

The Big Bang and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe cools and becomes less dense. All distant galaxies are moving apart from each other and away from us. On large scales, the universe looks the same in all directions and all parts of space. There is no preferred center. Our current understanding of the early universe is called the Big Bang model. Much more will be learned from astronomical observations and from accelerator-based experiments in the coming years.

Cosmology and Relics of History

Cosmology is the study of the universe as a whole. As in archaeology, cosmology finds clues to the past in relics. Looking out a distance d in space is looking back in time, because $t = d/c$ (light travels at a finite speed c). The laws of nature discovered on Earth can be applied to the early universe and tested by observing relics.

A Relic from the Early Universe

The Cosmic Microwave Background (CMB) is a universal bath of lightwaves (photons) from the hot, dense, early universe. They are stretched by the expansion of space. To a part in 100,000, the CMB is the same no matter where you look (it is isotropic). The remaining tiny variations (shown in figure) are images of the seeds that later form galaxies and larger cosmic structures.



This is an image of the universe from the time when atoms first formed. It is a map of the entire sky showing CMB light with the uniform part subtracted.

Age of the Universe A marvelous agreement that the age of the universe is about 14 billion years comes from studying its expansion and the lifecycles of stars and also by dating meteorites.

History of the Universe

Three major eras in the expansion history followed the hot, dense condition of the earliest universe. During each era, the expansion depended on the nature of the matter or energy that dominated the universe at that time.

Era 1 - Acceleration: Inflation speeds expansion

Observations seem to imply that the very early universe underwent an extremely rapid, accelerating expansion, called **Inflation**. In a tiny fraction of a second, inflation expanded each part of space by a factor of at least 10^{27} . Before inflation, the portion of the universe visible to us today was a smooth patch much smaller than a proton. As inflation ended, the visible universe had grown to the size of a ball (very approximately). Inflation explains how quantum fluctuations in the otherwise smooth and isotropic universe yielded tiny ripples that would eventually grow into galaxies and structures. In the 14 billion years after inflation, the universe expanded by another factor of about 10^{47} .



Simulated density fluctuations (ripples) in the early universe that eventually yield galaxies and clusters of galaxies.

Eras 2-3 - Deceleration: Expansion slows and structure forms

After inflation, the universe was a plasma or soup of fundamental particles. Photons and fast moving particles, generically called **radiation**, gradually lost energy (cooled) as the universe expanded (the energy went into the expansion). Eventually, slow-moving matter became dominant over radiation. Over time, larger and larger structures grew from galaxies to clusters of galaxies to superclusters. These began as small differences in the density of matter, but gravitational attraction made more and more matter clump together. Several interesting stages are indicated in the central figure. Stars created the heavier elements that eventually became part of Earth and of us. The early universe had both matter and antimatter in abundance, but today it is almost exclusively matter. How this came about is not fully understood.

Era 4 - Acceleration: Dark energy speeds expansion

A matter-dominated universe causes deceleration and might even reverse the expansion. So it was a great surprise in 1998 when observations showed that the expansion of the universe is now accelerating (see the "Expansion History" plot). This implies the existence of a new form of energy, referred to as **dark energy**. Scientists are pursuing the nature of dark energy.

Our Cosmic Address

Our sun is one of 400 billion stars in the Milky Way galaxy, which is one of more than 100 billion galaxies in the visible universe.



THE HISTORY AND FATE OF THE UNIVERSE

Eight major stages in the evolution of the universe are illustrated below.

The Big Bang occurred everywhere in the universe. Here one region has been illuminated and followed through time. The expansion is far greater than can be shown here.



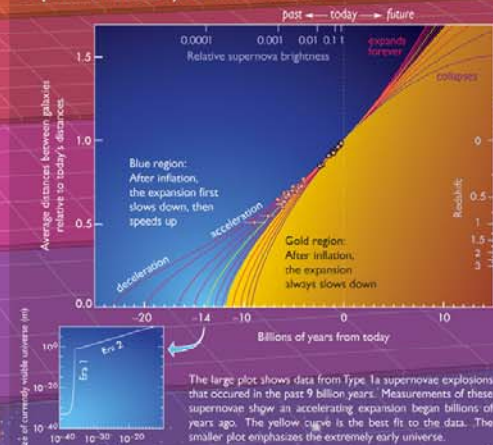
Redshifts and Expansion

Lightwaves stretch with the expansion of space. As the wavelength of visible light increases, it becomes redder (as shown for the photons in the central figure). Measuring this redshift tells us the velocity of the source. In 1929, Hubble observed that all distant objects are receding with a velocity proportional to their distance. This information and modern telescope observations show that the universe is expanding uniformly in all directions. Objects that are bound together (such as galaxies and atoms) do not expand as space expands.



The same local expansion represents a portion of the universe, and the raisins represent galaxies. Due to the nature of the Big Bang (the expansion of space), wavelength increases and galaxies move apart, but atoms do not expand.

Expansion History of the Universe



Fate of the Universe

Whether the expansion of the universe will speed up, slow down, or even possibly reverse into collapse depends through gravity on the amount and types of matter and energy in it.

The ordinary matter - atoms and nuclei - that formed in the early universe can account for the visible mass in galaxies and clusters. But it falls far short of the total mass needed to bind them together gravitationally and explain their internal motions. So an extraordinary new type of matter not made of atoms or nuclei must exist; it is called **dark matter** because it is not directly visible.

Even stranger recent observations of supernovae in distant galaxies show that the expansion of the universe is in fact **accelerating**. An exotic **dark energy** may be causing this acceleration through a cosmic repulsion that overwhelms the pull of gravity due to matter.

The nature of dark energy and dark matter are two of the great questions facing cosmology and particle physics. Perhaps dark energy is the cosmological constant introduced by Einstein in 1917. Perhaps both are new parts of particle physics, tied to the very earliest moments of the universe and having to do with the nature of physics and spacetime itself.

Not all answers in science are known yet! With the research and experiments under way in astrophysics and particle physics, we may be the first generation to learn what most of the universe is made of and what is the fate of the universe.

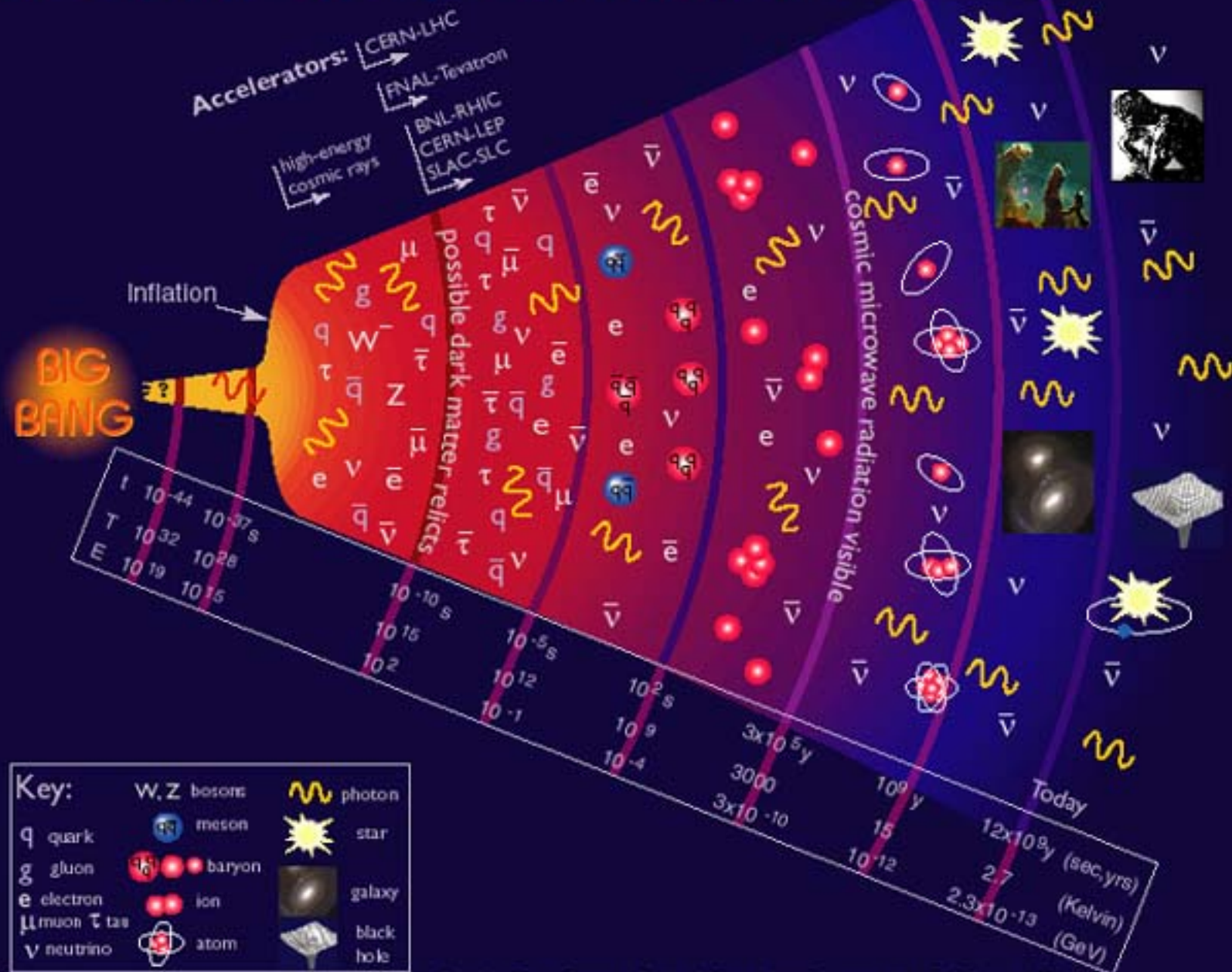


Learn more at
UniverseAdventure.org
and at **CPEPweb.org**

©2003 Contemporary Physics Education Project. CPEP is a non-profit organization of teachers, physicists, and educators. Send email to cpepeduc@cpepweb.org. Send mail to: CPEP MS 50R-6008, Lawrence Berkeley National Laboratory, Berkeley, CA 94720. For information on charts, websites, text materials, hands-on classroom activities and workshops, see: <http://CPEPweb.org>. This chart has been made possible by the generous support of: U.S. Department of Energy, U.S. National Science Foundation, Lawrence Berkeley National Laboratory. Photos courtesy of NASA.

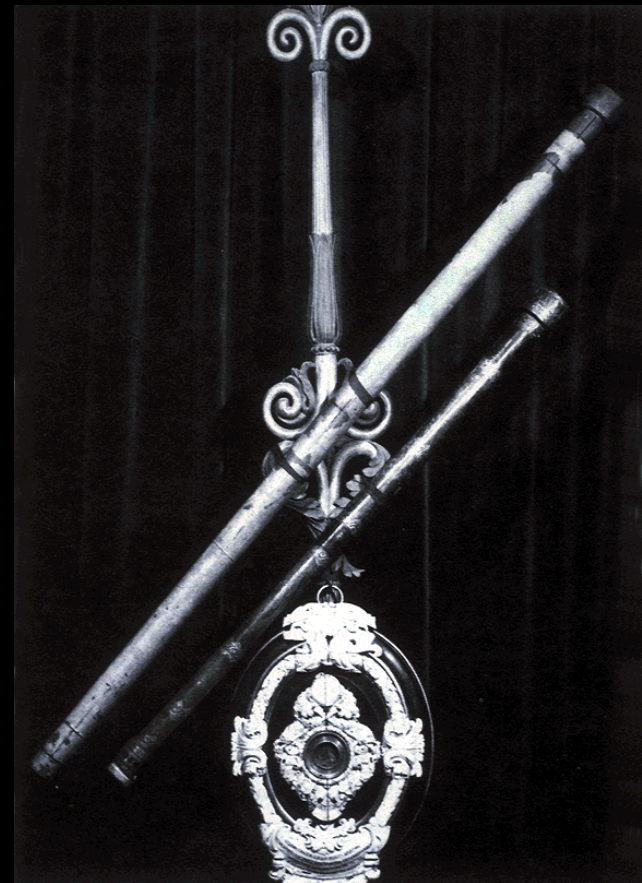
The Beginning of the Universe Professor George F. Smoot
Chaire Blaise Pascal U. Paris VII, LBNL & Physics Department, University of California at Berkeley

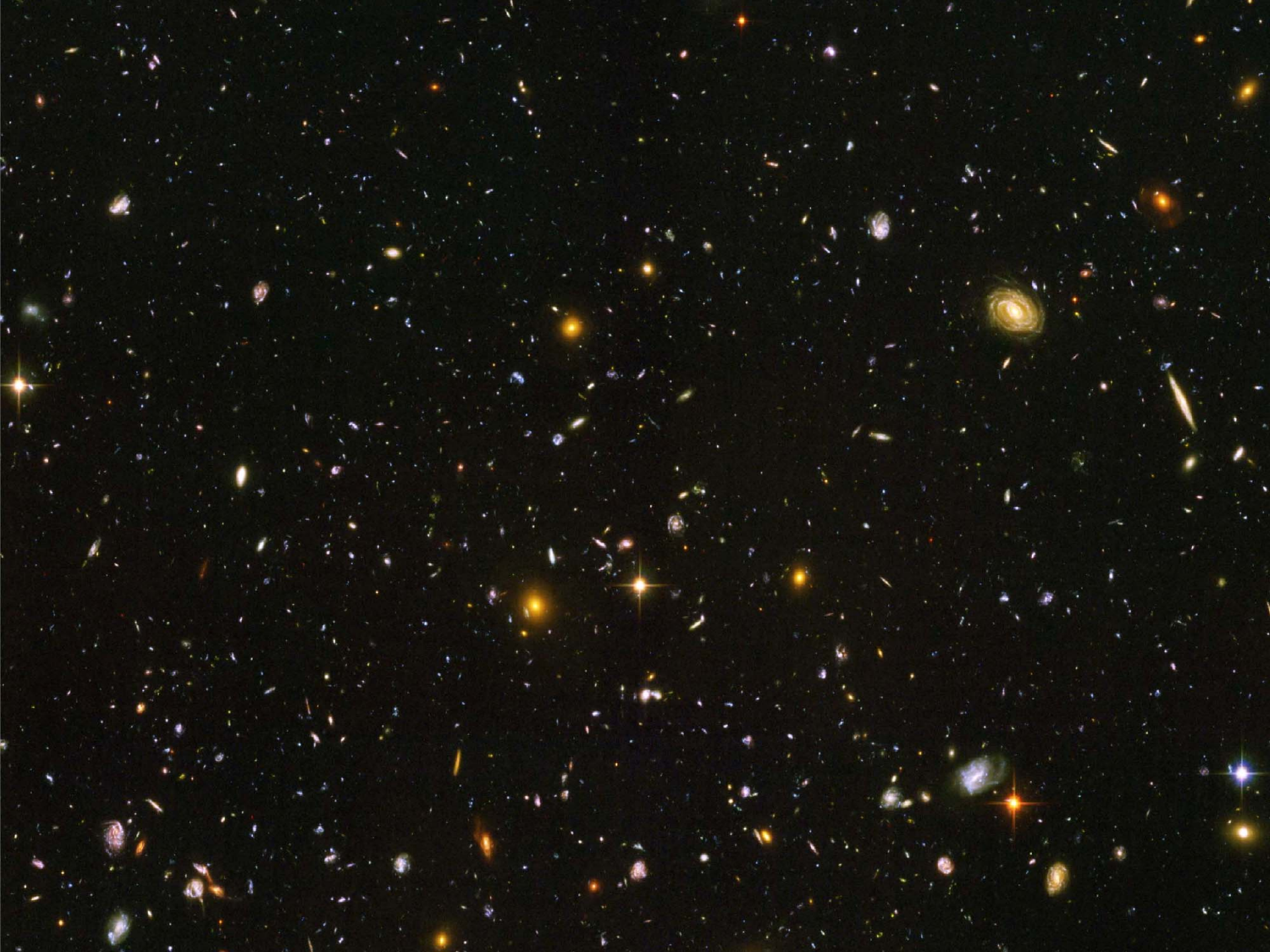
HISTORY OF THE UNIVERSE

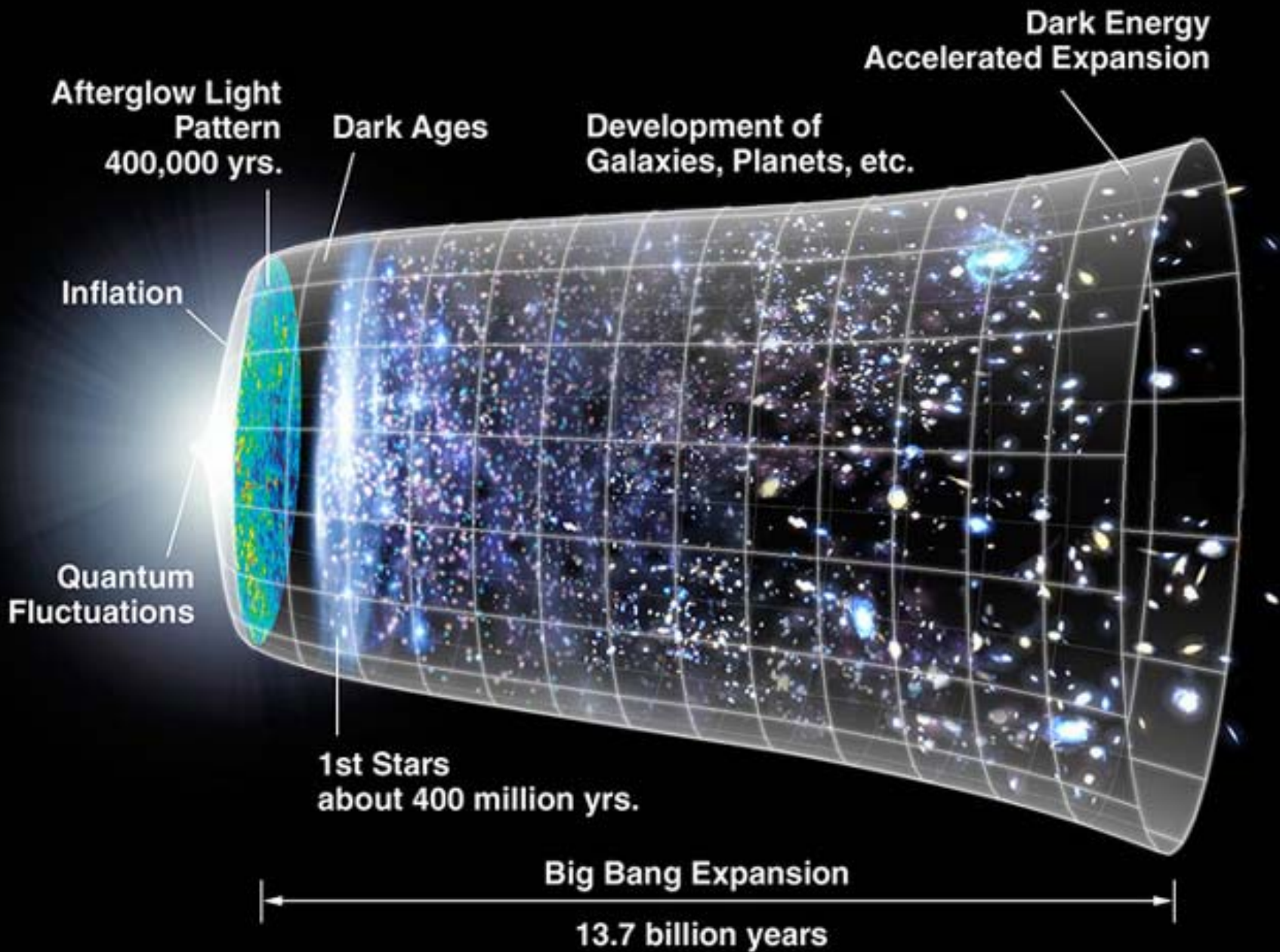


Galileo Galilei

- Galileo created an enormous sensation when he built one of the first telescopes in 1609, pointed it at the sky, and published his discoveries in 1610 in "Sidereus Nuncius" or "Starry Messenger". (moons of Jupiter, phases of Venus, etc.)
- Galileo's other investigations created the foundations of modern physics and cosmology.





