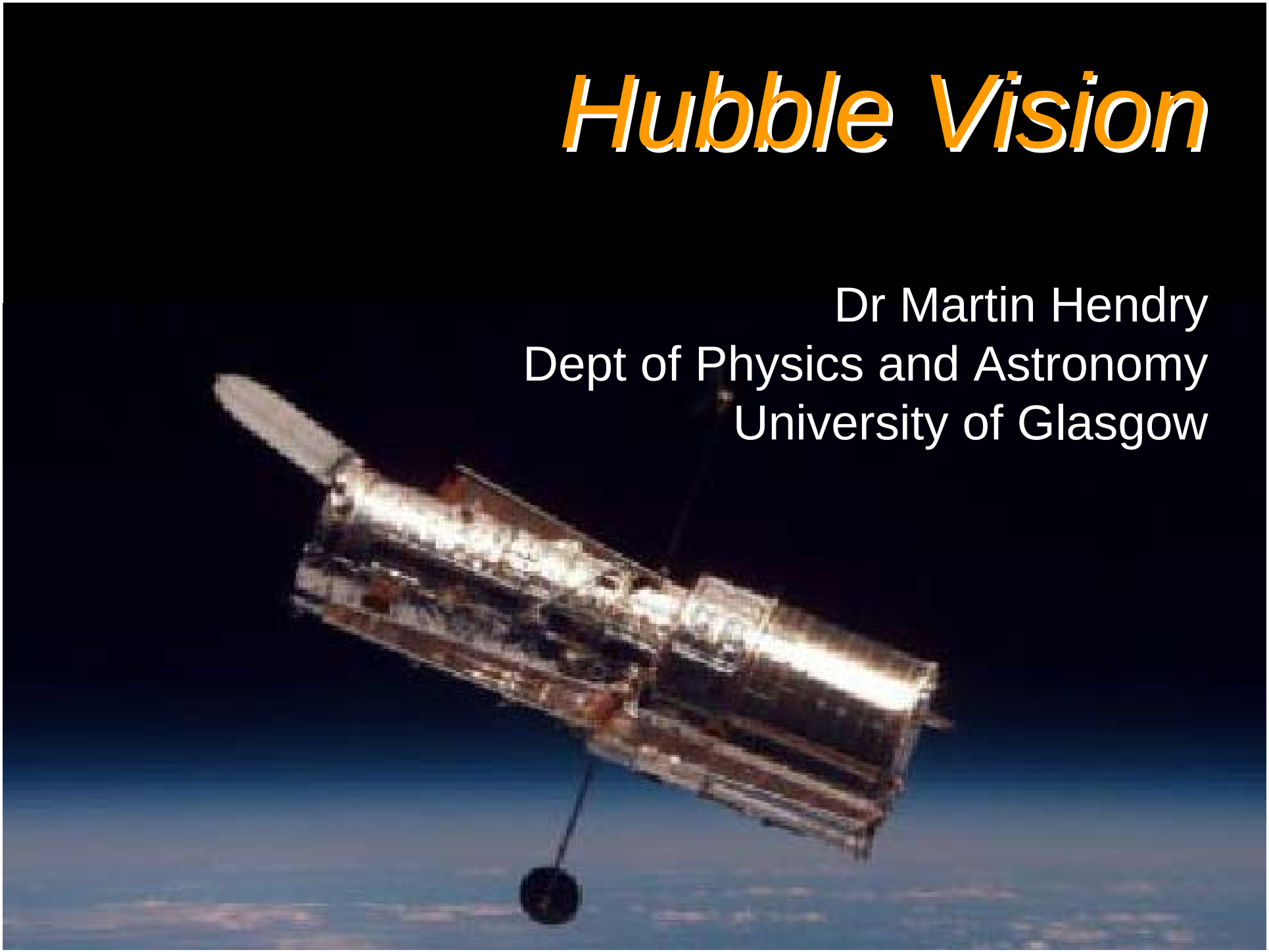
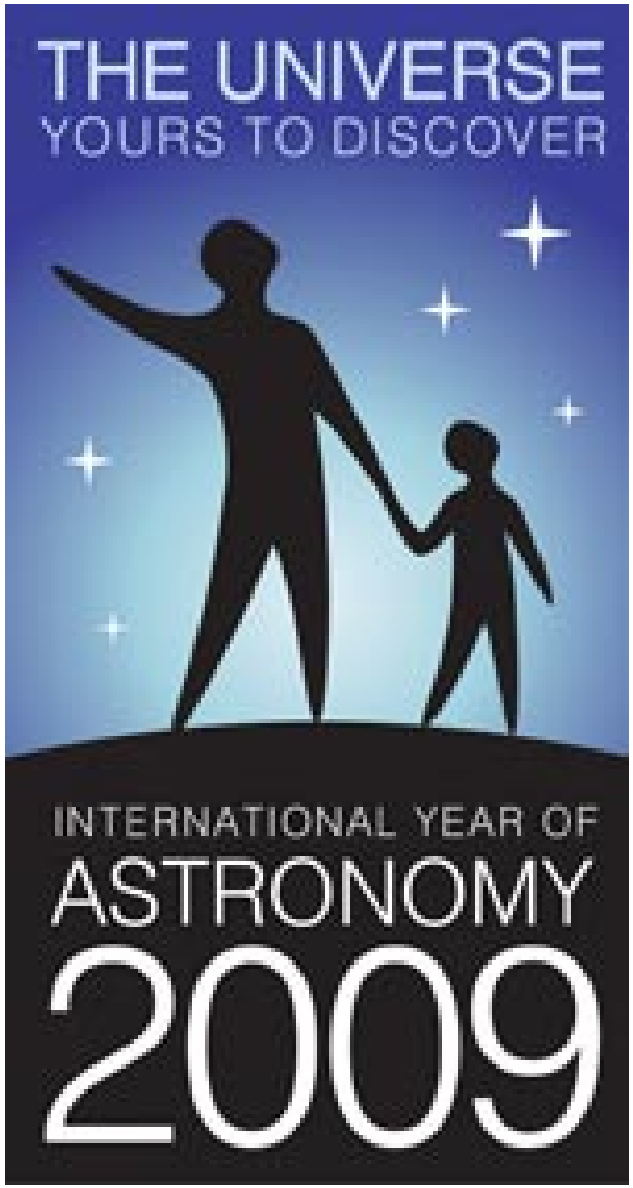
Hubble Vision

