

(Yester)Today in science...

- Happy 60th birthday, NASA!
- Bill to form passed Congress in July of 1958, Eisenhower signed into law a few weeks later
- A distinctly civilian, not military, organization for the peaceful exploration and application of space science
- Earth observing, heliophysics, astrophysics, and missions
- ISS and launch/crew vehicles
- \$20.7 billion annual budget
- 17,336 employees (plus many, many more support staff/contractors)

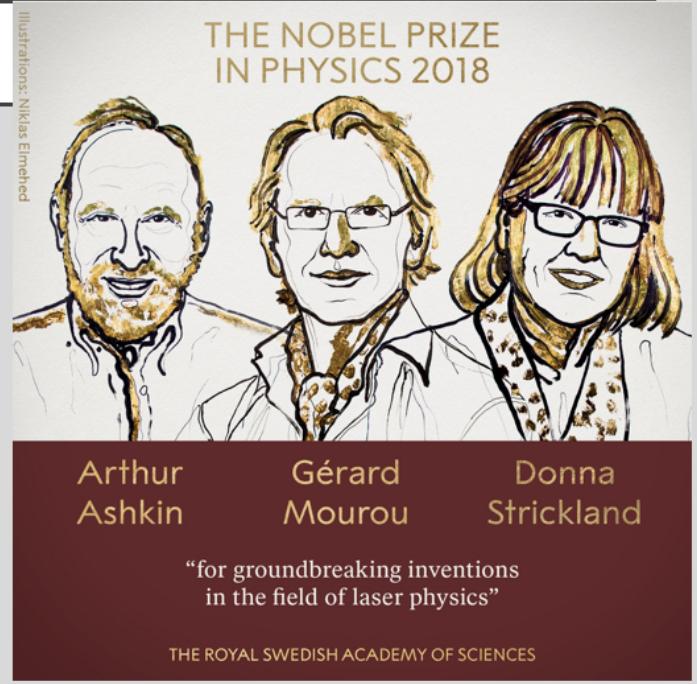


Today in science...



Today in science!

- Physics Nobel prize announced
- Optical tweezers
- Techniques that paved the way for most intense lasers ever created by humans



THE NOBEL PRIZE
IN PHYSICS 2018

Arthur
Ashkin

Gérard
Mourou

Donna
Strickland

“for groundbreaking inventions
in the field of laser physics”

THE ROYAL SWEDISH ACADEMY OF SCIENCES

https://www.washingtonpost.com/science/2018/10/02/nobel-prize-physics-awarded-tools-made-light-first-woman-years-honored/?noredirect=on&utm_term=.ea26207cd076



The Sun, part II.

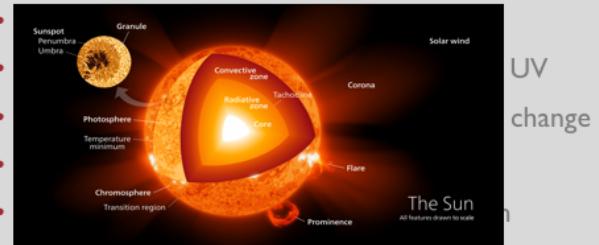
The Cosmic Perspective, Chapter 14

<https://www.nasa.gov/image-feature/goddard/potw627-active-regions-galore.html>

Recap: the Sun's structure, energy source

The Sun, from inside to outside

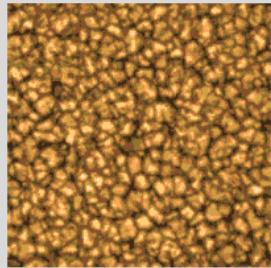
- Core
- Radiative zone
- Tachocline
- Convection zone
- Photosphere
- Chromosphere
- Transition region
- Corona
- Solar wind
- Where fusion happens
- Photons 'randomly walk' here
- Thin boundary between zones
- Energy is transported by convection here



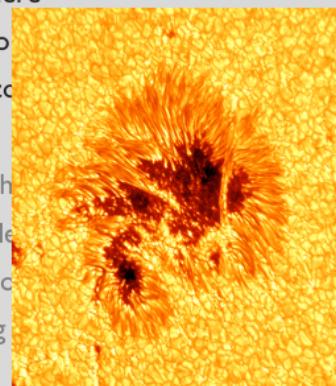
Recap: the Sun's structure, energy source

