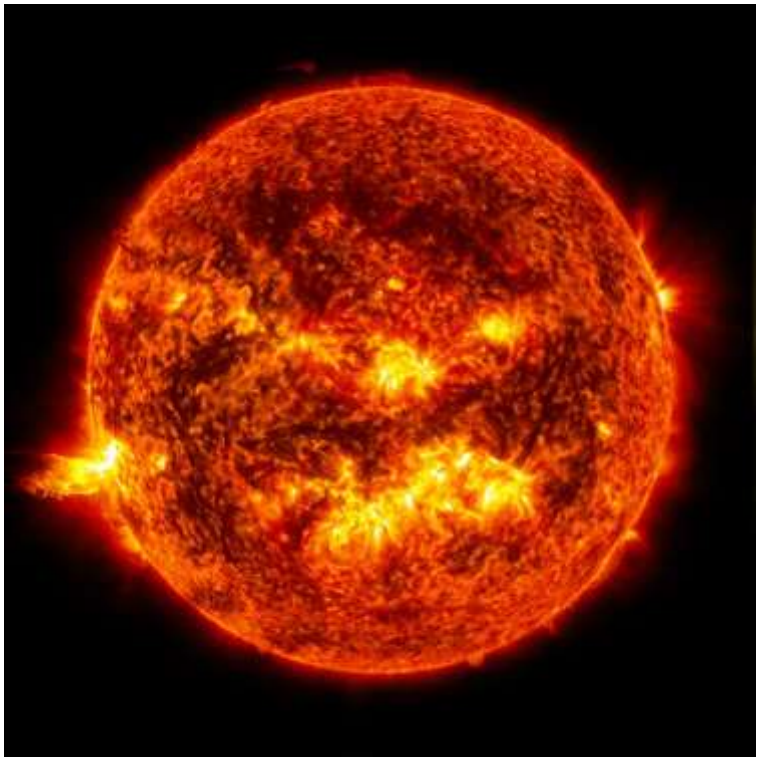
How the Sun Works Unit

Week 3 – How can we measure the sun?

WATERFORD ASTRONOMY

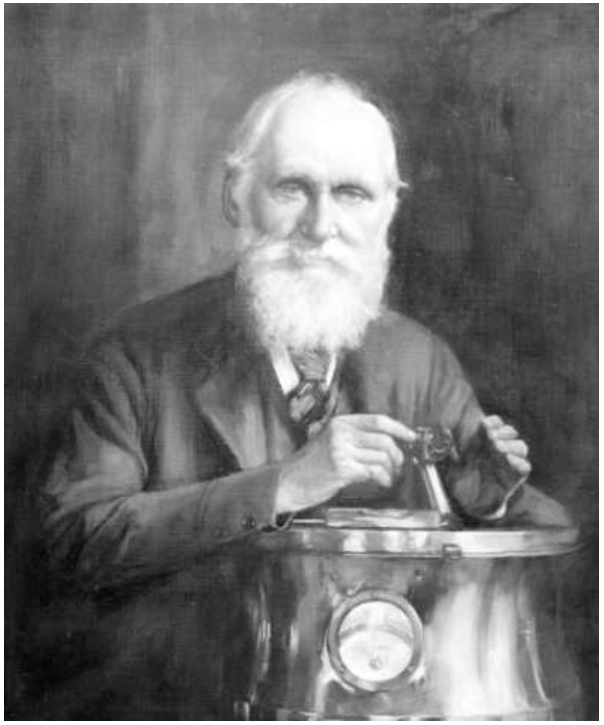
Sun Unit – W3 Driving Question

- **This week's driving question:** How can we measure the sun?
- *How can we determine the distance between the sun and the earth?*
- *How can we determine the size of the sun?*
- *How can we determine the temperature of the sun?*