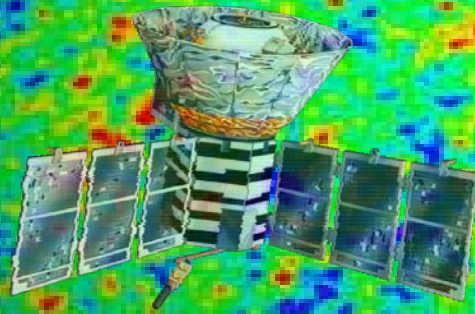


Connections: Quarks to the Cosmos



Beyond Einstein and the Big Bang

The Cosmic Microwave Background Radiation Anisotropies: Their Discovery and Utilization

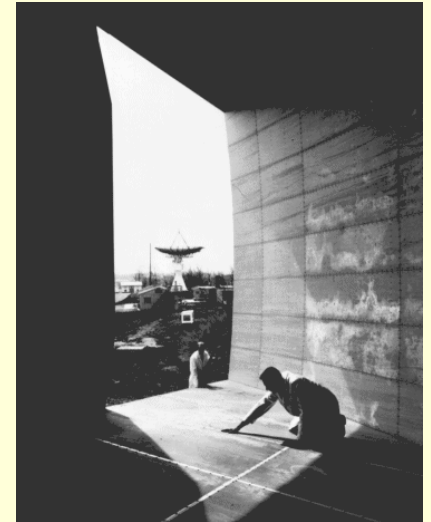


Prof. George F. Smoot
Lawrence Berkeley National Lab
Department of Physics
University of California at Berkeley

Relic Radiation from THE BIG BANG

λ

\pm

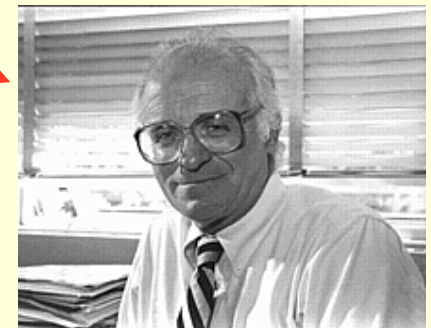


Arno Penzias & Robert
Wilson Nobel Prize (1978)

*Discovery of the Cosmic
Background Radiation
(CBR).*



Jim Peebles



Bernie Burke

Nature 215, 1155 - 1156 (09 September 1967)

Fluctuations in the Primordial Fireball

JOSEPH SILK

Harvard College Observatory, Cambridge, Massachusetts.



ONE of the overwhelming difficulties of realistic cosmological models is the inadequacy of Einstein's gravitational theory to explain the process of galaxy formation¹⁻⁶. A means of evading this problem has been to postulate an initial spectrum of primordial fluctuations⁷. The interpretation of the recently discovered 3° K microwave background as being of cosmological origin^{8,9} implies that fluctuations may not condense out of the expanding universe until an epoch when matter and radiation have decoupled⁴, at a temperature T_D of the order of 4,000° K. The question may then be posed: would fluctuations in the primordial fireball survive to an epoch when galaxy formation is possible

Cosmic Microwave Background Radiation

Relic Radiation from Big Bang

CMB produces electric field $\vec{E}(\nu, \theta, t)$ at observer

ν Frequency Spectrum - predicted thermal=blackbody

θ Angular distribution - map the sky

→ Polarization - low level linear expected

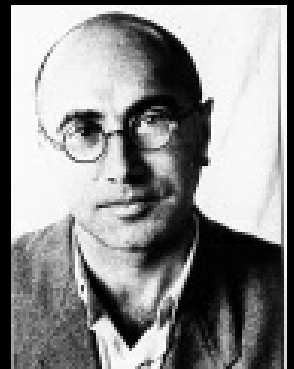
t Statistics - $1+z$, Bose-Einstein / Planckian

SZ effect - Clusters scatter some CMB

Rashid Sunyaev



Y. B. Zel'dovich



Penzias & Wilson / Bell Labs Receiver at Deutsches Museum



Dave Wilkinson's

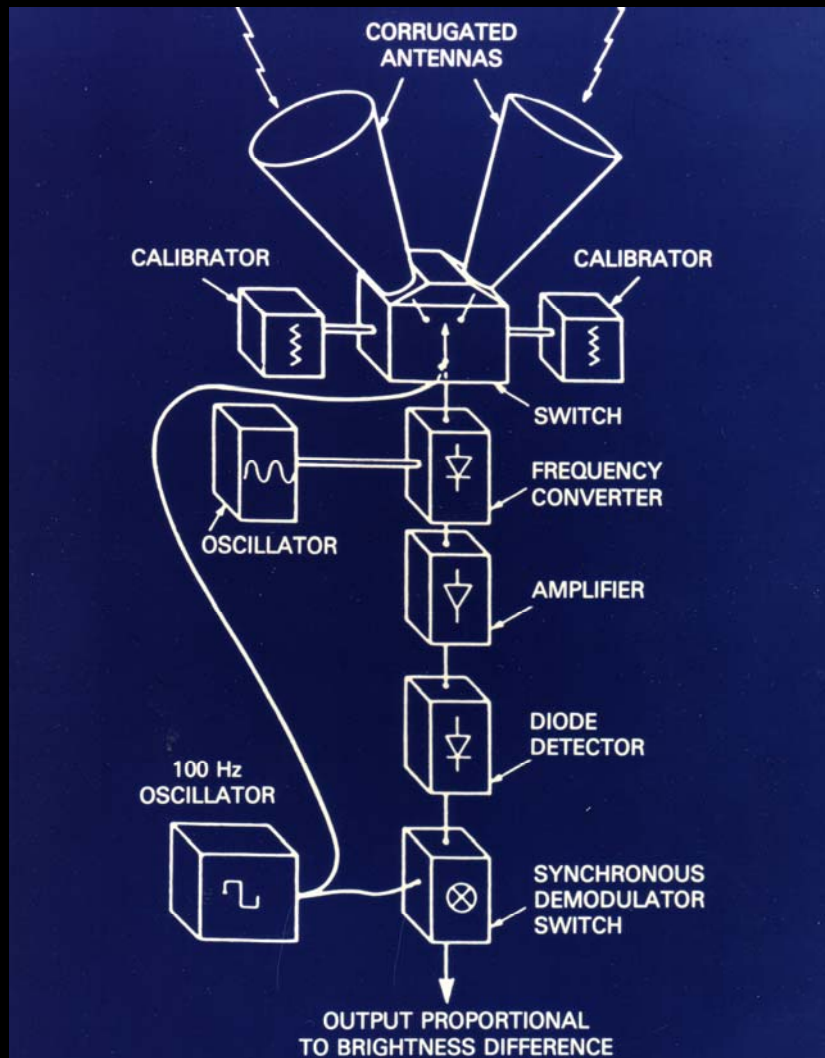


CMB: Seeking a very small signal in large background and noise

- Anisotropy Signal Anticipated (1970's) at mK level (thousandths of degree Kelvin)
- CMB temperature ~ 3 K
- Receiver Temperatures \sim few $\times 30$ K
- Earth Temperature ~ 300 K
- \Rightarrow signal $\sim 10^{-9}$ backgrounds
- part per million
- Technique: Compare with Signals of Same Level
 - 3K
 - Exclude, Reject, average out other signals and sources

DMR

Differential Microwave Radiometer



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Corrugated Horn Antennas

Standard Gain Horn

Corrugated Horn

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Radiometer system to map the cosmic background radiation

Rev. Sci. Instrum. **49**, 440 (1978)

Marc V. Gorenstein, - Ph.D. on project

Richard A. Muller,

George F. Smoot, &

J. Anthony Tyson

Technical and Engineering

Jon Aymon - software

Hal Dougherty - mechanical

John Gibson - electronics

Robbie Smits - rotation system

John Yamada - tech. assembly

Luis Alvarez

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

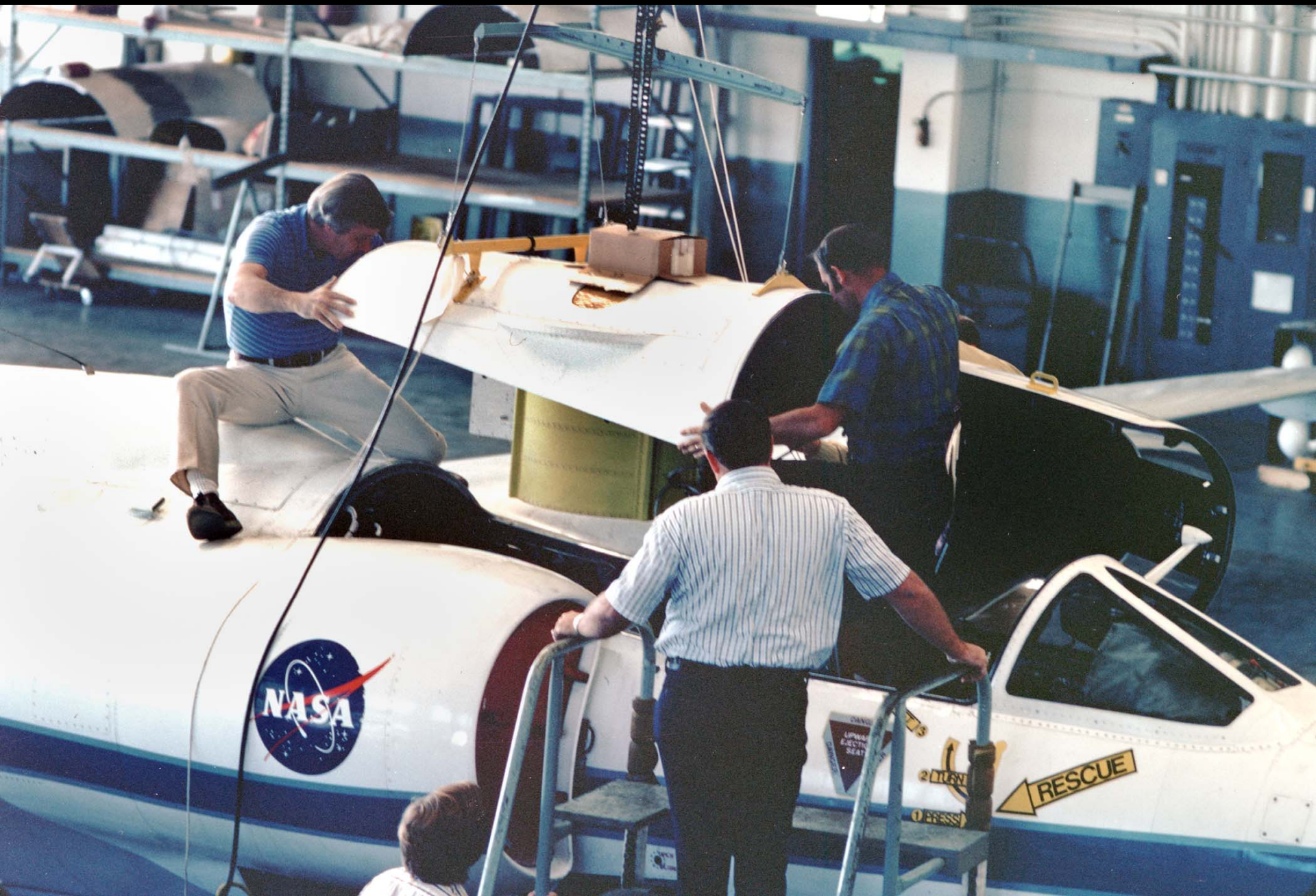
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

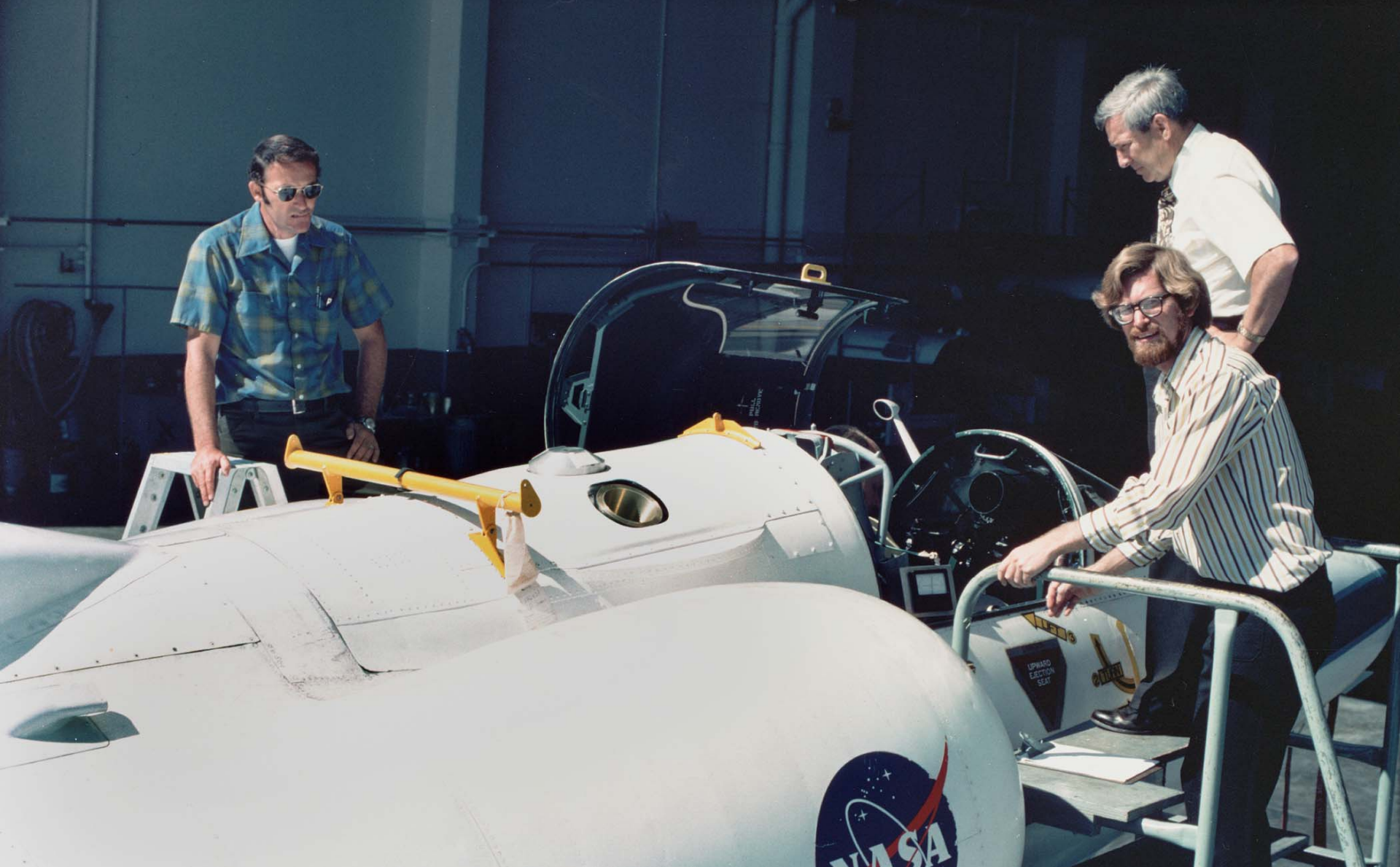
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Instrument into NASA craft



