Chapter 15

Advantages of Automated Observing with Small Telescopes

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Abstract: Advances in communications and electronics have made it possible to operate completely automatic telescopes reliably. This mode of operation lets one use moderately small telescopes to conduct research projects that would simply not be practicable otherwise. The principal advantages of automated observing, a) the ability to monitor objects over long times, b) flexibility of scheduling, and c) high productivity, are interrelated. We have operated state-of-the-art automatic photometric telescopes over the past fifteen years and are now adding automatic imaging and spectroscopic telescopes to give an integrated automatic observatory. We discuss how automating small telescopes can make them competitive research instruments through examples from this TSU Completely Automated Observatory.

Key words: automatic telescopes, robotic telescopes

1. INTRODUCTION

Moderately-sized telescopes automatically scheduled and controlled by computers are making it possible for the first time to do research projects requiring long-term monitoring and routine critical scheduling of observations. This advance is based on the application of inexpensive computers to the automation of observing and the use of telescopes small enough to be reliable.

Personal computers have revolutionized the way all of us do our jobs in research both in terms of how we collect data and how we analyze and publish the results. As a result of these advances, every astronomer has become much more productive, and consequently his time has become much more valuable. One possibly unrecognized product of this trend is that astronomers no longer have the time for making routine observations. Many educational institutions, e.g., Vanderbilt University, are even closing their small local research observatories. However, complete automation of the telescopes and their instruments makes gathering data cheap enough at last that it's possible to continue doing competitive research on many kinds of stars seemingly out of fashion and to begin doing other types of research simply not possible in the past because they required such a prohibitive commitment of personal effort.

Telescopes up to about two meters aperture are simple enough to automate because they can be designed around rugged passive systems to support the optics and move the telescope. This makes them ideal for completely automated operations and economically competitive.

At Tennessee State University (TSU) we have committed to building a completely automatic observatory with capabilities for very precise differential photometry, high dispersion spectroscopy, and multi-color imaging[1]. This facility includes seven photometric telescopes (APT's), one imaging telescope (AIT), a spectroscopic telescope (AST), and a control center for scheduling the telescopes and for collecting, reducing, archiving, and analyzing the data. The telescopes are located at the privately owned Fairborn Observatory site in southern Arizona; Table 1 lists the automatic telescopes operated by TSU, along with the number of years each has been operating and the primary observing program(s). We use our experience in operating this completely automatic observatory to discuss why automatic telescopes are effective, present some examples of successful research from the automatic telescopes, and outline future research plans for our totally automated observatory.

Table 1.
Automatic telescopes at Fairborn Observatory operated by TSU

Telescope	Years	Primary Observing Programs
T2 0.25m APT	15	Semi-regular and other miscellaneous variables
T3 .40m APT	14	Chromospherically active stars and early-F variables
T4 0.75m APT	9	Solar-type stars
T8 .080m APT	6	Solar-type stars and extrasolar planet search
T9 0.61m AIT	-	Under construction
T10 0.80m APT	1	Solar-type stars
T11 0.80m APT	1	Solar-type stars
T12 0.80m APT	1	Extrasolar planets, early-F variables, solar-type stars
T13 2.00m AST	-	Under construction

[1] See the TSU Automated Astronomy Group website at http://schwab.tsuniv.edu/

2. WHY AUTOMATED TELESCOPES ARE EFFECTIVE

At TSU we now have twelve years' experience in operating telescopes automatically and using them to do front-line niche research on stars. Consequently, we think we know quite a bit about how to operate small telescopes automatically and competitively. Under our operations model, which actually applies to the other groups with whom we share facilities (Adelman et al. 2000; Strassmeier et al. 2000), each automatic telescope is controlled by a single astronomer who manages its schedule and keeps tabs on how well it is working and fulfilling its mission. Maintenance is provided by a dedicated technician (in this case, the remarkably talented Lou Boyd, director of Fairborn Observatory) who lives on site and cares for very many automatic telescopes. His task is made easier by the fact that each telescope is dedicated to a particular type of observing, although not necessarily to a single project, and the instrumentation never changes unless it breaks or becomes obsolete. Henry (1995a)[2] discusses this operations model in more detail; with it, we are able to keep the automatic telescopes operating at roughly 95% capacity. One of our APTs is shown in Figure 1.

Figure 1. A modern automatic photometric telescope (T12) at Fairborn Observatory. This telescope is simple in design; it has no provisions for manual operation, although it does incorporate electronic cameras and apertures useful for periodically aligning it from the control room. It has a photometer that can be pulled out as a unit for maintenance and simple stepper drives adequate for finding and tracking stars reliably. Over the past 15 years, our APT's have collected over 400,000 group observations (a basic set of measurements of a group of three or four program and comparison stars) of the brightness of variable stars.

[2] Available at http://schwab.tsuniv.edu/papers/html/aptops/aptops.html

As a result of our experience, we can identify three primary reasons why automatic operations make “small” telescopes competitive for doing research now and into the future: (1) Projects can be done that are simply not feasible with conventional manual observing, on any telescope. (2) Automation makes the telescopes cheaper to operate for a variety of reasons. (3) Automation improves the quality of the data obtained with the telescope.

2.1 New Sorts of Research

The foremost advantage of automatic telescopes is that they make it possible to do new kinds of research. Such telescopes can be programmed to observe some star repeatedly in any way that one desires for years on end without much effort on any one person's part. This lets us conduct monitoring programs that can characterize the long-term light variations of many different kinds of stars. An early example of this is the studies we have done of chromospherically active binary stars with the APTs (e.g., Henry et al. 1995). Figure 9 shows the sort of data we have collected over the last 14 years with the T3 0.40-m telescope. Without that APT, we would never have been able to collect the data for this star and would never have continued research into the nature of starspots (e.g., Eaton, Henry, & Fekel 1996).

