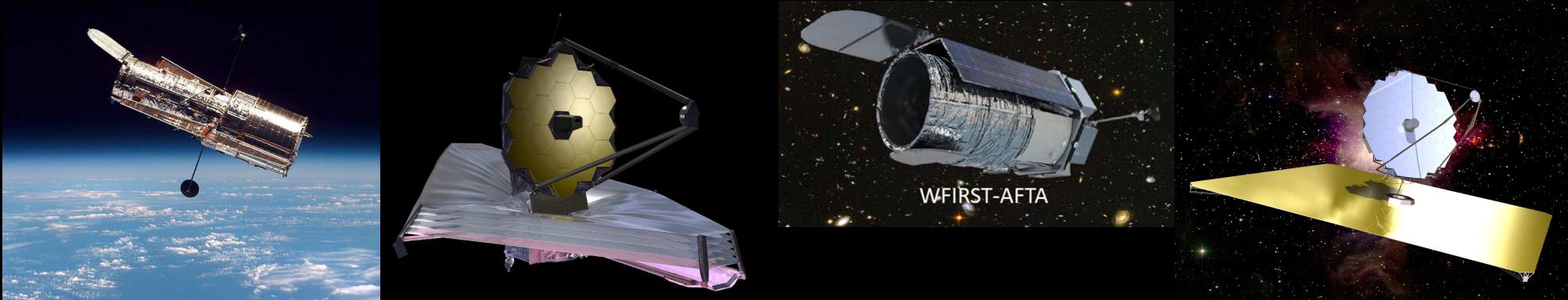


Lessons learned from JWST and HST, that may help with a large Far-IR Surveyor (FIRS) mission.

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

and Robert W. Smith (U. Alberta, Edmonton, Canada; HST& JWST historian)



Lunch talk at the Far-IR Surveyor Face-to-Face Meeting,

Thursday May 12, 2016; NASA Goddard Space Flight Center, Greenbelt (MD)

All presented materials are ITAR-cleared. These are my opinions only, not necessarily NASA's or ASU's.

Outline: Lessons from JWST

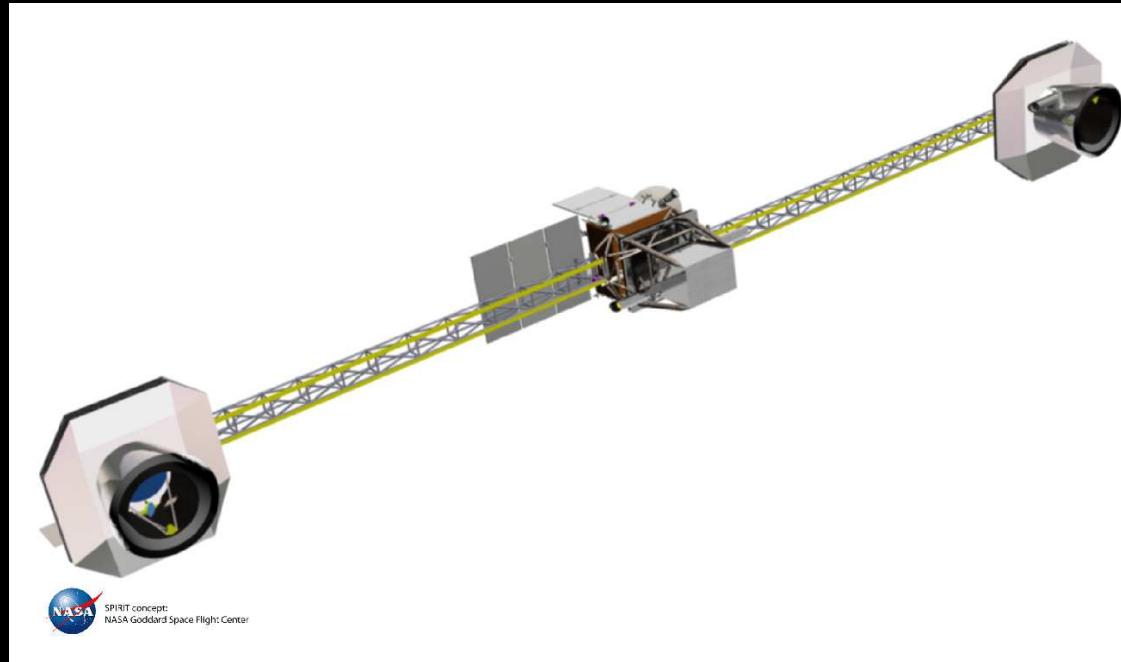
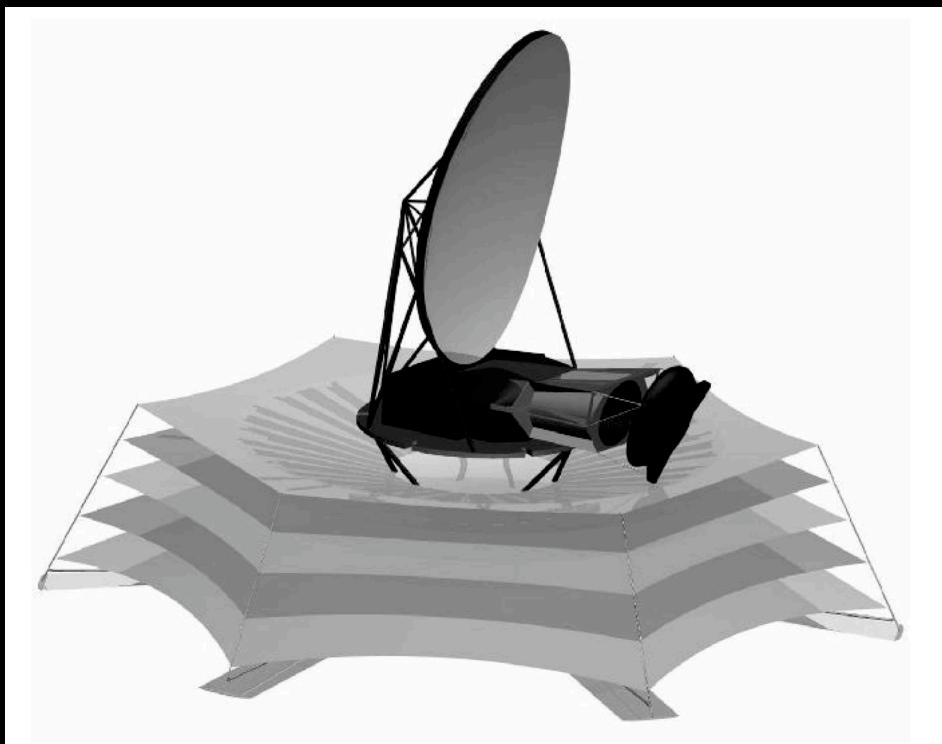
- JWST Lessons: Mega-project lessons also apply to HST & Supercollider. Key is that scale of efforts goes beyond what people are used to.
- Mega-projects demand new rules, in particular regarding building and keeping together a *strong Coalition* of project supporters and advocates.

