MAKING THE SKY INVITING: THE PROJECT TO MODERNISE THE UNDERGRADUATE OBSERVATORIES OF THE UNIVERSITY OF TORONTO

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Abstract.

We are upgrading the UTS 30cm Questar telescope for automated CCD imaging, and similarly automating and equiping for digital spectroscopy the existing Boller and Chivens 40cm reflector at the St. George campus. The 20cm Goto refractor will be retrofitted with digital encoders and a coordinate processing computer to make public and class viewing more efficient. With new computers, the 30cm and 40cm telescopes will be remotely accessible via the Internet. In the second year of the project, new CCDs with higher quantum efficiency will be purchased to replace the existing detectors. This project will result in a truly exceptional facility for training students in research techniques, capable of producing significant research results.

1. Background

Astronomy has undergone a revolution in the past twenty years, thanks to the development and application of charge-coupled devices (CCDs) and computers. The CCD has replaced photographic emulsions and photoelectric photometers. Small telescopes such as those used by our undergraduates can now measure the flux of stars 8 magnitudes fainter than before, and instead of one at a time we can measure hundreds or even thousands in a single short exposure. A million picture elements (or pixels) are recorded every three or four minutes. Such amounts of data are handled by small computers equivalent to the most powerful supercomputers of twenty years ago. Furthermore, by having the computers fully control the instruments, telescopes and even domes, this flood of data can be maintained whenever the sky is clear at night, saving the observer's time for the more creative activities of analysis and deduction rather than pushing buttons while getting cold and tired. This advanced technology is actually a simpler version of the huge imaging CCD arrays now coming into operation on large telescopes. The techniques undergraduates learn here are essential if they are to succeed later as graduate students in astronomy.

Our undergraduate telescopes were installed in 1967 at St George and 1980 at Scarborough, with support for photography. Photoelectric photometers, and more recently, CCDs, have been added, but the ability to point the telescopes has been quite unequal to the faintness of the stars which can now be observed.

The 20cm refractor is useful only for public viewing, and the 30 cm and 40cm reflectors are obsolete without computerization, despite their superb optical and mechanical quality. Furthermore, the 60cm and 48cm telescopes at DDO are not upgradeable for remote or robotic use; the 48cm is hopelessly obsolete (built in 1929) and we now have a computerized portable 25cm Meade LX-200 for public viewing at DDO.

Nearby universities have in recent years aggressively upgraded their on-campus or nearby undergraduate observatories. Both Queen's University and Royal Military College in Kingston in the past year have begun using robotic telescopes in the 35 to 40cm class. Vassar College in Poughkeepsie, NY,has built a whole new observatory on campus, including brand-new 81cm and 50cm computerized telescopes, replacing the historic observatory built for Maria Mitchell in 1868. Rochester Institute of Technology moved its observatory in 1998 to a better location on campus, with new robotic 40cm and computerized 25cm telescopes. The University of Rochester automated its 60cm B&C reflector 40 miles south of Rochester in 2000. York University has begun to acquire more modern on-campus facilities; its 40cm Schmidt-Cassegrain is computerized.

Further afield, numerous universities have successfully used automated or robotic telescopes for undergraduate research. The University of Victoria and St. Mary's University have had great success with relatively modest instruments, while the University of Iowa has been operating robotic facilities for undergraduates both on campus and remotely in Arizona for several years. The University of Indiana has had great research success since 1989 with a roboticized Boller and Chivens 40cm like ours, at an observatory just out of town similar to our own David Dunlap Observatory (DDO).

In other places, a number of outreach partnerships involving universities, schools and industry have concentrated on the development of automated telescopes accessible via the Internet. Among the best known are the Hands-On Universe project centered on Berkeley; Telescopes In Education centred on Mt. Wilson, Los Angeles; MicroObservatory centred on Centre for Astrophysics (Harvard/Smithsonian) and the National Schools Observatory sponsored by Britain's PPARC (equivalent to our NSERC). There are numerous other, more local outreach partnerships involving automated remotely-accessible observatories. A community group in Ottawa is acquiring a 40cm telescope, and similar efforts are under way in North York and the Niagara Peninsula.

2. University of Toronto Requirements

We need to have state of the art facilities so that our undergraduates can do meaningful research as part of their education, learning techniques which are used for most astronomical research today. Furthermore, faculty and graduate students often need informally scheduled imaging and photometric observations, to supplement or follow up what they have obtained at the major observatories such as CFHT, Gemini and Magellan, and at the DDO. The automated imaging telescope proposed here will help to satisfy that need.

Although one generally seeks the largest telescope possible, there are trade-offs involving size and angular field of view for given detectors. A quite modest system can have a harmony among its component parts which makes it very useful and productive. This has been obvious, for example, in the superb surveys for micro-lensing events, done mainly with 1-metre class telescopes, and the all-sky surveys for variable stars and gamma-ray burster optical counterparts, done with little wide-field telescopes of a few inches aperture. The CCD, and computer-controlled automation, have been the crucial developments enabling such surveys.

