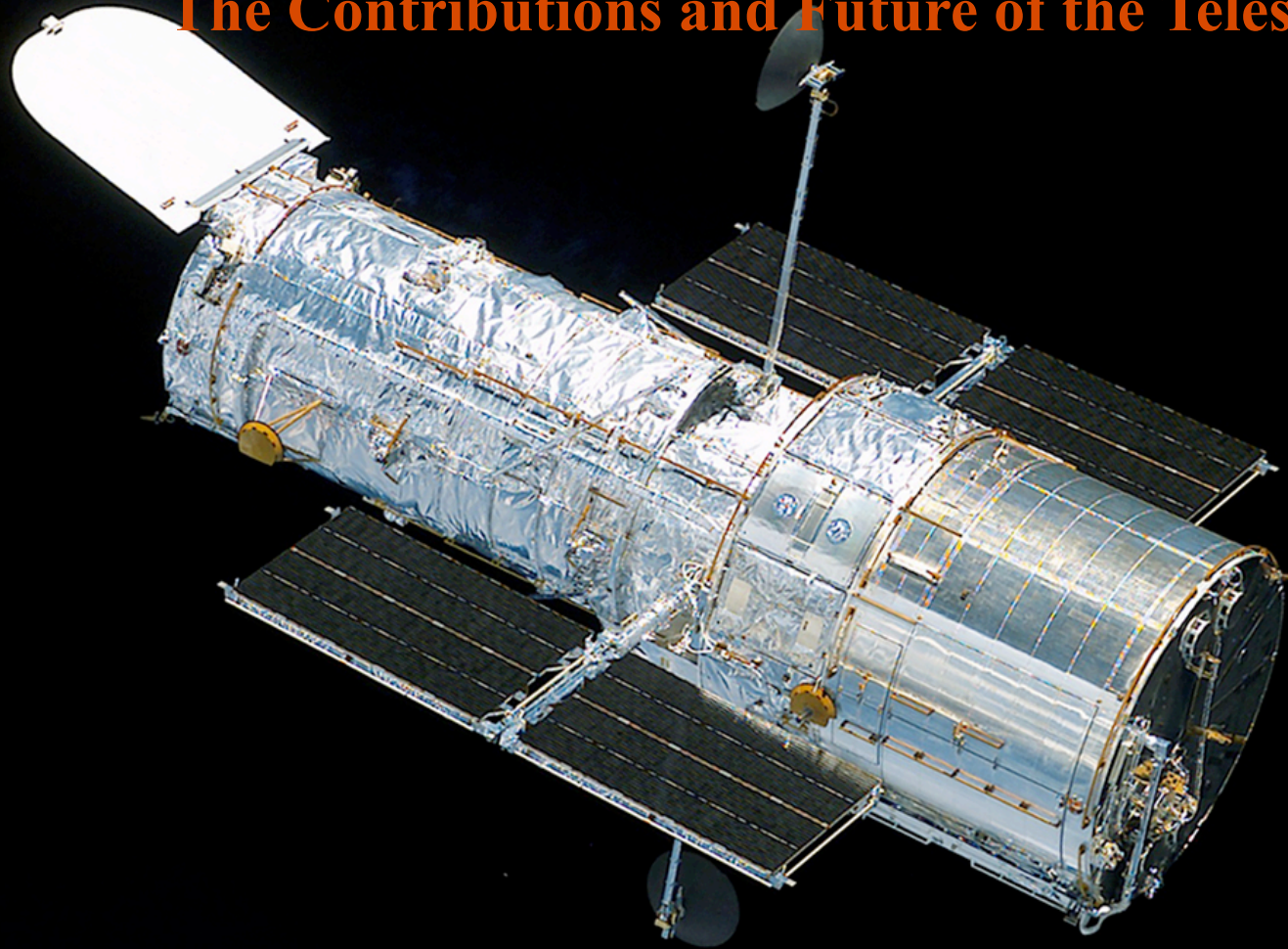


From Galileo to Hubble and Beyond: The Contributions and Future of the Telescope



*Interpreted by
George Helou*

The Extragalactic Perspective

Duccio Macchetto

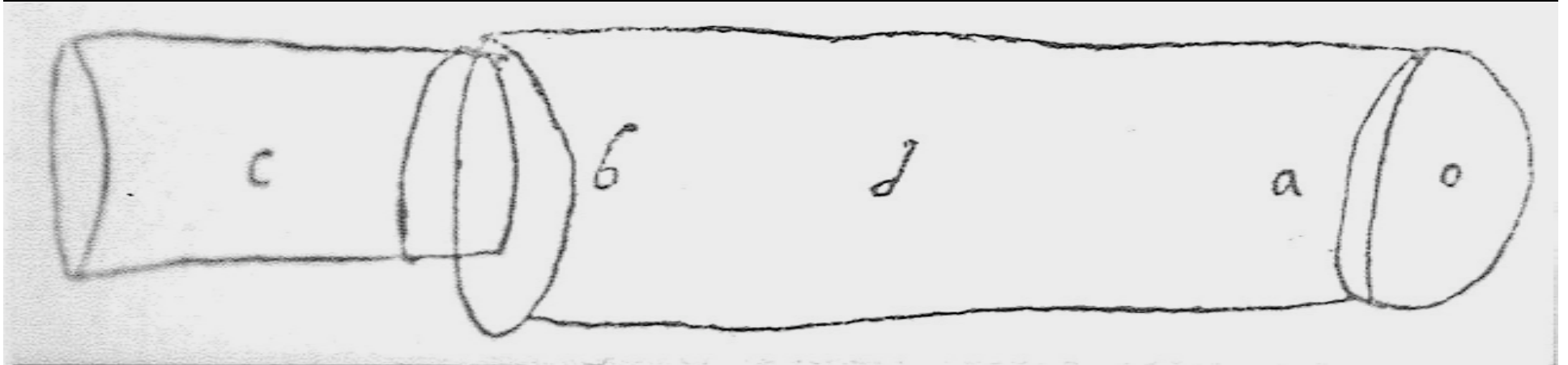
CALTECH, NOVEMBER 2009



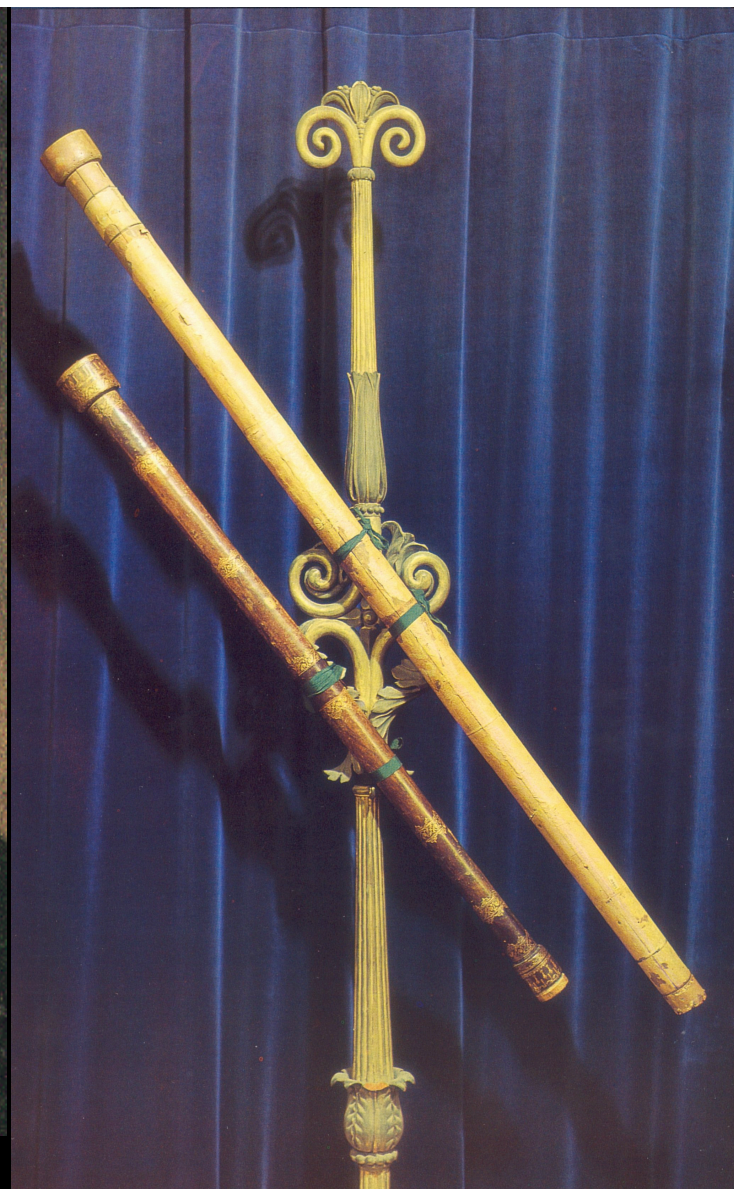
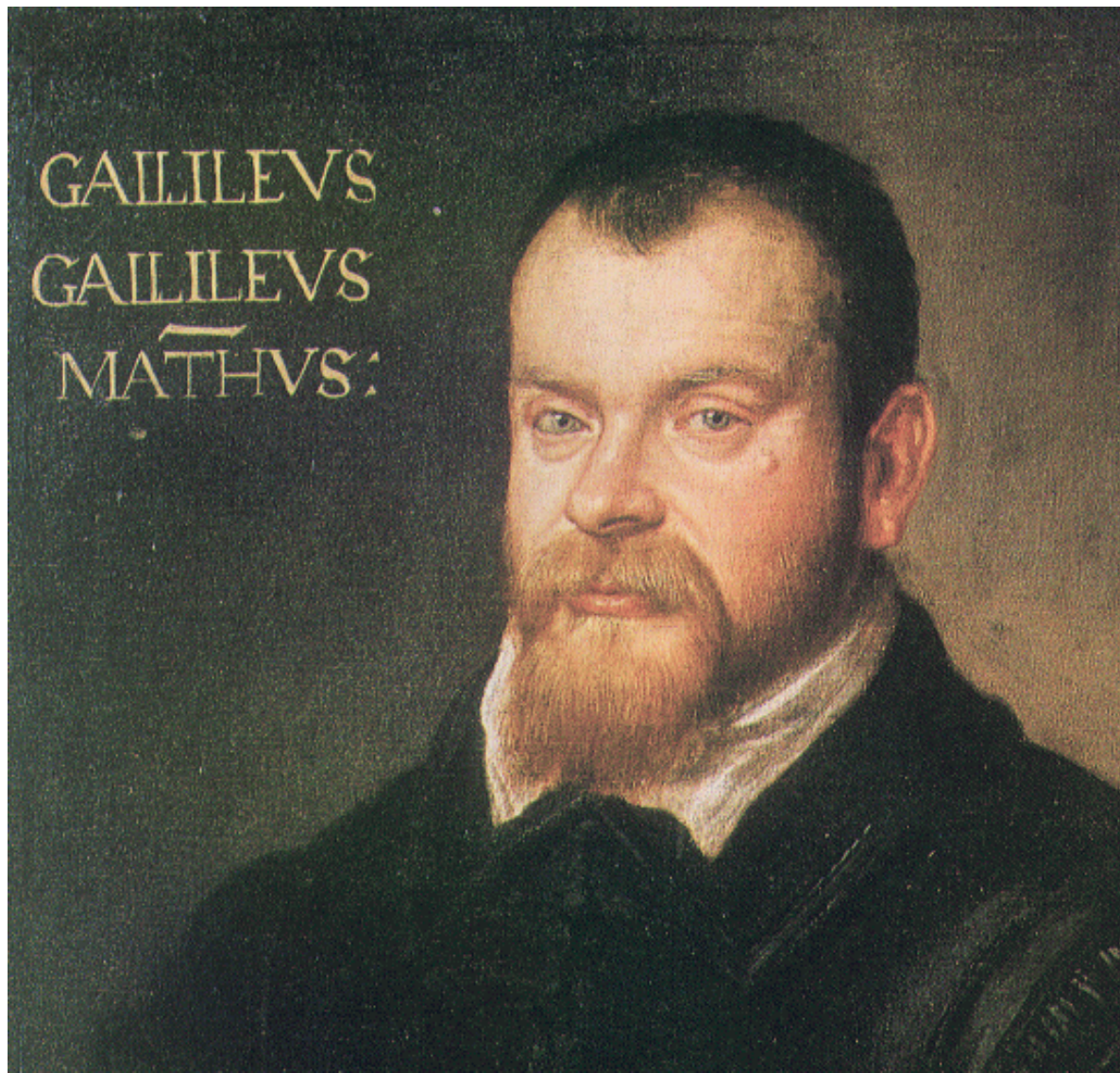


- The earliest record of the existence of the telescope is a letter of the government of Zeeland to its delegation to the States General of the Netherlands, dated 25 September 1608, which instructs them to be of help to the bearer, "who claims to have a certain device by means of which all things at a very great distance can be seen as if they were nearby, by looking through glasses which he claims to be a new invention."

Hans Lippersheim (Lippershey) 1570-1619, Wesel, Middelburg



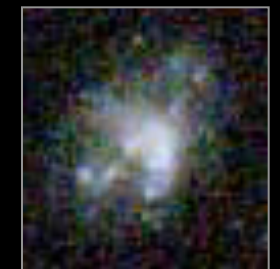
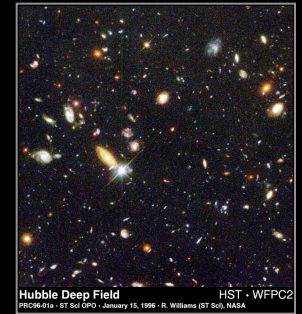
“PHASE A” SPECS!



