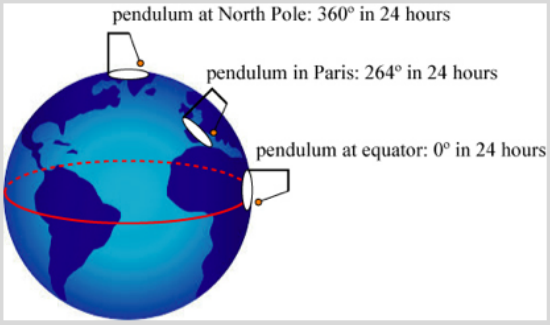
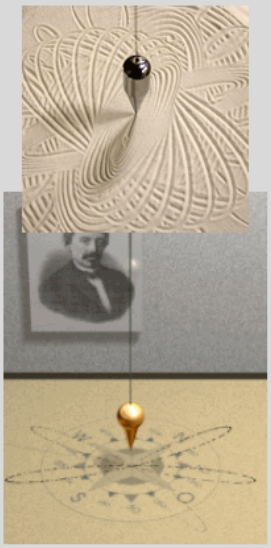
Today in science…

- Happy Birthday, Léon Foucault!
  - Born OTD in 1819
- Best known for Foucault Pendulum
- Measured speed of light, credited with naming the gyroscope





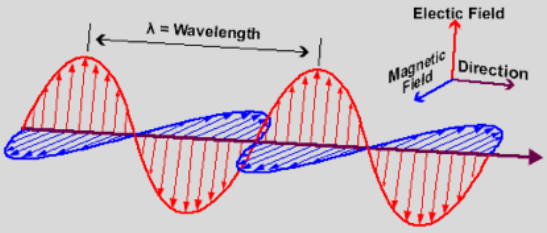
https://www.brown.edu/Departments/Italian_Studies/n2k/visibility/Alison_Errico/Soft%20Moon/pendulum.html

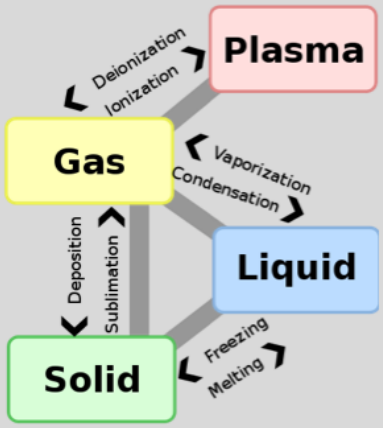
Logistical notes!

- New updated lecture outline on Canvas
- Ch 4 homework due Thursday, nothing else until after midterm (but maybe a good idea to do it anyway)
- Midterm is 1 week from today, here in this room, during regular class time
- If you requested testing accommodations, contact OARS asap
- Bring clickers on Thursday, there will be exam review and games! Maybe prizes also.

Recap from last class

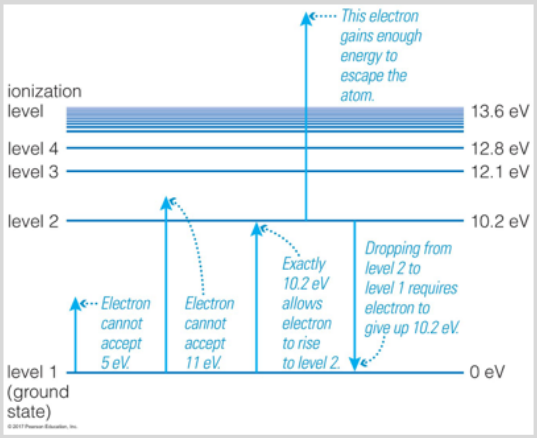
- Light, an electromagnetic wave, with wave and particle-like behaviors
- Properties of matter: phases, what's going on at the atomic/molecular level
- Ionization





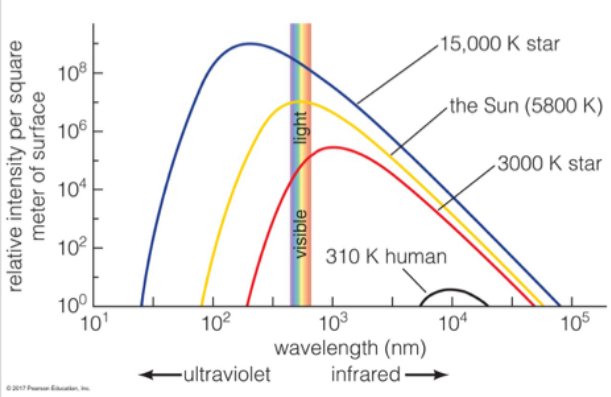
Recap from last class

- Light, an electromagnetic wave, with wave and particle-like behaviors
- Properties of matter: phases, what's going on at the atomic/molecular level
- Ionization
- Atomic energy levels and absorption, emission



Recap from last class

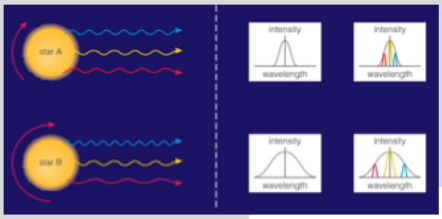
- Thermal radiation and two laws of thermal radiation

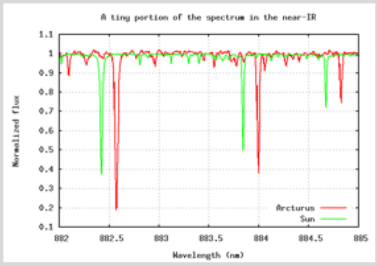


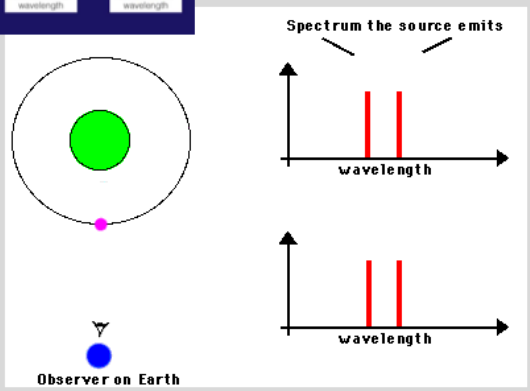
- Stefan-Boltzmann law
  - When you look at the same size piece of thermally emitting objects, the hotter object always emits more light at all wavelengths
- Wien's law
  - Hotter objects emit photons with higher average energy

