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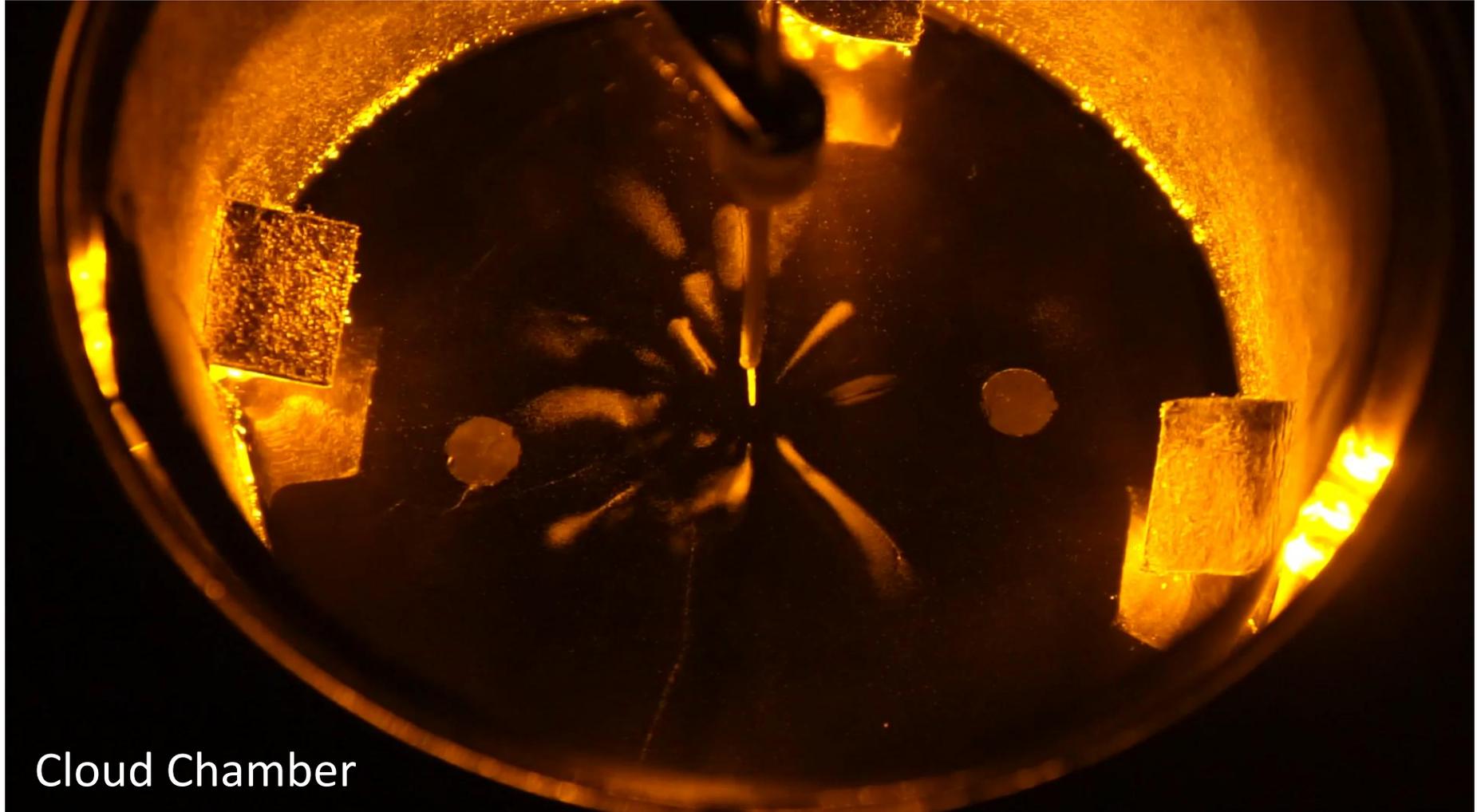
Wednesday, February 26, 2025 (Week 5, lecture 12) – Chapter 16.1-2, 6.

1. Nuclear particles … neutrinos

2. Astrolabe – ancient instrument

2. Refractive Telescopes

3. Reflecting Telescopes, part 1

REMINDER: **Midterm #1** is on Friday, February 20.

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

Cloud Chamber

Charged Particle Astronomy

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

(charge = +2)

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

$\rightarrow$ Stars emit p+ and e- as **solar wind**.

$\rightarrow$ **Cosmic rays** from violent stellar events.

Charged Particle Astronomy

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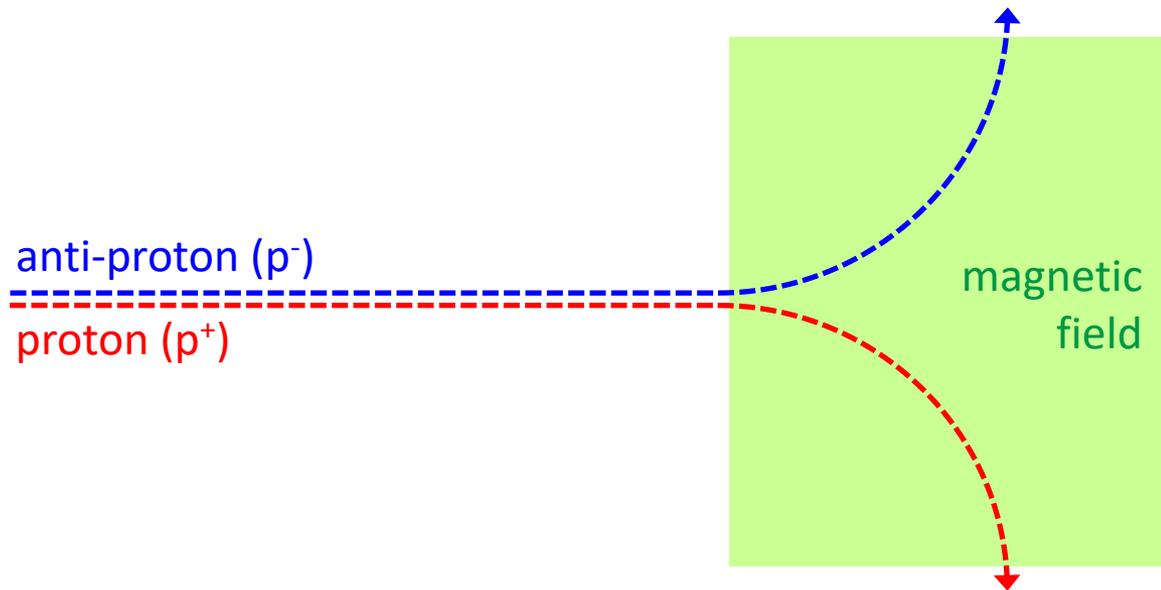
(charge = +2)

