The Making of Megascience:

The History of the James Webb Space Telescope

FISO PRESENTATION – 15 DECEMBER 2021

Robert Smith

University of Alberta


Moment ONE
30 August 1905
2

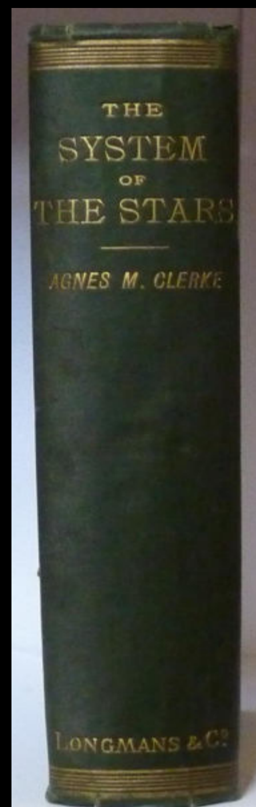
George Darwin, 1905, and the limits of astronomy

Was it not as futile to imagine that humans "can discover the origin and tendency of the universe as to expect a housefly to instruct us as to the theory of the planets?"

The One-Galaxy Universe, 1905

our Milky Way galaxy is the only visible galaxy in space

Agnes Mary Clerke

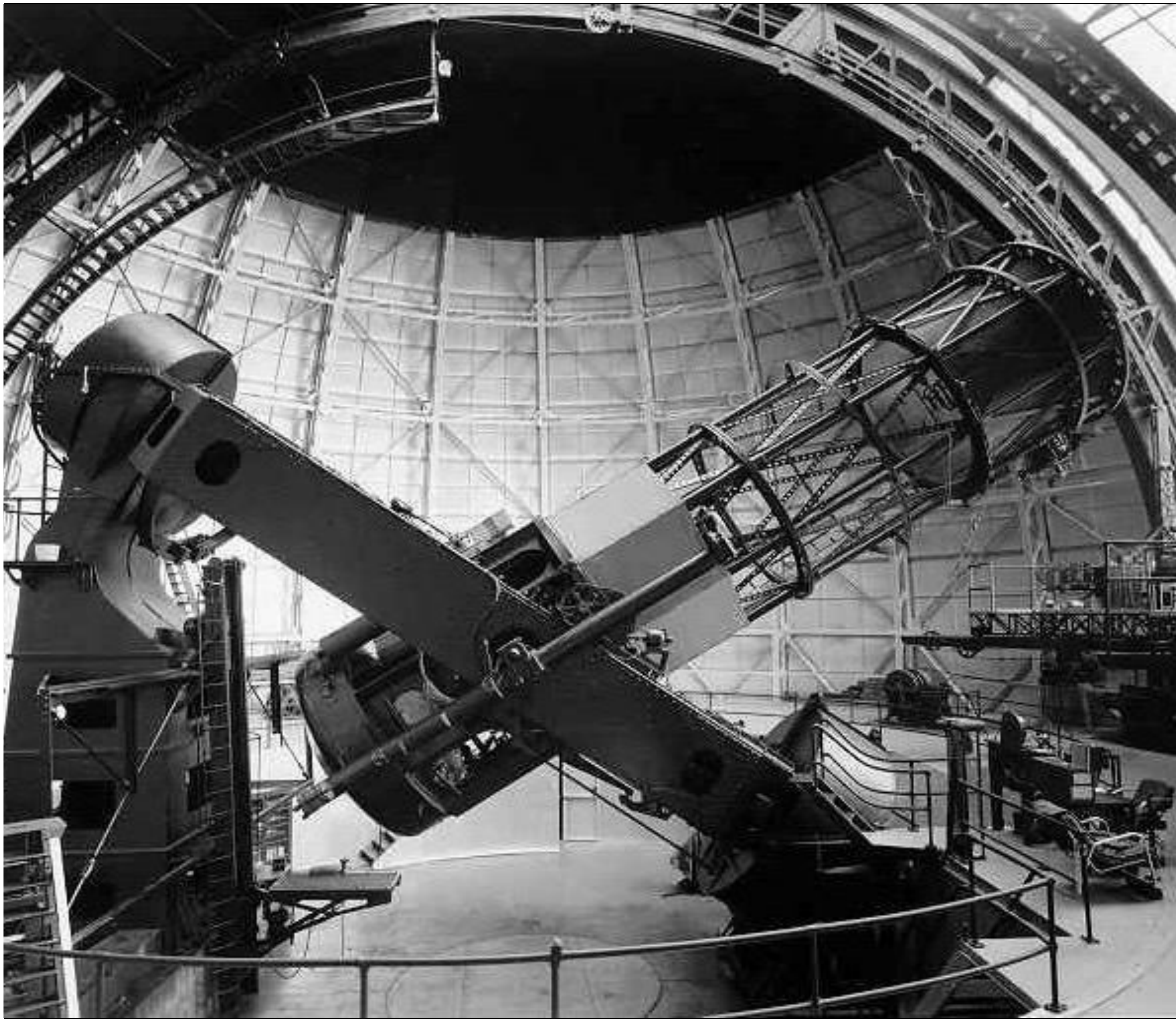


American astronomy remade by new forms of patronage

Andrew Carnegie

John D. Rockefeller

Charles Tyson Yerkes

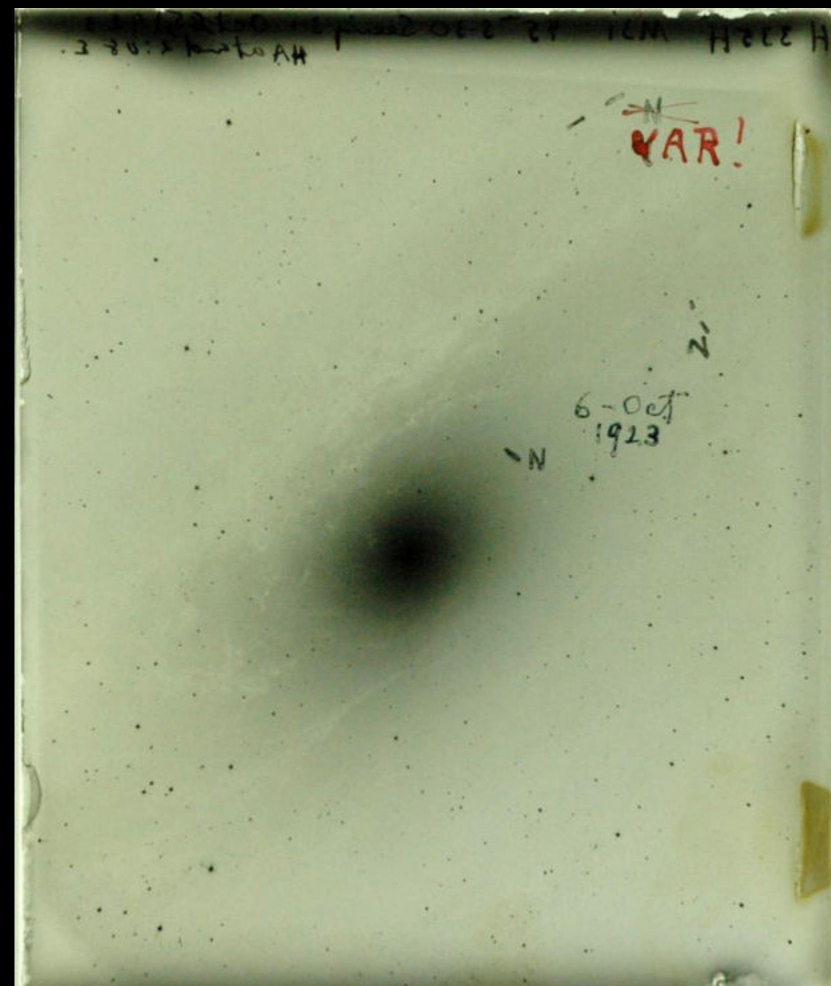


Hooker 100-inch
Mount Wilson

the most important result of the new wave of telescope building

Proof of Other Galaxies Secured in 1923

Discovery by Edwin Hubble
of Cepheid variable stars (VAR!)
in the Andromeda "Nebula"



Henrietta Leavitt, 1912

Established the

Period-Luminosity relationship

for Cepheid variable stars, a method of

determining distances to these stars

This relationship was crucial for determining:

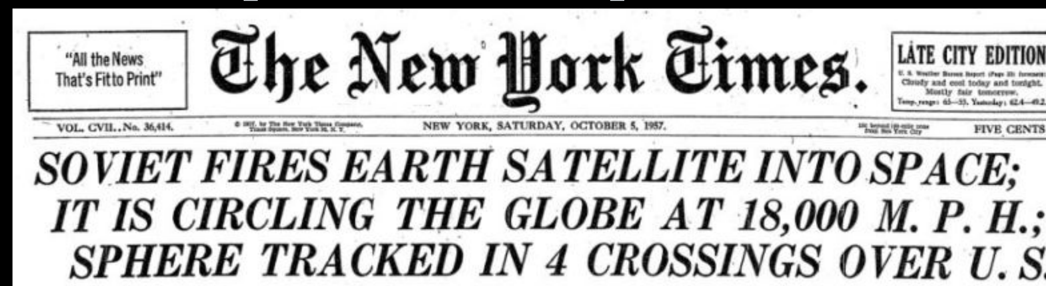
(1) the size and nature of our galaxy

(2) the existence of other galaxies

Moment TWO

4 October 1957

Soviet Union's *Sputnik I launch on* 4 October 1957, crucial step in the Space Race



"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

VOL. CVII..No. 36,414. NEW YORK, SATURDAY, OCTOBER 5, 1957. FIVE CENTS

SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

COURSE RECORDED

Navy Picks Up Radio Signals—4 Report Sighting Device

By WALTER SULLIVAN

560 MILES HIGH

Visible With Simple Binoculars, Moscow Statement Says

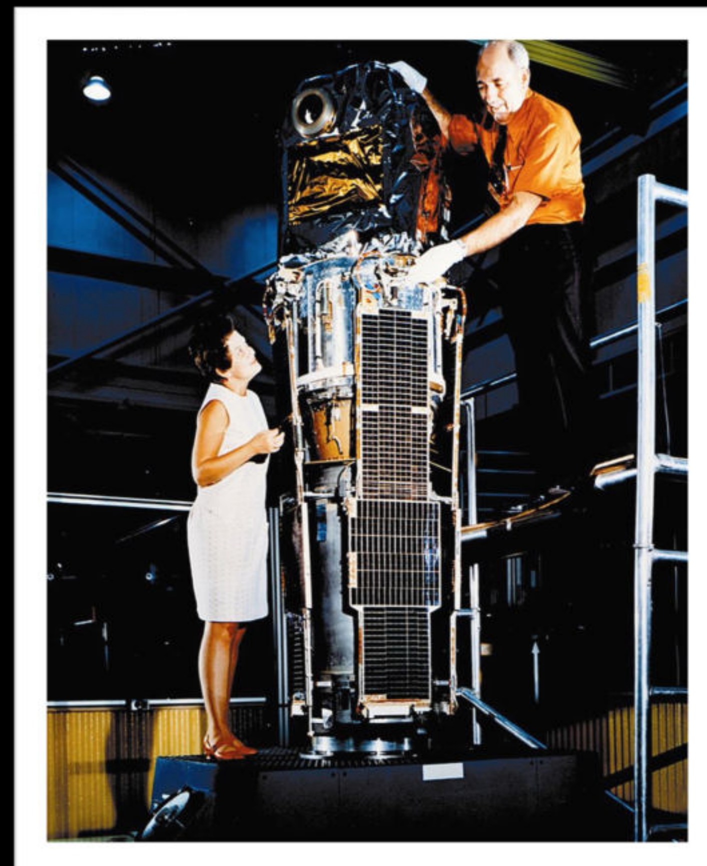
By WILLIAM J. JORDEN

Device Is 8 Times Heavier Than One Planned by U.S.

