Design Considerations for Monochromatic Imagers and Imaging Spectrographs

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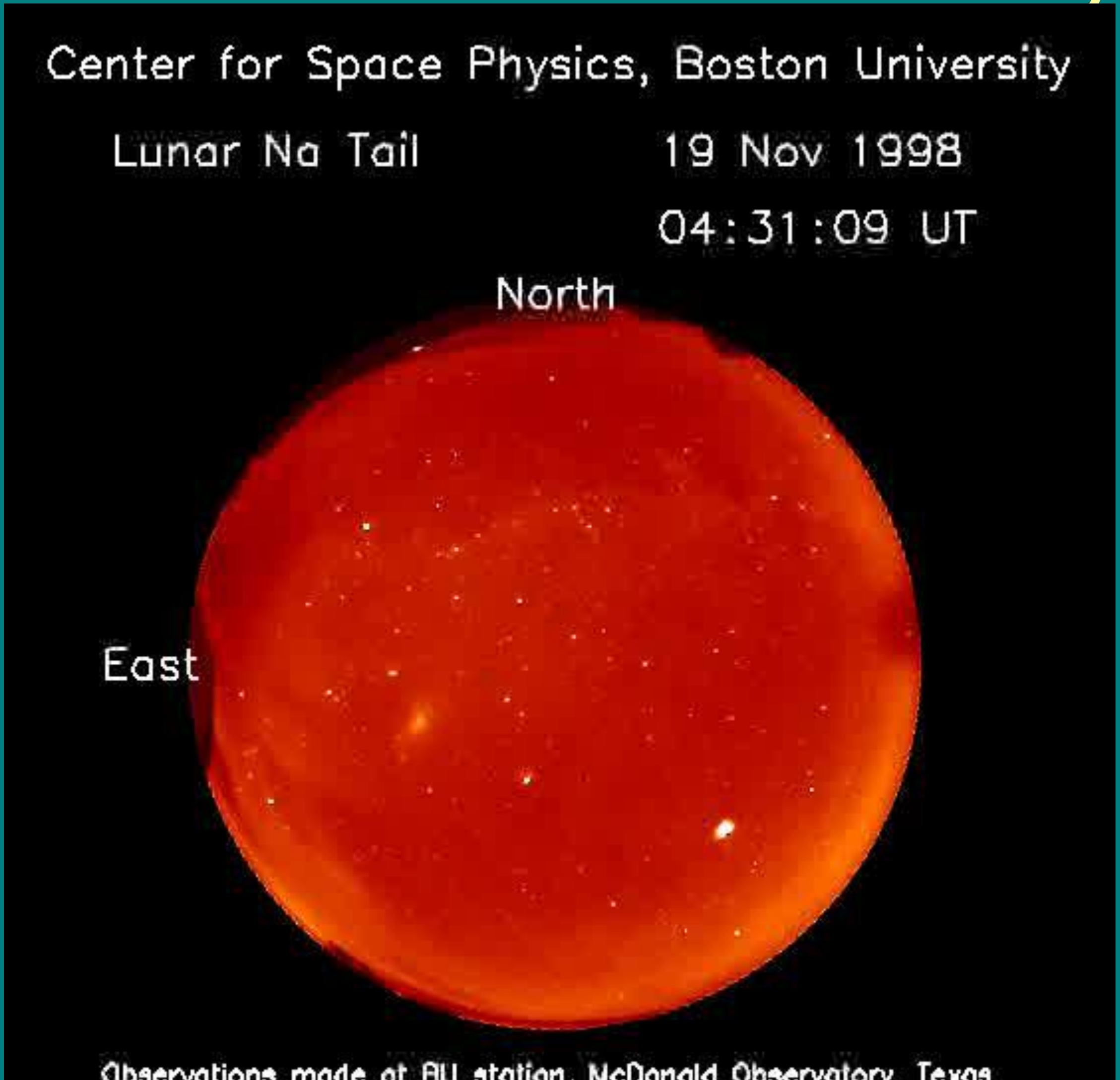
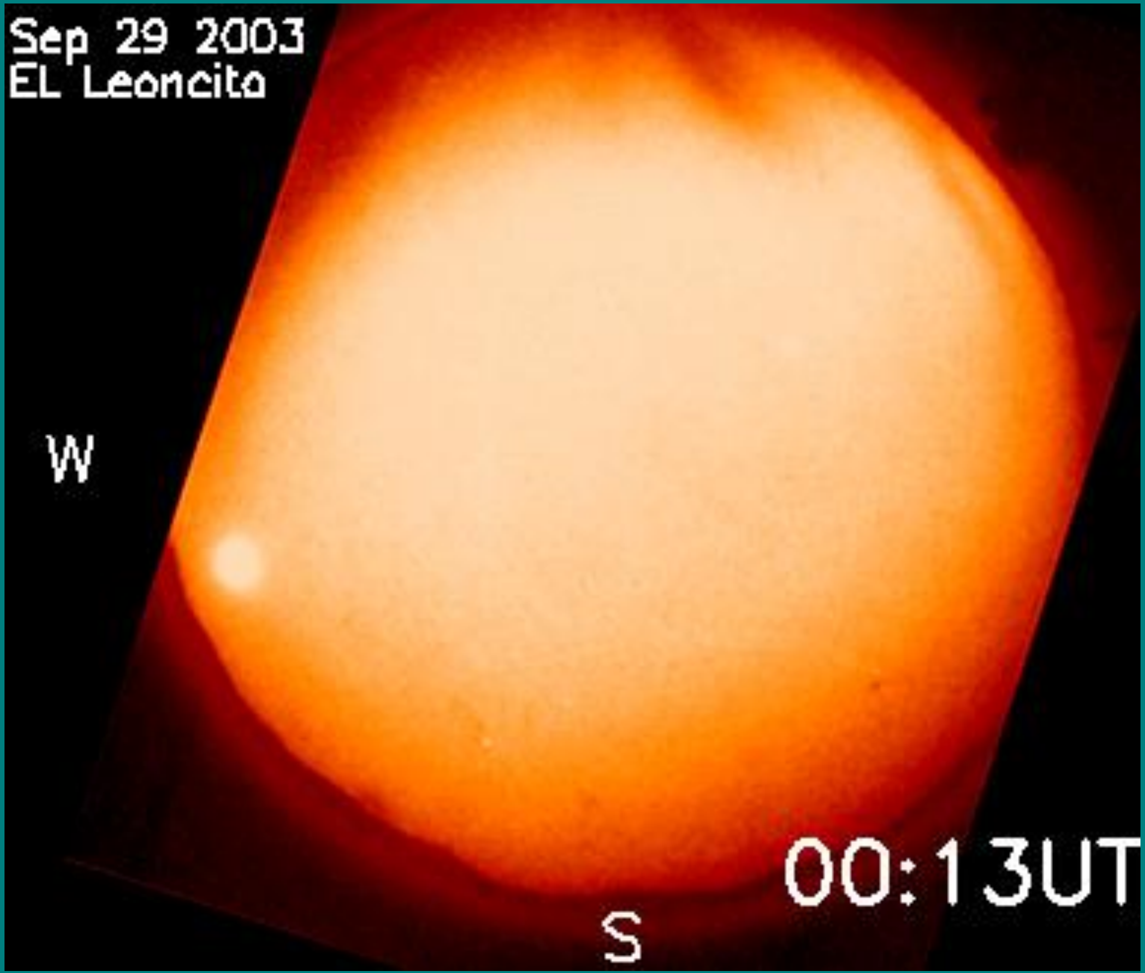
CEDAR Student Workshop
Santa Fe
June 27,2004