Scientists from DOE Lab put instruments on NASA Platform



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Marc Gorenstein

U2 can find

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

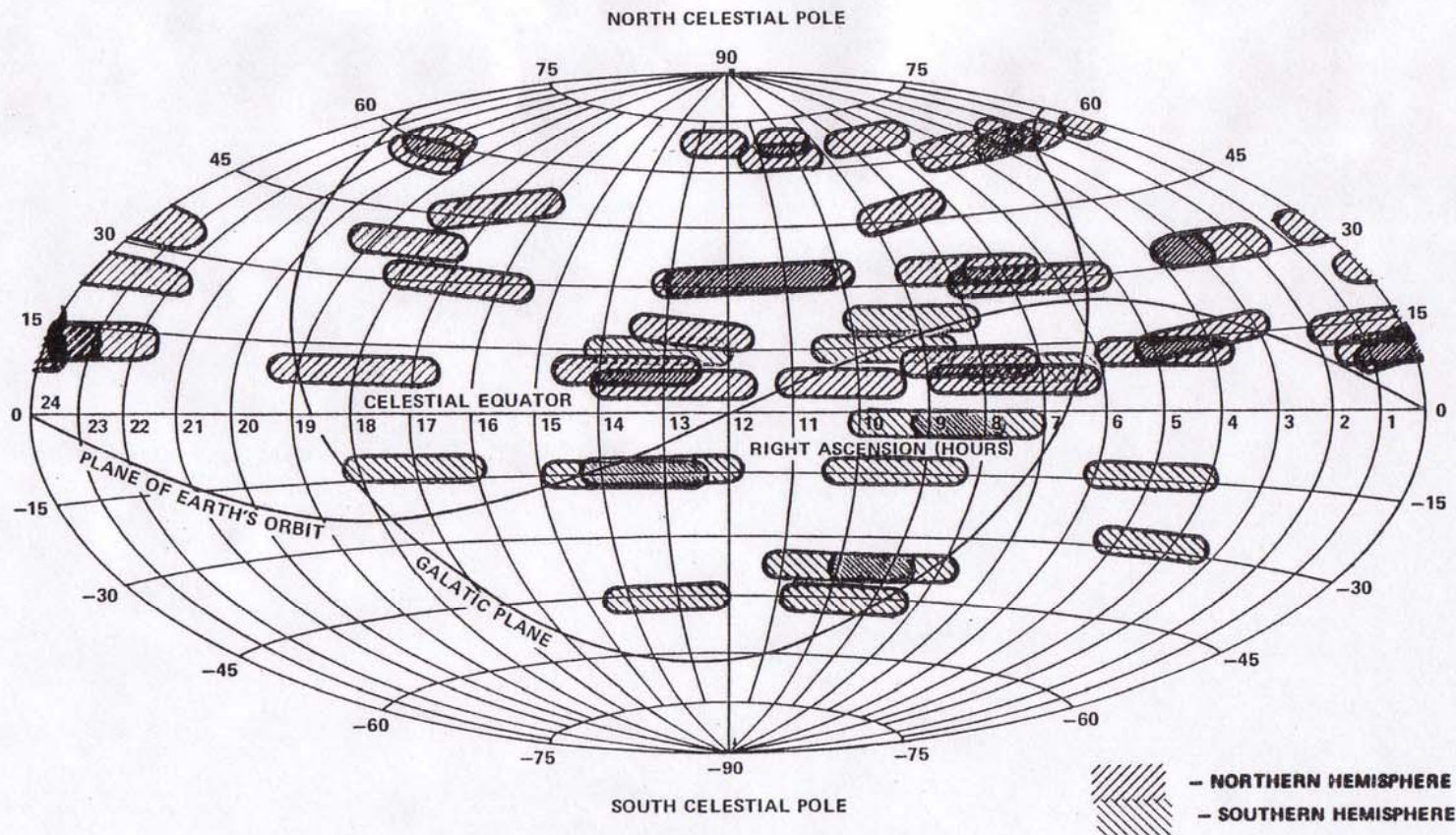
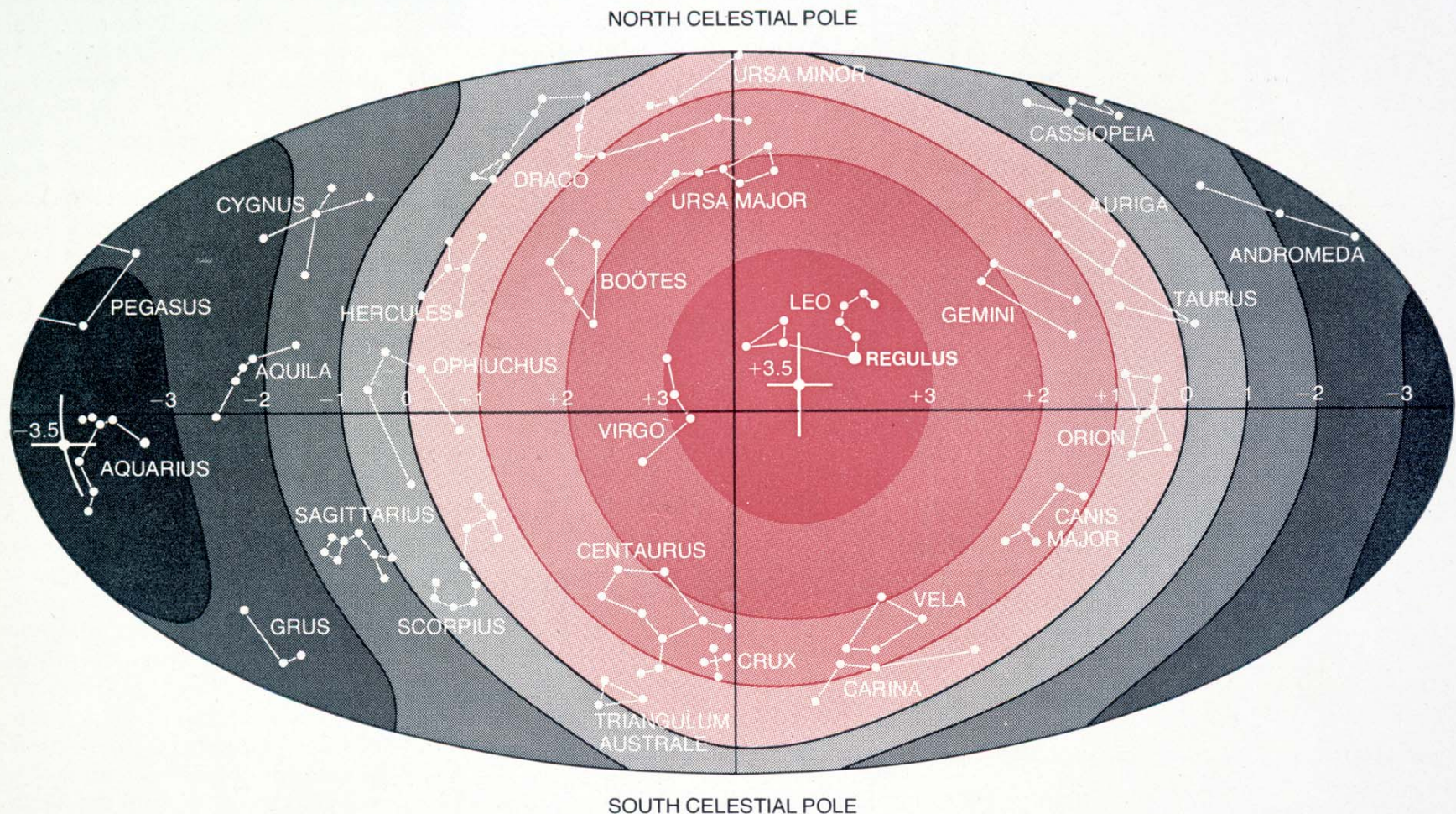


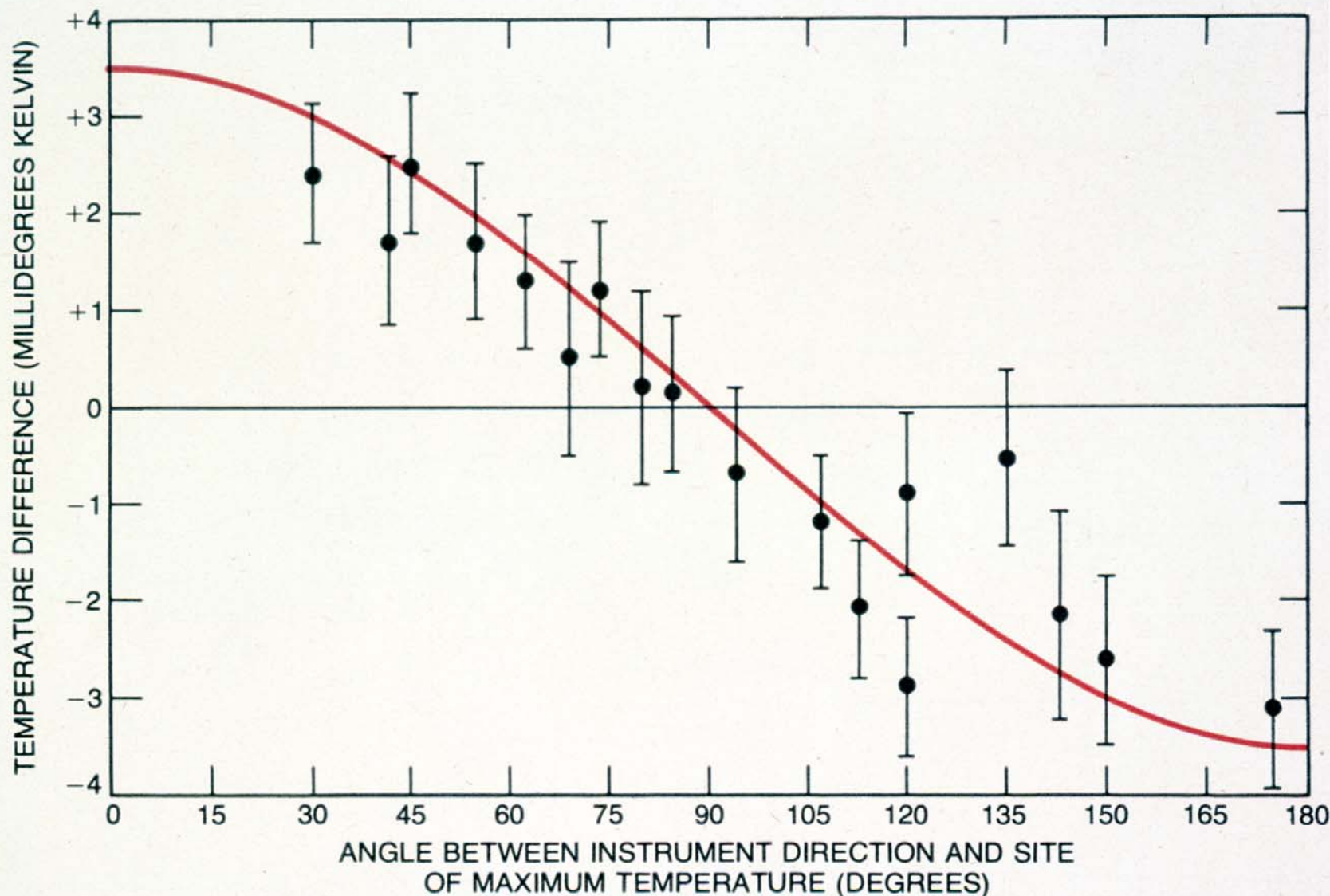
Figure 1. Plot of Sky Coverage in Celestial Coordinates. Sky coverage for the northern flights from NASA Ames in California and southern flights from Lima, Peru is indicated by the shaded regions. The width of each region is set by the 7° antenna beam widths, and the length is set by the rotation of the earth and the motion of the U2 back and forth along its flight path. The galactic and ecliptic planes are shown for reference.

Dipole Anisotropy $A = 3.5 \text{ mK}$



ANISOTROPY OF THE BACKGROUND RADIATION, as deduced from the U-2 survey, is plotted on the celestial sphere in contours of one millidegree K. The “hottest” spot, indicating the direction of the earth’s motion relative to the background

(± 5 hour) and latitude six degrees (± 10 degrees). The “coldest” spot, the direction in which the radiation is most “reddened” by the earth’s relative motion away from the incoming photons, lies 180 degrees away in Aquarius. If the temperature difference between the “hottest” and “coldest” spots is ΔT , then the dipole anisotropy is $A = \Delta T/2$.



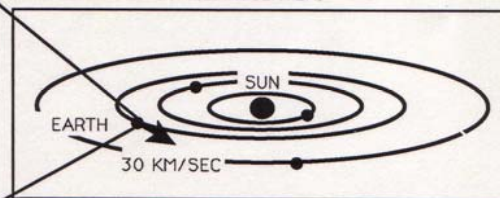
COSINE CURVE provides the best fit for the data (averaged into 18 points) taken by the author and his colleagues in the new aether-drift experiment. The horizontal axis represents the angle made by a line connecting the two horn antennas and the direction of maximum temperature in Leo. The cosine curve is temperature distribution to be expected in the cosmic background radiation if the solar system's peculiar velocity toward Leo is 400 kilometers per second.

VELOCITY COMPONENTS OF THE OBSERVED CMB DIPOLE

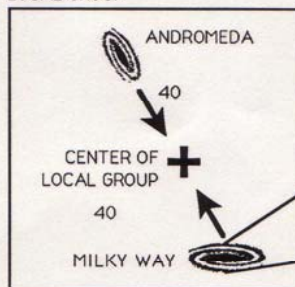
COBE AROUND EARTH



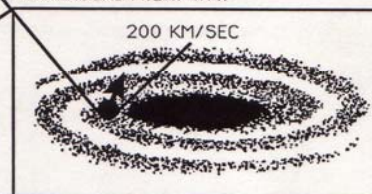
EARTH AROUND SUN (BARYCENTER)



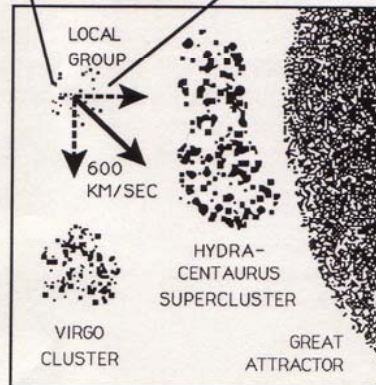
LOCAL GROUP



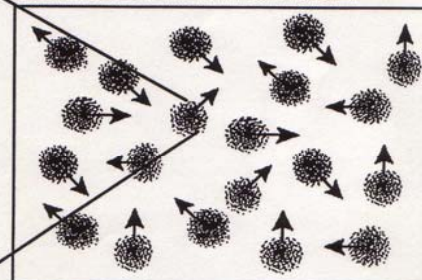
SUN AROUND MILKY WAY

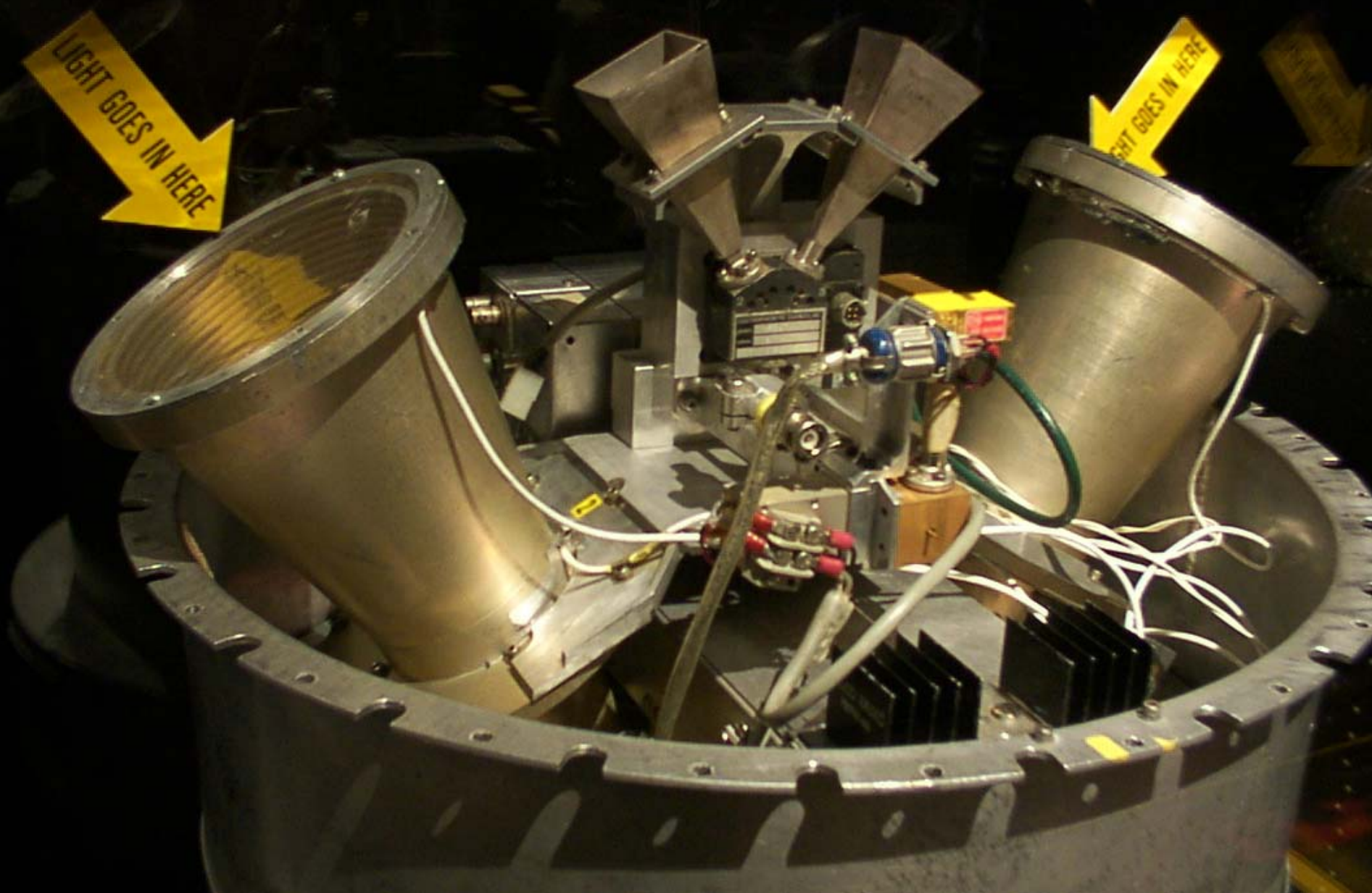


LOCAL GROUP TOWARD THE GREAT ATTRACTOR



GREAT ATTRACTORS IN THE UNIVERSE ?





Pioneer

TIFF (Un
are no

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

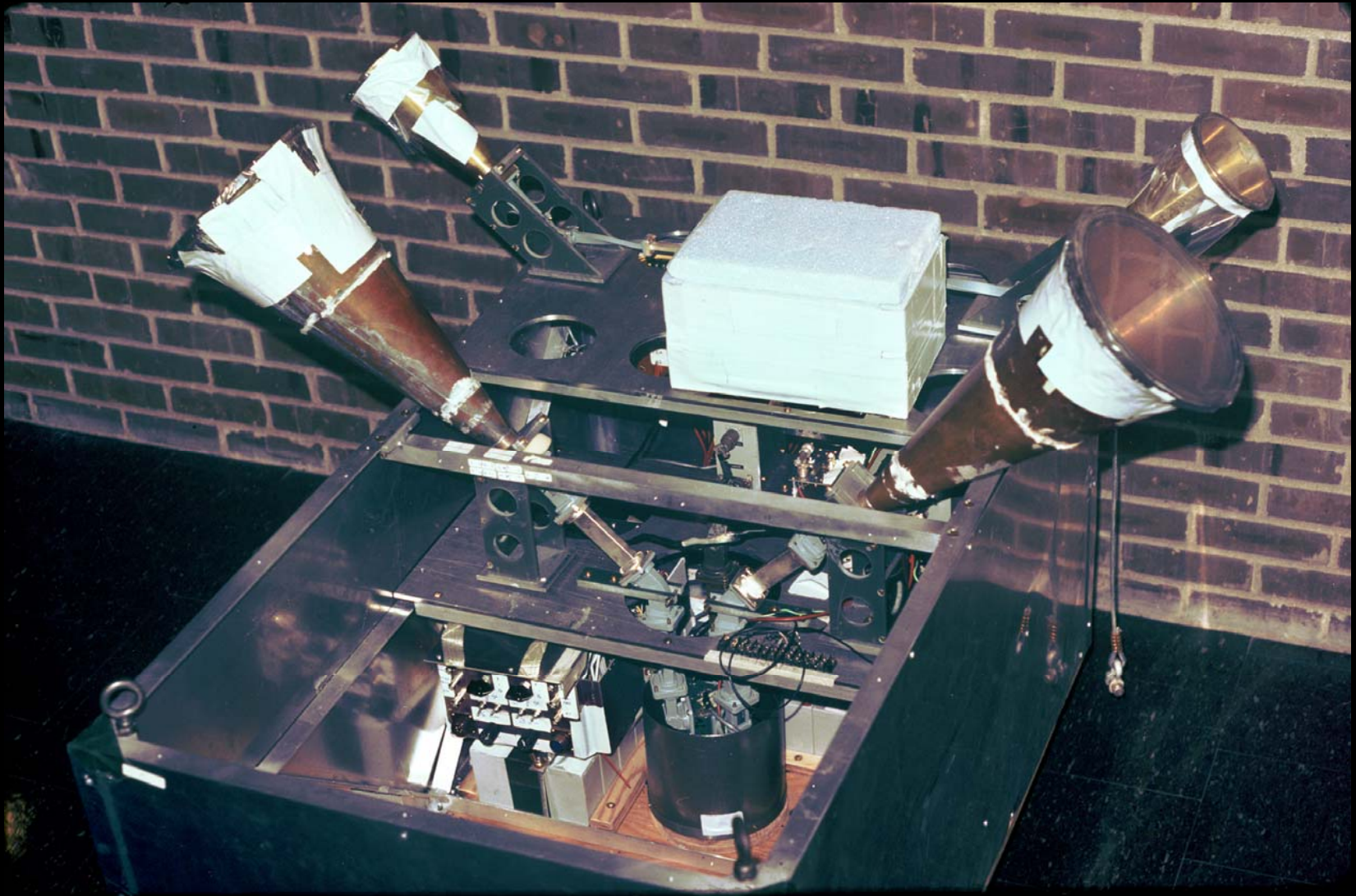
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Princeton large-angular scale anisotropy same epoch as Berkeley 3-mm



