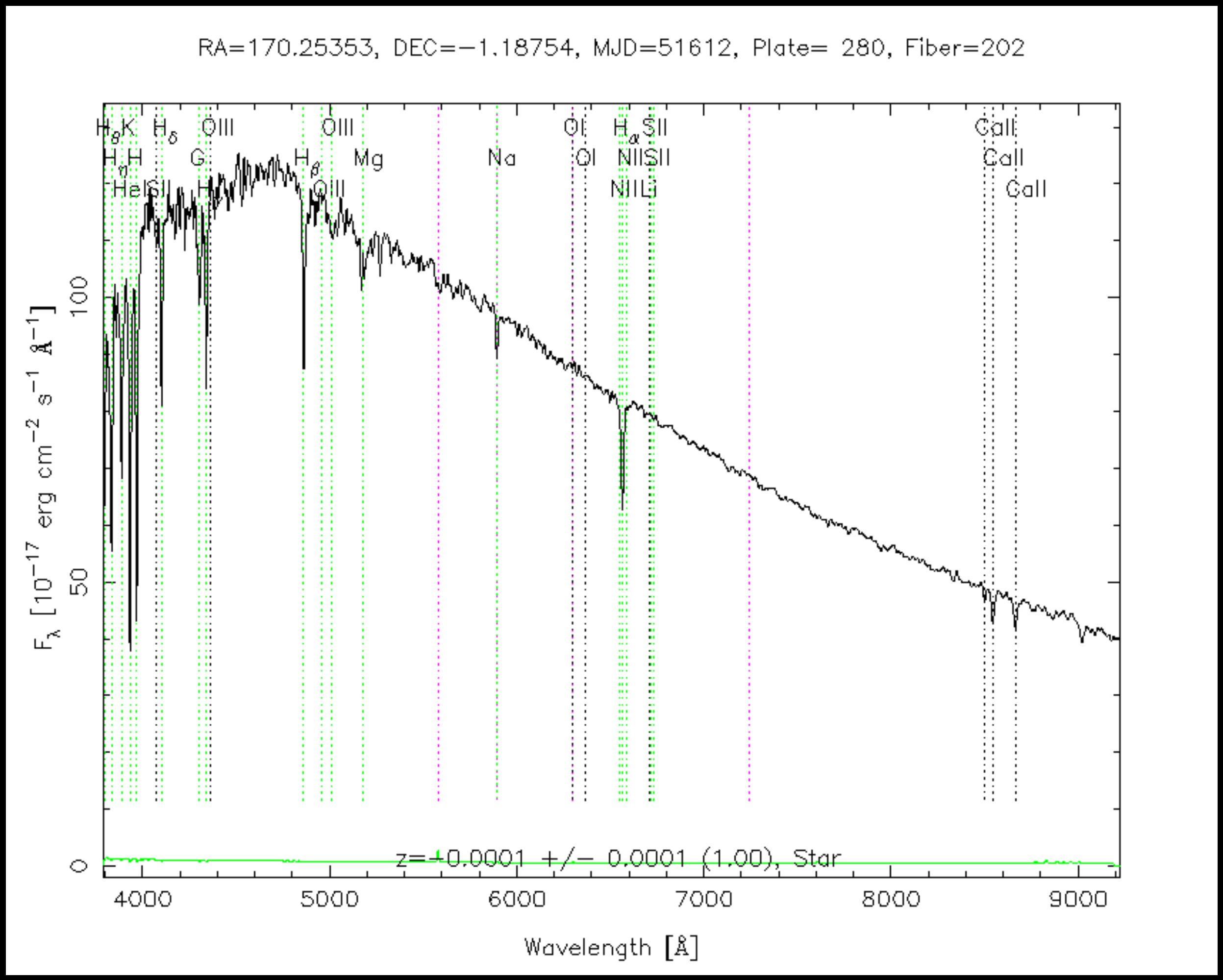
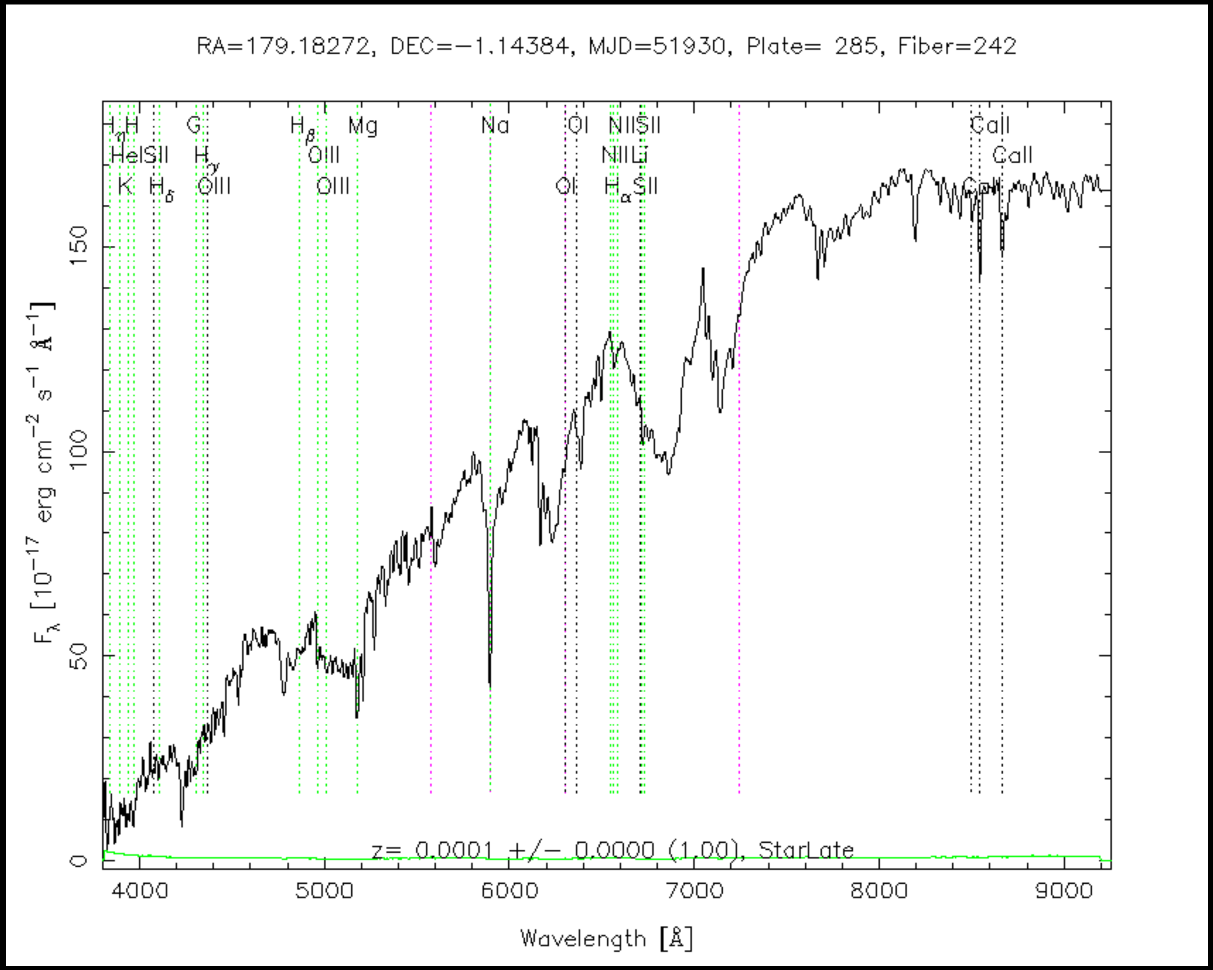
Spectroscopy





- Two different stellar spectra. Left hot star, right is cool star w/ molecular bands.

