The Final Lecture

Let’s Review!

Lesson 1: Radiation & Spectra

Lesson 2: Energy & Thermonuclear Radiation

Lesson 3: Stellar Evolution

Lesson 4: Stellar Spectra & Classification

Lesson 5: The Death of Stars

Lesson 6: Galaxies

Lesson 7: Hubble Tension and the Distance Scale

Lesson 8: High Energy Phenomena

Lesson 9: Protoplanetary Disks & Object Formation

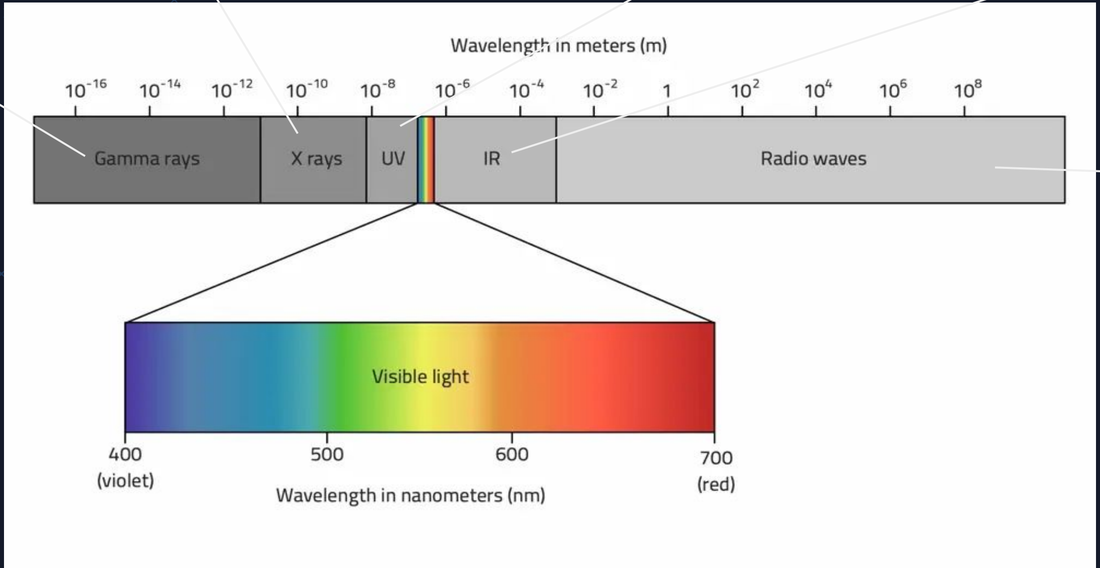
Radiation & Spectra

X-rays:
- Galaxy clusters
- X-ray binaries
- Brown dwarf flares
- Medical x-rays

UV:
- Starlight
- Flowers
- Fluorescence
- Blacklights

IR:
- Thermal heat
- Television remotes
- Planets

Gamma rays:
- High energy explosions
- Nuclear reactions
- Bananas!
- The Hulk



Radio:
- Cosmic microwave background (microwaves)
- Quasars
- Fast radio bursts
- Radio supernovae

Astronomy makes use of all of these wavelengths of radiation

Radiation & Spectra

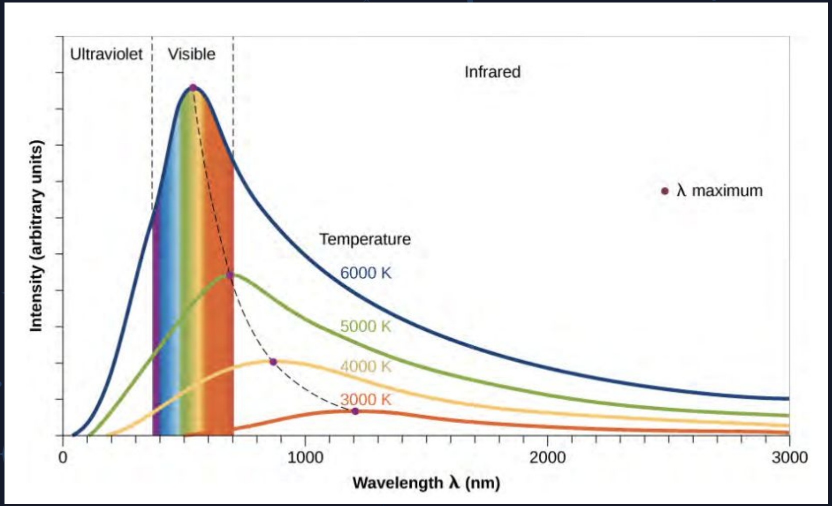
Key concepts:

The frequency, wavelength, and energy of electromagnetic radiation are all related!

$$c = \lambda\nu \qquad\qquad E = h\nu$$

Blackbody radiation:
We can tell the temperature of a star based on what wavelength of radiation it peaks at

$$\lambda_{\max} = \frac{3\times10^{6} nm\cdot K}{T}$$



Energy & Thermonuclear Radiation

Key concepts:

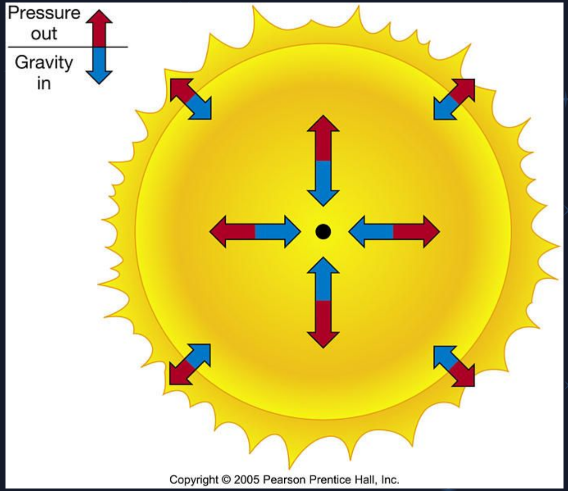
Our sun is held up due to a balance between gravity and radiation pressure– this is called Hydrostatic Equilibrium

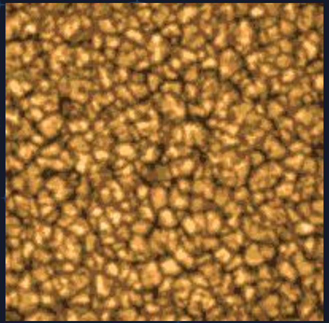
$$\frac{dP_r}{dr} = -G\frac{M_r \rho_r}{r^2}$$

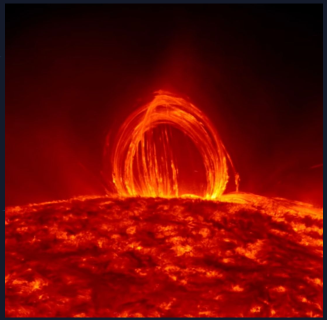
The surface of the sun is a convective, highly magnetically active place– this causes granulation, sunspots, flares, and coronal mass ejections

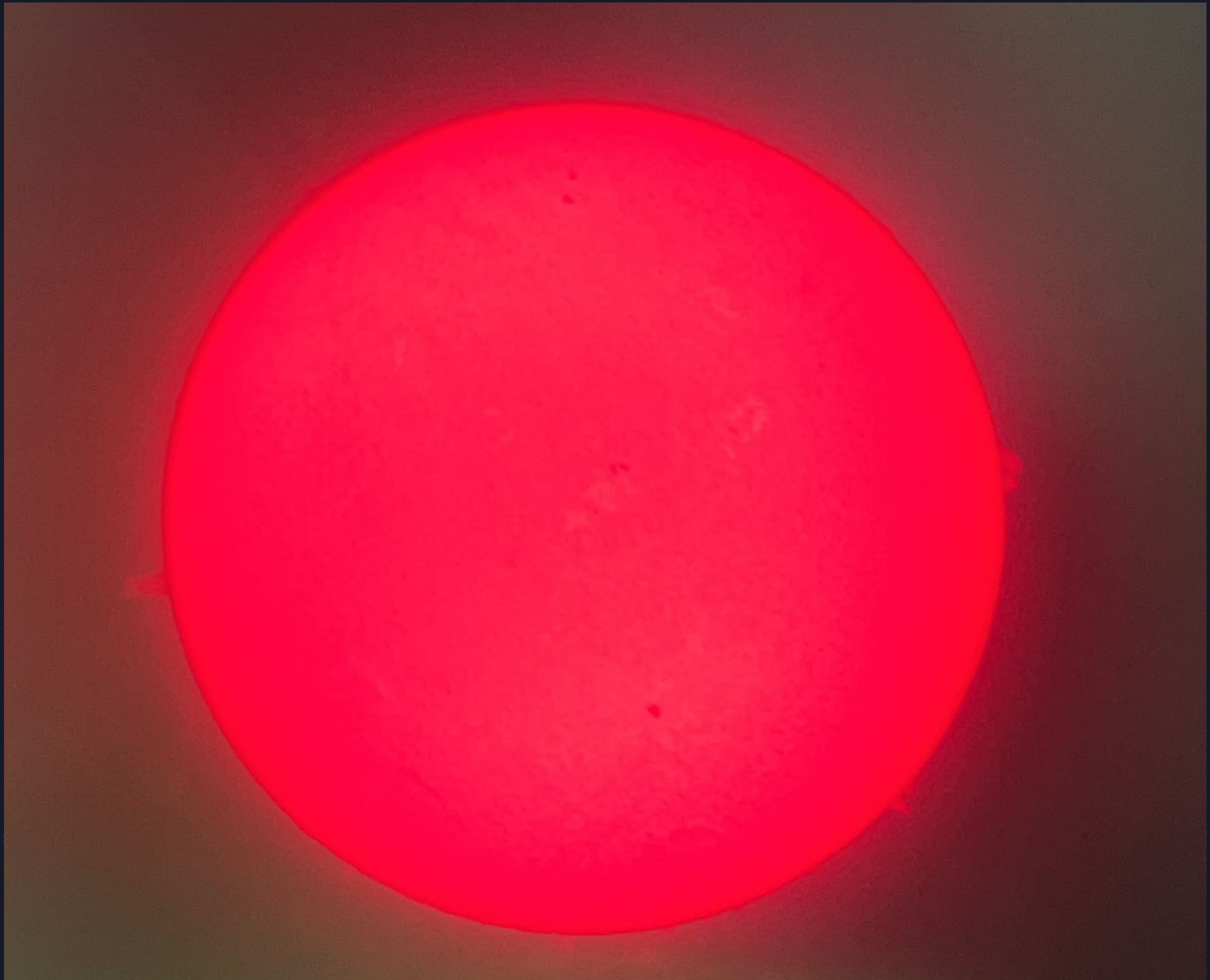
The interior of the sun is a nuclear fusion zone Hydrogen is converted into Helium, releasing energy equivalent to the mass loss

