Midterm Topics (next Monday, Sept. 14)

1. Scientific units, notations
2. Exponents, trigonometry
3. Length scales in the universe, astronomy units
4. Eratosthenes: radius of the Earth
5. Retrograde motion of the planets, epicycles
6. Earth’s axis tilt, seasons, precession
7. Important stars and constellations
8. Kepler’s Laws
9. Galileo’s & Newton’s contributions
10. Newton’s laws
11. Conservation laws: Energy, momentum, angular momentum
12. Kinetic & Potential Energy

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12. Kinetic & Potential Energy
13. Gravity
14. Circular Motion
15. Escape velocity
16. Tides
17. Electromagnetic waves
18. Electromagnetic spectrum
19. Blackbody radiation
20. Photons
21. Electronic structure of atoms
22. Spectroscopy
23. Doppler effect
24. Nuclear particles
25. P-P chain solar fusion

[Not today's topics]

Midterm Format

- 4 questions (or if two are really easy then 5 questions)
- Mix of quantitative and qualitative questions
- Time: 9 am – 9:50 am
- I will send you the PDF with the midterm questions at 9 am (via Blackboard and e-mail).
- You must upload your answers in PDF to Gradescope (same as homework).
- Submission window closes at 10 am.
- Answer each question on a separate piece of paper(s) – same as homework. You do not need to print out the test.
- Write legibly. Points will be taken off for messy and unreadable test answers.
- Take a picture of each answer for submission to Gradescope (same as homework).

Midterm Rules

- Closed book test.
- No internet searches ... No internet usage.
- No phones, except for taking photos of your test (after 9:50 am)
- No use of course website, Blackboard course notes, or OpenStax Astronomy book.
- Calculator recommended (with trig functions).
- **Proctoring:** The midterm will be taken during a Zoom session. You must have your **webcamera ON** so that I can see you, i.e. you should not be working at your computer, but instead working with pen and paper on your test. Please remove any digital backgrounds on Zoom.
- Install **Honorlock** add-in to your browser (Chrome is required).

Today's Topics

Friday, September 11, 2020 (Week 3, lecture 11) – 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**

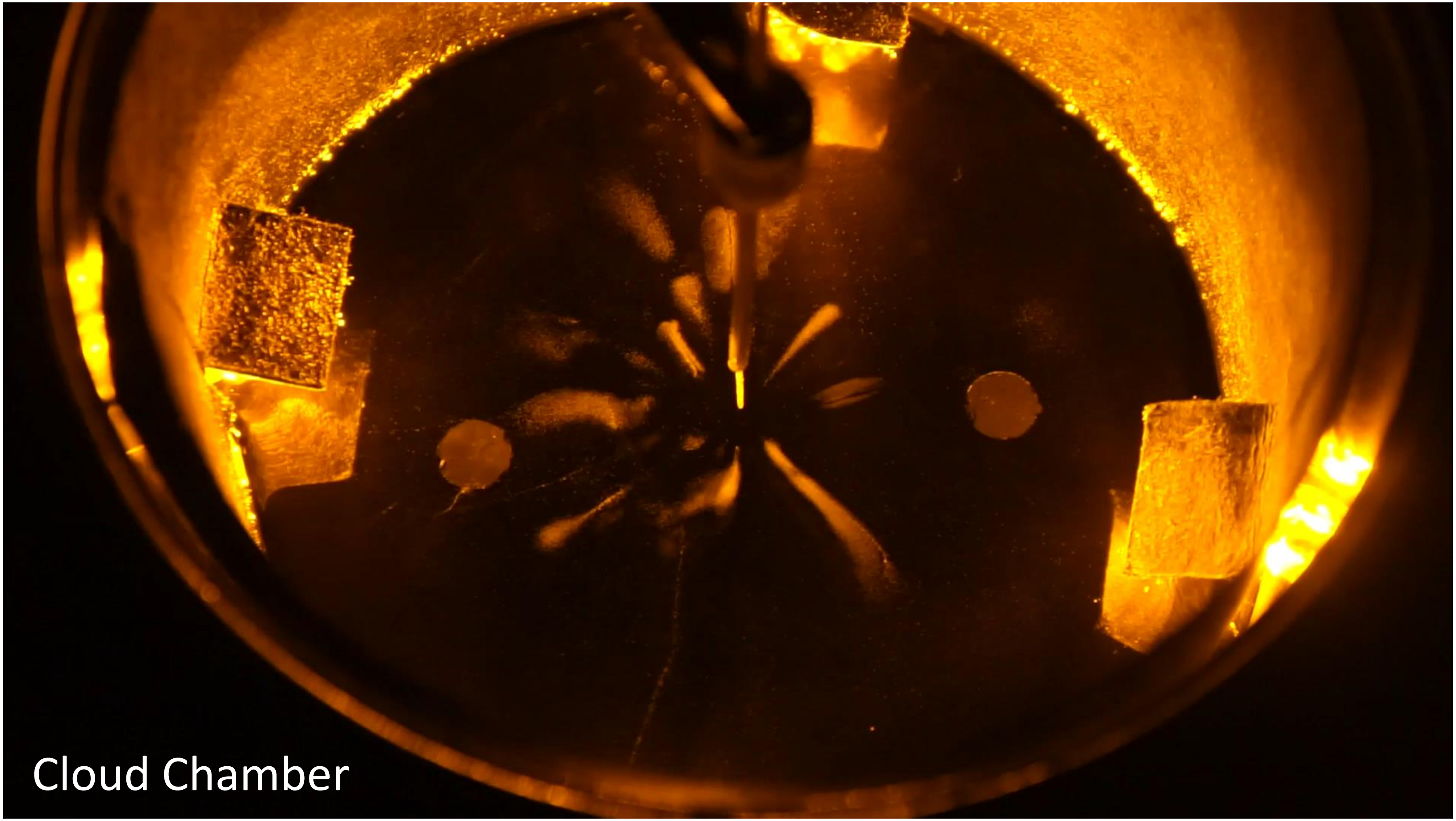
(charge = +2)

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]

