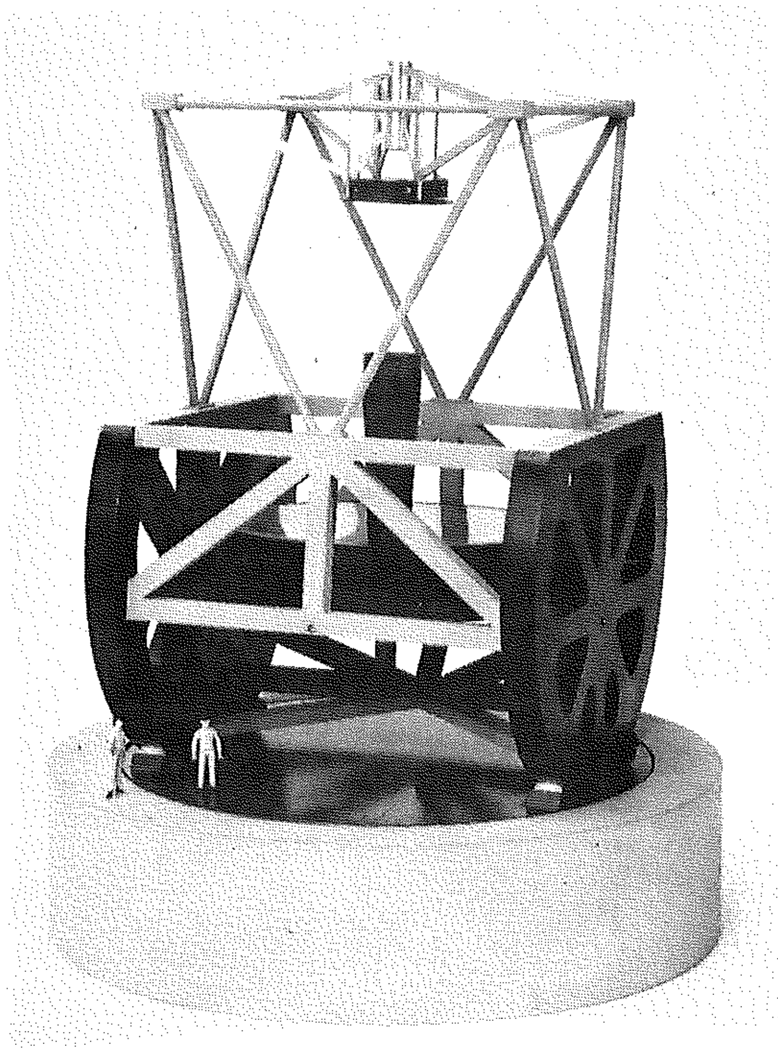

Optical Subsystem Alternatives for the Columbus and Magellan Telescopes

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CONTENTS

1. Introduction

At the present time the baseline optical geometries for the Magellan and Columbus telescopes are similar but not identical. The purpose of this report is to explore some ramifications of the differences between these current telescope geometries in terms of the impact on optical subsystems.

The present Magellan configuration calls for a 315-inch f/1.20 parabolic primary with an hyperbolic optical secondary which combines with a 3-element all-spherical field corrector with(ADC), to yield a 40-arcmin mildly curved field which is fully corrected over the (0.33 to 1.10)-micron chromatic range without refocus. The corrected f/6.50 focus lies approximately 80 inches behind the primary-mirror vertex.

The present Columbus configuration (UA-88-12, July 8, 1988) calls for a 315-inch f/1.20 hyperbolic primary (A_2=-1.00126, Ritchey-Chrétien at f/15) with an hyperbolic optical secondary which combines with an unspecified field corrector to provide a 45-arcmin field corrected over an unspecified chromatic range. The corrected f/5.40 focus location is doubly specified as being located 69.8 inches and 80.0 inches behind the primary mirror vertex.

In Section 2 it will be shown that there is no need to deviate from a strictly parabolic primary in order to achieve fully diffraction limited performance at the f/15 infrared focus for wavelengths of 2 microns and beyond. In Section 3, all-spherical 3-element f/5.40 and f/6.50 field correctors will be presented which are nearly equivalent in optical performance, thus establishing the fact that the final Cassegrain f/ratio choice has little impact on field corrector designs. A comparison of the f/5.40 and f/6.50 Cassegrain optical secondary mirrors and their light shrouds is given in Section 4.

All-refracting broad-passband collimator designs for 6-inch beam, imaging spectrometers are presented and compared in Section 5. These service the naked f/5.20 and f/6.26 Cassegrain foci which result from removal of the field corrector optics and refocus of the secondary mirror(s). It is shown that the spectroscopic performance of the f/6.26 collimator is appreciably better than that of the f/5.20 collimator. In Section 6 the question of pixel-matching for direct imaging at fine resolution with the field corrector and at coarse resolution through the imaging spectrometer is discussed. In Section 7, mention is made of the atmospheric dispersion compensator (ADC) problem, particularly at the naked Cassegrain focus. Conclusions are summarized in Section 8.

2. Wide-Field Diffraction-Limited Infrared Focus

The baseline Columbus Telescope (UA-88-12, July 8, 1988) proposes an f/15 Cassegrain infrared focus with a 10-arcmin diameter curved f.o.v., located some 80 inches behind the primary-mirror vertex. If this were a classical (parabolic primary) Cassegrain, such as Run No. 6619 (01/20/89) shown in Table 1, one would find that there exists 2.94 microns of rms pathlength error at full field if the average between the tangential and sagittal field curvatures is assumed and the best compromise focus over the 10-arcmin field is adopted.

Optimizing the field curvature and refocusing again reduces said pathlength error to 2.27 microns which suggests, roughly speaking, that the telescope would be diffraction limited at a wavelength of 5 microns or greater.

If it were desired to attain diffraction limited performance at shorter wavelengths, one approach would be to modify the figures on both mirrors so as to reduce the pathlength errors over the f.o.v. One such modification that is possible is the familiar Ritchey-Chrétien (R/C) configuration in which the conic constants of both the primary and secondary mirrors are adjusted such that 3rd-order spherical aberration and 3rd-order tangential coma are both zero. This leads to a slightly hyperbolic primary (rather than a parabola) and a slightly more hyperbolic secondary mirror than the classical Cassegrain has. Run No. 1168 (01/21/89) shown in Table 2 represents such a configuration with optimized field curvature and refocus over the 10-arcmin field. One finds that the rms pathlength error at full field is just 0.63 microns which appears to be satisfactory for all intents and purposes.

However it would seem quite undesirable to adopt an hyperbolic primary mirror for two reasons. The first is that it would foreclose the possibility of very deep coronagraphic ccd imaging over the 10-arcsec diameter f.o.v. in which 0.5-arcsec or better images will be available at prime focus with an absolute minimum number of optical surfaces in the beam. Suitable targets would be faint companions near bright stars, jets and fuzz near QSOs and AGN; low surface brightness knots and bridges; distant galaxies for morphology, etc. The second equally important reason is that it will be extremely desirable to mount a shearing interferometer directly at prime focus for the purpose of studying the effects of the mirror support system on the primary mirror figure and this is best done at a (potentially) aberration-free image without additional optics.

Fortunately the desire to correct residual pathlength errors at the infrared Cassegrain and to retain a parabolic figure on the primary mirror are not at all incompatible. The proper method is to simply design a diffraction-limited secondary (DLS). Run No. 7448 (01/20/89) shown in Table 3 contains a parabolic primary mirror and a (DLS) which deviates very slightly in figure from the classical hyperbola. Its residual rms pathlength errors are smaller than those in the previously mentioned (R/C) system over most of the field, as shown in the table below.

field radius (arcmin)	rms pathlength errors (microns) (R/C)	(DLS)
on axis	.02	.04
3.0	.32	.36
4.0	.46	.29
5.0	.63	.49

It should be emphasized that the data presented here are absolutely quantitative. Anyone who so chooses can verify the presented models and calculate expected diffraction patterns. Both the (R/C) and the (DLS) will produce acceptable diffraction images at wavelengths of 2 microns and beyond, but it is clear from the pathlength residuals that the (DLS) model will be somewhat better than the (R/C).

In view of the above result there appears to be no need to use an hyperbolic primary mirror. Therefore, a parabolic primary mirror is assumed for all subsequent calculations presented in this report.

3. All-Spherical Broad-Passband Wide-Field Correctors

In a previous report, "A 315-Inch f/1.20 Telescope for Las Campanas Observatory: Preliminary f/6.50 Wide-Field Corrector Alternatives" (Epps, February 1988), a 3-element, all-spherical, 40-arcmin, (0.33 to 1.10)-micron field corrector with (ADC) was presented which showed an rms image diameter averaged over all field angles and colors of 0.18 +/- 0.07 arcsec with 0.14 arcsec of maximum rms lateral color. The field of view is concave toward the sky with a radius of -162.7 inches. The primary and secondary mirrors can be used without the corrector to form a naked f/6.258 focus some 79.31 inches behind the primary-mirror vertex. For that purpose the secondary mirror must be moved toward the primary mirror by 0.0853 inches.

Run No. 5933 (01/18/89) shown in Table 4 is an analogous all-spherical corrector with (ADC) which uses a 315-inch f/1.20 parabolic primary mirror corrected to f/5.40. It contains 3 fused silica lens elements and the (ADC) is made of FK5 and LLF2 in the usual manner. It has rms image diameters averaged over all field angles and colors of 0.18 +/- 0.07 arcsec with 0.12 arcsec of maximum rms lateral color. The 40-arcmin field of view is concave toward the sky with a radius of -232.7 inches, somewhat less curved than the f/6.50 model. If the corrector is removed and the secondary mirror is moved toward the primary mirror some 0.1647 inches, the resulting naked Cassegrain operates at f/5.20.