Big Telescopes and Sensitive Detectors in Space

Big Telescopes and Sensitive Detectors in Space

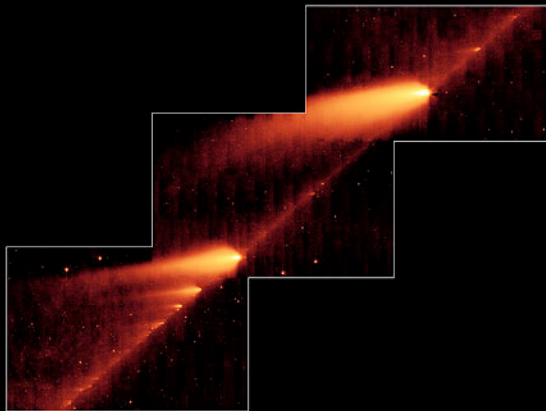
Sensitivity Improvement over the Eye



Adapted from *Cosmic Discovery*, M. Harwit

Spitzer Space Telescope

Infrared holds half the history of cosmic star formation



Comet 73P/Schwassmann-Wachmann 3

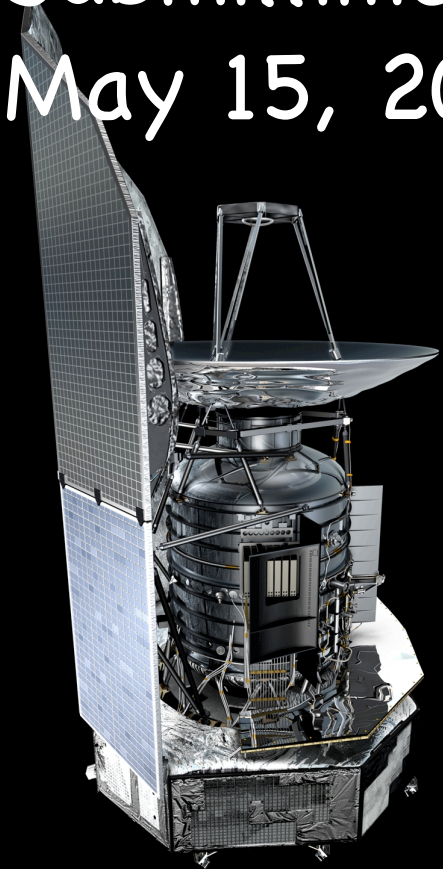
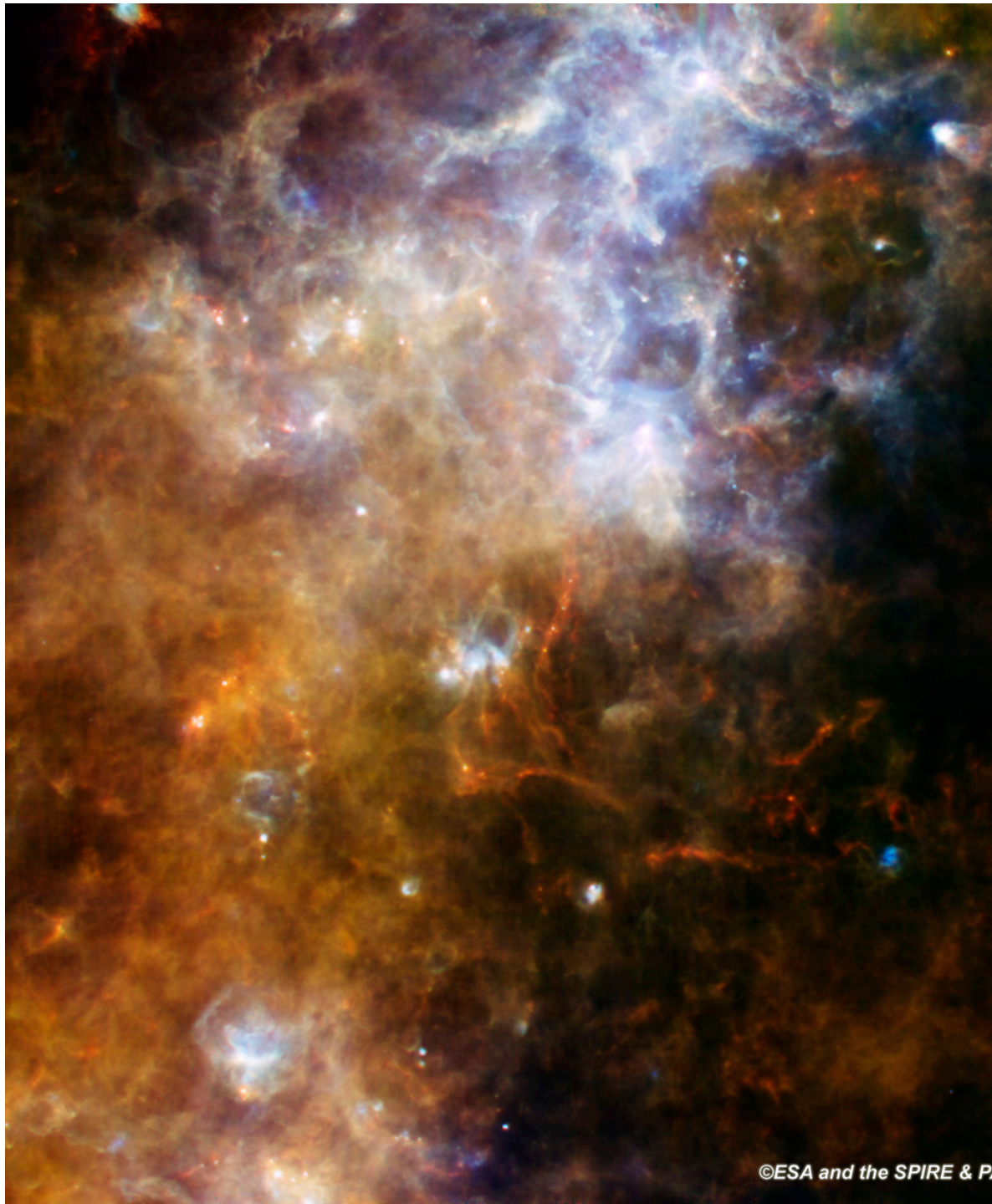
Spitzer Space Telescope • MIPS



Dusty Eye of the Helix Nebula (NGC 7293)

Spitzer Space Telescope • IRAC • MIPS

Herschel: Submillimeter May 15, 2009





WISE:
Wide-Field Infrared Survey Explorer
Launch date: Dec 9, 2009



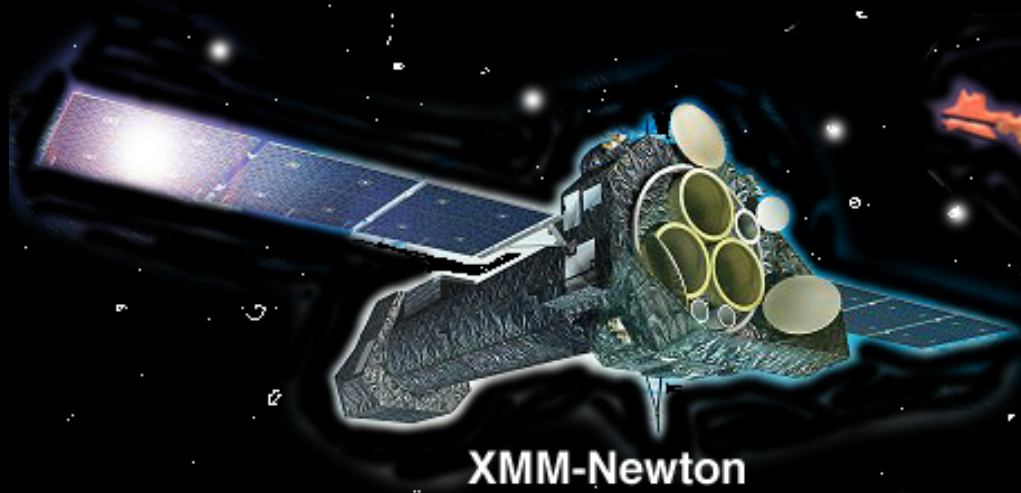
X-Ray Observatories reveal the violent Universe, probe Black Holes



Chandra



BeppoSAX

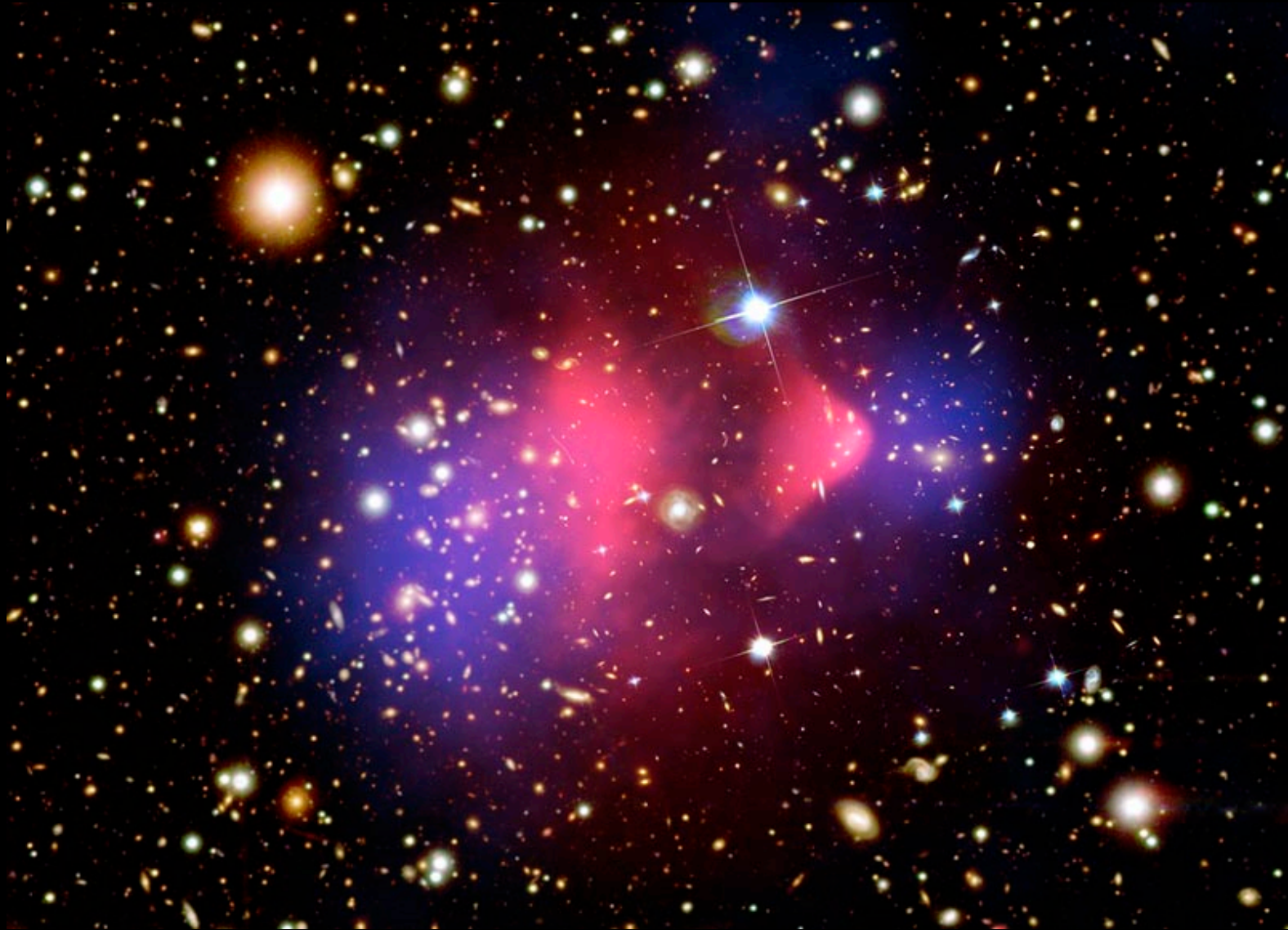


XMM-Newton



RXTE

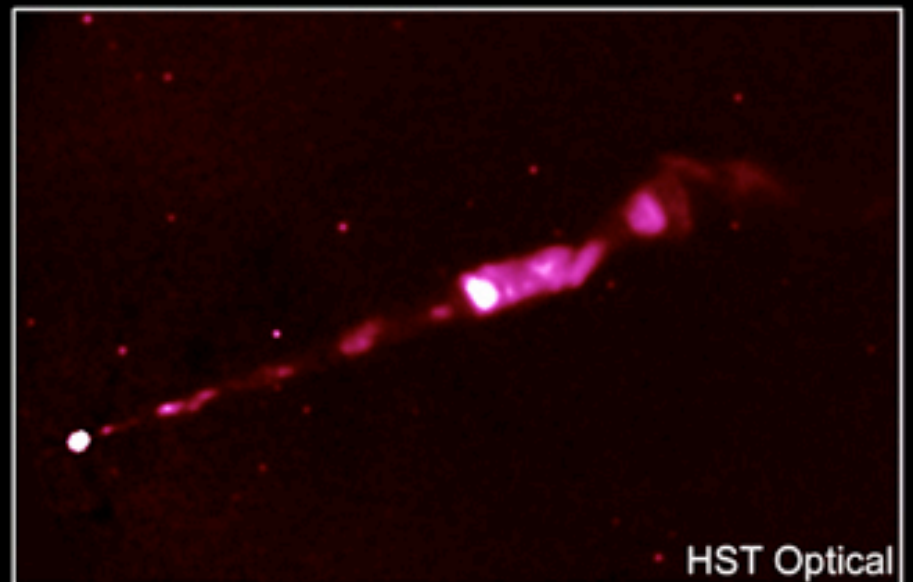
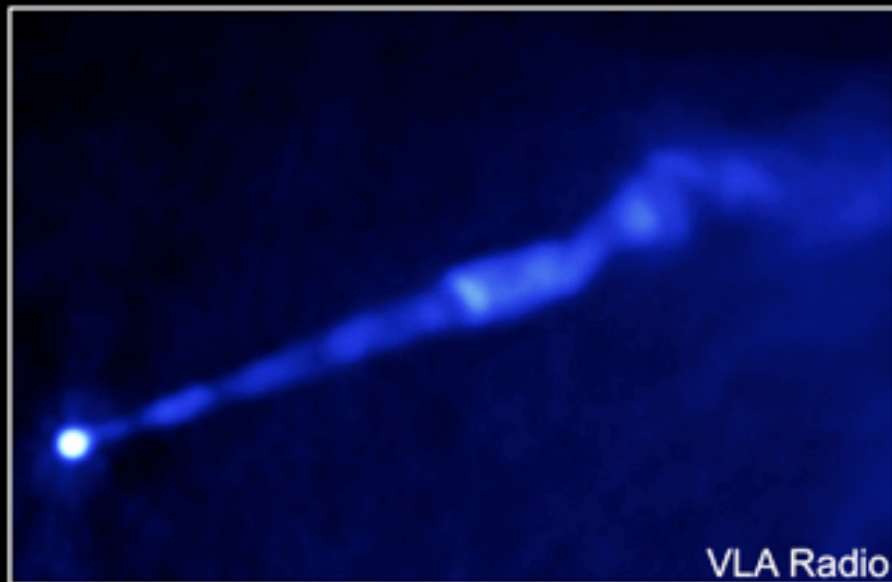
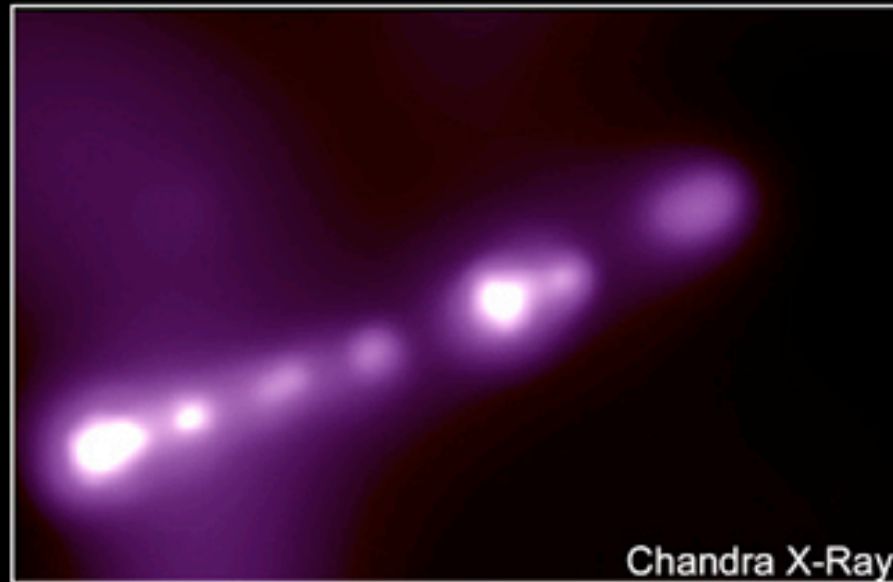
Normal and Dark Matter in two colliding clusters



