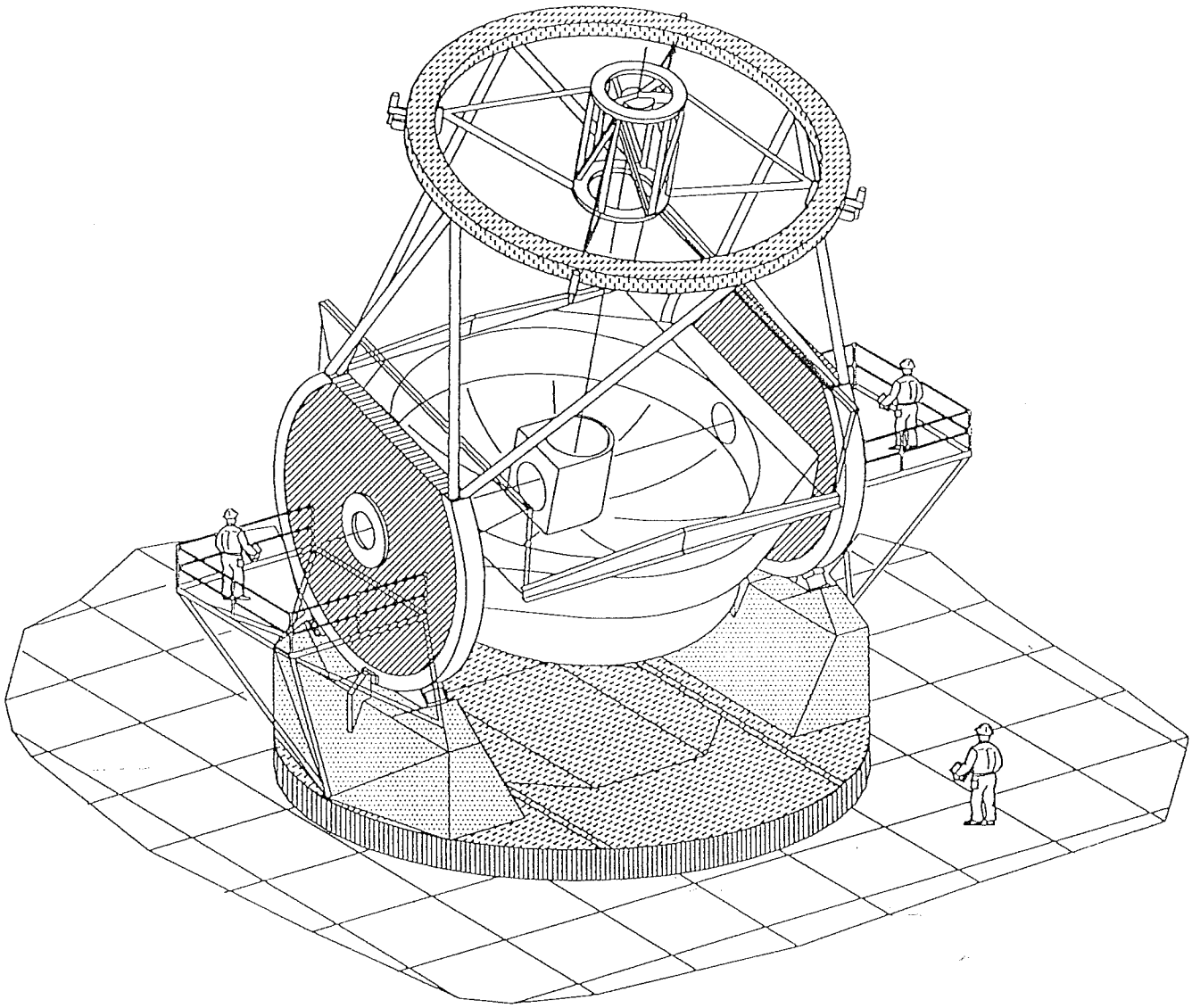

System Specifications for the 6.5-Meter Magellan Telescope

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Title: Technical Specifications for the Magellan 6.5 Meter Telescope

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.1 Section 5.3: Revise bandwidth specification for vane actuators.

.2 Section 3: Revise f/15 error budget and description.

.3 Section 8: Delete text. Guider specifications under review.

.4 Section 9.0: The area of enclosure vent openings is 9 sq. meters.

CONTENTS

1. General

The Magellan 6.5 M Telescope will be located at Las Campanas Observatory, Chile. The telescope is an alt-azimuth design as depicted on the cover. The principal foci will be f/11 at the two Nasmyth locations and f/15 in the Cassegrain position. The f/11 ports will be used for visible light astronomy and the f/15 for IR observations. In addition, three auxiliary f/11 ports will be provided on the center section. An ADC corrector will be available for f/11 use to provide unvignetted fields up to 24 arcminute. Platforms on either side will provide access to the instruments at the Nasmyth ports.

The telescope and enclosure are designed to minimize image degradation due to thermal effects. Separate ventilation systems for the enclosure, telescope structure, and primary mirror will maintain surfaces within the dome at the outside air temperature during night time observing.

Active controls are incorporated in the telescope optics. The mirrors will have position control for alignment. These will be active during observing. Figure control of the primary mirror will be used to correct low order aberrations in the optical system. In addition, both secondary mirrors have tip-tilt mechanisms for fast guiding. The f/15 secondary tip-tilt will also be used for chopping applications.

The plan for night time operation of the Observatory is the traditional model with the telescope operator and scientist on site.

2. Optical Design

The optical configurations of the telescope are shown in Figures 1-3. Two interchangeable secondary mirrors are provide a choice of system focal ratios of f/11 or f/15. An f/5 secondary is a future option.

The f/11 configuration is used at the two Nasmyth and three auxiliary ports on the optics support structure (OSS) and is intended primarily for observing in visible wavelengths. The tertiary mirror rotates on a turret to direct the beam to the selected port.

Each of the f/11 foci can be configured for wide-field use by inserting a corrector in the beam. The corrector includes atmospheric dispersion compensation (ADC). Use of the corrector shifts the optimum focal surface approximately 115 mm towards the tertiary mirror.

The f/15 secondary is used in a classical Cassegrain configuration with the focus behind the primary mirror. The secondary mirror is undersized with respect to the baffle mounted above the primary mirror and acts as the system stop. The amount of under sizing allows chopping the beam without vignetting by the primary mirror. The mirror will be polished out to its edge to reduce scattered light in the beam. A reflective cone will be mounted in the center of the mirror to eliminate the reflected view of the tertiary mirror and instrument as seem by the detector.

The following sections give the optical specifications subject to manufacturing tolerances.

2.1 Primary mirror

Diameter:	6,502.4 mm
Focal Length:	8128.0 mm
Shape:	Paraboloid
Coating:	Bare Aluminum
Focal ratio (ref.):	1.25

Entrance stop distance above primary vertex:	325 mm
Entrance stop diameter:	6478.4 mm

2.2 f/11 Narrow field

Design number:	950316
Diagram:	Figure 1.
Optical Prescription:	Appendix A.
Transmissive elements:	None.
Final focal ratio:	f/11.0
Nominal corrected field of view:	6 arc-min.
Unvignetted field of view:	24 arc-min.
Central obscuration (area):	7.4%
Secondary mirror coating:	Bare Aluminum
Focal length:	71,526 mm
Scale:	0.347 mm/arc-sec.
Focal surface curvature (concave away from M2):	1,519 mm
Distortion at 3 arcminute field angle:	0.005%

2.3 f/11 Wide Field with ADC

Design number:	950602
Diagram:	Figure 2.
Optical Prescription:	Appendix B.
Final focal ratio:	f/10.97
Unvignetted/corrected field of view:	24 arc-min.
Vignetting @ 15 arc-minute field angle:	9%
Central obscuration (area):	7.4%
ADC cut-off (50% transmission):	330 nm
Focal length:	71,089 mm
Scale:	0.345 mm/arc-sec.
Focal surface curvature (concave away from M2):	1,231 mm

Distortion at 12 arc-minute field angle (λ 500 nm):	0.12%

2.4 f/15 Infrared

Design number:	950317
Diagram:	Figure 3.
Optical Prescription:	Appendix C.
System stop:	Secondary mirror
Final focal ratio (with undersized secondary mirror):	f/15
Corrected field of view:	6 arc-min.
Secondary mirror coating:	Over-coated silver.
Focal length:	95,028 mm
Scale:	0.461 mm/arc-sec.
Focal surface curvature (concave towards M2):	831 mm
Field distortion @ 3 arc-minute field angle:	0.83%

3. Image size budget

The image size budgets set the imaging goals for the telescope and pre-allocate limits to the sources of image degradation.. As the design of the telescope progresses, allocations will be adjusted as necessary with the overall goal of keeping the total budget constant. Tables 1 and 2 give the f/11 wide-field and f/15 infrared budgets. The wavelength and field angles over which the budgets apply are noted in the tables. Additional conditions are discussed below.

The f/11 image sizes are specified in arcseconds 80% enclosed energy diameters at 500 nm. Specifying the budget this way avoids the problem that an image with broad wings can have an acceptable half width but unacceptable energy concentration. The conversion to RMS and FWHM diameters depends on the shape of the point spread function. For a Gaussian profile, a 1.0 arc-second 80% ee diameter has a 0.67 arc-second FWHM and 0.78 RMS diameter.

The f/15 optics budget is tabulated in RMS wavefront error. At wavelengths longer than 2 microns the telescope optics approach diffraction limited. In this case, RMS errors are more directly related to the optics specifications. The error budget for the primary mirror was derived from past polishing and support experience with the 3.5 meter telescopes and the thermal and wind error budgets from "Mirror Support System for Large Honeycomb Mirrors II" (UA-95-02). This approach gets around difficulties in translating polishing and support errors from the structure functions used by U. Arizona and recognizes the fact that low spatial frequency errors allowed by the structure function formalism will be canceled with the active supports.

The contribution to image size from atmospheric seeing grows as $(\cos z)^{-3/5}$ where z is the zenith distance. The image budgets for the telescope and enclosure are allowed to increase according to the same law up to 60° zenith distance and remain constant below 60° to the lower observing limit.

The environmental conditions under which the image budget applies are:

- night time observing,

- wind speeds up to 22 m/sec. and
- outside air temperature gradients less than 0.5°C/hour.

The error budget assumes that the following systems are operating:

- Closed loop (fast) guiding.
- Closed loop focus control.
- Active collimation and M1 figure control using corrections from elevation angle look-up tables.
- Primary mirror thermal controls.
- Mount and enclosure ventilation systems.

The median and lower quartile image sizes in the visible spectrum due to seeing at the Magellan site are about 0.59 and 0.44 arc-seconds FWHM respectively. The image sizes allowed by the f/11 error budget will degrade these by approximately 7% and 13%.