It appeared surprising that there was no penalty for having gone from f/6.50 to f/5.40. The question arose whether perhaps several improvements which had been implemented in my design code during the 11-month time interval between these designs could have favored the f/5.40 calculation. In order to find out, the f/6.50 model was reoptimized with the newer code. Run No. 7708 (01/18/89) shown in Table 5 is the new f/6.50 model which is in every respect similar to the previously reported f/6.50 model. The rms image diameters averaged over all field angles all colors are 0.16 +/- 0.06 arcsec with 0.11 arcsec of maximum rms lateral color. The concave field of view has a -161.1-inch radius. Removing the corrector and moving the secondary mirror some 0.0965 inches toward the primary mirror produces a naked f/6.24 Cassegrain whose focal surface lies some 79.3 inches behind the primary-mirror vertex.

One notes that these aforementioned field correctors do not contain vacuum windows near focus. This is appropriate for a field corrector designed to feed fibers for spectroscopy. However, if direct imaging were implemented with a vacuum window and perhaps filters near focus, some small change in the corrector design would be required. This could probably be accomplished by swapping out the last lens element without changing the others. This question should be addressed quantitatively in a subsequent study.

The nontelecentric angle for the f/5.40 model is 0.62 degrees while that of the f/6.50 model is a somewhat larger 2.16 degrees. This angle represents the nonorthogonality of the principal ray with respect to the local focal surface at the field edge. This amount of nontelecentricity will have no appreciable effect on direct imaging but could reduce the efficiency of fiber coupling for spectroscopy at the 10% to 30% level if the fibers were aligned with respect to the local focal surface normal rather than with respect to the local principal ray. Nontelecentricity is not readily controllable in the design of a field corrector of this type. It would best be dealt with by the mechanism which moves the fibers.

One concludes that the precise choice of corrected Cassegrain f/ratio has little bearing on one's ability to design an acceptable all-spherical field corrector with the possible exception of the nontelecentricity problem. It should prove very easy to increase the f.o.v. to 45 arcmin if desired.

4. Comparison of Optical Cassegrain Secondary Mirrors and their Light Shrouds

The f/5.40 model Run No. 5933 (01/18/89) described above and shown in Table 4 requires a 75.0-inch diameter hyperbolic secondary mirror whose maximum aspheric deviation is 0.0144 inches (732 waves). The f/6.50 model Run No. 7708 (01/18/89) shown in Table 5 requires a 65.9-inch diameter hyperbolic secondary mirror whose maximum aspheric deviation is 0.0129 inches (655 waves). One thus sees that the f/5.40 model has a secondary mirror with 30% more surface area and which is 12% more aspheric than the f/6.50 model.

To place these numbers in perspective one notes that the AAT Cassegrain secondary mirror, which was figured by the late David Brown of Grubb-Parsons, is roughly 58 inches in diameter with 48 waves of maximum aspheric deviation. It is the largest, most aspheric secondary mirror yet made. The Keck secondary, which is being figured by David Hilyard of Lick Observatory at the present time, is 55 inches in clear diameter with 230 waves of maximum aspheric deviation.

Thus one realizes that while the Keck secondary is comparable in area to the AAT secondary, it is 479% as aspheric. The f/6.50 Magellan secondary is 44% larger in area than the Keck and 285% as aspheric while the f/5.40 Columbus secondary is 86% larger in area than the Keck and 318% as aspheric.

As an additional (small) point of difference, one notes that while the Magellan secondary will require (roughly) a 100-inch light shroud, the Columbus secondary will require (roughly) a 110-inch shroud. This difference will amount to a 2% differential light loss in the Columbus geometry as compared with the Magellan geometry.

5. Broad-Passband All-Refracting Collimators for a Moderate-Resolution Imaging Spectrometer

Wavelength coverage over a (0.32 to 1.10)-micron passband, a 6.00-inch beam, and a 10-arcmin diameter field of view at the naked Cassegrain were adopted as exploratory optical parameters in seeking to design an imaging collimator. This requires a 4.88-inch field diameter for the naked f/5.20 (Columbus) geometry and a 5.86-inch field diameter for the naked f/6.26 (Magellan) geometry.

My experience in designing 5.50-inch beam collimators and 12.0-inch beam collimators for the f/15 Cassegrain and Nasmyth foci on the Keck telescope was that I could barely attain a 5-arcmin field diameter for the smaller and a (6 x 8)-arcmin field size for the larger of these beams, using reflecting optics. Therefore it seemed a waste of time to imagine that a larger field size could be attained with reflecting optics at the much faster Magellan and Columbus f/ratios. Therefore no attempt was made to investigate reflecting collimator designs. Instead, an all-refracting approach was adopted at the outset.

The requirement for operation in the ultraviolet (down to 0.32 microns) severely limits the choice of optical materials as can be seen in Figure 1 which shows internal transmission at 0.32 microns for inch-thick pieces of various optical materials as a function of Abbe number, a measure of reciprocal dispersive power. It is noted immediately that NaCl (salt) is the only moderately high dispersion material available in large diameter which does not absorb an unacceptably large amount of ultraviolet light if a reasonable thickness is assumed. It must be used in any broadband ultraviolet lens to effect color correction. Fortunately, the technology for producing large (18-inch diameter by 4-inch thick) single crystals of pure laser-grade optical NaCl and for polishing and coating this material are well known to the optical industry. The material is perfectly viable if properly handled, in spite of its well known hygroscopic properties and its unfamiliarity to astronomers. Fused silica and CaF_2 are the other materials of choice which are suitable for use in an ultraviolet lens. In practice it proved necessary to add a thin element of less desirable BAK2 optical glass in order to introduce aspherics and to complete the color balance.

Run No. 5350 (10/04/87) is a preliminary 6.00-inch beam collimator-lens design at f/5.88 that was reported in "Proceedings of the ESO Conference on Very Large Telescopes and their Instrumentation" (Epps, 1988). It is shown in Figure 2. It was designed in reverse infinite conjugate to a flat focal surface and therefore it is drawn "in reverse", relative to subsequent figures. For sake of consistency I will describe it here starting from the telescope focal surface (on the right) and proceed from right to left on the drawing. The glass configuration contains a thin double-aspheric meniscus singlet of BAK2 followed by a contact triplet of NaCl, CaF_2 and fused silica. The major problem with this lens is that the maximum aspheric deviation on the trailing BAK2 surface is 0.05415 inches (2751 waves) which lies very near (or perhaps just beyond?) the limit of what can be fabricated by conventional optical polishing techniques. The maximum aspheric deviation on the trailing fused silica surface is 0.14008 inches (7116 waves), which is clearly well beyond conventional limits and it did not appear possible during the optimization process to reduce these deviations to reasonable values.

In order to proceed with the design it became clear that what was required was a capability to limit the maximum aspheric deviation without artificially controlling the shape of the surface or any of the specific parameters such as vertex curvature and aspheric coefficients which influence the shape. The problem was one of deoptimizing the design in such a way that small reductions in image quality could be traded for large reductions in aspheric deviation. The required formalism was derived and implemented in my design code during the fall of 1988.

Run No. 1423 (01/14/89) shown in Figure 3 is an f/6.26 collimator lens which has been designed to work in conjunction with the naked Magellan telescope geometry and provide a 6.00-inch collimated beam. It is identical in description to the previous model except that the CaF_2 element has been split in order to keep the required lens-blank sizes within the limits of manufacture. One notes that the maximum aspheric deviation on the trailing fused silica surface is just 0.0515 inches (2616 waves) which is less than the smaller of the 2 previously reported aspheric deviations and is (just) within the limits of conventional polishing techniques. As a point of comparison one notes that the maximum aspheric deviation on a 315-inch f/1.20 parabolic primary mirror is 0.0456 inches (2316 waves).

Run No. 3299 (01/15/89) shown in Figure 4 is an f/5.20 collimator lens which has been designed to work in conjunction with the naked Columbus telescope geometry. It is similar to the f/6.26 model and it has an even smaller maximum aspheric deviation of 0.0410 inches (2082 waves) on the trailing fused silica surface and a slightly thinner BAK2 singlet, which is more favorable from the point of view of light loss in the ultraviolet.

The system prescriptions for Run No. 1423 (01/14/89) and Run No. 3299 (01/15/89) are given in Table 6 and Table 7 respectively. As a matter of convenience during the design, a correctorless Schmidt camera which reimages the telescope focal surface at a 1:1 ratio was added to each design for the purpose of image analysis. The very small amount of spherical aberration introduced by this artifice is entirely negligible. In a final design, the actual camera which will work with the collimator will replace the Schmidt and its own aberrations will be counterbalanced by those of the preceding optics to the extent possible.

Polychromatic spot-diagram image analysis in 8 colors ranging from 0.32 to 1.10 microns is shown to scale in Figure 5 for the f/6.26 and f/5.20 collimators. The triplets of numbers in parentheses give the polychromatic rms image diameter in arcsec (including lateral color); the total encircled energy (in %) within a 1/2 arcsec diameter centered on the image centroid; and the slit loss (in %) at a (1.0 x 1.0)-arcsec square entrance aperture centered on the image centroid.

It will be noticed that in general the imaging properties of the f/6.26 system are somewhat better than those of the f/5.20 though the differences are not dramatic, except perhaps for the slit loss differences at larger field angles. As a matter of calibration, note that each image is composed of approximately 1100 rays which produced the discrete dots. Thus the "fuzz" appearing near some of the images does not represent a large percentage of the total light in that image. A very few rays have been deleted in order to fit the images into the available format.

In practice the expected throughput of these collimators should exceed 65% at 0.32 microns, 80% at 0.335 microns and 85% at 0.35 microns and beyond, including (coated) surface losses.