Consumers Report: Very Good \Rightarrow Good \Rightarrow Neutral \Rightarrow Fair \Rightarrow Poor.

- (A) Scientific/Astro-Community Lessons
- (B) Technical Lessons
- (C) Management/Budget/Schedule Lessons
- (D) Political/Outreach Lessons

I thank Dr. Seth Cohen, Garth Illingworth, Rolf Jansen, John Mather, Eric Smith and Harley Thronson for useful comments.

Talk is on: http://www.asu.edu/clas/hst/www/jwst/jwsttalks/FIRS16_windhorst_jwstlessons.pdf



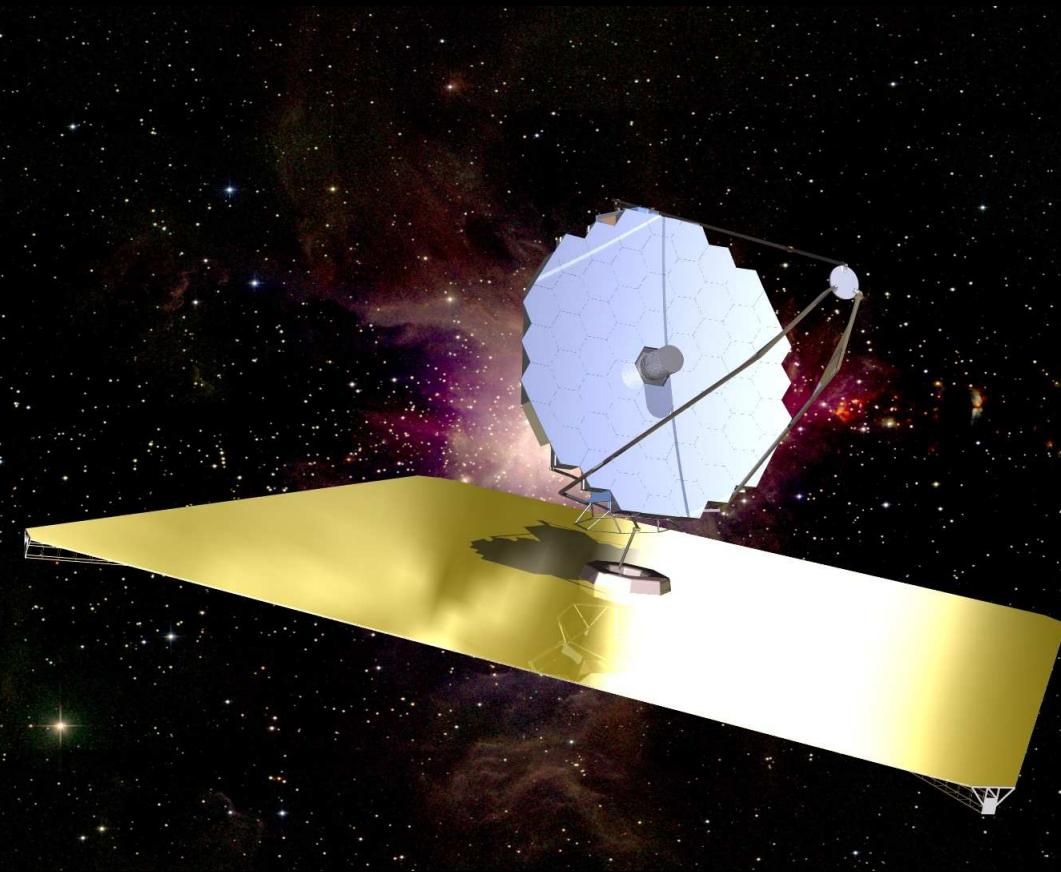
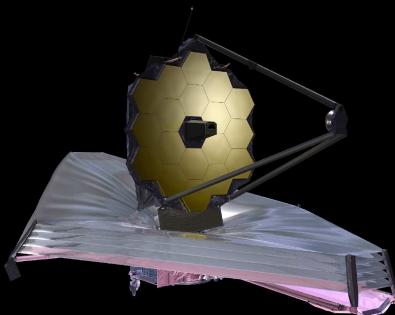
It is understood that the FIRS STDT, with help from the Study Office, will develop a new FIR mission concept, one that's driven by most compelling science goals for the end of the next decade.

Shown here are renderings of CALISTO (left) and SPIRIT (right). Below I assume that a large mission like FIRS will succeed in incorporating the best of both.

- I will henceforth use “FIRS” to mean a large Far-IR mission concept.

Past, Present and Future: Can and will the dream continue?

True relative size: Hubble, James Webb, WFIRST, & FIRS



1973–2018⁺

1996–2023⁺

2012–2035?

2020–2040?

Launch: 1990

2018

~2026

≥2030?