Dr Martin Hendry
Dept of Physics and Astronomy
University of Glasgow




THE UNIVERSE
YOURS TO DISCOVER
INTERNATIONAL YEAR OF
ASTRONOMY
2009

From March 2009

From March 2009

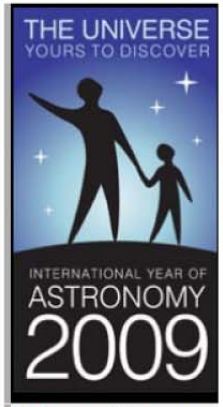
http://www.scottishsolarsystem.org.uk

Scottish Solar System :: IYA2009 :: Upcoming Events - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.astro.gla.ac.uk/users/martin/sss/sss_upcoming.html

Most Visited Getting Started Latest Headlines



- Welcome and homepage
- Scottish Solar System overview and map
- Scottish Solar System poster
- **Scottish Solar System events calendar**
- Projects for schools
- IYA2009 UK homepage
- The World at Night project
- **Contact us**

Scottish Solar System Events Calendar

Today ◀ ▶ Sunday, March 29 ▾ Print Week Month Agenda

19:30	Spring Star Watch
Sunday, March 29	
	Spring Moonwatch
10:00	SunDay at Glasgow Science Centre
Monday, March 30	
	Spring Moonwatch
20:00	Glasgow University Observatory open evening
Tuesday, March 31	
	Spring Moonwatch
20:00	Glasgow University Observatory open evening
Wednesday, April 1	
	Spring Moonwatch
20:00	Glasgow University Observatory open evening
Thursday, April 2	
	Spring Moonwatch
20:00	Glasgow University Observatory open evening
Friday, April 3	
	Spring Moonwatch

Events shown in time zone: London Google Calendar

LATEST NEWS

- **Upcoming events**
- IYA2009 discussion forum
- IYA2009 newsletter

INFORMATION ABOUT

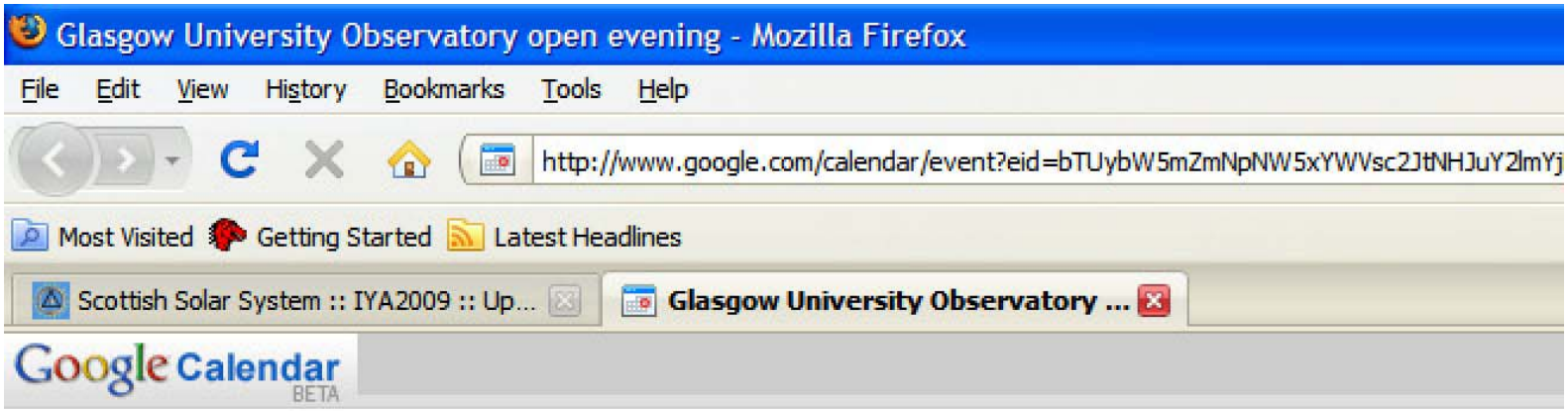
- Getting started with astronomy
- Scottish astronomy groups and societies
- Astronomy projects for schools
- IYA2009 across the world