All Sky Sodium (D1+D2) from McDonald Observatory

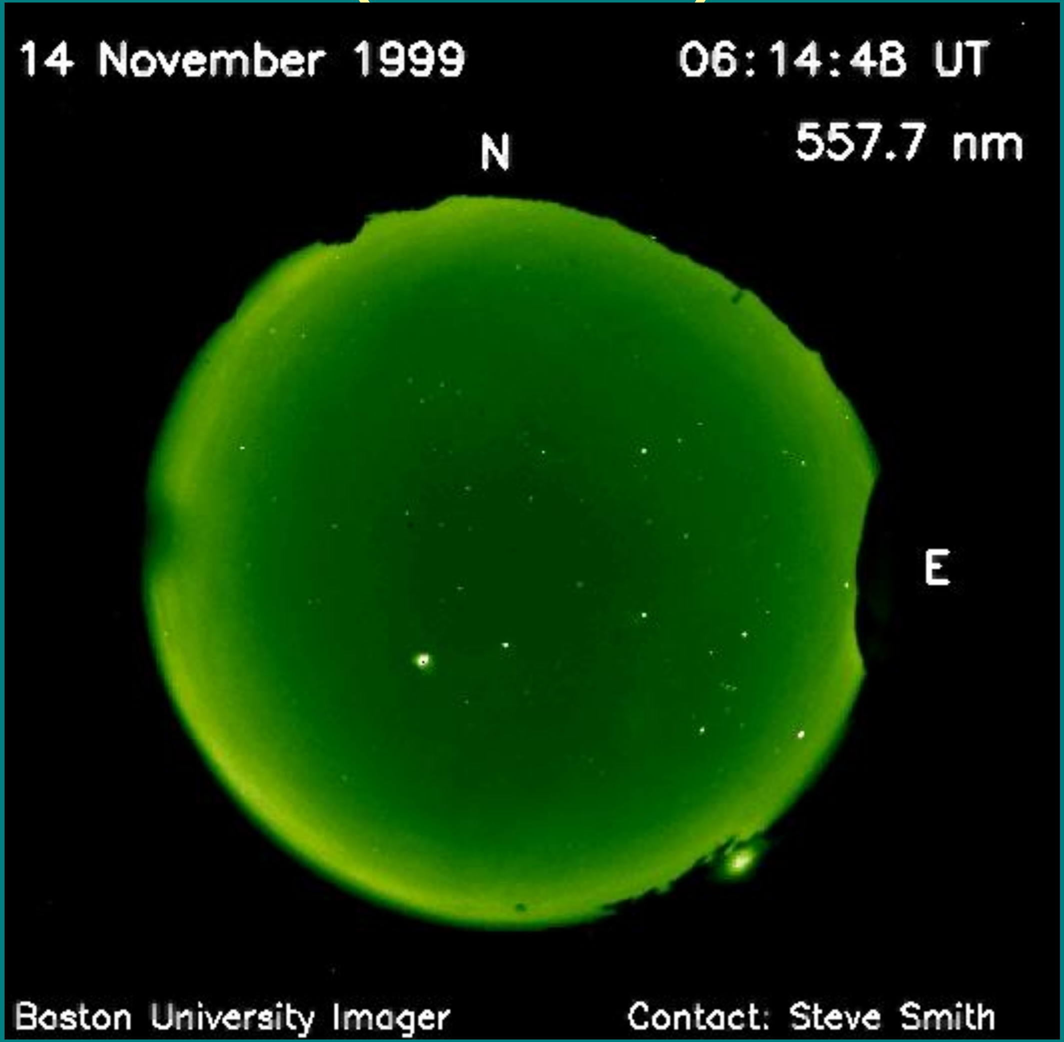


SAR ARC (6300A)
Millstone Hill

Low Latitude Airglow Depletions from El Leoncito Argentina



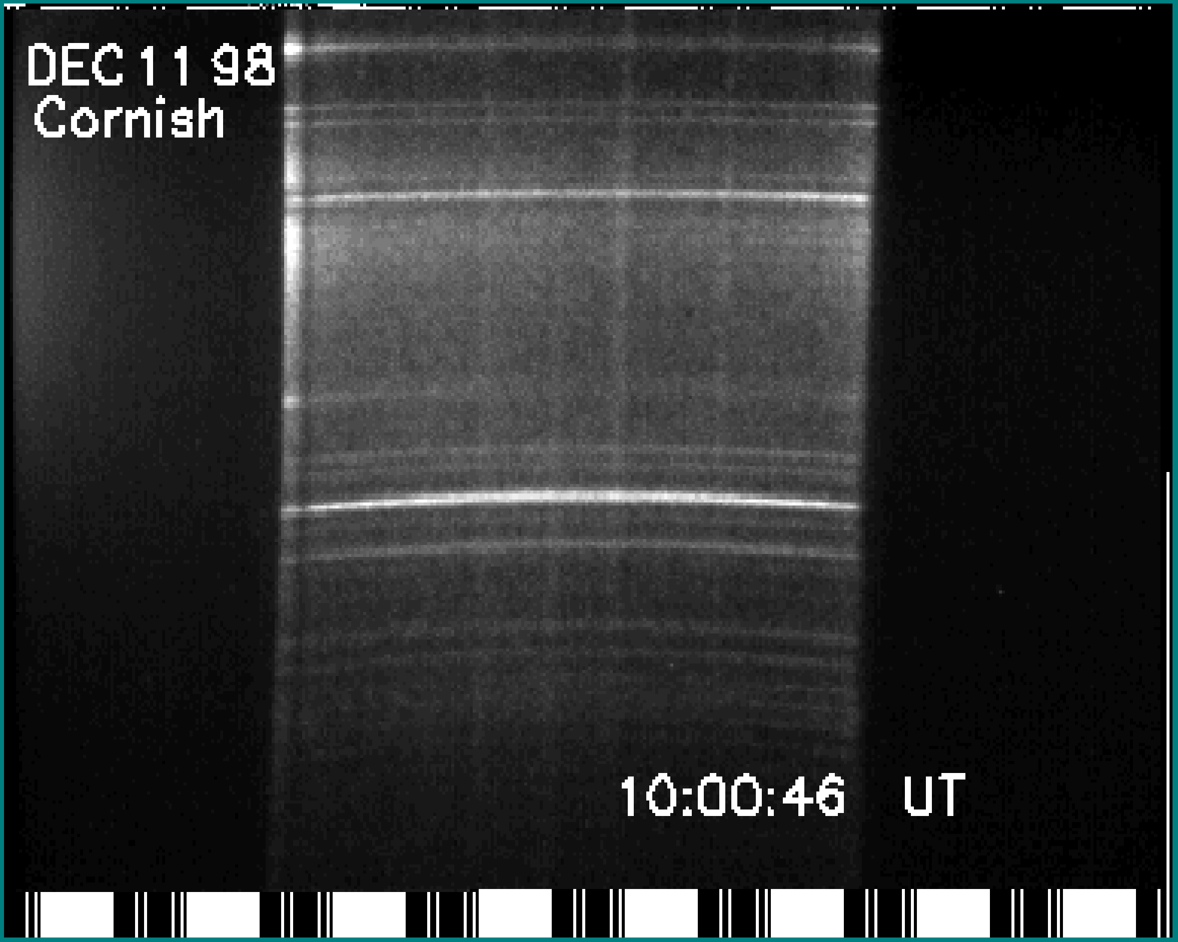
Mesospheric Gravity Waves (5577A)



Imaging Spectrograph (~5580A-7100A)