Numerous amateur astronomers now have the kind of equipment we need. The significant amateur market has resulted in the availability of good equipment well suited to undergraduate use. It is important that we provide our undergraduates with facilities at least equal to or superior to those widely used by amateurs.

We shall seek partnerships with Ontario Science Centre, the RASC and NYAA to extend outreach to the community, to be in a stronger position to attract financial sponsorship. Our initial robotic telescope project, combined with similar projects by our potential partners, will be the foundation upon which a future telescope can be realised at a dark site.

3. Scientific Justification

Although imaging undertaken as part of a public outreach programme often involves aesthetic motivations, with the sheer wonder of fine astronomical images the compelling driver, the principal uses of the instrument by undergraduates, graduate students and faculty will involve current research problems. These include:

- **Search for supernovae in external galaxies.** Systematic surveys of fields, using equipment similar to that proposed here, are being undertaken by a number of groups, but there is much room for more observers. The expansion of the Universe is best studied using distant supernovae.

- **Rapid response imaging.** Gamma ray and X-ray bursters are observed from space, and approximate positions are relayed via the Internet within seconds of an event being detected. Our automatic imaging telescope will allow rapid identification of optical counterparts and observation of them spectroscopically with the 1.9 metre telescope at DDO. Since such events fade rapidly, being able to train the 1.9 metre telescope within minutes of an event will give us a better chance of observing such an event earlier than most other observatories.

- **Near Earth asteroid detection.** Finding and mapping of all asteroids which may hit the earth is being undertaken by many groups, and is of great importance to humanity. There is much scope for work by students in this area. The instrument can also obtain light and colour curves of asteroids to determine rotational periods and compositional classes, and with time delay integration (TDI) capability, rare occultations of stars by asteroids can be observed to help measure sizes.

- **Comets and Planets.** Comets are another important planetary target of opportunity for astrometry and morphological studies. Finally, students could use images to study the evolution of atmospheric features on Jupiter, Saturn, Uranus and possibly Mars, although the resolution is less than ideal for this purpose.

- **Variable star surveys.** Automated surveys have found thousands of previously undiscovered variable stars, in a systematic manner which older visual and photographic searches were incapable of. Gravitational microlensing has been studied in this fashion, with variable star surveys as a by-product. We are now getting reliable stellar statistics thanks to automated imaging. (See item on clusters below).

- **Accurate light curves of individual binary stars.** Individual stars can be studied with the AIT, with hundreds of comparison stars instead of one or two as in old photometric techniques. Accurate, well-covered lightcurves are very efficiently obtained using an automatic imaging telescope, which can be combined with simultaneous spectroscopy to study phenomena such as the evolution of starspots and the transfer of mass between components of a binary star. The masses, absolute dimensions and luminosities of eclipsing binaries obtained with this technique are important in calibrating the stellar mass-luminosity and mass-radius relations which underpin all of astronomy.

- **Detection of extra-solar planets.** The ability to obtain accurate differential lightcurves of many stars at once will allow the detection of Jovian-type planets transiting stellar disks. The high quality CCD proposed will have the deep full-well capacity required for the high signal-to-noise ratios required, and the field of view will be wide enough to simultaneously measure a large number of stars.

- **Studies of quasars and active galactic nuclei.** Frequent monitoring of such objects has to be done with a facility of this type, since time at visitor observatories is still largely allocated in whole night blocks rather than a few pointings over each of many nights.

- **Studies of clusters.** The automatic imaging telescope allows extended observing to discover all the variables in star clusters. Such repetitive observing over many months is impossible at conventionally scheduled visitor observatories, and is often better suited to small, automated telescopes. Whereas the all-sky wide-field surveys will in a few years find all variables down to 14th V magnitude, the search for variables between 14th and 18th magnitude in clusters and rich fields of narrower extent is almost virgin territory. Mochnacki proposes to lead such a project, involving undergraduates, beginning in the 2002/2003 academic year.

4. Classroom Use

The robotic telescopes will be accessible from wired classrooms: they can be used during classes and presentations, in real time. They will also be accessible over the Web, giving students the ability to use the telescopes from home.

A Web interface for controlling access and scheduling observations will be implemented: a number of such systems have been developed elsewhere. Useful student computer science projects will be feasible.

5. The Proposal

The following budget is still subject to final quotes, but it should be reasonably accurate. An exchange rate of US$0.63 per Canadian dollar has been assumed.

