Announcements

- WebWork due on Monday
- Test 2 a week from Friday!
  - Chapters 7-14
  - I'll post review questions and old tests today if you want to start studying over the long weekend
  - Starting today, the new material presented will not be on Test 2!
- Polling: `rembold-class.ddns.net`

APOD

Original Link

Review Question!

I'm looking into trying to colonize a new planet, and the thing that is most important to me (for whatever reason) is the planet's *size*. Which method of detecting exoplanets would be most useful to me?

A. The astrometric method
B. The doppler method
C. The transit method
D. The guess and check method

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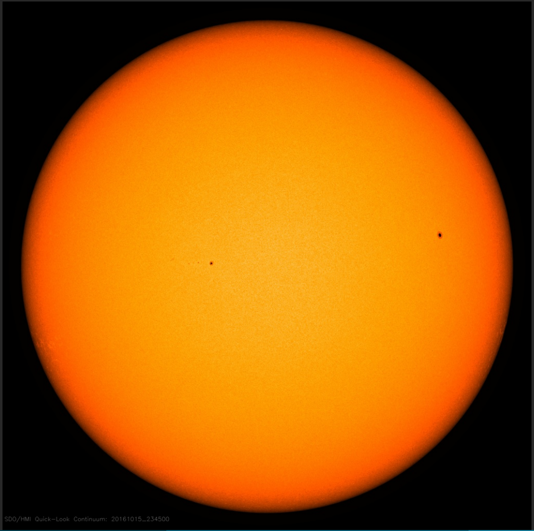
Let's talk: The Sun



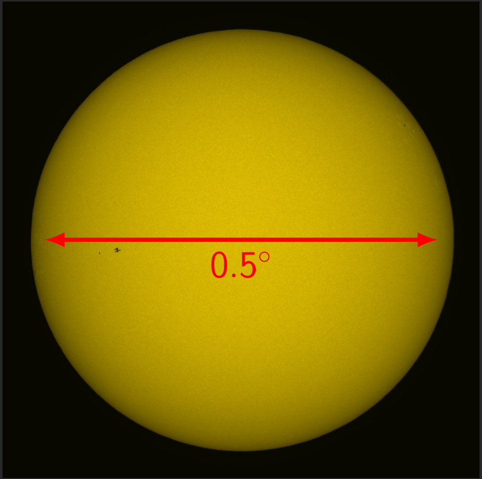
Let's talk: The Sun

"The sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth. By its heat are produced all winds,. . . By their vivifying action vegetables are elaborated from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those great deposits of dynamical efficiency which are laid up for human use in our coal strata"

–John Hershel in his 1833 Treatise on Astronomy

A Light Refresher

- There are 3 main attributes of light that we can measure:
  - its direction
  - its intensity
  - and its wavelength



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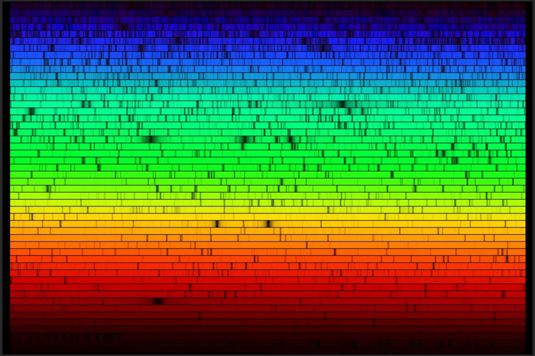
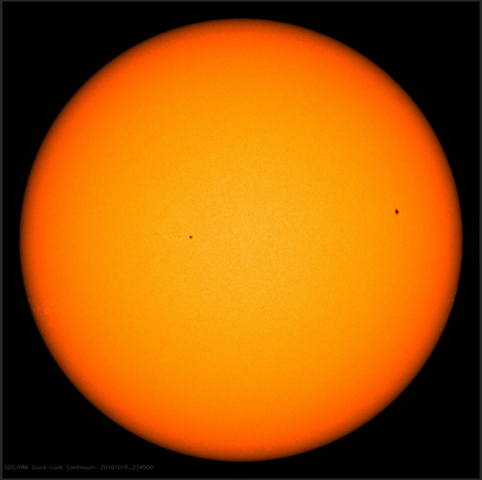