6. Imaging and Pixel-Matching at the Optical Cassegrain

High resolution direct imaging at the field corrected optical Cassegrain would be done at 252 microns/arcsec in the f/6.50 Magellan telescope and at 209 microns/arcsec in the f/5.40 Columbus telescope. If a "standard" 27-micron pixel is assumed, this translates to a linear sampling factor of 9.3 pixels per arcsec for f/6.50 or 7.8 pixels per arcsec for f/5.40. If one uses the experimentally verifiable "rule of thumb" that it takes about 3 linear pixels per "clean" resolution element to define the effective rms image spread function for a granular detector such as a ccd, one finds an equivalent rms spread function of 0.32 arcsec for the Magellan telescope and 0.38 arcsec for the Columbus telescope. The following resolution table can be constructed by adding in quadrature, assuming that all other factors combine to produce an equivalent rms spread function of 0.19 arcsec for Magellan and 0.21 arcsec for Columbus. All table entries are in arcsec. In practice one would reasonably expect to find 90% or more of the light within 1.5 rms "clean" resolution elements in any particular polychromatic image.

	polychromatic rms resolution	
seeing	(Magellan)	(Columbus)
.30	.48	.53
.35	.51	.56
.40	.55	.59
.45	.58	.63
.50	.62	.66
.55	.66	.70
.60	.71	.74

In the case of low resolution imaging through the spectrometer, the final image scale is independent of the naked Cassegrain f/ratio which feeds the spectrometer. The integrated optical system works like a direct camera having the diameter of the primary mirror and the effective f/ratio of the final reimaging camera.

Detailed cameras for the Magellan and Columbus imaging spectrometers have not yet been designed but one can reasonably expect that one such camera might look very much like (0.38 to 1.0)-micron camera Run No. 9905 (09/09/88) which is shown to scale in Figure 6 but without quantitative annotation. This camera has a 9.0-inch leading element diameter and a 12.0-inch focal length. It was designed for the 5.5-inch beam LRIS spectrometer of the Keck telescope and 2 copies of the camera are presently being fabricated at Lick Observatory. The second one will be used with the Norris spectrometer on the Hale telescope.

One can assume that the Magellan and Columbus cameras will eventually operate at roughly f/2.2, thus producing a final image scale of 85.3 microns per arcsec or 3.16 (27-micron) pixels per arcsec at the detector. By the previous method of calculating one finds an effective rms image spread function of about 0.95 arcsec for low-resolution imaging, which is large compared with the polychromatic collimator aberrations over most of the 10-arcmin diameter field of view. If a detector with 15-micron pixels were used, the image scale would become 5.69 pixels per arcsec. This would yield an rms image spread function of about 0.53 arcsec which is less than the polychromatic collimator aberrations at larger field angles, particularly for the f/5.20 system. However, the delivered rms "clean" resolution is a convolution of image spread by the telescope, collimator, camera, detector, and seeing. When all these factors are added in quadrature, the f/6.26 system final images are less than 0.05 arcsec smaller than those of the f/5.20 system for all field angles (assuming pixel sizes between 15 and 27 microns and seeing between 0.5 and 0.8 arcsec).

The full f.o.v. maps almost perfectly unto a Tektronics 2048 by 2048 by 27-micron ccd with the implied 13.2-inch camera focal length. The imaging characteristics are ideally matched to a 1.0-arcsec slit width in spectroscopic mode, yielding an estimated 700 odd spectral information elements. Typical gratings could be expected to produce reciprocal dispersions between 20 Angstroms per mm and 100 Angstroms per mm with a maximum "clean" resolution of about 1.5 Angstroms.

7. Atmospheric Dispersion Compensators (ADC)

The (FK5/LLF2 doublet) counter-rotating zero-deviation prism-pairs which have been incorporated into the 3-element all-spherical wide-field correctors discussed in Section 2 do not transmit well in the ultraviolet. They would be expected to transmit only about 75% at 0.34 microns and perhaps 35% at 0.32 microns.

They will produce 6 ghost images at the 0.01% energy level (per real point image) even with the most efficient antireflection coatings and these ghosts will each display a different amount of defocus at the detector. Some will move and some will be stationary as the prisms counter-rotate during an exposure.

Furthermore, the prisms cannot be removed from the corrector, as their aberrations are compensated by the lens elements and are therefore required. A possibility would be to design another rear section for the corrector, containing its own special 3rd lens element and no (ADC) prisms, for those observers whose work does not require them.

An interesting alternative would be to design a set of rear sections containing thin fixed, skewed prisms, each of which would be tailored to compensate the average amount of atmospheric dispersion anticipated during a (relatively short) exposure. These would be parfocal and could even be exchanged mechanically. However, the elements would be roughly 26 inches in diameter and somewhat expensive to manufacture.

A far more difficult problem, as yet to be addressed successfully, is the question of how to accomplish atmospheric dispersion compensation in the naked Cassegrain which feeds the imaging spectrometer. This problem urgently awaits our attention in a subsequent study.

8. Summary of Conclusions

A. It is undesirable and entirely unnecessary to deviate from a pure parabolic primary mirror. Better diffraction-limited infrared performance can be attained with a diffraction limited secondary mirror (DLS) for the anticipated f/15 infrared Cassegrain focus, than with a Ritchey-Chrétien design.

B. All-spherical 3-element broadband wide-field correctors with (ADC) and mildly curved focal surfaces can be designed for either an f/6.50 or an f/5.40 optical Cassegrain with little appreciable difference between them except the required secondary mirror size and asphericity. The nontelecentric angle should be taken into account in the mechanical design of a fiber alignment device for spectroscopy.

C. An alternate rear section(s) may be required in order to enable the wide-field corrector to operate with or without the (ADC) unit and/or a vacuum window (and filter) for direct imaging.

D. The 75.0-inch diameter secondary mirror for an f/5.40 optical Cassegrain is 30% larger in area and 12% larger in maximum aspheric deviation compared with the 65.9-inch diameter secondary mirror required for an f/6.50 design. Either of these secondaries represents a large step beyond any secondary mirror which has been or is currently being figured.

E. All-refracting broad-passband imaging collimators with 6-inch beam can be designed in conjunction with an f/6.26 or an f/5.20 naked (classical) Cassegrain but the imaging properties of the f/6.26 are clearly superior to those of the f/5.20, particularly in terms of slit loss at the larger field angles in spectroscopic mode.

F. There will be a minor difference between the high resolution imaging capabilities of the wide-field Cassegrain correctors in favor of the f/6.50 corrector. However, the faster Cassegrain will cover 45% more field area for a given detector size as compared with the slower one.

G. The low resolution imaging capabilities of the imaging spectrometer depend mostly on the choice of detector pixel size and f/ratio for the final reimaging camera and not on the Cassegrain f/ratio. A choice of f/2.2 is consistent with existing camera designs for the Keck telescope. The inferred 13.2-inch focal length (for a 6-inch beam) will yield typical spectral coverage, wavelength resolution, and an ideal plate scale to match a Tektronics 2048 by 2048 by 27-micron ccd detector.

H. Atmospheric dispersion compensation, particularly for the naked Cassegrain, remains as a recalcitrant problem area which requires further study.

Respectfully submitted,

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Consultant in Optical Design

APPENDIX

A. Referenced Tables

1. System Prescription: Classical f/15 Cassegrain Run No. 6619 (01/20/89)
2. System Prescription: Optimized f/15 (R/C) Run No. 1168 (01/21/89)
3. System Prescription: Optimized f/15 with (DLS) Run No. 7448 (01/20/89)
4. System Prescription: f/5.40 All-Spherical Corrector Run No. 5933 (01/18/89)
5. System Prescription: f/6.50 All-Spherical Corrector Run No. 7708 (01/18/89)
6. System Prescription: Collimator for Naked f/6.26 Run No. 1423 (01/14/89)
7. System Prescription: Collimator for Naked f/5.20 Run No. 3299 (01/15/89)

B. Referenced Figures

1. Ultraviolet Transmission at 0.32 Microns vs. Scaled Abbe Number for Various Optical Materials
2. Preliminary f/5.88 All-Refracting Collimator Run No. 5350 (10/04/87)
3. Magellan All-Refracting Collimator Run No. 1423 (01/14/89)
4. Columbus All-Refracting Collimator Run No. 3299 (01/15/89)
5. Image Analysis for Magellan and Columbus Collimators
6. Keck Telescope: 12.0-Inch Focal Length Broadband Camera for LRIS Spectrometer

Table 1

OPTICAL ANALYSIS RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

RN* 1 315-INCH F1.2 - F15.0 IR TELESCOPE MODEL01 RUN NO. 6619 (01/20/89)

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 4725.011 INCHES RMS IMAGE(S) TYP DIAM= 82.7 +/- 25.7 MICRONS
0.14 +/- 0.04 ARC SEC
OBJECT DISTANCE= INFINITY
APERTURE RADIUS= 157.50 INCHES FIELD RADIUS= 5.00 ARC MIN

CLR DIA	SAG	ASPH	NS	NNE,CRV, 5ASC,NNA NSE,X,4RN,2ICR,NSA		ALL REFLECTING									NS
			1	0										0	1
315.001	0.0	0.0	1	3	-0.38336456D+04	0.10000000D+01	0.0	0.10000000D+01	0.0		0	0		0	1
			2	3	-0.13227513D-02	-0.10000000D+01	0.0	0.0	0.0	0.0				0	2
327.898	-17.777	0.0525	2	8	-0.34407407D+03	-0.10000000D+01	0.0	-0.10000000D+01	0.0		0	0		0	2
			3	3	-0.13558952D-01	-0.13780718D+01	0.0	0.0	0.0	0.0				0	3
28.537	-1.375	0.0044	3	9	0.42407510D+03	0.10000000D+01	0.0	0.10000000D+01	0.0		0	0		0	3
			4	90	-0.29188547D-01	0.0	0.23774215D-02	0.95347011D-03	-0.23896885D-02	0.0				-1	4
13.739	-0.696	0.0	4	2	-0.32133304D-01	0.10000000D+01	0.0	0.10000000D+01	0.0		0	0		0	4

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM. TERMINATION WAS NORMAL.