MORE EXTERNAL LINKS

University of Glasgow

glasgow science centre

DARK SKY SCOTLAND



What Glasgow University Observatory open evening

When Mon Mar 30 20:00 – Mon Mar 30 22:30 (repeats Daily, until Apr 2, 2009)

Where Observatory Main Building, Acre Road Observatory, University of Glasgow map

Calendar Scottish Solar System Events

Description Open evening, as part of IYA2009 Spring Moonwatch week events and activities. All ages are welcome to this FREE event.

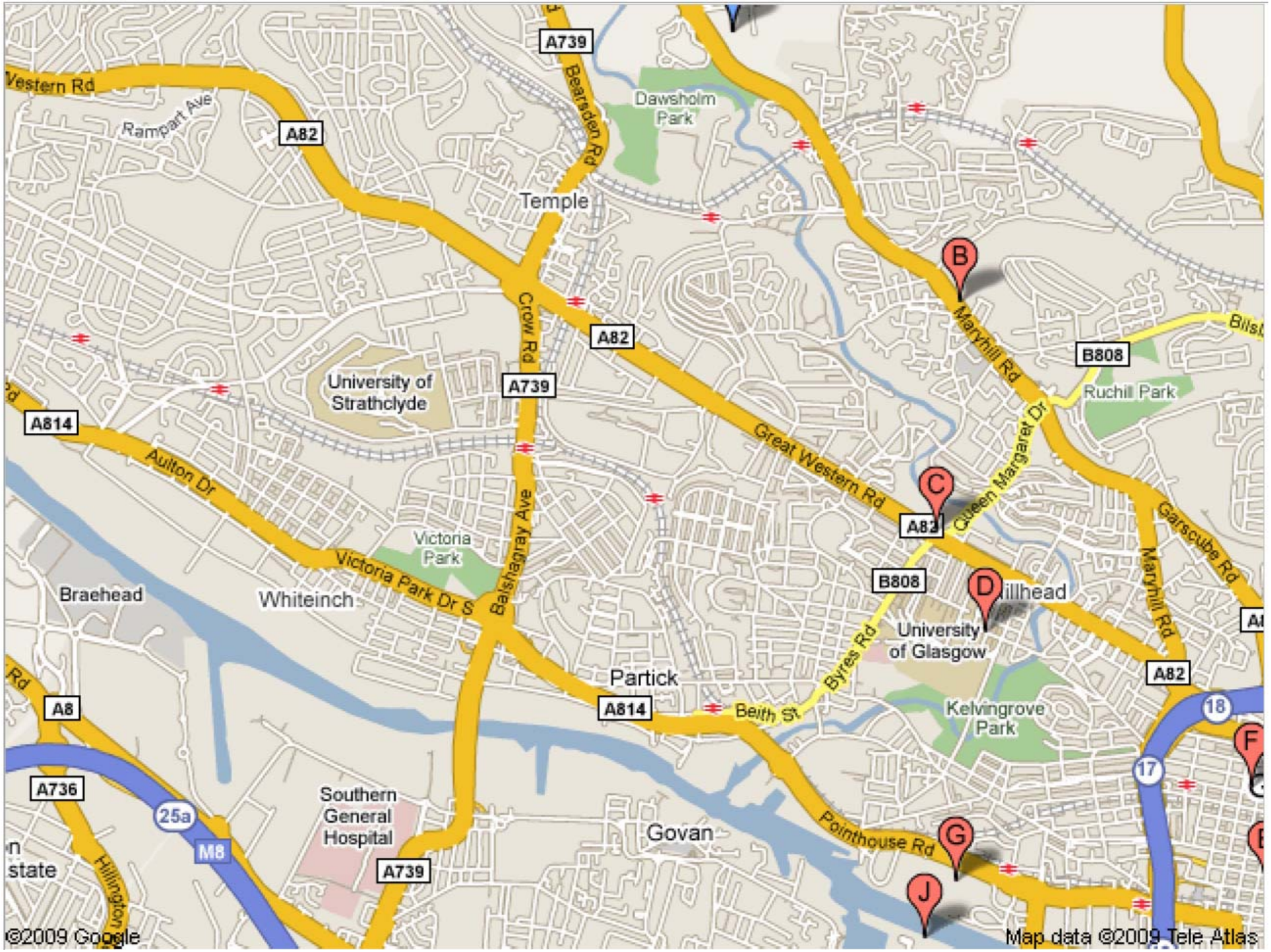
Come along and (weather permitting!) observe the Moon, planets, stars and galaxies through the University's telescopes.

