The best of Hubble Wide Field Camera 3, and what the James Webb Space Telescope, etc., will do after 2018.

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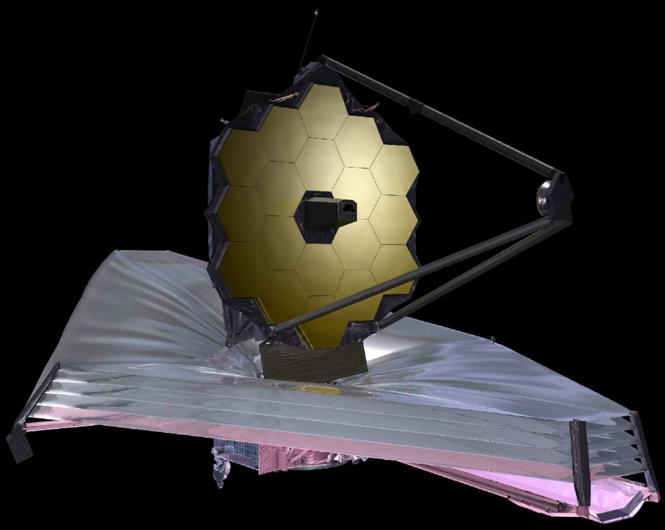


Space Vision 2013 — Students for the Exploration & Development of Space (SEDS)

Panel Discussion: "A Look into the Universe"; ASU, Tempe, AZ, Saturday, Nov. 9, 2013.

Outline

- (1) The Best of Hubble: Recent results from the Hubble Space Telescope (HST) and its Wide Field Camera 3 (WFC3).
- (2) Measuring Galaxy Assembly and Supermassive Black-Hole Growth.
- (3) What is the James Webb Space Telescope (JWST)?
- (4) How can JWST measure the Epochs of First Light & Reionization?
- (5) Summary and Conclusions.
- App: Synergy between future 20–40m telescopes (GMT/TMT/E-ELT) and JWST: When $1 + 1 > 2$.

Sponsored by NASA/HST & JWST

ARIZONA STATE UNIVERSITY

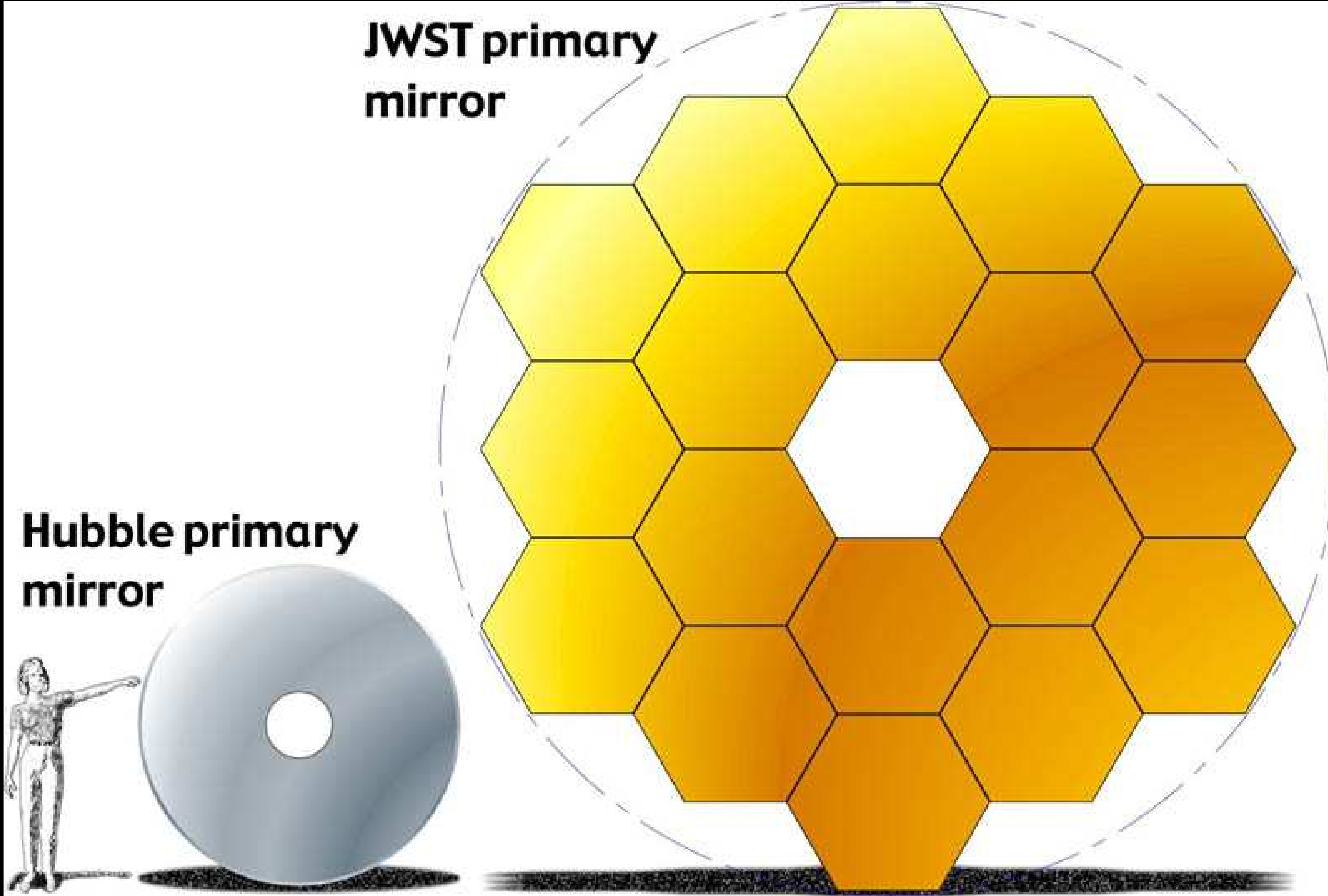
Any (space) mission is a balance between what science demands, what technology can do, and what budget & schedule allows ... (courtesy Prof. Richard Ellis).

Edwin P. Hubble (1889–1953) — Carnegie astronomer

James E. Webb (1906–1992) — Second NASA Administrator

HST: Concept in 1970's; Made in 1980's; Operational 1990–$\gtrsim$2014.

JWST: HST's sequel: concept 2000; made 2010's; oper. 2018-2023 (-2029?)

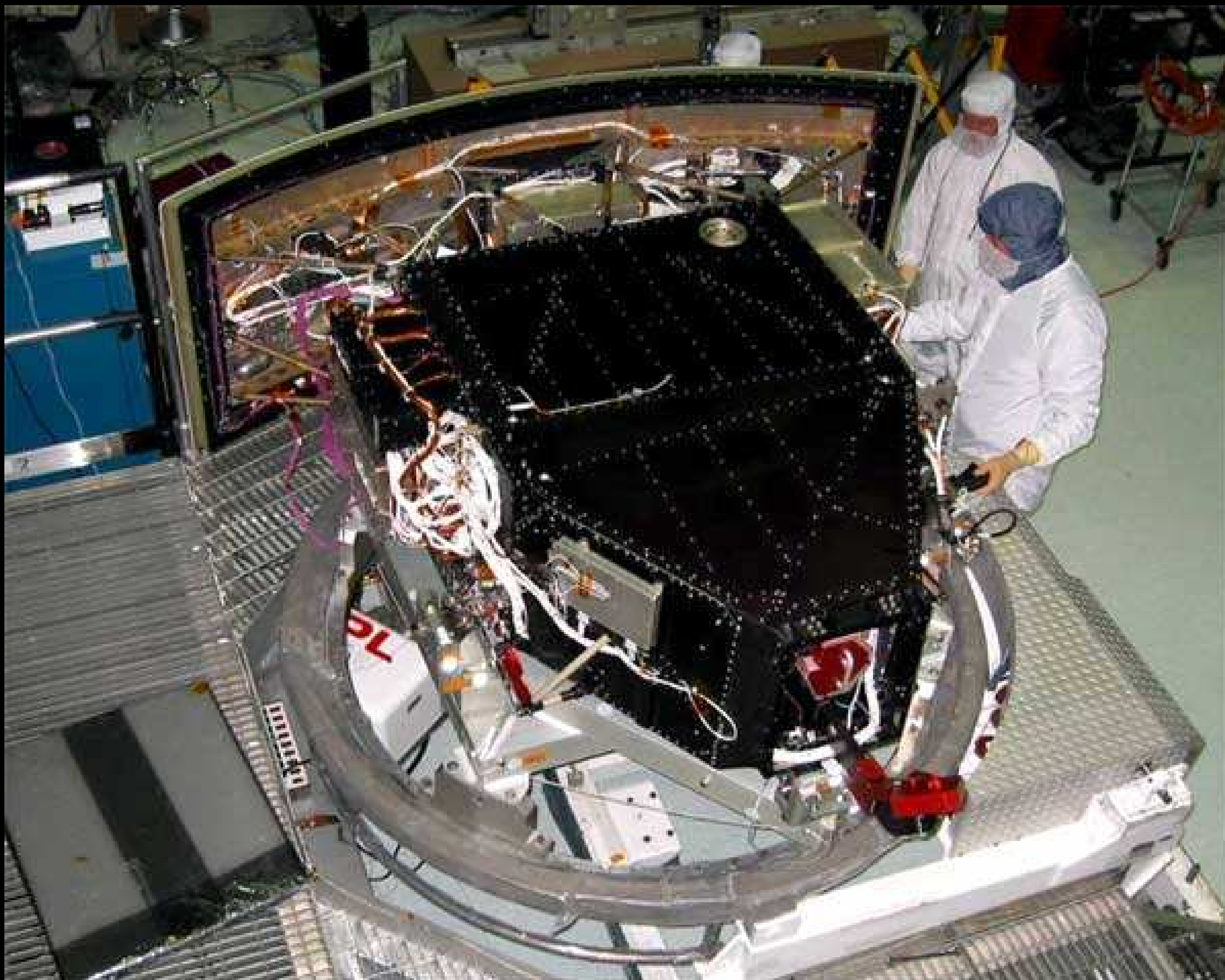


JWST $\simeq$2.5$\times$ larger than Hubble, so at $\sim$2.5$\times$ larger wavelengths:

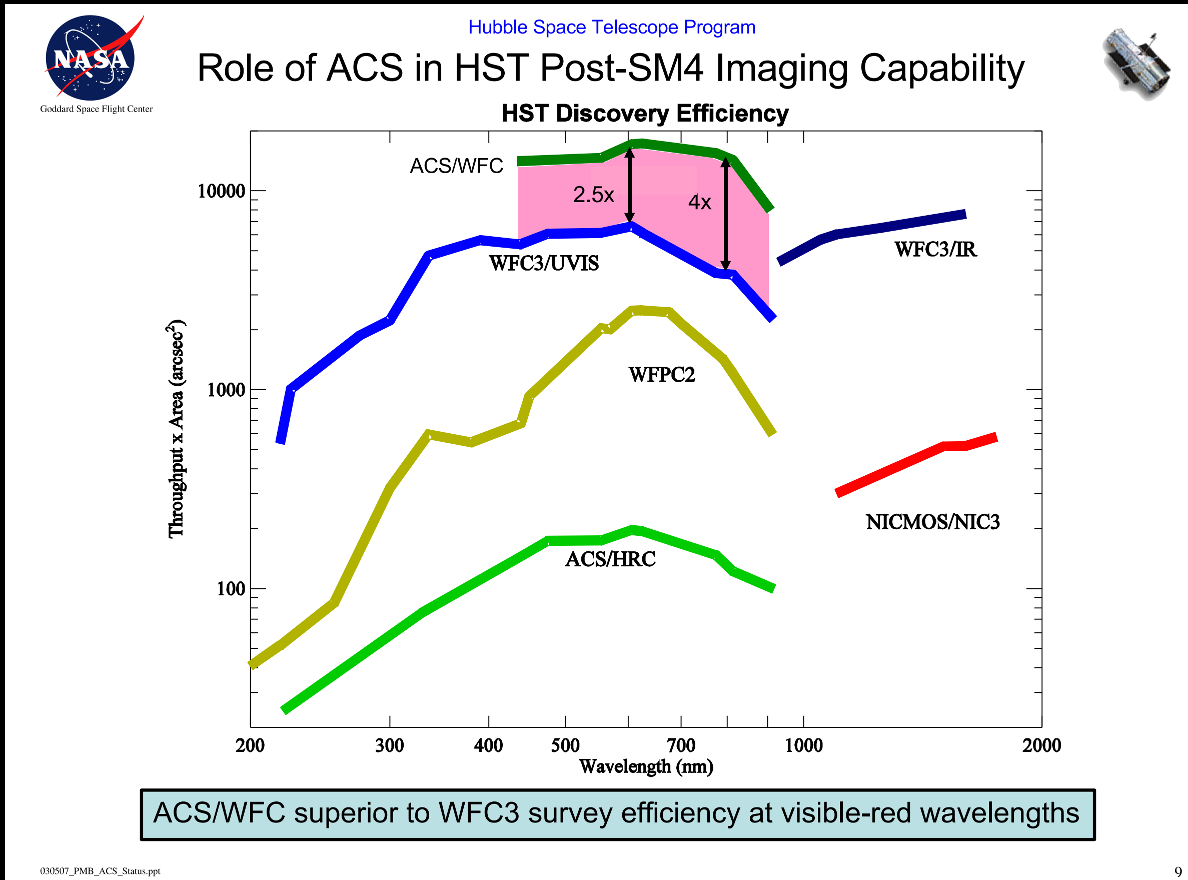
JWST has the same resolution in the near-IR as Hubble in the optical.

