f/5 Wave Front Sensor Manual

draft of September 17, 2003

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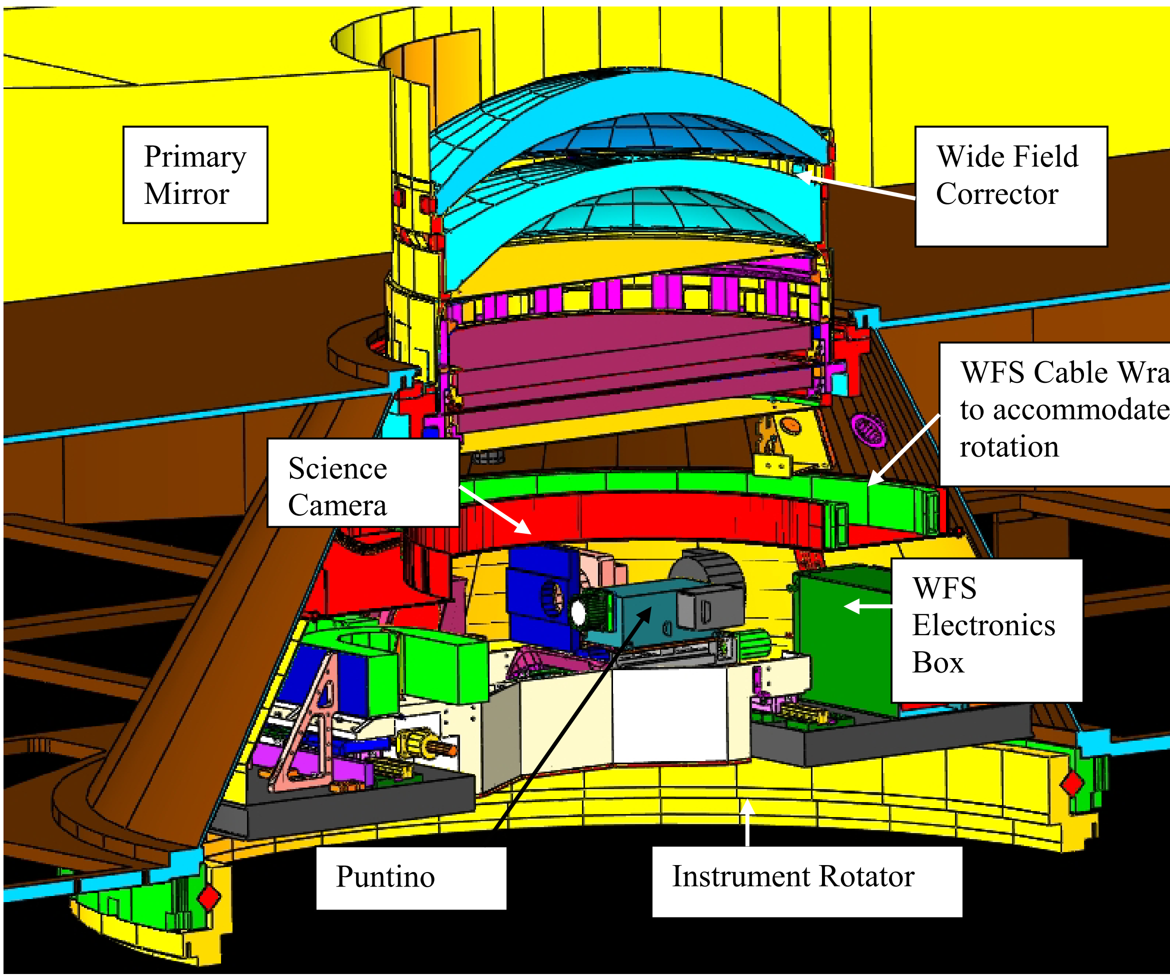


Figure 1. Wavefront sensor mounted inside the MMT's cone, above the instrument rotator and below the wide field corrector.

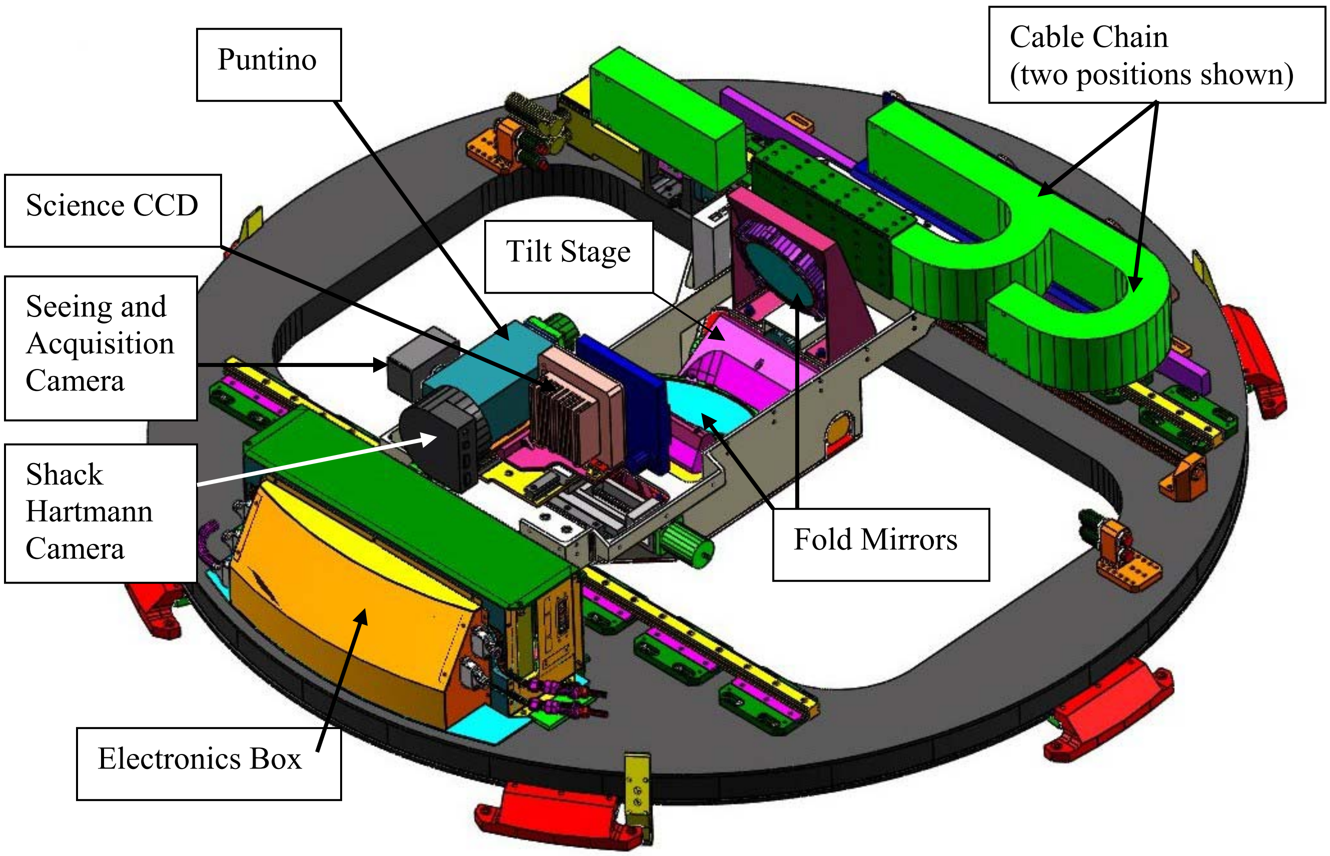


Figure 2. f/5 wavefront sensor with the cover removed. The stage assembly carrying the pickoff mirrors, Puntino and Apogee science camera is deployed to the on-axis position.

1 Introduction

The f/5 wavefront sensor includes two main components: (1) a commercial Shack-Hartmann wavefront sensor and (2) a rapid-deployment CCD camera to respond to time-critical imaging needs while a spectroscopic instrument is mounted at the f/5 focus. The wavefront sensor, the Puntino, is manufactured by Spot Optics (Italy). A cooled CCD camera, the SBIG ST9XE, is used to measure the Shack-Hartmann wavefront centroids. A beamsplitter sends ~50% of the light to the SBIG camera and ~50% to an acquisition/seeing camera, the Pixelink PL-A633. The CCD camera, the AP8p, is manufactured by Apogee and contains a thinned SITe 1024x1024 CCD. Its 24 µm pixels subtend ~0.14″ at the f/5 focus.

