Prominence Magnetometer Optics and Control

Rev.2 includes many suggestions by attendees at the ProMag meeting of 30 March, 2006.
Rev. 3 includes LC Drive, moving IR focus to retarder rotation, and FLC modulator.

Requirements:

Spectrum Lines:	587.6nm and 1083.0nm simultaneously and co-spatially
	656.3nm and 1083.0nm simultaneously and co-spatially
	Other lines one at a time between 587.6nm and 1350nm (goal)
Field:	Span a prominence, > 100 arc seconds
Spatial resolution:	2 to 4 arc seconds
Spectral resolution;	5pm @ 587.6nm
Polarimetry:	I, Q, U, and V: noise < .001 $I_{continuum}$ (< .0005 $I_{continuum}$ goal)

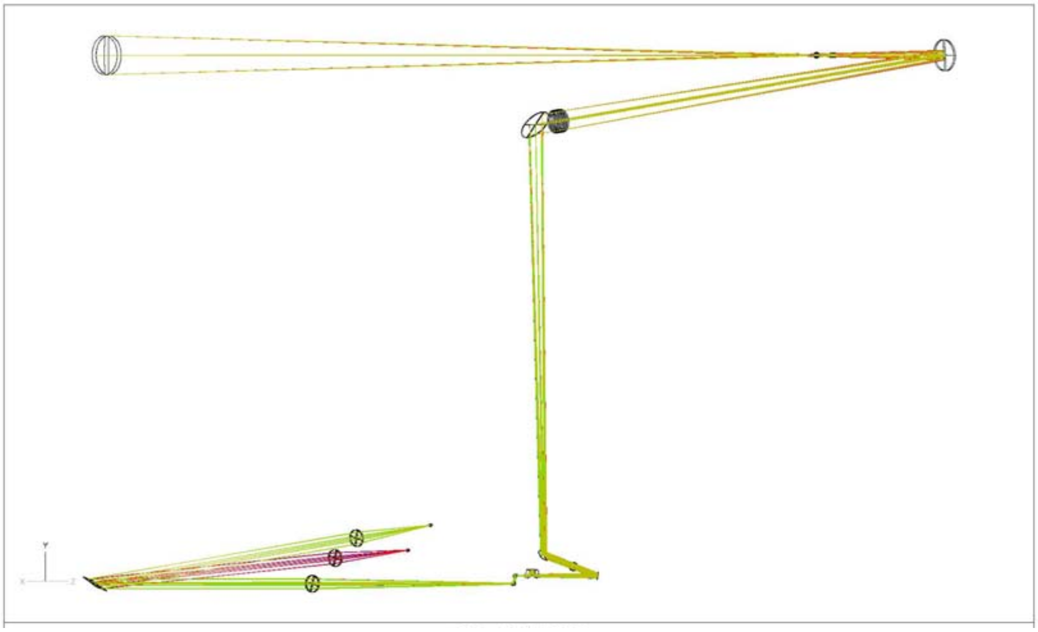
Constraints:

Cameras:	PixelVision Pluto, 652 x 488, 12µm pixels
	Rockwell IR camera, 1024 x 1024, 18µm pixels
Telescope:	Evans Solar Facility, 40cm coronagraph, East bench, and ESF control.

Design:

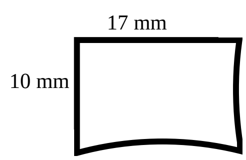
Telescope:

The 40cm aperture coronagraph in the Evans Solar Facility has low scatter, and low polarization preceding the prime focus. The polarization modulator and analyzer go at the prime focus so that following optics do not affect the polarization measurement. The polarimeter at the prime focus must rotate so that the orientation of the spatially separated dual beams is as desired (normally radial). An image rotator at East Bench is then required to align these beams with the entrance slit of the spectrograph. The telescope has been modeled in ZEMAX. Steve Hegwer provided an initial ZEMAX prescription. This has been updated with the as measured values for the O_2 surfaces and the actual angle between the beam for O_1 to F_1 and from F_1 to O_2 (7.45º).