Because our automated telescopes can be programmed to look at objects at particular times, they are ideally suited to making observations of periodic variables such as eclipsing binaries. We have used this quality to investigate the eclipses of RS CVn for example, finding that we could not fit the photometry and spectral line profiles simultaneously with a few large spots (Eaton et al. 1993). This led directly to our work on a random-spots model, the first new idea in spotted stars in a decade (Eaton, Henry, & Fekel 1996). Although our work with automatic telescopes to date has been photometry of a few kinds of variable stars, such telescopes can be used equally well to investigate any object that must be observed at a particular time.

Because automated telescopes can be rapidly reprogrammed, they can quickly be trained on flaring variables, such as supernovae, novae, and γ-ray bursters. For instance, when our 0.6-m automatic imaging telescope is completed, it will be used in part to search for optical counterparts to γ-ray bursts (GRBs) detected with orbiting spacecraft, such as NASA's Swift mission due for launch in 2003. When a spacecraft detects a γ-ray burst, it will automatically notify the GRB Coordinates Network (GCN), which in turn will issue a worldwide alert over the Internet giving the GRB's coordinates on the sky. When a suitable notice is received by our imaging telescope, it will instantly terminate its current observation, slew to the GRB's position, and begin a preprogrammed series of observations, all within a few seconds of the initial detection of the burst by the satellite.

2.2 Cheap to Operate

The second advantage of automatic telescopes is that they are relatively cheap to operate. Such telescopes save money in a myriad of ways. First, there are no observers to operate them. Therefore, few travel costs, no salaries, no fringe benefits, no managerial overhead wasted in hiring and motivating them, no lunch breaks, and minimal "facilities" at the site. Second, the maintenance and its cost are reduced by the fact that automatic telescopes (at least as we use them) do not allow instrument changes and consequently don't break down as often as conventional telescopes. Once the initial problems get shaken out, they are amazingly reliable. Of course, they do break down, or at least get out of alignment, but the problems are minimal in comparison with a conventional telescope. Furthermore, we have all our telescopes sited at Fairborn Observatory (Figure 2), a facility modeled after President Reagan's Densepack missile facility, which means that it is much easier for one superbly competent man to look after them and keep them operating.

So-called small telescopes are cheaper to maintain for another reason. They tend to be much simpler than large state-of-the-art instruments in that the mirrors are small enough to support easily. Instead of the complicated

Figure 2. Seven of the twelve 0.25 to 0.80-m automatic telescopes at Fairborn Observatory in southern Arizona. The TSU 2.0-m spectroscopic telescope is located behind the camera.

active supports on telescopes larger than about two meters required to maintain the image quality, mirrors of smaller telescopes, which can actually be rather large by historical norms, can be supported by passive mechanical systems. Figure 3 shows the counterweighted levers used to support the primary mirror in the APT of Figure 1; we are also using counterweighted levers in our 2.0-m automatic spectroscopic telescope. The drives also tend to be simpler than in large telescopes, since for telescopes up to 1–1.5-m, we may use fairly simple friction-coupled roller drives with stepper motors. For larger telescopes the bigger masses involved require more sophisticated roller drives with servomotors to actuate them.

The savings also apply to the reduction of the data and management of the scientific programs of the telescopes. Henry, for example, is managing the operations of seven(!) automatic photometric telescopes with the routine tasks of reducing the data and reviewing its quality, monitoring the performance of the telescopes and troubleshooting problems (in collaboration with Boyd), creating and overseeing the observing programs, and maintaining the data archive. He spends roughly one-quarter of his time on these tasks. Interestingly enough, much more of his time is spent on assessing the suitability of program and comparison stars for doing extremely precise differential photometry than on the routine tasks of overseeing the telescopes.

Figure 3. Passive primary mirror supports for the T12 0.8-m APT.

2.3 Much Higher Quality

The third advantage of automatic telescopes is that they achieve a quality of observations hardly ever approached by manual telescopes conducting the same kind of programs. There are several reasons for this. Since the telescopes operate completely automatically without the need of a human observer in attendance, they can be sited in remote, first-class observing locations; our telescopes reside at Fairborn Observatory in the Patagonia Mountains of southern Arizona and enjoy the clear, dry, dark skies of the desert southwest. The automatic telescopes are designed to do one thing over and over with mind-numbing regularity. The instrumentation never changes unless something fails; the procedures for acquiring and observing stars are always the same. This is especially important for precise photometry where positioning the stars is important for achieving consistency. Because the automatic telescopes operate so efficiently and each is dedicated to a particular kind of observing program, complete networks of the appropriate standard stars can be observed and other quality-control checks completed each night by each telescope in just a few percent of the observing time. This allows excellent transformations to the standard photometric systems and also allows an instrumental stability approaching 0.0001 mag to maintained over many years. Figure 4 shows the phenomenal improvement in the precision of our differential photometry as we have developed newer and better telescopes and photometers and refined our photometric techniques (see Henry 1995b; 1999 for more details).

Automatic telescopes do what they are told; there are no missed observations from going to sleep at the controls. The automation means that one must decide what observations must be made beforehand, and the sort of reliability required for successful automatic operation means the observations usually do get made.

3. SOME SUCCESSFUL RESEARCH FROM AUTOMATIC TELESCOPES

We have concentrated on long-term research projects that can take full advantage of the automatic telescopes. Here we'll discuss a few of them and their importance.