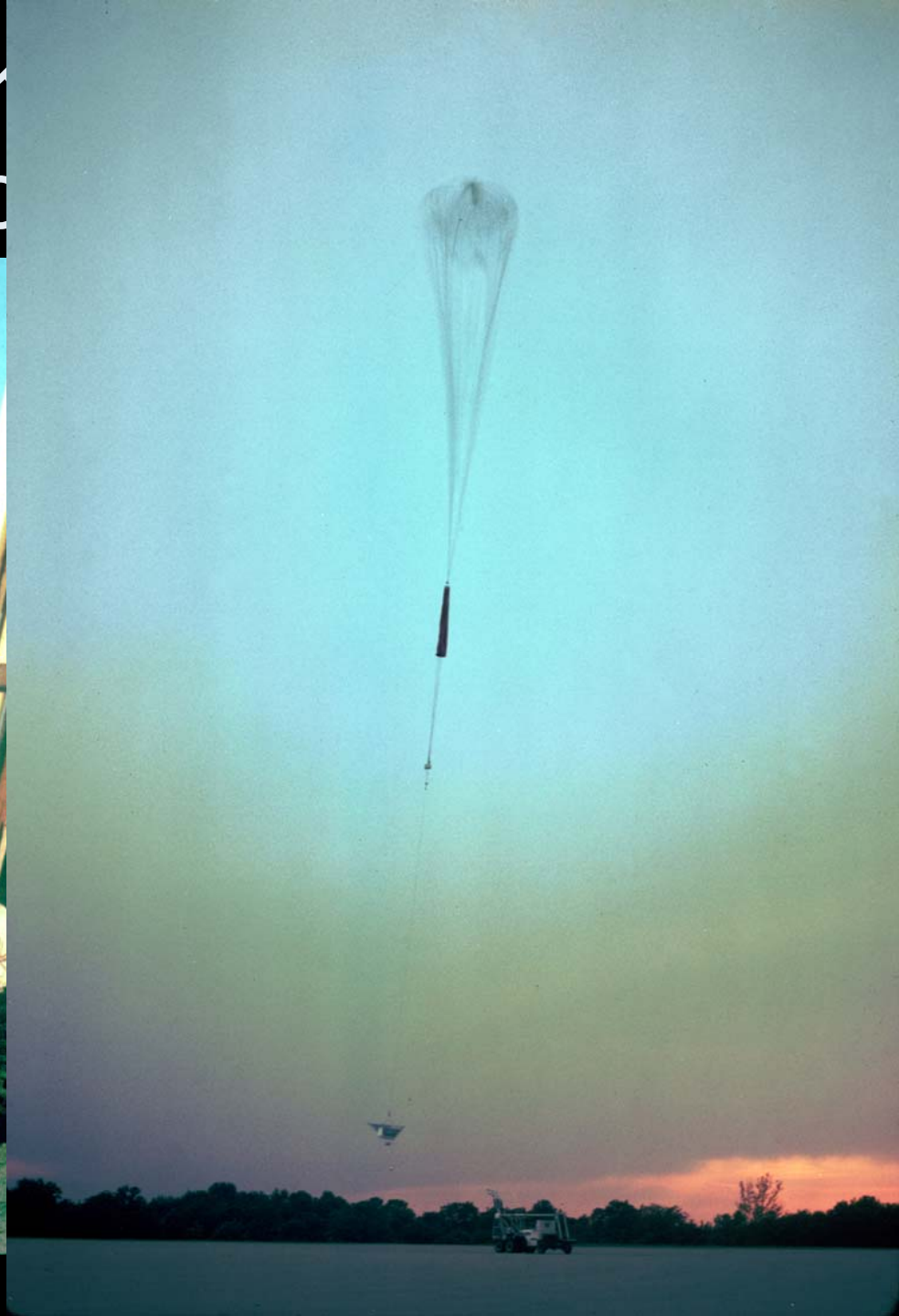
Peter Saulson & assembled payload



Princeton plus Berk being readied for



Peter Saulsen Dave Wilkinson



Three Balloon Flights Later- our CMB map

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Spectrum : Collaboration at White Mtn.



Low-Frequency Measurement of the Spectrum of the Cosmic Background Radiation

Physical Review Letters **51**, 12, 1099 (1983)

Original Team & Authors

G.F. Smoot,	LBL/UCB
G. De Amici,	UCB
S.D. Friedman,	UCB
C. Witebsky,	UCB
N. Mandolesi*,	Bologna
R.B. Partridge,	Haverford
G. Sironi,	Milano
L. Danese &	Padua
G. De Zotti	Padua

Added Participants

Marco Bersanelli ⁺	Milano
Alan Kogut	UCB
Steve Levin	UCB
Marc Bensadoun	UCB
S. Cortiglioni	Bologna
G. Morigi	Bologna
G. Bonelli	Milano
J.B. Costales	UCB
Michel Limon	UCB
Yoel Rephaeli	Tel Aviv

* Planck PI

⁺Planck Deputy PI

Heavy Manual Operations

George Smoot, Scott Friedman, Alan Benner



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Spectrum of the Cosmic Background Radiation

John Mather PhD Thesis

D. P. Woody and P. L. Richards

Received 15 December 1978

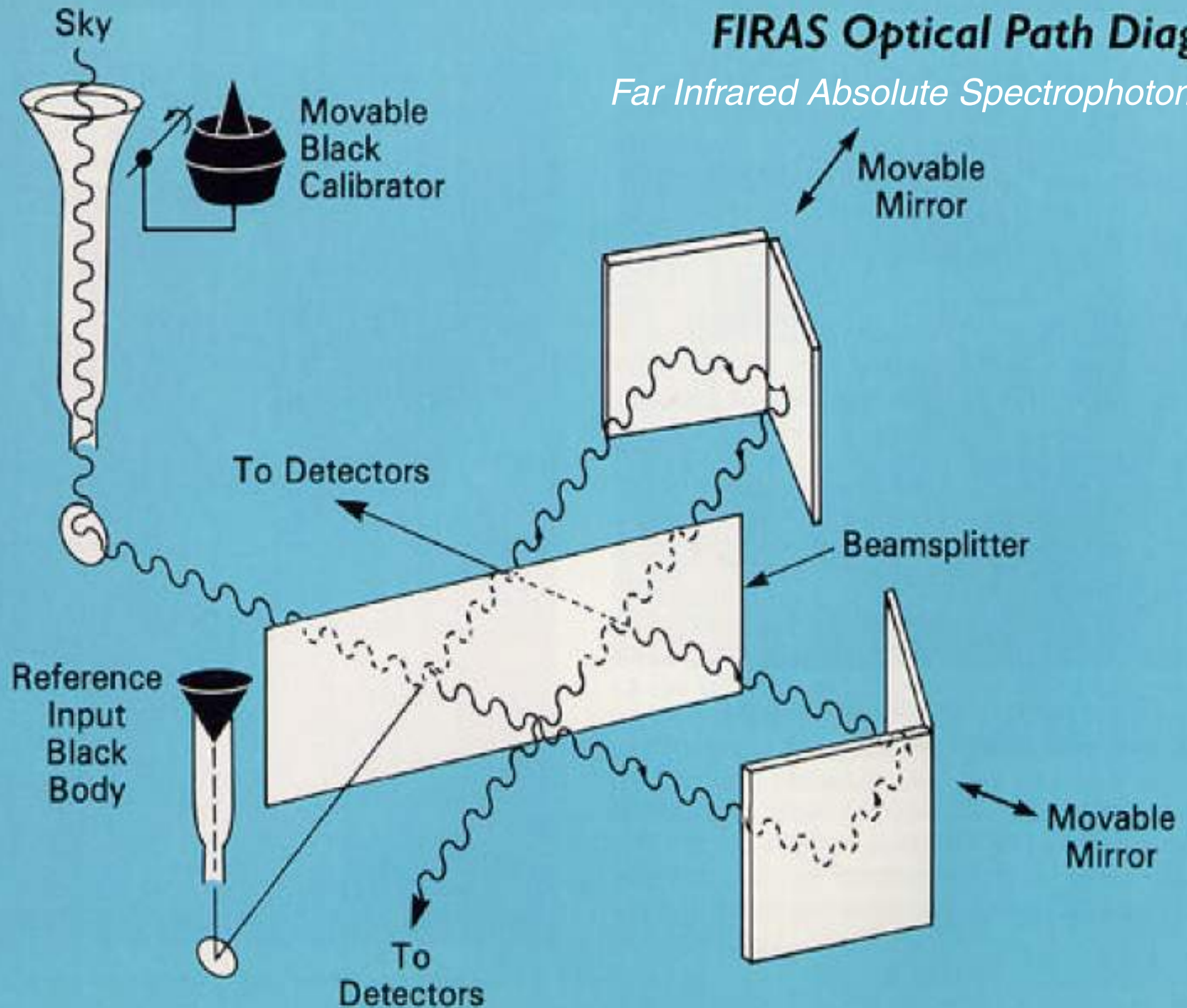
New measurements of the emission spectrum of the night sky have been made in the frequency range from 1.7 to 40 cm^{-1} using a fully calibrated, liquid-helium-cooled, balloon-borne spectrophotometer. The results show that the spectrum of the cosmic background radiation peaks at 6 cm^{-1} and is approximately that of a 3-K blackbody out to several times that frequency. However, the data show deviations from a simple blackbody curve.



Paul Richards stands with elements of the Woody-Richards cosmic microwave background instrument package, an historic balloon-borne experiment that now resides in the Smithsonian Museum's permanent national collection.

