THE JAMES WEBB SPACE TELESCOPE

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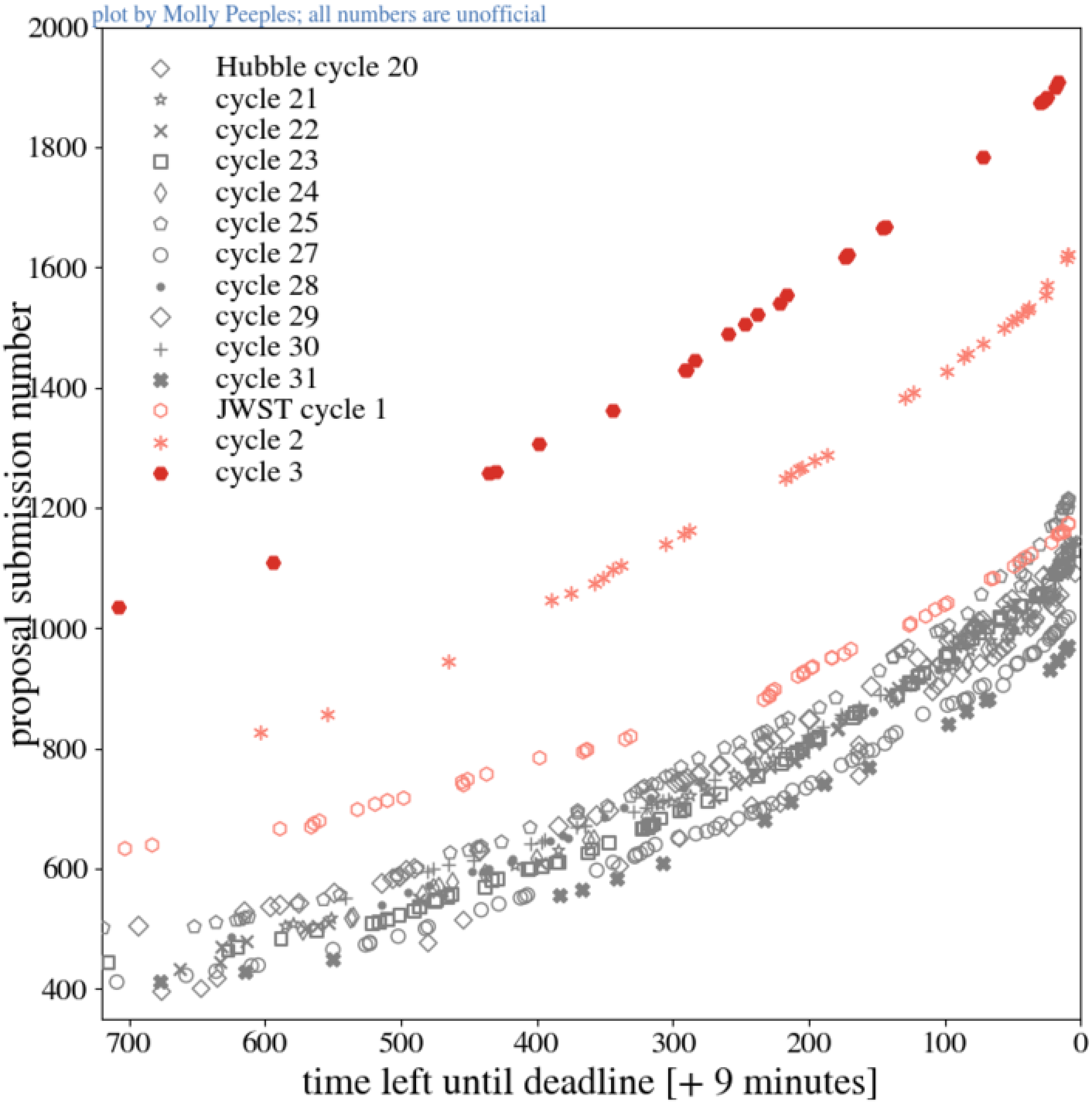
Plan

- **Day 1:**
  - **Introduction – motivation**
  - **Modern astronomical telescopes**
  - **JWST – history, design and deployment**

- Day 2:
  - Star & planet formation – the background
  - JWST – new results

- Day 3:
  - Galaxy formation & cosmology – the background
  - JWST – new results

[redacted]


plot by Molly Peeples; all numbers are unofficial
Hubble cycle 20
cycle 21
cycle 22
cycle 23
cycle 24
cycle 25
cycle 27
cycle 28
cycle 29
cycle 30
cycle 31
JWST cycle 1
cycle 2
cycle 3
proposal submission number
time left until deadline [+ 9 minutes]
2000
1800
1600
1400
1200
1000
800
600
400
700
600
500
400
300
200
100
0

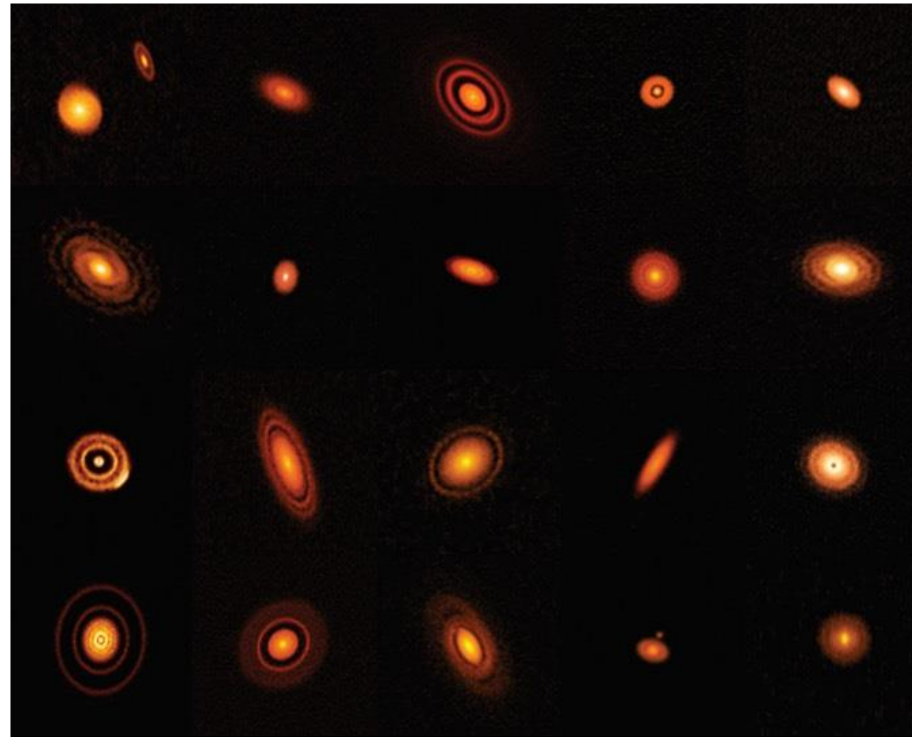
Why?

- Life is difficult enough
- Why plan a mission with
  - 50 major deployments
  - 140 release mechanisms
  - 344 single-point failure possibilities
- and no repair guy to call out?

- <u>Wavelength and size!</u>

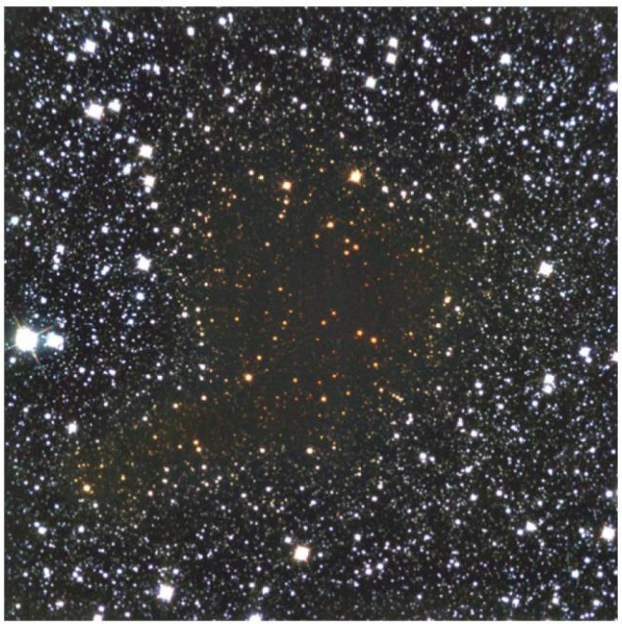
Star & Planet Formation

- The field has exploded with the discovery of the first exoplanet in the mid-90s and the revelations of instruments such as ALMA

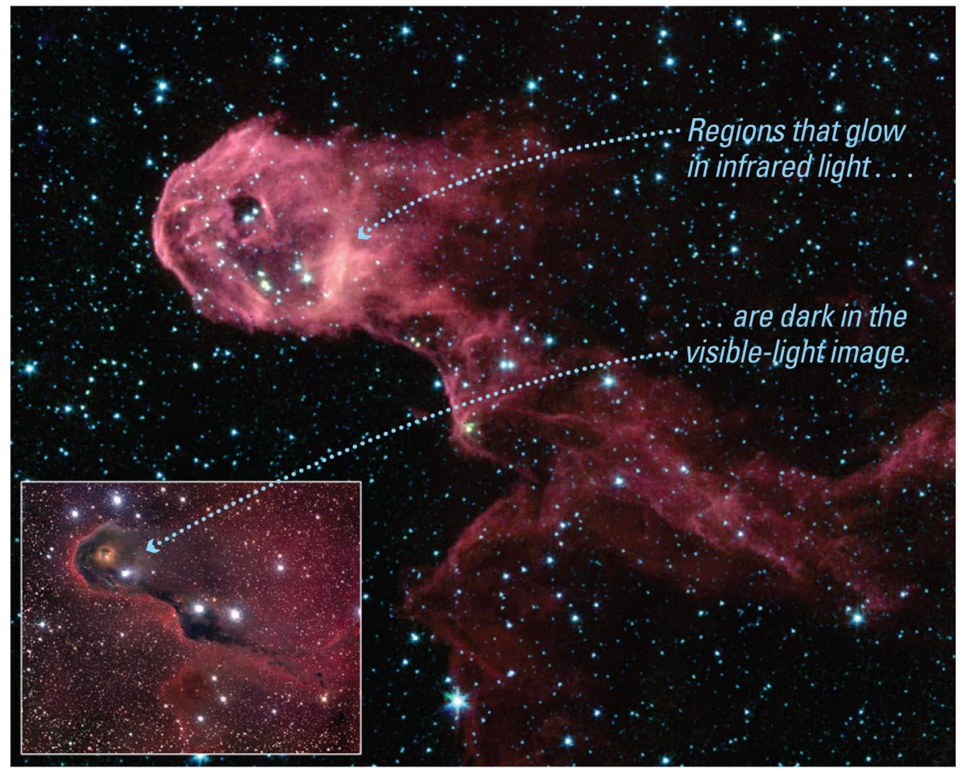


Star & Planet Formation

- **Star formation is shrouded in dust that blocks visible light, but which can be penetrated by infrared, and which glows in the infrared**