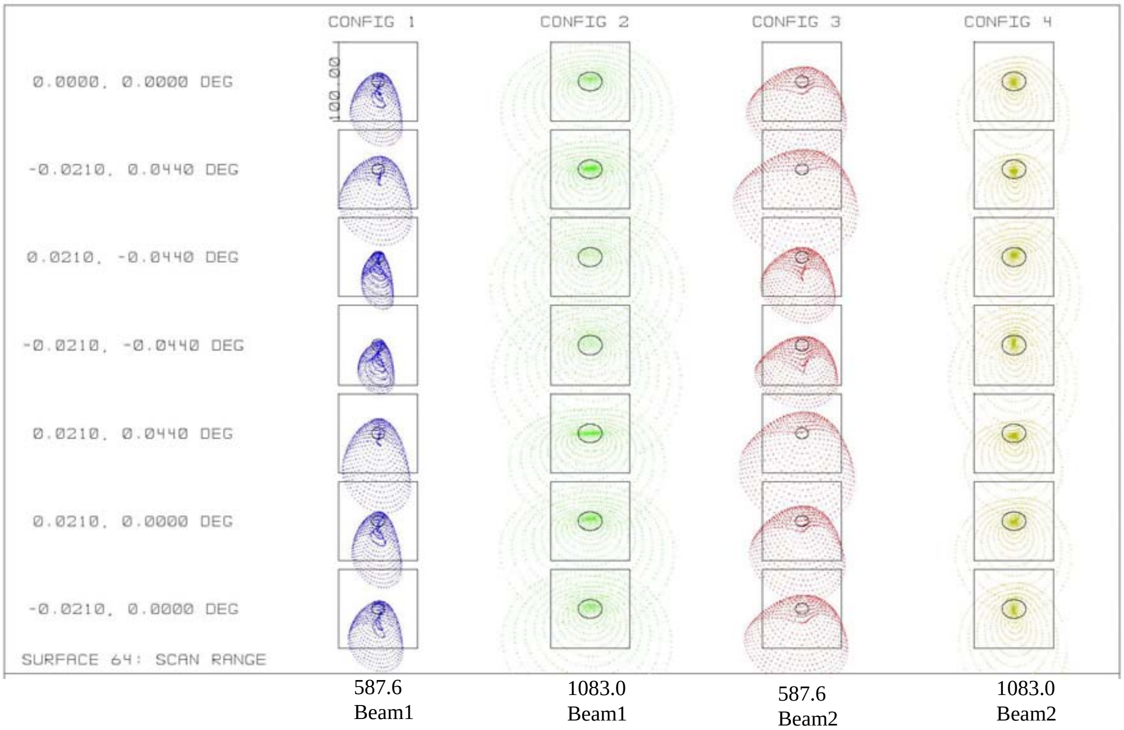


Focal Length: 11916mm
Plate Scale: 57.77 μm/arc-second, 17.31 arc-seconds/mm
Field of View: 151 arc-seconds x 317 arc-seconds

The design calls for a round pre-inverse occulter 22mm in diameter ahead of all prime focus optical elements. At the same focal position is an inverse occulter of the proper diameter for the Air Force coronal emission line scans. Also in the design is an inverse occulter mid way between the focal points for 587.6nm and 1083.0nm. The size of the aperture is 10mm x 17mm which will allow an unvignetted 151 arc second x 317 arc second field of view. Two sides of this inverse occulter have curved surfaces to match the mean diameter of the Sun. The radius of curvature of the mean solar image is 37.50 mm.



Dick Dunn's wonderful seven element second objective does a good job of eliminating chromatic aberration over visible wavelengths. Between 587.6nm and 1083.0nm, however, there is a focal shift. For the coronagraph alone without the ProMag optics this shift is 25mm with the 1083.0nm image ahead of the 5876.nm image (opposite in sign to what happens with a singlet lens). The focus positions of the two lines are changed with the considerable thickness of glass added by the polarimeter and image rotator. These tend to bring the focal points of the two lines closer together. The result is that the focal positions are within about 6mm. Considering other aberrations such as those due to the Wollaston prisms, this is small enough to neglect. The spot diameter at the slit is comparable to the slit size.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CONFIG 2
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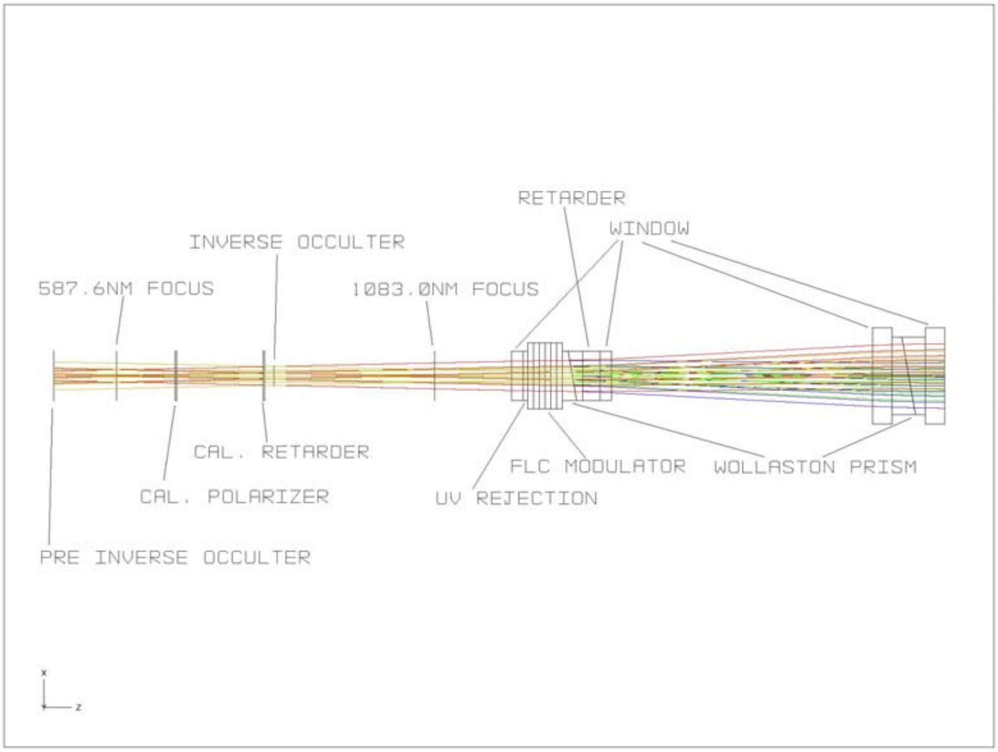
0.0210, 0.0000 DEG
-0.0210, 0.0000 DEG
SURFACE 64: SCAN RANGE
587.6
Beam1
1083.0
Beam1
587.6
Beam2
1083.0
Beam2

