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TITLE: **Beginning Research with the 1.8-meter Spacewatch Telescope**

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Overview: The purpose of Spacewatch is to explore the various populations of small objects within the solar system. Spacewatch provides data for studies of comets and asteroids, finds potential targets for space missions, and provides information on the environmental problem of possible impacts. This grant provided some of the funds to implement Spacewatch operations on the new 1.8-m Spacewatch Telescope. Support for this effort continues from NASA under grant NAG5-3938.

Building and Site: A site for the telescope in the Steward Observatory compound on Kitt Peak was decided upon by Gehrels and McMillan. Considerable savings in operating costs through the lifetime of the telescope will be accumulated because the telescope is so close to the facilities and support of the Steward Observatory and the National Optical Astronomical Observatory (NOAO). Non-federal funding for the dome and building was obtained by Gehrels. The building has a 30.5 ft. diameter dome and about 1100 square feet of floor space usable for telescope- and observing-related functions. Most of Perry and McMillan's time the past two years has been spent interacting with the machine shop, architect, and building contractor to sort out the details of telescope fabrication, building design, building electrical system, dome installation, telescope installation, and mirror handling accessories. Construction of the building began on Kitt Peak on 1996 July 1; the finished building and installed telescope were dedicated on 1997 June 7.

Telescope structure: We took the uncommon approach of installing all the large telescope components before assembling the dome. The large azimuth base would not fit through the dome slit without special rigging, and we were concerned that if any of the large and heavy components "bumped" the dome it would be seriously damaged. A week after the telescope was placed on the pier, the dome was installed over the assembled telescope.

Since the successful installation of the major telescope components and completion of the building, we have moved several tons of additional parts and accessories into the building. The telescope was welded together and to the pier. Careful priming and painting readied the telescope for the building dedication. Since then, the azimuth base and disk have been leveled to better than 40 arcseconds and the azimuth rotation axis has been centered on the azimuth journal to 0.014 inch TIR (total indicated runout). The telescope was balanced about the elevation axis and the axis was set level. The elevation drive sector now turns through 90 degrees of arc with less than 0.001 inch TIR. The elevation drive box with both drive motors installed has been mounted on the azimuth disk. The azimuth cable wrap has been installed.

Telescope Drive System: Both axes will be driven by DC servo motors directly coupled to friction rollers. Perry, Bressi, and Tubbiolo are developing the telescope drives in a series of stages. They set up the three azimuth-drive motors co-mounted on a benchtop axle with the servo system and computer driving the motors from test software and simulated the inertial load of the telescope with a flywheel driven through a large gear ratio. This load is equal to 50% of the reflected inertia that will be "seen" by the motors when on the telescope. Wind buffeting was simulated by adding a low-frequency disturbance to the load and watching the encoders to see whether the servo system was compensating correctly. Construction of the absolute-encoder microcontroller system is nearly finished.

Bressi has written the high level software for control of motion about the two telescope axes, and much of it has been tested in the lab as well. McMillan and Bressi worked on software to determine the projection of the telescope axis onto the sky from observations of stars with known positions.

The drive system for the so-called parallactic angle (compensated by the instrument rotator; the third axis) has been specified. Models for this motion have been completed, and software to generate the motion will be written. Examples of interesting tradeoffs are (1) whether the rotator should be controlled in realtime from a central processor or fed a trajectory and controlled locally by an autonomous processor, and (2) whether to encode the motion of the rotator directly or rely on an encoder attached to a motor shaft.

Detectors: NASA is not providing the funds for the detector on this telescope, but it is funding the CCD cryostat, readout electronics, and data analysis computer with an augmentation to grant NAG5-3938. We have a contract with the Lawrence-Livermore National Laboratory (LLNL) to procure a sensitive, low-noise CCD that will be very similar to the one we obtained in 1992 for the 0.9-m Spacewatch telescope.

Optics: The primary mirror was safely delivered in its special box to the ground floor of the Steward Observatory 2.3-m telescope building on Kitt Peak. The telescope secondary, a flat solid mirror 27 inches in diameter with a protected aluminum coating, was received from Zygo Corp. and meets specifications.

Montani got optical raytrace programs working on his PC and is investigating scattered light in coma corrector designs. A redesign of the coma corrector for the 1.8-m telescope before it is fabricated may be indicated by lessons learned with the coma corrector installed on the 0.9-m telescope in June of 1995.

Computer Hardware: Larsen and Tubbiolo have been investigating the relative merits of Unix-based workstations vs. PCs as processors of realtime Spacewatch data. Since NASA is providing "only" $23K for the computer(s) at the 1.8-m, we are carefully examining our choices. The operating system will doubtlessly be Unix/linux, but the choice of platform (between PC's and workstations) is open.

We are using a data-driven process to decide the best platform for our application. Our computer must read, calibrate, process, interactively examine and then archive CCD data in realtime with a throughput of 30-120 kbytes/sec. It is desirable that computational power be held in reserve for the implementation of additional image processing (object classification?) and data visualization as required. The capacity to support visualization graphics would be an aid in our attempts to cope with the increased data flow in real time. Benchmark comparisons have been performed using locally available equipment. Initial results have shown that the raw computational speed of the PC's is favorable under idealized conditions, although the ability to handle actual image processing is still being tested.

