Today's Topics

Wednesday, February 25, 2026 (Week 5, lecture 14) – Chapter 6.

A. Interlude 1 instructions

B. Angular resolution review

C. Interferometry

D. CCD cameras

E. Telescopes by wavelength

PHYS 172: Stellar Astronomy & Cosmology
Due date: Monday, March 23, 2026

Interlude I: Humanity and the Stars
Instructions

In this first of two interludes, you will explore a topic that is outside of the traditional purview of astronomy, physics, and the physical sciences, as well as mathematics and computer science. The topic will reach out to the "Arts, Letter, and Values" domain (ALV) and/or the "Cultures, Societies, and the Individual" domain (CSI). You will explore the topic through an essay.

Paper requirements

The paper should be 5 pages long (double spaced) and include **at least one figure** (i.e. photo, diagram, image, plot, table); the length includes the references. This figure can be of your own making or from a reference (the figure should be of high quality with no pixelation), and it should be used to explain and support the arguments and information in your paper (i.e., it is not a decoration); you can also have additional figures that are taken from other sources, so long as they are properly referenced in your bibliography (note: these additional figures are not included in the 5 page count). You are encouraged to discuss your essay topic with other students, but each student must turn in their own distinct paper.

Format: 12 point, Times New Roman, 1” margins, 8” × 11” paper.

Note: Your introduction should state the thesis of your essay.

N. B. The paper must have a title.

Paper requirements

The paper should be 5 pages long (double spaced) and include **at least one figure** (i.e. photo, diagram, image, plot, table); the length includes the references. This figure can be of your own making or from a reference (the figure should be of high quality with no pixelation), and it should be used to explain and support the arguments and information in your paper (i.e., it is not a decoration); you can also have additional figures that are taken from other sources, so long as they are properly referenced in your bibliography (note: these additional figures are not included in the 5 page count). You are encouraged to discuss your essay topic with other students, but each student must turn in their own distinct paper.

Format: 12 point, Times New Roman, 1” margins, 8” × 11” paper.

Note: Your introduction should state the thesis of your essay.

N. B. The paper must have a title.

Artificial Intelligence Usage

- The use of artificial intelligence (e.g., ChatGPT) is permitted for searching for information and for inspiring your writing.
- Artificial intelligence CANNOT be used for generating the text of your essay or the figures.
- Artificial intelligence engines CANNOT be used as references.

Topics

Pick one of the following topics:

0. Pick your own topic

Pick your own question/topic (please discuss it with the instructor for approval). Please note that while your essay can include technological and physics components, the topic of your essay must encompass ALV and/or the CSI domains of knowledge.

Topics

Pick one of the following topics:

0. Pick your own topic

Pick your own question/topic (please discuss it with the instructor for approval). Please note that while your essay can include technological and physics components, the topic of your essay must encompass ALV and/or the CSI domains of knowledge.

1. Astronomy in ancient civilizations

In many ancient civilizations, governing bodies supported official astronomers for various purposes (religion, timekeeping, navigation, predicting the future, etc). For example, ancient Chinese astronomical records are the oldest available. Ancient Babylonian astronomers kept records that survive to this day, and medieval Islamic astronomers assigned the names of the stars that are used in modern astronomy.

You should research the role of astronomy in an ancient civilization of your choice and **write an essay** that describes the role, position, and influence of official astronomers, the purpose of the astronomical observations, and any important astronomical events that were recorded (e.g., supernovas, comets, etc) and if they were attributed any meaning. For the purposes of this essay, we will define "ancient civilization", as any civilization before the advent of the heliocentric model of the solar system during the Renaissance.

2. Constellations in various cultures

The important constellations and asterism of a given civilization/culture often do not match those used by another civilization/culture, i.e., the how stars are grouped together to form a constellation varies from culture to culture (different people connect the dots in different ways). Historically, constellations have been used to organize the stars into different regions of the sky, and they are often used for navigation in places with few landmarks (e.g., at sea). Sometimes, constellations are given certain additional meanings (superstitious or not, e.g., astrology).

You should research the constellations in at least two different cultures (ancient or contemporary) and determine the organizational system of the constellations and how they fit into the broader culture. You should **write an essay** that compares and contrasts the constellation systems of at least two different cultures. Furthermore, the essay should also include an example of how the two cultures organize a specific set of stars (e.g., the big dipper stars, the stars of Orion's belt, the Pleiades, or Scorpio's head, etc).

3. Stars for navigation: The longitude problem

Determining your latitude (i.e., your north-south position on Earth relative to the equator and the north/south pole) using the stars is relatively straightforward, i.e., just measure the angle between the horizon and the North Star (Polaris). **Determining your longitude is much harder** to do via astronomical observations (i.e., determining your east-west position relative to the Greenwich Prime Meridian in London).

Before the advent of satellite-based navigation (GPS), determining one's longitude required the comparison of a Sun-based local clock with a reference clock at the Prime Meridian. Until the advent of high-quality mechanical chronometers, the local clock was typically calibrated using astronomical observations, e.g., using the tabulated orbits of the moons of Jupiter or very accurate measurements of the position of the Moon relative to the background stars. Indeed, in the 16th, 17th, and 18th centuries, several maritime powers (Great Britain, Spain, Holland, France) offered prizes for methods to determine longitude at sea to spur innovation in this domain. Galileo even applied for one of these, though unsuccessfully. John Harrison ultimately won the British prize for his mechanical chronometer, which can be used at sea. On land, the astronomical methods tended to be more successful.

You should research this topic and its historical importance and **write an essay** on an aspect of it (e.g., a method or an inventor).

4. Black hole time machine

As we will see when we study black holes, time slows down near the event horizon of a black hole. Indeed, the closer you are to the event horizon, the more time slows down for you (though you cannot tell). Time in the rest of the universe keeps ticking at it usual rate. In other words, as you get closer to a black hole you do not age as quickly as the rest of the universe. Indeed, if you could park yourself on the event horizon of a black hole you could watch the rest of universe's history unfold, while remaining ageless. Consequently, if you leave your fellow space travelers and travel close to a black hole, then when you return to your companions, you will have aged considerably less than them … or in other words, you will have travelled ahead in time (unfortunately, you cannot use this approach for travelling backwards in time). The movie *Interstellar* (2024), directed by C. Nolan, includes a fictional example of this phenomenon, when the lead characters visit a planet that is very close to a black hole.

Consider a human society on a planet or space station in the vicinity of an inactive large stellar mass black hole (i.e., we will assume that the black hole is not spewing out a bunch dangerous radiation due to material falling into it). For example, you can use a black hole similar to the one in the movie *Interstellar*. **Write an essay** that explores how a society or individual could make use of the black hole time machine.

One example of how such a black hole time machine could be useful is for medicine. If someone has a currently incurable disease, then they could be sent close to the black hole for a short time (to be determined) and then brought back to the main society. During the time near the black hole, the main society may have advanced sufficiently (due to the much longer passage of time, perhaps decades or centuries) that a medical cure has been developed for the previously incurable disease, and so the sick individual can now be cured. Of course, there may some major drawbacks as well, such as the fact that the person's family may no longer be alive. This is just one example, and you encouraged to look for other benefits (or apparent benefits).

Note: You have the option of exploring this specific topic as a short story (instead of a traditional essay), since this format may provide a more useful and creative way of engaging with the more human aspects of the topic.

5. Sketch how humanity will first explore a nearby star system

In this **essay**, you will consider the organizational requirements and challenges of sending a space probe to a nearby star system. For this essay, you can assume that the one-way travel time will be about 30 years (which is in-line with what the Breakthrough Starshot project claims is possible in principle).

Your essay should explain the following:

- The objectives of the mission and the possible benefits of such a mission (i.e., why send a space probe to another star system?).
- The target star system.
- Any interesting milestones to visit (before arriving at the target system)
- Will the mission be one-way or roundtrip.
- What the Earth-based organization would look like (you can read up on how space probe missions to other planets are organized). What sort of people and skills do you need?
- How the organization would maintain its integrity for the 30-year travel time.
- The most likely funding mechanism for such a mission.
- Roughly the scale of the budget for the mission ($1B, $10B, $100B, $1T, $10T, $100T USD) and the primary expenses.
- Would the mission be funded by a country, many countries, or privately?

Note: You are welcome to discuss the technology that would be involved to make such a space probe mission possible, but it should not be the main point of the essay, which is to focus on the mission and its organization.

6. The art of scientific astrophotography

Popular photos of various celestial objects (e.g., taken by the Hubble or Webb space telescopes, or a backyard astrophotographer) are typically very compelling to human observers due to their complexity and colors. The fact that they are photos or real places in the universe makes the photos all the more compelling. However, these photos are typically only partially real in that the colors in the photos have been manipulated for scientific and artistic reasons.

You should research this topic and **write an essay** that explores why and how colors are assigned to science grade photographs of celestial objects (e.g., nebulas, exploding stars, galaxies, planets, etc). Here is a first reference to get you started:
https://webbtelescope.org/contents/articles/how-are-webbs-full-color-images-made

Today's Topics

Wednesday, February 25, 2026 (Week 5, lecture 14) – Chapter 6.

