# THE RESEARCH POTENTIAL OF SMALL TELESCOPES

Brian Warner
Department of Astronomy,
University of Cape Town,
7700 Rondebosch. South Africa

ABSTRACT. The use of small telescopes for the production of significant research is examined from the points of view of cost-effectiveness, notable successes already achieved, the advantages over large telescopes in the areas of efficiency, availability, flexibility and serendipitous and speculative observation. It is concluded that small telescopes have an increasingly important role to play in modern astronomy.

## 1. INTRODUCTION

Interest in the design and construction of very large telescopes has never been greater than at the present time and there is no shortage of research projects for such instruments. The glamour associated with the very large can easily obscure the fact that small telescopes have a place, and an increasingly important place, in modern astrophysical research. It is vital that this assertion be understood and widely accepted: there are many Institutions, even entire countries, who cannot afford to enter the race for giant telescopes and who consequently consider themselves unable to contribute anything of significance. A study of past and present usage of small telescopes leads to a different conclusion: there is a need for more small telescopes, for better use of existing ones and for continual upgrading of the instrumentation used on them.

The purpose of this introductory article is to illustrate the truth of these statements; the remainder of the Symposium proceedings will provide a comprehensive survey by experts in their respective fields which will demonstrate better than I can the present and potential contributions made by users of small telescopes - and I choose my words with care here, for it is the users not the telescopes who do research, and the demands on comprehensive knowledge and ingenuity are if anything greater for the possessor of limited aperture than for the better endowed.

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## 2. COST EFFECTIVENESS

The cost effectiveness of a telescope or collection of telescopes can be considered from several points of view. A penetrating analysis has been given by Disney (1972) in comparing a large telescope versus an array of smaller ones working on the same kind of observation. This latter condition is not appropriate here - we will show that the most effective use of small telescopes is to carry out projects that large telescopes cannot do. Nor is Disney's definition of effectiveness - as the limiting faintness to which a telescope can carry a given observation *in a given time* - appropriate for our present purpose. Instead I will present a naive domestic argument that will amuse you by its presumption.

Let us define cost effectiveness E in the way that a commercial enterprise might: as the annual return on capital investment. Then

$$E = \frac{\text{Number of Publications per annum}}{\text{Cost of Telescopes}}$$

where we count only publications that are significant!

The cost of construction of a telescope is usually expressed in the form

$$C = AD^{\alpha}$$

where D is the diameter of the mirror and the exponent $\alpha$ is $\sim 3$ for traditional designs but may be $\sim 2$ for designs using the recent advances in technology. We further assume that the cost of instrumentation and of maintaining a telescope scales as the cost of construction and can therefore be absorbed into the constant A.

If we have constructed n telescopes and each one produces $\tau^{-1}$ publications per year ($\tau$ is the mean time taken to complete an observational project) then

$$E = \frac{n\tau^{-1}}{A \sum_{i=1}^{n} D_i^{\alpha}}$$

For simplicity we compare the cost effectiveness of using n small telescopes of diameter $D_s$ versus that of using one large telescope of diameter $D_\ell$ where the total capital cost of the alternative arrangements is the same

$$\text{i.e.} \quad nAD_s^{\alpha} = AD_\ell^{\alpha}. \tag{1}$$

Then

$$\frac{E_s}{E_\ell} = n\,\frac{\tau_\ell}{\tau_s} \tag{2}$$

where we recognise that it may take more observing time $\tau_s$ to achieve significant results on a small telescope than the time taken $\tau_\ell$ on a large instrument.

Equation (2) shows that provided $n > \tau_s/\tau_\ell$ it makes sense to invest one's money in several small telescopes rather than one large one. From equation (1) we see that $n = (D_\ell/D_s)^{\alpha}$, so for the choice between one 4m telescope and $n = 4^{\alpha}$ 1m telescopes we require $\tau_s < 4^{\alpha}\tau_\ell$ which must surely always be satisfied: my own estimate is that $\tau_s \sim 4\tau_\ell$, in which case it is at least as profitable (in terms of research output) to build four half-size telescopes as one full-size telescope, and even better to build more even smaller ones!

The above analysis breaks down when we reach apertures so small that no worthwhile research can be achieved with them. In fact, the whole analysis would be worthless if nothing significant at all could be achieved with telescopes of modest size - so we interrupt further development of the case for "small is beautiful" to illustrate what has already been accomplished.

