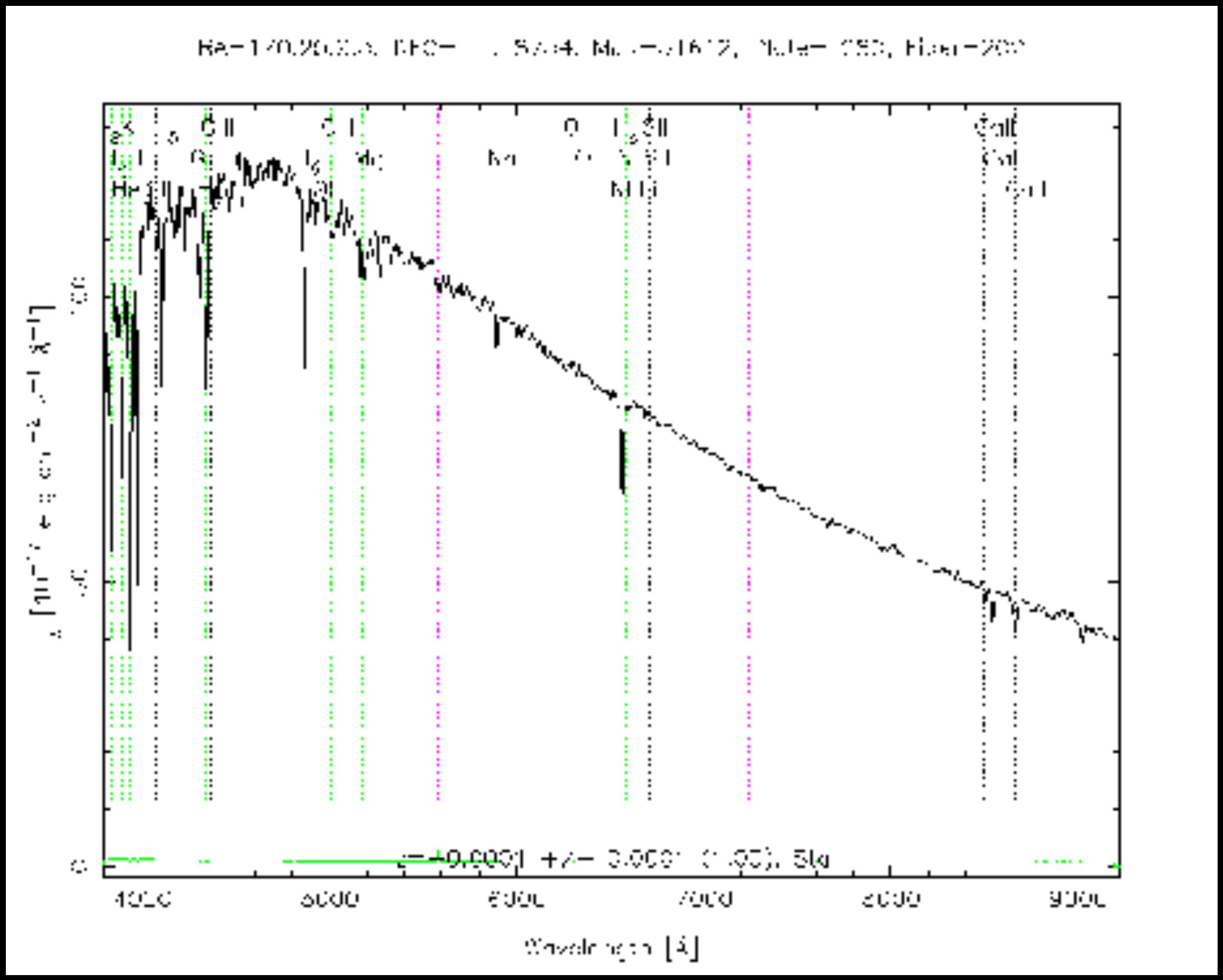
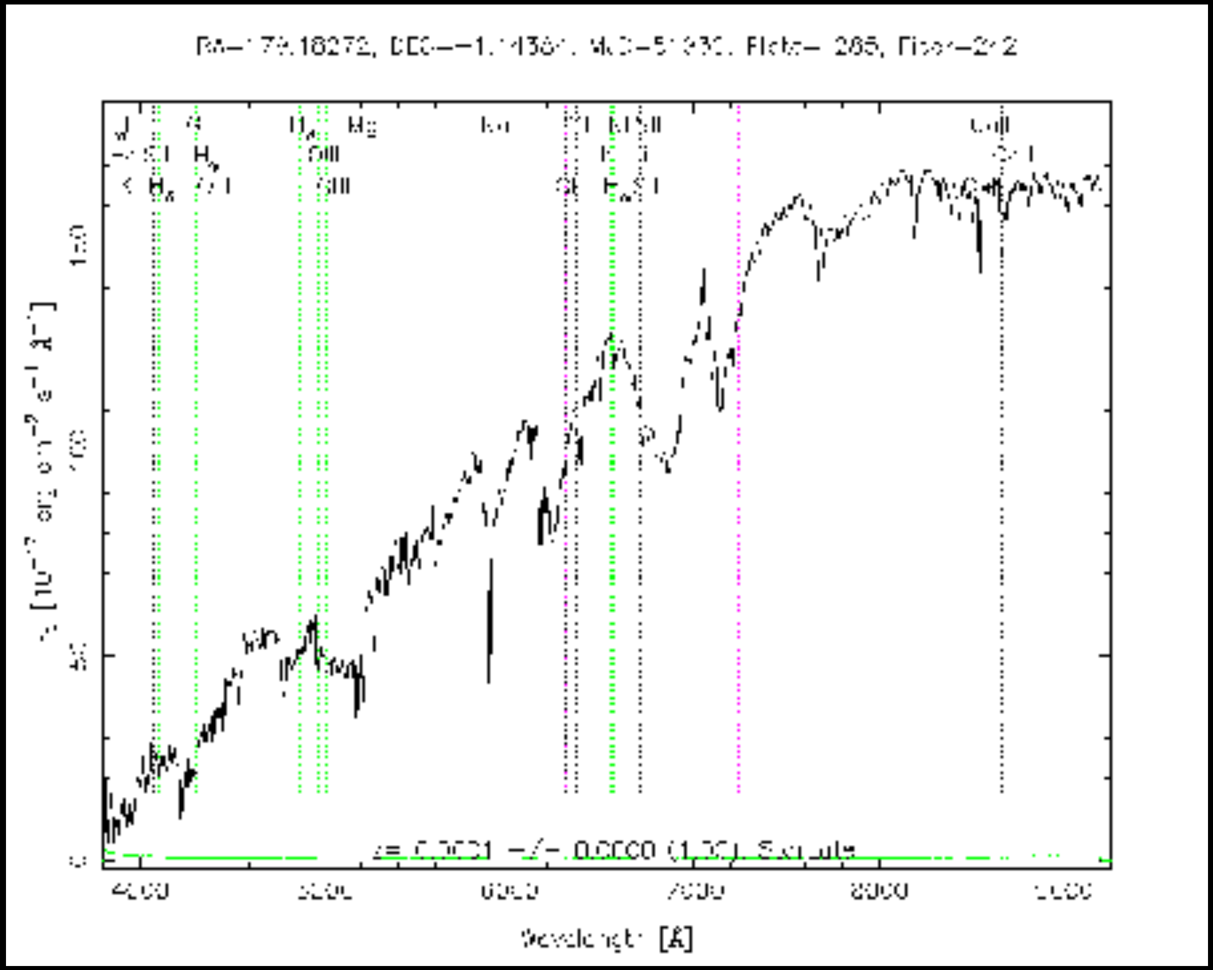
Abstracts

- Everyone present theirs…

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

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?