Gratings

- If every point on a wavefront acts like a source, why don't we see radiation everywhere in space?

- off-axis, phases add up sometimes with positive phase, sometimes with negative phase

- What would happen if we blocked everywhere radiation added up out-of-phase?

- This is a diffraction grating.

- If an angle θ makes the phase difference 2π beween adjacent gaps, an angle of $n\theta$ will make a phase difference of $2n\pi$, or still in phase. The different n are called different orders.

Reflection Grating/Blaze

- If we blocked half the light, that would make us sad
- Gratings in general have many sidelobes, called “orders”. Light in other orders also makes us sad
- Instead, can etch lines in a mirror, reflect off that
- More efficient, puts signal (mostly) in one order. Surface figure (the “blaze”) distributes how power goes into orders.

Spectral Resolution

- Say I use CCD to measure spectrum. What is the narrowest line I can see?
- Usually refered to as R, spectral resolution, $\lambda/\delta\lambda$
- How would you want spectrograph to behave if you had a 4k chip?

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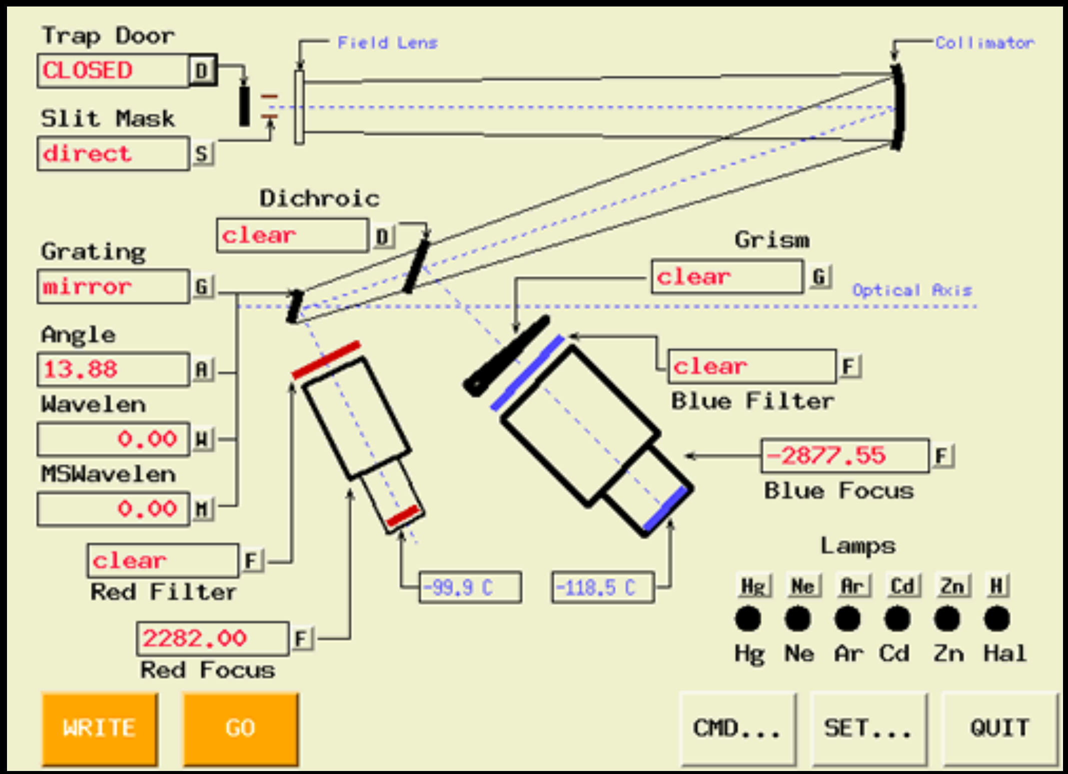
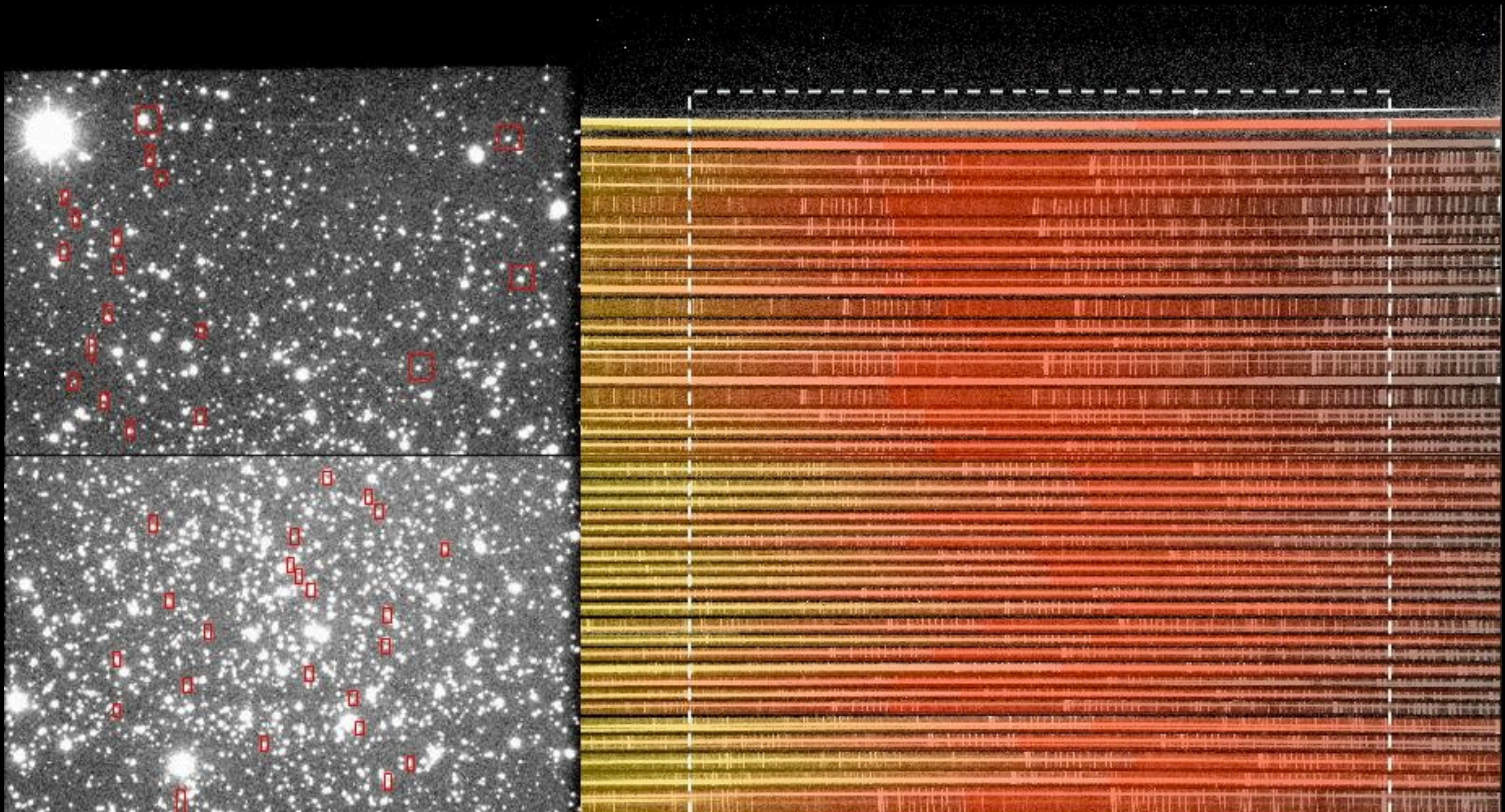
  - As usual, want to Nyquist sample. For fixed spectrograph, if seeing gets worse, star image will get fuzzier. Limit would be ~2k resolution elements.