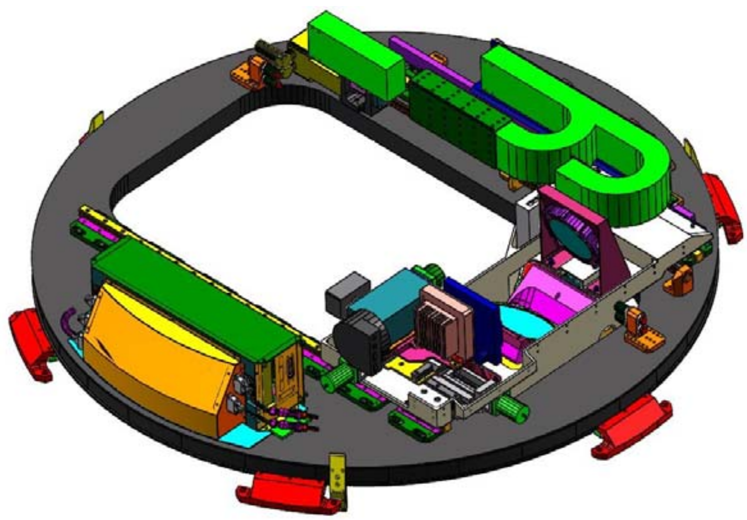


Figure 3. The wavefront sensor stage in the parked position,

2 Mechanical Configuration

The wavefront sensor mounts inside the instrument rotator, below the f/5 wide-field corrector and above the instruments. It has four axes of motion: (1) a long travel linear slide that carries the optic along a line intersecting the optical axis, (2) a select stage that allows selection of the Puntino or the science camera, (3) a focus stage (mounted on the select stage) that carries both the Puntino and the science camera, and (4) a tilt stage that carries the first fold mirror and allows the instruments to be aligned with the chief ray off-axis. In spectroscopic mode, the Puntino and science camera can be used out to the field edge. In imaging mode, the wavefront sensor can only be used on-axis because the large field-flattening element that forms the Megacam dewar window is not present.

3 Computer and Electronic Components

Part	Interface	Vendor/Part Number	Description
Computer motherboard		FV-25 Flex ATX	
CPU		Via C3 866 Mhz	
Operating system		Windows XP Pro	
Motion control board	PCI	Delta Tau PMAC	
Disk Drive	IDE	Fujitsu	2.5 inch 40 Gbytes
I/O Board	USB	Lab Jack U12	20 digital i/o, 4 analog in, 4 analog out
Cooled Shack-Hartmann CCD Camera	USB	SBIG ST9XE	Kodak KAF-0261E 512x512 pixels, 20x20μm
Acquisition/seeing camera	Firewire	Pixelink PL-A633	CMOS 1280x1024 pixels, 7.5x7.5μm
Science Camera	Parallel	Apogee AP8p	SITe SI-003AB 1024x1024 pixels, 24x24μm
Filter wheel	Serial	Optec IFW	
Servo Amplifiers		Copley Controls 5321	10 amps continuous, 20 amps peak

4 Power Dissipation

The following table summarizes power dissipations measured on 4/19/03 by Dusty Clark. AC voltage is 120 volts RMS.

Computer on, AC power on	0.66 amp
Computer on, both cameras on, cooling off	0.73 amp
Computer on, both cameras powered and cooling, no motors energized	1.05 amp

5 Puntino

The Puntino uses a 46 mm focal length collimator lens assembly (plano-convex lens and achromat) to form an 9 mm diameter pupil image of the primary mirror on the Shack-Hartmann lenslet array. The pitch of the lenslet array is 0.6 mm and the lenslet focal length is 40 mm. The imaging scale on the Shack-Hartmann camera is ~0.14″/pixel. The pitch of the lenslets imaged on the SH camera is ~30 pixels. The images of the reference light source are ~4 pixels in diameter.

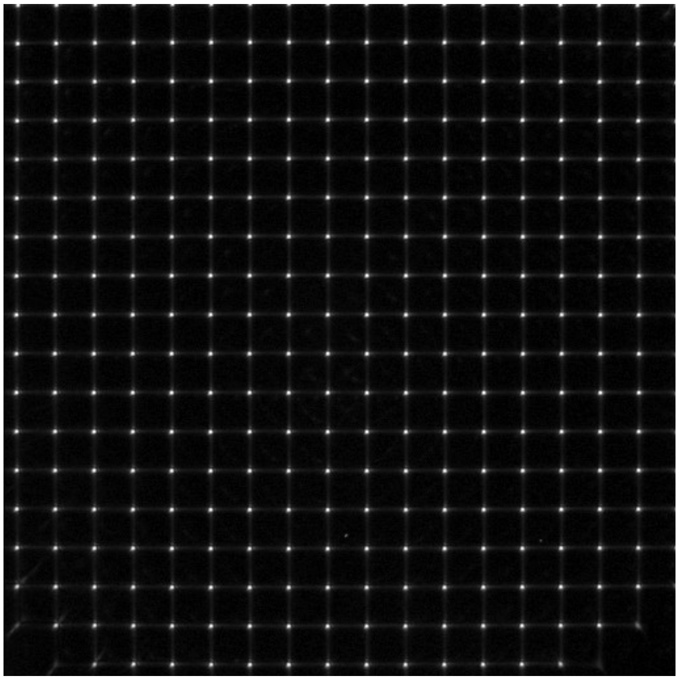


Figure 4: Portion of Shack Hartmann reference frame from Puntino

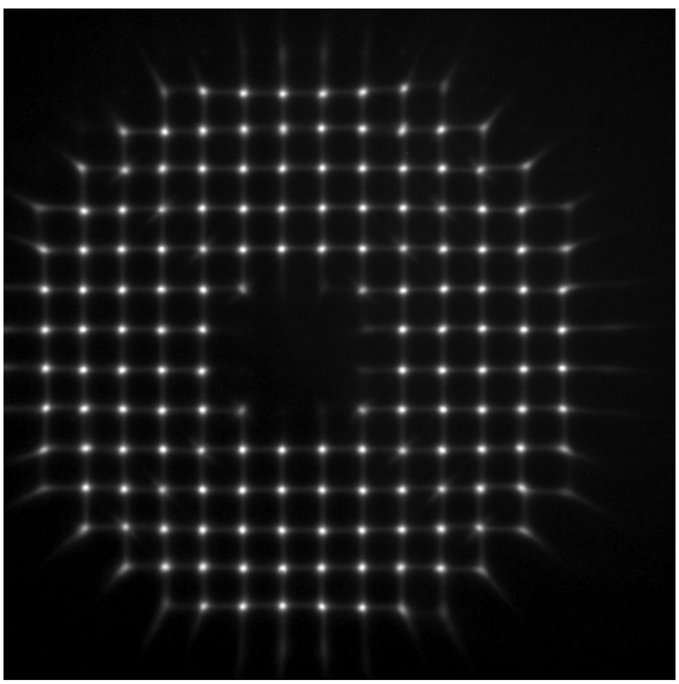


Figure 5. Shack Hartmann image from f/5 optics. Smeared images at the edge of the pupil result from the primary mirror's rolled edge.

Puntino Characteristics

Lenslet Array	Adaptive Optics Associates 0600-40-S (square array format, 25x25mm, 1 mm thick)
Lenslet array focal length	40 mm
Number of illuminated SH lenslets at f/5	~14x14
Lenslet array pitch	600 µm
Collimator focal length	46 mm
SH Camera: SBIG ST9XE pixel size	20 µm (~0.12″)
SH Camera: format	512x512
SH Camera: readout time (USB interface)	~1 sec
SH Camera cool down time	~35 °C maximum in 9 minutes
Dot pitch on SH camera	30 pixels
Reference image size	4 pixels full diameter
Pixelink camera lens focal length	45 mm (0.98 magnification)
Seeing Cam: Pixelink PL-A633 pixel size	7.5 µm (~0.046″ at 0.98 magnification)
Seeing Cam: format	1280x1024
Seeing Cam: frame rate	14 fps (1280x1024) to 60 fps (320x240)

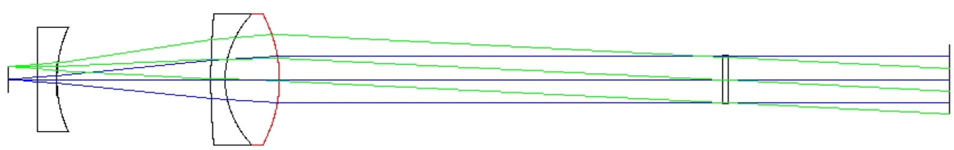


Figure 6. Optical layout of Puntino. The plano-convex field lens was added to throw the pupil back onto the lenslet array.

