NASA-CR-200685

FINAL REPORT

Vector Magnetograph Design

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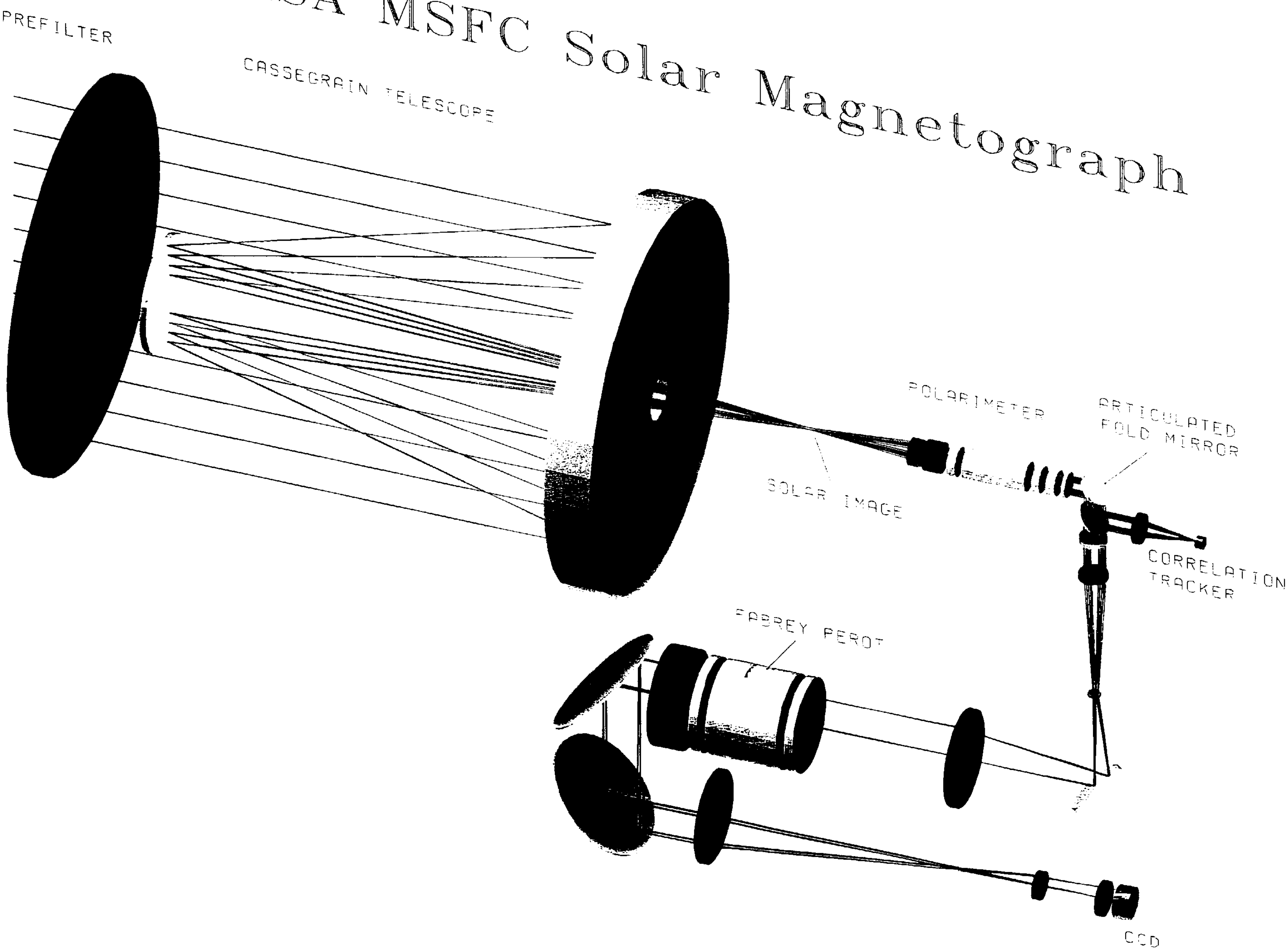
University of Alabama in Huntsville

March 1, 1996

To: Solar Physics Branch
Space Sciences Laboraotry
Marshall Space Flight Center

Contract NAG8-1112

NASA MSFC Solar Magnetograph



Final Report
Vector Magnetograph Design

This report covers work performed during the period of November 1994 through March 1996 on the design of a Space-borne Solar Vector Magnetograph. This work has been performed as part of a design team under the supervision of Dr. Mona Hagyard and Dr. Alan Gary of the Space Science Laboratory. Many tasks were performed and this report documents the results from some of those tasks, each contained in the corresponding appendix. Appendices are organized in chronological order.

Presentations:

Several presentations were given during the contract:

1. **National Solar Observatory, Sunspot, NM**
January 30, 1995
Presented Solar-B concepts

2. **Presentation to Prof. Tsuneta, Dr. Ogawara, and others from NAOJ and ISAS**
March 29 1995 at MSFC
Presented design issues for the Solar-B magnetograph

3. **National Astronomical Observatory of Japan**
July 17-20, 1996

12 hours of lectures on the MSFC magnetograph design, polarimetry, and polarization aberrations. The outline was as follows:

a. The NASA/Marshall Space-based Solar Vector Magnetograph Design.
2 hour plus backup

b. Introduction to the Jones and Mueller polarization calculus.
3 hours basic

c. Polarimetry, measuring polarization elements and optical systems.
3 hours
included Japanese language viewgraphs

d. Polarization ray tracing.
4 hours
polarization of interfaces
Cassegrain telescope polarization

4. Marshall Space Flight Center, Solar-B Review
March 4 & 5, with 8 Japanese astronomers in attendance

March 4, 1996
Solar-B Optical Design and Tolerance Analysis

March 5, 1996
Solar-B Optical Design Considerations

Tasks documented in Appendices:

Appendix 1	Solar-B Vector Magnetograph Specifications
Appendix 2	Notes from Meeting with Don Neidig, National Solar Observatory, Jan. 30, 1995
Appendix 3	Optical Design Modification for 2x System for the EXVM Magnetograph
Appendix 4	Design Studies for Reflective Field Stops for Gregorian Telescope

Appendix 1.

Solar-B Vector Magnetograph Specifications

Russell Chipman

Magnetograph:	
Measurement wavelength	630.2 nm
Spectral bandpass	0.0125 nm
Field of view.	4.3 x 8.6 minutes
Instantaneous Field of View	0.25 arcsec
Aberrations	Diffraction limited
Prefilter:	
Full Aperture	
Telescope:	
Aperture	60 cm
Cassegrain	
Polarization aberrations to 10^-4	
Polarimeter:	
Aperture	40 mm (changed for heat dissipation)
Length	~ 100 mm
Collimated beams	
Maximum ray angle	2 degree
6 measurements	
several measurement protocols	

Correlation tracker:		
Spectral band	What is left over from beamsplitter	
Blocking	?	
Fabry-Perot Filter:		
Aperture	140 mm	(changed)
Maximum ray angle	25 arcmin	
Telecentric beams, near image		
CCD		
Pixels	1024 x 2048	
Image height	22 mm	
S/N	>700	
Readout	12 bit	
Temperature	-30 degrees C	
Well depth	>500,000 electrons	
Quantum efficiency	>40%	
Window (if required)	BK7, 2 degree wedge, AR @ 630.2 nm	

Appendix 2.

Notes from Meeting with Don Neidig, National Solar Observatory, Jan. 30, 1995

Points on SOLAR-B design
Need for space based free flier
Need for several other wavelengths for context
Would package with a very short wavelength imager
- 60-100 angstroms
- small telescope will give sub arc sec resolution
- pick coronal line in EUV
- Hoover could build?

Advantages of our design:
high spatial resolution
Excellent polarization analysis

Our design will be criticized by HEO unless take full spectral lines
- at about 25 mA resolution, ours is 125
- Lockheed will propose 25 mA Lyot filter

Filling factor problem when don't have full line profile
Uncertainties from Doppler velocities and low spectral resolution

Our design will be criticized by Gene Parker (Guru) U of Chicago since 60 cm aperture doesn't quite get to mean free path of photon in the photosphere.
100 cm does get to that scale.
How much less costly to do 60 cm vs. 100 cm

Orbiting solar observatory failed
- too fancy
- high resolution spectrographs

Gregorian with 45 degree reflection

Tracking space debris with a coronograph, looking within minutes of solar surface.
Should be able to see objects to mm scale
Fraunhofer diffraction pattern analysis

Rust built balloon instrument mostly unfunded.
Couldn't do it carefully.
Preliminary tests in NM didn't work on balloon.
Will it work at S. Pole?

Appendix 3.

Optical Design Modification for 2x System for the EXVM Magnetograph

A lens system was designed which when inserted in the magnetograph breadboard would increase the magnification by approximately a factor of two while leaving the image in the same place.

Later in April, 1995, lens mounts were finished and this 2x optical system was mounted in the EXVM magnetograph, aligned, and its operation tested.

Progress Report

Date: March 9, 1995

To: Dr. Mona Hagyard
Marshall Space Flight Center

From: Russell A. Chipman
Steve McClain
University of Alabama in Huntsville

Re: Contract # NAG8-1112

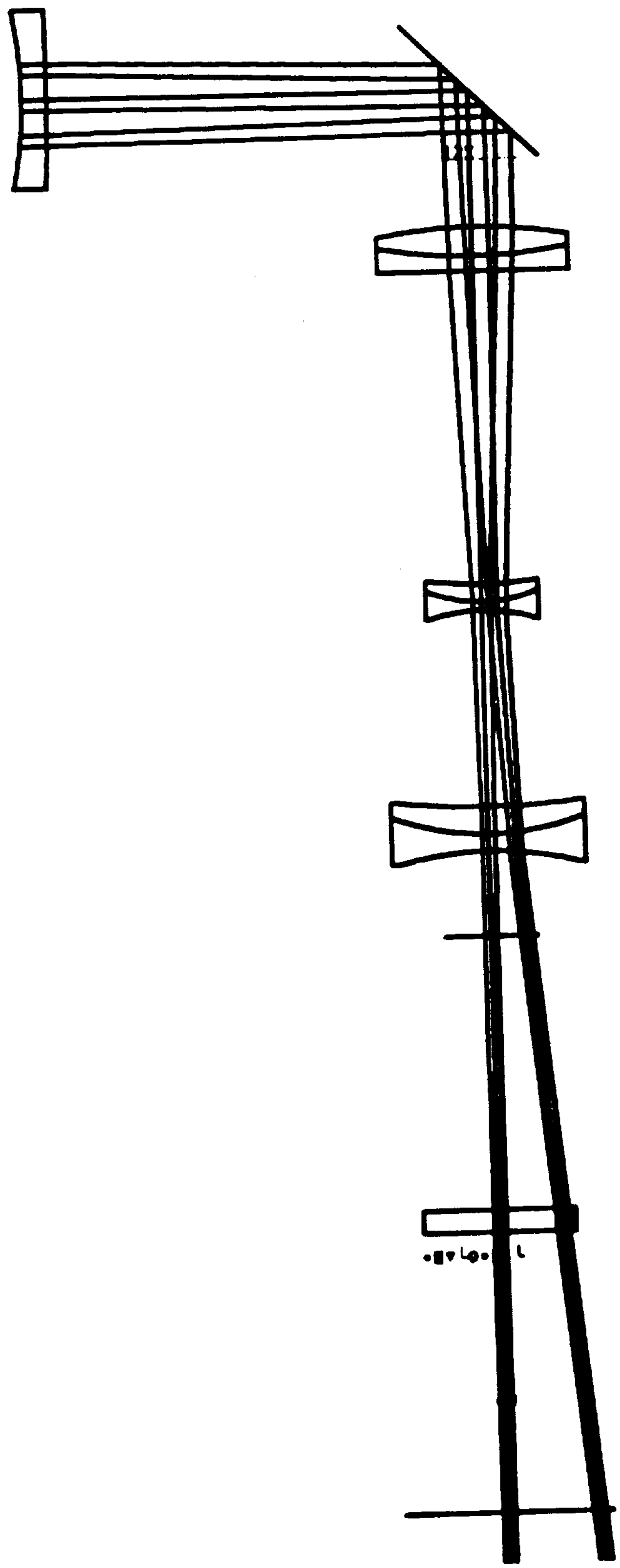
Laboratory magnetograph optical design modification:

We have modified the optical design of the laboratory solar magnetograph in order to facilitate testing of the Fabry Perot filter. The modification entail modification entails the insertion of two lenses to act as a 2x converter between the first and second fold mirrors. The design reduces the system field of view and the invariant by (approximately) a factor of two. As a result, the marginal ray angle at the Fabry Perot has been reduced to .003757 radians from 0.006831 radians. This enables the Fabry Perot spectrum to be tested with smaller angles of incidence for a single field value. Note, however, that the system is not telecentric at the Fabry Perot. This did not prove possible of a design utilizing catalog lenses without more drastic changes to the remainder of the optical system. However, for testing at a single field value (or a restricted field of view) this non-telecentricity will not affect the testing of the Fabry Perot spectral performance.

The additional lenses are catalog Spindler Hoyer achromats. Their insertion do not require movement of any other elements in the magnetograph. The optical system remains sentially diffraction limited. Insertion of a field aperture before the Fabry Perot may be prudent so that the Fabry Perot does not act the field stop.

Specifically, the 2x converter consists of a 200 mm efl achromat (SH322271) placed 25 mm beyond the first fold mirror and a -50 mm efl negative achromat (SH325221) placed 0 mm lens. A complete CODE V optical system specification and analysis is available on request.

$\Delta\lambda$ at center 79 mÅ, shift over field 250 mÅ
was 128 mÅ



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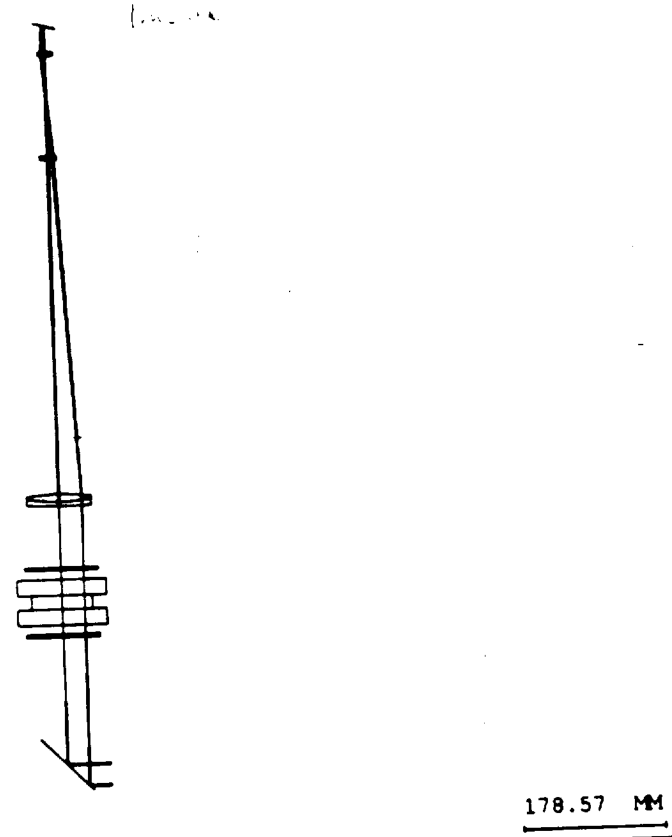
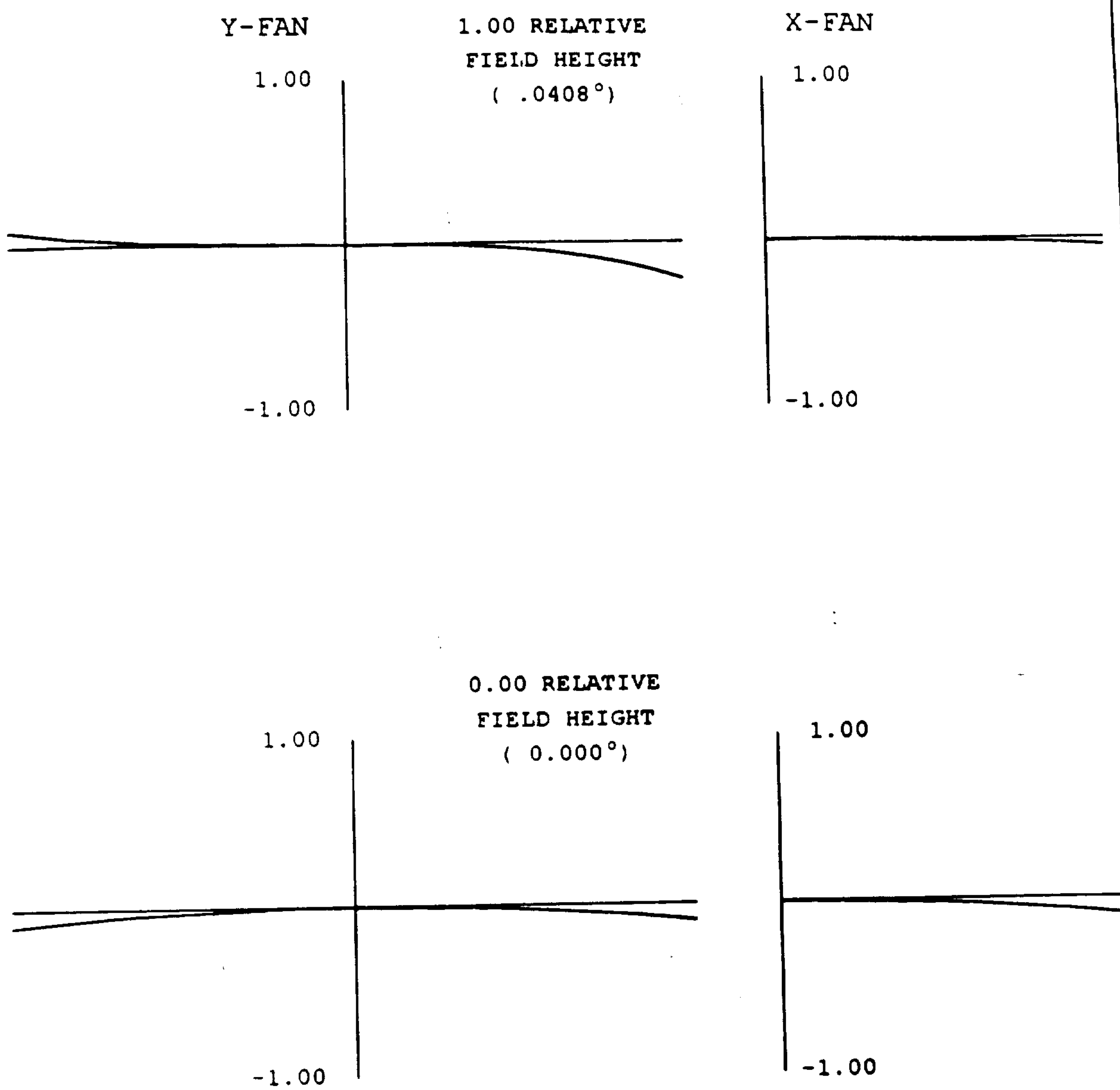


magnetograph w/2x

Scale: 0.14 SM 5-Mar-95



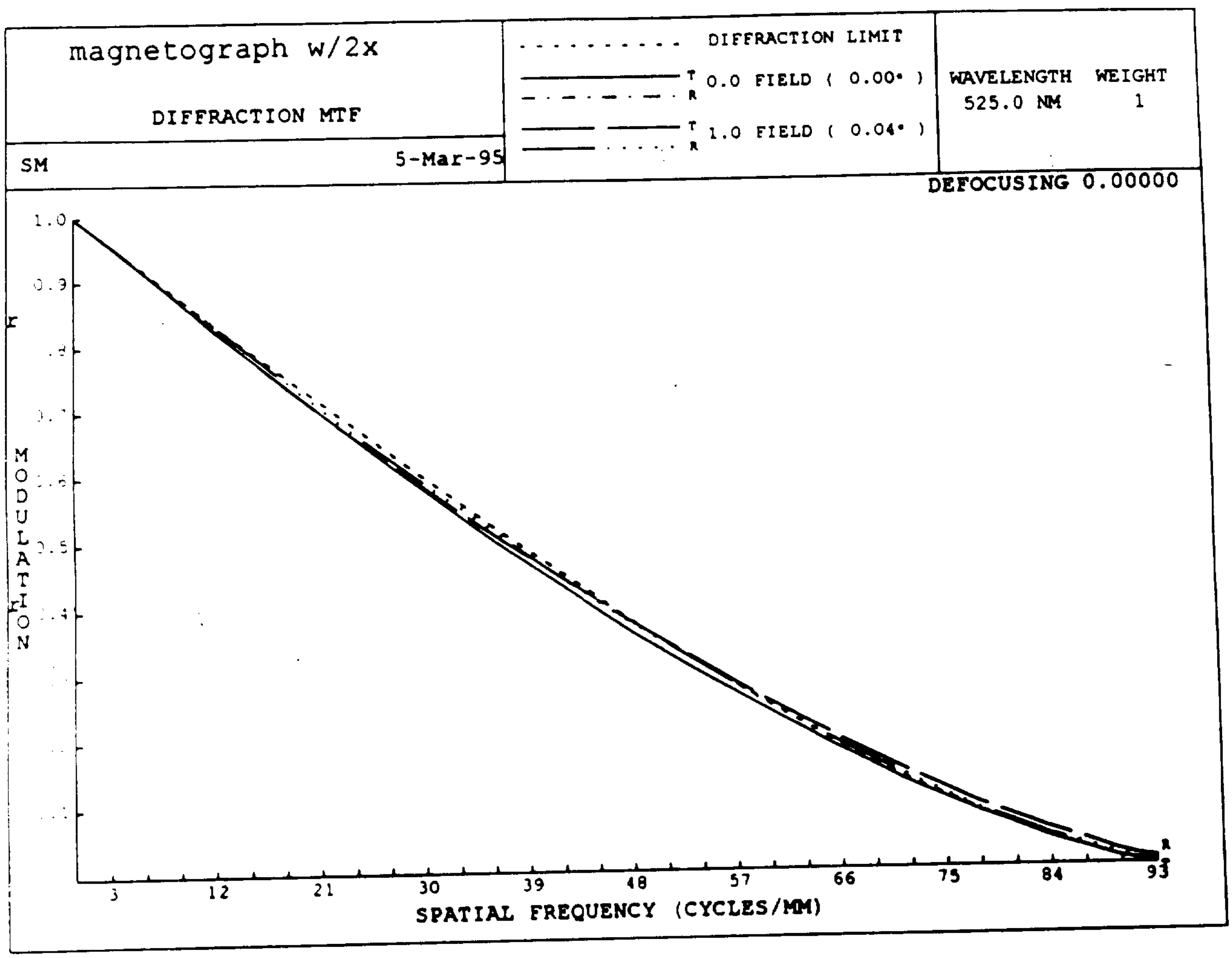
magnetograph w/2x

OPTICAL PATH DIFFERENCE (WAVES)

SM 5-Mar-95

525.0 NM

10:22:36


magnetograph w/2x
DIFFRACTION MTF
SM
5-Mar-95
DIFFRACTION LIMIT
T 0.0 FIELD (0.00°)
R
T 1.0 FIELD (0.04°)
R
WAVELENGTH WEIGHT
525.0 NM 1
DEFOCUSING 0.00000
1.0
0.9
MODULATION
3
12
21
30
39
48
57
66
75
84
93
SPATIAL FREQUENCY (CYCLES/MM)

magnetograph w/2x
Position 1, Wavelength = 525.0 NM
Global coordinates with respect to surface 1

	X	Y	Z	TANX	TANY	LENGTH
OBJ	0.00000	0.00000	-0.100E+14	0.00000	0.00000	
1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00000	0.00000	0.00100	0.00000	0.00000	0.00100
STO	0.00000	0.00000	650.00100	0.00000	0.00000	650.00000
4	0.00000	0.00000	-227.23880	0.00000	0.00000	877.23980
5	0.00000	0.00000	841.76120	0.00000	0.00000	1069.00000
6	0.00000	0.00000	848.76120	0.00000	0.00000	7.00000
7	0.00000	0.00000	853.76120	0.00000	0.00000	5.00000
8	0.00000	0.00000	903.76120	0.00000	0.00000	50.00000
9	0.00000	0.00000	908.76120	0.00000	0.00000	5.00000
10	0.00000	0.00000	914.76120	0.00000	0.00000	6.00000
11	0.00000	0.00000	919.76120	0.00000	0.00000	5.00000
12	0.00000	0.00000	926.76120	0.00000	0.00000	7.00000
13	0.00000	0.00000	931.76120	0.00000	0.00000	5.00000
14	0.00000	0.00000	934.76120	0.00000	0.00000	3.00000
15	0.00000	0.00000	1249.76120	0.00000	0.00000	315.00000
16	0.00000	0.00000	1253.76120	0.00000	0.00000	4.00000
17	0.00000	0.00000	1260.36120	0.00000	0.00000	6.60000
18	0.00000	0.00000	1365.36120	0.00000	0.00000	105.00000
19	0.00000	0.00000	1665.36120	0.00000	0.00000	300.00000
20	0.00000	0.00000	1698.86120	0.00000	0.00000	33.50000
21	0.00000	0.00000	1703.86120	0.00000	0.00000	5.00000
22	0.00000	0.00000	1708.26120	0.00000	0.00000	4.40000
23	0.00000	0.00000	1783.26120	0.00000	999.00000	75.00000
24	0.00000	-25.00000	1783.26120	0.00000	999.00000	25.00000
25	0.00000	-30.30000	1783.26120	0.00000	999.00000	5.30000
26	0.00000	-33.10000	1783.26120	0.00000	999.00000	2.80000
27	0.00000	-89.53075	1783.26120	0.00000	999.00000	56.43075
28	0.00000	-92.73075	1783.26120	0.00000	999.00000	3.20000
29	0.00000	-94.23075	1783.26120	0.00000	999.00000	1.50000
30	0.00000	-37.80000	1783.26120	0.00000	999.00000	-56.43075
31	0.00000	-129.18000	1783.26120	0.00000	999.00000	91.38000
32	0.00000	-133.98000	1783.26120	0.00000	999.00000	4.80000
33	0.00000	-136.98000	1783.26120	0.00000	999.00000	3.00000
34	0.00000	-151.98000	1783.26120	0.00000	999.00000	15.00000
35 E	0.00000	-151.97000	1783.26120	0.00000	999.00000	-0.01000
36	0.00000	-199.97000	1783.26120	0.00000	999.00000	48.00000
37	0.00000	-203.97000	1783.26120	0.00000	999.00000	4.00000
38	0.00000	-251.97000	1783.26120	0.00000	999.00000	48.00000
39 E	0.00000	-251.96000	1783.26120	0.00000	999.00000	-0.01000
40	0.00000	-363.97700	1783.26120	0.00000	999.00000	112.01700
41	0.00000	-376.47700	1783.26120	0.00000	999.00000	12.50000
42	0.00000	-382.47700	1783.26120	0.00000	999.00000	6.00000
43	0.00000	-437.47700	1783.26120	0.00000	0.00000	55.00000
44	0.00000	-437.47700	1618.02789	0.00000	0.00000	165.23331
45	0.00000	-437.47700	1614.02789	0.00000	0.00000	4.00000
46	0.00000	-437.47700	1602.02789	0.00000	0.00000	12.00000
47	0.00000	-437.47700	1581.02789	0.00000	0.00000	21.00000
48	0.00000	-437.47700	1581.02762	0.00000	0.00000	0.00028
49	0.00000	-437.47700	1563.02762	0.00000	0.00000	18.00000
50	0.00000	-437.47700	1563.02762	0.00000	0.00000	0.00000
51	0.00000	-437.47700	1542.02762	0.00000	0.00000	21.00000
52	0.00000	-437.47700	1530.02762	0.00000	0.00000	12.00000
53	0.00000	-437.47700	1526.02762	0.00000	0.00000	4.00000
54	0.00000	-437.47700	1446.02762	0.00000	0.00000	80.00000

55	0.00000	-437.47700	1440.02762	0.00000	0.00000	6.00000
56	0.00000	-437.47700	1430.02762	0.00000	0.00000	10.00000
57	0.00000	-437.47700	991.02762	0.00000	0.00000	439.00000
58	0.00000	-437.47700	987.22762	0.00000	0.00000	3.80000
59	0.00000	-437.47700	984.72762	0.00000	0.00000	2.50000
60	0.00000	-437.47700	853.69811	0.00000	0.00000	131.02951
61	0.00000	-437.47700	849.23811	0.00000	0.00000	4.46000
62	0.00000	-437.47700	847.73811	0.00000	0.00000	1.50000
IMG	0.00000	-437.47700	812.81250	0.00000	0.00000	34.92561
		OPD =	0.000 Waves			

CODE V> out t

Radiometry

Steve McClain
Department of Physics
University of Alabama in Huntsville
3/7/95

Source radiometry

■ Solar spectral radiance in wavelength:

Entire notebook is in MKS units

```
h=6.63 10^(-34);
c=3 10^8;
k=1.38 10^(-23);
T=5000;
lamb0=630.2 10^-9;
band=0.0125 10^-9;
```

lamb0 = center of Fabry Perot bandpass
band = bandwidth of Fabry Perot

T = effective temperature of solar region at lamb0 (estimate)

```
L[lambda_]:=2 h c^2/lambda^5 Exp[h c/(lambda k T) -1]^(-1);
```

■ Solar radiance in detection band

```
L[lamb0]
```

$3.36647\ 10^{13}$

```
radiance = L[lamb0] band
```

420.809

Radiance of sun in spectral band
= 420.809 W/m^2 sr

```
exitance = 3.1416 radiance
```

1322.01

Optical system radiometry

■ Etendue

image radius = hcy
marginal ray angle = umy
values from CODE V ray trace to image plane

```
hcy = 4.422 10^-3;
umy = 0.02456;
imagearea = 3.1416 (hcy)^2
```

```
0.0000614311
```

CODE V transmittance: quarter wave coatings assumed: 0.586
polarimeter and filters not modelled, guess transmittance = 0.2

```
transmittance = 0.1172
```

```
0.1172
```

```
etendue = transmittance 3.1416 imagearea (Sin[umy])^2
```

```
            -8
1.36407 10
```

Flux onto detector

```
flux = radiance etendue
```

```
            -6
5.74012 10
```

```
irradiance = flux / imagearea
```

```
0.0934399
```

irradiance in watts/m^2

Detector radiometry

```
pixelsize = 10 10^-6;
pixelarea = pixelsize^2;
```

Assumes square pixels

```
pixelpower = irradiance pixelarea
```

```
            -12
9.34399 10
```

```
quantumefficiency = 0.4;
detectedpower = pixelpower quantumefficiency
```

```
           -12
3.7376 10
```

power per pixel in watts

```
welldepth = 5 10^5;
```

photonenergy = h c / lamb0

$3.15614\ 10^{-19}$

photonflux = detectedpower/photonenergy

$1.18423\ 10^{7}$

filltime = welldepth/photonflux

0.0422215

filltime = time to saturate ccd pixel = 42 milliseconds

Appendix 4.

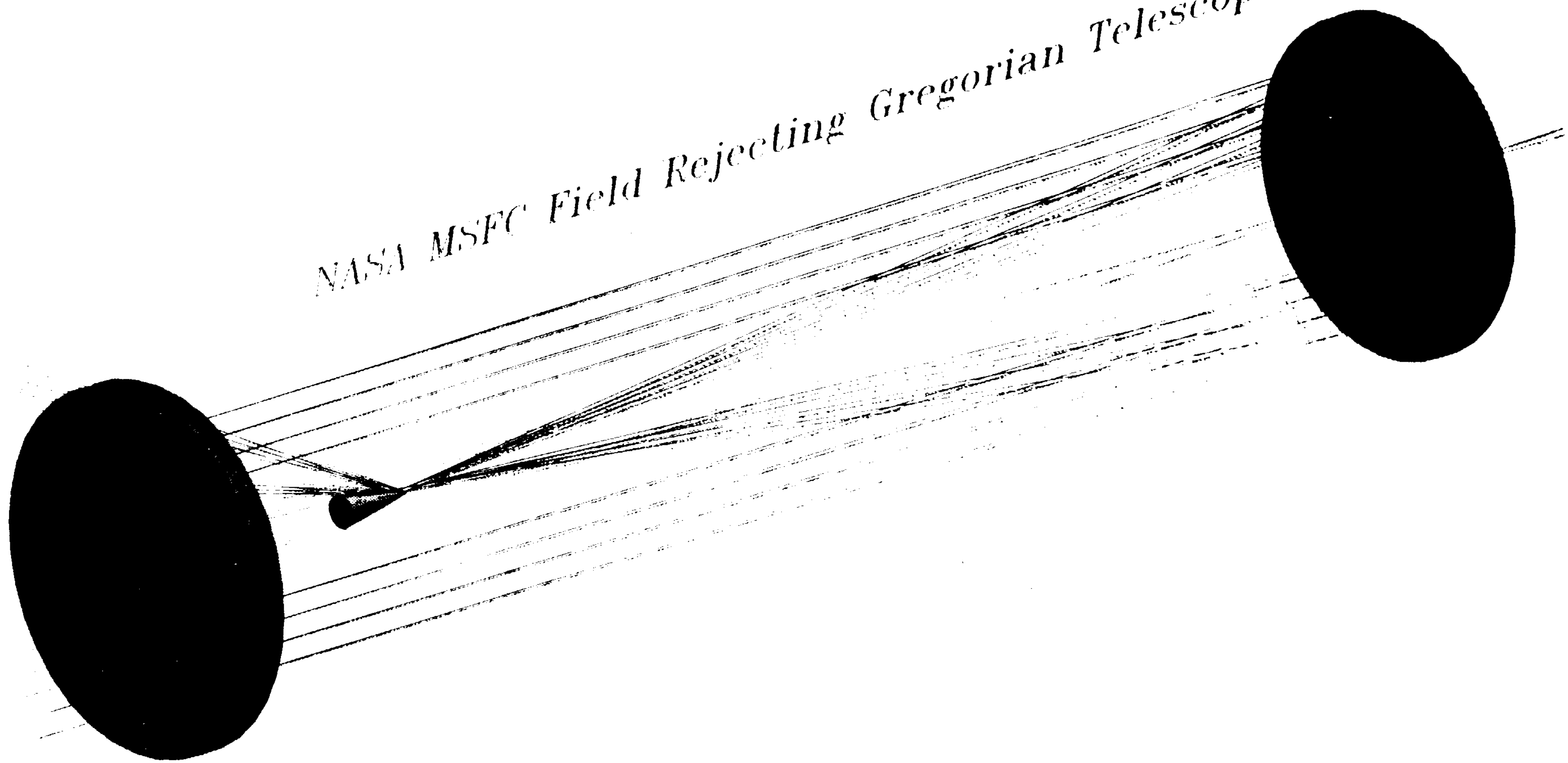
Design Studies for Reflective Field Stops for Gregorian Telescope

Due to the Japanese interest in a Gregorian telescope with a reflective field stop, I attempted with Matt Smith's assistance to design one. We used a new optical design program from Optical Research Associates called Light Tools, which allows a nonsequential ray trace. A Fast Gregorian telescope was set up and we manually varied the parameters on a field stop, with the intention of reflecting all of the light outside of a circular field of view past the secondary and back out the front of the telescope. We came close to achieving this objective but our best design still sent some light into the telescope barrel inside the prefilter.

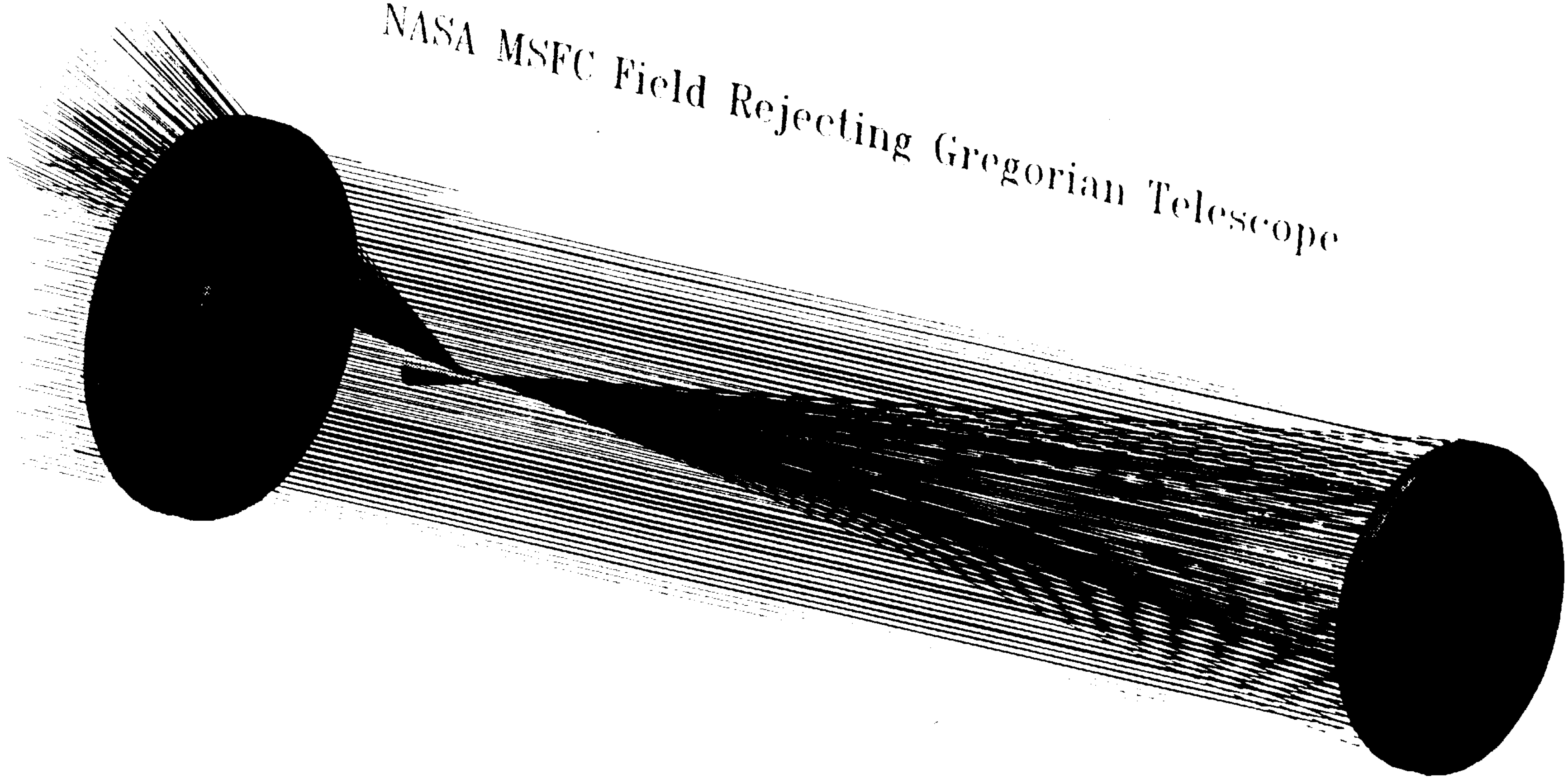
The enclosed figures document our design experiments.

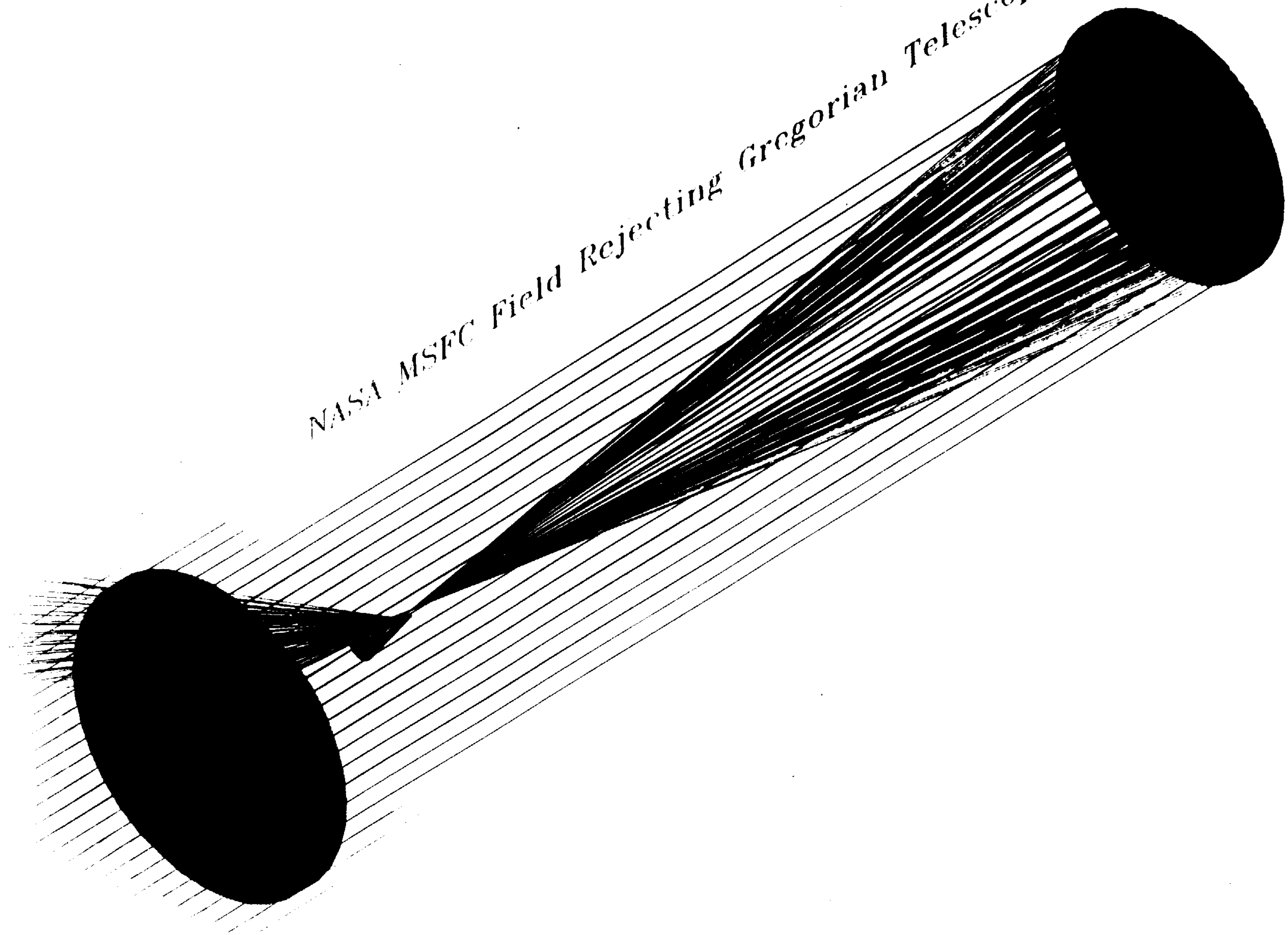
The second set of figures explore using a plane mirror with a hole at the intermediate image to reflect the out-of-field light back out the front of the telescope.

NASA MSFC Field Rejecting Gregorian Telescope



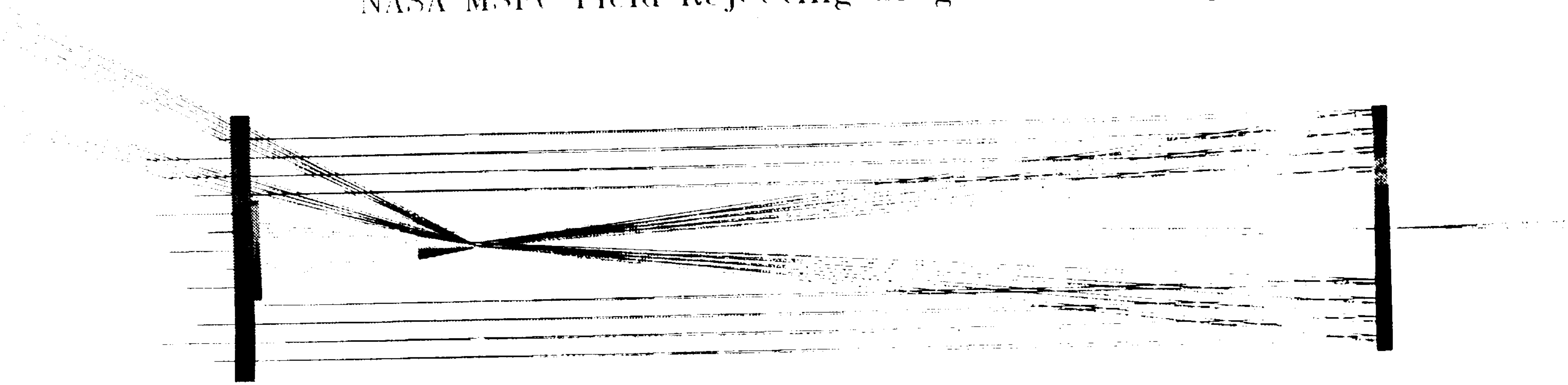
NASA MSFC Field Rejecting Gregorian Telescope



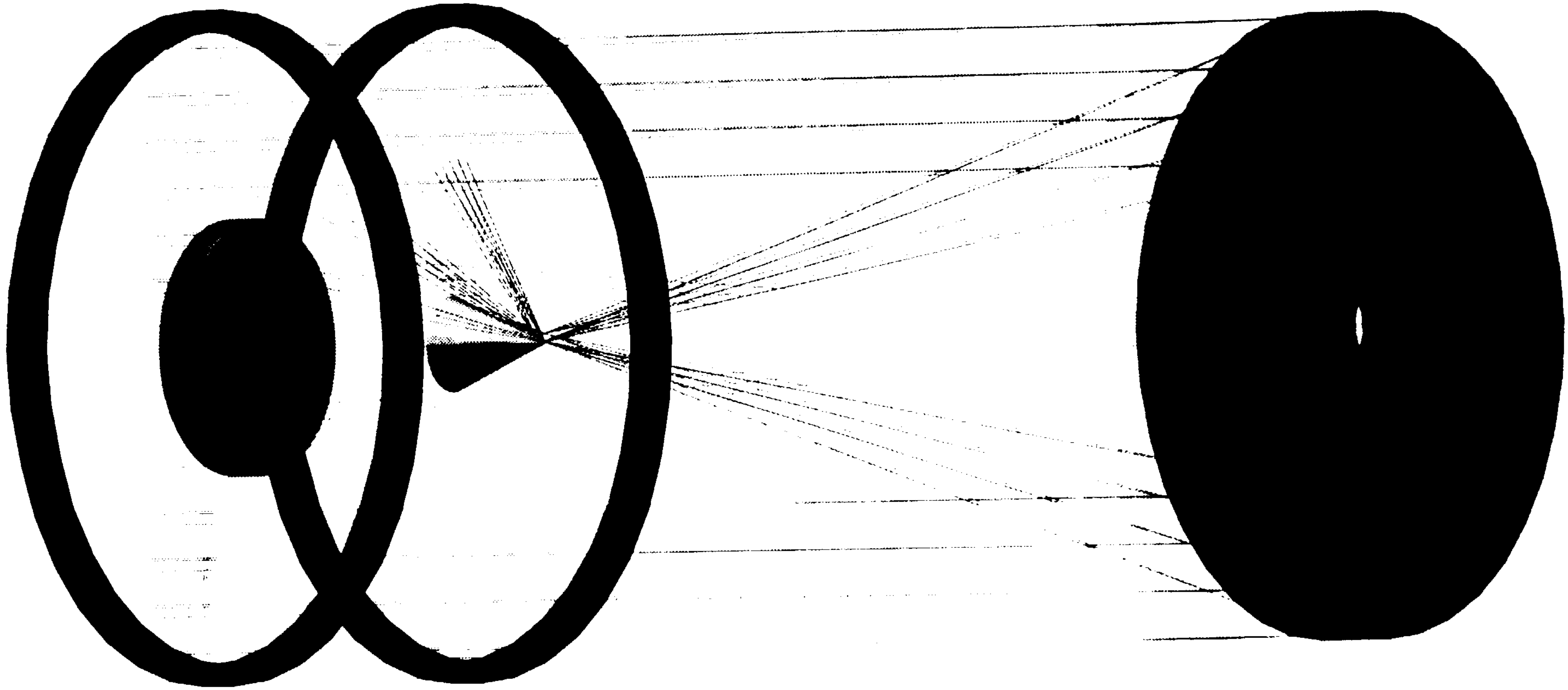


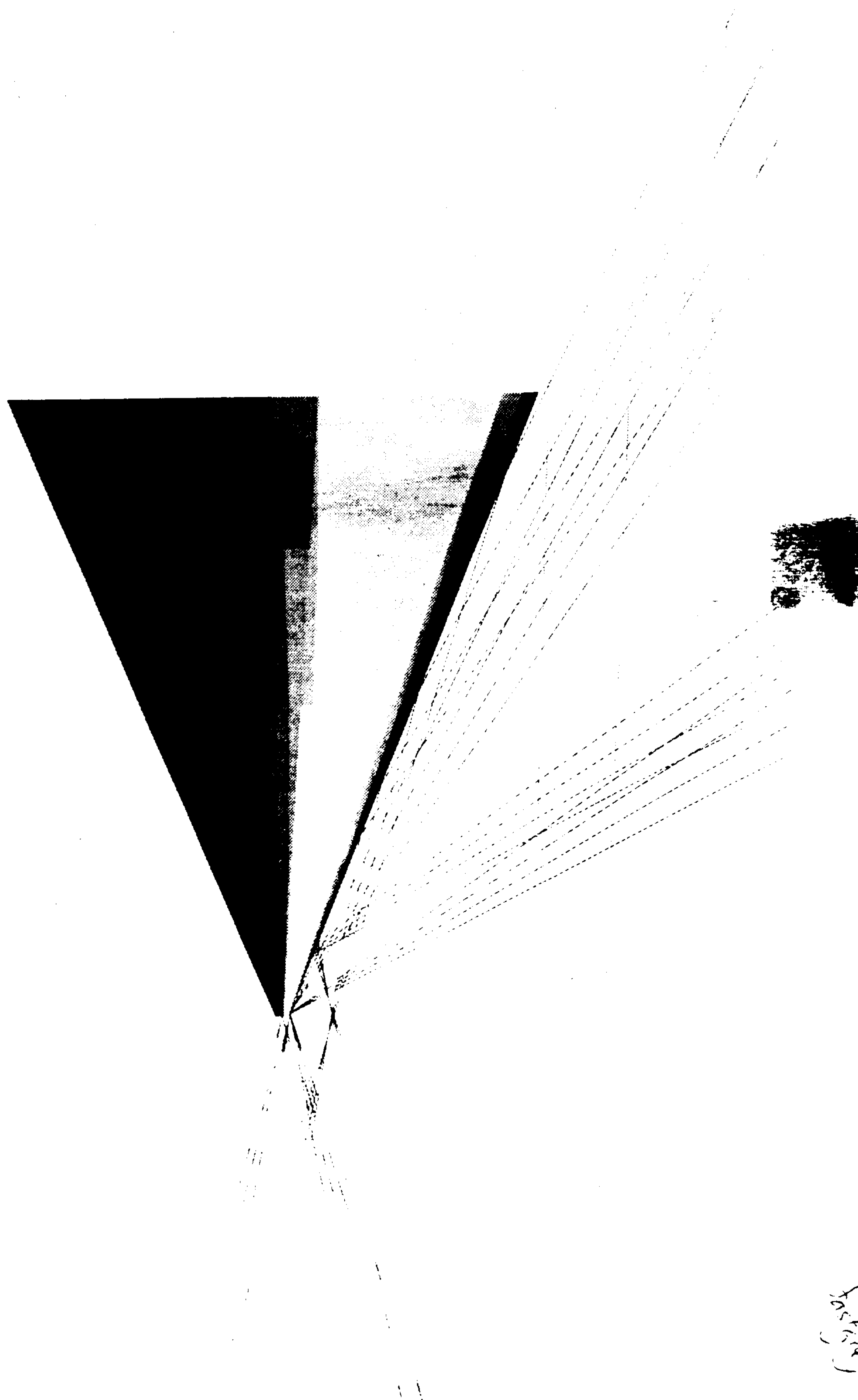
NASA MSFC Field Rejecting Gregorian Telescope

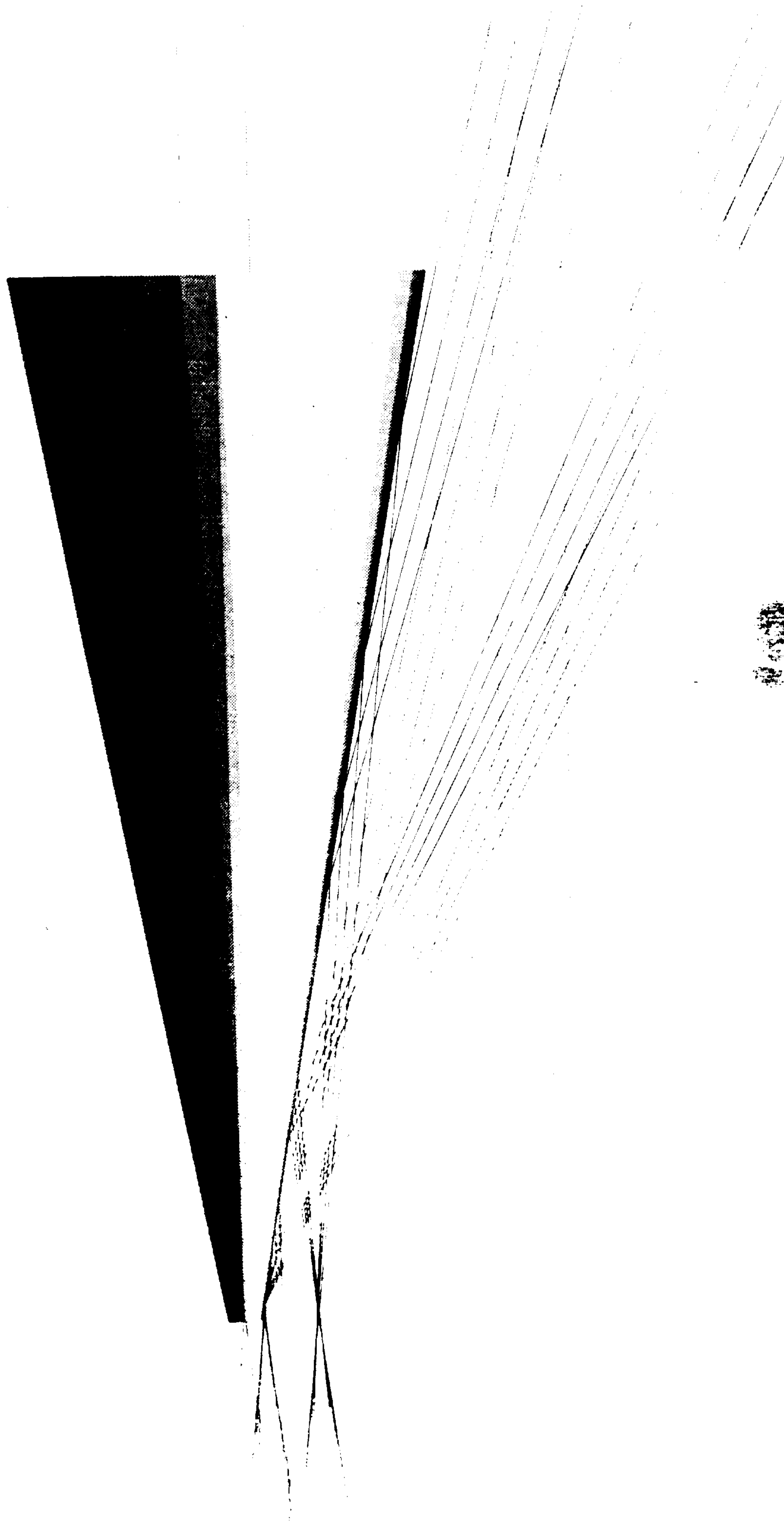
NASA MSFC Field Rejecting Gregorian Telescope