Spectral Resolution

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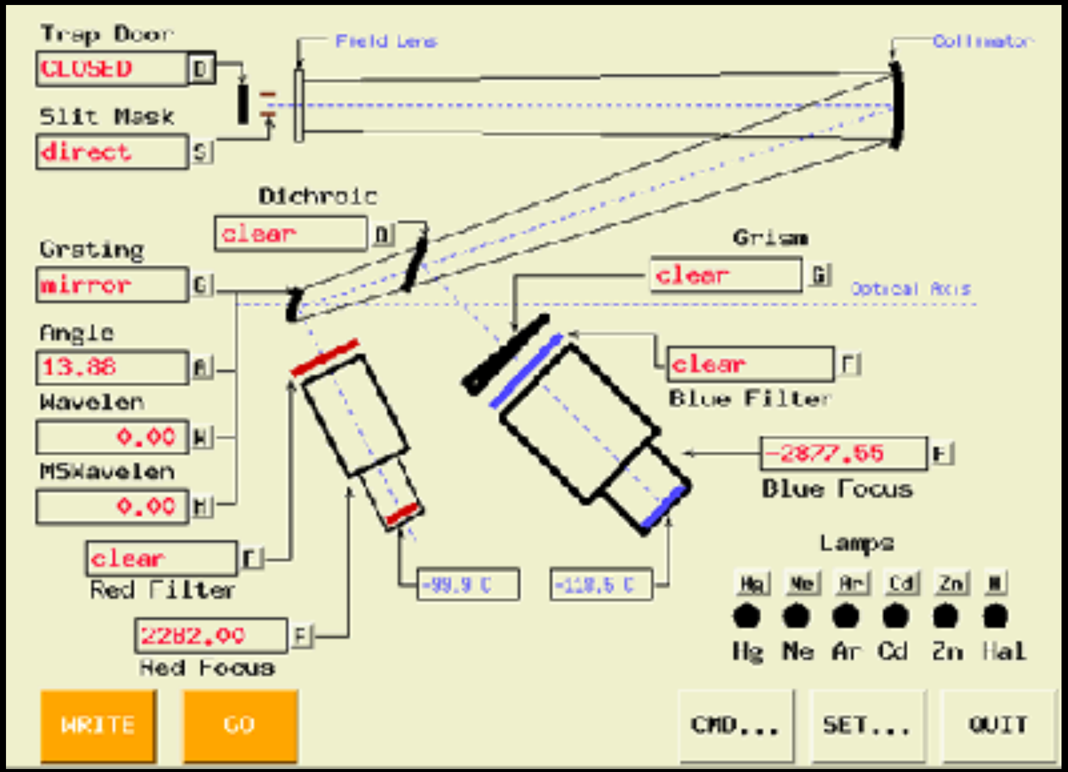
- How would you want spectrograph to behave if you had a 4k chip?
    - As usual, want to Nyquist sample. For fixed spectrograph, if seeing gets worse, star image will get fuzzier. Limit would be ~2k resolution elements.

Classical Slit Spectroscopy

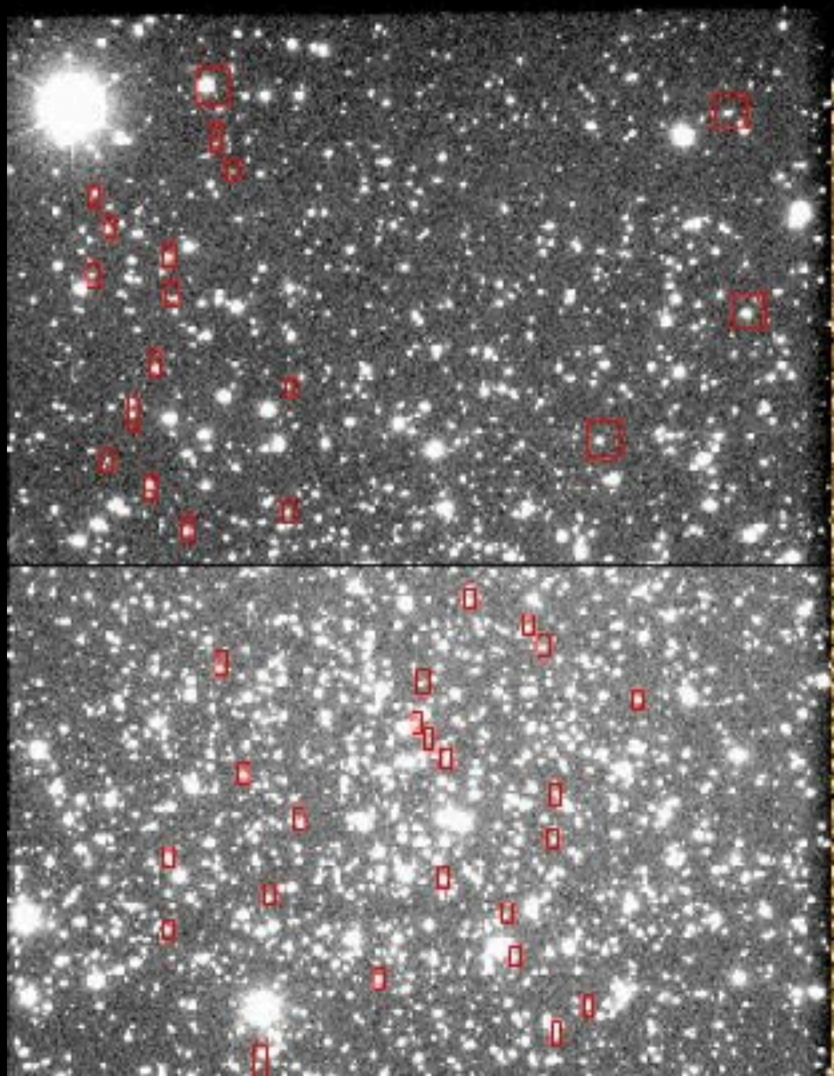
- If you want one or a few objects, send light onto grating, take picture with CCD

