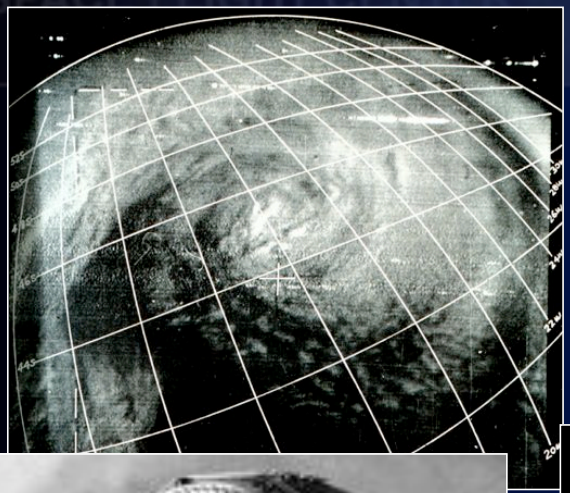
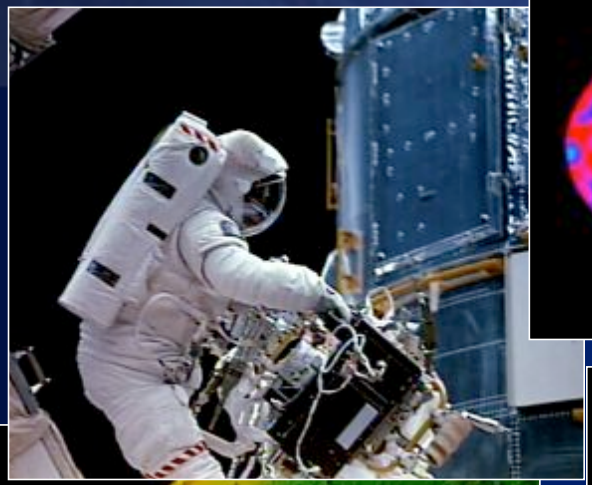
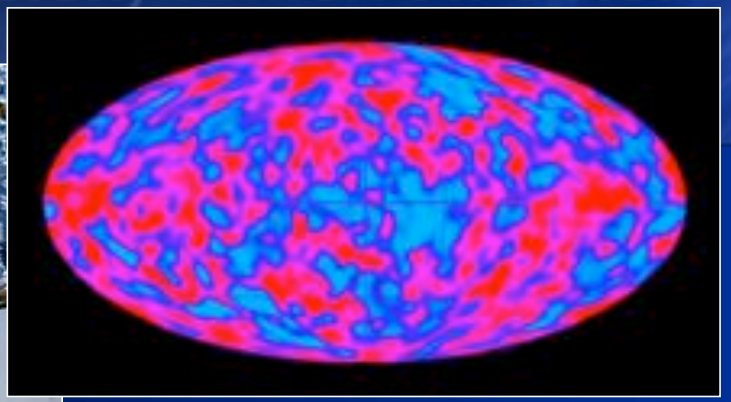
Goddard's Legacy

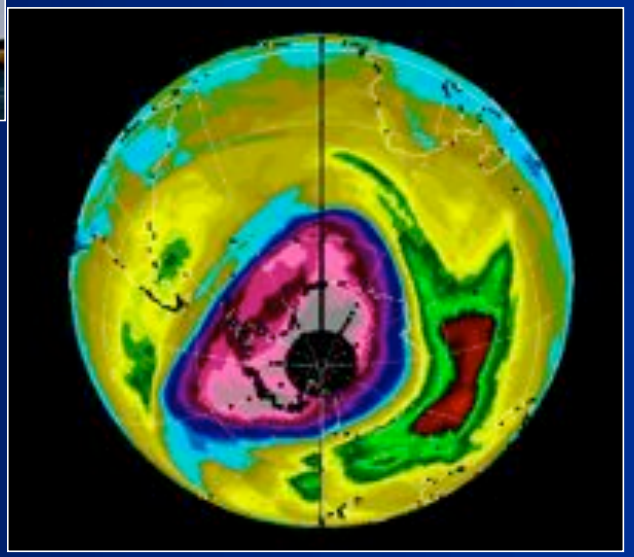
Andrew Chaikin

April 6, 2016









Goals of this lecture:

"Goddard's Legacy" is designed to provide

-- **Context for the case studies and analyses** in the Road to Mission Success course

-- **Inspiration about the achievements** of the Goddard teams over the course of the space age

-- **Insight into the ingenuity and persisitence** these teams have brought to the challenges of space exploration

-- **Better understanding of Goddard's past achievements** as a guide to what it can accomplish in the future

Slides will be available at:

www.andrewchaikin.com/NASA

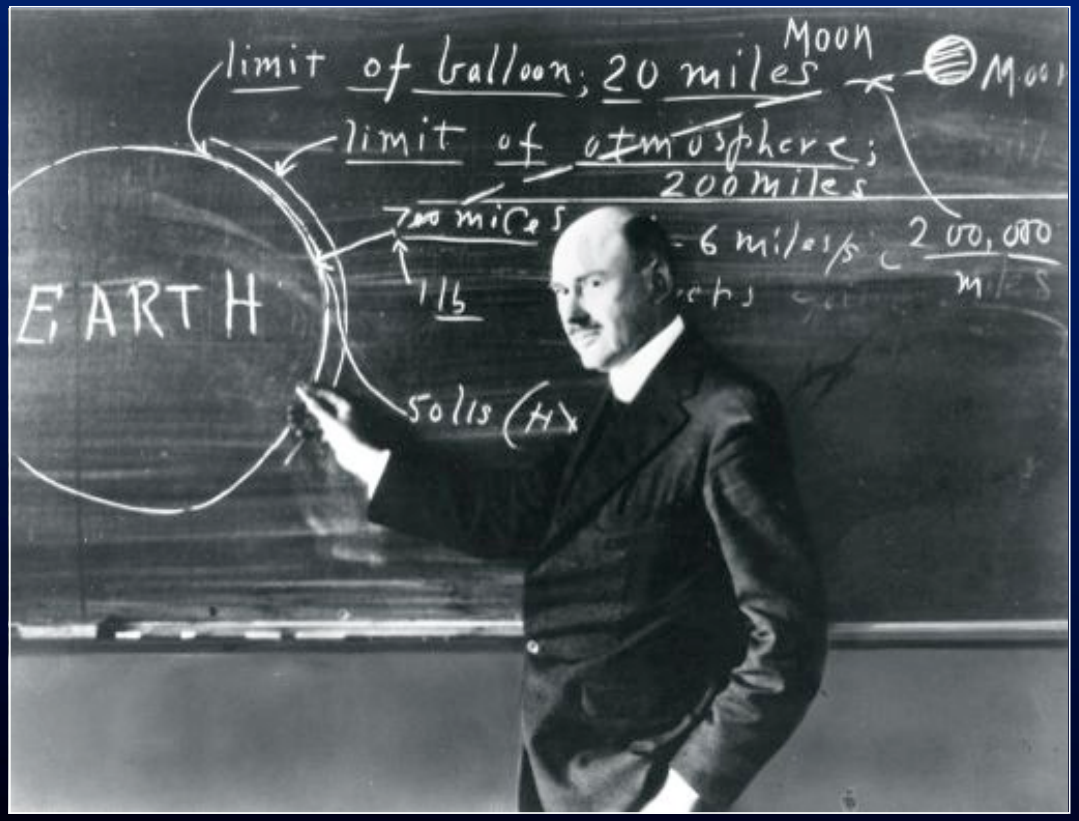
Acknowledgements

Many thanks to all who provided information for this lecture, including the Goddard veterans who gave interviews: Al and Nancy Boggess, Joe Burt, Frank Cepollina, Jim Garvin, Noel Hinners, Henry Hoffman, Jim Irons, Paul Lowman, Jaylee Mead, Dick Nafzger, Jay Smith, and Mike Weiss.

Robert Goddard (1882-1945), space visionary

Above: Goddard with 1926 rocket in Auburn, MA

"Every vision is a joke until the first man accomplishes it; once realized, it becomes commonplace."



The First Space Center

"You know when old folks look back and say, 'Those were the good old days?' Well, they really were. And you can back it up with what we did."

-- Dick Nafzger, Apollo television engineer

Vanguard: The Roots of Goddard

Engineers and scientists from Naval Research Lab who worked on the Vanguard satellite project became the nucleus of NASA Goddard

Assembly of Vanguard 4, 1959

Left: Roland Van Allen, later GSFC's data systems branch chief, solders components for a Vanguard satellite in 1957

From Beltsville to Goddard

Goddard opening, March 1961

January 1959: Four divisions of NASA designated as the Beltsville Space Center:
-- Construction Division
-- Space Sciences Division
-- Theoretical Division
-- Vanguard Division

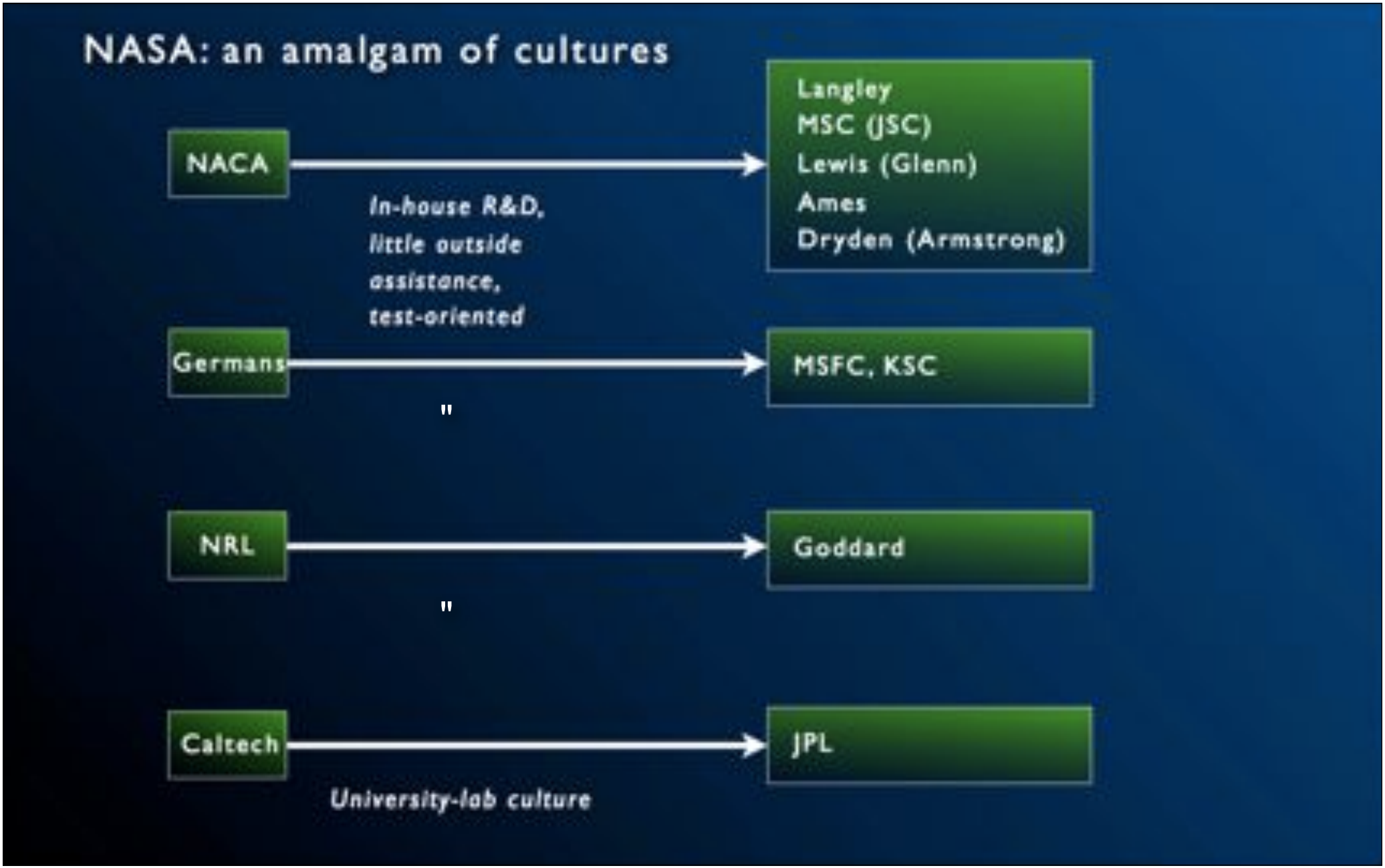
May 1959: NASA announces Beltsville Space Center will be redesignated the Goddard Space Flight Center

March 16, 1961: Goddard dedication

A Certain Independence

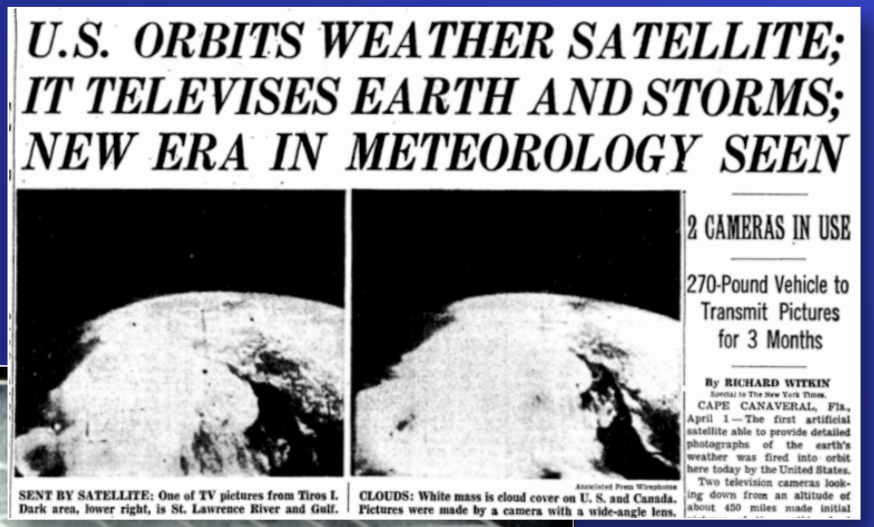
"What you had [at Goddard] was a bunch of people who weren't quite sure you had to have a Headquarters. They were pretty sure they didn't need to talk to it."

-- Sam Keller, former NASA Associate Deputy Administrator


NASA: an amalgam of cultures
NACA
Langley
MSC (JSC)
Lewis (Glenn)
Ames
Dryden (Armstrong)
In-house R&D, little outside assistance, test-oriented
Germans
MSFC, KSC
"
NRL
Goddard
"
Caltech
JPL
University-lab culture

April 1, 1960: Television and Infrared Observation Satellite (Tiros 1)

-- orbital altitude 450 miles
-- 42 inches diameter
-- 270 pounds
-- 2 slow-scan TV cameras (wide + narrow-angle)



U.S. ORBITS WEATHER SATELLITE; IT TELEVISES EARTH AND STORMS; NEW ERA IN METEOROLOGY SEEN

SENT BY SATELLITE: One of TV pictures from Tiros I. Dark area, lower right, is St. Lawrence River and Gulf.

CLOUDS: White mass is cloud cover on U. S. and Canada. Pictures were made by a camera with a wide-angle lens.

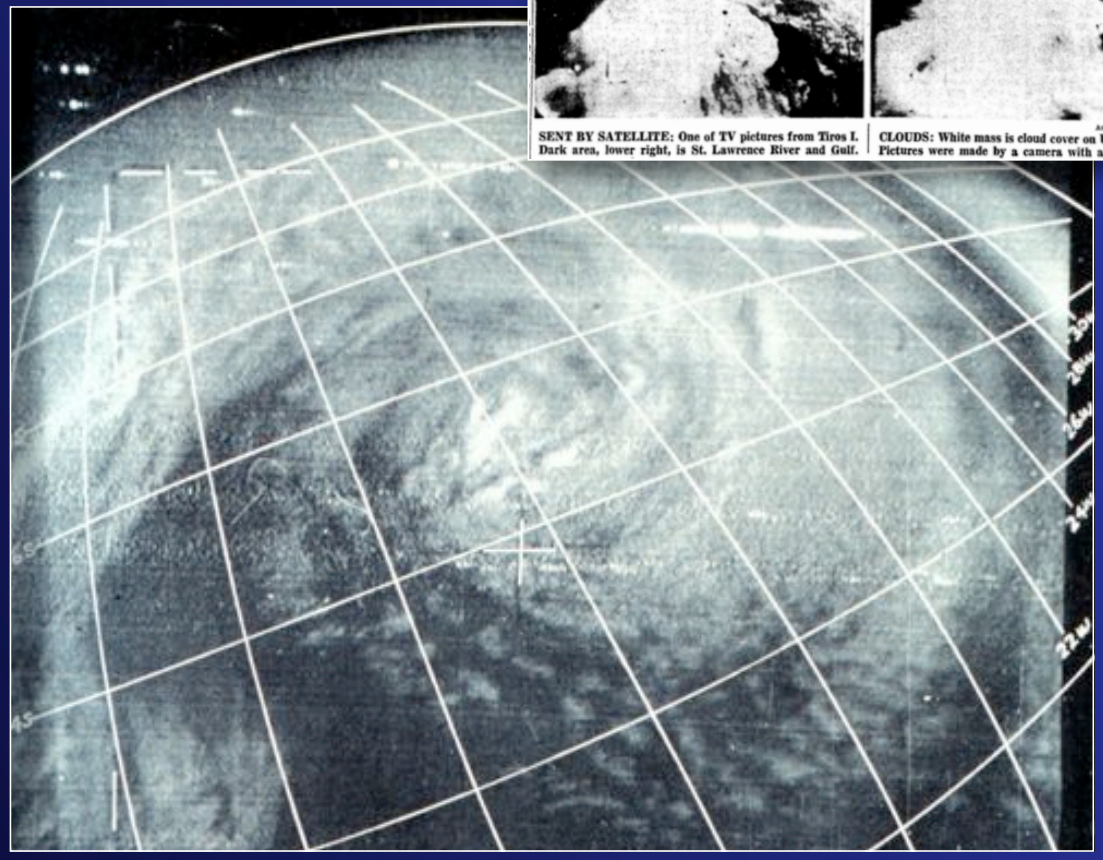
Associated Press Wirephoto

2 CAMERAS IN USE

270-Pound Vehicle to Transmit Pictures for 3 Months

By RICHARD WITKIN
Special to The New York Times.

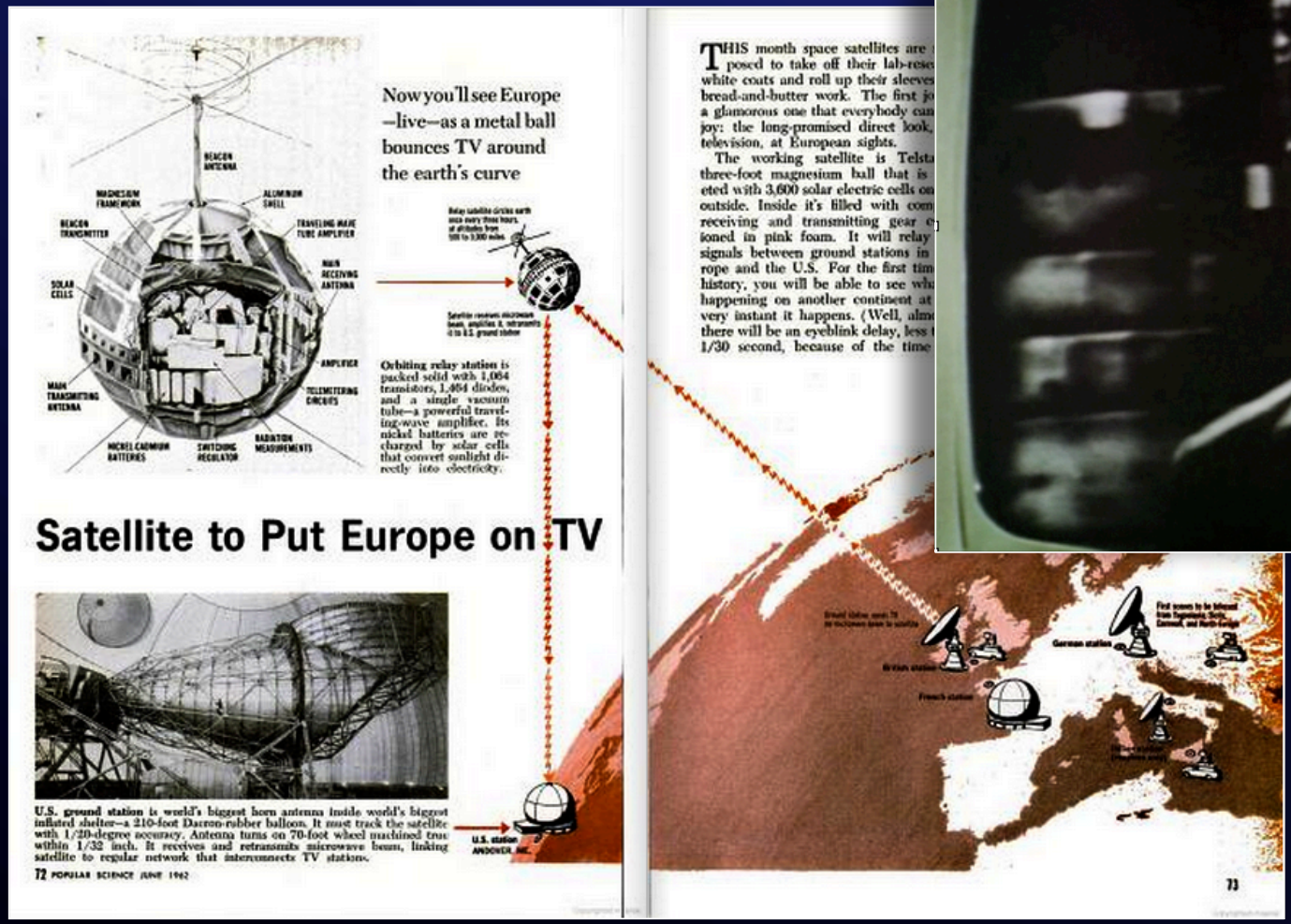
CAPE CANAVERAL, Fla., April 1—The first artificial satellite able to provide detailed photographs of the earth's weather was fired into orbit here today by the United States. Two television cameras looking down from an altitude of about 450 miles made initial



Cyclone in the South Atlantic, April 28, 1960.