Federal patronage transforms the prospects for Space Astronomy

Panchromatic Space Astronomy Emerges

IRAS



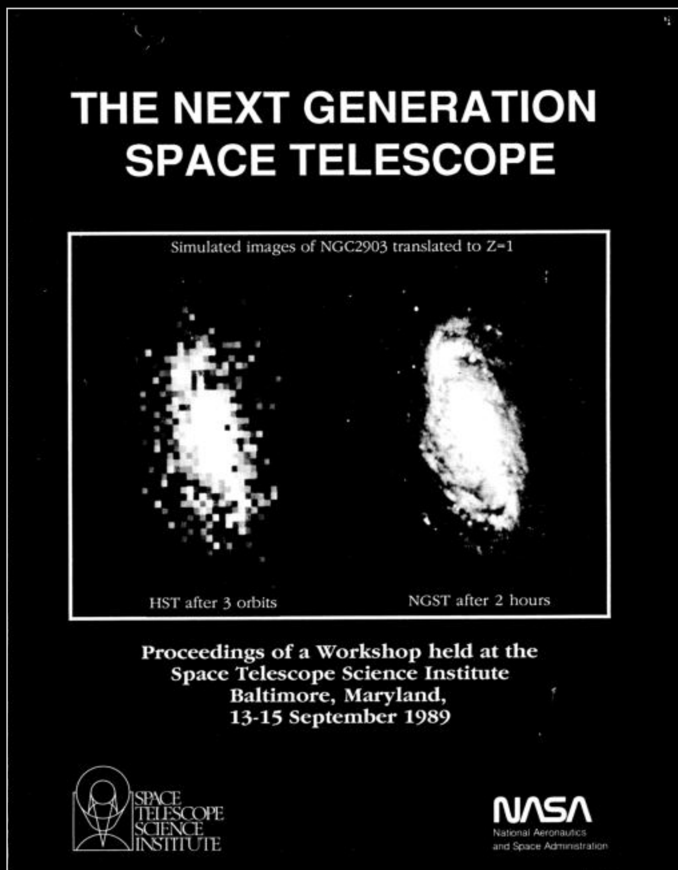
UHURU

With JWST's completion and operations, the builders and users of JWST will add to the remarkable adventure of the human spirit that is the enterprise of space astronomy, remarkable in that it has been so extremely productive while also being so incredibly hard.

Moment THREE

13 September 1989

1989 Workshop at the Space Telescope Science Institute to plan a successor to the Hubble Space Telescope



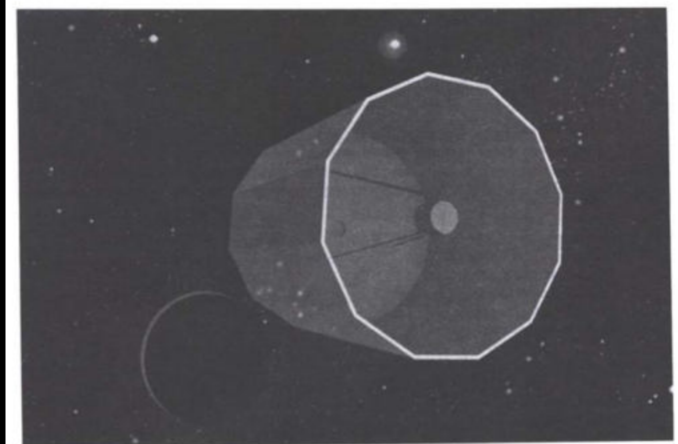


Figure 1. Artist's concept of a 10 meter telescope in high earth orbit. The telescope is very compact thanks to a fast primary and the short baffle that a relaxation of sun, moon and bright earth avoidance angles in high orbit permits. Solar panels are fixed on the rear of the spacecraft to minimize mechanical disturbances.

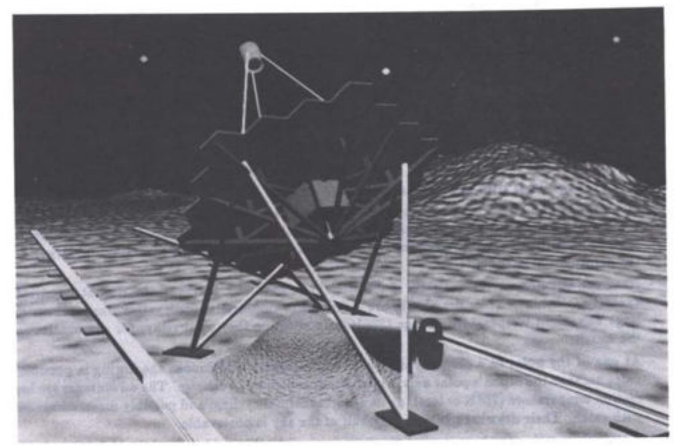


Figure 2. Artist's concept of a 16 meter telescope on the moon. The segmented primary mirror is supported by a hexapod mount, the legs of which are extendable for pointing and tracking. A coudé-like arrangement is used to feed the scientific instruments which are located underground for radiation and meteorite protection. The rails are for a hangar-type shield which is rolled over the telescope during lunar day.

At that time (1989) Hubble ***still had not launched***

Hubble's detailed design and construction had begun in **1978**

20 July 1989: President Bush and the Space Exploration Initiative

A ten-meter optical telescope in space

P.Y. Bely
Space Telescope Science Institute
3700 San Martin Drive, Baltimore, Maryland, 21218

Abstract

Site and configuration options for a successor to the Hubble Space Telescope are discussed and one candidate is presented. The telescope is a traditional Cassegrain with a 10-meter diameter monolithic primary, adaptive secondary, and passively cooled optics. Wavelength coverage is from the far ultraviolet to the near-infrared. The observatory is located in the geosynchronous orbit to minimize environmental constraints and increase observing efficiency.

Introduction

It takes from ten to fifteen years from inception to completion of a large astronomical telescope, whether on the ground or in space. Although the Hubble Space Telescope (HST) is not even launched, its limited operational lifetime of fifteen years means that it soon will be time to start making serious plans for a successor.

Several designs have been proposed which are summarized in Figure 1 as a function of the two main characteristics of telescopes, resolution and collecting power. With the exception of a conceptual study by Perkin-Elmer[1], all current proposals emphasize very high resolution imagery of bright objects[2,3,4]. Yet, no matter how exciting the prospects of high resolution optical imagery may be, the mainstream of astronomy will certainly still require the same general-purpose capability that HST will offer. A true successor should be as unspecialized as HST is, albeit with significantly improved flux, resolution and wavelength coverage. Cost will then become a major concern. At more than a billion US dollars, HST is a very costly observatory. For an even larger observatory to be affordable to the astronomical community, it will

TABLE OF CONTENTS

What Sort of Successor to Hubble? Suggestion from 1989 Workshop

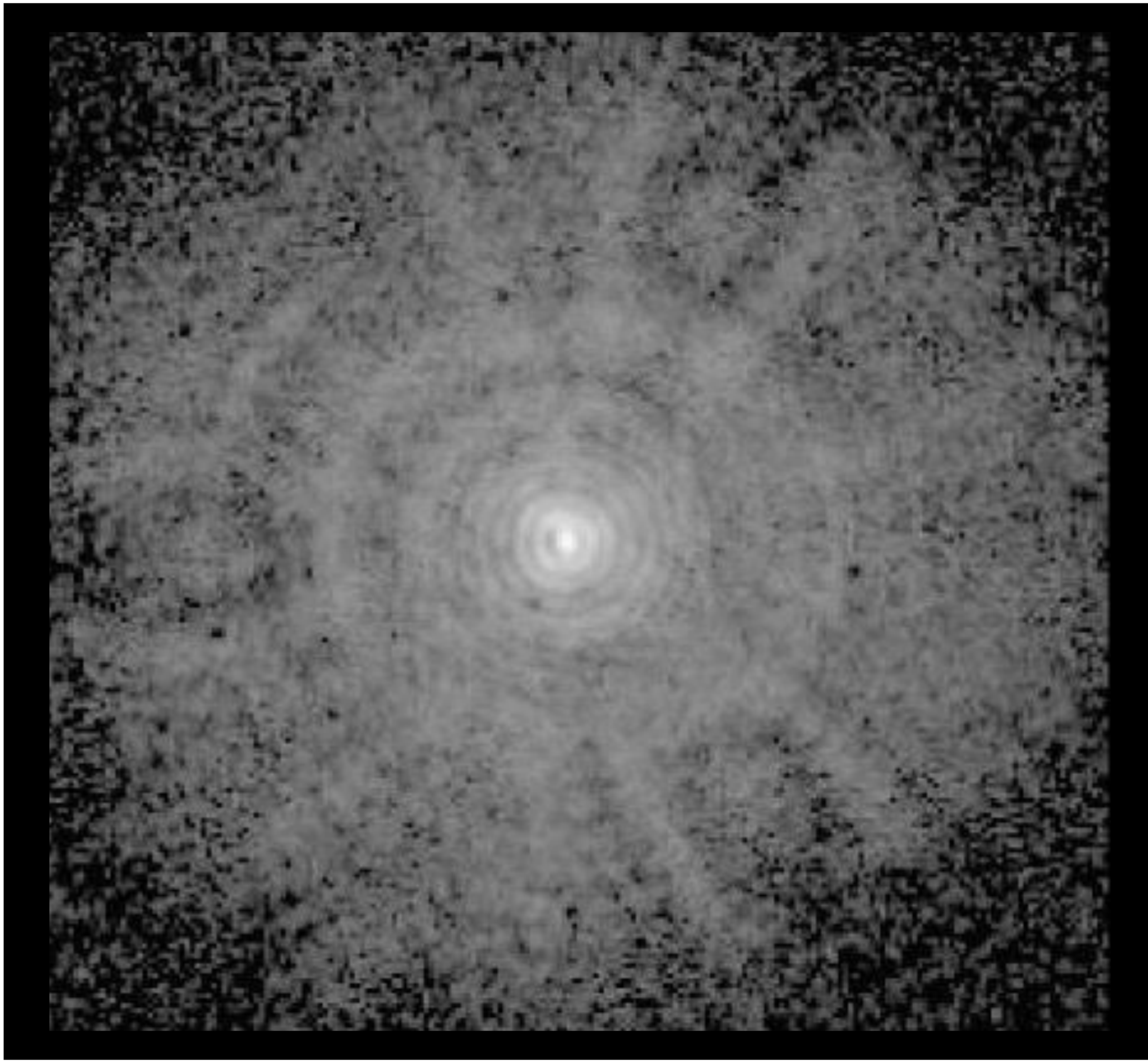
1. Scientific objectives:

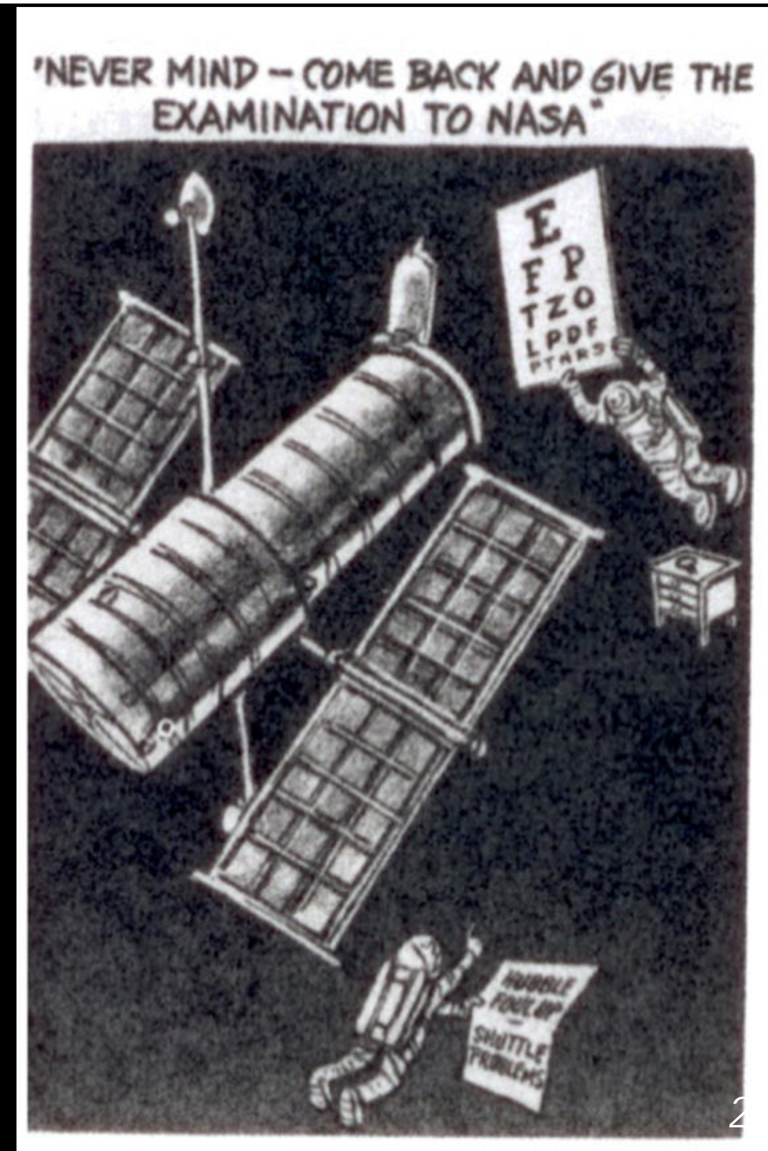
There will be a definitive need to continue and extend the observational capability offered by HST beyond its predicted lifetime. A gap of more than 5 years would be a blow to the vitality of forefront astronomical research.