Classical Slit Spectroscopy

- If you want one or a few objects, send light onto grating, take picture with CCD
- Often make a mask that covers focal plane with slits. Each slit can be put on object.

Keck LRIS

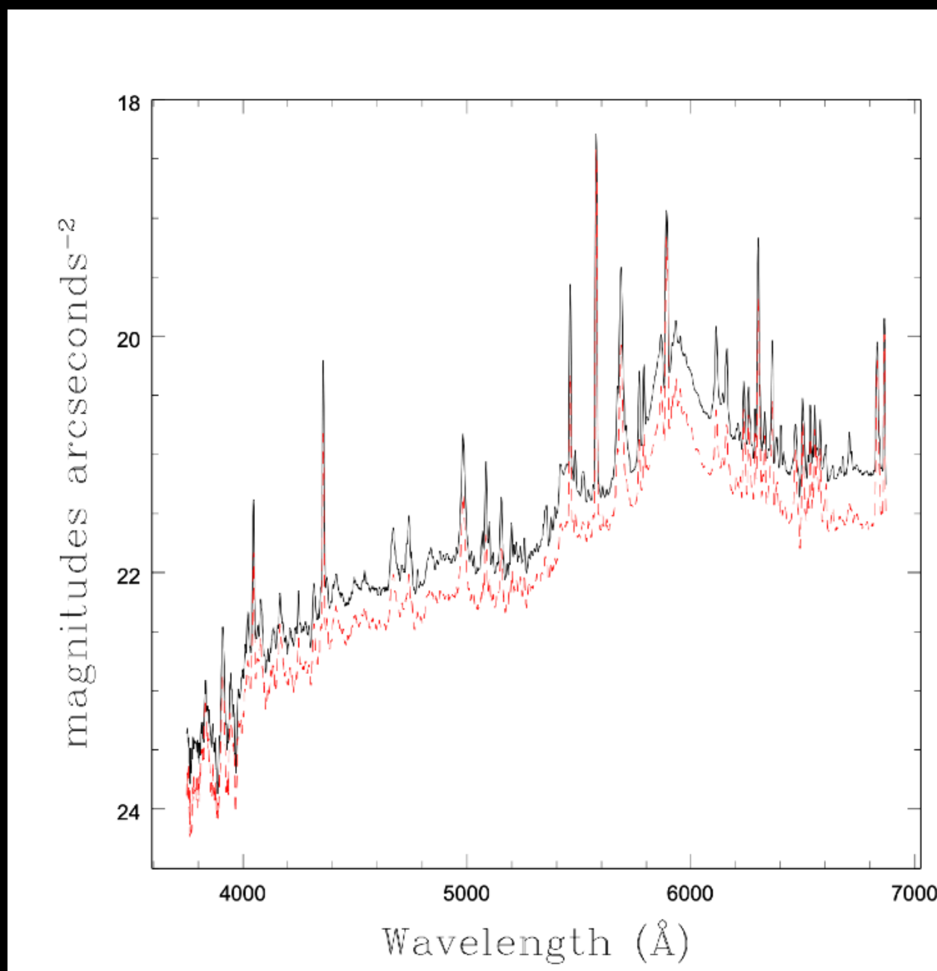

Trap Door
CLOSED
Slit Mask
direct
Field Lens
Collimator
Dichroic
clear
Grating
mirror
Grism
clear
Optical Axis
Angle
13.88
Wavelen
0.00
MSWavelen
0.00
clear
Blue Filter
-2877.55
Blue Focus
clear
Red Filter
-99.9 C
-118.5 C
Lamps
Hg Ne Ar Cd Zn Hal
2282.00
Red Focus
WRITE
GO
CMD...
SET...
QUIT