The Light We See



The Photosphere

- Almost all the light we see from the sun comes from two places:
  - The surface of the sun (called the photosphere)
  - To a much lesser degree, the expansive atmosphere of the sun (called the corona)

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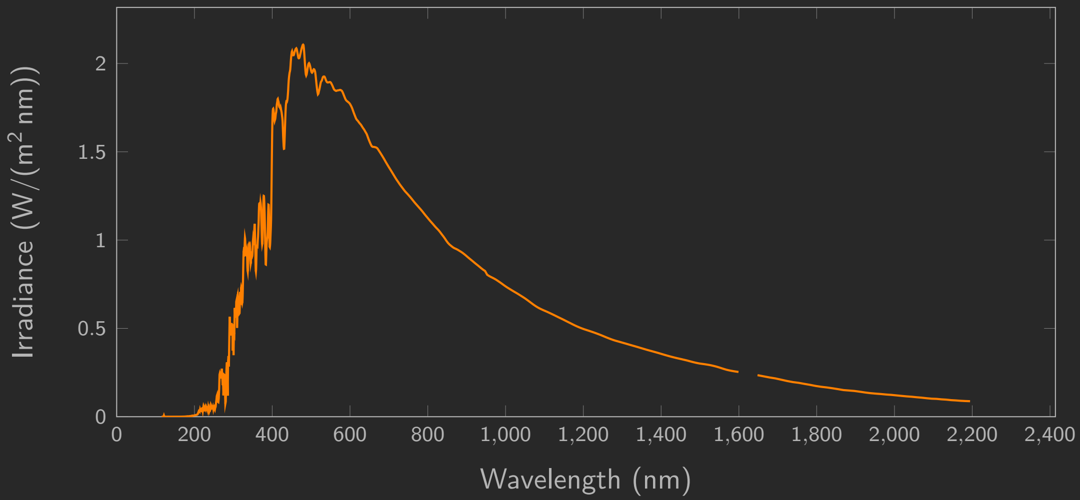
Our Solar Spectrum



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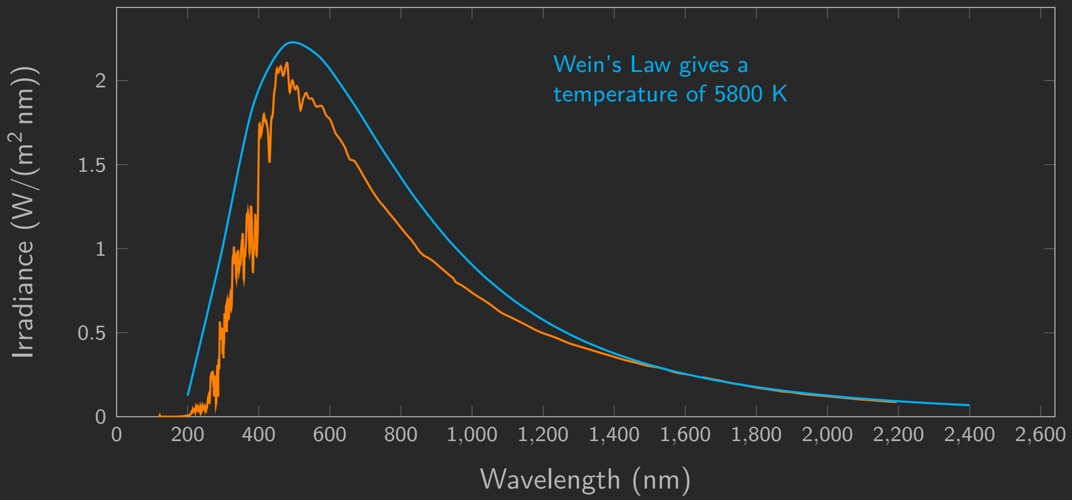