S

6563A

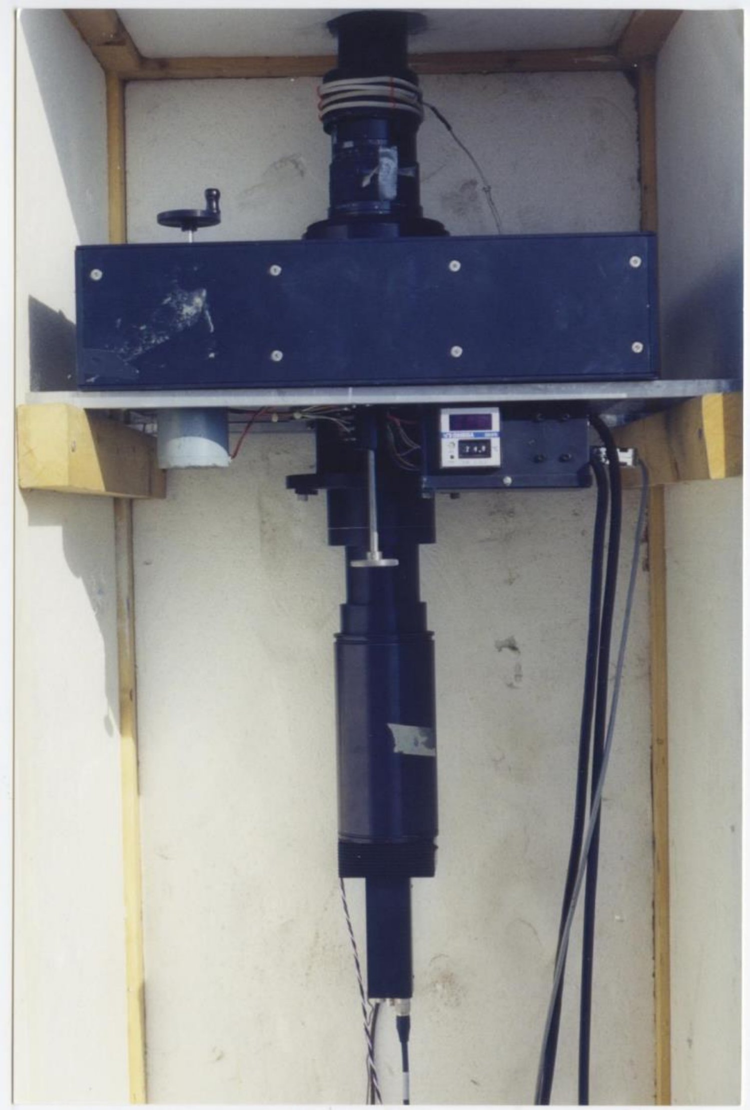


5893A

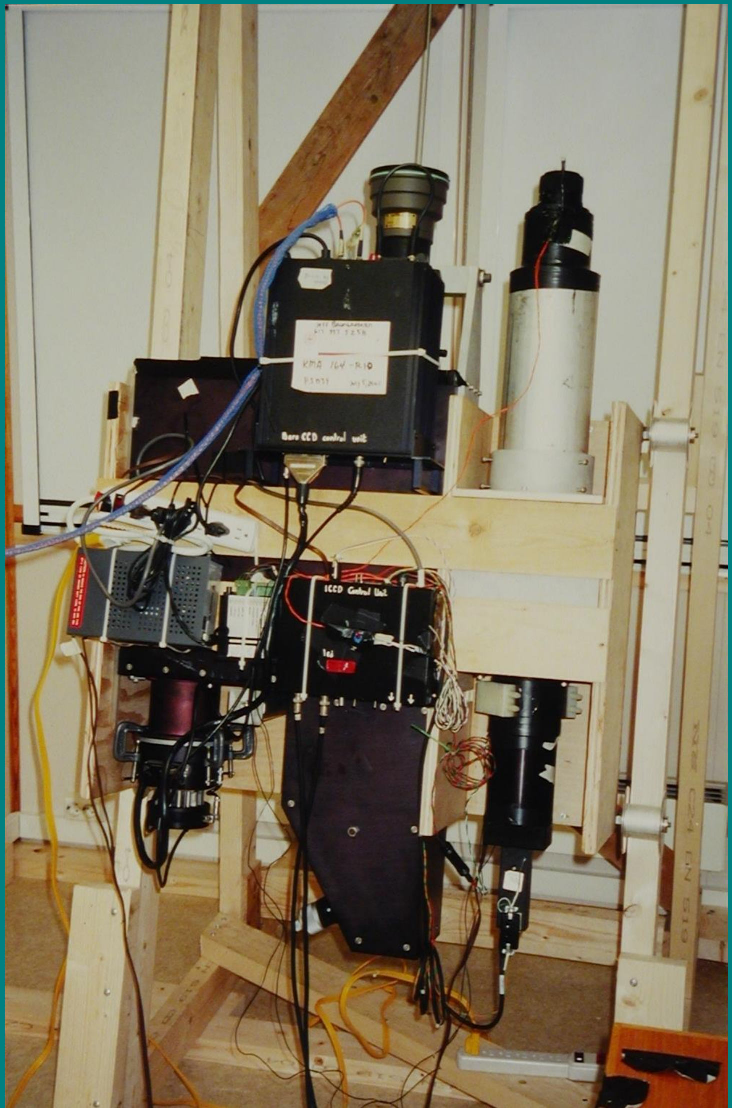
N

6300A

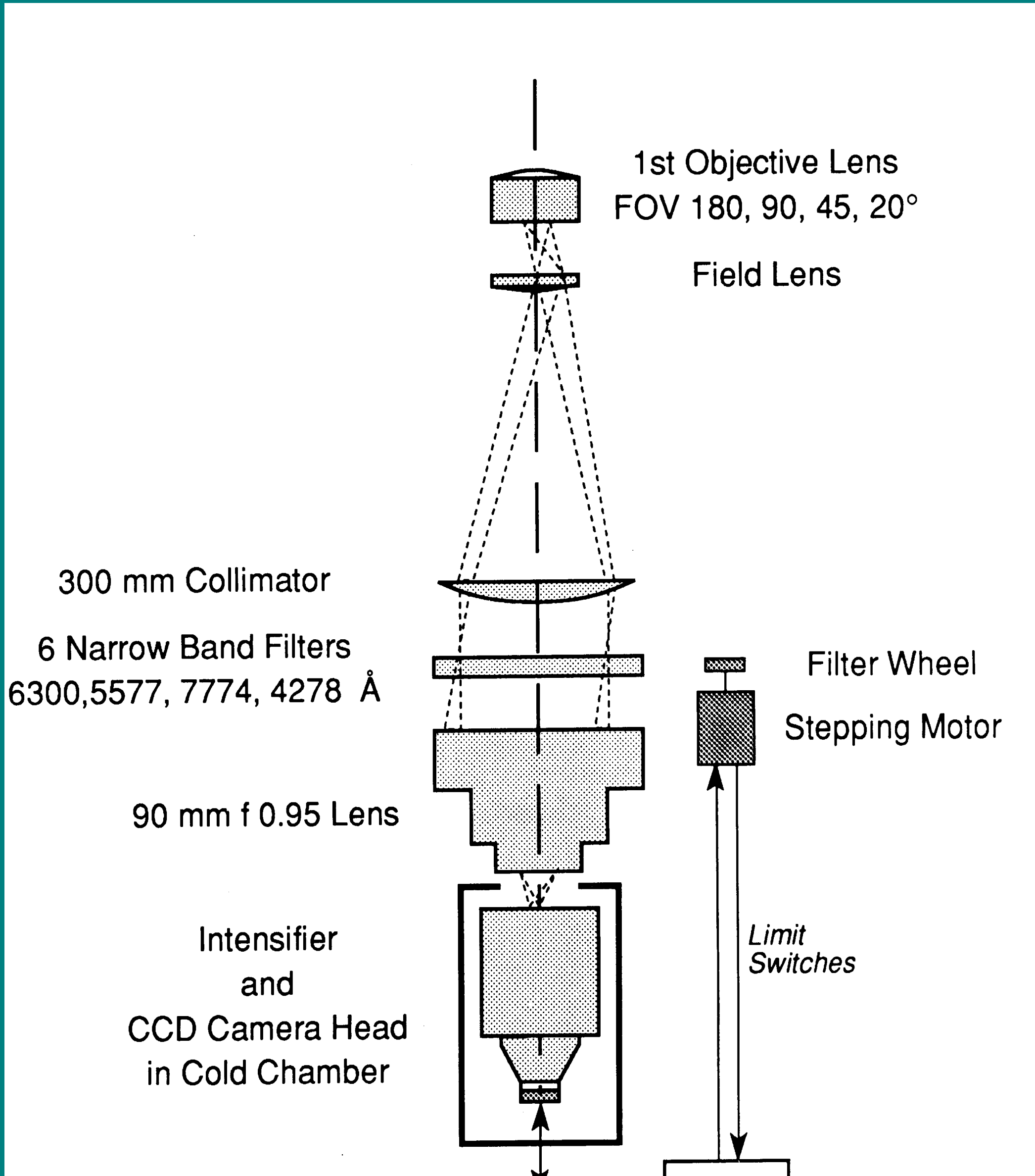
Typical Imager Installation Arequipa (1994 – 2000)



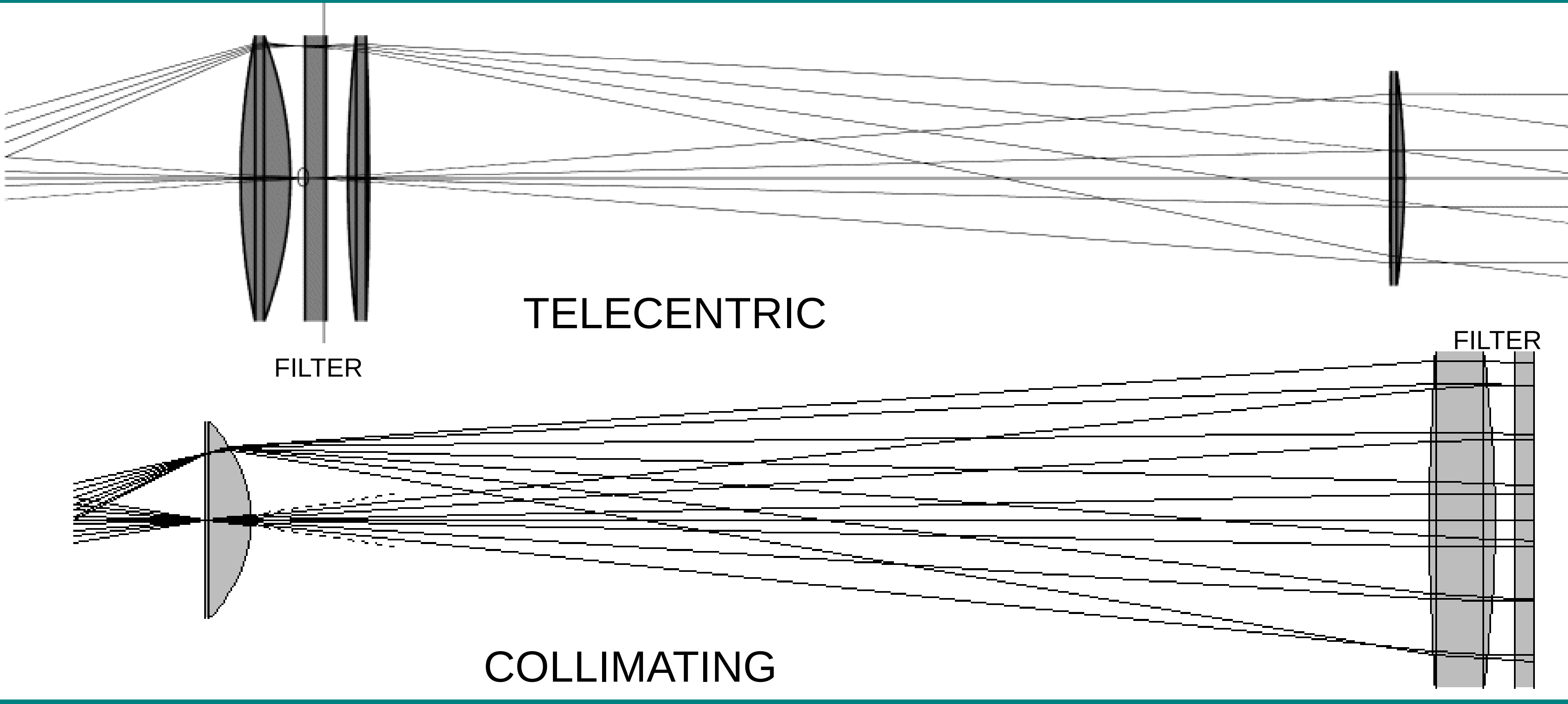
Imaging Spectrographs Installed at Tromso(winter 2002-2003)



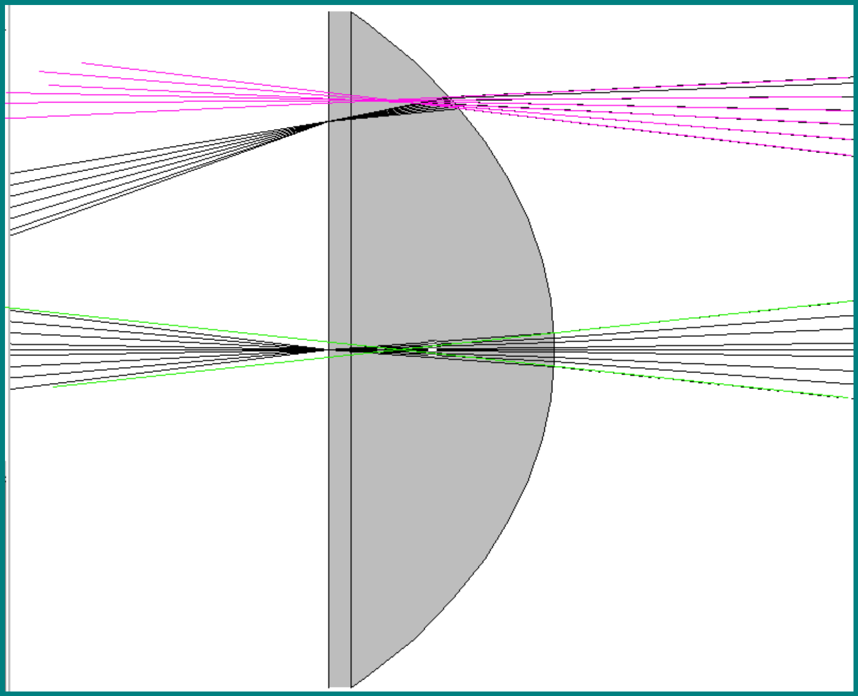
Optical path of an All Sky imager built at Boston University