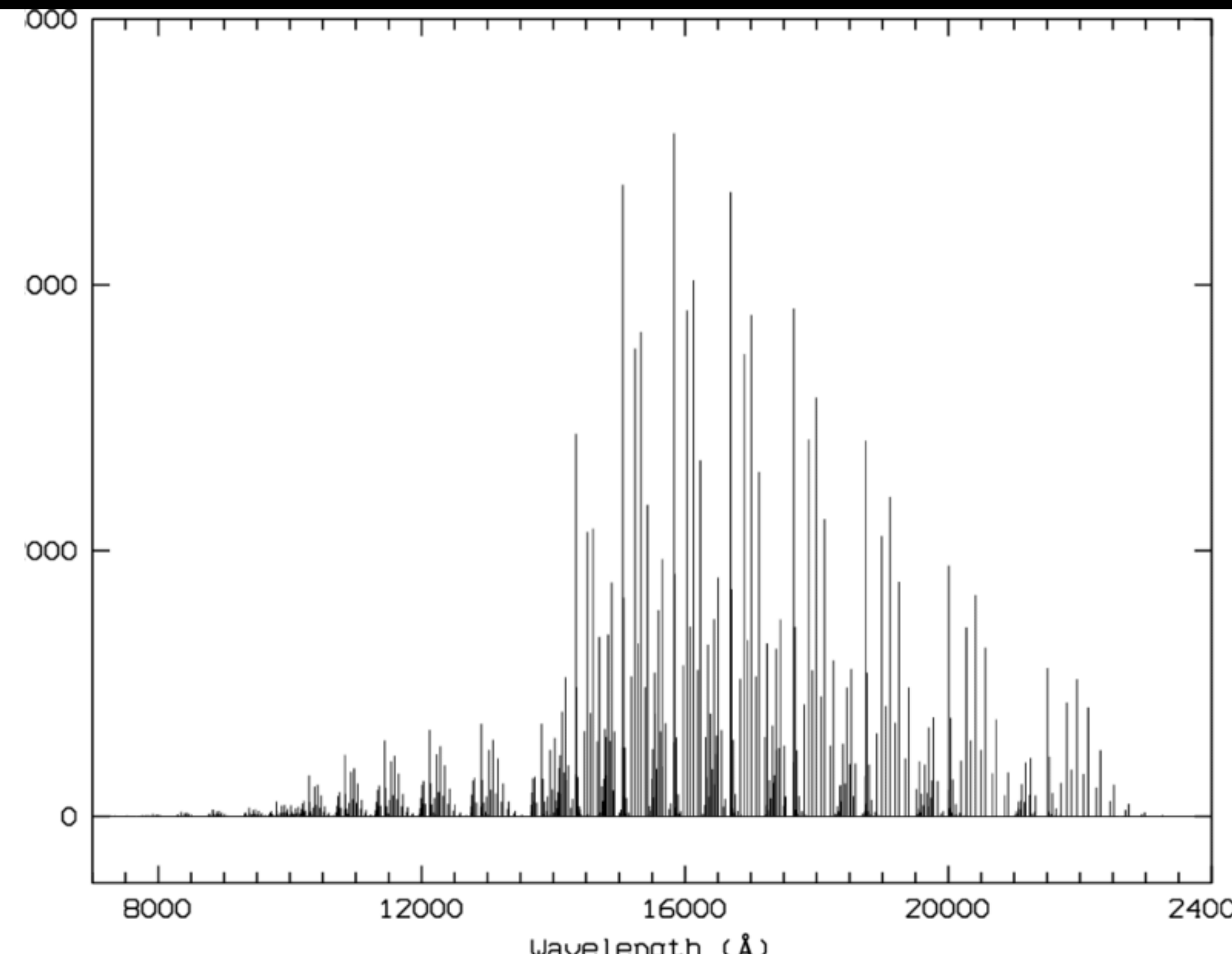


Sky Subtraction

- For faint sources, the sky will be brighter than the source.
- Sky has many lines that are spatially and temporally variable.
- Slit should be larger than source so you can fit night sky signal and subtract off.

Night Sky Spectra

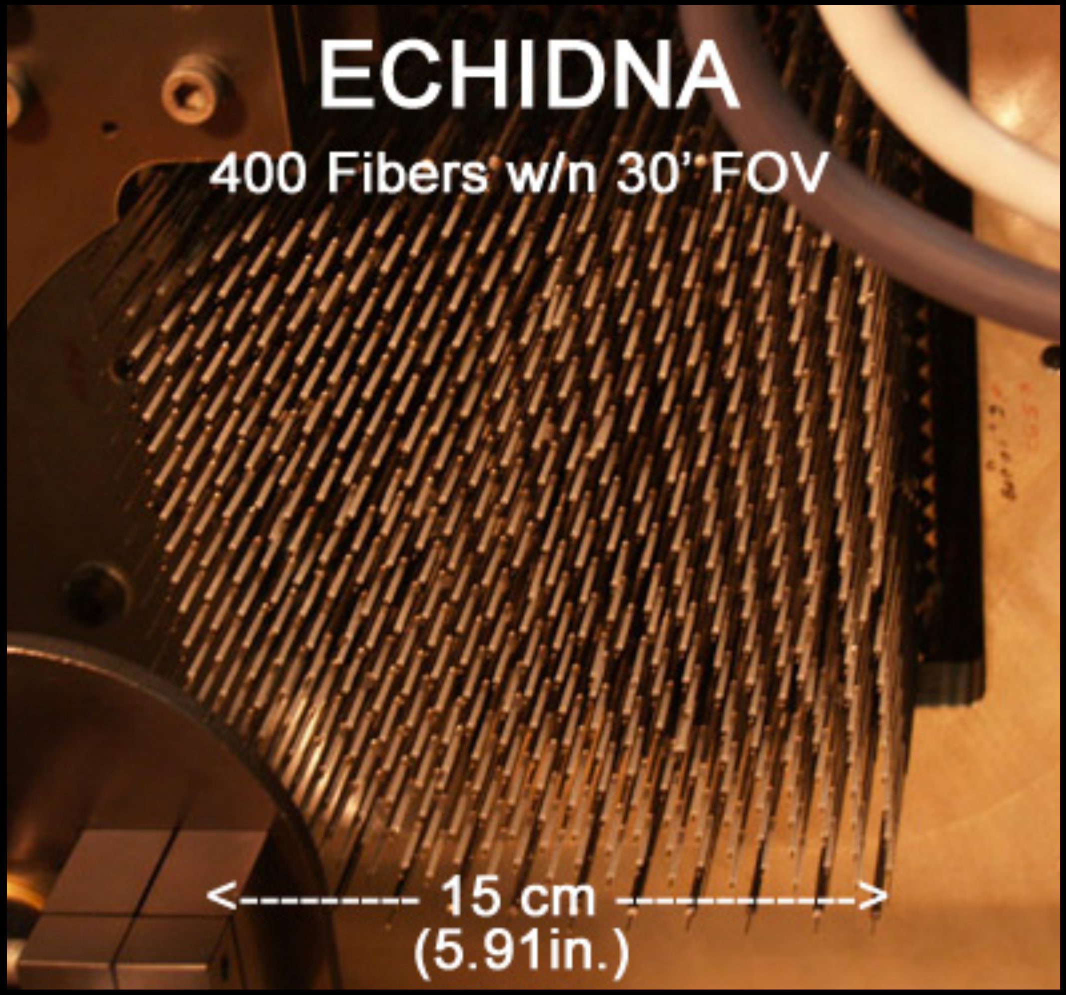




- Left: Optical (KPNO, Neugent & Massey)
- Right: “Typical” IR (Rousselot et al.)

Fiber Spectroscopy

- Rather than making slits, can also use optical fibers
- Position fibers where desired sources will be.
- Can do this with plates, but robots are now usually used.