3.1 Brightness Variations in Sun-Like Stars

We know from satellite observations over the last 20 years that the Sun's total irradiance varies by about 0.001 mag and that this variation occurs in step with the 11-year sunspot cycle (e.g., Frölich et al. 1991). Furthermore, comparison of long-term variations in solar magnetic

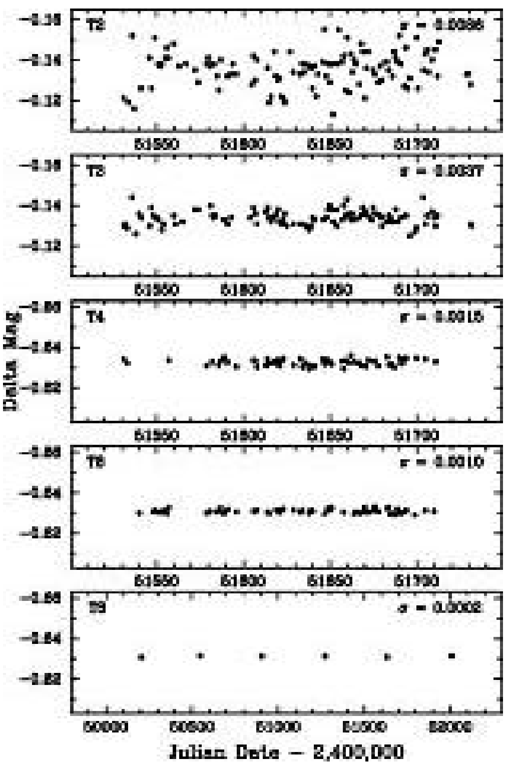

Figure 4. Observations of a pair of constant stars made with a series of progressively better APTs: T2 (0.25m with simple solid state photometer), T3 (0.40m with an improved, single-channel, precision photometer with a PMT detector), T4 (0.75m with single-channel, PMT precision photometer), and T8 (0.80m with two-channel precision photometer using two PMT detectors). The bottom panel plots yearly means from the T8 APT. Photometric precision (in magnitudes) is measured as the standard deviation of the observations, given in the upper right corner of each panel.

activity with terrestrial climate records reveals a close correlation (e.g., Eddy 1976; Friis-Christensen & Lassen 1991; Soon et al. 2000). In other words, our Sun is a variable star, and its variations probably influence the Earth's climate. While proxies for solar magnetic activity go back several millennia, direct measurements of solar brightness changes extend back only over the last two sunspot cycles (de Toma et al. 2001). In order to disentangle the climatic effects of solar brightness changes from the competing effects of anthropogenic increases of greenhouse gases and natural climate variability, we require a realistic model of how solar luminosity changes with magnetic activity.

We are seeking to construct such a model by measuring brightness changes in over 400 Sun-like stars with several of our APTs while collaborators at the Mount Wilson Observatory measure the corresponding changes in magnetic activity through the HK Project (Baliunas et al. 1998). Because of the tremendous improvement in photometric precision with our APTs and their ideal suitability for long-term projects, we are able to measure stellar brightness changes analogous to the 11-year, 0.001-mag brightness variations in the Sun. When these brightness measurements are combined with the magnetic variations from Mount Wilson, the resulting calibration will allow us to transform the historical record of solar magnetic activity into a history of solar brightness variations. By including solar-type stars with a large range of ages, we can construct a rough history of solar variability over the entire main-sequence lifetime of the Sun. Figure 5 shows our preliminary result for brightness changes in Sun-like stars ranging in age from 100 Myr to 10 Gyr.

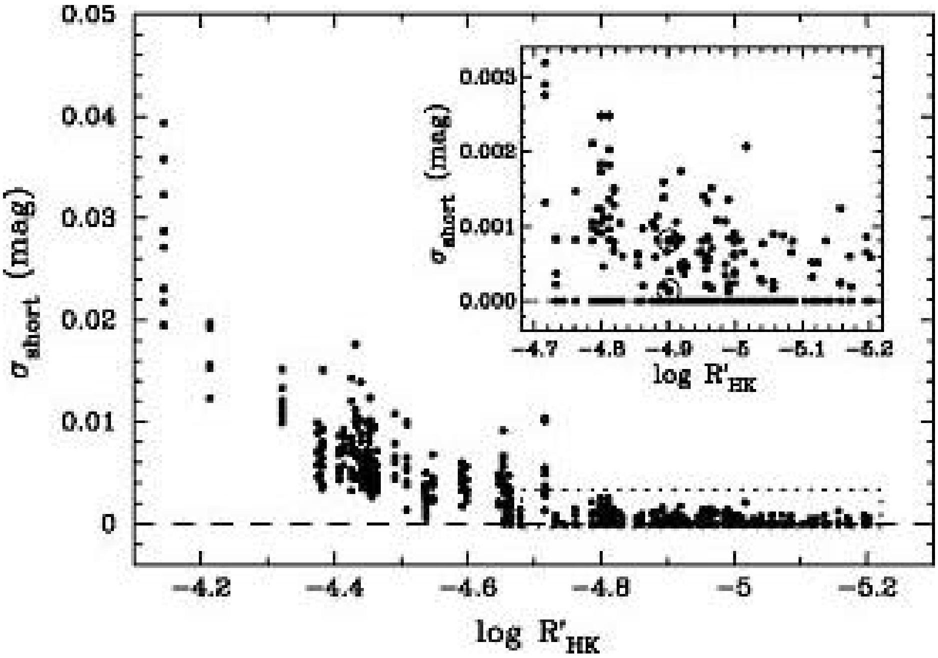

Figure 5. Night-to-night variability in Sun-like stars plotted against log R'_{HK} for roughly 150 stars in our sample that have been observed the longest. The log R'_{HK} values correspond to ages of approximately 100 Myr on the left to 10-Gyr on the right. The aging of Sun-like stars is accompanied by a decrease in their brightness variability as their rotation slows and their magnetic dynamo weakens. For comparison, the Sun, with a mean log R'_{HK} = -4.9, is plotted twice in the inset with the variability levels observed at the maximum and minimum of the sunspot cycle. Thus we see that the Sun exhibits brightness variability comparable to other stars its age.