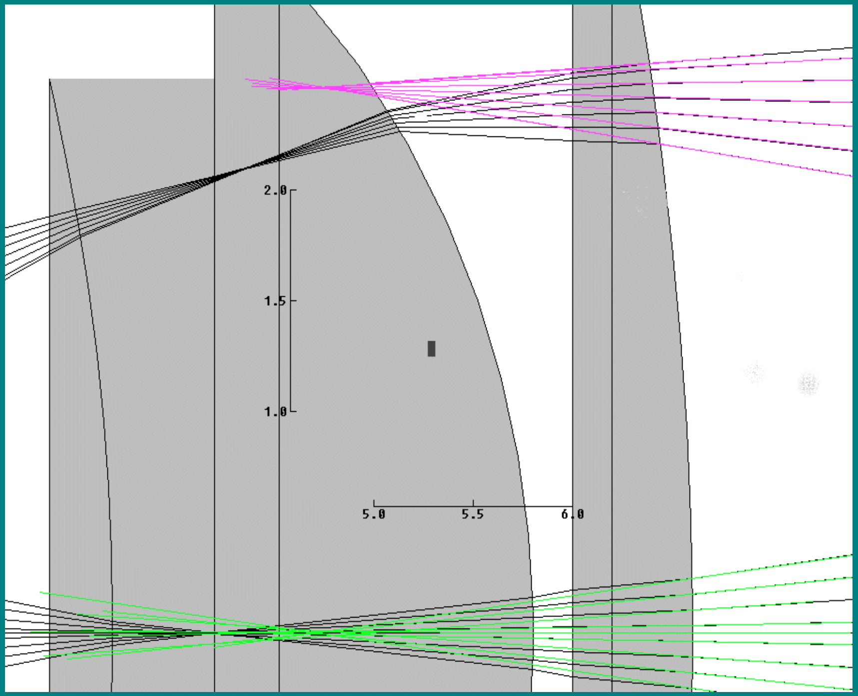
Collimating vs Telecentric Systems



Details of Collimating System

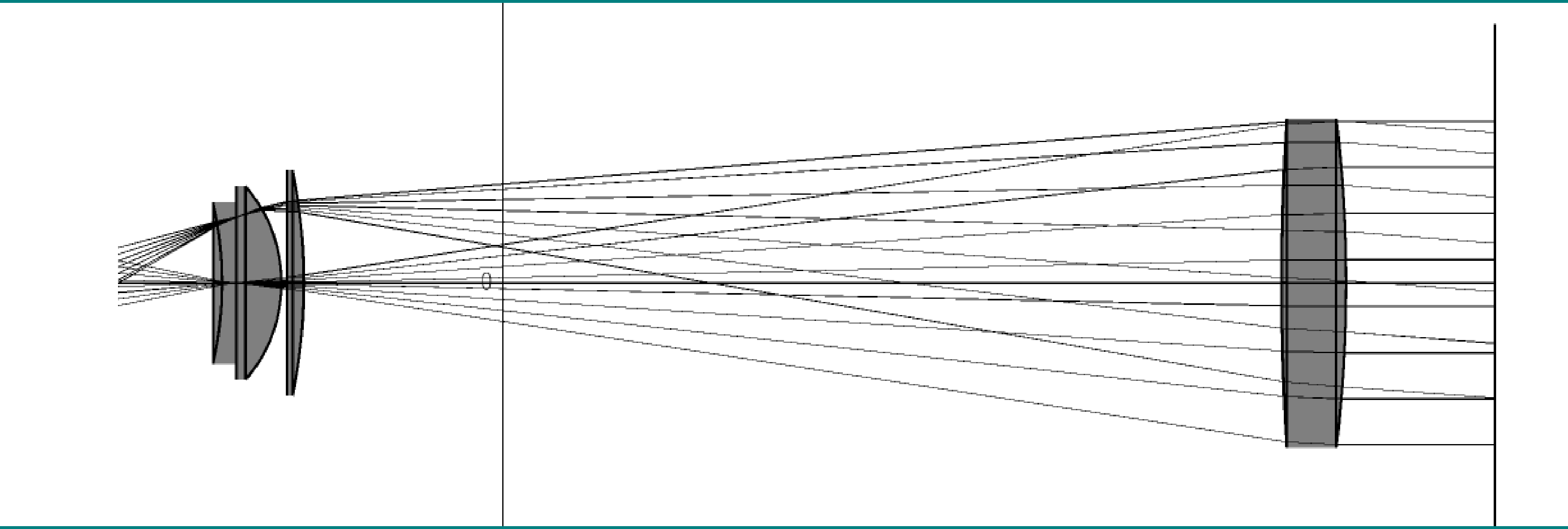


Simple Field Lens

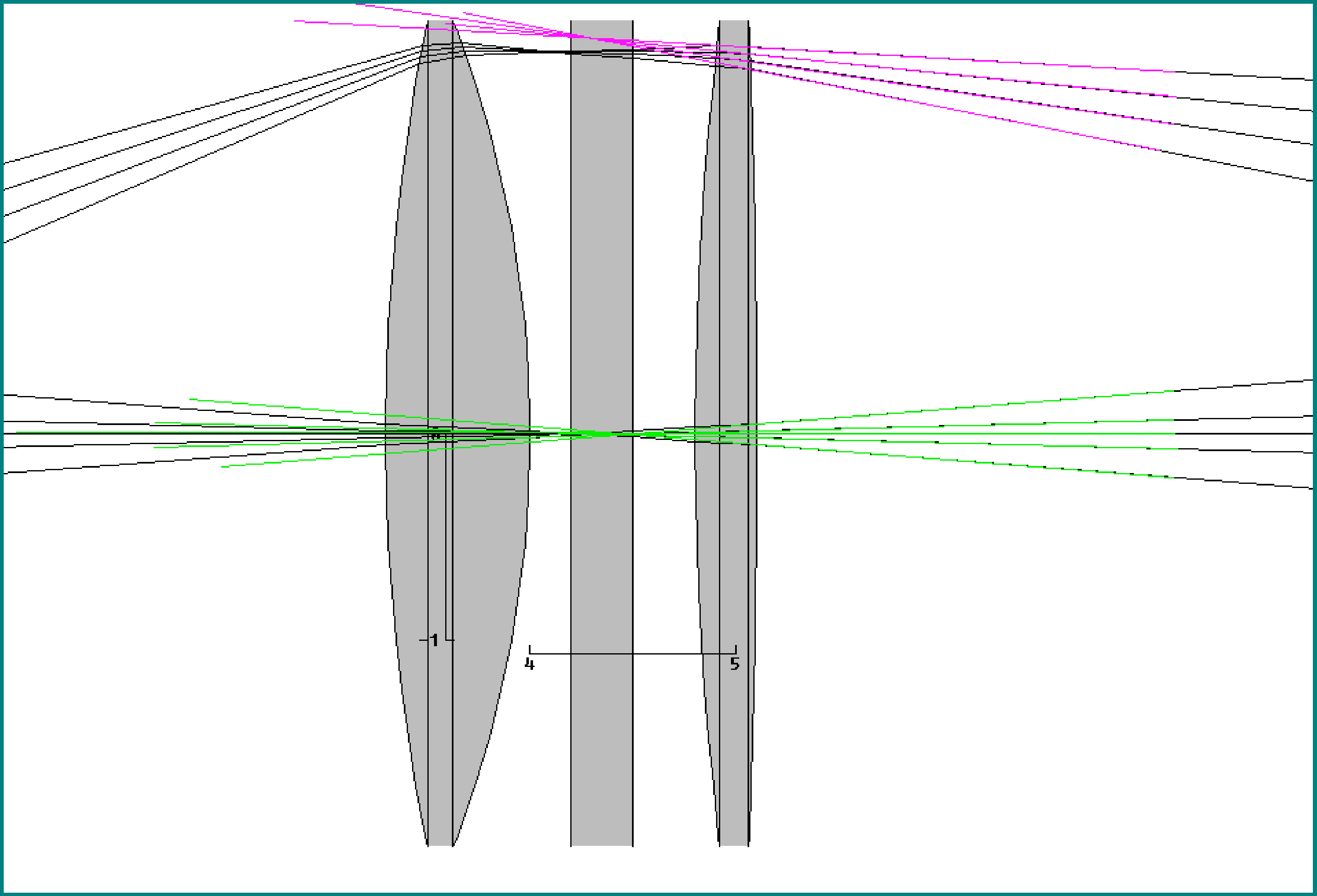


Field Lens with Field Flattener

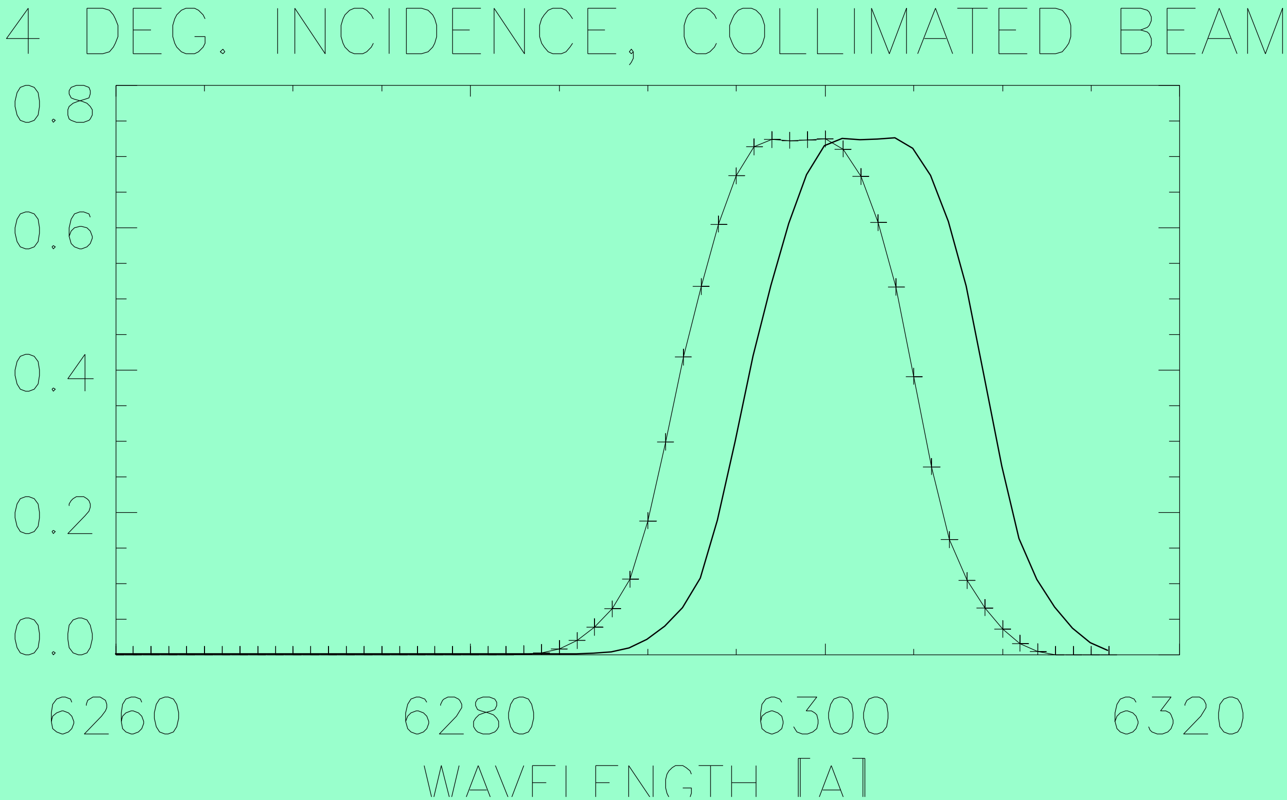
Details of Collimating System (cont.)



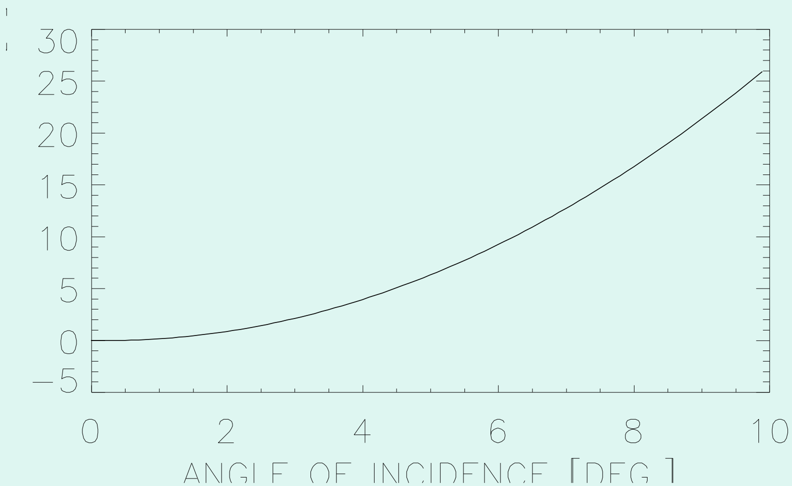
Details of Telecentric System



Some Basic Characteristics of Interference Filters



Some Basic Characteristics of Interference Filters (cont.)



$$\lambda = \lambda_{max}\sqrt{1 - \left(\frac{n_o}{n_e}\right)^2 \sin^2\phi}$$

Design Choices

- How does the size of the detector, the choice of the front objective lens, and the size of the filter affect the sensitivity of the complete system?........OR……..

Does Size Matter?

Design Choices (cont.)

A few terms to be familiar with:

- F ratio or F number (F/) = Focal Length/ Diameter
- Angle-aperture product or Grasp
- Chromatic aberration (focus shift with wavelength)
- Astigmatism
- Field curvature
- Back focal length

Design Choices (cont.)

- Consider two systems:

System1:

16mm fl F/2.8 fisheye (40mm dia. image)

1k by 1k, 24 micron pixel CCD

System2:

8mm fl f/2.8 fisheye (23mm dia. Image)

1k by 1k 13 micron pixel CCD

Design Choices (cont.)

- In both systems the images from the fisheye lenses are re-imaged to just fit onto the CCDs.
- In both systems the angular size of the pixels are the same when projected onto the sky.
