VARIABLE STAR OBSERVATIONS WITH AUTOMATIC TELESCOPES

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ABSTRACT. Small automatic telescopes have been used for several years to make wide band, differential photometric observations of brighter variable stars. For example, a single automatic telescope located in Arizona has been used to study essentially the entire class of RS Canum Venaticorum binaries. These stars have changing spot structures that require once-a-night photometric observations - an ideal job for an automatic telescope located in the clear skies of Arizona. The operation of such automatic systems has become so routine that an "Automatic Photoelectric Telescope Service" now makes photometric observations for any institution so requesting. A list of stars is sent to the Arizona site of this service, and every three months the observational results are returned, with the cost typically being similar to the publication page charges. Currently the use of automatic telescopes is being extended to fainter stars and narrower bandwidths. For instance, a highly specialized one-meter telescope has been designed for automatic observations of Ca II K-line emissions from brighter active chromosphere stars. Further extensions of such automation seem likely.

1. INTRODUCTION

Every clear night for the past two years, an automatic photoelectric telescope (APT), located in Phoenix, Arizona, has been making broadband photometric (UBV) observations of variable stars. It decides itself when observations should begin, and then selects, from a list of 80 variable stars, which star should first be observed. The APT then automatically finds, centers and measures the variable star, along with appropriate comparison and check stars. This process continues all night long until the APT decides it is time to stop observations and shut down. Four times a year the data is automatically reduced, and a computer in Phoenix transmits the reduced observations to a computer at Vanderbilt University in Nashville, Tennessee. There it is added to previously transmitted observations in a computerized data base. A wide range of computerized tools, such as plotting, editing, and period

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determination are then brought to bear on the observations by that vital non-computerized ingredient - experienced human astronomers.

Experience with the Fairborn Observatory's APT in Phoenix suggested that variable star observations with automatic telescopes could result in large amounts of high quality data being gathered with great efficiency. This seemed particularly true if: (1) routine photometric observations were required on a large number of different stars over a long period of time; and (2) the automatic telescope was located where there was a high frequency of photometric nights. As many other institutions besides Vanderbilt University would obviously benefit from automatic variable star observations, it seemed appropriate to organize such a service and offer it to astronomers world wide. To this end, the Fairborn Observatory (engineering and operations) and the Smithsonian Institution (buildings and site) have formed the Automatic Photoelectric Telescope Service.

The APT Service is located on Mt. Hopkins in southern Arizona near the well-known Multiple Mirror Telescope (MMT). The APT Service offers two basic options. With the first option, the participating institution completely owns and controls their own APT. The APT Service merely installs and maintains the APT for the participating institution. Currently 0.4-meter and 1.0-meter APT's are offered. With the second option, the participating institution places variable stars for some period of time on an existing APT owned by the APT Service. While the second option is necessarily limited to APT's and instrumentation already available (currently three 0.25-meter APT's and UBV or VRI differential photometry), it is very low in cost - typically the observations cost less than the page charges for publishing the results. Participating institutions currently include Vanderbilt University, the University of Toronto, Franklin and Marshall College, Wesleyan University, and the University of Arizona.

There is, of course, no reason why the operation of automatic telescopes should be limited to broadband photometry. For example, the Smithsonian Institution and the Fairborn Observatory are considering a light-weight and low cost 1-meter APT with a Ca II K-line photometer for dedicated observations of chromospheric activity in giant stars. The 3-Angstrom K-line filter's wavelength will be adjusted (by tilting slightly) to compensate for the earth's orbital velocity and the radial velocities of each star observed.

It will be the objective of this paper to cover in greater detail those areas summarized above. Specifically we shall discuss the operation of the Fairborn Observatory APT in Phoenix, the reasons for formulating the APT Service, the APT Service site on Mt. Hopkins, the two basic options offered by the APT Service, a proposed 1-meter APT and K-line photometer for observing chromospheric activity, and, finally, other options for full automation besides photometry.

2. VARIABLE STAR OBSERVATIONS WITH THE PHOENIX APT

The 0.25-meter Fairborn Observatory automatic photoelectric telescope (APT) located in Phoenix, Arizona, has now been in regular operation for over two years. As this system has been described in some detail elsewhere (Boyd et al 1984), we will not repeat this description here, but will instead concentrate on its operation and sample variable star observations.

