Today's Topics

Monday, March 3, 2025 (Week 6, lecture 14) – Chapter 6.

A. Angular resolution review

B. Interferometry

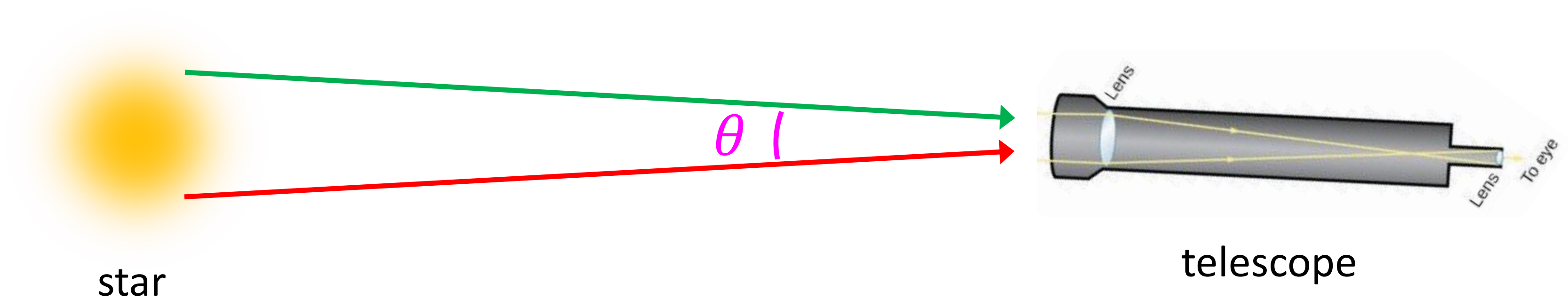
C. CCD cameras

D. 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.



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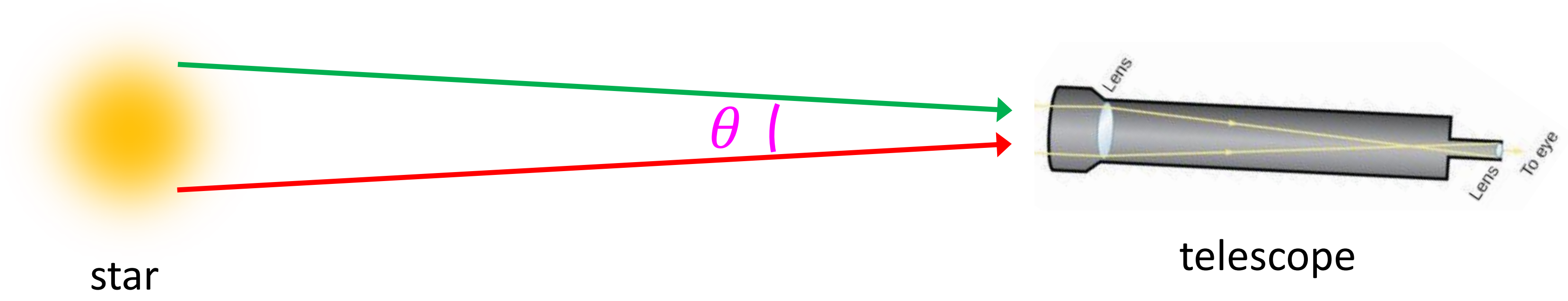

SI units: $\theta_{min} = 1.22\dfrac{\lambda}{D}$ (radians; λ: wavelength in meters)

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

Review: Angular Resolution

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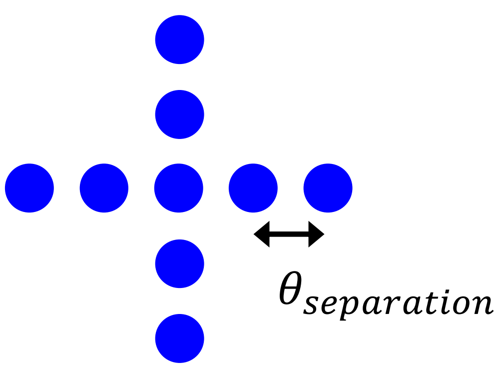
Key point

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 $\theta_{separation} \gg \theta_{min}$

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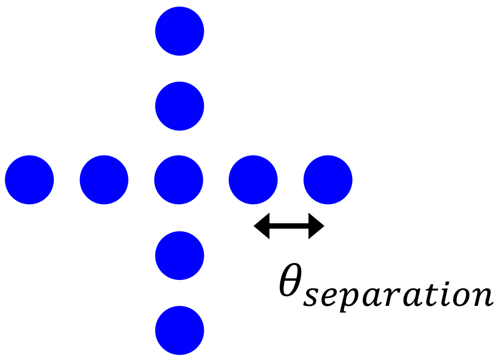

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Telescope image for $\theta_{separation} \sim \theta_{min}$

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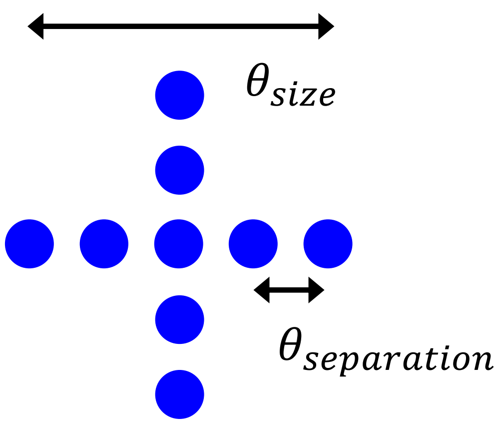

Stars in "plus" pattern

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

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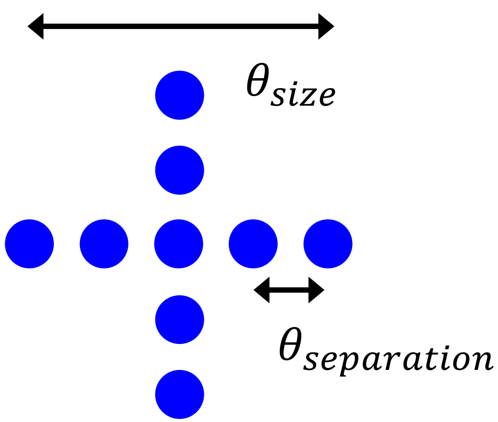

