Today's Topics

Wednesday, September 25, 2019 (Week 3, lecture 11) – Chapter 16.1-2, 6.

1. Nuclear particles vs Photons

2. Astrolabe – ancient instrument

2. Refractive Telescopes

3. Reflecting Telescopes

Charged Particle Astronomy

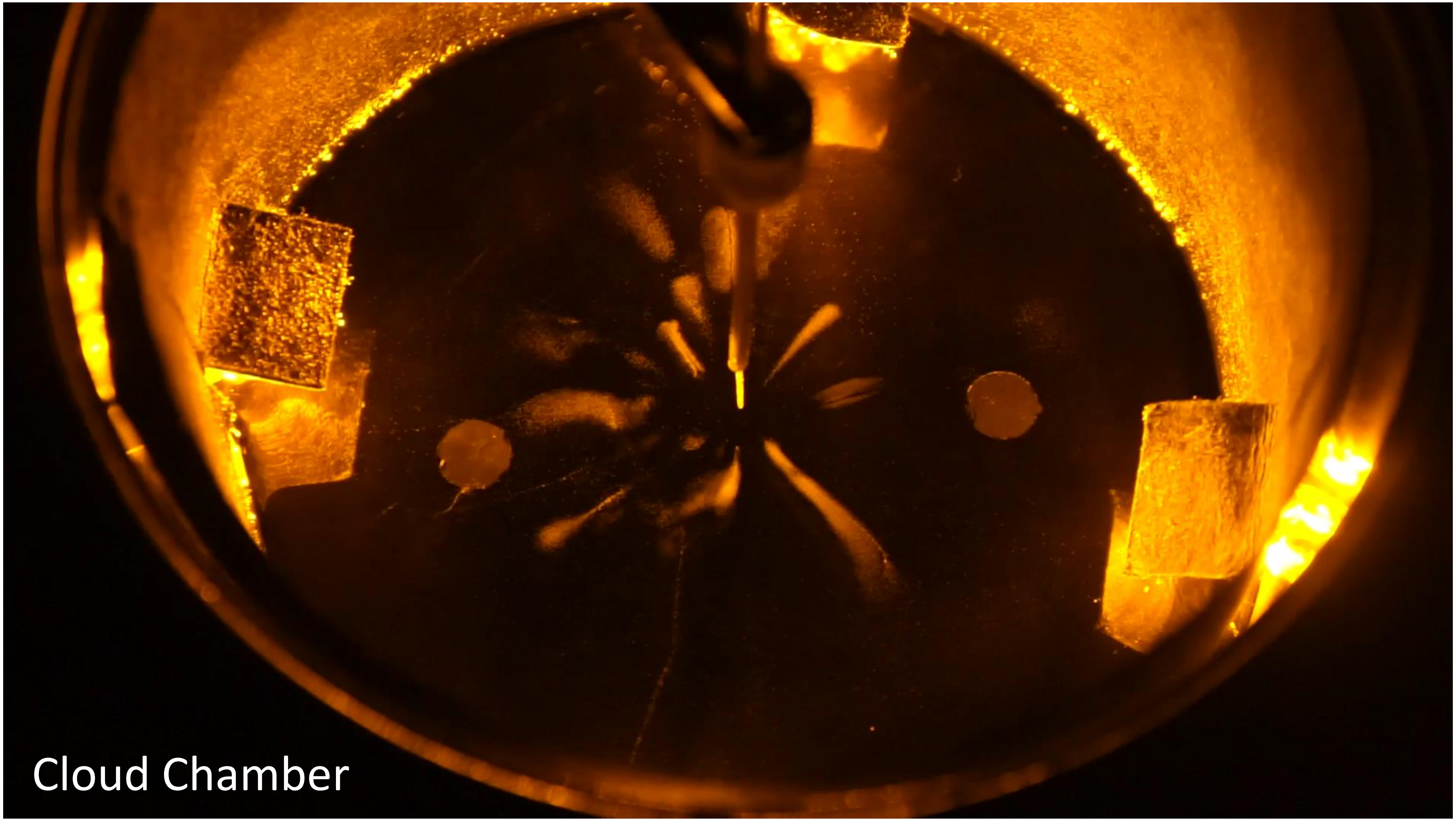
Protons and electrons (and anti-protons & positrons) + **α-particles**
(charge = +2)

Good: lots of them, easy to detect (in space).

→ Stars emit p+ and e- as **solar wind**.

→ **Cosmic rays** from violent stellar events.

Alphas, electrons, muons (muon = heavy electron) from radioactive Lead-210



[video by Megan Frayser, W&M 2019]

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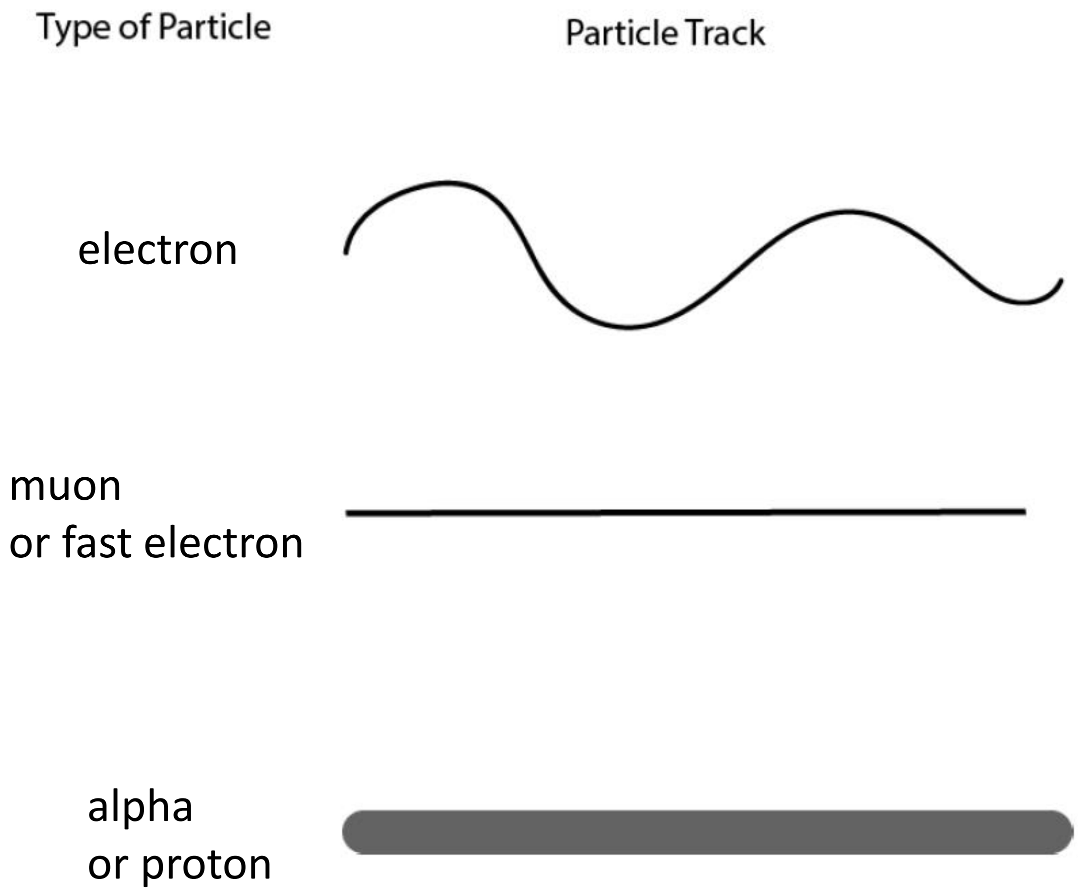
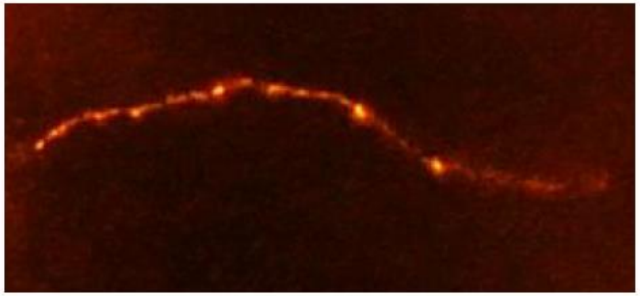
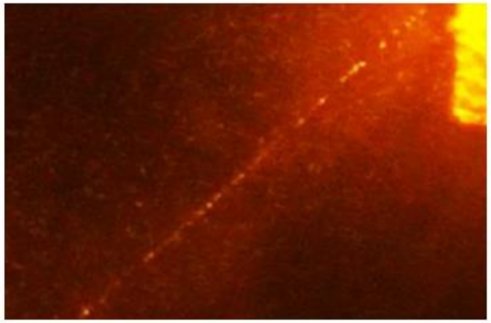
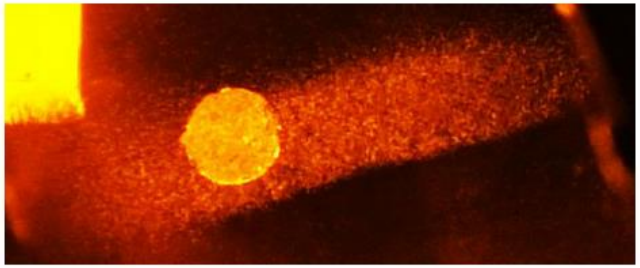