FIRAS Optical Path Diagram

Far Infrared Absolute Spectrophotometer

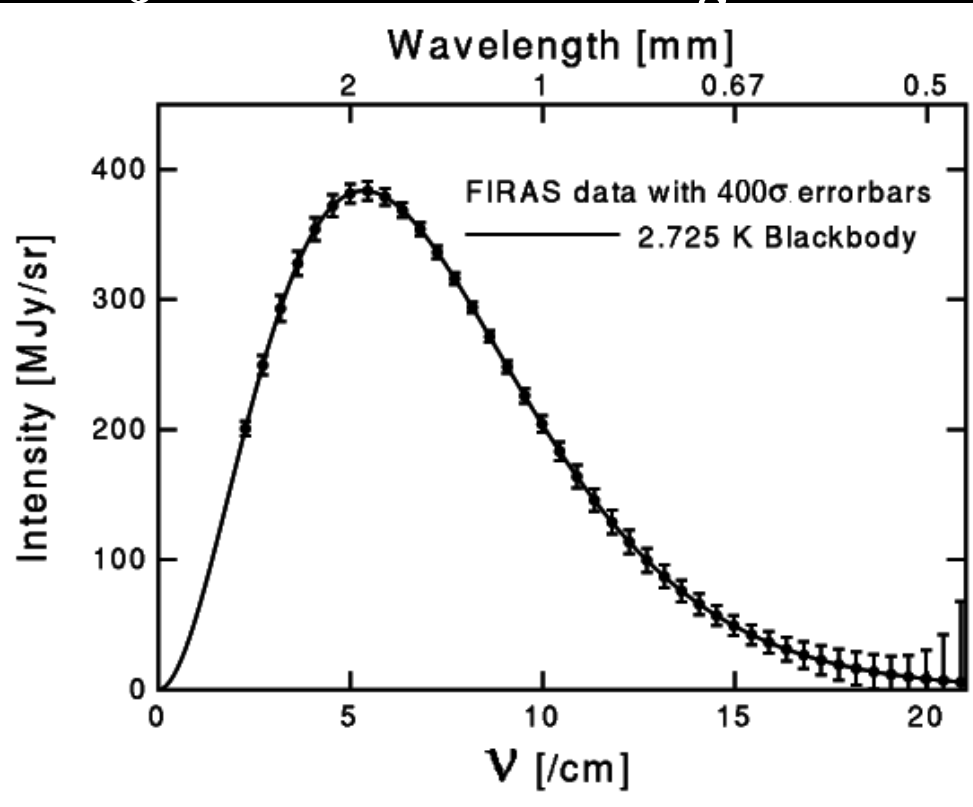


FIRAS Horn & External Calibrator

COBE Spectrum of the Universe

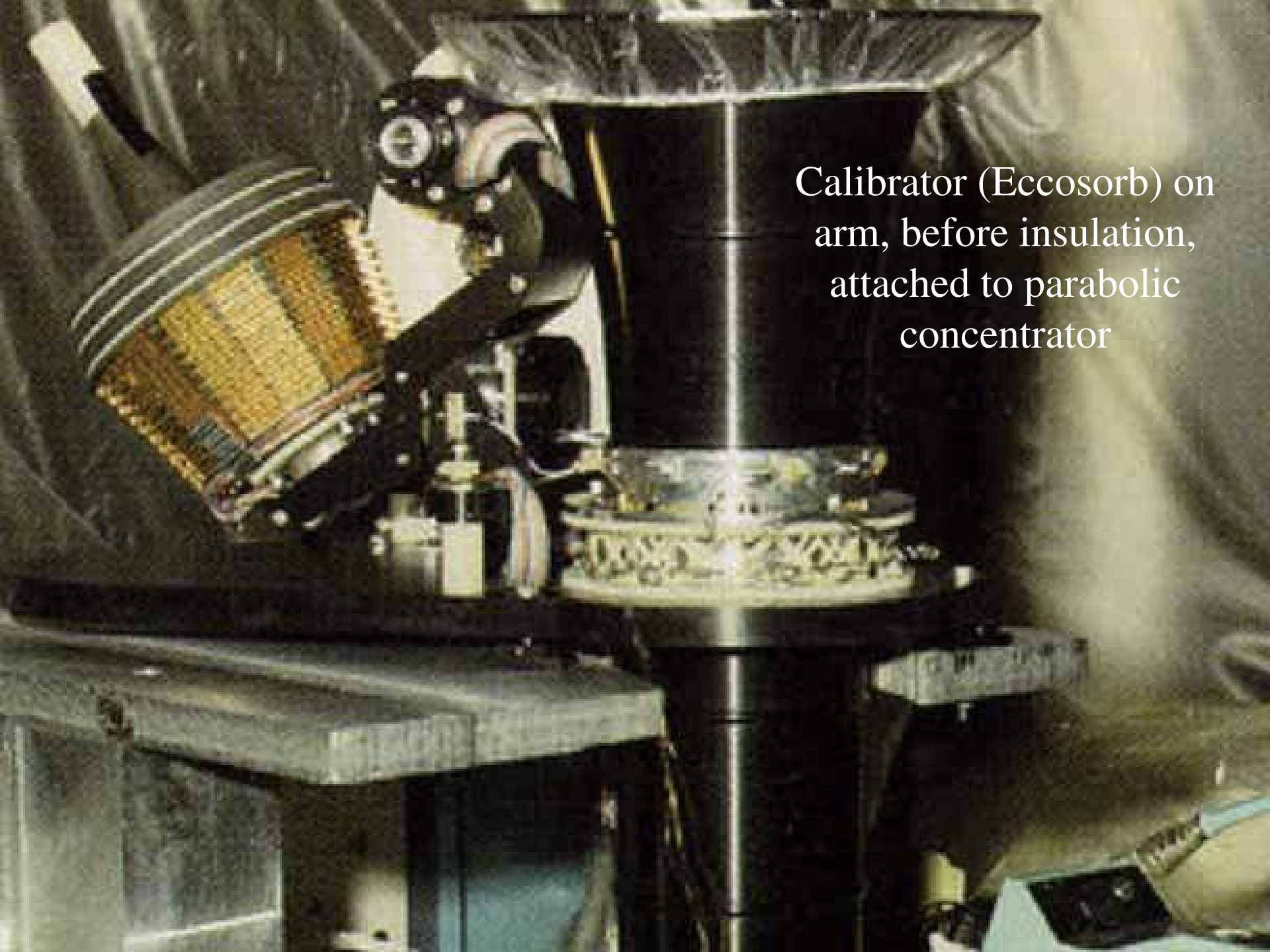
-first 9 minutes of data

Jan 1990 AAS meeting



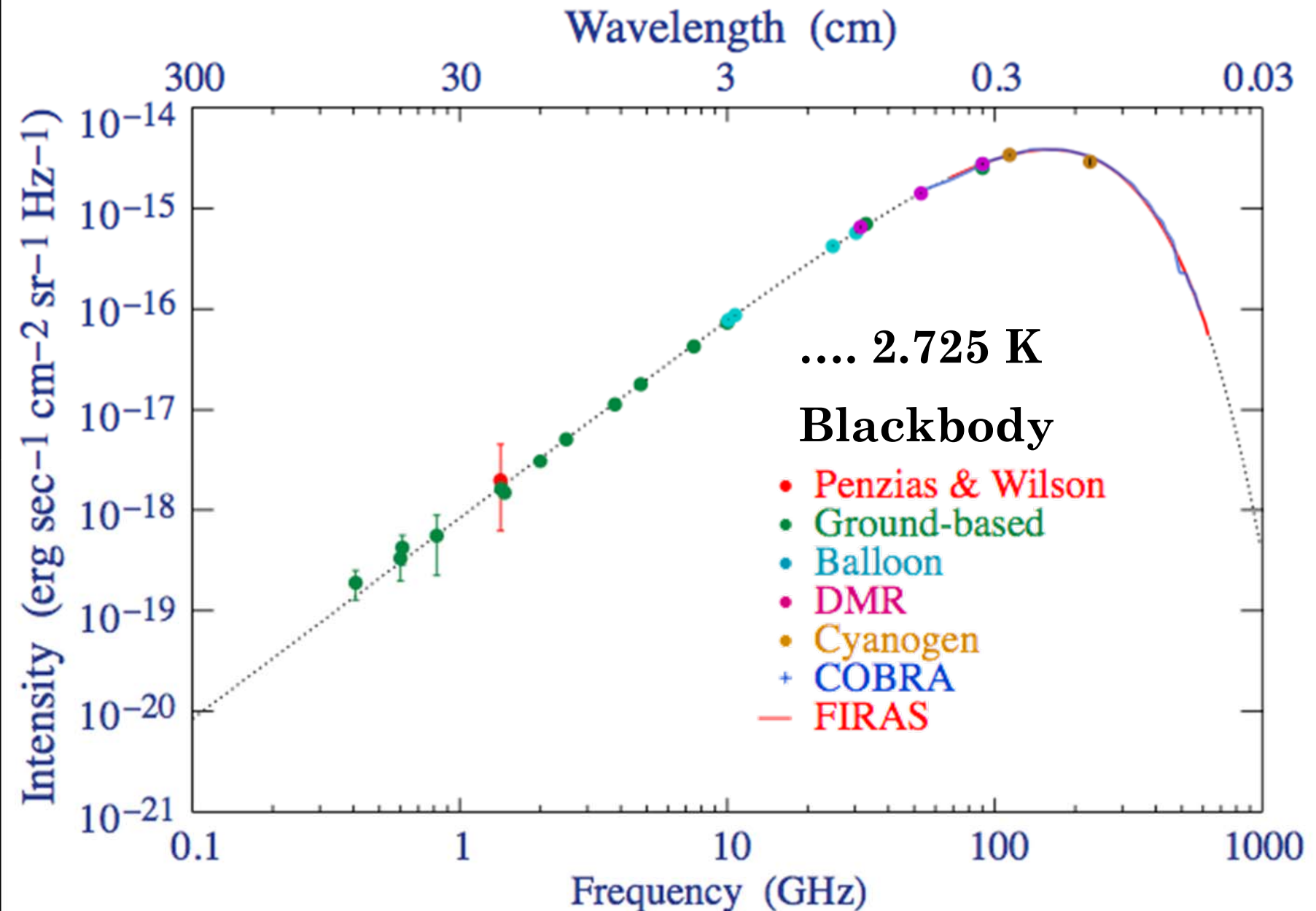
Frequency Spectrum

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

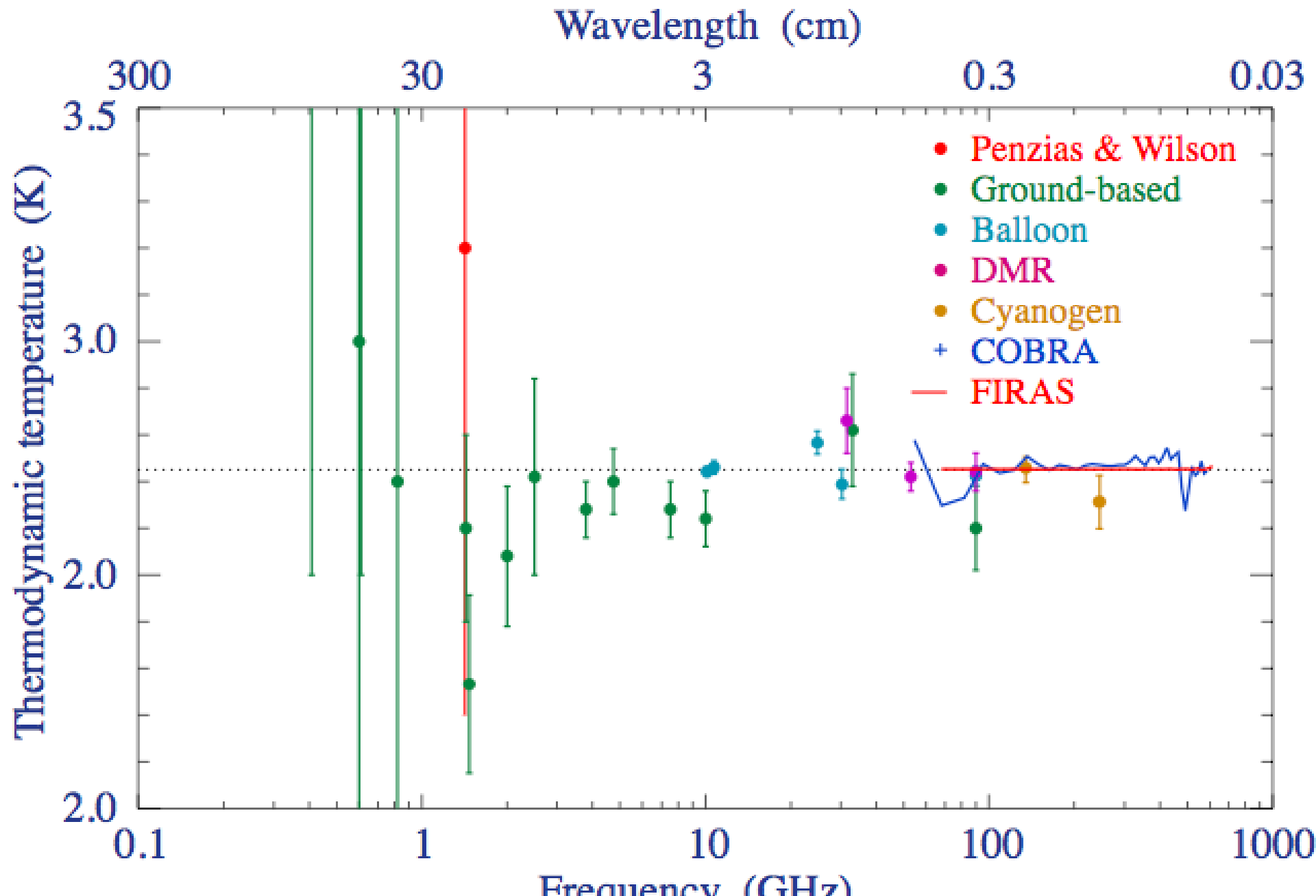
A photograph showing a mechanical assembly in a workshop. A cylindrical component with a woven mesh exterior, identified as a Calibrator (Eccosorb), is mounted on a black arm. The arm is positioned in front of a large, dark, parabolic concentrator. The scene is dimly lit, with a bright light source on the right creating a strong glare. Various mechanical parts, wires, and a workbench are visible in the background.

Calibrator (Eccosorb) on
arm, before insulation,
attached to parabolic
concentrator

CMB Intensity vs. Frequency or wavelength



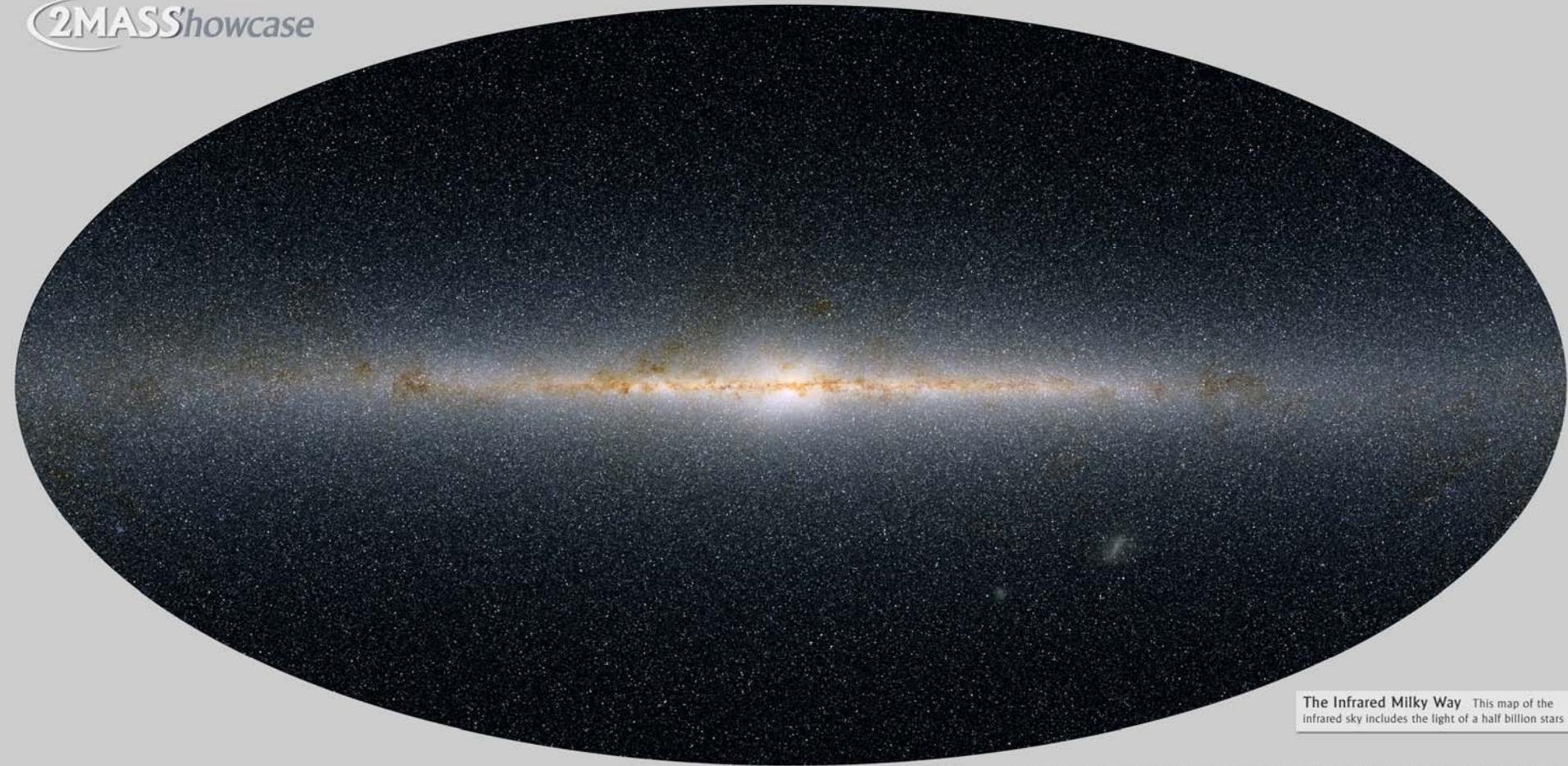
CMB Temperature vs Frequency/wavelength



Diffuse Infrared Background Experiment

DIRBE 1.25, 2.2, 3.5 μm Composite

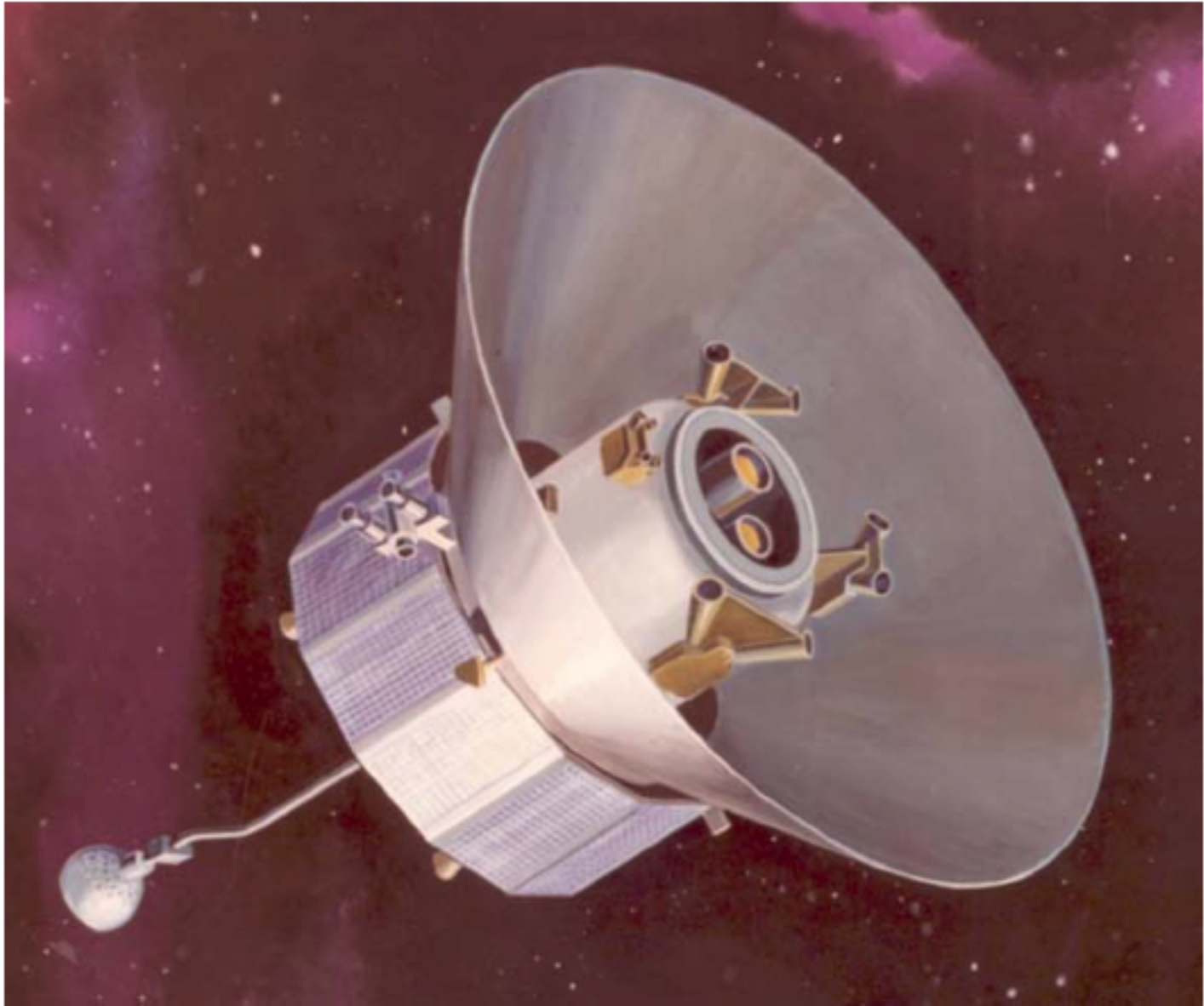
2MASShowcase



The Infrared Milky Way This map of the infrared sky includes the light of a half billion stars.

Two Micron All Sky Survey Image Mosaic; Infrared Processing and Analysis Center/Caltech & University of Massachusetts

Cosmic Background Explorer: COBE - artist concept





COBE DMR Hardware Effort

Huge List of People
Here are a few photos

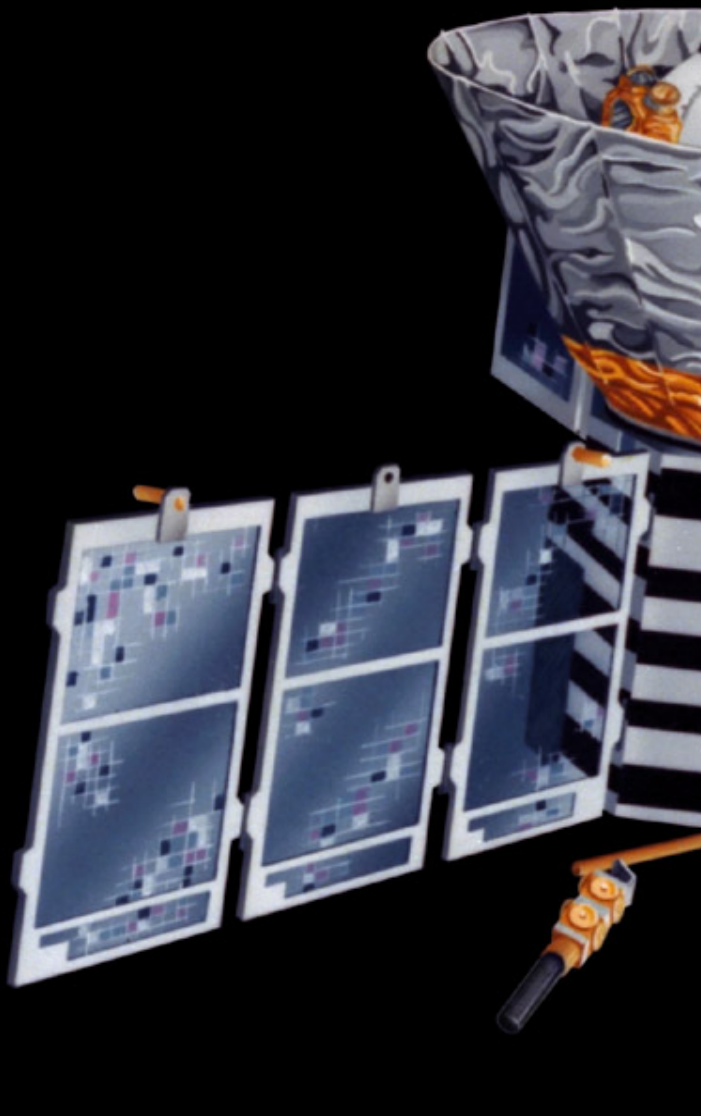
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