July 1962: Telstar sends first international TV via satellite

Telstar was managed by GSFC; funded by AT&T



Now you'll see Europe —live—as a metal ball bounces TV around the earth's curve

Satellite to Put Europe on TV

Orbiting relay station is packed solid with 1,064 transistors, 1,464 diodes, and a single vacuum tube—a powerful traveling-wave amplifier. Its nickel batteries are recharged by solar cells that convert sunlight directly into electricity.

U.S. ground station is world's biggest horn antenna inside world's biggest inflated shelter—a 210-foot Dacron-rubber balloon. It must track the satellite with 1/20-degree accuracy. Antenna turns on 70-foot wheel machined true within 1/32 inch. It receives and retransmits microwave beam, linking satellite to regular network that interconnects TV stations.

72 POPULAR SCIENCE JUNE 1962

THIS month space satellites are
posed to take off their lab-rese
white coats and roll up their sleeves
bread-and-butter work. The first j
a glamorous one that everybody can
joy: the long-promised direct look,
television, at European sights.

The working satellite is Telst
three-foot magnesium ball that is
eted with 3,600 solar electric cells on
outside. Inside it's filled with com
receiving and transmitting gear
ioned in pink foam. It will relay
signals between ground stations in
rope and the U.S. For the first tim
history, you will be able to see wh
happening on another continent at
very instant it happens. (Well, alm
there will be an eyeblink delay, less
1/30 second, because of the time

73

Above: French singer Yves Montand performs via Telstar

1963: Syncom 2 is first geosynchronous communications satellite

EXTRA-TERRESTRIAL RELAYS

Can Rocket Stations Give World-wide Radio Coverage?

By ARTHUR C. CLARKE

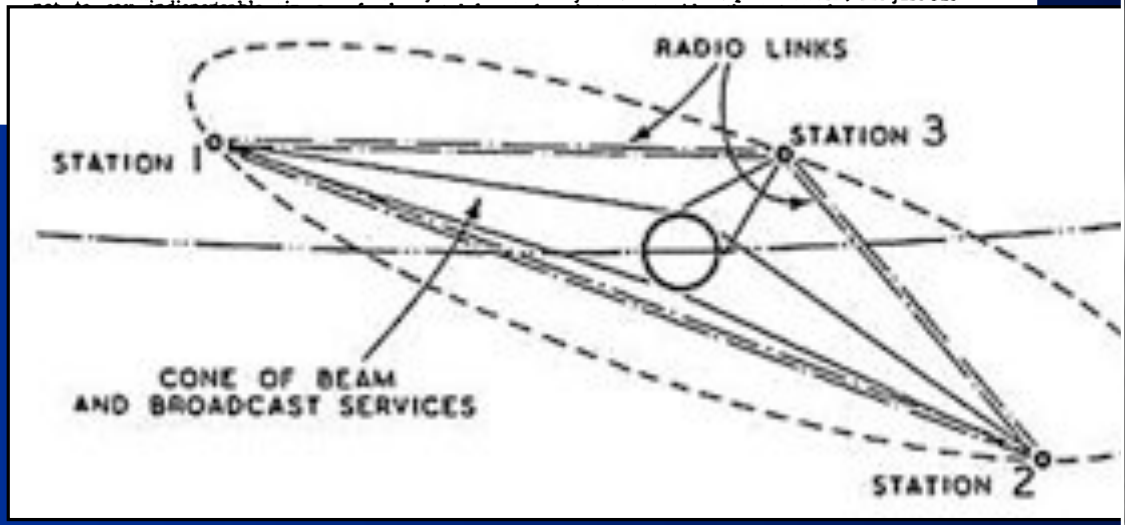
ALTHOUGH it is possible, by a suitable choice of frequencies and routes, to provide telephony circuits between any two points or regions of the earth for a large part of the time, long-distance communication is greatly hampered by the peculiarities of the ionosphere, and there are even occasions when it may be impossible. A true broadcast service, giving constant field strength at all times over the whole globe would be invaluable,

logical extension of developments in the last ten years—in particular the perfection of the long-range rocket of which V2 was the prototype. While this article was being written, it was announced that the Germans were considering a similar project, which they believed possible within fifty to a hundred years.

Before proceeding further, it is necessary to discuss briefly certain

the atmosphere and left to broadcast scientific information back to the earth. A little later, manned rockets will be able to make similar flights with sufficient excess power to break the orbit and return to earth.

There are an infinite number of possible stable orbits, circular and elliptical, in which a rocket would remain if the initial conditions were correct. The velocity of 8 km/sec. applies only to the closest possible orbit, one just out-

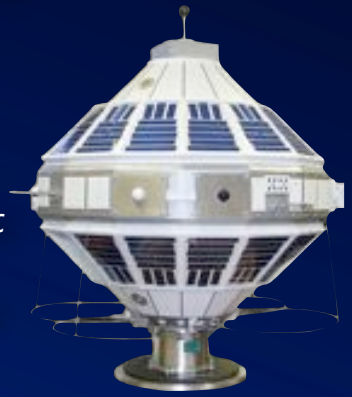


Above: Arthur C. Clarke's 1945 article proposing geosynchronous communications satellites

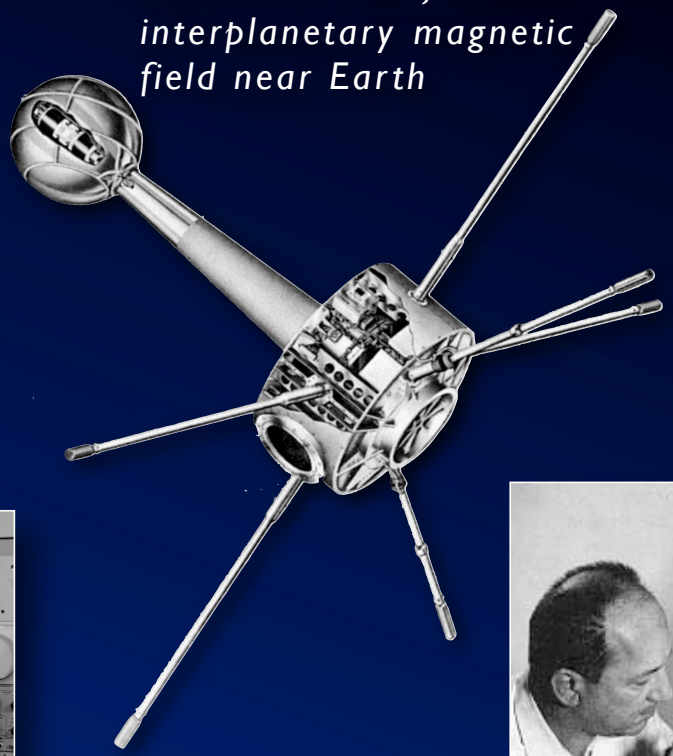
Explorer satellites

(Not to scale)

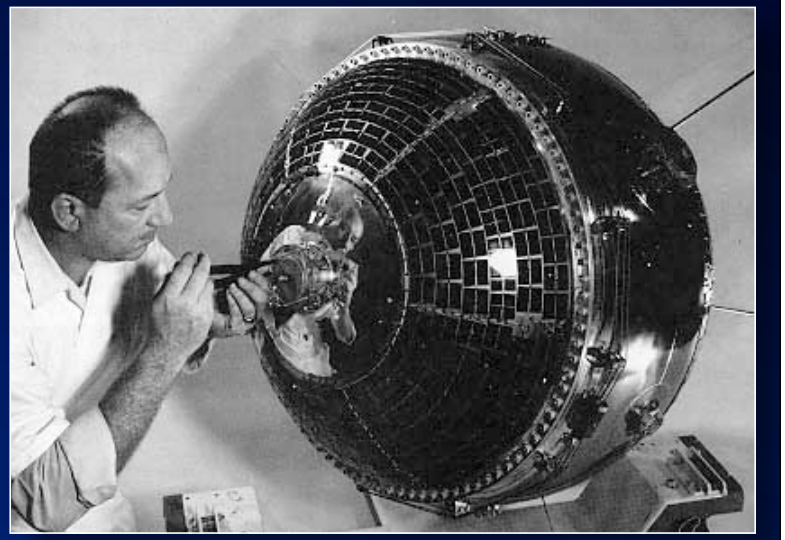
Explorer VII
Launched 1959; studied energetic particles and micrometeoroids



Explorer X
Launched 1961; studied interplanetary magnetic field near Earth



Explorer XI
Launched 1962; first gamma-ray astronomy satellite

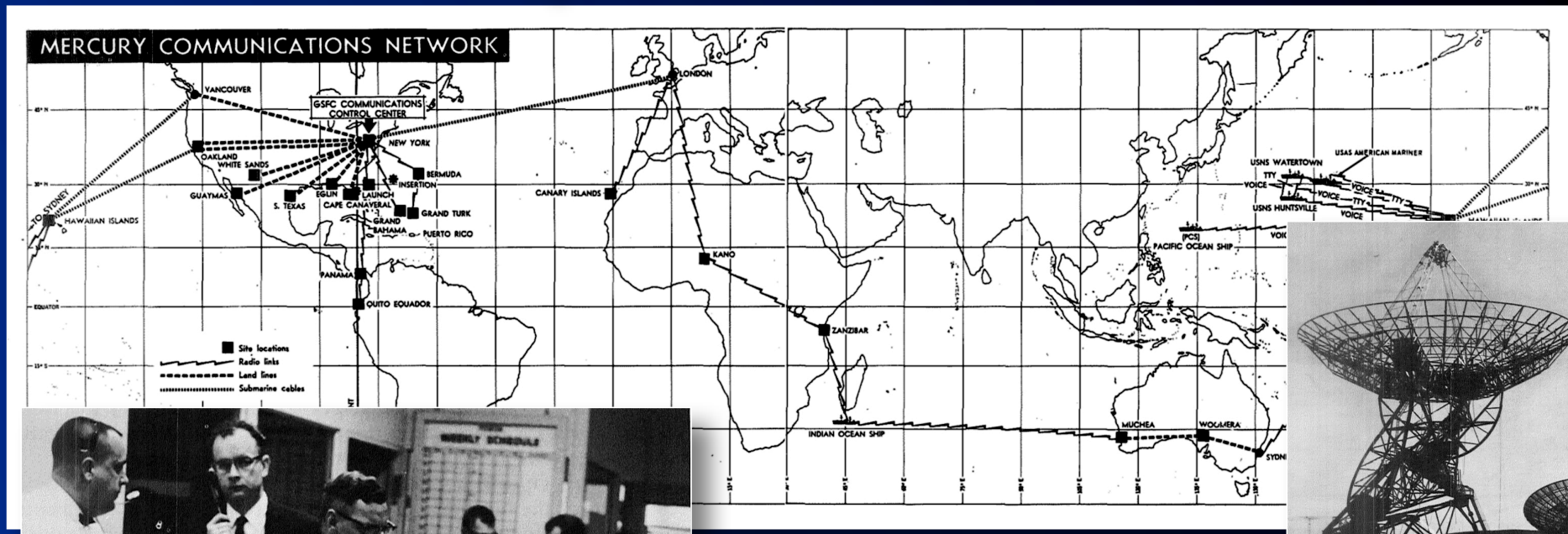


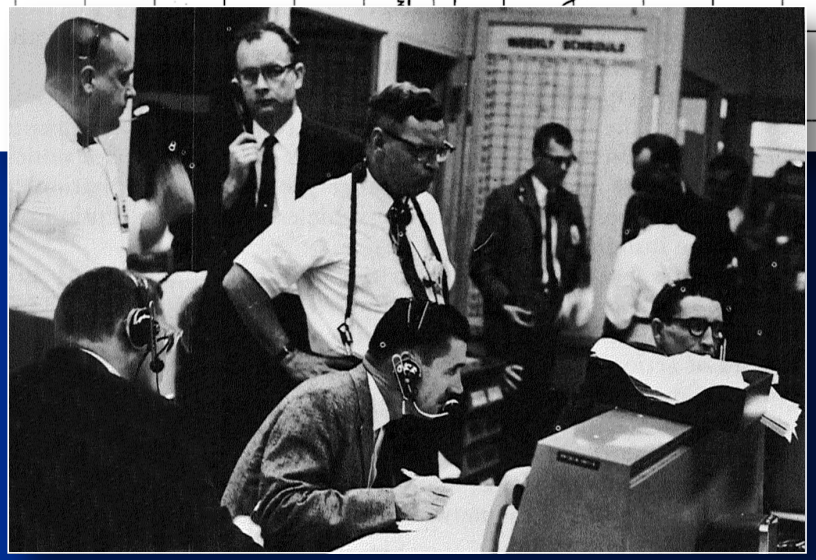
Left: Explorer XVII
Launched 1963

Right: Explorer XXXII
Launched 1966

Both collected data on upper atmospheric temperature, composition, density and pressure

Space Communications

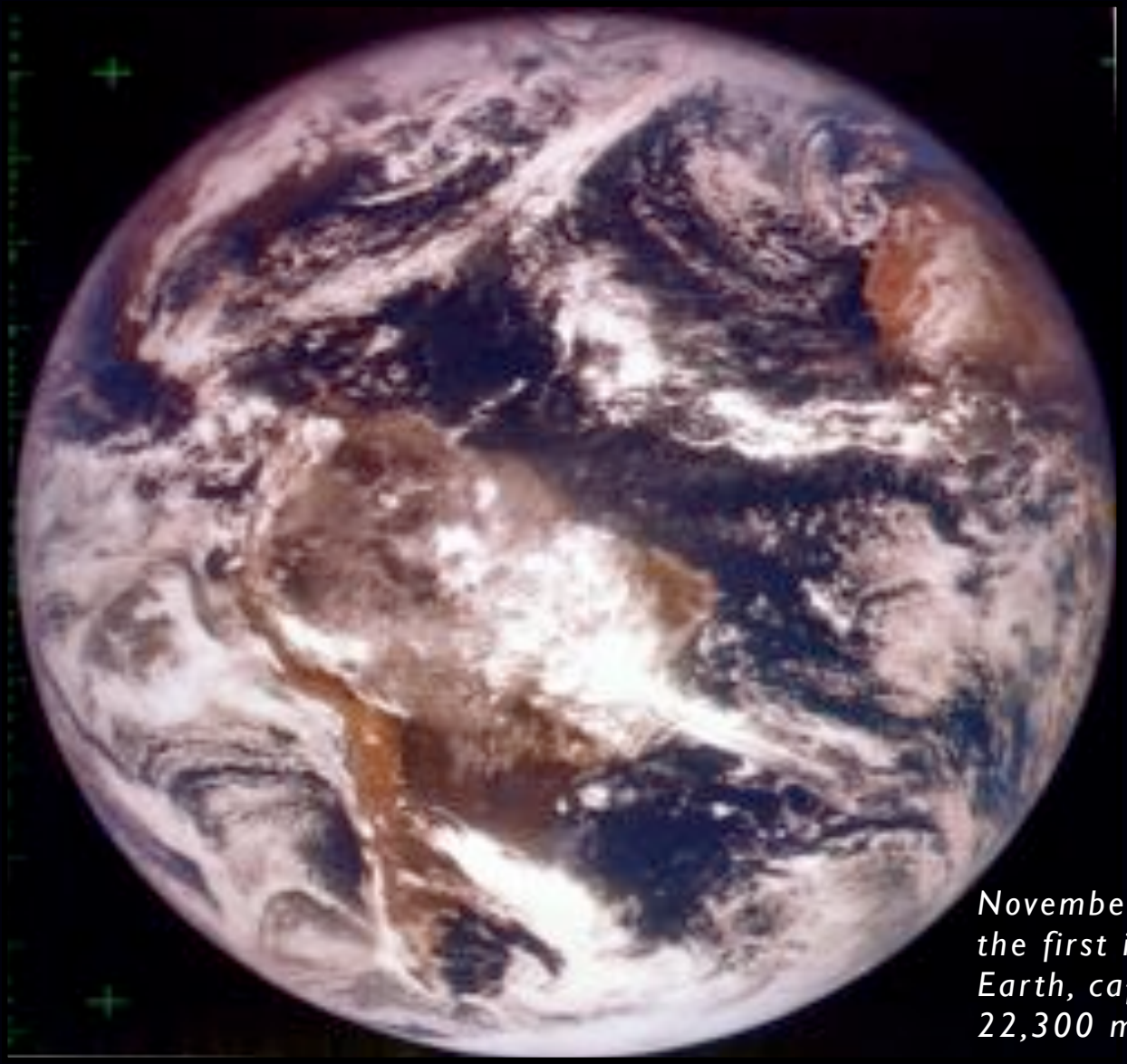




Mercury tracking network (top); Goldstone antennas (above right); tracking ships (right)

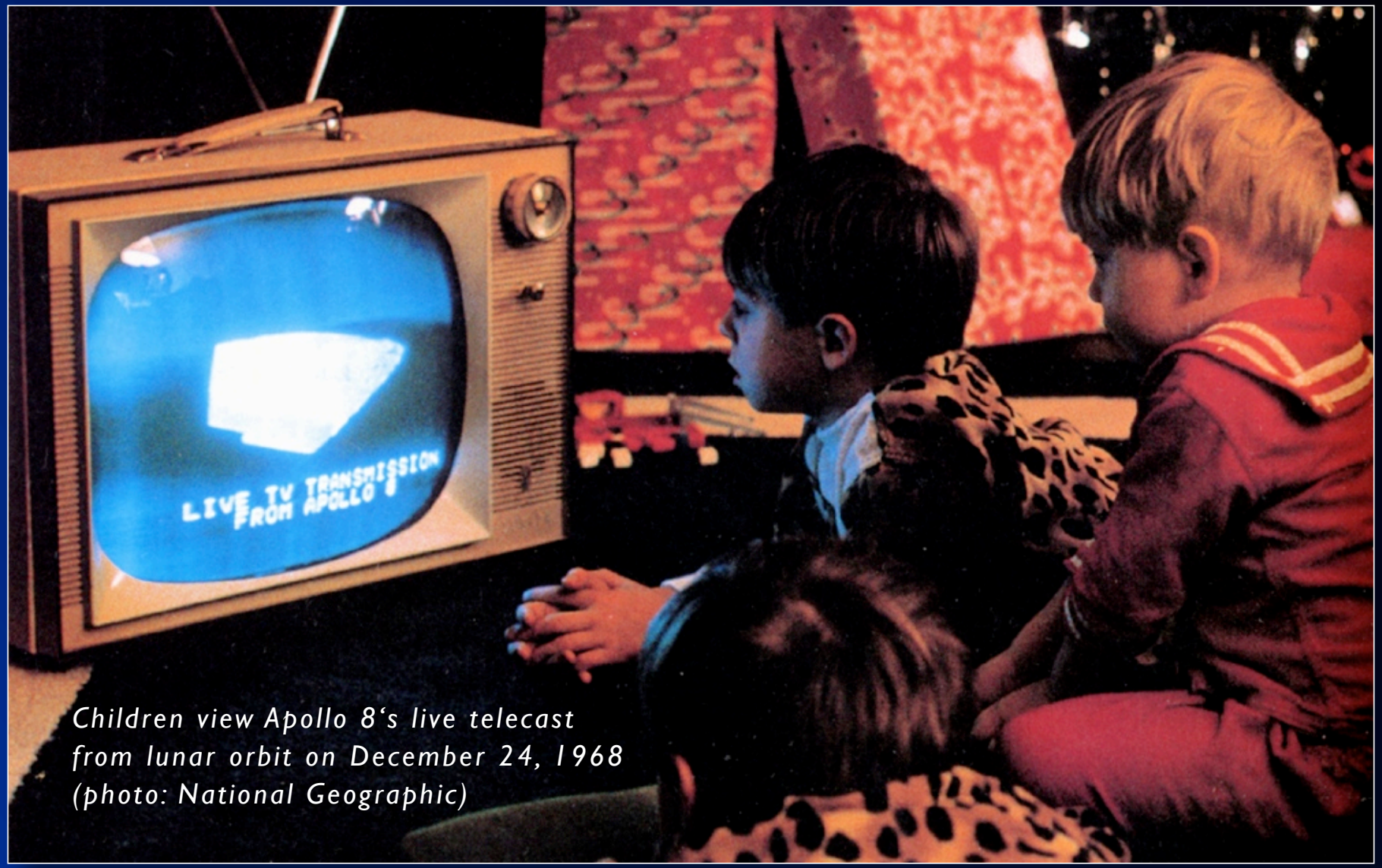
Activities at Goddard during John Glenn's MA-6 mission, February 20, 1962

1966-79: Applications Technology Satellites (ATS)



November 18 1967: One of the first images of the entire Earth, captured by ATS-3 from 22,300 miles

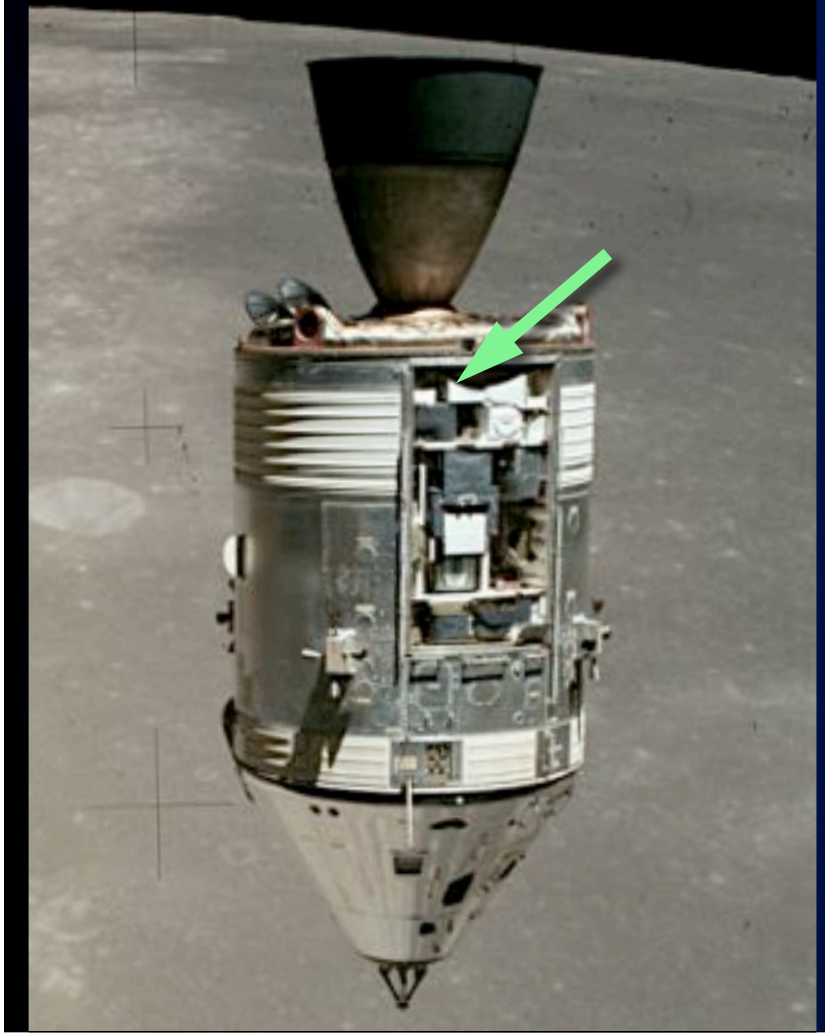
GSFC's "you are there" breakthrough: Live TV from the Moon