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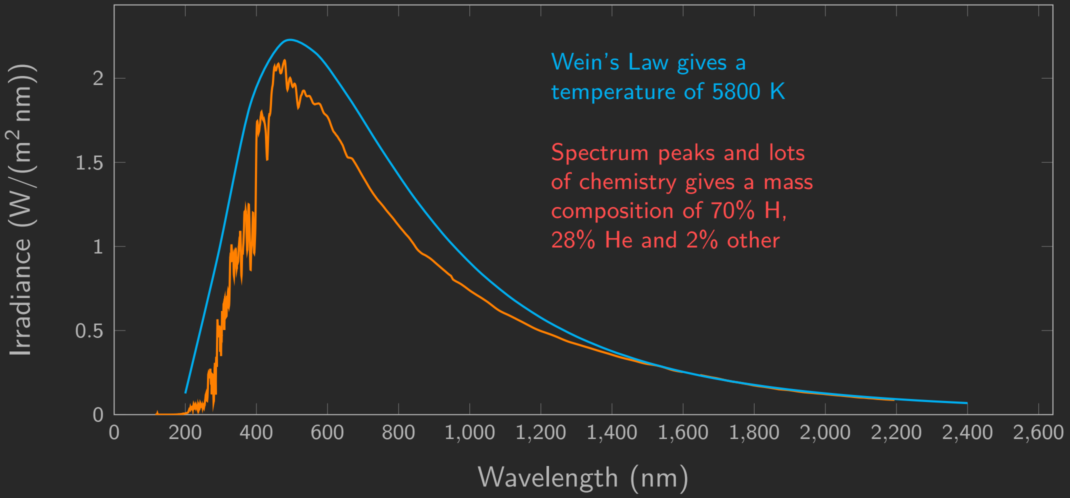
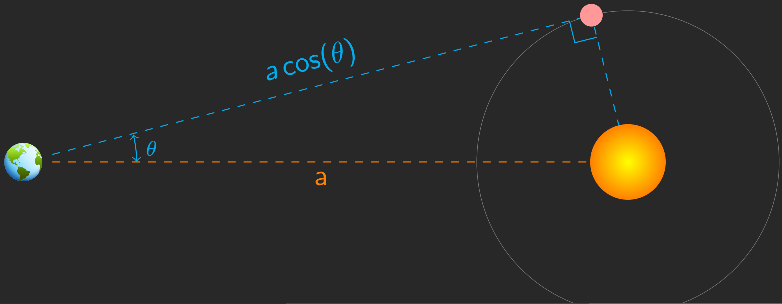


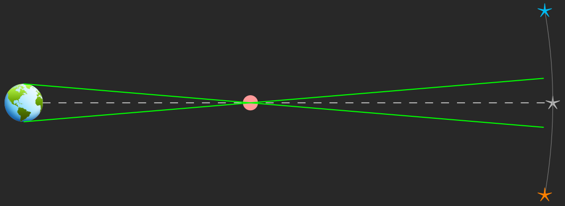
A Distant Tale

- In order to utilize the light we receive to determine properties of the Sun itself, it is imperative to know how far away the Sun is!
- Several different techniques:
  - Initially: parallax
  - Modern method: radar
  - Most accurate means find the distance to the planets and then use that to find the distance to the Sun



Parallax

- Parallax is using the idea that looking at the same objects from different vantage points will shift that object's apparent position relative to background objects.
- Basic Example: Holding your finger out at arms length and alternating which eye you have open
- The angle of that shift can be measured
- The further away the object, the smaller the effect
- The more widely spaced the vantage points, the larger the effect



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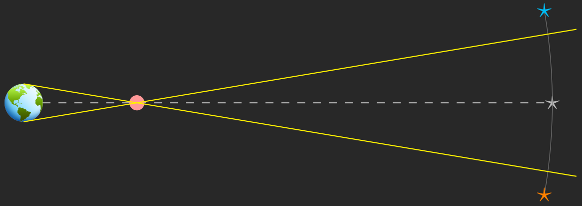


So how far is it?