- In System 1 and System 2 the F/ of re-imaging lens will be ~F/1.64
- However, System 1 has an aperture of 16mm/2.8 = 5.7mm while System 2, has an aperture of 8mm/2.8 = 2.8 which is 2 times smaller (0.25 in area) and therefore, 4 time less sensitive!

Design Choices (cont.)

- What if the smaller chip is used with the larger fisheye?
- 40mm dia. Image has to be reduced to 13mm to fit
- F/ of the re-imaging lens has to be 13/40 x 2.8 or f/0.9
- Same sensitivity as previous example with larger chip

Design Choices (cont.)

- What is the filter size and bandwidth needed in a collimating system?
- Angle at filter (and therefore bandwidth) is a function of size of image and the focal length of collimator
- Size of filter is a function of F/ and focal length of collimator
- Once filter diameter is fixed, all other parameters follow

Design Choices (cont.)

- Choose 100mm dia. Filter
- Both systems need an F/2.8 100mm dia. Collimator FL=280mm
- Max angle for system 1= arctan(20/280)= 4.1 deg. Minimum filter bandwidth = 12A or so
- Max angle for system 2 = arctan(12/280)= 2.5 deg. Minimum filter bandwidth = 4A or so (this filter is beyond the state of the art and would be prohibitively expensive!)

Design Choices (cont.)

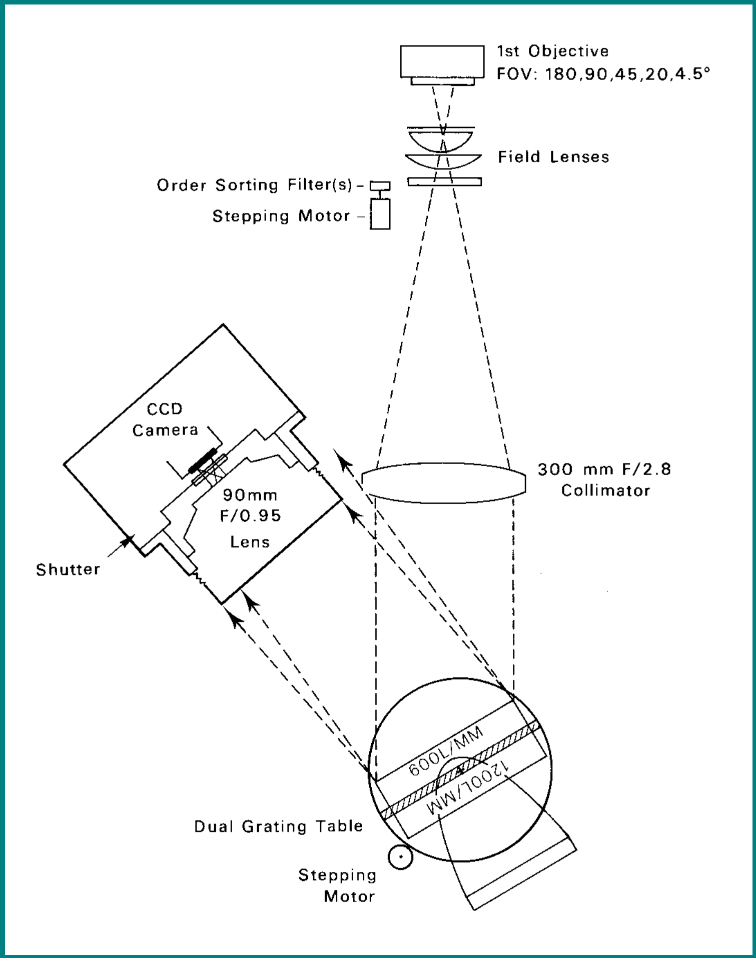
- If collimator in system 2 is reduced to 50mm dia. and 140mm FL, the angles are the same as system 1 and the filter can be 50mm dia. 12A FWHP (much less expensive!) Remember system 2 is 4 times less sensitive than system 1.