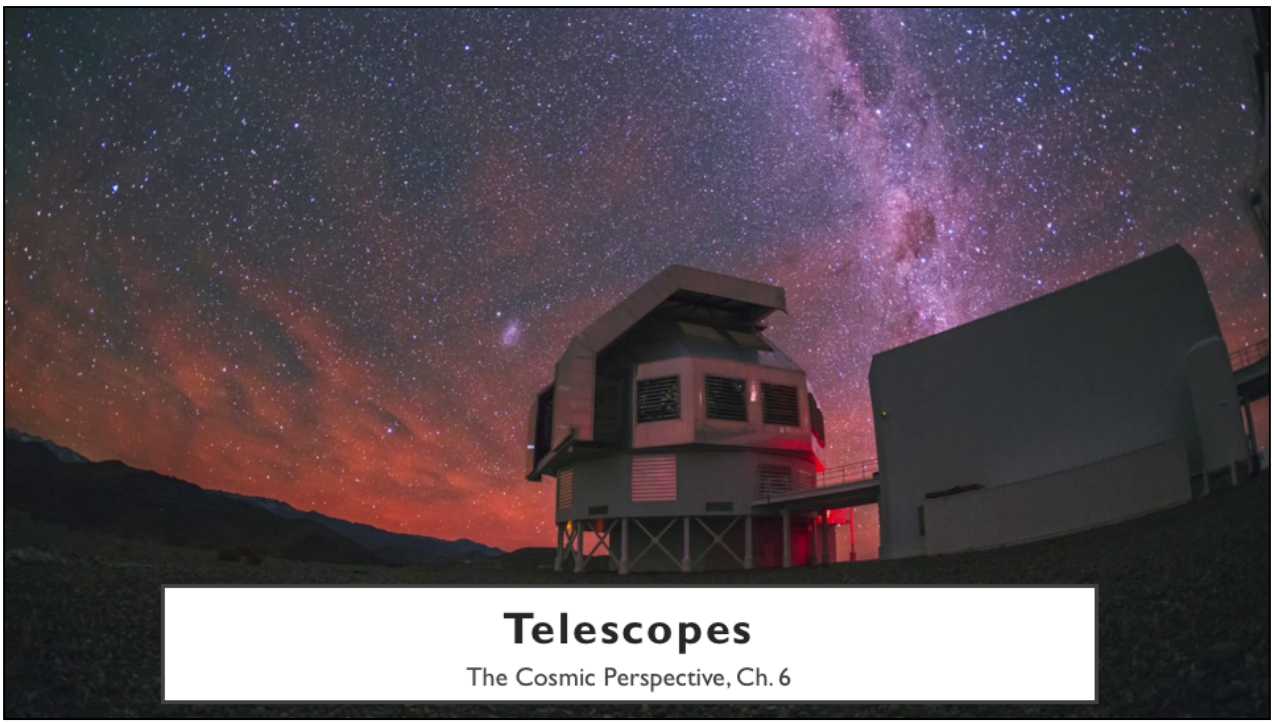
Recap from last class

- Stellar motions
  - Doppler shift
  - Radial velocity
  - Rotational velocity
  - Orbital perturbations due to a planet








Telescopes
The Cosmic Perspective, Ch. 6

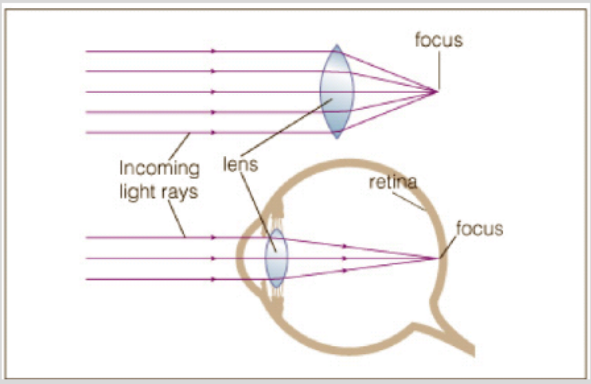
Everyday light sensors

- What are some ways we gather light every day?
  - Our eyes
  - Our eye…phones
  - Cameras
  - Solar-powered devices

Why is she … no, just no. Don't do that, no one should do that. Stop it. Why does this thing even exist..

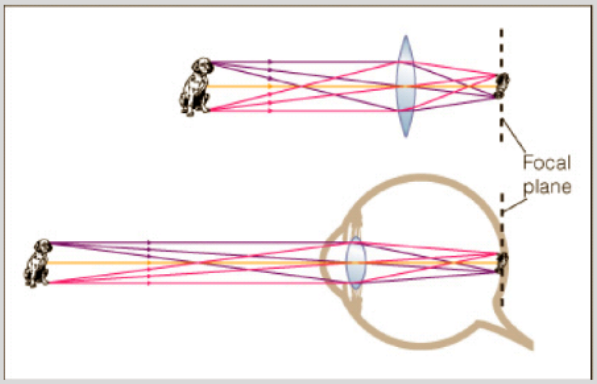
Our eyes: complex optics

- Refraction causes the light to converge to a focal point
  - Refraction is the bending of light
  - How much light is refracted depends on…
    - The material it passes through and
    - its shape



Focal plane

- The focal plane is where light from different directions forms a clear image
- With a single lens the image is upside-down
- Our brains autocorrect the image to be right-side up