4. Telescope Motions

4.1 Azimuth and Elevation Ranges

Azimuth Observing Range:	±255° about 90° True Azimuth.
Altitude Observing Range:	0.5° to 80° zenith distance.
Zenith blind spot:	1.0° diameter

4.2 Slew Accelerations and Rates

Slewing:

Max. Azimuth Acceleration:	+/- 0.2 °/sec^2
Max. Azimuth Rate:	+/- 2.0 °/sec
Max. Altitude Acceleration:	+/- 0.1 °/sec^2
Max. Altitude rate:	+/- 1.0 °/sec

Momentary accelerations and rates may exceed theses limits when necessary to maintain servo control.

4.3 Times to Reposition the Telescope

The time to reposition the telescope is defined as the time to move between two positions within the azimuth and elevation observing ranges ending up with the telescope pointing and tracking within specifications. The time to reposition shall not exceed the following:

Offsets up to 0.5° and $\Delta Az < 1°$:	5 seconds.
Offsets up to 10° and $\Delta Az < 20°$:	20 seconds.

Between any two allowed positions: 190 seconds worst case.

Worst case includes the situation where the azimuth is required to rotate 360° to avoid cable wrap-up.

4.4 Absolute Pointing and Offsetting

Pointing accuracy:

Offsets $\leq$ 1 degree:	$\leq$ 0.2 arc-sec. rms
Offsets > 1 degree:	$\leq$ 1 arc-sec. rms
Offsets > 10 degrees:	$\leq$ 2 arc-sec. rms

4.5 Tracking

The telescope will track unguided to 0.03 arc-second RMS or better for 1 minute of time. The maximum excursion shall not exceed 0.15 arc-second within this interval. This specification applies to the operation of the complete telescope system during normal operation in the absence of wind and includes pointing errors due to active optics adjustment.

The telescope shall meet the tracking specifications for the following range of track rates:

Azimuth Track Rates:	-0.4°/sec to +0.4°/sec.
Altitude Track Rates:	-15 to +15 arc-sec./sec

4.6 Instrument rotators

Instrument rotators are provided on the Cassegrain and Nasmyth ports to compensate for field rotation during tracking. Specifications for mounting instruments on the rotators are given in section 6.

Rotation range from the center stow position:	$\pm$ 179.5°
Rotation rate:	-5°/sec. to +5°/sec.
Ramp rate:	-1°/sec^2 to +1°/sec^2
Accuracy:	$\pm$ 5 arc-sec.

5. Active Controls

The mirror supports will include active controls to maintain optical alignment, correct for mechanical and thermal support errors, and provide fast guiding. These consist of:

- 3 axis (tip/tilt/piston) control of the primary mirror for initial alignment and to compensate for gravity deflection.
- Force control in the primary mirror actuators to correct low-spatial frequency wavefront errors introduced by the mirror supports.
- 5 axis control of the secondary mirror position for collimation and focus.
- Independent tip/tilt motions on the f/11 and f/15 secondary mirrors for fast guiding.

- 3 axis (tip/tilt/piston) control of the tertiary mirror position for active alignment.

Adaptive systems to correct for higher order atmospheric seeing are not included in the baseline requirements.

5.1 Primary Mirror Position

The position of the primary mirror in its cell is defined by the six hardpoint struts. The strut lengths are encoded and can be remotely adjusted. During the initial collimation of the telescope optics the mirror will be centered in the telescope and the tilt adjusted to minimize coma at one elevation angle near the zenith. During operation, the hardpoint control will automatically maintain the mirror position with respect to the attachment points on the cell.

5.2 Primary Mirror Figure

The primary will be supported by an actively controlled set of force actuators that attach to the back plate of the mirror. Support forces will be applied by 166 pneumatic actuators acting at 104 locations. The forces will be controlled by varying the air pressure in the actuators. Load cells incorporated in the supports will provide feed back for the actuator servo control. The pattern of forces applied to the mirror will be varied to control the mirror shape.

The operation of the mirror figure control will be transparent to the user under normal observing conditions. The pattern of forces for a given elevation angle of the telescope will be interpolated from pre-determined tables in the control system. The user will have the option of updating these forces from wavefront measurements taken in the focal plane in order to obtain the highest quality images. This technique will also compensate for low spatial frequency errors in the secondary and tertiary mirrors for reasonably small fields-of-view.

5.3 Secondary Mirror Position

The secondary mirror attaches to a cage that is suspended in the telescope by vanes that reach out to the top ring of the upper telescope truss. The end nodes of the vanes include actuators that allow the entire secondary assembly to the translated and tilted. They provide focus and alignment adjustment for slowly varying structural changes.

During normal operation the system will continuously adjust to compensate for predictable motions due to elevation angle and structure temperature change. The amount to translate and tilt will be interpolated from look-up tables in the control system. The user will have the option of updating the look-up table values from focus and wavefront measurements.

The control bandwidth for vane actuator adjustments will be much slower than for guiding or fast steering.

5.4 f/11 Fast Steering

Linear actuators in the axial supports of the f/11 secondary mirror allow tip-tilt steering of the mirror for fast guiding. The guide bandwidth and amplitude are limited by mechanical resonances in the cell and coma respectively to the following values:

Bandwidth:	20 Hz.
Guide Range from the centered position:	±0.7 arc-sec
Total mechanical throw:	±3.1 arc-sec.

5.5 f/15 Chopping and Fast Steering

Chopping of the f/15 secondary mirror for background subtraction in the infrared and fast guiding will be provided by the Magellan Infrared Chopping Secondary (MICS) assembly. MICS consists of a lightweight SiC mirror and a

counterbalanced 2-axis tip/tilt mechanism. The MICS assembly will be permanently mounted in the secondary cage and will be inserted in front of the f/11 secondary mirror on a swing arm.

5.5.1 Chop performance

Chop performance will be limited by the acceleration permitted by the allowable power dissipation and reaction forces for a given combination of chop amplitude and frequency. The full chop range will be ± 32 arc-seconds about the centered position in any direction on the sky.

MICS will be capable of chopping with a throw of 20 arc-seconds on the sky at 3.2 Hz with an 80% duty cycle and 0.3 arc-second error band.

The mean of the dwell positions of the chop cycle will be repeatable to 0.02 arc seconds on the sky for 60 seconds of time and 0.1 arc-seconds for 60 minutes of time. The mean chop throw shall be repeatable to 0.02 arc-seconds over 60 minutes.

5.5.2 f/15 Fast Steering Performance

Two axis fast steering about the x and y axes will be possible over the full +/-32 arc-second range of the mirror from its centered position. MICS will settle to within 0.02 arc-second of the target position on the sky from a 0.1 arc-second step within 2 ms.

Pointing error feed-back will be provided by a guide sensor in the focal plane. The telescope control system will compute centroids and send motion control signals to the MICS assembly.

5.6 Tertiary Mirror

Actuators in the tertiary mirror cell mounts will allow remote adjustment of the mirror tilt and piston. LVDTs will measure its position. These will be used during initial optical alignment and during f/11 port changes to accommodate port-to-port alignment differences.

5.7 Atmospheric Dispersion Compensation

The Atmospheric Dispersion Compensator (ADC) is used at the Nasmyth and Folded Ports with the f/11 secondary mirror. The ADC consists of a pair of wedged doublet lenses rotated independently by a pair of stepper motors with encoders. The ADC may be inserted into or retracted out of the beam remotely with commands in the control system. The control system will automatically track the ADC during observing.

Atmospheric dispersion at Las Campanas Observatory as a function of zenith distance and wavelength relative to 500 nm is shown modeled in Figure 4. The ADC is optimized to correct dispersion for zenith distances up to 51.6°. Figure 5 shows the dispersion (before compensation) and residual color (after compensation) at ZD = 51.6° as a function of wavelength. The zero point of the vertical scale is arbitrary and can be shifted amounting, in effect, to a re-pointing the telescope.

6. Instrument mounting

6.1 Nasmyth Ports

Mounting surface (S): Drawing E330314/15.

Back focus distance from S:

Without corrector:	508.0 mm
With corrector:	390.8 mm

Beam clearance through rotator:	863.6 mm
Maximum instrument properties:	
Weight:	1,364 kg
Moment of inertia:	396 kg-m^2
Cantilever moment from S:	16,972 N-m
Imbalance about optical axis:	1,358 N-m
Envelope:	Figure 6

6.2 Cassegrain Port

Mounting surface (S):	Drawing E330310.
Back focus distance from S:	1,016 mm
Beam clearance through rotator:	863.6 mm
Maximum instrument properties:	
Weight:	1,364 kg.
Moment of inertia:	396 kg-m^2
Cantilever moment from S:	16,972 N-m
Imbalance about optical axis:	1,358 N-m
Envelope:	Figure 6

6.3 Folded Ports

Three instrument ports are provided on the center section of the Optics Support Structure for future development. Indexed positions of the tertiary mirror turret direct the beam out to the ports. Instruments at the folded ports will bolt directly to a flange on the telescope structure. Instrument rotators are not be provided.

Mounting surface (S):	
Interface drawing:	E330106/107 Sh. 1
Back focus distance from S:	
f/11 with corrector:	1,019 mm
f/11 without corrector:	1,133 mm
Unvignetted field of view (f/11):	
with corrector:	16.2 arcminute
without corrector:	15.7 arcminute

Because of special counterbalancing requirements at these ports their use should be coordinated with the observatory staff.

7. Thermal design

A number of strategies will be adopted to control thermally induced image blur ("dome seeing") within the telescope chamber. These include (a) employing lightweight structures to reduce thermal mass, (b) ventilating the telescope and enclosure to minimize the time it takes those structures to come to thermal equilibrium, (c) trapping and exhausting all sources of waste heat, and (d) the use of special coatings to radiationally decouple structure exposed to the cold night sky. Where possible, heated work areas will be located away from the telescope chamber. The heated control building adjacent to the telescope chamber will be thermally isolated from the rest of the enclosure.

The primary mirror requires its own thermal control to maintain internal temperature uniformity and prevent warping of the mirror. The design of this system will also ensure that the surface of the mirror tracks the ambient air and prevents mirror seeing. The design goals are 0.1° C uniformity and within +0.2°/-0.5° C of air temperature (Hill LBT Technical Memo UA-94-02) when the ambient air is changing by up to 0.25°C/hr.

Science instruments will be limited to 50W the amount of heat they may release in the telescope chamber. Chilled liquid and ducted ventilation systems will be available to remove excess instrument heat.

8. Guider Assembly

[This section intentionally left blank.]

9. Enclosure

The Magellan telescope enclosure consists of a fixed base and observing floor and a rotating dome. The observing floor is 4.6 m above ground level and the elevation axis of the telescope is 4.9 m above that. The telescope control room is off to the side of the observing floor. Access to the telescope and control room is via stairways from the ground level. A lift platform and jib hoists are provided to bring instruments and equipment to the telescope.

Bi-parting doors are incorporated in the rotating dome to provide an opening for viewing. A windscreen in the lower section of the opening shields the telescope against wind shake. A second screen ("the moonroof") can be deployed across the top of the opening to block moon light and provide additional wind protection. Both screens can be tracked with the telescope.

Twenty eight openings in the sides of the fixed and rotation parts of the enclosure provide wind-driven ventilation in the telescope chamber. Each opening has an area of 9 m^2. Motorized louvers in the openings control the flow. The ground floor of the enclosure outside of the telescope pier and control building is kept open to promote air flow under the telescope.

