

Spectrographs for astronomy

Types of spectrographs: slit, multi-objects, IFUs

OUTLINE:

Multi-object slit spectrographs

- concept
- slit masks

Fiber spectrographs

- positioning fibers in multi-object spectrographs
- from fiber output to spectra

Integral Field Units (IFUs)

- lenslet
- fiber
- slicer
- Fabry-Perot

Sky emission suppression in spectrographs

Multiobject spectroscopy: many spectra at the same time



Multiobject spectroscopy: many spectra at the same time



Why not simply put a prism (or other dispersing element) ?

BAD idea:

- collisions between spectra
- spectra mixed with sky $\rightarrow$ poor sensitivity for faint targets

Light from the sources needs to be optically selected (mask, aperture) and dispersed

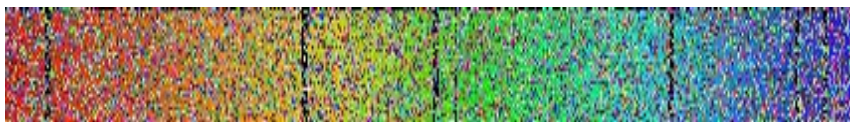
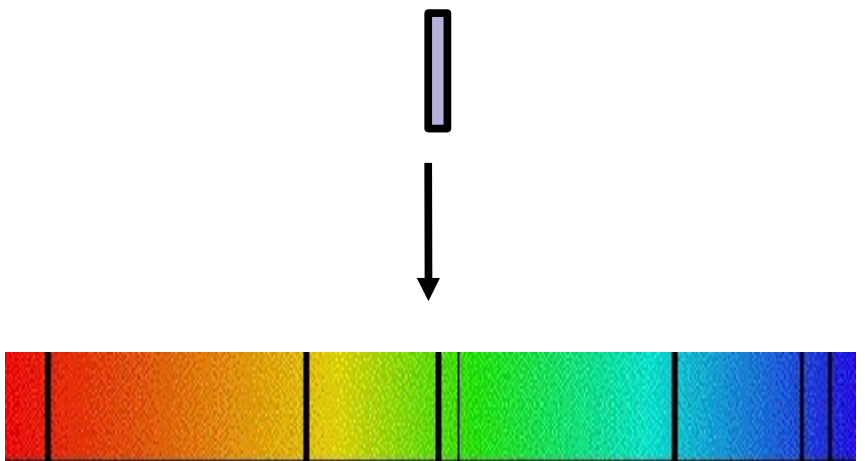
Total number of pixel in detector is a limit. At best:

spectral coverage ($\Delta\lambda$) x spectral resolution (R) x # of objects $\sim$ # of pixels
(unless measurement is done sequentially)

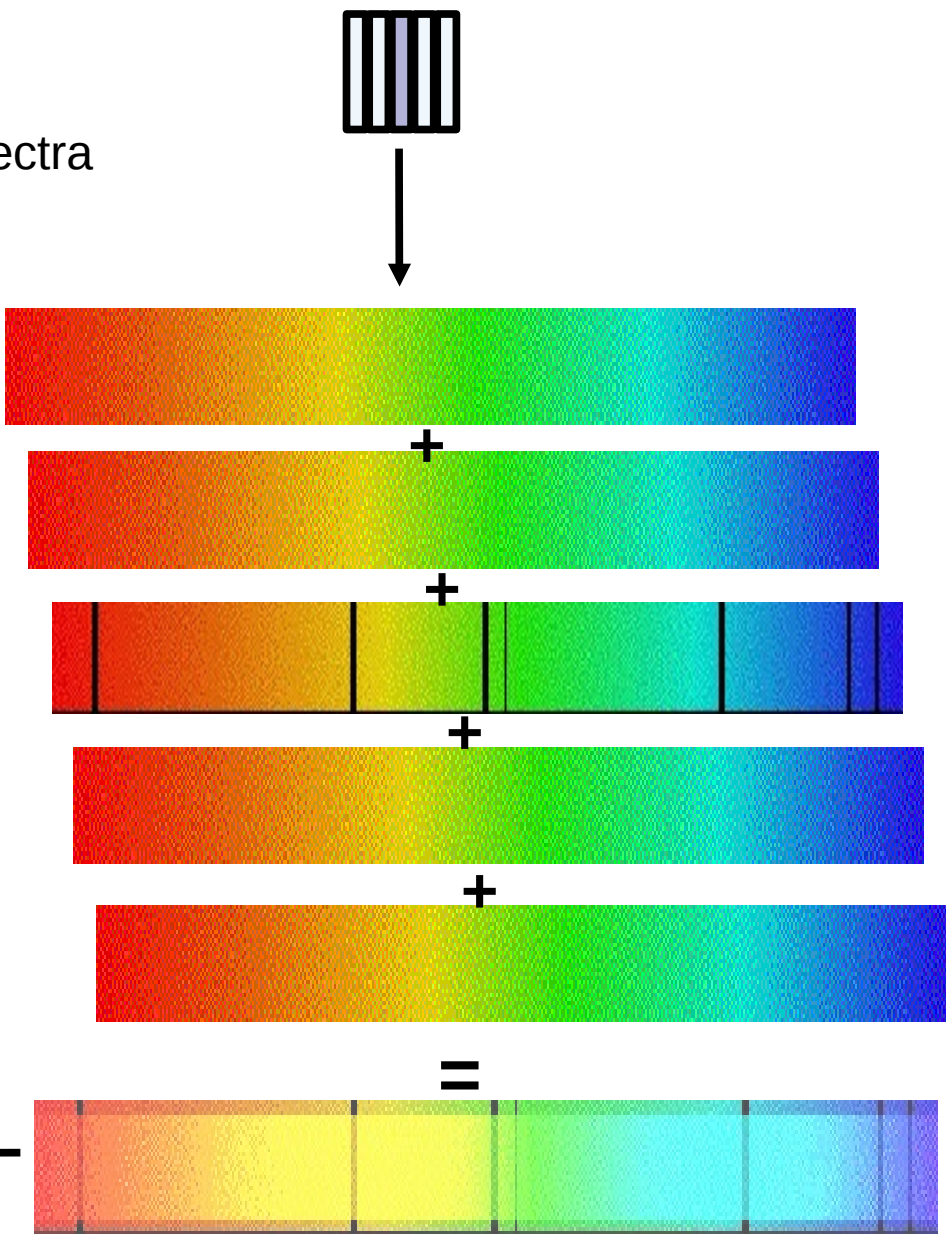
$\rightarrow$ multi-object spectroscopy is typically for low/mid resolution spectroscopy

Why use masks/slits ?