The scientific potential of an HST follow-up mission with enhanced flux collecting power and spatial resolution, and with spectral coverage extended through the near-infrared is enormous. It is viewed as complementary to large-baseline space interferometry missions which emphasize high spatial resolution imagery. An observatory providing high sensitivity and high-throughput spectroscopic capability at diffraction-limited spatial resolution from the UV to beyond 10 microns is vital for the study of the most fundamental questions of astrophysics. These include the formation and evolution of galaxies, stars and planets, and the nature of the young universe.


Moment FOUR
24 April 1990

Hubble Space Telescope launched but a blunder awaits discovery: spherical aberration

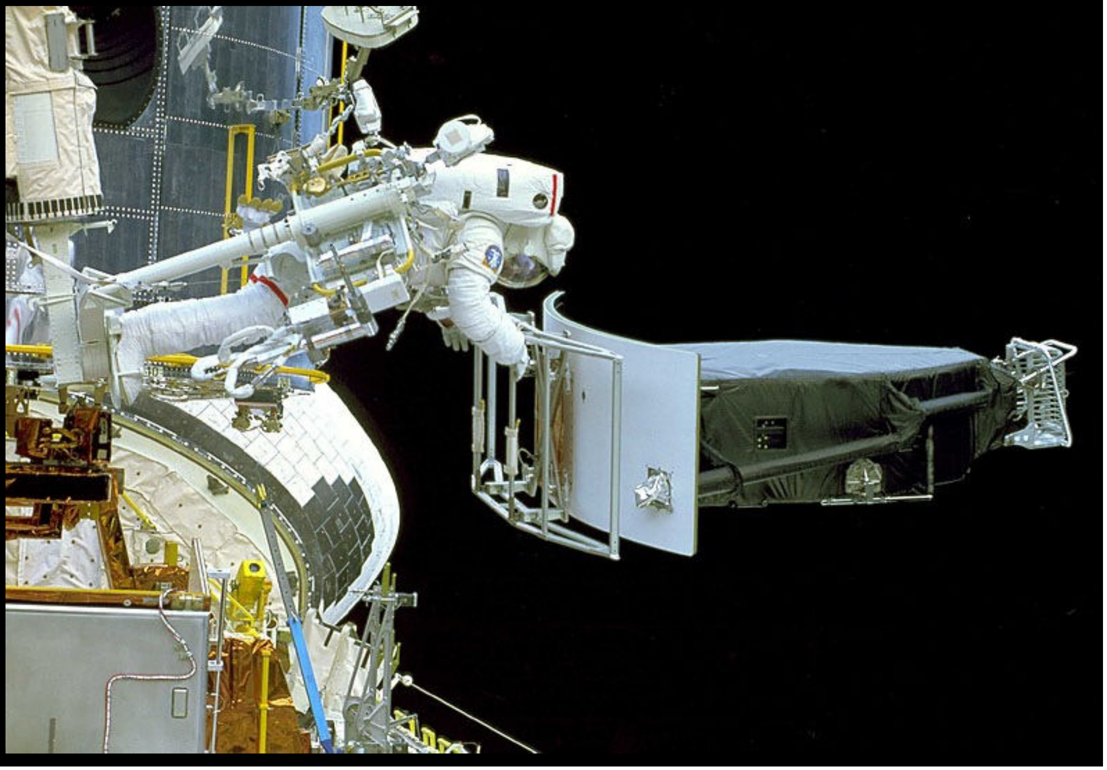



"NEVER MIND – COME BACK AND GIVE THE EXAMINATION TO NASA"
E
F P
T Z O
L P D F
HUBBLE FOUL UP
SHUTTLE PROBLEMS

Shuttle repair mission to Hubble

Shuttle Endeavour launch on 2 December 1993

Wide Field/Planetary Camera 1 being removed from Hubble by astronaut Jeff Hoffman



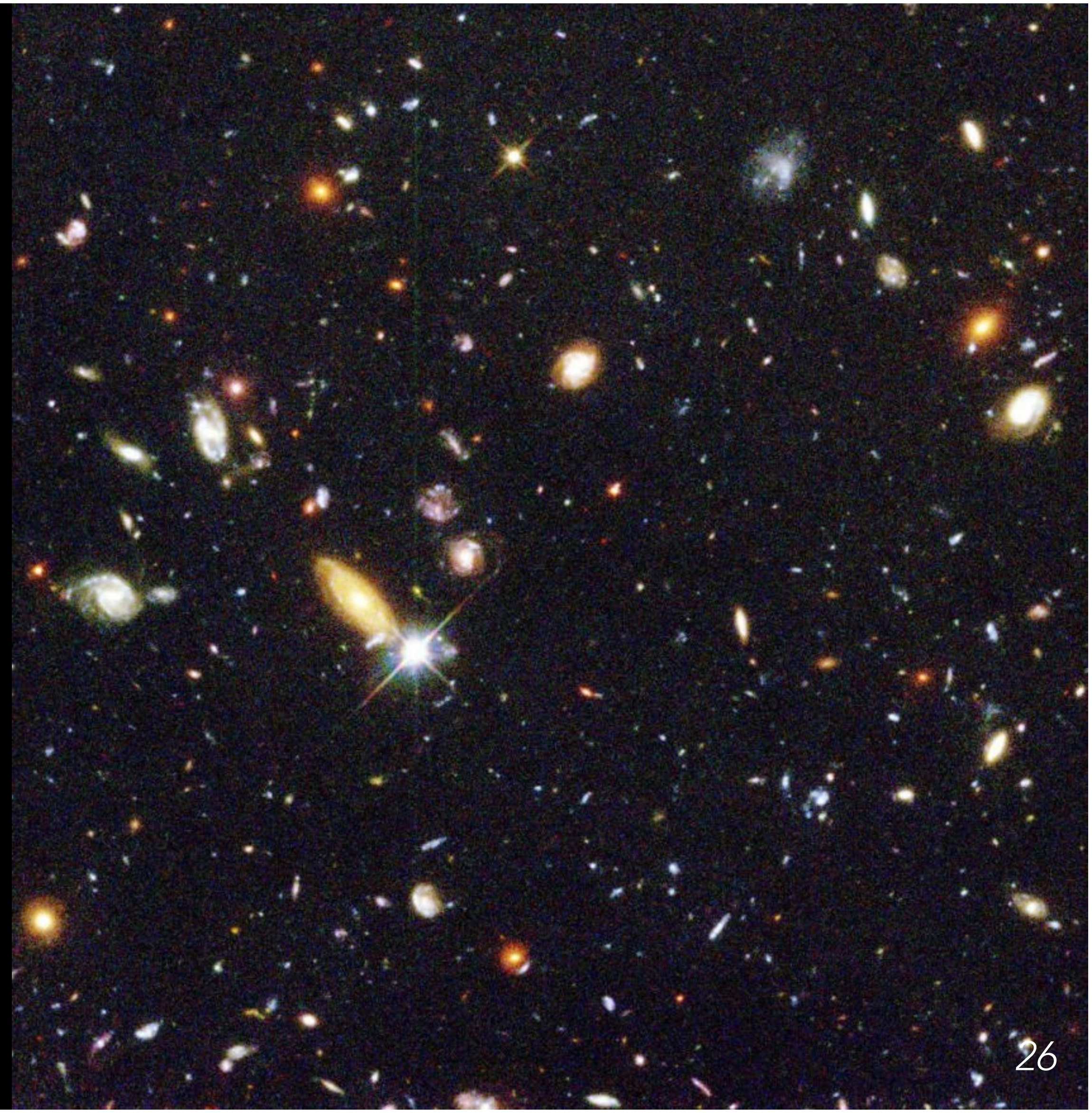
Iconic imagery: demonstrated Hubble was working as intended

Hubble Deep Field

Wide Field/Planetary Camera 2

Ten successive days in December 1995

Revealed close to 10,000 galaxies



Hubble's troubles slowed planning for a \`Next Generation Space Telescope,' but with Hubble's rebirth matters could move forward

Moment FIVE

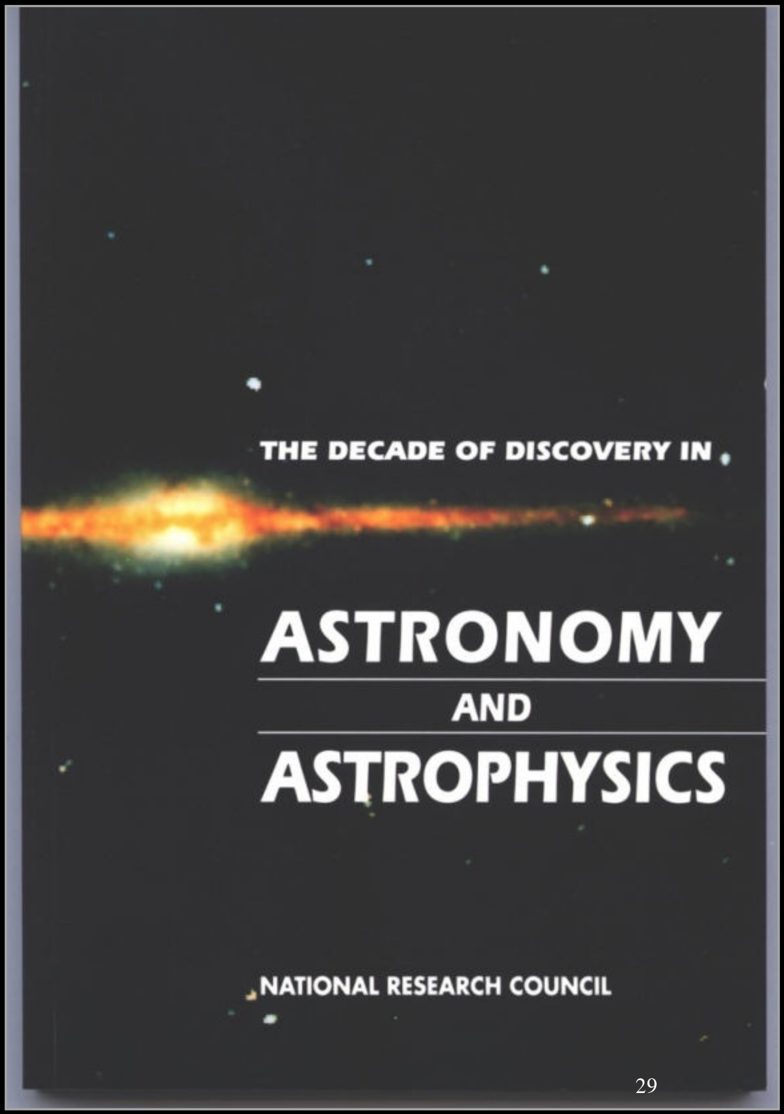
22 May 1991

Bahcall Committee 1991

Proposed priorities for U.S. ground-based and space astronomy in the 1990s

Declares the 1990s will be
the decade of the infrared,
with huge improvements in detectors

BUT DOES ***NOT*** SUPPORT
PROCEEDING WITH A UVOIR NGST



STATE OF IR ASTRONOMY: Malcolm Longair, May 1991

"…the enormous revolution in infrared astronomy which has taken place over the last ten years. The technology of infrared detector arrays and advances in all related aspects of instrumentation — mechanical, electronic, optical and cryogenic design — have led to quite staggering advances in scientific capability. Most major observatories now have programmes of advanced infrared instrumentation as a matter of course…"

Passive cooling opens the way to a BIG infrared space observatory

EDISON: THE NEXT GENERATION INFRARED SPACE OBSERVATORY

H. A. THRONSON, JR
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and
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The Aerospace Corporation, P. O. Box 92957, MS M2-266, Los Angeles, CA 90009, U. S. A.