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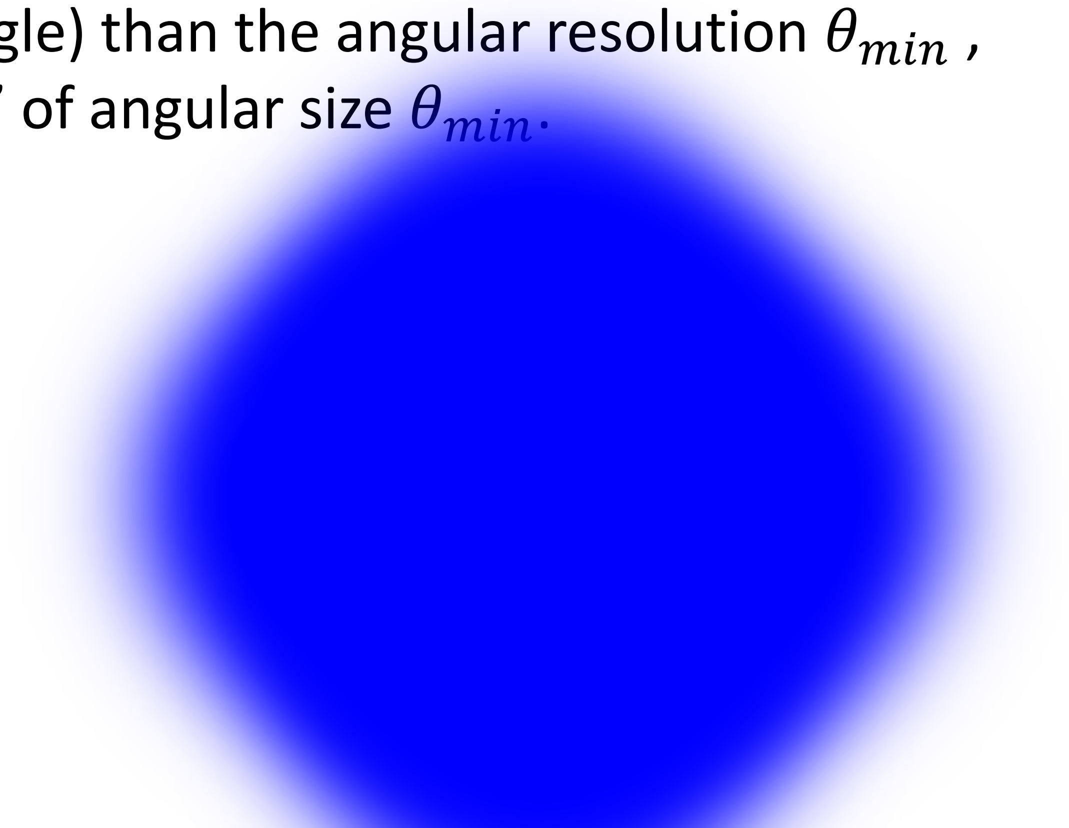


Telescope image for $\theta_{separation} \ll \theta_{min} \sim \theta_{size}$

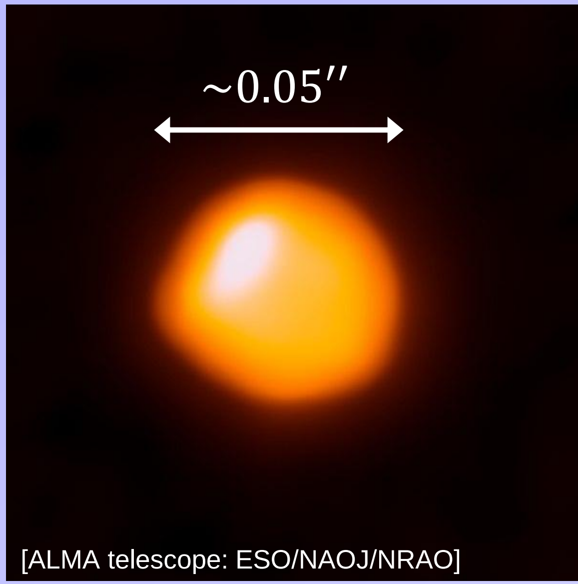
PollEv Quiz: PollEv.com/sethaubin

Telescope Interferometry

for

Super Angular Resolution

Image of Betelgeuse

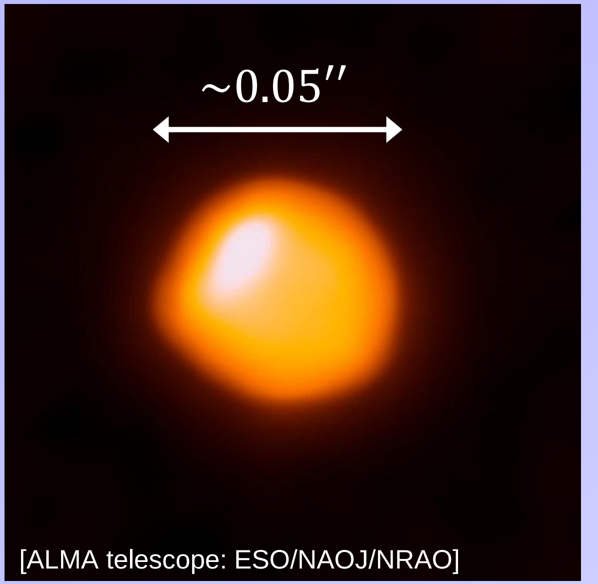


λ = 0.89 mm, f = 338 GHz

(mm-wave)
(microwave)

Constellation: **Orion**

Image of Betelgeuse



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

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

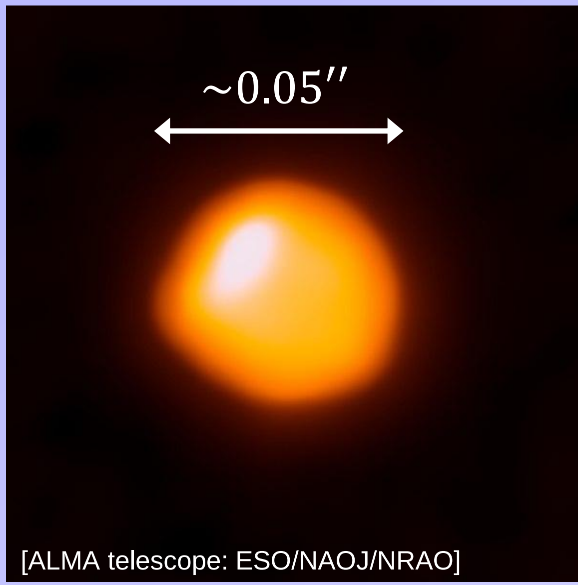
→ Angular resolution must be better than $0.01''$.

(5 times better than Gemini telescope)

Constellation: **Orion**

Question: How did the angular resolution get this good ?

Image of Betelgeuse



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Constellation: **Orion**

Question: How did the angular resolution get this good ?