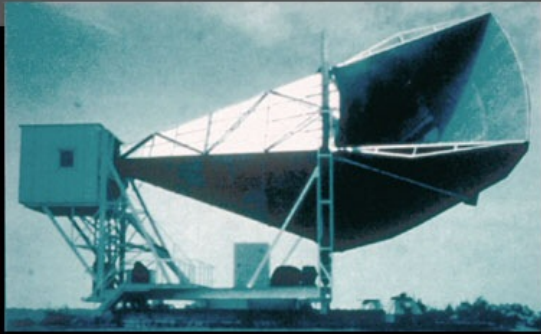
John Maruschak

Roger Ratliff

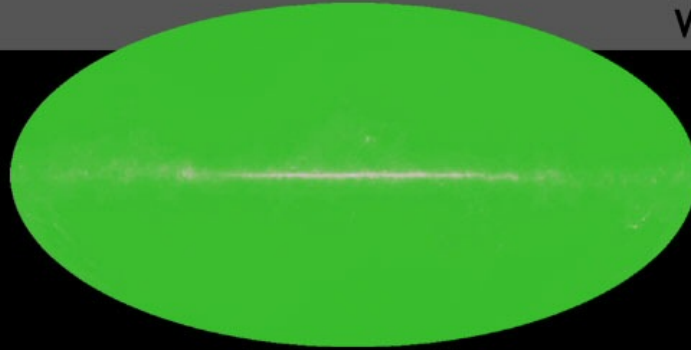


QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

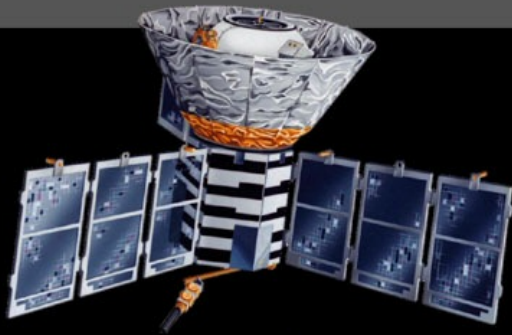
1965



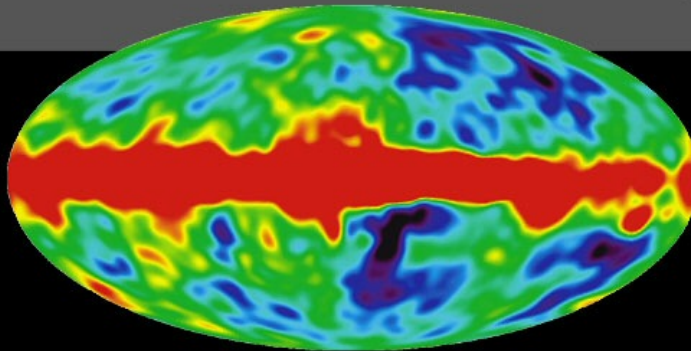
Penzias and
Wilson



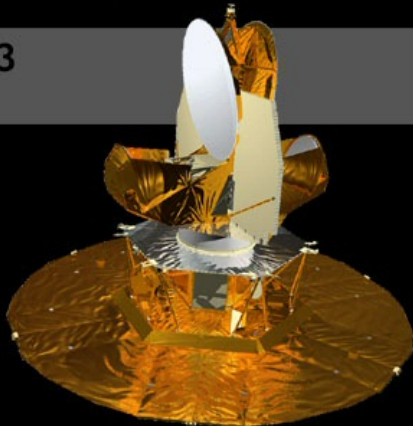
1992



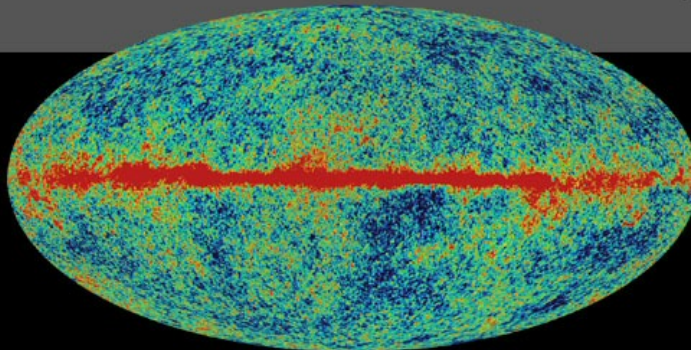
COBE



2003

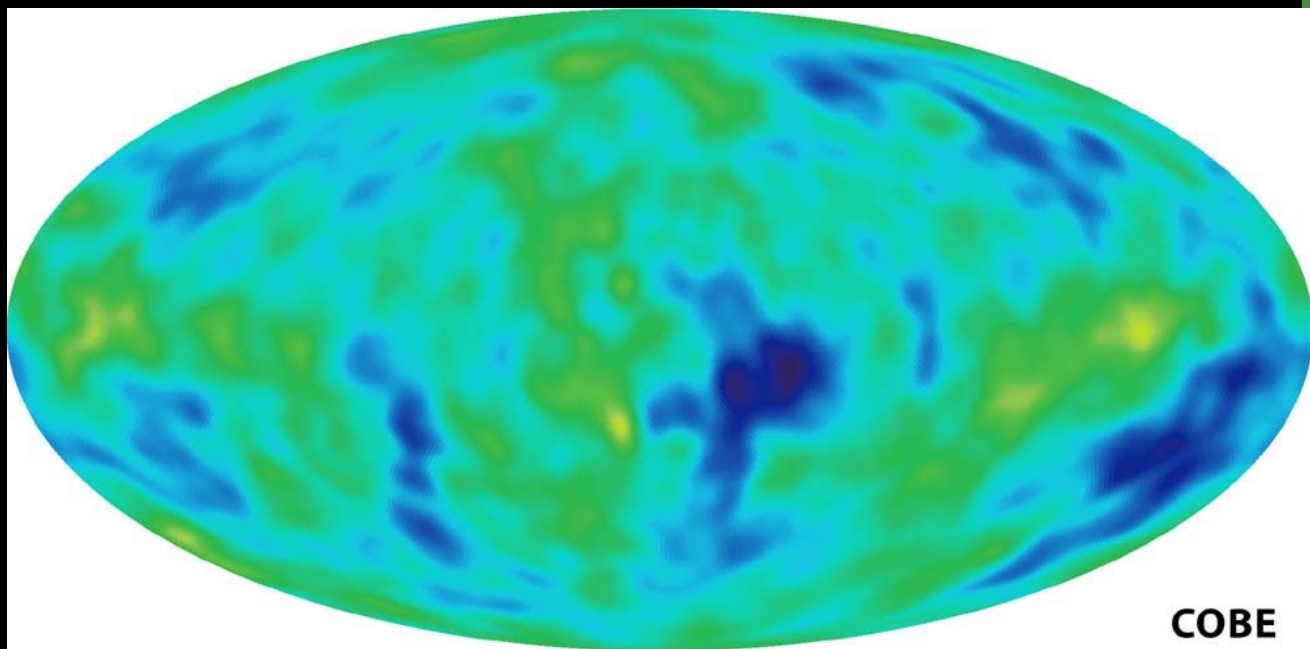


WMAP

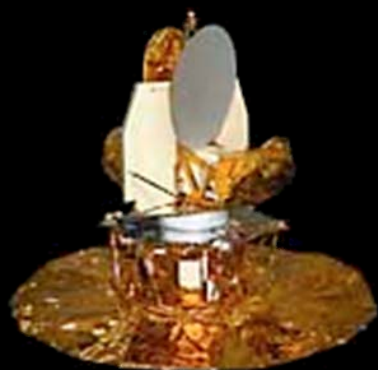




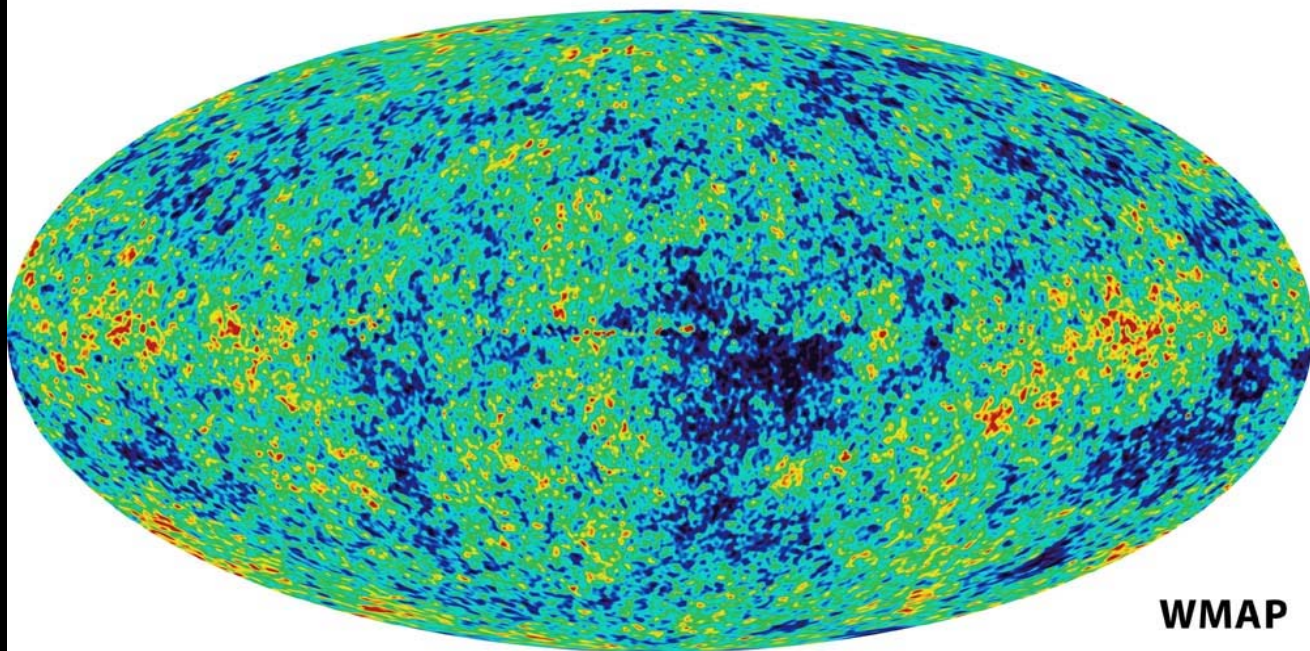
COBE 1992



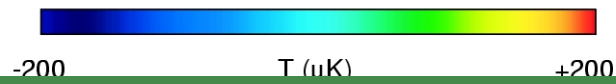
COBE



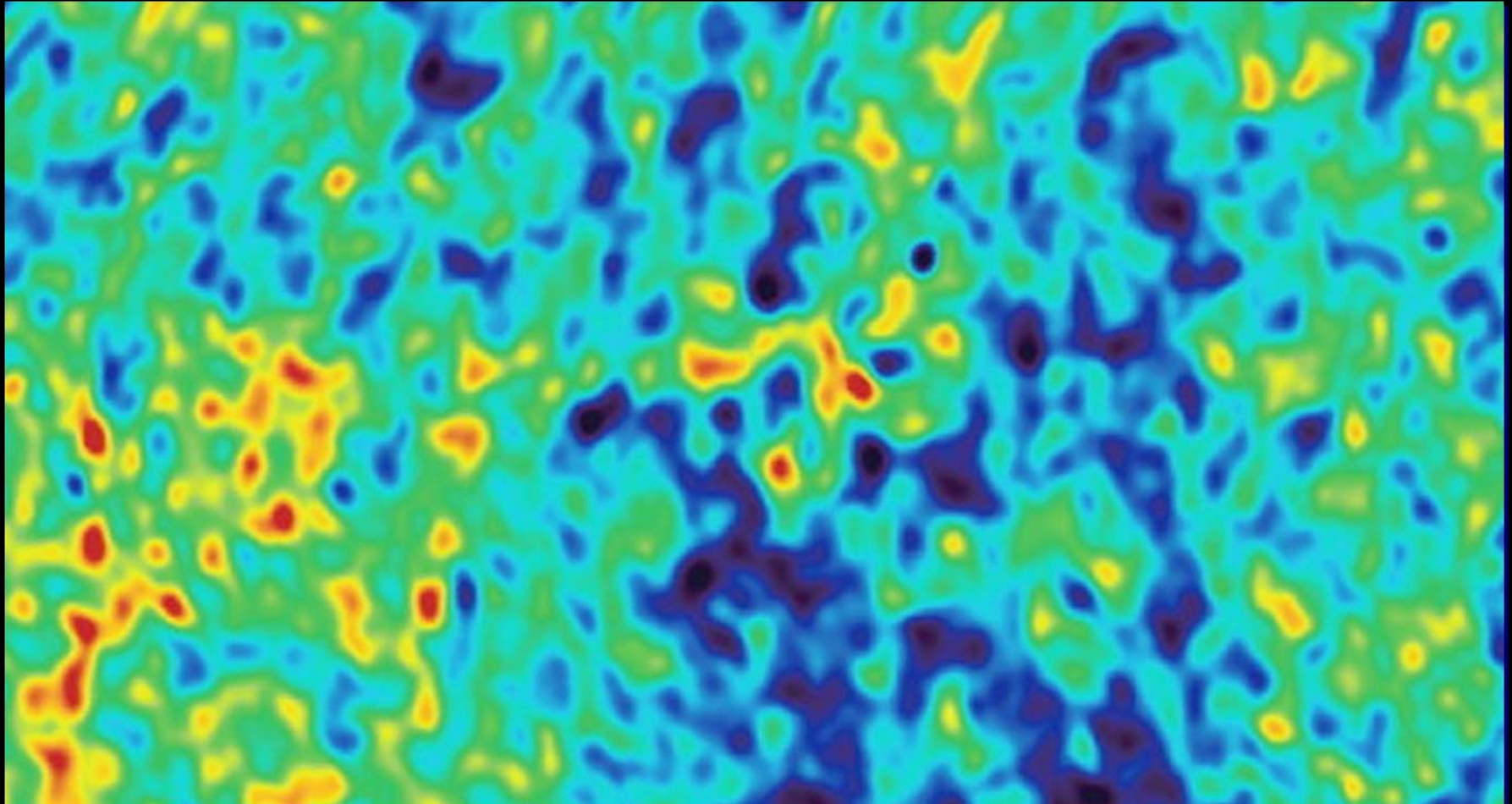
WMAP 2003



WMAP

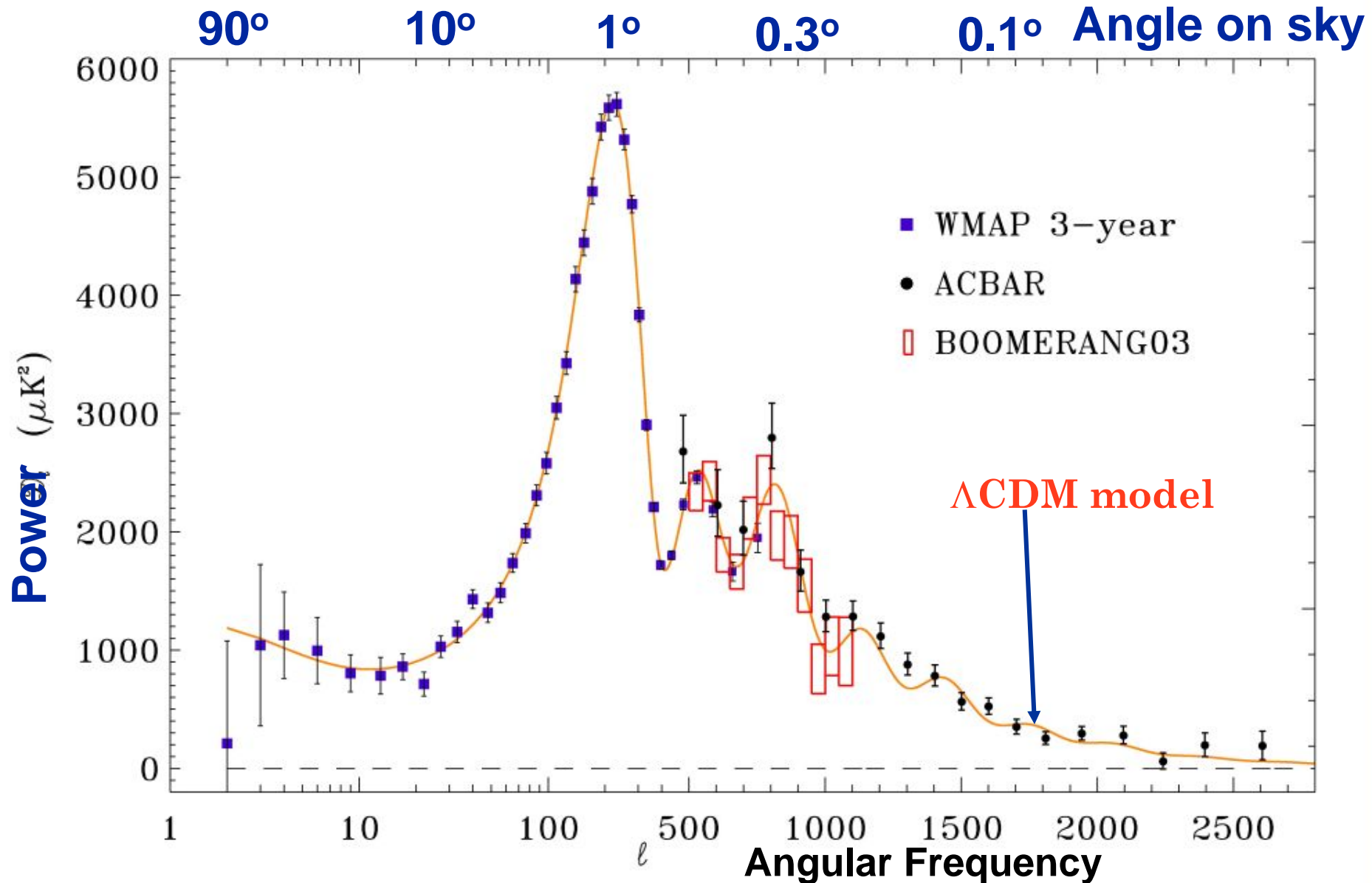


An image of quantum fluctuations
blown up to the size of the universe.



CMB Angular Power Spectrum

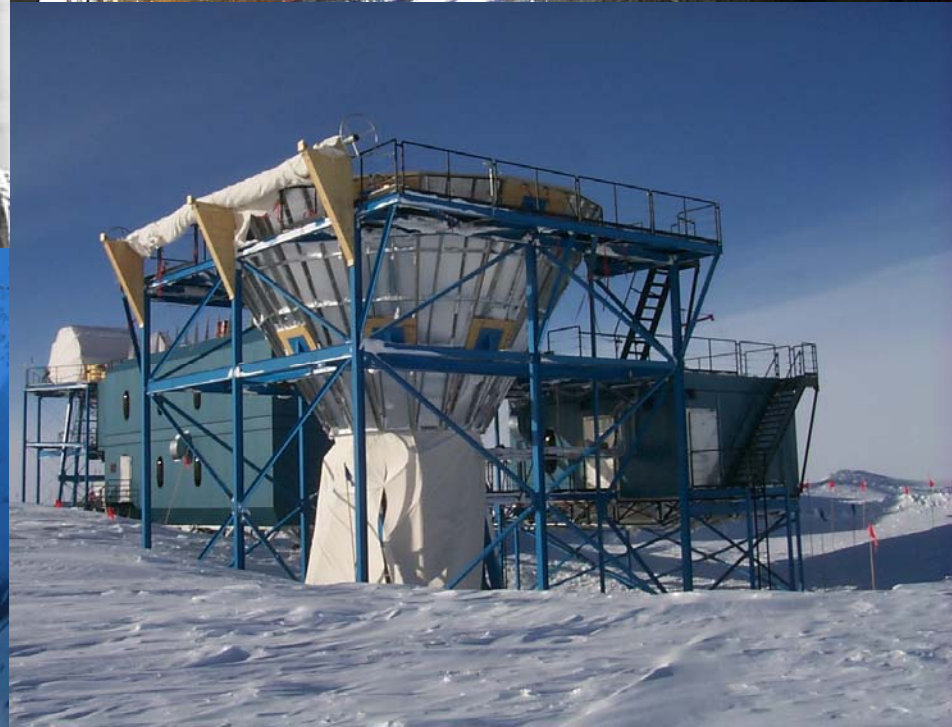
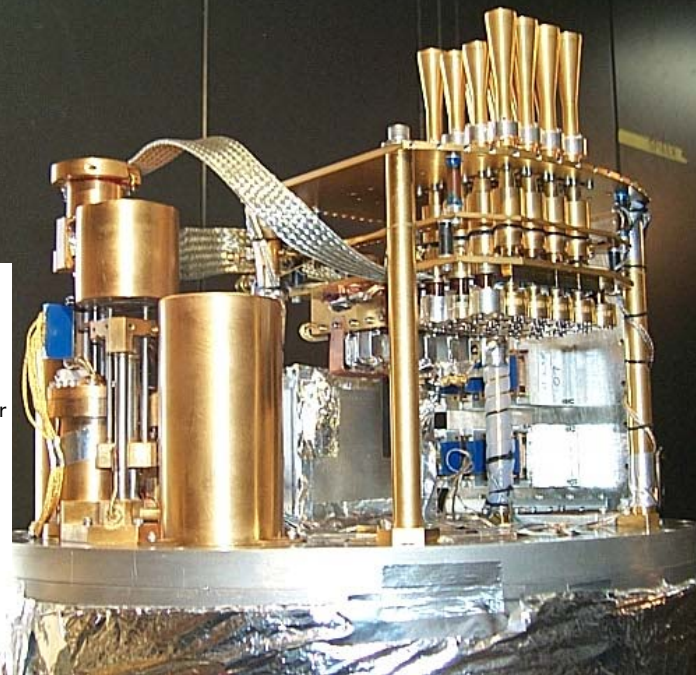
Current Best Observations as of Nov 2006

