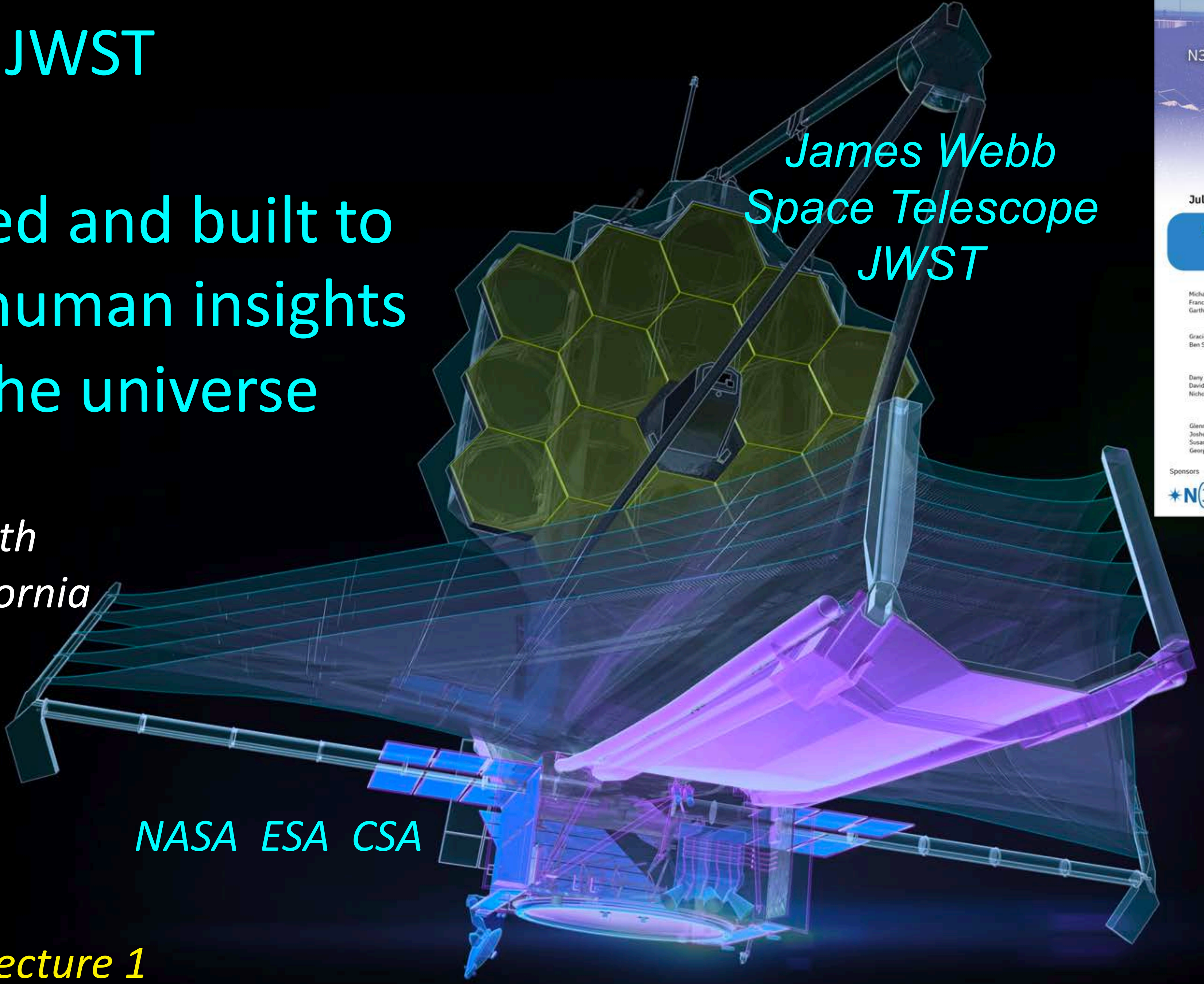
JWST

conceived and built to expand human insights into the universe

James Webb Space Telescope
JWST

Garth Illingworth
University of California Santa Cruz



NASA ESA CSA

N3AS Lecture 1

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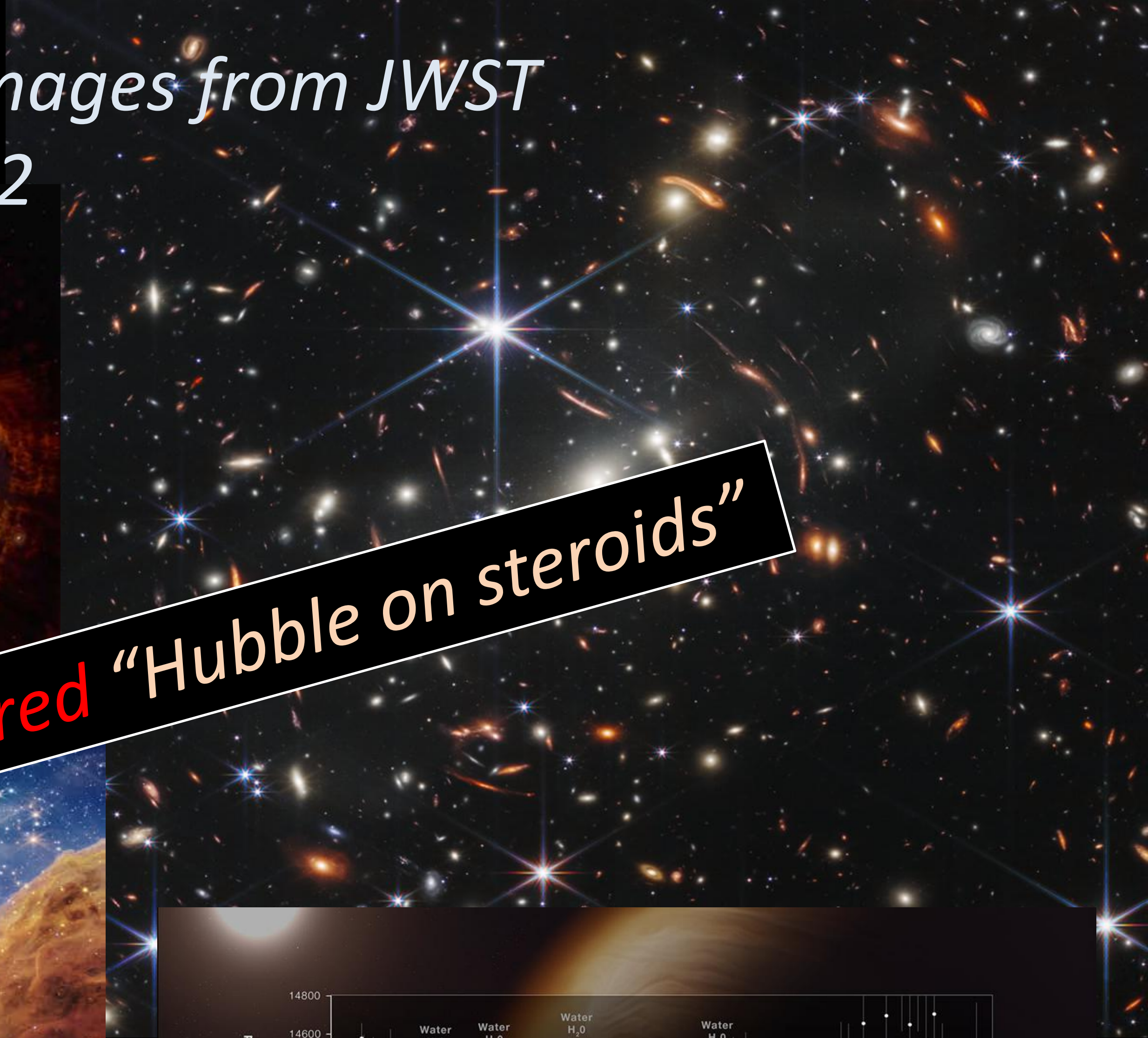
Q?

please ask questions anytime during the talk

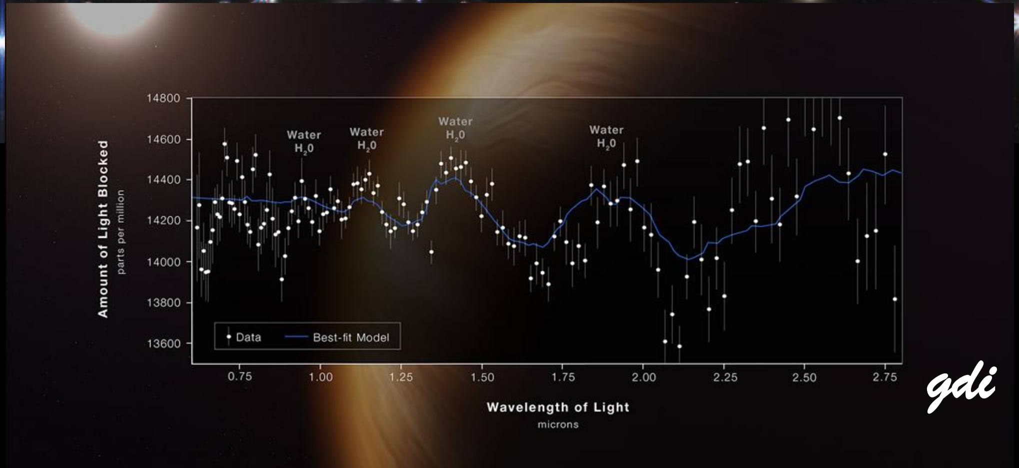
and particularly at the breaks labeled "Q?"

the first amazing science images from JWST

July 12 2022



JWST (“Webb”) is our infrared “Hubble on steroids”



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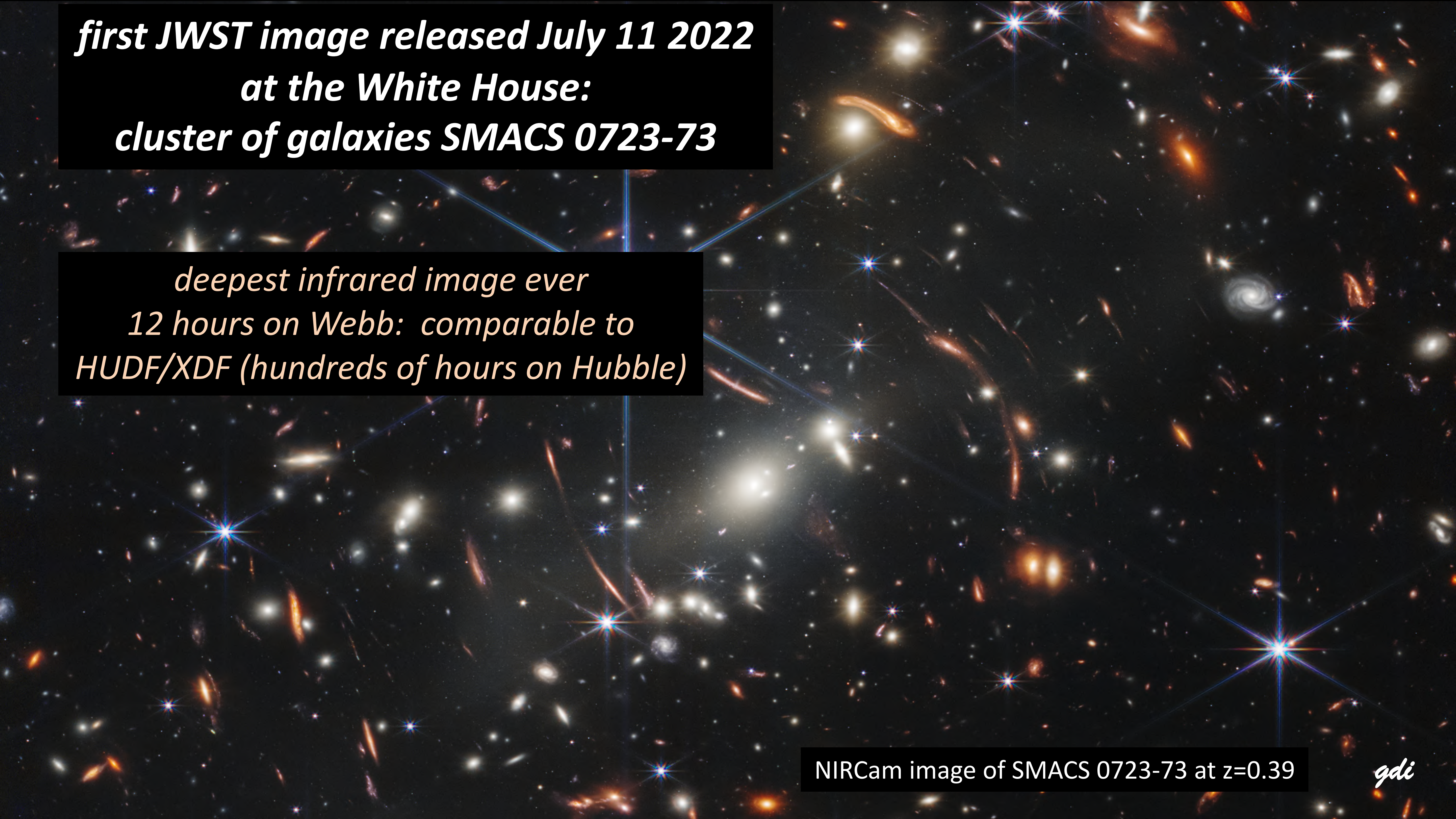
first JWST image released July 11 2022 at the White House: cluster of galaxies SMACS 0723-73

deepest infrared image ever
12 hours on Webb: comparable to HUDF/XDF (hundreds of hours on Hubble)



NIRCam image of SMACS 0723-73 at z=0.39

launch Christmas Day 2021   *first image release July 12 2022*

- *what is JWST*
- *the lead up to launch, launch, and then commissioning*
- *how NGST/JWST came about*
- *the science goals of NGST/ JWST*
- *the challenges of building our "Origins" telescope*
- *the first year of images and science results (Monday)*

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what is JWST?

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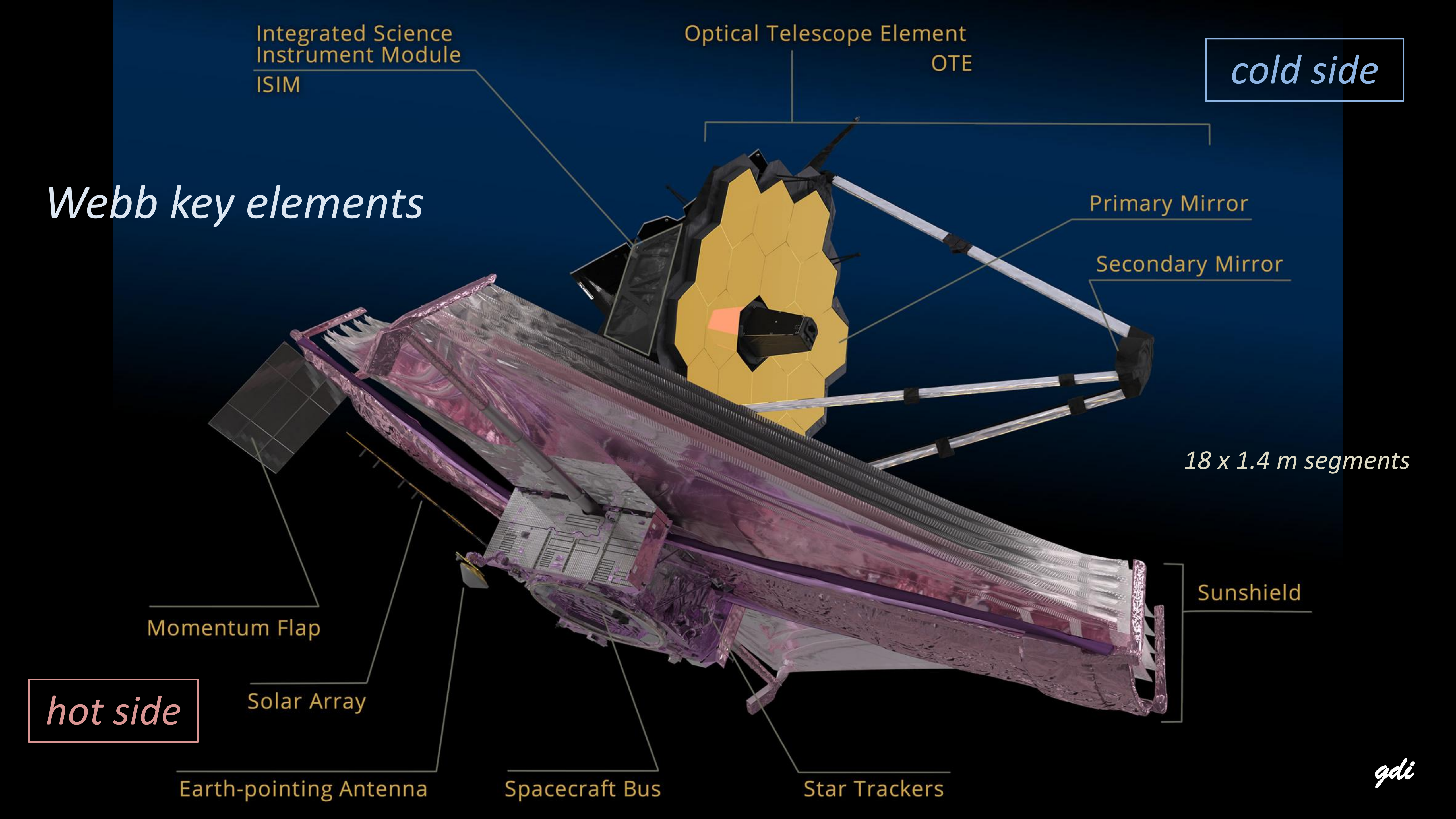
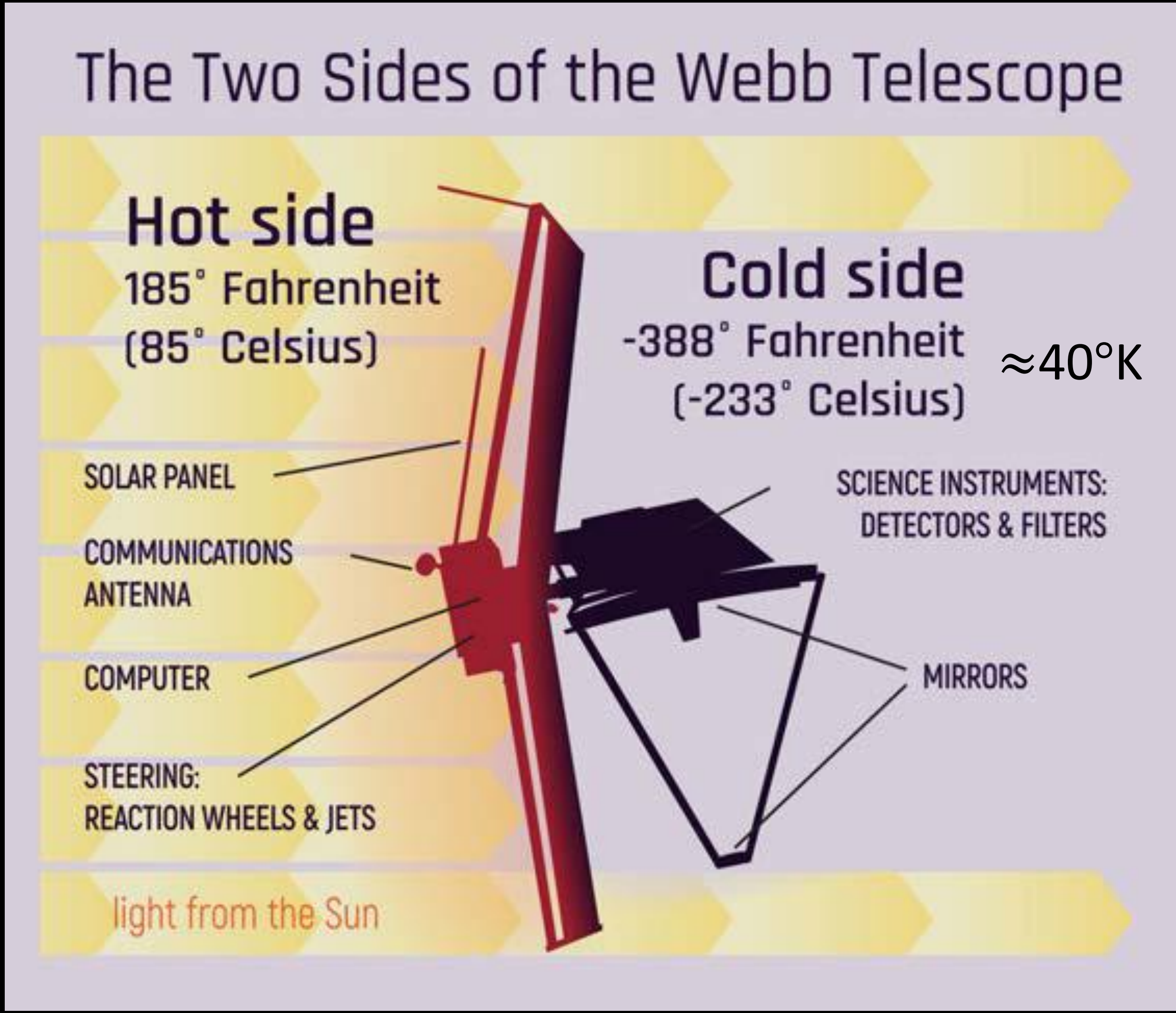
Webb key elements



Hot Side ⇔ Cold Side



≈40°K

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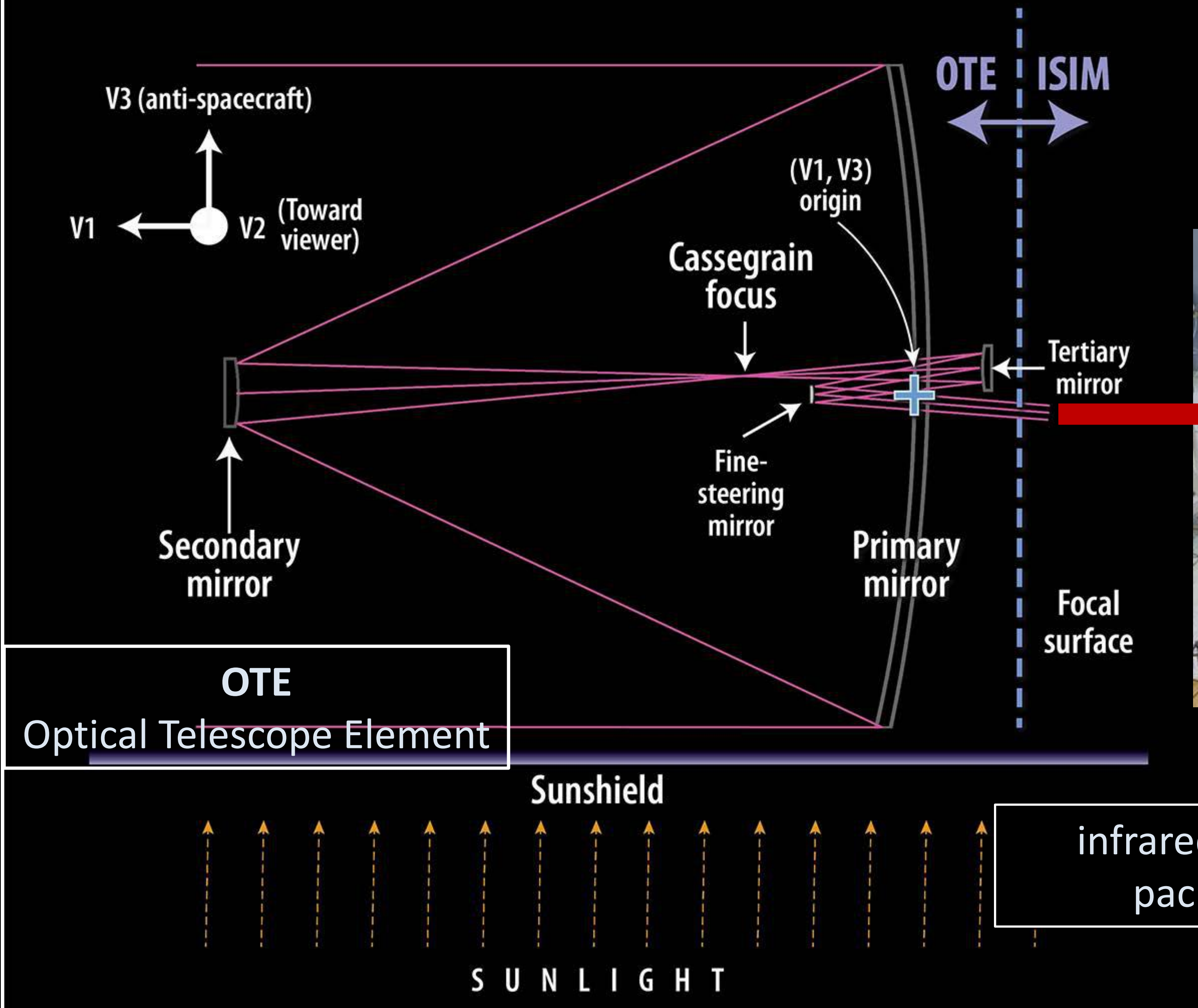
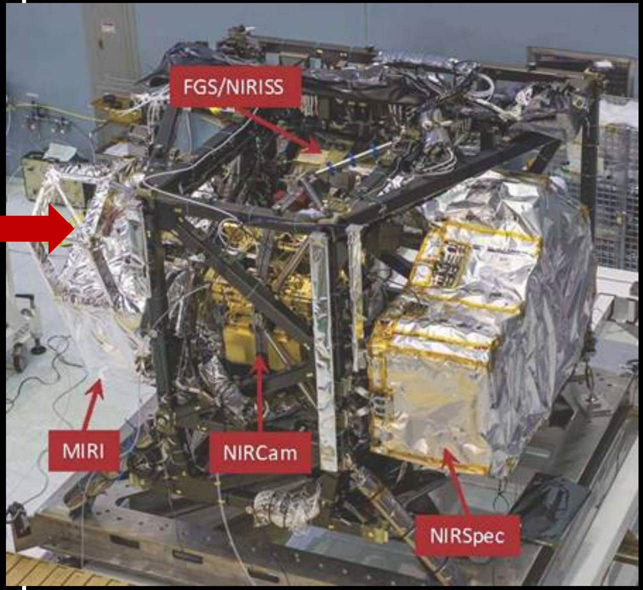
Webb light-path schematic



OTE
Optical Telescope Element

ISIM
Integrated Science Instrument Module



infrared light feeds into the science instrument package of 4 cameras and spectrographs

both OTE and ISIM are very cold ≈40°K

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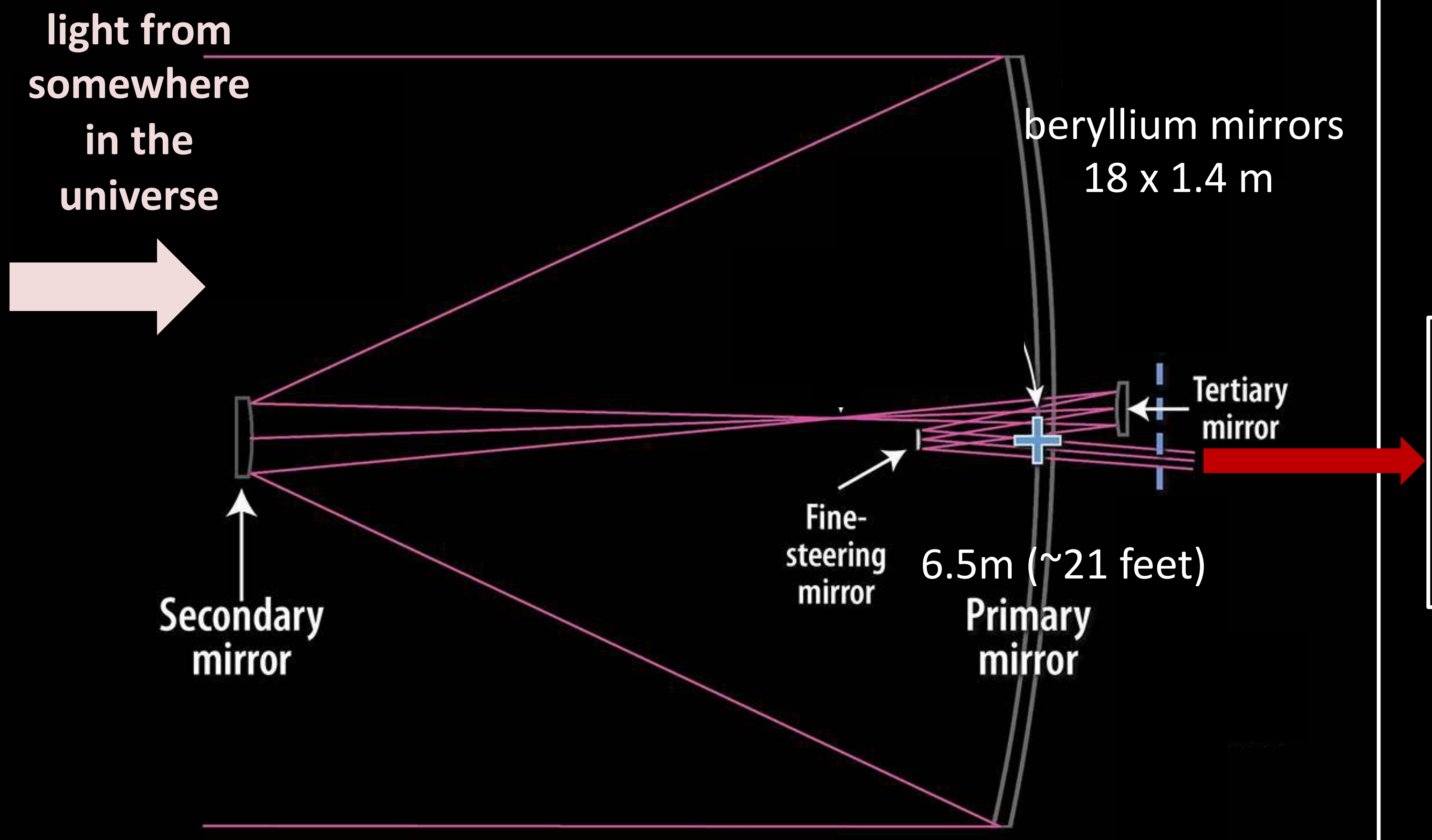
Webb light-path schematic



Korsch three-mirror anastigmat

polished at room temperature but required to have tens of nanometers surface figure errors at 40°K

ISIM

infrared instrument module

all nominal 1-5μm – except MIRI is 5-20μm

NIRCam	Near-Infrared Camera
FGS/NIRISS	Fine Guidance Sensor/ Near-InfraRed Imager and Slitless Spectrograph
NIRSpec	Near-Infrared Spectrograph
MIRI	Mid-Infrared Instrument

a Korsch anastigmat is corrected for spherical aberration, coma, astigmatism

and has a wide field of view in the focal plane with excellent image quality

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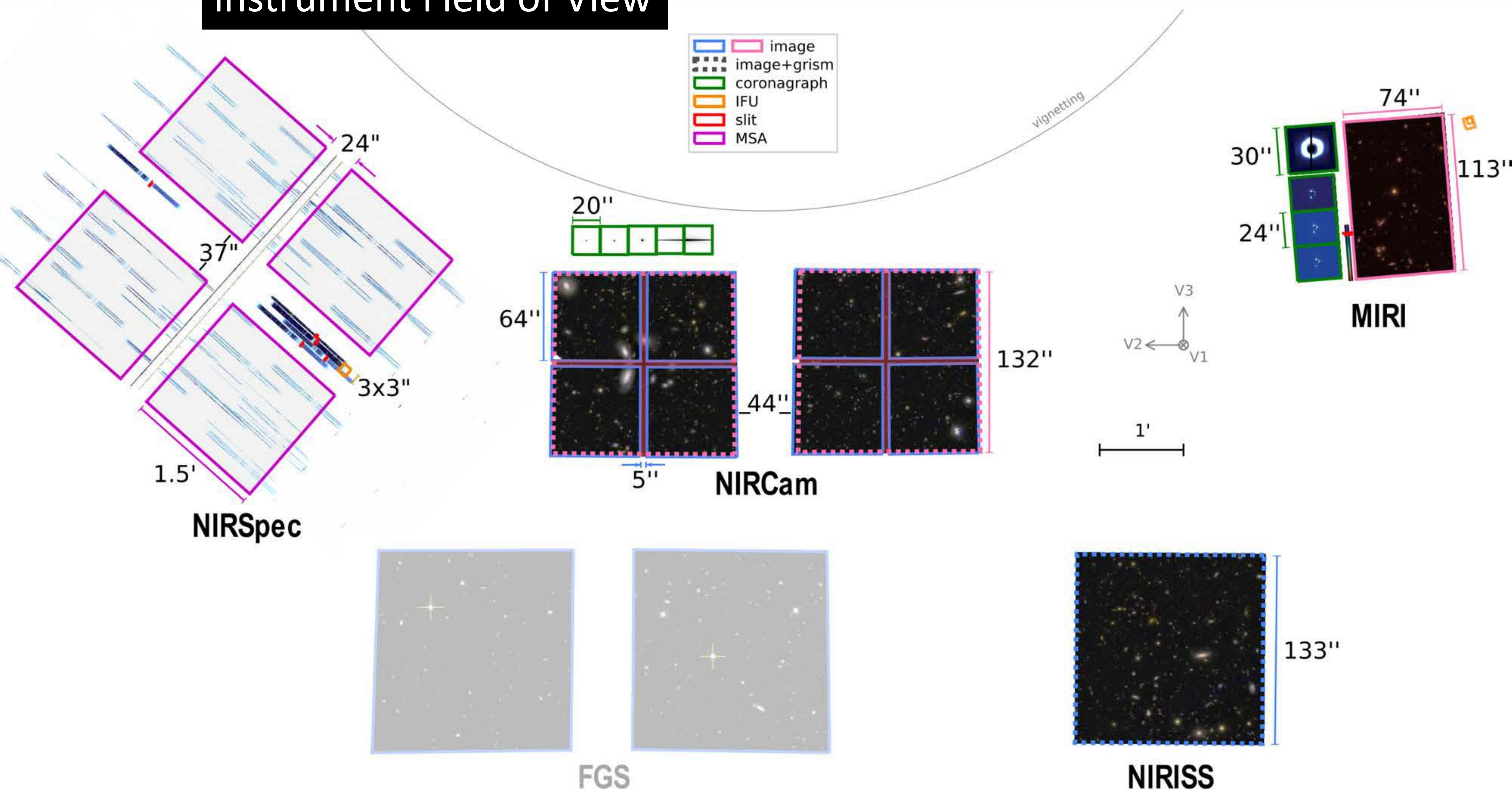
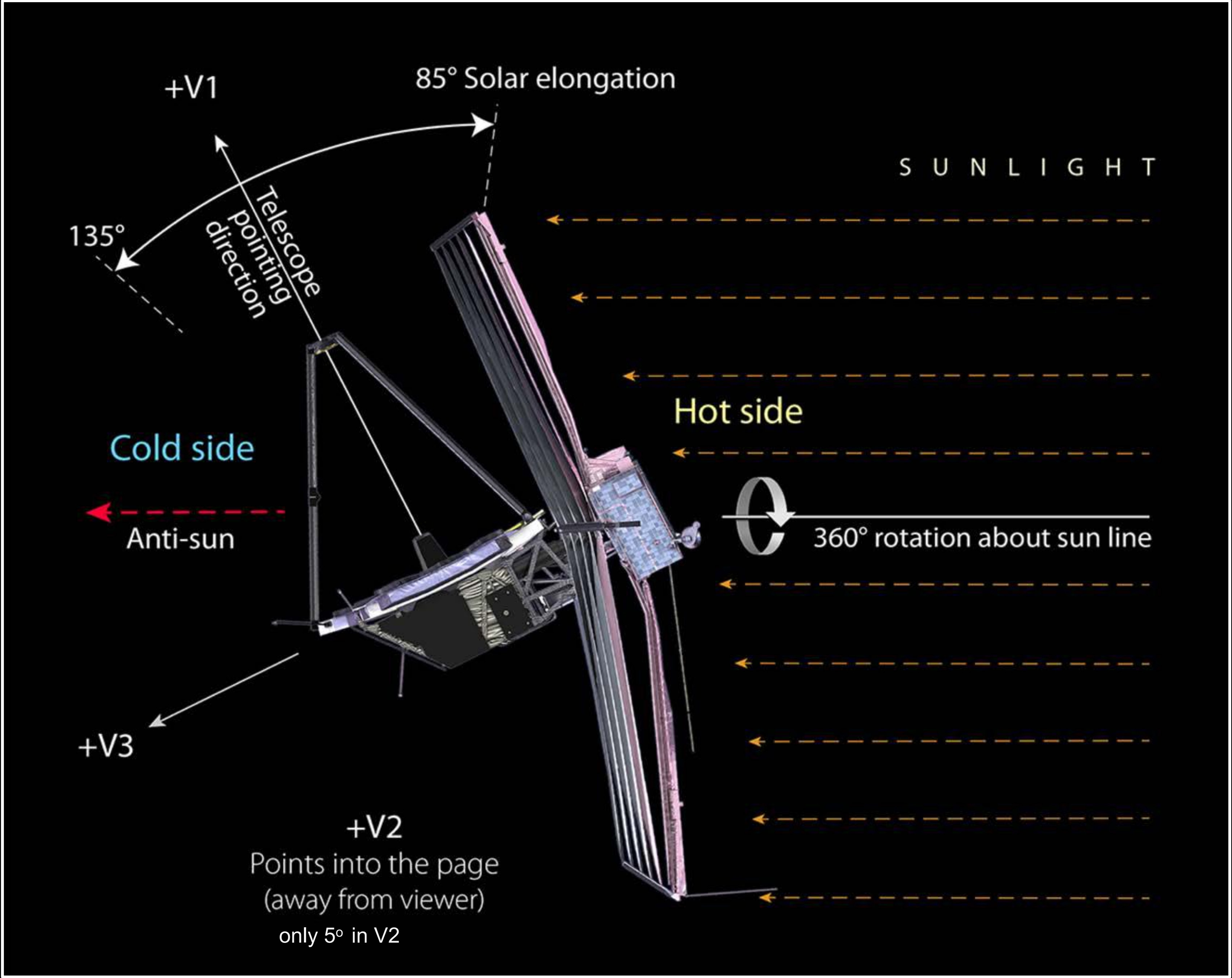
instrument Field of View





Webb orientation limits

how does Webb see anywhere in the sky?

