# Astro 500 Project #2

*Due Tue 08 Dec, 2022 1:45 PM local time*

*Show all work. You can discuss the problem with your classmates but your write up needs to be your own work.*

**The problem.** Your task is to design a spectrograph *concept* for a 30m diameter optical telescope for point-sources in 1 arcsec seeing (Gaussian FWHM). The spectrograph must achieve an average spectral resolution of $R = \lambda/\Delta\lambda = 8000$ from 360 nm to 1000 nm. Assume $\Delta\lambda$ is also a measure of FWHM for the monochromatic entrance aperture reimaged onto the detector.

Your spectrograph *concept* should *not* consider the details of compound lens design or optical aberrations. Consider the collimator and camera as idealized optics. What is relevant are their effective diameters and focal-lengths in addition to the grating design (angle, line density, order(s), size). You will only consider the spectrograph optical concept in the context of a single source, i.e., your slight length (height) need only be the length required for a single point source. For the detector(s) you will consider the impact of the formatting you choose to cover all wavelengths for that one source at the required spectral resolution.

**The boundary conditions.** There are a wide range of possibilities for this spectrograph design. To help constrain the problem and your thinking you have these boundary conditions:

- No larger than 250 mm diameter lenses and mirrors except for the collimator which can be up to 400 mm in diameter. Smaller optics are preferable.
- No larger than 250 mm (spatial) x 500 mm (spectral) grating, although you may consider a mosaic of up to 4 such gratings. Smaller gratings and no mosaics are preferable.
- No larger than 10560 x 10560 pixel CCD with 9 micron pixels, or equivalent detector area with pixels up to 24 microns. Smaller detectors are preferable, even in one dimension. If you do not cross-disperse then you are only concerned with overall size in one dimension.
- Camera and collimator focal-ratios no faster than f/0.9. Slower is better.
- No more than 5 spectrograph channels which you can chose to split via dichroics. You do not need to design the dicrhoices except to specify the cross-over wavelength. If you go for more than one channel, assume the dichroic(s) are placed in the collimated beam of the spectrograph before gratings and cameras unless you have another specific concept. In general the fewer channels the better.
- No smaller than 50 micron slit-width or image-slicing optics (including fibers).

If you need to exceed any of these dimensions you can *if there is very good reason*. See the evaluation rubric below for some reference values.

You can choose the telescope f-ratio. Convince yourself that this doesn't matter unless you are using fiber coupling which requires that the fibers are fed between f/4 and f/2.7. In this case you can assume the fiber output f/# is the same as the fiber input f/#.

You can also choose how the light is coupled from the telescope to the spectrograph, e.g., direct, via single fibers, or via an image-slicer (including an IFU). However, if you must reformat the focal surface, specify the reformatting from the telescope focal surface to the spectrograph input focal-surface and consider if the angular and physical requirements for the slicer are reasonable.

**Your report.** You will be given a report template. Depending on your design you may need to modify it. You will be asked to provide and specify the following in your project report:

A short narrative description of your concept accompanied by figures and summary tables.

- Spectrograph geometry:
    - Sketch of the spectrograph layout with all key component labeled.
    - Footprint dimensions: rectangular area inscribing all elements from the input focal surface to the detector (don't worry about detector or optics housings).
    - A summary table with:
        - Spectrograph entrance slit-width
        - Spectrograph entrance slit-height for single source
        - Collimator focal-length
        - Collimated beam size (and f/#)
        - Number of spectrograph channels and associated dichroic wavelength breaks
        - Camera focal-length(s) (and f/#)
        - Grating angle(s)
        - Camera-collimator angle(s)
        - Camera-grating distance(s)
        - System demagnification (spatial)
        - System demagnification (spectral)
- Component sizes (also include in the summary table)
    - Detector(s)
    - Optics
    - Grating(s)
- Grating (also include in the summary table)
    - Type: reflective, transmissive
    - Line-density, order(s)
    - Blaze (if appropriate)
    - Size (both dimensions)
- Pupil location: a short narrative discussing if this is important in your design and where you would place it and why.
- Use of image slicers / IFU: A short narrative of how you slice the telescope focal plane, if you choose to do so, and the physical size of the slicer elements are.
- Performance:
    - Angular dispersion and linear dispersion (in nm/micron and nm/pix)
    - Wavelength coverage on detector(s)
    - Monochromatic slit-width on detector(s), including anamorphic factors (ignore aberrations), in microns and pixels
    - Slit height on the detector(s) in microns and pixels
    - Spectral resolution
    - Total number of pixels required to cover single object over all wavelengths
    - Light lost on-axis at the slit, at the central wavelength, from vignetting
    - Light lost on-axis at the slit, for extreme wave (red or blue) from vignetting
    - Light lost at the slit or in the telescope focal plane, i.e., the fraction of light from the star entering into the spectrograph.

**The evaluation rubric.** In addition to the technical feasibility and suitability of your design (i.e., does it work as required), your design will be evaluated with these metrics relative to some baseline numbers provided as denominators below. *Hint on how to get started:* Consider these as baselines from which you start your design process.

Camera f/# / 1.2
Number of channels / 2
$(\text{optics diameter} / 150\ \text{mm})^2$
grating size / 150 x 250 mm
detector size in dispersion dimension / 96 mm
unbinned pixels per spectral element / 5
unbinned pixels per spatial element / 10
on-axis vignetting (%) / 100%
off-axis wavelength vignetting (%) / 70%

I will also consider any clever / novel schemes you have for achieving the design goals while limiting the overall design and cost of the spectrograph.