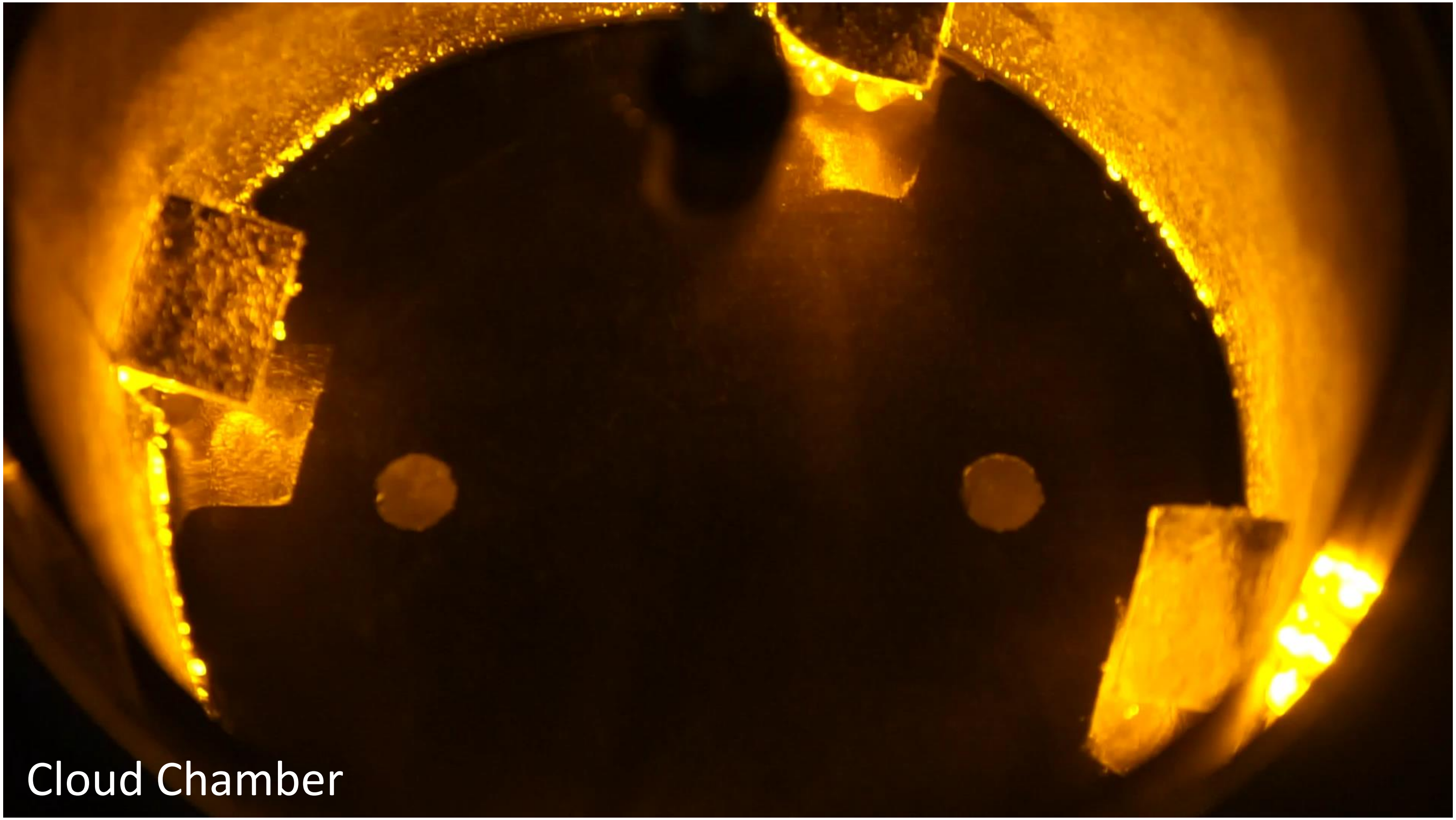






[photos by Megan Frayser, W&M 2019]

Alphas, electrons, muons (muon = heavy electron) from background cosmic rays & radioactivity



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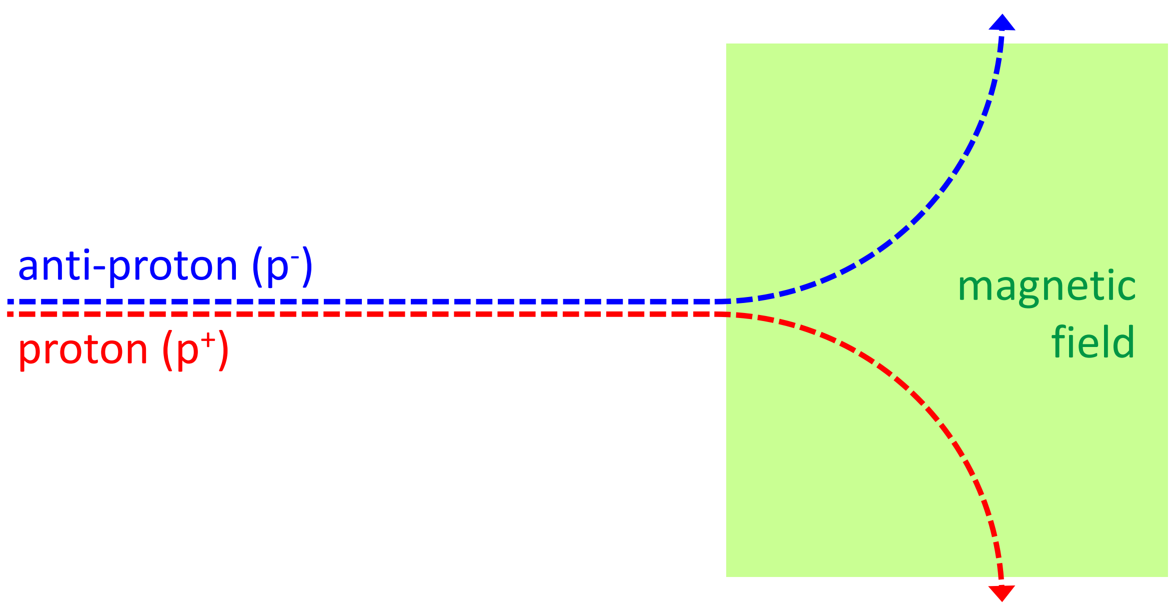
Bad: Strongly affected by planetary, solar, and galactic **magnetic fields**.

→ Hard to identify origin/source of particle.



Particle does not "point back" to its origin.

→ not useful for imaging.

What are anti-particles ?