NASA MSFC Field Rejecting Gregorian Telescope

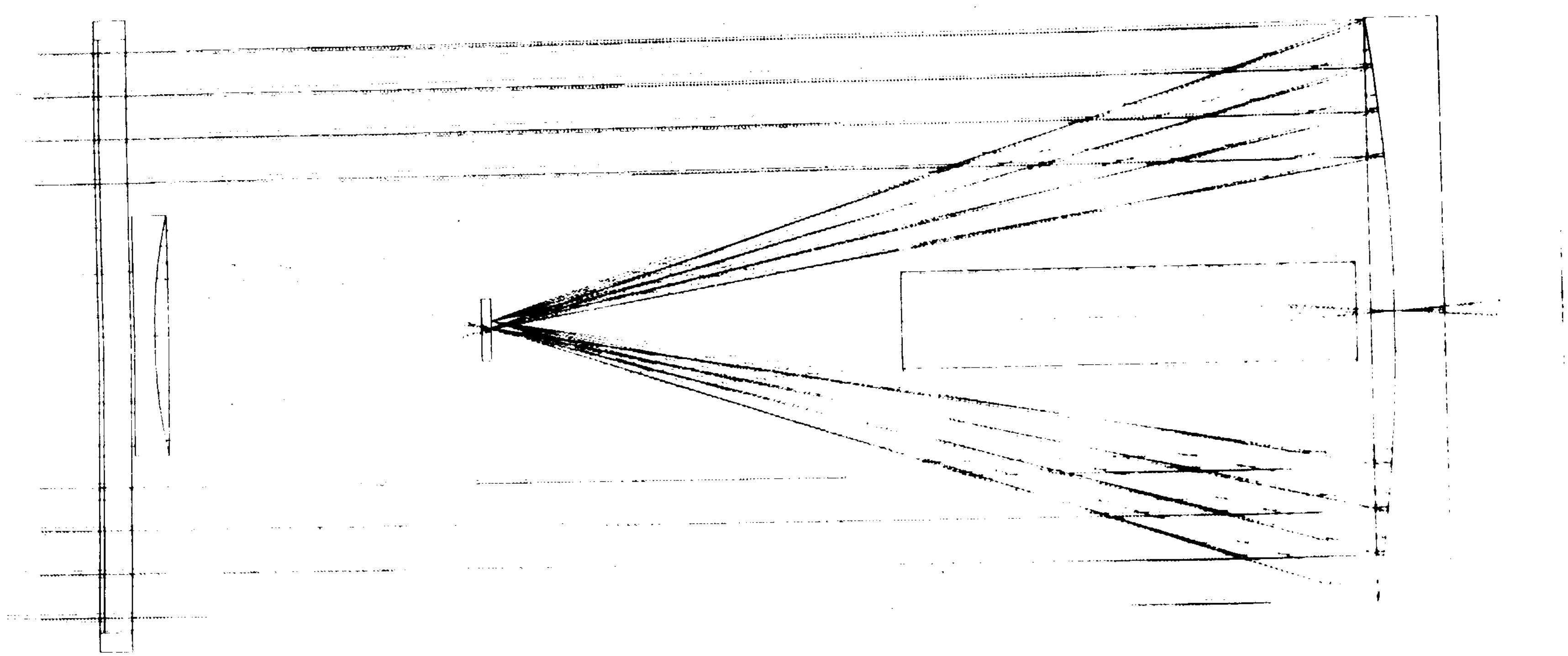






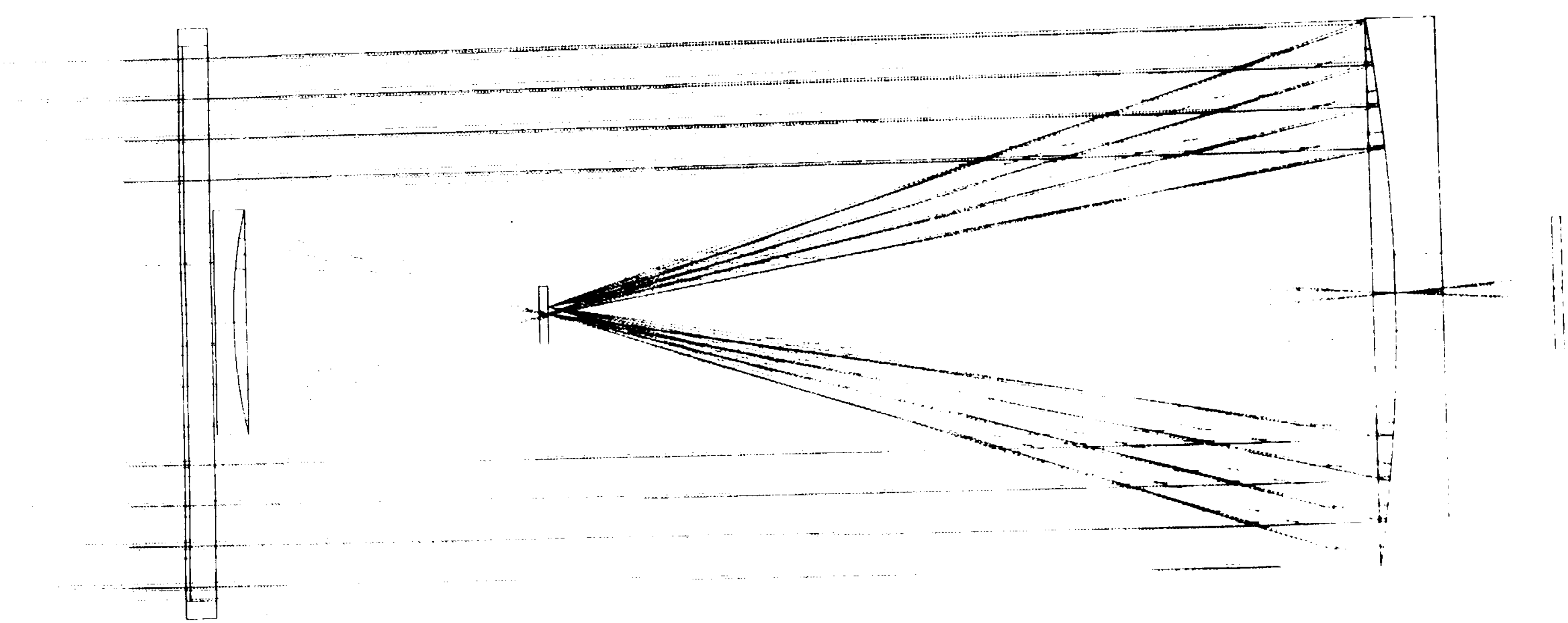
(2)

NASA MSFC Field Rejecting Gregorian Telescope

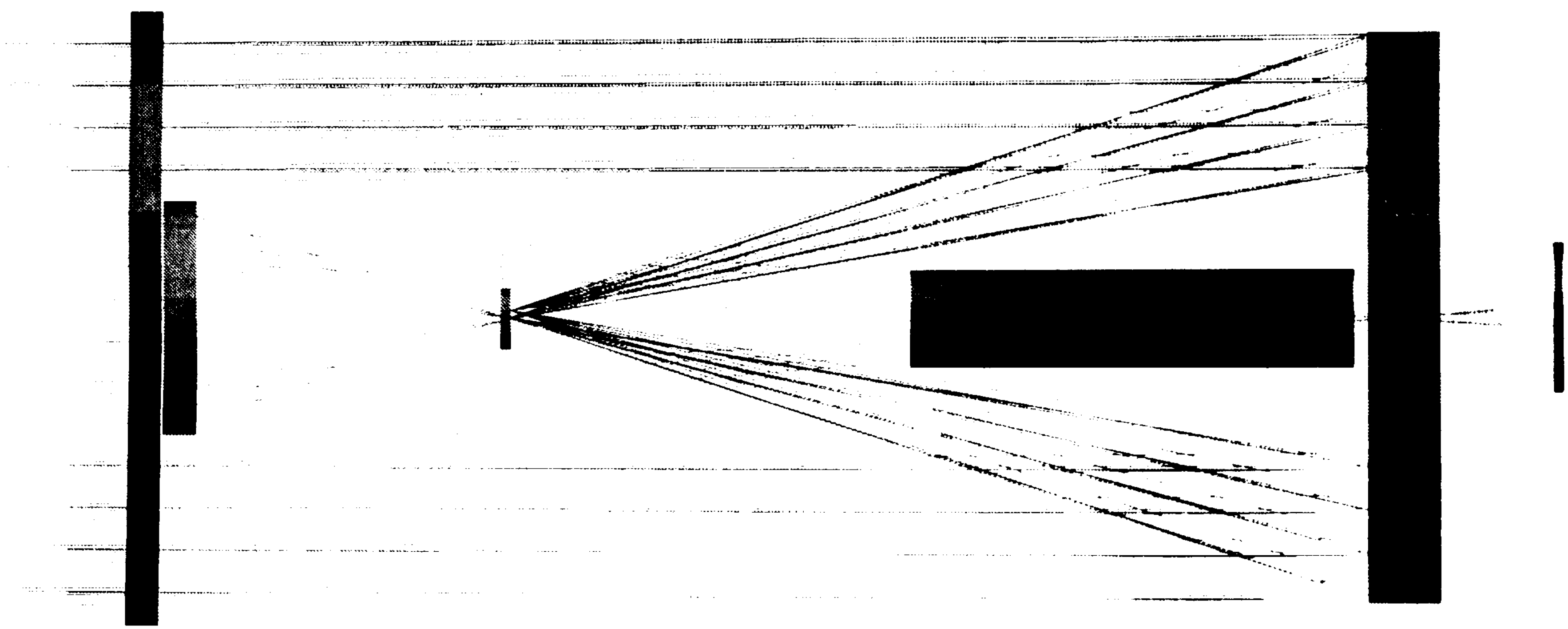


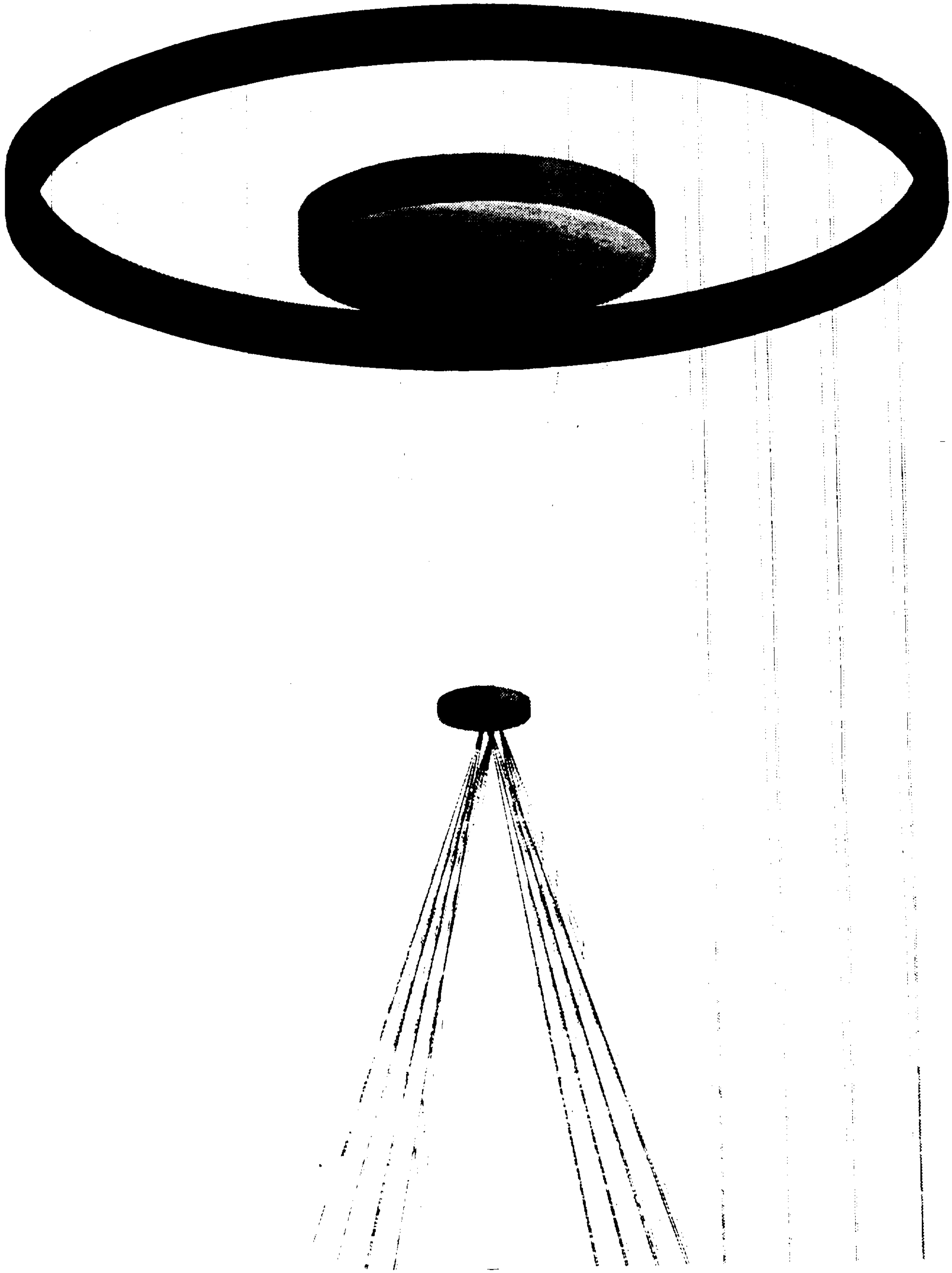
Fastgreg(3)

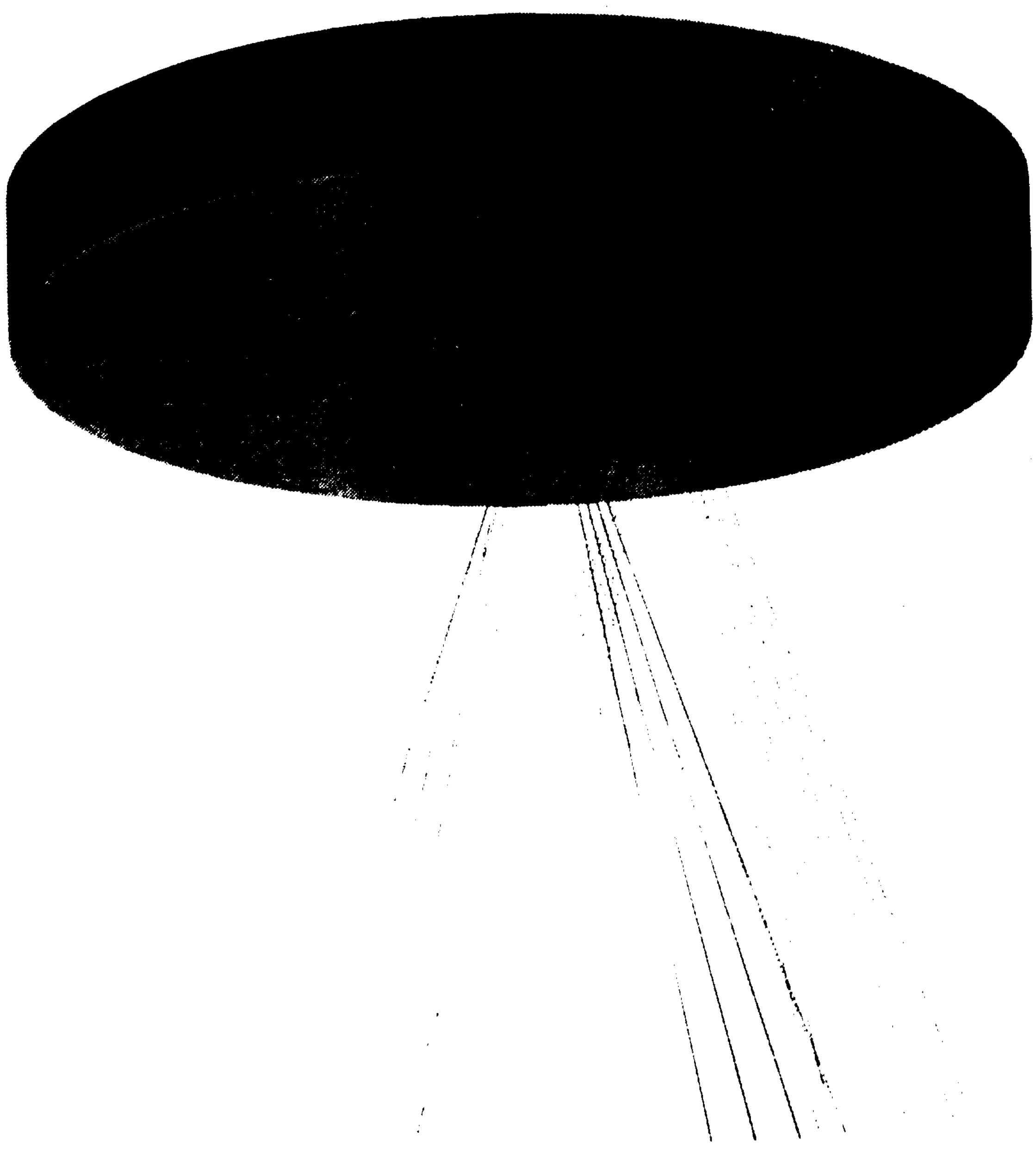
NASA MSFC Field Rejecting Gregorian Telescope

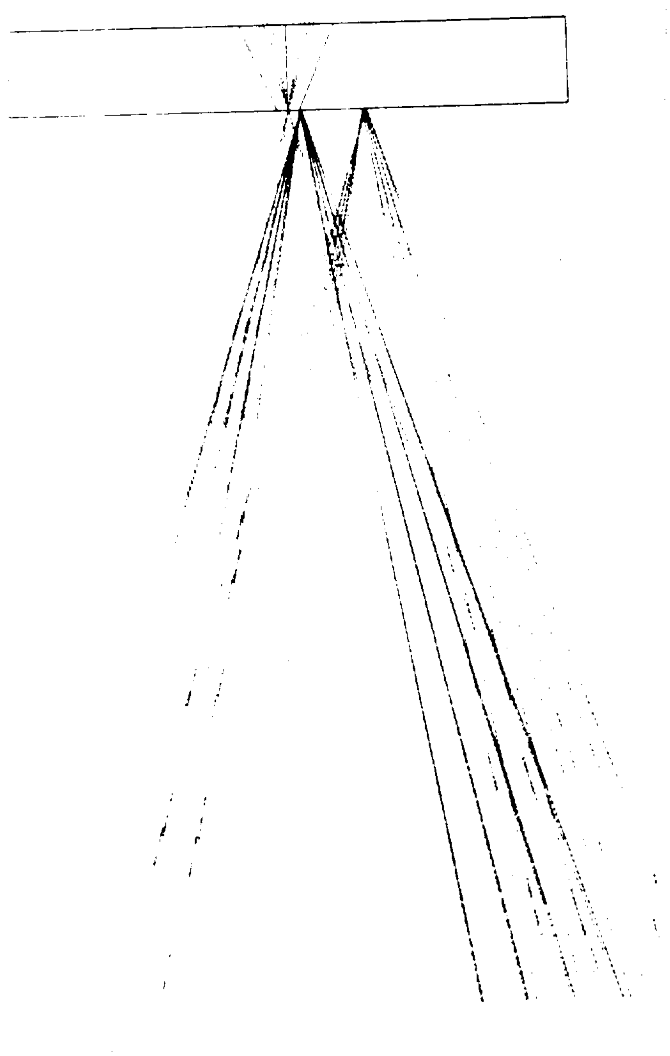


NASA MSFC Field Rejecting Gregorian Telescope









Appendix 5.

Radiation Hardened Doublet Design

Alan Gary has made a compelling argument for using radiation hardened glasses in the optical design due to the levels of radiation at a 600 km orbit.

In response I have designed a series of doublets using various combinations of radiation hardened glasses. I am seeking a lens appropriate for the polarimeter collimator. I would like to find the glass combination which yields the best achromatic correction with good wavefront quality.

A large number of radiation glass pairs were tried. Each combination was optimized with the constraint that the back focal lengths be equal at 630 and 525 nm to minimize chromatic aberration. An achromatic doublet generally has a positive and negative focal length element. For these experiments, each glass pair (g1, g2) was optimized in four configurations listed in order of position from the image:

1. g1 positive fl, g2 negative fl,
2. g2 positive fl, g1 negative fl,
3. g1 negative fl, g2 positive fl,
4. g2 negative fl, g1 positive fl,

None of the lens optimizations gave good color correction for wavelengths below 480 nm.

The best pair of glasses was bk7g25 and kzfs4g20. This combination worked well in all four configurations.
Best configuration lens file z2(2)

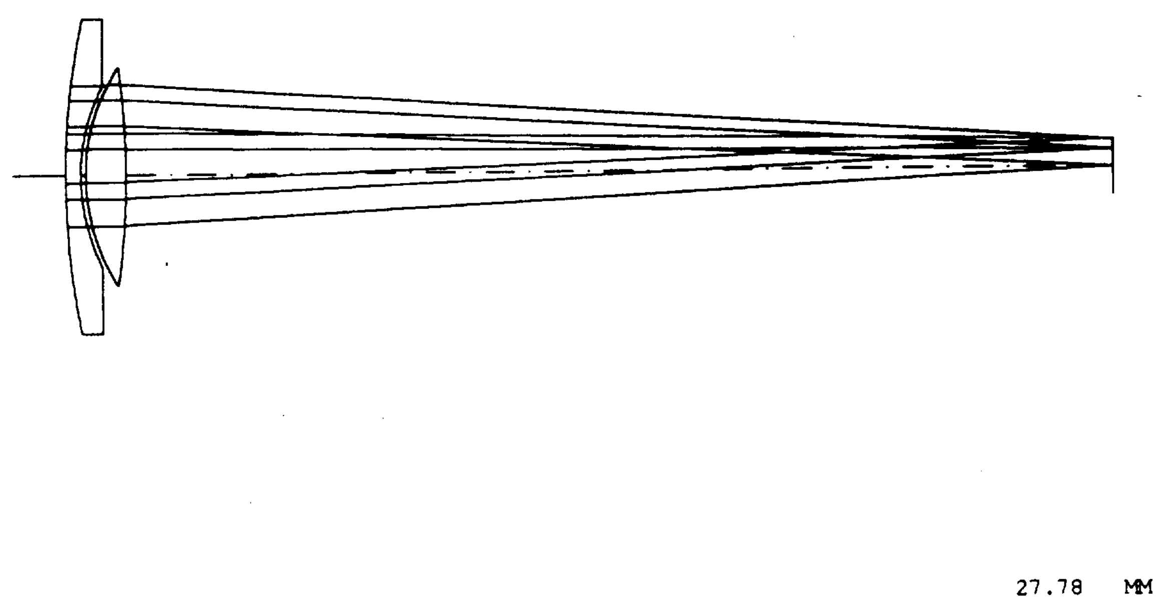
Other good pairs of glasses were:
K5g20 kzfs4g20
gg375g34 kzfs4g20

Overall, this was a frustrating exercise because none of the lenses was particularly good. All had large chromatic aberration and poor wavefront over a .8 degree field with the stop 1.5 efl away.

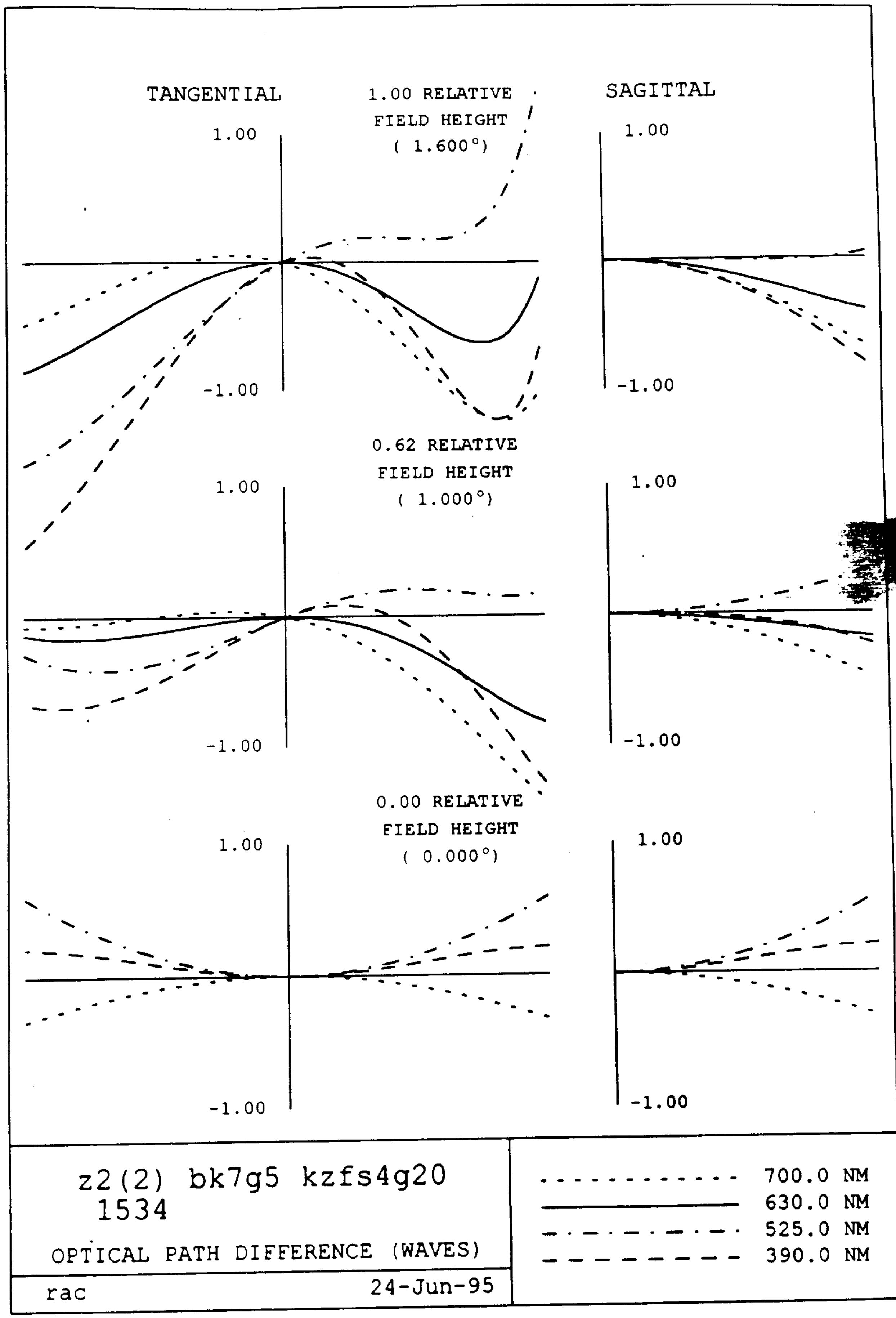
I am convinced that two element lenses from radiation hardened glass will never work below 450 nm.

The figures in this section show the best doublet layout, the wavefront aberration (showing the large chromatic aberration and other aberrations), and two plots of the focal length.

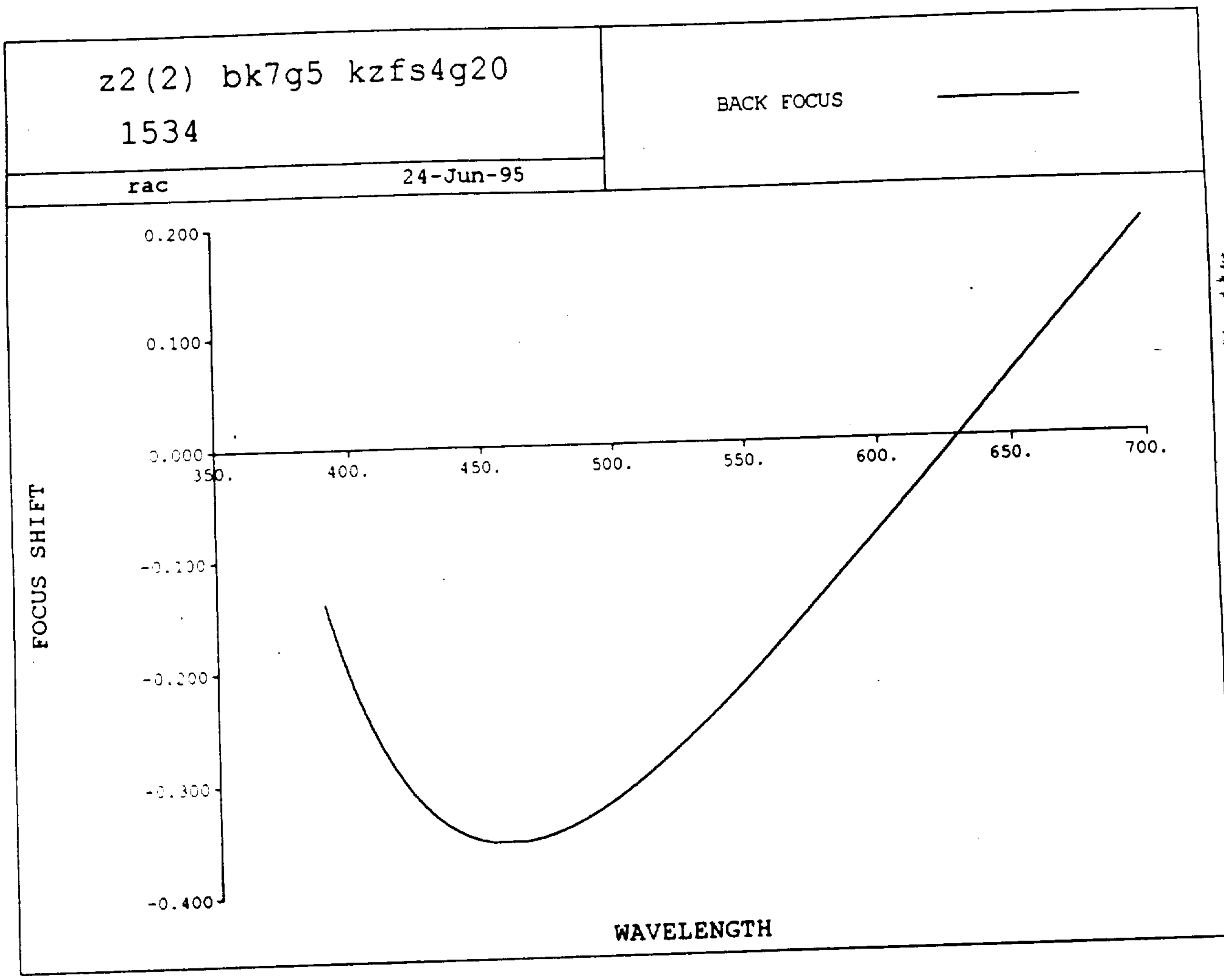
19:12:00



z2(2) 1497 Scale: 0.90 rac 24-Jun-95

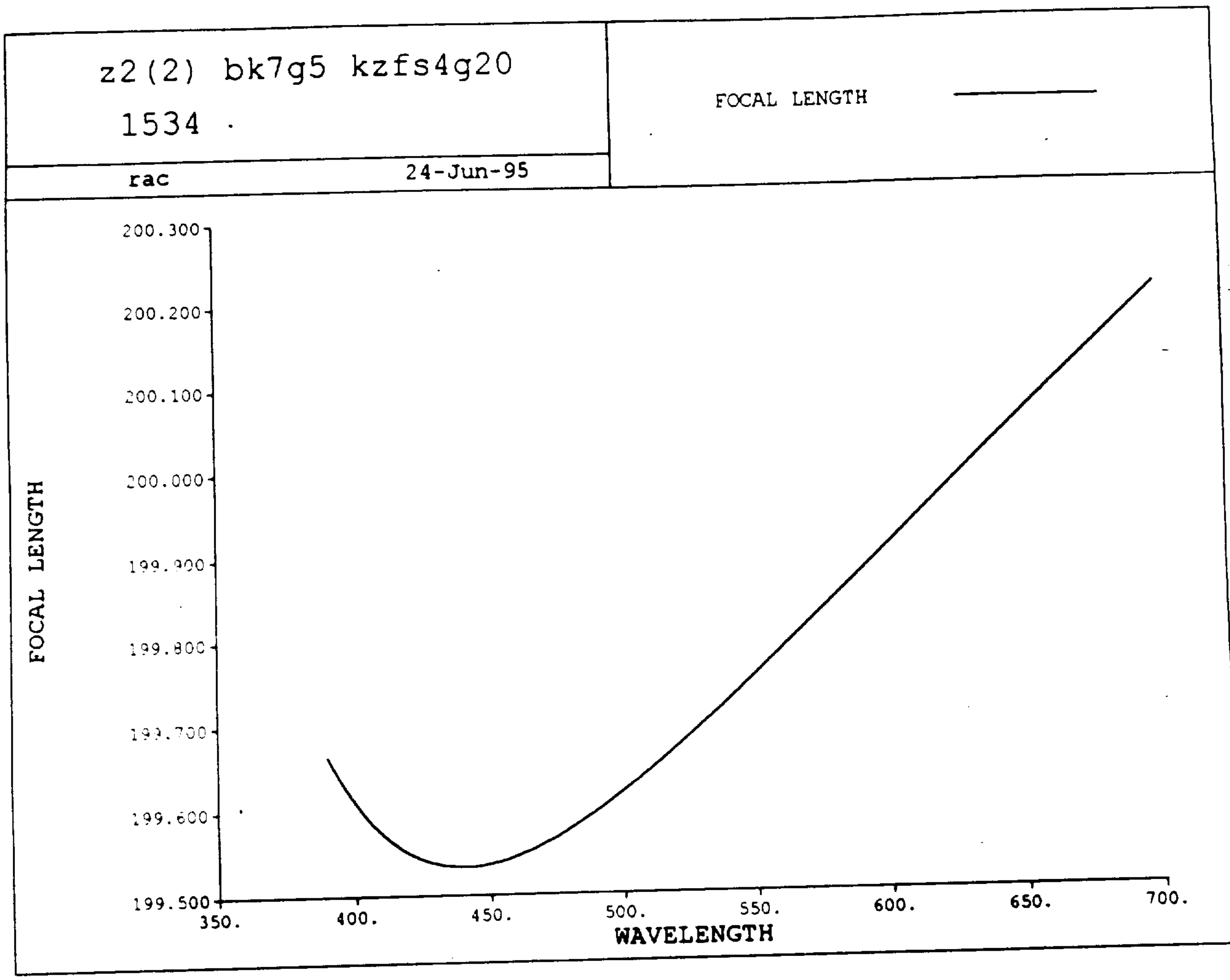

TANGENTIAL
SAGITTAL
1.00 RELATIVE
FIELD HEIGHT
(1.600°)
1.00
-1.00
0.62 RELATIVE
FIELD HEIGHT
(1.000°)
1.00
-1.00
0.00 RELATIVE
FIELD HEIGHT
(0.000°)
1.00
-1.00
z2(2) bk7g5 kzfs4g20
1534
OPTICAL PATH DIFFERENCE (WAVES)
rac
24-Jun-95
700.0 NM
630.0 NM
525.0 NM
390.0 NM

19:22:58



z2(2) bk7g5 kzfs4g20
1534
rac
24-Jun-95
BACK FOCUS
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
FOCUS SHIFT
350.
400.
450.
500.
550.
600.
650.
700.
WAVELENGTH

19:26:19



z2(2) bk7g5 kzfs4g20
1534
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24-Jun-95
FOCAL LENGTH
FOCAL LENGTH
200.300
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450.
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WAVELENGTH

Appendix 6.

Meeting Summary from Trip to National Astronomical Observatory of Japan, Mitaka Japan

Meeting Report

National Astronomical Observatory, Mitaka, Japan

To: Marshall Space Flight Center
Solar Physics Branch

From: Russell A. Chipman, University of Alabama in Huntsville

Meeting Topic:Solar B instrument design

Meeting Date:July 17-21, 1995

Report Date: August 9, 1995

Organization of Meetings:

The meetings took place at the observatory offices in Mitaka. Prof. Tsuneta of Tokyo University Astronomy Dept. was in charge and set the agenda. Dr. Ichimoto of Tokyo University Astronomy Dept. and Dr. Akioka of the governments Communications Dept. in Ibaraki were significant technical contributors. A group of graduate students also attended and presented. Prof. Sakurai attended occasionally, and only had a few questions and comments.

I gave four lectures for a total of about 10 hours, three on polarization, one on the Marshall Solar B design. A copy of this presentation was sent to Mitaka in advance, and copies were distributed at my talk.

In return, for three afternoons, I was given a detailed presentation of the present Solar-B baseline design. This consisted of a total of about 8 hours of lectures and discussion. This covered the optical magnetographs and the spacecraft systems. An EUV telescope and x-ray telescope were mentioned, but not discussed in the presentations. I received copies of these presentations, and copies will be forwarded to the Solar Physics Branch. I also took copious notes on my computer during the talk, and you should receive a copy by email. These are detailed, but do not stand well alone. These real time notes should indicate the direction of the presentations I received, and complement the copies of viewgraphs.

Dr Serge Koutchme(?), of Paris, France was also concurrently at the observatory on separate business, but partook of many of the meetings.

Every day the group went together to lunch and dinner, and we had good opportunities to get to know each other.

Summary:

Prof. Tsuneta's design is being developed by graduate students, post docs, Dr. Akioka from another government lab, and by some small support from studies performed by companies. They have identified and understand the key problems, but have difficulty performing the detailed design. They lack clear procedures for resolving the most difficult but important design issues.

They have what they call a "baseline design", but Prof. Tsuneta knows several key issues remain to be resolved, before it can be considered an actual baseline.

They now have 1 1/2 years to prepare their proposal, and they don't have to compete with anyone. They are the only group which can get the solar magnetograph approved; the hurdle is to have a proposal which will be approved. Then the announcement of opportunity is straightforward.

NASA support is key to project approval. They find the US difficult to collaborate with. They are surprised by the competition between the US groups, and have some difficulty dealing with this. They wish we would collaborate more, and that they could get the combined best from the various US groups.

Their principal technical concern is pointing accuracy; they repeatedly stated that pointing accuracy is the principal factor which limits pointing accuracy. They currently seek a polarimetric accuracy of 0.001. They desire a much faster measurement cadence then MSFC has proposed. They are using a polarizing beam splitter, sending one beam through the birefringent filter, and the orthogonally polarized beam to a echelle Littrow spectrograph.

Mission objective: A systems approach to photosphere-coronal activity:

1. to reveal solar MHD phenomena,
2. the photosphere as the origin of coronal magnetic activities,
3. high resolution x-ray and optical observations,
4. hard and soft x ray features

Planned instruments:

1. Vector magnetograph, 0.1-0.2 arc sec resolution,

2. Echelle spectrograph/polarimeter,
3. x ray telescope, magnetic behavior in solar corona,
4. xuv spectrograph, coronal velocity field measurement.

Satellite:
600 km orbit
680 kg scientific package

Launch date:
Baseline: 2004.

They might get to launch in 2003 if the satellite is ready, and the infrared satellite scheduled for 2003 slips. Indications are the IR satellite might not be ready on schedule. Although this would be during the solar minimum, they are proceeding with this plan. There is some but not a lot of concern about getting the flight approved during minimum.

They put this question to MSFC through me
"Is there a problem with science output if we launch in 2004 or 2005?"
They feel the mission objective can be addressed with quiet sun, revealing fundamental processes. There are less events, but Skylab was launched at solar minimum. So the mission is oriented to the quiet sun. Based on your 20 years of experience, what is your answer?

Baseline design:
50 cm aperture Gregorian telescope
no prefilter
rotating retarder in primary hole before Gregorian focus
folding mirror, articulated
polarizing beam splitter cube followed by two channels:
a. Lyot filtergram based imaging channel
b. Littrow echelle spectrograph based high spectral resolution channel

Lyot filtergram channel:
Collimator
Beamsplitter
Blocking filter wheel
Choice of Lyot filter or interference filters
Shutter
Beam splitter
Camera lens
CCD #1

Littrow Echelle Spectrograph Channel
Relay lens
Scanning mirror
Blocking filter wheel
Slit
Littrow lens
Echelle grating
Shutter
CCD #2
25 mA resolution
1 m Focal length
Designed together with HEAO

Lack of Baseline Design:
Prof. Tsuneta expressed the following opinions regarding this design.
First, the design is far to complex, and ways must be sought to simplify the design. Prof. Tsuneta does not like the two CCDs, nor the beamsplitters in the imaging path (filtergrams).
Second, they do not know how to make some of the trade-off comparisons, particularly Cassegrain/Gregorian and Lyot/Fabry Perot. Reliability is the driving consideration, but is not easily quantified. Further, his group is not skilled at the detailed design of many of

the subsystems.
Third, without an acceptable baseline design, it will be difficult to get an Announcement of Opportunity (AO) out of ISAS.

Telescope:
Prof. Tsuneta's primary concern is contamination; spectral control and heat is the second most important problem. The satellite will require thrusters which create a dirty environment which may contaminate the optics. A prefilter is far forward and exposed to a large solid angle of space. Thus the prefilter may be expected to collect more contamination than an open primary mirror, since much of the material deposited on the prefilter would land first on the walls and baffles of the telescope. The primary mirror sees a smaller solid angle of space.
The primary would be heated above the temperature of the walls, so much of the contamination might be moved from the primary to the walls.
The idea of the conical field stop seems to have fallen out of favor, but a 45 degree folding mirror heat dump is under consideration.

Polarimeter:
The present design uses a rotating retarder, a folding mirror, and a polarizing beam splitter (PBS), with the light analyzed/divided and sent to the two instruments.
They desired to place the retarder as far forward as possible, and placed it in the hole of the primary mirror.
The analyzer is a polarizing beam splitter. They are proposing taking 12 measurements per 360 degree rotation of the retarder.

Filter:
Their baseline design incorporates a universal birefringent filter, but they remain open to a Fabry-Perot, especially since it has been demonstrated in space. They mentioned the difference in near band spectral rejection of the birefringent vs. Fabry-Perot design.
Lockheed has proposed a filter using the SOUP design for the crystals and polarizers, but with different motors which operate in a sealed compartment driven by magnetic fields.

An important issue is how to perform a meaningful comparison of the birefringent vs. Fabry-Perot filter weighted toward reliability issues, but also considering stray light, tunability, and other engineering considerations.

Other:
Doppler compensation is considered essential. They intend to transmit up revised orbital elements every day. They plan to get simultaneous Doppler information from the Echelle spectrograph so a Doppler compensation can be made every 10 seconds or so.

My Comments to Prof. Tsuneta's Group on the Baseline Design:

1. Polarizing Beam Splitter Cube
They had not looked at any coating designs for PBSs. They did not realize that high extinction ratios are not available with polarizing beam splitters, nor that the polarizing axis rotates with angle of incidence. Further, a PBS with broad spectral coverage may be difficult to accomplish. I recommended designing this element as soon as possible to demonstrate feasibility, then fabricating a witness sample for test.

2. Broad spectral range
The baseline design includes vector magnetograph measurements at 5250 and 6302 A as well as narrow band filtergrams from 6563 A down to 3900 A. I emphasized that although a system can certainly be designed to cover this spectral range, that I felt the cost would be much higher. I expect that nearly every component will require more design and analysis; that much more testing will be necessary; and the likelihood of significant problems or failure is much higher. This continuous additional effort that might be difficult to quantify, but that two or more many years of additional design and procurement effort might easily be expended over the design effort for a system restricted to 5000-6600 A.

Prof. Tsuneta's Comments:
Prof. Tsuneta expressed interest in further collaboration with UAH/Marshall, particularly

for the polarimeter construction and calibration. He said the lectures were very helpful, and would help his group in the design of this system. He appreciated NASAs effort in arranging this opportunity.

Further Comments regarding NASA and US system:
"American research groups seem overly concerned with money".
"We are more affected by Washington politics than Tokyo politics, and therefore must pay a great deal of attention to Washington politics."
"There is so much competition between the US research groups, that it is difficult for us to collaborate with the US groups."
"We wish that somehow we could get the best from each of the various US groups, or that such would be proposed to us."
"For example, a birefringent filter from Lockheed, a spectrograph from the High Altitude Observatory, a polarimeter from NASA/UAH, etc."

Appendix 7.

Presentations from Prof. Tsuneta's Group on Solar B Magnetograph Design

This appendix contains copies of the viewgraphs from a series of presentations I received at the National Observatory of Japan. For four days, members of Prof. Tsuneta's group addressed a wide range of issues regarding the Solar-B Design.

The Solar B Magnetograph Design

Prof. Tsuneta's Group
University of Tokyo Tenmondai
National Observatory of Japan
Mitaka, Tokyo, Japan

Presentations:
July 11-14, 1995

Contents:

連続講義のお知らせ

アラバマ大学物理教室のチップマン教授が日本を訪問します。チップマン教授は、偏光光学系と精密偏光測定の専門家で、今回、偏光の測定と解析について連続講義をしていただくことになりました。皆様奮って御参加下さい。

—— 偏光の理論と応用 ——

Prof. Russel A. Chipman
(University of Alabama in Huntsville)

7月17日 14時～ (天文台講義室)
"Introduction to the Jones and Mueller polarization calculus

7月18日 9時30分～ (コスモス会館会議室)
"The NASA/Marshall Solar Vector Magnetograph Design"

7月19日 9時30分～ (コスモス会館会議室)
"Porlarimetry, measuring polarization elements and optical systems"

7月20日 9時30分～ (コスモス会館会議室)
"Porlarization ray tracing"

世話人　一本(天文台)　常田(天文センター)

Mission Objectives

Mitaka
7/18/95

Observations from Yohkoh

"Dynamic" corona rather than static

Magnetic reconnection:
Playing essential roles in various-scale coronal activities including solar flares.

Next Solar Mission (Solar-B)

Photosphere as the origin of coronal magnetic activities

Systems approach to the corona-photosphere connection
→ reveal solar MHD phenomena

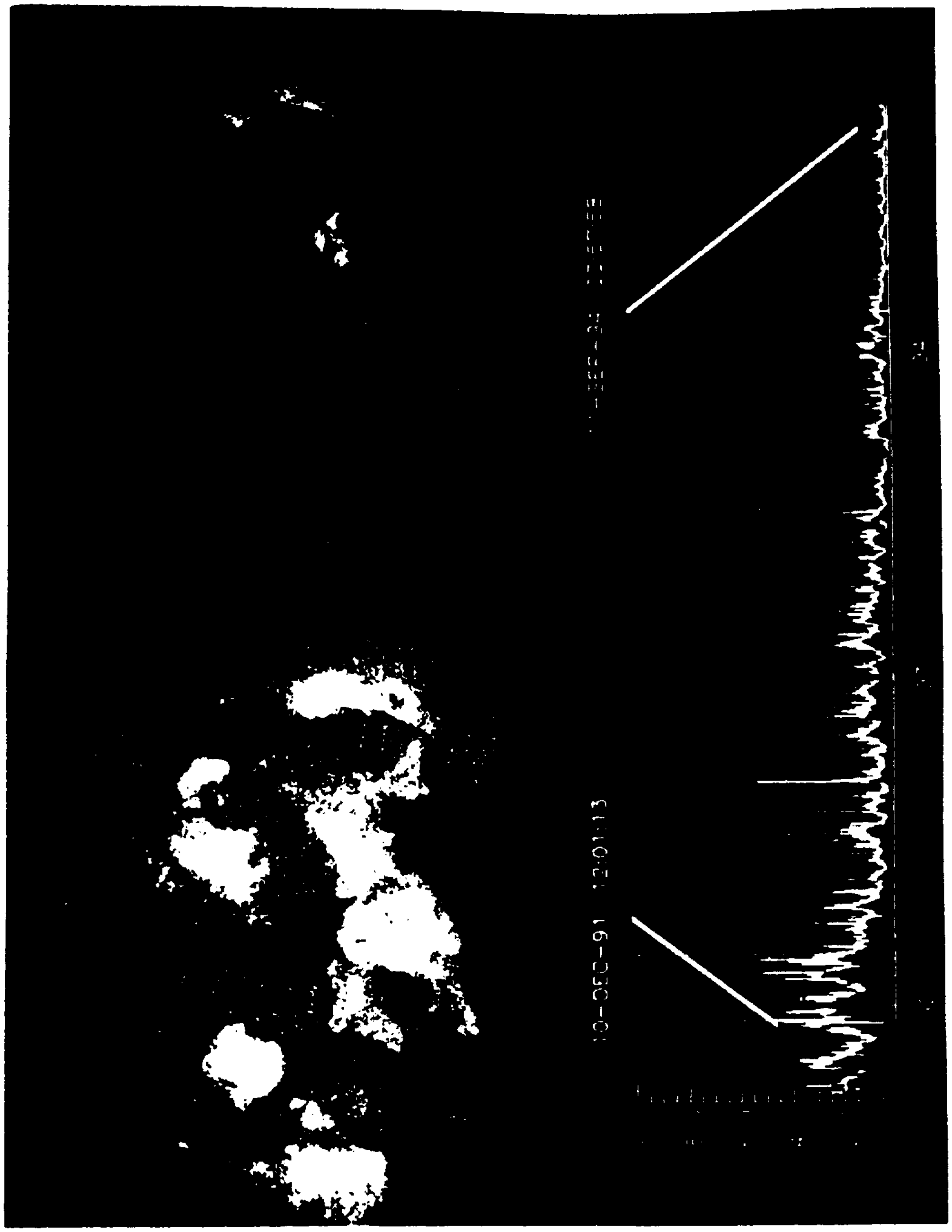
High resolution imaging observations of corona and photosphere with X-ray and optical telescopes

On-board Instruments:

- Optical Telescope:
  Vector magnetic measurement
- X-ray Telescope:
  Magnetic behavior in the solar corona
- XUV Spectrograph:
  Coronal velocity field measurement

The Next Japanese Solar Mission

Mission Objective	High spatial resolution observations of magnetic coupling between photosphere and corona as the engine of coronal/chromospheric MHD activities.
Orbit	Sun-synchronous orbit with $h \sim 600$ km
Weight	Scientific payloads and bus components: ~ 680 kg Thrusters: ~ 170 kg
Launch Timing	Around the year 2004
Mission Period	More than 2 yr of sun-synchronous operation using thrusters. Extended operation in the post-sun-synchronous phase.
S/C Body Control	X/Y: 0.02"/s (under study)
Image stabilization	X/Y: >> 0.02"/s (possible use of a tip-tilt mirror)
Data Rec. Rate	~ 500 kbps ~ 3 Gbits / orbit
Data Rep. Rate	~ 5 Mbps (desired)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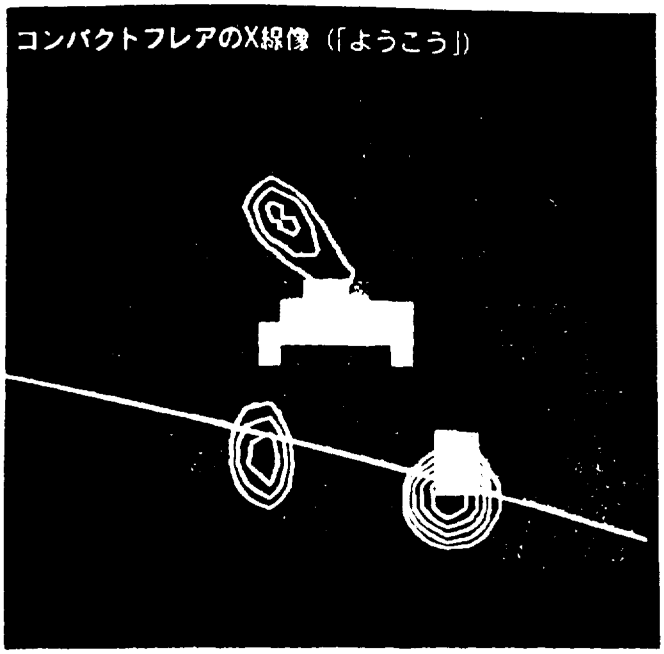
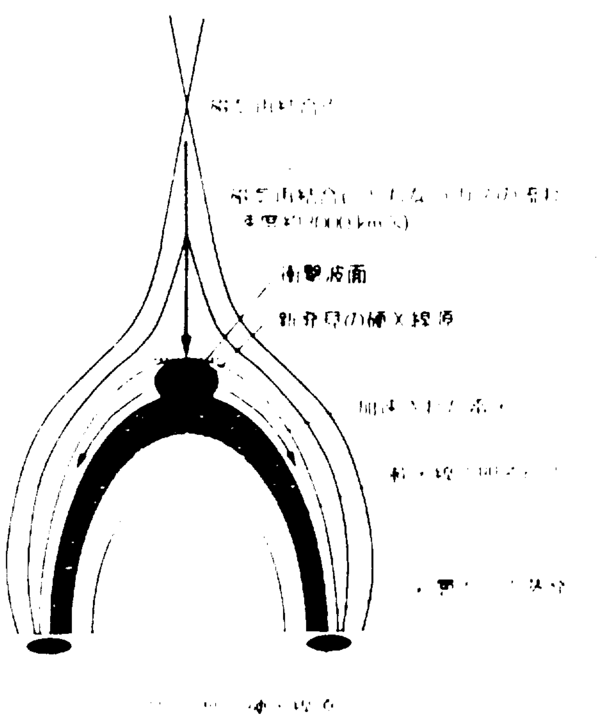
コンパクトフレアのX線像（「ようこう」）

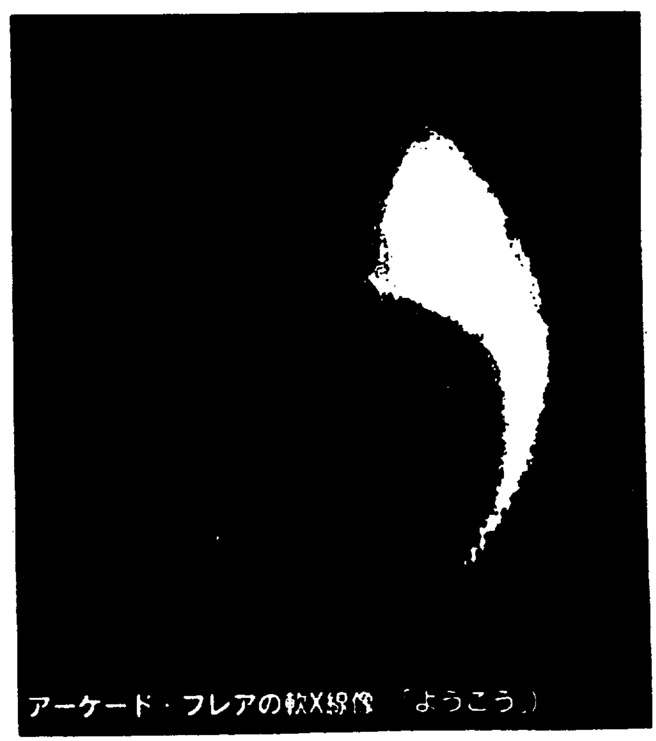


軟X線像（カラー）、硬X線像（等高線）

太陽フレアは太陽系の中で最も激しい爆発現象の一つです。最大規模のフレアの場合、1メガトン水素爆弾数10億発分ものエネルギーを放出します。「ようこう」はフレアにおける磁気リコネクションのはっきりした証拠を見つけました。その結果、フレアのリコネクション説はほぼ確立されたといえます。しかし、にもかかわらず、いくつか謎が残っています。磁気リコネクション理論によれば、リコネクション領域から秒速2000km以上の高速ジェットが噴出するはずですが、そのような高速のジェットはまだ見つかっていません。

さらに基本的な問題が残されています。フレアのエネルギー源が黒点近傍のコロナに蓄えられた磁気エネルギーであることはほぼ間違いないところですが、このエネルギーがどのように蓄えられたのか、まだわかっていません。エネルギーは磁力線が光球プラズマの運動でひねられることにより蓄えられたのでしょうか？　それとも、ねじれた磁束管の浮上という形で、直接、対流層内部から運ばれたのでしょうか？





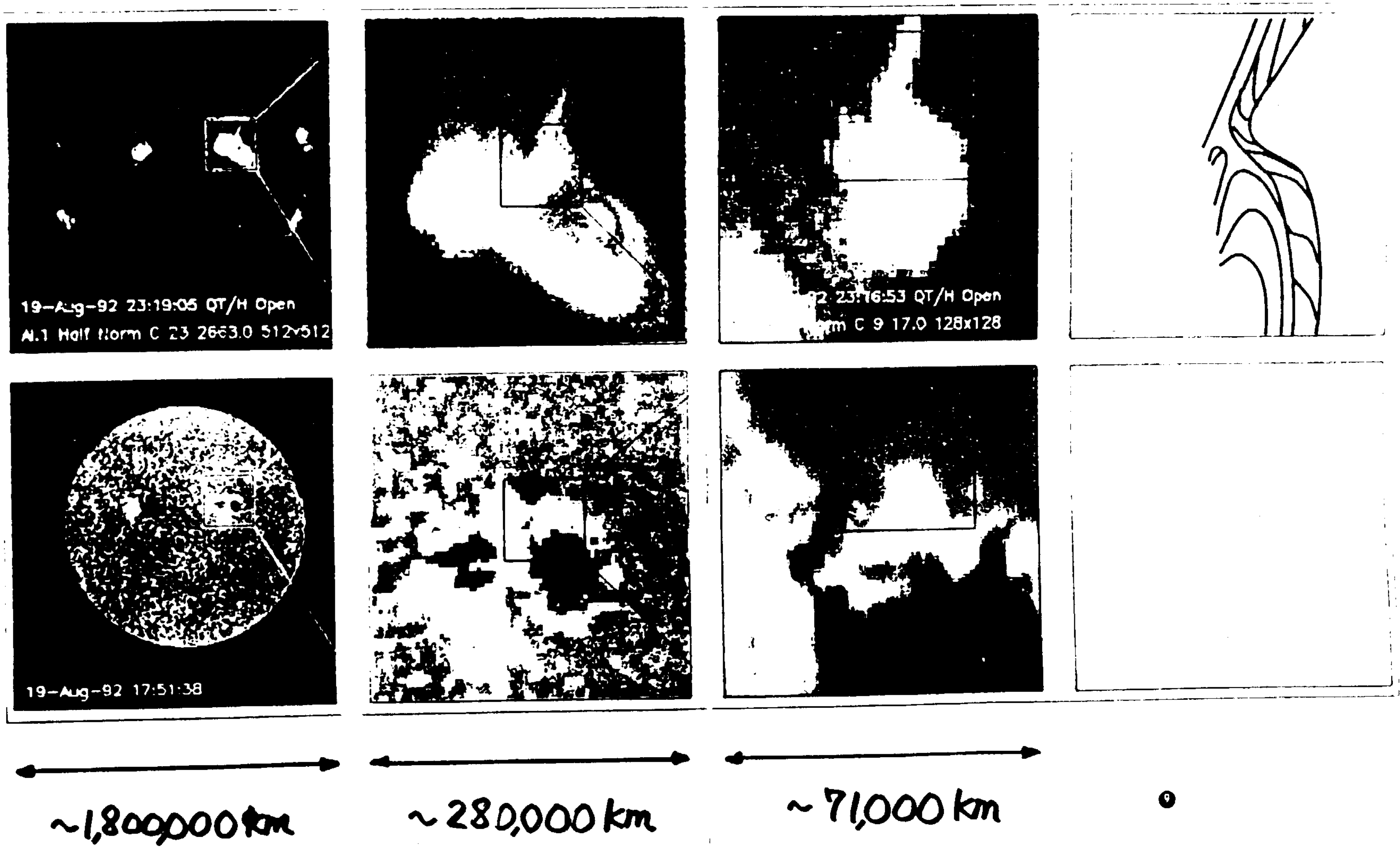
アーケード・フレアの軟X線像（「ようこう」）

「ようこう」の軟X線望遠鏡が撮影した連続写真は、コロナ磁場がダイナミックに激しく活動して、その様子をはっきりと見せてくれました。ほぼ同時刻に地上で撮影された光球磁場写真と比べてみると、光球ーコロナ間の磁気的カップリングこそがコロナのダイナミックスの謎を解くための鍵を握っているという印象を受けます。下図はその一例です。黒点（S極＝黒色の領域）のすぐ近くで、逆向きの磁場（N極＝白色の領域）が混じりあうような異変が生じると、激しいジェットとフレアが発生します。しかし逆向きの磁場の成因はまだわかっていません。

このようにコロナ活動が光球ーコロナ間の磁気的カップリングに支配されているのは、ほぼ疑いありません。しかし、「ようこう」のX線観測、地上の可視光磁場観測ともに空間分解能が十分ではなく、肝心の光球ーコロナ間の磁場構造が不明のままでした。SOLAR-B衛星では、高空間分解能のX線・可視光同時観測によって光球・コロナ間の磁場構造を明らかにして、コロナのダイナミックスの原動力としての光球ーコロナ間の磁気的カップリングの謎をさぐります。

軟X線でみたコロナ

光球面の磁場



Overview of Satellite System

Taro Sakao (NAOJ)

System Characteristics

1. Attitude Control System

Close relationship between ACS and PIs

- **Sub-arcsec pointing**
  (∼ ×6 higher stability than Solar-A)
- **Active control** (by a tip-tilt mirror) necessary ?
- **Signals between ACS and the optical telescope**
  OPT → ACS: solar rotation tracking (by feature tracking) ?
  ACS → OPT: gyro signal for tip-tilt control ?
  Tip-tilt mirror as a part of ACS ?