Table 2

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OPTICAL OPTIMIZATION RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

RN* 2  315-INCH F1.2 - F15.0 IR TELESCOPE MODEL01   RUN NO. 1168 (01/21/89)

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 4725.000 INCHES          RMS IMAGE(S) TYP DIAM= 52.1 +/- 19.0 MICRONS
              OBJECT DISTANCE= INFINITY                                                             0.09 +/- 0.03 ARC SEC
              APERTURE RADIUS=  157.50 INCHES   FIELD RADIUS=  5.00 ARC MIN

                               NNE,CRV,  5ASC,NNA
CLR DIA     SAG    ASPH   NS   NSE,X,4RN,2ICR,NSA   ALL REFLECTING                                                                  NS
                           1   0                                                                                                   0  1
315.000   0.0    0.0       1   3 -0.38336370D+04  0.10000000D+01  0.0              0.10000000D+01  0.0                    0        0  0  1

                           2   3 -0.13227543D-02 -0.10012621D+01  0.0              0.0             0.0               0.0              0  2
327.898 -17.777 0.0525     2   8 -0.34407330D+03 -0.10000000D+01  0.0             -0.10000000D+01  0.0                    0        0  0  2

                           3   3 -0.13558982D-01 -0.13961305D+01  0.0              0.0             0.0               0.0              0  3
 28.543  -1.376 0.0045     3   9  0.42407415D+03  0.10000000D+01  0.0              0.10000000D+01  0.0                    0        0  0  3

                           4  90 -0.29839435D-01  0.0            -0.15734034D-02 -0.43585098D-02 -0.91028081D-02  0.0            -1  4
 13.726  -0.710 0.0        4   2 -0.53900538D-02  0.10000000D+01  0.0              0.10000000D+01  0.0                    0        0  0  4

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM.  TERMINATION WAS NORMAL.
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Table 3

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OPTICAL OPTIMIZATION RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

RN* 2  315-INCH F1.2 - F15.0 IR TELESCOPE MODEL01   RUN NO. 7448 (01/20/89)

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 4725.000 INCHES          RMS IMAGE(S) TYP DIAM= 85.1 +/- 25.6 MICRONS
              OBJECT DISTANCE= INFINITY                                                              0.15 +/- 0.04 ARC SEC
              APERTURE RADIUS=  157.50 INCHES   FIELD RADIUS=  5.00 ARC MIN

                                NNE,CRV,  5ASC,NNA                                                                                     NS
CLR DIA      SAG    ASPH   NS   NSE,X,4RN,21CR,NSA   ALL REFLECTING                                                                 0   1
                            1   0
315.000    0.0    0.0       1   3 -0.38327542D+04  0.10000000D+01  0.0              0.10000000D+01  0.0                  0        0  0   1

                            2   3 -0.13227543D-02 -0.10000000D+01  0.0              0.0             0.0             0.0             0   2
327.895 -17.777 0.0525      2   8 -0.34406619D+03 -0.10000000D+01  0.0             -0.10000000D+01  0.0                  0        0  0   2

                            3   3 -0.13556140D-01 -0.13780718D+01 -0.10047033D-09 -0.54506368D-13  0.0             0.0             0   3
 28.542  -1.376 0.0044      3   9  0.42416306D+03  0.10000000D+01  0.0              0.10000000D+01  0.0                  0        0  0   3

                            4  90 -0.29576863D-01  0.0            -0.20213119D-02 -0.40564993D-02 -0.81008688D-02  0.0            -1   4
 13.736  -0.705 0.0         4   2  0.69565911D-02  0.10000000D+01  0.0              0.10000000D+01  0.0                  0        0  0   4

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM.  TERMINATION WAS NORMAL.
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OPTICAL OPTIMIZATION RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

Table 4

RN* 3 315-INCH F/1.2 PARABOLA CORRECTED TO F/5.4 AT (F/5.2?) CASS FOC

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 1701.000 INCHES
OBJECT DISTANCE= INFINITY
APERTURE RADIUS= 157.50 INCHES FIELD RADIUS= 20.00 ARC MIN

RMS IMAGE(S) TYP DIAM= 37.9 +/- 14.0 MICRONS
0.18 +/- 0.07 ARC SEC
MAX RMS LATERAL COLOR= 25.5 MICRONS (0.12 ARC SEC)

CLR DIA	SAG	ASPH	NS	NNE / NSE	CRV, 5ASC, NNA / X, 4RN, 2ICR, NSA	WAVLEN(MI)	PASBN(F-C)	WAV2ND(MI)	PA2BN(F-C)	WGHT(%)			NS
			C	0		0.35666	1.69840	0.61978	2.02314	76.42		0	C
315.000	0.0	0.0	1	0	0.0	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	2	1
			2	3	-0.13227513D-02	-0.10000000D+01	0.0	0.0	0.0	0.0		0	2
316.718	-16.586	0.0457	2	8	-0.29359527D+03	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	2
			3	3	-0.45477492D-02	-0.25603180D+01	0.0	0.0	0.0	0.0		0	3
75.005	-3.163	0.0144	3	9	0.29610235D+03	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	3
			4	3	0.40379949D-01	0.0	0.0	0.0	0.0	0.0		0	4
28.835	4.629	0.0	4	1	0.29999993D+01	0.14758040D+01	0.39590000D-02	0.14574120D+01	0.50660000D-02	21	-239	0	4
			5	3	0.35122365D-01	0.0	0.0	0.0	0.0	0.0		0	5
27.782	3.618	0.0	5	1	0.62897985D+01	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	5
			6	3	0.23472172D-01	0.0	0.0	0.0	0.0	0.0		0	6
26.464	2.107	0.0	6	1	0.13378958D+01	0.14758040D+01	0.39590000D-02	0.14574120D+01	0.50660000D-02	21	-239	0	6
			7	3	0.43374393D-01	0.0	0.0	0.0	0.0	0.0		0	7
25.316	3.786	0.0	7	9	0.60000002D+01	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	7
			8	3	0.0	0.0	0.0	0.0	0.0	0.0		0	8
25.317	0.0	0.0	8	1	0.11999994D+01	0.15053180D+01	0.40100000D-02	0.14864080D+01	0.50660000D-02	31	-189	0	8
			9	3	0.0	0.0	0.0	0.0	0.0	0.0		0	9
25.317	0.0	0.0	9	1	0.13999995D+01	0.15729500D+01	0.76290000D-02	0.15389730D+01	0.75140000D-02	28	21	0	9
			10	3	0.0	0.0	0.0	0.0	0.0	0.0		0	10
25.318	0.0	0.0	10	1	0.11999994D+01	0.15053180D+01	0.40100000D-02	0.14864080D+01	0.50660000D-02	31	-189	0	10
			11	3	0.0	0.0	0.0	0.0	0.0	0.0		0	11
25.318	0.0	0.0	11	1	0.12577623D+01	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	11
			12	3	-0.32075273D-03	0.0	0.0	0.0	0.0	0.0		0	12
25.318	-0.026	0.0	12	9	0.17874211D+01	0.14758040D+01	0.39590000D-02	0.14574120D+01	0.50660000D-02	21	-239	0	12
			13	3	-0.94556988D-02	0.0	0.0	0.0	0.0	0.0		0	13
25.321	-0.761	0.0	13	1	0.44193929D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	13
			14	3	0.0	0.0	0.0	0.0	0.0	0.0		0	14
20.615	0.0	0.0	14	1	0.50000044D+00	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	14
			15	3	0.0	0.0	0.0	0.0	0.0	0.0		0	15
20.563	0.0	0.0	15	1	0.20569441D+01	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	15
			16320		-0.42970432D-02	0.0	0.12050741D-01	0.57388160D-01	0.14122085D+00	0.0		1	16
20.073	-0.217	0.0	16	2	-0.14783643D-03	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	16
			16	*2	-0.30708221D-03	*SYSTEM WAS REFOCUSED FOR SECONDARY MEAN WAVELENGTH ANALYSIS							

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM. TERMINATION WAS NORMAL.

Table 5

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OPTICAL OPTIMIZATION RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

RN* 3  315-INCH F/1.2 PARABOLA CORRECTED TO F/6.5 AT (F/6.3?) CASS FOC

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 2047.500 INCHES          RMS IMAGE(S) TYP DIAM= 40.4 +/- 16.1 MICRONS
              OBJECT DISTANCE= INFINITY                                                              0.16 +/- 0.06 ARC SEC
              APERTURE RADIUS=  157.50 INCHES   FIELD RADIUS= 20.00 ARC MIN   MAX RMS LATERAL COLOR= 28.3 MICRONS ( 0.11 ARC SEC)

                                NNE,CRV,  5ASC,NNA
CLR DIA     SAG    ASPH   NS   NSE,X,4RN,2ICR,NSA   WAVLEN(MI)       PASBN(F-C)       WAV2ND(MI)       PA2BN(F-C)       WGHT(%)          NS
                           C   0                    0.35666          1.69840          0.61978          2.02314          76.42          0  C
315.000    0.0    0.0      1   0  0.0               0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  2  1

                           2   3 -0.13227513D-02 -0.10000000D+01   0.0              0.0              0.0              0.0            0  2
316.718 -16.586 0.0457     2   8 -0.30435260D+03 -0.10000000D+01   0.0             -0.10000000D+01   0.0                  0        0  0  2

                           3   3 -0.54767486D-02 -0.21785866D+01   0.0              0.0              0.0              0.0            0  3
 65.933  -2.948 0.0129     3   9  0.30719866D+03  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0  3

