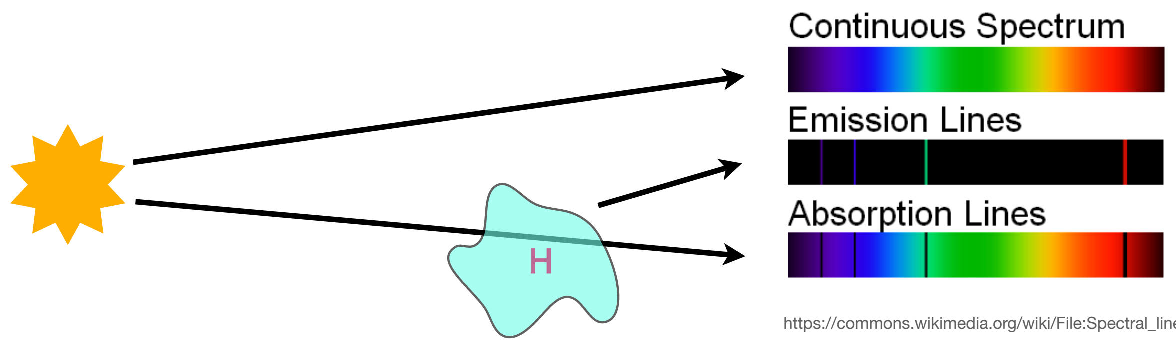
ASTR 421

Stellar Observations and Theory

Lecture 04
Spectroscopy: II

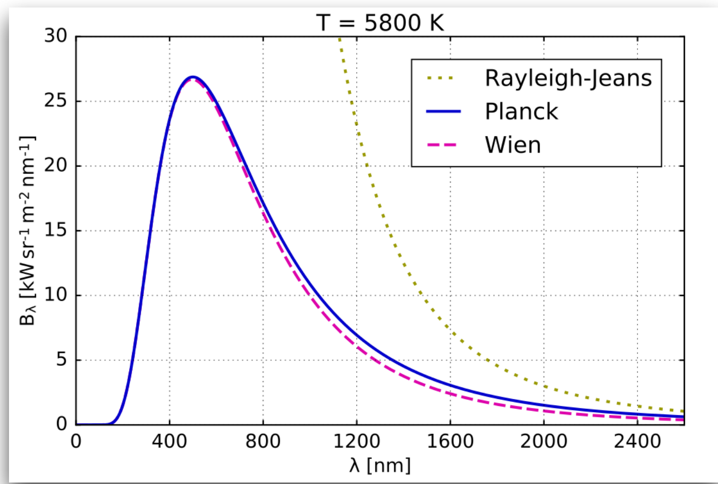
Prof. James Davenport (UW)

Last time:



https://commons.wikimedia.org/wiki/File:Spectral_lines_en.PNG

Blackbody Radiation



Boltzmann Eqn: excitation states

$$\frac{N_b}{N_a} = \frac{g_b}{g_a} e^{-(E_b - E_a)/kT}$$

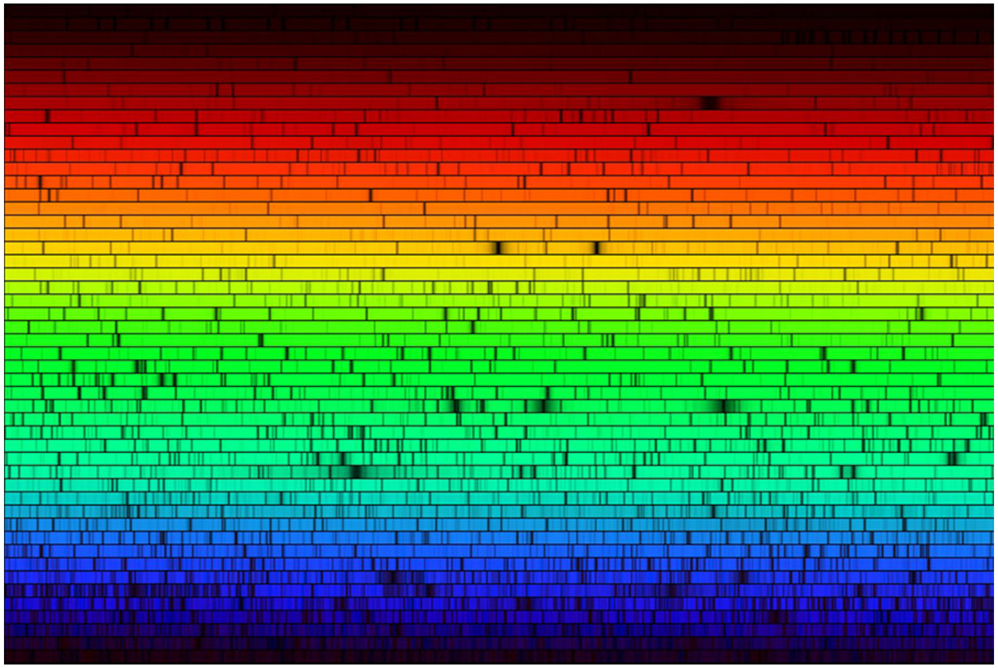
Saha Eqn: ionization states

$$\frac{N_{i+1}}{N_i} = \frac{2kT}{P_e} \frac{g_{i+1}}{g_i} \frac{(2\pi m_e kT)^{3/2}}{h^3} e^{-\chi_i/kT}$$

Today's Goal: Spectroscopy, past & present

- History of observing spectral lines
- Well known spectral lines
- History of spectral types

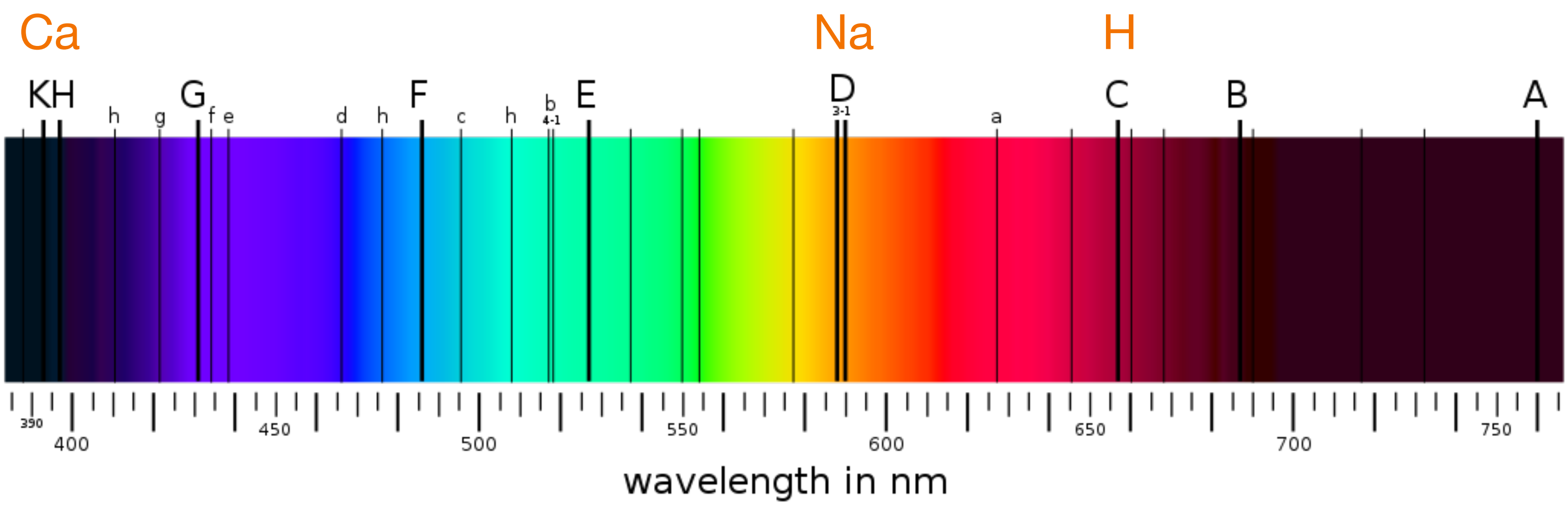
- Other observables we've neglected: [Fe/H], log g, velocity
- Spectrographs themselves!



https://scied.ucar.edu/image/sun-spectrum

Fraunhofer lines

- Cataloged in solar spectrum by Fraunhofer in 1814
- Seen in many other stars
- Kirchhoff & Bunsen noticed these == emission line from burning! (1859)
  Lines = chemical “fingerprints”!



https://en.wikipedia.org/wiki/Fraunhofer_lines

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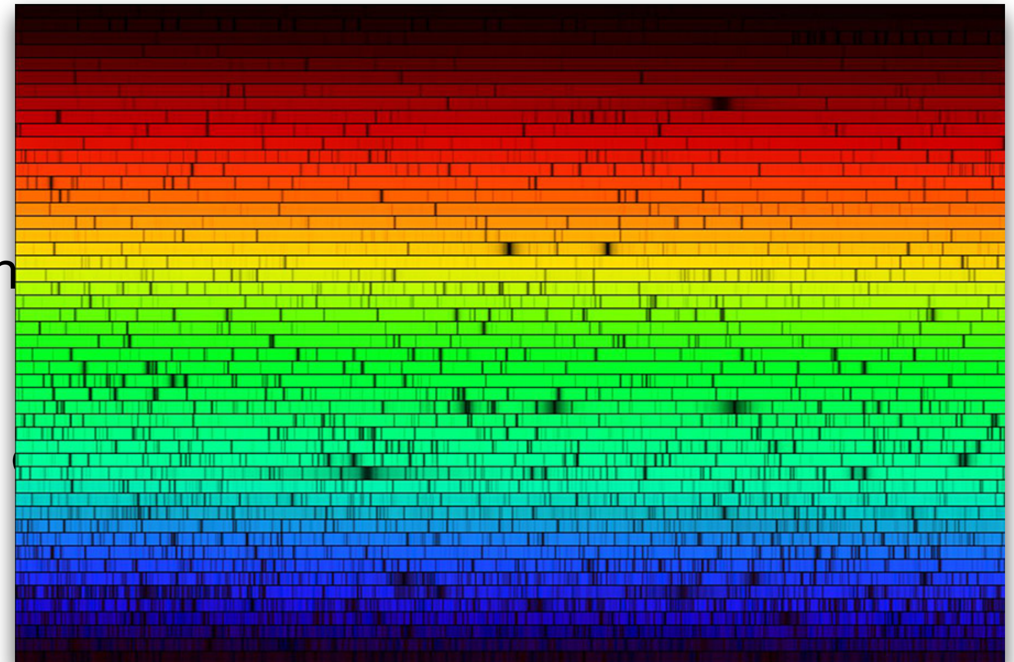