2. Spacecraft Orbit

Scientific requirements ↔ trade-offs with system requirement

- **Sun-synchronous** *vs* equatorial orbits
  merits and demerits (thermal control, weight penalty etc.)
- Use of thrusters (sun-synchronous orbit)
  Operation for post sun-synchronous orbit
  ⟶ Mission design **(extended/degraded mission)**
- Radiation environment
  System impact (shielding, radiation-hardened devices, ...)

3. Telemetry

- Scientific requirements and data production rate
  huge amount of data ($\gtrsim$ 7 Gbits/orbit of raw data)
- On-board data processing
  including Stokes demodulation and data compression etc.
- On-board data storage
  large volume DR & data buffers necessary
- **Telemetry downlink rate ($\sim$ 5 Mbps)**
  ← Possible ?

4. Ground facilities (TBD)

- Data downlink at KSC and DSN
  Telemetry downlink rate / Use of X-band
- Data transfer between KSC/DSN and ISAS
- Data storage and processing
  (data compression at ground facilities ?)

	Next Mission	Solar-A	
			Large difference i[n] S/C system
Att. control			
Short term	X,Y: $0.2''/s$ Z: $45''/s$	X,Y: $1.2''/s$ Z: $5'/s$	~ x6 higher attitude control
Med. term	X,Y: $0.4''/min$ Z: $1.5'/min$	X,Y: $7''/min$ Z: $7'/min$	
Abs. pointing	X,Y: $< 1'$ Z: $< 2'$	X,Y: $< 6'$ Z: $< 10'$	
Active control	maybe necessary (X,Y: $0.02''/s$)	not necessary	New
Orbit			
Orbit	Sun-synchronous, polar LEO ($h \sim 600$ km)	Equatorial, LEO	New orbit Launch procedure
Weight	~ 700 kg thruster ~ 150 kg	$\lesssim 400$ kg	
Mission period	> 1 yr	—	Mission design
Telemetry			
Data rec. rate	~ 500 kbps	32 kbps	several x 10 times larger
Rec. data size	~ 3 Gbit/orbit	80 Mbit/orbit	
Downlink rate	~ 5 Mbps	262 kbps	

Attitude Control System

Taro Sakao (NAOJ)

Key Issues

- **Sub-Arcsec Pointing**

X/XUV		OPT ?		
0.2"/s	→	0.02"/s (baseline target)	→	?

← Active image stabilization?

Requirements: for 20marcsec stability (c.f. HST: 7marcsec)

- Filter wheels : counter wheels necessary ← disturbance
- Gyro : pulse weight 0.004" (*c.f.* Solar-A: 0.08") ← sensor
- Momentum wheels : ← actuator

  ball-bearing type ← HST

  ... oil soak / wobble torque problems.

  magnetic-bearing type

  ... really feasible ? (under development) ⇒ 0.02"/s stability by S/C body pointin

- **Active Stabilization (by Tip-tilt mirror) ?**
  - Sensor ? (limb sensor / correlation tracking / or else ?) ← gyro signal ?
  - Tip-tilt mirror feasible ?

- **Signals between ACS & Optical Telescope**
  - Rotation tracking (attitude control w.r.t. the Sun)

    OPT → ACS : feature tracking signal
  - Tip-tilt mirror control

    ACS → OPT : high precision gyro signal

  } feasibility under study

Tip-tilt mirror as a part of ACS ?

Orbit Choices and Scientific Requirement

Taro Sakao (NAOJ)

Scientific Requirements

- **High Spatial Resolution Observations**
  - Minimize thermal distortion
  - Constant thermal environment
- **Continuous Observations**
  - Observe solar activities in various timescales
  - Increase efficiency of observations
  - pre- and post-flare activities
- **Minimize Doppler Effect due to Orbital Motions**
  Precise magnetic field measurements (line width ~ 100mÅ)

Orbit Choices

sun-synchronous orbit with $h \sim 600$km

- **Sun-synchronous orbit is preferable for the scientific requirements**
- **Weight penalty / Radiation environment / Orbit lifetime**
- **Need more careful study (Other orbit ?)**

Study Area

- Mission design for the post sun-synchronous orbit
- Most preferable orbit (height etc.)
- Launch sequence and initial operation

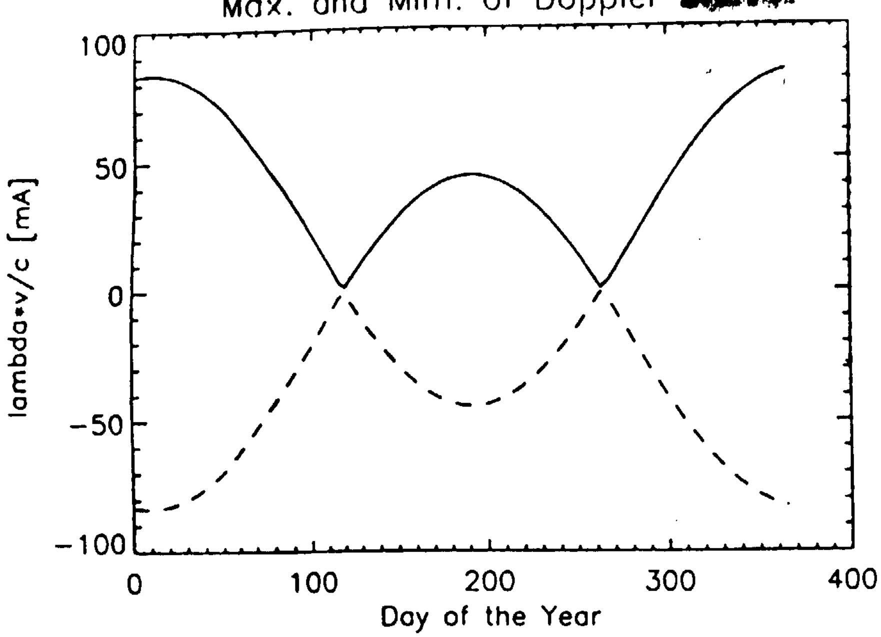
[redacted]

Comparison between Sun-Syncronous and Equatorial Orbits

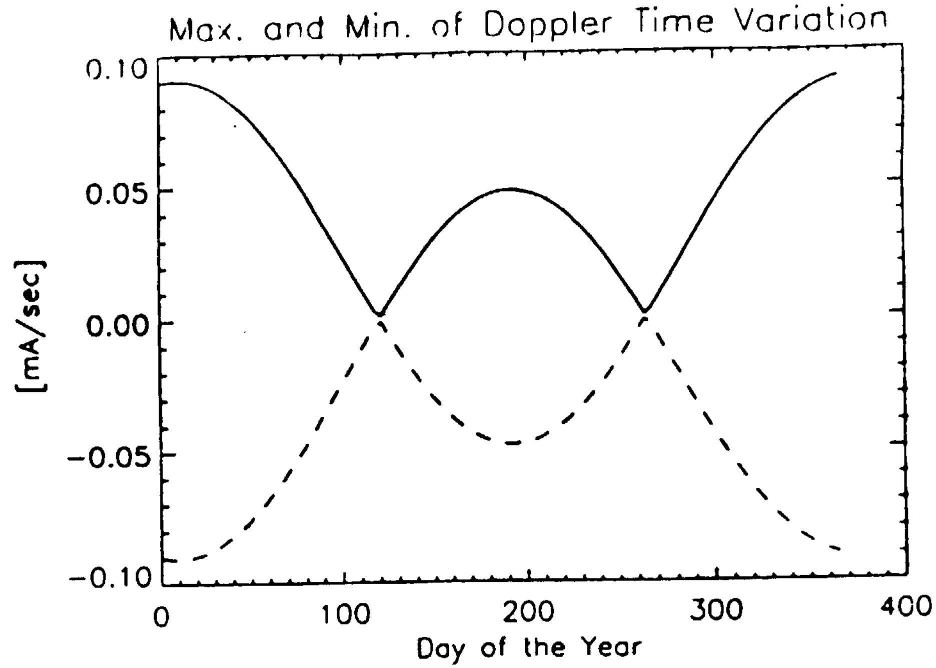
Orbit (*)	Sun-Synchronous	Equatorial
Observation	**Continuous observation** for $\sim$ 8 months / yr	S/C night: $\sim$ 40 min / orbit
Doppler shift (@ $\lambda = 5000$Å)	at most $\sim$ 130 mÅ$_{p-p}$/orbit max: $\sim$ 0.7 mÅ/10s	$\sim$ 250 mÅ$_{p-p}$/orbit max: $\sim$ 1 mÅ/10s
Thermal / power design	**Much easier** than equatorial orbits	Not easy
Total S/C weight (net dry weight)	$\sim$ 875 kg ($\sim$ 700 kg)	$\lesssim$ 1.5 t (with thrusters) ($\lesssim$ 1.3 t)
Launch	Constraints on i, h, and e	**Experienced** (resources available) Thruster desired
Thruster (**)	Necessary; $\sim$ 170 kg (fuel: $\sim$ 125 kg, tank: $\sim$ 45 kg) contamination ?	Desired
Radiation environment	SAA + auroral zone significant contrib. of flares	SAA

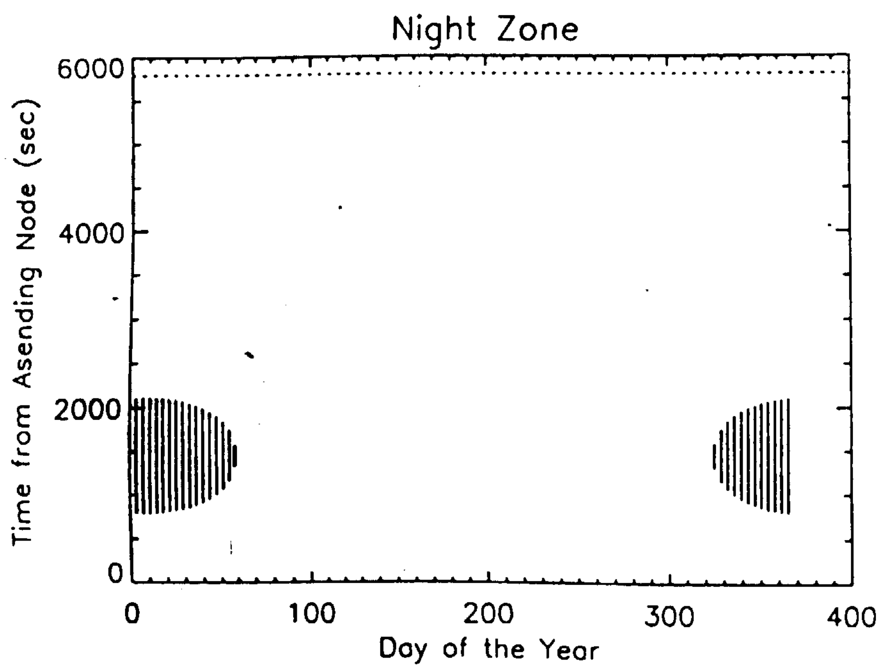
(*) $h = 600$ km, $e = 0$ assumed
(**) for 2 yr orbit lifetime

$\Delta\lambda_{Doppler}$



$\frac{d}{dt}\Delta\lambda_{Doppler}$

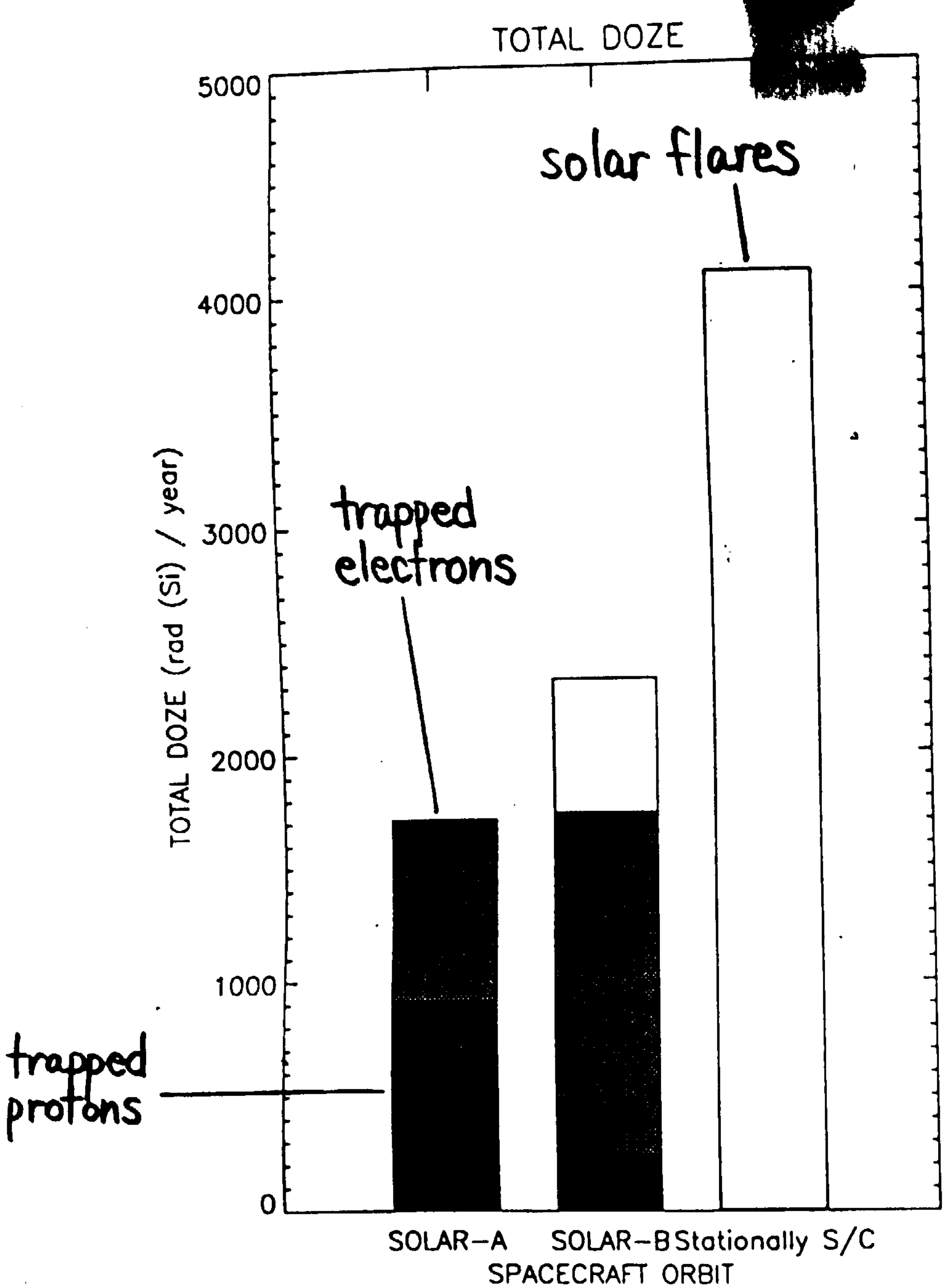


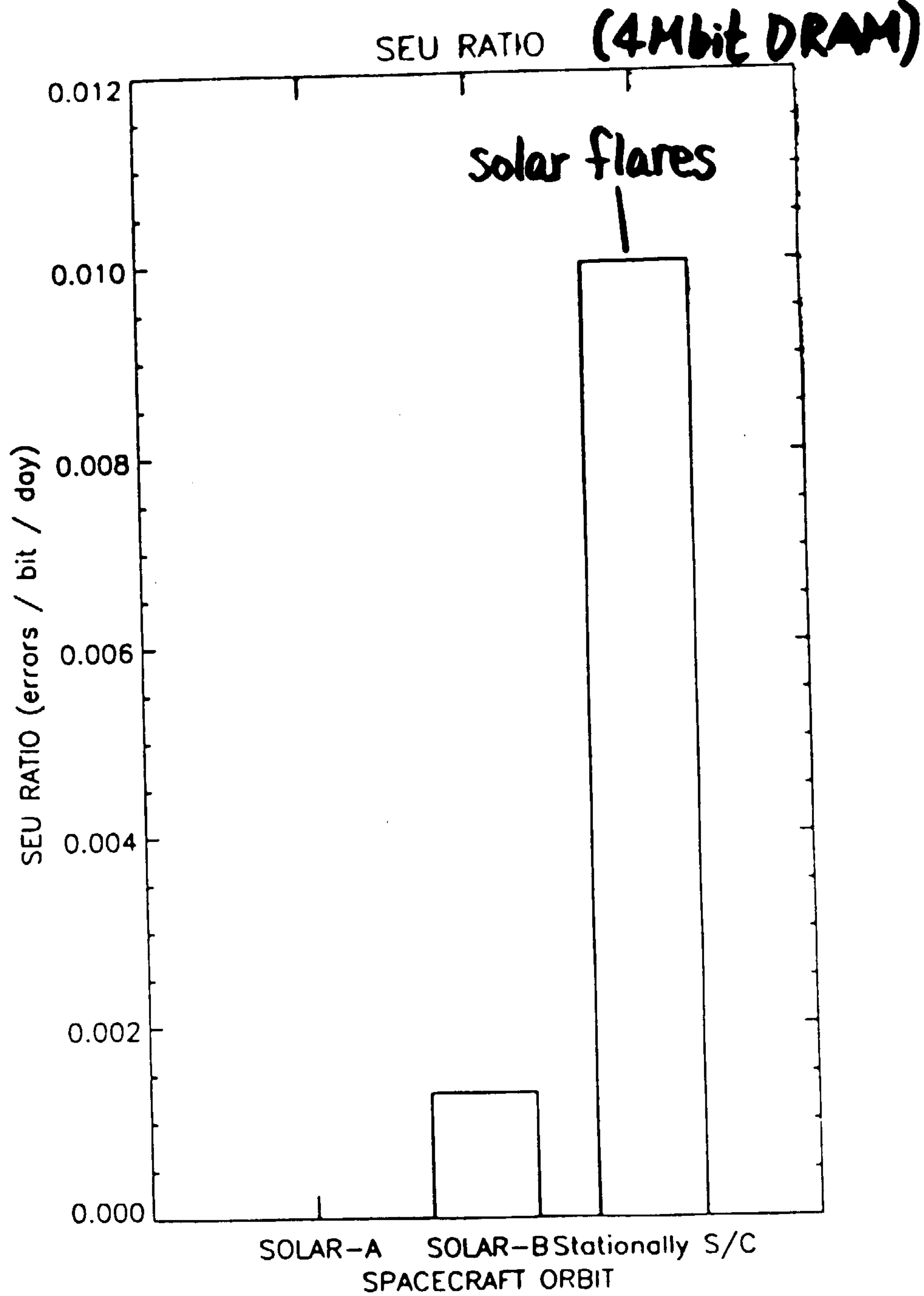


Doppler Shift by Orbital Motion

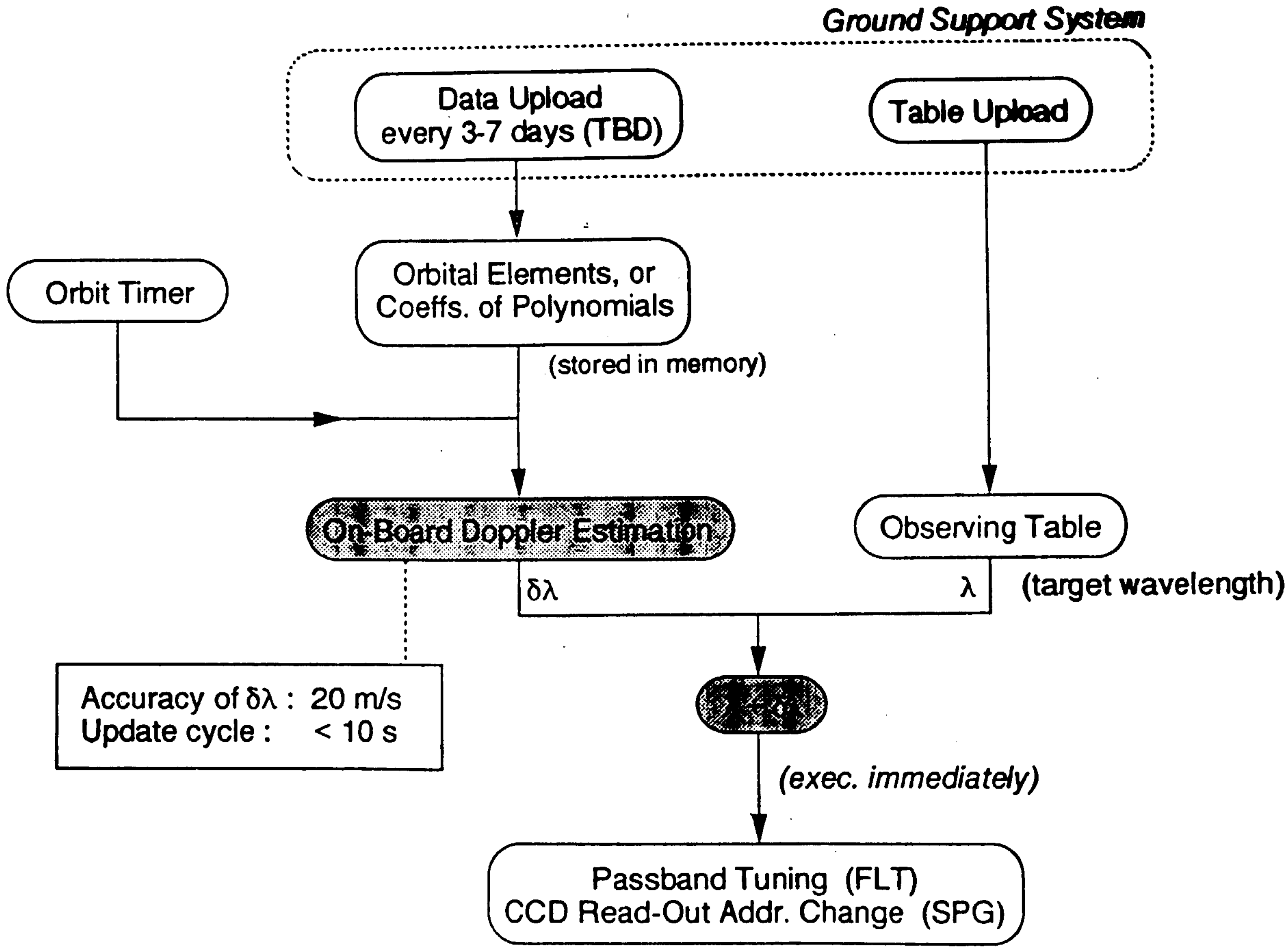
increnation = 97.79 deg
eccentricity= 0.00
w = 90.00 deg
hight = 600 km
wave length = 6303 A
time/orbit = 5801 sec
Night(max.) = 1322 sec

- S/C night appears for $\lesssim$ 4 months
- max. night interval : $\gtrsim$ 20 min (~23%)

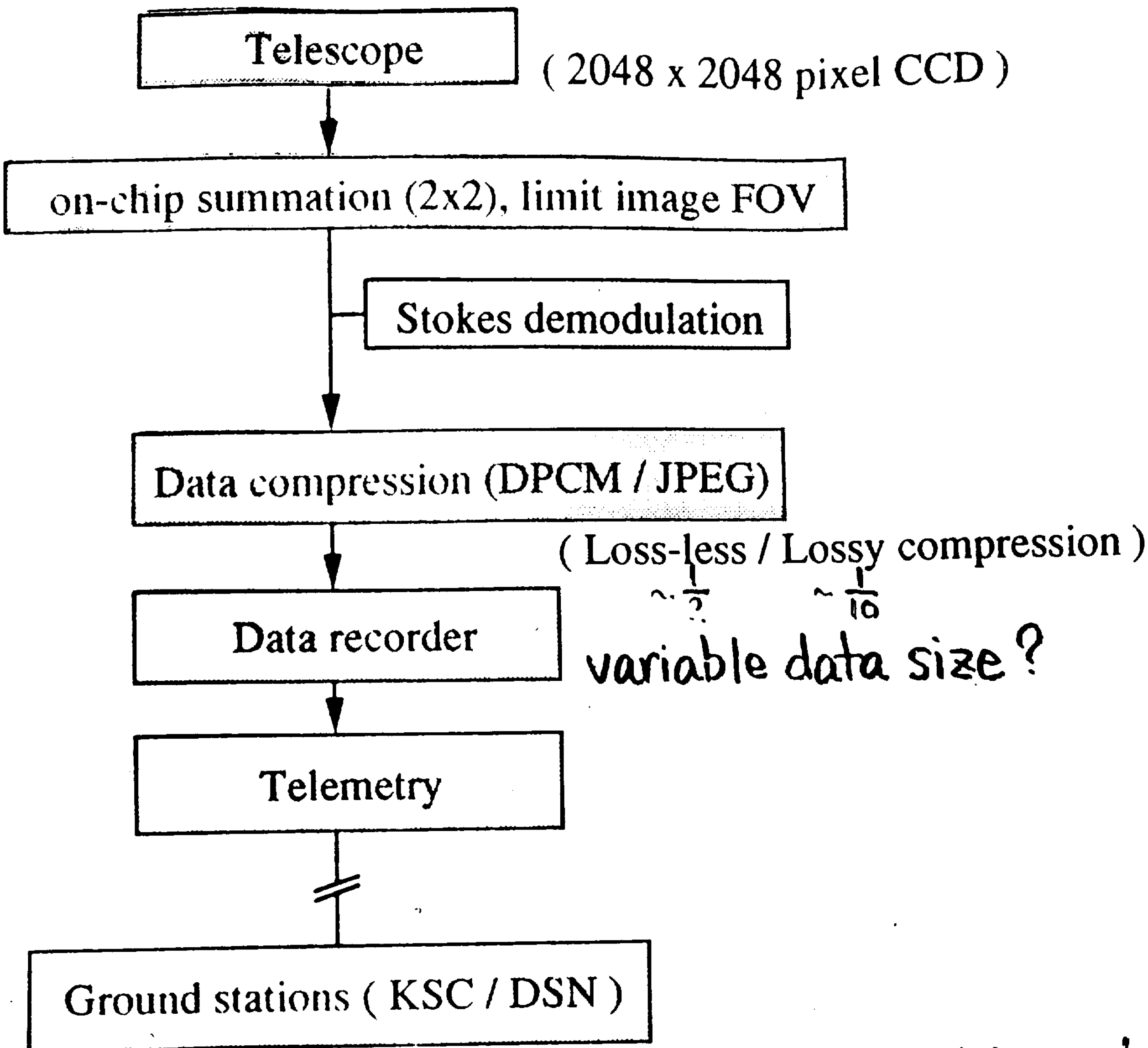

TOTAL DOZE
TOTAL DOZE (rad (Si) / year)
5000
4000
3000
2000
1000
0
solar flares
trapped electrons
trapped protons
SOLAR-A
SOLAR-B
Stationally S/C
SPACECRAFT ORBIT


SEU RATIO
(4Mbit DRAM)
SEU RATIO (errors / bit / day)
0.012
0.010
0.008
0.006
0.004
0.002
0.000
solar flares
SOLAR-A
SOLAR-B
Stationally S/C
SPACECRAFT ORBIT

On-Board Doppler Compens[redacted]n



On-board Data Flow



Data Rate (preliminary)

reduced by ≲ 1/2

Telescope	Raw data	Recorded data
X-ray	1.2 Gbit/orb (204 kbps)	396 Mbit/orb (66 kbps)
Optical *FLT*	4.2 Gbit/orb (700 kbps)	1.9 Gbit/orb (322 kbps)
SPG	2.2 Gbit/orb (367 kbps)	1.0 Gbit/orb (169 kbps)
TOT	6.4 Gbit/orb (1.1 Mbps)	2.9 Gbit/orb (491 kbps)
XUV	384 Mbit/orb (64 kbps)	384 Mbit/orb (64 kbps)
Total	8.0 Gbit/orb (1.4 Mbps)	≳ 3 Gbit/orb (≳ 500 kbps) →D

≳ 5 Mbps downlink rate ???

DR, Telemetry, and Ground Facilities

Requirements to Data Recorder

Satellite	Solar-A	Astro-D	Astro-E	IRIS	Solar-B(*)
REC	32 kbps	32 kbps	$\sim$ 200 kbps	$\sim$ 300 kbps	$\sim$ 500 kbps
REP	262 kbps	262 kbps	$\gtrsim$ 1 Mbps	$\sim$ 4 Mbps	$\sim$ 5 Mbps
Data/orbit	80 Mbit	128 Mbit	$\sim$ 1 Gbit	$\sim$ 2 Gbit	$\sim$ 3 Gbit
REP time	5min 20s	8min 32s	$\sim$ 10 min	10 min	10 min

(*) Preliminary. PI data only.

→ semiconductor memory for huge capacity
16 Mbit DRAM available ? (high radiation-hardness)

Packet Telemetry ?

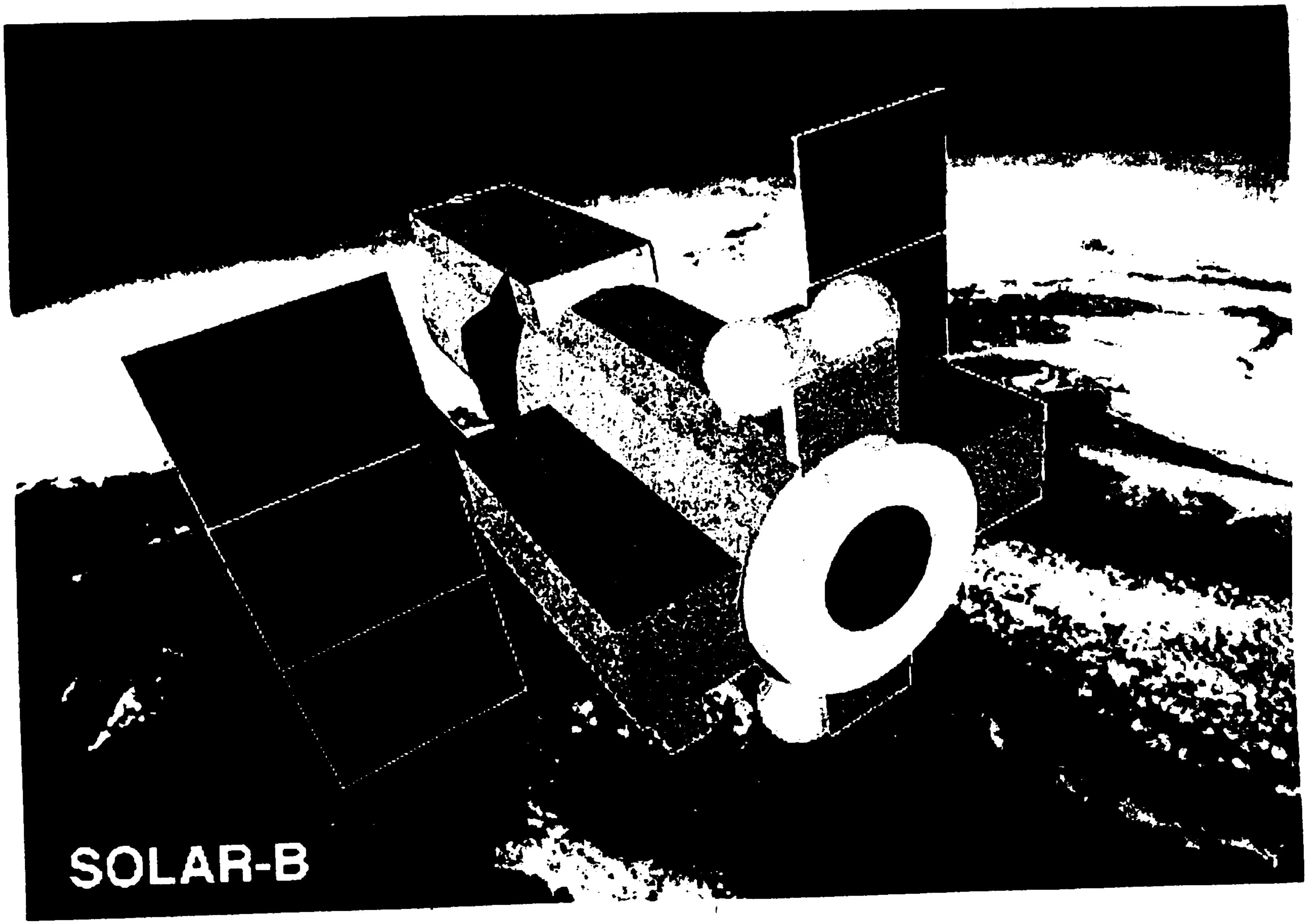
- On-board packet interface ?
- Packet downlink telemetry ? → Real-time monitor in X-band ?

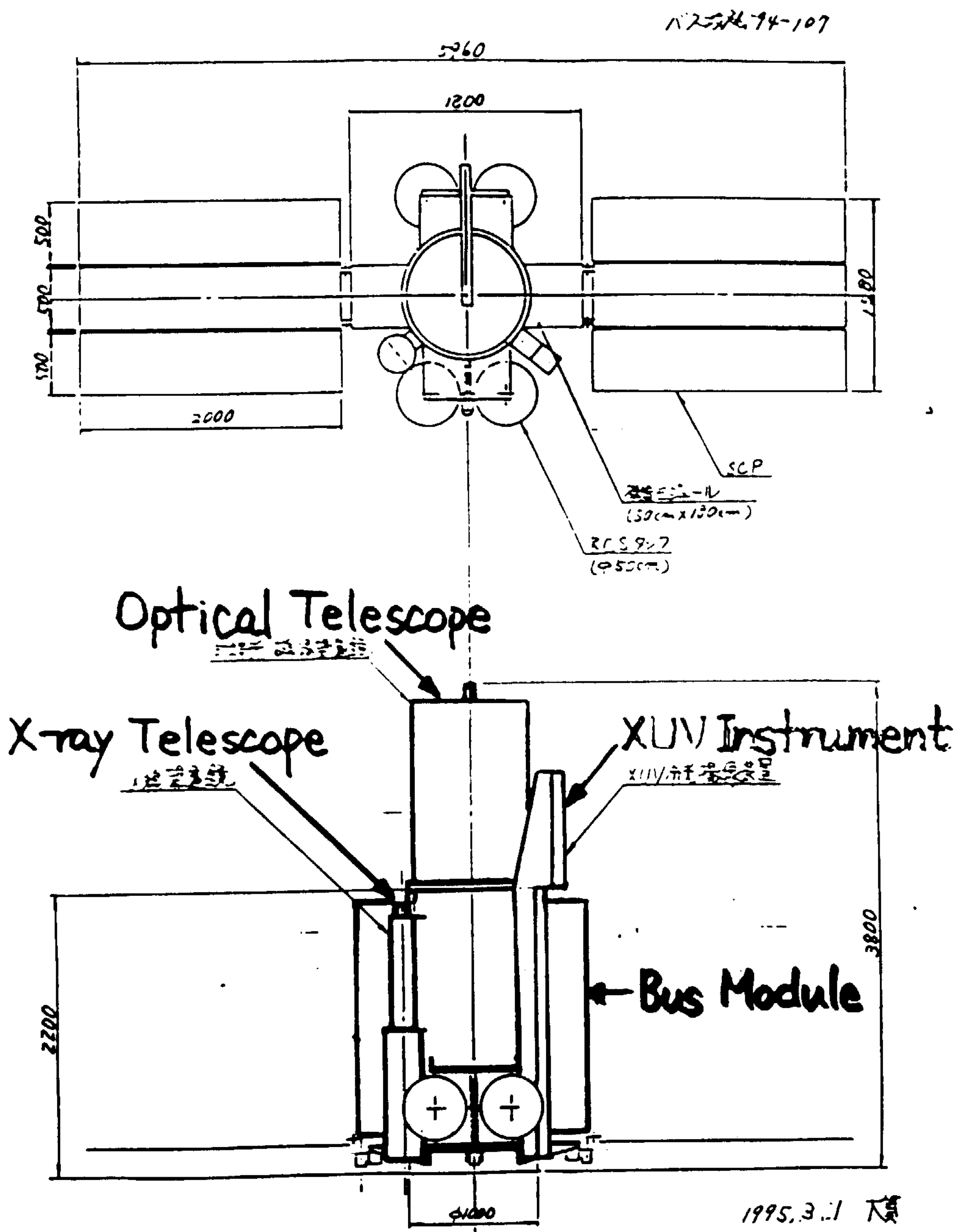
Ground Stations

		current status	future plan
KSC	S-band	max. 262 kbps	TBD (no high speed TLM available ?)
	X-band	max. 262 kbps	TBD ($\gtrsim$ 2 Mbps ?)
KSC	→ ISAS	384 kbps	?
DSN	S-band	max. 262 kbps	max 1.6 Mbps ?
	X-band	—	no high speed TLM available ?
DSN	→ ISAS		?

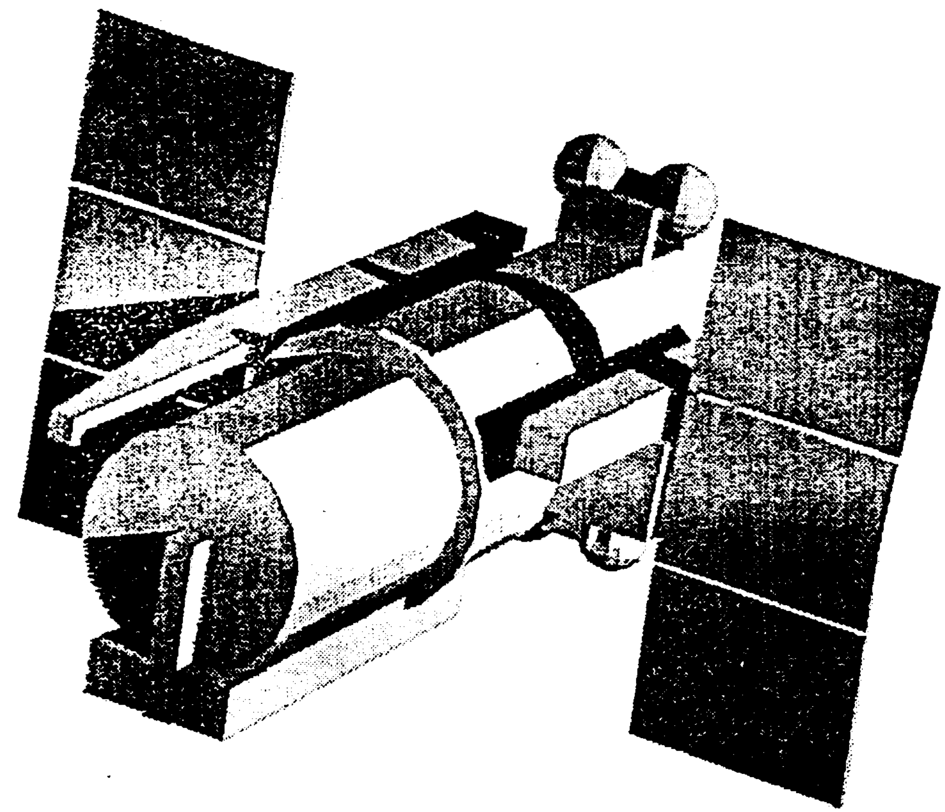
Concerns on DSN:

- low max. downlink rate ?
- location adequate for sun-synchronous orbits ?


SOLAR-B



SOLAR-B C案 (1/3)



SOLAR-B軌道上概念図

Overview of the Solar-B Optical Telescope

Ryouhei Kano
Institute of Astronomy, The University of Tokyo
kano@sxt1.mtk.s.u-tokyo.ac.jp

1995 July 18-20
Mitaka, Tokyo

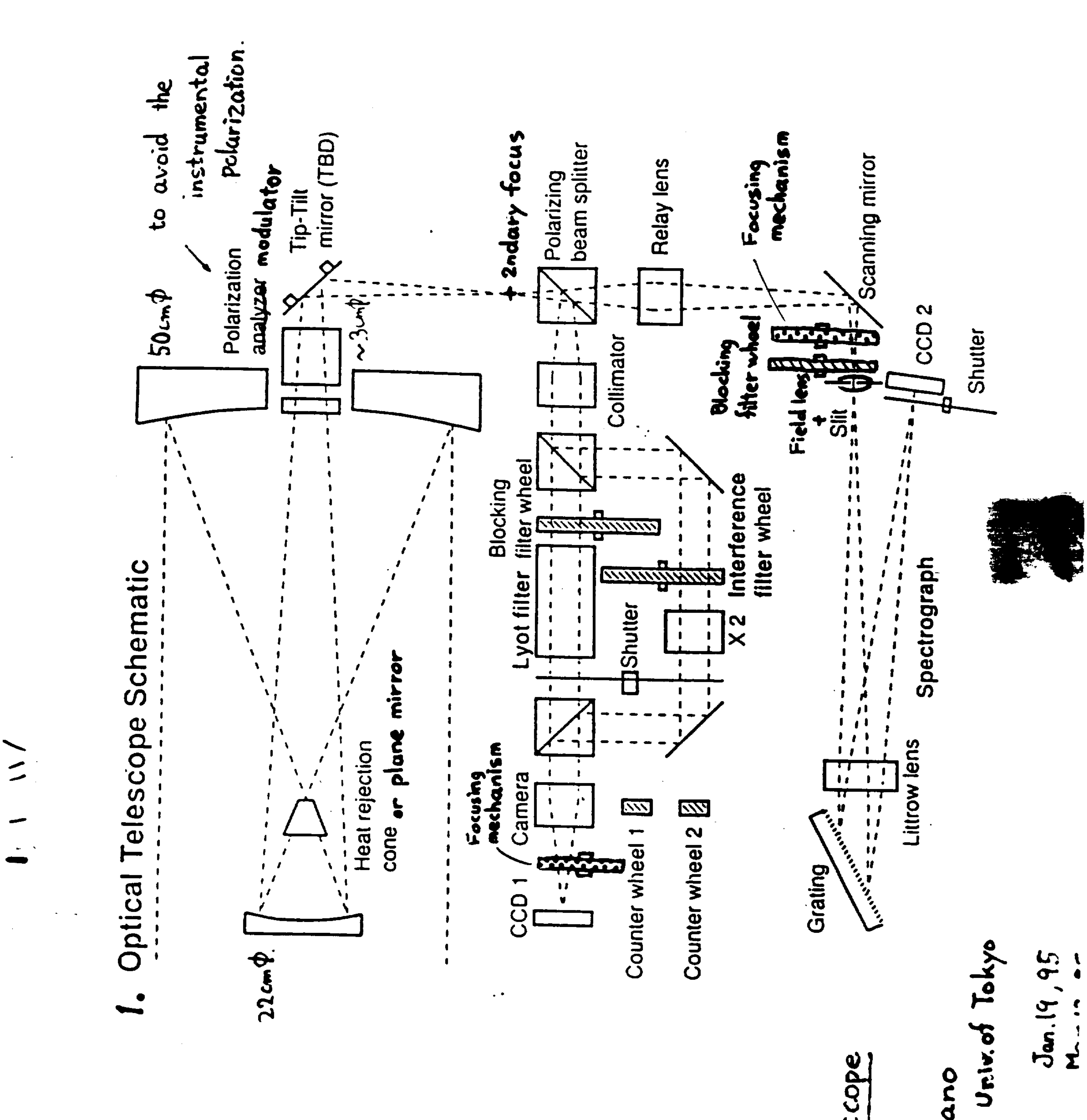


図 4.14: 焦点面光学コンポーネント模式図

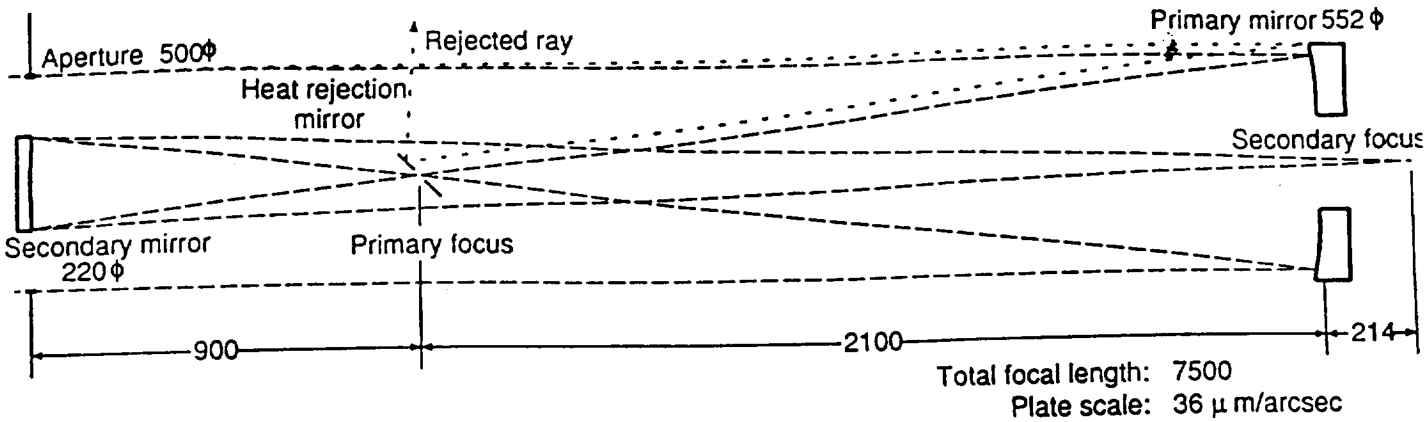
Optical Telescope

Ryouhei Kano

Univ. of Tokyo

Jan. 19, 95

Gregorian Telescope ver 95-Mar-10 R.Kano



Parameters of Optical Telescope

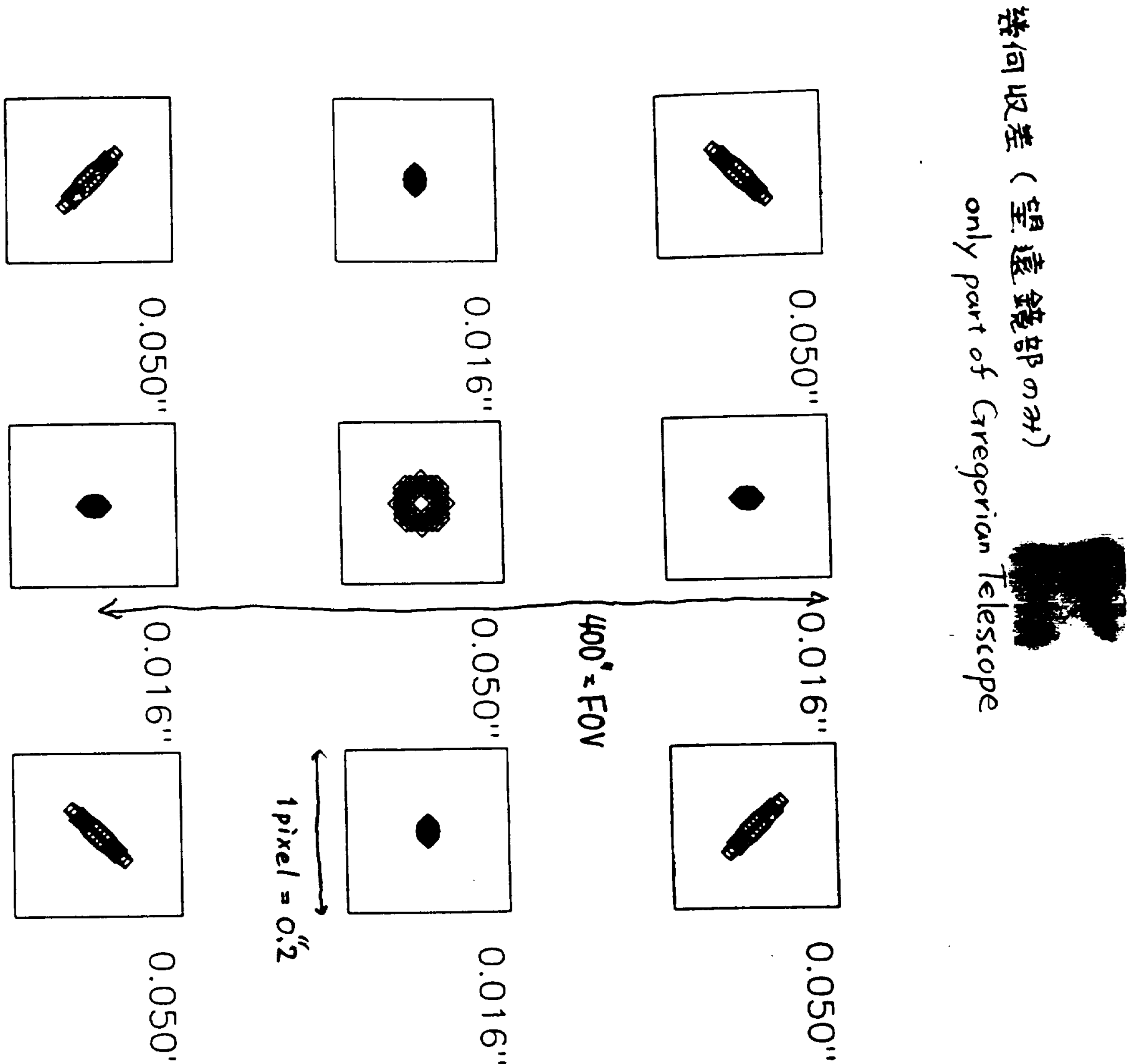
Aplanatic Gregorian	D=500 ϕ, f=7500, F/15
aperture	D0=500 ϕ
primary mirror	D1=552 ϕ, f1=2100, F/4.2
secondary mirror	D2=220 ϕ, m=3.57
distance between two mirrors = 3000	
back focus = 214	

CCD 9 μm/pixel, 2048x2048 pixels

Focal Plane Package

	F-value	PlateScale	FOV
Lyot filter	F/18.56	0.2"/pixel	400"
Interference filter	F/37.13	0.1"/pixel	200"
Spectrograph	F/18.56	0.2"/pixel	400"

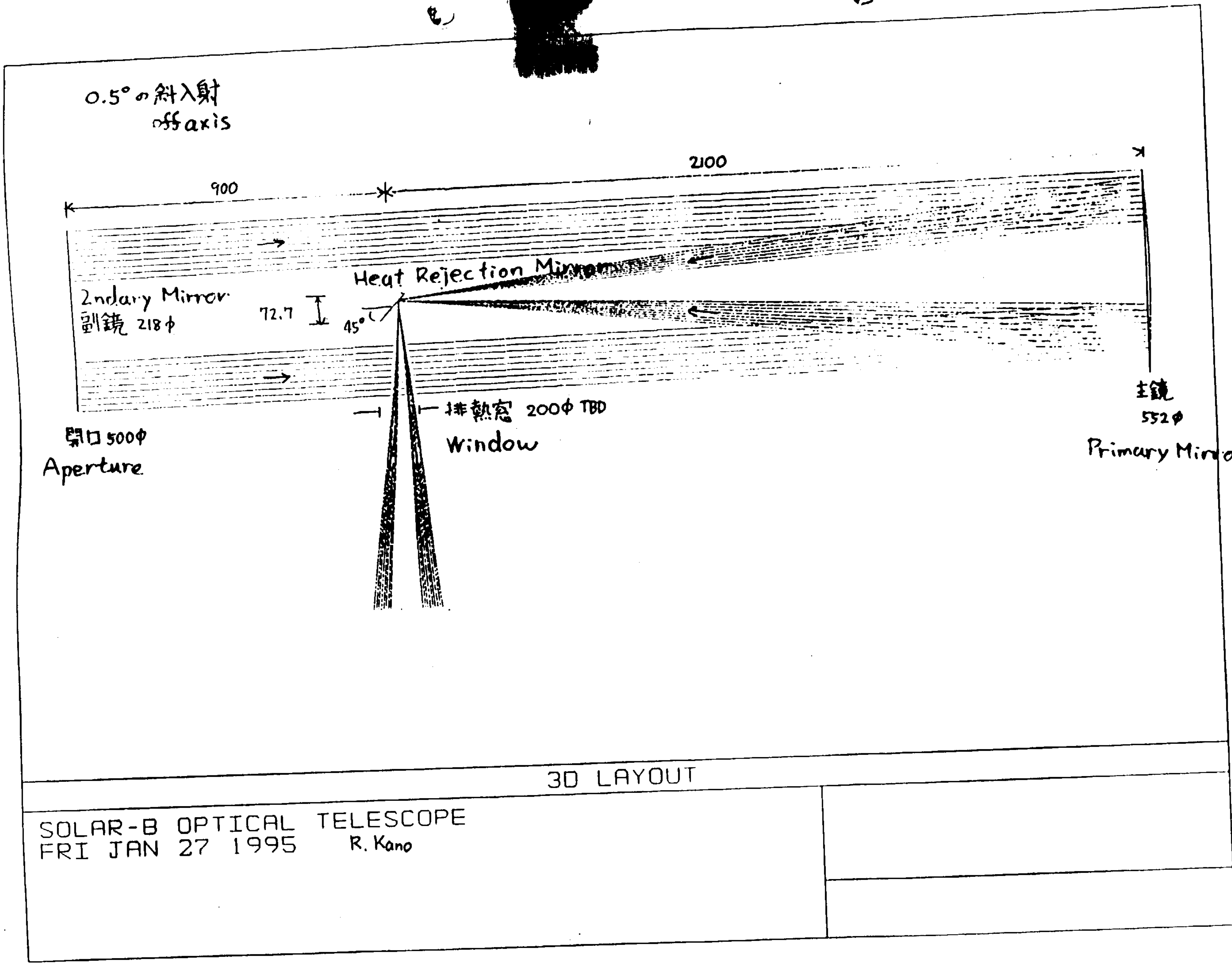
Aberration(F/18.56)	0.05"	within the FOV
Airy Disc Diameter	0.50"	@ 5000Å



<<<Aplanatic Gregorian System for the Solar Telescope>>>

D(0) = 500.mm fl = 7500.0mm bf = 214.mm
W = 0.mm dis = −3000.00mm
D(1) = 500.0mm R(1) = −4200.11mm K(1)= −0.95296
D(2) = 220.2mm R(2) = 1406.15mm K(2)= −0.36874
Field = 0.00 arcmin / 0.dec
Secondary Mirror
Despace (mm) = 0.000 0.000 0.000
Tilt angles = 0.00 arcsec / 0. dec
Spot Diagram at 214.04

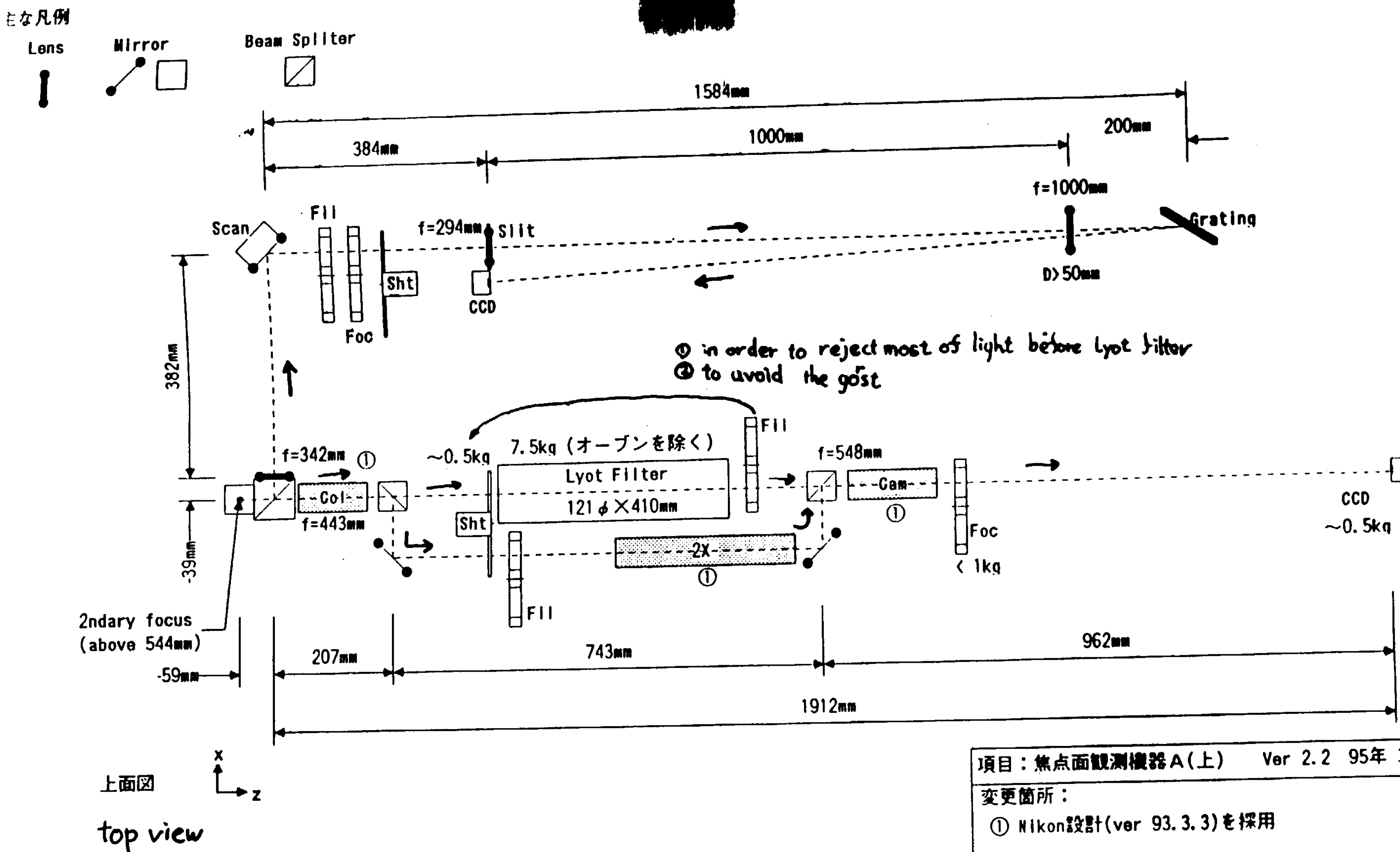
Fig 1.