Simple prism or grating, WITHOUT mask/slit:
Large amount of sky background mixed with spectra



Sky subtraction

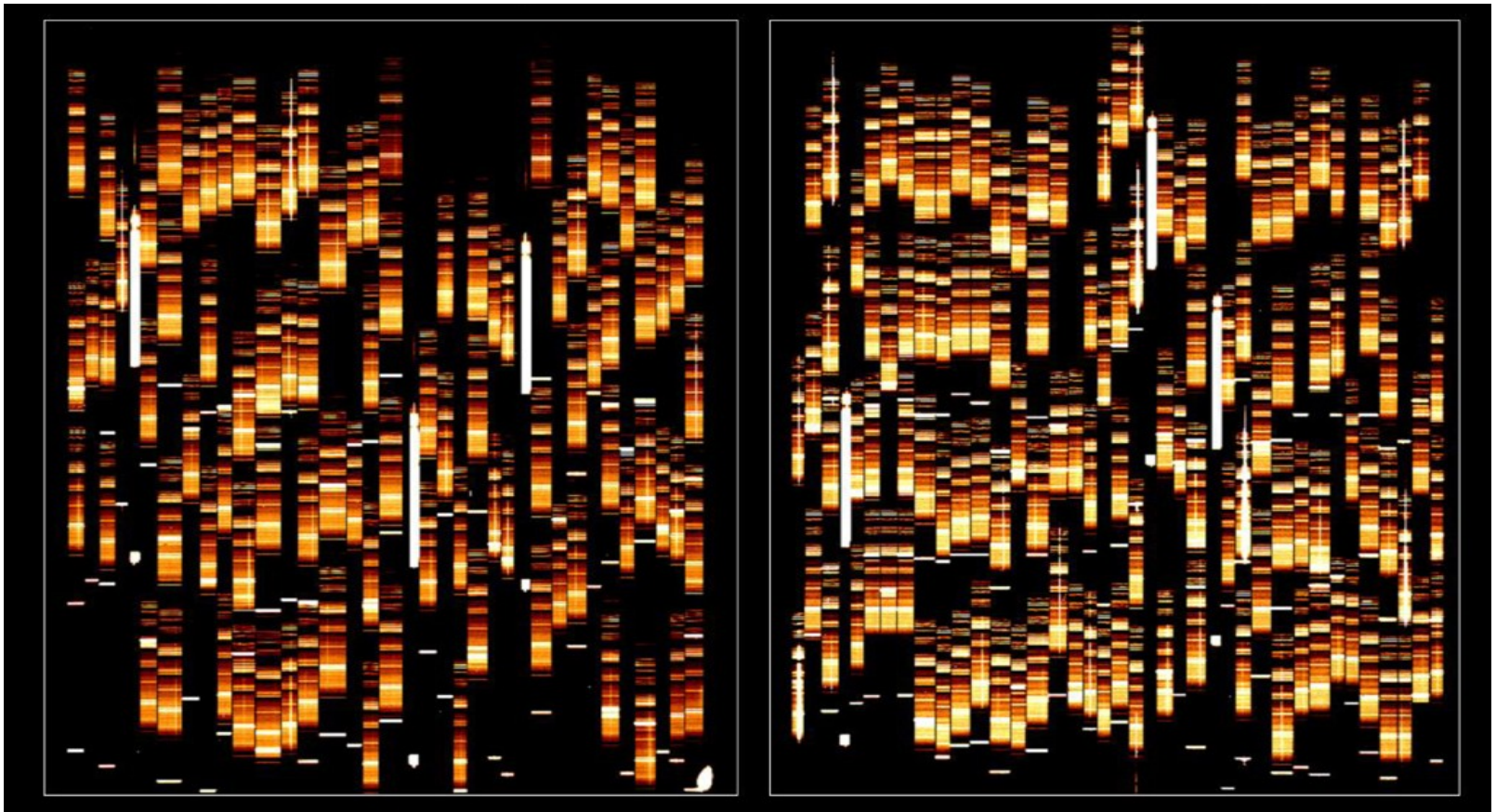


Multi-object slit spectrographs

Concept

Single object slit spectrograph: source is imaged on slit, and slit is then dispersed on detector(s)

Multi-object slit spectrograph: multiple sources imaged on multiple slits, and slits dispersed on detector(s)



First VIMOS Spectra of Faint Galaxies
(VLT MELIPAL + VIMOS)

Multi-object slit spectrographs

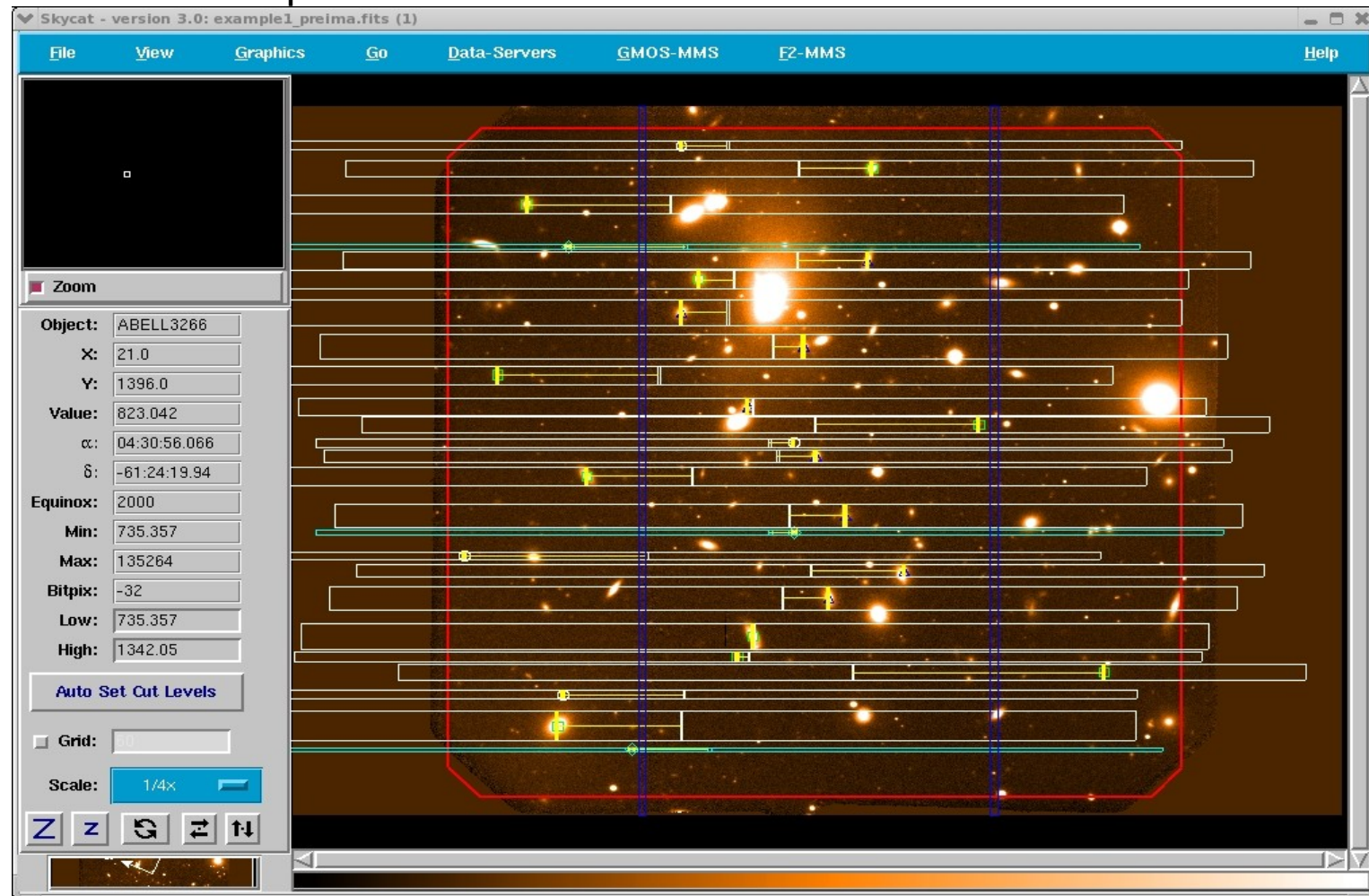
Pre-imaging:

Acquire image of the field to identify objects of interest and accurately measure their positions