A. Interlude 1 instructions

B. Angular resolution review

C. Interferometry

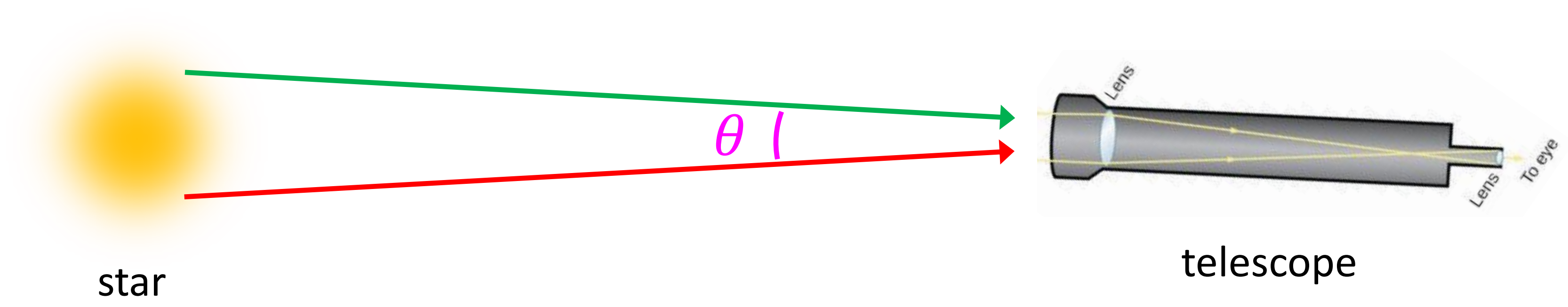
D. CCD cameras

E. Telescopes by wavelength

Review: Angular Resolution

Angular resolution (or resolving power) $\boldsymbol{\theta_{min}}$

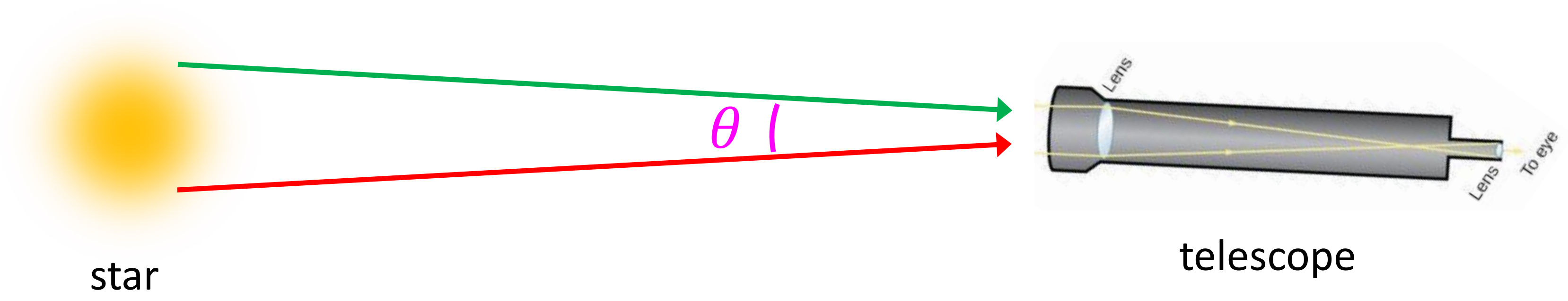
The minimum angle that a telescope can see, i.e. it's the "angular pixel" size.



Review: Angular Resolution

Angular resolution (or resolving power) $\boldsymbol{\theta_{min}}$

The minimum angle that a telescope can see, i.e. it's the "angular pixel" size.



radians

wavelength in meters

SI units: $$\theta_{min} = 1.22\frac{\lambda}{D}$$

- Typically, a telescope "tries" to reduce θ_{min}
- Bigger diameter D decreases θ_{min}
- Shorter wavelength λ decreases θ_{min}

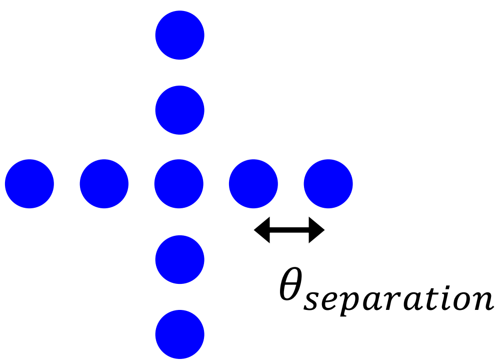
Review: Angular Resolution

Angular resolution (or resolving power) $\boldsymbol{\theta_{min}}$

The minimum angle that a telescope can see, i.e. it's the "angular pixel" size.

Key point

If an object is smaller (in angle) than the angular resolution θ_{min} , then it shows up as a "blob" of angular size θ_{min}.



Stars in "plus" pattern

Telescope image for $\theta_{separation} \gg \theta_{min}$

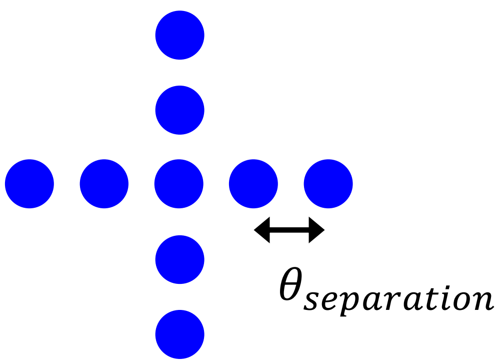
Review: Angular Resolution

Angular resolution (or resolving power) $\boldsymbol{\theta_{min}}$

The minimum angle that a telescope can see, i.e. it's the "angular pixel" size.

Key point

If an object is smaller (in angle) than the angular resolution θ_{min} , then it shows up as a "blob" of angular size θ_{min}.



Stars in "plus" pattern

Telescope image for $\theta_{separation} \sim \theta_{min}$

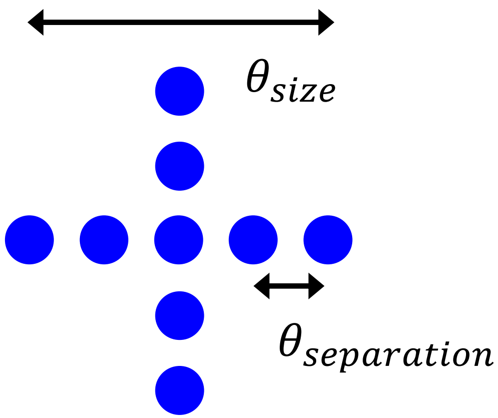
Review: Angular Resolution

Angular resolution (or resolving power) $\boldsymbol{\theta_{min}}$

The minimum angle that a telescope can see, i.e. it's the "angular pixel" size.

Key point

If an object is smaller (in angle) than the angular resolution θ_{min} , then it shows up as a "blob" of angular size θ_{min}.