Puntino Optical Prescription

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
8	STANDARD	F5 FOCUS	Infinity	5.00		--	-665
9	STANDARD		Infinity	3.50	BK7	20.0	0
10	STANDARD	F45-025	25.84	0.00		20.0	0
11	STANDARD		Infinity	26.92		--	0
12	STANDARD		152.94	2.50	SF10	25.0	0
13	STANDARD		18.85	9.50	BAFN11	25.0	0
14	STANDARD	32321	-27.97	0		25.0	0
15	STANDARD		Infinity	77.52		--	0
16	USERSURF		20.88	1.00	BK7	25.0	0
17	STANDARD	Infinity		38.62		25.0	0
IMA	STANDARD	Infinity				10.2	0

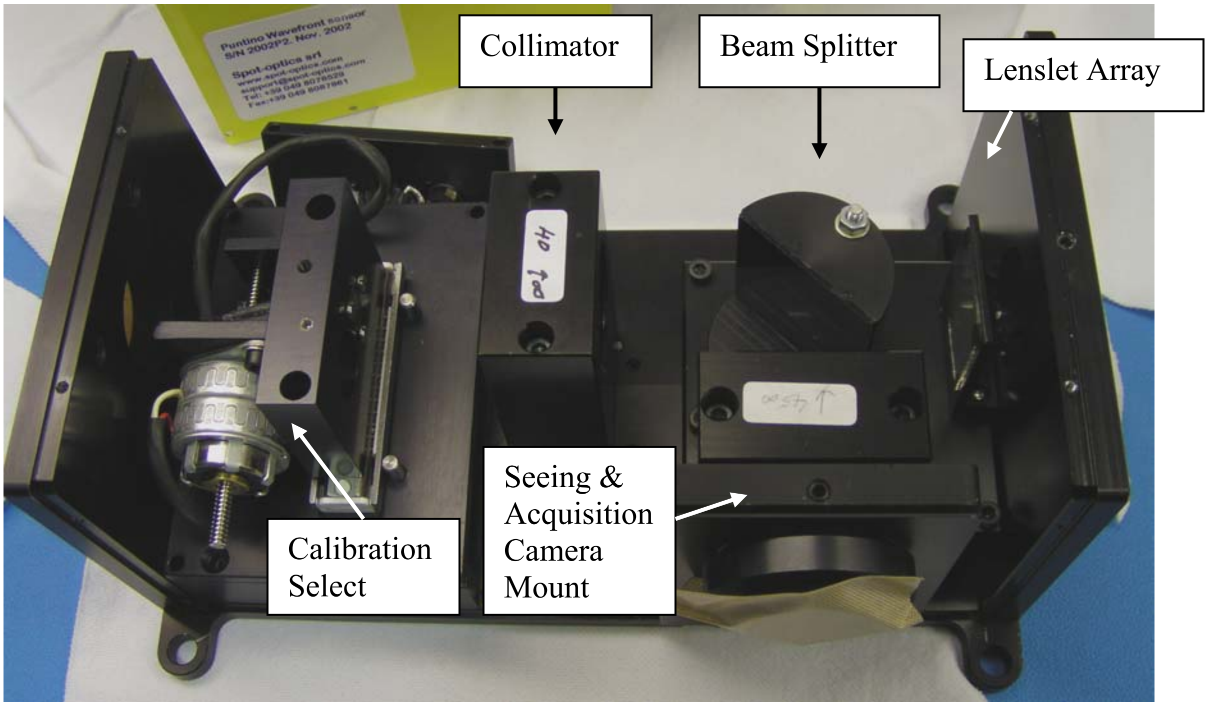


Figure 7: The Puntino. Light enters from the left. The stepper motor selects either an aperture or the calibration illuminator. The field lens used with the collimator is not shown in this picture. The field lens was added to move the pupil back onto the lenslet array. The field lens is mounted in a cylindrical bezel that is attached to the collimator mount, projecting to the left. The half round mount to the center right holds a 50/50 beam splitter. Straight through light strikes the lenslet array and then the SBIG Shack-Hartmann camera (not mounted here). The folded light strikes a 45 mm lens that forms an image on the Pixelink acquisition/seeing camera (not mounted here).

6 Mechanical Components

Axis	Component	Vendor/Part Number
Field Translation Stage	Rails (2)	THK HSR25LASSCOM+1240LM
	Ballscrew	NSK W2009FA-1P-02 20 mm diameter, 10 mm lead
	Motor/Integral Brake	Kollmorgen MT304B1-E2D2-Goldline XT Max cont current = 5.53 amps producing 365 oz-in of torque. Peak current 20.9 amps
	Hall Sensor	Phoenix America P3500
	Linear Encoder	RSF MSA-2216
	Shock Absorbers	Ace Controls MC225H2
Camera Select	Stage	THK KR3306A+269LP-1600
	Rail (1)	THK HSR20LR1SSCOM+260LPM
	Motor	Kollmorgen RBEH-00714-A00 Max cont current = 4.68 amps producing 35 oz-in of torque. Peak current 14.2 amps
	Hall Sensor	Phoenix America P3500
	Linear Encoder	Renishaw RGH24Z
	Brake	Warner Electric ERS-26, 90VDC
Camera Focus	Stage	THK KR3306C+196LP-1600
	Rail (1)	THK HSR20LA1SSCOM+200LPM
	Motor	Kollmorgen RBEH-00714-A00 Max cont current = 4.68 amps producing 35 oz-in of torque. Peak current 14.2 amps
	Hall Sensor	Phoenix America P3500
	Linear Encoder	Renishaw RGH24Z
	Brake	Warner Electric ERS-26, 90VDC
M1 Tilt	Stage	THK KR3306C+124LP-1600
	Motor	Kollmorgen RBEH-00712-A00 Max cont current = 4.56 amps producing 21 oz-in of torque. Peak current 12.6 amps
	Hall Sensor	Phoenix America P3500
	Rotary Encoder	Encoder Products Co. 755A-01-S-1000-R-OC-1-SSN
	Brake	Electroid EFSB-15-8-90V

7 Physics of Torque Calculations

7.1 How much motor torque is required to overcome gravity?

The energy equation for one turn of the screw is:

$$eT\theta = Fd$$

the required torque is: $$T = \frac{Fd}{e\theta}$$

e	all screw efficiency (dimensionless)
T	motor torque (in N-m)
θ	2*π (angle of motor rotation per turn in radians)
F	m*g (gravitational force in N)
M	mass (in kg)
G	9.8 meter s^{-2}
D	lead of ball screw per turn (m)

For the Field Translation axis-axis, e=0.9, m=100 kg, d=0.010, giving T = 1.73 N-m, or 245 oz-in. (1 N-m = 141.6 oz-in) At 4.6 amps continuous current, the motor can supply 308 oz-in. At 5.53 amps maximum continuous current, the motor can supply 365 oz-in.

For the camera select axis, e=0.9, m=14.5 kg, d=0.006, giving T = 0.15 N-m, or 21 oz-in.

For the focus axis, e=0.9, m=10 kg, d=0.006, giving T = 0.10 N-m, or 15 oz-in.

7.2 How much motor torque is required to accelerate the load?

The equation is the same except that ``g'' is replaced by ``a'', the acceleration. Accelerating to 1 m s^{-1} speed in 0.1 sec corresponds to 1 g. Accelerating to 50 mm/sec in 0.2 sec corresponds to 0.25 m s^{-2}, or 0.026 g. Therefore, accelerating the Field Translation stage with these parameters takes only an additional 6.4 oz-in.

Accelerating the camera select axis to 25 mm s^{-1} in 0.2 s corresponds to 0.013 g, so the acceleration requires 0.27 oz-in.

Accelerating the the focus axis to 10 mm s^{-1} in 0.2 s corresponds to 0.0051g, so the acceleration requires 0.08 oz-in.

7.3 How much torque is required to overcome the inertia of the motor and ball screw?

$$T = I\xi$$

I	inertia (in kg m^2)
ξ	Angular acceleration (in radians s^{-2})

For the Field Translation axis, an acceleration of 0.25 m s^{-2} corresponds to:

$$\xi = (0.25 \text{ m s}^{-2}) * (2\pi \text{ radians turn}^{-1}) * (100 \text{ turn m}^{-1}) = 157 \text{ radians s}^{-2}$$

The motor inertia is 8.1 x 10^{-5} kg-m^2; the ball screw inertia (0.5*mass*$radius^2$) is 1.2 x 10^{-4} kg-m^2. The total torque to accelerate the motor and ball screw to 0.25 m s^{-2} is therefore 0.032 N-m or 4.5 oz-in.

For the camera select axis, ξ=131 radians s^{-2}; the motor inertia is 3.2 x 10^{-6} kg-m^2; the ball screw inertia (0.5*mass*$radius^2$) is 2.4 x 10^{-6} kg-m^2. The total torque to accelerate the motor and ball screw is therefore 0.00073 N-m or 0.10 oz-in.

