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Optical characteristics of the EUV spectrometer for the normal-incidence region

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EUV spectrometer for SOLO

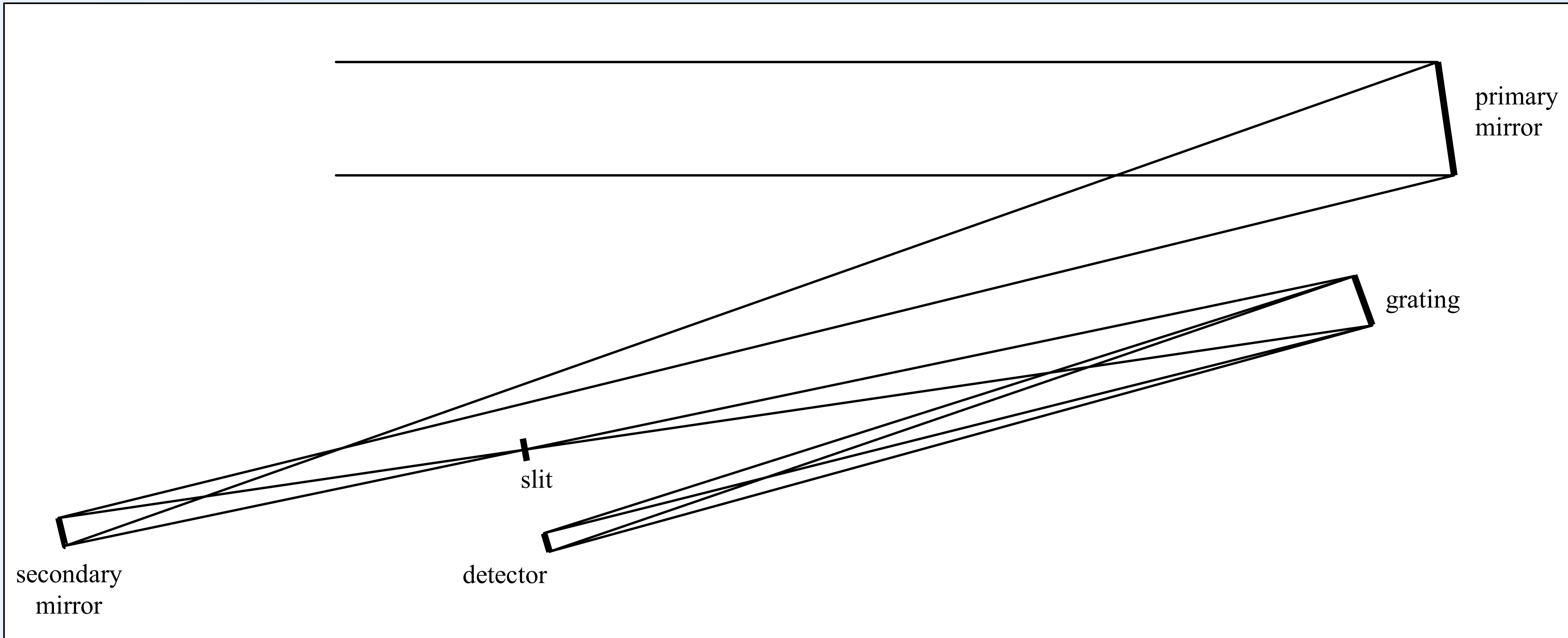
Two configurations have been analyzed:

Configuration A. A normal-incidence telescope feeding a normal-incidence variable-line-spaced-grating (VLS) spectrometer;

Configuration B. A grazing-incidence telescope feeding a normal-incidence VLS-grating spectrometer.

The spectral range of operation is the region 580-630 Å (first order)

Configuration A: normal-incidence telescope and normal-incidence VLS spectrometer (1/6)



ADVANTAGE:

