What I learned from Ned

John C. Mather
NASA's Goddard Space Flight Center
Aug. 25, 2017

Starting COBE

Pat Thaddeus

John & Jane Mather

Dave & Eunice Wilkinson

Mike & Deanna Hauser

Rai & Becky Weiss

George Smoot

Sam & Margie Gulkis,
Mike & Sandie Janssen

COBE Science Team


Chuck & Renee Bennett

Nancy & Al Boggess

Ed & Tammy Cheng

Eli & Florence Dwek

Tom & Ann Kelsall

Philip & Georganne Lubin

COBE Science Team

Steve & Sharon Meyer

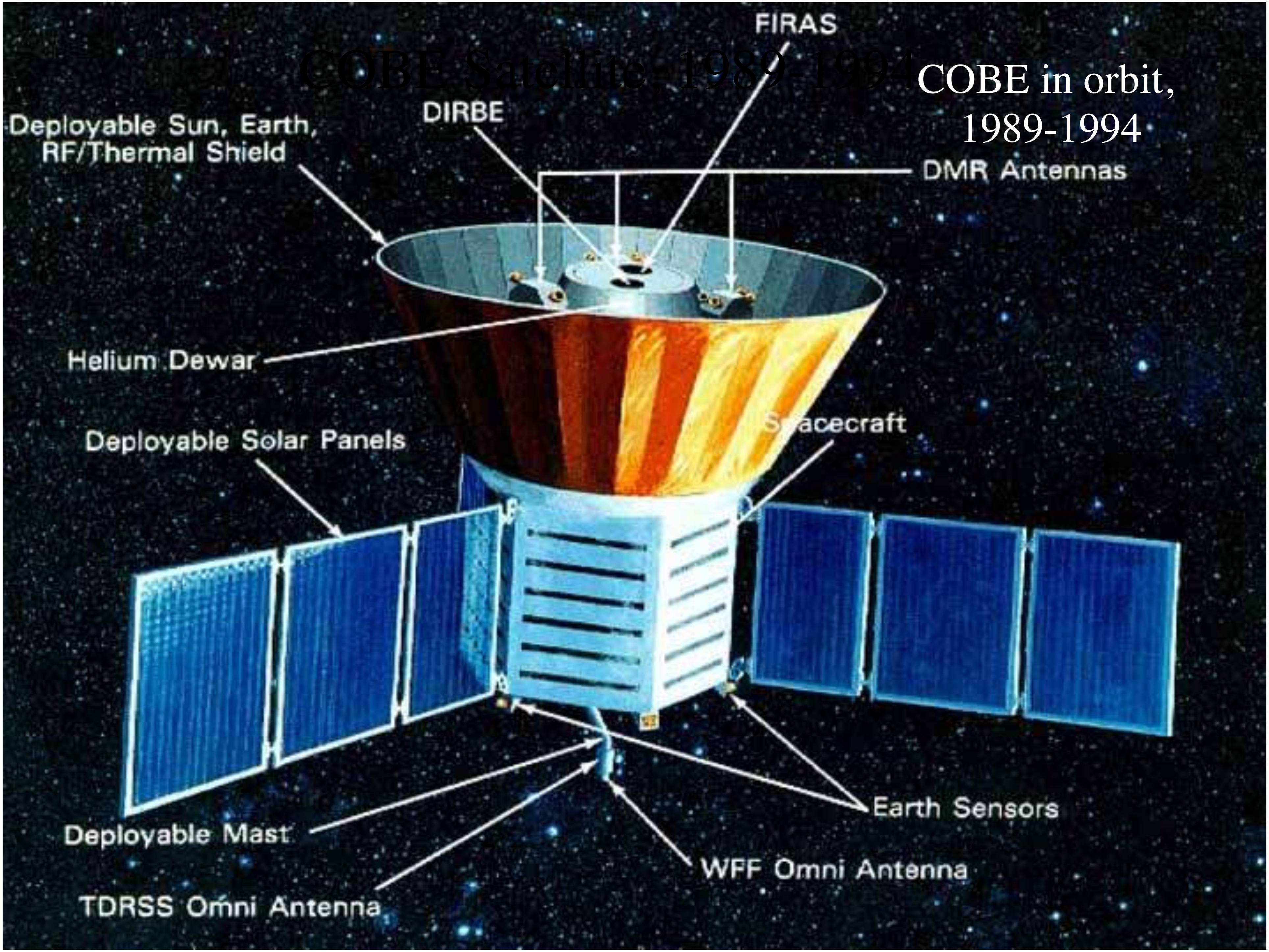
Harvey & Sarah Moseley

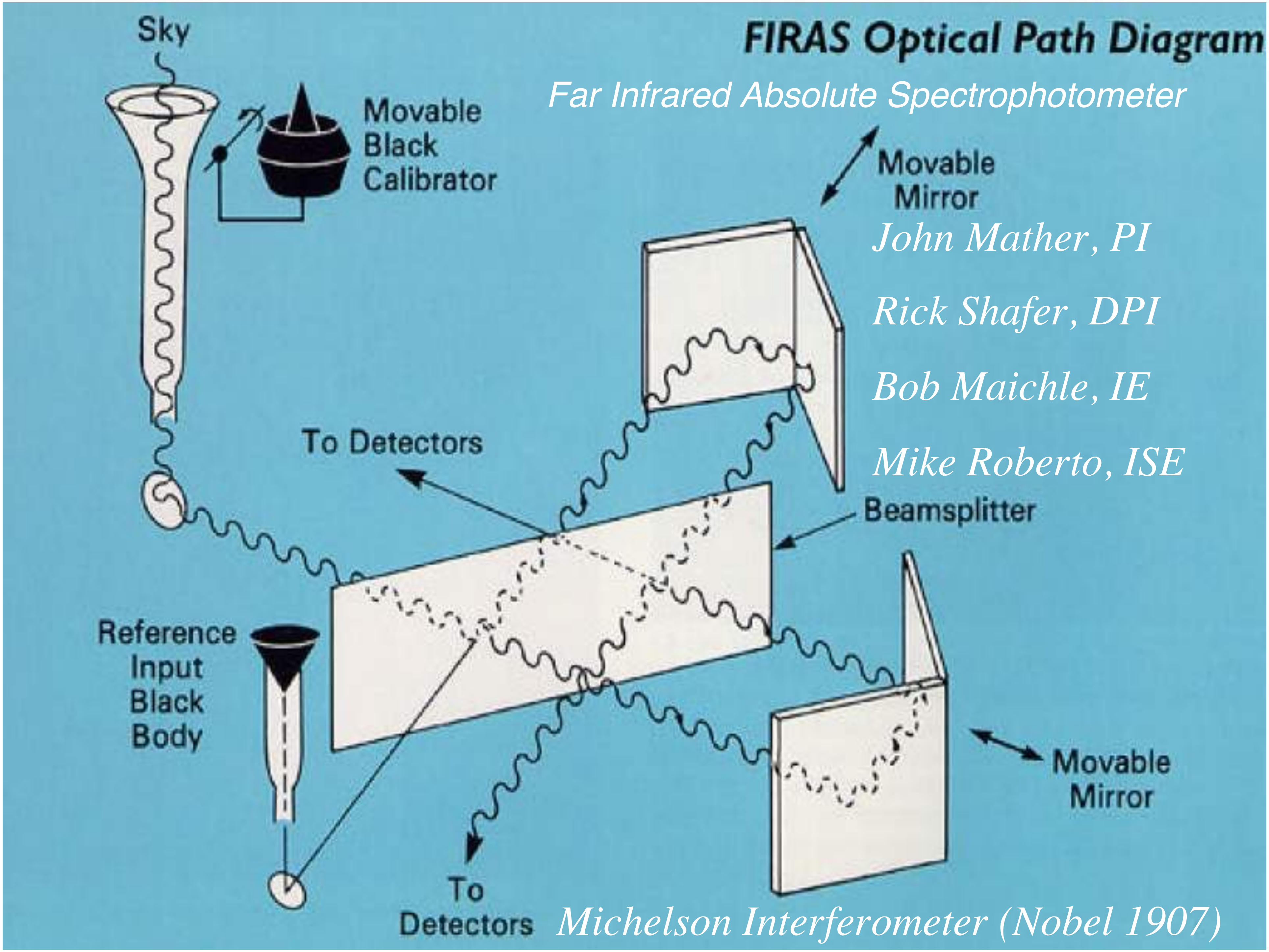
Tom & Jeanne Murdock

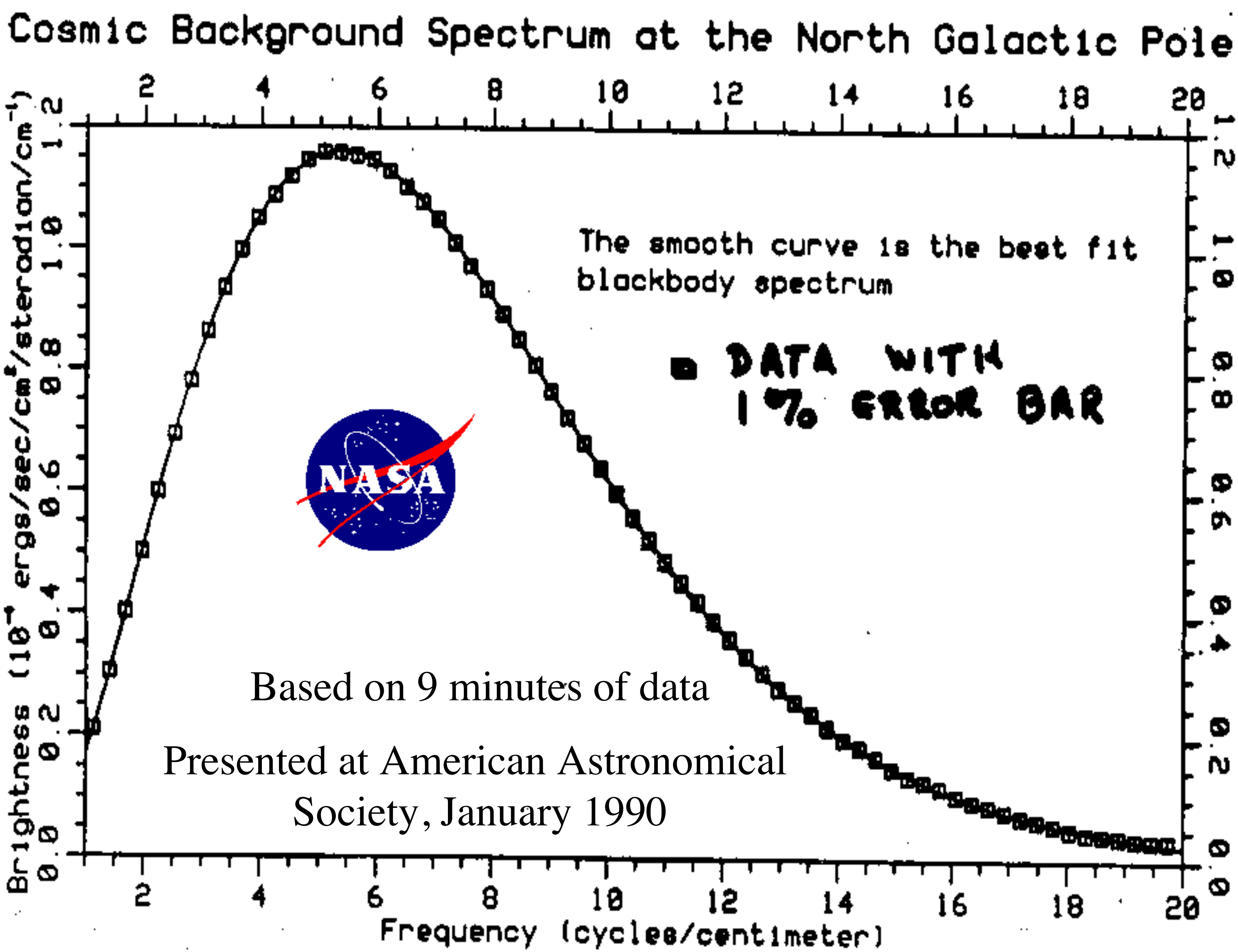
Rick & Gwen Shafer

Bob & Beverly Silverberg

Ned & Pat Wright


COBE in orbit,
1989-1994
FIRAS
DIRBE
Deployable Sun, Earth,
RF/Thermal Shield
DMR Antennas
Helium Dewar
Deployable Solar Panels
Spacecraft
Earth Sensors
Deployable Mast
WFF Omni Antenna
TDRSS Omni Antenna


FIRAS Optical Path Diagram
Far Infrared Absolute Spectrophotometer
Sky
Movable Black Calibrator
Movable Mirror
John Mather, PI
Rick Shafer, DPI
Bob Maichle, IE
Mike Roberto, ISE
To Detectors
Beamsplitter
Reference Input Black Body
Movable Mirror
To Detectors
Michelson Interferometer (Nobel 1907)


Cosmic Background Spectrum at the North Galactic Pole
Brightness (10^{-4} ergs/sec/cm^2/steradian/cm^{-1})
Frequency (cycles/centimeter)
The smooth curve is the best fit blackbody spectrum
DATA WITH 1% ERROR BAR
NASA
Based on 9 minutes of data
Presented at American Astronomical Society, January 1990

Ned said:

- FIRAS breadboard didn't focus right (Ned at MIT)
- FIRAS spectrum has cosmic implications:
  – Little energy release in early Universe, y and μ
  – Limits on exotic processes like antimatter annihilation, proton decay, cosmic explosions, cosmic strings, etc. etc. (very thorough!)
- Cold Big Bang isn't right, even interstellar needles can't convert starlight to a perfect blackbody spectrum

Ned on FIRAS

1994A

THE ASTROPHYSICAL JOURNAL, 420:450–456, 1994 January 10

INTERPRETATION OF THE *COBE*[1] FIRAS CMBR SPECTRUM

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E. S. CHENG,[3] R. F. SILVERBERG,[3] G. F. SMOOT,[6] AND R. WEISS[7]
Received 1993 February 5; accepted 1993 July 21

ABSTRACT

The cosmic microwave background spectrum measured by the FIRAS instrument on NASA's *COBE* is indistinguishable from a blackbody, implying stringent limits on energy release in the early universe later than the time $t = 1$ yr after the big bang. We compare the FIRAS data to previous precise measurements of the cosmic microwave background spectrum and find a reasonable agreement. We discuss the implications of the $|y| < 2.5 \times 10^{-5}$ and $|\mu| < 3.3 \times 10^{-4}$ 95% confidence limits found by Mather et al. (1994) on many processes occurring after $t = 1$ yr, such as explosive structure formation, reionization, and dissipation of small-scale density perturbations. We place limits on models with dust plus Population III stars, or evolving populations of IR galaxies, by directly comparing the Mather et al. spectrum to the model predictions.