Hubble Space Telescope and the Chandra X-Ray Observatory

X-ray/Radio Jets

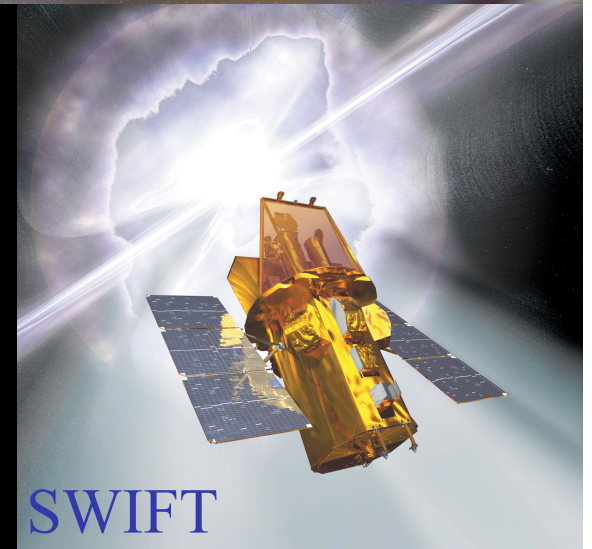
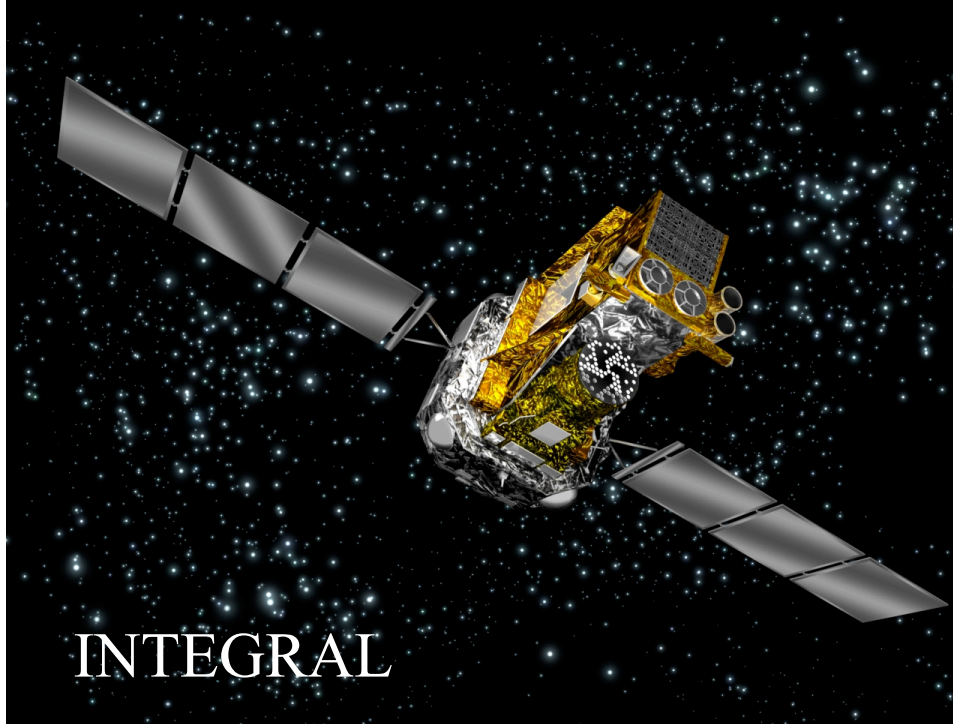
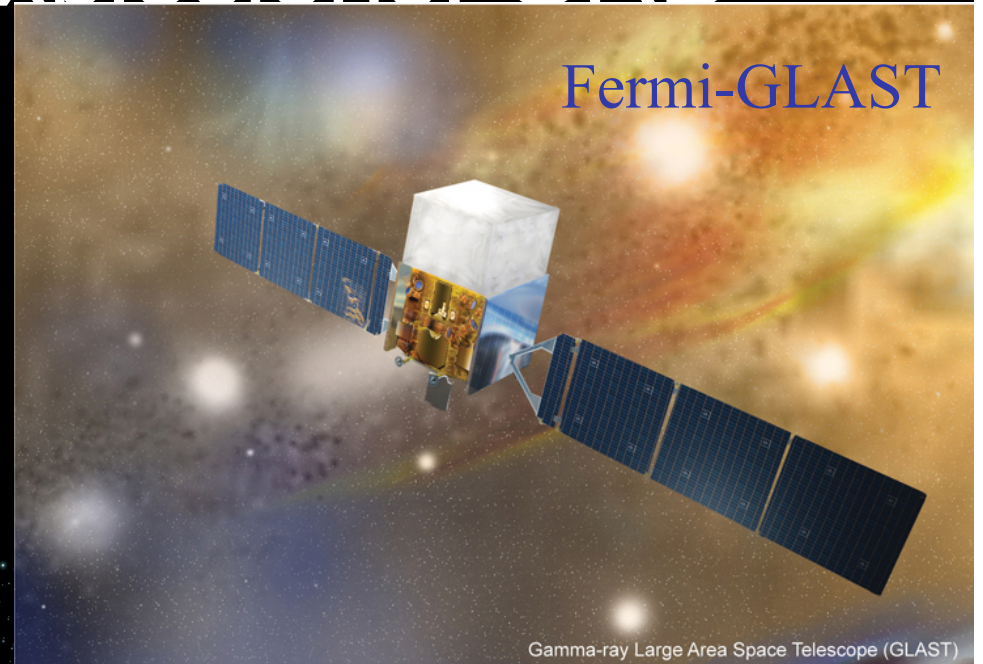
M87



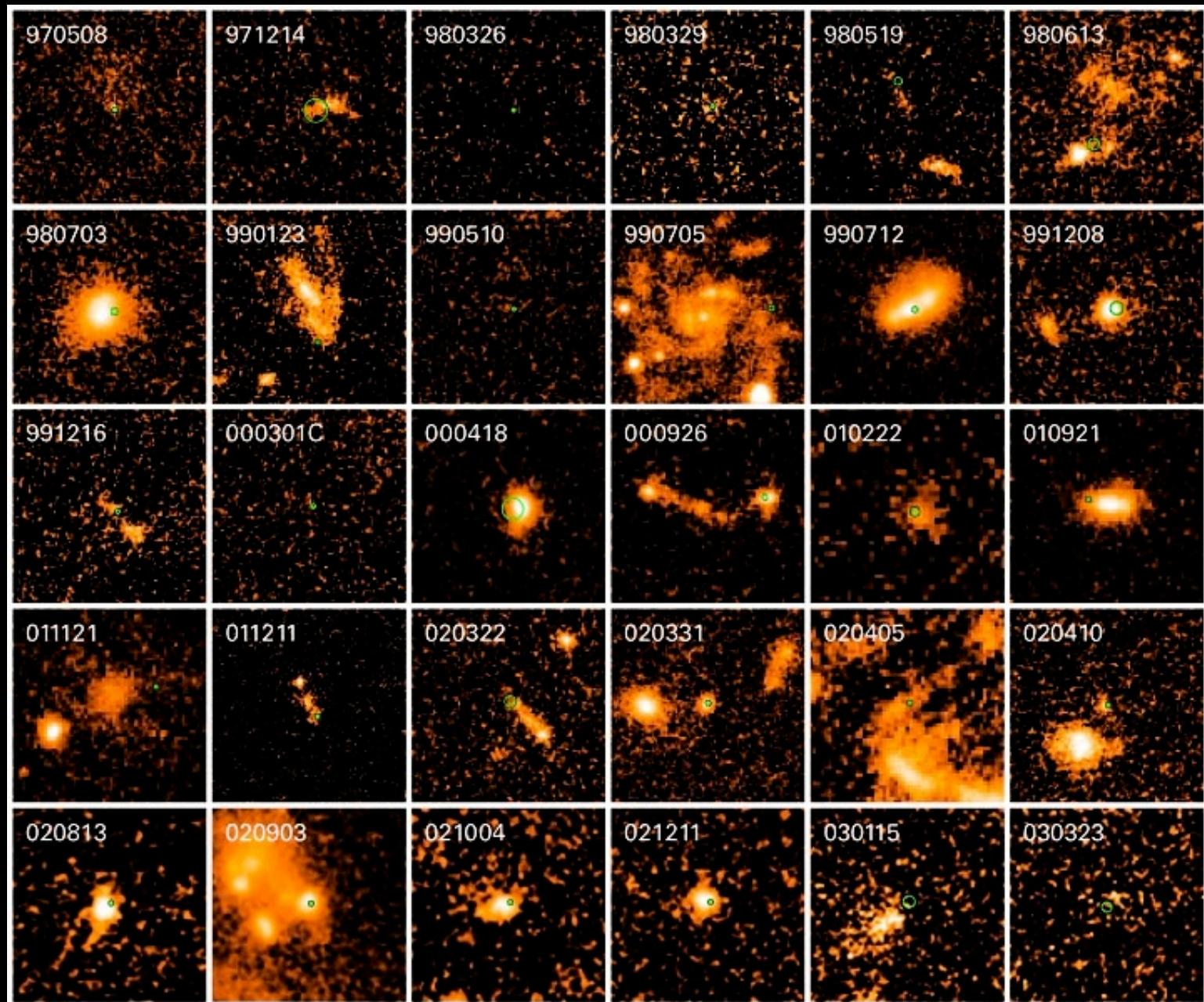


CEN A

Gamma-Ray Observatories reveal the most intense explosions: GRB



A Galaxy on (nearly) Every Burst

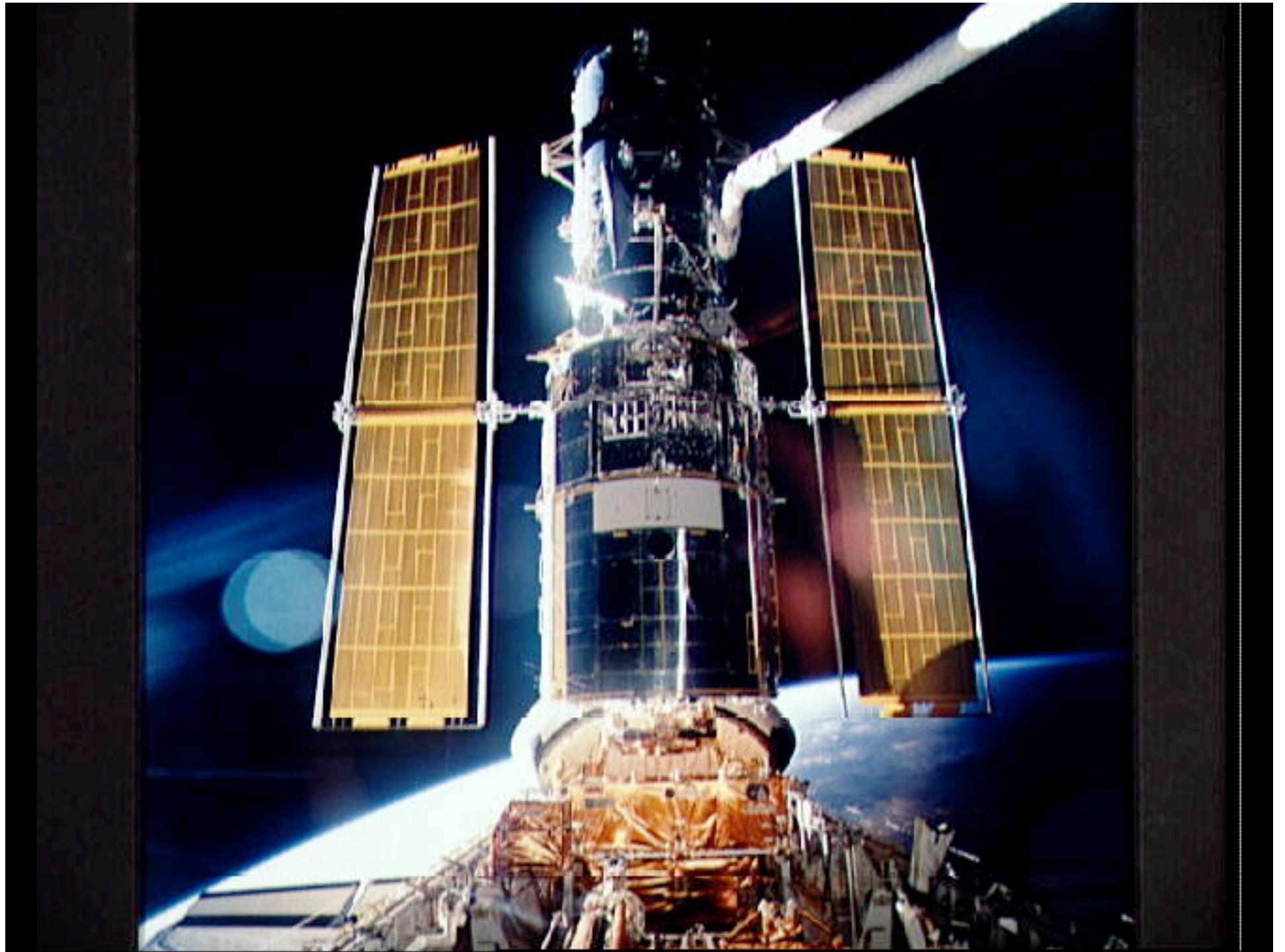




Hubble Space Telescope

- Length: 21 m
- Weight: 11,000 kg
- Mirror diameter: 2.4 m
- Launch: April 24, 1990







Hubble Servicing Missions

December 1993

February 1997

December 1999

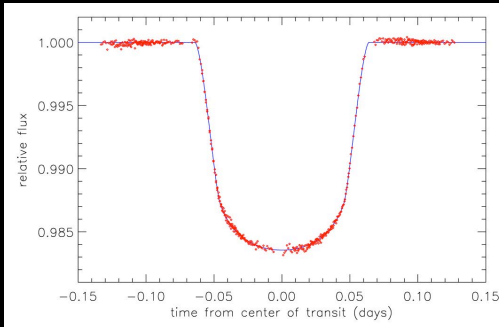
March 2002

MAY 2009!!!