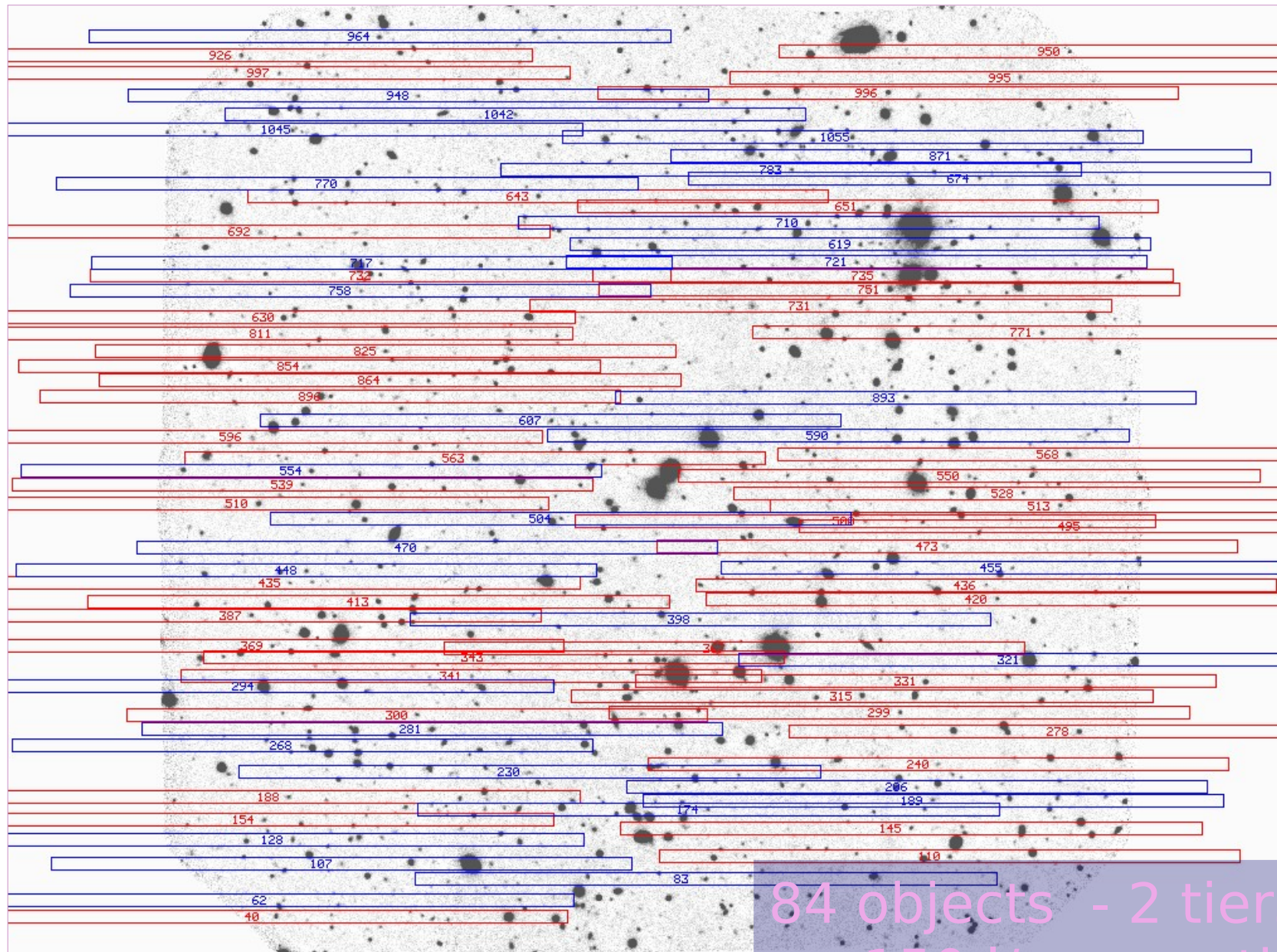
Mask design: design slit mask to acquire spectra of as many objects without collisions

Mask cutting: laser cutting machine cuts masks

Observation: mask is inserted in focal plane



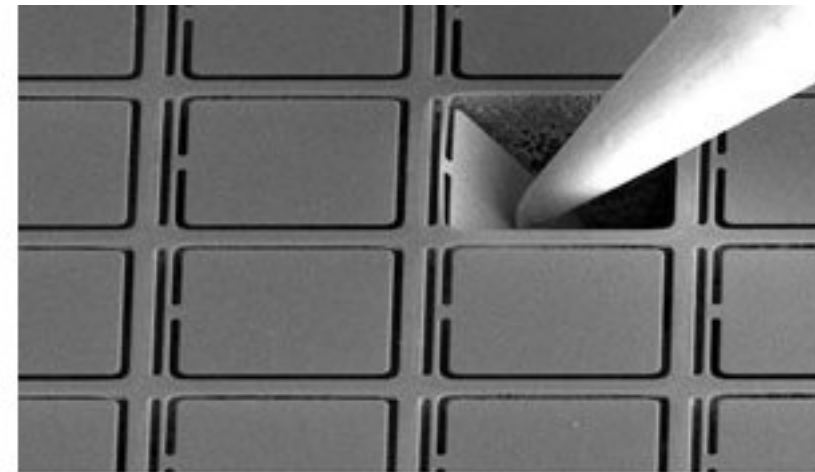
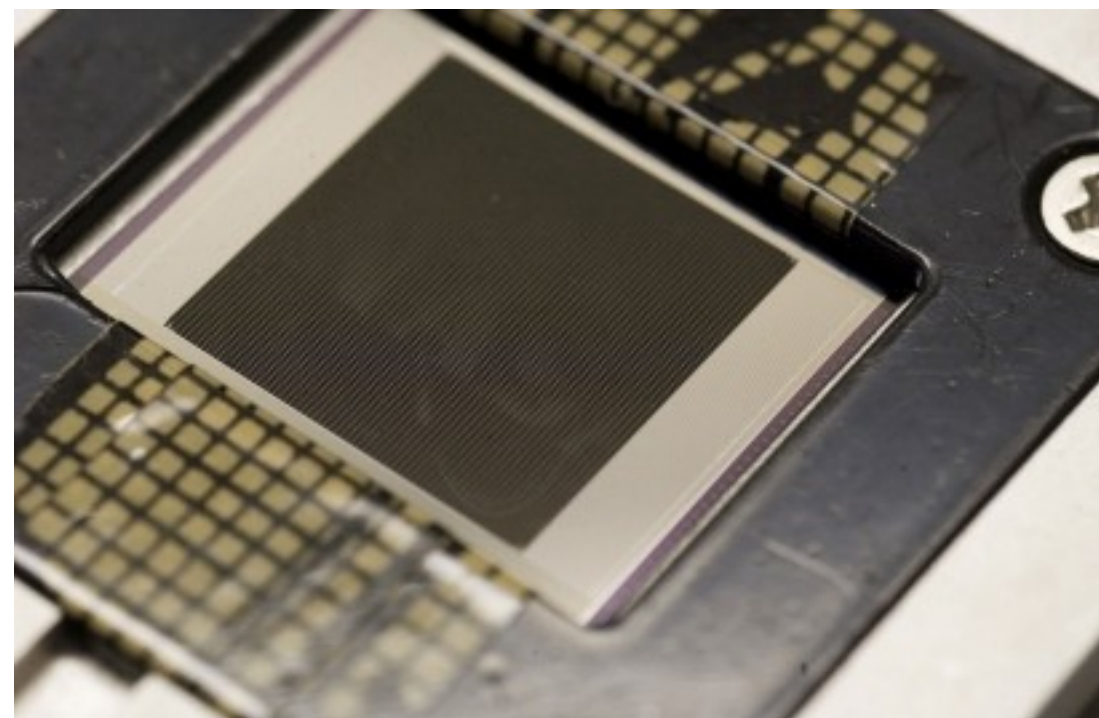
Sample GDDS Mask



84 objects - 2 tiers with
150 l/mm grating

Clever slit masks...