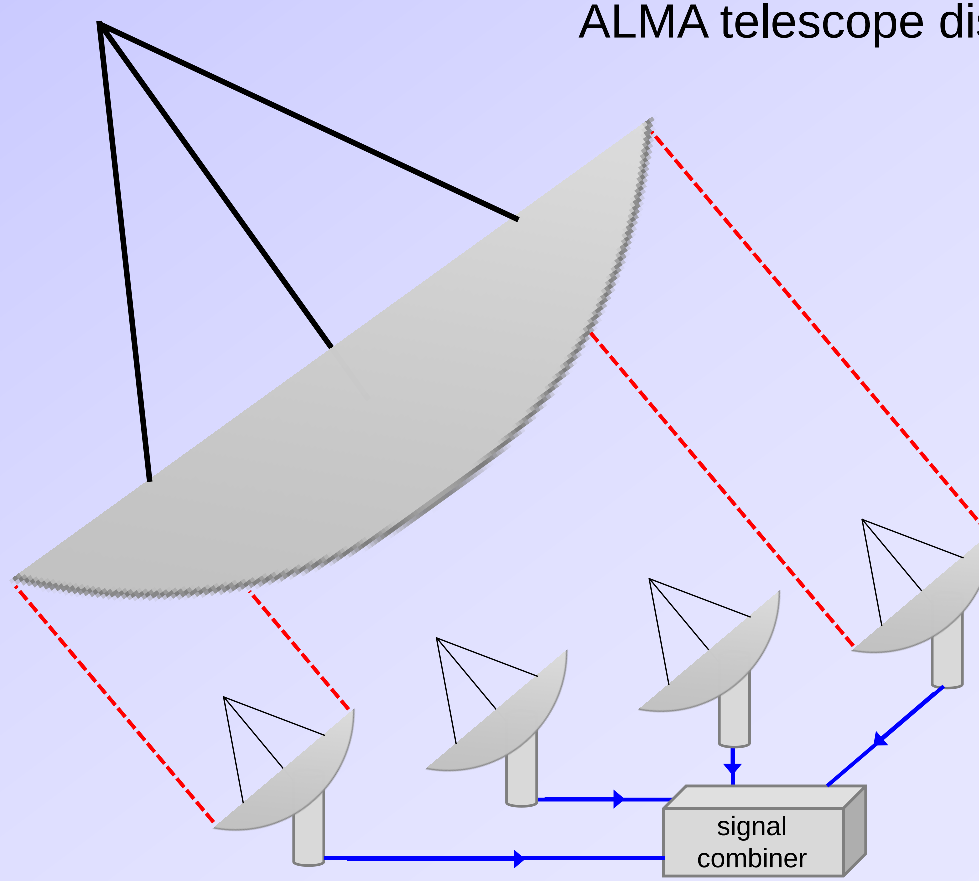
Answer: Interferometric array of telescopes.

Telescope Interferometry

ALMA telescope dish

Basic Idea

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



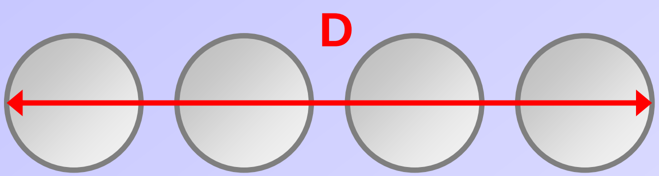
Telescope Interferometry

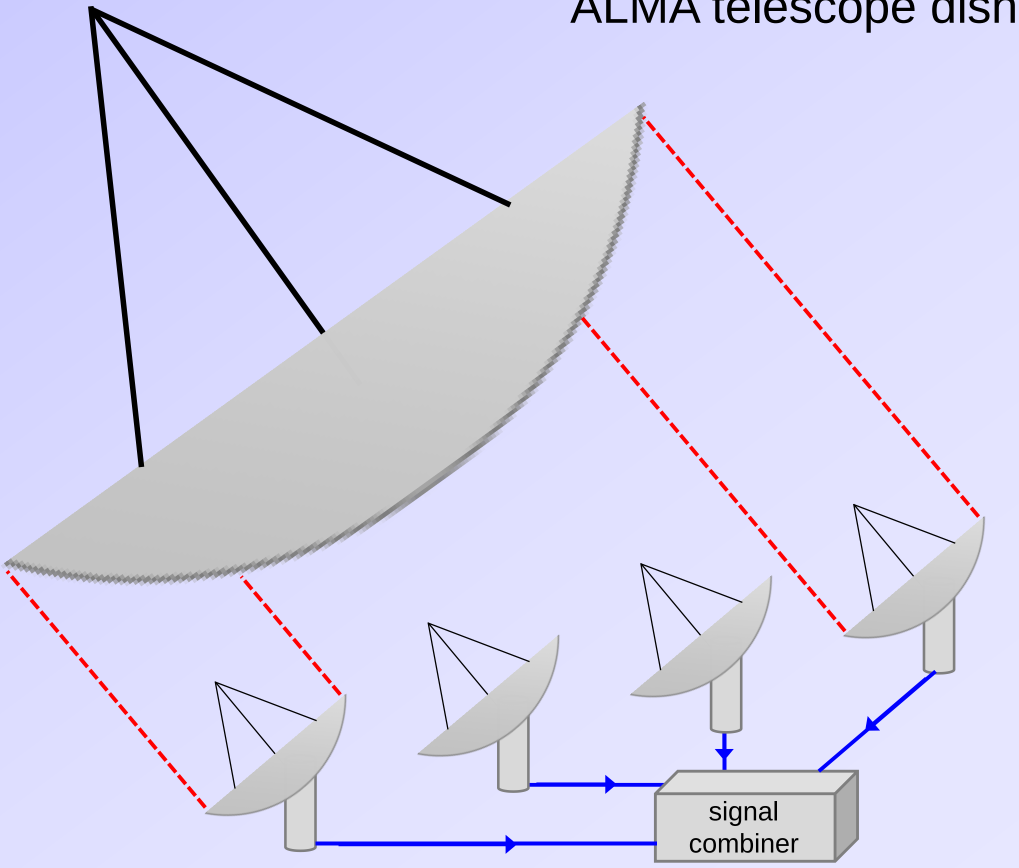
ALMA telescope dish

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.