0.5° の斜入射
off axis
900
2100
Heat Rejection Mirror
2ndary Mirror
副鏡 218φ
72.7
45°
排熱窓 200φ TBD
Window
開口 500φ
Aperture
主鏡
552φ
Primary Mirror
3D LAYOUT
SOLAR-B OPTICAL TELESCOPE
FRI JAN 27 1995
R. Kano

}. Focal Plane Package

[redacted]

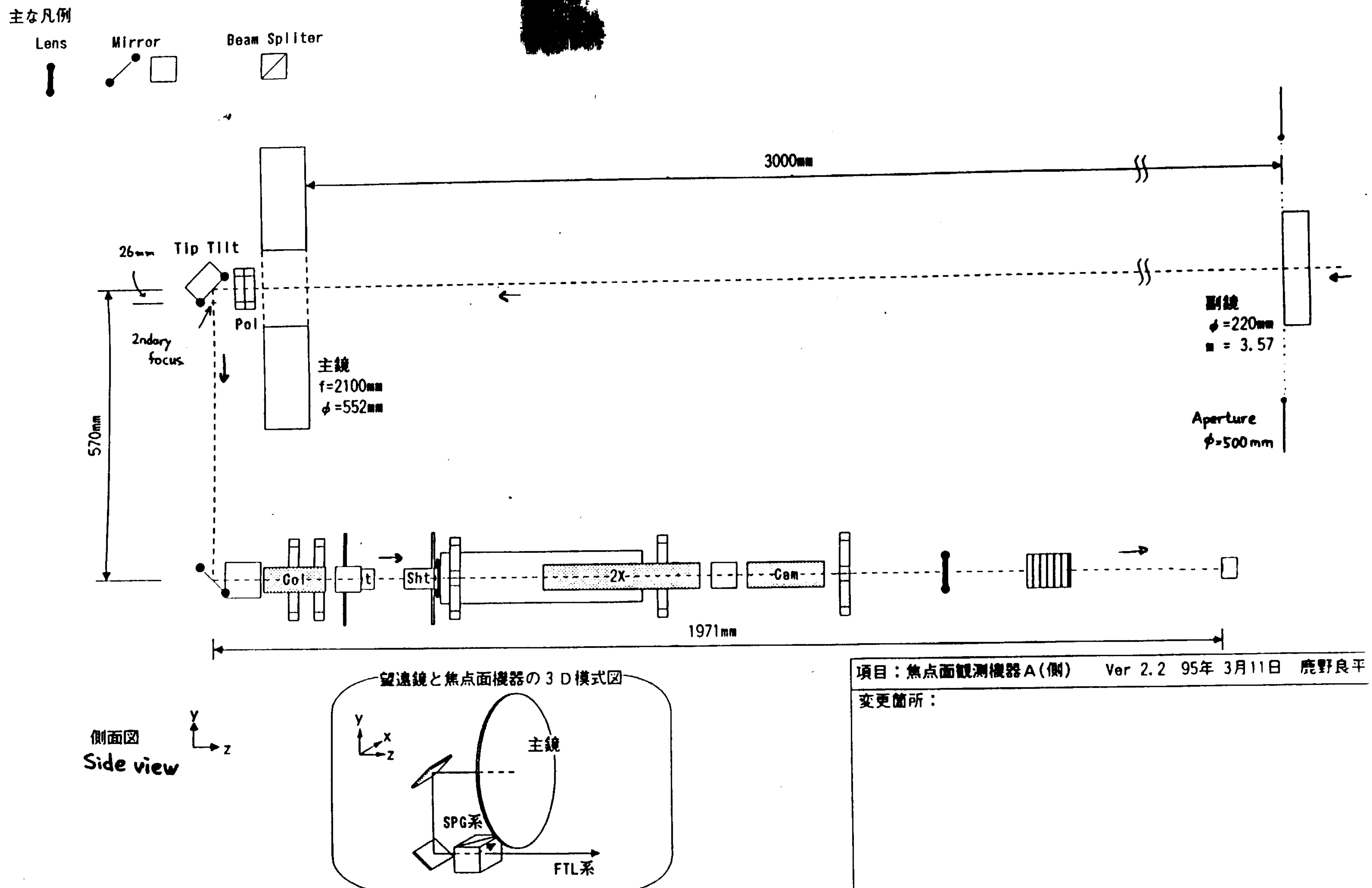


項目：焦点面観測機器A(上)　Ver 2.2　95年 3月11日　鹿野良平

変更箇所：

① Nikon設計(ver 93.3.3)を採用

[redacted]



項目：焦点面観測機器Ａ(側)	Ver 2.2	95年 3月11日	鹿野良平
変更箇所：			

SPOT DIAGRAM

1倍 (グレゴリアン望遠鏡含)

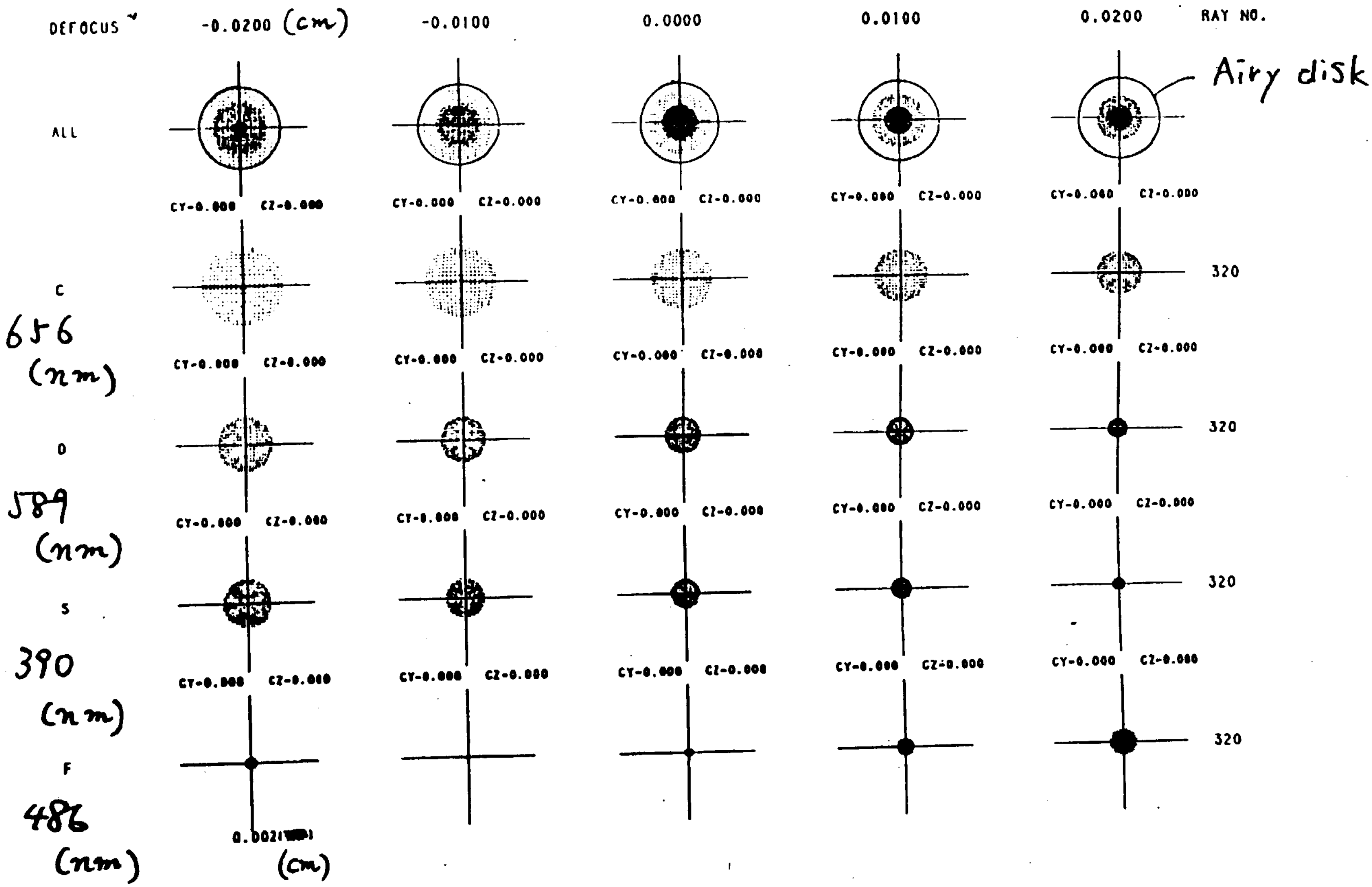
Lyot pass

IMAGE HEIGHT 0.000

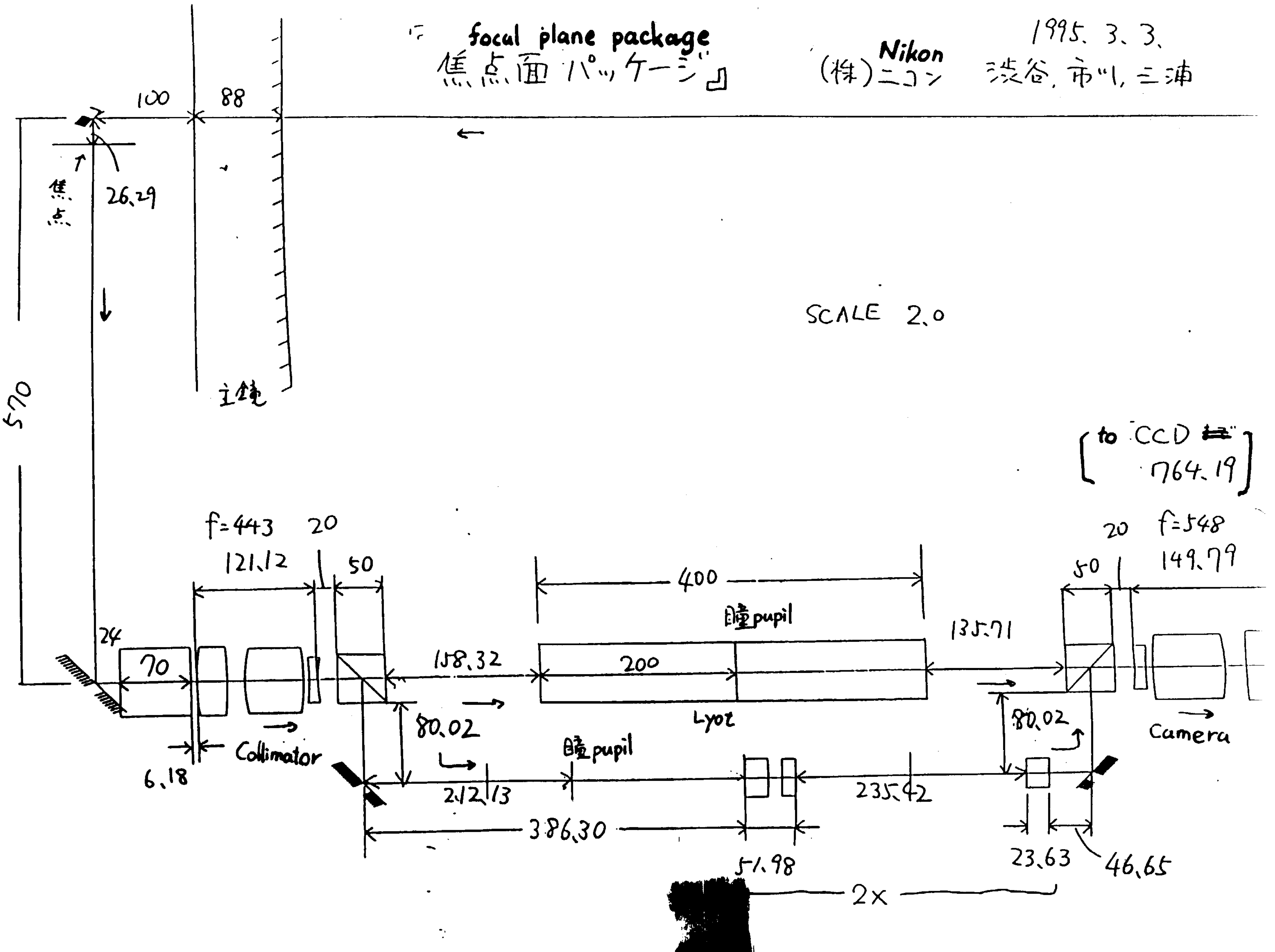
center (中心)

1995/03/09 09:43 by TRS2UNX

Nikon

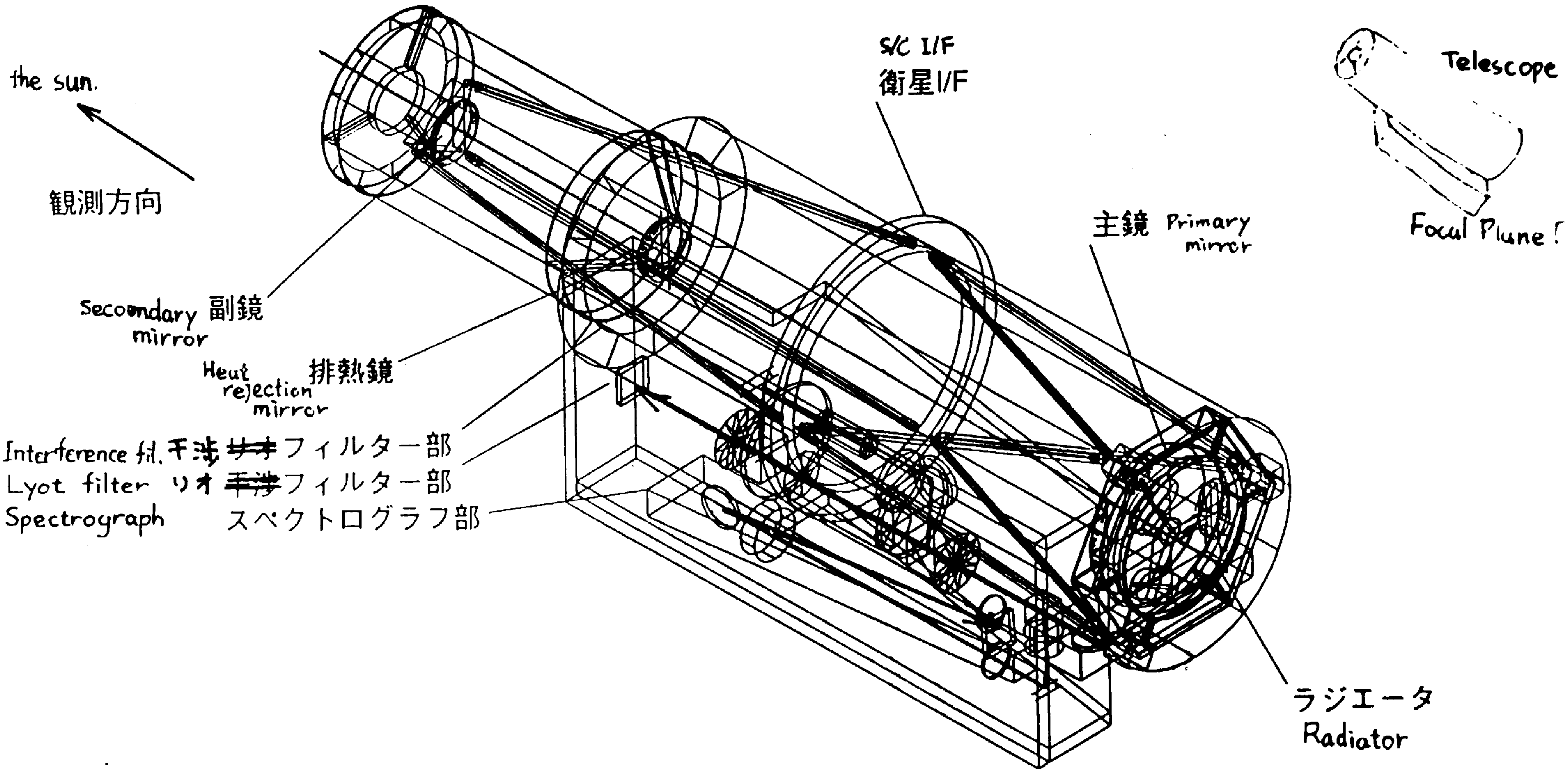


[redacted]


focal plane package
「焦点面パッケージ」
Nikon
(株)ニコン
1995. 3. 3.
渋谷, 市川, 三浦
SCALE 2.0
100
88
26.29
焦点
主鏡
570
to CCD
764.19
f=443
121.12
20
50
24
70
6.18
Collimator
158.32
80.02
212.13
386.30
400
200
瞳pupil
Lyot
瞳pupil
51.98
235.42
135.71
80.02
23.63
46.65
2x
20
50
f=548
149.79
Camera

Appendix.

MITSUBISHI | 可視光・磁場望遠鏡



可視光・磁場望遠鏡全体構造案

三菱電機株式会社

4. Tolerances (F/18.56.Lyot filter)

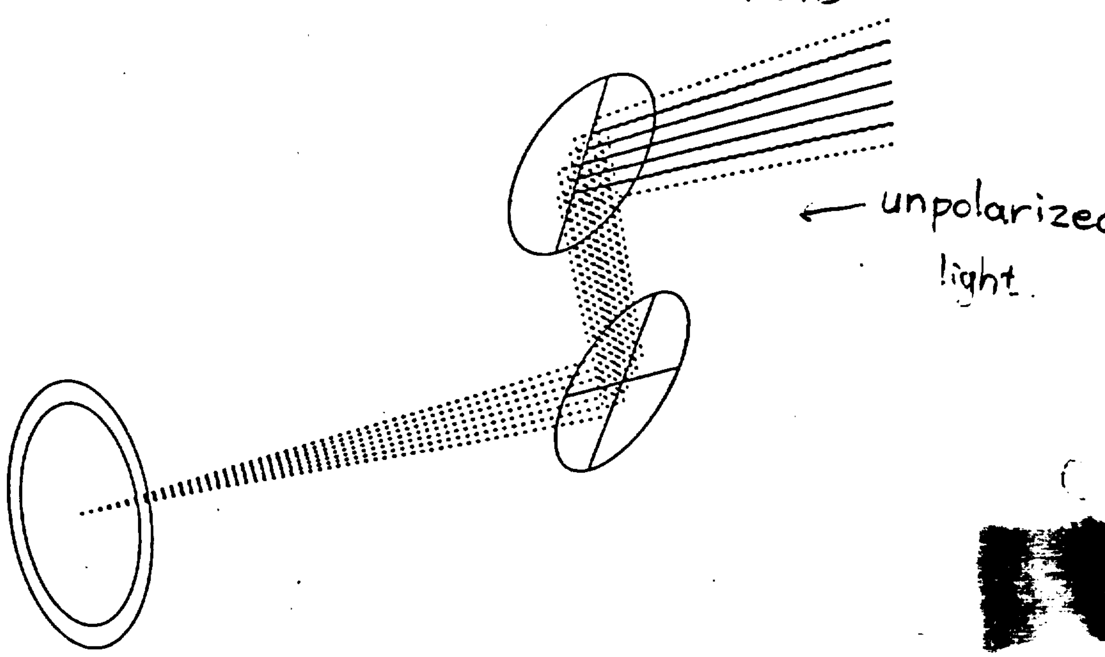
Nikon report (ver 95.03.08) & MITSUBISHI report (ver 95.03)

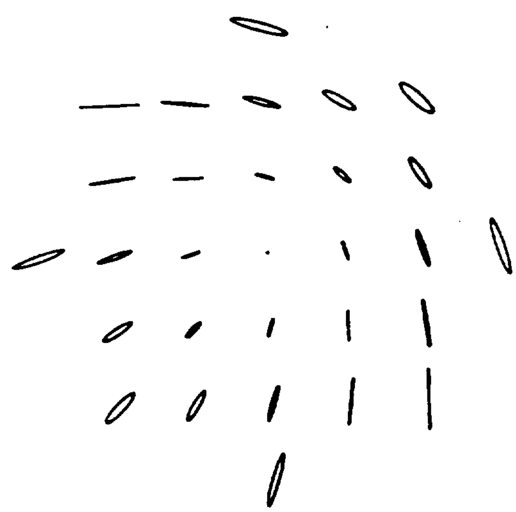
			Tolerance			Achievable? accuracy	gravitational (distorti
primary mirror (M1)	Decenter	+/-	70 µm	C(i)	<	+/- 100 µm	(~~gravity~~ +/- 70 µm)
	Tilt	+/-	7 "	C	<	+/- 30 "	(thermal +/-11", gravity +/-10")
distance between M1 and M2		+/-	450 µm	S			
	(stability)	+/-	5 µm	D	<<	+/- 50 µm	(thermal +/- 29 µm)
secondary mirror (M2)	Decenter	+/-	70 µm	C	>	+/- 50 µm	(gravity +/- 40 µm)
	Tilt	+/-	15 "	C	<	+/- 30 "	(thermal +/-11", gravity +/-10")
distance between M2 and Col		+/-	110000 µm	S			↑ the sources and their order of the deformation of the telescope
	(stability)	+/-	70 µm	D			
Collimator (Col)	Decenter	+/-	2200 µm	C			
	Tilt	+/-	2 '	C			
Lyot filter	Tilt	+/-	5 '	C			
Camera (Cam)	Decenter	+/-	3000 µm	C			
	Tilt	+/-	7 '	C			
distance between Cam and CCD	(stability)	+/-	110 µm	D			

Each tolerance is set to give the aberration of 0.13",which is 1/√14 of the Airy disc diameter.

(i) : The main term of the aberration = C; coma aberration, S: spherical aberration and D: defocus.

Appendix 2.





Max.angle= 120.0'   Pmax= 3.8e−03

Al. Coating

refraction index : $n - ik$

$n = 0.77$
$k = 6.1$ for Al.

Mitaka, NAOJ

Filtergraph

Aim:

- High resolution diagnostics of
  physical condition (B, v, T)
  and structure (morphological) changes
  in the photosphere and chromosphere

- Connection of the photosphere and chromosphere with
  the corona

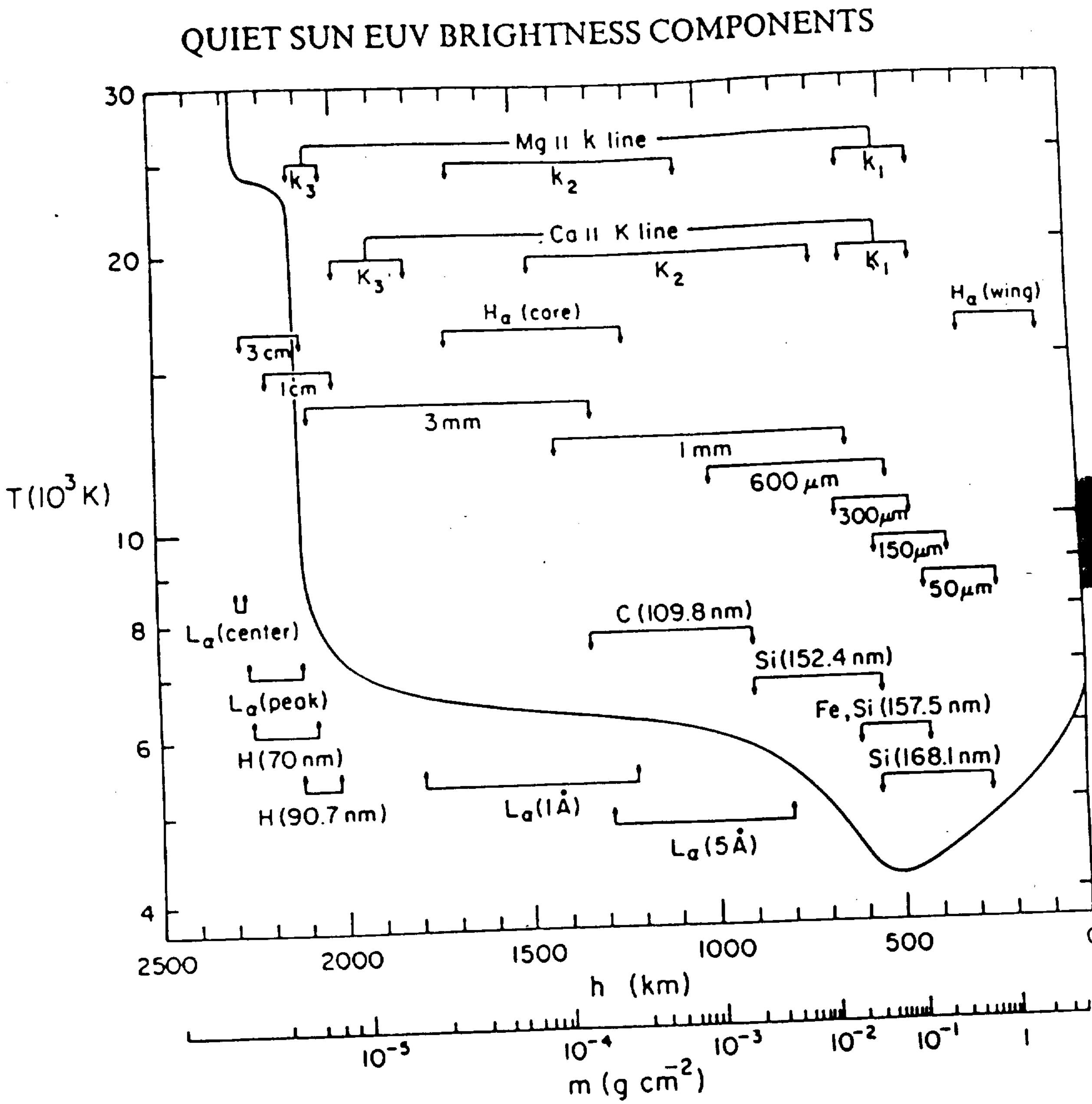
Current basic scheme:

Two channel filtergraph

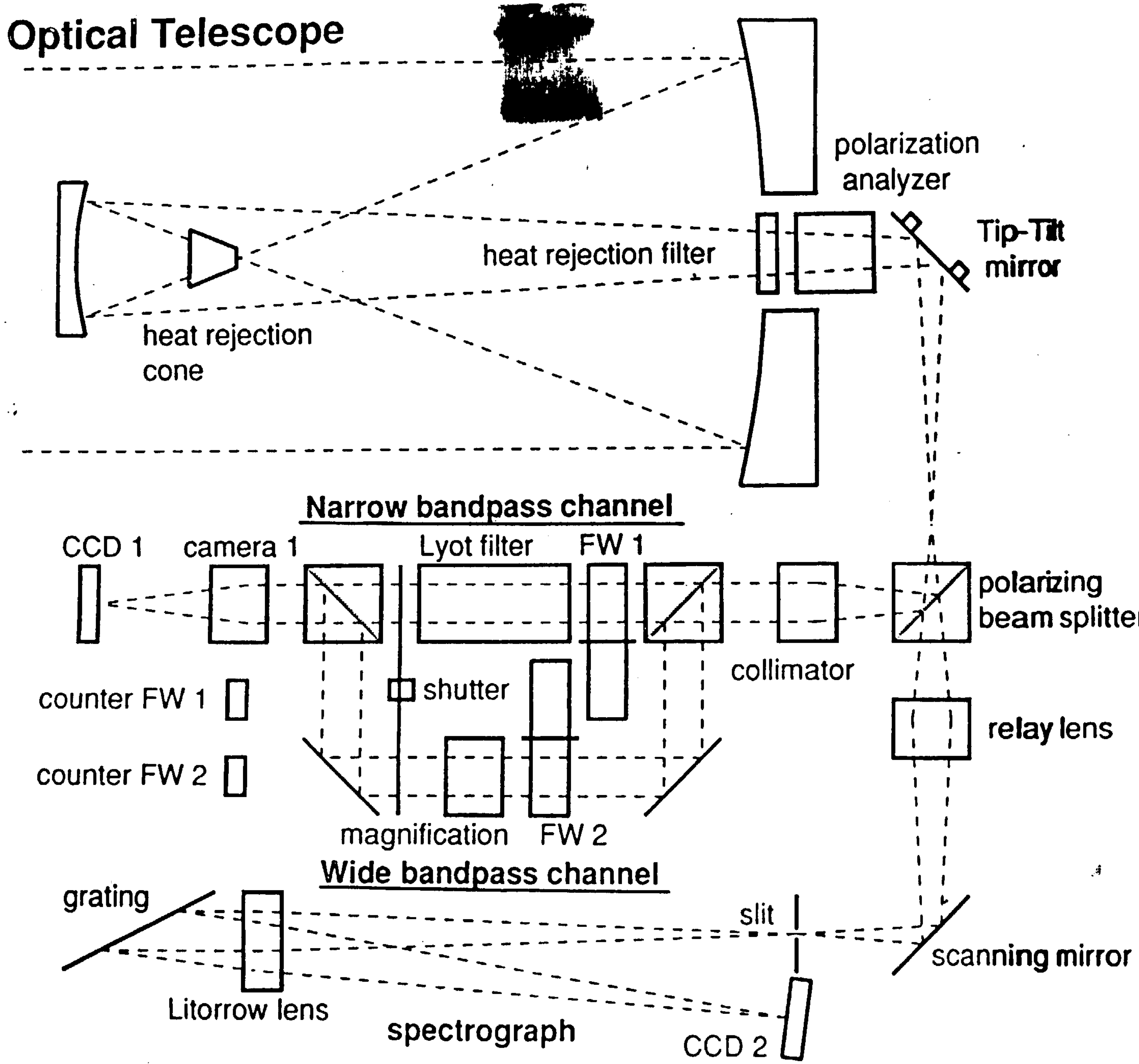
wide band and narrow band

\+ one CCD camera

981



— The average quiet-Sun temperature distribution derived from the EUV continuum, the Lα line, and other obser
te depths where the various continua and lines originate are indicated.



Lyot Filter

Length : 40 cm

Aperture : 3.5 cm

Weight : 7.5 kg

Constraints from Detector

CCD:

format: 2k x 2k (KODAK?)
pixel: 9 μm x 9 μm
full well: 8.5x10^4

READ-OUT:

clock: 512 kHz - (1 MHz)
frame read time: 8 sec - (4 sec)

Field of View (FOV)

200″ x 200″, one pixel = 0.1″ x 0.1″
400″ x 400″, one pixel = 0.2″ x 0.2″

S/N:

shot noise: photo-electron^1/2

one exposure: 225 (0.45%),
for n = 5x10^4 e

sum of 20 exposure: 1000 (0.1%),
for n = 1x10^6 e

Wide band

Filter central wavelength (Å)		passband (Å)	Airy disk radius (″)
3933 (Ca II K)	chromosphere	2	0.17
4305 (g-band)	faculae	10	0.18
4500 (cont.)	photosphere	10-20	
5670 (cont.)	photosphere	10-20	
6563 (Hα)	flare	3	
6690 (cont.)	photosphere	10-20	0.28

Narrow band

Spectral Lines

wavelength	diagnostics	UBF passband (mÅ)		Airy Disk radius(″)
Mg I 4571.1	T	50	(62)	0.194
Fe I 4705.0	B(g=2.5)	53	(66)	
H I 4861.3 (Hβ)	I, v	57	(71)	
Mg I 5172.7 (b2)	T, B(g=1.75)	66	(82)	
Fe I 5250.2	B(g=3.0)	68	(85)	0.22
Fe I 5576.1	v	77	(96)	
Fe I 6302.5	B(g=2.5)	100	(125)	0.27
H I 6562.8 (Hα)	I, v	109	(136)	0.28

Comparison: Fe [redacted]302 vs. Fe I 5250

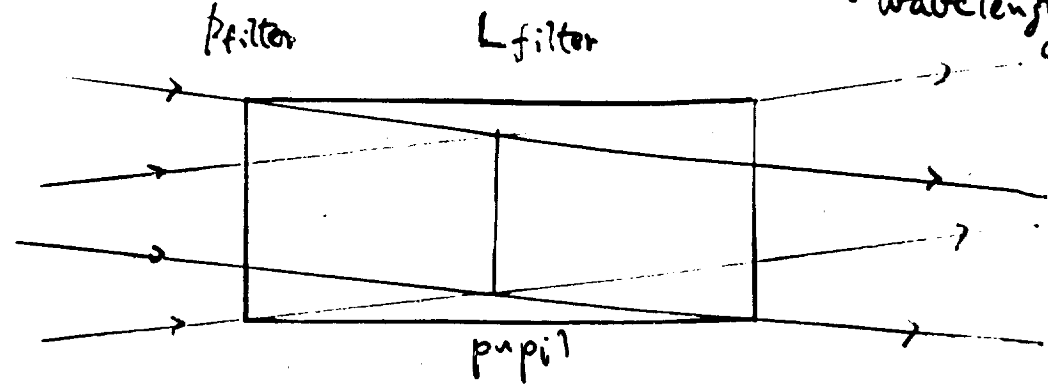
	Fe I 5250	Fe I 6302
ormation Height (see remarks)	higher -> B weaker if filling factor = 1	lower -> B stronger if filling factor = 1
-sensitivity V-signal(weak): Q-signal(weak):	high(g=3.0) B*1.0x10^-3 B^2*8.1x10^-7	high (g=2.5) B*7x10^-4 B^2*5.4x10^-7
lend	π-comp: weakly blended in spot	σ-comp: weakly blended in spot
-sensitivity	very sensitive -> B: atmospheric model depend	insensitive -> B: almost the same geometrical height
agneto-Optical ffect	large	small
earby lines	Fe I 5247.058 (g=2.0) Fe I 5250.654 (g=1.5) T-diag.:5247.058/5250.654	Fe I 6301.508 (g=1.67)
emarks	radius of Airy disk: 0.22 arcsec, for D_1=50 cm, D_2/D_1=0.45 T diagnostics other useful lines nearby h(km) QS PL PENUM UM 5250.2 260 230 406 592 5247.1 266 236 412 598	radius of Airy disk: 0.27 arcsec, for D_1=50 cm, D_2/D_1=0.45 accurate B measurement h(km) QS PL PNUM UM 6302.5 249 232 194 190 6301.5 337 314 253 321

Wide band vs. [illegible]row band filtergraph

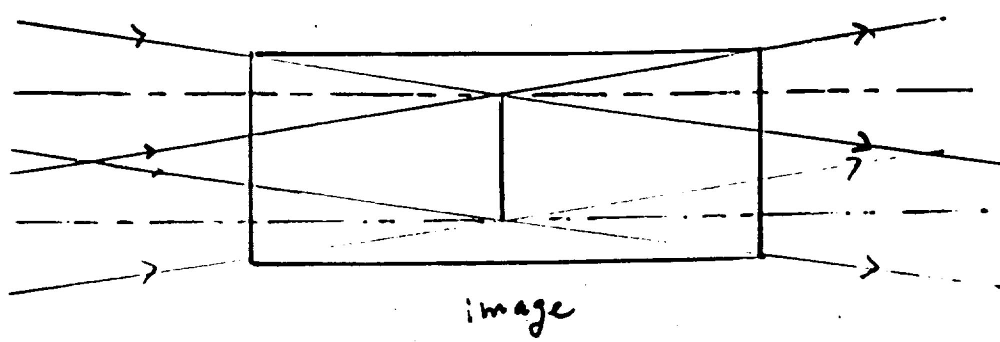
	Wide band filter	Narrow band filter
filter-type	e. g. interference simple optics high transmission	e. g. Lyot complicated low transmission
passband	2-20 A	0.05-0.1 A
image quality	high: short exposure	middle: long exposure need several images
diagnostics	photosphere-T_min: Temperature horizontal velocity intensity oscil. morphology	photosphere-chromosphere: vector B vertical velocity horizontal velocity (chromoshere) Temperature morphology
Current choices	several filters (f wheel) FOV: 200″x200″ (0.1″/pix) wavelength range: 3900-7000 Å	one UBF, several lines FOV: 400″x400″ (0.2″/pix) wavelength range: 4500-6600 Å

collimation

· FWHM
· wavelength change



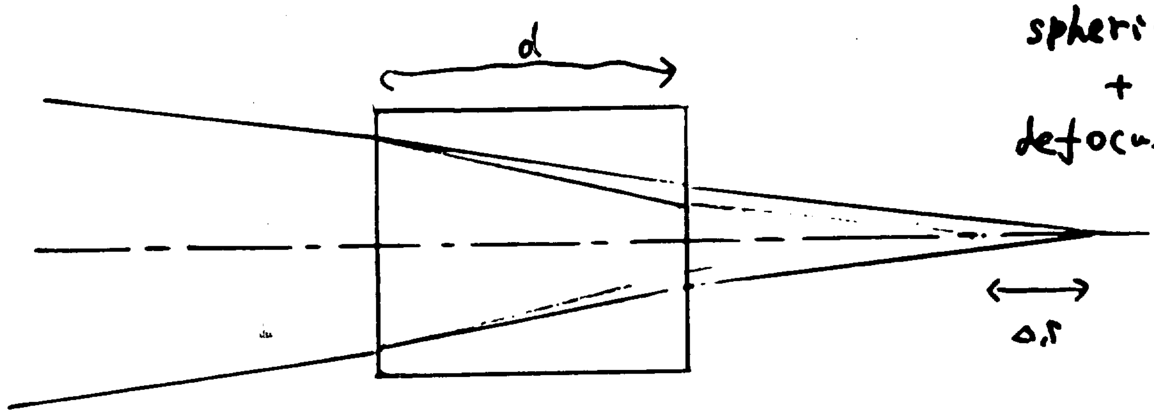
telecentric



· spectral homogeneity
· FWHM Broadening

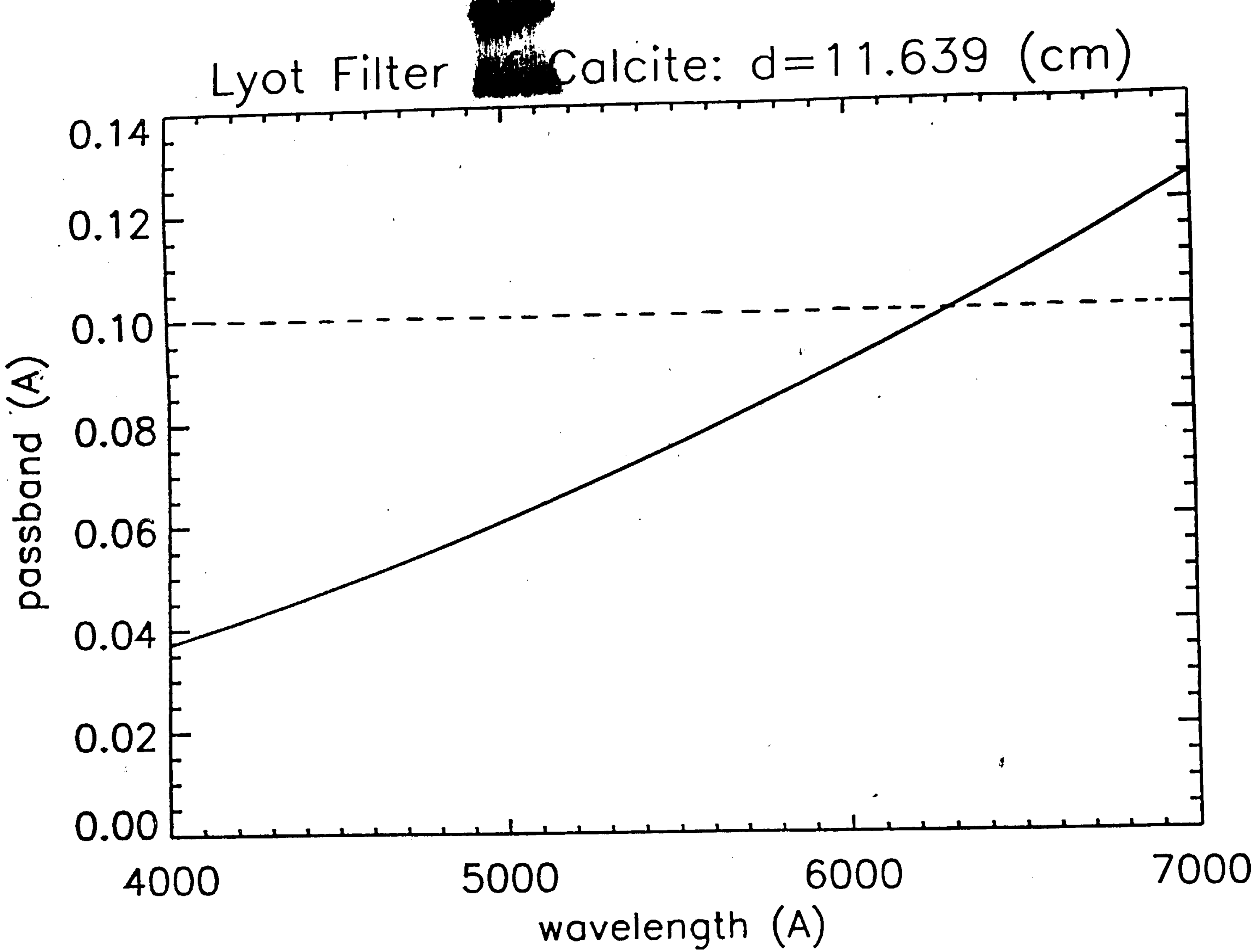
birefringent (n_o, n_e)

spheric ab.
+
defocus

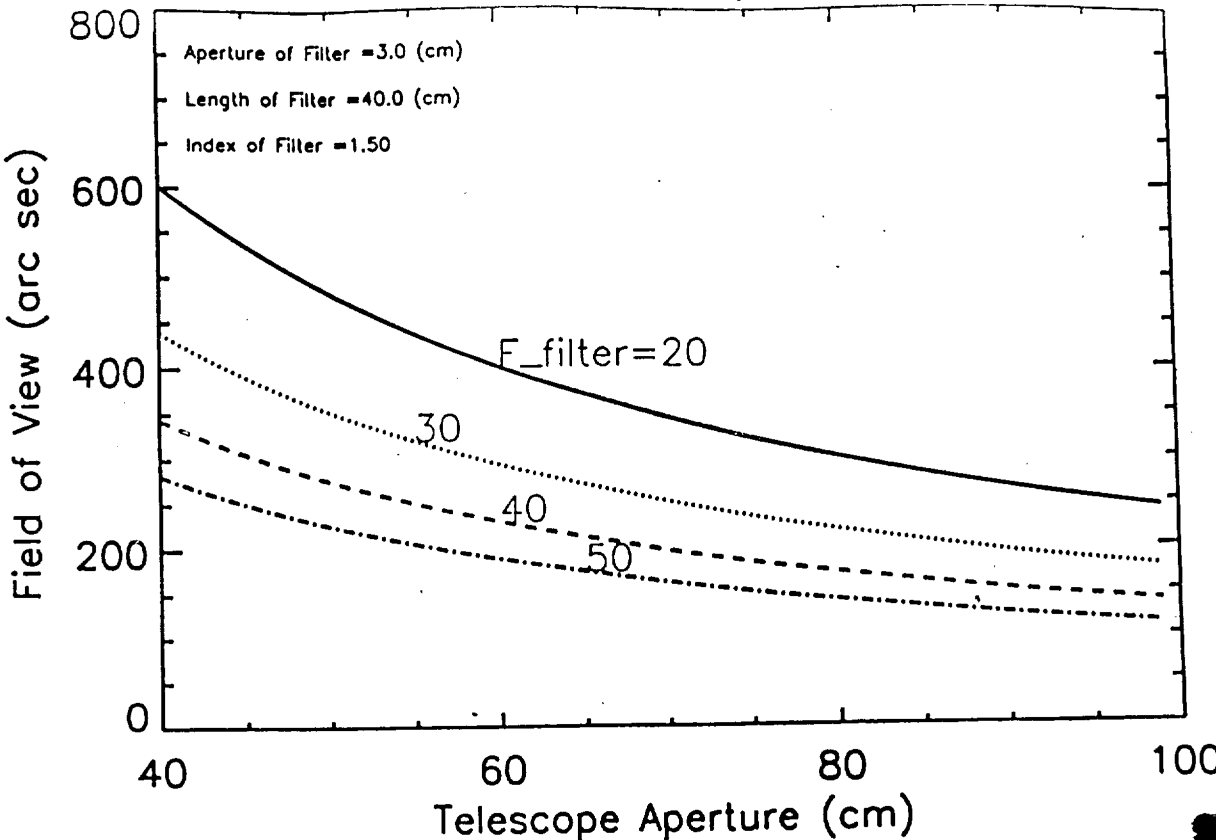


$$\Delta s = \frac{d(n_o - n_e)^2}{2 n_o^2 n_e}$$

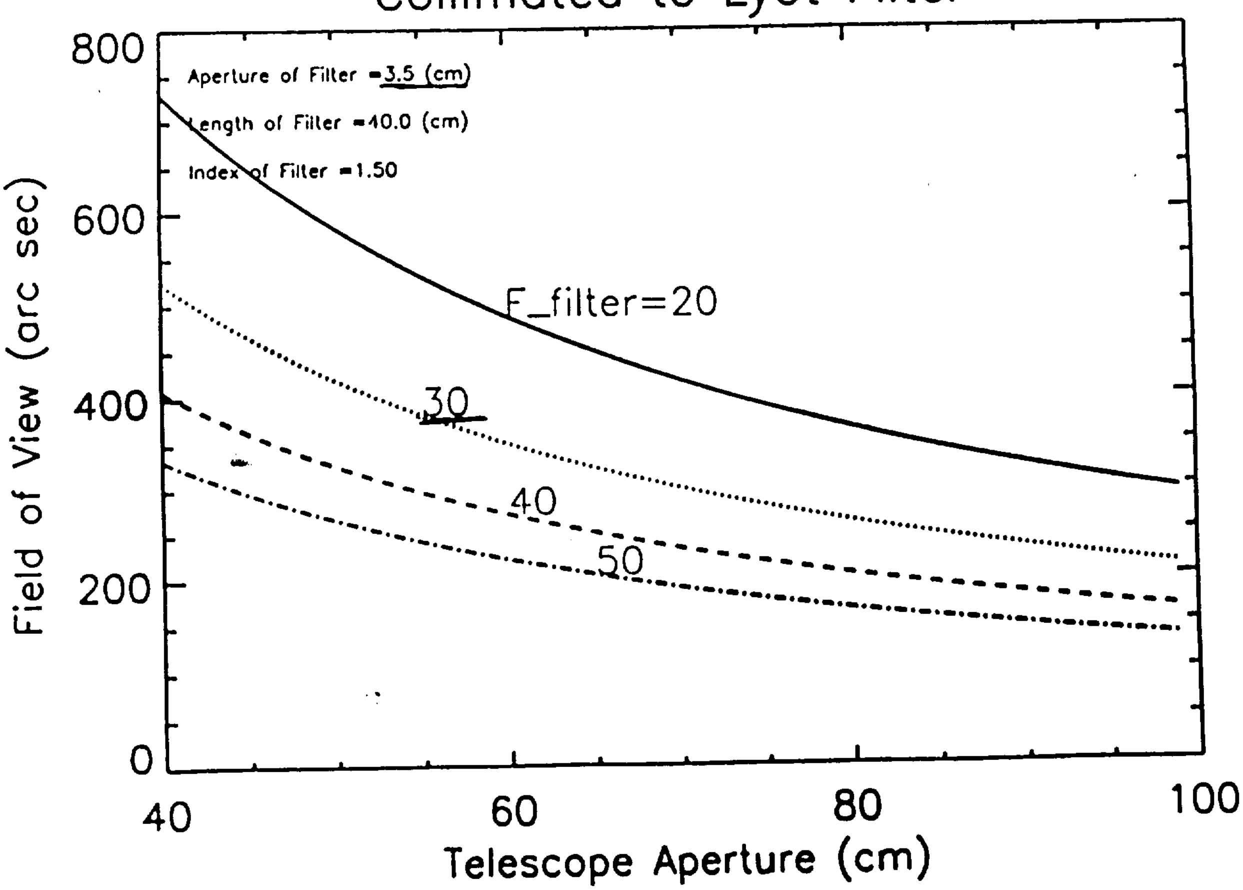
$$\frac{\Delta s}{2F} > \frac{(n_o^2 - 1)\, d}{8 n_o^3 F^3} \quad (\text{spheric ab.})$$

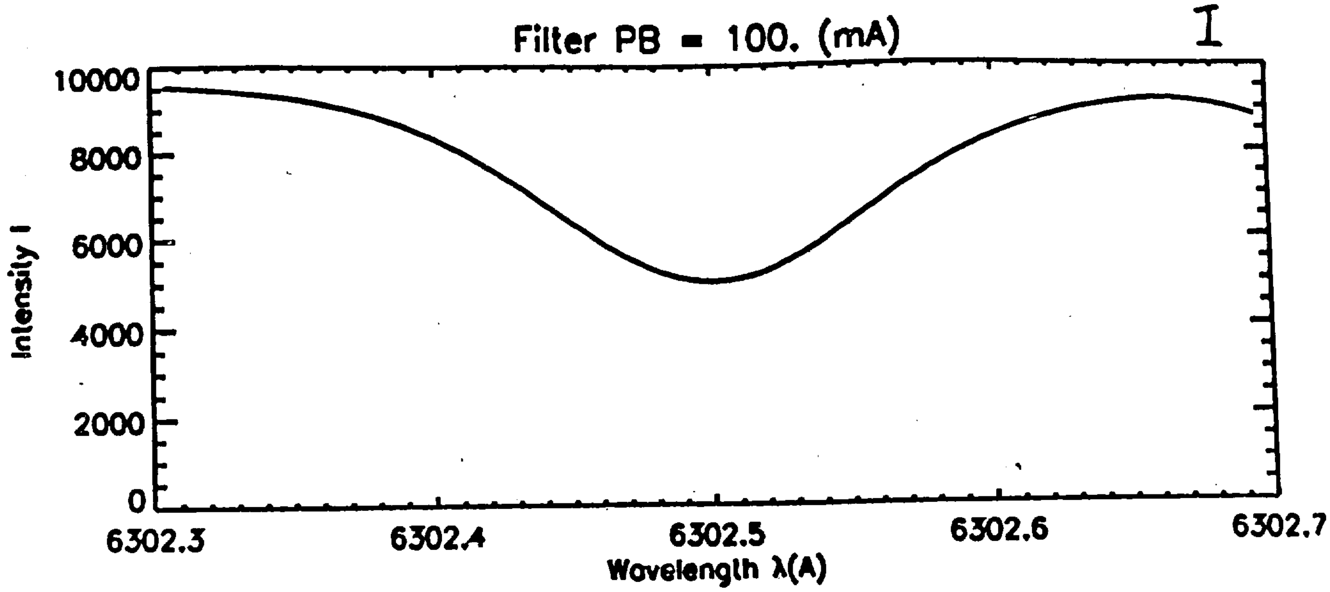


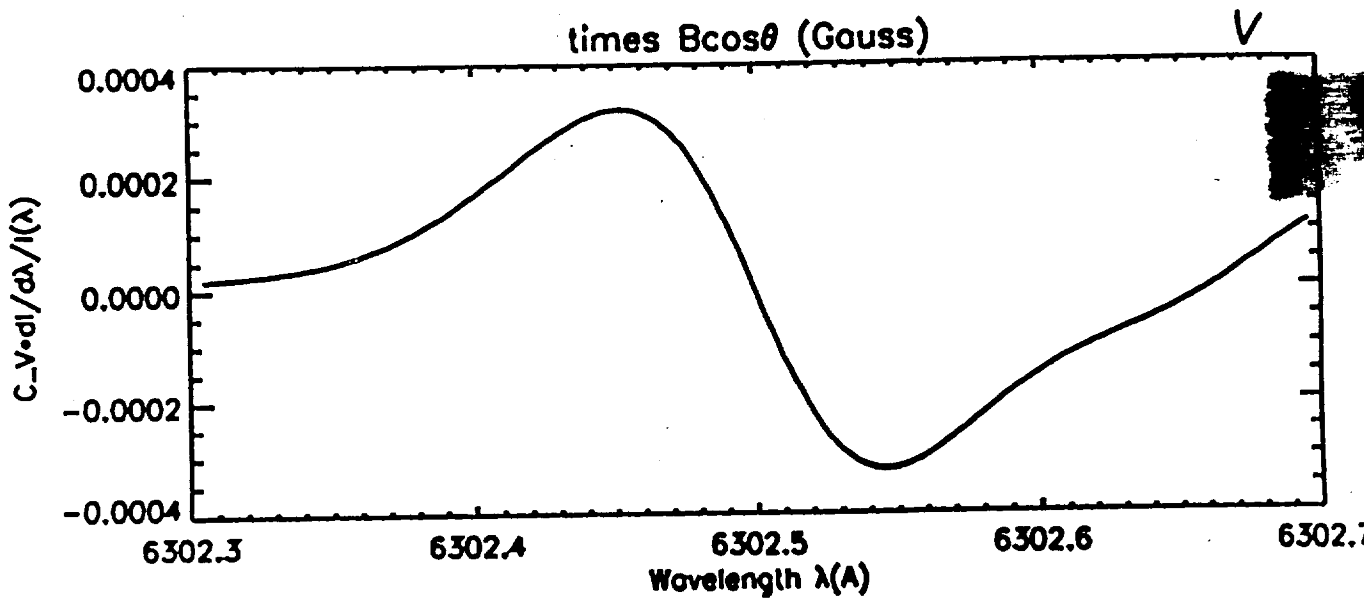
Lyot Filter Calcite: d=11.639 (cm)
passband (A)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
4000
5000
6000
7000
wavelength (A)

