MODERATE RESOLUTION 1 to 5 micron SPECTROGRAPH FOR NGST

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1) Required Spectral and Spatial Resolutions

A design goal for the NGST Multi-Object Spectrographs is to have spectral resolutions, R, from 100 to 5000. However, analyses of the Design Reference Mission appear to indicate that resolutions in the 1000 – 3000 range are central and so it was decided to try to achieve this at 2 microns wavelength, with a slit width of 0.1 arcsec (projected onto the sky). The desired spatial resolution along the slit of the imaging spectrograph, at least for the image slicer application, is diffraction limited at 2 microns wavelength, to match the anticipated performance of the telescope. The pixel size of the InSb detector was assumed to be 27 microns since Bely, in the SPIE paper "The NGST "YARDSTICK MISSION", states "the final aperture ratio is f/24 to match the angular resolution of the telescope at 2 microns with a typical pixel size of about 27 microns").

At f/24, the field scale of an 8 meter telescope is 1.09 arc seconds per mm. The NGST will have a segmented primary mirror but, if the equivalent of a single mirror, the full width at half maximum of the Airy disc at 2 microns is 0.063 arcsec, thus 58 microns or approximately two pixels on the detector at f/24.

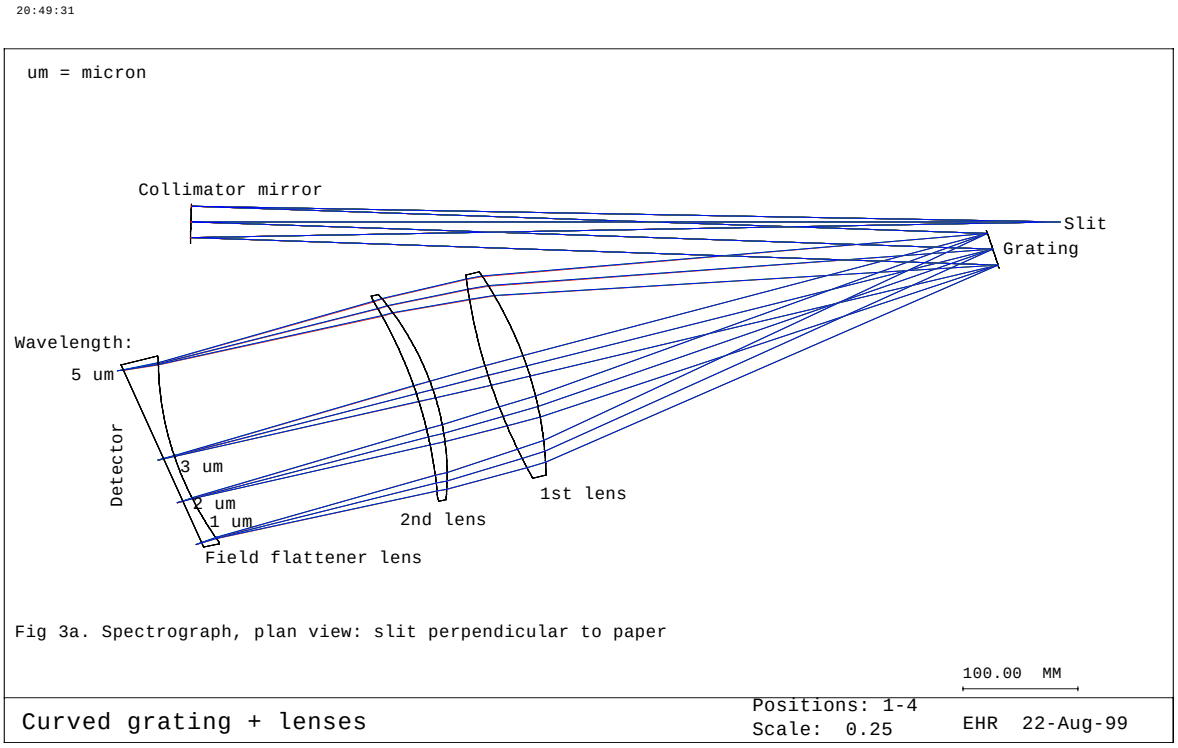
However, the image slicer was designed for a slit width of 0.1 arcsec and thus requires a f/15 spectrograph camera to match the spectral resolution of the detector in the direction of dispersion. In this case, the spatial resolution along the slit would be slightly under-sampled by the detector at 2 microns, but would be adequately sampled at wavelengths longer than 3.2 microns (because the diameter of a diffraction-limited image is proportional to the wavelength). The fixed width of the slit is a compromise, being larger than the Airy disc at 2 microns, but smaller than the Airy disc at wavelengths longer than 3.2 microns.