## 3. SOME SMALL TELESCOPE TRIUMPHS

In giving examples of what has been achieved with small telescopes I can be neither comprehensive nor unbiased. I will, however, choose principally from modern successes: if you go far enough back in time there are divers instances of important results obtained with small telescopes, but those resulted merely from the combination of the rarity of large instruments and the richness of opportunity for discovery. As an extreme case, the satellites of Jupiter and the phases of Venus were found using a refractor of only 3 or 4 cm aperture, but that was probably the world's largest telescope at the time! My examples are taken from the past thirty years or so and are intended to demonstrate that really significant achievements (and others that are important if less significant) have been made with the use of modest equipment.

### 3.1 Interstellar Polarization

In seeking the intrinsic linear polarization in stars predicted by Chandrasekhar (1946), Hiltner (1949) and Hall (1949) discovered that the interstellar medium impresses polarization on the light of distant galactic stars. Hall used the 40 inch reflector at the US Naval Observatory; Hiltner used the 82 inch reflector at McDonald Observatory but could have discovered the effect with a smaller telescope if one had been readily available! Much of the very extensive material now available on interstellar polarization has been gathered with modest telescopic power. The importance of these observations to studies of interstellar grains, the galactic magnetic field and to galactic structure in general needs no elaboration.

Curiously, the search for the Chandrasekhar effect has only recently met with success: in Algol, by Kemp *et al.* (1983), using a 61 cm telescope.

### 3.2 Circular Polarization

The first detection of circular polarization in optical astronomy was made with a 24 inch telescope (Kemp *et al.* 1971). This was the result of a deliberate search for circular polarization in white dwarf stars, stimulated by the theoretical prediction that such an effect should be present in stars with very large magnetic fields. Studies of polarization in white dwarfs have resulted in determination of magnetic field structures in isolated stars and in close binary stars (the Polars, or AM Her stars, e.g. Cropper 1985). Again much of the observational material has been obtained with modest telescopes - particularly for the Polars where circular polarizations of up to 50 per cent make worthwhile observations feasible on stars even as faint as 16 mag with telescopes of 1m or less.

## 3.3 The Crab Pulsar

Probably the most spectacular discovery made in recent years with the aid of a small telescope was that of the optical pulsar in the Crab Nebula (Cocke, Disney & Taylor 1969).

Soon after the discovery of radio pulsars was announced in February 1968 several groups (e.g. at Kitt Peak and at McDonald Observatory) had used large optical telescopes in attempts to produce optical identifications. After nearly a year with no success it was becoming difficult to obtain large telescope time to continue the search. Drs. Cocke and Disney "whose observing experience was virtually nil" (Cocke, Disney & Taylor 1972) found it relatively easy to obtain five nights on the Steward Observatory's 36 inch reflector. After equipment difficulties and poor weather had prevented a satisfactory search for the pulsar they managed to obtain a further two nights from the next observer (something less readily accomplished when using a large telescope) and thereby discovered the Crab Pulsar in extra time.

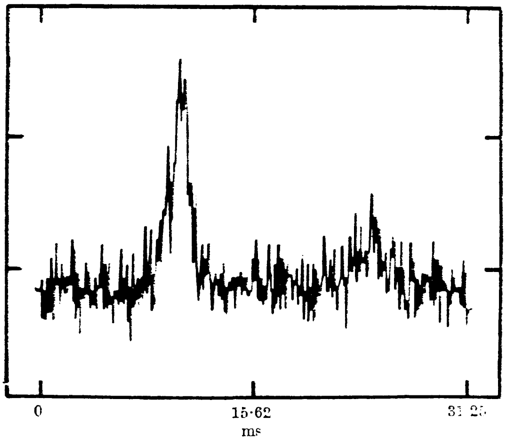

Fig. 1 *Optical pulses of the Crab Pulsar on 20 January 1969. From Cocke, Disney & Taylor (1969).*

Subsequent studies of the pulse arrival times of the Crab pulsar have been made almost exclusively with small telescopes (92 cm: Groth 1975; 60 cm: Lohsen 1981) and produce information on period changes fundamental to the understanding of the structure of neutron stars.