Chat to astronomy students and staff from the University, and meet enthusiasts from local astronomy societies. Find out about the latest astronomy research, or just ask for advice on how to get started as a stargazer!

Event organised in conjunction with the Scottish System Project.

(See http://www.scottishsolarsystem.org.uk).

For more details contact scottishsolarsystem@astro.gla.ac.uk, or call 0141 330 4152.


A739
Bearsden Rd
Dawsholm Park
Western Rd
Rampart Ave
A82
Temple
Crow Rd
A739
A82
University of Strathclyde
A814
Aulton Dr
Great Western Rd
Maryhill Rd
B808
Ruchill Park
Queen Margaret Dr
Garscube Rd
Victoria Park
Victoria Park Dr S
Balshagray Ave
Braehead
Whiteinch
B808
University of Glasgow
Maryhill Rd
A82
Partick
A814
Beith St
Byres Rd
Kelvingrove Park
A8
A736
25a
M8
Southern General Hospital
A739
Govan
Pointhouse Rd
18
17
B
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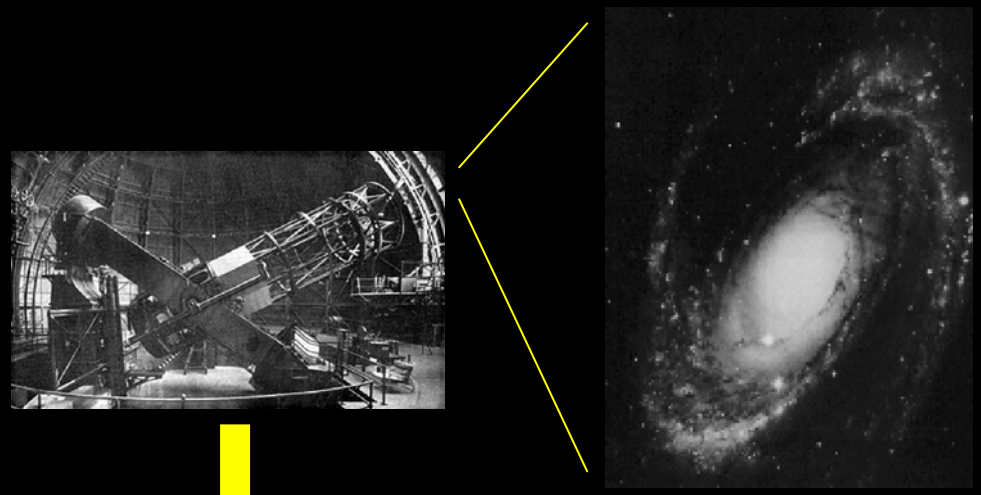
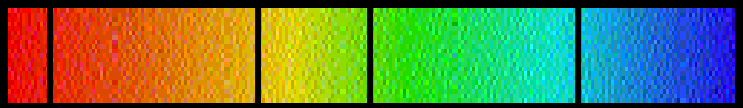
J
©2009 Google
Map data ©2009 Tele Atlas

Hubble also measured the shift in colour, or *wavelength*, of the light from distant galaxies.