Subject headings: cosmic microwave background — cosmology: observations — early universe

1. INTRODUCTION

Ever since the discovery of the cosmic microwave background radiation (CMBR), it has been recognized that the near-blackbody shape of the spectrum implies that at some earlier time the universe was opaque and isothermal, which is distortion produced by warm electrons. The second major process that can affect the spectrum at $z < 1000$ is interstellar dust absorbing starlight and reradiating it in the infrared. This infrared radiation is redshifted into the 2–20 cm^{-1} range that FIRAS observes (Negroponte, Rowan-Robinson, & Silk 1981; Wright 1981).

Ned's far IR galaxy

PRELIMINARY SPECTRAL OBSERVATIONS OF THE GALAXY WITH A 7° BEAM BY THE *COSMIC BACKGROUND EXPLORER* (*COBE*)[1]

E. L. Wright,[2] J. C. Mather,[3] C. L. Bennett,[3] E. S. Cheng,[3] R. A. Shafer,[3] D. J. Fixsen,[4] R. E. Eplee, Jr.,[5] R. B. Isaacman,[5] S. M. Read,[6] N. W. Boggess,[3] S. Gulkis,[7] M. G. Hauser,[3] M. Janssen,[7] T. Kelsall,[3] P. M. Lubin,[8] S. S. Meyer,[9] S. H. Moseley, Jr.,[3] T. L. Murdock,[10] R. F. Silverberg,[3] G. F. Smoot,[11] R. Weiss,[9] and D. T. Wilkinson[12]

Received 1991 February 21; accepted 1991 May 6

ABSTRACT

The far-infrared absolute spectrophotometer (FIRAS) on the *Cosmic Background Explorer* (*COBE*) has carried out the first all-sky spectral line survey in the far-infrared region, as well as mapping spectra of the Galactic dust distribution at $\lambda > 100$ μm. Lines of [C I], [C II], [N II], and CO are all clearly detected, [C II] (158 μm) and [N II] (205.3 μm) with sufficient strength to be mapped, and the wavelength of the [N II] line at 205.3 μm is determined by observation for the first time. The mean line intensities are interpreted in terms of the heating and cooling of the multiple phases of the interstellar gas. In addition, an average spectrum of the galaxy is constructed and searched for weak lines. The spectrum of the galaxy observed by FIRAS has two major components: a continuous spectrum due to interstellar dust heated by starlight with a total luminosity of $(1.8 \pm 0.6)(R_0/8.5\ \mathrm{kpc})^2 \times 10^{10}\ L_\odot$ within the solar circle; and a line spectrum dominated by the strong 158 μm line from singly ionized carbon, with a spatial distribution similar to the dust distribution, and a luminosity of 0.3% of the dust luminosity. There are in addition moderately strong 122 and 205.3 μm lines, identified as coming from singly ionized nitrogen, which contribute 0.04% and 0.03% of the total dust luminosity. The much weaker lines of neutral carbon at 370 and 609 μm are seen, as are the 2–1 through 5–4 CO lines. These low-*J* CO lines contribute 0.003% of the total dust luminosity. Maps of the emission by dust, [C II], and [N II] are presented.