The master list of stars to be observed was generated by the research astronomer (Hall), and included data on the names, positions and V-magnitudes of each of the variable, comparison, and check stars, as well as the sky measurement position. Before entry by the engineers (Boyd and Genet) onto the observing program diskette, a check was made to be certain that all requested observations were within the declination and magnitude limits of the system. If too few variable stars had been placed on the master list, then the APT would have run out of new stars to observe and would have started asking repeat observations. On the other hand, if too many variables had been placed on the list, then there would have been nights that some variables were not observed at all. We found that for UBV photometry of brighter stars that about 80 variables gave the right loading. Some thought was also given to the rough RA distribution of the stars so that they were not all bunched into one or two seasons.

Once the stars had been placed on the master list, then they were observed every clear night automatically without any human intervention or assistance. This automatic process has been described well in Boyd (1985) and Trueblood and Genet (1985), and need not be repeated here.

Every three months for the past eight quarters, the data was consolidated by star and reduced. This operation was computerized and consisted primarily of sorting the data and then reducing it using well known differential photometry procedures. The reduced data was then transmitted from Phoenix to Tennessee (Vanderbilt University) via modem at 1200 baud - a process that only takes about 15 minutes. Here the data from each star was merged with observational results from the APT for previous quarters, as well as results from nonautomatic telescopes. A very convenient set of computerized data manipulating, plotting, and analytic tools were then brought to bear on each variable star by the Vanderbilt University astronomers and graduate students.

3. FORMATION OF THE APT SERVICE

Shortly after the Phoenix APT became operational, we began examining ways of further increasing the already high efficiency of APT's. The system as originally configured and programed already spent 67% of its time making the scientific observations (the recorded integrations), and only 33% of its time moving between stars, finding and centering stars, changing filters, and deciding what to do next. Thus further efficiencies here could not be large. However, even a simple analysis showed that major increases in efficiency were possible if a number of APT's were operated together as a group.

A single engineer can readily take care of a number of APT's. The test equipment, software development equipment, and tools needed for a single APT are readily applied to a group of APT's if they are all at the same location. Much of the facilities and site support required for a single APT is applicable to a group of APT's, such as shop and office space, road construction and maintenance, utilities, etc. Also, the weather sensors can be common, and if there is a large roll-off roof, the roof and its control can be common.

With a group of APT's making observations for many different institutions in several countries, it becomes worthwhile to place the APT's at a first rate site. This not only improves the quality of the observations, but by having a high frequency of photometric nights, the continuity of the data is improved, thus reducing observational gaps.

As the Fairborn Observatory has had years of experience in the engineering development and operation of APT's, it seemed appropriate that these aspects of an APT Service should be handled by this organization. The critical questions of the site for the APT Service was studied for quite some time (Baliunas et al 1985b). The choice that clearly emerged as being best was the Mt. Hopkins site of the Smithsonian Institution's Fred L. Whipple Observatory. Not only was this site outstanding photometrically, but two buildings, including one with a very large roll-off roof, were available. The Smithsonian Institution, which has a research program of long standing on variable stars (particularly cool stars with active chromospheres), joined with the Fairborn Observatory to form the APT Service. This service is now being offered to institutions world wide that need routine photoelectric observations of variable stars.

4. APT SERVICE OPTIONS

In the first of the two basic APT Service options offered, the participating institution owns and completely controls the APT (Boyd et al 1985a). The role of the APT Service is that of installation, operation, and maintenance of the APT for the institution that owns it. While the choice of telescopes is currently limited to two (0.4-meter and 1.0-meter), there is considerable freedom of choice on filters and detectors, and limited customization of the control software to suit a unique situation is possible.

The 0.4-meter telescope is made by DFM Engineering (Melsheimer and Genet, 1984), and is a well-built Cassegrain system with a zero-backlash friction dirve and very rigid mount - characteristics very desirable for automatic telescopes. The telescope control electronics, and the computerized photometer are made by the Fairborn Observatory. The cost of an installed system is typically $35,000. Operation and maintenance of the system includes loading the list of stars sent from the institution that owns the APT, periodic maintenance, including re-aluminization of mirrors when required, repair of failed equipment (very rare), and reduction and transmittal of the data to the home institution. The annual cost of this service, which includes a share of the overall operation of the APT Service, is $15,000 per year.