                           4   3  0.38849651D-01  0.0              0.0              0.0              0.0              0.0            0  4
 30.777   5.106 0.0        4   1  0.35000006D+01  0.14758040D+01   0.39590000D-02   0.14574120D+01   0.50660000D-02      21     -239  0  4

                           5   3  0.33240927D-01  0.0              0.0              0.0              0.0              0.0            0  5
 29.594   3.891 0.0        5   1  0.40683783D+01  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0  5

                           6   3  0.22913295D-01  0.0              0.0              0.0              0.0              0.0            0  6
 28.918   2.465 0.0        6   1  0.11091545D+01  0.14758040D+01   0.39590000D-02   0.14574120D+01   0.50660000D-02      21     -239  0  6

                           7   3  0.40870968D-01  0.0              0.0              0.0              0.0              0.0            0  7
 27.792   4.329 0.0        7   9  0.60000001D+01  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0  7

                           8   3  0.0             0.0              0.0              0.0              0.0              0.0            0  8
 27.845   0.0   0.0        8   1  0.12000008D+01  0.15053180D+01   0.40100000D-02   0.14864080D+01   0.50660000D-02      31     -189  0  8

                           9   3  0.0             0.0              0.0              0.0              0.0              0.0            0  9
 27.868   0.0   0.0        9   1  0.13999986D+01  0.15729500D+01   0.76290000D-02   0.15389730D+01   0.75140000D-02      28       21  0  9

                          10   3  0.0             0.0              0.0              0.0              0.0              0.0            0 10
 27.895   0.0   0.0       10   1  0.12000008D+01  0.15053180D+01   0.40100000D-02   0.14864080D+01   0.50660000D-02      31     -189  0 10

                          11   3  0.0             0.0              0.0              0.0              0.0              0.0            0 11
 27.919   0.0   0.0       11   1  0.16766050D+01  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0 11

                          12   3 -0.27998178D-02  0.0              0.0              0.0              0.0              0.0            0 12
 27.960  -0.274 0.0       12   9  0.17840315D+01  0.14758040D+01   0.39590000D-02   0.14574120D+01   0.50660000D-02      21     -239  0 12

                          13   3 -0.99615764D-02  0.0              0.0              0.0              0.0              0.0            0 13
 28.008  -0.982 0.0       13   1  0.52611804D+02  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0 13

                          14   3  0.0             0.0              0.0              0.0              0.0              0.0            0 14
 24.674   0.0   0.0       14   1  0.49999950D+00  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0 14

                          15   3  0.0             0.0              0.0              0.0              0.0              0.0            0 15
 24.643   0.0   0.0       15   1  0.21035364D+01  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0 15

                          16320 -0.62069709D-02  0.0              0.15332903D-01   0.73043914D-01   0.18036663D+00   0.0            1 16
 24.183  -0.454 0.0       16   2 -0.39106709D-02  0.10000000D+01   0.0              0.10000000D+01   0.0                  0        0  0 16
                          16  *2 -0.40785580D-02 *SYSTEM WAS REFOCUSED FOR SECONDARY MEAN WAVELENGTH ANALYSIS

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM.  TERMINATION WAS NORMAL.
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OPTICAL OPTIMIZATION RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

Table 6

RN* 4 CARNEGIE F/6.258 ALL-REFRACTING BROADBAND COLLIMATOR MODEL02

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 1971.151 INCHES
OBJECT DISTANCE= INFINITY
APERTURE RADIUS= 157.50 INCHES FIELD RADIUS= 5.00 ARC MIN

RMS IMAGE(S) TYP DIAM=101.8 +/- 42.0 MICRONS
0.42 +/- 0.17 ARC SEC
MAX RMS LATERAL COLOR= 75.3 MICRONS (0.31 ARC SEC)

CLR DIA	SAG	ASPH	NS	NNE / NSE	CRV, 5ASC,NNA / X,4RN,2ICR,NSA	WAVLEN(MI)	PASBN(F-C)	WAV2ND(MI)	PA2BN(F-C)	WGHT(%)			NS
			C	0		0.34795	1.99672	0.65506	1.74588	60.98		0	C
315.000	0.0	0.0	1	0	0.0	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	1
			2	3	-0.13227516D-02	-0.10000000D+01	0.0	0.0	0.0	0.0		0	2
316.575	-16.571	0.0456	2	8	-0.30441396D+03	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	2
			3	3	-0.54917658D-02	-0.21742424D+01	0.0	0.0	0.0	0.0		0	3
63.066	-2.707	0.0108	3	8	0.38372772D+03	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	3
			4	3	0.0	0.0	0.0	0.0	0.0	0.0		0	4
5.857	0.0	0.0	4	1	0.32832110D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	4
			5	3	-0.78340341D-01	0.0	0.64934263D-04	0.78812528D-06	0.0	0.0		0	5
11.348	-1.237	0.0249	5	9	0.53238821D+00	0.15660830D+01	0.52890000D-02	0.15372520D+01	0.61410000D-02	56	6	0	5
			6	3	-0.28533015D-01	0.0	0.13742277D-04	0.26421231D-06	0.0	0.0		0	6
11.870	-0.478	0.0085	6	9	0.82894790D-01	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	6
			7	3	0.64159994D-01	0.0	0.0	0.0	0.0	0.0		0	7
12.762	1.366	0.0	7	1	0.15002116D+01	0.15830840D+01	0.80150000D-02	0.15406770D+01	0.77000000D-02	-156	515	0	7
			8	3	0.76020592D-01	0.0	0.0	0.0	0.0	0.0		0	8
12.661	1.623	0.0	8	1	0.30036578D+01	0.14468730D+01	0.27460000D-02	0.14325680D+01	0.32750000D-02	-30	87	0	8
			9	3	-0.34984668D-01	0.0	0.0	0.0	0.0	0.0		0	9
12.695	-0.714	0.0	9	1	0.72160337D+00	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	9
			10	3	0.80274023D-02	0.0	0.0	0.0	0.0	0.0		0	10
12.475	0.156	0.0	10	1	0.15018299D+01	0.14468730D+01	0.27460000D-02	0.14325680D+01	0.32750000D-02	-30	87	0	10
			11	3	-0.42489431D-01	0.0	0.0	0.0	0.0	0.0		0	11
12.406	-0.832	0.0	11	1	0.16990830D+01	0.14772350D+01	0.38970000D-02	0.14564050D+01	0.51590000D-02	35	-214	0	11
			12	3	-0.19433409D-01	0.0	0.13418609D-03	0.32771025D-06	0.0	0.0		0	12
12.141	-0.161	0.0515	12	9	0.39135127D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	12
			13	3	0.0	0.0	0.0	0.0	0.0	0.0		0	13
6.075	0.0	0.0	13	1	0.75091458D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	13
			14	3	-0.13317094D-01	0.0	0.0	0.0	0.0	0.0		0	14
17.674	-0.522	0.0	14	1	-0.37545722D+02	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	14
			15	320	-0.26634188D-01	0.0	0.81209427D-03	0.17345462D-02	0.30149353D-02	0.0		-1	15
5.740	-0.110	0.0	15	2	-0.17406883D-02	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	15
			15	*2	-0.10189861D-01	*SYSTEM WAS NOT REFOCUSED FOR SECONDARY MEAN WAVELENGTH ANALYSIS							

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM. TERMINATION WAS NORMAL.

Table 7

OPTICAL OPTIMIZATION RUN----PROGRAM OARSA(01/11/89 VERSION)----EPPS/ASTRONOMY/UCLA

RN* 3 COLUMBUS F/5.20 ALL-REFRACTING BROADBAND COLLIMATOR MODEL01

FINAL SYSTEM: SCALED TO DABS(GAUSSIAN FOCAL LENGTH)= 1638.000 INCHES   RMS IMAGE(S) TYP DIAM= 98.6 +/- 37.7 MICRONS
OBJECT DISTANCE= INFINITY   0.49 +/- 0.19 ARC SEC
APERTURE RADIUS= 157.50 INCHES   FIELD RADIUS= 5.00 ARC MIN   MAX RMS LATERAL COLOR= 51.5 MICRONS (0.26 ARC SEC)