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Q?

the lead-up to Launch

on Dec 25 2021 0720

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Webb's last sunshield deployment at Northrop Grumman

August 2021 – Webb folded up ready to leave Northrop

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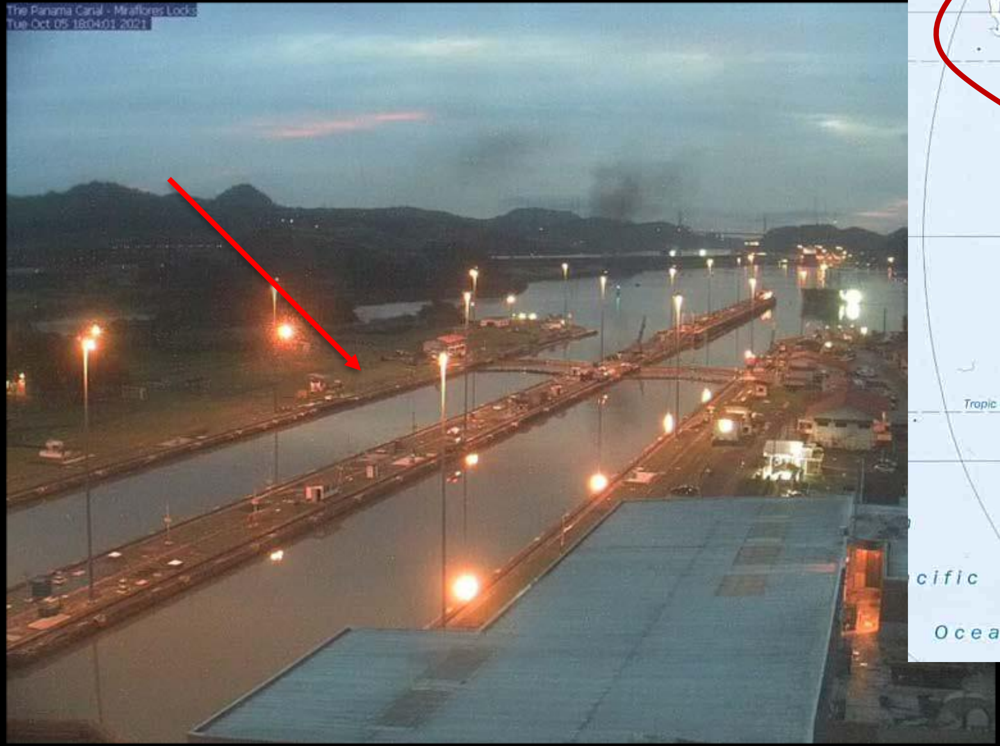
shipping Webb from Northrop in LA to Kourou French Guiana

loading MN Colibri in Los Angeles

going through the Panama Canal



MN Colibri arriving in Kourou

Webb in Kourou

loading propellant for Webb's 12 thrusters

170 kg of hydrazine
130 kg of dinitrogen tetroxide

Webb being lifted into position onto the rocket

Ariane 5 fairing being put over Webb

Ariane 5 with Webb being towed out of the vehicle assembly building

$10B Webb ready to go at the pad

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launch day cookies at Space Telescope Science Institute – home of Mission Control

Ariane 5 + Webb launch of JWST
Christmas Day Dec 25 2021 0720

absolutely flawless Ariane 5 launch

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[JWST drifting away after release from the upper stage](https://www.youtube.com/watch?v=dRqHlta6lr8)

~10 s after release

https://www.youtube.com/watch?v=dRqHlta6lr8

Credit Arianespace, ESA

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VIKKI camera video from Ariane 5 upper stage (first time camera used)

Q?

deployments and commissioning

the 6 months from Dec 25 2021

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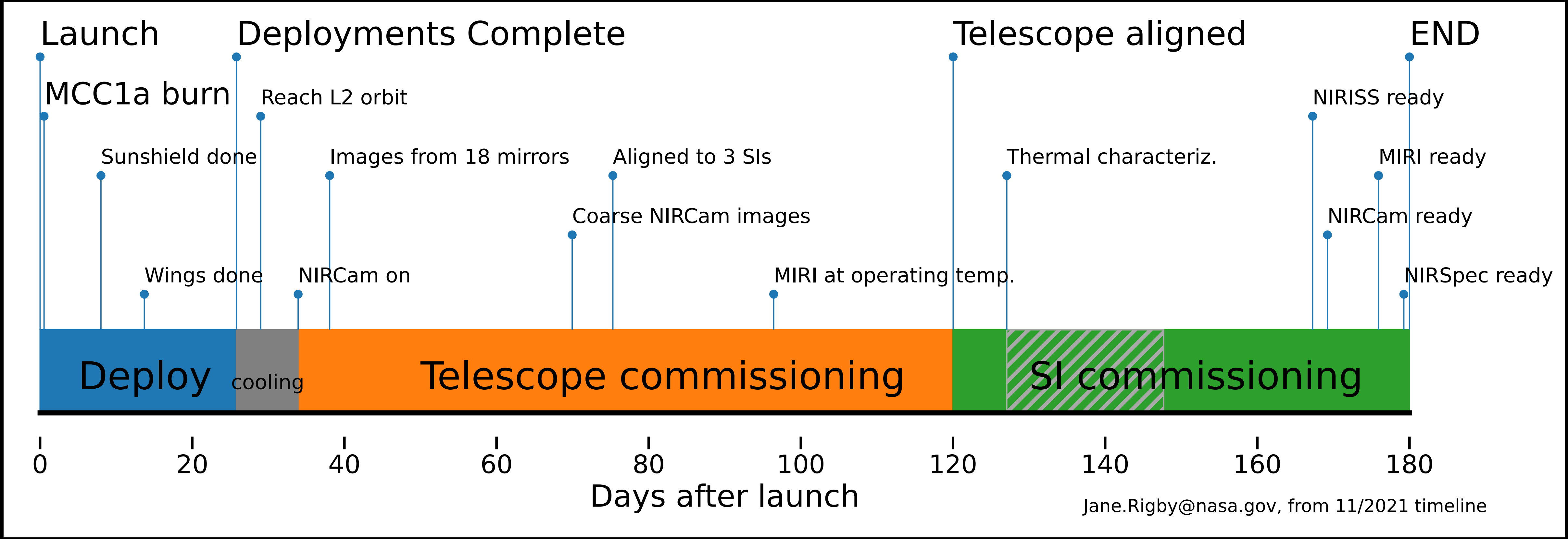
Commissioning Timeline



the commissioning activity sequence timeline was scripted with 730 high-level activities, with nearly 10,000 steps, of which roughly 7000 remained after deployments, mostly for the telescope!

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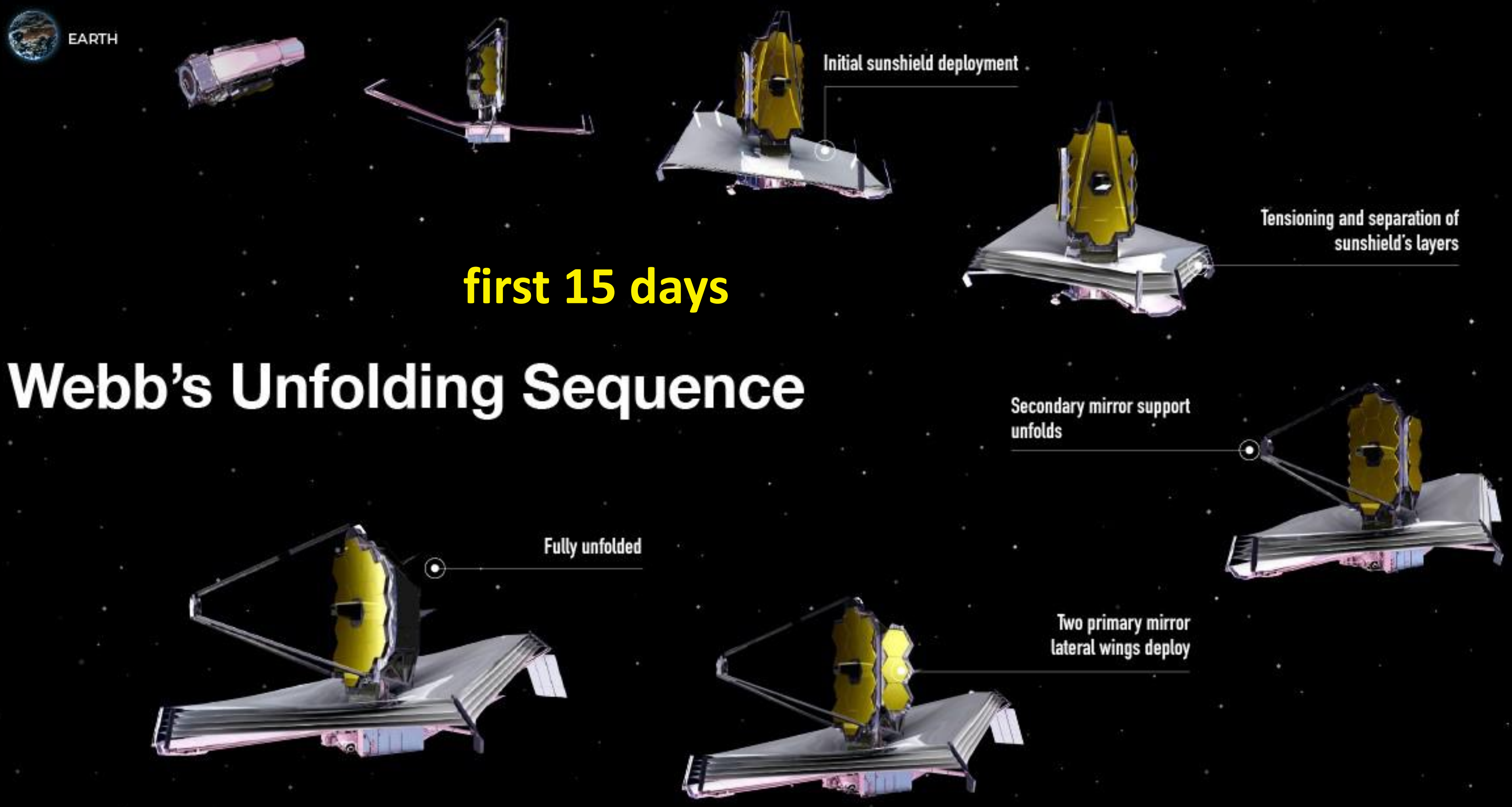
first 15 days
Webb's Unfolding Sequence
EARTH
Initial sunshield deployment
Tensioning and separation of sunshield's layers
Secondary mirror support unfolds
Two primary mirror lateral wings deploy
Fully unfolded

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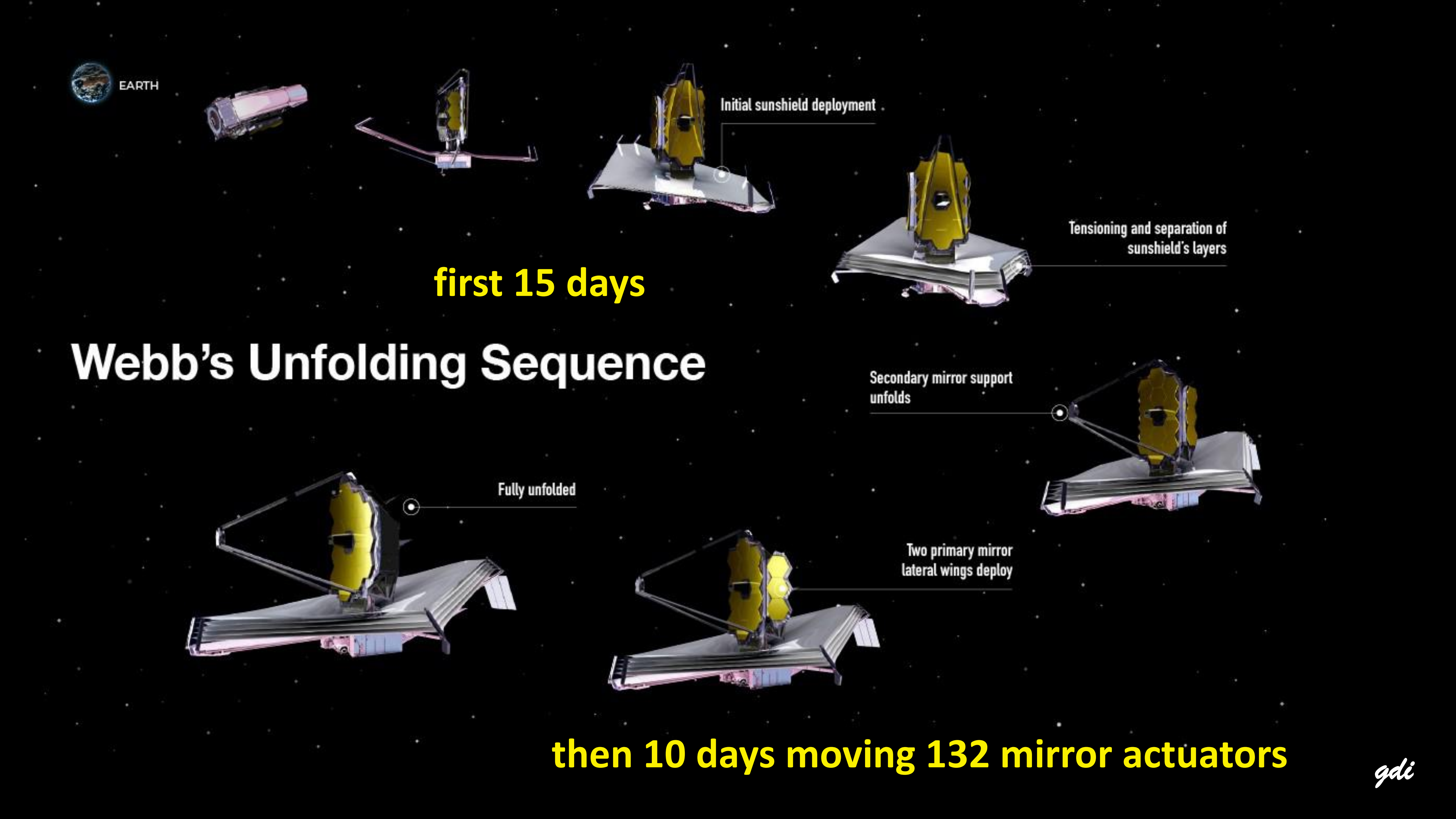
EARTH
Initial sunshield deployment
first 15 days
Tensioning and separation of sunshield's layers
Webb's Unfolding Sequence
Secondary mirror support unfolds
Fully unfolded
Two primary mirror lateral wings deploy
then 10 days moving 132 mirror actuators
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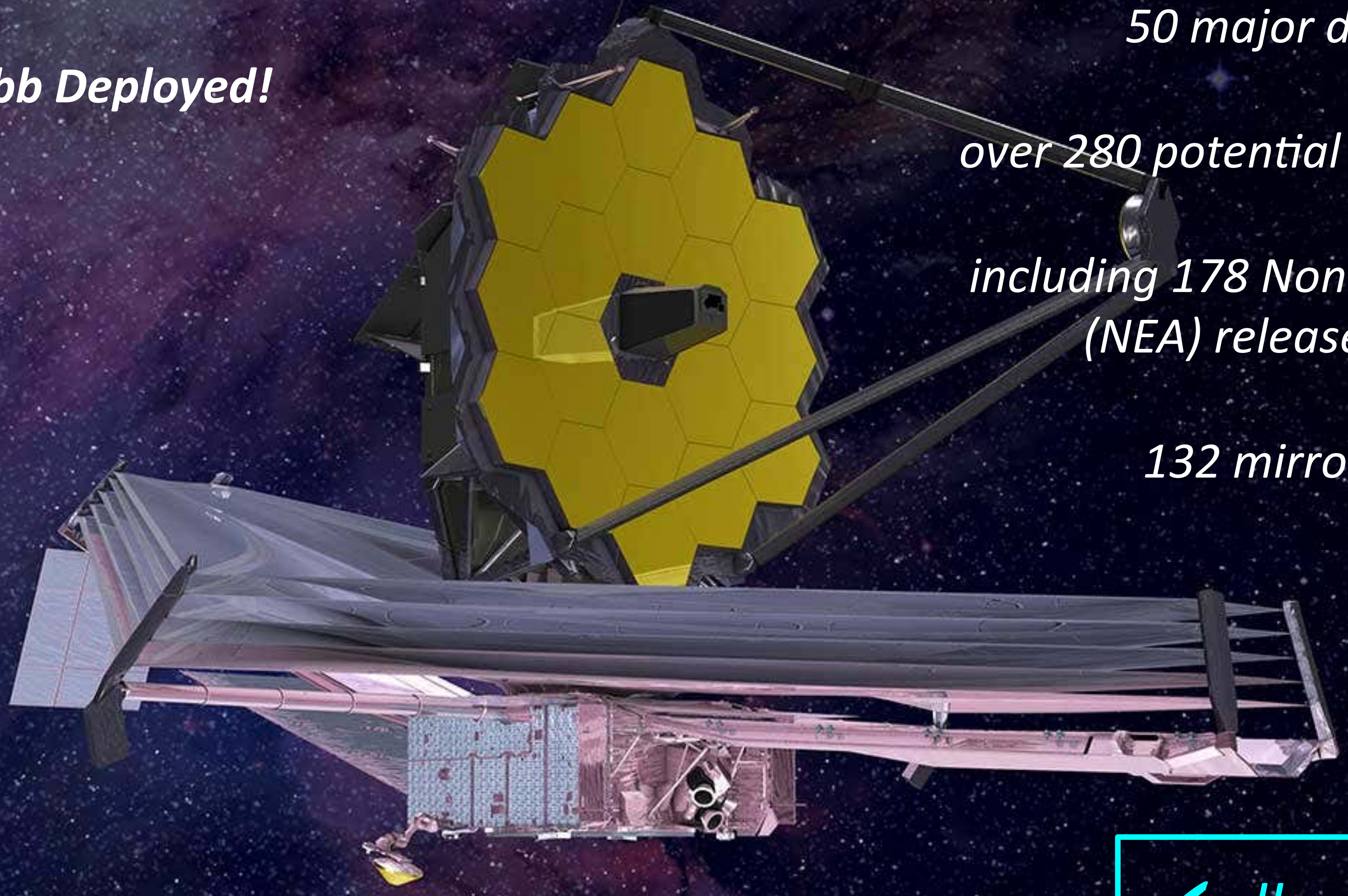
Webb Deployed!



50 major deployments

over 280 potential single point failures

including 178 Non-Explosive Actuator (NEA) release mechanisms

132 mirror actuators

✔ all worked ✔

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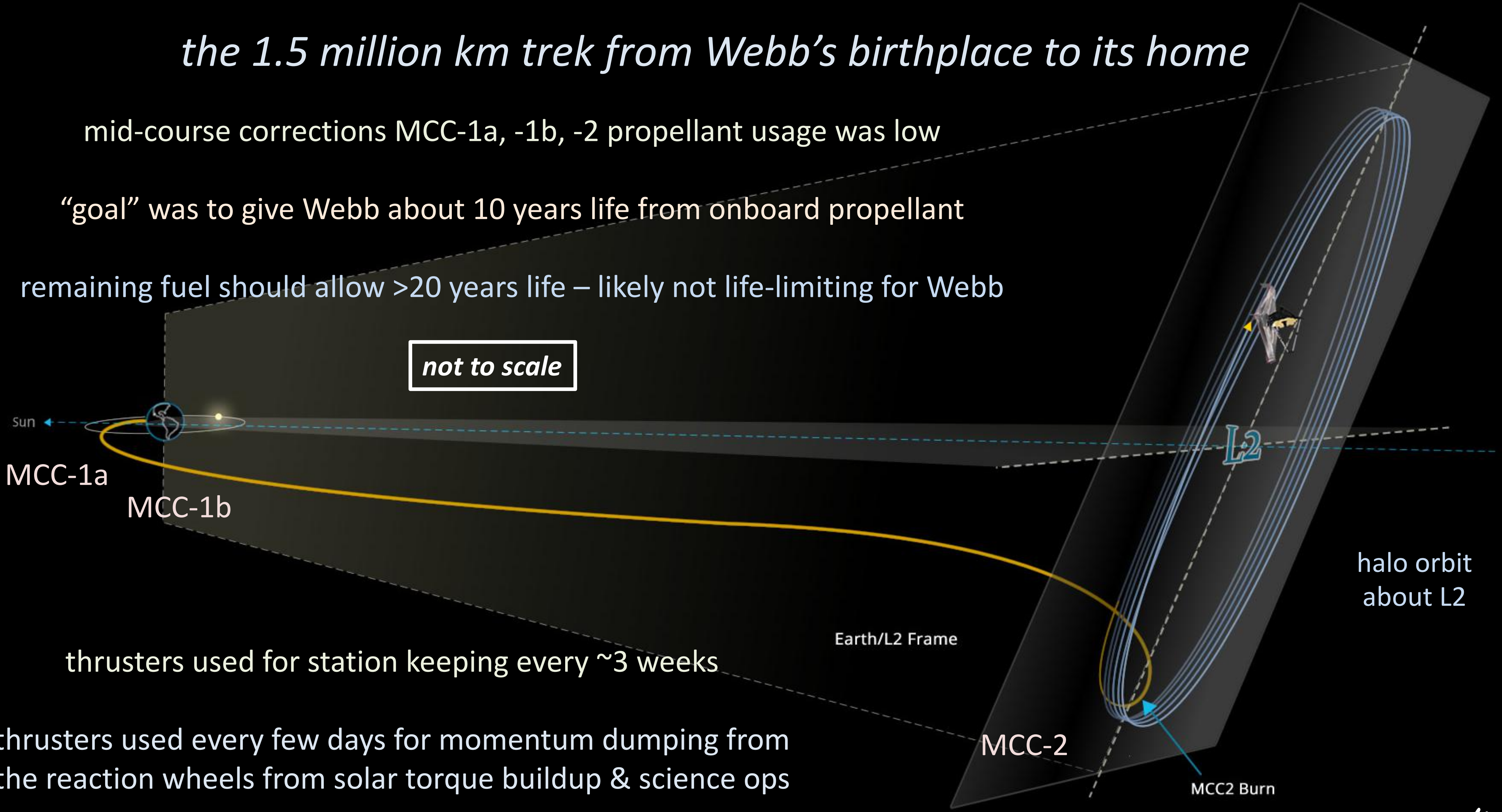
the 1.5 million km trek from Webb's birthplace to its home

mid-course corrections MCC-1a, -1b, -2 propellant usage was low

"goal" was to give Webb about 10 years life from onboard propellant

remaining fuel should allow >20 years life – likely not life-limiting for Webb

not to scale



thrusters used for station keeping every ~3 weeks

thrusters used every few days for momentum dumping from the reaction wheels from solar torque buildup & science ops

Credit: Steve Sabia/NASA Goddard

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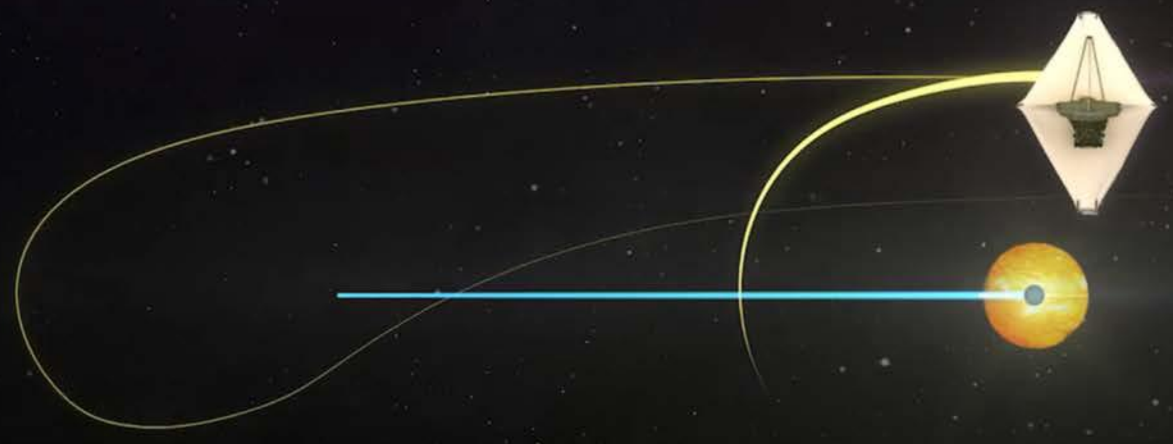
cute animation showing Webb doing its yearly dance in L2



this video (as in next slide):
https://www.youtube.com/watch?v=6cUe4oMk69E

annotated discussion and video about L2
https://www.youtube.com/watch?v=mt3xbJxdO8E

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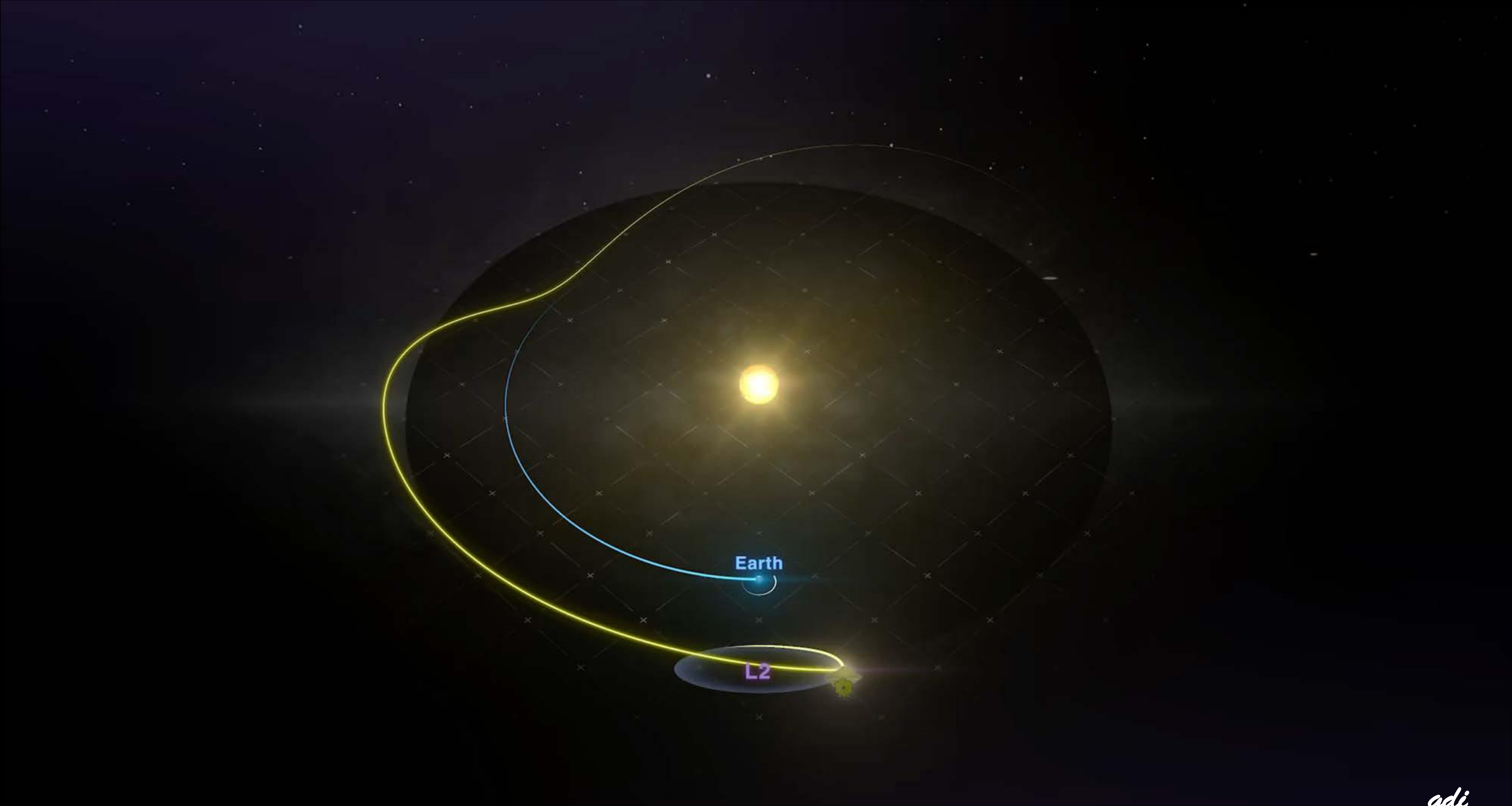

animation showing JWST doing its yearly dance in L2

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sunshield:
1,000,000 SPF

reduces 200,000 watts
(~10 large houses!)