The 1.0-meter telescope is made by the Fairborn Observatory, and is described later in this paper. The installed cost of this telescope including normal photometric instrumentation, is $100,000, and the annual cost for operation and maintenance is $25,000.

In the second basic APT Service option offered, the participating institution places a number of stars for some given time on one of the already existing APT's owned by the APT Service itself. Typically a number of stars might be placed on the program to supplement observations made at the home institution, observations might be requested for a limited time (a year or two) in support of a grant, or favourite stars might be followed at low cost. This second option has been described in some detail by Boyd et al (1985b). There are currently two suboptions that can be considered.

In the first suboption, stars are not observed more frequently than once per night (one differential sequence per night). It can be specified that they be observed less frequently than this, such as every other night, every fifth night, etc. The cost per observational sequence (some 33 measurements made over seven minutes) is only $2. This is so low that on a typical star if one observation is made every clear night, the cost for a year is only $400 (observations on some 200 nights). This can easily be less than the page charges to publish the results! Currently stars can be observed in UBV on a 0.25-meter APT, or in VRI on another (separate) 0.25-meter APT.

In the second suboption, a single variable star can be observed differentially for hours or even all night for several nights in a row. A single 0.25-meter APT with a VRI photometer is being set aside for these sorts of observations as they can not be readily mixed with the "once a night or less" types of observations because if mixed this would cause unfair gaps in the observations of stars supposed to be observed once a night. The cost of this service is $25 per hour.

5. ONE-METER AUTOMATIC TELESCOPE DESIGN

Having met with considerable success with the first and second generation small APT's, it was only natural that something considerably larger, say one-meter, would be considered. This is not as straightforward as one might think because the small APT's typically make about 25,000 separate motions each night - mainly to find and center the stars to be observed. The physical smallness of these APT's is an advantage because they can be moved about quickly and settle down in a fraction of a second. If a one-meter APT had a large moment of inertia and took a long time to settle down, it would not work well with the current control system and software. Additionally, for several one-meter telescopes to fit in the roll-off-roof building on Mt. Hopkins along with the smaller APT's, they would need to be very compact in size, and should have minimal interference with each other's light paths.

Simplifying the situation somewhat is the relaxed optical requirement inherent in on-axis photometry. As the one-meter telescope is only intended for automatic photometry, no provisions need be made to accomodate a human observer in any way. For instance, the telescope can be very low to the floor, and the Dec drive can run up the middle of the back of the telescope instead of being placed on one side so as to not block the observer. Also, as only photometry will be done with a photometer permanently put in place, provisions for other instruments are not required. In short, the telescope can be a dedicated, special purpose instrument not intended for human operation.

With the above requirements and simplifications in mind, it is not surprising that the resulting design is unusually compact and lightweight yet stiff. The new mirror technology is capitalized on in terms of a lightweight, low f-ratio primary. Friction drives are utilized in both RA and Dec to achieve zero backlash without preloading. A tripod has been used to support the lightweight secondary mirror. While this increases the diffraction image somewhat above that of a spider, it has a very low moment of inertia, and it allows the telescopes to be placed close to each other without interference.

6. GIANT STAR PROJECT AND K-LINE PHOTOMETER

A good example of a specialized photometry project that is ideal for a dedicated large APT is the giant star project proposed by Sallie L. Baliunas at the Harvard Smithsonian Center for Astrophysics. In preliminary observations made at Mt. Wilson in the Ca II H and K lines, it was clear that at least some of the more rapidly rotating giants had areas of chromospheric acitivity. If a large number (several hundred) of the brightest giants visible from the northern hemisphere were monitored in the Ca II K line nearly nightly for a decade or so, not only could many rotational periods be accurately determined, but activity cycles could be determined at the lower end of the scale of chromospheric activity and perhaps lower bounds could be placed on such activity with respect to rotational speeds.