$$E = mc^2$$



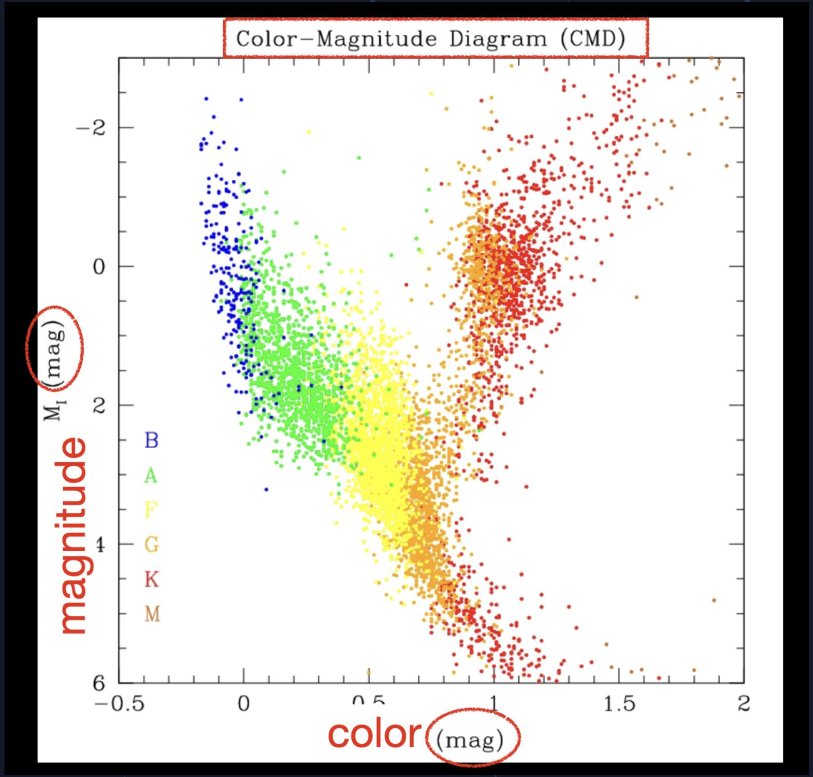




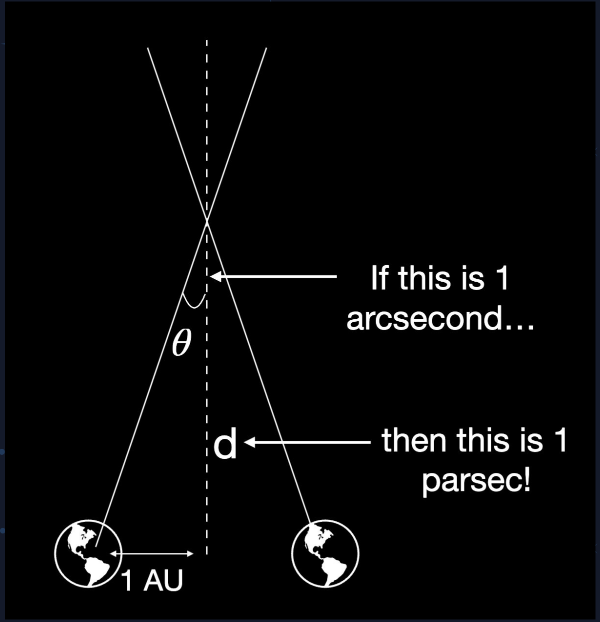

Your photo of the sun taken at Yerkes Observatory on July 19, 2023

Stellar Evolution

- Stars evolve over their lifetime according to their mass



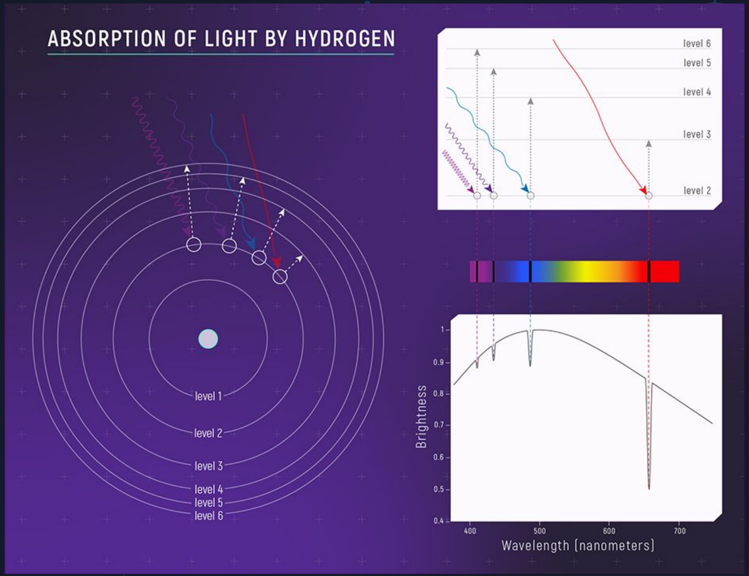
$$m = -2.5\log_{10}\left(\frac{F}{F_{\mathrm{ref}}}\right)$$



