this category should concentrate their efforts in reviewing their degree of standardization and work toward correcting deficiencies. I applaud the work of the IAPPP as well as the amateur level texts of Hall and Genet (1982) and Henden and Kaitchuck (1982) here in disseminating information on observing technique and standardization.

A telescope network can evolve out of these types of installations if they can be organized. Training workshops should be conducted to instruct observers on techniques of maximizing the usefulness of their equipment. These gatherings would have the more important function of also allowing network participants to become acquainted, which will tend to increase participation. Working at quite a different level than the GNAT this could be called the GNUT (Global Network for Unautomated Telescope). Doug Hall has been encouraging various worthy observing projects for years. These efforts might bear more fruit if standardization and teamwork became goals of the GNUT.

III. THE COMPUTER-ASSISTED TELESCOPE

The computer-assisted telescope is becoming the norm among those of you here. The computer is used for a variety of tasks from data logging to telescope control, but the observer is still assumed to be present. The observer may only have a supervisory role or he may be an integral part of the operation. There is still much to be learned by participating in the data collection process on site. One gains a better appreciation for sources of error, limits of precision, and proper observing procedures by seeing the photons come in. While users of the APT's would argue that one or two exposures to this sort of masochism is sufficient for any photometrist, there are other reason why computer-assisted telescopes will persist into the future.

Converting to a fully robotic observatory is an expensive proposition (Markworth and Dennis, 1990), much more so than computer assisted control. If the experience of the Stephen F. Austin State University Observatory is any guide, the conversion to robotic status will require:

1. A retrofit of the dome
2. Another computer to work at the remote control site
3. Communications hardware and software
4. A computer controlled weather station
5. A noninterruptable power supply
6. Software changes to handle untended operation

Another excellent reason for remaining in the computer assisted mode is student training. Although telescope operations are becoming a less necessary skill among astronomers, many of my students are attracted by the challenge of observational astronomy. The 18-inch telescope at the Observatory has been maintained at its current level of automation to act as a teaching telescope.

It is, of course, much easier for a computer assisted telescope to actively participate in any GNAT that develops. The critical need as I see it is to develop interfaces between local control and data logging software and the network standard (ATIS or its descendents). I have star catalogs prepared in my system as well as observing sequences which I prefer. I could, if need be, place any modifications in observing sequence or catalog stars onto the system, but I may not be happy to do this on a continuing basis. The interface software would do precisely this. Of course, it now becomes contingent upon all members of the GNAT to run there local systems in a flexible enough mode to allow for ATIS request from other users. A computer assisted telescope used with an ATIS interface would be functionally indistinguishable from a fully robotic telescope.

We must consider that several different forms of telescope networks are possible. Whether GNUT's or GNAT's these networks will each have their own special membership requirements.

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GLOBALIZED HIGH SPEED PHOTOMETRY

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INTRODUCTION

We seek information about what the early universe was like before we came along to look at it. The history of star formation and evolution is written in the white dwarf stars, the end-products of the nuclear burning processes that make the stars shine, and we are just now learning how to explore the archeological records these stars contain. To do so we must reach beneath their surfaces and explore their inner structure --- we can't learn very much from the traditional spectroscopic analysis of their surface gasses, which just tells us that most of the interesting material has sunk out of sight due to their intense surface gravities. About 80% of the white dwarf stars have atmospheres containing only hydrogen, perhaps 15% show only helium, and most of the remaining 5% are too cool to analyze. Until recently details of their inner structure were not observationally accessible.

The exploration of white dwarf interiors is made possible by their intrinsic variability. After a white dwarf is formed from the core of a red giant star, and its confining cocoon of gasses is ejected as a planetary nebula, it begins to cool off. Its internal nuclear furnace has shut down, so the only sources of radiant energy available are gravitational contraction and its remaining residual heat. Degeneracy pressure soon stops contraction, so the star cools at essentially a constant radius thereafter. In the process of cooling, the star glides through several temperature regions where it becomes unstable to oscillations --- a kind of continuing starquake -- and it sends forth its light encoded with information about its internal composition and structure. With the proper tools we can read those signals and start to reconstruct the galactic history they represent.

Time-series photometry --- the continuous measurement of the time-varying luminosity of a star --- is the observational tool we need to probe the interior of oscillating white dwarf stars. Unfortunately continuous measurement is hard to come by on this rotating planet, because a bright G2 dwarf comes up every morning and interrupts the time series, and clouds don't help very much either. Yet we need light curves lasting several complete 24-hour days to resolve from each other the individual frequencies present in the light curves.

THE WHOLE EARTH TELESCOPE

To get the extended time-series observations we need for our seismological analysis of white dwarf stars we have organized and are operating a global observing cooperative we call the Whole Earth Telescope (Figure 1). It can be thought of as a multi-mirror photometric telescope whose individual elements cooperate in time, rather than in space, to obtain the observations. At least one of its sites is always in darkness, often more than one. We use long distance telephone connections and electronic mail to coordinate the operation. Along the bottom of the map is a 24-hour section of the light curve of the white dwarf PG1159-035 we obtained in March, 1989, plotted so it corresponds to the observatories which produced it. Time runs from right to left, the way the world turns.

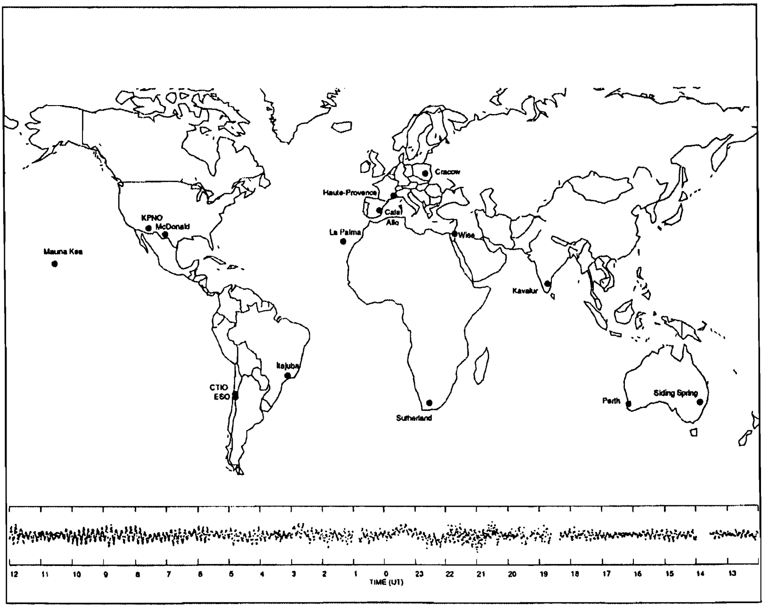

Figure 1.

The control center in Austin, Texas contacts each site prior to its twilight, to make sure the site can get observations of the primary target before a site farther east must lose it to daylight. In case of cloud or equipment trouble another site may be able to take over the primary target, if one is available near that longitude.

Overlapping observations are valuable --- they can certify that effects in the light curve are astrophysical, and not an artifact of local weather or instrumentation. We used a mixture of 2 and 3 channel photometers to get the light curve shown --- single channel photometers are simply not capable of getting all the information required for this kind of analysis. Two-star photometers can do the job, but at some sacrifice in measurement precision arising from variations in sky brightness, which they must sample rather than measure continuously. Three channel photometers, which measure simultaneously the target, sky transparency (by watching a nearby constant star) and sky brightness are the instruments of choice for this kind of work.

We were forced into this global operation by the demands of our research, not just because we thought it was a really neat idea. We saw the administrative burdens involving multinational collaboration and coordination as a strong argument against this global approach, but decided to endure them because we could think of no other way to get the data. Figure 2 illustrates the problem. The top panel shows a small portion the power spectrum of the light curve of PG1159-035 from a single site on a single (6-hour) night. The oscillations are separated into bands of power, but the bands are not resolved: their amplitudes change from one night to the next, due to constructive and destructive interference among their components (beating).

The center panel shows the result of tacking together a set of light curves taken on six successive nights from a single location. Some improvement in resolution is achieved, but at an awful price: gaps in the stream of data cause ambiguities to arise in the power spectrum --- we call them aliases ---in such a way that a single frequency, which should be represented by a single peak in the power spectrum, becomes a forest of peaks that soon becomes impossible to interpret.

The bottom panel shows the result of combining the light curves from all of the sites active during six successive dates in March, 1989 and then taking the power spectrum of the composite whole. The bands of power are now clearly resolved into apparently single, double and triple groups of frequencies which are completely stable in both frequency and amplitude. Note that the vertical scale is different for each panel; the signal-to-noise ratio is large enough that all of the significant details are not evident in a linear plot. Peaks which appear single or double can have additional components which fail to show up because of their small amplitudes. Although there are still a few data gaps they are small, and the effects of spectral leakage --- aliases --- are small and predictable. The light curve has been resolved into its individual components.

EXPLORING THE STELLAR INTERIOR

The full power spectrum of a light curve this long is a rich source of information about the internal structure of the star (Figure 3). It is comparable in information content to high resolution wavelength spectroscopy of a main sequence star, and has led us to label this process ``high resolution power spectroscopy." The two kinds of spectroscopy complement each other very well, because we learn different kinds of things from each of them.

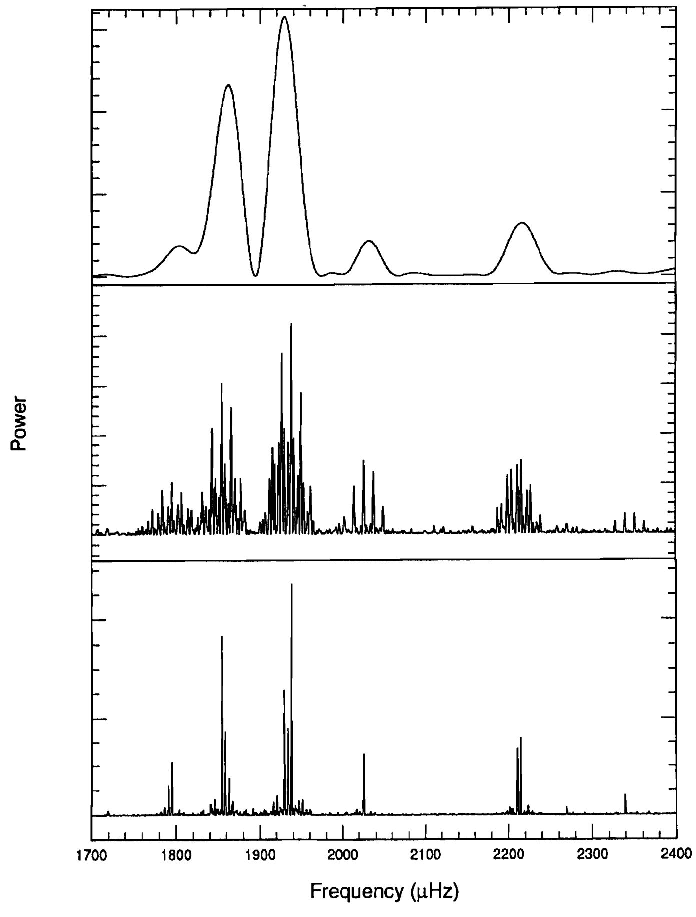

Figure 2.

We find that all of the individual frequencies present in Figure 3 between 1000 and 2600 microhertz (1000 s and 385 s periods), the only region we have analyzed in detail, consist entirely of closely spaced triplets or quintuplets. Of the 125 individual frequencies in this spectral region, 101 of them fit this pattern, and the others may well fit, but have some of their component amplitudes too small to be identified. The theory of nonradial stellar pulsations predicts just this type of arrangement.

We can turn to pulsation theory to interpret our findings in terms of the physics of white dwarf stars. To begin with, the pulsation pattern we have identified clearly shows that we are not dealing with radial pulsations --- the type of pulsations seen in the Cepheids and RR Lyrae stars --- but rather with the g-mode pulsations that have gravity (rather than pressure) as a restoring force, and consist almost entirely of material moving along the surface of the star, rather than radially in and out from the center. The very high surface gravities exhibited by white dwarfs make radial pulsations extremely hard to excite and sustain, but they are much more tolerant of nonradial processes. Where the material piles up it heats up (and brightens up), and where it is thinned out it cools off (and darkens). The theory describes the different quantized oscillation modes possible under these circumstances, and this is just what we see.

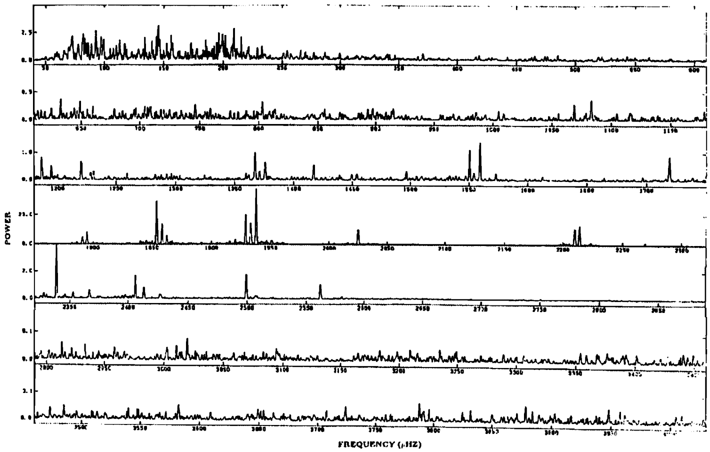

Figure 3.

By comparing our observations with theoretical models of the nonradial pulsation process, we can measure several important stellar parameters. The individual members of each triplet are equally spaced in frequency, for example, as are the members of the identified quintuplets. The spacing between the triplets is different from that of the quintuplets, and this difference allows us to identify the individual pulsation modes involved, and to show that their separations result from rotation of the star, which removes perfect spherical symmetry by making the star slightly oblate. From the average separations we can deduce that the star rotates once on its axis every 1.38 days, with an uncertainty of about 0.01 days.

Groups of triplets (and groups of quintuplets) are equally spaced in period (not in frequency) from each other, and from our stellar model of the process and the average of these separations we can measure the total mass of the star. From the average triplet spacing we measure the mass as 0.587 solar masses, and from the spacing of the quintuplets we get 0.582 solar masses. The weighted average of these values (we see more triplets than quintuplets) gives our best estimate for the mass as 0.586 solar masses, with an uncertainty of measurement of about 0.003 solar masses.

This value is model dependent, however: should further analysis show that the model we chose is not the best one, this value would be affected. We are reasonably confident, however, that the value we have extracted is within about 1% of the correct one.

The presence of a magnetic field can affect the spacing between individual members of a multiplet, and affects the different multiplets by differing amounts. From the uniformity we observe in the spacings we can set an upper limit on the magnetic field which can be present: it must be less than about 6000 Gauss. We believe this is a very conservative limit; observations of a different white dwarf in May, 1990 show fairly direct evidence for the presence of a magnetic field whose value is much smaller.

The even spacing in period between multiplets is the same on average, but individual spacings can differ from this average in a systematic way. Nonradial pulsation theory ascribes this effect to the presence of discontinuities in the star's interior. For example, we expect the different chemical elements to separate into layers under the strong gravitational fields present, with the heavier elements sinking to the center and the lighter ones floating on top. Boundaries between different elements will show up as a discontinuity, as will the transition from degenerate to normal matter. The presence of these discontinuities affects the spacing between individual modes in a predictable way, and the actual effects observed can be matched by adjusting the basic parameters of our stellar model until they agree.

We have compared our observational results with published models and find that, as expected, the outer atmosphere of the star is stratified: it fits best a model with a carbon core, a layer of helium, and a very thin layer of hydrogen on top. The fit is far from exact, however; we are sure we can do far better by adjusting the model parameters, and can then pin down interior details of composition and temperature with considerable precision.

We also observe several phenomena that are NOT described by linear pulsation theory, at least in its current form, and which suggest ways in which the theory can be improved. For example, the relative amplitudes in the triplet of greatest power have changed markedly in just a few years: the pattern we now resolve could not have been present earlier, or it would have resulted in amplitude modulation in that power band, which was not seen. Further, linear theory predicts the triplet and quintuplet amplitudes should be symmetric about the central frequency, and they clearly are not. Observational constraints can now help guide theoretical development so important effects can be identified and included.

CONCLUSIONS

The use of multiple telescopes, spaced in longitude around our planet and coordinated from a single control center, provides a new way to study stars which are intrinsic variables --- including the sun, the Delta Scuti stars, the Be stars, interacting binary stars, and oscillating white dwarfs. These telescopes can be thought of as a single instrument, and can be used to study variable stars in a new and rewarding way.

INVESTIGATING THE Be PHENOMENON THROUGH MULTIWAVELENGTH, MULTILONGITUDE CAMPAIGNS

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ABSTRACT:

Multiwavelength campaigns have proven to be useful for investigating the cause for the short-term (*rapid*) optical photometric variability in Be stars. The fact that the photometric periods are close to one day has further necessitated extended observations from spacecraft and the collaboration of astronomers worldwide. Some initial results from three campaigns are presented. We found that the light variability is apparently caused by a modulation of the photospheric temperature due to nonradial pulsations and there is evidence that these pulsations also cause an azimuthal variation in the wind. Long-term variability in the wind and FUV radiation field has been confirmed in a few objects and multiwavelength, multilongitude campaigns have also contributed toward our understanding of this heretofore unknown activity and how it relates to the Be phenomenon. Automated telescopes capable of monitoring the continuous and line spectra in the FUV would further our knowledge of the activity in hot stars and such instruments could be placed either in earth orbit or on the moon.