## 3.4 Double Degenerate Close Binary

The faint blue star HZ 29, recognised spectroscopically as a white dwarf, was found by Smak (1967) using a 36 inch telescope to be a variable with a period of 17½ mins. This provided the impetus that stimulated later work (Warner & Robinson 1972a; Faulkner, Flannery & Warner 1972) which showed that HZ 29, renamed AM CVn, is a short period mass transferring close binary with both components degenerate whose evolution may be controlled by the emission of gravitational waves.

## 3.5 DB White Dwarf Variables

The theoretical prediction that a new kind of variable star - oscillating DB white dwarfs - should exist was verified with the use of a 36 inch reflector in the discovery of pulsations in GD 358 (Winget *et al.* 1982).

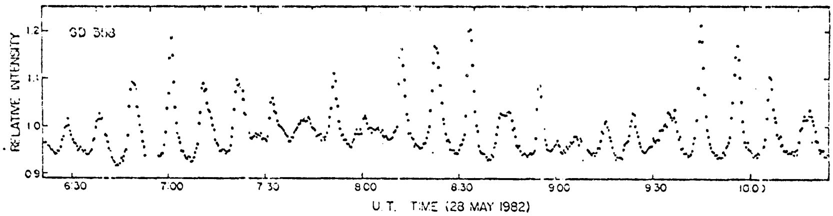

Fig. 2 *Light curve of the DB White Dwarf variable GD 358 observed with a 36 inch reflector. From Winget et al. (1982)*

## 3.6 Cataclysmic Variables

Because of the faintness of white dwarfs the study of their physical properties was once the almost exclusive privilege of 200 inch telescope users. However, for once nature conspires to aid the small telescope user and many unique optical phenomena associated with the white dwarfs or their accretion discs in cataclysmic variable stars occur conveniently during the eruptions of dwarf novae when they reach brightnesses (8-12 mag) within easy reach of small telescopes. The demonstration that it is the accretion disc that brightens (and not the secondary star as had been previously thought and enthusiastically modelled by theoreticians) during a dwarf nova outburst was made with a 20 inch telescope (Warner 1974). The enigmatic superhump structures present during supermaxima of SU UMa stars were discovered with 61 cm and 1 m telescopes (Vogt 1974, Warner 1975). The rapid (10-50 sec) periodic oscillations often present during eruptions of dwarf novae (Warner and Robinson 1972b) are well within reach of small telescopes.

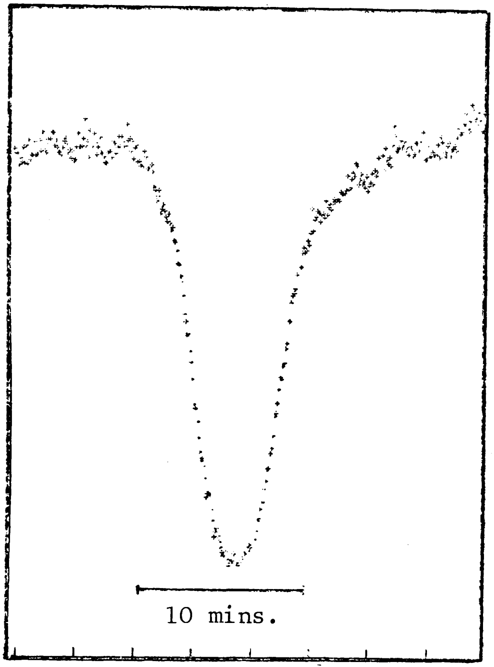

Fig. 3 *Eclipse of Z Chamaeleontis 8 January 1973, observed with 20 inch telescope. The deep eclipse demonstrates that it is the accretion disc that brightens during outburst of a dwarf nova. From Warner (1974).*

## 3.7 Optical Flashes from Gamma-Ray Bursters

Although not yet satisfactorily verified, the possible detection of three optical flashes from the Gamma-Ray burst source GBS0526-66 in $\sim$910 hours of monitoring with a high speed photometer on a 50 cm telescope (Pedersen *et al.* 1984) is an example of how a small telescope can contribute crucial information at the forefront of high energy astrophysics - and as this source is probably located in the supernova N49 in the Large Magellanic Cloud, the contribution is also one to extragalactic research.

