30 — The Sun $[Revision : 1.1]$

- The Sun as a Low-Mass Star
  - Sun exemplifies principal characteristics of low-mass stars
    * Hydrogen burning by PP chain
    * Radiative core
    * Convective envelope
  - About 4.5 billion years old (age from radioactive dating of moon rocks)
  - Surface composition $X = 0.94$, $Y = 0.24$, $Z = 0.02$
  - Initial composition $X = 0.71$, $Y = 0.27$, $Z = 0.02$; surface values changed by diffusive settling
  - Core composition $X = 0.34$, $Y = 0.64$; so, about half way through hydrogen burning
- The Solar Neutrino Problem
- Solar atmosphere
  - Photosphere
    * Where optical light comes from
    * Bottom level arbitrary; 100 km below $\tau = 1$ at 5000 Å
    * Top level defined where $T = 4400\,\mathrm{K}$; this is a local **temperature minimum**
    * Absorption lines
  - Chromosphere
    * Gradually increasing temperature (up to $\sim 10,000\,\mathrm{K}$)
    * Low densities, high temperatures lead to ionization
    * Emission lines due to recombination
  - Transition Region
    * Sharply increasing temperature
    * Narrow ($\sim 100\,\mathrm{km}$)
    * Emission lines
  - Corona
    * High temperature (up to million-K)
    * Components
      · K corona — white-light emission from scattering of photospheric radiation by electrons
      · F corona — scatering of photospheric radiation by dust grains
      · E corona — emission lines from highly ionized elements
    * Corona is heated by input of mechanical energy from below
- Magnetic field
  - 11-year Solar cycles
  - Sunspot polarity
  - Butterfly diagram
  - Prominences
  - CMEs

- The Solar Wind
  - Hydrostatic equilibrium in corona:

$$\frac{\mathrm{d}P}{\mathrm{d}r} = -\rho \frac{GM_\odot}{r^2}$$

    (assume mass in corona is negligible)
  - Assume isothermal ideal gas:

$$\frac{\mathrm{d}P}{\mathrm{d}r} = -\frac{P\mu m_H}{kT}\frac{GM_\odot}{r^2}$$

  - Solve:

$$P(r) = P_\odot \exp\left[\frac{GM_\odot \mu m_H}{kT}\left(\frac{1}{r} - \frac{1}{R_\odot}\right)\right]$$

    where $P_\odot$ is surface pressure
  - Asymptotic value as $r \longrightarrow \infty$:

$$P \longrightarrow= P_\odot \exp\left[-\frac{GM_\odot \mu m_H}{kTR_\odot}\right]$$

  - Typically much larger than pressure of interstellar medium; so, hydrostatic equilibrium cannot occur
  - Instead, the Sun has a steady **pressure-driven wind**
    * Terminal velocity $\sim 700\,\mathrm{km\,s^{-1}}$
    * Mass-loss rate $\dot{M} \sim 10^{-14}\,\mathrm{M_\odot\,yr^{-1}}$
  - Reason for the solar wind is heating which keeps corona hot