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Conference summary: Looking inward

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CONFERENCE SUMMARY: LOOKING INWARD

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Abstract. This final presentation at the symposium attempted to provide some perspective on where we are going in the areas of hardware, software, scientific results, and interactions with the rest of the astronomical community for automated, robotic, and remotely operated telescopes on traditional and non-traditional sites.

1. Introduction

Remote, automated, and robotic observing, broadly defined, have a considerable paleolithic history, prior to the commissioning of the Phoenix 10" telescope (described by L. Boyd). The very early UV and X-ray rocket experiments did not much more than open and close the "dome" on their own, parachuting the packages down for investigators to retrieve and examine. By 1960, Sputnik I, Explorer, and Vanguard had collected and returned data automatically, while the Wisconsin X-15 rocket plane UV observations had both remote operation (from the pilot's cabin!) and automatic tracking and observing. Their Pine Bluff Observatory could operate for several days without human intervention, albeit primarily as an extinction monitor. OAO-2 collected real data (though with frequent hints from the ground on what to do next) for the four years 1968-72, and the Coralitos supernova search had automated aspects at about the same time. Prior to the HST repair mission and the SMM "fix-it" mission mentioned at the symposium, ISEE-3 (International Sun-Earth Explorer) had been reconfigured, or at least re-aimed, as ICE (International Comet Explorer) remotely in anticipation of Halley's return (which occurred on schedule, though neither NASA nor ESA can take much of the credit). And the all-time success story remains IUE, which was launched when many of the present participants had not yet received their first degrees.

Increasing our temporal magnification by about an order of magnitude permits comparison of current conditions with the state of the subject in June 1991, when ASP hosted "Robotic Telescopes in the 1990s" (ASP Conf. Vol. 34, ed. A.V. Filippenko) at Laramie, Wyoming, an even higher-elevation site than Flagstaff.

2. Hardware

The shear numbers of partly- and fully-automated telescopes are increasing rapidly, from about five in 1989 to about 30 now (L. Boyd, R. Genet, G. Henry). Photometric precision has also unambiguously improved over the period from night-to-night variations of 0.01 mag down to 0.001 mag for those installations that monitor extinction frequently (G. Henry). Long term stability is always more difficult to achieve. G. W. Lockwood's presentation indicated that real stellar drifts as small as 0.001 mag/yr could be identified by traditional observer-operated systems. It is not clear that the APTs can yet match this level.

Sizes of operating automated telescopes are also increasing, in the sense that most now being commissioned are larger than the pioneering Phoenix 10" and Fairborn 10". (The Pine Bluff was an 8".) The MACHO-search 50" (formerly the Great Melbourne Telescope!) seems to be the largest with largely automated data collection at the present time, while HST is the largest fully-remote mirror in operation. L. Ramsey and P. W. Kelton pointed out that the Hobby-Eberly (formerly spectroscopic survey) Telescope will be a 9 to 11 meter (depending on where you put your meter stick), but is intended for only partially remote or automated operation.

Guiding has become more common, permitting both longer exposure photometry and imaging, as in the Berkeley Automated Imaging Telescope (R. Treffers). There was little discussion of this or other aspects of long-term stability. The rapid sort of guiding normally called active and adaptive optics is of necessity an automated procedure, also not discussed except in the infrared context of the Berkeley Infrared Spatial Interferometer (C. H. Townes).

Interferometry is clearly the most extreme version of coordination of two or more mirrors, and the provision of delay lines indicates the intention to make operation "hands-off". The Berkeley ISI currently operates in an intermediate mode, but increasing automation is intended. The 36 Keck mirrors were designed to maintain their collective figure of revolution continuously, and generally do so. Keck I and II and the four mirrors of the ESO Very Large Array are intended for interferometric operation with a minimum of human intervention, though not in the near future. The first fully automated optical array could well be that of CHARA (center for High Angular Resolution Astronomy, T. ten Brummelaar), which, if funding were guaranteed tomorrow, could be operational by 2001 or thereabouts.

Automated coordination (though not coherence!) is intended for both GNAT (Global Network of Automated Telescopes, D. Crawford) and ORT (Oriental Robotic Telescopes, F. Querci). The closest to an operational system of this sort is the Whole Earth Telescope, which is already producing data on variable stars, but was not discussed at the symposium.