Week 2 Recap

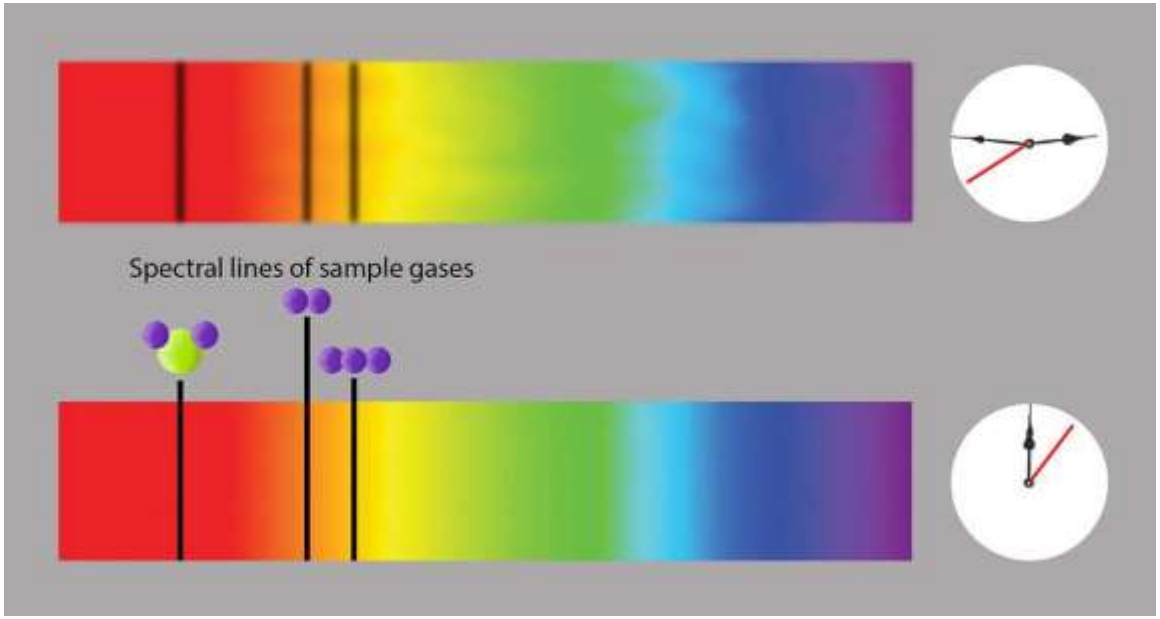
- **Last week we determined that the sun is primarily composed of hydrogen and helium.**
  - However, we still haven't answered our original question – *how can the Sun burn continuously for more than a few tens of millions of years at most without exhausting its fuel?*



Maybe you can do better than Lord Kelvin?

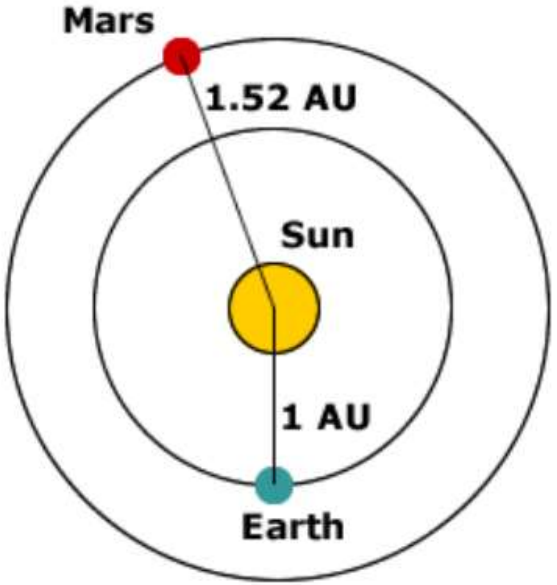
Studying Sunlight

- **Spectral analysis provides us with most of what we know about the sun and other stars.**
  - Spectral analysis can tell us the kinds of elements that comprise the sun, among other information.
  - However, we still need more information to determine how the sun actually produces heat and light.



Distance to the Sun

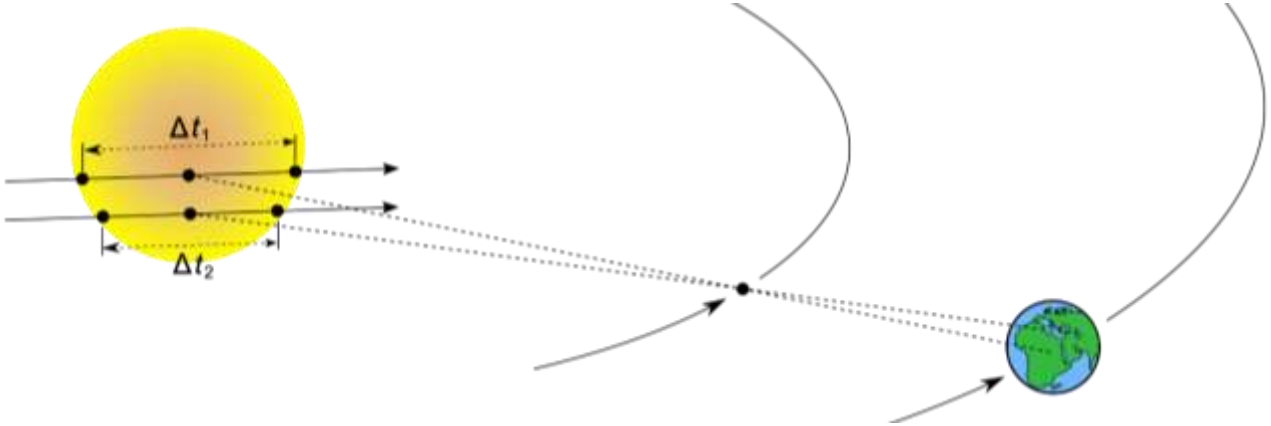
- **Astronomers were able to determine the distance between the earth and the sun in 1771.**
  - They were able to determine this distance (known as an astronomical unit, or AU) long before spaceflight was a possibility using what is known as a parallax.
  - A parallax is when the position of an object appears different when viewed from different positions.
  - For example, if you hold your index finger at arm's length, it appears to change position if you view it from your left eye and then your right eye.



