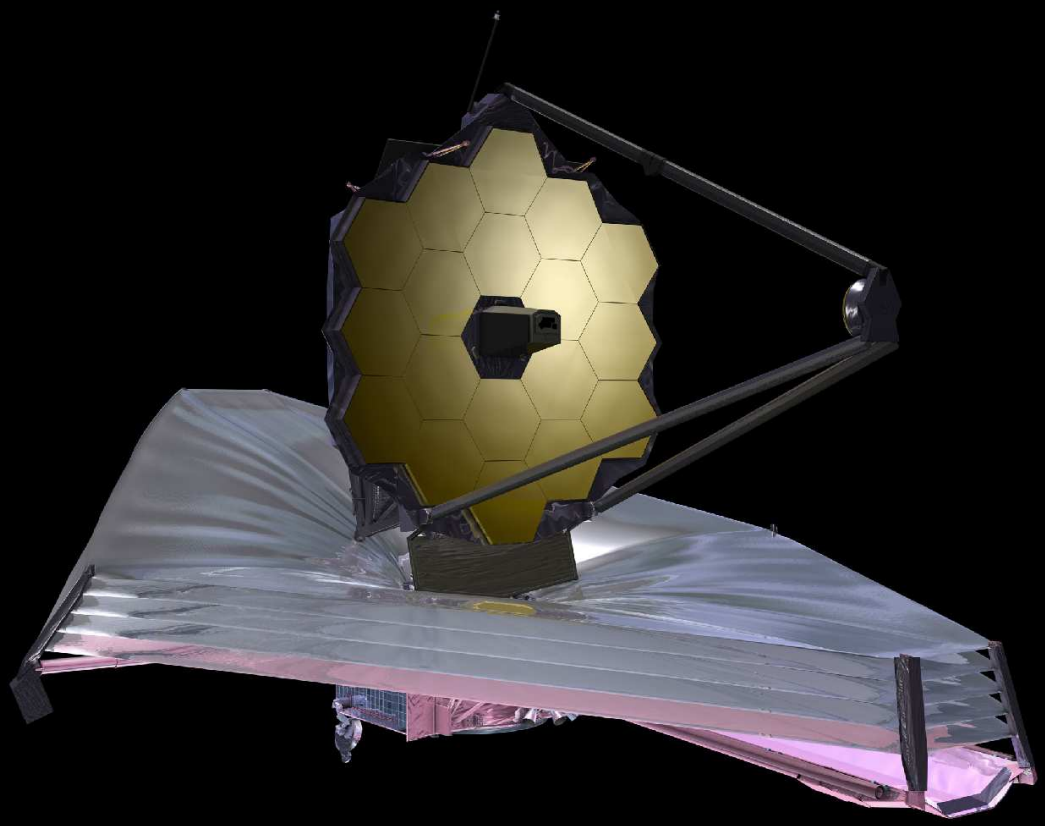
Lessons learned from JWST: What is required to make Mega-Science Projects succeed?

Rogier Windhorst (ASU) — JWST Interdisciplinary Scientist

and Robert W. Smith (Univ. of Alberta, Edmonton, Canada) — HST and JWST Historian



