Astrophysics I: Stars and Stellar Evolution
AST 4001

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Stars and Stellar Evolution, Fall 2008

Agenda

1. Recap
   - Course Administration
   - Web site access
2. Introduction
   - Basic Assumptions About Stars
   - The Sun
3. Closing
   - Summary
   - Web site access
   - Build your own star

Overview

Textbook

- **Diana Prialnik:**
  An Introduction to the Theory of
  Stellar Structure and Evolution
  Cambridge University Press, Paperback, 2000.
  2007 reprint: ISBN 978-0-521-65937-6

Course requirements

- **2 mid-term quiz** (Oct 2, Nov 6; drop one) (25%)
- **1 final** (December 13) (25%)
- **6 homework problems**
  due every second Tuesday **before class** starting September 23. (25%)
- **stellar evolution project**
  different problems/projects, usually due along with homework assignments. (25%)

Contact

- **Location & Dates:**
  Physics 236A, MTWTh 10:10-11:00 AM
- **Office hours:**
  Wednesdays, 13:00-14:30, 342F Tate
- **email:**
  I cannot guarantee that I will receive all emails due to SPAM filters. On class days I will try to reply to email within 24 h.
- **Web site:**
  `http://stellarevolution.org/AST-4001`
  I will post notes, updates, problem sets, etc.
- **Google course calendar** (on Web site):
  `o86pe6r5paic30h4qv6acm9ej0%40group.calendar.google.com`

Web site access

- user name: **Ast-4001**
- password: **&32y^nbY**

Overview

What are Stars?

Stars

1. are bound by self-gravity
2. radiate energy supplied by an internal source

Usually stars have a nuclear energy source

Energy Sources

What energy sources are conceivable?

- gravitational binding energy
  - contraction
  - gravitational settling
- chemical energy / burning
- heat capacity (just cooling down)
- pulsation energy dissipation
- rotational energy dissipation

What are Stars? (continued)

- Stars usually live and shine steadily for a long time
- From (1) follows that stars usually are spherical unless they rotate strongly
- Planets mostly shine by reflection of sun light
- Because stars radiate - lose energy - energy conservation requires that they must evolve; they burn nuclear fuel
- “Death” of stars by disruption or running out of fuel; often a combination of both (“compact” remnant formation - white dwarf, neutron stars, black hole, in the latter two cases a powerful “supernova” may occur in the process)

What are Stars? (continued)

- Star formation is very complicated
- We will follow stars from the early time when they fulfill conditions (1) and (2)
- Galaxies are large systems of stars, some $10^6 \ldots 10^{12}$
- Clusters of galaxies can contain some 100,000 galaxies

Brightness of stars

- Observed (apparent) brightness “intensity”

$$I_{\mathrm{obs}} = \frac{L}{4\pi d^2}$$

where d is the distance to the star
- “luminosity” describes how much energy a star radiates per unit time
- intrinsic stellar luminosities range from $10^{-5}\,\mathrm{L}_\odot$ to $> 10^5\,\mathrm{L}_\odot$.

The Sun

- Luminosity
  $L_\odot = 3.84 \times 10^{33}\,\text{erg/s} = 3.84 \times 10^{26}\,\text{J/s}$
- Mass
  $M_\odot = 1.98 \times 10^{33}\,\text{g} = 1.98 \times 10^{30}\,\text{kg}$
- Radius
  $R_\odot = 6.98 \times 10^{10}\,\text{cm} = 6.98 \times 10^{5}\,\text{km}$

Gravitational Binding Energy

Binding energy can be approximated by

$$E = \frac{\mathrm{G}M^2}{2R} \quad , \qquad G = 6.67259 \times 10^{-8} \frac{\mathrm{cm}^3}{\mathrm{g\,s}}$$

The lifetime of the star is then defined by how long it takes to radiate away that energy, hence dividing by luminosity

$$\tau_{\mathrm{KH}} = \frac{E}{L} = \frac{\mathrm{G}M^2}{2RL}$$

This is called the *Kelvin-Helmholtz time-scale*.
It tells how long a star takes to radiate away it gravitational binding energy. This is also the time-scale for stars to get in *gravo-thermal* equilibrium.

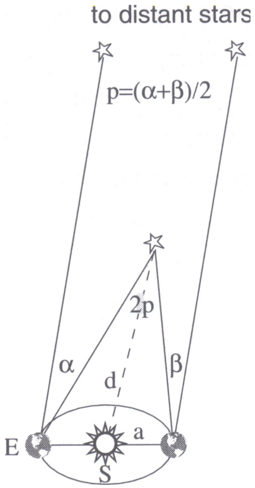
Gravitational Binding Energy

For the Sun we obtain

$$\tau_{\mathrm{KH},\odot} = \frac{\mathrm{G}M_\odot^2}{2R_\odot L_\odot}$$

$$\tau_{\mathrm{KH},\odot} = 4.9 \times 10^{14}\,\mathrm{s} = 15.6 \times 10^{6}\,\mathrm{yr}$$

Parallax



- Sufficiently close objects change their position in the sky relative to an infinitely remote background as the earth moves around the sun.
- maximum "baseline" is 2 AU, about 3×10^{13} cm
  1 AU = Earth-Sun Distance
- distance can be obtained from
  $p = (\alpha + \beta)/2$
  $\frac{a}{d} = tan(p) \approx p$, $d = p/a$
- Proxima Centauri: p=0".76, $d = 4.3$ lyr
- method works till about 500 pc

Basic Assumptions

- stars evolve *in isolation*
  distances between stars are large compared to their radii
- spherical symmetry
  sun rotates once in 27 days, $\omega \approx 2.5 \times 10^{-6}$/s

$$\frac{M\omega^2 R^2}{GM^2/R} = \frac{\omega^2 R^3}{GM} \approx 2 \times 10^{-5}$$

- only small variation in (initial) composition of stars
  sun: $X = 0.70$, $Y = 0.28$, $Z = 0.02$, $X + Y + Z = 1$
- small magnetic fields - even for $B \sim 0.1\,\mathrm{T}$:

$$\frac{B^2/\mu_0}{GM^2/R^4} = \frac{B^2 R^4}{\mu_0 GM^2} \sim 10^{-11}$$

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Summary

- Stars are bound by self-gravity
- Stars radiate energy supplied by an internal, usually nuclear, energy source
- Stars are usually in good approximation spherically symmetric

Web site access

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- password: **&32y^nbY**

Stellar Evolution Project

- Bill Paxton's **EZ Stellar Evolution** code
  `http://www.kitp.ucsb.edu/~paxton/EZ-intro.html`
- Uses Linux `gfortran`
- g95 FORTRAN compiler can be downloaded for most platforms.
  `http://www.g95.org`

Compiling on Physics Linux Machines

- `gfortran` is part of the gcc compiler suite Linux
- use `gfortran` 4.3.1 or later
- on physics machines you can list available version using
  `ups list -aK+ gcc`
- you can switch to the desired version using, e.g.,
  `setup gcc v4_3_1`
- then show current `gcc` version using
  `gfortran -v`
- to switch back to default compiler use
  `unsetup gcc`