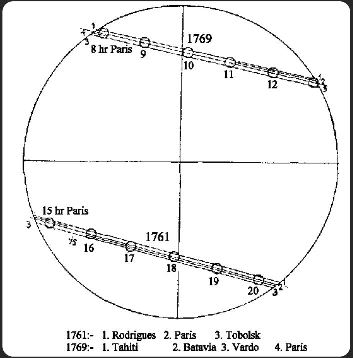
- Parallax of Mars first measured in 1672
  - Used Paris and French Guyana as the two observation points
  - Sun's distance was estimated to approximately 10% of currently accepted value
  - Not bad, but not great either

Observations of a Lifetime

- Edmund Halley (of comet fame) predicted that transits of Venus in front of the Sun could be used to calculate Venus's parallax very precisely
- He was going to be dead by the time of the next 8 year transit cycle (1761 and 1769), so he laid out very careful instructions
- Theory is easier than reality
  - Astronomer had to know their location on Earth very precisely
  - Areas where the transit would be visible were in remote parts of the Earth
  - Most astronomers were English or French, who were in the middle of the 7 years war
  - Wild stories including:
    - Warding off superstitious peasants
    - Drinking away harsh winters
    - Surviving multiple attacks by ship
    - Keeping sailors from trading the very nails in your ship for "favors" from Taihitan women
    - More stories here

Success!

- In the end, the mission was successful!
- Calculated the distance to the Sun within 2% of the established value
- Discovered the "Black Drop" effect, caused by Earth's atmosphere
- Today the value of 1 AU is known within 30 m!



Understanding Check

Suppose we see some distant (orange) object from the Earth, and measure its angular distance from the star Antares at different points of the year. When will we see the object as being closest to Antares?

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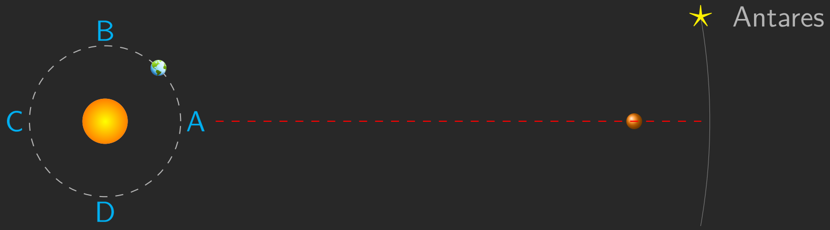

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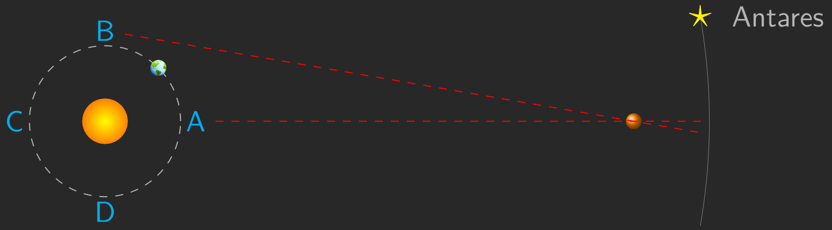

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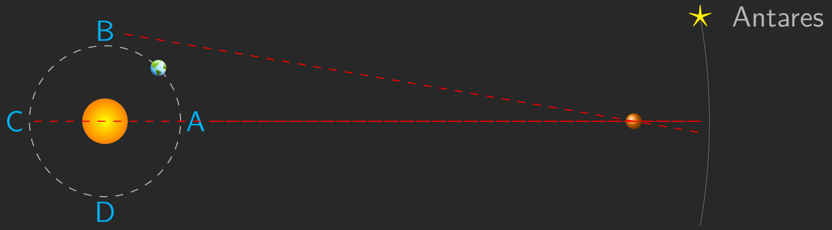