Sun side

to a fraction of a watt
(tiny LED flashlight)

hot side
50 – 200ºF

cold side
≈40ºK
–400ºF

the 3K (6K?) universe is a pretty-good refrigerator

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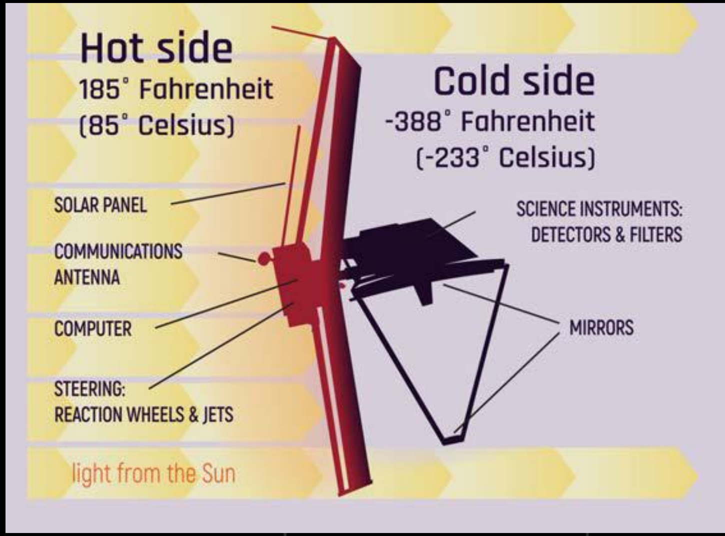
Hot Side ⇔ Cold Side



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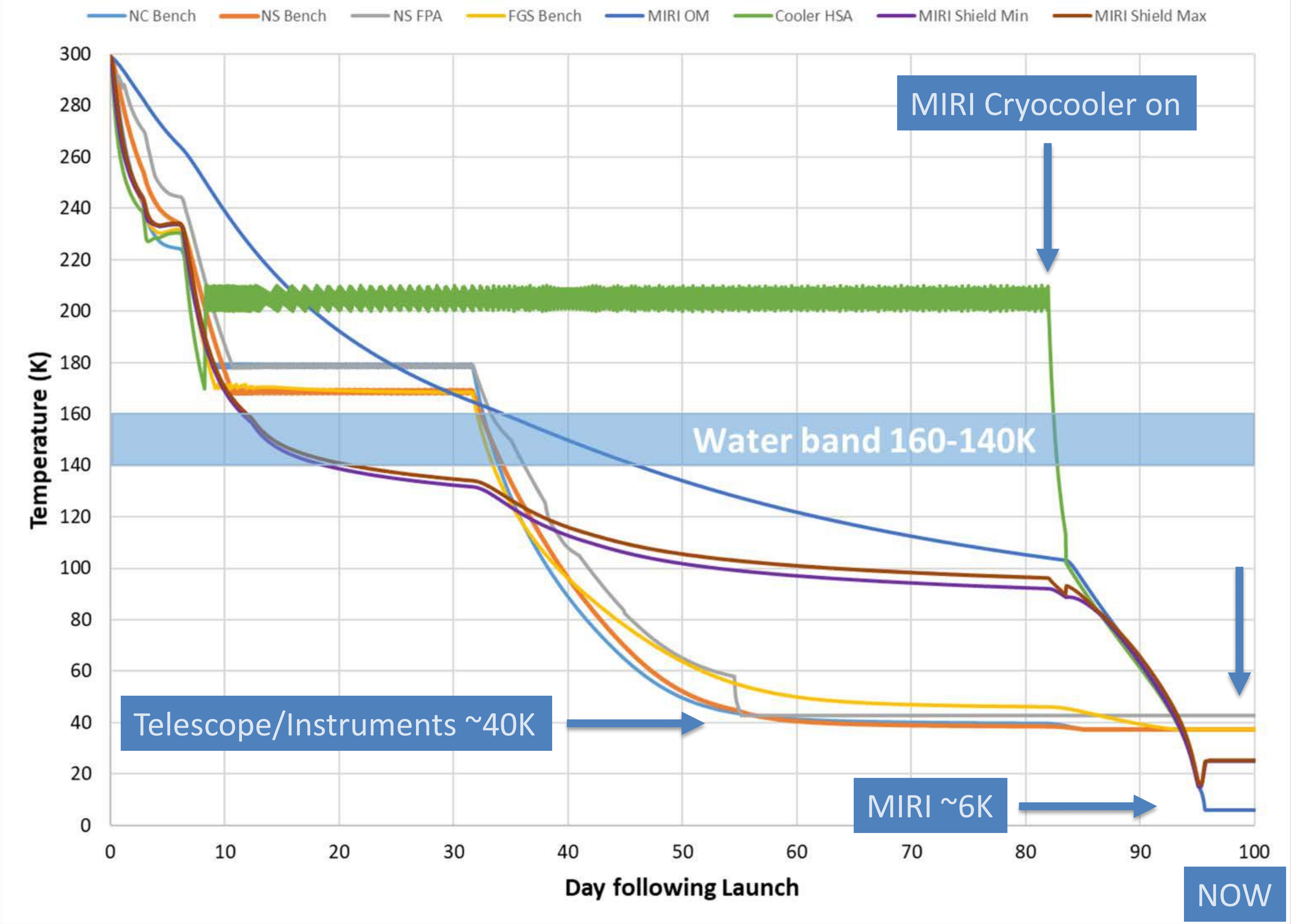

cooling profile

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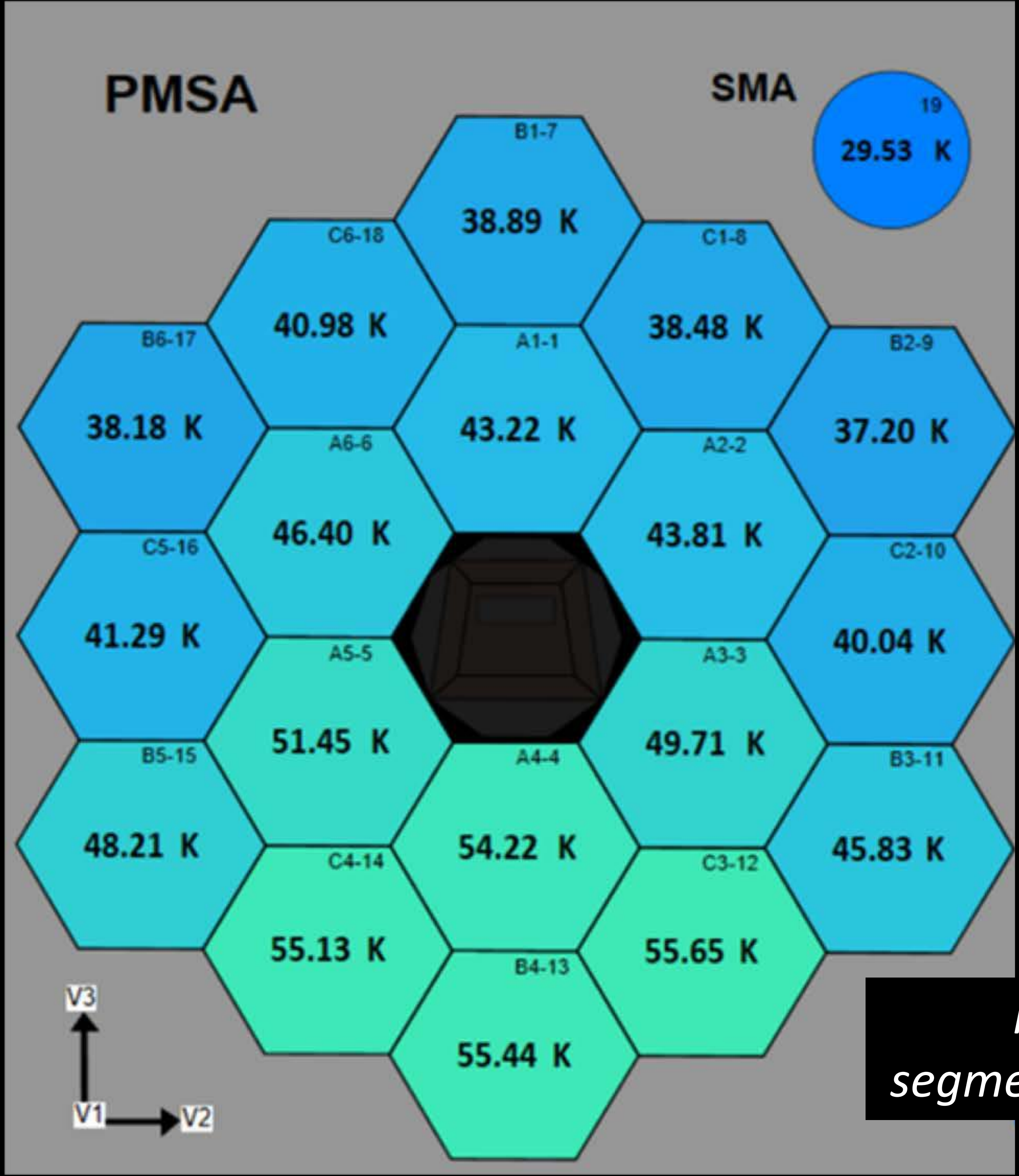

primary and secondary mirror temperatures

range of temperatures was expected, and does not affect optical performance (beryllium mirrors)

mid March 2022
segments ~1-2 K cooler now

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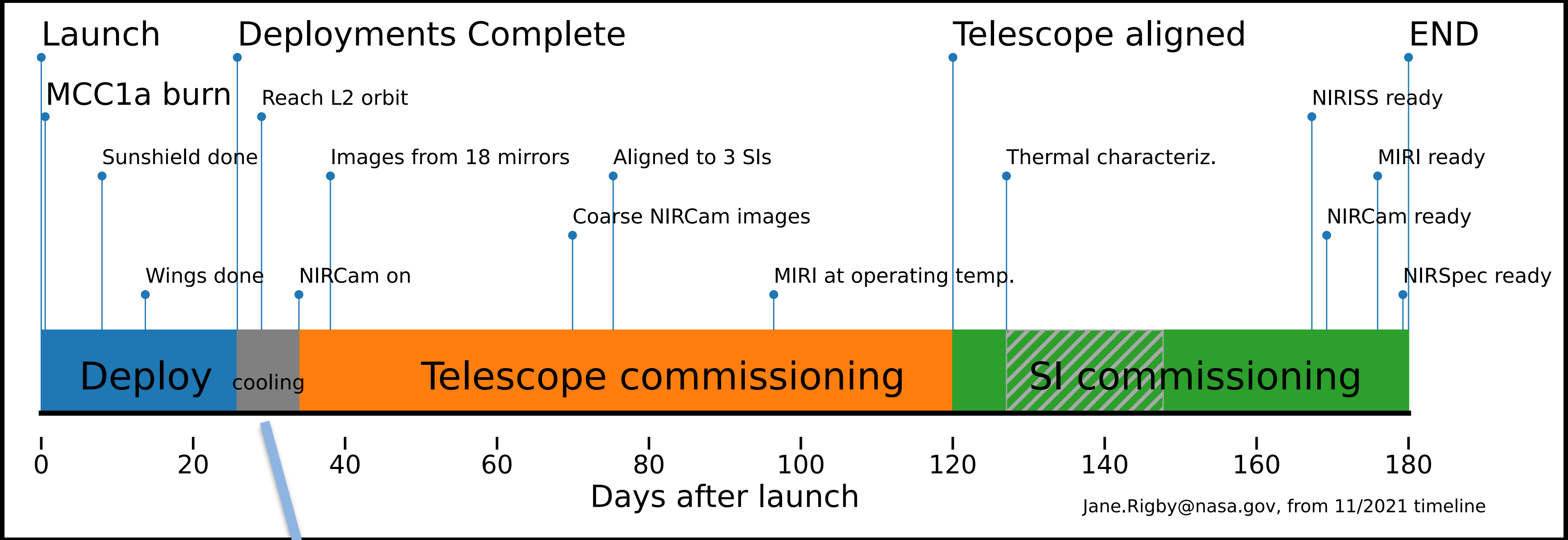

Commissioning Timeline

the commissioning activity sequence timeline was scripted with 730 high-level activities, with nearly 10,000 steps, of which roughly 7000 remained after deployments, mostly for the telescope!

after deployment and insertion into L2:

- ✶ *fine tuning of optics*
- ✶ *instrument checkout*
- ✶ *first science images*

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6 months: steps for telescope (optics) commissioning

Telescope Commissioning Stage	Goal
Segment Deployments	release segments from launch positions and nominal deploy
Segment Image Identification	determine segment positions and telescope boresight
Segment alignment	minimize wavefront error within each segment
Image Stacking	overlaps the 18 individual segment PSFs
Coarse Phasing	aligns segments within a wavelength
Fine Phasing	aligns segments to fraction of a wavelength
Telescope alignment over field of view	achieves good alignment seen from all SIs
Iterate alignment for final correction	repeat process as needed to iterate to convergence
Thermal Stability Assessment	characterization of on-orbit stability
Monitoring and Maintenance	ensures alignment over time

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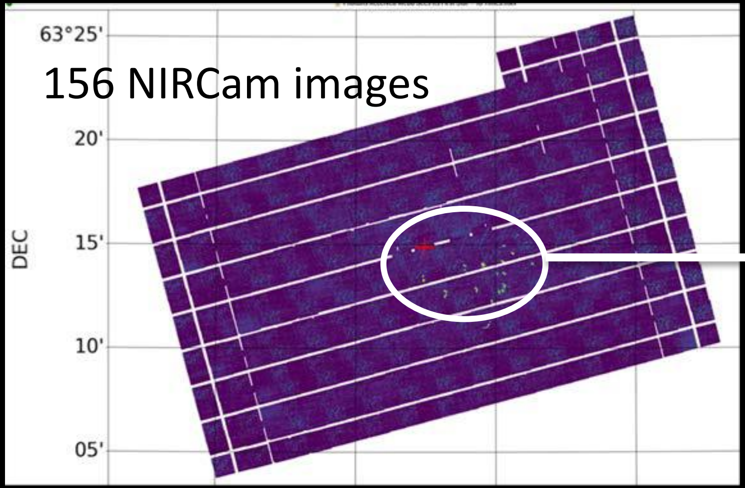
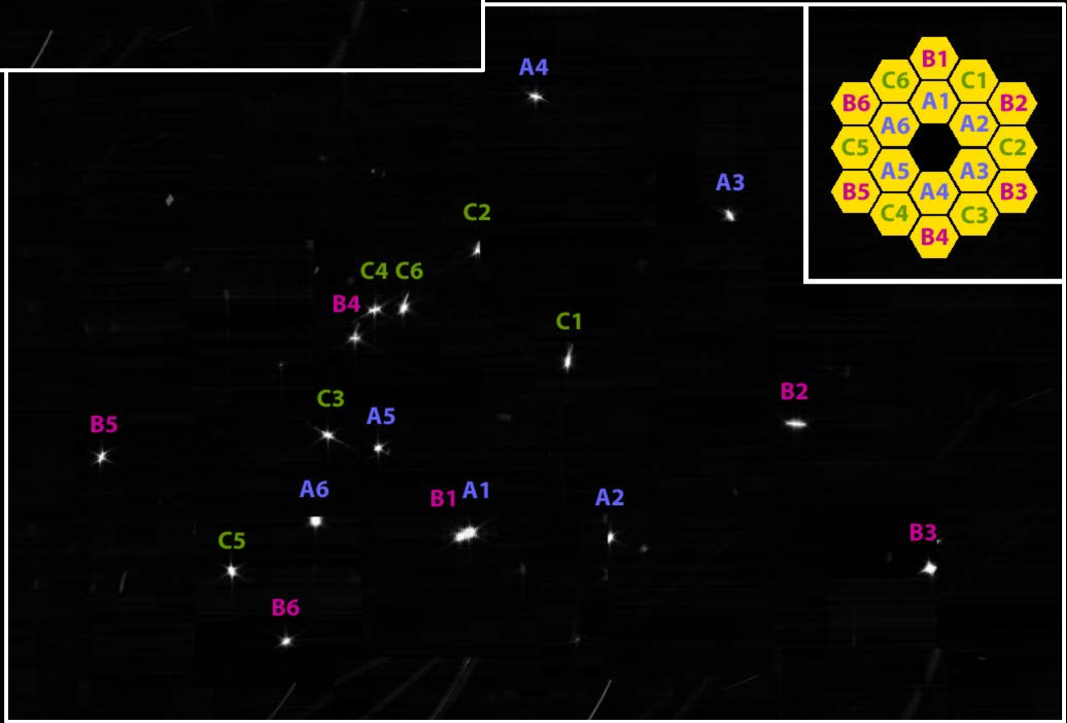


February 11 Media Headline: "Photons Received: Webb Sees Its First Star – 18 Times"

selfie (pupil) image from NIRCam

HD84406
G5
6.94 mag
75 pc
Ursa Major



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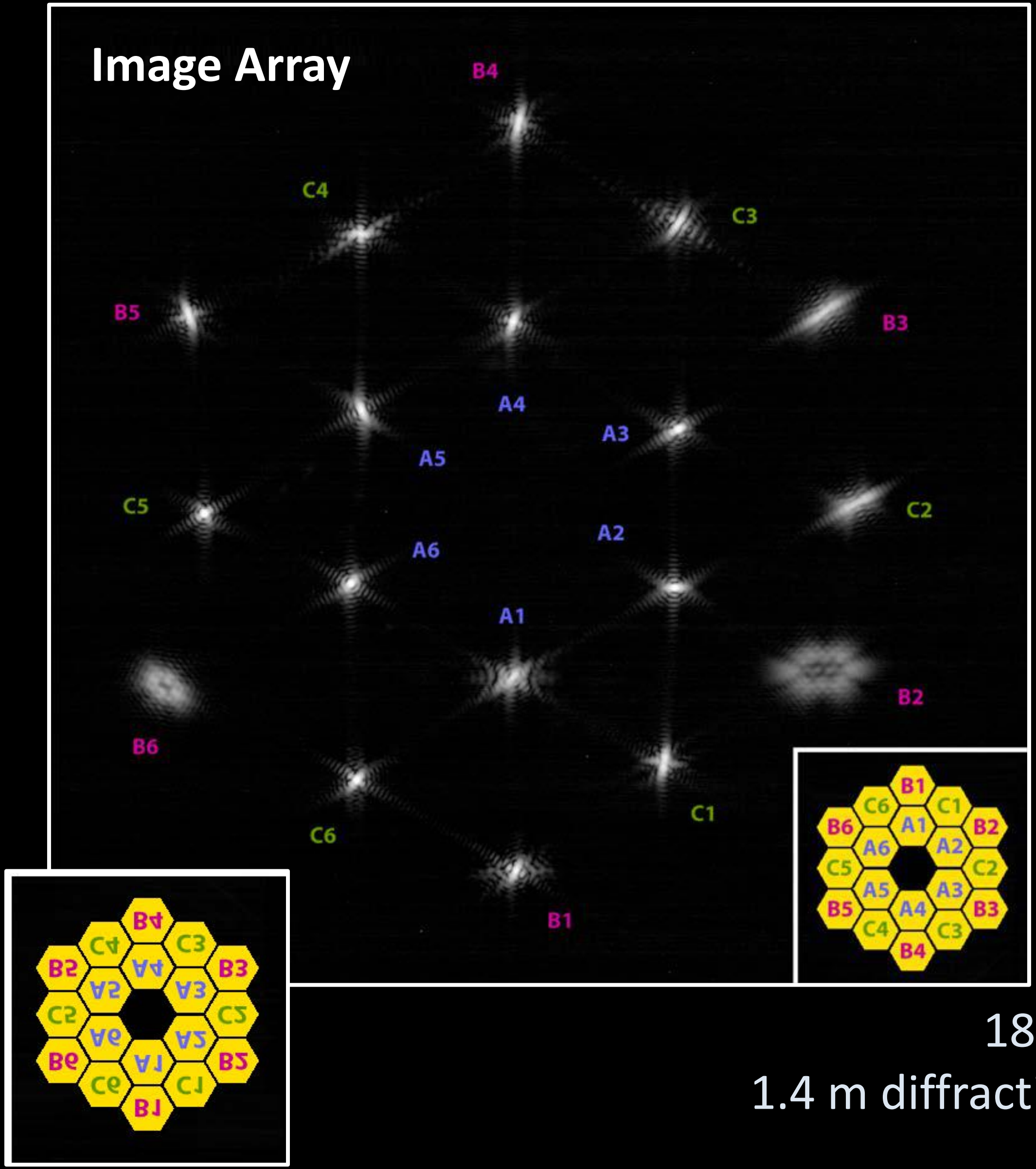
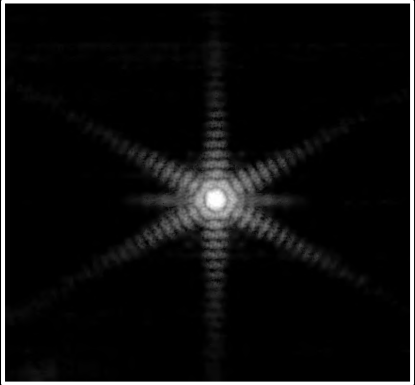
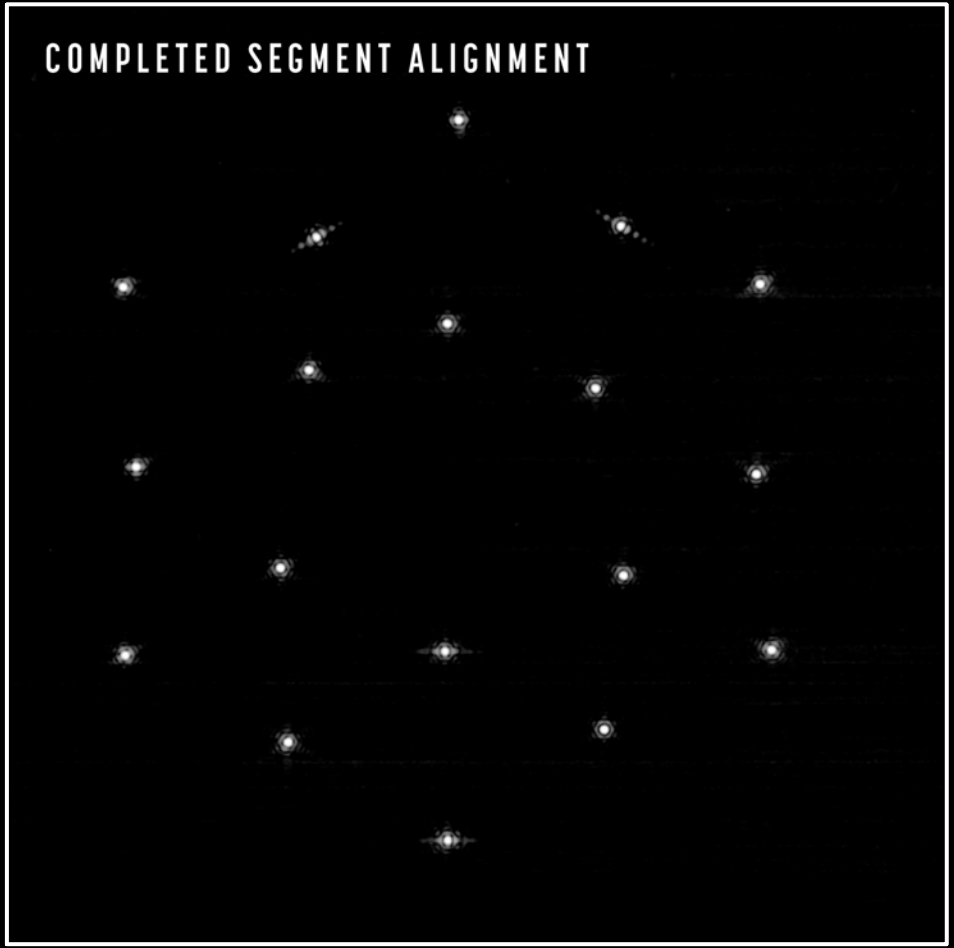
February 18 – 18 segment image array

February 25 – 18 segment alignment and stacked image



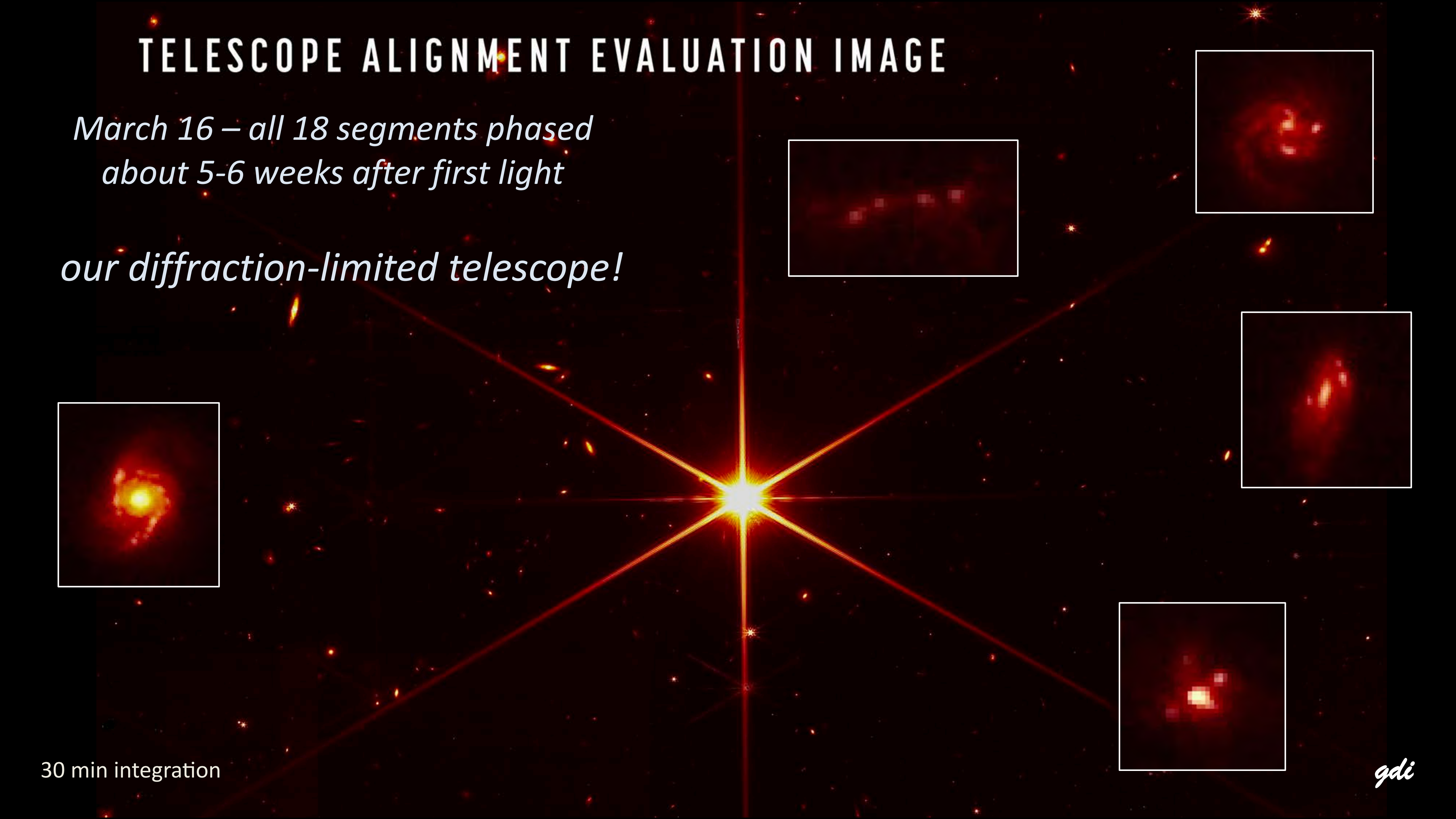




stacked (but not phased) image

18 separate 1.4 m mirror images aligned

1.4 m diffraction-limited – but will be 5X sharper when phased


TELESCOPE ALIGNMENT EVALUATION IMAGE
March 16 – all 18 segments phased
about 5-6 weeks after first light
our diffraction-limited telescope!
30 min integration
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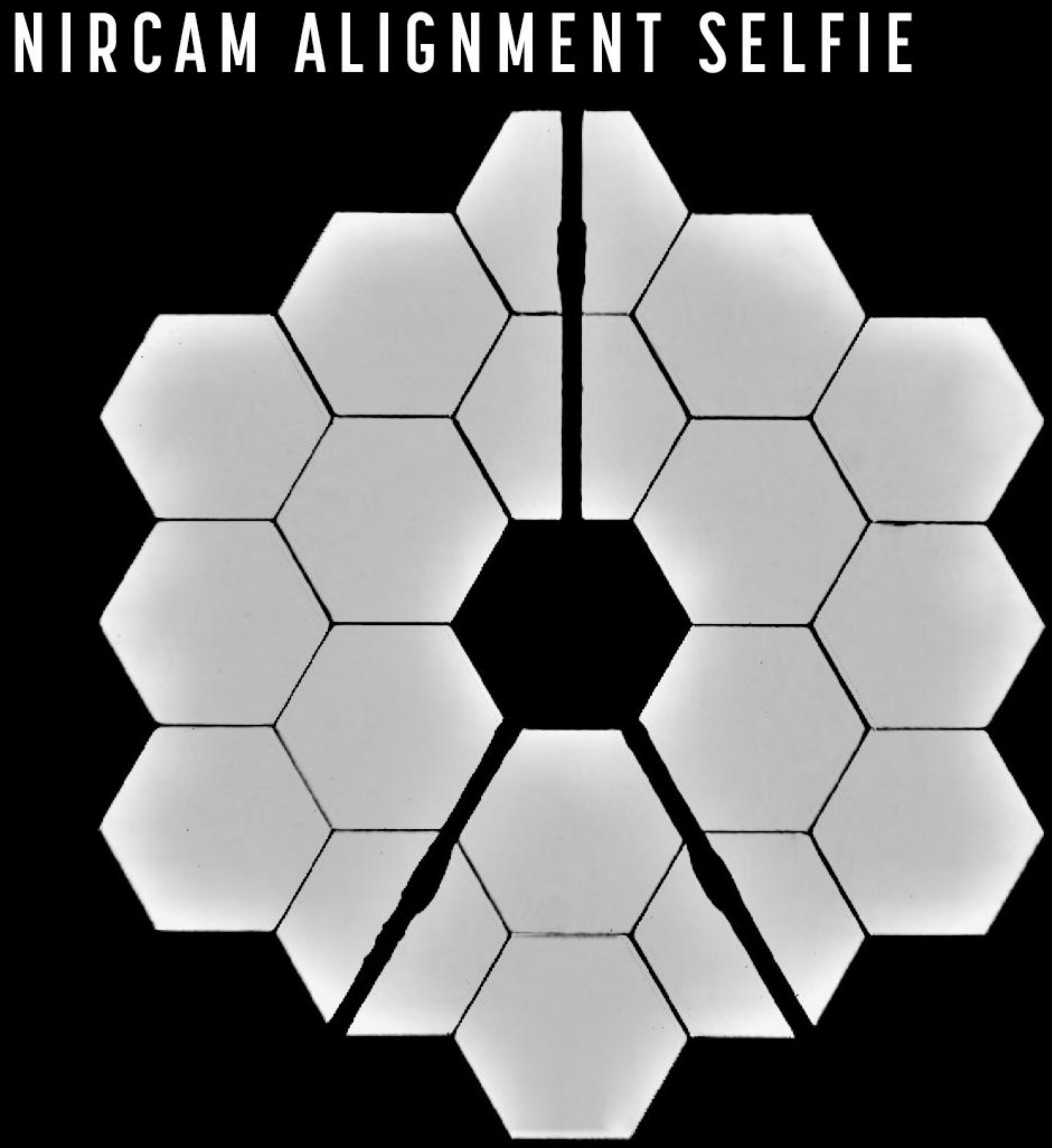
NIRCam pupil image



Webb “selfie”

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Spitzer-Webb comparison

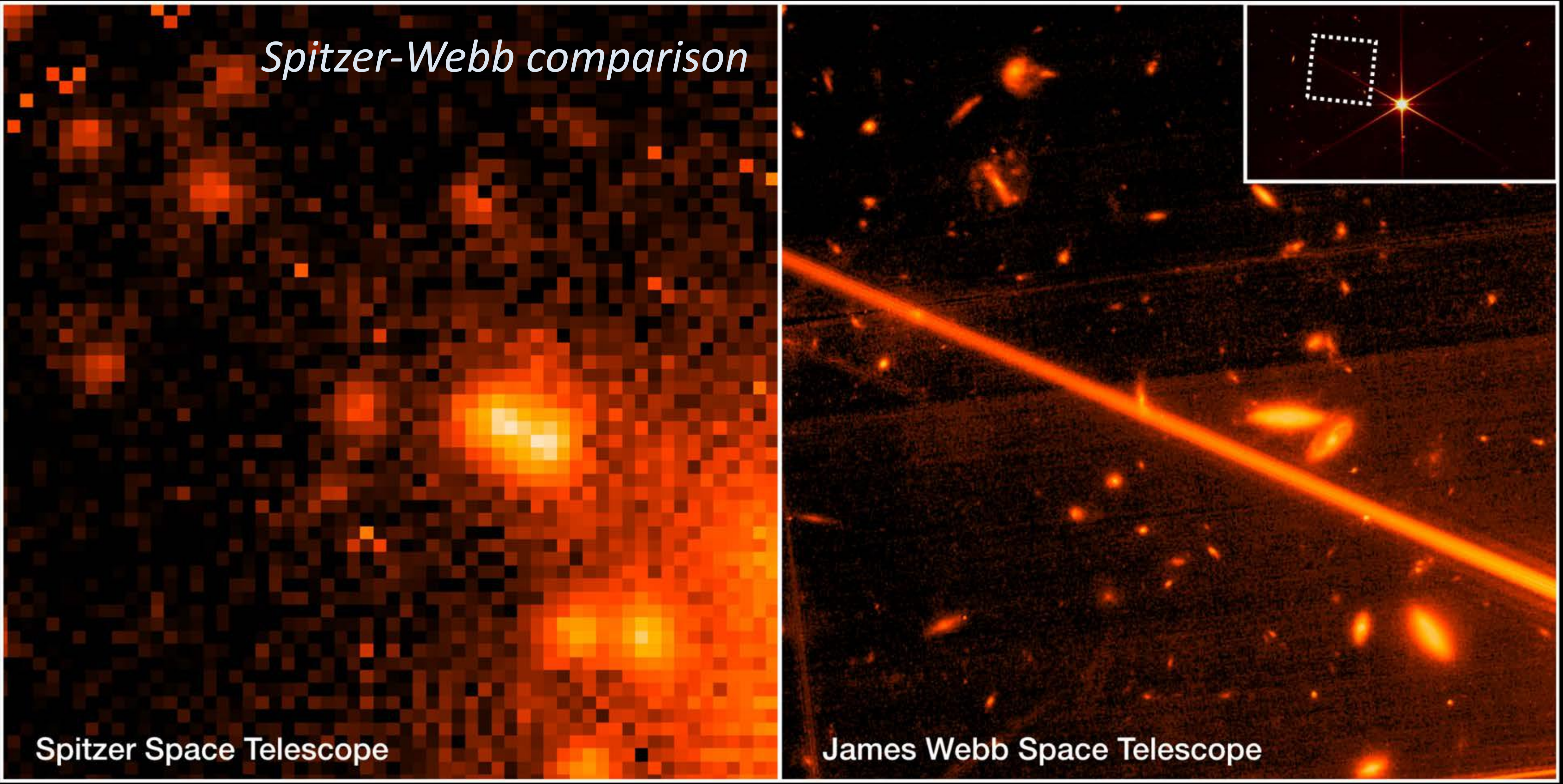

image comparison from Gabe Brammer – 3 hrs Spitzer 30 min Webb

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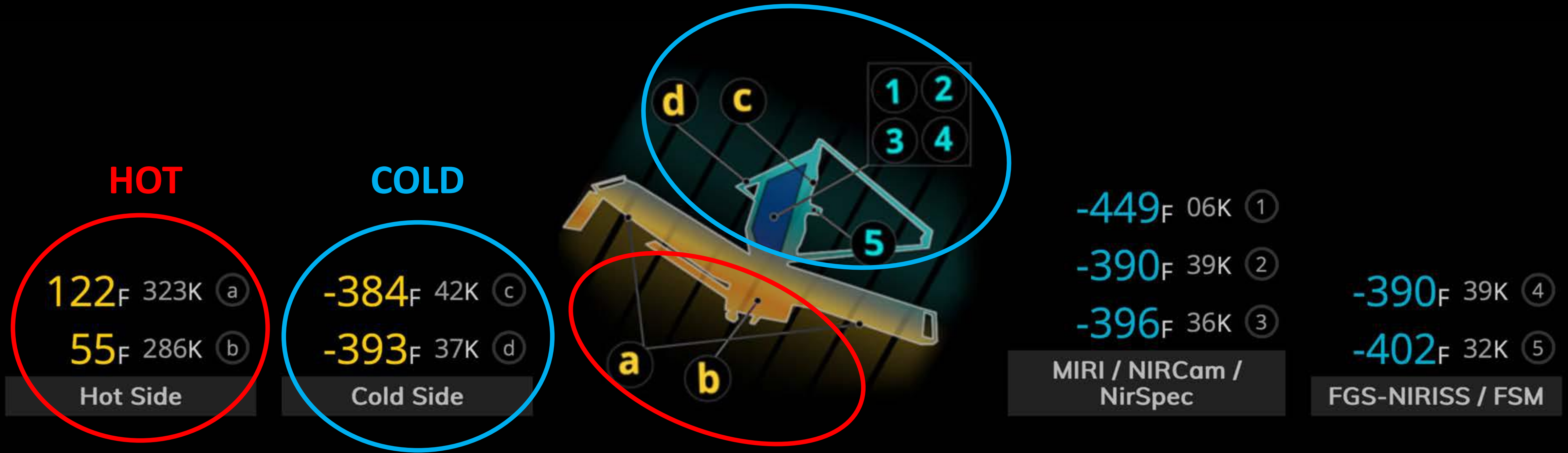
- *optical performance is twice as good as required*
  - *4 instruments: exceptional performance*
    - *Webb exceeds requirements and expectations*



NASA.gov WhereisWebb

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the NASA Goddard JWST Project science team

WEBB SPACE TELESCOPE


John Mather
Sr. Proj. Sci


Jonathan Gardner
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Scientist



Chuck Bowers
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Knicole Colon
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Matt Greenhouse
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Mike McElwain
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Susan Neff
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Bernie Rauscher
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Jane Rigby
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Erin Smith
Observatory