I. INTRODUCTION

During the 1980's a great deal of progress was made in our attempt to learn the cause for the impressive mass loss in Be stars. As a class these objects display the most variable spectra of all early-type stars. The Balmer emission lines, the FUV wind lines, and sometimes even shell features can range from strong to nonexistent in an individual object (cf. review by Doazan 1982, and Doazan et al. 1985, Peters 1988a). Since the FUV radiation field is too weak to dominate the mass loss in Be stars, the effects of mechanical transport of energy and its modulations become important and discernible.

The first Be star was discovered over 120 years ago when Secchi (1867) found Hβ emission in the bright star γ Cas. Fifty years later Struve (1931) proposed a model for the Be phenomenon which explained the mass loss as a consequence of a near-zero gravity at the star's equator due to critical rotation. This model remained essentially unchallenged until IAU Symposium No. 98 (*Be Stars*) held in Munich, W. Germany in 1981 (Jaschek and Groth 1982) where new observations in the FUV from spacecraft and high resolution ground-based spectroscopy were presented which suggested alternative explanations including rotationally enhanced stellar winds, nonradial pulsations, magnetic fields, and binary mass transfer.

II. SHORT-TERM VARIABILITY

Photometric variability on a time scale of days appears to be commonplace in Be stars. Although the first evidence for this activity was discovered in the early 1940's (Guthnick 1941), it was not until the late 1970's-early 1980's that the phenomenon was found to be widespread. The light curves of these Be stars (often called *rapid variables*) are usually non-sinusoidal, have two unequal minima (*double-wave curves*), amplitudes of 0.01-0.10 mag, and remarkably stable periods of 0.2-2.0 days. Sometimes *single-wave* or *triple-wave* light curves are observed, amplitudes can abruptly change, and variability in the absorption and emission line profiles on the same time scale has been confirmed in several stars (cf. Percy 1987 for additional details).

To investigate the cause for short-term variability in Be stars three multiwavelength campaigns (including five objects) were undertaken. Since the periods are very close to one day, continuous spacecraft and multilongitude ground-based coverage were necessary. Typically a campaign included 40-56 hours of uninterrupted coverage with the *International Ultraviolet Explorer (IUE)* with supporting ground-based spectroscopy, photometry, and polarimetry worldwide (15-25 participants). For two stars we also obtained simultaneous observations in the FUV with the *Voyager UVS* (900-1700Å, $\Delta\lambda \approx 18$Å).

FUV light curves obtained with *IUE* support an earlier suggestion that the optical variability results primarily from an azimuthal modulation of the star's photospheric temperature. In all five program stars one observes an increase in the amplitude of the light curve with decreasing wavelength suggesting values of ΔT from 300-900 K. Selected FUV light curves for λ Eri are presented in Figure 1. An interesting trend in the amplitude of the FUV light curves with orientation of the star to our line-of-sight has emerged from the observations to date (Figure 2). Be stars viewed more equator-on (Be-shell stars or objects with high $v \sin i$) appear to display a larger variation in flux.

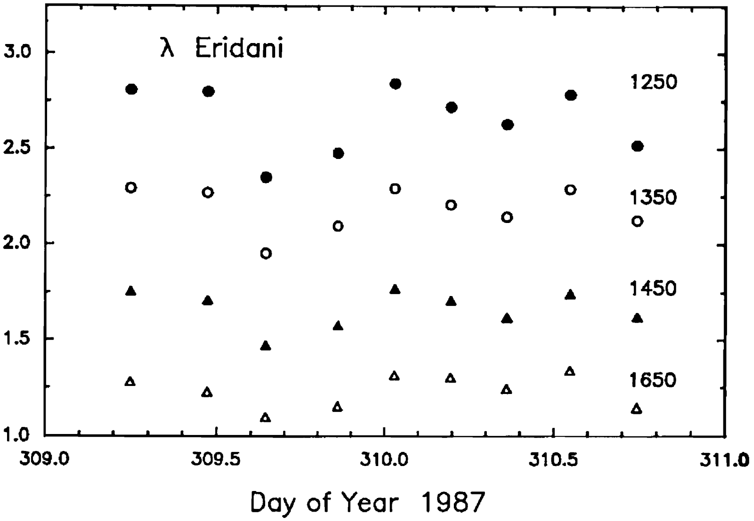

Figure 1. FUV light curves for the Be star λ Eri. A double-wave curve is seen with an amplitude that increases toward shorter wavelengths. Kurucz (1979) models suggest a $\Delta T_{phot} \approx 850$ *K.*

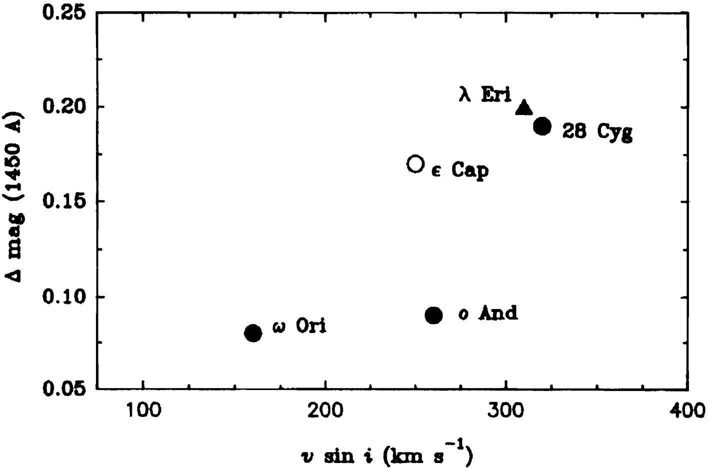

Figure 2. The amplitude of the light curve at 1450Å versus the star's v sin i. Bin widths for all FUV curves are 50Å. ε Cap is a Be-shell star; λ Eri has been especially active lately.

IUE observations have also revealed an azimuthal variation in the wind which correlates with the phase in the light curve. Illustrated in Figure 3 are some results from the Be-shell star ε Cap obtained in 1988 September. The FUV light variations were found to be large ($\Delta T \approx 600$ K), and the period very close to 24 hours (23.6±0.4). With $\Delta M_V < 0.05$ mag and such a period, it would be very difficult to confirm the temperature modulation from ground-based observations at a single site alone. High resolution *IUE* images revealed the phase-dependent variations in C IV 1550Å shown in Figure 3. The overall absorption equivalent width tended to be larger when the FUV flux was near maximum. Alternatively, the absolute intensity of the C IV emission component was anticorrelated with the absorption strength and FUV flux.

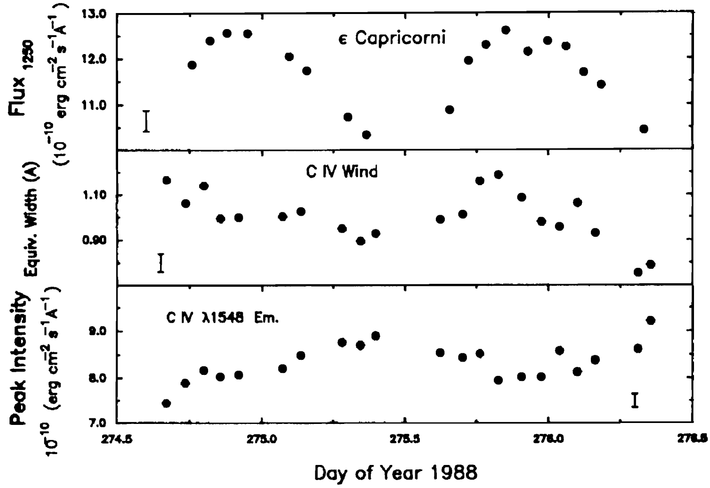

Figure 3. Variation in the wind in ε Cap versus phase in FUV light curve. Shown are the 1250Å flux, equivalent width of the C IV wind line, and the peak intensity of its emission component.

Our multiwavelength campaigns have furnished strong support for the model that explains the phenomenon of *rapid* variability in Be stars as being caused by the presence of nonradial pulsations in low-order sectorial modes, and these pulsations apparently modulate the mass loss as well. Many features of the generic model shown in Figure 4 are apparent: the temperature modulation (a result of the hot/cool patches swinging into our line-of-sight as the star rotates), the trend in ΔM with orientation (in pole-on stars one views most of the hot/cool patches continuously), and the enhancement of the wind above a hot crest (C IV absorption largest when a crest is along our line-of-sight and the emission component strongest when it is near the limb and a cool trough is in front). A more complete preliminary report on the results from our campaigns can be found in Peters (1990), and the full details will be published later.

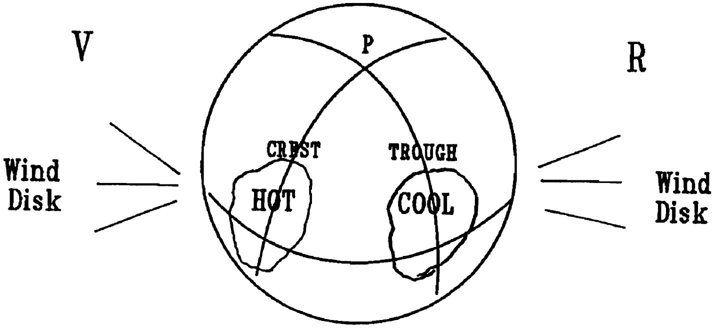

Figure 4. *Generic model for a Be star pulsating in a sectorial* $\ell = 2$ *mode. Equatorial hot and cool patches due to the pulsations are shown. Only a general location for the wind/disk is indicated. The star rotates counterclockwise.*

III. DISCUSSION

Multiwavelength, multilongitude campaigns appear to be an effective approach for investigating the cause for the copious mass loss in Be stars. We have learned much about the phenomenon of *rapid* photometric variability already, but the results discussed above need to be confirmed in other objects. In addition to short-term variability, multiwavelength monitoring has also revealed some interesting heretofore unknown long-term effects including *abrupt* changes in the mass loss and condition of the photosphere (Peters 1988a,b,c). A recent noteworthy result is that variations in the Hα emission and wind in 66 Oph are correlated and thus link the mass loss in the disk to that observed in the wind at intermediate latitudes (Peters and Dempsey 1990).

To learn the nature of activity in the hot stars intensive, long-term observations are required. Within the past few decades, activity cycles have been confirmed in many cool stars as a result of monitoring programs (Baliunas and Vaughan 1985), but the interpretation of the results are guided by our knowledge of the sun's variability. However for the early-type stars we do not have a paradigm to follow, and therefore observation becomes exceptionally important. Certainly an automated telescope capable of monitoring both the continuous and line spectra in the FUV is needed. Such an instrument could be placed either in earth orbit or on the moon.

The campaigns discussed in this paper could not have succeeded without the participation of many astronomers whose names are too numerous to mention here. I would like however to especially thank J.R. Percy, H.F. Henrichs, D. Gies, and D.

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Section VI.

Research Programs

THE TENNESSEE STATE UNIVERSITY ROBOTIC ASTRONOMY PROGRAM

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The robotic astronomy program in the Center of Excellence in Information Systems Engineering was established in 1988 at Tennessee State University, an historically black university (HBCU) located in Nashville, TN (Busby, 1989). In only two years, the Center has made substantial progress in the development and use of robotic telescopes for making systematic astronomical observations. With a permanent staff of two astronomers, a program analyst, and a mechanical engineer along with consultants and visiting professors from Vanderbilt Dyer Observatory, Fairborn Observatory, and the Harvard-Smithsonian Center for Astrophysics (CfA), we are applying a combination of photometry, spectroscopy, and theoretical calculations to form models of stars and their physical processes. Generally, we are investigating the properties of dark spots and bright active regions on cool dwarf and giant stars, the structure of the chromospheres of cool giant stars, cycles in the magnetic activity in the outer envelopes of cool stars, the interior structure of stars with convection zones, and the structure of a wide variety of binary stars. Specific questions being addressed are: (1) On what timescales does the brightness of spotted stars vary, and what does this tell about the spots and the way they are generated? (Hall and Busby, 1989), (2) How are spots related to the hot dense gas of active regions seen emitting above the surfaces of cool magnetic stars? (Hall, 1990), (3) Are there spots on all cool stars, specifically on the cool luminous giants thought not to have solar-style active regions?, (4) Are all cool stars magnetic, and is the chromospheric heating different in the coolest stars than in the sun? (Eaton, Johnson, and Cadmus, 1990), (5) What role does convection play in the structure and evolution of binary systems? (Eaton, 1990a), and (6) Do the new-est theories on circularization and synchronization agree with observations of chromospherically active binaries? (Hall and Henry, 1990).

Stellar photometric data relevant to answering these questions are being obtained from APT's. The Center of Excellence, in collaboration with Vanderbilt University, operates an APT on Mt Hopkins in southern Arizona. The data from this 0.4-m telescope are transmitted to the Center of Excellence where they are reduced, analyzed, and archived. In addition, a new collaboration has begun with astronomers at the Harvard-Smithsonian Center for Astrophysics (CfA) to expand the study of stellar magnetic activity on additional types of stars. The Center now manages a second APT on Mt Hopkins to gather the necessary data, and soon a third, larger (0.75-m) and more efficient telescope will be put into operation at the same site. To expand the possibilities of networking these telescopes together to further improve data collection, TSU and CfA astronomers are currently planning and seeking funding to build a fourth APT at Mt Wilson Observatory in southern California.

APT's have the promise of addressing a number of outstanding problems in stellar astrophysics. Their strength lies in their ability to observe tirelessly for long periods of time. Thus, investigations that study the long-term (months-to-decades) changes in stars can be profitably undertaken, while using manual telescopes for these has become prohibitively expensive in terms of astronomers' time. The most exciting use of APT's to date has been in the systematic study of dark spots on the surfaces of stars as cool as the sun's. These spots appear on almost all rapidly rotating dwarf (diameters like the Sun's) and giant (10 times the Sun's diameter) stars with surfaces cooler than about 6500K. Our observations with APT's have begun to measure the lifetimes of individual spots and to show that there are magnetic cycles in these stars, just as in the sun. Seven years of APT observations now exist for many such heavily spotted stars, and these are now beginning to define the systematic properties of stars with very high levels of magnetic activity (Hall, Henry, and Sowell, 1990). In the future we anticipate using the same techniques for systematically studying cool stars more like the sun, those that rotate slowly and do not have spots dominating their visible light. Preliminary results based on very painstakingly manual photometry indicate these stars become brighter when they are more magnetically active. If the sun, along with these similar stars, actually does this, it would have dramatic effects on the Earth's climate and could explain most of the temperature rise observed over the past 150 years.

We are currently developing computer systems and procedures for the routine, nearly automatic reduction and cataloguing of the vast amounts of data being generated by these APT's and for controlling these devices more imaginatively. To date, the telescopes have been programmed to measure a target star only once per night. Given the advances in communication between computers, it will be possible to direct APT's to observe a star that may be eclipsing or otherwise changing brightness rapidly for large parts of a night and to integrate such observations into our general program of photometry of variable stars with long periods. This feature will make the APT's much more capable of supporting real-time spectroscopic observing with satellites or ground-based telescopes.

With the use of APT's, the most tedious part of obtaining photometry has become the planning stage, i.e. selecting comparison stars, checking for background stars that would contaminate the measurements, and assembling the resulting information in electronic files for transmission to the APT's. To date, this has involved searching printed catalogues and star charts by hand to cull the appropriate information. We have now established a system for doing this electronically in collaboration with the library at Vanderbilt University. It utilizes astronomical catalogues stored on computers, which allows us to search the region of the sky near a variable star to find appropriate comparison stars, to detect contaminating background stars, to make electronic files of information about the stars for direct transmission to the APT's, and to plot charts at convenient scales for comparing with the Palomar Sky Survey and to serve as finders for ancillary spectroscopic observing. Catalogues in hand are the Yale Bright Star Catalogue, which contains stars brighter than about 6th magnitude, and the SAO Catalogue, which contains almost all the stars that can be observed with the present generation of APT's. In the future we expect to obtain the Space Telescope guide star catalogue, which contains all possible background stars that could conceivably contaminate our observations of even the fainter variables. Having this catalogue will also give the advantage of allowing us to prepare finder charts electronically that are at least as good as a photograph of the sky.

The second thrust of our program in astrophysics is to apply spectroscopy to stellar astrophysical problems, most related to the general question of magnetic activity of cool stars. Data are being collected with the International Ultraviolet Explorer satellite, which contains spectra for the range 1200-3200 A, and with the ground-based telescopes of the National Optical Astronomy Observatories (KPNO, NSO, and CTIO).