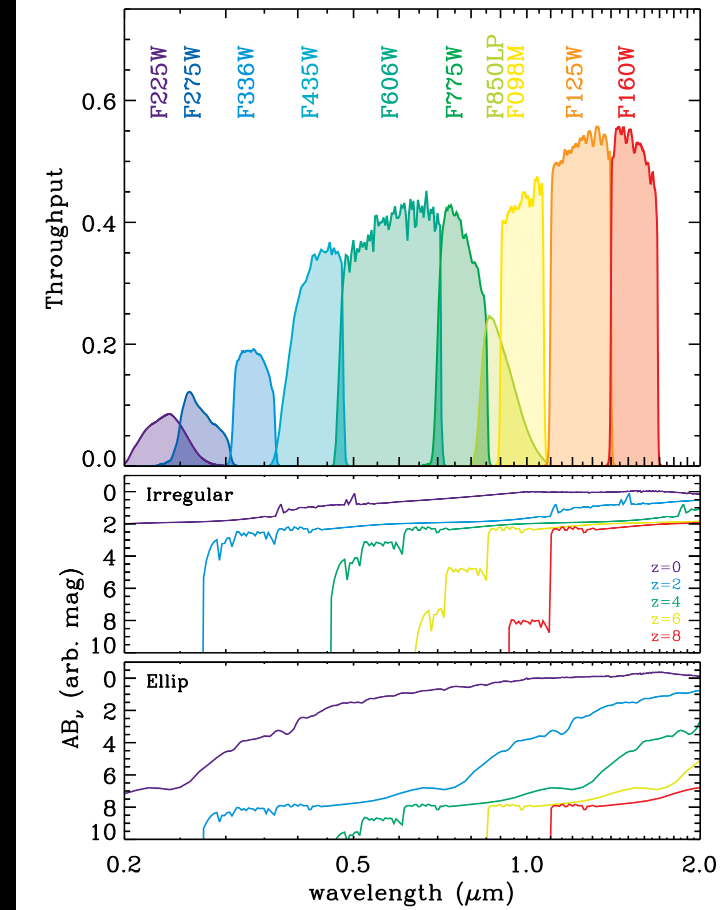
(1) The Best of Hubble: Recent results from the HST and its WFC3

WFC3: Hubble's new Panchromatic High-Throughput Camera



HST WFC3 and its IR channel: a critical pathfinder for JWST science.





WFC3/UVIS channel unprecedented UV–blue throughput & area:

- QE$\gtrsim$70%, 4k$\times$4k array of $0''.04$ pixel, FOV $\simeq$ $2'.67 \times 2'.67$.

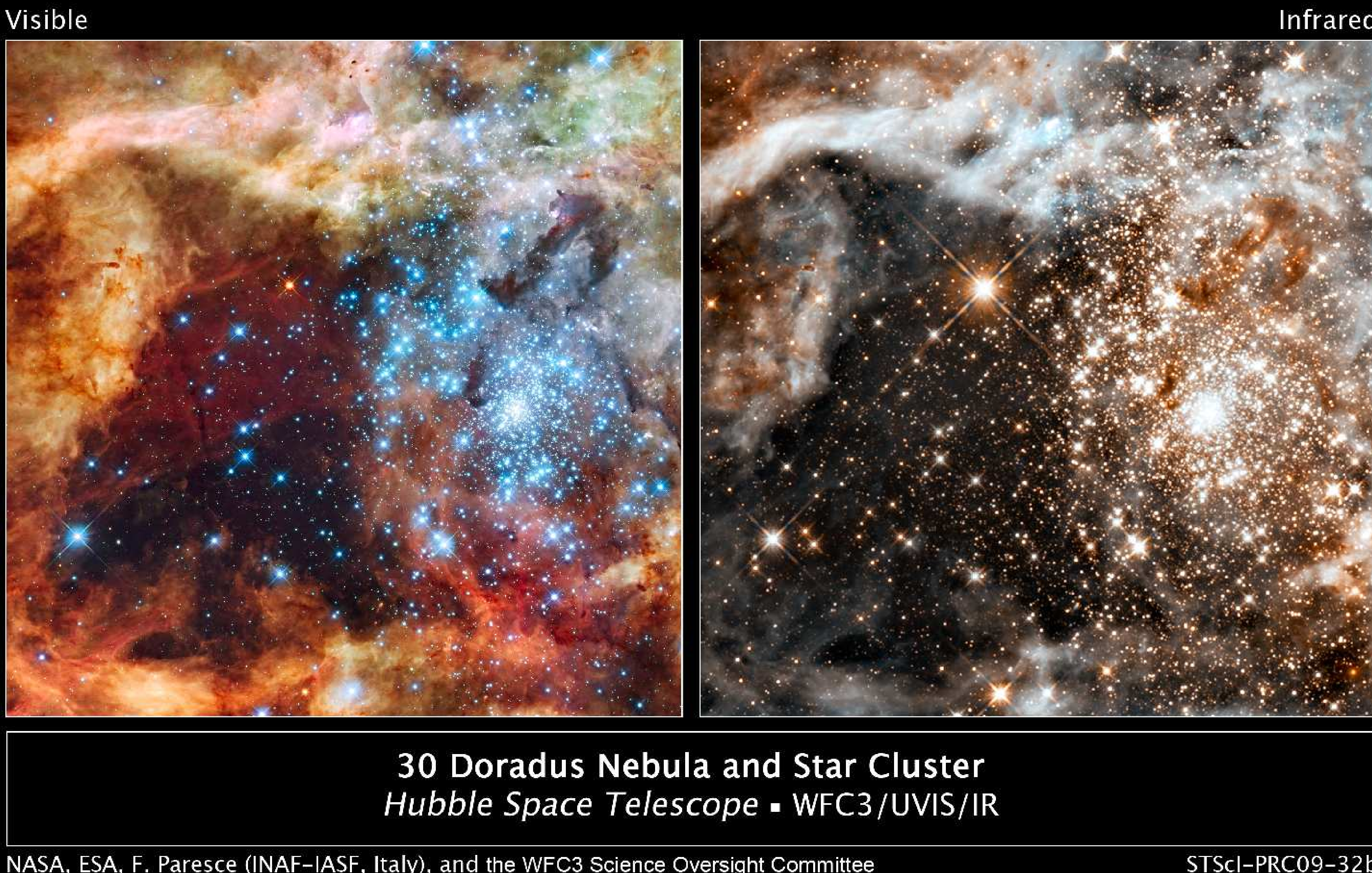
WFC3/IR channel unprecedented near–IR throughput & area:

- QE$\gtrsim$70%, 1k$\times$1k array of $0''.13$ pixel, FOV $\simeq$ $2'.25 \times 2'.25$.

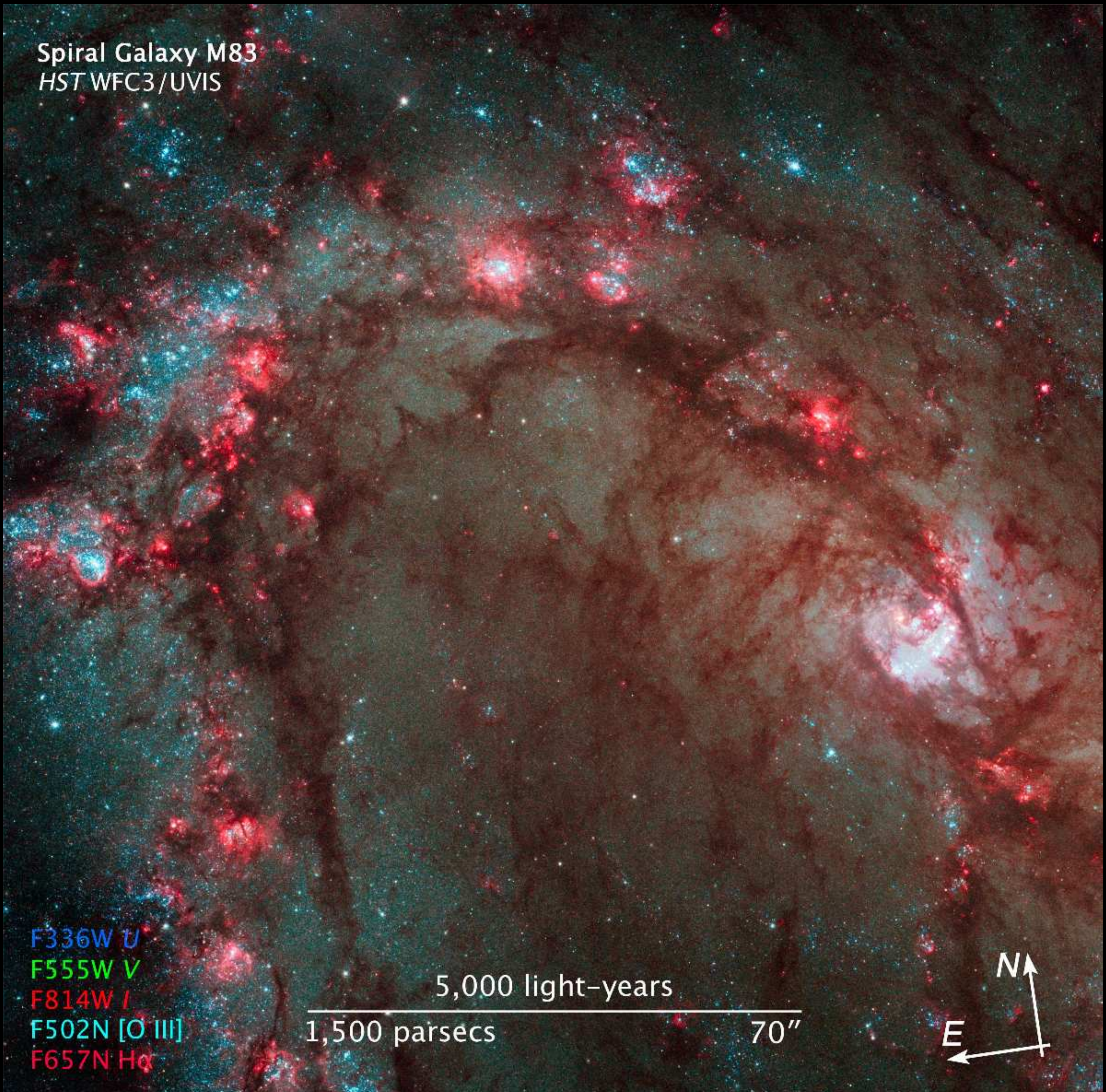
$\Rightarrow$ WFC3 opened major new parameter space for astrophysics in 2009:

WFC3 filters designed for star-formation and galaxy assembly at z$\simeq$1–8:

- HST WFC3 and its IR channel a critical pathfinder for JWST science.