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.

anti-proton (p⁻)

proton (p⁺)

magnetic field

Particle does <u>not</u> "point back" to its origin.

→ not useful for imaging.

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 <u>almost no mass</u> and **barely interact** with anything.

→ They travel at speed of light (roughly).
→ They feel gravity and weak force (in nucleus).

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

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

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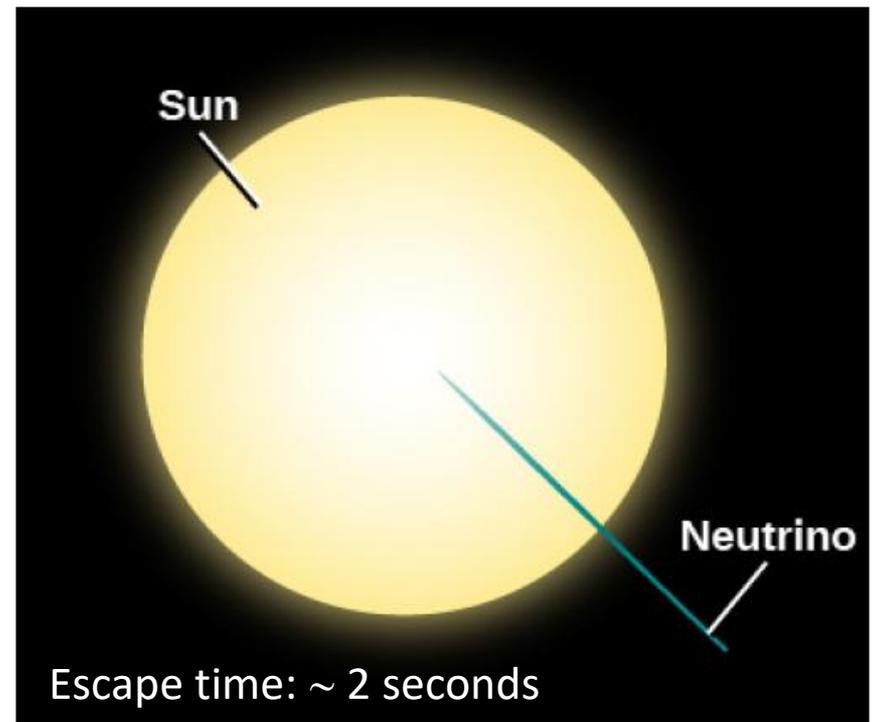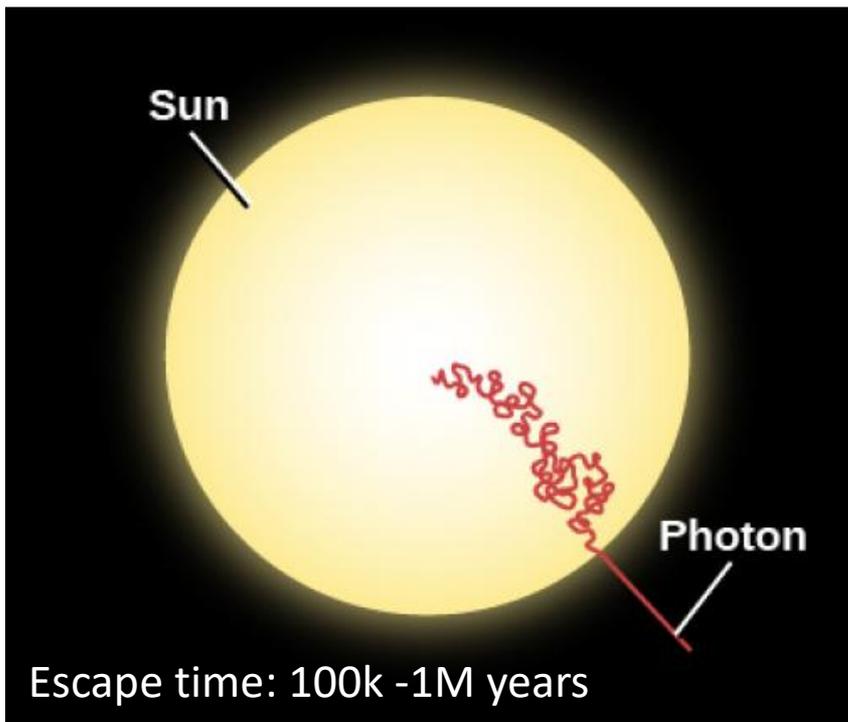
Neutrino Astronomy

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).

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).