Stars in "plus" pattern

Telescope image for $\theta_{separation} < \theta_{min} < \theta_{size}$

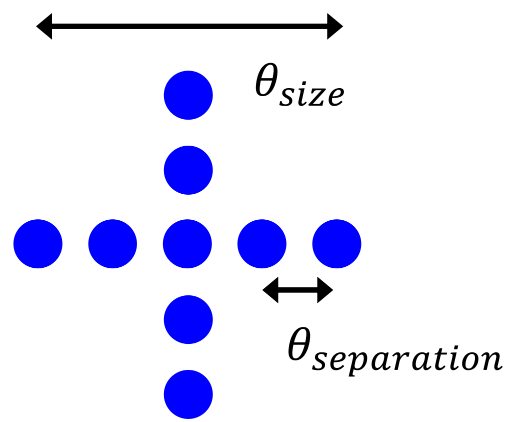
Review: Angular Resolution

Angular resolution (or resolving power) $\boldsymbol{\theta_{min}}$

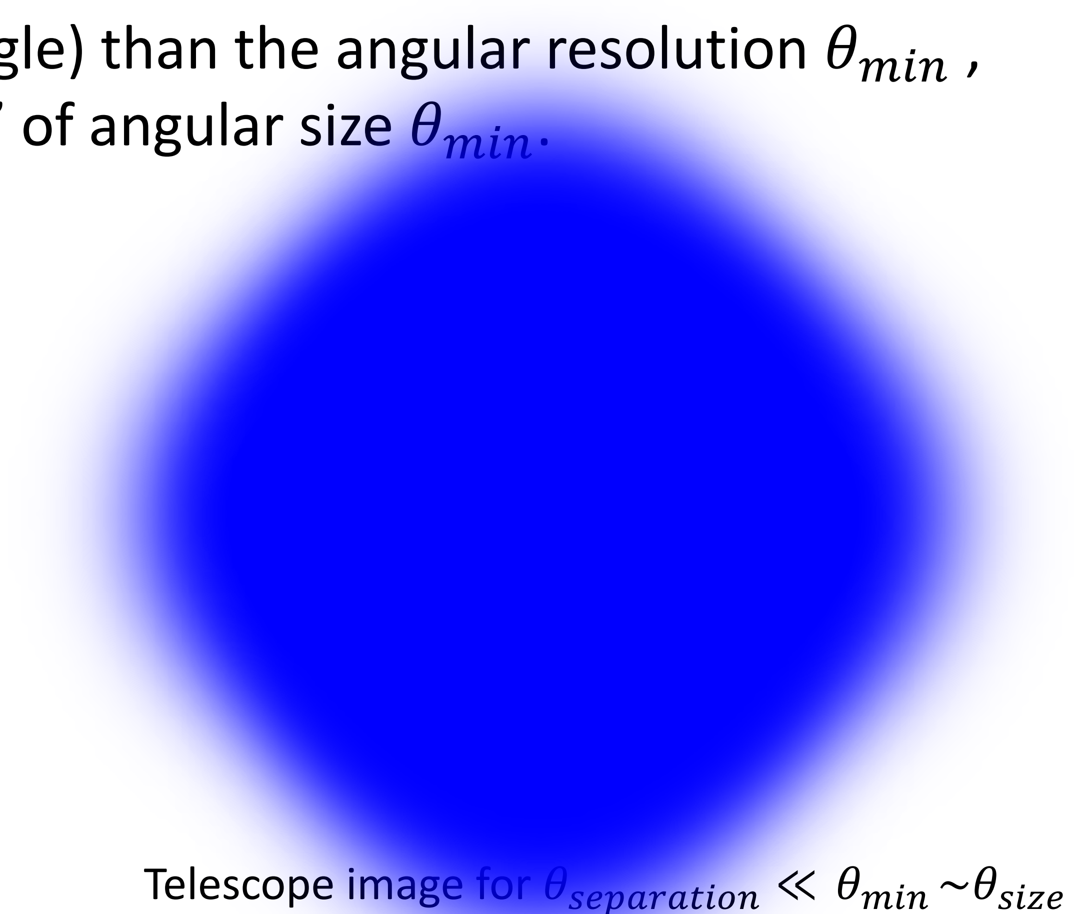
The minimum angle that a telescope can see, i.e. it's the "angular pixel" size.

Key point

If an object is smaller (in angle) than the angular resolution θ_{min} , then it shows up as a "blob" of angular size θ_{min}.



Stars in "plus" pattern



Telescope image for $\theta_{separation} \ll \theta_{min} \sim \theta_{size}$

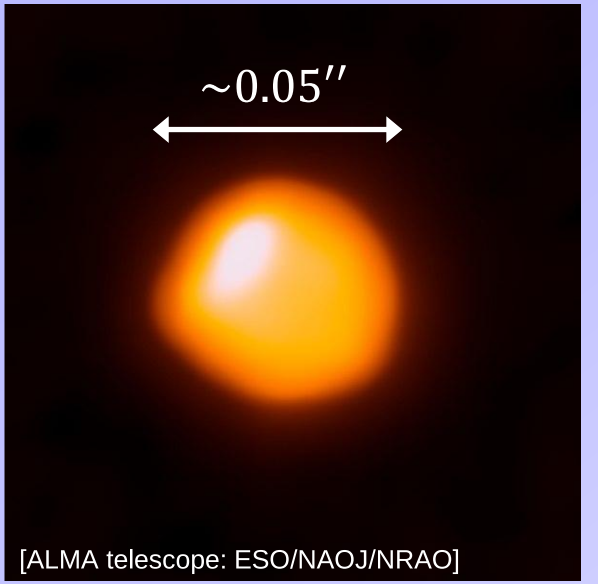
PollEv Quiz: PollEv.com/sethaubin

Telescope Interferometry

for

Super Angular Resolution

Image of Betelgeuse

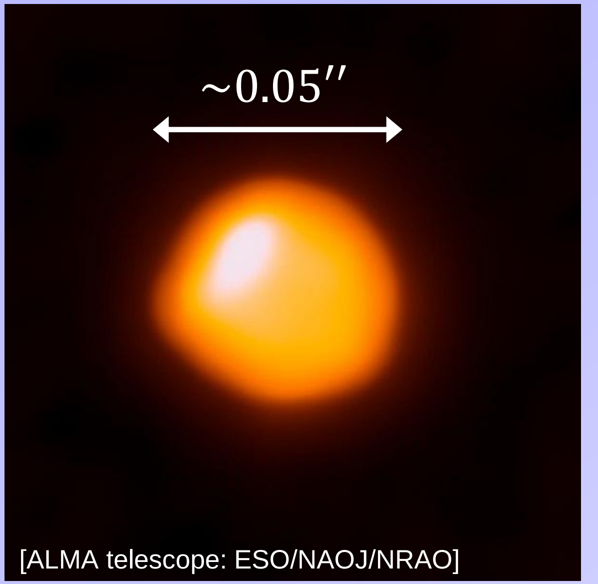


λ = 0.89 mm, f = 338 GHz

(mm-wave)
(microwave)

Constellation: **Orion**

Image of Betelgeuse



λ = 0.89 mm, f = 338 GHz (mm-wave) (microwave)

Constellation: **Orion**

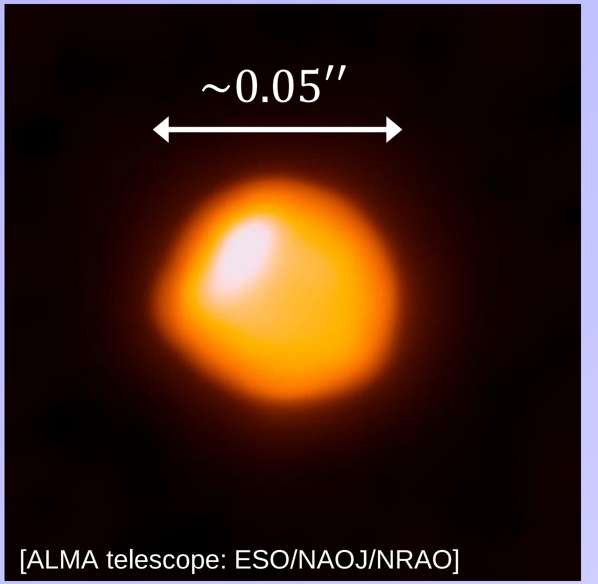
The white "hot" feature is about 1/5 of the size of the star, i.e. $0.01''$.

→ Angular resolution must be better than $0.01''$.

(5 times better than Gemini telescope)

Question: How did the angular resolution get this good ?

Image of Betelgeuse



λ = 0.89 mm, f = 338 GHz (mm-wave) (microwave)

The white “hot” feature is about 1/5 of the size of the star, i.e. $0.01''$.

→ Angular resolution must be better than $0.01''$.

(5 times better than Gemini telescope)

Constellation: **Orion**

Question: How did the angular resolution get this good ?

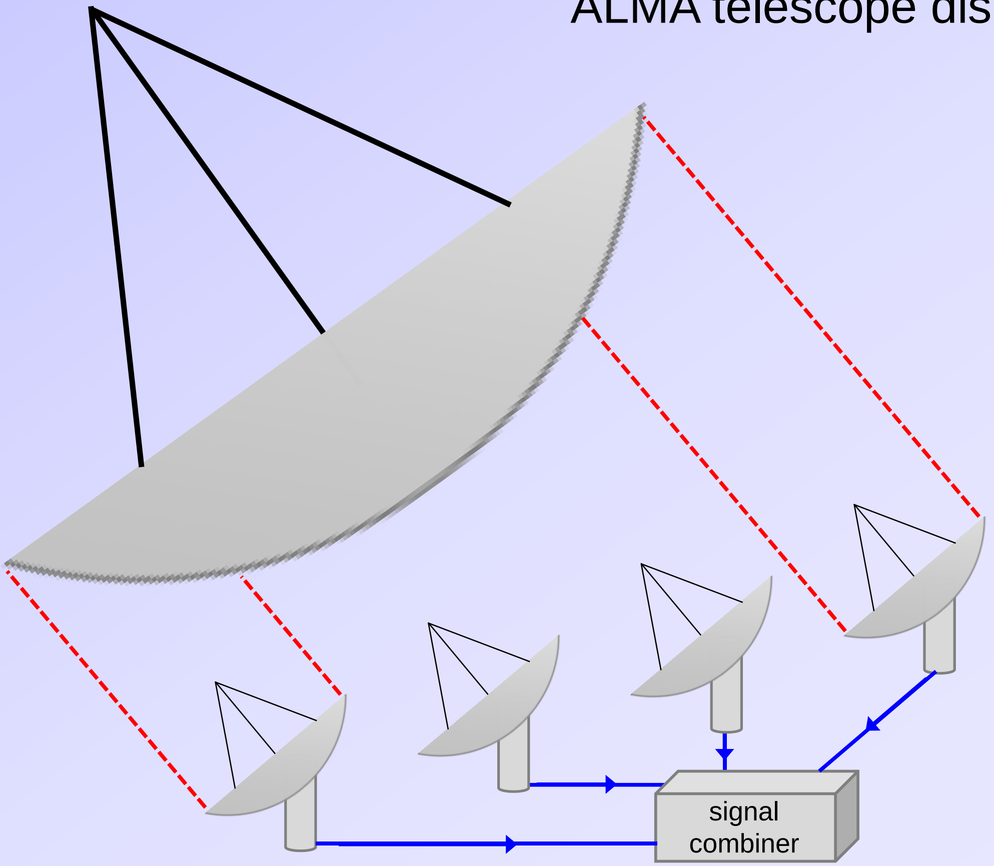
Answer: Interferometric array of telescopes.

