# Ast 241
# Stellar Atmospheres and Interiors

- Goal: basic understanding of the nature of stars
  - Very important for astronomers
    - Most of (known) mass and luminosity from stars
      - Normal galaxies
      - To understand galaxies (and universe), need to understand stars
    - Elements heavier than H and He created inside stars
      - Spewed out into space to form new stars
      - Planets, people made from this 'stardust'
    - Our Sun is crucial for life
      - Primary source of energy
      - Lifetime must be billions of years to permit life to arise

# Cradle-to-grave understanding of stars

- Where/how/why do stars form?
  - Trapezium stars of Orion Nebula < $10^6$ years old
  - Why are most stars on “main sequence”?
    - What determines their position in H-R diagram?
      - Answer: mass
  - Source of energy of stars
    - Lifetime of stars
  - What happens after fuel runs out?
  - What determines 0.1-100 $M_{sun}$ mass range of stars?

# Stellar Atmospheres & Interiors

- We must decode the light (E-M radiation) from stars
  - Light comes from an extremely thin layer (the photosphere) at the surface of a star
    - Need to know how light is created and modified as it passes through the outer layers
    - Need to use this info to learn as much as possible about the star
      - Temperature, Luminosity, gas Pressure, gas density, composition
  - 99.99% of star is not seen
    - Need theory to understand the stellar interior

# Physics required

- Mechanics
  - Mechanical structure of star
- Thermodynamics/Stat Mech
  - Excitation, ionization of atoms
  - Black body radiation
- Quantum Mechanics
  - Atomic energy levels, transition probabilities, line strengths
- Electricity and Magnetism
  - Radiation, photons

# Back of envelope considerations

- Stars are giant gas balls held together by gravity
  - Why are stars (and planets) spherical?
    - Minimum energy configuration
  - Why don't stars collapse?
    - Pressure (gradient)
  - What is source of pressure
    - Most stars, ideal gas $PV = NkT$
      - $N$ = # atoms, ~ $10^{57}$ for sun
      - $V = (4/3)\pi R^3$
    - Therefore P implies T (i.e. thermal pressure)
      - $T \sim 5\ 10^6$ K for sun

# Consequences of extremely high Interior temperature

- $2^{nd}$ law of Thermodynamics
  - E flows from hotter (interior of sun) to colder (interstellar space is 3 K)
  - $L_{sun} = (3/2)NkT/\text{time}$
    - Time = time it takes for energy to leak out, $\sim 10^7$ y for sun
- How is surface T ($\ll 5\ 10^6$ K) determined?
  - Blackbody: $L_{sun} = 4\pi R^2 \sigma T^4$
    - T here is "effective temperature"

# Start with Chap. 3 Carroll and Ostlie

- Basic ideas needed to measure/understand stars
  - Distance – stellar parallax
  - Needed to know sizes of stars and intrinsic brightness (luminosity)
    - We measure the radiant flux at earth
      - The wavelength integral is the bolometric flux
      - The luminosity depends on the distance
    - We measure the angular size of a star $\theta$
      - The physical size R depends on the distance r
        - $R = r\theta$ (2 light seconds for the sun)

At earth we can measure the radiant flux:

$$F_\lambda = \frac{\text{Power}}{\text{area}\cdot\Delta\lambda} = \frac{W}{m^2\cdot nm}$$ 'monochromatic flux'

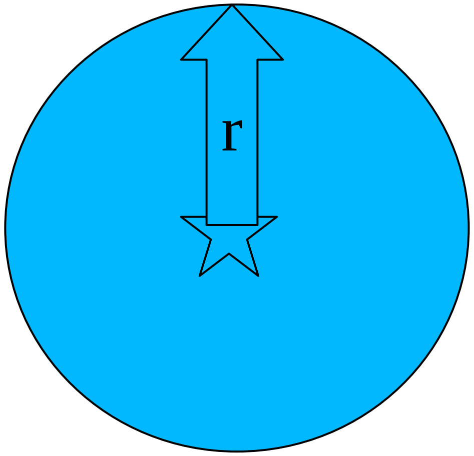
Taking the integral over wavelength gives flux:

$$F = \int_0^\infty F_\lambda \, d\lambda$$ 'bolometric flux'