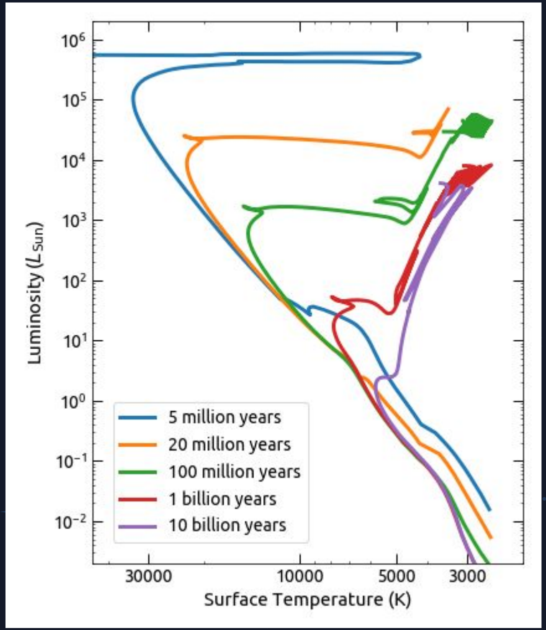
Stellar Spectra and Classification

Stars absorb certain wavelengths according to their composition, and this gives us spectral lines

Can give us a star's temperature, metallicity, rotation, and whether or not there are companions



