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Grazing-incidence stigmatic telescope-spectrometer

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Grazing-incidence spectroscopy on the Solar Orbiter

The grazing-incidence region (below ≈40 nm) is particularly rich in spectral lines for diagnostics of temperature, density, abundances and flows

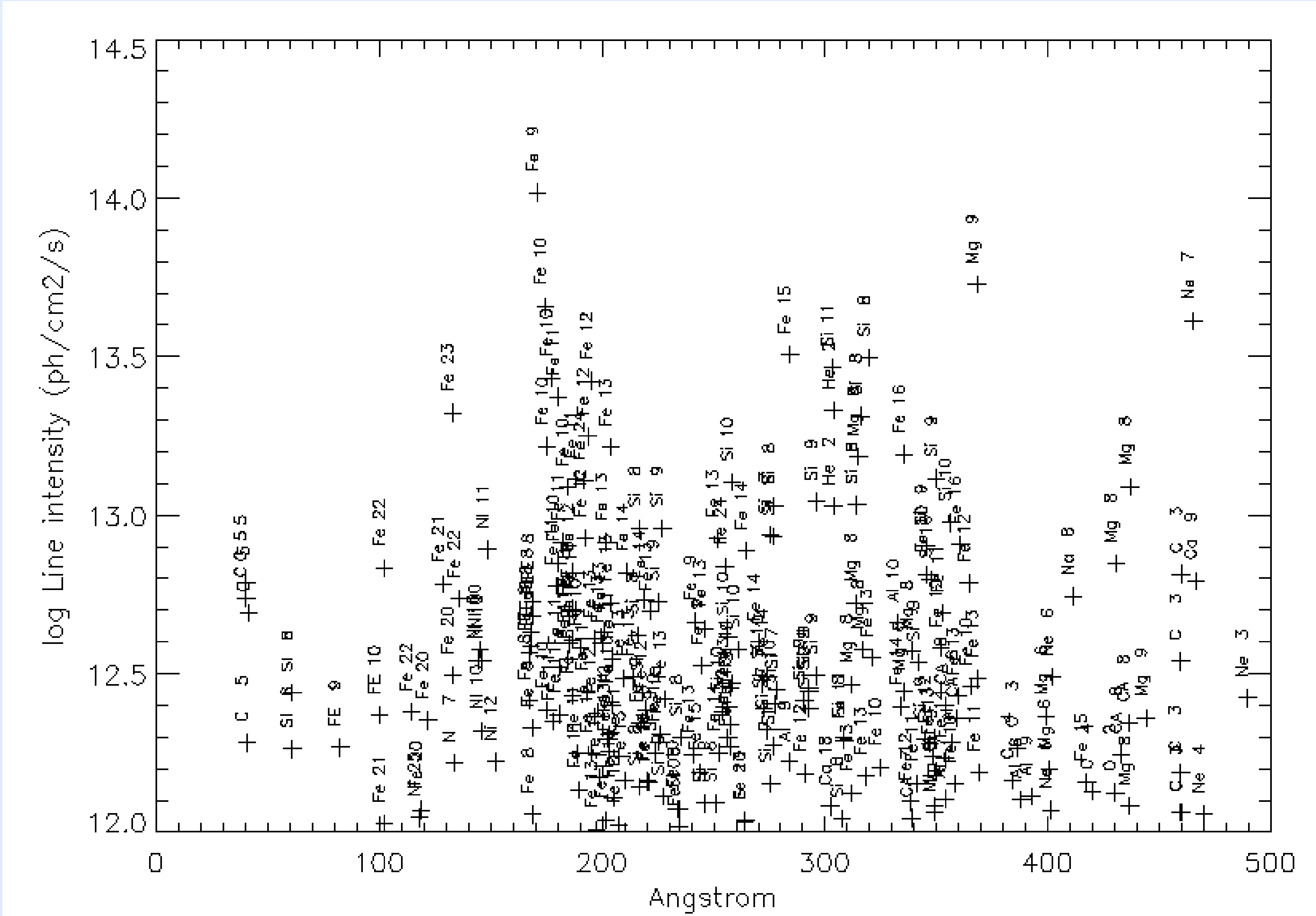
It is meaningful to analyze the possibility of mounting on SOLO a telescope-spectrometer with grazing-incidence optics for the shorter wavelength region complementary to the normal-incidence spectrometer EUS.