If a detector with 18 micron pixels were used with the spectrograph, the ideal focal ratio for a 2-pixel resolution match would be f/18, i.e., close to the nominal f/15 ratio of the spectrograph camera. In that case, at 2 microns wavelength, the spatial image would be only slightly under-sampled and the spectral resolution slightly over-sampled, the slit projecting to 3 pixels.

2) Optical Layout of a Simple Spectrograph Option for a Single Long Slit

Some options for spectrographs for NGST use Three Mirror Anastigmats (TMA) designs. These offer considerable versatility but require six or seven reflections within the spectrograph. Some designs (cf. ESO MOS/IFS study) also have additional mirrors in the fore-optics resulting in 13 reflections after the focus of the telescope, not including the grating, plus a refractive filter and possibly a window on the detector. These spectrographs in their “high resolution” mode are designed to cover only a portion of the required 1 to 5 micron wavelength region at a time. However, if it is acceptable to have a dedicated spectrograph that does not require changes in dispersion for different spectral regions, the number of reflections can be drastically reduced and the wavelength coverage increased.

One example is shown in Figures1a, 1b and 1c. Fig 1a is a top view where the entrance slit and the spectral lines are perpendicular to the plane of the paper, and Fig1b is a side view where the slit and the spectral lines are in the plane of the paper. These two drawings start at the slit, the optics preceding the slit are an 8-meter telescope with an f/24 output and an exit pupil located 2 meters before the focus of the telescope, which could include the solid block image slicer described by Richardson (1999)



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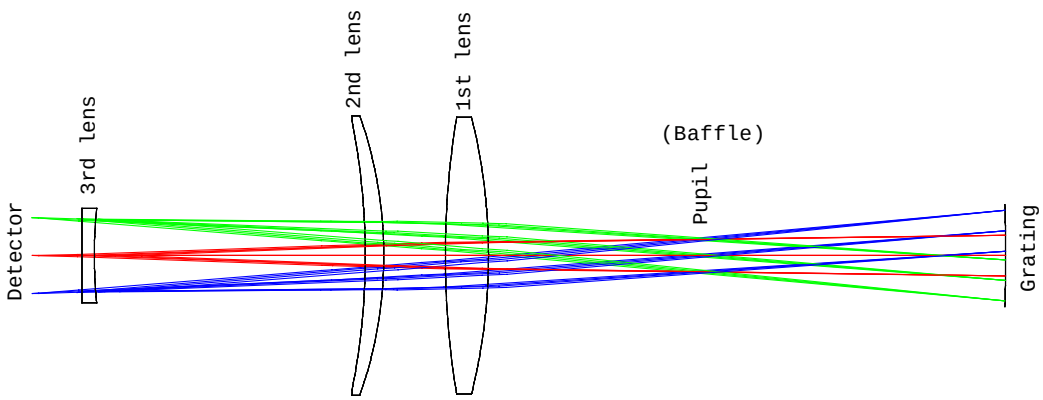