Light recorders

- When light gets focused to a plane, what captures it?
  - CCDs: Charge-Coupled Device
    - Photons hit material (often silicon), knock electrons off into pixel "wells," collected charge is read out and recorded
    - CCDs are what most astronomers use: precise, less noise (work better in low-light conditions)
    - Down side: can't control exposure automatically, pixels can overflow with electrons

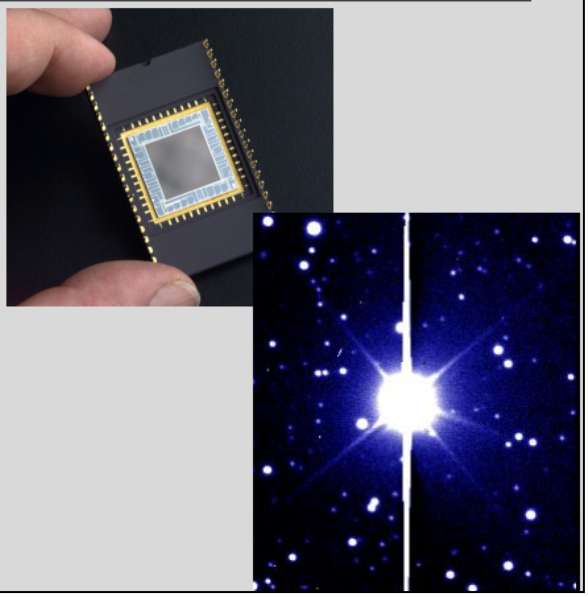
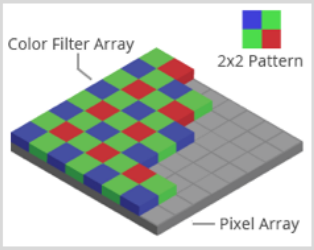


Image of star is showing two effects, diffraction and saturation. Saturation you can diagnose by looking at it, you can see the individual pixels in the saturation (vertical) spikes as a jagged, but organized, pattern with blocky step-like transitions as it narrows

Light recorders

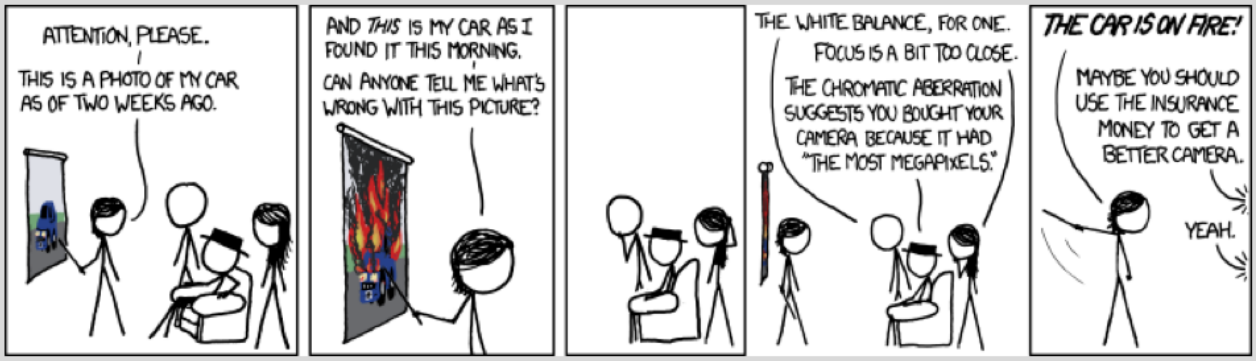
- CMOS: Complementary Metal Oxide Semiconductor
  - Used in high-end DSLR cameras, iPhone has a version of this
  - Fast, cheap, use less power than a CCD
  - Each pixel read immediately, so auto-adjustments work (e.g., exposure time)
- Color Filter Array Sensors
  - Have a grating over the sensor, each pixel can detect one R, G, B color; others inferred from nearby pixels
  - If low-resolution (fewer pixels), this can affect image quality
  - Many DSLRs have this



https://www.lifewire.com/what-are-image-sensors-493722

https://www.quora.com/How-does-the-iPhone-6-camera-work

Light recorders



http://xkcd.com/1014/

Collecting Light with Telescopes

- Telescopes are giant eyes, collecting more light than we could with our naked eyes
  - Sometimes called "light buckets"
- Telescopes are characterized by 2 key properties
  - Light-collecting area (depends on the telescope size)
  - Angular resolution (how much detail we can see in the telescope's images)

Telescope Design

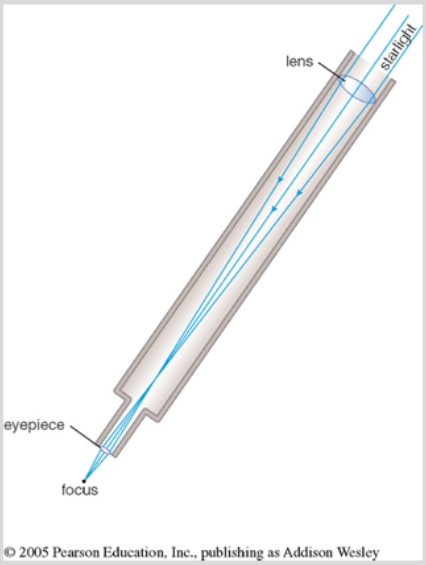
- Two basic designs: Refracting and Reflecting telescopes
- Refracting telescope uses transparent glass lenses to focus the light
  - Refraction: change in light's path due to moving from one medium to another
- Refractor problems:
  - Large lenses are heavy (1m lens weights 500 lbs)
  - Different colors focus in different places

A pair of Galileo's telescopes:

Galileo took what was used at the time, spyglasses used by sailors, and turned it to the sky.

