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THE ALLEGHENY OBSERVATORY SEARCH FOR PLANETARY SYSTEMS

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Final Technical Report

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The achievements accomplished under the auspices of this grant have greatly exceeded the expectations of all but its most ardent supporters. Foremost on the list of goals for the proposal was to build and implement a new astrometric detector, the Multichannel Astrometric Photometer (MAP) (Gatewood 1987). So successful was the development of this instrument that we will simply attach the paper to which we have referred. Suffice it to say that the new detector is the most accurate instrument of its kind, and as we will see below, the instrument is now in regular use.

A secondary accomplishment, resulting directly from the above was the design, private funding, successful construction, installation, and now regular use of the largest refractor objective built during the second half of this century, Gatewood et al. 1986). Again we have attached the paper describing this project.

Because the objective of the overall effort was the implementation of an observing program, we will use the rest of this report to describe that program (now funded by other sources) during the last year supported by this grant.

The primary goal of the program is to observe. The MAP observing program is divided 60/40 between the NSF parallax and NASA planetary programs respectively. During the last year, more than 2,000 ruling sweeps were recorded. This amounts to approximately 500 MAP observations each with a "zenith target star" precision of approximately 3.5 mas (milliarcseconds) (Gatewood 1987). The high data flow and the resultant prereducations (during which the photometer output of up to 12 channels is converted to rectangular field coordinates for a similar number of stars) has increased our tape library to approximately 200 2400 ft reels and kept one of our technicians tied down approximately 75 percent of his time.

A second goal was to place additional regions on the observing program, a move from the testing and calibration phase of the program into actual production. We succeeded by increasing the observing program by nearly 30 percent. A major component of these new regions were centered upon binary star systems with well determined orbits. However 5 of the 12 new regions were centered on targets for the NASA planetary system search program.

Each region placed on the program requires approximately one and one half weeks of preparation. This includes: acquisition of the prerequisite plates of the region; the examination of previous data (in various catalogs and in the general literature) concerning stars in the region (approximately 36 arc minutes square centered

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on the target object); the selection of the 11 stars that will actually serve as references; the measurement of the new, and if available old (for proper motions) plates of the region; reduction of their positions to a star catalog; preparation of the table and figure for the manufacture of the region's platen; and preparation of similar tables and figures for those who will later observe the magnitudes, colors and spectral types of the stars. The MAP program now includes 55 regions, 18 of them centered on targets of the NASA program¹.

An unmentioned goal was to find better ways to characterize the nature, and distance of the reference stars in each region. Since there are an order of magnitude more reference stars than target objects, this is a substantial effort. However, to use parallaxes that are twice as precise as those to be achieved by the space-bore instruments HIPPARCOS or the HST, we must have an accurate value for the conversion from relative to absolute parallax. In this we were most fortunate in obtaining the cooperation of Bruce Stephenson of Case. Using the 24 inch Case Schmidt, and its 10 degree objective prism, Stephenson has been able to obtain the temperature class of approximately half of the stars in the ten regions for which we have thus far provided him with charts. On the average he has also been able to obtain luminosity classes for one-third of the reference stars in these regions. This information sometimes proves critical in the determination of the correction of relative parallaxes to absolute.

Just as important as the temperature and luminosity is the apparent magnitude and interstellar absorption. In pursuit of these values we had to finally fall back on our own people. Thus we organized a trip to Kitt Peak for the use of the 36 inch (# 2) telescope and its associated photometric equipment. This was a huge success yielding the photometry in 10 band passes of the stars in ten regions. The latter provided not only the data needed to determine the above but that required to obtain the approximate luminosity and temperature classes of the rest of the stars in each region. The agreement between the relative parallaxes and the

¹ NASA regions are observed 12 to 16 times per year and thus constitute approximately one-half of the actual observations. Since there are more parallax regions, a larger share of that time is spent in setting up.

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distribution in the spectro-photometric parallaxes has given us dramatic proof of the accuracy of the Thaw/MAP system, see Tables II and III.

Another stated goal was the testing of solid state detectors in the MAP. These tests, of a photodiode similar to that used in standard photometers, were completed. Unfortunately, the device proved less satisfactory for our purposes than the photomultiplier tubes we now have in use. The tests of the CCD, by Robert McMillan (of the LPL at the University of Arizona and part of the ATF effort) also proved less than inspiring. Both of these systems outperform the PMT in some applications of photometry. But our need for high-speed low-noise time-resolved photometry was not met by these prototype systems. However, the gallium-arsenide PMT appears to have the specifications sought and may increase our magnitude limit by a full magnitude. Tests of such a system have not yet reached formal planning.