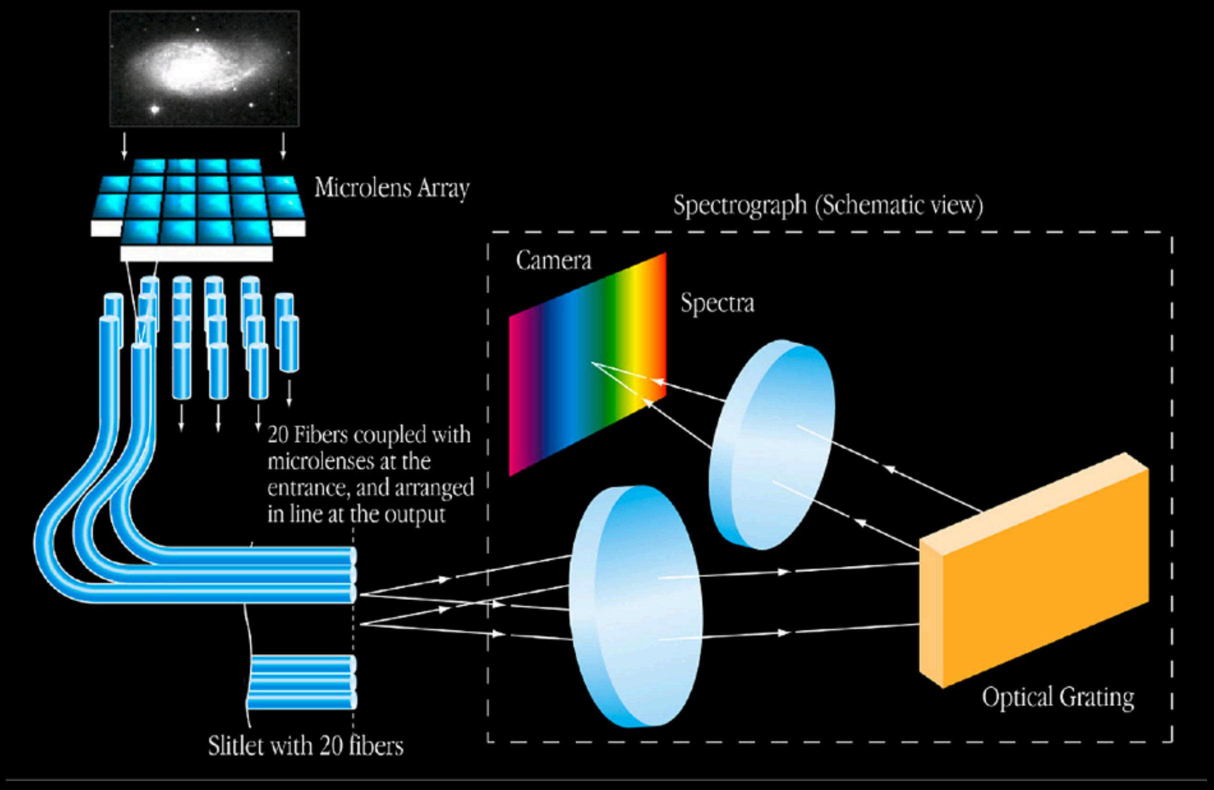
Top: fiber plug plate on SDSS
Bottom:Fiber robot for FMOS instrument on Subaru

IFU

- Integral field units a way of taking spectra over area - say for mapping out velocity dispersion of face-on galaxy.

- Variety of techniques, including lenslets into fibers.

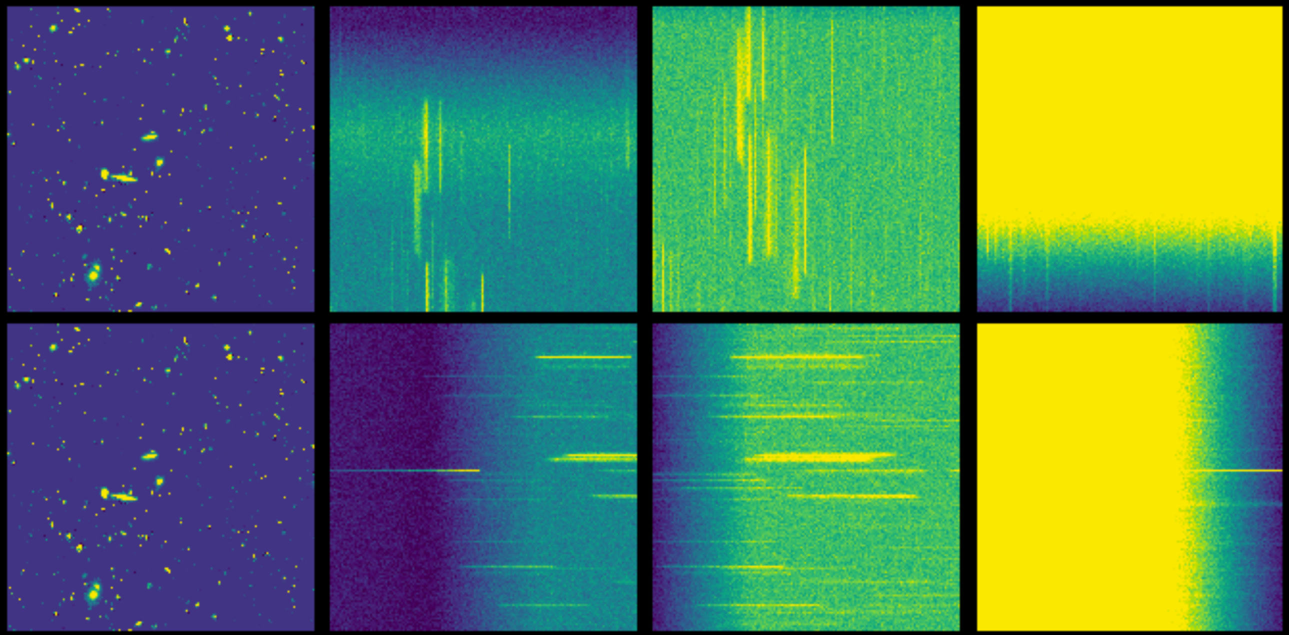
- Top: MUSE (VLT) image, bottom: instrument schematic

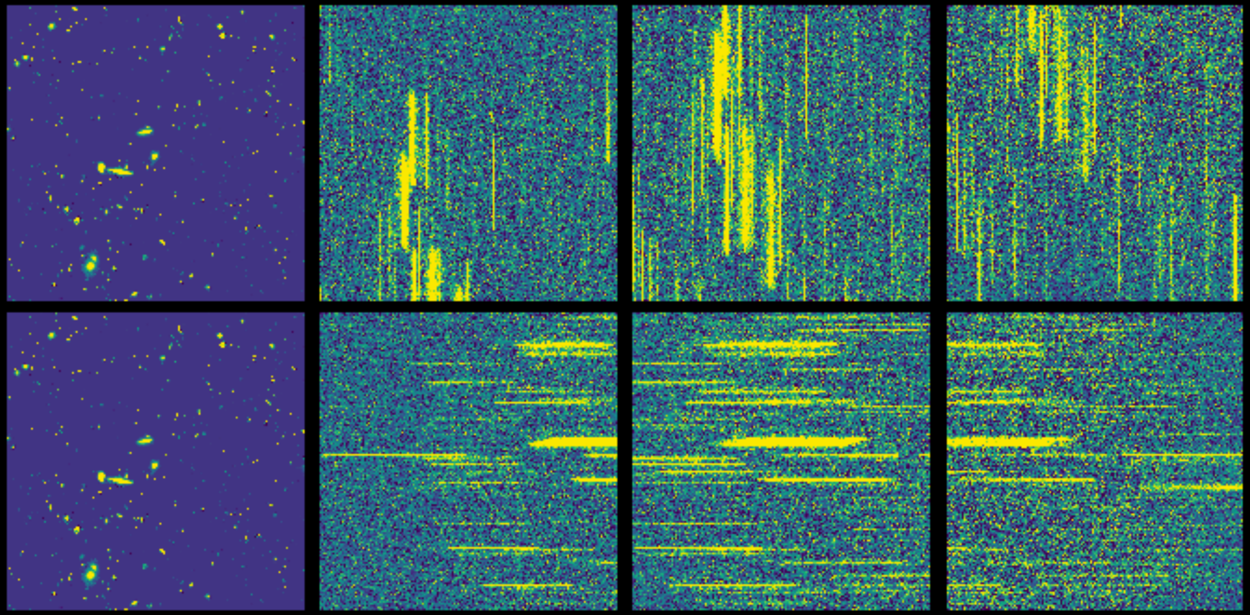


Grism

- Can do hundreds to thousands of spectra with fibers/ IFUs.
- Alternatively, can put a grating+prism (“grism”) that spreads out light but leaves reference frequency unchanged.
- Can take spectra of every point in a large field. Downside - each pixel sees different frequencies from different points on sky.