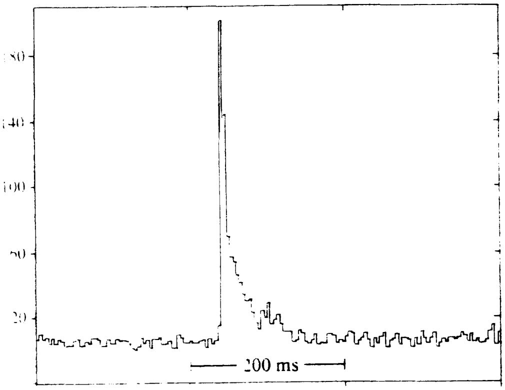

Fig. 4 *Possible optical flash from Gamma-Ray Burster GBS 0526-66 on 27 October 1983. From Pedersen et al. (1984).*

### 3.8 Rapidly Oscillating Ap Stars

The announcement in 1978 (Kurtz 1978) of a hitherto unsuspected class of rapid variable star, which includes among its members a star as bright as second magnitude, came as a surprise. The initial and most subsequent observations were made with a 20 inch reflector. Analysis of these low amplitude pulsators (Kurtz 1982) shows promise of providing details of the interaction between pulsations and magnetic fields and provides one of the first examples of the study of the seismology of stars other than the sun (Christensen-Dalsgaard, Gough & Toomre 1985).

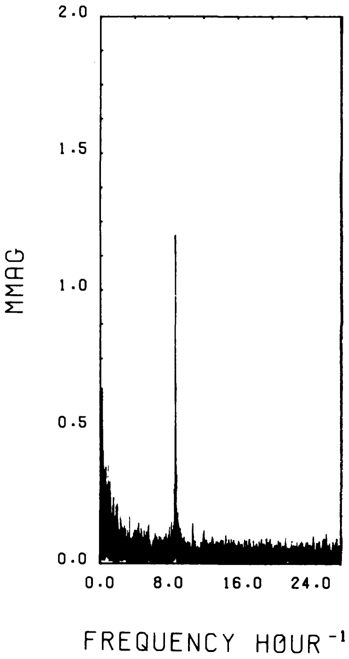

Fig. 5 *Amplitude spectrum of 70 hrs of photometry of the Oscillating Ap Star α Cir showing the presence of coherent 6.8 min pulsations. Note the very low noise (∿0.1 millimags) obtainable from extended photometry. From Kurtz & Balona (1984).*

### 3.9 The Rings of Uranus

The rings around the planet Uranus were discovered (Elliot *et al.* 1978) by various observers of an occultation of a star by the planet, including ones using 46, 61, 102 and 104 cm telescopes. These were the first planetary rings to be discovered since Huygens correctly interpreted the appendages of Saturn in 1655.

## 3.10 Charon: the Satellite of Pluto

In 1978 astronomers at the U.S. Naval Observatory claimed from photographic evidence that Pluto has a satellite, which they named, Charon. This discovery was received with some scepticism until proven correct by Walker (1980) who observed an occultation of a star by Charon on 7 April 1980. The observation was made with a 1.0m telescope.

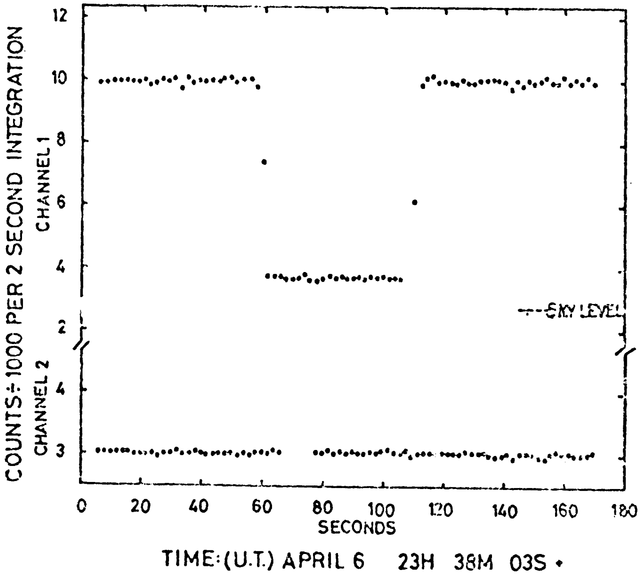

Fig. 6 *Occultation of a star by Charon (upper curve). From Report of the South African Astronomical Observatory 1980.*

## 3.11 Radial Velocity Measurements

Until 15 years ago almost the only source of high accuracy radial velocities was from massively designed high stability spectrographs at the Cassegrain and coudé foci of large telescopes. The quiet revolution started by Griffin's (1969) application of multiplex techniques to radial velocity measurements, using the 36 inch reflector at Cambridge, has taken much of the production away from large instruments. Apart from Griffin's own contributions, important results are being obtained with a variety of telescopes, one example of which is the radial velocity curve of the 104 day binary Capella, measured with the radial velocity meter at the coudé focus of the 61 cm reflector at the Fick Observatory (Beavers & Eitter 1977, Shen *et al.* 1985).