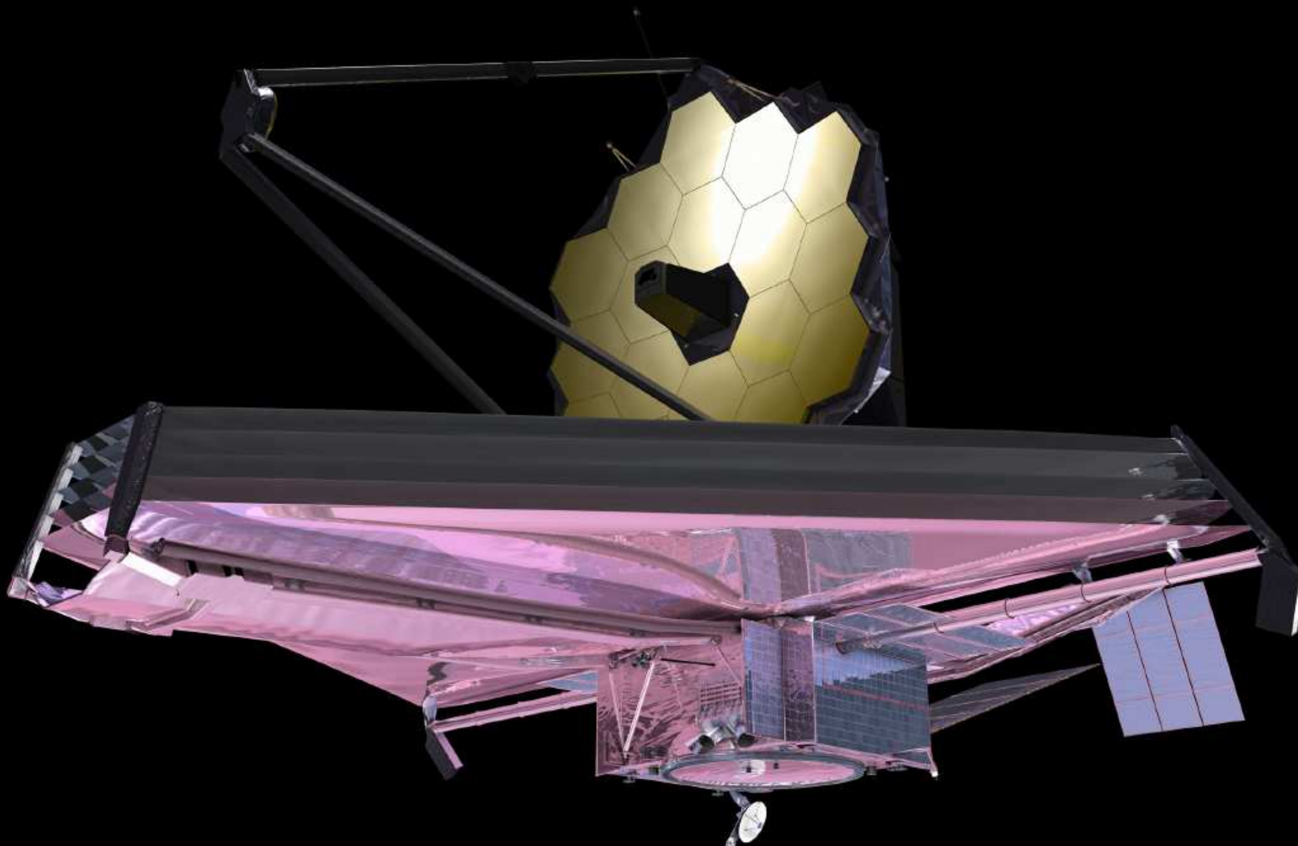
30 Doradus: Giant young star-cluster in Large Magellanic Cloud (150,000 ly), triggering birth of Sun-like stars (and surrounding debris disks).


Spiral Galaxy M83
HST WFC3/UVIS
F336W U
F555W V
F814W I
F502N [O III]
F657N Hα
5,000 light-years
1,500 parsecs
70″
N
E

HST/WFC3 & ACS reach AB=26.5-27.0 mag ($\sim$100 fireflies from Moon) over 0.1$\times$full Moon area in 10 filters from 0.2–2μm wavelength.

JWST has 3$\times$sharper imaging to AB$\simeq$31.5 mag ($\sim$1 firefly from Moon) at 1–5μm wavelengths, tracing young and old stars + dust.

(3) What is the James Webb Space Telescope (JWST)?



- A fully deployable 6.5 meter (25 m^2) segmented IR telescope for imaging and spectroscopy at 0.6–28 μm wavelength, to be launched in Fall 2018.
- Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging (31.5 mag = firefly from Moon!) and spectroscopy.

The James Webb Space Telescope

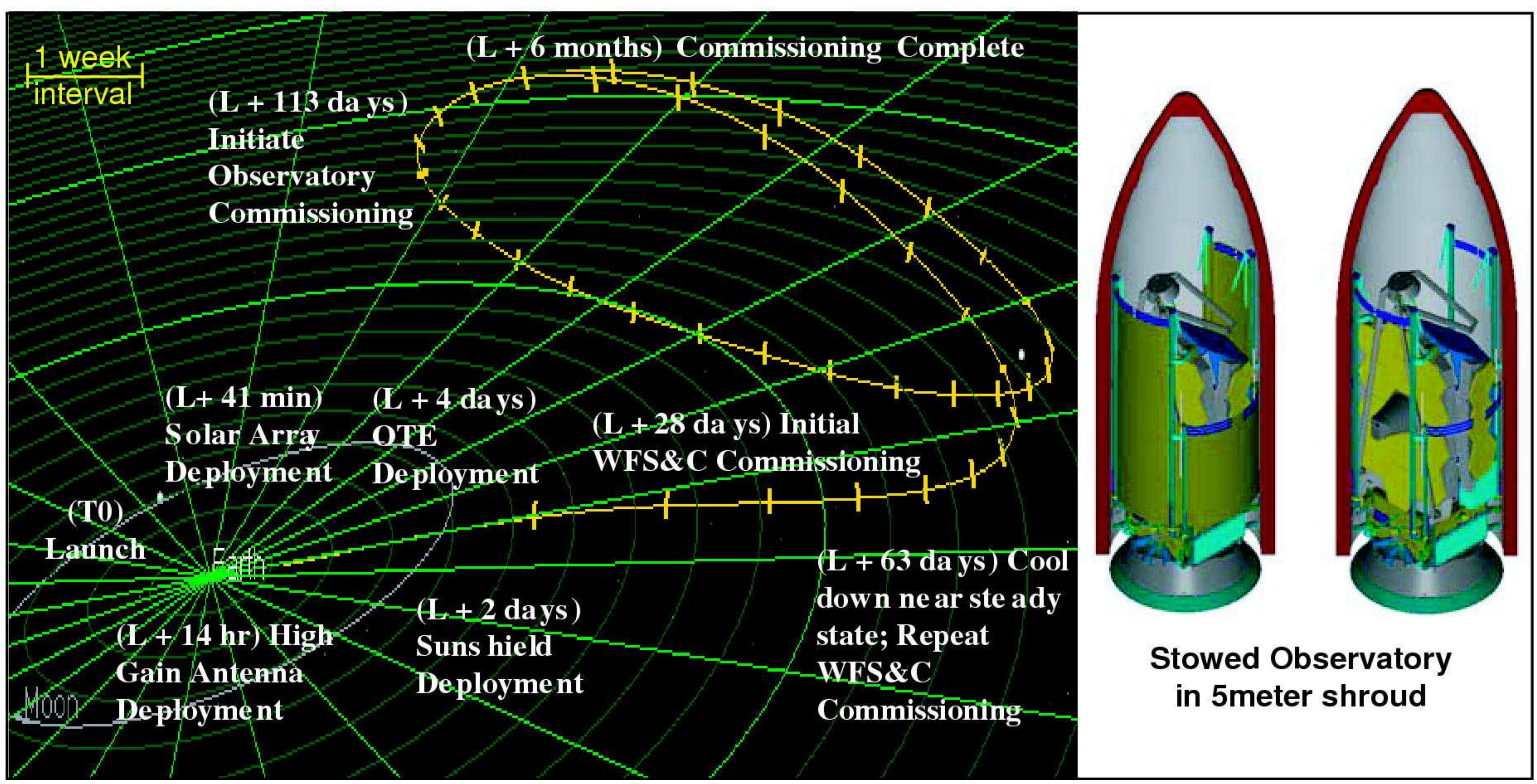
JWST Launch

- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana

ARIANESPACE – ESA - NASA

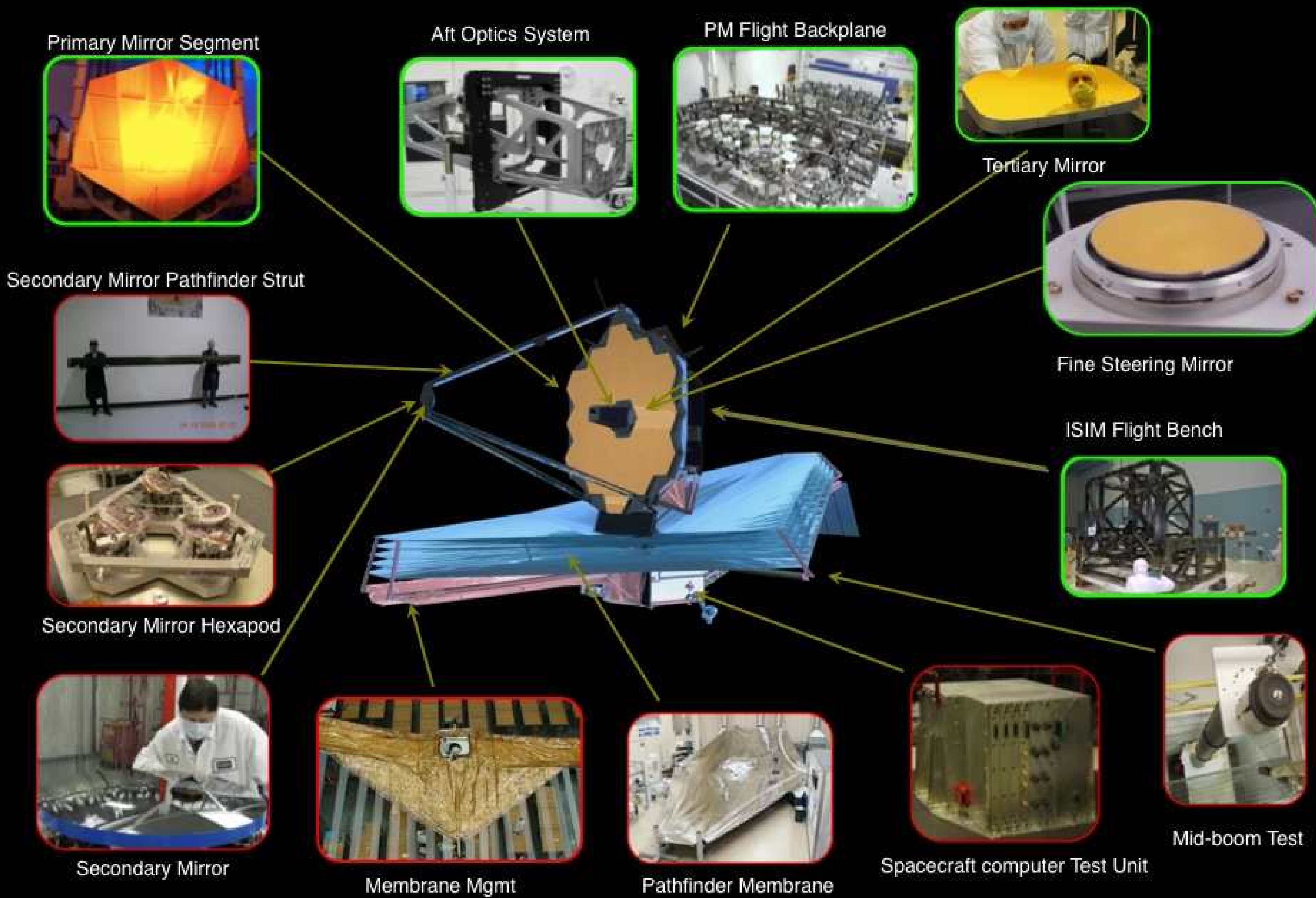
- The JWST launch weight will be $\lesssim$6500 kg, and it will be launched to L2 with an ESA Ariane-V launch vehicle from Kourou in French Guiana.

