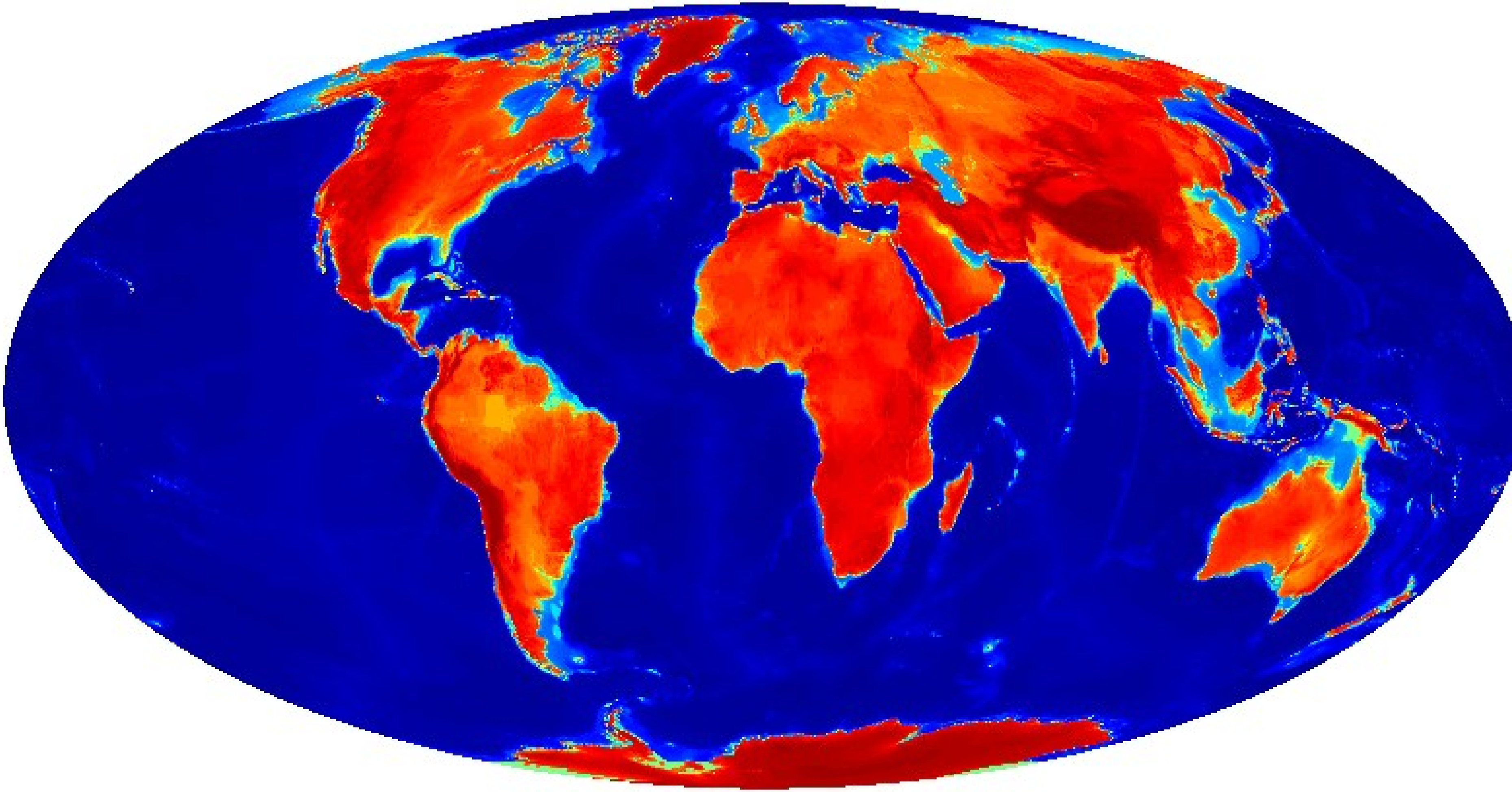
Hefei, September 2009

Understanding our Universe:

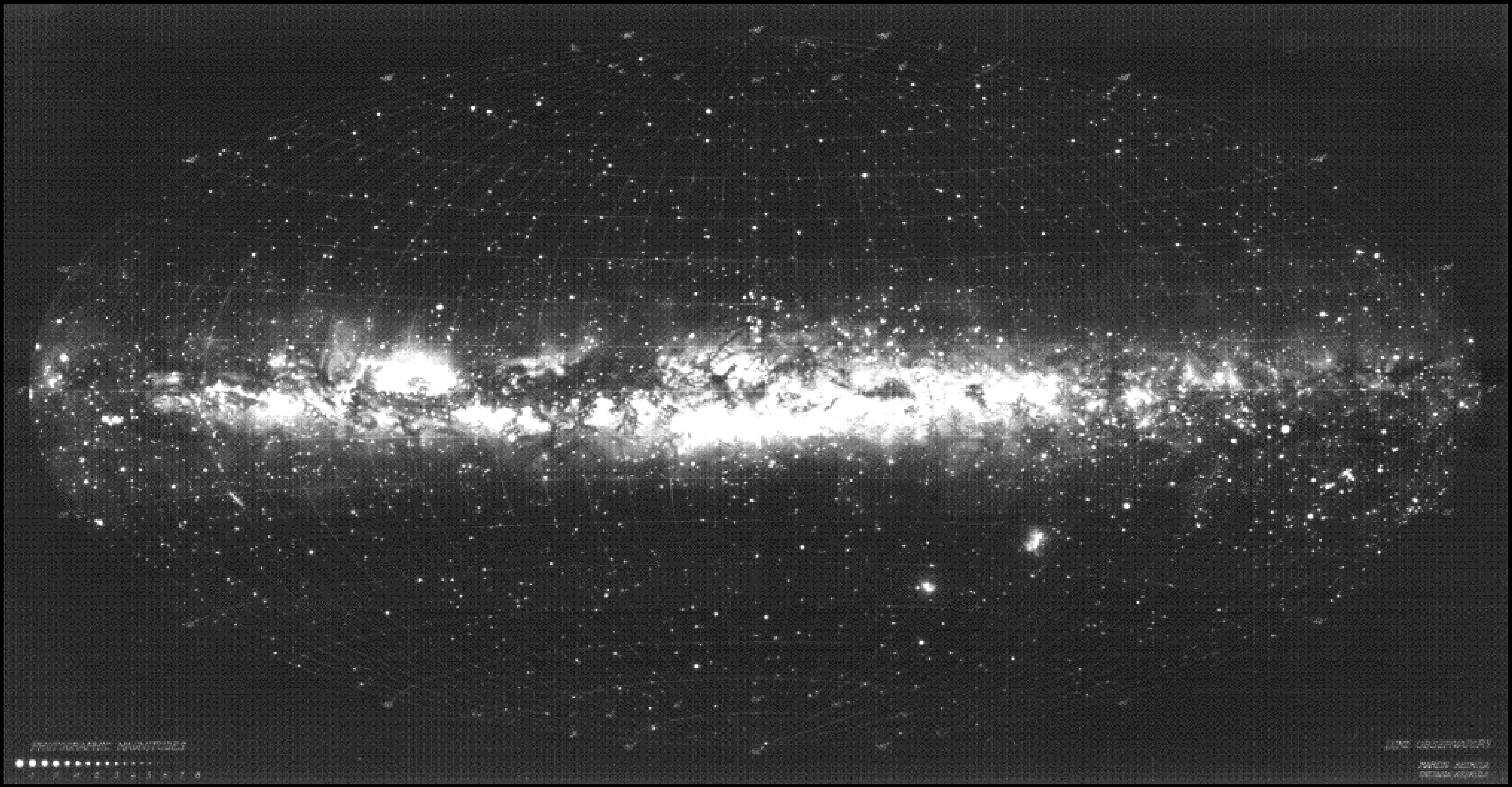
Ideas and opportunities in modern astrophysics

Simon White
Max Planck Institute for Astrophysics

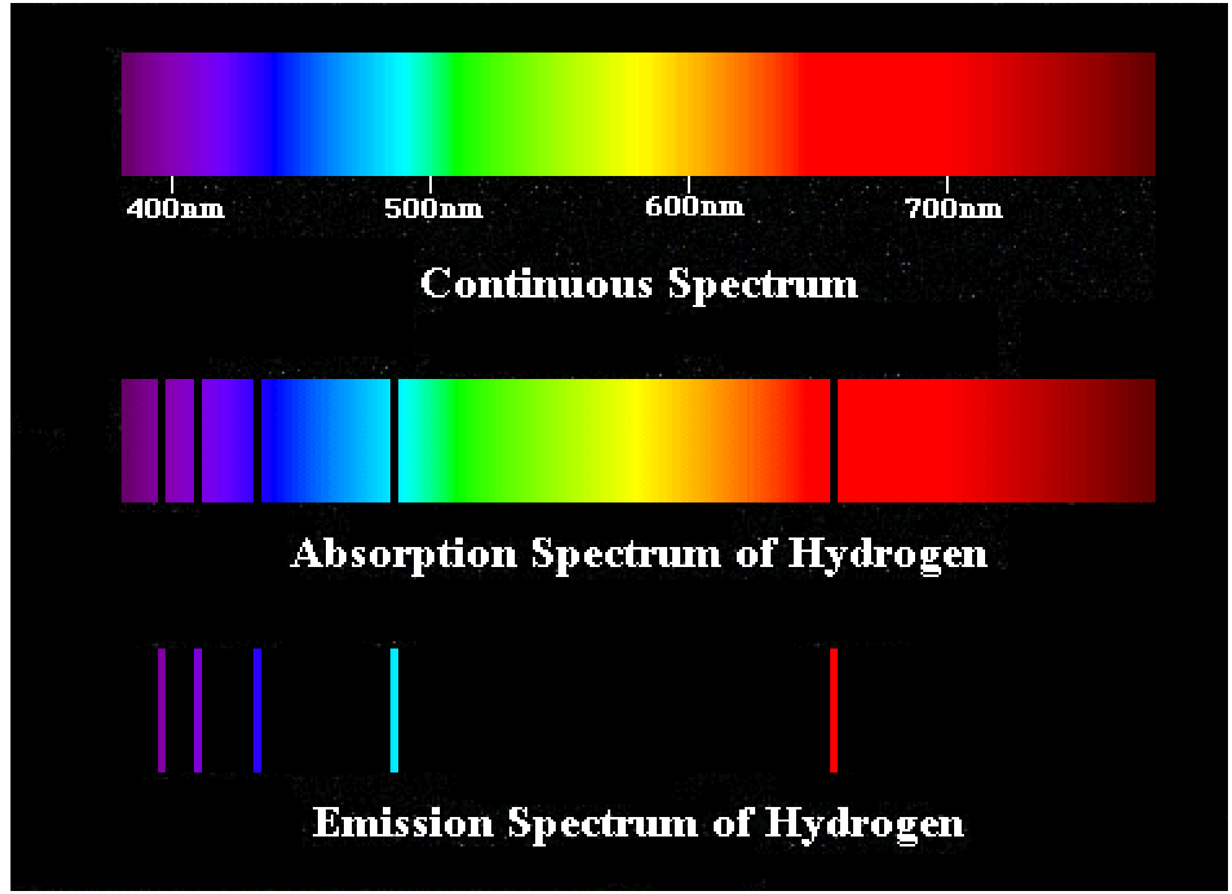
What can we know about things we cannot touch?

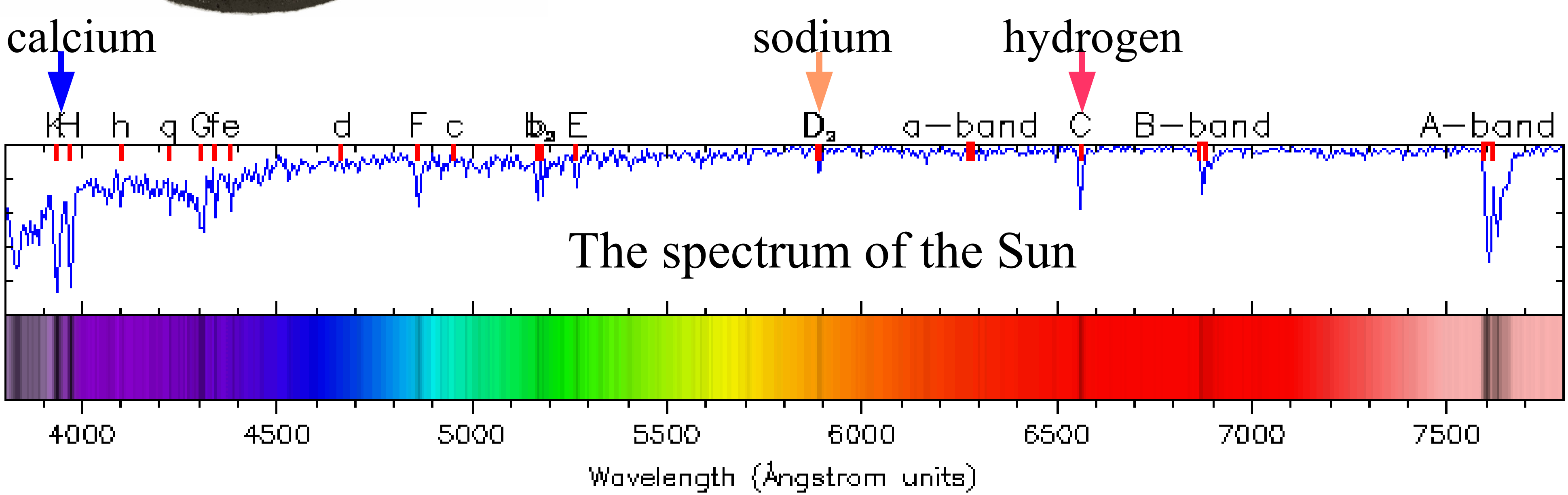


Star map of the whole sky

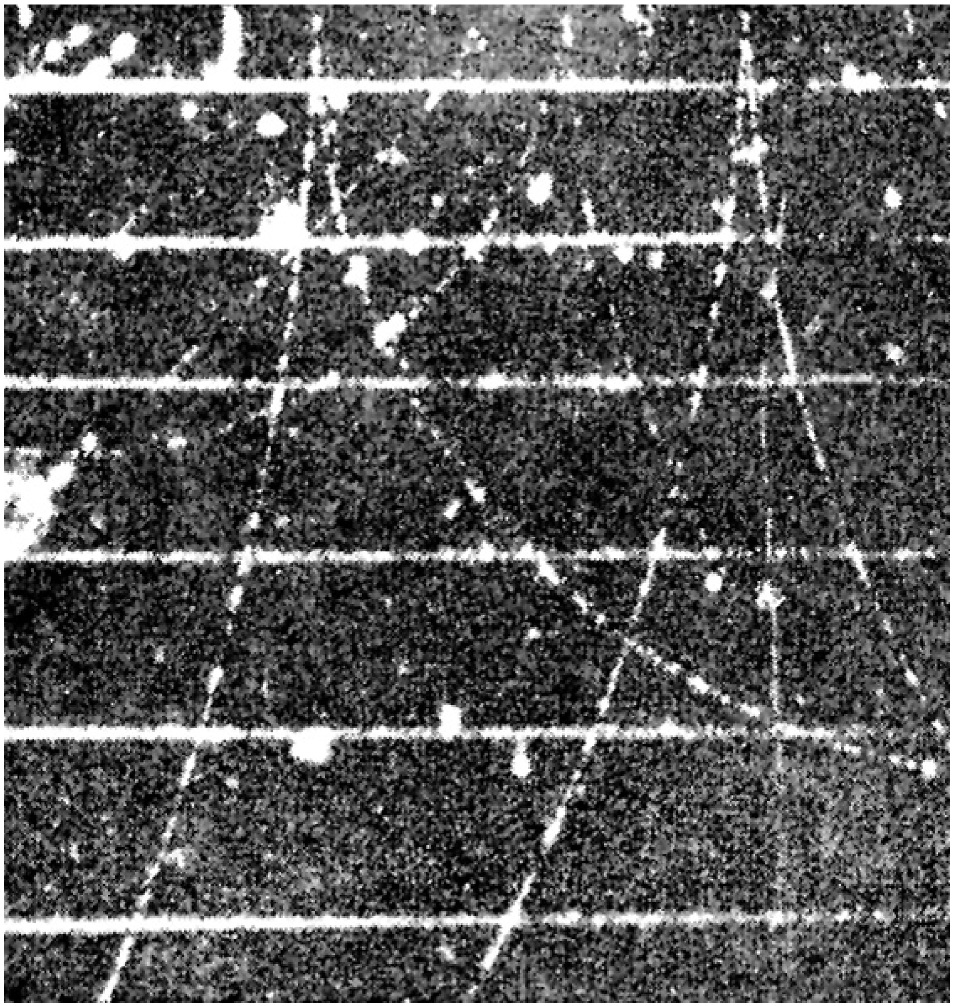



Joseph
von Fraunhofer


400nm
500nm
600nm
700nm
Continuous Spectrum
Absorption Spectrum of Hydrogen
Emission Spectrum of Hydrogen


calcium
sodium
hydrogen
K H h g G fe d F c b E D a-band C B-band A-band
The spectrum of the Sun
4000
4500
5000
5500
6000
6500
7000
7500
Wavelength (Ångstrom units)

What can we know about things we cannot see?



