A NEW OBJECTIVE FOR THE ALLEGHENY OBSERVATORY 30-INCH REFRACTOR

George D. Gatewood, Joost Kiewiet de Jonge,
John Stein, Charles DiFatta
University of Pittsburgh
Allegheny Observatory
Observatory Station
Pittsburgh, Pennsylvania 15214

ABSTRACT. As a follow-up to the development of astrometric detectors of sufficient accuracy to detect extrasolar planetary systems, the Allegheny Observatory is modernizing their 30-inch Thaw Refractor. Changes include a new objective lens and the transition of the observational bandpass from blue light to red. The new system will have sufficient accuracy to detect jovian planets orbiting any of several dozen of the Sun's nearest stellar neighbors.

DISCUSSION. Disappointed by their findings in our own planetary system, a growing number of life scientists are becoming interested in the possibilities for life beyond it. Here the prospects are less discouraging but far from reassuring. As of this writing, no extrasolar planetary system has been detected and confirmed. That such systems probably do exist is suggested by the recent IR observations of what might well be the nebula from which planetary systems are forming around such stars as Vega and Beta Pictoris. But, if we assume that life forms and evolves upon planetary surfaces, our most immediate task is to show that this larger realm warrants our enthusiasm.

A series of studies conducted through NASA's Ames Research Center have studied the problem of the detection and study of extrasolar planetary systems. For example, see the minutes of the SECOND WORKSHOP ON EXTRASOLAR PLANETARY DETECTION (Greenstein 1976) or AN ASSESSMENT OF GROUND-BASED TECHNIQUES FOR DETECTING OTHER PLANETARY SYSTEMS (Black and Brunck 1980). These studies conclude

M. D. Papagiannis (ed.), The Search for Extraterrestrial Life: Recent Developments, 65–74.

that the technique currently best suited to the effort is that of astrometric observation and analysis of the motion of the central stars of suspected planetary systems. Much of that opinion was based upon the evolution of a new class of electronic astrometric detectors. To date the most successful of these is the Multichannel Astrometric Photometer (MAP) (Gatewood et al 1980 and Gatewood 1983).

This detector gathers considerably more astrometric information per region per hour than the previous detector (the photographic plate) did during the average observing year. In fact, the detector is so accurate that it can detect the optical errors in many existing astrometric optical systems (Gatewood and Stein et al 1984). To circumvent this problem, the authors of that paper recommend 3 new optical systems. The design and progress in construction of the first of those systems is reported on here.

Based upon the frame of one of the largest and most productive astrometric telescopes, the Allegheny Observatory's Thaw 30-inch photographic refractor, the revised system is designed not only to take full advantage of the properties of the new detector, but to overcome some of the age-old difficulties faced by its predecessors. Probably the last of the large astrometric refractors, the designers struggled (as did most of their predecessors) with the harassments of surrounding city lights and the restrictions of glass inhomogeneity. It was not originally intended that these revisions should be as extensive as they have become. At first the plans to reconstruct the telescope's drives and electronic systems included the usual modernization, but did not include such items as the new control room or the control computer. However, when it was realized that even the objective lens would need to be replaced, it became clear that by the time work was complete little of the original system would be left. From that point on, the planned revisions were viewed as a whole, and as the creation of a new system.

The realization that the objective lens was a source of some error began with a study by Kamper (1972) and, somewhat later, in several overlapping studies by Gatewood and Russell. The first results suggested a variation in a weak color term while later results suggested that there was a minimum value associated with each night below which repeated observation could not push the standard error of the mean positions obtained using wide spectral band photography. The latter is a direct indication of an unresolved, slowly-changing systematic error. This conclusion was strengthened by a series of tests conducted, in 1975, by Gatewood and Russell that showed that stellar images obtained during periods of exceptional seeing had a small flare. The latter is probably related to a line of inhomogeneity in the objective glass shown clearly in focal grams taken by Kamper. More recently the effect of the flare has been noted in the electronic scans of the MAP where it directly affects the image profile and thus the standard error of the measurements.

Of course the detection of a problem, its theoretical resolution, and its actual physical resolution are all too often not successive steps. The desire to replace the objective lens was a result of the realization that the current objective would severely limit the accuracy of future astrometric studies made at our Pittsburgh site. Another technical consideration was the central wavelength of the current system. The choice of a blue bandpass (an advantage in the early days of photography) now placed the limiting magnitude totally at the mercy of modern city lighting. However, no matter how compelling the technical reasons, the desire to modernize is usually quelled quickly and mercilessly by the realities of finance. Our salvation came in the form of a federation of private sources (noted below). To this group, in no small part, should go much of the credit for the science that the improved telescope will produce.

