Today's Topics

Wednesday, February 26, 2025 (Week 5, lecture 12) – Chapter 16.1-2, 6.

1. Nuclear particles vs Photons

2. Astrolabe – ancient instrument

2. Refractive Telescopes

3. Reflecting Telescopes, part 1

Charged Particle Astronomy

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

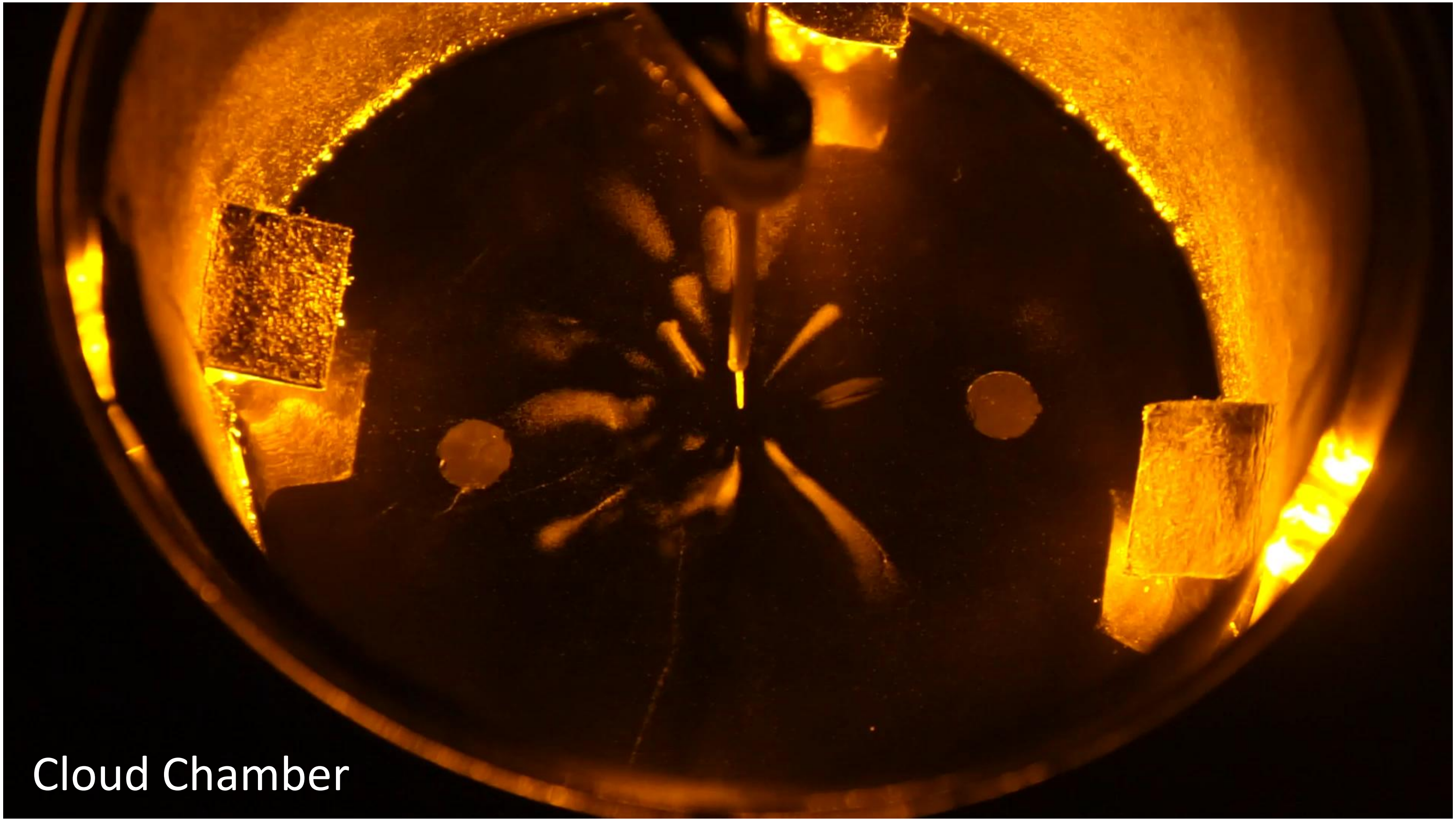
(charge = +2)

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

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

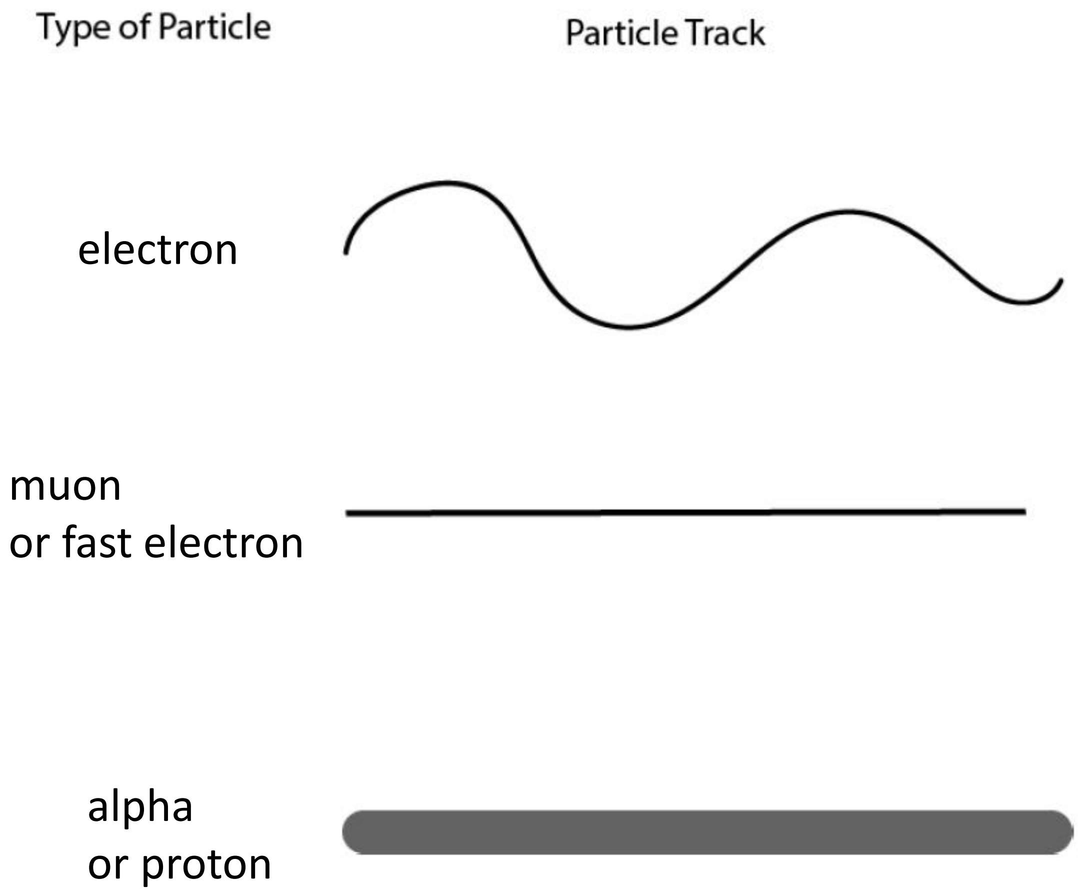
→ **Cosmic rays** from violent stellar events.