## 4. MISSED OPPORTUNITIES

In addition to the achievements already listed there are numerous phenomena well within the reach of small telescopes that by historical accident were found first with large telescopes: often much of the later work was in fact carried out with the more readily available smaller instruments. Choosing just two examples from my own field of interest, Merle Walker's discoveries (Walker 1954, 1956) that the nova remnant DQ Her is a short period ($4^h39^m$) eclipsing binary and a 71 sec oscillator were made with the Mount Wilson 100 inch telescope, and the first of the pulsating white dwarf stars, HL Tau 76, was discovered by Landolt (1968) with an 84 inch telescope, whereas ZZ Cet (Lasker & Hesser 1971) and several others were subsequently found with telescopes in the range 30-40 inches.

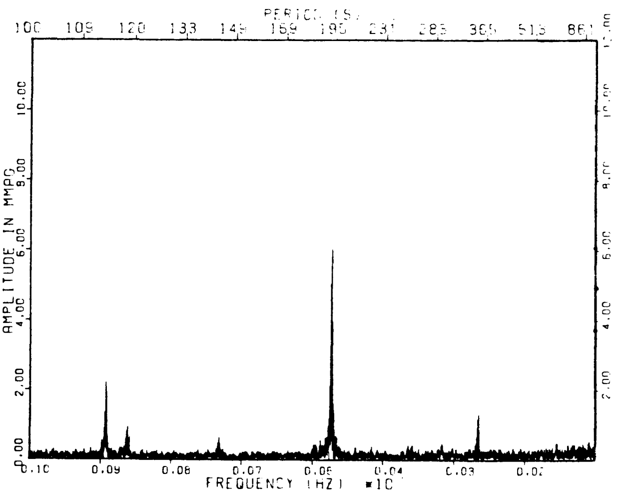

Fig. 7 *Amplitude spectrum of 38 hrs of photometry of the pulsating white dwarf (ZZ Cet type) star L19-2 showing presence of 5 coherent oscillations. From O'Donoghue & Warner (1982)*

## 5. ADVANTAGES OF SMALL TELESCOPES

My arguments about the greater output of astronomy for a given input of funds require of course a number of caveats and qualifications. The most obvious is that for many kinds of research (photometry and spectroscopy of faint objects, high time resolution) there is simply no substitute for photons. However, claims that a given observation can always be made more efficiently or more quickly on a larger telescope need to be considered in the light of practicability.

In the remainder of this review I will look at large versus small from various perspectives, concentrating on direct research applications and omitting indirect usages such as text bedding of equipment destined for large telescopes, or aid in education and training.

### 5.1 Efficiency

Large telescopes are often designed to be as versatile as possible - multipurpose instruments not always efficient at their tasks. In contrast, a small dedicated telescope can be optimised for a single purpose using, for example, special optics, superreflective coatings or distinctive mounting. Examples are the DAO 48 inch reflector whose coudé spectrograph is faster than that of the 200 inch (Richardson 1971) and the 61 cm rotatable tube polarization telescopes at Yerkes and Siding Spring Observatories (Hiltner & Schild 1965).

Furthermore, the permanent installation of instrumentation on a dedicated telescope ensures stability of performance, improved monitoring of calibrations and reduced loss of time from instrument malfunctions associated with equipment changes. A site with several small telescopes, each dedicated and optimised, is an ideal arrangement; there can even be a large telescope if desired.

For some purposes, particularly in the study of rapid photometric variability in stars where only the frequency domain is of interest, it is an advantage to abandon the filters of standard photometric systems and use "white light". For very blue stars such as ZZ Cetis or cataclysmic variables, a gain in signal of 4 or 5 times that measured through a B filter is obtained, thus effectively doubling the aperture of the telescope. The use of large telescopes for such unstandardised use as "white light" photometry might not be countenanced, but there should be no such neurosis about small telescopes, which are thereby surreptitiously converted into large ones.

It is sometimes possible also to exploit the usually better seeing in small telescopes, for example with a smaller entrance aperture or slit and faster optics. This can improve the signal-to-noise for small telescopes and make larger ones less advantageous.