CLR DIA	SAG	ASPH	NS	NNE,CRV, 5ASC,NNA NSE,X,4RN,2ICR,NSA		WAVLEN(MI)	PASBN(F-C)	WAV2ND(MI)	PA2BN(F-C)	WGHT(%)			NS
			C	0		0.65506	1.74588	0.34795	1.99672	39.02		0	C
315.000	0.0	0.0	1	0	0.0	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	1
			2	3	-0.13227516D-02	-0.10000000D+01	0.0	0.0	0.0	0.0		0	2
316.575	-16.571	0.0456	2	8	-0.29362495D+03	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	2
			3	3	-0.45584054D-02	-0.25600000D+01	0.0	0.0	0.0	0.0		0	3
72.261	-2.945	0.0125	3	8	0.36562494D+03	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	3
			4	3	0.0	0.0	0.0	0.0	0.0	0.0		0	4
4.876	0.0	0.0	4	1	0.26791008D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	4
			5	3	-0.13809424D+00	0.0	0.24795188D-03	-0.25442735D-05	0.0	0.0		0	5
9.983	-1.881	0.0181	5	9	0.44240742D+00	0.15372520D+01	0.61410000D-02	0.15660830D+01	0.52890000D-02	6	56	0	5
			6	3	-0.99665655D-01	0.0	0.67894450D-04	-0.40460849D-05	0.0	0.0		0	6
10.537	-1.529	0.0273	6	9	0.12392060D+01	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	6
			7	3	0.56213719D-01	0.0	0.0	0.0	0.0	0.0		0	7
11.975	1.038	0.0	7	1	0.12466556D+01	0.15406770D+01	0.77000000D-02	0.15830840D+01	0.80150000D-02	515	-156	0	7
			8	3	0.75433510D-01	0.0	0.0	0.0	0.0	0.0		0	8
11.916	1.414	0.0	8	1	0.24959991D+01	0.14325680D+01	0.32750000D-02	0.14468730D+01	0.27460000D-02	87	-30	0	8
			9	3	-0.54725619D-01	0.0	0.0	0.0	0.0	0.0		0	9
11.925	-1.000	0.0	9	1	0.48075245D+00	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	9
			10	3	0.24197039D-01	0.0	0.0	0.0	0.0	0.0		0	10
11.505	0.402	0.0	10	1	0.14507995D+01	0.14325680D+01	0.32750000D-02	0.14468730D+01	0.27460000D-02	87	-30	0	10
			11	3	-0.44134930D-01	0.0	0.0	0.0	0.0	0.0		0	11
11.419	-0.731	0.0	11	1	0.10000006D+01	0.14564050D+01	0.51590000D-02	0.14772350D+01	0.38970000D-02	-214	35	0	11
			12	3	0.13227121D-01	0.0	0.18516611D-03	-0.35389118D-07	0.0	0.0		0	12
10.954	0.364	0.0410	12	9	0.32163681D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	12
			13	3	0.0	0.0	0.0	0.0	0.0	0.0		0	13
6.094	0.0	0.0	13	1	0.62399988D+02	0.10000000D+01	0.0	0.10000000D+01	0.0	0	0	0	13
			14	3	-0.16025644D-01	0.0	0.0	0.0	0.0	0.0		0	14
15.730	-0.498	0.0	14	1	-0.31199988D+02	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	14
			15320		-0.32051288D-01	0.0	0.75915926D-03	0.12067460D-02	0.22758387D-02	0.0		-1	15
4.764	-0.091	0.0	15	2	-0.69549680D-02	-0.10000000D+01	0.0	-0.10000000D+01	0.0	0	0	0	15
			15	*2	-0.17049610D-02	*SYSTEM WAS NOT REFOCUSED FOR SECONDARY MEAN WAVELENGTH ANALYSIS							

NOTICE: END OF COMPUTATIONS FOR THIS SYSTEM. TERMINATION WAS NORMAL.

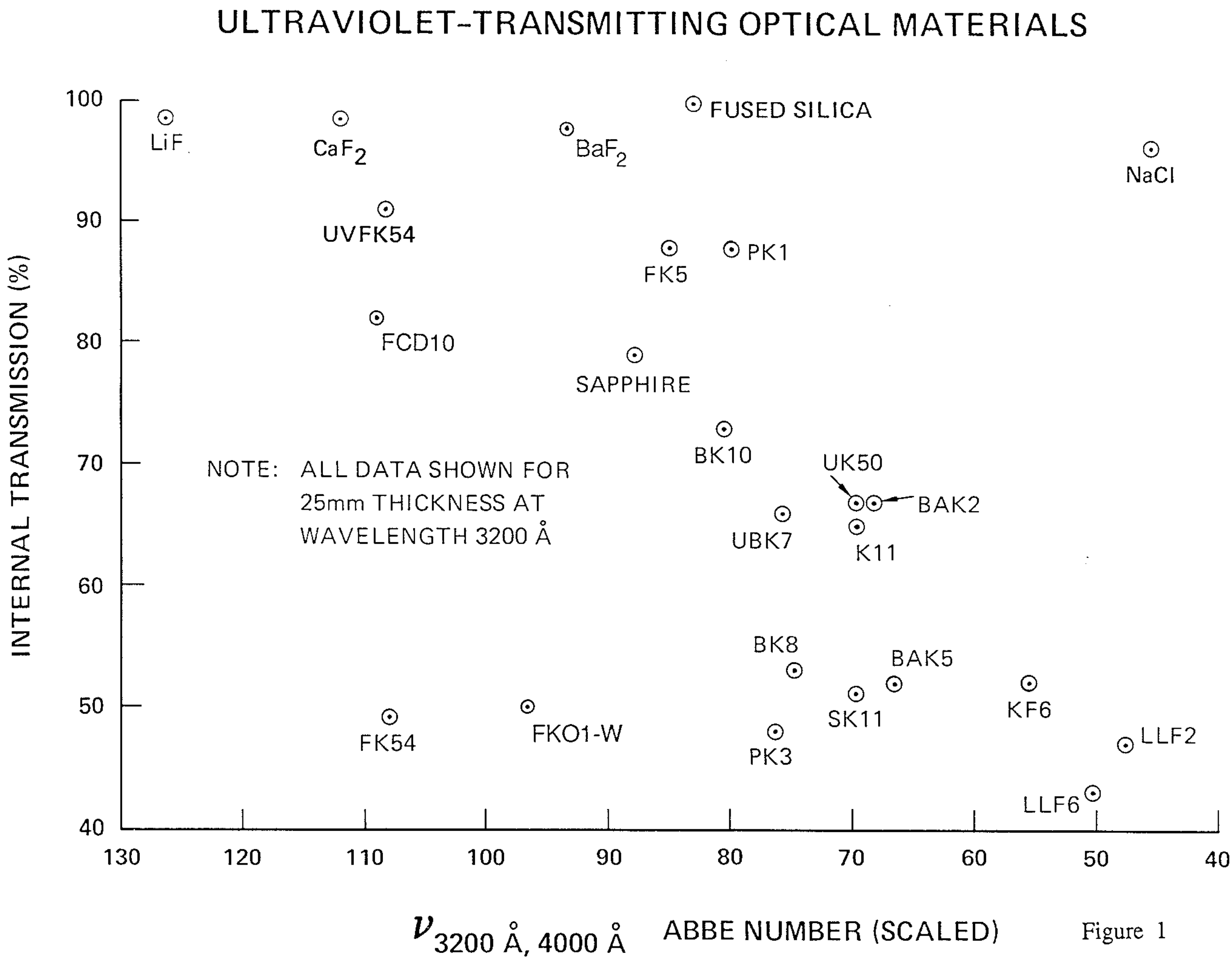

ULTRAVIOLET-TRANSMITTING OPTICAL MATERIALS
INTERNAL TRANSMISSION (%)
100
90
80
70
60
50
40
130
120
110
100
90
80
70
60
50
40
LiF
CaF2
BaF2
FUSED SILICA
NaCl
UVFK54
FK5
PK1
FCD10
SAPPHIRE
BK10
UK50
BAK2
UBK7
K11
NOTE: ALL DATA SHOWN FOR
25mm THICKNESS AT
WAVELENGTH 3200 Å
BK8
BAK5
KF6
FK54
FKO1-W
SK11
PK3
LLF2
LLF6
ν 3200 Å, 4000 Å ABBE NUMBER (SCALED)