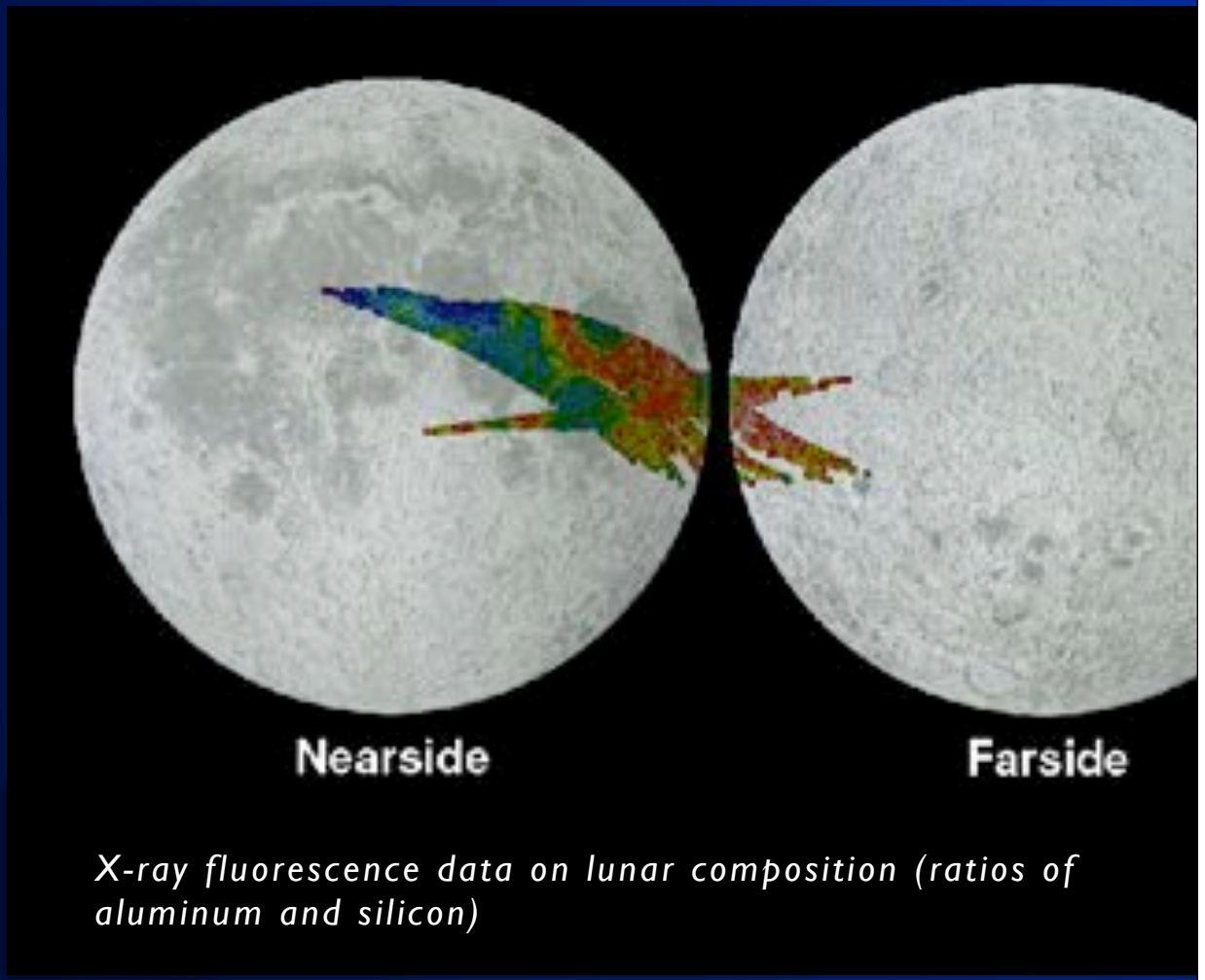


Children view Apollo 8's live telecast from lunar orbit on December 24, 1968 (photo: National Geographic)

Apollo J-Missions: Scientific Exploration from Lunar Orbit

J-Mission orbital surveys featured new scientific Instruments, including an X-ray Spectrometer (arrow) experiment led by Goddard's Isidore Adler and Jacob Trombka

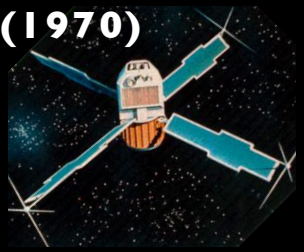


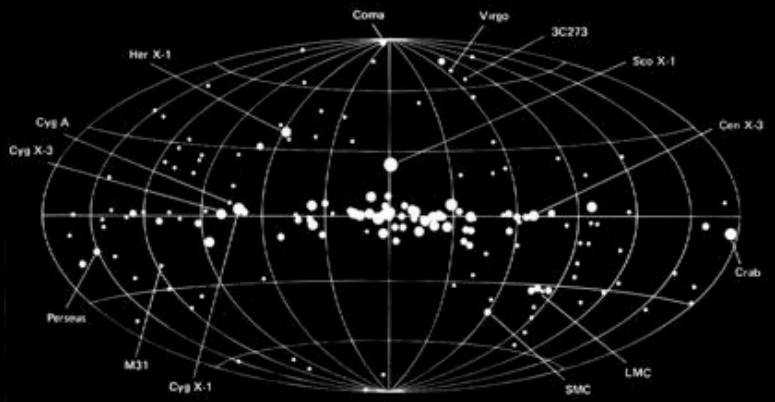


X-ray fluorescence data on lunar composition (ratios of aluminum and silicon)

1970s: Astronomy from Earth Orbit

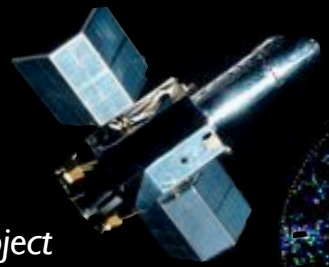
Uhuru x-ray satellite (1970)



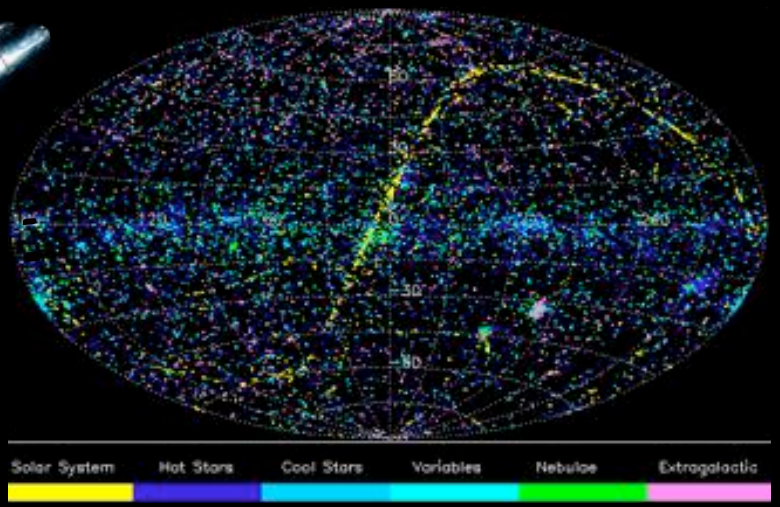


Discovered x-ray emissions from neutron stars, active galaxies, and clusters of galaxies. First evidence for black holes.

International Ultraviolet Explorer (1978)



Joint project of NASA GSFC, United Kingdom, and European Space Agency. Operated for 19 years; turned off for budgetary reasons.

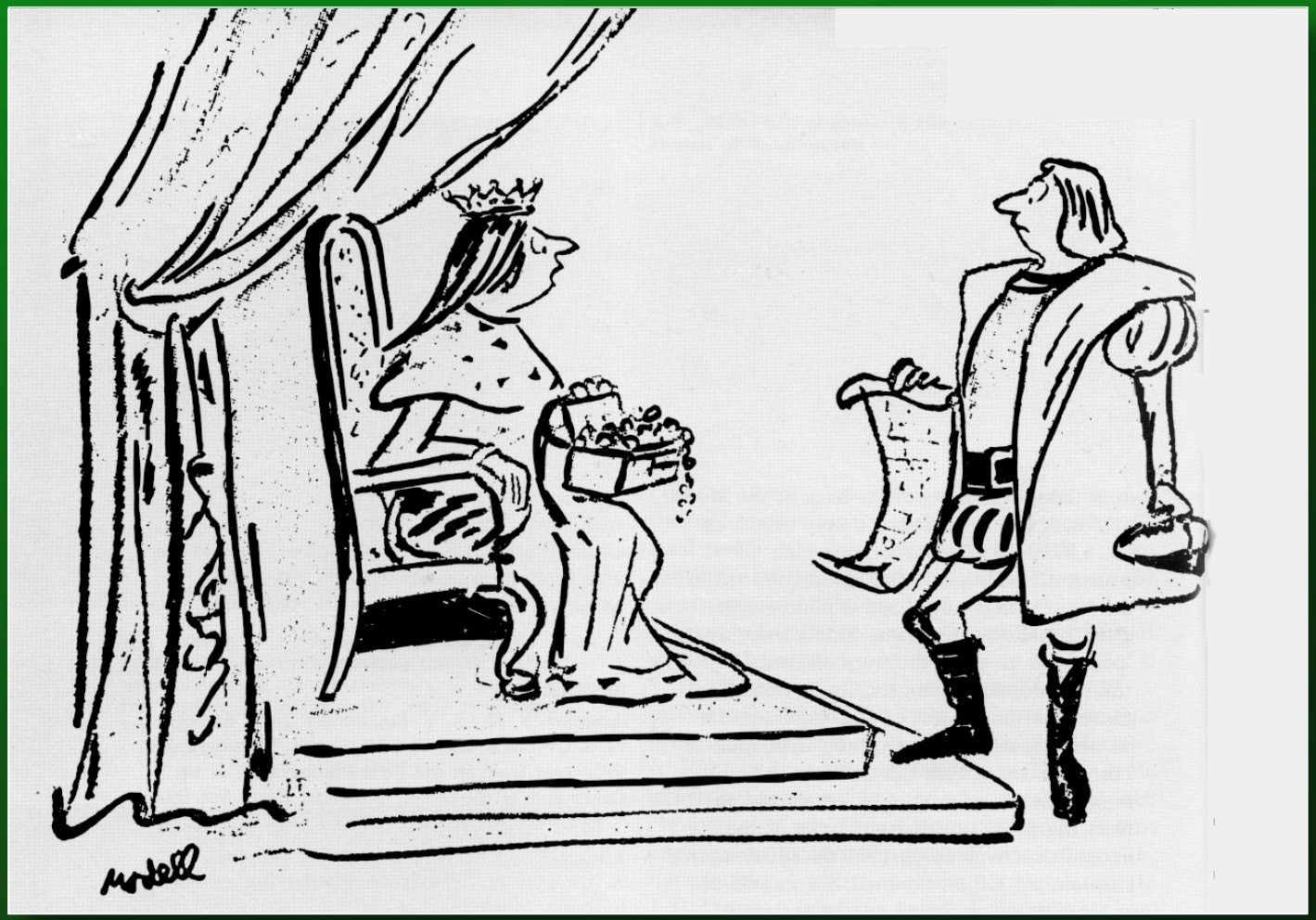


Einstein x-ray imaging satellite (1978)

First x-ray images of celestial objects

Mission to Earth

A Nation Divided



Chapter 2

"Three ships is a lot of ships. Why can't you prove the world is round with <u>one</u> ship?"

The New Yorker, 1970

1972: GSFC's Earth Resources Technology Satellite, a.k.a. Landsat

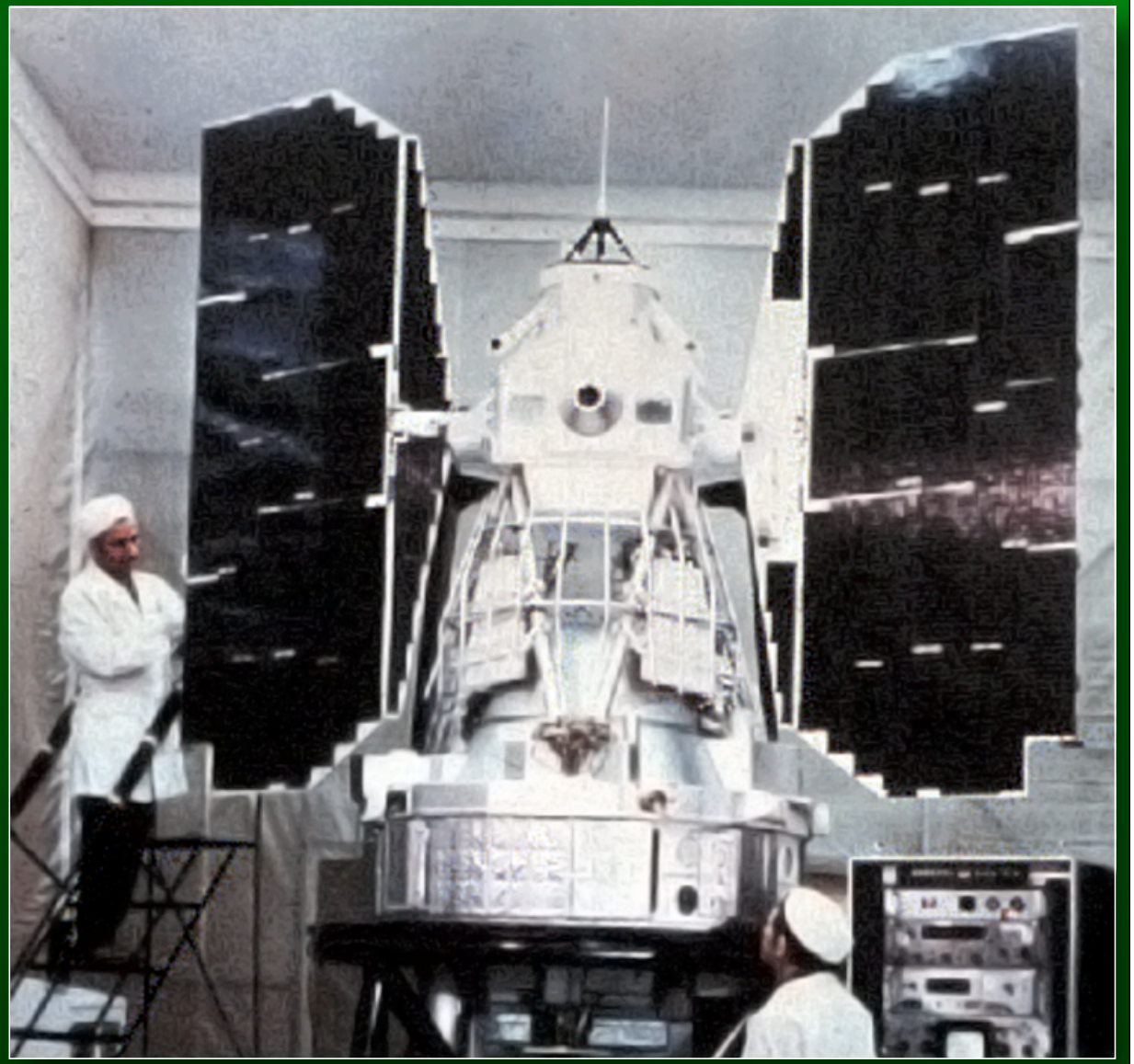
GSFC's Paul Lowman (1931-2011)

Using multi-spectral imaging, Landsat performs "remote sensing" that can:

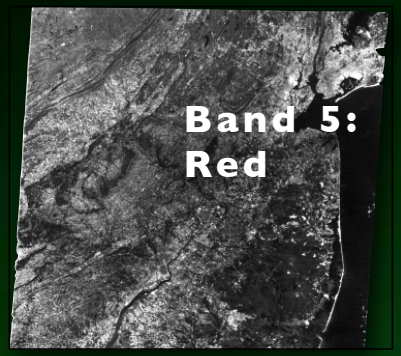
-- Distinguish plant types, land use, silt content in water

-- Identify large-scale, hydrocarbon-bearing structures not seen on aerial photographs

-- Reveal important minerals and metals, especially in hostile environments

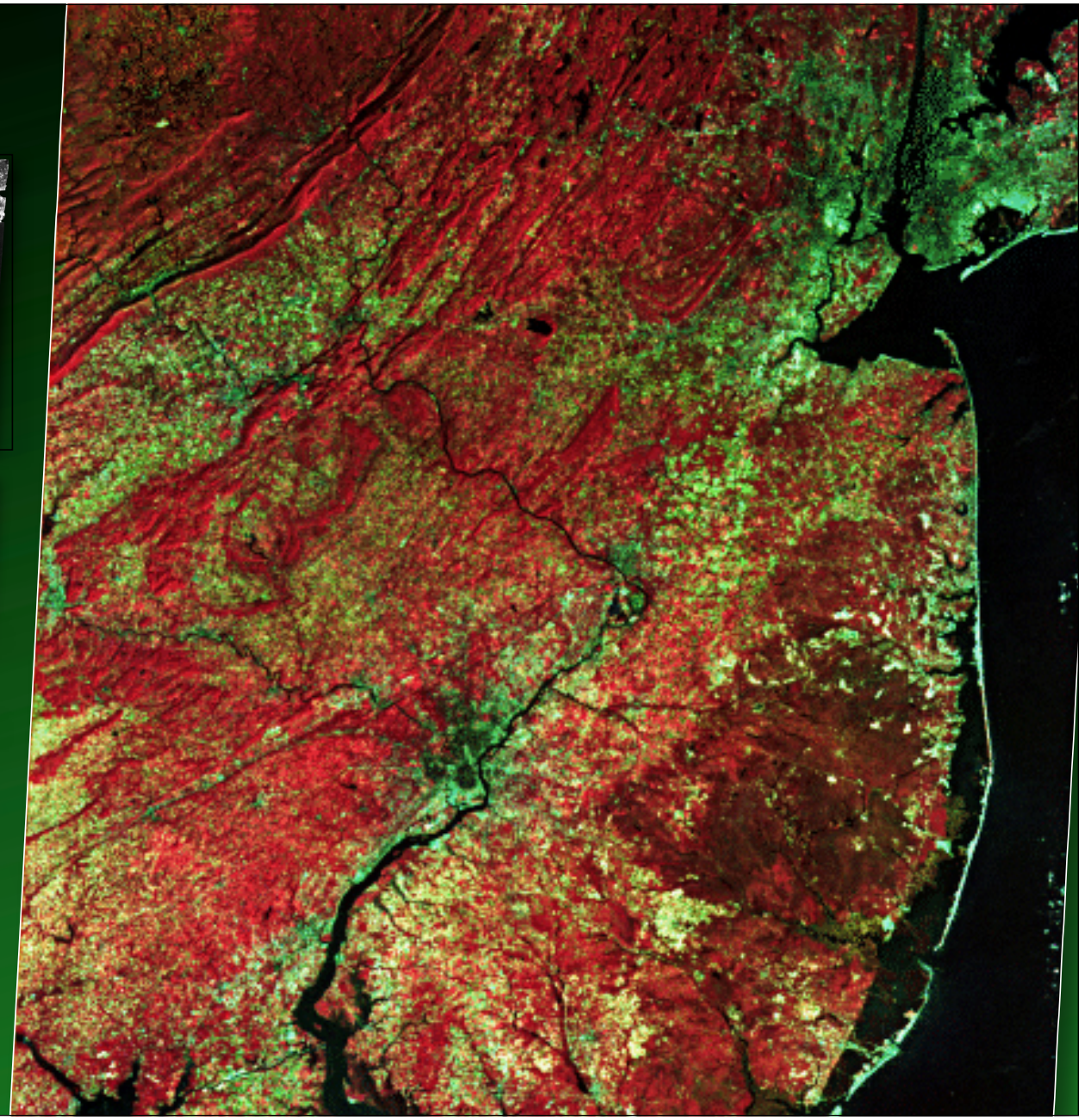


Landsat Multispectral Imaging



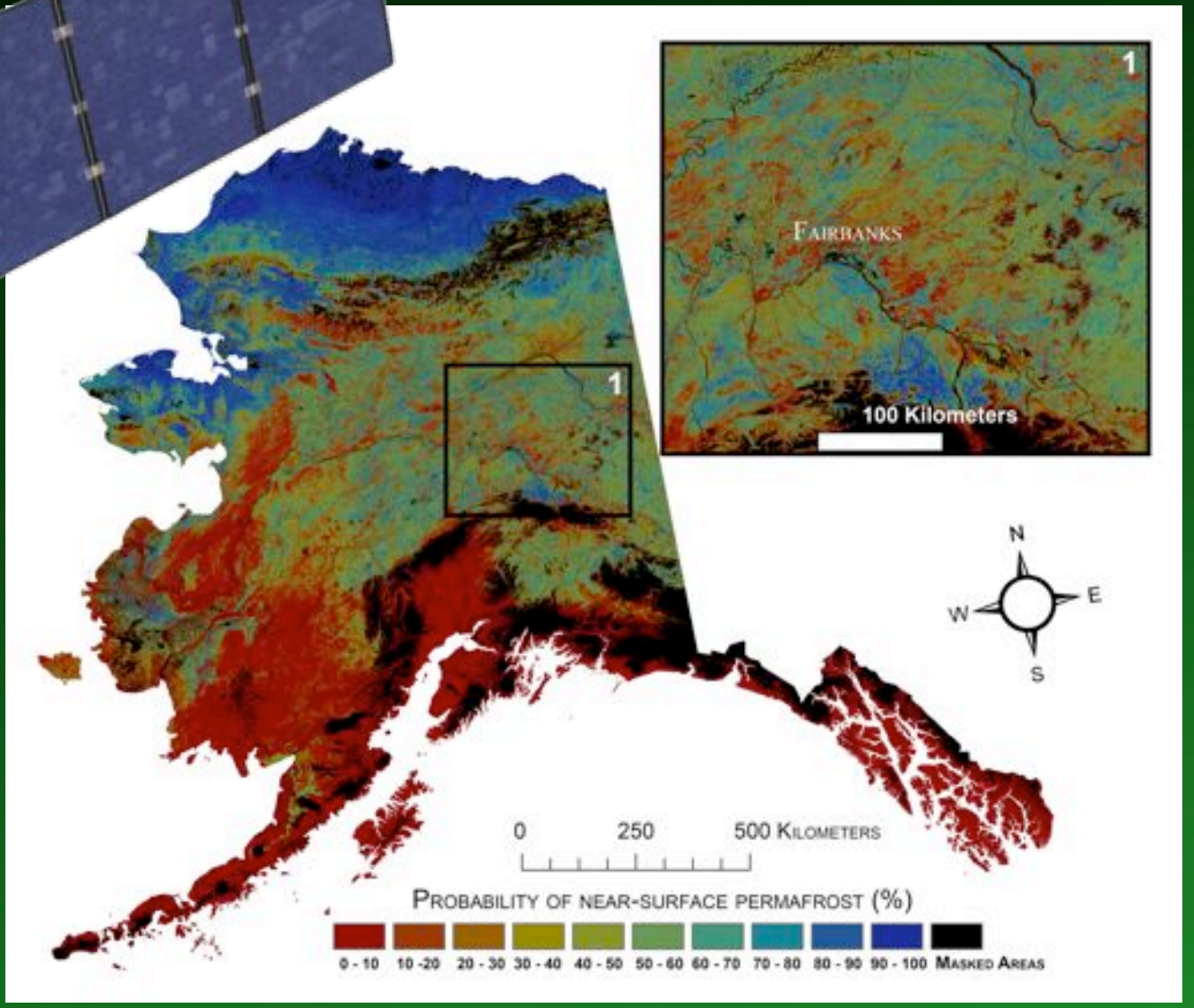
Bright red = deciduous trees
Reddish brown = coniferous trees
Green = urban areas
Dark blue = water