## 5.2 Adequacy

There should be a general rule not to use a large telescope where a small one will suffice. This is not to imply that all telescopes should be used near their limiting magnitudes, which would make every observation a time consuming one. Rather I have in mind that, especially for optimally designed specialised small telescopes, some extensive observing programs can be taken away from large telescopes. For example, with an efficiently designed spectrograph it would be feasible to carry out with a 40 inch telescope the surveys of radial velocities of bright galaxies currently in progress on larger telescopes (Da Costa et al. 1984). Radial velocities of stars with $m_V \lesssim 12$ are already mostly measured by the Griffin (1969) technique on small instruments. An example of the use of a 20 inch telescope in stellar population studies of elliptical galaxies is the aperture photometry performed by Wegner (1979). The adequacy of modern small telescopes is illustrated by the fact that by far the largest and most homogeneous set of integrated spectra of globular clusters (once the prerogative of large telescopes) is that obtained at 120A/mm with the 1.0m CTIO-Yale telescope by Hesser & Shawl (1985).

A further example of important extragalactic research achievable on small telescopes is the CCD photometry of clusters in the Magellanic Clouds described in more detail later in this Symposium by Alistair Walker. In the southern hemisphere a 20 inch telescope has approximately the same absolute magnitude limit in the Clouds as the 200 inch has in M31.

For rapid variables of low amplitude, non-coherent oscillations may only be detectable with the low photon and scintillation noise obtainable with large apertures, but for variables with periods in the range 5-15 mins sky transparency variations dominate the noise and large aperture has no advantage (Kurtz 1984).

## 5.3 Availability

Probably the dominant advantage of small telescopes is their availability - not only are there many more small than large telescopes, they are less in demand by astronomers seduced by the alure of mere size. It is common at major observatories to find that the largest telescopes are oversubscribed by factors of 5 while the smallest telescopes are underutilized. No well-equipped telescope with an aperture of 16 inches or more should find itself idle - particularly in the southern hemisphere.

The observing time available on existing small telescopes and to become available on those yet unborn constitutes a major research resource for astronomy. It is here that the small outclasses the large: projects requiring intensive use of a telescope for many weeks, or guaranteed access for a few nights a month for several years, or simply large amounts of time for the forseeable future, cannot be serviced with a large telescope. In fact, for some observers restricted to the use of large apertures, such small amounts of observing time are available that the pressure to make conspicuous use of the time generates the "temptation to do first class second-rate astronomy" (Disney 1972).

The need for generous allotments of time is obvious for photometric programs on variable stars with long periods, for photometry of standard stars or for general photometric or spectroscopic surveys. Galactic stellar population studies such as the Strömgren-Olsen project to obtain Strömgren photometry of the 15,014 HD stars brighter than V=8.3 with spectral types A5-G0 (Stromgren 1976, Olsen 1979, 1980) can only be done on small telescopes.

Large amounts of observing time are also required for studies of short period variables with complicated frequency spectra. Examples are β Cep, δ Sct, PG1159, Rapidly Oscillating Ap and ZZ Cet stars, any member of which may require hundreds of hours of photometry spread over months or years in order to decipher the oscillation modes. The research rewards here are particularly exciting:- the oscillations reveal aspects of the interior structures of stars that cannot be obtained any other way. For example, using small telescopes, a measurement of dP/dt has been obtained for one of the oscillation frequencies in PG1159-035 (Winget et al 1985). Interpretation of this is currently ambiguous but should eventually test models of neutrino cooling in the cores of hot subdwarfs (Kawaler, Hansen & Winget 1985). Similar work in progress on the ZZ Cet stars will in a few years test the theory of cooling of white dwarfs (Robinson & Kepler 1980, O'Donoghue & Warner 1982).

In recent years, a new demand on small telescopes has arisen - that of monitoring (usually photometrically) objects observed simultaneously by IUE or EXOSAT. This important service will increase with the advent of the HST, AXAF, RHOSAT and other planned astronomical satellites. In order to obtain adequate longitude coverage from the ground good international cooperation and coordination is required. It may even become necessary to build new small and moderate size telescopes dedicated to such uses.

Optical monitoring of Gamma Ray Bursters, described above, is a good example of a project feasible only on small telescopes where large amounts of time are available.