Escape time: 100k -1M years

Escape time: ~ 2 seconds

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 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.
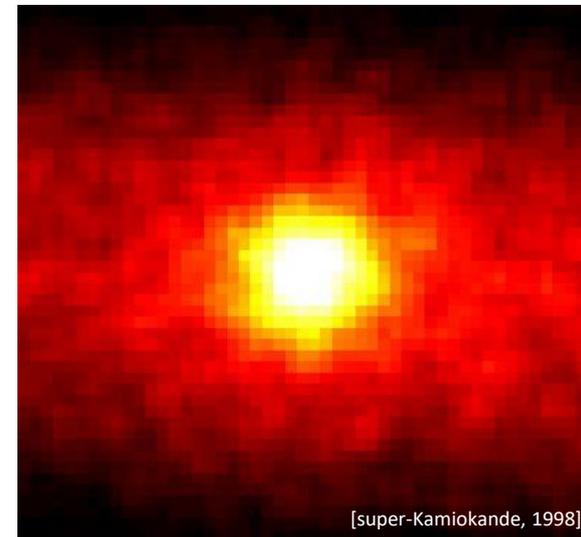
Neutrino Astronomy

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.

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

[super-Kamiokande, 1998]

500 day exposure, full sky view.
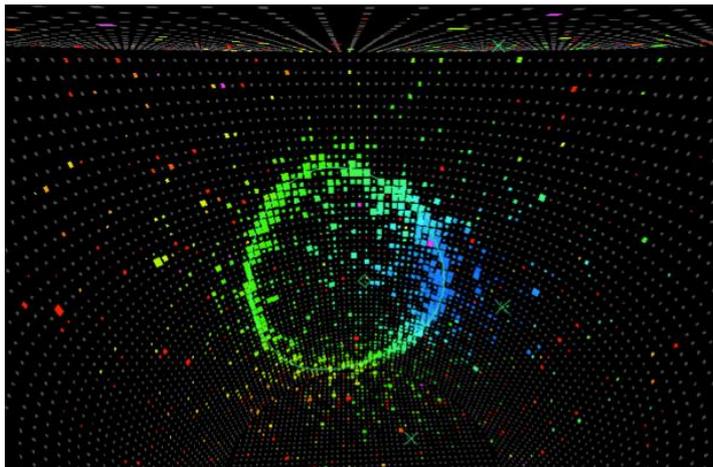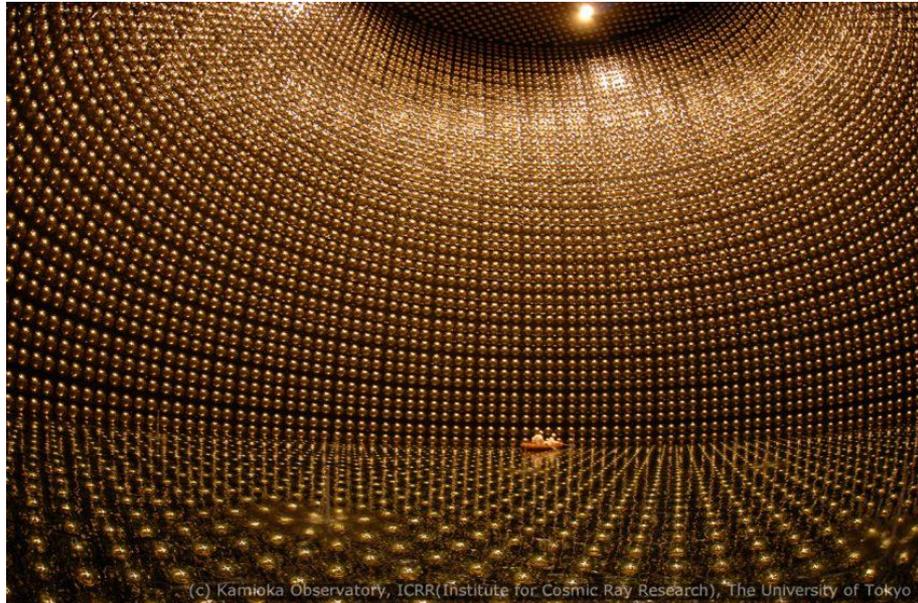
Neutrino Detectors