e^-

e^+

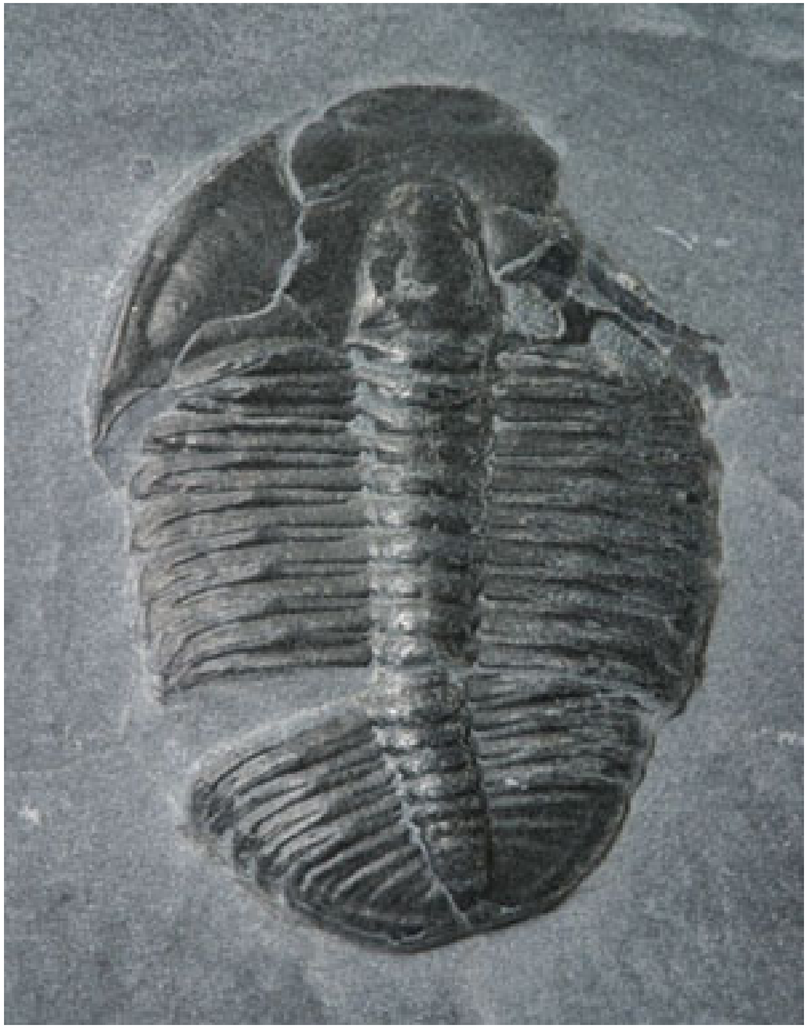
e^- e^-

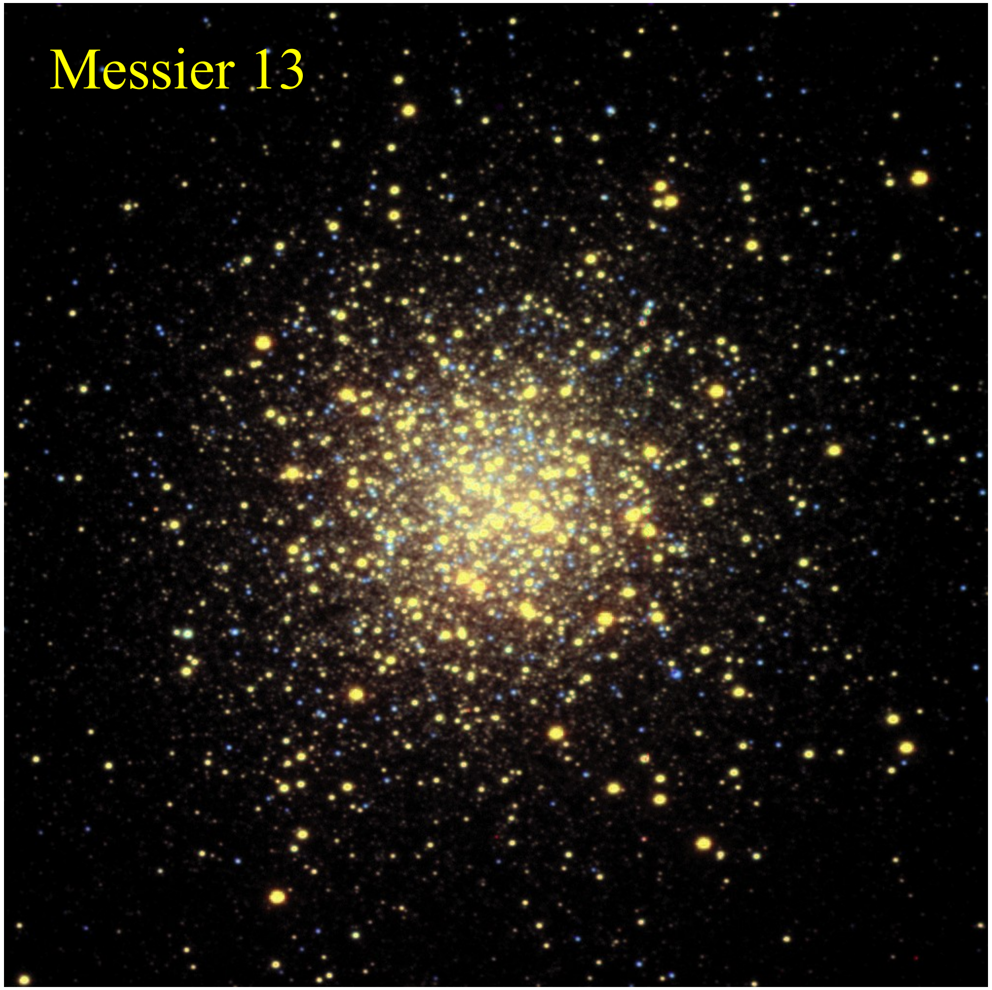
What can we know about things that we cannot see or touch?

The Coma Galaxy Cluster

What can we know about processes which act over billions of years when we live for only seventy years?

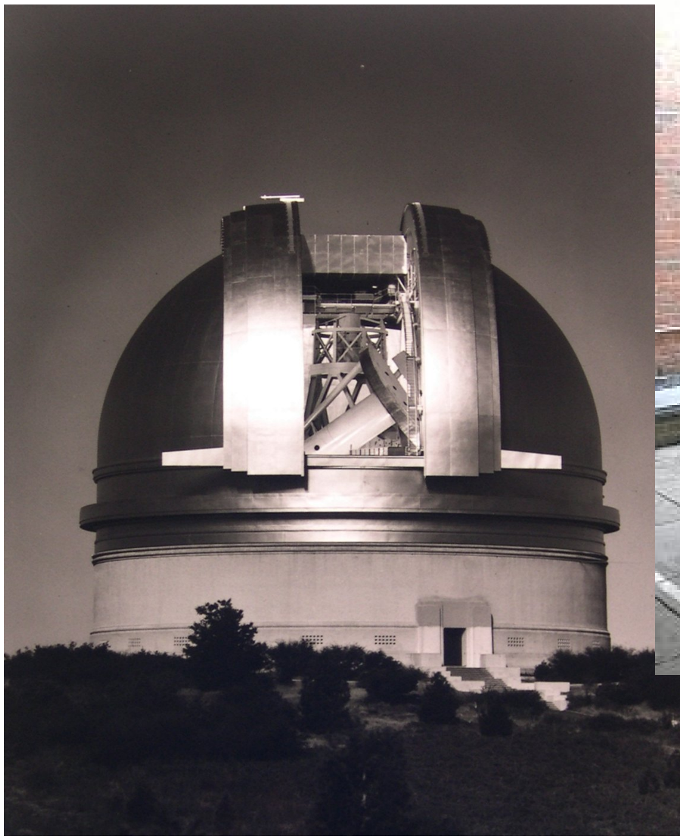
Do archaeology!





Use old objects to find out what the Universe was like when they were young.

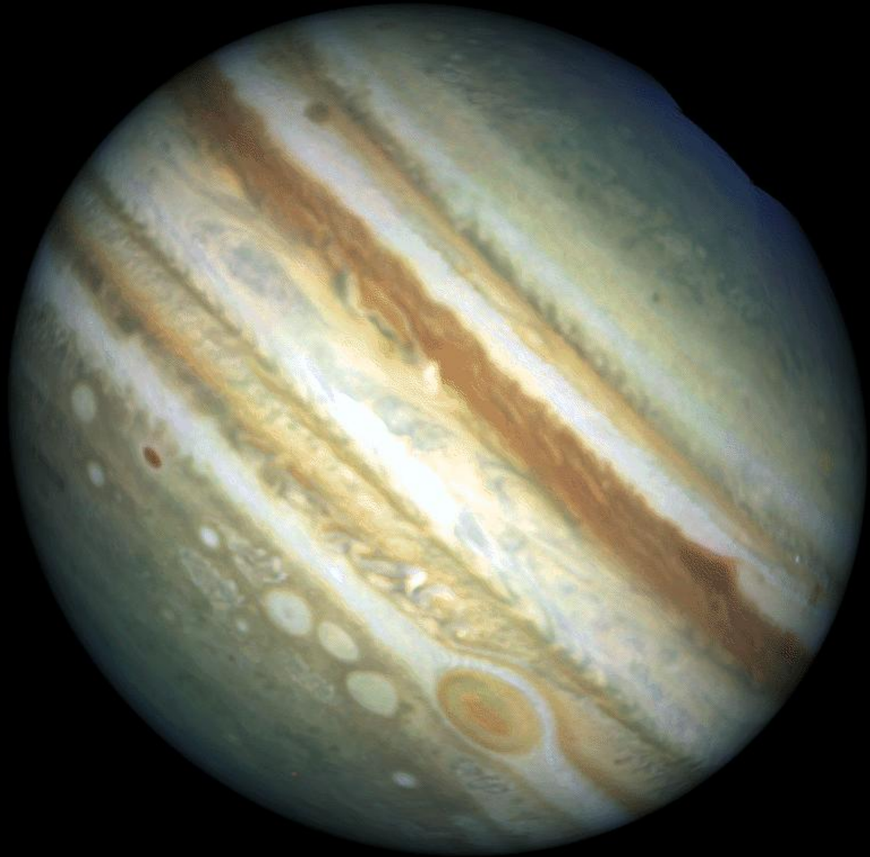
Use telescopes as time machines - look directly into the past

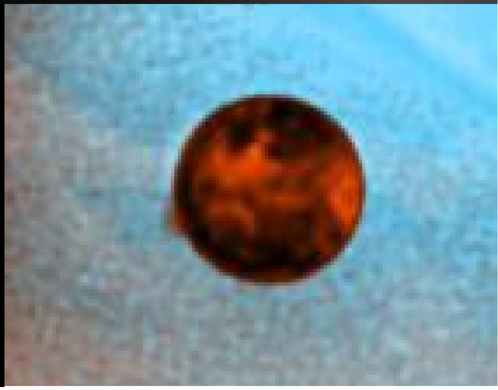


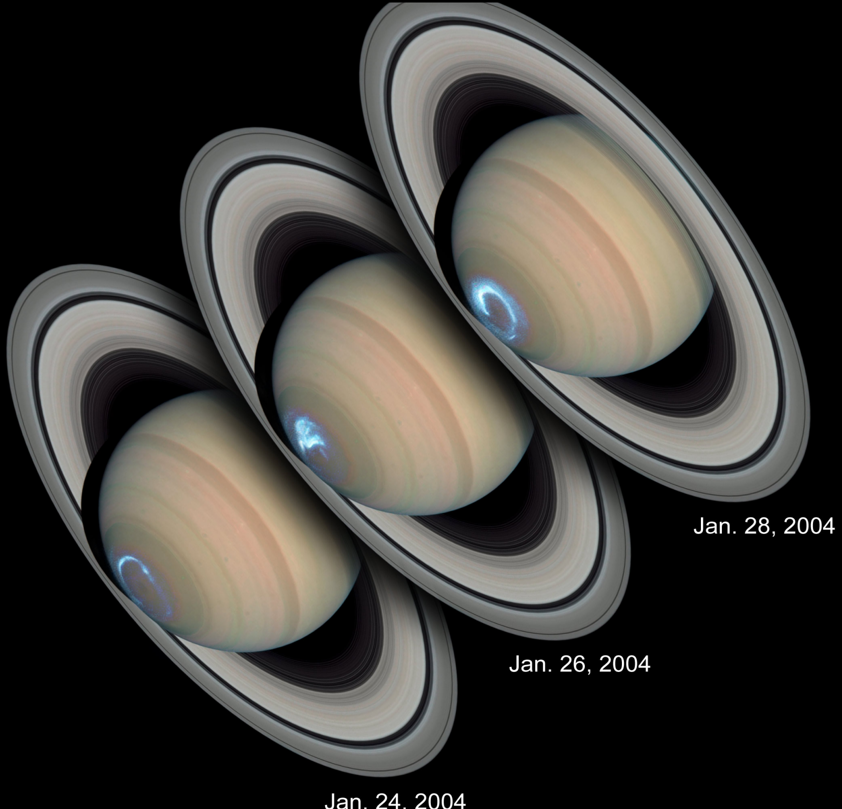
We see objects as they were when the light left them, <u>not</u> as they are today

Astrophysics

- puts our Earth in its cosmic context
- allows us to study physics under *very* extreme conditions
- has taught us the origin of the elements
- has shown us what our Universe is made of
- allows us to see back in time, almost to the beginning
- makes cosmic evolution directly visible to us
- provides insight into our long-term future
- is unveiling new worlds, and (perhaps) other life