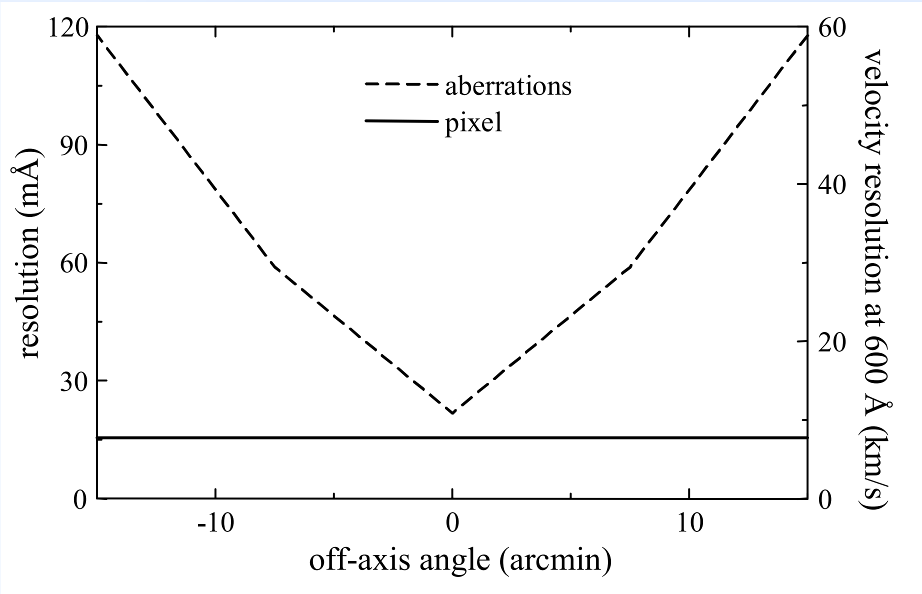
The size is 1.5 m × 0.6 m × 0.3 m

Configuration A: characteristics (2/6)

Telescope	Off-axis Gregorian
Entrance aperture	diameter 135 mm
Field of view	30 arcmin (‖ to the slit, simultaneous) 30 arcmin (⊥ to the slit, to be acquired by rastering)
Telescope tube	
Diameter	135 mm
Length	1500 mm
Primary mirror	
Diameter	120 mm
Focal length	1200 mm
Secondary mirror	
Entrance arm	300 mm
Exit arm	500 mm
Diameter	40 mm
Focal length	2000 mm
Slit	
Size	5 μm × 18 mm
Resolution ⊥ to the slit	0.5 arcsec
Spatial resolution @0.2 AU (⊥ to the slit)	75 km

Grating	VLS
Groove density	3600 lines/mm
Wavelength	580-630 Å
Entrance arm	915 mm
Exit arm	900 mm
Incidence angle	8.87°
Radius	900 mm
Size	55 (⊥ to the grooves) × 130 mm
Plate factor (I order)	3.1 Å/mm
Detector	
Pixel size	5 μm
Format	3200 × 3600 pixel
Area	16 (⊥ to the slit) × 18 mm
Spectral resolving element	15 mÅ
Velocity resolution	7.5 km/s
Spatial resolving element (// to the slit)	0.5 arcsec
Spatial resolution @0.2 AU (// to the slit)	75 km

Configuration A: optical performance (3/6)

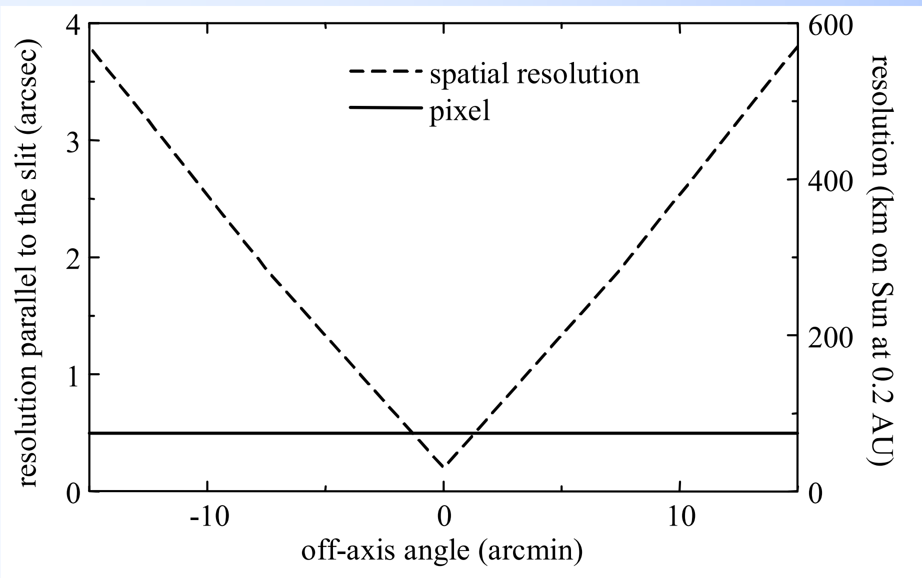


1)