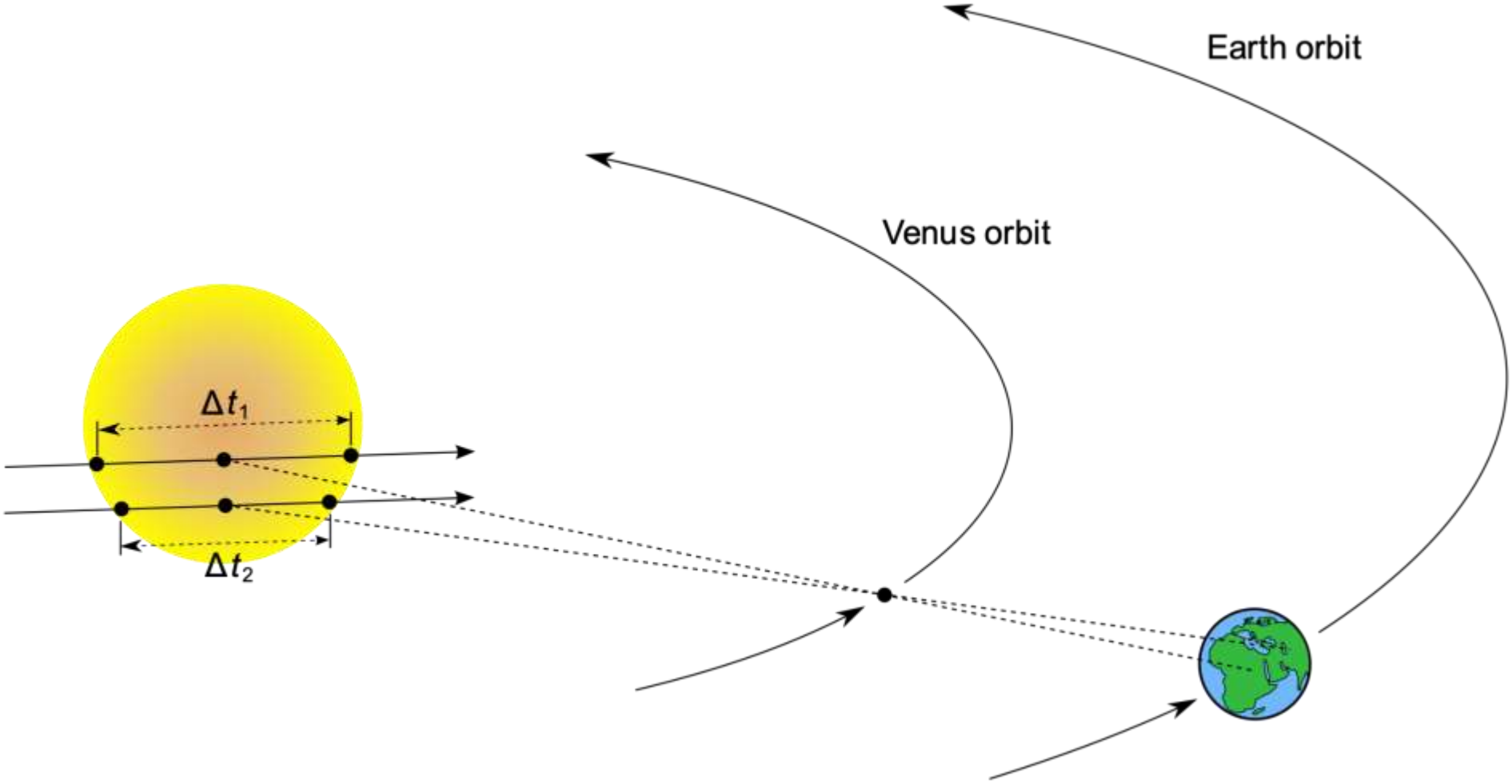
Source: http://blogstronomy.blogspot.com/2009/08/what-is-astronomical-unit-au.html

Distance to the Sun

- **In 1761 and 1769, Venus provided a metaphorical finger that could be used to measure an AU.**
  - Venus makes predictable transits across the sun (i.e., it appears to pass directly across the sun).
  - By precisely timing the length of time that Venus spent travelling across the sun from different locations on the planet, astronomers could infer the distance of an AU.