http://www.pbs.org/wgbh/nova/tech/inventing-telescopes.html

Refractors



Refractors

- 40-inch Yerkes Observatory refractor

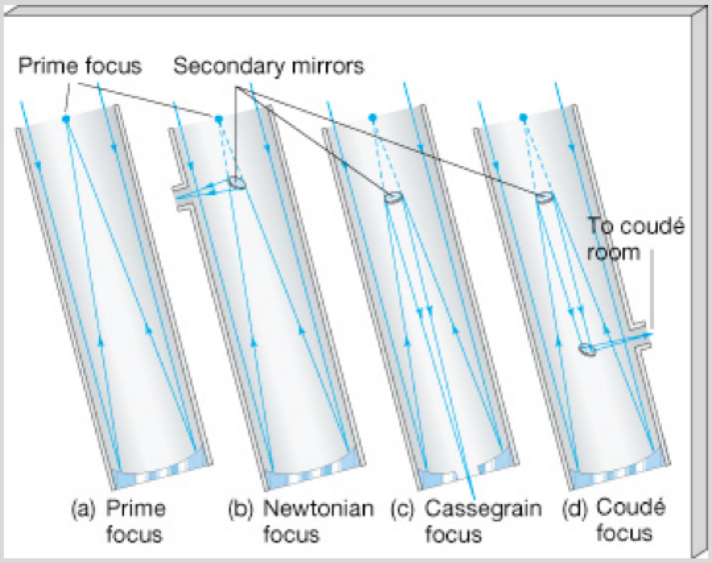
Telescope Design

- Reflecting telescopes use precisely curved mirrors
- Most contemporary telescopes are reflectors
- Primary mirror gathers and focuses the light
- Secondary mirror reflects the light to a convenient location

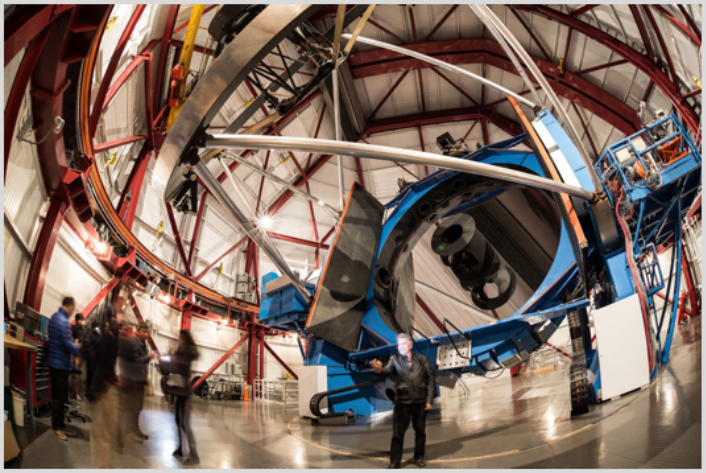
Newton's reflector:

http://www.pbs.org/wgbh/nova/tech/inventing-telescopes.html

Reflectors


Prime focus
Secondary mirrors
To coudé room
(a) Prime focus
(b) Newtonian focus
(c) Cassegrain focus
(d) Coudé focus

Reflectors

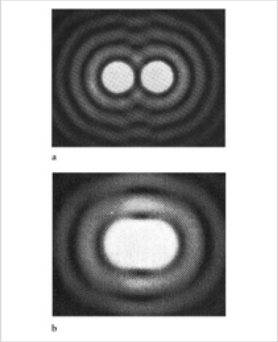


Left: 3-college observatory 0.8m primary mirror

Right: Magellan Clay telescope, 6.5m primary mirror
http://lascampanasbelles.blogspot.com/2015/11/giant-magellan-telescope-groundbreaking.html

Limit on Angular Resolution

- Angular resolution is the minimum angle (θ_{min}) between any two objects to be viewed separately
- Wave nature of light puts a limit to the ability to resolve distant objects (diffraction limit)
- Two objects are considered just resolved if the central maximum of one image positionally coincides with the first minimum of the second image



- $\theta_{min} = 2.5*10^5 \lambda/D$ (arcseconds)
- λ – wavelength of the incoming light
- D – diameter of the telescope's primary mirror

http://physics.bgsu.edu/~stoner/P202/interfere/sld013.htm

https://www.courses.psu.edu/astro/astro001_pjm25/telescopes.html

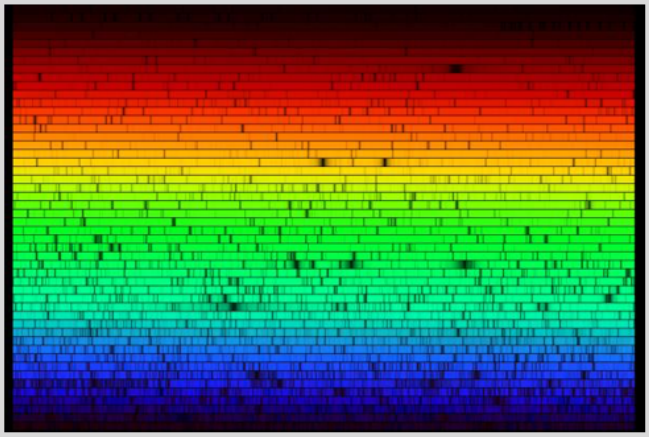
Uses of Telescopes

- Imaging: pictures of celestial objects

https://apod.nasa.gov/apod/ap050908.html

Uses of Telescopes

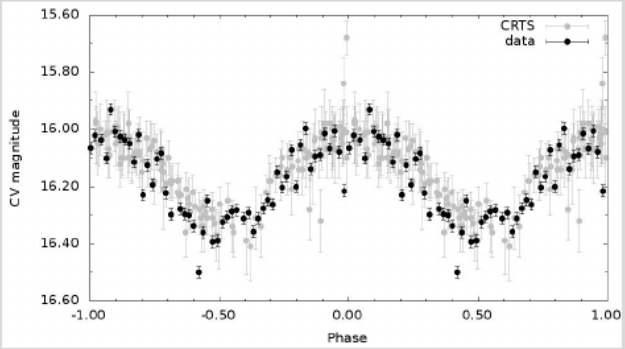
- Imaging: pictures of celestial objects
- Spectroscopy: dispersing light into a spectrum



https://apod.nasa.gov/apod/ap050227.html

Uses of Telescopes

- Imaging: pictures of celestial objects
- Spectroscopy: dispersing light into a spectrum
- Timing: tracking time variations of light