Such spectroscopic observations are being used to determine the physical conditions (such as temperature, density, extent, and mechanisms of heating) of chromospheres of cool giant stars. These regions are thought to be supported above the stellar surface by magnetic fields which are important in heating the gas they confine, either through magnetohydromatic waves or simple shocks generated in the stellar surface but channelled by the fields. In an extensive set of studies we use observations of eclipsing binaries to sample chromospheric gas above the limb of a cool giant star (Eaton, 1990b; Eaton, 1988; Eaton, et. al., 1990). As light of a small, hot dwarf star passes through the gas, some of it is absorbed in ways that let the temperature, density, ionization, and chemical abundance of the gas be determined. Such observations are best done and scheduled in much the same way as APT observations, and the photometry of APT's is instrumental for their interpretation by allowing the phasing and geometry of these atmospheres to be determined. Satellite observations of the binary AL Vel, analyzed this past year, show that atmospheric eclipses can be applied to somewhat less luminous stars than those studied in the past, indicate a lower chromospheric extent than in the more luminous stars, but suggest that temperatures in the upper chromosphere are at least as hot as in supergiant stars (Eaton, et al, 1990). Systems currently being observed are δ Sge, 31 Cyg, 32 Cyg, ζ Aur, and 22 Vul. Satellite observations showing atmospheric eclipses and variation of the cool giant's wind are being collected for the first two, and the whole group is being observed in the optical at the National Solar Observatory to study atmospheric eclipses in hydrogen lines.

In another investigation, we have studied the effect of stellar pulsations on chromospheres of semiregular variables to determine how chromospheres of M giants are heated and to estimate the spatial extent of these chromospheres and how they are related to the stars' photospheres. (Eaton, Johnson, and Cadmus, 1990) Variations of chromospheric emission in three cool semiregular variables are intimately related to changes in luminosity in ways suggesting chromospheric heating by pulsationally driven shock waves.

High-dispersion spectra have been used to reveal the distribution of dark spots on rapidly rotating stars by the way dark areas change the Doppler broadening of line profiles. When combined with photometry, this technique offers very accurate views of stellar surfaces. A case in point is HD 26337, recently studied by Strassmeier (1990), for which a combination of polar and non-polar spots was found to fit observed line profiles.

Spectroscopic observations are being used to determine the effect of convection in binary stars of moderate effective temperature (7000-9000 K) and to form models of circulation of convective common envelopes in contact binaries (Eaton, 1990c). Stars as cool as the sun have convective energy transport through about the outer 20% of their radii, but in stars of higher surface temperature, this convective zone becomes less extensive, and the magnetic activity it generates is lessened. Knowing the temperature at which convection becomes unimportant is necessary for constraining models of convection zones in all cool stars, the sun included.

In a related group of studies, rapidly rotating K giants (5 Ceti and UU Cnc) in binary systems are being used to determine the response of a normally slowly rotating evolved cool star to rapid rotation (Eaton, 1990b; Eaton, Hall, and Honeycutt, 1990; Tout and Hall, 1990). We are using spectroscopy to determine the effect on chromospheric emission and APT photometry of such stars to study the effect of production of star spots. These observations indicate, contrary to some theoretical predictions (e.g. Tout and Hall, 1990), binary systems containing cool giants can transfer mass from the giant to its companion by Roche lobe overflow without suffering catastrophic orbital decay. Emissions from chromospheres of such giants is only ~4x that of comparable single stars.

It is anticipated that the robotic astronomy research program will continue to expand at TSU. The university is committed to the effort, and we are optimistic about obtaining continued external funding.

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NEW RESULTS ON V711 TAU FROM THE VANDERBILT - TENNESSEE STATE 16-INCH APT

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I. INTRODUCTION

V711 Tau (= HR 1099 = ADS 2644A) is a well known double-lined, chromospherically active binary system with a period of 2.8 days and spectral types K1 IV and G5 V-IV. It has been studied extensively at visible, ultraviolet, radio, and X-ray wavelengths and has been observed photometrically by robotic telescopes every year since the fall of 1983 when Lou Boyd put it on the menu of his newly completed Phoenix 10-inch APT at the request of Hall. Seven years of APT data now exist for V711 Tau (Figure 1), the 16-inch having taken over observing in the fall of 1987. The light curve is dominated by a slowly migrating spot wave (Figure 2) with an amplitude of up to 0.22 mag. in V (Bartolini et al. 1983) and a period very nearly equal to the orbital period (Strassmeier et al. 1989). Dorren and Guinan (1982) have successfully modeled the changing shape and amplitude of the light curve using two cool, circular spots that vary in area and position on the K1 star, which has the stronger Ca II H and K emission. Dorren and Guinan (1990) have also examined the magnetic activity changes on V711 Tau as revealed in ultraviolet emission lines and related these changes to spot activity. The first spectroscopic orbital solution was given by Bopp and Fekel (1976) and was updated by Fekel (1983) where the following parameters are given:

$e = 0.0$ (assumed)
$T_{conj} = 2{,}442{,}766.080$ (K1 star in front)
$P_{orb} = 2.^{d}83774 \pm 0.^{d}00001$
$a_1 \sin i = 1.93 \pm 0.02 \times 10^6$ km $\qquad a_2 \sin i = 2.41 \pm 0.02 \times 10^6$ km

$M_1 \sin^3 i = 0.224 \pm 0.005\ M_\odot$ $M_2 \sin^3 i = 0.180 \pm 0.004\ M_\odot$

$M_1 / M_2 = 1.25 \pm 0.02$

$V_1 \sin i = 38 \pm 1$ km / sec $V_2 \sin i = 13 \pm 1$ km / sec

The subscript 1 refers to the brighter, more massive, more evolved, and more active K1 star.

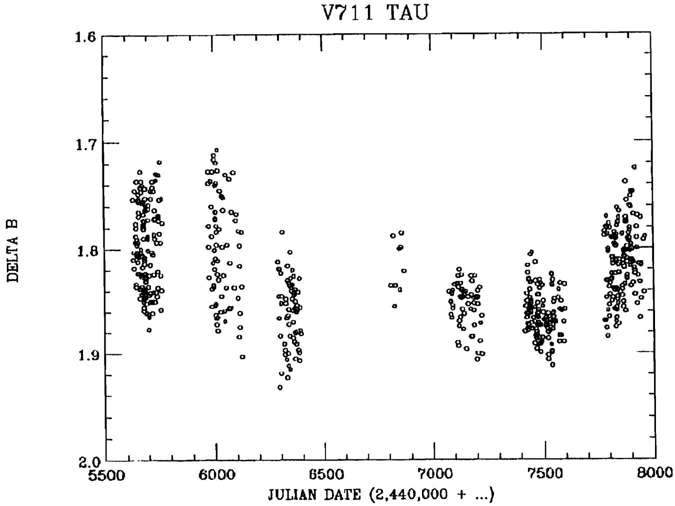

Figure 1. *Over 600 group observations were made with the 10 and 16-inch APT's from 1983 to 1990, covering 7 observing seasons. The first 4 seasons are 10-inch data, season 5 contains 10 and 16-inch data, while seasons 6 and 7 are 16-inch data. Note the amplitude, mean magnitude, maximum magnitude, and minimum magnitude are all variable.*

ADS 2644B is a K3 V (V = 8.83) visual companion six arcseconds distant from V711 Tau. Because of the fortunate existence of this physically associated yet non-interacting companion, Bopp and Fekel (1976) were able to use observations of its Ca II H and K emission lines to derive the age of the system from the inverse relationship between age and H and K emission strength. Using the resulting age estimate of 2×10^9 years, along with the evolved nature of the primary and its minimum mass from the spectroscopic orbital solution, Fekel (1983) was able to significantly constrain the mass of the primary and hence derive an estimation for the inclination of the system. His inclination, along with the resulting masses, radii, and equatorial rotation velocities are:

$i = 33^\circ \pm 2^\circ$

$M_1 = 1.4 \pm 0.2\ M_\odot$ $M_2 = 1.1 \pm 0.2\ M_\odot$

$R_1 = 3.9 \pm 0.2\ R_\odot$ $R_2 = 1.3 \pm 0.2\ M_\odot$

$V_1 = 70 \pm 4$ km / sec $V_2 = 24 \pm 4$ km / sec

As will be shown below, the expanding primary now fills 80 percent of its Roche lobe radius, indicating the system is in a pre-mass transfer evolutionary state and should begin mass transfer in only 70 - 80 million years (Fekel 1983).

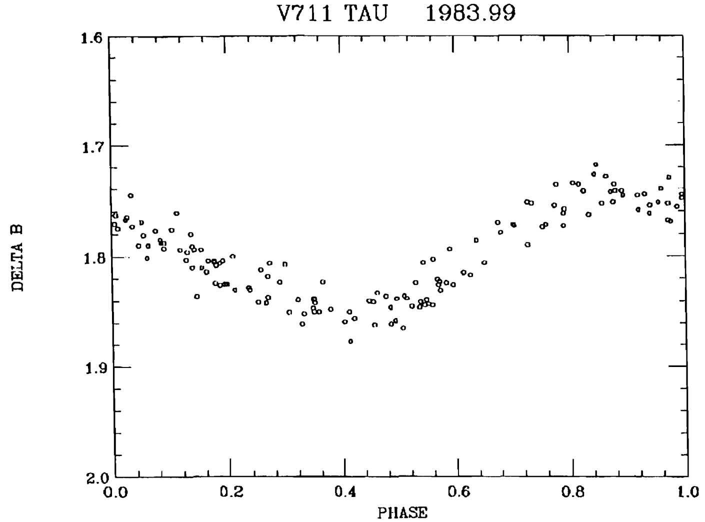

Figure 2. Phase plot of the first season of data from Figure 1 using Fekel's time of conjunction and orbital period. A spot wave is evident with an amplitude of 0.10 mag. and a minimum at phase 0.4. The comparison star for all photometry was 10 Tau.

II. SEARCH FOR THE ELLIPTICITY EFFECT

Because an evolved star is present in this short period binary system, resulting in a large relative radius for the primary star, it is reasonable to expect an ellipticity effect to be present in the light curve, even though that effect is masked by the larger spot wave. As a first step in searching for an ellipticity effect, a period search was performed by fitting sine curves to phase plots using a range of trial periods and looking for minima in the resulting sums of the squares of the residuals. Separate period searches using the B and V data from the APT's covering 1.0 to 3.0 days with a 0.001 day step size were executed with identical results. Figure 3 shows the periodogram resulting from the blue APT data. The deepest minimum occurs at 2.837 days and corresponds to the spot rotation period. The two shallower minima on each side of the spot period (at 2.811 and 2.859 days) are the one year aliases of the spot period resulting from the seasonal gaps in the data. Another alias corresponding to the sidereal day is present at 1.538 days. Finally, a very shallow minimum at 1.419 days is present. Because this minimum occurs at precisely half the orbital period, it does suggest the existence of a small ellipticity effect.

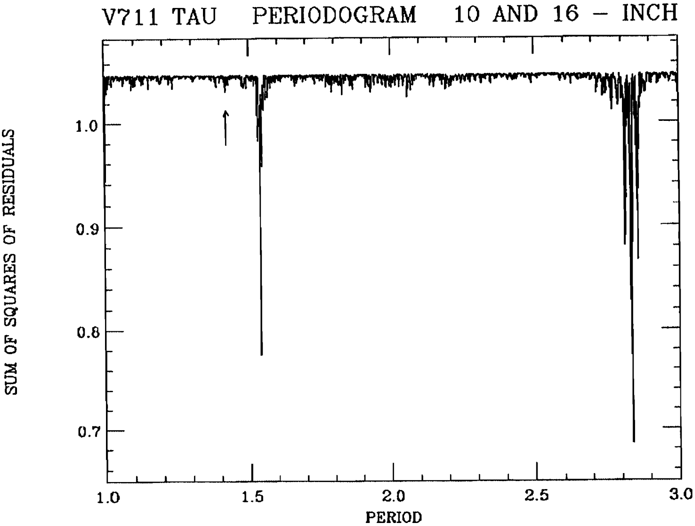

Figure 3. *Periodogram using 7 years of the blue APT data. The 2.837 day spot period as well as its 1 sidereal day and 1 year aliases are present along with a shallow minimum (arrowed) at 1.419 days, precisely half the orbital period, indicating a small ellipticity effect is present.*

If the 1.419 day periodicity is real and the result of the ellipticity effect (and not, for instance, the result of two spots on opposite sides of the K1 star), then the minima of the light variation at that period must occur at the conjunctions. To check this, least squares sine fits were made to the entire B and V data sets where the abscissae were phase units computed with the spectroscopic time of conjunction and one half the orbital period. In this case, the light variations due to migrating spots should produce a random scatter, and only a coherent 1.419 day periodic effect would produce a significant amplitude. Figure 4 shows the resulting phase plot and sine curve fit for the blue data. The full amplitude is 0.016 ± 0.005 magnitudes and the phase of minimum is 0.070 ± 0.050 in one half orbital phase units. Converting the phase of minimum back to orbital phase units and including the results from the visual data, we have:

	B	V
Full Amplitude	0.016 ± 0.005	0.017 ± 0.006
Phase of Minimum	0.035 ± 0.025	0.034 ± 0.028

It can be seen for both B and V that a significant amplitude is present and that the phase of minimum matches the time of conjunction very closely. Fekel did not publish an uncertainty for his spectroscopic time of conjunction, so his original radial velocity data were obtained and independently analyzed to derive the errors in the period and time of conjunction. Carrying the errors forward to the current epoch results in an uncertainty of 0.014 phase units. Therefore the photometrically determined time of minimum of the ellipticity effect agrees with the spectroscopically determined time of conjunction to within their errors. It could still be argued that this effect is caused by two small spots on opposite sides of the star and lined up with conjunction. However, since this result is derived from seven years of APT data, and since larger spot waves on V711 Tau have always migrated, the ellipticity effect seems the most likely explanation.

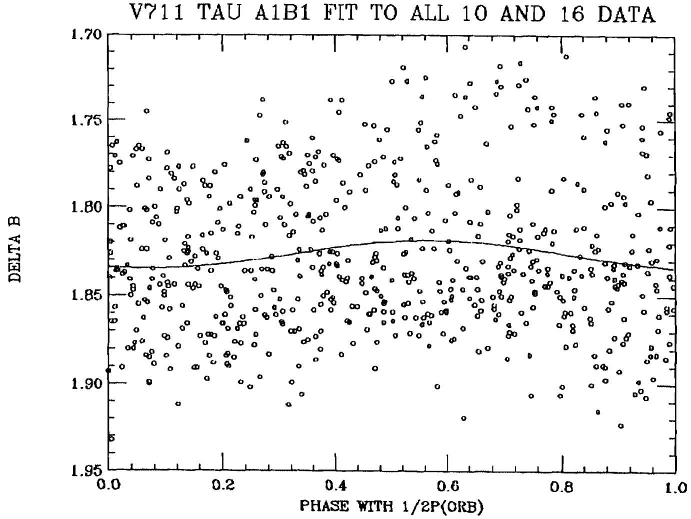

Figure 4. Sine curve fit to the blue APT data using phases computed with the time of conjunction and one half the orbital period. The 1.5% full amplitude and the minimum at conjunction confirm the presence of the ellipticity effect.

Further confirmation comes from examining light curves from epochs where the amplitude of the spot wave is greatly diminished. Figure 5 show a phase plot of the 16-inch APT data taken during our sixth observing season (1988.95). This low amplitude light curve is double humped with minima near the times of conjunctions suggesting that the spot wave has decreased in amplitude to the point where the ellipticity effect can begin to show up. Bartolini et al. (1983) present 14 light curves between 1978.85 and 1981.19. In all cases where the amplitude was small (from

1980.73 on), the light curve was also double humped with minima near phases 0.0 and 0.5.

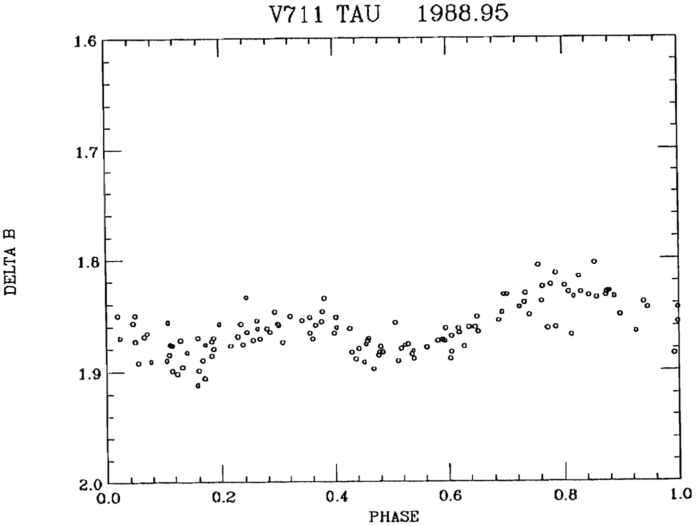

Figure 5. *Phase plot of the sixth season of APT data demonstrates that the spot wave has diminished to the point that the ellipticity effect can be seen.*

III. DERIVATION OF THE INCLINATION

The relative radius of the K1 primary is three times that of the G5 secondary and, as will be seen below, the amplitude of the ellipticity effect depends on the cube of the relative radius. This, combined with the fact that the primary is brighter, means it can be assumed that all of the ellipticity effect is due to the primary. The observed full amplitude of 0.017 mag. in V must be scaled up to correct for the light of the second and third components measured in the 60 arcsecond aperture of the APT's. Eggen (1966) gives V = 5.88 for the combined light of components 1 and 2 (i.e. the SB2 pair) and V= 8.83 for the third component six arcseconds away. From the equivalent widths of their spectral lines, Fekel (1990) gives 6.30 and 7.23 as the best estimates of the individual V magnitudes of components 1 and 2, with an uncertainty in the difference of about 0.2 mag. Therefore, the ratio of the combined intensity of the three stars to the intensity of component 1 is 1.52 : 1. The full amplitude of the intrinsic ellipticity effect due to component 1 is then

$$E_1 = 0.026 \pm 0.009 \text{ mag.}$$

where the uncertainty is due to the uncertainty in both the observed ellipticity effect and the magnitude difference between components 1 and 2.