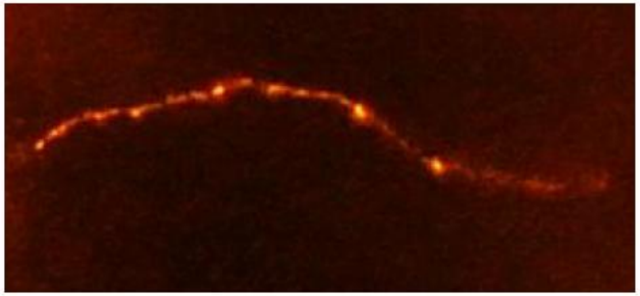
Alphas, electrons, muons (muon = heavy electron) from radioactive Lead-210

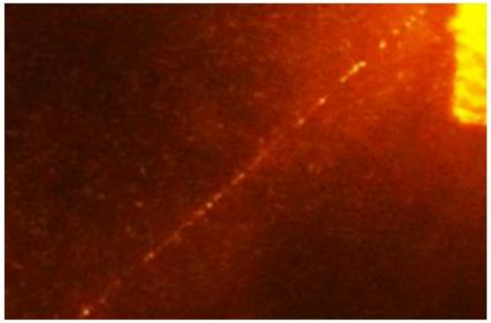


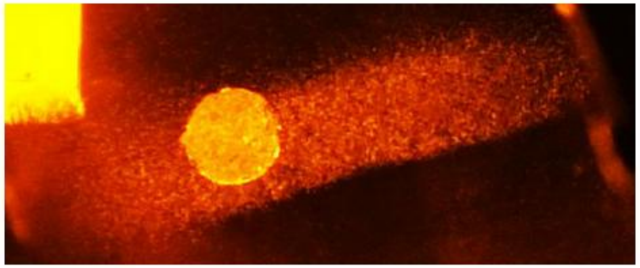
[video by Megan Frayser, W&M 2019]

Alphas, electrons, muons (muon = heavy electron) from radioactive Lead-208



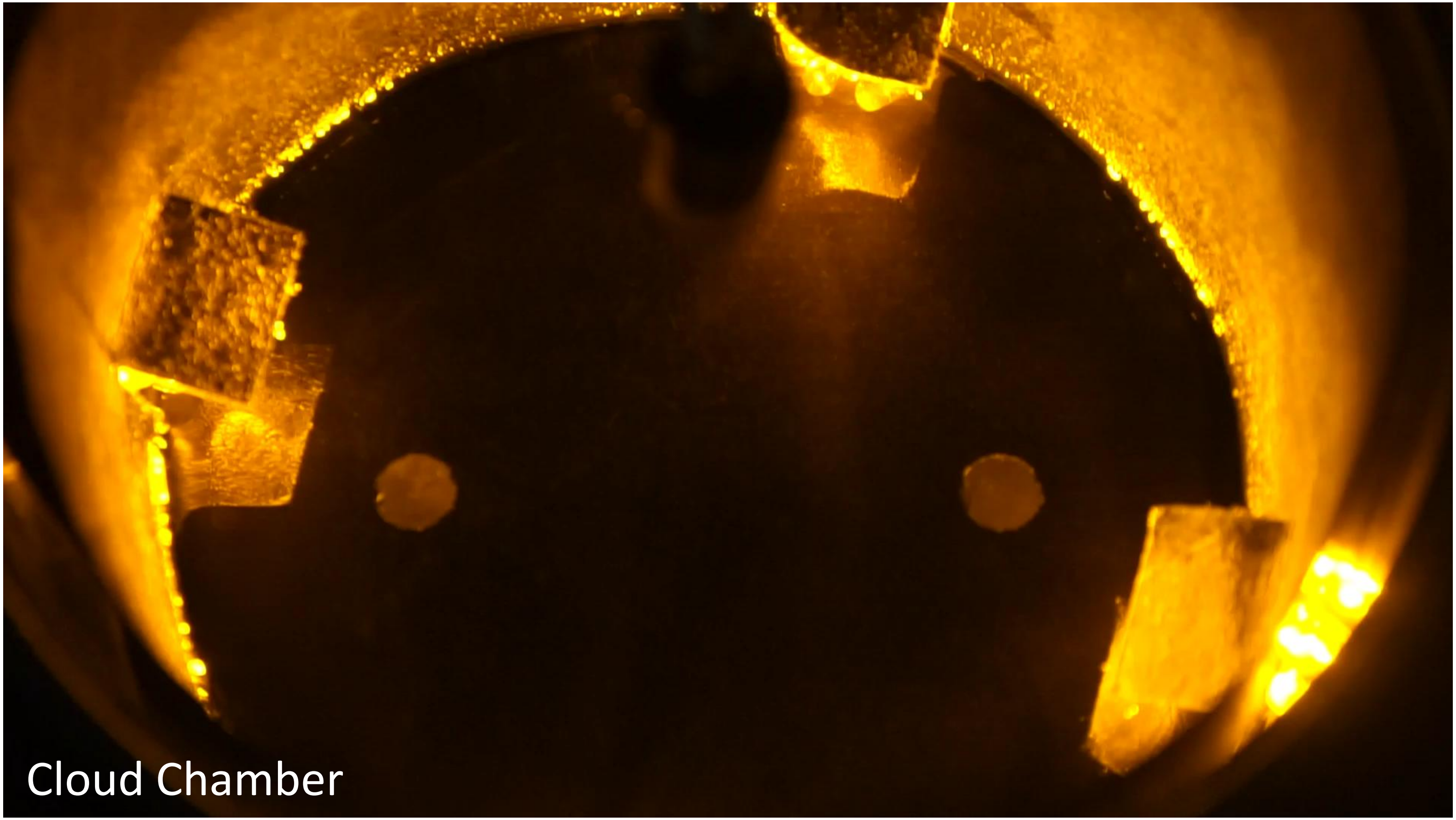






[photos by Megan Frayser, W&M 2019]

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



[video by Megan Frayser, W&M 2019]

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.

Charged Particle Astronomy

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

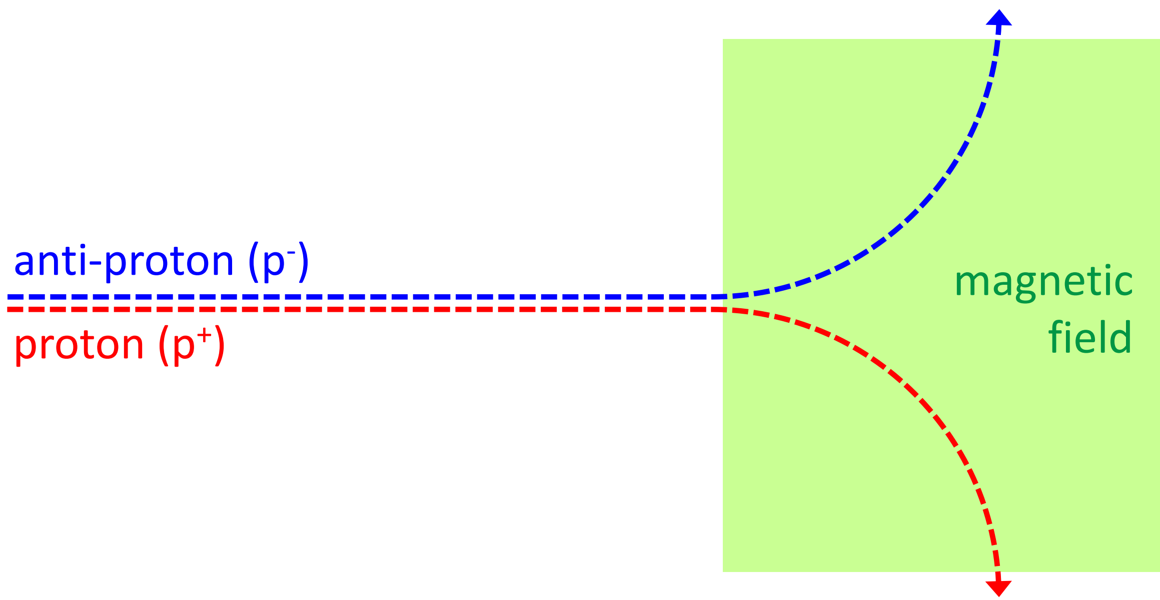
Good: lots of them, easy to detect (in space).