This spectrograph performs **imaging spectroscopy of extended solar regions.**

As a region particularly reach in spectral lines for temperature and density diagnostics, we baseline the **17-25 nm range.**

Spectroscopy in the 8-40 nm region (1/3)

Emission of the most intense lines with their related ion



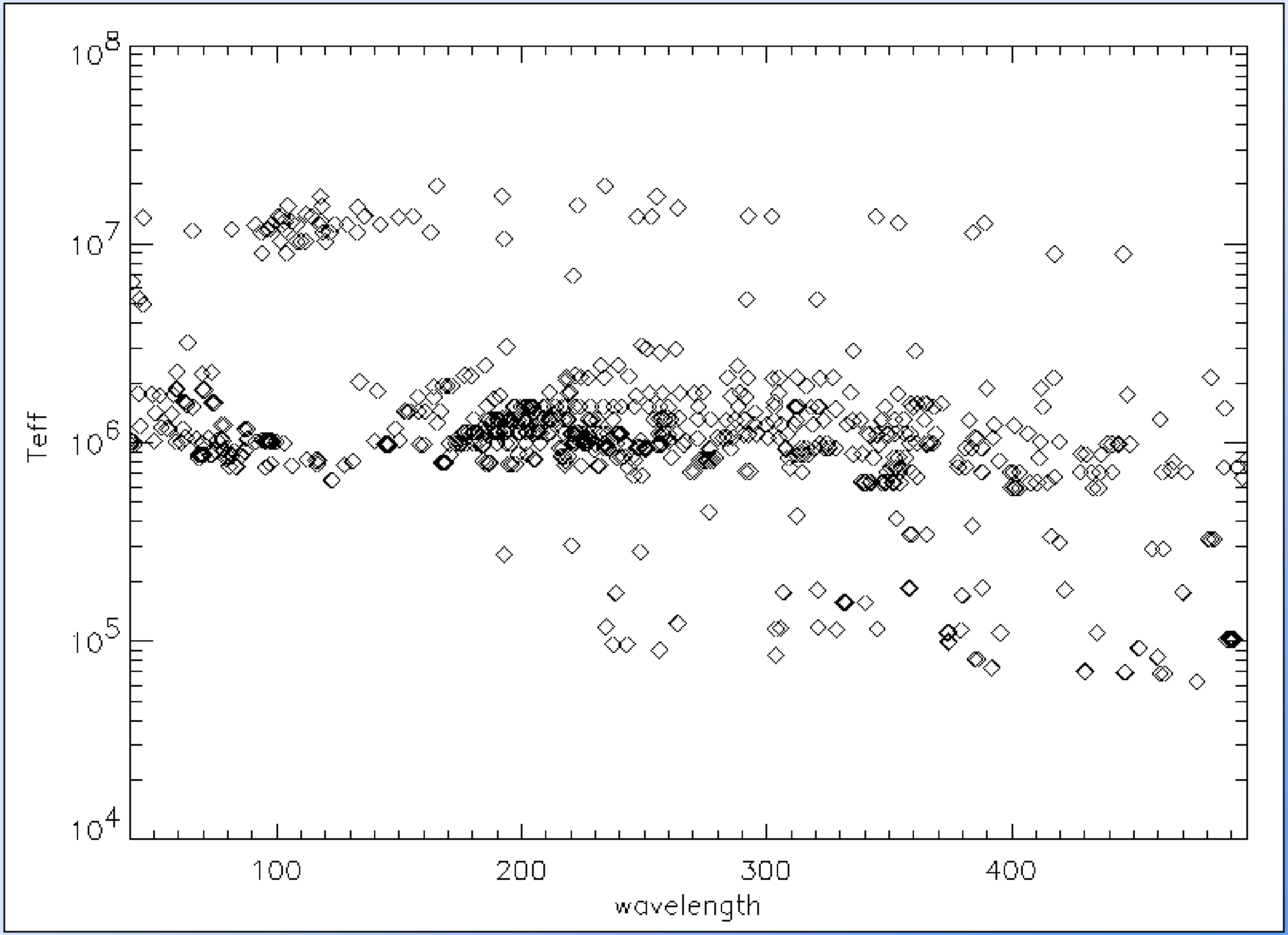
Spectroscopy in the 8-40 nm region (2/3)

Simulation of a situation of medium solar activity with a normal flare

Emission temperature of lines exceeding $2 \cdot 10^{11}$ photons/cm^2/s on Sun

Most of the lines characterizing the 10^6 K region, and partially the flare and the 10^5 K region, are found in the **15-25 nm region**