3.2 Search for Extrasolar Planets

In 1995 October, Mayor & Queloz (1995) announced the first detection of a planetary companion in orbit around a solar-type star; in the intervening six years, the number of known extrasolar planets has increased to nearly 80, with several stars hosting multiple planets. All of these planets were detected via ultra-precise radial velocity measurements capable of detecting the reflex motion of a star caused by an orbiting planetary-mass companion. However, radial velocity measurements alone are not sufficient to prove conclusively the existence of these planets. Radial velocity variations can arise due to pulsations in a star's outer layers or magnetic activity on a star's surface carried along by rotation. Indeed, not long after the announcement of the first extrasolar planet (around the star 51 Pegasi), Gray (1997) announced that he had evidence for pulsations in the star at the reported planetary orbital period thus, he claimed, nullifying the existence of its planet.

If the observed radial velocity variations in these stars were due to stellar pulsations or surface magnetic activity, they would be expected to undergo small, but measurable, changes in their brightness. Most of the host stars of the purported planetary companions were already on our Sun-like stars observing program with the APTs, so we began to search for evidence of low-level photometric variability in these stars to support or refute the existence of their planetary companions. Because many of the planets have very short-period orbits, we also began searching for transits of the planets; the observation of a planetary transit would provide final, conclusive proof of the planet's existence as well as allow the planet's size, mass, and mean density to be determined. Our study of a number of stars with suspected short-period planetary companions (including 51 Pegasi) revealed them to be constant to a high level of precision (typically one or two parts in 10^4), thus providing strong support for the existence of the planets (see, e.g., Henry et al. 2000a) even though none of the initial sample of stars revealed planetary transits. In one exceptional case, photometric variations of the star HD~166151 revealed that its suspected planet did not exist (Queloz et al. 2001).

In 1999 November, Henry et al. (1999) announced the discovery of the first transiting extrasolar planet. Photometric observations of the star HD209458 with the T8 APT revealed a dip in the star's brightness of 1.58% at precisely the time of conjunction computed from radial velocity observations obtained with the Keck I telescope in Hawaii. The observed transit provided final, indisputable confirmation of the existence of extrasolar planets as well as the first opportunity to derive some of the physical properties of one of these objects. The combination of the radial velocity observations and the photometric transit resulted in the true mass of 0.62 M_{JUP}, a radius of 1.42 R_{JUP}, and a mean density of 0.27 g cm^{-3} (Henry et al. 2000c). The planet is unambiguously a gas giant with a radius inflated due to its close proximity to its host star. Figure 6 shows the transit light curve as obtained by one of our APTs.

3.3 Photometric Variability in the H-R Diagram

One of the greatest challenges to obtaining photometry at the limits of precision allowed by our APTs (~0.0001 mag) is low-amplitude, intrinsic variability in our comparison stars. Perversely, the old solar- type stars we are seeking to monitor for low-amplitude variability turn out to be among the

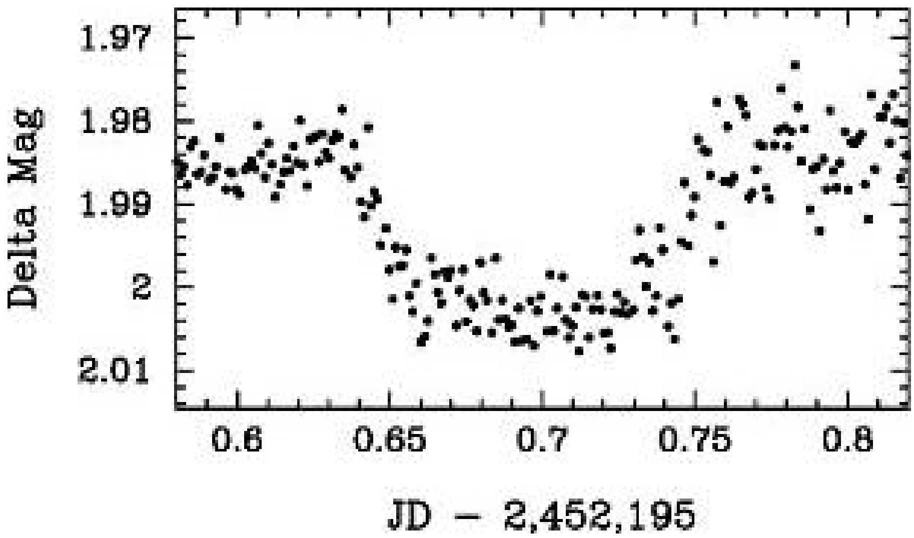

Figure 6. Photometric transit of the planet around HD~209458. The observed depth of the transit allows the true mass, the radius, and the mean density of the planet to be determined. The transit duration is three hours.

most constant stars in the H-R diagram. Henry (1999) documented the occurrence of short-term and long-term variability in a wide range of comparison stars used over the years. Thus, the study of variability of stars throughout the H-R diagram has been an unexpected bonus resulting from our APT research.

In the past, we often chose G and K giants as comparison stars because they are bright, relatively numerous, and not generally expected to be intrinsically variable. However, Henry et al. (2000b) found that 43% of a sample of 187 G and K giant comparison stars were variable, most at a level of less than 0.01~mag. Figure 7 places these 187 giants in the H-R diagram. From a combination of photometry and spectroscopy, we were able to show that the primary variability in these stars is not due to rotational modulation of surface magnetic activity. Instead, for stars on the cool side of the coronal dividing line (CDL), the variability mechanism is radial pulsation. Thus, the mechanism operating in M giants extends into the K giants up to about spectral class K2. Furthermore, the variability mechanism for stars on the hot side of the CDL is most likely nonradial, *g*-mode pulsation with a few stars possibly varying by rotational modulation of starspots.