An auxiliary building located near the telescope enclosure contains facilities for mirror coating and other support functions. The primary mirror is brought to the coating plant on the second floor of the auxiliary building over a bridge between the two buildings at that level.

9.1 Dome specifications

Dome rotation:

Azimuth range:	Unlimited.
Rotation rate:	-3°/sec. to +3°/sec.
Minimum track speed:	0.03 °/sec

Maximum acceleration:	$0.4°/sec^2$
Positioning accuracy:	±0.28° p-v
Encoder resolution:	0.09°

Doors:

Unobstructed width open:	8.5 m
Distance from dome center:	11.7 m
Minimum unvignetted telescope elevation angle:	18°

10. Control System

The observatory will be controlled by an operator sitting at a workstation ("the Console") in the Control Room. A user interface running in a windows environment on the Console will provide control functions and status information to the operator. The Console will send control messages to the underlying Telescope Control System (TCS) and receive back position and status telemetry. In addition, status pages generated by the TCS and displayed on video monitors in the Control Room will provide the operator with a real-time display of the most frequently required information (e.g. time, telescope pointing, fault conditions) and guide camera images.

The scientist/observer sits at a second workstation in the control room and controls the Science Instrument. The operator's and observer's workstations are linked by the observatory LAN. Telescope status, observing lists, star catalogs, finder images, etc. are shared over the LAN. A second set of system status and guide camera monitors is provided for the observer. The science instrument is connected to the observer's workstation by the LAN or private bus. Additional instrument and data reduction workstations may be added to the LAN when necessary.

11. Site & Environmental

The 6.5-meter Magellan telescope will be located on Cerro Manqui at the Las Campanas Observatory, located approximately 150 km north of La Serena, Chile at Longitude -70° 42' W, Latitude -29° 0' S. The elevation at the site is 2,392 m above sea level.

11.1 Operating conditions

Operating conditions are:

Wind speed:

Peak outside free air:	22 m/s
Mean speed at telescope:	<6.6 m/s
Temperature:	-10°C to +25°C
Humidity:	95% non-condensing

Table 1a: f/11 Image Error Budget		80% Enclosed Energy		Revised:	10/11/01
Configuration:	f/11 Nasmyth				
Corrector:	Inserted				
ADC:	Operating				
Field of View:	24	arcmin.			
Active optics:	Operating				
Wind speed limit:	22	m/s			
Telescope elevation:	Zenith				
Wavelength	500	nm			
		80% ee (Arc-seconds)			
1. Optical Design	0.076				
1.1 Theoretical image size		0.076			
2. Optical Elements	0.278				
2.1 Primary mirror		0.239			
2.1.1 Figure			0.130		
2.1.2 Thermal			0.157		
2.1.2.1 Mirror seeing				0.120	
2.1.2.2 Distortion				0.101	
2.1.3 Support			0.113		
2.1.3.1 Actuator errors				0.080	
2.1.3.2 Active control				0.080	
2.1.4 Wind			0.040		
2.1.5 Ventillator vibration			0.030		
2.1.5 Coating			0.010		
2.2 Secondary Mirror		0.107			
2.2.1 Figure			0.081		
2.2.1.1 Surface Figure				0.040	
2.2.1.2 Surface Quality				0.070	
2.2.2 Thermal			0.050		
2.2.3 Support			0.050		
2.2.4 Coating			0.010		
2.3 Tertiary Mirror		0.078			
2.3.1 Figure			0.060		
2.3.2 Thermal			0.030		
2.3.3 Support			0.040		
2.3.4 Coating			0.010		
2.4 Corrector		0.054			
2.4.1 Figures			0.050		
2.4.2 Assembly			0.020		
3. Optical Alignment	0.121				
3.1 Focus		0.086			
3.1.1 Sensor sensitivity			0.050		
3.1.2 Wind shake			0.070		
3.2 Collimation		0.073			
3.2.1 Primary-secondary			0.060		
3.2.2 Tertiary			0.038		
3.2.2.1 Tilt				0.030	
3.2.2.2 Rotation about z				0.015	
3.2.2.3 Piston				0.017	
3.2.3 Corrector Assembly			0.017		
3.2.3.1 Piston				0.002	
3.2.3.2 Translation				0.008	
3.2.3.3 Tilt				0.015	
3.2.4 Corrector Internal alignment			0.019		
3.2.4.1 Concentricity				0.010	
3.2.4.2 Tilts				0.015	
3.2.4.3 ADC Rotation Angle				0.005	
3.3 Instrument mount		0.020			
3.3 Fast guiding coma		0.040			
4. Tracking	0.135				
4.1 Sensor alignment		0.100			
4.2 Centroid errors		0.050			
4.3 Fast guide correction		0.075			
5. Enclosure Seeing	0.086				
6. Unallocated	0.098				
Total budget:	0.365				

Table 1b: f/11 Image Error Budget		FWHM		
Configuration:	f/11 Nasmyth			
Corrector:	Inserted			
ADC:	Operating			
Field of View:	24	arcmin.		
Active optics:	Operating			
Wind speed:	22	m/s		
Telescope elevation:	Zenith			
Wavelength	500	nm		
		FWHM (arcsec)		
1. Optical Design	0.050			
1.1 Theoretical image size		0.050		
2. Optical Elements	0.183			
2.1 Primary mirror		0.157		
2.1.1 Figure			0.086	
2.1.2 Thermal			0.103	
2.1.2.1 Mirror seeing				0.079
2.1.2.2 Distortion				0.066
2.1.3 Support			0.074	
2.1.3.1 Actuator errors				0.053
2.1.3.2 Active control				0.053
2.1.4 Wind			0.026	
2.1.5 Ventillator vibration			0.020	
2.1.5 Coating			0.007	
2.2 Secondary Mirror		0.071		
2.2.1 Figure			0.053	
2.2.1.1 Surface Figure				0.026
2.2.1.2 Surface Quality				0.046
2.2.2 Thermal			0.033	
2.2.3 Support			0.033	
2.2.4 Coating			0.007	
2.3 Tertiary Mirror		0.051		
2.3.1 Figure			0.039	
2.3.2 Thermal			0.020	
2.3.3 Support			0.026	
2.3.4 Coating			0.007	
2.4 Corrector		0.035		
2.4.1 Figures			0.033	
2.4.2 Assembly			0.013	
3. Optical Alignment	0.080			
3.1 Focus		0.057		
3.1.1 Sensor sensitivity			0.033	
3.1.2 Wind shake			0.046	
3.2 Collimation		0.048		
3.2.1 Primary-secondary			0.039	
3.2.2 Tertiary			0.025	
3.2.2.1 Tilt				0.020
3.2.2.2 Rotation about z				0.010
3.2.2.3 Piston				0.011
3.2.3 Corrector Assembly			0.011	
3.2.3.1 Piston				0.001
3.2.3.2 Translation				0.005
3.2.3.3 Tilt				0.010
3.2.4 Corrector Internal alignment			0.012	
3.2.4.1 Concentricity				0.007
3.2.4.2 Tilts				0.010
3.2.4.3 ADC Rotation Angle				0.003
3.3 Instrument mount		0.013		
3.3 Fast guiding coma		0.026		
4. Tracking	0.089			
4.1 Sensor alignment		0.066		
4.2 Centroid errors		0.033		
4.3 Fast guide correction		0.049		
5. Enclosure Seeing	0.057			
6. Unallocated	0.064			
Total budget:	0.240			

Table 2: f/15 Optics Error Budget			Revised:	3/21/96
Configuration:	f/15 Cass			
Corrector	None			
Field:	0	arcmin.		
Active optics:	Operating			
Windspeed limit:	22	m/s		
Fast steering mirror	Active			
Telescope elevation:	Zenith			
Wavelength:	2.2	micron		
	RMS Wavefront (microns)			
1. Optics Alignment	0.087			
1.1 Focus		0.077		
1.1.1 Sensor resolution			0.020	
1.1.2 Sensor position			0.064	
1.1.3 Actuator stability			0.020	
1.4.4 Actuator accuracy			0.020	
1.4.5 Dynamic piston			0.025	
1.2 Collimation	0.040			
1.2.1 M2 dynamics		0.020		
1.2.2 Static		0.020		
1.2.3 Thermal		0.020		
1.2.4 Adjustment		0.020		
1.3 Fast guiding	0.097			
2. Optical Design	0.000			
3. Optical Elements	0.210			
3.1 Primary mirror		0.188		
3.1.1 Polishing			0.044	
3.1.2 Thermal			0.143	
3.1.3 Support			0.046	
3.1.4 Wind			0.102	
3.1.5 Fan vibration			0.020	
3.1.5 Coating			0.009	
3.2 Secondary Mirror		0.093		
3.2.1 Polishing			0.081	
3.2.1.1 Figure errors				0.040
3.2.1.2 Surface quality				0.070
3.2.2 Thermal			0.025	
3.2.3 Support			0.040	
3.2.4 Coating			0.010	
Total budget:	0.247			