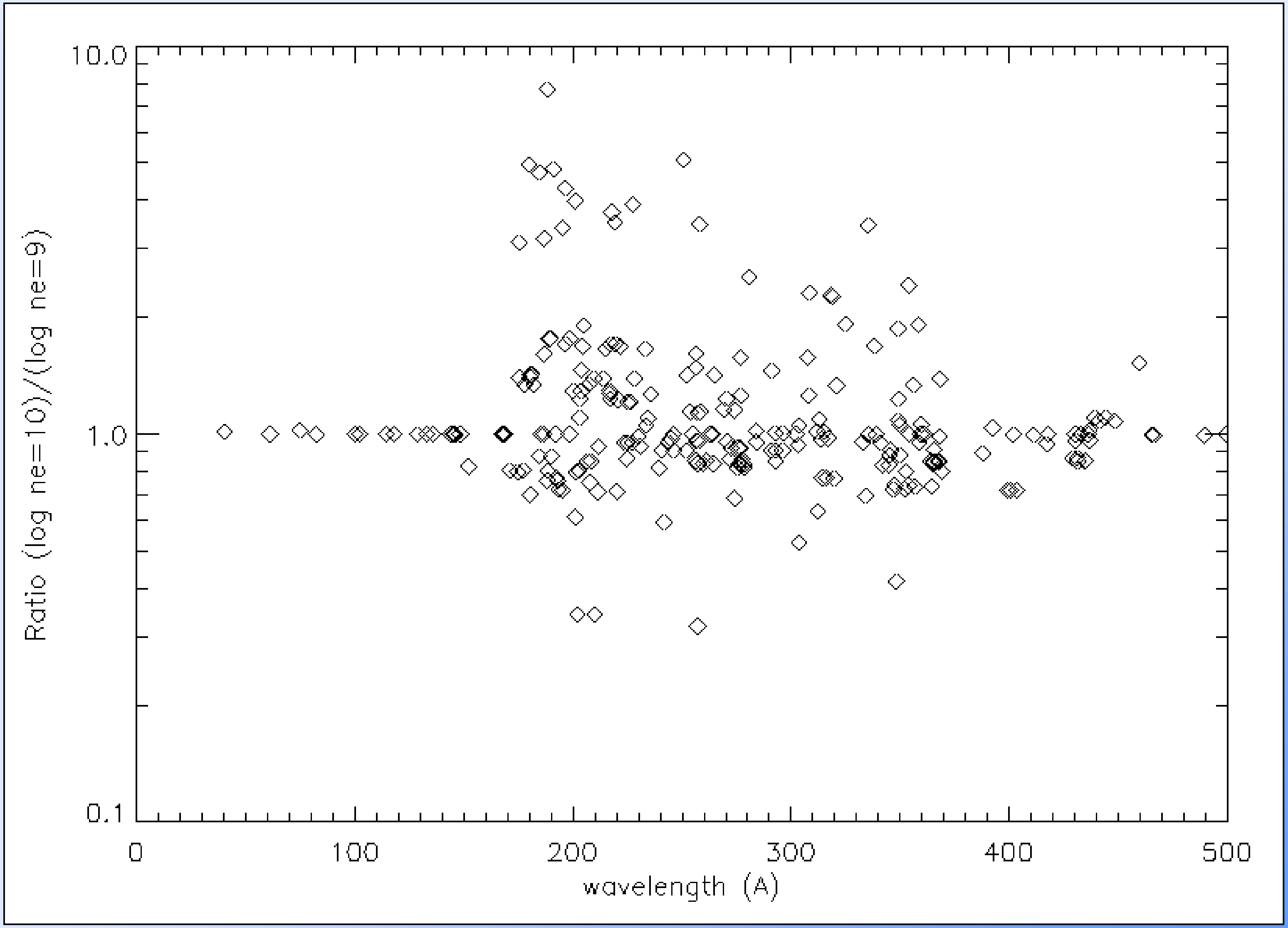
In addition, the flare is well characterized by lines in the **8-13 nm region**.



Spectroscopy in the 8-40 nm region (3/3)

Ratio of the line intensities with density $n_e=10^{10}$ cm^{-3} over line intensities with $n_e=10^9$ cm^{-3}

The 18-24 nm region has a discrete number of density- dependent lines.