- **Antiprotons** are protons with negative charge (q=-1).
- **Positrons** (anti-electrons) are electrons with positive charge (q=+1).
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Antimatter

You can build nuclei and atoms using antiprotons, positrons, and antineutrons.

- Anti-hydrogen consist of an anti-proton + positron.
  → Anti-hydrogen still feels attractive gravity.
- Anti-helium consists of anti-alpha particle + 2 positrons.
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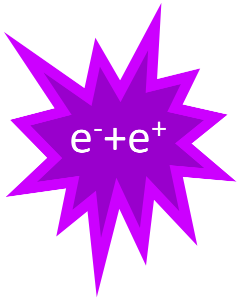
Matter-Antimatter Annihilation

When matter and antimatter meet they **annihilate** each other to ultimately produce **gamma rays** and **neutrinos**.



Neutral Particle Astronomy

Neutrons

Good: Not very affected by magnetic fields.

Bad: Short lifetime of 12 minutes → Not useful.

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Neutrinos

Neutrinos have almost no mass and **barely interact** with anything.

→ They travel at speed of light (roughly).

→ They feel gravity and weak force (in nucleus).

A **light year of lead** would only stop half the neutrinos going through it !!!

Good: Not affected by magnetic fields or matter, points back to source

Bad: ***Hard to detect, hard to image with.***

Neutrino Astronomy

Neutrino Benefits

- Neutrinos go through most astrophysical objects: **no shadowing**.
- Neutrinos are unaffected by light, electric fields, magnetic fields.
- Neutrinos allow you to **"see" inside stars** (i.e. stellar cores).

[OpenStax: Astronomy]

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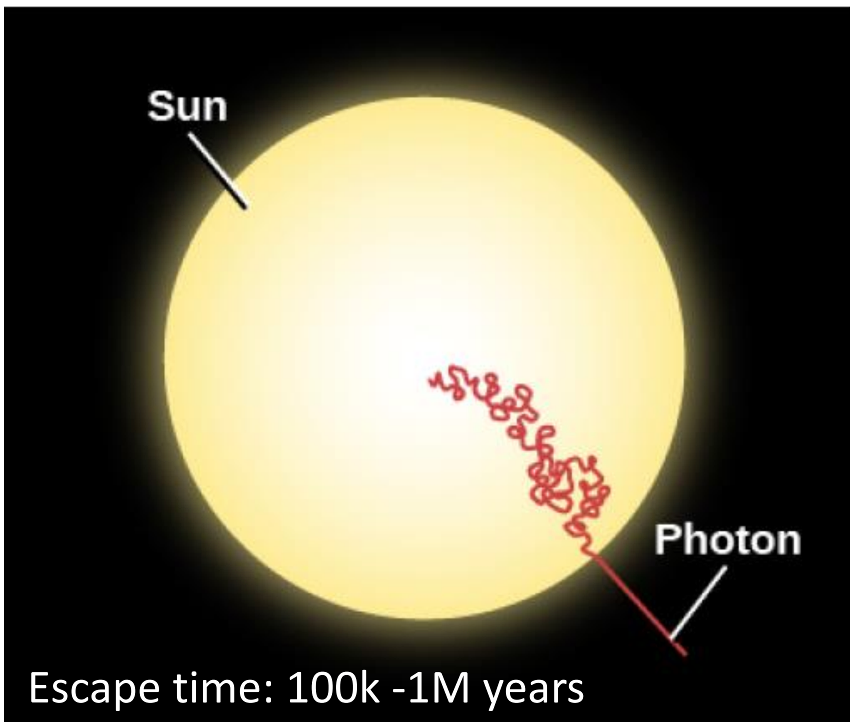

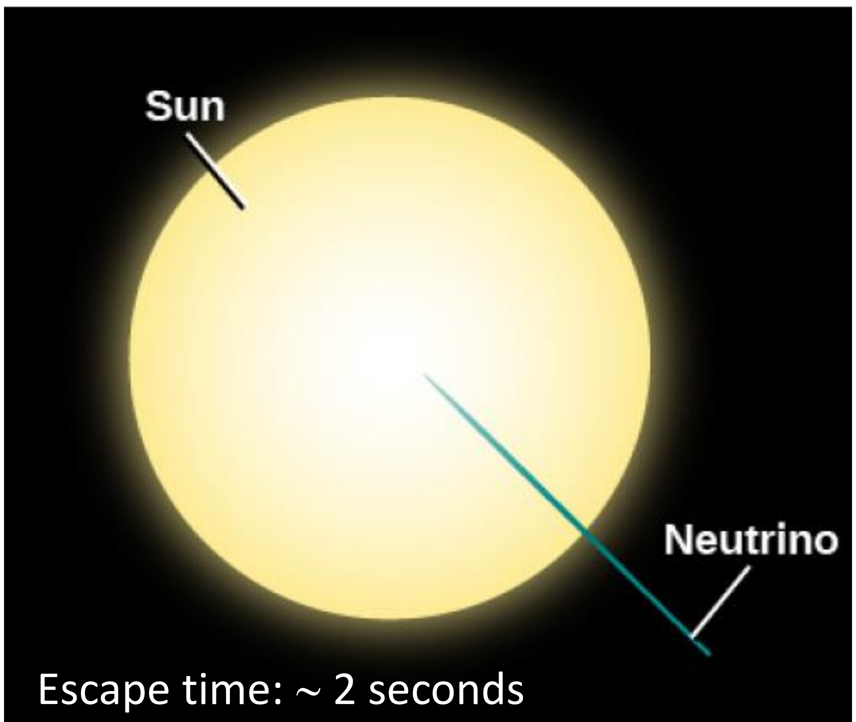

[OpenStax: Astronomy]

Neutrino Astronomy

Neutrino Drawbacks

- There are lots of neutrinos, but they barely interact.

  → About 60 billion solar neutrinos pass through every cm^2 of your body every second … but they don't affect/interact with you!!!

- Neutrinos are hard to detect.

  → Only 1 in 10^{18} neutrinos passing through a 1 m thick detector will interact and be detected.

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- Very large detectors with very low count rates.
  → Event rate ~ 1 count per day (varies significantly).
  → Imaging is possible, but slow and low resolution.
- Detectors are generally far underground to avoid cosmic rays.
  → Lots of infrastructure needed; only possible in special locations.

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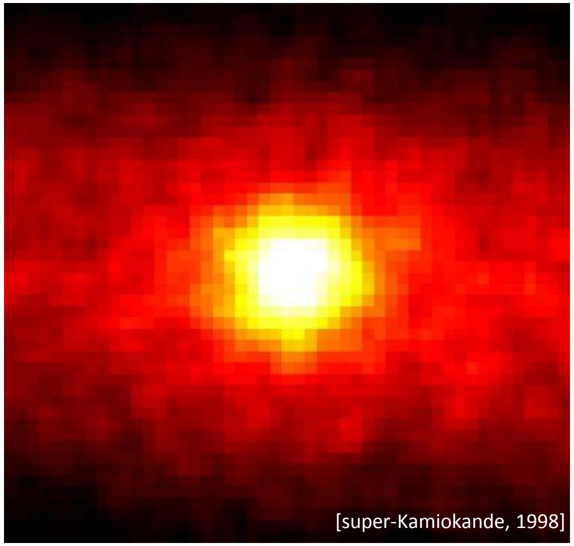

500 day exposure, full sky view.