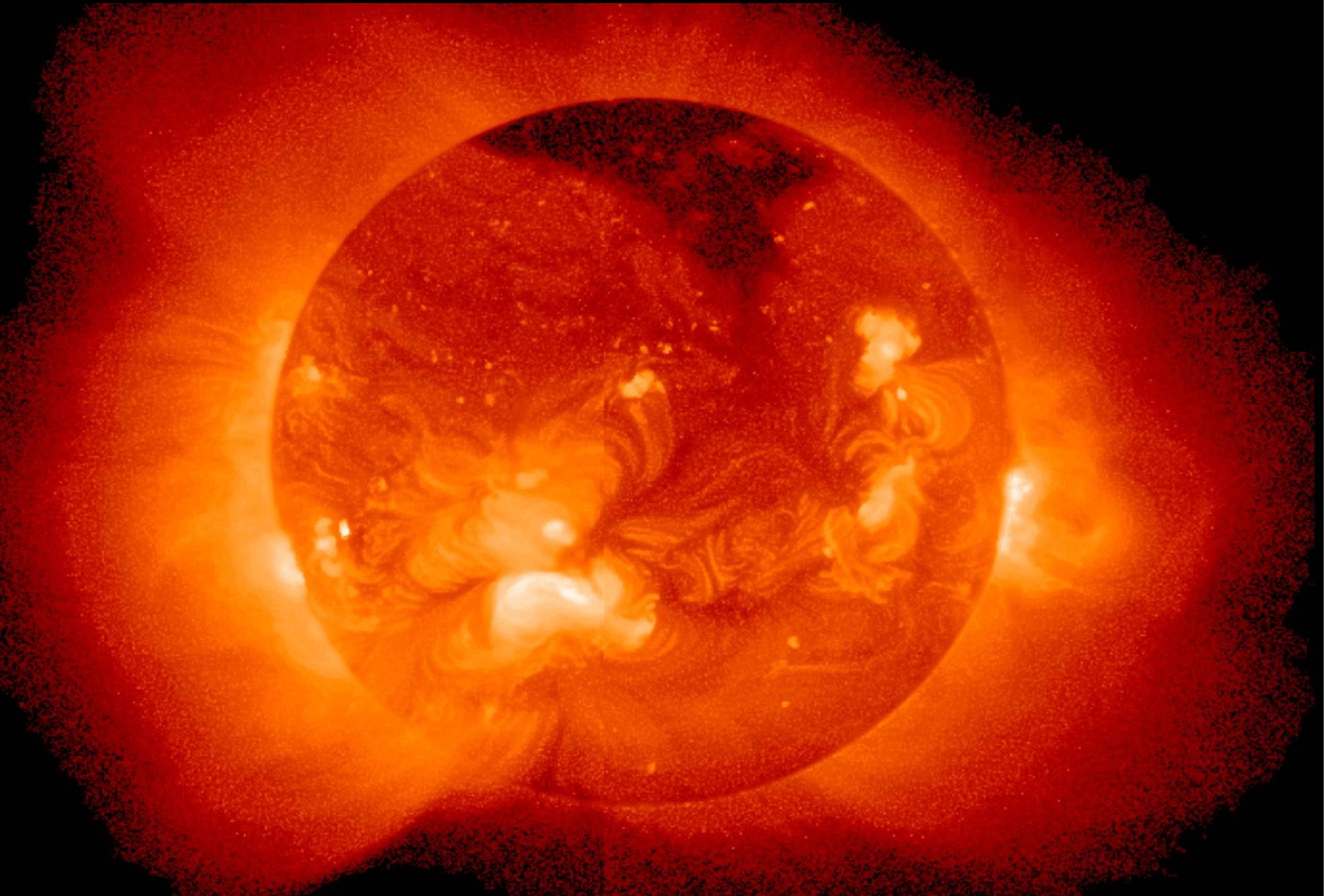




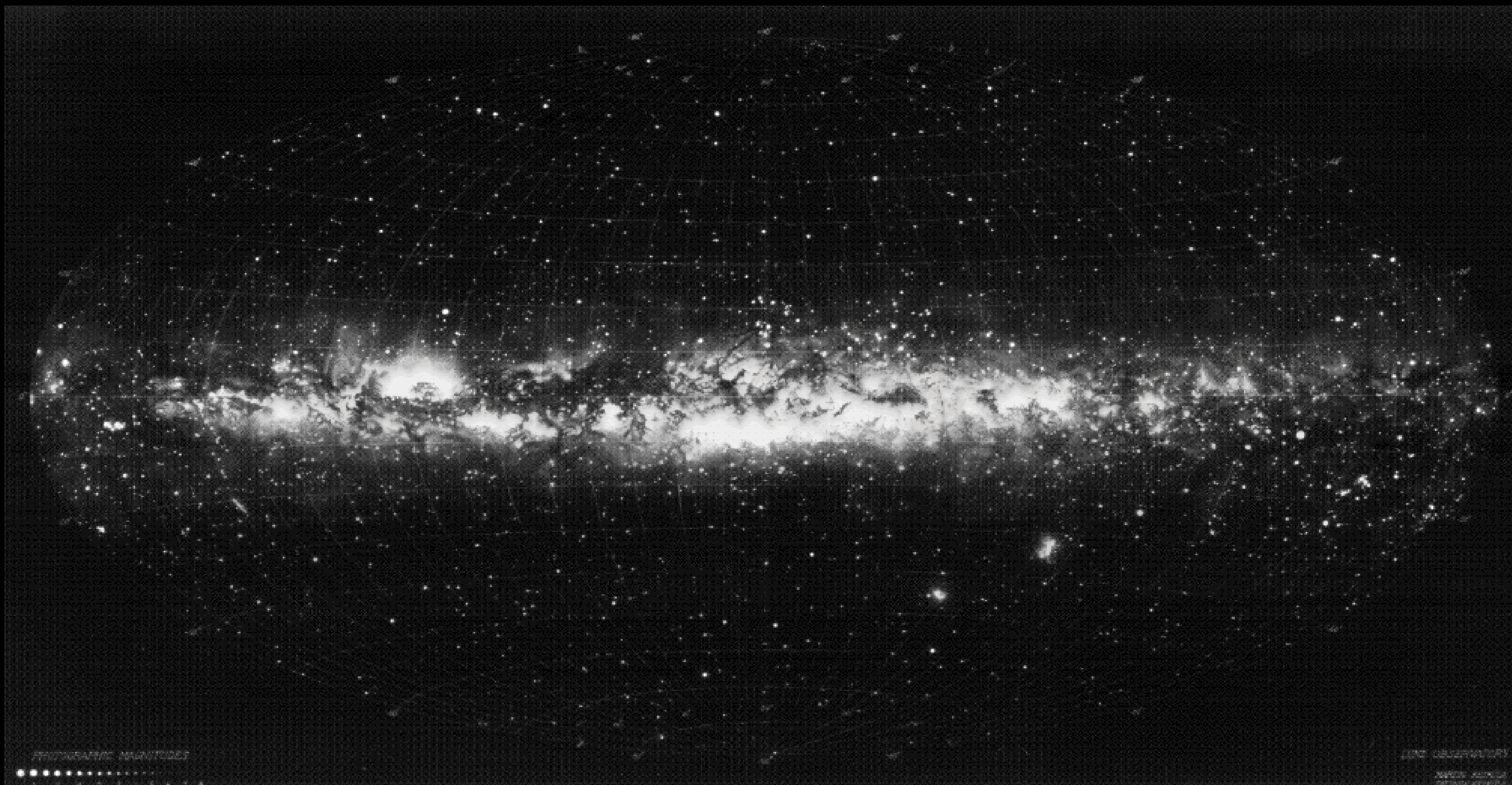


Atmospheric phenomena on other worlds

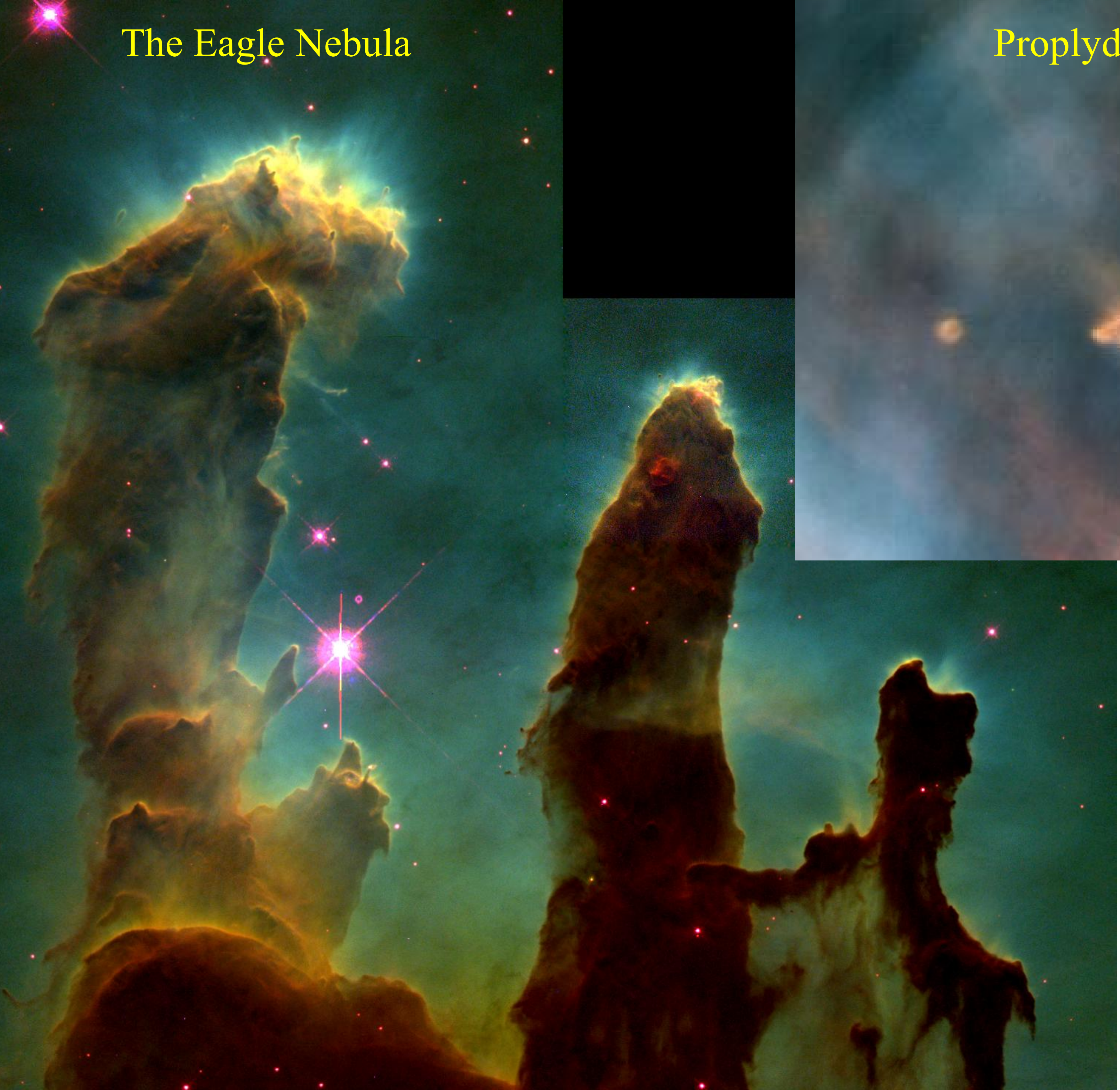
X-ray image of the Sun



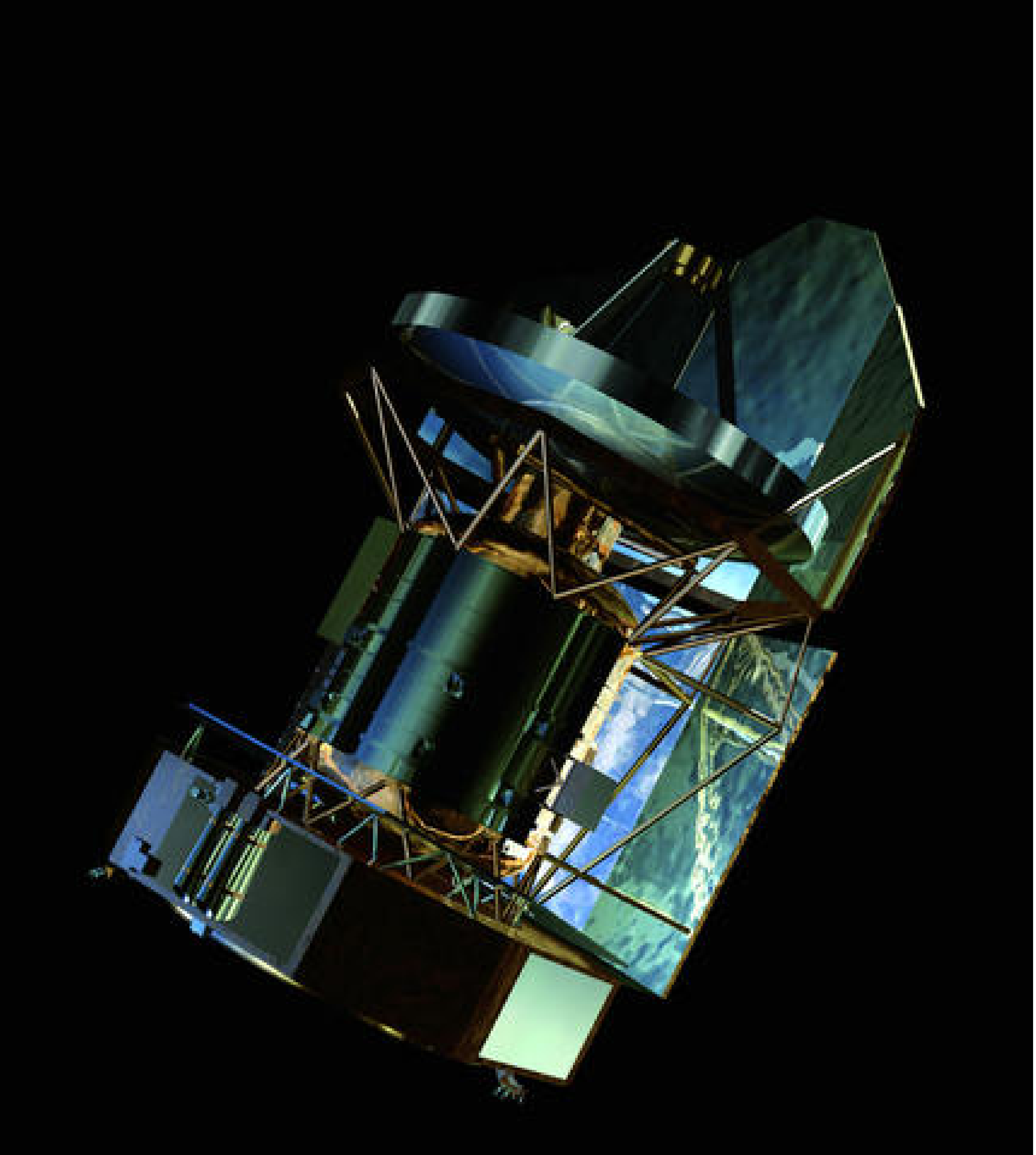
Star map of the whole sky



to 10,000 light years

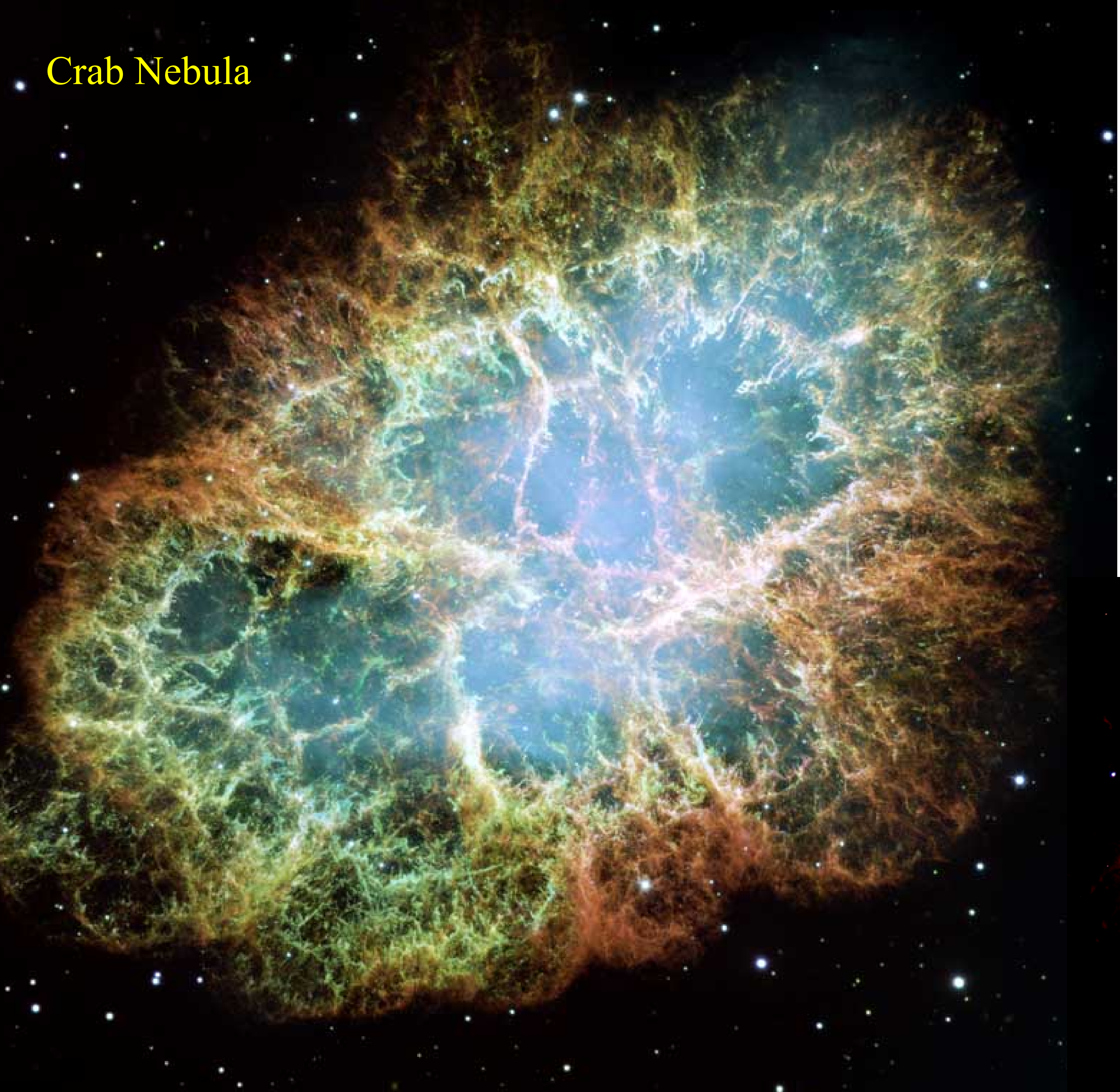


The birth of stars

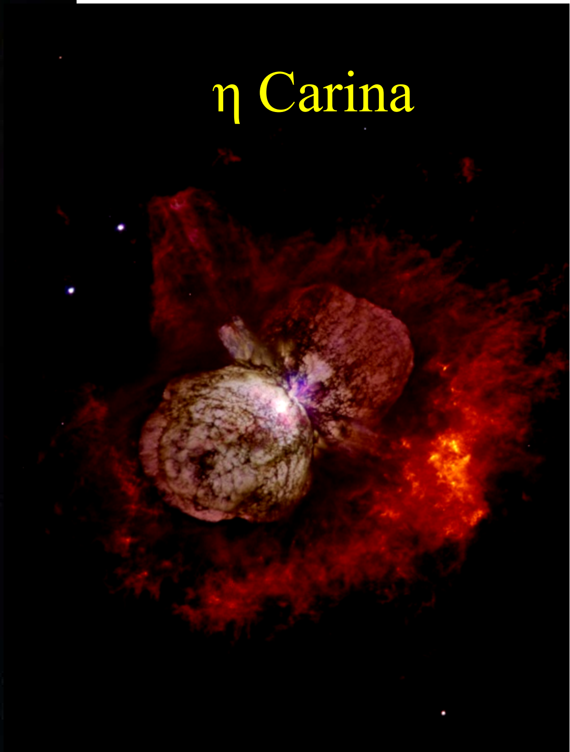


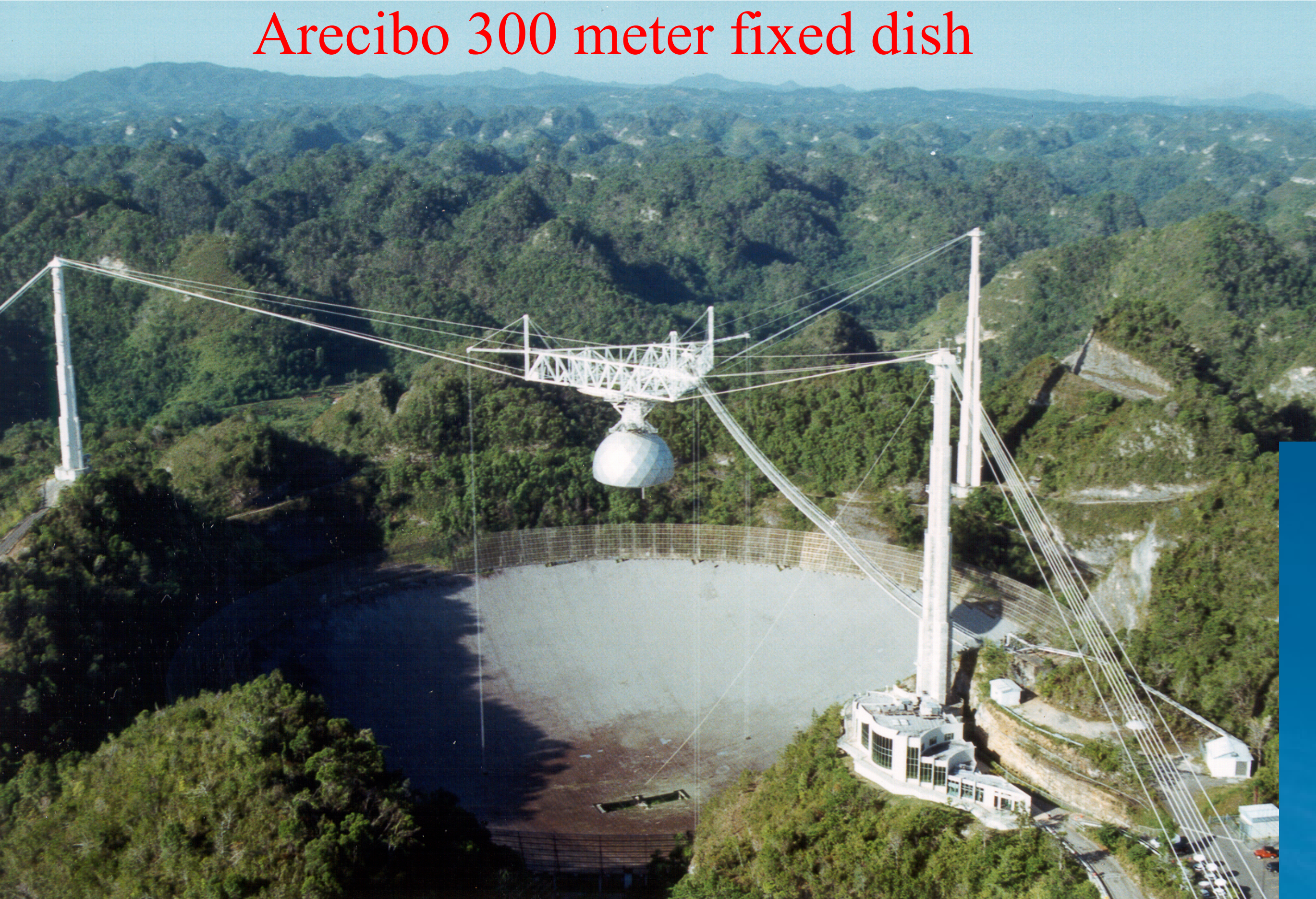
Herschel

The newest space telescope, launch May 2009

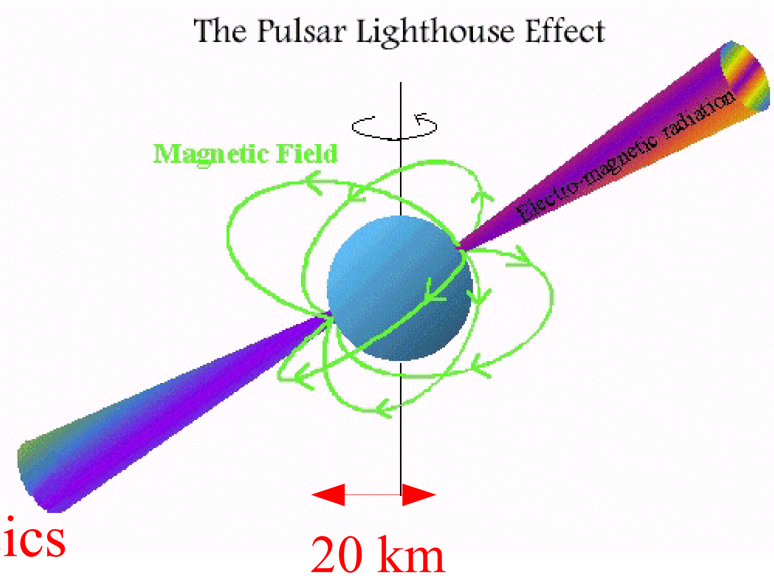


The death of stars



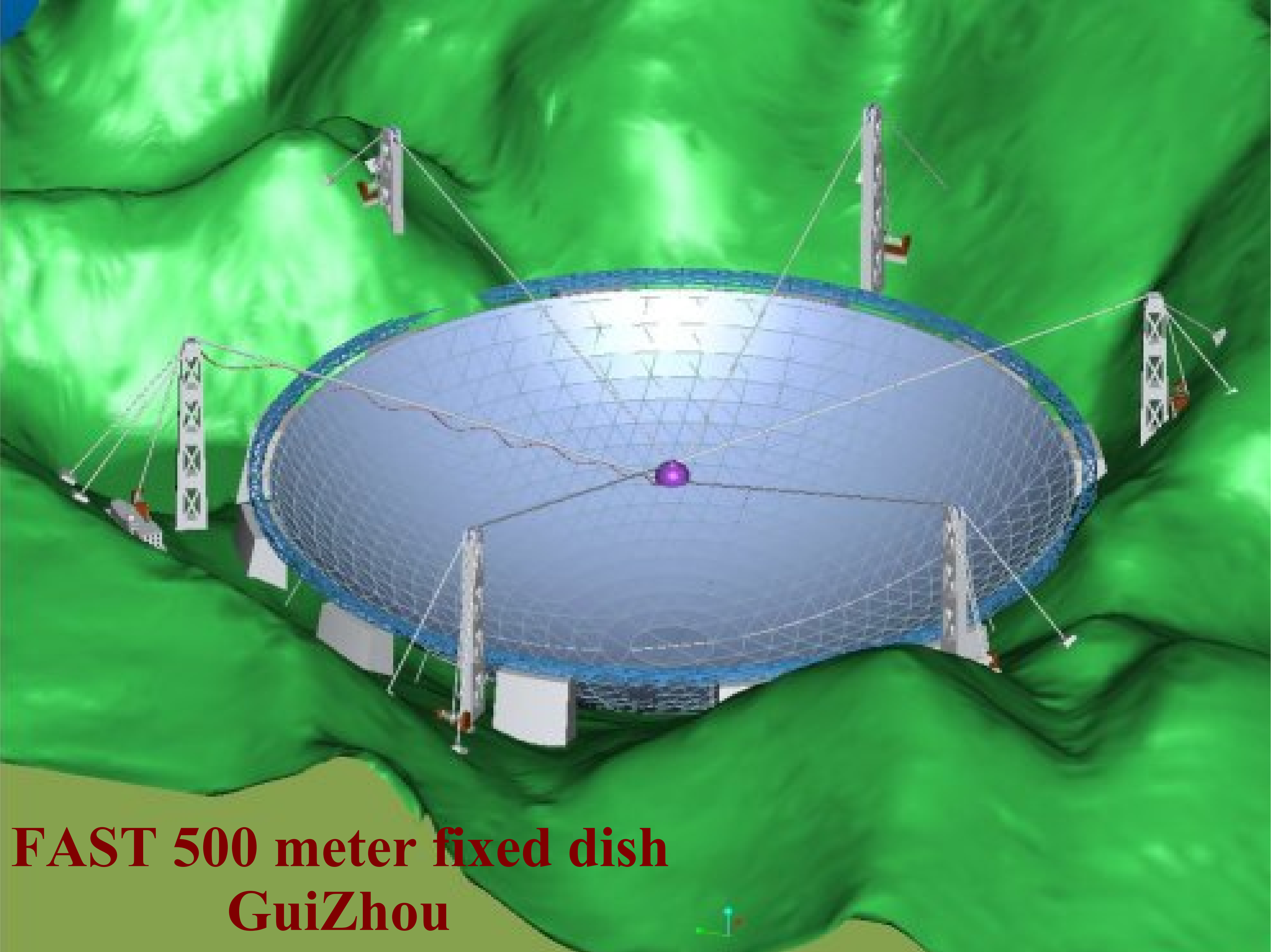


Pulsar Hunters



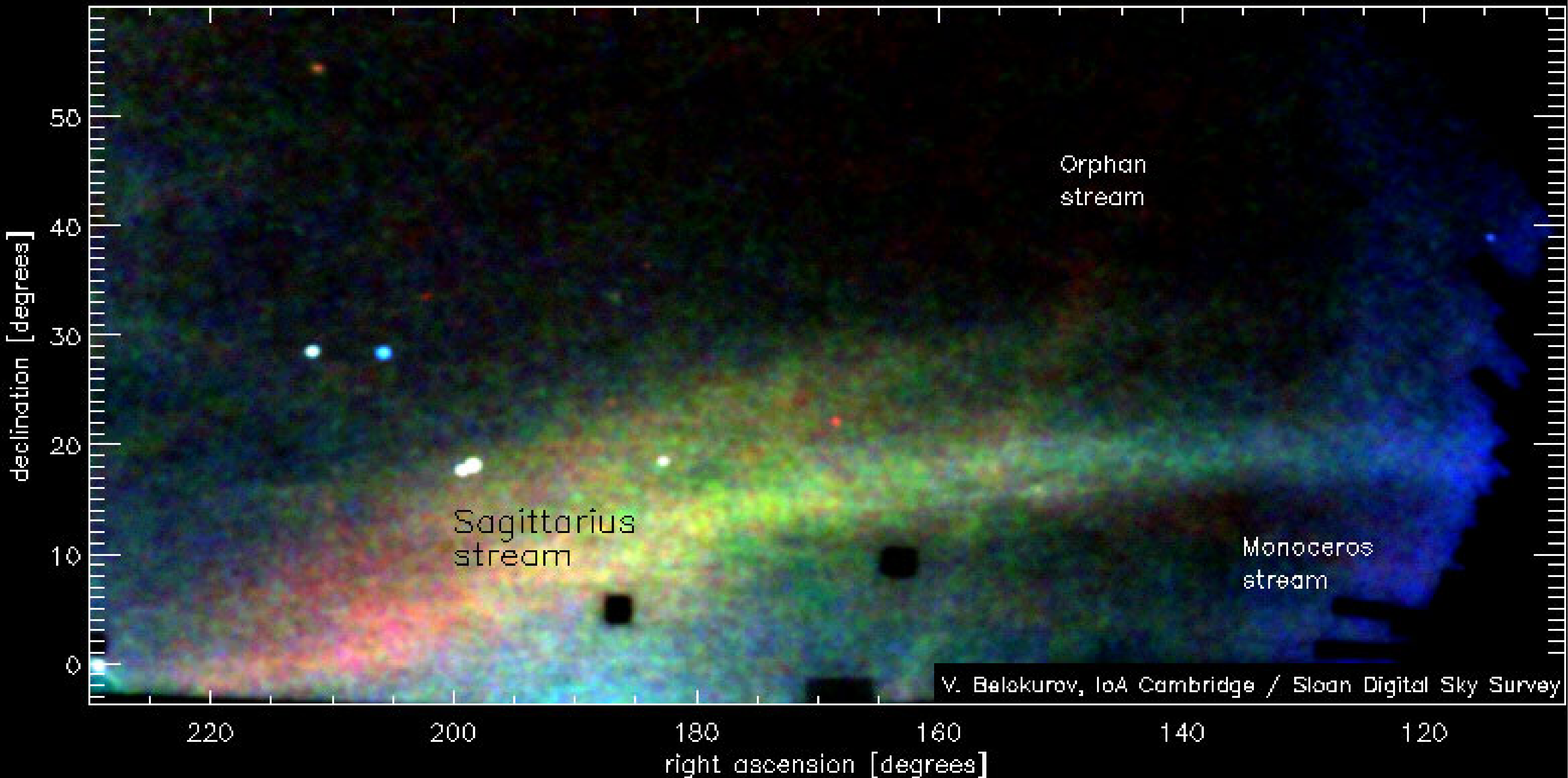