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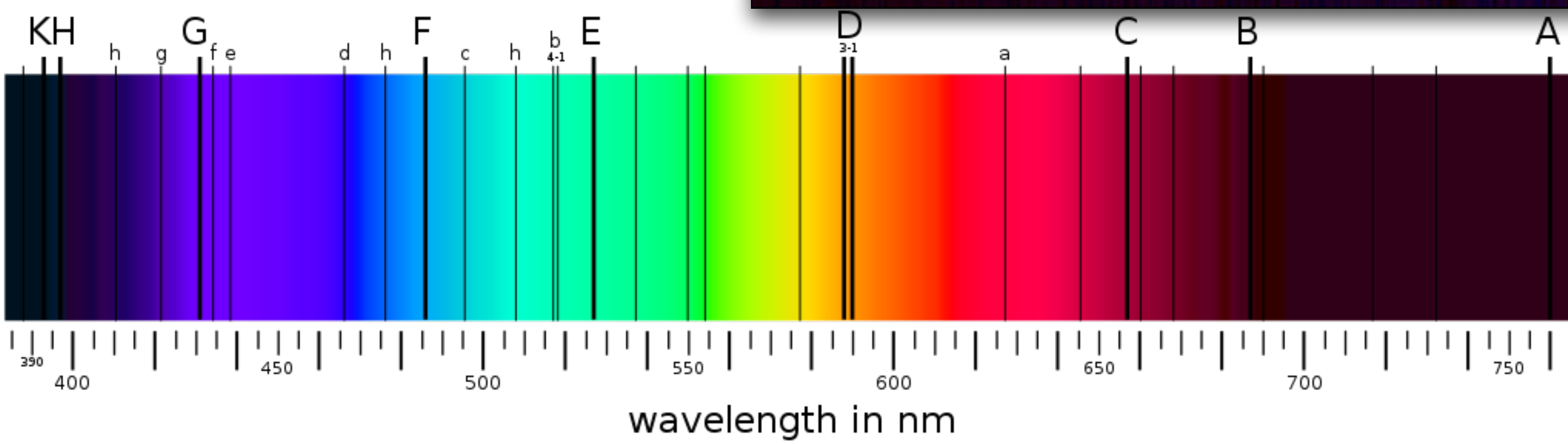
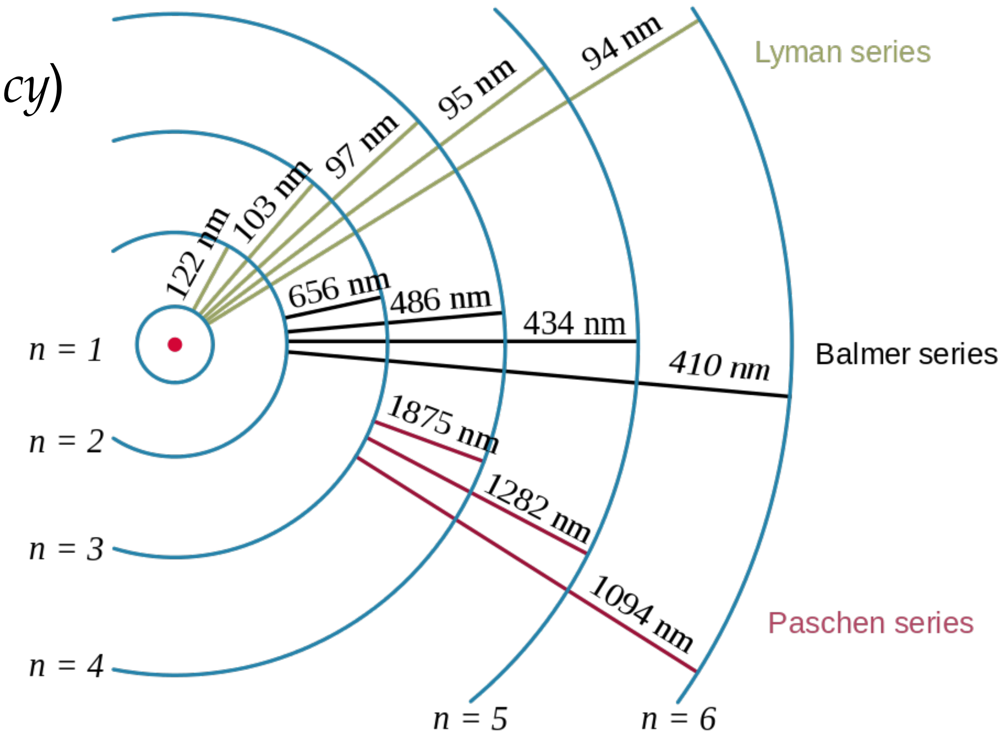


https://en.wikipedia.org/wiki/Fraunhofer_lines

Hydrogen Lines

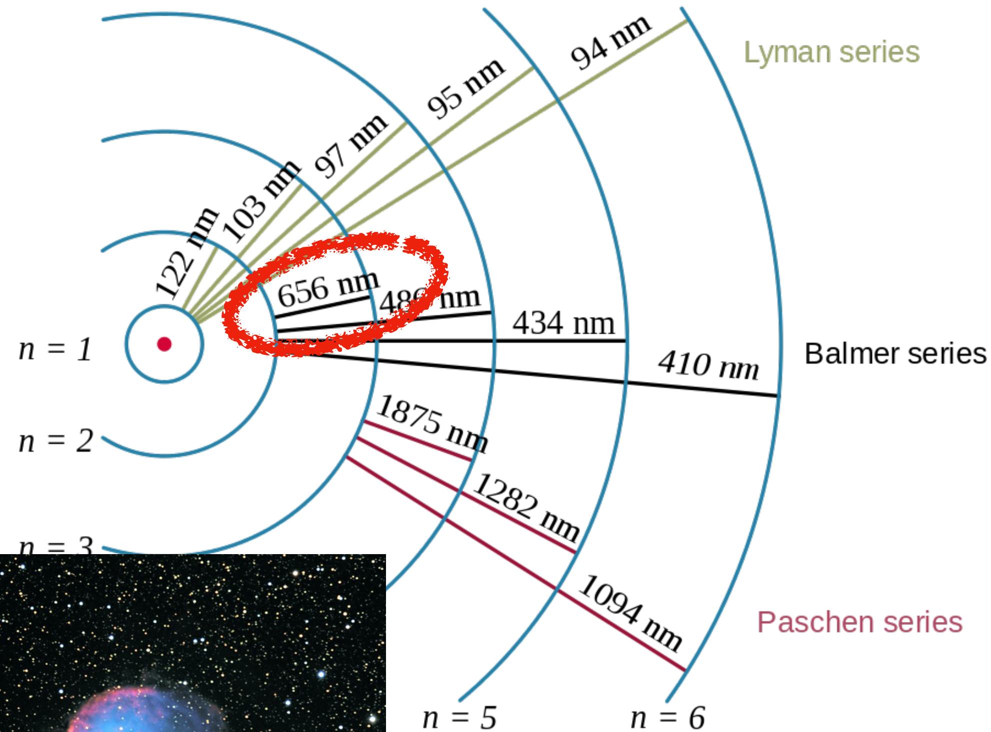
- Well studied, have famous names (*fancy*)
  - Lyman (n=1, 91nm)
  - **Balmer (n=2, 365nm)**
  - Paschen (n=3, 821nm)
  - Brackett (n=4, 1459nm)
  - Pfund (n=5, 2280nm)
  - Humphreys (n=6, 3283nm)



https://commons.wikimedia.org/wiki/File:Hydrogen_transitions.svg

Balmer lines

- Most famous: $H\alpha$: 656.3nm
- (Fraunhofer line *C*)
- Seen in both absorption AND emission in stars!
- Seen ALL OVER