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R. F. KNACKE
State University of New York, Dept. Earth and Space Sciences, Stony Brook, NY 11794, U. S. A.

D. LESTER
University of Texas, Dept of Astronomy, RLM Hall, Austin, TX 78712, U. S. A.

and

C. M. MOUNTAIN
Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, U.K.

(Received 19 September, 1991)

Abstract. EDISON, a large-aperture, radiatively-cooled telescope, is proposed as the major international mission to follow the current generation of cryogenically-cooled infrared space telescopes. It is being studied at present as a 2.5–3.5 m mixed radiatively- and mechanically-cooled facility optimized to investigate the wavelength range 3–100+ μm. This paper outlines the status of the project, discusses some aspects of a smaller-aperture 'precursor' mission, and describes a portion of the baseline science mission.

1. The Infrared Universe and First Generation Space Observatories

So long as observations in the infrared (1–500 μm) are limited, so too will be our understanding of the cosmos. This is a direct consequence of the richness of this wavelength regime: critical diagnostic features of the solid state and gaseous interstellar medium (ISM) are found in the infrared, as are photospheric or atmospheric features of planets, brown dwarfs, and other sub-stellar objects. Supernovae and novae, enriching the ISM with heavy elements, can be studied via their infrared spectra. Finally, the expansion of the universe shifts major visual diagnostic lines

Space Science Reviews **61:** 145–169, 1992.

Conference Participants
May 1991 (above)

Examining prospects for a big infrared space observatory

Tim Hawarden (Left)

POIROT

POIROT

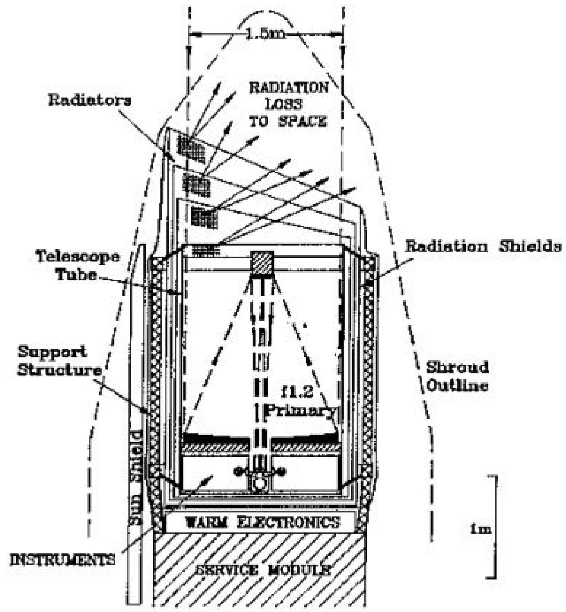
Passively Cooled Orbiting InfraRed Observatory Telescope

- Aperture 1.5 Metres
- Temperature 40 Kelvin
- No Cryogens

An elegant solution for Infrared Astronomy in space.

P01

POIROT

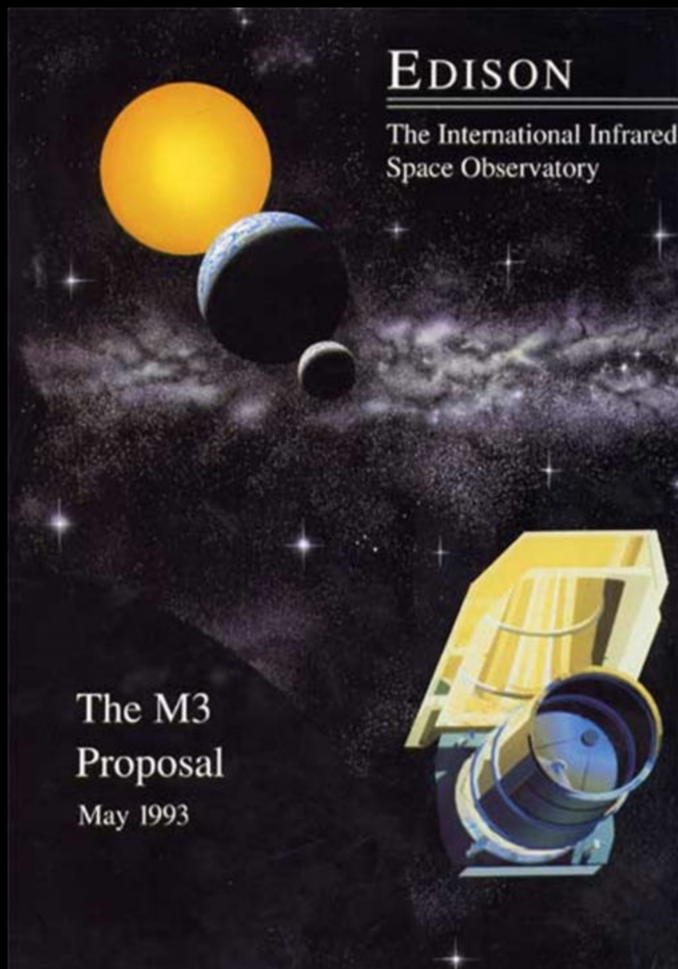


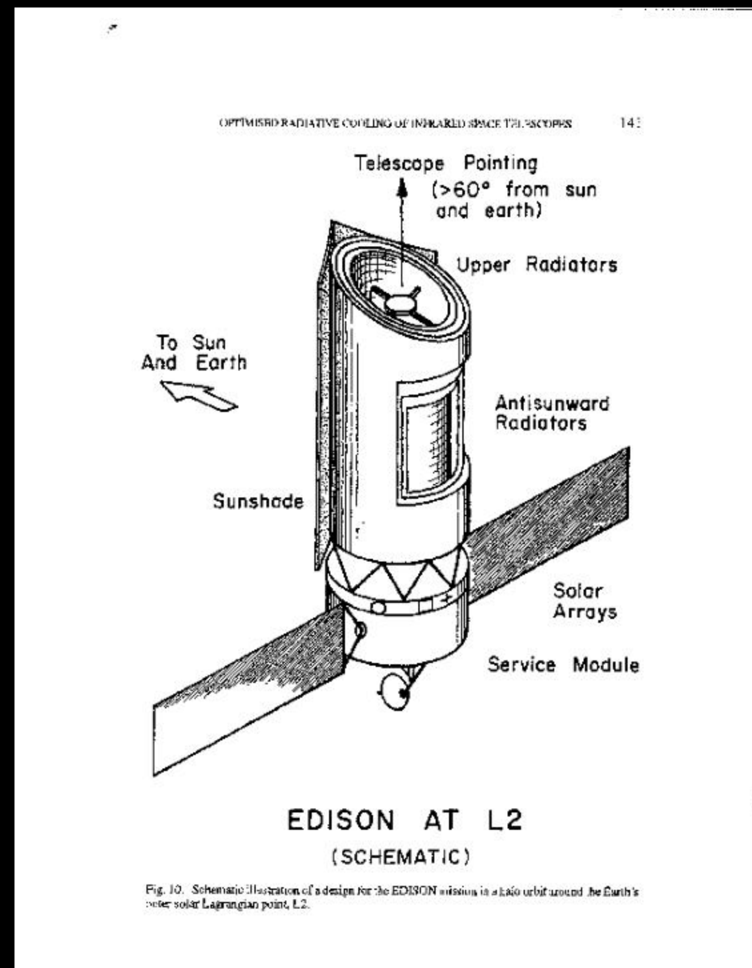
POIROT in ARIANE 4 TYPE 02 SHROUD

P11

POIROT

Edison (Planned Infrared Observatory)






Moment SIX
17 January 1996

Longair again, 1991

"…it is still mostly the pioneers and afficionados who are using these wonderful new [infrared] instruments…

The point of this argument is that, when the case is being made for a major new astronomical facility such as POIROT, it is plainly of the **greatest importance that the scientific case for the facility is very broadly supported within the whole astronomical community** and not just among infrared astronomers…

It will be essential to further the case for the next generation infrared telescope that the scientific case be absolutely first-class."