Figure 1

EPPS/ASTRONOMY/UCLA
RUN No. 5350 (10/04/87)
(3200 Å to 11000 Å) WITHOUT REFOCUS
ALL DIMENSIONS IN INCHES

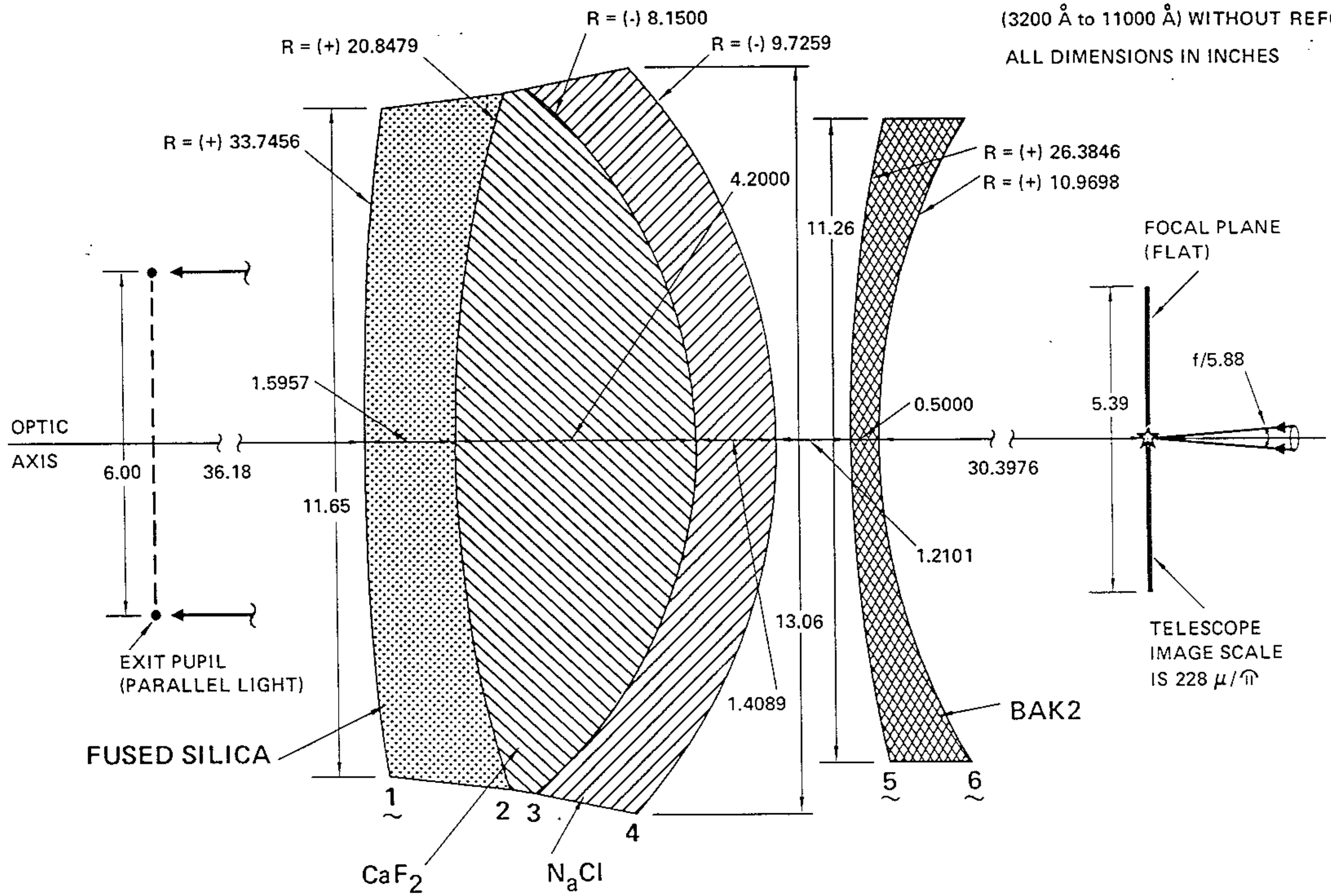


Figure 2

1 ASPHERIC

$A_2 = 0.0$

$A_4 = -2.9392946 \times 10^{-4}$

$A_6 = -3.8156317 \times 10^{-6}$

5 ASPHERIC

$A_2 = 0.0$

$A_4 = 1.1984252 \times 10^{-4}$

$A_6 = 1.6773935 \times 10^{-6}$

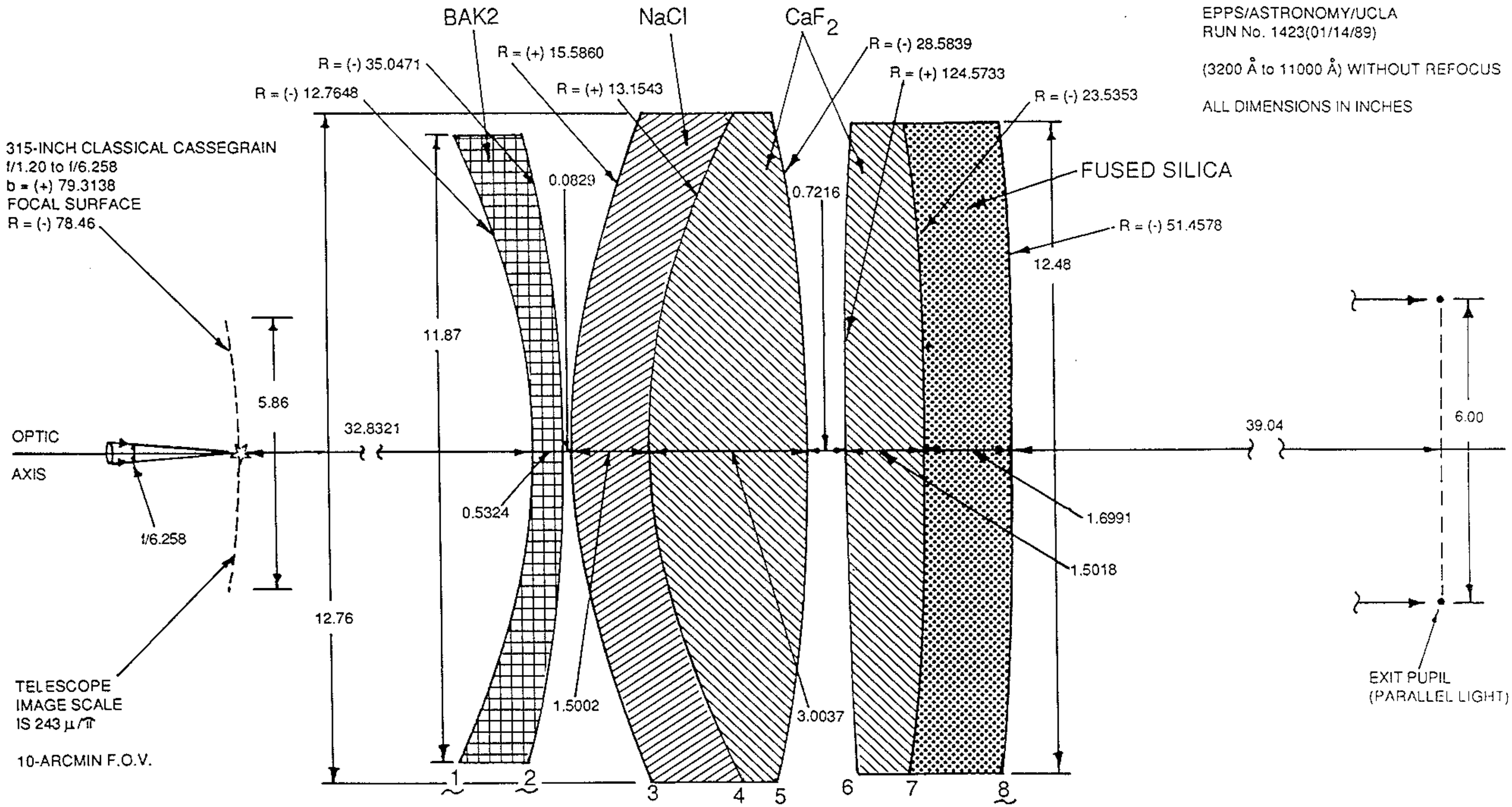
6 ASPHERIC

$A_2 = 0.0$

$A_4 = 7.1826913 \times 10^{-5}$

$A_6 = -8.3448271 \times 10^{-7}$

MAGELLAN TELESCOPE: 6.0 - INCH f/5.88 WIDE-FIELD (DISTANT EXIT PUPIL) COLLIMATOR



1 ASPHERIC (MAD = 0.0249)

$A_2 = 0.0$

$A_4 = 6.4934263 \times 10^{-5}$

$A_6 = 7.8812528 \times 10^{-7}$

2 ASPHERIC (MAD = 0.0085)

$A_2 = 0.0$

$A_4 = 1.3742277 \times 10^{-5}$

$A_6 = 2.6421231 \times 10^{-7}$

8 ASPHERIC (MAD = 0.0515)

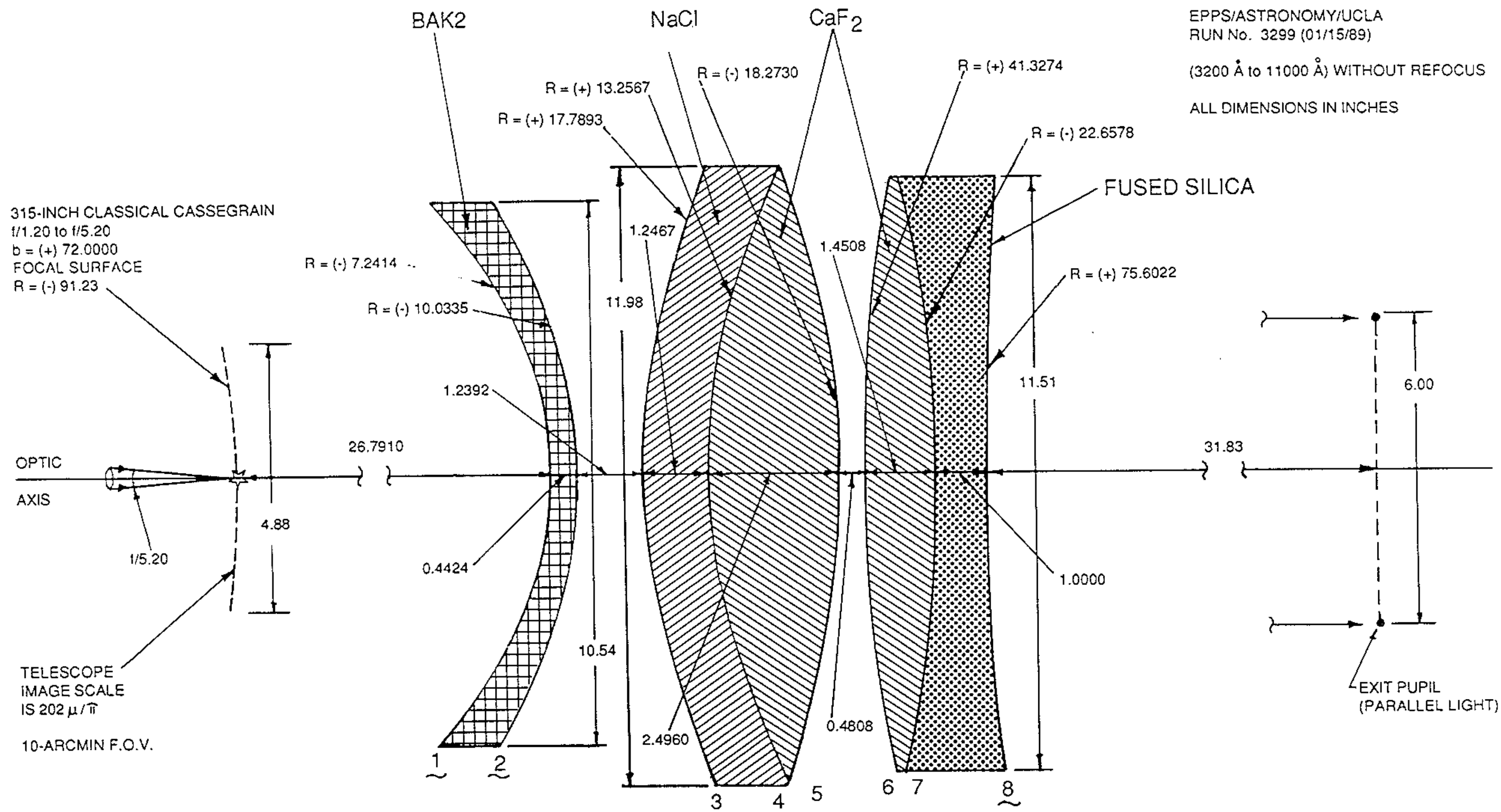
$A_2 = 0.0$

$A_4 = 1.3418609 \times 10^{-4}$

$A_6 = 3.2771025 \times 10^{-7}$

MAGELLAN TELESCOPE: WIDE-FIELD f/6.258 COLLIMATOR WITH DISTANT 6.00 - INCH EXIT PUPIL

Figure 3



1 ASPHERIC (MAD = 0.0181)

$A_2 = 0.0$

$A_4 = 2.4795188 \times 10^{-4}$

$A_6 = -2.5442735 \times 10^{-6}$

2 ASPHERIC (MAD = 0.0273)

$A_2 = 0.0$

$A_4 = 6.7894450 \times 10^{-5}$

$A_6 = -4.0460849 \times 10^{-6}$

8 ASPHERIC (MAD = 0.0410)

$A_2 = 0.0$

$A_4 = 1.8516611 \times 10^{-4}$

$A_6 = -3.5389118 \times 10^{-8}$

COLUMBUS TELESCOPE: WIDE-FIELD f/5.20 COLLIMATOR WITH DISTANT 6.00 - INCH EXIT PUPIL Figure 4

Magellan/Columbus All-Refracting Collimators
(6-Inch Beam)