NIRCam simulations



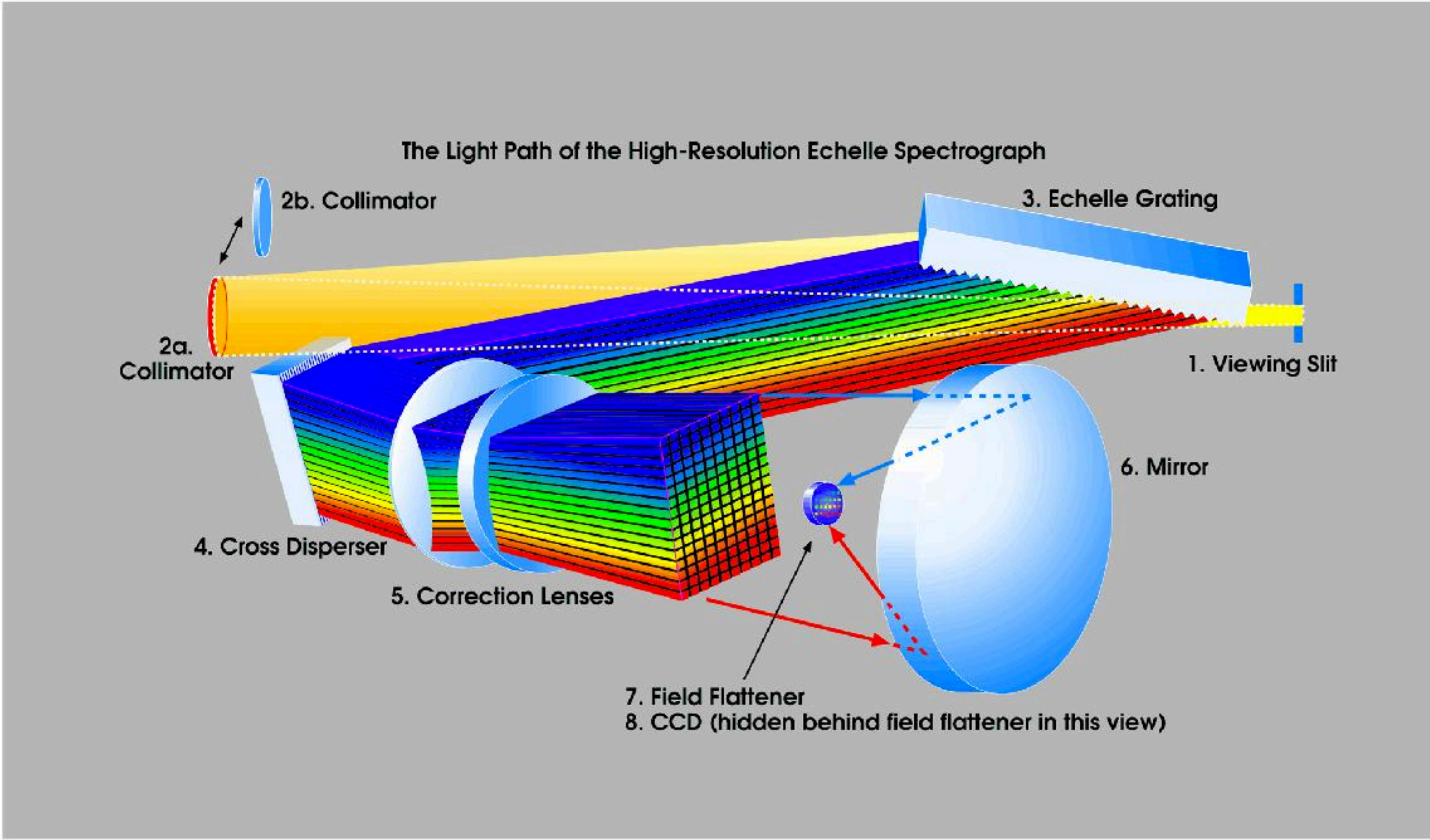


- What grism data can look like
- Can take multiple directions to try to break sky/frequency degeneracy.
- Could I get good spectrum at every map pixel this way?
    - No - two directions gives two bits of information per pixel. Could do more rotation angles

High Resolution

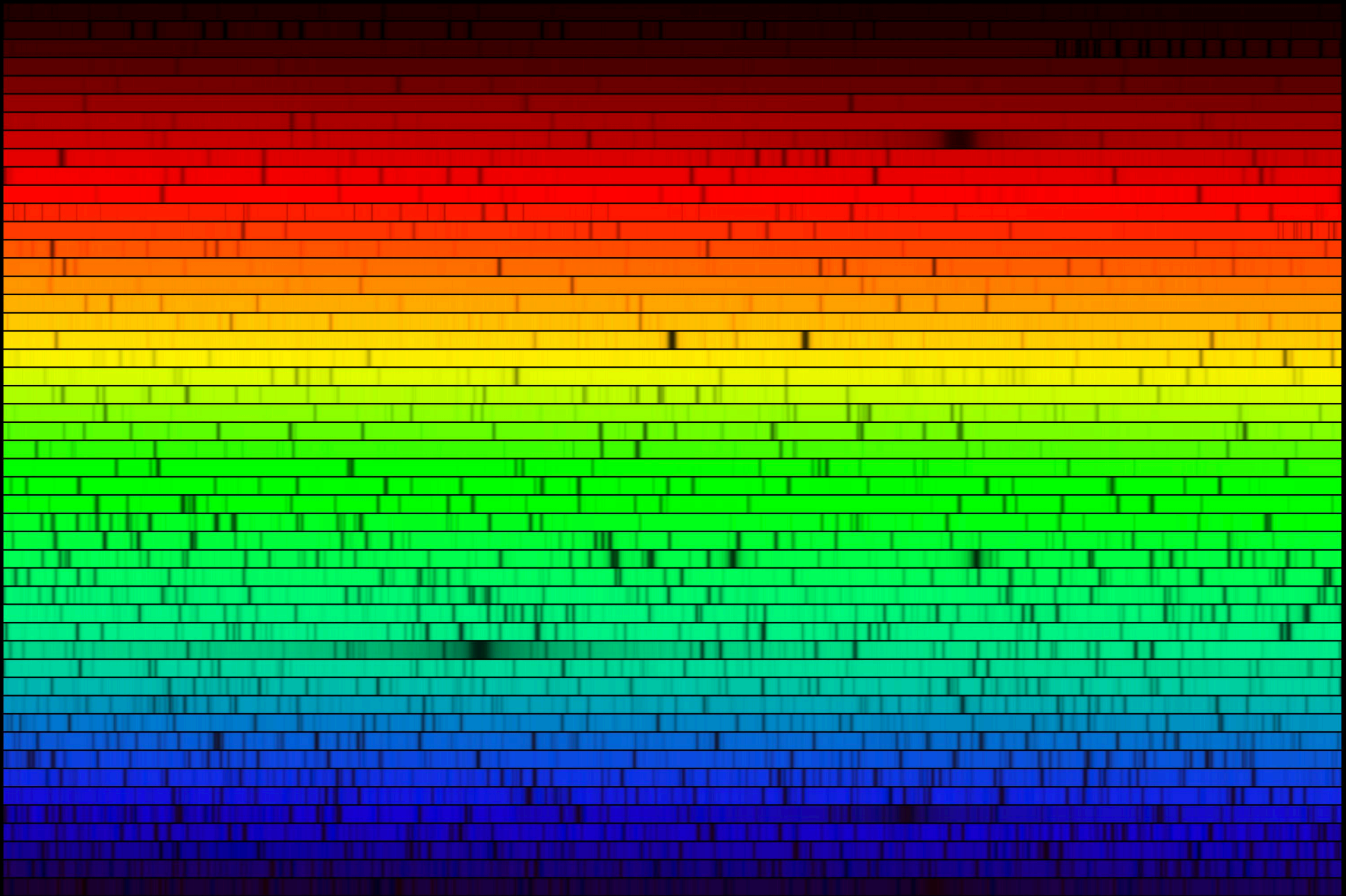
- If I want to measure radial velocity from a planet, what R would I need?
- Take hot jupiter - M=1e-3 solar masses, R=0.4 AU
- Typical scale 10s of m/s. Lower for habitable planet
- c/10 m/s=30,000,000. Need much higher resolution than simple grating will usually give us.
- Solution - echelle. Coarse grating in one direction that stacks up many orders on top of each other. Fine grating in other direction to spread them out.