Observing the K-line in giant stars requires a large telescope to overcome the limited photons available, a very narrow filter (only 3 Angstroms), and an accurately adjustable filter center wavelength to match the rotational velocity of the earth and the radial velocities of the giant stars being observed. A photometer designed for this specific task has already been described by Baliunas et al (1985a). Briefly, the K-line narrowband filter is tuned by slight tilting from a geared stepper. To avoid the effects of changing atmospheric transparency, it is necessary to go back and forth between the K-line and continuous filters at frequent intervals. This is accomplished by two very light-weight mirrors mounted on miniature stepper motors that rotate in opposite directions (keeping the net angular momentum constant). The entire unit, including the thermoelectric cooled photomultiplier, is small enough to fit directly behind the primary mirror of the one-meter APT discussed earlier.

7. EXTENSIONS BEYOND CONVENTIONAL PHOTOMETRY

Broadband differential photometry of brighter stars provided a logical starting point for routine automated observations of variable stars. Extending this approach to very narrow band (K-line) photometry of bright giant stars requires primarily a larger automatic telescope, as

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discussed earlier. When some experience has been gained with one-meter-class automatic telescopes, it seems likely that besides photometric observations of fainter stars, that extensions to other forms of observation would be natural.

One of the easiest extensions would be to stellar polarimetry. One is concerned here with an on-axis image, the equipment is mainly an "add-on" to conventional photometric equipment, and the data rates are similar to photometry. One could quickly come up with many useful programs that could combine photometry and polarimetry on a dedicated automatic system that would observe almost every night for a decade.

Area photometry using CCD's is producing good results as has been suggested by others at this Symposium. There is no reason why such area photometry could not be automated, although the volume of data to be recorded and transmitted would increase by orders of magnitude over conventional photometry. A program of area photometry of the brightest 20 or so open clusters every clear night for a decade would produce a treasure trove of variable star photometry for those interested in stellar evolution.

The spectroscopists have already been asking for suggestions as to how dedicated AST's (Automatic Spectroscopic Telescopes) could take over some of their routine, long-term observations, work on catalogs, etc. Here, automatic telescopes larger than one-meter quickly enter any discussion. Such "very large" automatic telescopes and their various potential applications have been discussed recently by Boyd, et al (1986). While such speculations may be interesting, it seems likely that at least in the near future the primary contribution of automatic telescopes will continue to be in the area of photometry of variable stars.

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DISCUSSION

Osborn: What precision do you obtain from a single measure?

Genet: The system in Phoenix (10s integration on a 10" telescope) is typically a hundredth of a magnitude. That is, no different from a non-automatic telescope.

Moffett: How do you detect cloud or rain?

Genet: This is the crucial point of the technique. There is no sense in having an automatic telescope if you have a person there to check for clouds and/or rain. We solve this in two ways. After the fact, we collect the data and look for internal consistency in three colours. If they are not consistent the data is rejected. At the telescope, if the clouds are too thick, the procedure is to make 4 tries at centering on the star. If this fails it closes itself down.

Cameron: Have you given any consideration to using red-sensitive tubes suitable for VRI photometry in these systems? If synoptic modelling of the evolution of starspot groups in RSCVn and related objects is one of your major programmes, UBV photometry has the disadvantage that problems with line-blanketing make it very difficult to resolve the ambiguity between the temperatures and the areas of the spots. Steve Vogt has shown that using the relationships between VRI colours and the visual surface brightness found by Barnes, Evans and Moffett.

Genet: The Phoenix system is just UBV. The Mt. Hopkins system uses a VRI photometer and we have ordered a Hamamatsu GaAs tube. UBVRI observations should start in January 1986.

Andrews: What is the effect of a Schmidt correcting plate of a Celestron 14 on the ultraviolet band for photoelectric observing? Have you made comparisons with conventional cassegrain scopes?

Genet: I think you just lose light (especially in U) with the corrector plate but one can transform onto the standard system using standard stars.

White: The problem of observing lunar occultations of stars showing measurable angular diameters with small telescopes is scintilation. If there exists an array of small telescopes their spatial integration will reduce the scintillation effects, as long as photons are not a limiting factor.

Schülte in den Baümen: What is the positioning accuracy of your telescope?

Genet: Long slew: within 2 arcmin of object correcting only for precession
Short slew: within 10-15 arcsec.

Page: What aperture diameters are used for the APT?

Genet: In Phoenix: 90, 60, 45 arcsec aperture, but we usually use the 60 arcsec one (10" telescope on stars brighter than 8th mag). VRI photometer: fixed aperture of ~60 arcsec.

Hickey: What is cost per observation?

Genet: $US2 per set of observations.

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