Another area of development was instrumentation controlling the Thaw refractor. The control computer and required electronics were purchased (using private funds). Also acquired were the motors, power supplies, and computer boards required to improve the slew and guide controls. At this point in time we have a working system in our electronics lab and have run most of the necessary wires to the telescope pier from the control booth.

Also acquired (with private funds) was a 10-inch reflecting finder telescope to which we added a closed circuit intensified TV system. This allows acquisition of target regions from the control booth. Tests of this system have shown that fainter stars can be seen with the TV system than with the 8-inch visual finder attached to the bottom of the Thaw refractor. This has given us the courage to proceed with the installation of a TV guide system.

A similar area of development is our reconstruction of the Keeler reflector. Using private funds we were able to design and have manufactured a new set of optics for this 30-inch aperture instrument. The glass is a very low expansion ceramic and the design is an astrometric version of the Ritchey-Chretien (similar to but not the same as the design now being considered for the two mirror version of the ATF). The optician, Donald Loomis (who is reputed to be one of the best in his field) indicates that the surfaces are unusually smooth and better than diffraction limited.

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In preparation for the optics, the original clock drive has been replaced with one virtually identical to the stepping motor design used on the Thaw. A declination guide system identical to that on the Thaw is also partially installed.

Yet another area of substantial progress was the Theiss measuring machine. The new 10-by-10 inch granite machine (purchased with funds given by George Theiss in memory of his father) has been installed and put into full operation. The machine is now used regularly (approximately 20 hours per week) in both the platen process described above and in a series of preliminary looks at plates related to ongoing MAP studies. It has also been used in the study of trail plates from one-half dozen observatory sites, another study which will eventually further threaten NASA'S dwindling resources.

Most critical of our goals is to publish. It is through publications (as long as they are not about nonexistent planetary systems) that we gain the credibility needed in grant competition. The publications detail: the system; what we have shown it's precision to be; and where this instrumentational development may lead. The July 1987 paper (attached) describing the MAP and its atmospheric limitations was a logical beginning. This was followed by a number of minor publications, also listed in Table I, some of which are attached. Next is a paper scheduled for the September issue of the Ap.J. detailing a study of the proposed open cluster Uppgren 1. This will be followed by an already reviewed paper for the Ap. J. describing a study of the nature of the evolved binary Beta Delphini. There are also three additional papers in final preparation, one is a preliminary report detailing our observations of BD 68 946, the subject of an unseen mass search (none was found but the observations cover only 2.2 years).

The precision, of what is now and what will remain the most accurate astrometric system for a number of years into the near future, is evident in the study of Uppgren 1. Uppgren and Rubin (1965) had suggested that a small group of bright F stars, in the direction of the galactic north pole at an approximate distance of 100 parsecs, might be the remnant of an old cluster. Utilizing the Thaw/MAP we determined the parallaxes of six of the candidate stars with an average precision of 1.1 mas. Thus producing a set of parallaxes with precision not much below the usual 10 percent criteria for "good" parallaxes at four times the usual limit for such quality. The derived distances for the proposed cluster members were, as suggested, similar and an unusual space density of F stars seems indicated.

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The validity of the derived distances is attested to by the agreement found between the trigonometric and spectroscopic values. These derived parallaxes confirm the unusually high density of stars in the region of Upgren 1. Excluding Upgren-Rubin star 7, which both the trigonometric and spectroscopic values suggest is behind the group, we found a mean parallax of 9.4 mas (106 parsecs) with a standard deviation (per star) of only 1.1 mas for Upgren-Rubin stars 1,3,4,5 and 6. Since the average estimated standard error of the parallax measurements is 1.1 mas, this would seem to imply that there is very little difference in the distances of these stars. Within, or more probably slightly behind, this group there are two other stars. Upgren-Rubin star 2 has a photometric parallax of 7.5 mas, while AO 692 appears to be a somewhat later spectral type star with a trigonometric parallax of 7.4 +/- 1.0 mas.

The proper motions we obtained for the Upgren-Rubin stars with the MAP, though several times more accurate, were in general agreement with previous much longer-term studies and with our own photographic study, which used the new Theiss machine, of the same objects. However, when we computed the space velocities we found that the proposed cluster is composed of members of two dynamically different groups of stars.