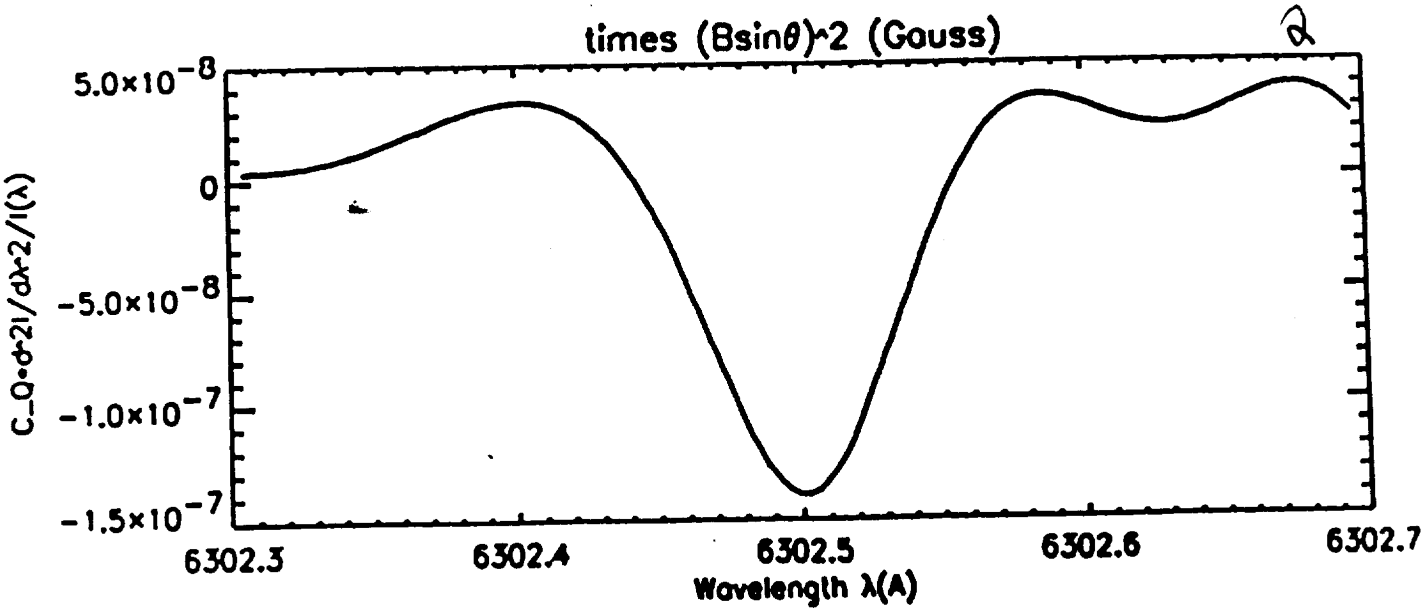


Collimated to Lyot Filter




Filter PB = 100. (mA)
I
Intensity I
10000
8000
6000
4000
2000
0
6302.3
6302.4
6302.5
6302.6
6302.7
Wavelength λ(A)

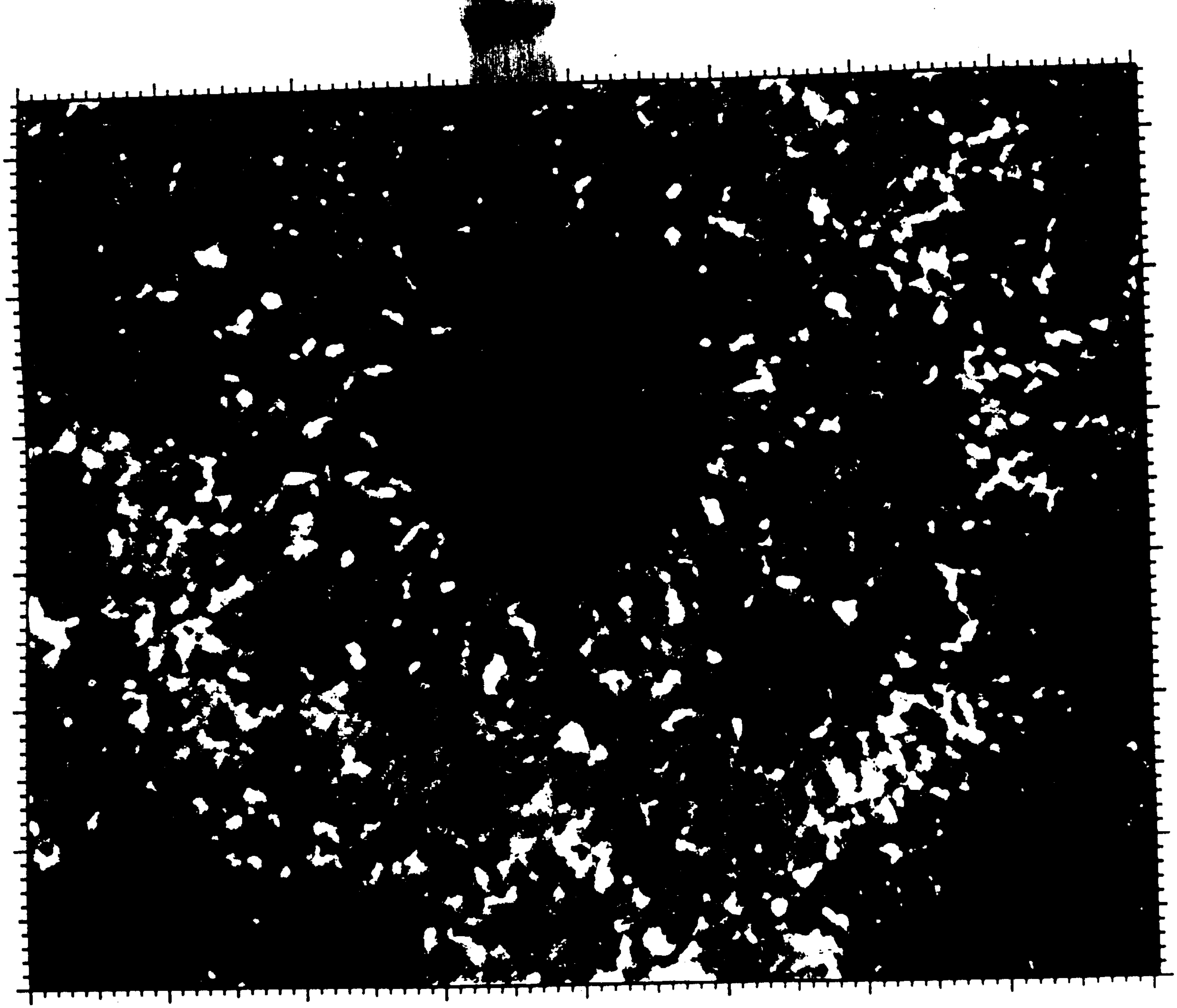

times Bcosθ (Gauss)
V
C_V•dI/dλ/I(λ)
0.0004
0.0002
0.0000
-0.0002
-0.0004
6302.3
6302.4
6302.5
6302.6
6302.7
Wavelength λ(A)


times (Bsinθ)^2 (Gauss)
Q
C_Q•d^2I/dλ^2/I(λ)
5.0×10^-8
0
-5.0×10^-8
-1.0×10^-7
-1.5×10^-7
6302.3
6302.4
6302.5
6302.6
6302.7
Wavelength λ(A)

Baseline Items (+) & Open Questions (−) for Fitergraph

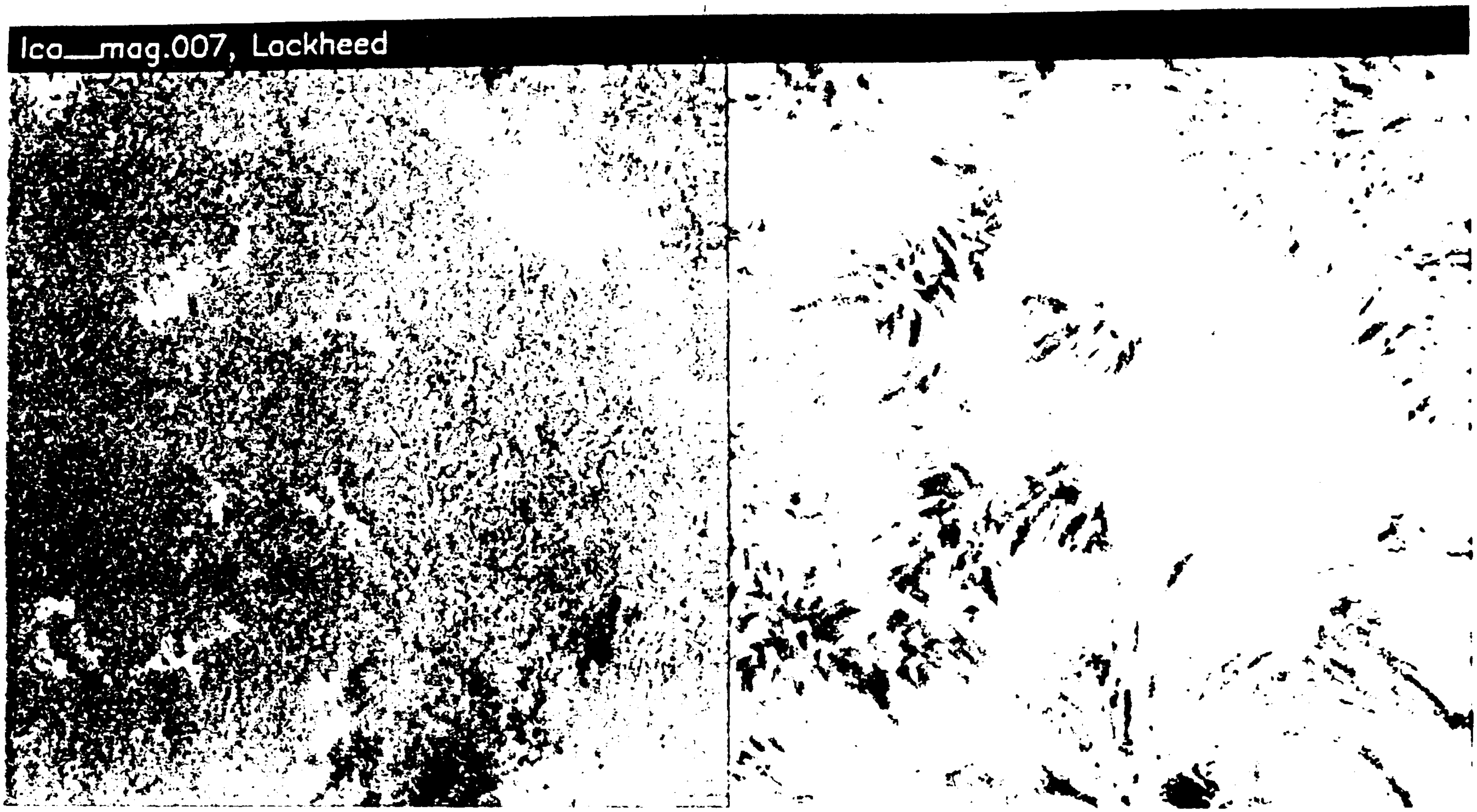
+ Two channel (narrow and wide band)
+ filter type
  - narrow band: one Universal Birefringent Filter
  - wide band: several interference filters
+ wavelength range:
  - narrow band: 4500 − 6600 Å
  - wide band: 3900 − 7000 Å
+ passband:
  - narrow band: 100mÅ at 6303Å
+ tuning accuracy (stability)
  - narrow band: 0.5mÅ (0.5% S/N)
+ CCD camera: one 2k x 2k
+ CCD read-out clock: 512 kHz/pixel
+ filter location: inbetween collimator (not telecentric) and camera lens

- image scale: 0.1 or 0.2 arcsec/pixel?
- FOV: 200 or 400 arcsec?
- focusing method: glass plates of different thickness, linear stage?
- wide band: wavelength and passband?
- Temperature control: entire focal plane package or each instruments?
  optical bench, UBF, blocking filters, lenses
- lines, OK?
  - narrow band: H I 6563, Fe I 6302, Fe I 5576, Mg I 5173,
    H I 4861, Fe I 4705, etc.
  - wide band: Ca II K 3933 (2Å), G-band 4305 (10Å), Hα (3Å)
    continuum in 4500, 5670, 6690, etc.
- S/N: 0.5%, OK?
- CCD camera: Kodak?
- image registration: software or hardwired, method?
- flat fielding: how?



Ca II K, 3 A wide filter, La Palma, 14-June-1994, 13:36 UT.
Brandt and Simon observing. Tick marks are 1 arc second.

R Shine Jun 19 1994

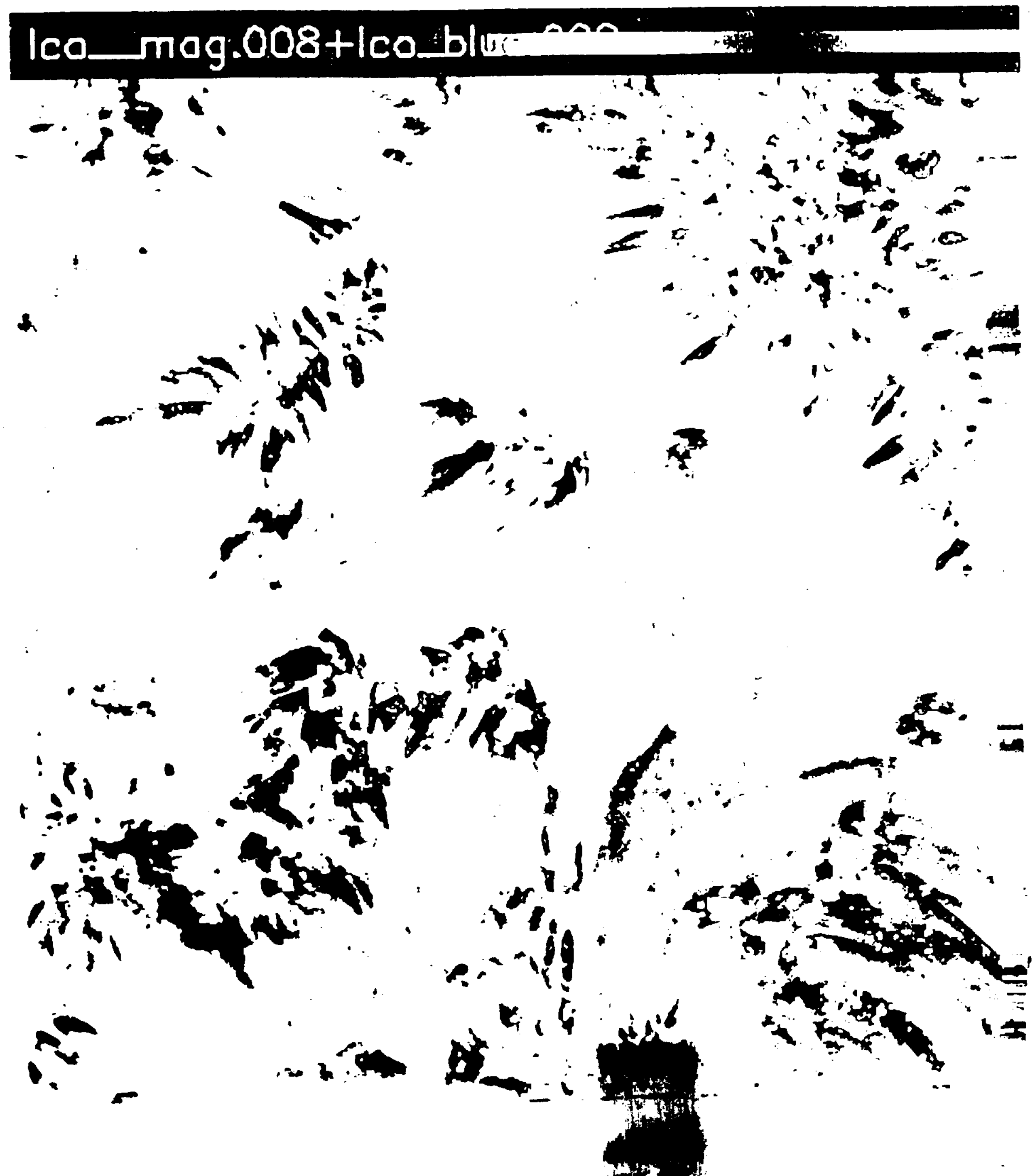


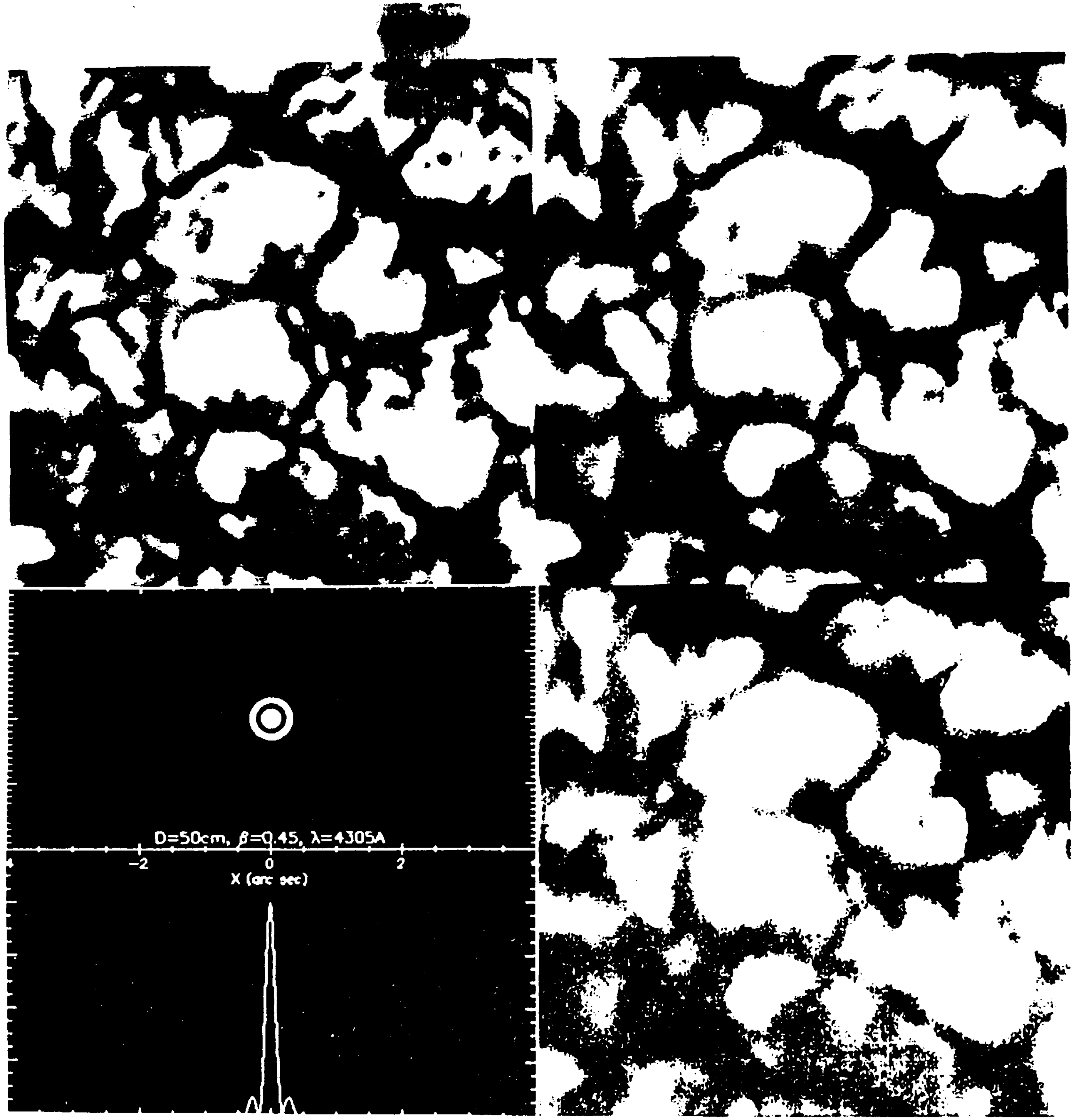
FeI 6303Å − 60mÅ

Hα −0.75

0.27"/pixel

S11 W17 (AR 6142)


lca__mag.008+lca_blu



D=50cm, β=0.45, λ=4305A
-2
0
2
X (arc sec)
La Palma
D=48cm, β=0
D=50cm
β=0.45

pixel = 0.4"

0.2"

0.1"

0.02"

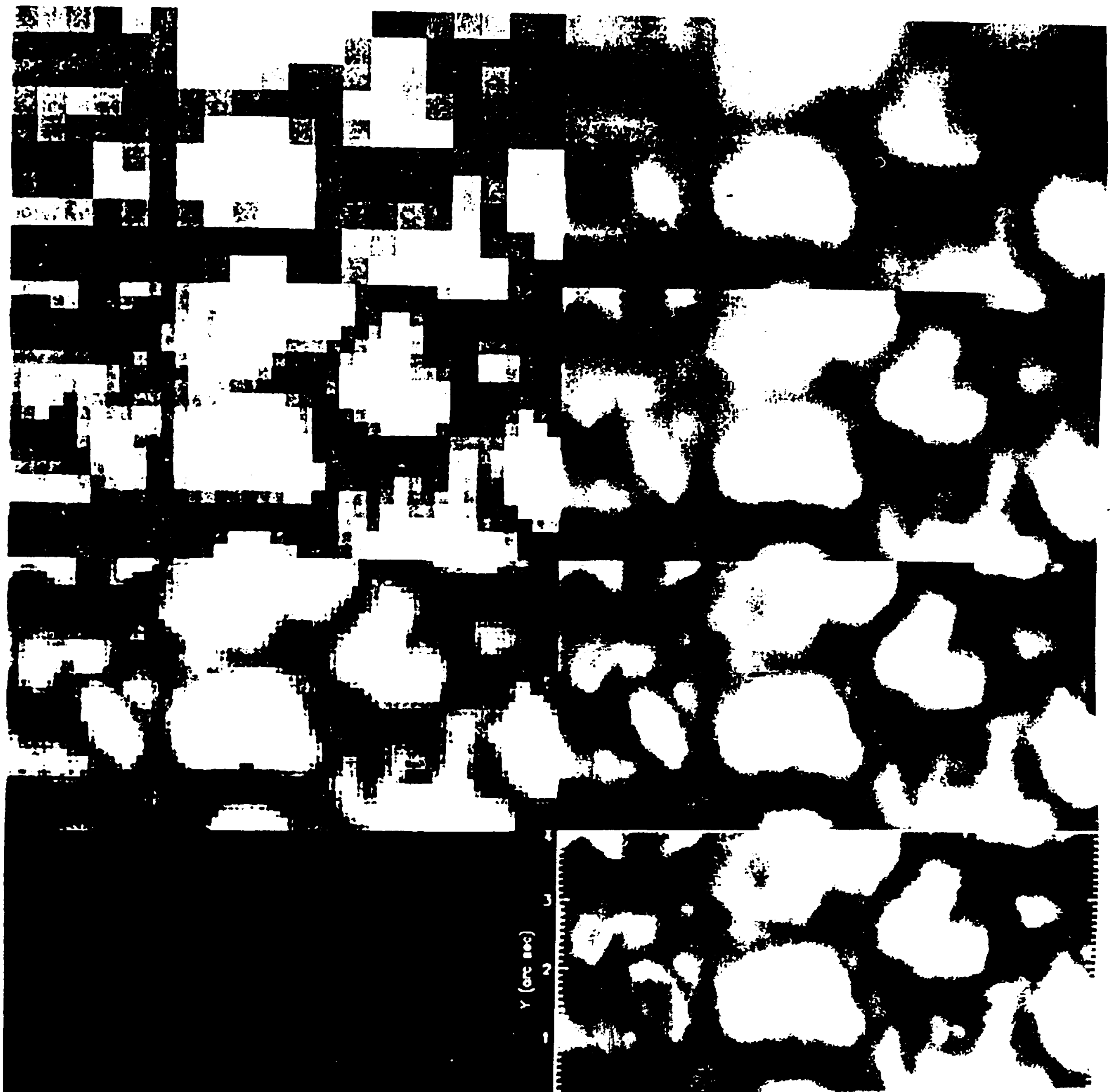


image by
bidimension
interpolation

D = 50 cm
ρ = 0.45
λ = 4305 Å

SPECTROGRAPH for SOLAR-B

M. Akioka (Hiraiso, CRL)

1、Intro.

Stokes Polarimetry with Grating Spectrograph
- Physics of Flux Tube
- Precise Observation of Active Region Structure
- Inversion of Stokes Profile

0.2" world => Localized V and I
(Granulation, faculae .....)
Profile will be different from standard model
↓
Ambiguity of interpretation for filter obs.

Stokes Profile with Grating Spectrograph

2,Basic Requirement

- 25mA resolution
- 0.2" / pix
- Small Size (1 or 1.5 m length)
- Light Weight
- Simple Mechanism
  (moving mecha. not Preferred)
- CaK Observation with no grating rotation

3; K line observation

K-line Option

<No Graing rotation and one CCD>

K line => outside of CCD in case of n=79/mm

CCD: 2K by 2K (9 μ)

↓

Higher order with coarse grating

=> Small FSR => many orders overlap

<n=31.6/mm ruling>

- Many lines are observable without grating rotation

  3933,3968,4571,5250,6303 etc....

- FSR is 70Å for 6303 · · ·

  blend of 6233.6

more narrow blocking filter(<70A)

Performance

Case 1 (No Frame Integration and slow modulation)

<Grating Optics>
Littrow type Echelle
<Grating>
Grating Constant   31.6grooves/mm
Braze Angle   63.5
Blank Materials   ULE or Zerodur
Coating   Al
<Spectrograph Optics>
F of Main Optics   19
f of Littrow Lens   1000mm
<CCD Detector>
Pixel Number   2K by 2K
Pixel Size   9 micron (=0.2")
Full Well   85,000
S/N   0.3 % (Photon Noise)
<Performance>

	6303	CaK
Diffraction Order	90	144
Anguler Disp.	6.36*10^-4	1.02*10^-3
mA/pix	14	9
Resolv. Power(mA)	19	9
Electron on CCD (1/S)	5*10^5	6×10^4
(in continium)	(Depends onQE etc)	

λ drift due to TE
CTE = 7.7·10^-6/K
Δλ ~ 19pix/20
CTE = 1×10^-8/K
Δλ ~ 1.5pix/20C

Observable Lines with Fixed Eschell SPG
for Solar-B(Case1)

M.A March 1995

n=31.6 grooves/mm   grating angle = 63.50
f=1000mm   Width of CCD = 18mm

m	λ−Range	Line	
90	6279−6307	6301/2 (Fe I)	Photospheric Magnetic
90	6279−6307	6297 (Fe I)	Photospheric Magnetic
96	5887−5913	5895 (D1) (Na I)	Chromospheric Magnetic
99	5709−5734	5713 (Ti I)	Photospheric Velocity
103	5487−5512	5506 (Fe I)	Photospheric Magnetic Largest V-Amp
103	5487−5512	5501 (Fe I)	Photospheric Magnetic Largest V-Amp
103	5487−5512	5497 (Fe I)	Photospheric Magnetic Largest V-Amp
105	5382−5407	5394 (Mn I)	Photospheric Temperature
[illegible]8	5233−5256	5250/47 (Fe I)	Photospheric Magnetic and Temp (Line Ratio)
112	5046−5069	5052 (C I)	Photospheric Temperature
115	4914−4936	4923 (Fe II)	Photospheric Magnetic
115	4914−4936	4912 (Ni I)	Photospheric Velocity
123	4595−4615	4607 (Sr I)	Photospheric Magnetic Weak B (Hanle effect)
124	4558−4578	4571 (Mg I)	Photospheric Temperature LTE, Temperature Min.
139	4065−4084	4080 (Fe I)	Photospheric Magnetic
143	3952−3970	3968 (H) (Ca II)	Chromospheric Temp and Vel.
144	3925−3842	3933 (K) (Ca II)	Chromospheric Temp and Vel.

Observable Lines with Fixed Eschell SPG for Solar-B(Case2)

M.A March 1995

n=23.2 grooves/mm grating angle = 64.03
f=1217mm Width of CCD = 4.819mm

m	λ−Range	Line	
123	6297.9−6304.0	6301/2 (FeI)	Photospheric Magnetic
139	5573.0−5578.3	5576 (FeI)	Photospheric Velocity
144	5379.5−5384.7	5380 (CI)	Photospheric Temperature
151	5130.1−5135.1	5132 (FeII)	Photospheric Temperature
190	4077.1−4081.0	4080 (FeI)	Photospheric Magnetic
197	3932.2−3936.0	3933 (CaII)	Chromosphere

Case 2 (Fast Modulation with Continuous Rotating WP)

<Grating Optics>
Littrow type Echelle
<Grating>

Grating Constant	23.3grooves/mm
Braze Angle	63.5
Blank Materials	ULE or Zerodur
Coating	Al

<Spectrograph Optics>

F of Main Optics	19
f of Littrow Lens	1213mm

<CCD Detector>

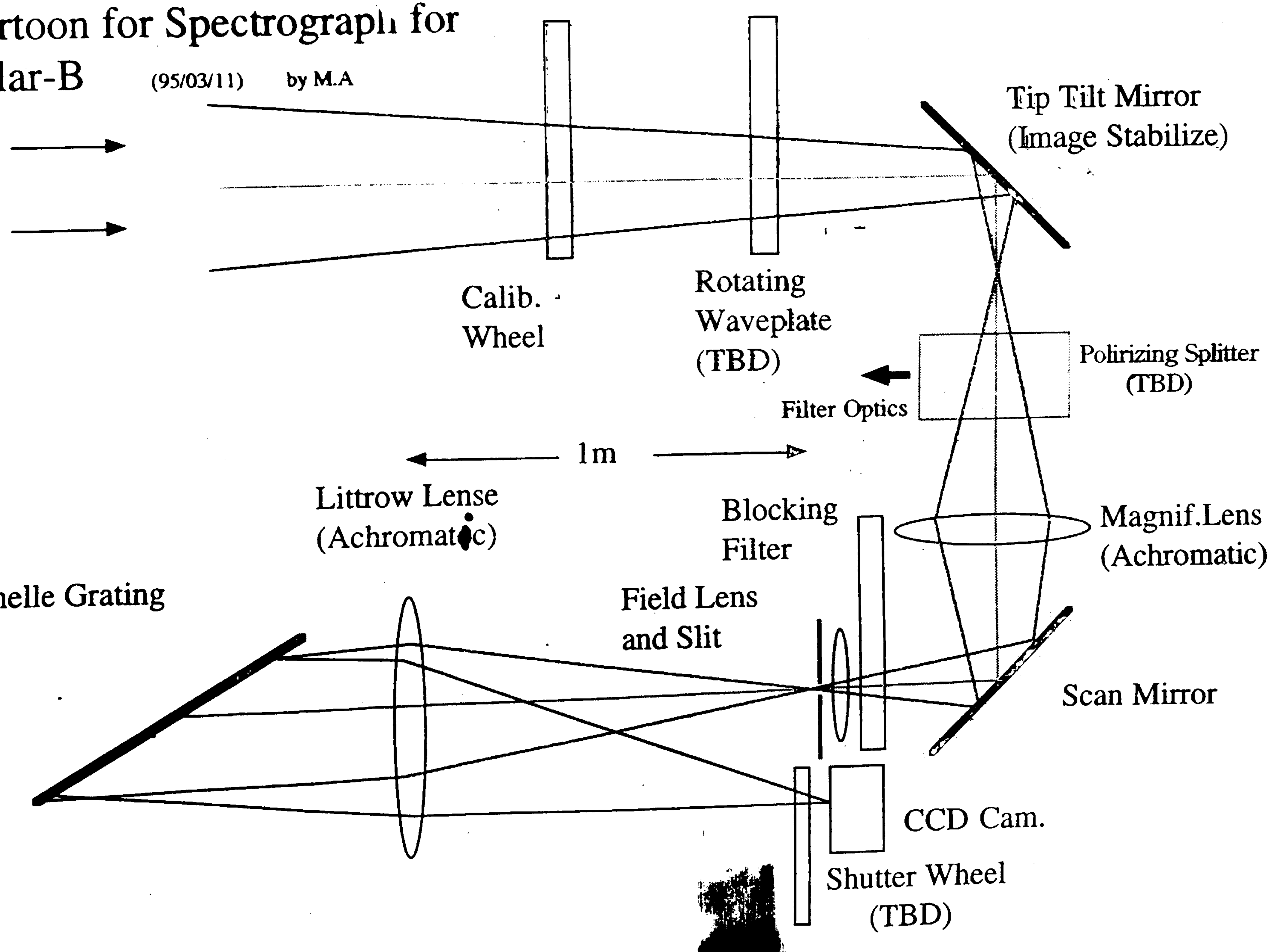
Pixel Number	758(x)×244(λ)
Pixel Size	8.5μm(x)×19.75μm(λ)
Spatial Scale	0.2"/pix (or 0.1"/pix)
Full Well	60,000
S/N	0.1 % (Frame Integration)

<Performance>

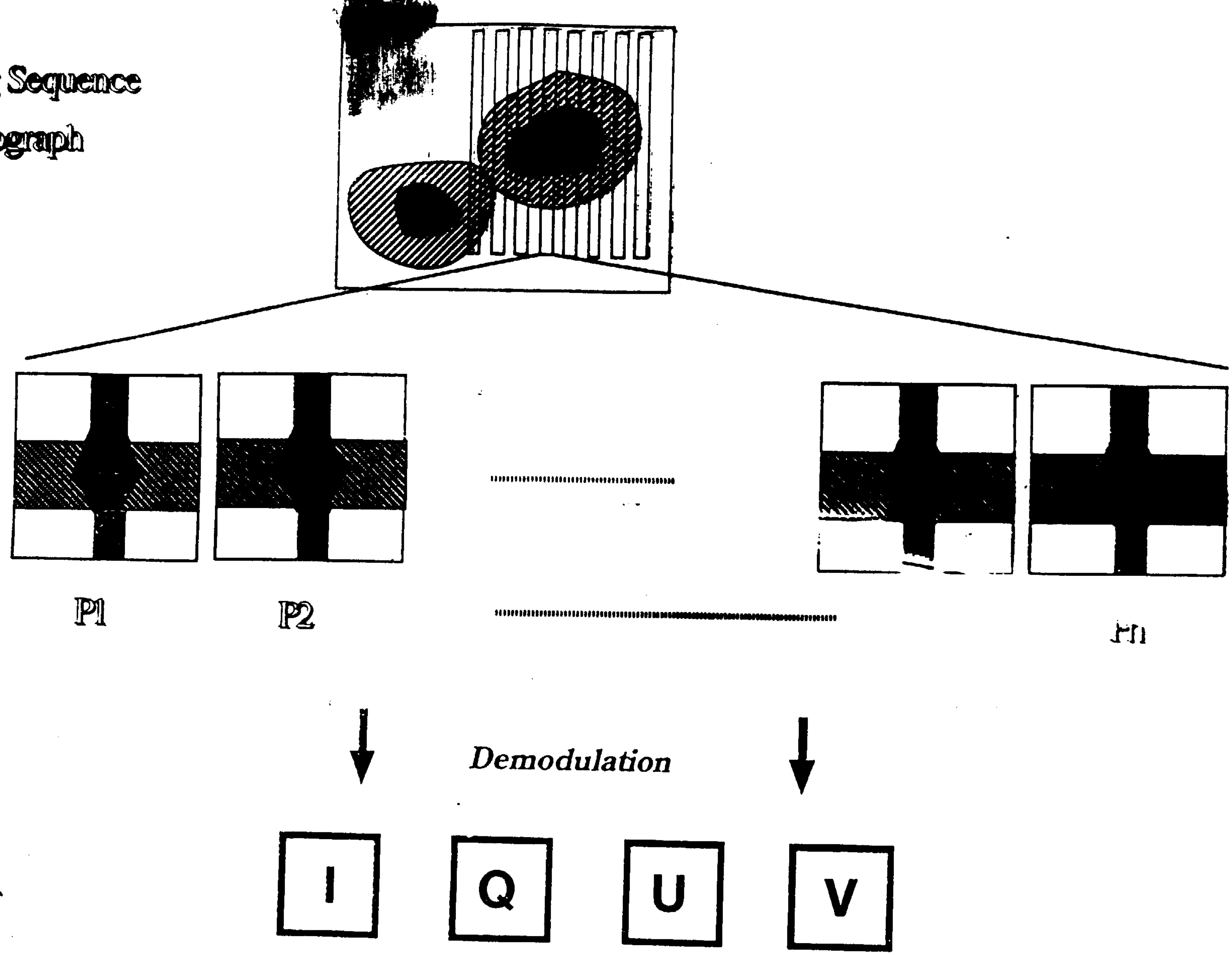
	6303	CaK
Diffraction Order	123	197
Anguler Disp.	6.51*10^-4	1.04*10^-3
mA/pix	25	16
Resolv. Power(mA)	15	7
Electron on CCD (1/S) (in continium)	9.5*10^5	1×10^5
	(Depends onQE etc)	

Cartoon for Spectrograph for Solar-B

(95/03/11) by M.A



Observing Sequence for Spectrograph



Tip Tilt Mirror Consideration

M.Akioka (Hiraiso,CRL)

1,Requirements

< Image Stabilize >

Filter Obs. : 0.01 arcsec / 10 sec(?)

(SPG : Obs. : < 0.002 arcsec / several sec.)

(see Lite's sans comments on Jan.)

<Requirement for Tip Tilt Mirror>

Location 150mm far from secondary focus

diam. about 30mm

resolution of tilt angle 0.5 μrad

Drv. freq. ??? 10 or 20 Hz?

2,Tip-Tilt Mirror on Japanese Satellites

Used for Engineering Sat. for Laser Communications

(1)Laser Comminications Experiments(LCE) of ETS-6 (by NASDA and CRL)

Communication Experiment between Satellite and Ground

Satellite Launch had troubled but experimets was successful

<Fine Pointing Mechanism>

Detector : Quadrant Detector

Mirror Actuator : Moving Coil Actuator

Pointing Accuracy : 2 μrad (system)

(2)OISETS (Inter Satellite Communication)

Now under development

<Fine Pointing Mechanism>

Detector : Quadrant Detector

Mirror Actuator : Low Voltage Piezo Stack

Pointing Accuracy : 1 μrad (system with testing model)

3,Moving Coil Actuator for LCE

Permanent Magnet + Coil

response frequency : about 300Hz

(in case of LCE with 1.5cm mirror)

resolution of mirror angle : 0.87 μrad (with test model)

(depends on noise and senser)

tracking range : $\pm$0.4mrad

- Low Hysterisis
- Two Axis module is easily available
- Range for tilting is large

4.Piezo Actuator for OISETS

Stack of Low Voltage Piezo

response frequency : 2kHz

(Mirror Diam. = 20-30mm)

< Now under evaluation for Solar-B >

- Hysterisis
- Higher response frequency
- Smaller size

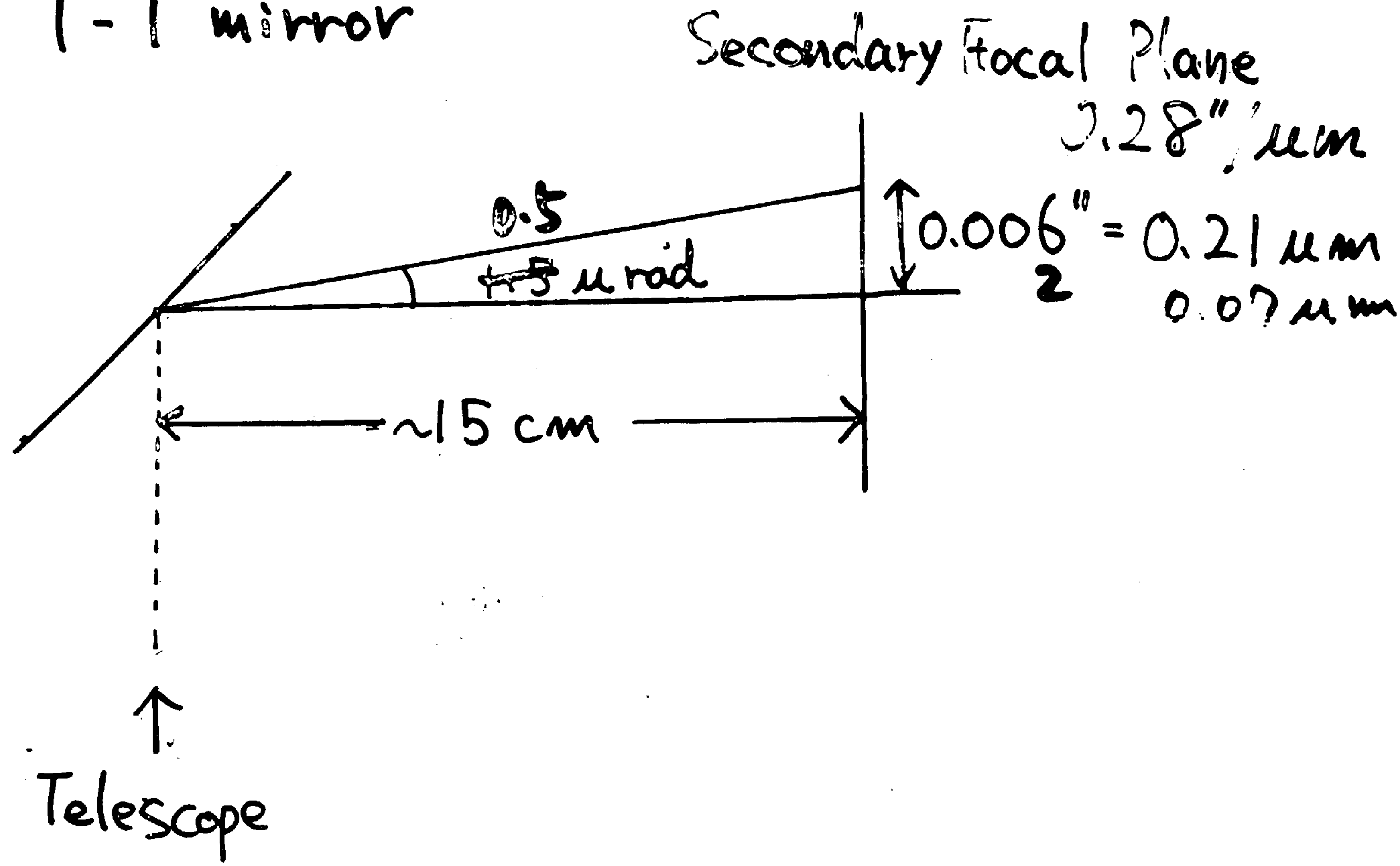
5:Problem and future action

- Evaluation of Mirror angle resolution for Piezo
  (for Open loop control with gyro signal)
- Evaluation of Gyro performance for open loop
- Error sensing for Closed Loop

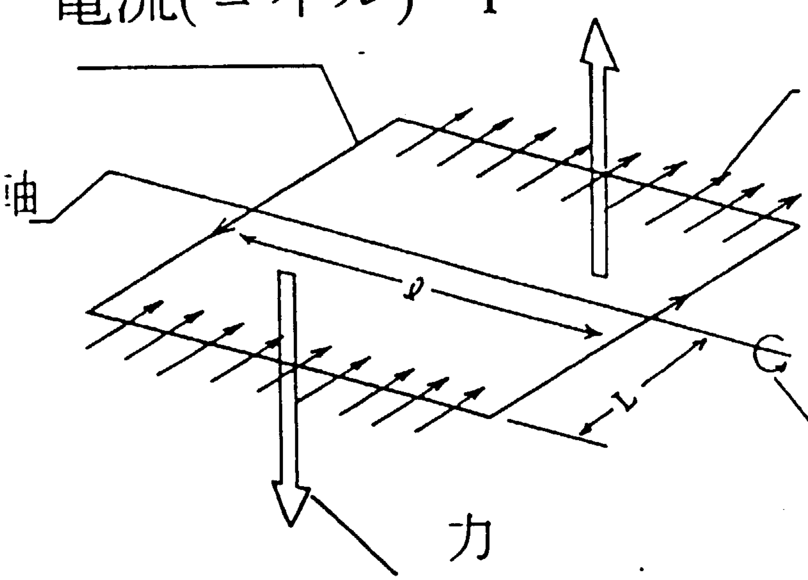
No good concept for error detection for closed loop control

Limb sensing	: Not enough resolution
Correlation Track	: No experience in space
Sunspot Track	: Limitation for target selection

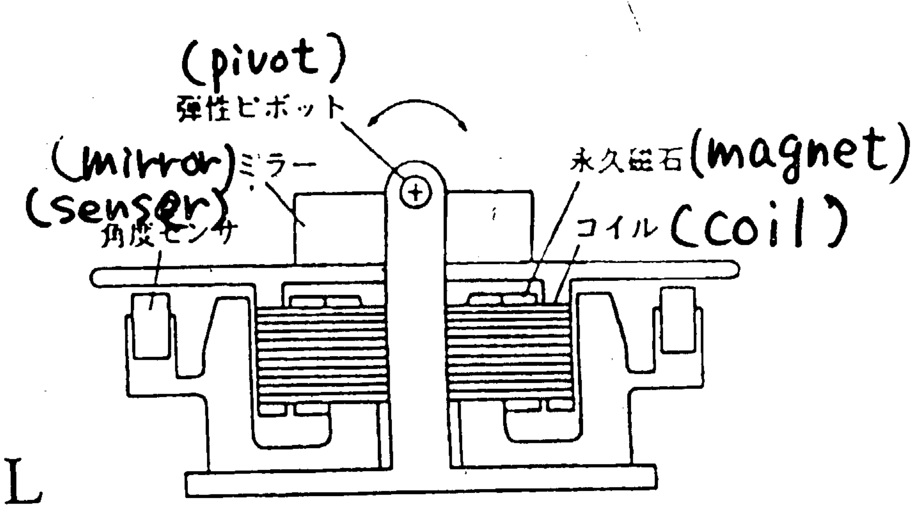
Required Resolution for T-T mirror



ムービングコイルタイプアクチエータ

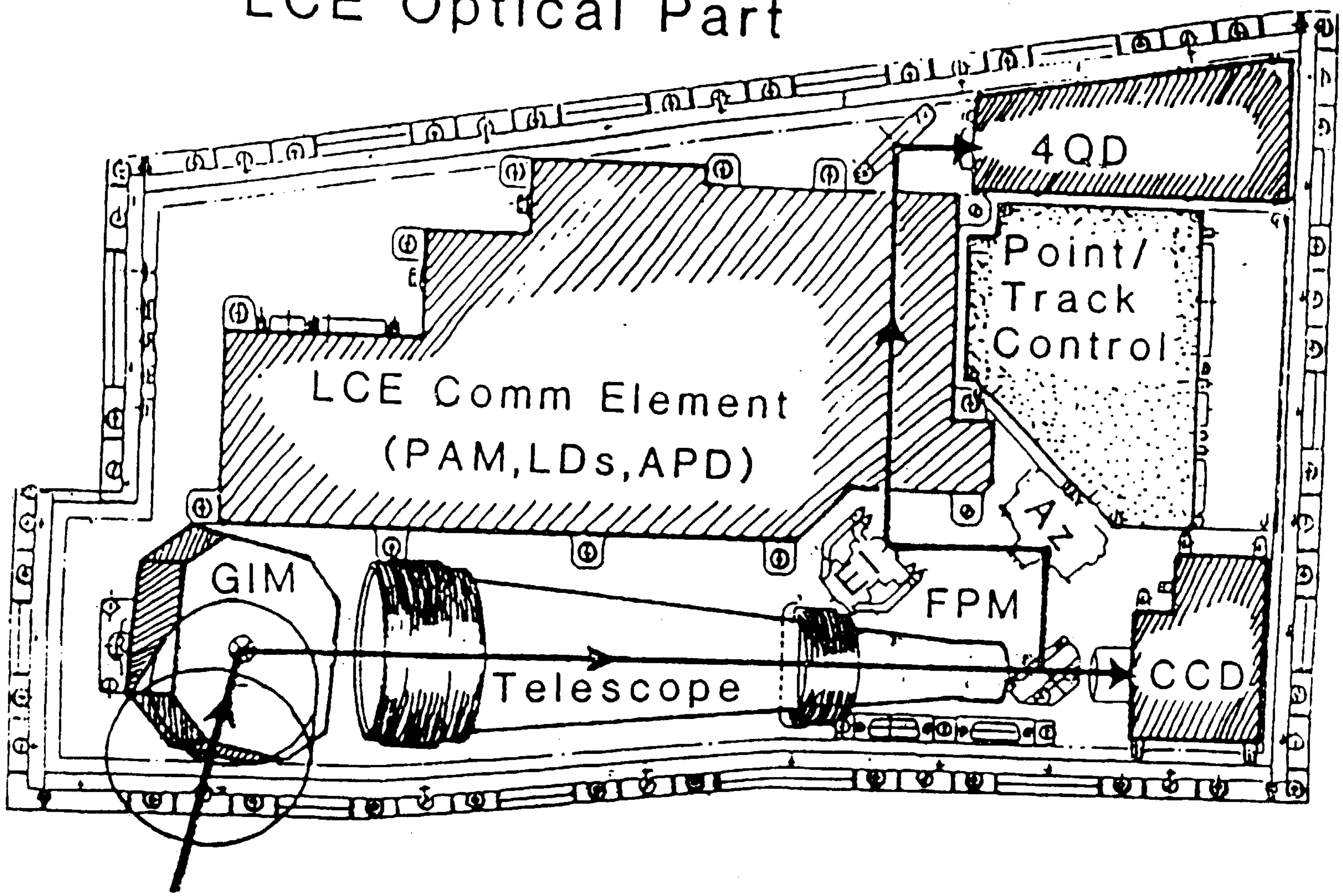


原理図



アクチエータ概念図
Moving Coil

LCE Optical Part



第5図　LCE 光学部のレイアウト

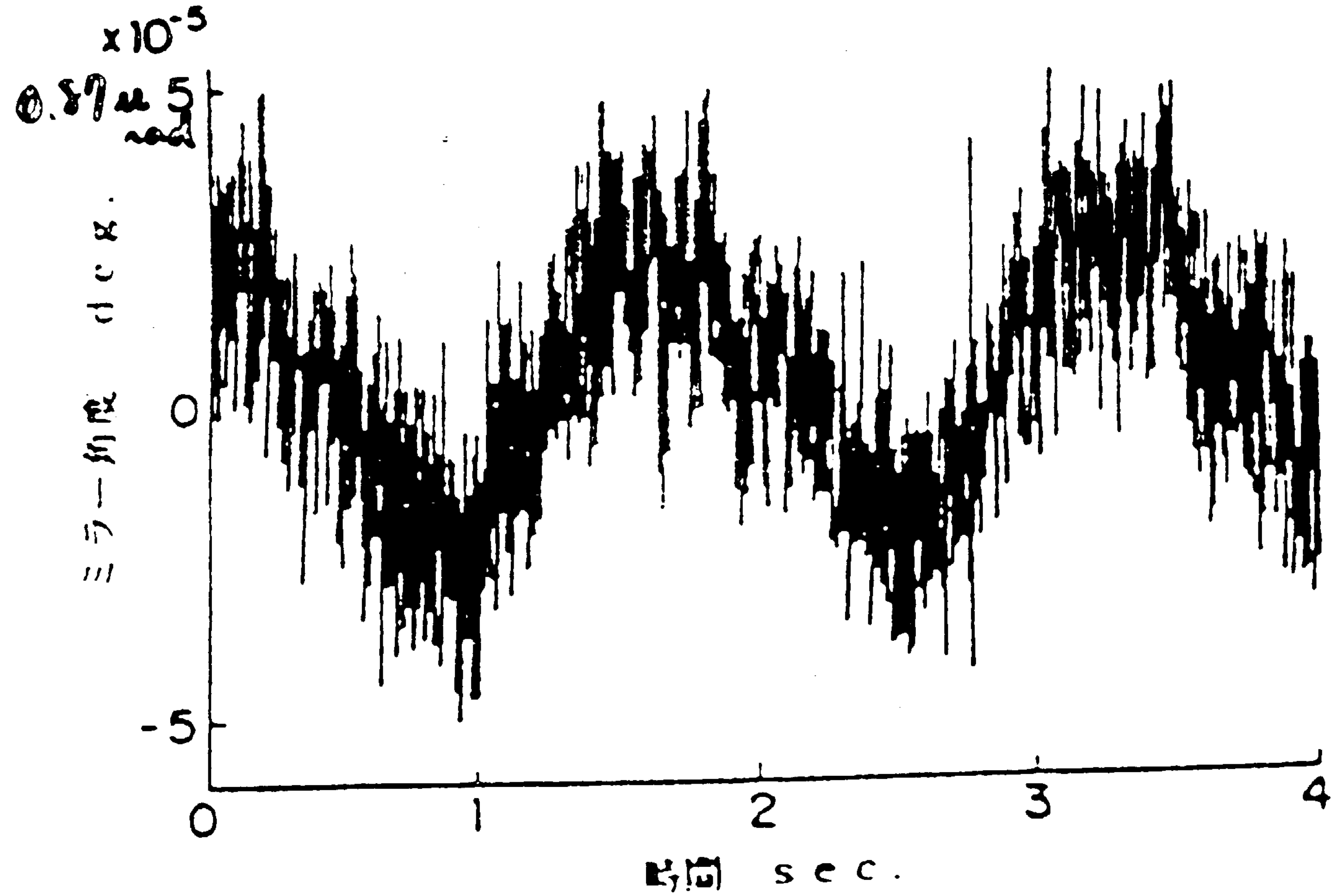


図 5　精追尾系の外乱に対する応答

polarization accuracy and physical quantities

$B \leftrightarrow P$ relation

$$\begin{aligned} B_l &\sim \alpha P_V \\ B_t &\sim \beta P_Q^{1/2} \end{aligned}$$

$\alpha \sim 1.7 \cdot 10^3$、$\beta \sim 2.0 \cdot 10^3$ (for FeI6303Å , B in Gauss),

detection limit

$$\begin{aligned} \delta B_l &\sim \alpha \delta P_V \\ \delta B_t &\sim \beta (\delta P_Q)^{1/2} \end{aligned}$$

uncertainty

$$\begin{aligned} \Delta B_l &\sim \alpha \delta P_V \sim \delta B_l \\ \Delta B_t &\sim \frac{dB_t}{dP_Q} \delta P_Q \sim \frac{1}{2} \beta P_Q^{-1/2} \delta P_Q \sim \frac{1}{2} \frac{\delta B_t^2}{B_t} \end{aligned}$$

1. ϕ : azimth angle of B_t

$$\Delta \phi \sim \frac{\Delta B_t}{B_t} \sim \frac{1}{2} \left(\frac{\delta B_t}{B_t} \right)^2$$

2. j : electric current
   resolvable element of J for pixel size dx

$$j \sim \frac{1}{\mu_0} \left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y} \right) dx^2 \sim \frac{1}{\mu_0} \frac{\partial B_t}{\partial x} dx^2$$

maybe modified for pixel smaller than Airy disk

$$\delta j \sim \frac{1}{\mu_0} \delta B_t dx \sim 4.1 \cdot 10^7 \delta B_t dx \quad Amp.$$

(B in Gauss, dx in arcsec)

$$\Delta j \sim \frac{1}{\mu_0} \Delta B_t dx \sim \frac{1}{2} \frac{\delta B_t}{B_t} \delta j$$

3. ε : energy element

J along a coronal loop of length l

$$\varepsilon \sim \frac{1}{2} L j^2$$

$L = 2l(log\frac{2l}{dx} - \frac{3}{4})$: inductance

$$\delta\varepsilon \sim \frac{1}{2} L (\delta j)^2$$

$$\Delta\varepsilon \sim \frac{\partial\varepsilon}{\partial I} \Delta I = L I \Delta I$$

4. E : total energy

(B.C.Low 1982, Solar Phys. 77, 43)。

$$\Delta E = \frac{1}{\mu_o} \int\int_{z=0} dxdy \left\{ x(B_x^{ff} - B_x^p) + y(B_y^{ff} - B_y^p) \right\} B_l^{ff}$$

B^{ff}: force free field

B^p : potectial field

$B^{ff} - B^p \rightarrow \Delta B_t$

$$\Delta E \sim \frac{1}{\mu_o} \int\int_{z=0} dx^2 x \Delta B_t B_l \sim \frac{L^3}{\mu_o} < B_l \Delta B_t >$$

$< \ >$: spatial average, $B_l \sim B_t$

$$< B_l \Delta B_t > \sim \frac{1}{2} < \delta B_t^2 > \sim \frac{\beta^2}{2} < \delta P_Q > \sim \frac{\beta^2 \delta P_Q}{2N^{1/2}}$$

N: total pix. number $(n^2 = (L/dx)^2$

$$\Delta E \sim \frac{1}{2\mu_0} \beta^2 L^2 dx \delta P_Q$$

noise level of linpol.