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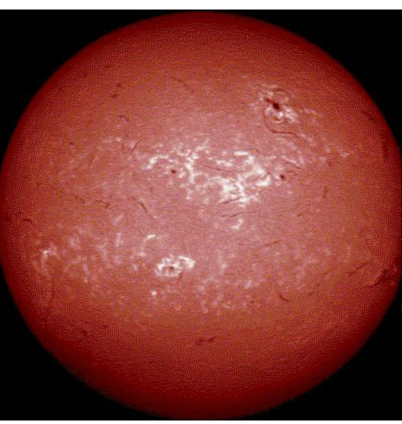
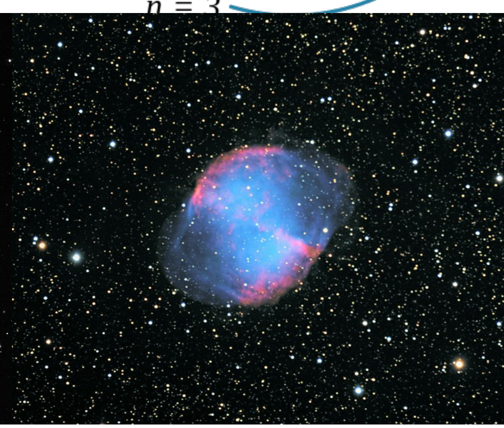
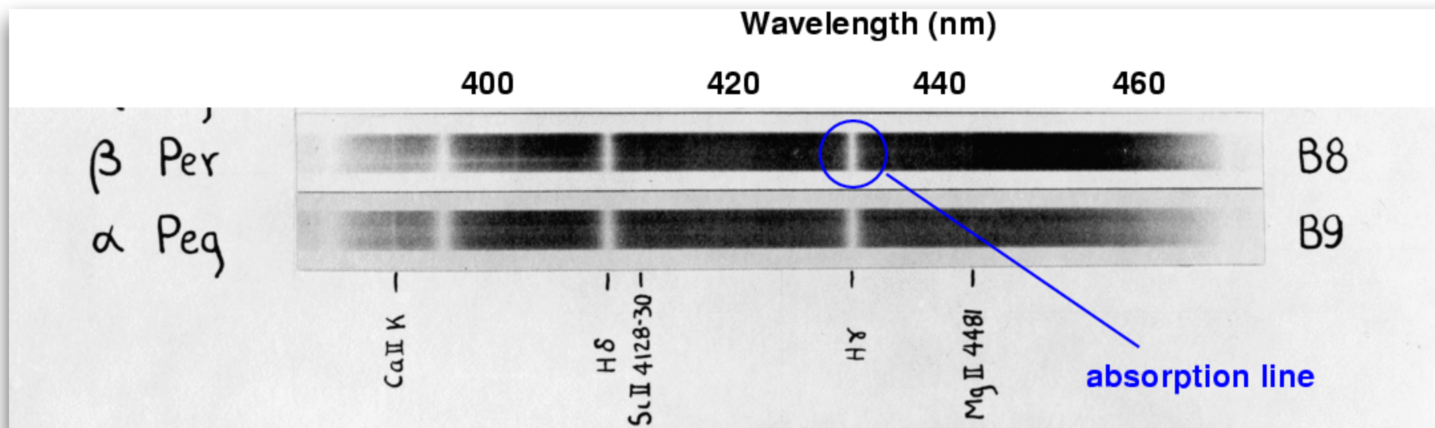




The Story of Spectral Types

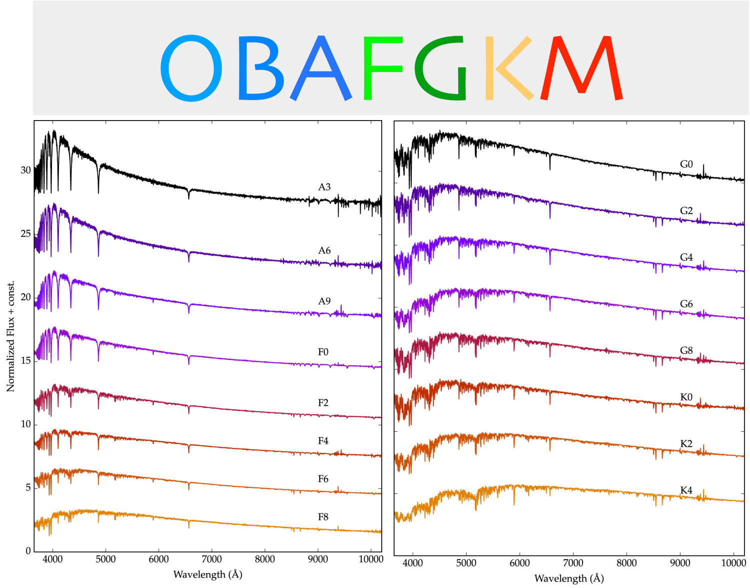
- After late 1800's, lots of stellar spectra being collected
- The "Harvard Computers" started classifying them based on Hydrogen absorption line strengths
  - A = strongest, O=weakest



http://spiff.rit.edu/classes/phys301/lectures/class/class.html

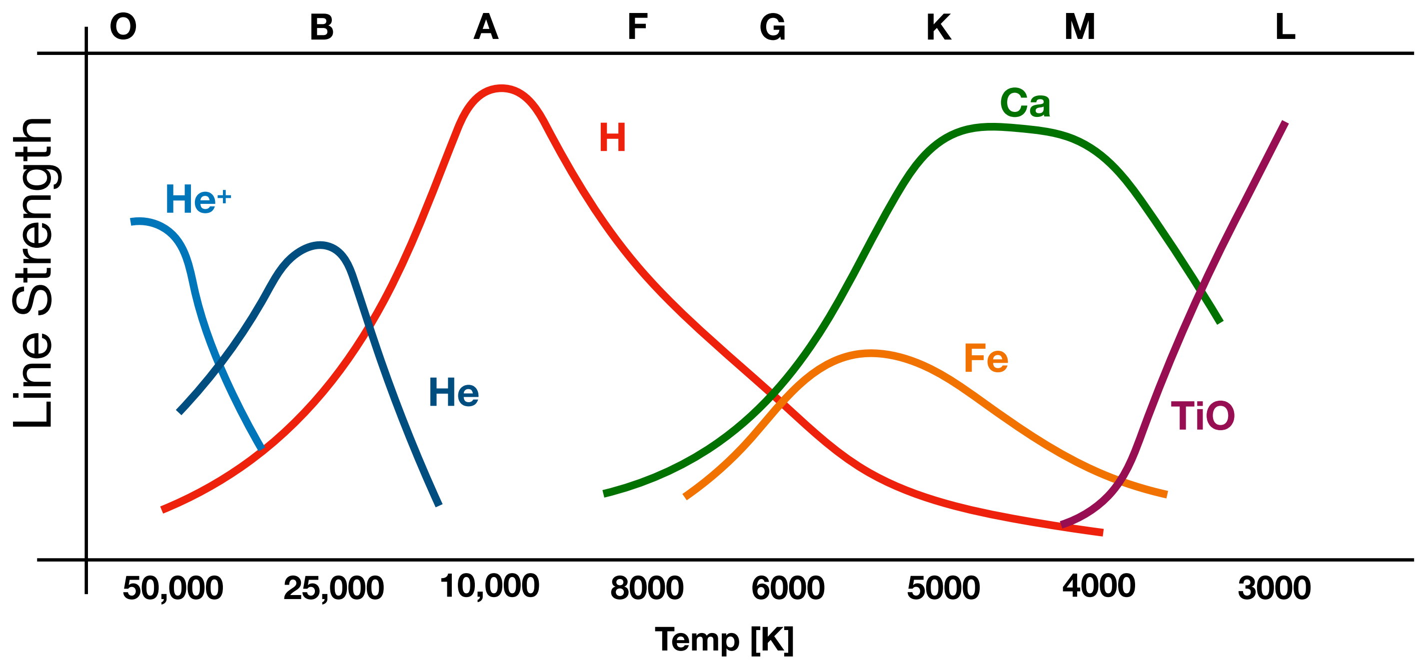
The Story of Spectral Types

- **Annie Jump Cannon** famously realized the sequence didn't quite follow temperature from overall blackbody shape (1912)
- System still in place today



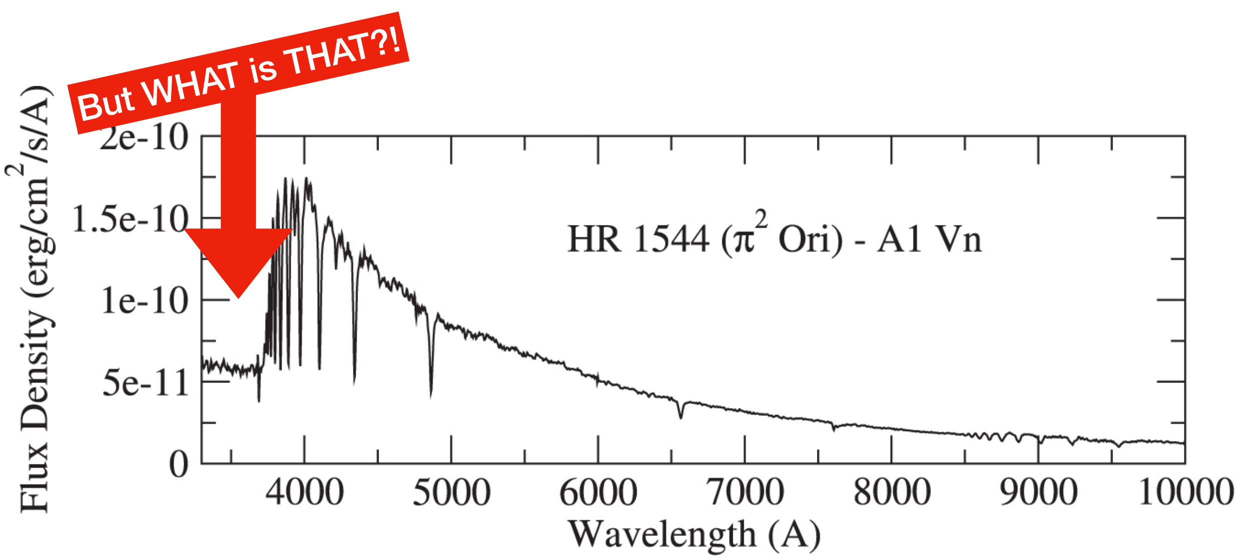
Line Strength vs Temp

The Saha & Boltzmann equations in action!