Galaxy

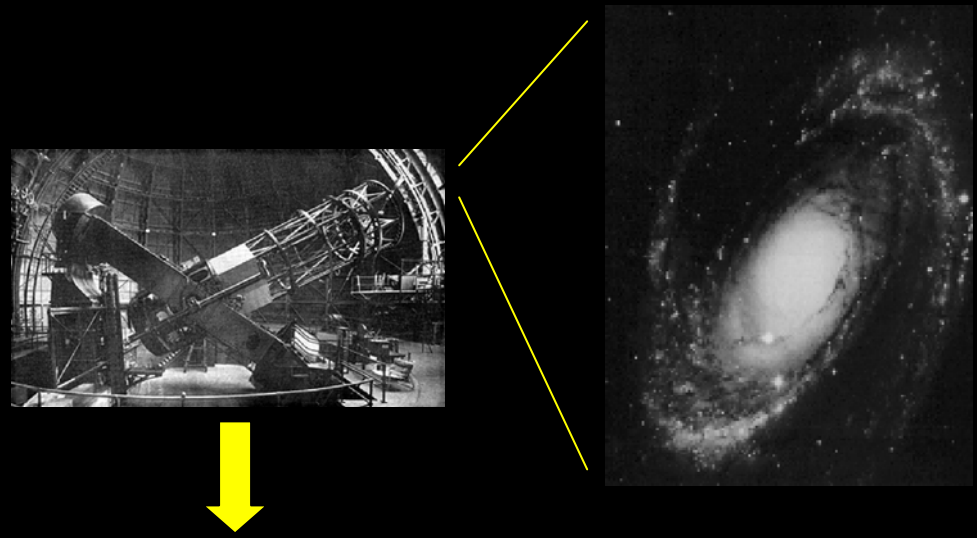


Hubble also measured the shift in colour, or *wavelength*, of the light from distant galaxies.