Super-Kamiokande (Japan)
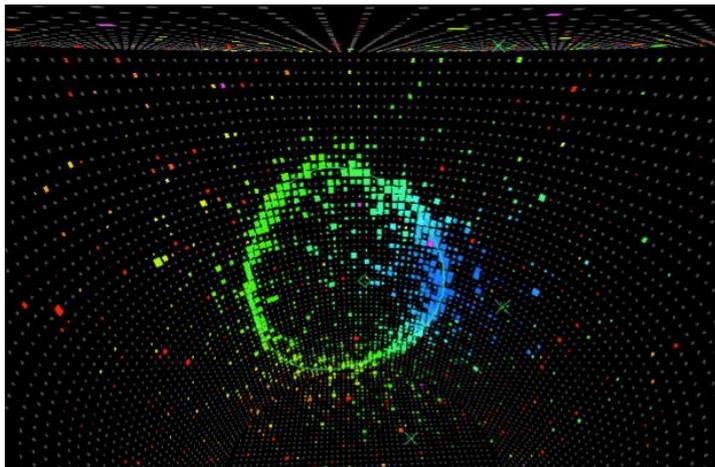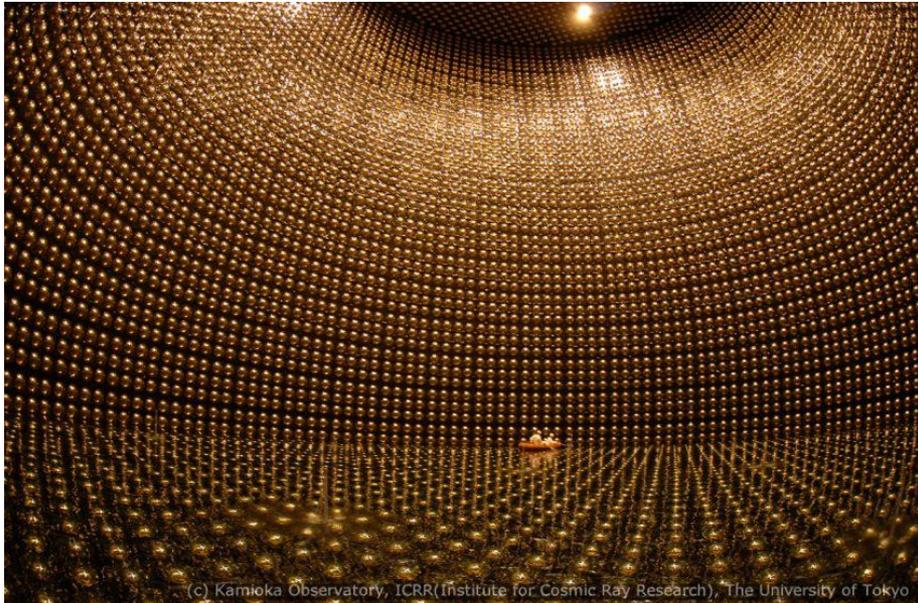
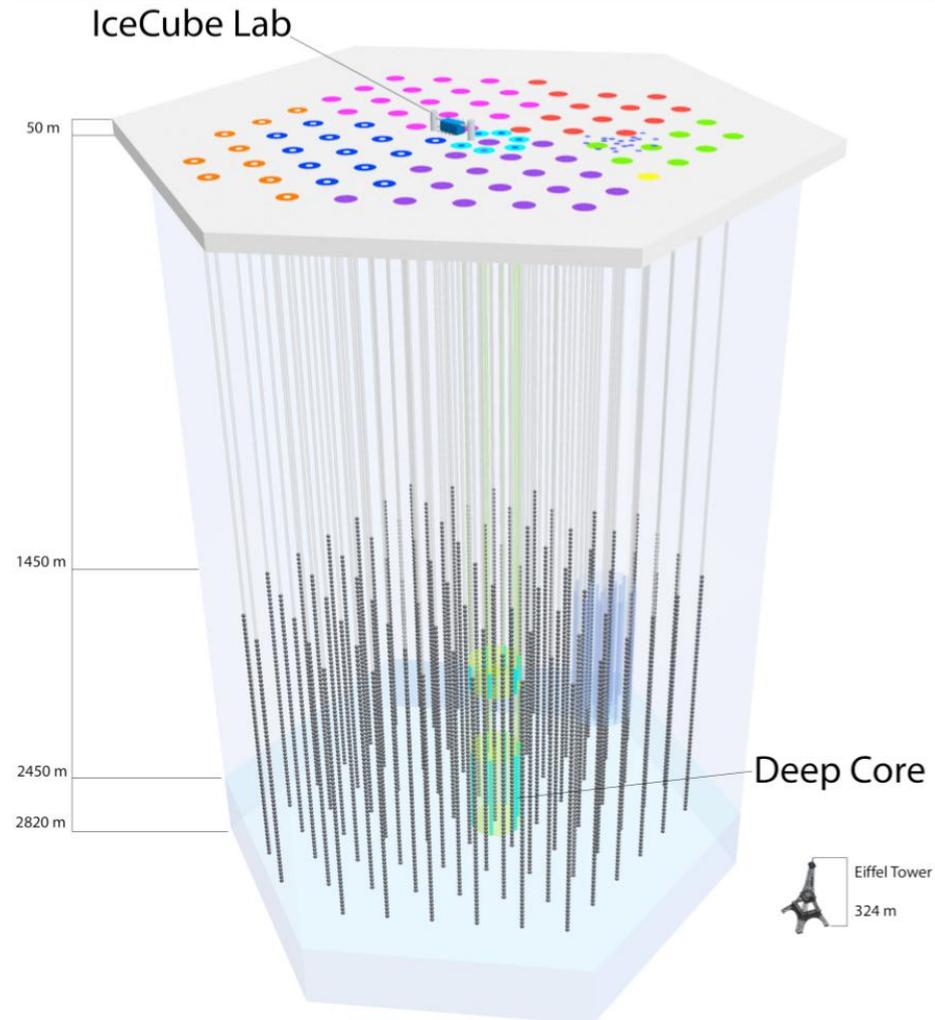*Super-Kamiokande neutrino (ν_e) event.*

Neutrino Detectors

Super-Kamiokande (Japan)

Super-Kamiokande neutrino (ν_e) event.

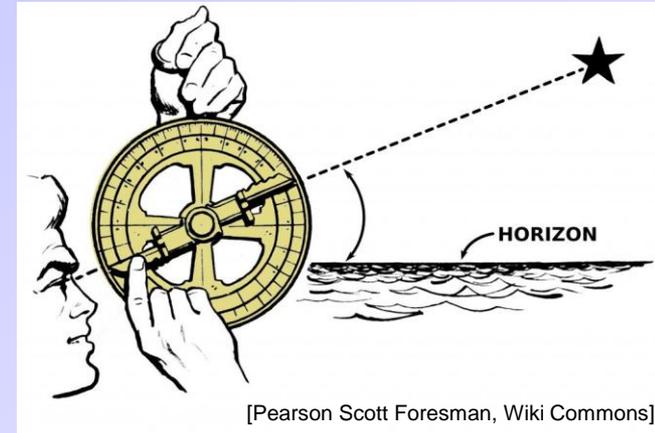**IceCube** (Antarctica)
Cubic kilometer of detectors in very deep ice.

IceCube Lab

50 m

1450 m

2450 m

2820 m

Deep Core

Eiffel Tower
324 m

[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
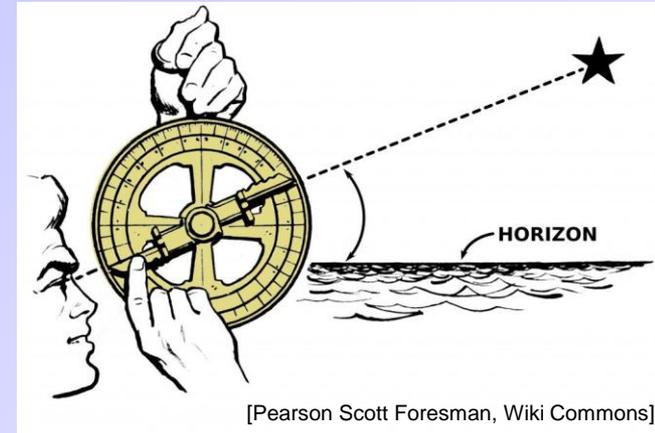

[Pearson Scott Foresman, Wiki Commons]

➢ 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).