Upgren-Rubin stars 3, 5 and 7 appear to be intermediate velocity stars moving at approximately 55 km/sec mostly in a minus Y direction. Because these stars are passing over the galactic plane in the vicinity of the Sun, the radial velocities fail to give any hint of their nature. The other set of stars, composed of Upgren-Rubin 1, 4, and 6 do not show a significant motion relative to the local standard of rest and their relative velocities are similar to those found for unassociated field stars. The motions of the two sets of stars would lead to the dissolution of the group in a few times ten thousand years.

As noted above, the publication of the Upgren 1 study is being followed by an already reviewed paper on the binary star Beta Delphini. This system presents particularly stringent tests of the theory of stellar evolution since it is composed of an evolved giant F5 III and a subgiant F5 IV star.

Since the two stars in the system must have a common origin, it is reasonable to assume that they both have the same age and chemical composition. If theory is correct, the two stars must then satisfy two different sets of constraints simultaneously. One set of constraints relates to their luminosities and surface

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temperatures, the other relates to their masses. In other words, the two components A and B of Beta Delphini must:

1. when plotted in the HR-Diagram, both lie on the same theoretical isochrone, compatible with their chemical composition;
2. have orbital masses which both agree, within the error of observations, with the masses predicted for their position on the theoretical isochrone.

In his discussion of the Mass-Luminosity Relationship, Heintz (1978) lists several binary systems that contain luminosity class III giant stars, but only one for which the listed values do not depend upon the approximation yielded by a dynamical parallax, Beta Delphini. However, the accepted masses for this system, which is beyond the effective range of previous parallax techniques, have been called into question by van de Kamp (1954) (who performed the original study in 1938) and Underhill (1963).

The perturbation due to 26.6 year orbital motion (which is approximately equal, over this interval to the total perturbation a Jupiter would impart to Barnard's Star) is clearly shown in this 1.9-year study and allows the most precise determination of the relative masses of the component stars to date. Our² study of the evolutionary status of the system indicates it to be approximately 1.3 billion years old and to have near-solar chemical composition.

We also happen to have several hundred plates of this region, which will now be measured on the Theiss machine. Since these cover two full periods of the orbit they will give a significant check of the MAP results. If you are wondering, of course we took a quick look. Our preliminary photographic value, based upon 18 plates is within its error of the MAP result.

² It should be noted that, besides several astronomers from the University of Pittsburgh and Bruce Stephenson of Case Western Reserve University, this paper included authors Pierre Demarque and Sabatino Sofia of Yale University.

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TABLE I

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TABLE 1, PUBLICATIONS ... continued

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TABLE 1, PUBLICATIONS ... continued

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TABLE II
(from the study of the MAP region centered on Upsilon 1)

DISTANCE MODULI AND RELATIVE PARALLAXES

AO#	Dist.Mod. mag.	Spectroscopic parallax mas	Relative parallax mas	Adjustment to absolute mas	Residual mas
695	5.43	8.2	3.2	5.0	-2.7
699	4.82	10.9	1.7	9.2	1.5
702	5.04	9.8	2.2	7.6	-0.1
704	5.28	8.8	0.3	8.5	0.8
709	5.28	8.8	1.0	7.8	-0.1
703	6.27	5.6	-3.5	9.1	1.4
697	9.06	1.5	-5.5	7.0	-0.7

Average adjustment to absolute = 7.7 mas
Standard deviation one comparison = 1.5 mas

The standard deviation of the mean is a measure of the combined errors of the spectroscopic and trigonometric parallaxes. The average estimated standard error of the trigonometric parallaxes of the above stars is 1.1 mas which implies that the spectroscopic parallaxes have similar errors of estimation.

TABLE II
(from the study of the MAP region centered on Beta Delphini)

SPECTROSCOPIC AND RELATIVE PARALLAXES

AO#	Spectroscopic parallax mas	Relative parallax mas	Adjustment to absolute mas	Residual mas
719	10.2	2.8	7.4	2.1
720	0.8	-4.3	5.1	-0.2
721	8.3	5.3	3.0	-2.3
722	0.9	-3.4	4.3	-1.0
724	1.7	-3.0	4.7	-0.6
726	2.4	-3.9	6.3	1.0
727	1.1	-5.9	7.0	1.7
728	11.3	6.8	4.5	-0.8

Average adjustment to absolute = 5.29 mas
Standard deviation one comparison = 1.49 mas
Standard error of the mean = 0.53 mas

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