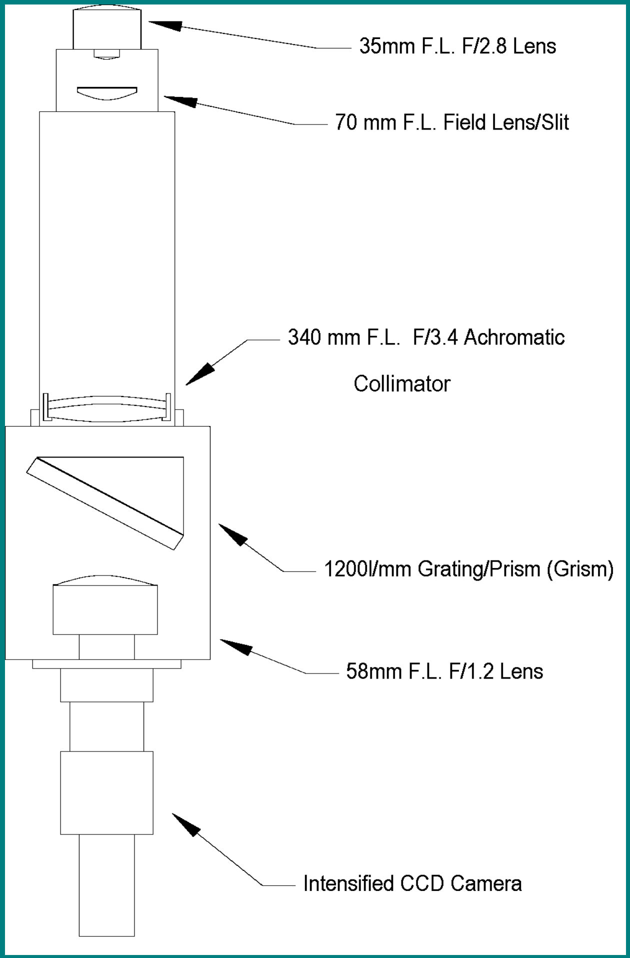
- If 75mm dia. filters are used in system 1 the angle at the filter would increase to 5.4 deg. and the FWHP to 18A or so.

Design Choices (cont.)

- Telecentric systems have filters the same size as the image.
- Typical 24mm fl F/4 system uses 20A HPFW filters
- “grasp” is similar to system 1 above

Imaging Spectrograph Schematics





“COTIF” SPECTROGRAPH

Parameters for COTIF Spectrographs

ANGLE OF INCIDENCE = -11.0 BLAZE ANGLE = 11.5
ANGLE BETWEEN THE INCIDENT AND THE EXIT BEAM = 45.0
LINE DENSITY = 600.0 lines/mm
DIFFRACTION ANGLE RANGE =   8.0

ORDER	MIN	MAX	DISP (A/DEG)	DISP (A/pix)	OCURRENCE
1	5153.2	7080.9	240.9615	1.8825	4
2	2576.6	3540.4	120.4807	0.9413	0

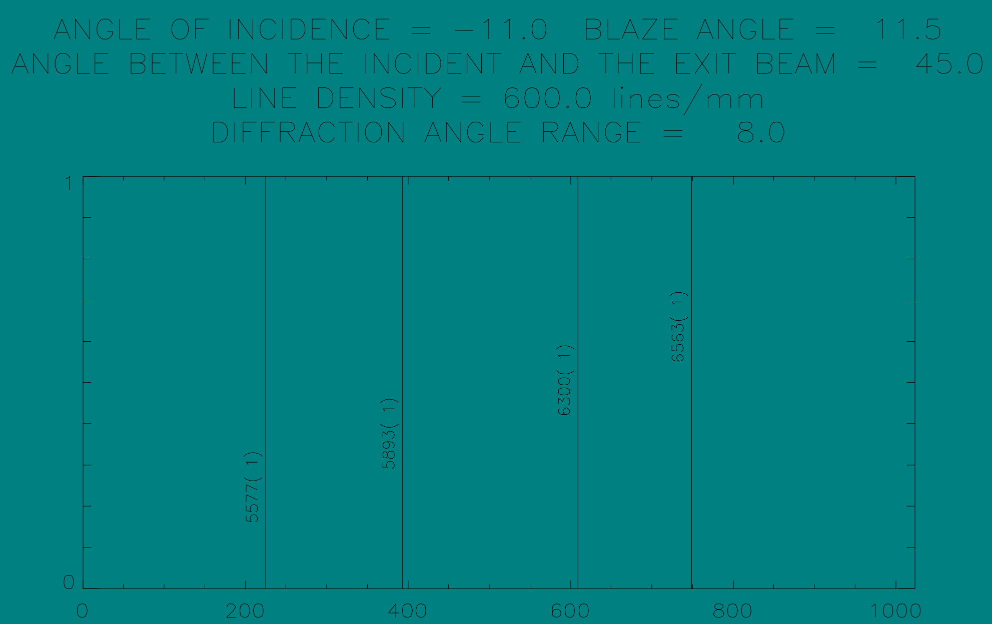


FIG 3b

Grating Equation

For reflection Gratings:

$$m\lambda = d\,(\sin\beta' + \sin\beta)$$

For Grisms:

$$m\lambda = d\,(n-1)\,(\sin\beta' + \sin\beta)$$

Slit Curvature

$$m\lambda = d\,(\sin\beta' + \sin\beta)\,(\cos\alpha)$$

$$\cos\alpha(\sin\beta + \sin\beta') = m\lambda/a$$

where a is the grating spacing (instead of $(a + b)$ as previously).

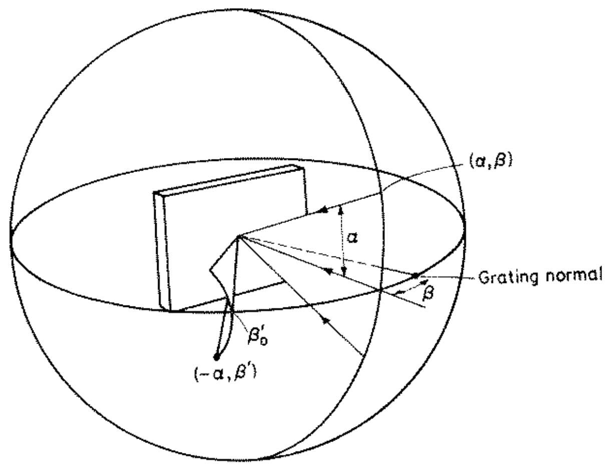


FIGURE 5.7(*a*). Radiation at oblique incidence from a straight slit not on the grating normal.