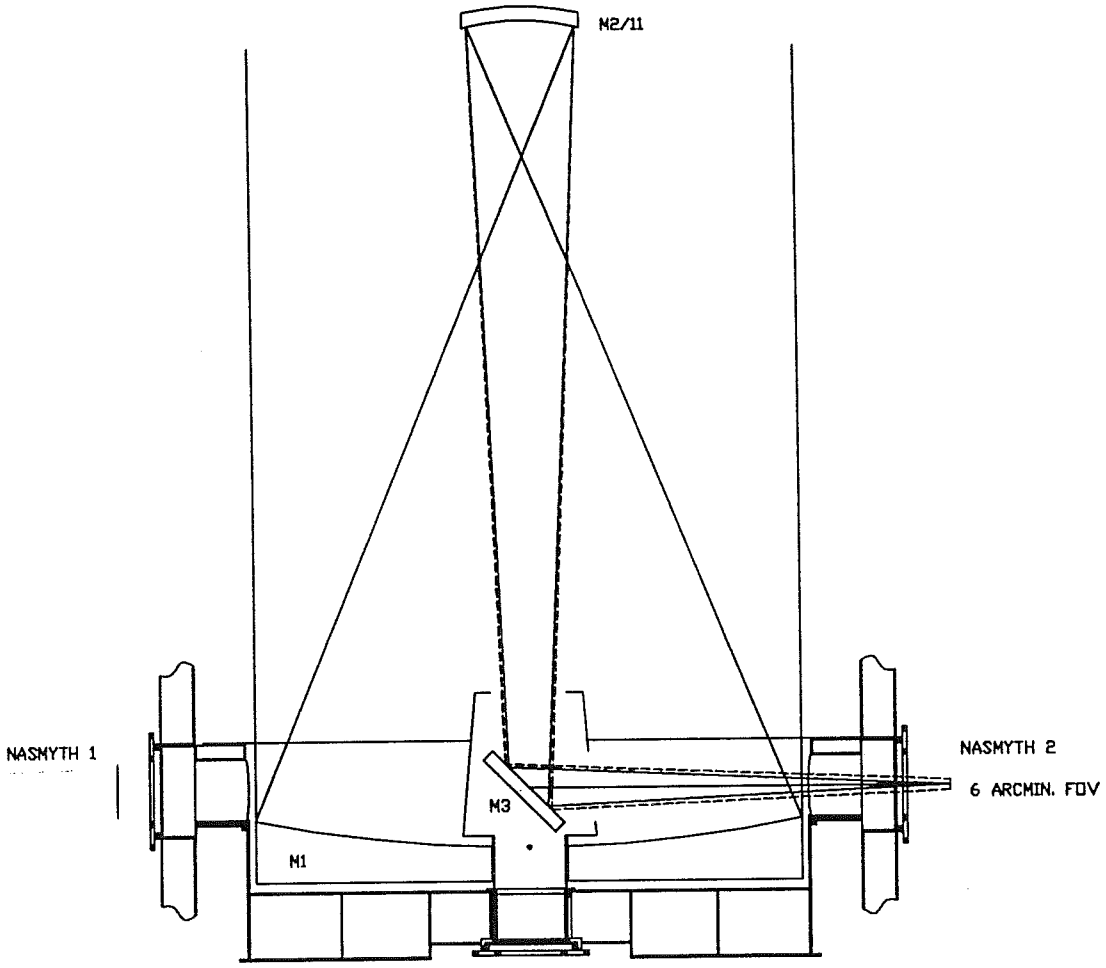

f/11 GREGORIAN NASMYTH FOCUS
M2/11
NASMYTH 1
NASMYTH 2
6 ARCMIN. FOV
M3
M1

Figure 1

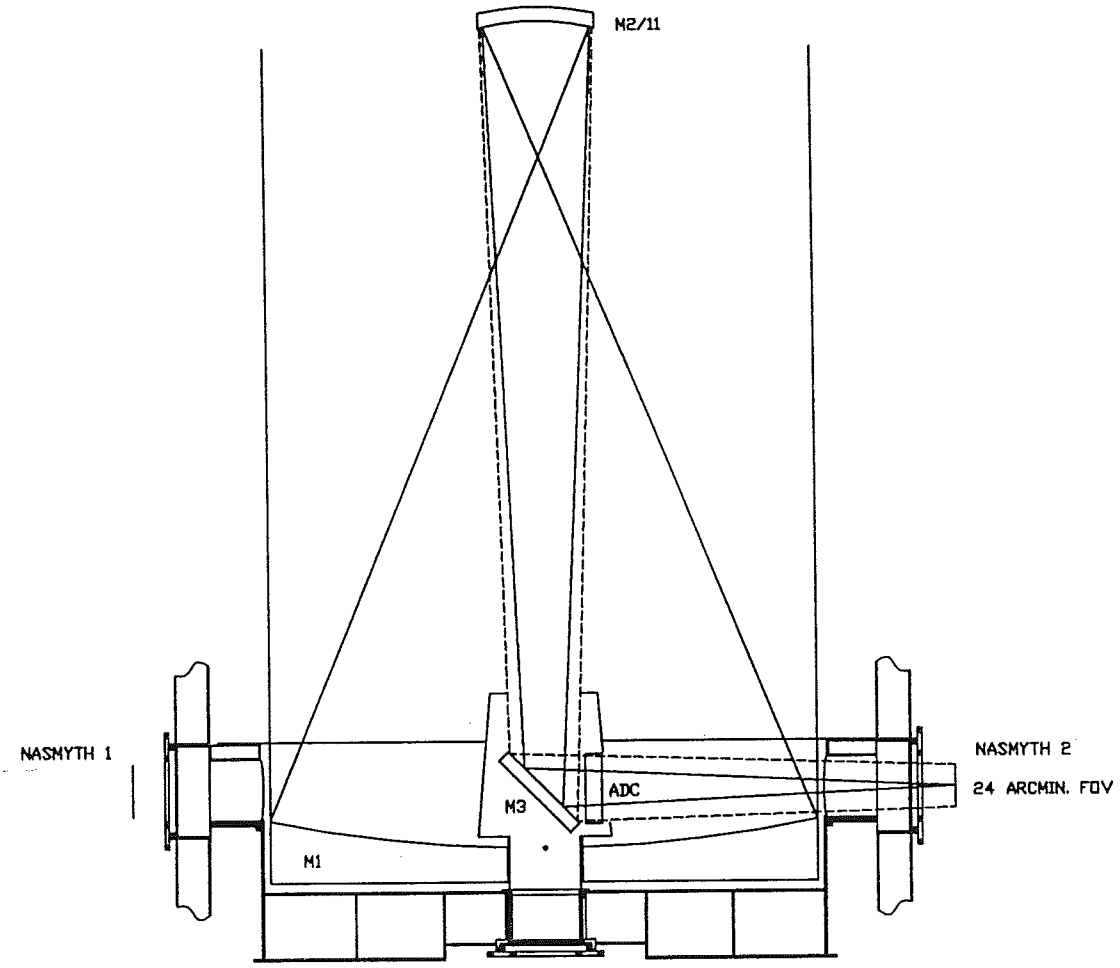

f/11 NASMYTH FOCUS W/ ADC
M2/11
NASMYTH 1
NASMYTH 2
24 ARCMIN. FOV
ADC
M3
M1

Figure 2

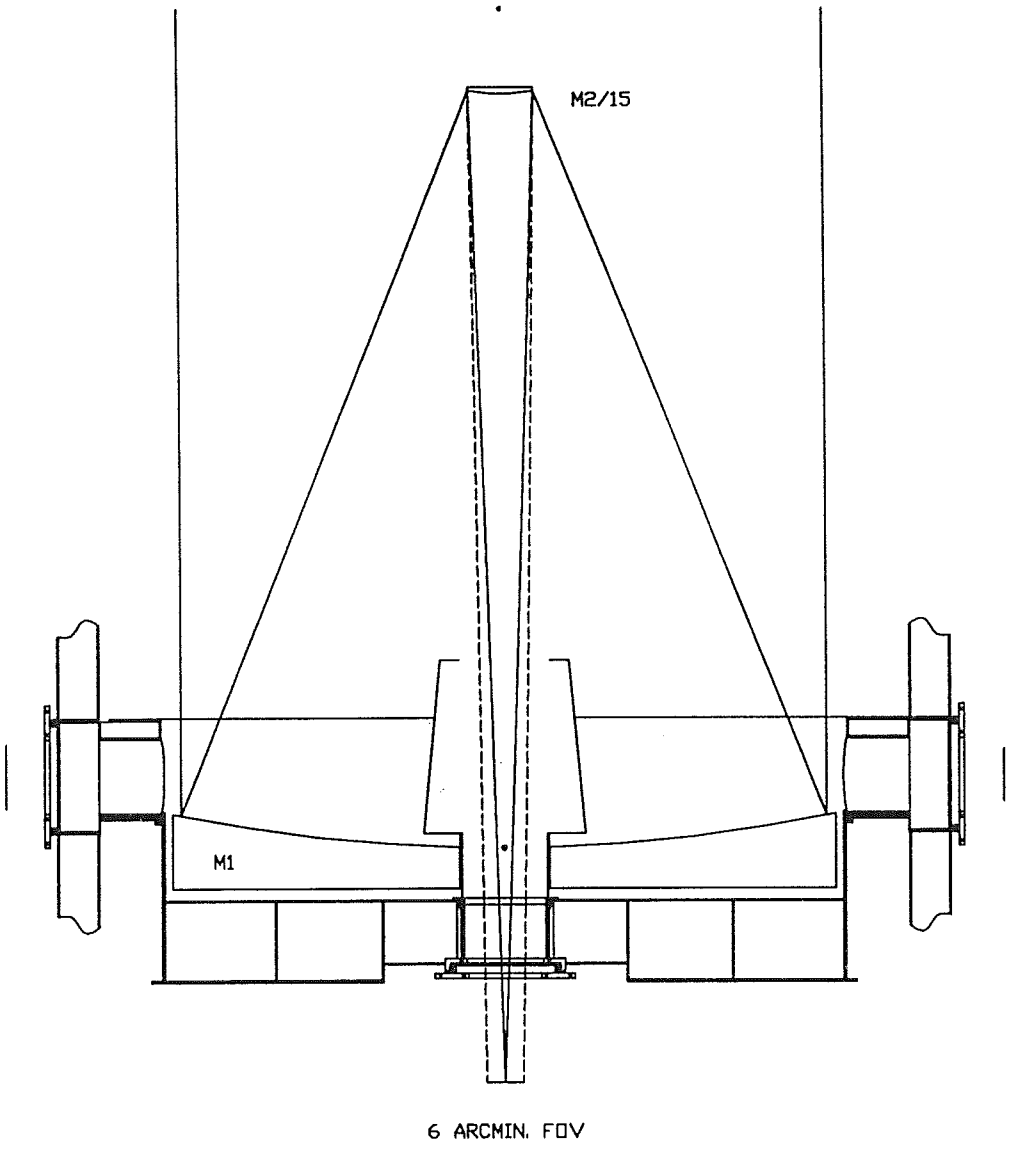


Figure 3

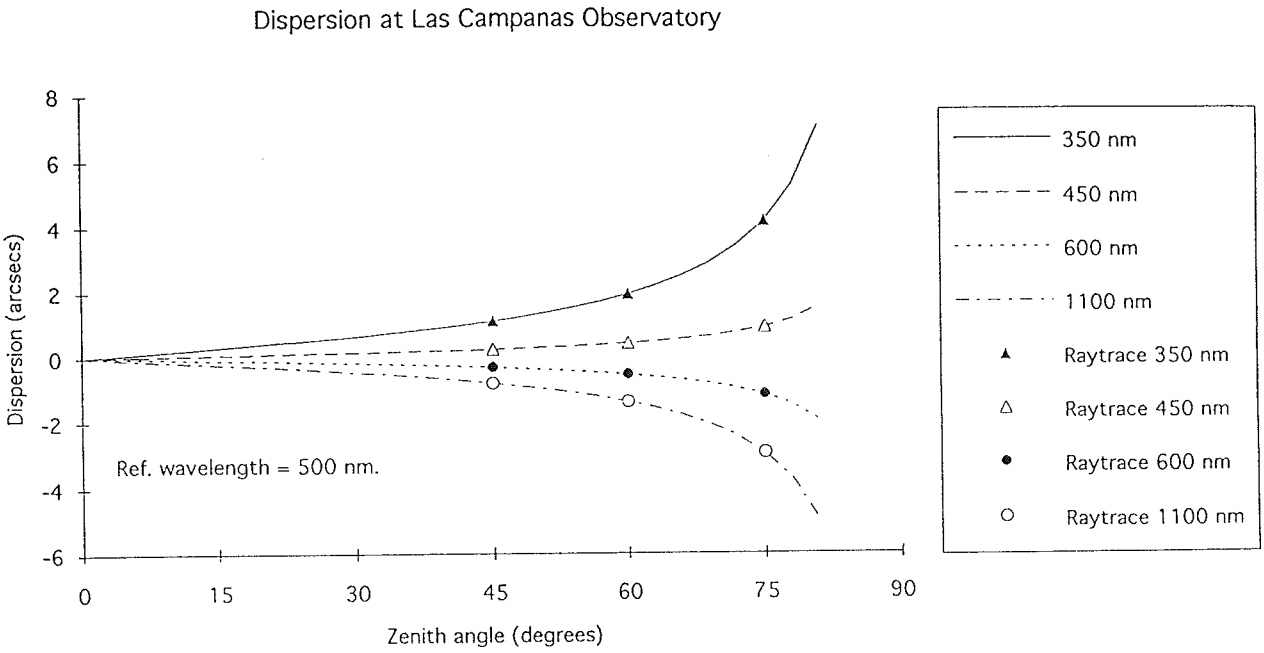


Figure 4. Model atmospheric dispersion at LCO relative to 500 NM. P=568mm HG and T=10°C.