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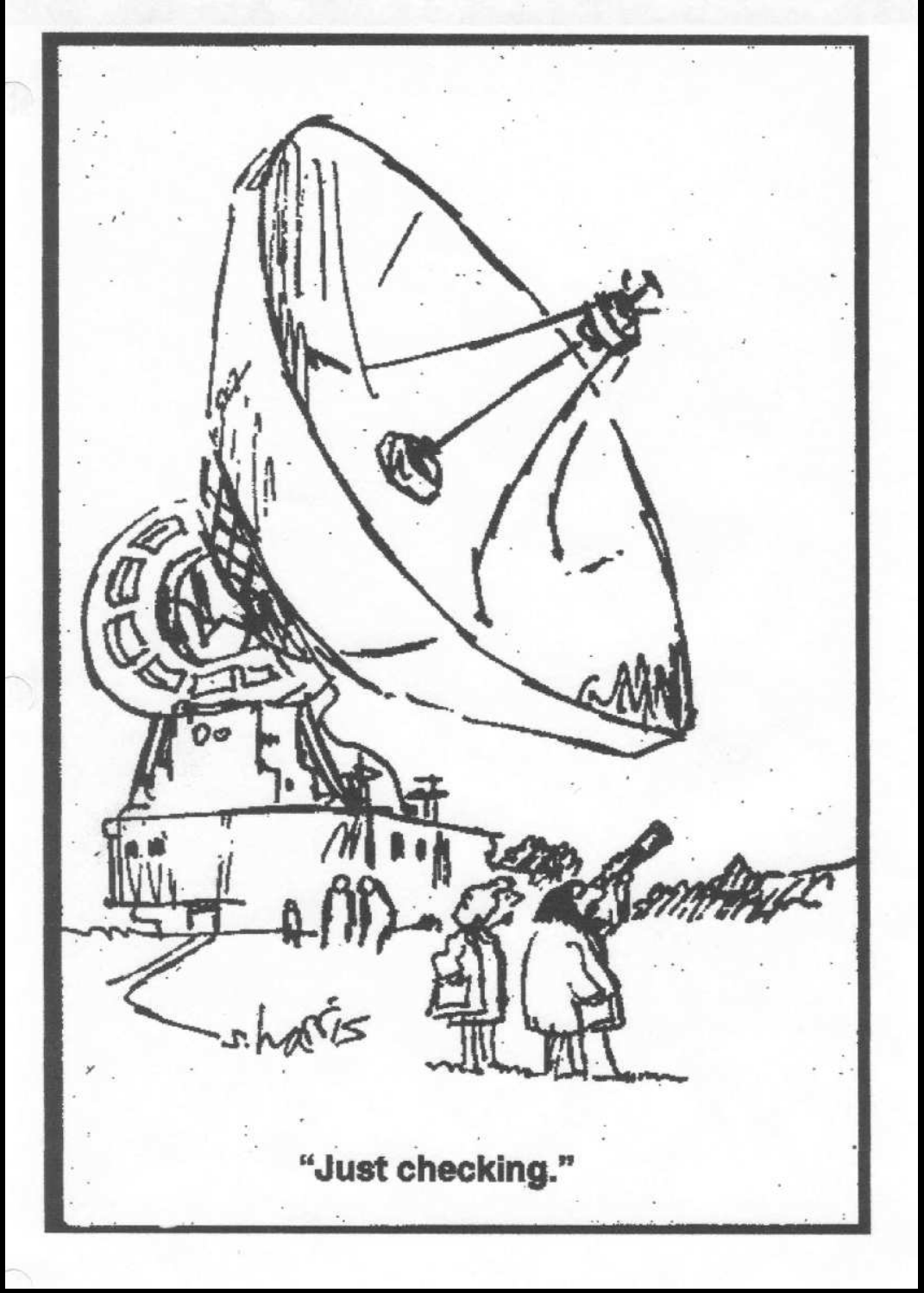
All presented materials are ITAR-cleared. These are my opinions only, not necessarily NASA's or ASU's.



Apologies to the radio astronomers in the audience for talking about small Opt–IR telescopes ...

Outline: Lessons learned from JWST

The following Mega-project lessons also apply to HST and Supercollider. Key is that scale of these 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

We thank Drs. Seth Cohen, Garth Illingworth, Rolf Jansen, and Eric Smith for useful comments.

Thank you, George Miley, for helping save Hubble WFC3 in Aug 2001:

10 filters HST/WFC3 & ACS in ERS reaching AB=26.5-27.0 mag (10-σ) over 40 arcmin^2 at 0.07–0.15" FWHM from 0.2–1.7μm (UVUBVizYJH).

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

(A) Scientific/Astro-community lessons learned from JWST

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

- 1) Have a killer app with full community support. (Be exciting enough that some dedicate a good fraction 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, highlight, & sell complementarity with other large facilities.
- 5) Still like the science and the project $\gtrsim$10–20 years later.
- 6) Offer project science and grant support to the whole community.
- 7) Keep selling the Mega-project to community until launch/first light.

(A) Scientific/Astro-community lessons learned 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).
- 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 SSC).

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 learned 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 app.
- 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).
- 5) Only design to specs you need and can afford to fabricate & test.
- 6) Test, test, and retest where needed.