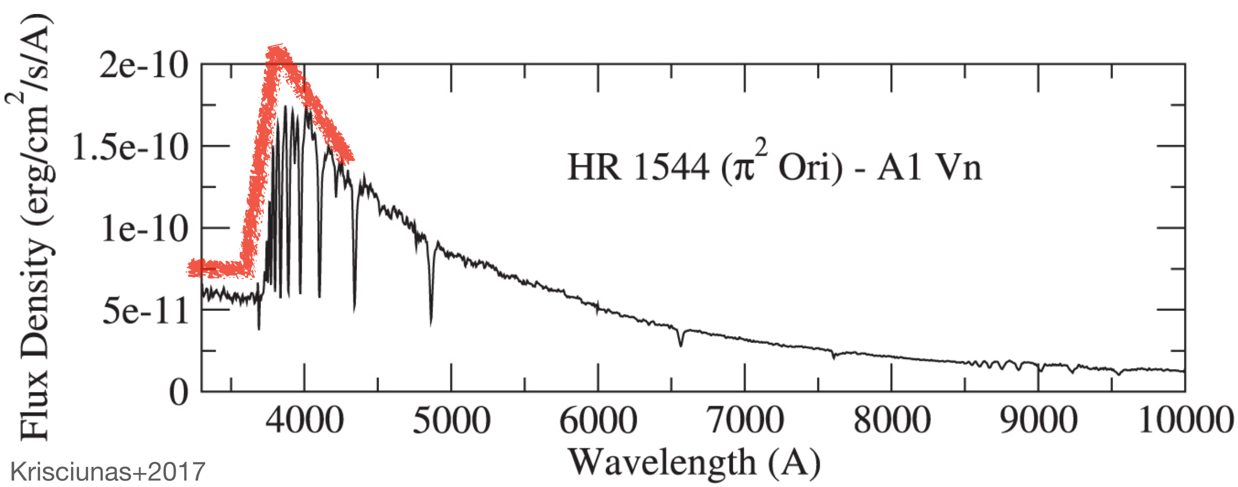
Adapted from:
http://cas.sdss.org/dr7/en/proj/basic/spectraltypes/followup.asp

- **Now we can say a lot about this spectrum!**
  Overall smooth shape ~ blackbody temp
  Lines = chemistry
  Line strength due to temp

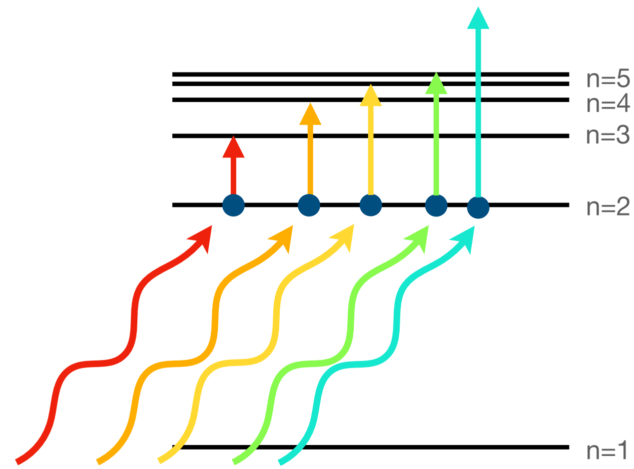


Balmer break/jump

- The “end” of the line series, no more transitions
- Star still producing plenty of photons above the break, but they totally absorbed, ionizing all the available H
- Balmer Jump is strong when Balmer lines are strong



Krisciunas+2017



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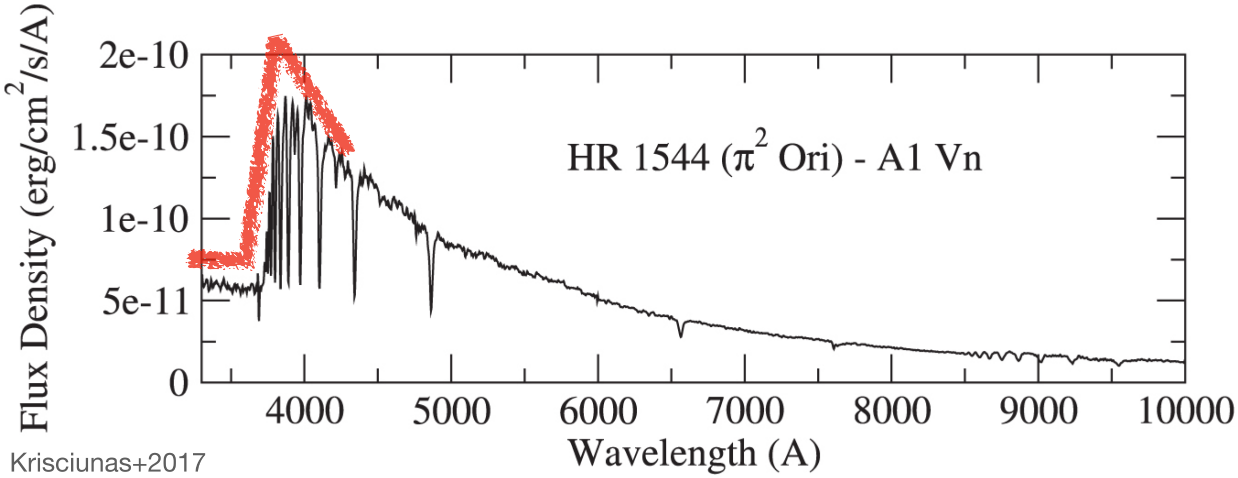
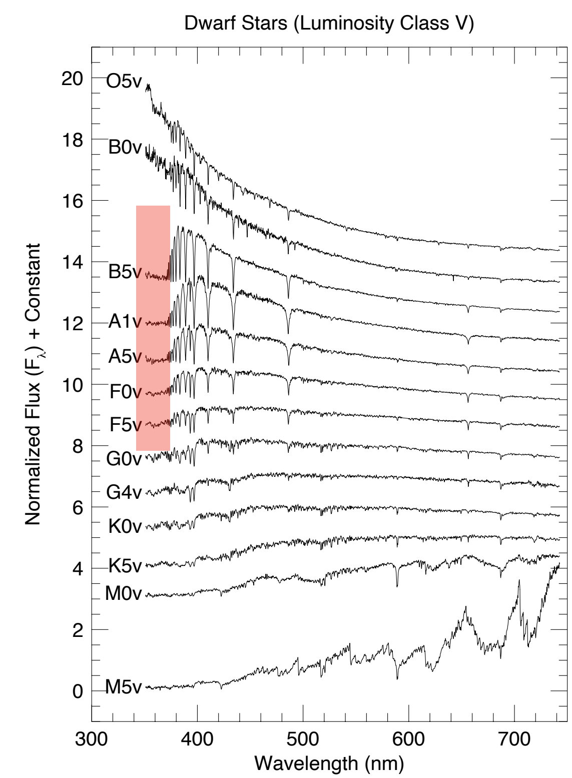
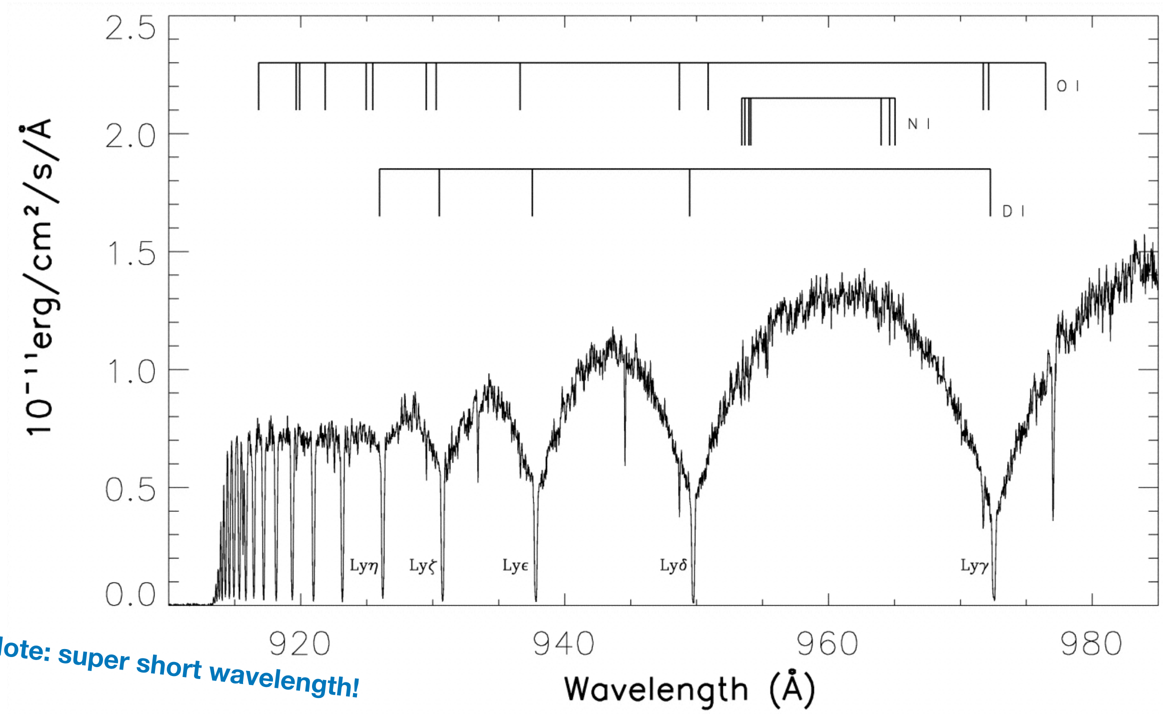


Krisciunas+2017



Lyman Limit

- Same concept as the Balmer Break (& w/ awesome alliteration)
- In the UV: **91.2nm**
- Commonly observed in *galaxy* spectra (thanks to redshift!)