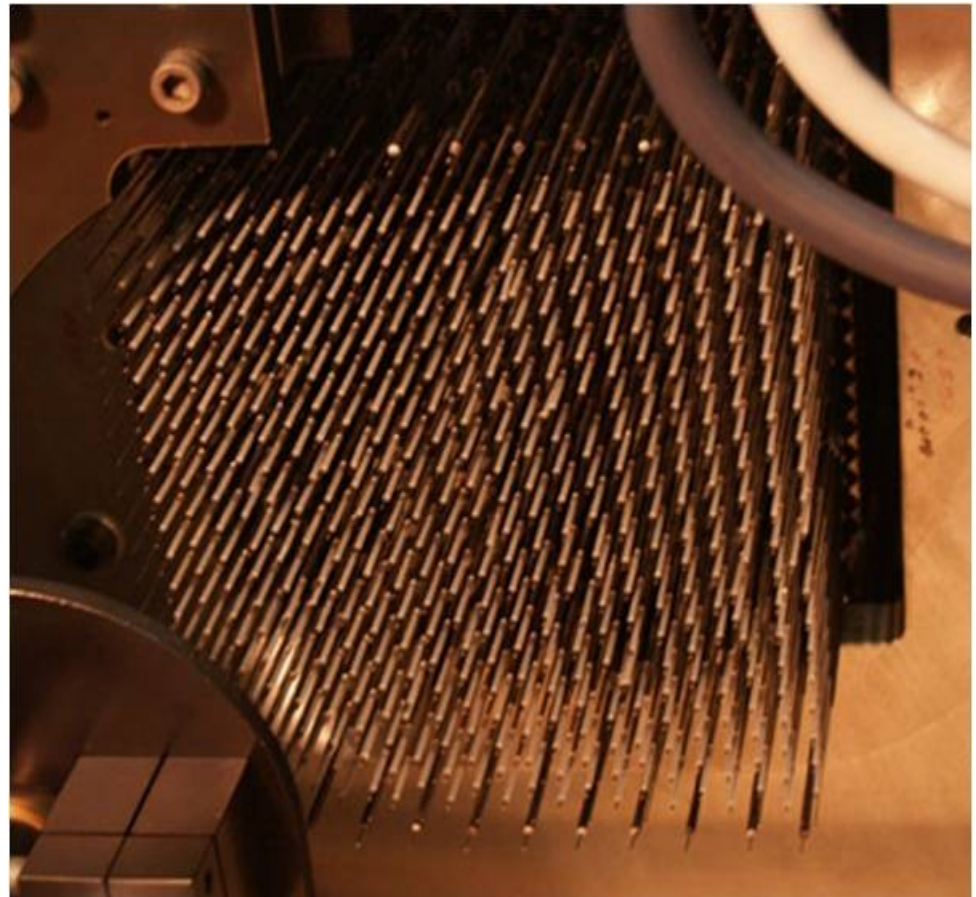
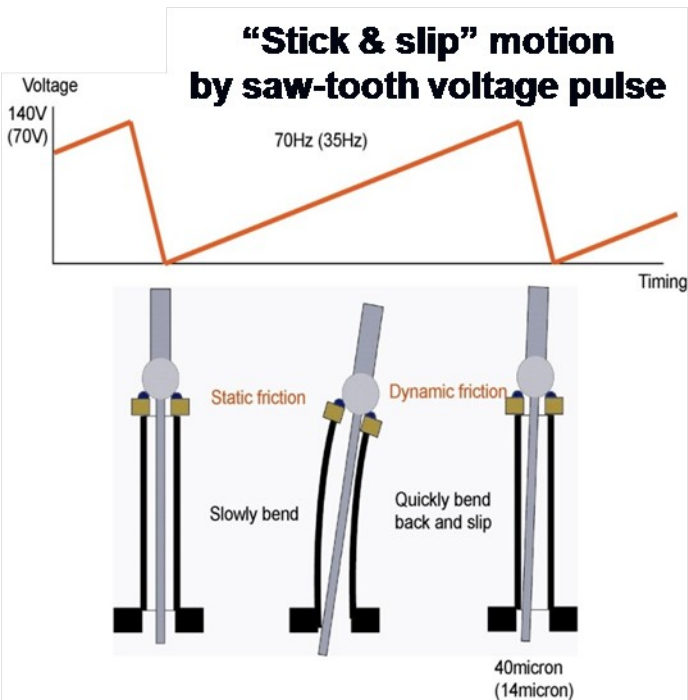
NIRSPEC, for the JWST, uses an array of microshutter to produce any slit geometry



Fiber Spectrographs

Concept: light transported from focal plane to spectrograph by a fiber

Concept can be expanded to multiple objects: one fiber per object



FMOS fibers

Integral Field Units (IFUs)

