Announce/Remind

Magazine Extra-Credit: Due Today.


OBAFKM double-secret extra-credit (2 points on Exam #3): email by next Monday.
Apod Today: Enceladus: Saturn’s Icy Moon
**Last Time: Stars**

- **Stars are, at first approximation, amazingly simple.**

- **The sun is an “average” star: not the brightest, biggest, hottest, nor the faintest, smallest, coldest.**

- **We study stars by their colors and their spectrum, and position (“proper motion”).**
Last Time: Stars

- **Luminosity** (c.f. 100 W light bulb) vs. **apparent brightness** (c.f. 100 W light bulb 100 yards away).

- $1/d^2$ **fall-off of light intensity**: low-luminosity but close can look as bright to us as high-luminosity, but far.

- **Photometry**: the study of brightness of objects.
**Last Time: Stars**

- **Magnitude system**: lower magnitude = fainter.

- **Apparent magnitude**: what we see.

- **Absolute magnitude**: what we **would** see if a star were at a distance of 10 parsecs.

- "Parsec" = "Parallax Second": the distance an object would have to be to subtend 1 arcsec of parallax.

- 1 pc = 3.26 light years.
Spectrum of a star tells us much about it. Used to classify stars by type: OBAFKM (from hottest to coldest).

All stars have spectra lines or “gaps” in their continuous spectrum, just like the sun, but the lines differ, and depend on how hot the star is.

Recently cool stellar types “L” and “T” were added, down to 700K at their surface!
Best Entries So Far

- Only Big Armies Fight Green Kamikaze Martians
- Organic beans are farm grown kitchen meals
- Often Boys Are Forgetting Girls Kiss Men
- On Birthdays American Families Go Kick Meatballs
- Our Boyfriends Are Fine Gorgeous Kissable Muscular Lovable Things
The importance of Mass

- A star's mass determines its fate.

- The more massive the star, the bigger and brighter it is.

- The “thermostat” of nuclear fusion controls this: more mass = more gravity = more pressure in the core = more temperature = much faster nuclear fusion.
But how do we measure it?

- **Binary stars!**

- **Visual Binary:** Can see both stars in telescope

- **Spectroscopic Binary:** Can only see one star, other inferred from spectroscopy.
Binary Star Orbits

- Stars orbit around each other
- Each star orbits around the Center of Mass
Sirius A and B
Sirius A and B

1960

1970
Sometimes we get lucky, and the binary is eclipsing.
Measuring Diameters

Doppler shift gives speed

Measure time for star to disappear

\[ R = (t_B - t_A)v \]
Spectroscopic Binaries

As each star orbits, the spectral lines of both are Doppler-shifted back and forth.
Mass Limits

Smallest star mass: about $0.08 \times$ mass of sun.

Any smaller, and it’s never hot enough to fuse hydrogen!

Largest Star Mass: about $150 \times$ mass of sun (very rare).

Any larger a star can’t maintain hydrostatic equilibrium. They blow themselves apart.
The lives of Stars

- A star’s life begins when it begins fusing hydrogen in its core.

- Most of its life, it continues to fuse hydrogen in its core.

- Small stars have lower core temperatures, and use their hydrogen fuel very slowly. Thus, they live a long time.

- Big stars are much hotter, and burn their fuel recklessly: they live fast, and die young.
The more massive the star, the higher the rate of nuclear fusion (just hotter!).

The higher the rate of nuclear fusion, the brighter and hotter (bluer) the star is, and the faster it uses up its supply of H.

Note M stars are $10^{12}$ yrs!
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Note M stars are $10^{12}$ yrs!
The Solar Neighborhood

- 4 blue A stars
- 1 greenish F star
- 5 yellowish G stars
- 22 orange K stars
- 87 M red stars
- 9 white dwarfs
- Just as many red L and magenta T stars
- Note: no hot O and B stars
- In general, lots of low-mass stars, few high-mass stars.
The Hertzsprung-Russell Diagram

- One of astronomy’s most important tools
- Its plots temperature on the x-axis (backwards though!) and luminosity on the y-axis.
H-R Diagram

- Supergiants
- Giants
- Main sequence
- White dwarfs

Luminosity ($L_{\odot}$)

Spectral class

Surface temperature (K)

O B A F G K M

25,000 10,000 6000 3000
Main Sequence Stars

- **Main Sequence stars** are normal stars that fuse hydrogen into helium.

- **Our Sun** is a main sequence star.

- **Brighter main sequence stars** are hotter and thus bluer.

- **Fainter main sequence stars** are cooler and thus redder.
Main Sequence Stars

- For main sequence stars, there is a relationship between mass, temperature, size, luminosity, and lifespan.

- The more massive a star is, the hotter, larger, and more luminous it is, and the shorter its lifespan.

- Only works for main sequence stars!
Workbook Time


- The more talking I hear, the happier I am.
Which of the following statements is always true of two stars that have the same absolute magnitude?