Telescope Interferometry

ALMA telescope dish

Basic Idea

- You **combine** the signal **waves** from multiple telescopes.
- Important: the signal waves must stay **in-sync**.



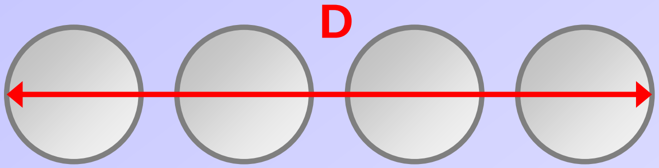
Telescope Interferometry

ALMA telescope dish

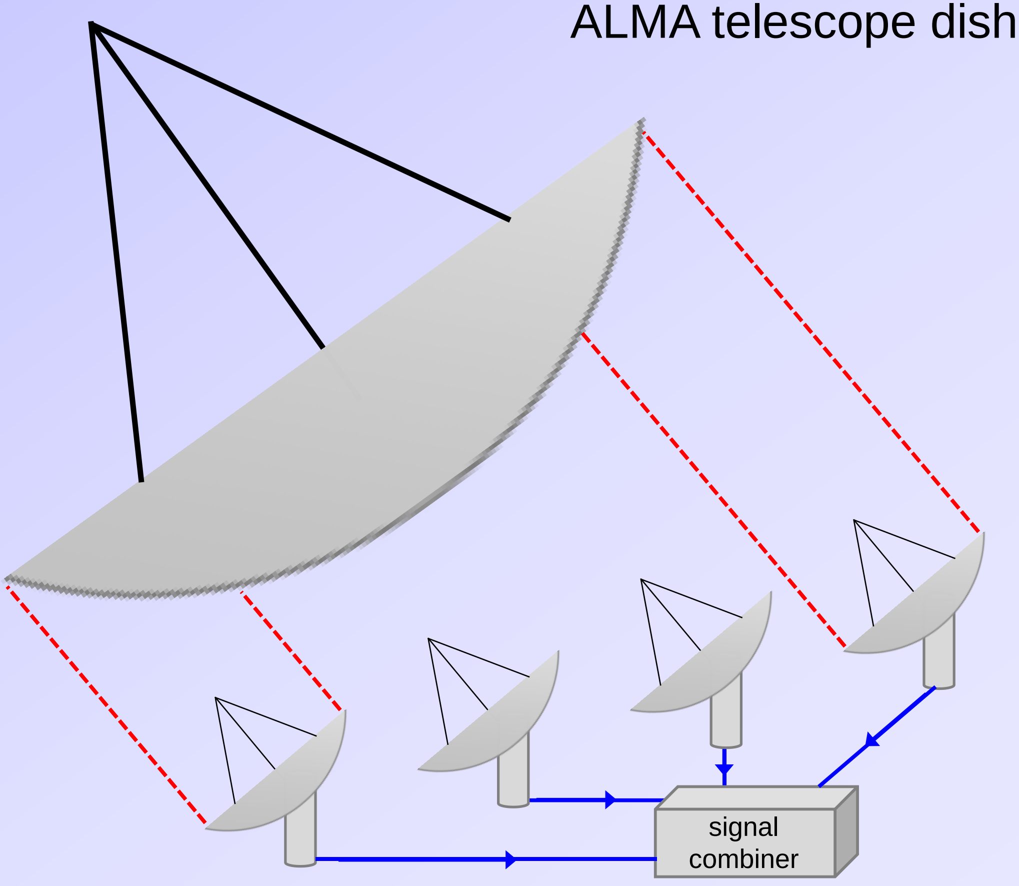
Basic Idea

- You **combine** the signal **waves** from multiple telescopes.
- Important: the signal waves must stay **in-sync**.

- It is like having pieces of a much **larger mirror**.
- Gets around the aperture limit by making a **giant composite mirror**.
- The **aperture is now the "span"** of the mirrors (D).



- The **collection power** is the combined area of these individual mirror.



ALMA radio telescope array

- Wavelength: λ = 0.3 – 9.6 mm.
- 66 dishes with 7-12 m diameters.
- Dish separation up to 16 km.
- Atacama plateau, Chile.
- Multinational collaboration.
- $1.5 billion USD.

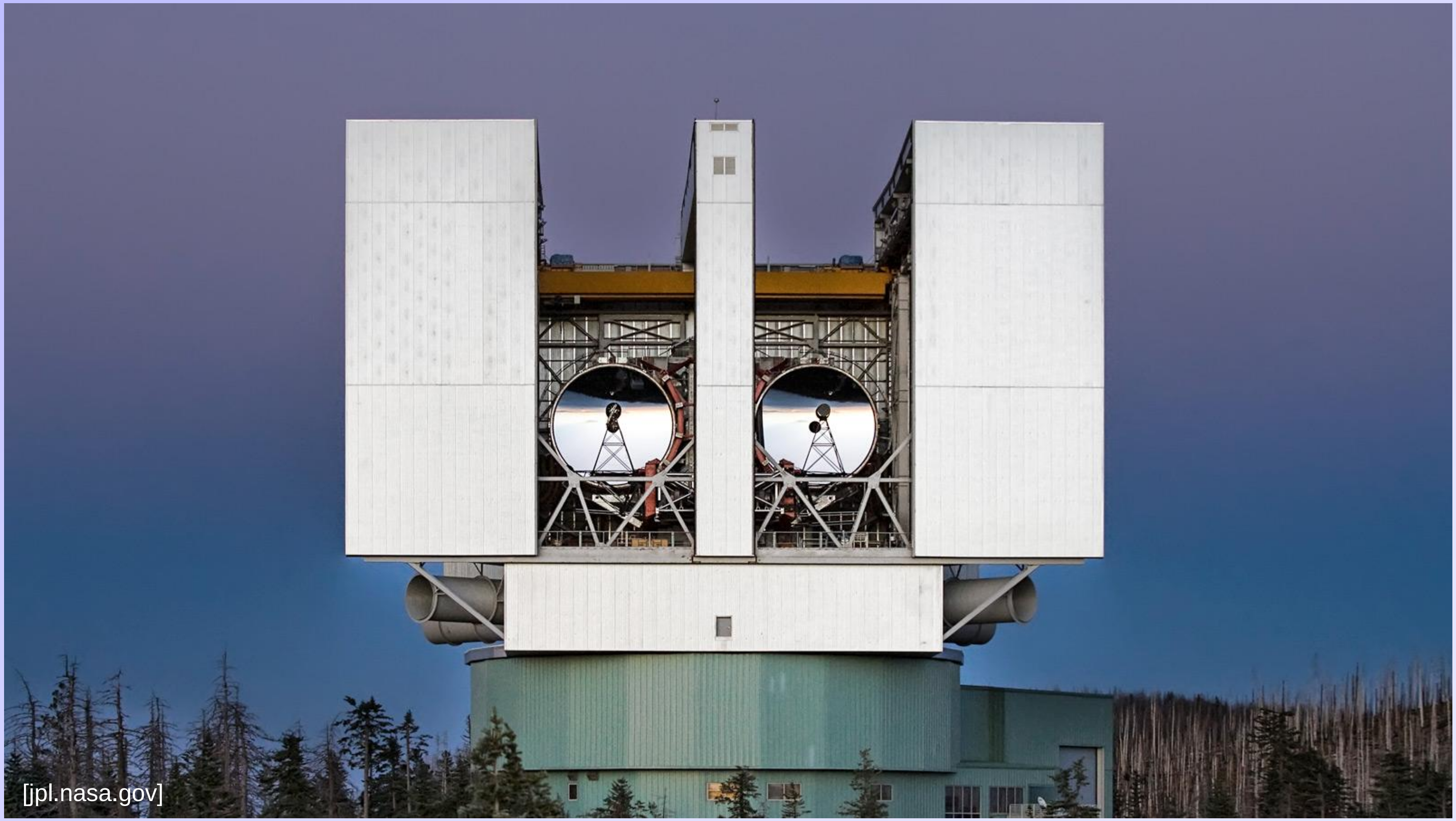

[Ariel Marinkovic – ALMA (ESO/NAOJ/NRAO)]

Large Binocular Telescope

[jpl.nasa.gov]