Concept: acquire spectra for each point in the field, no gaps

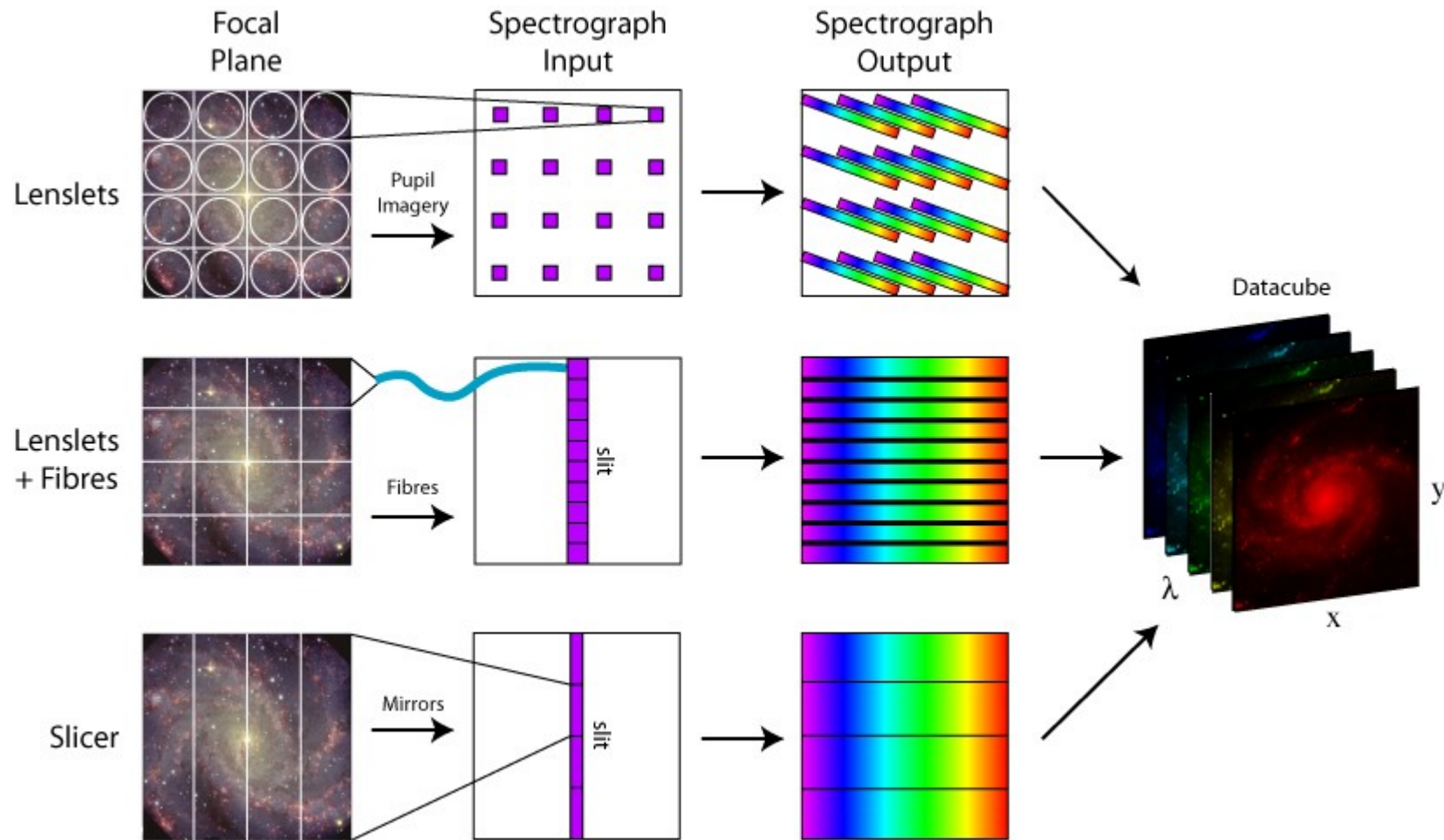
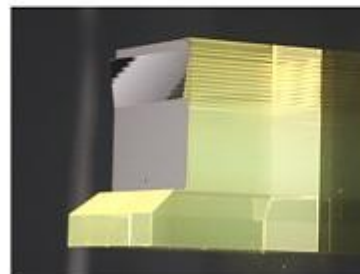
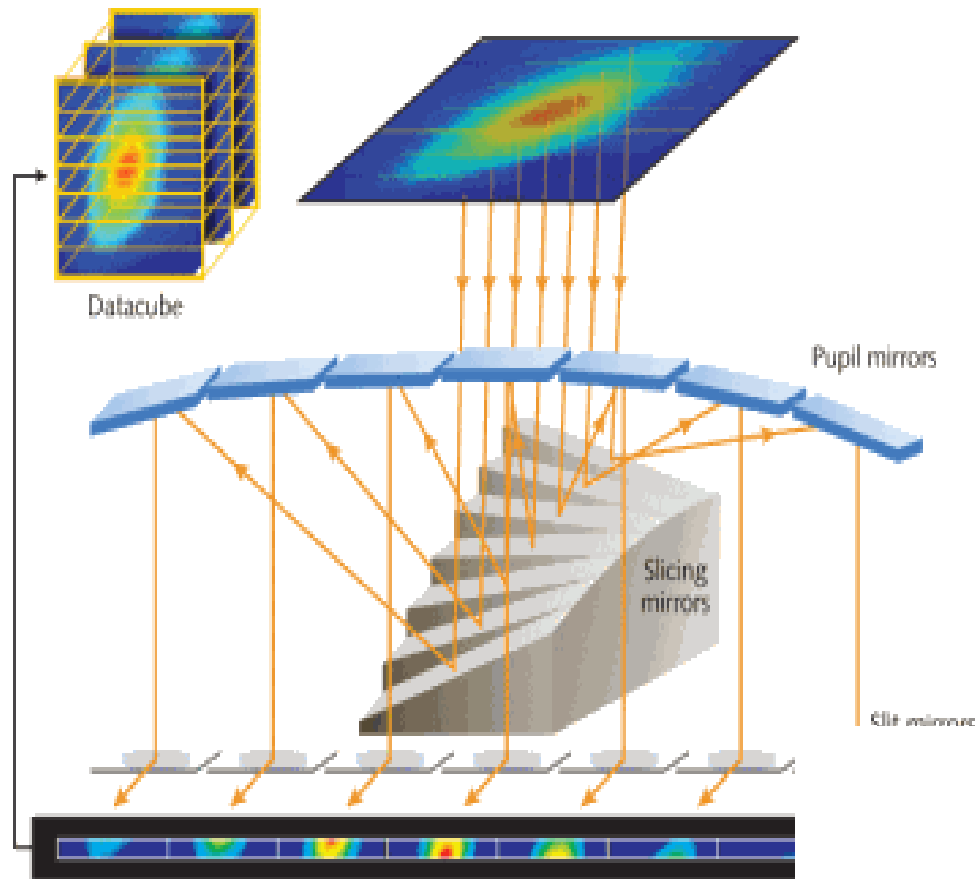