The Sun, from inside to outside

- Core
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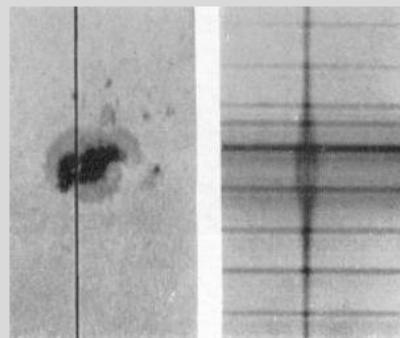
- Where fusion happens
- Photons 'randomly walk' here
- Thin boundary between zones
- Energy is transported by convection
- Visible 'surface' of the Sun
- Atmosphere starts to get hot
- Where temperature and density peak
- $\sim 10^6$ K upper atmosphere can glow
- Stream of particles flowing away from the Sun



Recall: iron filings, that sort of filamentary structure- that's what you're seeing in the edges of the sunspot, magnetic field– George Hale observed this resemblance in 1908!

Aside: sunspots and magnetic fields

- George Hale was the first to discover magnetic fields in sunspots in 1908
- Remember atomic energy levels? Atoms do funny things under the influence... of a magnetic field
- This was another huge moment in science history: the discovery of magnetic fields existing beyond Earth!
- Aside to an aside: George Hale was a very interesting guy (in a good way)

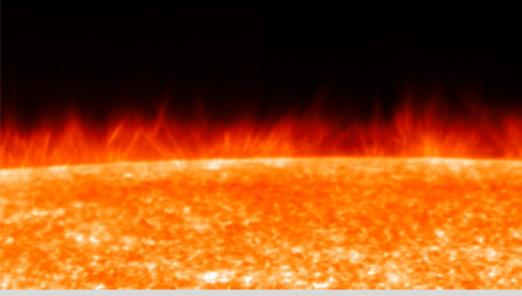


<https://www2.hao.ucar.edu/Education/FamousSolarPhysicists/magnetic-nature-sunspots>

<http://adsabs.harvard.edu/full/1999ApJ...525C..60H>

Recap: the Sun's structure, energy source

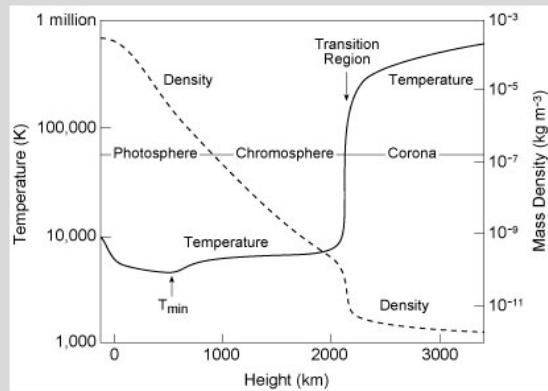
The Sun, from inside to outside

- Core
 - Radiative zone
 - Tachocline
 - Convection zone
 - Photosphere
 - Chromosphere
 - Transition region
 - Corona
 - Solar wind
- 
- Atmosphere starts to get hotter, radiates UV
 - Where temperature and density abruptly change
 - $\sim 10^6$ K upper atmosphere of the Sun
 - Stream of particles flowing away from Sun

Recap: the Sun's structure, energy source

The Sun, from inside to outside

- Core
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- Where temperature and density abruptly change
- $\sim 10^6$ K upper atmosphere of the Sun
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Recap: the Sun's structure, energy source

The Sun, from inside to outside

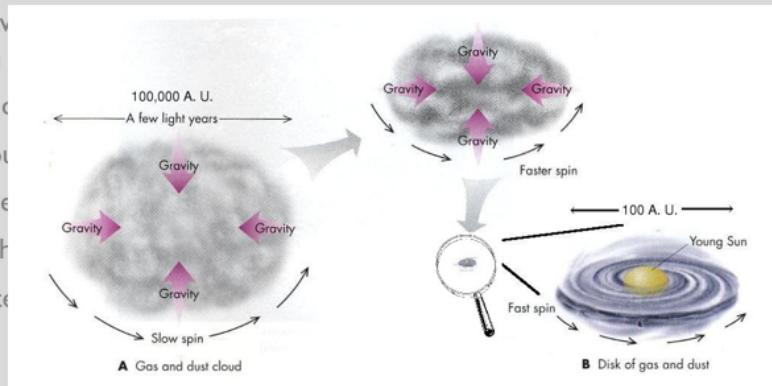
- Core
- Radiative zone
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- Convection zone
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- Solar wind
- ~ 10^6 K upper atmosphere of the Sun
- Stream of particles flowing away from Sun



© 2007 Jerry Lodriguss / AstroPix.com

Recap: the Sun's structure, energy source

- Gravitational collapse converts gravitational potential energy into thermal energy
- When center of collapsing region gets hot and dense enough, fusion begins
 - High temperature needed to get particles moving fast enough
- Ionized nuclei and electrons have to move close enough to each other to overcome repulsion
 - For a sun-like star or cooler, density has to be high
 - For hotter stars, there is enough energy to overcome repulsion
- For most of the Sun's life, it fuses hydrogen into helium
- The total number of nuclei in the Sun is about 10^{57}
- The core shrinks with time, temperature increases



should I get into quantum tunneling or no?