The easiest, quickest and most robust asteroid-finding algorithms we could implement would require holding all three passes of scan data in RAM at once. For our current scanning program at the 0.9m, this would require 300Mb of RAM. Forseeable programs at the 1.8 meter could quadruple this requirement. At the current time, PC's seem to be limited to 500Mb RAM (although improvements on this are expected shortly). Workstations could handle this requirement today, but at a price currently outside of our allowed range.

The relatively low cost of disk space makes the ability to manage 10-50 Gb of disk space appealing (from the standpoint of asteroid/comet recoveries). Archival storage should be more permanent than magnetic tape, although optical disks are currently more expensive and of lower capacity than magnetic tape (making the archival process more difficult). We would like the ability to upgrade when it becomes available.

We have learned from experience at the 0.9-m telescope that a second workstation that is not committed to processing and display of realtime observations allows the observer to do other important things without interrupting the data collection. These tasks include email about recently discovered objects, looking at- and processing data collected earlier, and accessing the 'web for information about objects discovered by other groups during the observing run. The second workstation at the 1.8-m will most likely be a PC running linux, which provides the same user environment as a more expensive Sun workstation.

Software and Data Analysis: Software and concepts of analysis developed to analyze data collected on the 0.9-m telescope also benefit the future operation of the 1.8-m telescope. Larsen has been developing code to search the Spacewatch data archive for faint, slow-moving objects. One of his goals is to establish the bright end of the absolute magnitude distribution of the Trans-Neptunian Objects (TNOs). In the process of this development he has been discovering ways to more efficiently process realtime Spacewatch data, and these innovations will be transplanted to the computer system to be installed at the 1.8-m telescope.

Selected Relevant Publications

(1995-1997, in chronological order):

Starting with *Minor Planet Circular* 919 in 1984, Spacewatch has been reporting asteroid and comet observations on a monthly basis.

In *I.A.U. Circulars*, Spacewatch reports the recovery of comets and the discovery of interesting asteroids such as those of near-Earth asteroids 1989 UP and 1990 SS.

"CCD Scanning for the Discovery of Comets and Asteroids", 1995, Gehrels, T., Jedicke, R., McMillan, R. S., Perry, M. L., Scotti, J. V., & Bressi, T. in *Proc. of the Planetary Defense Workshop,* Lawrence-Livermore National Laboratory CONF-9505266, pp. 125-127.

"Automated CCD Scanning for Near Earth Asteroids", 1995, R. Jedicke, in *New Developments in Array Technology and Applications,* A. G. Davis Philip *et al.* (Eds.) Kluwer, pp. 157-165.

"Orbital evolution of Comet 1995 O1 Hale-Bopp", 1996, M. E. Bailey, V. V. Emel'yanenko, G. Hahn, N. W. Harris, K. A. Hughes, K. Muinonen, and J. V. Scotti, *MNRAS,* **281,** 916-924.

"Detection of Near Earth Asteroids Based Upon Their Rates of Motion", 1996, R. Jedicke, *Astron. J.* **111,** 970-982.

"The Population of Near-Earth Objects Discovered by Spacewatch", 1996, T. Gehrels and R. Jedicke, *Earth, Moon, & Planets* **72,** 233-242.

"Collisions with Comets and Asteroids", 1996, T. Gehrels, *Scientific American,* **274,** No. 3, 34-39.

"Spacewatch Survey for Trans-Neptunian Objects" (abstract), 1996, T. Gehrels, J. D. Herron, R. Jedicke, R. S. McMillan, T. S. Metcalfe, J. L. Montani, J. Nichol, & J. V. Scotti, *Bull. A. A. S.* **28,** 1081.

"The Spacewatch 1.8-meter Telescope" (abstract), 1996, M. L. Perry, R. S. McMillan, L. D. Barr, T. H. Bressi, and T. Gehrels, *Bull. A. A. S.,* **28,** 1096.

"Spacewatch Model-Independent Technique for Correcting Observational Bias" (abstract), 1996, T. S. Metcalfe and R. Jedicke, *Bull. A. A. S.* **28,** 1096.

"Near-Earth Object Surveying in the Late 20th Century", 1996, J. V. Scotti, in *Completing the Inventory of the Solar System,* T. W. Rettig, J. M. Hahn, Eds., ASP Conf. Series, **107,** 107-113.

"Physical and Dynamical Evolution of Comets" (abstract), 1996, J. V. Scotti, *Bull. A. A. S.* **28,** 1086.

"Observation of Small Solar System Objects with Spacewatch", 1996, J. V. Scotti and R. Jedicke, in *Dynamics, Ephemerides, and Astrometry of the Solar System,* S. Ferraz-Mello *et al.* (Eds.), Kluwer, 389-398.

"Spacewatch", 1997, T. Gehrels, in *The Encyclopedia of Planetary Sciences,* J. H. Shirley & R. W. Fairbridge, Eds. London: Chapman and Hall, 774-775.

"Charge-coupled Devices", 1997, R. S. McMillan, in *The Encyclopedia of Planetary Science,* J. H. Shirley & R. W. Fairbridge, Eds. London: Chapman and Hall, 98-102.

"Observational Constraints on the Centaur Population", 1997, R. Jedicke and J. D. Herron, *Icarus* **127**, 494-507.

"The Orbital and Absolute Magnitude Distribution of Main Belt Asteroids", 1997, R. Jedicke and T. S. Metcalfe, Submitted to *Icarus.*