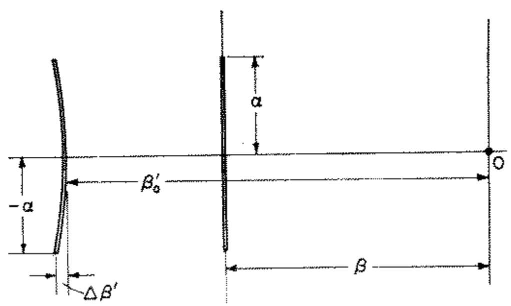
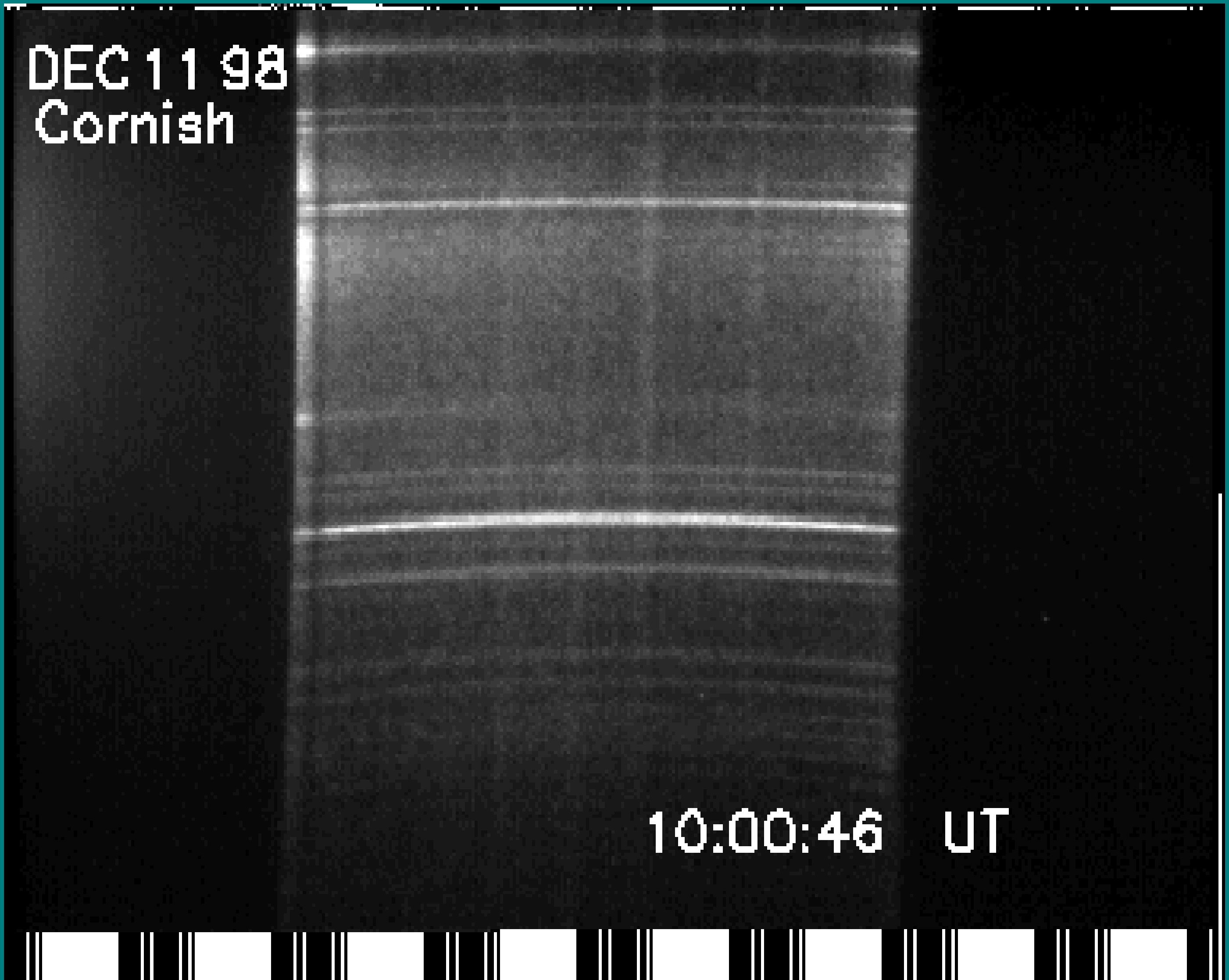
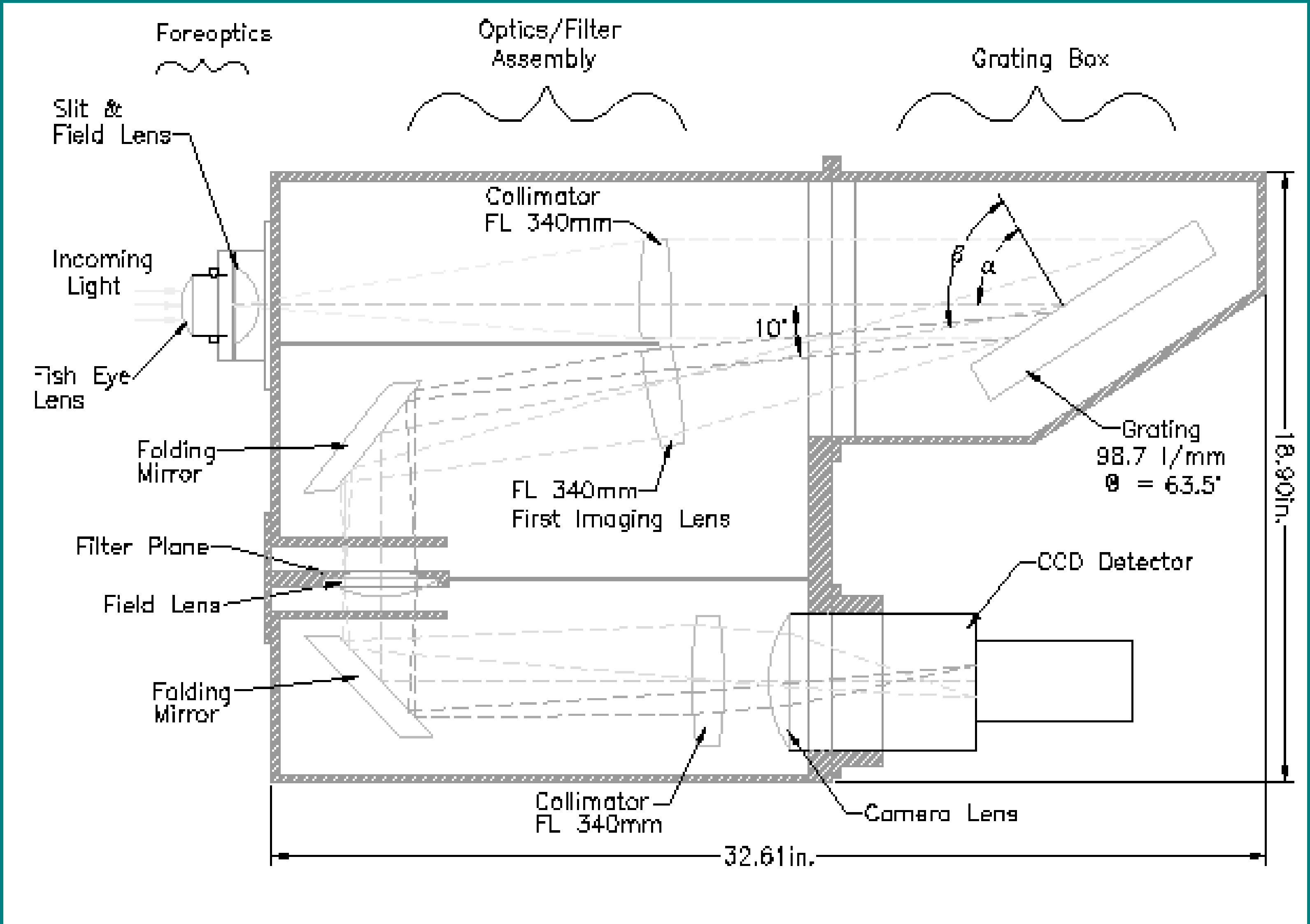


FIGURE 5.7(*b*). Radiation at oblique incidence from a straight slit. Mercator projection of the unit sphere, showing the formation of a parabolic image of the slit.

COTIF Spectra from Cornish Maine



HITIES Schematic



HITIES (cont.)

HITIES (cont.)

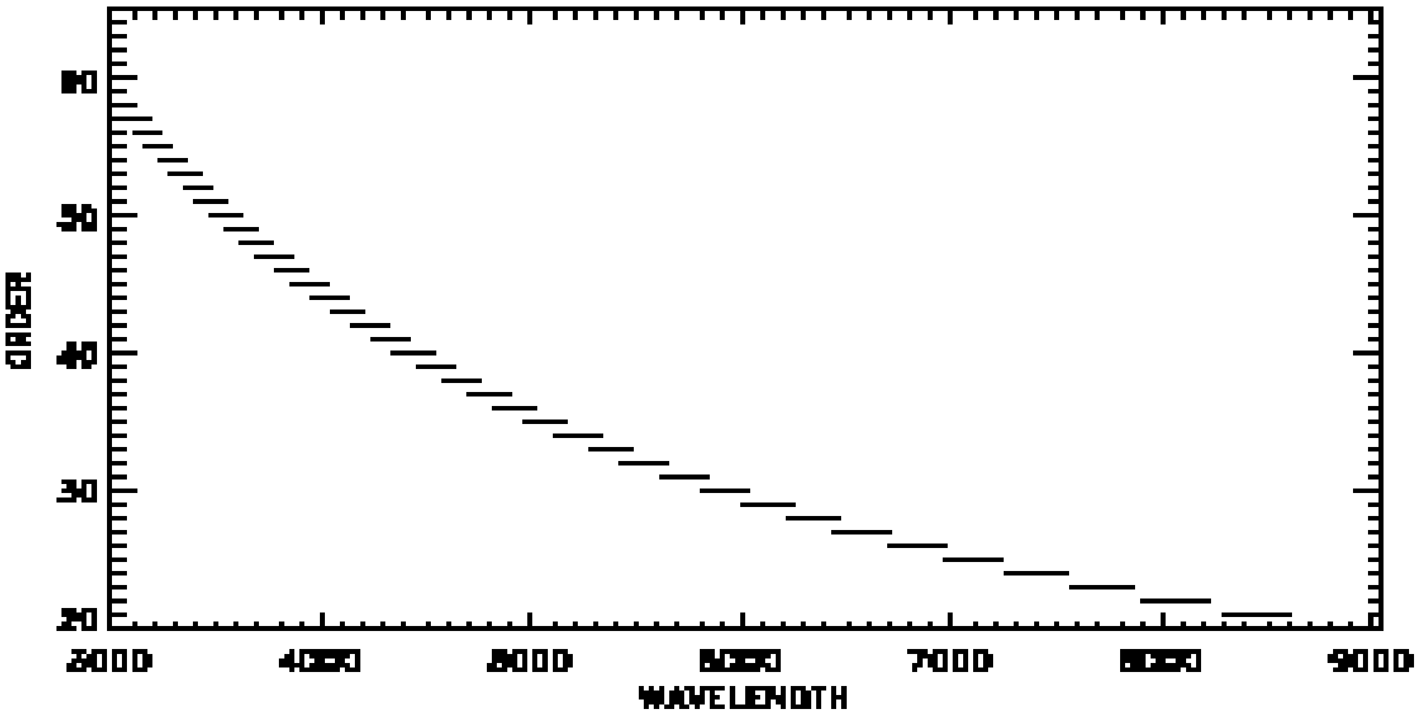
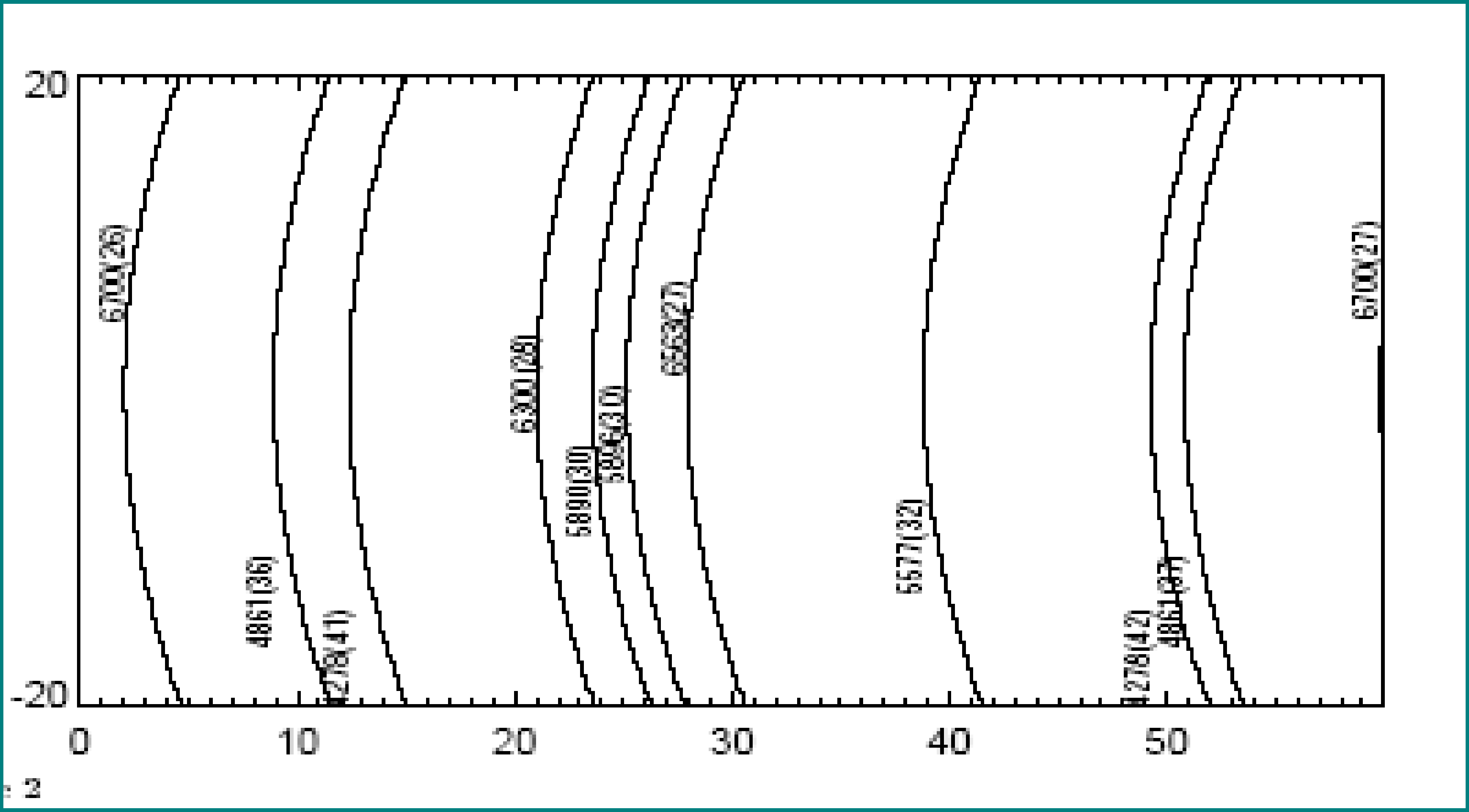