Isochrones help us tell the age of a population of stars

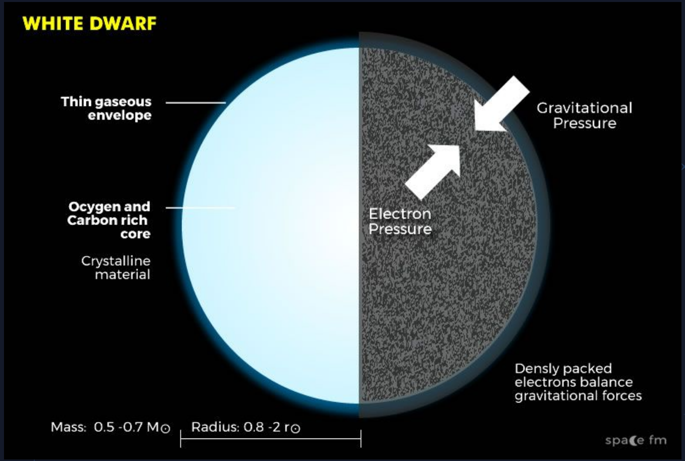


The Death of Stars

The fate of stars depends on their mass at the time of death

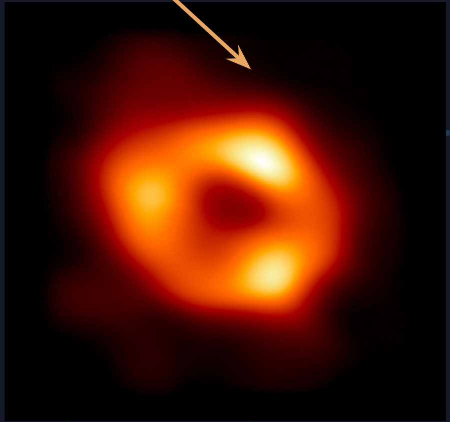
$$0.25\,M_\odot < M < 8M_\odot$$

$$M > 8M_\odot$$

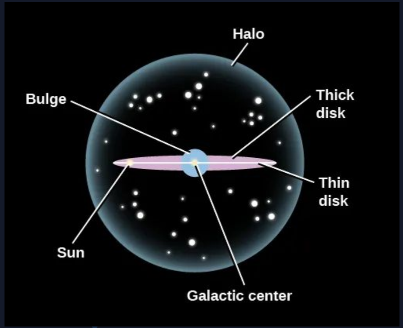


Earth-sized diamond

Chicago-sized nucleus

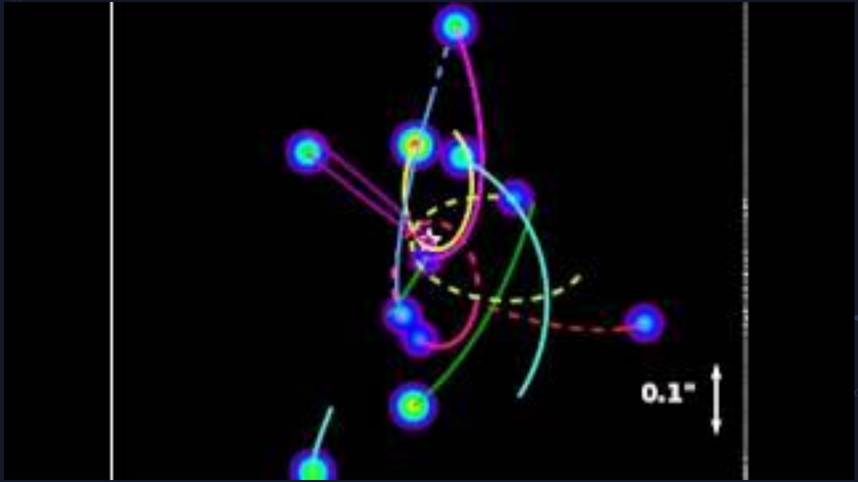


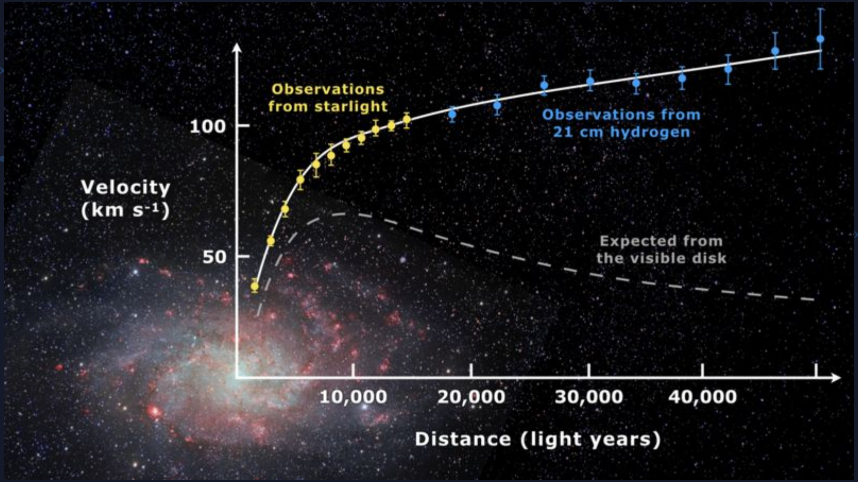
Galaxies



Population I stars: all ages, hang out in the spiral arms
Population II stars: older, and hang out in globular clusters and the nucleus of the galaxy

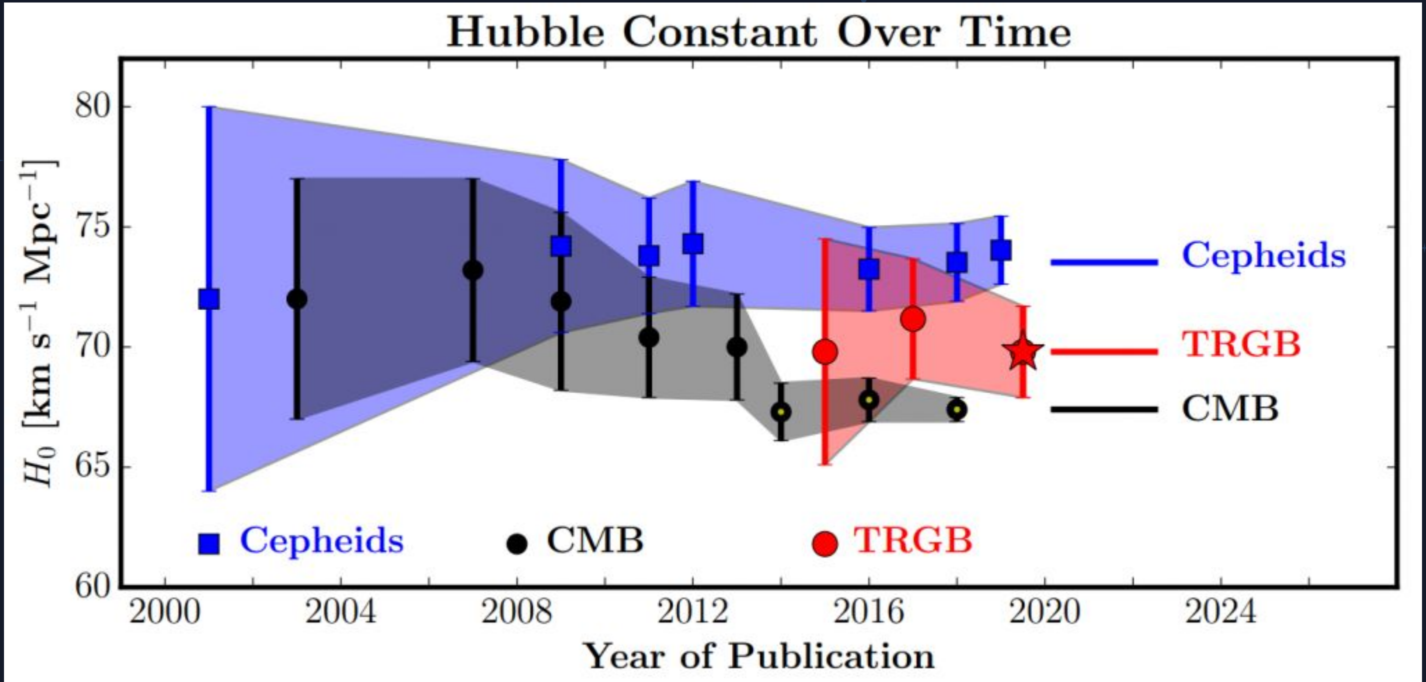
We can gravitationally infer the presence of dark matter and of our central supermassive black hole