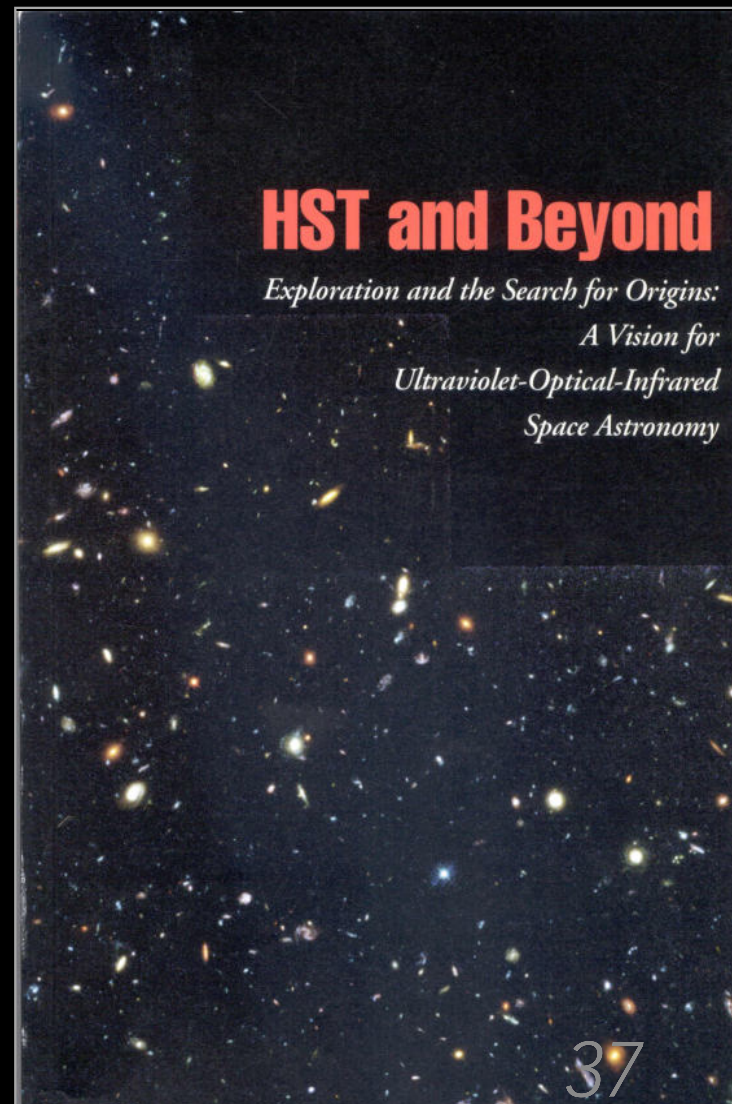
Dressler Committee 1996

Argues that the "Origins" theme should guide space astronomy in the next decade

Desire to 'break' the cost-curve represented by Hubble

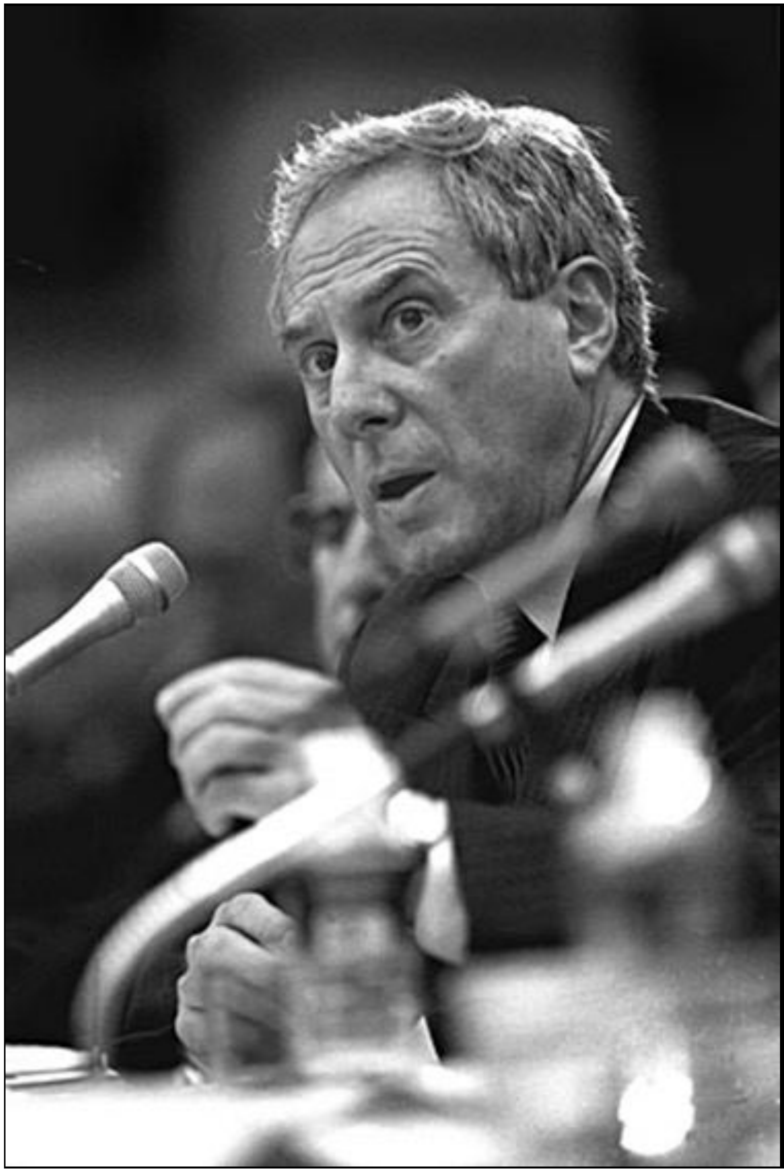
Recommends a passively-cooled infrared space observatory (not UVOIR)

"NASA should develop a space observatory of aperture 4m or larger, optimized for imaging and spectroscopy over the [infrared] wavelength range."



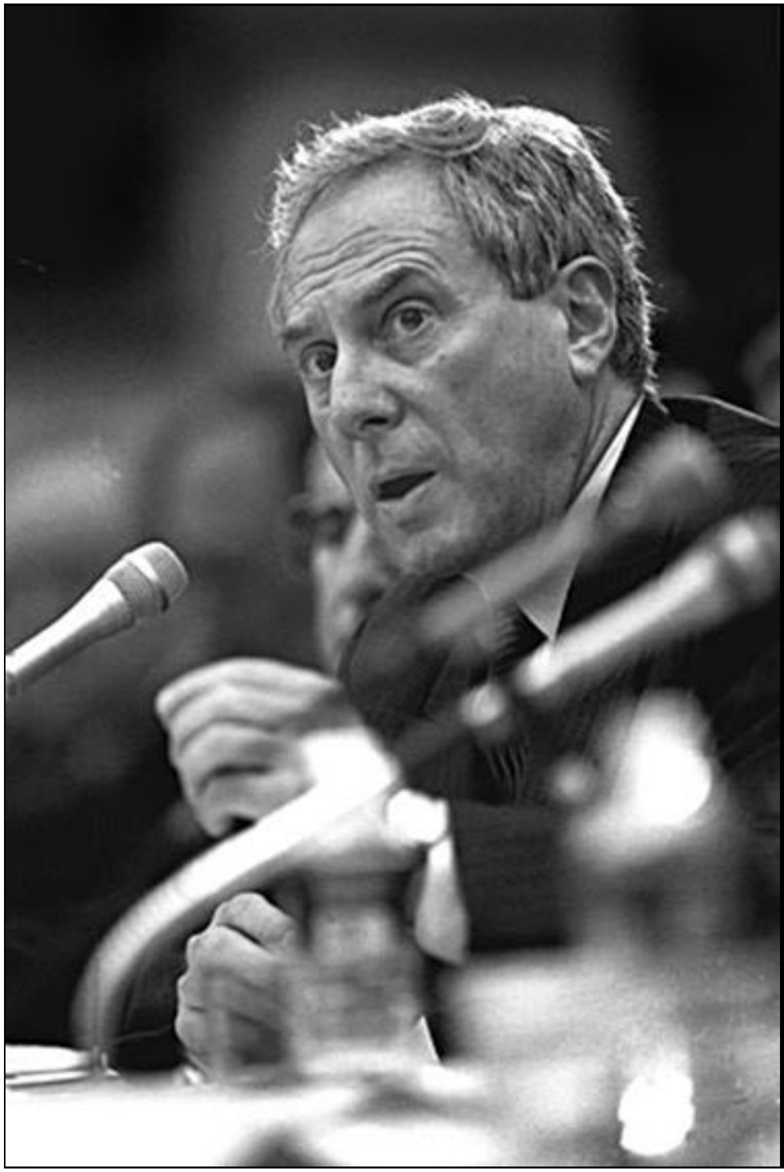
At this point, the future telescope is sometimes referred to as ‘the first light machine’ however…

“Our recommended large-aperture IR-optimized space telescope will be essential for the detailed studies of the early universe at 1-5 microns. However, we also recommend that it be operated as a powerful general purpose observatory, serving a broad range of scientific programs over the wavelength 0.5 to 20 microns, the exact coverage to be determined on the basis of future technical evaluation.” [HST and Beyond p. 69]



NASA’s Dan Goldin Speech to the American Astronomical Society in 1996

“Our ***next big step*** in space astronomy is in the ***infrared***. We have to move beyond the visible… We’re going to open up the whole universe to our eyes; young stars, planets, faint IR galaxies…”



NASA's Dan Goldin Speech to the American Astronomical Society in 1996

"I see Alan Dressler here. All he wants is a four-meter optic that goes from half a micron to 20 microns. And I said to him, ***'Why do you ask for such a modest thing? Why not go for six or seven metres?'*** … we have years to work this, so I think we ought to relax and not make these major commitments."

By late 1995, NASA planning for "Next Generation Space Telescope" (NGST) is underway

October 1995: Study contract established with Goddard Space Flight Center; John Mather is lead

Goddard takes the lead for NASA, working closely with the Space Telescope Science Institute

Industry also involved on a serious scale

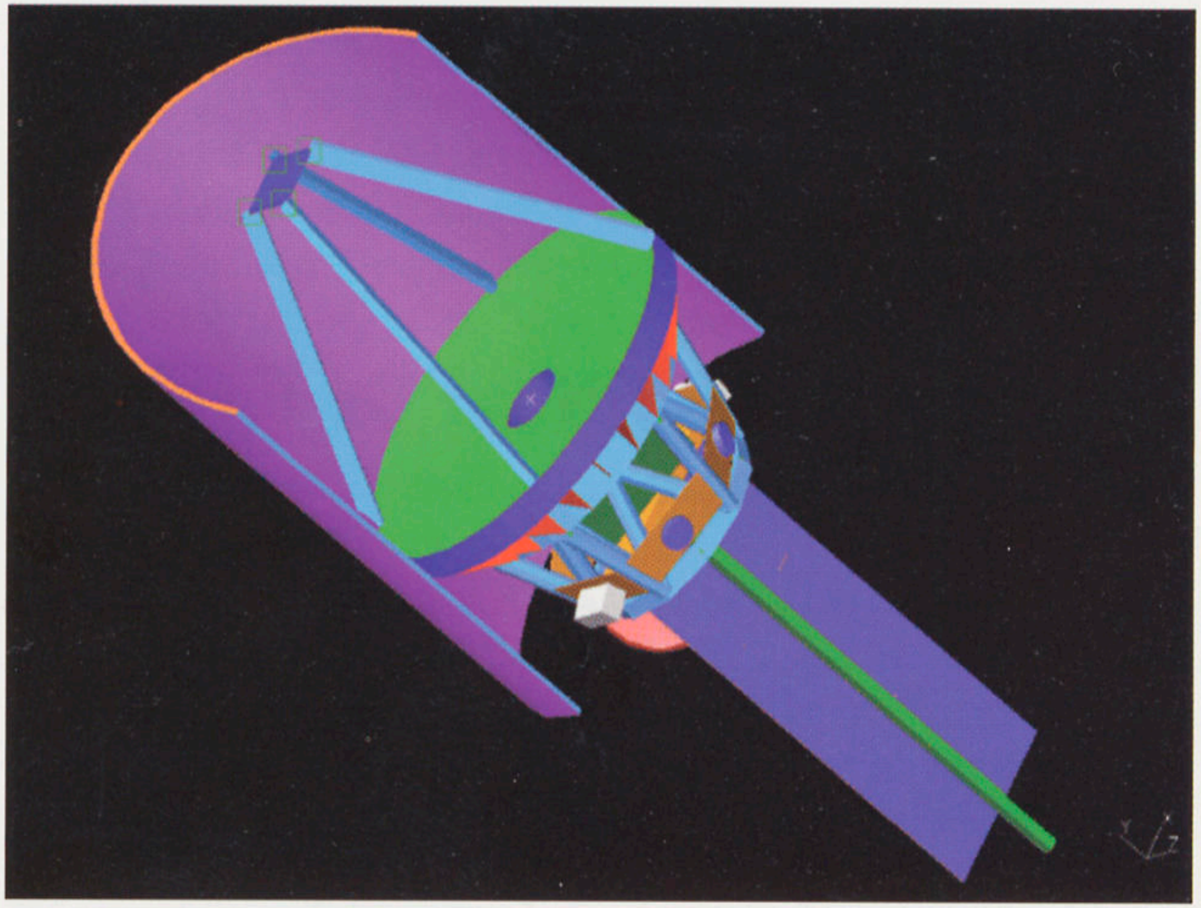
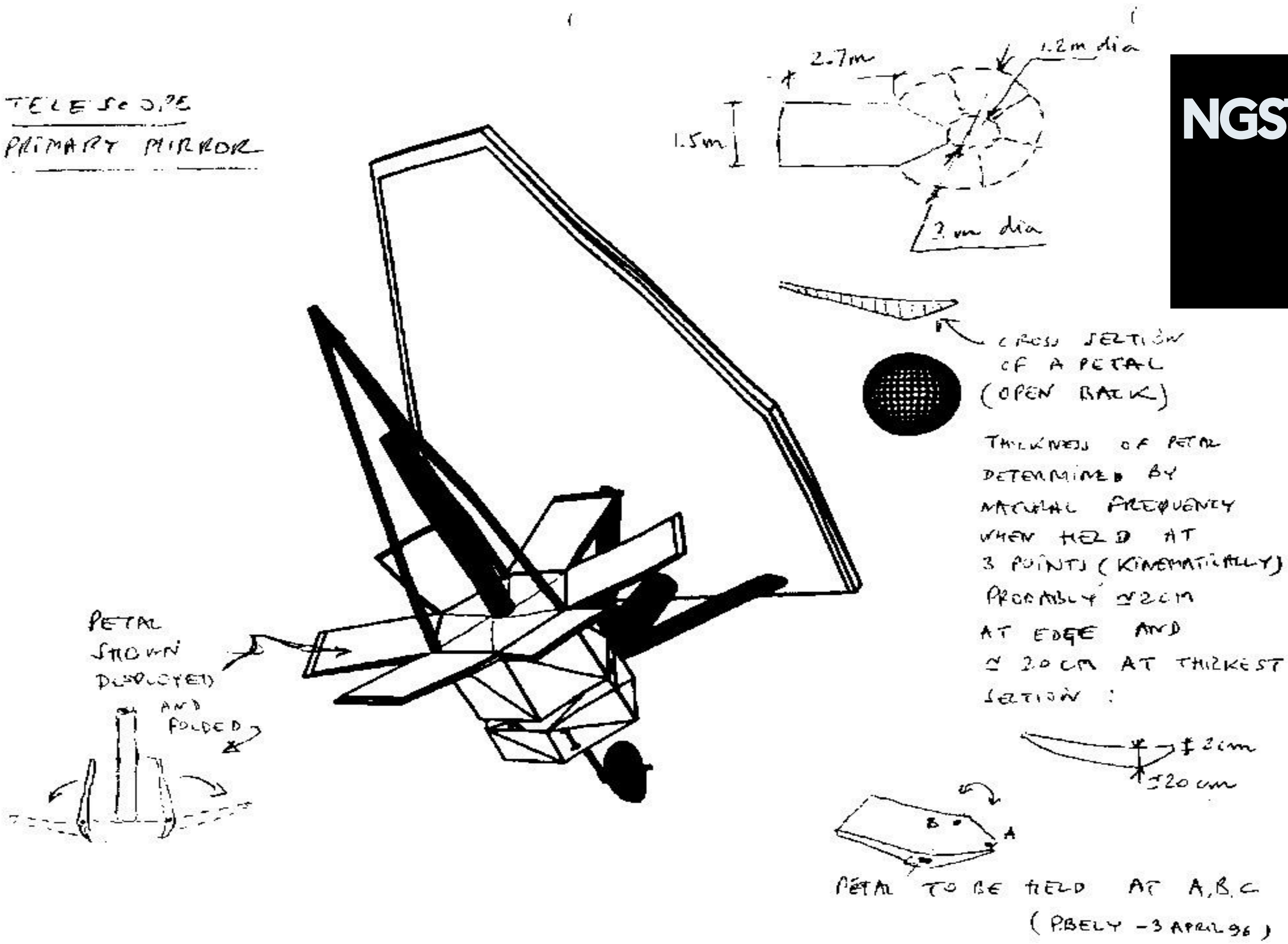