At a still looser level of linkage, R. Genet discussed multi-telescope and multi-purpose sites. Many such operations are under way (most notably Mauna Kea, already shared by at least 5 countries - US, UK, Canada, France, and Japan), partly as an economy measure and partly because excellent sites are rare. The south pole and the moon are both unique and cases where even small reductions in numbers of people make a big difference in dollars.

On a less cheerful note, automated spectroscopy is still not a reality. My 1991 summary described it as "components exist; some assembly required."

Judging from the presentations of J. Eaton and J. Hernshaw, this is still the case, though AutoScope is working on 1.5 – 2.5m class telescopes particularly suited for the purpose. The prime mover for automated radial velocity spectroscopy, seemingly an especially appropriate mating, has apparently given up on the project. A bright spot is the Sloan Digital Sky Survey, for which both hardware and software are being formulated for computerized data acquisition, processing, and storage (M. Richmond, not a participant).

In recent years, professional optical astronomers have typically not been closely involved in designing and building their own telescopes (in contrast to the radio, X-ray, Gamma-ray, and, of course, amateur optical communities). It has been suggested that Alvan G. Clark was the last astronomer to make a fundamental discovery with a telescope he had himself built (it was the companion of Sirius, the first white dwarf), and that some of modern astronomical woes may derive from this decoupling. The involvement of NOAO in industrial plans for 0.5 – 2.5m telescopes (D. Crawford) is, therefore, an encouraging development.

3. Software

Real progress has occurred in the software for scheduling remotely and automatically operated telescopes. A few years ago, standard APTs spent a very large fraction close either to the western horizon (chasing objects about to set) or to the eastern horizon (chasing ones just coming into view). The graphs shown by L. Boyd, G. Henry, and R. Dukes made clear that this is no longer typically the case. Comparable improvement has occurred for other kinds of telescopes. At the time HST was first scheduled for launch, it took 30 hours of computing time to prepare for 24 hours of observing (ominous in the extreme). The same schedule can now be assembled in 30 minutes, and redone a couple of times per day, if necessary, with an appropriate mix of Spike and SPSS for long- and short-term management (G. Miller). IUE "observing runs" are arranged with comparable efficiency, additional flexibility coming from the assignment of 8-hour blocks to particular projects (B. McCollum). Thus a bright supernova can be targeted during a particular shift previously assigned to K giant winds and the wind project given a later shift without having to displace anything else. And the 7 second scheduling time per night of the Berkeley Automatic Imaging Telescope (R. Treffers) allows its plans to be "rethought" after every observation, even though scientific priorities, as well as logistical criteria, are considered by the program.

Another piece of good news is that, although grabbing back manual control in real time is not generally available (M. Drummund) post-observation human intervention can effectively identify unexpected, as well as expected, data patterns. The OGLE lensing search, for instance, will (though not discussed at the symposium) yield a complete catalog of all variable point sources observed.

On the "better luck next time" side N. Markworth and N. Muscettola warned of built in glitches, like a control system that turns off the guider as soon as a target is acquired, or two subsystems that need to talk to each other to make sure the operation of locking the pointing device on to a target is coordinated with the target being visible!

A large fraction of the symposium was devoted to ongoing work on scheduling and other kinds of software (G. Henry, L. Boyd, J. L. Bresina, C. Monahan – the other female speaker, and T. H. Morgan), including the importance of standardization (D. Crawford). It is perhaps best not to mention which of these various talks made me wonder about the correct name for a software system that is the analog of hardware designed by Rube Goldberg, but there is perhaps some tendency to continue to use and adapt inappropriate packages that one is comfortable with. The issues are in any case important. While most installations do not have quite the $20/second cost of HST "open-slit" time, actually using 20% more of the time available to a given telescope is the equivalent of building 20% more of them.

4. Using your APT (etc.)

4.1. Kinds of Uses

Monitoring of weather conditions and atmospheric transparency have been part of most APT operations since the times of Pine Bluff and the Phoenix 10". It is not necessary to close down, short of actual rain, just because things get hazy. The TSU telescope keeps going as long as it can, interspersing quality control observations. A human observer looks at these later and decides which data points to keep. And, of course, a robotic telescope is less likely than a night assistant to object to re-opening at 4 AM if conditions improve. A system need not be very complicated to be useful. B.A.I.T. simply "assumes" that if it fails to acquire 6 targets in a row, clouds are in the way. It waits for an hour and then tries again.