Because cool giants turned out to be rather poor choices for high-precision comparison stars, we were forced to move to hotter regions of the H-R diagram in search of constant stars and began using large numbers of early- to mid-F dwarfs located just to the right of the δ Scuti instability strip. Unfortunately, this landed us right in the middle of a newly identified class of variable stars known as the γ Doradus stars (e.g., Handler 1999; Kaye et al.

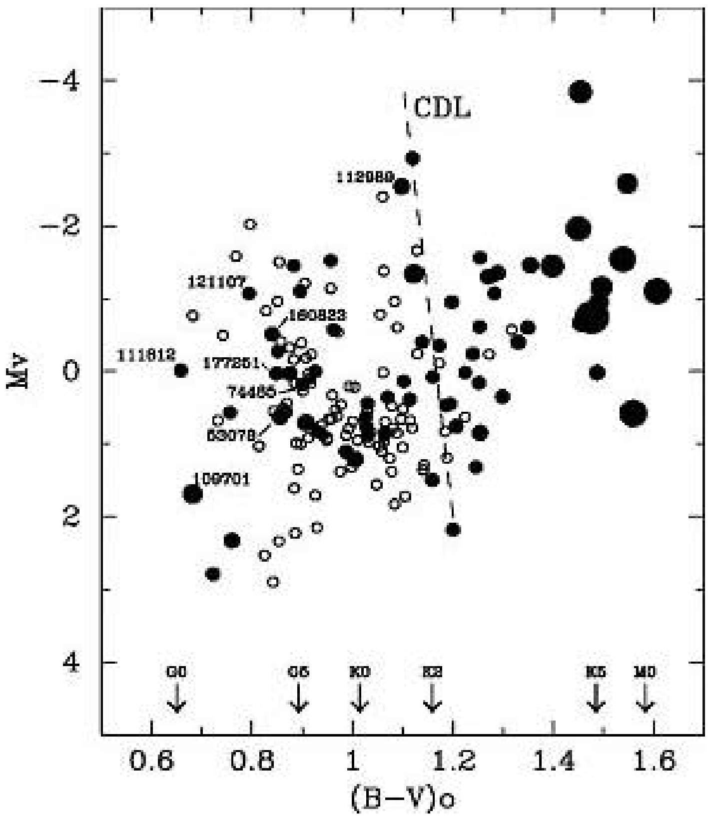

Figure 7. Variability in a sample of 187 G and K giants from Henry et al. (2000b) plotted in the H-R diagram. Photometrically constant giants are plotted with open circles, while variable giants are plotted as filled circles with sizes that scale with the amplitude of variability. The coronal dividing line, separating giants with hot coronae on the left from those with cool, massive winds on the right, is shown.

1999). Although few of these stars are known as yet, a large percentage of them have been discovered serendipitously as comparison stars used with our APTs (Henry et al. 2001). Our T12 APT is currently monitoring a sample of nearly 300 carefully chosen candidates in this region of the H-R diagram to greatly expand the number of known γ Doradus stars and to map their extent in the H-R diagram.

4. FUTURE RESEARCH

In the future we imagine these instruments working in the following areas:

4.1 Mapping the Giant Branch of the H-R Diagram

Basic parameters of stars, such as mass, radius, and luminosity come primarily from observations of binary and multiple stars. For nearly 20 years

Fekel has obtained such spectroscopic observations at the Kitt Peak National Observatory (KPNO) with the 1m Coudé feed telescope. In addition to a variety of chromospherically active binaries, a group of over 40 close visual multiple systems and binaries resolved by speckle interferometry has been observed. An example is the spectroscopic-visual quadruple system HR 3337. The visual pair has an orbital period of 52.6 years, and each of those two components is a double-lined spectroscopic binary. Figure 8 shows the center-of-mass velocities for the spectroscopic pair of the visual secondary, which so far cover about one-half of the long-period orbit, compared with the predicted velocity curve. A collaboration with other spectroscopists and the CHARA group at Georgia State University has resulted in several papers (e.g., McAlister et al. 1995; Fekel et al. 1997) on such systems. The combination of visual and spectroscopic orbits also results in an orbital parallax that is usually more accurate than that obtained by *Hipparcos*.

While perhaps 50 main-sequence stars with spectral classes from B to G have well-determined masses, there are less than a half-dozen giants. This is because most mass determinations come from spectroscopic-eclipsing binaries, and known eclipsing giants are much rarer than dwarfs. The sample under observation at KPNO contains at least six systems with giant components. Thus, the evolutionary state of the giants will be accurately determined and studied in detail.

Over the past two decades the advent of speckle interferometry has significantly increased the period overlap of visual and spectroscopic systems. In the very near future several optical interferometers including the CHARA interferometric array on Mt. Wilson will be in routine operation, and the resolution of numerous spectroscopic binaries will be a high priority program.

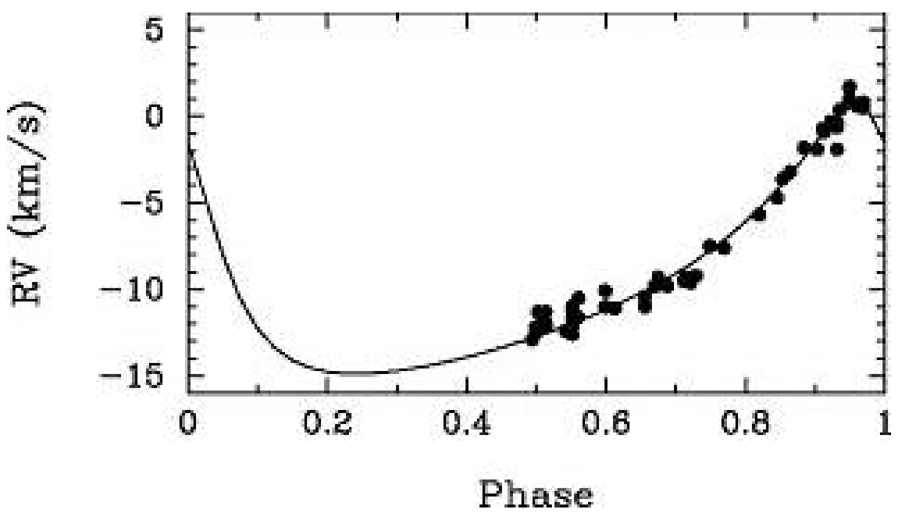

Figure 8. Radial velocities of the spectroscopic pair of the visual secondary in HR 3337.