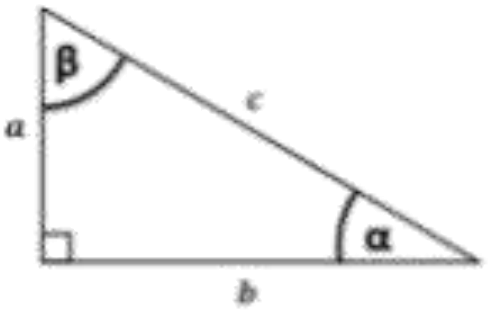


Parallax & Transit of Venus



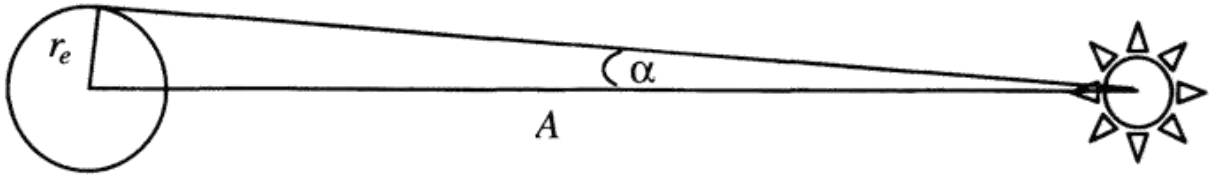
The Rest is Just Math

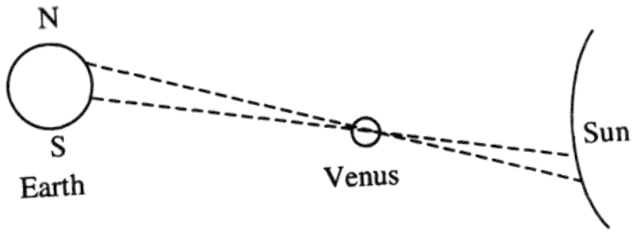
- **Trigonometry is key for determining the size of the AU.**
  - If you can determine the size of α (the angle between lines drawn from both the equator and north pole to the sun), and the radius of the earth you can use trigonometry to determine AU (shown as A below).
  - AU = r_e * tan (90-α)

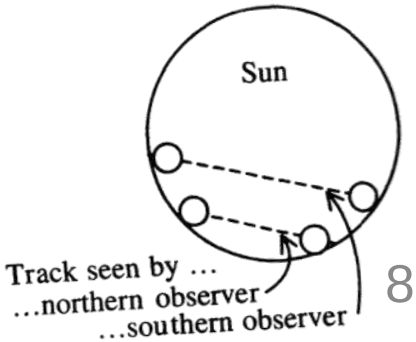


b = a * tan(β)