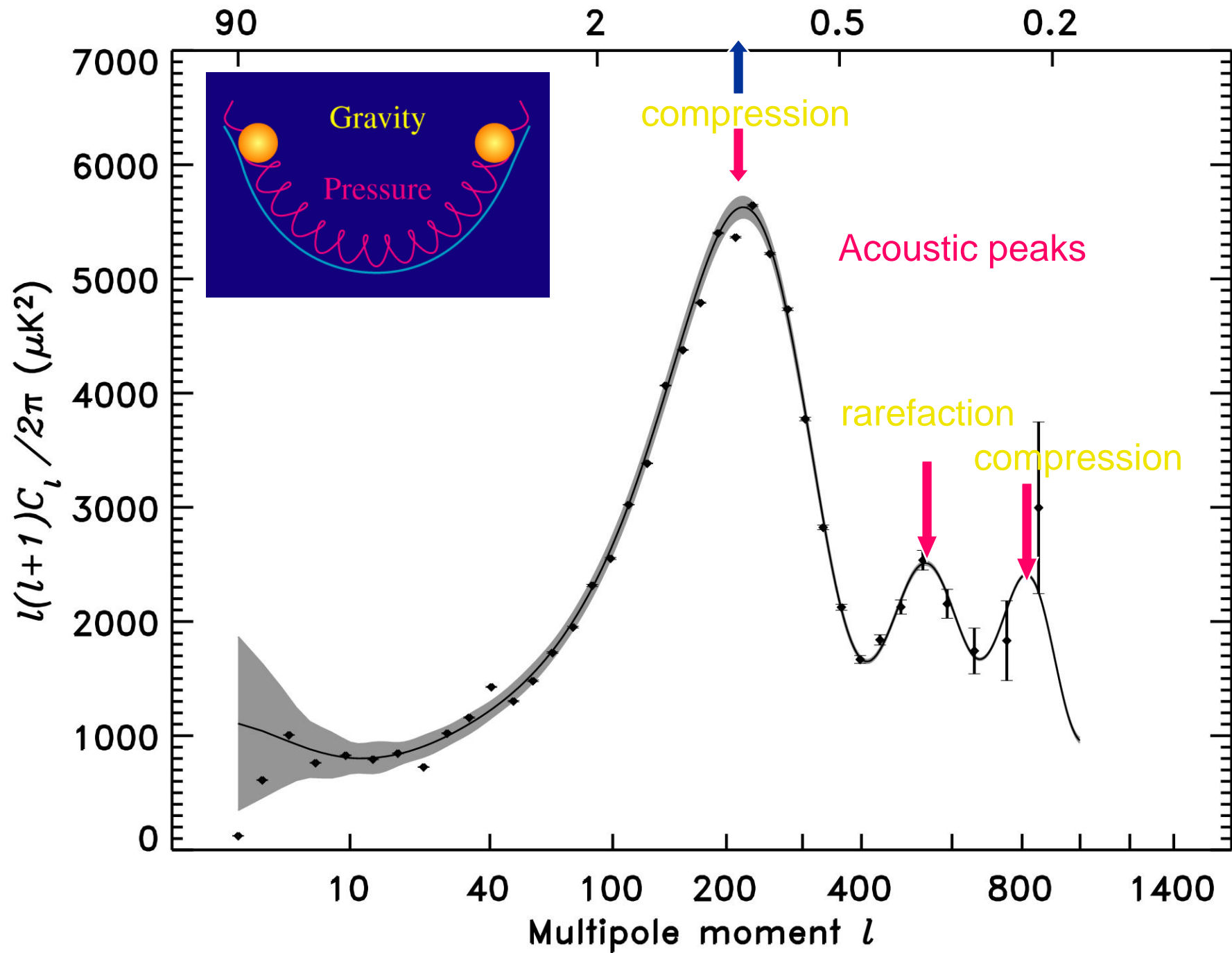


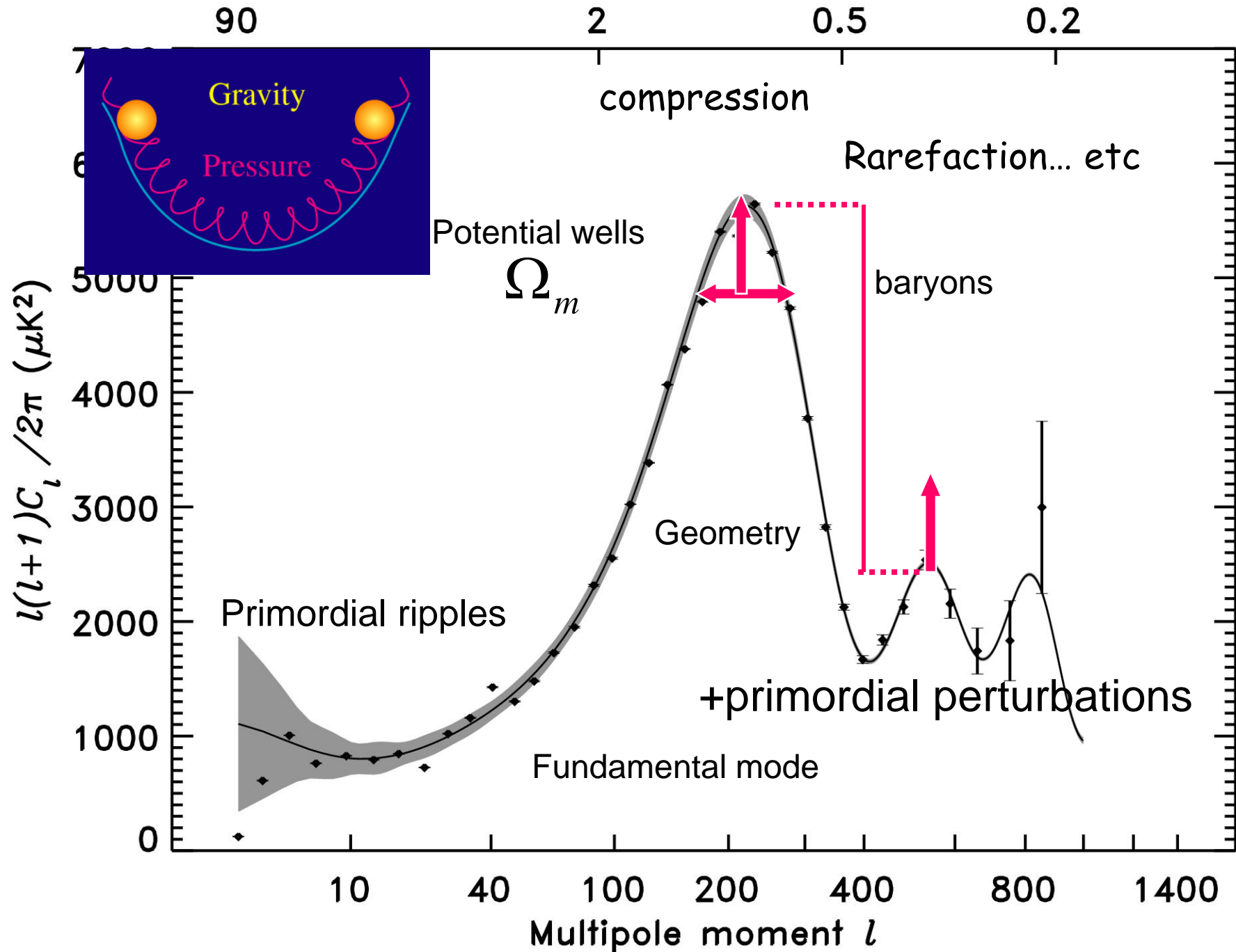
Arcminute Cosmology Bolometer Array Receiver (ACBAR)

2005 Finished observations
at South Pole
New constraints on CMB
Damping tail and
secondary Anisotropies
John Ruhl &
Bill Holzapfel

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.







State-of-the-Art of the Universe 2003 Data

13.7 billion years old, expanding
Composition: 73% dark energy,
23% dark matter,
4% ordinary matter

table 28-2 Some Key Properties of the Universe

Quantity	Significance	Value*
Hubble constant, H_0	Present-day expansion rate of the universe	71^{+4}_{-3} km/s/Mpc
Density parameter, Ω_0	Combined mass density of all forms of matter <i>and</i> energy in the universe, divided by the critical density	1.02 ± 0.02
Matter density parameter, Ω_m	Combined mass density of all forms of matter in the universe, divided by the critical density	0.27 ± 0.04
Density parameter for ordinary matter, Ω_b	Mass density of ordinary atomic matter in the universe, divided by the critical density	0.044 ± 0.004
Dark energy density parameter, Ω_Λ	Mass density of dark energy in the universe, divided by the critical density	0.73 ± 0.04
Age of the universe, T_0	Elapsed time from the Big Bang to the present day	$(1.37 \pm 0.02) \times 10^{10}$ years
Age of the universe at the time of recombination	Elapsed time from the Big Bang to when the universe became transparent, releasing the cosmic background radiation	$(3.79^{+0.08}_{-0.07}) \times 10^5$ years
Redshift z at the time of recombination	Since the cosmic background radiation was released, the universe has expanded by a factor $1 + z$	1089 ± 1

State-of-the-Art of the Universe 2006 Data

13.8 billion years old, accelerating expansion rate

Composition: 74% dark energy, 22% dark matter, 4% ordinary matter

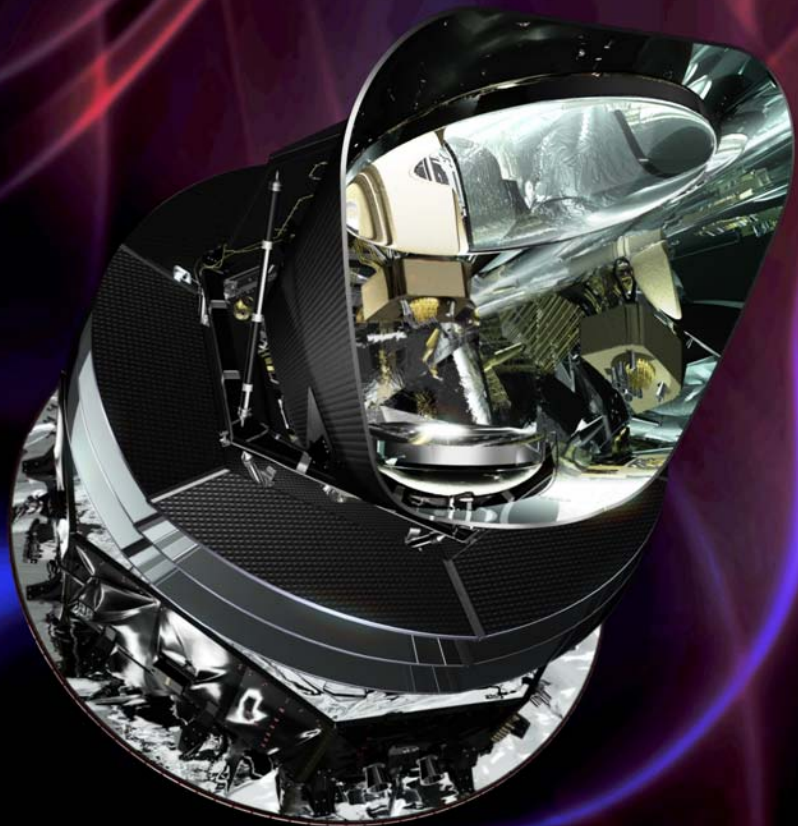
3-yr WMAP, 2df, SDSS, BOOMERanG,
ACBAR, CBI, VSA, SN astier, SN gold, WL and BAO

Quantity		Significance	Value
Hubble Expansion Rate	H_0	Current Expansion Rate of Universe	$70.8 \pm 1.5 \text{ km/s/Mpc}$
Density Parameter	Ω_0	Total energy density / critical density	1.01 ± 0.015
Mass Density Parameter	Ω_m	Total matter density / critical density	0.262 ± 0.016
Ordinary Matter Density	Ω_b	Ordinary matter density /critical density	0.044 ± 0.002
Dark Energy density	Ω_Λ	Dark Energy density / critical density	0.738 ± 0.016
Age of Universe Now	t_0	Elapsed time from Big Bang to now	$13.84 \pm 0.14 \text{ Gyr}$
Age of Universe at recomb	t_{ls}	Elapsed time Big Bang to last scattering	$0.379 \pm 0.007 \text{ Myr}$
Redshift of recombination	$1+z_{ls}$	Ratio of size of universe now / size then	1089 ± 1
Scalar spectral index	n_s	Index of amplitude power law $1=\text{invariant}$;	0.938 ± 0.015
Scalar amplitude	$\Delta\phi/c^2$	no scale dependence	10^{-5}
$\Delta\rho/\rho$ on $8 \text{ h}^{-1} \text{ Mpc}$ scale	σ_8	matter fluctuations on $\sim 10 \text{ Mpc}$ scale	0.751 ± 0.032
Reionization Optical Depth	τ	Fraction CMB scattered	0.070 ± 0.028



PLANCK

Looking back to the dawn of time



European Space Agency
Agence spatiale européenne

More information can be found on:
<http://www.esa.int/science/planck>

CMB Missions Revolutionise Our Understanding of the Universe

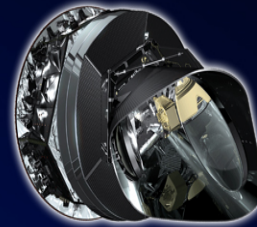
PLANCK



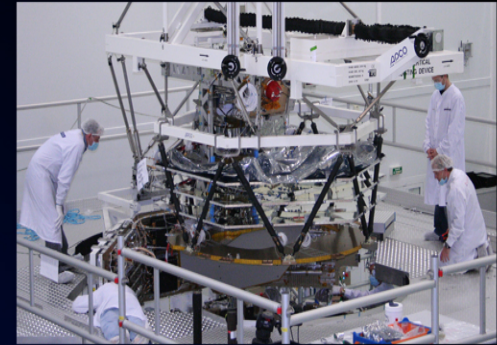
1989



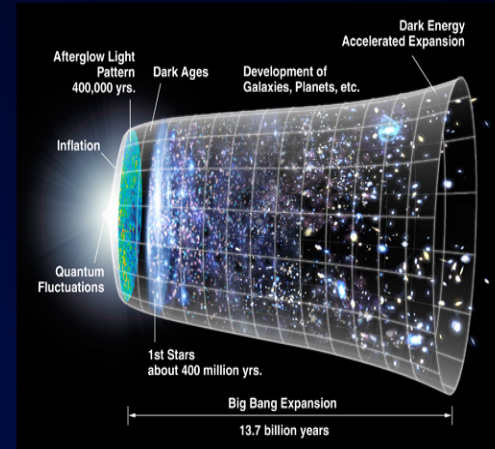
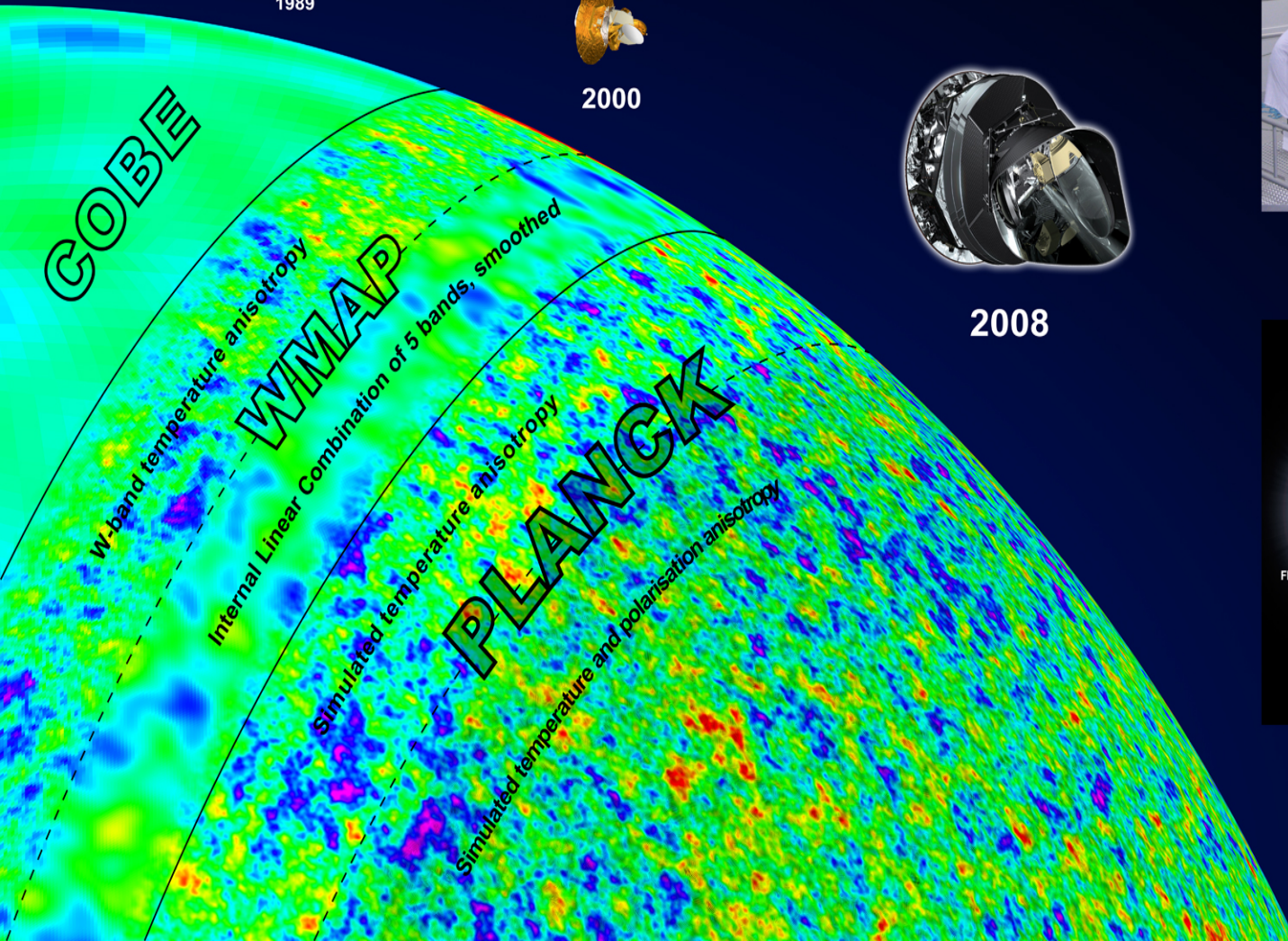
2000



2008



Planck spacecraft in clean assembly at Alcatel Alenia Space in January 2007



Golden Age of Cosmology

- Tremendous opportunities
- Intellectual Understanding of Universe
- Probe of Potential New Physics
- Strong Tests of our Knowledge
- Very Attractive and Exciting to public and for bringing next generation along.

Big questions: Seeking Answers

What is the right physics to describe the Universe?