For the camera select axis, ξ=52 radians s^{-2}; the motor inertia is 3.2 x 10^{-6} kg-m^2; the ball screw inertia (0.5*mass*$radius^2$) is 1.6 x 10^{-6} kg-m^2. The total torque to accelerate the motor and ball screw is therefore 0.00025 N-m or 0.04 oz-in.

8 Motion Control Parameters

8.1 Motion Axis Parameters

Axis	Travel Range	Maximum Speed	Ball Screw Lead	Encoder Resolution (per quad ct)	Estimated Motor Torque Requirement and Comments
Field Translation	+490 mm -343 mm	50 mm s^{-1}	10 mm	1.0 µm	245 oz-in continuous 260 oz-in peak
Camera Select	+/-75 mm	25 mm s^{-1}	6 mm	0.5 µm	21 oz-in continuous 22 oz-in peak
Camera Focus	+/- 51 mm	10 mm s^{-1}	6 mm	0.5 µm	15 oz-in continuous 16 oz-in peak
M1 Tilt	Linear +/-10 mm Rotary +/-6.5°	2 mm s^{-1}	6 mm	4000 rev^{-1} of drive motor, or ~3.48″ of stage tilt.	8 oz-in continuous 16 oz-in peak Tangent arm is 88.9 mm

8.2 Copley Control 5321 Servo Amp Settings

Axis	Motor K_T	RH20 – Motor Inductance	CH18	RH15 – Peak Current	RH16 – Ave Current
Mirror Tilt	5.19 oz-in/A	40.2KΩ (L= 2-5.9mH)	6.8pF	5.36KΩ I_{pk}=9A	10KΩ I_{ct}=4.6A
Focus	8.26 oz-in/A	40.2KΩ (L= 2-5.9mH)	6.8pF	5.36KΩ I_{pk}=9A	10.5KΩ I_{ct}=4.7A
Select	8.26 oz-in/A	40.2KΩ (L= 2-5.9mH)	6.8pF	5.36KΩ I_{pk}=9A	10.5KΩ I_{ct}=4.7A
Translation	67 oz-in/A	220KΩ (L= 6-9mH)	6.8pF	7.5KΩ I_{pk}=10A	15KΩ I_{ct}=5.4A

8.3 PMAC Settings

PMAC Parameter	Field Translation	Camera Select	Camera Focus	Mirror Tilt
***Encoder Resolution	1000 mm^{-1}	2000 mm^{-1}	2000 mm^{-1}	4000 rev^{-1} 666.67 mm^{-1}
Proportional Gain	75000	50000	50000	100000
Derivative Gain	600	600	600	600
Velocity Feed Forward	600	600	600	600
Integral Gain	30000	30000	30000	30000
Integral Mode	1	1	1	1
Integration Lim (1/16 cnt)	20000	20000	20000	20000
Big Step Limit (1/16 cnt)	8000	8000	8000	8000
Feed Rate (mm s^{-1})	50	25	25	5
Home Speed (mm s^{-1})	50	25	10	5
Acceleration Time (msec)	200	200	200	200
***Acceleration	250 mm s^{-2} 0.25 cnt $msec^{-2}$	125 mm s^{-2} 0.125 cnt $msec^{-2}$	125 mm s^{-2} 0.125 cnt $msec^{-2}$	10 mm s^{-2} 0.0067 cnt $msec^{-2}$
S-curve Time (msec)	50	50	50	50
Home Offset (mm)	80.000	-1.000	0.000	-1.500
Max Velocity (cnt $msec^{-1}$)	50 (50 mm s^{-1})	50 (25 mm s^{-1})	50 (25 mm s^{-1})	3.333 (5 mm s^{-1})
Max Accel (cnts $msec^{-2}$)	0.5	0.25	0.25	0.1
Position Tolerance (mm)	0.005	0.005	0.005	0.005
Following Error (1/16 cnt)	16000	16000	16000	5333
Hold Deceleration Rate	6576	6576	6576	6576
Err Decel Rate (cnts $msec^{-2}$)	10	5	5	5

History of servo parameter changes:

(1) 4/18/03 Mirror tilt axis proportional gain increased from 50000 to 100000 to stop oscillation problem near +0.388 mm, and possibly other locations

8.4 PMAC I/O

8.4.1 PMAC Input

MI1	-	FAULT1 (0 Indicates drive on and enabled. Formerly FLAG1)
MI2	-	FAULT2 (0 Indicates drive on and enabled. Formerly FLAG2)
MI3	-	FAULT3 (0 Indicates drive on and enabled. Formerly FLAG3)
MI4	-	FAULT4 (0 Indicates drive on and enabled. Formerly FLAG4)
MI5	-	ESTOP (1 indicates ESTOP button out.)
MI6	-	WFS MOTOR OVERTEMP (1 indicated a motor case temp > 60C)
MI7	-	Unused
MI8	-	XLT interlock to CAM SEL override readback. (1 indicates interlock o/r)

8.4.2 PMAC Output

MO1	-	TILT BRAKE Control	(1 = energise <release> brake.)
MO2	-	XLT BRAKE Control	(1 = energise <release> brake.)
M03	-	CAM SEL BRAKE Control	(1 = energise <release> brake.)
MO4	-	FOCUS BRAKE Control	(1 = energise <release> brake.)
MO5	-	CAMSEL/FOCUS encoder power. (1 = power on.)	
MO6	-	SERVO AC POWER	(1 = Servo power on.)
MO7	-	Brake Override	(1 allows brake operation w/axis disabled.)
MO8	-	AMP Reset	(1 resets all four Copley drives.)

8.5 LABJACK I/O

8.5.1 Terminal Block I/O

IO0	-	Analog MUX LSB	(MUX_A0)
IO1	-	Analog MUX 2LSB	(MUX_A1)
IO2	-	Analog MUX MSB	(MUX_A2)
IO3	-	Unused	

8.5.2 Multiplexing Code for Analog Inputs 1 and 2

MUX_A2,	A1,	A0	ANA_IN0	ANA_IN1
0	0	0	TILT Motor Temp.	HSK Temp. 1
0	0	1	XLT Motor Temp.	HSK Temp. 2
0	1	0	CAMSEL Motor Temp.	HSK Temp. 3
0	1	1	FOCUS Motor Temp.	HSK Temp. 4
1	0	0	TILT Struct. Temp.	HSK V1
1	0	1	XLT Struct. Temp.	HSK V2
1	1	0	CAMSEL Struct. Temp.	HSK V3
1	1	1	FOCUS Struct. Temp.	Drive Temp.

8.5.3 Analog Inputs 2 to 7 (Not Multiplexed)

ANA_IN2	-	MMTS-5100 PWB Temp.	10mV/K
ANA_IN3	-	+12V Readout	500mV = 1V
ANA_IN4	-	-12V Readout	500mV = 1V
ANA_IN5	-	+5V Readout	1V = 1V
ANA_IN6	-	V+TEMP Readout	500mV = 1V
ANA_IN7	-	V+LIM Readout	500mV = 1V

8.5.4 Analog Outputs

ANA_OUT0	-	Unused
ANA_OUT1	-	Unused

8.5.5 Digital Outputs

D00	-	SBIG Camera Power Control	(0 = ON)	(110VAC)
D01	-	APOGEE Camera Power Control	(0 = ON)	(110VAC)
D02	-	SPARE AC Power 1 Control	(0 = ON)	(110VAC)
D03	-	SPARE AC Power 2 Control	(0 = ON)	(110VAC)
D04	-	Puntino Power Control	(0 = ON)	(+12V)
D05	-	IFW Power Control	(0 = ON)	(+12V)
D06	-	Unused		
D07	-	Unused		
D08	-	Unused		
D09	-	Unused		
D10	-	Unused		
D11	-	Unused		
D12	-	Unused		
D13	-	Unused		
D14	-	Unused		
D15	-	Unused		

Note: For Labjack power control. Labjack powers-up with these bits set as inputs. This is a safe state for the power control. Bit states should be set high before setting bits aas outputs. Conversely, power could be switched by leaving bit states LOW and changing direction between Input (OFF) and Output (ON).