(3a) How will JWST travel to its L2 orbit?

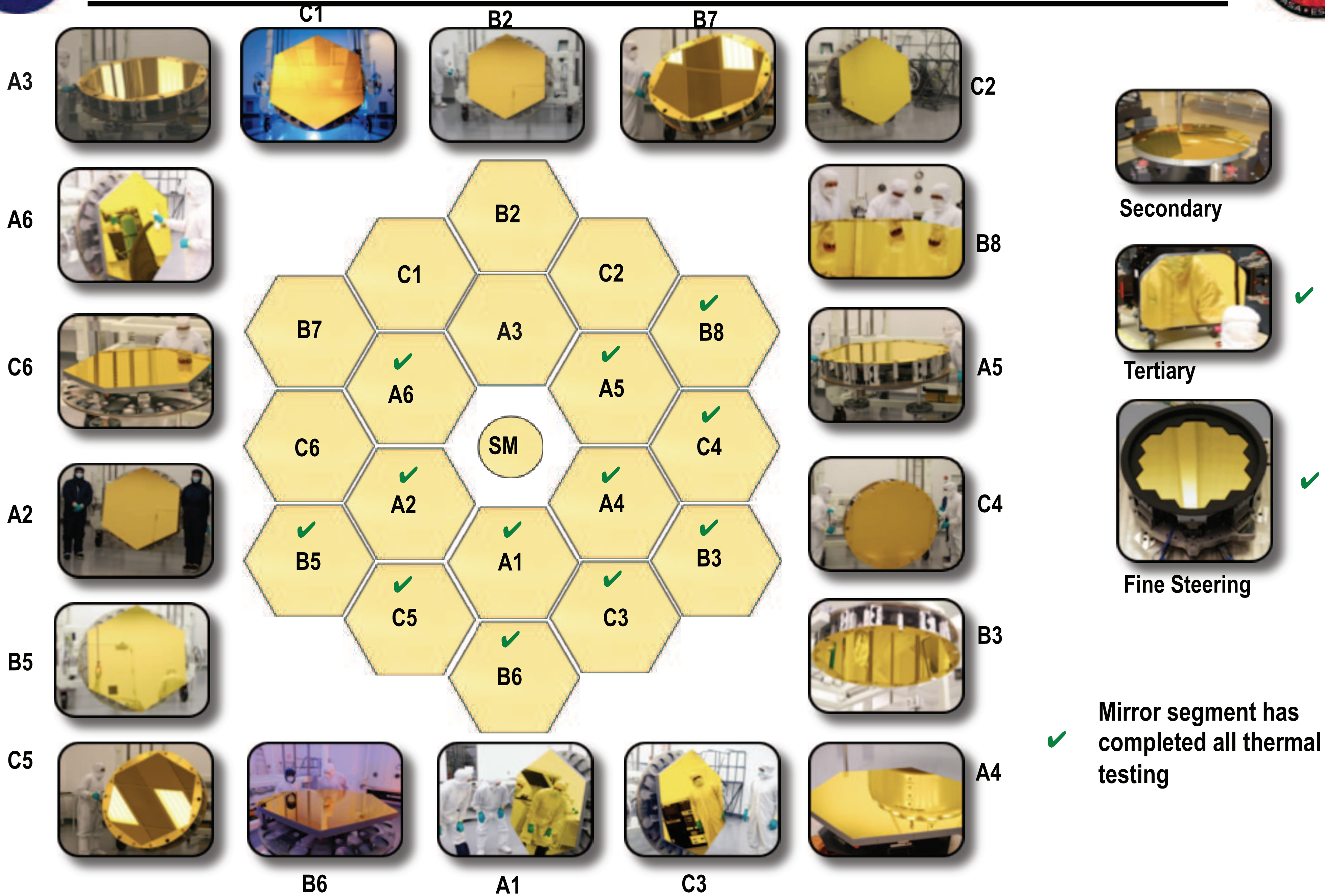


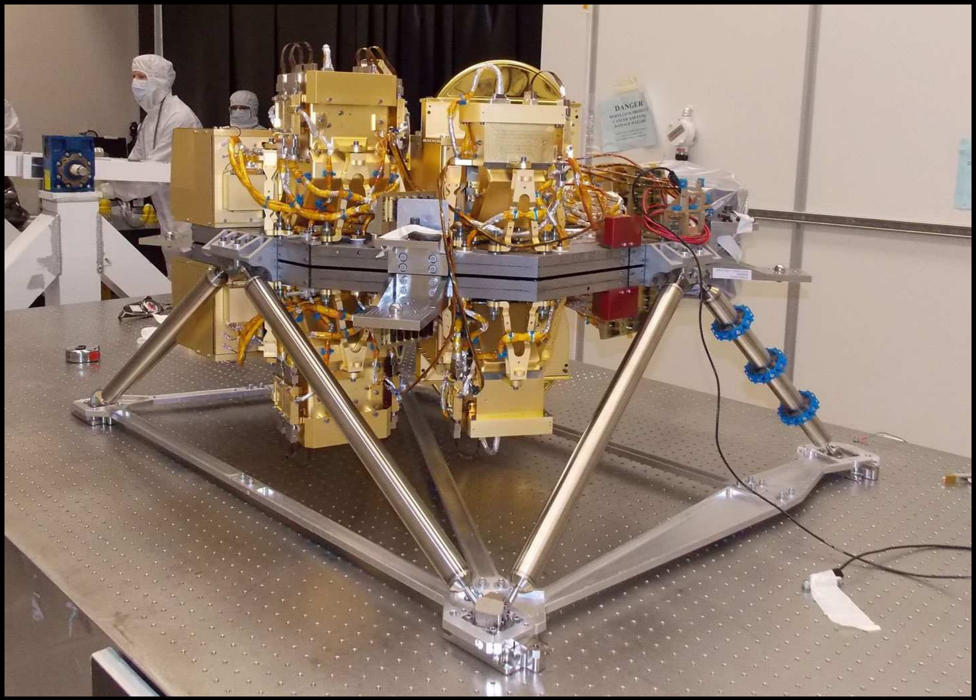
- After launch in 2018 with an ESA Ariane-V, JWST will orbit around the Earth–Sun Lagrange point L2, 1.5 million km from Earth.
- JWST can cover the whole sky in segments that move along with the Earth, observe $\gtrsim$70% of the time, and send data back to Earth every day.

JWST Hardware Status



Family Portrait

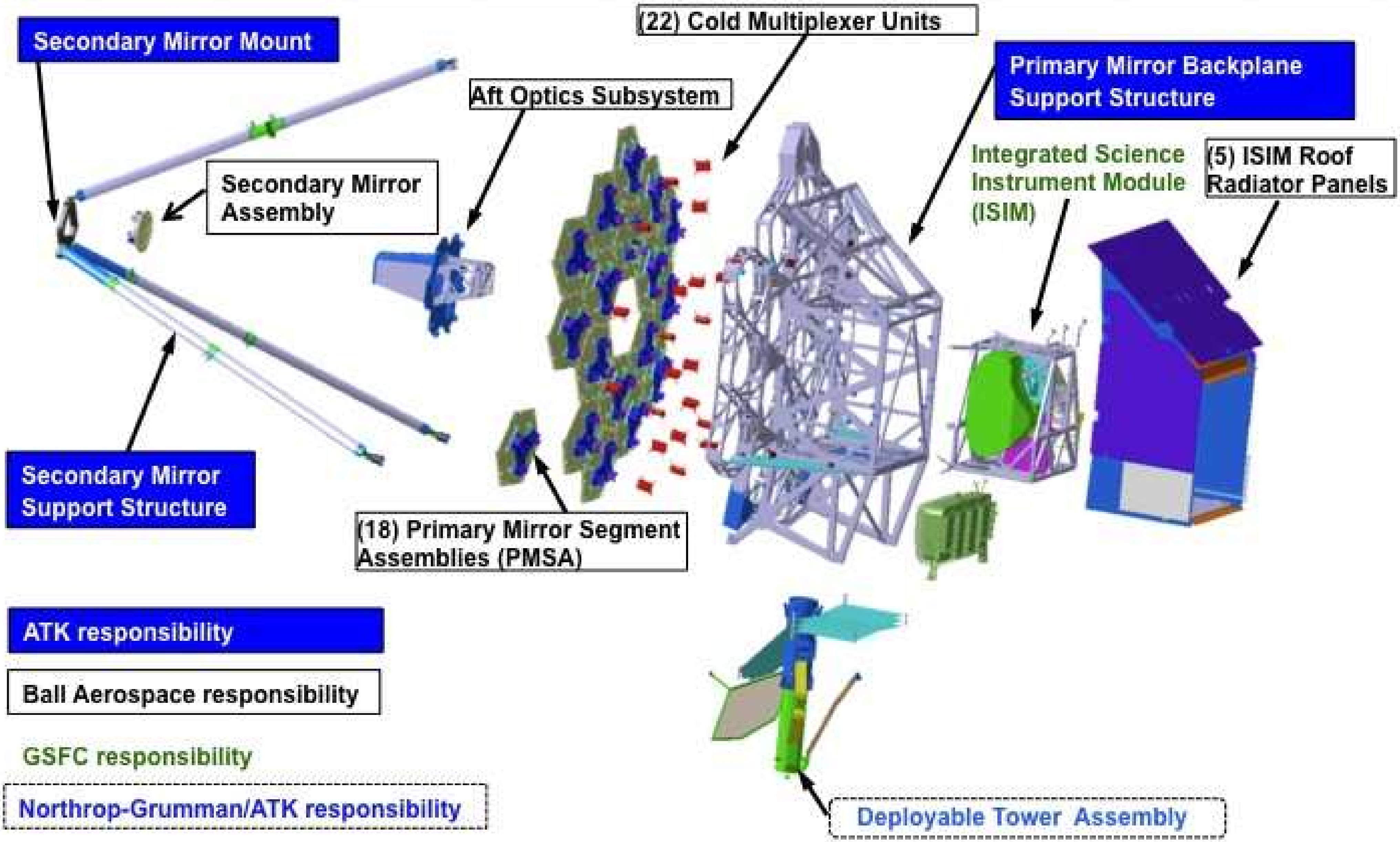


JWST's short-wavelength (0.6–5.0μm) imagers:

- NIRCam — built by UofA (AZ) and Lockheed (CA).
- Fine Guidance Sensor (& 1–5 μm grisms) — built by CSA (Montreal).
- FGS includes very powerful low-res Near-IR grism spectrograph
- FGS delivered to GSFC 07/12; NIRCam delivered July 28, 2013.