Chris Stark
Commissioning


Amber Straughn
Communications


Mark Clampin


Mal Niedner


George Sonneborn

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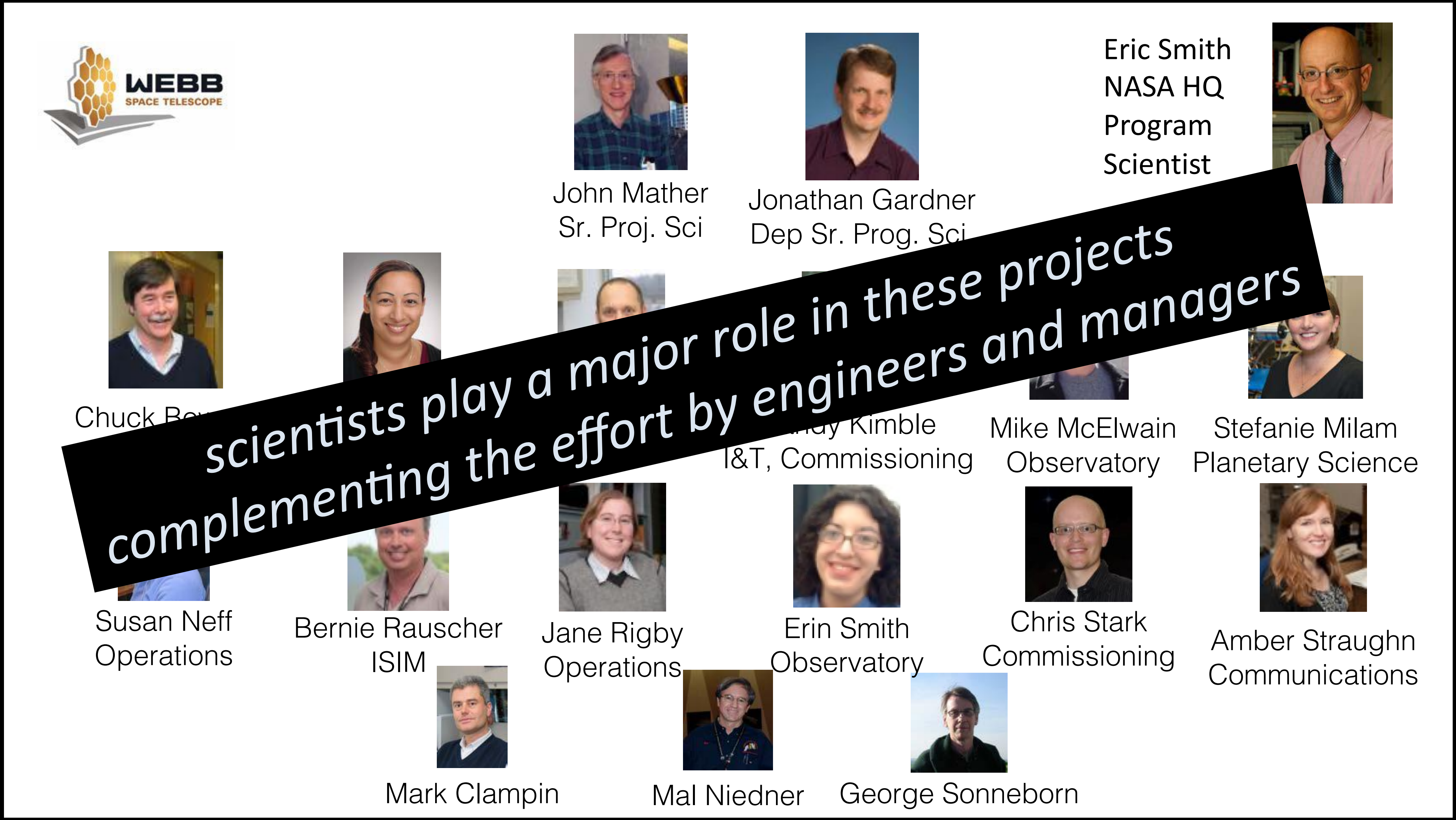
the NASA Goddard JWST Project science team



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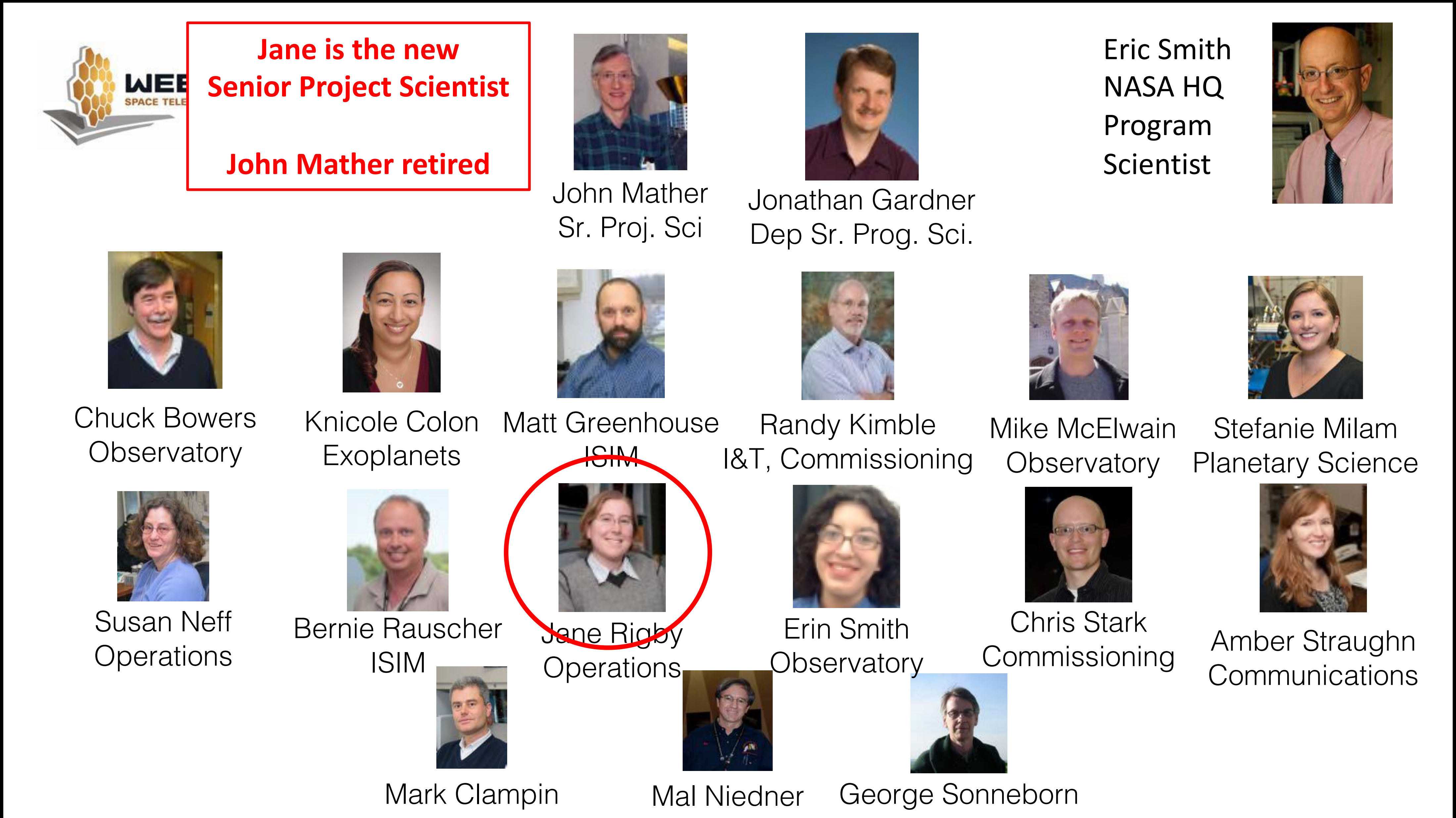
the NASA Goddard JWST Project science team



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July 11 – NIRCam image of SMACS 0723-73 at z=0.39

Q?

what did it take to do JWST?

how did we get to this point?

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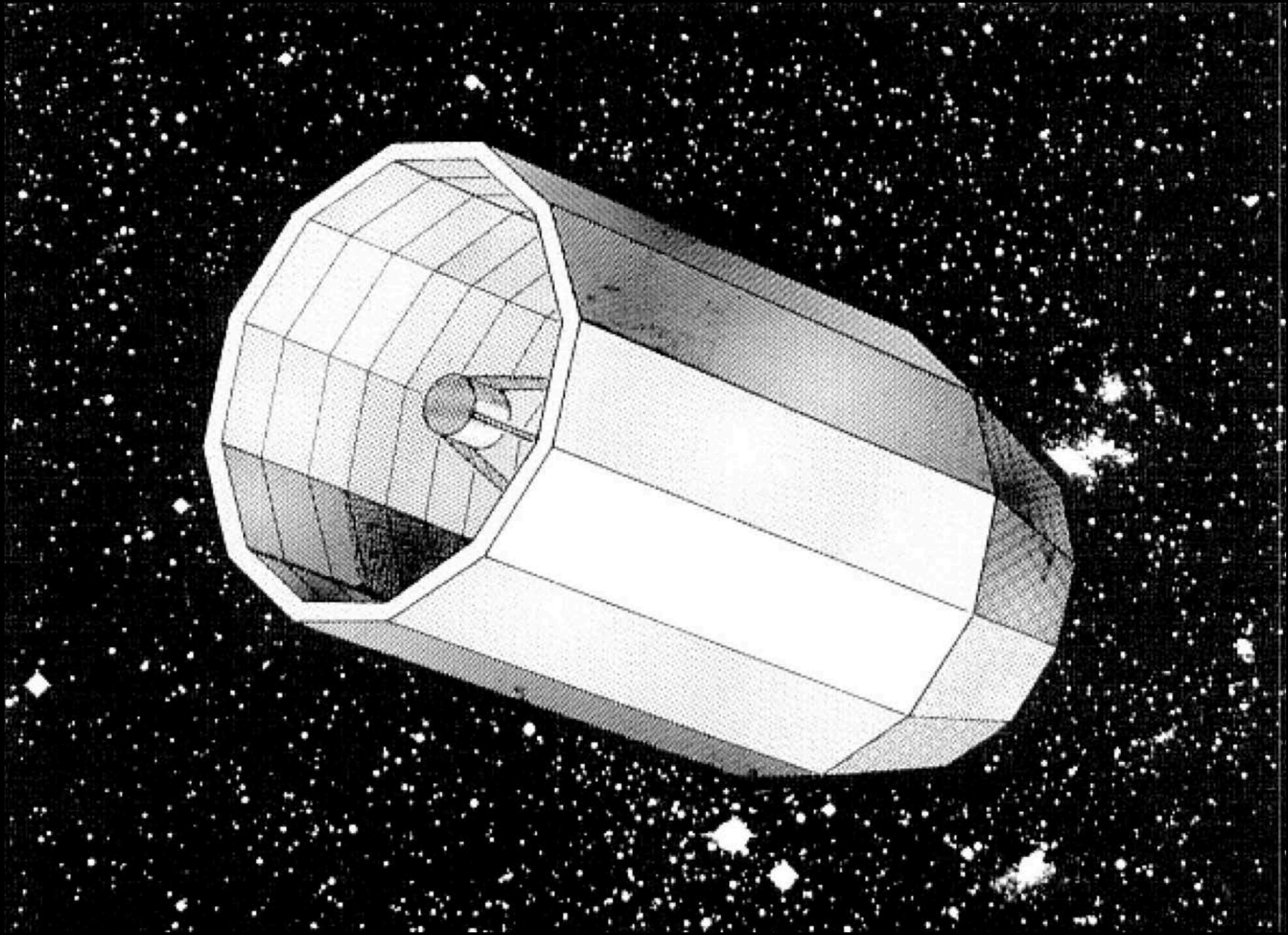
started ~36 years ago

Next Generation Space Telescope – NGST –

1985-2002



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“start working on the next big mission
– it will take a very long time”

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“start working on the next big mission – it will take a very long time”

Riccardo Giacconi (STScI Director, later Nobel laureate)
surprised me (Deputy-Director) in the mid-1980s with these words

especially since we had yet to launch “Space Telescope” (Hubble)!

Garth working with Pierre Bely, Peter Stockman, and Chris Burrows
developed the concept of NGST from 1986—
– the Next Generation Space Telescope –

a really-cold, infrared, very large 8-10m space telescope in orbit far from Earth

it was a topic of discussion at STScI during a very vibrant (and stressful) Hubble pre-launch period –
many people contributed thoughts and ideas

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the NGST people at Space Telescope Science Institute (STScI) in 1985-6-7

Credit: STScI

Riccardo Giacconi
Director and Future
Nobel Prize Winner

Garth Illingworth
Deputy Director

Peter Stockman
Division Head

Pierre Bely
Chief
Engineer

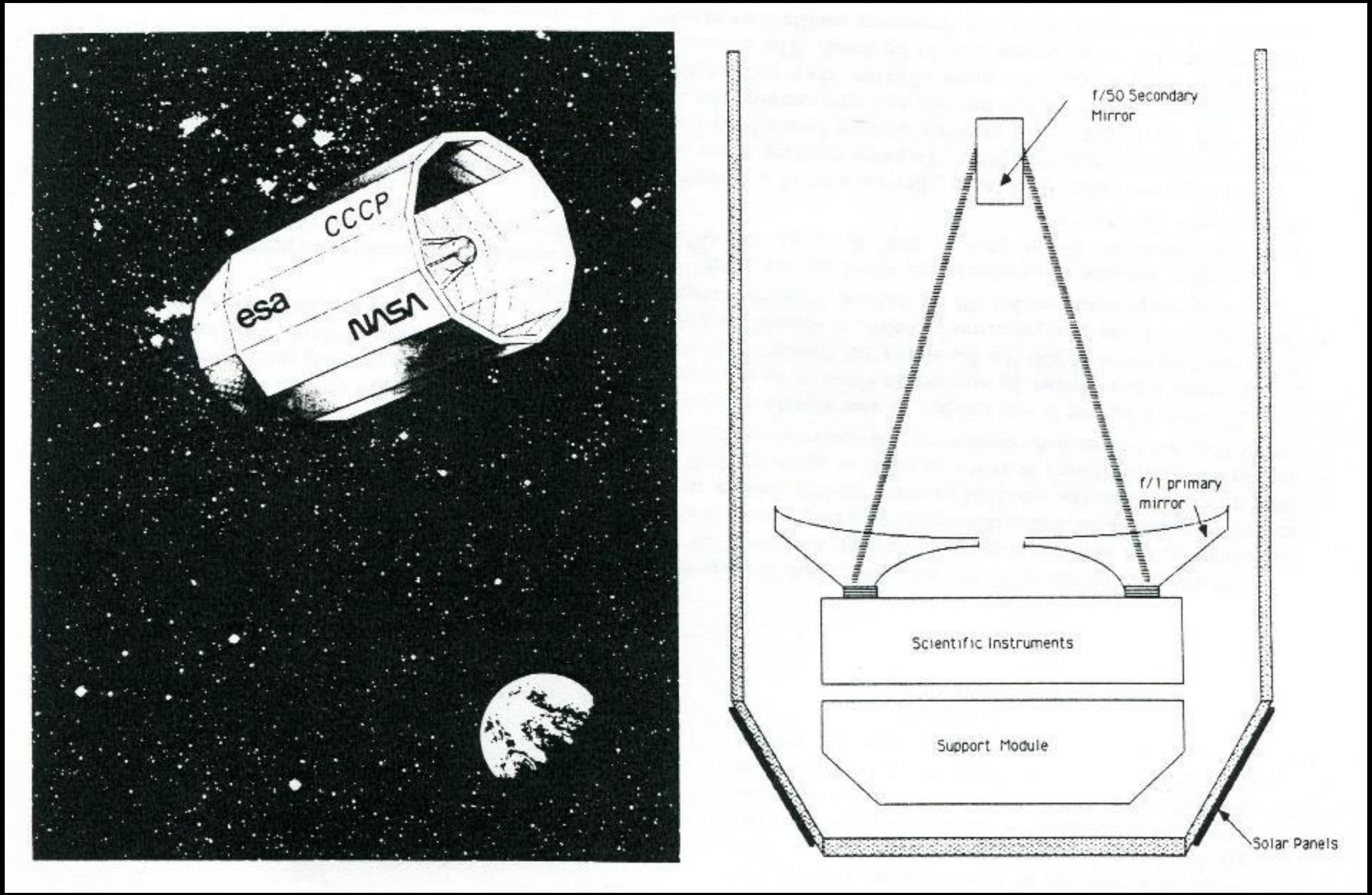
Credit: Pierre Bely

Chris Burrows

Next Generation Space Telescope – NGST

1985-1992 The Birth of JWST

Conceptualizing what comes beyond Hubble, before Hubble!



Credit: Pierre Bely 1985

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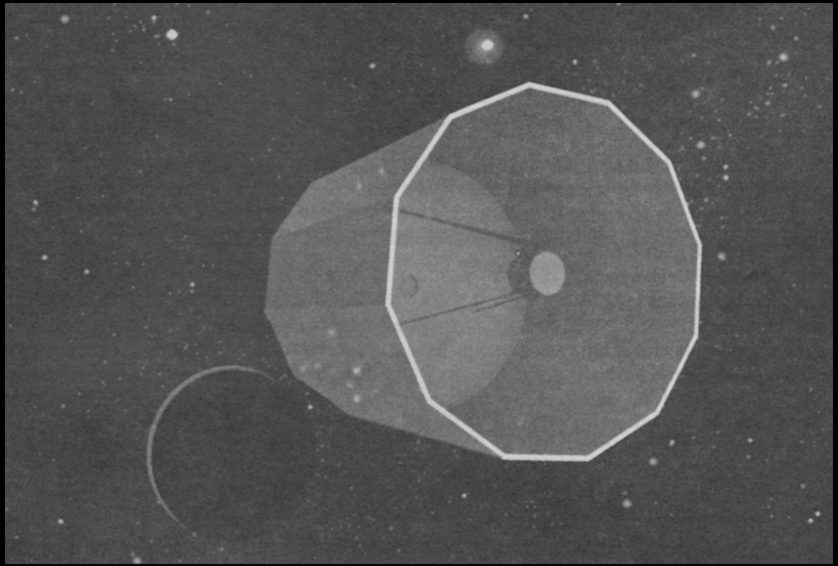
1989: First NASA & STScI conference about NGST

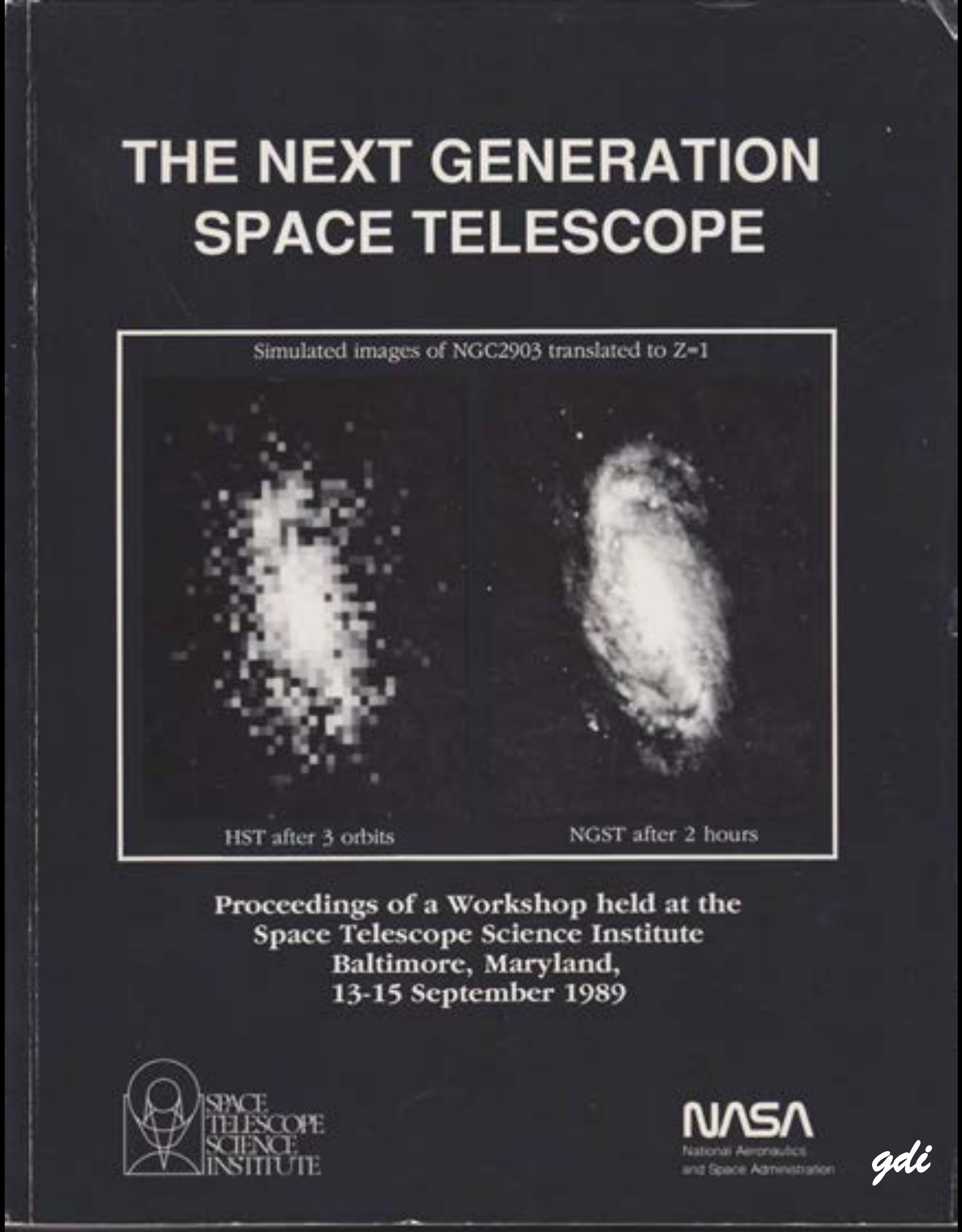
developing the NGST science case and the concept



an 8-10 m NGST: 4X the size of Hubble

(or an even bigger NGST on the moon??)

Credit: NASA, STScI, Pierre Bely, Garth Illingworth, Peter Stockman, Chris Burrows



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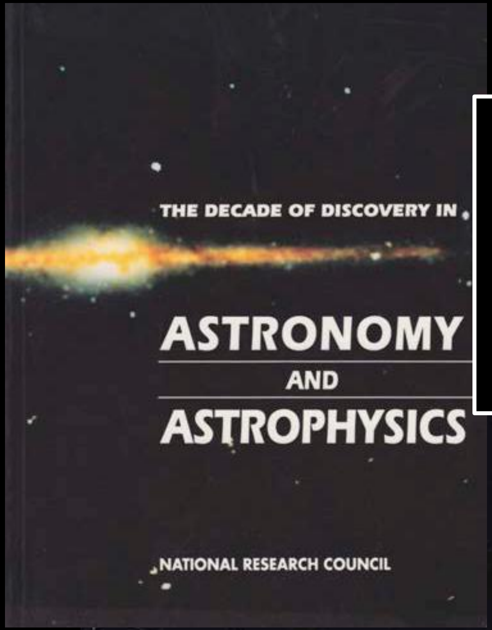
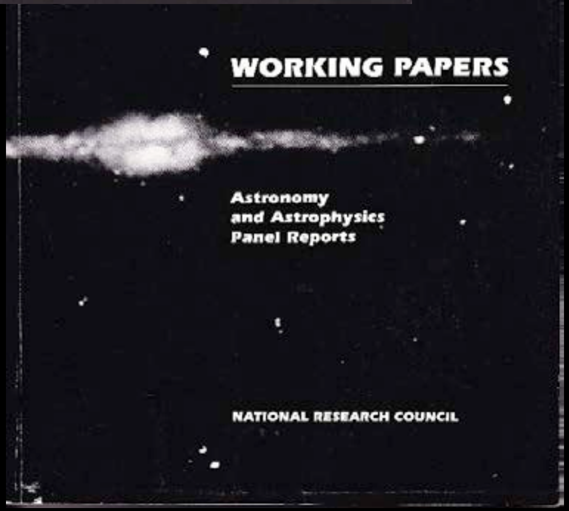
1990: Astronomy Decadal Survey "The Decade of Discovery"

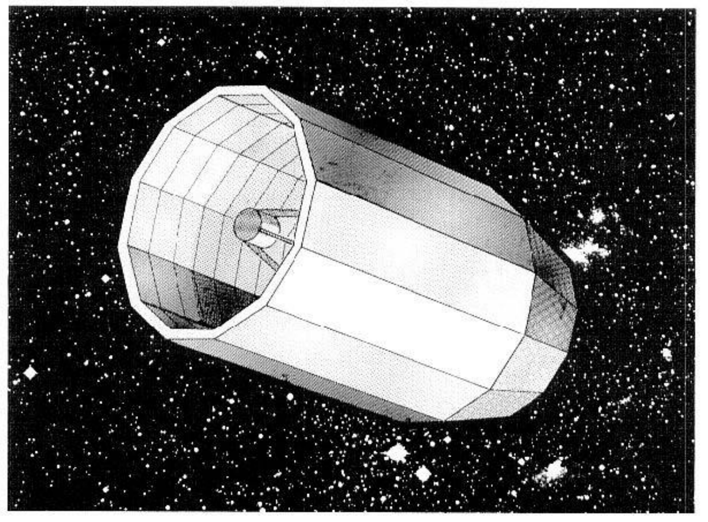
Panel recommends a cold UV-optical-infrared telescope with a large 6 m mirror

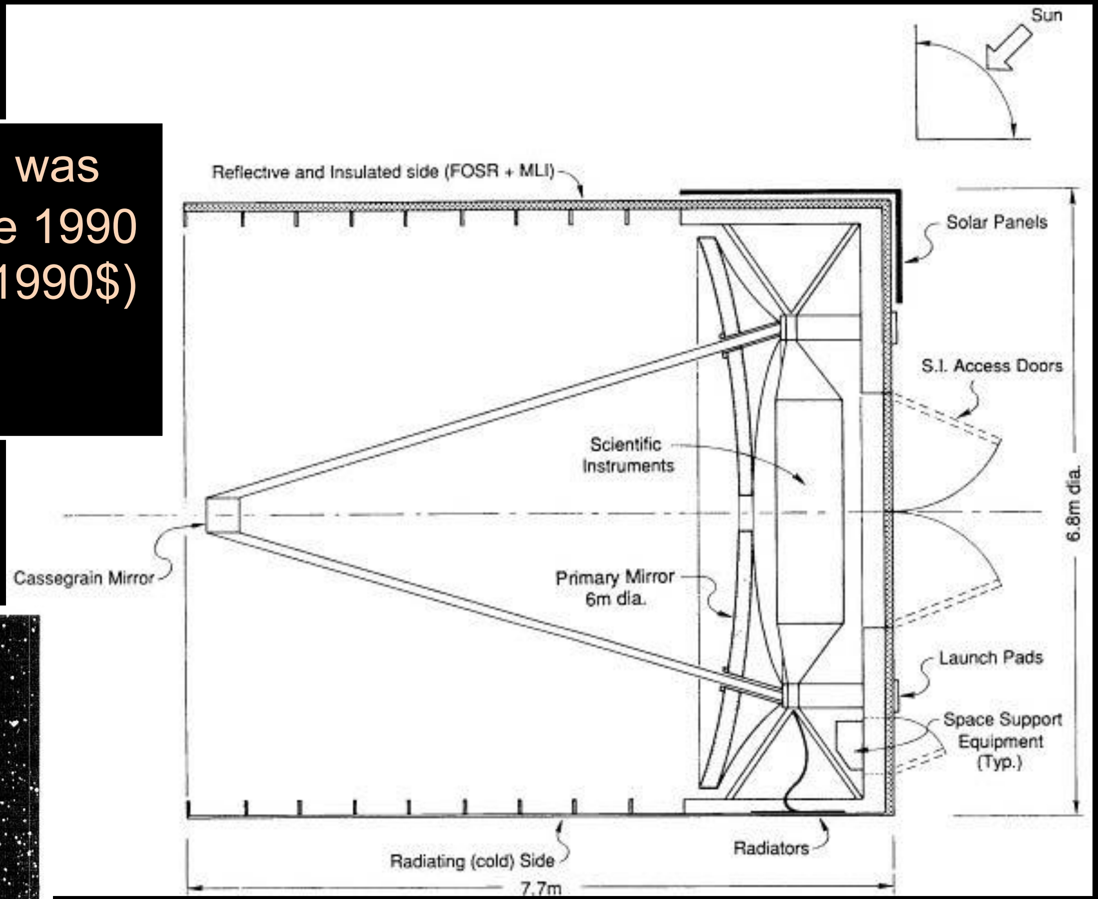




a 6-m UV-optical-infrared space telescope was recommended by the UV-Optical Panel of the 1990 Decadal Survey for launch in 2009 for $2B (1990$)

– ~$3.3B 2009$ or ~$4.5B today –





Credit: NRC, 1990 Decadal Survey,
UV-Optical from Space Panel, Garth Illingworth, Chair

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1991: NGST workshop

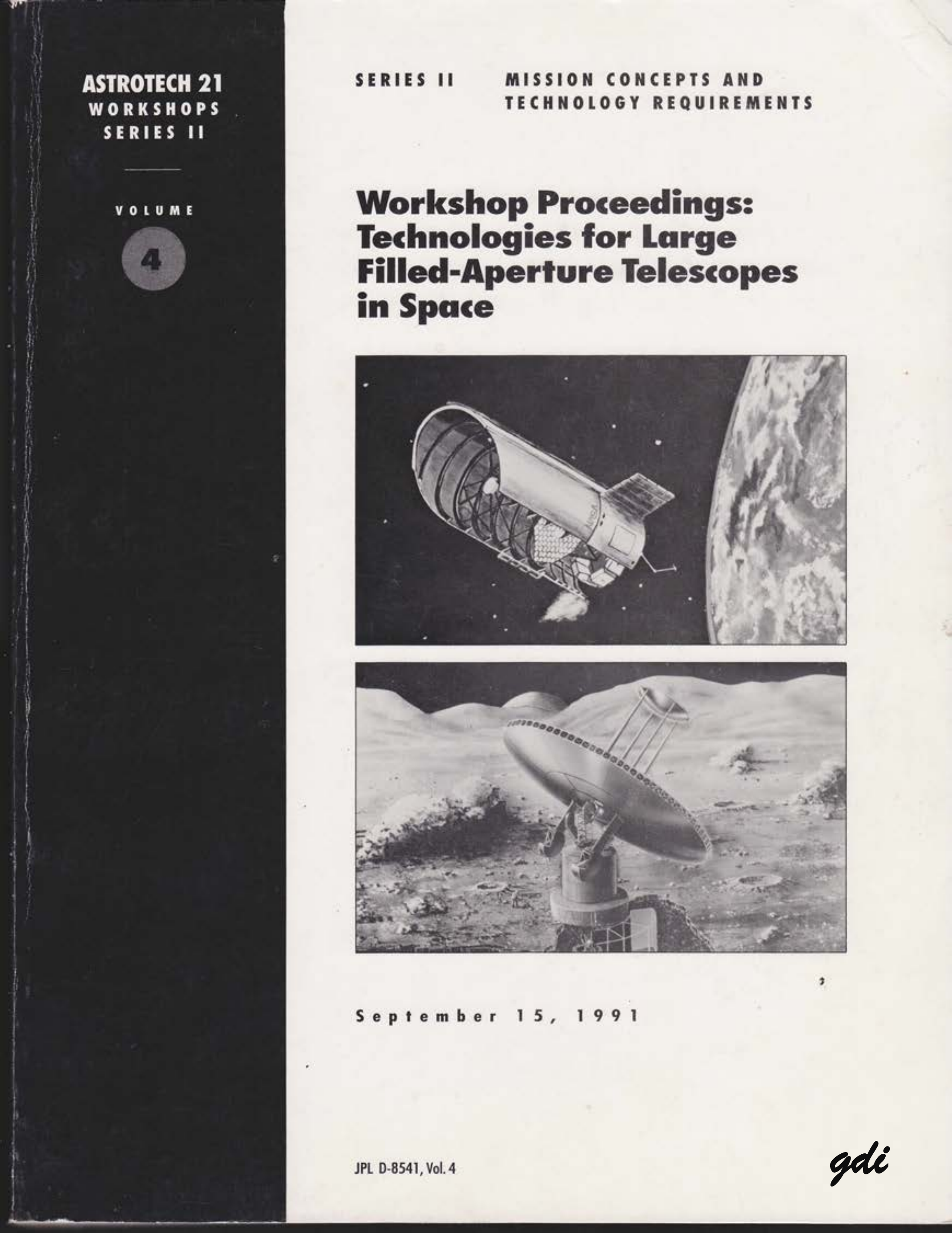
setting the stage for the future – technologies

Astrotech 21 (NASA HQ/JPL)

- large, infrared space telescope
- cooled by the universe to <100K
- 8 meter (26 foot) mirror (2x larger if on moon)
- located far away from Earth

https://www.ucolick.org/~gdi/early_jwst/

Credit: NASA, JPL, James Cutts, Garth Illingworth, Dayton Jones



1991: NGST workshop

setting the stage for the future – technologies

Astrotech 21 (NASA HQ/JPL)

- large, infrared space telescope
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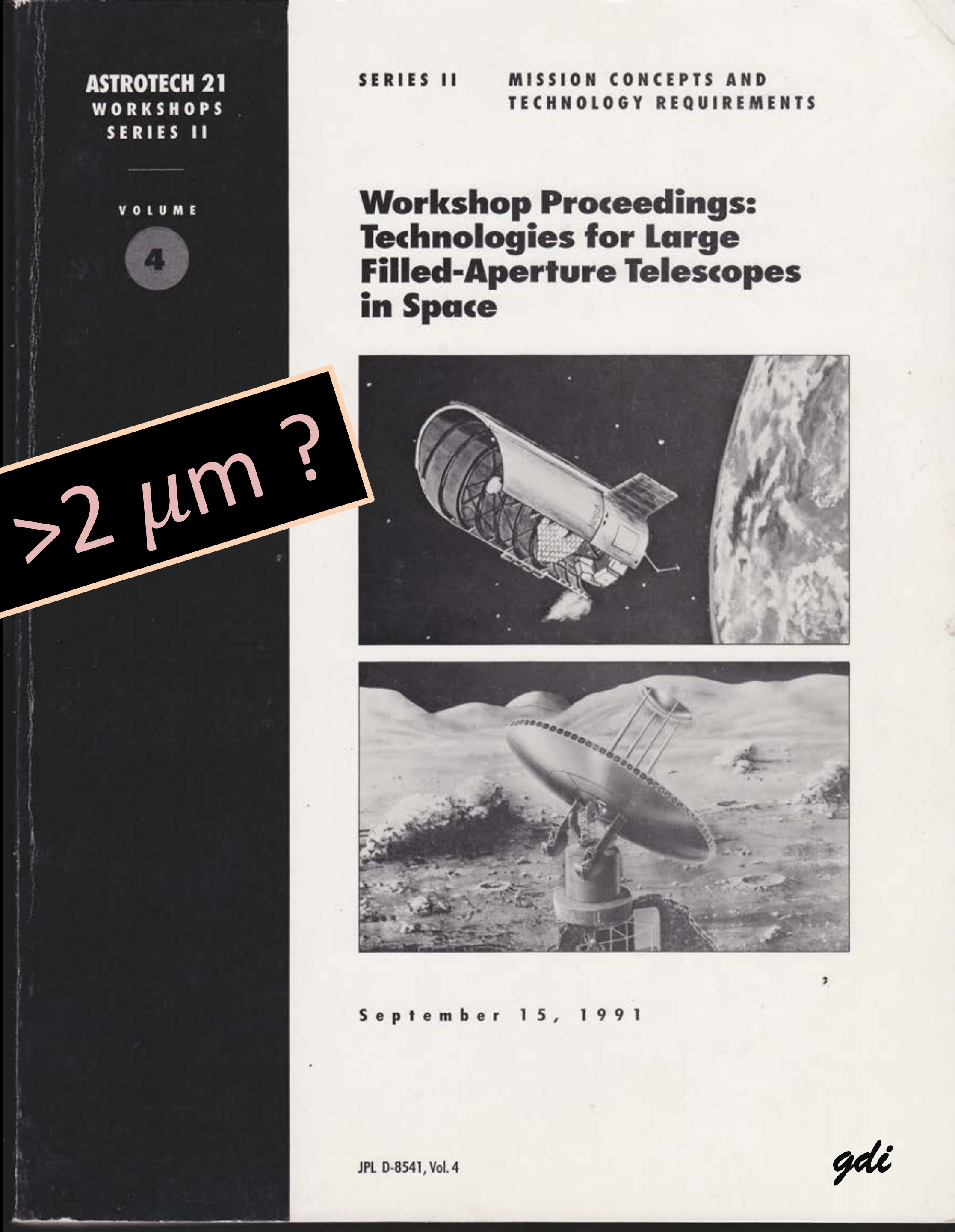
? why infrared >2 µm ?