Grazing-incidence stigmatic spectrometers for extended regions (1/2)

The spectrum acquired by a grating spectrometer has information on the spatial distribution of an extended source only in the plane perpendicular to the plane of spectral dispersion (i.e. parallel to the entrance slit)

In the case of an **astigmatic spectrometer**, only **spectral aberrations are corrected**

⇒A point-like source on the entrance slit is imaged on the focal plane as a narrow and slightly curved line parallel to the slit itself

⇒Two-dimensional images are built scanning over the whole region to be observed point by point (e.g. CDS/SOHO)

In a **stigmatic spectrometer**, optical aberrations are corrected both on the plane of dispersion and on the plane perpendicular to this

⇒A point-like source on the entrance slit is imaged on the focal plane as a point

⇒Two-dimensional images are built scanning only in the direction perpendicular to the slit

Grazing-incidence stigmatic spectrometers for extended regions (2/2)

The **stigmaticity** is guaranteed in an extended field-of-view parallel to the entrance slit only in **normal-incidence** configurations

⇒Stigmatic spectrometers with a **single optic**, namely the grating, are being successfully used in EUV space applications (e.g. UVCS/SOHO)

In **grazing-incidence** configurations, the correction of the astigmatism in an extended spectral region requires at least **two optics**

⇒The aberrations are more severe than in the normal-incidence case: it is more difficult to obtain a large field-of-view parallel to the slit

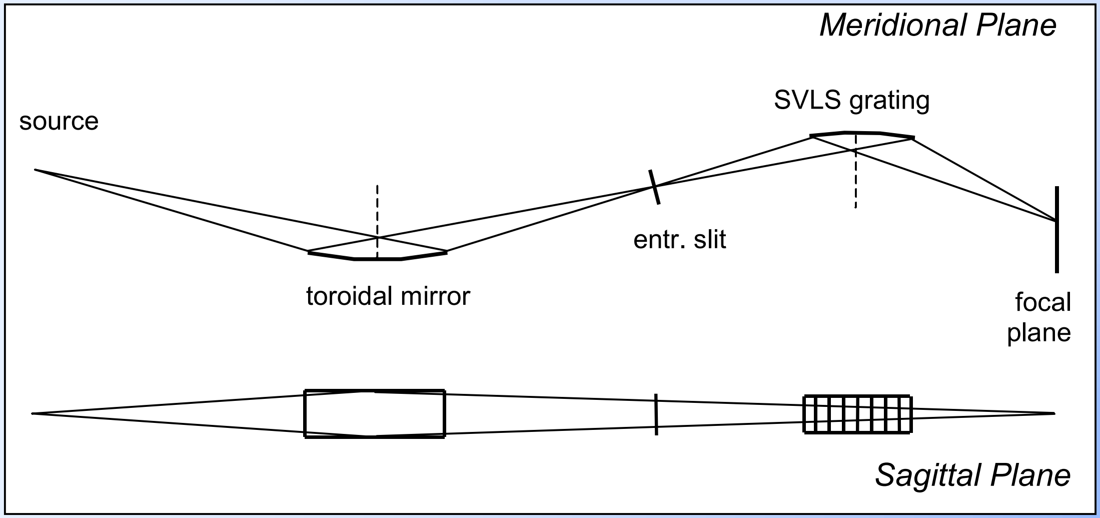
Classical designs for grazing-incidence spectrometers (e.g. CDS/SOHO) use the **ROWLAND CONFIGURATION**

⇒**In Rowland configurations it is very difficult to correct for the astigmatism in an extended spectral region and in an extended field-of-view**

Stigmatic grazing-incidence configurations with VLS gratings

In a **variable-line-spaced (VLS) grating** the groove density changes along the surface following a polynomial law

⇒The grating parameters can be chosen to obtain a **<u>nearly flat focal field at normal incidence on the detector</u>**



Spherical VLS (SVLS) grating with a toroidal mirror that corrects for the astigmatism