Σ_{FC} : 10–18 B\$

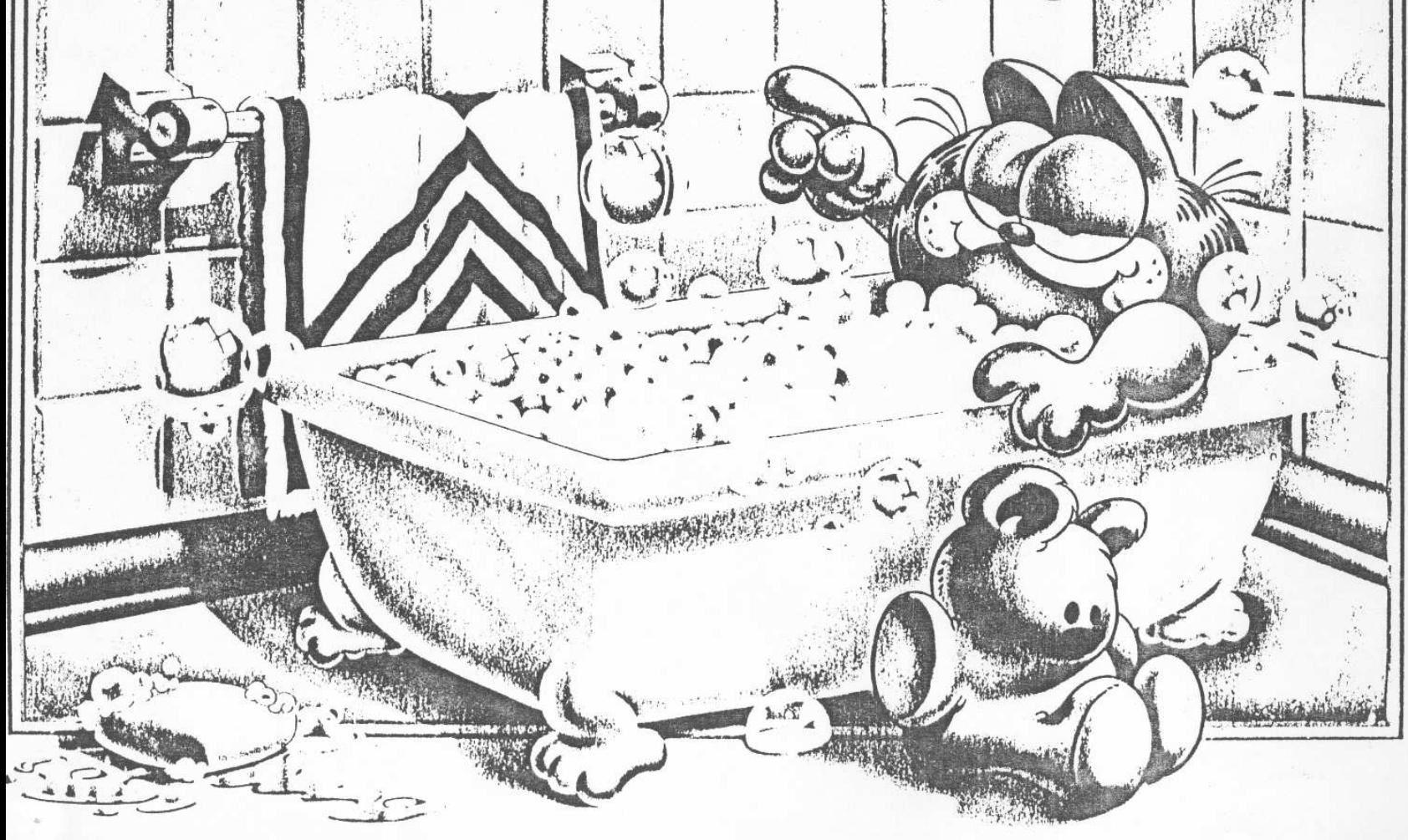
8.8 B\$

~1–2 B\$?

?? B\$

My goal today: Inspire the younger folks to successfully build a Far-IR Surveyor (FIRS) telescope for the 2030's.

JWST is like a hot bath. It feels good while you're in it; but the longer you stay, the more wrinkled you get.



WARNING: Both Hubble and James Webb are 30–45+ year projects:
You will feel wrinkled before you know it ... :) (chart from Jim Westphal's office, 1987).

James Webb said in 1969: “In our pluralistic society, any major public undertaking requires for success a working consensus among diverse individuals, groups, and interests. A decision to do a large, complex job cannot simply be reached “at the top” and then carried through. Only through an intricate process can a major undertaking be gotten under way, and only through a continuation of that process can it be kept going.”

(See quotes in front of Robert Smith’s 1993 book: “The Space Telescope”).

- Main message: Build and maintain a “Coalition” of strong project supporters for a “Mega-Project”.
- A Mega-project not only has to be technically feasible, but it also must be and remain politically feasible.

Edmund Burke (1729–1797): “Those who carry on great public plans must be proof against the worst delays, the most mortifying disappointment, the most shocking insult, and what is worst of all, the presumptuous judgment of the ignorant upon their design. ”

Avoid: “History *teaches* us that mankind *learned* nothing from history” (G. W. F. Hegel 1832).

(1) JWST Lessons: (Hubble WFC3 images, \gtrsim 10 years after it was nearly “canceled” twice ...)



10 filters HST/WFC3 & ACS in ERS reaching AB=26.5–27.0 mag (10- σ) over 40 arcmin² at 0.07–0.15" FWHM from 0.2–1.7 μ m (UVUBVizYJH).

JWST provides 0.05–0.2" FWHM images to AB \simeq 31.5 mag (1 nJy) at 1–5 μ m, and 0.2–1.2" FWHM at 5–29 μ m, tracing young+old SEDs & dust.

(A) Scientific/Astro-community lessons from JWST

For a Mega-project to succeed, make sure that you DO:

- 1) Have ($\gtrsim 1$) killer apps with full community support. (Be exciting enough that some dedicate most of their careers to make it happen).
- 2) Project is a must-do scientifically and cannot be done any other way.
- 3) Project highly ranked by community reviews/Decadal surveys.
- 4) Identify and highlight complementarity with other large facilities.
- 5) Still like the science and the project $\gtrsim 10\text{--}20$ years later.
- 6) Offer project science and grant support to the whole community.
- 7) Keep *advocating* Mega-project to community until launch/first light.