Image slicer

Uses stack of mirrors to slice 2D image into a 1D slit



From image slicer to 3D data cube

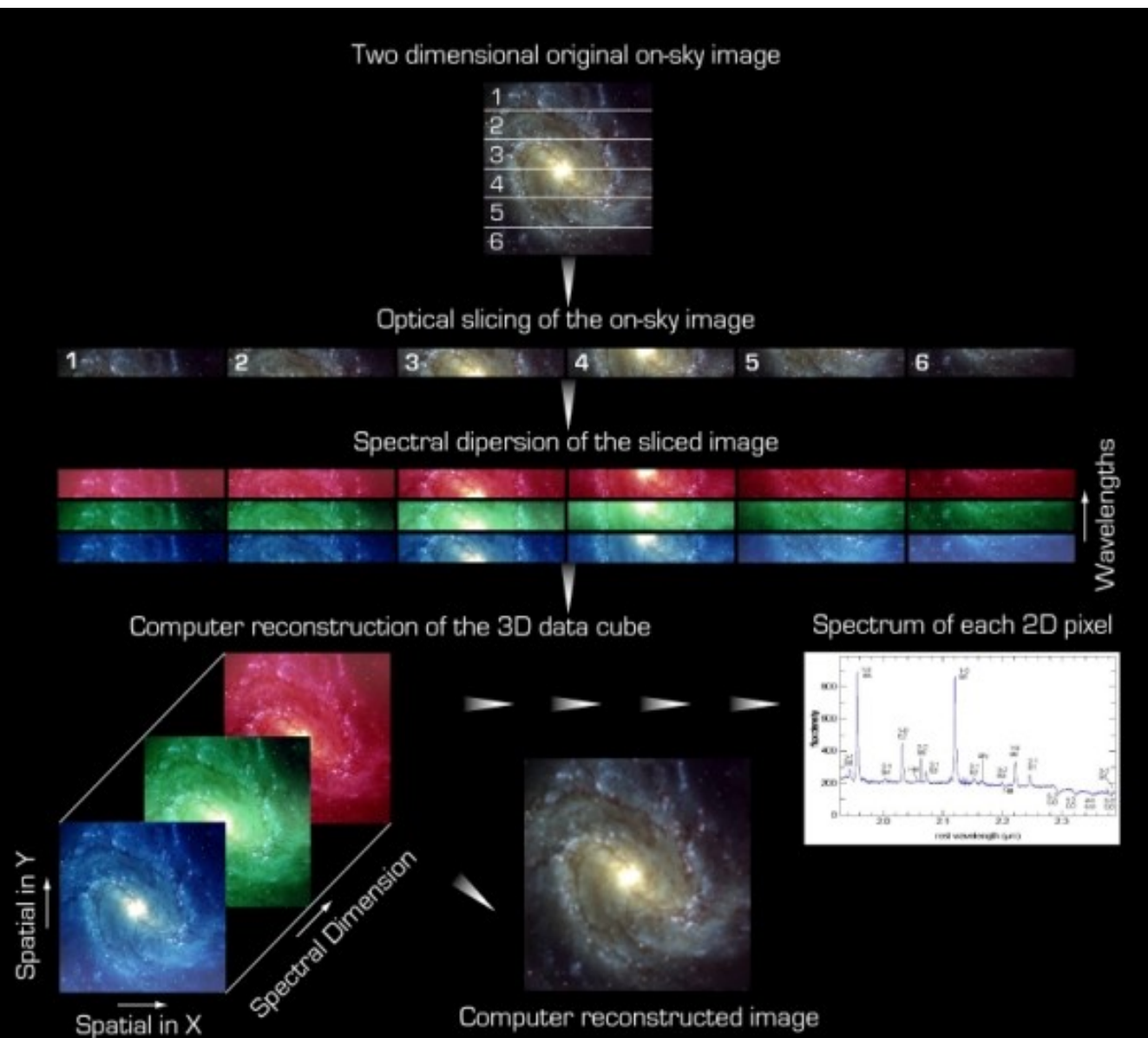
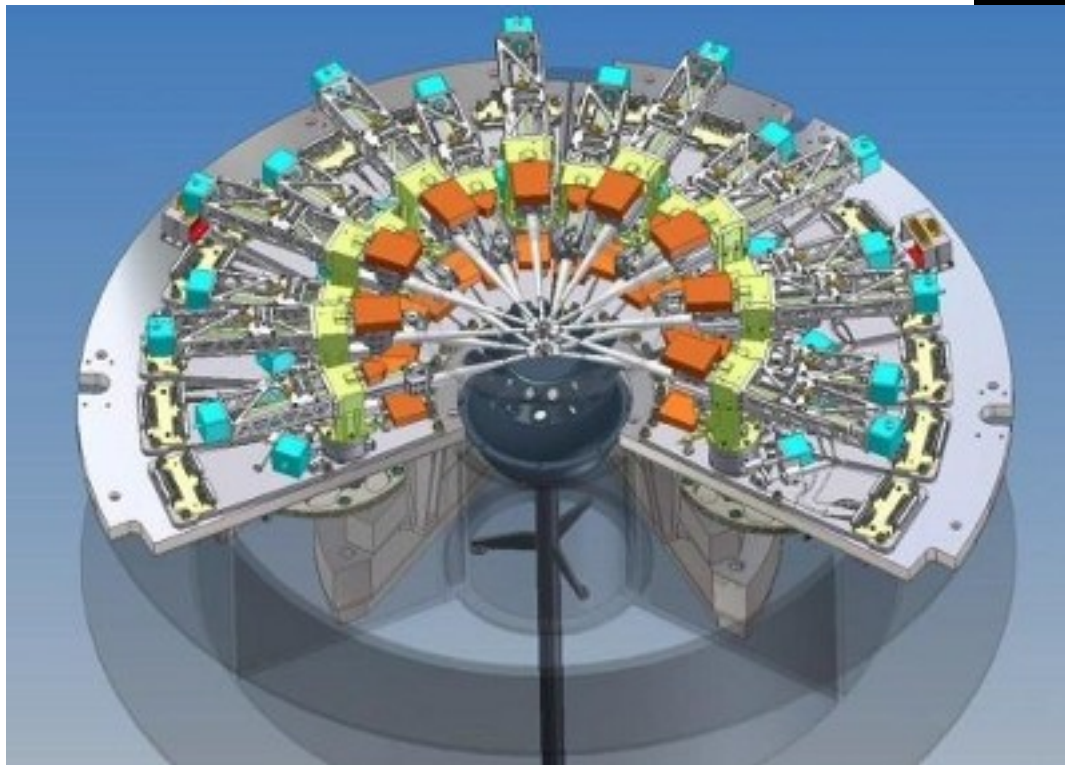
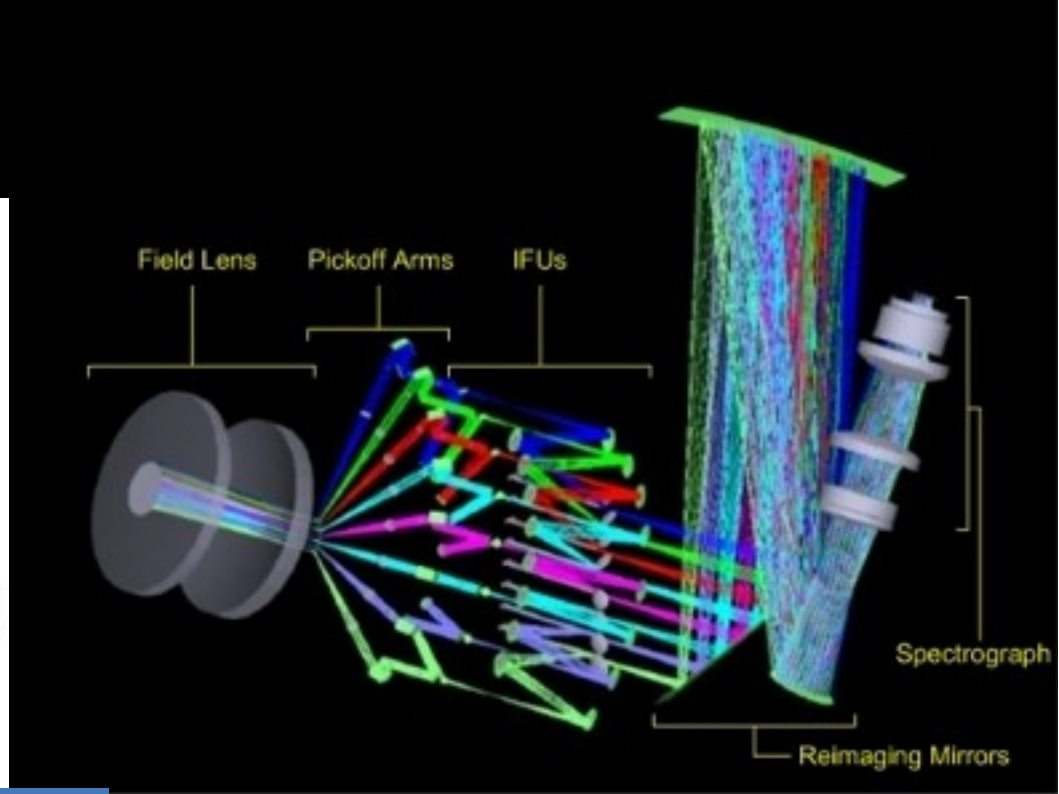


Image slicer concept:
slice image in small slices,
line them up into a long slit
and disperse