TELESCOPE ARCHITECTURE



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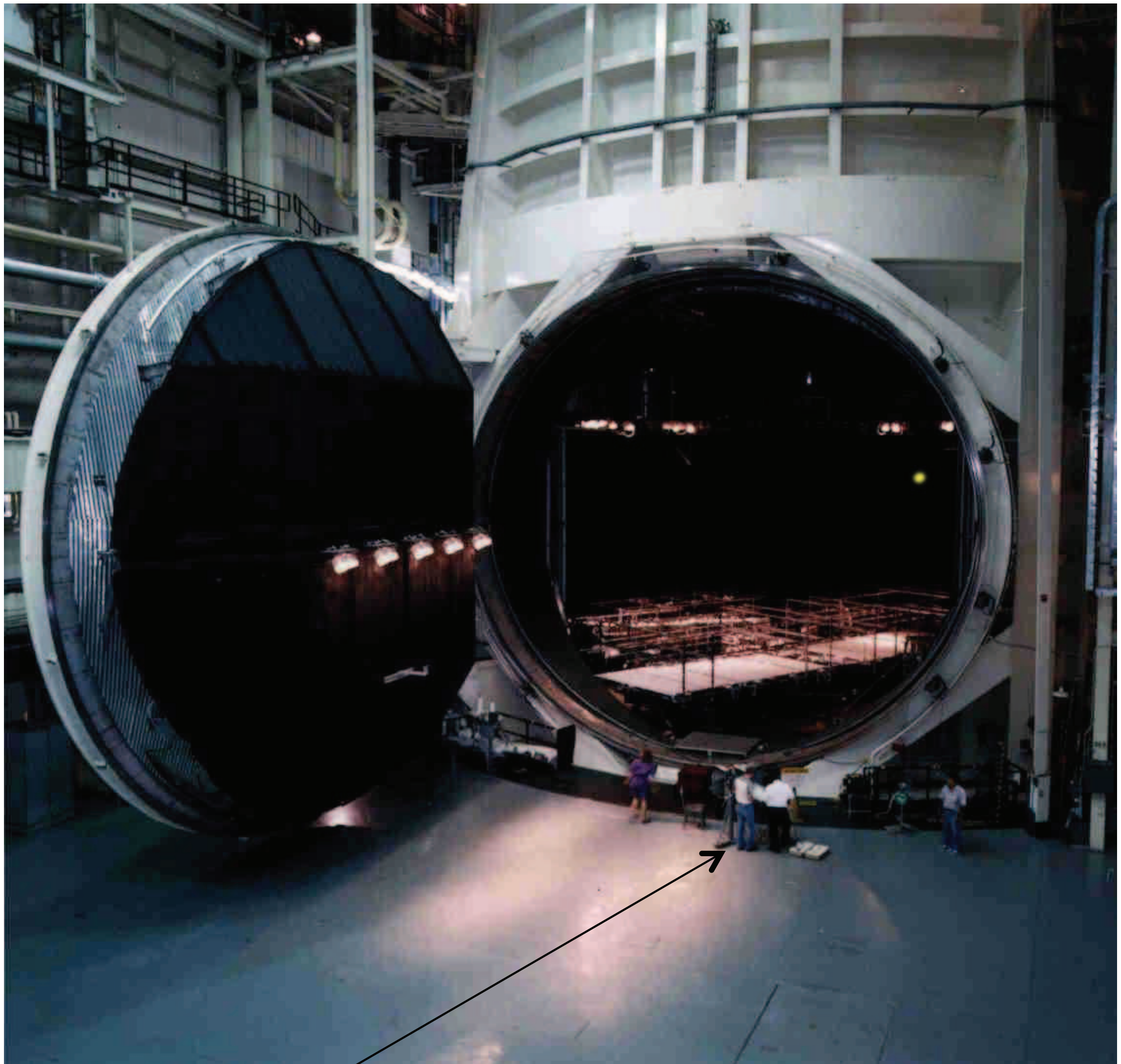
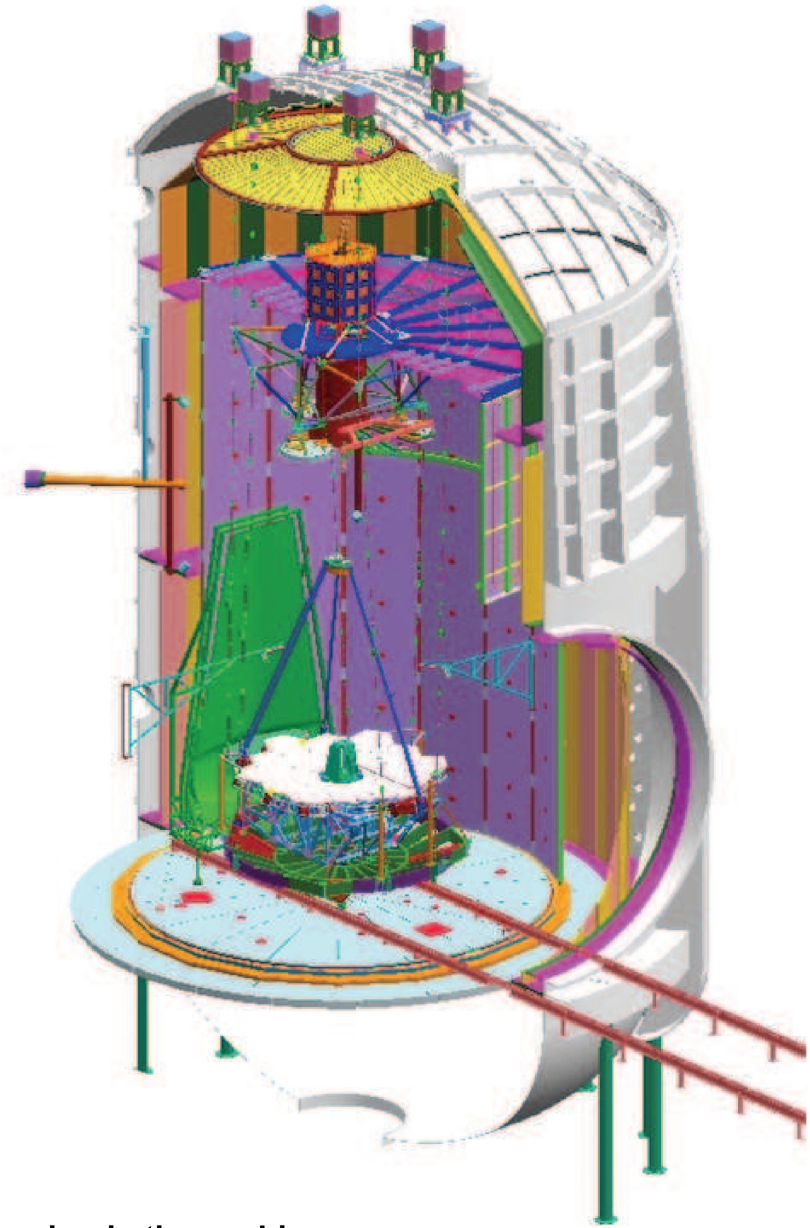
OTE Testing – Chamber A at JSC





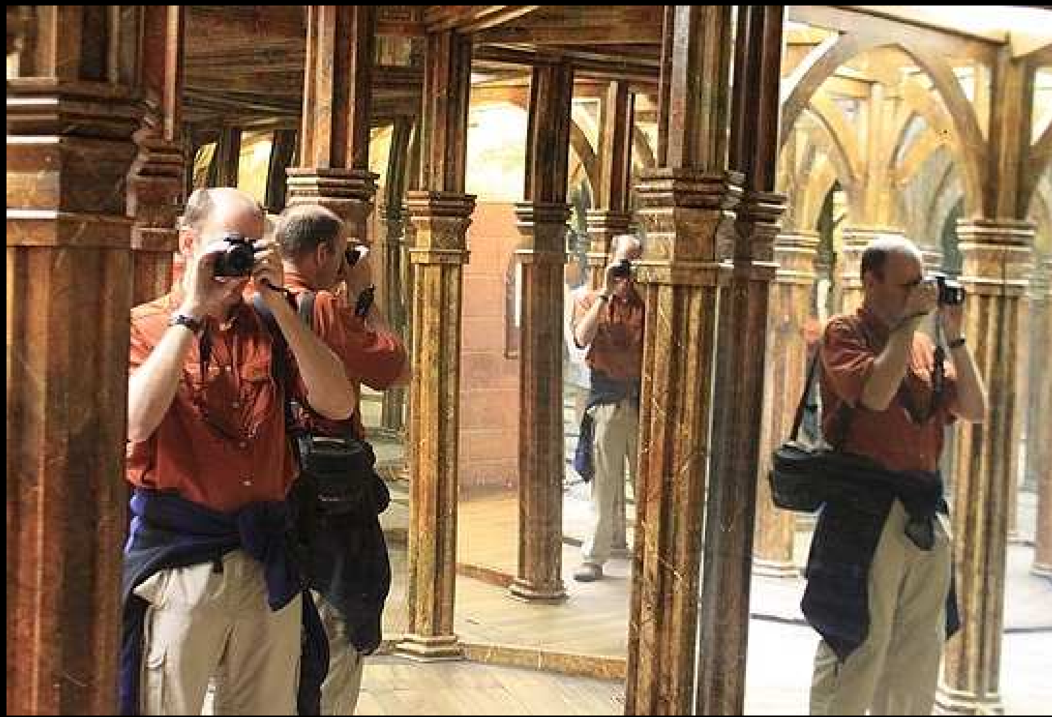
Notice people for scale

Will be the largest cryo vacuum test chamber in the world

OTIS: Largest TV chamber in world: will test whole JWST in 2015–2016.

(4) Massive clusters as gravitational Lenses: Cosmic House-of-Mirrors:

(4) Gravitational Lensing to see the Reionizing population at $z \gtrsim 8$?



Two fundamental limitations determine Webb's ultimate image depth:

(1) Cannot-see-the-forest-for-the-trees effect: Background objects blend into foreground neighbors $\Rightarrow$ Need multi-λ deblending algorithms!

(2) House-of-mirrors effect: (Many?) First Light objects can be gravitationally lensed by foreground galaxies $\Rightarrow$ Must model/correct for this!

- Proper JWST 2.0μm PSF and straylight specs essential to handle this!

(5) Conclusions

(1) HST set stage to measure galaxy assembly in the last 12.7-13.0 Gyrs.

(2) JWST passed Preliminary & Critical Design Reviews in 2008 & 2010.

- Budget and Management replan in 2011. No technical showstoppers.
- More than 80% of JWST H/W built or in fab, & meets/exceeds specs.

(3) JWST is designed to map the epochs of First Light, Reionization, and Galaxy Assembly & SMBH-growth in detail.

- JWST Cycle 1 proposals due early 2017: in less than 3.5 years!

(4) JWST will have a major impact on astrophysics this decade:

- IR sequel to HST after 2018: Training the next generation researchers.
- JWST will define the next Deep Space Frontier: the Dark Ages at $z \gtrsim 20$.

SPARE CHARTS

One day we will need a UV-optical sequel to Hubble (Paul Scowen's talk):

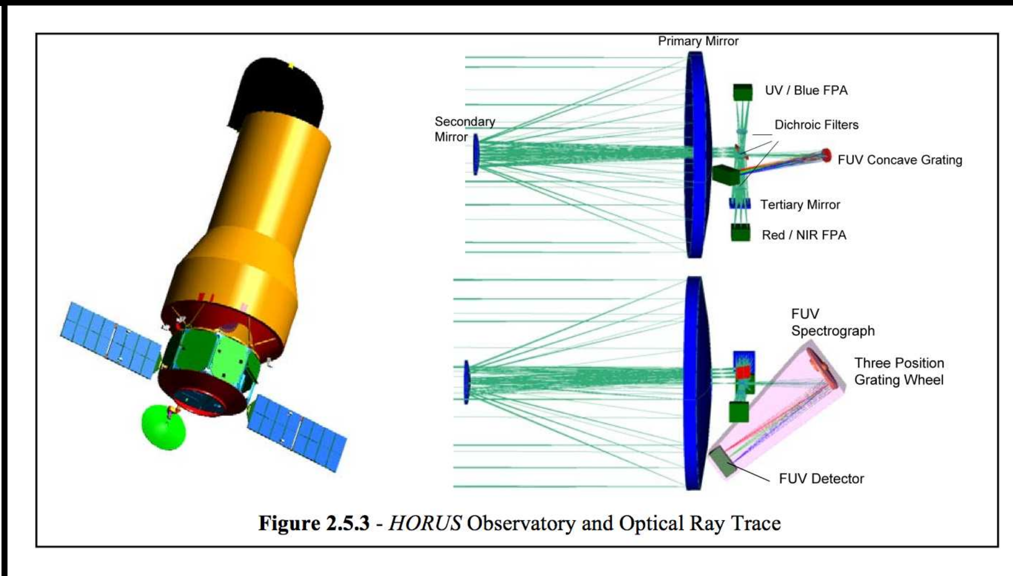
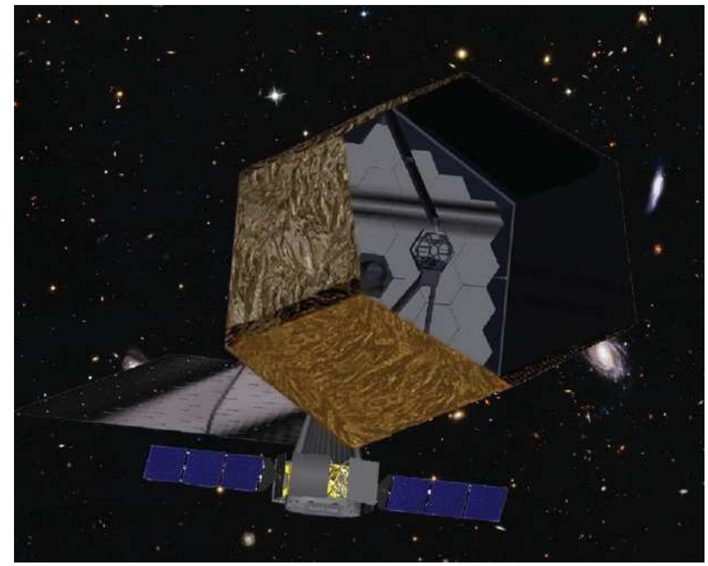


Figure 2.5.3 - *HORUS* Observatory and Optical Ray Trace



[Left] One of two spare 2.4 m NRO mirrors: one will become WFIRST.