1) Spectral resolution

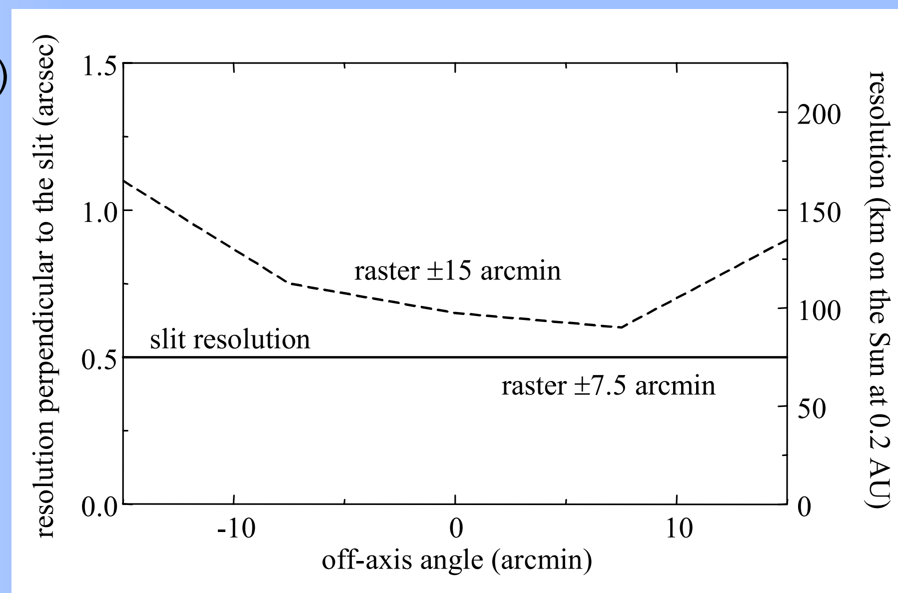
2) Spatial resolution parallel to the slit

3) Spatial resolution perpendicular to the slit



2)

3)



Configuration A: optical performance (4/6)

- The on-axis resolutions are limited by slit width and pixel size

- The telescope aperture is large (f/17)

⇒ this means that the also off-axis aberrations of the spectrometer are large

⇒ the off-axis spectral resolution and the spatial resolution parallel to the slit **are degraded by a factor 8** with respect to the nominal performance at the extremes of the field-of-view

OPEN QUESTIONS:

The optical performance of the telescope are severely degraded if the rastering is performed by a simple rotation of the secondary (or primary) mirror.

The **rastering** is performed by **rotating the secondary (or primary) mirror around its focal point**
The **image stabilisation** is performed by the same mechanism
⇒ **THE SCANNING MECHANISM IS COMPLEX** (exapod ?)

⇒ **THE FEASIBILITY OF THE VLS GRATING HAS TO BE EVALUATED** (130 mm in height)

Configuration A: effective area (5/6)

Primary mirror	Gold	0.13@600 A
Secondary mirror	SiC	0.32@600 A
Grating	SiC	
Grating efficiency	0.4	
Detector efficiency	0.4	

No filter in front of the detector

⇒ **EFFECTIVE AREA** 0.24 cm^2 @600 A

Emission from the line **10^{13} photons/cm^2/sr/s**

⇒ **COUNTS/LINE/S ON 0.5 × 0.5 ARCSEC** **14 c/s @600 A**

OPEN QUESTIONS:

⇒ **LOW COUNTS/PIXEL**

⇒ **LONG INTEGRATION TIME**

⇒ **WHY VERY HIGH SPATIAL RESOLUTION WITH VERY LOW TEMPORAL RESOLUTION ?**

Configuration A: thermal load @ 0.2 AU (6/6)

Entrance aperture area	143 cm^2
Entrance thermal load @ 0.2 AU	485 W
Flux stopped by the entrance tube	0.3
Thermal load on the primary	340 W
Primary absorption	65 W 0.58 W/cm^2 (4.3 solar constants)
Thermal load on the field-stop	275 W 2.4 W/cm^2 @ 60 deg (18 solar constants !) 250 W reflected toward the entrance aperture

OPEN QUESTIONS:

⇒ **FEASIBILITY OF THE FIELD-STOP**

⇒ **CONTAMINATION ON THE PRIMARY**

⇒ **RADIATORS (485 W entering, 235 W absorbed by the optics/structure)**

Configuration A with multilayer coatings (1/3)

The configuration A could be optimized for the spectral region 600 Å in I order and 300 Å in the II order, by using multilayer coated optics.