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.

HORIZON

[Pearson Scott Foresman, Wiki Commons]

Hypatia
[by Elbert Hubbard, 1908]

Astrolabe

Ancient Astronomy Instrument

[Pearson Scott Foresman, Wiki Commons]

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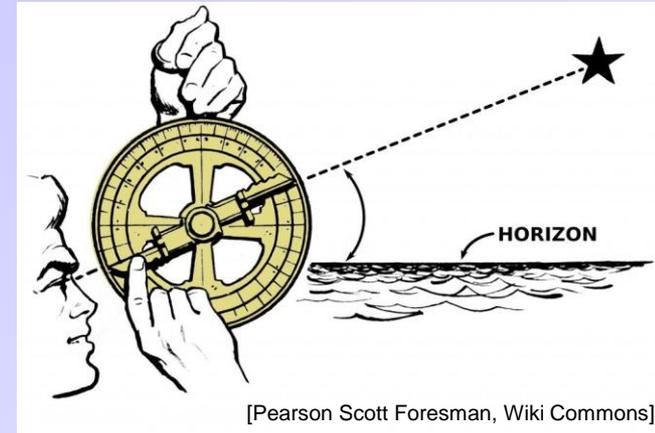
➢ Refined by **Islamic astronomers** (starting in 8th century AD).

  → 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).

[By Sailko - Own work, CC BY-SA 3.0]

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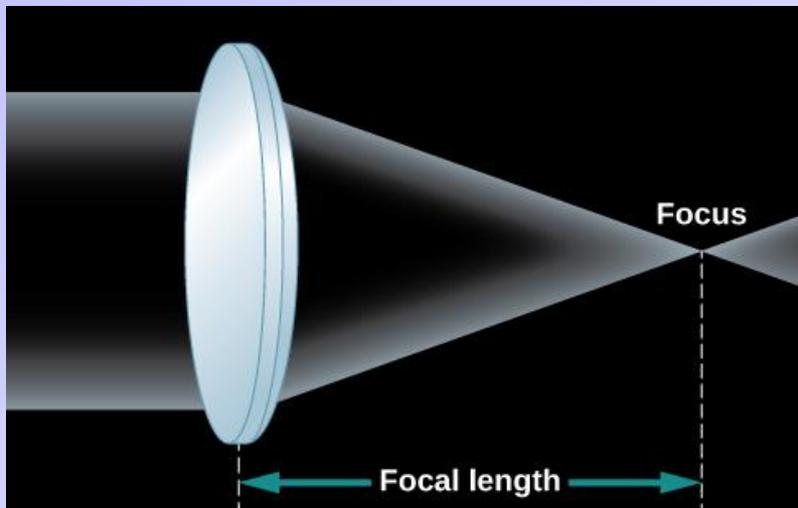
→ Galileo develops his own telescope and points it at stars and planets (1609).

[By Sailko - Own work, CC BY-SA 3.0]

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

Basic Lens Physics

Focus

Focal length

[OpenStax: Astronomy]

Telescope

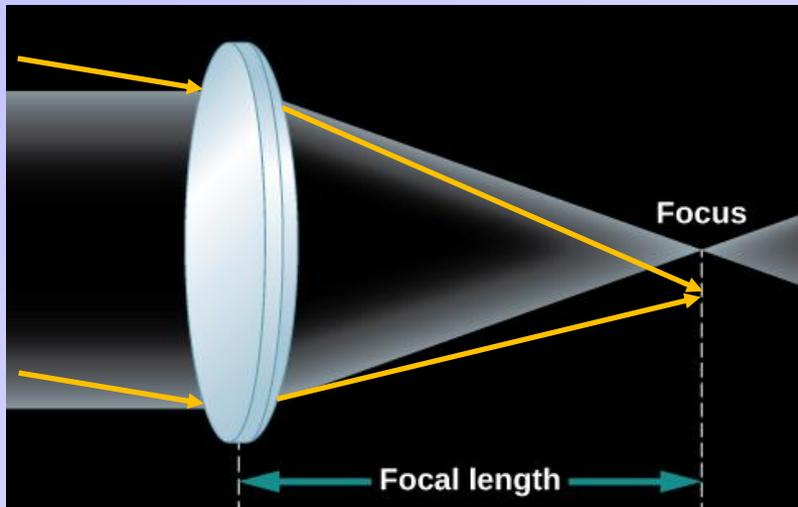Modern astronomy starts with the invention of the telescope.

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

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

[By Sailko - Own work, CC BY-SA 3.0]

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

Basic Lens Physics

Focus

Focal length

[OpenStax: Astronomy]

Telescope

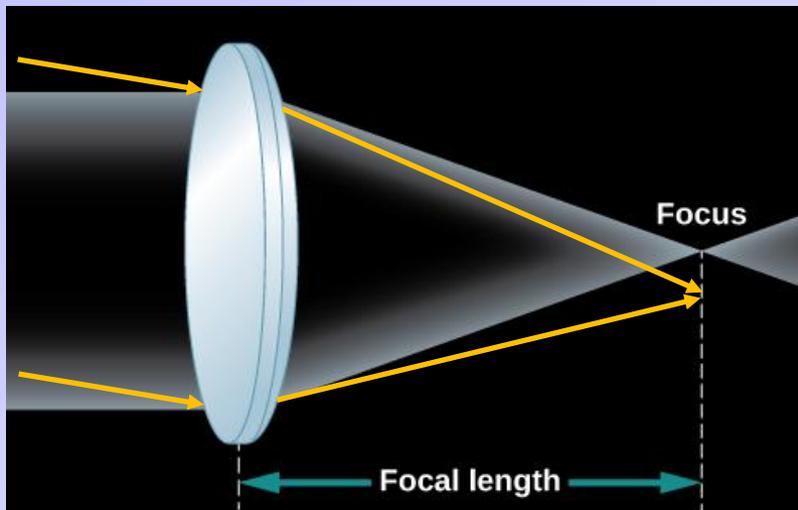Modern astronomy starts with the invention of the telescope.