Large Binocular Telescope

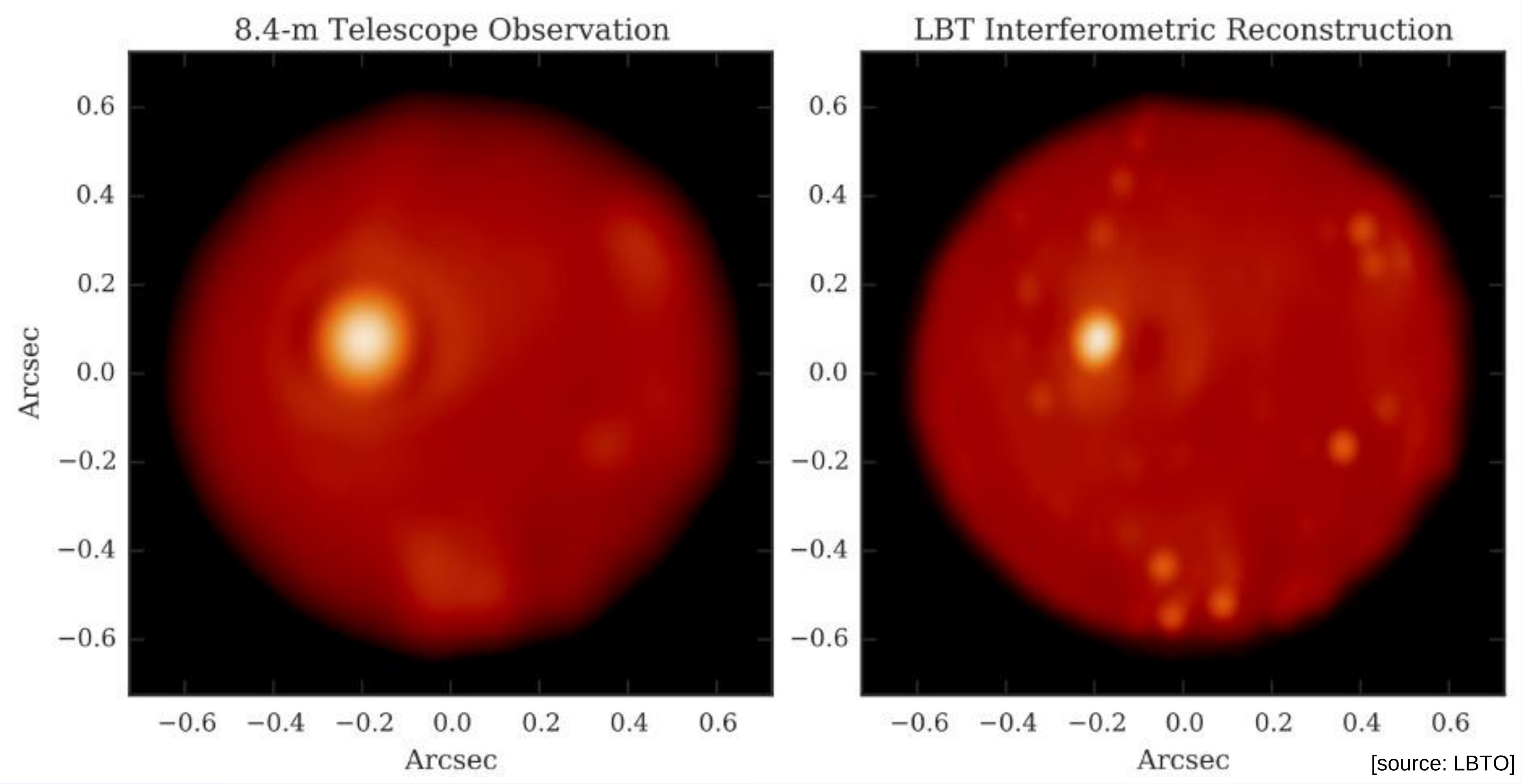
- Two 8.4 m mirrors
- Produces images with the resolution of a 23 m telescope (interferometer).
- Angular resolution $\theta_{min} \backsimeq 0.02'' = 20\ mas$ for a wavelength of λ = 2.2 µm.
- In Arizona at an altitude of 3200 m (10,500 ft).



[jpl.nasa.gov]

Large Binocular Telescope

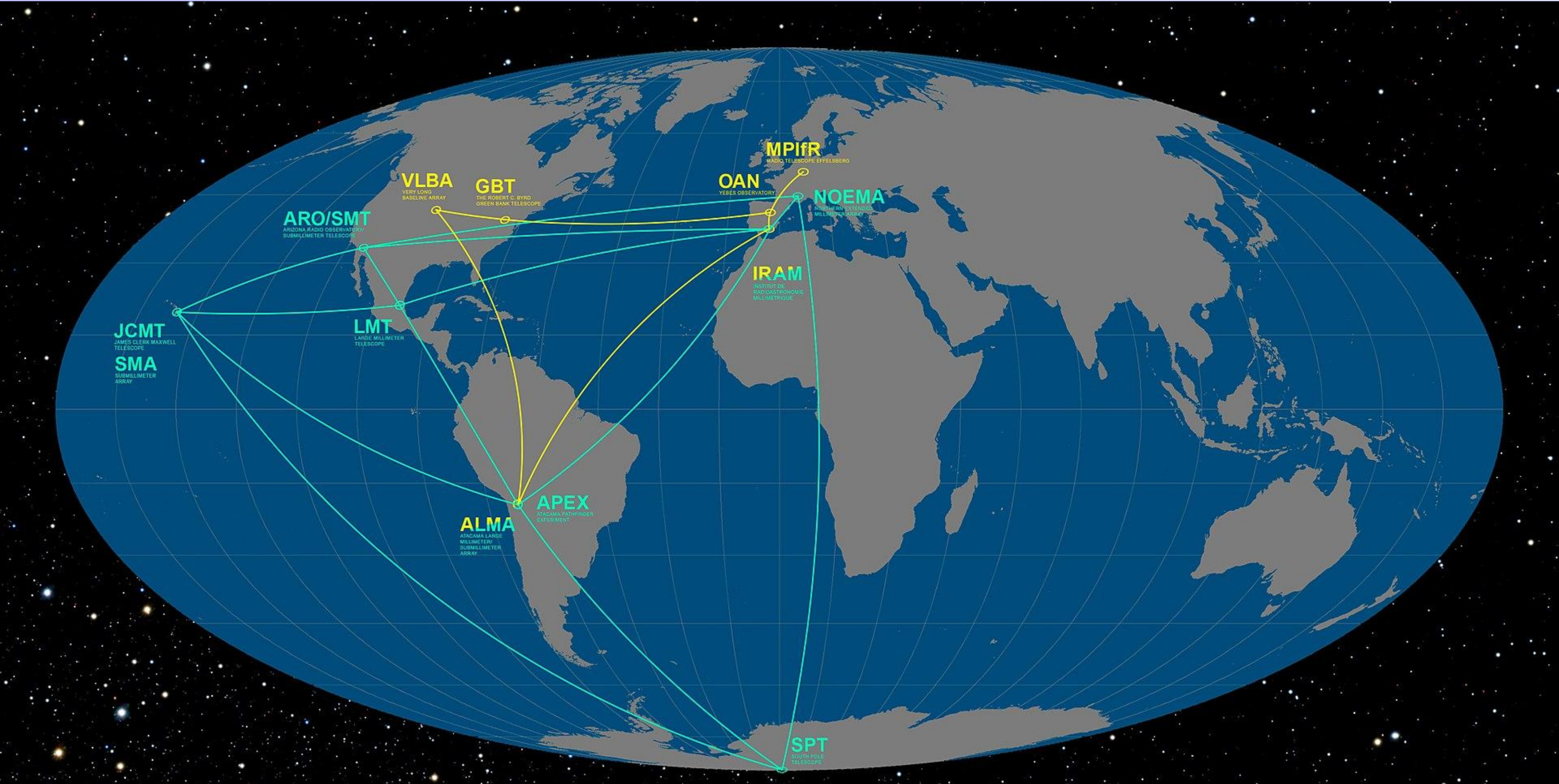
Volcanos on Io (moon of Jupiter) observed at λ = 3-5 μm (infrared)



(simulated) (reconstructed from data)

Event Horizon Telescope

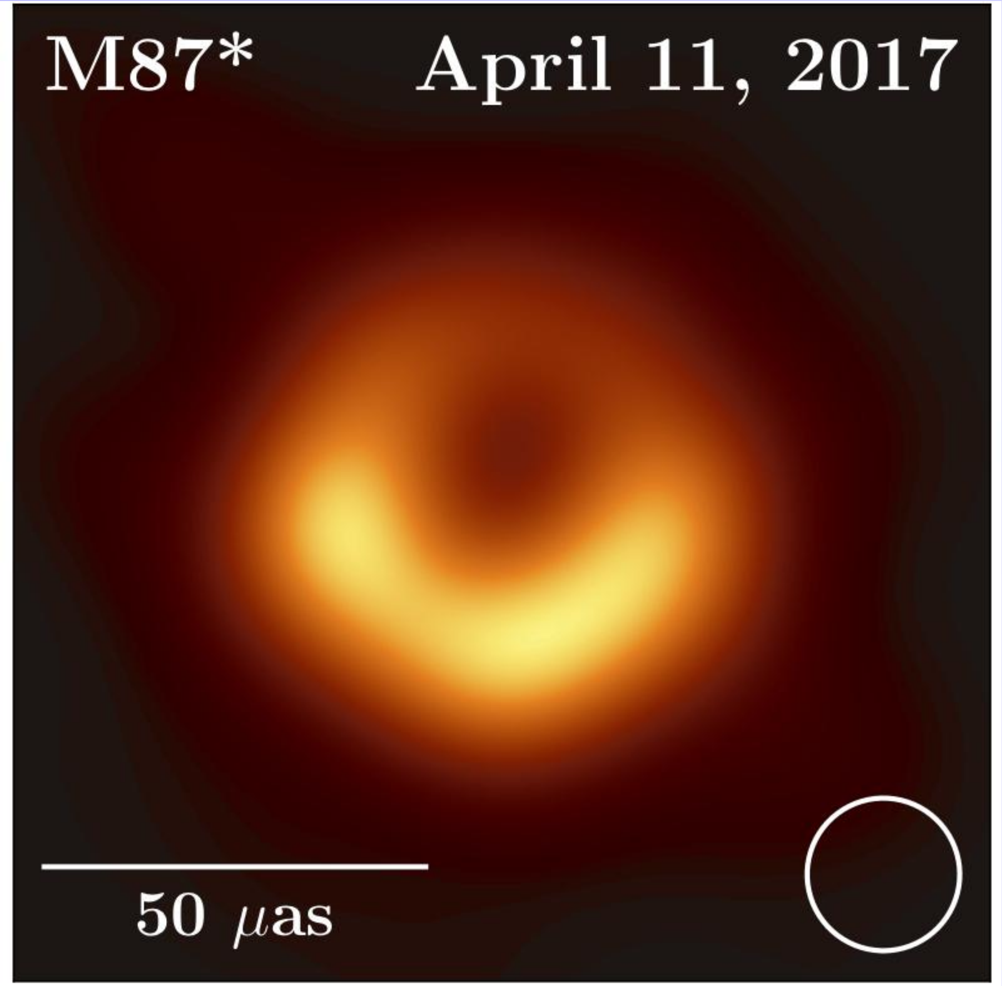
- Network of 8 radio telescopes spread over entire planet.
- Wavelength: $\lambda \sim 1$ mm.