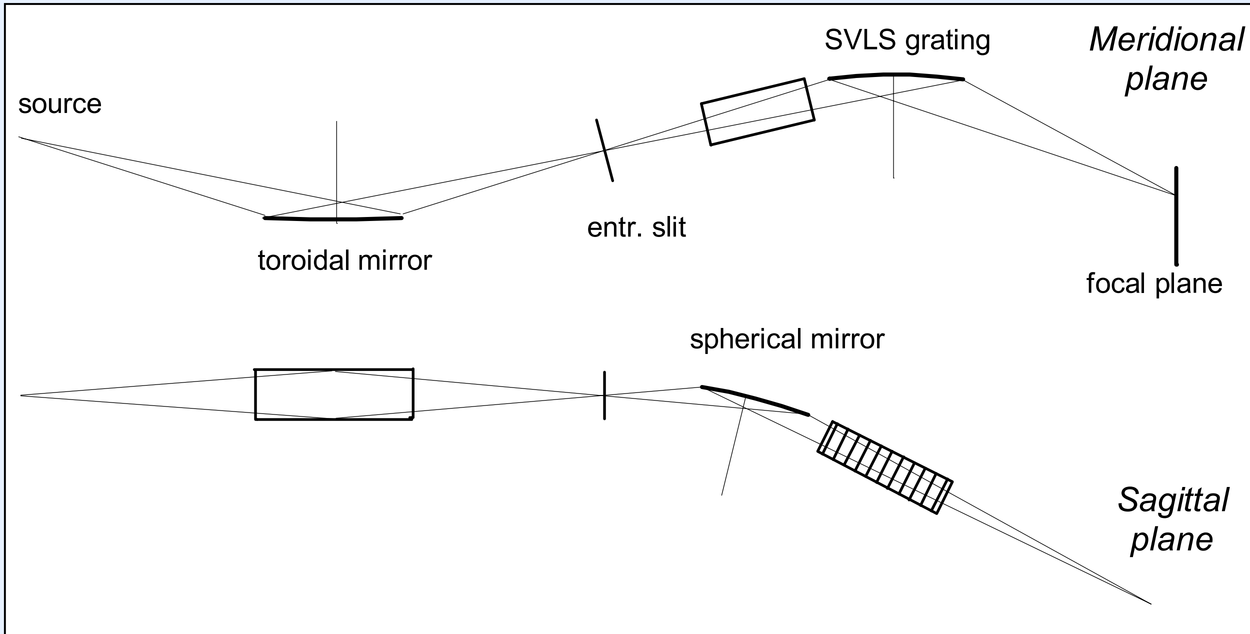
In existing stigmatic configurations with VLS gratings

⇒ The image is **<u>stigmatic only on-axis</u>** but ...

⇒ high spectral and spatial aberrations are expected for off-axis points

⇒ **<u>The spectral and spatial resolutions are not preserved in the direction parallel to the slit for extended sources</u>**

Configuration with a SVLS grating and a crossed spherical mirror



The spherical mirror is mounted **with its tangential plane coinciding with the grating equatorial plane**

⇒The spherical mirror focuses the radiation in the direction parallel to the slit

⇒The SVLS grating focuses the radiation in the direction perpendicular to the slit

ADVANTAGES

⇒**The off-axis spectral aberrations are constant**

⇒**<u>The spectral resolution is preserved also for off-axis points</u>**

Grazing-incidence telescope-spectrometer with spatial resolution capability for solar imaging spectroscopy (1/2)

The crossed configuration is applied to a **telescope-spectrometer** for EUV solar observations.

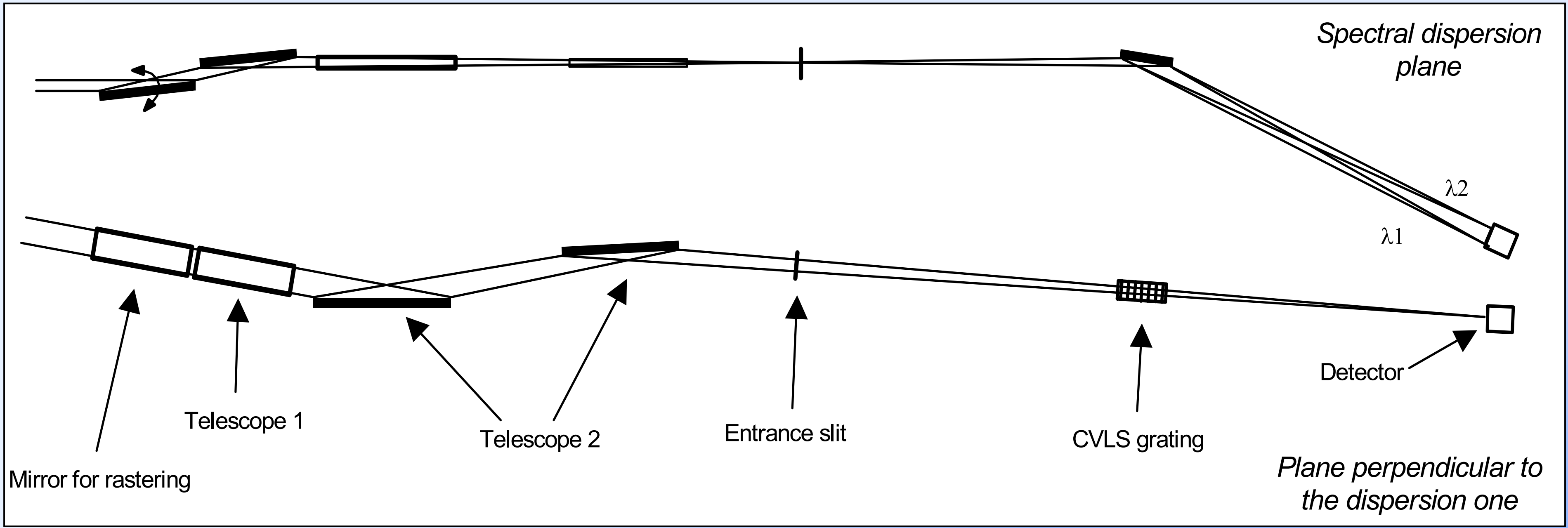
The **telescope** is divided into two sections:

- **Telescope 1**: one grazing-incidence mirror focusing the radiation on the entrance slit of the spectrometer only in the direction perpendicular to the slit.
- **Telescope 2**: two grazing-incidence mirrors in Wolter configuration, focusing the radiation on the focal plane only in the direction parallel to the slit.

The **spectrometer** consists of a grazing-incidence cylindrical VLS (CVLS) grating with flat-field properties.

⇒**The telescope 2 is crossed with respect to the grating and to the telescope 1**.

Grazing-incidence telescope-spectrometer with spatial resolution capability for solar imaging spectroscopy (2/2)

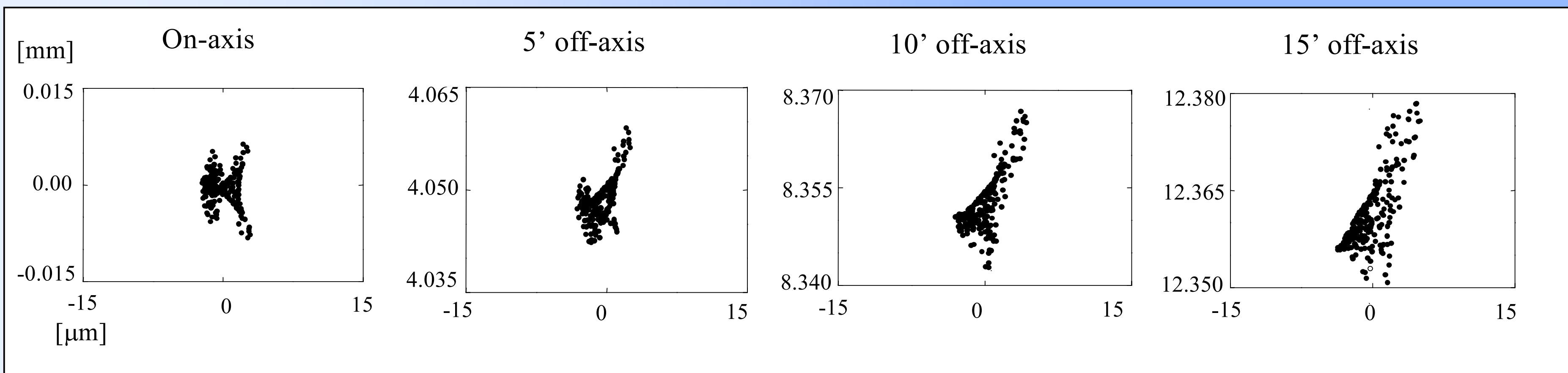


The image within the field-of-view in the direction parallel to the slit has **constant spectral resolution** and **slightly degrading spatial resolution**

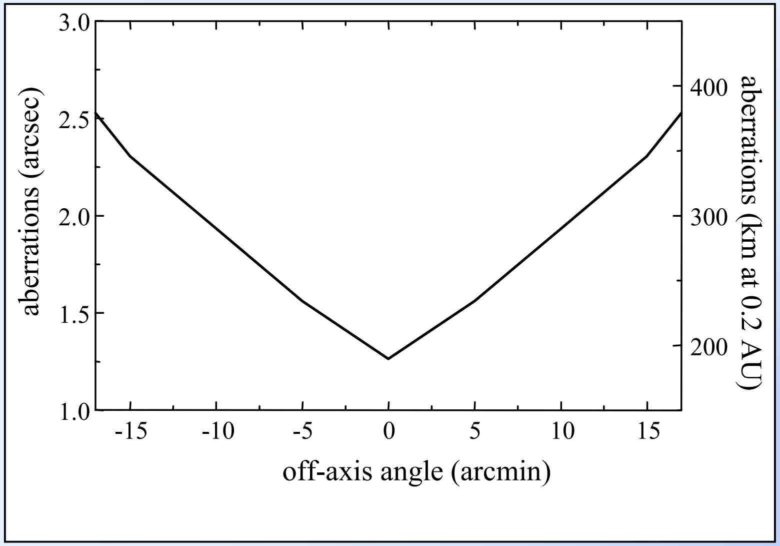
Two-dimensional images of extended regions are obtained by a one-dimensional rastering in the direction perpendicular to the slit