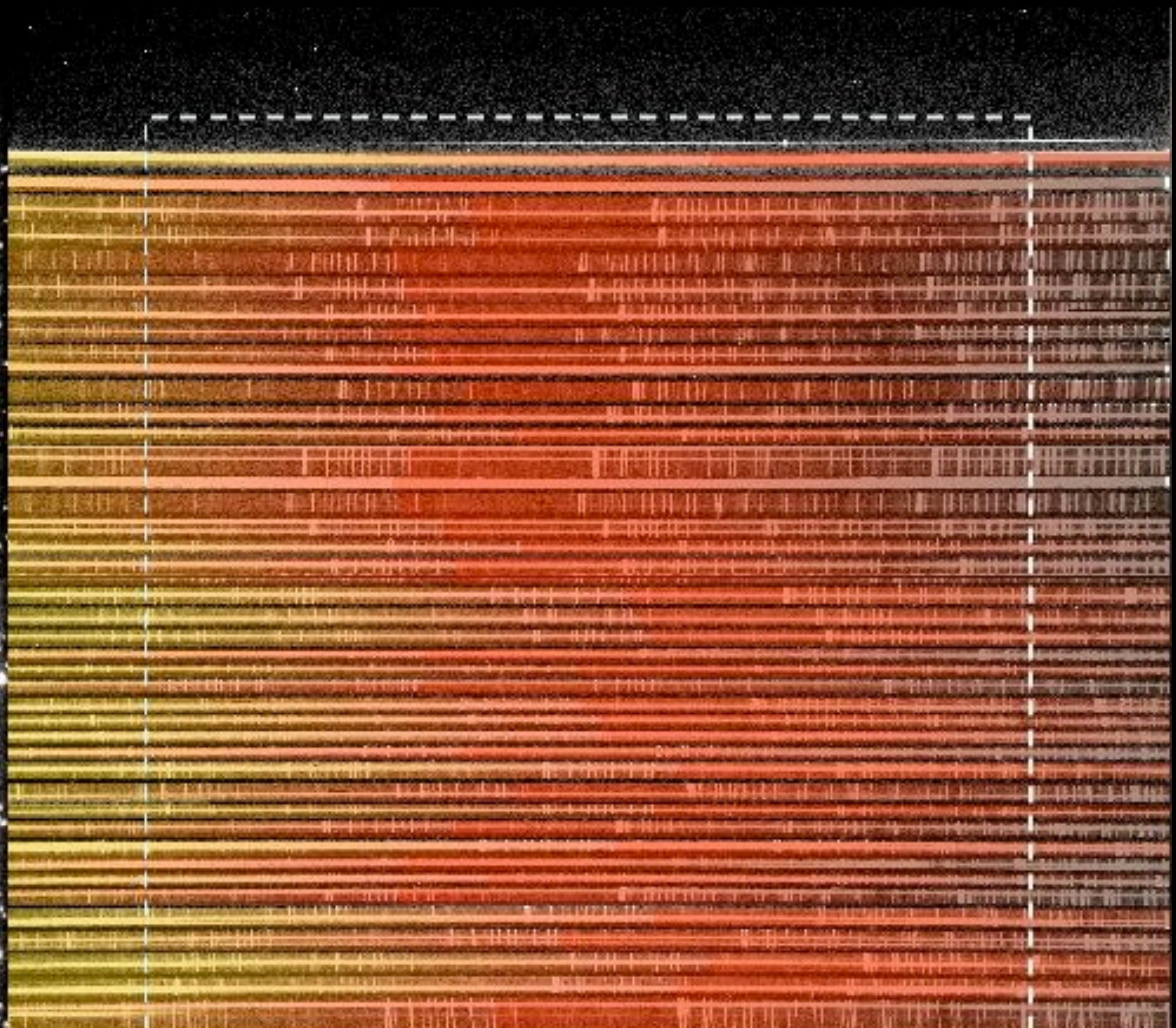
- Often make a mask that covers focal plane with slits. Each slit can be put on object.

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
-2877.65
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



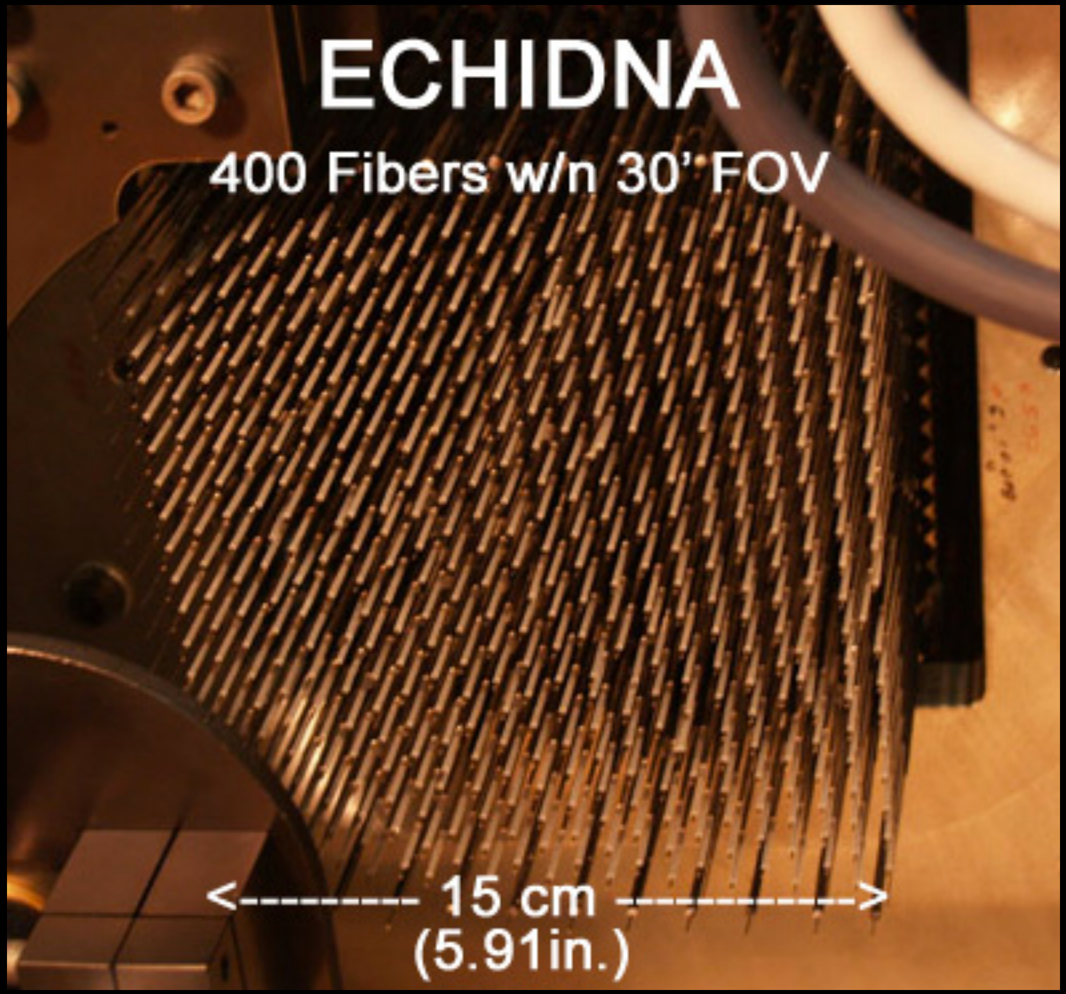


Sky Subtraction

- 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.

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.