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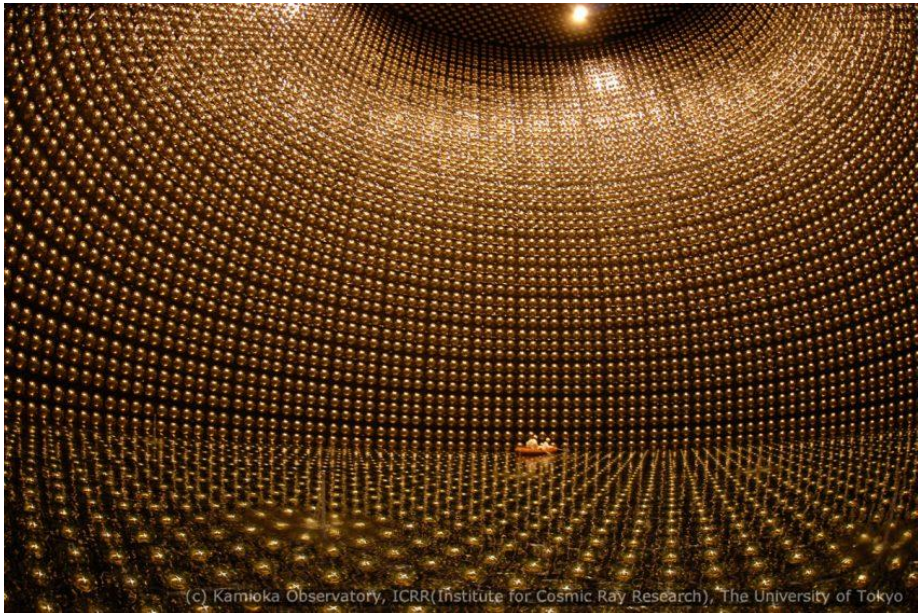
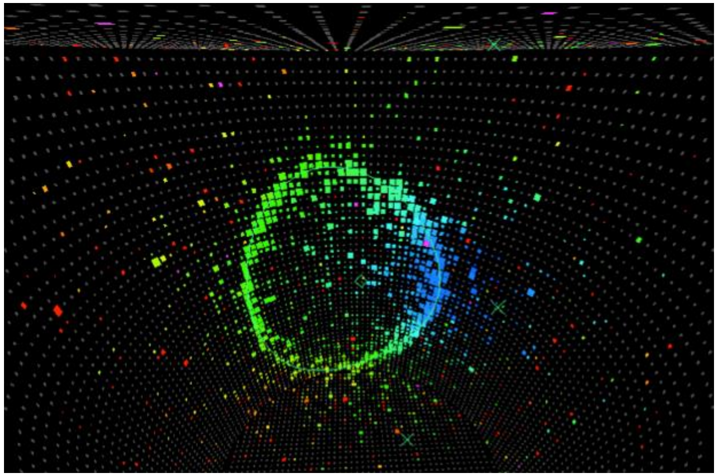
Neutrino Detectors

Super-Kamiokande (Japan)





Super-Kamiokande neutrino (ν_e) event.

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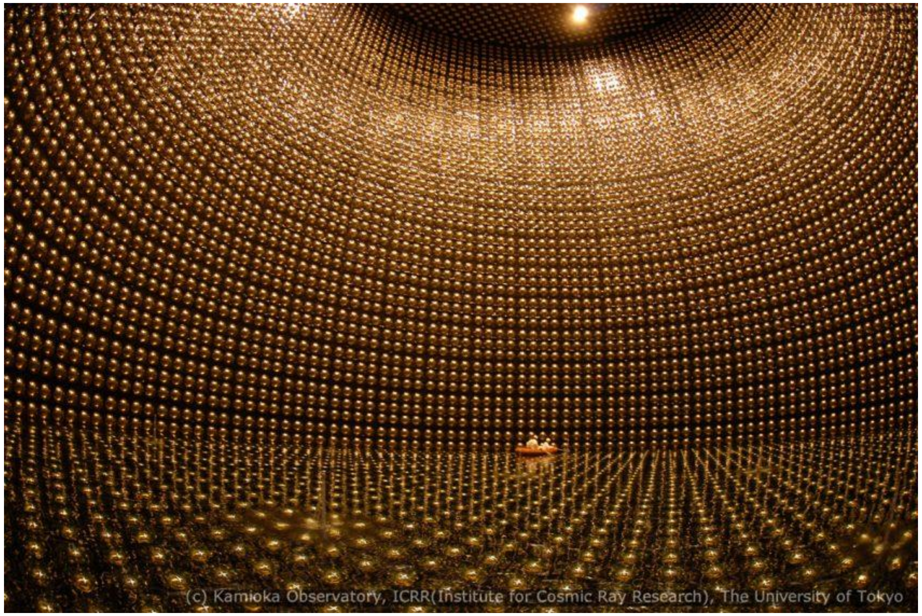

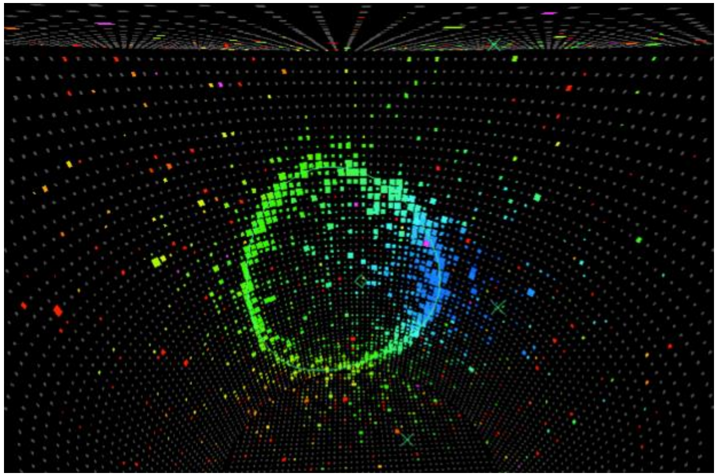

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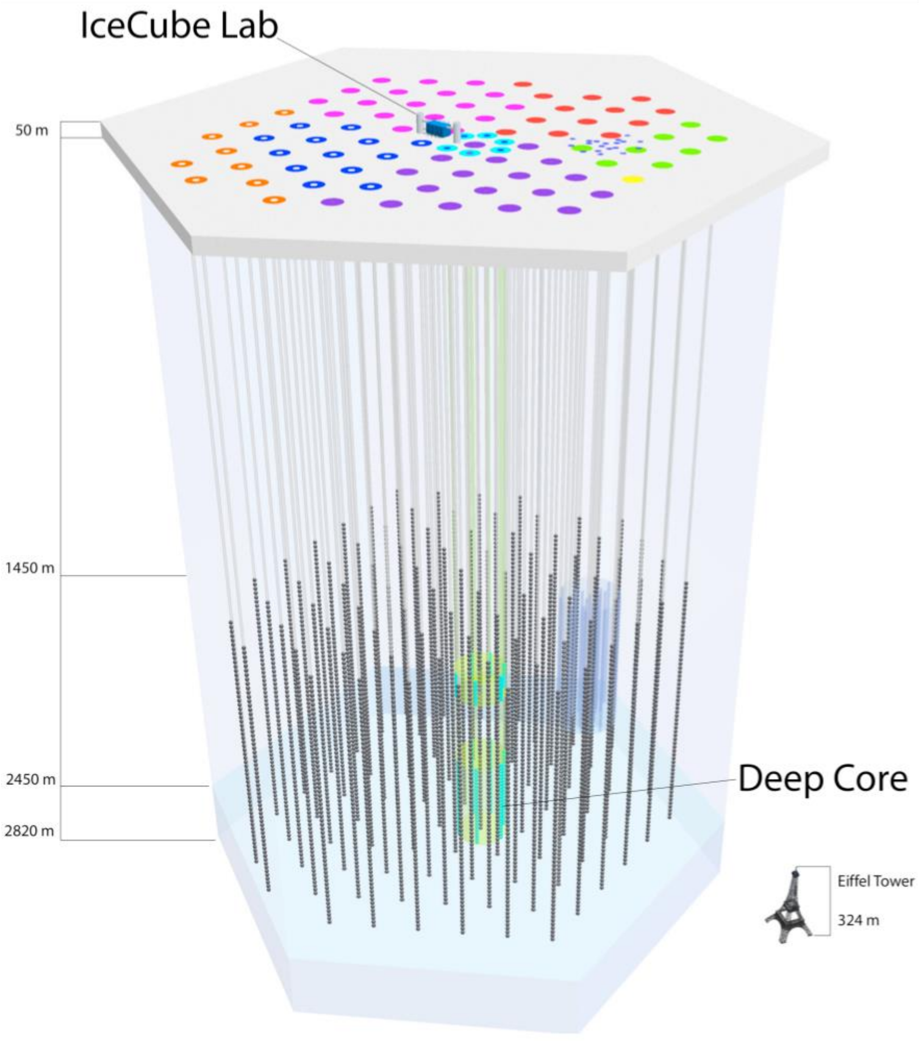
IceCube (Antarctica)

Cubic kilometer of detectors in very deep ice.