(J. Bahcall and L. Spitzer said they had to “Sell” the HST Project to shepherd it through the approval process. We prefer to call it: “Advocate”. We must make all stakeholders aware of mission purpose and progress throughout its long life cycle).

(A) Scientific/Astro-community lessons from JWST

For a Mega-project to succeed, make sure that you DON'T:

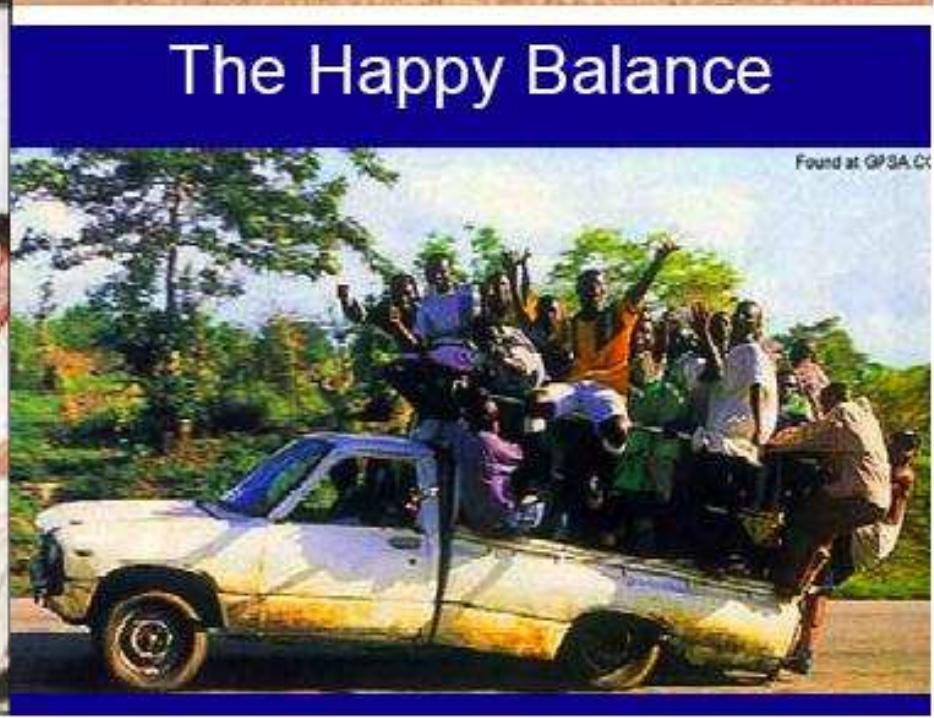
- 1) Have community infighting (“My mission is better than yours” — One key reason for Supercollider (SSC) demise).

(John Mather: “Management levels above the Mega-project need to help avoid community infighting, and work with advisory groups to ensure that everyone can see the choices. Complete openness is the key”).

- 2) Have other projects canceled because of your Project, or perception thereof. Don't make enemies whenever possible.
- 3) Have science and grant support for a selected few.
- 4) Have GTO's be elite: they must serve & represent the community.
- 5) Ignore community input on project science priorities.
- 6) Ever ignore importance of great communication with U.S. patrons: Scientists, contractors, tax-payers, Congress, White House.
- 7) Ever ignore importance of great communication with foreign partners. (International projects are more robust politically, see e.g., SSC).

What the Scientists See:

What the Project Manager Sees:



The Happy Balance

Found at GPSA.CX

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

(B) Technical Lessons from the JWST Project

For a Mega-project to succeed, make sure that you DO:

- 1) Use advanced technologies being developed elsewhere, if possible.
- 2) Use latest proven technology where you can for killer science apps.
- 3) Know when not to select the most risky technologies.
- 4) Do your hardest technology development upfront. Have all critical components at TRL-6 before Mission Preliminary Design Review (PDR).

(Eric Smith: “Even after insuring TRL-6, you need to prove and test manufacturability of the technologies. Creation in a laboratory is not the same as proving something can be built reliably by industry.”)

- 5) Only design to specs you need and can afford to fabricate & test.
- 6) Test, test, and retest where needed.
- 7) Have strong central control of systems engineering.