Recap: the Sun's structure, energy source

- Gravitational collapse converts gravitational potential energy into thermal energy
- When center of collapsing region gets hot and dense enough, fusion begins
 - High temperature needed to get particles moving fast enough
- Ionized nuclei and electrons have so much kinetic energy, moving fast enough like charges don't repel before strong force binds them together
 - For a sun-like star or cooler, quantum tunneling is necessary
 - For hotter stars, there is enough energy
- For most of the Sun's life, it fuses H into He in the proton-proton chain
- The total number of nuclei in the Sun's core decreases with time
 - The core shrinks with time, temperature goes up, fusion rate increases

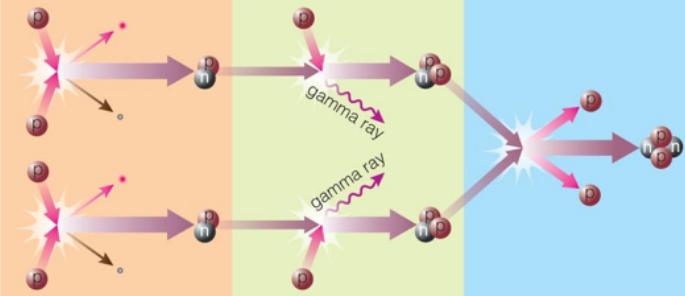
Special guest today: Dr. Belmont, nuclear physicist!

Fusion in the Sun

Hydrogen Fusion by the Proton-Proton Chain

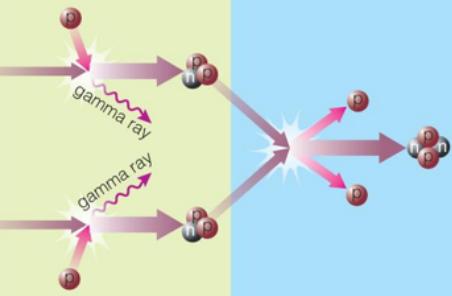
Step 1

Two protons fuse to make a deuterium nucleus (1 proton and 1 neutron). This step occurs twice in the overall reaction.



Step 2

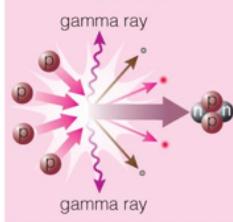
The deuterium nucleus and a proton fuse to make a nucleus of helium-3 (2 protons, 1 neutron). This step also occurs twice in the overall reaction.



Step 3

Two helium-3 nuclei fuse to form helium-4 (2 protons, 2 neutrons), releasing two excess protons in the process.

Overall reaction



Key:

- (n) neutron
- (p) proton
- ~~~~ gamma ray
- neutrino
- * positron

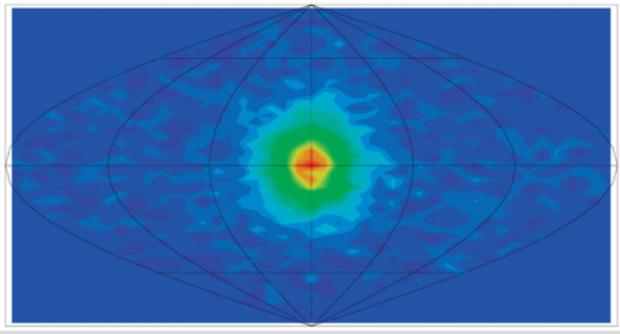
© 2017 Pearson Education, Inc.

Fusion depends on temperature and density

Aside on fission...

Recap: the Sun's structure, energy source

- Neutrinos
- Yes, they have mass
- Yes, they just keep going out into the universe! (Until they run into something they interact with)
- Proof fusion is the source of energy for Sun



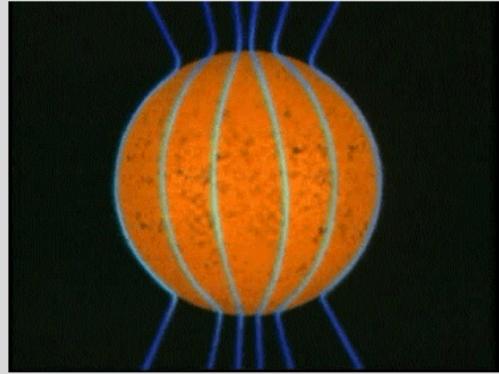
Quantifying the Sun's energy output

Recall: energy balance in Sun means energy produced at core = energy output at solar surface

- We measure energy in Joules
- Power is the rate that energy is used; Watts
 - 1 Watt = 1 Joule/s
- The Sun's total power output, which we call *luminosity*, is 3.8×10^{26} Watts
 - Compare to a 100 Watt light bulb, that uses 100 Joules of energy per second it's on!

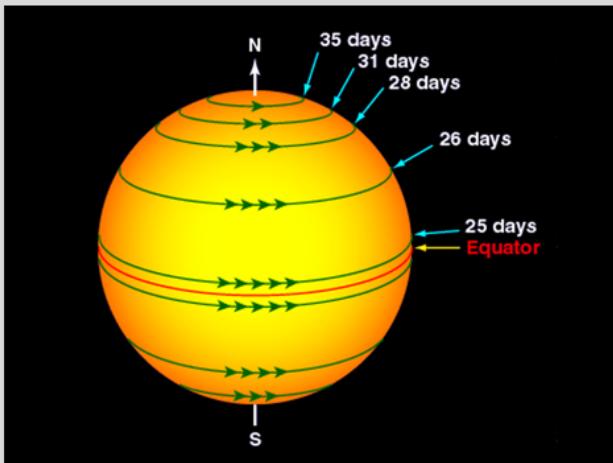
Solar activity

- Charged plasma and magnetic fields interact
 - Depends on plasma properties (density) and magnetic field properties (strength)
- Magnetic fields stop plasma from moving
 - Sunspots
 - Magnetic loops
 - Solar streamers
- Or, plasma can move magnetic fields
 - Solar magnetic cycle
 - Energy transfer: kinetic energy of plasma → stored magnetic energy
- Sun's magnetic field generated by *dynamo*



<https://solarscience.msfc.nasa.gov/dynamo.shtml>

Solar rotation

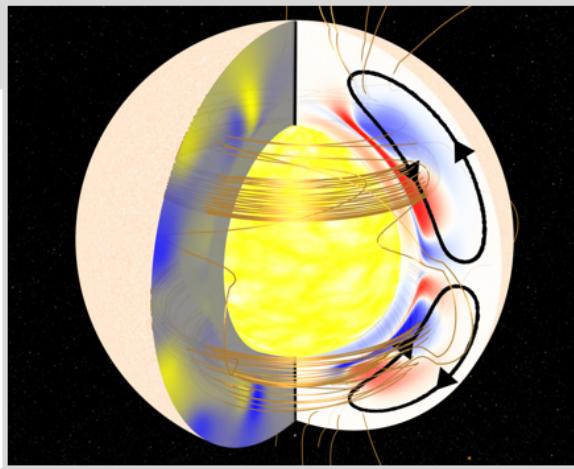
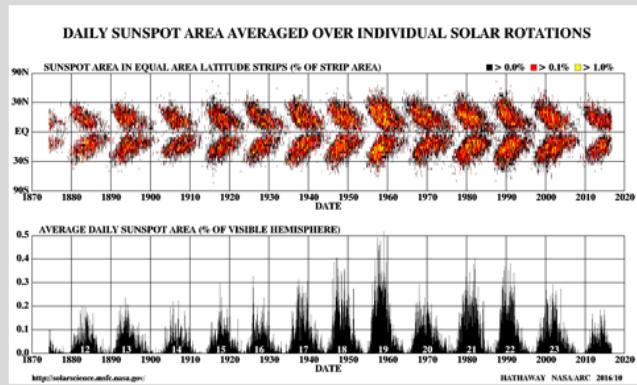


- Remember Earth's rotation? Called a rigid body
- As a plasma, different latitudes on the Sun can have different rotation rates! And they do!

https://www.nasa.gov/mission_pages/sunearth/science/solar-rotation.html

Solar interior motions

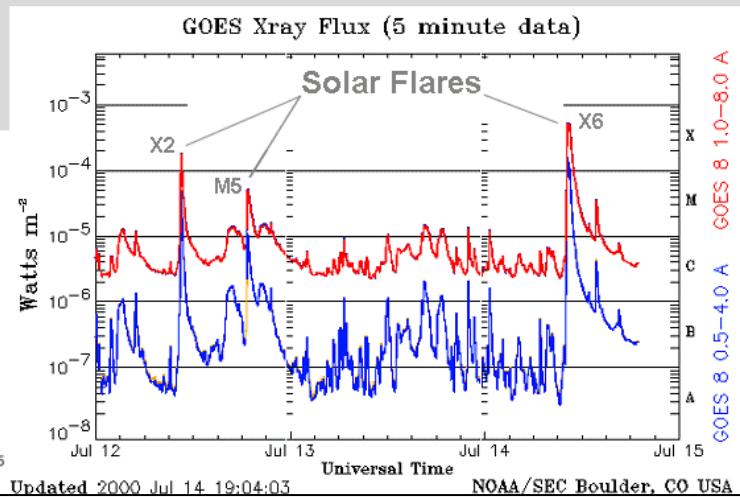
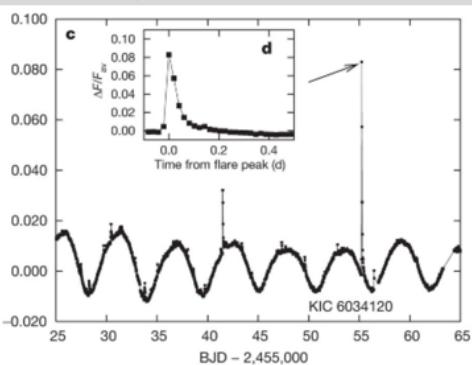
- “Conveyor belt” → meridional flow



https://www.nasa.gov/mission_pages/sunearth/science/plasma-flow.html

Solar activity: observations