Subject headings: infrared: spectra — interstellar: grains — interstellar: matter — interstellar: molecules

1. INTRODUCTION

The far-infrared absolute spectrophotometer (FIRAS) on the *Cosmic Background Explorer* (*COBE*) offers a unique capability to measure the absolute flux from our galaxy in the millimeter

Field, Goldsmith, & Habing (1969) proposed that the interstellar medium (ISM) would have multiple stable equilibrium phases. McKee & Ostriker (1977) expanded on this model, introducing four phases of the ISM. McKee & Ostriker maintain that most space is filled by a hot ionized medium (HIM),

Ned's Needles

THERMALIZATION OF STARLIGHT BY ELONGATED GRAINS: COULD THE MICROWAVE BACKGROUND HAVE BEEN PRODUCED BY STARS?

EDWARD L. WRIGHT
Department of Astronomy, University of California, Los Angeles, and
Department of Physics, Massachusetts Institute of Technology
Received 1981 August 14; accepted 1981 October 21

ABSTRACT

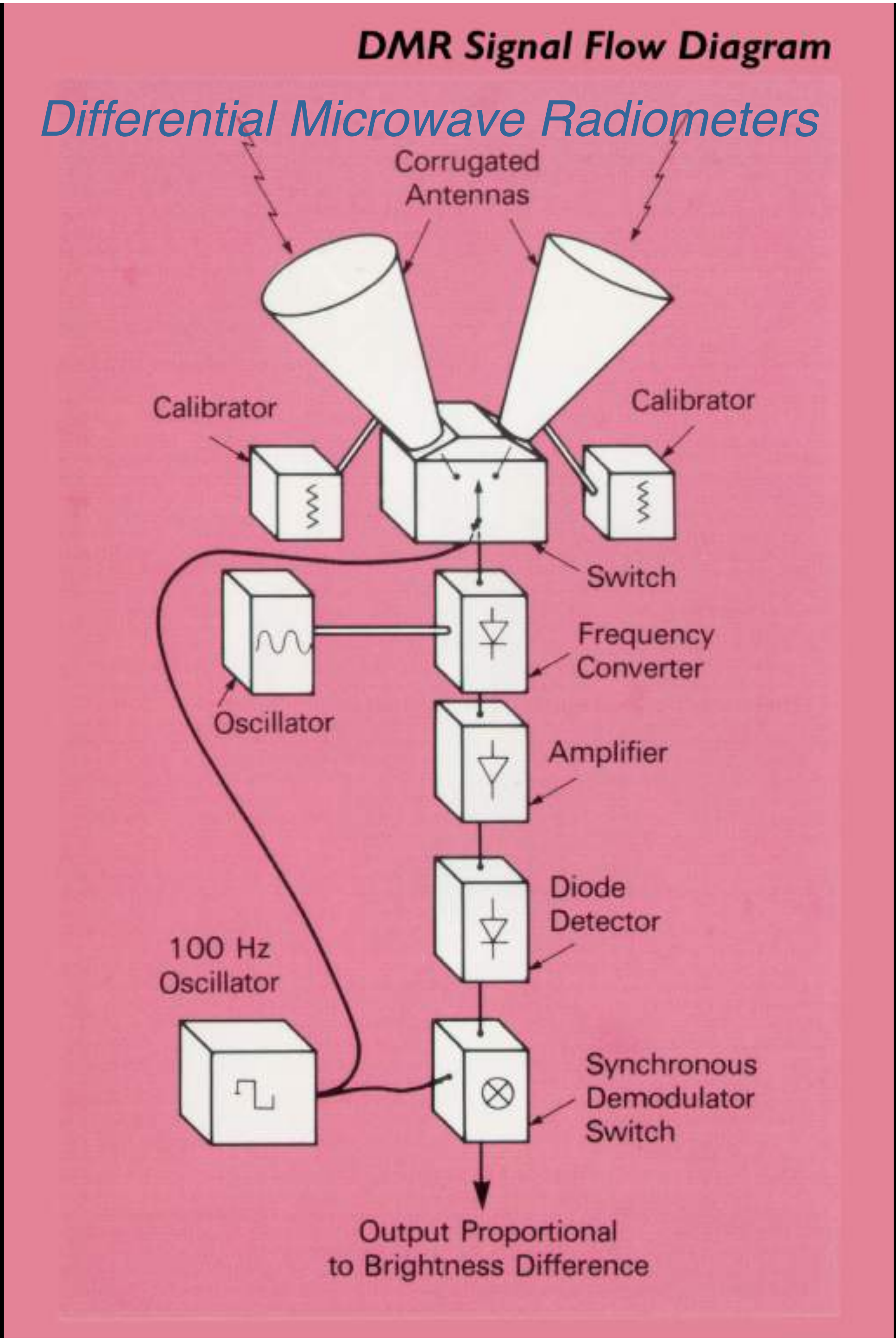
I consider the possibility of the microwave background being produced by stars after the big bang. The critical problem for this hypothesis is the source of the long-wavelength opacity for observed wavelengths greater than 10 cm. I show that free-free opacity cannot thermalize the background. Spherical dust grains also fail, but needle-shaped conducting grains can provide sufficient opacity to produce the observed spectrum with a metal abundance $Z \sim 10^{-7}$.

Subject headings: cosmic background radiation — interstellar: matter — radiative transfer

I. INTRODUCTION

The microwave background is one of the strongest arguments for the standard, hot big bang cosmology. However, the recent measurement of Woody and Richards (1979) shows a distortion of the spectrum from a blackbody that contains 20%–30% of the total energy. Rowan-Robinson, Negroponte, and Silk (1979) and

10^3. In § III of this paper, I consider what kind of dust grains could provide the required opacity. I find that a very small abundance of needle-shaped, conducting grains is sufficient to thermalize the microwave background at all observed wavelengths. Layzer and Hively (1973) mention a private communication from Purcell on a "low-mass antenna for millimeter waves,"