Telescope-spectrometer for the 17-25 nm (8.5-12.5 nm) region (1/5)

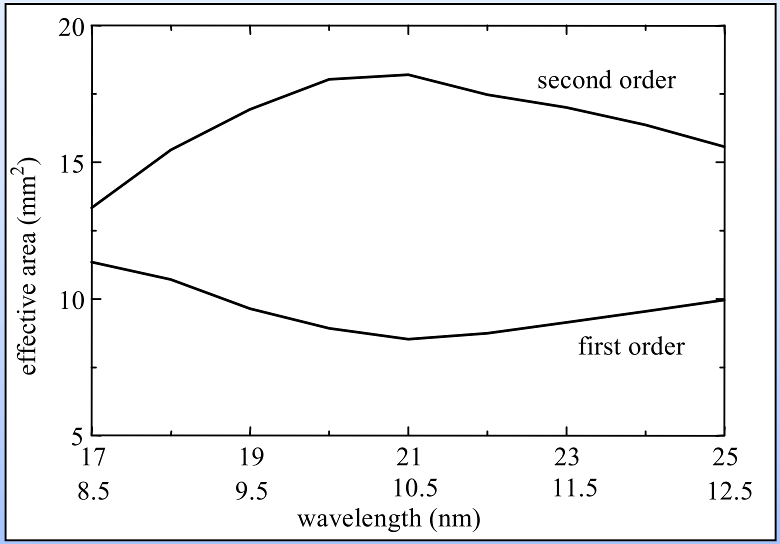
Wavelength range	17 -25 nm (**first order**) and 8.5 - 12.5 nm (**second order**)
Field-of-view	34 × 34 arcmin (1/5 of the solar disk at 0.2 AU)
Spectral resolving element	45 mÅ/pixel at 20 nm (67 km/s)
Spatial resolving element parallel to the slit	1.1 arcsec (165 km on Sun at 0.2 AU)
Resolution perpendicular to the slit	1.7 arcsec (250 km on Sun at 0.2 AU)



Telescope-spectrometer for the 17-25 nm (8.5-12.5 nm) region (2/5)