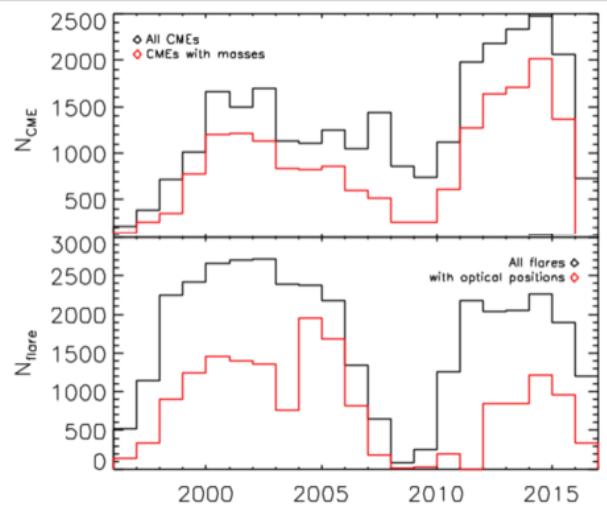
- "Activity" refers to phenomena resulting from magnetism, release of magnetic energy
 - Sunspots
 - Flares
 - Mass ejections



Figures from maehara et al 2013 and
<http://spaceweather.com/glossary/flareclasses.html>

Solar activity: observations

- "Activity" refers to phenomena resulting from magnetism, release of magnetic energy
 - Sunspots
 - Flares
 - Mass ejections
- Activity follows Sun's 11-year magnetic cycle
 - Sunspot number
 - Flare, CME number
 - Overall solar irradiance
 - Solar wind speed



(plot made by Prof A)

Aurorae

Caused by high-speed solar wind or coronal mass ejections: high-energy particles stream along Earth's magnetic field, collide with molecules in our atmosphere



Is this image false color?

What do you think the colors are from?

Why do you think aurorae are seen most at northern latitudes?

<https://phys.org/news/2015-10-fast-solar-aurora.html>



Surveying the Stars

The Cosmic Perspective, Chapter 15.1-15.2

<https://www.spacetelescope.org/images/heic1509c/>

Properties of stars

- Imagine that...
 - You're looking up at the sky from a field outside of Greensboro
 - You take out a pair of binoculars
 - You point a telescope at a random place in the galaxy.
- What will we see?

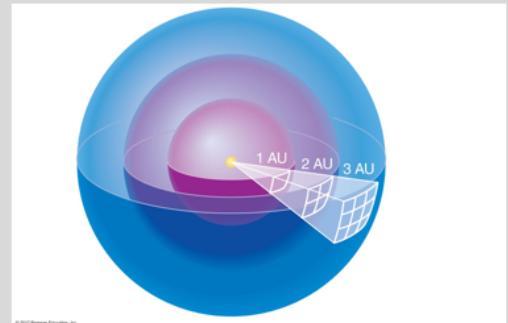
Properties of stars

- Imagine that...
 - You're looking up at the sky from a field outside of Greensboro
 - You take out a pair of binoculars
 - You point a telescope at a random place in the galaxy.
- What will we see?
 - More and more stars the more magnified our view
 - Stars of different brightness
 - Stars of different colors
 - Maybe the milky way, or a nebula, or some galaxies

Properties of stars

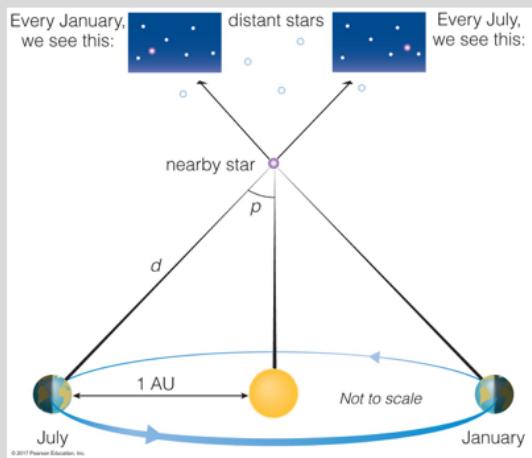
- How bright stars appear is called *apparent brightness*
- Their actual brightness depends on how far away they are, how big they are, how hot they are!