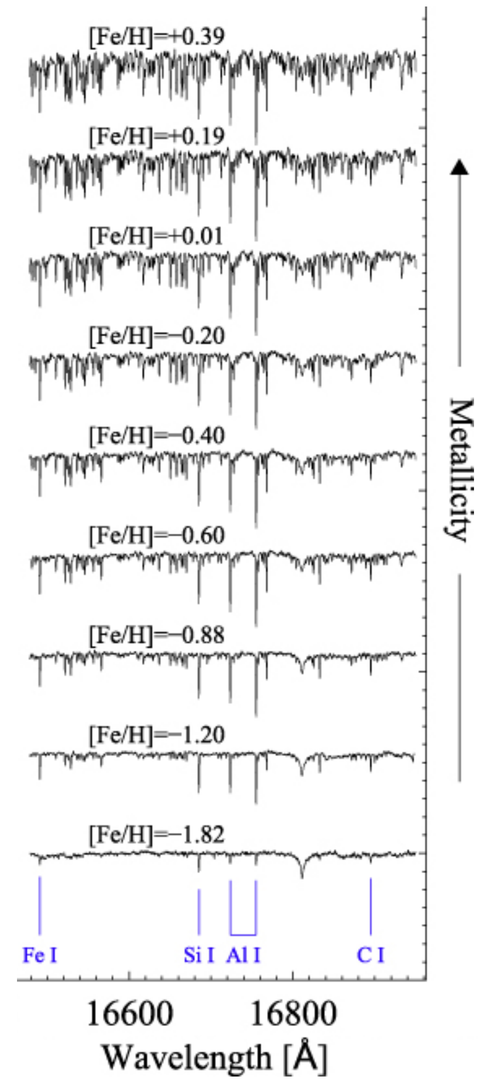


Note: super short wavelength!

Lemoine+2002 (FUSE data)

Composition (aka Metallicity)

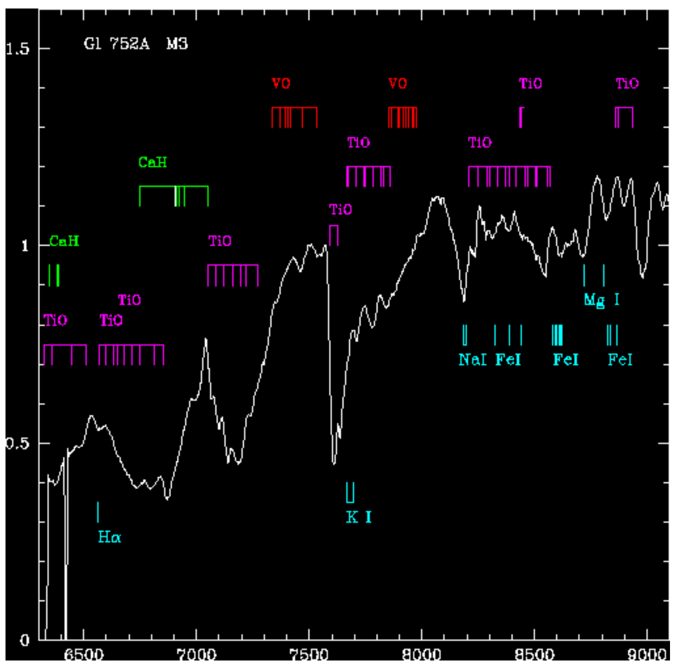
- Recall the [Fe/H] notation from last week
- Primarily determined via spectroscopy, modeling atomic absorption lines
  - **High resolution VERY helpful**

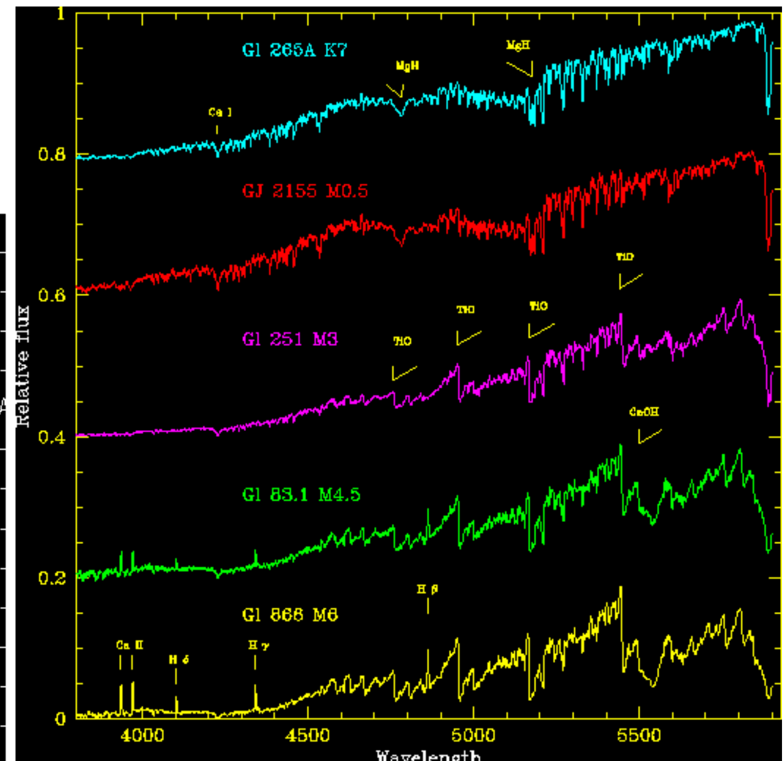


Majewski+2017 (APOGEE)

Composition (aka Metallicity)

- The situation is… more difficult for low-mass stars
- Cool temperature, spectra dominated by *molecules*
    - Molecules are *wild…*



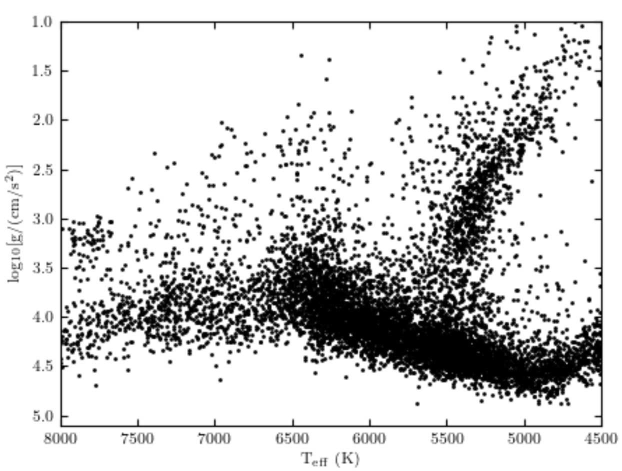


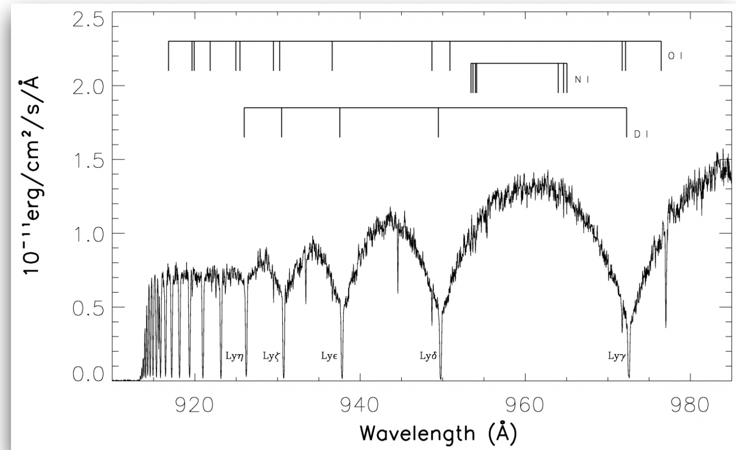
N. Reid

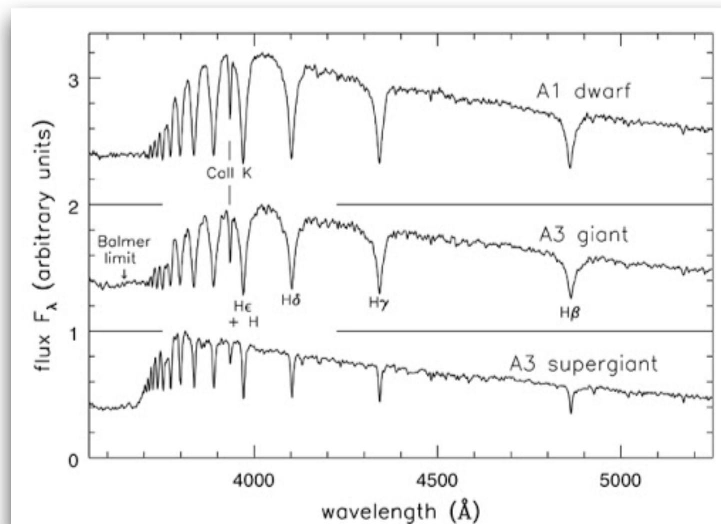
Surface Gravity

- $g = GM/R^2$,
  usually measured w/ spectroscopy
  (line broadening)