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

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

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).
- **Antineutrons** are neutrons with opposite magnetic moment.

What are anti-particles ?

- **Antiprotons** are protons with negative charge (q=-1).
- **Positrons** (anti-electrons) are electrons with positive charge (q=+1).
- **Antineutrons** are neutrons with opposite magnetic moment.

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.
  (charge = +2)

What are anti-particles ?

- **Antiprotons** are protons with negative charge (q=-1).
- **Positrons** (anti-electrons) are electrons with positive charge (q=+1).
- **Antineutrons** are neutrons with opposite magnetic moment.

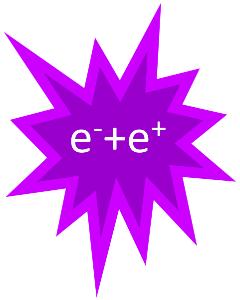
Antimatter

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.
  (charge = +2)

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.

Neutral Particle Astronomy

Neutrons

Good: Not very affected by magnetic fields.

Bad: Short lifetime of 12 minutes → Not useful.

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

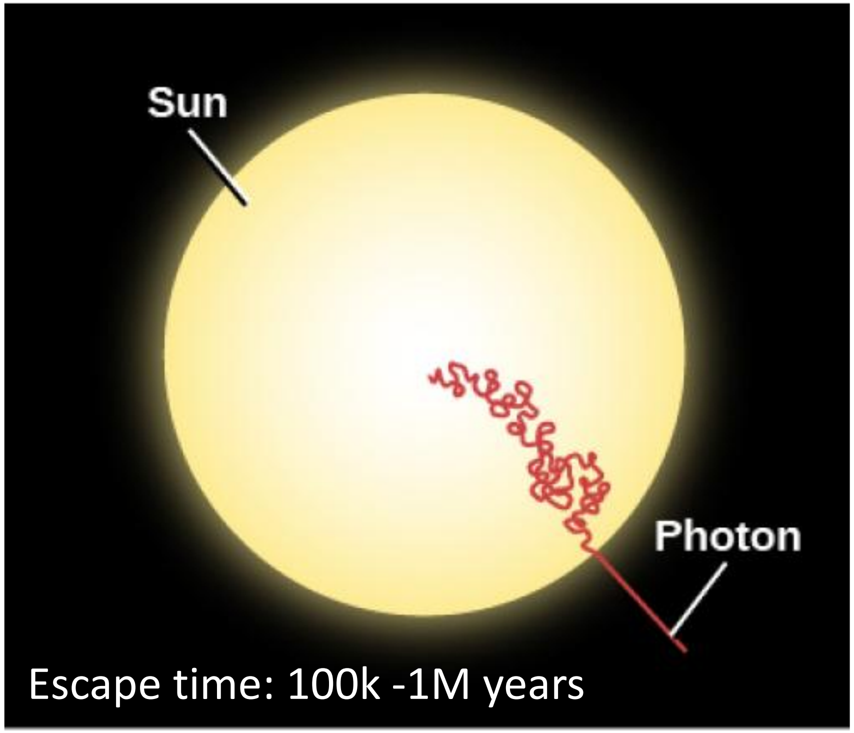
- Neutrinos go through most astrophysical objects: **no shadowing**.
- Neutrinos are unaffected by light, electric fields, magnetic fields.
- Neutrinos allow you to **“see” inside stars** (i.e. stellar cores).

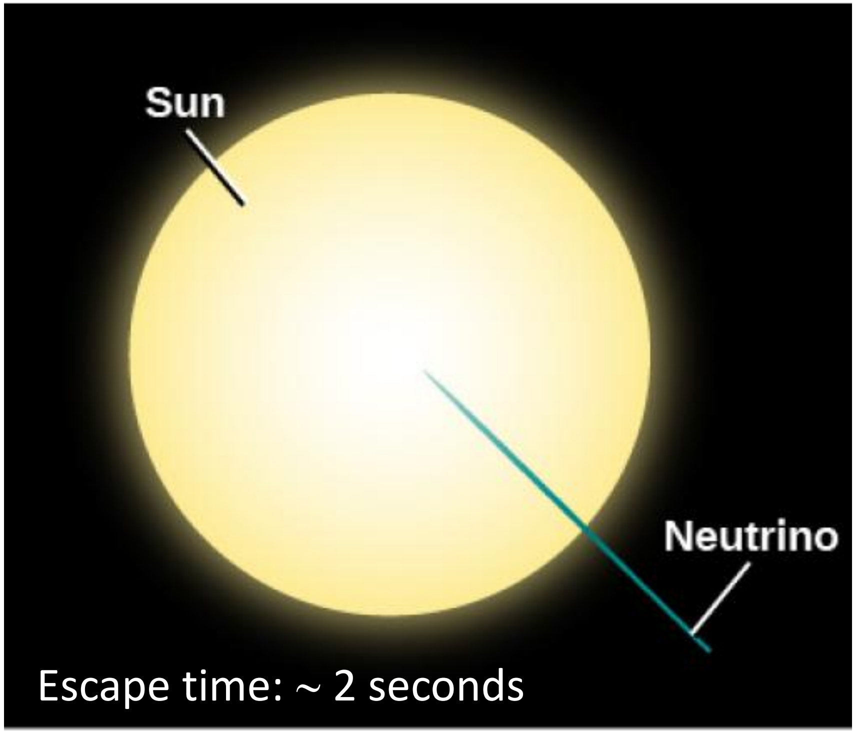
[OpenStax: Astronomy]

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]

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.

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.
- Physics of neutrinos is not completely known.
  → 3 flavors of neutrinos with different masses.
  → Neutrinos oscillate between flavors as they travel.

Neutrino Astronomy

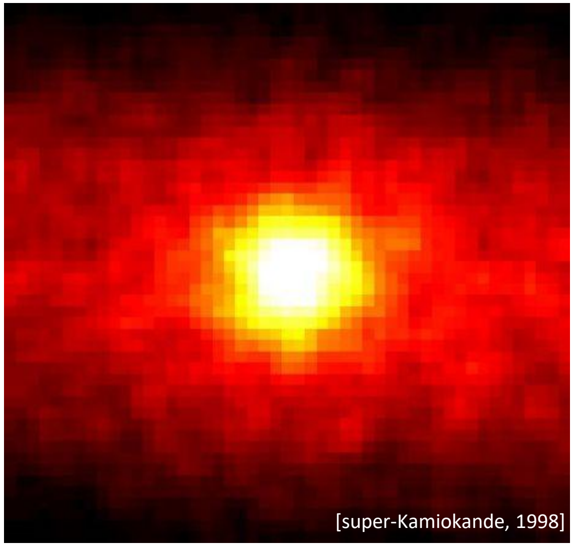
Neutrino Drawbacks

- 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.
- Physics of neutrinos is not completely known.
  → 3 flavors of neutrinos with different masses.
  → Neutrinos oscillate between flavors as they travel.
- 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.

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.
- Physics of neutrinos is not completely known.
  → 3 flavors of neutrinos with different masses.
  → Neutrinos oscillate between flavors as they travel.
- Very large detectors with very low count rates.
  → Event rate ~ 1 count per day (varies significantly).
  → Imaging is possible, but slow and low resolution.