https://www.ucolick.org/~gdi/early_jwst/

Credit: NASA, JPL, James Cutts, Garth Illingworth, Dayton Jones



? why infrared >2 μm ?

because (1) unexplored territory with new technology &
(2) the sky background from the ground in the IR is brighter by $10^{6\text{-}7}\times$ that in space

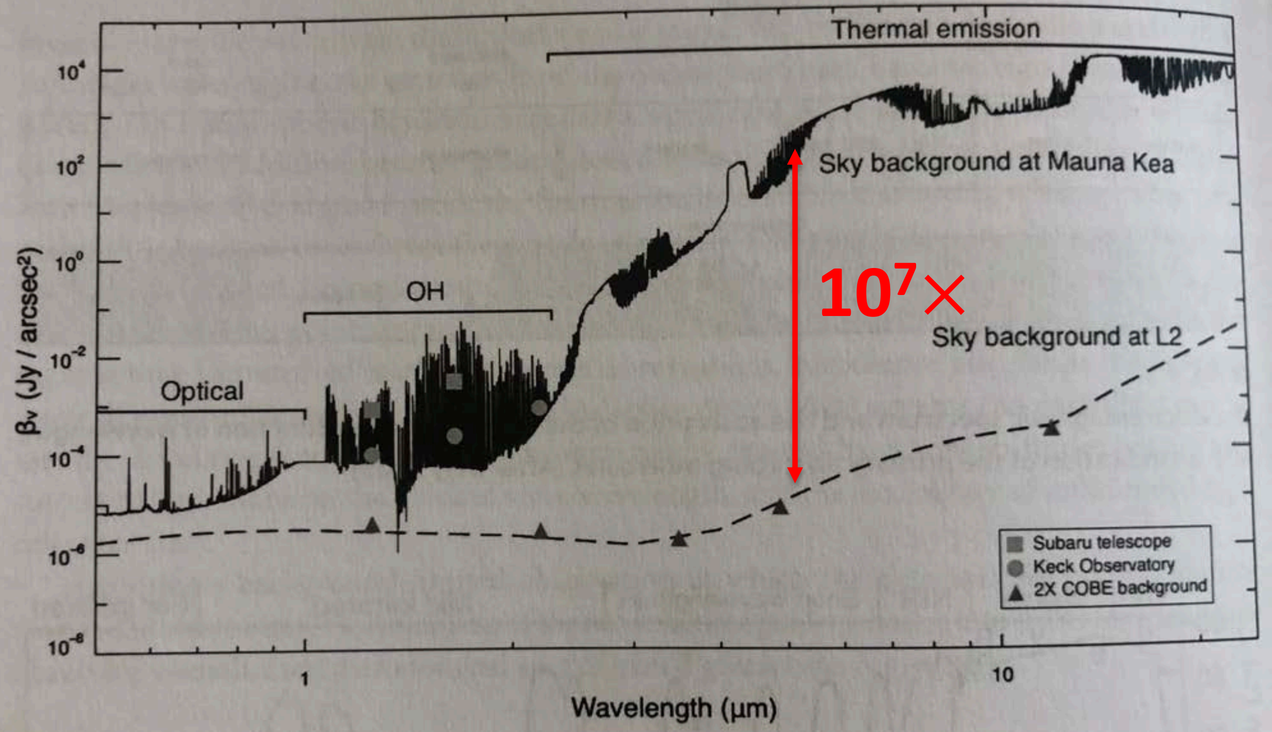
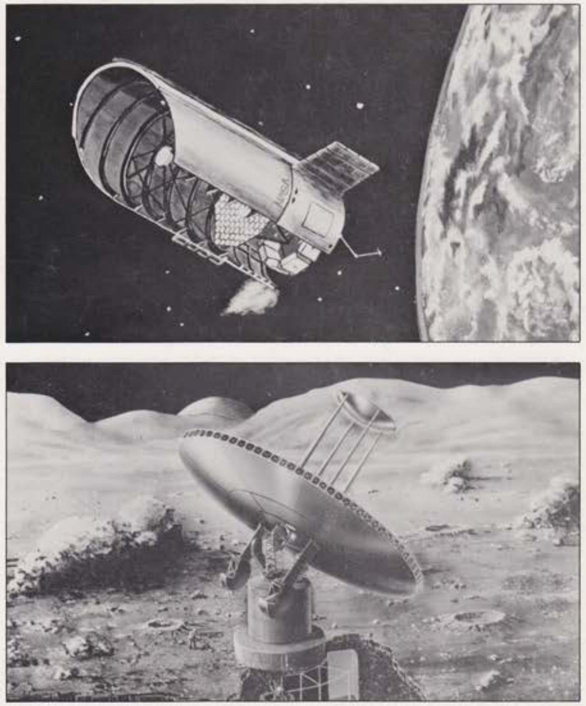


Fig. 9-3
Typical "dark time" visible and infrared background emission for a ground-based telescope as measured at Mauna Kea (Hawaii). An estimate of the background for a cryogenically cooled telescope at L2 is shown for comparison (After Gillet and Mountain 1998)

ASTROTECH 21 WORKSHOPS

SERIES II MISSION CONCEPTS AND TECHNOLOGY REQUIREMENTS

Filled-Aperture Telescopes in Space



September 15, 1991

1991

JPL D-8541, Vol. 4

gdi

Q?

the post-Hubble phase

NGST after Hubble's launch in 1990

but more so – after Hubble was fixed in 1993

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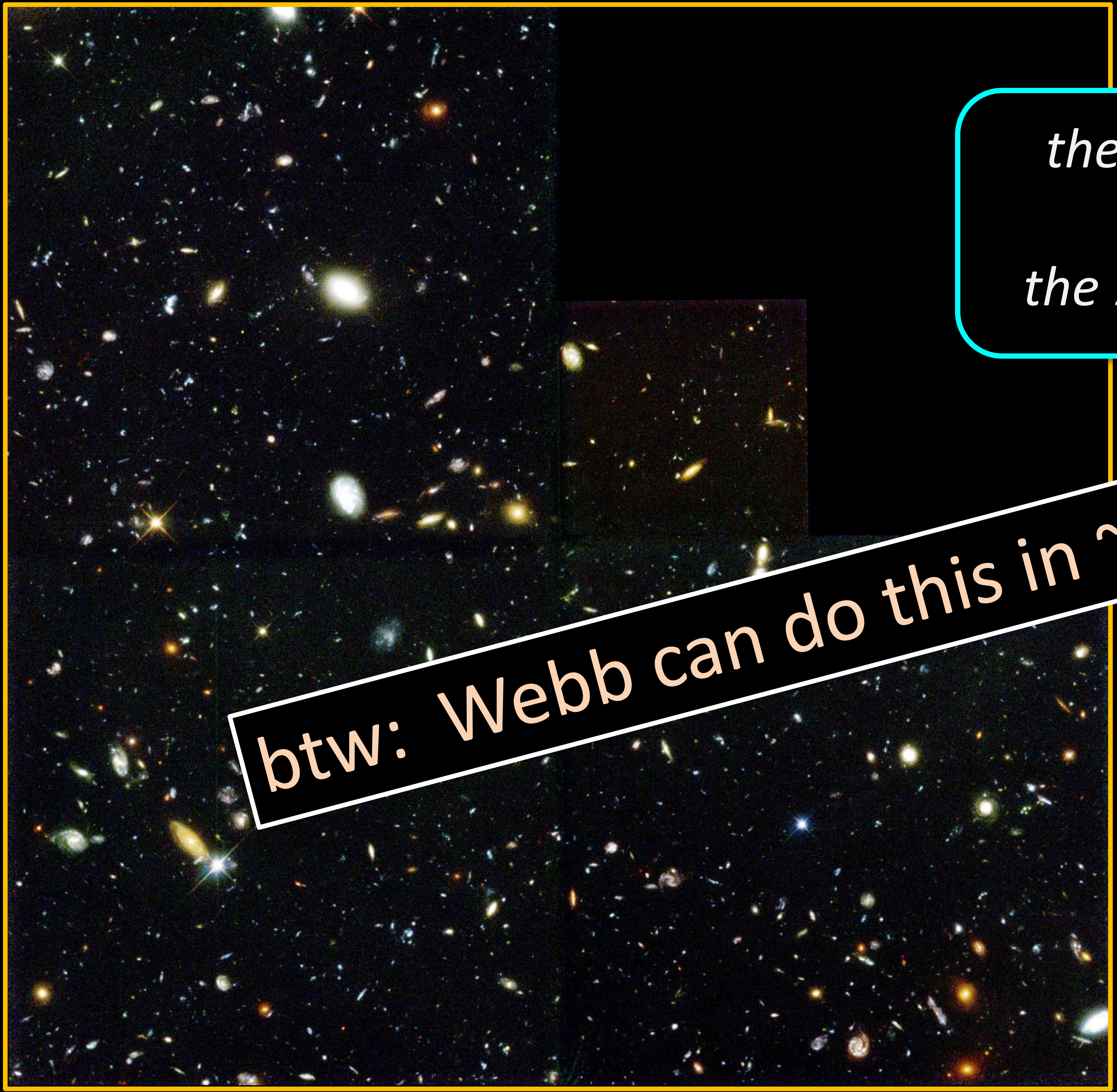
the first deep Hubble image

the 1995 “Hubble Deep Field”

Hubble’s Wide-Field Camera 2
exposed for 10 days with Hubble!

Credit: Bob Williams and the HDF Team

gdi



the first deep Hubble image

the 1995 "Hubble Deep Field"

btw: Webb can do this in ~6-7 hours!

Hubble's Wide-Field Camera 2
exposed for 10 days with Hubble!

Credit: Bob Williams and the HDF Team

gdi

1996: a 4-m IR telescope

the "HST and Beyond" Study

AURA-initiated *HST and Beyond study* (Chair Dressler) in 1993

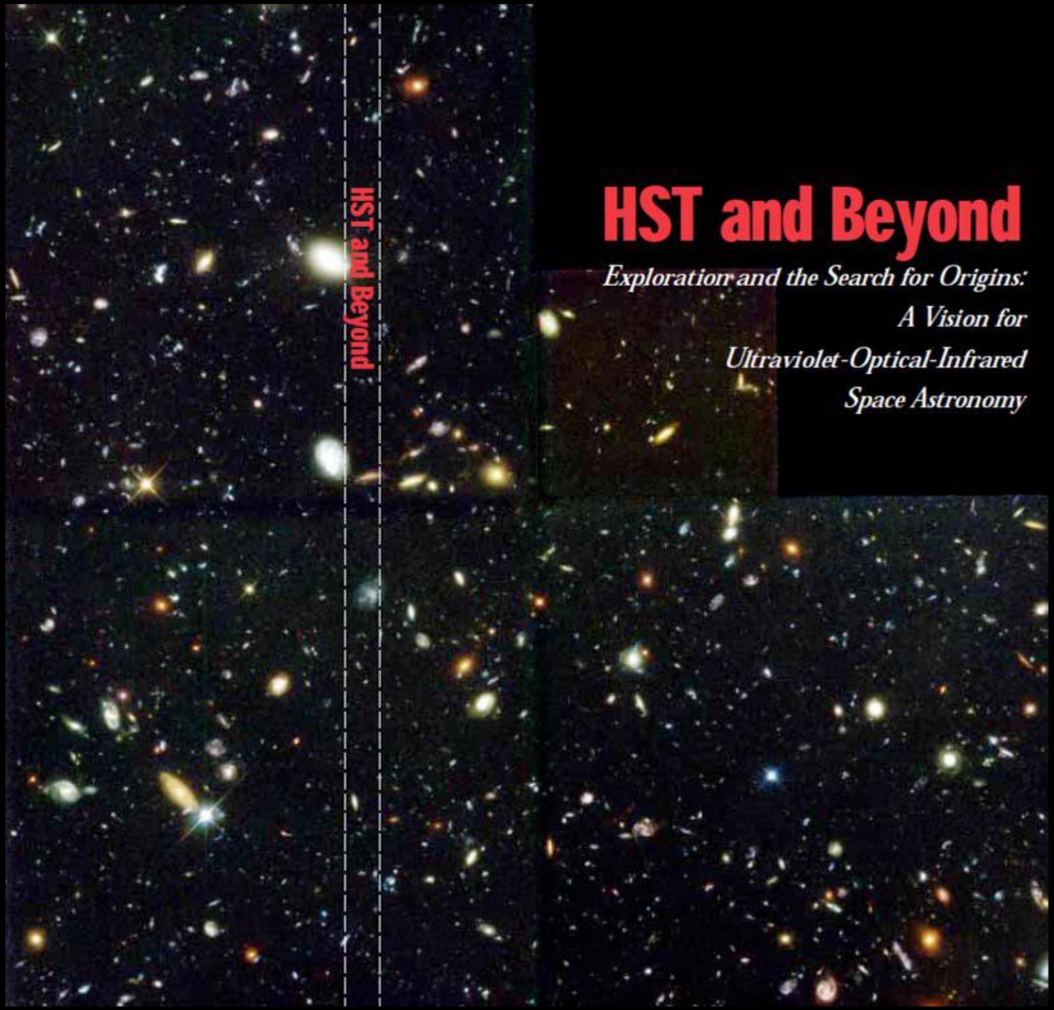
comprehensive, very well-written science case

released 1996 with 3 recommendations re
HST future, an IR telescope, and interferometry.

recommended an IR telescope "….of aperture 4 m or larger,
optimized for imaging and spectroscopy over …. 1-5 μm."

4 m & 1-5 μm seemed very incremental though
since Hubble was 2.4 m
and there was an instrument in development
for Hubble that would go to 1.6 μm

fortunately the *HST and Beyond* team had opened the door
by noting "4 m or larger" and 0.5-20 μm



Credit: AURA, HST and Beyond Committee, Alan Dressler, Chair

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1996: 4 m ⇒ 6-7 m

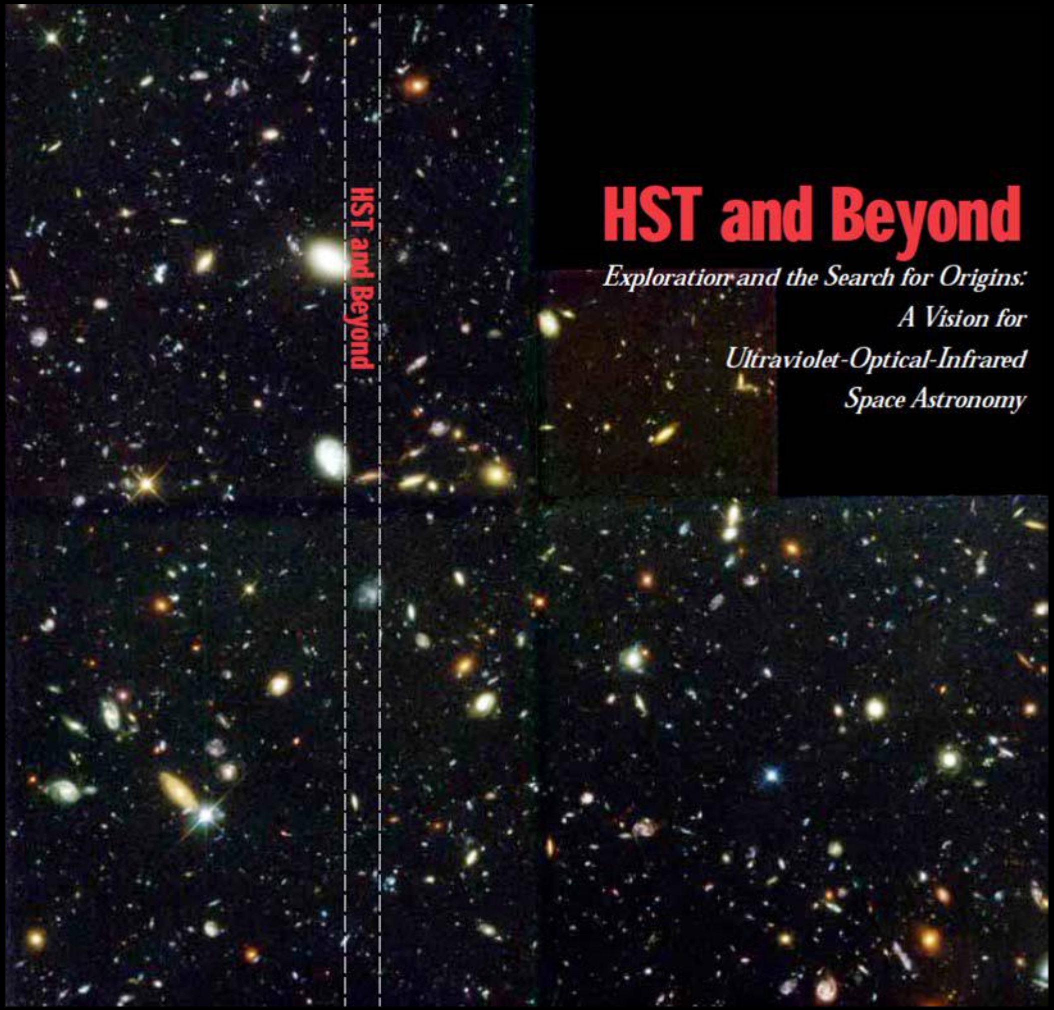
going beyond the "HST and Beyond" recommendation

Dan Goldin, NASA
Administrator
mid-late 1990s.

key step at 1996 American Astronomical Society meeting

making the 4 m IR telescope a 6-7 m

NASA Administrator Dan Goldin says: "I see Alan Dressler here. All he wants is a four meter optic that goes from a half micron to 20 microns. And I said to him, "Why do you ask for such a modest thing? Why not go after six or seven meters?""



Credit: AURA, HST and Beyond Committee, Alan Dressler, Chair

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1996: 8 m NGST again

NASA Science Associate Administrator Ed Weiler initiates Goddard effort on NGST

NASA Office of Space Science AA Ed Weiler requests that Goddard Space Flight Center (GSFC) study NGST with a small $100K budget

John Mather is lead, and many others at GSFC, take NGST forward, including Eric Smith, Berny Seery, Pierre Bely and Peter Stockman

NASA Administrator Dan Goldin says that he is supportive of an 8-m NGST

8-m becomes the baseline for the NGST studies in the late 1990s and into the 2000 Decadal

(now sized like the earlier 1987-1991 discussions which were at 8-10 m)

I was delighted with this change since starting at 4 m was a scientifically-bad and politically-risky step – 4 m is just too small….

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1996-1997: NGST

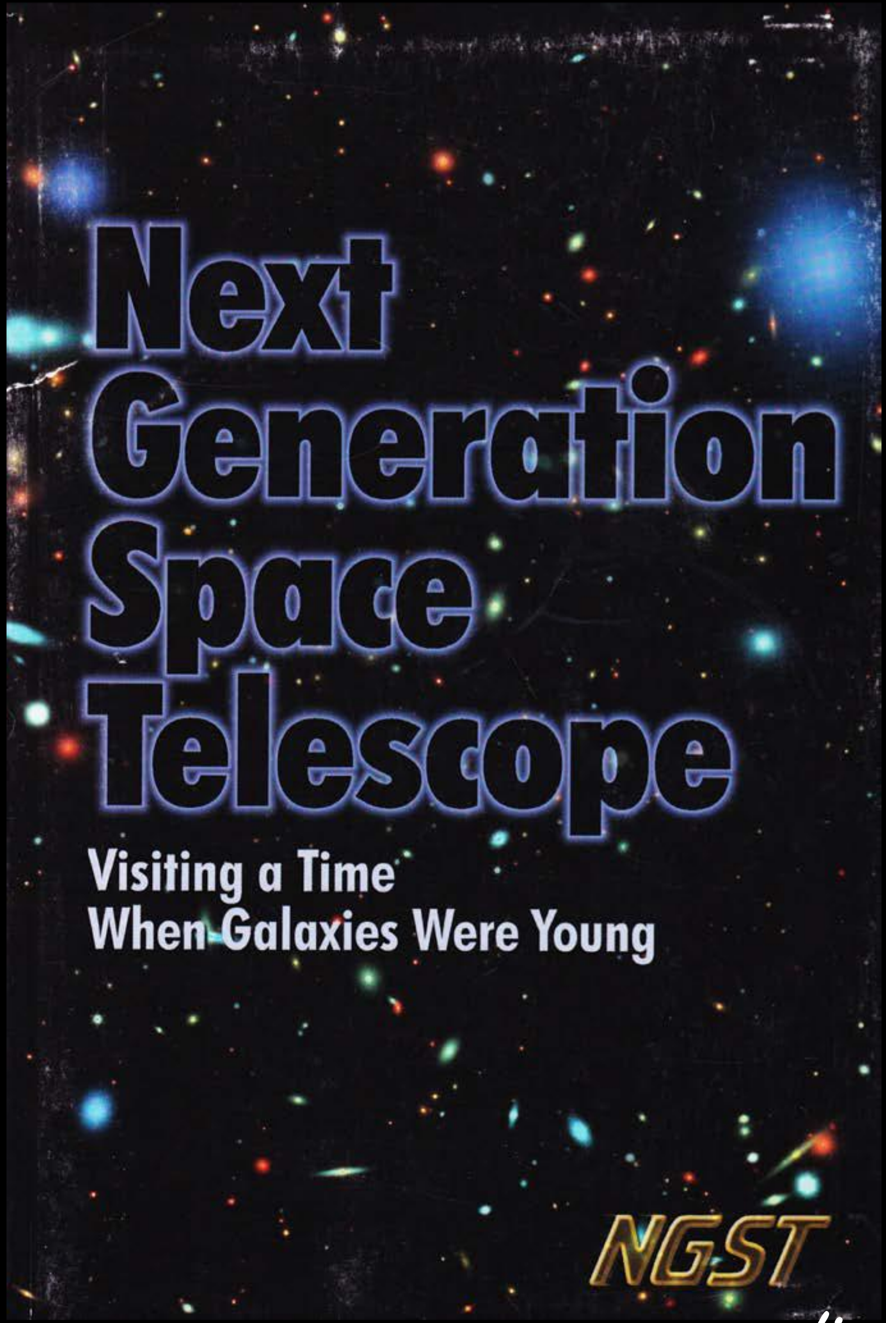
study: "NGST – Visiting a Time When Galaxies Were Young"

the NGST Study team undertakes a comprehensive broad-based study involving a very large team from NASA, industry, and academia:

Detailed in the report: *Next Generation Space Telescope – Visiting a Time When Galaxies Were Young* (editor Peter Stockman)

includes a report of three studies of 6-8 m NGST led by teams from Lockheed, TRW & GSFC

begins to clarify the possibilities of deployable systems



Credit: NASA, STScI, The NGST Study Team, Peter Stockman, Editor

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1999-2000-2001: 8 m NGST

⬣ *March 1999 FAD signed by AA Ed Weiler* ⬣

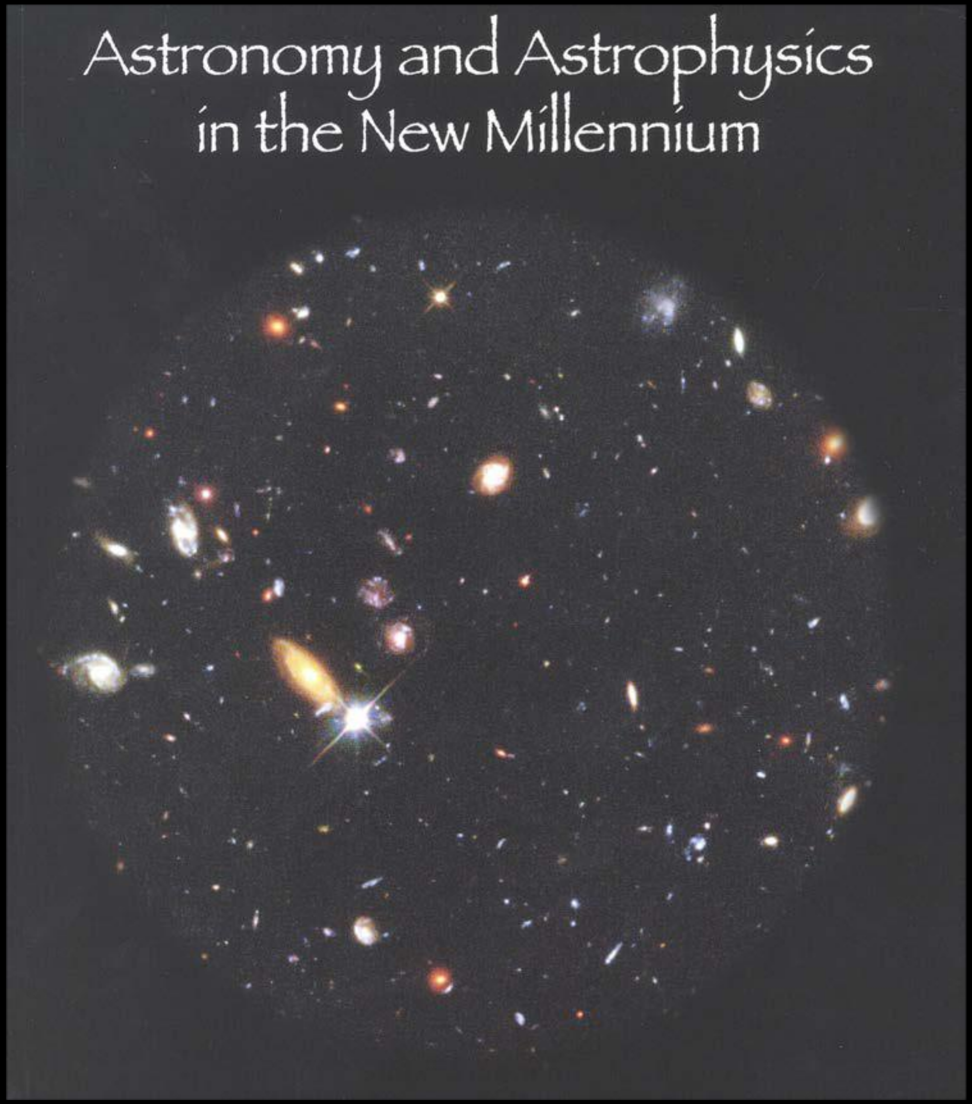
March 1999 – SMD AA Ed Weiler signs *Formulation Authorization Document* (FAD) – formal start of Phase A

⬣ **NASA initiates NGST** ⬣

⬣ *2001 Decadal Survey recommends 8 m NGST* ⬣

The 2000 Decadal Survey *Astronomy and Astrophysics in the New Millennium* (Co-Chairs Chris McKee & Joe Taylor) top-ranks NGST

accepting the recommendation of the *Panel On Ultraviolet, Optical, And Infrared Astronomy From Space* (chair Steve Beckwith) for an 8 m NGST



Credit: NASA, STScI, The NGST Study Team, Peter Stockman, Editor

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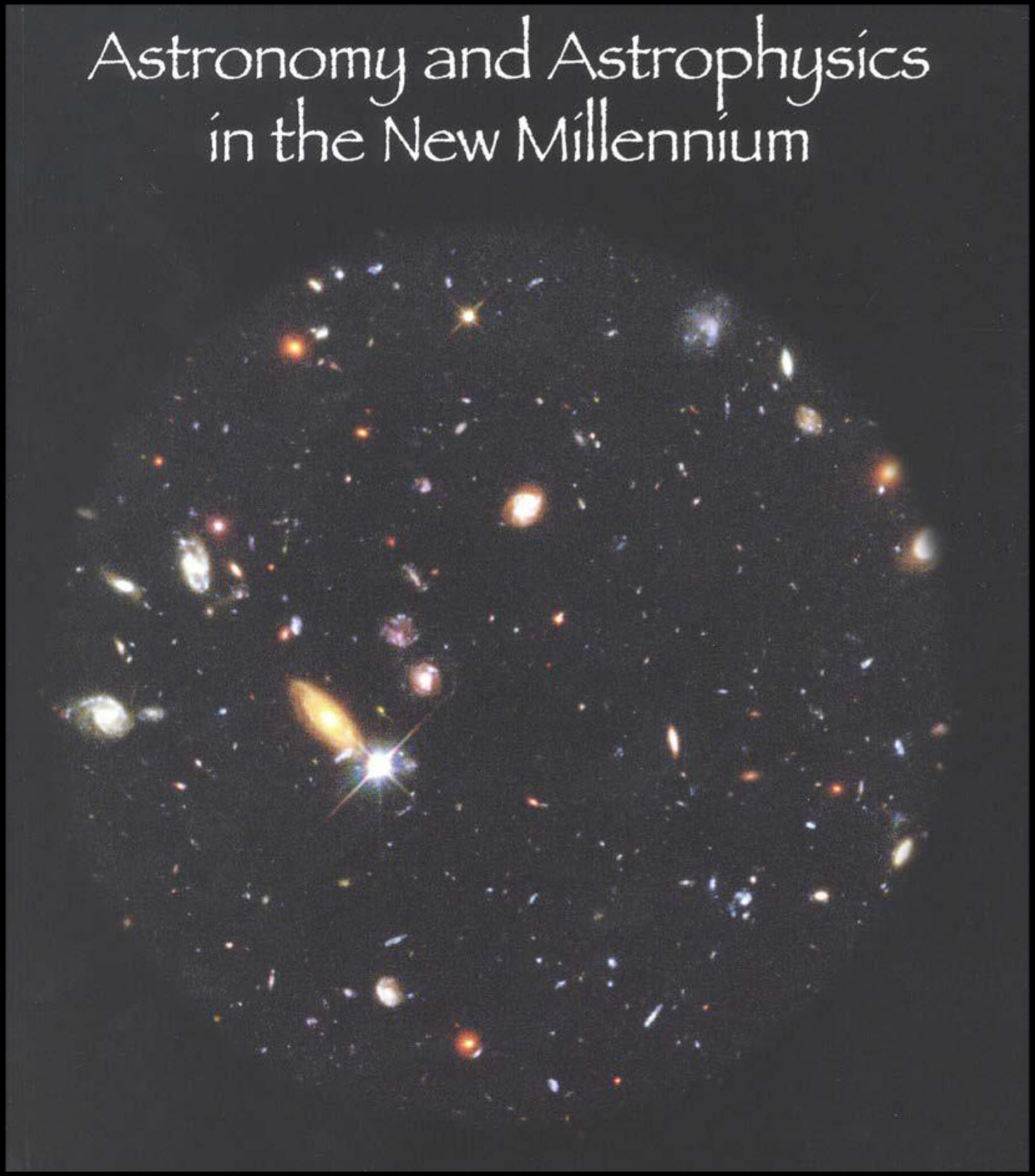
already concerns about budget for NGST
down to 6.5 m!

FAD says baseline is 4 m 1-5 μm with an 8 m goal
construction phase C/D cost $500M
lifecycle cost of $900M
(start of mission to end of operations)

2000 Decadal Survey top-ranks 8 m NGST
gives cost-estimate about $1B!

compare to our 1990 estimate of $2B ($2.6B in 2000$)

2001: NGST de-scoped from 8-m to 6.5-m
NGST development begins
budget is a major challenge



Credit: National Academy of Sciences

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Q?

what about the science goals of NGST?

exciting science is crucial to "sell" the mission

so – why were we doing NGST?

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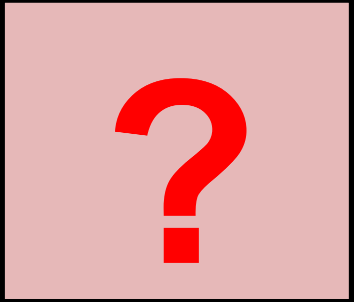
1985-1989: NGST science potential

thinking science beyond Hubble before Hubble was launched!