NEUTRON STAR
Mass of the Sun
Size of Hefei
Made of neutrons
Almost a black hole

Nobel Prizes in Physics
1974, 1996

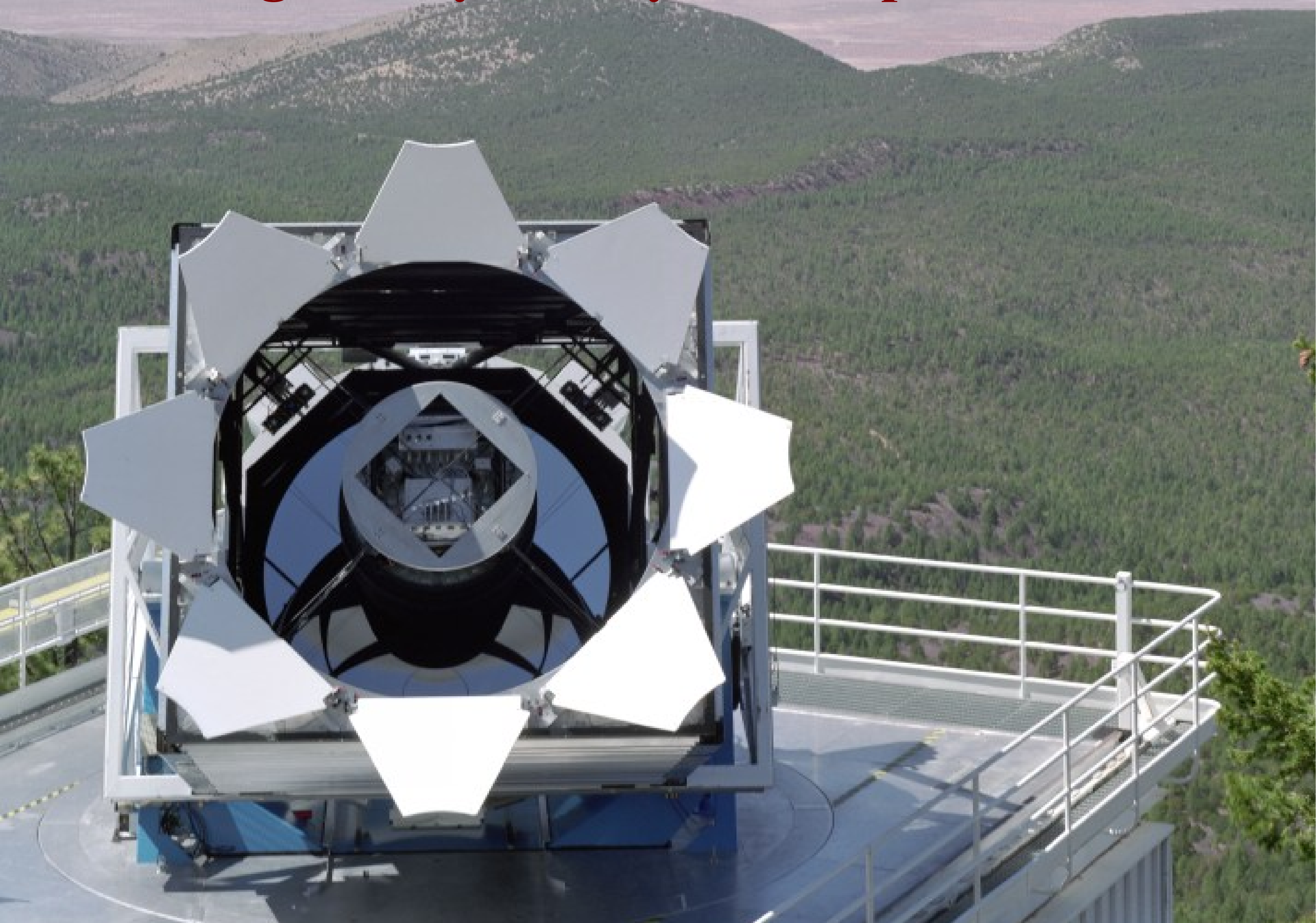

FAST 500 meter fixed dish
GuiZhou

The Field of Streams

Stars in the outer parts of our own Galaxy
The remains of old, tidally shredded satellite galaxies

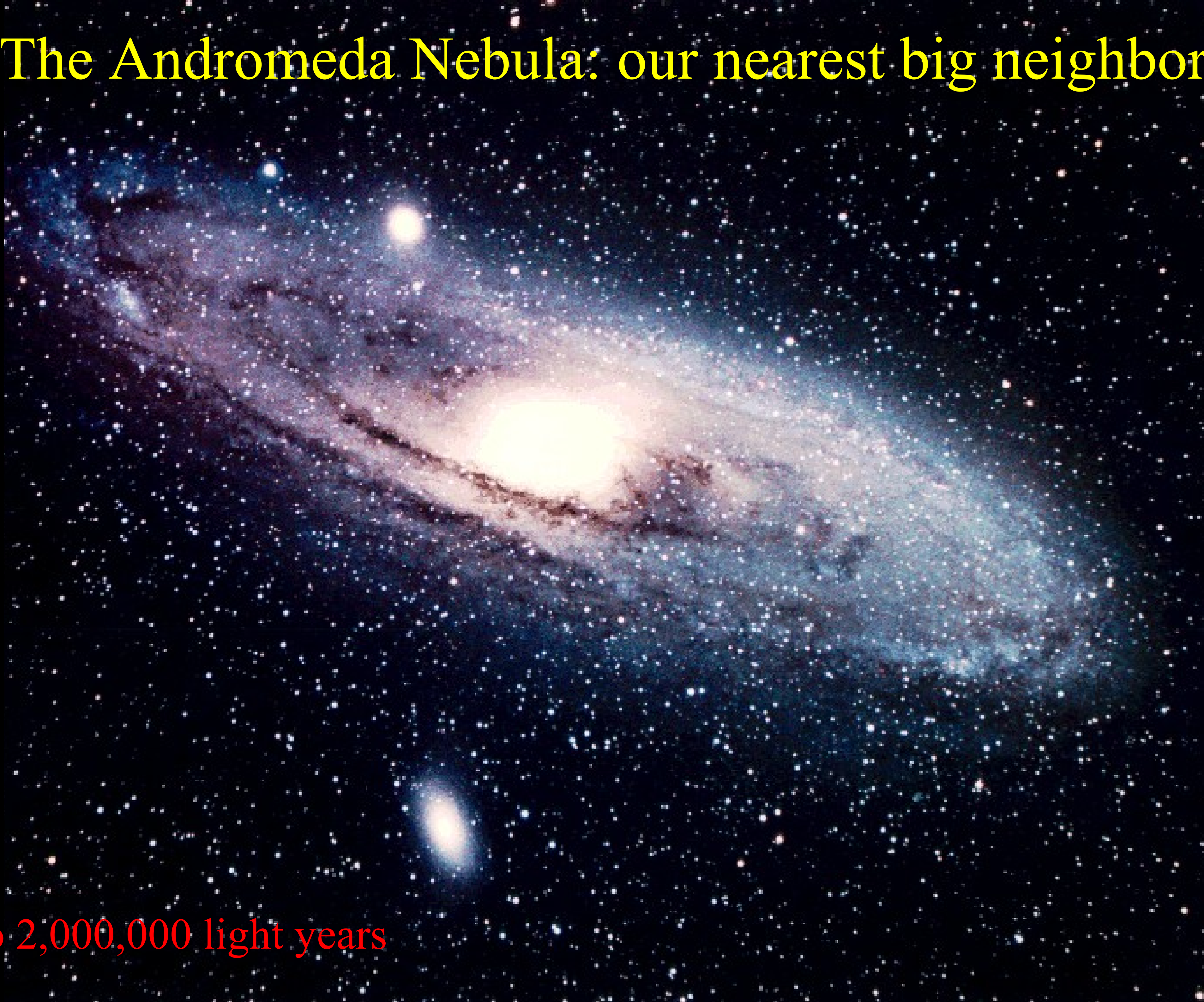


Sloan Digital Sky Survey Telescope, New Mexico




LAMOST telescope
Hebei

The Andromeda Nebula: our nearest big neighbor

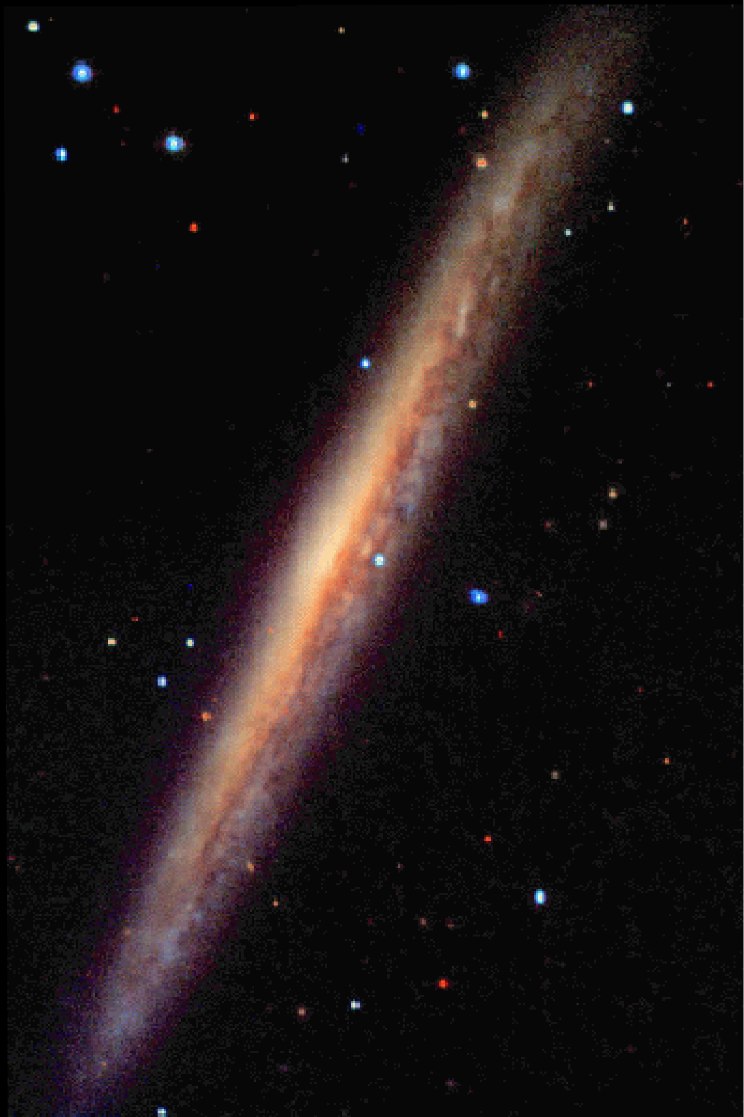


to 2,000,000 light years

Spiral galaxies

M101

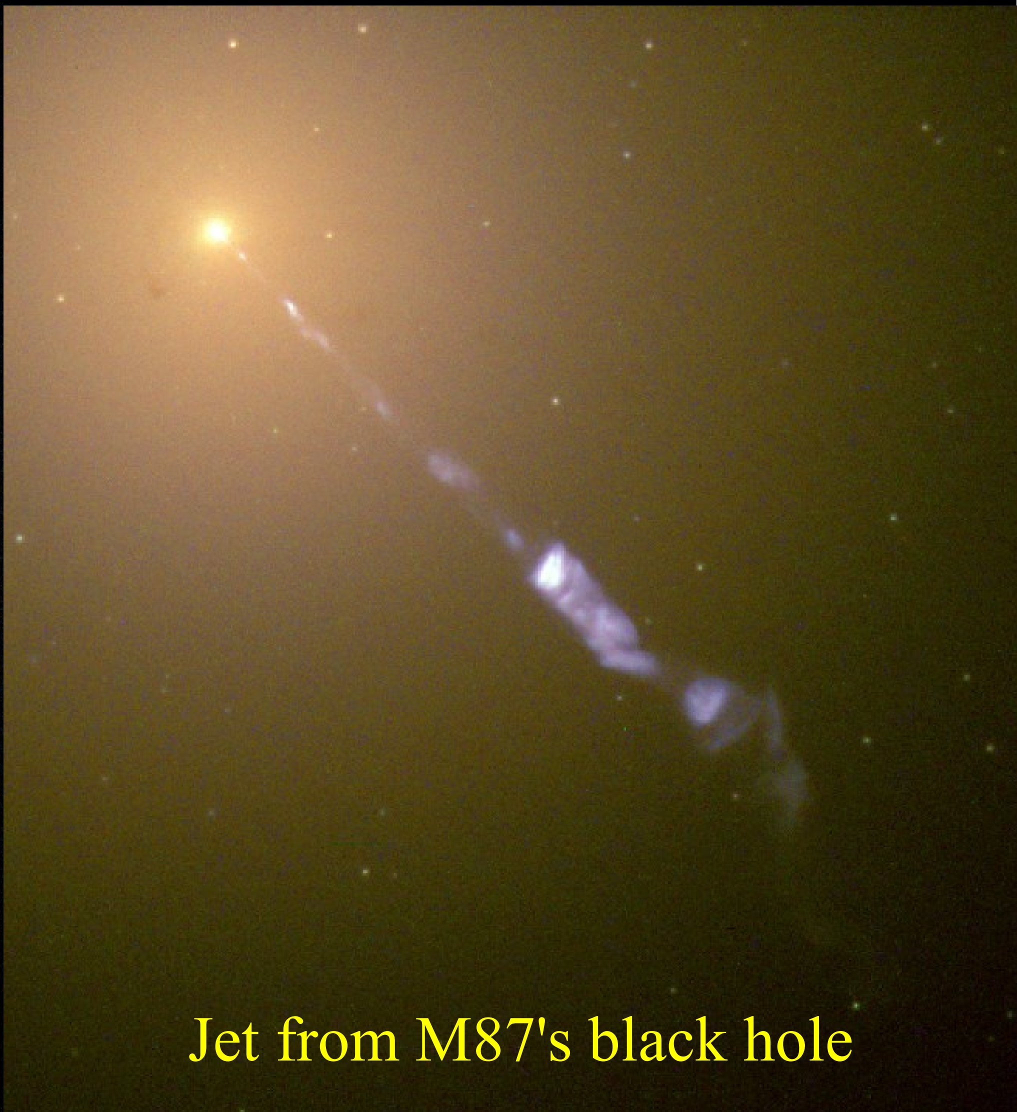
NGC 5907



A Galactic Traffic Accident....