Following the behavior of known interesting objects is the commonest current APT task, like the Be stars and multi-mode Cepheids studied by R. Dukes and R. K. Honeycutt's cataclysmic variables. The latter noted that the process (especially if all your program objects are the same type) is likely to yield nothing informative for ages and then a sudden deluge of product – a lot like growing zucchini.

Searches for known classes of objects have been successfully automated, including supernovae and gravitational lenses. APT data bases have not yet been much used for searching for new classes of objects, in the way that the IRAS and ROSAT catalogs are used, and this would seem to require human intervention at some stage.

Finally, many installations are intended at least partially for instructional purposes, including the Harvard Micro Observatory (S. Leiker) and the AutoScope imaging telescope recently installed at one of my two institutions (UCI). Four or five students are currently involved in debugging the hard- and software (we bought a fixer-upper at cut rate price), and this may well be the most educational part of the experience.

4.2. Scientific Results

Many of the projects under discussion three years ago have begun to produce interesting astronomy, including the Whole Earth Telescope, OGLE, MACHO, and EROS. Others are operating, including the Explosive Transient Camera and Rapidly Moving Telescope (intended to catch gamma ray bursts with their photons down). None of these was heard from at the present symposium.

Among the projects reporting, Townes and the Berkeley ISI have now measured enough infrared angular diameters at enough times to conclude that some evolved stars produce dust continuously, other episodically, and that the latter tend to have longer pulsation periods (normally meaning lower surface temperature and more evolved state).

Extended, reliable light curves, are of course the raw materials for classifying variable stars in terms of the underlying physical mechanism (as presented by D. S. Hall), which then leads with luck, to classification by evolutionary phase and initial star or system properties. A particularly interesting case is Honeycutt's subset of CVs that seem to cycle between a bright, relatively steady, nova-like state, and a fainter, oscillatory dwarf-nova-like state. He suggests that the former, longer-term change arises in changes in the amount of material being contributed by the donor star (an instability first suggested by Bohdan Paczyski and strongly advocated by Geoff Bath) and the latter, rapid changes from an instability in viscosity (and so accretion rate) within the disk itself (first suggested by Osaki and advocated by Paczyski).

Even the sun is a variable star if you look hard enough (at its rotation period, owing to spots, and through its 11 year cycle, for more complicated reasons.) G. W. Lockwood has been monitoring solar analog stars for many years and has concluded that, while we are fairly normal in terms of cycle length and chromospheric emission for our rotation speed and age, the solar level of brightness fluctuation is anomalously low, by a factor of about three, when normalized to H & K emission, age, etc. The reason for this is not known, but it must have implications for long term climate change on earth.

5. Political issues

5.1. The External Image of the Field

As R. Dukes noted, APT users began publishing their more important results in standard journals (especially PASP) about the time I recommended this in 1991. Post hoc non ergo propter hoc! This seems a step in the right direction. And, when the first events from EROS, MACHO, and OGLE preprinted across the skies, they were doubted, but for reasons quite disjoint from the (varying) degrees of automation of the searches. This represents a significant advance, along the same lines as being able to say that you have found a cure for a particular kind of cancer when most of the people who have it survive long enough to die of something else.

5.2. Archiving

Archiving was given generic high priority in the Bahcall report as well as at previous APT symposia and at an IAU Symposium last summer on wide field imaging. So far, only NASA and ESA seem to have made much progress. Their experience has been that it costs about 10% as much as you spent acquiring the data to store it in a form useful to most astronomers (the catch is that storage is cheap, retrieval expensive, and documentation very expensive). A participant mentioned that preliminary indications from the Sloan Digital Sky Survey (for which both cameras and programs are now being assembled) is that 10% remains a good number when your telescope sits still.

5.3. Cooperation and the User Pool

Multi-user automated telescopes are quite common. We heard specifically from the Four College (Dukes), BAIT (Treffers), and Rent-A-Star (M. Seed) programs, none of which seem to be adversely affected by the horses pulling the sled in different directions. Dukes noted that ATIS scheduling for multiple users was already almost too efficient – they all get back more data than they have time to deal with!