Year 1: Acquire:

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20cm (DA):                                                  $ CDN
=========
        - 2 x Encoders (US Digital S1-1000-BHS)               260
        - Nova Astronomics Micro Guider III complete          150
        - Power supply and enclosure (est.)                    50
        - ECU software (CD-ROM) + firmware                     68
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                                                     TOTAL    528
                                                             ====
          (An old computer will need to be dedicated to the 20cm)


40cm (DA):                                                   $ CDN
=========
        - Astrometrics Skywalker 1
          (Controller, handset, Sky-Guide-Win software,)       2400
        - 2 x motors+gearing+encoders                          1100
        - Power supplies and drivers in enclosure              1600
        - Assorted cables, harnesses                            400
        - Digital Domeworks (hardware+software)approx.         2200
        - Dome automation dome mods., relay interfaces (est)    600
        - Weather station                                       750
        - F & S Electrician for Relay Connection (est.)         500
        - SBIG SGS Spectrograph                                6400
        - Accessories for spectrograph (lamp, filters) est.    1000
        - New computer: data acquisition and overall control   2000
        - CCD control, field finding,scripting,TPOINT software 3000
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                                                     TOTAL    21950
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        (An old computer will also be dedicated to 40cm control)

           No accounting has been made of technicians' time.
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30cm (UTS):                                                   $ CDN
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        - Astrometrics Skywalker 1
          (Controller, handset, Sky-Guide-Win software,)        2400
        - 2 x motors+gearing+encoders                           1100
        - Power supplies and drivers in enclosure               1600
        - Assorted cables, harnesses                             400
        - Dome control system (est.)                            2200
        - Dome automation modifications, relay interface (est.) 1000
        - F & S Electrician for Relay Connection (est.)          500
        - New computer: data acquisition and overall control    2000
        - Motorized digital focuser.                            1000
        - Weather station                                        750
        - CCD control, astrometry, scripting, TPOINT software   3000
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                                                        TOTAL  15950
        (Existing old computer used for 30cm control)          =====
                                              2001/2002 TOTAL  38428
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Year 2: Acquire:

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                                                               $ CDN
        - SBIG ST-7E Dual CCD Camera (for spectrograph)         4000
        - AP-8 or FLI 1024S 1024x1024x24mu CCD Camera          22000
        - CFW-1 50mm filter wheel                               1500
        - Set of confocal UBVRI (or Gunn) 50mm filters          2900
        - Additional disk drives and a data archiving unit      3000
                                                               =====
                                              2002/2003 TOTAL  33400
                                                               =====
                                              PROJECT TOTAL    71828
                                                               =====
                                SHIPPING, TAXES  add 15 %      10528
                                                               =====
                                               GRAND TOTAL     82356
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- The existing DA ST-8 and filter wheel will be used on the UTS 30cm, together with the existing DA f/6.3 focal reducer or equivalent. After acquisition of the new thinned, back-illuminated CCD, the ST-8 can be mounted on one of the guide scopes on the UTS 30cm.
- The existing UTS ST-7 CCD will fit exactly into the DA SBIG spectrograph, and will autoguide the 40cm telescope as well. The new ST-7E will have nearly double the quantum efficiemcy; the old unit will serve as backup and can be mounted on the 10cm guidescope of the 40cm Boller and Chivens telescope.

The software bought for the automated imaging telescope will produce a data stream of differential stellar magnitudes with positions accurate to a second of arc or better for every object. The goal is to build up a unified and calibrated database which will rapidly exceed many thousands of objects, providing an opportunity for student training in archiving and database techniques. There are at least two good software products available for every major step of the data pipeline, including significant Canadian contributions. Thanks to some interface standardization efforts, one can "mix and match" these software components. The dome control software is "open source" and the telescope control interface follows the industry standard.

For a 3-minute integration, the table below shows the signal-to-noise attainable, considering only quantum noise and readout noise. The number of stars brighter than each magnitude on the chip is adapted from Allen's Astrophysical Quantities, 4th edition, averaged over the sky. Sky brightnesses of 17 and 21 magnitudes per square arc second are considered (bright suburban and dark skies). Seeing of 2.5 arc seconds is assumed. S/N above 100 is probably unrealistic given flat-fielding uncertainties. At f/15 on a 30cm telescope, the SITe SI003 chip has a field of view of 19 x 19'. The plate scale is 1.1 arc seconds per pixel.

V Magnitude	Ave. No. of stars on CCD	S/N(sky=17) (suburban)	S/N(sky=21) (rural)
12	4	830	855
13	11	502	538
14	25	289	338
15	57	153	212
16	122	73	131
17	245	32	79
18	470	13	45
19	865	5	23
20	1570	2	11

These numbers show that by going to a dark site, well over a magnitude is gained at the faint limit, doubling the number of stars available for study at the same signal to noise ratio. This is significant in the 15-19 magnitude range. A larger telescope would also improve the numbers.

The SBIG spectrograph has been used effectively by amateurs such as the British observer Maurice Gavin. SBIG quote signal to noise ratio of 10:1 for a 9th Mag star, 20 minute exposure using a non-ABG ST-7 and a 10 inch (25cm) aperture in "high resolution" mode (2.4 angstroms FWHM). The 40cm telescope and ST-7E should improve on this by well over a magnitude. Use of the lower dispersion grating gains another 1.5 magnitudes. Useful observations should therefore be feasible down to about 12th magnitude, with emission features of objects like quasars detectable to 14th magnitude. The sky brightness has recently been measured at the St. George campus to be about V=16.0 per square arc second.