β = 90 - α







Source: https://www.maa.org/sites/default/files/pdf/pubs/mm_dec03-Venus.pdf

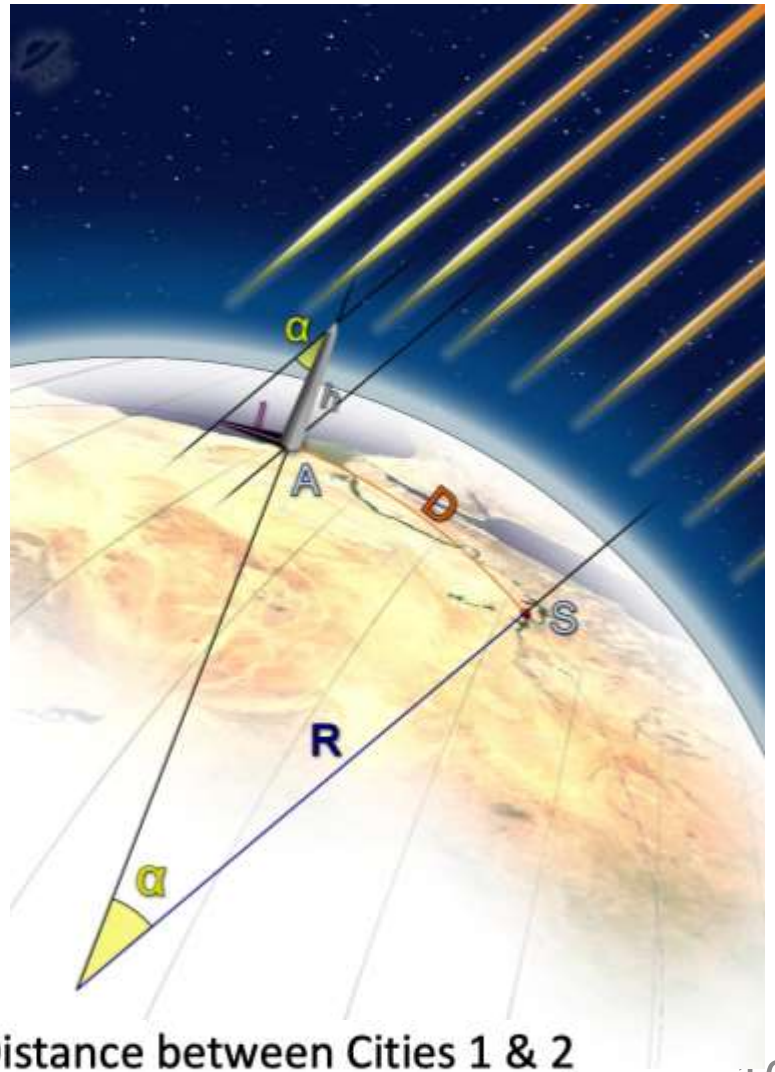
How Big is the Earth?

- **Trigonometry also was useful for determining the size of the earth… as early as 200 B.C.E.**
  - Greek mathematician Eratosthenes observed that on the summer solstice at noon, the sun's reflection was visible at the bottom of a deep well in Syene.
  - This meant the sun had to be directly overhead (90^o)
- **Eratosthenes realized that this created a right triangle that could be used to determine the circumference and radius of the earth.**
  - $\frac{\text{Angle of shadow in City 2}}{360^o} = \frac{\text{Distance between Cities 1 \& 2}}{\text{Circumference of Earth}}$

Source: https://www.maa.org/sites/default/files/pdf/pubs/mm_dec03-Venus.pdf

Determining the Size of the Earth

- **Eratosthenes knew that the distance between Syene and Alexandria was 926 km.**
  - He measured the angle of a shadow at noon in Alexandria to be 7.2°
  - 7.2/360 = 0.02
  - 0.02 x 926 km = 46,300 km (*the actual size is 40,007.9 km*)



$$\frac{\text{Angle of shadow in City 2}}{360^\circ} = \frac{\text{Distance between Cities 1 \& 2}}{\text{Circumference of Earth}}$$

Calculating the Sun's Size

- **Once you know the distance of an AU, you can also determine the radius of the sun.**