Polarization modulation/analysis unit

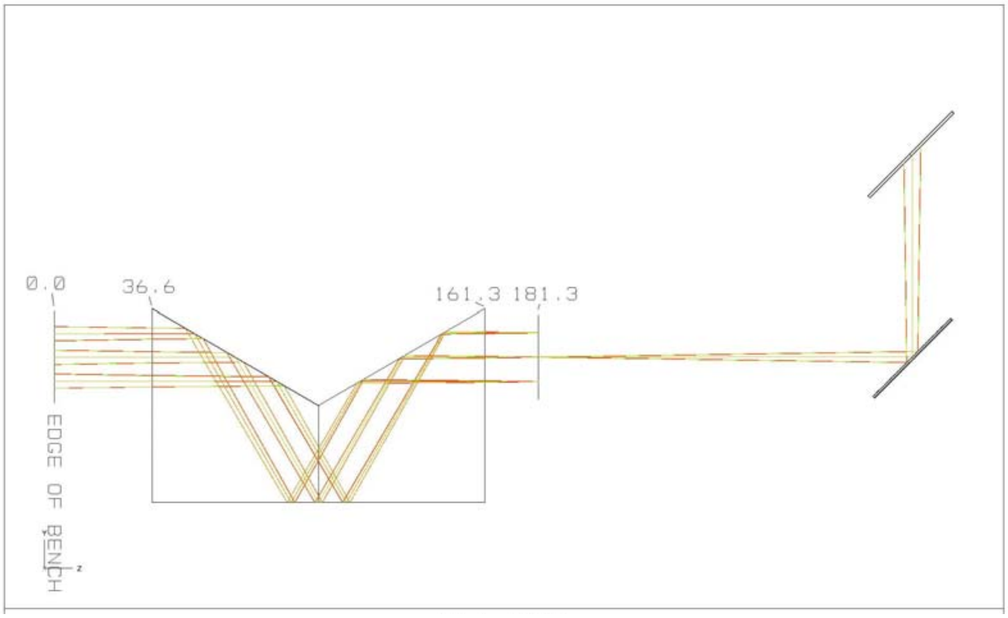
Polarization modulation and analysis are both at prime focus to avoid instrumental polarization before the modulator and variation of polarization response matrix with solar elevation if the analyzer were to follow the coudé mirror. The polarimeter package at prime focus replaces the normal occulting unit. It has two positions, one for prominence magnetometry, the other has a choice of two inverse occulters which can be used for the Air Force coronal photometer. The modulator is a pair of liquid crystals. In front of the modulator is a UV blocking filter to protect the liquid crystal material. A calibration linear polarizer and calibration retarder can simultaneously be placed in the beam in front of all other optics. The linear polarizer and retarder rotate to any angle. Behind the liquid crystals is a Wollaston prism, a half wave retarder, and another Wollaston prism. The prisms separate the two orthogonally polarized beams by approximately 9mm then make them parallel.



The entire polarimeter rotates so that the beam separation from the Wollaston prisms can be placed in the solar radial direction for any given solar azimuth.

Image Rotator

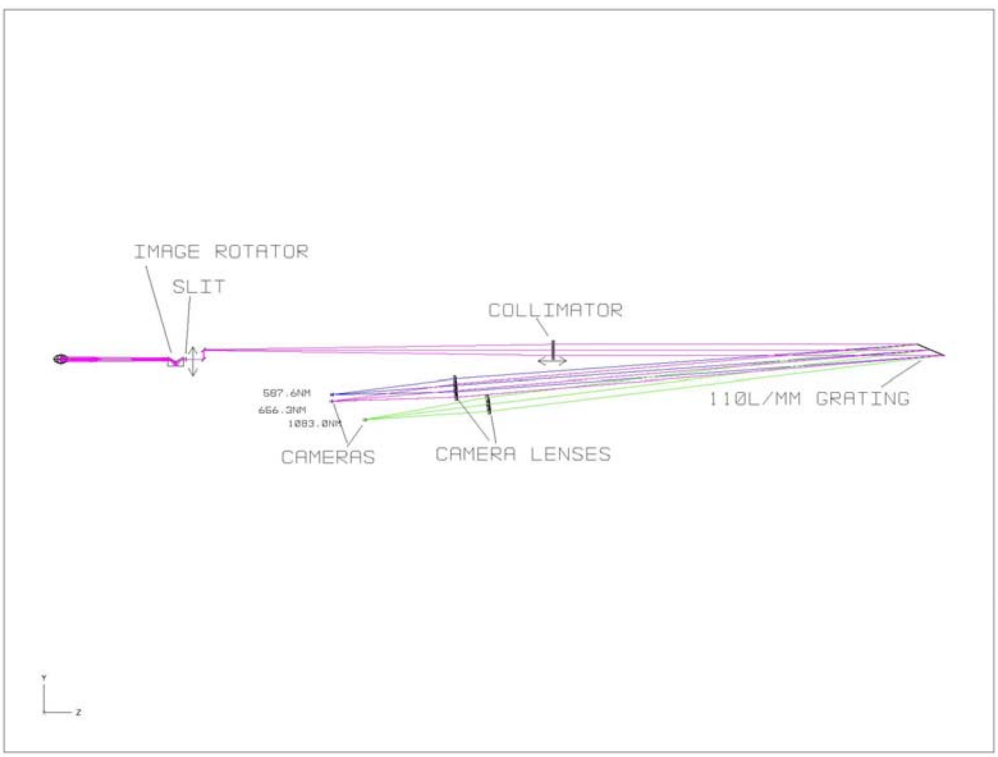
The separated beams from the Wollaston prisms need to be aligned in the spatial dimension at the slit. To perform this function and to maintain this alignment as the telescope moves in hour angle, an image rotator is placed in front of the slit.