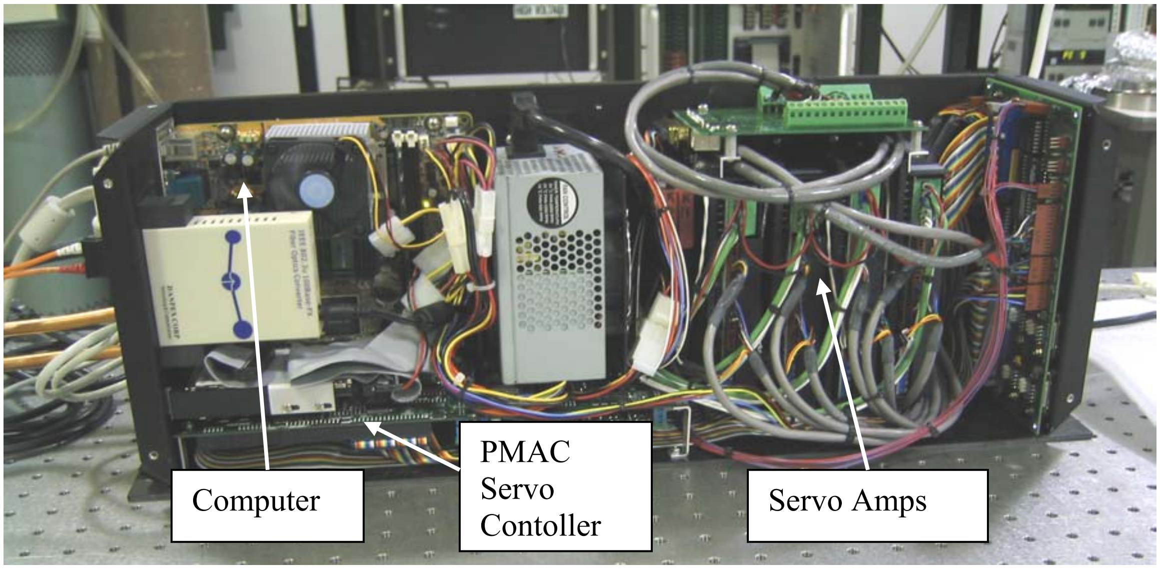


Figure 8. WFS electronics module. The computer motherboard is mounted vertically at the left of the box. The four servo amps are mounted to the right. The Delta Tau PMAC board is mounted horizontally on the bottom left. The Lab Jack IO board is the green board mounted above the servo amps.

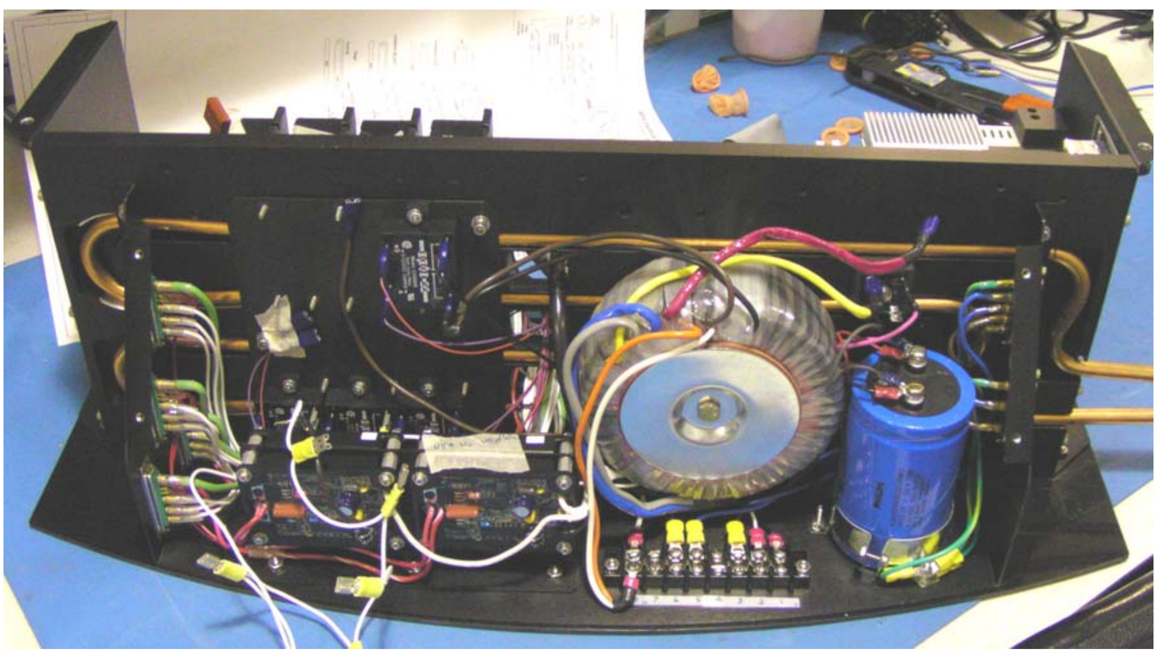


Figure 9. The reverse side of the electronics module containing the power supply for the servo amps and connectors. The optional cooling lines exit to the right.

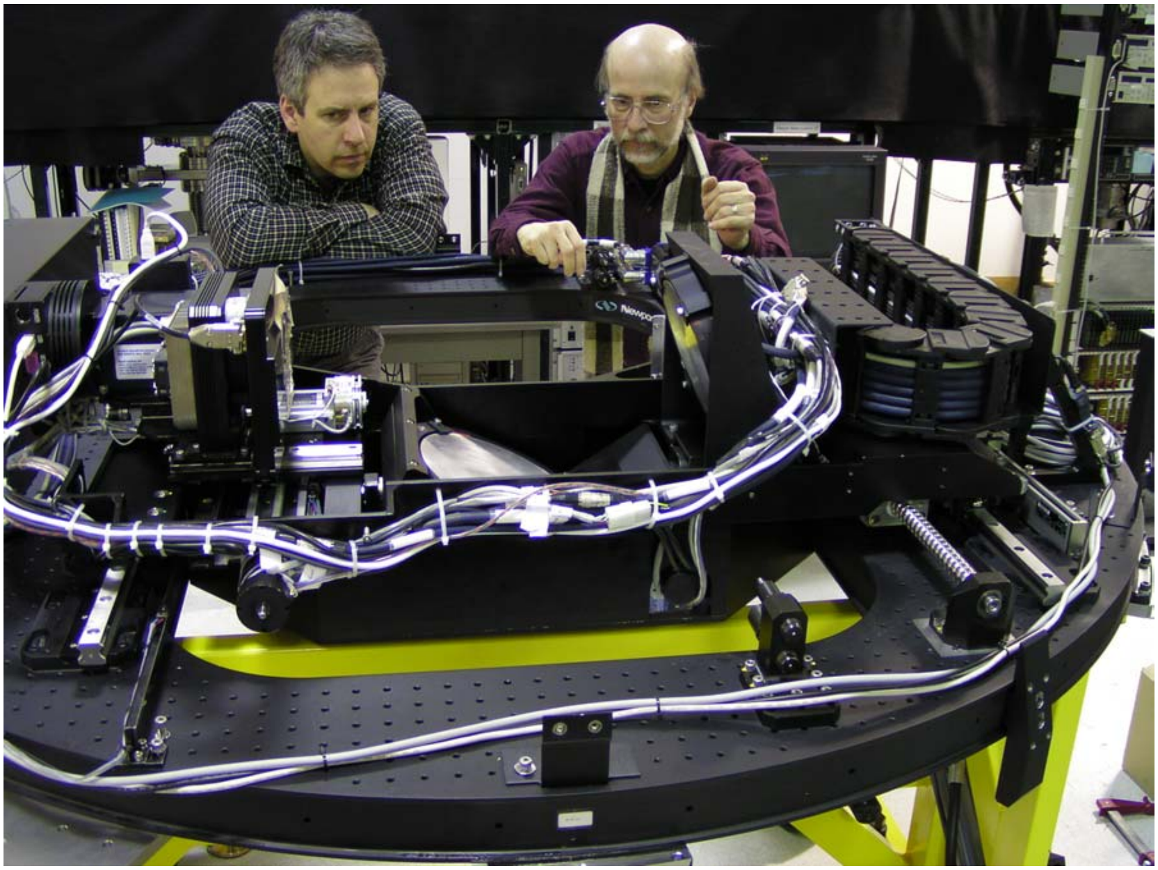


Figure 10. Wavefront sensor in the laboratory with the covers and cable wrap removed.

9 Off Axis Operation

When either the Puntino or the science camera is operated off axis in the spectroscopic mode of the corrector, the first fold mirror, M1, must be tilted to keep the image centered. This is necessary because the chief ray angle with respect to the optical axis increases with field angle, reaching 2.8° at the edge of the field of view. The tilt angle is half of the angle of the chief ray divided by $\cos^2(26°) = 0.80783$ to correct for the angle of M1. Other subtle features of off-axis operation include a slight rotation of the pupil and a small image displacement in the direction perpendicular to the tilt correction. The main reason to operate the Puntino off-axis will be to check for field-dependent low order aberrations caused by collimation errors. Correction of primary figure is best performed on-axis because the intrinsic aberrations of the "ideal" off-axis images are significant.