This is fortuitous because the availability of TSU's 2m automatic spectroscopic telescope will enable us to greatly increase our observed sample of binaries. Since red-wavelength observations will turn some single-lined binaries into more useful double-lined systems (Stockton & Fekel 1992), we have already begun to expand our observing program to include likely double-lined systems. Continued collaboration with interferometry and speckle groups is planned.

4.2 Clarifying Magnetic Activity in Chromospherically Active Stars

Chromospherically active (CA) stars seem to be highly spotted and to have chromospheric emission so strong that their surfaces may as well be saturated with solar active regions (e.g., Giampapa 1994). As such, they represent an extreme condition of the magnetic activity excited by the solar dynamo. We have spent the last 25 years investigating the spots and activity of these stars, trying to decide if they have magnetic/spot cycles like the Sun's, and thinking up new ways of understanding these stars. Challenges remaining for them still include determining: (1) How big are the spots, and what are their temperatures and structures? (2) How are the strong active regions distributed over the star, and do such stars have magnetic cycles detectable in chromospheric emission? (3) Do such stars really exhibit spot cycles, the most prominent manifestation of the Sun's magnetic cycle, or are the photometric cycles we observe in such stars just the variation of a random distribution of spots? (4) How do intermediate-age stars differ from the chromospherically active stars and the slowly rotating stars like the Sun?

Automatic telescopes give us the means to answer some of these questions. We see two ways of doing this. The first is to continue to monitor these stars photometrically and to begin monitoring them spectroscopically to investigate the levels and timescales of their variability and to extend the monitoring to emission lines formed in the stars' active regions. The second is to use very extensive Doppler images to map spots on the surfaces of a few stars.

Photometric/Spectroscopic Indications of Cycles: We have monitored about 100 chromospherically active stars over the past decade, thus continuing a difficult program of manual photometry we started at Dyer Observatory and Kitt Peak using telescopes no longer in service. Figure 9 shows some typical data obtained by this program, the long-term light curve of λ And. Features of the light variation include short-term changes of the order of 10%, presumably on the rotational period of the star, discontinuous changes of a few percent, and long-term variations of years to decades. For a variety of reasons, the short-term variations are almost certainly rotational modulation of the light by dark starspots irregularly distributed in stellar longitude (Hall 1972, 1996). The discontinuities are probably related to changes in the number of spots on the star, through emergence or rapid dissipation of spots. The long-term changes remain controversial, however. They have often been cited as evidence for spot cycles in chromospherically active stars (e.g., Olah et al. 2000). Fourier analysis of the data for λ And gives a period of 3500 days = 9.6 years (obviously a stellar reflection of the Solar cycle?), and yet these active stars do not show the segregation of spots into narrow latitude bands as on the Sun, for they must have spots spread over very many latitudes to give the extreme light losses they show (e.g., Byrne 1996; Eaton et al. 2001). Furthermore, we know that a random distribution of spots coming and going on timescales of a few years will give this kind of apparently cyclical variation simply because of statistical fluctuations in the number of spots (Eaton, Henry, & Fekel 1996; Eaton et al. 2001).

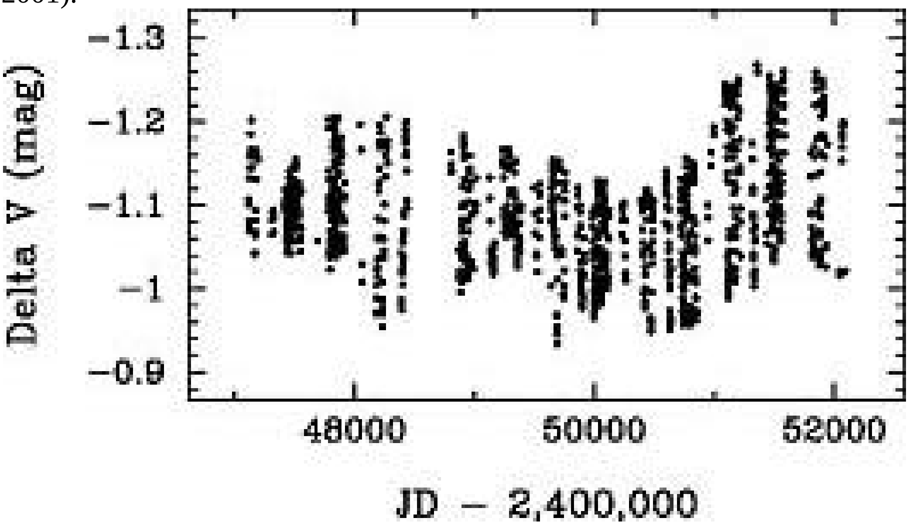

Figure 9. Long-term light variation of λ and from the T3 0.40m APT.

How might we begin to sort out the differences between random changes resembling spot cycles and true spot cycles, if there actually are such things in active stars? One way is to monitor the stars long enough to observe many of the putative cycles, requiring another decade or so of data. Presumably this will give the cycles plenty of time to manifest themselves by repeating, if they actually exist. Such observations are pretty boring and would not be feasible except through the stamina and efficiency of automatic telescopes.