For the sun, this is called the 'solar constant' = 1.4 kW/m $^2$

To determine the luminosity L, we need the distance r

$$F = \frac{L}{4\cdot\pi\cdot r^2}$$




i.e. the $1/r^2$ law of apparent brightness

# Fundamental distance measurement Trigonometric parallax

- Uses trig and the largest baseline available – the earth's orbit
  - Same geometry as angular size consideration
    - R = 1 AU, r = d (distance), θ = p (parallax)
    - d = 1 AU/p
      - Since 1 rad = (360*60*60)/2π = 2.06 $10^5$ arcsec
    - d = 2.06 $10^5$ AU/p[arcsec]
      - 2.06 $10^5$ AU = parsec = pc
  - So distance in pc is given by 1/p[arcsec]
    - The angle p is called the parallax
      - Note parallax using two eyes as baseline and finger held 1.5 and 3 ft away

# Closest stars very distant

- Largest parallax 1”
  - Galaxy mostly empty space between stars
  - Angular size of stars extremely small
    - Calculate for sun at 1 pc
  - Planets 10-100 times smaller than stars
    - Very challenging to detect, much less resolve
- Most accurate parallax Hipparchos space experiment
  - Bright stars to $p = 0.001''$ accuracy
    - Nearby environs of sun
    - Note: Galactic center 8 kpc distant

# Magnitudes

- Convenient measure of brightness
  - Logarithmic
    - Like dB's for sound power/area
  - Relative
    - Brightness ratio of unknown star to hypothetical zero magnitude star
      - Vega close to zero mag at all wavelengths
  - Used in UV-visible-near IR
    - i.e. where stars dominate
  - Comes from Greeks (Hipparchus)

Greeks (Hipparchus) using naked eyes:

brightest stars: $m=1$

dimmest stars: $m=6$

In 19th century, photometers used to measure monochromatic flux at visible wavelengths, call this $F_V$.

$$F_V = \frac{\int_{500\cdot nm}^{600\cdot nm} F_\lambda \, d\lambda}{100\cdot nm}$$

Found the m=1 stars were 100 times as bright as the m=6 stars

therefore $\Delta m = 5$ implies $\frac{F_1}{F_2} = 100$

and larger magnitudes are dimmer. In general

$$\frac{F_2}{F_1} = 100^{\frac{-(m_2 - m_1)}{5}} = 10^{\frac{-(m_2 - m_1)}{2.}}$$

or

$$-2.5\cdot\log\left(\frac{F_2}{F_1}\right) = m_2 - m_1$$

These are ***apparent*** magnitudes

Absolute mag M - all stars at a common distance d of 10 pc

since $$F = \frac{L}{4\cdot\pi\cdot d^2}$$

$$F = F_{10pc}\cdot\left(\frac{10\cdot pc}{d}\right)^2$$

therefore $$10^{\frac{m-M}{2.5}} = \left(\frac{d}{10\cdot pc}\right)^2$$

gives the correspondence between apparent mag m, absolute mag M, and distance d

Handy rule of thumb, #mag(brightness) = 2 #mag(distance), i.e. take log of equation:

$$m - M = 2\cdot\left(2.5\log\left(\frac{d}{10\cdot pc}\right)\right)$$

Example, : $m_{sun} = -26.8$ $\quad d = 1\cdot AU \quad \rightarrow \quad M = 5$

At galactic center (d ~ 10 kpc)

$$\frac{d}{10\cdot pc} = 10^3$$

i.e. 3 x 2.5 = 7.5 mags of distance
therefore 15 mags of brightness
therefore m ~ +20

i.e. we could detect solar type stars at the galactic center if it weren't for the 30 mag of extinction which gives m' = +50, too faint even for HST (dimmest m = 29)

Check out the Andromeda galaxy at 1 Mpc. $m_{sun}$ = 30