Field Angle (degrees)	Position of Field Translation Stage (mm)	Angle of Chief Ray (degrees)	Tilt Angle to set M1 (degrees)	Focus Position (mm)
0	0	0	0	0
.05	27.2	0.24	0.15	0.125
.10	54.4	0.49	0.30	0.480
.15	81.6	0.74	0.46	1.024
.20	108.8	1.00	0.62	1.707
.25	136.1	1.27	0.79	2.488
.30	163.3	1.54	0.95	3.334
.35	190.7	1.84	1.14	4.223
.40	218.1	2.15	1.33	5.138
.45	245.6	2.48	1.53	6.065
.50	273.2	2.84	1.76	6.993

10 Operating Modes

10.1 Shack Hartmann Wave Front Testing

The instrument will normally be deployed between exposures of one of the f/5 science instruments (e.g., Hectospec, Hectochelle, or Megacam) somewhat analogously to the way "stacking" was performed with the original MMT. Given that the wavefront sensor (WFS) is mounted in the instrument rotator approximately 65 cm above the focal surface, an f/5 pickoff mirror vignettes a good deal of the focal surface. Continuous operation of the WFS is therefore not practical with instruments like Hectospec/Hectochelle or Megacam that use the entire available focal surface.

The plan is to test the f/5 telescope optics on-axis at an interval yet to be determined, supplemented by occasional off-axis measurements. Each measurement will result in at least a pair of images: one of the reference dot pattern, and one (or more) providing the measurement of the f/5 optics. Both images are stored as FITS files on the WFS computer hard disk, where they can be uploaded to the MMT's WFS analysis software.

We expect that the most rapidly changing wavefront error will be telescope focus, and tracking focus through periodic deployment of the Puntino is unlikely to be satisfactory. Each of the f/5 instruments will derive focus information from their onboard guide cameras.

10.2 Observations with the Science Camera

The quick look science camera uses a 1024x1024 SITe CCD that is of professional quality. The read noise, which is dominated by the electronics, is high by current standards, and is advertised as 10-15 electrons RMS. The dark current is also higher than we see in typical professional instruments because the CCD is thermoelectrically cooled to about -30 °C. We expect about 2-3 electrons pixel^{-1} s^{-1} of dark current. As shown in the table below, the dark current is only a significant issue in the U band. The scale is about 0.14″ pixel^{-1}.

Apogee AP8p Characteristics

Pixel Size	24 µm (~0.14″)
Digitization	16 bits
Gain	4 electrons/ADC
Readout Noise	~10 electrons RMS
Dark Current	2-3 electrons pixel^{-1} s^{-1}
Readout Time (Full Frame)	30 seconds

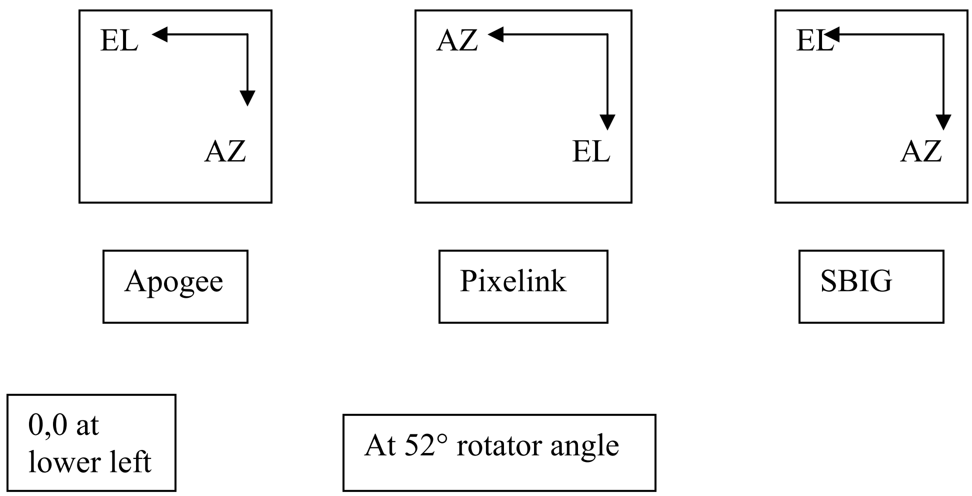
Cool Down Time	~50 °C in 20 minutes

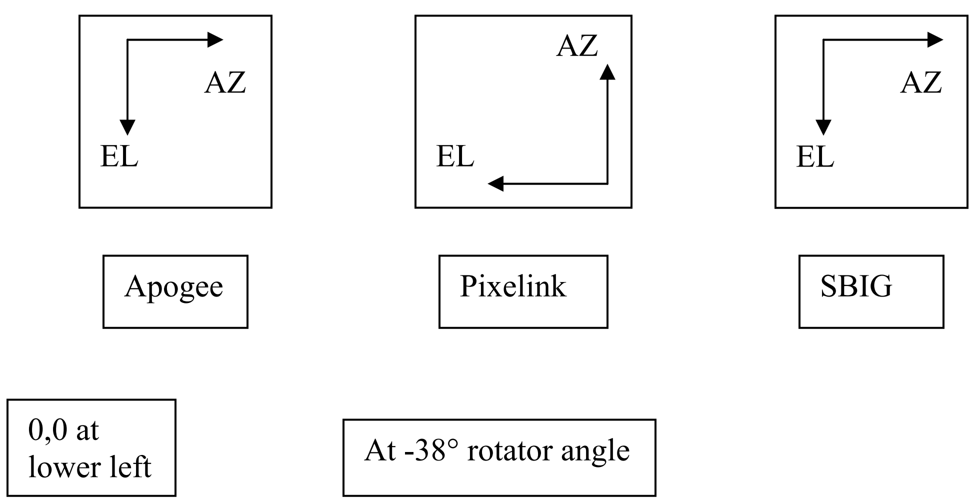
Filter	Minicam background e^{-1} pix^{-1} sec^{-1} at f/9 (13.5 µm pixels)	Estimated science camera bkgd at f/5 e^{-1} pix^{-1} sec^{-1} (24 µm pixels)
U	0.36	3.3
B	< 2.0	<18
V	2.6	24
R	4.5	41
I	11.1	101

The science camera uses an Optec Intelligent Filter Wheel that carries five 50 mm diameter filters. We have installed Bessel U,B,V,R, and I filters; these can be remotely selected under computer control. The filter transmission curves are reproduced below.

11 Alignment of Wavefront Sensor at MMT

The fixed point for the wavefront sensor energy chain was drilled on the cell cone reflected about the North-South axis from the proper position. As a result, the wavefront sensor must be mounted rotated 52° from the intended position in order to have sufficient rotational travel.





With the nominal 80 mm home offset on the field translation axis, a position of 5.0 mm on the field translation axis places the center of rotation at pixel 650, 688 in the Pixelink camera and pixel 514, 304 in the Apogee camera.

12 Wavefront Sensor Software and User Interface

A server runs on the wavefront sensor internal Windows XP Pro computer "wavefront". It accepts commands to control the wavefront sensor cameras and stages. Commands are sent via the f5wfs client program. This program must be in your path in order to address the wavefront sensor. A typical command line looks like:

f5wfs home

Command Interface:

home - home the wfs system.
stow - stow the wfs off axis.
sky - wfs views the sky.
ref - wfs views the reference light

In the following commands <camera> is wfs or sci.

select <camera >
setbox <camera> x1 nx y1 ny bin_factor (units are all pixels)
expose <camera> seconds file [exptype] (exptype is either light or dark)

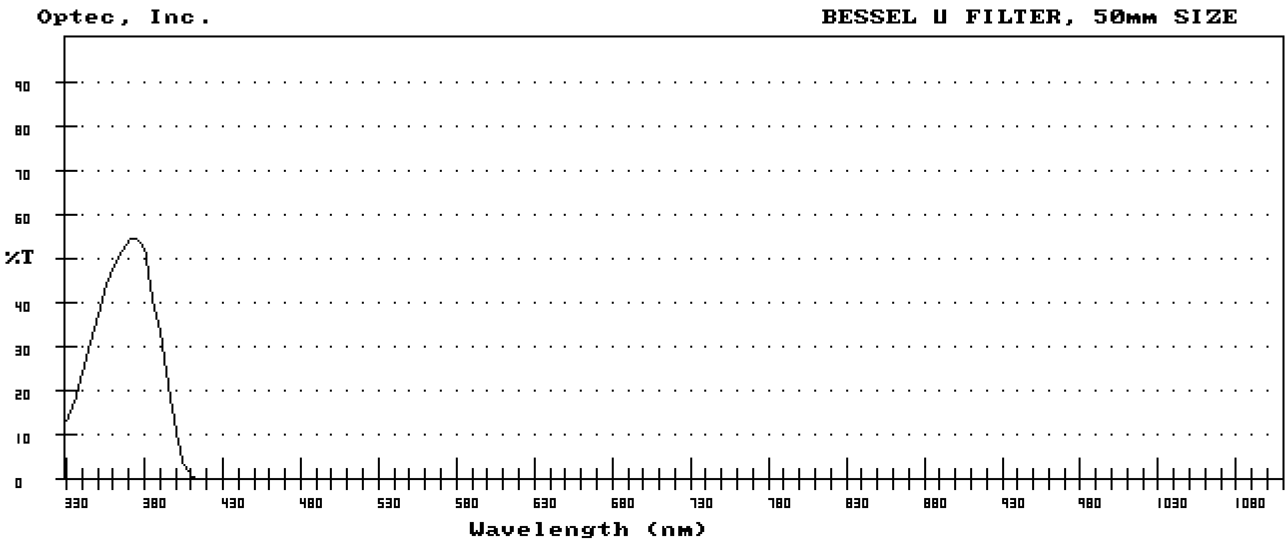
In the following commands <value> is in mm.