(B) Technical Lessons from the JWST Project

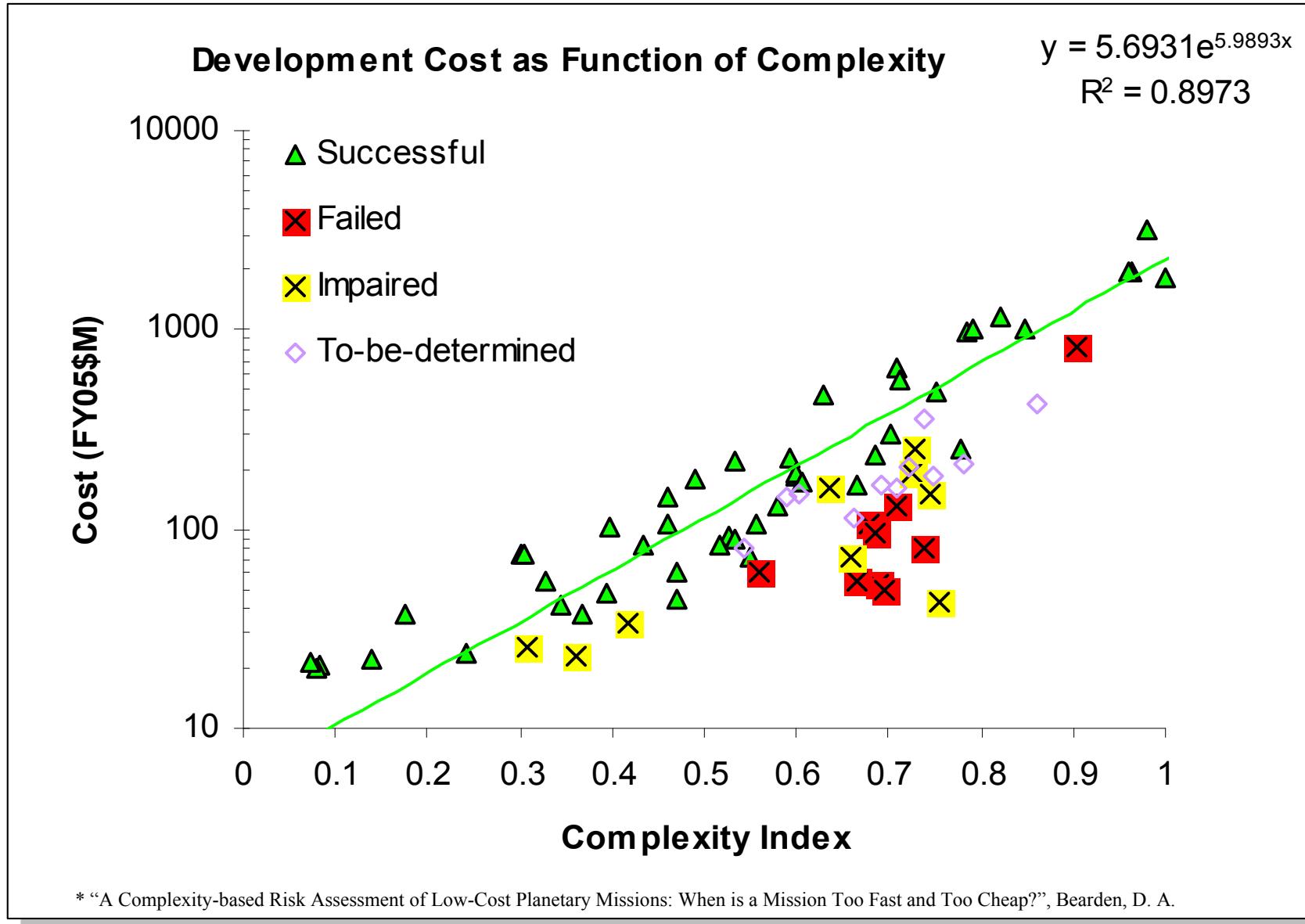
For a Mega-project to succeed, make sure that you DON'T:

- 1) Use technologies below TRL-6 at Mission PDR.
- 2) Defer project component PDR's or CDR's to well after Mission PDR or CDR, resp.
- 3) Do system tests whose outcome do not make you change course.
- 4) Ask for $1\mu\text{m}$ diffraction limit unless you must have & can afford it.
- 5) [If you can't afford $1\mu\text{m}$ JWST diffraction limit, HOLD ground at 2.0μ , AND insist best effort made at 1μ without being cost-driver.]
- 6) Allow scientists to change requirements after Phase A (unless to reduce risk).

Def: TRL-6 = “(Sub-)system model or prototyping demonstration in a relevant end-to-end environment (ground or space).”

Def: PDR = Preliminary, CDR = Critical Design Review.

When is a Mission Too Cheap?*



* "A Complexity-based Risk Assessment of Low-Cost Planetary Missions: When is a Mission Too Fast and Too Cheap?", Bearden, D. A.

(C) Management/Budget/Schedule Lessons from JWST

For a Mega-project to succeed, make sure that you DO:

- 1) Have competent *AND* project-friendly management in *ALL* of NASA.
- 2) Make conservative full end-to-end budget before Mission CDR.

(John Mather: Need correct cost analysis before final commitments are made. NASA has the responsibility to get it right).

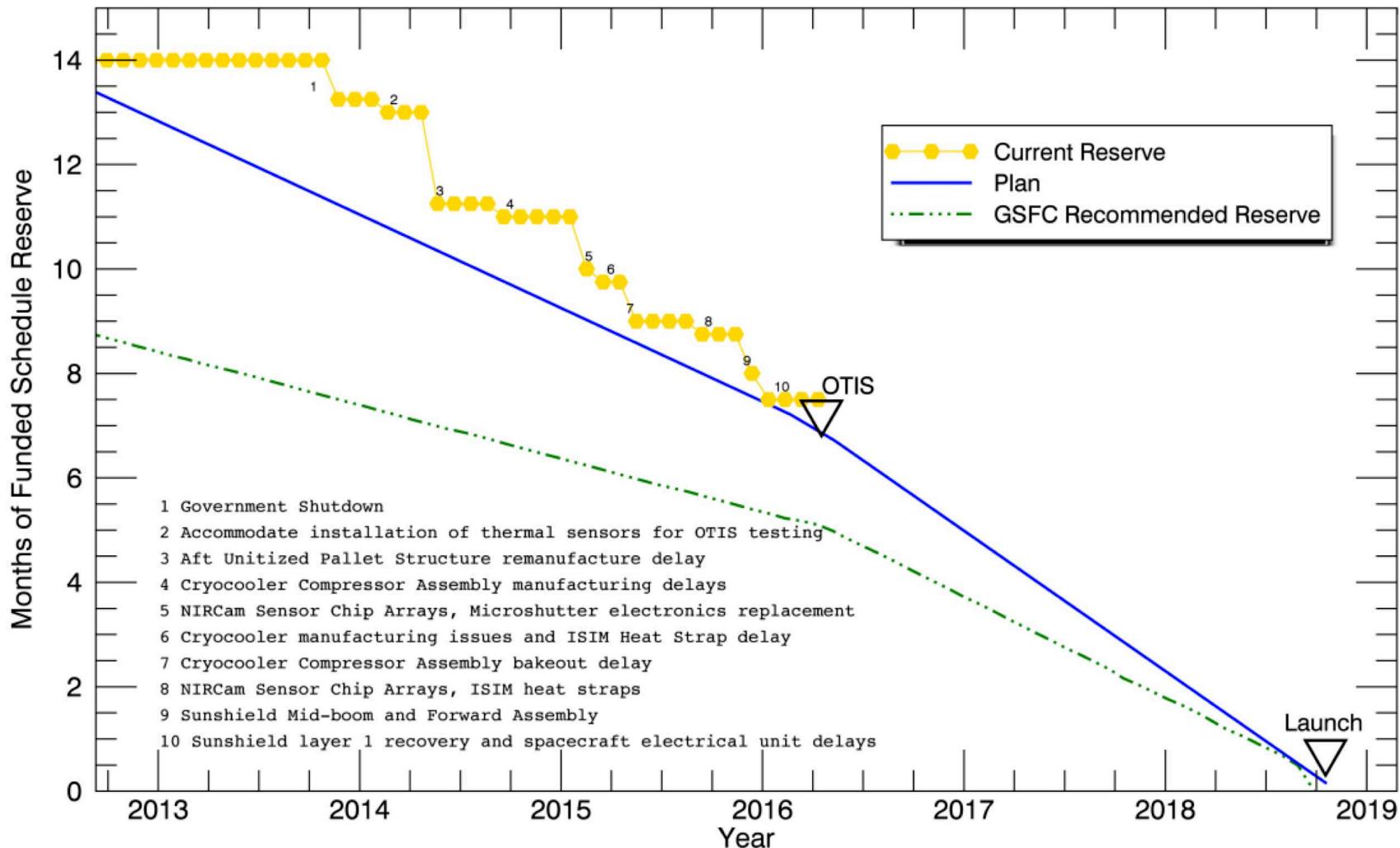
- 3) Make sure budgets are externally reviewed, and at $\gtrsim 80\%$ joint cost+schedule confidence level. (Could not do $\lesssim 2010$; Did so early 2011).
- 4) Plan & effectively use 25–30% (\$+schedule!) contingency each FY.