- Typically expressed as $\log g$
  stars: ~4
  giants: 3-1
  white dwarfs: 6-9





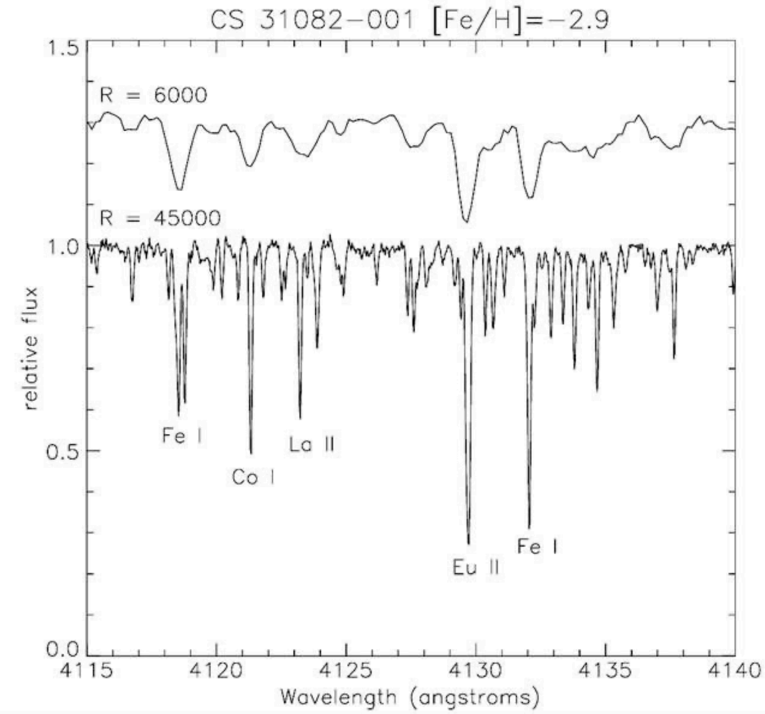


Spectral resolution

Wavelength resolution Velocity resolution

- $R = \dfrac{\lambda}{\Delta\lambda}$ *or* $R = \dfrac{c}{\Delta v}$

- Low resolution: 100-1000
- Medium resolution: 1000's
- High resolution: +10,000
- Ultra-high res: +100,000
(mostly only for the Sun… *many* photons available)

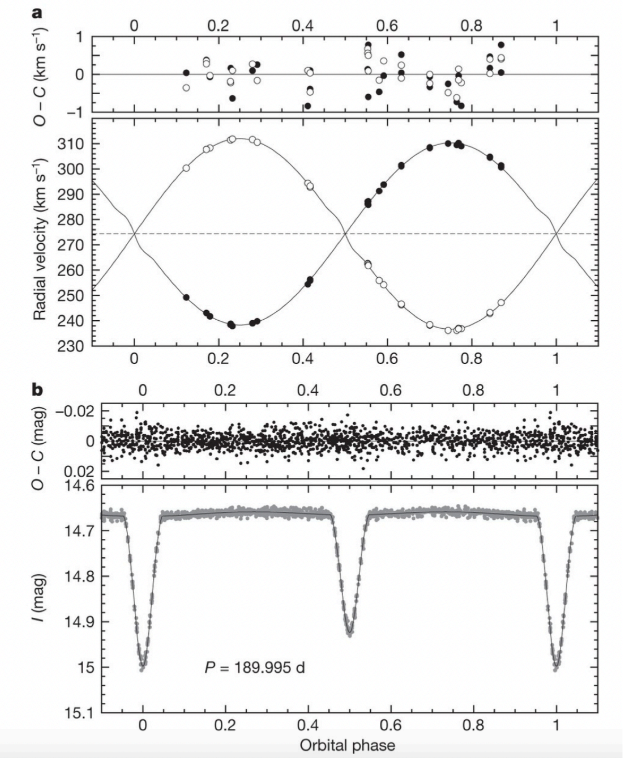


https://tmt.iiap.res.in/sites/tmt.iiap.res.in/files/TMT-DSC-2007-R1.pdf

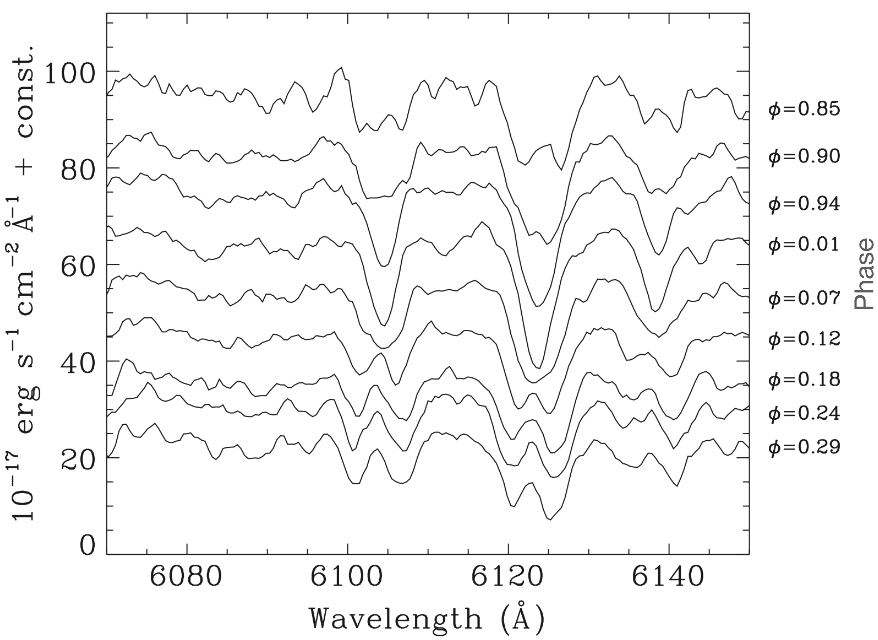
Doppler Shift & Radial Velocity

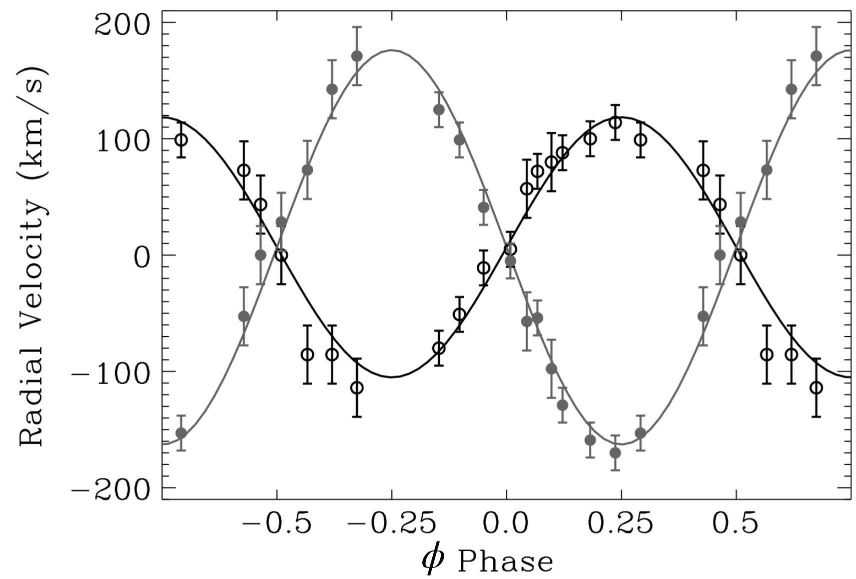
- All stars have RV (velocity towards/away from us)
- Recall from Lecture 2: Eclipsing + double-lined binary
- RV computed via classic doppler shift:

$$\frac{\lambda_i - \lambda_{rest}}{\lambda_{rest}} = \frac{v_i}{c}$$



Doppler Shift & Radial Velocity





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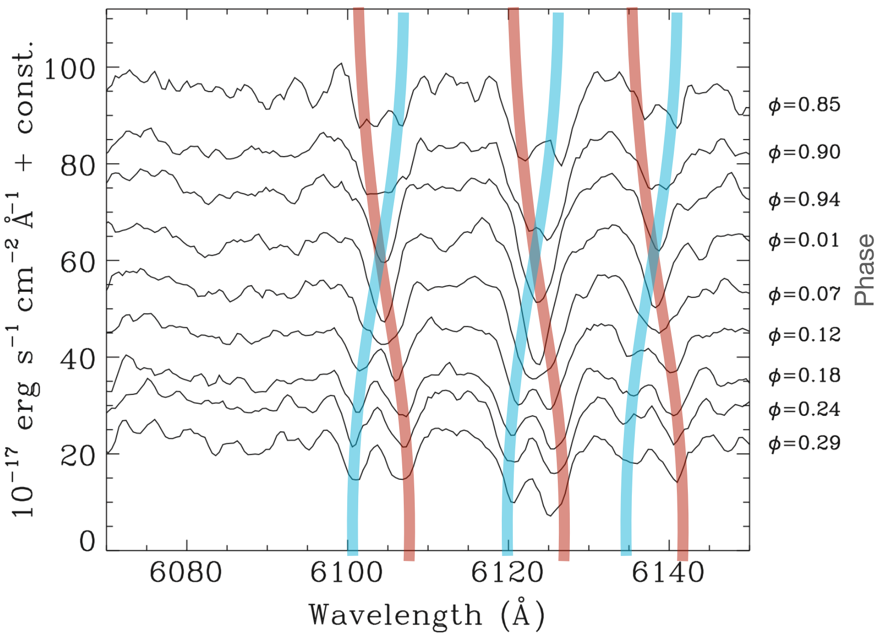
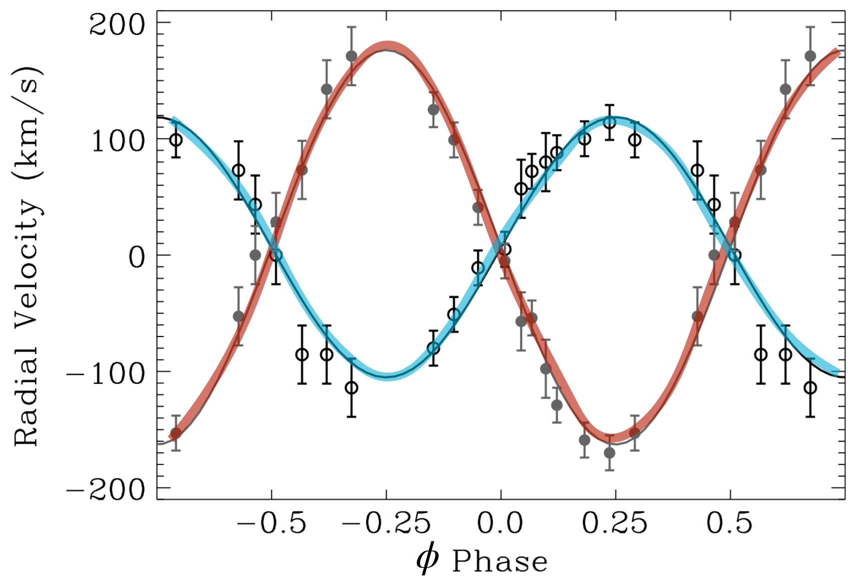