New York - New Jersey area viewed from Landsat-1 on October 10, 1972

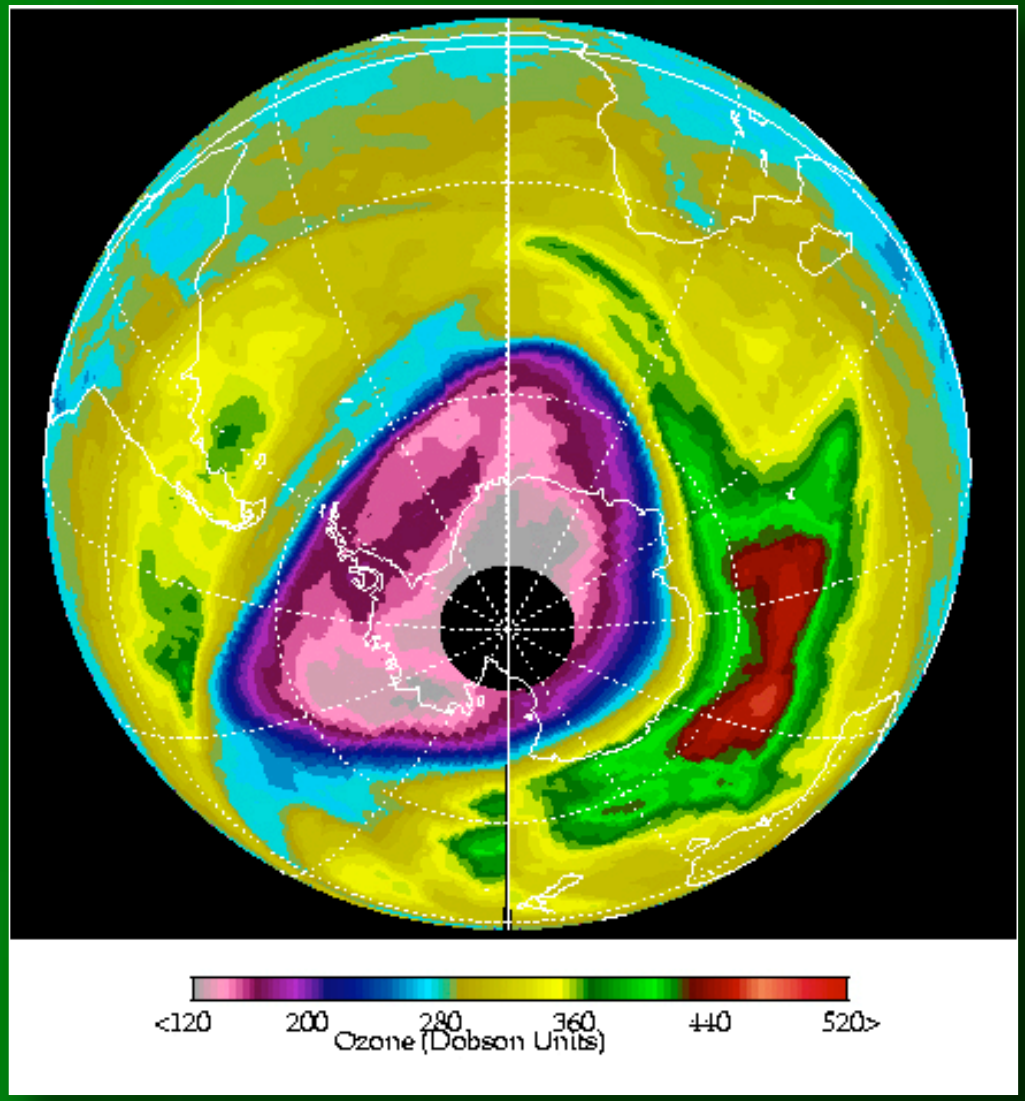


The Landsat missions continue

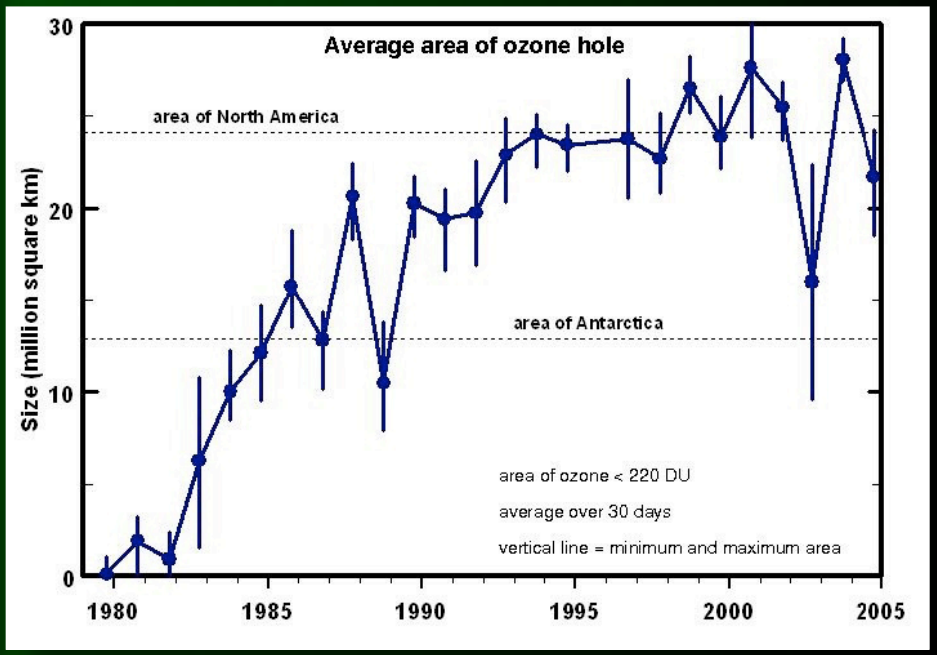
Landsat 8 (launched 2013)



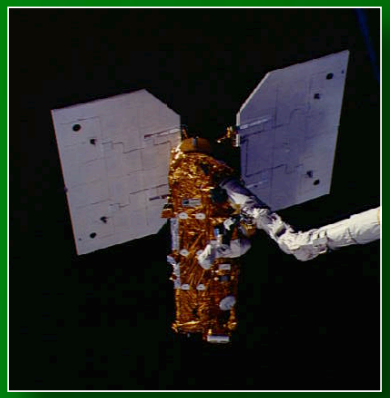
1978-2006: Total Ozone Mapping Spectrometer (TOMS)



TOMS has been critical to the detection of long-term damage to the ozone layer, including ozone hole at South Pole



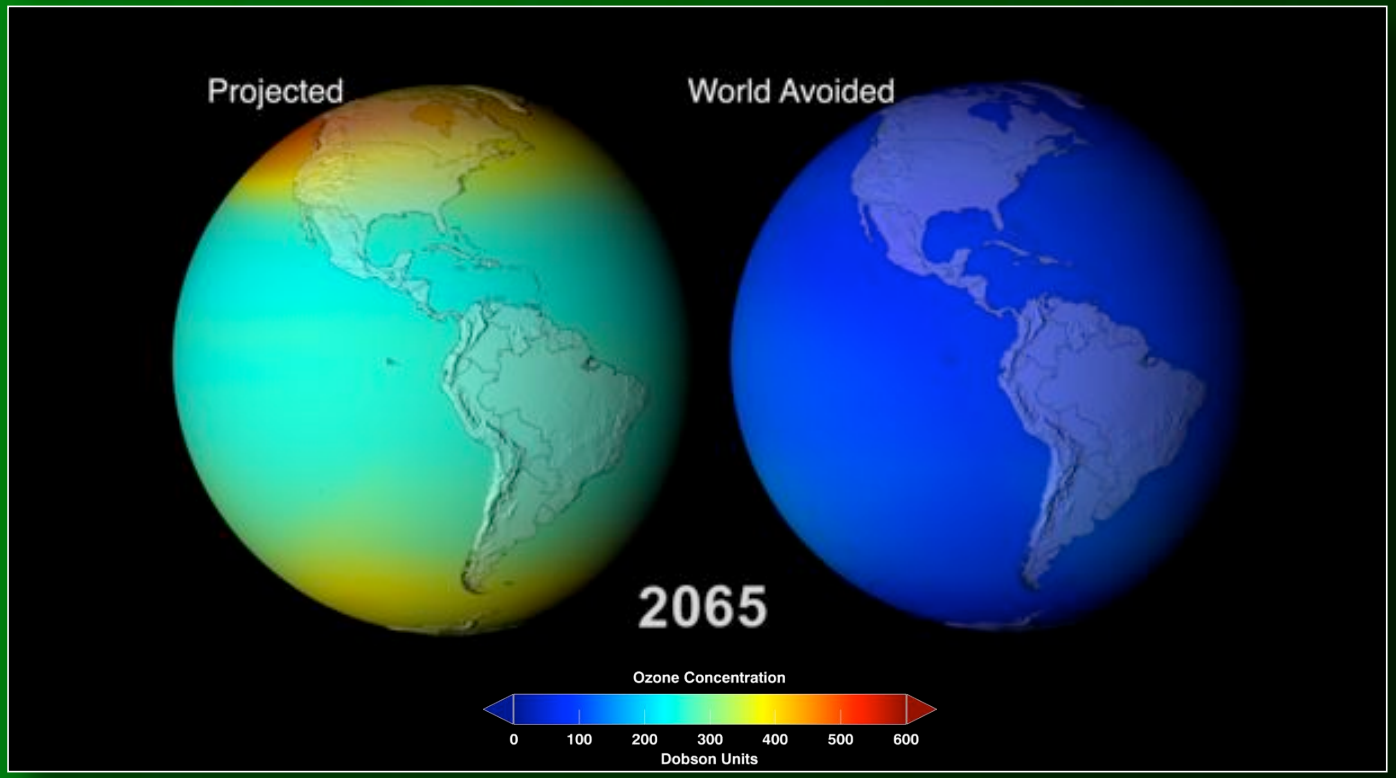
Left: Antarctic ozone hole in 2007
Above: Growth of ozone hole from 1980-2005



1984-2005: Earth Radiation Budget Satellite

ERBS measured diurnal variations of incoming solar radiation and its differential absorption by the atmosphere.

ERBS data on the ozone layer was key in the Montreal Protocol Agreement, which went into force in 1989, and has nearly eliminated chlorofluorocarbons (CFCs) in industrialized countries.



2009 study led by GSFC scientist Paul Newman simulated what might have been if CFCs and similar ozone-depleting chemicals were not banned through the Montreal Protocol.

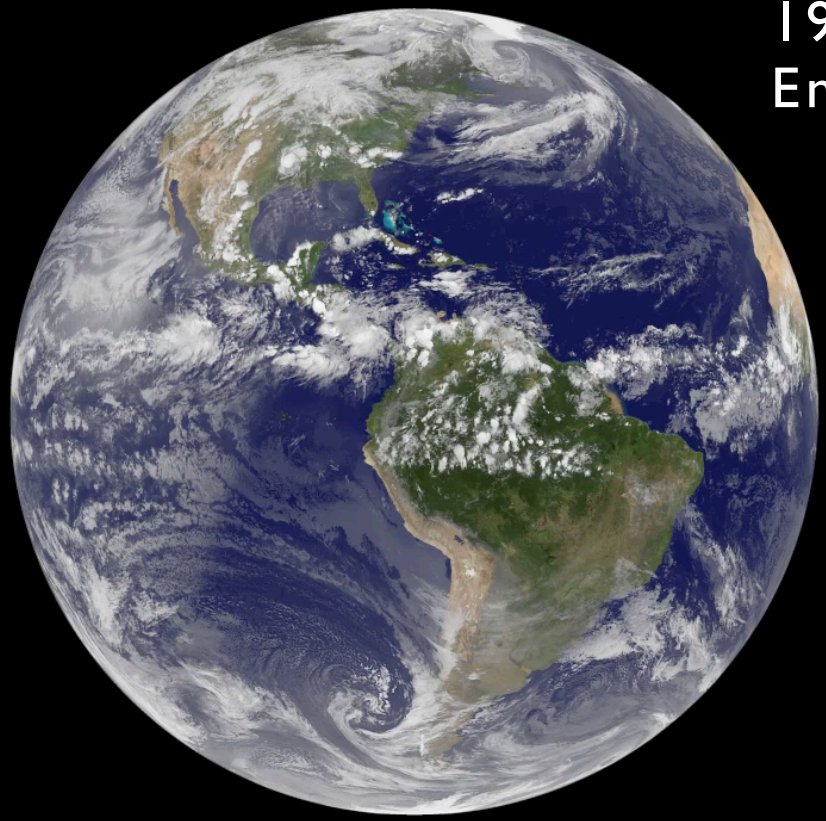
1976-Present: Laser Geodynamics Satellite

LAGEOS 1 and 2 refined our knowledge of Earth's shape, rotation, and the motion of tectonic plates. LAGEOS data helped make GPS possible.

-- Aluminium-covered, 60-cm brass spheres covered with retro-reflectors

-- Pulsed laser beams from ground stations; travel times yield positional info better than 1 inch in 1,000s of miles

1975-Present: Geostationary Operational Environmental Satellites (GOES)



Above; Global weather for June 20, 2010 from GOES East; Right: Hurricane progresses past Baja California, June 18-20

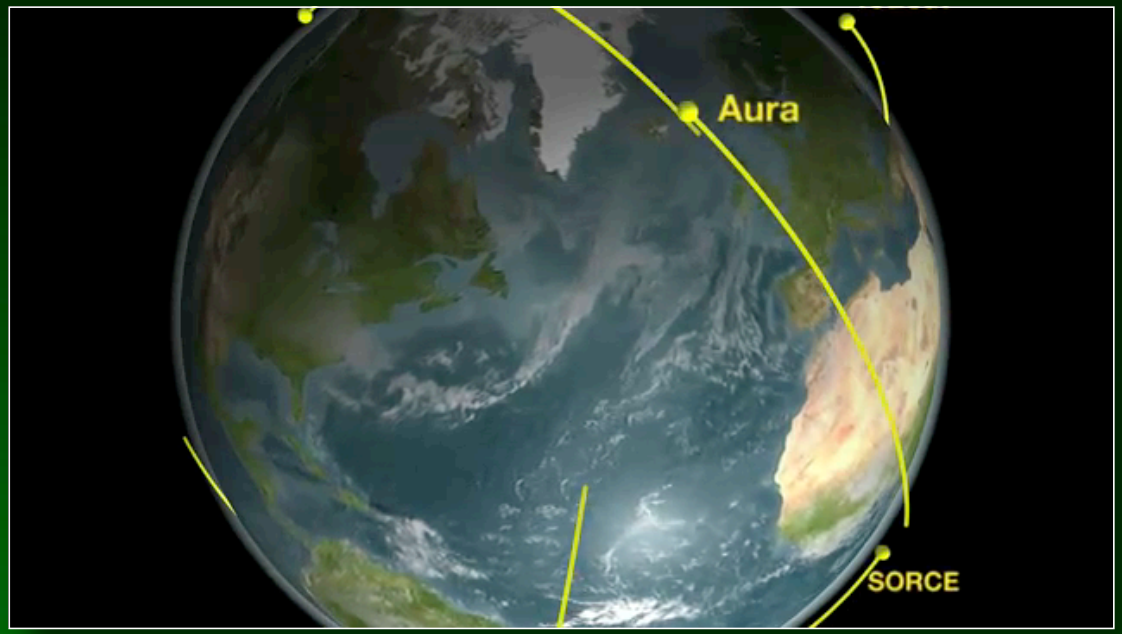
Earth Observing System:
A multi-disciplinary view of the home planet

"In the past, Earth was studied by looking at its parts: oceanographers studied the oceans, geologists studied the land. But planetologists have a global perspective. And one goal of EOS is ... to answer the question of how the interacting parts of Earth operate together."

-- Gerald Soffen, 1st EOS Project Scientist, 1990

1999-Present: Earth Observing System

EOS is a series of coordinated polar-orbiting satellites (currently 11 active) designed for long-term global observations of key climate system components and their interactions.