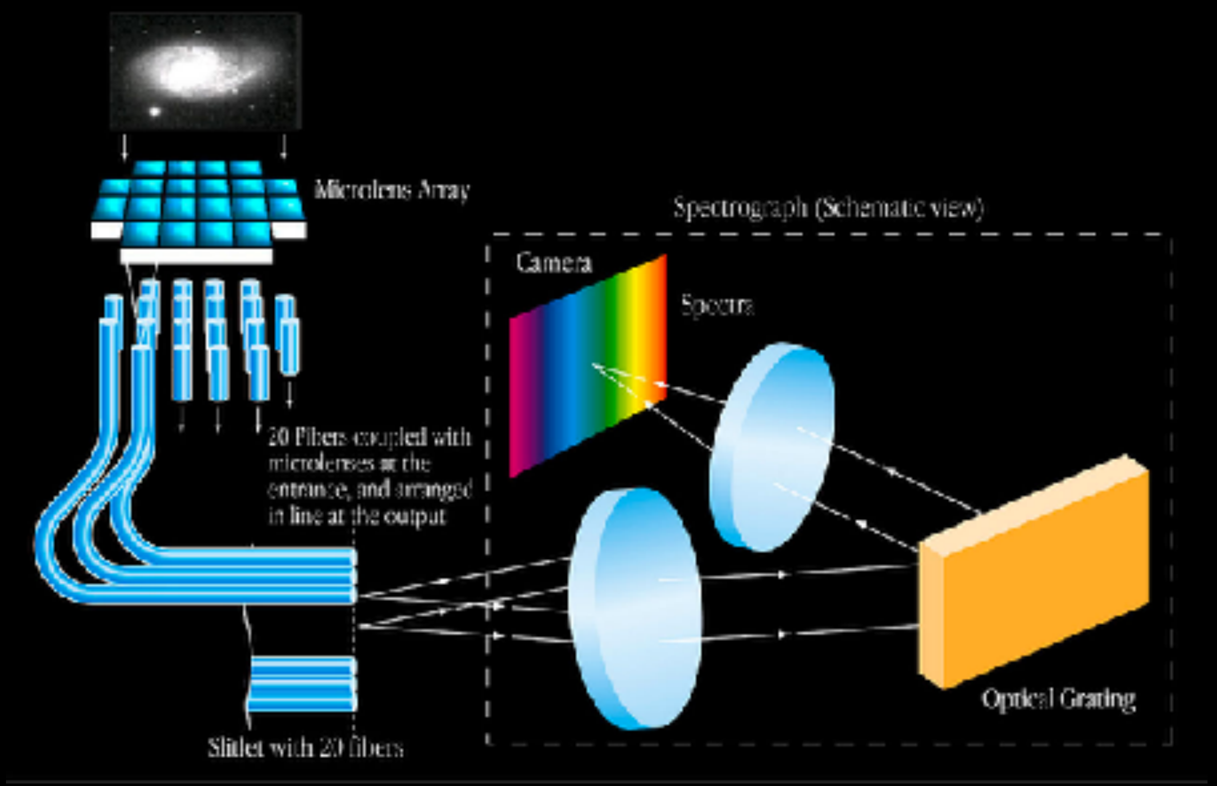
Top: fiber plug plate on SDSS
Bottom:Fiber robot for FMOS instrument on Subaru