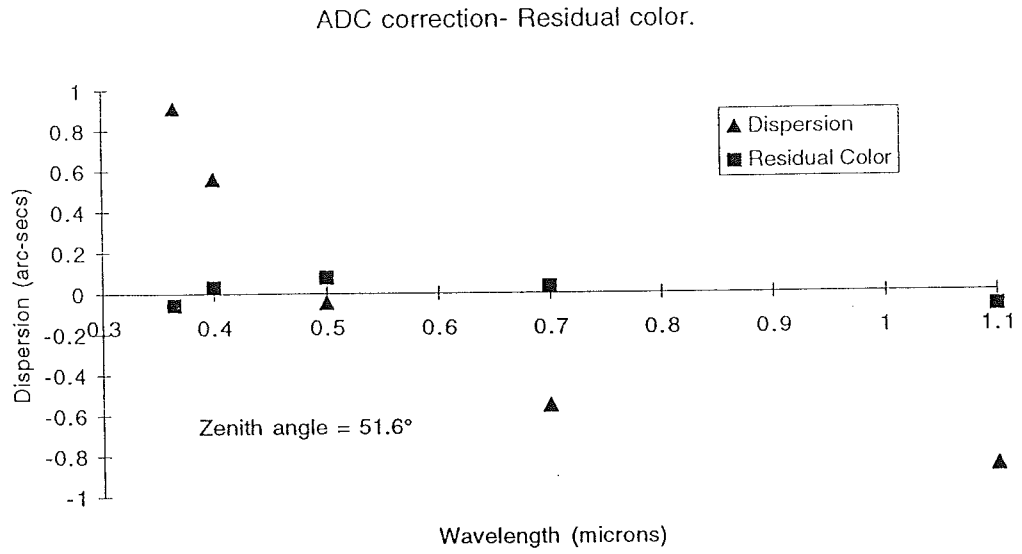
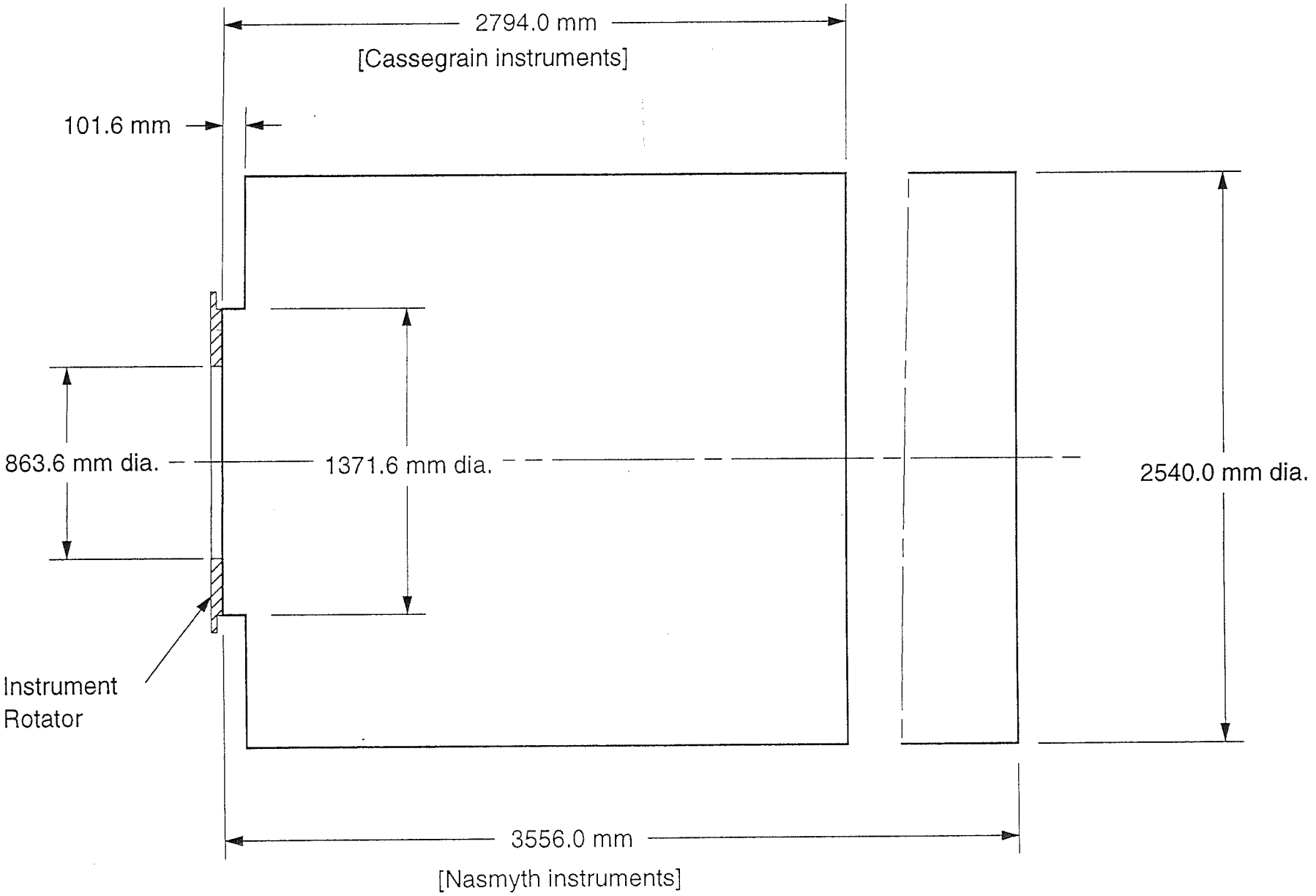


Figure 5. Model dispersion at LCO and residual color after ADC correction at zenith distance 51.6°.



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NASMYTH & CASSEGRAIN INSTRUMENT ENVELOPES	Scale: 1:25	Drawing Number	Rev.
	Issued:	**Figure 6**	

Appendix A: f/11 Narrow Field Optical Prescription

GENERAL LENS DATA:

```
Title           : MAGELLAN F/11 NARROW FIELD 950316
Surfaces        :           9
Stop            :           3
System Aperture :Float By Stop Size
Ray aiming      : Off
Gaussian Factor :    0.000000
Eff. Focal Len. :    -71526.4
Total Track     :     9721.92
Image Space F/# :     11.0407
Working F/#     :     11.0464
Obj. Space N.A. : 3.2392e-007
Stop Radius     :      3239.2
Parax. Ima. Hgt.:     62.4186
Parax. Mag.     :           0
Entr. Pup. Dia. :      6478.4
Entr. Pup. Pos. :      -325.1
Exit Pupil Dia. :     1119.29
Exit Pupil Pos. :     12357.8
Maximum Field   :        0.05
Primary Wave    :    0.500000
Lens Units      : Millimeters
Angular Mag.    :     5.78796

Fields          : 3
Field Type: Angle in degrees
#         X-Value         Y-Value          Weight
1        0.000000        0.000000        1.000000
2        0.000000        0.025000        1.000000
3        0.000000        0.050000        1.000000

Wavelengths     : 3
Units: Microns
#           Value          Weight
1        0.365000        1.000000
2        0.500000        1.000000
3        1.000000        1.000000
```

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	Infinity		0	0
1	STANDARD	Infinity	-9568.94		6478.967	0
2	STANDARD	Infinity	9243.84		6494.534	0
STO	STANDARD	Infinity	325.1		6478.4	0
4	STANDARD	-16256	-9721.916	MIRROR	6502.4	-1
5	STANDARD	2862.543	9022.656	MIRROR	1282.182	-0.633486
6	COORDBRK	--------	0		0	--------
7	STANDARD	Infinity	0	MIRROR	777.0783	0
8	COORDBRK	--------	-5003.8		0	--------
IMA	STANDARD	-1518.686	0		125.0575	0

SURFACE DATA DETAIL:

```
Surface OBJ     : STANDARD
Surface   1     : STANDARD
Surface   2     : STANDARD
 Aperture       : Circular Obscuration
 Minimum Radius :              0
 Maximum Radius :            965
Surface STO     : STANDARD
Surface   4     : STANDARD
Surface   5     : STANDARD
Surface   6     : COORDBRK
 Decenter X     :              0
 Decenter Y     :              0
 Tilt About X   :             45
 Tilt About Y   :              0
 Tilt About Z   :              0
Surface   7     : STANDARD
Surface   8     : COORDBRK
 Decenter X     :              0
 Decenter Y     :              0
 Tilt About X   :             45
 Tilt About Y   :              0
 Tilt About Z   :              0
Surface IMA     : STANDARD
```

GLOBAL VERTEX COORDINATES AND DIRECTIONS:

Surf	X coord	Y coord	Z coord	X direc	Y direc	Z direc
1	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
2	0.000000	0.000000	-9568.940000	0.000000	0.000000	1.000000
3	0.000000	0.000000	-325.100006	0.000000	0.000000	1.000000
4	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000

Appendix B: f/11 Wide Field Optical Prescription

GENERAL LENS DATA:

```
Title           : MAGELLAN F/11 950602
Surfaces        :          32
Stop            :           7
System Aperture :Float By Stop Size
Ray aiming      : Off
Gaussian Factor :    0.000000
Eff. Focal Len. :    -71088.9
Total Track     :     17325.1
Image Space F/# :     10.9732
Working F/#     :     10.9731
Obj. Space N.A. : 3.2392e-007
Stop Radius     :      3239.2
Parax. Ima. Hgt.:     248.148
Parax. Mag.     :           0
Entr. Pup. Dia. :      6478.4
Entr. Pup. Pos. :    -326.408
Exit Pupil Dia. :     1083.37
Exit Pupil Pos. :     11888.3
Maximum Field   :         0.2
Primary Wave    :    0.400000
Lens Units      : Millimeters
Angular Mag.    :     5.97984

Fields          : 9
Field Type: Angle in degrees
#         X-Value         Y-Value          Weight
1        0.000000        0.000000        1.000000
2        0.000000       -0.140000        1.000000
3        0.000000        0.140000        1.000000
4       -0.140000        0.000000        1.000000
5        0.140000        0.000000        1.000000
6       -0.200000        0.000000        1.000000
7        0.200000        0.000000        1.000000
8        0.000000       -0.200000        1.000000
9        0.000000        0.200000        1.000000

Wavelengths     : 5
Units: Microns
#           Value          Weight
1        0.365000        1.000000
2        0.400000        1.000000
3        0.500000        1.000000
4        0.700000        1.000000
5        1.100000        1.000000
```