Satellites:

Terra (flagship mission, launched 1999)

Aqua (2002)

Ice, Cloud, and land Elevation Satellite (**ICESat 2**, 2017 estimated launch)

Aura (ozone, air quality, and climate monitoring, 2004)

Studies include:

-- the oceans

-- greenhouse gases

-- glaciers, sea ice, ice sheets

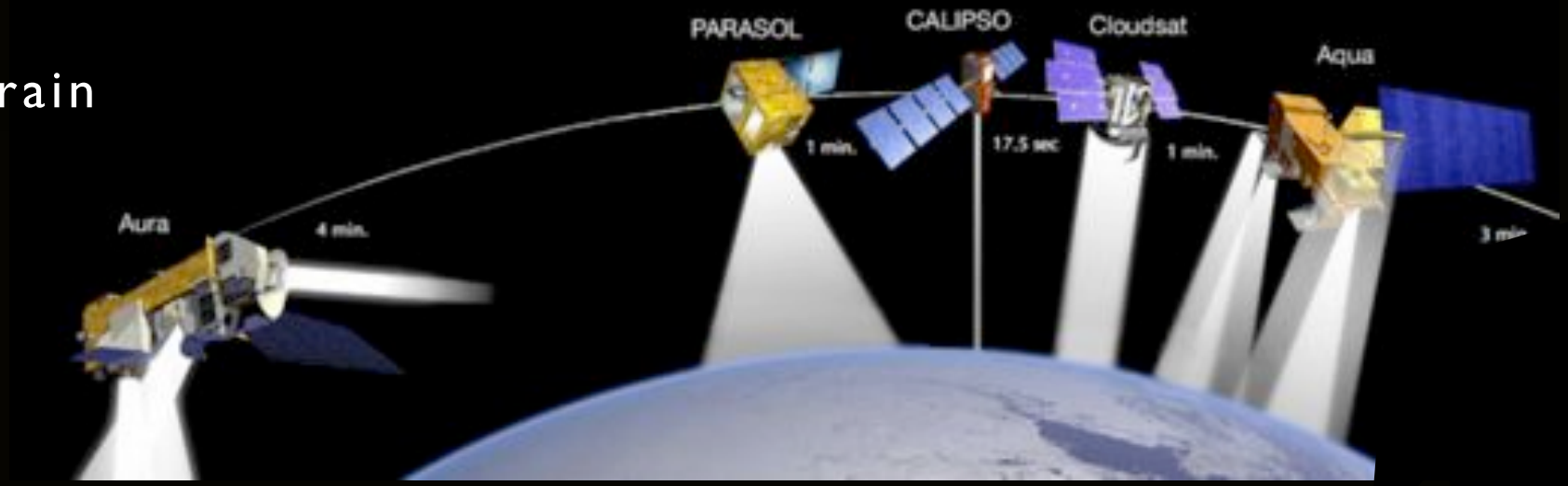
-- radiation, clouds, water vapor, precipitation

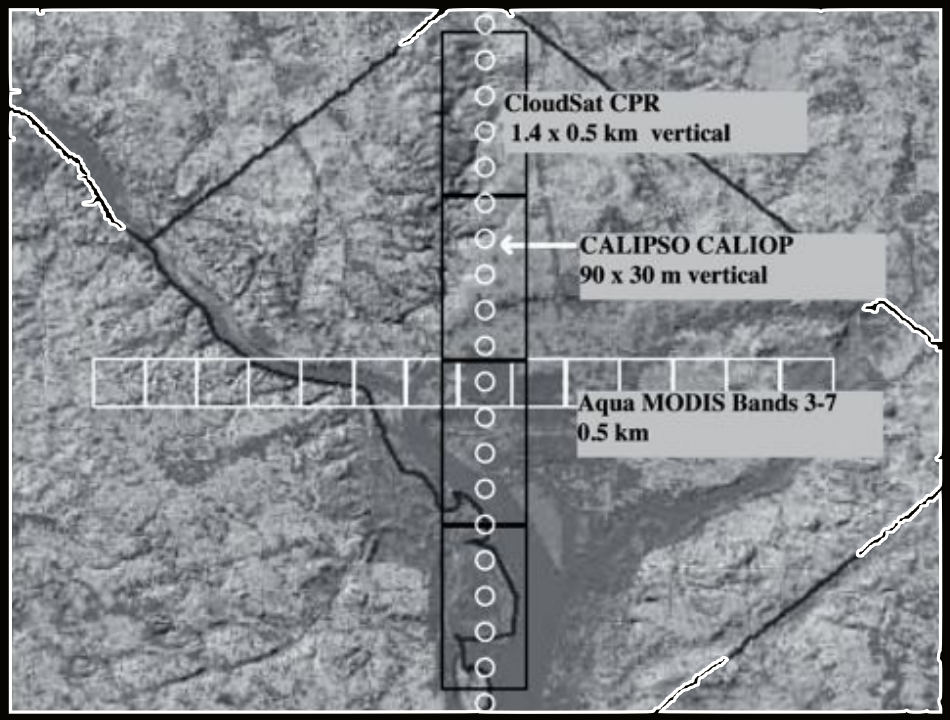
-- ozone and stratospheric chemistry

-- natural and anthropogenic aerosols

-- land-surface hydrology and ecosystem processes

The A-Train



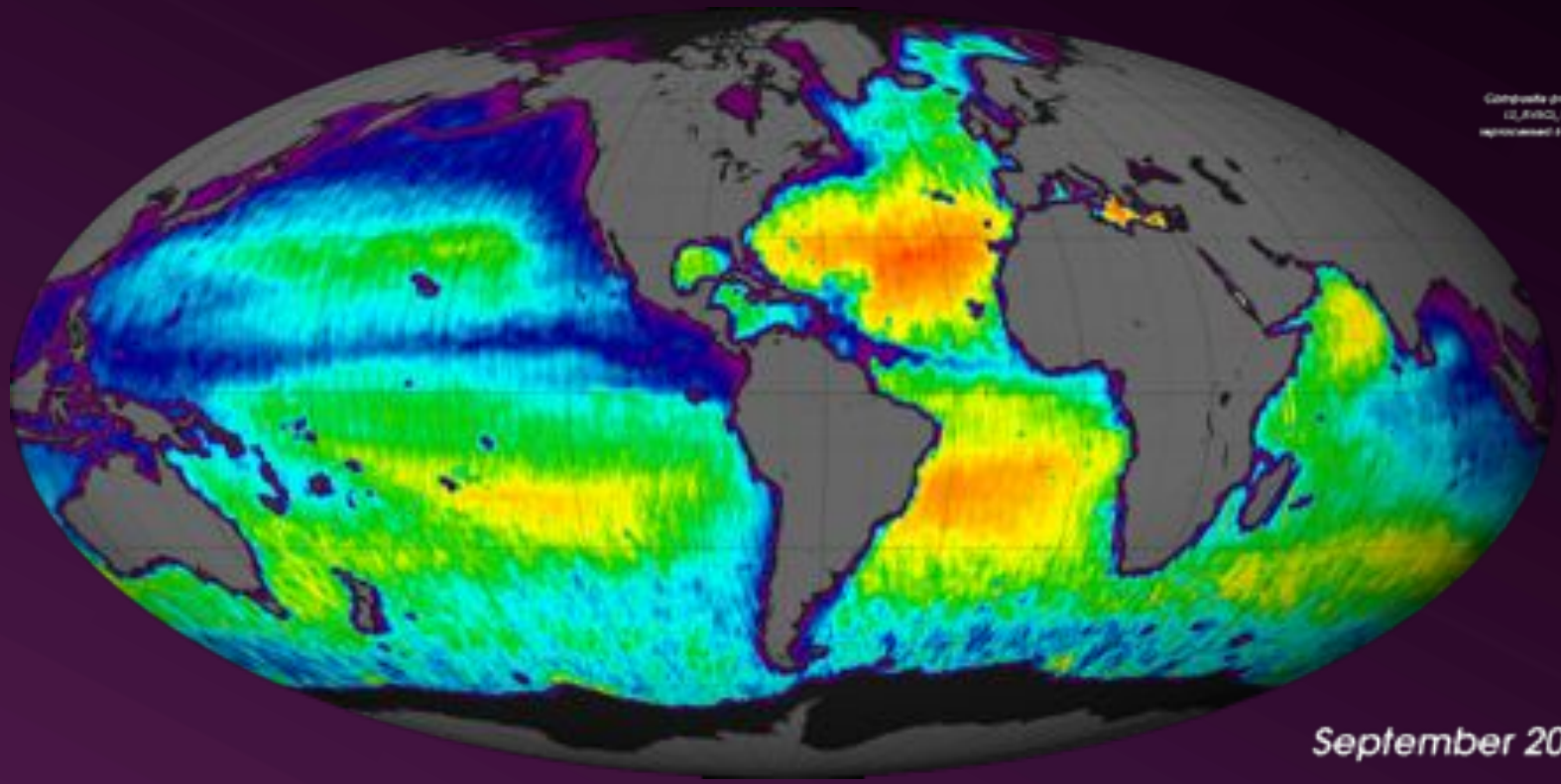


Flying in formation, a constellation of Earth observing satellites provide synergistic data (including stereo coverage) on clouds, aerosols, water cycling, and atmospheric chemistry.

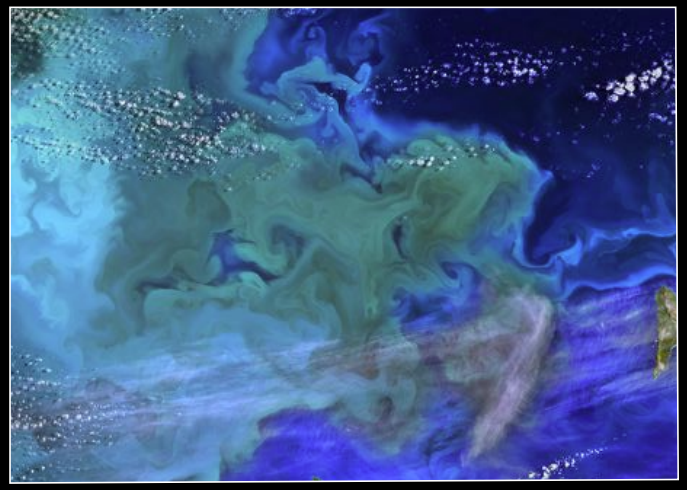
Left: An example of synergistic A-train observations (in this case, of cloud layering) by selected instruments aboard three different satellites

2011: Aquarius begins measuring global sea salinity

The Aquarius instrument provides unprecedented accuracy and coverage, measuring changes in sea surface salinity equivalent to about a "pinch" (1/8 of a teaspoon) of salt in 1 gallon of water.



Future missions: Earth observations



Pre-Aerosol, Cloud, ocean, Ecosystem mission (PACE) -- 2019 launch

Study ocean ecology, including mass and distribution of phytoplankton

Document clouds and atmospheric aerosols and their influence on climate

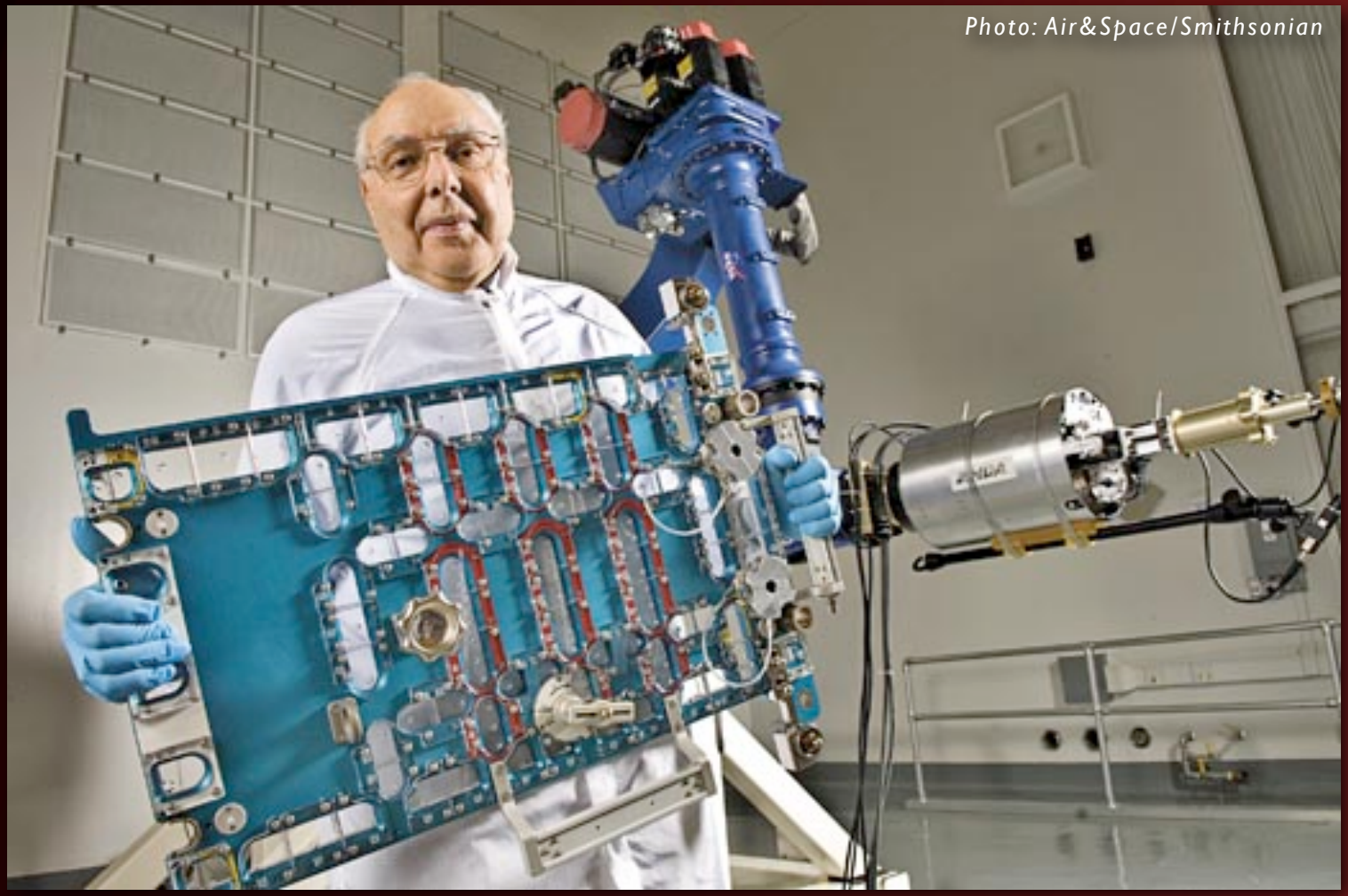
Global Ecosystem Dynamics Investigation (GEDI) -- launch to ISS after 2018

How do forests respond to changes in climate and land use?

GEDI will use LIDAR to create detailed 3D maps and measure the biomass of forests.

2018+ scheduled launch to the International Space Station

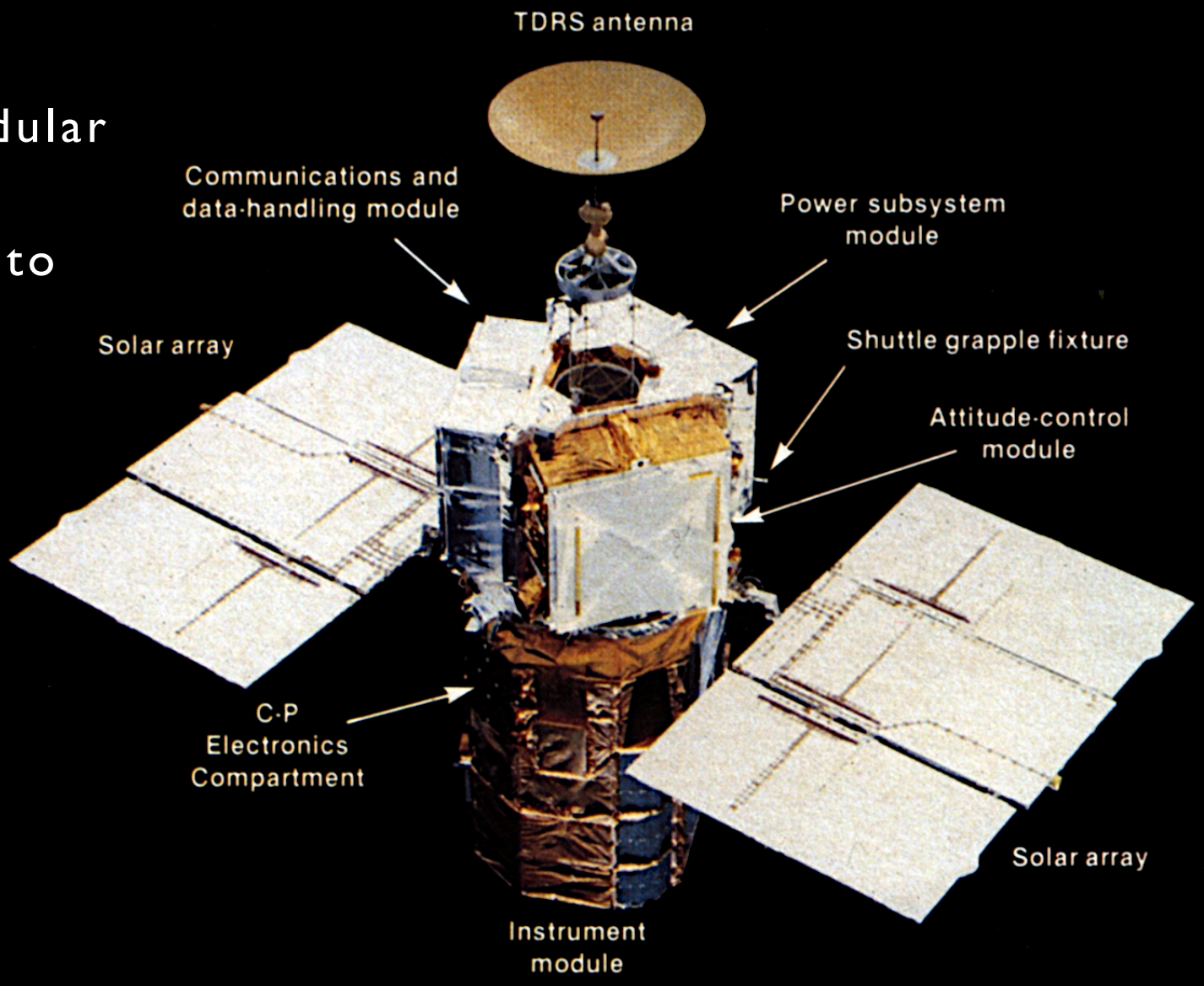
The Shuttle Era



"Cepi had this vision that we ought to start making spacecraft compatible with the shuttle, and serviceable, so we could go maintain and upgrade them on-orbit."

-- Satellite repair engineer Mike Weiss on Frank Cepollina (*pictured*)

Frank Cepollina's Multi-mission Modular Spacecraft: First satellite designed to be serviced by astronauts

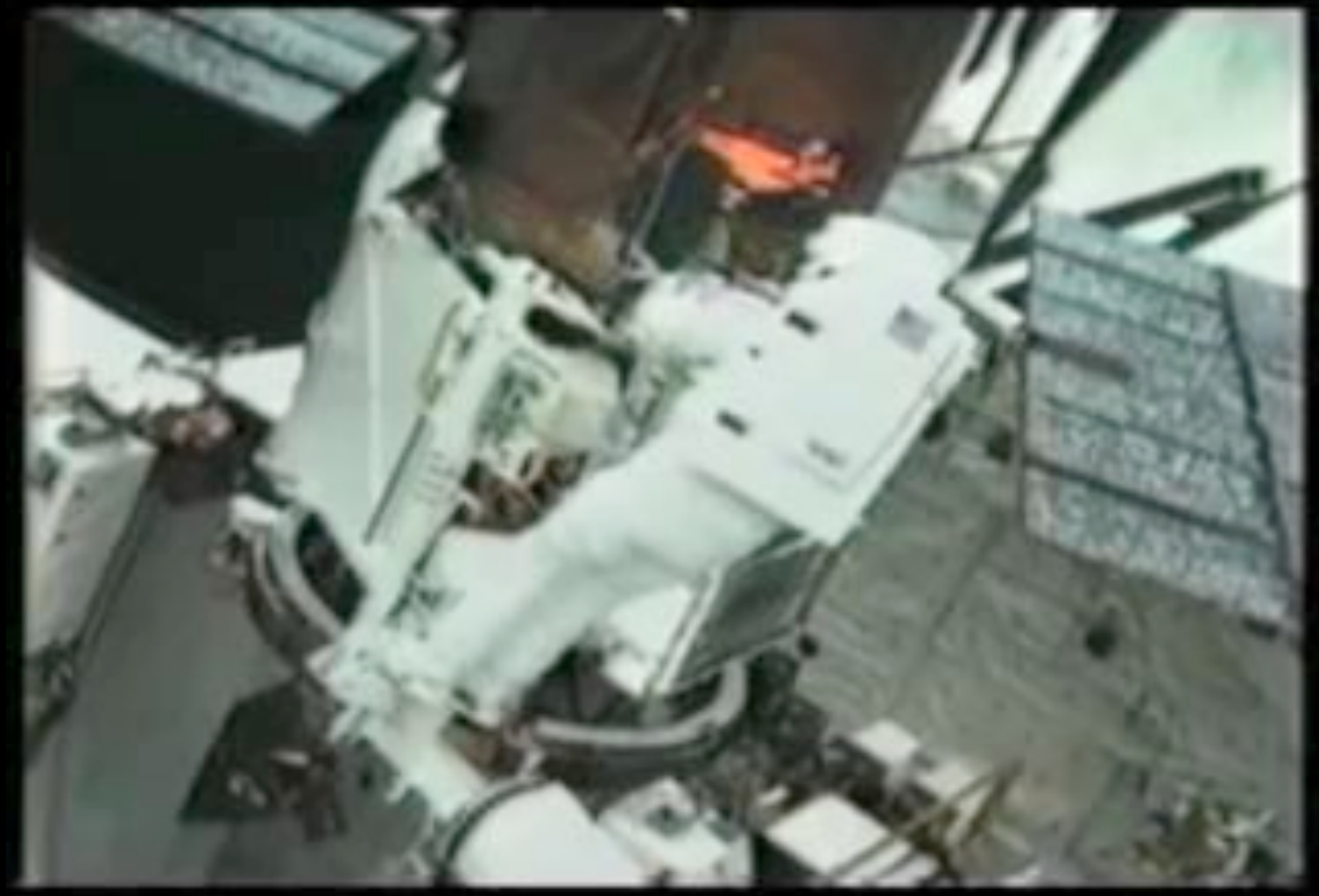


Solar Maximum Mission satellite "Solar Max" was launched in February 1980 to study the Sun during it's period of maximum activity.

April 11, 1984: Fixing Solar Max

"We learned a lot on that Solar Max mission. Things don't always go right, so get prepared for contingencies."

-- GSFC engineer Mike Weiss



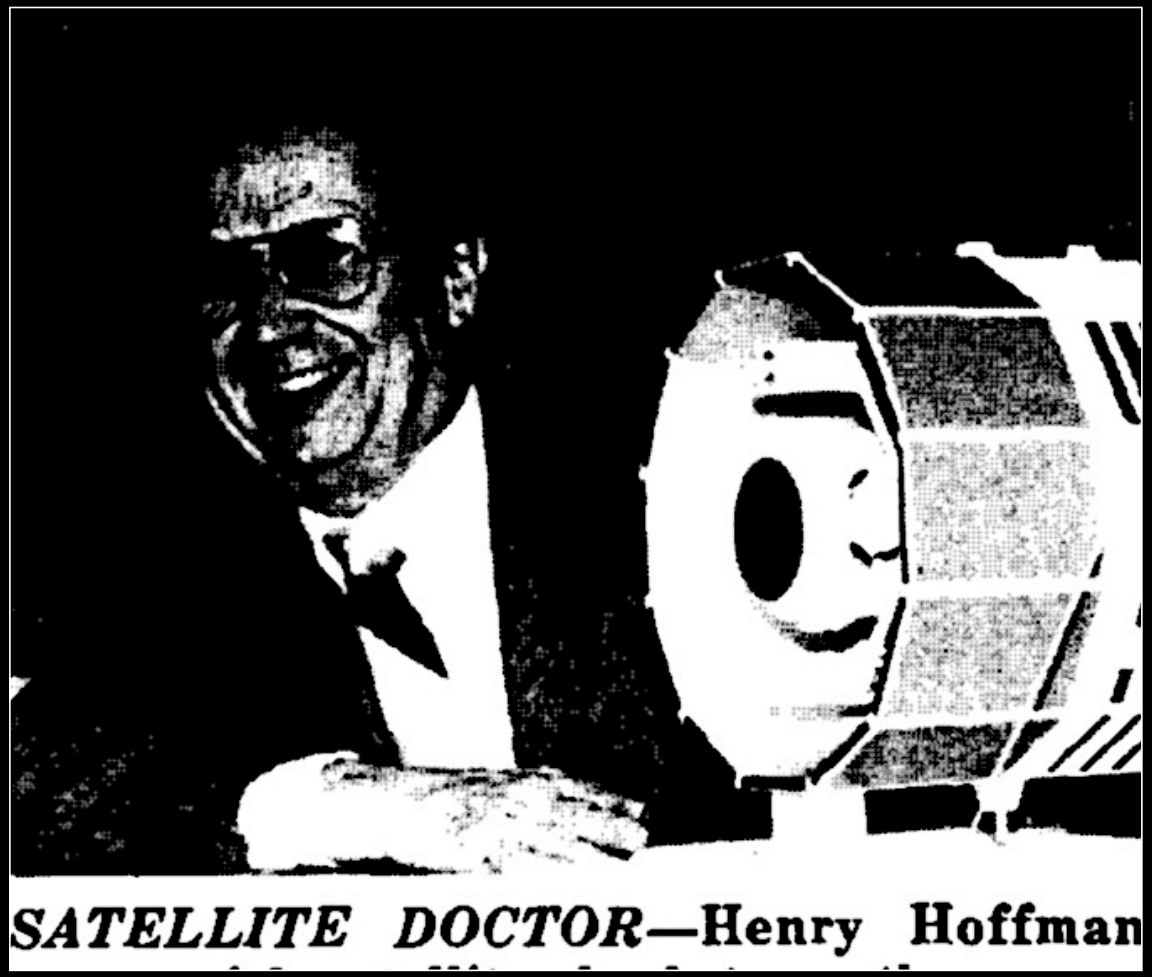
Pinky Nelson and Ox Van Hoften work on Solar Max in Challenger's *cargo bay.*

1983: A Different Kind of Rescue

Your little finger would not fit in the exit cone of those thrusters. It took 39 burns to get up there. Some of 'em were upwards of an hour."