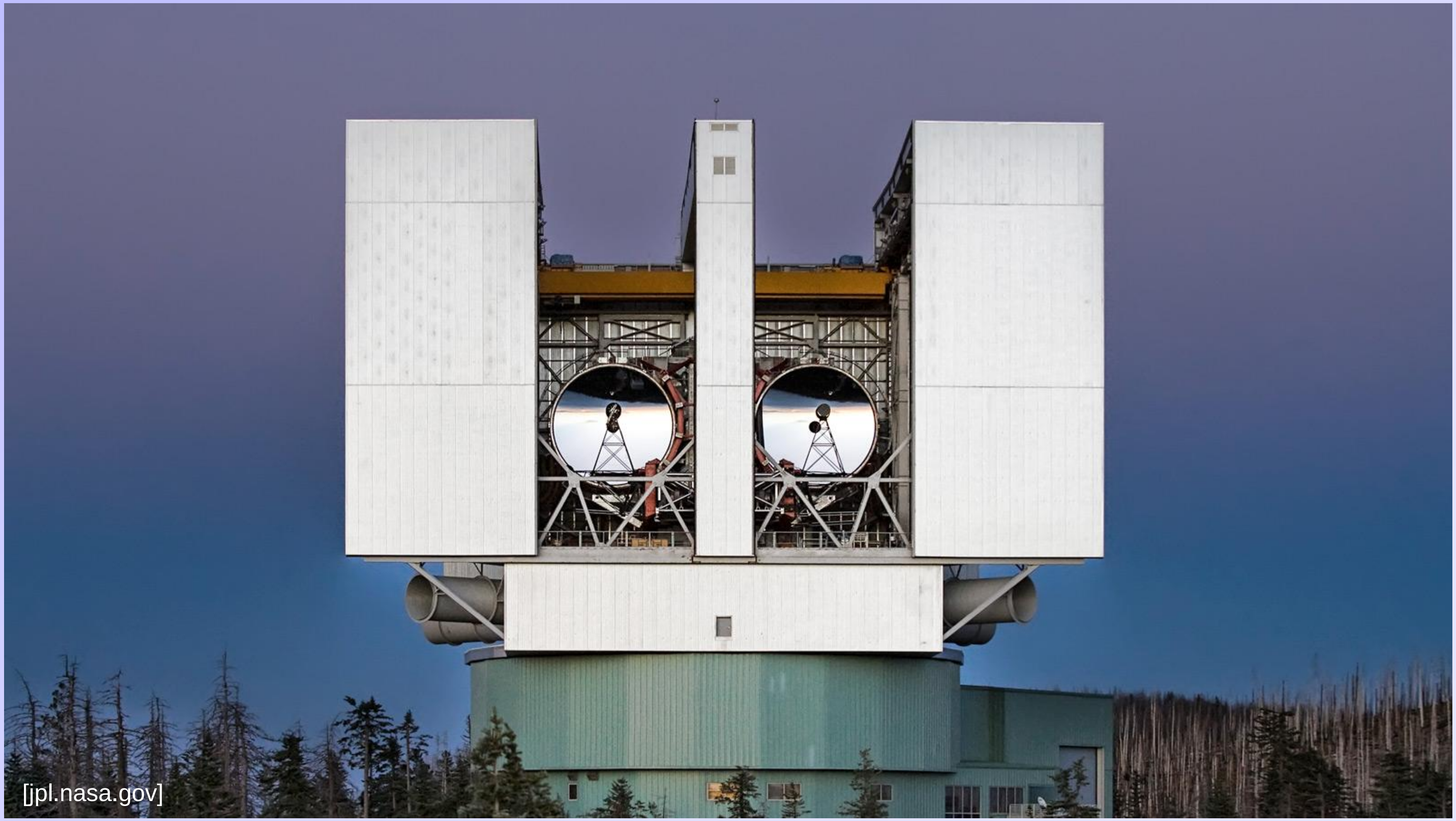

[Ariel Marinkovic – ALMA (ESO/NAOJ/NRAO)]

Large Binocular Telescope

[jpl.nasa.gov]

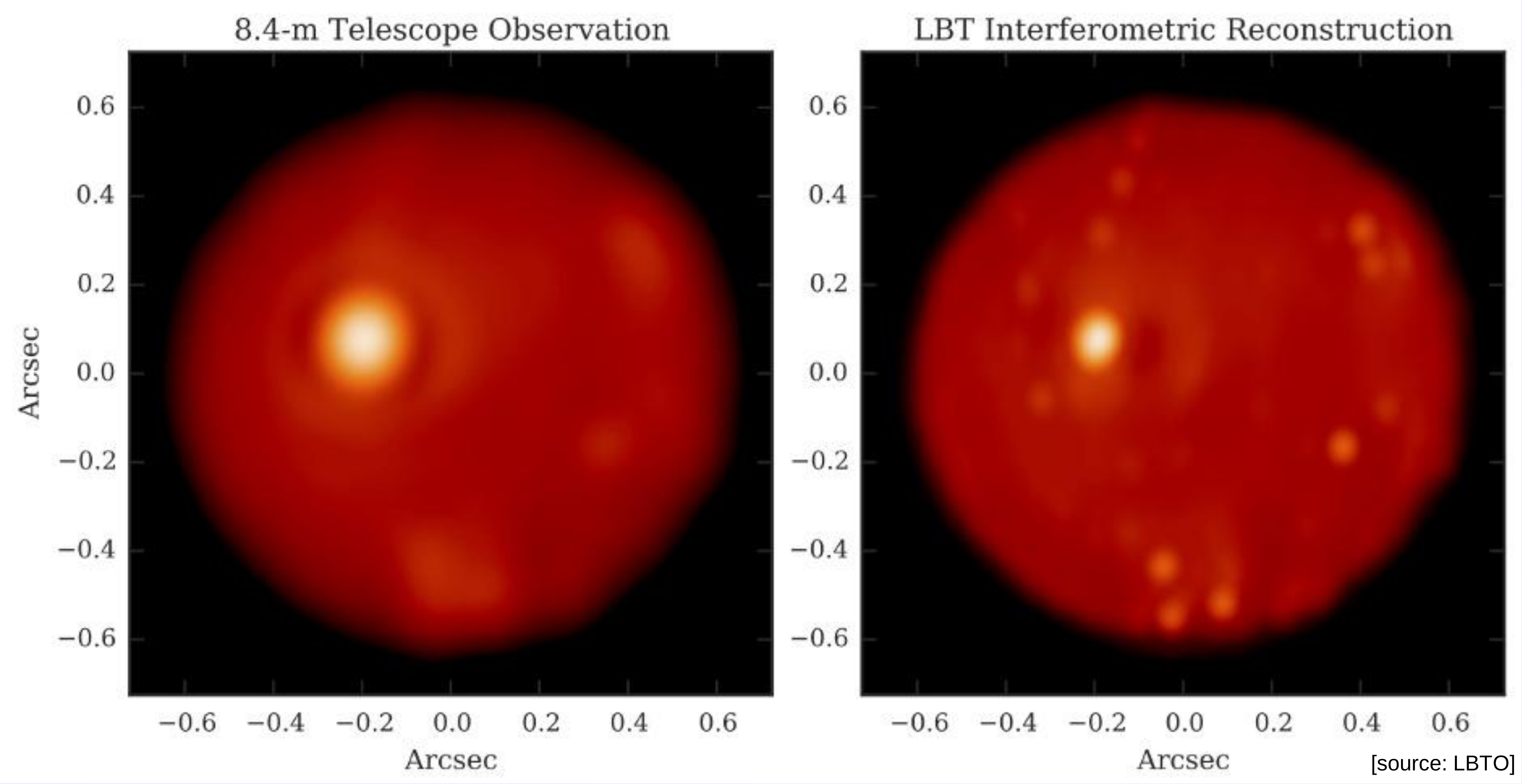
Large Binocular Telescope

- 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)