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

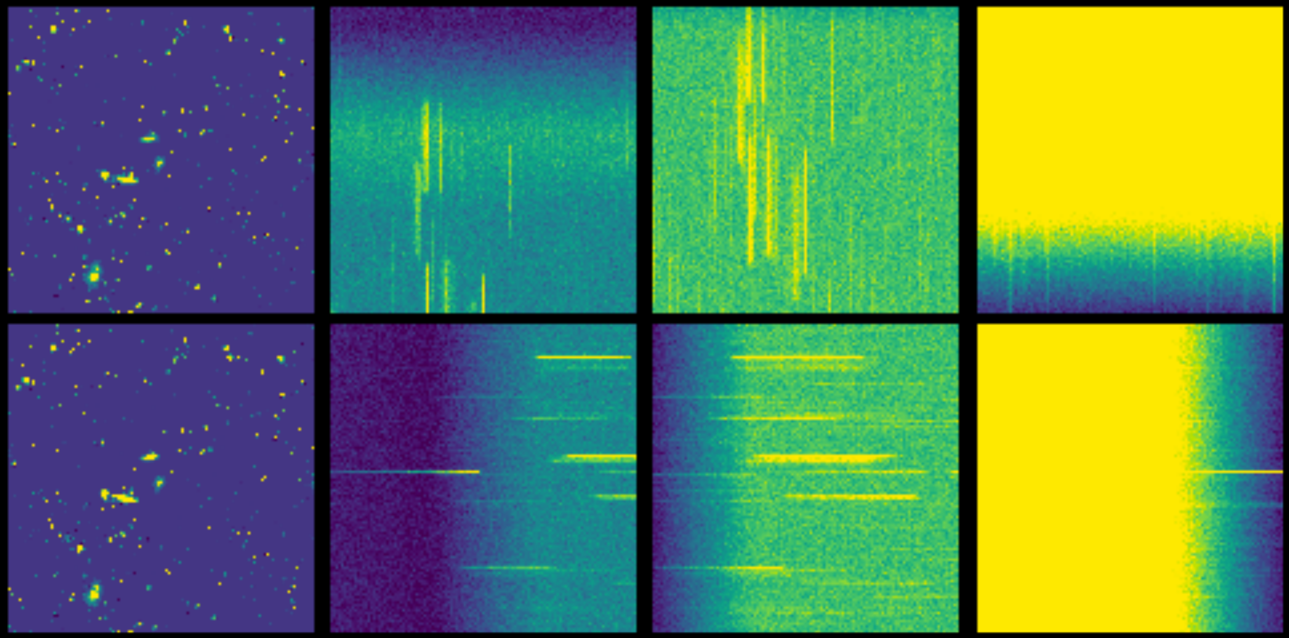


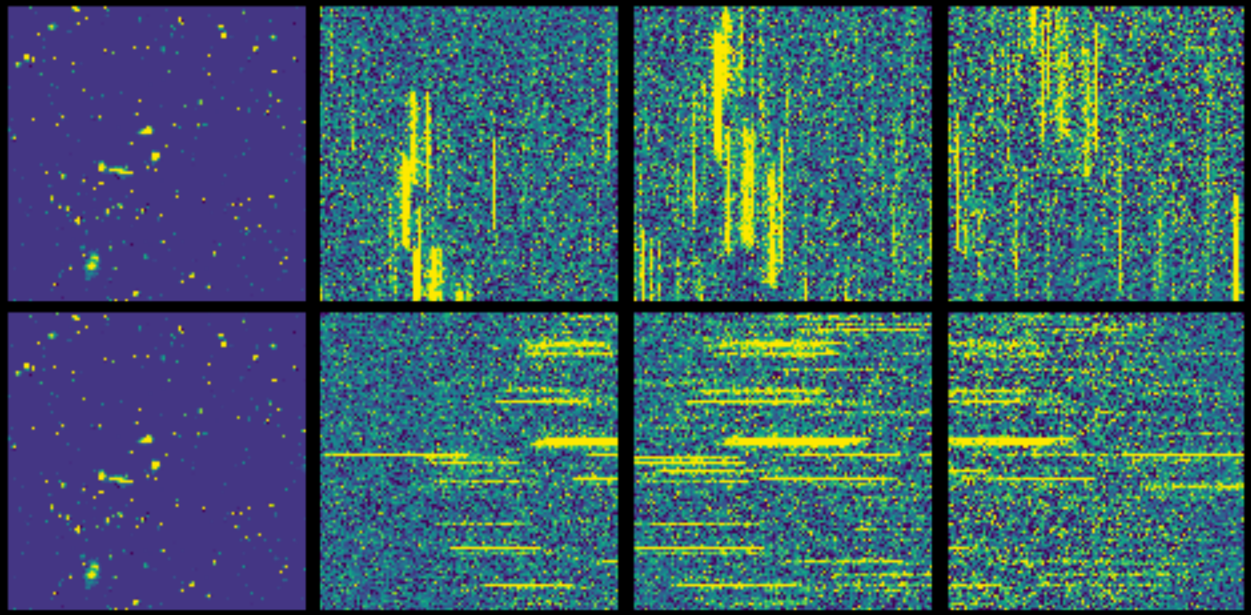
Grism

- 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

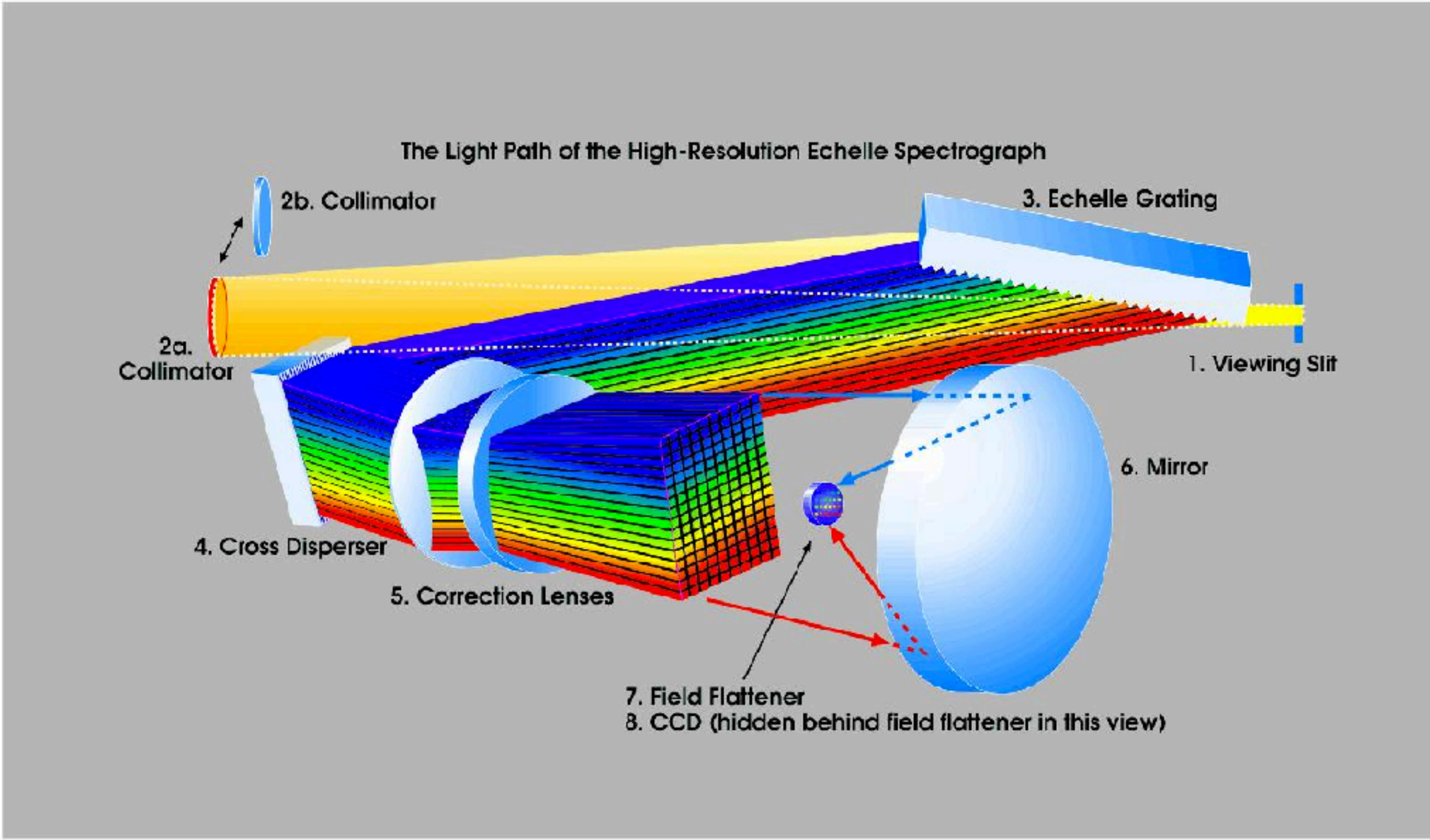