CONVENTIONAL MULTILAYER OPTICS

A conventional multilayer coating has **poor visible reflectivity** (around 0.5)

• the absorbed power is very high

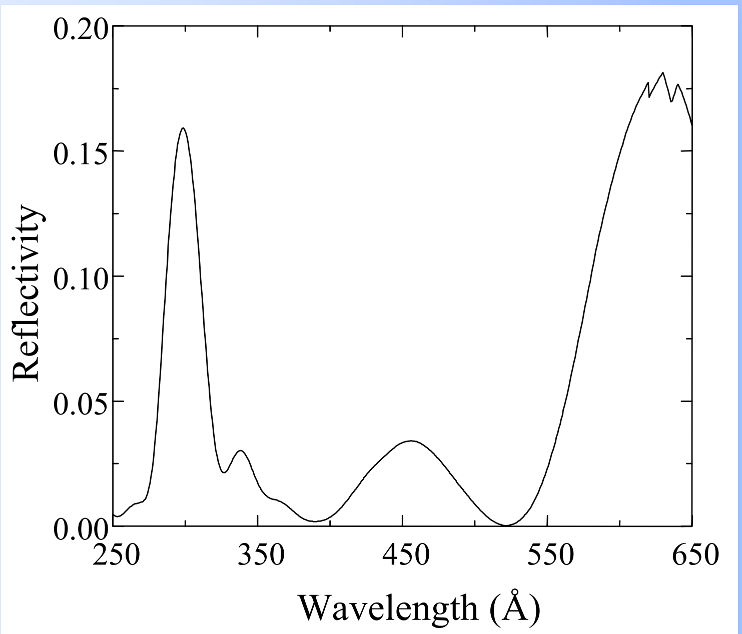
⇒ **It is difficult to use a multilayer coated element as the first optical element at 0.2 AU**

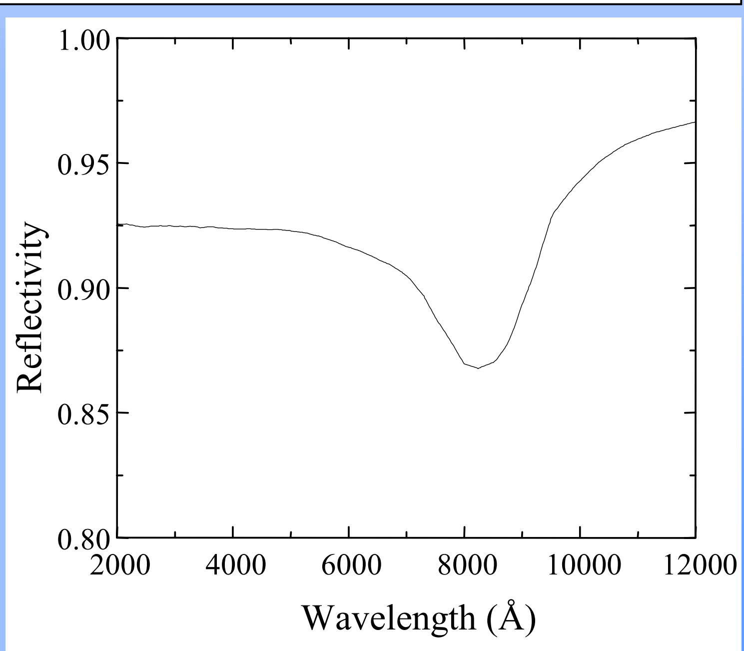
MULTILAYER OPTICS WITH A THIN ALUMINUM LAYER

The **visible reflectivity** could be higher (≈0.9)

• the absorbed power is low

Al cap layer
Si-C multilayer





Configuration A with multilayer coatings: effective area (2/3)

Optics	Multilayer 0.20@600 A	0.20@300 A
Grating efficiency	0.4	
Detector efficiency	0.4	
No filter in front of the detector		
$\Rightarrow$ **EFFECTIVE AREA**	0.18 cm^2 @600 A	0.18 cm^2@300 A

Emission from the line	**10^{13} photons/cm^2/sr/s**	
$\Rightarrow$ **COUNTS/LINE/S ON 0.5 $\times$ 0.5 ARCSEC**	**10 c/s @600 A**	**10 c/s @300 A**

Configuration A with multilayer coatings: thermal load @ 0.2 AU (3/3)

Entrance aperture area	143 cm^2
Entrance thermal load @ 0.2 AU	485 W
Flux stopped by the entrance tube	0.3
Thermal load on the primary	340 W
Primary absorption	34 W 0.29 W/cm^2 (2.2 solar constants)
Thermal load on the field-stop	306 W 2.7 W/cm^2 @ 60 deg (20 solar constants !) 275 W reflected toward the entrance aperture