- A 100 W light bulb a foot away is much brighter than a 100 W bulb 100 feet away; light rays diverge
- How bright stars actually are is called *luminosity*
- Apparent brightness is related to luminosity:
 - Apparent brightness = $\frac{\text{luminosity}}{4\pi \times \text{distance}^2}$

Units=Watts/m²

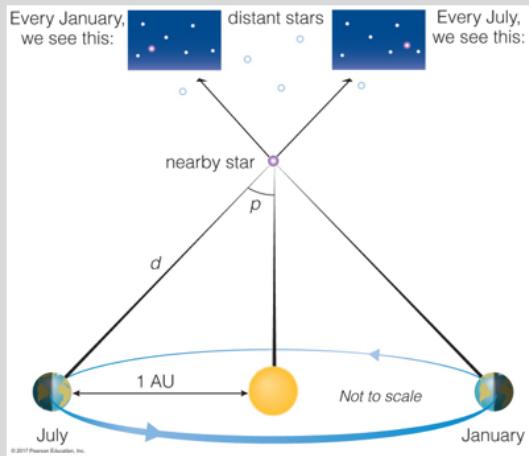


Apparent brightness, parallax, and luminosity

- How can we measure a star's apparent brightness?
- In parts of the electromagnetic spectrum
 - How do we know star's brightness across entire EM spectrum? Multiple measurements, or hypotheses about star's overall emission
- With a detector that can measure watts/m^2
- If we know the distance to the star and its apparent brightness, we can calculate its luminosity!
 - How do we get its distance? Parallax!



Parallax



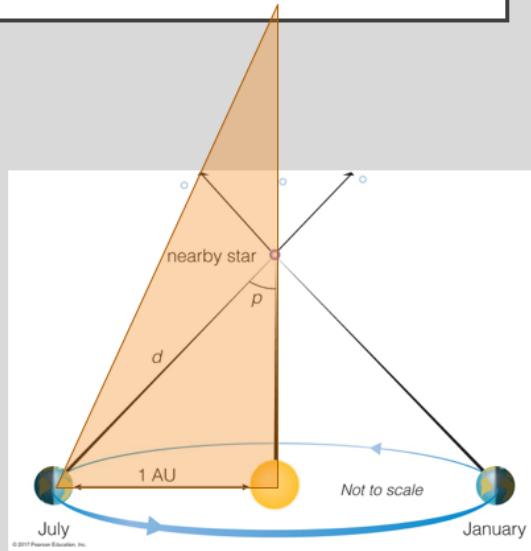
- Use trigonometry to calculate distances to stars based on angle they subtend in the sky over the course of a year of observations
- New distance definition: the **parsec**, pc
 - Portmanteau of *parallax* and *arcsecond*
 - The distance to an object with a parallax angle of 1 arcsecond
 - Reminder: the arcsecond
 - 360 degrees on the sky
 - 1 degree = 60 minutes of arc (')
 - 1 arcminute = 60 seconds of arc (")
 - $d \text{ (in pc)} = 1 / p \text{ (in arcsec)}$

Portmanteau literally means to carry a coat, it's the word for a suitcase that opens on a hinge into two equal parts. In English usage, it refers to a combination of two words—like breakfast and lunch (brunch), golden retrievers and poodles (goldendoodles), frappuccino (frappe and cappuccino), etc ... I think ginormous is one of my favorite portmanteaus

https://en.wikipedia.org/wiki/List_of_portmanteaus

Parallax

- d (in pc) = $1 / p$ (in arcsec)
- Example: a star with a parallax angle of 0.5 arcsec
 - $d = 1 / (0.5'') = 2\text{pc}$
- Example: a star with a parallax angle of 0.1''
 - $d = 1 / (0.1'') = 10\text{pc}$