Courtesy: KMOS

Multiple small field IFUs

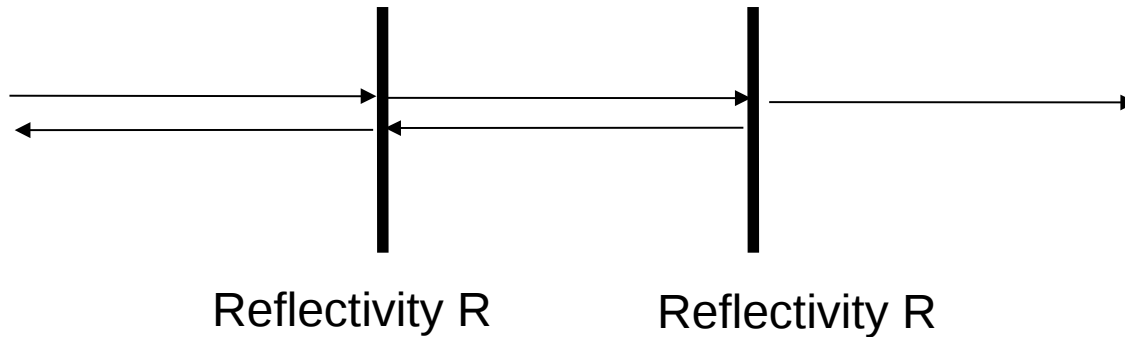


KMOS design (ESO)
24 IFUs, each 14x14 elements

Fabry-Perot cavity

Resonant cavity consists of two // semi-reflective mirrors

Very good for high spectral resolution imaging, but poor efficiency



n : refractive index in cavity

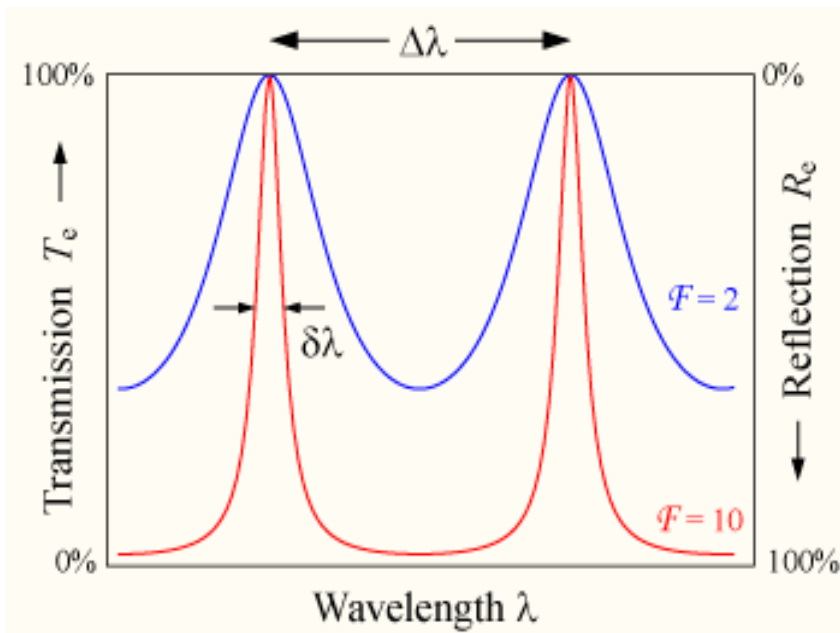
l : cavity length

θ : angle of incidence inside cavity

$$\delta = \left(\frac{2\pi}{\lambda} \right) 2n\ell \cos \theta.$$

Finesse:

$$F = 4R / (1-R)^2$$



Fabry-Perot transmission:

$$T_e = \frac{(1-R)^2}{1 + R^2 - 2R \cos \delta} = \frac{1}{1 + F \sin^2(\delta/2)}$$

Suppressing sky emission

Concept: remove narrow emission line due to Earth's atmosphere

Problem : sky emission is spatially and temporally variable. It may interact with pixels in ways that are not well characterized (series of narrow spectral lines, can cause interference within pixel)

Removal by software:

- in slit spectroscopy, slit is larger than object, and contains sky only emission which can be subtracted from object location
- in multi-object spectroscopy, some slits (or resolution elements) only contain sky emission

Software + observing technique:

Nod & Shuffle technique: acquire sky and object on same pixels by nodding the telescope back and forth. Shuffle charges to avoid readout noise penalty

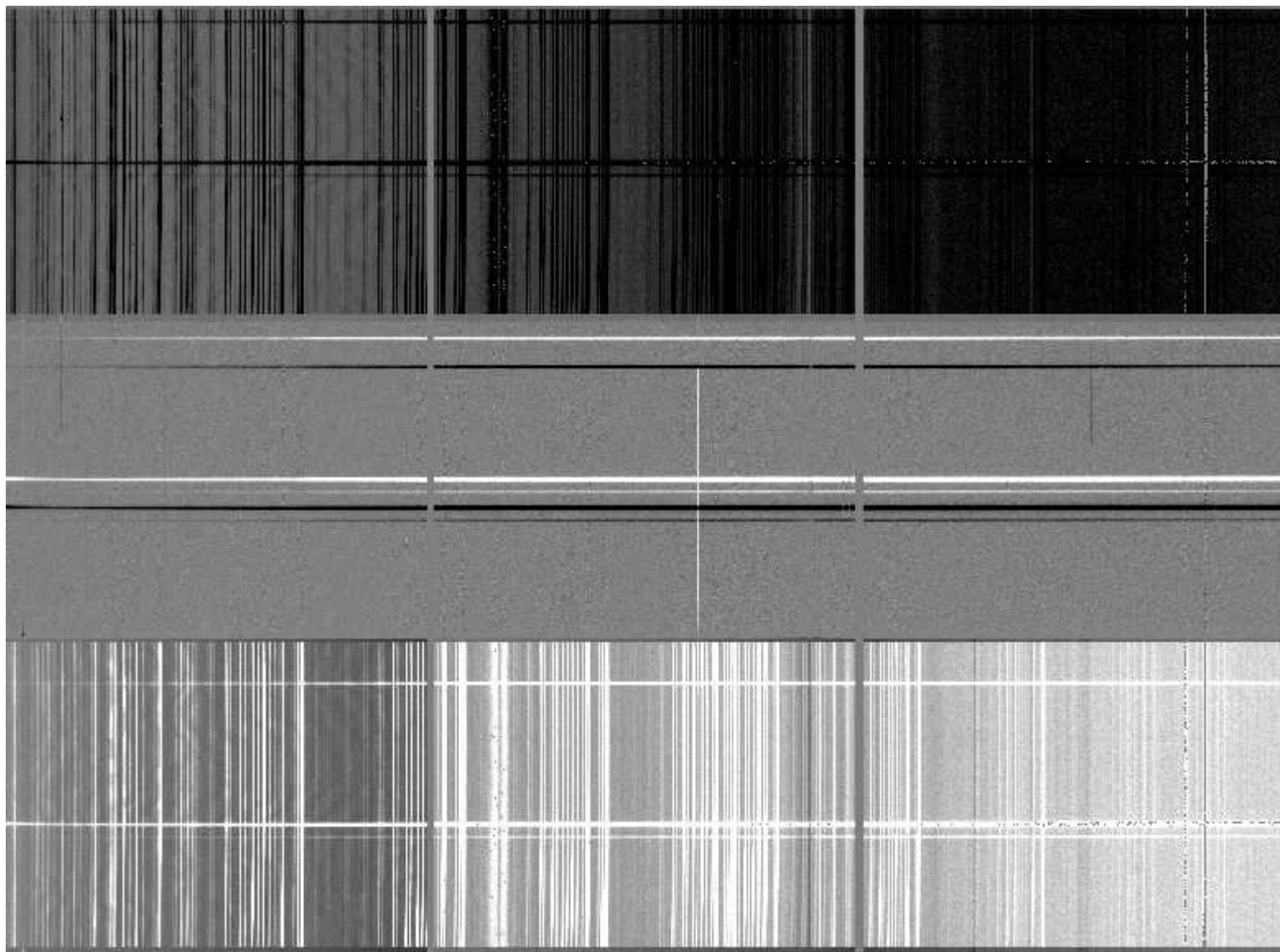
Hardware:

Physically block sky emission with a mask before it hits the detector. The mask may be in a plane where spectral resolution is larger than on the detector