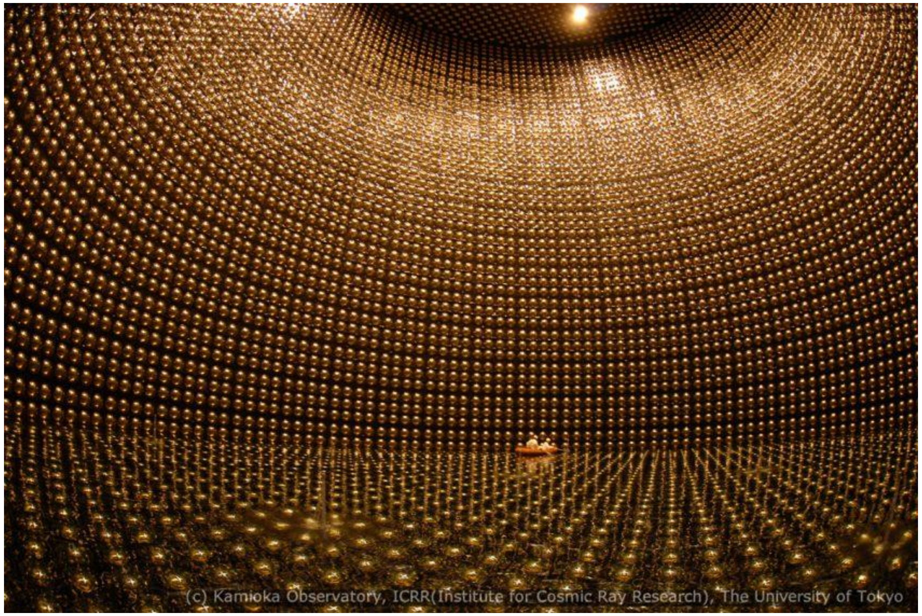


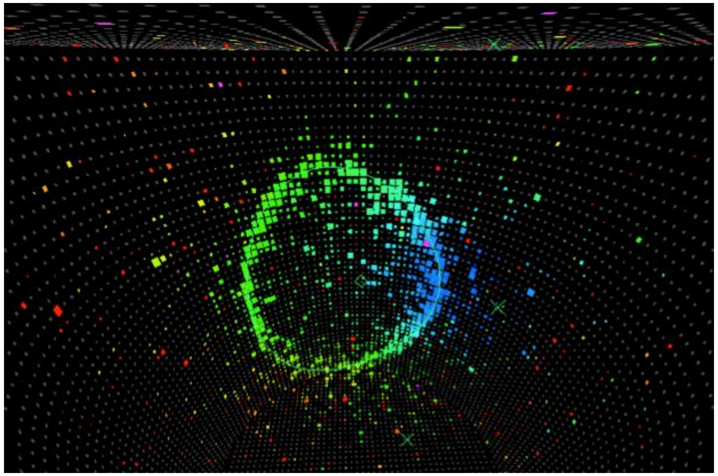
500 day exposure, full sky view.

- Detectors are generally far underground to avoid cosmic rays.
  → Lots of infrastructure needed; only possible in special locations.

Neutrino Detectors

Super-Kamiokande (Japan)

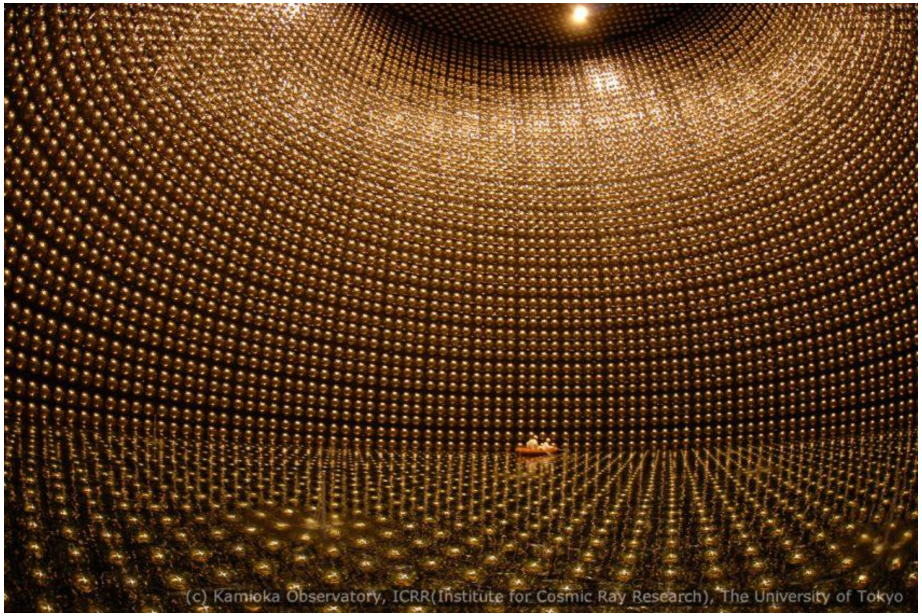


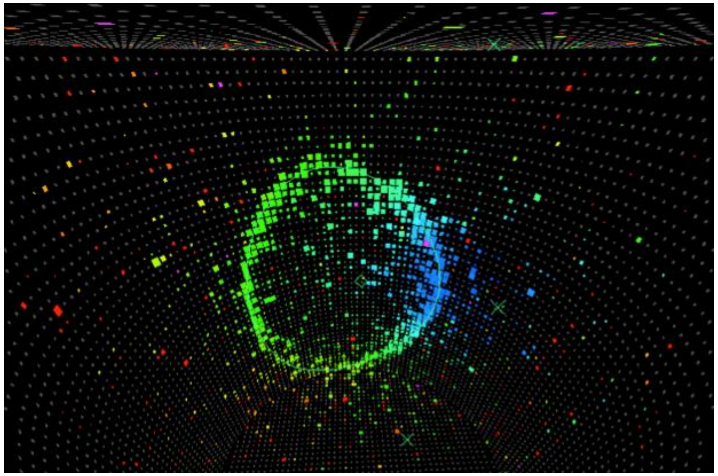


Super-Kamiokande neutrino (ν_e) event.

Neutrino Detectors

Super-Kamiokande (Japan)

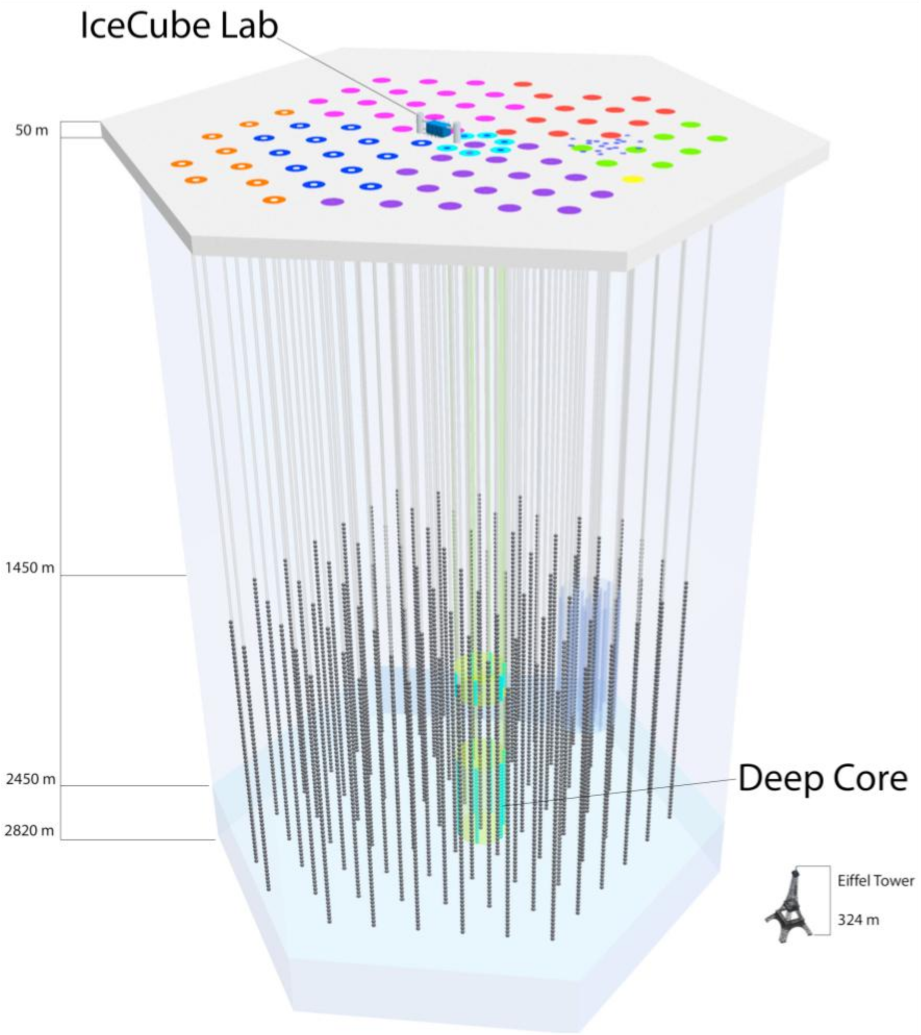




Super-Kamiokande neutrino (ν_e) event.