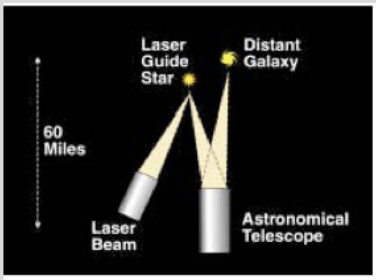
https://www.aavso.org/variables-what-are-they-why-observe-them

https://www.researchgate.net/figure/Folded-light-curve-of-2MASS-J20060657-1230376_fig7_285413773

(images on the left and light curve on the right are not of the same star)

Uses of Telescopes

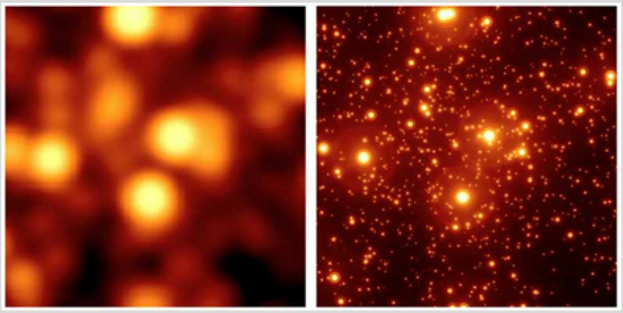
- Imaging: pictures of celestial objects
- Spectroscopy: dispersing light into a spectrum
- Timing: tracking time variations of light
- Atmosphere affects observations: light pollution, turbulence
  - Turbulence can be corrected by adaptive optics

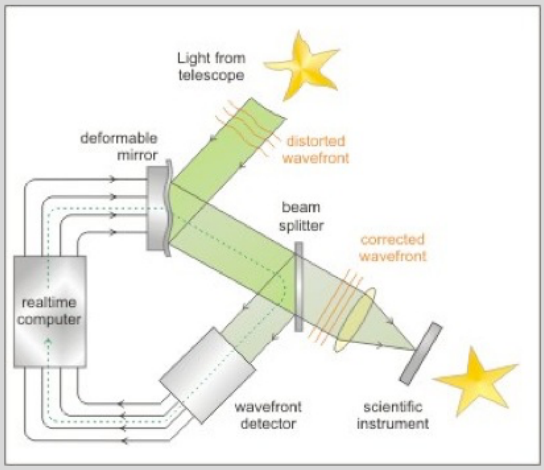


http://www.ucolick.org/~max/History_AO_Max.htm

Adaptive optics

- Uses a guide star (sometimes a fake guide star, a laser) and a deformable mirror to correct for atmospheric turbulence

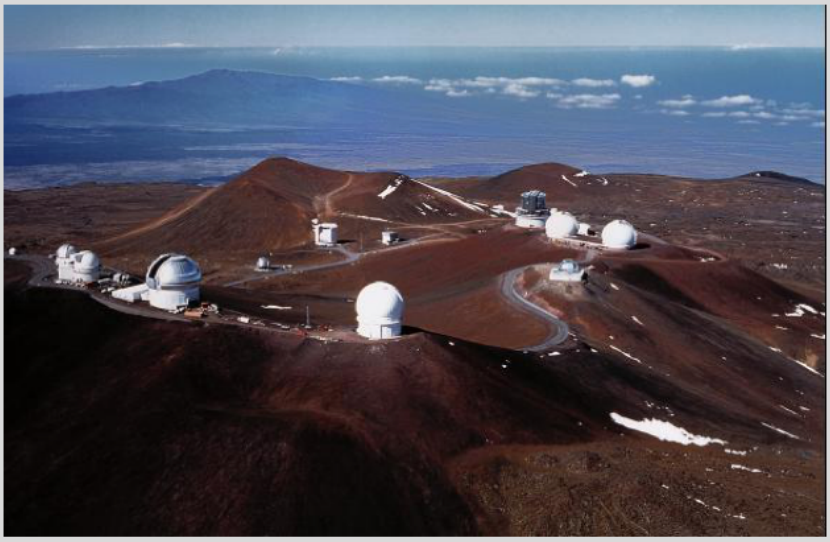




http://www.astronoo.com/en/articles/adaptive-optics.html

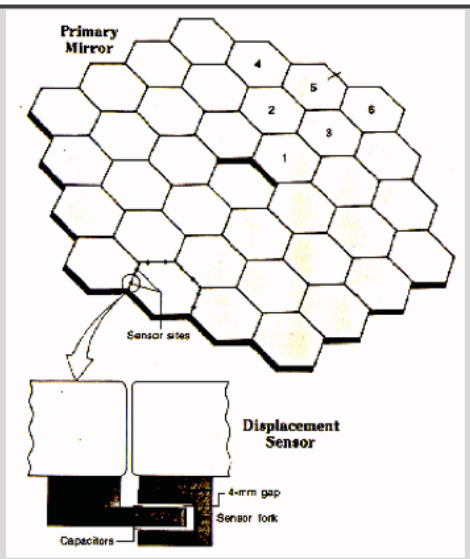
http://davide2.bo.astro.it/ter5/ter5/ao_eng.html

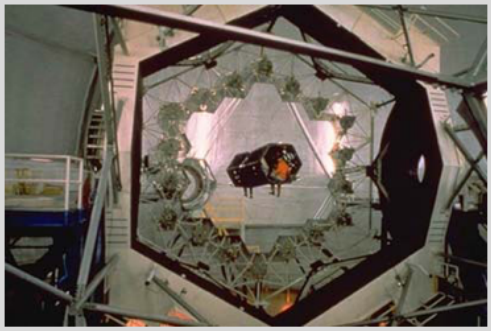
Observatories (Mauna Kea, Hawaii)