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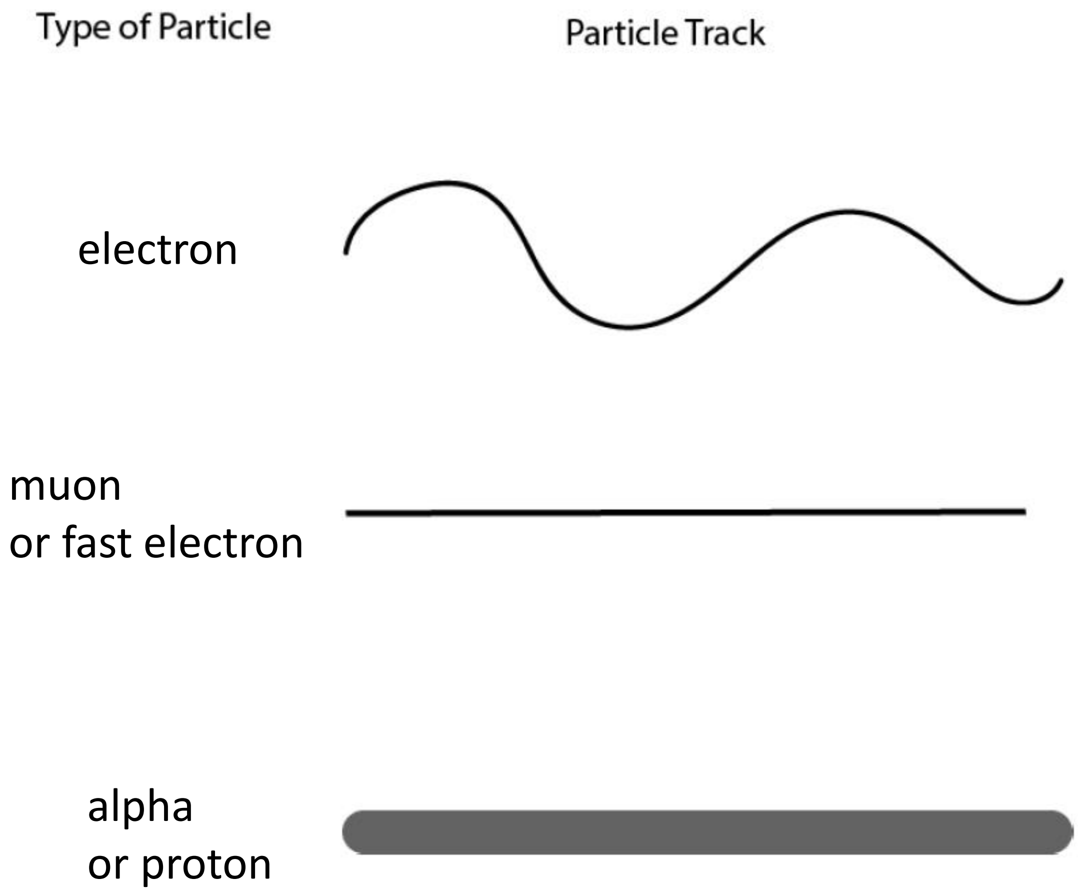
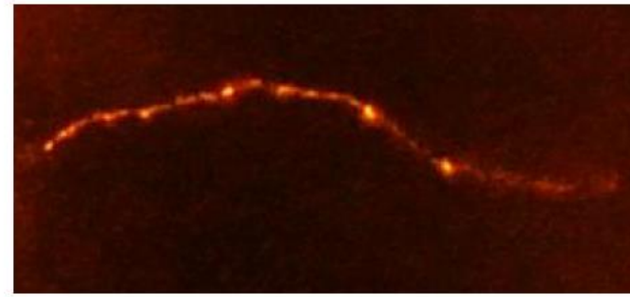
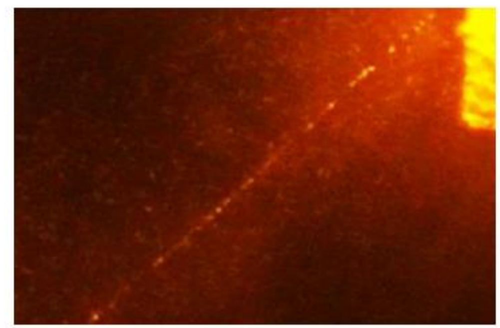
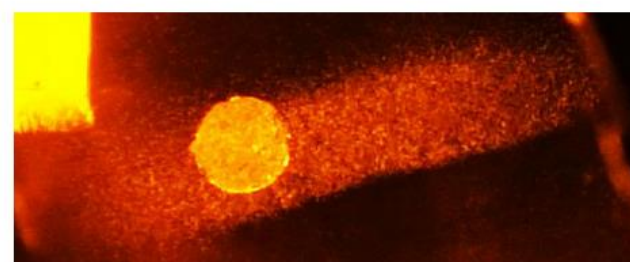


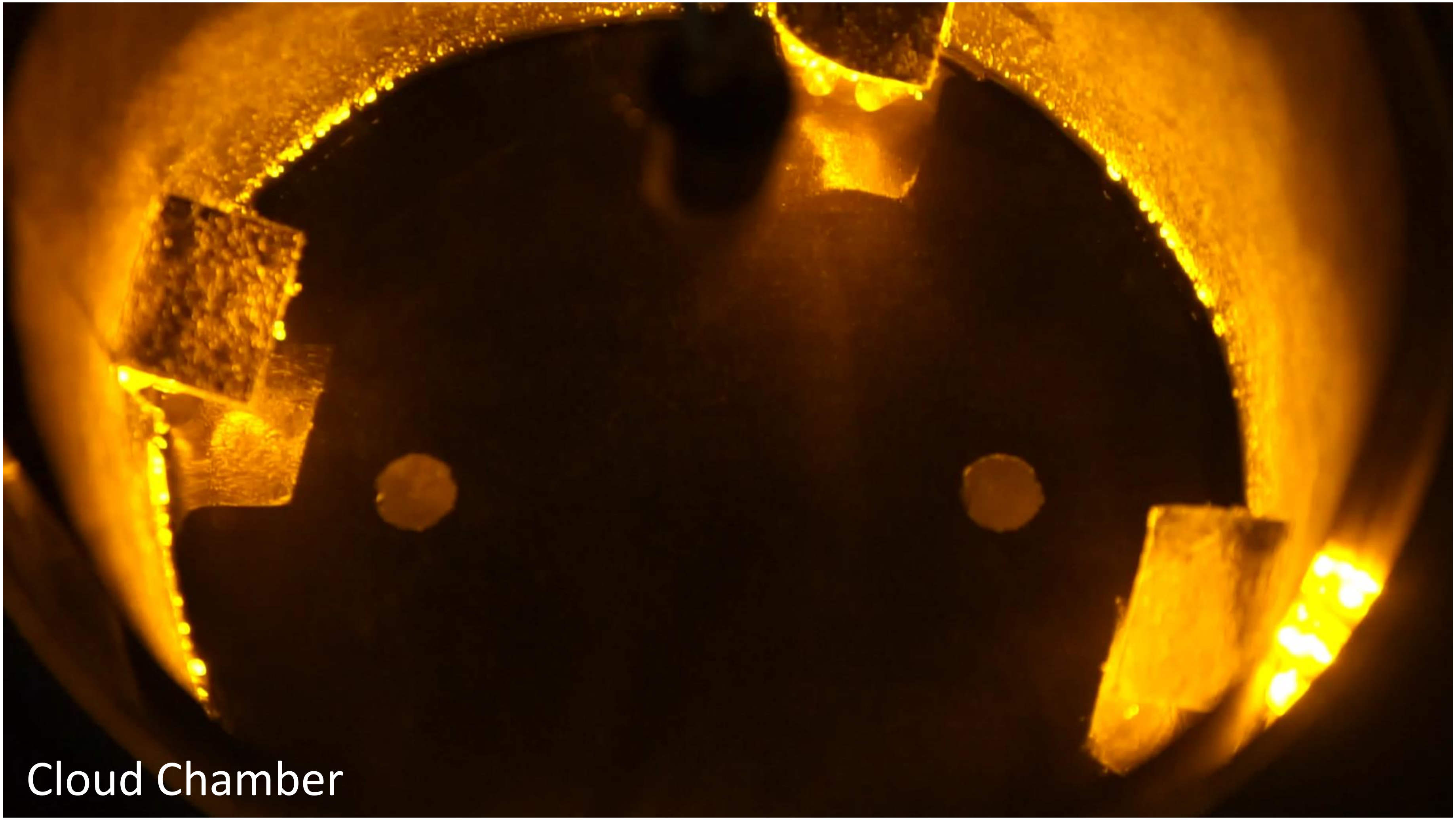






[photos by Megan Frayser, W&M 2019]