IceCube (Antarctica)

Cubic kilometer of detectors in very deep ice.



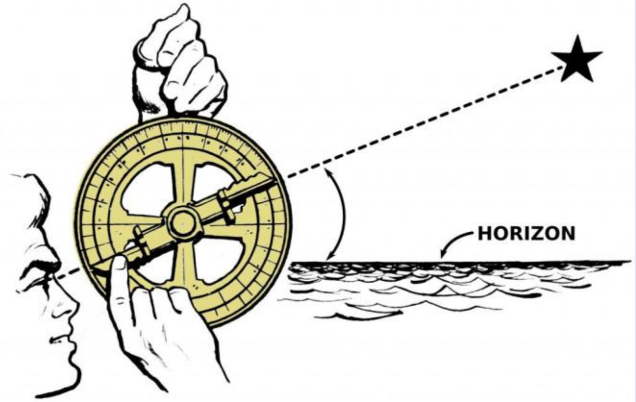
[M.G. Aartsen et al., J.Parallel Distrib.Comput. 75, 198-211 (2015); arXiv:1311.5904]

PollEv Quiz: PollEv.com/sethaubin

Astrolabe

Ancient Astronomy Instrument

- Used for measuring **inclination** of stars.
- Applications: astronomy, navigation, timekeeping.
- Developed by ancient greeks, c. 220-150 BC.
    - → Hypparchus, Apollonius of Perga.
    - → Possibly used by Ptolemy (100-170 AD).

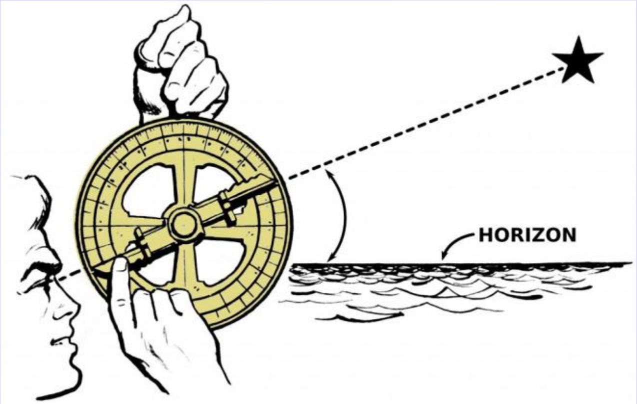


[Pearson Scott Foresman, Wiki Commons]

Astrolabe

Ancient Astronomy Instrument

- Used for measuring **inclination** of stars.
- Applications: astronomy, navigation, timekeeping.
- Developed by ancient greeks, c. 220-150 BC.
  - → Hypparchus, Apollonius of Perga.
  - → Possibly used by Ptolemy (100-170 AD).
- Studied and built by Theon of Alexandria and **Hypatia** (philosopher, astronomer, mathematician), c. 400 AD.



[Pearson Scott Foresman, Wiki Commons]

Hypatia

[by Elbert Hubbard, 1908]

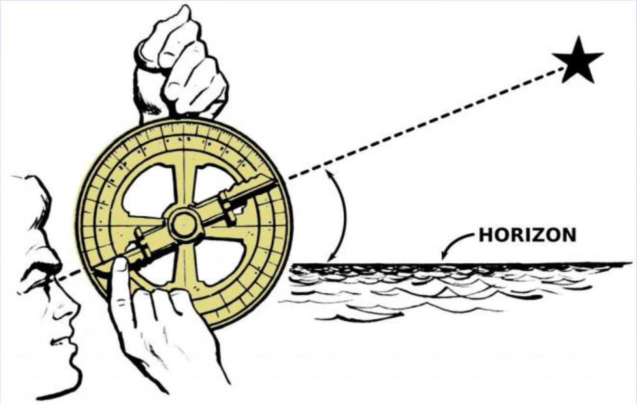
Astrolabe

Ancient Astronomy Instrument

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

  → Hypparchus, Apollonius of Perga.

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



[Pearson Scott Foresman, Wiki Commons]

- Studied and built by Theon of Alexandria and **Hypatia** (philosopher, astronomer, mathematician), c. 400 AD.
- 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.

→ Galileo develops his own telescope and points it at stars and planets (1609).

Galileo's "cannocchiali" telescope
(Museo Galileo, Florence)

Telescope

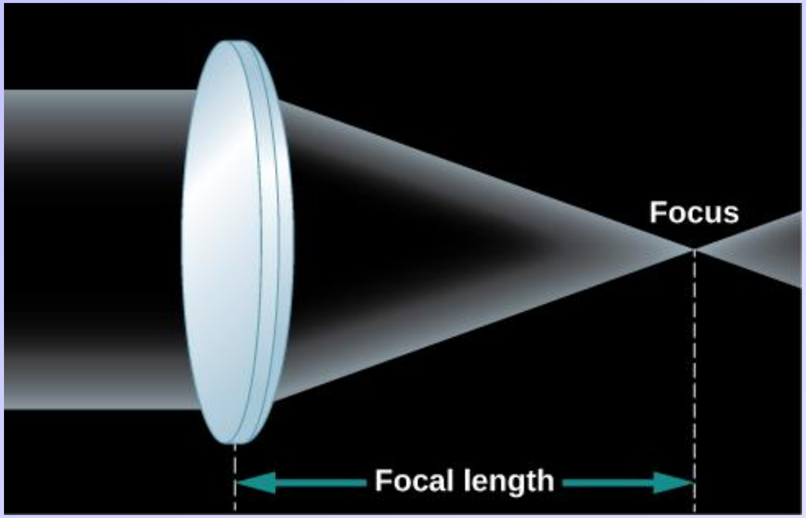
Modern astronomy starts with the invention of the telescope.

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

→ Galileo develops his own telescope and points it at stars and planets (1609).

Galileo's "cannocchiali" telescope
(Museo Galileo, Florence)

Basic Lens Physics



[OpenStax: Astronomy]

Telescope

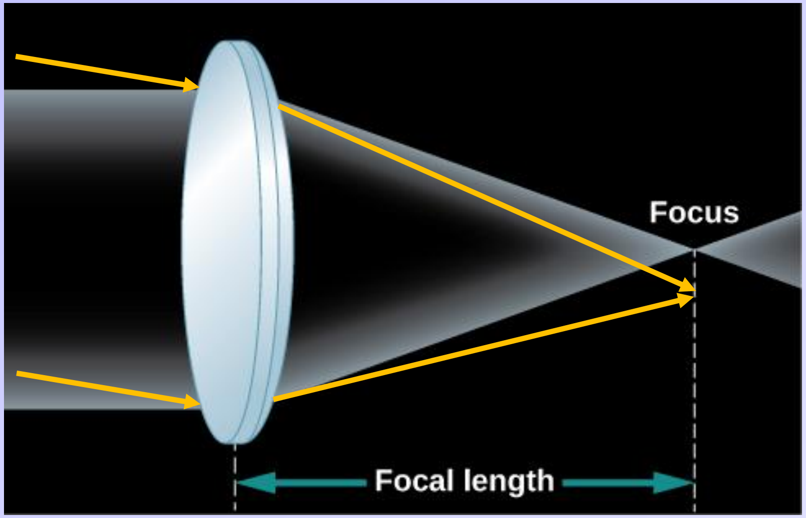
Modern astronomy starts with the invention of the telescope.