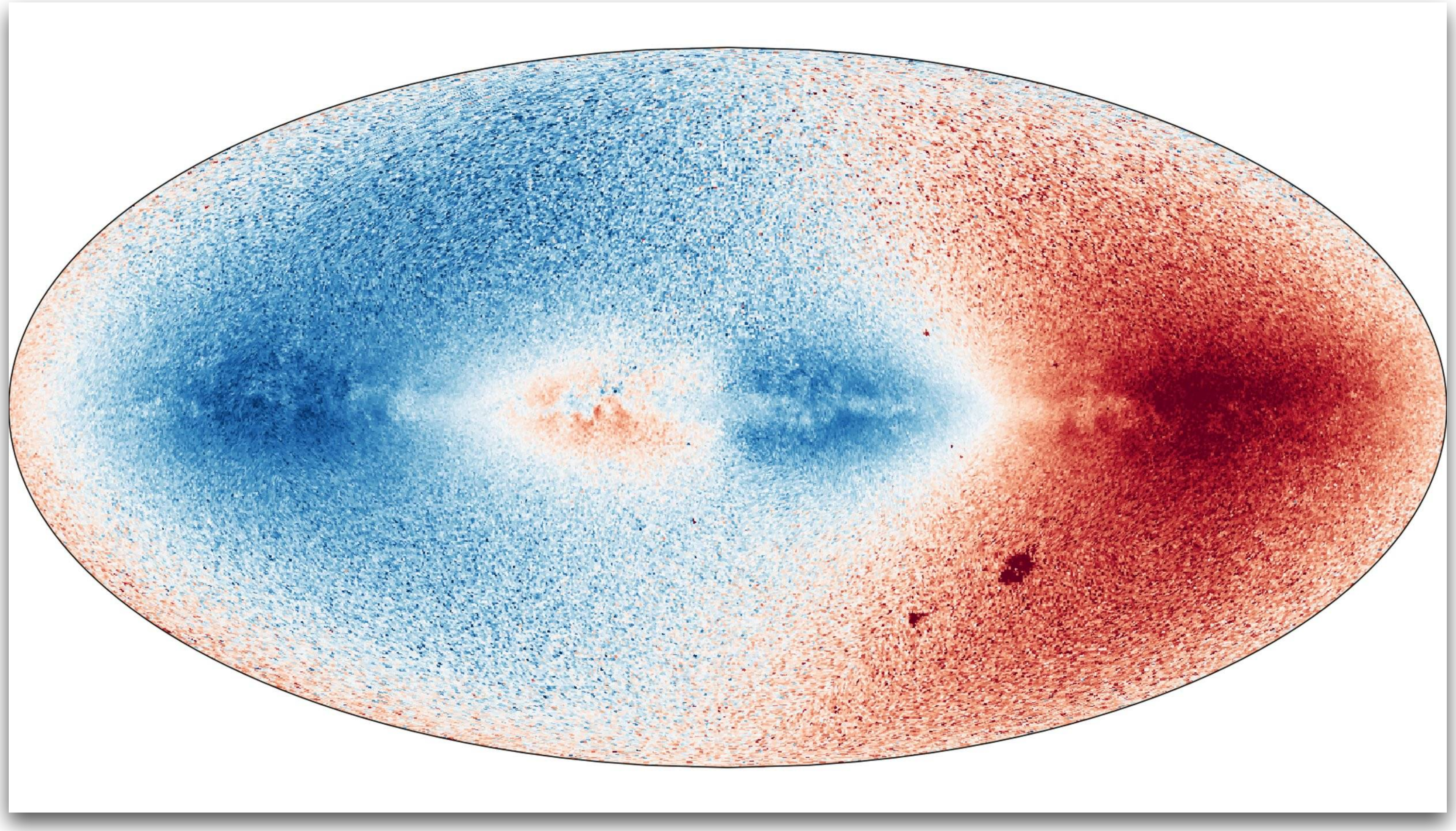
Doppler Shift & Radial Velocity

- Depends on resolution, precision, and stability
  - All 3 are unique engineering challenges!

Important new field: **EPRV**
Extreme Precision Radial Velocity

Doppler Shift & Radial Velocity

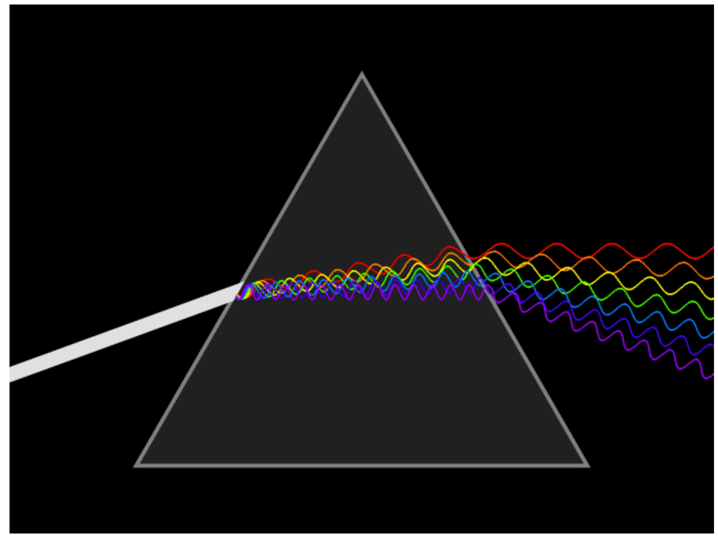
Rotation of the Milky Way (Gaia DR2)