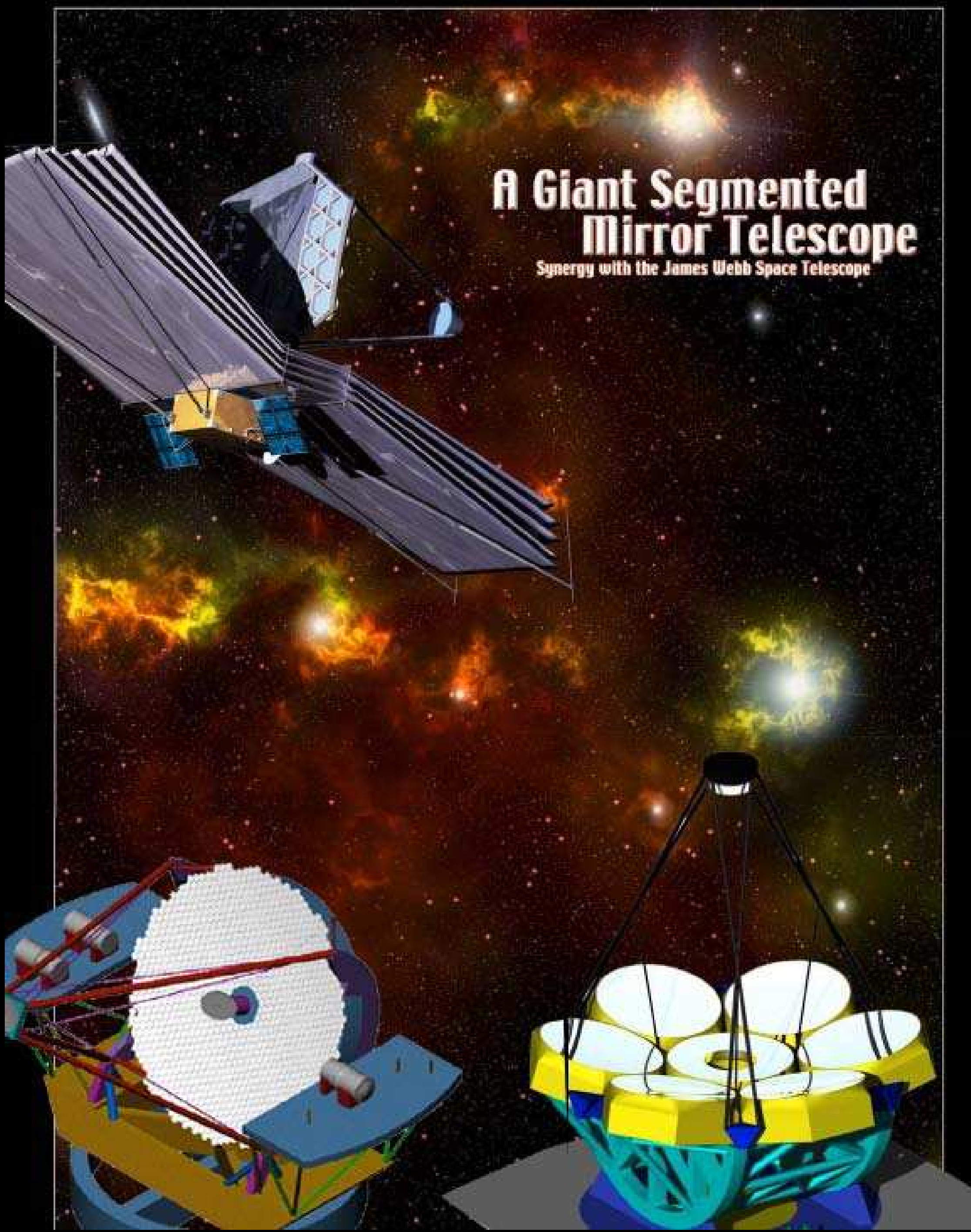
- NASA may look for partners to turn 2nd NRO into UV-opt HST sequel.

[Middle] HORUS: 3-mirror anastigmat NRO as UV-opt HST sequel.

- Can do wide-field ($\sim$0.25 deg) UV-opt $0\farcs06$ FWHM imaging to AB$\lesssim$30 mag, and high sensitivity (on-axis) UV-spectroscopy (Scowen et al. 2012).

[Right] ATLAST: 8–16 m UV-opt HST sequel, with JWST heritage.

- Can do same at 9 m.a.s. FWHM routinely to AB$\lesssim$32-34 mag, [and an ATLAST-UDF to AB $\lesssim$38 mag $\sim$1 pico-Jy].



(6) GMT/TMT/E-ELT & JWST Synergy: (Kudritzki, Frogel+ 2005):

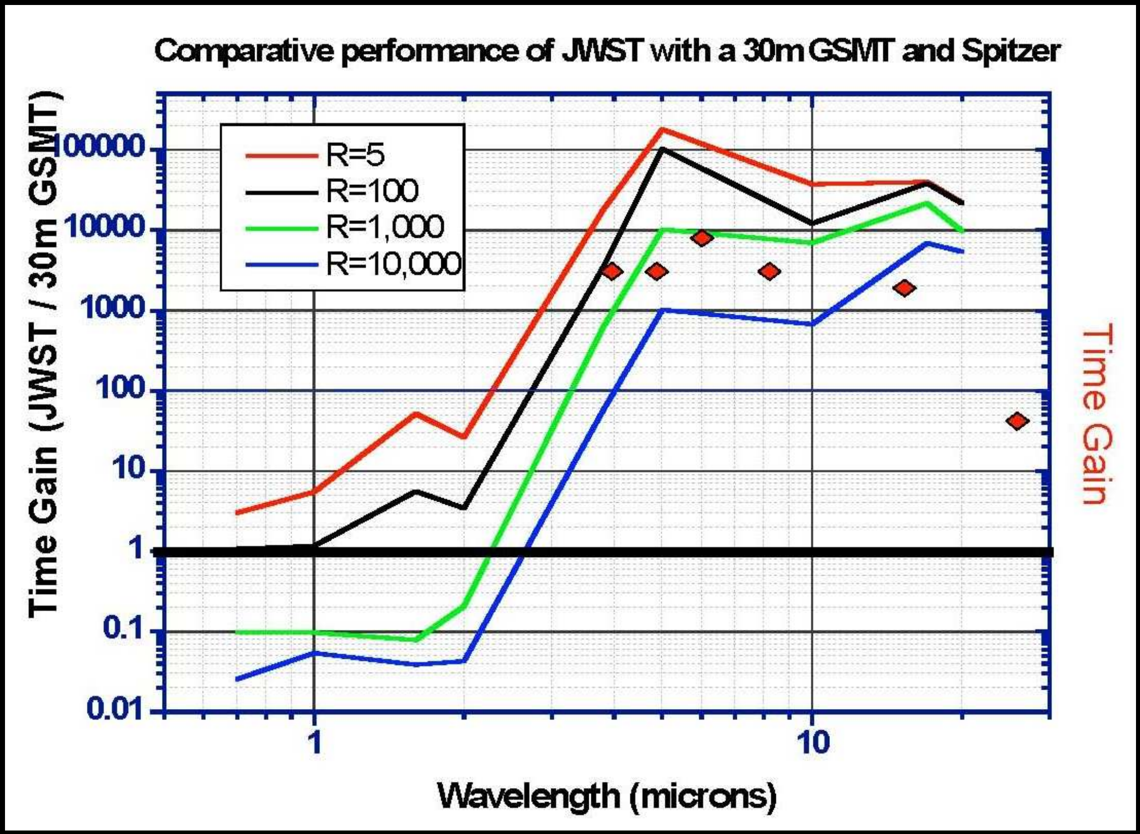
- (1) Are the top two priority missions of the 2001 Decadal Survey in Astronomy & Astrophysics.

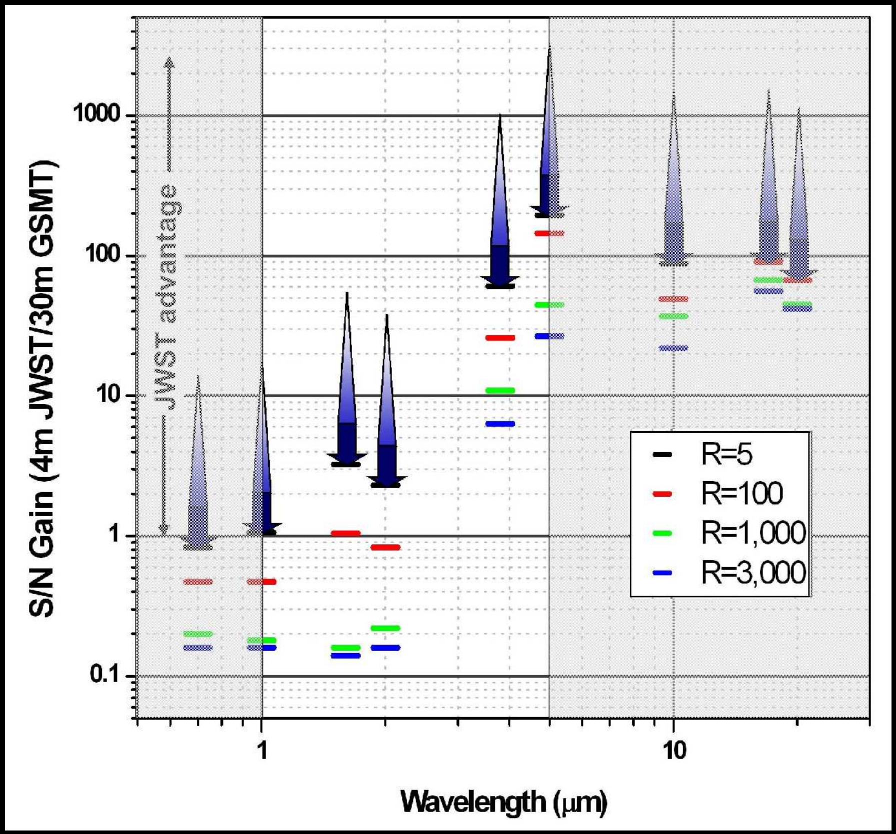
- (2) Each give orders of magnitude gain in sensitivity over existing ground and space telescopes, resp.

- (3) Have complementary capabilities that open a unique new era for cosmic and planetary discovery.

- (4) Maximize concurrent operation of GMT/TMT/E-ELT and JWST!

(6) Synergy between the GMT/TMT/E-ELT and JWST





LEFT: Time-gain(λ) of JWST compared to GMT/TMT/E-ELT and Spitzer. GMT/TMT-AO competition is why JWST no longer has specs at $\lambda \lesssim 1.7 \mu$m.