Galaxy

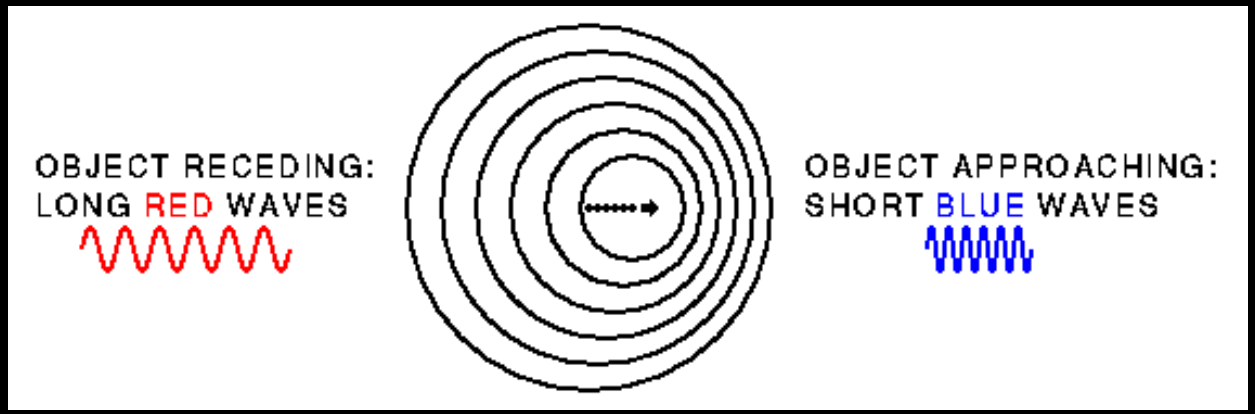
Laboratory

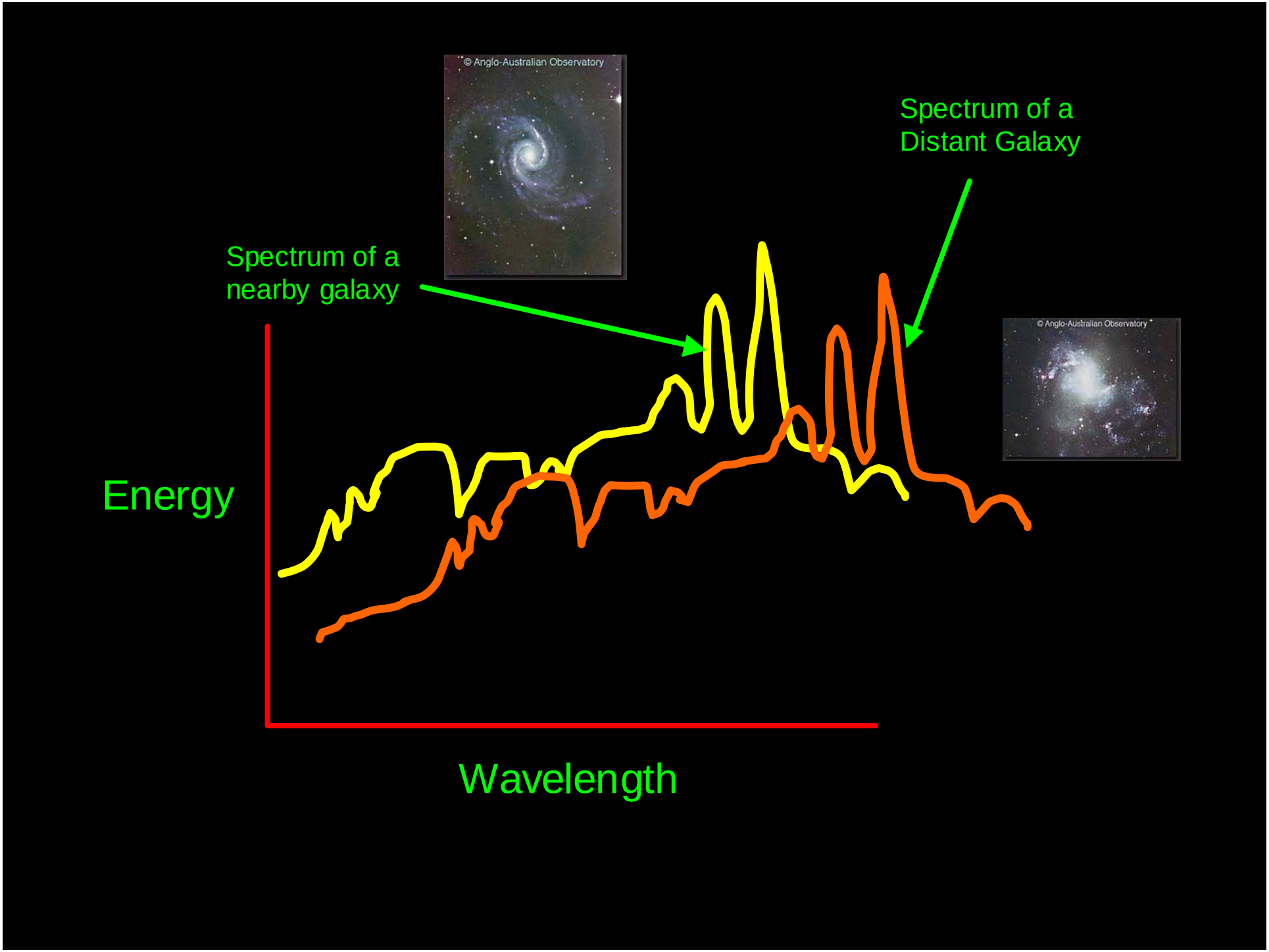
Hubble also measured the shift in colour, or *wavelength*, of the light from distant galaxies.



Galaxy

Laboratory




© Anglo-Australian Observatory
Spectrum of a
Distant Galaxy
Spectrum of a
nearby galaxy
© Anglo-Australian Observatory
Energy
Wavelength