....and its result

Elliptical galaxy NGC 4458



Jet from M87's black hole

Infrared images of the centre of the Milky Way

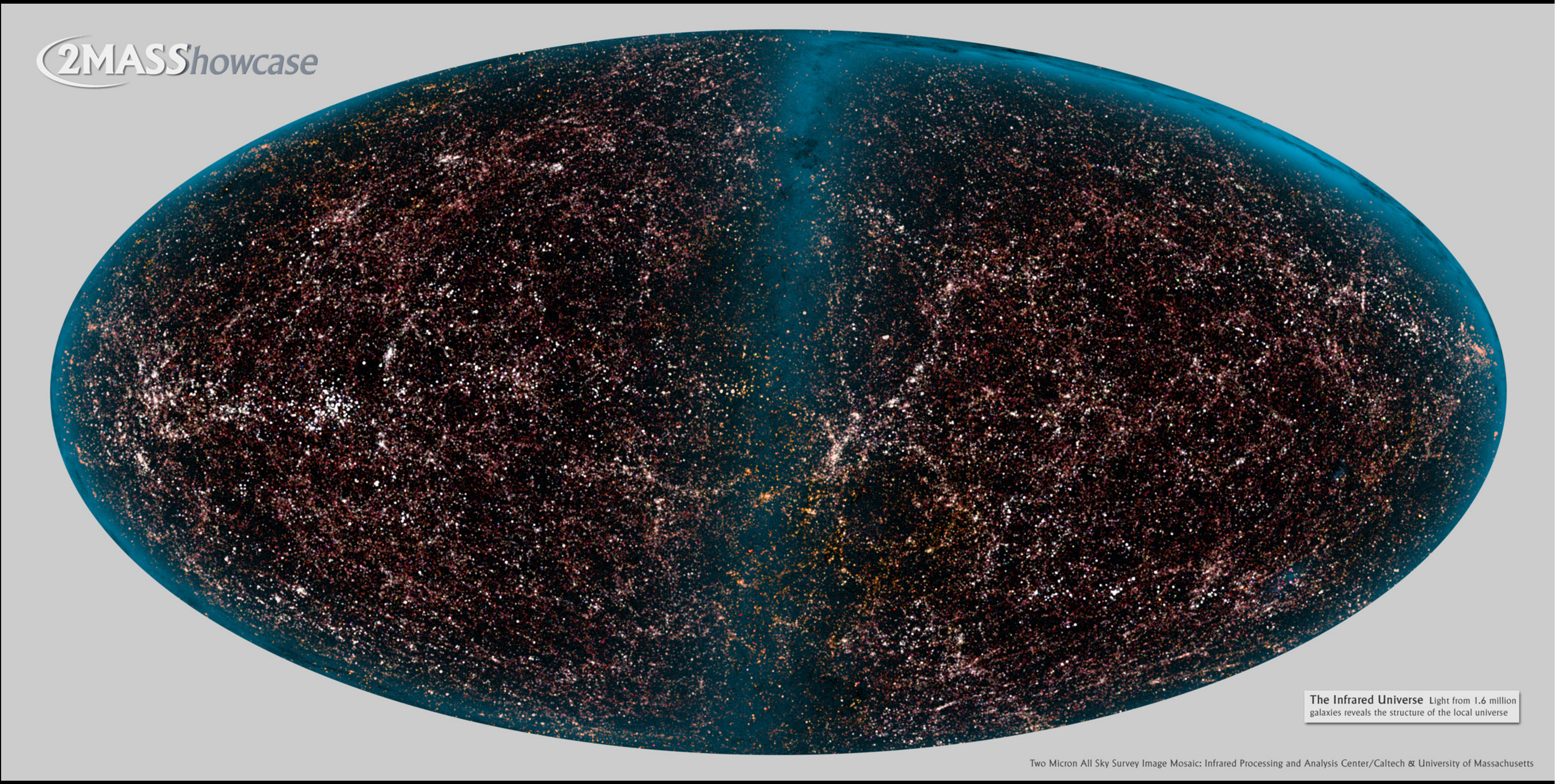
1992 to 2008

The stars orbit a central black hole 4 million times the Sun's mass

The galaxy cluster, Abell 2218
a gravitational telescope

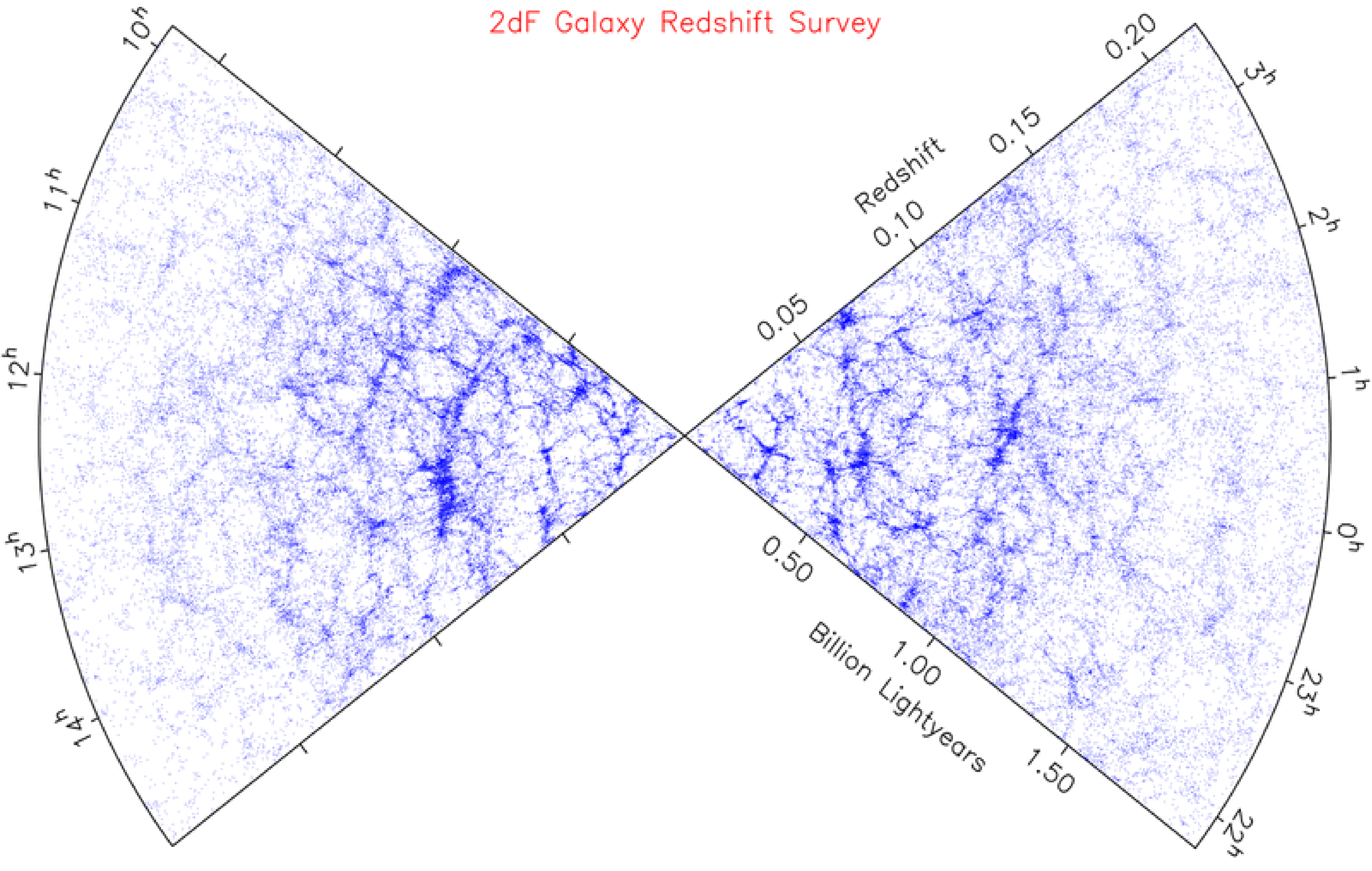
to 4 billion light years (cluster), 15 billion light year (background)

Map of galaxies across the whole sky

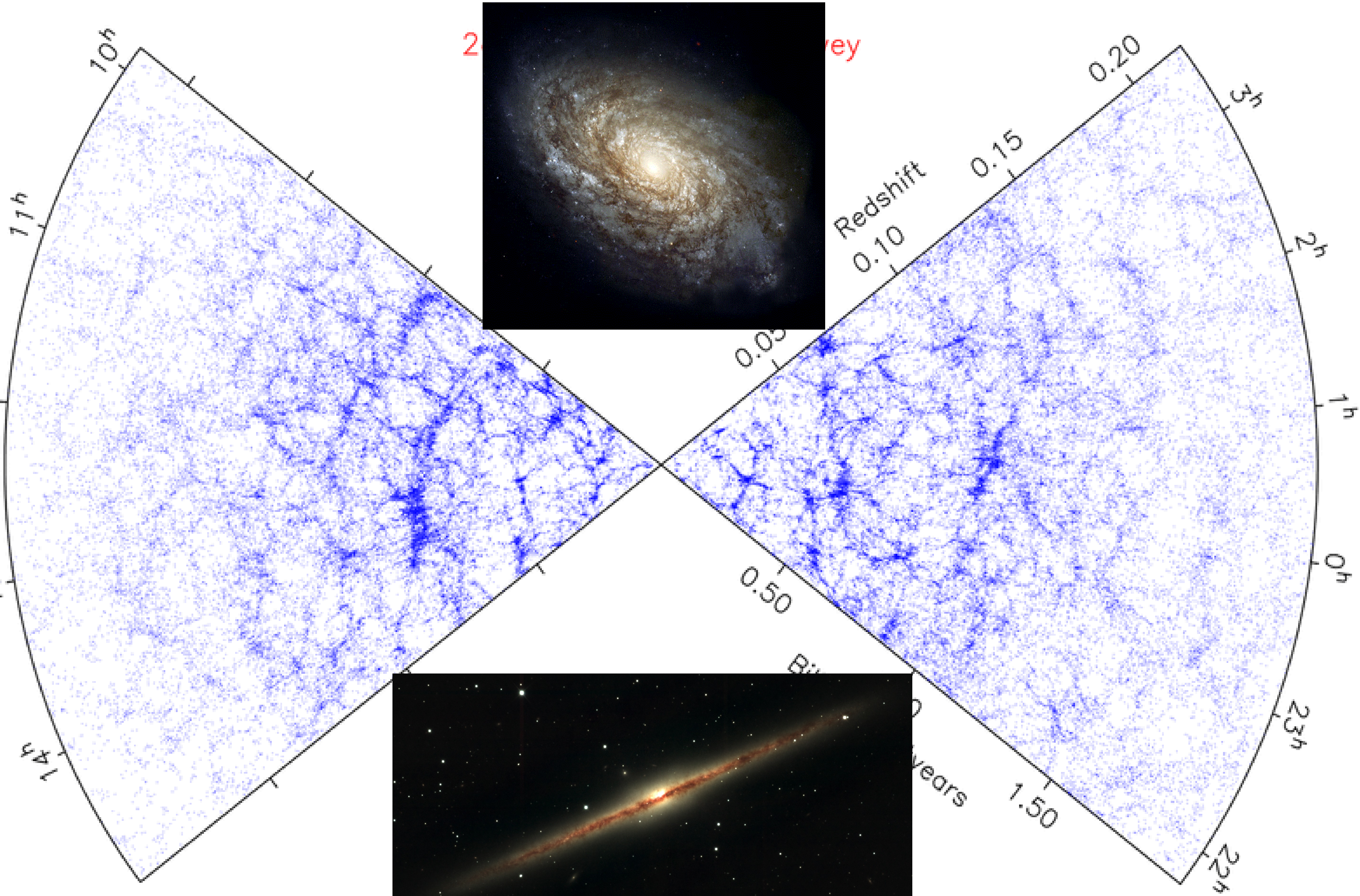


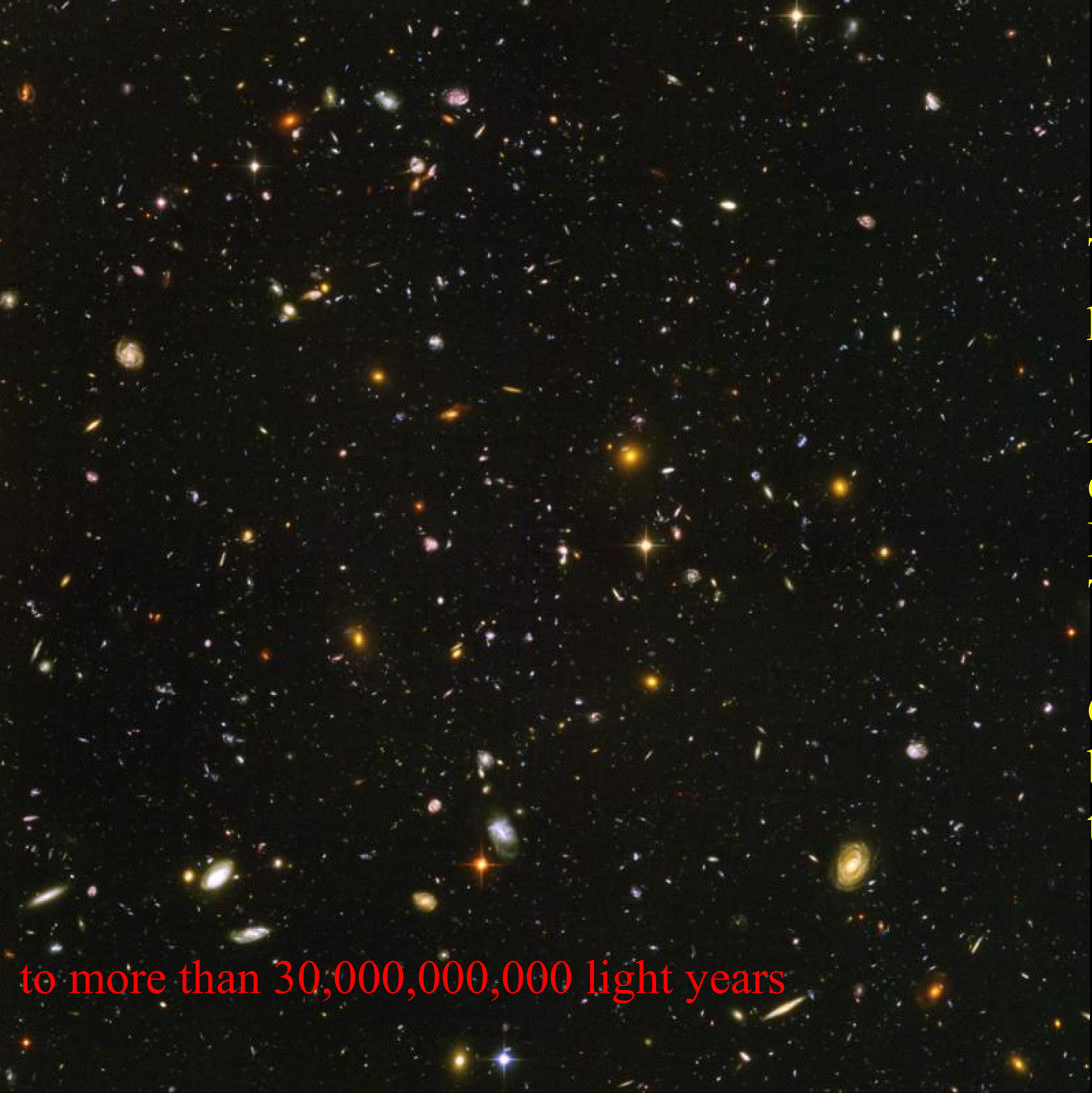
to 1,000,000,000 light years

Nearby large-scale structure



Nearby large-scale structure





The deepest photo ever made

A 300 hour exposure with the Hubble Space Telescope

Galaxies seen back 90% in time to the Big Bang

Hubble Space Telescope

European Southern Observatory: Very Large Telescope

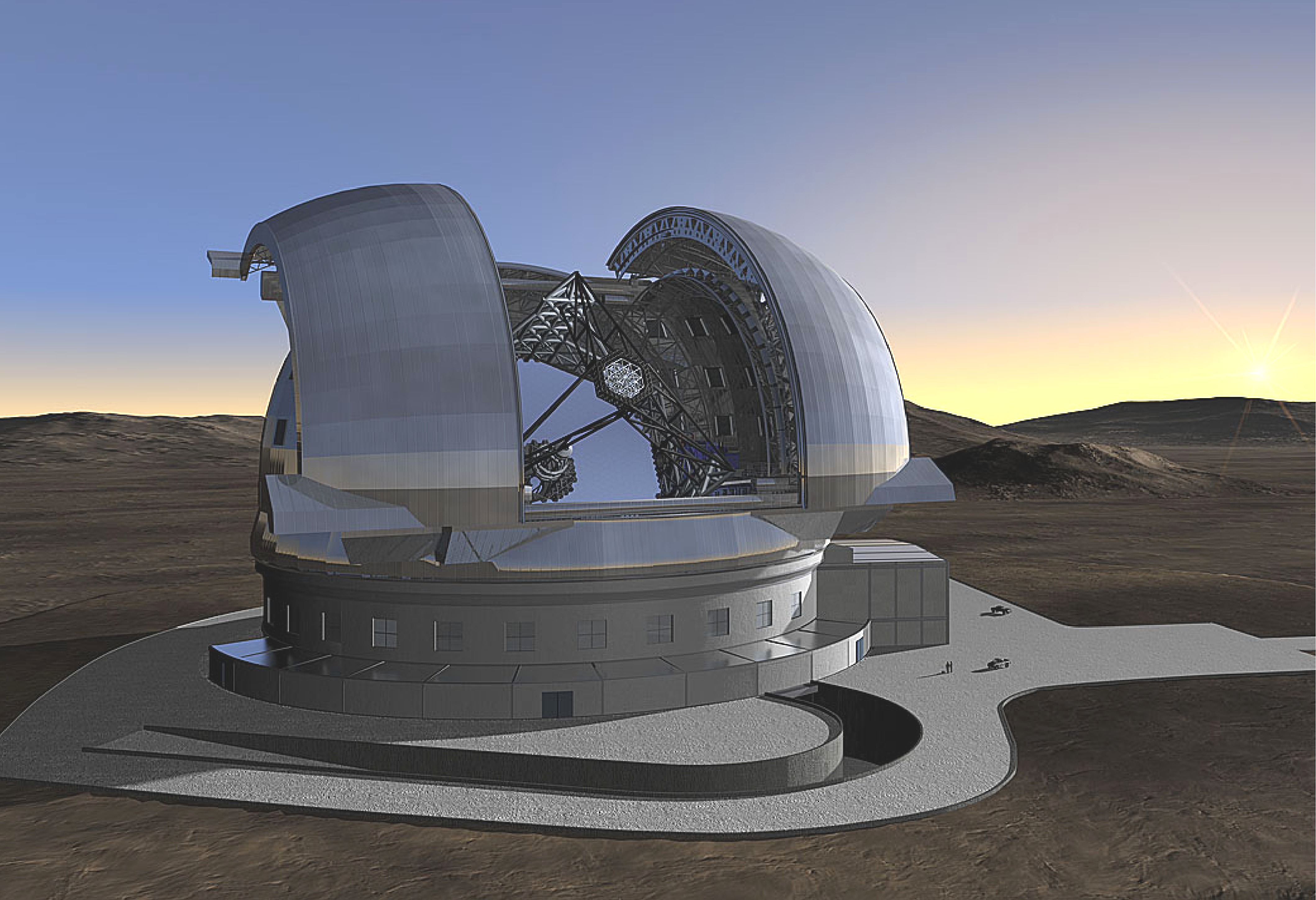
The Very Large Array: New Mexico, United States