Polychromatic Images:
(Wavelengths = 0.32, 0.35, 0.39, 0.46, 0.57, 0.72, 0.90, 1.10 Microns)

* { RMS Image Diameter (Arcsec)
Encircled Energy Within 1/2 Arcsec (%)
Spectroscopic Mode (1.0 Arcsec Square) Slit Loss (%) }

f/6.26 Run No. 1423 (01/14/89) | f/5.20 Run No. 3299 (01/15/89)

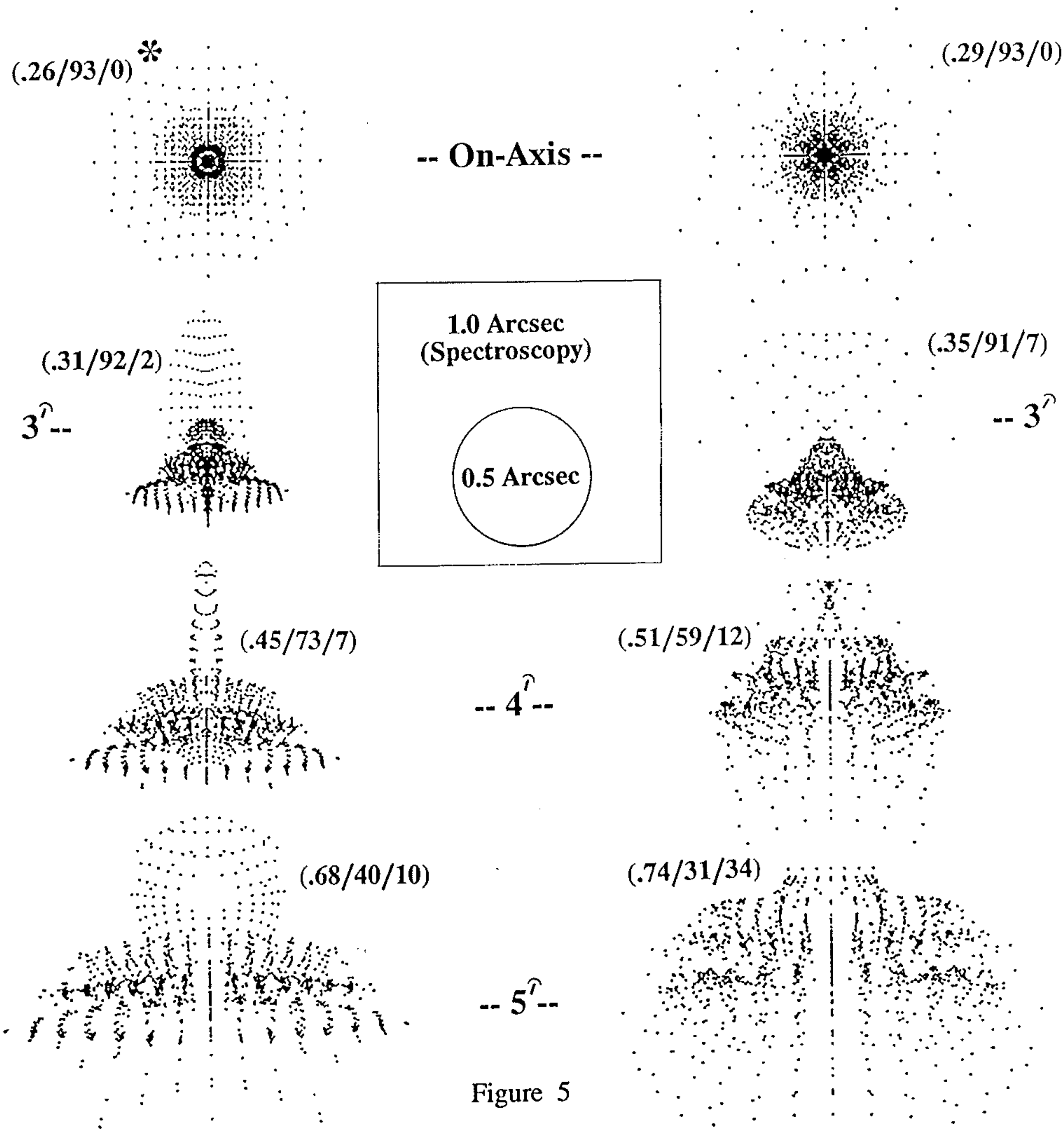


Figure 5

EPPS/ASTRONOMY/UCLA
RUN NO. 9905 (09/09/88)

(0.38 TO 1.00) MICRONS WITHOUT REFOCUS
BEAM SIZE: (5.5 BY 7.1)-INCH ELLIPSE

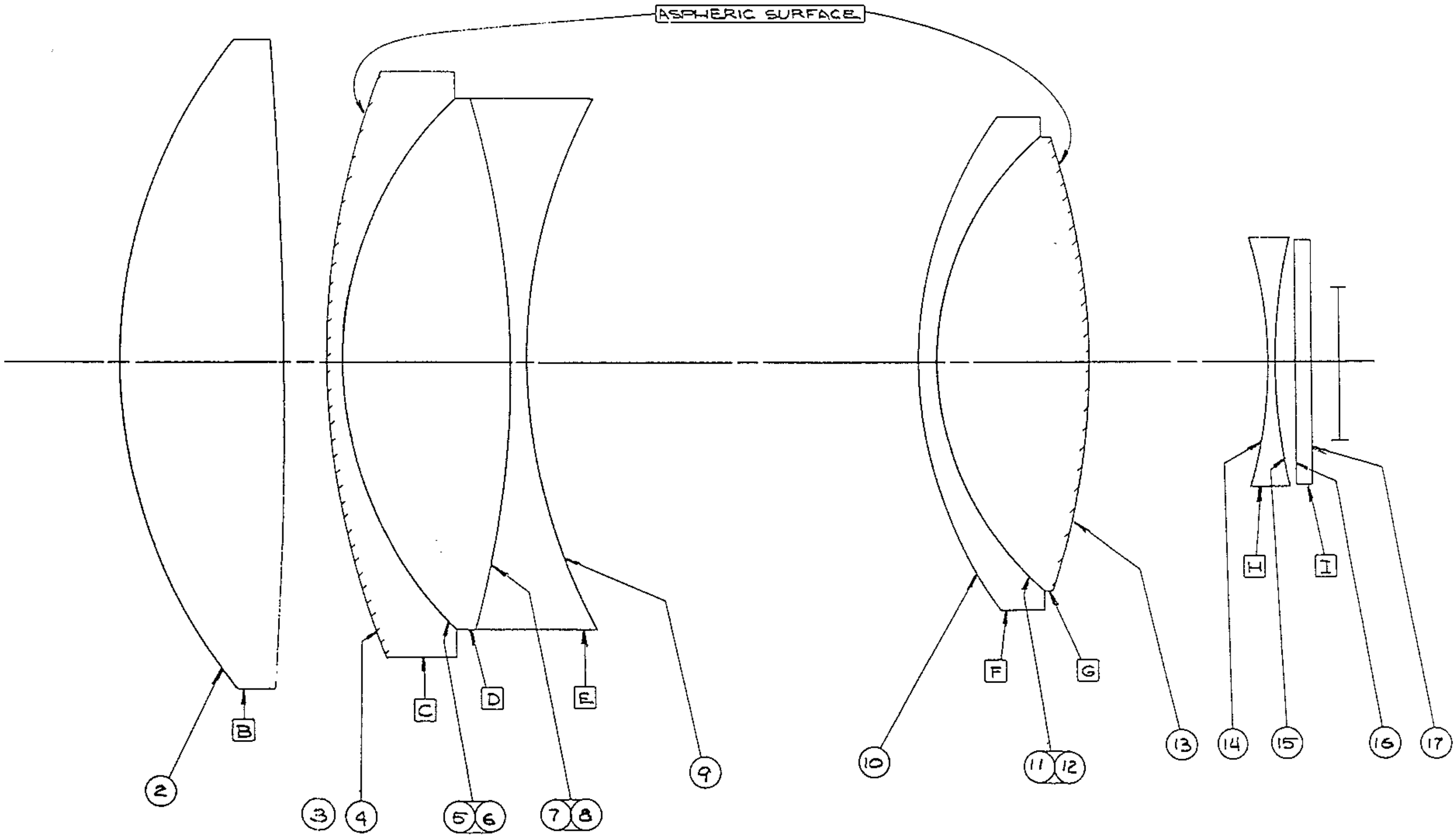


Figure 6

KECK TELESCOPE: 12.0-INCH FOCAL LENGTH BROADBAND CAMERA FOR LRIS SPECTROMETER