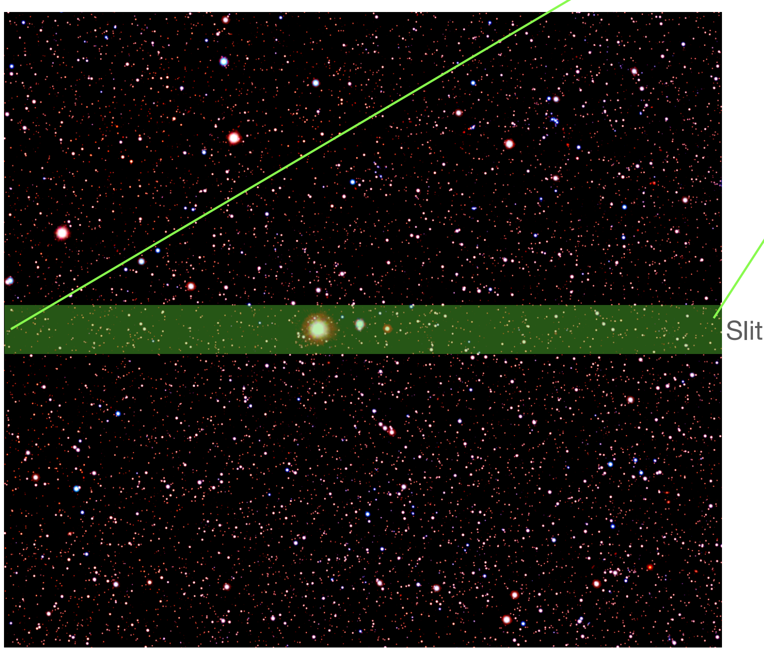
Spectroscopy

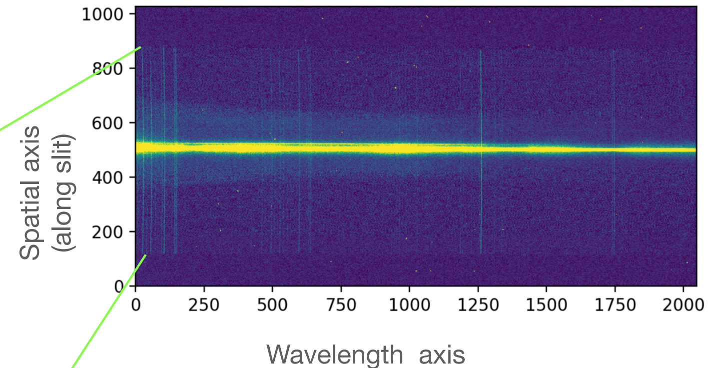
- Basic layout of a spectrograph…

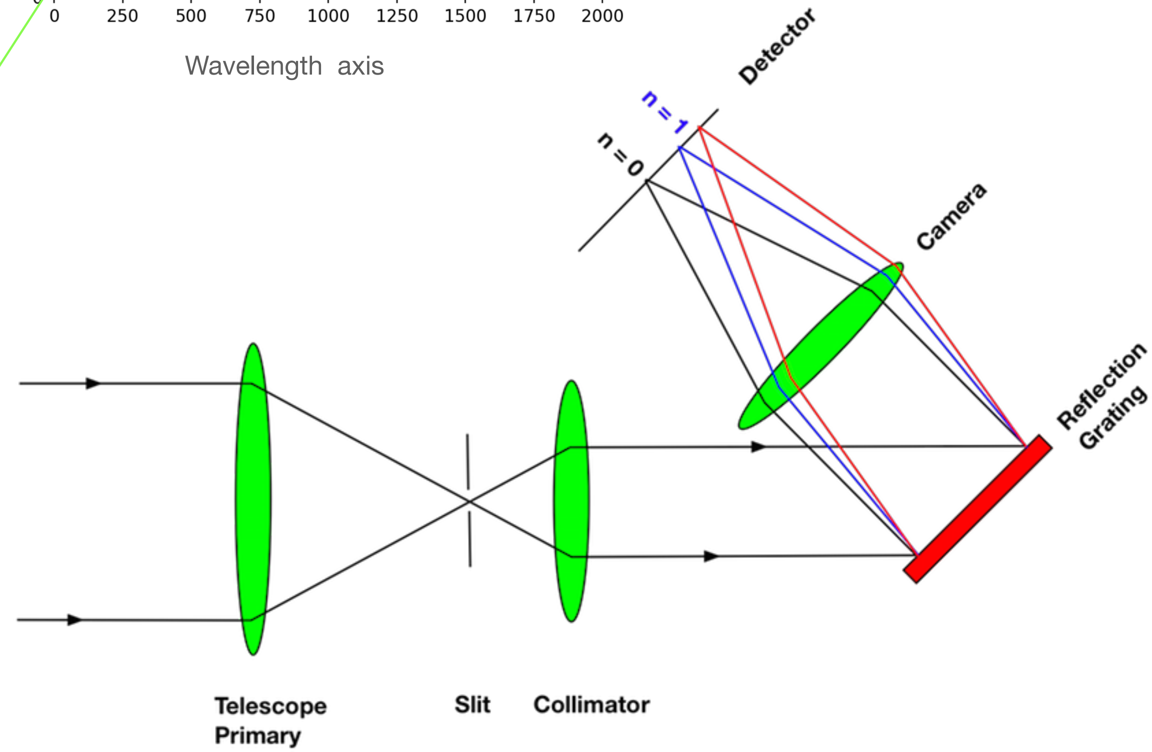
  This isn't quite the whole story



Spectroscopy



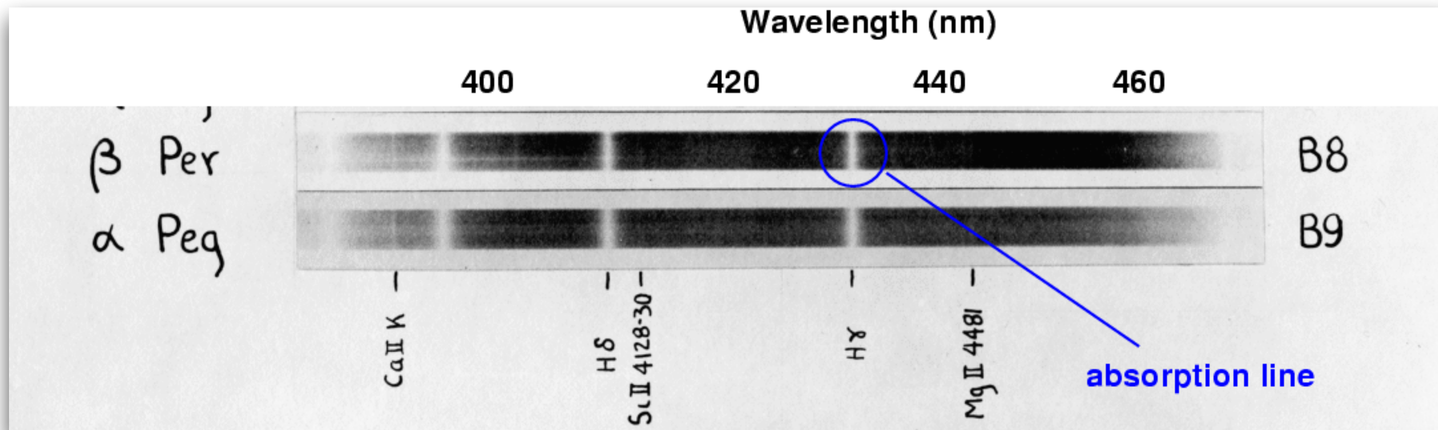




http://slittlefair.staff.shef.ac.uk/teaching/phy217/lectures/instruments/L16/index.html

Spectroscopy

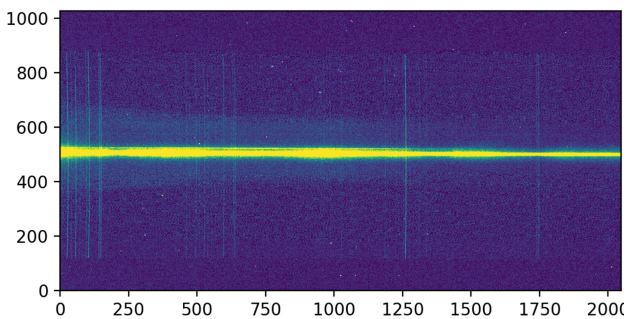
- Historical spectra… glass plates, and lots of careful measurements



Spectroscopy

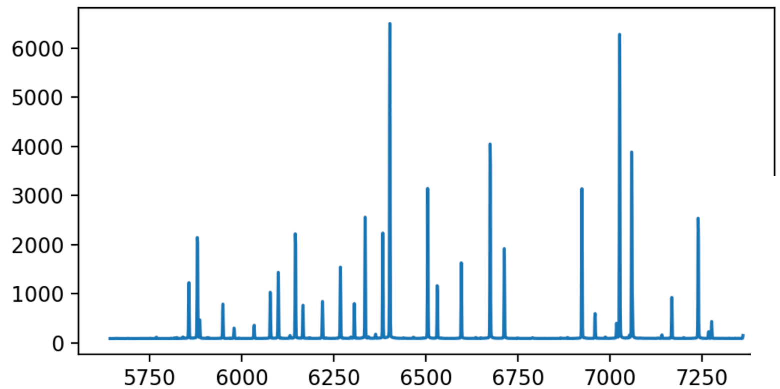
- Modern spectroscopy: *computers!*

Computer “trace” and “extract” of flux



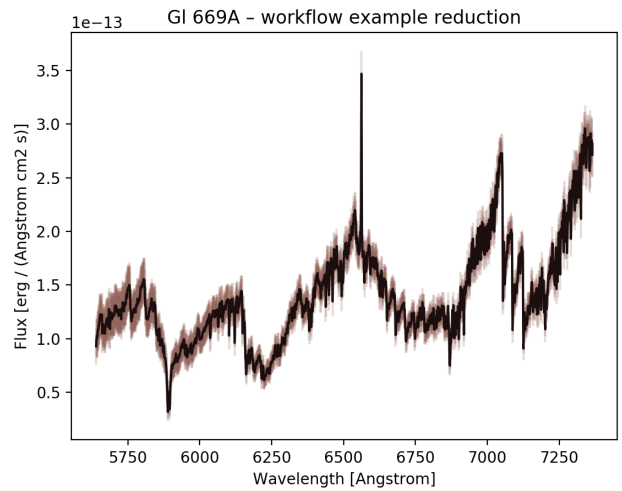
Can do many objects at once, also resolved objects like galaxies

Reference “arc” lamps for precision wavelength calibration



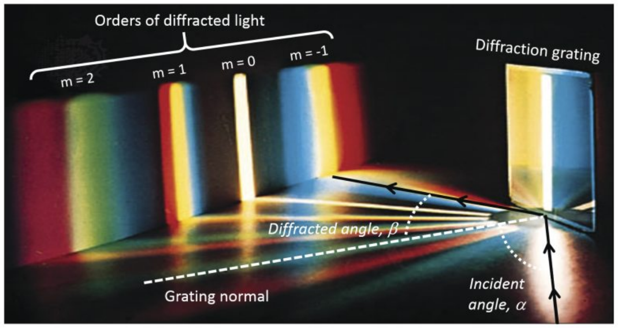
EPRV uses fancier wavelength calibration schemes

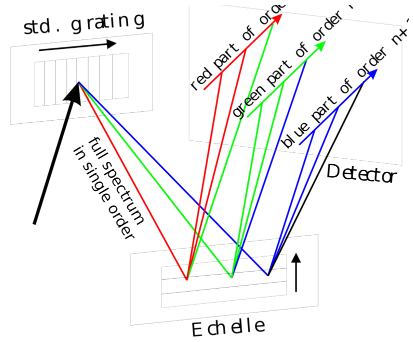
Flux calibration!



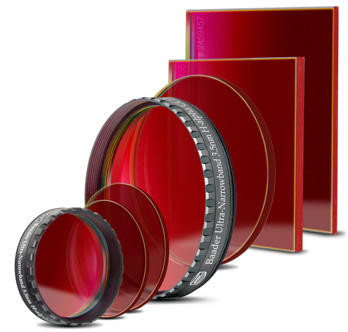
Types of Spectrographs

- <u>Each resolution has different technical requirements</u>
  - Low resolution: R=100-1000
    - Prism, *grism*, or **gratings**
  - Medium resolution: R=1000's
    - mostly gratings (many kinds)
  - High resolution: R=+10,000
    - Primarily "echelle" spectrographs
  - Ultra-high res: R=+100,000
    - Highly customized, mostly for the Sun





Spectroscopy



- Imaging is just super low-res spectra
- There is narrow-band imaging!
  - VERY narrow-band imaging for the Sun (~1Angstrom)