Table 1 lists some of the differences between the current system and its revision. As noted above, a major change involves wavelength. As most readers will know, unlike a reflector, a refractor does not bring all wavelengths of light to the same focus. In fact, a two element lens only brings two wavelengths to the same focus. But, if these two wavelengths are chosen properly, the wavelengths between them will cross close enough to the focus that a considerable bandpass will fall within the diffraction limited focal depth of the telescope. Other things being equal, the size of this bandpass depends upon the glass type and the central wavelengths. For the glass types we could obtain in the sizes sought (Schott's BK7 and F2) the bandpass which can be brought into focus broadens as the central wavelength is increased. For 4400 Angstroms, the central wavelength of the old photographic lens, the bandpass (defined in this manner) is less than 250 Angstroms. At 6500 Angstroms, the value chosen for the new objective, it is 700 Angstroms. Thus, by changing the central wavelength of the objective lens, we have increased the white light photon gathering power of the Thaw Refractor by a factor of nearly 3.

Another factor arguing for the chosen wavelength has to do with the nature of the targets that the instrument will be used to study. Blue stars are usually intrinsically bright and can thus be observed at relatively great distances. The intrinsically fainter stars which make up such a large percentage of the nearby stars are usually red. Thus, they produce more photons at longer wavelengths. The chosen bandpass contains the peak of Planck's curve (expressed in photons emitted) for K stars.

Finally, as noted above, the night skies over cities have recently become line sources. Currently favored lighting includes mercury arc, high pressure sodium, and metal halide sources. Mercury arc lamps produce a strong line at the center of the bandpass of the current photographic lens. However, none of these sources produce strong emissions between 6150 and 6850 Angstroms. Several photographs of the spectrum of the Pittsburgh night sky indicated that this part of the reflected spectrum was indeed quite dark.

Working against the chosen wavelength was the lower energy of the longer wavelength photons and the consequent lower sensitivity of the materials currently available for the cathodes of the photomultiplier tubes used in the current configuration of the MAP. Nevertheless, operating at the central wavelength chosen in the compromise of these several factors, the instrument will be several times more sensitive to the intrinsically faint stars which frequent the solar neighborhood. This sensitivity, combined with a much darker sky, should significantly improve the system's limiting magnitude and accuracy at fainter magnitudes.

Another feature hopefully to be incorporated at a later date, is the addition of a light-weight optical flat that can be mounted on the front of the objective cell and utilized for tests of the optics while the telescope is pointed into various observing positions. This would allow regular high precision checks of the performance of the telescope's optics, helping to insure the long-term stability of the system of the observations.

Table 2 contains the specific design characteristics of the objective lens as derived by Steve Lang of the University of Arizona Optical Sciences Center (now with the WYKO Optical Company of Tucson). The design was subjected to a second set of programs by James G. Baker of Harvard and checked further by one of us (J.K.de J.). Both lateral color and coma conditions are met to very high tolerances and the design promises near gnomonic projection over a field 0.6 degrees in diameter. The contract for grinding and figuring the lenses was awarded to the Optical Sciences Center. The senior optician is Richard E. Sumner. At this writing, all four surfaces of the new objective have been ground and polished and final figuring will start within the month.

The cell shown in Figure 1 is a variant of the system designed by Frank Schlesinger (1936) and used successfully on the Thaw refractor for over 70 years. We have doubled the number of points of edge contact with the glass and modified the design to allow the elements to be mounted closer together. As in the original system, the lens elements are essentially mounted in separate cells. Radially, around the optical axis, there are eight points of contact. These points are arranged in pairs, each pair resting on a pivot. Two of the pivots, in the south and west when the cell is mounted on the vertical tube, are built directly on the stainless steel wall of the cell. The other two, one in the north and the other in the east are supported on pivots that are pushed towards the optical axis by a spring and a weight driven arm. The spring is mounted inside the cell (with the arm passing through it) so that it always develops a force of 15 percent of the 200 lb weight of a single element (the elements are very similar in weight); thus insuring that the lens is always pushed towards the opposite defining position. As the orientation of the cell shifts the weight of an element towards one of the movable arms, the weight on the end of the arm causes the supports attached to it to push upward against the glass with a force that can become equal to the weight of the glass. As a result the elements are always held gently but firmly against the positions defined by the south and west pivots. As the slight differences in the coefficients of expansions of the stainless steel and glass react to the changing temperatures, the north and east arms adjust their positions. The slight offset of the flint and crown at the center of the lens system that will result at extreme temperatures, is well within the lens design tolerances.