- 1. Did inflation happen? How?**
- 2. What is the dark matter?**
- 3. What is the dark energy?**
- 4. What generated the matter-antimatter asymmetry?**
- 5. Are there other relics to be found (e.g. cosmic strings)?**
- 6. Are there extra dimensions?**
- 7. Do fundamental constants vary?**
- 8. What other exotic forces might come in play?**

The Big Bang and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe cools and becomes less dense. All distant galaxies are moving apart from each other and away from us. On large scales, the universe looks the same in all directions and all parts of space. There is no preferred center. Our current understanding of the early universe is called the Big Bang model. Much more will be learned from astronomical observations and from accelerator-based experiments in the coming years.

Cosmology and Relics of History

Cosmology is the study of the universe as a whole. As in archaeology, cosmology finds clues to the past in relics. Looking out a distance d in space is looking back in time, because $t = d/c$ (light travels at a finite speed c). The laws of nature discovered on Earth can be applied to the early universe and tested by observing relics.

A Relic from the Early Universe

The Cosmic Microwave Background (CMB) is a universal bath of lightwaves (photons) from the hot, dense, early universe. They are stretched by the expansion of space. To a part in 100,000, the CMB is the same no matter where you look (it is isotropic). The remaining tiny variations (shown in figure) are images of the seeds that later form galaxies and larger cosmic structures.

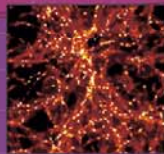


This is an image of the universe from the time when atoms first formed. It is a map of the entire sky showing CMB light with the uniform part subtracted.

Age of the Universe A marvelous agreement that the age of the universe is about 14 billion years comes from studying its expansion and the lifecycles of stars and also by dating meteorites.

History of the Universe

Three major eras in the expansion history followed the hot, dense condition of the earliest universe. During each era, the expansion depended on the nature of the matter or energy that dominated the universe at that time.



Simulated density fluctuations (ripples) in the early universe that eventually yield galaxies and clusters of galaxies.

Era 1 - Acceleration: Inflation speeds expansion

Observations seem to imply that the very early universe underwent an extremely rapid, accelerating expansion, called **Inflation**. In a tiny fraction of a second, inflation expanded each part of space by a factor of at least 10^{27} . Before inflation, the portion of the universe visible to us today was a smooth patch much smaller than a proton. As inflation ended, the visible universe had grown to the size of a ball (very approximately). Inflation explains how quantum fluctuations in the otherwise smooth and isotropic universe yielded tiny ripples that would eventually grow into galaxies and structures. In the 14 billion years after inflation, the universe expanded by another factor of about 10^{47} .

Eras 2-3 - Deceleration: Expansion slows and structure forms

After inflation, the universe was a plasma or soup of fundamental particles. Photons and fast moving particles, generically called **radiation**, gradually lost energy (cooled) as the universe expanded (the energy went into the expansion). Eventually, slow-moving matter became dominant over radiation. Over time, larger and larger structures grew from galaxies to clusters of galaxies to superclusters. These began as small differences in the density of matter, but gravitational attraction made more and more matter clump together. Several interesting stages are indicated in the central figure. Stars created the heaviest elements that eventually became part of Earth and of us. The early universe had both matter and antimatter in abundance, but today it is almost exclusively matter. How this came about is not fully understood.

Era 4 - Acceleration: Dark energy speeds expansion

A matter-dominated universe causes deceleration and might even reverse the expansion. So it was a great surprise in 1998 when observations showed that the expansion of the universe is now accelerating (see the "Expansion History" plot). This implies the existence of a new form of energy, referred to as **dark energy**. Scientists are pursuing the nature of dark energy.

Our Cosmic Address

Our sun is one of 400 billion stars in the Milky Way galaxy, which is one of more than 100 billion galaxies in the visible universe.



THE HISTORY AND FATE OF THE UNIVERSE

Eight major stages in the evolution of the universe are illustrated below.

The Big Bang occurred everywhere in the universe. Here one region has been illuminated and followed through time. The expansion is far greater than can be shown here.



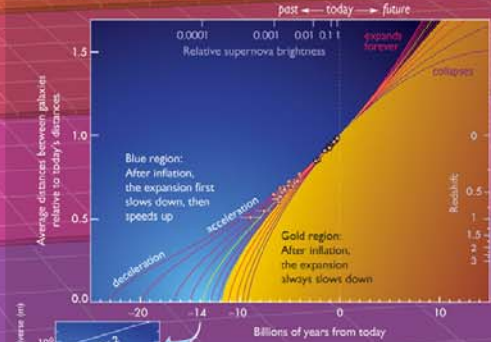
Redshifts and Expansion

Lightwaves stretch with the expansion of space. As the wavelength of visible light increases, it becomes redder (as shown for the photons in the central figure). Measuring this redshift tells us the velocity of the source. In 1929, Hubble observed that all distant objects are receding with a velocity proportional to their distance. This information and modern telescope observations show that the universe is expanding uniformly in all directions. Objects that are bound together (such as galaxies and atoms) do not expand as space expands.



The spiral bands represent a portion of the universe, and the red dots represent galaxies. Due to the ruling of the laws of physics, the expansion of space stretches lightwaves and galaxies move apart, but atoms do not expand.

Expansion History of the Universe



The large plot shows data from Type Ia supernovae explosions that occurred in the past 9 billion years. Measurements of these supernovae show an accelerating expansion began billions of years ago. The yellow curve is the best fit to the data. The smaller plot emphasizes the extremely early universe.

Fate of the Universe

Whether the expansion of the universe will speed up, slow down, or even possibly reverse into collapse depends through gravity on the amount and types of matter and energy in it.

The ordinary matter — atoms and nuclei — that formed in the early universe can recombine for the visible mass in galaxies and clusters. But it falls far short of the total mass needed to bind them together gravitationally and explain their internal motions. So an extraordinary new type of matter not made of atoms or nuclei must exist; it is called **dark matter** because it is not directly visible.

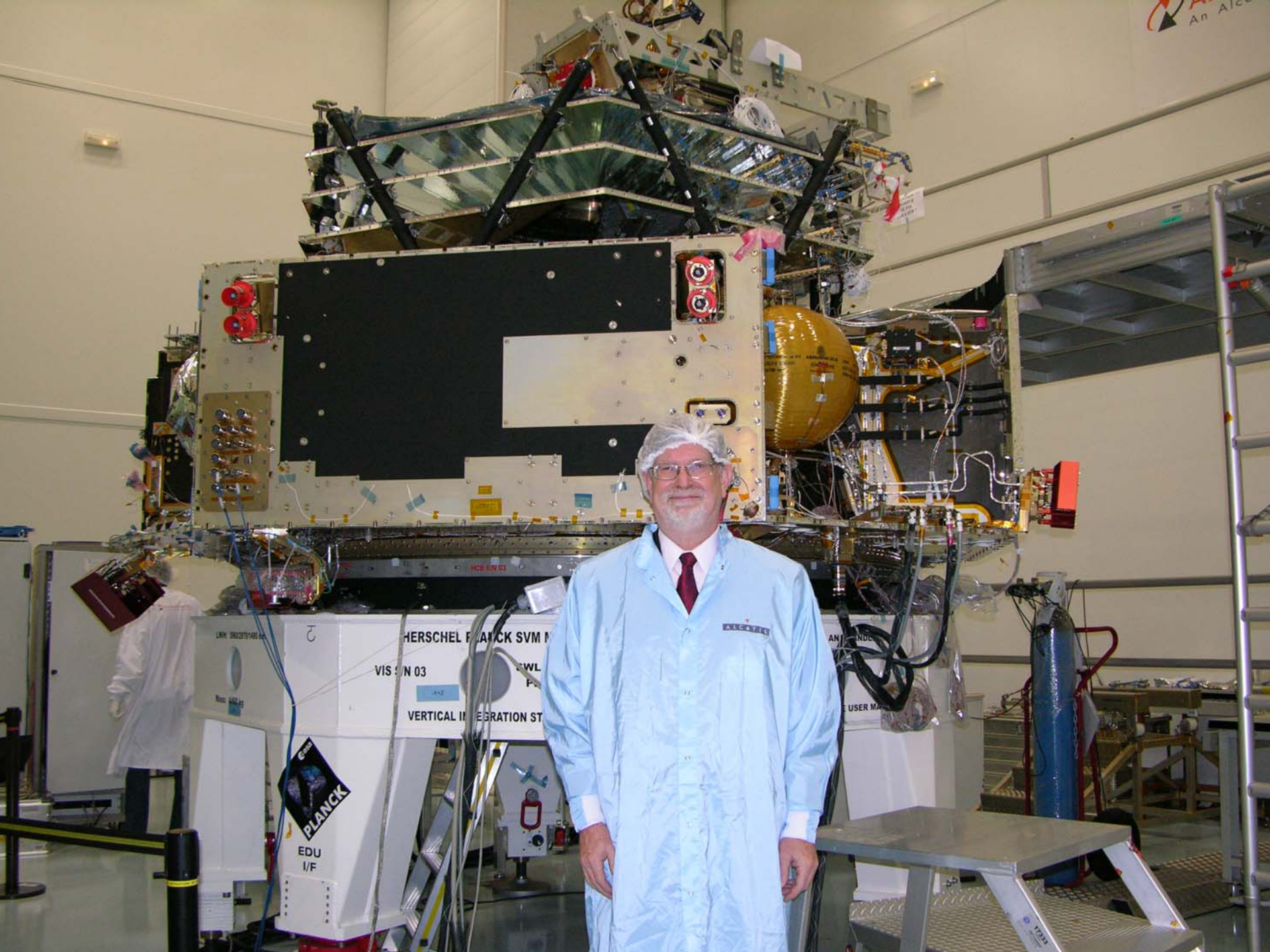
Even stranger recent observations of supernovae in distant galaxies show that the expansion of the universe is in fact **accelerating**. An exotic **dark energy** may be causing this acceleration through a cosmic repulsion that overwhelms the pull of gravity due to matter.

The nature of dark energy and dark matter are two of the great questions facing cosmology and particle physics. Perhaps dark energy is the cosmological constant introduced by Einstein in 1917. Perhaps both are new parts of particle physics, tied to the very earliest moments of the universe and having to do with the nature of physics and spacetime itself.

Not all answers in science are known yet! With the research and experiments under way in astrophysics and particle physics, we may be the first generation to learn what most of the universe is made of and what is the fate of the universe.



Learn more at
UniverseAdventure.org
and at **CPEPweb.org**



HERSCHEL PLANCK SVM

VIS N 03

VERTICAL INTEGRATION ST

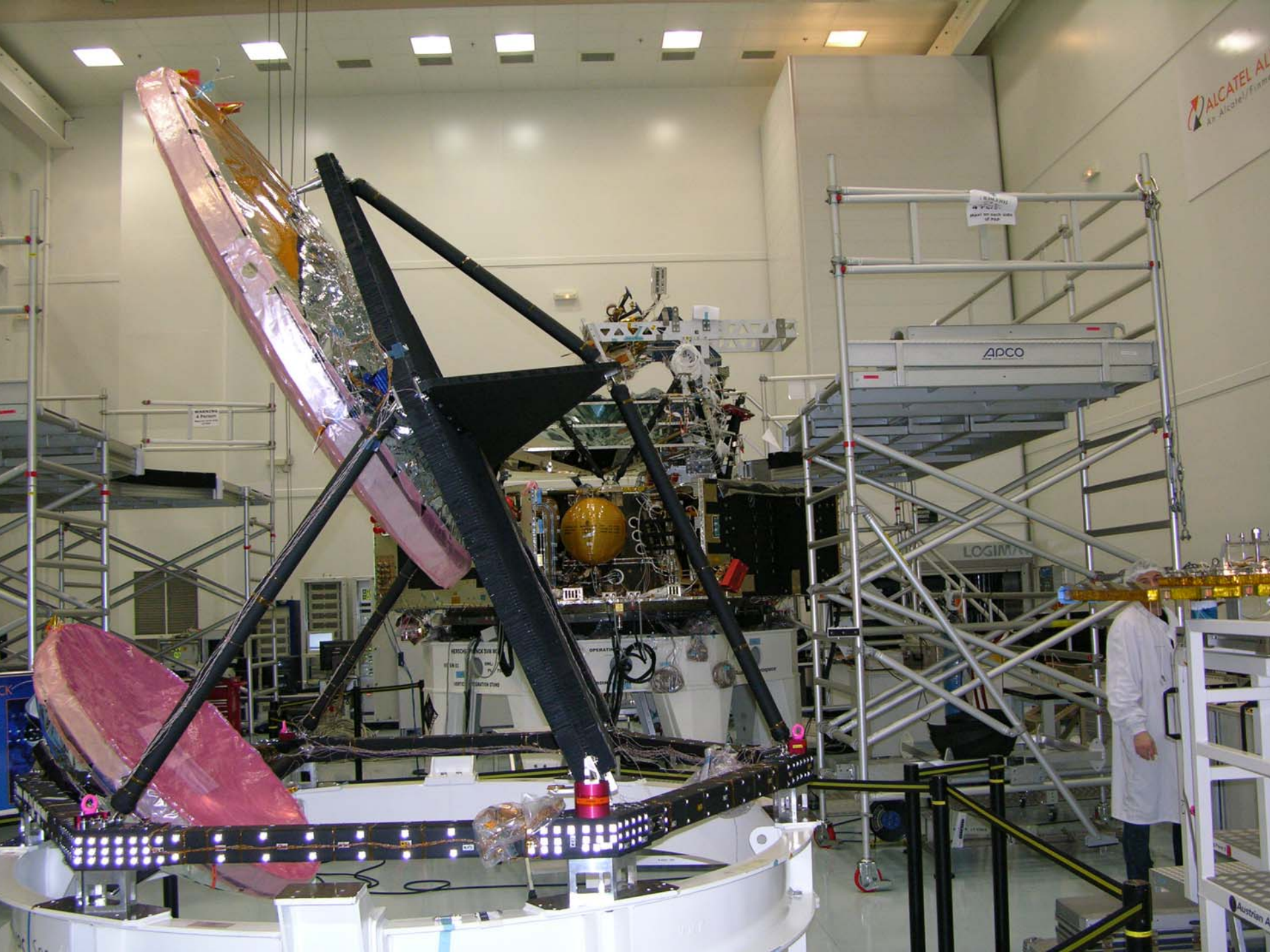


EDU
I/F

ALCANTARA

AN ALCANTARA

USER MA



ALCATEL AL
An Alcatel Firm

LOGIMAT

APCO

WARNING
& Precaution

RESEARCH SPACE TUNING
UNIT 10 11
OPERATION STAGE

OPERATION

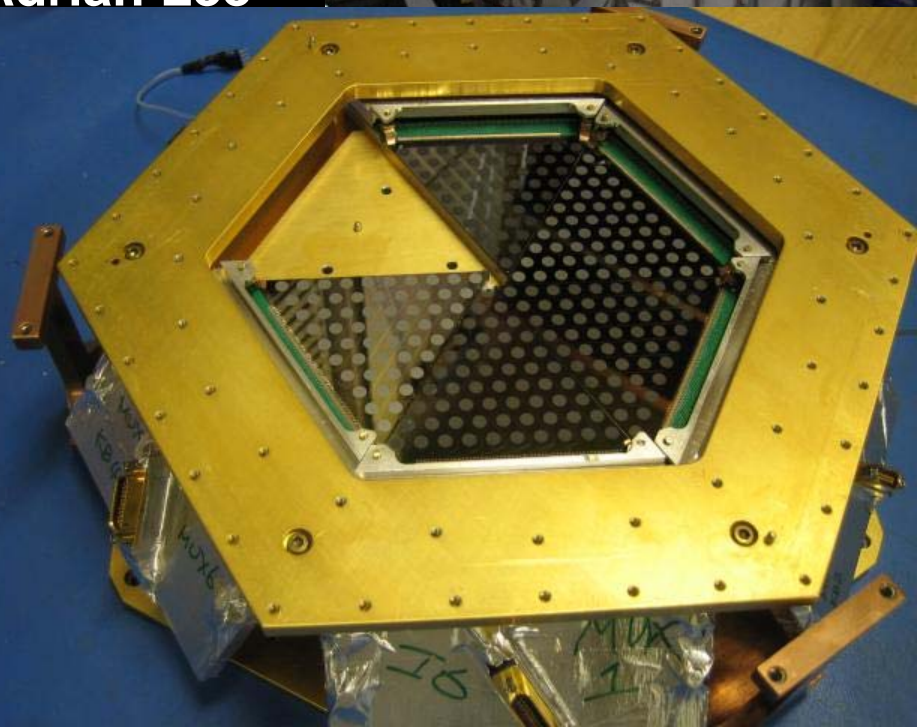
Austrian A

APEX-SZ

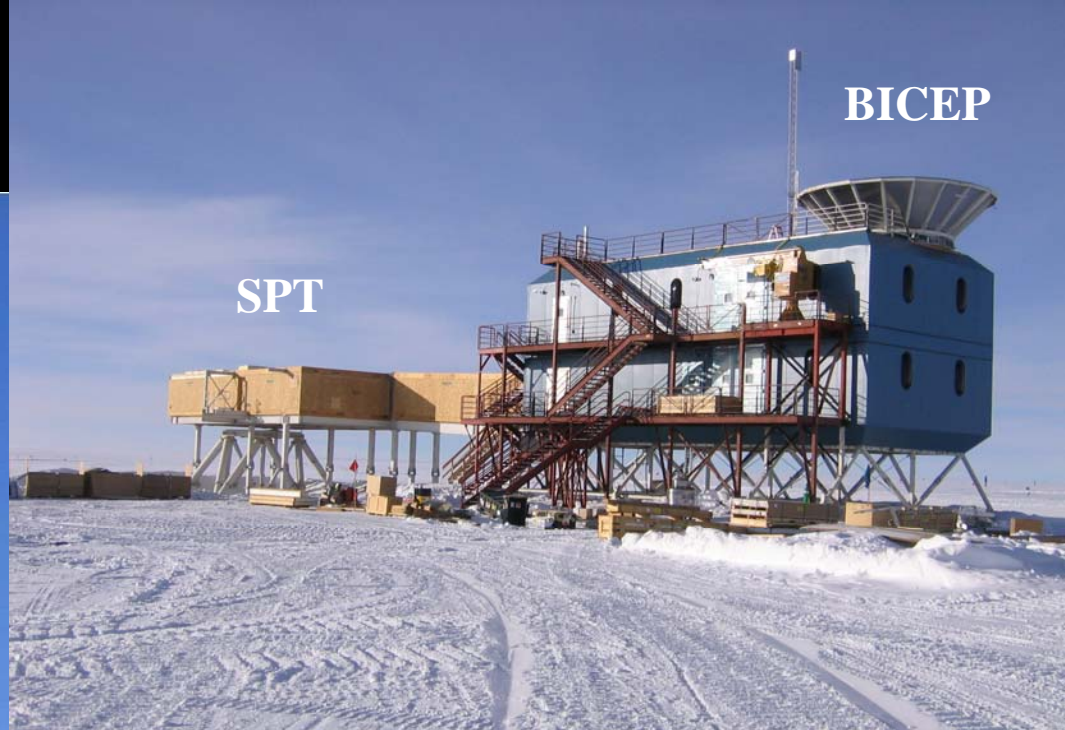
Receiver being
Installed for
engineering
run

First Science
In Spring 07

Adrian Lee



**SPT began observations
from the Pole this February**



SPT

BICEP