[ESO/O: Furtak - https://www.eso.org/public/images/ann17015a/]

Event Horizon Telescope

Super massive black hole at center of M87 galaxy



distance = 53 Mly

λ = 1.3 mm

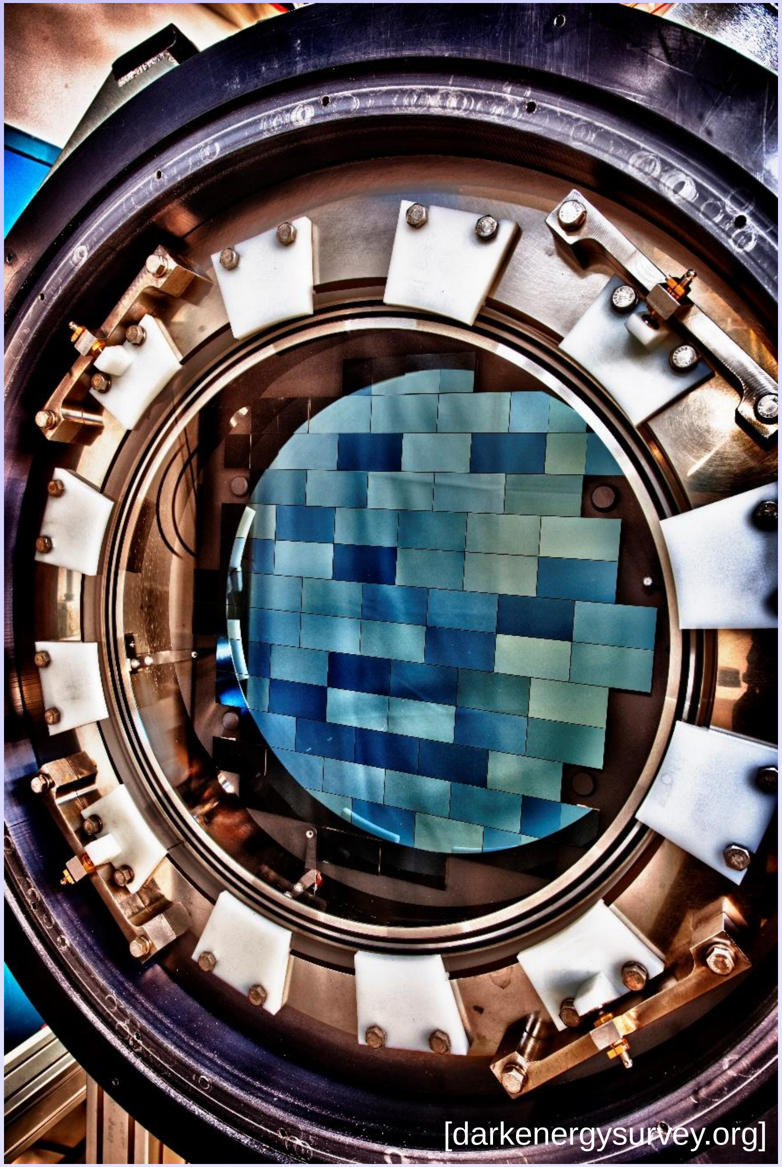
[aasnova.org, EHT collaboration (2019)]

Theoretical angular resolution of EHT: $\theta_{min} \sim 25\ \mu as = 0.000025''$

CCD Cameras

- CCD = Charge Coupled Device
- Standard digital camera sensor
- Wavelength

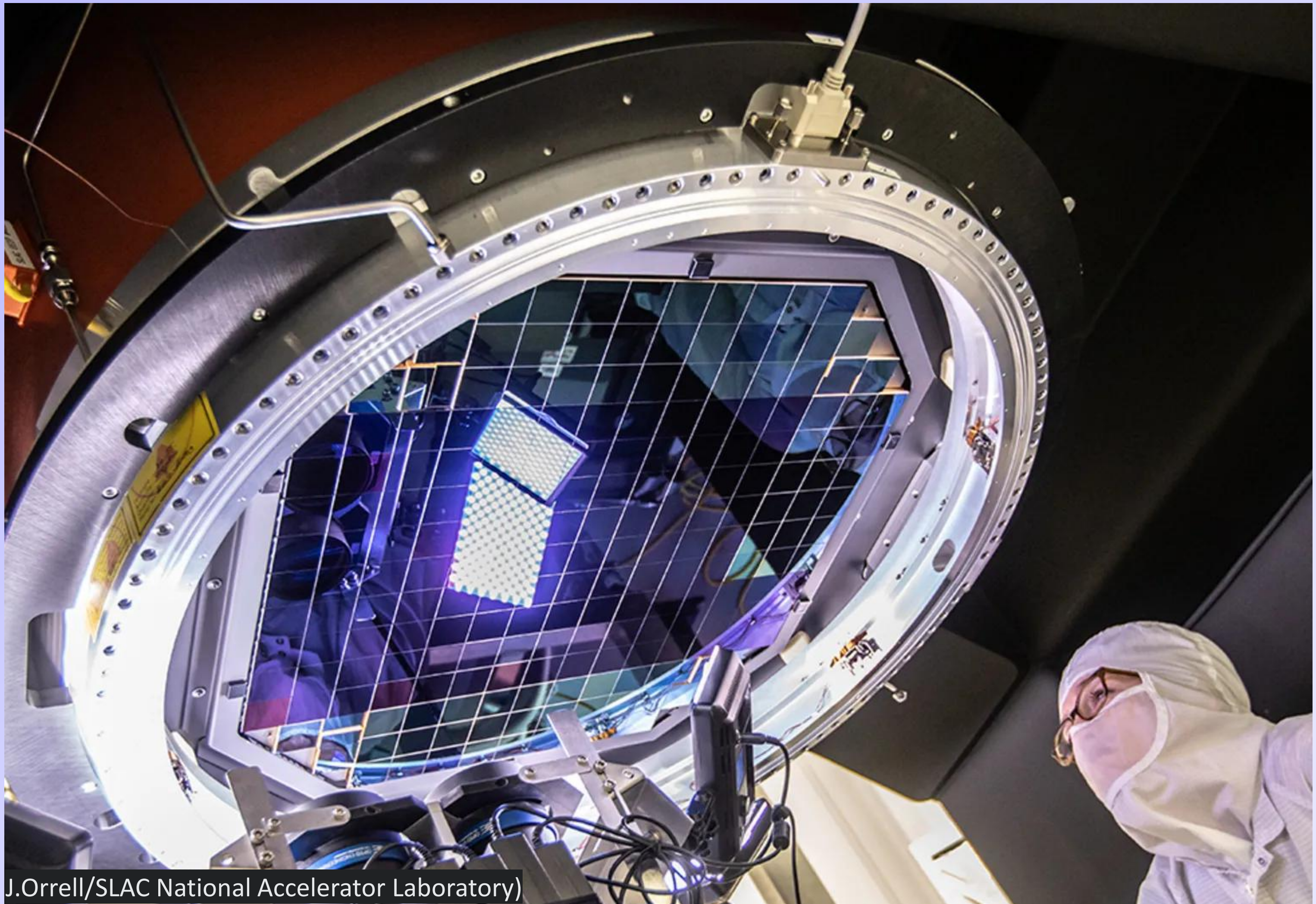
  → can cover X-ray to IR.
- **Efficiency:** 30-90% of photons detected (human eye ~ 20% in dark).
- Data is stored on a computer for later analysis (often made public).
- Often combined with a **spectrometer**.
- Does not work for microwaves and radio-waves (antenna sensor)...yet.