The Atacama Large Millimeter Array

5000 meter altitude, Chajnantor Plateau, Chile

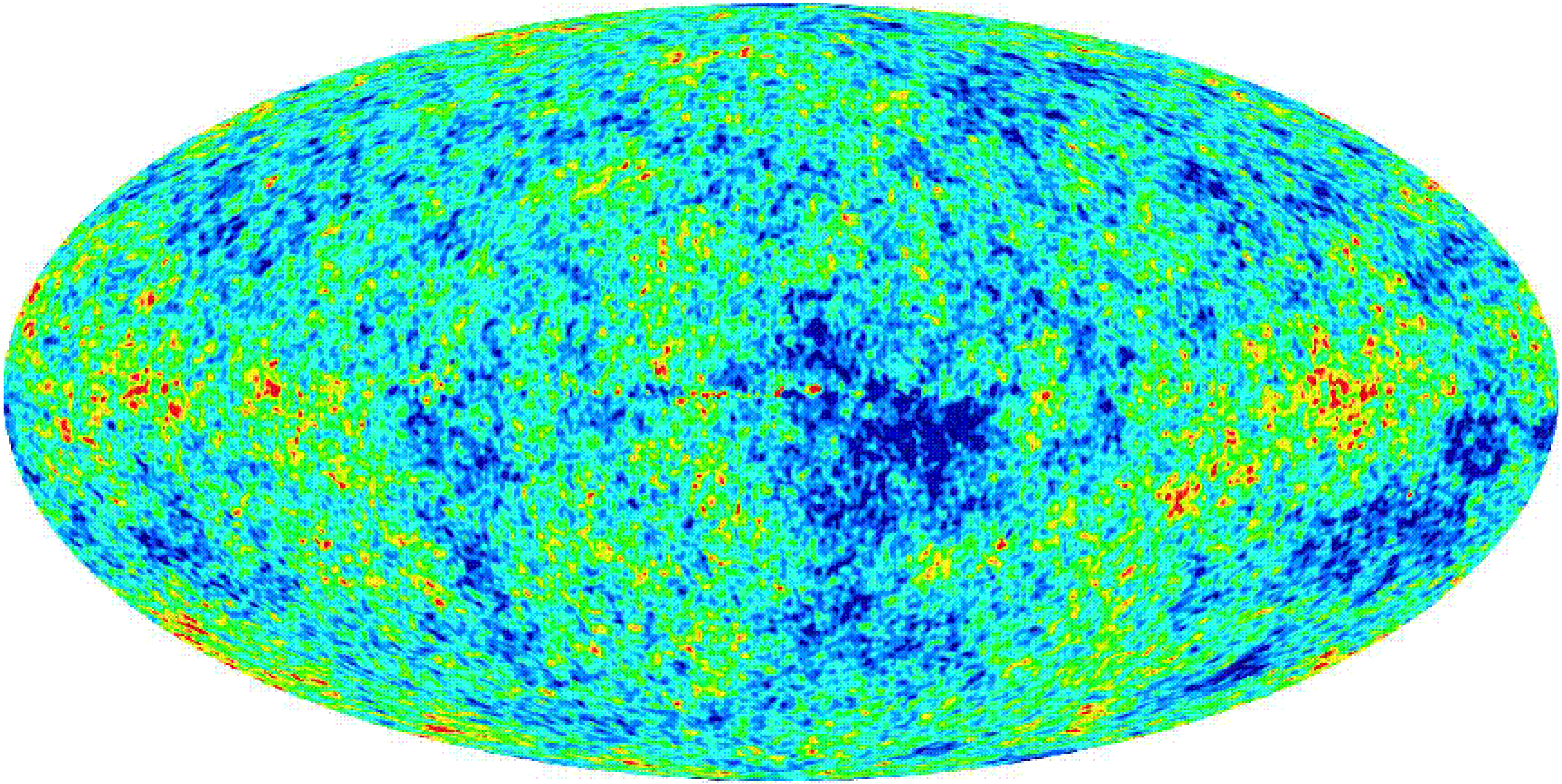
Europe/US/Japan collaboration

Planned 42m European Extremely Large Telescope



The 21cm Array Telescope, Xinjiang

Map of the Cosmic Microwave Background
Our Universe at the age of 400,000 years

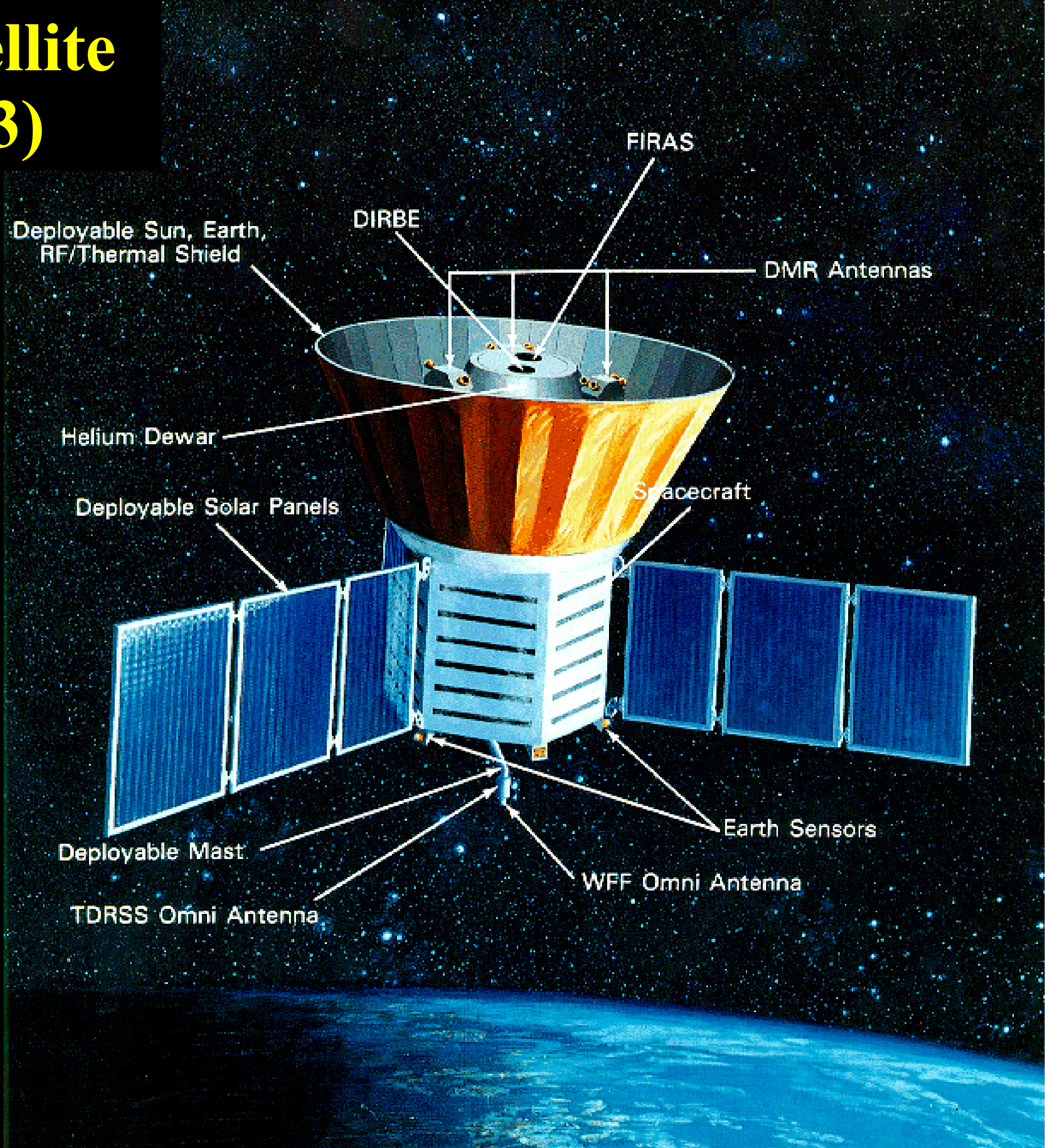


Structure which is 40 billion light-years away today

The COBE satellite (1989 - 1993)

- Two instruments made maps of the whole sky in microwaves and in infrared radiation
- One instrument took a precise spectrum of the sky in microwaves

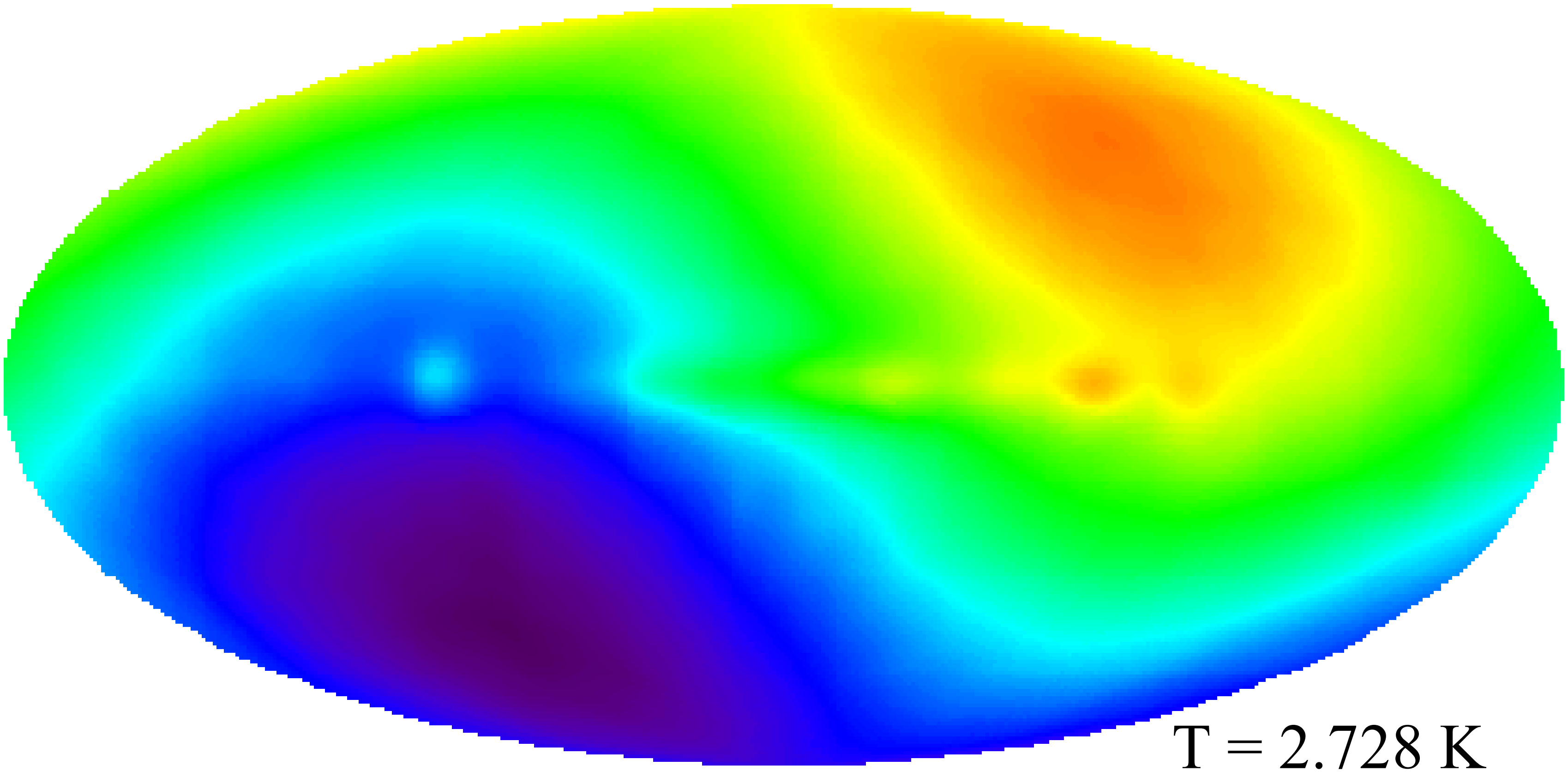
Nobel Prize in Physics 2006



COBE's temperature map of the entire sky

T = 2.728 K
ΔT = 0.1 K

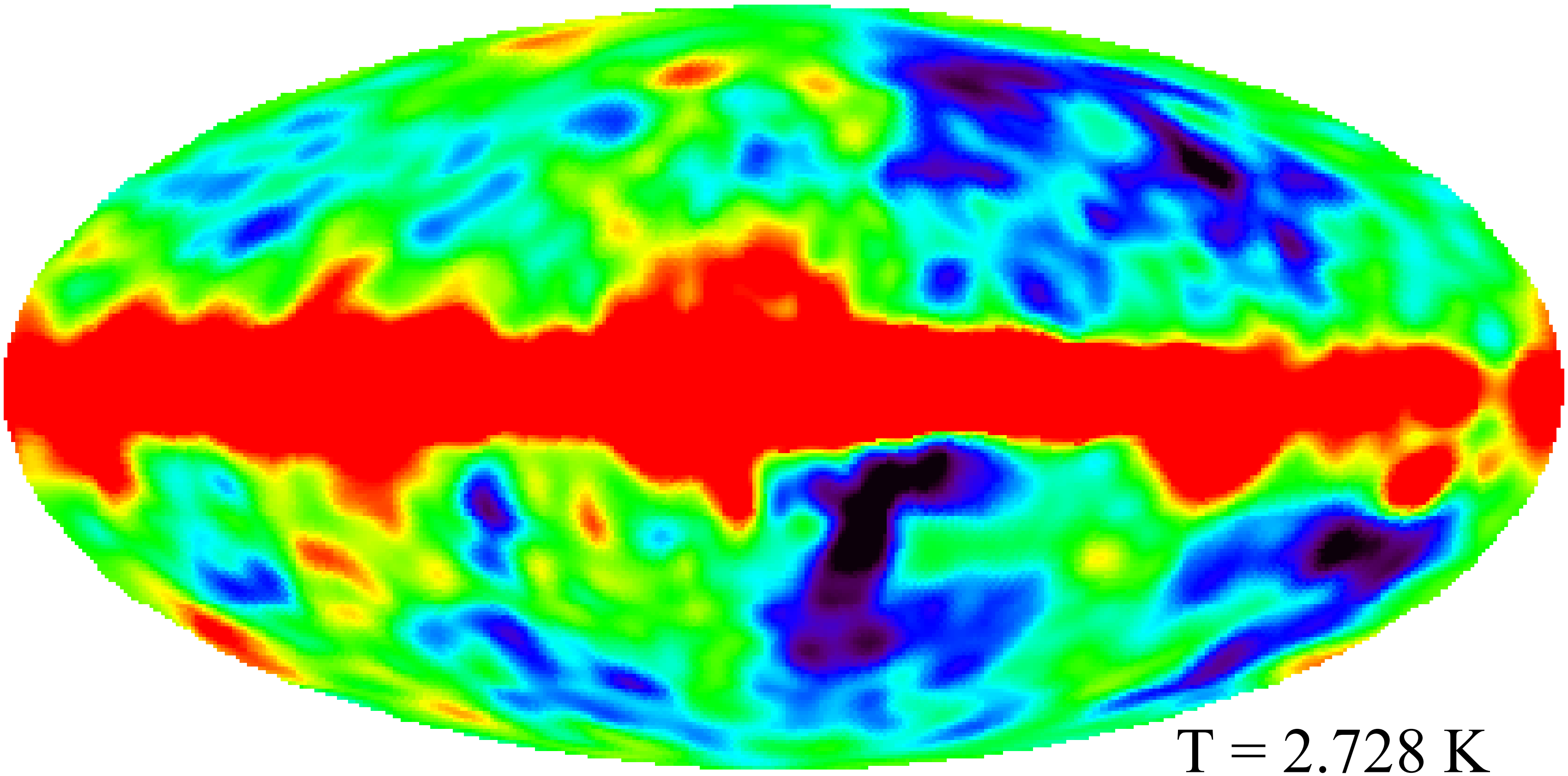
COBE's temperature map of the entire sky