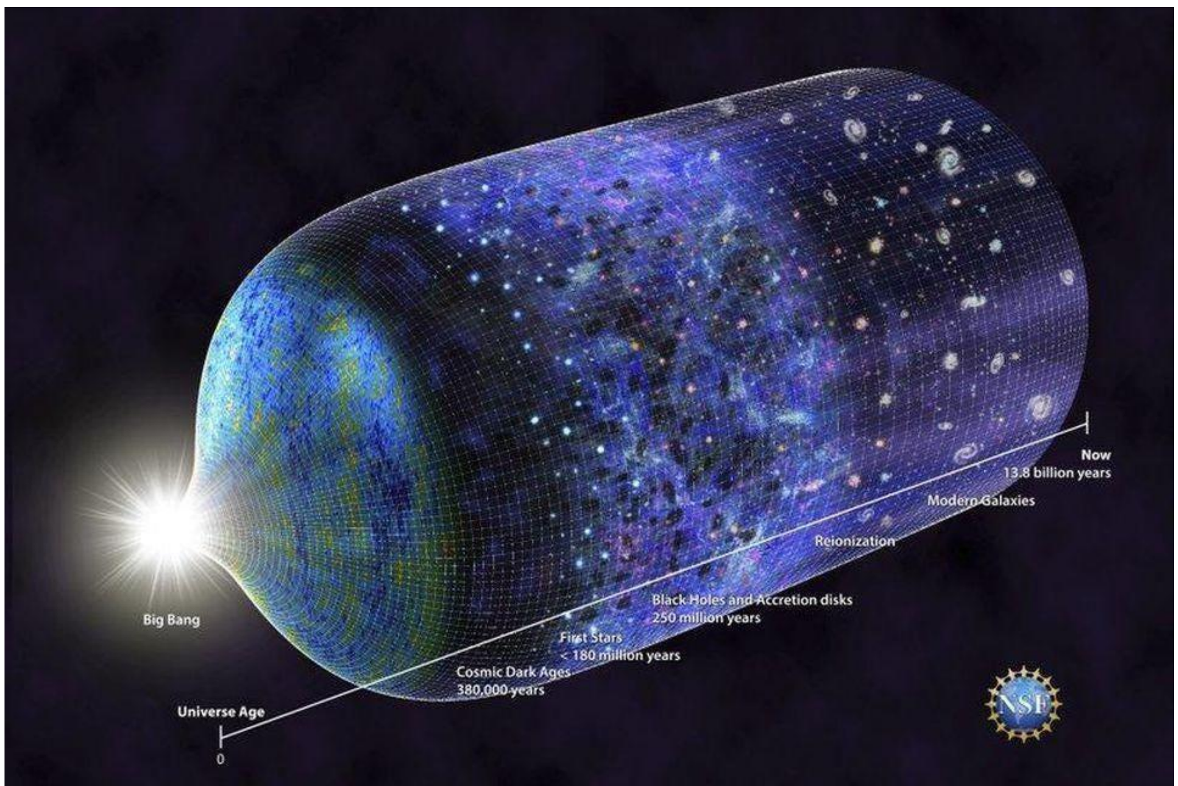


b An infrared image of Barnard 68 showing the stars that lie behind the clouc



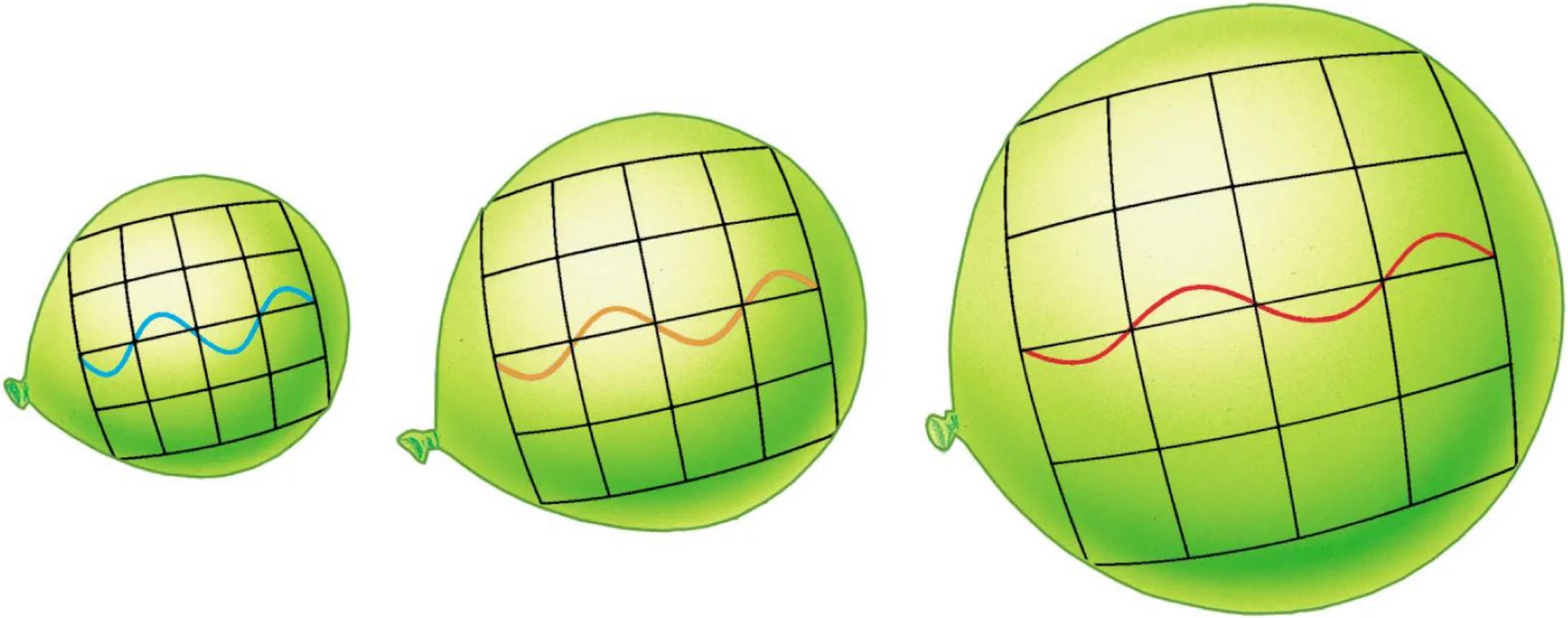
First Stars & Galaxies

- First stars would have shone ultraviolet hot
- First galaxies would form around supermassive black holes with accreted matter glowing blue or ultraviolet hot



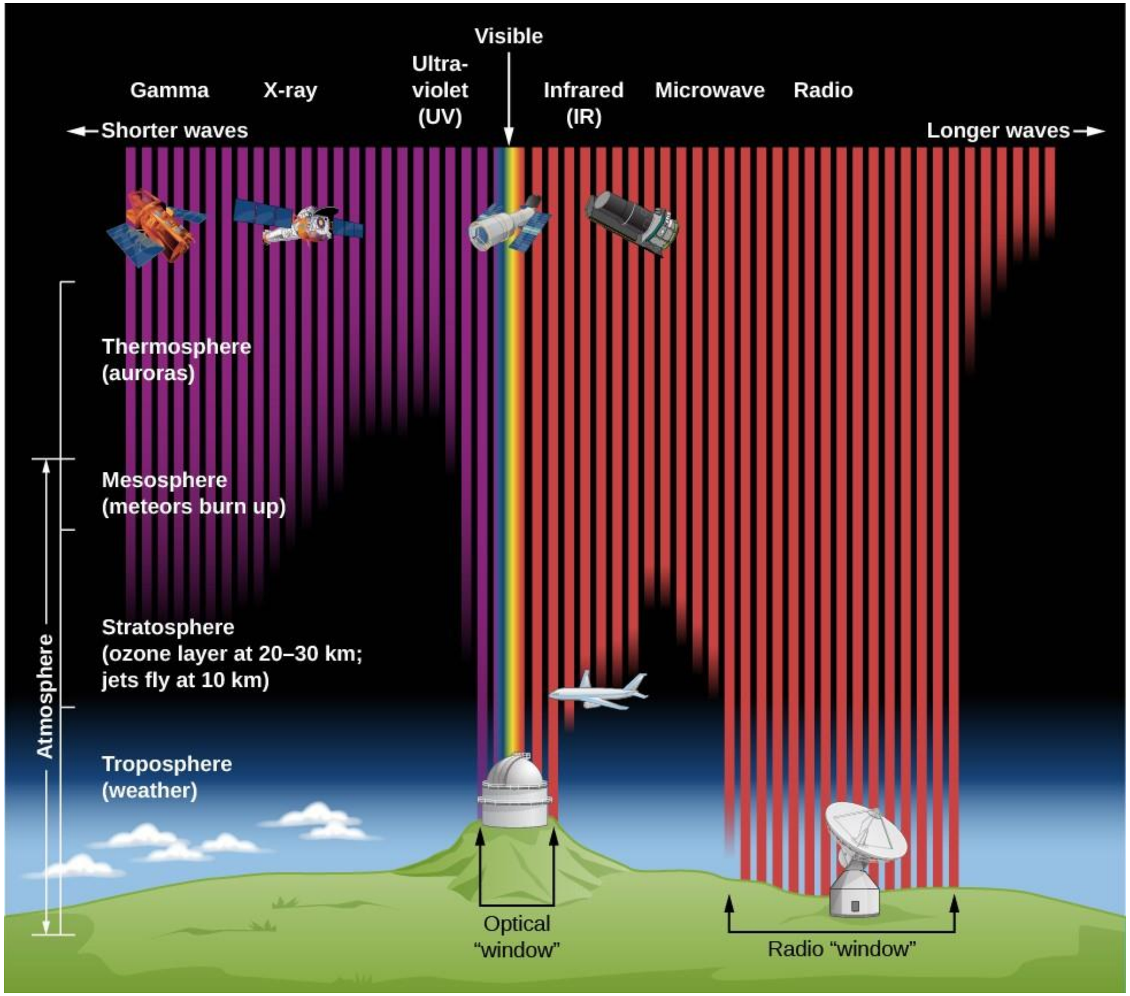
First Stars & Galaxies

- But the Universe expands, stretching light to infrared wavelengths



Infrared

- **Infrared is the new frontier – but is largely absorbed by our atmosphere**



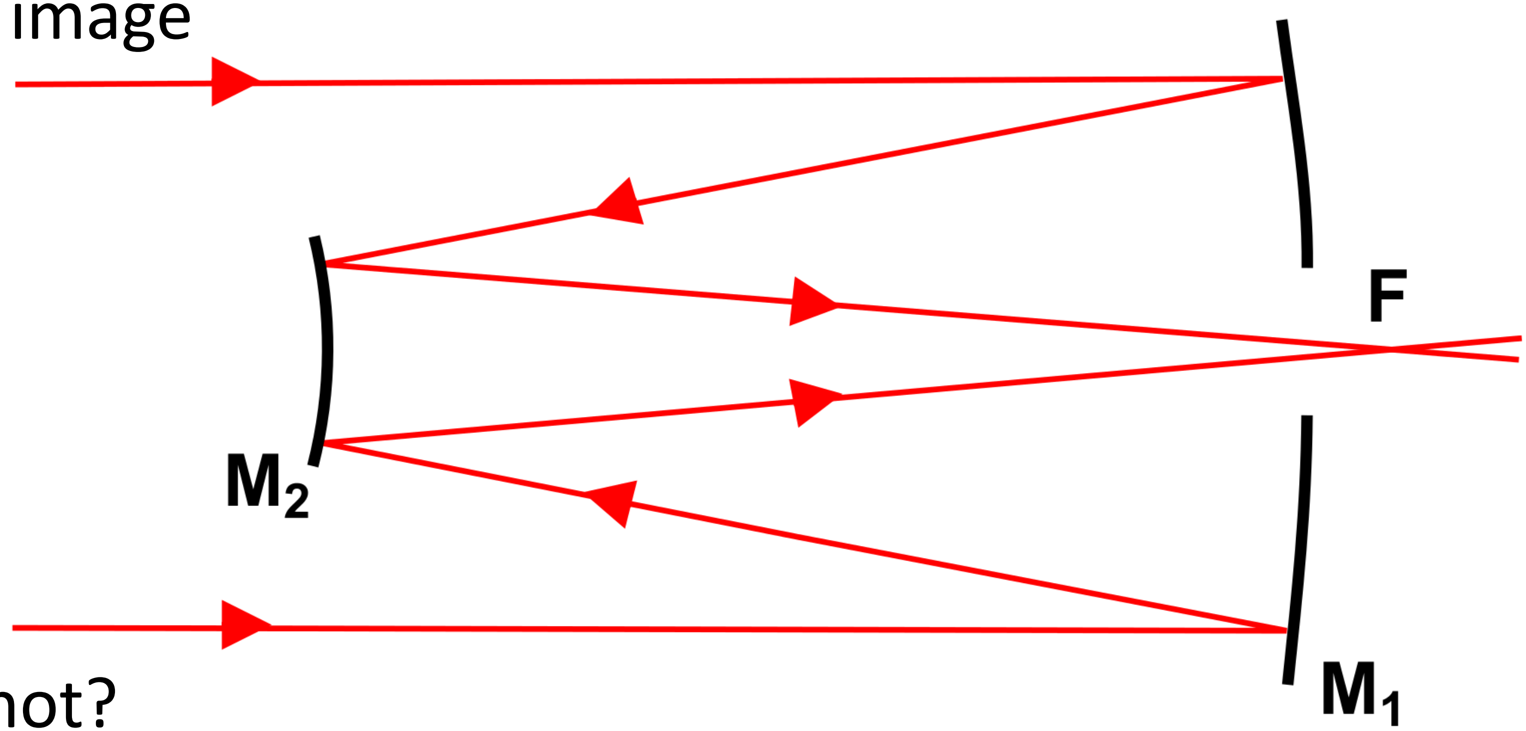
Telescopes

- Modern technology

- Light gathering – size matters!
- Resolution – size matters!
- Magnification – not so much!
  - Spectroscopy is often a major goal
  - Magnification can be a liability – fainter images, degraded quality
- Location matters – above atmosphere

Reflecting Telescopes

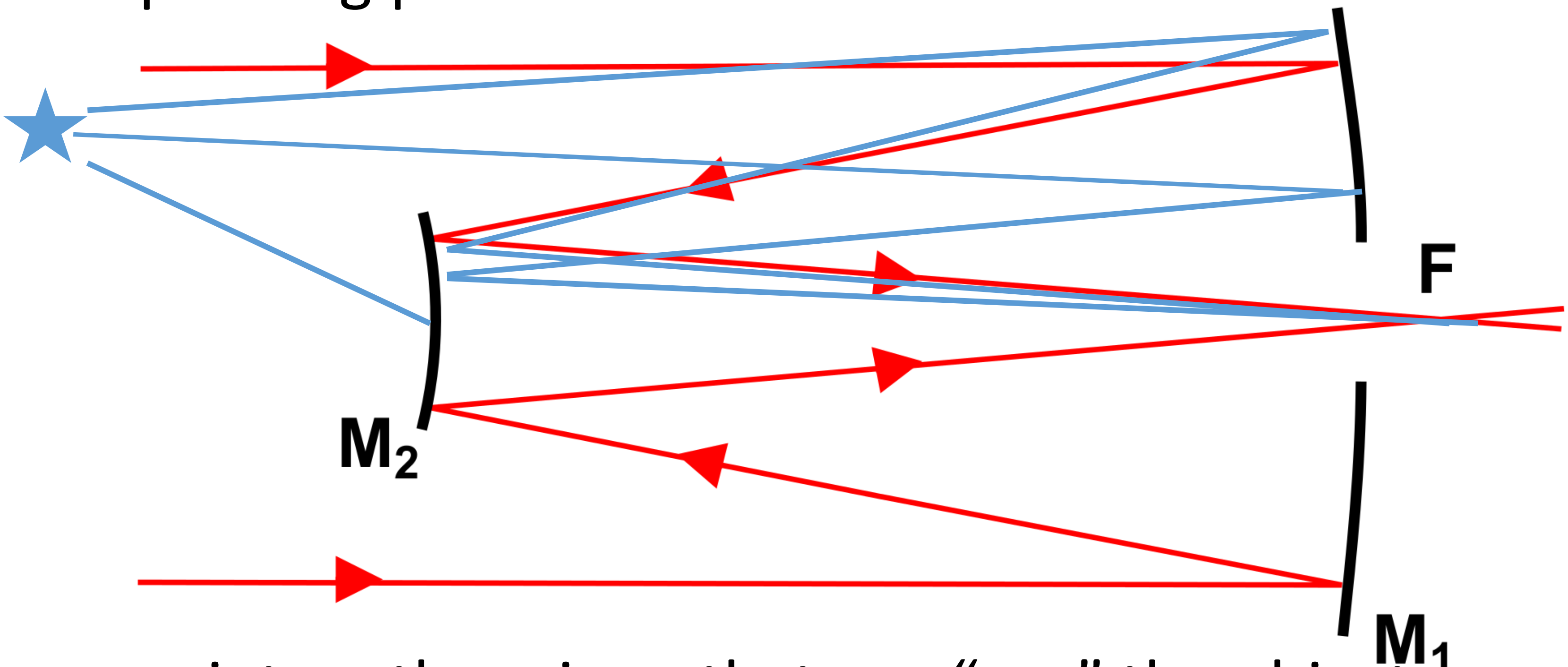
- The novice's mistake: there should be a shadow on every image



- Why not?