As pointed out by Hall (1990), knowing the amplitude of the ellipticity effect for one component of an SB2 binary provides an additional constraint on the elements of the system that allows the explicit derivation of the inclination of the orbit to our line of sight. For V711 Tau, using Fekel's spectroscopic orbital solution, the projected semi-major axis is

$$a \sin i = a_1 \sin i + a_2 \sin i = 4.34 \times 10^6 \text{ km} = 0.029 \text{ a.u.}$$

Because the primary star rotates synchronously with the orbital period and its Vsin i is known, it follows that

$$V_1 \sin i = (.92)(2\pi) R_1 \sin i / P_{\text{orb}} = 38 \text{ km / sec}$$

and

$$R_1 \sin i = 0.0091 \text{ a.u.}$$

The factor of 0.92 above is the ratio of the transverse radius of the star to its mean radius and, as explained by Hall (1990), is necessary because the value used for Vsin i was determined from observations over a range of orbital phases and so refers to a mean radius while the value of r1* below refers to the transverse radius. The relative radius of the primary star is

$$r_1 \equiv R_1 / a = R_1 \sin i / a \sin i = 0.314 \text{ a.u.}$$

The relative (transverse) radius of the primary's Roche lobe (Kopal 1959, table 3-1) is

$$r_1^* = 0.39501$$

so the Roche lobe filling factor is

$$F_1 = r_1 / r_1^* = 0.795.$$

The full amplitude of the ellipticity effect in magnitude units as a function of system parameters is given by Hall (1990) to be

$$E_1 = k (M_2/M_1) r_1^3 \sin^2 i$$

where

$$k = 3.5 + 0.8 (F_1)^6.$$

Solving this equation for the inclination gives

$$i = 32° \pm 6°$$

where the error arises primarily from the uncertainty in the size of the ellipticity effect.

IV. IMPLICATIONS

Because the inclination derived above agrees so closely with Fekel's estimated value, no revision of his masses, radii, or equatorial rotation velocities is necessary. In addition, since the calculated orbital phase of the minimum of the ellipticity effect agrees with the spectroscopic time of conjunction, no revision of the orbital period is needed. It can be noted, however, that such a photometric analysis a few years hence could allow an improvement to the spectroscopically determined orbital period and time of conjunction.

The presence of the ellipticity effect in V711 Tau does affect the interpretation of the light variations in terms of spot models. As noted above, whenever the amplitude of the spot wave decreased below a few hundredths of a magnitude, the light curve always revealed double minima near the conjunctions. The sixth season of APT data, shown in Figures 1 and 5, most clearly shows this effect. Yet Figure 1 reveals that even at maximum light during the sixth season, the light level of the system was still about 0.1 mag. lower than it was during the second season of APT data indicating that significant spot coverage was still present. This can be explained by a large spot near the pole that would depress the light level and yet cause minimal modulation (any spot above 32 degrees latitude would be circumpolar) combined with a dissipation of the lower latitude spots that do effectively modulate the light which then allows the ellipticity effect to become visible. This is consistent with the Doppler images of Vogt (1988) that often show a large spot centered on the pole. Rather than interpreting these light curves as resulting from two spots on opposite hemispheres of the star, the ellipticity effect should first be removed and then the light curve examined for any remaining spot activity.

ACKNOWLEDGMENTS

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MONITORING A COMPLICATED CEPHEID

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We obtained 88 V and 89 B observations of the unique Cepheid, HR 7308, over a period of 570 days, during which the amplitude was of the star was observed to increase from $0^m.12$ to $0^m.36$. The period of the star is shown to be around $1^d.490808 \pm 0^d.000010$. It is also shown that while the amplitude change is cyclical, it does not appear to be simply periodic.

INTRODUCTION

HR 7308 (HD 180583, V473 Lyrae) was originally discovered as an semiregular variable in 1969 by Breger (1969) and was later independently rediscovered as a periodic variable in 1979 by Percy, et. al. (1979). Since the early 1980's, several papers have appeared noting HR 7308's unique behavior. HR 7308 appears to be a classical Cepheid (Burki and Mayor, 1980b) lying beyond the red edge of the instability strip (Fernie, 1982) on the H-R diagram. It has the shortest known period for a classical cepheid, about 1.49^d, and it is the only known example of an amplitude changing classical Cepheid. And while several explanations of this amplitude variation have been proposed (Burki, et. al., 1986), it should be noted that it appears that the beating of two modes with closely spaced frequencies has been ruled out (Percy & Ford, 1981).

Fairborn Observatory's Phoenix 10 Telescope, an Automatic Photoelectric Telescope (APT) on Mt. Hopkins (Boyd, et. al., 1986), was used to monitor the star from early 1987 to late 1988, a time interval of about 570 days.

OBSERVATIONS

The APT obtained differential magnitudes with respect to the commonly used comparison star HR 7280 (HD 179422). During the time interval between JD 2446905 and JD 2447477, we obtained 88 delta V and 89 delta B observations. In Figure 1, data from early 1987 and late 1988 is compared, clearly showing a rise in amplitude by a factor of 3 during this time interval. Also seen in Figure 1 is the change from a sinusoidal light curve at low amplitude to a non-sinusoidal light curve at high amplitude, when the rise to maximum light is steeper than the fall to minimum.

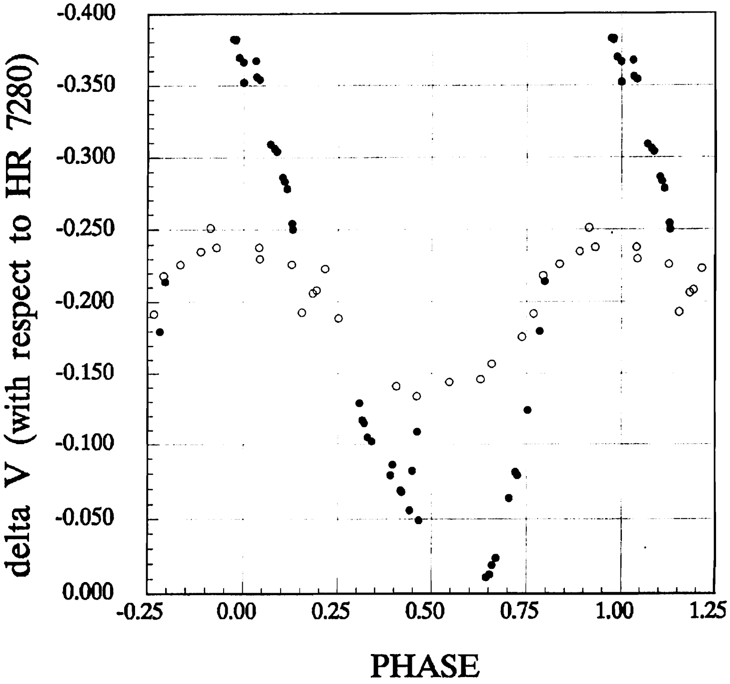

Figure 1. This graph shows the changing light curve of HR 7308 during two different time intervals near minimum amplitude (JD 2446905-2446985; hollow dots) and near maximum amplitude (JD 2447415-244747;filled dots). These light curves were constructed using a period of $1^d.490808$ and an epoch of maximum of JD 2439302.795. Notice that when the amplitude is small, the light curve is sinusoidal and when the amplitude is large, the light curve is asymmetric.

ANALYSIS

The APT V observations on HR 7308 were divided into 4 time intervals so that there would be a roughly constant amplitude during each time interval. The harmonic filter in Ferraz-Mello's (1981) Date Compensated Discrete Fourier Transform was used to obtain values for the amplitude and mean of the light curve during each of the four time intervals, assuming a period of about $1^d.491$. The light curves from the various time intervals were then normalized to have an amplitude of 1.00 and their individual epoch of maximum determined. The normalized data were folded at the known period and smoothed to obtain an average curve.

The smoothing program adopted divides the light curve into bins of a specific phase width. The program used finds the mean magnitude value for that bin and then advances to the next bin, a submultiple of a bin width down the curve, and finds the mean of that bin. This process is repeated until the entire smoothed light curve has been constructed numerically. The fact that the light curve of HR 7308 changes shape does present the possibility of some error in the smoothed curve, however by creating this composite light curve from 4 separate, normalized light curves (with a range of amplitudes), it was hoped that an average light curve for the star would be obtained.

A non-linear least squares curve fit (Belserene, 1986) was used to find the O-C values of these 4 separate light curves based on the smoothed composite curve. In this case, the value of O-C is calculated by comparing the smoothed light curve with a period of $1^d.490975$ (Burki, et. al., 1986) and an epoch of maximum at JD 2439302.795 (Breger, 1981) to the actual phase data, giving us a phase shift.

O-C values for previously published data (Percy and Evans, 1980, Breger, 1981, & Burki, et. al, 1986) were computed in the same fashion and plotted with our data on one O-C graph (Figure 2). On this graph, a least squares line is plotted. It corresponds to a period of $1^d.490808 \pm 0^d.000010$ and an epoch of maximum of JD 2443745.330± 0.019.

Previous work had indicated that the amplitude variations were possibly periodic with reported periods of 955^d (Percy and Evans, 1980), 1210^d (Percy and Evans, 1980, Percy and Ford, 1981), or 1400^d (Burki, et. al., 1986). Analysis of previous data (Percy and Evans, 1980, Breger, 1981, & Burki, et. al., 1986) combined with the new APT data indicates that there is no constant period for the long-term amplitude modulation. This can be seen by noting that there appear to be two observed minima, at JD 2439300 (Breger, 1981) and at JD 2444000 (Burki and Mayor, 1980a). The difference of 4700^d between these minima indicates that a submultiple of 4700 days would have to be the period if the change in amplitude was simply periodic. The data show that the long-term period must be shorter than 4700^d and longer than 550^d (Since our data only shows a rise in amplitude over a time interval of at least 550 days). All the submultiples in between imply minima at dates our data do not support with the exception of the submultiple of 2350^d. We note that there have been two consecutive maxima observed, around JD 2444840 and JD 2446240 (Burki, et. al., 1986), indicating a period of amplitude oscillation of about 1400^d. Therefore, it appears that there is no simple period of amplitude oscillation that can account for both the pervious observations and our APT observations. It can only be said that HR 7308's amplitude change is cyclical, on a time scale of 1000^d to 1500^d.

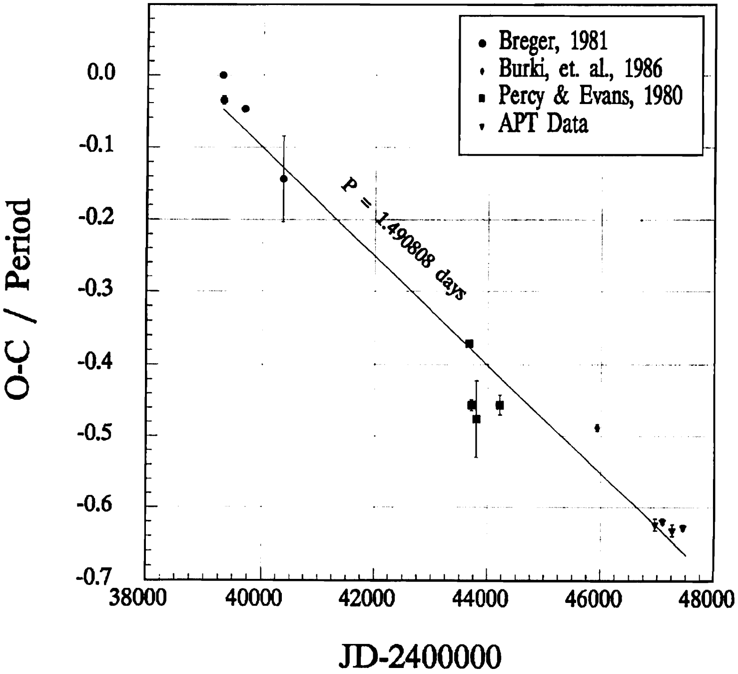

Figure 2. In this O-C graph, O-C is calculated by comparing a smoothed light curve with period $1^d.490975$ and an epoch of maximum of JD 2439302.795 to the actual phase data, giving us a phase shift. The line represents the least squares fit for this data, indicating an revised period of $1^d.490808 \pm 0^d.000010$ and an epoch of maximum of JD 2443745.330± 0.019.

It should also be noted that two consecutive minima were noticed around JD 2444000 and JD 2445200 (Burki, 1984), indicating a period of only 1200^d. Subsequently, we can see that HR 7308 rose from minimum to maximum amplitude in about 840 days and then quickly dropped from maximum to minimum amplitude in about 360 days. Apparently, HR 7308 has a very asymmetric amplitude change.

DISCUSSION

Our delta V photometric analysis of HR 7308 shows that it has a period of $1^d.490808 \pm 0^d.000010$, that the amplitude is strongly variable, and that this amplitude variation is not simply periodic, although it is cyclical.

Our set of data appears to be one of the more extended collections of data on HR 7308, in that we have 88 delta V data points over a period of 570 days, with only a maximum of one data point a night. This sampling can be considered random, since no consideration was made for the phase of the light curve when the APT took its measurement. And while this form of sampling makes it impossible to get a continuous light curve, it is possible, with the proper period, to generate a light curve using this data (Figure 1). This sampling also makes it possible to separately calculate light curves near both maximum and minimum amplitude.

Future work to be done on this star includes analysis of the APT's 89 delta B data points, incorporation of previous delta B (and B-V) observations, and examination of the amplitude change to see if it is truly non-periodic or if it has simply changed period since its discovery.

ACKNOWLEDGEMENTS

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THE MODES OF TU CAS

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INTRODUCTION

TU Cas is a double mode cepheid variable star which exhibits two distinct periods in its light curve. These periods have been identified as the fundamental and the first overtone (Oosterhoff 1957). There is suspicion that the ratio of the amplitudes of these two periods has decreased over the years (Hodson et al 1979, Niva 1979). A suspected second overtone (Faulkner 1977) has been discredited (Hodson et al. 1979

The star has been observed for us at the Fairborn Observatory in Arizona with the Phoenix 10, an automatic photoelectric telescope (Boyd et al., 1986). We have received data in the V wavelength bands starting the third quarter of 1987 and continuing through the first quarter of 1990. The photometric comparison star used was HD 1976 = HR 91and the check star was HD 1976 = HR 96. Our aim has been to model the light curve as the sum of sinusoids to see whether two modes are sufficient to describe the data, and whether the amplitude of the first overtone has continued to decrease.

METHOD AND RESULTS

The first method we used was to apply Ferraz-Mello's (1981) Date Compensated Discrete Fourier Transform (DCDFT) and harmonic filter to find and remove one sinusoid at a time. The Maria Mitchell implementation of the DCDFT (Belserene, 1986) allows the user to generate an equation of each sinusoid curve, in the form:

$$\mathrm{mag} = A0 - A1 \cos (2*\mathrm{pi}*(JD - A2) / A3).$$

The parameters are:

A0: the magnitude around which the oscillation occurs.
A1: the semi-amplitude, or the amplitude divided by 2.
A2: the Epoch, or a time at which maximum light occurs.
A3: the period, or the reciprocal of the frequency.

This method allowed us to find the strongest peak in the power spectrum; presumably the fundamental; remove it and its first two higher harmonics; then search the residuals for the next strongest component, presumably the first overtone; and remove it and its first two higher harmonics. (see Arndt and Belserene, 1990, for a discussion of the nomenclature of modes, harmonics, and aliases.) This process was continued to look for an additional overtone.

Although a second overtone appeared to exist in our data, it was later recognized as an alias of a cross-coupling term. Cross-coupling terms are additional sinusoidal forms that show in the data due to the interactions between the fundamental and first overtone (Cox et al., 1978). Using the DCDFT in another attempt, we also removed any cross-coupling terms, along with additional harmonics of the fundamental and the first overtone, which seemed to have non-negligible semi-amplitudes. Still, we were left with some unexplainable sinusoids in the data.