Spectrograph

The Prominence Magnetometer uses a new spectrograph constructed on the East Bench. It uses a 110 line/mm, 64° blaze angle grating from Newport RGL. A slit width of 72µm is equivalent to 1.24 arc seconds on the Sun. This is the nominal width providing spatial resolution between 2 and 4 arc seconds and is a multiple of the spatial pixel size. Since there is sufficient flux to avoid read noise, pixels will not be binned in the camera though could be after the fact to improve signal to noise. Refractive optics are used in the spectrograph due to large angle of reflection difference between the visible and IR lines. The spectrograph uses a collimator lens with 3m focal length and camera lenses of 1 m focal length. Angles of reflection are nearly the same for 587.6 and 656.3 (52°), and for 854.2 and 1083.0 (50°).

Rockwell spatial sample:	0.935 arc seconds/pixel	
Pluto spatial sample:	0.62 arc seconds/pixel	
Spatial pixel height:	1.87 arc seconds @ 108µm	(3 Pluto, 2 Rockwell pixels)
	1.24 arc seconds @ 72µm	(2 Pluto pixels)
	0.935 arc seconds @ 54µm	(1 Rockwell pixel)
	0.62 arc seconds @ 36µm	(1 Pluto pixel)



An angle of incidence of 67° is used so that the two primary lines fall comfortable away from the input beam. Both lines are detected with good efficiency and spectral resolution meeting the requirement. Resolution shown is the root sum square of the spectral slit width, spectral pixel width, and grating resolution. Some additional lines are shown. Due to angles of reflection for various lines, an arbitrary combination is not possible.

The following table assumes a slit width of 72µm, 1.24 arc seconds.

Wavelength (nm)	Pixel width (pm)	Slit width (pm)	RSS Resolution (pm)	Length (nm)	Efficiency
587.6	1.78	3.05	3.64	0.87	0.66
1083.0	5.45	5.68	8.43	5.58	0.97
656.3	2.04	3.41	4.12	0.99	0.87
854.2	2.88	4.49	5.66	1.41	0.93
1435.0	8.60	7.75	12.80	8.81	0.37

The full length of the Pluto camera CCD is needed to record the two spatially separated beams along the long 652 pixel axis of the detector. Of these, 242 are illuminated by each beam and the two beams are separated by 157 pixels. The short 488 pixel axis is in the spectral direction. The Rockwell camera has 1024 pixels in both axes. There are 161 pixels illuminated in each beam and 86 pixels separate the two beams.