-- GSFC's "Satellite Doctor"
Henry Hoffman

When its Inertial Upper Stage failed to put TDRS-1 in the proper orbit, GSFC controllers used tiny attitude-control thrusters to correct the errant satellite's path.



SATELLITE DOCTOR—Henry Hoffman

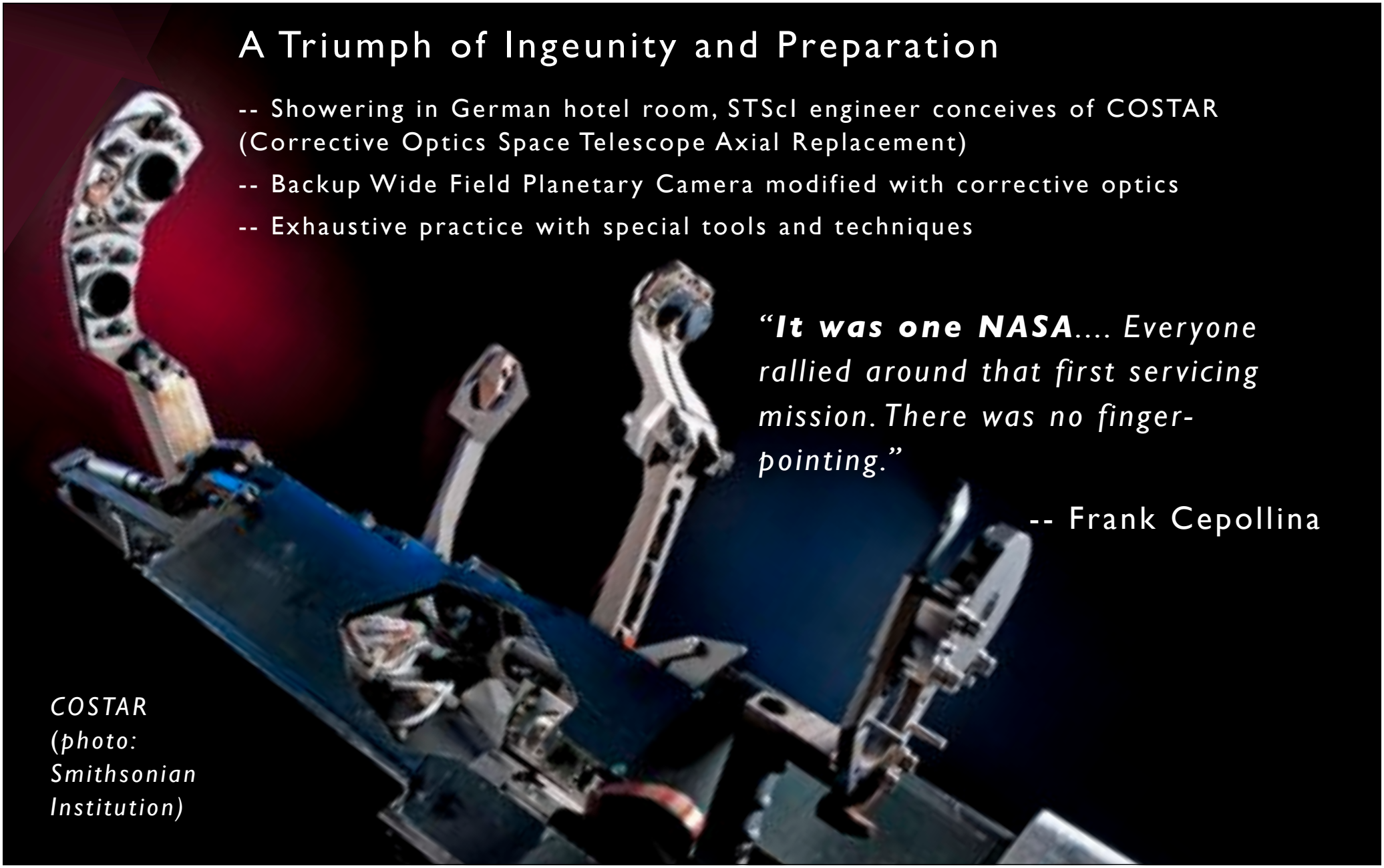

1990-1993: Fixing Mr.
Hubble's Telescope

A Triumph of Ingeunity and Preparation

-- Showering in German hotel room, STScI engineer conceives of COSTAR (Corrective Optics Space Telescope Axial Replacement)

-- Backup Wide Field Planetary Camera modified with corrective optics

-- Exhaustive practice with special tools and techniques



*"**It was one NASA**.... Everyone rallied around that first servicing mission. There was no finger-pointing."*

-- Frank Cepollina

COSTAR (photo: Smithsonian Institution)

Success!

The heart of the galaxy M100

BEFORE …

Success!

The heart of the galaxy M100

... AFTER

The Servicing Missions: Making Hubble Even Better

"What amazes me about this repair is that the servicing mission folks didn't just throw up their hands and say, 'It's impossible!'"

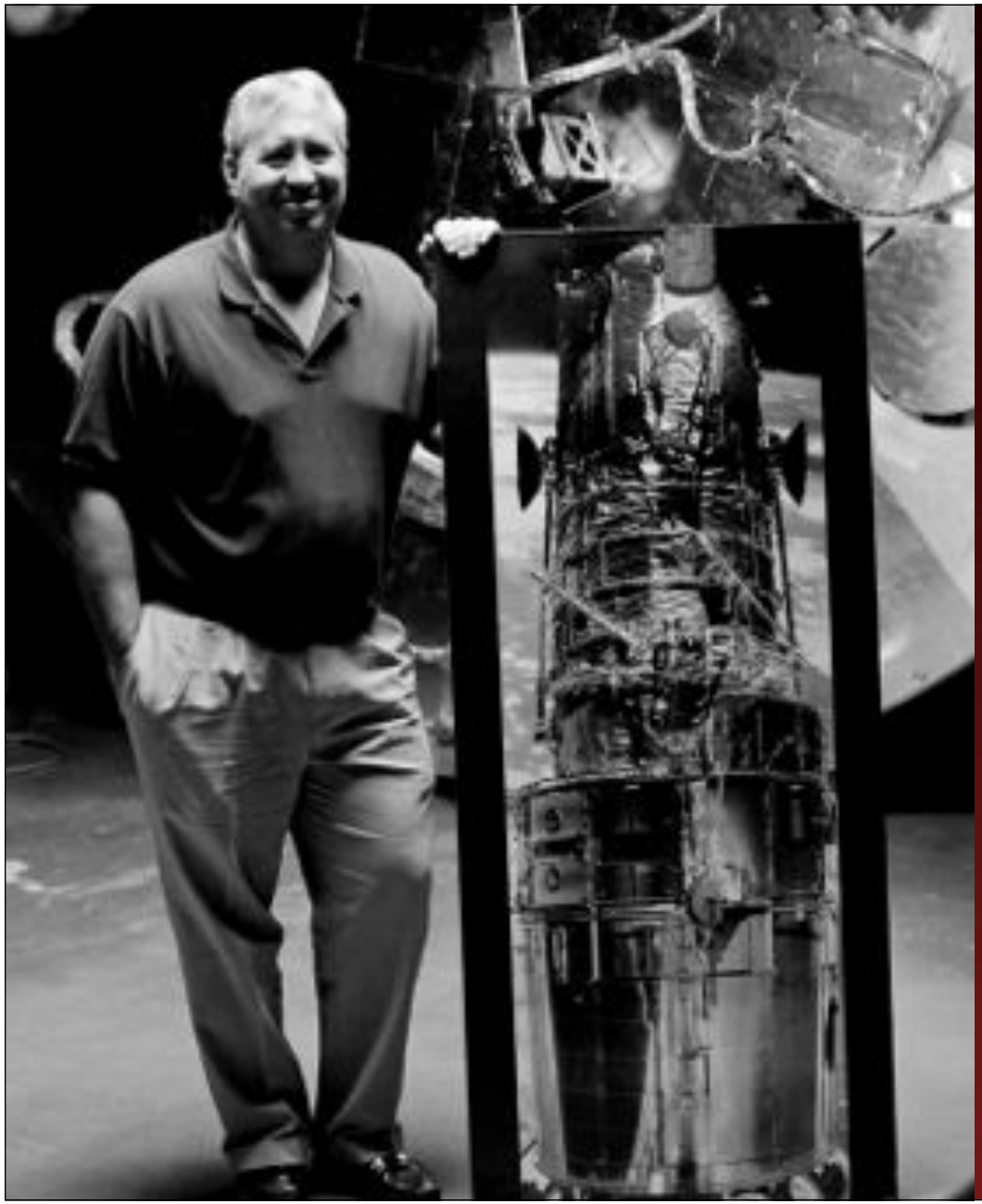
-- GSFC engineer Brent Warner on the 2010 repair of Hubble's imaging spectrograph

In four servicing missions between 1997 and 2010, astronauts transformed the Hubble Space Telescope again and again.

Older scientific instruments were replaced with newer ones extending the telescope's capabilities and reach into space.

They also replaced or repaired faulty components--even the telescope's power supply, in a task likened to brain surgery.

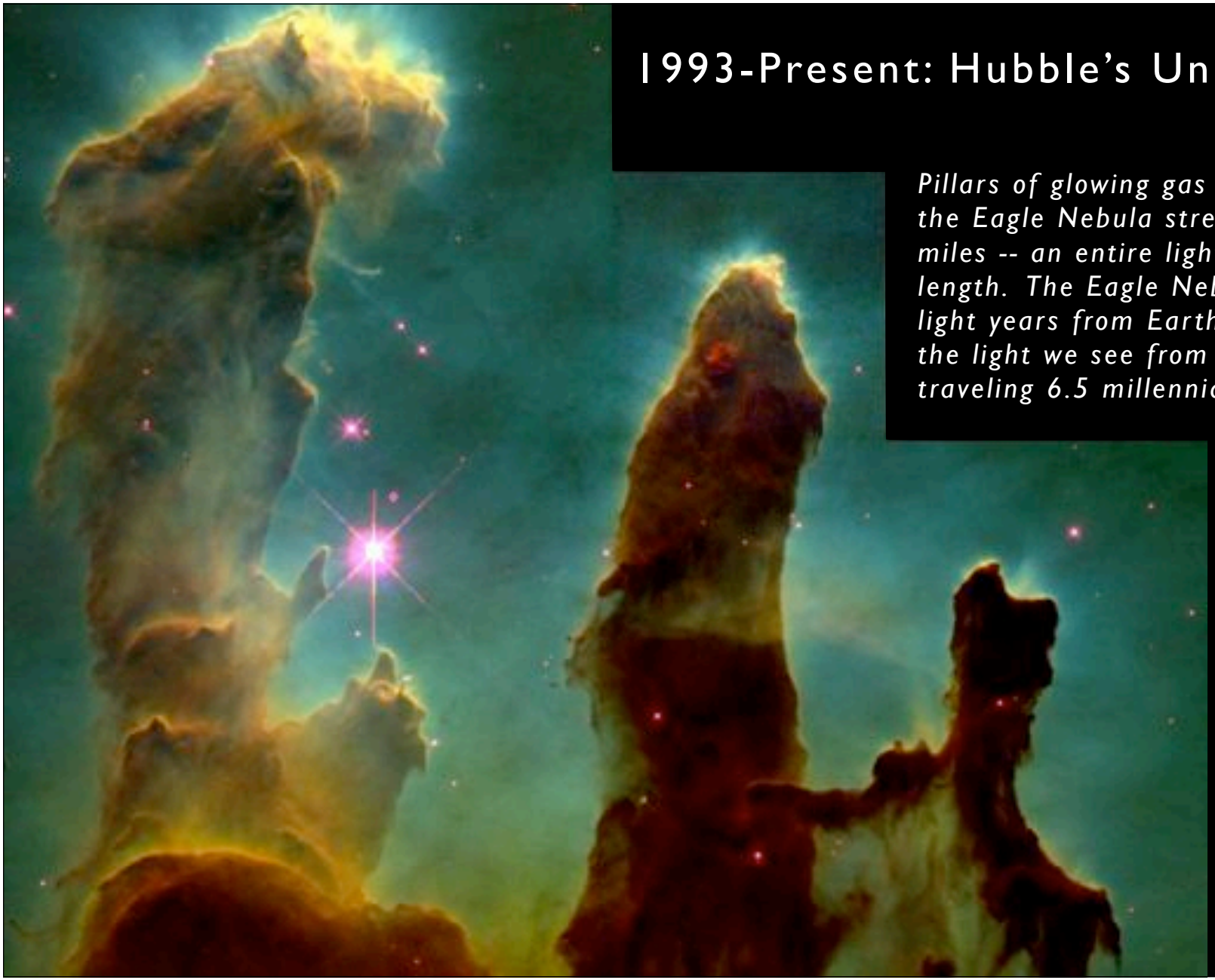
Each of these missions demonstrated the increasingly sophisticated capabilities of Goddard's satellite servicing teams.



"Hubble was a pathfinder. If we're going to go do exploration, we're not going to do exploration by just putting boxes together and replacing components. These things are going to be complex and we're going to have to learn how to fix them."

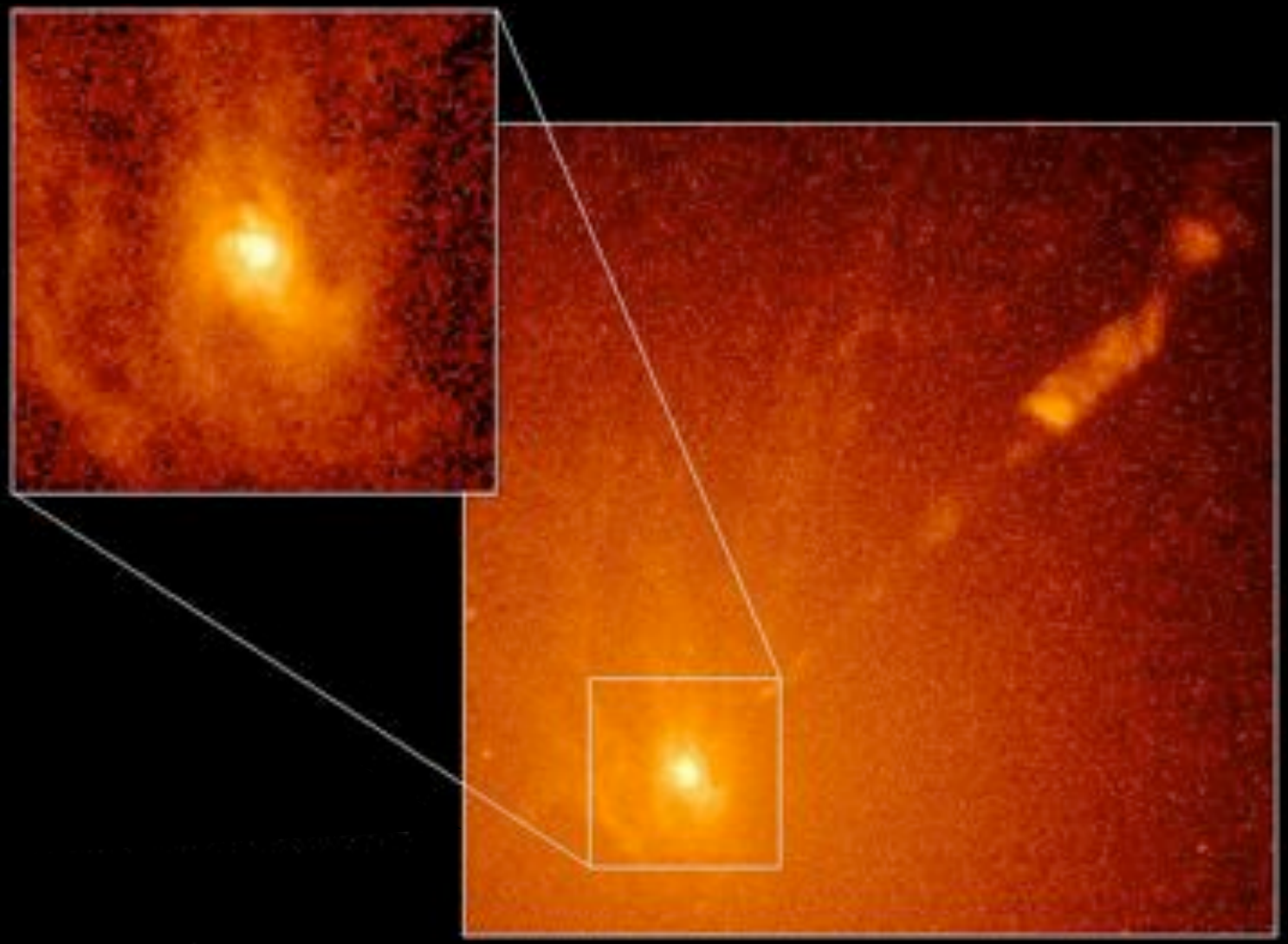
-- HST Deputy Program Manager Mike Weiss

1993-Present: Hubble's Universe



Pillars of glowing gas and dust in the Eagle Nebula stretch 6 trillion miles -- an entire light year -- in length. The Eagle Nebula is 6,500 light years from Earth, which means the light we see from it has been traveling 6.5 millennia to reach us.

1994: Hubble confirms massive black hole at galaxy's core



-- Hubble photographed the galaxy M87, 50 million light years distant, beginning in 1994

-- The jet is composed of electrons and other subatomic particles expelled from a disk of superheated gas (inset) around a black hole with as much mass as 2 billion Suns

-- Today astronomers know that supermassive black holes lurk at the cores of most galaxies


2009: The Hubble Ultra-Deep Infrared Field
Hubble's 48 hour exposure, the deepest image of the universe ever made, sees galaxies up to 13.1 billion light years away.

Outward Bound

Planetary Exploration

"The team, the engineers who make this possible are dauntingly good. You watch them and you say, 'These guys could do anything!' They make dreams possible every day of the week."