[M.G. Aartsen et al., J.Parallel Distrib.Comput. 75, 198-211 (2015); arXiv:1311.5904]

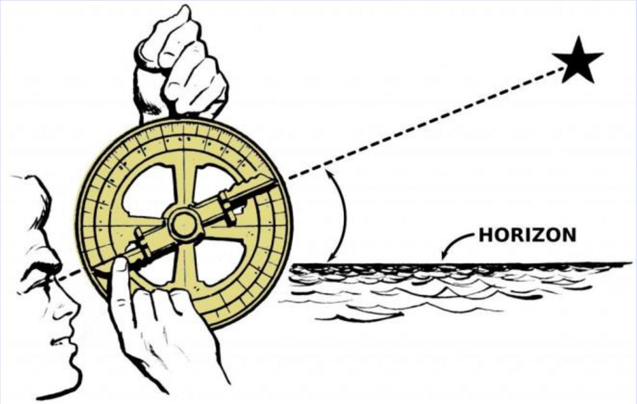
Astrolabe

Ancient Astronomy Instrument

- Used for measuring **inclination** of stars.
- Applications: astronomy, navigation, timekeeping.
- Developed by ancient greeks, c. 220-150 BC.

→ Hypparchus, Apollonia of Perga.

→ Possibly used by Ptolemy (100-170 AD).



[Pearson Scott Foresman, Wiki Commons]

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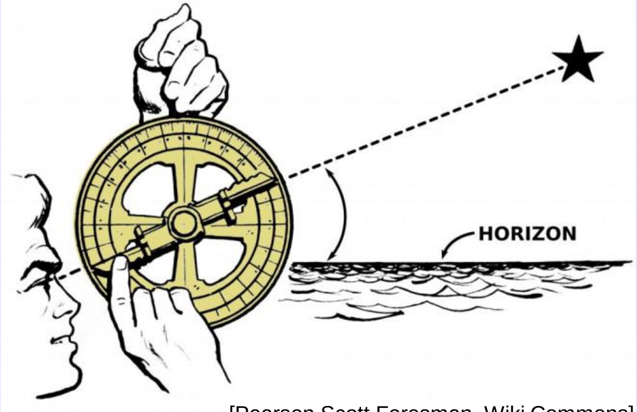

[Pearson Scott Foresman, Wiki Commons]


Hypatia
[by Elbert Hubbard, 1908]

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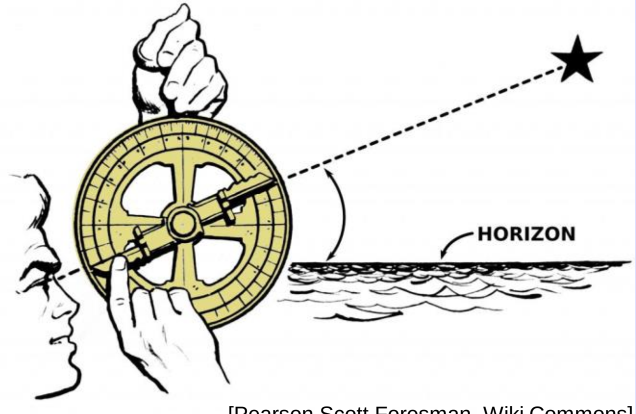

[Pearson Scott Foresman, Wiki Commons]

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- Refined by **Islamic astronomers** (starting in 8th century AD).

  → Al-Fazari, Albatenius, al-Sufi, al-Tusi, Ibn al-Sarraj.

  → Many stars retain their Islamic names (e.g. Altair, Aldebaran, Mizar, Alcor, etc)

- Propagated to medieval Europe, India, China.

Hypatia
[by Elbert Hubbard, 1908]

Telescope

Modern astronomy starts with the invention of the telescope.

→ Developed by Dutch spectacle/lens makers (Lippershey, Janssen, Metius), c. 1608.

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Galileo's "cannocchiali" telescope
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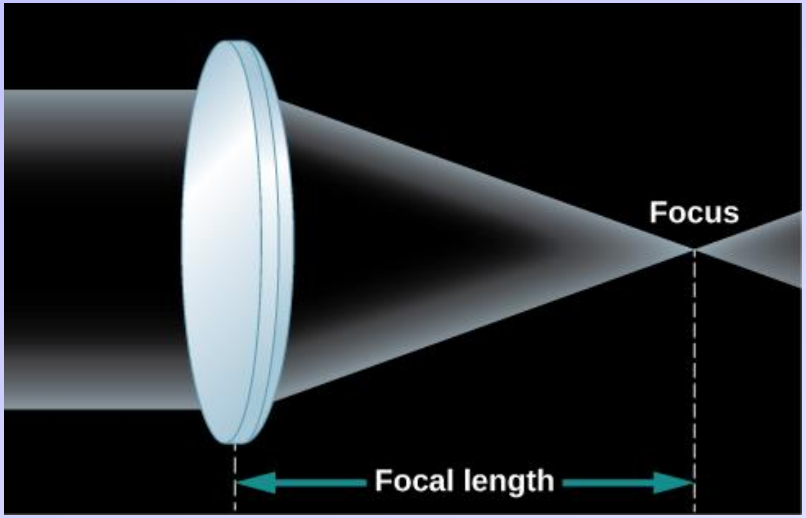

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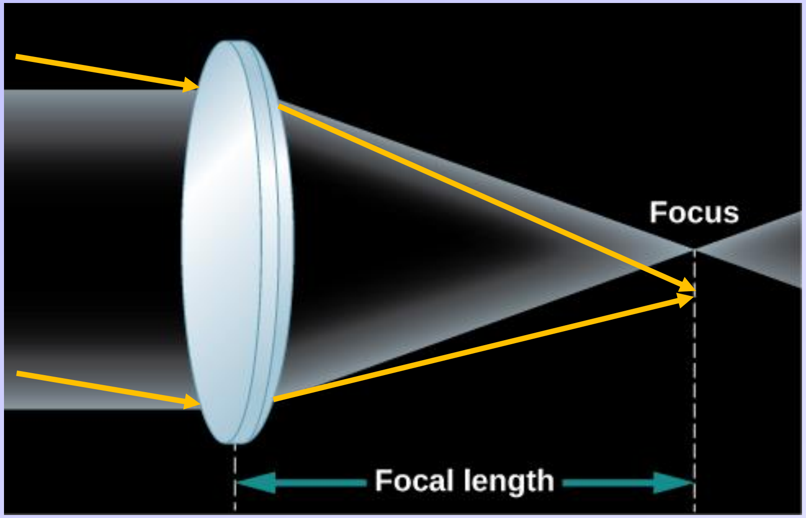

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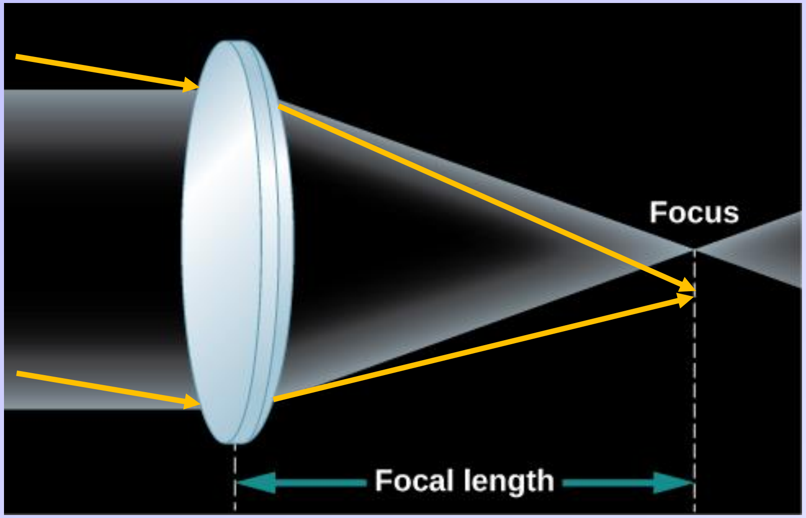