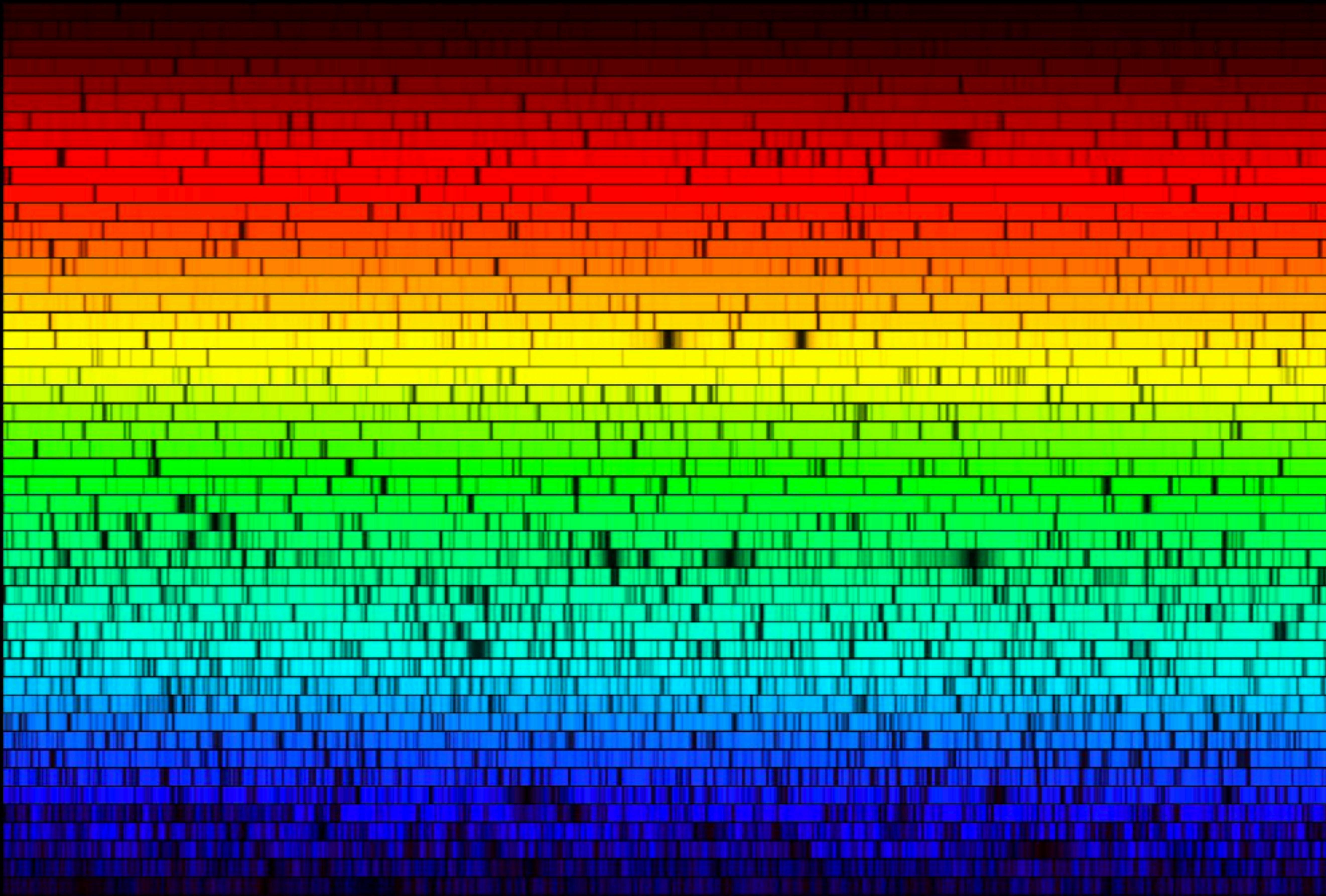
High Resolution

- 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.

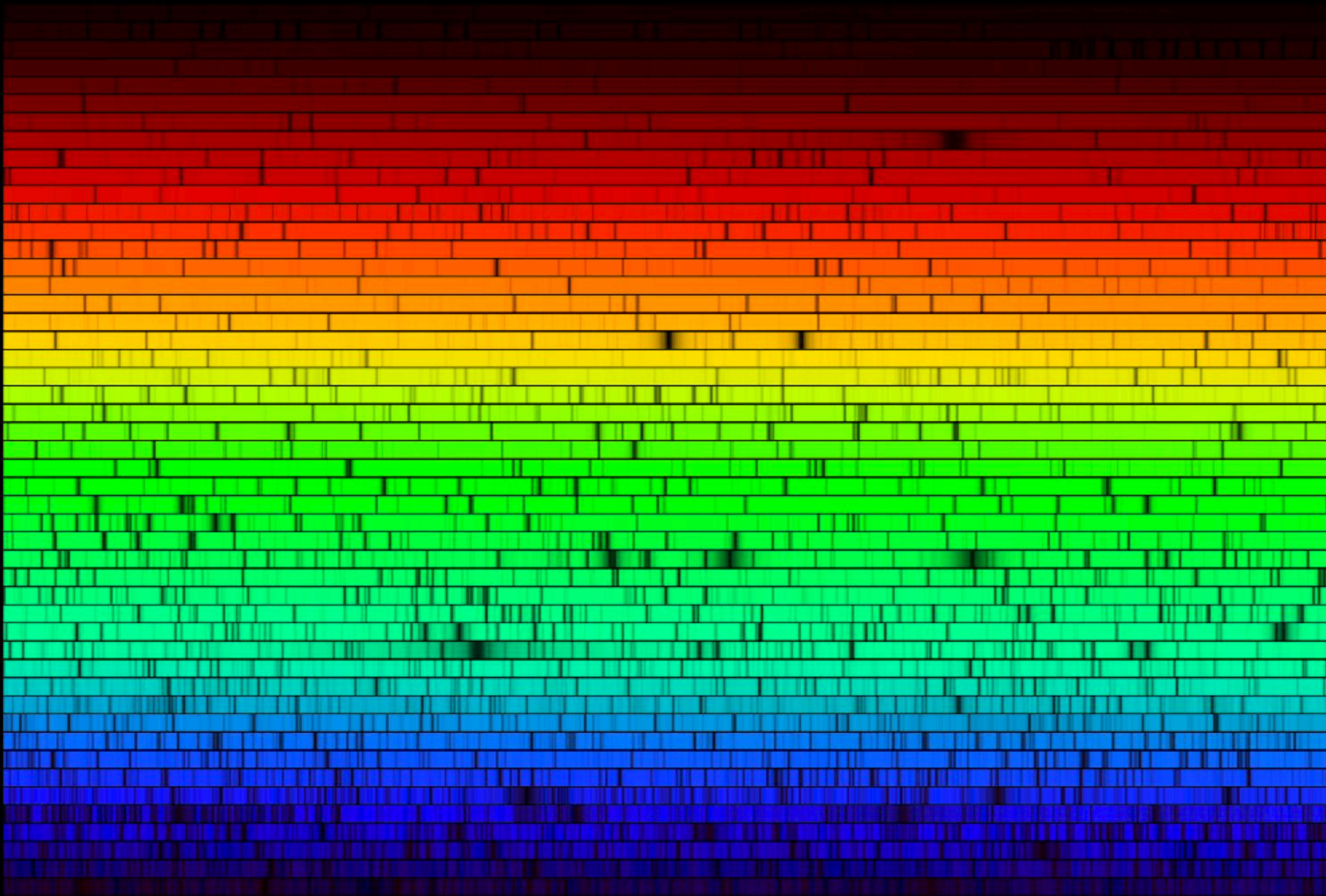
Keck HI-RES


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)