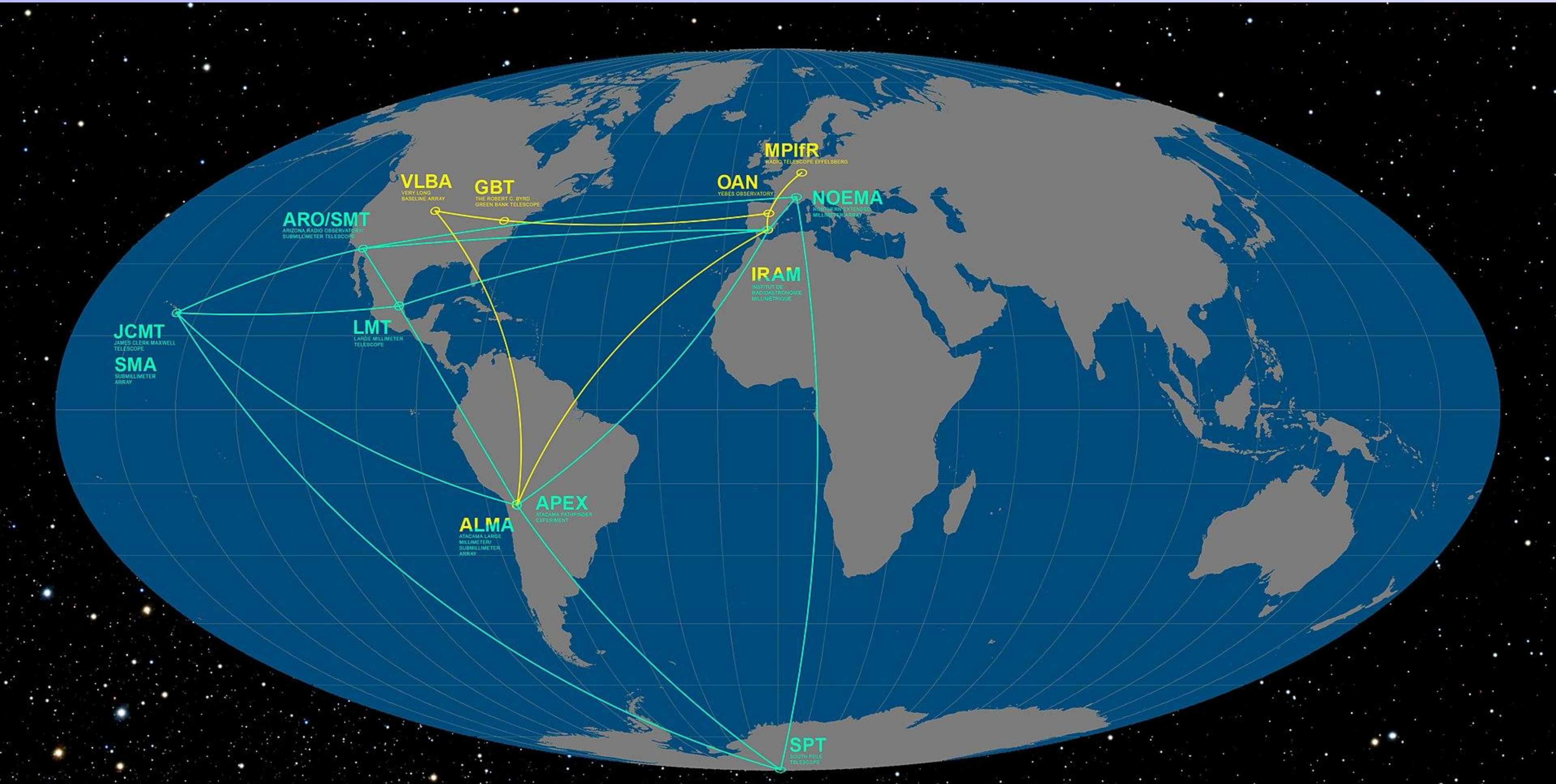


(simulated)

(reconstructed from data)

Event Horizon Telescope

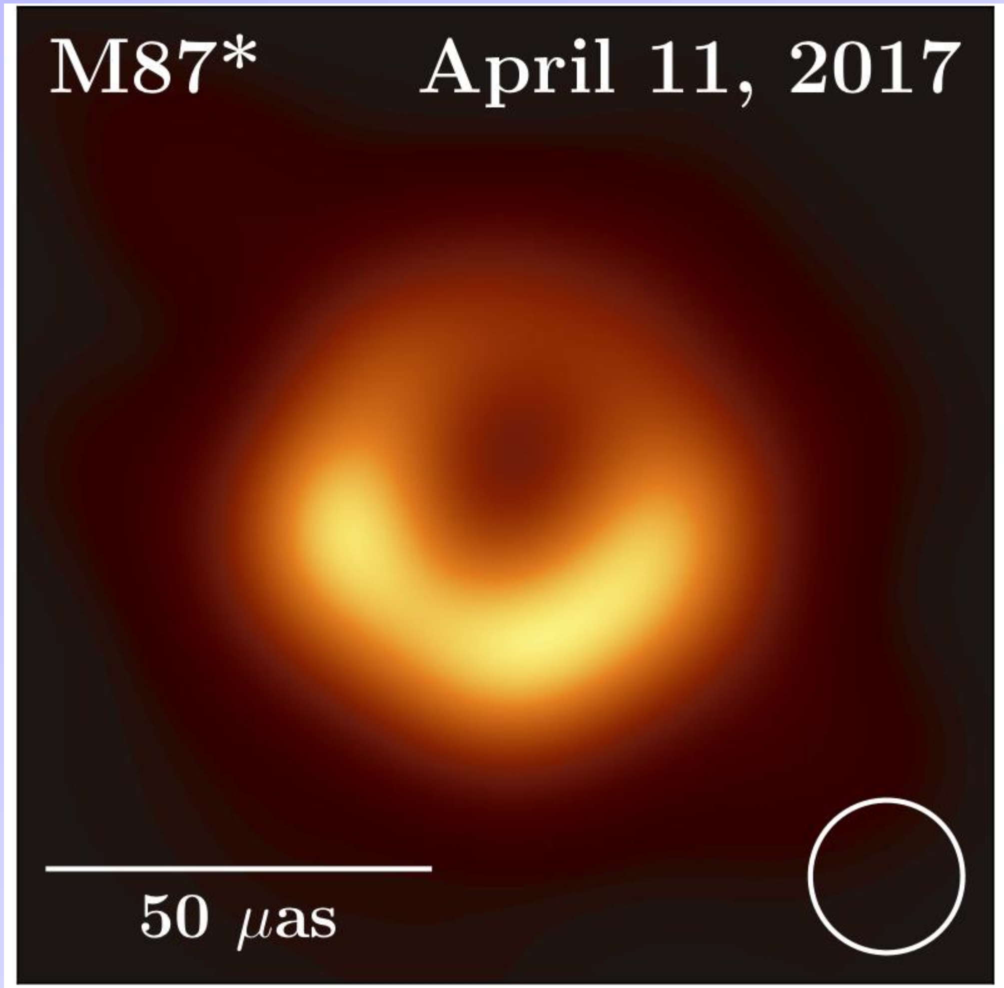
- Network of 8 radio telescopes spread over entire planet.
- Wavelength: λ ~ 1 mm.