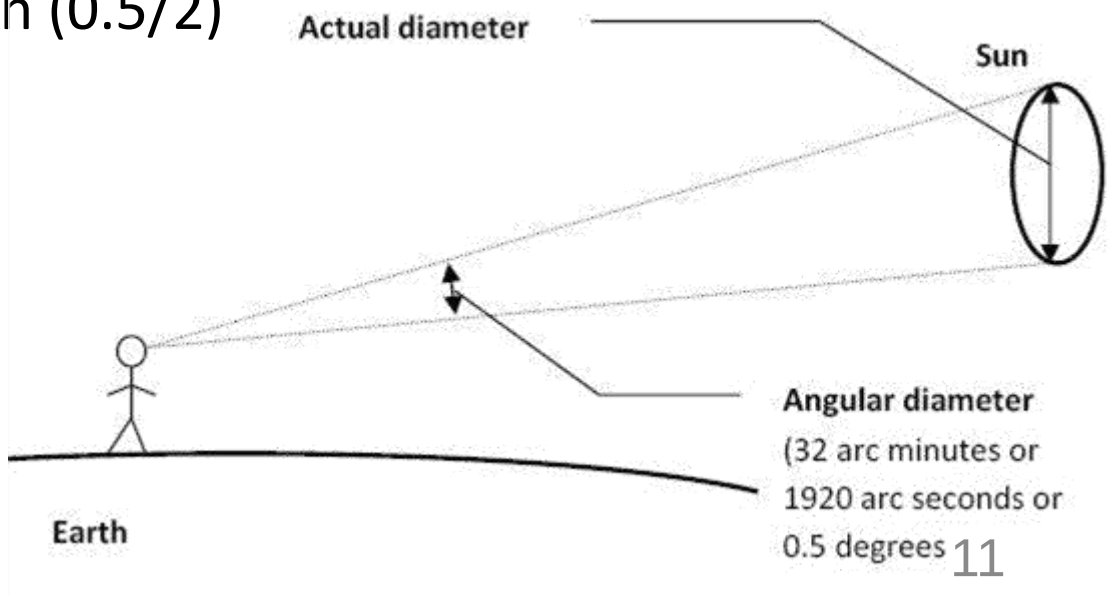
  $R_{sun} = d * \tan(a/2)$

  d = 150,000,000 km

  a = 1920 arc seconds (or 0.5^{o})

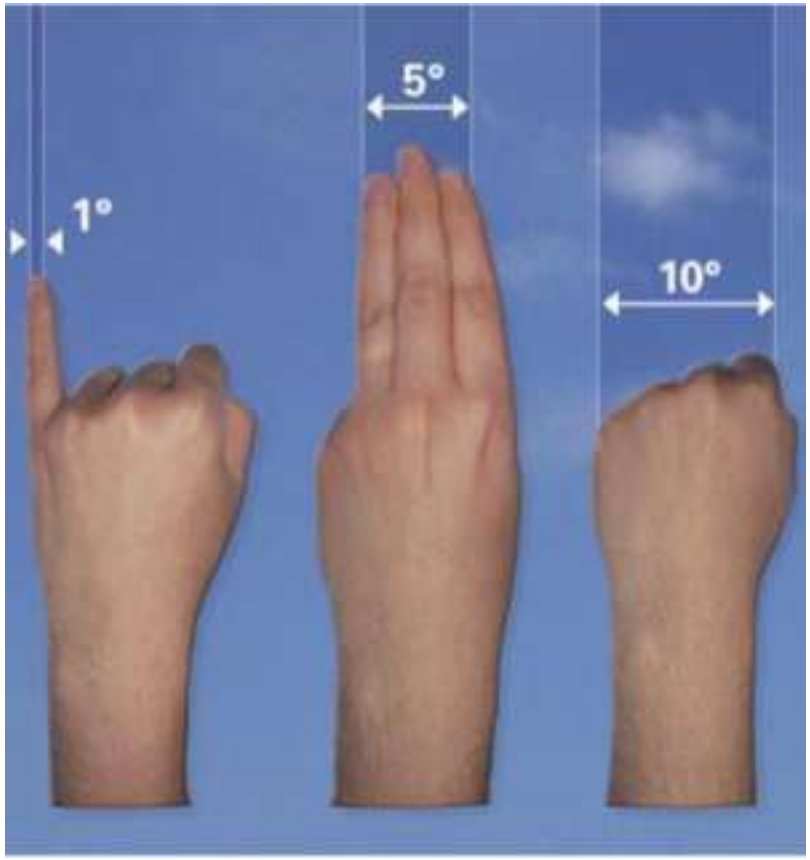
  $R_{sun} = 150{,}000{,}000 \times \tan(0.5/2)$

  $R_{sun} = 700{,}000$ km.



What is an Arcsecond?

- **Our visible sky creates perfect circle from our perspective.**
  - Every circle has 360 degrees, which simplifies astronomical equations
- **Each degree has 60 arcminutes**
  - Each arcminute has 60 arcseconds.
  - Each degree (1/360th of the sky) contains 3600 arcseconds.
- **The sun's size from our perspective equals 1920 arcseconds of the sky**.
  - Knowing this size as well as the length of an AU, we can determine the sun's radius is 700,000 km.