T = 2.728 K

$\Delta T = 0.0034$ K

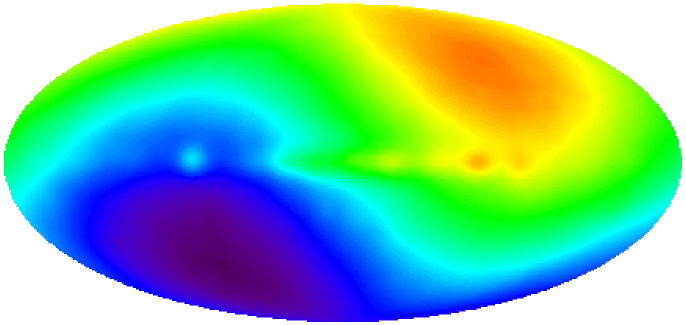
COBE's temperature map of the entire sky



$T = 2.728$ K

$\Delta T = 0.00002$ K

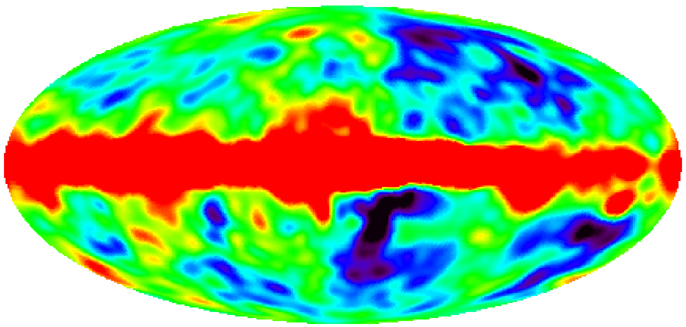
Structure in the COBE map



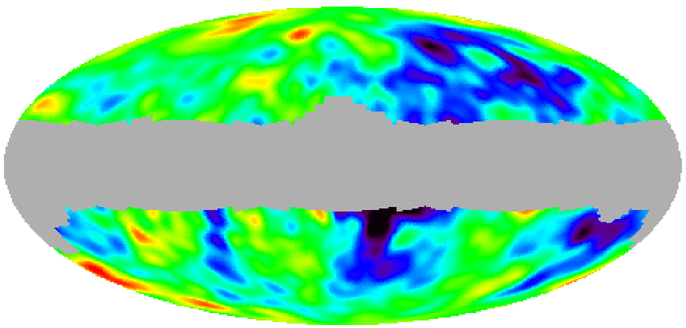
- One side of the sky is `hot', the other is `cold'

→ the Earth's motion through the Cosmos

$V_{\text{Milky Way}} = 600$ km/s

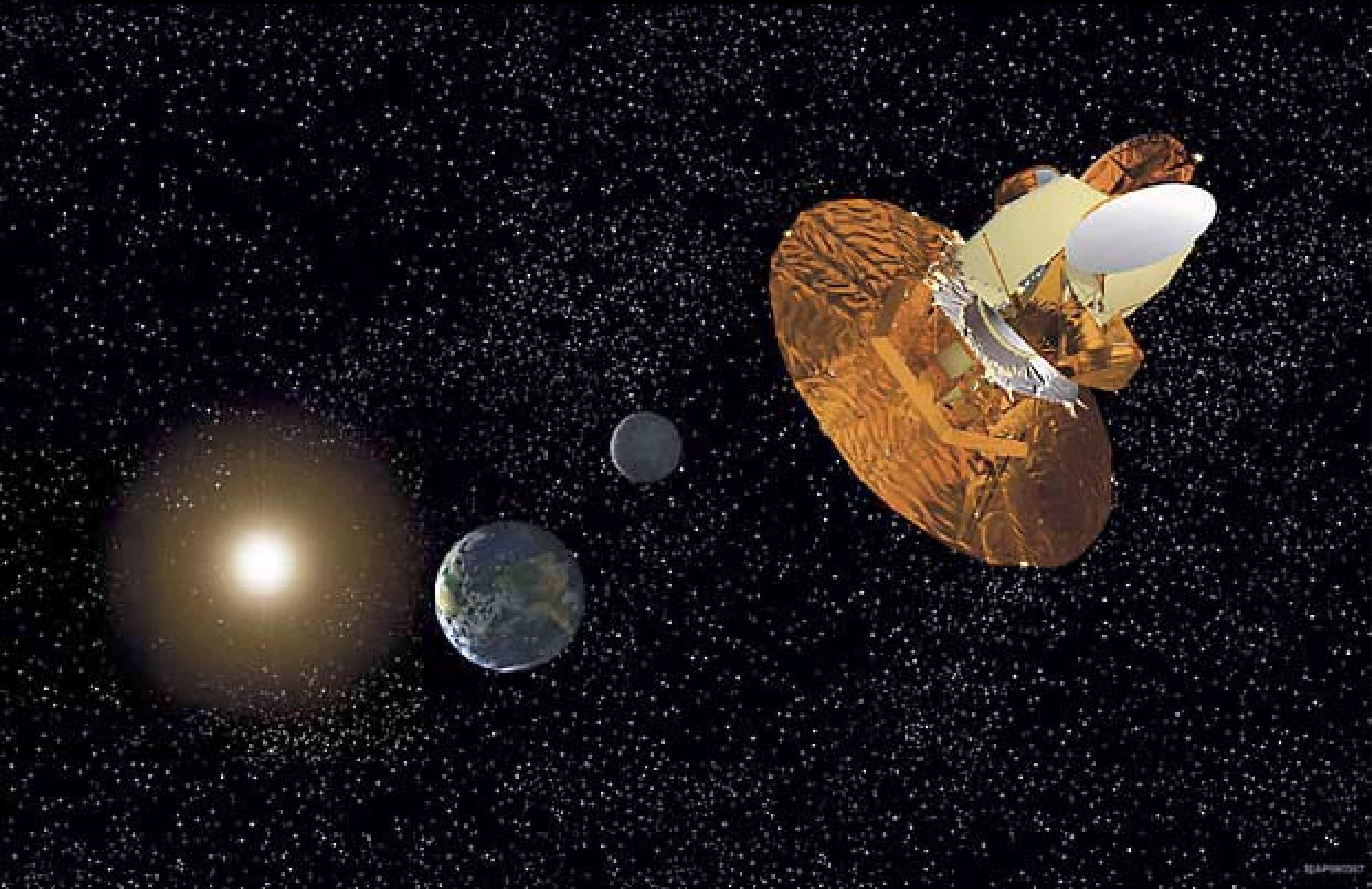


- Radiation from hot gas and dust in our own Milky Way

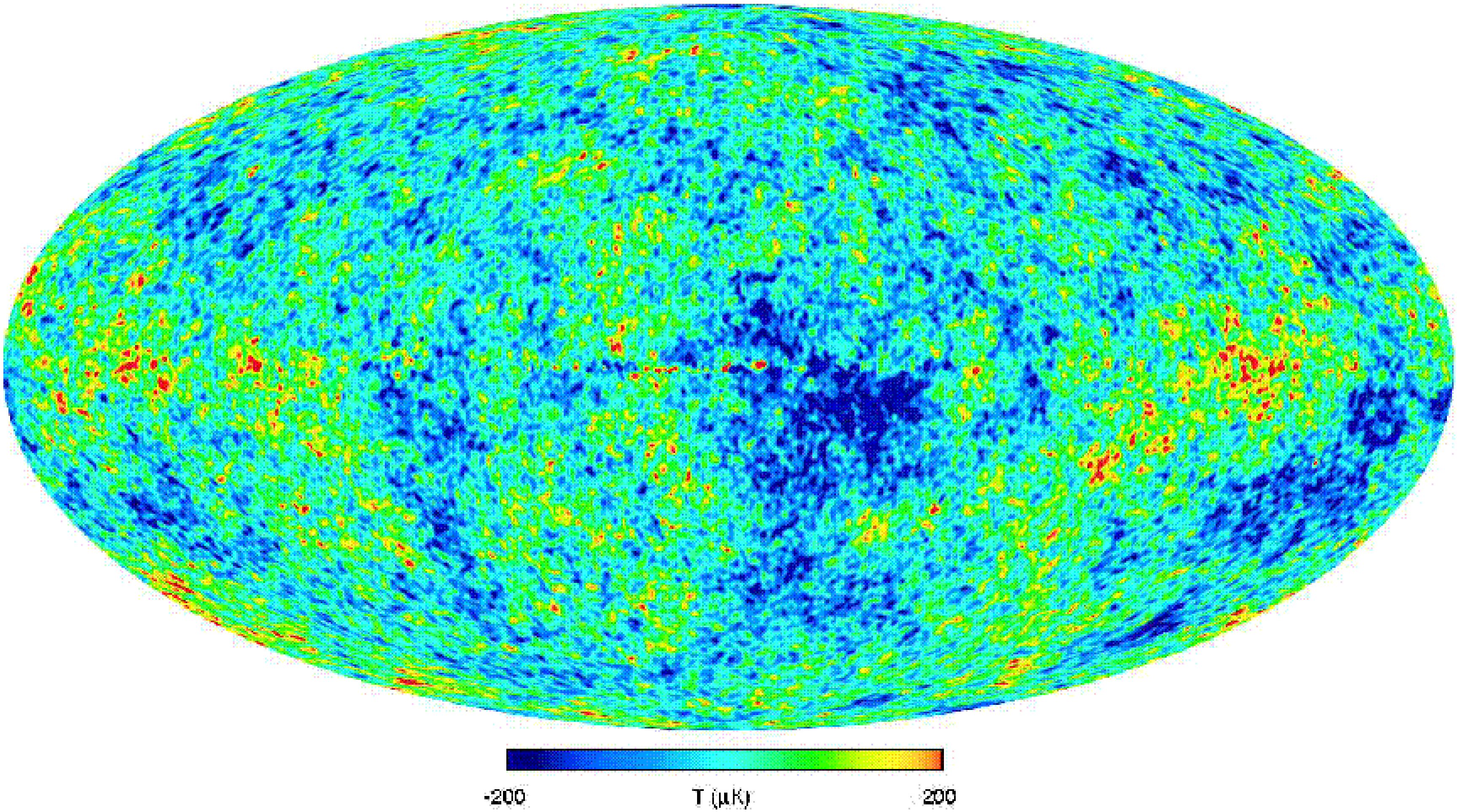


- Structure in the Microwave Background itself

The *WMAP* Satellite at Lagrange-Point L2



The *WMAP* of the whole CMB sky



Bennett et al 2003

Structure in the Microwave Background

- The structure lies in cosmic "clouds", ~ 4 10^{10} l-yrs away
- It reflects weak "sound" waves, A ~ 10^{-4}, in the clouds
- At the time the Universe was only 400,000 years old, and was 1,000 times smaller and 1,000 times hotter than today

The *pattern* of structure reflects

A: The global geometry of the Universe

B: The material content and thermal evolution of the Universe

C: The process which generated the structure

What has WMAP taught us?

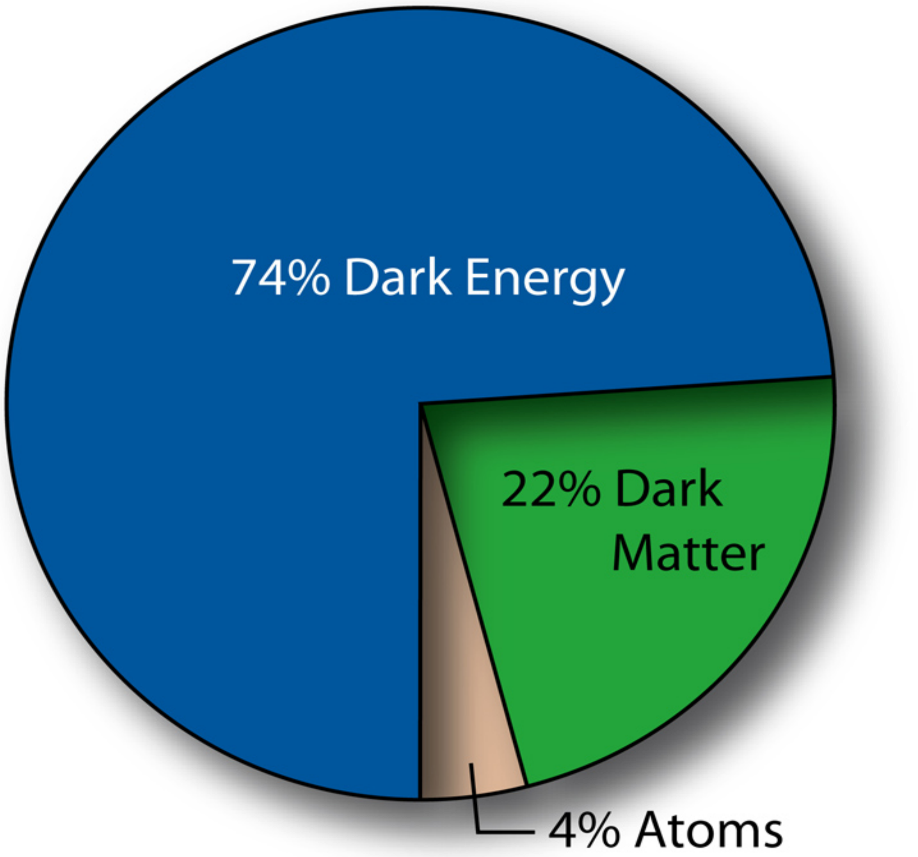
- Our Universe is flat -- its geometry is that described by Euclid

- Only a small fraction is made of ordinary matter -- about 4% today

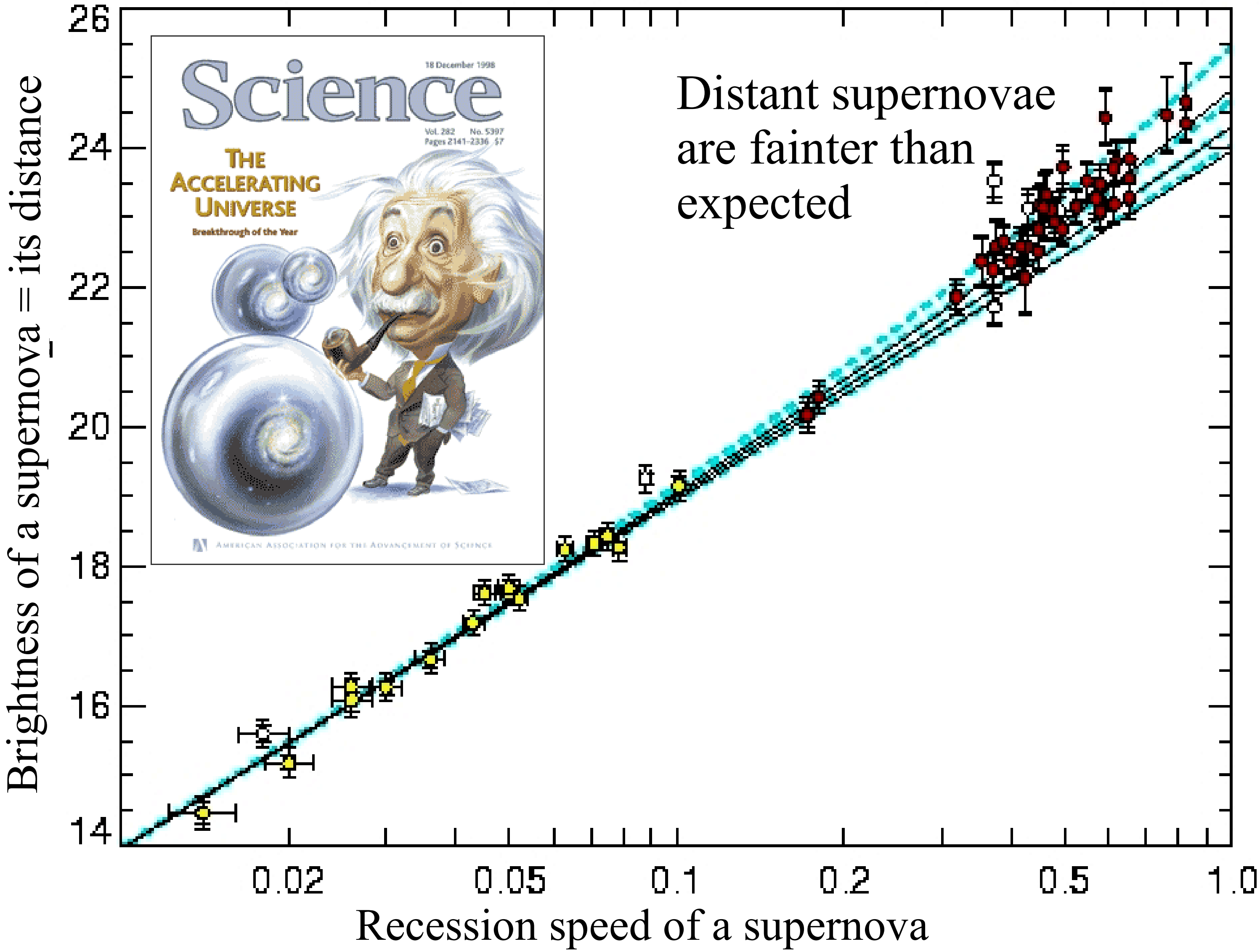
- About 21% of today's Universe is <u>non-baryonic</u> Dark Matter neutralinos? axions? ...?

- About 75% is Dark Energy

- All structure was apparently produced by quantum fluctuations in the <u>vacuum</u> at a very early time

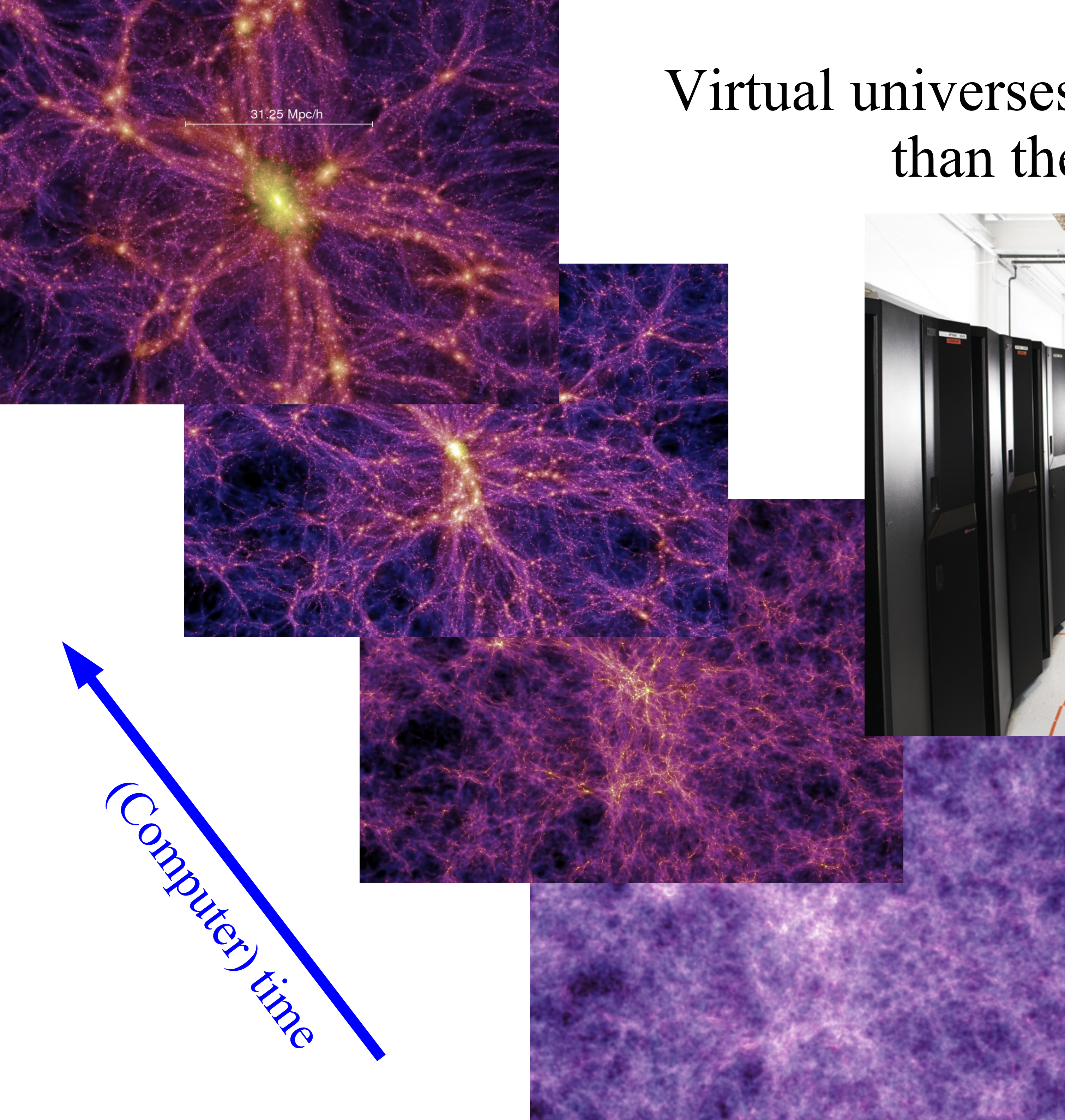


The Universe expands faster today than in the past!