TABLE I. The Fifteen Sinusoids

Period	A0	A1	A2	A3	Description
P0	2.196	.286	2446820.129	2.139298	fundamental
P0/2	.000	.097	46821.035	1.069649	harmonic
P0/3	.000	.036	46821.307	.713099	harmonic
P0/4	.000	.015	46821.478	.534824	harmonic
P1	.000	.112	46821.279	1.518300	1st overtone
P1/2	.000	.017	46821.147	.759150	harmonic
1/P0 + 1/P1	.000	.076	46821.576	.888041	CCT
1/P1 - 1/P0	.000	.036	46818.306	5.230446	CCT
2/P0 + 1/P1	.000	.053	46821.038	.627542	CCT
2/P1 + 1/P0	.000	.023	46821.380	.560316	CCT
1/P0 - 2/P1	.000	.008	46820.482	1.176720	CCT
2/P0 - 1/P1	.000	.011	46820.109	3.619847	CCT
3/P0 + 1/P1	.000	.029	46821.248	.485211	CCT
2/P0 + 2/P1	.000	.020	46821.487	.444020	CCT
4/P0 + 1/P1	.000	.016	46821.360	.395506	CCT

CCT = Cross-Coupling Terms

This, however, proved to be a result of the way in which we removed the Fourier components one at a time. It is better to solve simultaneously by least squares for a single constant value and the amplitudes and phases of all of the sinusoids. The least squares solution (based on Press et al., 1986 p. 515) generates a single value of A0 along with individual semi-amplitudes and epochs for any number of sinusoids. The period for the fundamental and first overtone were adopted from the General Catalog of Variable Stars, Vol. 4 (Kholopov, 1985) as 2.139298 for P0 and 1.518300 for P1. The periods of the other sinusoids were calculated from these values.

Using the results of this solution, we could remove all sinusoids with significant semi-amplitudes at once. We used the DCDFT results to decide which ones to consider. In our data, we found a total of 15 sinusoids having non-negligible semi-amplitudes. After removing these sinusoids, we were left with only a small, negligible semi-amplitude at a period of about one day. These residuals, when plotted against the phase, appear as a straight line.

Table I shows the parameters of all sinusoids apparent in our model. These are the fundamental, the first overtone, the harmonics associated with each, and the cross-coupling terms that were non-negligible in our data.

Figure 1a shows the data folded at the fundamental period. By "folded" we mean that the data set has been cut into short segments the length of the fundamental period and stacked one upon another. The ordinate is the differential magnitude, variable minus comparison. In 1b we see these same results but with the first overtone, its harmonics, and all cross-coupling terms removed. The curve is the sum of the fundamental and its three higher harmonics.

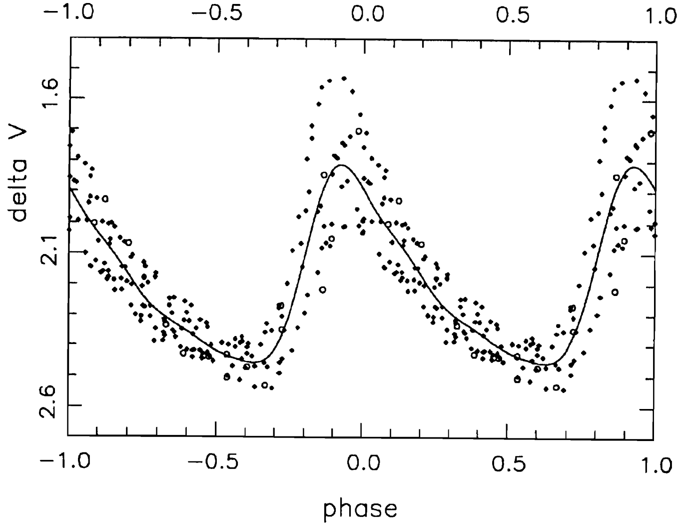

Figure 1a. The data set folded at the fundamental. The curved line represents the sum of the fundamental and its three higher harmonics.

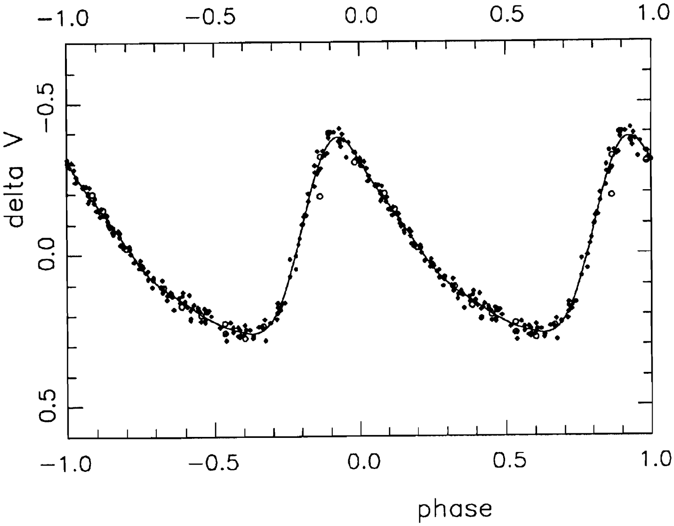

Figure 1b. The first overtone, its harmonic, and all of the cross-coupling terms have been removed from the data set. Again, the curved line is showing the sum of the fundamental and its three higher harmonics.

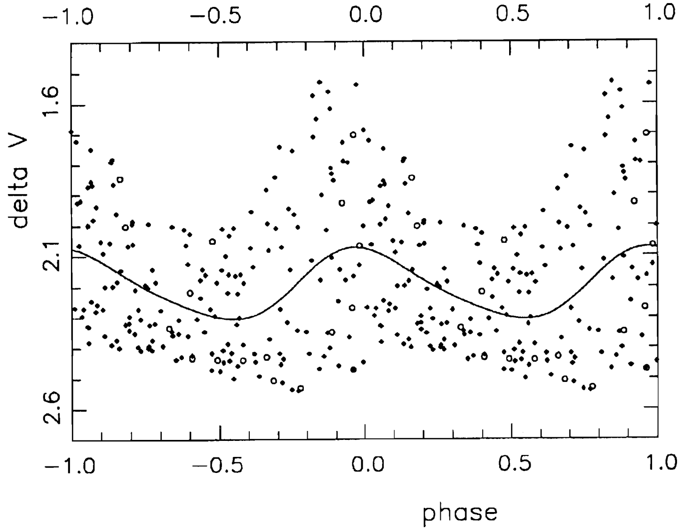

Figure 2a. The data set folded at the first overtone. The curved line is the sum of the first overtone and its first higher harmonic.

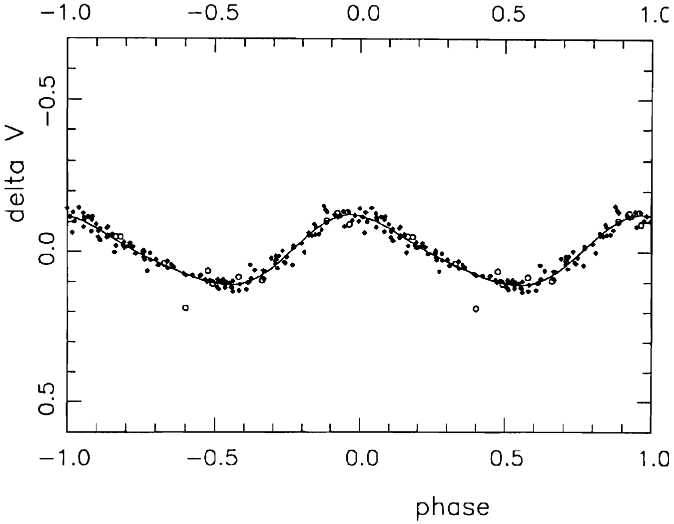

Figure 2b. *The fundamental, its harmonics, and all cross-coupling terms have been removed from the data set. Again, the curved line is showing the sum of the first overtone and its higher harmonic.*

Figure 2 shows similar results for the first overtone. In 2a we see the data folded at the first overtone. In 2b the fundamental, its harmonics, and all cross-coupling terms have been removed. The curved line is the sum of the first overtone and its first higher harmonic.

Another graphic example of the removal of sinusoids from data can be seen in Figure 3. Figure 3a shows a power spectrum of our data displaying the strongest periods and where they occur on the frequency scale. The power is normalized to give a mean power of 2 to Gaussian noise whose standard deviation equals that of the input data. The maximum possible power is about equal to the number of observations, 189 in this case. Figure 3b shows the power spectrum after filtering out the fundamental and its 3 higher harmonics. Figure 3c shows the power spectrum after removing the fundamental, first overtone, and their harmonics. We can see that the cross-coupling terms become much more obvious when the fundamental and first overtone are removed.

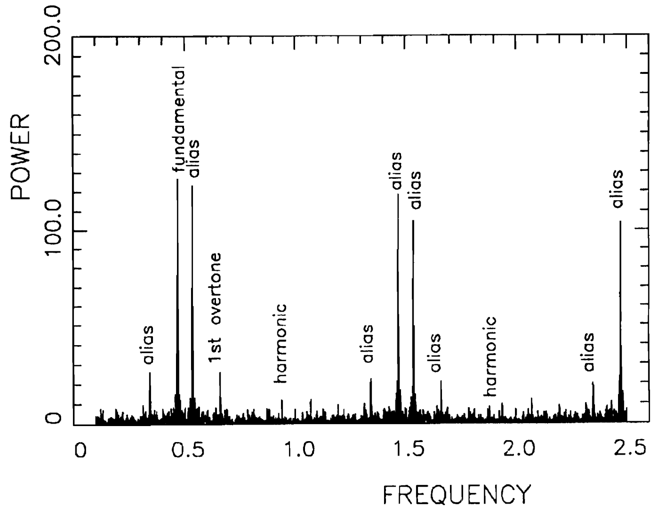

Figure 3a. Power spectrum of our data set displaying the strongest sinusoids and their frequencies. The fundamental, first overtone, their harmonics and aliases, along with some cross-coupling terms appear on this graph.

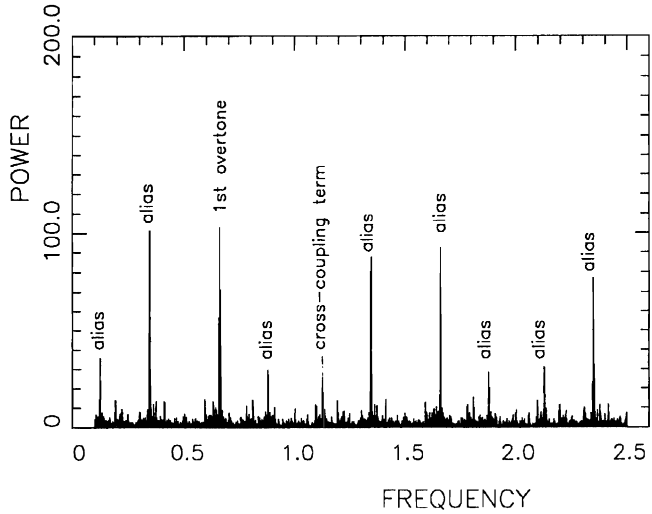

Figure 3b. Here the fundamental and its harmonics have been filtered from the data set. Notice that the aliases associated with the fundamental are removed along with it. The first overtone and cross-coupling terms become more prominent.

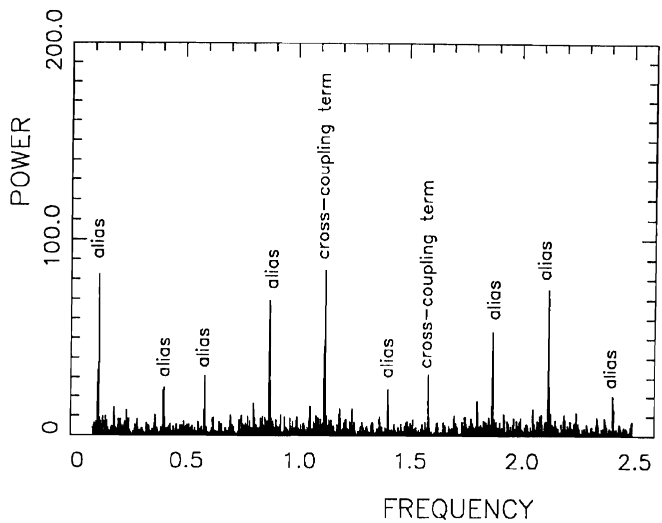

Figure 3c. *The fundamental, first overtone, and their harmonics have been filtered from the data set. The cross-coupling terms and their aliases show more prominently.*

Table II summarizes the amplitude ratios from our results (column 4) and from Hodson et al (1979) (columns 1 - 3). The amplitudes in this table are the differences between magnitudes at minimum and at maximum light, not the Fourier semi-amplitudes in Table I. According to this table, the decrease in a1 and in the ratio a1/a0 has not continued and a slight increase in the ratio of a1/a0 is apparent. The comparison is not entirely valid, however, since the various data sets were not reduced in the same way. We plan to reduce these data sets using the methods described here in order to better justify this comparison.

TABLE II. Amplitudes and Their Ratios

	(1) 1911-1912	(2) 1946-1959	(3) 1962-1978	(4) 1987-1990
Amp. of P0 (a0)	0.68	0.69	0.67	.646
Amp. of P1 (a1)	0.31	0.23	0.22	.232
a1 / a0	0.46	0.34	0.33	.359

SUMMARY

On the basis of 189 differential V magnitudes of TU Cas taken with the Phoenix 10 in third quarter 1987 to first quarter 1990, we find that two modes sufficiently describe the light curve produced by this star. We have determined that the ratio of the amplitudes of the two modes has not continued to decrease and may be displaying a slight increase.

We have learned that cross-coupling terms must be acknowledged in our Fourier analysis (Cox et al.,1978). We have also found that filtering sinusoids out of data not only depends on which ones are taken out, but the way in which they are removed. Removing all necessary sinusoids at once proved to be a much more effective method of reducing the data.

ACKNOWLEDGEMENTS

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PHOTOMETRY AND SPECTROSCOPY OF BINARIES: A SYMBIOTIC RELATIONSHIP

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ABSTRACT:

A number of instances in which photometric and spectroscopic data compliment each other are discussed. Both photometric and spectroscopic (O-C) residuals have led to the detection of a third body in several systems. Some photometric eclipse periods are doubled after the discovery that the system is a double-lined spectroscopic binary. Period aliasing problems can be resolved. The assumption of synchronization in short-period chromospherically active binaries can be used to identify spurious periods. Masses and radii are determined for double-lined eclipsing binaries. Orbital elements can be used to confirm the ellipticity effect. Analysis of this effect plus certain spectroscopic observations may result in the determination of the masses of a non-eclipsing binary and the radius of its primary.

I. INTRODUCTION

I'm an observational astronomer who primarily uses high-dispersion spectroscopy to analyze binary stars. It was my good fortune to come to Vanderbilt University where several astronomers have been using an automatic photoelectric telescope to obtain photometry of many of the chromospherically active stars in which I am interested. Being just down the hall from each other allowed us to exchange ideas and get the latest information about various systems in real time.

Often asked are such questions as the following ones. What is the photometric period of the star's light variations? Does this period vary with time? What are the star's V magnitude and colors? Is there any evidence for eclipses in this system? Is the star a binary and if so, what is its orbital period? Are lines from both stars seen in the spectrum? Is this star really a dwarf? What is the star's projected rotational velocity? Let us now look at several types of binary systems to see the importance of such questions.

II. DISCUSSION

From photometric observations many binaries are found to have period changes. Such changes may be the result of mass loss, mass transfer, magnetic cycles, or a third body, to name just a few possibilities.

Van Buren examined the validity of the three-body theory for period changes in eight chromospherically active systems. In a more general review Mayer (1990) examined the evidence for (O-C) variations caused by a third body in 25 eclipsing systems, including several active-chromosphere stars such as V471 Tau (Beavers, Herczeg, and Lui 1986) and SV Cam (Sarma, Sarma, and Abhyankar 1985). For XY Leo this third body hypothesis has been confirmed by spectroscopy.

XY Leo is a short-period (P = 0.2841 days) W Ursa Majoris system consisting of two early K stars. Studies of the times of minimum light (O-C) values indicate cyclical changes (Gehlich, Prolss and Wehmeyer 1972; Hrivnak 1985). Such changes led Gehlich et al. to suggest that a third body, possibly a white dwarf having a period of 20 years, was responsible. Vilhu and Rucinski (1983) found XY Leo to be one of the strongest known ultraviolet emission sources among contact binaries, but found no evidence of a white dwarf continuum in the ultraviolet. Hrivnak (1985) suggested that the third body might itself be a binary composed of two late K or early M dwarfs, a prediction confirmed by spectroscopy.

Barden (1987), observing at red wavelengths with a CCD detector, discovered the existence of the binary companion suggested by Hrivnak (1985). The strong Hα emission of both components indicated that this 0.805 day binary is probably a BY Draconis system. Since Barden found that the M star binary dominates the Hα emission and is probably responsible for most of the Ca II emission noted by other observers, he suggested that at least one-half of the ultraviolet and x-ray emission also comes from it. Thus, although the reason for the cyclical (O-C) changes has been found, the detection of two additional stars has severely complicated the analysis of the x-ray and ultraviolet fluxes. Finally, since (O-C) variations are relatively common among late-type W UMa systems (e.g., Rucinski 1985) Barden (1987) suggested that some of these systems also have undiscovered stellar companions. XY Leo is a prime candidate for detection of the new binary pair with speckle interferometry.