- Parsecs take prefixes like other SI units:
 - $1000\text{pc} = 1\text{kpc}$
 - $1,000,000\text{pc} = 1\text{Mpc}$
- $1\text{pc} = 3.26\text{ly}$



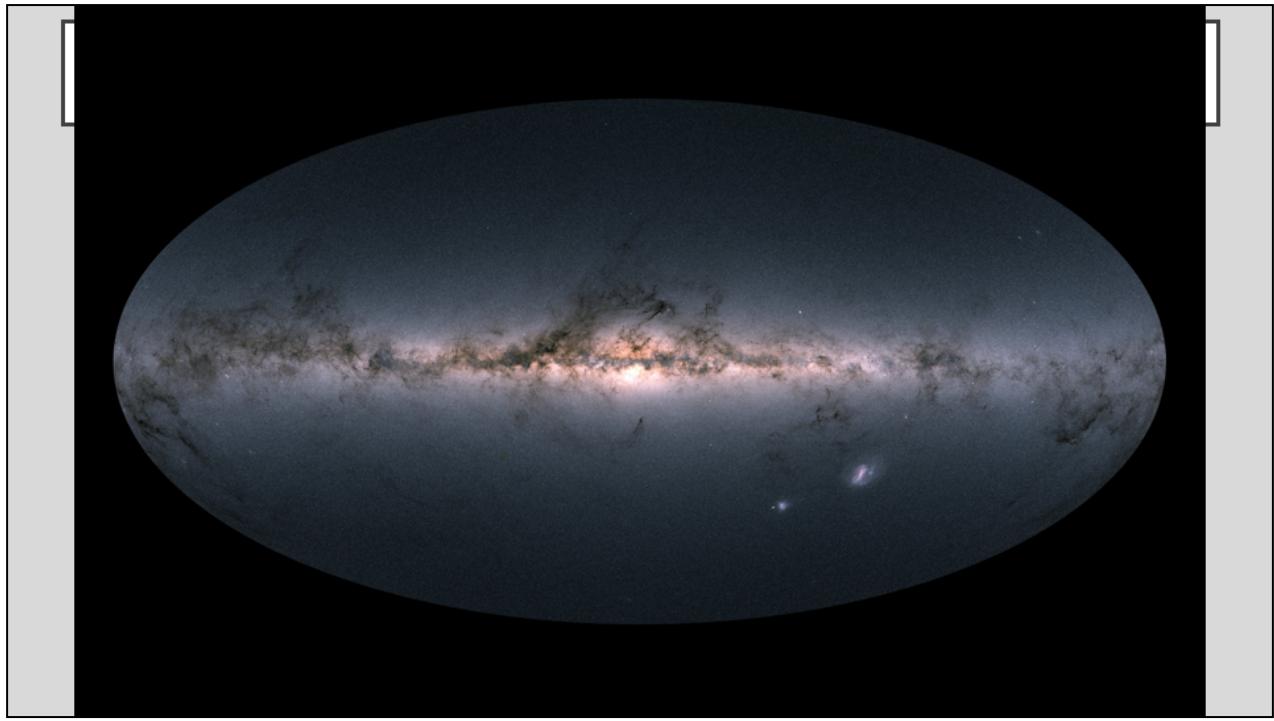
Notice as the parallax angle gets smaller, the distance gets bigger... does this make sense?

The book works with light years because it's more intuitive; I tend to not know distances to things in light years because I'm working with stars at ~hundreds of pc; the factor of 3.26 is a little awkward

Parallax

- Difficult for early astronomers to measure- recall Galileo attempting to overthrow geocentrism
- Still difficult, but currently the best way to measure distances to stars: no assumptions about stellar properties needed
- Limited to...

How do you think parallax is limited? How far can we measure?



GAIA mission

<https://phys.org/news/2018-04-gaia-richest-star-galaxyand.html>

Pause here. All these points of light are stars. They're in a disk, because like the solar system formation.. Something spinning will flatten out, remember the pizza dough solar system analogy.

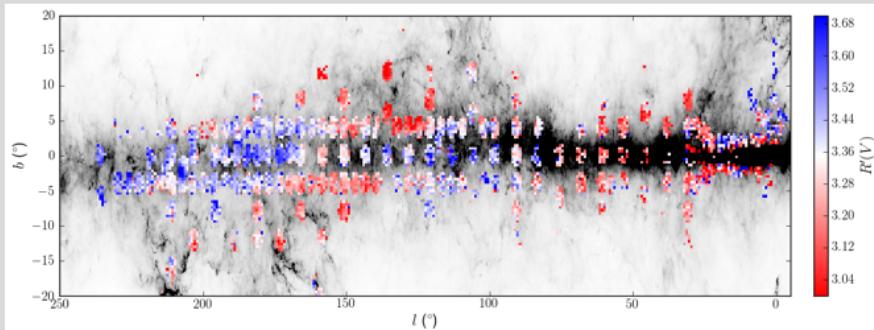
Parallax

- Difficult for early astronomers to measure- recall Galileo attempting to overthrow geocentrism
- Still difficult, but currently the best way to measure distances to stars: no assumptions about stellar properties needed
- Limited to...
 - Nearest stars!
- GAIA surveying >1.7 billion stars
 - Positions
 - Apparent motions across sky (*proper motions*)
 - Only 10% are good parallax candidates

How do you think parallax is limited? How far can we measure?

Apparent brightness, apparently

- When does and doesn't light's inverse square law work?
- If light follows uninterrupted path, not absorbed or scattered on its way to us
- Does this actually ever happen? (not really, no.)

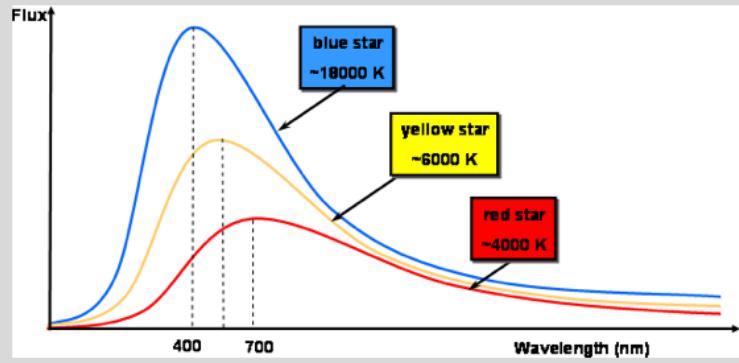


<http://e.schlaf.ly/rvthreed/>