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

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

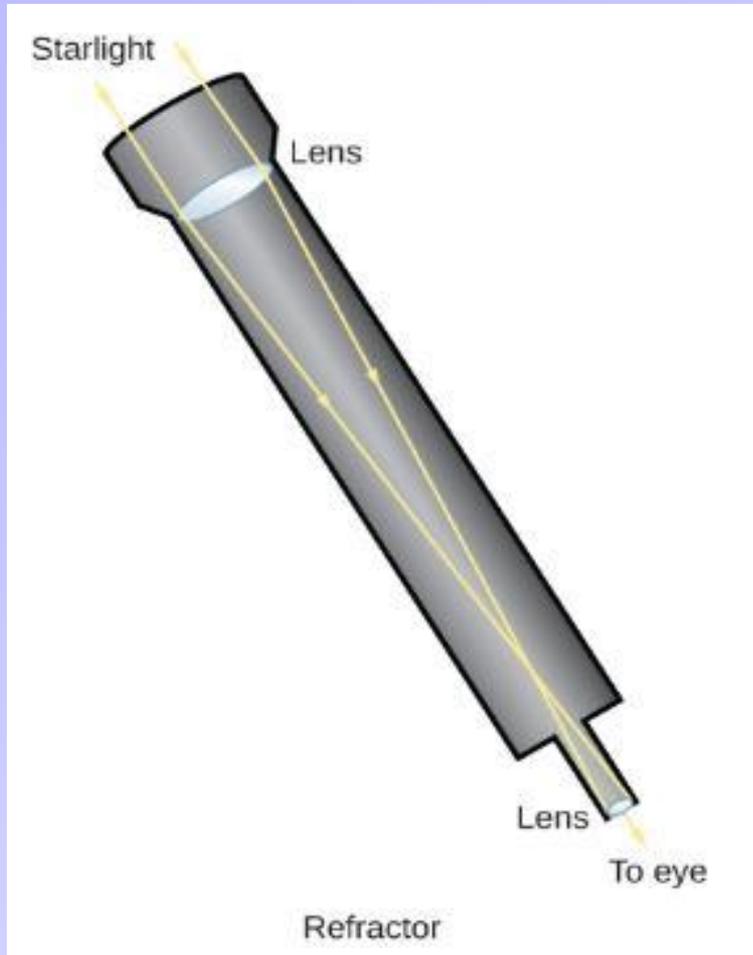*Galileo's "cannocchiali" telescope* (Museo Galileo, Florence)

Basic Lens Physics

Focus

Focal length

[OpenStax: Astronomy]

Benefits

▪ **More light** forms image (compared with eye).

▪ Image **magnification**.

Refracting Telescope
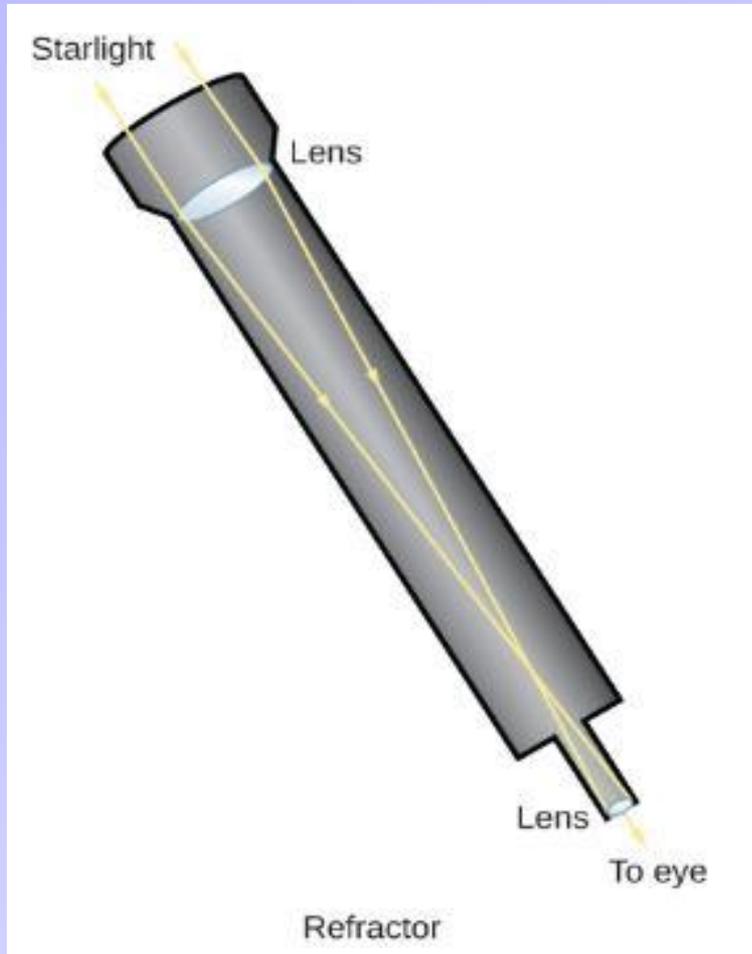
Two or more lenses are used to form an image

Refractor

[OpenStax: Astronomy]