“Top 10”

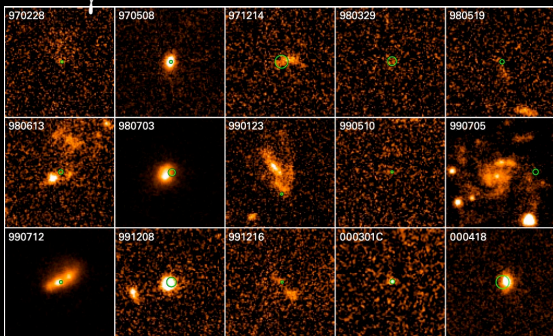
Dark energy



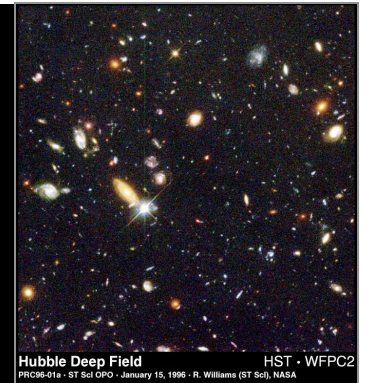
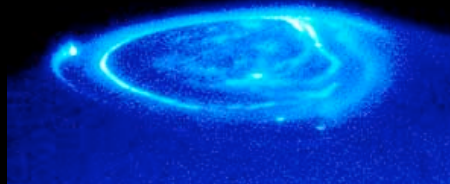
- Distance scale of the universe: H_0
- Giant black holes in galaxies
- Emission lines in active galaxies
- Intergalactic medium (QAL)
- Interstellar medium chemistry

- Formation of galaxies (HDF, UDF)
- Acceleration of the universe: SN Ia
- Gamma Ray Burst sources
- Proto-planetary disks
- Extra solar planets

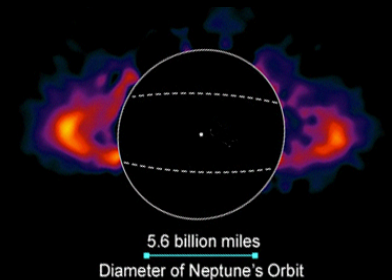
E_γ



Aurorae on Jupiter



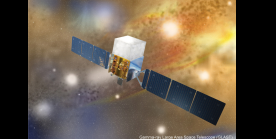
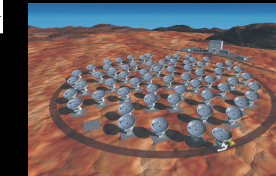
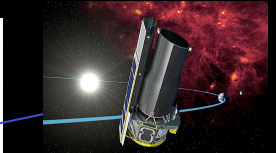
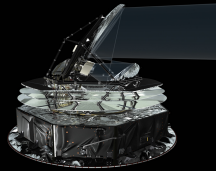
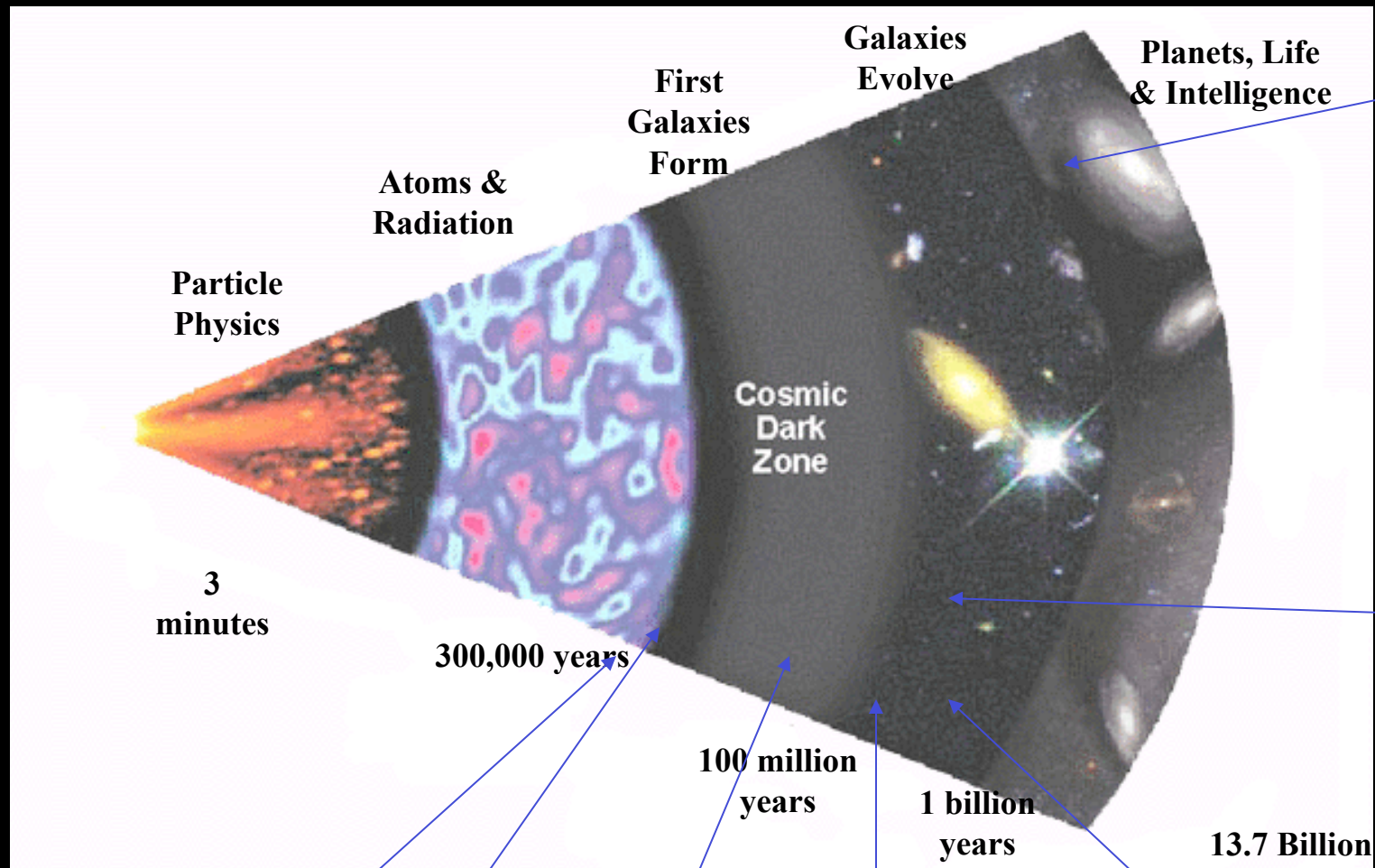
Early galaxies



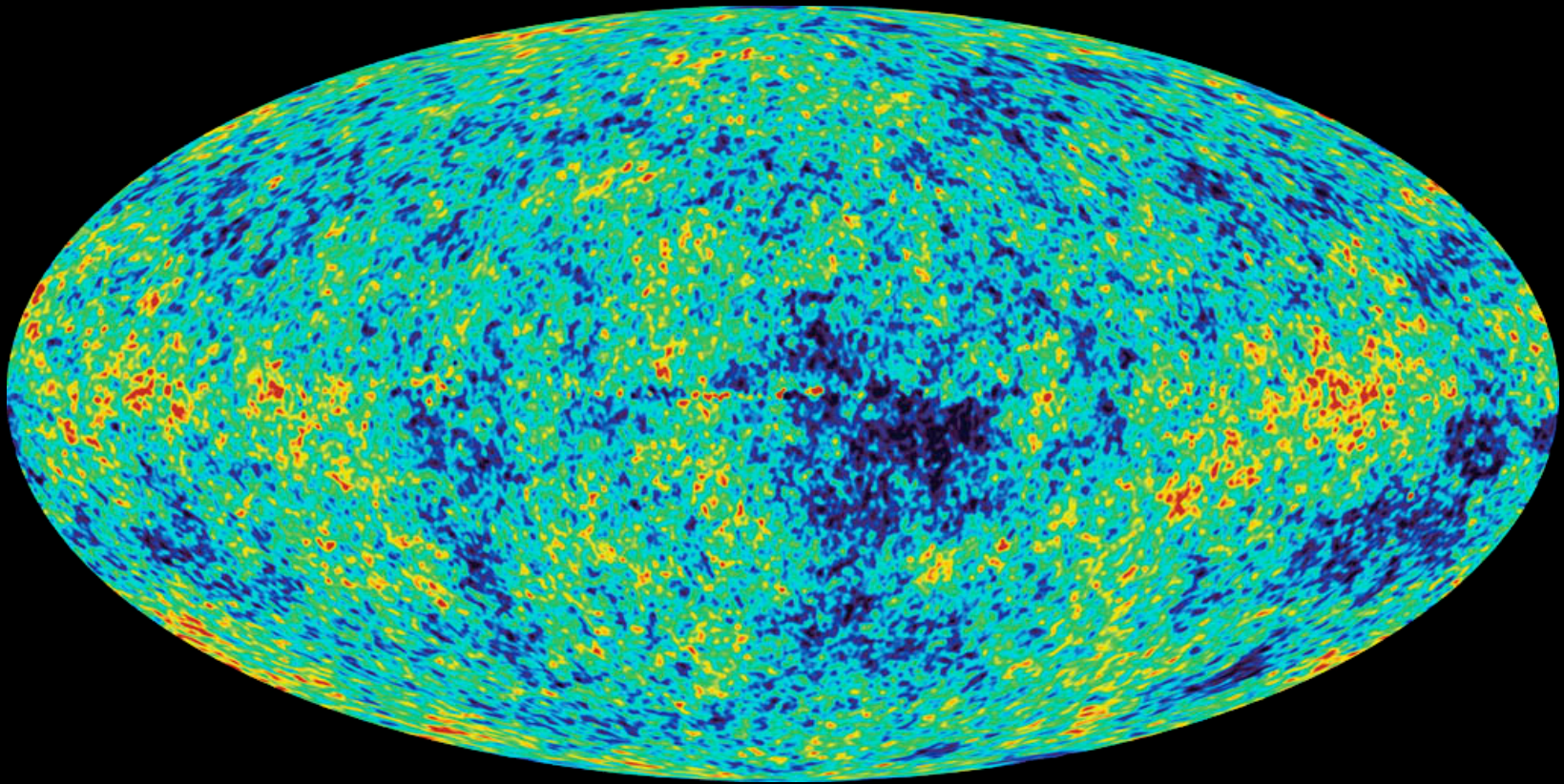
Young planetary systems



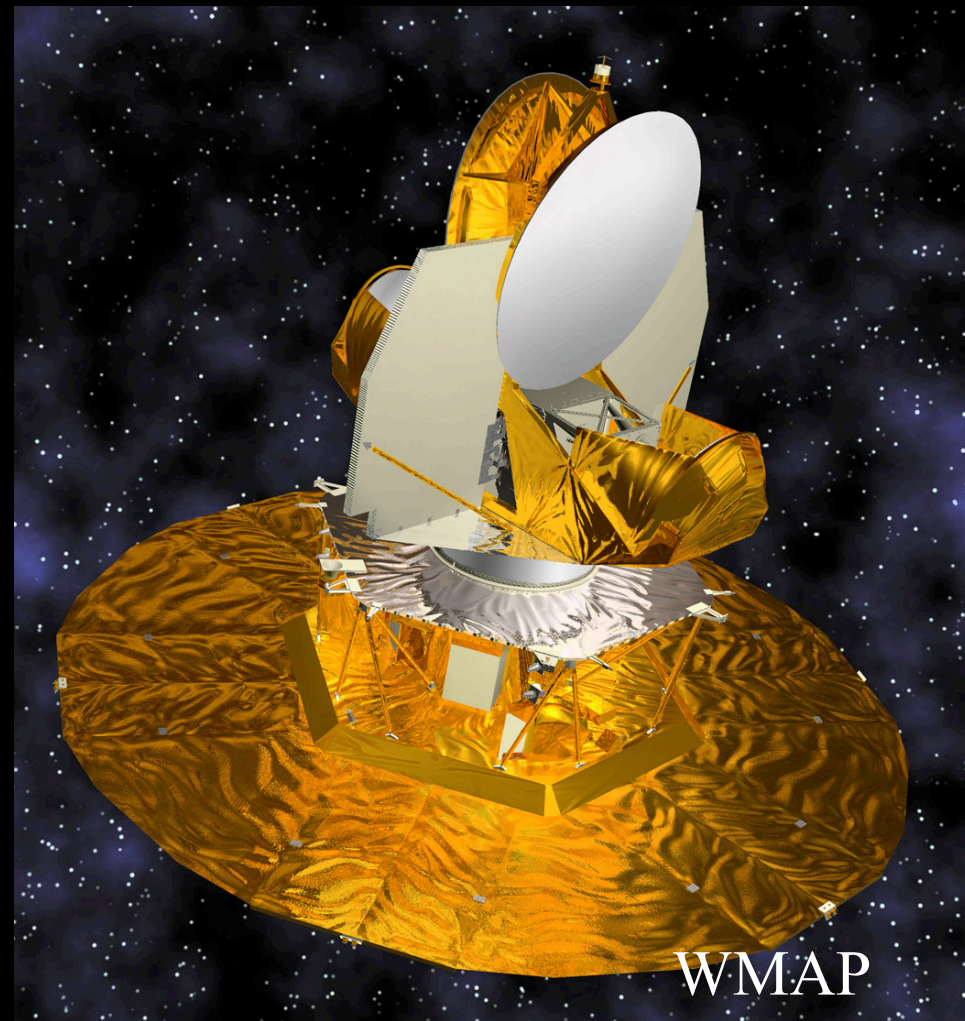
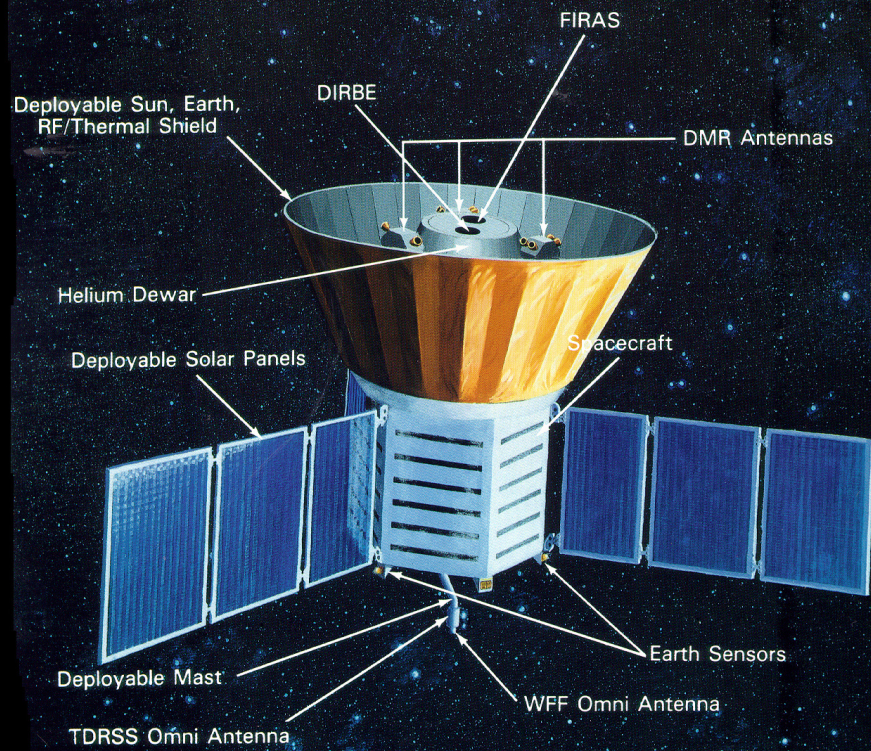
Mapping our History takes a range of facilities