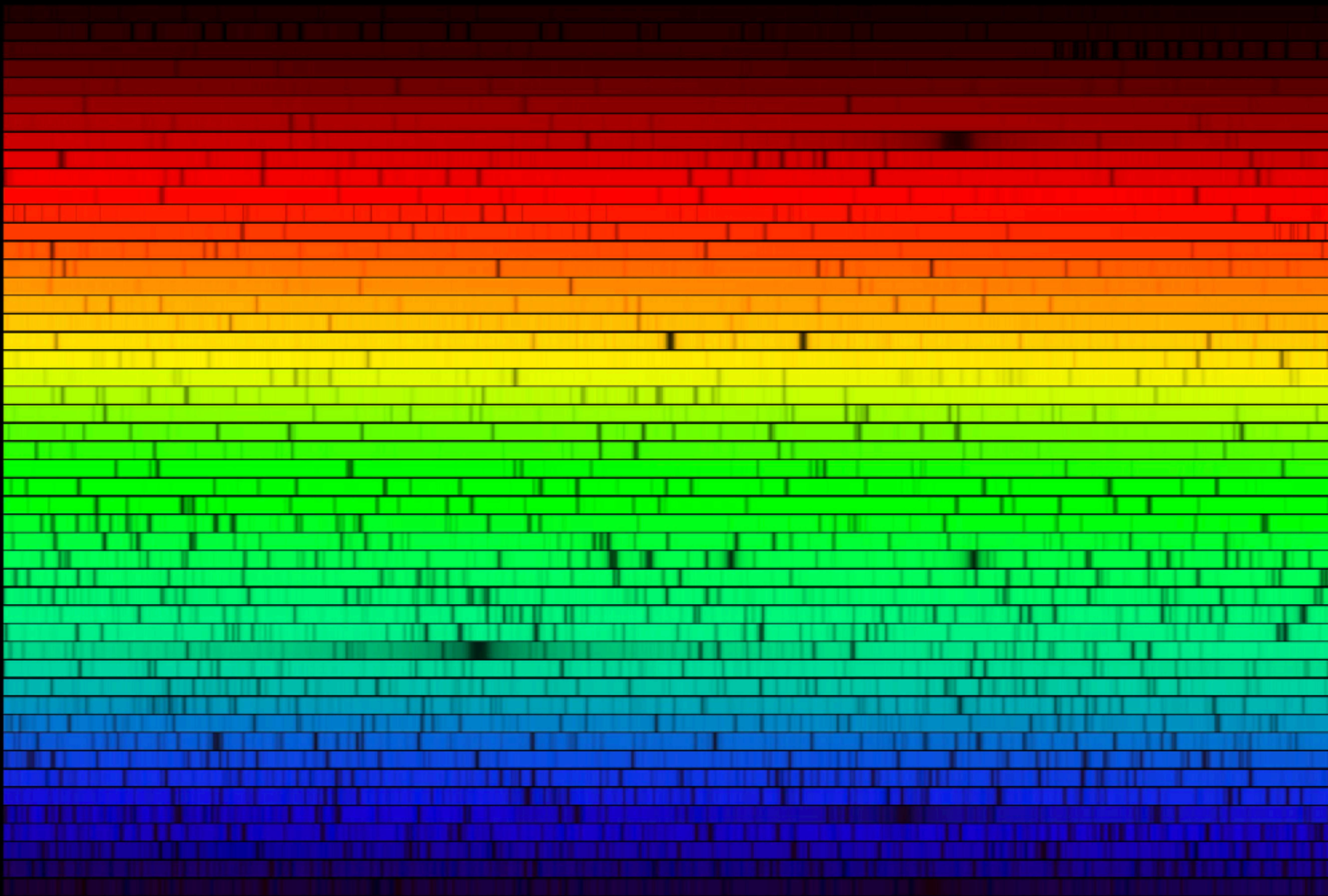
Arcturus



Sun



Procyon

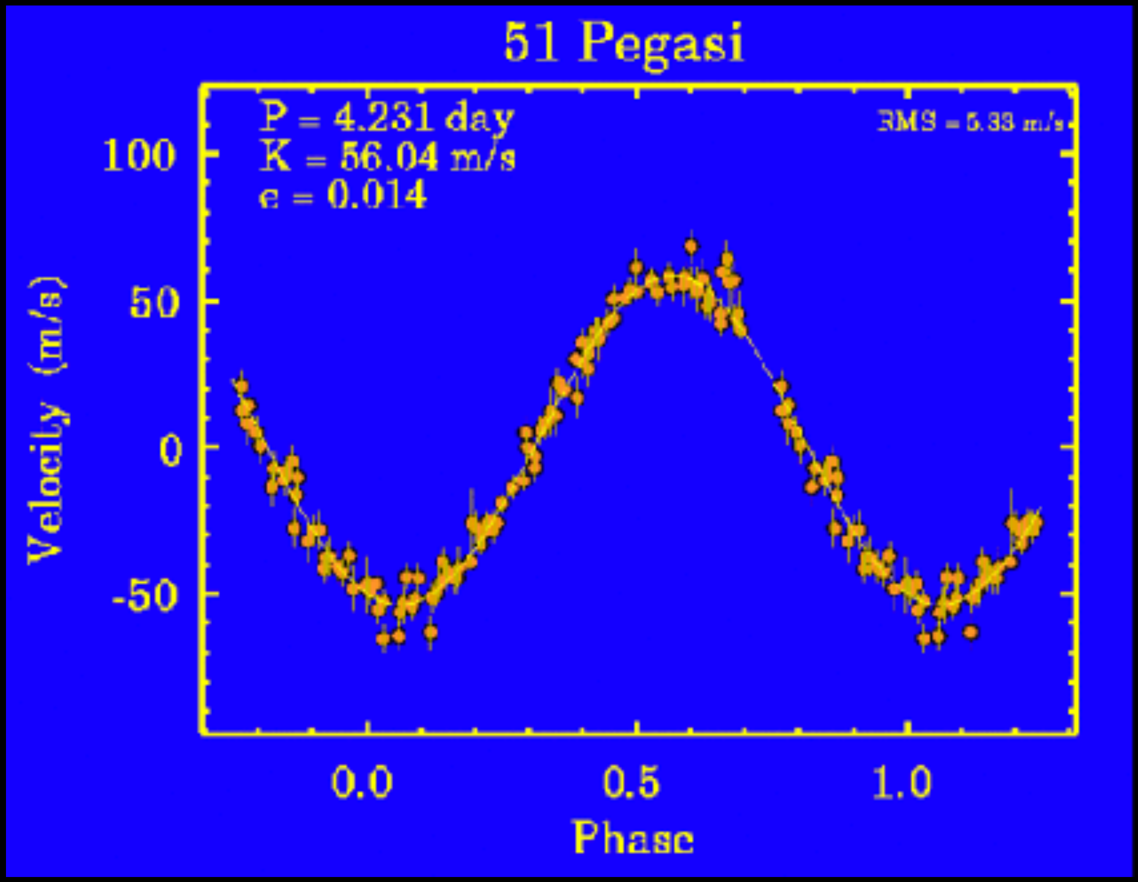


How would you find a planet?

- Native spectral resolution of high resolution spectroscopy ~1e5. Need a factor of 300 more.

- 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).



Why are Metals Shiny?

- Moving on…
- Because they conduct.
- So why can we see through sea water?
- Well, sometimes we can’t. Radio doesn’t make it through.

Plasma Frequency

- Say I have a block of plasma, and move all electrons by x. What is electric field?
- Surface charge is $en_e x$. From Gauss's law, $E = en_e x/2\varepsilon_0$, where factor of 2 is from 2-sided cylinder.
- Of course, have protons have charge, so total field is $en_e x/\varepsilon_o$.
- $F = qE = -e^2 n_e x/\varepsilon_0$. also $F = ma = mx''$, so $x'' = -(e^2 n_e/m_e \varepsilon_o)x$
- Plasma will oscillate with angular frequency $\omega_p = \sqrt{(e^2 n_e/m_e \varepsilon_o)}$.

Dispersion Relation

- If I send an EM wave into plasma, plasma can adjust if low frequency, not if high frequency.
- Dispersion relation is $\omega^2=\omega_p^2+k^2c^2$.
- Phase velocity is $\omega/k=c(1+\omega_p^2/k^2c^2)^{1/2}$, $>c$
- Group velocity $d\omega/dk=kc^2/(\omega_p^2+k^2c^2)^{1/2}$, $<c$

Low Frequency

- Recall wave equation is $\exp(i(kx-\omega t))$. If $\omega<\omega_p$, $k=(\omega_p^2-\omega^2)^{1/2}i/c$ and spatial part of wave equation is $\exp(-kx)$
- Wave decays exponentially with decay length $c/(\omega_p^2-\omega^2)^{1/2}$
- Limit is c/ω_p, the plasma skin depth.
- What is skin depth of typical conductor?
- Other effects (like collisions) become important in real media, e.g. submarines can communicate underwater at very low (few kHz) frequencies.