The cosmic expansion is accelerating! According to Einstein's theory of gravity, this requires negative pressure, $p = -\rho$ --- Dark Energy

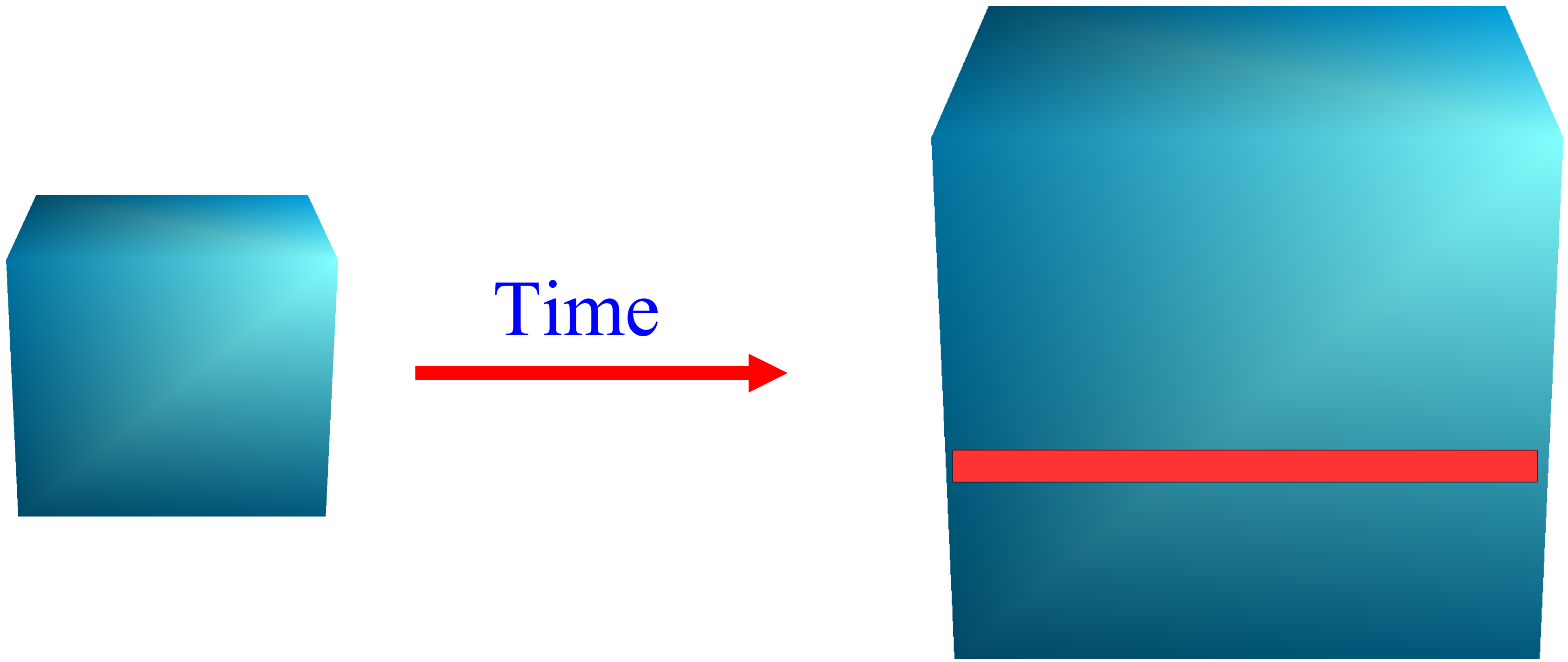
Virtual universes can run faster than the real Universe



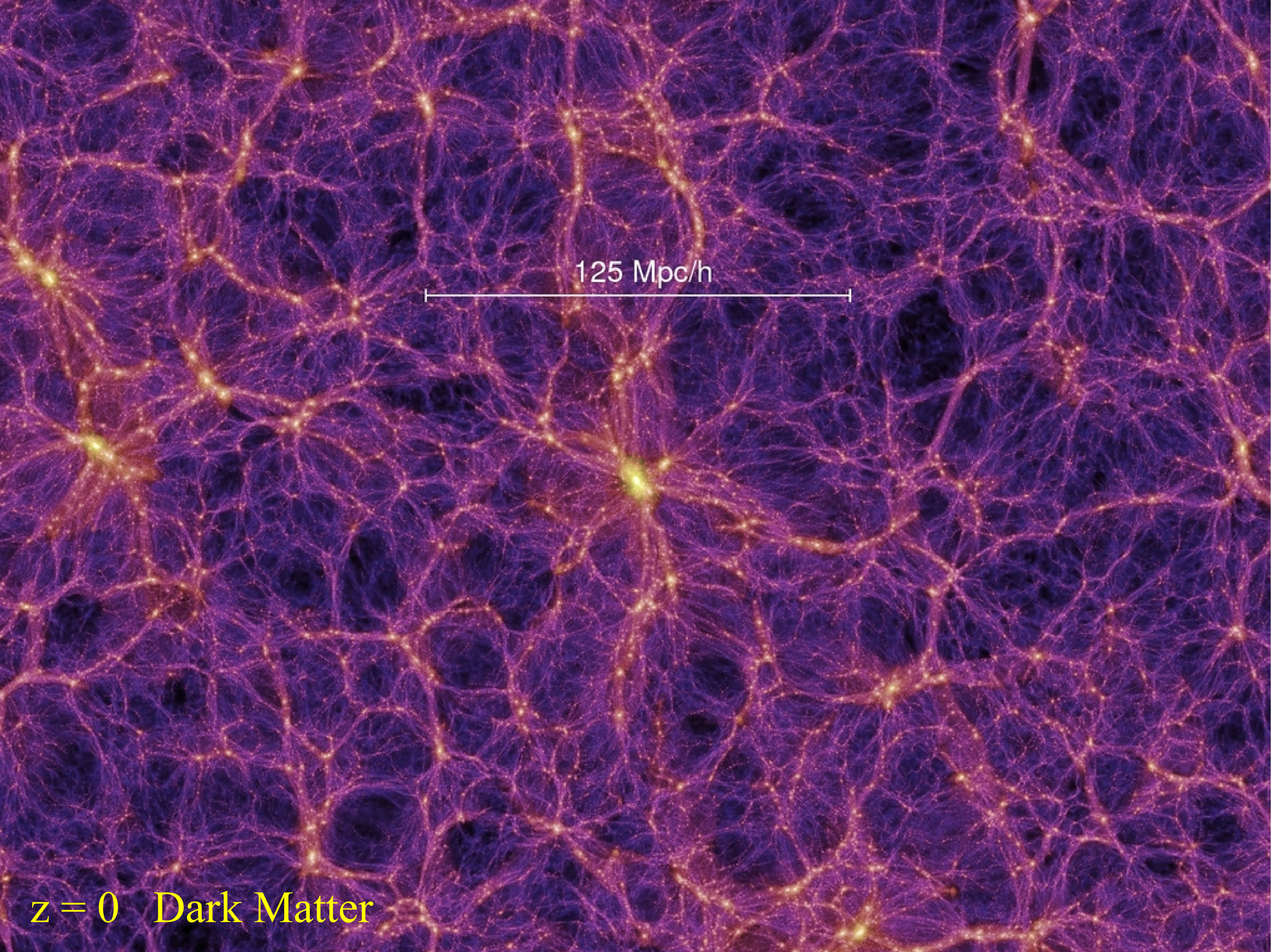
Leibniz Computer Center, Munich

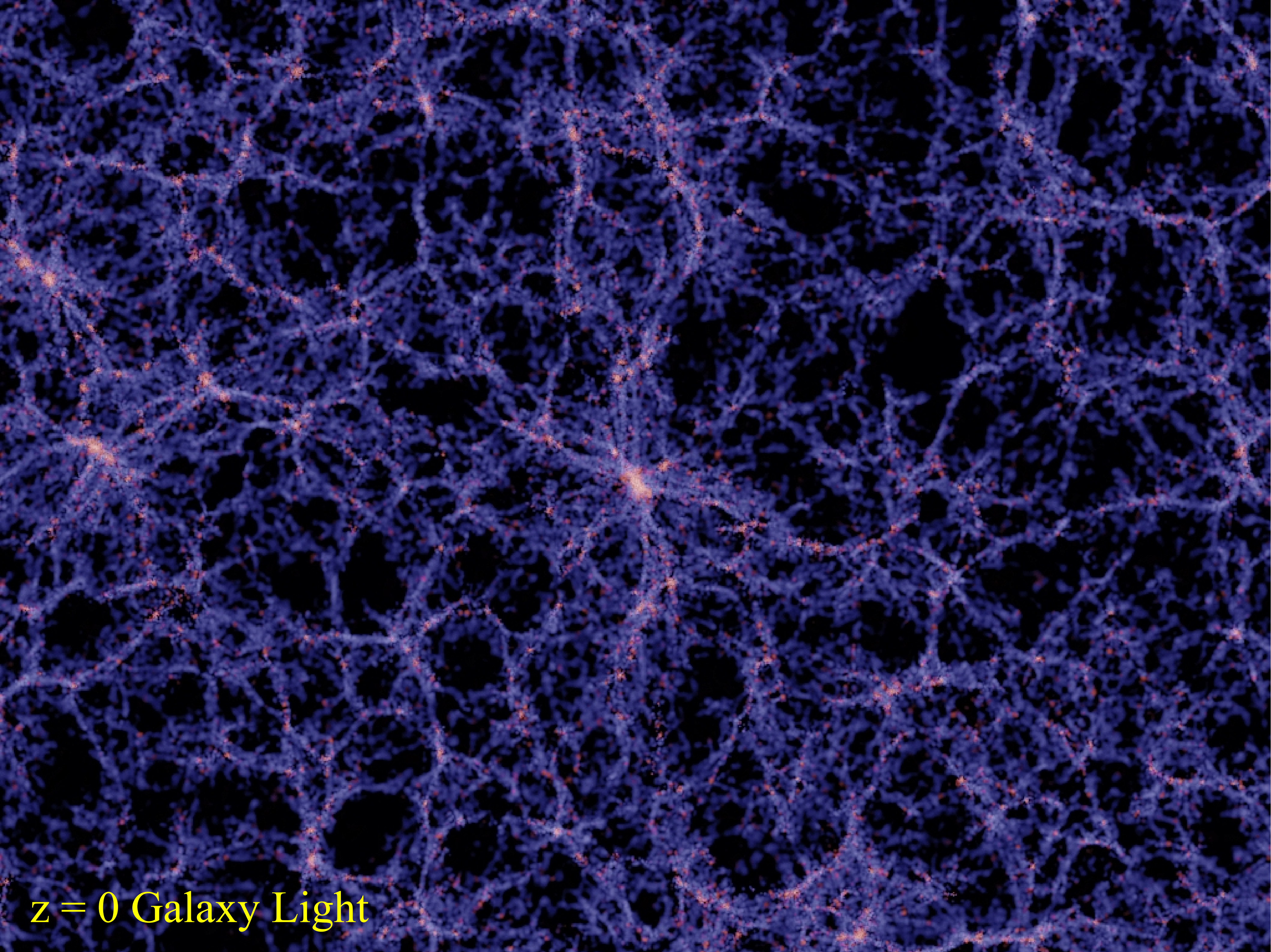
Since April 2007
9728 core Altix-4700
62.3 Tflop/s peak
39 Tbyte hard memory
600 Tbyte direct disk

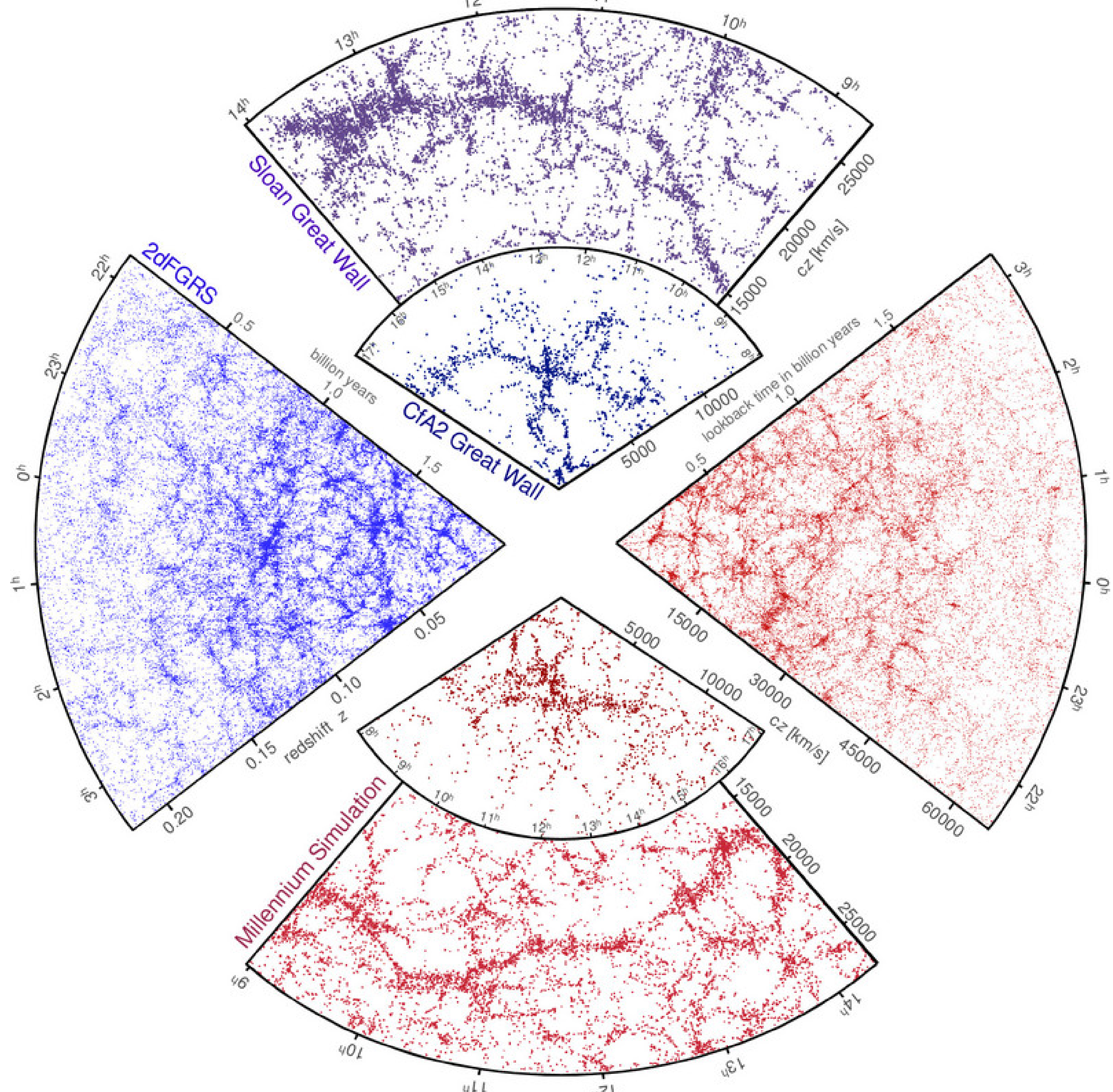
Evolving the Universe in a computer



- Follow the matter in an expanding cubic region
- Start 300,000 years after the Big Bang
- Match initial conditions to the observed Microwave Background
- Calculate evolution forward to the present day


125 Mpc/h
z = 0 Dark Matter


z = 0 Galaxy Light



Sloan Great Wall
2dFGRS
CfA2 Great Wall
Millennium Simulation
cz [km/s]
billion years
lookback time in billion years
redshift z

Astrophysics

- puts our Earth in its cosmic context
- allows us to study physics under *very* extreme conditions
- has taught us the origin of the elements
- has shown us what our Universe is made of
- allows us to see back in time, almost to the beginning
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The new USTC/MPS Astrophysics Centre

- A joint program of USTC, CAS and the Max Planck Society

- Involves all astronomy/astrophysics Max Planck Institutes
  -- Max Planck Institute for Astrophysics
  -- Max Planck Institute for extraterrestrial Physics
  -- Max Planck Institute for Astronomy
  -- Max Planck Institute for Radioastronomy

- Extended Graduate Research School at USTC teaching modern astronomy, astrophysics and cosmology with help of MPS staff

- Research projects joint with MPI's and involving extended stays at the partner institute in Germany (1 to 2 years)

MPI for
Astrophysics

MPI for
extraterrestrial Physics

MPI for Radioastronomy

MPI for Astronomy

International Max-Planck Research School on Astrophysics at the University of Munich IMPRS - Mozilla Firefox

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The International Max-Planck Research School on Astrophysics at the Ludwig-Maximilians-University Munich

IMPRS

A Marie-Curie Early Stage Training Site of the European Commission

- Basics

- About us
- Where we are
- IMPRS Lecturers
- IMPRS Committees

- Academic Matters

- Application & Admission
- PhD Projects
- Current PhD Supervisors
- Degree Requirements

Summer in the city -Leopoldstraße on a sunny day in Munich

Should you become a USTC/MPS astronomer?

- Contribute to our understanding of fundamental questions about our Universe and the objects which fill it
- Become part of a global research community
- Participate in China's rapidly growing programme to reach the forefront of modern astrophysics
- Keep ties to USTC, the CAS's university, and one of the best places in China for astrophysics
- Experience european research and life with the MPS, the world's highest ranked research institution in Space Science*

* Ahead of NASA, Harvard, Caltech/JPL and University of California, according to the US-based Institute of Scientific Information (2008).