George Smoot

Chuck Bennett

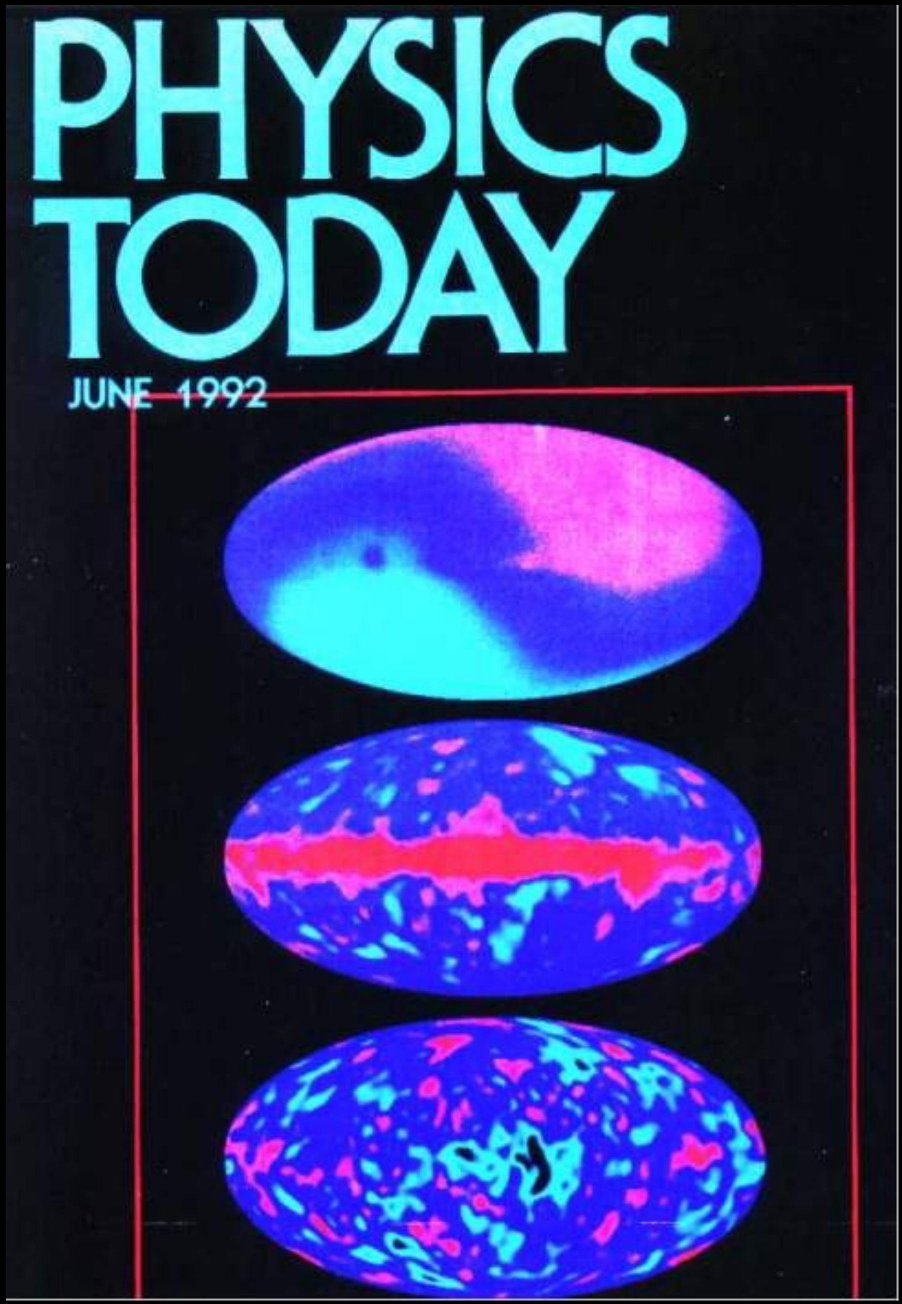
Bernie Klein

Steve Leete

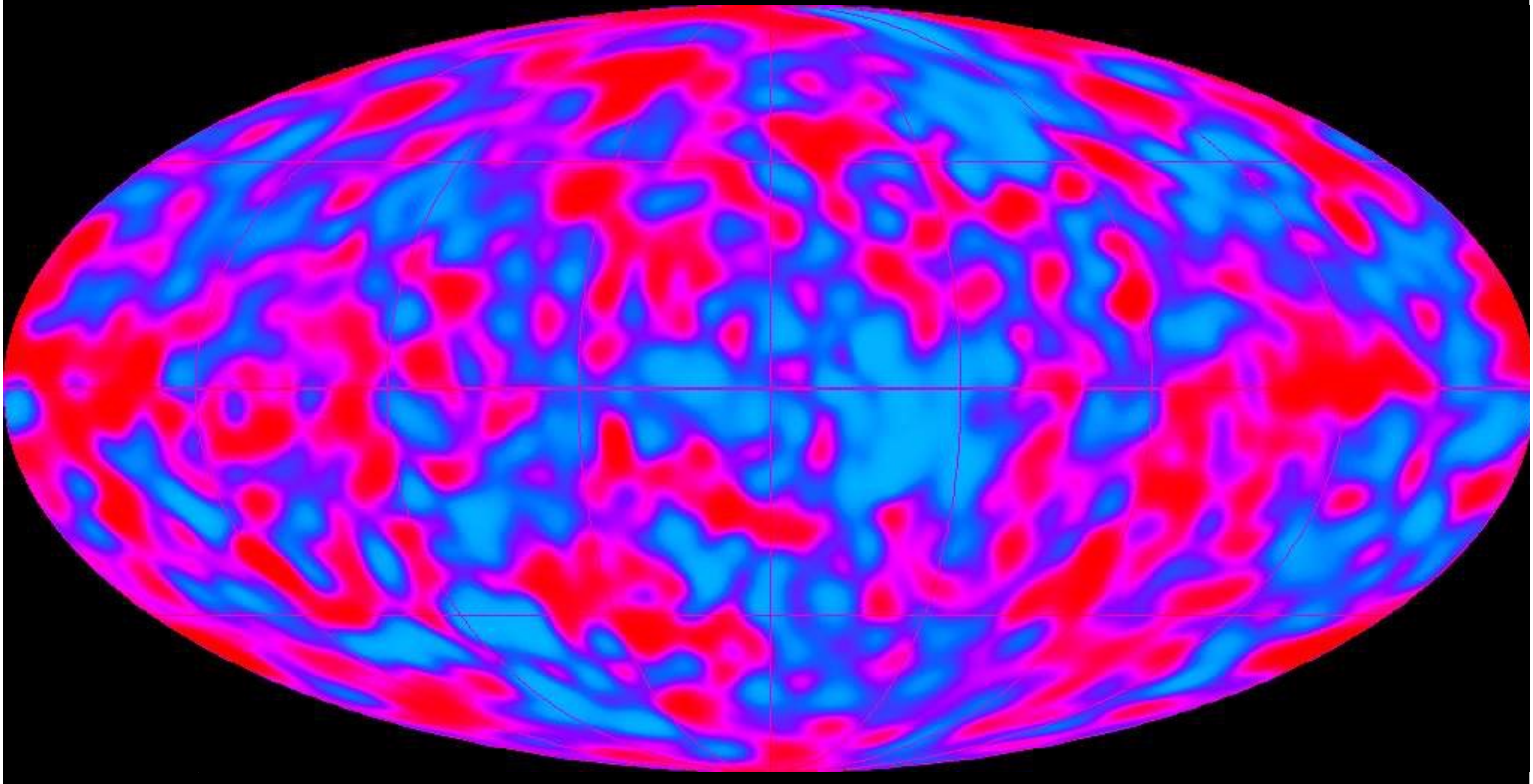
Sky map from DMR, 2.7 K +/- 0.003 K

Doppler Effect of Earth's motion removed (v/c = 0.001)

Cosmic temperature/density variations at 389,000 years, +/- 0.00003 K



COBE Map of CMB Fluctuations
2.725 K +/- ~ 30 μK rms, 7° beam



Ned said:

- The sky has spots! First person to show them to the Science Working Group.
- Cosmic implications: many!!
  - Cold Dark Matter fits
  - Dark Energy (not yet required but OK)
  - Scale free spectrum (over a narrow range)

Ned said:

1992

THE ASTROPHYSICAL JOURNAL, 396:L13–L18, 1992 September 1

INTERPRETATION OF THE COSMIC MICROWAVE BACKGROUND RADIATION ANISOTROPY DETECTED BY THE *COBE*[1] DIFFERENTIAL MICROWAVE RADIOMETER

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Received 1992 April 21; accepted 1992 June 12