L field of view

	$\epsilon = 1\%$	$\epsilon = 0.3\%$	$\epsilon = 0.1\%$
δB_l (G)	17	5.1	1.7
δB_t (G)	200	110	63
ΔB_t (G)			
B_t=100G	200	60	20
500	40	12	4.0
1000	20	6.0	2.0
$\Delta\phi$ (deg.)			
B_t=100G	–	34	11
500	4.6	2.3	0.45
1000	1.1	0.34	0.11

Accuracy of Measurement for this error in Q, U or V for 1 wavelength

表 1: accuracy of polarization and B

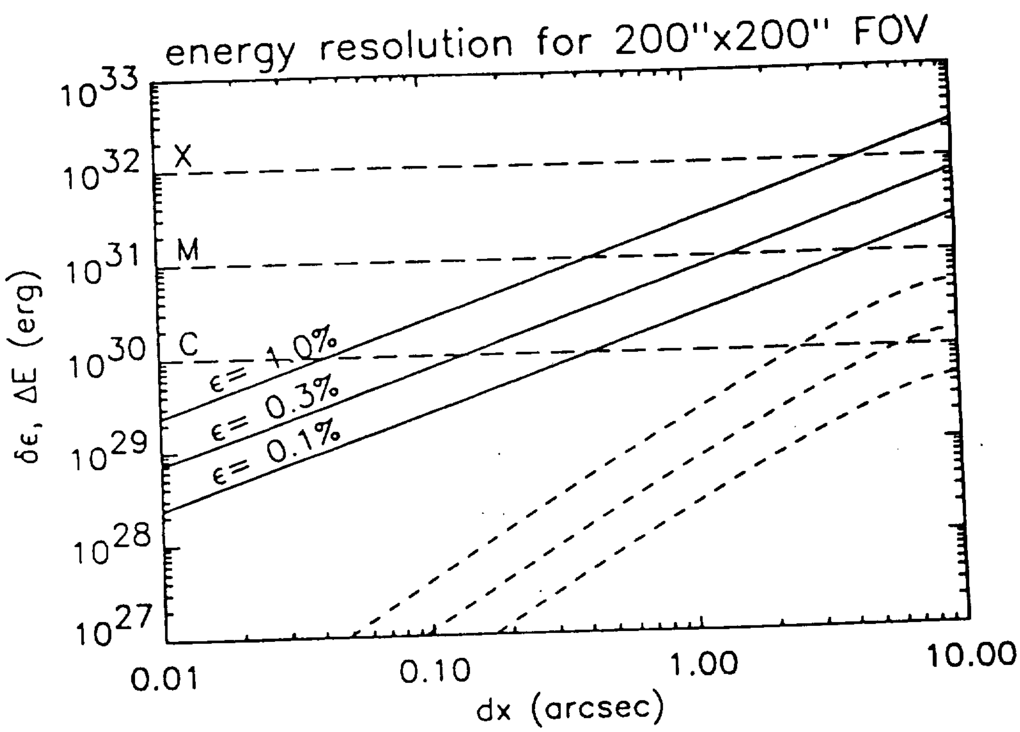


図 1: spatial resulution, pol. accuracy and energy resolution

sources of polarization errors

polarization measurement:

$$
\begin{aligned}
I_1' &= c_{i1}I + c_{q1}Q + c_{u1}U + c_{v1}V \\
I_2' &= c_{i2}I + c_{q2}Q + c_{u2}U + c_{v2}V \\
&\vdots \\
I_N' &= c_{iN}I + c_{qN}Q + c_{uN}U + c_{vN}V
\end{aligned}
$$

$$I_n's \quad \Rightarrow \quad I, Q, U, V$$

error in $I_n's$ $\leftrightarrow$ noise

error in $c_{i,q,u,v}$ $\leftrightarrow$ crosstalk by optics instrument

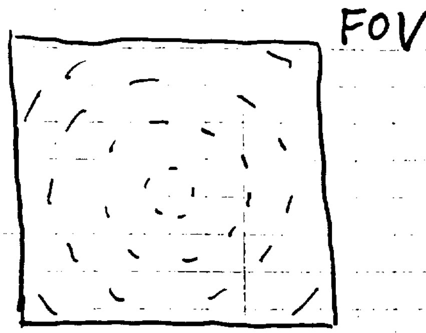
change of I $\leftrightarrow$ image motion

1. noise
   a) photon noise $\cdots$ $\delta(Q,U,V) \sim \epsilon I \sim (ntE_Q/E_M)^{\frac{1}{2}}$
   b) dark noise
   c) read noise

2. crosstalk by optics components
   a) $I \rightarrow Q,U,V$ $\cdots$ $\delta(Q,U,V) \sim \delta c_i I$
   b) $V \rightarrow Q,U$ $\cdots$ $\delta(Q,U) \sim \delta c_v V$
   c) $Q \leftrightarrow U$ $\cdots$ $\delta(Q,U) \sim \delta c_{u,q}(U,Q)$

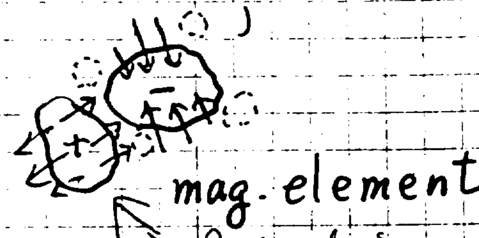
3. image motions
   a) telescope jitter, drift $\cdots$ $\delta(Q,U,V) \sim \delta x \frac{dI}{dx}$
   b) beam wobbling by Rot. WP $\cdots$ "
   c) time cgange of solar feature $\cdots$ $\delta(Q,U,V) \sim \delta t \frac{dI}{dt}$

I → Q U V



Telescope instrumental polarization

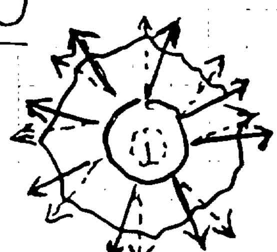
V → Q U

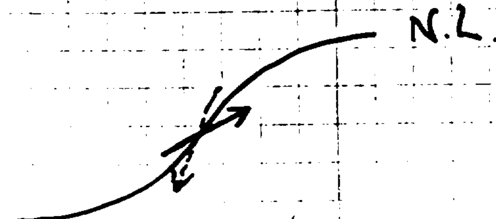


Longitudinal element

false linear polarization

Q ↔ U





In example

True field has no curl but spurious field does.

image motion

Spurious Linear polarization follows gradient

	noise	crosstalk by optics			image motion
		I→Q,U,V	V→Q,U	Q↔U	
estimation	$\delta(Q,U,V) \sim \epsilon \dot{I}$	$\delta(Q,U,V) \sim \delta c_i I$	$\delta(Q,U) \sim \delta c_v V$	$\delta(Q,U) \sim \delta c_{u,q}(U,Q)$	$\delta(Q,U,V) \sim \delta x \frac{dI}{dx}$
spatial distribution	random	fixed on device	fixed on device	fixed on device	solar feature
effect on B	detection limit noisy weak filed	false B even B=0 c_i pattern	false B_t assoc. B_l spot, mag.element	rotation of B_t penumbra, neutral line	false B assoc. I(x) granulation、mag.elem.
false j	random	deviec pattern trend → small effect uniform → no effect	assoc. above features	assoc. above above features	assoc. above above features
source	photon noise dark noise read noise	obliq. refl. dust on WP error in exp. time etc.	obliq. refl. error of WP obliq. trans. of WP etc.	obliq. refl. error of WP error of LP angle etc.	jitter of telescope rot. WP solar change
calibration demand	impossible ϵ	continuum $\delta c_i \leq \epsilon$	DC plage $\delta c_v \leq 3\epsilon$	? $\delta c_{q,u} \leq 3\epsilon$	interporation $\delta x('') \leq \epsilon, \Delta t \leq 2000\epsilon$ (s)

表 1: characteristics of polarization errors

		spatial distrib.	time variation	calibration SP,FL	to aboid	adopt SP	adopt FL
NOISE							
photon noise		random	random	impossi.	integration	○	
dark noise		random	random	impossi.	cooling	○	○
read noise		random	random	impossi.	slow A/D		
CROSSTALK BY OPTICS							
telescope refl.	I ⇒ Q,U,V V ⇒ Q ⇔ U	trend	const	possible	coating	△	△
folding mirror	I ⇒ Q,U,V V ⇒ Q ⇔ U	trend	const	possible	no folding mirr. caliblation	△	△
dust on WP	I ⇒ Q,U,V	irreg.	vari.	difficult	WP at pupil image		
fringe by WP	I ⇒ Q,U,V	irreg.	vari.	difficult	oil bath wedge		
exposure error	I ⇒ Q,U,V	uniform	random	possible	no mech. shutter	○	
inhomo. sensitivity	I ⇒ Q,U,V	irreg.	const	possible	use same pixel flat fielding	○	(○)
ghost	I ⇒ Q,U,V	irreg.	slow var.	difficult			
error of WP retard.	V ⇒ Q ⇔ U	uniform	slow var.	possible	stable element	(○)	(○)
error of WP setting	V ⇒ Q ⇔ U	uniform	const.	possible	calibration	(○)	[illegible]
imparfect. of Pol.	V ⇒ Q ⇔ U	uniform	const.	possible	calibration	(○)	[illegible]
obliq. trans. to WP	V ⇒ Q ⇔ U	trend	const.	possible	calibration	(○)	(○)
non-uniform WP	V ⇒ Q ⇔ U	trend?	const.	possible	calibration	(○)	(○)
error in WP rot.	V ⇒ Q ⇔ U	uniform	random	difficult	stable rot.	(○)	(○)
CCD read out	V ⇒ Q ⇔ U	trend	const?	possible	calibration	(○)	-
IMAGE MOTION							
atoms. scintilation	I ⇒ Q,U,V	sun	random	impossi.	space	○	○
WP wedge,tilt	I ⇒ Q,U,V	sun	random	imp.、pos.	oil bath Tip-Tilt mirr.	△ △	△ △
telescope jitter	I ⇒ Q,U,V	sun	random	imp.、pos.	symmetric samp. fast moduration Tip-Tilt mirr.	(○) (○) △	
solar change	I ⇒ Q,U,V	sun	random	imp.、pos.	fast moduration interpolation	(○)	 △

表 1: error sources

Which are dominant
Image motion
Beam splitter
Dust on waveplate
ghost brightness

calibration of crosstalk

polarization modulation:

$$\begin{bmatrix} I'_1 \\ I'_2 \\ \vdots \\ I'_N \end{bmatrix} = \begin{bmatrix} 1+\Delta c_{i1} & c_{q1}+\Delta c_{q1} & c_{u1}+\Delta c_{u1} & c_{v1}+\Delta c_{v1} \\ 1+\Delta c_{i2} & c_{q2}+\Delta c_{q2} & c_{u2}+\Delta c_{u2} & c_{v2}+\Delta c_{v2} \\ & \vdots & & \\ 1+\Delta c_{iN} & c_{qN}+\Delta c_{qN} & c_{uN}+\Delta c_{uN} & c_{vN}+\Delta c_{vN} \end{bmatrix} \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}$$

calibration = to know Δc_i, Δc_q, Δc_u, Δc_v

1. Δc_i: $I \rightarrow Q, U, V$
   - continuum at disk center ⇒ unpolarized

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad \rightarrow \quad \Delta c_i(x, y)$$

make observation

2. Δc_v: $V \rightarrow Q, U$
   - plage near disk center ⇒ $V >> Q, U$

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ V \end{bmatrix} \quad \rightarrow \quad \Delta c_v(x, y)$$

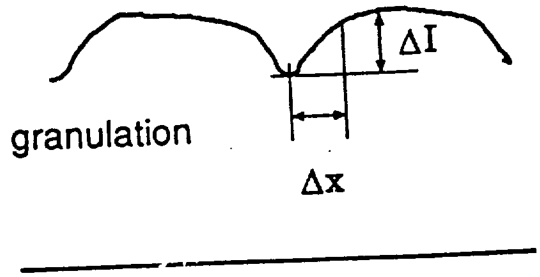
   - Q,U,V profiles ⇒ Q,U: symmetric, V: asymmetric

$$(Q, U)_{asym} = f(\Delta c_v) \cdot V$$

3. $\Delta c_{q,u}$: $Q \leftrightarrow U$
   - penumbra near disk center ⇒ B_t // filaments
   - compare with well calibrated ground-based observation

image shift and δI

granulation contrast:

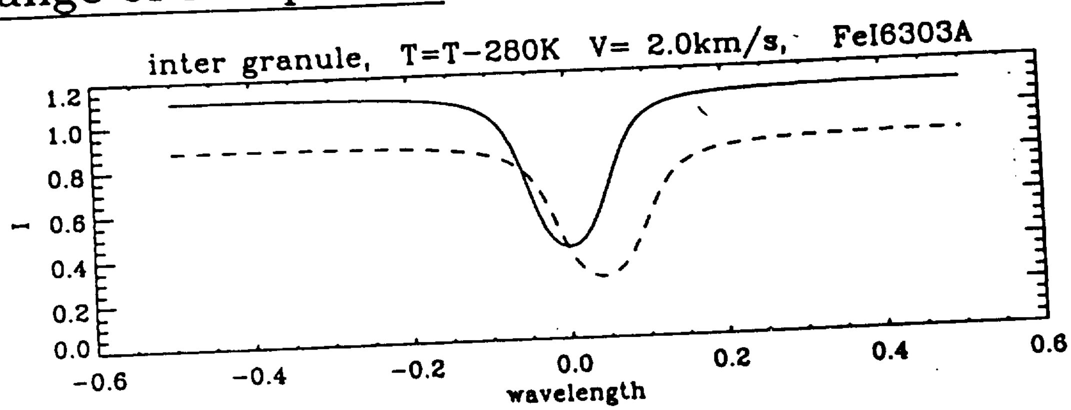


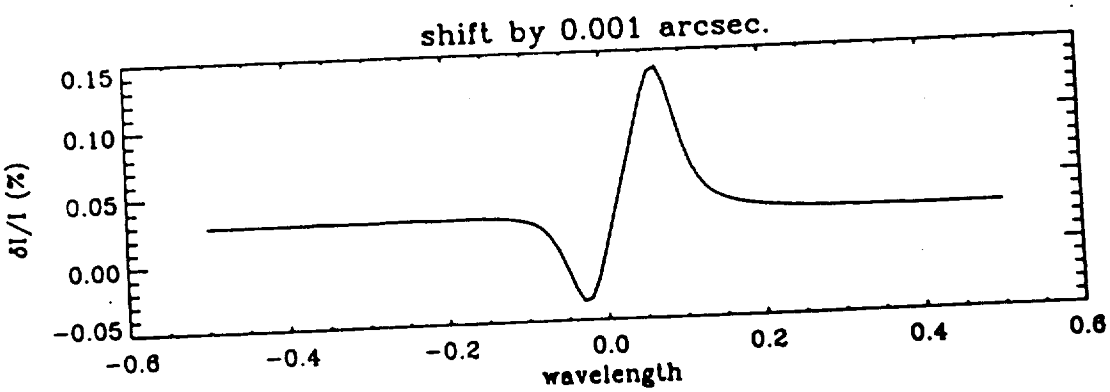
$\Delta I/I = 0.2$

$\Delta x = 0.''4$

$$\delta I = \frac{dI}{dx}\delta x = 0.5 I \delta x \quad \Rightarrow \quad \frac{\delta I}{I} = 0.1\% \longleftrightarrow \delta x = 0.''002$$

change of line profile:





$$\frac{\delta I}{I} = 0.1\% \longleftrightarrow \delta x = 0.''001$$

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requirment on image stability

assumptions:

- $\delta I/I = 0.1\%$ is produced by image shift of 0."001
- photometric accuracy — 0.1% (SP) and 0.5% (FLT)
- 0.75Hz for rotating wave plate (filter exp=0.33s)
- fullset of filter images taken in 10 sec
- no correction by tip-tilt mirror

	spectrograph	filtergraph	
		case 1	case 2
beam wobble	0."02 ($\frac{1}{10}$PSF)	0."005	0."02 ($\frac{1}{10}$PSF)
satellite drift	0."003/s (0."001/0.33s)	0."0005/s (0."005/10s)	0."06/s ($\frac{1}{10}$PSF/0.33s)
" jitter	0."001 at 1.5 and 3.0 Hz	0."005 at 0.1 ~ 3 Hz	0."02 in 0.33 s
		Δx ~ 0."015	

case1 : Polarized intensities are measured with the same pixel.

case2 : Image registration is made after observation.

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time variation of intensity and S/N

more compact magnetic element

1. **change of granuration** / average / mag. element
   contrast of granules: $g = 0.2$ → 0.5
   width of boundary: $x = 0.''5$ → 0.''2
   horizontal motion: $v = 1$ km/s
   $$\Rightarrow \quad \frac{1}{I}\frac{dI}{dt} = \frac{gv}{x} = 5.6 \times 10^{-4}\mathrm{s}^{-1} \quad \rightarrow 3.5 \times 10^{-3}\,\mathrm{s}^{-1}$$
   (0.1% ↔ 1.8s) (0.3s)
2. **five minute oscillation**
   v amplitude: $\delta v = 250$ m/s
   time scale: $\delta t = 150$ s
   $dv/dt = 1.67$ m/s^2
   $$\Rightarrow \quad \frac{1}{I}\frac{dI}{dt} = 1.6 \times 10^{-4}\mathrm{s}^{-1} \quad \text{(in FeI6303Å)}$$
3. **Doppler shift by orbital motion**
   max. rate of V change for polar orbit: $d\lambda/dt = 0.084$ mÅ /s
   $$\Rightarrow \quad \frac{1}{I}\frac{dI}{dt} = 3.8 \times 10^{-4}\mathrm{s}^{-1} \quad \text{(in FeI6303Å)}$$

integration time and S/N

flux budget → $N \sim 6 \times 10^5$ electrons/s/pix

(for Φ=50cm, 0.''2× 25mÅ pix., FeI6303Å , QE=0.4)

$$\Rightarrow \quad \frac{\delta I}{I} \sim (N \cdot t)^{-\frac{1}{2}} \sim 0.0013 \times t^{-\frac{1}{2}}$$

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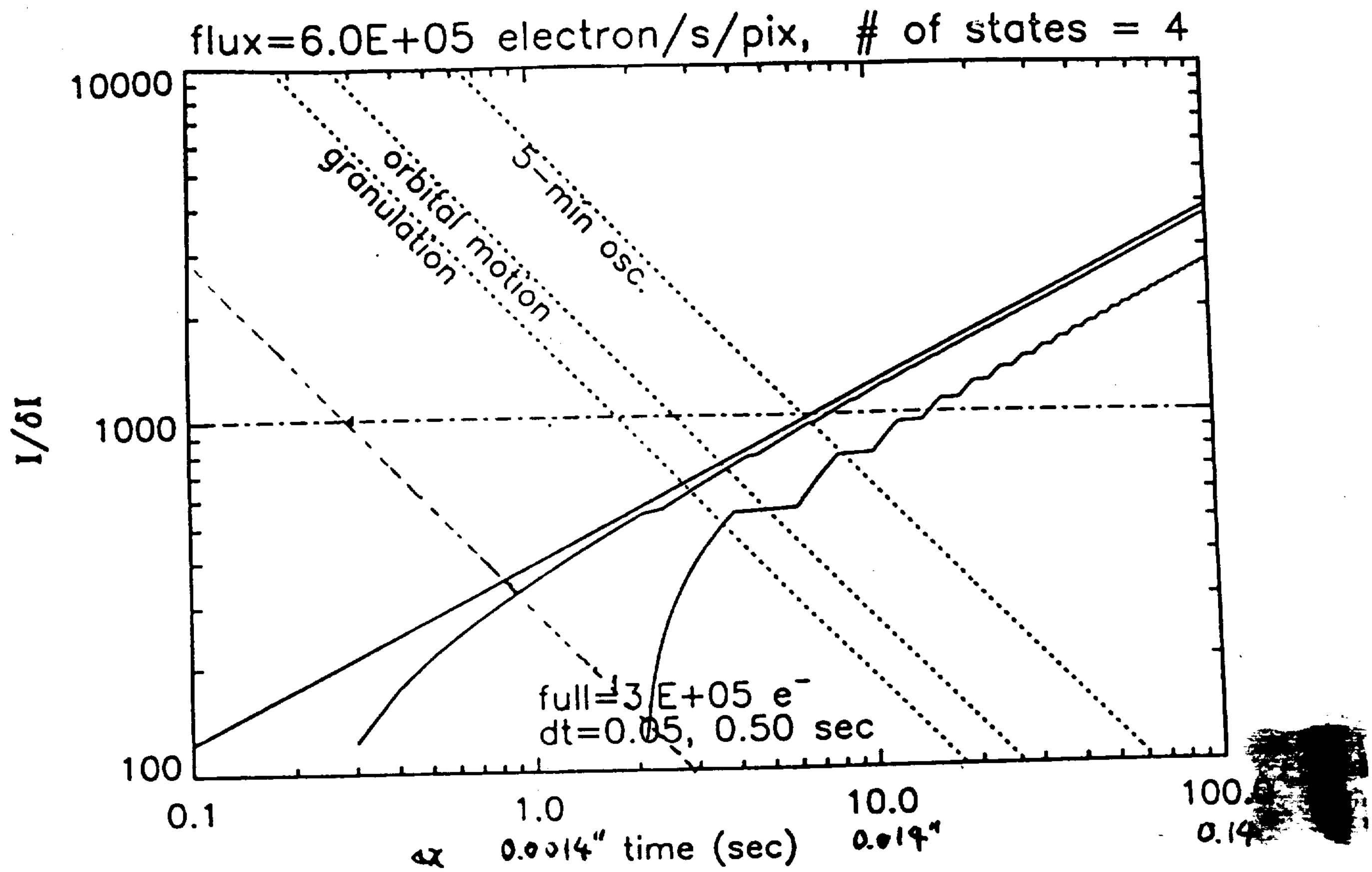
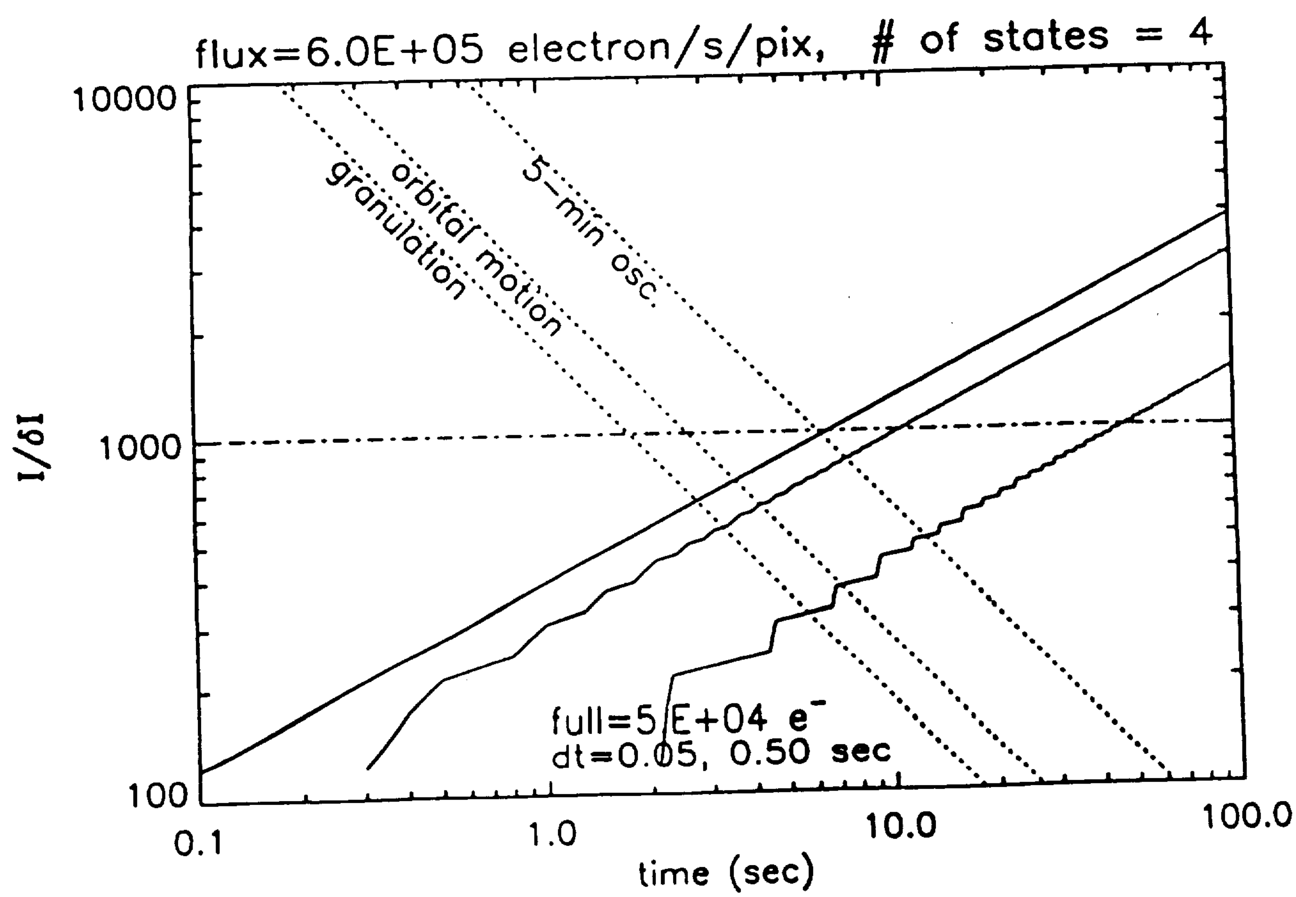
flux budget

++++++++++ telescope throughput ++++++++++			
Telescope aperture (50)	1963	1.96e+03	cm^2
Sub mirror (22)	390	1.57e+03	cm^2
Mirror (0.93x3)	0.804	1.27e+03	cm^2
IR,UV cut filter	0.90	1.14e+03	cm^2
Pol. modulator	0.95	1.08e+03	cm^2
Beam splitter	0.45	4.87e+02	cm^2
Solar intensity	5.88e-05	2.86e-02	erg/A/s/$arcsec^2$
erg/photon	3.15e-12	9.08e+09	photon/A/s/$arcsec^2$

++++++++++ spectrograph (6303A) ++++++++++			
Spatial sample(0.2x0.1)	2.00e-02	1.82e+08	photon/A/s/pix
Spectral sample(20.0)	0.0200	3.63e+06	photon/s/pix
lens(0.97x4)	0.885	3.21e+06	photon/s/pix
mirrors(0.93x1)	0.930	2.99e+06	photon/s/pix
Blocking filter	0.50	1.49e+06	photon/s/pix
Grating efficiency	0.50	7.47e+05	photon/s/pix
Quantum efficiency	0.40	<u>2.99e+05</u>	electron/s/pix

++++++++++ filtergraph (6303A) ++++++++++			
Spatial sample(0.1x0.1)	1.00e-02	9.08e+07	photon/A/s/pix
Passband width	0.111	1.01e+07	photon/s/pix
lens(0.97x2)	0.941	9.48e+06	photon/s/pix
Beam splitter	0.90	8.53e+06	photon/s/pix
Blocking filter	0.50	4.27e+06	photon/s/pix
Lyot transmission	0.22	9.38e+05	photon/s/pix
Quantum efficiency	0.40	<u>3.75e+05</u>	electron/s/pix


flux=6.0E+05 electron/s/pix, # of states = 4
I/δI
10000
1000
100
0.1
1.0
10.0
100.0
time (sec)
Δx
0.0014"
0.019"
0.14"
orbital motion
granulation
5–min osc.
full=3 E+05 e⁻
dt=0.05, 0.50 sec


flux=6.0E+05 electron/s/pix, # of states = 4
I/δI
10000
1000
100
0.1
1.0
10.0
100.0
time (sec)
orbital motion
granulation
5–min osc.
full=5 E+04 e⁻
dt=0.05, 0.50 sec

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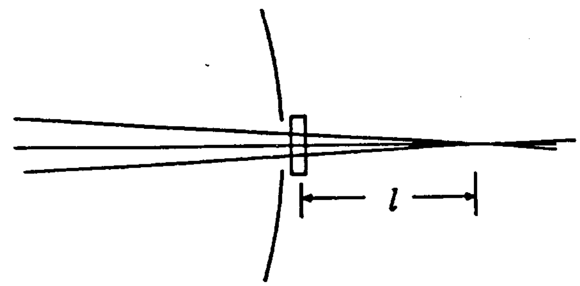
beam wobbling by a rotating waveplate

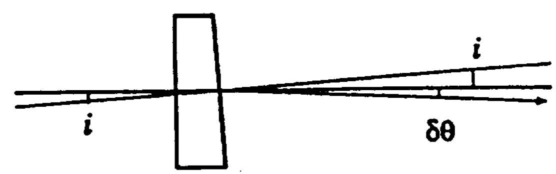
i : wedge angle

α : tilt angle



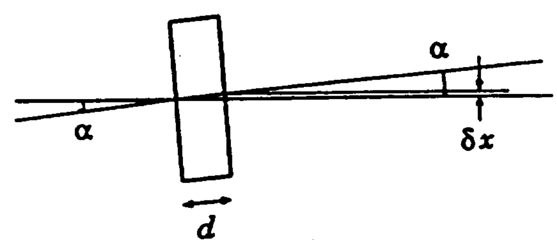
- **wedge**

$$n \sin = \sin(i + \delta\theta)$$
$$\delta\theta \sim (n-1) \cdot i$$
$$\delta x_w \sim (n-1) \cdot l \cdot i$$



- **tilt**

$$\sin\alpha = n \cdot \sin(\alpha - \theta)$$
$$\theta \sim \frac{1}{n}(n-1) \cdot \alpha$$
$$\delta x_t \sim d \cdot \theta = \frac{1}{n}(n-1) \cdot d \cdot \alpha$$



parameters

- image size: 1" $= 3.64 \cdot 10^{-2} mm = 36.4 \mu m$ (base line)
- location of WP: $l = 21cm$
- wave plate: $d = 2mm$, $n = 1.55$ (quartz)

tolerance of i and α

allowable image motion: $2\delta x \leq 0''.002 \Rightarrow \delta x = 3.64 \cdot 10^{-5} mm$

$$i \leq 3.15 \cdot 10^{-7} rad = 6''.5 \cdot 10^{-2}$$
$$\alpha \leq 5.13 \cdot 10^{-5} rad = 10''.6$$

※ $i \rightarrow$ 95 mÅ$\sim \frac{1}{50}\lambda$ parallelism of WP for 3cm diameter.

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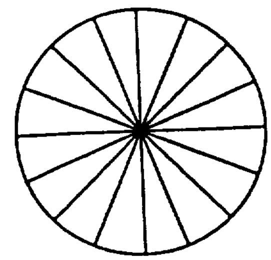
avoiding influence of the image motion

1. symmetric sampling

cancel the I→Q,U,V crosstalk



16 samples for 1 rotatin

$$\Rightarrow \quad 2\,\delta x < \frac{1}{10}\,\mathrm{PSF} \sim 0.''02$$

※ candidate mode for the spectrograph

2. compensate by tip tilt mirror

$i = 10''$ $\quad\rightarrow\quad$ $2\delta x = 0''.154$

rotation = 0.5 Hz $\quad\rightarrow\quad$ $dx/dt \sim 0''.154$ /s

$$\Rightarrow \quad \frac{dx}{dt}/\delta x = 0''.154/0''.002 = 79 \text{ /s}$$

i.e. ∼ 100 Hz is required for tip-tilt mirror.

※ Result changes with assumed parameters.

※ Detection of image motion may be a difficult problem.

3. cancel the wedge and tilt (for rot.WP)

$\delta x_w + \delta x_t = 0$ $\quad\rightarrow\quad$ $\alpha = -n \cdot \frac{l}{d} i = 2'.72$

※ 10".6 aqqurracy is still required for the direction of rot. axis.

※ Interference fringe?

4. put WP in oil bath (for rot.WP)

※ This solves also fringe problem.

5. use LQVR

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fast system vs. slow system for polarization measurement

	fast system	slow system
rot. wave plate	coutinuous($\sim$ 0.75Hz)	step-wise ($\sim$ 0.5Hz)
CCD clock	fast ($\sim$ 1MHz $\times$ 2)	slow (0.5MHz)
fullwell	$\sim 5 \cdot 10^4$	$\sim 2 \cdot 10^5$
shutter	frame transfer	mechanical shutter(?)
shutter timing	$\sim$ 1ms	-
exposure	$\sim$ 80 ms	$\sim$ 300 ms
accumulation	yes ($\sim$ 60 times)	no
accuracy	0.1 %	0.3 %
sampling	16pos. / rot.	4 or 5 position
duration for 1set	$\sim$ 5 sec	$\sim$ 3-4 sec
total electron #	$1 \cdot 10^6$	$1.1 \cdot 10^5$
efficiency	100%	20 $\sim$ 30 %
required image stability (without tip-tilt mirror)		
wobble by WP	$< \frac{1}{10}$ PSF $\sim 0.''02$	$< 0.''003$
satellite drift	$< 0.''003/s$	$\leq 0.''0008/s$
" jitter	$< 0.''001$	$< 0.''003$
	at 1.5 and 3.0Hz	at 0.2$\sim$1Hz
problems	compatibility with filter	0.3 % accuracy
	fast clock	image stability
	(flat fielding?)	

classification of polarization measurement

1. mechanisms of polarization modulation

(a) rotating wave plate (continuous)

(b) rotating wave plate (stepping)

(c) wave plate wheel

(d) liquid crystal variable retarder

2. Modulation sequence

(a) take I $\pm$ Q, I $\pm$ U, I $\pm$ V

(b) take 4 sets of $I_i = \frac{1}{2}(I + c_{qi} \cdot Q + c_{ui} \cdot U + c_{vi} \cdot V)$

(c) take more than 5 kinds of I_i

(d) take only I$\pm$ V

3. onboard accumulation, make or not

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tradeoff between polarization modulators

modulator mechanism	modulator retardation	efficiency vector (Q,U,V)	efficiency v-only	speed	mechanical disturbance	control	beam wobble	stability	raliability
Rot.WP	$\lambda/4$	0.318, 0.318, 0.636	<1.0[1]	○	○	△[2]	× (○)[3]	○	○
(continuous)	127°	0.511, 0.511, 0.511	<0.8[1]						
Rot.WP	$\lambda/4$	0.354, 0.354, 0.653	1.0	△	×	○	△ (○)[3]	○	○
(stepping)	123°	0.547, 0.547, 0.547	<0.837[1]						
Turret	$\frac{\lambda}{4}$x2,$\frac{\lambda}{2}$x4	0.333, 0.333, 0.333	1.0	×	×	○	△	○	○
	$\frac{\lambda}{4}$x2,123°x4	0.547, 0.547, 0.547	1.0						
LCVR×2		0.577, 0.577, 0.577	1.0	○	○	?	○	△[4]	?

1. Pure I cannot be obtained with 2 exposures due to Q->I crosstalk.
2. Continuously rotating WP requires precise shutter timing.
3. Continuously rotating WP causes image motions even during exposure. But image motion can be surpressed by putting the WP in oil bath.
4. LCVR is sensitive to temperature variation but the calibration seems not to be very difficult.

merits of the fast system:

- a high photometric accuracy
- small mechanical disturbance by the modulator
- the symmetric sampling reduces I→Q,U,V crosstalk caused by beam wobbling by the rotating wave plate by factor of 10
- quick modulation relaxes the requirment on satellite drift rate
- only limitted frequencies of satellite jitter are responsible to the I→Q,U,V crosstalk
- controling principle may be simple because the modulator can be a reference for both filter and spectrograph operations

demerits of the fast system:

- compatibility with the filter instrument
  - pure I and V cannot be obtained with 2 exposures (Q → I crosstalk)
  - exposure of the filtergram should be shorter than twice of the spectrograph for Q,U-measurement and 4 times for V-measurement
  - precise timing is required for the mechanical shutter
  - image moves even during exposures
  - shutter by a moving slit may cause a different modulation phase in FOV
- fast clock of CCD and fast demodulator are required

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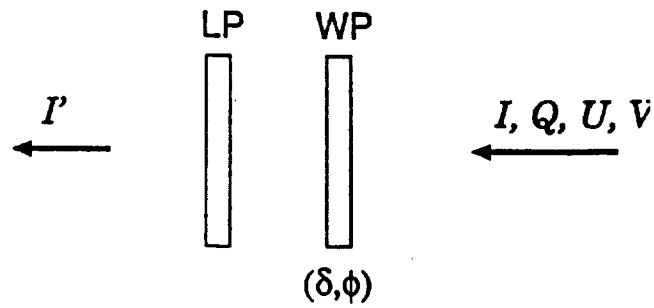
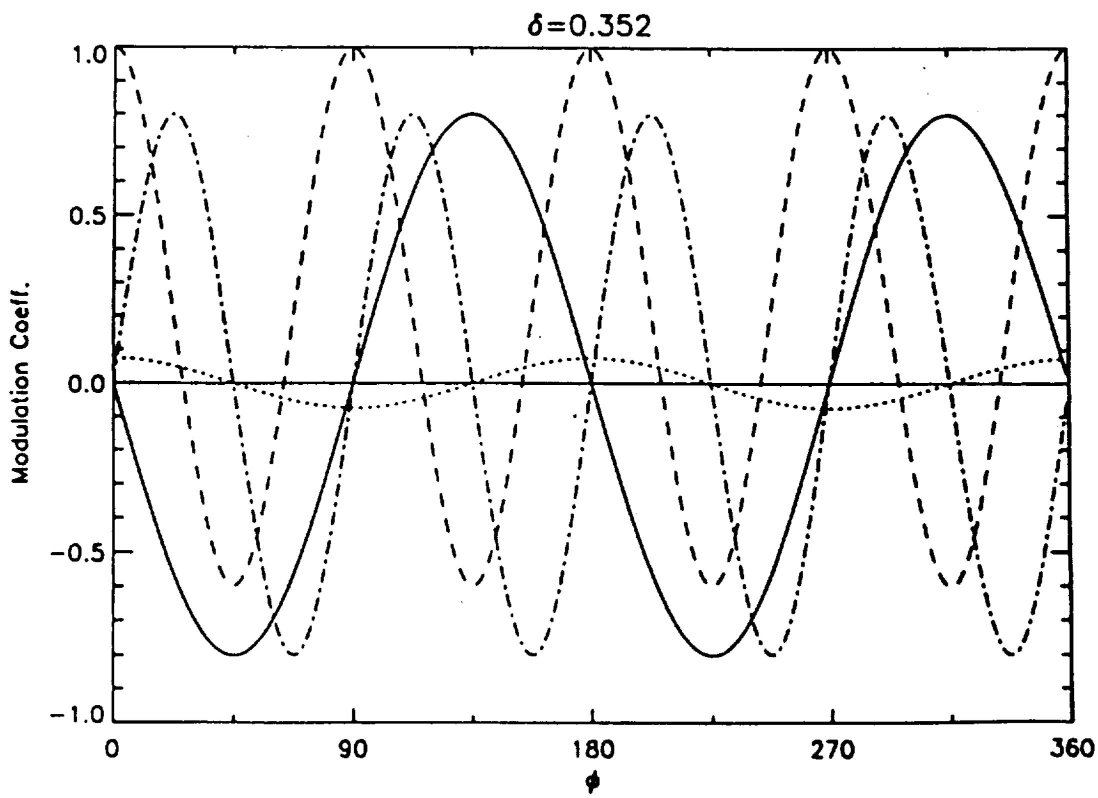
modulation by a rotating waveplate



$$
\begin{aligned}
2I' &= \{1 + R\sin(4\pi dn/\lambda)\sin\delta\cos 2\phi\}\cdot I \\
&+ \{\frac{1+\cos\delta}{2} + \frac{1-\cos\delta}{2}\cos 4\phi\}\cdot Q \\
&+ \frac{1-\cos\delta}{2}\sin 4\phi\cdot U \\
&- \sin\delta\sin 2\phi\cdot V
\end{aligned}
$$

$R = 2\left(\frac{n-1}{n+1}\right)^2$: reflection index, n : refraction index, d: thickness



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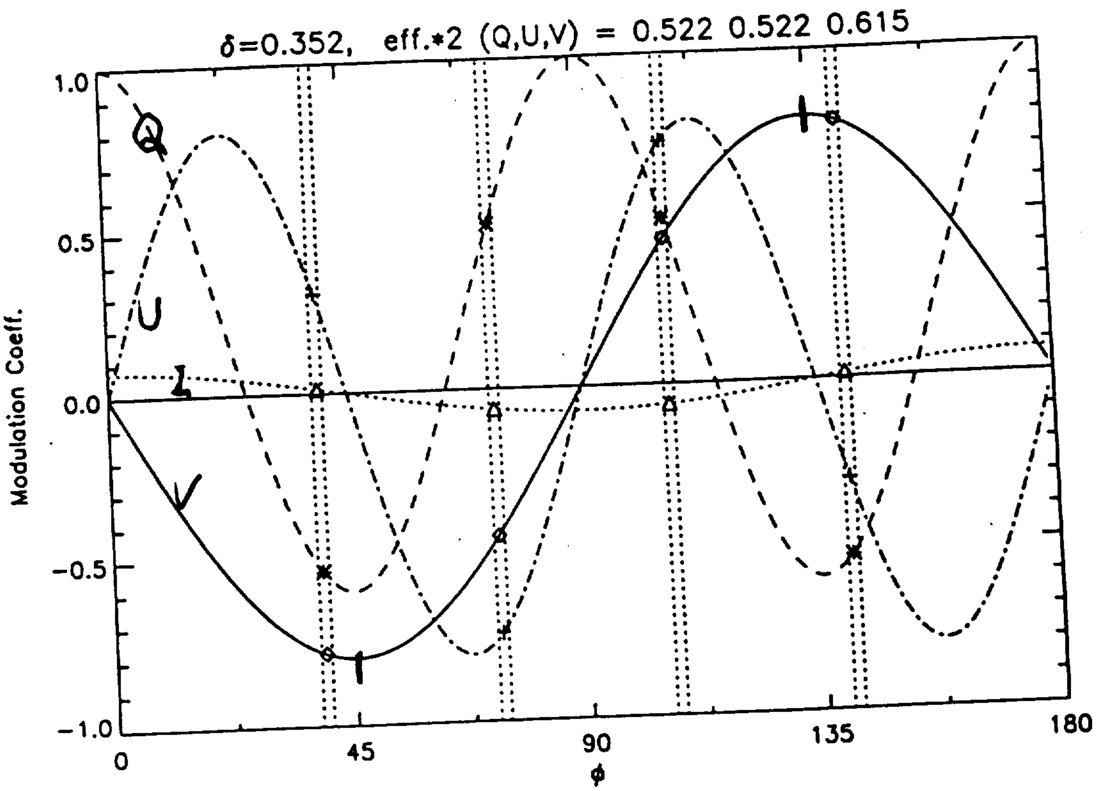
effective sampling for filter system



ϕ	c_i	c_q	c_u	c_v
39.38	0.015	-0.538	0.306	-0.785
73.12	-0.062	0.506	-0.738	-0.444
106.88	-0.062	0.506	0.738	0.444
140.62	0.015	-0.538	-0.306	0.785
M.E.	0.038	0.522	0.522	0.615
M_p	0.513	0.960	0.891	0.790

M_p is defined by $\sqrt{\sum_i m_{ip}^2}$, where m_{ip} are elements of the inverse matrix.

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} m_{1i} & m_{2i} & m_{3i} & m_{4i} \\ m_{1q} & m_{2q} & m_{3q} & m_{4q} \\ m_{1u} & m_{2u} & m_{3u} & m_{4u} \\ m_{1v} & m_{2v} & m_{3v} & m_{4v} \end{bmatrix} \begin{bmatrix} I'_1 \\ I'_2 \\ I'_3 \\ I'_4 \end{bmatrix}$$

constraint on filter obs. from the continuously rot. WP

Q → I crosstalk :	$\Delta I_{max} \sim 8.8\%$	⇒	vector sampling error in 2 measurements V determination
exposure limittation :	$\Delta t < 167$ ms (Q,U)	⇒	flux budget of SP and FLT
	$\Delta t < 333$ ms (V)		OK for long λ
reduced efficiency :	factor 0.64 for 45° exp.	⇒	not serious
shutter timing :	$\delta t < 4$ ms ($\delta I = 0.5\%$)	⇒	investigation of mech. shutter
			($\delta t \sim 8$ ms 15 μs for SXT shutter)
beam wobbling :	$\delta x < \frac{1}{10}$ PSF (during exp.)	⇒	same with spectrograph
	$\delta x < 0.''005$ (between exp.)	⇒	image registration on ground?
non-uniform phase :	?	⇒	investigation of mech. shutter
			calibration scheme?

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tradeoff between locations of polarimator
(case of rotating wave plate)

	at pupil image (collimated)	at solar image (converging)	no image (converging)
image motion by tilt	no	*large*	middle
" by wedge	*large*	no	middle
plate inhomogeneity (I→Q,U,V cross talk)	insensitive	*sensitive*	middle
distance from primary	*large*	small	small

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estimation of Q→I crosstalk (I-ambiguity)

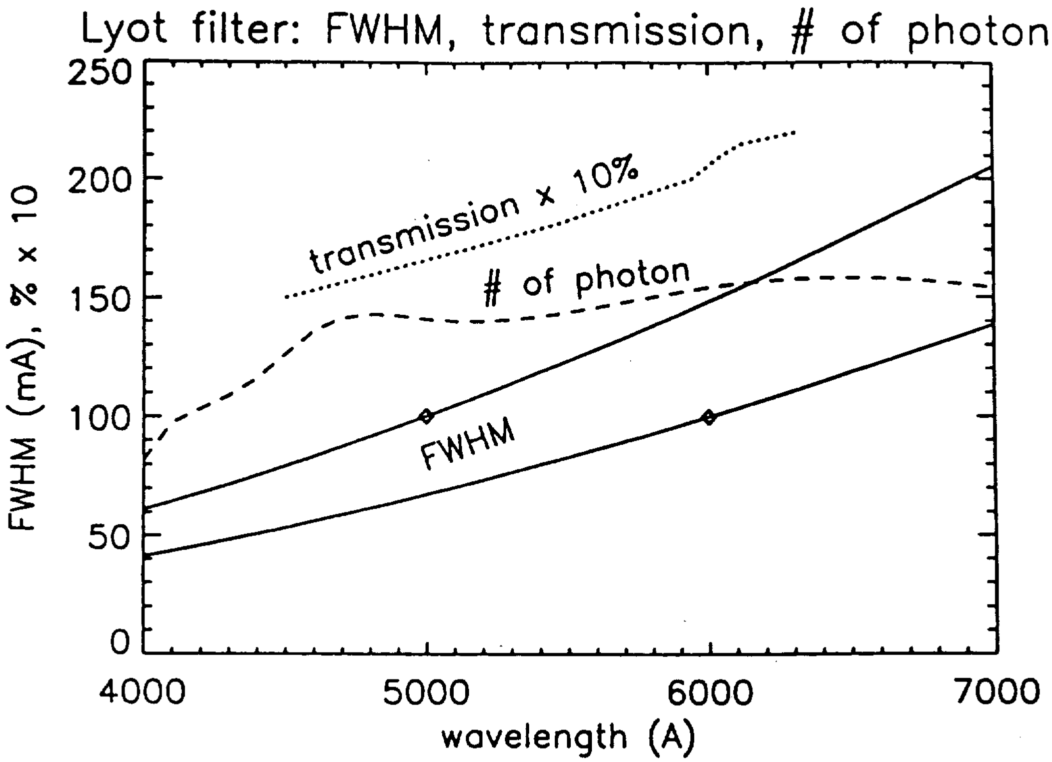
assumptions:

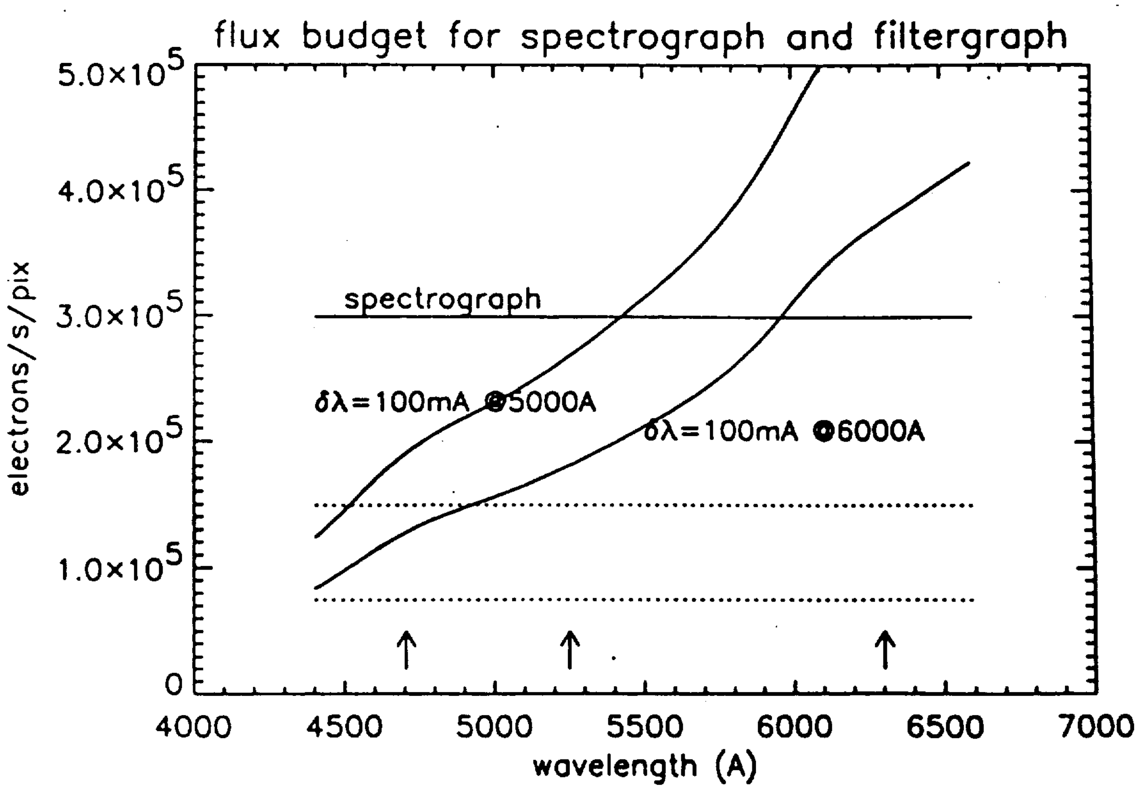
- LTE line formation
- magnetic field — 2000G, horizontal
- filter width — 100mA at 6000Å
- retardation of WP — 126.8°
- sampling around 45° and 135°
- exposure duration — 1°, 71°, 90°

	Δ I_{max} (%)		
line	1°	71°	90°
FeI6303Å	-7.5	0.	2.5
FeI5506Å	-8.8	0.	2.9
FeI5250Å	-8.4	0.	2.8
FeI4442Å	-4.5	0.	1.5

consideration:

- Exposure duration of ~70° rotation reduces Q→I crosstalk. Allow small I-ambiguity.
- Take vector magnetic field with 4 exposures always when accurate I is required from the scientific objective.


Lyot filter: FWHM, transmission, # of photon
transmission x 10%
# of photon
FWHM
FWHM (mA), % x 10
wavelength (A)
0
50
100
150
200
250
4000
5000
6000
7000


flux budget for spectrograph and filtergraph
spectrograph
δλ=100mA @5000A
δλ=100mA @6000A
electrons/s/pix
wavelength (A)
0
1.0×10^5
2.0×10^5
3.0×10^5
4.0×10^5
5.0×10^5
4000
4500
5000
5500
6000
6500
7000

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degradation of modulation efficiency

$\mathrm{ME} = \frac{1}{N}\Sigma_{i=1}^{N} |c_{pi} - \overline{c_{pi}}|$, $\mathrm{M}_p = \sqrt{\Sigma m_{ij}^2}$

sampling at 39.38°, 73.12°, 106.88°, 140.62°

rot. angle during exposure = $\Delta\phi$

	ME			M_p		
$\Delta\phi$	q	u	v	q	u	v
1.0	0.522	0.522	0.615	0.957	0.891	0.790
10.0	0.509	0.509	0.611	0.982	0.914	0.795
22.5	0.470	0.470	0.599	1.063	0.989	0.811
45.0	0.333	0.333	0.553	1.503	1.399	0.877
70.0	0.137	0.137	0.473	3.637	3.386	1.027
90.0	0	0	0.391	-	-	1.364

consideration:

- If $\Delta\phi < 45°$, S/N does not dgrade more than factor 0.66
  → not very serious

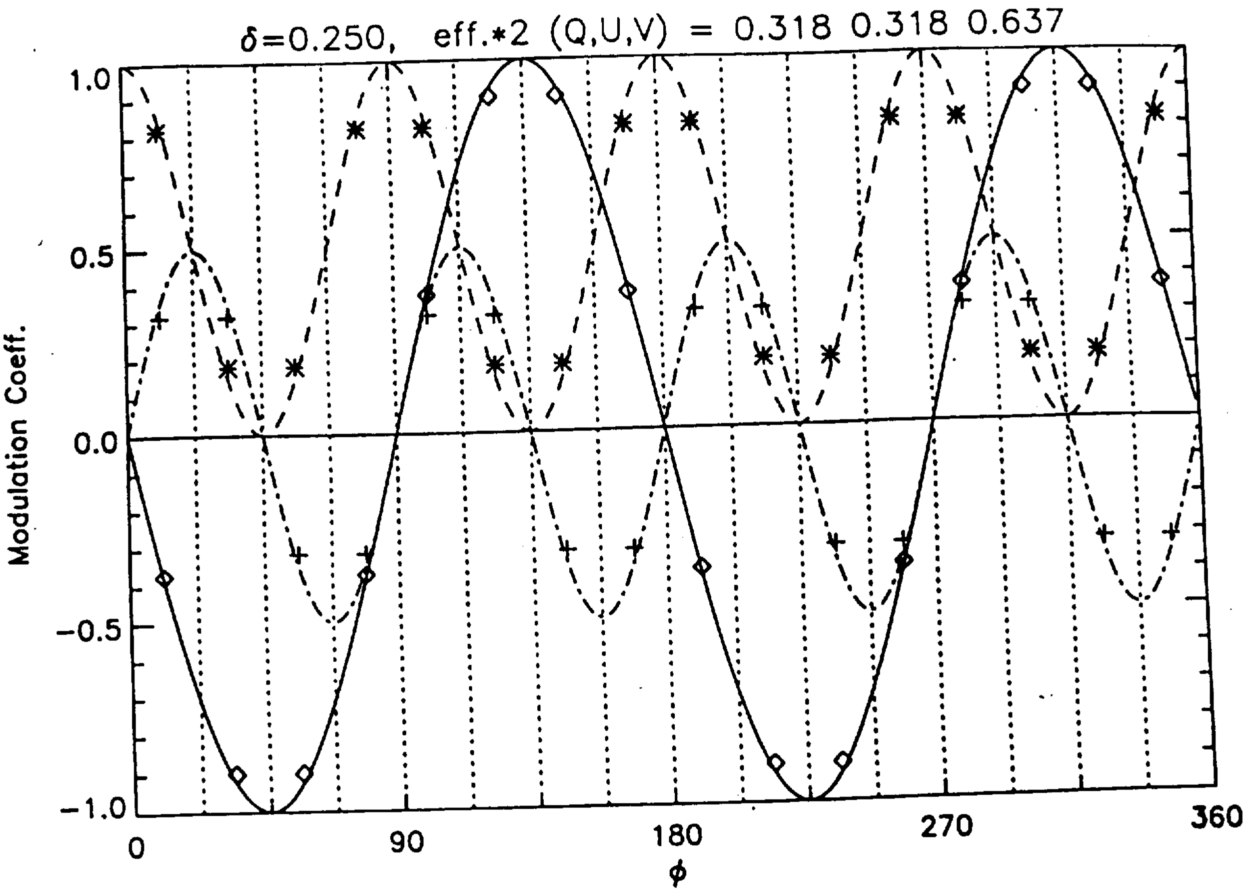
requirment on the mechanical shutter

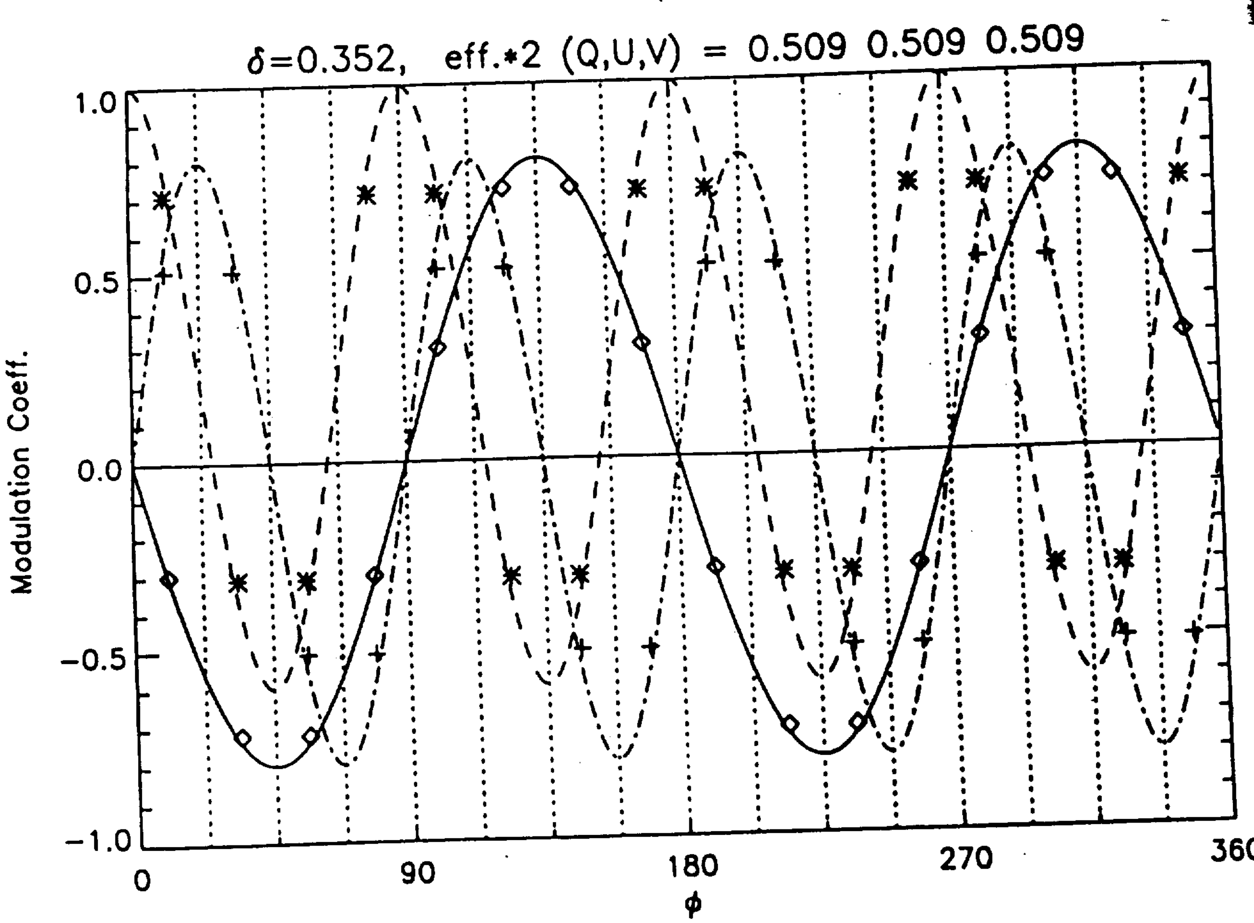
$\delta I/I = 0.5\%$ (40,000 electrons) → $\delta\phi \sim 1.1°$

rotation freq. = 0.75Hz → timing accracy (δt) ~4 ms

consideration:

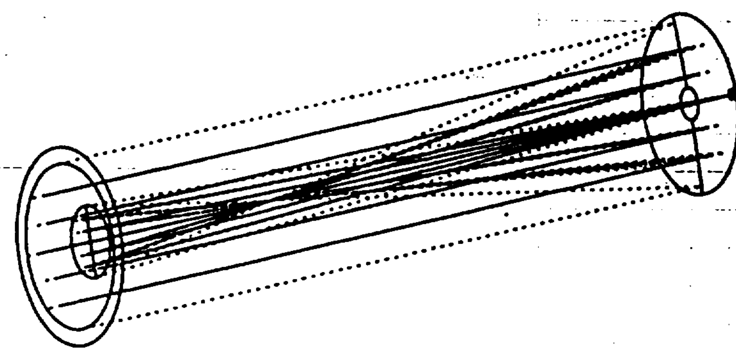
- *Yohkoh* SXT shutter → $\delta t \sim 8$ ms → 15μs
- further study of shutter mechanism
- monitor timing and calibrate on data analysis?