Support along the optical axis comes from 6 nylon cylinders placed between the glass elements and 6 metal supports placed below (closer to the focal plane) the lower (crown) element. The cylinders are located 60

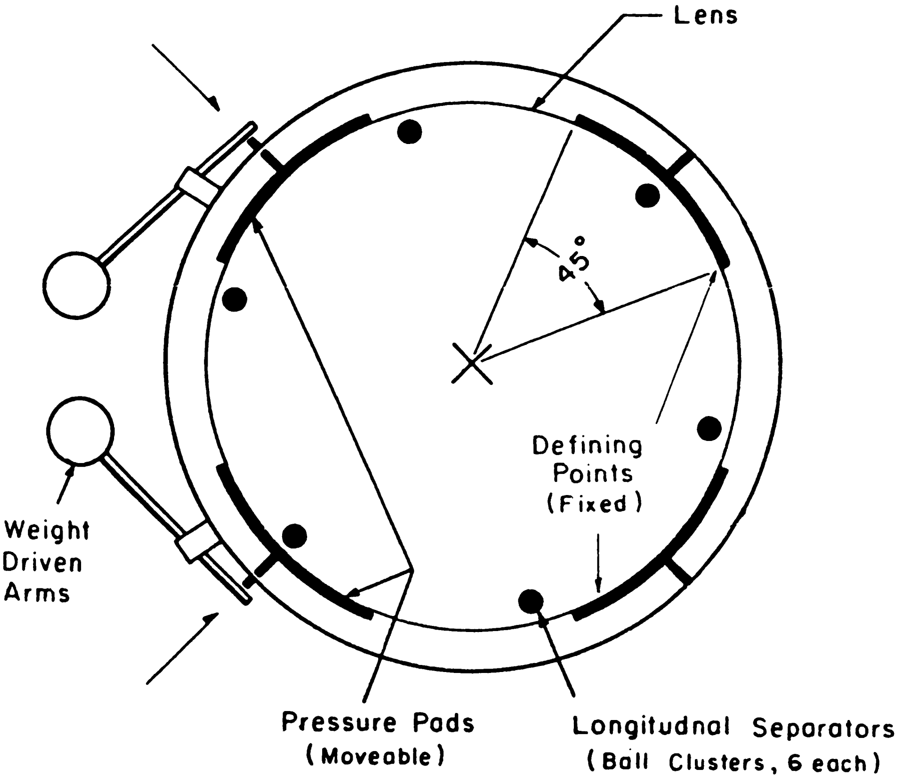

FIGURE 1 CELL ASSEMBLY FOR OBJECTIVE LENS

Shown here is one of the two very similar cells that hold the flint and crown elements of the objective lens. Lateral position is defined by the pair of rocker arms located in the south and west. These pivot on supports attached to the cell wall. In the north and east are similar arms attached to weight driven arms. Surrounded by springs, these arms each exert a minimum force equal to 15 % of the weight of the lens. When the lens is resting directly over the arms, a maximum of 115 % of the lens weight is exerted. The separation of the lenses, when their cells are joined, is maintained with 6 0.375 inch diameter curved nylon rods laying in the plane of the Figure. The lower (crown) element rests on three soft metal defining points and 3 springs. These 6 evenly spaced points give equal support at a zenith distance of 22 degrees, the expected average value during use.

degrees apart radially and have a diameter of 0.3750 inches each with a uniformity of 0.0002 inches. With the telescope pointed to the zenith, the cylinders transmit the weight of the flint element onto the crown element. The weight of the flint element causes the cylinders to be compressed by 0.001 inches each; 5 times their variation in thickness. Thus the weight of the glass is distributed over 6 broad points. The change in element separation is well within the error budget of the lens design, while the tilt between the elements is guaranteed by the uniformity of the cylinders and their tendency to increase their resistance rapidly with compression. The cell is being designed and built by Ronald Hilliard of the Optomechanics Research Company of Tucson, Arizona. This is the same firm that built the mechanical portions of the MAP. At this writing, the major portions of the cell have been formed, annealed and machined. They will be used to mount the elements during their final figuring and testing.

The currently estimated completion date for the lens and its cell is the winter of 1984/85. Installation and on-site testing will require several additional months.