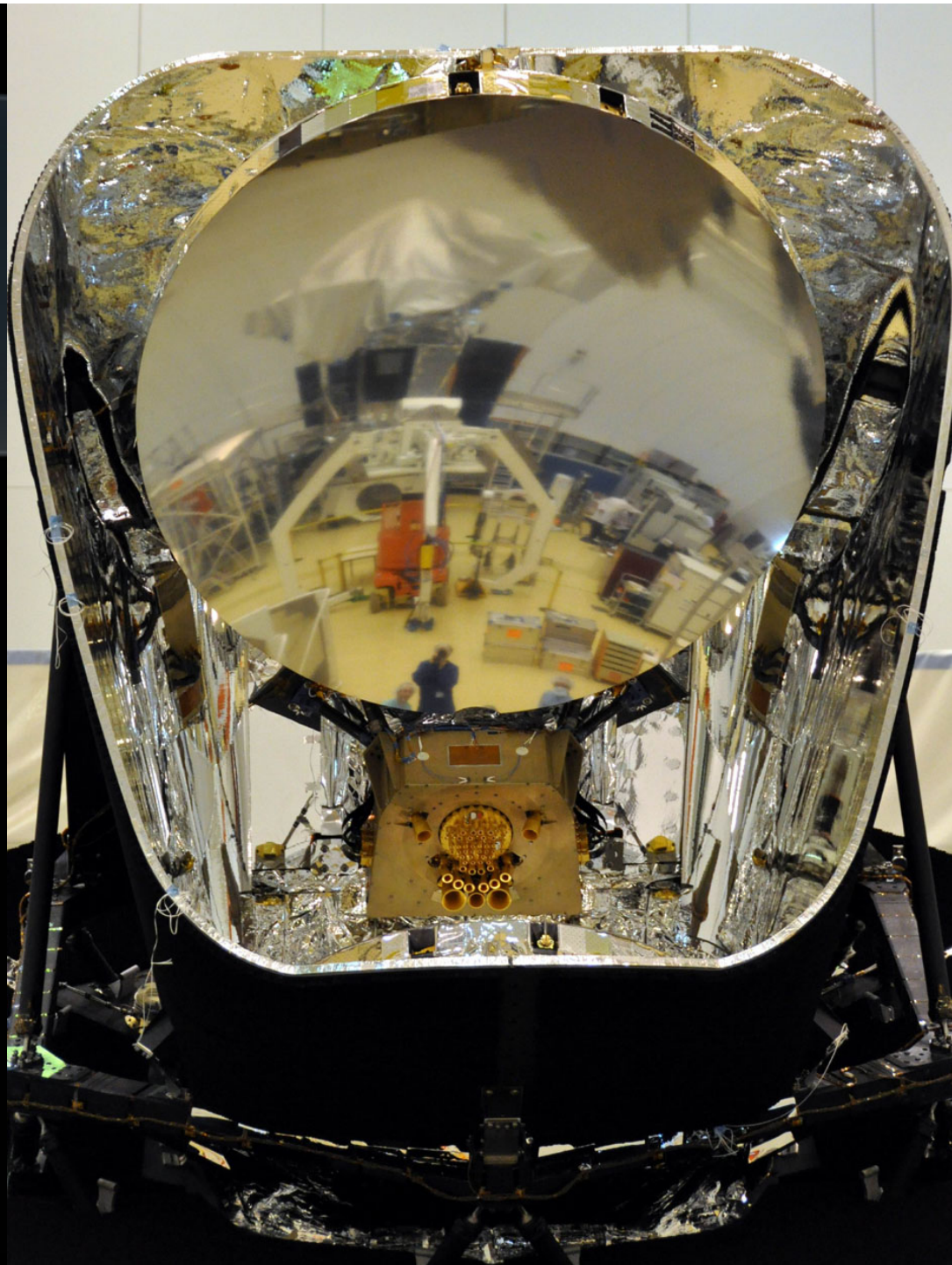


The Universe 380,000 Years After the Big Bang



The COBE Satellite

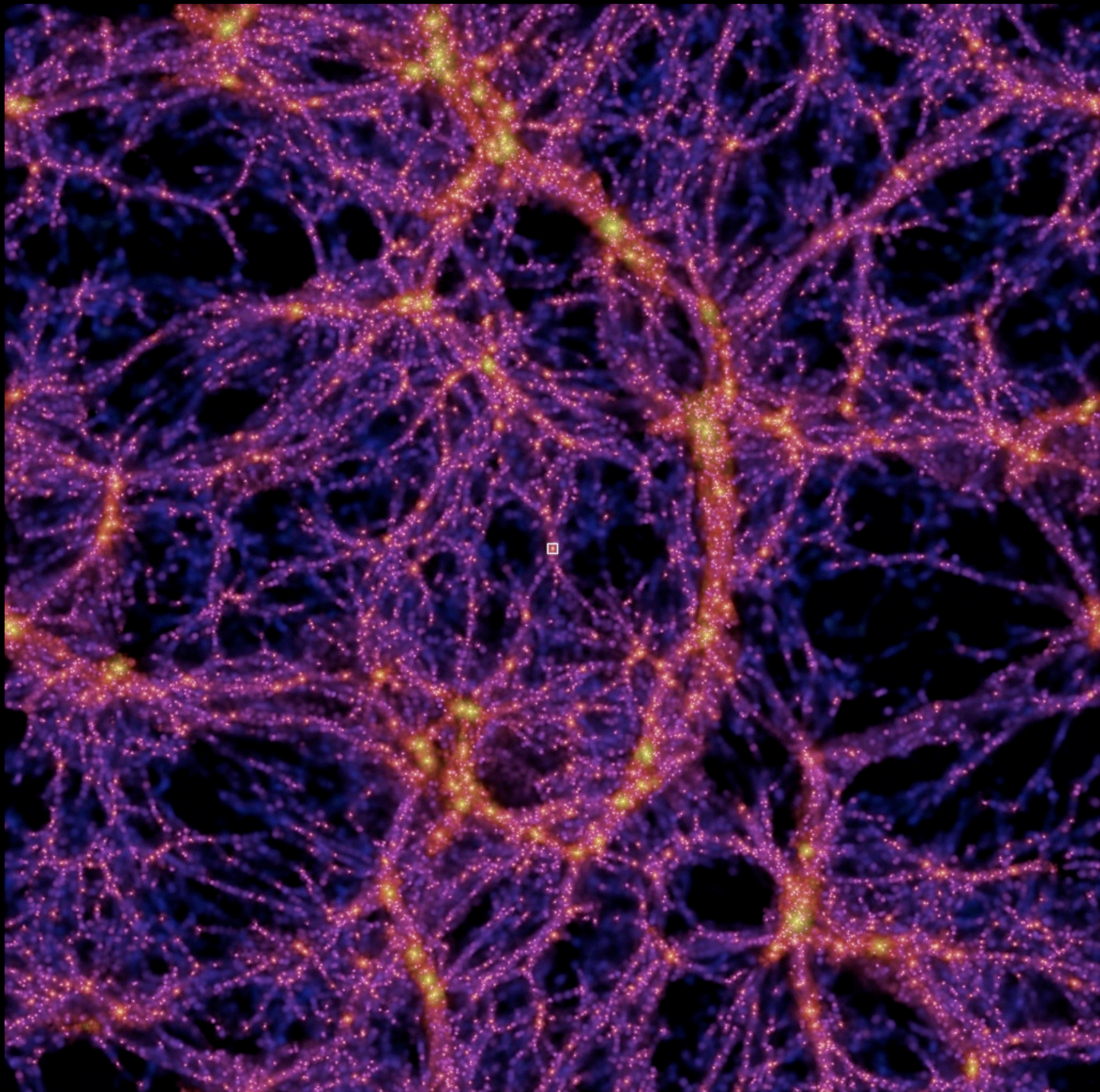




PLANCK
Launched
15 May 2009

A deep-field astronomical image, likely from the Hubble Space Telescope, showing a vast universe filled with galaxies and stars. The background is a deep black, densely populated with numerous small, distant galaxies and stars. In the center, there is a large, bright, yellowish-white elliptical galaxy. To the right, there is a prominent, well-defined spiral galaxy with a bright core and distinct spiral arms. Other galaxies of various shapes and sizes are scattered throughout the field, some appearing as small, distant points of light and others as more complex structures. The overall scene conveys the immense scale and complexity of the universe.

How did the primordial fireball
evolve to what we see today?







The Mice • Interacting Galaxies NGC 4676
Hubble Space Telescope • Advanced Camera for Surveys

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI), G. Hartig (STScI) and the ACS Science Team • STScI-PRC02-11d



Earth & Moon imaged with Galileo

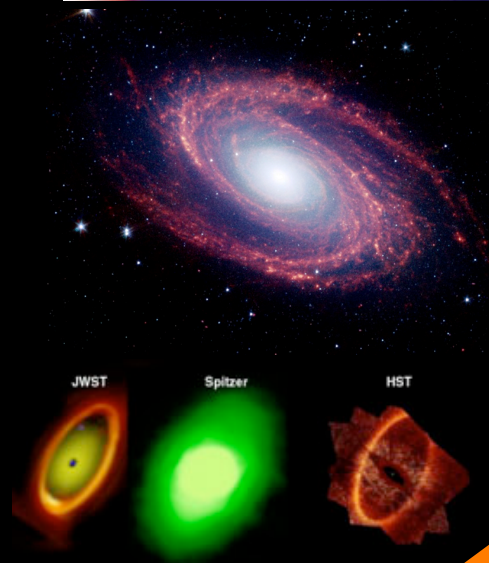
Main Science Themes

First Light (after the Big Bang)