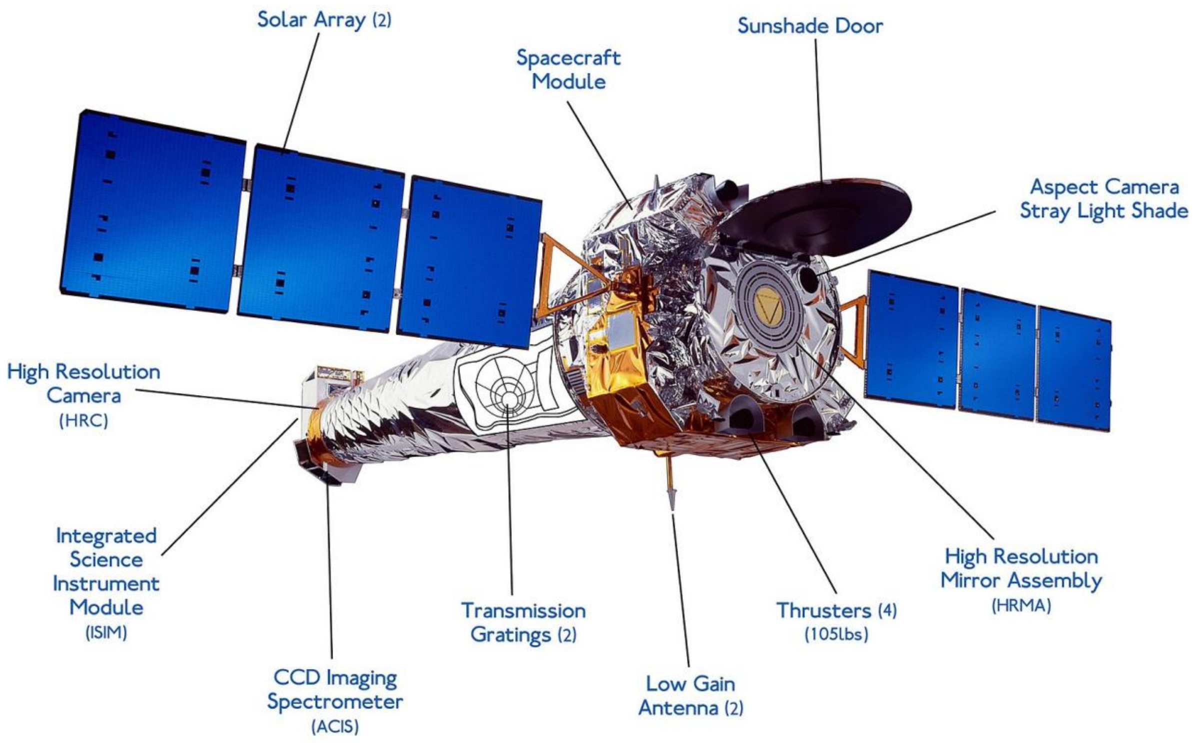
CCD array for Dark Energy Survey camera

Largest CCD camera in the world !!

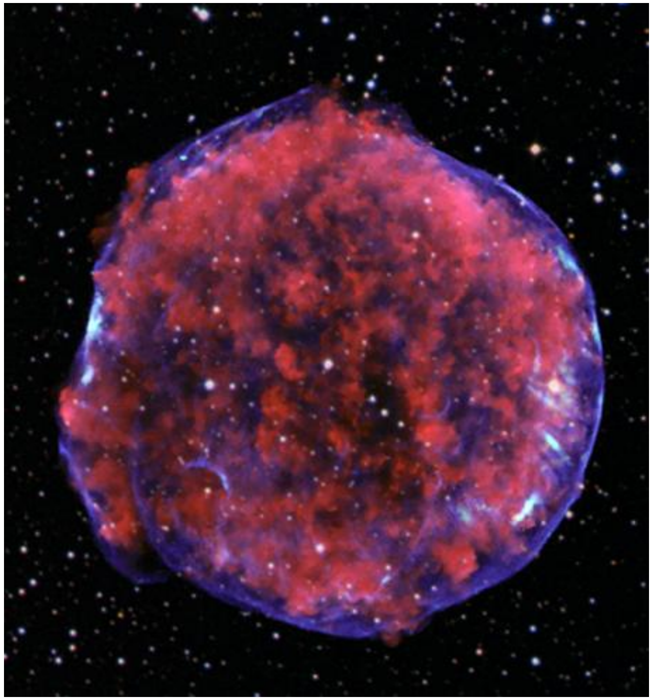
The Vera Rubin telescope has 3,200 Megapixels (189 CCD sub-arrays).



Chandra X-ray Telescope

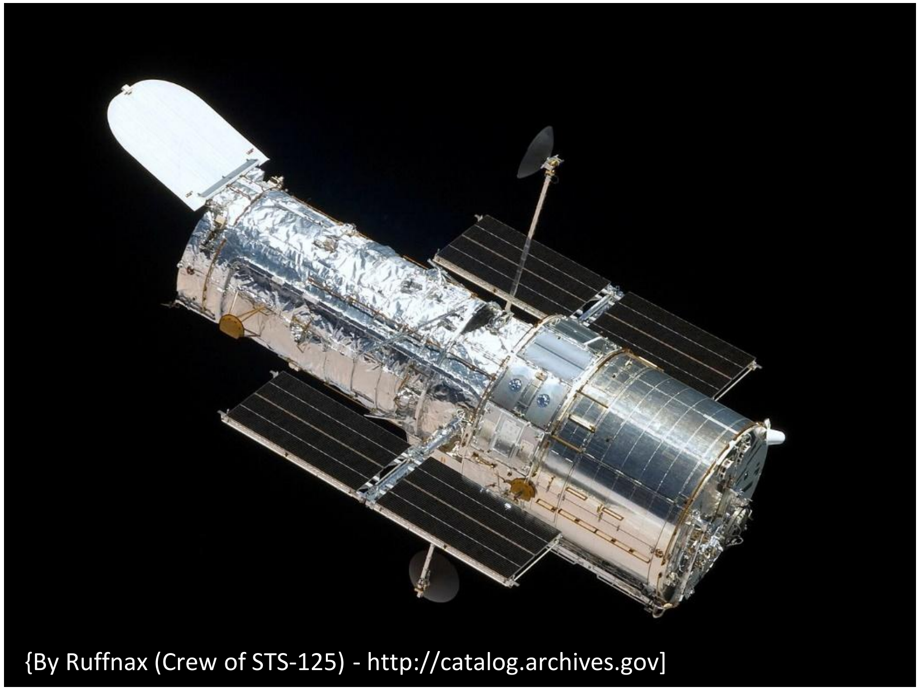


[NASA/CXC/NGST - http://chandra.harvard.edu]



Tycho's supernova (1572 AD).
X-ray: red & blue. Stars are optical.

Hubble Space Telescope



"pillars of creation" in the Eagle Nebula

(Serpens constellation, northern hemisphere)

Wavelengths: near-IR, visible, ultraviolet.

Main mirror diameter: D = 2.4 m

Angular resolution: $\theta_{min} \sim 0.05'' = 50\ mas$

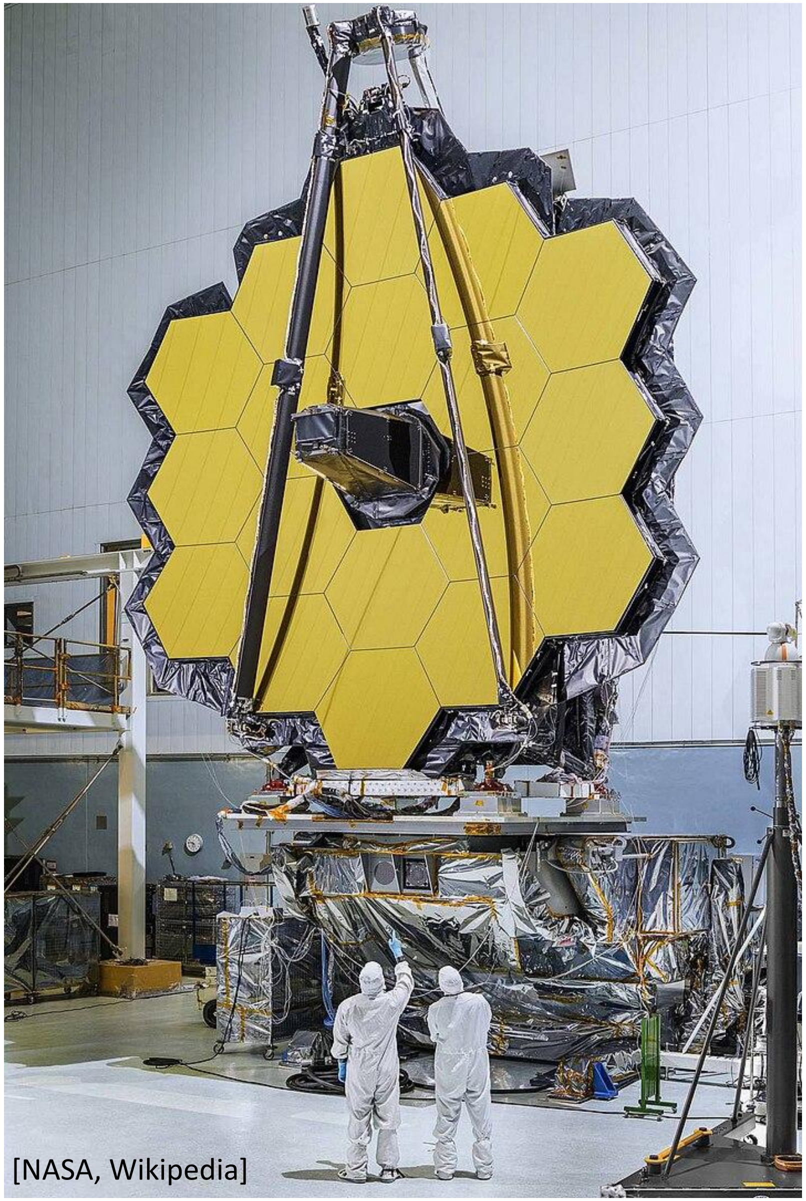
James Webb Space Telescope

Full size mock-up model [NASA/Goddard, Wikipedia]

Wavelengths: near-IR, mid-IR (0.6-28 microns).