With its predicted accuracy of approximately 0.002 arc seconds per hour and effective limiting magnitude of 13 or 14 in red, the new objective is ideally suited to a survey for jupiter-like planets orbiting any of several dozen of the Sun's nearest stellar neighbors. The time required to observe a complete signal (orbital perturbation) from a star orbited by a jupiter like planet is a dozen or so years. Shorter periods might occur if there are indeed such planets in the sample to be surveyed. The only way we will know for sure is to start; and start we will.

ACKNOWLEGMENTS

By its very nature, a project of this size must owe its success to many. Although the funding for the lens itself came, as noted below, from other sources, we have been fortunate in having the continious support of both the National Aeronautics and Space Administration (current Grant NAG 2-53) and the National Science Foundation (current Grant AST-8315455). These agencies, along with the University of Pittsburgh and contributions from the Allegheny Observatory Endowment, supported the development of the detector and the ongoing observational program.

However, no such project can continue for long without broader support. There are times when that which needs to be done cannot be done with the available financial resources. Such was the circumstance that surrounded the decision to upgrade the Allegheny Observatory's main instrument. It is at these times when the individual, and the institutions that are formed for such purposes, can make a large difference. Dr. Bernard Oliver, retired Vice President of Research for Hewlett Packard was the first to make a matching gift toward the new objective lens. This offer was met by the Helen Clay Frick Foundation of Pittsburgh with an additional matching gift. Additional contributions were made by the Extrasolar Planetary Foundation, the Planetary Society, the Foundation for SETI, the National Science Foundation, the Office of Research of the University of Pittsburgh, the Department of Physics and Astronomy of the University of Pittsburgh and the Allegheny Observatory Endowment. Altogether, more than one hundred and thirty thousand dollars were raised for the new lens and its objective cell.

As one experienced in these matters will undoubtedly surmise from the quoted price, we also owe a note of gratitude to the organizations that cooperated to make the new objective lens and its cell possible: the Schott Glass Company of Mainz Germany and Duryea Pennsylvania, the Optical Sciences Center of the University of Arizona, and the Optomechanics Research Company of Tucson Arizona.

REFERENCES

Black, D. C. (1980). "An Assessment of Ground-Based Techniques for Detecting Other Planetary Systems", NASA Conference Publication 2124.

Gatewood, G. (1983). United States Patent # 4,397,559.

Gatewood, G., Breakiron, L.A., Goebel, R., Kipp, S., Russell, J.L., and Stein, J.W. (1980). "On the astrometric detection of neighboring planetary systems II", Icarus, 39, 205.

Gatewood, G., Stein, J., DiFatta, C., and Kiewiet de Jonge, J. (1984). "Three Astrometric Systems", Proceedings of IAU Symposium 109 (editor H.K. Eichhorn) (in press).

Greenstein. J. (1976). "Minutes of the Second Workshop on Extrasolar Planetary Detection" NASA-Ames Research Center.

Kamper, K. (1972). "The Thaw Photographic Refractor", Ph.D. Thesis, University of Pittsburgh.

Schlesinger, F. (1936). "Parallaxes of 851 stars", Transactions of the Astronomical Observatory of the Yale University, 8, Introduction.

TABLE 1

ALLEGHENY OBSERVATORY REFRACTOR OBJECTIVES

Feature	Characteristic
Aperture	30 inches
Central Wave Length	6500 A
Bandpass (with MAP)	700 A
Focal Length	570 inches
F Ratio	19.00
Focal Plane Scale	14.25 arcsec/mm
Glass:	
element 1	F2 Flint
element 2	Bk7 Crown
Lens Design	Aplanat (red light)
Field Size (design)	0.6 x 0.6 degree
Cell:	
material	stainless steel
lens positioning:	
a) horizonial	4/2 point definition
b) vertical	3 pad, 3 spring
c) separation	6 nylon spacers
Figure Monitoring	Optical Flat with Laser and Modeling

TABLE 2

OPTICAL DESIGN OF NEW ALLEGHENY OBSERVATORY OBJECTIVE LENS

Surface	Radius (inches)	Central Thickness (inches)	Medium	Index of Refraction	DF
0	0.0000	infinite	air		
1	247.5254	1.5000	F2	1.615690	0.941
2	119.0529	.3572	air		
3	117.8908	3.0000	BK7	1.514972	0.315
4	-7965.2321	567.3156	air		

EFL (inches)	BFL (inches)	F ratio	Length (inches)	GIH
570.00	567.32	19.00	4.857	2.985

SA3	PACY	PLCY	CMA3	COL
0.000004	-0.000231	-0.000006	0.000002	0.000233