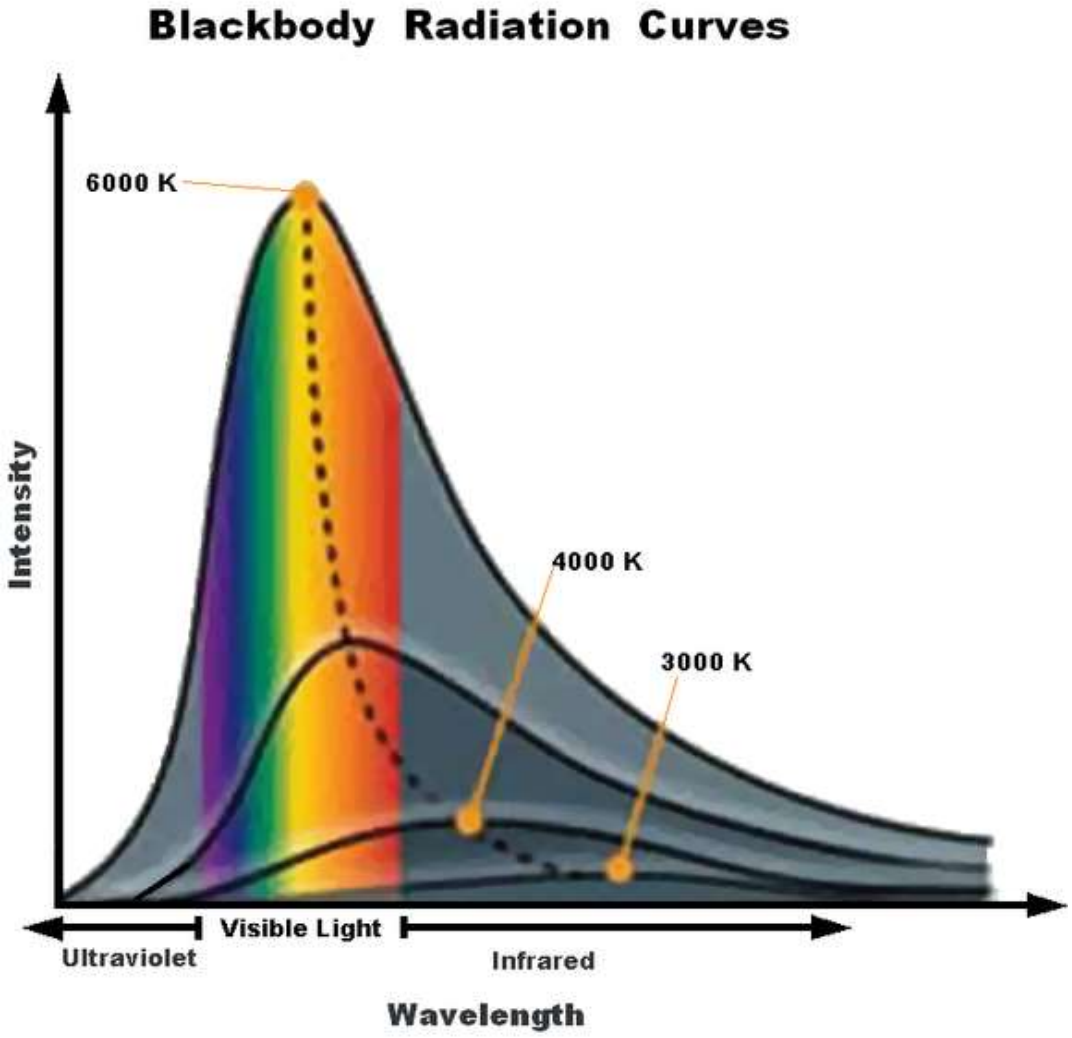


Holding your hands out at arm's length provides a quick measure of degrees (e.g., your pinky = 1/360th of the sky).

Source: https://earthsky.org/astronomy-essentials/sky-measurements-degrees-arc-minutes-arc-seconds/