[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

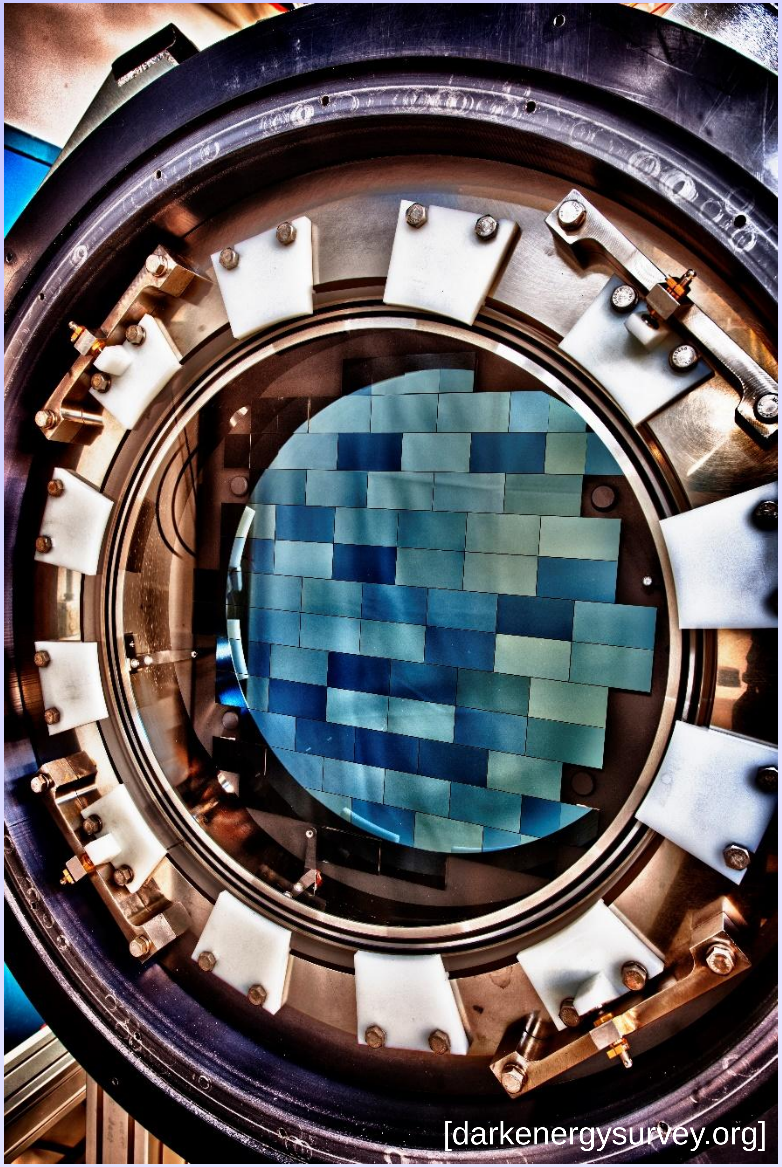
[aasnova.org, EHT collaboration (2019)]

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

CCD Cameras

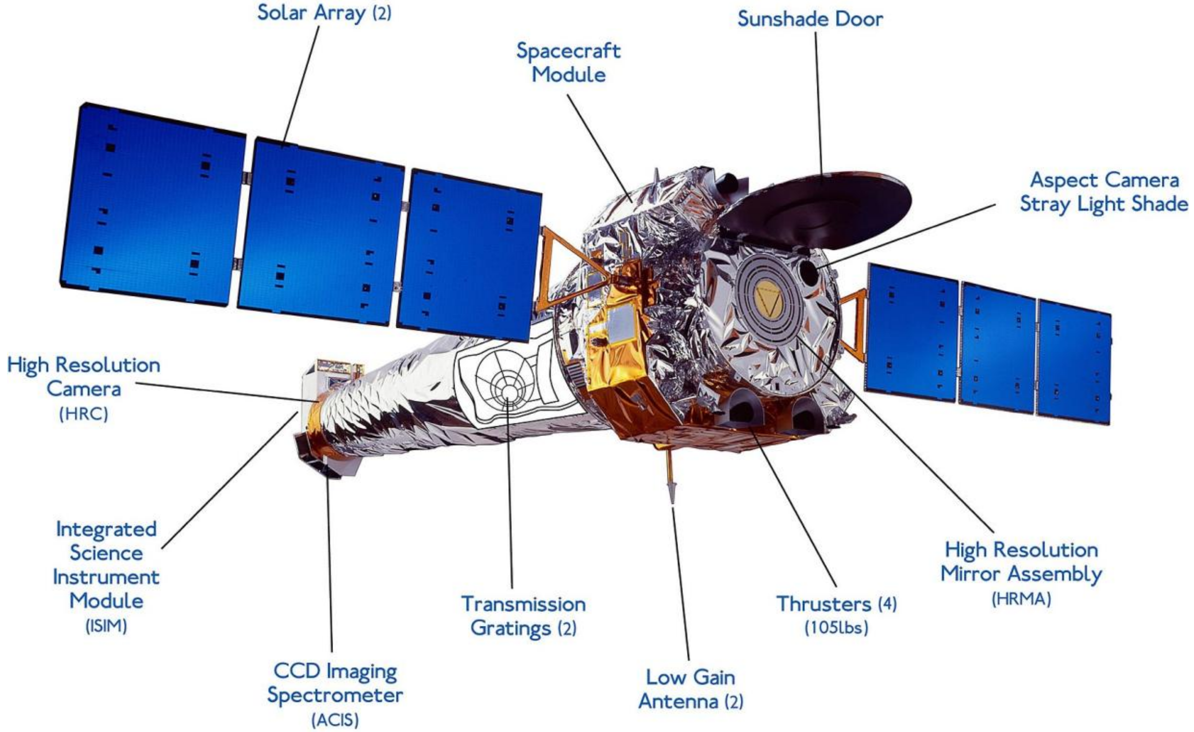
- CCD = Charge Coupled Device
- Standard digital camera sensor
- Wavelength

  → 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.