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	Infinity		0	0
1	STANDARD	Infinity	-17325.12		6480.679	0
2	COORDBRK	--------	0		0	--------
3	STANDARD	Infinity	0	AIR6.5	6597.074	0
4	COORDBRK	--------	6000	AIR6.5	0	--------
5	STANDARD	Infinity	0		6555.195	0
6	COORDBRK	--------	11000		0	--------
STO	STANDARD	Infinity	325.12		6478.4	0
8	STANDARD	-16256	-9723.621	MIRROR	6478.417	-1
9	STANDARD	2862.543	9024.361	MIRROR	1335.774	-0.633486
10	COORDBRK	--------	0		0	--------
11	STANDARD	Infinity	0	MIRROR	1078.548	0
12	COORDBRK	--------	-545		0	--------
13	COORDBRK	--------	0		0	--------
14	STANDARD	Infinity	-30	FK5	715.8636	0
15	COORDBRK	--------	0	FK5	0	--------
16	STANDARD	5762.973	0	LLF6	715.4795	0
17	COORDBRK	--------	-25	LLF6	0	--------
18	COORDBRK	--------	0	LLF6	0	--------
19	STANDARD	7903.77	0		714.471	0
20	COORDBRK	--------	0		0	--------
21	COORDBRK	--------	-5		0	--------
22	COORDBRK	--------	0		0	--------
23	COORDBRK	--------	0		0	--------
24	STANDARD	-2690.28	0	LLF6	711.0013	0
25	COORDBRK	--------	-25	LLF6	0	--------
26	COORDBRK	--------	0	LLF6	0	--------
27	STANDARD	-3067.046	0	FK5	707.7239	0
28	COORDBRK	--------	-25	FK5	0	--------
29	STANDARD	-1965.938	0		702.1061	0
30	COORDBRK	--------	-4234.069		0	--------
31	STANDARD	Infinity	0		499.1874	0
IMA	STANDARD	-1231.742	0		497.9763	0

SURFACE DATA DETAIL:

```
 Tilt About X    :          0.025
 Tilt About Y    :              0
 Tilt About Z    :              0
Surface  24      : STANDARD
Surface  25      : COORDBRK
 Decenter X      :              0
 Decenter Y      :              0
 Tilt About X    :         -0.025
 Tilt About Y    :              0
 Tilt About Z    :              0
Surface  26      : COORDBRK
 Decenter X      :              0
 Decenter Y      :              0
 Tilt About X    :            0.4
 Tilt About Y    :              0
 Tilt About Z    :              0
Surface  27      : STANDARD
Surface  28      : COORDBRK
 Decenter X      :              0
 Decenter Y      :              0
 Tilt About X    :           -0.4
 Tilt About Y    :              0
 Tilt About Z    :              0
Surface  29      : STANDARD
Surface  30      : COORDBRK
 Decenter X      :              0
 Decenter Y      :              0
 Tilt About X    :              0
 Tilt About Y    :              0
 Tilt About Z    :             90
Surface  31      : STANDARD
Surface IMA      : STANDARD
```

INDEX OF REFRACTION DATA:

Surf	Glass	0.365000	0.400000	0.500000	0.700000	1.100000
0		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
1		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
2		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
3	AIR6.5	1.00021645	1.00021477	1.00021188	1.00020946	1.00020800
4	AIR6.5	1.00021645	1.00021477	1.00021188	1.00020946	1.00020800
5		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
6		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
7		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
8	MIRROR	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
9	MIRROR	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
10		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
11	MIRROR	1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
12		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
13		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
14	FK5	1.50400889	1.49945230	1.49144862	1.48424878	1.47807217
15	FK5	1.50400889	1.49945230	1.49144862	1.48424878	1.47807217
16	LLF6	1.55973711	1.55154395	1.53801292	1.52682584	1.51869369
17	LLF6	1.55973711	1.55154395	1.53801292	1.52682584	1.51869369
18	LLF6	1.55973711	1.55154395	1.53801292	1.52682584	1.51869369
19		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
20		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
21		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
22		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
23		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
24	LLF6	1.55973711	1.55154395	1.53801292	1.52682584	1.51869369
25	LLF6	1.55973711	1.55154395	1.53801292	1.52682584	1.51869369
26	LLF6	1.55973711	1.55154395	1.53801292	1.52682584	1.51869369
27	FK5	1.50400889	1.49945230	1.49144862	1.48424878	1.47807217
28	FK5	1.50400889	1.49945230	1.49144862	1.48424878	1.47807217
29		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
30		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
31		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000
32		1.00000000	1.00000000	1.00000000	1.00000000	1.00000000

GLOBAL VERTEX COORDINATES AND DIRECTIONS:

Surf	X coord	Y coord	Z coord	X direc	Y direc	Z direc
1	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
2	0.000000	0.000000	-17325.120000	0.000000	0.000000	1.000000
3	0.000000	0.000000	-17325.120000	0.000000	0.000000	1.000000
4	0.000000	0.000000	-17325.120000	0.000000	0.000000	1.000000
5	0.000000	0.000000	-11325.120000	0.000000	0.000000	1.000000
6	0.000000	0.000000	-11325.120000	0.000000	0.000000	1.000000
7	0.000000	0.000000	-325.120000	0.000000	0.000000	1.000000
8	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
9	0.000000	0.000000	-9723.621190	0.000000	0.000000	1.000000
10	0.000000	0.000000	-699.260010	0.000000	-0.707107	0.707107
11	0.000000	0.000000	-699.260010	0.000000	-0.707107	0.707107
12	0.000000	0.000000	-699.260010	0.000000	-1.000000	-0.000000
13	0.000000	545.000000	-699.260010	0.000000	-1.000000	-0.000000

Appendix C. f/15 Optical Prescription

GENERAL LENS DATA:

```
Title           : MAGELLAN F/15  (VER. 950317)
Surfaces        :            7
Stop            :            6
System Aperture :Image Space F/#
Ray aiming      : On   Pupil shift = 0
Gaussian Factor :     0.000000
Eff. Focal Len. :      95027.7
Total Track     :      11646.6
Image Space F/# :           15
Working F/#     :      15.0084
Obj. Space N.A. :3.16757e-007
Stop Radius     :      320.733
Parax. Ima. Hgt.:      82.9273
Parax. Mag.     :            0
Entr. Pup. Dia. :      6335.18
Entr. Pup. Pos. :      69589.2
Exit Pupil Dia. :      641.466
Exit Pupil Pos. :     -9622.01
Maximum Field   :         0.05
Primary Wave    :     2.200000
Lens Units      : Millimeters
Angular Mag.    :       9.8761

Fields          : 3
Field Type: Angle in degrees
#         X-Value         Y-Value         Weight
1        0.000000        0.000000        1.000000
2        0.000000        0.025000        1.000000
3        0.000000        0.050000        1.000000

Wavelengths     : 1
Units: Microns
#           Value          Weight
1        2.200000        1.000000
```

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD	Infinity	Infinity		0	0
1	STANDARD	Infinity	-9360.6		6463.84	0
2	STANDARD	Infinity	2387.6		6480.177	0
3	STANDARD	Infinity	6973		6476.01	0
4	STANDARD	-16256	-7307.446	MIRROR	6464.4	-1
5	STANDARD	-1794.605	-28.568	MIRROR	641.4661	-1.409112
STO	STANDARD	Infinity	9622.015		641.4661	0
IMA	STANDARD	-831.5241	0		165.9524	0

SURFACE DATA DETAIL:

```
Surface OBJ     : STANDARD
Surface   1     : STANDARD
Surface   2     : STANDARD
 Aperture       : Circular Obscuration
 Minimum Radius :              0
 Maximum Radius :            965
Surface   3     : STANDARD
 Aperture       : Circular Obscuration
 Minimum Radius :              0
 Maximum Radius :            965
Surface   4     : STANDARD
Surface   5     : STANDARD
Surface STO     : STANDARD
Surface IMA     : STANDARD
```

GLOBAL VERTEX COORDINATES AND DIRECTIONS:

Surf	X coord	Y coord	Z coord	X direc	Y direc	Z direc
1	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
2	0.000000	0.000000	-9360.600000	0.000000	0.000000	1.000000
3	0.000000	0.000000	-6973.000000	0.000000	0.000000	1.000000
4	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000
5	0.000000	0.000000	-7307.446230	0.000000	0.000000	1.000000
6	0.000000	0.000000	-7336.014230	0.000000	0.000000	1.000000
7	0.000000	0.000000	2286.000520	0.000000	0.000000	1.000000