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



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

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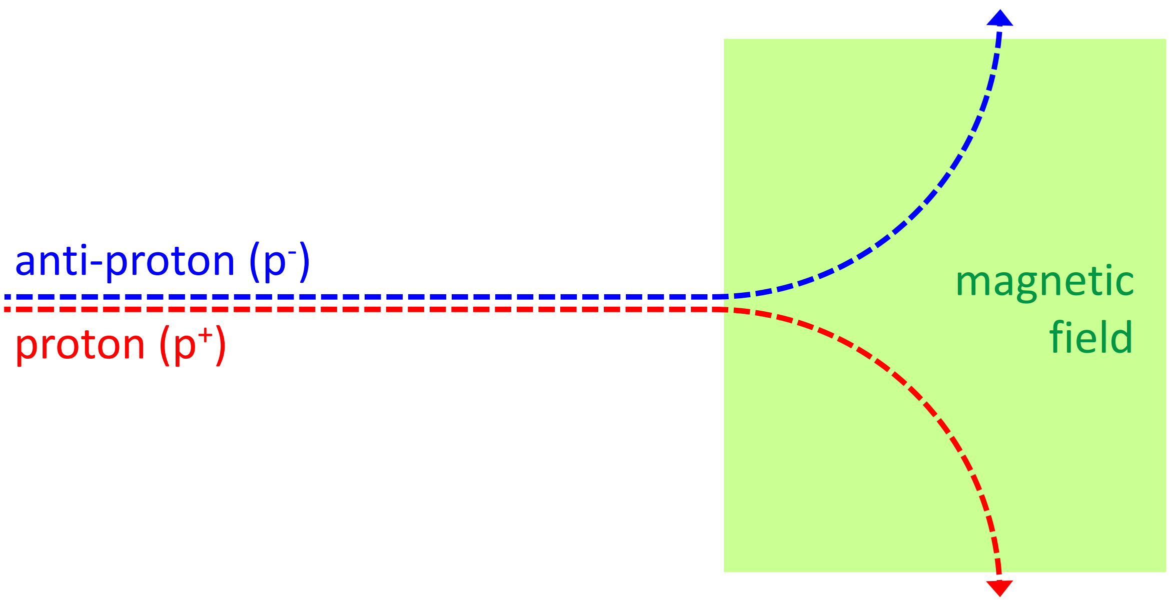
Bad: Strongly affected by planetary, solar, and galactic **magnetic fields**.

→ 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 <u>negative</u> charge (q=-1).
- **Positrons** (anti-electrons) are electrons with <u>positive</u> charge (q=+1).
- **Antineutrons** are neutrons with <u>opposite magnetic moment</u>.

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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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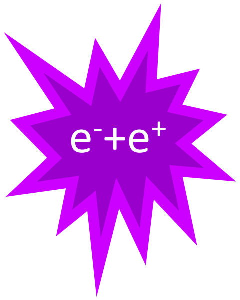
Matter-Antimatter Annihilation

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.

Neutral Particle Astronomy

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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).

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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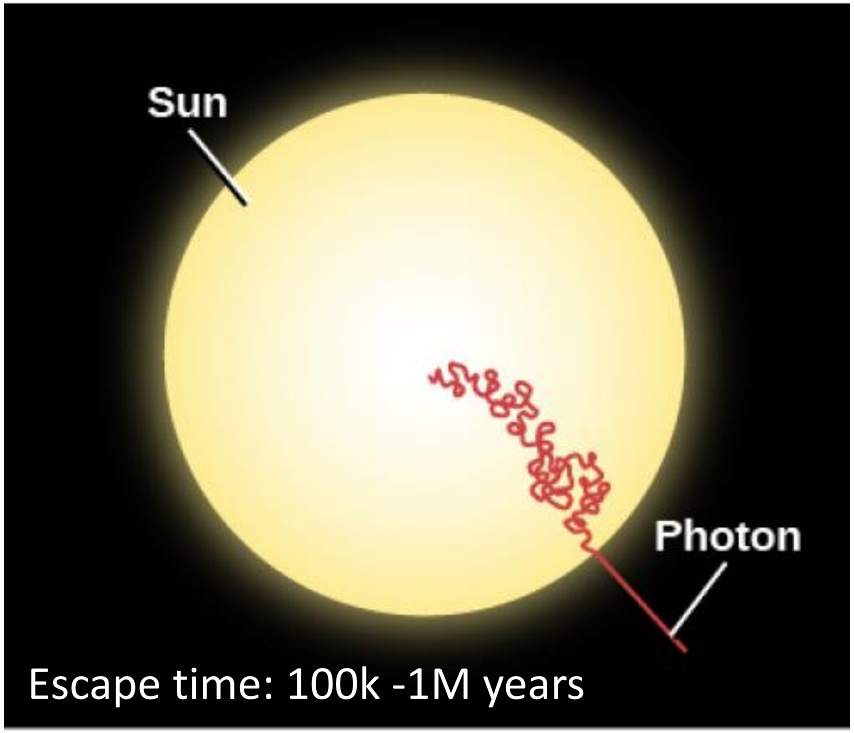

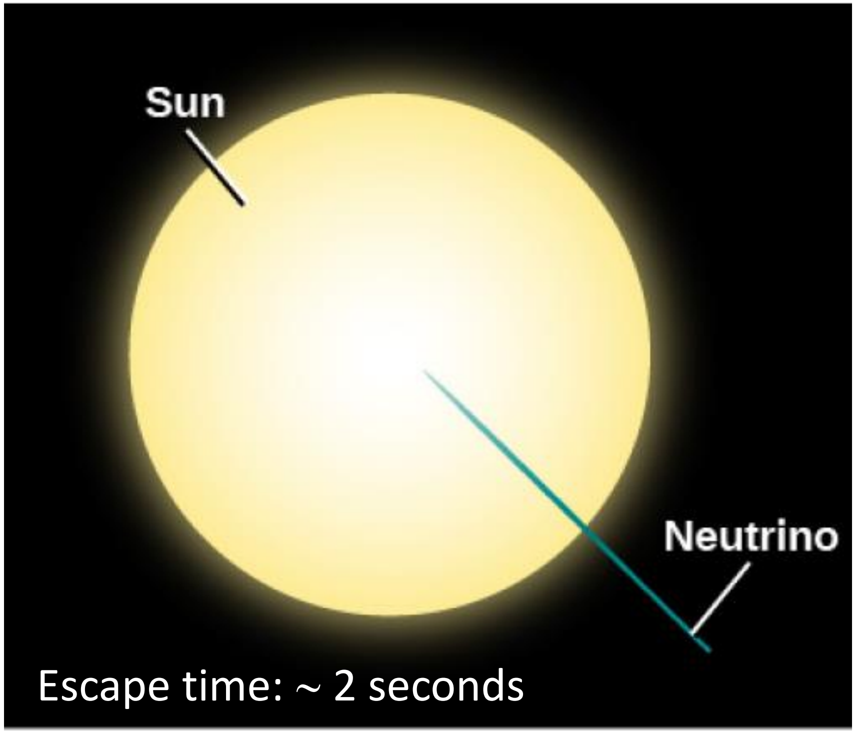

[OpenStax: Astronomy]

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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  → 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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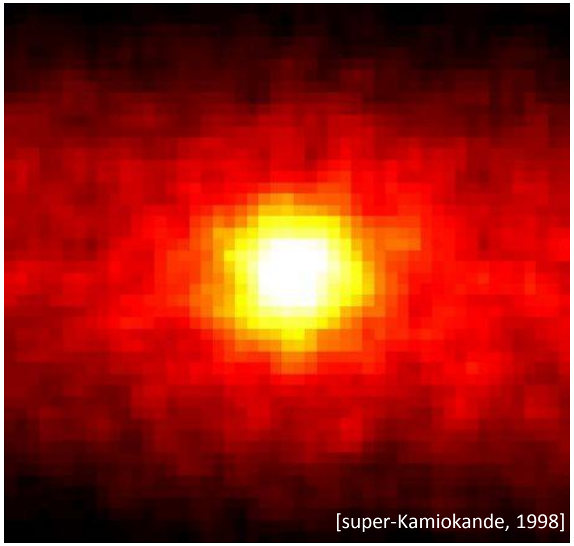

500 day exposure, full sky view.