RIGHT: S/N-gain(λ) of JWST compared to ground-based:

- Top of arrows: 6m JWST/Keck; Middle: 6m JWST/TMT; Bottom: 4m JWST/TMT.

(6a) Unique Capabilities of the 6.5 meter JWST in L2

- (1) Full sky coverage & high observing efficiency.

- (2) Above the atmosphere, JWST will have:
- Continuous wavelength coverage for 0.6 $\lesssim \lambda \lesssim$ 28.5 μm.
- High precision and high time-resolution photometry and spectroscopy.

(3) JWST is a cold telescope ($\lesssim$40 K):

- Minimizes thermal background (for $\lambda \lesssim$ 10 μm, set by the Zodi: 10^3–$10^4\times$ or 7–10 mag lower than ground-based sky!).
- Very high sensitivity for broad-band IR imaging ($\Leftarrow$ no atm OH-lines).

(4) Diffraction limited for $\lambda \gtrsim$ 2.0 μm over a wide FOV ($\gtrsim 5'$), hence:

- PSF nearly constant across the FOV.
- PSF stable with time — WFS updates on time-scales of ($\sim$10) days.
- Very high dynamic range.

(6b) Unique Capabilities of the GMT/TMT/E-ELT

(1) Sensitivity 25$\times$ greater than JWST in accessible spectral regions.

• Very high optical sensitivity (0.32–1.0 μm) over a wide FOV ($\gtrsim$10$'$).

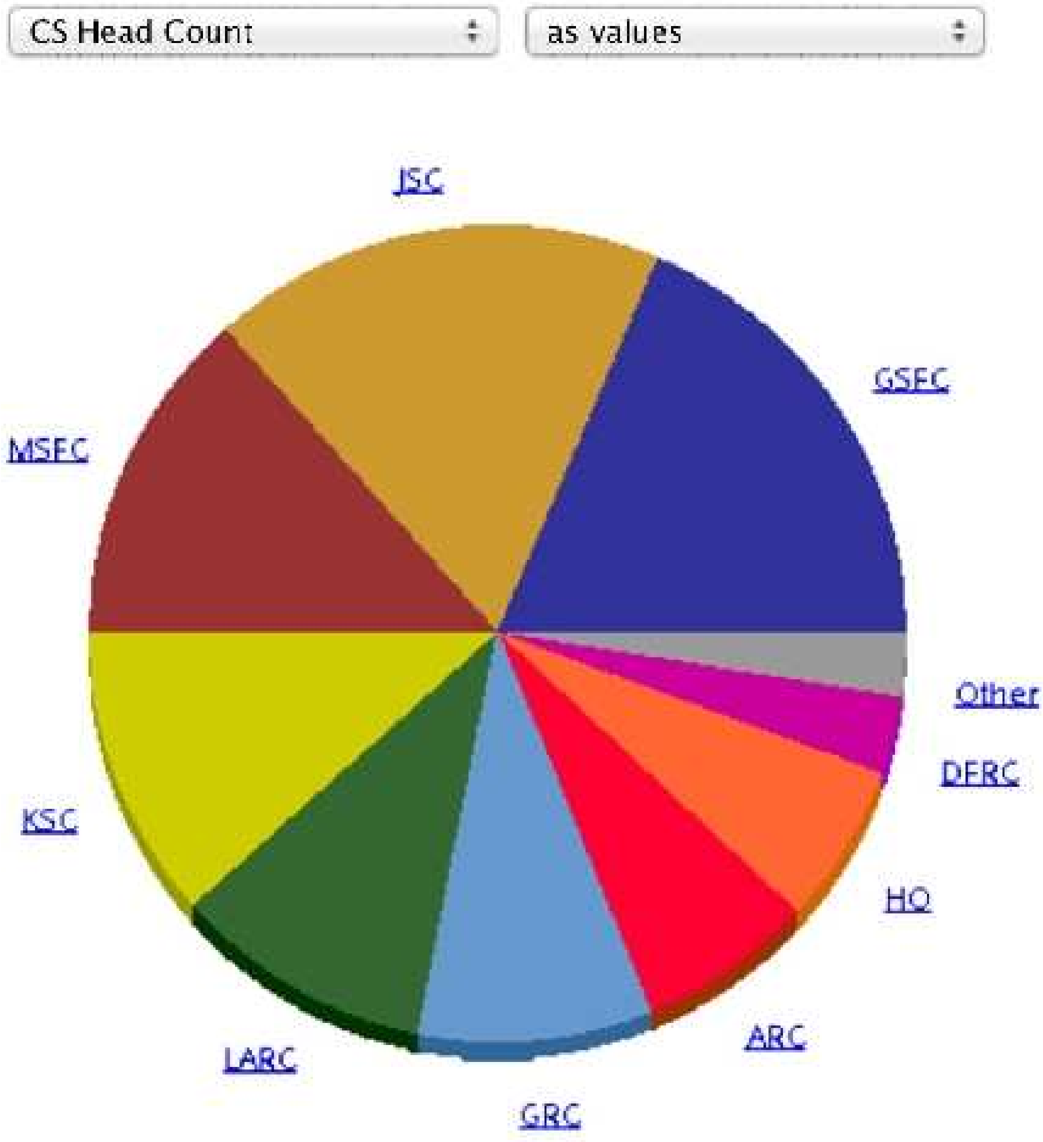
(2) Very high spatial resolution, diffraction-limited imaging in mid- and near-IR — with AO can get PSF 4–6$\times$ better than JWST.

• High sensitivity for non-background limited IR imaging and high-resolution spectroscopy (between OH-lines).

(3) Very high resolution spectroscopy — (R $\gtrsim 10^5$) in optical–mid-IR.

(4) Short response times — few minutes for TOO's.

(5) Flexible and upgradable — take advantage of new developments in instrumentation in the next decades.



	Centers & NSSC	CS Head Count
	GSFC	3,354
	JSC	3,203
	MSFC	2,432
	KSC	2,055
	LARC	1,881
	GRC	1,640
	ARC	1,215
	HQ	1,152
	DFRC	558
	Other	454

NASA workforce as pie-chart and in numbers — 2013 total: about 18,000).

Nation-wide NASA contractors (Northrup, Lockheed, Boeing, etc): 150,000.

See also: `https://wicn.nssc.nasa.gov/generic.html`

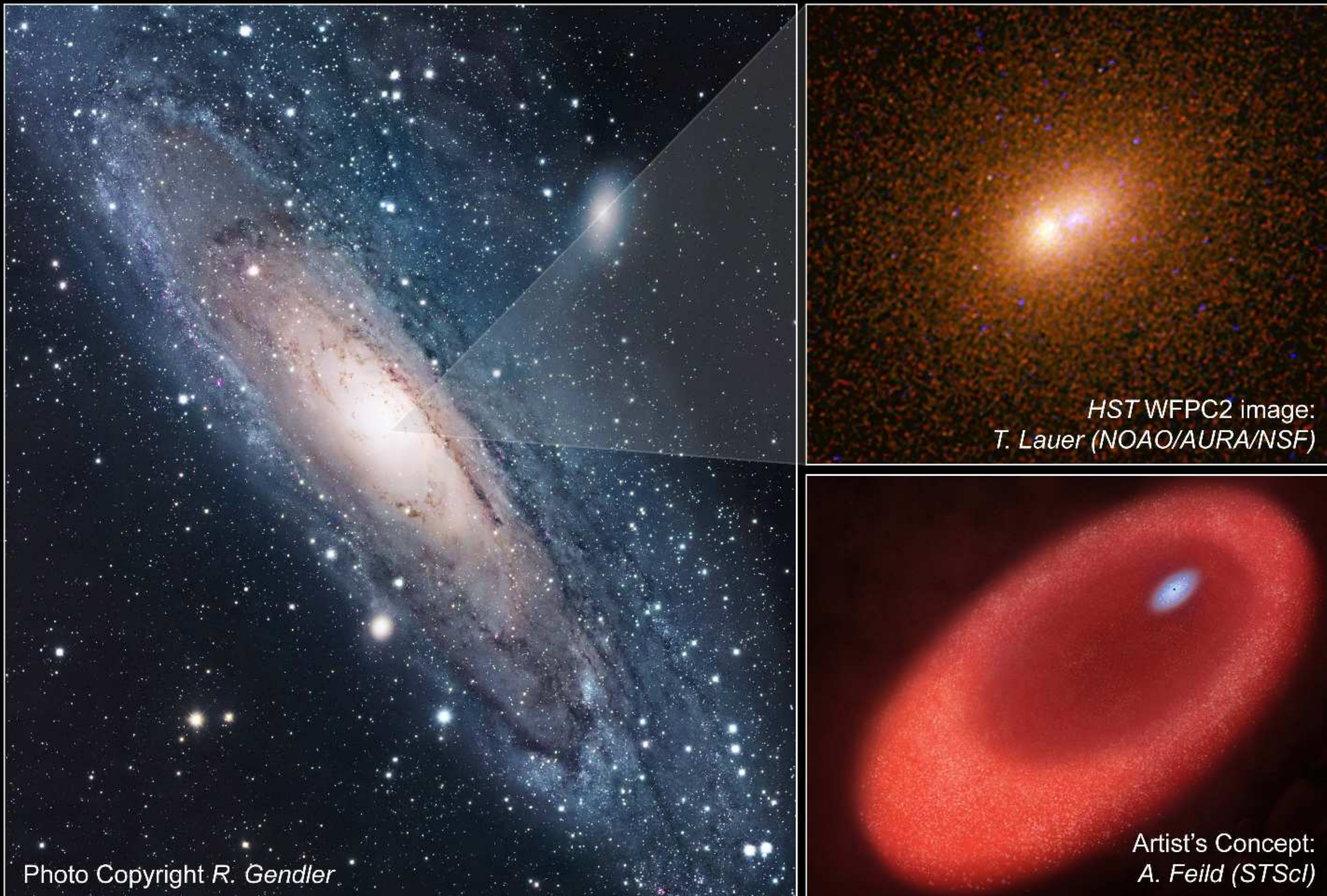
Future Careers at NASA:

What do our Astrophysics College Graduates do?

- Over the last 25 years, (ASU) Astrophysics College Graduates typically:
- (0) Have low unemployment ($\lesssim$few %).
- (1) About 25% faculty & researchers at universities or 4-yr colleges.
- (2) About 30% are researchers at NASA or other government centers.
- (3) About 25% work in Aerospace or related industries.
- (4) About 20% are faculty at Community Colleges or Highschools.