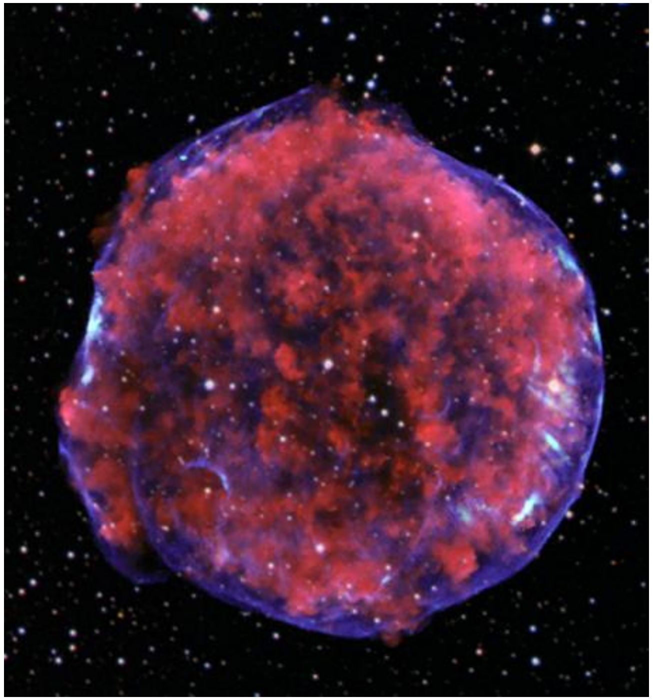


CCD array for Dark Energy Survey camera

Chandra X-ray Telescope

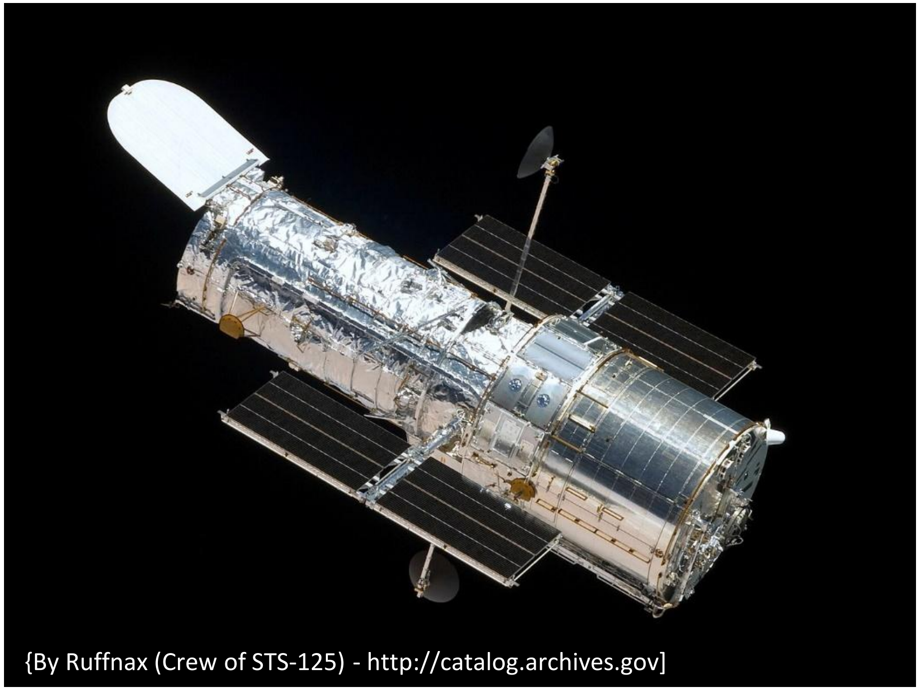


[NASA/CXC/NGST - http://chandra.harvard.edu]



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

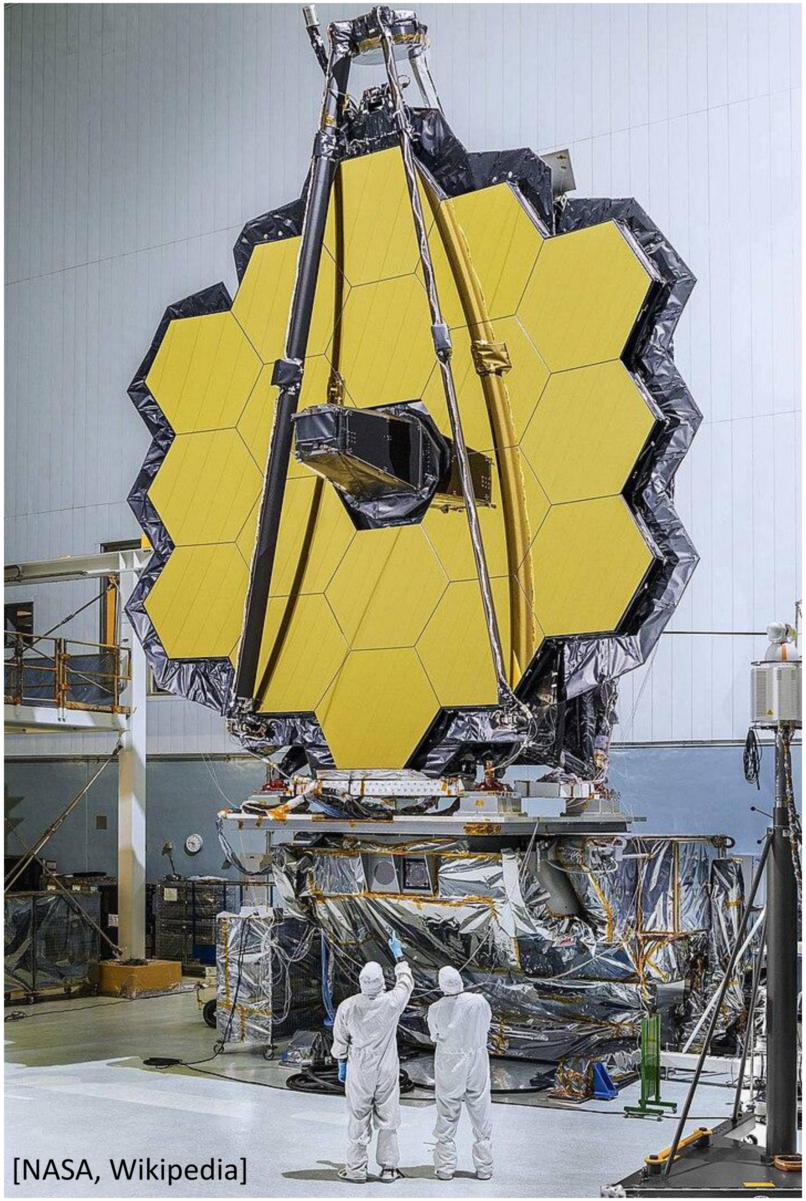
James Webb Space Telescope

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]