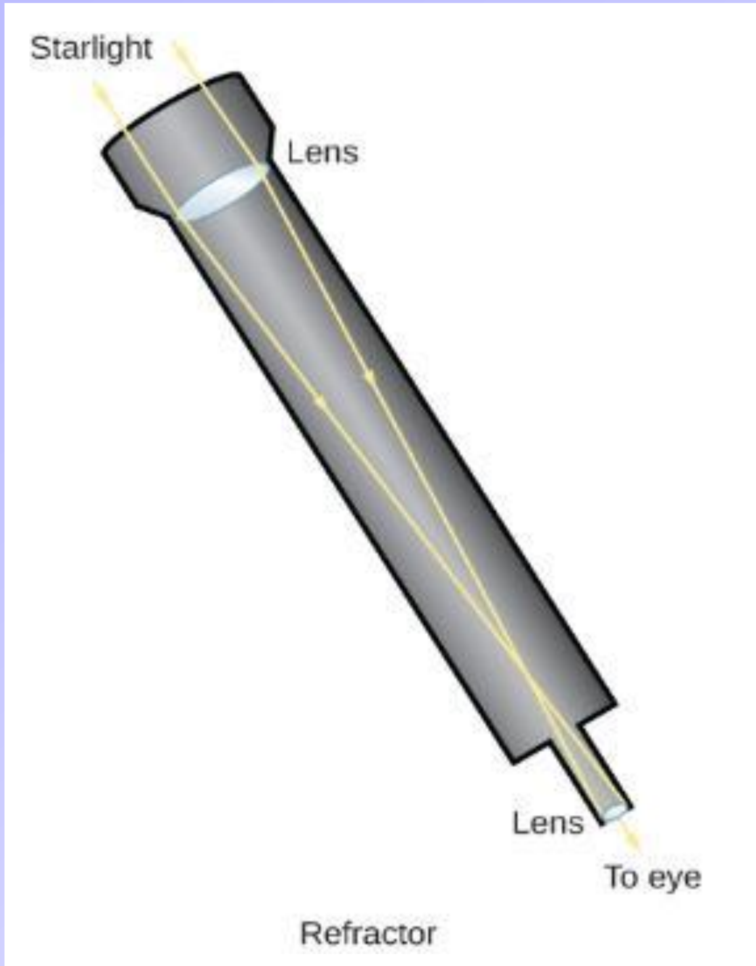
[OpenStax: Astronomy]

Benefits

- **More light** forms image (compared with eye).
- Image **magnification**.

Refracting Telescope

Two or more lenses are used to form an image



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Benefits

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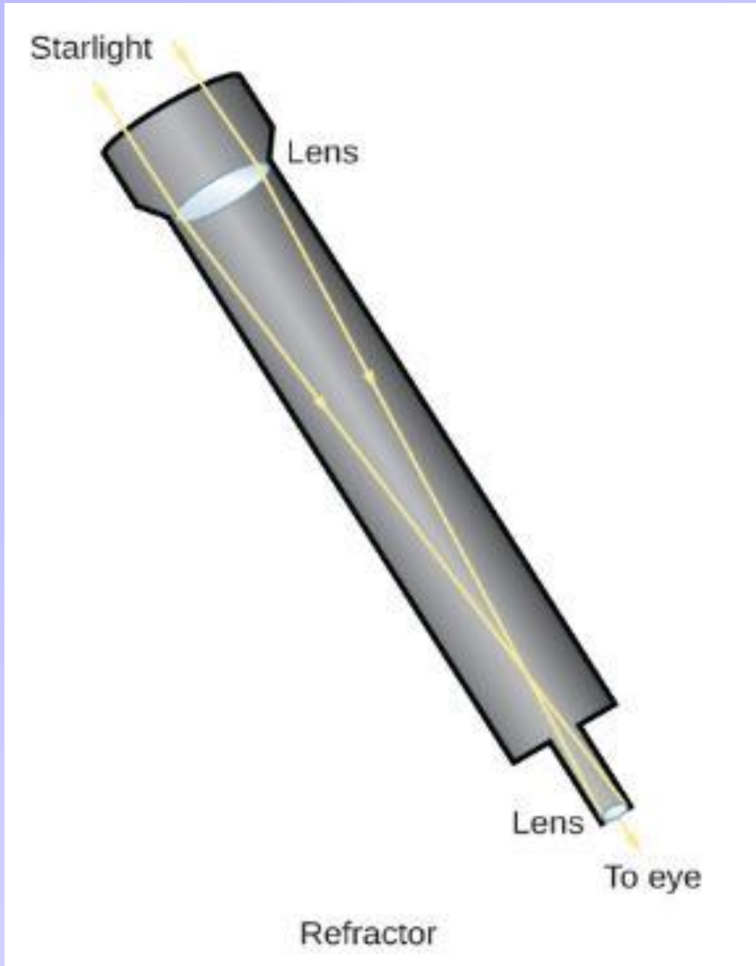

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Drawbacks

- Focal length of lens depends on wavelength (e.g. prism).
  - → **chromatic aberrations**.
  - → Achromatic lens reduce this problem.
  - → Long focal lengths help.
- **Defects in glass** distort image.
- Large lenses experience **sag** in the unsupported middle.
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Refracting Telescope

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Largest refracting telescope in the US: Yerkes Observatory, Williams Bay, Wisconsin (U. of Chicago).

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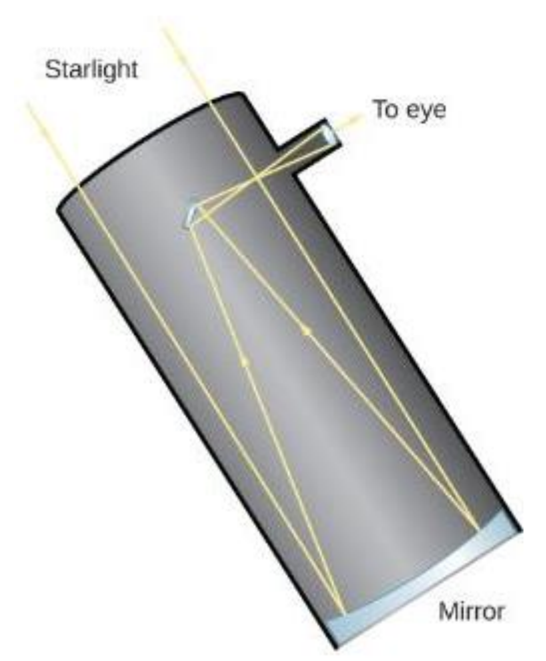
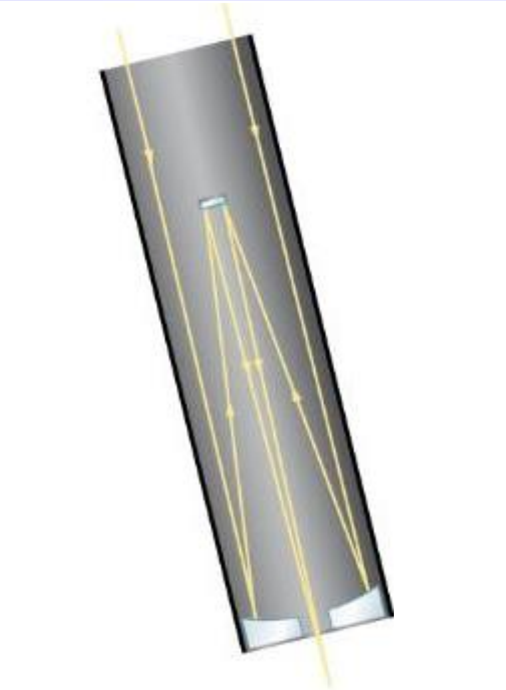
Reflecting Telescope

A **large curved mirror** collects the light and then focuses it onto a secondary smaller mirror.