Fig 3c. Side view of spectrograph from grating to detector

92.59 MM XZ

Curved grating + lenses

Positions: 1-4
Scale: 0.27

EHR 22-Aug-99

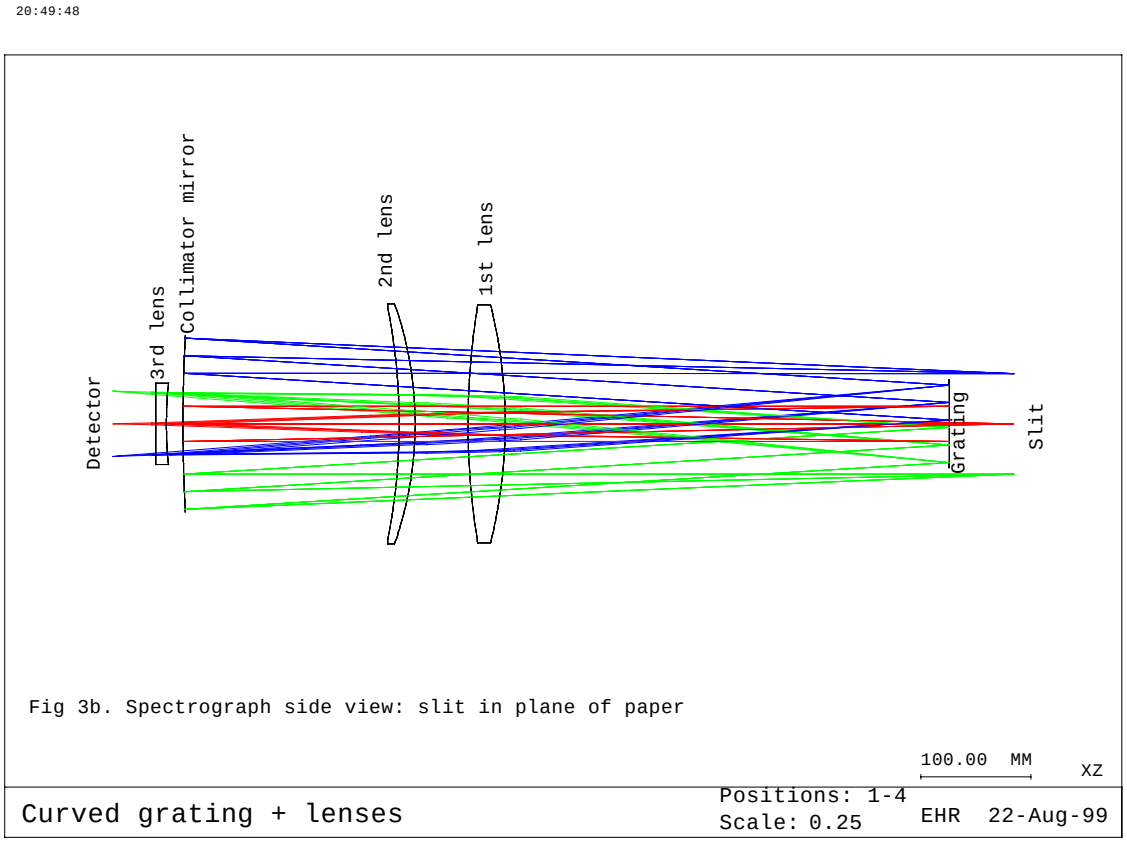

Figure 1: Three views of the proposed spectrograph

The collimator of this spectrograph is f/24, which is the same as that of the output of the NGST and the output of the image slicer. This long focal ratio simplifies the collimator design so that it consists of only one mirror (as is common in many astronomical spectrographs). The grating is concave and thus serves both as a dispersing element and as a focusing element in the camera of the spectrograph. The grating has 100 grooves/mm. It could be interchanged with gratings with different blazed wavelengths to enhance priority wavelength bands. The grating is followed by three lenses, which can also serve as filters. The field flattener lens close to the detector could also serve as a protective window and perhaps as an order sorter if given a suitable coating. The feasibility of wedged coatings for such use requires investigation.