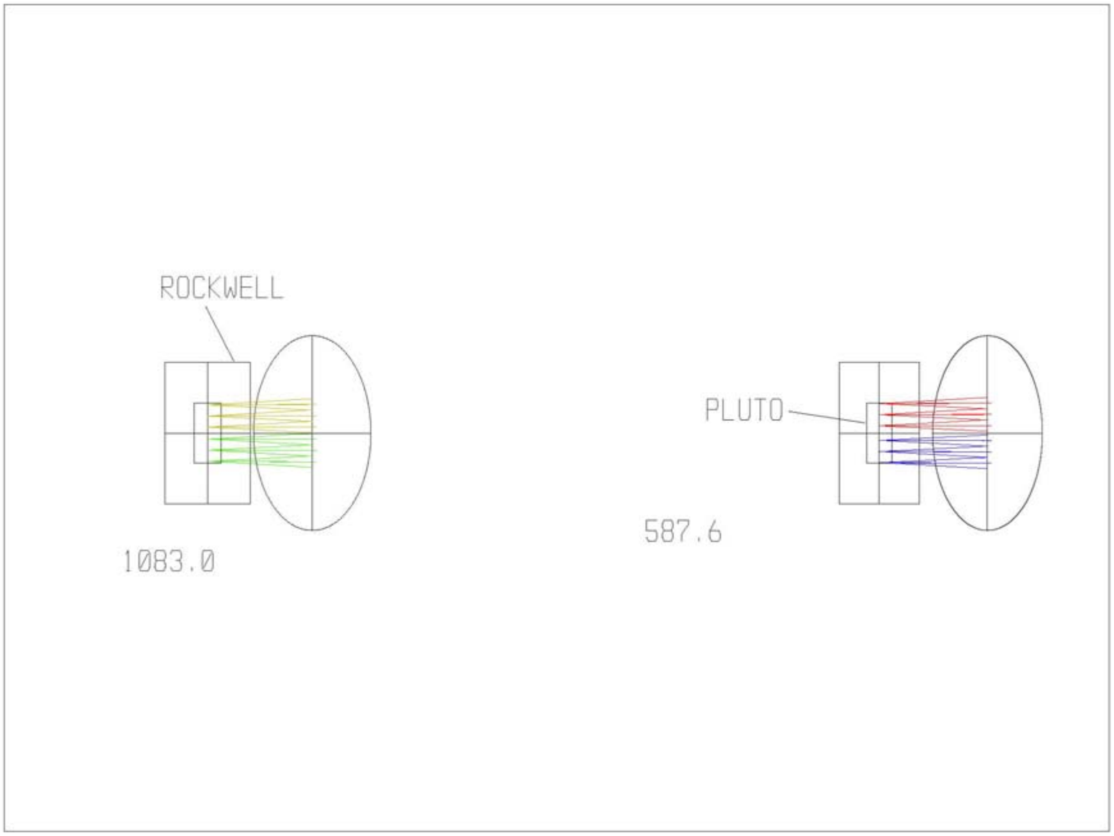
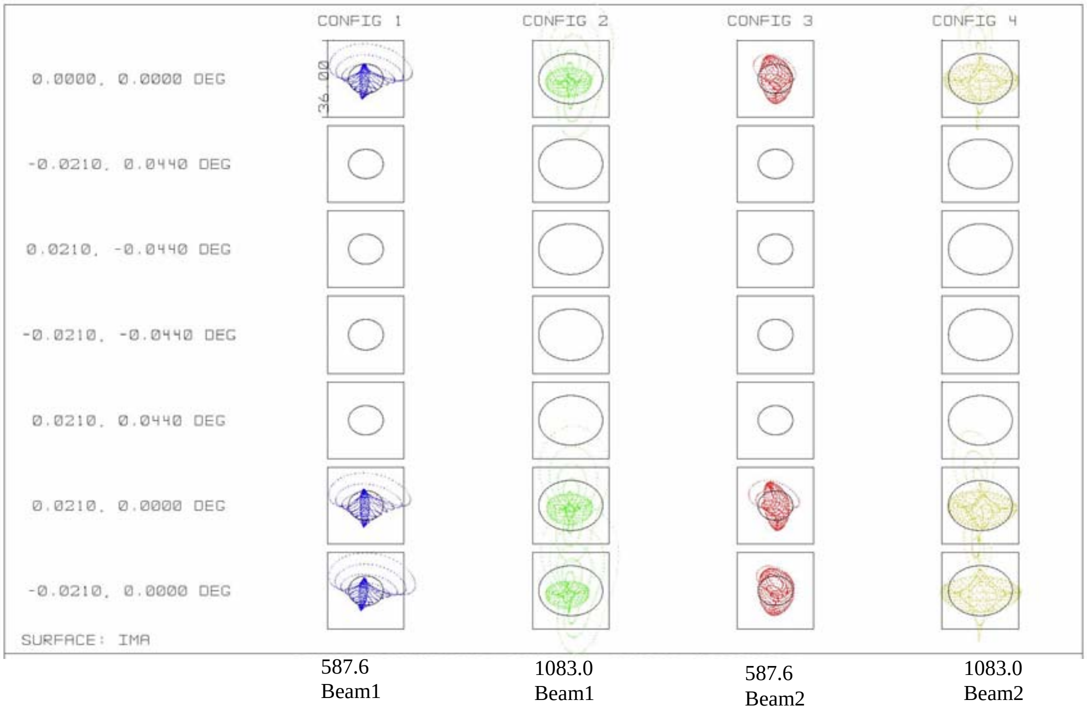


Image quality in the spectrograph is shown by the spot diagram in the focal plane. Ellipses show the diffraction spot size. Boxes are 36 µm across, 2 Rockwell pixels or 3 Pluto pixels.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0.0210, 0.0440 DEG
0.0210, 0.0000 DEG
-0.0210, 0.0000 DEG
36.00
SURFACE: IMA
587.6
Beam1
1083.0
Beam1
587.6
Beam2
1083.0
Beam2

Flux Budget:

A flux budget has been constructed using estimates for transmissions of all the optical elements, nominal spatial sample size, and spectrograph spectral sample size and efficiency. Assumed prominence brightness was 1% for visible lines and 2% for IR lines. The spreadsheet is shown as well as polarization signal to noise vs. wavelength for an 8.6 second integration. The polarization noise level is well below 10^{-3} for all wavelengths, even for the 1% of disk brightness assumed for the visible lines.