→ invented by Isaac Newton.
→ Parabolic curved mirror is ideal.



Newtonian Reflector



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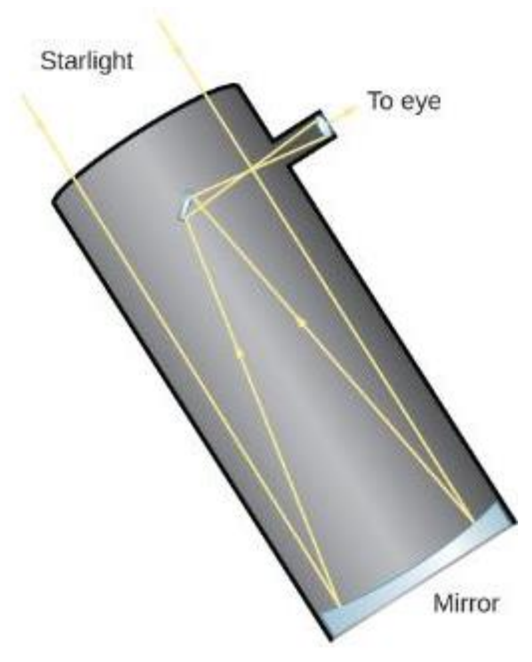

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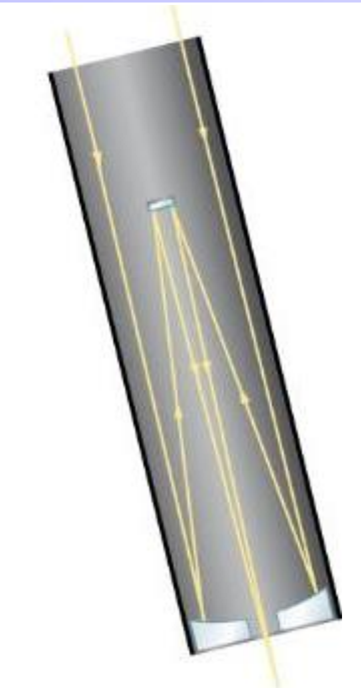

Cassegrain Reflector

Benefits

- No chromatic aberrations.
- Glass defects do not matter.
- Large mirror can be supported across its entirety.
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Drawbacks

- Open to air: more cleaning.
- Secondary mirror and support structure introduce diffraction effects from their shadows.

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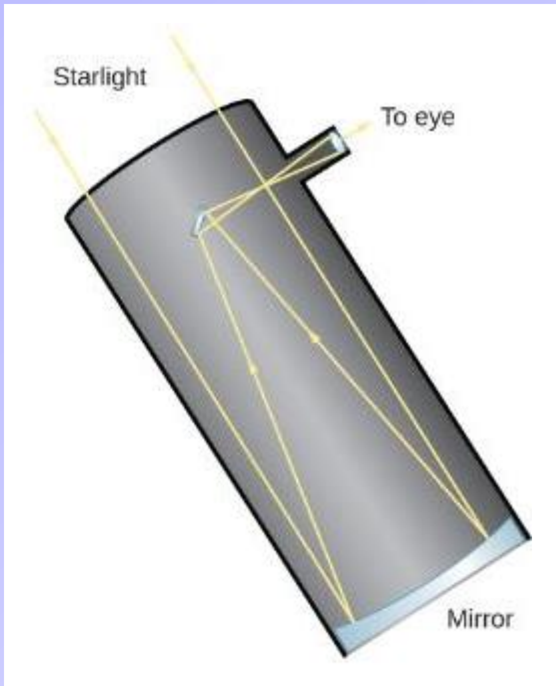

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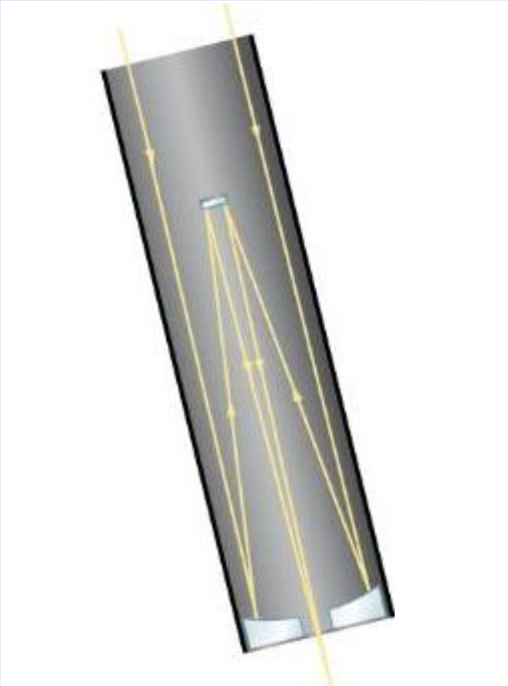

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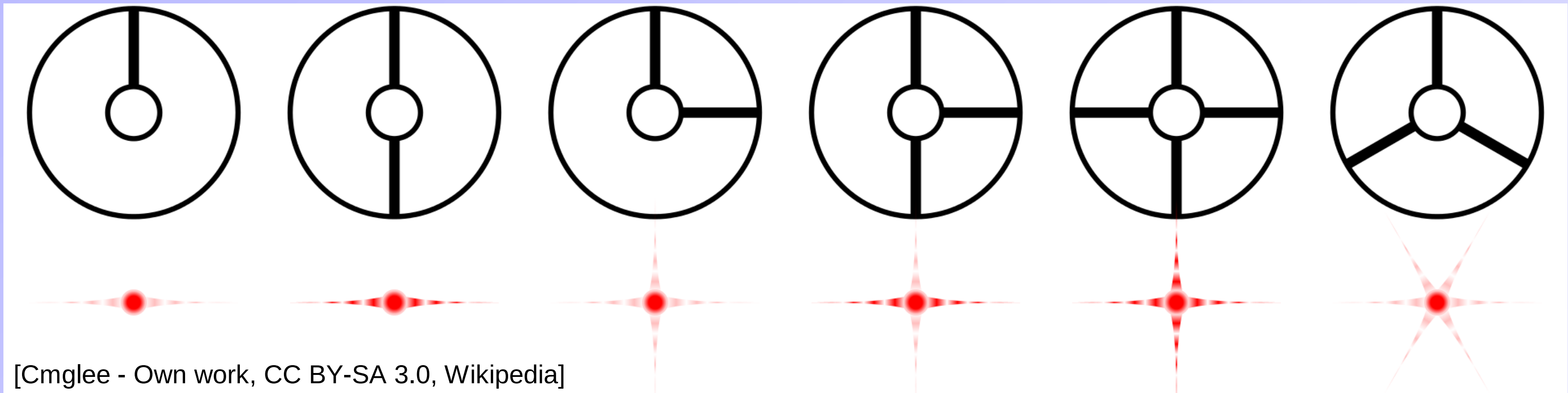
Almost all scientific telescopes are reflectors.