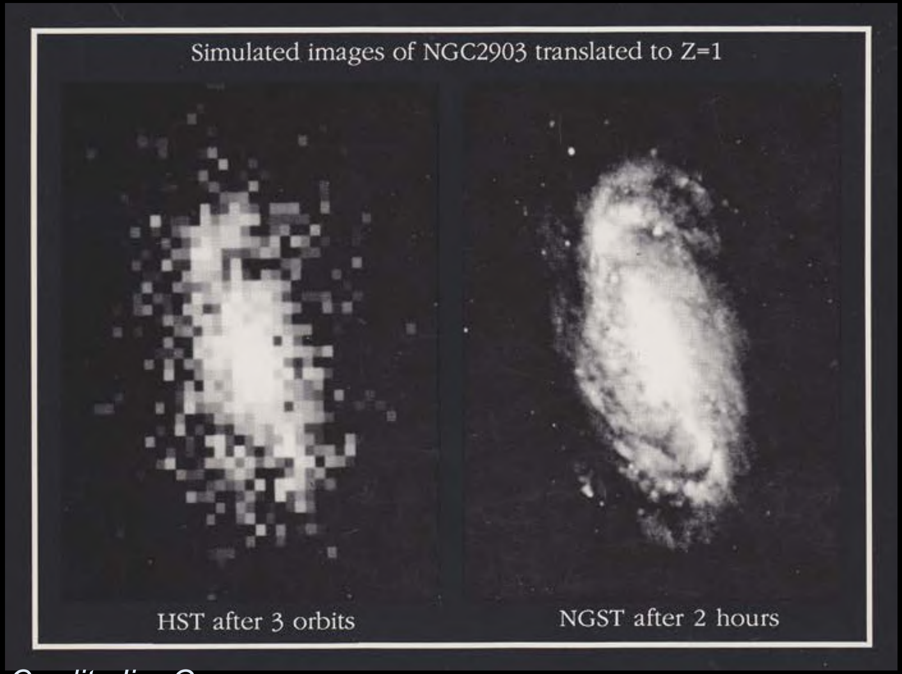


revealing unknown unknowns;
exploration; discovery

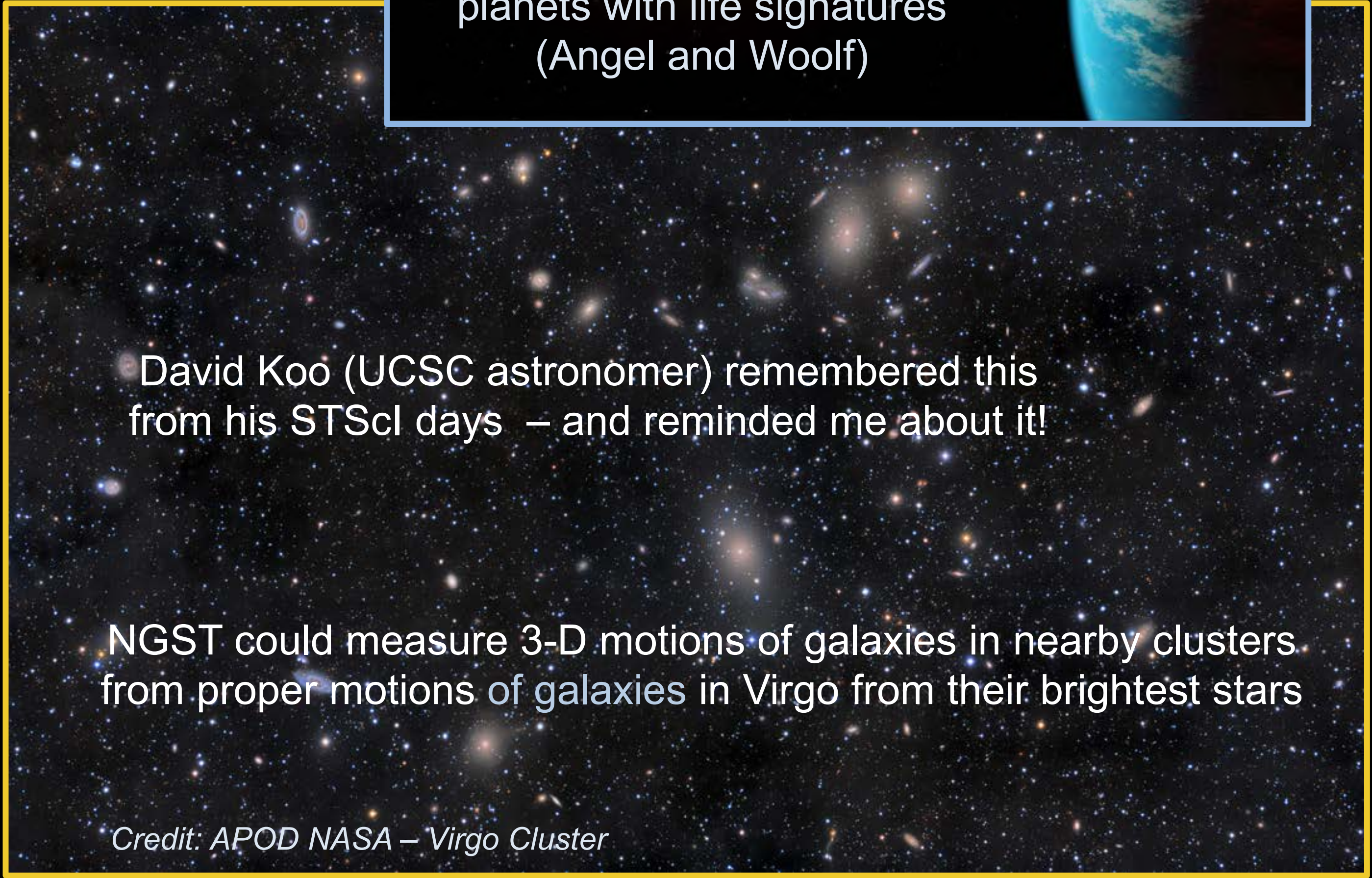
Credit: NASA

searching for earth-like planets with life signatures (Angel and Woolf)

seeing distant galaxies way better than expected with either Hubble or Keck



Credit: Jim Gunn



David Koo (UCSC astronomer) remembered this from his STScI days – and reminded me about it!

NGST could measure 3-D motions of galaxies in nearby clusters from proper motions of galaxies in Virgo from their brightest stars

Credit: APOD NASA – Virgo Cluster

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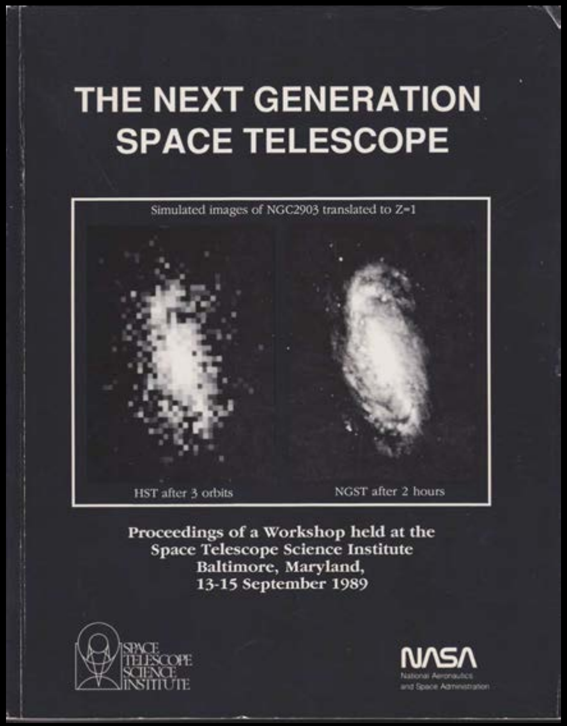
science circa 1989 – pre-Hubble – at the Next Generation Space Telescope workshop

science talks at the 1989 workshop
(a year before Hubble flew and 4 years before Hubble was "fixed")



- NGST and Distant Galaxies, J. Gunn, Princeton
- Planetary Astronomy with a Large Space Telescope, R. Brown, STScI
- Star Formation Studies with a Large Space Telescope, L. Blitz, U of Maryland
- Quasi-stellar Objects and Active Galactic Nuclei: Prospects for a 10 meter Space Telescope, J. Miller, Lick Obs
- Stellar Populations in Galaxies: the Scientific Potential for a 10-16 m Space Telescope, J. Gallagher, AURA
- Quasar Absorption-line Studies with HST Successor, R. Green, NOAO
- Use of 16m Telescope to Detect Earthlike Planets, R. Angel, Steward Obs

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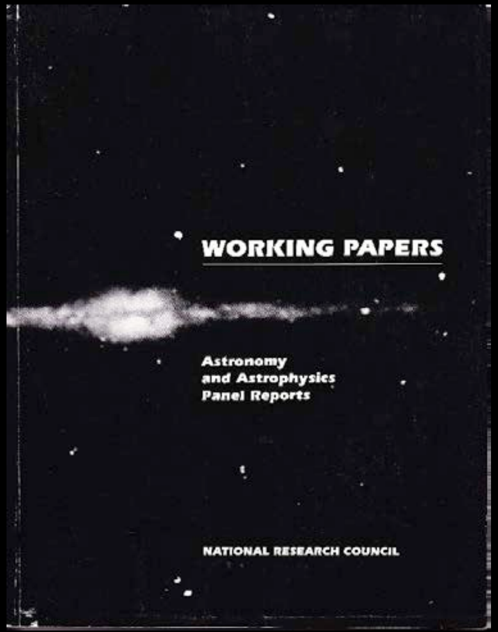
science circa 1990 – examples from the 1990 Decadal Panel (LST = NGST)



science topics covered for LST (NGST) in the 1990 Decadal Panel:

Planetary Systems (detection of (exo)planets – particularly earth-like planets)
Star formation and origins of planetary systems
Structure and Evolution of the Interstellar medium
Stellar Populations
The galactic and extragalactic distance scale
Nature of galaxy nuclei, AGNs, and QSOs
Formation and evolution of galaxies at high redshifts
Cosmology

"The 6 m LST would resolve 3 AU in the nearest star-forming complexes, or 8 AU at Orion at 0.5 μm in the visible. At 3 μm the resolution would be ~ 20 AU and 50 AU respectively. ….. With cooling to ~ 100°K, the background out to ~ 10 μm can be > 18 mag fainter *per resolution element* (< 10^{-7}) than that from the ground."

"The technical challenges confronting the detection and measurement of Earth-like planets are substantial. Such planets would be found ~0.25" from a star at a distance of a few parsecs. An optimal approach would be to detect such an object at ~ 10 µm with a cooled, 16+ m telescope where the first dark diffraction ring corresponds to the planet's orbit. Apodization or interferometric instruments would be used to greatly enhance the contrast of the planet against the light from the star. Then the telescope's low resolution spectroscopic system (with R~100) would be used to obtain a spectrum to search for the signature of ozone (O_3) at 9.5 µm. ……."

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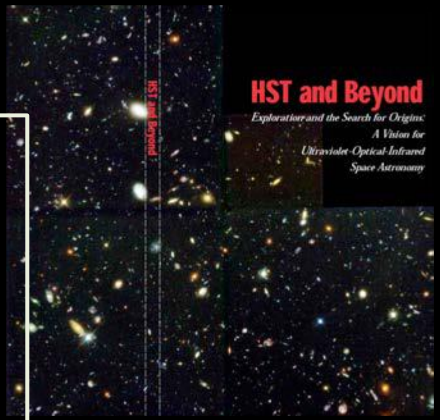
science goals for NGST 1995-2000

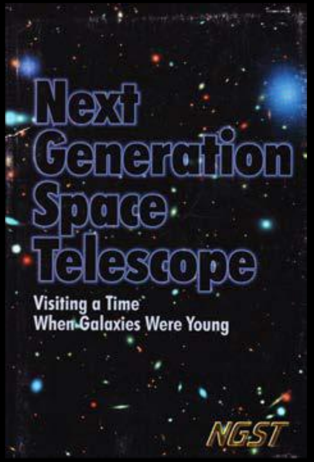
The "HST and Beyond" Panel. *Exploration and the Search for Origins: A Vision for Ultraviolet-Optical-Infrared Space Astronomy* Chaired by Alan Dressler May 1996 excellent science discussion

"….. A cooled telescope optimized for the wavelengths λ ≈ 1 - 5 μm, with 4m or larger aperture, is the key tool for studying the very high redshift universe. In particular, it will enable the Committee's science goal of studying galaxies like the Milky Way in the process of formation."



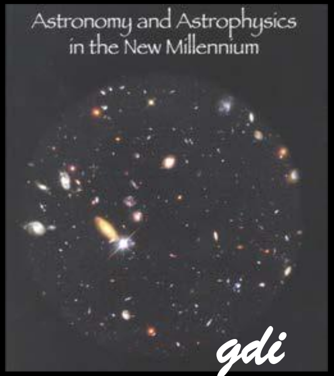
THE NEXT GENERATION SPACE TELESCOPE Visiting a Time When Galaxies Were Young
The NGST Study Team Edited by Peter Stockman *June 1997*

"The observatory will allow astronomers to study the first protogalaxies, the first star clusters as they make their first generation of stars, and the first supernovae as they release heavy chemical elements into the inter- stellar gas. With its exceptional sensitivity and wide fields of view, it will let scientists study a range of topics, everything from interstellar chemistry to brown dwarf stars to potential planets around nearby stars."



2000 Decadal Survey *ASTRONOMY AND ASTROPHYSICS IN THE NEW MILLENNIUM* Released 2001
Page 36 Explanation of new initiatives NGST was the top-ranked project

"Next Generation Space Telescope. NGST is the top priority for this decade because it will reveal the first epoch of star formation and trace the evolution of galaxies from their birth to the present. It will also provide a unique window onto the birth of stars and planets in our own galaxy. Having NGST's sensitivity extend to 27 μm would substantially improve its ability to study Kuiper Belt objects (KBOs) in our solar system, the formation of stars and planets in our galaxy, and the dust emission from galaxies out to redshifts of 3."



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Q?

interestingly the science evolved surprisingly little
in the broad goals

though the details evolved greatly

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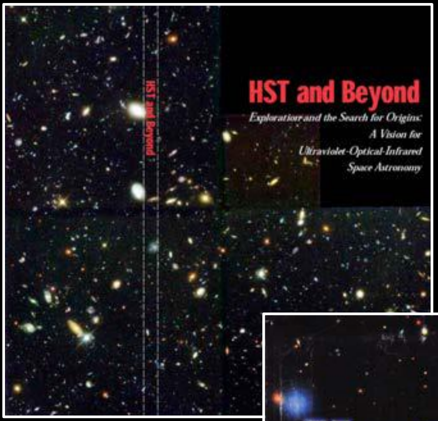
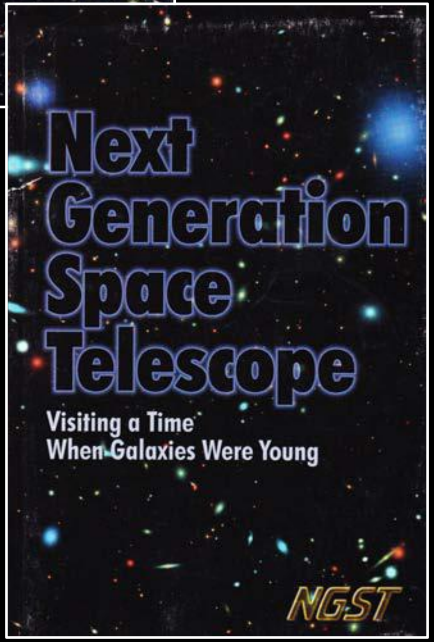
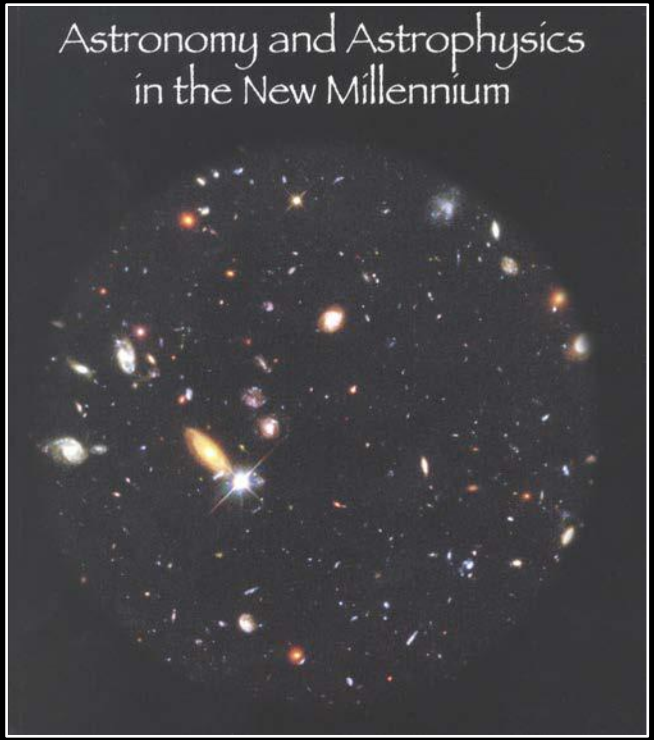
the science case was broad and astronomers were excited

but what was the science used to "sell" NGST to policymakers (Congress, OMB, OSTP, media, etc)





what was the "elevator" speech?



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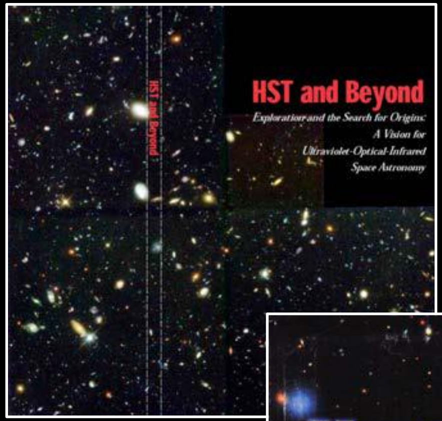

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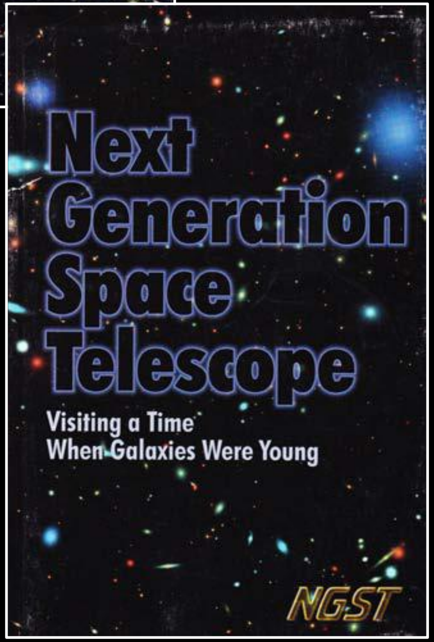
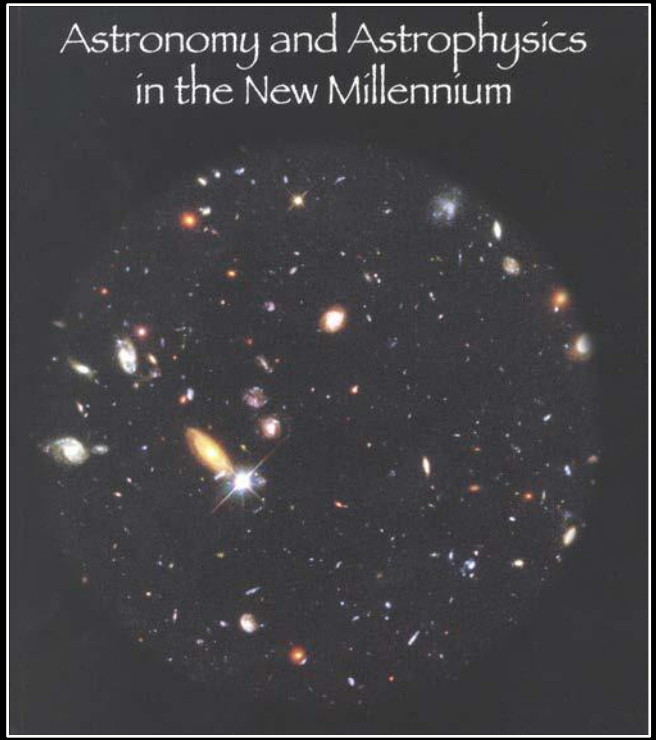


core science goal:

"first light"

"find the first galaxies!"



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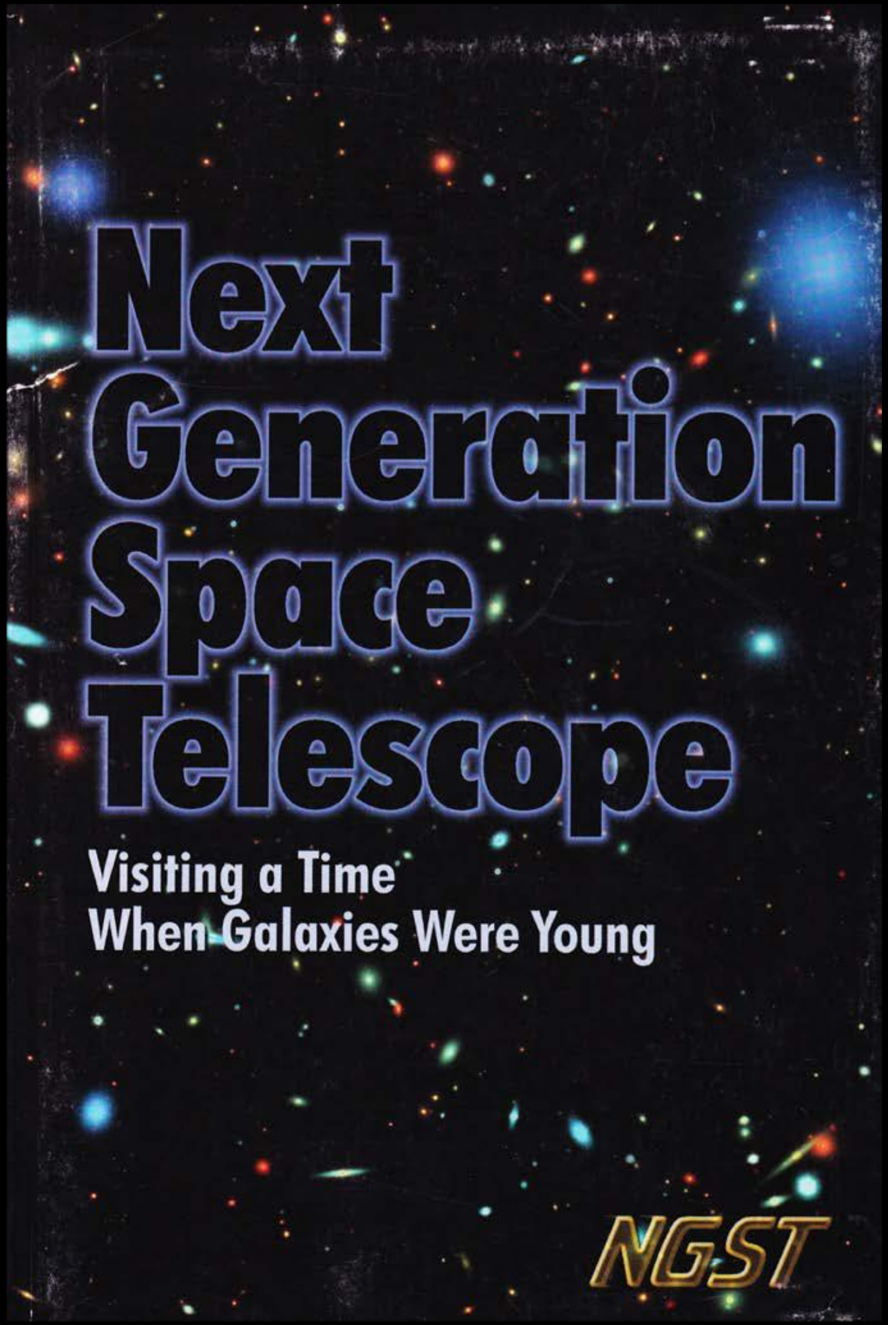

the initial science case:

built largely around “first stars and galaxies”

but for astronomers:

NGST/JWST was always seen as an
“Observatory” – like Hubble –
capable of a huge range of science

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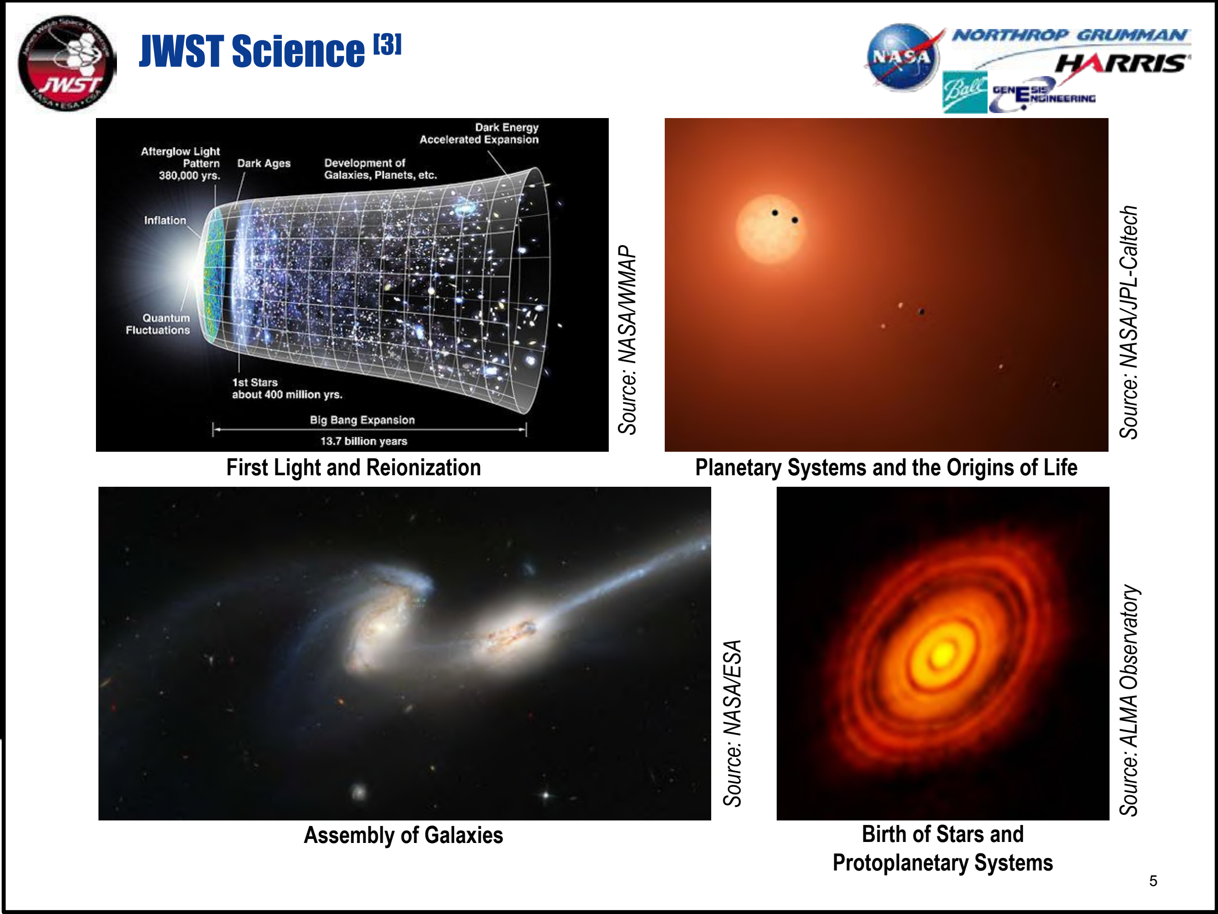
exciting science is crucial

that science case developed further in the 2010-2020 time frame

and expanded as launch approached



SCIENCE

Webb's Science Themes

The James Webb Space Telescope will be a giant leap forward in our quest to understand the Universe and our origins. Webb will examine every phase of cosmic history: from the first luminous glows after the Big Bang to the formation of galaxies, stars, and planets to the evolution of our own solar system.

Early Universe | *Galaxies Over Time* | *Star Lifecycle* | *Other Worlds*

Webb has embarked on a voyage of discovery
Webb is about unearthing the unexpected
Webb will stumble across "unknown unknowns"

JWST's pre-launch Science Themes

Webb will shed light on our cosmic origins

Webb will observe the Universe's first galaxies, reveal the birth of stars and planets, and look for exoplanets with the potential for life.

The End of the Dark Ages: First Light and Reionization - JWST will be a powerful time machine with infrared vision that will peer back over 13.5 billion years to see the first stars and galaxies forming out of the darkness of the early universe.

Assembly of Galaxies - JWST's unprecedented infrared sensitivity will help astronomers to compare the faintest, earliest galaxies to today's grand spirals and ellipticals, helping us to understand how galaxies assemble over billions of years.

The Birth of Stars and Protoplanetary Systems JWST will be able to see right through and into massive clouds of dust that are opaque to visible-light observatories like Hubble, where stars and planetary systems are being born.

Planetary Systems and the Origins of Life JWST will tell us more about the atmospheres of extrasolar planets, and perhaps even find the building blocks of life elsewhere in the universe. In addition to other planetary systems, JWST will also study objects within our own Solar System.

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having great science goals was necessary – but not sufficient

how to ensure that the future Webb user community's science interests were going to be well-served by JWST?

"…..maximizing the science return from JWST….."

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maximizing the science return from JWST

the JWST Advisory Committee (JSTAC)

eight(!) years of JSTAC deliberations and recommendations

JSTAC set up by STScI Director Matt Mountain, with Agency ex-officio participation.

Matt asked me to Chair JSTAC to provide advice that would help STScI and NASA maximize the science return from JWST for the future science community users

excellent committee with very experienced international members

https://www.stsci.edu/jwst/about/history/jwst-advisory-committee-jstac

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JSTAC members

an amazingly capable, experienced and committed group of members

JSTAC members (* new members in 2015/16)

• Roberto Abraham	University of Toronto
• Neta Bahcall	Princeton University
• Natalie Batalha*	NASA Ames Research Center
• Stefi Baum	Rochester Institute of Technology
• Roger Brissenden	Smithsonian Astrophysical Observatory
• Timothy Heckman	Johns Hopkins University
• Kelsey Johnson*	University of Virginia
• Heather Knutson*	Caltech
• Malcolm Longair	Cavendish Laboratory, University of Cambridge
• Garth Illingworth	Chair, University of California, Santa Cruz
• Christopher McKee	University of California, Berkeley
• Bradley Peterson	Ohio State University
• Joseph Rothenberg	JHR Consulting
• Sara Seager	Massachusetts Institute of Technology
• Lisa Storrie-Lombardi	Spitzer Science Center, Caltech
• Tommaso Treu*	University of California, Los Angeles
• Monica Tosi	INAF – Osservatorio Astronomico di Bologna

JSTAC Ex-officio observers from the Space Agencies

Hashima Hasan	NASA HQ
John Mather	NASA GSFC
Mark McCaughrean	ESA
Alain Ouellet / Jean Dupuis	CSA
Eric Smith	NASA HQ

Key STScI Interfaces

Massimo Stiavelli	JWST Mission Office Head
Neill Reid	Science Mission Office Head
Nikole Lewis	JWST MO Project Scientist
Jason Kalirai	JSTAC Executive Secretary (1)
Janice Lee	JSTAC Executive Secretary (2)

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The JWST Advisory Committee (JSTAC) charter & some letters

"The committee is charged with advising the STScI Director on the optimum strategies and priorities, consistent with NASA policy and international agreements, for the operations of the James Webb Space Telescope in order to maximize its scientific productivity."

18 letters from 2009 to 2017. Several presentations and reports. Several STScI newsletter articles.

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April 14, 2016

the negative impact of proprietary time on JWST science productivity

Dr Ken Sembach, Director
Space Telescope Science Institute
3700 San Martin Drive
Baltimore, MD 21218

Re: Update regarding JSTAC discussion of the Proprietary Time/Exclusive Use period for JWST

Dear Director Sembach:

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GO funding – study recommendation for $64M/yr

May 22, 2015

Dr. Kathryn Flanagan, Interim Director
Space Telescope Science Institute
3700 San Martin Drive
Baltimore, MD 21218

Re: JSTAC assessment of GO funding levels for JWST

Dear Director Flanagan:

on JSTAC STScI website

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Early Release Science programs and open access fields

March 26, 2014

Dr. Matt Mountain, Director
Space Telescope Science Institute
3700 San Martin Drive
Baltimore, MD 21218

Re: JSTAC recommendations regarding Early Release Science and Community Fields

Dear Director Mountain:

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Early Release Science (ERS) programs

December 19, 2016

Dr Ken Sembach, Director
Space Telescope Science Institute
3700 San Martin Drive
Baltimore, MD 21218

Re: JSTAC recommendations regarding the JWST ERS program

Dear Director Sembach:

gdi

JSTAC members

an amazingly capable, experienced and committed group of members

JSTAC ran for nearly 8 years with only a little turnover since the team were an almost uniquely-experienced group dealing with complex issues of science policy in an evolving environment

recommendations were developed with discussions with STScI (science center), space agency JWST key leadership people (international – NASA, ESA, CSA), and with JWST Project science team members and community instrument team members

many of its recommendations were implemented and many are still very relevant for "*maximizing the science return from JWST*" 10-15 years later

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Q?

we have seen what NGST was in 2002

and its science framework

how did we get to launch from 2002
and the first images in 2022?

and why did it take so long!

gdi

slowly, painfully and at great expense

but with astonishingly capable people who made it all happen

gdi

doing a space science mission:
NASA's life cycle phases of Formulation and Implementation

Program Pre-Formulation:

- Pre-Phase A: Concept Studies — NGST – 1986 to 1999 informally much of the time

Program Formulation

- Phase A: Concept and Technology Development — NGST – 1999
- Phase B: Preliminary Design and Technology Completion — JWST – 2003

Program Implementation:

- Phase C: Final Design and Fabrication — JWST – 2008
- Phase D: System Assembly, Integration and Test, Launch — JWST – 2018?
- Phase E: Operations and Sustainment — JWST – 2022
- Phase F: Closeout — **JWST – 2045???**

(Phase E is where we do science)

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NGST "started" 2001 (though FAD in 1999 – Phase A start)

2001: tight budget – NGST de-scoped from 8m to 6.5m

Late 2002: Prime contractor selected (TRW)

NGST renamed James Webb Space Telescope (JWST)

(prematurely without any consultation with JWST Project or Program or JWST scientists)

rough road after 2002

NGST became "real" with the selection of TRW as prime contractor in late 2002
(TRW was soon after bought out by Northrop Grumman)

NGST, now JWST, entered Phase B in 2003

(still in Formulation Phase: Preliminary Design and Technology Completion)

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many rocky shoals on JWST's path to delivery

almost immediately cost and schedule issues arose

each year was a budgetary challenge

Mike Griffin (NASA administrator from 2005-2009)
noted (with some frustration):
"JWST was undercosted from the start"

- ⎔ budget increased each year
- ⎔ efforts to minimize cost growth
- ⎔ but problems continued.....