## 5.4 Flexibility

For coordination with space observations where Target of Opportunity time has been awarded in order to catch an unpredictable event (e.g. a nova eruption) great flexibility of scheduling is required for the terrestrial telescopes. This is most easily satisfied on small telescopes, where trading of time or interruption of programs is more readily accommodated than on large telescopes where time is jealously held. Even without short lead-times, there are observations which require flexibility and exchanges of observing time: examples are planetary and lunar occultations, mutual phenomena of Jupiter's satellites etc.

As one illustration of successful coordination of observations of an unpredictable event I can cite the November 1984 supermaximum of the dwarf nova VW Hyi, which was observed (by prearrangement and only after two false alarms in the form of ordinary maxima) by Voyager 1, IUE, EXOSAT and at SAAO and ESO (Pringle *et al.* 1985).

### 5.5 Serendipity and Speculation

The large systematic programs, particularly of the survey type frequently undertaken with small telescopes, often disclose unusual behaviour of familiar objects or rare events or unusual objects. Many low amplitude variable stars, eclipsing binaries or spectroscopically peculiar objects have been found this way. A recent discovery, found during routine UBV photometry of hot stars, is that BD $-7^{\circ}3477$ is a hot subdwarf binary with a period of $2^{h}48^{m}$ and a strong reflection effect resembling the nuclei of some planetary nebulae (Menzies & Marang 1985).

Again, the low cost and relatively low demand for time on small telescopes enables speculative observations to be carried out that may be excluded from large telescopes, either because of pressures to carry out more certainly rewarding observations or because of reluctance to chance wasting time. The discovery of the Crab pulsar is a fine example of the reward of speculative observation.

## 6. RECOMMENDATIONS

There is no shortage of important research programs for small telescopes; more such telescopes are required, some of them can be had at no cost - they already exist but are not being used fully, sensibly, or at all. Many small telescopes at major observatories are starved of first rate instrumentation; this is criminal negligence - provision of off-set guiding facilities, two-star photometers and microcomputer data capture equipment can convert any small telescope into a major research tool - even at sites with poor weather (Warner 1971, Grauer & Bond 1981). At sites with very good seeing, on which small telescopes capitalize, limiting magnitudes are surprisingly faint - for example the 24 inch at Las Campanas produces spectra at classification dispersion (120 Å/mm) to $\sim$11 mag photographically, $\sim 13\frac{1}{2}$ mag with image tube enhancement and $\sim$16 mag for untrailed spectra. The spectral classifications produced by Corbally (1984a) with this instrument for close visual binaries - with separations 1"-5", all of which were provided with accurate UBV measurements using an area scanner on small telescopes (often operating through thin cloud - Hurly & Warner 1983), have proved useful in checking the latest isochrones derived from stellar evolution computations (Corbally 1984b).

To use a small telescope effectively requires willingness to exploit the special advantages. A basic equation in research productivity appears to be

$$\text{Current Research} = \frac{\text{Research Potential}}{\text{User Resistance}}$$

Small telescopes have the potential; it is up to us to reduce resistance to their use.

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## DISCUSSION

*Graham:* I want to emphasise the importance of long term standard star programs. They can only be done with small telescopes and yet much of the work done with large telescopes depends fundamentally upon them. Work of this sort, if done well is of tremendous value. The best example is Dr Cousins in South Africa, who with care and by paying careful attention to errors has provided a set of fundamental observations. No similar set of data exists for the northern hemisphere and it is an area in which people with small telescopes could become involved.

*Gaustad:* Although I agree with your emphasis on the contributions of small telescopes to high energy astrophysics, which we might not otherwise think of, I should like to point out the many contributions of small telescopes in the field of astronomy. They have given us the masses of stars and distances of many stars and the basis of such fundamental knowledge as the mass-luminosity relation.

*Djorgovski:* Surface photometry of almost anything - galaxies, globular clusters, or comets - is now an almost exclusive province of small telescopes. It may be a misuse of large telescopes to do such things with them.

*Schober:* Through recent observing experience I have found that small telescopes are not well maintained and that for this reason several nights of a two week observing run may be lost. Additional improvement in observing efficiency (maybe by a factor of 3 to 5) could be attained through automation. This improvement factor relates to pointing accuracy, automatic storage of coordinates and other areas.

*Warner:* Dedicated, optimised and well-maintained telescopes and instrumentation, which are always in operation, have stable properties and produce an efficient system.