ABSTRACT

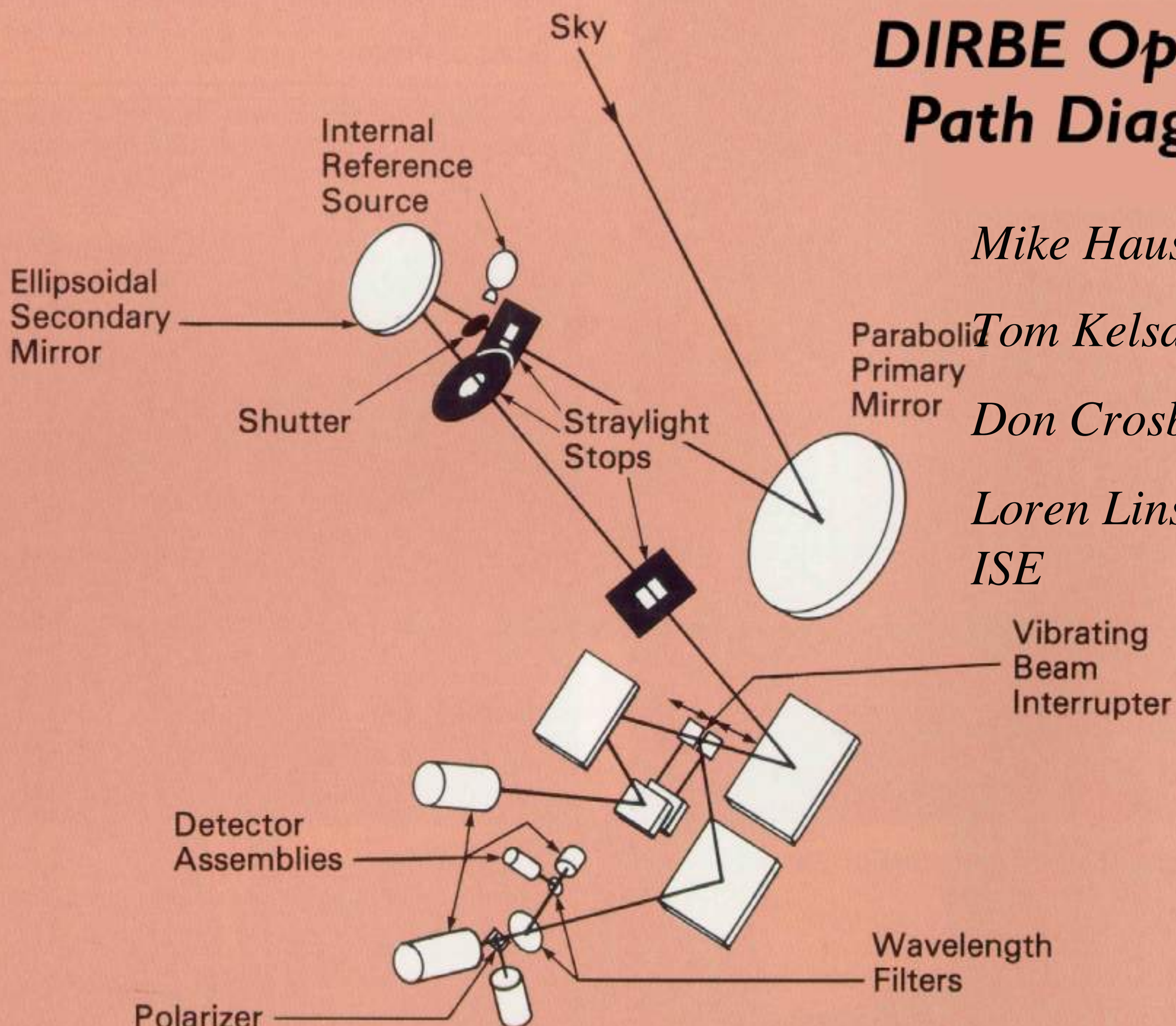
We compare the large-scale cosmic background anisotropy detected by the *COBE* Differential Microwave Radiometer (DMR) instrument to the sensitive previous measurements on various angular scales, and to the predictions of a wide variety of models of structure formation driven by gravitational instability. The observed anisotropy is consistent with all previously measured upper limits and with a number of dynamical models of structure formation. For example, the data agree with an unbiased cold dark matter (CDM) model with $H_0 =$ 50 km s^{-1} Mpc^{-1} and $\Delta M/M = 1$ in a 16 Mpc radius sphere. Other models, such as CDM plus massive neutrinos [hot dark matter (HDM)], or CDM with a nonzero cosmological constant are also consistent with the *COBE* detection and can provide the extra power seen on 5–10,000 km s^{-1} scales.

Subject headings: cosmic microwave background — cosmology: observations — cosmology: theory — galaxies: clustering