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

→ Galileo develops his own telescope and points it at stars and planets (1609).

Galileo's "cannocchiali" telescope
(Museo Galileo, Florence)

Basic Lens Physics



[OpenStax: Astronomy]

Telescope

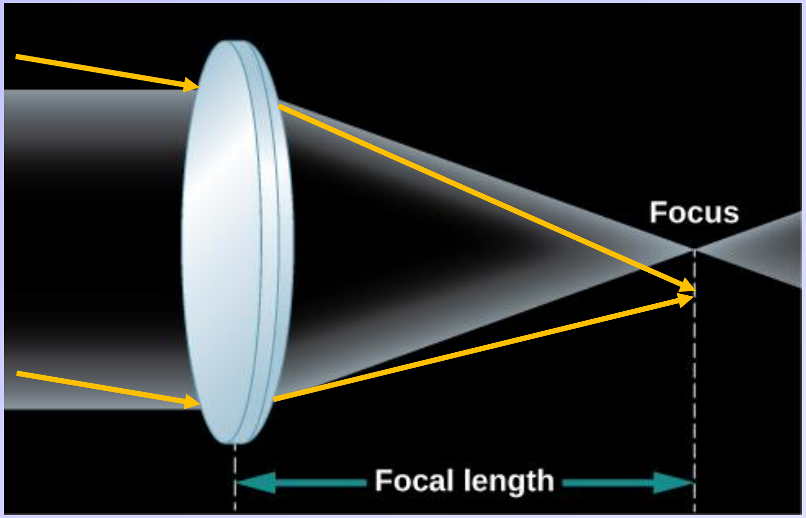
Modern astronomy starts with the invention of the telescope.

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

→ Galileo develops his own telescope and points it at stars and planets (1609).

Galileo's "cannocchiali" telescope
(Museo Galileo, Florence)

Basic Lens Physics



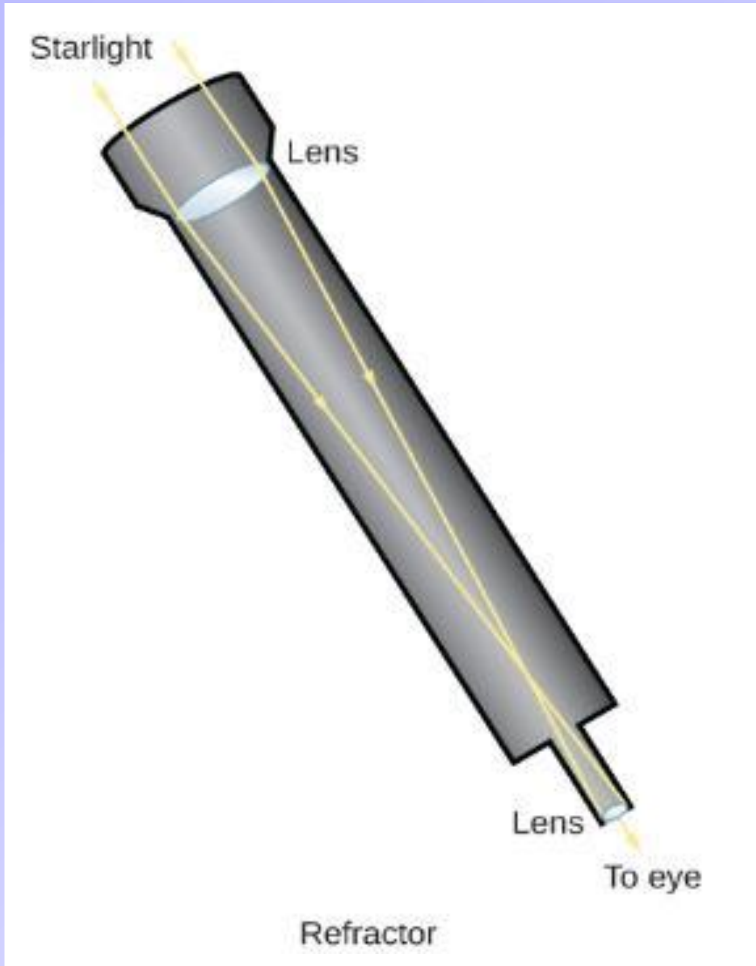
[OpenStax: Astronomy]

Benefits

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

Refracting Telescope

Two or more lenses are used to form an image



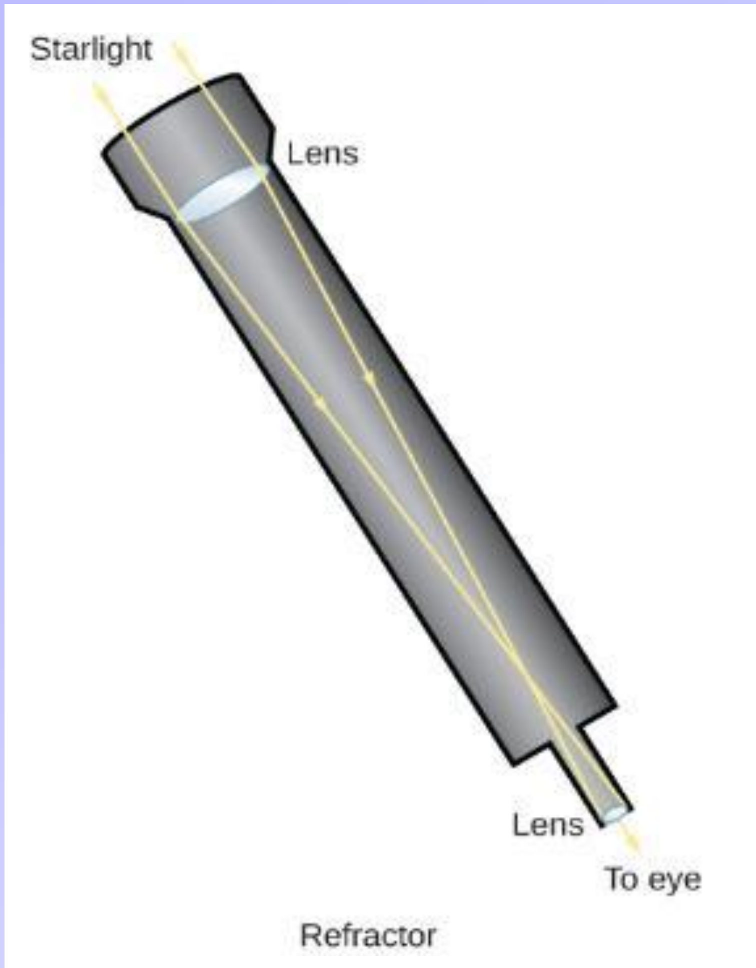
[OpenStax: Astronomy]

Benefits

- Simple to construct.
- Rugged, easy to clean.

Refracting Telescope

Two or more lenses are used to form an image



[OpenStax: Astronomy]

Benefits

- Simple to construct.
- Rugged, easy to clean.

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.
  - → Image is distorted.

Refracting Telescope

Two or more lenses are used to form an image

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

Benefits

- Simple to construct.
- Rugged, easy to clean.