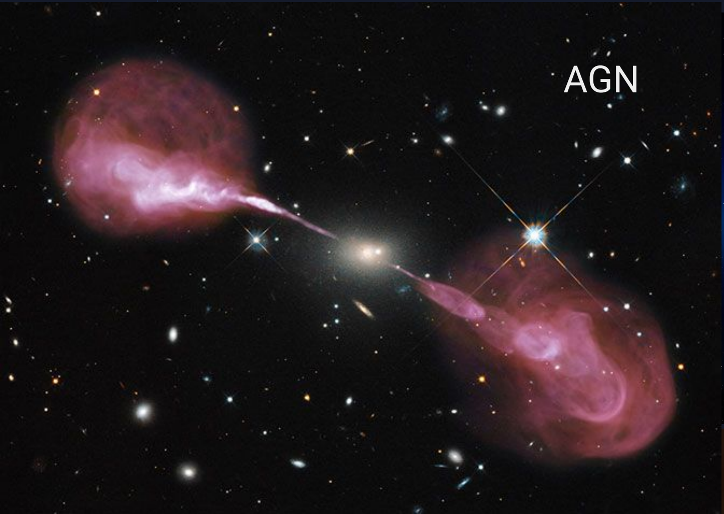


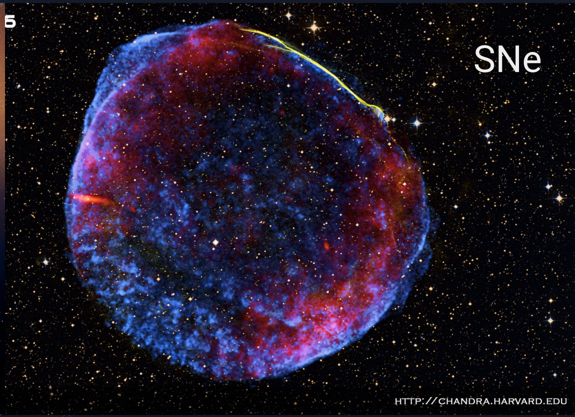
Distance Scale

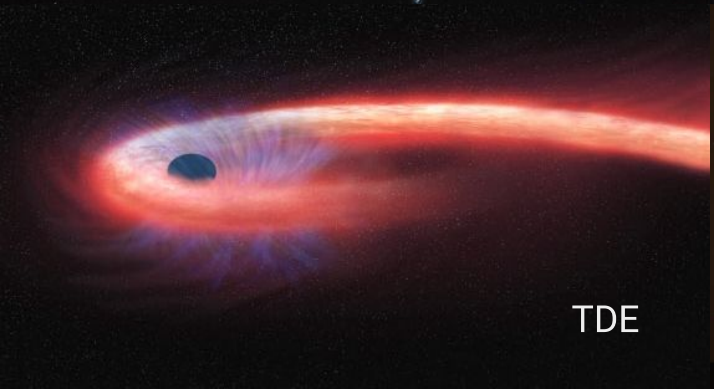
The universe is not expanding [source: 65/23 of our students on slido]