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

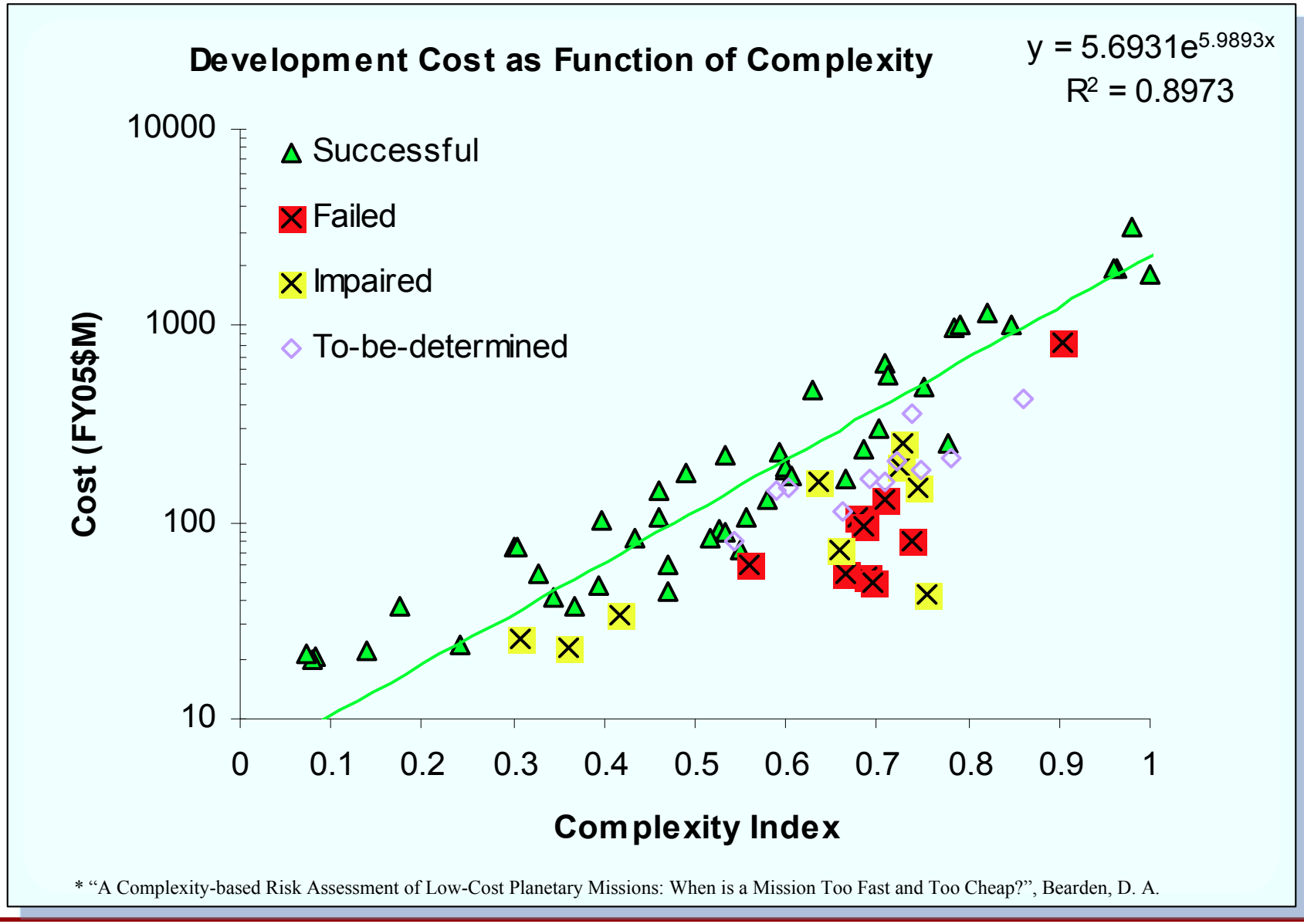
(B) Technical Lessons learned from the JWST Project

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 1μm diffraction limit unless you must have & can afford it.
- 5) [If you can't afford 1μm 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: 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.

AEROSPACE

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

(C) Management/Budget/Schedule Lessons from JWST

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

- 1) Sell project with initial unrealistic budget estimates.
(Lesson number 1 from HST: Don't buy in at bargain prices).

- 2) Cut project contingency to below critical mass ($i.e.$ $\lesssim$25-30%/yr).

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

- 4) Change science requirements after Phase A (unless essential to simplify, reduce risk and cost).