vset toffset <value> - set T axis offset
vset foffset <value> - set F axis offset

vset tinsoff <value> - set T axis instrument offset
vset finsoff <value> - set F axis instrument offset

vset wfscpos <value> - set wfs C axis position
vset wfstins <value> - set wfs T axis instrument offset
vset wfsfins <value> - set wfs F axis instrument offset

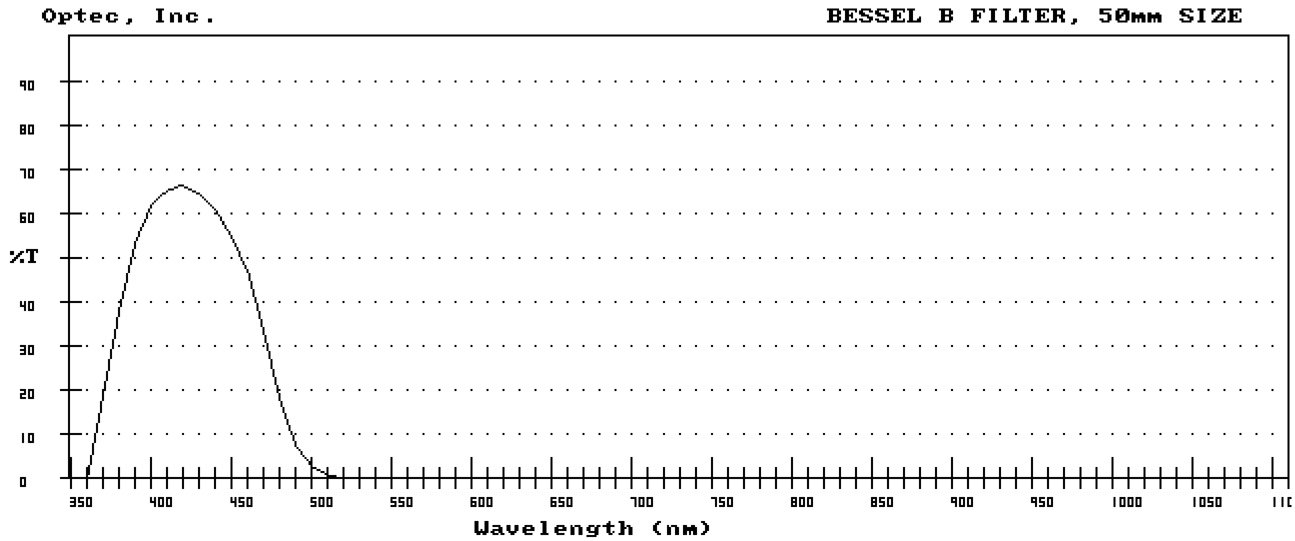
vset scicpos <value> - set sci C axis position
vset scitins <value> - set sci T axis instrument offset
vset scifins <value> - set sci F axis instrument offset



λ	T	λ	T	λ	T	λ	T	λ	T	λ	T	λ	T	λ	T	λ	T	λ	T
330	0.1305	405	0.0351	480	0	555	0	630	0	705	0	780	0	855	0	930	0	1005	0
335	0.1757	410	0.0110	485	0	560	0	635	0	710	0	785	0	860	0	935	0	1010	0
340	0.2457	415	0.0020	490	0	565	0	640	0	715	0	790	0	865	0	940	0	1015	0
345	0.3134	420	0	495	0	570	0	645	0	720	0	795	0	870	0	945	0	1020	0
350	0.3768	425	0	500	0	575	0	650	0	725	0	800	0	875	0	950	0	1025	0
355	0.4306	430	0	505	0	580	0	655	0	730	0	805	0	880	0	955	0	1030	0
360	0.4780	435	0	510	0	585	0	660	0	735	0	810	0	885	0	960	0	1035	0
365	0.5150	440	0	515	0	590	0	665	0	740	0	815	0	890	0	965	0	1040	0
370	0.5398	445	0	520	0	595	0	670	0	745	0	820	0	895	0	970	0	1045	0
375	0.5447	450	0	525	0	600	0	675	0	750	0	825	0	900	0	975	0	1050	0
380	0.5213	455	0	530	0	605	0	680	0	755	0	830	0	905	0	980	0	1055	0
385	0.3981	460	0	535	0	610	0	685	0	760	0	835	0	910	0	985	0	1060	0
390	0.3292	465	0	540	0	615	0	690	0	765	0	840	0	915	0	990	0	1065	0
395	0.2042	470	0	545	0	620	0	695	0	770	0	845	0	920	0	995	0	1070	0
400	0.0994	475	0	550	0	625	0	700	0	775	0	850	0	925	0	1000	0	1075	0

17250.DAT

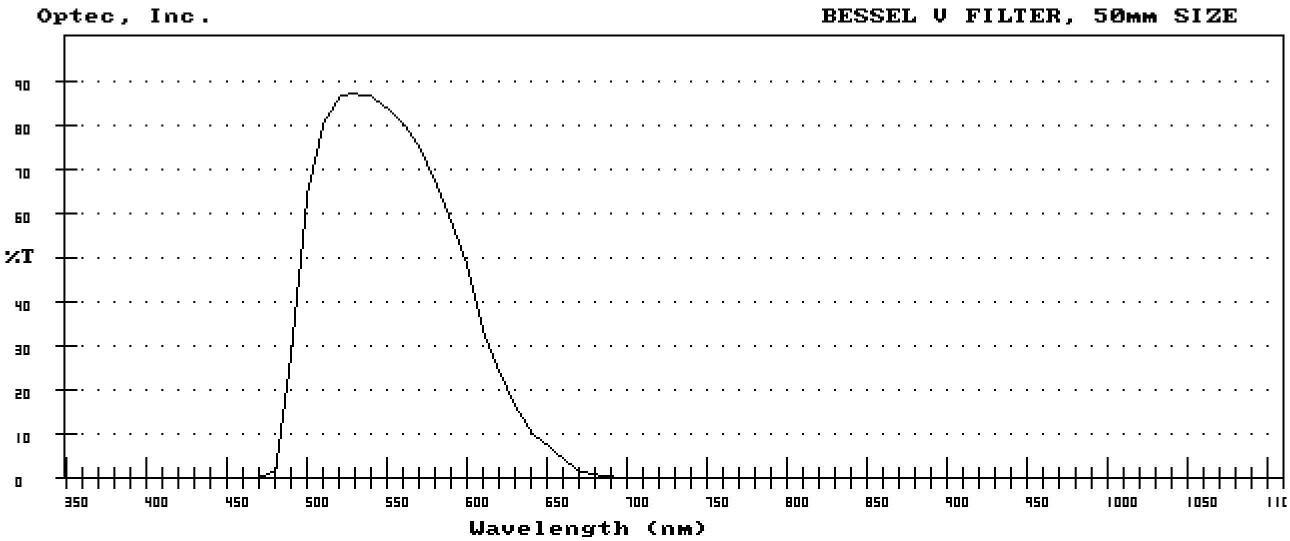
Figure 11. U filter transmission.