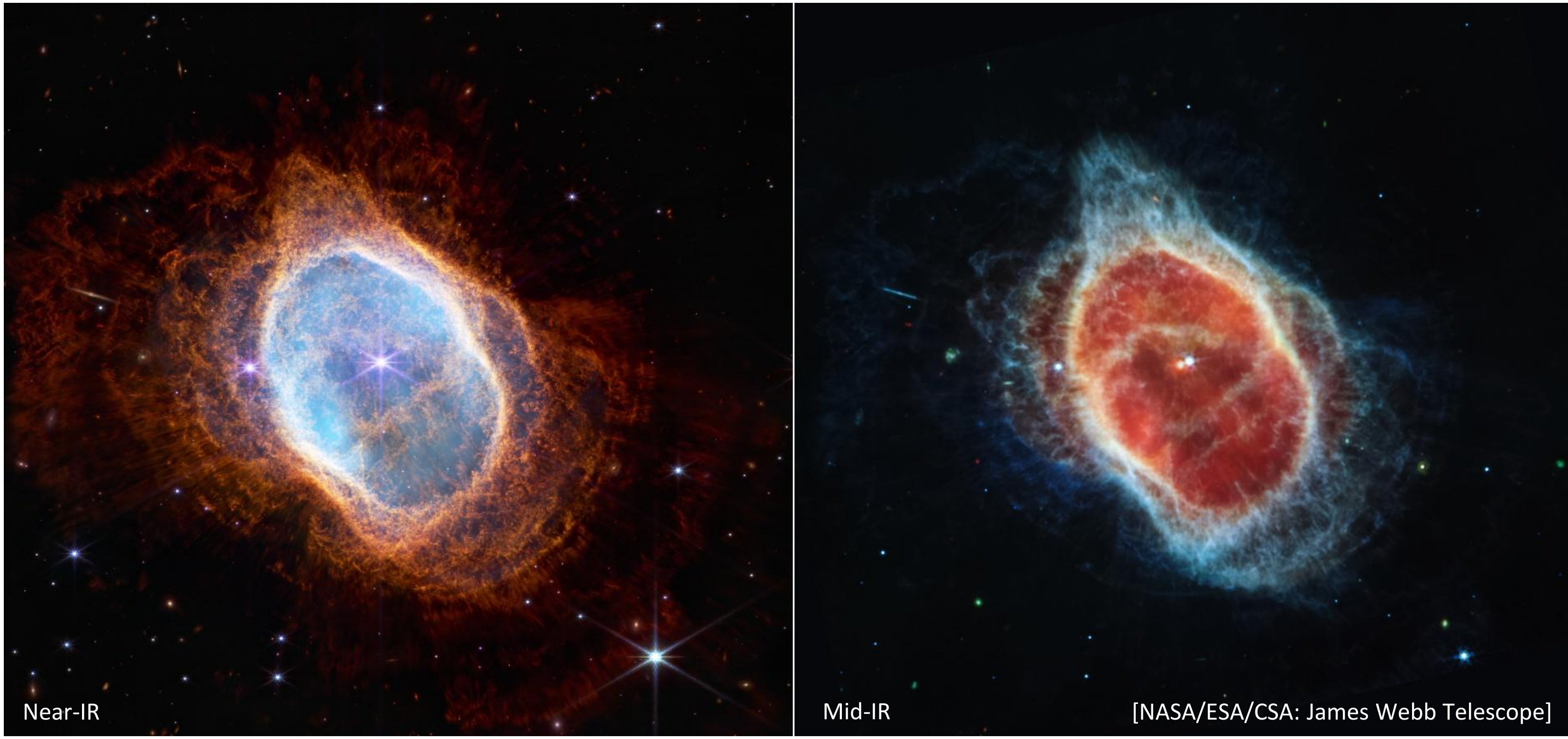
Main mirror diameter: D = 6.5 m

Angular resolution: $\theta_{min} \sim 0.1'' = 100\ mas$



[NASA, Wikipedia]

James Webb Space Telescope



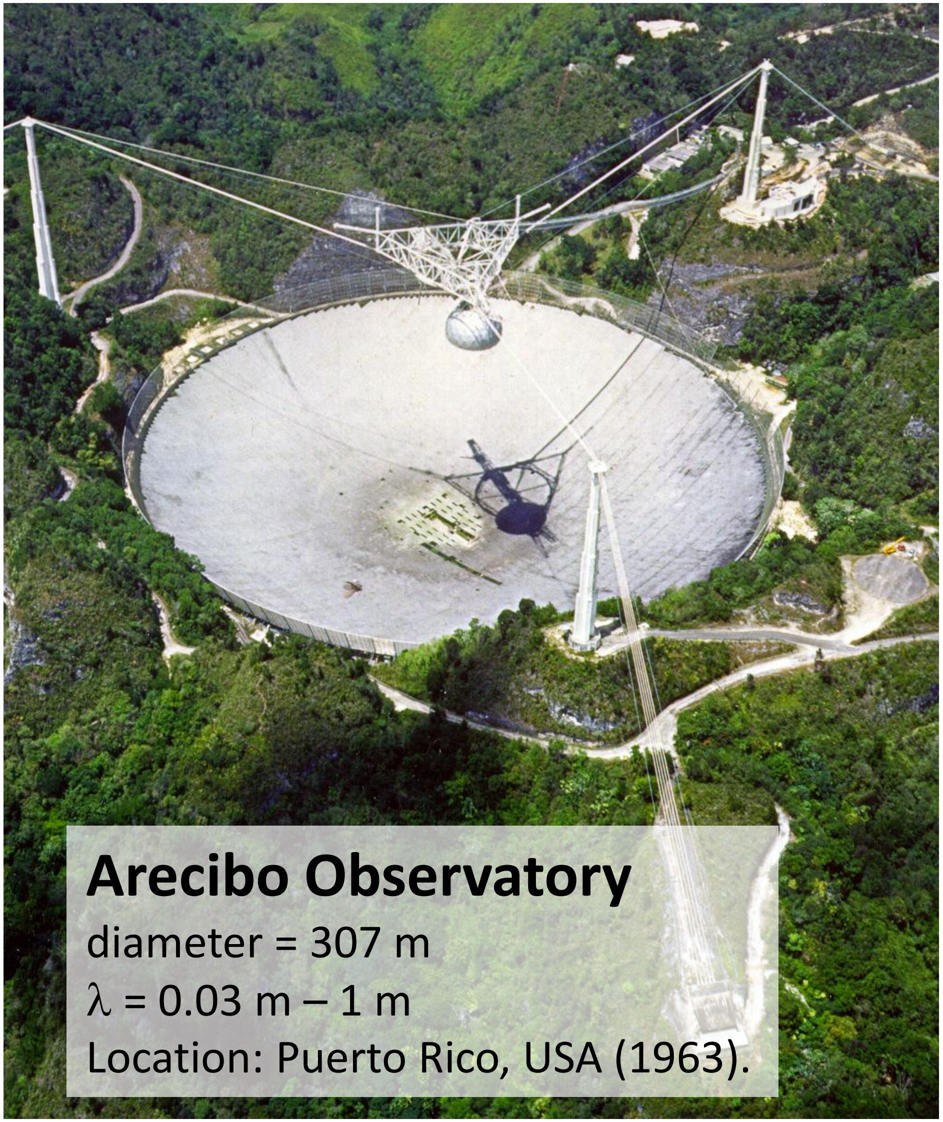
Southern Ring Nebular, constellation of Vela

Wavelengths: near-IR, mid-IR (0.6-28 microns).

Main mirror diameter: D = 6.5 m

Angular resolution: $\theta_{min} \sim 0.1'' = 100\ mas$ (at λ=2 microns)

Arecibo Radio Telescope



Arecibo Observatory

diameter = 307 m

λ = 0.03 m – 1 m

Location: Puerto Rico, USA (1963).

[source: naic.edu]

FAST Radio Telescope

[source: Wikipedia, Xinhua News]

Tianyan FAST Telescope

"Five-hundred-meter Aperture Spherical Telescope"

λ = 0.1 m – 10 m

Location: Guizhou, China (operational in 2020).