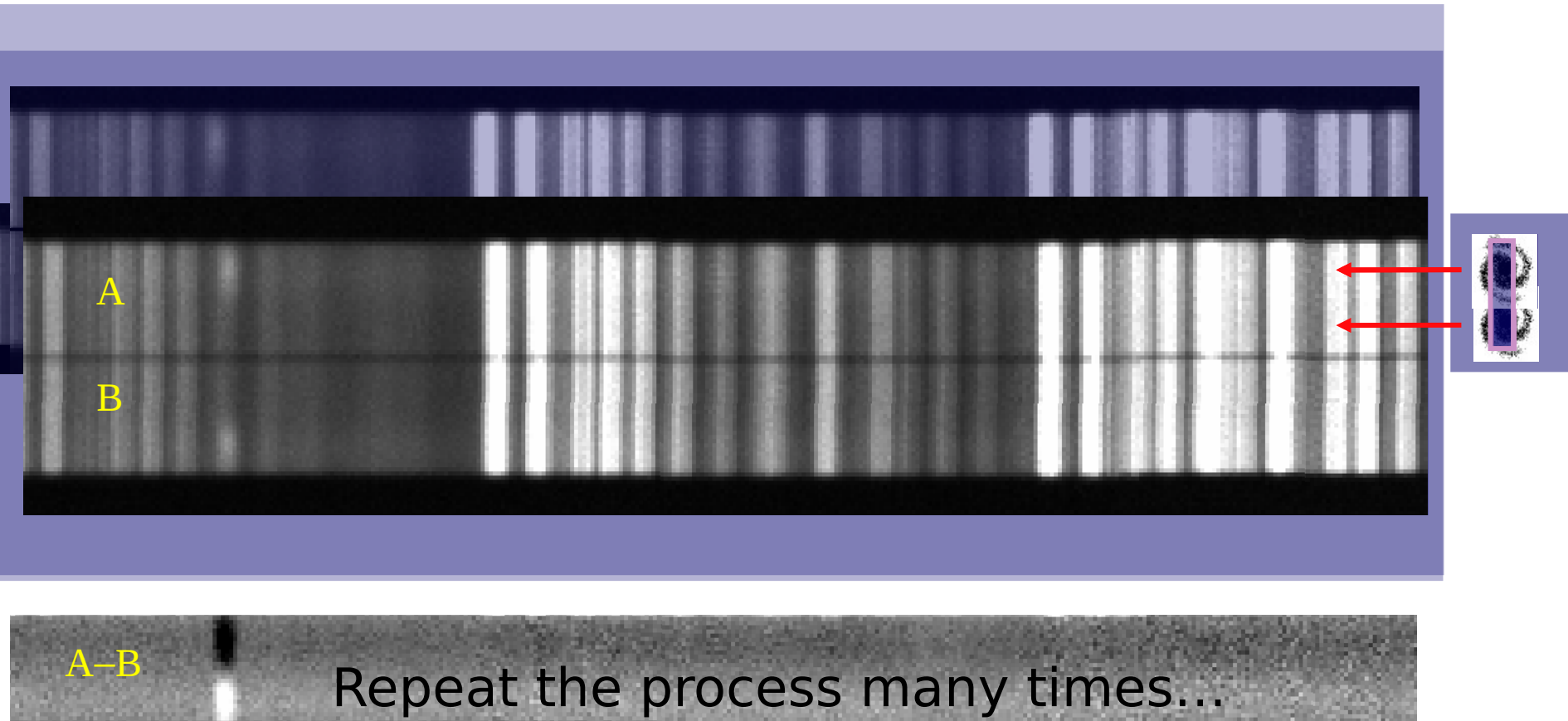
Suppressing sky emission

Concept: remove narrow emission line due to Earth's atmosphere

*Nod and Shuffle
(GMOS, Gemini)*



Sky cancellation: Nod & Shuffle Demonstration

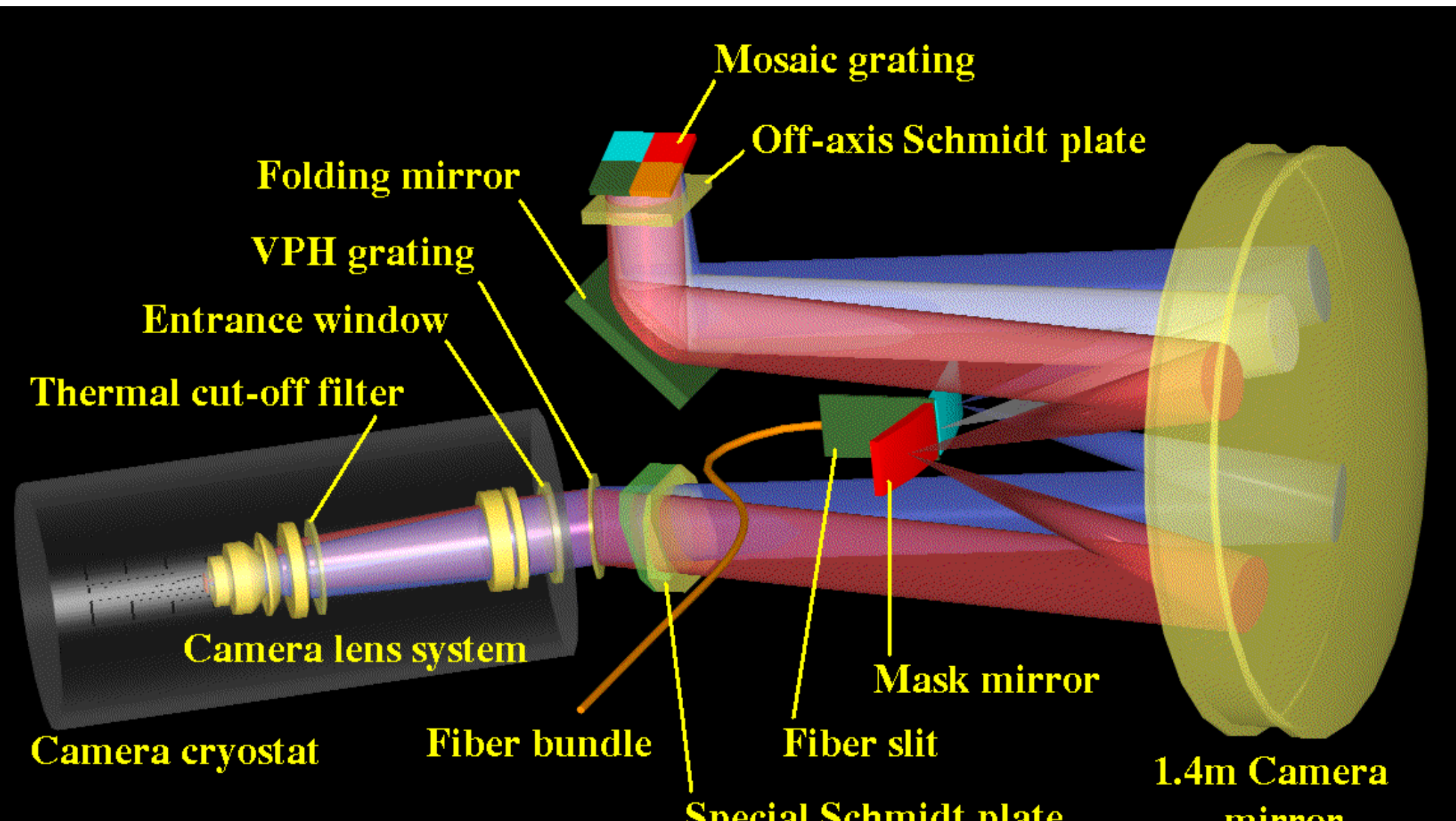


Typically $A=60\text{s}/15\text{ cy}$: 1800s exposure $\Rightarrow 10^{-3}$ subtraction

Credit: Kathy Roth (Gemini)

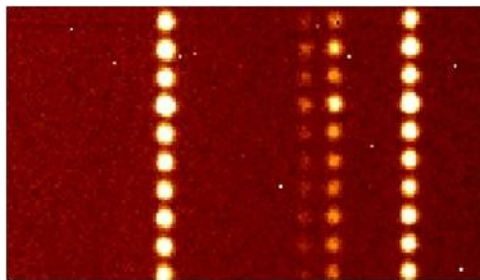
Fiber Spectrographs: from fibers to spectra

Example below shows FMOS optical design, shows sky emission blocked by mask mirror



Fiber Spectrographs: from fibers to spectra

FMOS spectra



individual fibers visible
in this calibration image
(narrow emission lines)