λ	T	λ	T	λ	T	λ	T	λ	T	λ	T
350	0	500	0.0293	650	0	800	0	950	0	1100	0
360	0	510	0.0077	660	0	810	0	960	0		
370	0.1892	520	0.0013	670	0	820	0	970	0		
380	0.3811	530	0	680	0	830	0	980	0		
390	0.5347	540	0	690	0	840	0	990	0		
400	0.6184	550	0	700	0	850	0	1000	0		
410	0.6512	560	0	710	0	860	0	1010	0		
420	0.6615	570	0	720	0	870	0	1020	0		
430	0.6436	580	0	730	0	880	0	1030	0		
440	0.6112	590	0	740	0	890	0	1040	0		
450	0.5445	600	0	750	0	900	0	1050	0		
460	0.4678	610	0	760	0	910	0	1060	0		
470	0.3311	620	0	770	0	920	0	1070	0		
480	0.1756	630	0	780	0	930	0	1080	0		
490	0.0741	640	0	790	0	940	0	1090	0		

17446.DAT

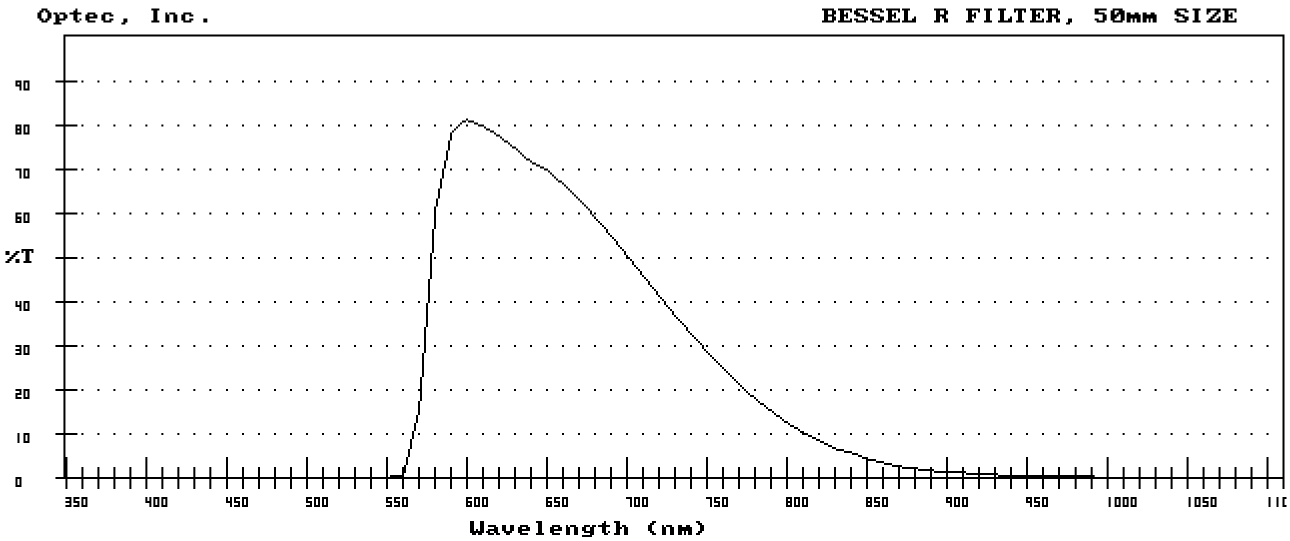
Figure 12. B filter transmission.



λ	T	λ	T	λ	T	λ	T	λ	T	λ	T
350	0	500	0.6471	650	0.0763	800	0	950	0	1100	0
360	0	510	0.8041	660	0.0440	810	0	960	0		
370	0	520	0.8642	670	0.0196	820	0	970	0		
380	0	530	0.8731	680	0.0084	830	0	980	0		
390	0	540	0.8670	690	0.0036	840	0	990	0		
400	0	550	0.8415	700	0	850	0	1000	0		
410	0	560	0.8023	710	0	860	0	1010	0		
420	0	570	0.7485	720	0	870	0	1020	0		
430	0	580	0.6720	730	0	880	0	1030	0		
440	0	590	0.5840	740	0	890	0	1040	0		
450	0	600	0.4829	750	0	900	0	1050	0		
460	0	610	0.3315	760	0	910	0	1060	0		
470	0	620	0.2406	770	0	920	0	1070	0		
480	0.0154	630	0.1617	780	0	930	0	1080	0		
490	0.2855	640	0.1024	790	0	940	0	1090	0		

17447.DAT

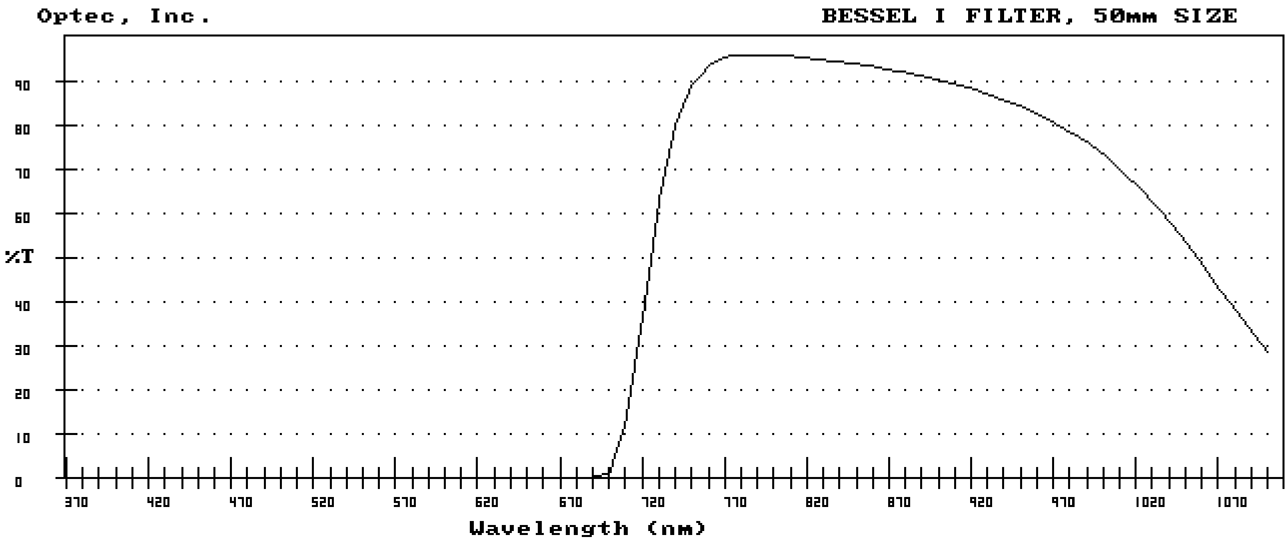
Figure 13. V filter transmission.



λ	T	λ	T	λ	T	λ	T	λ	T	λ	T
350	0	500	0	650	0.7018	800	0.1275	950	0.0047	1100	0
360	0	510	0	660	0.6668	810	0.1056	960	0.0039		
370	0	520	0	670	0.6327	820	0.0878	970	0.0032		
380	0	530	0	680	0.5918	830	0.0703	980	0.0025		
390	0	540	0	690	0.5494	840	0.0572	990	0.0025		
400	0	550	0	700	0.5025	850	0.0457	1000	0.0020		
410	0	560	0.0045	710	0.4583	860	0.0363	1010	0.0020		
420	0	570	0.1573	720	0.4127	870	0.0288	1020	0.0014		
430	0	580	0.6094	730	0.3687	880	0.0230	1030	0.0016		
440	0	590	0.7803	740	0.3261	890	0.0177	1040	0.0008		
450	0	600	0.8124	750	0.2870	900	0.0139	1050	0.0011		
460	0	610	0.7980	760	0.2490	910	0.0115	1060	0.0013		
470	0	620	0.7778	770	0.2135	920	0.0093	1070	0		
480	0	630	0.7506	780	0.1813	930	0.0072	1080	0		
490	0	640	0.7183	790	0.1527	940	0.0063	1090	0		

17448.DAT

Figure 14. R filter transmission.



λ	T	λ	T	λ	T	λ	T	λ	T
370	0	520	0	670	0.0014	820	0.9553	970	0.8102
380	0	530	0	680	0.0013	830	0.9504	980	0.7872
390	0	540	0	690	0.0011	840	0.9463	990	0.7625
400	0	550	0	700	0.0111	850	0.9420	1000	0.7347
410	0	560	0	710	0.1229	860	0.9359	1010	0.7017
420	0	570	0	720	0.3741	870	0.9291	1020	0.6672
430	0	580	0	730	0.6382	880	0.9220	1030	0.6260
440	0	590	0	740	0.8058	890	0.9137	1040	0.5829
450	0	600	0	750	0.8907	900	0.9054	1050	0.5369
460	0	610	0	760	0.9367	910	0.8961	1060	0.4845
470	0	620	0	770	0.9525	920	0.8853	1070	0.4324
480	0	630	0	780	0.9578	930	0.8731	1080	0.3805
490	0	640	0	790	0.9586	940	0.8599	1090	0.3320
500	0	650	0	800	0.9575	950	0.8458	1100	0.2850
510	0	660	0	810	0.9578	960	0.8289		

17449.DAT

Figure 15. I filter transmission.