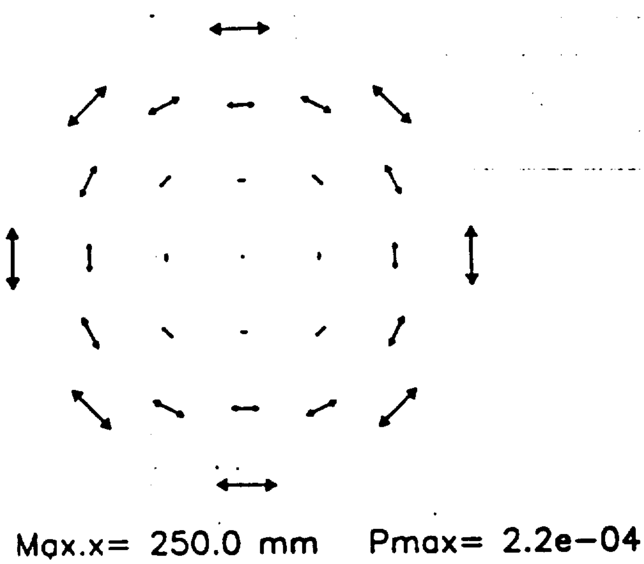

δ=0.250, eff.*2 (Q,U,V) = 0.318 0.318 0.637
Modulation Coeff.
1.0
0.5
0.0
−0.5
−1.0
0
90
180
270
360
φ

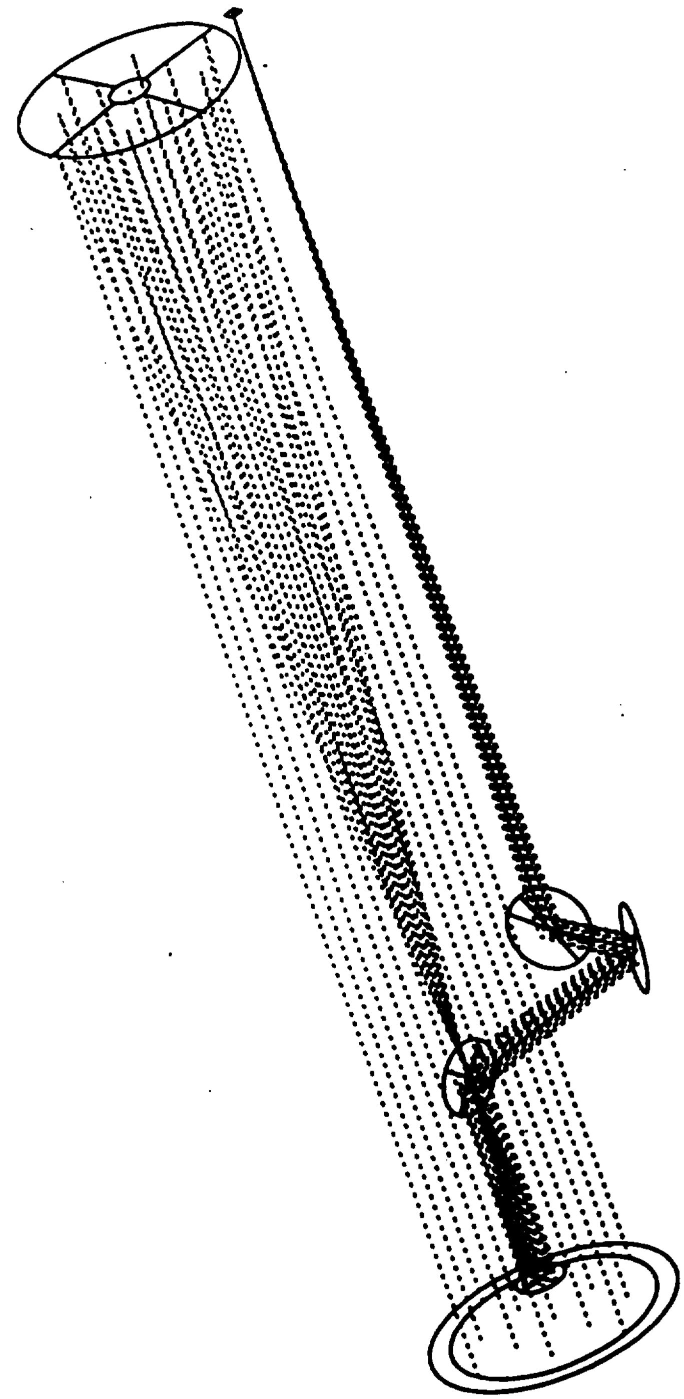

δ=0.352, eff.*2 (Q,U,V) = 0.509 0.509 0.509
Modulation Coeff.
1.0
0.5
0.0
−0.5
−1.0
0
90
180
270
360
φ

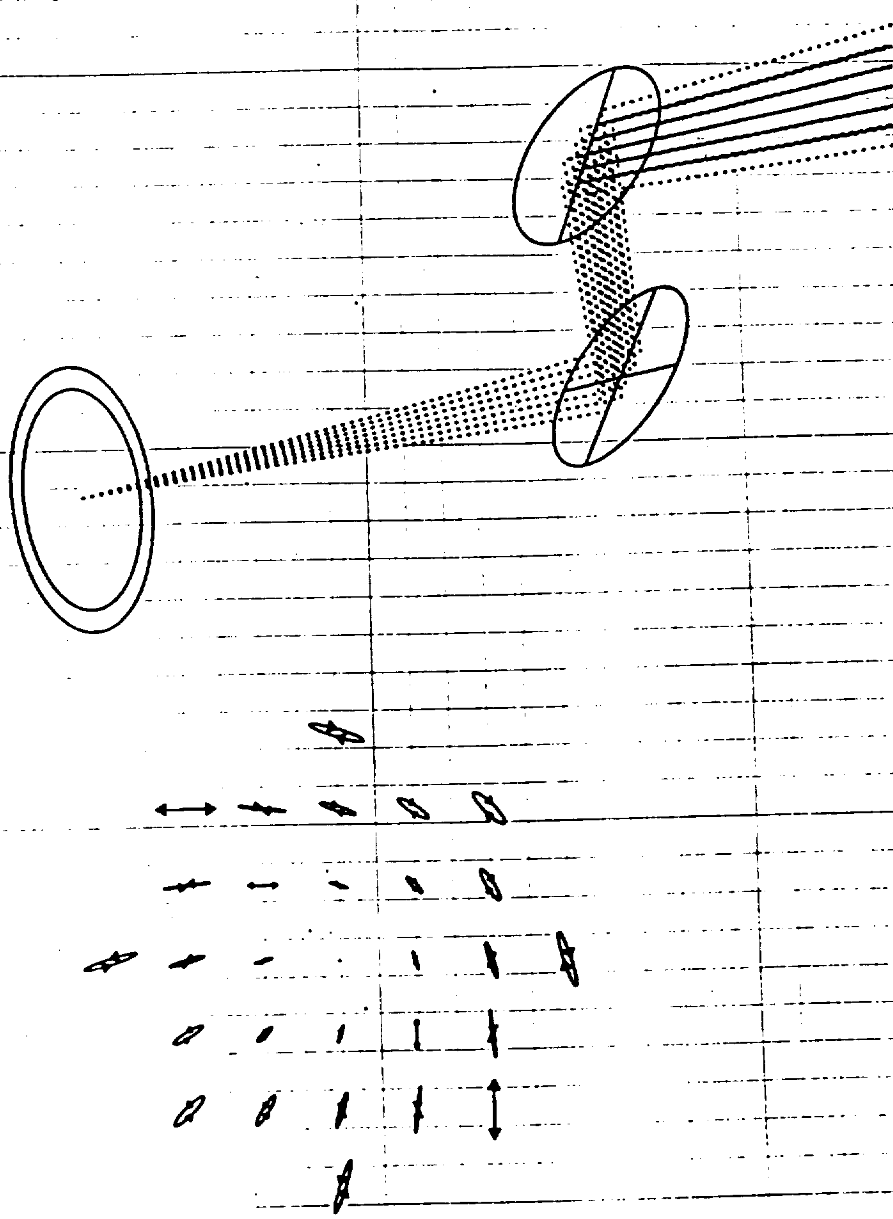
3.1.1 グレゴリー望遠鏡

口径５０ｃｍ、主鏡 f2100mm、副鏡 f703mm、主鏡副鏡間距離 3000mm のグレゴリー望遠鏡を考える。図のように光軸に平行な光線も、入射点が光軸から離れるに従って同心円状の直線偏光を示し、その大きさは周辺で約 2×10^{-4} 程度になる。しかし、視野中心に於いては Mueller 行列を平均すると単位行列となり、全体として疑似偏光は発生しない。また、視野の端 (200") に於いても平均した Mueller 行列の成分は、最大で 10^{-7}程度の大きさであり、疑似偏光はほとんど問題とならないであろう。









Max.angle= 120.0'   Pmax= 3.8e−03

Appendix 8.

Meeting Notes from Presentations by Prof. Tsuneta's Group on Solar-B Magnetograph Design

During the Solar-B presentations I attempted to keep detailed notes of the speakers comments. These notes are not intended to stand alone but to accompany the speakers handouts. The purpose of the notes is to highlight the topics which the speakers emphasized, catch some information which might not have been presented quite the same in the notes, and to get a sense of some of the dialog which ensued.

25 July 18 Mitaka

Meeting notes on Solar B presentations to Russell Chipman
From Prof. Tsuneta's group
National Astronomical Observatory
Mitaka, Japan
July 18-20, 1995

Attendees include:
Dr. Tsuneta
Dr. Ichimoto
Serge Koutchme (spelling?), France

Tsu: U Hawaii, High Altitude Observatory, Lockheed, and German meetings have already occurred.
Purpose - free exchange on designs on baseline
develop baseline plan
Day 1 spacecraft and mission
2 spectrograph, and polarimeter; Ichimoto summary
3 polarization

Dr. Sakao Presentation Spacecraft and Mission

- Hard x-ray person, spacecraft systems

Mission objectives
Result from Yohkoh
Dynamic rather than static corona
Magnetic reconnection role, including solar flares

For solar-b .

Objective : systems approach to photosphere-coronal activity

reveal solar MHD phenomena

photosphere as origin of coronal magnetic activities

high resolution x-ray and optical

hard and soft x ray features

Plan

Vector magnetograph, 0.1-0.2 arc sec resolution

x ray telescope, magnetic behavior in solar corona

xuv spectrograph, coronal velocity field measurement

must have high resolution for optical and x ray

600 km orbit

680 kg scientific package

170 kg thrusters

launch 2004

2 year period of sun synchronous observation using thrusters

image stabilization 0.02"/sec, higher with tip/tilt mirror

data recording rate 500 kbps or 3 Gbps per orbit

downlink rate 5Mbps desired (under study)

serg: what about 10 km/sec orbital velocity

Sakeo: on-board Doppler compensation system

(RC mostly transverse)

Attitude control

sub arc sec for spacecraft body

6x higher that Yohkoh

instrument active control does not require active control?

Solar rotation tracking

disturbance: counter wheels needed for filter wheels sensor: gyro signal for tip tilt mirror control, experiments under way

Actuator: momentum wheels noise

type 1, ball bearing type, ... oil soak / wobble torque problem (HST)

type 2, magnetic bearing

need to suppress torque and noise

really feasible? Under study. Solve? Then 0.02"/sec in spacecraft body

otherwise need tip-tilt mirror, studying feasibility

Sensor? Limb sensor?

Spacecraft orbit

Scientific requirements

baseline sun synchronous (vs. equatorial)

then need thrusters to maintain

also thrusters at launch

Radiation environment worse in sun synchronous vs equatorial

Scientific considerations:

a. high spatial resolution observation

minimize thermal distortion, constant thermal environment

b. continuous observation

solar activities in various timescales

more efficient observations

pre and post flare

c. Minimize Doppler effect for 100 mA line width spectral measurements

orbit choice

Sun synchronous has weight penalty

1.3 tons equatorial

.85 in sun synch. including thrusters
8 months / yr observing   vs 40 min night/orbit
Doppler shift 130 mA vs 250 mA
Thermal design   much easier vs not easy
more experience in equatorial launch
no previous sun syn. launch from Kagoshima

thrusters
170 kg required vs desired

radiation load on electronics
more trapped electrons in 1 4 Mbit Dram per day
0 errors/ bit/day
0.002   Solar B
0.010   Solar B during flare

Doppler shift graphs shown at 600 km
causes 0.09 mA shift/sec
8 months no night
max. 20 min night per orbit ~23%

Telemetry:
huge amount of data
>7 Gbits/orbit, cannot downlink all
On board data processing including Stokes demodulation and data compression
Solar A "80 Mbit/sec
5 Mbit/sec downlink"

On-board large volume data recorders and data buffers (using 16 Mbit DRAM?).

Downlink 5 Mbps? Possible?

Kagoshima has 10 min downlink window

RC: TRDS downlink?

On-board data flow

Telescope

may sum 2x2 pixels, usually limit FOV

Stokes demodulation

JPEG lossless data reduction

Data recorder

Telemetry

Ground Stations KSC/DSN?

Reduce 8 to 3GBit/sec

Data recorder req.

compare Solar A IRIS Astro-D Astro-E Solar-B

Solar-B has highest requirements

Packet telemetry?

On-board packet interface?

Packet telemetry? In x-band?

Ground Stations

KSC

    s band current 262 kbps, future TBD

    x band " 262

KSC to ISAS "384

DSN is Goldstone, Wallops, Madrid, Australia

    262 plan to 1.6Mbps

Spacecraft layout
current plan
Optical on main axis
X-ray one side
XUV other side
Bus module on each side
Thruster tanks
solar panels

artist's rendering

Serg: optical aperture?
Sakao: studying best place for thrusters to minimize contamination to telescopes
also studying damage if off-axis sunlight focused inside telescope
studying need for telescope door

On board Doppler compensation
Data up-load every 3-7 days orbital element info (TBD)
calculate detailed orbital elements, polynomial coefficient
Orbit timer
On board Doppler estimation
Accuracy of delta lambda combined with target wavelength yields lambda + dlambda
perform passband tuning
CCD readout address change (for spectrograph)
update every 10 sec or faster

Serg: should include solar rotation elements
RC: 5 min oscillation Doppler correction
general laughter

mission objective can be addressed with quiet sun
reveal fundamental processes
less events
more oriented to quiet sun

Tsu: Q to MSFC
is their problem with science output if we launch in 2004 or 2005
MSFC best people to ask because we have 20 years of operation
2004 is near minimum
2002 is out of question
2003 is not the baseline,
based on performance of IR telescope
Skylab launched at solar minimum

Serg: tilt axis can correct 2 axis. What about spin?
Tsu: largest effect at edge of FOV, 2d order, first two axes are first order
team who builds telescope must have very close interaction with spacecraft builders

Sakao finish

Ryouhei Kano
U Tokyo Grad Student

Optical Telescope Schematic
Gregorian
heat rejecting cone or plane mirror
rotation retarder analyzer in primary hole
tip tilt mirror

Pol. BS
Lyot filter arm
Spectrograph arm

Telemetry.
Aplanatic Gregorian
50 cm
f/15 at image
CCD 9 micron/pixel
nose cone limits telescope length
Focal plane
Lyot filter f/18 0.2/pixel FOV 400"
Interference filter f/37 0.1"/pixel
Spectrograph f/18.5 0.2"/pixel
Aberration 0.05" at edge of FOV
Airy Disc 0.5" @ 5000A

Kano wrote ray trace program for mirrors
spot diagrams shown

Polarization analyzer
to avid instrumental polarization, analyzing retarder inside primary
then folding mirror
then Polarizing beam splitter for analyzer

RC: stray light problem of retarder so far forward
critical surfaces seen by both primary and secondary
About 1.8 degree cone through retarder and beamsplitter

Q. Secondary mirror position

Tolerance analysis

Primary: 70 micron decenter, 7" tilt

mirror separation 450 micron +-5

Secondary 70 micron decenter, 15" tilt

expect gravitational distortion of 40 microns (Mitsuchika (?) Co. quote)

collimator decentration 2200 micron, 2′ tilt

Lyot, 5′ tilt

Camera, 3000 micron decenter, 7′ tilt

Each tolerance yields aberration of 0.13" or 1/Root14 of airy disk diameter

Main aberration terms, coma, spherical ab, defocus

Tsuneta: baseline plan, no prefilter, nothing over telescope aperture

Serg: protection of telescope coatings

Tsuneta: reflecting not refracting. If you have a cover, contamination problem is the same. Also distortion of full aperture window.

UV protection?

Heat rejection cone

50 cm primary

22 cm secondary

Tilted heat rejection mirror, flat, 45 deg.

Window on side of tube, 280 mm diam.

even with heat rejecting cone, the rays strike the barrel

Focal plane package
BS sends light to two channels
Nikon studied BS and lens achromatization

Filter arm
Collimator
Lyot
Filter
BS to 2x arm with interference filter for high spatial resolution
shutter to select Lyot/Interference
Camera lens
CCD

Spectrograph
Littrow lens, Echelle grating
Field lens
Slit
1000 m spectrograph lens, double pass
70A band
order, greater than 100

Spot diagrams from Nikon for Lyot arm
390 -56 nm
mainly defocus

Mitsubishi structure study

instrumental polarization ray trace of crossed folding mirror system
2 degree cone angle

for aluminum
ellipse map 0.38% polarizance, calculation for unpol. light
RC: this is diattenuation only, retardance often 5x larger

end of Kino's presentation

Tsuneta -- Daily summary

serious problems
1. Spatial resolution vs FOV
some want highest resolution
others want largest FOV at cost of resolution
assume 2000x2000
currently emphasize FOV more
since space telescope should emphasize resolution
RC: aliasing
Serg: telescope aperture, not optimum for radiometry, time cadence
too many photons, CCD limited, computer limited
redundant

issue 2. Large secondary mirror
to get polarization analyzer in hole.
Also heat rejection system
4300-6563
6302 only for magnetograph?

Issue 3. Critical tolerances
3 m long system
need a refocus mechanism?
5 DOF mechanism for secondary? Don't like

how can we relax critical tolerance.
RC: refocus mechanism increase tolerances about 10x removing defocus limitation, now coma, SA limitation

initial option was Cassegrain. because of tolerances.

Issue 4: thermal design/ contamination
back side of primary is for heat dump, need large clean area for radiation dump
bad place for retarder and tilt mirror
Nihon spacecraft not clean
how to protect from out-gassing?
Organic material exposed to solar UV may become black
Heat primary above ambient
but have no heater power
Historically, Nihon spacecraft have passive control
Can we continue observations after contamination?

How share tasks
Telescope Mitsubishi/Nikon, have made earth observing telescopes
Focal plane package US?
Small complaint - US people only talk about money

July 19, 1995, Mitaka Observatory, Second Day of Presentations

Mr. Suematsu's presentation

Spectrographs
Narrowband, Lyot, This talk
Wideband, Littrow,
Aim: high resolution diagnostics of physical condition and structure, morphological, in photosphere and chromosphere
Connections with corona
Two channel filtergraph, one CCD

Graph of solar temperature and lines with altitude

Constraints of detector
2K x 2K Kodak
9x9 microns
85000 electrons/well
512 KHz readout (maybe 1MHz) at 12 bits
8 sec readout
FOV .1x.1" per pixel yields 200"x200" FOV
S/N 225 for one exposure
S/N 1000 for 20 exposure w/ 1,000,000 electrons

Wideband filters
3933 CaII 2A
4305 g-band 10A faculae
4500 continuum 10-20A photosphere
5670
6563
6690

Narrowband

4571	50 mA	.194 A Airy disk
4705		
4861		
5172		
5250		
5576		
6302		
6562.8	109 mA	0.28" Airy Disk

Comparison of 5250 vs 6302
5250 is Temp sensitive
since don't have full line profile, this causes more error
6302 less temp sensitivity

Compare narrow vs. wide band filtergraph
Wideband interference filter, high transmission, short exposure
study temperature, horizontal velocity, intensity oscillations, morphology
Filter wheel
3900-7000 range
2-20 A passband

Narrowband
Lyot
<5% transmission, complicated, long exposure
lower image quality, need image averaging
study vector B
vertical and horizontal velocity
morphology

26

Current choice: one universal birefringent filter, several lines

wavelength range, 4500-6600

.05-.1 A passband

Beam at filter

Collimated

Telecentric

mention birefringent pol. ab of converging beam in calcite

pupil in middle of Lyot filter

Show Stokes profile through Zeeman line

only observe blue and red wings, not measure line center

RC: why not scan FP while building up spectrum rather that taking all MSFC averages at one wavelength

Q: beamsplitter design

Q: wavelength range

Baseline:

collimated beam

4500 -6600A

3.5 cm aperture

40 cm length

ray angle f/30 in air

Lockheed filter

Open questions:

image scale 0.1 or 0.2

FOV 200 or 400"

focussing method adjustment, linear stage
temp control, entire focal package or each instrument
Spectral lines
S/N 0.5% OK?
CCD Kodak?
Image registration: software or hardwired, method?
Gain equalization

example of Lockheed 3A filtergram CaII K
Lockheed FeI magnetogram and H alpha
4305 A Lockheed image

RC: Explanation of Aliasing if too few pixels
more pixels is better
Serge: error is related to intensity derivative
which is linear function in OTF domain
so maybe central obscuration helps

Dr. Akioka's presentation
Hiraiso, CRL (n of Tokyo on coast)

Spectrograph channel
Stokes polarimetry with Grating Spectrograph
Physics of flux tube
Precise observation of active region structure
Inversion of Stokes profile

Requirements.
25 mA resolution
0.2"/pixel

small, 1 or 1.5 m
light weight, simple, no moving mechanisms
CaK observation with no rotation

Observing sequence
Slit FOV
Baseline:
sixteen analyzer positions per slit location
then move slit

Rotating retarder
Tip tilt mirror
PBS
Lens, Slit, scan mirror
blocking filter
Field lens and slit
Achromatic Littrow lens
Echelle Grating
Shutter
CCD camera

1 m EFL yields 25 mA

0.2 world -> localized V and I (granulation will be different from standard model) (??)
Profile will be different from standard model
Additional information gleaned from full line profile, temp, velocity fields
at 0.1", this may become important

Echelle order ~100

Lens to adjust image size on slit

Want to observe CaK with no grating rotation

Current baseline parameters, designed together with High Altitude Observatory
23.3 lines/mm
63.5 deg blaze
Al coating
Diff order 123 for 6303 and 197 for CaK
Blocking filter wheel
25 mA / pixel

Another case
larger format CCD 18 mm
quicker readout, TI chip
758x244 pixels
continuous rotating retarder
31.3 grooves/mm
90th order 6303
144th CaK

problem for CaK line
transmission of PBS

RC: need PBS cube demonstration

Timing:
Reference clock
retarder encoder

CCD triggers
Adders for Stokes demodulation
Image frame buffers

Status of tip-tilt mirror
Requirements.
Spectrograph needs 0.002 arcsec for several sec.
See B. Lites comments
Location, far from solar image, 150 mm
30 mm diameter
0.5 microrad resolution
10-20 Hz drive freq.
been used previously on Jap. satellite

Future action
Action may be available with requirements
but don't have design for sensing image jitter
considering gyro for spacecraft jitter and correlation tracker
tilt mirror may need to be open loop
limb sensing, not enough resolution
    partial sun, small field image
correlation tracking, no experience in space
sunspot tracking--limits target selection

gyro testing is ongoing

July 20, Mitaka, Third Day of Presentations

Dr. Ichimoto.

"equations in notes"
Longitudinal polarization proportional to circular polarization

Transverse to sqrt of linear polarization

Detection limit of field and uncertainty equations based on noise

relation between B azimuth

resolvable element of current J

smallest element of energy resolution for 200" FOV

Polarization errors

I=W S

errors in I are noise

errors in W, crosstalk in instrument

Change of I, image motion

Photon noise

dark current

read noise

Crosstalk

I -> Q,U,V	artificial polarization from unpolarized light
V -> Q,U	circular to linear
Q <-> U	orientation error

Image motion

telescope jitter/drift dI/dx delta_x alignment of images

Beam wobble from wave plate

Time change of solar feature delta_t dI/Dt time between images

Characterization of polarization elements

Noise limits detection limit on B

Optics crosstalk causes false B even when B is zero

Image motion gives false B around granulation, flare, sunspot features

I,Q,U,V error
dust on waveplate, error in exposure time, gain, oblique reflection

calibration requirement
noise must be as small as possible
calibrate crosstalk better than epsilon
circular crosstalk should be 3 times smaller than epsilon,
intensity accuracy
image motion

ghost brightness varies with aim point on sun
calibration of crosstalk
1. Measure unpolarized continuum at disk center
2. Phage near center [I,0,0,V] yields circular to linear crosstalk
3. Q,U,V profiles, Q,U symmetric; V antisymmetric
4. Penumbra near disk center, Q <-> U
assume penumbra near disk center
compare with well calibrated ground based observations

Tsu: calibration wheel?
Tsu: Yohkoh filter wheel, already 10,000,000 rotations

granulation contrast
relation of image shift and polarization noise
0.1% intensity change at granule comes from 0.002" motion

Serge: granulation has very sharp steep boundary and field is strongest in small area between granules

Change of line profile
Doppler shift due to 2/km line of sight motion
0.001 arc sec shift cause >0.1 dI

requirements on image stability

Tsu: do we really need 0.1%, this is what High Altitude Observatory says they need

RC: analyzing image shift in the case of the Airy disk gives limiting crosstalk present. Then if structures have 20% contrast, multiply by 0.2
smallest possible uncorrelated areas in image.

Tsu: what about velocity field on sun? How long for objects to move by 0.001"

Ichimoto:
Change of granulation
typical velocity field - 1/km/sec
(1/I) dI/dt 5x10e-4 /s

5 minute oscillation, not so important
(1/I) dI/dt 1.6x10e-4 /s

Integration time and S/N

Flux Budget

bind: need 7 sec to get 0.1% dI
but granulation changes in 2 sec

each set of Stokes components should be measured in 1 sec, and repeated to build up accuracy
Only the part of the spacecraft jitter near the modulation freq of polarimeter affects the measurement.
(RC:The MSFC measurement profile has long power spectrum, very low freq response and susceptibility)

Beam wobbling by rotating waveplate
wedge effect, conical deviation
tilt of waveplate
(RC: rotating element at image eliminates beam wander)
with waveplate 21 cm from image 2mm thick waveplate, n=1.55
allowable image motion 0.002"
parallelism needed 0.0065 arc sec.
similar to parallelism needed for Fabry-Perot
ideas:

1. Symmetric sampling, rotate through 16 positions in 360 degrees
2. Compensation by tilt mirror after calibration
3. Cancel the wedge versus tilt
4. Put waveplate in oil bath
5. Some other polarization modulator

fast vs slow polarization measurement
fast, continuously rotating waveplate
slow, stepwise rotation
fast CCD, frame transfer, 1 mS timing, 80 ms exposure, accumulate 60x
0.1 accuracy, measure 16 positions/per rotation, 1 data set in 5 sec, total electrons 10e6, acceptable wobble is .1 PSF
Tradeoff between polarization modulators
most critical, reliability, then speed

Merit of fast system
high accuracy
symmetric sampling reduces beam wobbling
relaxes requirement on satellite drift
only limited frequencies of satellite jitter cause I ->Q,U,V
crosstalk

Problems
compatibility with filter instrument
pure I and V cannot be determined in 2 exposures
needs a shutter, frame transfer CCD is not available at full
2kx2k pixels
precise shutter timing
fast CCD clock and stokes modulation required

Alternative telescope/polarimeter configuration
use pickoff mirror at plane of intermediate image
primary
interm. Image
secondary
pickoff at interm image plane
crossed folding mirror
polarimeter

Tsu: this requirement for 0.002 arcsec image stabilization cannot
be measured with CCD, so there is no baseline
Trying to justify mission
You must examine this assumption.

Serg: separate problem of image subtraction from integrating
signal in analysis.
Still combined.

Appendix 9.

My Presentation to Prof. Tsuneta's Group on the UAH/Marshall Space Based Vector Magnetograph Design

During my visit to the National Observatory of Japan I presented 12 hours of lectures on the MSFC magnetograph design, polarimetry, and polarization aberrations. The outline was as follows:

a. The NASA/Marshall Space-based Solar Vector Magnetograph Design.
2 hour

b. Introduction to the Jones and Mueller polarization calculus.
3 hours basic

c. Polarimetry, measuring polarization elements and optical systems.
3 hours
included Japanese language viewgraphs

d. Polarization ray tracing.
4 hours
polarization of interfaces
Cassegrain telescope polarization

This Appendix contains the viewgraphs for a. The NASA/Marshall Space-based Solar Vector Magnetograph Design. The other notes are taken from corresponding chapters in my short course notes, and in the interest of brevity they are not included here.

The NASA/Marshall Space-based Solar Vector Magnetograph Design

Russell A. Chipman
Department of Physics
Optics Building, Room 318
University of Alabama in Huntsville
Huntsville, AL 35899
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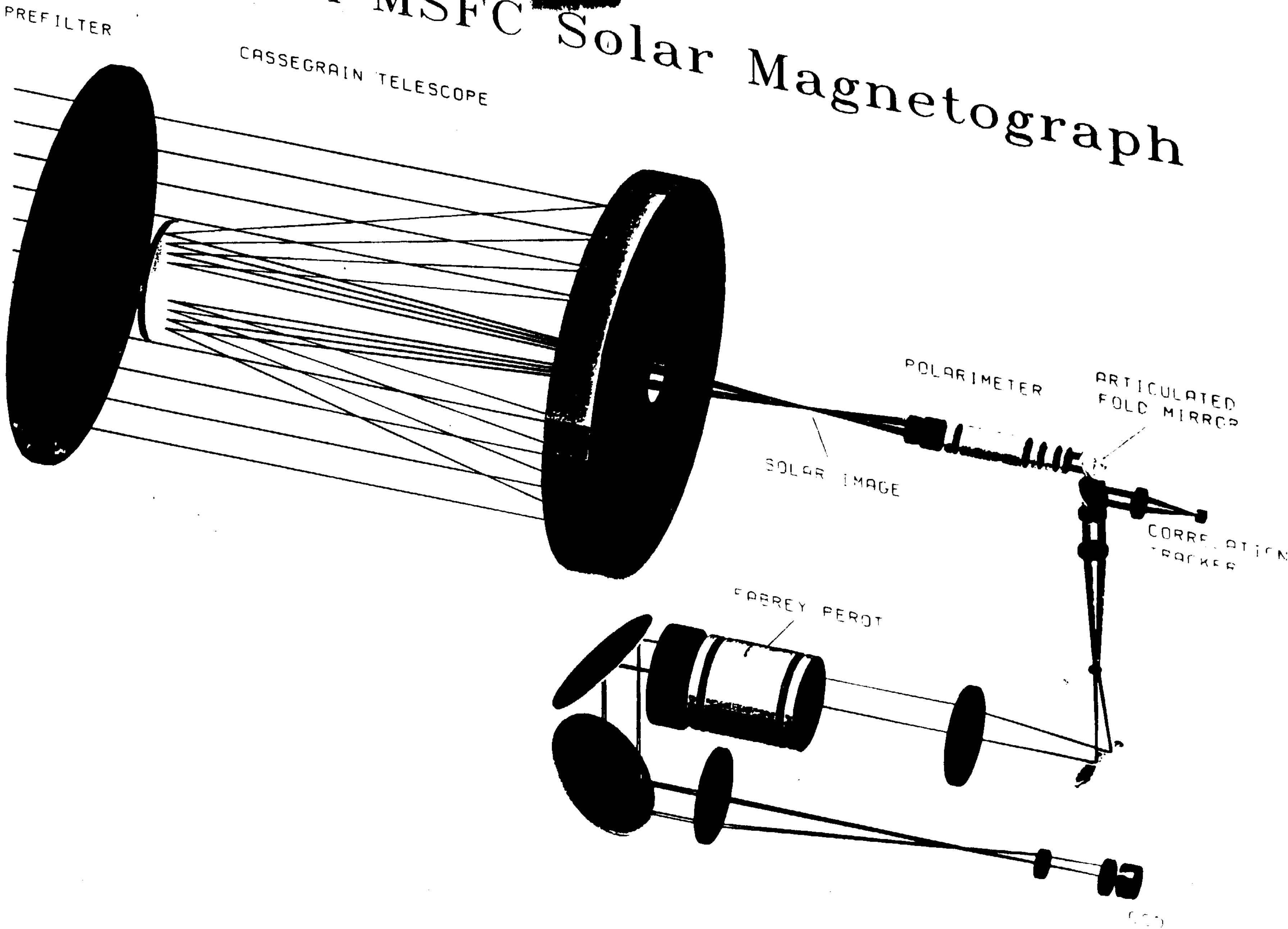
Fax. (205) 895-6873

With Viewgraphs Contributed by:

Mona Hagyard
Alan Gary
Ed West
NASA Marshall Space Flight Center
Huntsville, AL

NASA MSFC Solar Magnetograph



Objectives

Present the NASA Marshall Space Flight Center Solar Vector Magnetograph optical design

Review the components of the optical system

Discuss design tradoffs

- Cassegrain vs. Gregorian
- Fabry-Perot ve Birefringent Filter
- Design of Polarimeter

Status of the prototype EXVM Magnetograph

Instrumental Polarization

Marshall Space Flight Center
Vector Magnetograph

BACKGROUND

- **MSFC VECTOR MAGNETOGRAPH**
  - 22 YEARS IN OPERATION (1973 – 1995)

- **STUDY FOR AIR FORCE 1988**
  - SOLAR ACTIVITY MEASUREMENTS EXPERIMENT (SAMEX)
  - 30 cm VECTOR MAGNETOGRAPH, H–ALPHA TELESCOPE, XUV IMAGER

- **EXPERIMENTAL VECTOR MAGNETOGRAPH (EXVM)**
  - GROUND–BASED SAMEX CONCEPT

- **MSFC SPACE VECTOR MAGNETOGRAPH (MSVM)**
  - BASED ON EXVM DESIGN
  - BALLOON OR SATELLITE INSTRUMENT (MSVM -> SOLAR–B)

Marshall Space Flight Center
Vector Magnetograph

IMPORTANT FEATURES OF THE MSVM

- **LARGE FIELD OF VIEW**
  - 4.3 x 8.6 ARCMIN WITH 0.50 ARCSEC SPATIAL RESOLUTION
  - 2.2 x 4.3 ARCMIN WITH 0.25 ARCSEC SPATIAL RESOLUTION
- **OPTIMUM MAGNETIC SENSITIVITY**
  - SYMMETRIC TELESCOPE WITH SPECIAL COATINGS
  - MAXIMUM LINEAR POLARIZATION SENSITIVITY
  - MINIMUM CIRCULAR CROSSTALK
  - 1×10^{-4} POLARIMETRIC ACCURACY $\Rightarrow$ 30 G TRANSVERSE FIELDS
- **HIGH TEMPORAL RESOLUTION**
  - ~5 MINUTE CADENCE
  - FILTER MAGNETOGRAPH
  - SPECIAL CCD CAMERA
  - VERSATILE DATA ACQUISITION SYSTEM

Marshall Space Flight Center
Vector Magnetograph

AN ADAPTABLE DESIGN

- CASSEGRAIN ⇔ GREGORIAN TELESCOPE
- SPECTROGRAPH "ARM"
- MULTI–BANDPASS SEGMENTED PREFILTER
  - EXAMPLE: λ 6302 ± 75 Å. λ 5250 ± 75 Å. λ 6563 ± 75 Å.
    λ 5250 ± 75 Å. λ 4508 ± 75 Å. λ 4305 ± 75 Å.
- 1X ⇔ 2X OPTICS
- 125 mÅ ⇔ 63 mÅ BANDPASS AT λ 6302

MSVM Optical Design

Marshall Space Flight Center

Concept developed from a MSV Balloon Proposal for a 60 cm Telescope

Components:

Telescope: Symmetric Diffraction Limited 60cm Cassegrain with UAH Low Polarization Optical Coatings

Prefilter: Full Aperture Prefilter

Polarimeter: A 50mm Glan-Thompson Rotating Analyzer in a Collimated Beam

Image Motion Compensator: Spot Tracker and Articulated Folding Mirror which Follows the Polarimeter

Blocking Filters: Set of Insertable Narrow Band Interference Filters (2.5 Å)

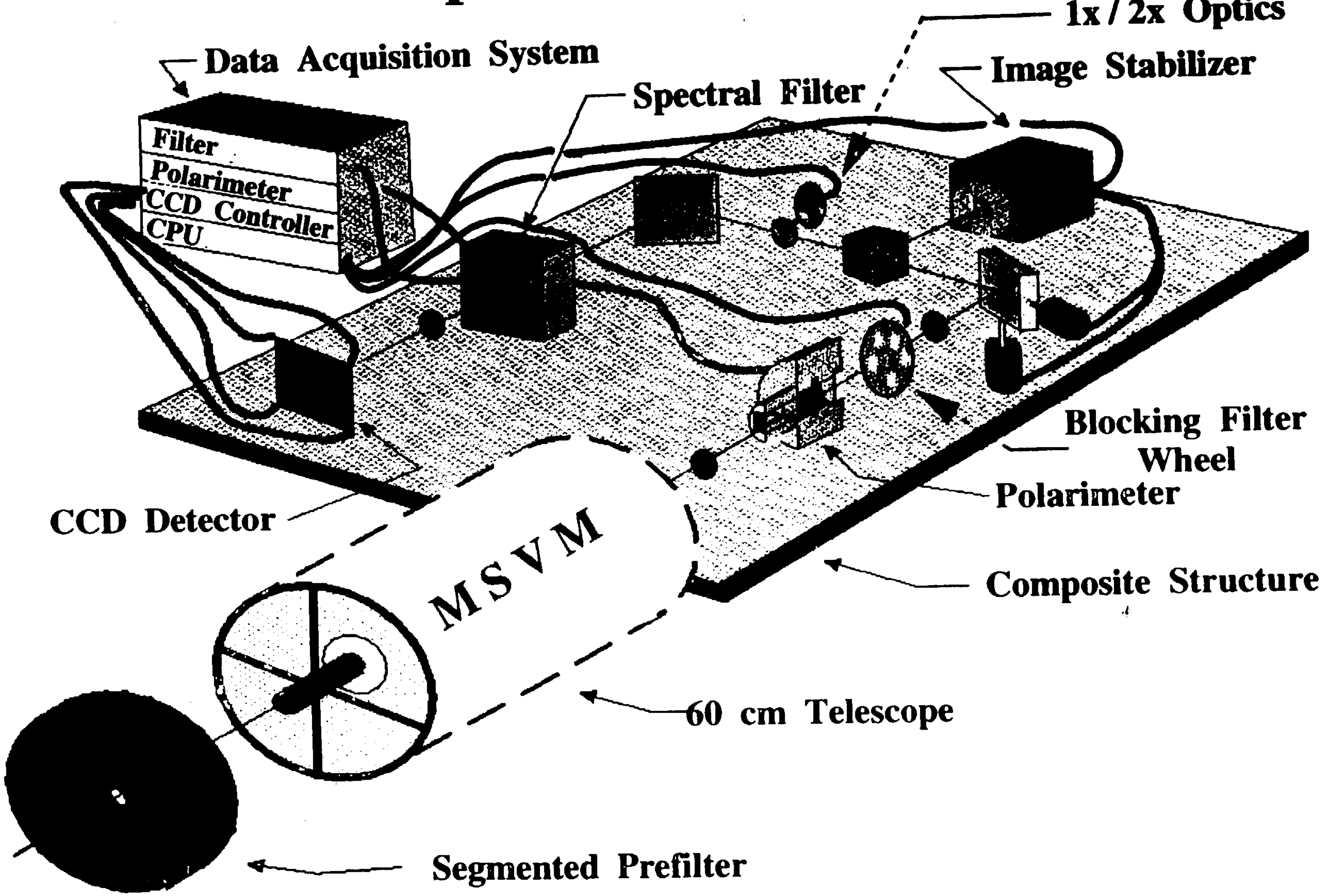
Zoom Lens Optics: Dual Set of Optics: 1x for Large FOV and 2x for Diffraction Limit

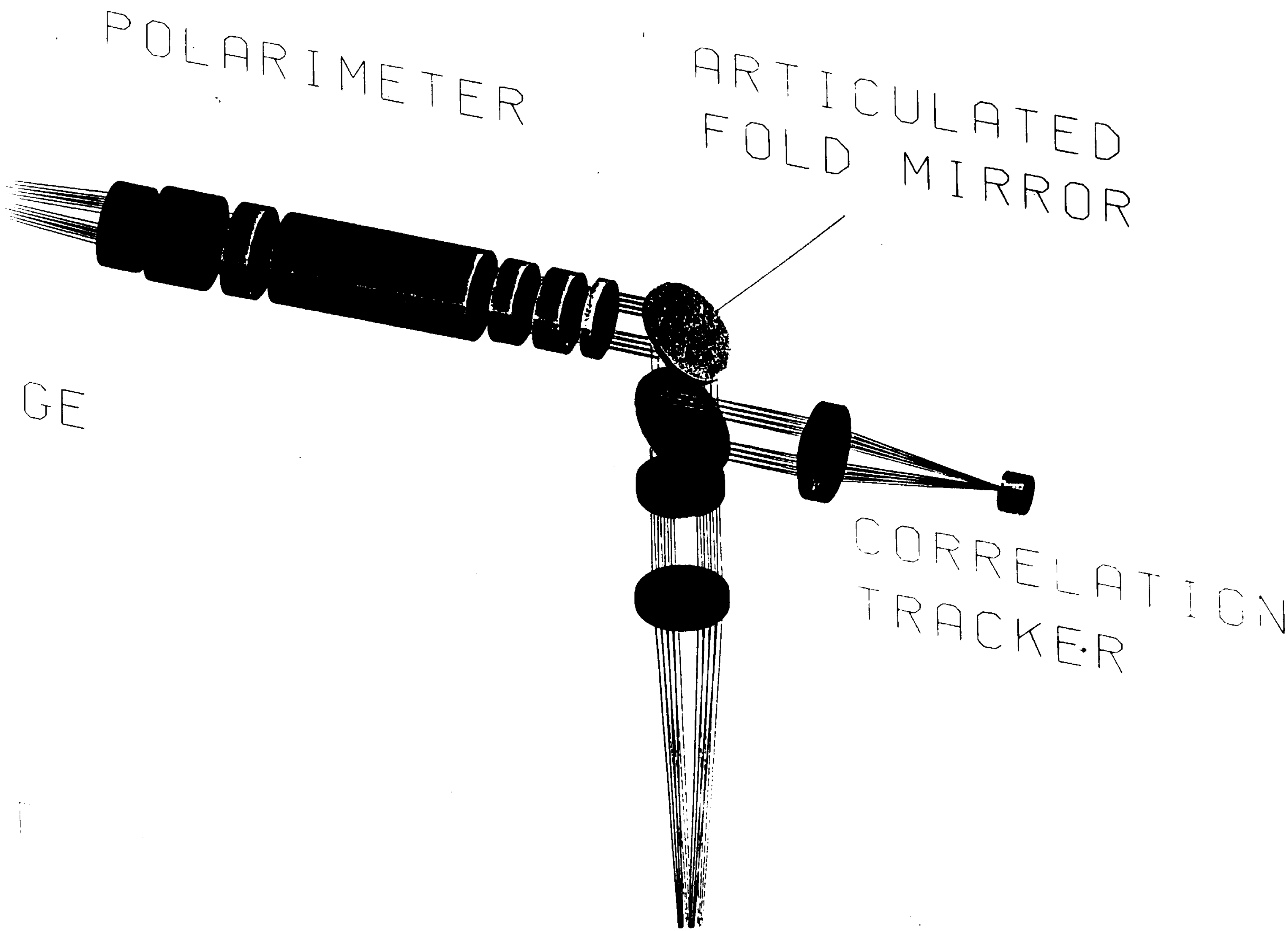
Fabry-Perot Etalon: A 140mm Etalon in a Telecentric Beam with High Reflectivity Broadband Coating

Detector: A 1024 by 2048 (Active Pixels) Camera System

Marshall Space Flight Center Vector Magnetograph

Proposed Instrument




POLARIMETER
ARTICULATED
FOLD MIRROR
GE
CORRELATION
TRACKER

Polarimeter

High polarimetric sensitivity, 1:4000

Rotating retarder polarimeter

Followed by additional polarizer for intensity control

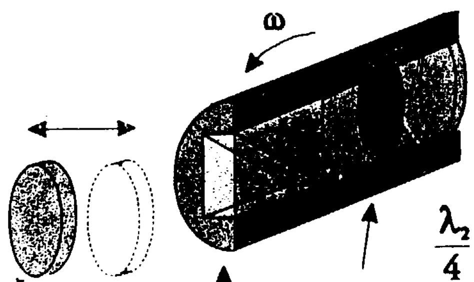
Quartz quarter wave linear retarder

Large aperture Glan-Thompson polarizer

Six measurement sequence for Stokes vectors

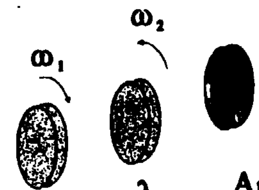
Operational Modes

EXVM polarimeter



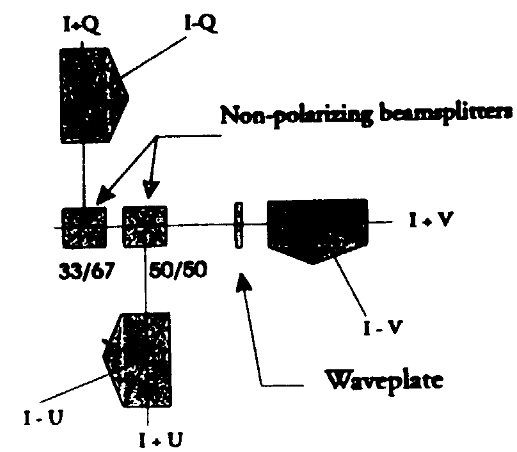
Polarization	ω	$\frac{\lambda_1}{4}$
I+Q	0	out
I-Q	90	out
I+U	45	out
I-U	135	out
I+V	45	in
I-V	135	in

Rotating waveplate polarimeter



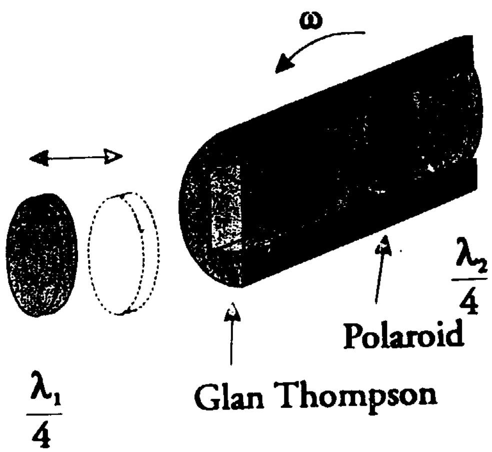
Polarization	ω_1	ω_2
I+Q	0	0
I-Q	45	45
I+U	45	45
I-U	45	135
I+V	0	45
I-V	0	135

Beamsplitting Stokes Polarimeter



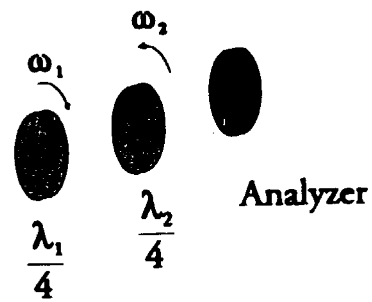
Advantages

EXVM polarimeter



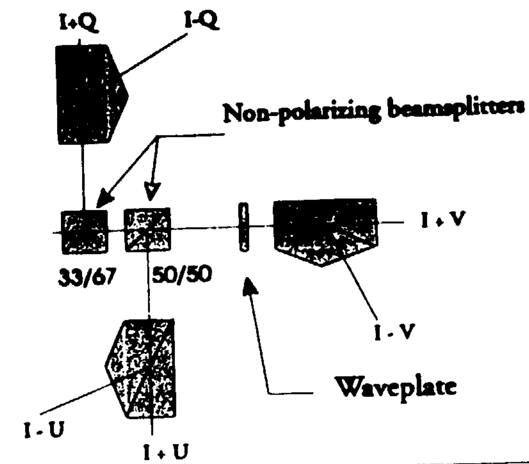
1. No circular crosstalk
2. Single detector
3. Large field of view
4. Polarization resolution designed for $1x\ 10^{-4}$

Rotating waveplate polarimeter



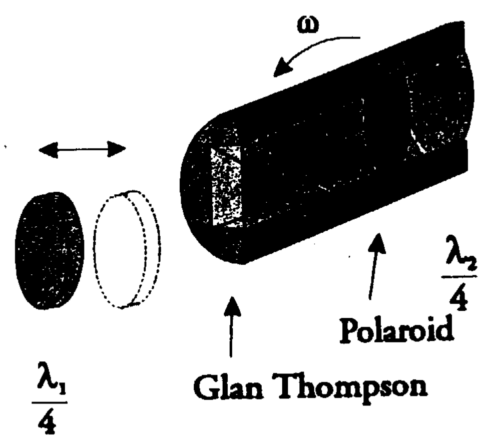
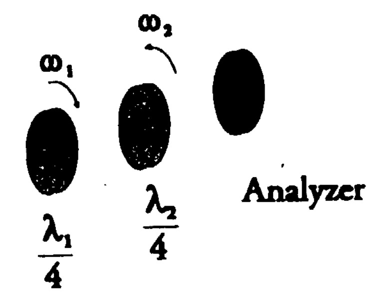
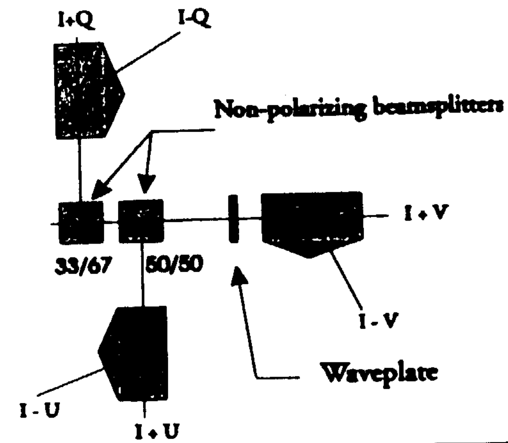
1. Single detector

Beamsplitting Stokes Polarimeter

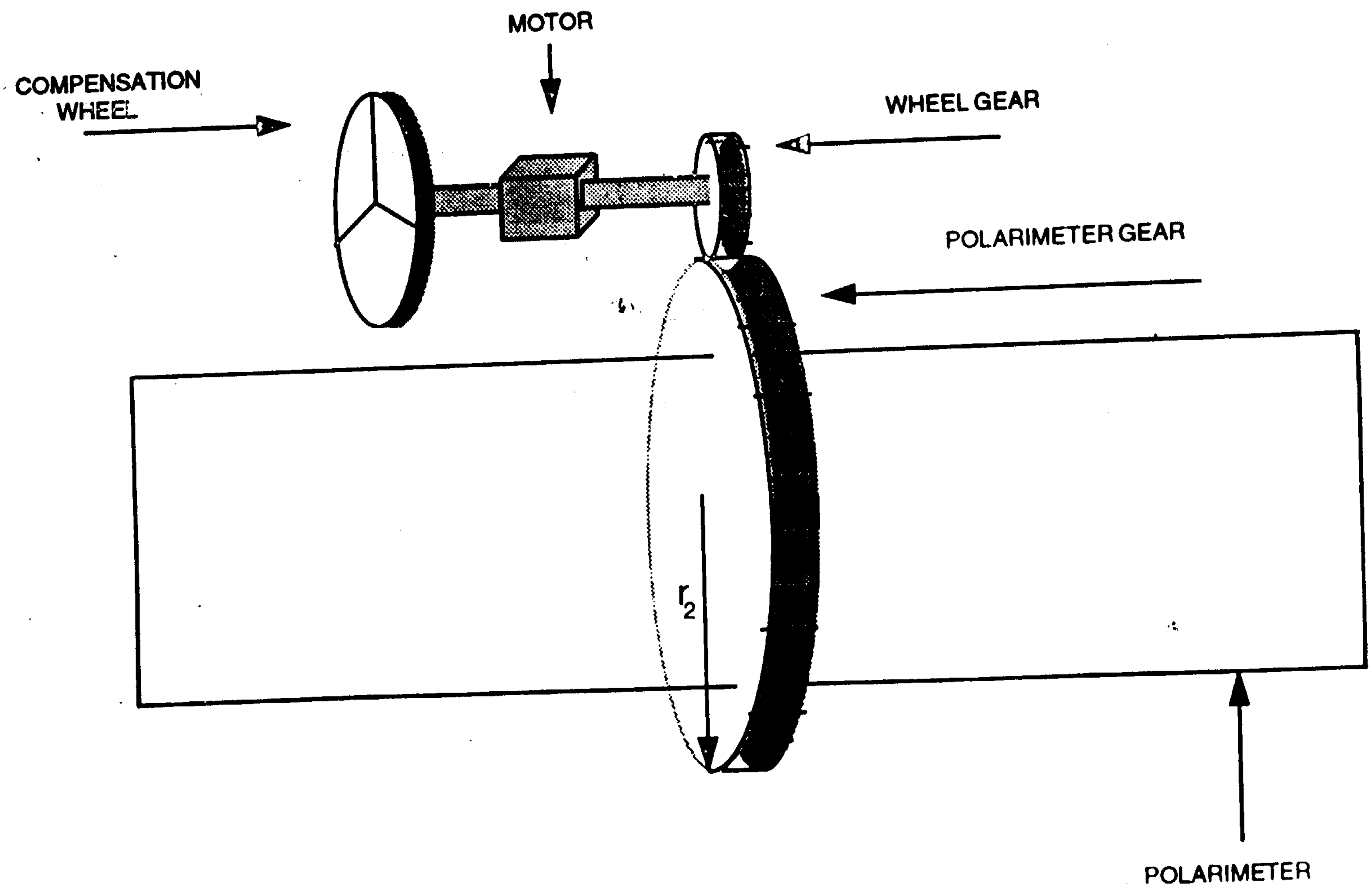


1. Circular crosstalk should be small
2. No rotating parts

Disadvantages (emphasis on lin[illegible]olarization measurements)