A) They have the same temperature.
B) They have the same luminosity.
C) They have the same spectral class.
D) They have the same surface area.
E) None the above.
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C) They have the same spectral class.
D) They have the same surface area.
E) None of the above.
On an H-R diagram, stars at the same temperature are found

A) aligned horizontally (i.e., next to each another).

B) aligned vertically (i.e., one above the other).

C) along the main sequence.
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Giants and Supergiants

Some stars are cool and thus red, but as bright as the blue main sequence stars. How can this be?
Properties of Thermal Radiation

- Hotter objects emit more light at all wavelengths.
- Hotter objects emit more of their light at shorter wavelengths (Wien 1893).

Intensity per square meter!
Giants and Supergiants

Giants: 10 to 100 times the radius of the Sun

Supergiants: 100 to 1000 times the radius of the Sun

Blue Main Sequence Star
(Sun 10x smaller!)

Orbit of Mars

Red Supergiant
Sun  Sirius  Pollux  Arcturus

Jupiter is about 1 pixel in size

Earth is invisible at this scale

Courtesy UCI Observatory
Supergiants

Atmosphere of Betelgeuse
PRC96-04 · ST ScI OPO · January 15, 1995 · A. Dupree (CfA), NASA
White Dwarfs

Some stars are extremely faint, but very hot. We call these white dwarfs.
White Dwarfs

White dwarfs are about the size of the Earth. But they have about the mass of the Sun, so they are very, very dense.

A sugar cube of white dwarf material would weigh a ton on the Earth.
Sirius B (White Dwarf)
Main Sequence Stars

- **Spica**
  - B1 V
  - $11M_{\text{Sun}}$
  - Lifetime $10^7$ yrs

- **Sirius**
  - A1 V
  - $2M_{\text{Sun}}$
  - Lifetime $10^9$ yrs

- **Sun**
  - G2 V
  - $1M_{\text{Sun}}$
  - Lifetime $10^{10}$ yrs

- **Proxima Centauri**
  - M5.5 V
  - $0.12M_{\text{Sun}}$
  - Lifetime $10^{12}$ yrs

Relative Sizes of Stars from White Dwarfs to Supergiants

- **Betelgeuse supergiant star**
  - M2 I, 3,400 K,
  - 38,000$L_{\text{Sun}}$,
  - 500 solar radii

- **Aldebaran giant star**
  - K5 III, 4,500 K,
  - 350$L_{\text{Sun}}$,
  - 30 solar radii

- **Procyon B white dwarf**
  - 0.01 solar radii

Sun
- main sequence star
  - G2 V, 5,800 K,
  - $1L_{\text{Sun}}$,
  - 1 solar radius

Earth
- (for comparison)
Luminosity Classes

Besides the spectral type, stars are also assigned a luminosity class.

The general classes are:
I : supergiants
III : giants
V: main-sequence stars
Giants and Supergiants

- Some stars are cool and thus red, but as bright as the blue main sequence stars. How can this be?
- They emit less light per square meter than a blue main sequence star, but, they are much, much bigger (more square meters)!
Full Spectral Classification

Includes both a spectral type and luminosity class.

Examples:

Sun: G2 V
Alpha Centauri: M5 V
Betelgeuse: M2 I
Spica: B1 V
Arcturus: K1.5 III
An Aside on Star Names

Do all stars have names?

No, most do not, only brightest stars visible by the naked eye: about 300 stars.

Can you purchase a star to name it for someone?

Yes, but no astronomer (or anyone else) will recognize that name, so it's pretty useless.
Clusters of Stars

- Stars don’t just occur in binaries and multiples, but large clusters as well.
- Held together by their gravitational attraction to each other.
- Born out of the same gas cloud (almost the same location) and at the same time.
- Contains stars of different masses
- Permits study of stellar evolution
Two Types of Clusters

“Open Clusters”: 100–1000 loosely packed stars.

Relatively Young: at most a few billion years.
Two Types of Clusters

“Globular Clusters”: 100,000 to 1 million tightly packed stars.

Among the oldest objects in the universe (up to 13 billion years).

Only ~200 in the galaxy.
The Main Sequence Turn Off

- Assume all stars in the cluster start fusing H at the same time.

- Clusters of different ages have different “main sequence turnoff” points.

- We can use this fact, and mathematical models to determine the age of a star cluster.
Cluster Evolution

NGC 6791
Three stellar ages

Stars that were once here evolved into red giants

Turn-off point: 8 billion years old

White dwarf stars

Main-sequence stars

4-billion-year-old white dwarfs

6-billion-year-old white dwarfs

Brightness

Bluer

Color

Redder
**Remind**

- **Read Chapter 12 for Monday.**
- **OBAFGKM mnemonic extra credit.**
- **Karen Bjorkman’s Astronomy Lecture Series Extra Credit: tomorrow night @7:30 in Ritter Planetarium.**