Hubble's Law: 1929

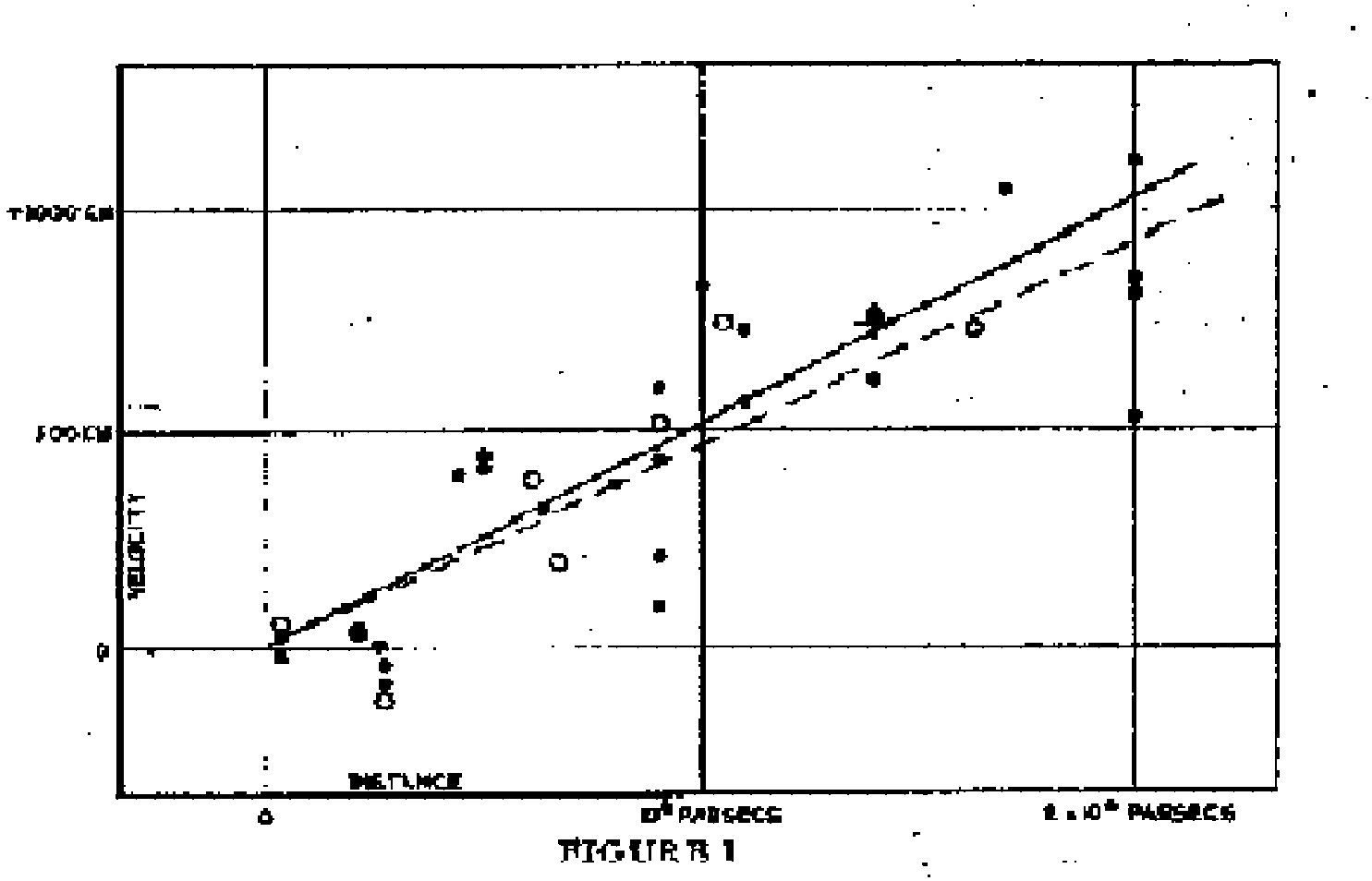
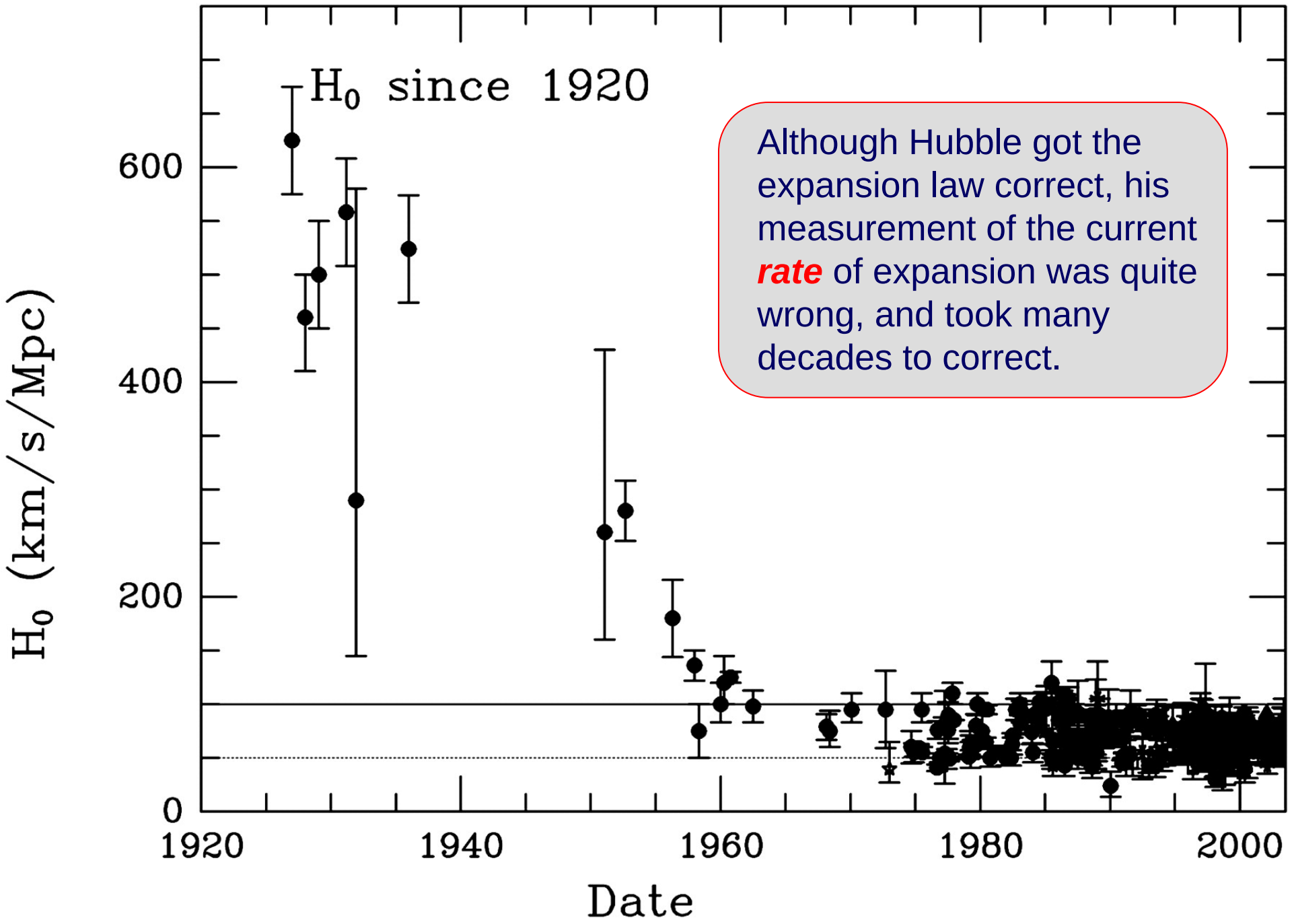