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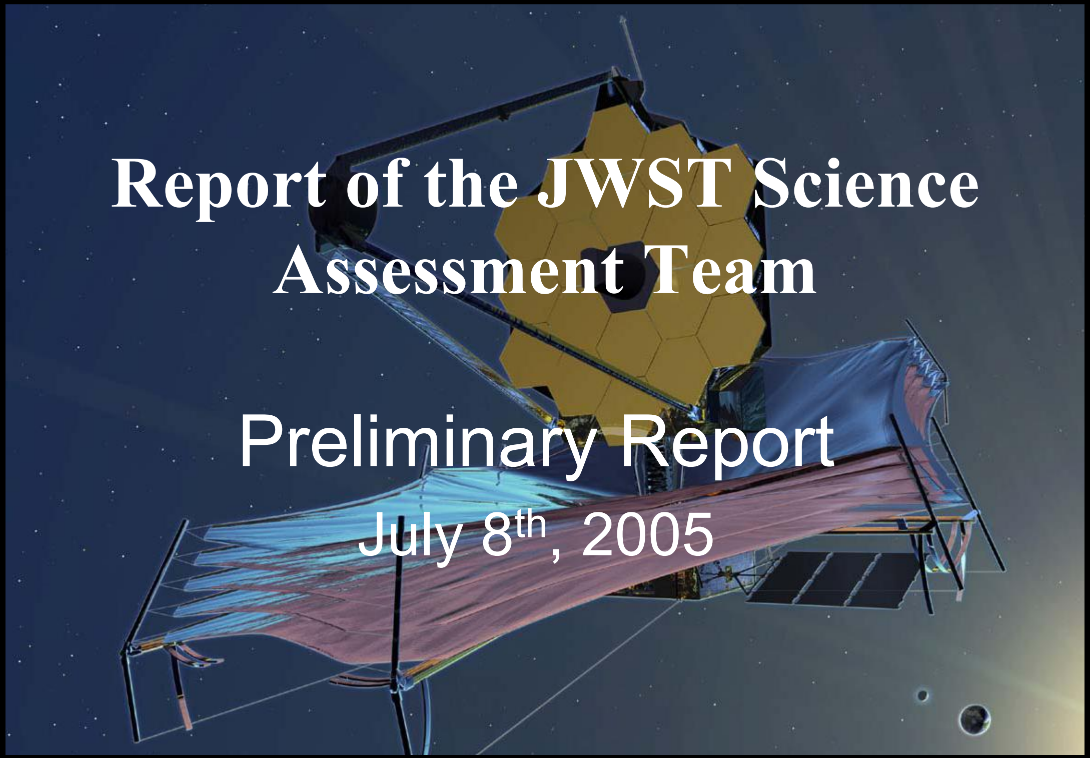
2005 Science Assessment Team (SAT)
co-Chaired by two scientists
Matt Mountain and Peter Stockman

well-written report with considerable discussion and assessment of science goals to frame their recommendations

provided rationale for significant cost savings for the Project



The SAT recommended a number of key changes that saved the JWST Project a substantial amount of money and time (= money):

1) change the encircled energy requirement (diffraction-limited) from 1 μm to 2 μm; also lessened stability requirements; also lessened anisotropy requirement
2) lessened the scattered light requirement (eased contamination requirements)
3) supported simplified I&T as a result of (2) and endorsed "cup-up" testing approach

gdi

SAT endorsed “cup-up” approach

instead of hanging JWST upside down for cryogenic vacuum testing (then current plan!) SAT committee recommended **“cup-up”**

– cheaper and safer approach –

optical telescope and instruments (OTIS) going into Chamber A in Houston at Johnson Space Center

three month cryogenic vacuum test

excellent progress on JWST in many technical areas (mirrors, instruments, required technologies)

but four more years of budget problems ensued

re-baselining the Project cost (and schedule) every two years

NASA approved JWST for Phase C in July 2008
(Final Design and Fabrication)

launch set mid-2014, construction budget of ~$4B

but by 2010, there were still serious budget issues

Office of Management and Budget (OMB) and Congressional support was waning

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2010 Test Assessment Team (TAT)
Chaired by John Casani
(JPL Cassini/Galileo Project Manager)

TAT team was asked to assess the JWST Project's plans:
(1) for thermal vacuum testing for ISIM (instrument module)
(2) testing for OTIS (the cold telescope-instrument system)

the TAT said the cold thermal vacuum (T-V) testing must go ahead to ensure mission success

but recommended a number of key changes
– added I&T leadership; shorter T-V tests; etc –

saved both cost and schedule while minimizing risk

James Webb Space Telescope (JWST)
Test Assessment Team (TAT)

FINAL REPORT

Team Members	
John Casani, Chair	Jet Propulsion Laboratory
Alan Dressler	Observatories of the Carnegie Institution
William Irace	Jet Propulsion Laboratory
Matt Mountain	Space Telescope Science Institute
Jerry Nelson	University of California, Santa Cruz
Jim Oschmann	Ball Aerospace & Technologies Corp.
Al Sherman	Allan Sherman, LLC
Georg Siebes	Jet Propulsion Laboratory
Erick Young	Universities Space Research Association
NASA Consultants	
Milt Heflin	NASA Johnson Space Center
Jeff Kegley	NASA Marshall Space Flight Center
Mike Ryschkewitsch	NASA Headquarters
Executive Secretary	
Erin Elliott	Space Telescope Science Institute

August 27, 2010

JPL
Jet Propulsion Laboratory
California Institute of Technology

the independent teams, the SAT and the TAT helped the Project take cost-saving approaches that did not impact the science capability

gdi

2009-2010 political/budget crisis

the continual cost growth, and schedule slips, of JWST since 2002 was raising the specter of congressional action to kill JWST

Senator Mikulski was a JWST supporter –
but was worried and finding it hard to defend JWST

the Launch Readiness Date LRD of mid-2014, at a budget level for Phase A-D of ~$4B, was losing credibility

– JWST actually had already lost credibility amongst some policymakers –

Senator Mikulski decided that action was needed and wrote to NASA Administrator Bolden

gdi

2010

request for an independent review by Senator Mikulski

BARBARA A. MIKULSKI
MARYLAND

SUITE 503
HART SENATE OFFICE BUILDING
WASHINGTON, DC 20510–2003
(202) 224–4654
TDD: (202) 224–5223

United States Senate
WASHINGTON, DC 20510–2003

June 29, 2010

Lt. General Charles Bolden (Ret.)
Administrator
National Aeronautics and Space Administration
300 E Street, SW
Washington, DC

Dear Mr. Administrator:

The James Webb Space Telescope (JWST) will be the most scientificall
NA ever built – 100 times more powerful than the Hubble which
tex provided all of the funding requested for the J
ov have required an additional
ye

I request that you immediately init
by experts from outside of NASA. I recommend
office and that you appoint individuals with the depth and range o
complete development of JWST within budget and on schedule. The members o
should be familiar with NASA management processes for large projects, as well as the Centers,
contractors, and science involved in this project.

The panel should examine carefully four areas:

1. The technical, management and budgetary root causes of cost growth and schedule delay
2. Current plans to complete development, with particular attention to the integration and testing program and management structure

SUITE 400, 1629 THAMES STREET, BALTIMORE, MD 21231, (410) 962–4510
SUITE 202, 60 WEST STREET, ANNAPOLIS, MD 21401–2448, (410) 263–1805
SUITE 406, 6404 IVY LANE, GREENBELT, MD 20770–1407, (301) 345–5517
ROOM 203, 32 WEST WASHINGTON STREET, HAGERSTOWN, MD 21740–4804, (301) 797–2826
SUITE 1, BUILDING B, 1201 PEMBERTON DRIVE, SALISBURY, MD 21801–2403, (410) 546–7711

http://mikulski.senate.gov/

r diminish the risk of future c
ce

h the associated launch date a

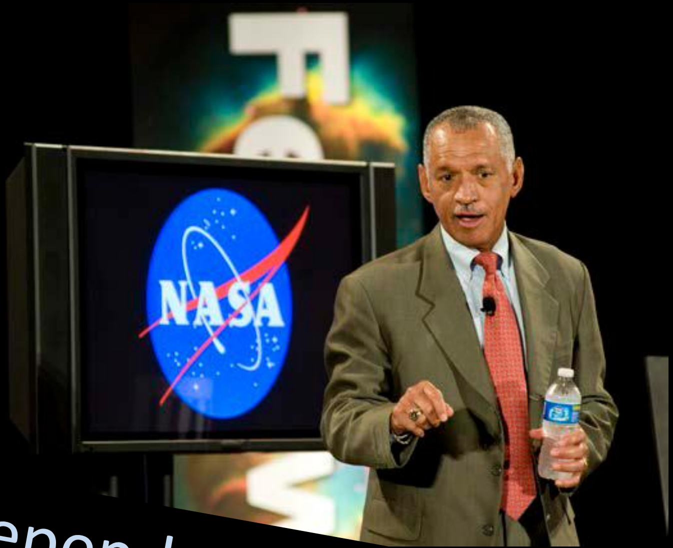
te reserves

lowest overall co

Thank yo
and an appropriate respo
any questions about this request.

Sincerely,

Barbara A. Mikulski
Chairwoman
Subcommittee on Commerce, Justice, Science
and Related Agencies
Committee on Appropriations

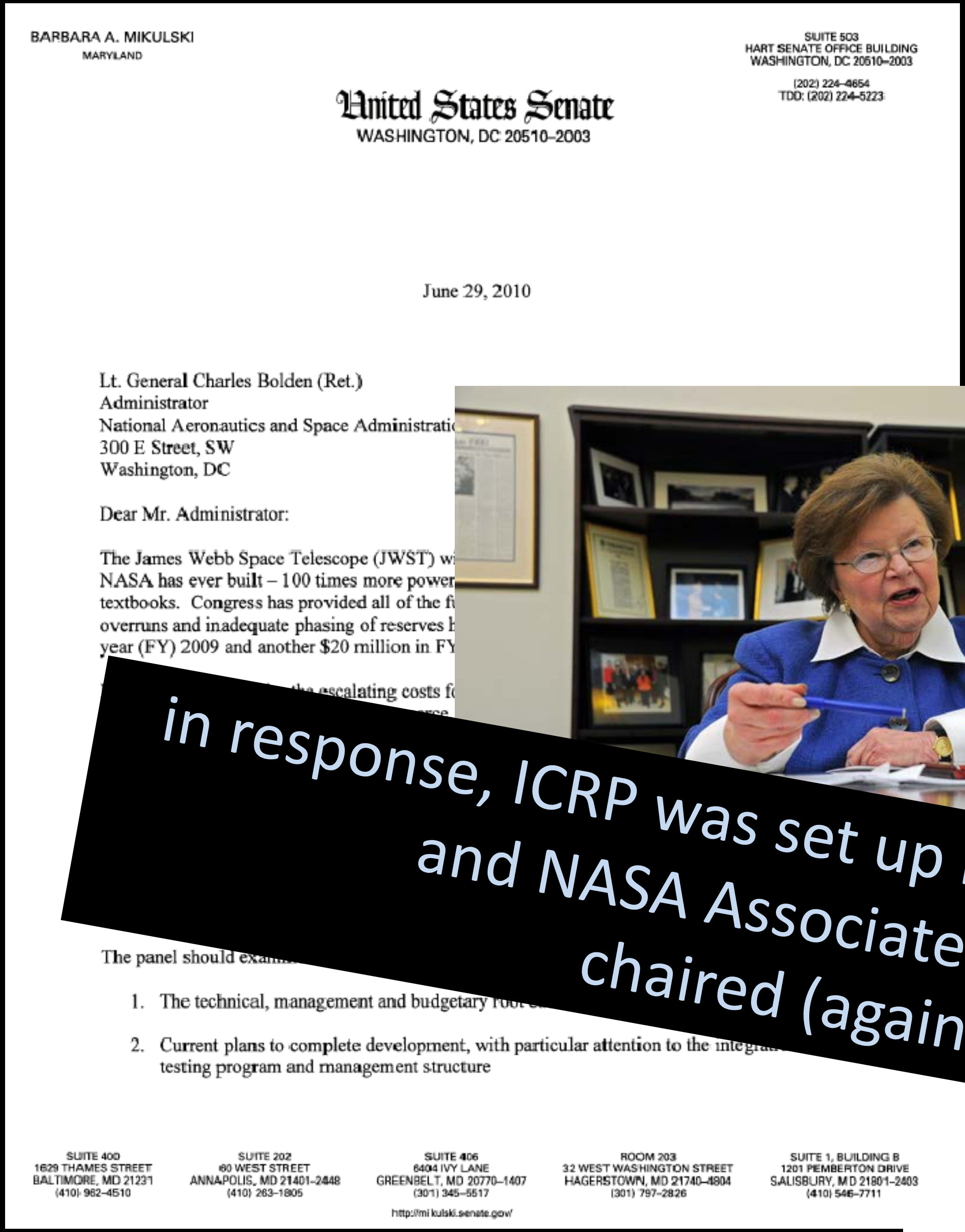


Senator Mikulski ‘requested’ that NASA set up an independent review
June 29 2010 letter to NASA Administrator Bolden

gdi

late 2010

Independent Comprehensive Review Panel (ICRP)



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June 29, 2010

Lt. General Charles Bolden (Ret.)
Administrator
National Aeronautics and Space Administratio
300 E Street, SW
Washington, DC

Dear Mr. Administrator:

The James Webb Space Telescope (JWST) wi
NASA has ever built – 100 times more power
textbooks. Congress has provided all of the fu
overruns and inadequate phasing of reserves h
year (FY) 2009 and another $20 million in FY

The panel should exam

1. The technical, management and budgetary roo

2. Current plans to complete development, with particular attention to the integra
testing program and management structure

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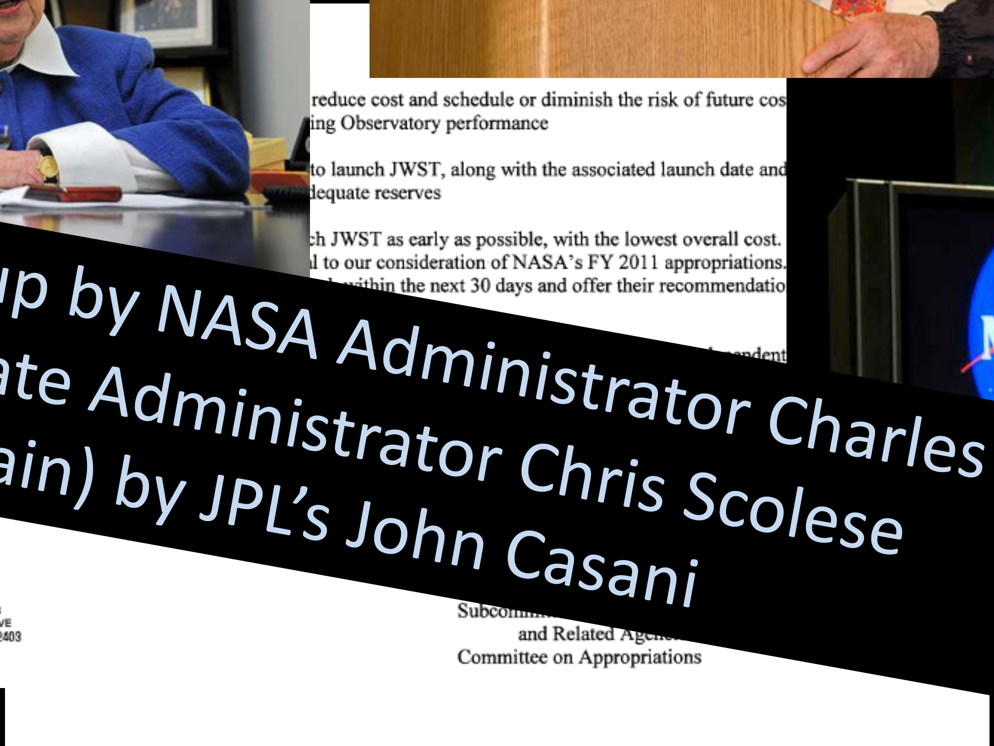
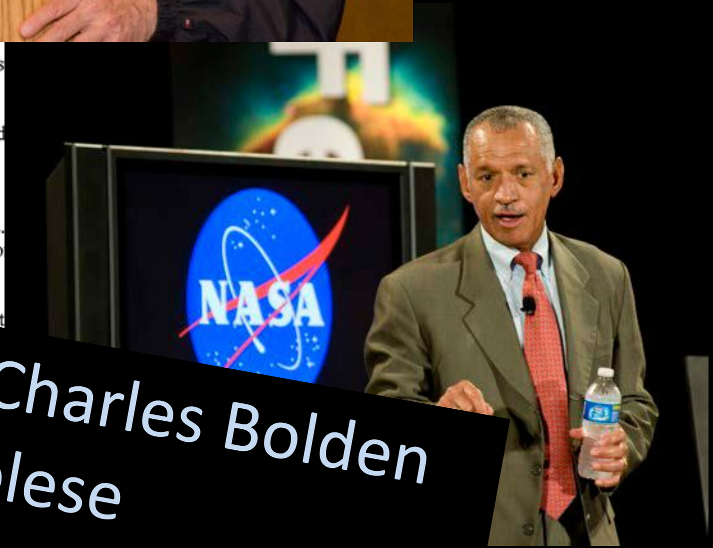


reduce cost and schedule or diminish the risk of future cos
ing Observatory performance

to launch JWST, along with the associated launch date and
dequate reserves

ch JWST as early as possible, with the lowest overall cost.
l to our consideration of NASA's FY 2011 appropriations.
within the next 30 days and offer their recommendatio

Subcomm
and Related Agen
Committee on Appropriations



in response, ICRP was set up by NASA Administrator Charles Bolden and NASA Associate Administrator Chris Scolese chaired (again) by JPL's John Casani

gdi

Independent Comprehensive Review Panel report

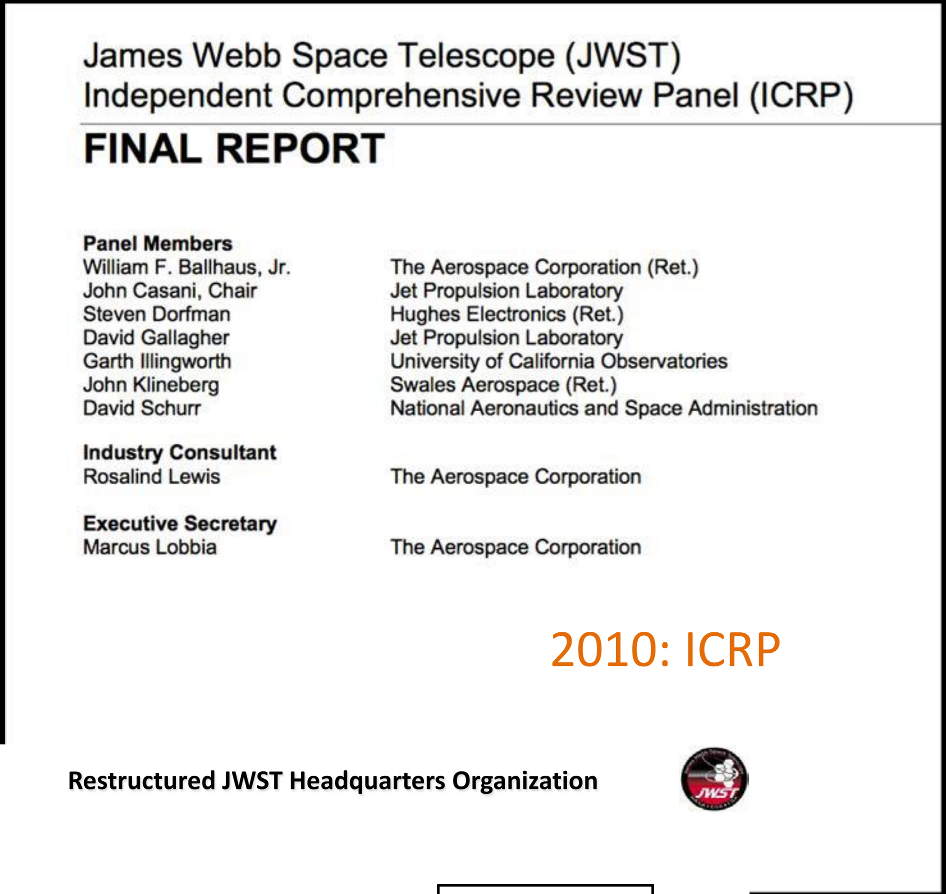
hard-hitting, forthright report!

key recommendations:

- do a bottoms-up cost and schedule assessment to get a more realistic launch date and total cost
- budget with adequate cost reserves (to 80% cost confidence), requiring >~25% cost reserves each year
- remove JWST Program from Astrophysics and make it a stand-alone Division within SMD, reporting to the NASA Administrator's office

detailed findings with 22 recommendations
NASA accepted all

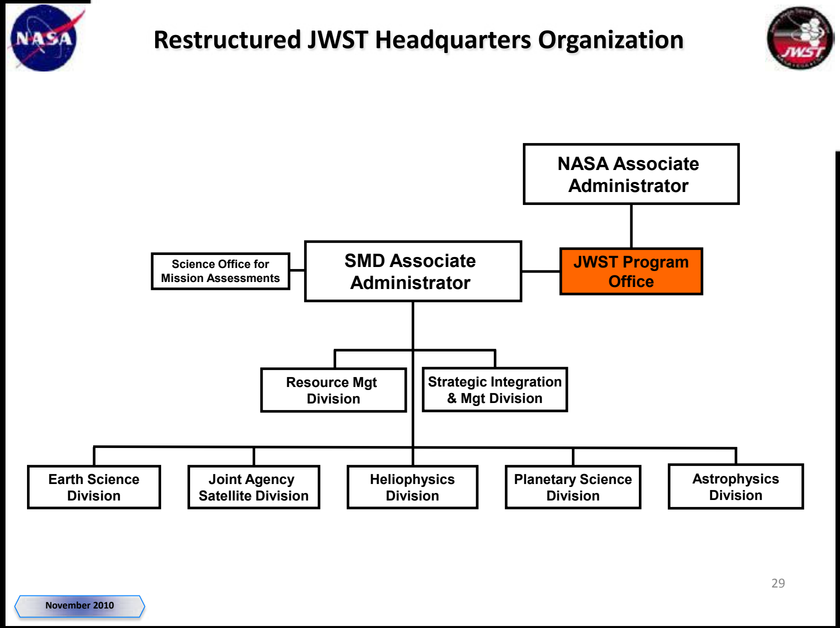
without this report, and the subsequent budget and schedule reassessment, in my view, JWST would have died
– like the Superconducting Super Collider (SSC) –


James Webb Space Telescope (JWST)
Independent Comprehensive Review Panel (ICRP)

FINAL REPORT

Panel Members	
William F. Ballhaus, Jr.	The Aerospace Corporation (Ret.)
John Casani, Chair	Jet Propulsion Laboratory
Steven Dorfman	Hughes Electronics (Ret.)
David Gallagher	Jet Propulsion Laboratory
Garth Illingworth	University of California Observatories
John Klineberg	Swales Aerospace (Ret.)
David Schurr	National Aeronautics and Space Administration
Industry Consultant	
Rosalind Lewis	The Aerospace Corporation
Executive Secretary	
Marcus Lobbia	The Aerospace Corporation

2010: ICRP



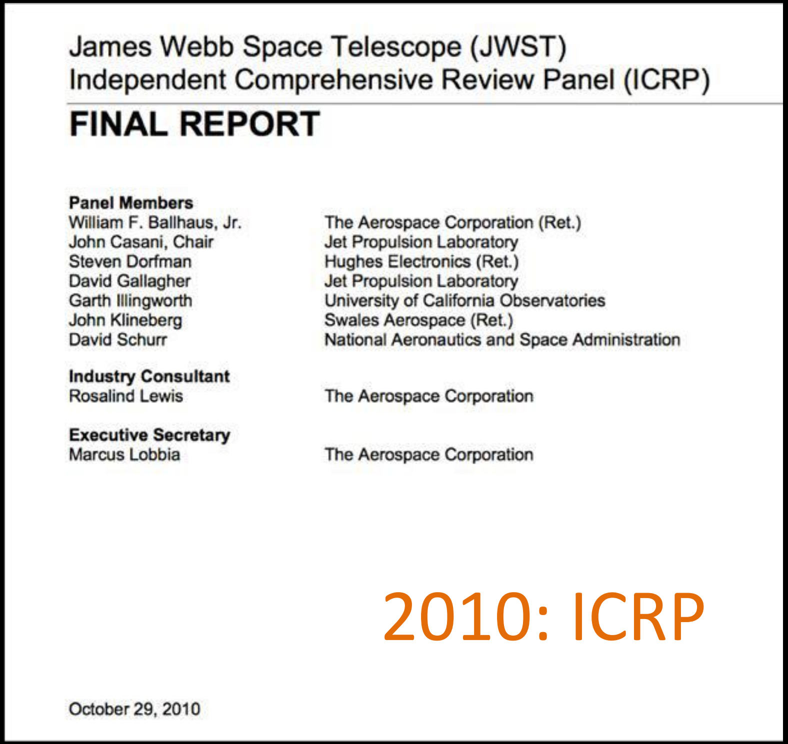
gdi

Independent Comprehensive Review Panel report

why did JWST go so wrong?

1) low initial budget
2) lack of reserves
3) challenging new technologies being developed late
4) deferral of work at crucial times

item 4) deferral of work proved to be very damaging to progress and resulted in uncontrollable cost growth – without reserves to rectify an issue quickly the cost impact is typically 2-3X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Executive Secretary	
Marcus Lobbia	The Aerospace Corporation

October 29, 2010

2010: ICRP

(1) ICRP said that JWST needed at least 2 more years to launch (from 2014 to late 2015) and would have a lifecycle cost LCC of ~$6.5B, up from an LCC of ~$5B….

(2) ICRP recommended that NASA do a more comprehensive cost and schedule analysis (Joint Confidence Level – JCL) assessment to 80% cost confidence

Congress & OMB (Office of Management and Budget) very unhappy

gdi

Q?

NASA stepped up to the plate to support and replan JWST.….

gdi

NASA's excellent response to ICRP

Rick Howard – new JWST Division Director

Rick led replan effort with full involvement of the JWST Project

Rick Howard, HQ
JWST Program Director

replan was a bottoms-up activity that required a cost/schedule assessment of all the elements of the project from the contractors and NASA – a JCL

a Joint Cost and Schedule Confidence Level (JCL) analysis involves cost, schedule, risk and uncertainty in a probabilistic analysis

a JCL analysis gives the probability that a project's cost will come in at (or below) the resulting cost, and that the schedule will be no later than the given date.

the JWST 2011 JCL was a very comprehensive re-assessment
the replan exceeded the ICRP's recommendation at 80% cost confidence

NASA's JCL response to ICRP

replan completed in May 2011 ~6 month after ICRP

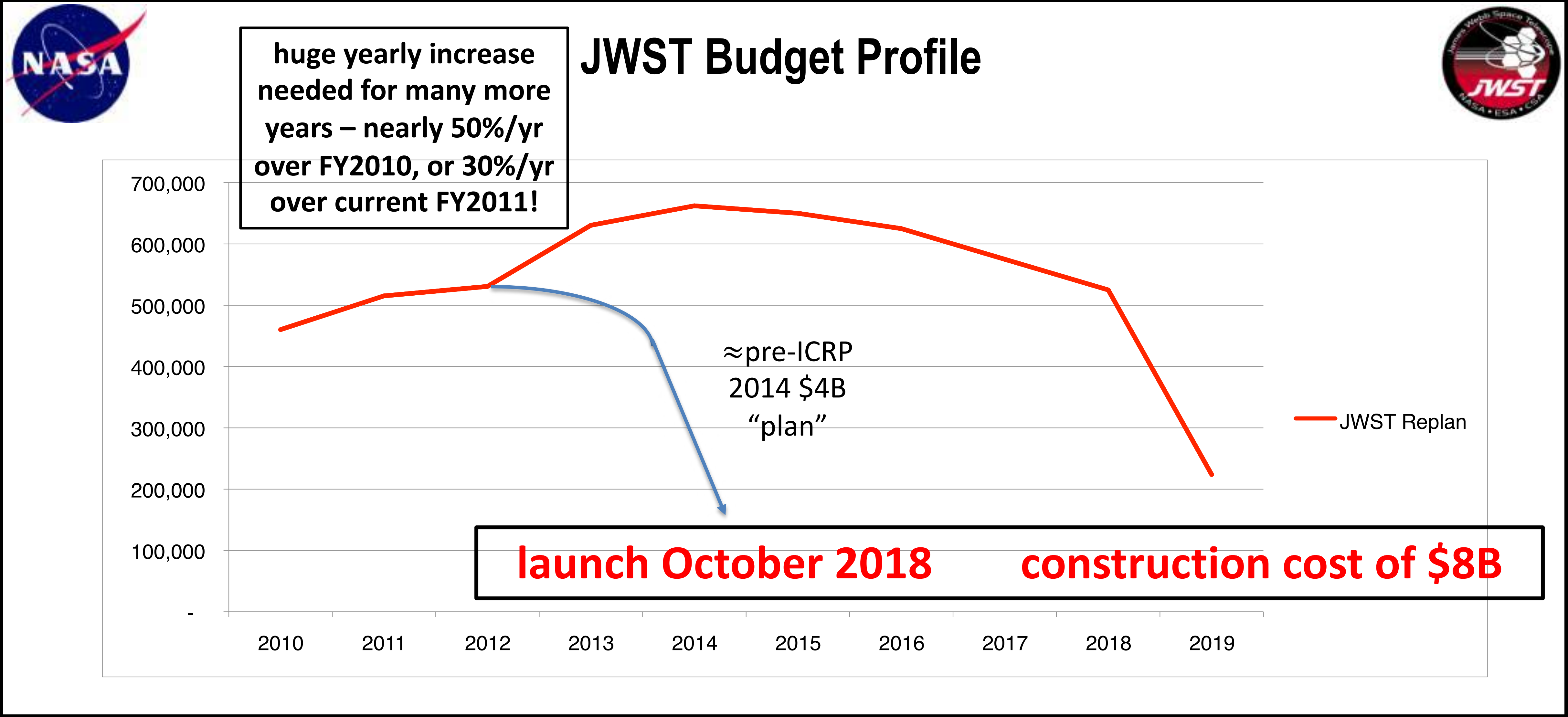
Launch Readiness Date (LRD) was October 2018

Phase A-D (Formulation through Implementation/Construction) cost would be $8B
includes Integration and Test (I&T) and launch

LifeCycle Cost (LCC) that includes science operations of $8.837B

this required:
(1) a huge increase in funding for many more years
(2) an *immediate* increase so that JWST could launch (LRD) October 2018!

NASA's replan completed in May 2011



OMB (Office of Management and Budget) and Congress were even unhappier than before!

gdi

the day JWST died.....

gdi

July 7 2011 the day JWST died....

on July 7 2011 JWST was killed by Chairman Frank Wolf of the
House Appropriations Commerce, Justice, Science Subcommittee:

"$4.5 billion for NASA Science programs, which is $431 million below last year's level. The bill also terminates funding for the James Webb Space Telescope, which is billions of dollars over budget and plagued by poor management"

this was a real risk to JWST and a hugely challenging time

there were people who said "Senator Mikulski will get the funding restored"

but folks who had been in Congress said "take this seriously"

so we did!

so many folks worked hard to set the stage so that the House and Senate
could negotiate a way out with the Senate

gdi

working to recover JWST….

misinformation from critics, astronomers and others, was a serious problem (what's new!)

so there were efforts to provide "talking points" for the media, astronomers and supporters (9 page example here)

support for JWST from the astronomy community was necessary, but not sufficient – other support was needed

great support from Nobel laureates (letter from 32 Nobel Laureates)

and support from other prominent people

Re: JWST – Section 1 of 3 – Background and Challenges

From: Garth Illingworth

This memo set consists of three parts: (1) discusses the background and the consequences of terminating JWST; (2) summarizes the impacts of terminating JWST in 10 "talking points"; and (3) highlights 10 myths regarding JWST that occur in conversation and print.

This is Part (1)

(1) Background and Challenges

****

Re: JWST – Section 2 of 3 – Impacts ("Talking Points")

From: Garth Illingworth

This memo set consists of three parts: (1) discusses the background and the consequences of terminating JWST; (2) summarizes the impacts of terminating JWST in 10 "talking points"; and (3) highlights 10 myths regarding JWST that occur in conversation and print.

This is Part (2)

(2a) Ten Impacts of Terminating JWST

(2b) Ten Reasons to do JWST

****

Re: JWST – Section 3 of 3 – Myths

From: Garth Illingworth

This memo set consists of three parts: (1) discusses the background and the consequences of terminating JWST; (2) summarizes the impacts of terminating JWST in 10 "talking points"; and (3) highlights 10 myths regarding JWST that occur in conversation and print.

This is Part (3)

(3) Ten JWST Myths

gdi

letter from 32 Nobel Laureates

3400 Rosemary Lane
Hyattsville, MD 20782
August 22, 2011

Thomas Feyer
Letters to the Editor
The New York Times
620 Eighth Avenue
New York, NY 10018
letters@nytimes.com

Dear Mr. Feyer:

I am submitting the following letter on behalf of the 32 Nobel Prize winners (including me) listed below. I read your instructions on the Times web site and the actual text of our letter is 150 words long as you recommend, but the list of signers is much longer. I note that you also require a letter to be submitted within 7 days of the Times article; needless to say it takes a little while to obtain the support of 32 Nobelists!

Sincerely,

John C. Mather

In reference to the NY Times editorial entitled "Way Above the Shuttle Flight", on July 9th, 2011, and frequent columns and letters regarding the future of NASA and space exploration:

The James Webb Space Telescope is the natural successor to the iconic Hubble Space Telescope, reaching well beyond Hubble's limits, revealing secrets even Hubble cannot. From seeing the first galaxies in the universe, to studying extrasolar planets with liquid water, JWST will provide humanity with new insights on the origin of the cosmos, and on our place within it.

The discoveries of JWST will be the source of awe and inspiration for the next generation. Cancellation of JWST would deal a fatal blow to large and ambitious space science missions for the foreseeable future, and would deny the public access to new and exciting images of the type that have captured the imagination of people of all ages.

We support careful oversight over the future plans and budgets of the JWST mission, and we believe that every possible effort should be made to launch JWST as early as possible.

Signed by 32 Nobel Prize winners:

Peter Agre, Nobel Laureate, Chemistry 2003
Sidney Altman, Nobel Laureate, Chemistry 1989
Robert Aumann, Nobel Laureate, Economics 2005
Elizabeth Blackburn, Nobel Laureate, Physiology or Medicine 2009
Günter Blobel, Nobel Laureate, Physiology or Medicine 1999
Mario Capecchi, Nobel Laureate, Physiology or Medicine 2007
Thomas Cech, Nobel Laureate, Chemistry 1989
Martin Chalfie, Nobel Laureate, Chemistry 2008
James W. Cronin, Nobel Laureate, Physics 1980
Johann Deisenhofer, Nobel Laureate, Chemistry 1988
Val Fitch, Nobel Laureate, Physics, 1980
Riccardo Giacconi, Nobel Laureate, Physics 2002
Roy J. Glauber, Nobel Laureate, Physics 2005
Sheldon Glashow, Nobel Laureate, Physics 1979
Joseph L. Goldstein, Nobel Laureate, Physiology or Medicine 1985
David J. Gross, Nobel Laureate, Physics 2004
Carol W. Greider, Nobel Laureate, Physiology or Medicine 2009
John L. Hall, Nobel Laureate, Physics 2005
Russell A. Hulse, Nobel Laureate, Physics 1993
Roger D. Kornberg, Nobel Laureate, Chemistry 2006
Roderick MacKinnon, Nobel Laureate, Chemistry 2003
John C. Mather, Nobel Laureate, Physics 2006
Craig Mello, Nobel Laureate, Physiology or Medicine 2006
Douglas D. Osheroff, Nobel Laureate, Physics 1996
William D. Phillips, Nobel Laureate, Physics, 1997
Phillip Sharp, Nobel Laureate, Physiology or Medicine 1993
Hamilton Smith, Nobel Laureate, Physiology or Medicine 1978
George F. Smoot, Nobel Laureate, Physics, 2006
Thomas A. Steitz, Nobel Laureate, Chemistry 2009
Jack W. Szostak, Nobel Laureate, Physiology or Medicine 2009
Steven Weinberg, Nobel Laureate, Physics 1979
Frank Wilczek, Nobel Laureate, Physics 2004

working to recover JWST….

JWST got great support from physicists and physics societies who did not want a major science project demise like the Super Conducting Supercollider (SSC) in the 1990s

but there were senior astronomers working to kill JWST (sadly)!

much less support from the Astronomy society (AAS)
than physics societies and planetary societies

fortunately, JWST got impressive public support in emails/letters to Congress from planetarium groups around the country, and even more remarkably from school groups, teachers and school kids

that was incredibly impressive and very effective!