f/11 GREGORIAN NASMYTH FOCUS

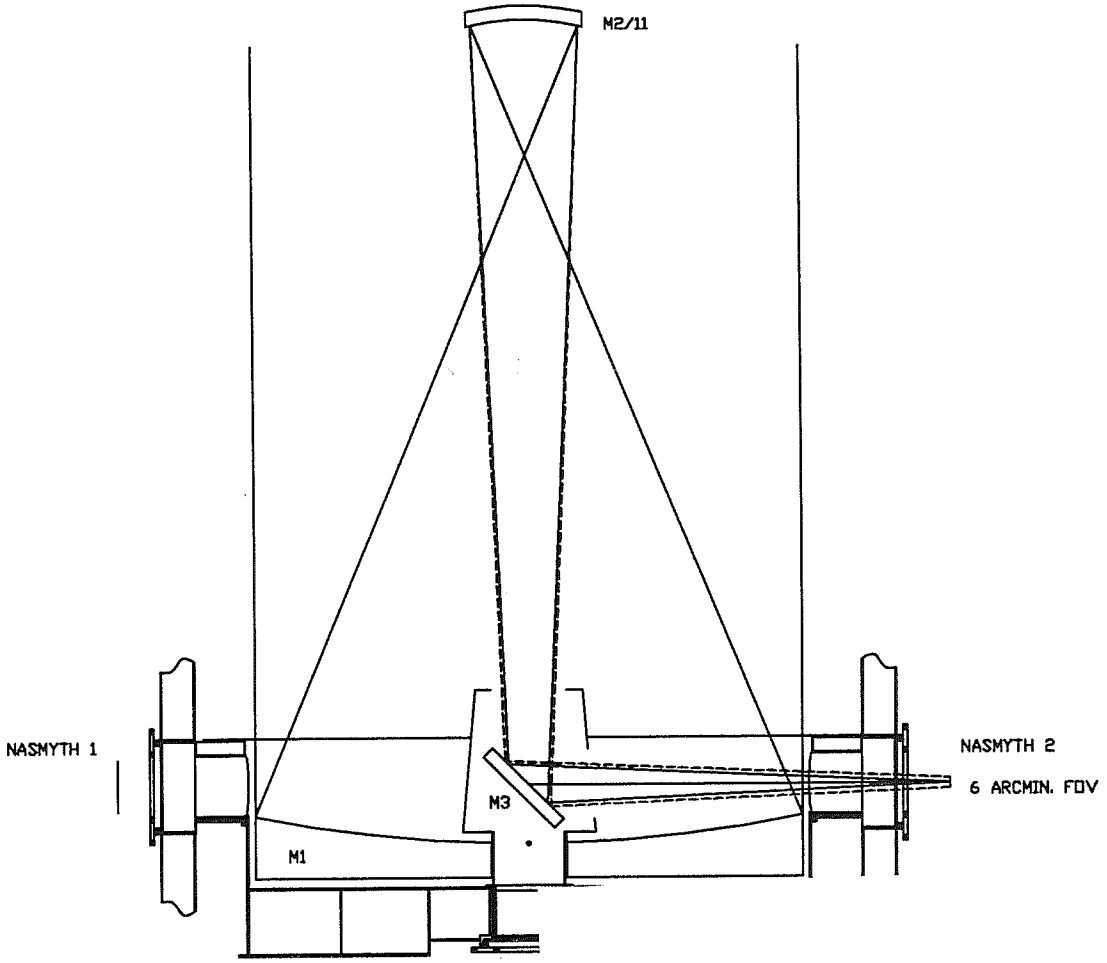


FIGURE 1

f/11 NASMYTH FOCUS W/ ADC

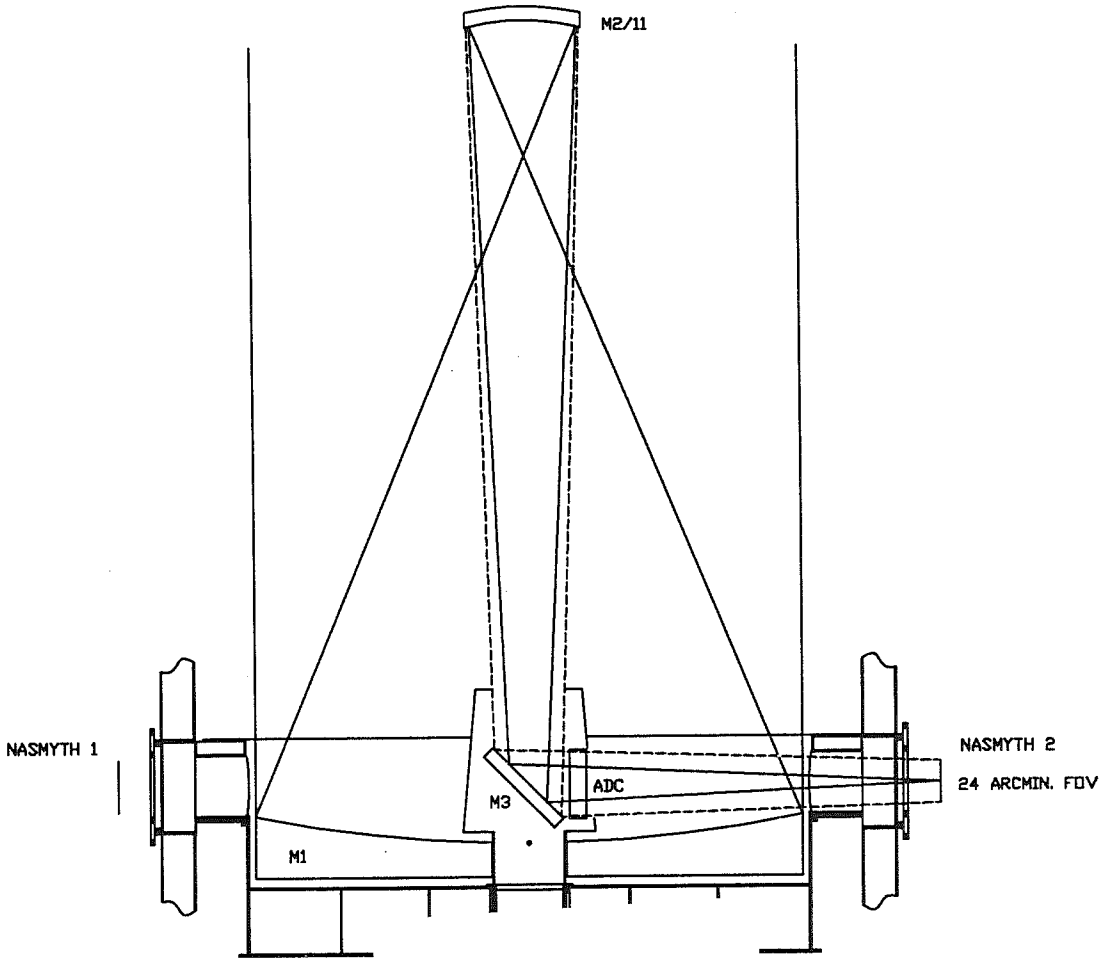


FIGURE 2

F/15 IR CASSEGRAIN CONFIGURATION

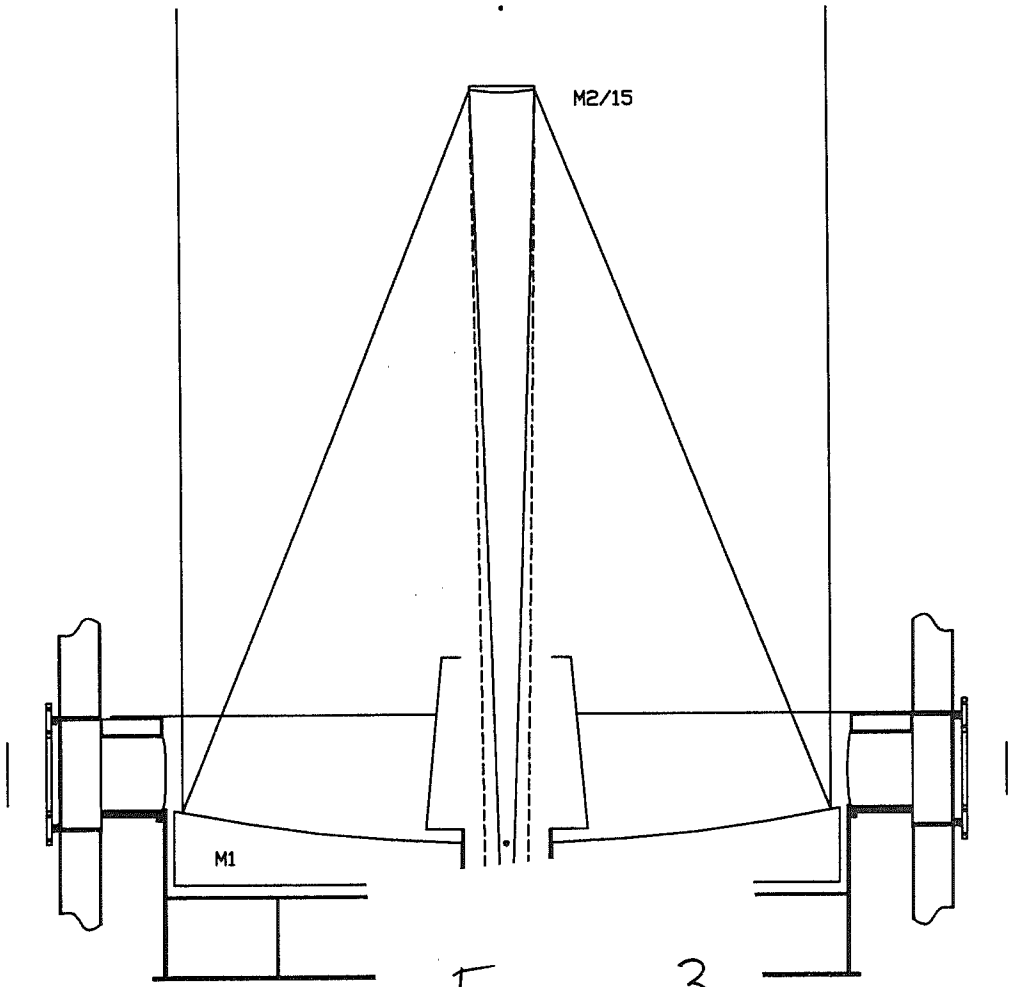


FIGURE 3

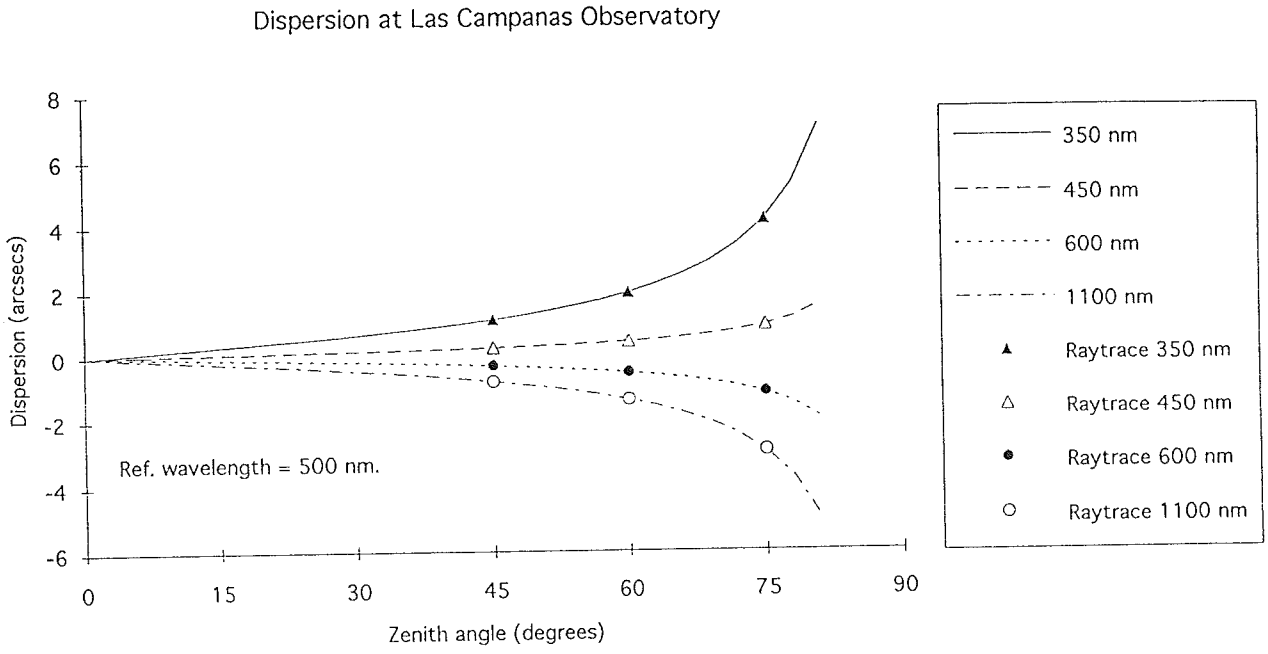


FIGURE 4

(TEXT)