See: `http://aas.org/learn/careers-astronomy`

and: `http://www.aip.org/statistics/`



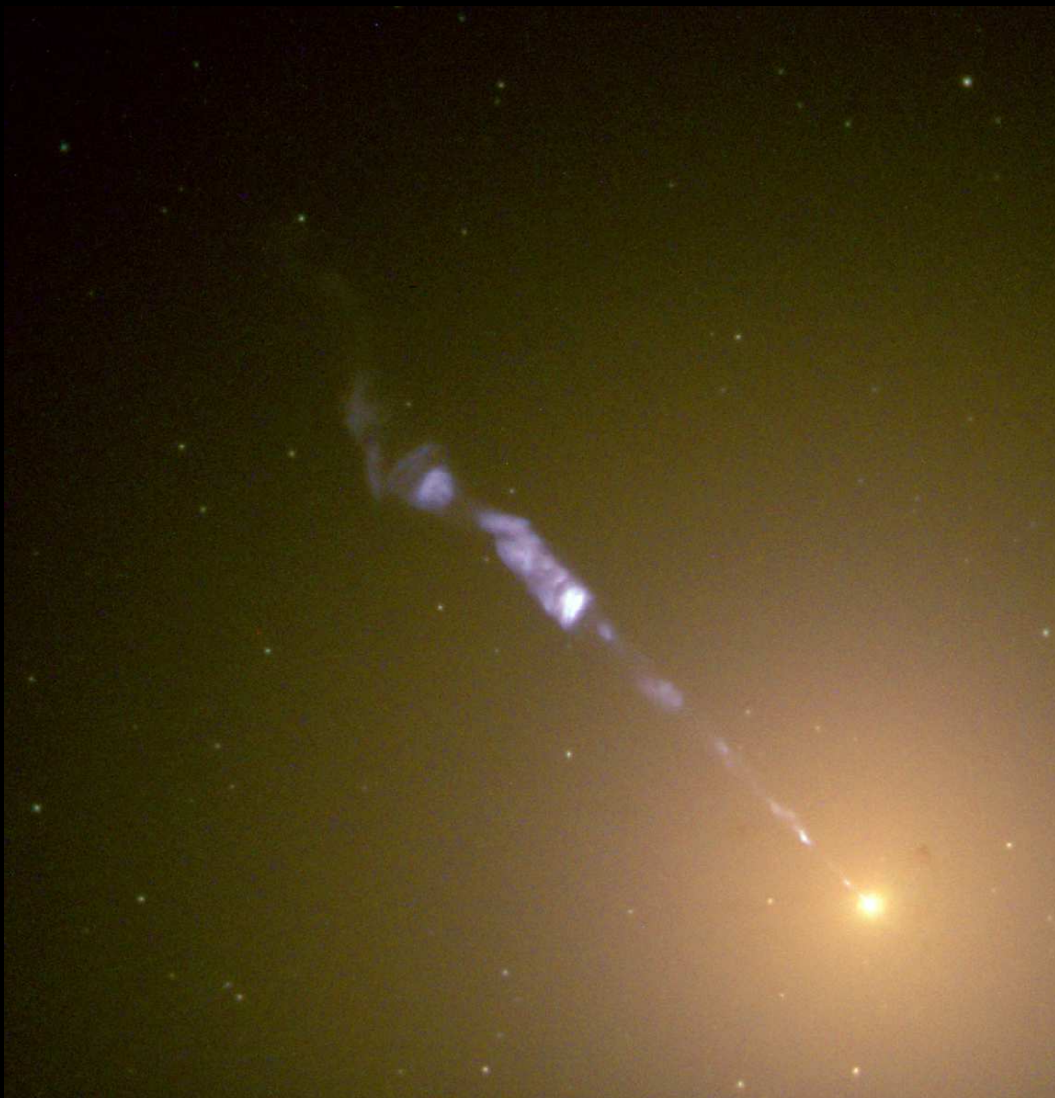
Andromeda Galaxy Nucleus ▪ M31

Hubble Space Telescope ▪ WFPC2

NASA, ESA, R. Gendler, T. Lauer (NOAO/AURA/NSF), and A. Feild (STScI)

STScI-PRC05-26

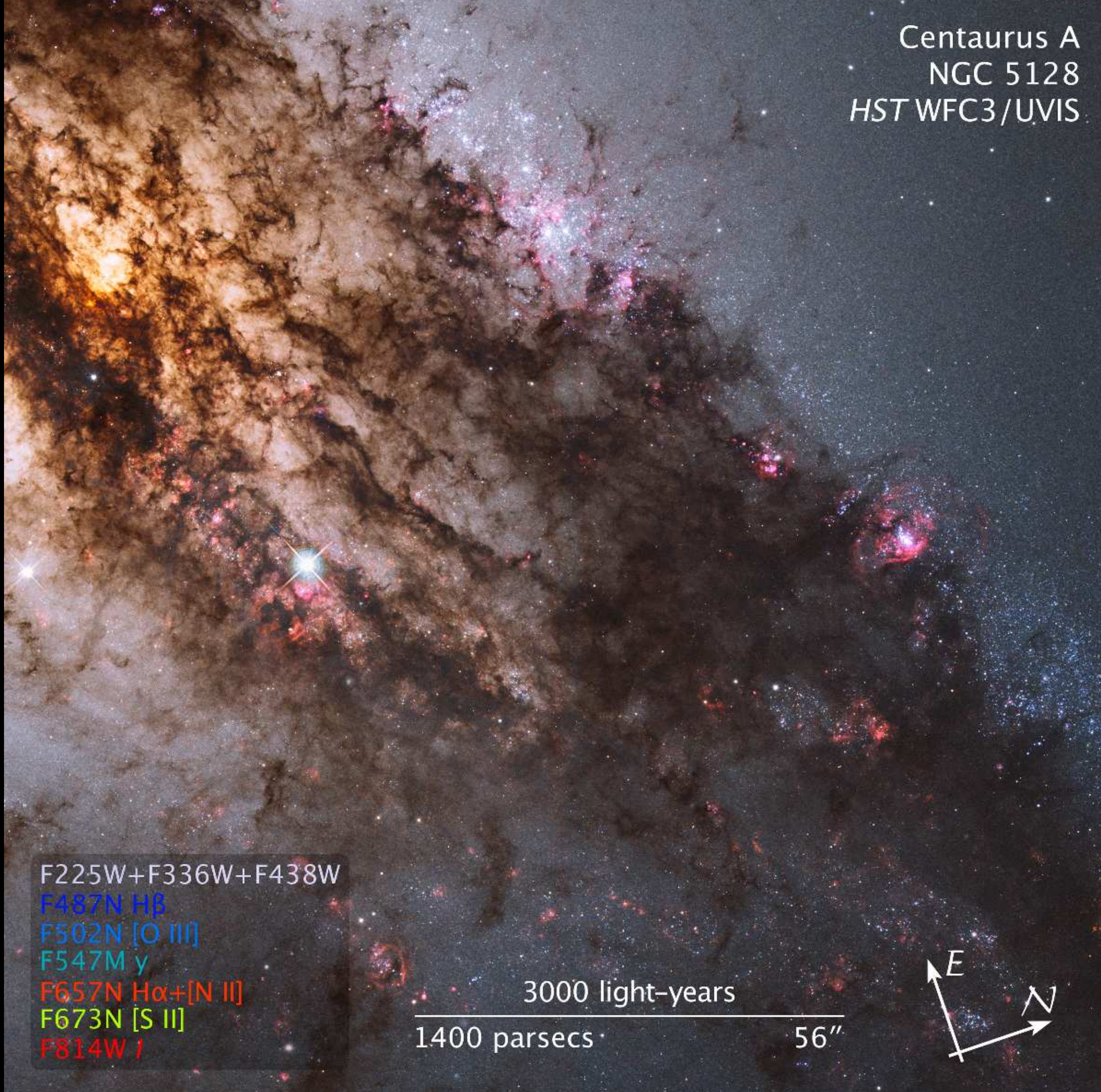
Elliptical galaxy M87 with Active Galactic Nucleus (AGN) and relativistic jet:



The danger of having Quasar-like devices too close to home ...

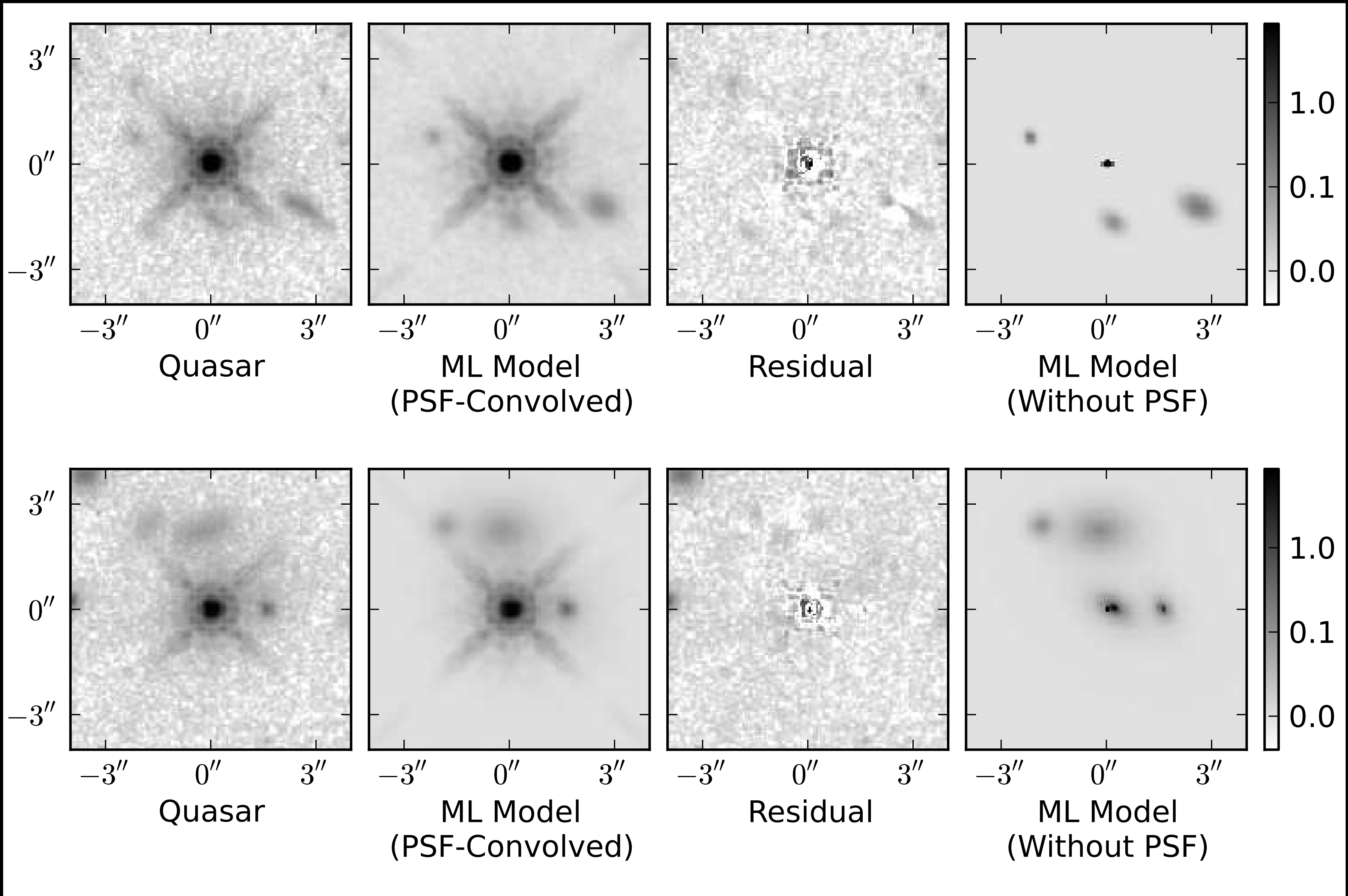
Quasar = super-hot accretion disk around supermassive black-hole (SMBH):

Luminosity $\simeq 10^{3}$ Gyxs $\simeq 10^{14}$ Suns inside 100 AU ($\simeq$Pluto's orbit)!



Centaurus A
NGC 5128
HST WFC3/UVIS
F225W+F336W+F438W
F487N Hβ
F502N [O III]
F547M y
F657N Hα+[N II]
F673N [S II]
F814W I
3000 light-years
1400 parsecs
56″
E
N

(2) WFC3 observations of quasar host galaxies at z≃2 (age=3 Gyrs)



- Very accurate point-source subtraction: WFC3 can see quasar host galaxies merging with neighbors (Mechtley, Jahnke, Windhorst et al. 2013).
- JWST Coronagraphs can do this 10–100× fainter (& for z$\lesssim$20, $\boldsymbol{\lambda}\lesssim 28\boldsymbol{\mu}$m).

- References and other sources of material shown:

http://www.asu.edu/clas/hst/www/jwst/ [Talk, Movie, Java-tool]

http://www.asu.edu/clas/hst/www/ahah/ [Hubble at Hyperspeed Java–tool]

http://www.asu.edu/clas/hst/www/jwst/clickonHUDF/ [Clickable HUDF map]

http://www.jwst.nasa.gov/ & http://www.stsci.edu/jwst/

http://ircamera.as.arizona.edu/nircam/

http://ircamera.as.arizona.edu/MIRI/

http://www.stsci.edu/jwst/instruments/nirspec/

http://www.stsci.edu/jwst/instruments/fgs

Gardner, J. P., et al. 2006, Space Science Reviews, 123, 485–606

Mather, J., & Stockman, H. 2000, Proc. SPIE Vol. 4013, 2

Windhorst, R., et al. 2008, Advances in Space Research, 41, 1965

Windhorst, R., et al., 2011, ApJS, 193, 27 (astro-ph/1005.2776)