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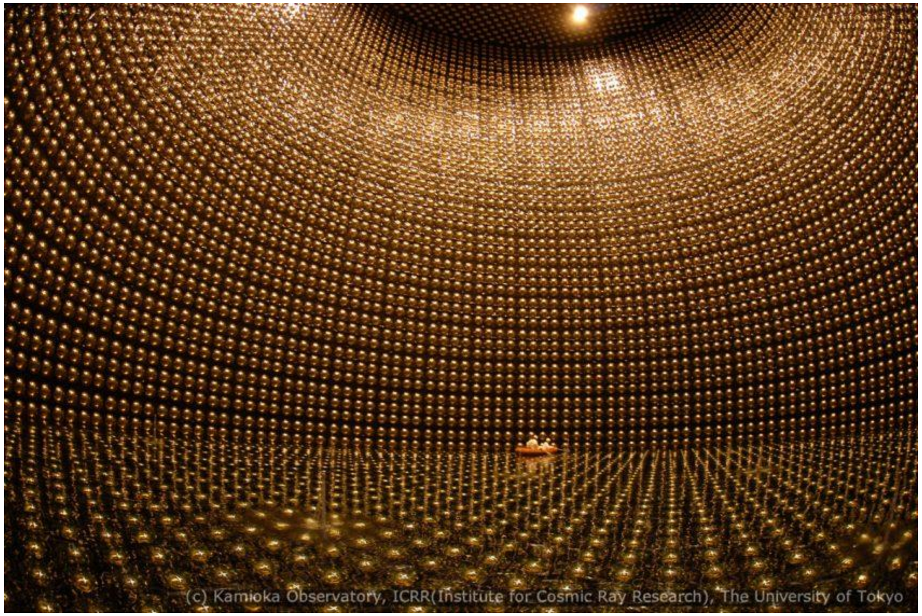
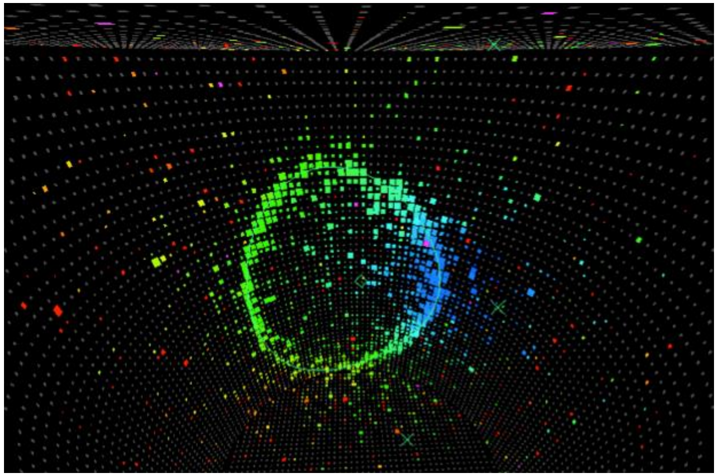
Neutrino Detectors

Super-Kamiokande (Japan)





Super-Kamiokande neutrino (ν_e) event.

Neutrino Detectors

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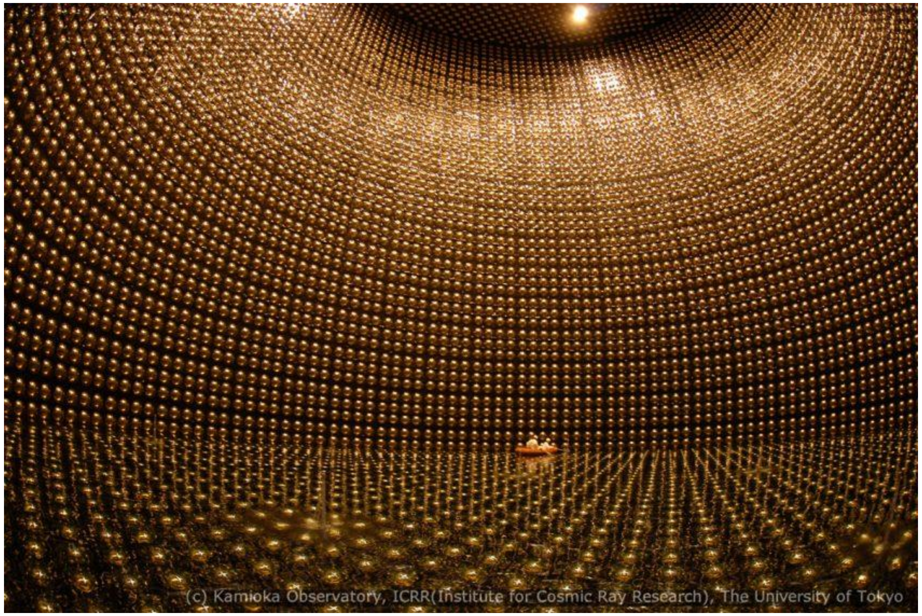

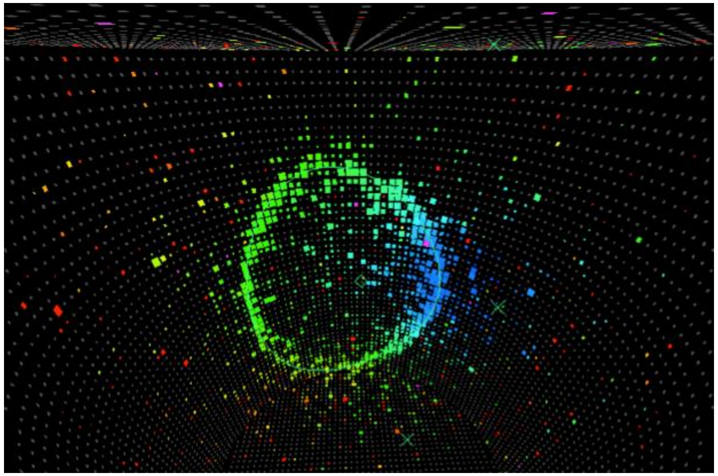

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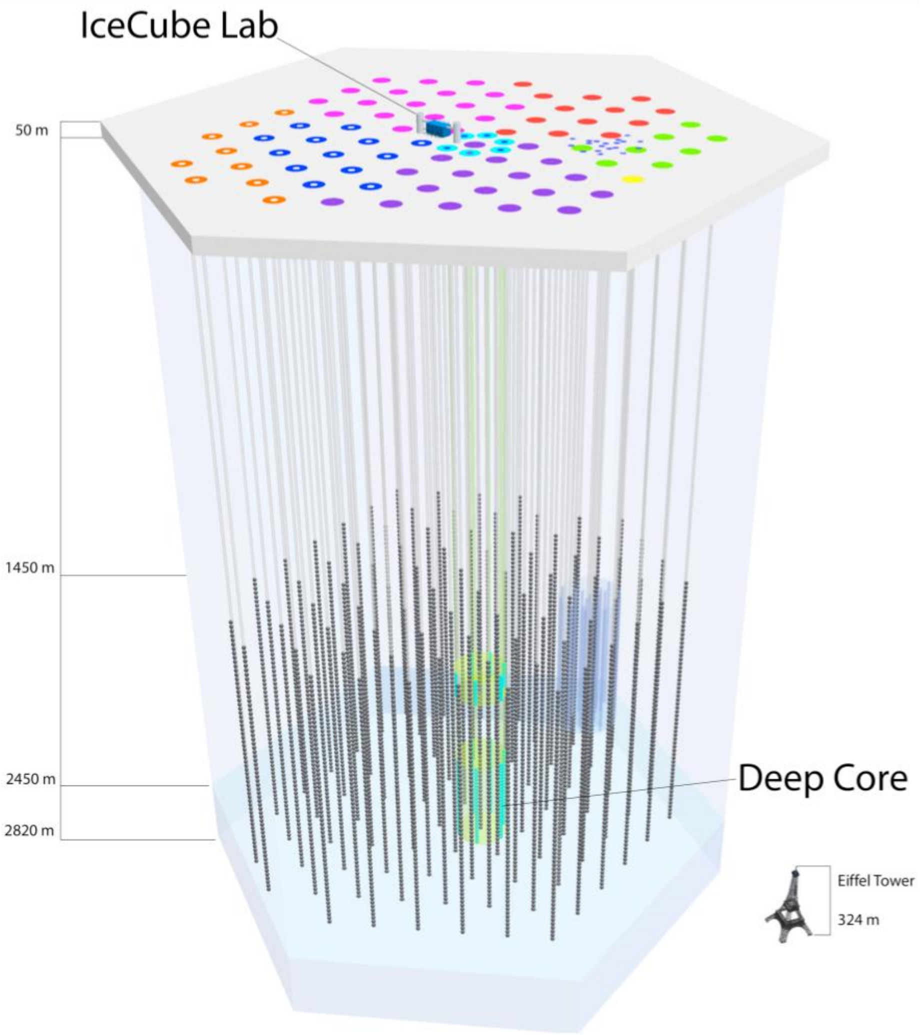
IceCube (Antarctica)