Assembly of Galaxies

***Birth of Stars and
Protoplanetary Systems***

***Planetary Systems and
the Origins of Life***

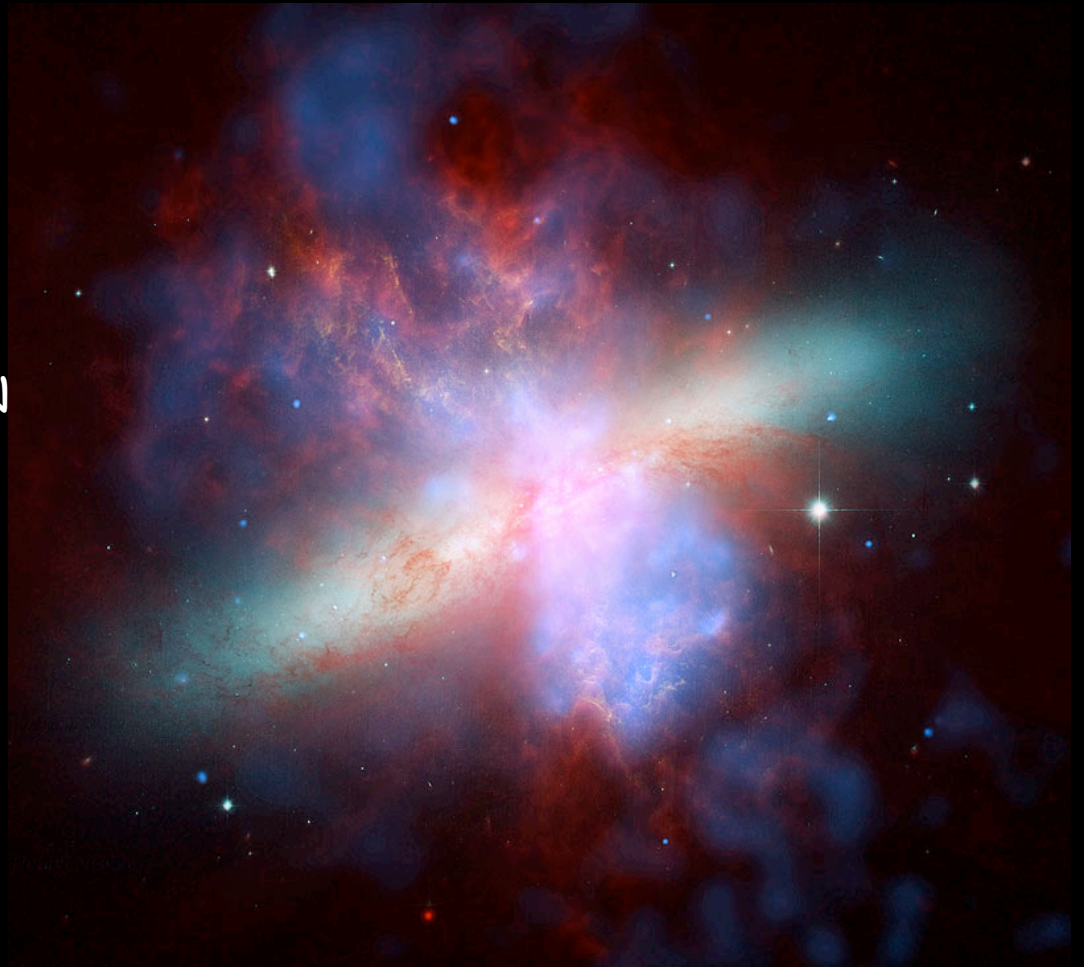


Along the way, we study key processes,
mysterious Dark Matter and Dark Energy

CXO/XMM/HST/Spitzer Science

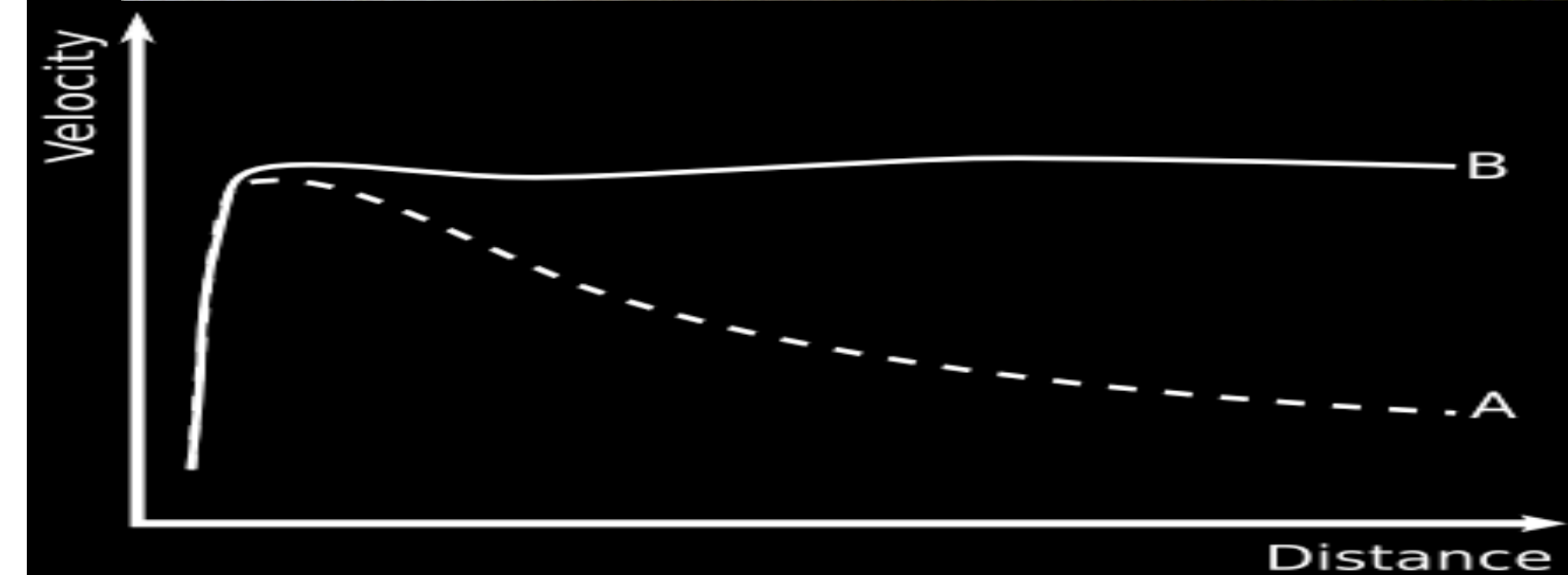
Mechanisms in Starbursts

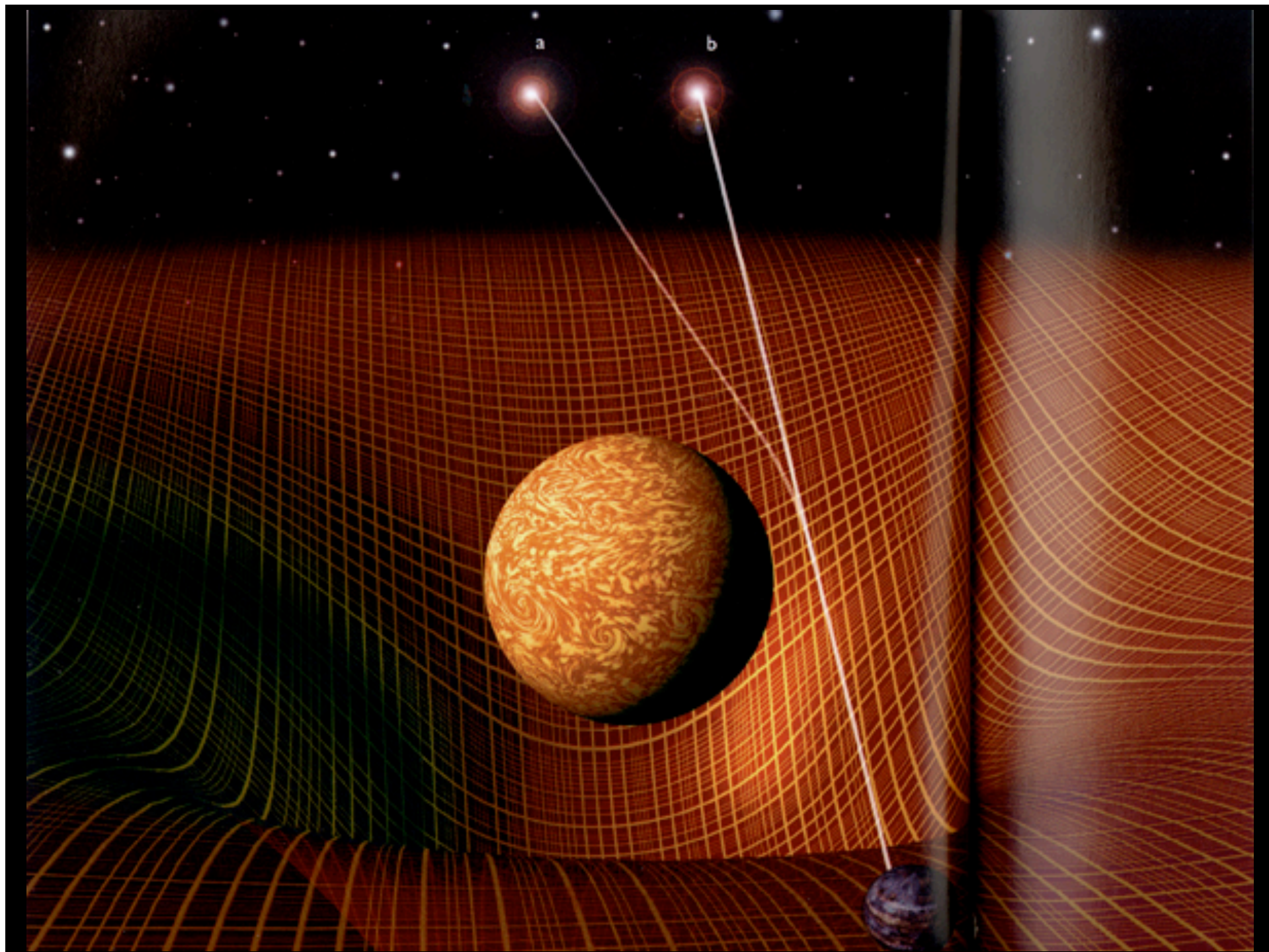
- triggering, regulation of SF, bursts
- feedback and galactic winds, superwinds, metal, dust ejection
- central starbursts: the AGN connection
- SF in extreme environments, IMF, abundances, etc