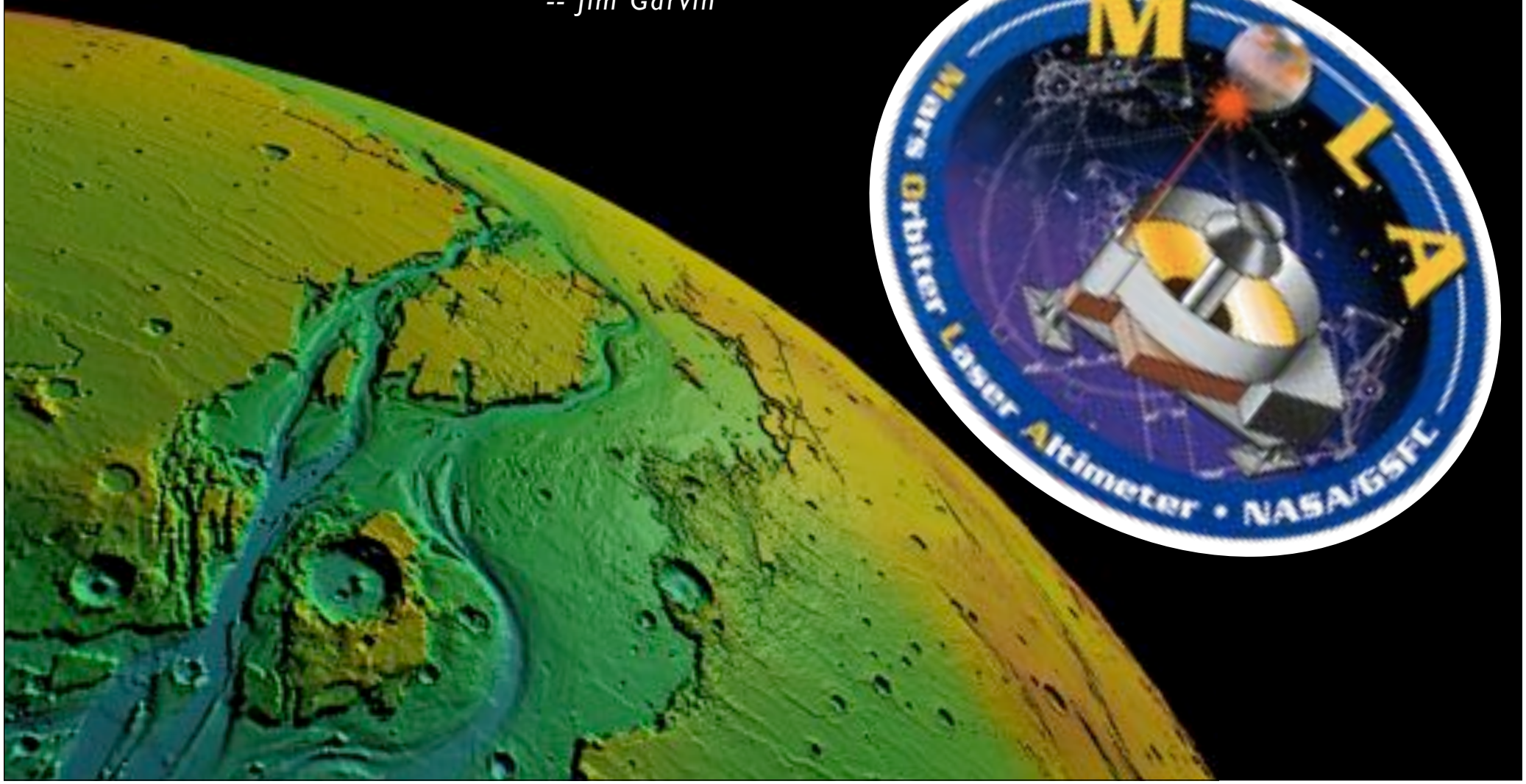
-- Jim Garvin, GSFC Chief Scientist

Mars Global Surveyor

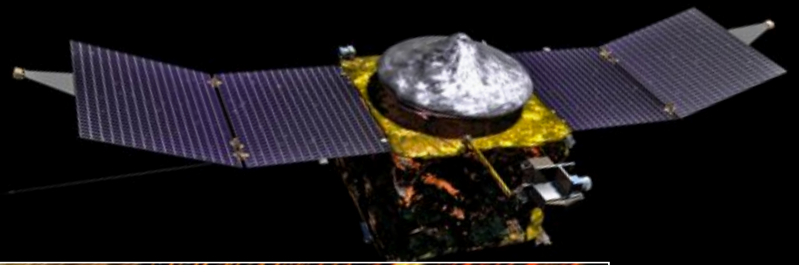
1997: Mars Orbital Laser Alimeter (MOLA) flies on MGS

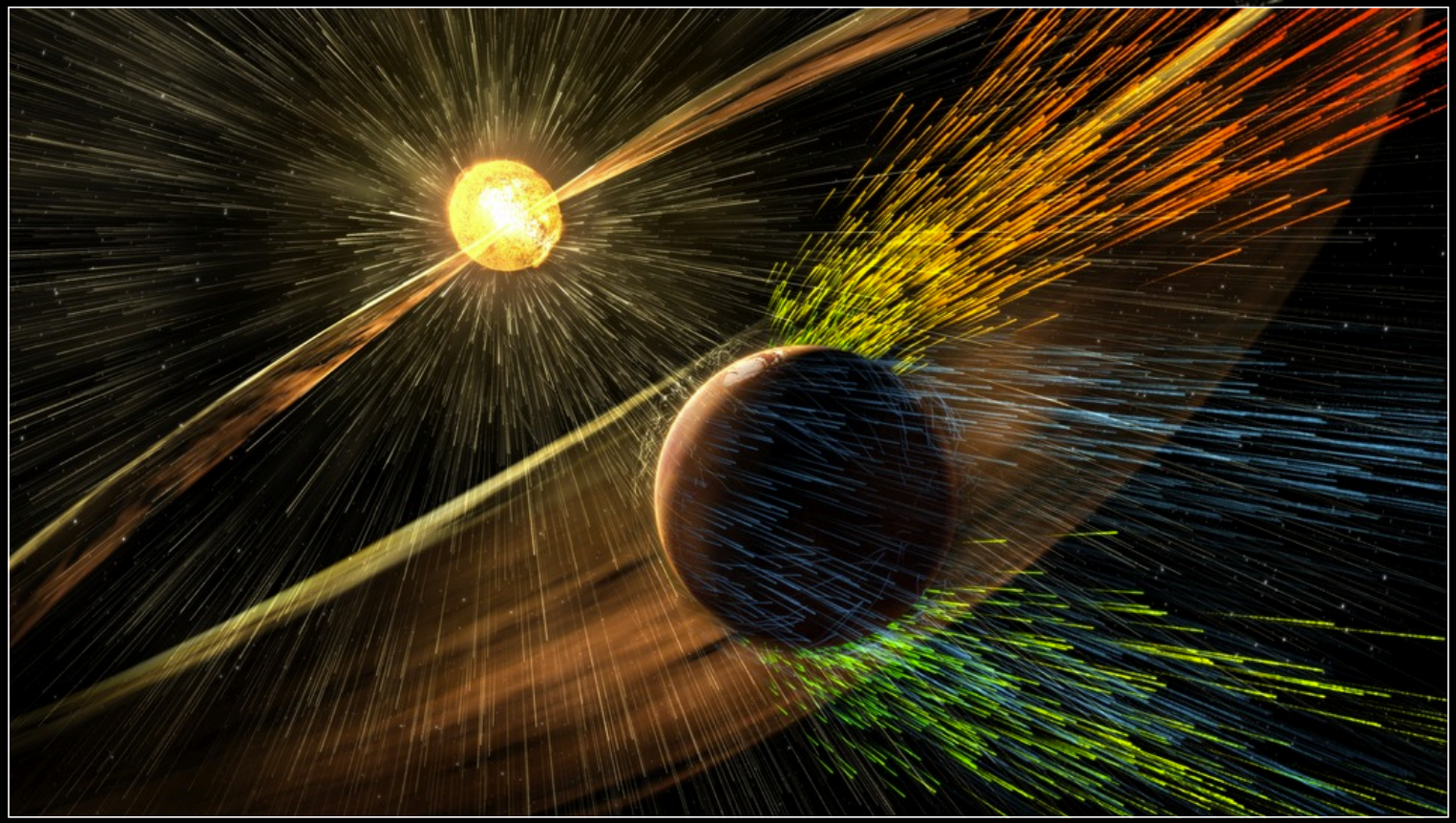
"We wanted to give Mars its third dimension."

-- Jim Garvin



2014-present: MAVEN studies the Martian atmosphere

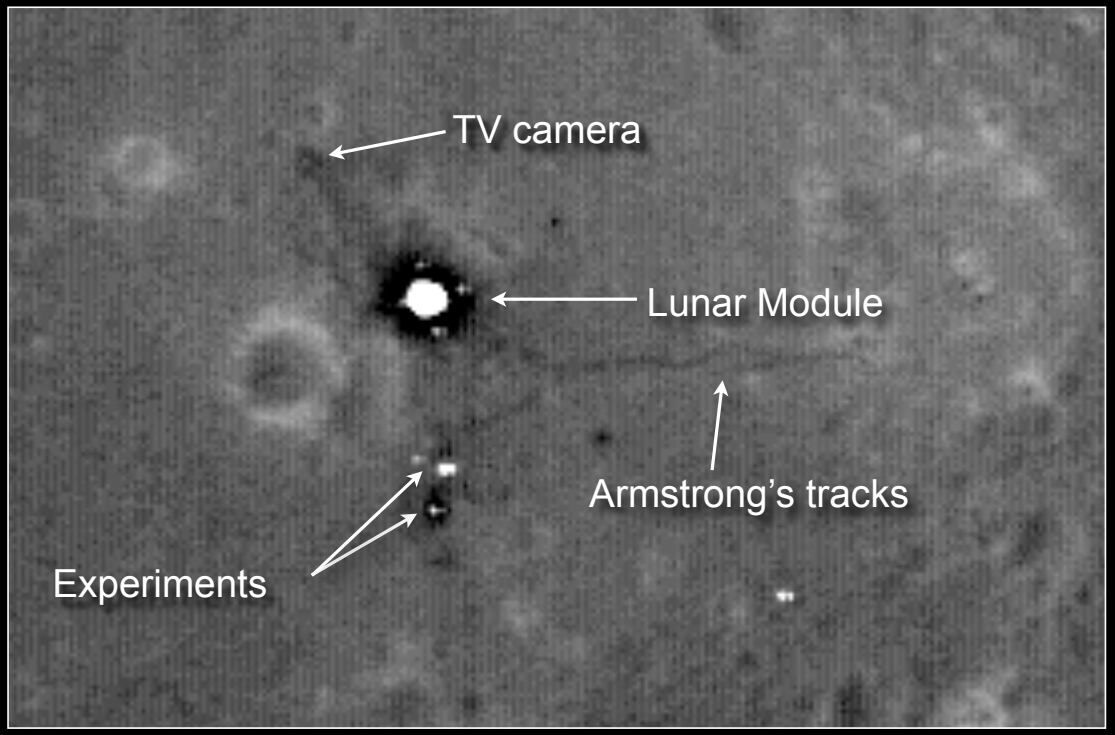




MAVEN data supports the theory that the atmosphere of Mars has been stripped away by the solar wind.

2009: Lunar Reconnaissance Orbiter

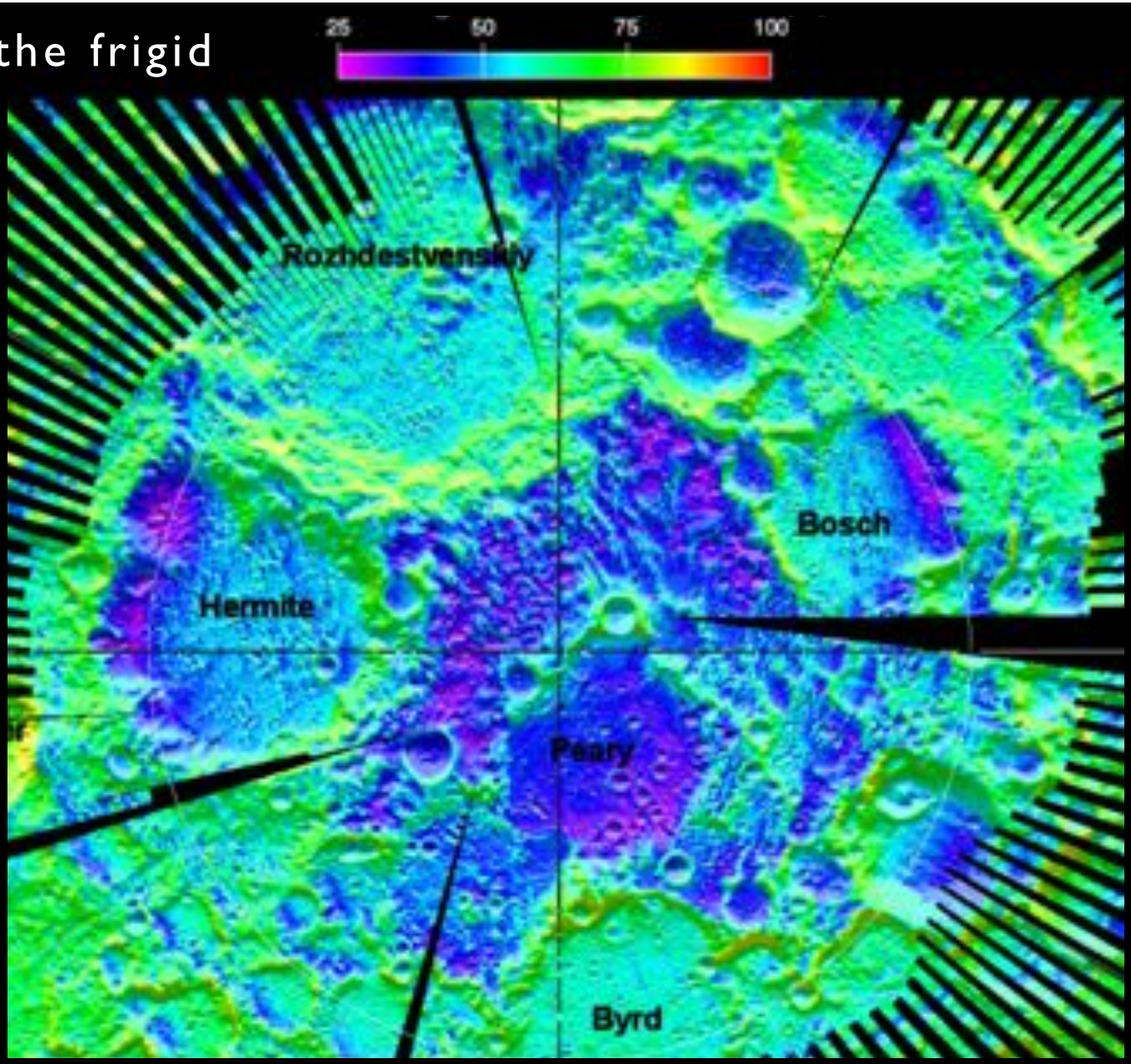
-- Very high resolution imaging and topography
-- Search for surface ice
-- Analyze rough terrain and rock abundance
-- Analyze lunar radiation environment



LRO image of Apollo 11 landing site

LRO's Diviner charts the frigid lunar north pole

Flying over the moon's north pole in the depths of winter night, LRO found a place in the floor of the moon's Hermite Crater at minus 415 degrees Fahrenheit, the coldest temperature measured anywhere in the solar system.



Diviner's temperature map of the lunar north pole is color-coded for degrees Kelvin.

1995-Present: SOHO (Solar and Heliospheric Observatory)

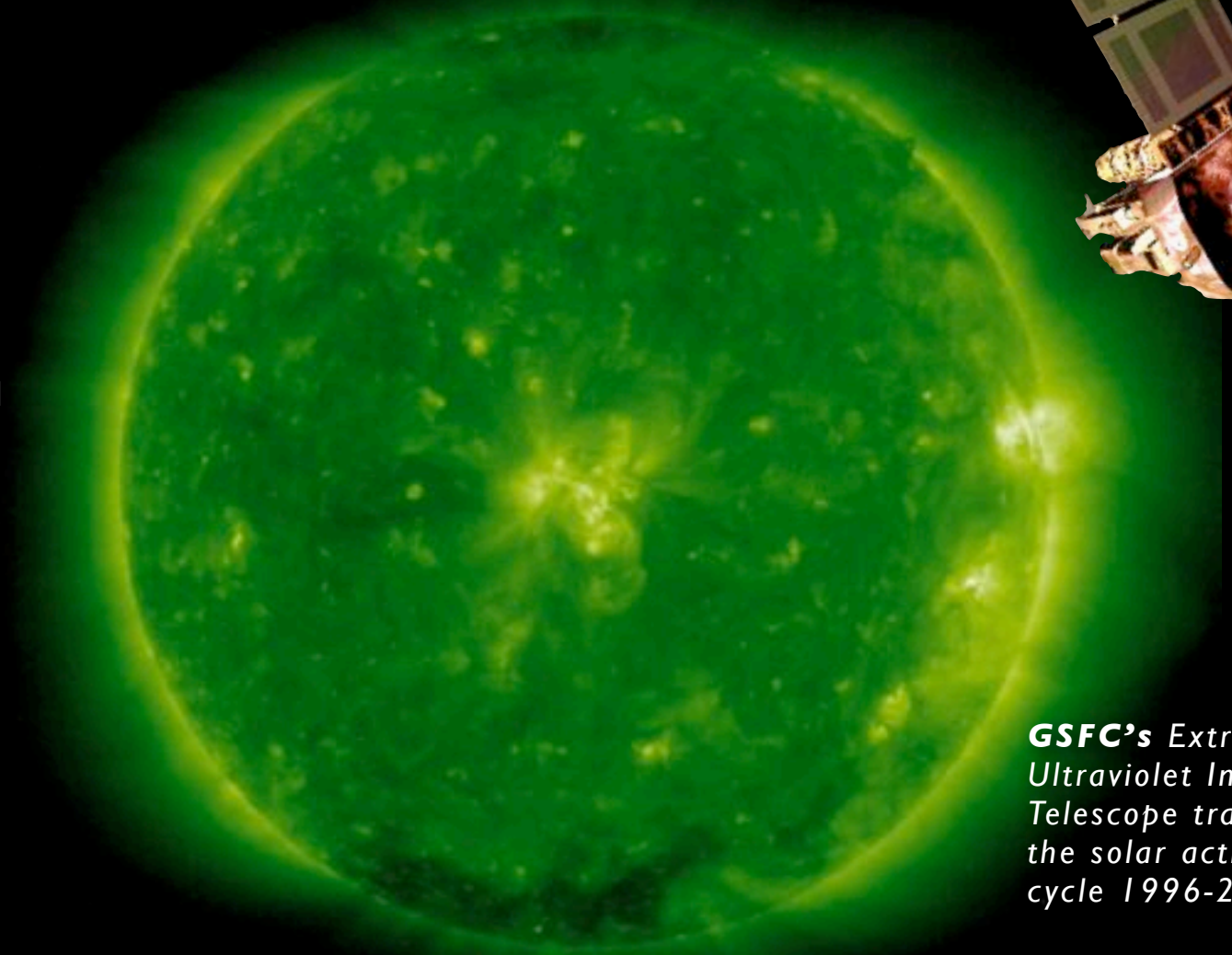
-- Launched December 1995 to the L-1 Lagrange point 1.5 million km from Earth

-- Joint project of European Space Agency (ESA) and NASA Goddard (spacecraft built in Europe)

-- Studied solar wind particles, oscillations on solar surface, magenetic fields, outer atmosphere (corona)

-- Originally planned as a 2-year mission

-- Extended mission through 2014



GSFC's *Extreme Ultraviolet Imaging Telescope tracks the solar activity cycle 1996-2005*

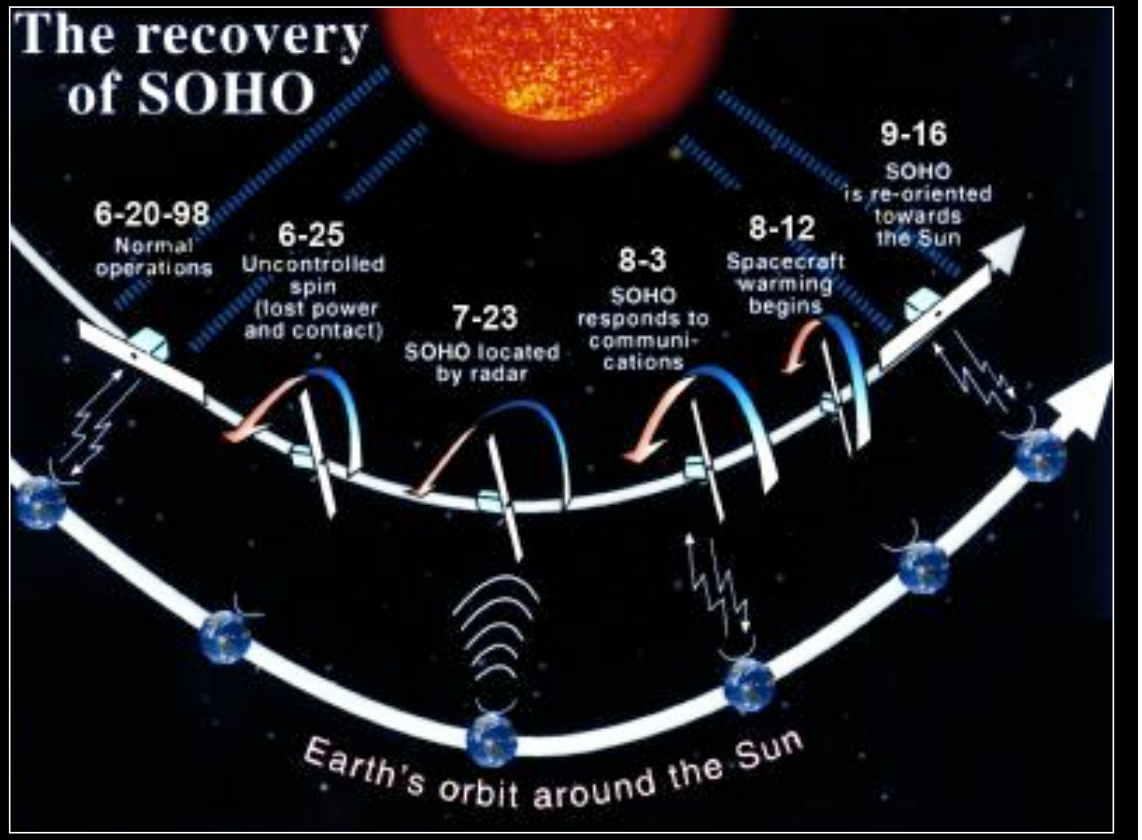
1998: SOHO's million-mile rescue

In June 1998 a command error by the ground sent SOHO tumbling, causing it to lose power and communications. The craft froze, damaging the electronics in its control system.

At Goddard, calculations showed that after 90 days the craft's solar arrays would receive sunlight again, giving controllers an opportunity to regain control of SOHO.

Beginning in early August power and communications were restored. Goddard used special techniques, previously developed for the IUE mission, that allowed the craft to be controlled without any gyroscopes.

By late September, SOHO was fully operational.



SOHO orbits about the 1st Sun-Earth Lagrange Point (L1), an equilibrium point about 1.5 million km from earth in the direction of the Sun.