Cubic kilometer of detectors in very deep ice.

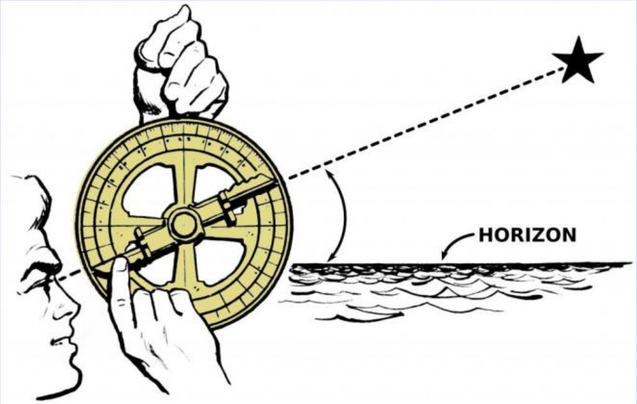


[M.G. Aartsen et al., J.Parallel Distrib.Comput. 75, 198-211 (2015); arXiv:1311.5904]

Astrolabe

Ancient Astronomy Instrument

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



[Pearson Scott Foresman, Wiki Commons]

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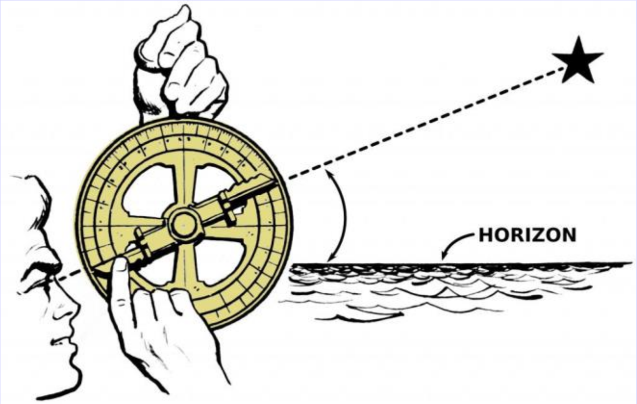

[Pearson Scott Foresman, Wiki Commons]

Hypatia

[by Elbert Hubbard, 1908]

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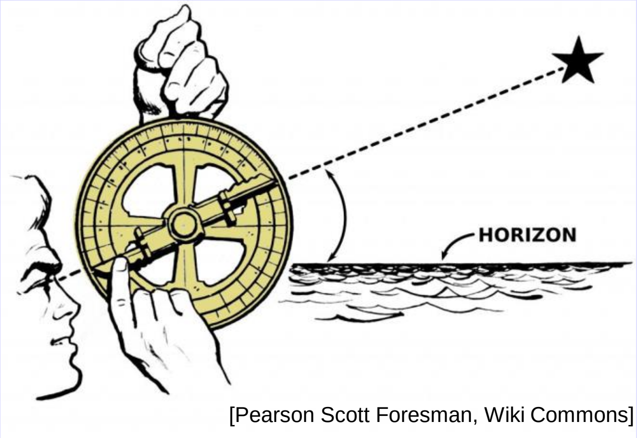

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- Refined by **Islamic astronomers** (starting in 8th century AD).

  → 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.

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

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

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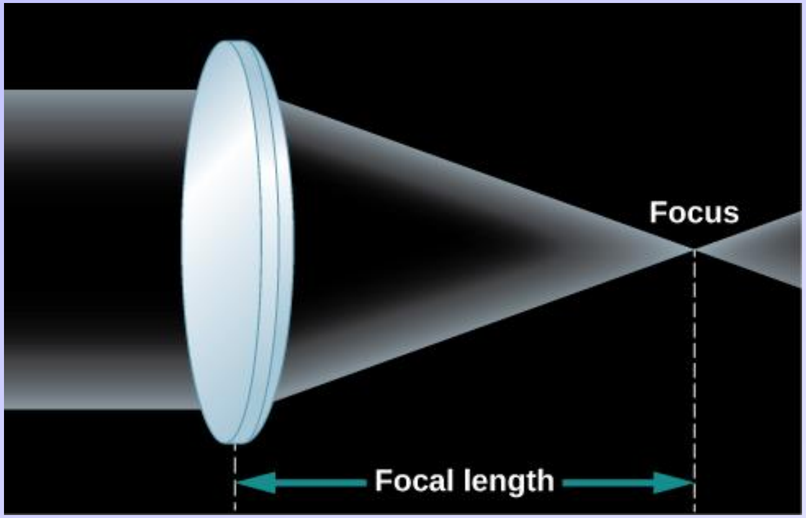
Basic Lens Physics



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

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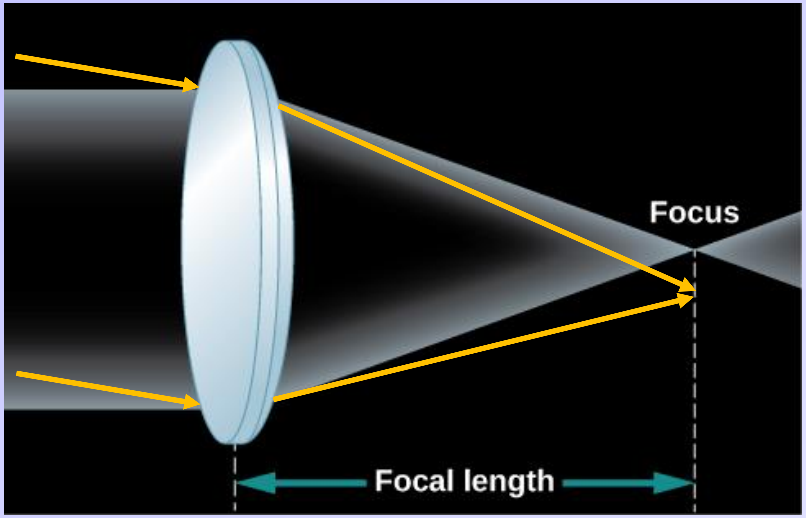