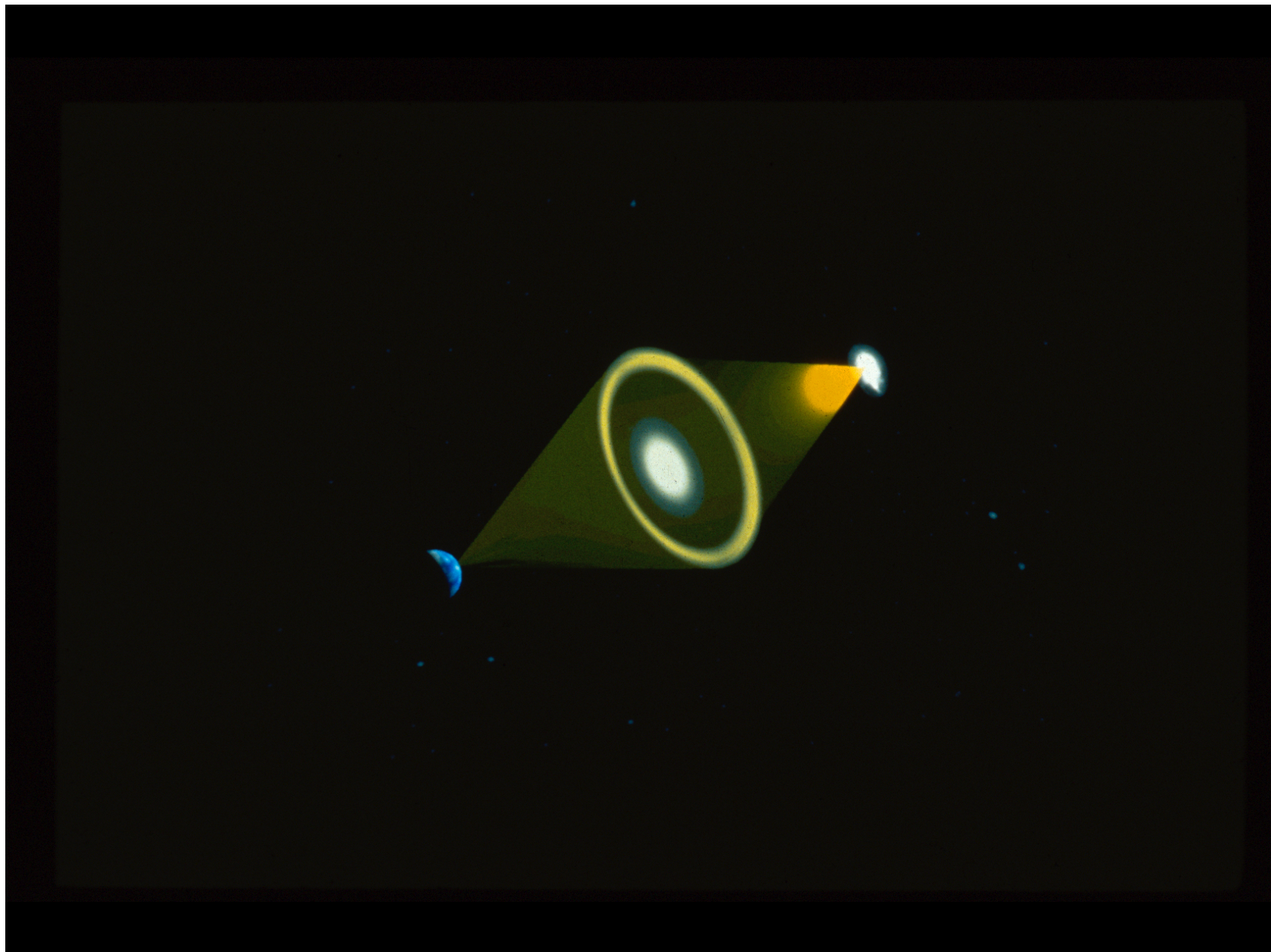


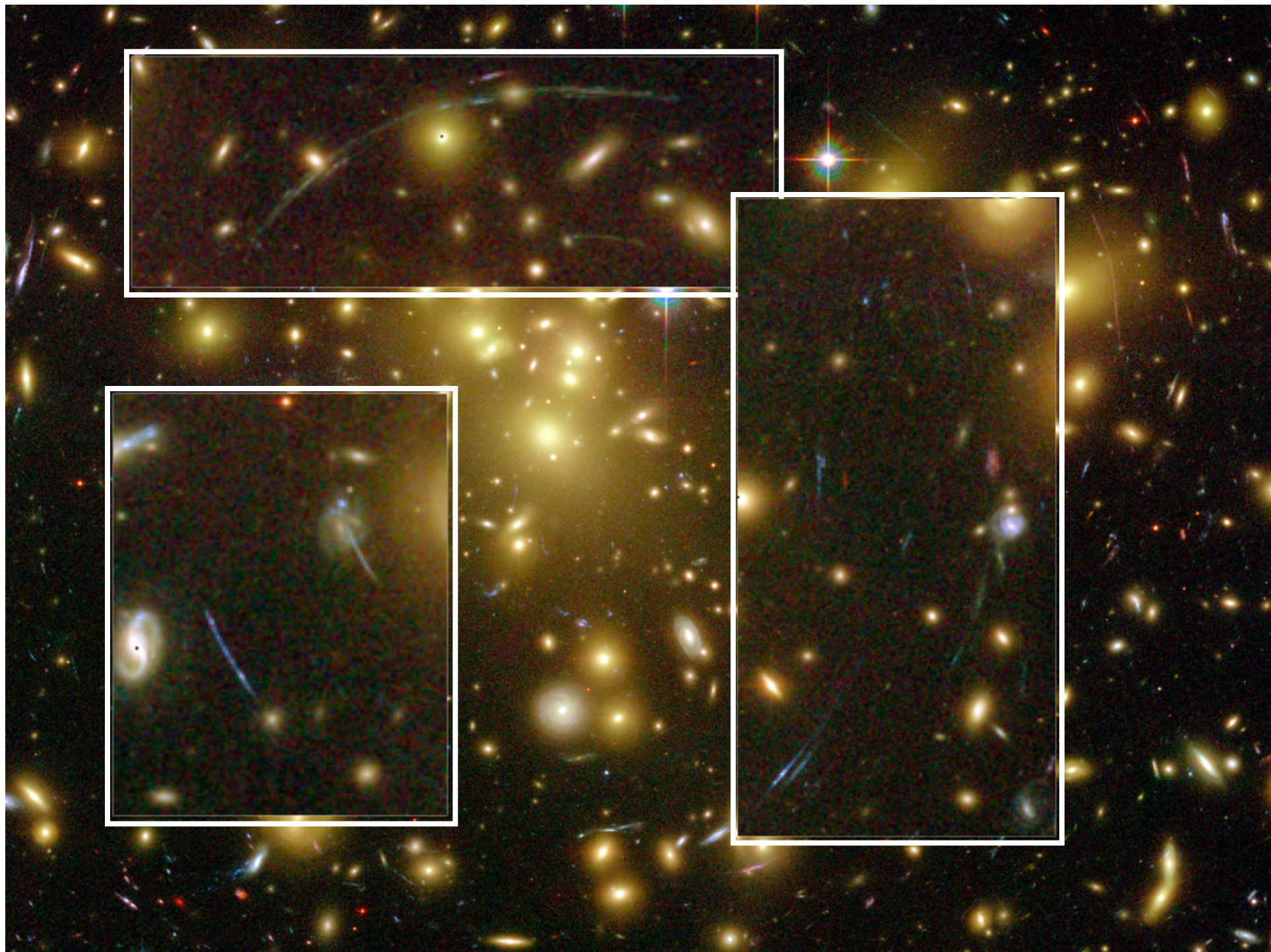
DARK MATTER

Rotation Curves of Spiral Galaxies





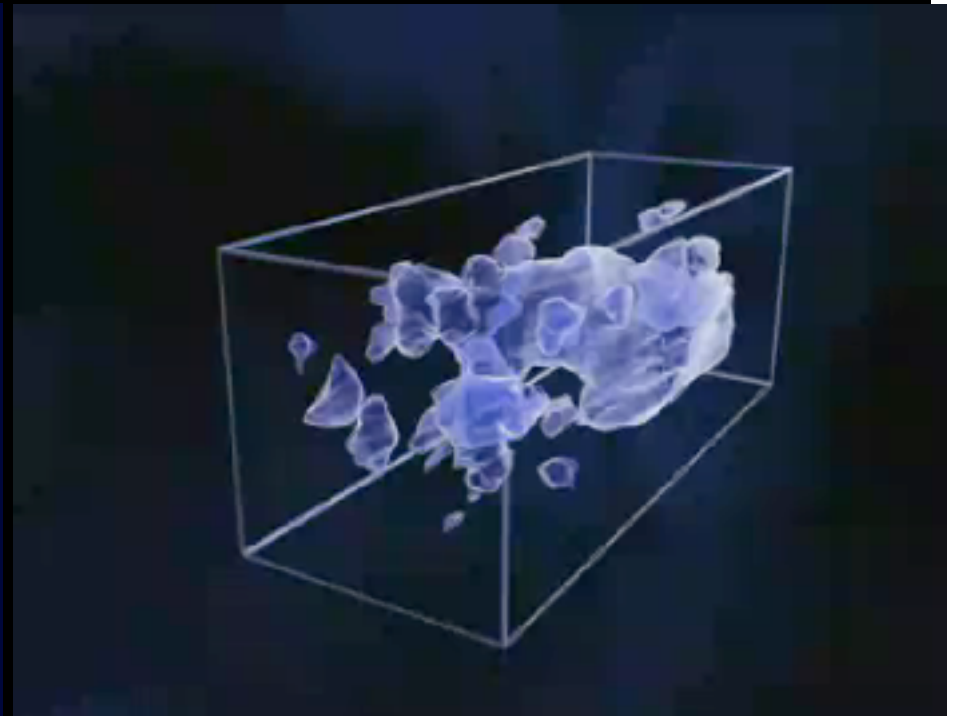
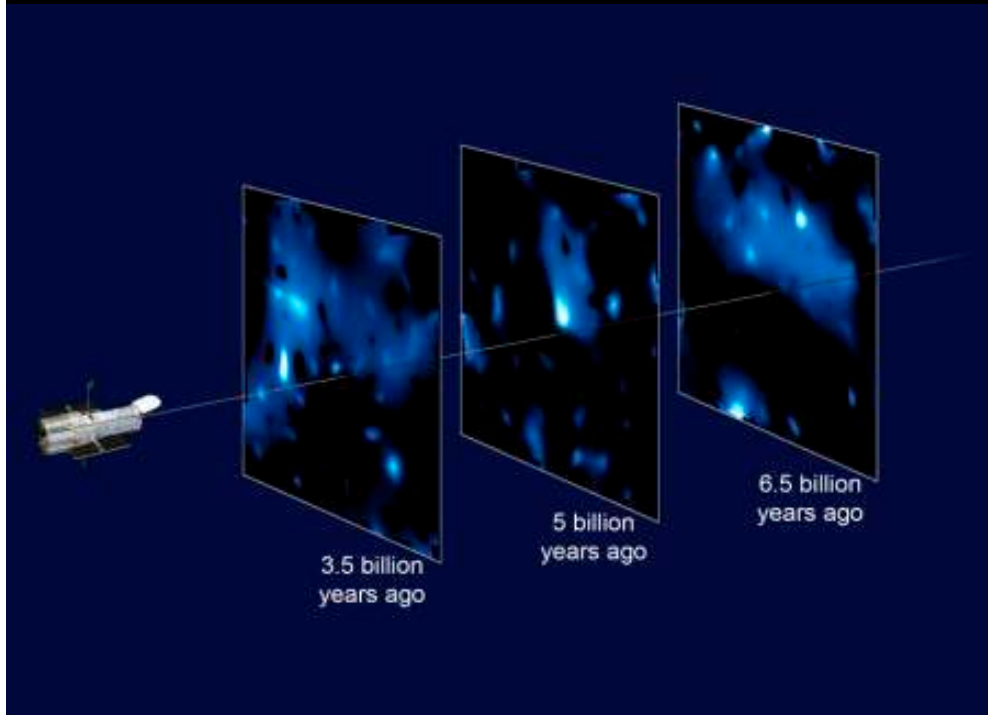




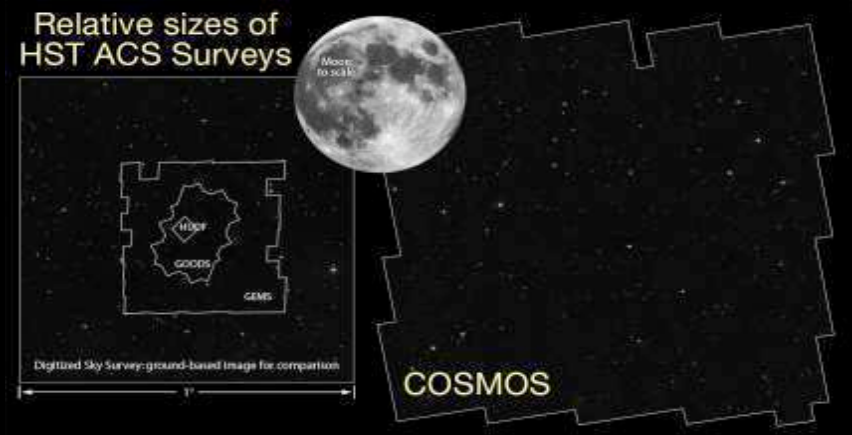


$$\Omega_d = 10 \Omega_m$$

Hubble Maps the Cosmic Web of "Clumpy" Dark Matter in 3-D



Three-Dimensional Distribution of Dark Matter in the Universe offers a first look at the web-like large-scale distribution of dark matter. This milestone takes astronomers from inference to direct observation the dark matter "Cosmic web". The map stretches halfway back in time to the beginning of the universe.



EXPANSION VELOCITY AND DARK ENERGY



Edwin P.
Hubble

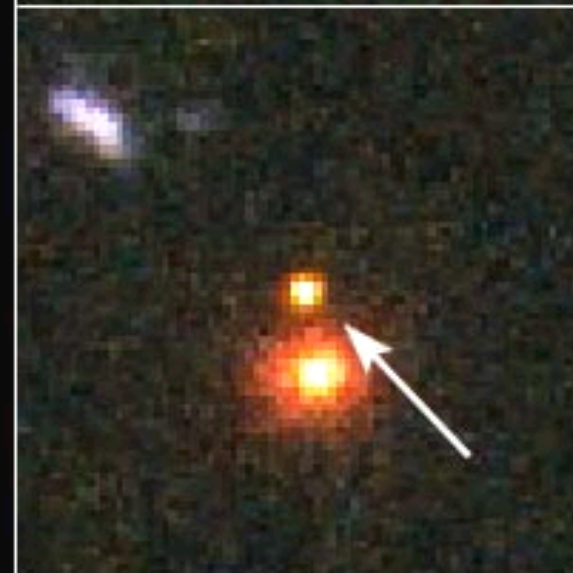
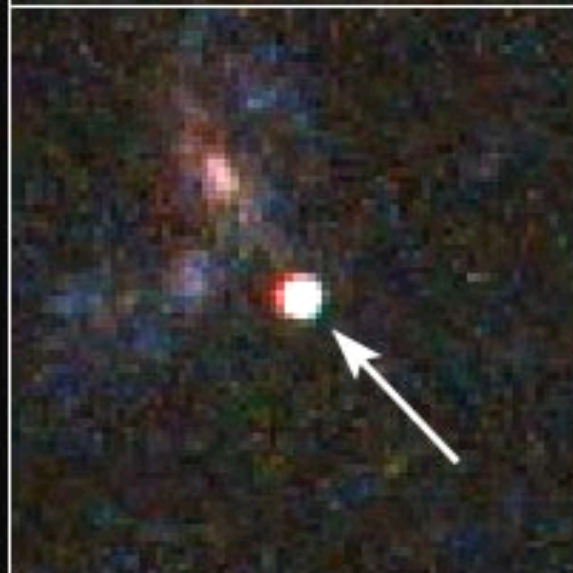
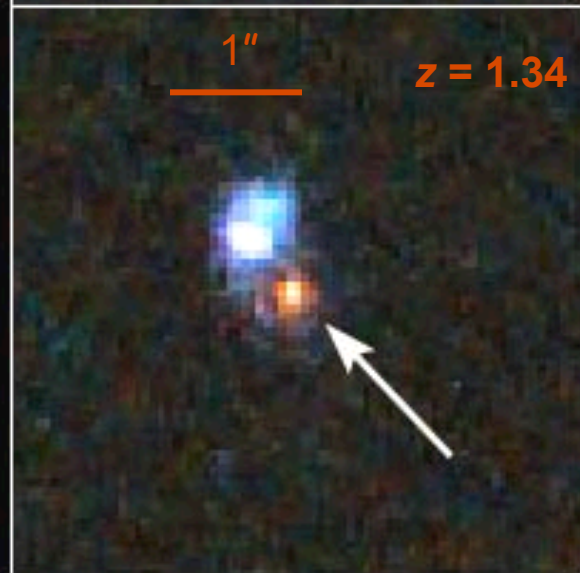
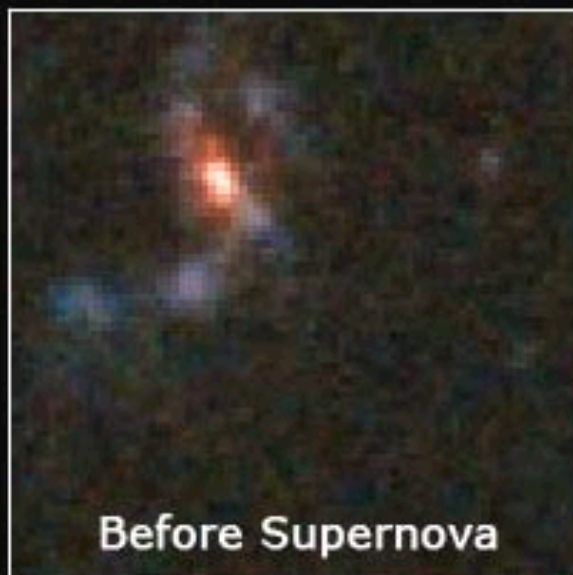
(1889-1953)

Mt. Wilson
Observatory
Pasadena, CA

HST Images of SN Ia

Distant Supernovae

Hubble Space Telescope - ACS

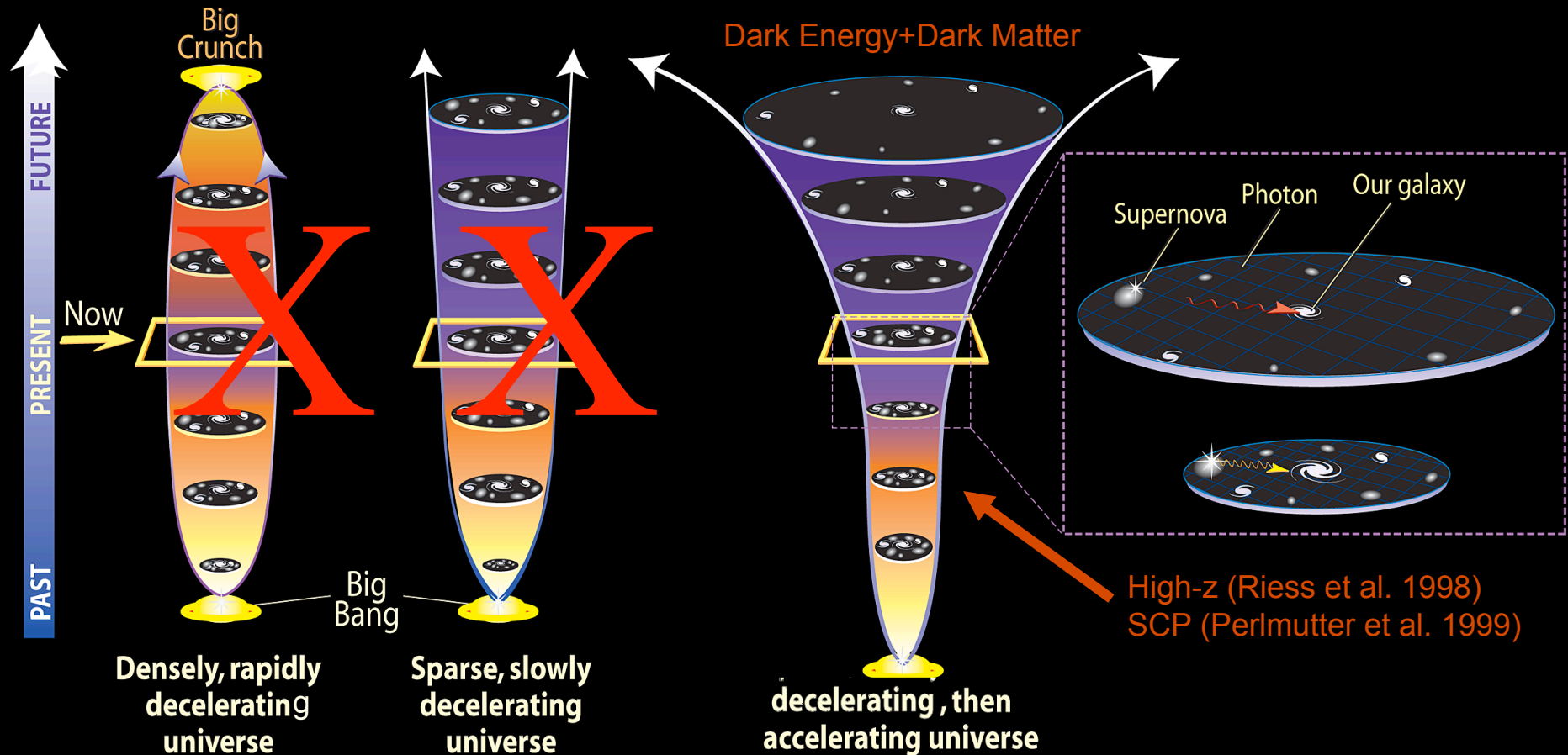


NASA and A. Riess (STScI)