High Energy Phenomena







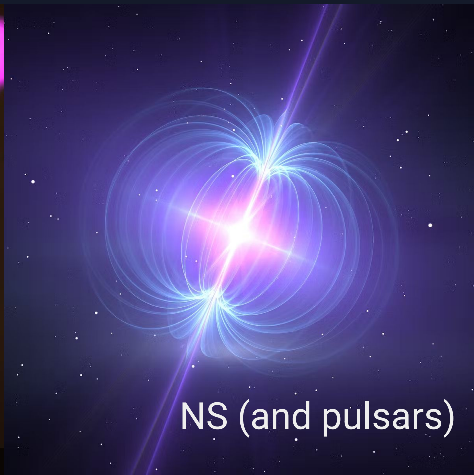
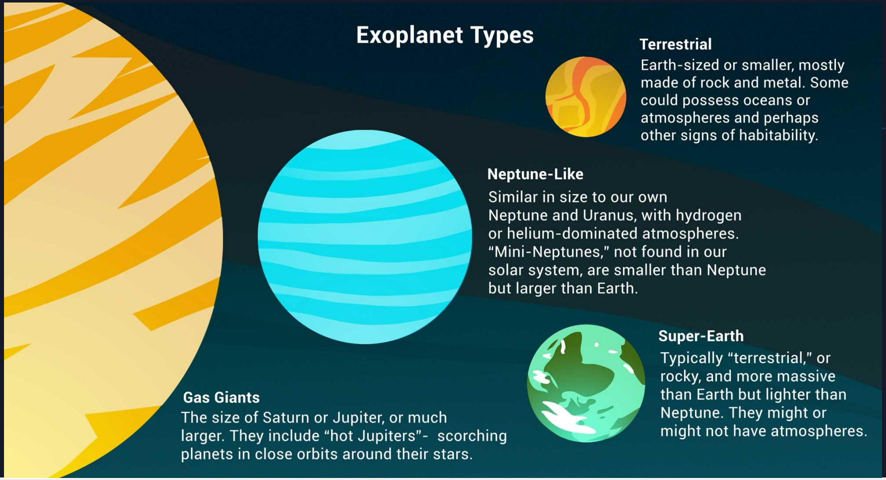
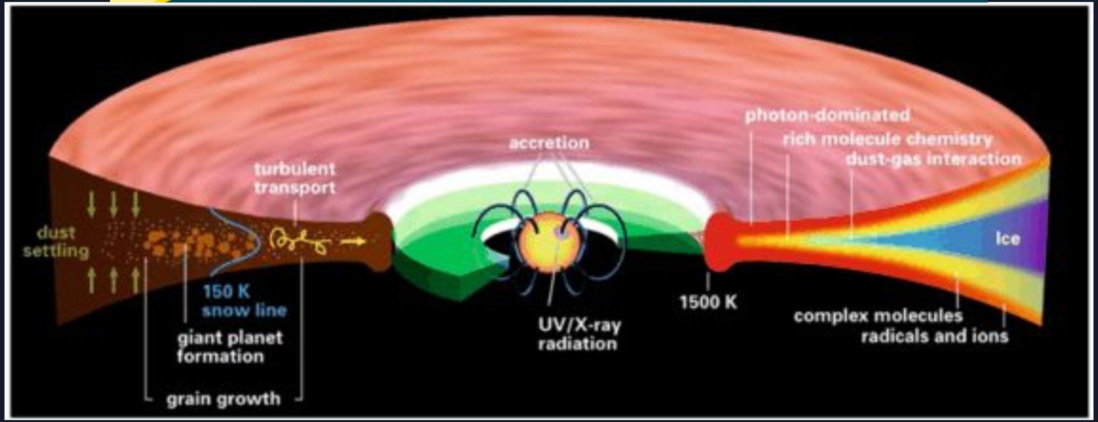
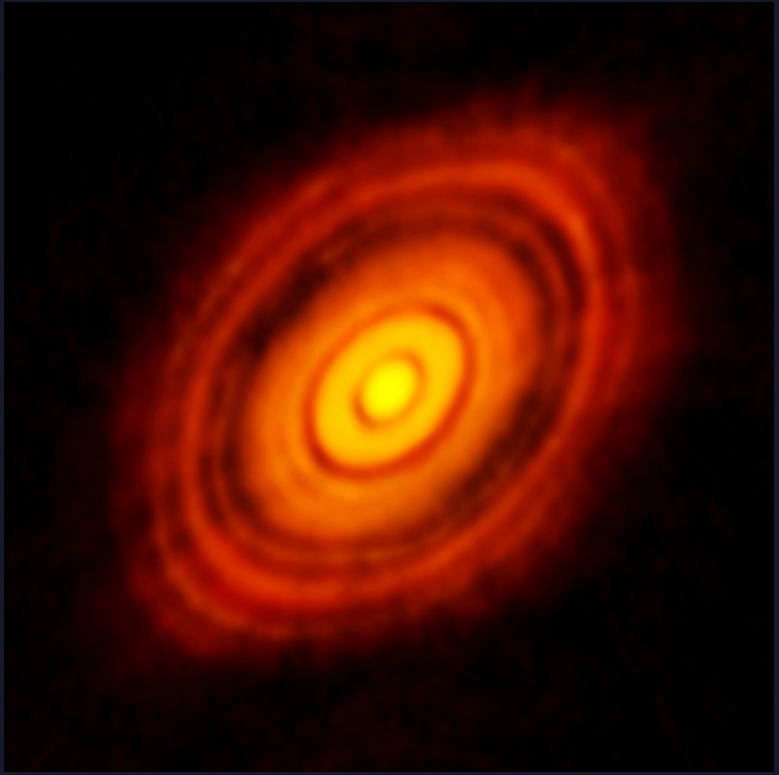


Image credit: nasa.gov

Protoplanetary Disks







Now let’s go back to day 1 of our course.

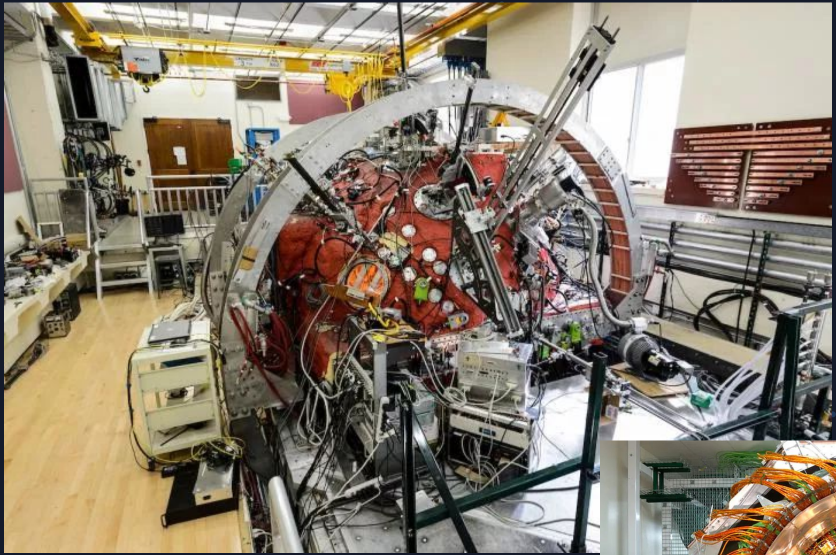
Our original questions about the sun:

Intrinsic Properties of the Sun

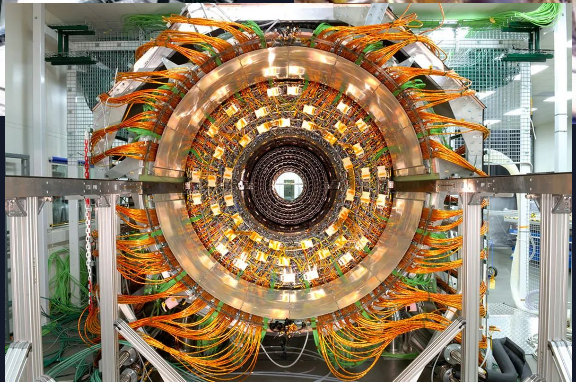
- Why is the sun yellow?
- How big is the sun?
- Chemical composition of the sun?
- Age?
- Can you make an artificial sun (lab)?
- Why does it look different in different wavelengths?
    - What wavelength does it emit in the most?

Sun in a lab???

Big Red Ball at UW Madison



PPPL



CERN:
5.5 trillion
degrees

The Sun in Time

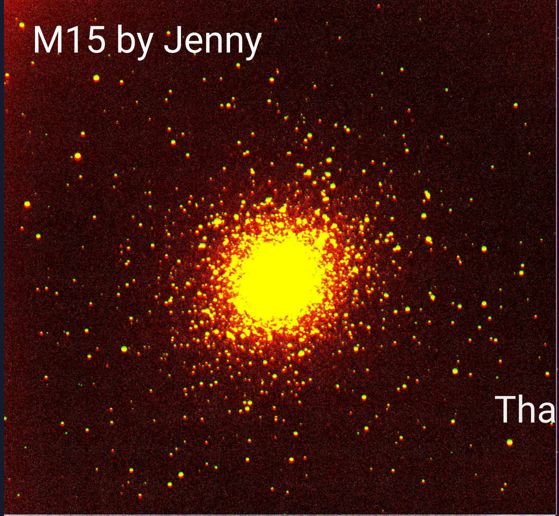
- Why is the sun so powerful?
    - Where is the energy coming from?
    - How does it provide energy continuously?
    - When will it stop generating energy?
- How will the sun die?
- How was the sun formed?
- What causes sunspots, solar flares, and coronal mass ejections?
    - What is responsible for the shape of solar prominences?
- What’s the magnetic field like on the sun?

Relative to the Sun

- Where is the sun located?
- Is the sun moving and how?
- FALL OUT aka: what would happen if the sun went away?
- How does the sun compare to other stars?
    - How many other stars are there?
- How do stars support life on planets?
- How many things orbit stars?
- How many galaxies are there?
- Are all shiny things in galaxies stars? What else is there?
- How typical is the Milky Way?
- What is at the center of the Milky Way?
- How will the universe change over time?

Your beefed up resume 💪

- General astrophysical knowledge (topics covered in previous slides)
- Python experience (including Numpy, Pandas, and Astropy)
    - Experience working with data analysis of large data sets
- Led your own scientific inquiries, accessed and manipulated large open access astrophysical data sets, did error analysis, practiced the scientific method
- Experience with DS-9 and TOPCAT
- Observational experience with the Dob, the solar telescope, and the giant refractor at Yerkes
- Experience making prints in the dark room
- Found 8 Cepheids and 1 UFO


M15 by Jenny


Eagle Nebula by Ethan

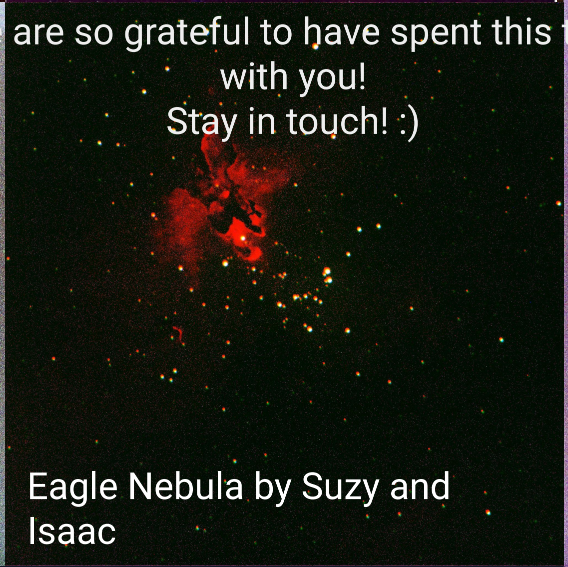

Cygnus Cocoon by Oliver C

That's a wrap!

Thank you for your hard work, enthusiasm, curiosity, and dedication!

We are so grateful to have spent this time with you!
Stay in touch! :)


M101 by Meadow


Eagle Nebula by Suzy and Isaac


Helix Nebula by Edgar