FIGURE 4.1. Lockheed Martin 6 m aperture monolithic telescope. The large solar arrays are deployed well to the rear of the telescope to reduce heating effects. (Lockheed Martin)

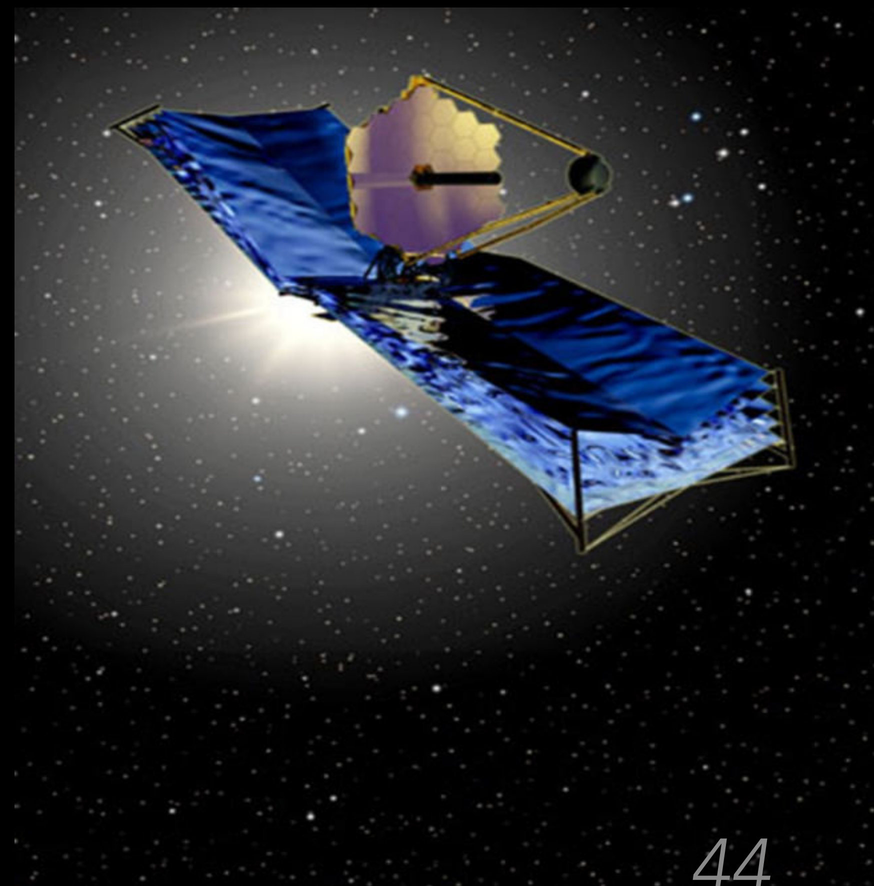
Lockheed Martin's Original NGST Concept: Monolithic 6 m telescope. Lockheed had been responsible for the spaecraft part of Hubble.

NGST Design Notes

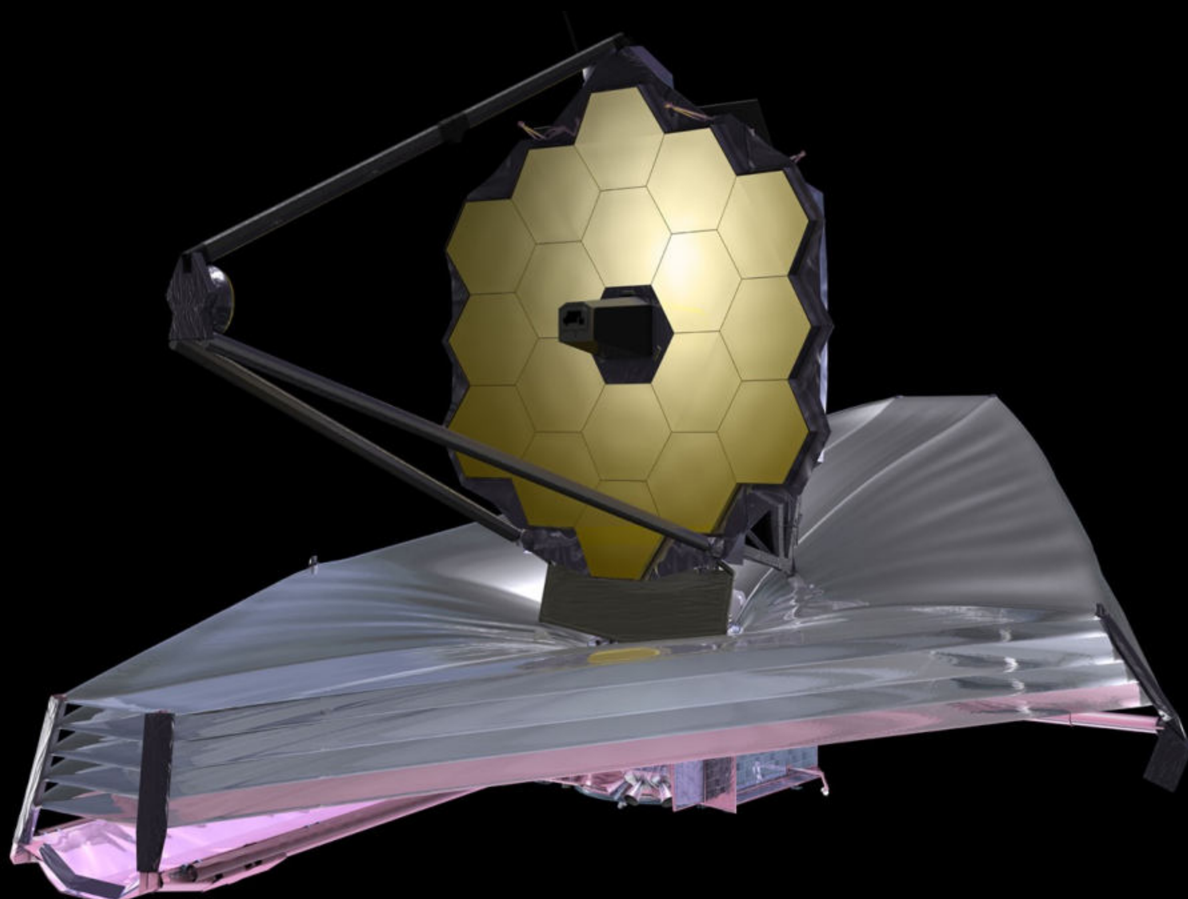
April 1996



c 1996: Goddard yardstick design (left), TRW design (right)

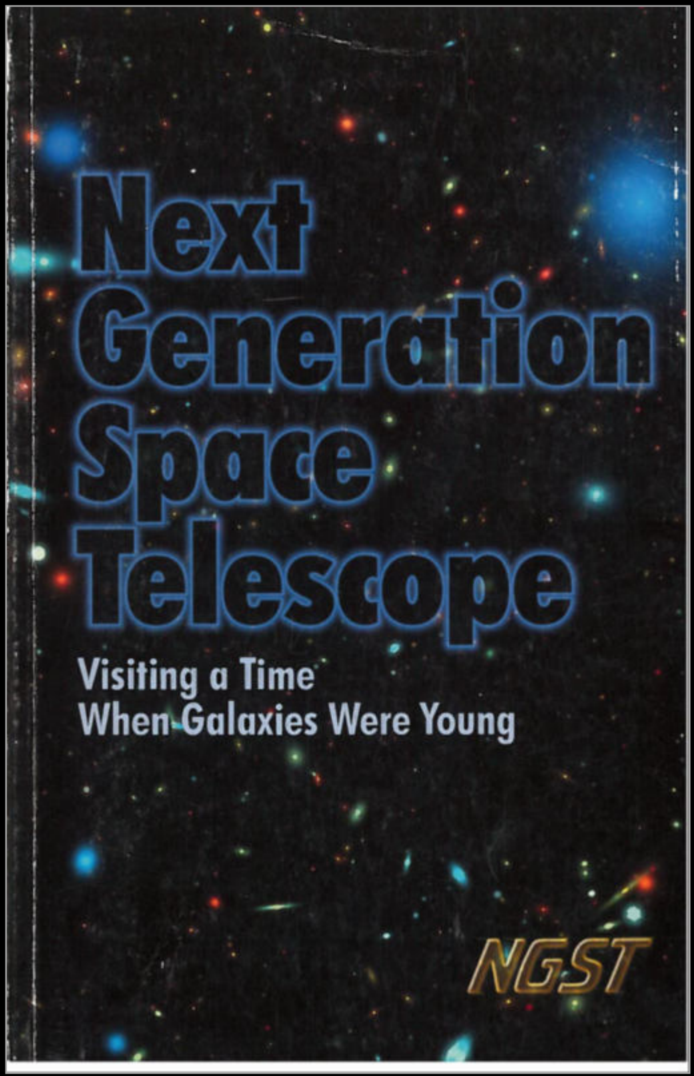


Current conception of JWST



1997

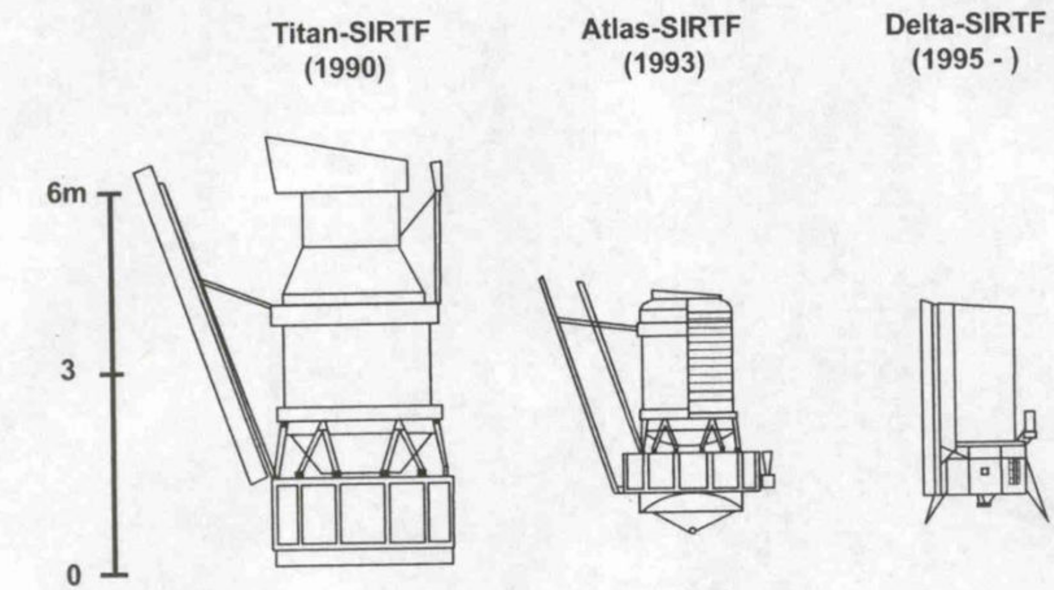
Study has been greatly influenced "by many other concepts of ***passively cooled telescopes,*** in particular POIROT and the Edison Infrared Space Observatory and MIRORs."