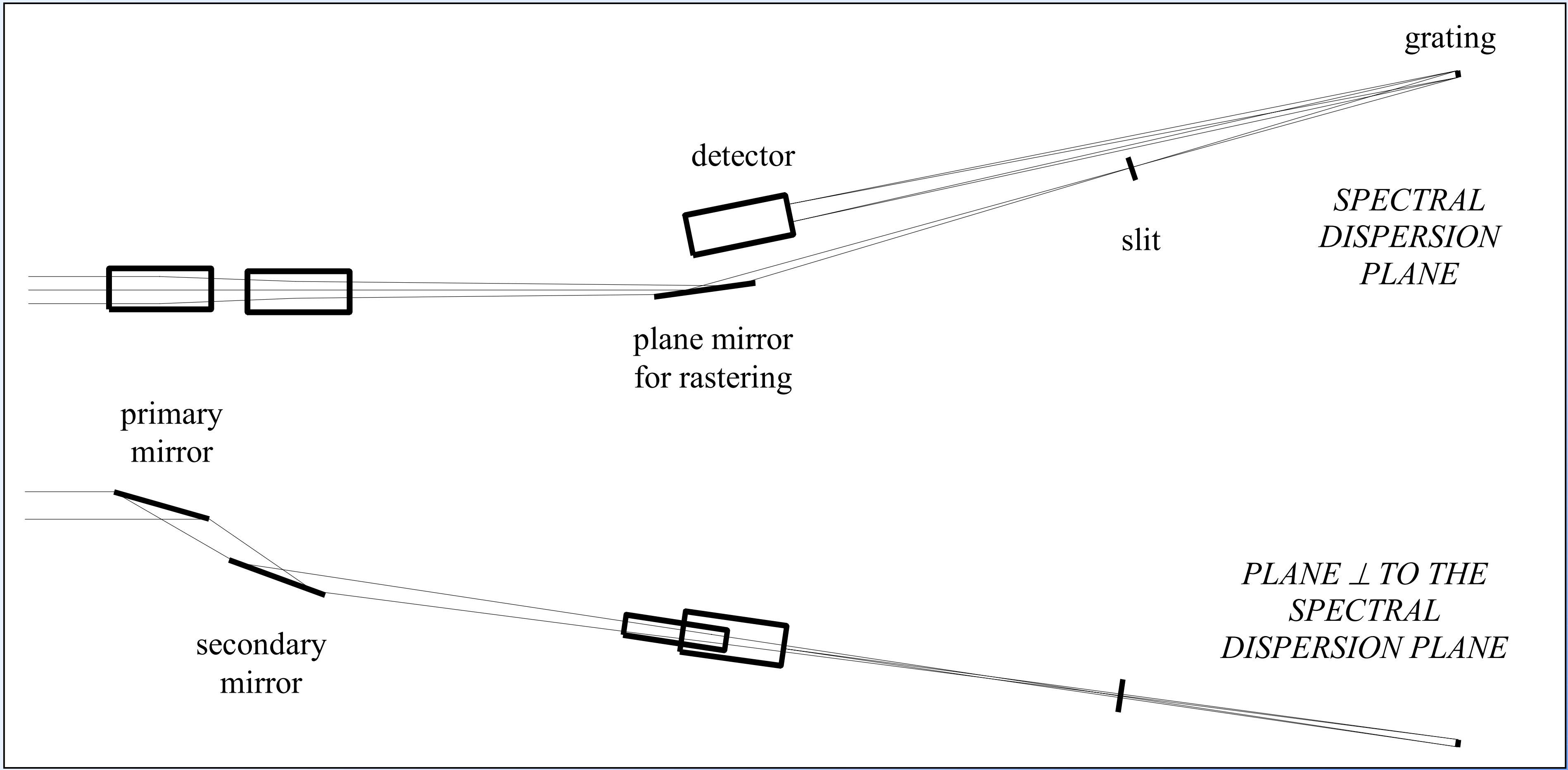
OPEN QUESTIONS:

⇒ LOW COUNTS/SEC

⇒ FIELD-STOP FEASIBILITY

⇒ RADIATORS (485 W entering, 210 W absorbed by the optics/structure)

Configuration B: grazing-incidence telescope and normal-incidence VLS-grating spectrometer (1/6)



SIZE:

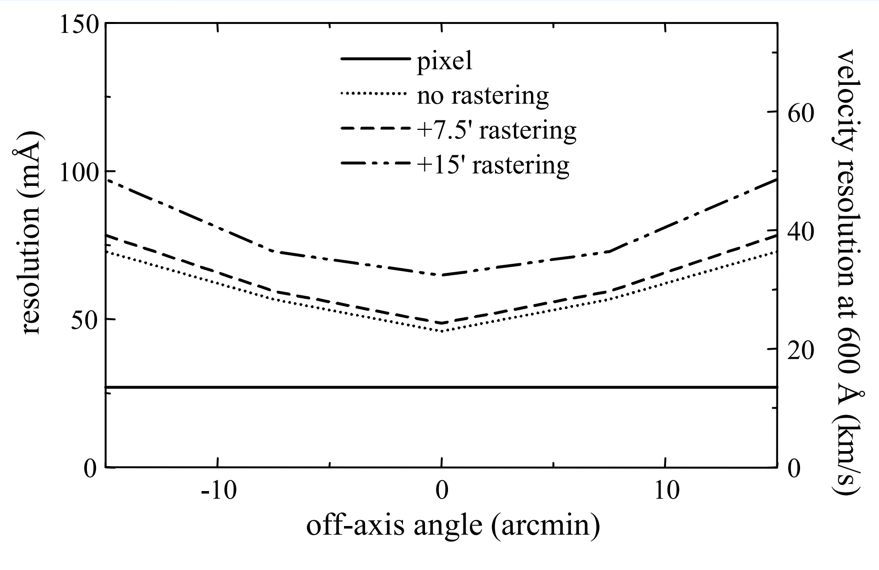
The size is 2.0 m × 0.4 m × 0.4 m

Configuration B: characteristics (2/6)

Telescope	Wolter II
Field of view	30 arcmin (‖ to the slit, simultaneous) 30 arcmin (⊥ to the slit, to be acquired by rastering)
Entrance aperture	
Size	35 mm × 35 mm
Primary mirror	Paraboloid
Size	130 mm × 35 mm
Incidence angle	74°
Secondary mirror	Hyperboloid
Distance from the primary	200 mm
Distance from the slit	1250 mm
Size	120 mm × 25 mm
Incidence angle	78°
Focal length	2030 mm
Mirror for the rastering	Plane
Distance from the slit	650 mm
Size	130 mm × 25 mm
Incidence angle	81°
Slit	
Size	10 μm × 18 mm
Resolution ⊥ to the slit	1 arcsec

Grating	Spherical VLS
Central groove density	3600 lines/mm
Wavelength	580-630 Å (II order)
Entrance arm	500 mm
Exit arm	1035 mm
Incidence angle	8.5°
Radius	670 mm
Size	20 (⊥ to the grooves) × 35 mm
Plate factor (I order)	2.7 Å/mm
Detector	
Pixel size	10 μm × 20 μm
Format	1850 × 1800 pixel
Area	18.5 (⊥ to the slit) × 36 mm
Spectral resolving element	27 mÅ
Velocity resolution	13.5 km/s
Spatial resolving element (// to the slit)	1 arcsec
Spatial resolution @0.2 AU (// to the slit)	150 km

Configuration B: optical performance (3/6)

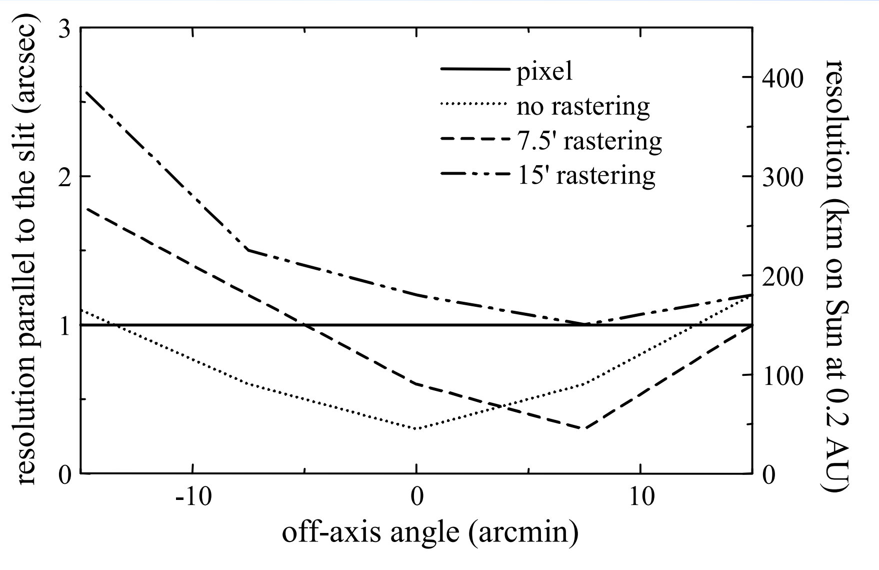


1)