Reflecting Telescopes

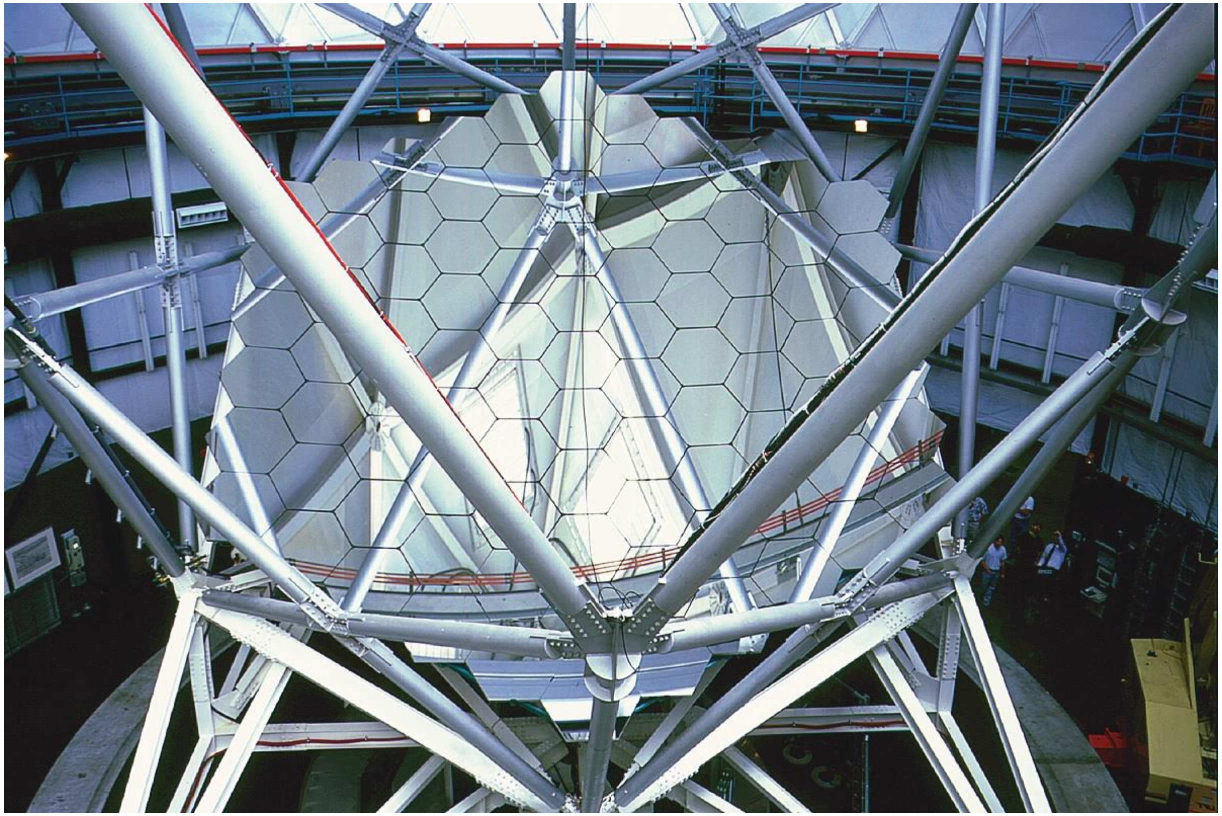
- The novice's mistake: each point on the image has a corresponding point on the mirror



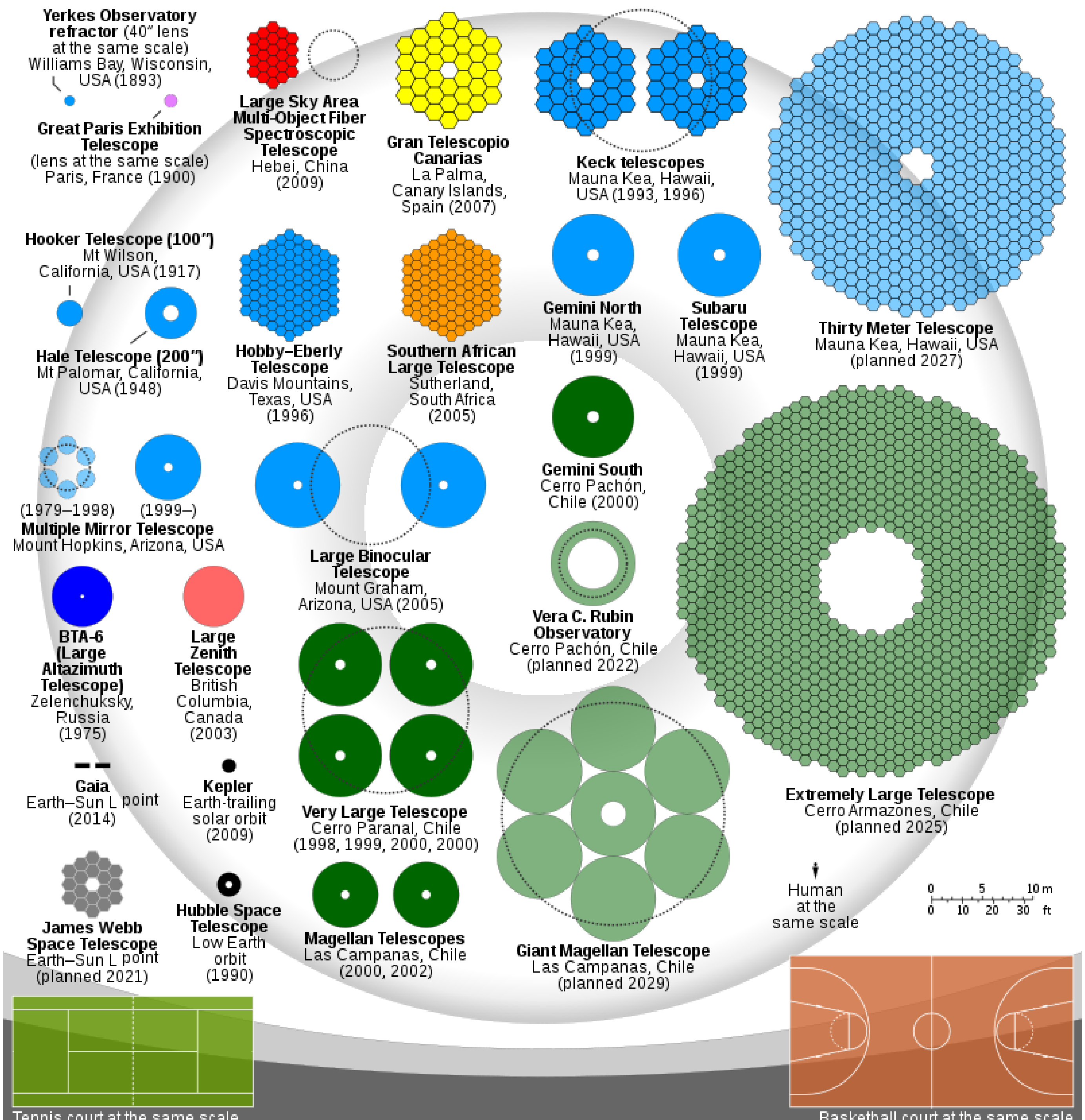
- Every point on the mirror that can "see" the object contributes to the corresponding point on the image

Reflecting Telescopes

- Corollary: any array of reflecting surfaces works (as long as they are aligned!)
- Segmented mirror telescopes allow the construction of large telescopes