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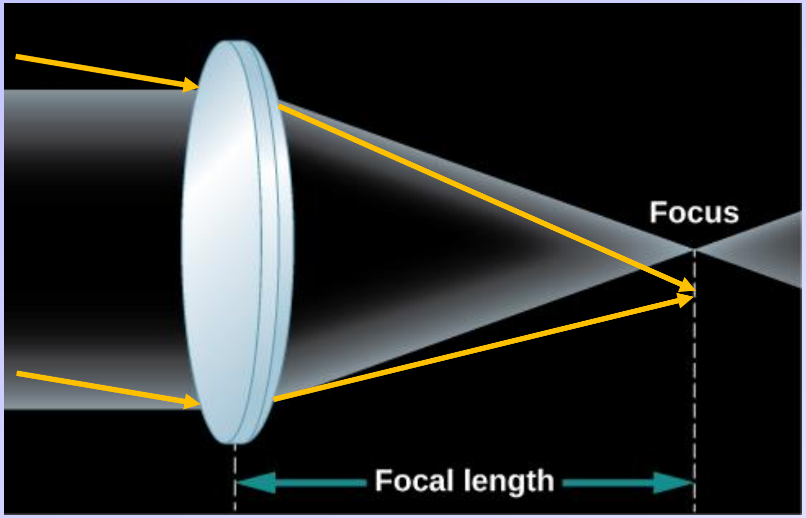


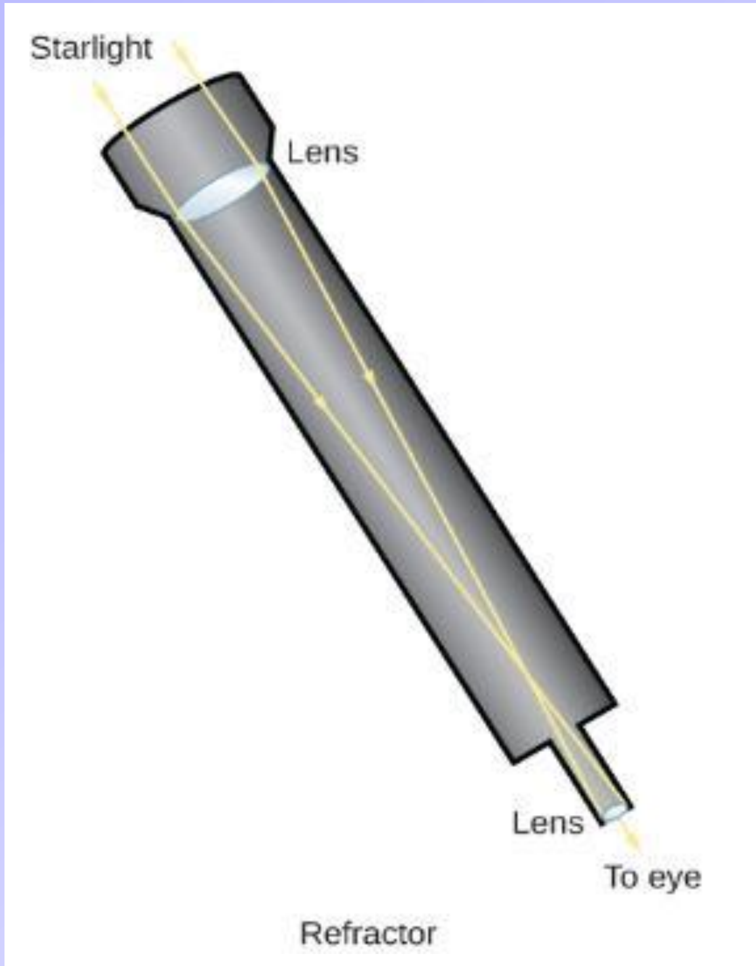
[OpenStax: Astronomy]

Benefits

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

Refracting Telescope

Two or more lenses are used to form an image



[OpenStax: Astronomy]

Benefits

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

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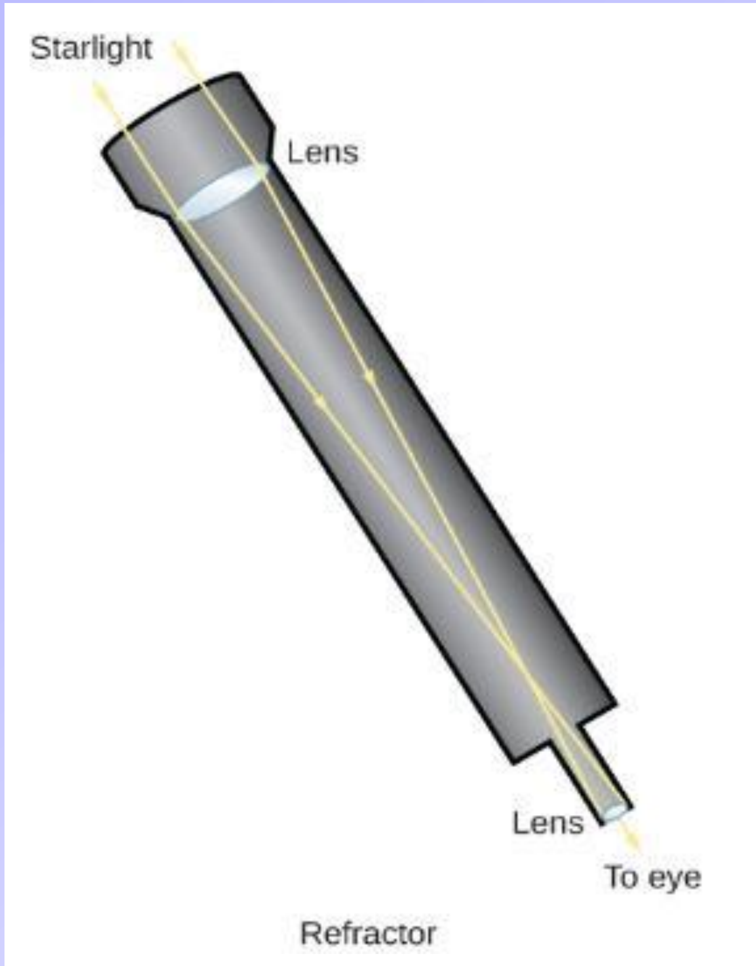

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- Simple to construct.
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Drawbacks

- 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.
  - → 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).

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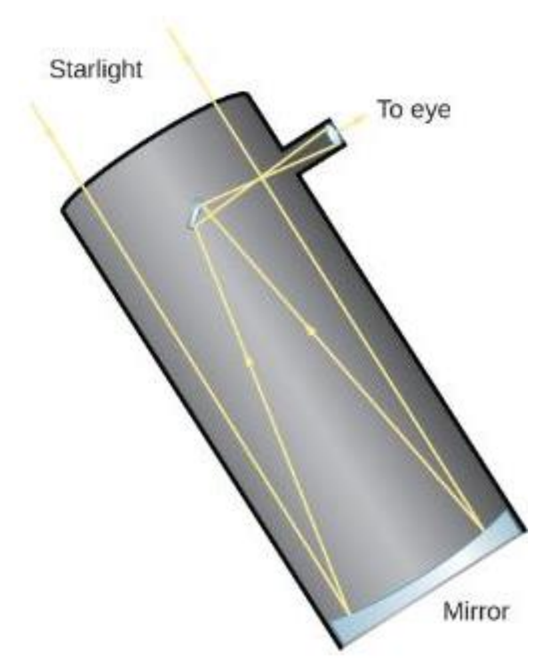
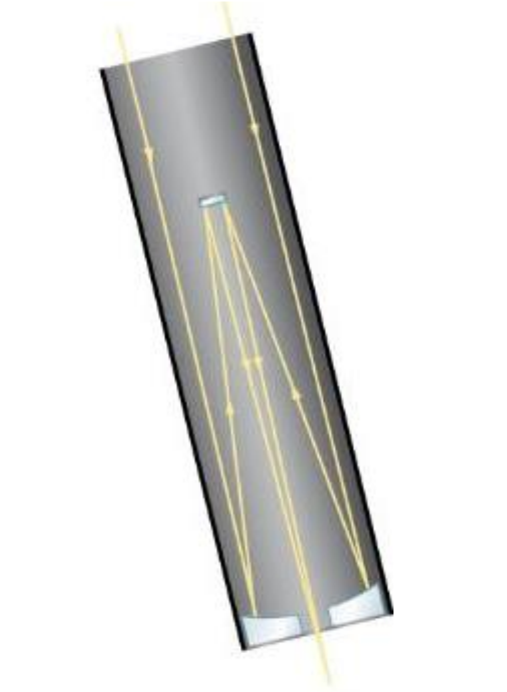
Reflecting Telescope