1998-2010: GSFC's TRACE explores the solar coronal transition region

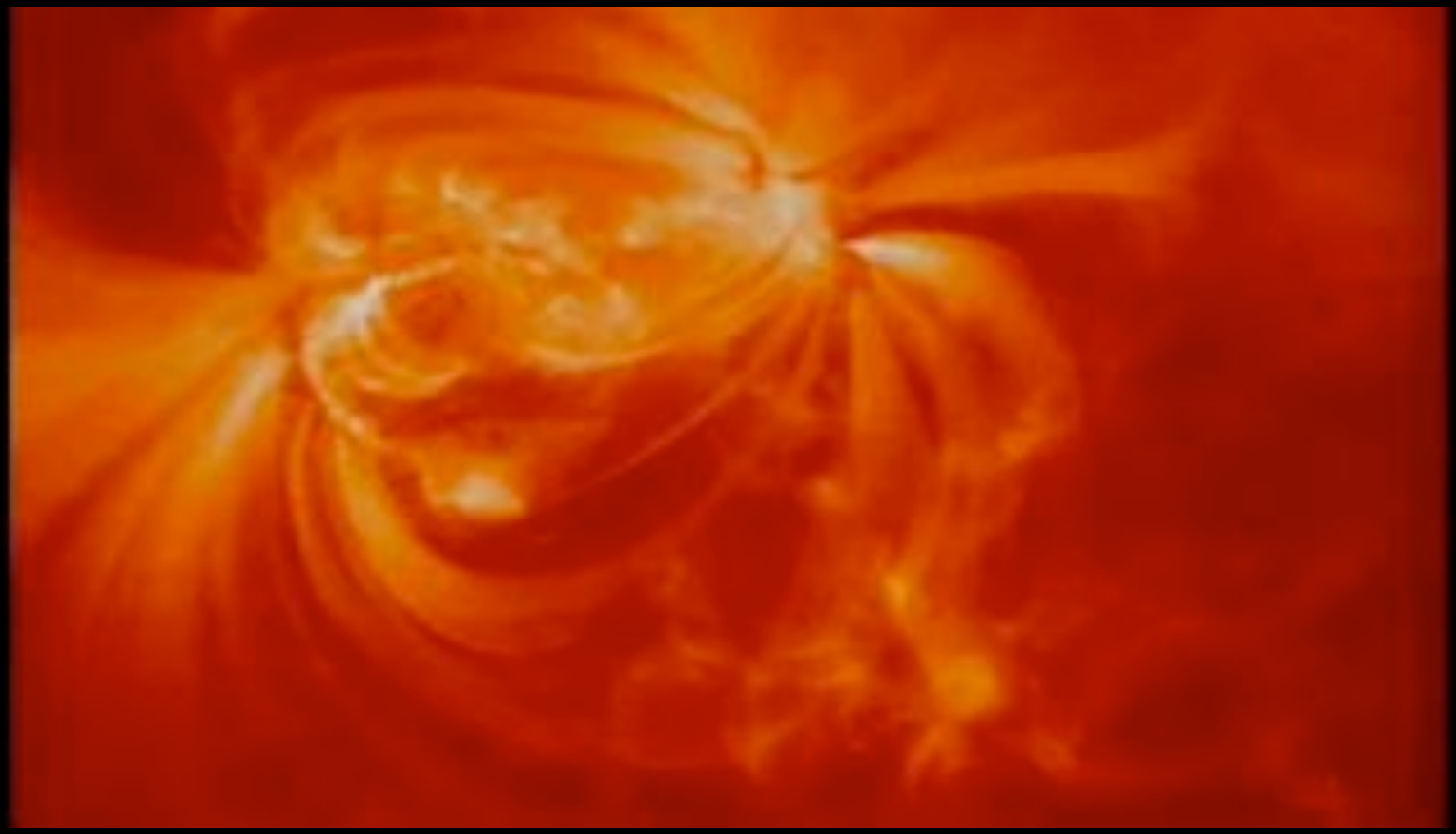
TRACE explored the magnetic field in the solar atmosphere by studying:

-- 3-dimensional field structure

-- temporal evolution in response to photospheric flows

-- time-dependent coronal fine structure

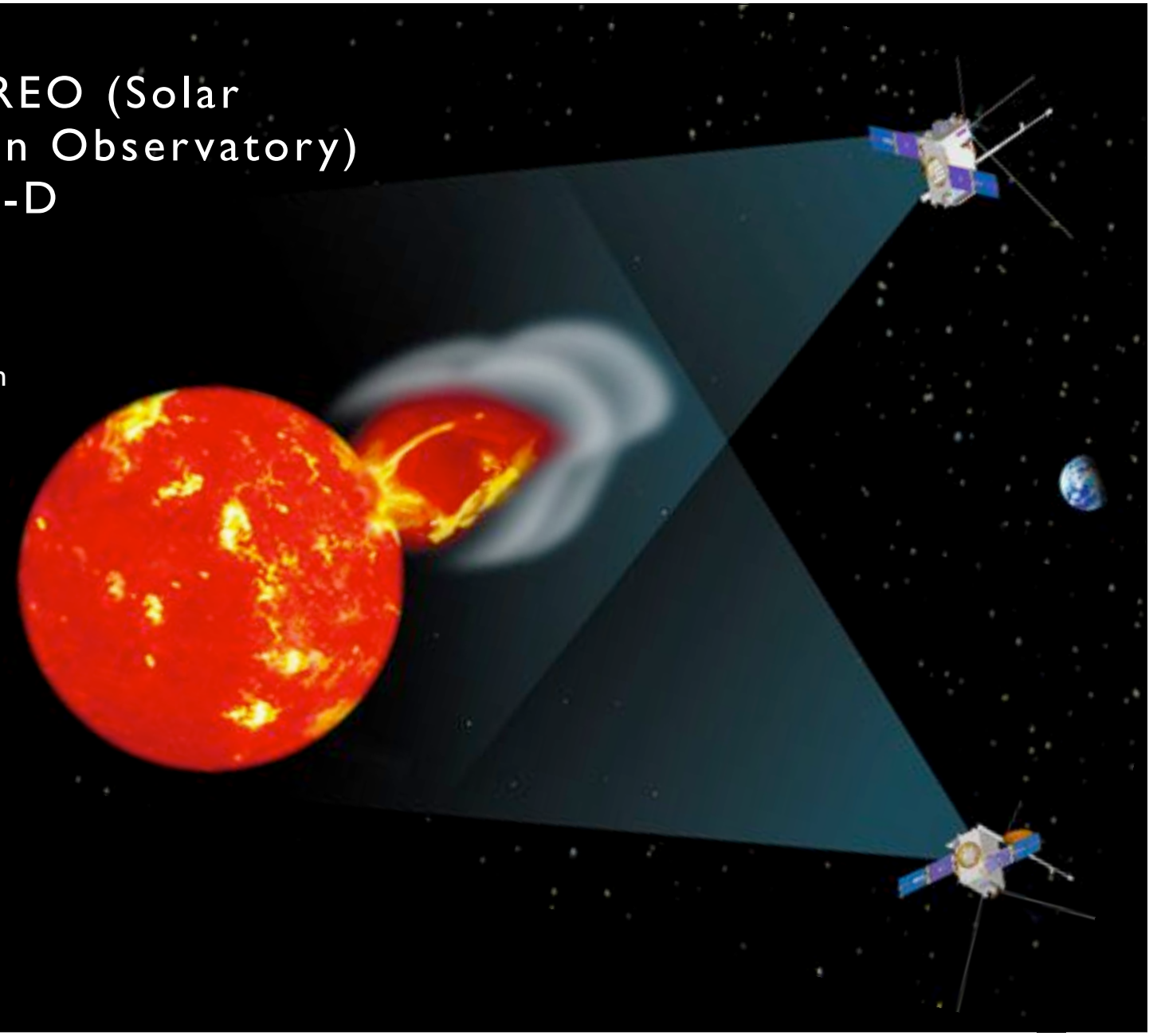
-- coronal and transition region thermal topology.



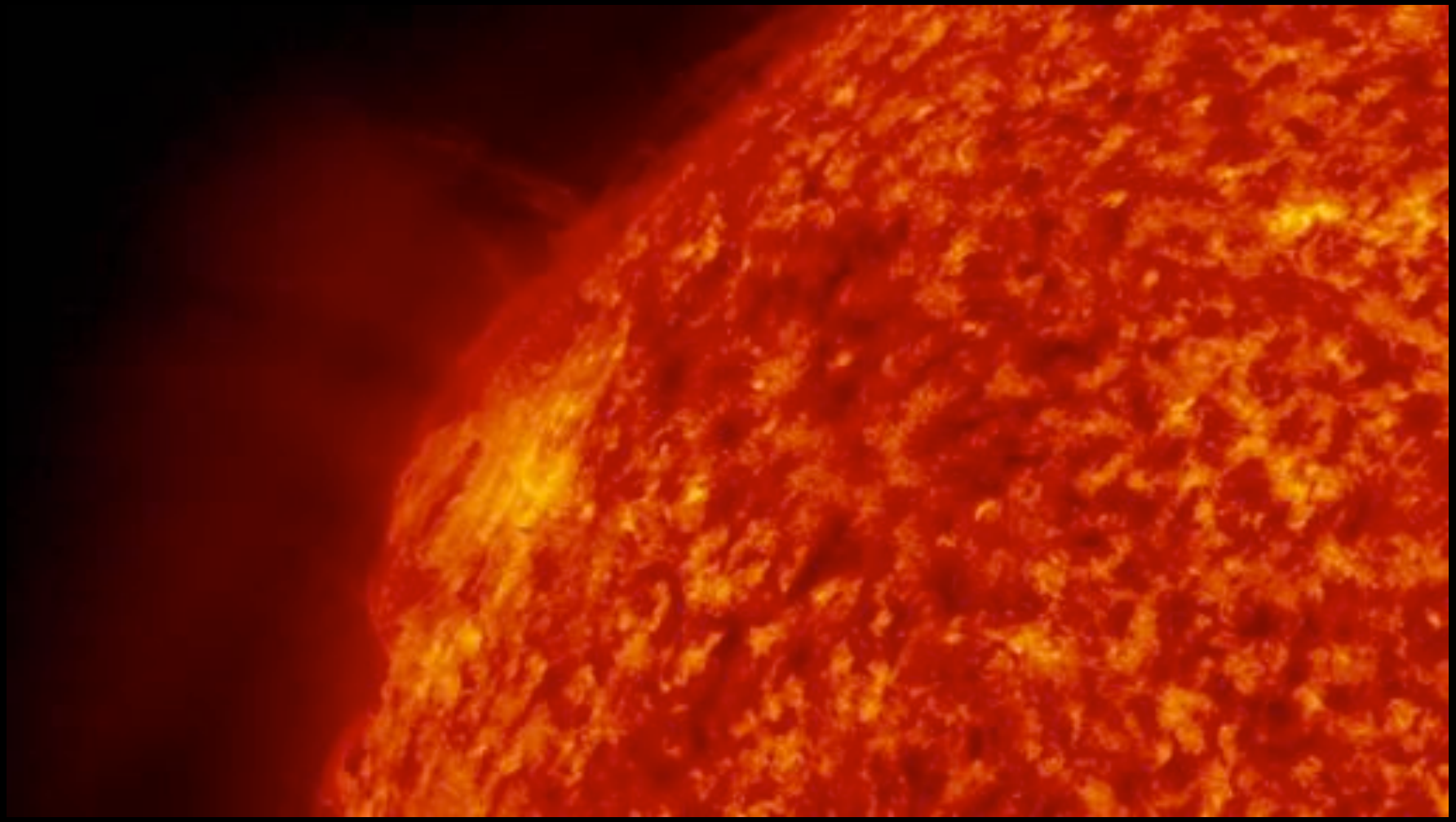
2006: GSFC's STEREO (Solar Terrestrial Relation Observatory) views the Sun in 3-D

STEREO's depth perception will improve forecasts of the arrival time and effects of Earthbound Coronal Mass Ejections (CMEs)

CMEs can cause magnetic storms that can overload power line equipment and radiation storms that disrupt satellites



2010: GSFCs Solar Dynamics Observatory



1989-1994: The Cosmic Background Explorer (COBE)

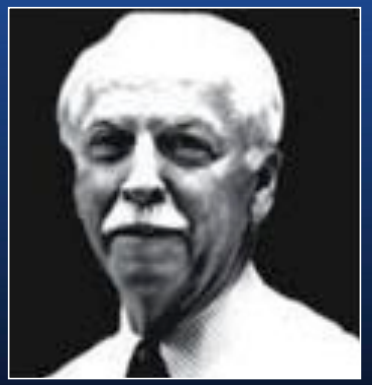
COBE's mission was to answer one of the most profound questions humans know how to ask: How did the universe begin?

NASA established COBE at Goddard Space Flight Center as an in-house project, meaning that the engineering work was done by civil servants rather than contractors.

"You could never have written a specification on a contract or a statement of work to have someone build COBE. It was Nobel Prize science that depended on groundbreaking technology. Nothing like the instruments we needed had ever been built before.

"We had a 100% failure rate along the way, when we put the instruments in test dewars and tried to test materials' properties and electronics. You couldn't afford to have a contractor do that."

-- Dennis McCarthy, COBE Deputy Project Manager



COBE Science and Engineering: A Meeting of Minds

"When I first spoke with engineers and we were building the detectors to be used on COBE, they asked well, how sensitive you want them to be? And I said, of course, as sensitive as you can make them. And they answered, that no, I need a number. And gradually, we got to speak and respect each other's language."

-- Astronomer Nancy Boggess

Transforming COBE

"The Challenger *accident forced us to rethink every aspect of the spacecraft's design, including moving from a shuttle launch to a Delta rocket."*

-- Dennis McCarthy

Shuttle version:

15 foot diameter, 10,594 pounds

Delta version:

8 foot diameter, 4,828 pounds

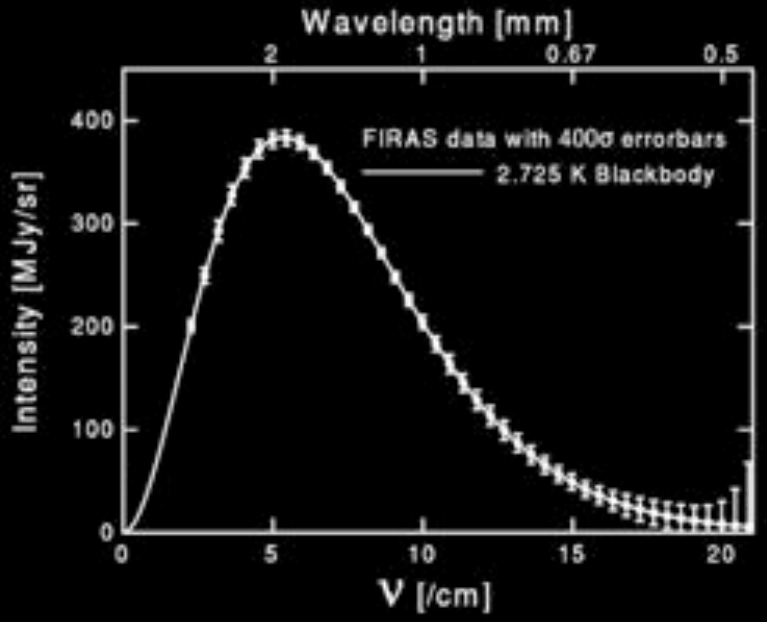
Goddard Director Noel W. Hinners (left) played a key role, making sure the resources necessary for the redesign effort were available to the COBE team.

John Mather and COBE

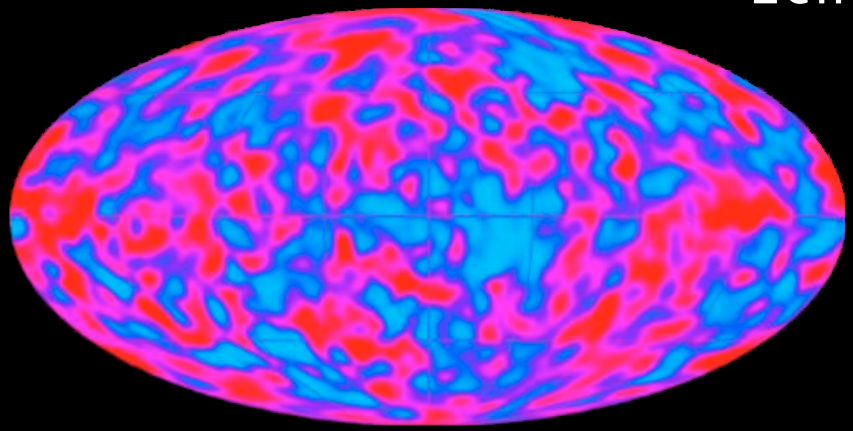
"The hunt for the eureka moment, the light bulb going off, the sudden enlightenment, some way to build new equipment that could make a spectacular measurement, has always been one of my greatest pleasures. Getting the universe itself to yield its secrets is even harder, but finding a way to make a measurement is a big step."

-- GSFC's John Mather

Right: The spectrum of the cosmic microwave background, measured by COBE's Far Infrared Absolute Spectrometer, agrees perfectly with the "blackbody" spectrum that the Big Bang theory predicted.

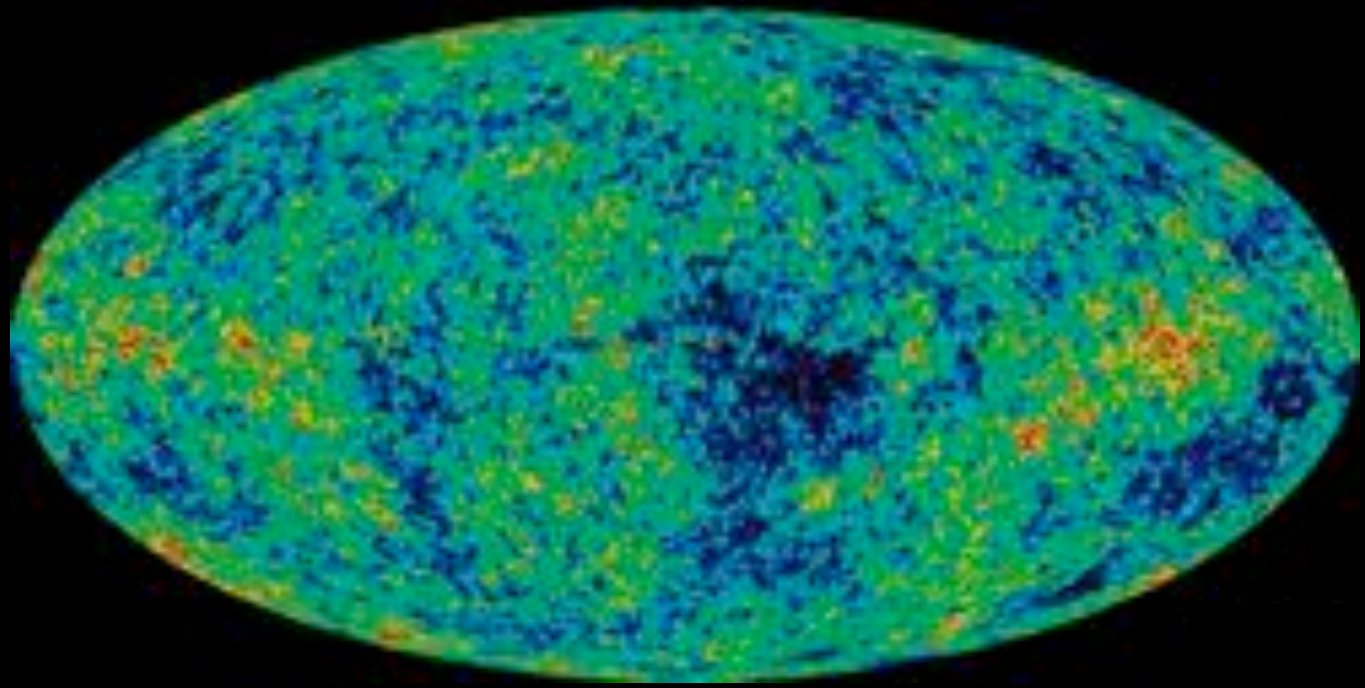


Echoes of the Big Bang: COBE and WMAP



Left: COBE's all sky portrait (left) revealed minute variations in the temperature of the Cosmic Microwave Bacground, interpreted as the first seeds of galaxies.

Below: WMAP (launched 2001) was 45 times more sensitive and had 33 times finer angular resolution, recording temperature variations of 35 millionths of a degree K.

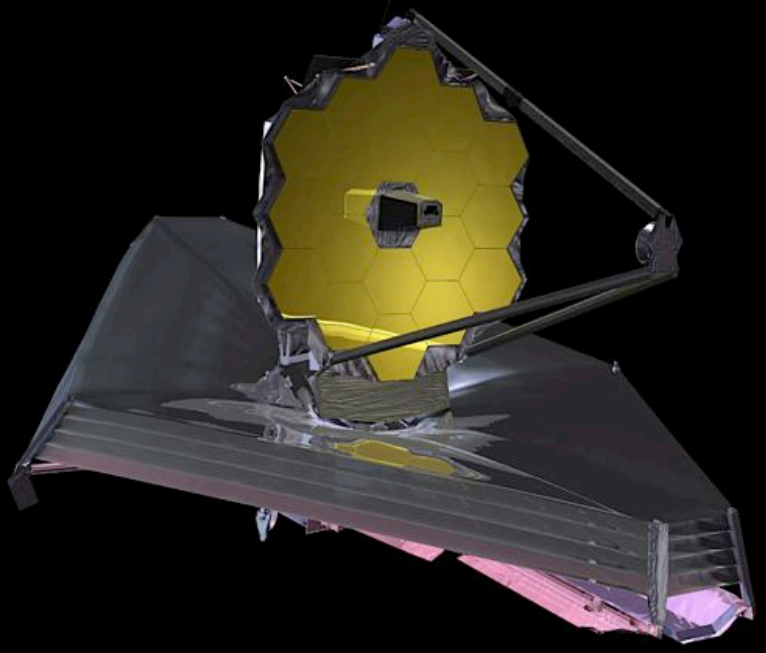


WMAP's definitive, extraordinary findings:

-- The universe is 13.73 billion years old (+/- 120 million years)

-- The universe is made up of 72 percent dark energy and 23 percent dark matter

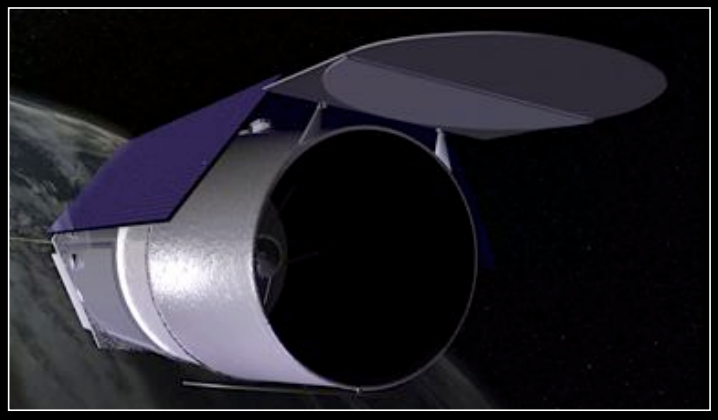
Future missions: astronomy



James Webb Space Telescope (JWST)

6.5 meter mirror; sunshield as big as a tennis court
Detect the first light after the Big Bang
Probe the formation of the earliest galaxies
Study the birth of stars and planetary systems

2018 scheduled launch



Wide Field Infrared Survey Telescope (WFIRST)

What is the nature of the so-called Dark Energy that is driving the current accelerating expansion of the universe?

2022 scheduled launch

A Journey Without End

"There can be no thought of finishing for 'aiming for the stars,' both figuratively and literally, is a task to last the generations. But no matter how much progress one makes, there is always the thrill of just beginning."

-- Robert Goddard