Keck HI-RES

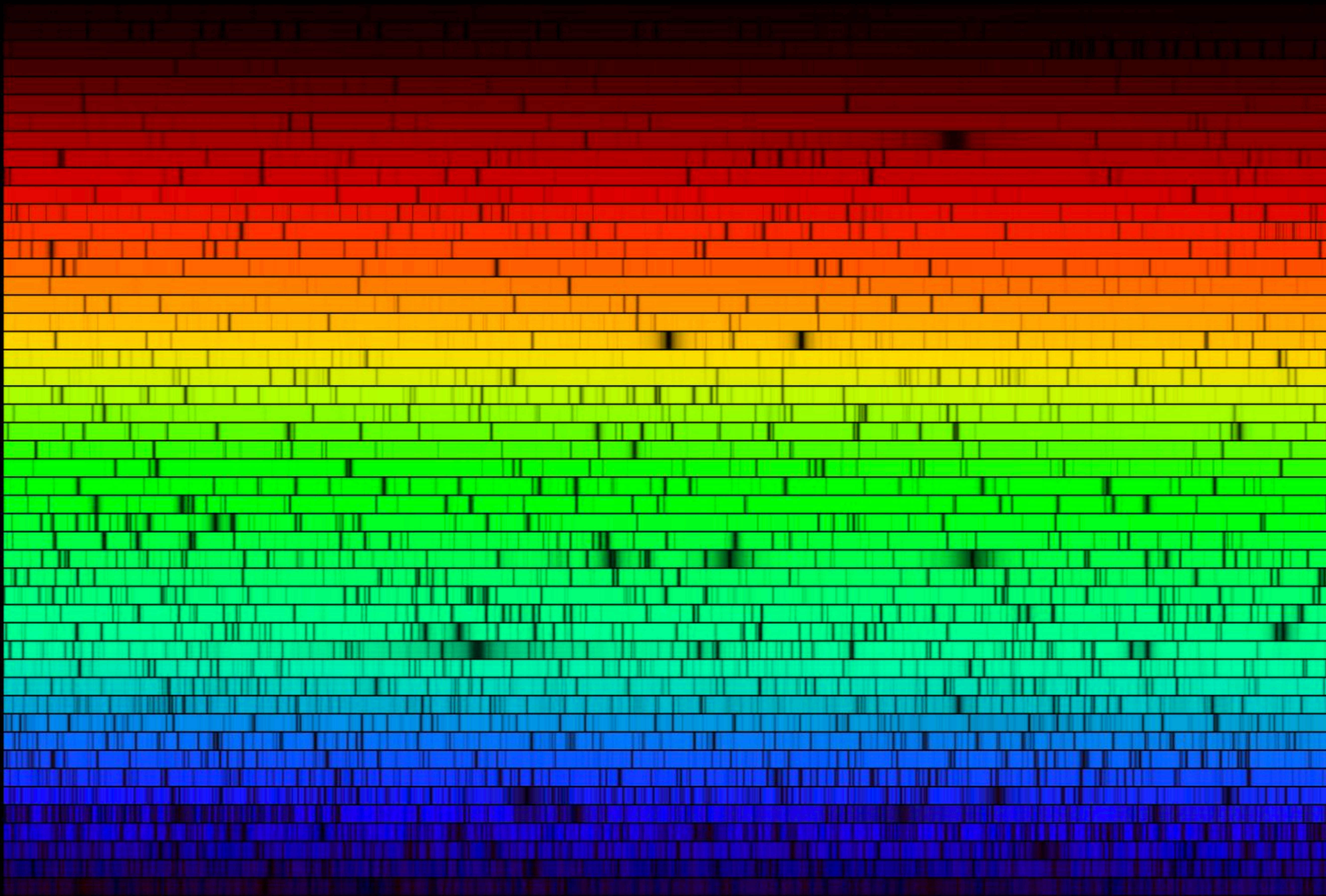


The Light Path of the High-Resolution Echelle Spectrograph
2b. Collimator
3. Echelle Grating
2a. Collimator
1. Viewing Slit
6. Mirror
4. Cross Disperser
5. Correction Lenses
7. Field Flattener
8. CCD (hidden behind field flattener in this view)