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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[OpenStax: Astronomy]

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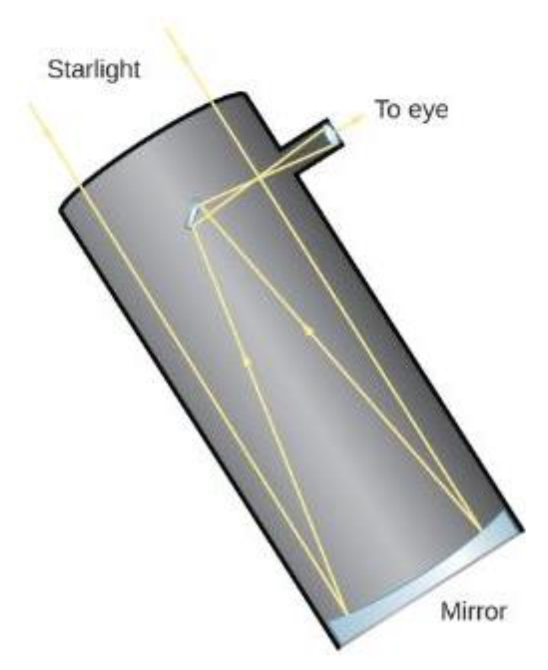

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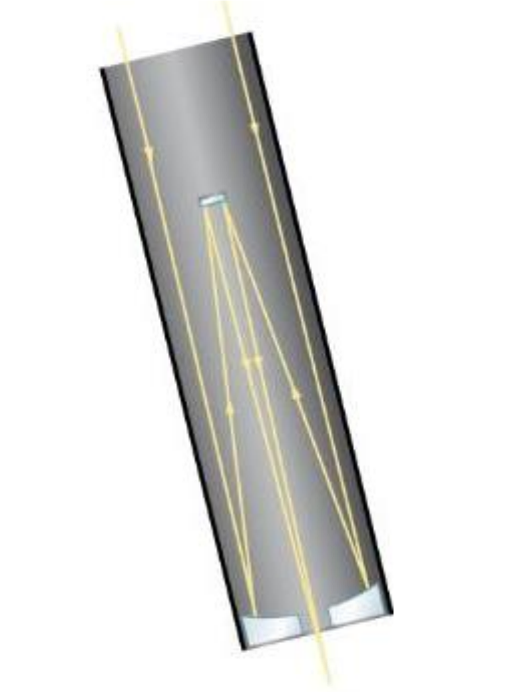

Cassegrain Reflector

Benefits

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

Drawbacks

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

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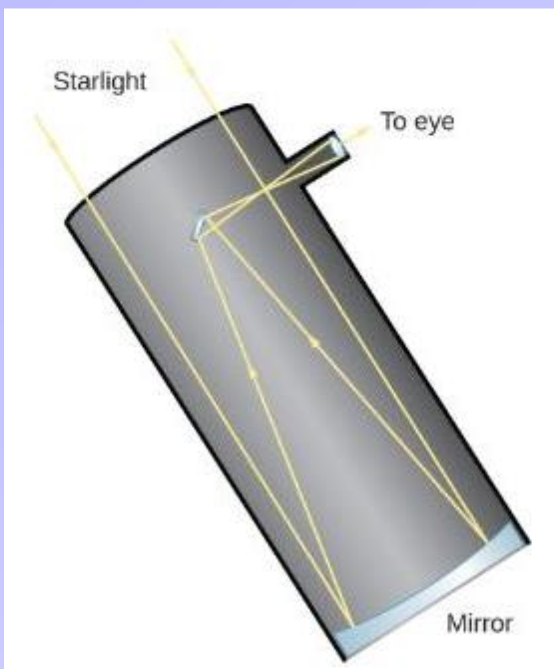

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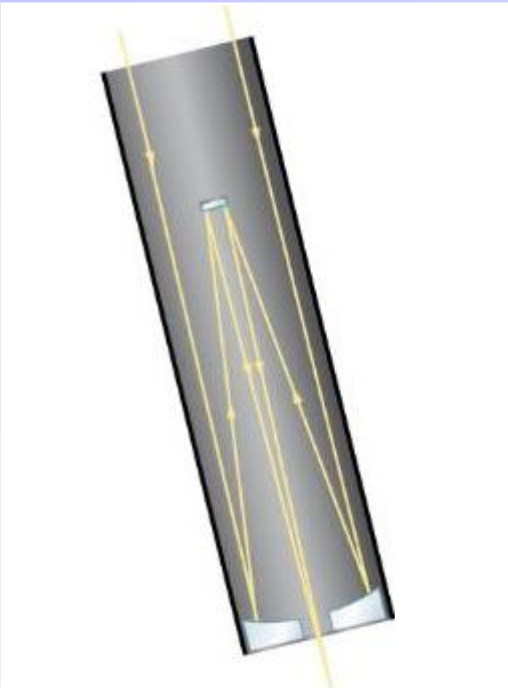

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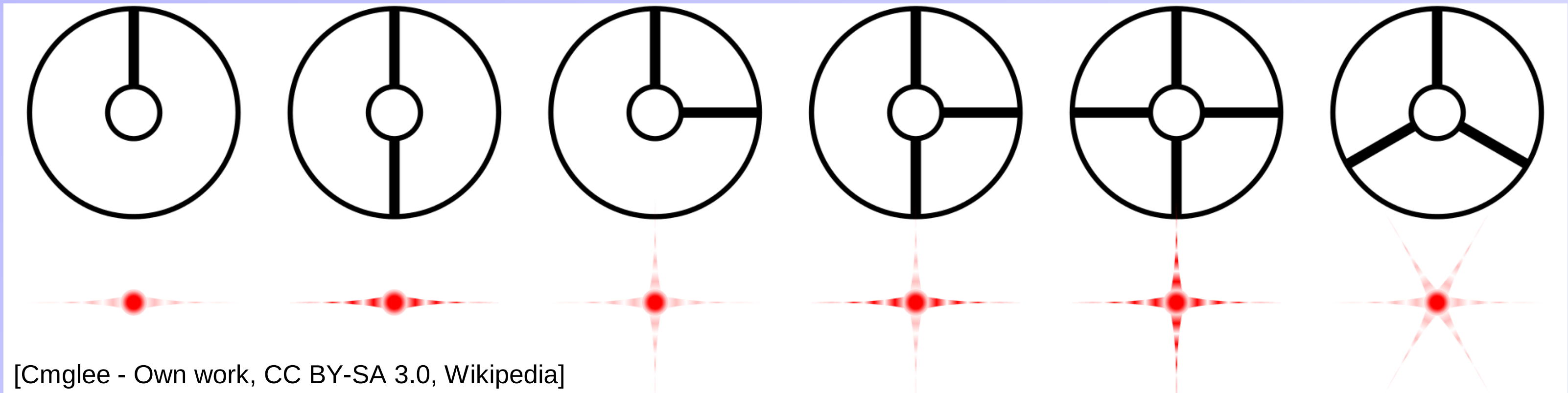
Almost all scientific telescopes are reflectors.