From George Rieke's *The Last of the Great Observatories: Spitzer and the Era of Faster, Better, Cheaper at NASA*

Illustrates the move to passive cooling made in 1993, and the shift from launching a telescope in a large cryogenic system

Also underlines the major problems of funding for space astronomy in the post-Cold War 1990s



	Titan-SIRTF (1990)	Atlas-SIRTF (1993)	Delta-SIRTF (1995 -)
Launch Mass	5700 kg	2500 kg	750 kg
Liquid Helium Vol.	3800 liters	920 liters	250 liters
Planned Lifetime	5 year	3 year	2.5 year
Cost	> $2 billion	~ $1 billion	$450 million

Figure 5.3. Evolution of SIRTF. This figure was one of the critical elements in finally getting the mission started.

their telescope optics; but unlike the goal for NGST, they continued technology development during the manufacturing period. This practice results in redesign, wasted efforts, and prolonged manufacturing periods which all increase costs.

Breaking the Hubble Paradigm

Demonstrating cost feasibility for such a complex observatory is as daunting as proving technical feasibility. We surely can learn from HST and other mission experiences and not fall into the same cost traps. But HST and NGST are not commensurate. Table 3.2 illustrates some of the major differences in the two missions, differences which are described in the following chapters. Many of the infrastructure dependencies of HST are not relevant for NGST. Advances in materials and electronics in the last 20 years make HST appear almost antiquated. On the other hand, NGST uses ultralightweight optics and must deploy and operate at very low temperatures, temperatures comparable to the cryogenic temperatures of ISO and SIRTF. These are the chief technologies that must be developed before NGST construction should begin.

Strategies for Cost Containment

Our best strategies for cost containment are the use of new, paradigm-shifting technologies and the adoption of new ways of doing business that have already been used successfully in other recent development pro-

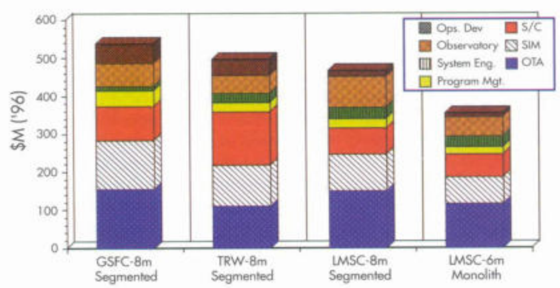


FIGURE 3.1. Manufacturing Cost Estimates for the Three Independent Studies. These estimates do not include predevelopment studies (Phase AB), technology development, and contingency (~30%). The three teams have allocated certain development costs to different cost elements. (NASA/GSFC)

grams. The first strategic element ensures that NGST is developed with the most advanced, most cost-effective technology available. For example, all three NGST concepts use on-orbit wavefront adjustment of the primary mirror assembly. This will significantly reduce or eliminate the cost and schedule burden associated with elaborate optical figuring and polishing to severe optical tolerances. On the recent AXAF Program and for HST, the figuring process for the mirrors cost \$200–250M (96).

The aggressive use of timely technology is essential for producing the lowest-cost telescope that meets our science requirements. The chief problem with this approach is the difficulty of accurately predicting future construction costs. We will reduce these uncertainties using a series of ground testbed and flight experiments. For NGST, we have included several precursor flight experiments or pathfinders, in the early mission-development

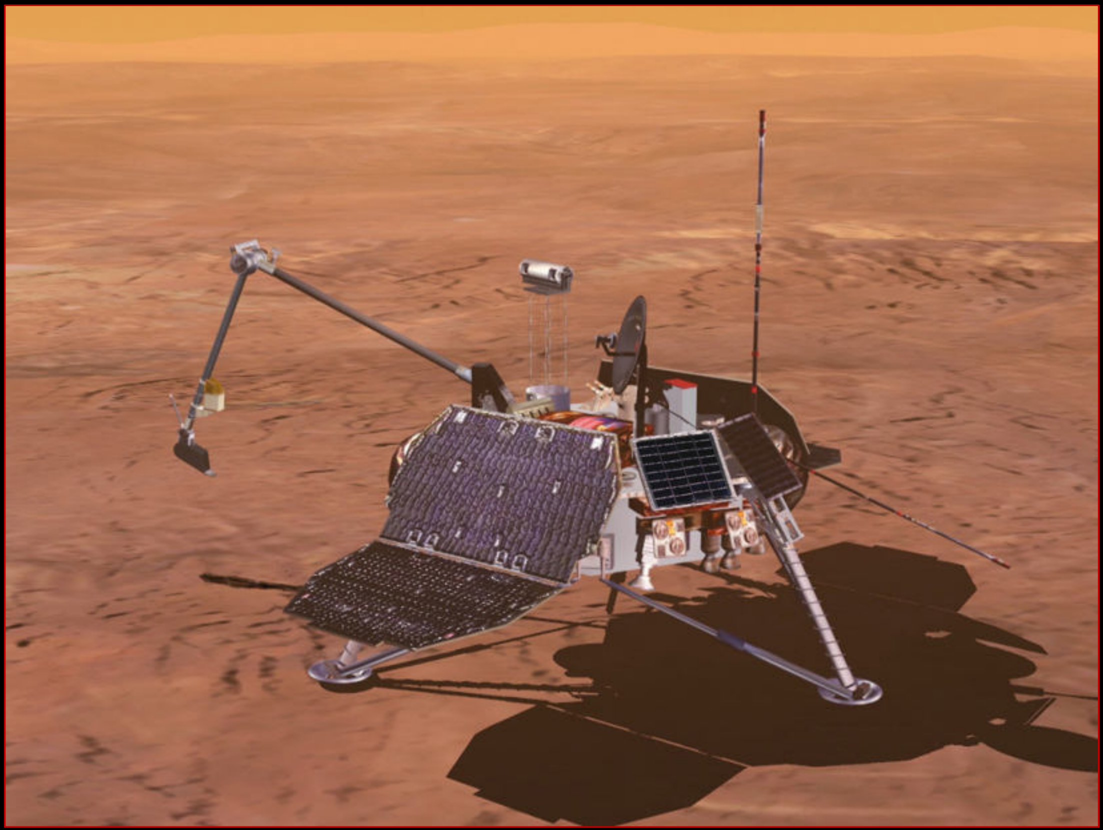
TABLE 3.2. Comparison of HST and NGST

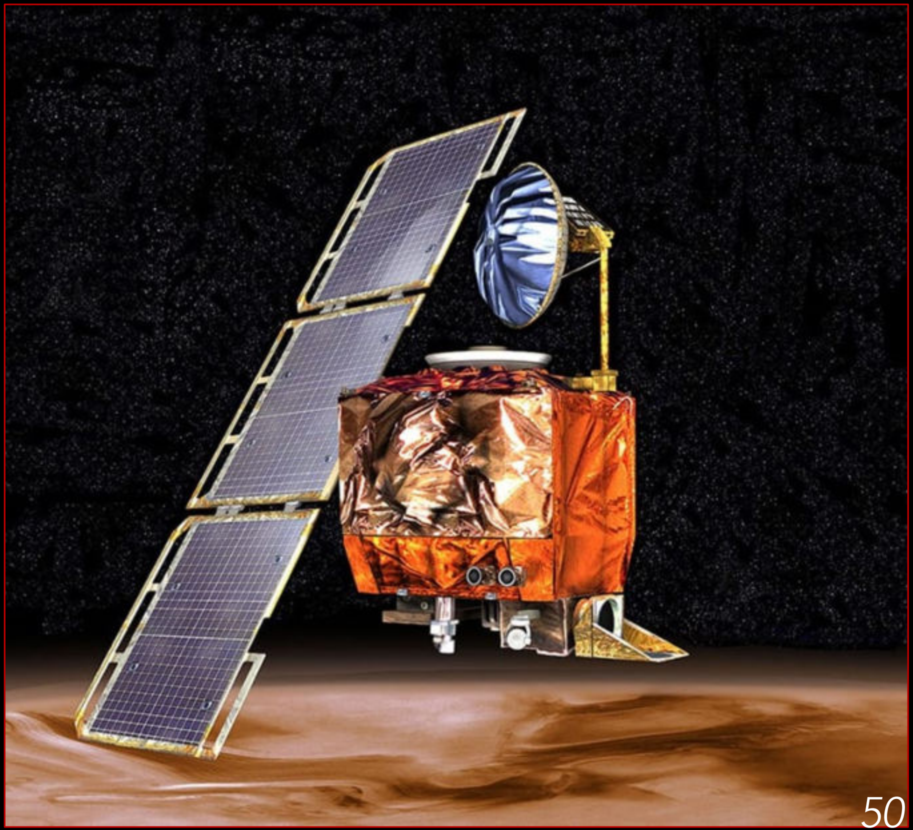
HST	NGST
Astronaut-rated and serviceable	Not serviceable, no astronaut safety issues
Shuttle launched, 11,000 kg	ELV launched, 3000 kg
Body pointed to <0.01"	Body pointed to 1" and fast steering mirror
Shared, distributed programmatic responsibility	Single prime contractor
UV/VIS/NIR space wavelengths	Optimized for near infrared
Superbly polished stable primary	Adjustable optics and wavefront sensing
Multiple science instruments	Single, integrated instrument
Paper and pencil engineering	CAD/CAM, concurrent engineering via internet
Complex, frequent commanding	High levels of autonomy
South Atlantic Anomaly pass each orbit	Outside radiation belts
Long integration and test; challenger delay	Four year development
Contamination concern high for UV	Contamination concern low for IR
Eclipses each orbit	Stable thermal environment
Complex communications using NASA's geosynchronous satellites	Single dedicated ground station
Ground telescope taken to space	Ultralightweight telescope designed for space
Limited phases A/B	Extended phase A/B with technology development
No precursor flight tests	Two to three precursor flight tests
Diffuse system engineering	Systems group at prime is responsible
Classified technology for primary	DOD technology becoming public

Moment SEVEN

3 December 1999

Loss of Mars Polar Lander (and later Mars Climate Orbiter) heralded the end of "Faster, Better, Cheaper"





Faster, Better, Cheaper (FBC)

16 FBC missions launched between 1996 and 1999

Represented five Science Mission Directorates at NASA, including missions to do with planetary science, earth observation, astrophysics