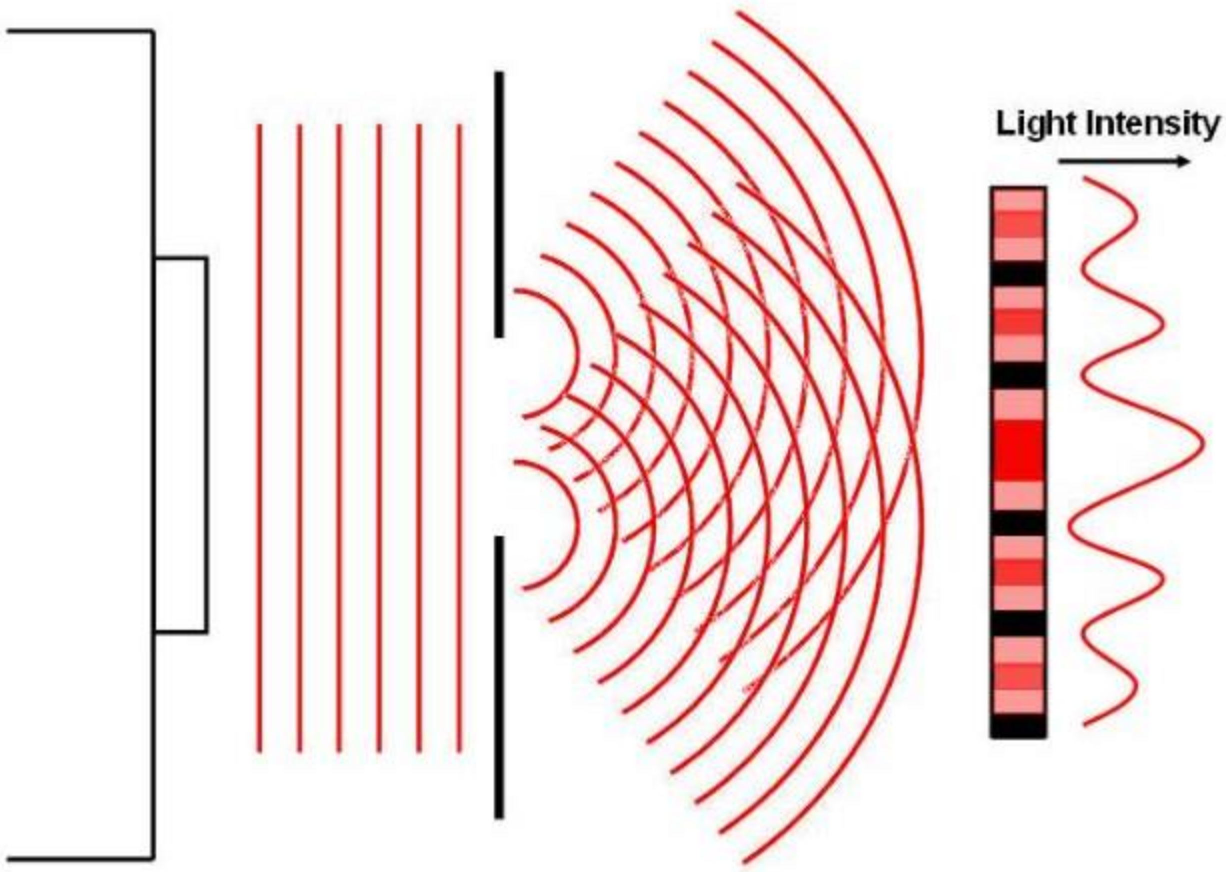


Hobby-Eberly 10m

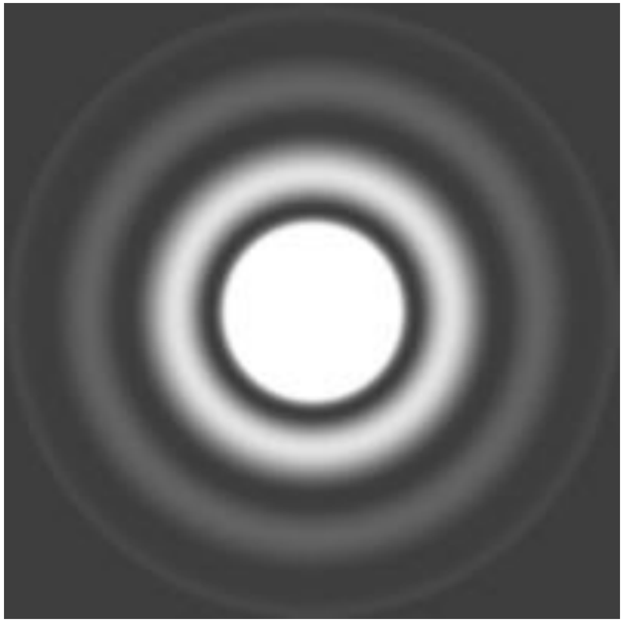


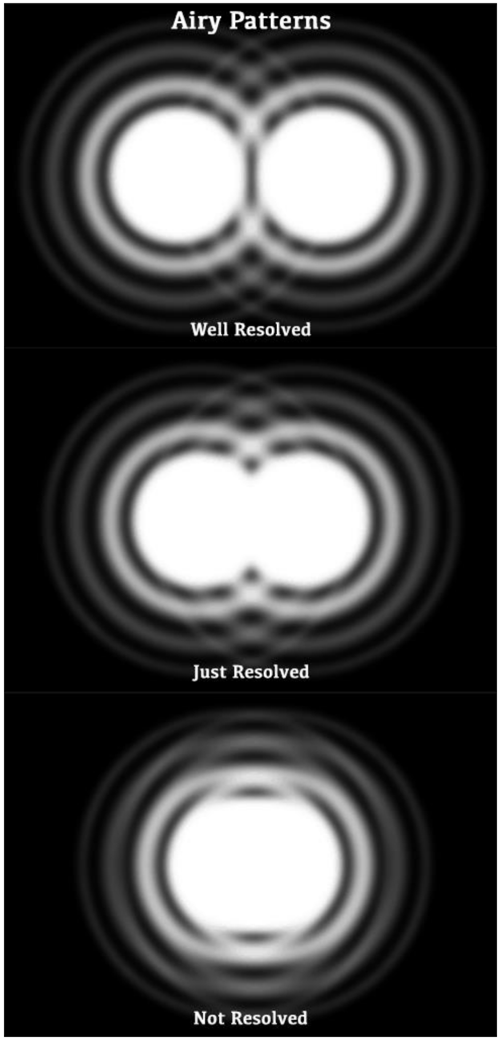
Yerkes Observatory refractor (40″ lens at the same scale) Williams Bay, Wisconsin, USA (1893)
Great Paris Exhibition Telescope (lens at the same scale) Paris, France (1900)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope Hebei, China (2009)
Gran Telescopio Canarias La Palma, Canary Islands, Spain (2007)
Keck telescopes Mauna Kea, Hawaii, USA (1993, 1996)
Thirty Meter Telescope Mauna Kea, Hawaii, USA (planned 2027)
Hooker Telescope (100″) Mt Wilson, California, USA (1917)
Hale Telescope (200″) Mt Palomar, California, USA (1948)
Hobby–Eberly Telescope Davis Mountains, Texas, USA (1996)
Southern African Large Telescope Sutherland, South Africa (2005)
Gemini North Mauna Kea, Hawaii, USA (1999)
Subaru Telescope Mauna Kea, Hawaii, USA (1999)
Gemini South Cerro Pachón, Chile (2000)
(1979–1998) (1999–)
Multiple Mirror Telescope Mount Hopkins, Arizona, USA
Large Binocular Telescope Mount Graham, Arizona, USA (2005)
Vera C. Rubin Observatory Cerro Pachón, Chile (planned 2022)
Extremely Large Telescope Cerro Armazones, Chile (planned 2025)
BTA-6 (Large Altazimuth Telescope) Zelenchuksky, Russia (1975)
Large Zenith Telescope British Columbia, Canada (2003)
Very Large Telescope Cerro Paranal, Chile (1998, 1999, 2000, 2000)
Gaia Earth–Sun L point (2014)
Kepler Earth-trailing solar orbit (2009)
Giant Magellan Telescope Las Campanas, Chile (planned 2029)
James Webb Space Telescope Earth–Sun L point (planned 2021)
Hubble Space Telescope Low Earth orbit (1990)
Magellan Telescopes Las Campanas, Chile (2000, 2002)
Human at the same scale
0 5 10 m
0 10 20 30 ft
Tennis court at the same scale
Basketball court at the same scale

Adaptive Optics



Diffraction

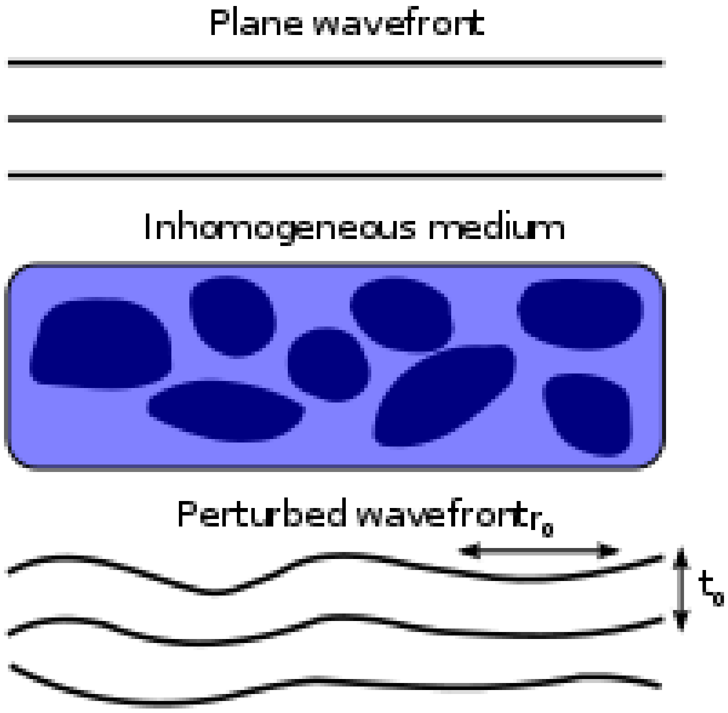


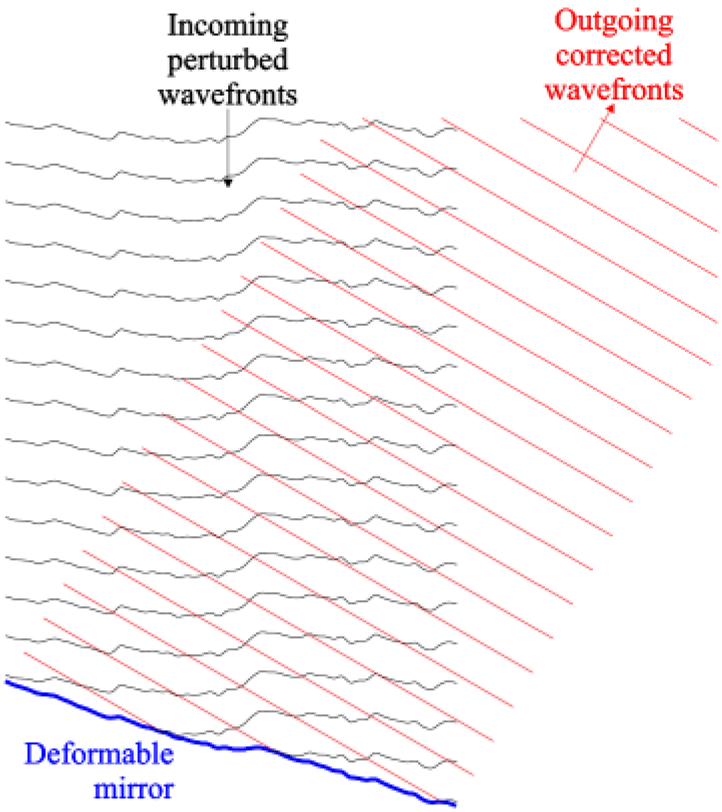


Adaptive Optics

- Wavefronts are distorted by inhomogeneity in intervening medium

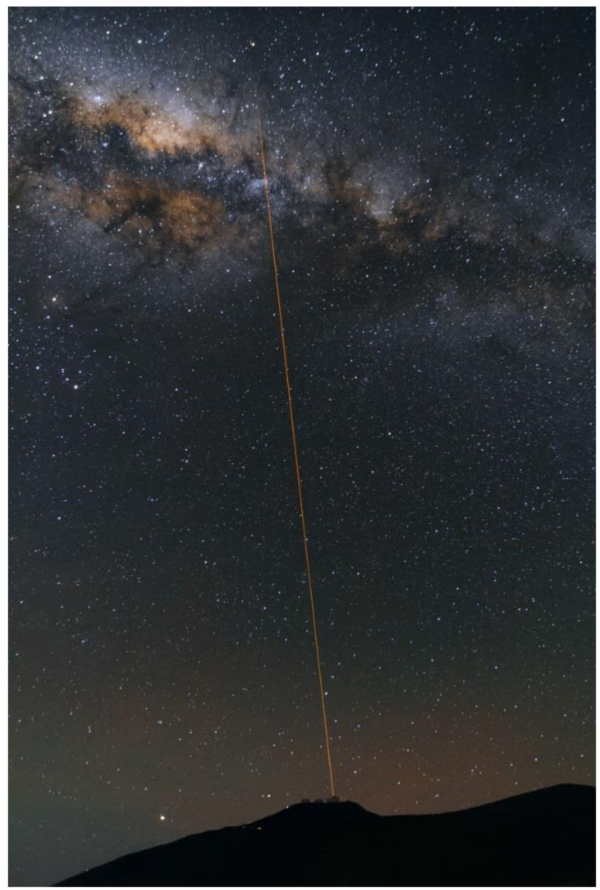
- Wavefronts are corrected by mirror – arbitrarily deformable in an ideal world


Plane wavefront
Inhomogeneous medium
Perturbed wavefront
r_0
t_0


Incoming perturbed wavefronts
Outgoing corrected wavefronts
Deformable mirror

A Practical Approach…

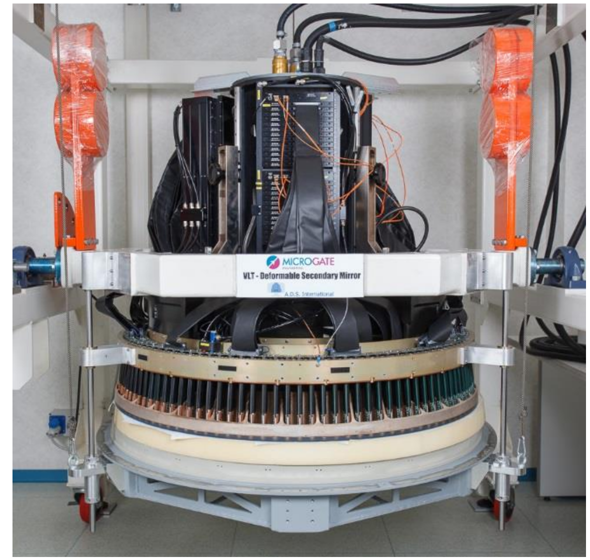
- Bright star or laser – sample incoming wavefronts