People from within and without the APT community continue to worry about a generation of new astronomers coming along who are unable either to make best use of their data or to understand its limitations because their experience of the telescopes, detectors, and programs used to collect it is so limited. I share this concern, but suspect that it may all come out all right as long as all systems break down thoroughly once per generation (5 years?) and have to be taken apart and fixed. It is vital that the occurrence of the breakdown be unambiguously clear, and hardware tends to be more user friendly in this respect than software. Notoriously, we all keep twiddling the dials on our program until we like the answer, and the hardware equivalent is much less common – though folklore preserves a story of Alvan Clark trying valiantly to polish away the companion of Sirius, having taken it for an internal reflection.

5.4. What to Automate and Why

The two obvious drivers for various forms of automation are higher quality and lower cost. J. Percy suggested that students should observe the variable stars and APTs the constant ones, so that boredom would not set in and affect reliability (or the probability of the students finishing the course!). Digital plate blinkers are not always more accurate than biomechanical ones (the "false positive" rate, particularly, is high), but they are a lot faster, and this matters when the telescope is running continuously.

Cost is much lower even for accessible sites, a factor of ten per observation according to an estimate from the TSU group. No dollar estimates were given for the South Pole, but most of the cargo flights in carry stuff for the observers, not for the observatories, including the Spirex search for a dark 2.35 window (B. Rauscher), the helioseismology program (T. Duvall), and the (probably best-known) IR and sub-mm programs AST/RO, Cobra, and so forth (D. A. Harper).

At some level of inaccessibility, automation becomes essential. Among the various polar programs discussed by J. Lynch, the dividing line occurred for multiple-week balloon flights. In the early days of scientific ballooning, scientists normally accompanied their packages (e.g. Hess's demonstration that cosmic rays come from up above, not from down below), but flights were shorter and astronomers seem to have been made of steel in the days when telescopes were made of wood.

The Apollo science experiments were deployed and sometimes operated by people. This is not going to happen on the moon again in the next decade or, perhaps, at any time in the lifetime of anyone who was at the symposium. Thus the various possible lunar telescopes and observatories discussed by J. Burns, M. Colavita, and P. Chen were all self-deploying and fully operated by remote and/or automatic methods.

Thus one can contemplate hands-off over a whole range of time scales, from between servicing missions (one per night for Spirex, to one per five years for HST), through the time line after construction, on out of the entire assembly and deployment process (Colavita).

I had a qualitative impression that the lunar programs under discussion are considerably less ambitious than those of a few years ago and that this reflects realistic evaluation of what might conceivably be done with existing dollars and launch vehicles.

5.5. Conferences as the Pulse of a Field

I have participated in, and so have proceedings volumes from three previous meetings in this series – 1989 (Tucson), 1990 (Boston), and 1991 (Laramie). The numbers of invited and contributed papers were, respectively, 40, 53, 35, and 38 here in Flagstaff. The impression, therefore, is of subdiscipline that is still not making enough contact with the rest of the astronomical community to draw many of them into participation.

As the shadows of 1939 deepened, a British general is supposed to have said that there would always be a place in battle for the well-bred horse. He seems to have been wrong (though there are more horses, nearly all recreationally employed, in the US now than there were when they worked). But I both expect and hope that there will always be a place in astronomy for the well-bred photometrist – not to mention the ill-bred summarizer.

Acknowledgments. It is the traditional privilege of the last speaker at events like these to thank those who have made the gathering possible. First, our local hosts from Lowell Observatory, Northern Arizona University, the Conconino Astronomers, and NAU Astronomy Club, chaired by Larry Wasserman (Lowell). Second, Robert Havlen, Lonny Baker, and their associates at ASP for managing the whole sweep of the Annual meeting. Third, the scientific organizers and editors of the present symposium and its proceedings, Russ Genet, Greg Henry, and Mark Drummond. Russ has sworn that this is his last APT symposium (at least as an organizer), and we wish him well in his new endeavors. Finally, I would like to say a word in praise of the usually-maligned, extraordinarily complicated network of automated scheduling systems that enabled nearly all participants to have valid airplane reservations and on-time arrivals. Some things are even harder to arrange than observing runs.

PART I

CURRENT CAPABILITIES