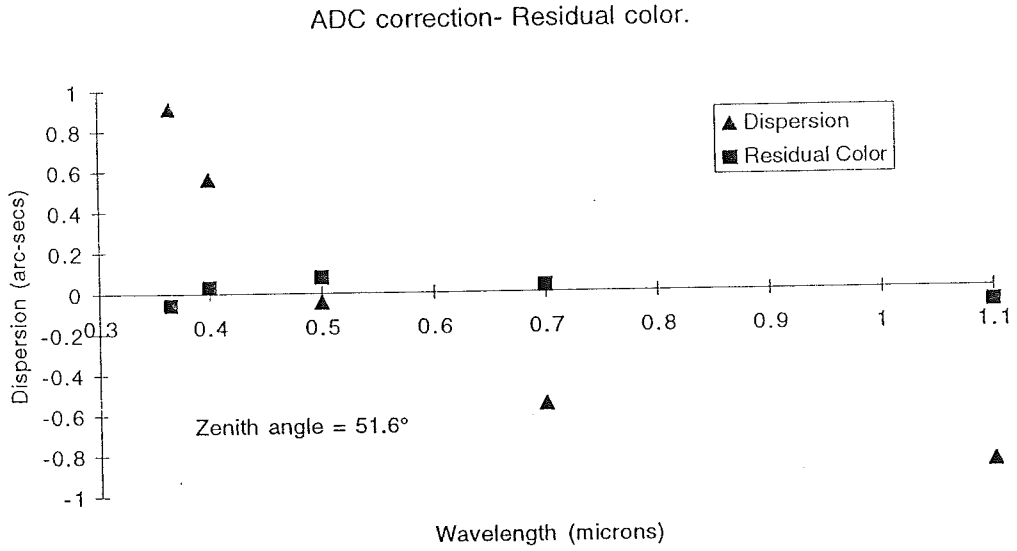
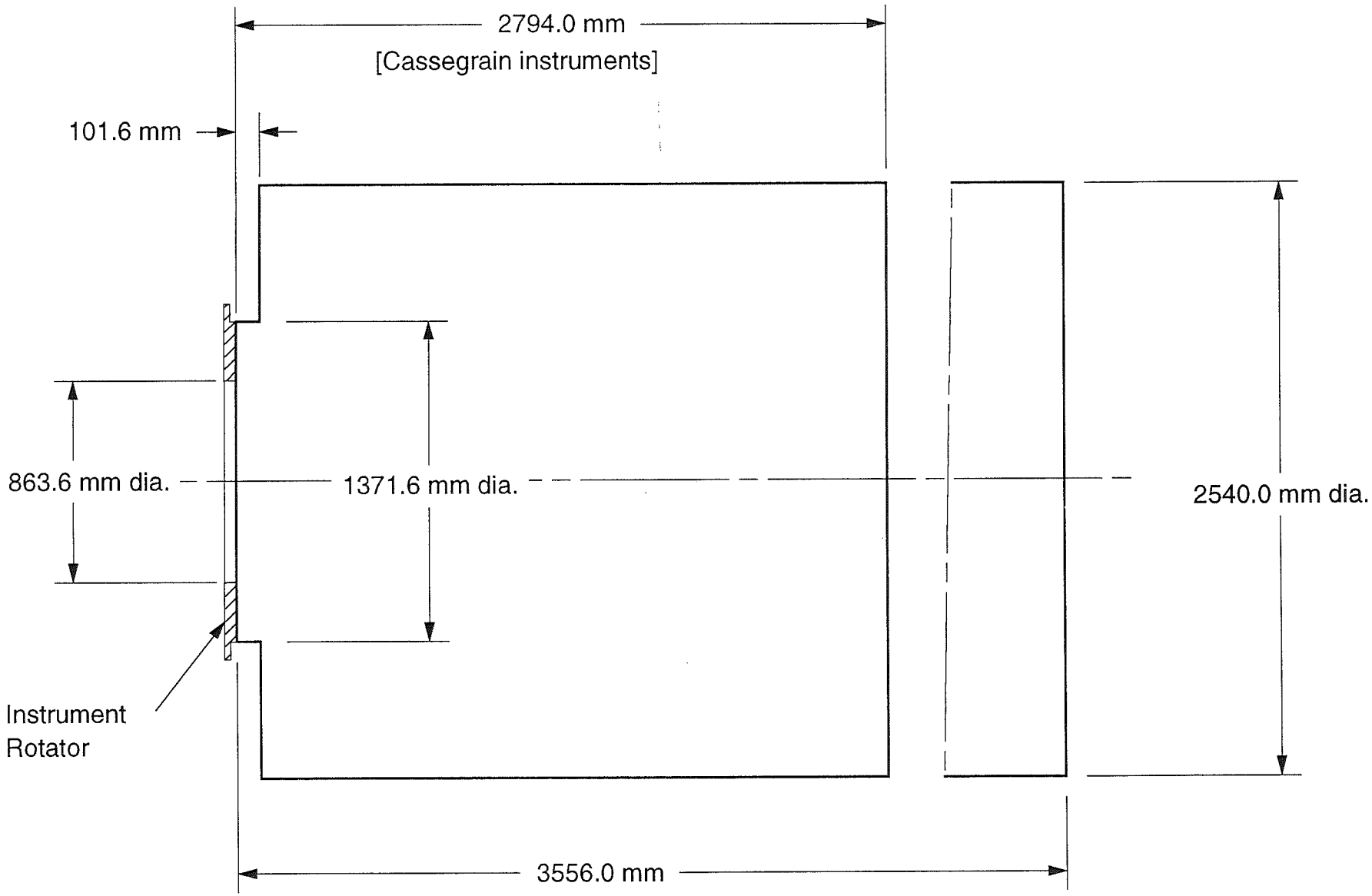


FIGURE 5

(TEXT)



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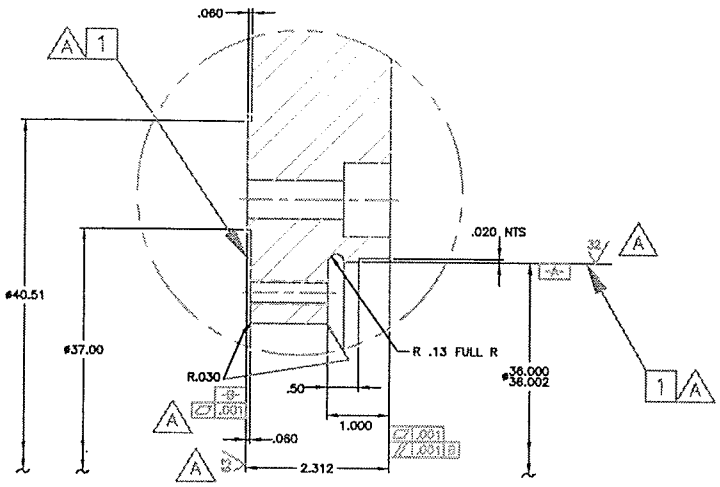
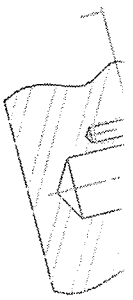
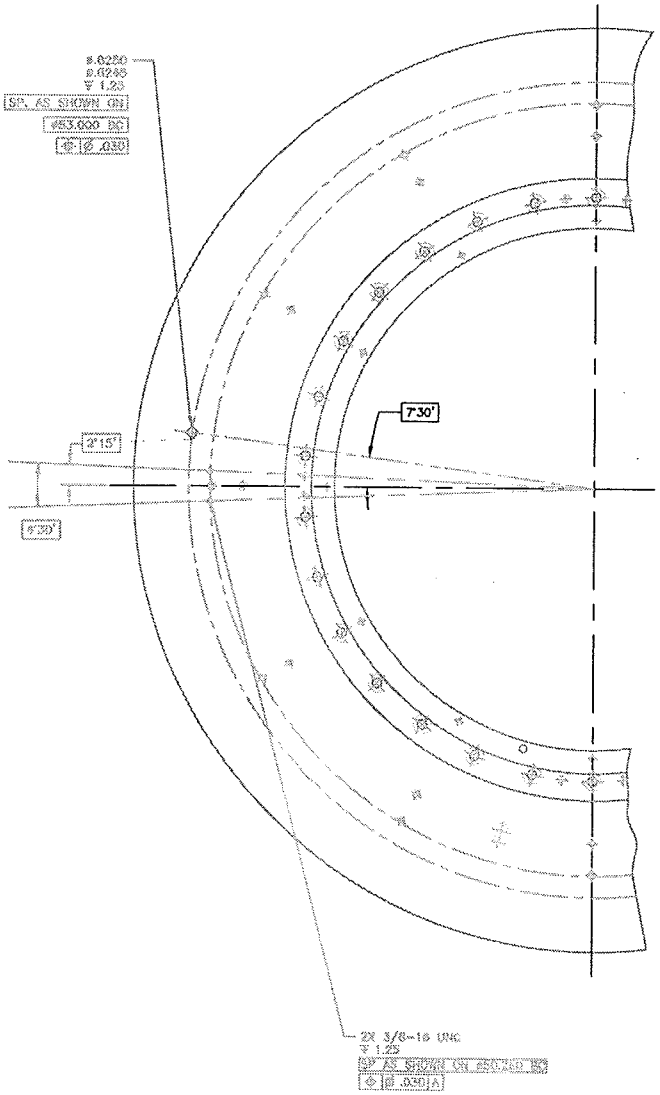
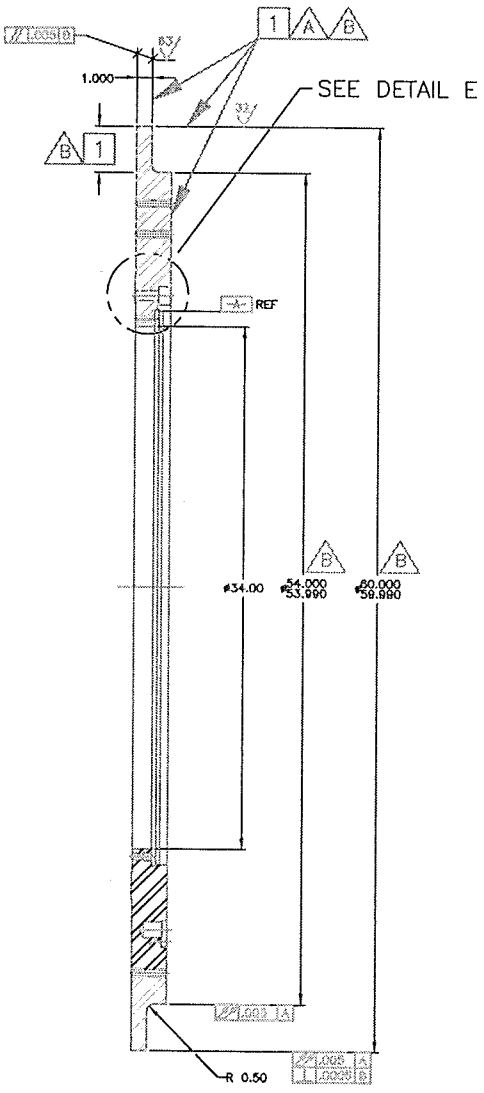


DETAIL-E SCALE: FULL



SECTION
SCALE: FU





SECTION A-A

2X ø.5603 ±.
.50 DEEP ON
ON ø55.000