Spatial aberrations in the direction parallel to the slit

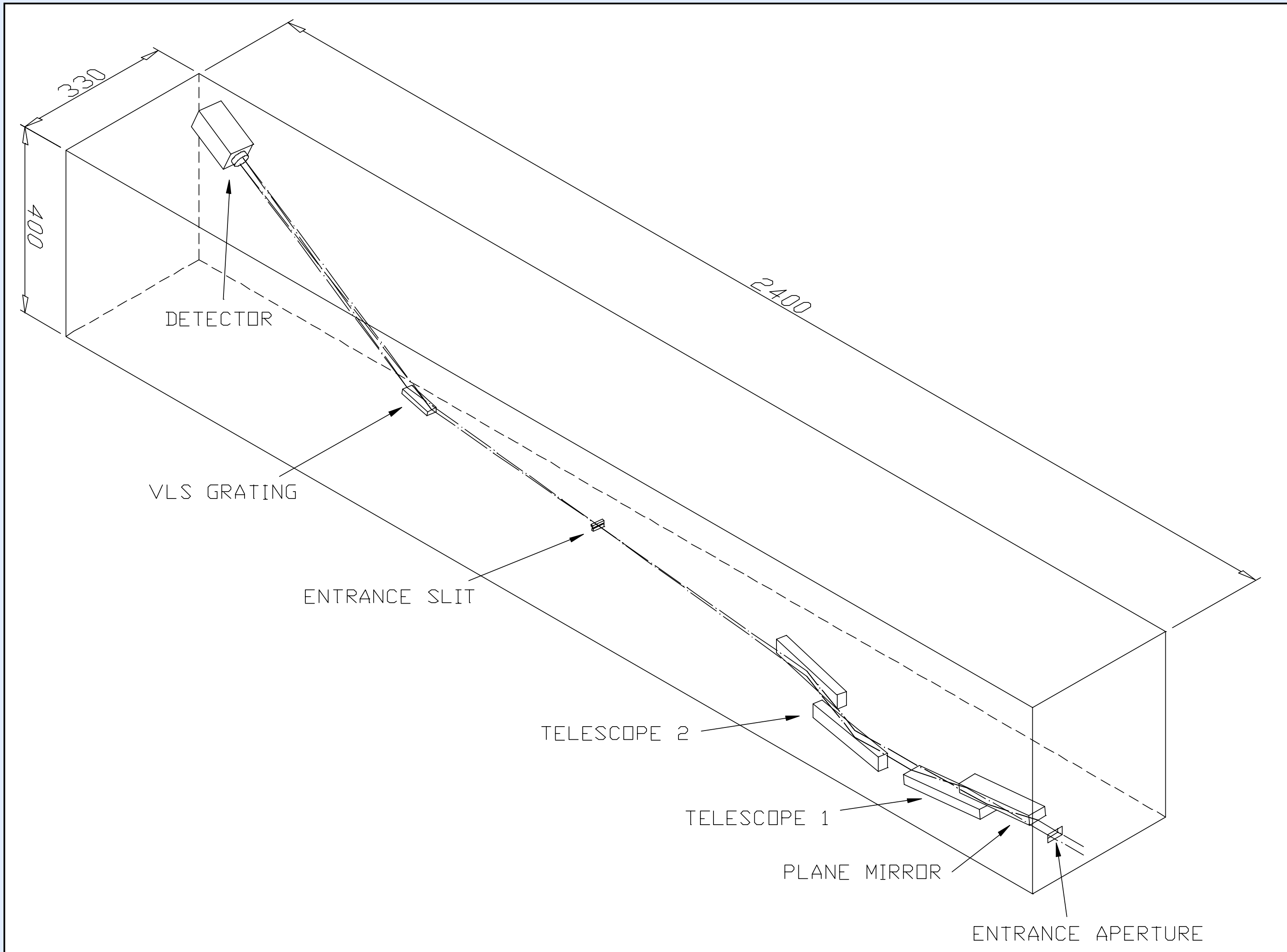


Effective area

⇒**The spatial resolution parallel to the slit is slightly degrading within the field-of-view (from 1.2 arcsec to 2.5 arcsec)**

⇒**The spectral resolution is constant within the field-of-view (45 mÅ/pixel)**

Telescope-spectrometer for the 17-25 nm (8.5-12.5 nm) region (3/5)



Telescope-spectrometer for the 17-25 nm (8.5-12.5 nm) region (4/5)

ACQUISITION TIME

The emission intensity is **10^{13} photons/cm^2/sr/s**
(Fe X at 18.5 nm, Fe XII at 19.3 nm, Fe XIII at 20.3 nm, Fe XIV at 21.1 nm)

The whole line is **spectrally sampled by a single pixel**

$\Rightarrow$ The flux collected by a pixel looking at a region on the Sun of 2 $\times$ 1.1 arcsec at 0.2 AU with an effective area of 10 mm^2 is $\approx$**50 counts/pixel/s**

$\Rightarrow$An acquisition time of 8 s is required to have a noise to signal of 5% (400 counts)

$\Rightarrow$A rastering in the direction perpendicular to the slit throughout a typical solar loop (60000-90000 km on the Sun) requires 25-40 minutes

Fast dynamic processes can be followed only on strong spectral lines and well defined spatial regions

Telescope-spectrometer for the 17-25 nm (8.5-12.5 nm) region (5/5)

THERMAL LOAD

The average solar intensity at 0.2 AU is 25 times the solar constant, i.e. ≈34 kW/m²

Gold-coating at grazing incidence reduces **the absorption to ≈0.2**.

The plane mirror, which sees the full Sun, **receives 23 W**.
The absorbed powers on the four mirrors are 4.5 W, 3.7 W, 3.0 W and 2.0 W, corresponding to **≈0.07 W/cm²**.

Cooling at grazing incidence is less critic than in the normal incidence case
⇒ a normal-incidence golad-coated mirror looking at the disk absorbs **0.7 W/cm²** !

Grazing-incidence optics are more robust also with respect to the surface contamination (deposition of light contaminants due to high photon fluxes)

Conclusions

- **Innovative optical configuration for imaging spectroscopy at grazing incidence**
  - **To our knowledge, this configuration is the only capable to give imaging spectroscopy at grazing incidence, i.e. simultaneous observations of extended regions**
- **Design very versatile: it can be optimized in almost any interval within the grazing-incidence EUV and soft X-ray domain (1-40 nm)**
- **The design is applied to a grazing-incidence telescope-spectrometer for the Solar Orbiter in the 17-25 nm region**
- **The spectroscopic capability of the Solar Orbiter would be considerably reinforced by observations also in the grazing-incidence region.**
  - **We are analyzing the possibility of coupling two spectroscopic channels, i.e. a section for observations at long wavelengths and a section for wavelengths below 30 nm. The two channels could share part of the structure, the coarse pointing mechanism and part of the electronics, obtaining a remarkable saving in mass with respect to the case of two distinct spectrometers.**