(Harley Thronson: “Corollary of (3)–(4): Although cost and schedule control must be introduced from the start, do not (cannot) undertake costing too early in the process.”)

- 5) Have a viable list of cost-saving and meaningful descopes.

(John Mather/Eric Smith: “Don’t overestimate the benefit of descopes. After a commitment is made (in Phase C/D), it is extremely expensive — and may be an international incident — to delete components that have been accepted into the mission. Scientists must learn to accept descopes in Phase A — the power-point phase — when they are still feasible, and often essential to have a mission survive.”)

Funded Schedule Reserve



Keys to stay on schedule: 1) Sufficient Project contingency ($\gtrsim 25\%$ of total).
2) Well replanned and managed Project (starting late summer 2011).

(C) Management/Budget/Schedule Lessons from JWST

For a Mega-project to succeed, make sure that you DO (cont):

- 6) Have great communication with all (sub-)contractors.
- 7) Put management pressure on contractors, when necessary.
- 8) Have best work-force from contractors for entire length of project.
- 9) Prioritize testing, and test extensively.
- 10) Carefully construct the incentives in your industrial contracts.

(Eric Smith: For-profit companies are very adept at insuring their teams win incentives. Hence, the Project contract needs to balance its incentives to get the best possible outcome in terms of both technical performance, cost *and* schedule).

(C) Management/Budget/Schedule Lessons from JWST

For a Mega-project to succeed, make sure that you **DON'T**:

- 1) Advocate project with optimistic budget estimates.

(Lesson number 1 from HST: Don't buy in at bargain prices):

HST was 450 M\$ in FY78. At its 1990 launch, it was 1.5 B\$ *without* the Shuttle launch or servicing cost. Jean Oliver said: "When someone asks you: Can you build it for xx \$, the answer is invariably "Yes", and then folks go about making that work" (see Robert Smith's book).

(John Mather: "Our job includes communicating progress, and being as open with the world as possible. Eric Smith: Everyone is trying their best to understand the costs of things that have never before been attempted.)"

- 2) Cut project contingency to below critical mass (*i.e.* $\lesssim 25\text{-}30\%/\text{FY}$).

When project contingency is cut to below $\lesssim 25\text{-}30\%/\text{FY}$, Project managers have no choice but to defer essential tasks to next FY's, which can ruin the Project's long-term budget plan very quickly.

- 3) Try (or allow Contractors to try) to save funds by cutting corners.

(Eric Smith: If jobs are not properly allocated, the work can't be done for any price. You need individual key people and organizations, and strong central oversight.)

(C) Management/Budget/Schedule Lessons from JWST

For a Mega-project to succeed, make sure that you **DON'T** (cont):

- 4) Change science requirements after Phase A (unless essential to simplify, reduce risk and cost).
- 5) Allow contractors to change requirements, or have requirements jeopardize/delay project budget/schedule.
- 6) Change contract midstream, unless it is to reduce risk.

(Eric Smith: Sometimes it's better to take the paperwork hit if it is technically required to change a requirement as you go).

- 7) Defer project component PDR's or CDR's to well after Mission PDR or CDR, resp.
- 8) Test items without a clearly defined decision path.



Mega-project needs heritage/links to technology from other parts of govt.

Mega-project needs strong technology benefits/lessons TO other parts of govt!

(D) Political/Outreach Lessons from JWST

For a Mega-project to succeed, make sure that you DO:

- 1) Assemble, maintain and fully use a *strong Coalition* of supporters and advocates who will fight for the project, since there will be storms and budget cancellations (HST did so successfully, SSC did so too late).

(Robert Smith: JWST didn't have its full "Coalition" in place until it got into serious budget trouble in 2010/2011).

- 2) Understand & foresee full political landscape of contractor world.
- 3) Have strong multi-partisan & multi-national support for project.
- 4) Educate, educate, and re-educate government & general public about project's essence.

(Harley Thronson: "Strong support for and opposition to Mega-projects can be as much *emotional* as rational. Not only does it matter to Coalition stakeholders whether it can be built, my state gets dollars, it is affordable, the technology is ready, and whether its science is exciting and possible. Both support and opposition can be emotional (or non-rational): pride, ego, bragging rights, reaction to animations and visualizations, and to project appearance/home institution, etc, all do matter. A Mega-project must be mindful of the very real human characteristics involved as well.")