STScI-PRC04-12

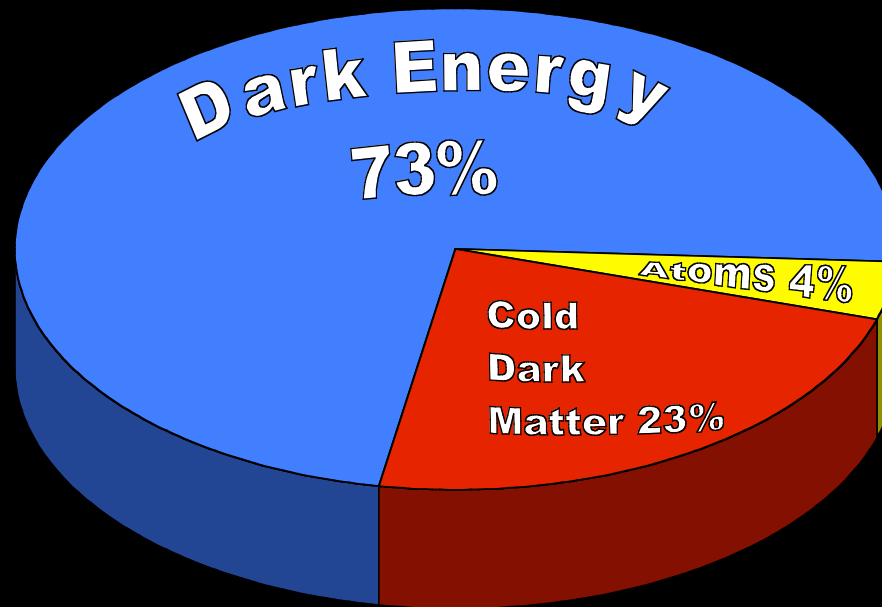
Expansion History reveals: THE ACCELERATING UNIVERSE

Models of the Expanding Universe



Now need greater precision, longer history to understand Dark Energy!

The new Galilean revolution



Not only we are NOT at the center of the Universe
We are not even made of that most of the Universe is made of !!!!

VLBA

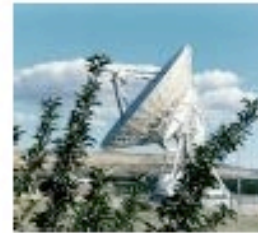
Planet Earth as the "telescope's" backbone



Mauna Kea
Hawaii



Owens Valley
California



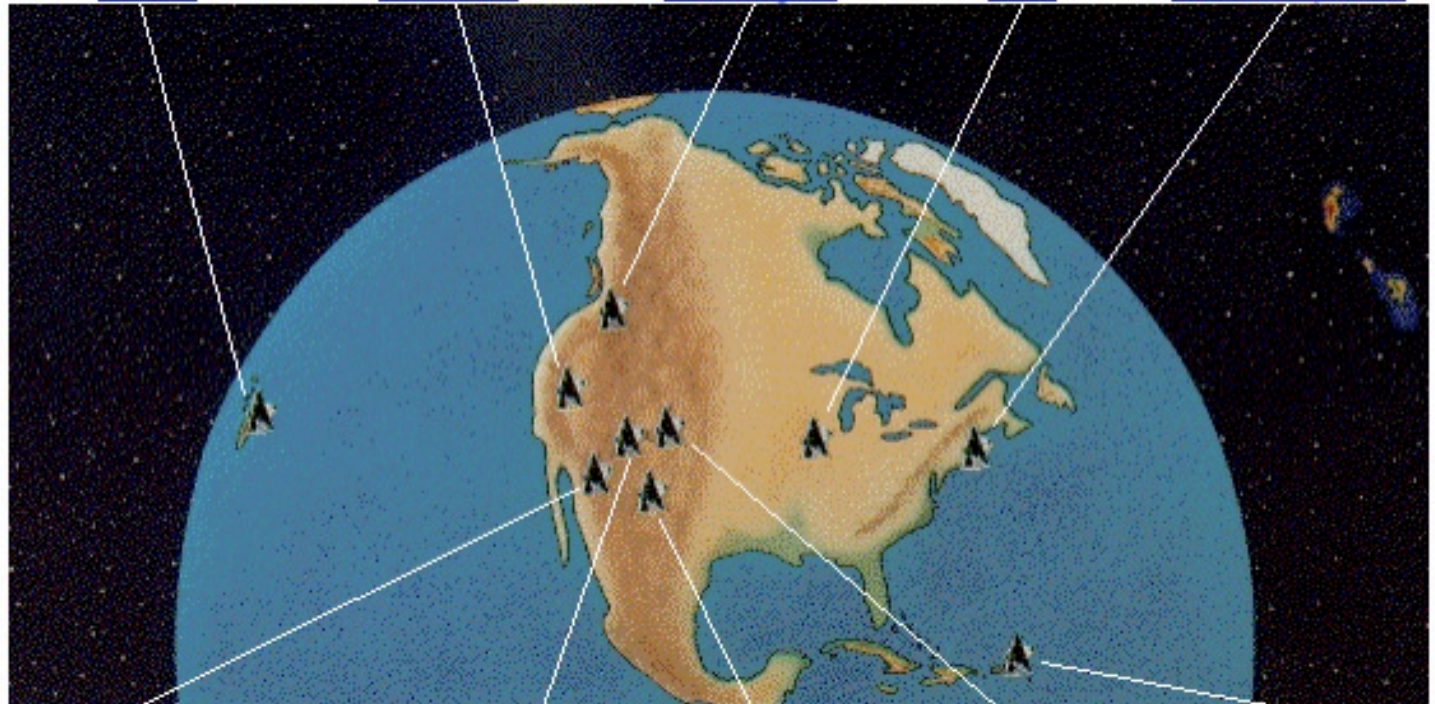
Brewster
Washington



North Liberty
Iowa



Hancock
New Hampshire



Kitt Peak
Arizona



Pie Town
New Mexico



Fort Davis
Texas



Los Alamos
New Mexico



St. Croix
Virgin Islands

VERITAS (Very Energetic Gamma Rays)

Earth's atmosphere is part of the “telescope”



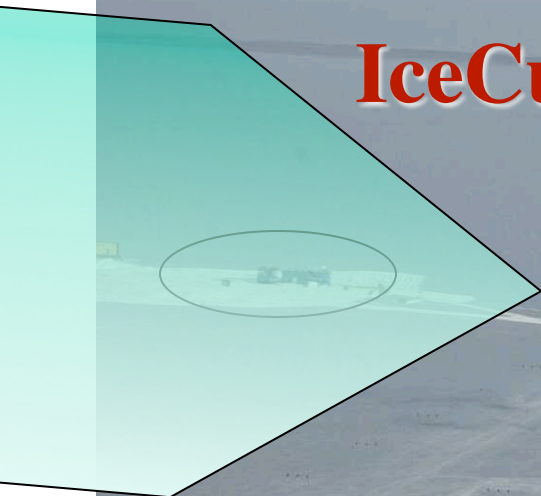
How big is IceCube? (Neutrinos)

IceCube Detector Array – 1 Km across!

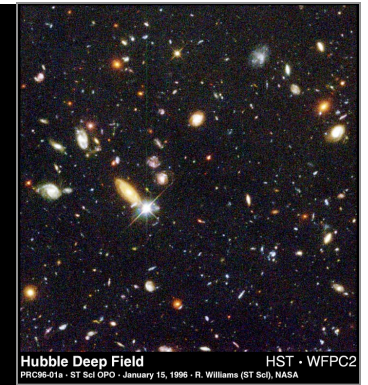
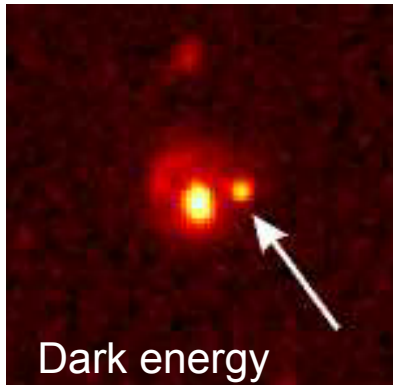
Skiway

Station

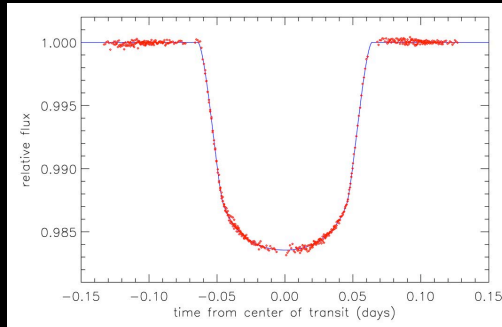
Antarctic Ice is part of the “telescope”



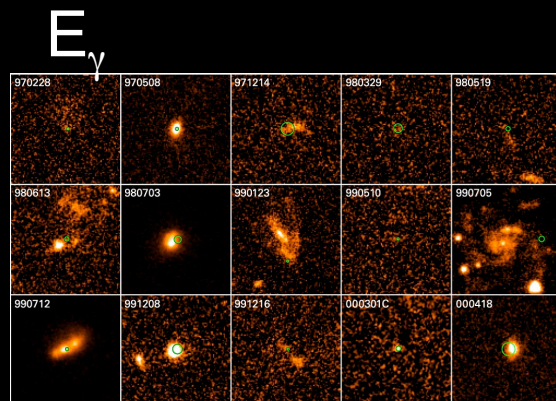
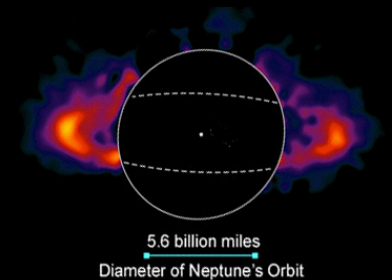
“Top Problems”



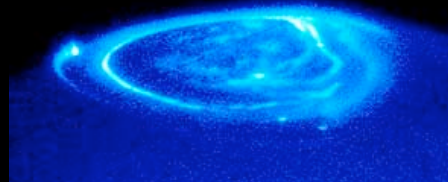
Early galaxies



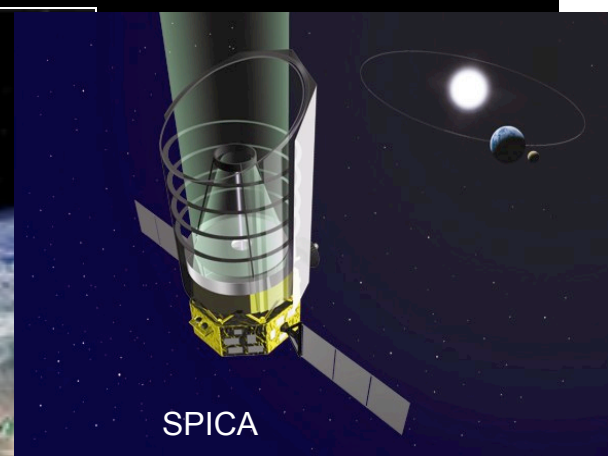
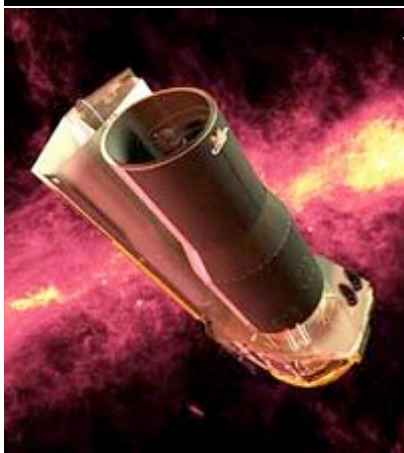
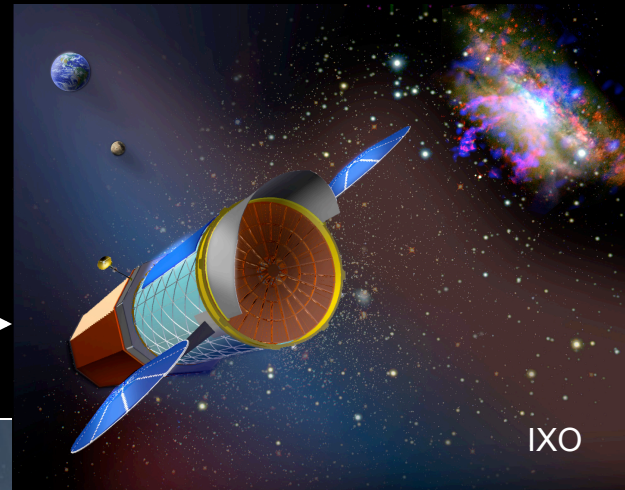
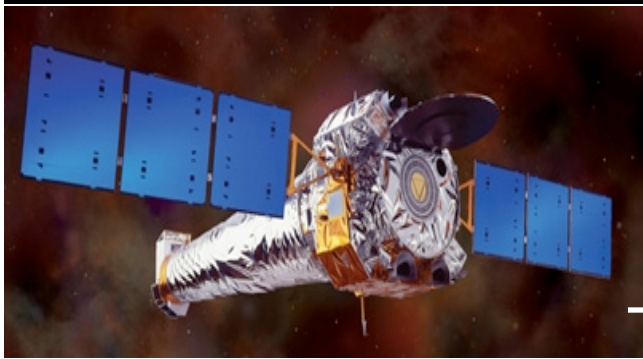
- Acceleration of the universe; dark energy
- Dark matter
- Formation of galaxies
- Formation and evolution of supermassive black holes; the BH galaxy connection
- Gamma Ray Burst sources
- Star formation and feed-back
- Protoplanetary disks
- Extra solar planets



Aurorae on Jupiter



New Capabilities



Galileo: Ahead of his time in many ways

Recognizing the potential of
new technology



Adapting new technology for
Astronomy



Doing the research,
recognizing the breakthrough



Publishing quickly,
while proposing for more!



- “Grandissima mi par l’innezzia di coloro che vorrebbero che Iddio avesse fatto l’Universo più proporzionato alla piccola capacità del loro discorso...”

- “It’s very great the “stupidity” of those who wish that God had made the Universe more proportionate to the small size of their intellect...”



Galileo Galilei
Opere VII, 397