Benefits

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

Refracting Telescope

Two or more lenses are used to form an image

Starlight

Lens

Lens

To eye

Refractor

[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

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.
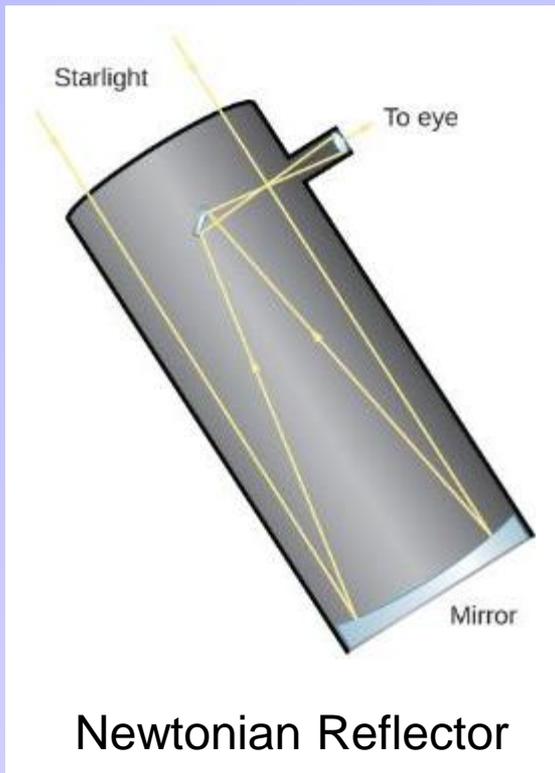
   → Image is distorted.

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

Reflecting Telescope

A **large curved mirror** collects the light and then focuses it onto a secondary smaller mirror.
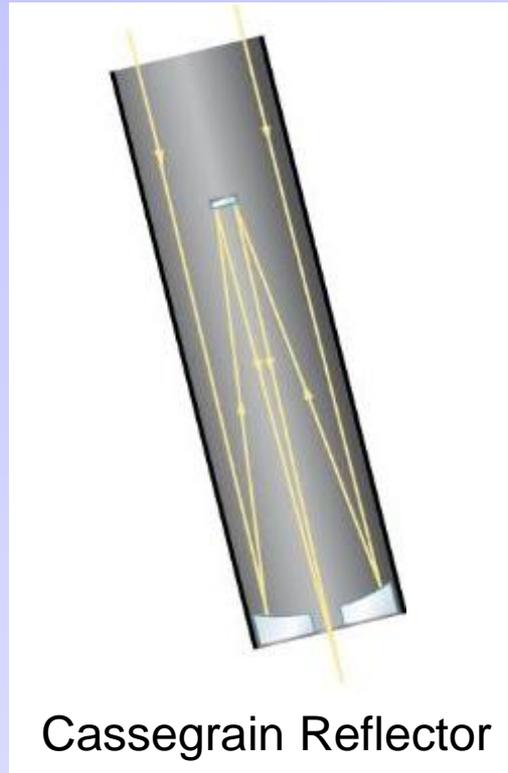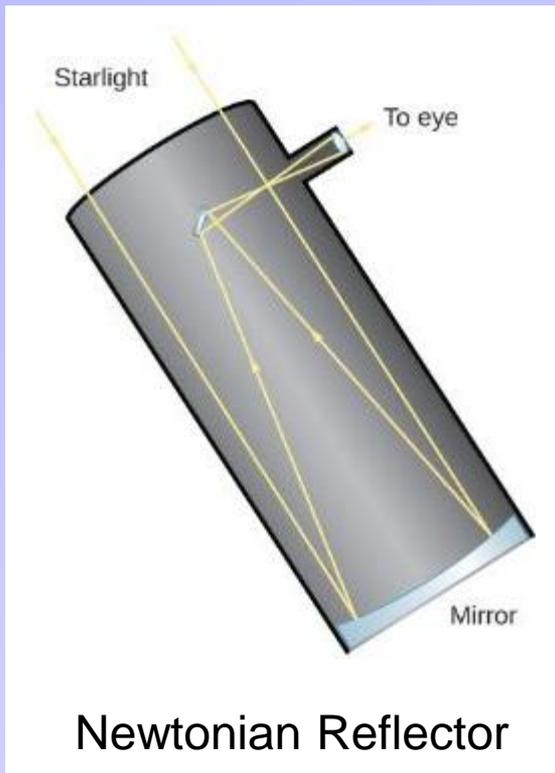
→ invented by Isaac Newton.
→ Parabolic curved mirror is ideal.

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.

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.

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.

Benefits

➢ No chromatic aberrations.

➢ Glass defects do not matter.