ProMag 587.6 and 1083.0 Flux Budget and others 17-Aug-06

Prominence Brightness

Wavelength nm	Line Bright. Bline/B0	I sun erg/cm2-s-strad-A	I line erg/cm2-s-strad-A	Phot Energy erg/hnu	I line hnu/cm2-s-strad-A
587.60	1.00e-2	2.96e+6	2.96e+4	3.38e-12	8.76e+15
656.30	1.00e-2	2.50e+6	2.50e+4	3.03e-12	8.25e+15
854.20	2.00e-2	1.53e+6	3.06e+4	2.33e-12	1.31e+16
1083.00	2.00e-2	9.50e+5	1.90e+4	1.83e-12	1.04e+16

Sky Brightness

Wavelength nm	Sky Bright. Bsky/B0	I sun erg/cm2-s-strad-A	Isky erg/cm2-s-strad-A	Phot Energy erg/hnu	Isky hnu/cm2-s-strad-A	Isky + Iline hnu/cm2-s-strad-A
587.60	3.69e-5	2.96e+6	1.09e+2	3.38e-12	3.22e+13	8.79e+15
656.30	3.30e-5	2.50e+6	8.25e+1	3.03e-12	2.72e+13	8.28e+15
854.20	2.54e-5	1.53e+6	3.89e+1	2.33e-12	1.67e+13	1.31e+16
1083.00	2.00e-5	9.50e+5	1.90e+1	1.83e-12	1.04e+13	1.04e+16

Telescope Parameters 40 cm aperture 25 f/ratio

Telescope cm^2	1 Glass surface	Number of uncoated surfaces	Total Glass	Filter & grating	5 0.9	Telescope eff. cm2
1257	0.96	8	0.72	0.25	0.59	133
1257	0.96	8	0.72	0.25	0.59	133
1257	0.96	8	0.72	0.25	0.59	133
1257	0.96	8	0.72	0.25	0.59	133

Sample Parameters Frame rate 0.057142857

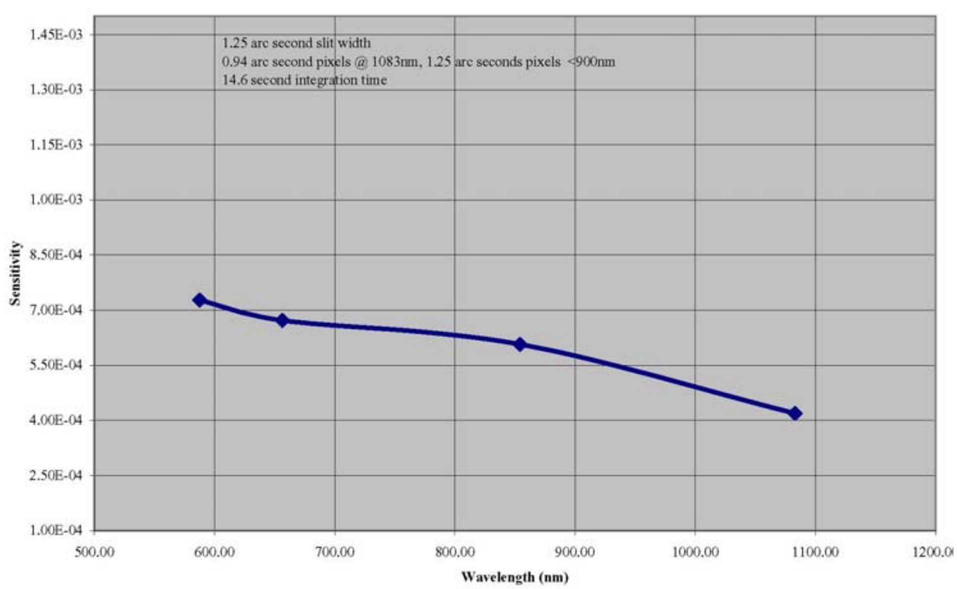
Pixel size A	D.Q.E	Pixel size arc-sec	Slit Width arc-sec	Pixel Size strad	Exp. Time (sec)	Pixel Sample strad-s-cm2-A
0.0178	0.78	0.625	1.25	1.84e-11	0.0571	1.94E-12
0.0204	0.85	0.625	1.25	1.84e-11	0.0571	2.42E-12
0.0288	0.45	0.625	1.25	1.84e-11	0.0571	1.81E-12
0.0545	0.80	0.938	1.25	2.75e-11	0.0571	9.11E-12

Noise Contributions pol efficiency 0.5 100,000 Full well

Flux e-/frame	Read Noise e-/frame	Photon Noise e-/frame	Total Noise e-/frame	Pol. Signal e-/frame	Saturation?
17053	50	131	140	8527	OK
20038	50	142	151	10019	OK
23711	50	154	162	11856	OK
94744	75	308	317	47372	OK

Signal to Noise

Signal/Noise 1/frame	Spatial Binning	Signal/Noise 1/frame	Integration reads	Signal/Noise per integration	Wavelength nm	Min S:N	Observing time sec
61	2	86	256	1376	587.60	7.27E-04	14.6
66	2	93	256	1488	656.30	6.72E-04	14.6
73	2	103	256	1648	854.20	6.07E-04	14.6
149	1	149	256	2384	1083.00	4.19E-04	14.6