I got one from a teacher in Kansas asking how they could help – just wonderful!

gdi

Chairman Wolf responded to the support for JWST and a solution was worked between the Senate and House appropriation committees

a formal announcement to support JWST came in the November 2011 – in the senate-house conference budget language –

Goddard Director Chris Scolese
with Senator Mikulski

the support and efforts by Senator Mikulski helped greatly

Congress put on a strongly-worded cap of $8B for JWST construction cost with launch 2018

gdi

a saga – but obviously JWST recovered ....

effort still needed to help build support in Congress and OMB for much larger budget

December 06 2011 Hearing on JWST:
U.S. House of Representatives Committee on Science, Space, and Technology
"The Next Great Observatory: Assessing the James Webb Space Telescope"
Witnesses were: Rick Howard, Program Director, JWST, NASA HQ
Roger Blandford, Stanford , 2010 Decadal Chair
Garth Illingworth, UCSC, [ICRP & AAAC & JSTAC]
Jeffrey D. Grant, VP & GM, Space Systems Division, Northrop Grumman

post-recovery it was still a hard slog for NASA and supporters to ramp up to the NASA JCL budget profile

but within a year or so OMB and Congress kept JWST's budget on the profile

until....

gdi

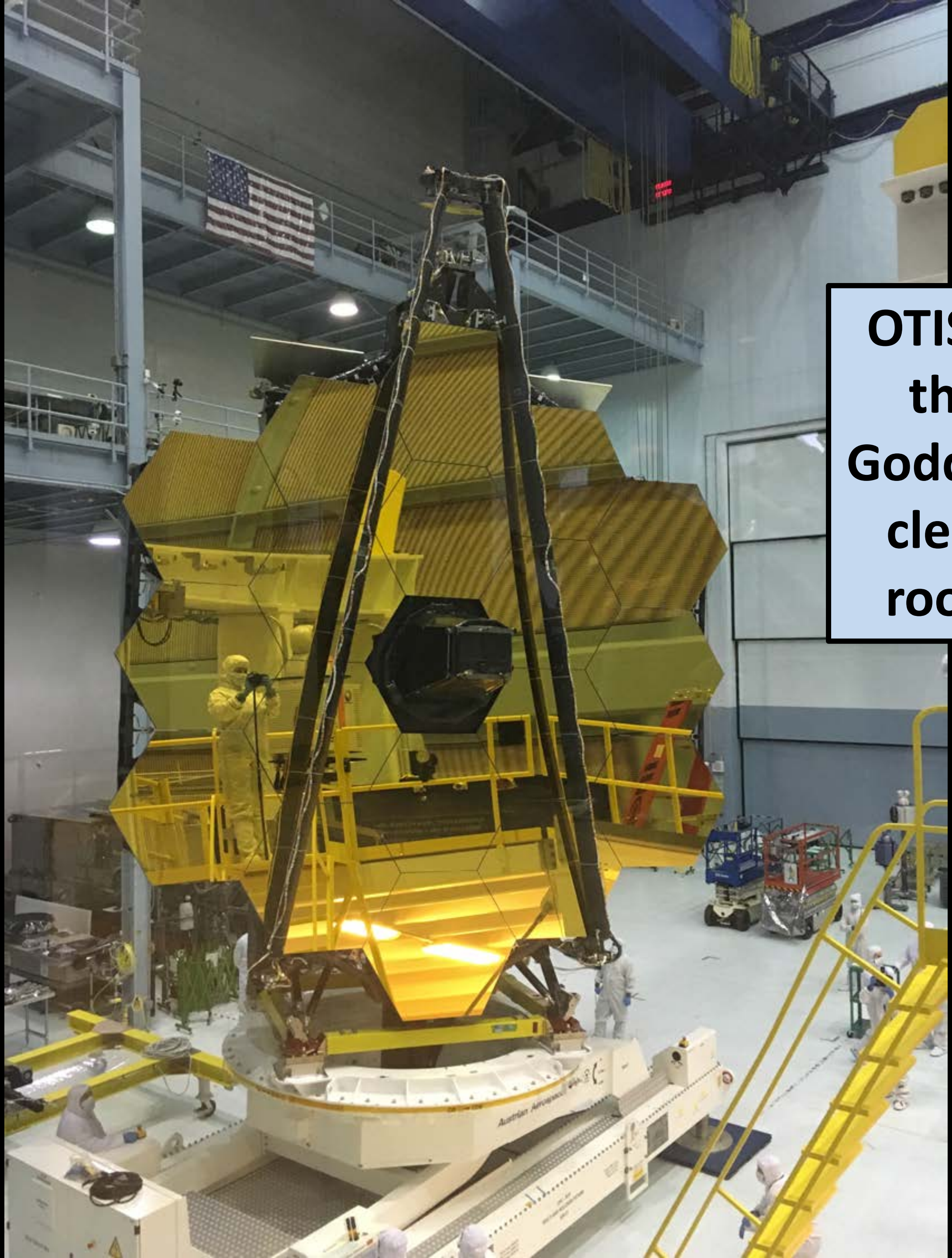
Q?

the mostly good five years….

gdi

ISIM being attached to the OTE in the Goddard clean room

OTIS in the Goddard clean room



OTIS in Goddard clean room

gdi

good progress on JWST for next 5 years from 2012 to 2017

telescope and instruments at Goddard Space Flight Center (GSFC) in Maryland (2016)

in parallel, sunshield and spacecraft were being built up at Northrop Grumman in Los Angeles

Rick Howard and I led a small group that provided some independent oversight of the JWST project reporting to the Goddard Center Director from 2015

gdi

largely good progress on JWST for 5 years

sunshield was particularly challenging, but Northrop was making good progress

MIRI cryocooler was challenging – running behind schedule and over cost (Northrop effort managed by JPL) but eventually a good unit was delivered to the Project

telescope and instruments (OTIS) assembled at Goddard (GSFC), readied for testing and then shipped to the huge Chamber A at Johnson Space Center (JSC) Houston

summer 2017 – ~90 day complicated cryogenic vacuum test for OTIS went remarkably well, though Hurricane Harvey whacked Houston and flooding almost derailed the test

(17 inches of rain in <2 days in August when OTIS was at its coldest)

gdi

OTIS in JSC Chamber A
(old chamber from Apollo days)

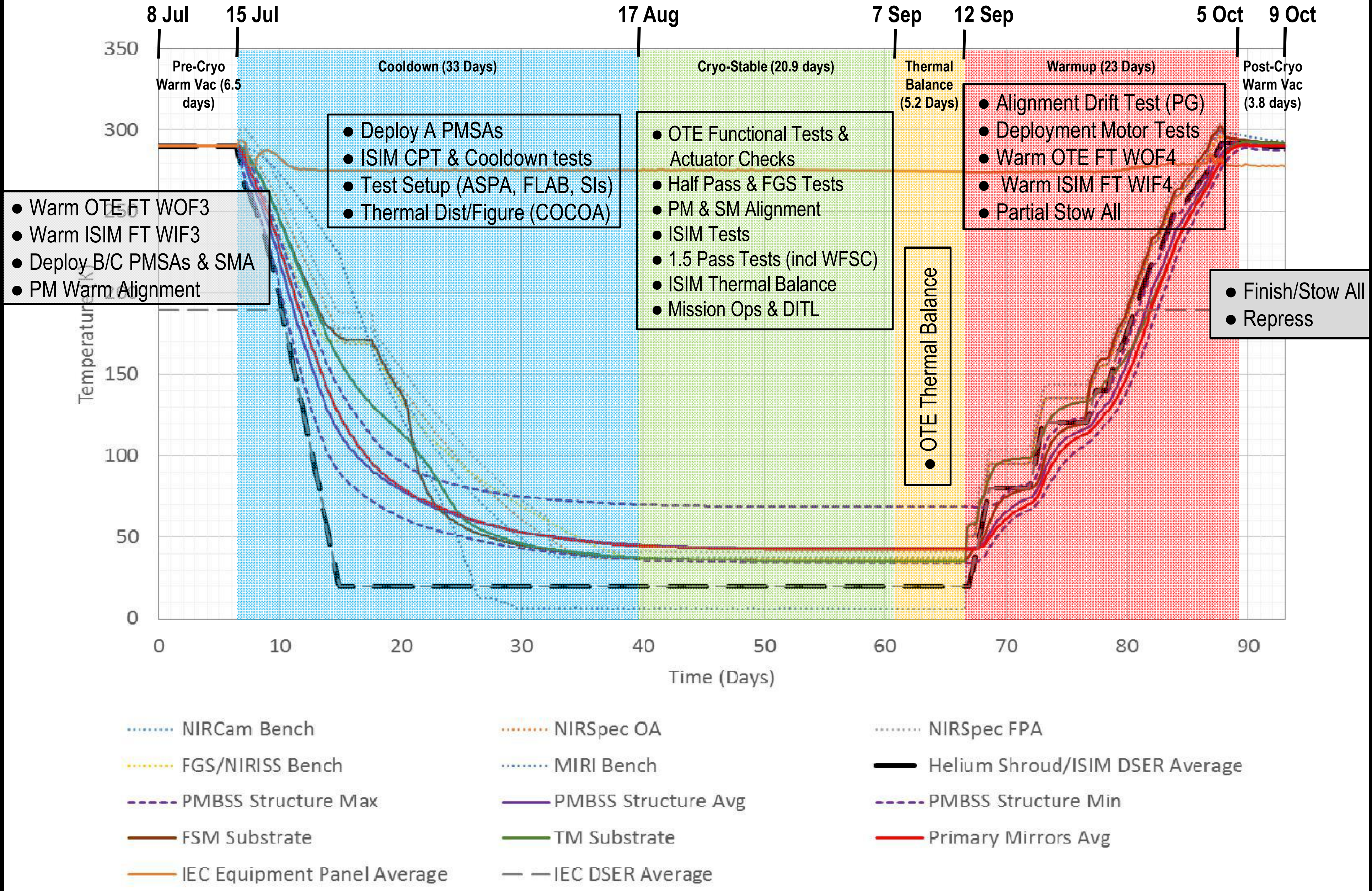
telescope and instruments (OTIS)
cooled down in **huge** vacuum
chamber to about –230 C

summer 2017
90 day test at
Johnson Space Center Houston
cryogenic vacuum test

gdi

Current Rough Guess Dates

Summary Test Flow/Timeline



JSC OTIS cryogenic vacuum test

the telescope and instruments get cold!

primary mirrors at 45K for >month

gdi

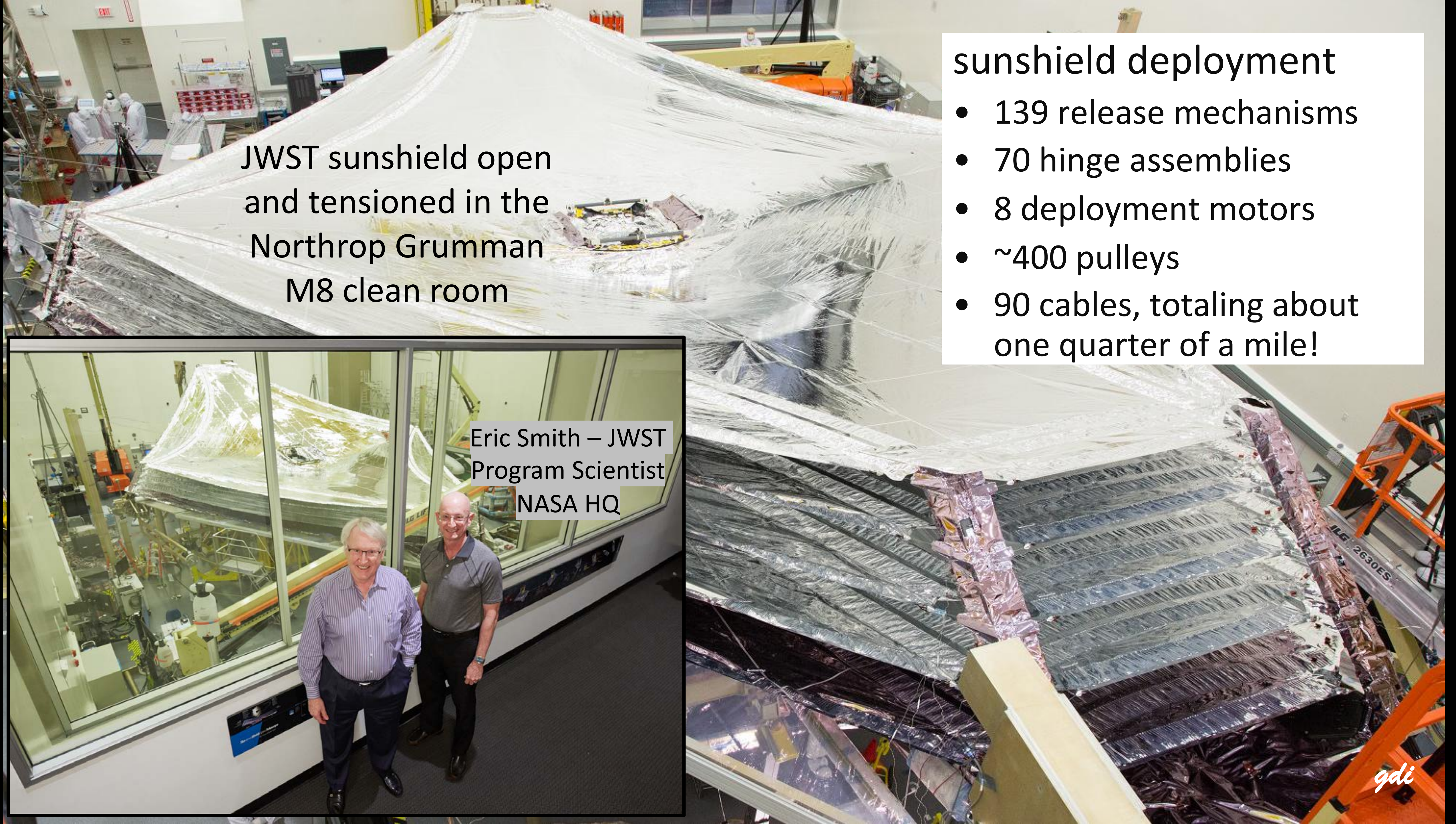
JWST sunshield in the Northrop Grumman M8 clean room in 2016

5 layers of this flimsy stuff are what we deployed in space last year!

gdi

sunshield deployment

- 139 release mechanisms
- 70 hinge assemblies
- 8 deployment motors
- ~400 pulleys
- 90 cables, totaling about one quarter of a mile!



JWST sunshield open and tensioned in the Northrop Grumman M8 clean room

Eric Smith – JWST Program Scientist NASA HQ

after 5 years of good progress within budget and broadly within schedule,
some issues arose in 2017 that started to eat into the schedule

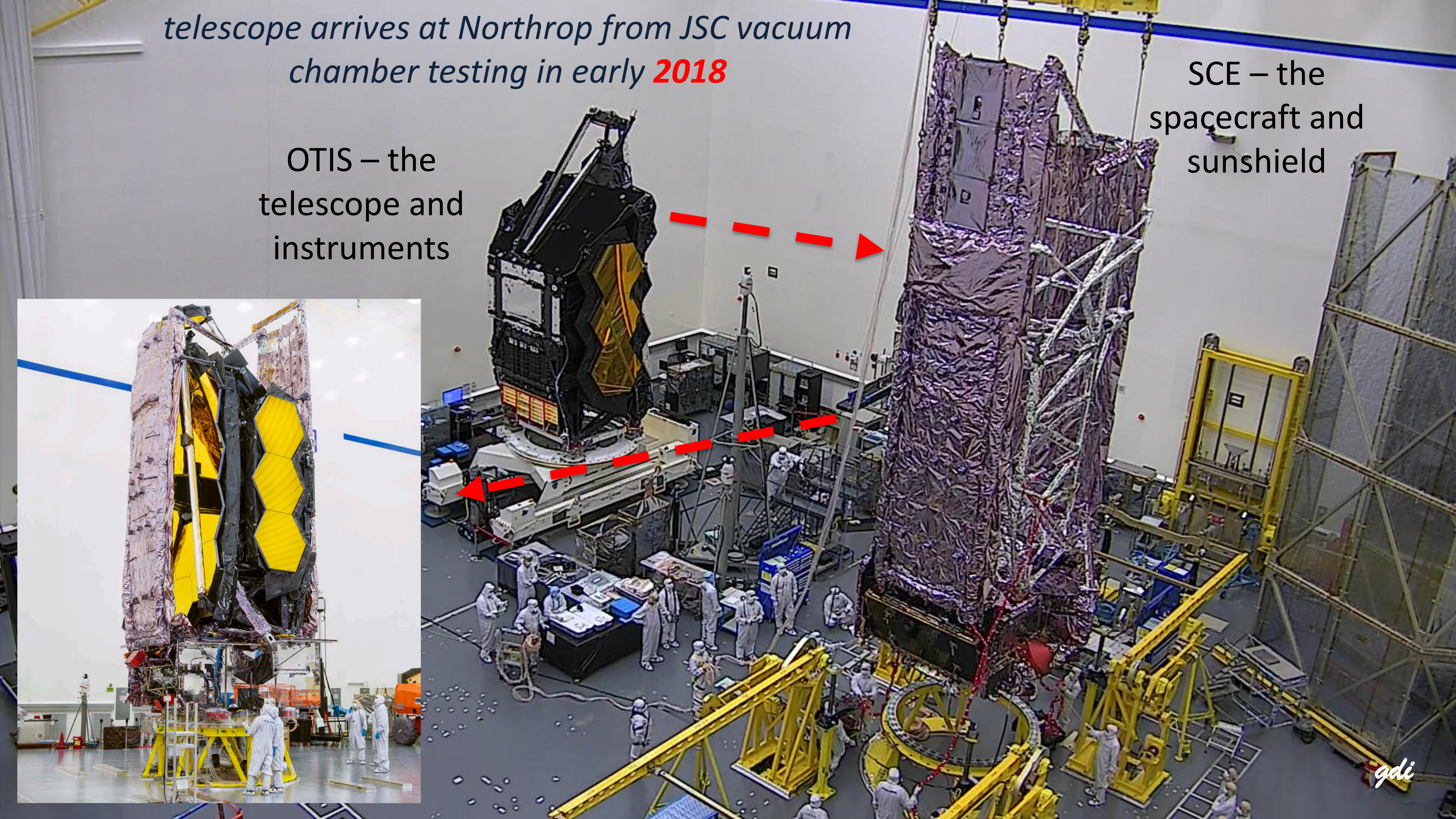
early in 2017 a problem was found with the thruster valves on the spacecraft
this required many months to fix

OTIS arrived at Northrop from JSC in early 2018
OTIS needed to be mated to Spacecraft Element (SCE)

some good progress but a 2018 launch was rapidly becoming unlikely

announcement of a initial delay in launch occurred in spring 2018

gdi


telescope arrives at Northrop from JSC vacuum chamber testing in early 2018
OTIS – the telescope and instruments
SCE – the spacecraft and sunshield
gdi

rough times again for Webb in 2017 and 2018

more funding needed

initial LRD delay was expected to be short, but further events (nuts, washers found in April 2018 from sunshield after SCE environmental testing) led to a longer LRD delay likely into 2021

Independent Review Board (IRB) instituted to report by late May 2018 chaired by Tom Young

IRB set up to evaluate and recommend activities and changes that would help JWST get to launch

gdi

IRB reported back May 31 2018

IRB emphasized criticality of "mission success" for a mission of this cost

JWST Project and Standing Review Board (SRB) estimated that development cost to LRD in early 2021 required another $0.8B for a Phase A-D total of $8.8B and an LCC of $9.66B

LRD set to be March 2021

new plan and agreement on funding increase
$8.8B for Phase A-D!

Congress & OMB (Office of Management and Budget) very unhappy (again!)

gdi

very clear Congressional language in the "Omnibus" from Congress

SEC. 540. None of the funds provided in this Act shall be available for obligation for the James Webb Space Telescope (JWST) after December 31, 2019, if the individual identified under subsection (c)(2)(E) of section 30104 of title 51, United States Code, as responsible for JWST determines that the formulation and development costs (with development cost as defined under section 30104 of title 51, United States Code) are likely to exceed $8,802,700,000, unless the program is modified so that the costs do not exceed $8,802,700,000.

Congress reluctantly approved the revised budget

gdi

very clear Congressional language in the "Omnibus" from Congress

James Webb Space Telescope (JWST).—The agreement includes $304,600,000 for JWST. There is profound disappointment with both NASA and its contractors regarding mismanagement, complete lack of careful oversight, and overall poor basic workmanship on JWST, which has undergone two significant reviews because of failures on the part of NASA and its commercial sector partner. NASA and its commercial partners seem to believe that congressional funding for this project and other development efforts is an entitlement, unaffected by failures to stay on schedule or within budget. This attitude ignores the opportunity cost to other NASA activities that must be sacrificed or delayed. The agreement includes a general provision to adjust the cap for JWST to $8,802,700,000, an increase of $802,700,000 above the previous cap. NASA should strictly adhere to this cap or, under this agreement, JWST will have to find cost savings or cancel the mission. NASA and its contractors are expected to implement the recommendations of both the most recent independent review and the previous Casani report and to continue cooperation with JWST's standing review board. The agreement does not adopt the reorganization of JWST into Astrophysics, and the JWST Program Office shall continue the reporting structure adopted after the Casani report and reiterated by the recent Webb Independent Review Board.

gdi

I&T continued towards the new launch date within the new budget cap

JWST Project activated, with Northrop, in 2018 an end-to-end audit of SCE systems to help build confidence that no other issues might eventuate

lengthy, thorough and comprehensive audit process involving Northrop and NASA teams that took many months

revealed a few minor items, but greatly enhanced confidence that JWST assembly and final environmental testing should move forward

NASA Project personnel and Northrop increasingly working together
– very productive to have two teams with different experience and different "cultures" –

gdi

the last deployment of the secondary before being in 0 G

not possible to do on the ground once OTIS was mated to SCE

1 G gravity could not be offloaded properly

(cables supporting the secondary here)

gdi

OTIS being mated to SCE in Sept 2019

we finally had an observatory!

the full mirror with the sunshield

OTIS+SCE = JWST

gdi

progress in 2019-2021 was hugely better

NASA and Northrop teamed

delivery within the new budget

Webb ready in fall 2021 for its Ariane 5 launch

successful Dec 25 launch and commissioning

Webb exceeds requirements in every area

first observations and science July 2022!

gdi

Tuesday July 12 2022: *Early Release Observations – EROs*

Space Telescope Science Institute – Baltimore

same auditorium where we held the very first NGST workshop 33 years ago in 1989!

JWST Mission Operations Center MOC

JWST has become a cultural icon too

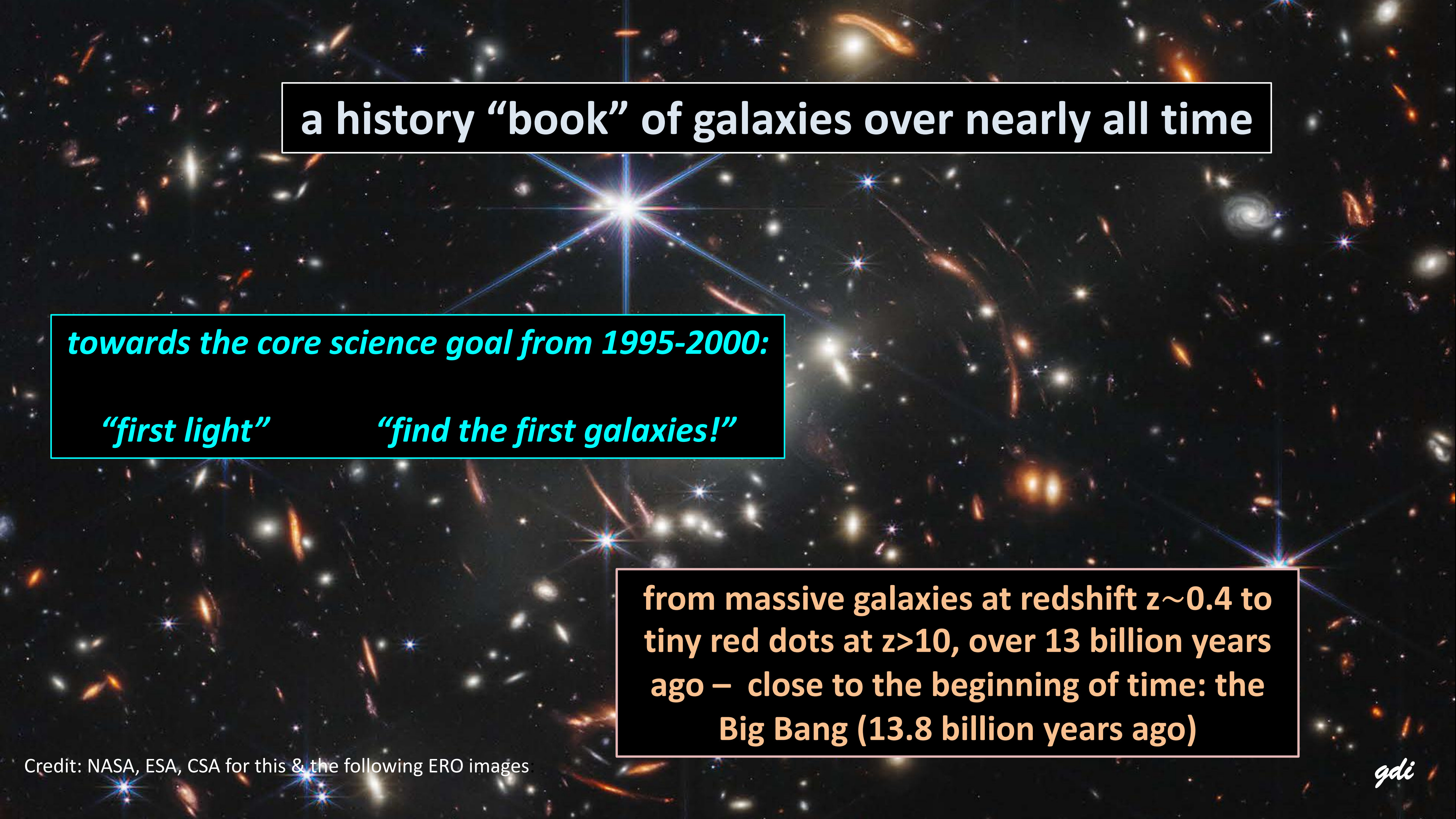
manifesting at times though in curious ways....

JWST fame has spread far and wide....

posted Salem MA during Halloween 2022

sunshield deployment challenge though

gdi



a history "book" of galaxies over nearly all time

towards the core science goal from 1995-2000:

"first light" *"find the first galaxies!"*

from massive galaxies at redshift z~0.4 to tiny red dots at z>10, over 13 billion years ago – close to the beginning of time: the Big Bang (13.8 billion years ago)

Credit: NASA, ESA, CSA for this & the following ERO images

gdi

Q?

JWST has been a remarkable success

a crucial take-away though is:

JWST was "undercosted" from the start

for future missions we must ensure a level of budgetary reality with robust reserves from the earliest conceptual days

like many aspects though, this is "necessary but not sufficient"

gdi

JWST was "undercosted" from the start
as per Mike Griffin (NASA Administrator who "inherited" JWST in 2005)

for context lets look at mission costs given to the AAAC in 2006-7 by the NASA Science Mission Directorate Associate Administrator's Office

I was Chair of the Astronomy and Astrophysics Advisory Committee (AAAC) at this time and did a Hearing in 2007 before the House Science Committee

a question from congressional staff led to getting this information from NASA after the Hearing in Congress

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The Table below summarizes lifecycle mission costs (LCC) in constant 2007 dollars, with a summary of the caveats/comments appropriate for the derivation of these numbers. These numbers are from the NASA Science Mission Directorate (SMD). They were provided in response to Questions for the Record from testimony given by the AAAC Chair to the House Committee on Science and Technology's Subcommittee on Space and Aeronautics on May 2, 2007 at a hearing on *NASA's Space Science Programs: Review of Fiscal Year 2008 Budget Request and Issues*. Since these numbers were supplied by NASA, they can be considered baseline numbers for subsequent discussions of mission costs. Obviously taking costs from past missions done under very different accounting structures and converting them to present day structures will be uncertain, but they provide a very useful guideline for planning purposes and for setting the scale for missions under discussion. They are estimated as likely to be accurate to better than 10%, probably about ±5%. The NASA SMD AA's office provided these numbers and notes for a public response to a Congressional inquiry relating to Testimony in May 2007. The AAAC greatly appreciates that the agency made such costs available so that consistent costing is available as we go into the next Decadal Survey.

NASA SMD Lifecycle Costs for Science Missions (in constant 2007 dollars)

Mission (alphabetical)	$B (constant 2007 dollars)	Comments
Cassini	$3.9	Launch included
CGRO	$1.5	Launch included
Chandra	$4.0	Shuttle cost not incl. (IUS incl.)
Galileo	$3.2	Shuttle cost not incl. (IUS not incl.*)
HST	$12.8	Shuttle cost not incl.; Servicing mission costs incl.**
JWST	$4.4	2013 Launch; 10 yrs operations
SIM	$2.6	Nominal 2015/16 Launch; 10 yrs ops***
SOFIA	$2.7	Full science ops 2013; 20 yrs ops
Spitzer	$1.7	Launch included; Ops to 2009

All costs are lifecycle (LCC), adjusted for full cost prior to FY04 (full cost accounting used since FY04), and converted to constant 2007 dollars (rounded to nearest $0.1B).
*Inertial Upper Stage (IUS) number too uncertain for inclusion (maybe $0.2B?);
**ESMD funding of robotic servicing not included.
***Based on FY07 budget data; SIM-Lite under consideration.

Mission costs from NASA SMD – in 2007 & 2008 AAAC reports

Astronomy and Astrophysics Advisory Committee

FACA committee advising NSF, NASA, DOE, OSTP & Congress

from 2008 AAAC report
page 45

www.nsf.gov/mps/ast/aaac/reports/annual/aaac_2008_report.pdf

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Mission costs from NASA SMD – in 2007 & 2008 AAAC reports

assembled by AAAC Chair GDI from NASA SMD input

NASA SMD Lifecycle Costs for Science Missions (in constant 2007 dollars)

Inflate by 30% to year-end 2021 (small overestimate for long Ops)!

Mission (alphabetical)	$B (constant 2007 dollars)	Comments
Cassini	$3.9 now $5B	Launch included
CGRO	$1.5 now $2B	Launch included
Chandra	$4.0 now $5.2B	Shuttle cost not incl. (IUS incl.)
Galileo	$3.2 now $4.2B	Shuttle cost not incl. (IUS not incl.*)
HST	$12.8 now $16B	Shuttle cost not incl.; Servicing mission costs incl.**
JWST	$4.4 now $11B	2013 Launch; 10 yrs operations now 2022; 10 yrs ops
SIM	$2.6 NA	Nominal 2015/16 Launch; 10 yrs ops***
SOFIA	$2.7 now $3.5B	Full science ops 2013; 20 yrs ops
Spitzer	$1.7 now $2.2B	Launch included; Ops to 2009

All costs are lifecycle (LCC), adjusted for full cost prior to FY04 (full cost accounting used since FY04), and converted to constant 2007 dollars (rounded to nearest $0.1B).
*Inertial Upper Stage (IUS) number too uncertain for inclusion (maybe $0.2B?);
**ESMD funding of robotic servicing not included.
***Based on FY07 budget data; SIM-Lite under consideration.

clearly JWST was "undercosted" from the start

but the perception of huge 10-20X cost growth is wrong –
exacerbated by comparing apples to pears to oranges

costs quoted have been Phase A-D, Phase C-D and LCC, and even assuming substantial international contributions (which do not happen directly)

nonetheless the early "undercosting" was real, and hurt the program's credibility

fortunately we have learned and the new 2021 Decadal is much more realistic *lessons learned…..*

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my "lessons learned" for a flagship mission

- ☞ ***start very early*** – it inevitably takes a very long time….
- ☞ ***start optimistically and ambitiously*** – the "vision thing" counts and re-scopes only go one way….
- ☞ ***key technologies*** – focus early on demonstrating the key make-or-break technologies and models….
- ☞ ***cutting-edge exciting science is key*** – "just because it has unique capabilities does not make it interesting"
- ☞ ***policy-maker & public appeal is crucial*** – science community interest is necessary, but not sufficient
- ☞ ***persevere*** – there will be severe political and technical challenges
- ☞ ***decadal survey*** – get strong support in the decadal survey
- ☞ ***experienced, dedicated, motivated team*** – people are key to success
- ☞ ***capable, experienced managers*** – managing strategic missions takes extraordinary skills
- ☞ ***combine teams with different experience bases*** – different perspectives, working together are synergistic
- ☞ ***get the right budget profile and a high level of reserves*** – both are crucial for meeting cost and schedule
- ☞ ***maintain good, open and honest communications –*** up and down the chain – contractor to project, project to program, HQ to community and congress
- ☞ ***expect to get hit by the unexpected – "it's not over until it's over" – until it is completed and operational***….

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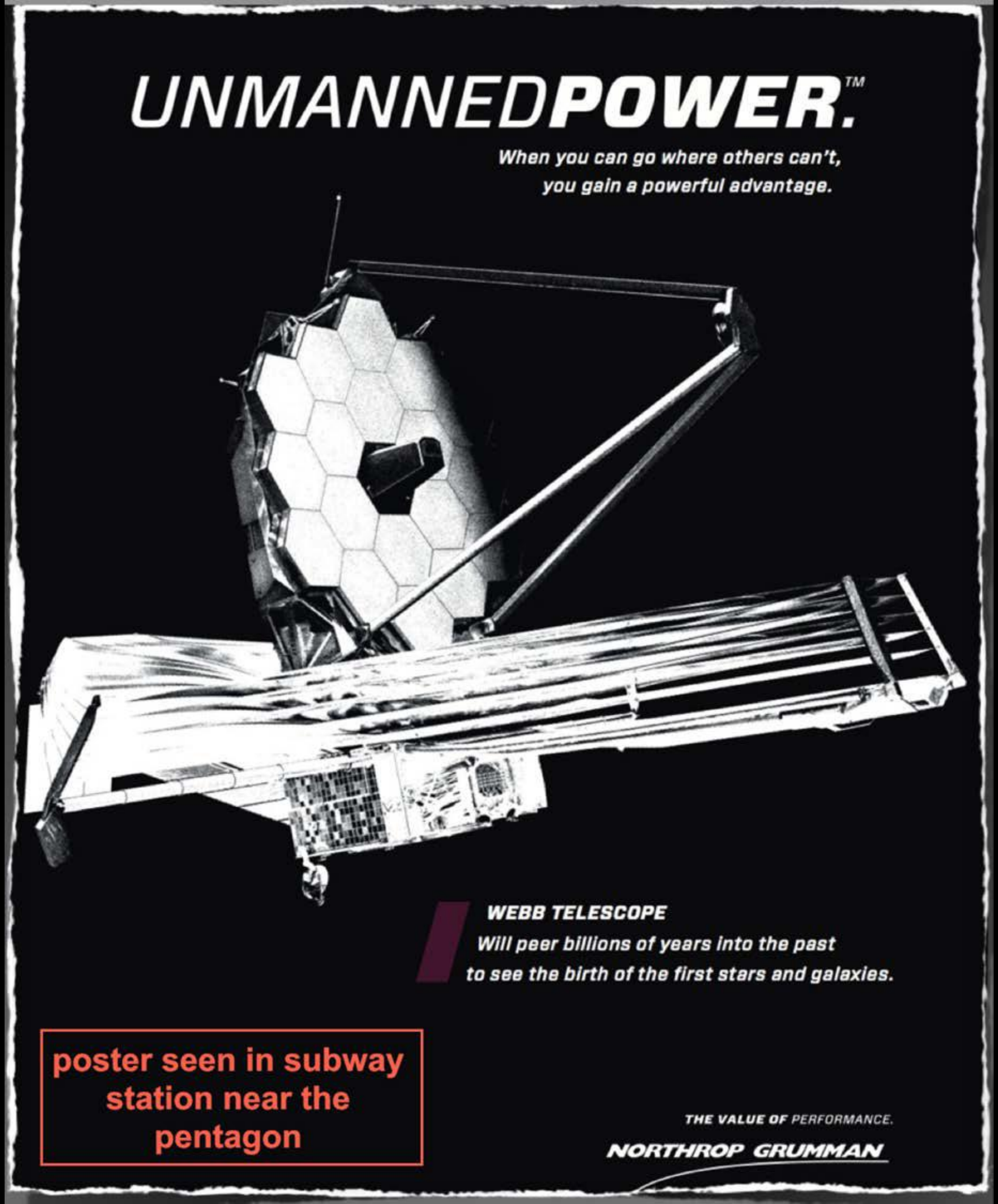

what's next?

JWST's technology and success will open up new horizons and give us all* confidence that we can do even greater missions

*policy-makers, government, industry, scientists

*e.g., 2021 Decadal recommended a >6 m large UVOIR telescope for characterizing **earth-like** planets (now called Habitable Worlds Observatory)*

how JWST is showing a larger audience that what we do as astronomers has national relevance

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2022 – the beginning of a new era…

from the "first stars & galaxies"
to "nearby planets"
….and everything in between across all time….

our
"cosmic sunrise"
telescope

N3AS Lecture 1

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