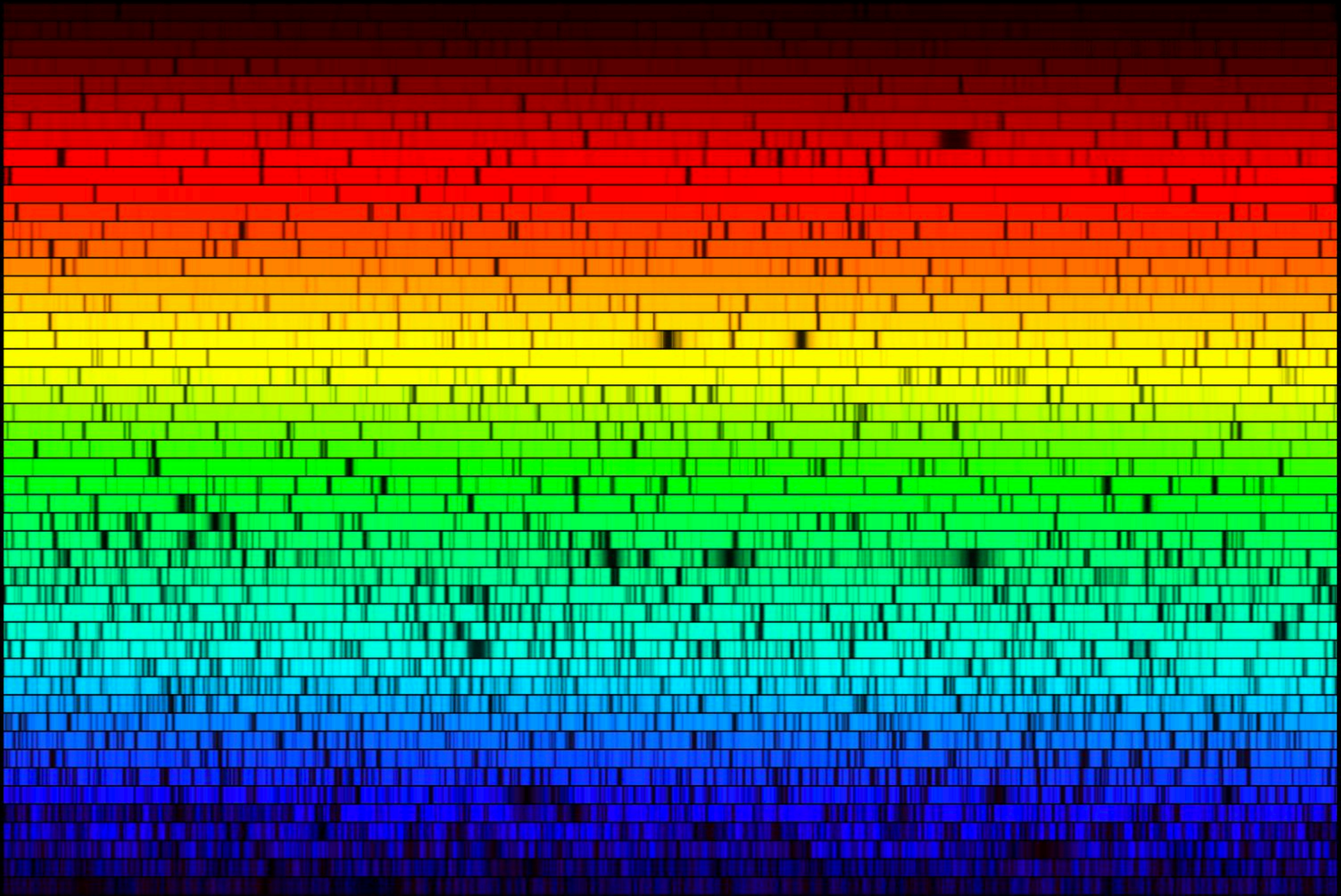
Procyon



Sun

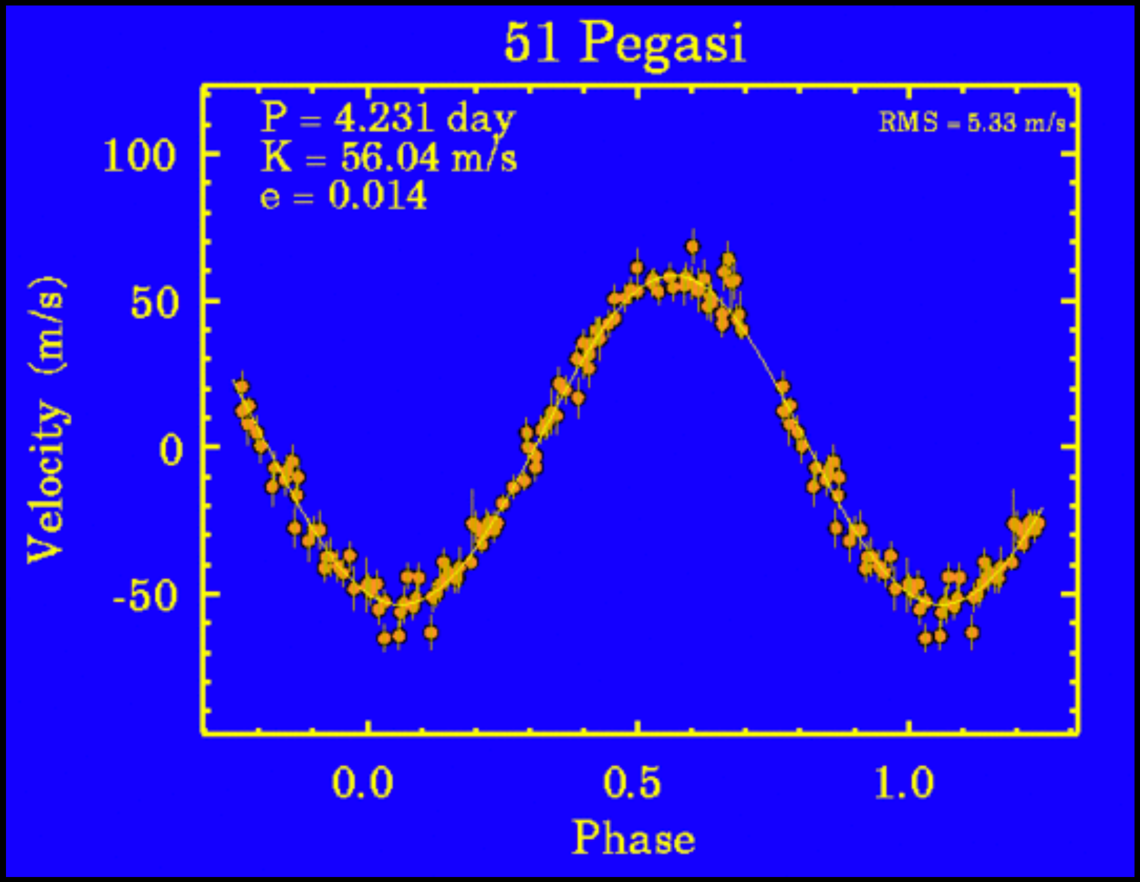


Arcturus



How would you find a planet?

- Native spectral resolution of high resolution spectroscopy ~1e5. Need a factor of 300 more.
- NB - can't often go much past ~1 km/s (R=300,000) anyways,since stars rotate
- If you have many lines at high SNR could centroid shifts to R*SNR
- Reference important as well - e.g. use iodine lamps (which have lots of lines).



If I were giving you a problem set…

- Say we have a star with intrinsic line width of 1 km/s from rotation.
- If we had a 10m telescope, how faint a star could we measure radial velocity to 5 m/s in one hour?
- Assume say 300 lines, and line depth is 50% of continuum.

Quick Estimate

- Say R ~10^5. 100 lines, target RMS of 1 m/s. Means per-line error of 1*sqrt(100)=10 m/s.
- Intrinsic width ~3 km/s, so need SNR of 3km/s/10 m/s = 300. Takes 10^5 photons.
- New bandwidth is 25,000x smaller than old, so need 25000*10^5 =2.5e9 photons.
- 50 m^2 for 3600s = 15,000 photons/m^2/s in V band. If telescope is 50% efficient, 30,000 photons/m^2/s.
- We found 25th mag AB is 1 photon/m^2/s in V, so need a star that's 25-2.5*log10(30000) ~14^{th} magnitude.
- Will do this from ground. Sun is ~4th mag absolute, so 10 mags fainter, factor of 10^4 in flux, or 10^2 in distance. Abs defined at 10 pc, so we can look for planets around stars at (sub-)kpc distances.