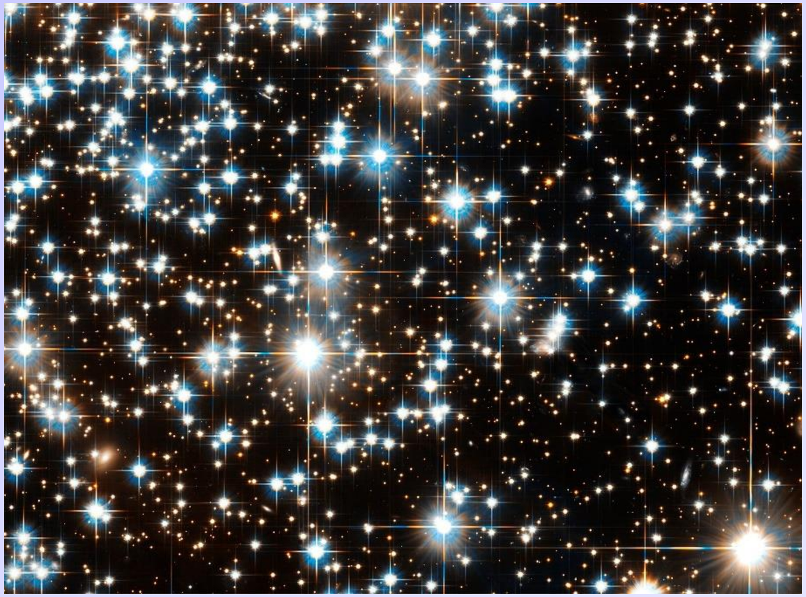
[OpenStax: Astronomy]

Star Spikes

Shadow from support structure for secondary mirror generates “star spikes”.



[Cmglee - Own work, CC BY-SA 3.0, Wikipedia]



Star Spikes from a Hubble Space Telescope image (NGC 6397).

[NASA, ESA, and H. Richer (University of British Columbia), Wikipedia]

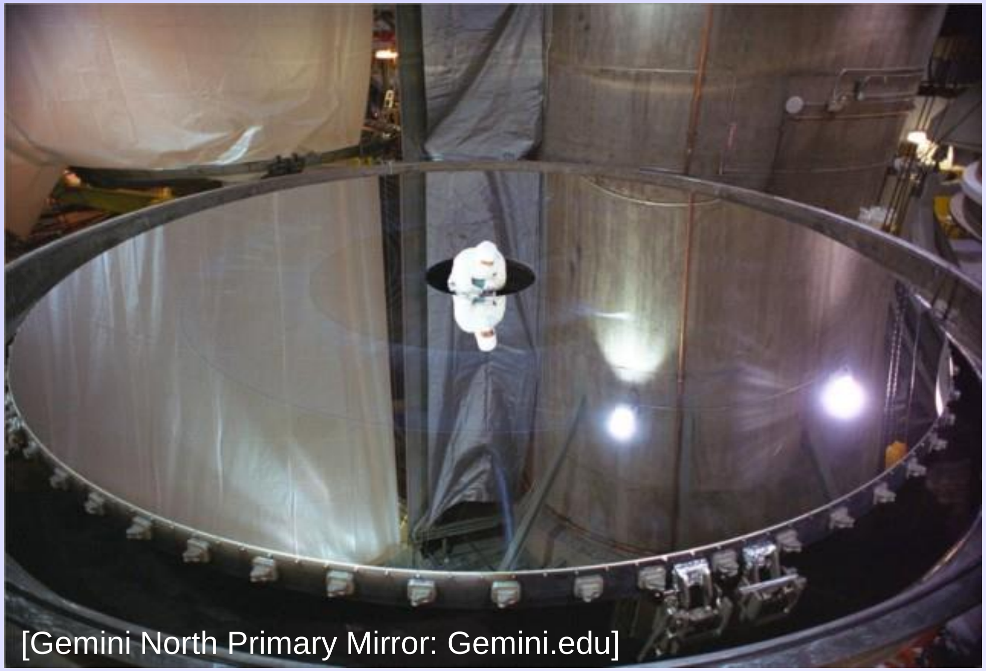
Single Mirror Telescopes

The Gemini telescopes are some of the largest single mirror telescopes.

→ 8.1 m primary mirror.

→ 1 m secondary mirror.

→ Locations: Hawaii & Chile



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Problem: A single mirror larger than 8 m will experience significant sag issues.

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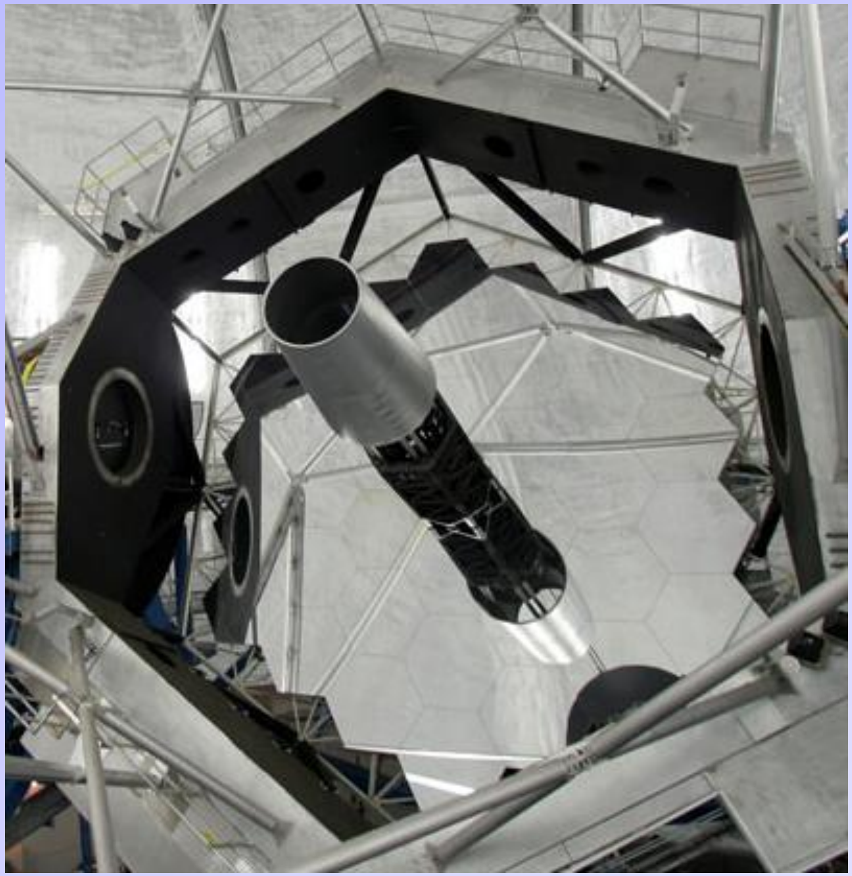
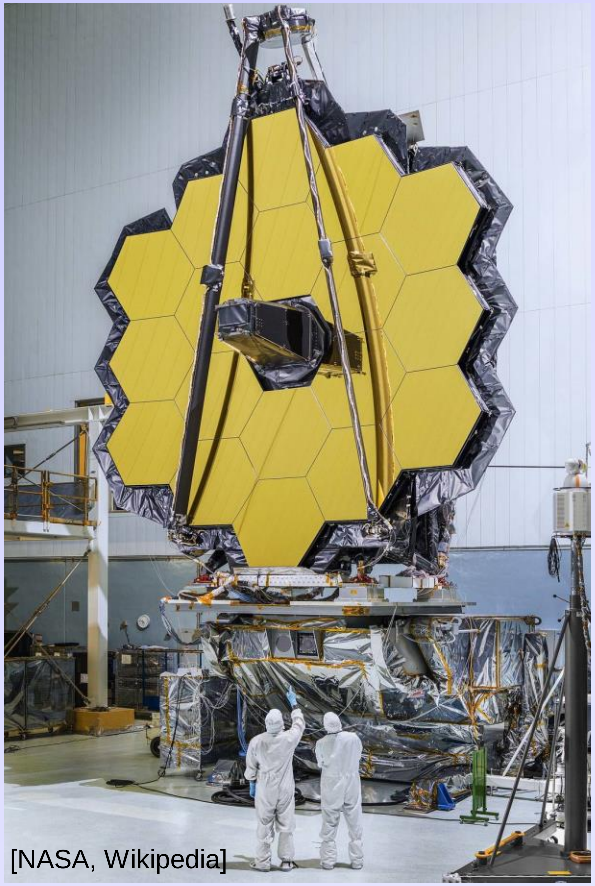


36-segment mirror of the Keck telescope (Hawaii)

[by SiOwl - Own work, CC BY 3.0, Wikipedia]



[NASA, Wikipedia]

18-segment mirror of the future James Webb Space Telescope.