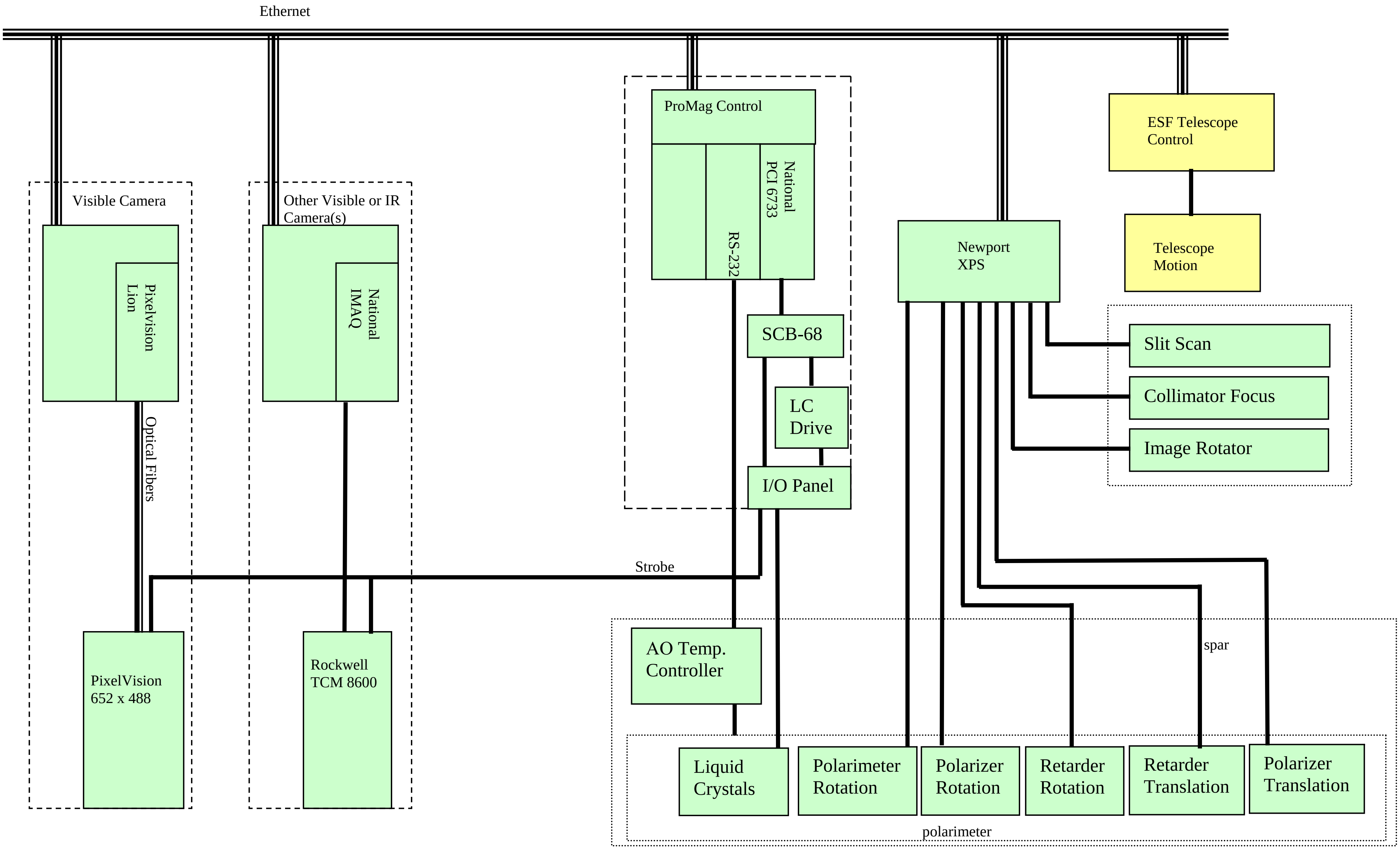
Control System:

NSO ESF control system: This is used to set up the telescope for the limb observations. Pointing, occulting assembly X-Y-Z motion, O2 focus, telescope aperture, diffuser in or out, and the position of relay optics are adjusted manually through the ESF control system. No connection is required between the ESF control system and the magnetometer control system, though communication of solar coordinates would be a plus.

Pluto camera control system: Camera control software is based upon that used for SPINOR. This is the existing 'Netspin' application with TCP/IP control. This configuration expects strobes to the camera, and the computer receives modulator position information via TCP/IP.

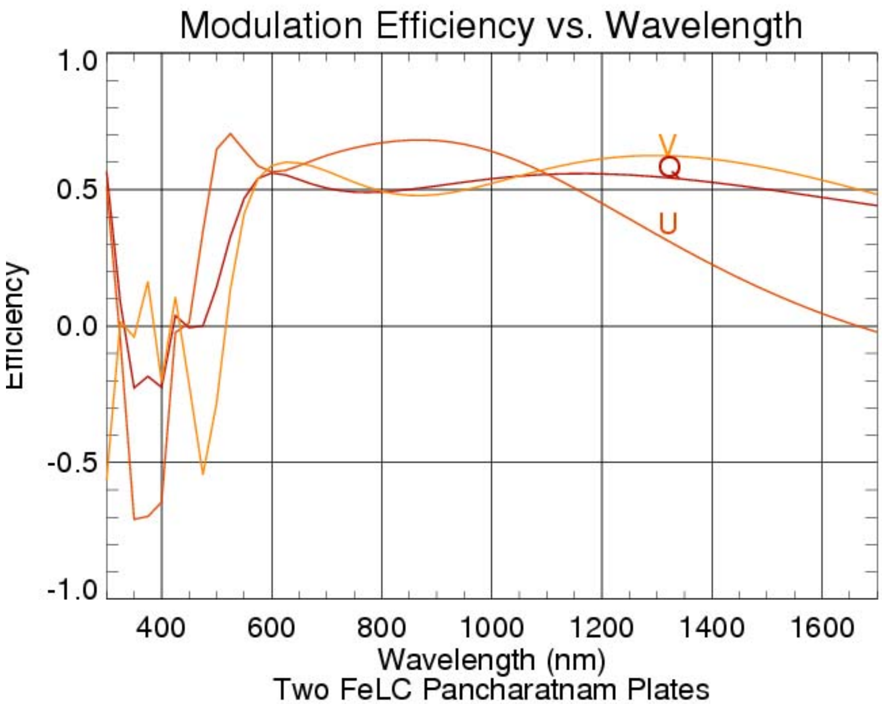
IR camera control system: Camera control software is based upon that used for SPINOR. This is the existing LabView application with TCP/IP control. This configuration expects strobes to the camera, and the computer receives modulator position information via TCP/IP.