The Keck Telescopes

The Keck Mirrors

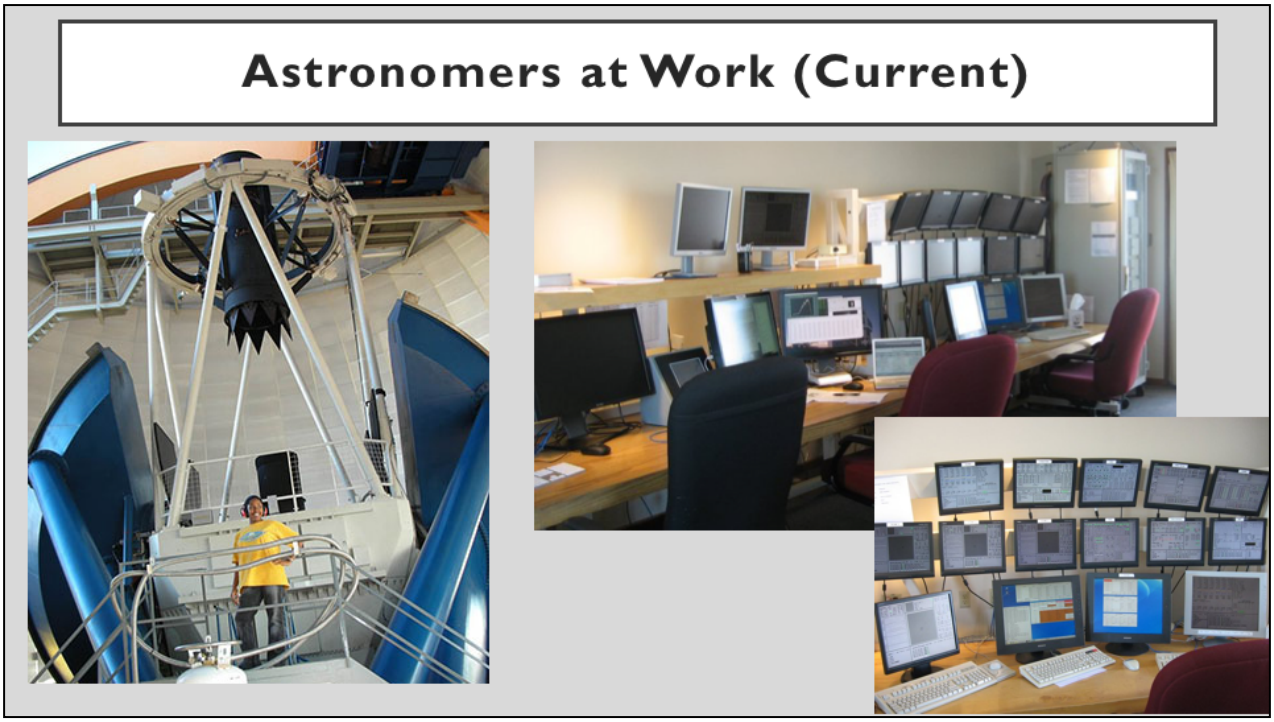




Astronomers at Work (Past)

Left: Vera Rubin

Right:



Professor Jedidah Isler (left)

Photos on the right I took on an observing run at a 6.5m telescope (Magellan/Clay). I was running the less complicated setup to the left, just controlling the instrument while an operator pointed the telescope for me.

Infrared Astronomy

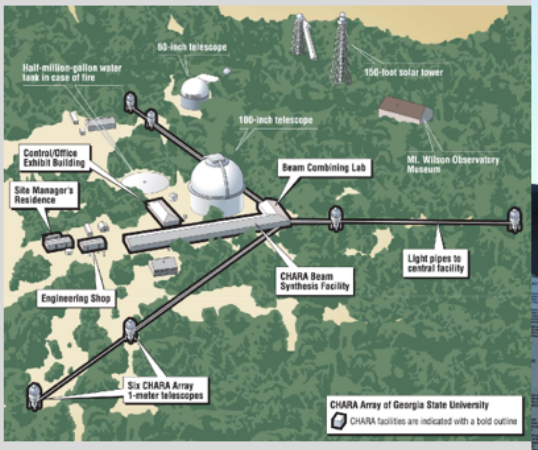
- Infrared (IR) spectral region lies just outside of the optical (visual) one.
- Characteristic wavelengths: 0.8 microns – 1 mm.
- Typical temperature for us on Earth is ~300 K (80 F).
- At this temperature, objects emit IR waves peaking at ~10 microns.
- Therefore, IR detectors need to be cooled down to temperatures of a few K (~ –400 F).
- IR telescopes are located at a high elevation to reduce atmospheric absorption of IR radiation.

Radio telescopes

Interferometry

- Remember how I talked about destructive and constructive interference of light?
  - Interferometry constructively interferes light from multiple telescopes like one huge telescope would be able to resolve
  - Angular resolution depends on the separation of the telescopes
  - Total spatial resolution depends on the number of telescopes and angles between them