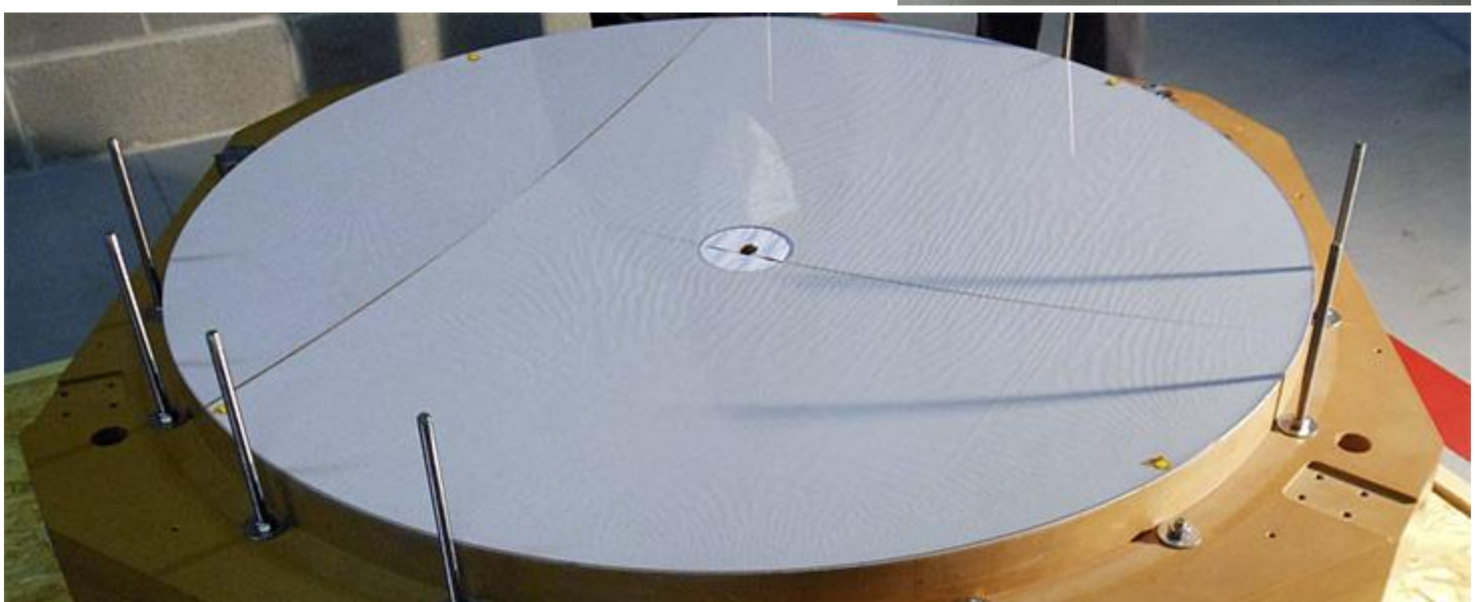


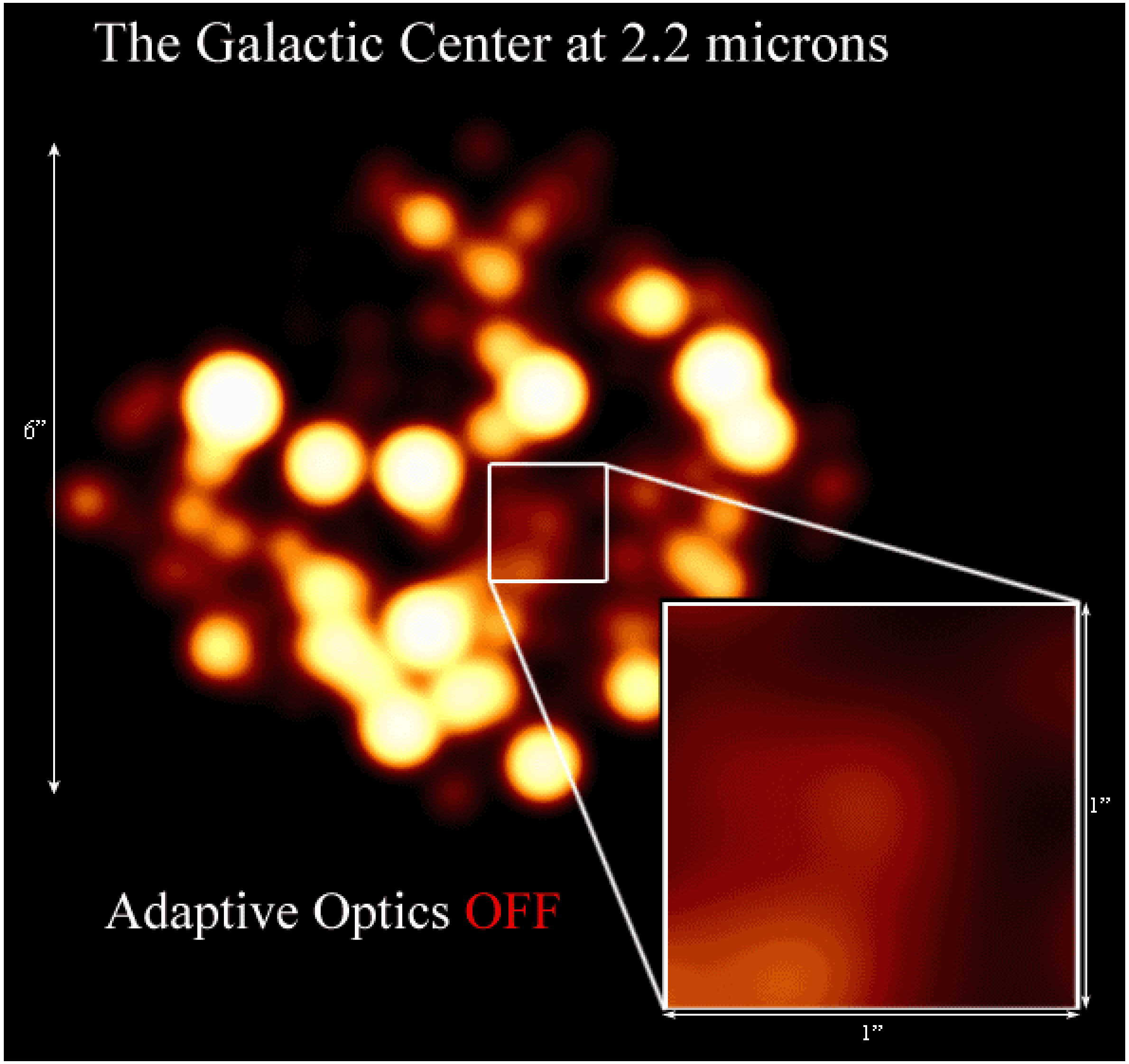
ESO VLT, Paranal, Chile

A Practical Approach…

- Deformable mirror
  - eg, ESO shell mirror
  - 1.2m diameter, 2mm thick, deformed > 1000 times per second by > 1000 actuators



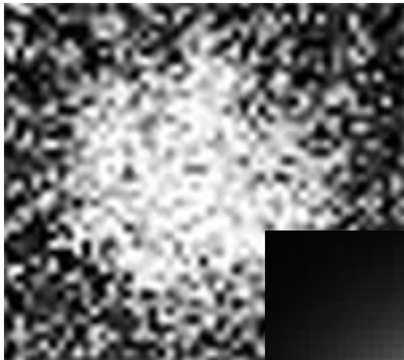




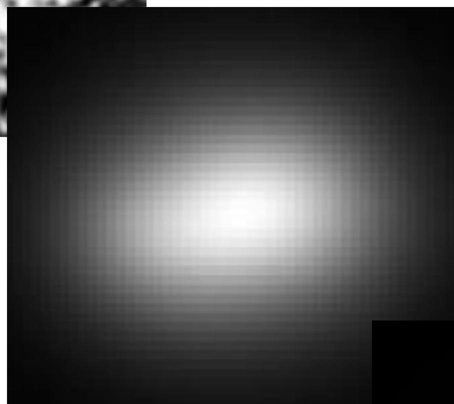
The Galactic Center at 2.2 microns
6”
1”
1”
Adaptive Optics OFF

Lucky Imaging

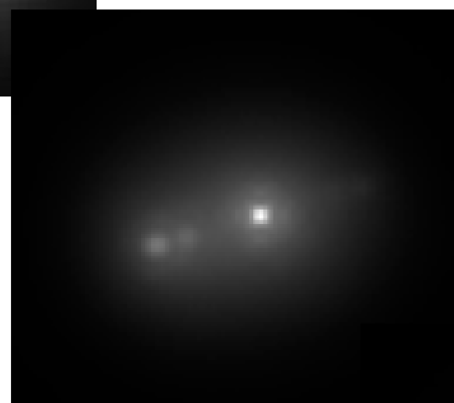
- High speed camera (and bright object!) with exposure time less than 100 ms
- During any one frame change in Earth's atmosphere is minimal
- Select a subset (10%) least influenced by atmosphere, shift and add
- Example shows triple star system with 50,000 images, 40 images per second [see Wikipedia for more details]



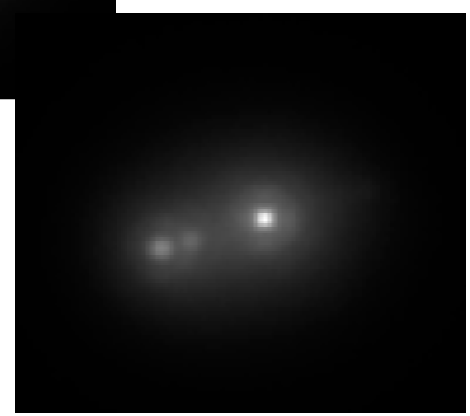
single exposure, low image quality



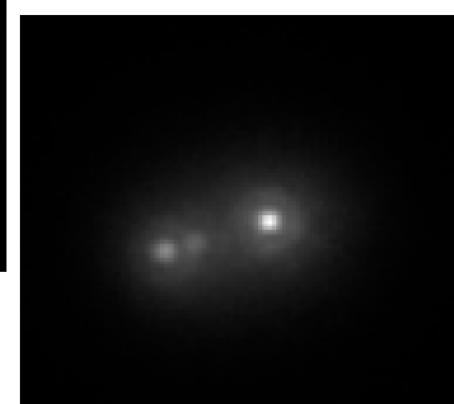
100%



50%



10%



1% of all 50,000 frames

Conclusion

- There is only so much you do on Earth
- Need
  - **a big telescope**
  - **in space**
  - **working in the infrared**

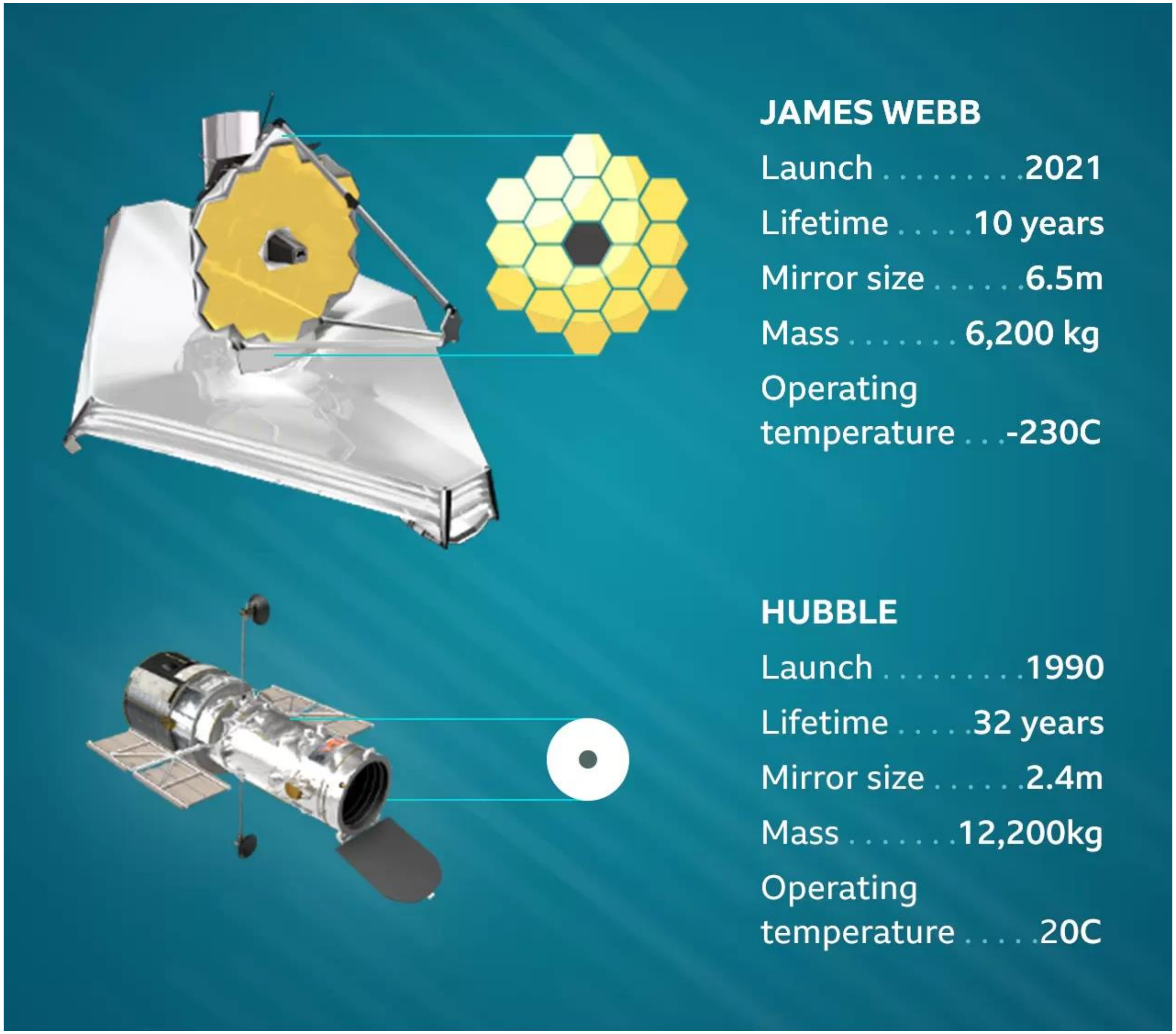
JWST: A brief history

- 1996 – 8m mirror NGST proposed
- 2002 – reduced to 6.5m, renamed JWST
- 2003 – Northrop Grumman contracted
- 2007 – ESA joins NASA
- 2010 – critical mission review passed
- 2011 – cancellation proposed!!!
- 2016 – final assembly
- 2021 – launch!!!

JWST: Cost overruns

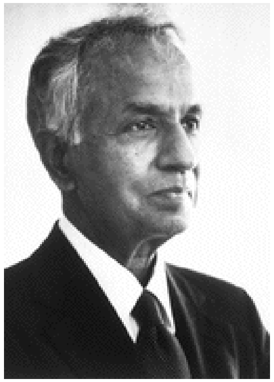
Year	Estimated Cost ($billions)
1998	1
2000	1.8
2002	2.5
2003	2.5
2005	3
2006	4.5
2008	5.1
2010	6.5
2011	8.7
2017	8.8
2018	>8.8
2019	9.6
2021	9.7

JWST: HST comparison

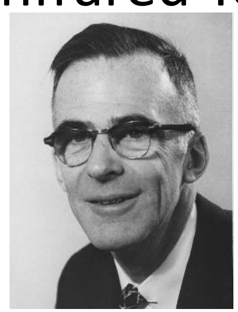


JWST: What's in a name?

- Large Space/Orbiting Telescope $\Rightarrow$ Hubble Space Telescope




- Advanced X-ray Astrophysics Facility $\Rightarrow$ Chandra X-ray Observatory
- Space Infrared Telescope Facility $\Rightarrow$ Spitzer Space Telescope




- Large Synoptic Survey Telescope $\Rightarrow$ Vera C. Rubin Observatory

JWST: What's in a name?

- So who was James Webb?