1. INTRODUCTION

first year of data taken by the DMR instrument on COBE

DIRBE Optical Path Diagram



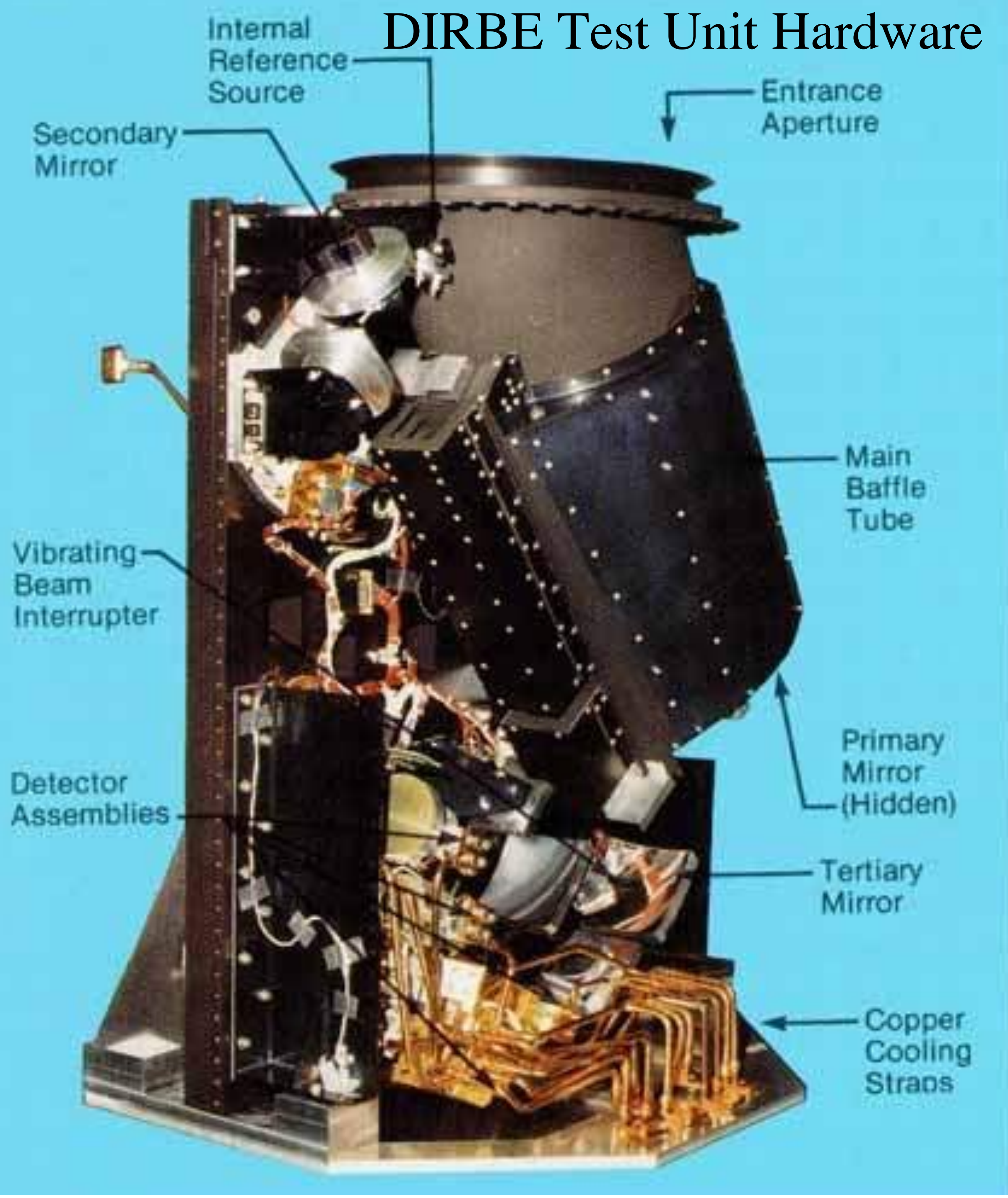
Mike Hauser, PI

Tom Kelsall, DPI

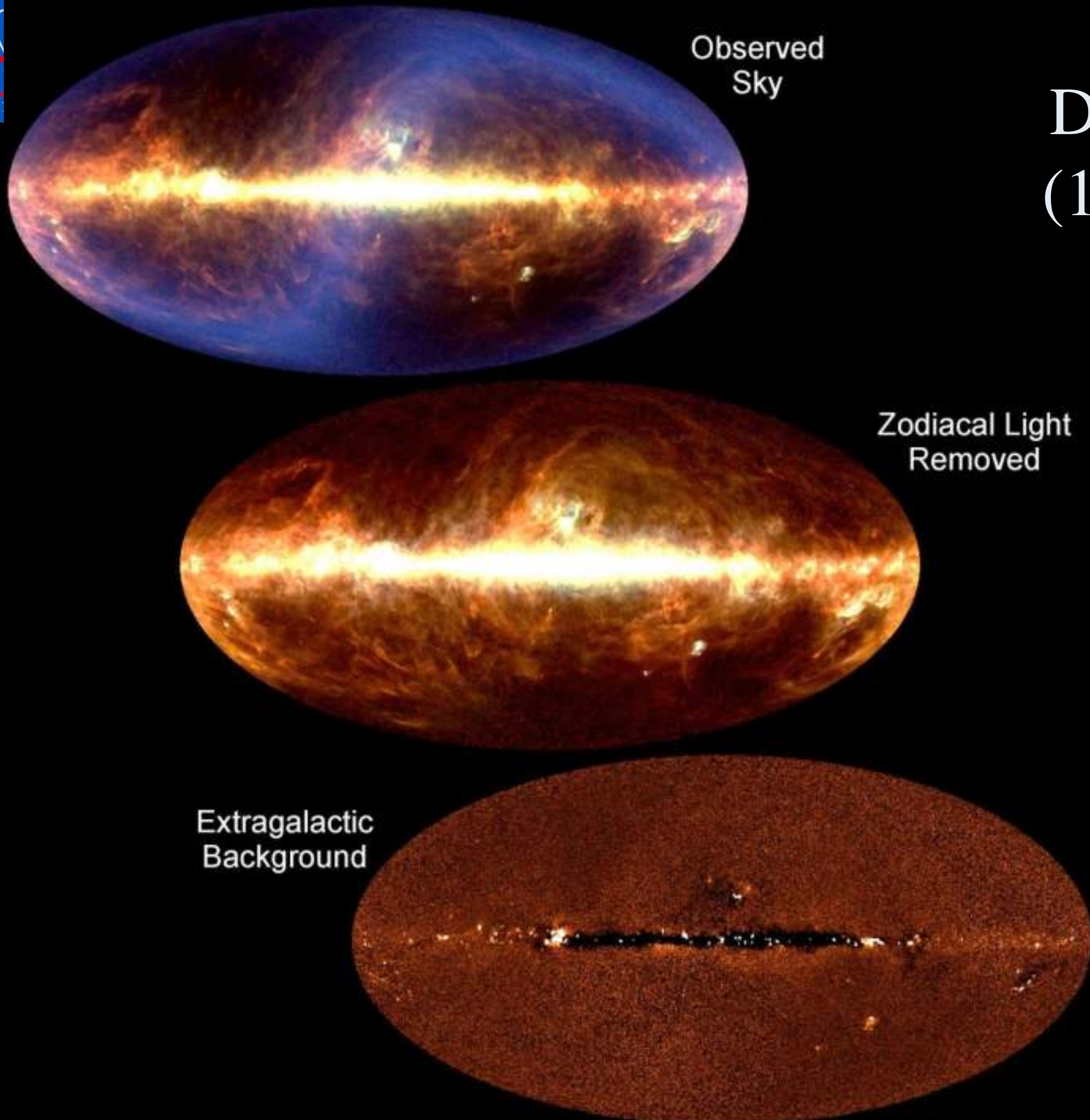
Don Crosby, IE

Loren Linstrom, ISE

DIRBE Test Unit Hardware



DIRBE far IR (100, 140, 240 μm) Sky Modeling



DIRBE cosmology results

- Cosmic Infrared Background has 2 parts, near (few microns) and far (few hundred microns
  - Each with brightness comparable to the known luminosity of visible & near IR galaxies
  - Luminosity of universe is ~ double expected value
  - Does not mean the CMB spectrum is distorted

Ned said:

- I can get the spacecraft pointing to 1 arcmin from the DIRBE star crossing times (and 0.7^{o} beam), and a model for the spinning spacecraft
- I can calibrate using thermal models of asteroids, etc. and get % photometry
- I can model the zodiacal light (somewhat different answers from Kelsall et al.)

Ned subtracts the IR foreground

DIRBE MINUS 2MASS: CONFIRMING THE COSMIC INFRARED BACKGROUND AT 2.2 MICRONS

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Received 2000 April 13; accepted 2001 January 31

ABSTRACT

Stellar fluxes from the Two Micron All Sky Survey catalog are used to remove the contribution owing to Galactic stars from the intensity measured by the Diffuse Infrared Background Experiment in four regions in the north and south Galactic polar caps. After subtracting the interplanetary and Galactic foregrounds, a consistent residual intensity of 14.8 ± 4.6 kJy sr^{-1} or 20.2 ± 6.3 nW m^{-2} sr^{-1} at 2.2 μm is found. At 1.25 μm the residuals show more scatter and are a much smaller fraction of the foreground, leading to a weak limit on the cosmic infrared background of 12.0 ± 6.8 kJy sr^{-1} or 28.9 ± 16.3 nW m^{-2} sr^{-1} (1 σ).

Subject headings: cosmology: observations — diffuse radiation — infrared: general

1. INTRODUCTION

The Diffuse Infrared Background Experiment (DIRBE) on board *COBE* (see Boggess et al. 1992) observed the entire sky in 10 infrared wavelengths from 1.25 to 240 μm. Hauser et al. (1998) discuss the determination of the cosmic infrared background (CIRB) by removing foreground emission from the DIRBE data. This paper detected the CIRB at 140 and 240 μm but gives only upper limits at shorter wavelengths. From 5 to 100 μm, the zodiacal light foreground owing to thermal emission from interplanetary dust grains is so large that no reliable estimates of the CIRB can be made from a position 1 AU from the Sun (Kelsall et al. 1998). In the shorter wavelengths from 1.25 to 3.5 μm, the zodiacal light is fainter, but uncertainties in modeling the foreground owing to Galactic stars are too large to allow a determi-

ed in § 3. In this paper, Kashlinsky & Odenwald (2000) is treated as an upper limit on the CIRB, which is compatible with previous limits and the results found here. E. Wright (2001, in preparation) will discuss the possible cosmic fluctuation signal in the DIRBE minus 2MASS residuals in more detail.

2. DATA SETS

The two main data sets used in this paper are the DIRBE maps and the 2MASS point-source catalog (PSC). The DIRBE weekly maps were used: DIRBE_WKnn_P3B.FITS for $04 \leq nn \leq 44$. These data and the very strong no-zodi principle described by Wright (1997) were used to derive a model for the interplanetary dust foreground that is described in Wright (1998) and

LDR (Large Deployable Reflector)