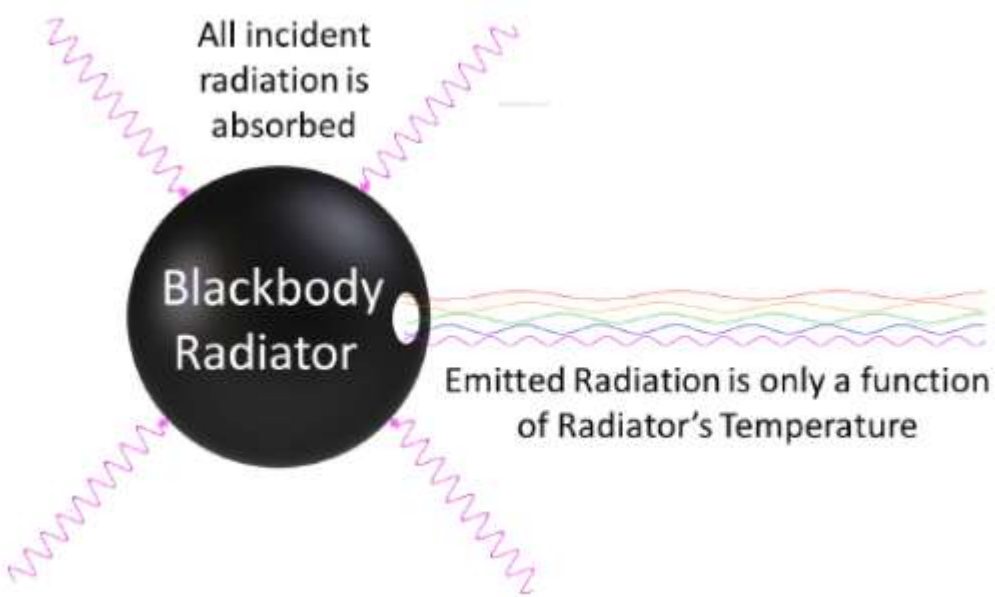
Taking the Sun's Temperature

- **If we know the sun's size and temperature, we can begin to determine how the sun functions.**
  - We can determine the sun's temp (or any star's temp) using a blackbody radiation curve.
  - This refers to how particular objects emit radiation as they are heated.



Taking the Sun's Temperature

- **A <u>blackbody</u> is an object that absorbs all radiation that reaches it.**
  - When blackbody objects are heated, they reemit radiation in a predictable pattern.
  - This radiation will produce a particular color based on the temperature of the object when viewed through specialized filters.



Blackbody radiator is any object that is a perfect emitter and a perfect absorber of radiation.

Source: https://chem.libretexts.org/Courses/Pacific_Union_College/Quantum_Chemistry/01%3A_The_Dawn_of_the_Quantum_Theory/1.01%3A_Blackbody_Radiation_Cannot_Be_Explained_Classically

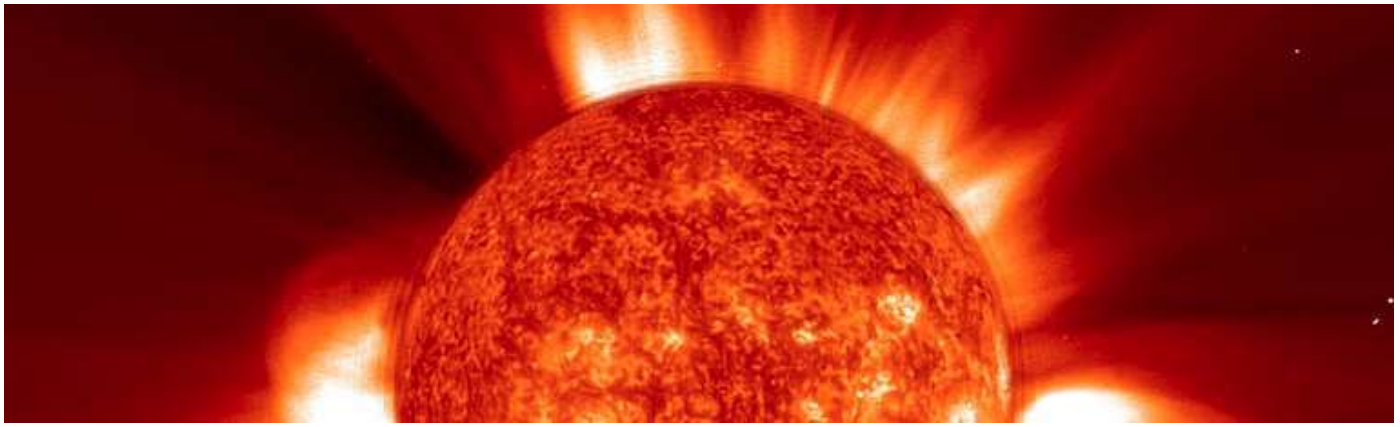
Photometry

- **A star's temperature can be determined by comparing the light received through these filters**.
  - This process is called photometry, which is different from spectral analysis.

Surface Temp (K)	Color	Example
30,000	Blue-violet	Mintaka
20,000	Blue	Rigel
10,000	White	Vega, Sirius
7000	Yellow-White	Canopus
6000	Yellow	Sun, Alpha Centauri
4000	Orange	Arcturus, Aldebaran
3000	Red	Betelgeuse, Barnard's

Looking Ahead

- **We now know key pieces of information, including**:
  - The size of an AU (from parallax calculations).
  - The size of the sun (using the AU and arcseconds).
  - The temp of the sun (using photometry).
- **This info enables us to determine the kinds of activity that occur at the atomic and subatomic levels inside the sun**.
  - This will help us to determine how the sun can burn continuously for billions of years.



Revisions to W3 Driving Question

- **Can we now improve our answers to our driving questions?**
- *How can we measure the sun?*
- *How can we determine the distance between the sun and the earth?*
- *How can we determine the size of the sun?*
- *How can we determine the temperature of the sun?*