Lecture 1

- **Course overview.** Hand out syllabus, discuss schedule & assignments.

- **Astrophysics**: effort to understand the nature of astronomical objects. Union of quite a few branches of physics --- gravity, E&M, stat mech, quantum, fluid dynamics, relativity, nuclear, plasma --- all matter, and have impact over a wide range of length & time scales

- **Astronomy:** providing the observational data upon which astrophysics is built. Thousands of years of history, with plenty of intriguing baggage. E.g.:

  - Sexagesimal notation: Base-60 number system, originated in Sumer in ~3000 BC. Origin uncertain (how could it not be?), but we still use this today for time and angles: 60'' in 1', 60' in 1^o, 360^o in one circle.

  - **Magnitudes**: standard way of measuring brightnesses of stars and galaxies.
    - Originally based on the human eye by Hipparchus of Greece (~135 BC), who divided visible stars into six primary brightness bins. This arbitrary system continued for ~2000 years, and it makes it fun to read old astronomy papers ("I observed a star of the first magnitude," etc.).
    - Revised by Pogson (1856), who semi-arbitrarily decreed that a one-magnitude jump meant a star was ~2.512x brighter. This is only an approximation to how the eye works! So given two stars with brightness l_1 and l_2:
    - Apparent/relative magnitude: $m_1 - m_2 = 2.5 \log_{10} (l_1/l_2)$ (2 stars)
      - So 2.5 mag difference = 10x brighter.
      - Also, 2.5x brighter ~ 1 mag difference. Nice coincidence!
      - Also, 1 mmag difference = 10^{-3} mag = 1.001x brighter
    - Absolute magnitude (1 star): $m - M = 2.5 \log_{10} [(d / 10\text{pc})^2] = 5 \log_{10} (d / 10\text{pc})$ (assumes no absorption of light through space)
    - Magnitudes can be :
      - "bolometric," relating the total EM power of the object (of course, we can never actually measure this – need models!) or
      - wavelength-dependent, only relating the power in a specific wavelength range
    - There are two different kinds of magnitude systems – these use different "zero-points" defining the magnitude of a given brightness. These are:
      - Vega – magnitudes at different wavelengths are always relative to a 10,000 K star
      - AB – a given magnitude at any wavelength always means the same flux density

- **Astronomical observing**:
  - Most astro observations are electromagnetic: photons (high energy) or waves (low energy)
  - EM: Gamma rays X-ray UV Optical Infrared sub-mm radio
  - Non-EM: cosmic rays, neutrinos, gravitational waves. Except for a blip in 1987 (SN1987A), we only recently entered the era of "multi-messenger astronomy"

- **Key scales and orders of magnitude.**
  - We'll spend a lot of time on stars, so it's important to understand some key scales to get ourselves correctly oriented.
  - Mass:
    - Electron, $m_e \sim 10^{-27}$ g
      Proton, $m_p \sim 2 \times 10^{-24}$ g
      $m_p/m_e \sim 1800 \sim R_{WD} / R_{NS}$ ← not a coincidence!
    - Meanwhile, $M_{sun} \sim 2 \times 10^{33}$ g
    - So it might seem that this course is astronomically far from considerations of fundamental physics. This couldn't be further from the truth! Many quantities we will calculate are almost 'purely' derived from fundamental constants. E.g.:
      - $M_{WD} = (hbar\ c / G)^{3/2}\ m_H^{-2}$ maximum mass of a white dwarf
      - $R_S = 2\ G / c^2\ M_{BH}$ Schwarzchild radius of a black hole

    - Assume N hydrogen atoms in an object with mass M, packe d maximally tightly under classical physics. When are the electrostatic and gravitational binding energies roughly comparable?
      - $E_{ES} = N\, k\, e^2 / a$ a = *Bohr radius*
      - $E_G = G\, M^2 / R$
        - $M = N\, m_p$
        - $R \sim N^{1/3}\, a$
          - $E_G = G\, N^{5/3}\, m_p^2 / a$
      - So the ratio is:
        - $$E_G / E_{ES} = \frac{G\, N^{2/3} m_p^2}{e^2} \approx \left(N / 10^{54}\right)^{2/3}$$
        - So the biggest hydrogen blob that can be supported only by electrostatic pressure has
          M = $10^{54}\, m_p \sim 0.9\, M_{Jup}$
          R ~ $(10^{54})^{1/3}\, a \sim 0.7\, R_{jup}$ Roughly a Jovian gas giant!

  - **Physical state of the sun:**
    - $T_{center} \sim 1.5e7$ K
      $\rho_{center} \sim 150$ g/cc
      (we'll see why later; one of our key goals will be to build models that relate interiors to observable, surface conditions)
      Is the center of the Sun still in the classical physics regime?
    - Simple criterion: $d >> \lambda_D$ $\lambda_D = h / p$
      So, classical means $n << \lambda_D^{-3} << (p/h)^3$
      where $kT \sim p^2/2m$
    - So for electrons, $$\frac{p}{h} = \frac{\sqrt{2\, m_e\, k\, T}}{h}$$
      and so $$n \ll \left(\frac{2\, m_e\, k\, T}{h^2}\right)^{3/2}$$

- How do we relate *n* and *ρ*? Sun is ~totally ionized, so both electrons and protons contribute by number; but only protons contribute substantially to mass.:
  $\rho = m_p n / 2$
- Then our requirement for classical physics means:
  $$\rho \ll \frac{m_p}{2}\left(\frac{2 m_e k T}{h^2}\right)^{3/2} \quad or$$
  $$\rho \ll \left(2800\, g\, cm^{-3}\right)\left(\frac{T}{10^7 K}\right)^{3/2}$$ … classical, but only by a factor of ~10. Not so far off!
- Is the sun an ideal gas? If so, thermal energy dominates:
  $kT >> e^2 / a$, so
  $T >> e^2 n^{1/3} / k$
  $T >> e^2 (2 \rho / m_p)^{1/3} / k$
  $T >> (15000\ K) (\rho / 1 g/cc)^{1/3}$
  This is satisfied throughout the entire sun: it's valid to treat the Sun's interior (and most other stars) as an ideal gas.