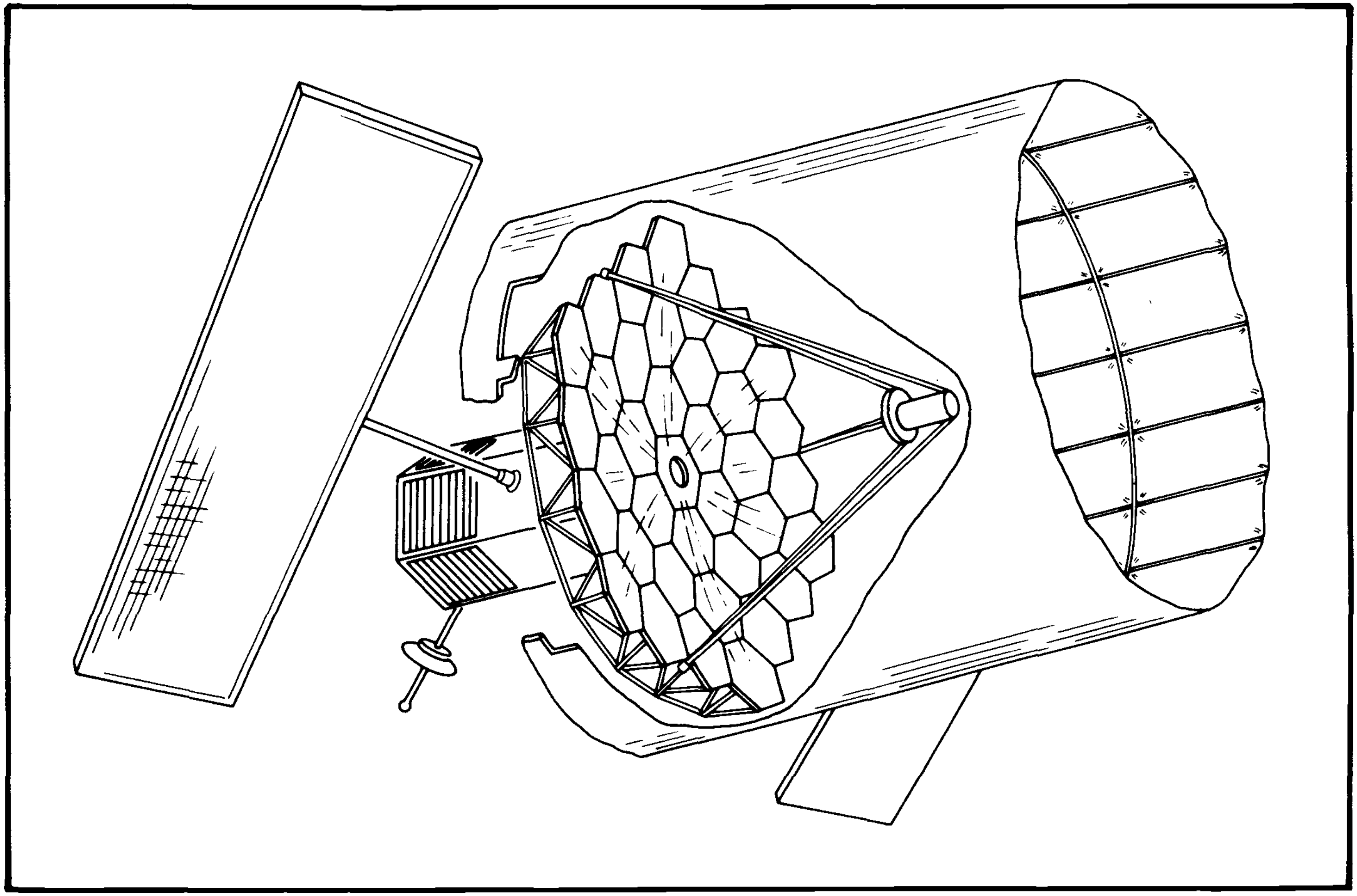
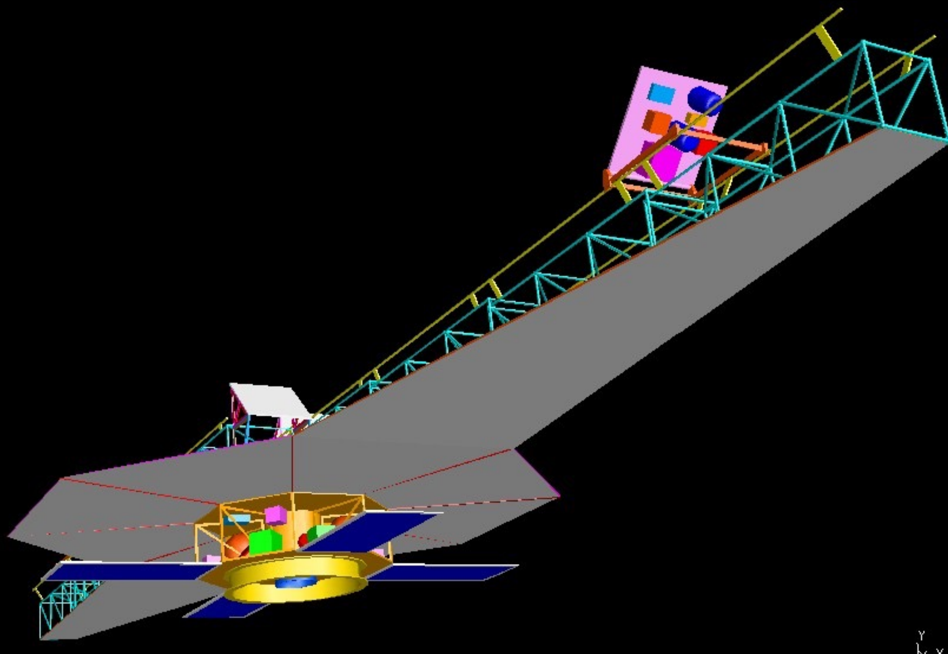


Fig. 5. LDR concept.

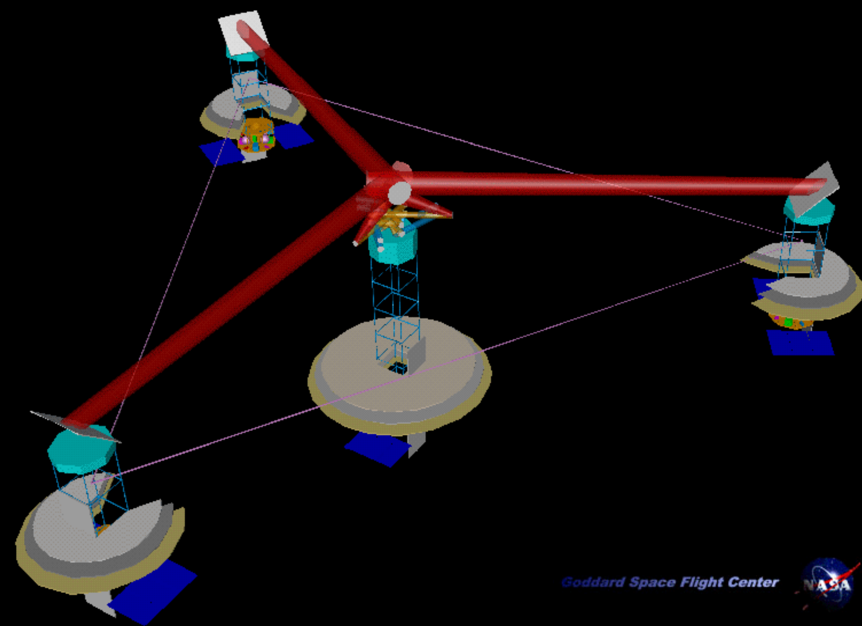
SWANSON, GULKIS, KUIPER, KIYA

SPIRIT AND SPECS

Space Infrared Interferometric Telescope



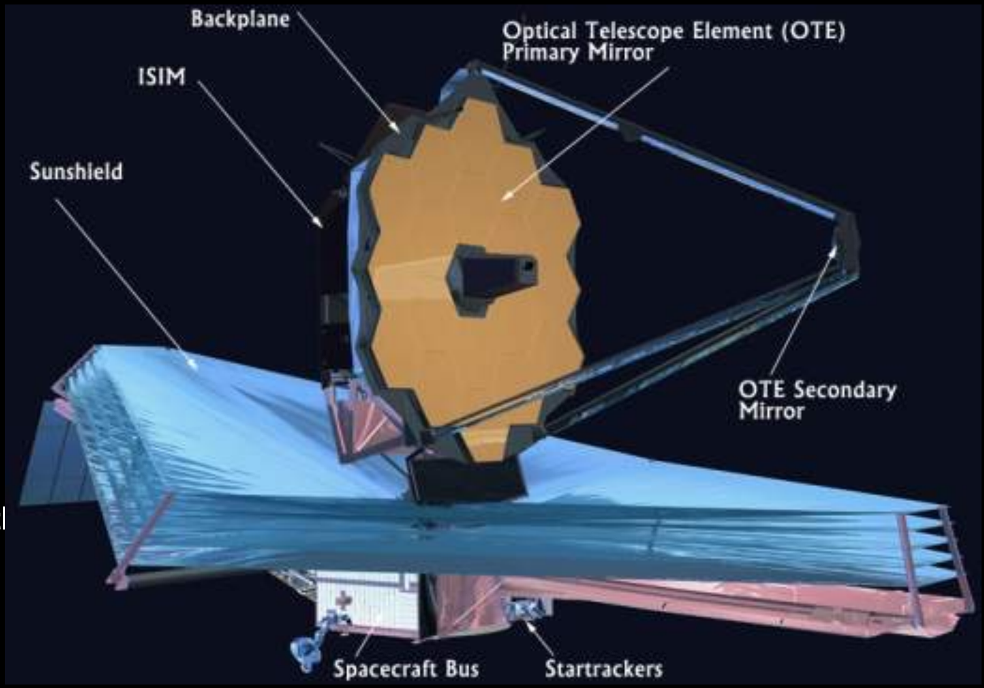
Submillimeter Probe of the Evolution of Cosmic Structure



SPIRIT is a scientific and technology pathfinder for SPECS. Both instruments are Michelson imaging and spectral interferometers that would operate over the wavelength range ~40 - 500 μm and provide spectral resolution $\lambda/\Delta\lambda$ ~ 10^4.