Another approach to determining the reality of magnetic cycles is to look at line emission from active regions with an automatic spectroscopic telescope. It is still not clear how (chromospheric) active regions on CA stars are distributed over their surfaces or whether they are associated with starspots. Some evidence of rotational modulation of active-region emission has suggested an association with spots; most evidence has been ambiguous, showing little if any rotational modulation of chromospheric emission lines. All such studies have suffered from a paucity of data. Similarly, coronal X-ray emission seems to be moderately uniformly distributed over stellar surfaces in some instances (Schmitt & Stern 1994) but concentrated into a few active regions in others (Schmitt & Kürster 1994). We may attack this question by using our automatic spectroscopic telescope to monitor chromospheric emission lines (e.g., Ca II H&K and Hα) intensively enough in a moderately large group of bright chromospherically active stars also observed photometrically to have enough data to prove or disprove an association with spots and to begin to look for long-term cycles in the line emission (a 20-year project).

Use of Doppler Images: The other way automated telescopes will add to our understanding of chromospherically active stars is through more extensive Doppler imaging of their surfaces. Specifically, we would need to obtain Doppler images with better temporal coverage than we have for the best photometric studies. Korhonen et al. (1999) have dramatically demonstrated how it is possible to follow the evolution of groupings of spots on active stars with series of Doppler images. This initiative will let us collaborate with modelers doing the best Doppler imaging to follow individual spots as they move over the surface of a star during an observing season. It has the prospect of giving a much better indication of the sizes and numbers of spots on active stars and for assessing the true virtues and limitations of the Doppler-imaging technique by forcing continuity between successive images. The ability to schedule an autometric spectroscopic telescope effectively will be crucial in this effort.

4.3 Determining the Structure of Giant Stars' Chromospheres

One of the continuing challenges of stellar astronomy is to understand the structures of chromospheres of cool stars. These regions of elevated temperature above the photospheres of all cool convective stars are heated non-radiatively and seem to be extremely non-homogeneous. In the Sun we can observe their clumping on the smallest scales one can observe, < 1000 km, and there is further evidence for significant temperature inhomogeneities in the Sun and other cool stars in observations of photospheric CO (e.g., Ayres 1998). Many brave theoreticians have entertained themselves constructing models to explain the emission lines of such regions with one-dimensional, laterally homogeneous distributions of gas. Even less is known about the massive chromospheres of cool giants and supergiants, which have significant winds originating in or blowing through their chromospheres. The structures of a few such stars can be deduced from eclipses of the ζ Aur binaries (Wright 1970; Wilson & Abt 1954) in which the outer atmosphere of a K supergiant eclipses a B dwarf. Line absorptions in the shell spectra produced during such eclipses provide a way to measure densities, temperatures, turbulence, ionization, and perhaps even clumping of the gas at different heights above the supergiant's photosphere. Indeed, these stars give us the best, essentially the only, opportunity other than the Sun actually to measure properties of a star's chromosphere directly as a function of height and form an empirical model of the chromosphere and wind (Eaton 1996).

Great progress in understanding the *outer layers* of these stars' chromospheres and winds has resulted from ultraviolet observations made from space by IUE and HST (Eaton & Bell 1994; Baade et al. 1996; Harper 1996; Eaton 1996). The UV is ideally suited for studying tenuous gas in winds of supergiants because the wings of Lyman-α give a direct measure of mass column density along the line of sight, numerous strong Fe II multiplets give reliable measures of excitation temperature, shapes of lines of many different intrinsic strengths give a way of deducing the velocity structure along the line of sight, and many weaker lines of a wide variety of elements give measures of the ionization. Ironically, though, much less is known about the inner chromospheres, which were the subject of the pioneering work of Wilson and Abt. Those zones near the star are so dense that ultraviolet lines of singly ionized iron-peak elements saturate and are impossible to interpret reliably. Instead, they must be analyzed by using the much weaker lines of neutral metals and a very few lines of singly ionized metals in the near ultraviolet. Because no one has yet managed to obtain enough modern calibrated spectra of the inner atmospheric eclipses of these objects, we still do not know what structure connects the photosphere and the upper chromosphere plus wind and whether these structures are continuous.

Of course, it's quite possible to observe atmospheric eclipses of ζ Aur binaries with conventional spectroscopic telescopes, but obtaining such spectra is an ideal job for an automatic telescope because the thing can be programmed to take the spectra whenever they are needed and in whatever sequence without having to program a human observer. We envision observing the innermost phases of atmospheric eclipse of the classical ζ Aur binaries (ζ Aur, 31 Cyg, and 32 Cyg) intensively with our AST in violet lines. There will be several eclipses of such stars coming up in the next few years very well timed for observing from Earth. Especially important is an eclipse of 31 Cyg in July 2003, because this is most widely separated of the classical systems, hence the least complicated of them. Other well-timed eclipses are those of ζ Aur in November 2003 and of 32 Cyg in March 2003 and May 2006. The observations of the inner atmospheric eclipses of these stars will lead to empirical chromospheric models for the supergiants, which relate temperature and density to height above the photosphere. They will tell us the stratification of the inner chromospheres and the rate of chromospheric heating with height. If we're lucky, they will also tell us whether the chromospheres can be continuous with the winds, how highly the gas is clumped in the inner chromosphere, and roughly how electron density changes with height.

4.4 Doing Lots of Other Science

These are a few of the programs we intend to use automatic telescopes on in future. We realize that there are many other programs for which even our own telescopes would be ideally suited, but we don't claim to have the imagination to begin to construct a comprehensive list of them. Therefore, we encourage you to think for yourself about what programs you would use such instruments to conduct.