Experiment control system: Software controls the LCs and distributes read strobes and modulator status to the PixelVision camera and IR camera control. Control of polarimeter rotation is on this machine. It also drives the translation mechanisms for the slit and collimating lens. This is an entirely new application expected to have an experiment control application and a GUI application. ProMag experiment control is discussed in detail in another memo.

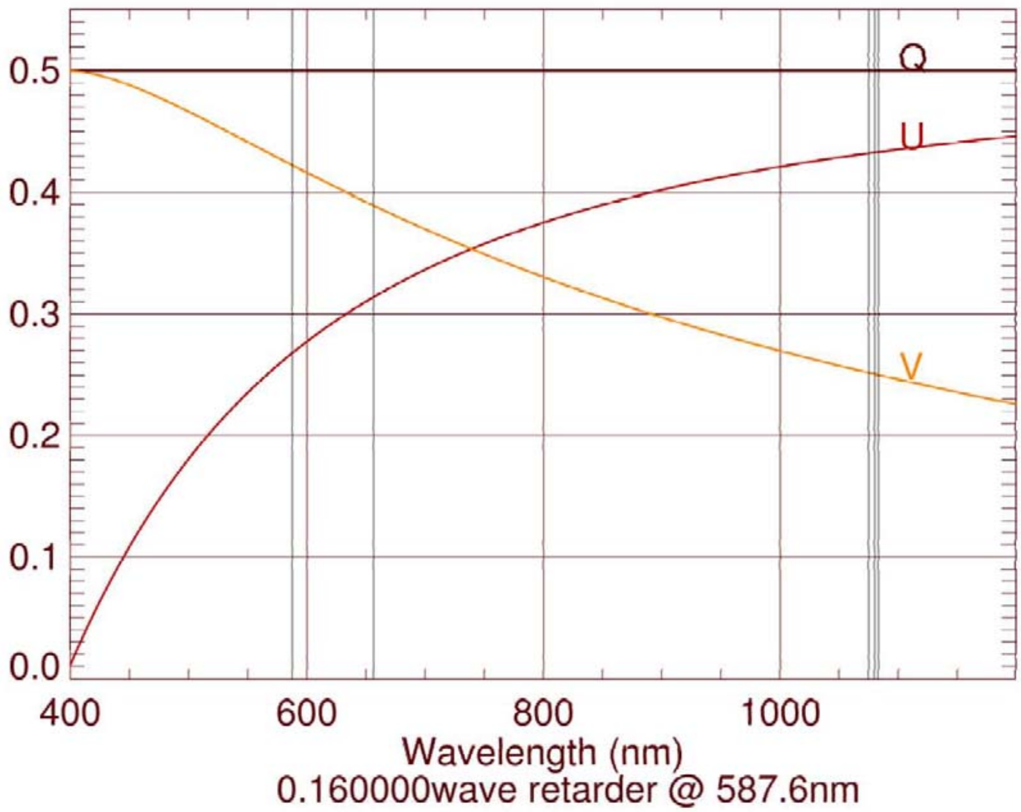

Ethernet
Visible Camera
Pixelvision Lion
Optical Fibers
PixelVision 652 x 488
Other Visible or IR Camera(s)
National IMAQ
Rockwell TCM 8600
Strobe
ProMag Control
RS-232
National PCI 6733
SCB-68
LC Drive
I/O Panel
Newport XPS
ESF Telescope Control
Telescope Motion
Slit Scan
Collimator Focus
Image Rotator
AO Temp. Controller
spar
Liquid Crystals
Polarimeter Rotation
Polarizer Rotation
Retarder Rotation
Retarder Translation
Polarizer Translation
polarimeter

Polarimerty

The polarization modulator is to be a pair of achromatic ferrorlectric liquid crystal (FLC) retarders. Each retarder is a Pancharatnam plate consisting of three FLCs. Predicted efficiency of this modulator design is good between 587.6nm and 1083.0nm.



Calibration will be done using a linear polarizer (Versalight) followed by a compound zero order quartz retarder. This retarder has a retardation of 0.25 waves at 400nm or 0.16 waves at 587.6nm. The magnitude of modulation of intensity over one rotation of the linear polarizer keeping the retarder fixed is an indicator of calibration efficiency. The calibration scheme uses sufficient combinations of orientations of the polarizer and retarder so that the retardation of the retarder is determined as part of the calibration.


0.5
0.4
0.3
0.2
0.1
0.0
400
600
800
1000
Q
U
V
Wavelength (nm)
0.160000wave retarder @ 587.6nm

-End-