- 5) Change contract midstream, unless it is to reduce risk.

- 6) Allow contractors to change requirements at will, nor to hold requirements hostage against project budget/schedule.

- 7) Allow contractors to 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.

(D) Political/Outreach Lessons learned 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 didn't).

- 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.

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

- 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?).

(D) Political/Outreach Lessons learned from JWST

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

- 1) Have project politicized in the government (lesson from SSC).
- 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) Ever fall asleep, not until launch anyway ...

OVERALL CONCLUSION: JWST is now on the right track, but we did have to learn our lessons.

G. W. F. Hegel (1832): "History teaches us that mankind learned nothing from history."

Some things are better left discussed during ...

Miller time!

Het Borrel uur!

SPARE CHARTS

(from Robert Smith's Sarton talk on HST Lessons)

(E) References and other sources of material shown:

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

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

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

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

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

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

Casani, J. et al. 2010, Final Report of the JWST Independent Comprehensive Review Panel (ICRP) (NASA: http://www.nasa.gov/pdf/499276main_casani_letter.pdf)

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

Hegel, G. W. F. 1832, in "Lectures on the Philosophy of History", trans. by J. Sibree (McMaster)

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

Smith, R. W. 1993, "The Space Telescope: A Study of NASA, Science, Technology, and Politics" (Cambridge University Press)

Smith, R. W. 2011, Sarton talk on "Lessons learned from HST"

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

The Making of Successful Mega-projects: Coalition Building

To succeed, Mega-projects like HST must:

- 1) Be scientifically enormously attractive for an entire community.
- 2) Be made technically feasible.
- 3) Be made politically feasible.
- Assemble a Mega-project team in technical, institutional and political terms: Patronage matters! (Not simply an issue of securing enough money to proceed).
- The 'selling' of a Mega-project has to be done over and over and over again.

SSC Failed its Efforts at Coalition Building:

- 1) Lack of international partners.
- 2) Dissent among physicists.
- 3) Program 'design' created serious tensions.
- 4) Congressional concern over deficits.
- 5) Widespread perception of unrealistic cost estimates.
- 6) Shift in the 'political economy' and loss of influence for Texas.

Successful Mega-projects before and after World War II

World War II and the Cold War meant an enormously enlarged role for the federal government as scientific patron, starting with the Manhattan Project.

This was not just a matter of project size, but contained:

- 1) New social roles.
- 2) Scientists as Coalition Builders.
- 3) Coalition Builders and the Hubble Space Telescope as prime example.

The Hubble Space Telescope and Coalition Building

A big scientific instrument placed at the frontiers of knowledge represents a political and managerial achievement every bit as significant as the technical feat:

- Hubble Space Telescope (HST) helped to reconstitute the astronomical enterprise.

- HST helped remake what it means to be an astronomer.

- Advocacy of new telescopes was no longer left to a few elite astronomers: we engaged a community of scientists.

Coalition Building: The Ground-Based Astronomers

- Assured ground-based astronomers that space astronomers would promote a 'balanced' program.

Coalition Building: Gain the Interest of NASA

- Not just state-of-art science,
- But also provided a justification for the Space Shuttle,
- And ties to the human space flight program.

Coalition Building: The Contractors

- Financial interest in new projects.
- Institutional interest in bringing new sorts of business and skilled engineers of various sorts into companies.

Coalition Building: The White House

- Justification of the national investment in the space shuttle.
- U.S. leadership in science.
- Attractive science.

Coalition Building: The U.S. Congress

- Jobs across all 50 states.
- U.S. leadership in science.
- International partnership.

Coalition Building: The Department of Defense

- An important part of the Hubble Space Telescope's technical heritage comes from reconnaissance satellites.
- NASA and the DOD therefore had to agree on how to build HST without revealing classified information.

Coalition Building For Hubble's last Servicing Mission

- NASA canceled the final planned servicing mission to HST in 2004.
- 2004: Coalition of Supporters enters the field one more time.
- In time, the Coalition would involve members of the media and the public.
- Public and Congressional outcry resulted in the decision being overturned.

Steven Weinberg's Question: Is Big Science in Crisis?

- "We may see in the next decade or so an end to the search for the laws of nature which will not be resumed again in our own lifetimes".

- What is the Answer? It depends on the success of scientists as coalition builders.