(D) Political/Outreach Lessons from JWST

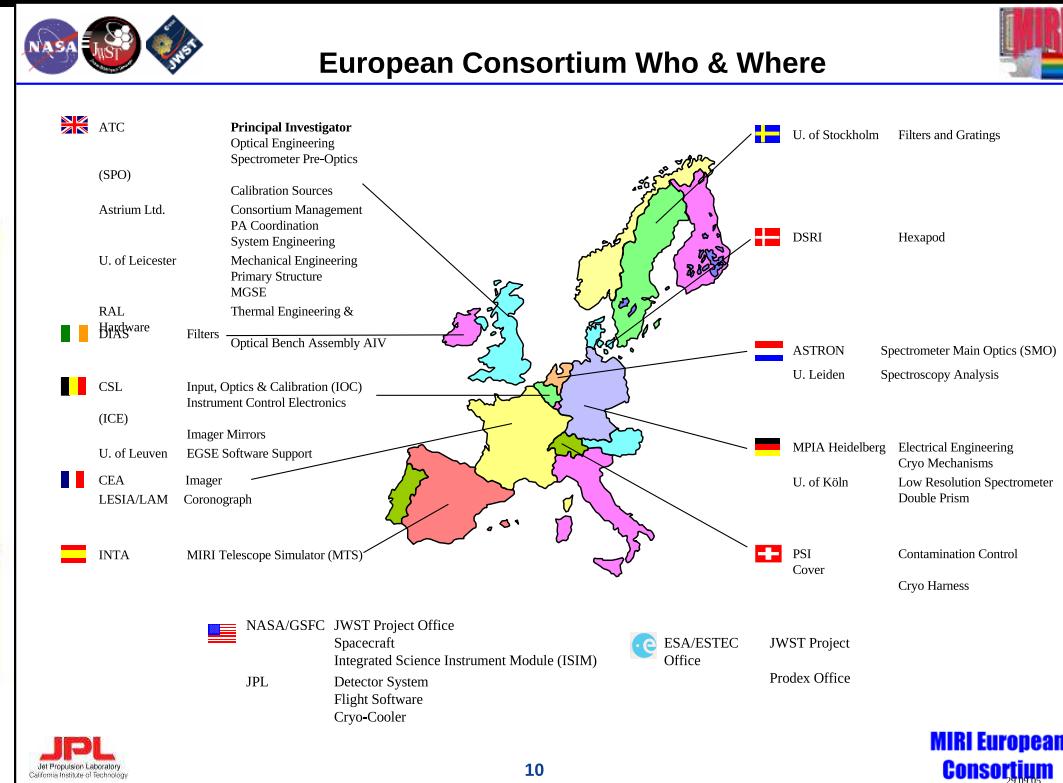
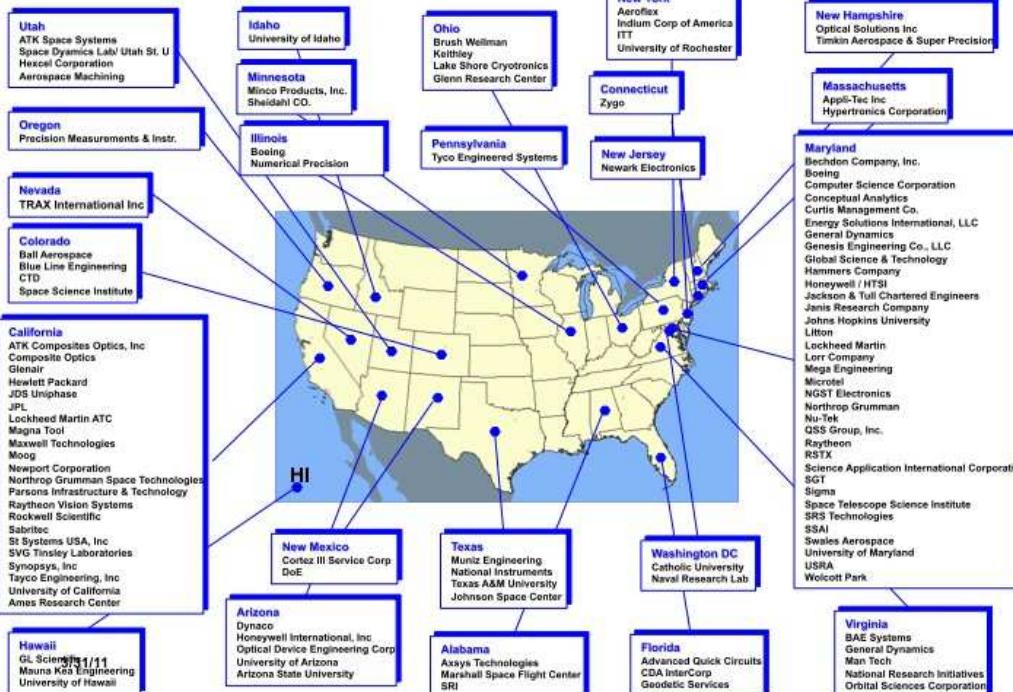
For a Mega-project to succeed, make sure that you **DO** (cont):

- 5) Strong heritage/links to technology *from* other parts of government.

(Eric Smith: “Unless an item is “build-to-print”, the heritage benefit may not be great. We often have to modify items enough that we are making a new item effectively.”)

- 6) Strong technology benefits/lessons *TO* other parts of government.
- 7) Strong, compelling benefits to society (“must-have” applications).
(SSC could not explain to a broad audience: Why SSC?).
- 8) Know your (funding-) decision makers: what exactly makes them tick?
- 9) Have a last resort (“nuclear”) option, but plan to never have to use it.
- 10) Expect the unexpected. This includes: be willing to do (legal and moral) things to help save a Mega-Project that may cost you your job.

JWST: A Product of the Nation



- JWST hardware made in 27 US States: $\gtrsim 98\%$ of launch-mass finished.
- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.
- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.
- JWST NIRCam made by UofA and Lockheed.

This nationwide + international coalition was critical for project survival!

Keep all levels of government informed about your mission:



Annual Girl Scout Stargazing at the White House South lawn (July 2015).

The White House knows about the importance of NASA and JWST.

(D) Political/Outreach Lessons from JWST

For a Mega-project to succeed, make sure that you DON'T:

- 1) Have project politicized in the government (lesson from SSC).