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6. REFERENCES

Adelman, S. J., Boyd, L. J., Dukes, R. J., Jr., Guinan, E. F., McCook, G. M., & Pyper, D. M. 2000, Astronomy for Developing Countries, 24th meeting of the IAU, Special Session, p. 68

Ayres, T. R. 1998, in IAU Symp. no. 185, New Eyes to See Inside the Sun and Stars, ed. F.-L. Deubner, J. Christensen-Dalsgaard, & D. Kurtz (Boston: Kluwer), p. 403

Baade, R., Kirsch, T., Reimers, D., Toussaint, F., Bennett, P. D., Brown, A. & Harper, G. M. 1996, ApJ 466, 979

Baliunas, S. L., Donahue, R. A., Soon, W., & Henry, G. W. 1998, in ASP Conf. Ser. 154, Cool Stars, Stellar Systems, and the Sun, eds. R. A. Donahue & J. A. Bookbinder (San Francisco: ASP), p. 153

Byrne, P. B. 1996, in IAU Symp. no. 176, Stellar Surface Structure, ed. K.G. Strassmeier and J. L. Linsky (Dordrecht: Reidel), p. 299

de Toma, G., et al. 2001, ApJ 549, L131

Eaton, J. A. 1996, in ASP Conf. Ser. 109, Cool Stars, Stellar Systems, and the Sun, eds. R. Pallavicini & A. K. Dupree (San Francisco: ASP), p. 503

Eaton, J. A., & Bell, C. 1994, AJ 108, 2276

Eaton, J. A., Henry, G. W., Bell, C., & Okorogu, A. 1993, AJ 106, 1181

Eaton, J. A., Henry, G. W., & Fekel, F. C. 1996, ApJ 462, 888

Eaton, J. A., Henry, G. W., Henry, S. M., & Fekel, F. C. 2001, in preparation
Eddy, J. A. 1976, Science 192, 1189
Fekel, F. C., et al. 1997, AJ 113, 1095
Friis-Christensen, E., & Lassen, K. 1991, Science 254, 698
Frölich, C., Foukal, P. V., Hickey, J. R., Hudson, H. S., & Willson, R. C. 1991, in The Sun in Time, eds. C. P. Sonnett, M. S. Giampapa, & M. S. Matthews (Tucson: Univ. Arizona Press), p. 11
Giampapa, M. S. 1994, in ASP Conf. Ser. 64, Cool Stars, Stellar Systems, and the Sun, ed. J.-P. Caillault (San Francisco: ASP), p. 509
Gray, D. F. 1997, Nature 385, 795
Hall, D. S. 1972, PASP 84, 323
Hall, D. S. 1996, in IAU Symp. no. 176, Stellar Surface Structure, eds. K. G. Strassmeier & J. L. Linsky (Dordrecht: Reidel), p. 217
Handler, G. 1999, MNRAS 309, L19
Harper, G. 1996, in ASP Conf. Ser. 109, Cool Stars, Stellar Systems, and the Sun, ed. R. Pallavicini & A. K. Dupree (San Francisco: ASP), p. 481
Henry, G. W. 1995a, in ASP Conf. Ser. 79, Robotic Telescopes: Current Capabilities, Present Developments, and Future Prospects for Automated Astronomy, eds. G. W. Henry & J. A. Eaton (San Francisco: ASP), p. 37
Henry, G. W. 1995b, in ASP Conf. Ser. 79, Robotic Telescopes: Current Capabilities, Present Developments, and Future Prospects for Automated Astronomy, eds. G. W. Henry & J. A. Eaton (San Francisco: ASP), p. 44
Henry, G. W. 1999, PASP 111, 845
Henry, G. W., Baliunas, S.L., Donahue, R.A., Fekel, F. C. & Soon, W. 2000a, ApJ 531, 415
Henry, G. W., Eaton, J. A., Hamer, J., & Hall, D. S. 1995, ApJS 97, 513
Henry, G. W., Fekel, F. C., Henry, S. M., & Hall, D. S. 2000b, ApJS 130, 201
Henry, G. W., Fekel, F. C., Kaye, A. B., & Kaul, A. 2001, AJ 122, in press
Henry, G. W., Marcy, G. W., Butler, R. P., & Vogt, S. S. 1999, IAU Circular No. 7307
Henry, G. W., Marcy, G. W., Butler, R. P., & Vogt, S. S. 2000c, ApJ 529, L41
Kaye, A. B., et al. 1999, PASP 111, 840
Korhonen, H., Berdyugina, S. V., Hackman, T., Duemmler, R., Ilynin, I. V., & Tuominen, I. 1999, A&A 346, 101
Mayor, M., & Queloz, D. 1995, Nature 378, 355
McAlister, H. A. et al. 1995, AJ 110, 366
Olah, K., Kollath, K., & Strassmeier, K. G. 2000, A&A 356, 643
Queloz, D., Henry, G. W., et al. 2001, A&A, in press
Schmitt, J. H. M. M., & Stern, R. A. 1994, in ASP Conf. Ser. 64, Cool Stars, Stellar Systems, and the Sun, ed. J.-P. Calliault (San Francisco: ASP), p. 134
Schmitt, J. H. M. M., & Kürster, M. 1994, in ASP Conf. Ser. 64, Cool Stars, Stellar Systems, and the Sun, ed. J.-P. Calliault (San Francisco: ASP), p. 137
Soon, W., Baliunas, S., Posmentier, E. S., & Okeke, P. 2000, New Astronomy 4, 563
Stockton, R. A., & Fekel, F. C. 1992, MNRAS 256, 575
Strassmeier, K. G., Granzer, T., Boyd, L. J., & Epand, D. H. 2000, Proc. SPIE Vol. 4011, Advanced Global Communications Technologies for Astronomy, ed. R. I. Kibrick and A. Wallander, p. 157.
Wilson, O. C., & Abt, H. A. 1954, ApJS 1, 1
Wright, K. O. 1970, Vistas in Astron. 12, 147