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- Limit is c/ω_p, the plasma skin depth.
- What is skin depth of typical conductor?
  - copper atomic wt. is 63.5, density is 9. If 1 e^- per atom, then ω_p=1.6e16, and skin depth is ~200 Å.
  - NB - sea water has ions instead of electrons, and only ~2% vs. H_20, so simple plasma model would put frequency at ~1e12, skin depth of 0.3mm.
- Other effects become important in real media, e.g. submarines can communicate underwater at very low (few kHz) frequencies.

High Frequency

- Group velocity $d\omega/dk=kc^2/(\omega_p^2+k^2c^2)^{1/2}$
- For large ω, $kc>>\omega_p$, and $v_g \sim kc^2/kc(1+ \omega_p^2/k^2c^2)^{1/2}=c(1-\omega_p^2/2k^2c^2)$
- But, $kc \sim \omega$, so $v_g/c=1-\omega_p^2/2\omega^2$.
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- If I had 1 e/cm3 for 1 pc, how long would a 1 MHz signal be delayed relative to high frequency?
  - ωp~56kHz/νp~9 kHz. Fractional velocity change is 0.5*(9 kHz/1 MHz)^2=4e-5. Light travel time is 3.26 years, so total delay is 4e-5*3.26=4150 seconds.
  - Origin of pulsar delay law that dt=4150*DM/ν^2 where ν in MHz and DM defined to be column density of electrons relative to 1/cm^3 for 1 pc.

Waves in Plasma/Why Metals Reflect

- If free space wave hits plasma, if frequency below plasma frequency wave can't propogate, gets reflected by plasma.

- If above ν_p, wave can go through, with group velocity $<c$, phase velocity $>c$.

- Metals have ν_p~2e15 Hz ~10 eV. Optical photons reflect, but hard UV/x-rays will go through.

- If I want to build an X-ray telescope, I can't use traditional mirrors.

Refraction

- If I have a wave propagating at some angle going between two different media, what happens?
- Wave phase has to be continuous across boundary.
- Wave will bend so that phase velocity along boundary is same on both sides.
- Phase velocity vs. free space is inverse of index of refraction, n.
- Snell's law is phase continuity constraint: $\sin(\theta_1)n_1=\sin(\theta_2)n_2$.

Total Internal Reflection

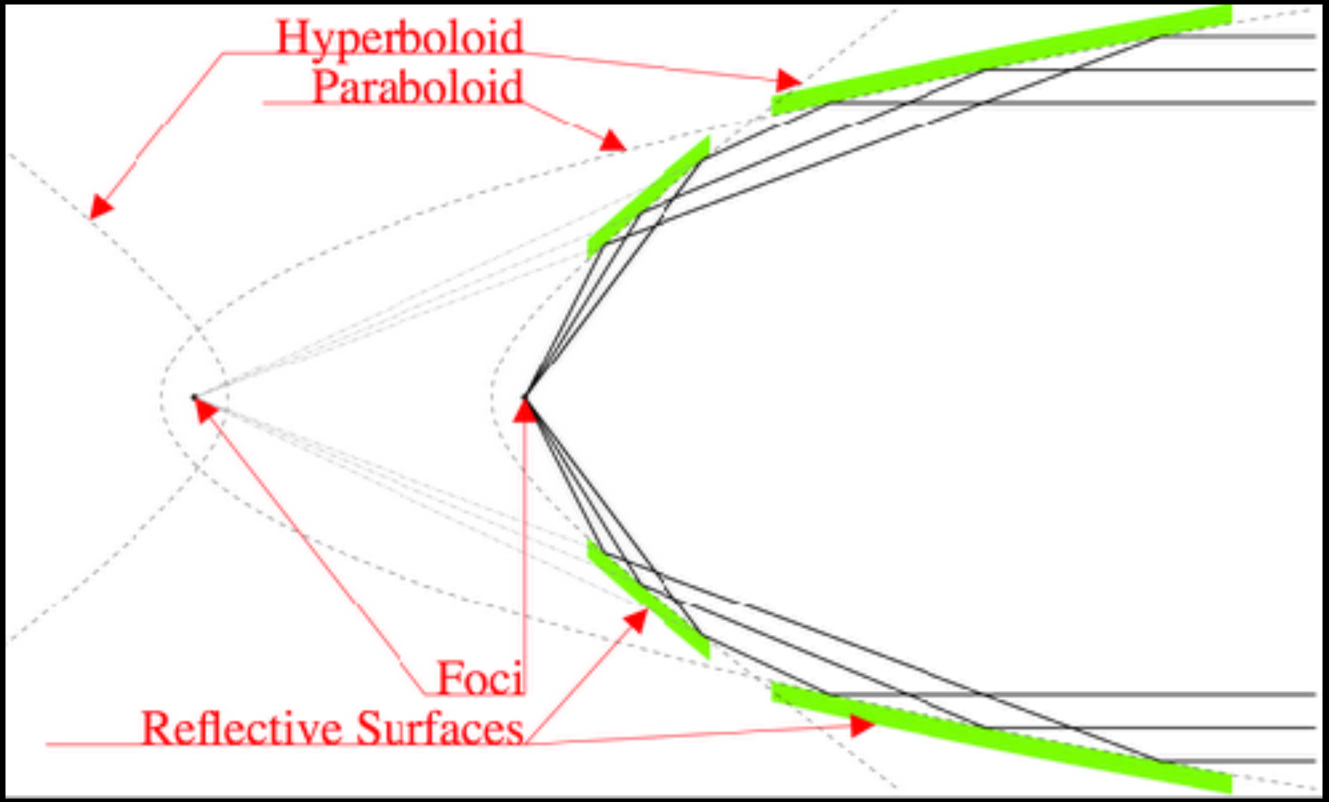
- $\sin(\theta_2)$ can't be larger than 1. So, $\sin(\theta_1)<n_2/n_1$.
- If $n_2<n_1$, then there's a critical angle at which we can no longer go through. Instead, wave reflects.
- This is called total internal reflection.
- Only happens if we go from medium with low phase velocity to medium with high phase velocity.

Grazing Incidence

- What is index of refraction of metals at 1 keV?
- phase velocity=$c(1+\omega_p^2/k^2c^2)^{1/2}$,~$c(1+v_p^2/v^2)^{1/2}$,$v^p$/ c~$1+0.5(v_p/v)^2$.
- Index of refraction ~$1-0.5(v_p/v)^2$.
- At 1 kHz, n~$1-0.5(10/1000)^2$=1-5e-5 Critical angle is asin(1-5e-5)~89.5 degrees.
- So, if X-ray comes in within half degree of parallel, it will reflect. This is *grazing incidence*.

X-ray Telescope Design

- Turns out FOV is tiny for single grazing incidence mirror.
- Solution is to have multiple element to correct coma.
- Few different designs possible (Wolter types 1-3)
- To get collecting area, have to stack many elements.



Top: Wolter type 1 diagram
Bottom: Chandra primary mirror