1) Spectral resolution

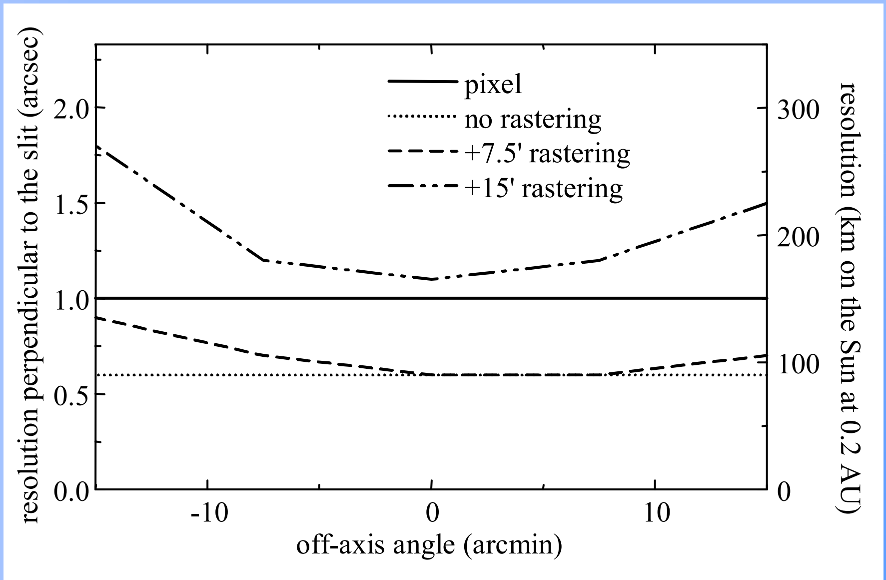
2) Spatial resolution parallel to the slit

3) Spatial resolution perpendicular to the slit



2)

3)



Configuration B: optical performance (4/6)

- The telescope aperture is relatively low (f/55)

⇒ this means that the also off-axis aberrations of the spectrometer are low

- The spatial resolution is almost limited by slit width and pixel size on the whole FOV // to the slit and on ±7.5’ ⊥ to the slit

⇒ the medium spatial resolution decreases to ≈1.5 arcsec when rastering at ±15’

⇒ the spectral aberrations are 2-3 pixels: a centroiding technique can be used for sub-pixel resolution

REMARKS

The **image stabilisation** is performed by two independent rotations of the plane mirror (simple mechanism)
The **rastering** is performed by a rotation of the plane mirror (simple mechanism)
The VLS grating has a small ruled area (feasible)

OPEN QUESTIONS
The total length is 2 m

Configuration B: effective area (5/6)

Primary mirror	Si + Gold	0.70@600 A
Secondary mirror	Si + Gold	0.75@600 A
Plane mirror	Si + Gold	0.80@600 A
Grating	SiC	0.32@600 A
Grating efficiency	0.4	
Detector efficiency	0.4	

No filter in front of the detector

⇒ **EFFECTIVE AREA** 0.26 cm^2 @600 A

Emission from the line **10^{13} photons/cm^2/sr/s**

⇒ **COUNTS/LINE/S ON 1 × 1 ARCSEC** **60 c/s @600 A**

REMARKS:

⇒ **JUSTIFY THE HIGH SPATIAL RESOLUTION WITH RELATIVELY LOW TEMPORAL RESOLUTION**

Configuration B: thermal load @ 0.2 AU (6/6)

Entrance aperture area	12.3 cm^2
Entrance thermal load @ 0.2 AU	42 W
Thermal load on the primary	42 W
Primary absorption	9 W 0.18 W/cm^2 (1.3 solar constants)
Thermal load on the secondary	33 W
Secondary absorption	7 W 0.23 W/cm^2 (1.7 solar constants)
Thermal load on the plane mirror	16 W (0.60 of the power reflected from the secondary)
Plane mirror absorption	3 W 0.10 W/cm^2 (0.7 solar constants)

REMARKS:

$\Rightarrow$ **RADIATORS (42 W entering, 42 W absorbed by the optics/structure)**

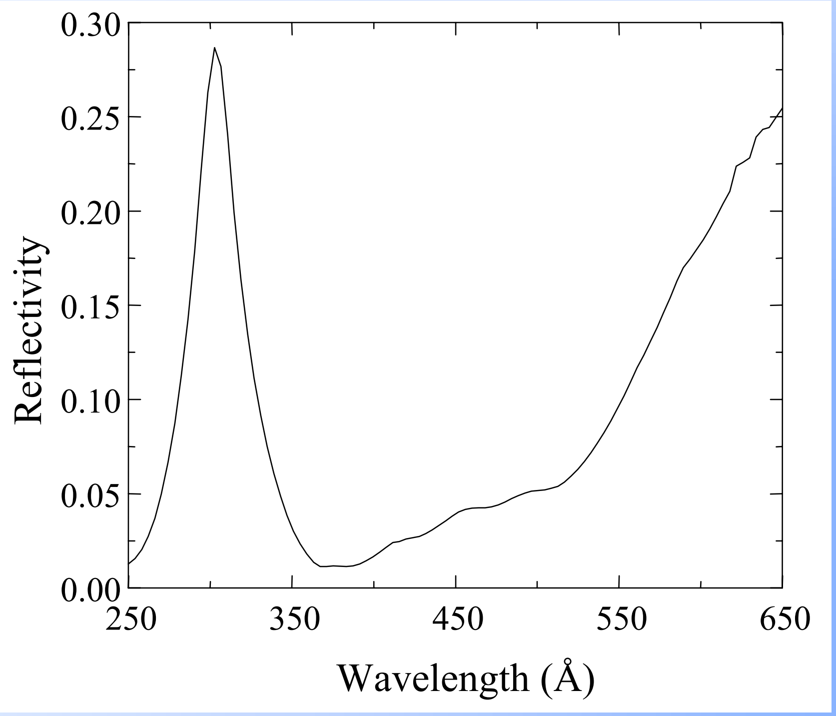
Configuration B with multilayer coatings (1/2)