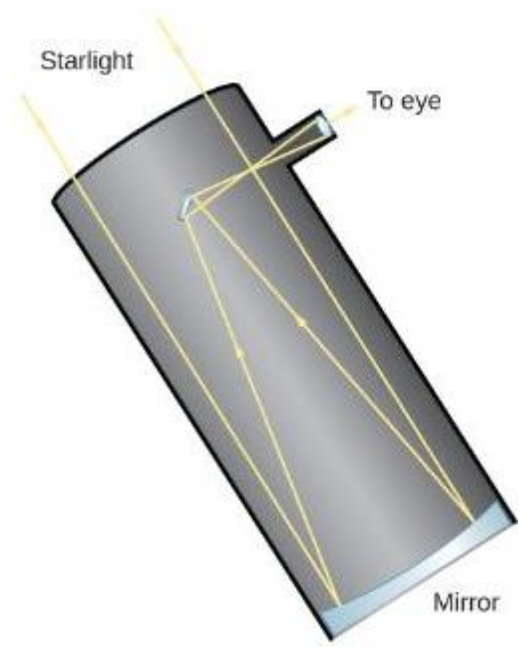
Drawbacks

- 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.
  - → Image is distorted.

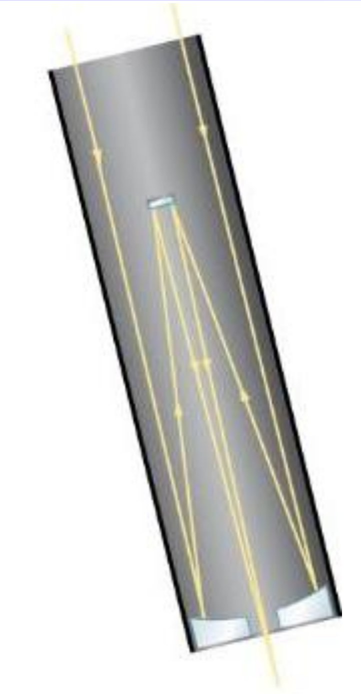
Reflecting Telescope

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



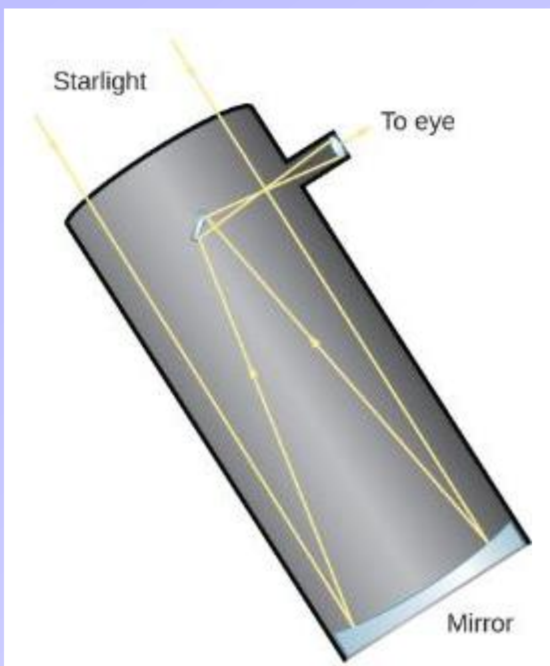
Cassegrain Reflector

[OpenStax: Astronomy]

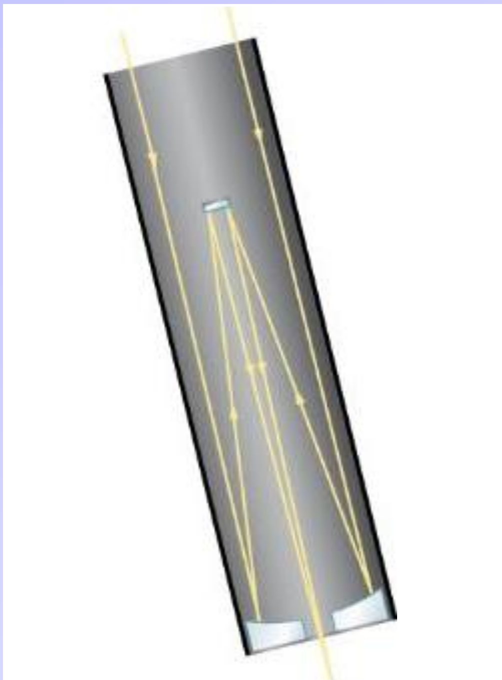
Reflecting Telescope

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



Cassegrain Reflector

Benefits

- No chromatic aberrations.
- Glass defects do not matter.
- Large mirror can be supported across its entirety.
  → Sag is less of problem.

Drawbacks

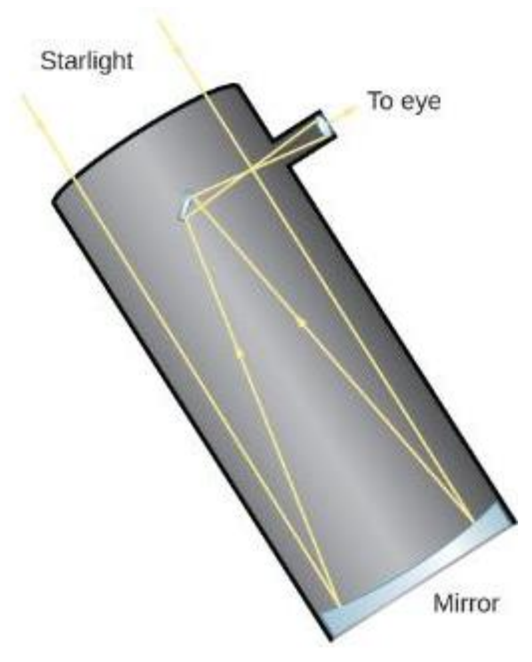
- Open to air: more cleaning.
- Secondary mirror and support structure introduce diffraction effects from their shadows.

[OpenStax: Astronomy]

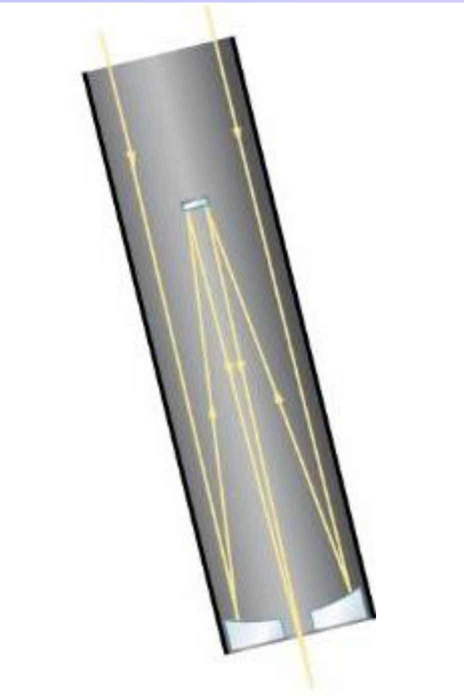
Reflecting Telescope

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


Cassegrain Reflector

Benefits

- No chromatic aberrations.
- Glass defects do not matter.
- Large mirror can be supported across its entirety.
  - → Sag is less of problem.

Drawbacks

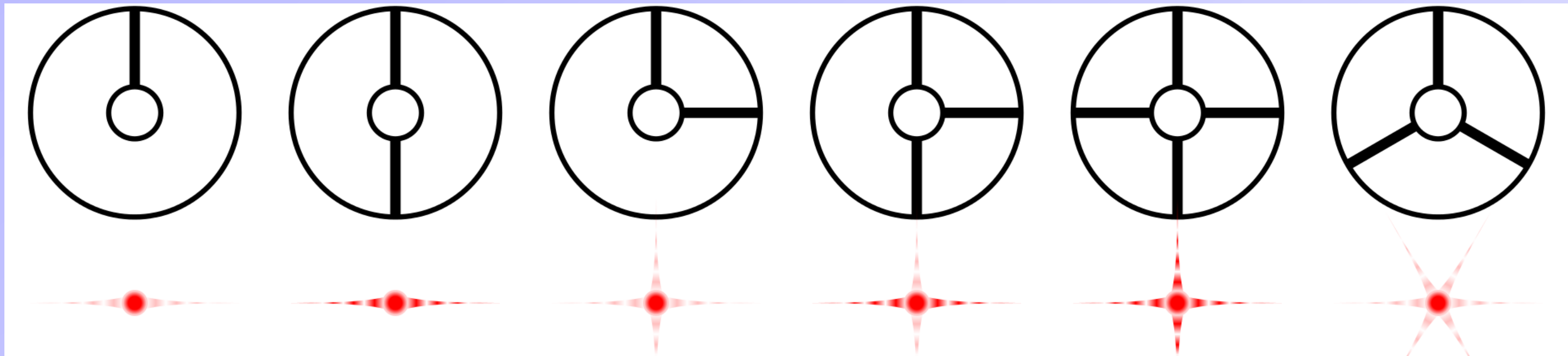
- Open to air: more cleaning.
- Secondary mirror and support structure introduce diffraction effects from their shadows.