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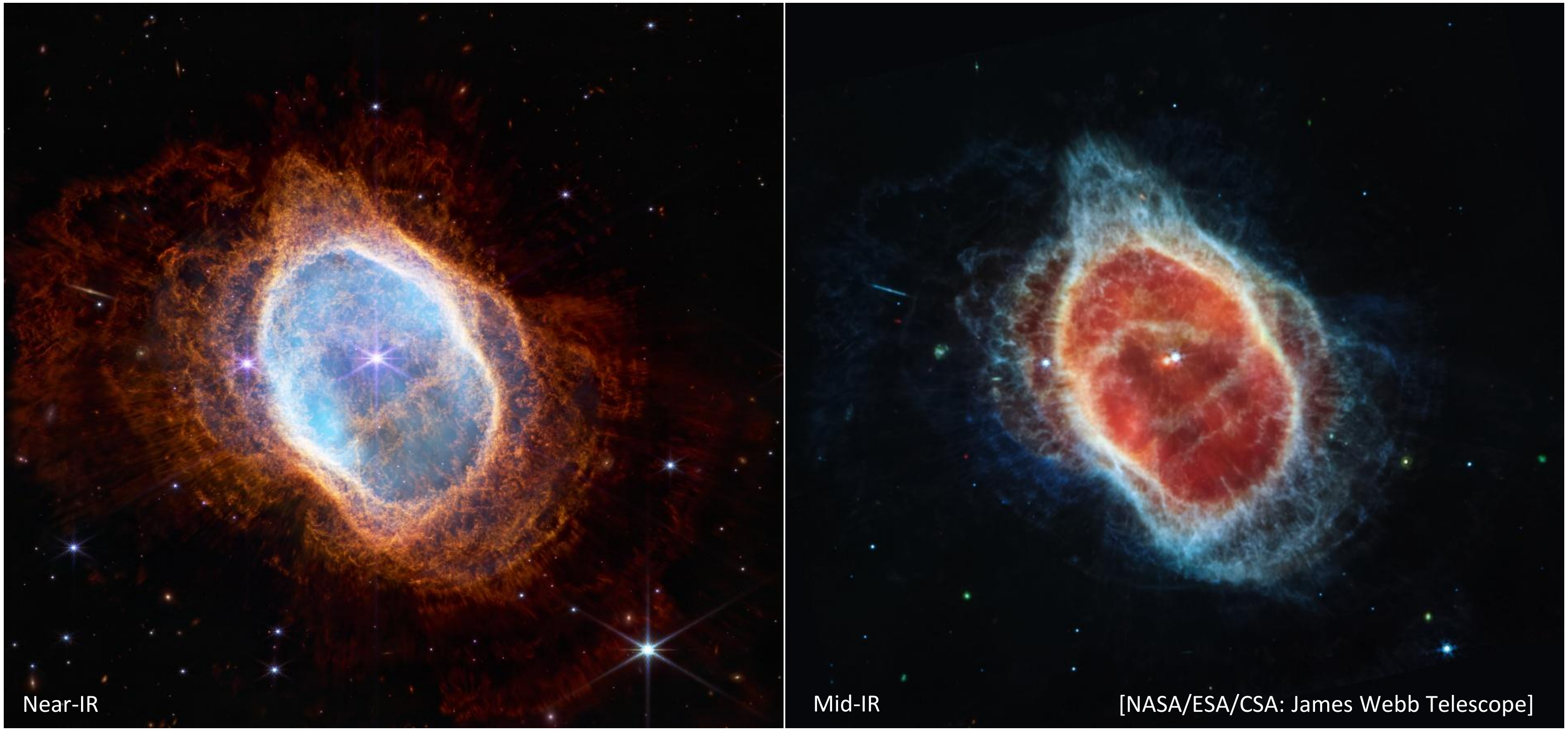


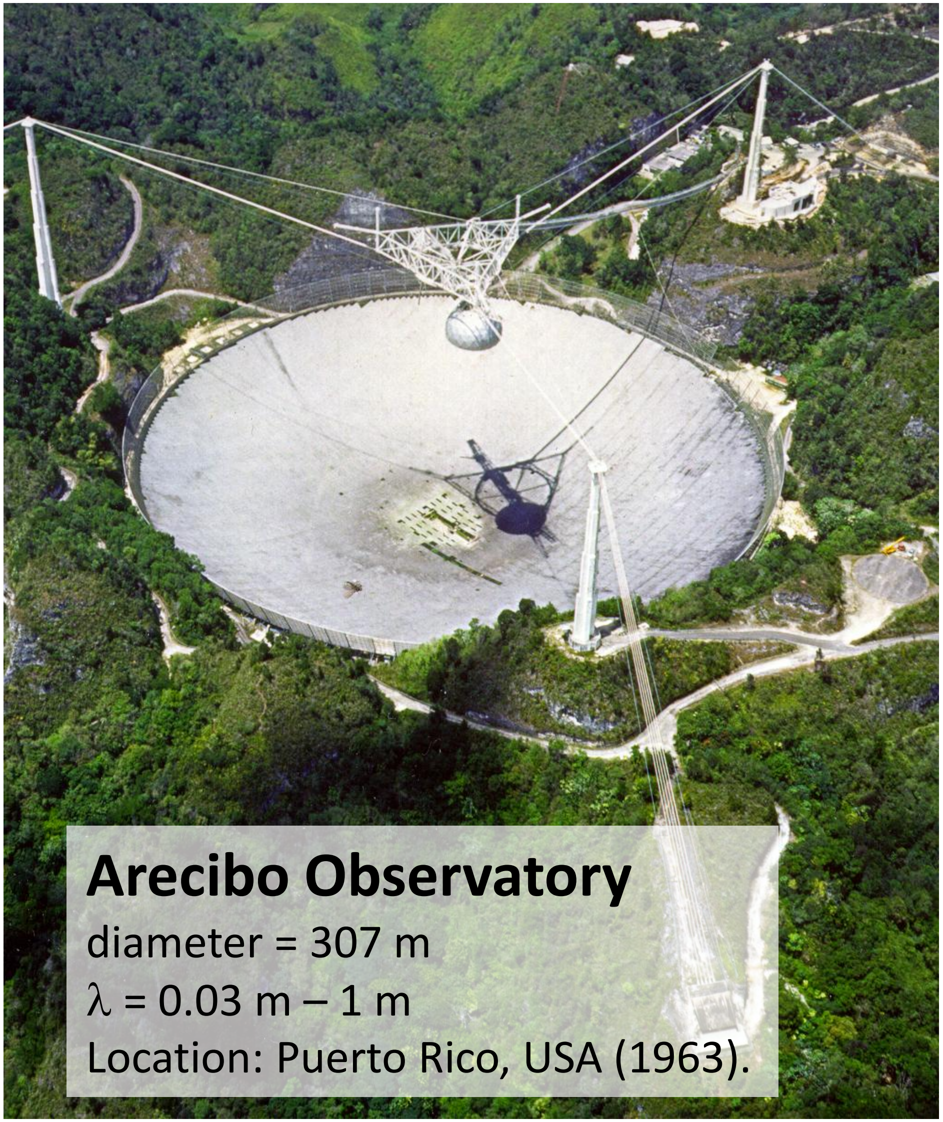
Southern Ring Nebular, constellation of Vela

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).