ASTR 498N Lecture 1 Stars: Why and What?

(online at www.astro.umd.edu/~drabin/)

Twinkle, twinkle, little star,
How I wonder what you are?
Jane Taylor (1806)

Why study stars?

Stars are

- Large
  - Self-contained (often)
  - Gaseous (usually)

  systems about which much can be learned from first principles.
- Stars can be relatively simple or extraordinarily complex.
- Stars are a major constituent of the universe.
- A star keeps us alive.
- We are made of stars.
- [You can't get an astronomy degree without taking this course?]
- Stars are fascinating!

What do we seek to understand about stars?

- Why can they exist?
- Why do they shine?
- Why do they have the sizes they do?
- Why do they have the masses they do?

- Why do they have the luminosities they do?
- Why are they as hot as they are?
- What are they made of?
- How old are they?
- How are they born?
- How do they age and die?

We will address most of these questions, although not in the order listed and often rather superficially (i.e., indicating what is understood but not deriving results from first principles). We'll find that many of the questions are inter-related.

There is still much we *don't* know—otherwise the subject wouldn't be as interesting as it is.

If you complete this course, you will go outside one starry night and realize that you *understand* a lot about what you see—knowledge that people have sought for thousands of years. [Fortunately, you won't find starry nights any less beautiful.]

Questions

1. How massive is the Sun relative to the Earth?
2. How massive is our galaxy relative to the Sun?
3. How large is the Sun relative to the Earth?
4. How old is the Sun? [y]
5. How far away is the Sun?
6. How far away is the second nearest star?
7. How far away is the center of our galaxy?
8. How massive is the most massive star relative to the least?
9. How large is the largest star relative to the smallest?
10. How luminous is the most intrinsically luminous star relative to the least?

11. What is the luminosity of the Sun? [W]
12. How much energy from the Sun falls on the Earth? [W m^{-2}]
13. Is the Sun a variable star? If so, how?
14. What is rate of energy production per gram in the core of the Sun relative to your metabolic rate per gram?
    a. 10^3 times smaller
    b. About the same.
    c. 10^6 times greater.
15. How hot is the Sun at its surface? At its core?
16. Which of the following equations describes hydrostatic equilibrium?
    a. $\frac{dP}{dr} = -\frac{GM\rho}{r^2}$
    b. $\frac{dT}{dr} = -\frac{GP\rho}{r^2}$
    c. $\frac{\partial^2 P}{\partial r^2} = -\frac{GMr}{\rho}$
17. An approximate expression for the mean molecular weight μ of a fully ionized gas composed of hydrogen, helium, and heavier elements with respective mass fractions *X*, *Y*, and *Z* (*X*+*Y*+*Z*=1) is
    a. $\mu = X + 2Y + 10Z$
    b. $\mu = 2X + Y + 0.5Z$
    c. $\mu^{-1} = 2X + 0.75Y + 0.5Z$
18. What astronomy courses have you taken? [Please include course title and text.]
19. What physics courses have you taken? [Ditto.]

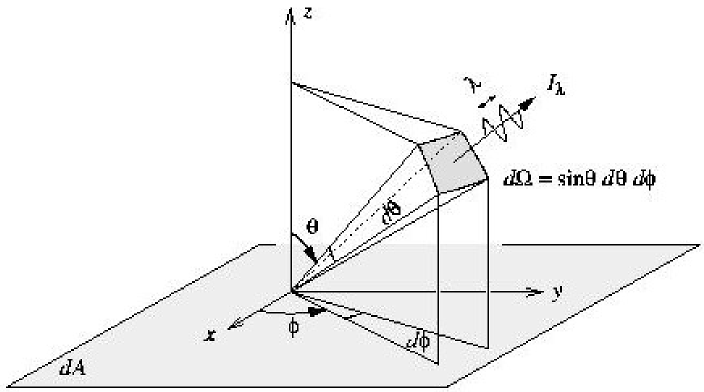
Note on units and the text

I'll try to use SI units in the lectures, as SI is widely preferred in physics. However, most astronomy books and papers (at least until recently) have used cgs units, so you'll need to get used to both systems. I use bracket notation for "has units of" — for example, [n_e] = m^{-3}.

The course text (Ostlie & Carroll—O&C for short) uses cgs. Note that O&C has a web site that may be of some use.

Review

Intensity and Related Quantities
(O&C §9.1)



$$dE_\nu = I_\nu \cos\theta \, dA \, d\nu \, d\omega \, dt$$

$$[I_\nu] = \mathrm{W\,m^{-2}\,Hz^{-1}\,sr^{-1}}$$

$I_\nu \equiv$ (specific) intensity

In the SI system, what astronomers call intensity is properly known as spectral radiance (go here for more than you need to know). $d\omega$ (or $d\Omega$) is an element of *solid angle* (see figure).

For given $\cos\theta dA d\omega dt$, consider the energy of radiation in the frequency range $[\nu_1, \nu_2]$ or the *corresponding* wavelength range $[\lambda_1, \lambda_2]$, where $\lambda_1 = c/\nu_1$, $\lambda_2 = c/\nu_2$. It's the same energy: we must have

$$\int_{\nu_1}^{\nu_2} I_\nu \, d\nu = \int_{\lambda_1}^{\lambda_2} I_\lambda \, d\lambda$$

P Show that $\nu I_\nu = \lambda I_\lambda$.

I_ν and I_λ are *density functions* like those used in probability theory. Physicists usually call them distributions, but this is unfortunate—in probability theory, the density function is the derivative of the (cumulative) distribution function.

Flux density $\quad F_\nu = \int_{4\pi} I_\nu \cos\theta \, d\omega \qquad$ Emittance $\quad F_\nu^+ = \int_{2\pi} I_\nu \cos\theta \, d\omega$

where $\int_{4\pi} \ldots \, d\omega$ stands for $\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} \ldots \sin\theta \, d\theta d\phi$ and

$\int_{2\pi} \ldots \, d\omega$ stands for $\int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi/2} \ldots \sin\theta \, d\theta d\phi$.

P Why do we need to distinguish F_ν and F_ν^+?

P What is F_ν^+ if I_ν is isotropic?

Radiation energy density
$$u = \frac{1}{c} \int_{4\pi} I \, d\omega = \frac{4\pi}{c} \bar{I}$$

Radiation momentum flux
$$dP_\nu = \left(\frac{I_\nu}{c} \cos\theta\right)(dA \cos\theta) \, d\nu \, d\omega \, dt$$

Radiation pressure
$$P_\nu = \frac{1}{c} \int_{4\pi} I_\nu \cos^2\theta \, d\omega$$
$$= \frac{2\pi}{c} \int_{-1}^{1} I_\nu \mu^2 d\mu = \frac{4\pi}{c} K_\nu$$

P Is radiation pressure important in stars?

This radiation pressure is defined as a scalar quantity.

P Can we use this definition if the radiation field is anisotropic?

Astronomers are notoriously careless with the names of radiation quantities. You can be tripped up by terms like “astrophysical flux” or the distinction between linear and specific opacity. Scrutinize the terminology and units in each paper or book.