The reverse situation also can occur. EE Peg is an Am eclipsing binary with an F5 secondary. Popper (1981) detected the Na D lines of the secondary and determined the fundamental properties of the system. Lacy (Lacy and Popper 1984) found larger than expected velocity residuals in his Reticon velocities of both the primary and secondary, and also in Popper's primary velocities. From these residuals, Lacy and Popper (1984) determined a long period of 4.0 years and an eccentricity of 0.52. They estimated that the third component has a mass of 0.7 to 0.3 $M_\odot$. They reanalyzed the photoelectric data with the addition of third light. The main effect of this addition is to increase the inclination by 0.5 deg. With speckle interferometry McAlister et al. (1987) have detected a fourth component of the system.

Determining the period of a binary can sometimes require additional data. Photometric surveys find eclipsing binaries and often determine an eclipse period as well as an ephemeris. If the system consists of two stars of nearly equal luminosity, spectroscopic observations will show double lines, increasing the presumed period by a factor of two (e.g. Marschall et al. 1990).

From my perspective as an observational astronomer, theorists are almost always wrong. But then that is what keeps them in business. Naturally observational astronomers are rarely wrong. There are of course notable exceptions such as the recent "great supernova pulsar caper." Years ago there was also the "potassium flare star fiasco." For those of you who may not remember the event, you may find potassium emission lines in your infrared spectrum if you light a match while making spectroscopic observations (Wing et al. 1967). I must confess that I also have stubbed my toe at least once.

There are often aliasing problems with period determinations especially for a period near one or two days. Fekel et al. (1982) found a preliminary period of 2.04 days for EI Eri = HD26337 for both the photometric and spectroscopic observations. Additional photometric data, obtained nightly when the star was near the meridian, showed two possible periods of 1.95 and 2.04 days (Hall et al. 1987). Their period analysis weakly suggested that the true period was 1.95 days and the alias was 2.04 days. This conclusion became obvious when two independent sets of spectroscopic data (Fekel et al. 1987 and Balona 1987) obtained at very different longitudes in Arizona and South Africa, respectively, were combined. A similar technique is used sometimes in photometry.

Most chromospherically active stars are binaries. Their most common light variations are caused by starspots rotating in and out of view, from which one can determine the star's rotation period. The vast majority of these binaries, 90% or more, are rotating synchronously if their orbital periods are less than 30 days (Fekel and Eitter 1989). That is, their photometric rotation period and spectroscopic orbital period are the same, within a few percent.

Sometimes the photometric amplitude is small relative to the errors of the observations. For LR Hya = HD 91816 Bopp et al. (1984) found a photometric period of 3.1 days. Thus, it was quite surprising to find an orbital period of 6.87 days for this double-lined, late-type dwarf binary (Fekel et al. 1988), more than twice the photometric period. Strassmeier et al. (1989) obtained additional photometry during the 1984 - 1985 observing season. They found three possible periodicities, none of which were similar to the previously suggested photometric period or the orbital period. They were unable to make any firm conclusions, but if the system is synchronously rotating, as are 98% of the chromospherically active binaries with periods less than 10 days, then all the previous photometric periods are spurious. If not, the system is extremely unusual and interesting.

Times of orbital conjunction can prove useful in determining shallow eclipses. Hall et al. (1990) used this information (Fekel 1988) to help confirm that the chromospherically active binary V478 Lyr = HD 178450 has a shallow primary eclipse of 0.05 mag.

More traditionally, from spectroscopy minimum masses and the minimum absolute separation of the stars of a double-lined eclipsing binary may be combined with the photometrically determined inclination and relative radii to produce masses and absolute radii for the stars. This subject will be discussed more extensively by Lacy at this meeting.

Although masses and radii have been determined for a number of stars close to the main sequence, such information is still quite minimal for giant stars. Table I shows the current situation. There are only six systems containing at least one giant. For three systems the masses are determined by combining spectroscopic and speckle orbits, so radii are unknown, while the other three V643 Ori, TZ For, and V792 Her are double-lined eclipsing binaries. The masses of the giants range from 1.47 $M_{\odot}$ to 3.4 $M_{\odot}$. Several multiple systems and ellipsoidal variables eventually will be added to this list when their masses become more accurately determined.

TABLE I. Accurate masses of late-type giants

System	Component A			Component B		
	Sp.	Ty.	Mass	Sp.	Ty.	Mass
V643 Ori	K2	III[a]	3.4[a]	K7	III[a]	2.0[a]
γPer	G8	III[b]	3.06±0.3[b]	A3[b]		2.03±0.15[b]
Capella	K0	III[c]	2.64± 0.02[d]	G1	III[c]	2.49± 0.02[d]
φCyg	G8	III-IV[e]	2.50± 0.09[f]	G8	III-IV[e]	2.39± 0.08[f]
TZ For	G8	III[g]	2.05± 0.06[g]	F7	III-IV[g]	1.95± 0.03[g]
V792 Her	K0	III[c]	1.47± 0.03[h]	F2	IV[c]	1.41± 0.03[h]

[a] Imbert (1987)
[b] Popper and McAlister (1987)
[c] Strassmeier and Fekel (1990)
[d] Fekel, unpublished
[e] Roman (1952), integrated spectral type
[f] McAlister (1982)
[g] Andersen (1990)
[h] Fekel (1990)

For chromospherically active binaries the luminosity class of a star can often be determined or confirmed. The photometrically determined rotational period, combined with a $v \sin i$ value, results in the minimum radius of the star, $R \sin i$ (e.g. Fekel et al. 1986).

Examining the times of orbital quadrature as well as conjunction can be used to help identify another phenomena. In some of the more evolved chromospherically active systems, the light variations may be a combination of spots and ellipticity. The ellipticity for stars in a circular orbit will have a period that is half the value of the orbital period, with maxima at quadratures and minima at conjunctions. The situation has been discussed for V1764 Cyg = HD 185151 (Lines et al. 1987) and GX Lib = HD 136905 (Fekel et al. 1985).

Strassmeier et al. (1989) found UV CrB = HD 136901 to have ellipsoidal light variations and concluded that the two unequal minima of the light curve resulted from a substantial reflection effect. Since the reflection effect implies a hot secondary, spectroscopic observations at both visual and ultraviolet wavelengths were obtained. Fekel et al. (1989) found no evidence for a hot secondary. They also found that the orbit of the system was not circular, but had a modest eccentricity of 0.06. The puzzle was solved by Hall (1990) who showed that the different depths of the two light minima could be reproduced by an ellipsoidally shaped star moving in an eccentric orbit. In that paper Hall analyzed 12 other chromospherically active ellipsoidal variables. For a non-eclipsing single-lined spectroscopic binary with $v \sin i$ determined from rotationally broadened line profiles, a knowledge of the mass function, the amplitude of the ellipticity effect, and one other constraint can be used to determine the two masses of the stars and the radius of the primary.

Following the lead of Morris (1985), Hall (1990) was able to determine the two masses and the radius of the primary for three systems and place substantial constraints on these parameters for 10 other systems all of which contain late-type giant stars. As reported at this meeting Henry and Hall are analyzing additional systems.

The above review points out some of the many ways in which photometry and spectroscopy compliment each other. Thus, photometry and spectroscopy have a special symbiosis that results in a substantial increase in our knowledge of binaries.

ACKNOWLEDGEMENTS

I wish to thank J. Andersen, P. Mayer, and D. Hall for communicating information in advance of publication. Financial support from Vanderbilt University for travel to this meeting is gratefully acknowledged. Part of this work was supported by a grant from the Vanderbilt University Research Council.

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ULTRA-HIGH ACCURACY MASSES AND RADII FROM ROBOTIC PHOTOMETRY OF ECLIPSING BINARIES

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I. INTRODUCTION

This study was stimulated by the changing rules-of-thumb in observational stellar astronomy. The old rules-of-thumb were that differential photometry could be done to-at best-about 0.005 mag accuracy, and that radial velocities could be determined to about 1 km/s per observation. Young et al. (1990) argue that photoelectric photometry at the level of 0.001 mag accuracy is possible and feasible, and Boyd and Genet (1990) are committed to an attempt to achieve this goal with robotic telescopes. On the spectroscopic front, Brown et al. (1990) have achieved a radial velocity accuracy of a few m/s on short time-scales for Procyon with the FOE at KPNO. Brown has the opinion that it is likely that an accuracy of 0.1 km/s night-to-night repeatability is feasible with this instrument. The combination of these improvements in observational techniques and the adoption of new strategies made possibly by computer-controlled data acquisition is expected to result in orders-of-magnitude improvements in the determinations of absolute stellar properties such as masses and radii.

In order to determine just how much improvement could be expected and in order to test the effects of new observing strategies, I have designed a computer simulation system for generating and analyzing synthetic photometric and spectroscopic observations of eclipsing binary stars. The photometric model is the NDE model as defined by Etzel (1981) and Popper and Etzel (1981) and realized in the EBOP program. I have used my programs to estimate the accuracies that could be achieved in the astrophysical parameters if observations could be obtained with the assumed accuracies and these are summarized in Tables I and II below.

Table I. Results of Photometric Simulations for ZZ Boo

		90% Confidence Limits			
σ(mag)	J_s(%)	r_g(%)	k(%)	i (degrees)	Ave. No. Obs.
Two Seasons (1991-2) in Arizona					
0.005	0.60	1.50	3.23	0.110	1216
0.001	0.07	0.27	0.56	0.014	1238
Two Optimum Seasons (1995-6) in Arizona					
0.005	0.20	0.52	0.94	0.009	1314
0.001	0.04	0.09	0.18	0.002	1294
Two Optimum Seasons (1995-6), Limb Darkening Included as Variables					
0.001	0.37	0.15	0.23	0.008	1270

Table II. Results of Spectroscopic Simulations for ZZ Boo

	90% Confidence Limits		
σ(km/s)	M_1(%)	M_2(%)	Ave. No. Obs.
Two 6-Night Runs (Jan., May 1991), Circular Orbits			
1.0	0.59	0.59	92
0.5	0.21	0.32	91
0.1	0.06	0.06	85

II. PHOTOMETRIC SIMULATIONS

Input parameters of the photometric simulation system were: (1) a specified set of observing run dates and observing location; (2) the probability that a given night during the observing run would be usable (40% was used in all simulations discussed here); (3) eclipsing binary parameters (orbital period, zero-epoch, relative radii, orbital inclination, etc.); (4) observation frequency near eclipses and far from eclipses (4 minutes and 90 minutes, respectively, were used below); (5) observational random errors (0.005 and 0.001 mag Gaussian distributions were used). On each simulated night of a specified observing run, a random number determined whether observations would be attempted or not, simulating the effects of weather variability. If observations were to be obtained, they were begun at a time after dusk when the star rose to a suitable airmass, then obtained at a frequency that was determined by how close the binary was to an eclipse - more frequently near and during eclipses. Observations continued until a time when the star exceeded a suitable airmass or dawn occurred. Data were generated in this way for the specified set of observing run dates.

In order to determine how realistic the data produced by this scheme would appear, I simulated the data for UZ Dra (Lacy et al. 1989). Figures 1 and 2 show the comparison between the real and simulated data. Which one do you think is real? In fact, Figure 2 is the real data. This verifies that the simulation system produces realistic-looking data.

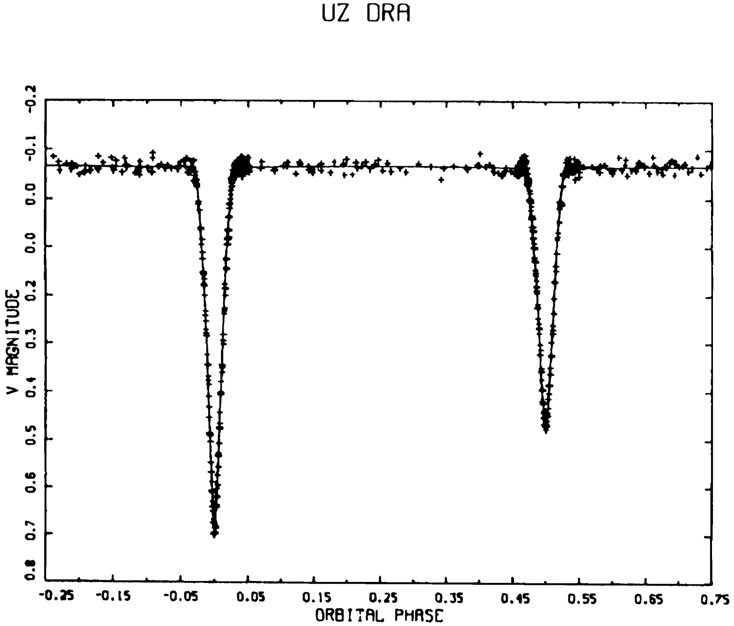


Figure 1. A light curve of UZ Dra.

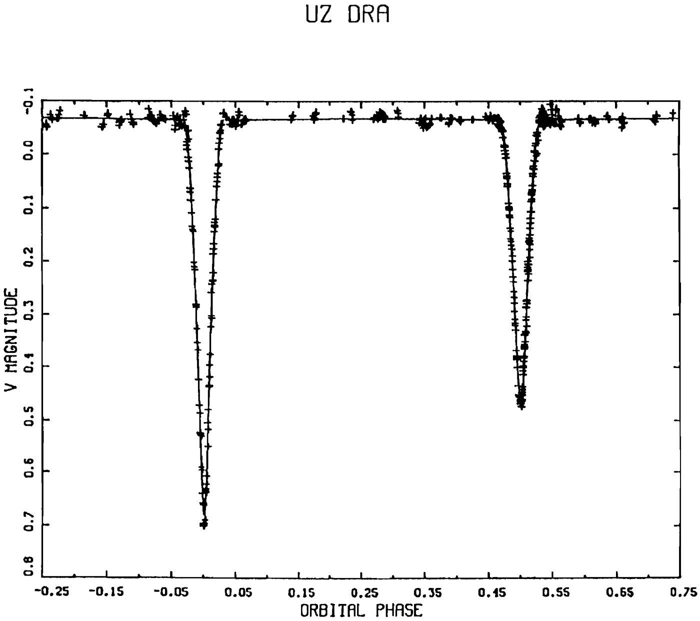


Figure 2. *Another light curve of UZ Dra.*

Once the simulated data were produced, they were then analyzed in the same way as real data would be handled. The results were collected, then another set of simulated data was produced, etc. Ensembles of 100 simulated sets of runs were produced and analyzed in this way. The output results were then compared to the input parameters. Histograms of the results were produced and 90% confidence limits were constructed. The meaning of a 90% confidence limit λ is that in 90% of the simulated sets of observing runs, the output result was within λ of the true value. Thus, with a given set of observational data, the chances are 90% that the analyzed results will be within λ of the true value.

This approach is quite different from that adopted by Popper (1984), who has also investigated the effects of observational errors on the accuracy of photometric orbits. He assumed that the observations would be uniformly distributed with phase (every 0.001 in phase), then varied the size of observational errors and investigated a range of light curve types for determinacy. This is a useful approach for investigating the relationships between light curve types and the determinacy of solutions, and the interrelationships between different parameters in the solutions. My own approach is most useful as an experimental design tool in planning and justifying an observing campaign on a particular eclipsing binary. In some cases (see ZZ Boo below) it is not practical to obtain observations even remotely close to uniformly-spaced in phase, and the effects on the accuracy of light curve solutions must be investigated in the context of the observational campaign strategy for this specific binary star.

The results for ZZ Boo are discussed here. This is an F2 main-sequence pair with narrow lines and an orbital period of 4.99171618 days. Preliminary results of a spectroscopic run at the KPNO coude feed with a fiber-scrambler input in February 1990 gave residuals of 0.2-0.3 km/s per observation, so this is a good candidate for the FOE. A single observing season of simulated data (Figure 3) is not adequate to determine accurate photometric parameters because its orbital period is so close to 5 days that either primary or secondary eclipse can be adequately covered in a "good" year, but not both. Two seasons of data (Figure 4) may not really be adequate, either. The "right" pair of years (Figure 5) give data that are marginally adequate by ultra-high-accuracy standards. A histogram of the results for the parameter r_g, the relative radius of the larger star, is shown in Figure 6.

Confidence limits derived from the statistics are shown in Table 1. These show that, at best, about an order-of-magnitude improvement may be expected over the best results usually achieved these days (1% accuracy in relative radii), and about 20 times better than the best available results for ZZ Boo (Popper 1983). The difficulties of observing this particular binary could be greatly alleviated by using two observing sites on opposite sides of the Earth in a coordinating observing program. This may soon become possible with a network of robotic telescopes.