  1906 – 1992

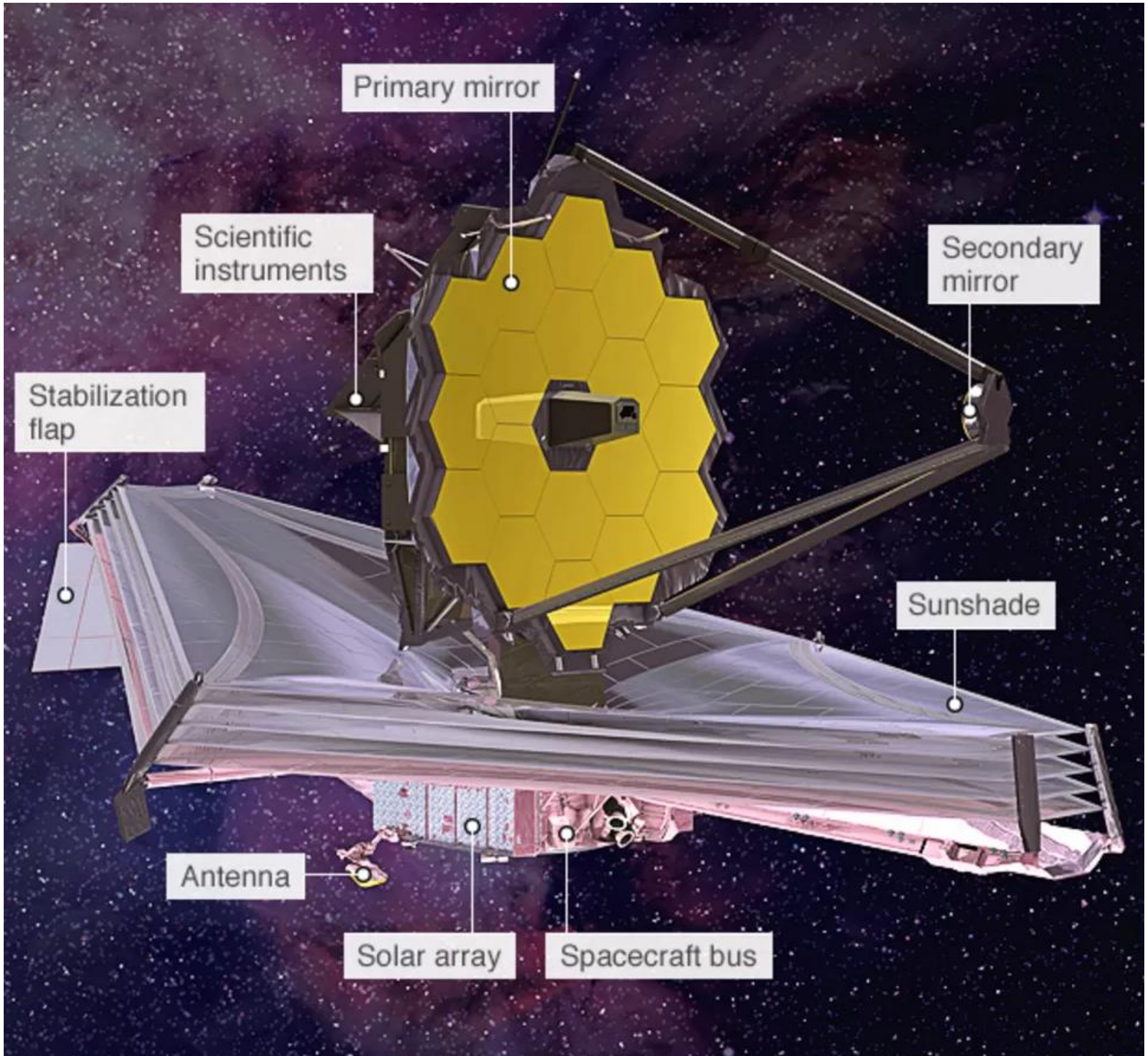
- 2nd NASA administrator

  1961 – 1968

- Oversaw Mercury & Gemini programs

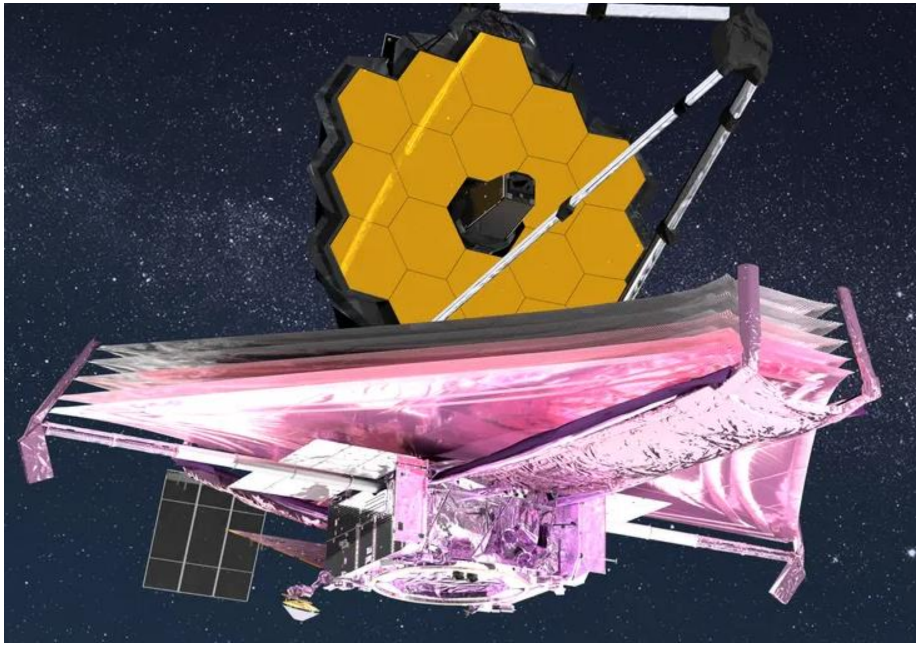
- Controversy: oversaw purge of gay employees in 50s & 60s? (Lots of material online)

JWST: Major systems

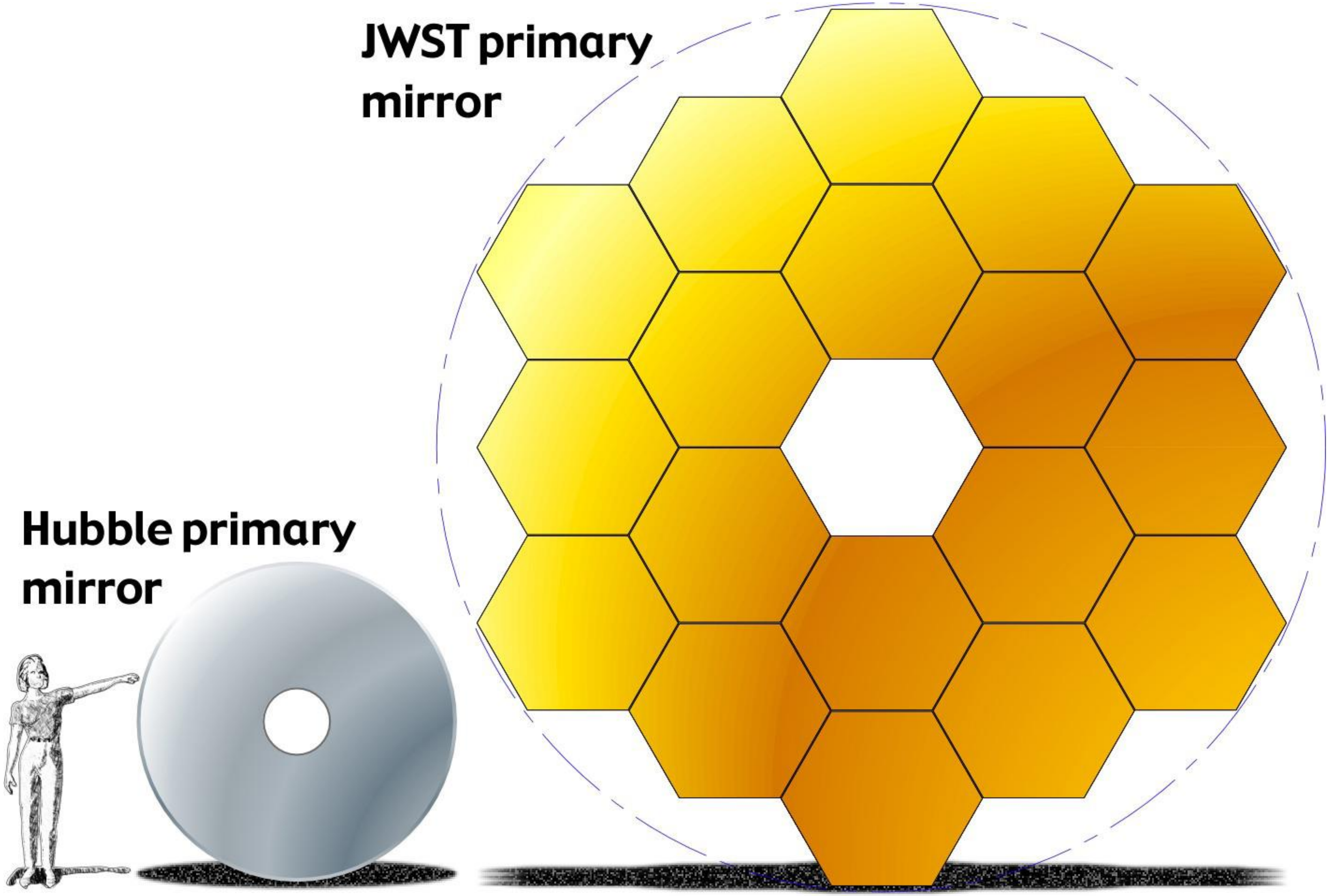


JWST: Sun shield

- Provides passive thermal control with temps < 50K
- Five layers of aluminum coated plastic, 69ft x 46ft (think tennis court)
- One 50 micron, four 25 micron thick sheets, the Sun-pointed outer sheet doped with Silicon (gives it its purple color) to reflect heat and toughen it

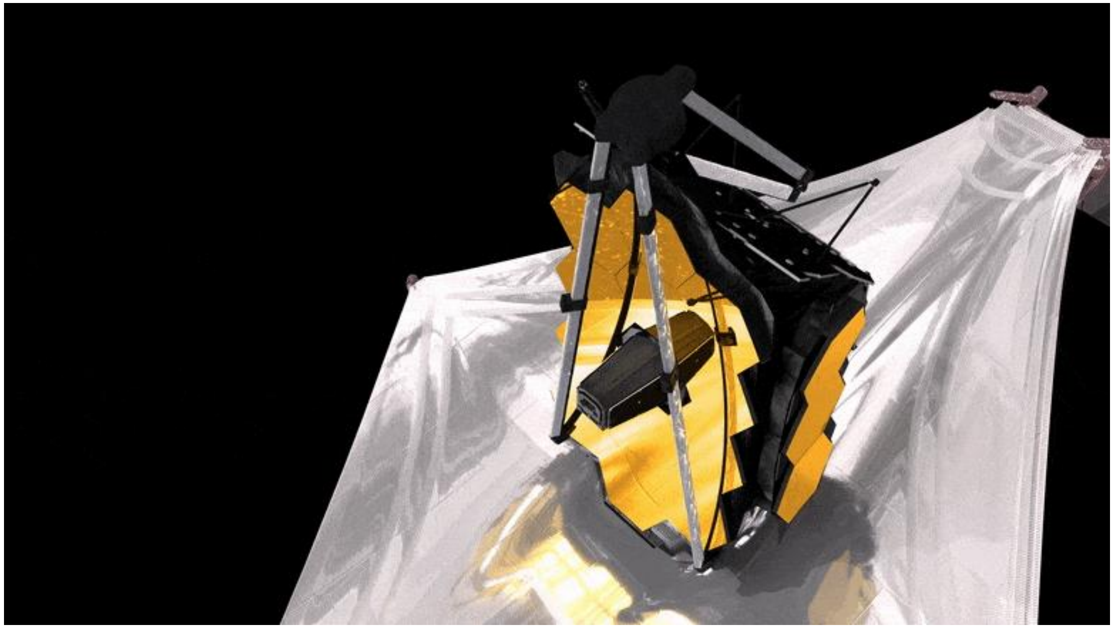


JWST: Mirror



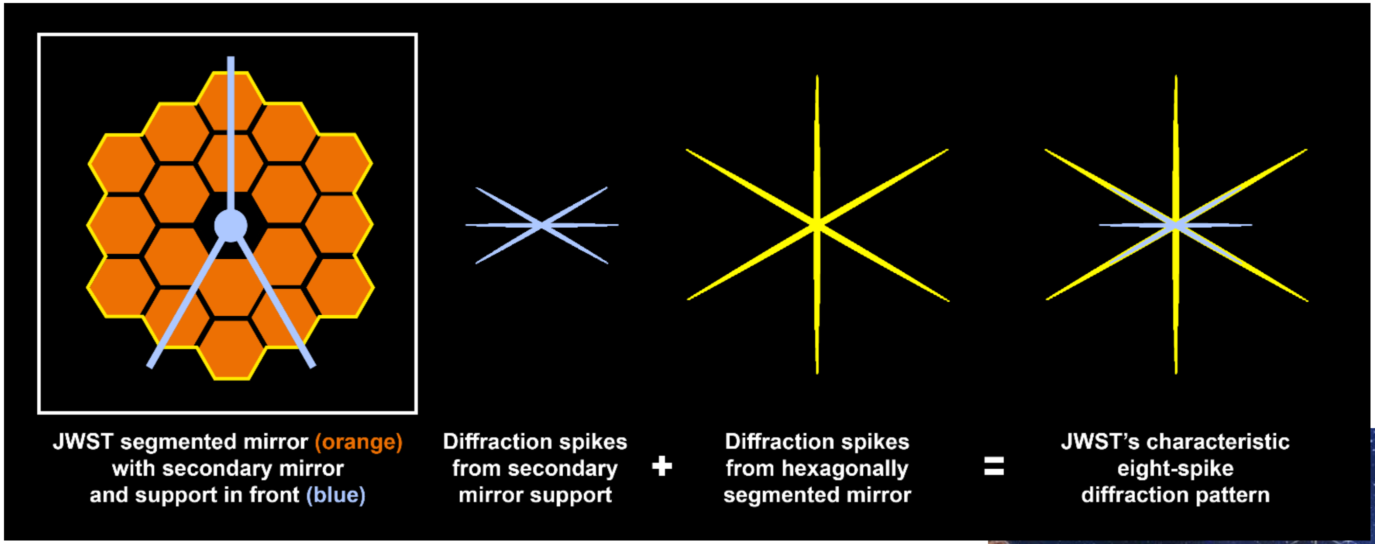
JWST: Mirrors

- Primary: 18 hexagons
- gold-coated (for infrared reflectivity) beryllium (light, strong, and stable across a range of temperatures) covered by thin layer of glass (for durability)
- Secondary: held by 3 struts



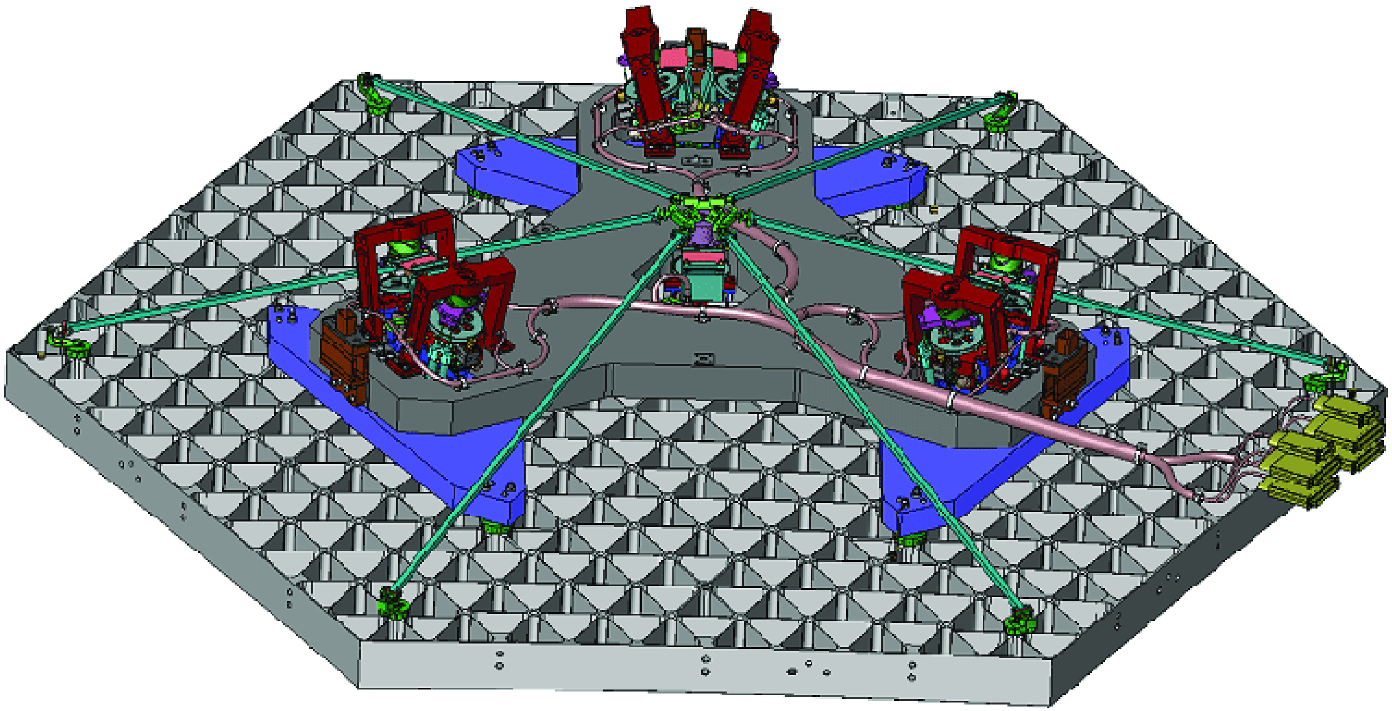
JWST: Mirrors

- Secondary: held by 3 struts
- Contributes to "iconic" diffraction spike pattern