The images are diffraction limited from 1 to 5 microns wavelength. The dispersion is 21 NM/mm and so for 27 micron pixels, R = 3000 at 3.6 microns. The length of the spectrum is 190 mm and the length of the spectral lines is 60 mm in this notional design. The angular length of the slit is 100 arcsec (similar to the image slicer) but could be longer. A design with a 164 arcsec (151 mm) long slit has been evaluated and is satisfactory.

Because the telescope outlined in the Yardstick Design is not telecentric (i.e., does not have a very distant exit pupil) and because the spectrograph collimator consists of only one mirror, the exit pupil is not imaged onto the diffraction grating, which is unusual. It can be seen in Figure 1c, which is a side view limited to the path from the grating to the detector, that the re-imaged pupil is located about one

third of the distance from the grating to the detector. That would be a convenient place to place a baffle.

The distance from the slit to the collimator is 0.75 meters, which is well within the space available for instruments. The optical prescription for this spectrograph is available in both CodeV and Zemax formats.

This spectrograph design which incorporates a refractive camera will not work well for a wide range of spectral resolutions unless the last lens element is changed when the grating is changed. Panchromatic reflecting camera designs are now being investigated to provide more versatility.

3) Minimum Required Width of Grating

Some spectrograph design options, such as those in the ESA MOS design, have large gratings, 140 mm wide, which is much bigger than necessary for the required spectral resolution (in the case of the ESA HR (high resolution) spectrograph, the collimated beam was made large to suit the optical design, not because it was required to achieve the resolution.)

For a grating, the spectral resolving power, R = lambda/(delta lambda) = W /s, where W is the width of the grating and s is the separation of adjacent grooves. In our case, if both lambda and s equal 2 microns, and if R = 3000, then W = 6 mm, a very small grating. Although gratings with s = lambda are available, it is more usual to have s ~ 2*lambda. Also, if the same grating is to be used at longer wavelengths, say to 5 microns, the choice of width of the grating should be s=10 microns. This implies that W should be about 30 mm. Note that the width of the grating in our design, 34 mm, is larger than the theoretical minimum but is still small compared with the 140 mm wide grating in some of the other NGST spectrograph designs.

To achieve R=3000 at 2 microns requires that each pixel cover 0.33 micron (for 2 pixels per resolution element), thus the dispersion would be 0.33/0.027 =12.3nm/mm for 27mu pixels.

In the spectrograph design described above, the dispersion was selected to be 21 nm/mm, thus it is at the wavelength of 3.4 microns that the spectral resolving power of 3000 is achieved. The width of the grating is 34 mm, the groove spacing is 10 microns (i.e., 100 grooves/mm), and the angle of incidence is 18 degrees. This increases the width of the beam in the direction of dispersion by 1/(cos 18). The angle of diffraction is negligible at 1 degree. The effective focal ratio of the camera is f/14 in the direction of dispersion and f/15 perpendicular to dispersion. In this imaging spectrograph, the spatial field scale of the 8 meter telescope at the focus of the spectrograph is 1.75 arcsec/mm and so the spatial resolution (2 pixels) is 0.09 arcsec at 2 microns wavelength.

4) Multi-Slit Spectrograph Designs

One approach to having several slits feeding the same spectrograph is to use a three-mirror collimator (TMA). However, the separation of slits such as those at the outputs of fiber feeds can be positioned and tilted to send the beam in different directions and so a collimator mirror could be associated with each of the fiber feeds. Thus, instead of having a large TMA, an array of single collimator mirrors is

possible, thus eliminating two reflections in the light path. Design work on such a spectrograph is still proceeding.

References

Richardson, E.H. et al. 1999 in “3D Spectroscopy”, ASP Conf. Series, in press, and in Appendix B7 of the Canadian NGST MOS/IFS report.