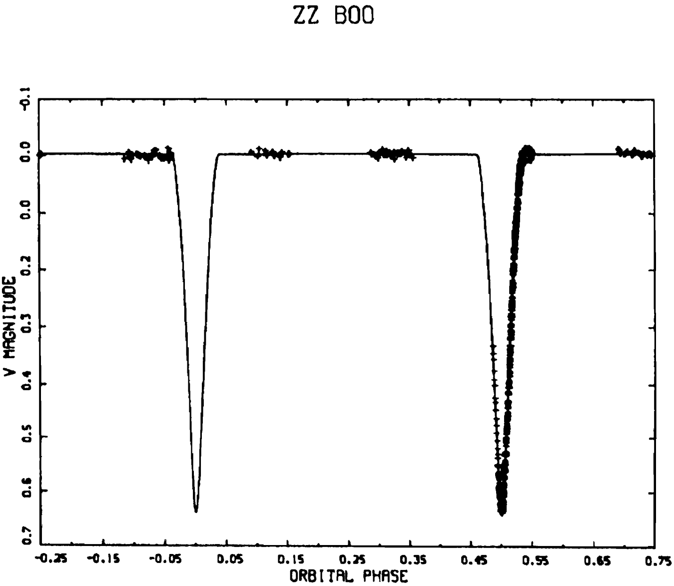


Figure 3. A synthetic light curve of ZZ Boo from one observing season (1991), σ 0.005 mag.

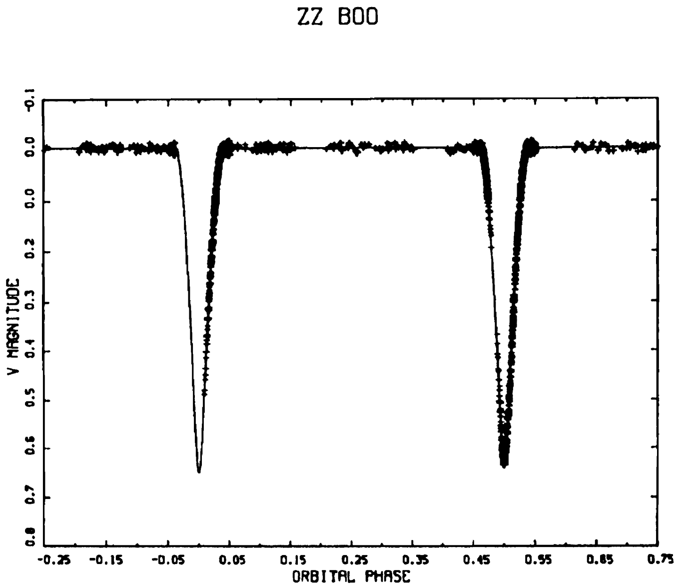
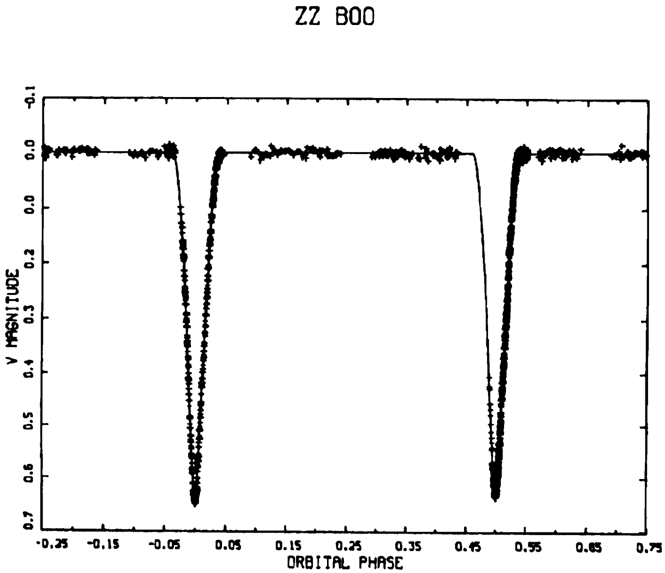


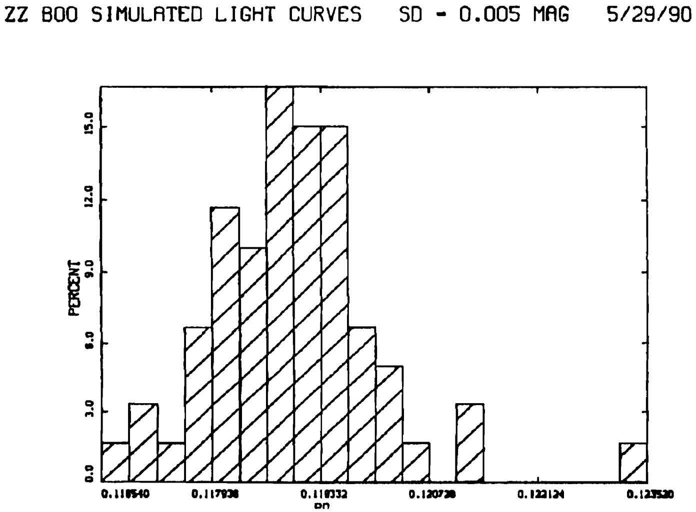
Figure 4. A synthetic light curve of ZZ Boo from two observing seasons (1991-2). σ = 0.005 mag.

III. SPECTROSCOPIC SIMULATIONS

Input parameters of the spectroscopic simulation system were: (1) a specified set of observing run dates (6-night runs in January and May 1991 were used below) and observing location (Arizona was used below); (2) the probability that a given night during the observing run would be usable for spectroscopy (65% was used below); (3) eclipsing binary parameters (orbital period, zero-epoch, radial velocity semi-amplitudes, center-of-mass radial velocity); (4) observing frequency (excluding zones near eclipses where lines blend, with evenly-spaced observations far from eclipses - 30 minutes was used below); (5) observational random errors (1.0, 0.5, and 0.1 km/s Gaussian distributions were used below).



re 5. A synthetic light curve of ZZ Boo from the "best" pair of seasons (1995-6). 0.005 mag.



re 6. A histogram of analyzed values of r_g from simulated photometric data b darkening assumed known).

Procedures for generating the simulated radial velocities were similar to those discussed above for the photometric simulations. Circular orbits were used. Note that spectra of the programs star are obtained in a continuous manner, not just once or twice per night as is usual these days. Thus, many more observations per night are obtained than is customary.

Simulated data sets for 1 km/s and 0.1 km/s are shown in Figures 7 and 8. The nearly 5-day period shows up as phase gaps, but these are not as much of a problem spectroscopically as photometrically (at least for circular orbits).

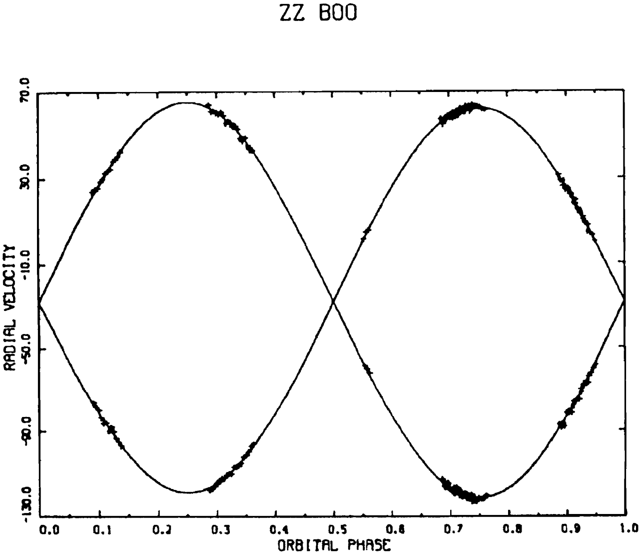


Figure 7. A synthetic radial velocity curve for ZZ Boo from two 6-night runs in 1991. σ = 1.0 km/s.

Again, the simulated radial velocities were analyzed in the same way as real data. The results for ensembles of 100 simulated sets of observing runs are shown in Table II. These show that in just two 6-night observing runs the present state-of-the-art accuracy in stellar masses can be improved by more than an order-of-magnitude!

IV. DISCUSSION

It's pretty clear we're going through a period when conventional rules-of-thumb are rapidly changing due to advances in observing technology and strategy. My results show that order-of-magnitude improvements in the astrophysical accuracies may be expected. This will place incredibly strong constraints on the models of stellar evolution. All of this assumes, of course, that as we go to higher accuracy, new phenomena don't show up to complicate our interpretation of the data.

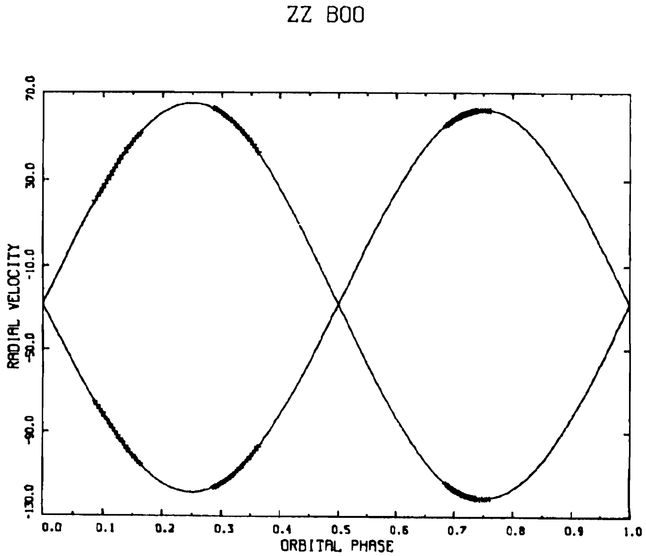


Figure 8. A synthetic radial velocity curve for ZZ Boo from two 6-night runs in 1991. $\sigma = 0.1$ *km/s.*

I was thinking about these ideas a few weeks ago (June 1990) as I was preparing to leave CTIO after a successful observing run - thinking about how the conventional wisdom in a field consists of rules-of-thumb that sometimes mutate into myths, and wondering what rules-of-thumb and myths were being passed down by the elders during the transformation rituals these days. It so happened that a "brand-spanking-new" Ph.D. astronomer was also leaving that morning, and I was interested to know what was the current conventional wisdom on the accuracy with which Photometry could be done, so I put the question to him and waited expectantly as he though for a few seconds, then he said, "That depends...," and I thought, "Ah, he's debating the merits of RCA vs. EMI photomultipliers, deadtime correction errors, variability of second-order extinction coefficients, ...," then he finished "you mean with a TI or a TEK chip?" I felt about 100 years old.

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IS PHI CASSIOPEIAE A VARIABLE STAR?

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Phi Cassiopeiae (HR382, HD7927, F0Ia, V=5.00) is a bright, luminous supergiant with a long history of suspected light and velocity variability. Recently, I reported on several months of intensive UBV photometric monitoring of this star using the Phoenix-10 telescope of the APT Service (Percy 1989). There were apparent variations of 0.015^m, 0.020^m, and 0.030^m in V, B and U, respectively, but these were considered to be at the limit of what the APT could detect, especially as there were systematic variations in the checkstar as well. However, the apparent variations were suggestive, especially in U, so I left the star on my APT program.

The search for and study of microvariable stars with the APTraises the question of how the user knows the true accuracy of the observations. This is particularly important in cases in which the variable has an unusual spectral energy distribution, and comparison stars which are not ideally matched by color and spectral type. This is the case with Phi Cassiopeiae: the star itself is abnormally luminous, and the comparison stars are HR326 (B8V) and HR442 (G9III). Photometrists who regularly observe a large variety of standard stars in order to determine their transformation coefficients are usually aware of any potential problems of this kind. Sporadic users of the APT Service depend on the Principal Astronomer (PA) to provide this information.

PA Professor Michael Seeds has done so through the very useful"P-10 Users' Notes," and one of the purposes of this short paper is to point out how useful this publication can be in assessing the reality of microvariability. It reports that, since 1988, there have been several changes to both the instrumentation, filters, and reduction procedures of the Phoenix-10 telescope. In addition, there may be seasonal effects which are not apparent to me or the PA. These may explain some or all of the apparent variations, such as those shown in Figure 1.

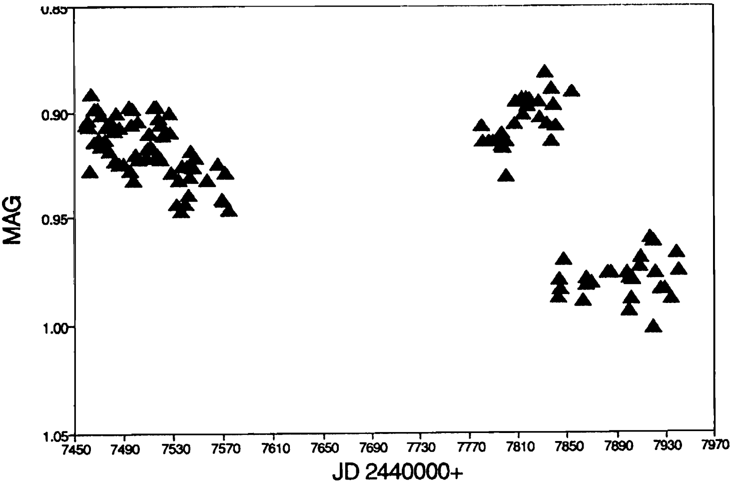

Figure 1. *The U magnitude difference between the check star HR442 and the comparison star HR321. The apparent variations of 0.1^m are probably due to changes in the instrumentation and reduction procedure. There are similar variations in the differential U magnitude of the program star Phi Cassiopeiae.*

On the other hand, my observations of Phi Cassiopeiae with thePhoenix-10 continue to show variability which is marginally greater in the program star than in the check star, so I can still not answer the initial question: is Phi Cassiopeiae a variable star? It would be unreasonable to suggest that APT's not be used to look for and study microvariables, since many microvariables have been studied successfully in this way. Observers should, however, take great care when choosing program and comparison stars, and when interpreting theresults.

ACKNOWLEDGEMENTS

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OBSERVING VARIABLE STARS WITH ROBOTIC TELESCOPES: PERIODS OF CHEMICALLY PECULIAR A-TYPE STARS

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I. INTRODUCTION

The Smithsonian 0.75-m APT (SAPT) saw first light on Oct. 16, 1989. By previous agreement with Sallie Baliunas, the Four-College Consortium was to have first run on the SAPT. Saul Adelman and I had our program for variable upper main sequence chemically peculiar (CP) stars ready to run at this time, so this program was the first on the first "new generation APT." The Four-College 0.75-m telescope (CAPT) came up in the first quarter of 1990 (1Q90), but had software and hardware bugs which persisted into 2Q90, so essentially all of our usable data was from the 4Q89, 1Q90 and 2Q90 on the SAPT.

In addition to our CP variable stars in differential mode, Lou Boyd ran nights for both UBVRI and uvby standard stars in all-sky mode. In this presentation I will discuss some new software, the results to date for the four-color standard stars and the periods of two CP variable stars. The CAPT is now bug-free, we hope, and is waiting for some more optimized data to be run in 4Q90, after the Arizona monsoon season is over.

II. STATISTICS FOR STANDARD STARS

a) Reduction Software

We were primarily interested in the Stromgren four-color standards with Filter Set uvby. In the three quarters under discussion there were a total of 17 four-color standard nights. The remaining nights were run with the ATIS Input File for the CP variable stars.

Table I. Extinction And Transformation Coefficients.

Averages For JD2447870*, 2447900, 2447901, 2447920, 2447921

Filter	k'	S.D k'	Z	S.D. Z	e	S.D. e
y	0.135	0.009	18.815	0.012	0.065	0.008
b	0.187	0.004	19.058	0.012	0.089	0.003
v	0.305	0.004	19.106	0.017	0.0:	---
u	0.549	0.011	19.651	0.014	-0.024	0.003

* Z values not averaged; about 0.2 mag. brighter due to mirror cleaning

A typical ATIS Output File from the APT includes all data recorded by the telescope. On poor nights, or if the instruments are not operating properly, these data can include many aborted or truncated groups. In our observing scheme, an all-sky group consists of s-*-*-*-s (s = sky, * = star), while a differential photometry group consists of s-ck-c-v-c-v-c-v-c-ck-s (ck= check, c = comp., v = var.). As the first step in reduction, I wrote a filter program, ATISFilt, which eliminates all aborted/truncated groups from the original ATIS output file. Along with the filtered ATIS output file, the program produces a statistics file that gives a tally of the number of groups that were discarded, and for what reason, making use of the ATIS 110 "Comment" instruction (Boyd, et al. 1989). In general, the data produced by ATISFilt helps the observer to do a preliminary screening of the data on a run. Nights that had a small number of total observations or a large number of aborted groups can be discarded at this point. Also a first pick of potentially good nights can be made on the basis of a large percentage of complete groups observed and a small number of "Object Not Found" aborts, since this is the most likely abort on nights that are partially cloudy or where the seeing is poor.

In order to calculate extinction and transformation coefficients for an all-sky standard star night, a new version of the Spreader program (Seeds and Genet 1989) was required. Spreader converts ATIS output files to ASCII files that can be read into a spreadsheet for reduction with the spreadsheet program written by Hayes (Hayes, et al. 1989). My updated version, Spreader3, does this for standard star data in the all-sky format, using the filtered ATIS output file as input. I have also included the ability to process differential photometry data for those who have spreadsheet reduction programs or who wish to examine the quality of such nights. In addition to the ASCII files to be reduced by the spreadsheet program, Spreader3 also produces a Log File which records all the counts, sky and star, for each group in the file. Standard deviations are also calculated and recorded in the Log File for counts within a group. The standard deviation of the counts is displayed next to a value which is 1% of the average count, as this is the criterion for quality of photometry used by most observers. In the discussion below, I have I have only included standard star nights where the majority of the observations meet the "< 1%" criterion.