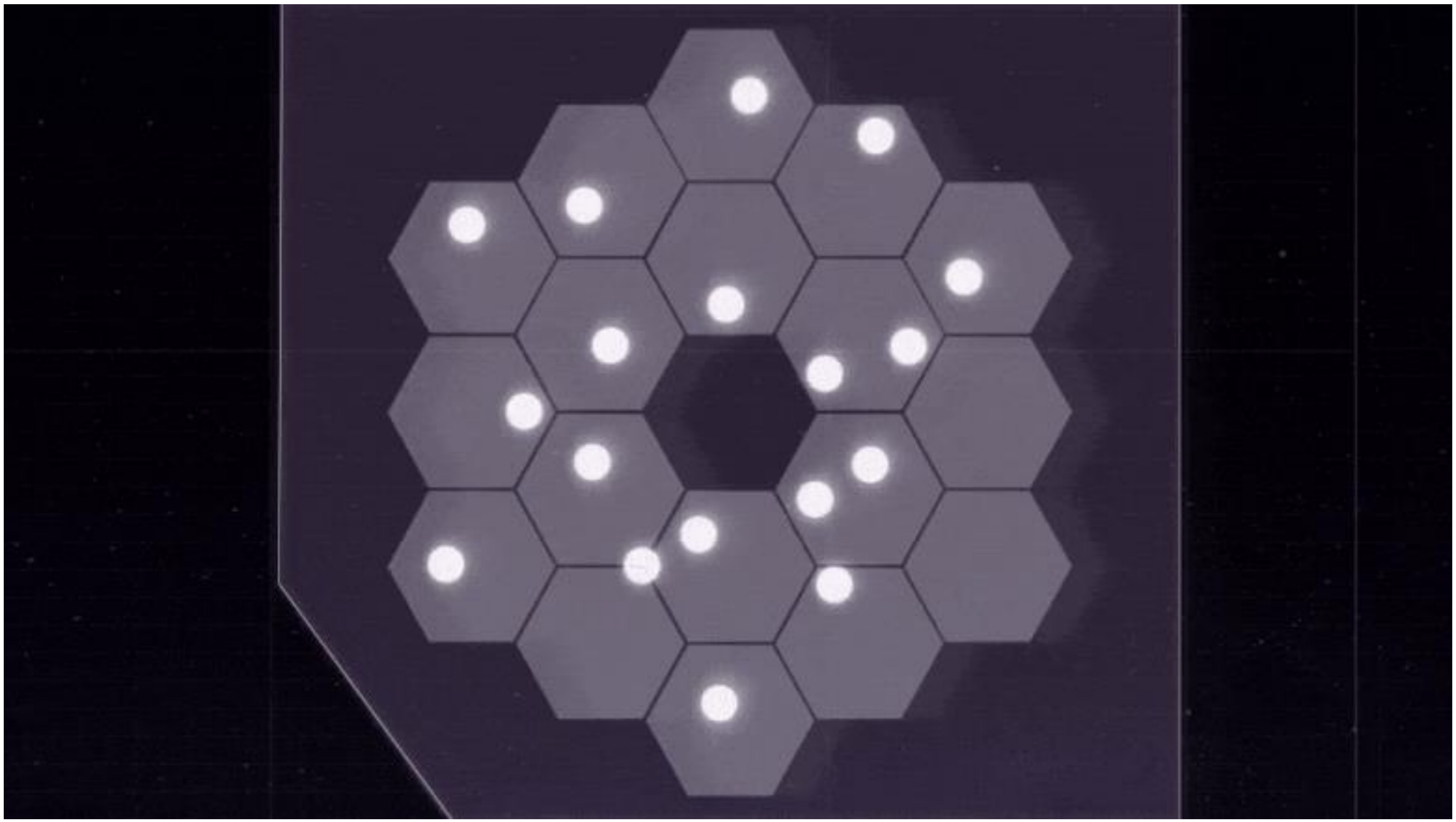


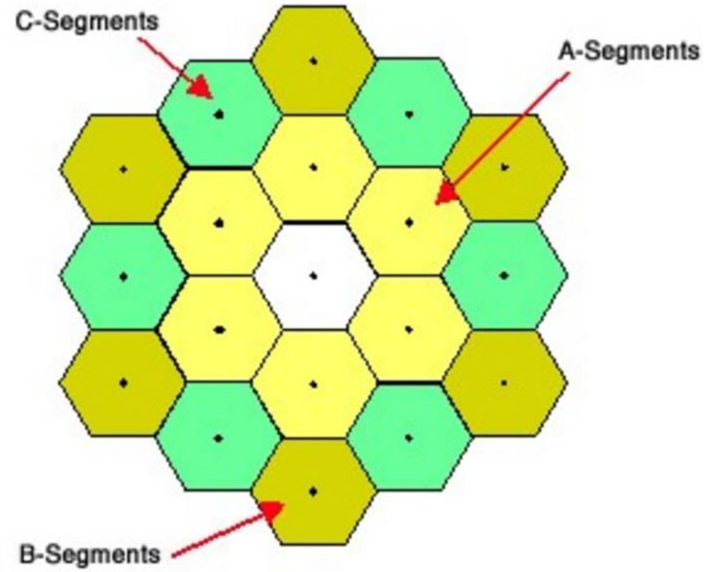
JWST: Mirror alignment

- Each hexagon has 6+1 actuators to control position and curvature

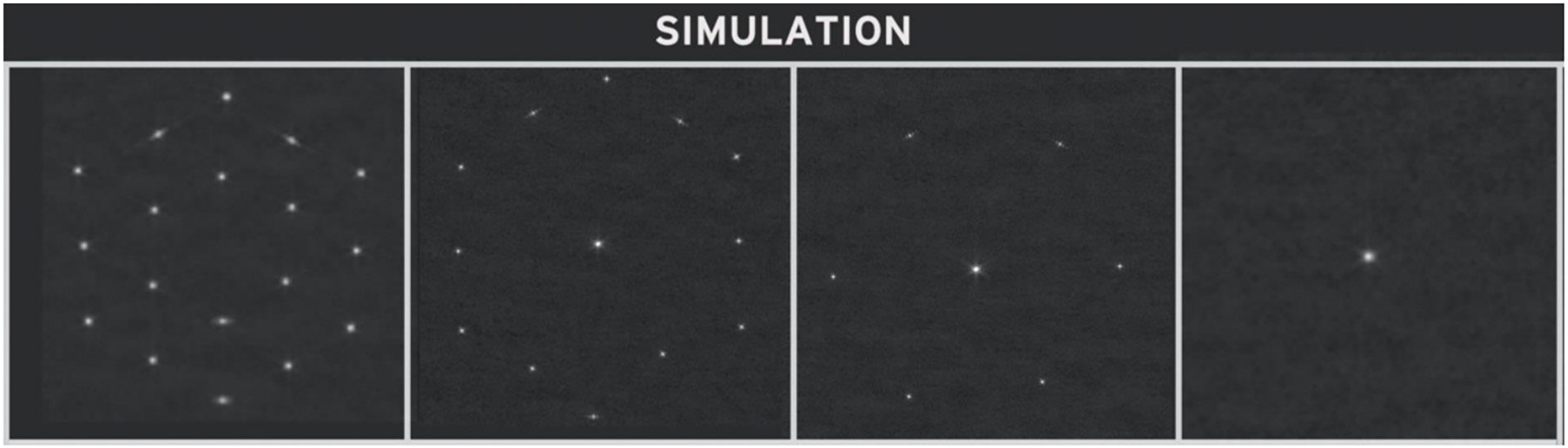


JWST: Mirror alignment





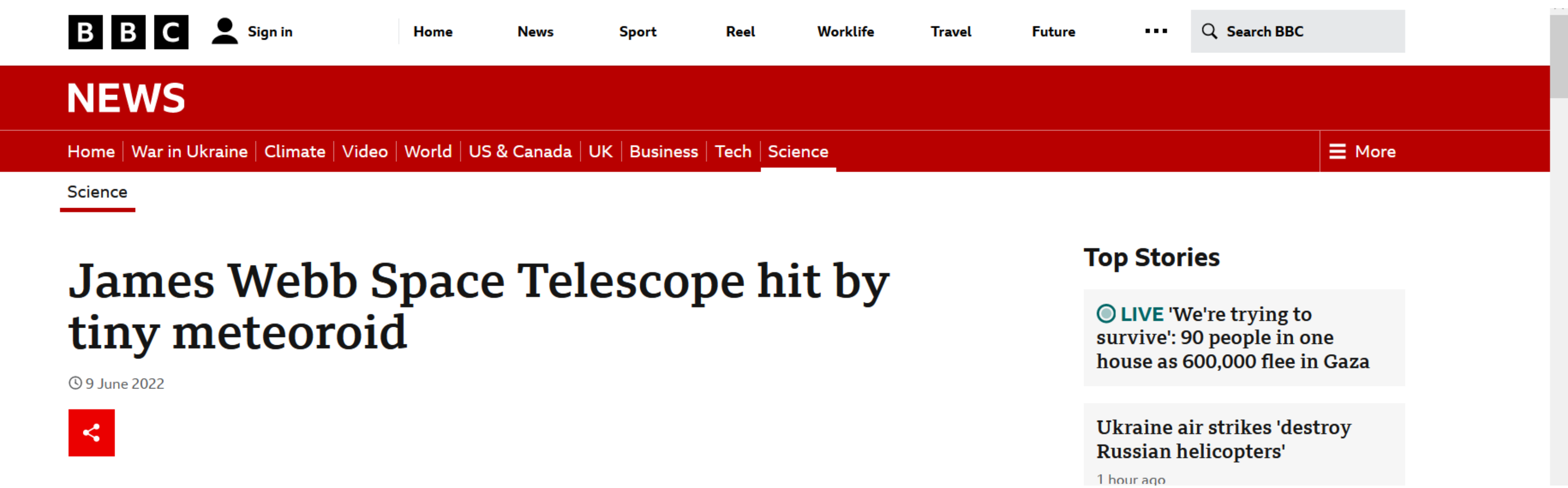
Credit: NASA



Simulation of image stacking. First panel: Initial image mosaic. Second panel: A-segments stacked. Third panel: A- and B-segments stacked. Fourth panel: A-, B-, and C-segments stacked. Credit: NASA.

JWST: Dust!

- Some degrading is inevitable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Science

James Webb Space Telescope hit by tiny meteoroid

9 June 2022

Top Stories

LIVE 'We're trying to survive': 90 people in one house as 600,000 flee in Gaza

Ukraine air strikes 'destroy Russian helicopters'

1 hour ago

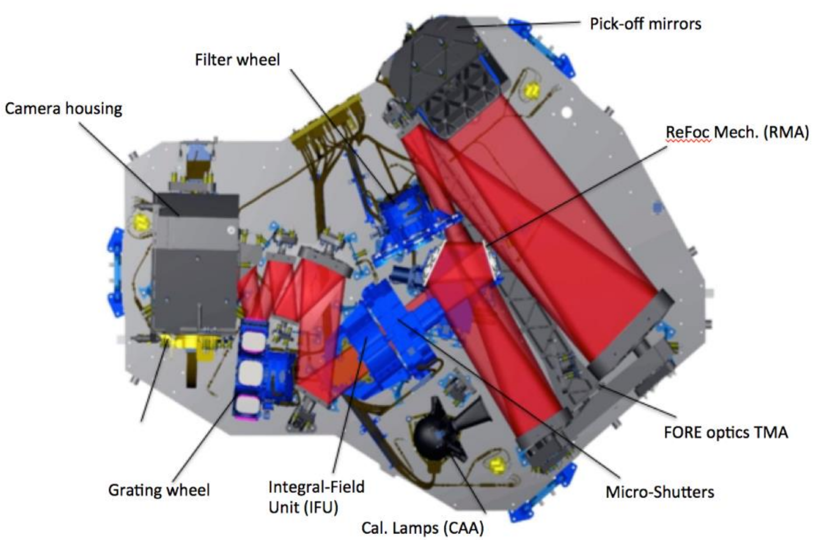
JWST: Science instruments

- NIRCam – Near Infrared Camera – an imager built at U . Arizona by PI Marcia Rieke (see October National Geographic)
- 10 x 2048 x 2048 detector arrays (think your phone camera) with various filter options