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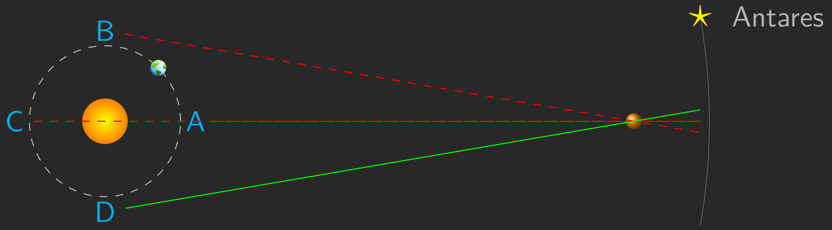
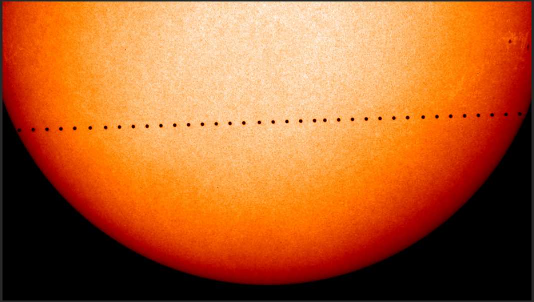


The Pieces Fall Together

- Once we have a handle on the distance, we can determine:
  - The Radius of the Sun ($\approx 700\,000\,\mathrm{km}$)
    - From the angular size and distance
  - The Luminosity of the Sun ($\approx 4 \times 10^{26}\,\mathrm{W}$)
    - From the apparent brightness and distance
  - The Mass of the Sun ($\approx 2 \times 10^{30}\,\mathrm{kg}$)
    - From Kepler, Newton, and the Earth's orbit



Aren't You Bright!

- The luminosity of the Sun is the total power output of the Sun, measured in watts (eg. joules per second)
- You can estimate it two different ways:

Brightness from Earth

$$
\begin{aligned}
L &= 4\pi d^2 \times B \\
&= 4\pi \left(1.5 \times 10^{11}\,\mathrm{m}\right)^2 \times \left(1400\,\mathrm{W/m^2}\right) \\
&\approx 4 \times 10^{26}\,\mathrm{W}
\end{aligned}
$$

where B is the brightness we see at Earth and d is the distance to the Sun

Size and Temperature

$$
\begin{aligned}
L &= 4\pi R^2 \times I \\
&= 4\pi R^2 \times \left(\sigma T^4\right) \\
&= 4\pi \left(7 \times 10^{8}\,\mathrm{m}\right)^2 \\
&\quad \times \left(5.7 \times 10^{-8}\,\mathrm{W/m^2/K^4}\,(5800\,\mathrm{K})^4\right) \\
&\approx 4 \times 10^{26}\,\mathrm{W}
\end{aligned}
$$

where R is the radius of the Sun, T is the temperature of the Sun, and σ is the Stefan-Boltzmann constant.

Confusion!

- Be careful not to confuse the luminosity with the intensity of the Sun!
- Intensity is the same as Brightness, and is a measure of how much energy hits an area in a certain amount of time
- Luminosity is a measure of how much energy is spewed out of an object (regardless of size) in an amount of time

Rule of Thumb:

When in doubt, let the units guide you. W/m^2 is a brightness or intensity, while just W is a luminosity!

Asking the Key Questions. . .

- Now that we understand the physical parameters of the Sun, we can attempt to answer some questions about it
- Most obviously:

Why does the Sun shine?

Has the Sun been shining forever?

Why so shiny?

- Shining means the Sun is giving off energy
- Where it gets this energy was a major question of the early 1900s
  - Originally thought to be some sort of chemical burning
    - First estimates of the luminosity demanded WAY too much energy
    - Would only have enough fuel for 16000 years
  - Gravitational Contraction?
    - Could burn for 25 million years. . .
    - But Earth's fossil record indicates Earth is older than that?