Interferometry



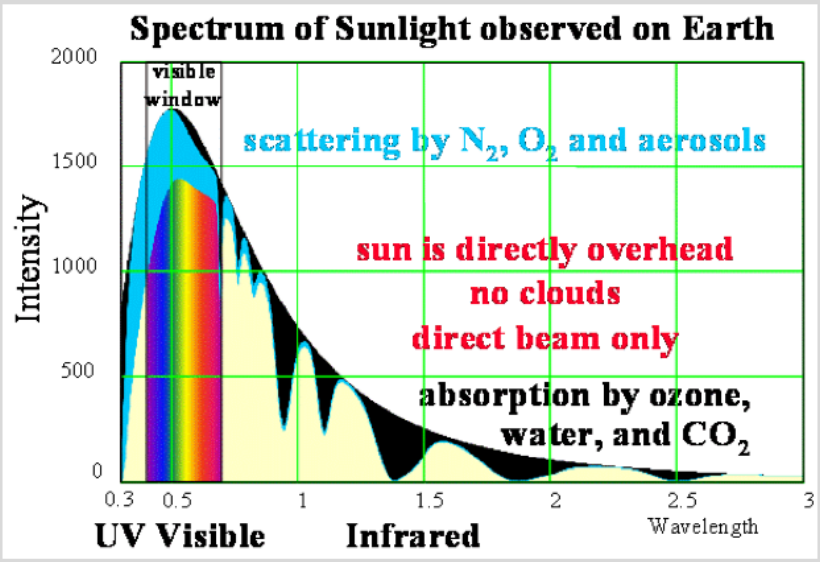
Interferometry

Interferometry

- What's the advantage of more telescopes/farther separated?

Keck telescopes being used together as interferometer

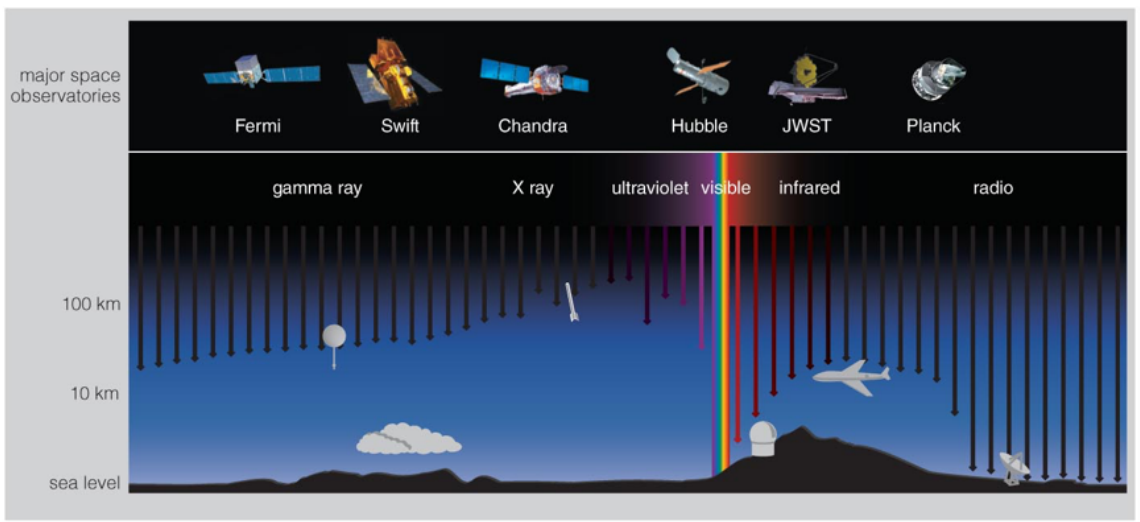
Getting out of the atmosphere



Why would we want to leave Earth's atmosphere to look at the Universe?

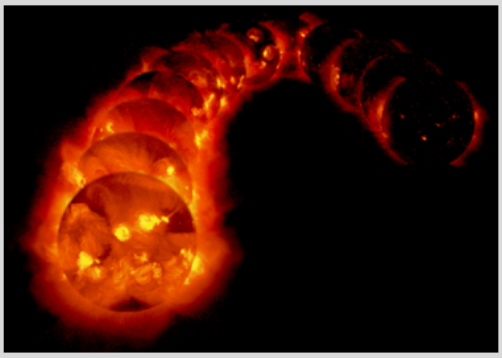
https://web.calpoly.edu/~rfield/Thermalstructure.htm

Getting out of the atmosphere



Getting out of the atmosphere

- How to get out of the atmosphere?
  - Balloons – 40 km above sea level, above 99.997% of Earth's atmosphere
  - Sounding rockets – sub-orbital; don't go into orbit or reach escape velocity, but do exit Earth's atmosphere
  - Satellites – Earth-orbiting or in some stable orbit between Earth and Sun
- In 1949, a sounding rocket discovered the Sun emits X-rays

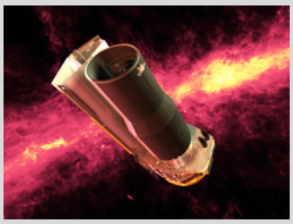


https://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/solar_system/yohkoh_solar_cycle.html

Satellites

- First satellite – 1957 Soviet Sputnik
- First astronomical satellites – late 1960's
- Discovery of cosmic X-rays – 1964, sounding rocket; confirmed 1970, Uhuru Satellite
- The Hubble Space Telescope (HST) – 1990
- The Chandra X-ray Observatory – 1999
- The Spitzer Space (IR) Observatory – 2003





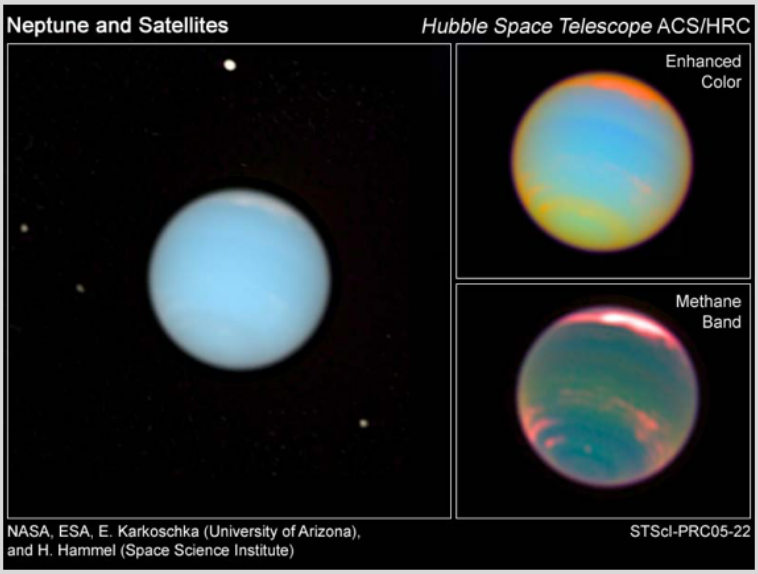
Cosmic x-ray sources https://en.wikipedia.org/wiki/Cygnus_X-1