The configuration B could be optimized for the spectral region 600 Å in I order and 300 Å in the II order, by using a multilayer coated grating.

THE MULTILAYER IS DEPOSITED ONLY ON THE GRATING
⇒ NO THERMAL LOAD

SiC cap layer (100 Å)

Mo-Si multilayer
N=10
d=164 Å
gamma=0.8



Configuration B with multilayer coatings: effective area (2/2)

Primary mirror	Si + Gold	0.70@600 A	0.65@300 A
Secondary mirror	Si + Gold	0.75@600 A	0.70@300 A
Plane mirror	Si + Gold	0.80@600 A	0.75@300 A
Grating	Multilayer	0.15@600 A	0.25@300 A
Grating efficiency	0.4		
Detector efficiency	0.4		

No filter in front of the detector

$\Rightarrow$ **EFFECTIVE AREA** 0.12 cm^2 @600 A 0.17 cm^2 @600 A

Emission from the line **10^{13} photons/cm^2/sr/s**

$\Rightarrow$ **COUNTS/LINE/S ON 0.5 $\times$ 0.5 ARCSEC** **28 c/s @600 A** **40 c/s @300 A**

Conclusions (1/5)

- **Two configurations for an imaging spectrometer at 600 Å**
  - **A) normal-incidence telescope and VLS-grating spectrometer**
  - **B) grazing-incidence telescope and VLS-grating spectrometer**

- **Optical performance**
  - **the on-axis performance are better for configuration A (7.5 km/s versus 13.5 km/s and 0.5 arcsec versus 1 arcsec)**
  - **the off-axis spectral aberrations are higher for configuration A (60 km/s versus 50 km/s)**
  - **the off-axis spatial aberrations parallel to the slit are better for configuration B (2.5 arcsec versus 4 arcsec)**
  - **the off-axis spatial aberrations perpendicular to the slit are better for configuration A (1 arcsec versus 1.8 arcsec)**

Configuration B gives more uniform performance on the whole field-of-view and a spatial resolution of 0.2 arcsec from Earth (best case) and 0.35 arcsec (worst case)

Conclusions (2/5)

- **Rastering**
  - **Configuration A: the rastering has to be performed by rotating the secondary mirror around its focal point ⇒ complex mechanism**
  - **Configuration B: the rastering is performed by a simple rotation of a plane mirror**
- **Grating feasibility**
  - **Configuration A: the VLS grating is very large in height (13 cm) ⇒ it is difficult to obtain straight lines on such a large area ⇒ the of-axis aberrations could be higher than the theoretical calculations**
- **Effective area**
  - **The effective area is similar**
  - **The counts per pixel of configuration B are ≈4 times higher due to the lower resolution**

Conclusions (3/5)

- **Counts/pixel**
  - **Configuration A: on a relatively intense line, the counts per pixel per second are ≈14 c/s (on the whole line) ⇒ integration times of the order of tens of seconds are expected**
  - **Configuration B: on a relatively intense line, the counts per second are ≈60 c/s (on the whole line) ⇒ integration times of the order of several seconds are expected**

- **Thermal load**
  - **Configuration A: ≈500 W are entering into the instrument and ≈260 W are absorbed by the optics/structure**
  - **Configuration B: ≈40 W are entering into the instrument and absorbed by the optics/structure**
  - **THE THERMAL LOAD IN CONFIGURATION B IS MORE THAN 10 TIMES LOWER, THE ABSORBED POWER IS 6 TIMES LOWER**

Conclusions (4/5)

- Optics degradation
  - The decrease in reflectivity due to contamination effects is expected to be considerably higher for configuration A, due to the normal incidence and to the higher thermal load
- Size
  - Configuration A: the total length is 1.5 m
  - Configuration B: the total length is 2.0 m
- Use of multilayer coatings
  - Configuration A: the primary mirror (looking directly at the Sun) must be multilayer coated
    - high thermal load on the multilayer
  - Configuration B: the grating only must be multilayer coated
    - no thermal load on the multilayer

Conclusions (5/5)