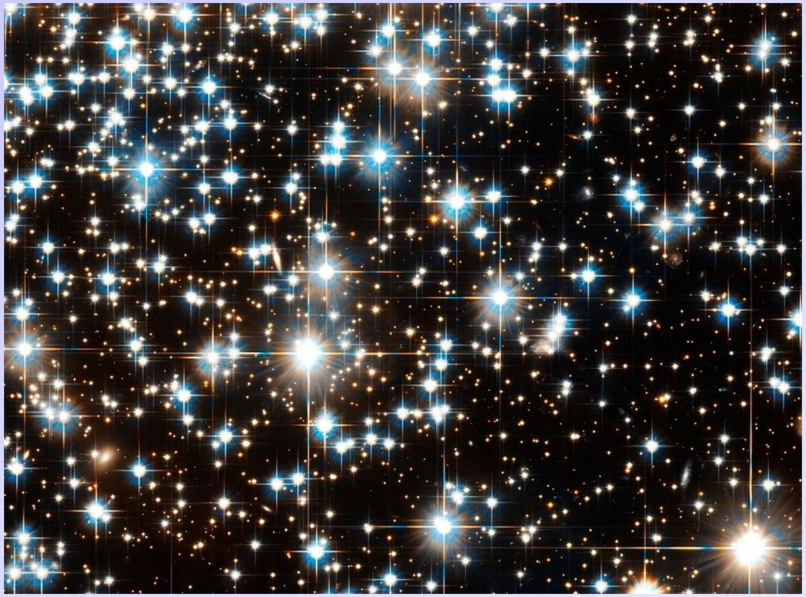
[OpenStax: Astronomy]

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

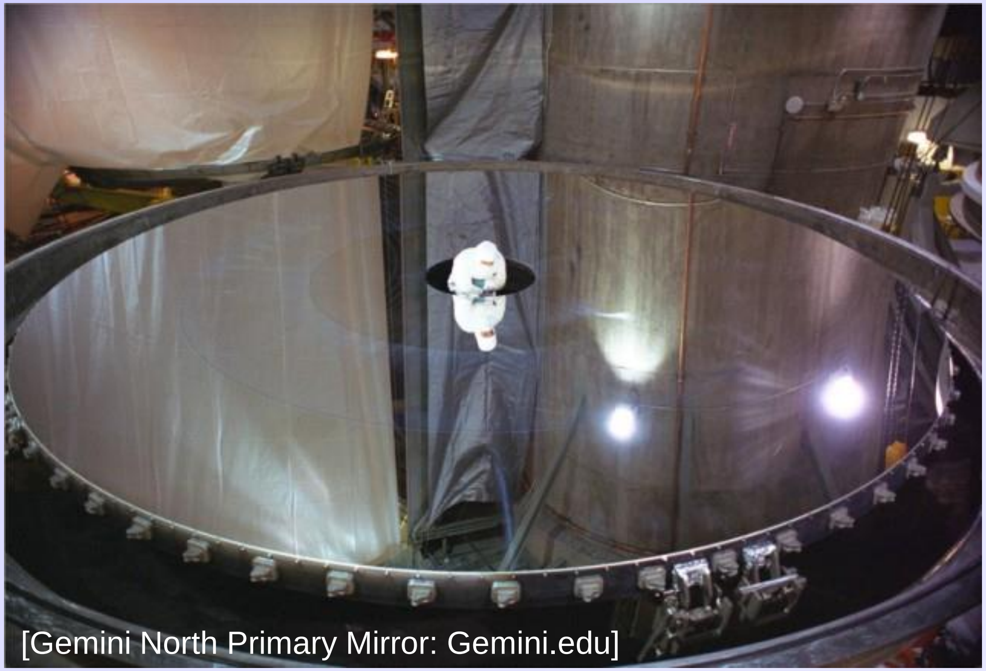

[Gemini North: OpenStax]

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.

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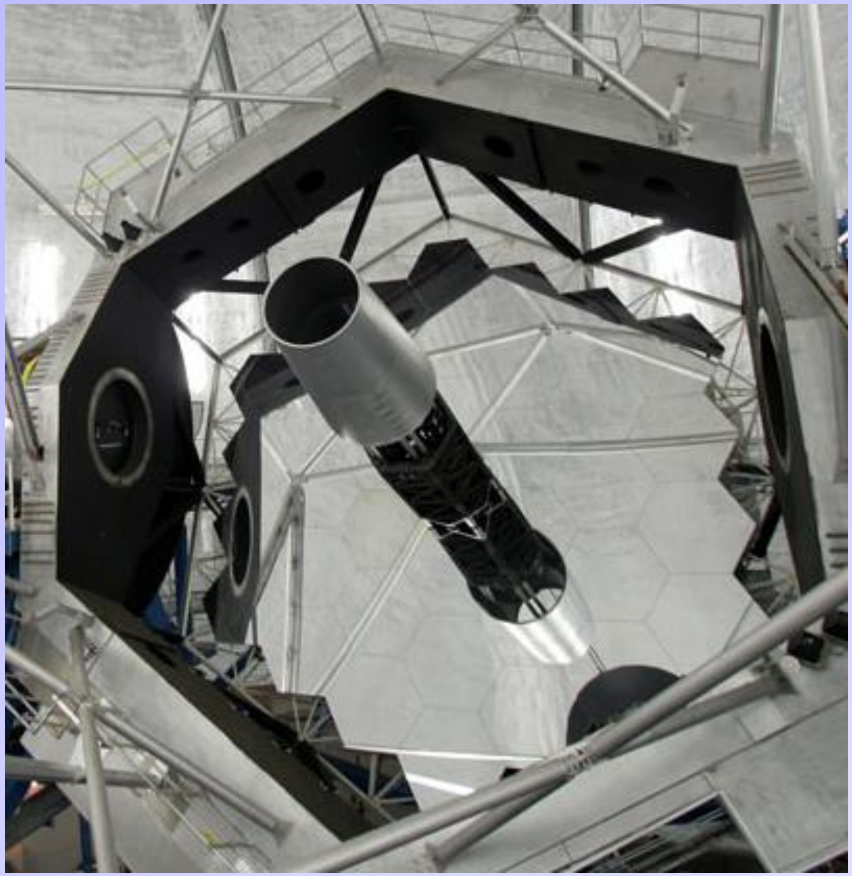
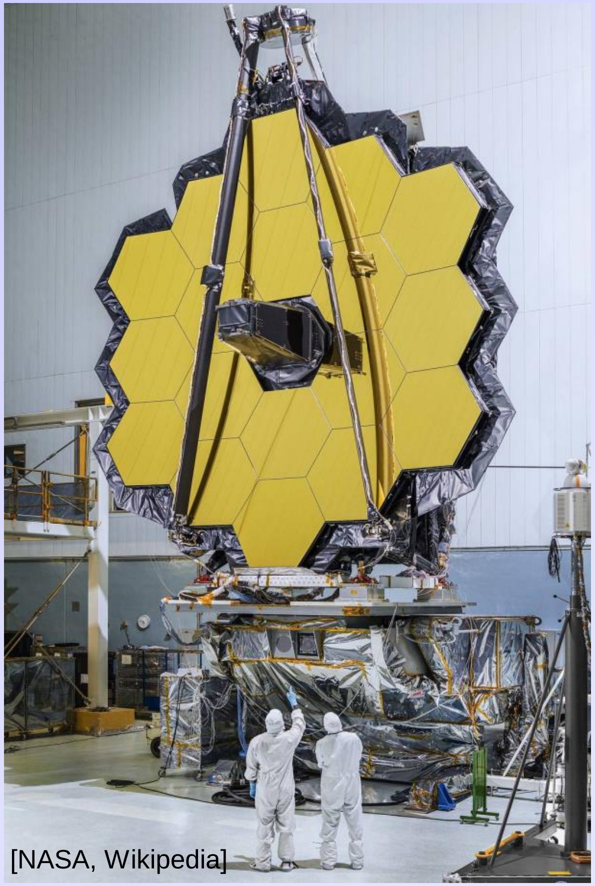
Problem: A single mirror larger than 8 m will experience significant sag issues.

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]



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