This plot is showing dust in the galactic plane, and the color-coded part is how the dust changes apparent brightnesses of stars in the V, or visual (green) wavelength band

Stellar luminosities

- Luminosity refers to intrinsic brightness, as if you were right by the star- no distance, no dust, nothing in the way
- Total (or, bolometric) luminosity: light added up over all wavelengths
- Stars' luminosity range:
 - The Sun = $1 L_{\odot}$
 - Betelgeuse = $120,000 L_{\odot}$
 - Proxima Centauri = $0.0006 L_{\odot}$



Recall thermal emission curves.. All of these are plotted scaled- the same little element of surface area emits more if it's hotter. Now, imagine you have more surface area.. You get more overall emission with more surface area. So Betelgeuse is cooler than the sun but way, way bigger, so it has a higher luminosity. Proxima centauri is cooler than the sun and smaller, so it has a much, much lower luminosity

Stellar magnitudes

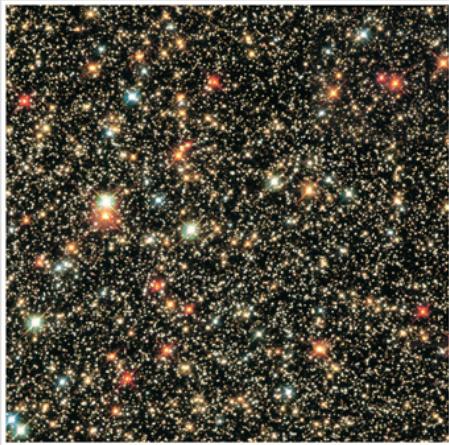
- Apparent brightnesses often expressed as *magnitudes*
 - All initially defined by eye
 - Hipparchus defined brightest stars he could see as “first magnitude”
 - Fainter stars had higher numbers: second magnitude, third, etc
 - When brighter stars observed, went to 0, and then negative
 - Sirius is the brightest star in our sky: its apparent magnitude is -1.46
 - In the Visual, or V, wavelength range!
 - Every 5 magnitudes \sim 100x difference in brightness
- Later calibrated to an absolute scale: how bright would the star be if it were at 10 pc?

Patterns in stars



- What do you notice about this picture?

Patterns in stars



- What do you notice about this picture?
- Stars are in a cluster: assume they're all at about the same distance
- Biggest, brightest ones are red or blue-white
- Rest are different sizes, some blue, most yellow-white-ish, some small red dots
- There's some kind of relationship between stars' color and luminosity

More about this.. Next time.