6 FBC missions failed

(perhaps worth noting that of the first 10 FBCs, just 1 failed)


Moment EIGHT
24 September 2002


THE STEVEN MULLER BUILDING

SWG Meeting at STScI

By September 2002: TRW selected as Prime Contractor; ESA and CSA had agreed to make contributions to project

SWG coping with impacts from earlier cost summit at Goddard

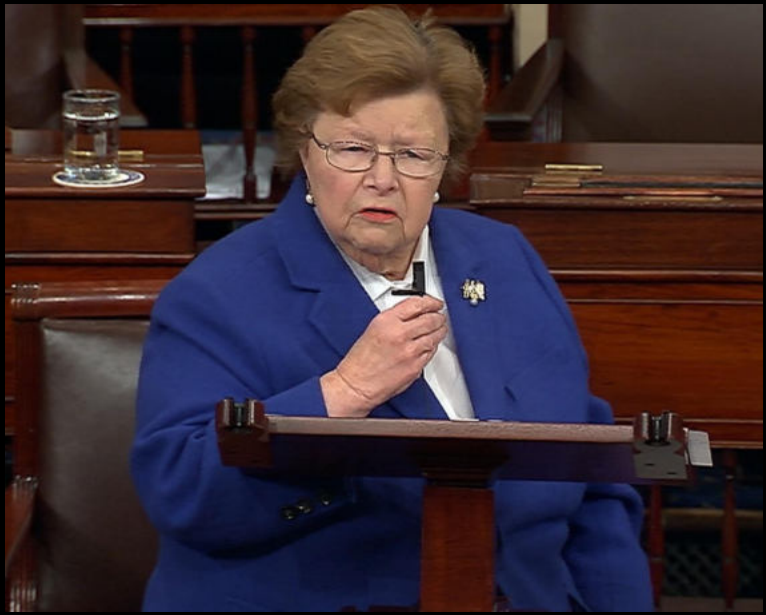
- Descope from 8m to 6-6.5m
- Mid Infrared Instrument (MIRI) under threat
- Aim for 2009 launch
- No NEXUS (a technology `test bed')
- "Magic" cost number of $800 Million

Moment NINE

6 July 2011

JWST zeroed out of budget on July 6, 2011

Frank Wolf's House Appropriations Subcommittee for Commerce, Justice and Science says: "billions of dollars over budget and plagued by poor management"



Maryland Senator Barbara Mikulsi was a key figure in the subsequent budget fight; also key figure in Hubble history

Establish a Coalition of Support on the Run

PLANETARY EXPLORATION NEWSLETTER – SPECIAL EDITION

Volume 5, Number 40 (September 8, 2011)

…We individually and together reject the premise that JWST must be restored at all costs. We further stand by the following positions:

(1) There are important national priorities in space beyond the goals of JWST that as a country we cannot afford to sacrifice.

(2) If Congress believes JWST is so important that it must be restored, then Congress should commit to adding funds to the NASA budget sufficient to cover JWST's expenses from here forward, recognizing that it may well cost more than $8.7B.

(3) Without additional funds to NASA, JWST should not be restored unless and until an open science community assessment is made of the value of what will be gained and what will be lost across the entire NASA science portfolio.

(4) If Congress cancels JWST, it is important to preserve the NASA astrophysics budget and mandate the formulation of a plan to retain US astrophysics leadership.

A NASA technician prepares six of the James Webb Space Telescope's mirror segments for cryogenic testing.

THE TELESCOPE THAT ATE ASTRONOMY

NASA's next-generation space observatory promises to open new windows on the Universe — but its cost could close many more.

BY LEE BILLINGS

It has to work — for astronomers, there is no plan B. NASA's James Webb Space Telescope (JWST), scheduled to launch in 2014, is the successor to the Hubble Space Telescope and the key to almost every big question that astronomers hope to answer in the coming decades. Its promised ability to peer back through space and time to the formation of the first galaxies made it the top priority in the 2001 astronomy and astrophysics decadal survey, one of a series of authoritative, ten-year plans drafted by the US astronomy community. And now, the stakes are even higher. Without the JWST, the bulk of the science goals listed in the 2010 decadal survey, released this August, will be unattainable.

"We took it as a given that the JWST would be launched and would be a big success," says Michael Turner, a cosmologist at the University of Chicago, Illinois, and a member of the committee for the past two decadal surveys. "Things are built around it."

Hence the astronomers' anxiety: the risks are also astronomical. The JWST's 6.5-metre primary mirror, nearly three times the diameter of Hubble's, will be the largest ever launched into space. The telescope will rely on a host of untried technologies, ranging from its sensitive light-detecting instrumentation to the cooling system that will keep the huge spacecraft below 50 kelvin. And it will have to operate perfectly on the first try, some 1.5 million kilometres from Earth — four times farther than the Moon and beyond the reach of any repair mission. If the JWST — named after the administrator who guided NASA through the development of the Apollo missions — fails, the progress of astronomy could be set back by a generation.

And yet, as critical as it is for them, astronomers' feelings about the JWST are mixed. To support a price tag that now stands at roughly US$5 billion, the JWST has devoured resources meant for other major projects, none of which can begin serious development until the binge is over. Missions such as the Wide-Field Infrared Survey Telescope, designed to study the Universe's dark energy and designated the top-priority space-astronomy project in the most recent decadal survey, will have to wait until after the JWST has launched. "Until then, we're not projecting being able to afford large investments" in new missions, says Jon Morse, director of NASA's astrophysics division. And all the space telescopes currently operated by NASA and the European Space Agency will reach the end of their planned lifetimes in the next few years.

Worse, the JWST's costs keep growing. In 2009, NASA required an extra $95 million to cover cost overruns on the telescope. In 2010 it needed a further $20 million. And for 2011 it has requested another $60 million — even as rumours are swirling that still more cash infusions will be required (see 'Cost curve').

Senator Barbara Mikulski (Democrat, Maryland), chairwoman of the government subcommittee that oversees NASA's budget, responded to these requests in June by calling for an independent panel to investigate the causes of the JWST's spiralling cost and delays, and to find a way

Forum on Megascience (OECD, 1993)

"What is 'megascience,' and why should it have an important place on the international science and technology policy agenda? A primary reason is the fact that over past decades, `big science' has constantly become bigger, absorbing more and more of the science resources of individual countries, requiring larger facilities and programmes, augmenting the need for extensive long-term and often international collaborative efforts.

While the scientific results of such projects have often been extremely valuable in advancing the frontiers of scientific knowledge, the number of projects and the human and financial resources involved have meant that, more and more often, difficult choices must be made, priorities must be set not only within, but also among, disciplines and new modes of operation have to be envisaged.

It is for this reason that `big science' has gradually come to be viewed as `megascience' and, as such, raises pressing questions about its role in the overall scientific effort."

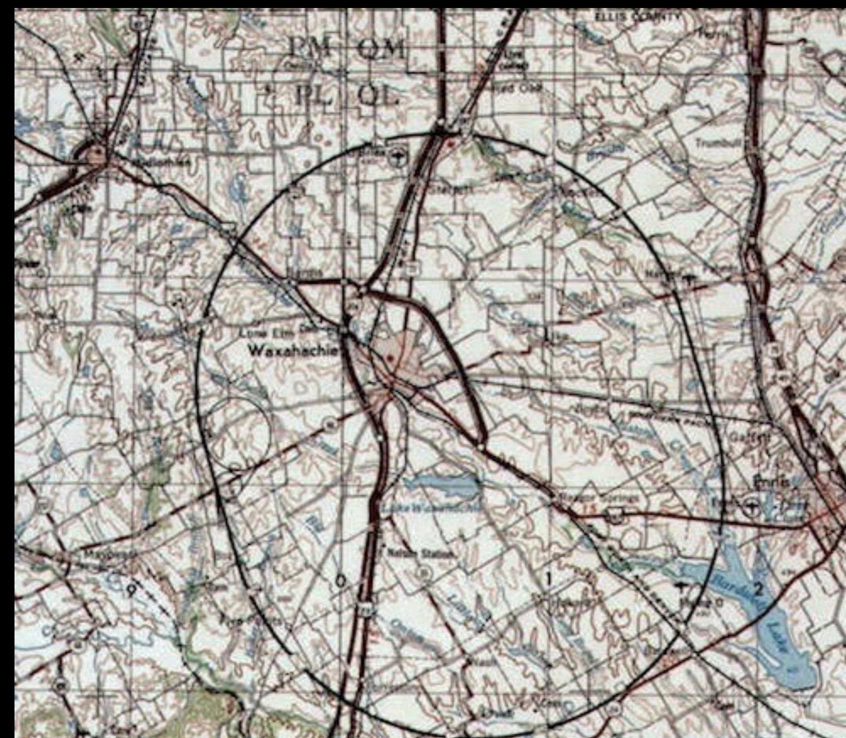
Compare to another example of a Megascience project: the Superconducting Super Collider (SSC)

President Reagan approved the project in 1987 at an estimated cost of $4.4 Billion

Cancelled in 1993 by President Clinton, by which time the cost had risen to at least $10 Billion

Department of Energy project for High Energy Physics; required a 54-mile-long tunnel

SSC ring around Waxahatchie, Texas



Initially very strong support from Texas
(George Bush, Vice-President and Jim Wright, House Speaker)

Loss of influence for Texas by 1993
Wright no longer House Speaker and George Bush defeated by Bill Clinton in November 1992

SSC effort at coalition building FAILED: cancelled 1993

Failure factors:

Lack of international partners

Dissent among physicists

Program 'design' created serious tensions

Congressional concern over deficits

Widespread perception of unrealistic cost estimates

Shift in the 'political economy' and loss of influence for Texas

The Making of a Megaproject: Some Lessons from HST, SSC and JWST

Need to make a megaproject scientifically and technically feasible

Need to make a megaproject politically feasible

Need to assemble a megaproject in technical, institutional and political terms

Patronage matters! *Not* simply an issue of securing enough money to proceed

Finally: the advocacy of a megaproject has to be done OVER and OVER and OVER again

Management of Scale

Hubble exemplified (after serious initial problems) the successful management of increasing scale, which is central to the broader success of large-scale science in the twentieth century

Hubble demonstrated the ability of ‘science managers’ and astronomers to operate successfully in — and to shape — the prevailing ‘political economy’ of science

How JWST will be seen?

A very big scientific instrument placed at the frontiers of knowledge represents huge political and managerial achievements that have to be taken into account along with the scientific and technical feats.

Policy Issue: International Partnerships

Historian and Particle Physicist Michael Riordan on the SSC: *"The project was just too large and too expensive to have been pursued primarily by a single nation, however wealthy and powerful."* The SSC was *"a bridge too far."*

SAGE ADVICE

"International cooperation may be critical for such a major project". *Bahcall*

Other Policy Issues

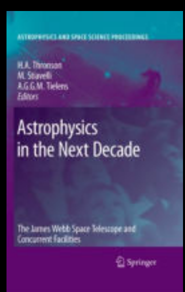
Costs: How to initiate a Megascience project at a realistic cost?

Reaction of Astro2020: how to pursue multigenerational very-large-scale projects? (Flagships in NASA-ese)

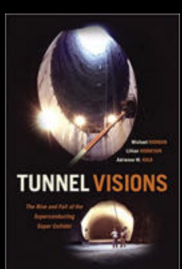

Moment TEN
yet to come.....

FURTHER READING

Robert W. Smith (with contributions by Paul Hanle, Robert Kargon and Joseph Tatarewicz), *The Space Telescope: A Study of NASA, Science, Technology and Politics* (Paperback, 1993)



Robert W. Smith and Patrick M. McCray, "Beyond the Hubble Space Telescope: Early Development of the Next Generation Space Telescope," in *Astrophysics for the Next Decade*, edited by H. A. Thronson, A. G. G. Tielens, and M. Stiavelli (2009)



Michael Riordan, Lillian Hoddeson, Adrienne W. Kolb, *Tunnel Visions: The Rise of the Superconducting Super Collider* (2015)