Hubble http://hubblesite.org

Chandra https://www.nasa.gov/audience/forstudents/k-4/dictionary/Chandra_X-ray_Observatory.html

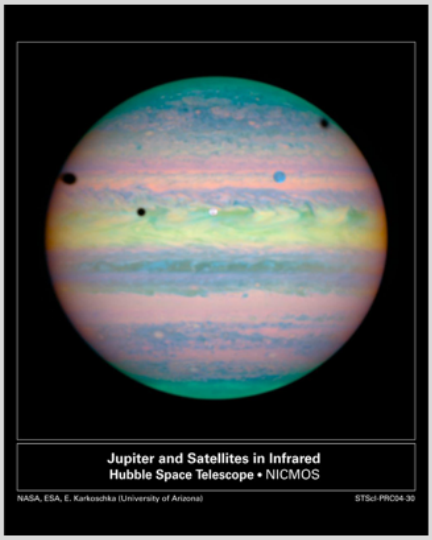
Spitzer https://en.wikipedia.org/wiki/Spitzer_Space_Telescope

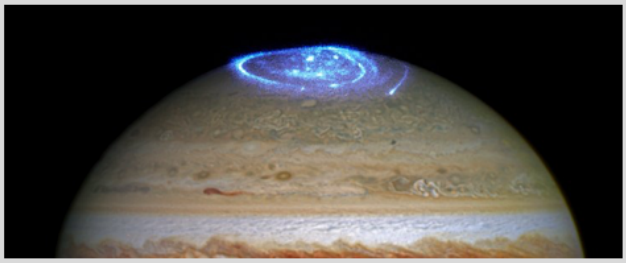
Hubble observes... Neptune



http://imgsrc.hubblesite.org/hu/db/2005/22/images/a/formats/web_print.jpg

Hubble observes... Jupiter

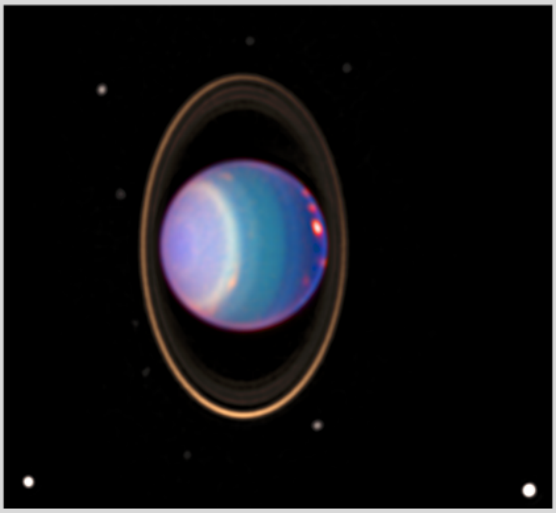


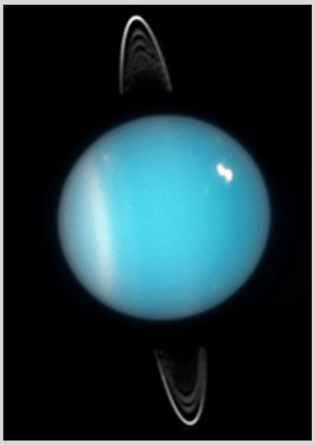


http://hubblesite.org/image/1598/news_release/2004-30

https://www.spacetelescope.org/news/heic1613/?lang

Hubble observes... Uranus

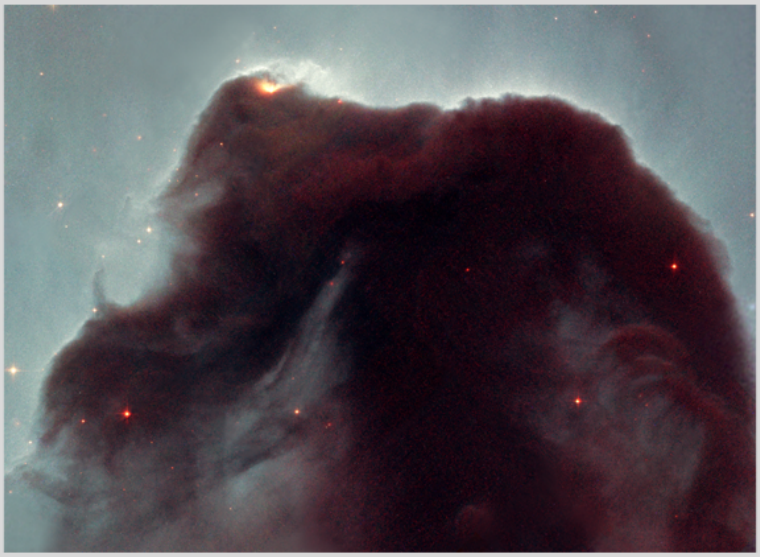




http://hubblesite.org/image/719/news_release/1998-35

https://www.skyandtelescope.com/astronomy-resources/astronomy-questions-answers/why-dont-we-say-it-has-a-direct-spin-with-the-axis-tilted-82176-instead-of-98176/

Hubble observes... Nebulae



http://hubblesite.org/image/1040/news_release/2001-12

Summary

- Spectral information gives us more knowledge about celestial objects (composition, surface temperature, moving properties)
- Visible light is only a small portion of the electromagnetic spectrum
- Telescopes work as giant eyes, enabling us to see the Universe in great detail
- The ultimate place to observe the Universe is space!

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