Almost all scientific telescopes are reflectors.

[OpenStax: Astronomy]

Star Spikes

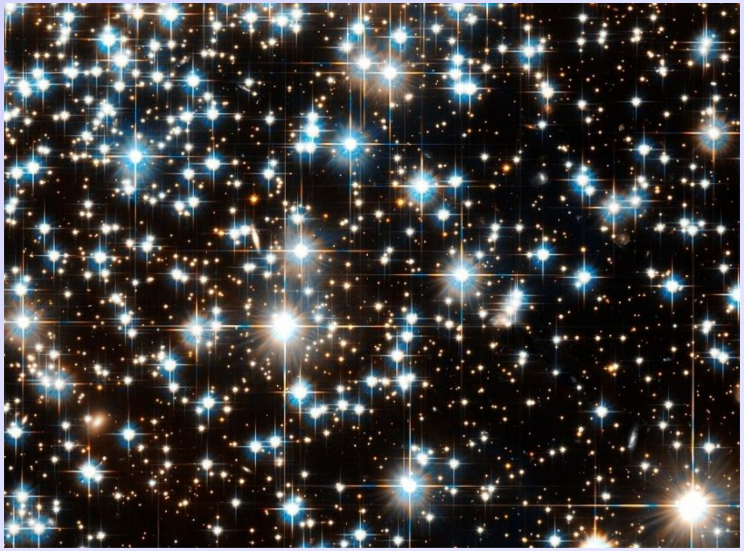
Shadow from support structure for secondary mirror generates “star spikes”.



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

[ESA/Webb, NASA & CSA, M.Zamani, M. G. Guarcello, and the EWOCS team]

Star Spikes from James Webb Space Telescope image (Westerlund 1 super star cluster).



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

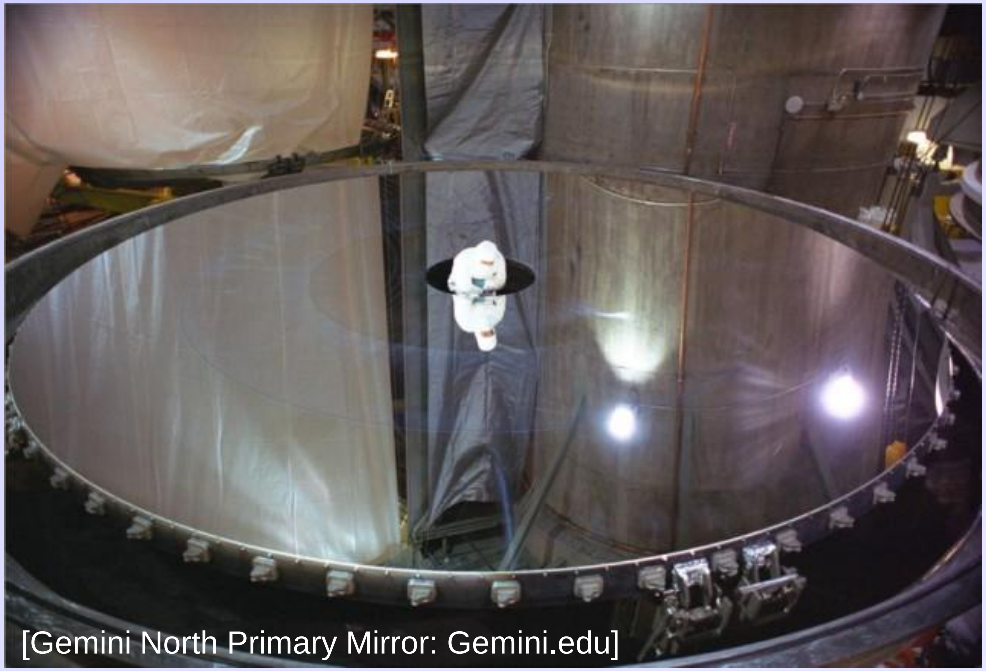
Star Spikes from a Hubble Space Telescope image (NGC 6397).

Single Mirror Telescopes


[Gemini North: OpenStax]

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

- → 8.1 m primary mirror.
- → 1 m secondary mirror.
- → Locations: Hawaii & Chile


[Gemini North Primary Mirror: Gemini.edu]

Segmented Telescopes

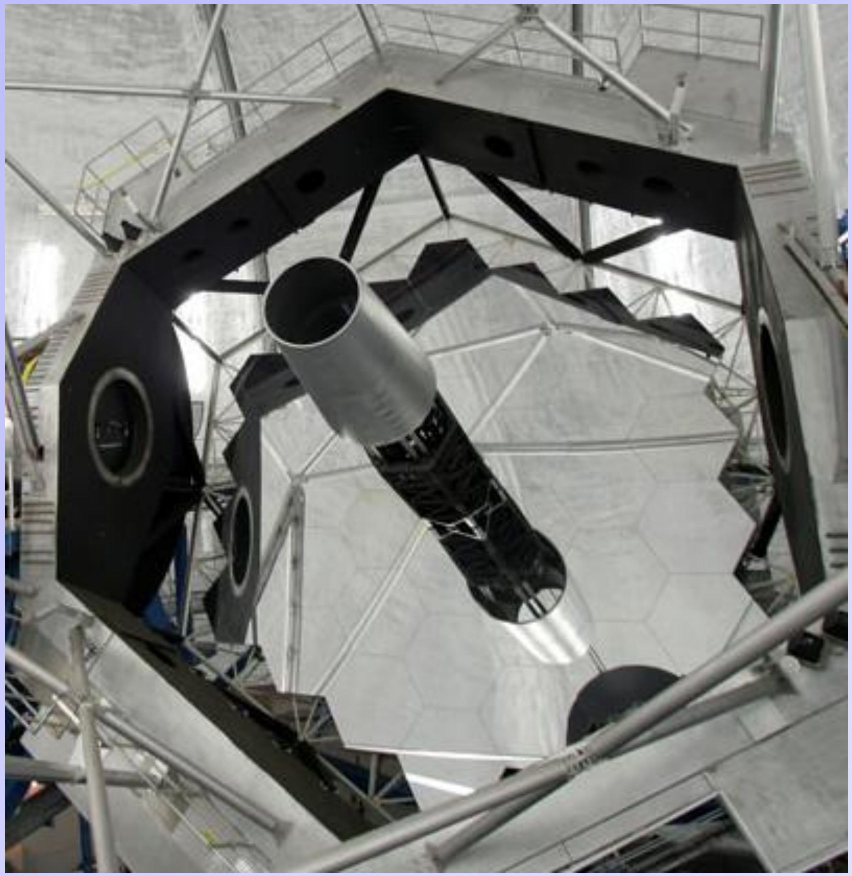
Problem: A single mirror larger than 8 m will experience significant sag issues.

Solution: Segment the mirror into smaller sections for easier support.

Segmented Telescopes

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

Solution: Segment the mirror into smaller sections for easier support.



36-segment mirror of the Keck telescope (Hawaii)

18-segment mirror of the James Webb Space Telescope.