	EXVM polarimeter	Rotating waveplate polarimeter	Beamsplitting Stokes Polarimeter
			
[illegible]	[illegible]	[illegible]	[illegible]
Minor	1. Large moving mass 2. Some instrumental modulation IF following optics polarization sensitive (k_5-k_6) AND retarder $\lambda_2/4$ imperfect 3. Image motion at detector	1. Wavelength or temperature dependent 2. Limited field of view 3. Fast axis misalignment errors 4. Possible image motion at detector	1. Non-polarizing beamsplitters limit wavelength range 2. Field of view dependent on beamsplitters

SCHEMATIC OF COMPENSATION WHEEL



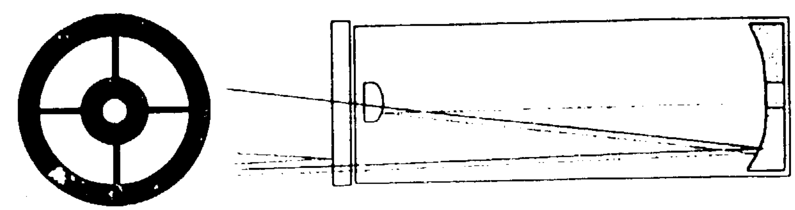
Prefilter options for the MSVM magnetograph

Design goal: Three wavelength bandpasses

a. 15nm at 525nm
b. 15nm at 630nm
c. 15nm at 656nm

Options that are being studied:

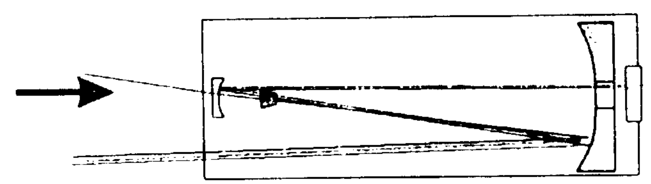
1. Segmented multi-bandpass prefilter



Advantages

a. Smaller thermal load on optics and polarimeter

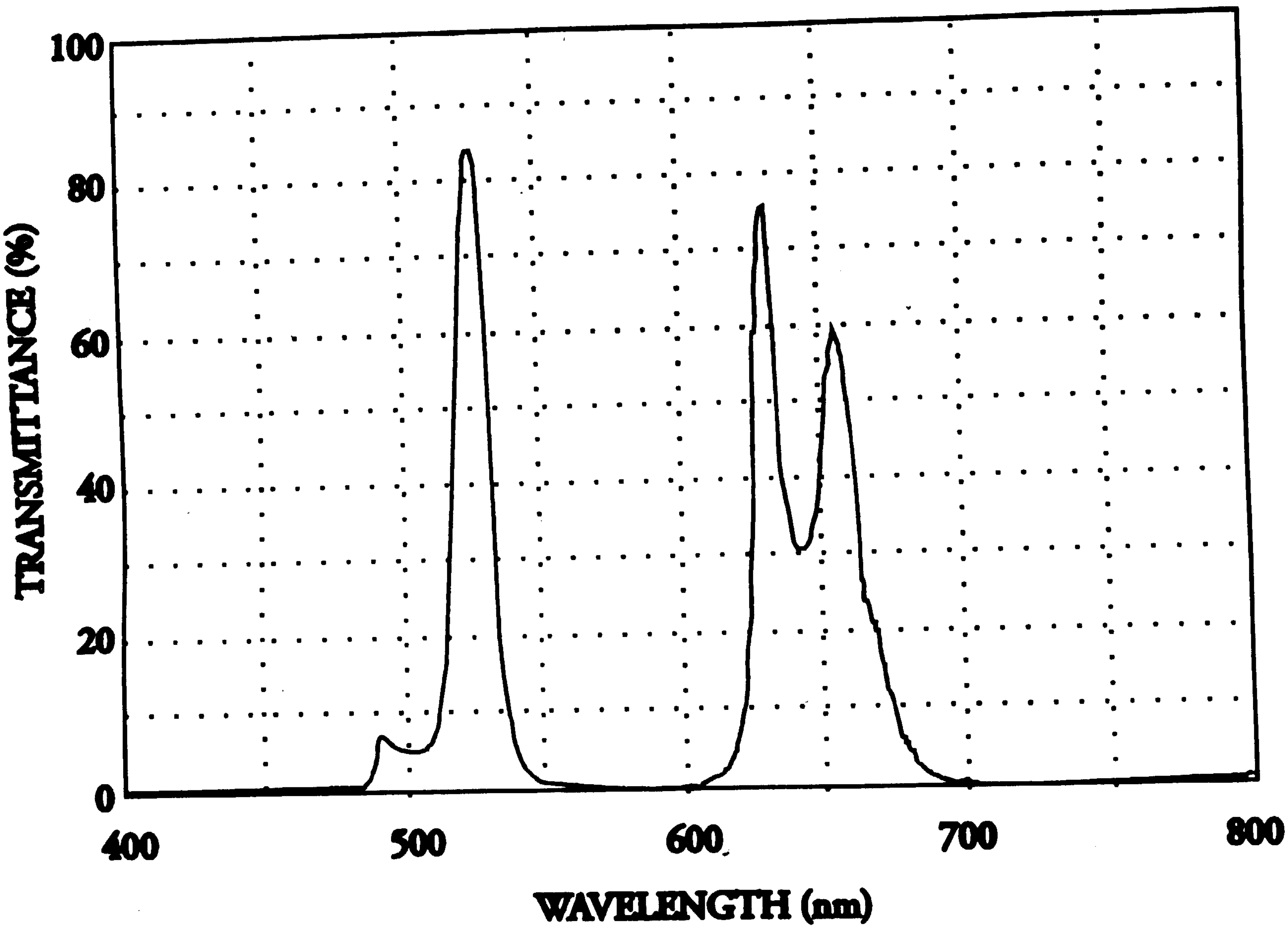
2. Cold mirror coating on secondary (transmit infared)

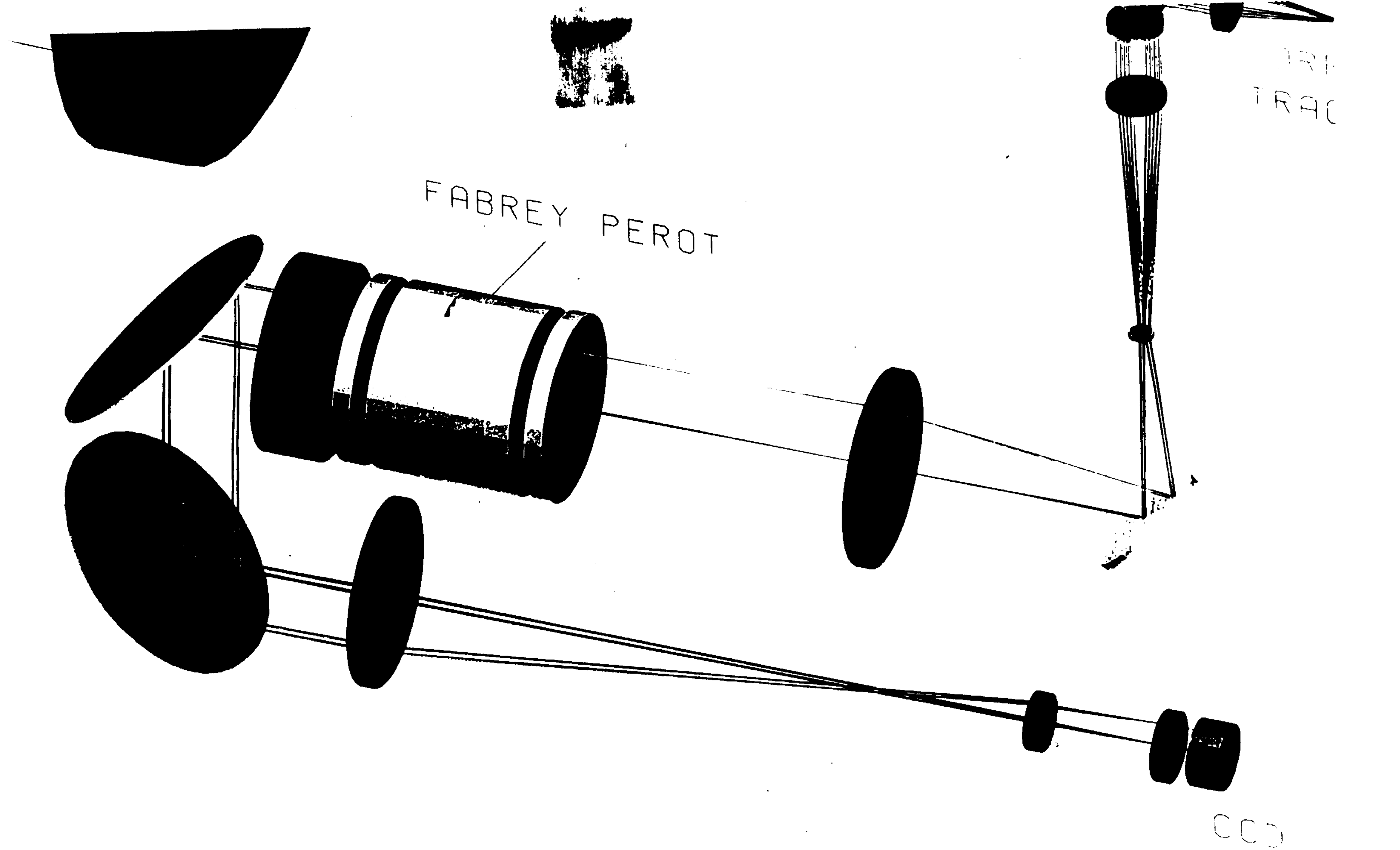


Advantages

a. No optical aberrations from full aperture prefilter

b. Smaller mass


100
80
60
40
20
0
TRANSMITTANCE (%)
400
500
600
700
800
WAVELENGTH (nm)


FABREY PEROT
CCD

Fabry-Perot Etalon

Tunable 0.125 Angstrom resolution (0.0125 nm)

Solid substrate, not air spaced. Rigid.

Electrically controlled, piezoelectric transducers
4x10E-4 Angstrom/volt

Located at a telecentric image,
Identical spectral response over the entire field of view.

Fabry-Perot Filter

Rationale

1. Commensurate Spectral Resolution	70-120 mÅ
2. High Etendue	>50%
3. Mechanically Simple	PZT/3 Year Lifetime
4. Rapid Tunability	0.2 msec/ Red-Blue / Orbital Doppler
5. Minimum Complexity	Weight, Length, Cost, Temperature Sensitivity, and Scattered light
6. Minimum Polarization Sensitivity	Compatible with Polarimeter

Philosophy

1. Magnetic Sensitive Lines
2. Telecentric Configuration
3. Multiline Diagnostics
4. Maximum Sensitivity
5. Coarse Spectrographic Mode

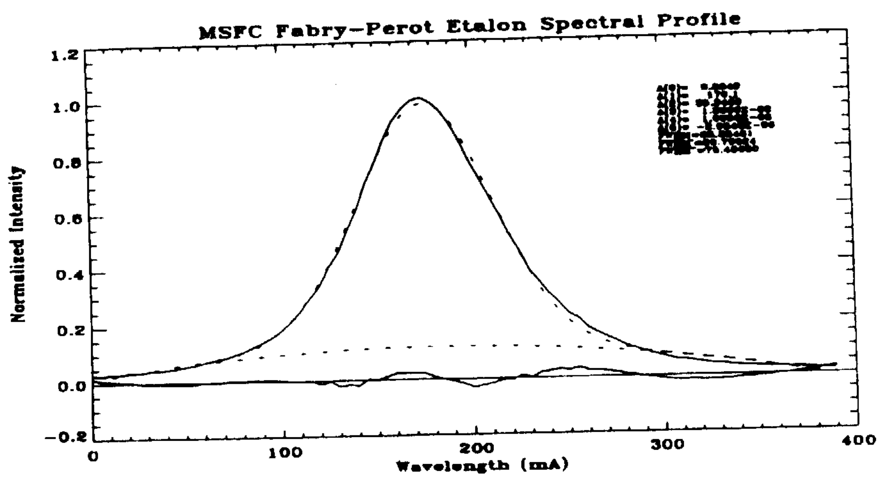
Presentation

1. Spectral Capabilities
2. Finesse Selection
3. Measured Values for ET70
4. Spectral Bands 5250/6302

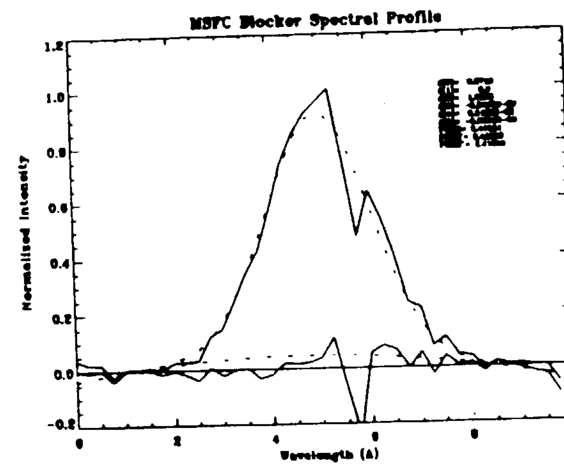
Filter Widths

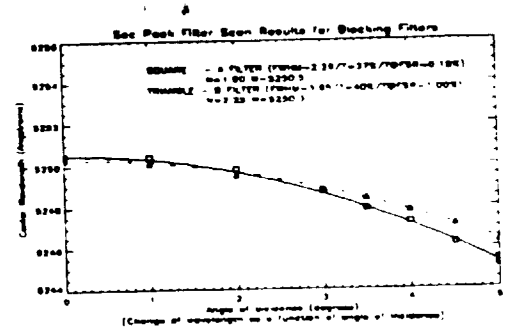
Measured Values

Queensgate ET70 Fabry-Perot Etalon 80 mÅ



Andover Blocker 2.5 Å





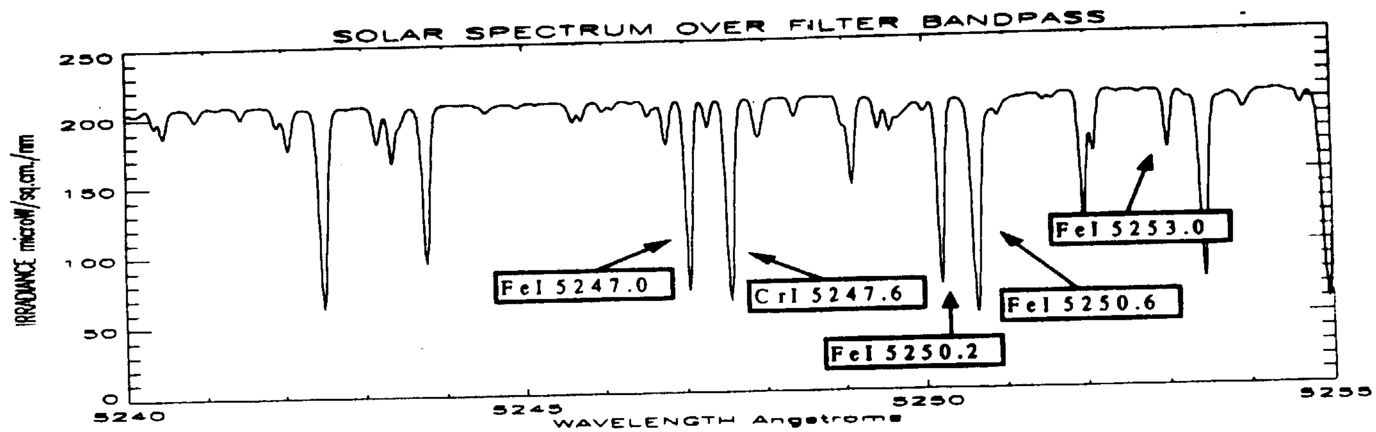
1. **Delivered Filters Met Specifications**
2. **Confirms Manufacturing Capabilities with Required Specifications**

Solar Spectrum

Minimum Three Blocker Configuration using Tilt Shifting for Wavelength Selection

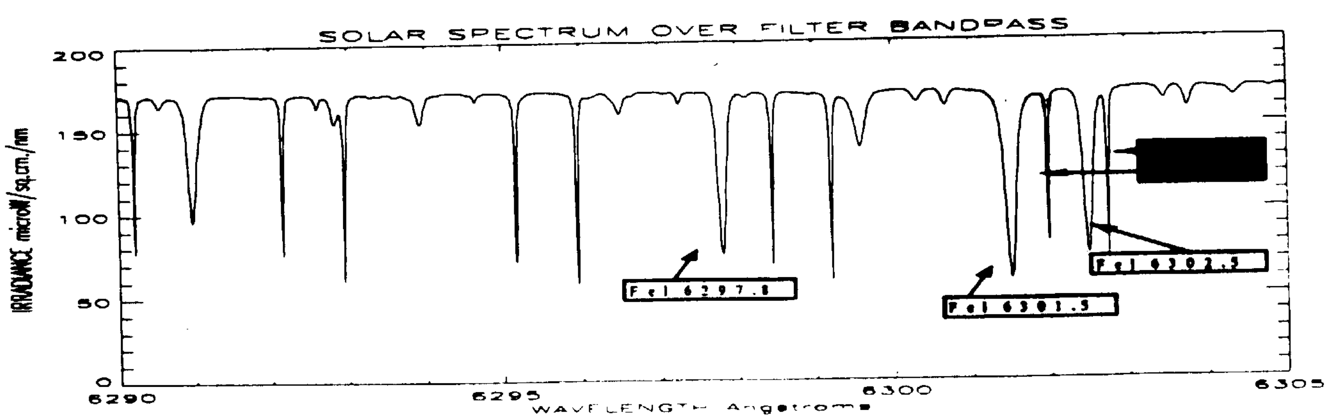
5250 Å

Multiline Diagnostics of Magnetic Field



6302 Å

Photospheric Magnetic Field



6563 Å Hα

Zeeman Line Selecton

The Selection of the 5250 Region for Fabry-Perot Filter Optimization

5250

Advantages
- Cleanest Multiplet Pair
- Pair for Temperature Diagnostic
- Optimization Allows the 6302 Region to be Accessible

Disadvantages
- Slightly Lower Splitting (17%)
- Slight TiO Blend (5250.24) in Umbra
- Temperature Sensitivity (2x)

6302

Advantages
- Multiplet Pair
- Slightly Larger Splitting (17%)
- Nearby Telluric Lines Diagnostic for Ground Observations
- Higher CCD Quantum Efficiency (.4x)

Disadvantages
- No Temperature Diagnostic Lines
- Not Optimum for Etalon Design

Fabry-Perot vs. Birefringent Filter

Fabry-Perot

- electrically addressable
- simpler optical system
- solid
- limited by scattering

Birefringent filter

- larger field of view
- many moving parts
- index matching, bubble formation in space
- optical quality of large pieces of calcite

Locating Filter at a Telecentric Image vs. a Collimated Pupil

Bandpass shifts to blue proportional to angle of incidence squared

Telecentric image,
- spectral band is broadened
- spectral band is the same for all image points

Collimated pupil
- spectral band is minimum
- spectral band varies over image
- shifts to blue toward edge

Both have same bandpass when averaged over all rays

The larger the pupil/image, the narrower the bandpass

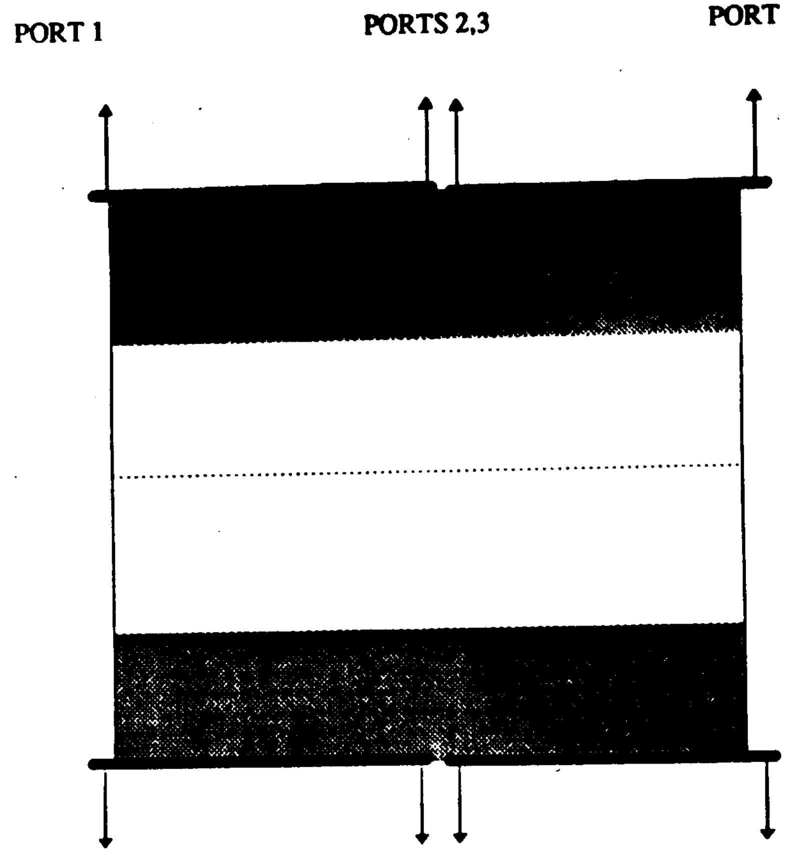
MSVM FRAME-TRANSFER CCD CAMERA

- LARGE FIELD OF VIEW
- HIGH TIME RESOLUTION
- MAXIMUM SENSITIVITY

- LARGE PIXEL ARRAY
- FAST READOUT
  - FRAME TRANSFER CHIP
  - MULTI-PORT READOUT
- HIGH SIGNAL TO NOISE

MODIFIED MIT LINCOLN LABS CCD CAMERA

- 1024 x 2048 PIXELS
- 24µ PIXEL SIZE
- 500 Ke WELL DEPTH
- QE = 65%
- 1 M-PIXEL/s READOUT AT EACH PORT



MSVM CCD CAMERA

(MODIFIED MIT LINCOLN LAB AXAF CCD)

- **ARRAY:** 1024 x 2048 PIXELS
- **WELL DEPTH:** 500,000 ELECTRONS (N_W)
  - $S / N = \sqrt{N_W} = 700$
  - $S / N = 10^4$ REQUIRES 200 INTEGRATIONS
- **EXPOSURE TIMES**
  - 0.24 S , 0.96 S IN 1-X , 2-X OPTICAL CONFIGURATIONS
- **READOUT TIME:** 0.26 S

TYPICAL TIMELINE AND DATA RATES: 1 X OPTICS

OBSERVING SEQUENCE

- Hα LINE CENTER
- Hα LINE WING
- λ 5250 PROFILE (I $\pm$ V AT 0, $\pm$ 90, $\pm$ 120 m$\mathring{A}$)
- I $\pm$ V WITH 20 INTEGRATIONS (1 G)
- I $\pm$ Q, I + U WITH 200 INTEGRATIONS (40 G)
- λ 5250 PROFILE (I $\pm$ V AT 0, $\pm$ 90, $\pm$ 120 m$\mathring{A}$)
- Hα LINE CENTER
- Hα LINE WING

TIMELINE AND DATA RATES : 2 X OPTICS

- **REDUCE I ± V INTEGRATIONS TO 10 (2 G)**
- **REDUCE I ± Q, U INTEGRATIONS TO 100 (60 G)**
- **TOTAL TIME = 6 MINUTES**
- **TOTAL DATA = 71.4 MB (200 kB/s)**

10-TAPE EXABYTE CAROUSEL ≡ 50,000 MB CAPACITY

TAPE RECORDING AT 0.5 MB/s ⇒ 2.8 MINUTES (1 X)

2.4 MINUTES (2 X)

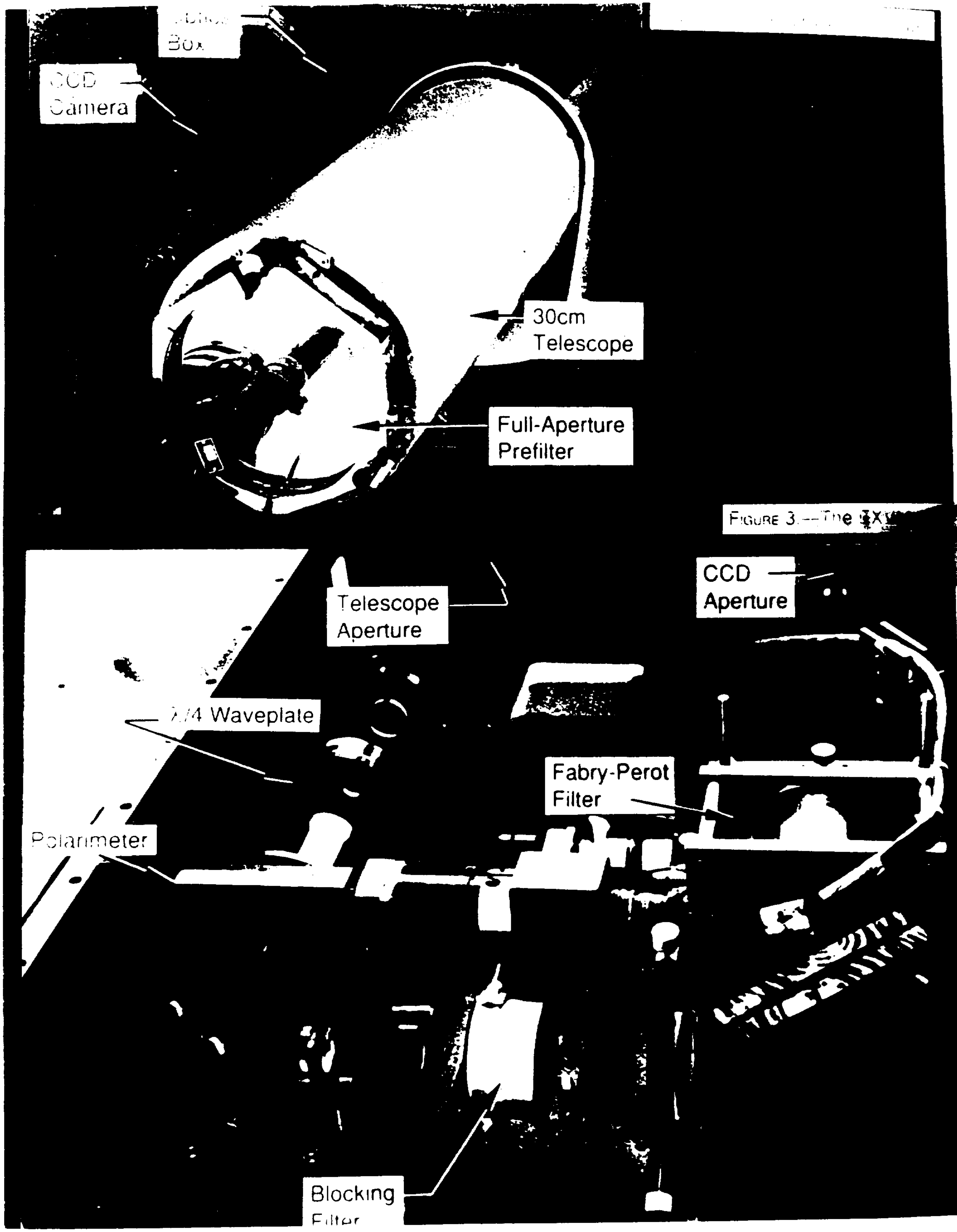
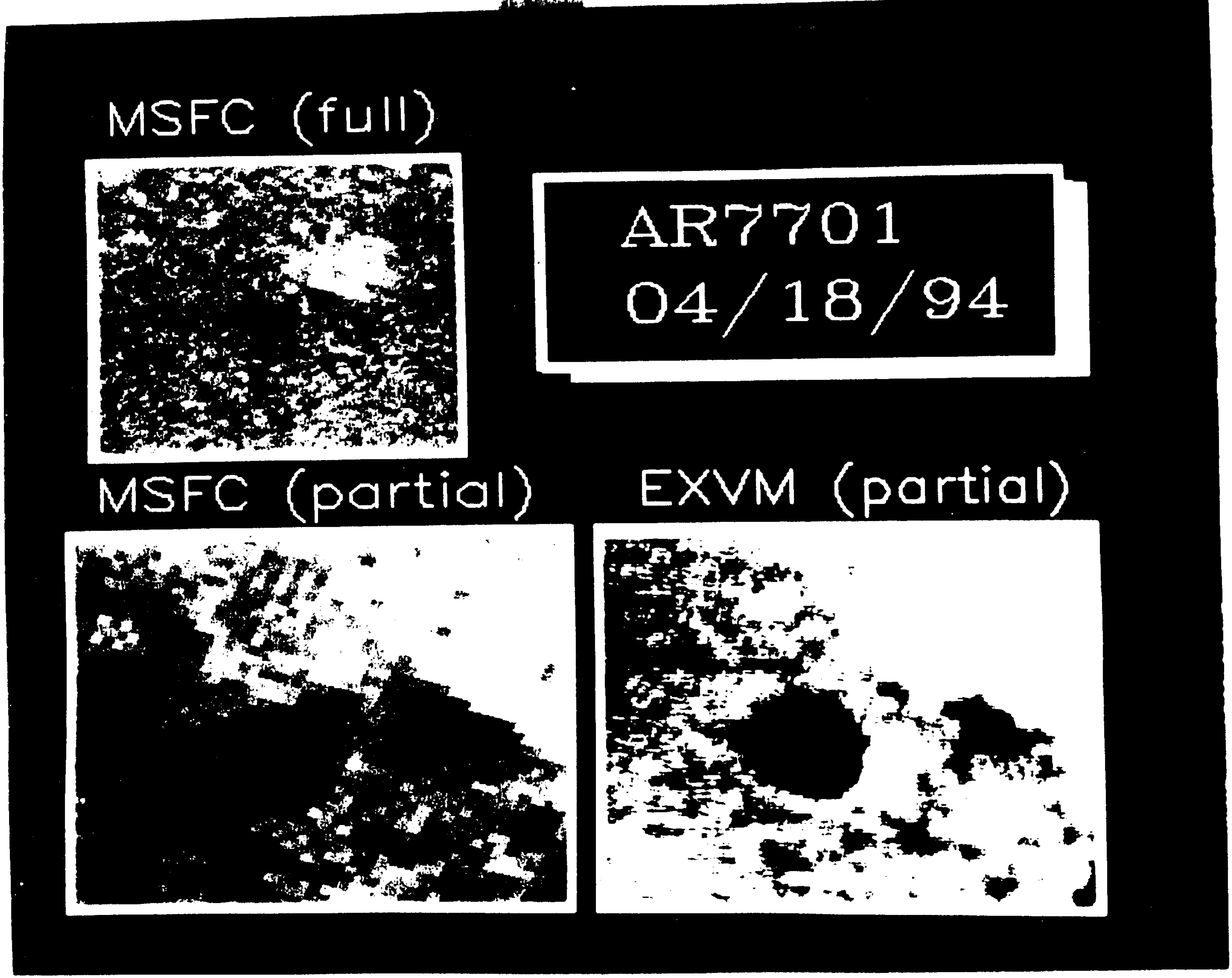
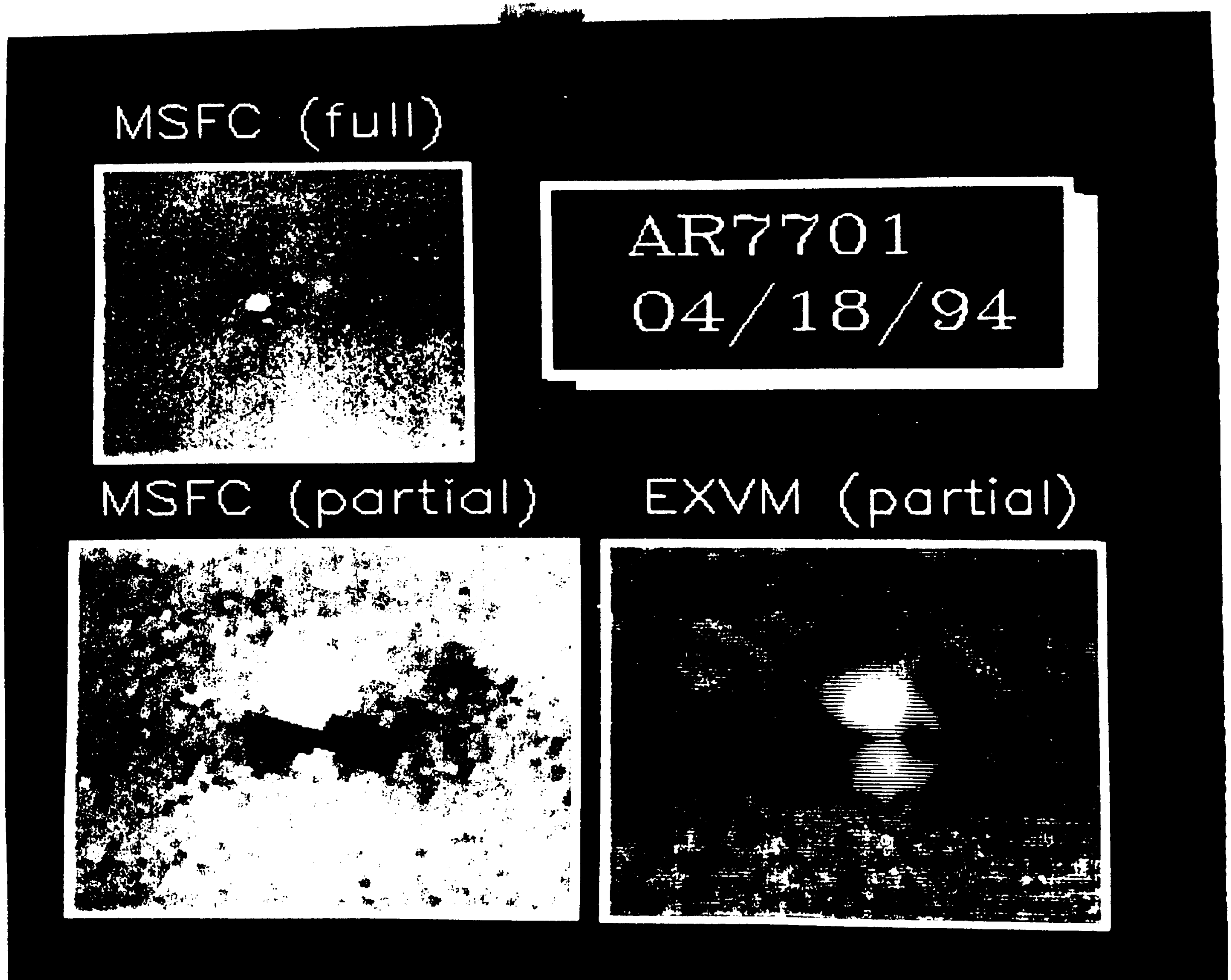

CCD
Camera
30cm
Telescope
Full-Aperture
Prefilter
Telescope
Aperture
CCD
Aperture
λ/4 Waveplate
Fabry-Perot
Filter
Polarimeter
Blocking

FIGURE 3.—The


MSFC (full)
AR7701
04/18/94
MSFC (partial)
EXVM (partial)


MSFC (full)
AR7701
04/18/94
MSFC (partial)
EXVM (partial)

Polarimetry: Measuring Polarization Elements and Optical Systems

Russell A. Chipman

Associate Professor of Physics
University of Alabama in Huntsville
Huntsville, AL 35899
(205)895-6417 x318

Telescope

Aperture: 50 or 60 cm

Configuration:

Cassegrain with full aperture prefilter (shown)

or

Gregorian with reflective conical field stop

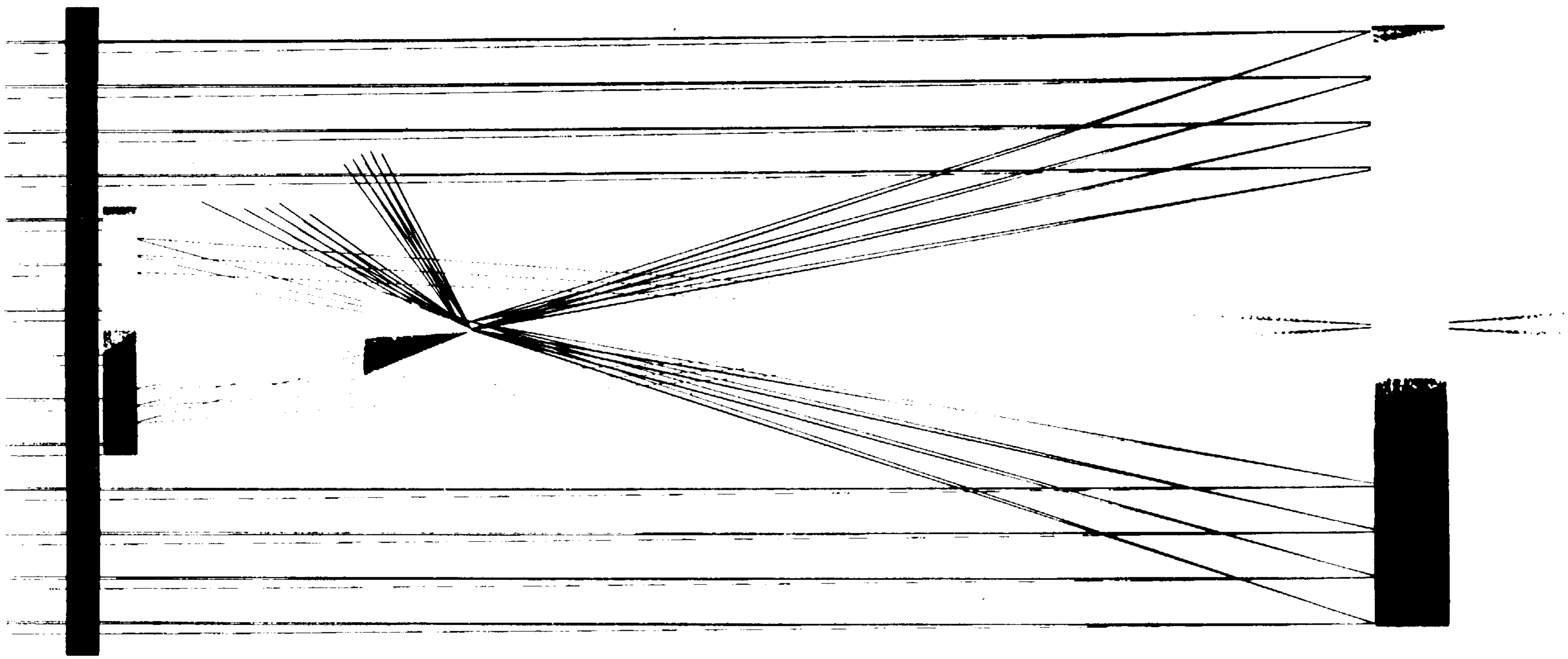
Aspheric mirrors:

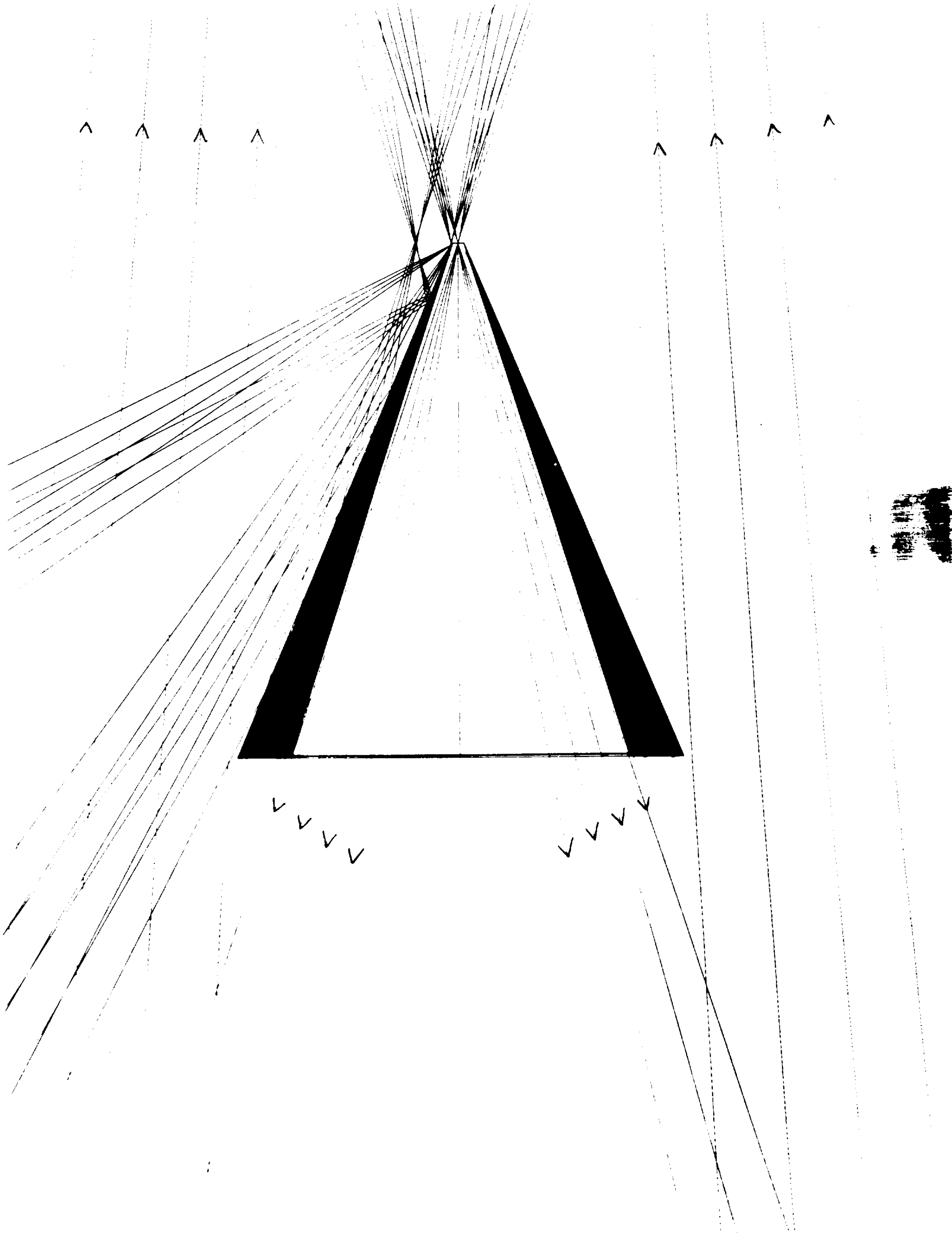
Hyperboloids plus aspheric terms

will utilize NASA/Marshall large aspheric mirror fabrication facilities

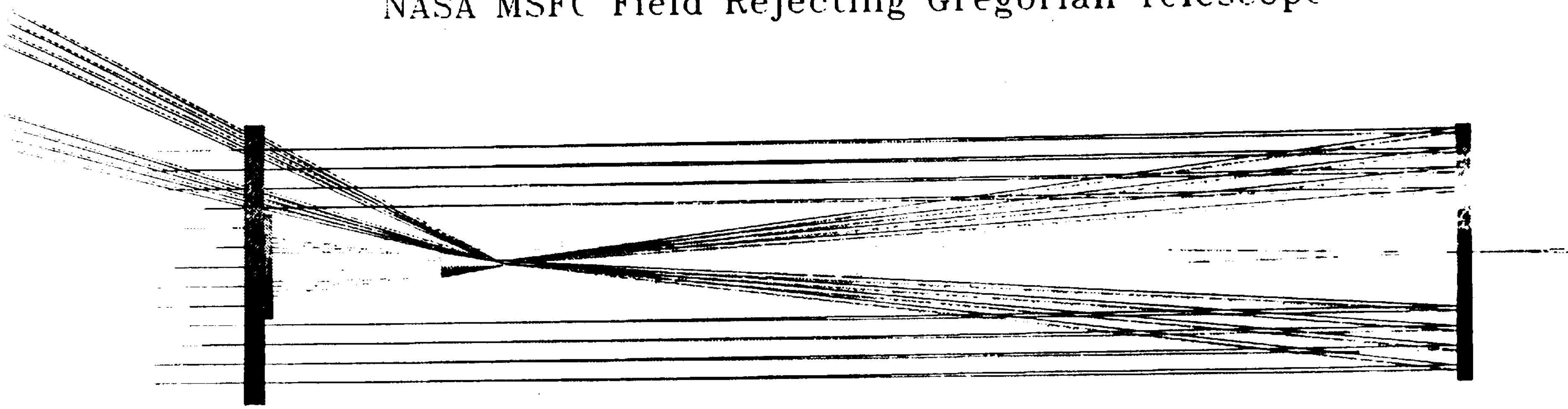
Low polarization enhanced reflective coatings

NASA MSFC Field Rejecting Gregorian Telescope

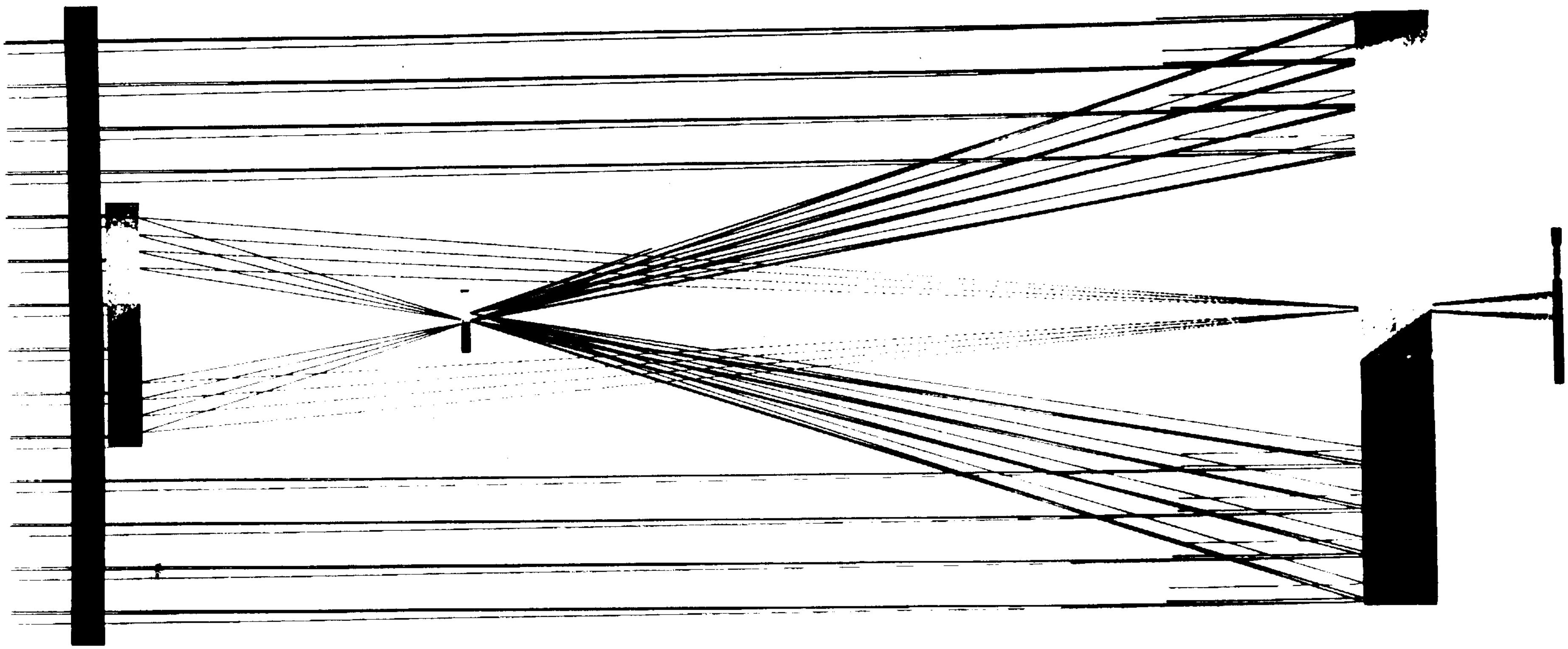


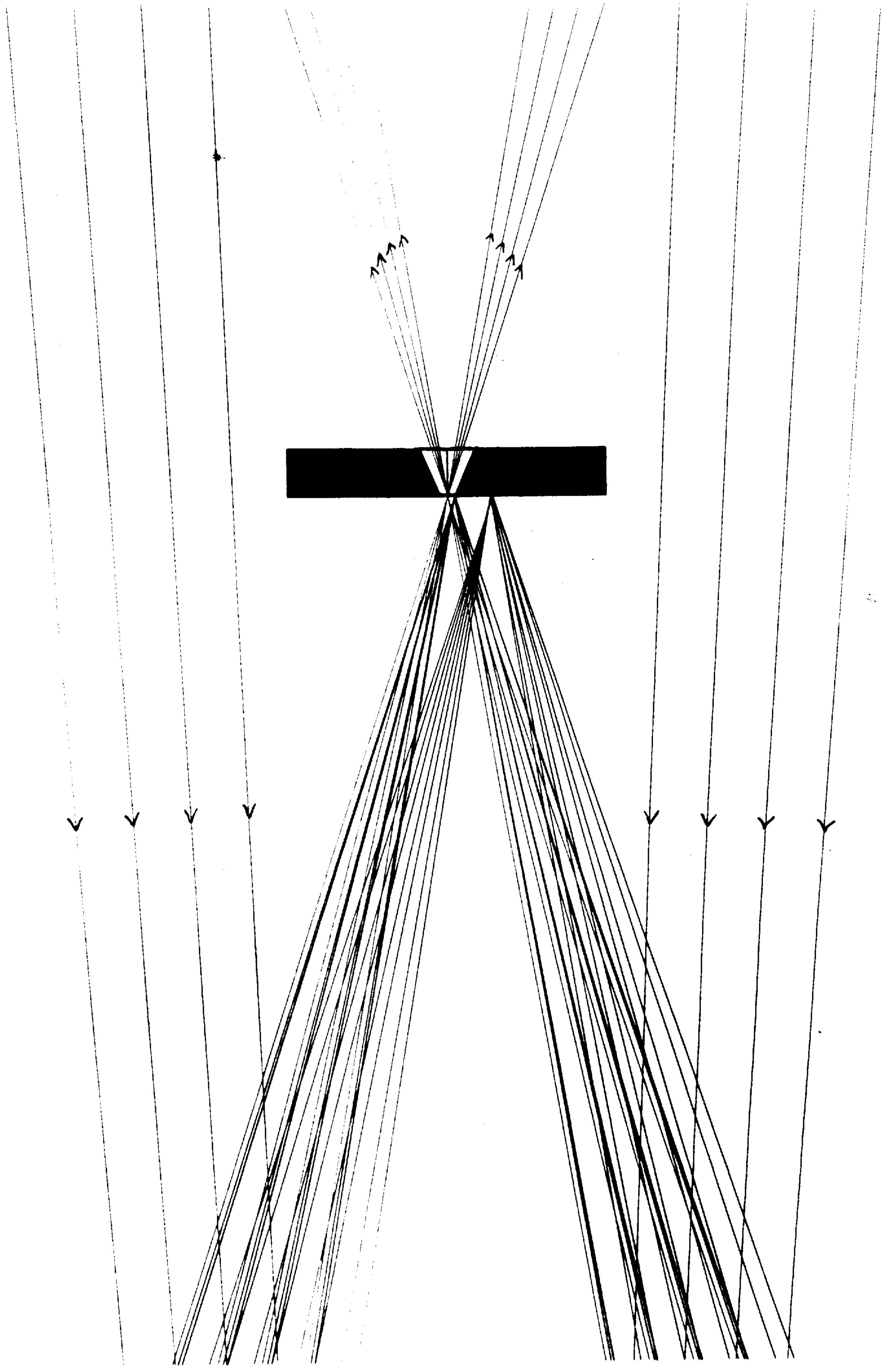


NASA MSFC Field Rejecting Gregorian Telescope



NASA MSFC Field Rejecting Gregorian Telescope





Instrumental Polarization

Polarization sensitivity is compromised by nonnormal angles of incidence at surfaces before polarimeter

Larger angles of incidence cause larger polarization state changes

Particularly couple circular polarization into linear polarization

Seek to minimize instrumental polarization, particularly coupling of the generally larger circular component into linear polarization.

Subject of Polarization Ray Tracing talk

Polarization Aberration Analysis and Minimization

Mirrors and Lenses induce polarization aberrations

Polarization Aberrations reduce accuracy of polarimeter measurements

Accurate magnetic field measurement requires reduction of polarization aberrations

Tools for analyzing polarization aberrations:

Polarization ray tracing
Polarization aberration theory
Polarization optical testing with imaging polarimeter

Polarization compensation:

Low polarization design techniques
Balancing polarization aberrations

Polarization Aberration Resuction in SAMEX Design

SAMEX Solar Magnetograph Study (1988)

Polarization Aberration Correction:

Designed with low angles of incidence
Coatings optimized for low polarization
Second order polarization aberrations balanced

Polarization Aberration Reduction:

Design had 1/1000 the instrumental polarization of equivalent Cassegrain telescope with aluminum mirror coatings at 5250 A.

21.6 Telescope and Polarimeter Polarization Calibration

When system is assembled and aligned:

Illuminate with large number of precicely calibrated polarization states.

Determine exact response of system to arbitrary states on pixel-by-pixel basis.

Determine alignment of sequential images to 1/100 of pixel.

Incorporate into polarimeter data reduction routines.

SPECIAL SPACEFLIGHT QUALIFICATIONS

- **"COOL" TELESCOPE OPTICS**
  - REDUCED THERMAL PROBLEMS

- **FABRY-PEROT FILTER**
  - QUEENSGATE INSTRUMENT ON UARS/WIND II
  - HIGH TRANSMISSION $\Rightarrow$ HIGH TEMPORAL RESOLUTION
  - MINIMUM POLARIZATION RESPONSE $\Rightarrow 10^{-4}$ SENSITIVITY

- **SIMPLE DESIGN**
  - OPTICS (COMPACT AND UNCOMPLICATED)
  - SPECTRAL FILTER (MINIMUM NUMBER OF MOVING PARTS)
  - ACCESSIBLE FOCAL PLANE

- **POLARIMETER TORQUE COMPENSATION**

Additional Engineering Studies

Underway:

Mechanical design

Thermal analysis

Optical tolerance analysis

Low polarization coating design

Expecting Funding:

Low polarization coating prototype fabrication and test

Further polarization element refinement

2.1.4 How accurately can the transverse and longitudinal solar magnetic fields be measured?

Accuracy of Stokes vector measurements

Polarimeter accuracy

Instrumental polarization

Minimizing crosstalk between circular polarization and linear polarization in optical coatings.

Wavelength accuracy

Control of Fabrey-Perot etalon

Space-based wavelength calibration

Noise

Detector

Temporal fluctuations of solar irradiance

21.5

How is the standard deviation of the magnetic field measurements related to the following:

Detector noise

Accuracy of calibration

Polarimeter alignment

Telescope and folding mirror instrumental polarization

Calibration drift in orbit

Image mismatch, four corresponding pixels not having exactly the same instantaneous fields of view

Image motion during measurement

Averaging due to pixel size relative to small intense features,

Appendix 10.

Development of Method for Generating a 2x Lens Magnifier

A lens system was desired which when inserted in the magnetograph would increase the magnification by a factor of two, with a corresponding decrease in the field of view. The size of the image would remain the same, but the f/# of the light at the image would be increased by a factor of two. The entire primary mirror would still be used, but at one half the field of view. The Fabry-Perot would be illuminated with a telecentric beam the same size, but with half the angular bandwidth in each axis.

I realized that this 2x magnifier had the following paraxial implications. Consider first the chief and marginal paraxial rays which are tabulated in this appendix. Since the field of view has been reduced by a factor of two, we desire to reduce the height and angle of the chief ray by a factor of two from the front of the system through to the 2x magnifier. Exiting the magnifier, the chief ray should attain its initial values all the way to the image. This ensures the image size is unchanged. Similarly, the marginal ray height should be unchanged from the entrance to the system to the 2x magnifier. Following the magnifier, the marginal ray height and angles should be reduced to one half the initial values.

The system with the 2x magnifier will have one half the Lagrange invariant and one fourth the etendue of the 1x system without the magnifier.

Using these principals, I developed a graphical method on the y-ybar diagram to connect an incident beam with one half the chief ray, and an emerging beam with one half the marginal ray and find a family of thin lens solutions. One result was that there were no one or two lens solutions to this problem. This explained the difficulties that Ron Eng and Mary Acree had been having in trying to optimize a 2x magnifier with two lenses.

I then developed one solution for the 2x magnifier using three thin lenses of focal lengths: 239 mm, -10 mm, and 33.5 mm. The attached paraxial ray trace shows that this system satisfies the 2x magnifier requirements. The "2x system to insert" table specifies the lens placements.