(John Mather: Entire professional societies went to war to stop the Space Station. They didn't have to do that. This rubbed off negatively onto the SSC as well ... Astronomy has done well because our Decadal Survey sets priorities, which the community is willing to accept and abide by).

- 2) Assume your government understands or likes the project: Educate, educate, and re-educate.
- 3) Have project become target of social media: Must continuously educate instead and reach out to opponents.
- 4) Have project too concentrated in one state (or nation): MUST distribute efforts and wealth.
- 5) Don't pick fights you cannot win.
- 6) Ever fall asleep, not until launch anyway ...

Conclusion: How can we knock it out of the ball-park in the next 30 years?



Missions like FIRS could fill most of the Yankee ballpark ...

- New paradigm: Too large for individual institutions to take on.
- Institutions must closely collaborate world-wide to make this happen.

SPARE CHARTS

DISCLAIMERS:

- (1) The materials below are our opinions only (Rogier Windhorst & Robert Smith's), not necessarily NASA's or our Universities' opinion.
- (2) When we get to (*D*) *Political Lessons* and suggest “One should”, or “One should not”, we do NOT imply to address civil servants. (I.e., only those individuals who are allowed to reach out to Congress should consider doing so, or should ever feel encouraged doing so).
- (3) No NASA funds or resources are used to reach out to Congress, nor are University funds or resources used to reach out to State legislators.
- (4) No ITAR sensitive materials are ever presented in outreach talks or activities for Mega-Projects, and certainly not in such talks given abroad.
- (5) We are not here to judge, but to learn.

Fiscal Year 2016 JWST HQ Milestones

| Month | Milestone | FY2015 Deferral | Comment |
|--------|---|-----------------|---|
| Oct-15 | 1 Start Integrated Science Instrument Module (ISIM) cryovacuum test #3 2 Deliver update for launch and activation sequence of events for JWST commissioning | | • Completed 10/27/15 <u>Completed 10/29/15</u> |
| Nov-15 | 3 Deliver the Observatory Operations Handbook Vol 1&2 updates 4 Deliver new build of the proposal planning software for Telescope plus ISIM (OTIS) testing | | <u>Completed 10/30/15</u> <u>Completed 10/30/15</u> |
| Dec-15 | 5 Complete second test of Pathfinder Telescope equipment at the JSC Chamber A 6 Complete Solar Array panel #2 cell installation 7 Complete Sunshield Mid-Boom Assembly #1 functional test 8 Complete Delivery of Reaction Wheel Assemblies to Observatory Integration and Test (I&T) 9 Deliver Data Management Subsystem build for basic data search and distribution functionality | | <u>Completed 10/31/15</u> Completed 12/24/15 Delayed to <u>May</u> for reassembly of mid-boom #1 Two of 3 wheels delivered in December, 1 in <u>June</u> , being rebuilt, no schedule impact <u>Completed 11/30/15</u> |
| Jan-16 | 10 Deliver flight Aft Optics System to Telescope I&T 11 Complete final checkout of new GSFC vibration shaker table 12 Sunshield Flight Layer #4 shipped to Northrop-Grumman 13 Sunshield Forward Cover Assembly shipped to Northrop-Grumman 14 Complete Flight Operations Subsystem System Design Review #2 15 Complete Mission Operations Center construction at STScI | | <u>Completed 12/14/15</u> Horizontal shaker table accepted 3/3/2016, Vertical shaker acceptance delayed to May <u>Completed 12/3/15</u> Delayed till <u>June</u> . Nexolve revised schedule to implement NGAS design changes. No anticipated schedule impact <u>Completed 12/17/15</u> <u>Completed 12/29/15</u> |
| Feb-16 | 16 Deliver Aft Deployable Instrument Radiator to Observatory I&T 17 Deliver Command & Telemetry computer to Observatory I&T 18 Deliver Secondary Mirror Support Structure verification report to GSFC 19 Complete deliveries of Spacecraft wire harnesses 20 Deliver spare Cryocooler Compressor Assembly to JPL | | <u>Completed 2/15/16</u> <u>Completed 4/11/16</u> <u>Completed 1/28/16</u> <u>Completed 1/22/16</u> • Delayed to <u>May 2016</u> , no schedule impact |
| Mar-16 | 21 Start Spacecraft Panel Integration 22 Complete Sunshield Mid-Boom Assembly #2 functional test 23 Complete cryocooler thermal performance acceptance testing | | <u>Completed 10/26/15</u> Forecasting <u>July</u> completion date due to latch and detent pin redesign and tubesegment rebuild <u>Completed 3/5/16</u> |

Blue font(underline) denotes milestones accomplished ahead of schedule, orange font denotes milestones accomplished late. "*" denotes 2015 milestones carried forward.

Milestones: How the Project reports its progress monthly to Congress.

Milestone Performance

- Since the September 2011 replan JWST reports high-level milestones monthly to numerous stakeholders

| | Total Milestones | Total Milestones Completed | Number Completed Early | Number Completed Late | Deferred to Next Year | Deferred more than one quarter |
|---------|------------------|----------------------------|------------------------|-----------------------|-----------------------|--------------------------------|
| FY2011 | 21 | 21 | 6 | 3 | 0 | 0 |
| FY2012 | 37 | 34 | 16 | 2 | 3 | 3 |
| FY2013 | 41 | 38 | 20 | 5 | 3 | 2 |
| FY2014❖ | 36 | 23 | 10 | 8 | 11 | 10 |
| FY2015 | 48 | 44 | 22 | 12 | 4 | 3 |
| FY2016 | 46 | 24 | 19 | 10* | 0 | 0 |

*Late milestones have been or are forecast to complete within the year. Deferred milestones are not included in the number-completed-late tally.

❖ Milestone accounting in FY2014 was complicated by the government shutdown and multicomponent milestones

FY14: 8 milestones late by 1 month due to Oct 13 Government shutdown.

FY15, F16: Most “Lates” are not on critical path, nor cause a launch delay.

we do not want this to
happen to U.S. astrophysics



Avoid ending up like SSC (left). Canceled project funds never returns!

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