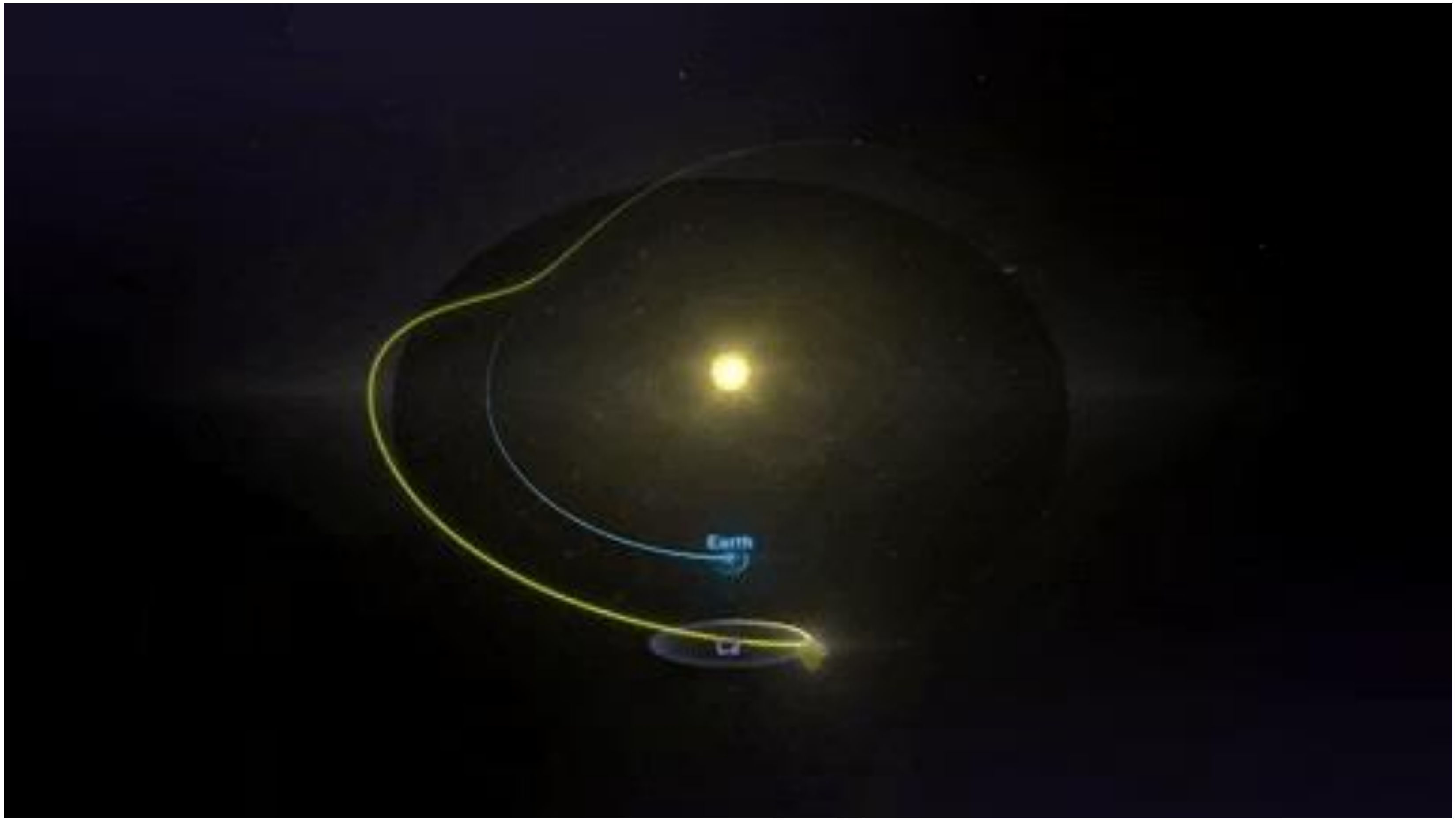
JWST: Science instruments

- NIRSpec – Near Infrared Spectrograph – contributed by ESA
- MIRI – Mid Infrared Instrument – developed by a large NASA/European consortium led by PIs George Rieke (U. Arizona) and Gillian Wright (UK Tech Centre, Edinburgh, Scotland) contains both camera and spectrometer

NIRSpec Optical Design

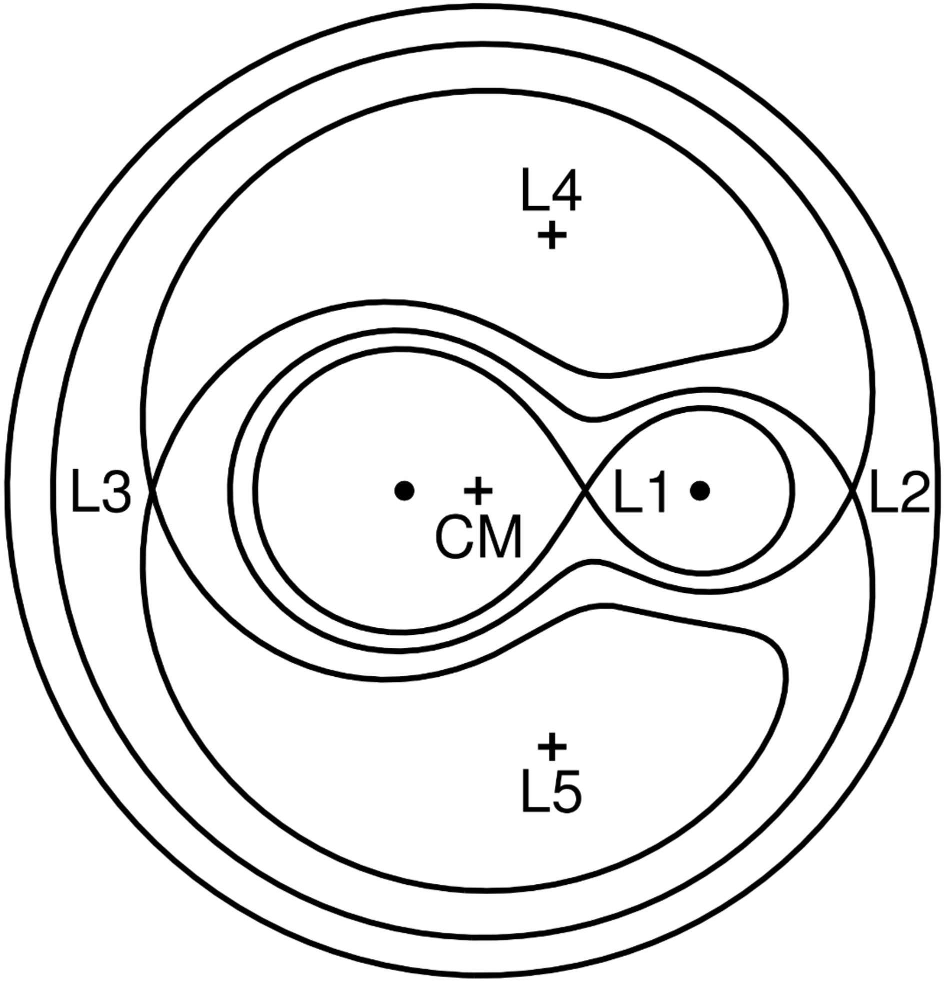


JWST: Orbit

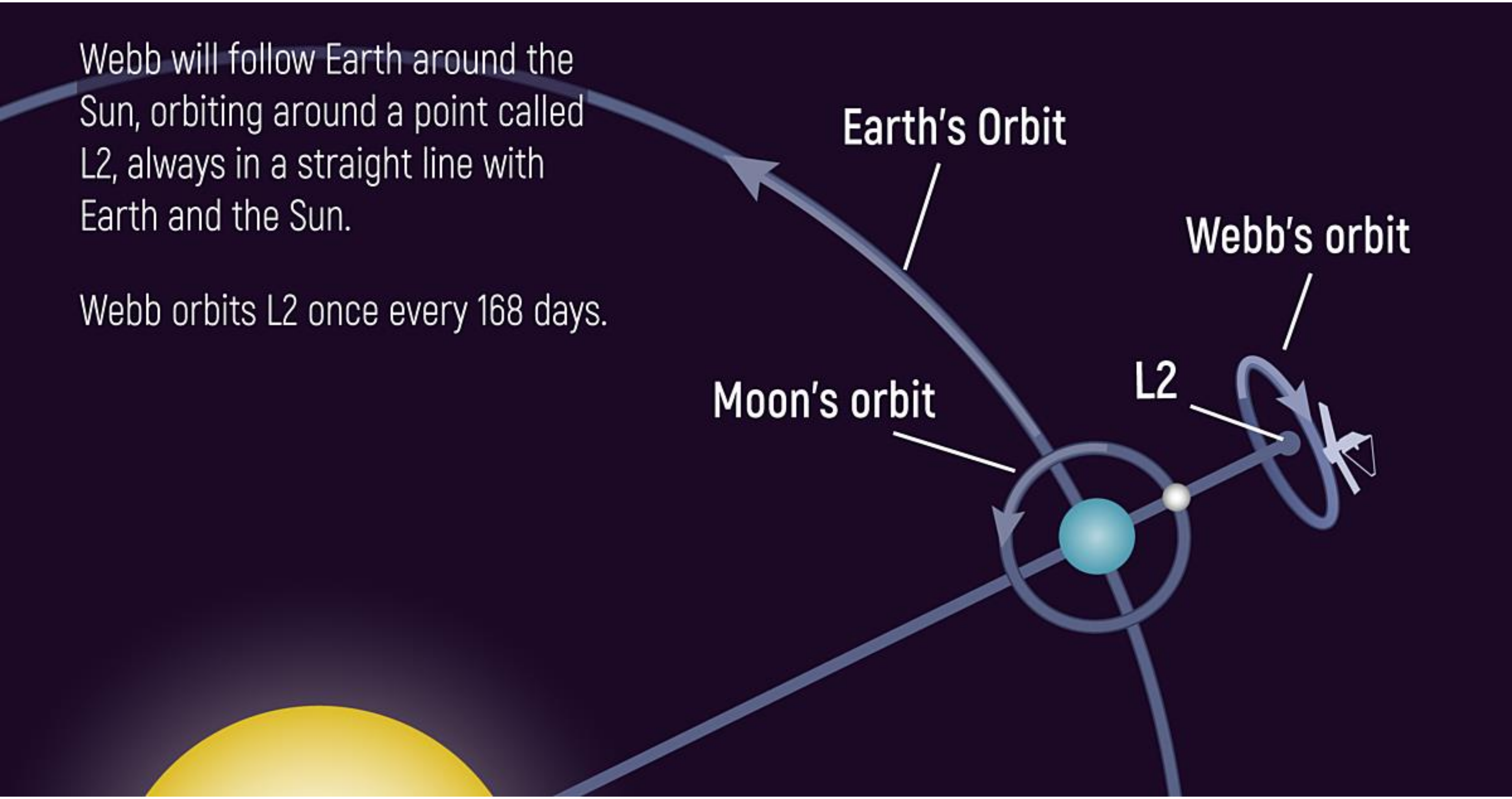


Background: Lagrange points

- Equilibrium points in the 3-body system



JWST: Orbit



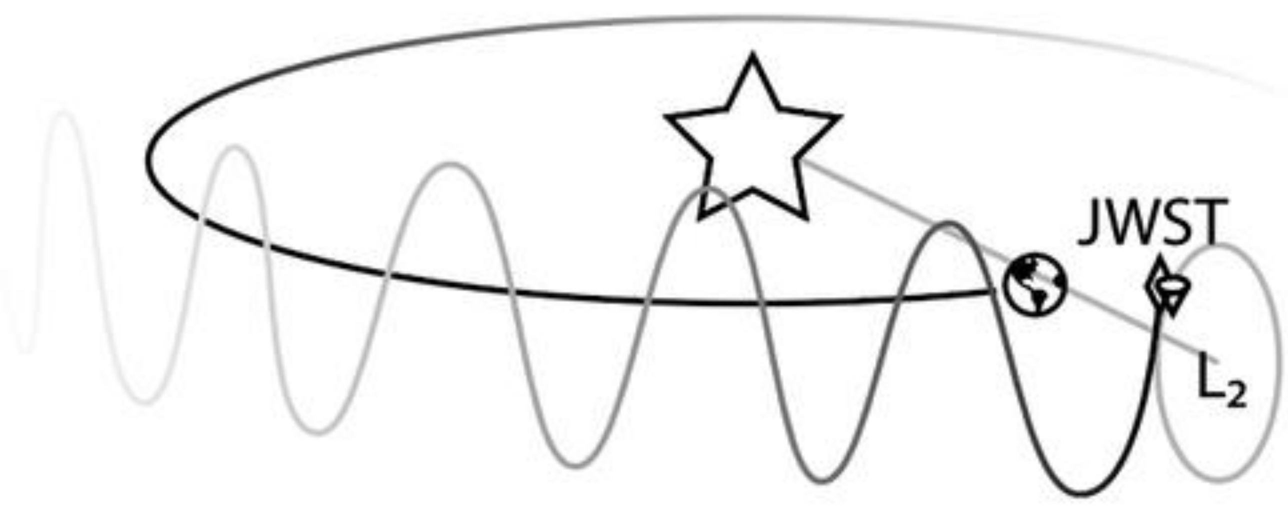
Webb will follow Earth around the Sun, orbiting around a point called L2, always in a straight line with Earth and the Sun.
Webb orbits L2 once every 168 days.
Earth's Orbit
Webb's orbit
L2
Moon's orbit

JWST: Orbit

- “Halo” orbit at L_2
- Approx 1.5 million km from Earth (no visits for repair or upgrade!)
- Keeps it out of both Earth’s and Moon’s shadow, but with sunshield and equipment bus pointing to Sun/Earth/Moon
- Shields telescope from incoming radiation from these objects, allowing stable, low temperature (50K), while giving uninterrupted solar power and communication

JWST: Orbit

- JWST doesn't "orbit nothing"!
- It orbits the Sun (+Earth)
- But the pull of the Earth means it's sometimes ahead and pulled back, sometime behind and pulled forward, and it oscillates about the plane towards the Sun (think pendulum)



Next Week….

And now for the science: star & planet formation