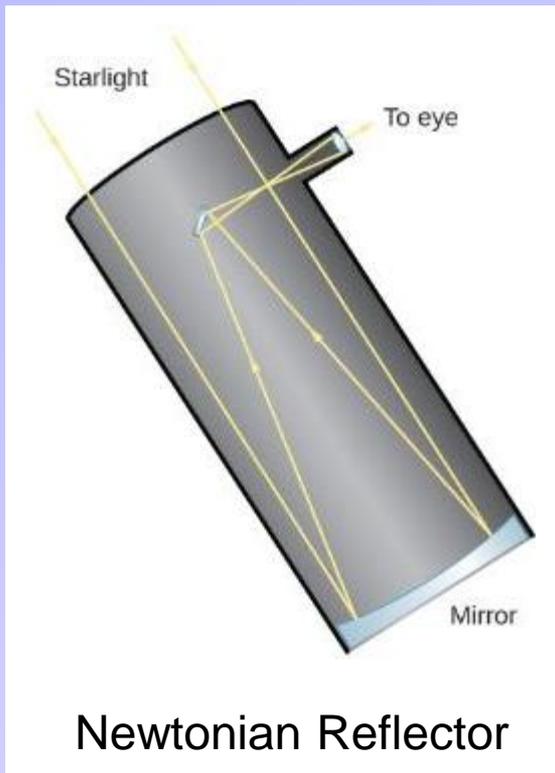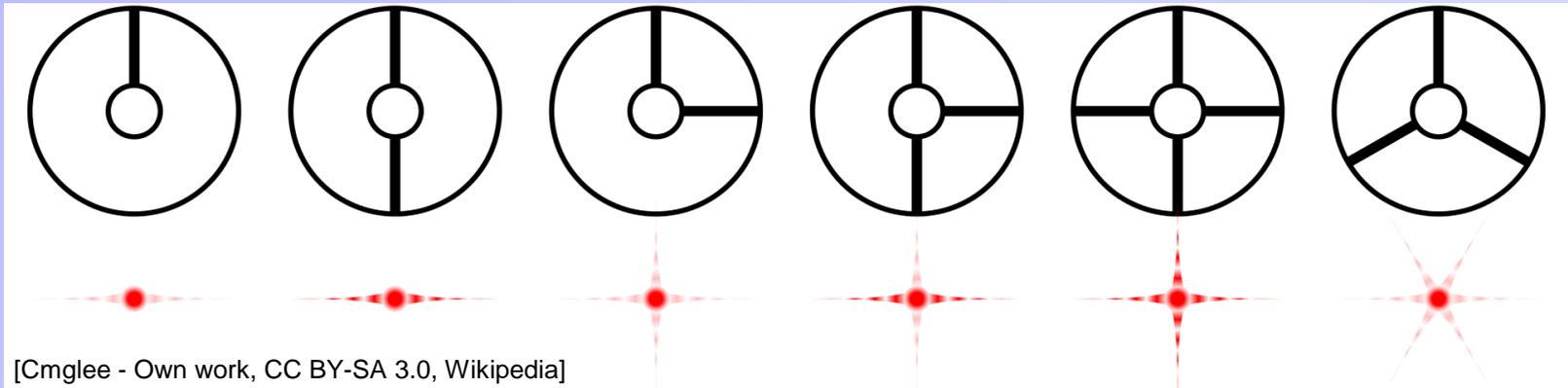➢ Large mirror can be supported across its entirety.

→ Sag is less of problem.

Drawbacks

▪ Open to air: more cleaning.

▪ Secondary mirror and support structure introduce diffraction effects from their shadows.
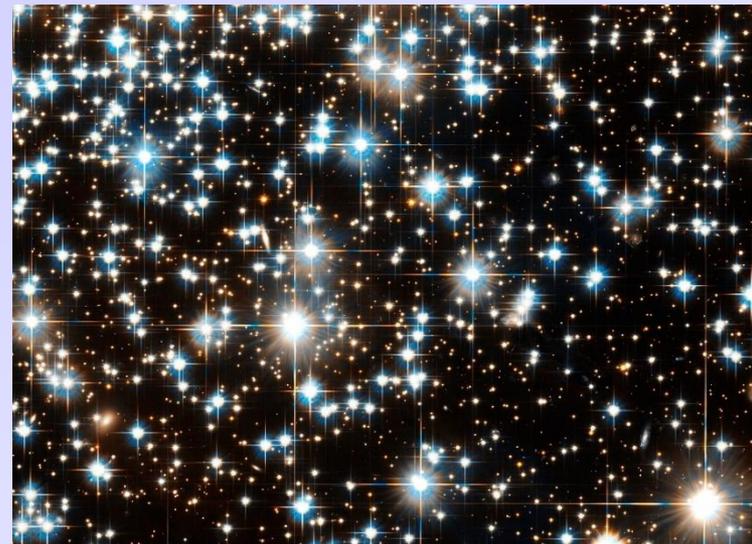
Newtonian Reflector

Cassegrain Reflector

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]

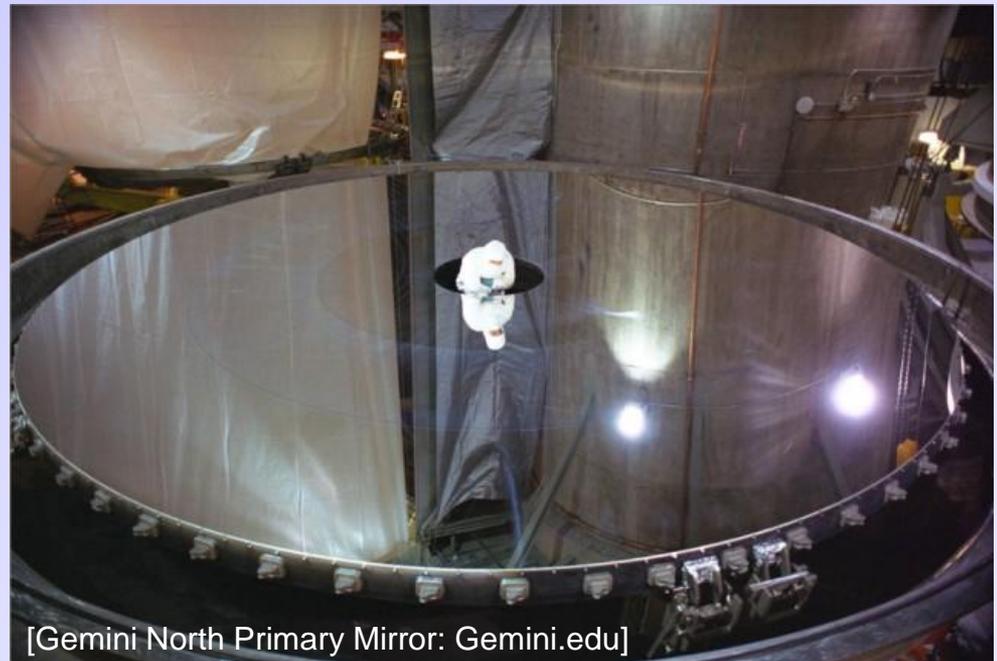Star Spikes from a Hubble Space Telescope image (NGC 6397).

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

[NASA, Wikipedia]

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