	SPIRIT	SPECS
Maximum Baseline, b_{max}	30 m	1 km
Number of Collecting Mirrors	2	3
Mirror Diameter	3 m	4 m
Angular Resolution, $\lambda / 2b_{max}$	0.7 arcsec * (λ / 200 μm)	0.02 arcsec * (λ / 200 μm)
Field of View	3.4 arcmin	3.4 arcmin
Typical Image Size	240 x 240 resolution elements at 200 μm x ~10^4 spectral channels	6,000 x 6,000 resolution elements at 200 μm x ~10^4 spectral channels
Typical Exposure Time	3 x 10^4 s	3 x 10^5 s
Typical Sensitivity, νS_ν (1σ) At $\lambda/\Delta\lambda$ = 1,000 At $\lambda/\Delta\lambda$ = 3 (SED mode)	 2-5 x 10^{-18} W/m^2 (2-5 x 10^8 Hz Jy) 0.3-2 x 10^{-19} W/m^2 (0.3-2 x 10^7 Hz Jy)	 0.5-2 x 10^{-18} W/m^2 (0.5-2 x 10^8 Hz Jy) 0.3-1 x 10^{-19} W/m^2 (0.3-1 x 10^7 Hz Jy)

James Webb Space Telescope (JWST)



Organization

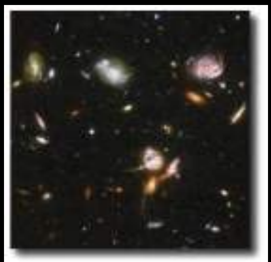
- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) and Near IR Slitl Spectrometer (NIRISS)– CSA
- Operations: Space Telescope Science Institute

Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov

JWST Science Themes



End of the dark ages: First light and reionization

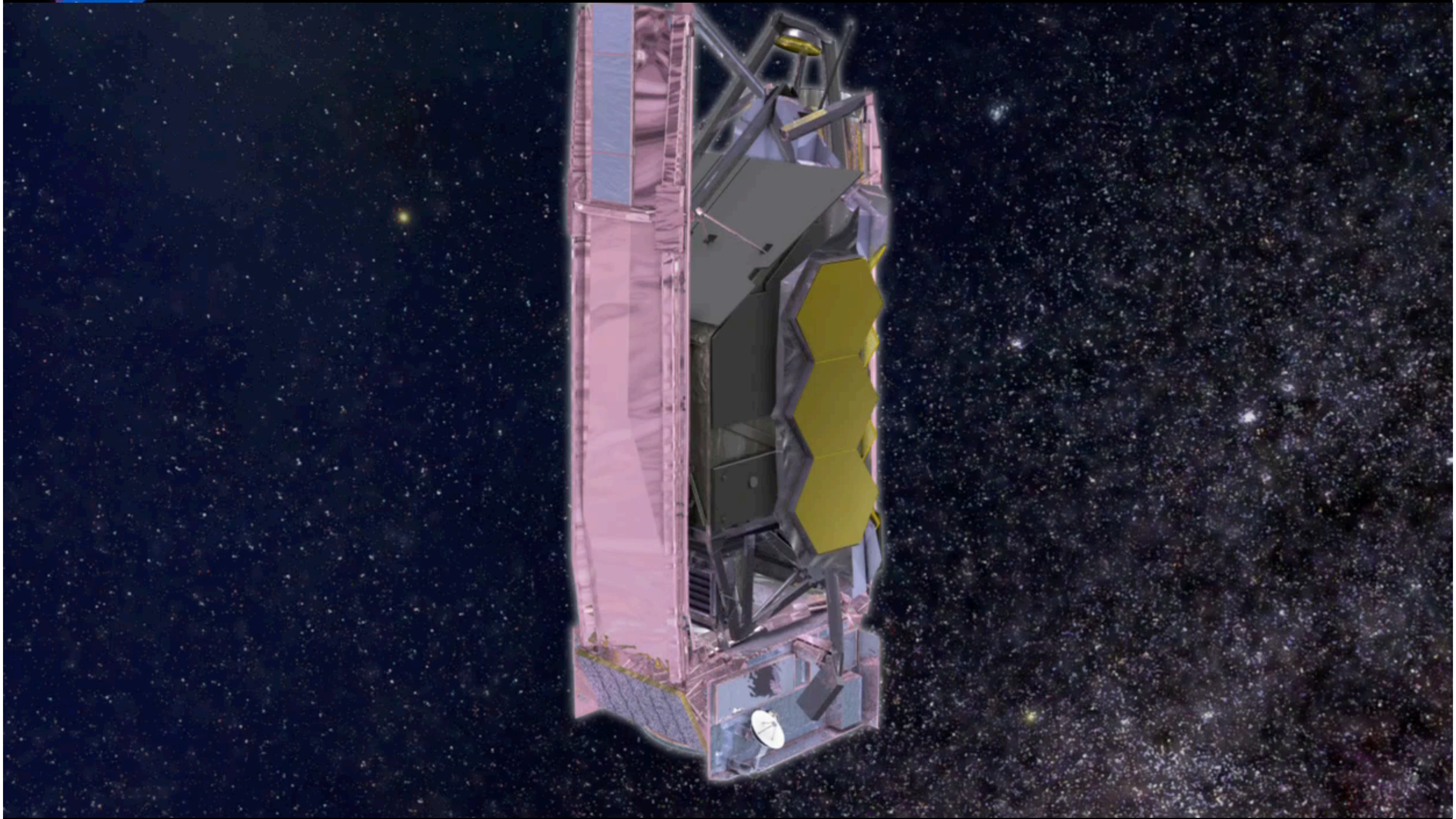
The assembly of galaxies

Birth of stars and proto-planetary systems

Planetary systems and the origin of life

Ned said:

- Use the cosmology calculator: we didn't know how to design for detecting the first galaxies before H_0 and Λ were measured
- (Ned was on the Ad Hoc Science Working Group, ASWG)

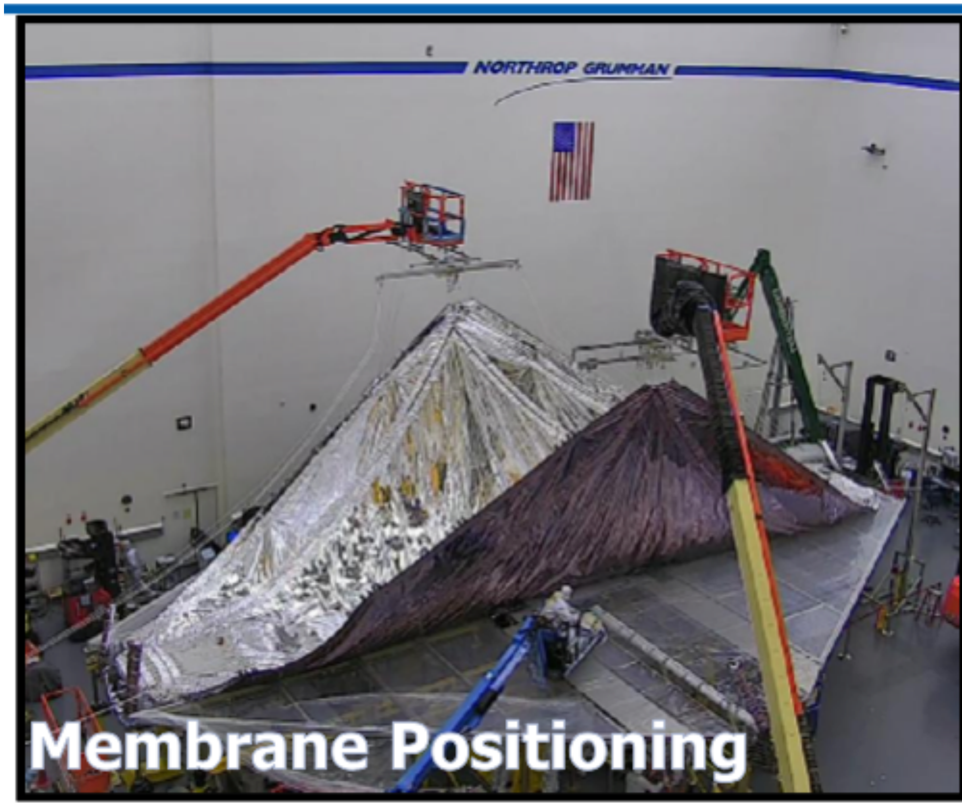


JWST status

- Telescope/Instrument module in test at JSC in Chamber A, all cold and working well
  - Hurricane Harvey approaching but we're ready
- Spacecraft bus being finished at Space Park Redondo Beach, by Northrop Grumman Aerospace (NGAS)
  - Final deployment tests after telescope is attached

Program Updates: Spacecraft and Sunshield

NORTHROP GRUMMAN



Proposals

- Cycle 1 call for proposals: 11/30/17
- Cycle 1 proposals due: 3/2/18
- Use the APT (google JWST APT), includes exposure time calculator
- Analysis software being written in Python

The End