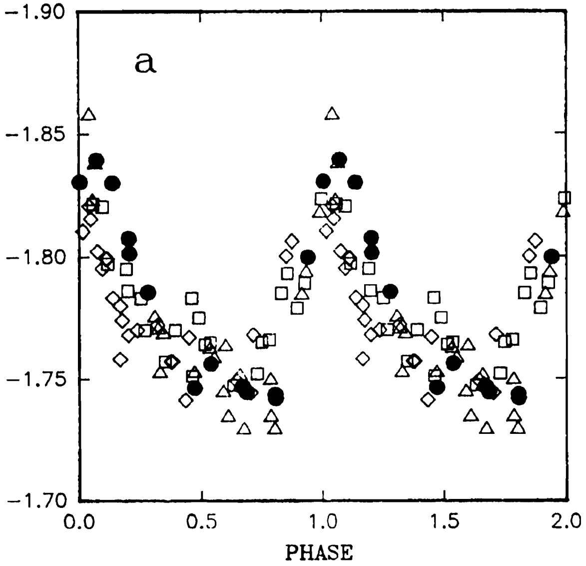

Figure 1. Plot of variations of u with phase for CG And. Filled circles, open squares, diamonds and triangles represent the data of this paper, Stepien (1967), Provin (1951-52) and Pyper (1979-85), respectively. Phases in (a) are for P = 3.73975 days .

b) Standard Star Nights

Of the 17 nights on which four-color standard stars were observed, 12 were either not reducible or of poor quality. Although there were still some bugs in the system, 5 nights showed a small number of "Object not Found" rejections. This implies that at least the transparency was fairly good (no thin clouds). On these nights, most groups showed deviations less than 2% of the average count. Lastly, examination of the nightly site logs (where available) showed no comments of roof closings due to clouds or shutdowns due to instrument problems. Therefore spreadsheet reductions (see Hayes, et al.1989 for a description of this procedure) were performed for all 5 nights to determine pulsewidth and the transformation and extinction coefficients, as I had done previously for JD2447870 (Pyper 1990). A summary of the data for these nights is given in Table I, for groups observed with no neutral density filter.

The values summarized in Table I appear to be reasonable for Mt.Hopkins. Along with data from the other instruments of the Automatic Telescope Service, these data will become part of an ongoing program to determine the sky conditions at the Mt. Hopkins APT site. At present they will serve as average coefficients in the reductions of differential photometric observations.

III. PERIODS OF MAGNETIC CP STARS

The magnetic CP (MCP) stars of the upper main sequence are characterized by the presence of strong coherent magnetic fields in their atmospheres that can be measured from the Zeeman effect in their absorption spectra. These stars are also characterized by peculiar atmospheric abundances of elements such as He, the iron-group elements and the lanthanide rare earth elements (REE). Most or all of the MCP stars are variable in brightness; in the majority, the magnetic field and spectrum also vary with the same period as the brightness. A number of investigators have constructed models for these stars that are collectively known as "oblique rotator" models (ORM's), wherein the variations are due to aspect effects of "frozen-in" magnetic field and element distributions as the star rotates. In these models, the brightness variations are due to flux redistribution from the ultraviolet where there isexcessive absorption by overabundant REE and Fe-group elements in a patchy distribution. The periods of most MCP stars are about a week or longer, implying that they rotate more slowly than the average star in the same temperature range. It has been suggested that the cause of this slow rotation is magnetic braking due to the interaction of the stars' magnetic fields with interstellar matter or to mass loss during their formation (see Borra, et al. 1982 and references therein)

In order for these models to be compared with observations, it is very important for their precise periods to be known. For example, it is often not possible for simultaneous observations to be made by orbiting and ground-based observatories in order to compare the light or spectrum variations over a wide wavelength range. Comparisons with observations made by observers over long periods of time and with different instrumental systems are also required, for example to detect secular variations in the amplitudes or shapes of variation curves that may indicate slow changes in the magnetic field or element distribution on the surface of the star. Another problem is that a few CP stars exist that apparently have extremely long periods; on the order of decades. It is important to establish whether these stars' behavior is also consistent with the ORM's or whether they display cycles similar to that of the sun.

IV. RESULTS FOR TWO CP STARS

a) CG Andromedae

CG And (HD 224801) is a relatively cool MCP star that has a fairly short period of variation, thereby implying it is a relatively rapid rotator for this class of stars. This is borne out by the relatively broad spectral lines, which make the magnetic field difficult to determine. This is a good candidate for period improvement, due to its short period, its relatively large amplitude of variation and the fact that it has been observed photometrically since the early 1950's. My previous four-color photometry for CG And with the KPNO No. 4 16-inch telescope had not produced enough high-quality data to publish an improved period over the 3.73975-day period previously determined (see Catalano and Renson 1984). We obtained 14 observations of CG And in four-colors during the fourth quarter of 1989. The quality of the data appears to be good and our light curves show relatively small scatter. Figures 1a and 1b show our data plotted with those of previous investigators (see Catalano and Renson 1984 for references) for *u* (or *U* in the *UBV* system), normalized to our *u* values. Figure 1a is the previous period and 1b is our improved period with the ephemeris:

$$JD = 2440101.6502 + 3.73993\ E.$$

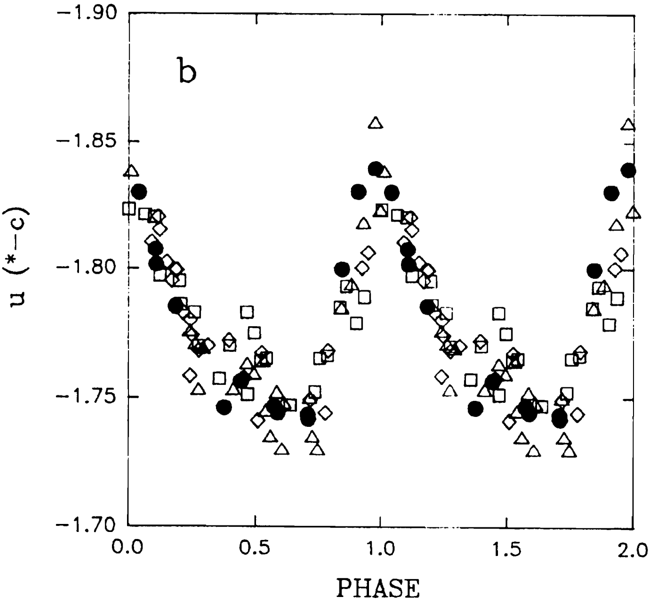

Figure 1b. Plot of variations of u with phase for CG And. Filled circles, open squares, diamonds and triangles represent the data of this paper, Stepien (1967), Provin (1951-52) and Pyper (1979-85), respectively. Phases in (b) for P = 3.73993 days.

b) GY Andromedae = HR 465

Originally GY And (HD 9666) was thought to be non-variable in brightness and magnetic field. However, its spectrum and probably its magnetic field were found to vary with a possible period of about 8000 days. Photometric observations made by various observers since the 1950's (see Catalano and Renson 1984) also show a large amplitude variation (for CP stars) that is consistent with an 8000 day period (Figure 2). Our APT data from 4Q89 and 1Q90 show a fainter average value of V than those of the previous "minimum." This may mean that the actual period is double that originally proposed or that the amplitude varies. More observations must be made of this star before it is determined whether the variations are consistent with a rigid rotator model or solar cycle model.

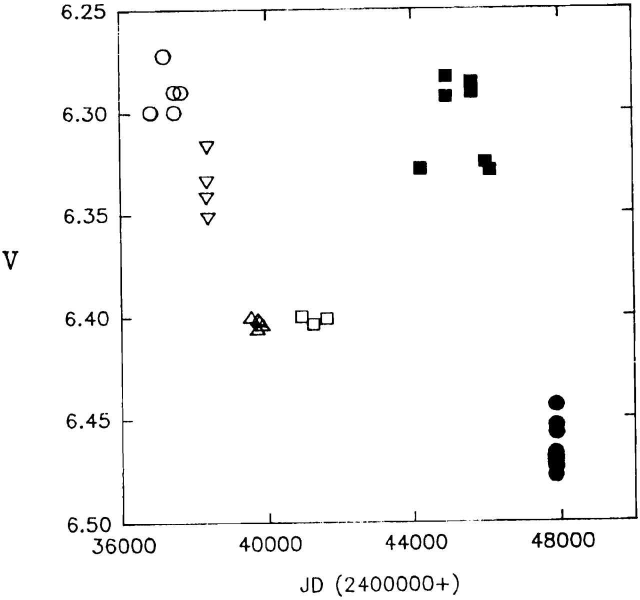

Figure 2. *Plot of V vs. JD for GY And. Open circles, inverted triangles, triangles, squares, closed squares and closed circles represent data of Abt and Golson (1959-62), Rakos and Fiedler (1963), Stepien (1967), Winzer (1970-72), Pyper (1979-85) and this paper, respectively.*

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ROBOTIC OBSERVATORIES AND THE COMMON STARS OF OUR GALAXY

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In this day of sophisticated observations of faint extragalactic sources, it would seem incredible that the properties of the nearest stellar neighbors are still so poorly known. Yet decades after work on them has been held in little regard, and perhaps because of this attitude, the only stellar parameters known for all of them are proper motion and an often imprecise apparent magnitude. Neither a photoelectrically determined magnitude or color, nor a spectral classification, nor a parallax is available for many of them; nothing upon which a distance and an absolute magnitude can be based. As for radial velocities and metallicity determinations, one is at a loss to explain the present paucity. Such shortages lead inevitably to gross and uncalibrated selection effects in our knowledge of the properties of the stars setting the distance scale for the rest of the Universe.

The stars nearest the solar system have been found, catalogued and compiled using one of several limiting criteria. Here we will discuss briefly the stellar samples which are limited by distance, apparent magnitude or proper motion. In Table I are listed some of the major sources of nearby stars found using each criterion. It has been the goal of the authors to determine observed properties of as many stars in each source as possible, beginning with broad-band photometry in the BVRI colors. The observations can be used to define samples of stars which by their properties are useful for further analysis. The emphasis has been on stars whose parallaxes and proper motions are likely to carry special significance for problems of galactic structure and dynamics and are thus suitable candidates for the astrometric program of observation of the Van Vleck refractor.

The first-named source consists of the five catalogues of dwarf K and M stars found spectrophotometrically by Vyssotsky (1963) and his colleagues at the McCormick Observatory. To date they have been the most thoroughly examined of the sources listed. Photometry of every one of the 895 stars has now been obtained and thus a photometric distance is available for all. These data are being prepared for publication by the author and others. The following source is a list by Upgren et al. (1972) which in effect extends the McCormick lists of stars to the southerly declinations that were inaccessible to Vyssotsky. These stars too have photometry in BVRI colors, obtained mostly by Eggen (1974). More recently Stephenson (1986a, 1986b) has detected and catalogued about 4000 similar stars in the sky north of about -20° in declination and farther than 10 from the Galactic Equator. His lists contain many stars in common to the McCormick lists and allow the completeness of each source in identifying the stars forming the objective of their searches to be determined. Before this can be done, however, the Stephenson stars must be scanned for evolved stars among the others. Unlike Vyssotsky whose lists contain no more than four evolved stars, Stephenson used classification criteria which do not always sift out the evolved stars of the K and M spectral classes, and these must first be recognized and rejected.

TABLE I. SAMPLES OF COMMON STARS

Source	No of stars /systems	dominant sp types	lim. mv	sky coverage	complete info
1. Magnitude Limited					
Vyssotsky et al.	895	K3-M2	V	11	ë > -30° æ, BVRI
Upgren et al.	624	K3-M2	V	10.5	ë < -10° æ, BVRI
Stephenson	3989	K4-M2	V	12	ë > -25° + lbl > 10°
2. Distance Limited (ã > 0.045" or 0.040")					
Gliese, 2nd Ed	915	F5-M	V	all sky	æ, mv
Woolley et al.	1744	F5-M	V	all sky	"
Gliese & Jahreiss ext.	453	F5-M	V	all sky	"
Gliese, 3rd Ed (in prep)	3800	F5-M	V	all sky	"
3. Magnitude and Distance Limited (ã > 0.010")					
HIPPARCOS Proposal	192	7000	A0-K	V	12.5mv, sp class
McCuskey LF Regions	+ G-K	III	b near		0°
Midlatitude Regions	+ G-K	IV	b near		45°
NGP Regions			b near		90°
4. Proper Motion Limited					
LHS					æ, BVRI
NLTT					æ, BVRI

The catalogues of nearby stars listed in the table have recently received some attention. These are compilations from the existing literature and are only as good and complete as their sources. In the last few years, Gliese (1990) has reported a striking increase in the number of stars recognized as being within 25 parsecs of the Solar System, to not less than 3800 stellar systems containing some 4700 objects. The new stars are mostly very faint and are not likely to vitiate the work done on the completeness of the earlier editions of the catalogues. For those stars brighter than absolute magnitude +9 (B-V < 1.40 or spectral class M0 on the main sequence) the previous catalogues (Gliese 1969, Gliese and Jahreiss 1979) are statistically complete (Upgren and Armandroff 1981) whereas those fainter than that limit are complete only to about 13 parsecs (Gliese, Jahreiss and Upgren 1986). Almost all of the brighter stars have been observed photometrically, thus positioning them along the main sequence with confidence, but for many of their fainter counterparts the position had to be estimated from one or another of many spectral classifications. Photometry of these and the newly discovered nearby stars would help to firm up these conclusions and a major contribution has just been made by Bessel (1990) who obtained photometry for 937 stars from Gliese's 1969 edition.

The stars in the Catalogue of Nearby Stars (CNS) within about 13 parsecs of the Solar System may form the most important sample of all just because this is the volume of space within which stars are virtually completely known, at least to a limiting absolute magnitude beyond the maximum of the stellar luminosity function. The proximity of the stars allows the present-day parallaxes determined at the Van Vleck Observatory and elsewhere to derive a transverse velocity of a precision about equal to the best radial or line-of-sight velocities, and a successful completion of the mission of the astrometric satellite HIPPARCOS may extend highly precise space motions of this kind to more of this important sample. Photometry in more than one system of this sample from APT's would form a very useful adjunct to these data.

The next entry of the table refers to a proposed investigation on HIPPARCOS by the author. The goal is to extend the horizon of completeness for bright stars to a much greater distance than the limit of 25 parsecs of the Gliese survey. The stars between absolute magnitudes of about 0 and +6 are too few within 25 parsecs for study as a sample. But to the effective distance horizon of 75 to 100 parsecs expected for precise parallaxes from the satellite these stars, which include the A, F, and early G stars of the main and subdwarf sequences as well as the giant and subgiant branches, will constitute a complete sample within the volume covered. Details have been described elsewhere (Upgren 1983). These stars form another candidate group for attention by APT's.

The proper motion limited sources are the most obviously biased, but they tend also to be the most extensive. Photometry has progressed here too; all stars in the LHS Catalogue of Luyten brighter than V = 15 now have broad-band photometry. Weis (1990) has just completed observations of the stars missed by Eggen (1987), most of which lie north of +30° in declination and therefore are inaccessible to Eggen. Weis has also completed a photometric survey of the NLTT Catalogue which is limited but includes the stars in it that are the most likely to be previously undetected stars within 25 parsecs of the Sun and therefore are now included in Gliese's current nearby star catalogue. The survey is published in four parts (Weis

1988) and is limited to the stars north of the Celestial Equator with no trigonometric parallaxes and with proper motions not larger than 0.5"/yr. They are also constrained to those of color class m (the reddest class as estimated by Luyten) with red magnitudes > 13.5, corresponding to a visual magnitude between 14 and 15. Of the 2013 stars covered, 295 have photometric parallaxes larger than 0.040", placing them in Gliese's list, and only ten have parallaxes placing them within ten parsecs. Since most of these ten are near the faint limit of the survey, their absolute visual magnitudes must be not much brighter than 15, indicating that the statistical completeness within about 13 pc referred to above is correct.

Although final calculations are not yet complete, the stars in common to Luyten's proper motion lists and to the objective prism based surveys of Vyssotsky and Stephenson have been used to indicate the degrees of completeness of the latter. Indications at this point are that the Vyssotsky lists include about 90 per cent of the proper motion stars within his magnitude and color limits whereas the corresponding figure for Stephenson's stars stands between about 60 and 70 per cent.

The recent progress described here has been mostly in the form of broad band photometry in the BVRI colors. These data are fine for positioning stars on color-magnitude planes with the kind of precision needed to compare one survey with another, unlike the non-photometric apparent magnitudes and spectral class estimates of earlier days. But the samples listed in the table are the best we have to represent stellar populations faithfully. More extensive photometry, radial velocity estimates and abundance measures are needed to determine, for example, metal abundances, chromospheric activity levels, binary and multiple star percentages, and their gradients as functions of loci in the galaxy. Much of this is routine work not suited to a poor climate or to most mountaintop observatories limited, as they are, to large telescopes and short observing runs. APT's seem the likely answer to this kind of need.

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