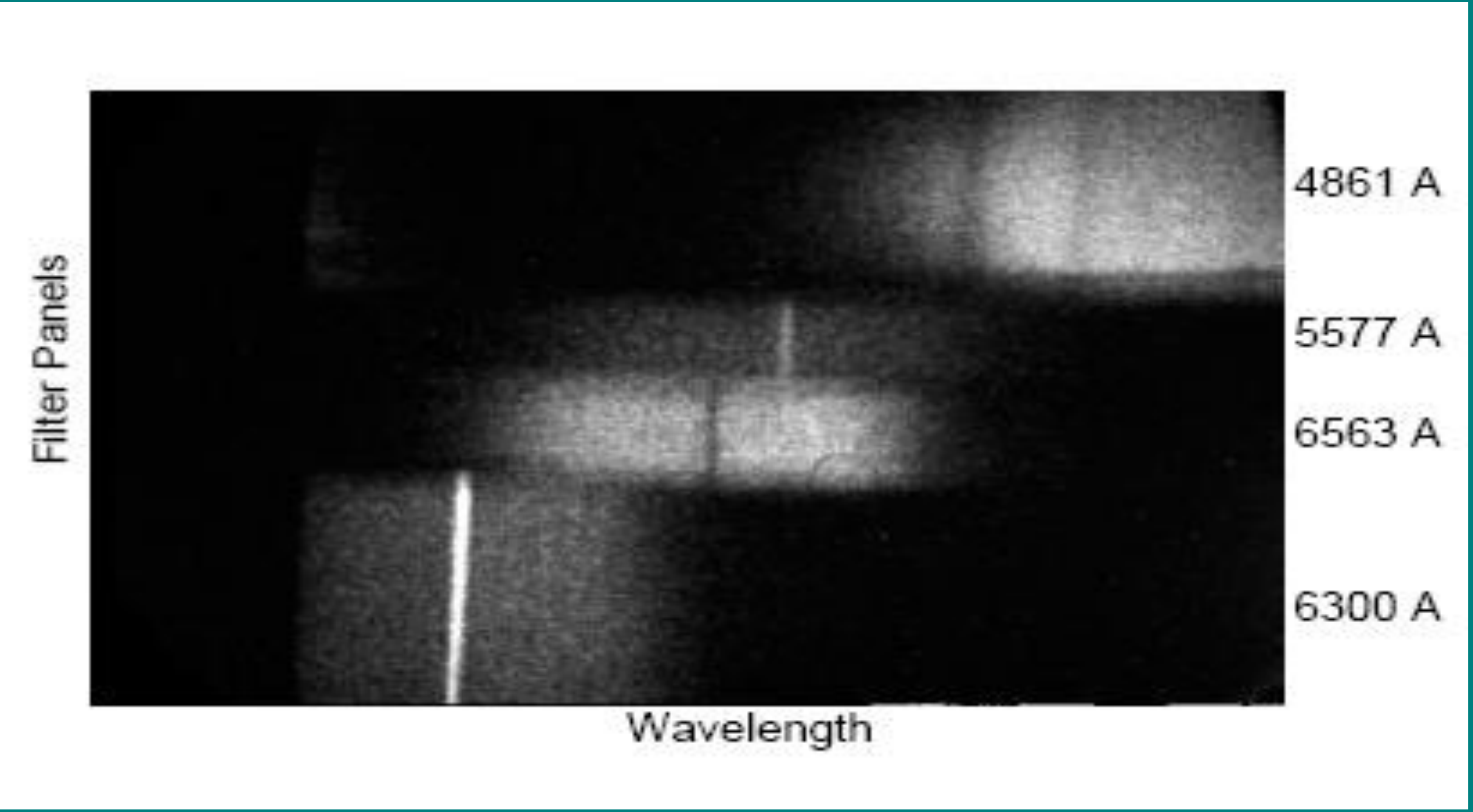
Figure 4

HITIES (cont.)

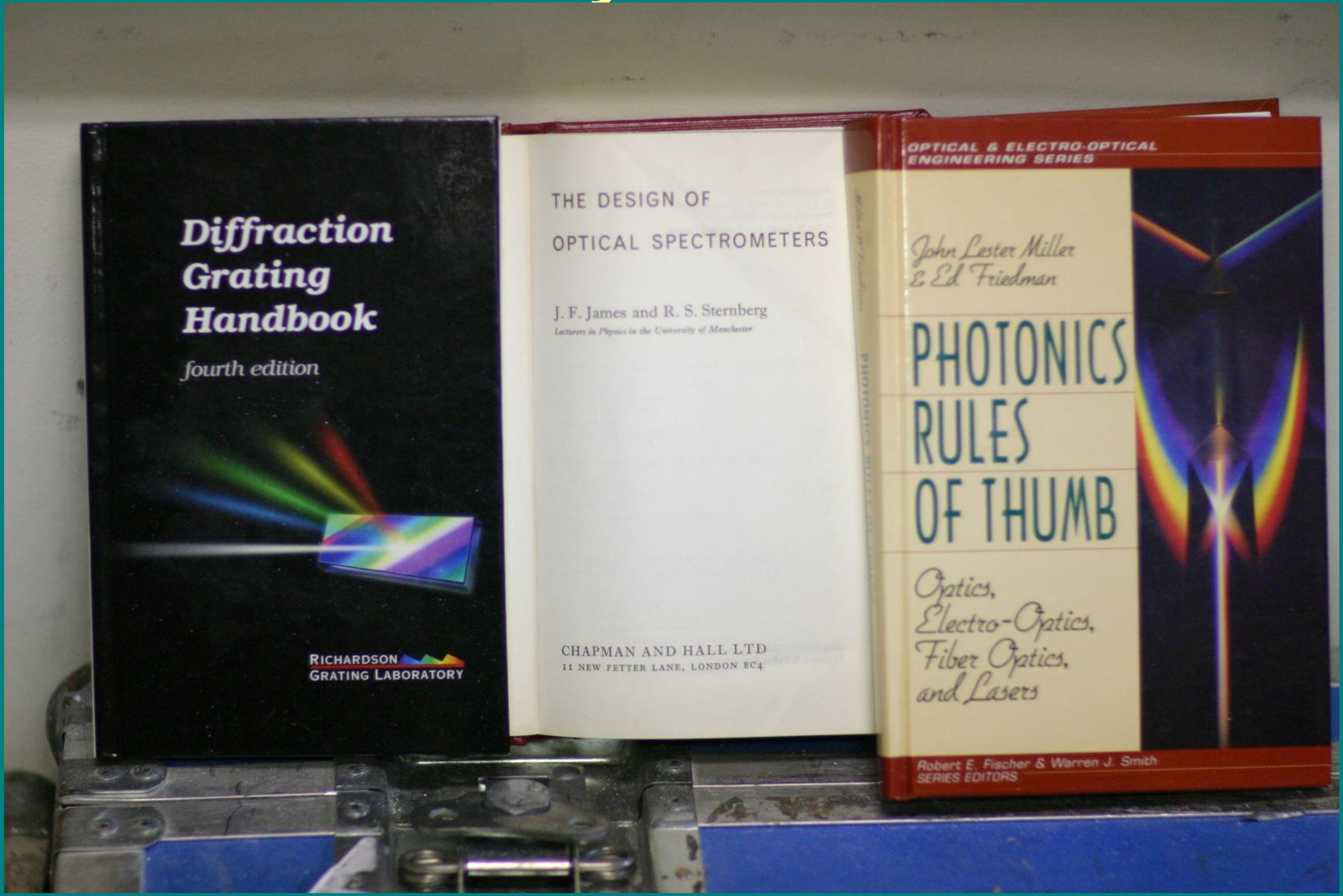


20
-20
0
10
20
30
40
50
6700(26)
4861(36)
6300(28)
5890(30)
6563(27)
5577(32)
6700(27)

HITIES (cont.)



Some Really Useful Books!



Don't hold you breath for this book!