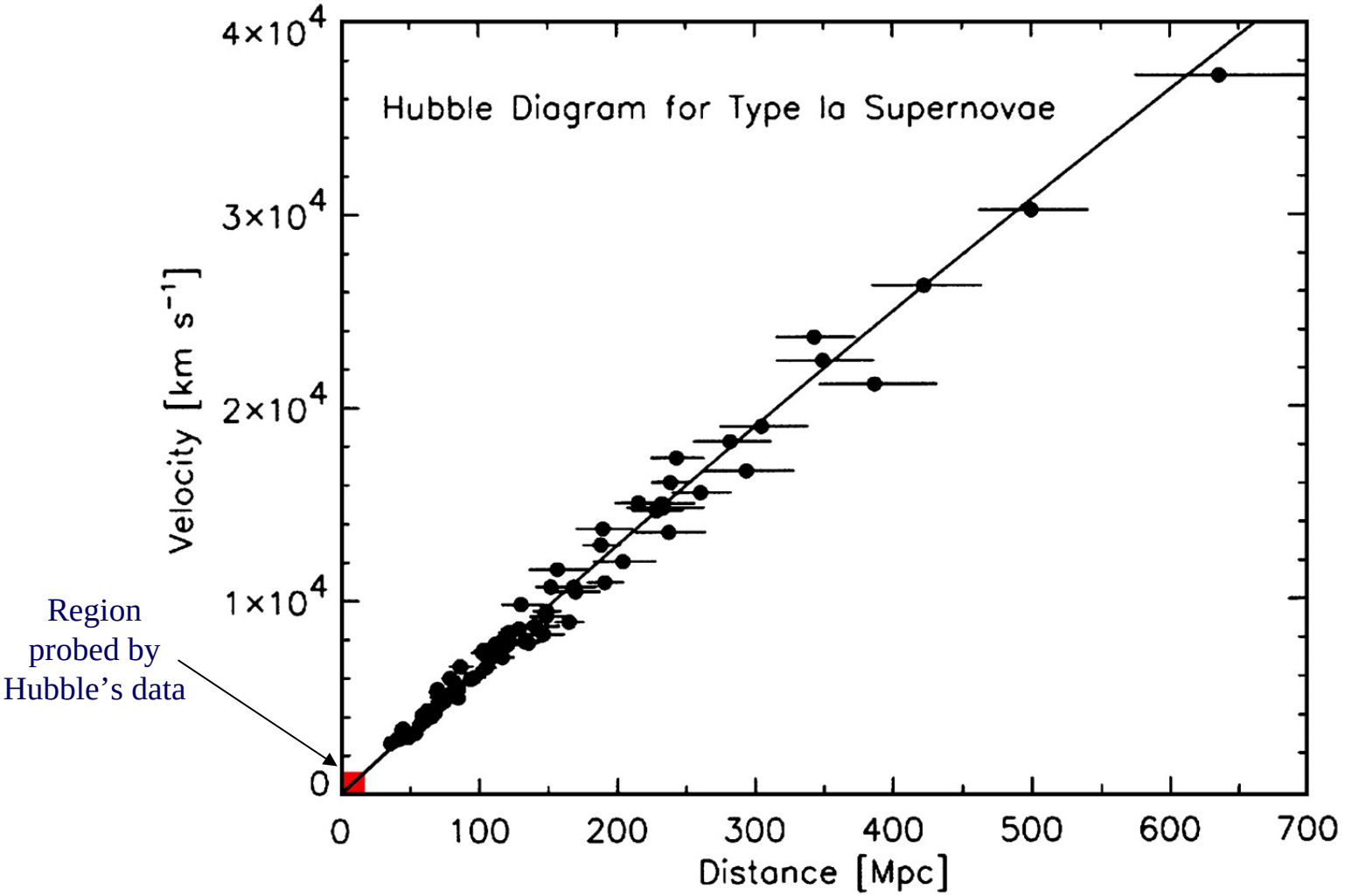
FIGURE 1

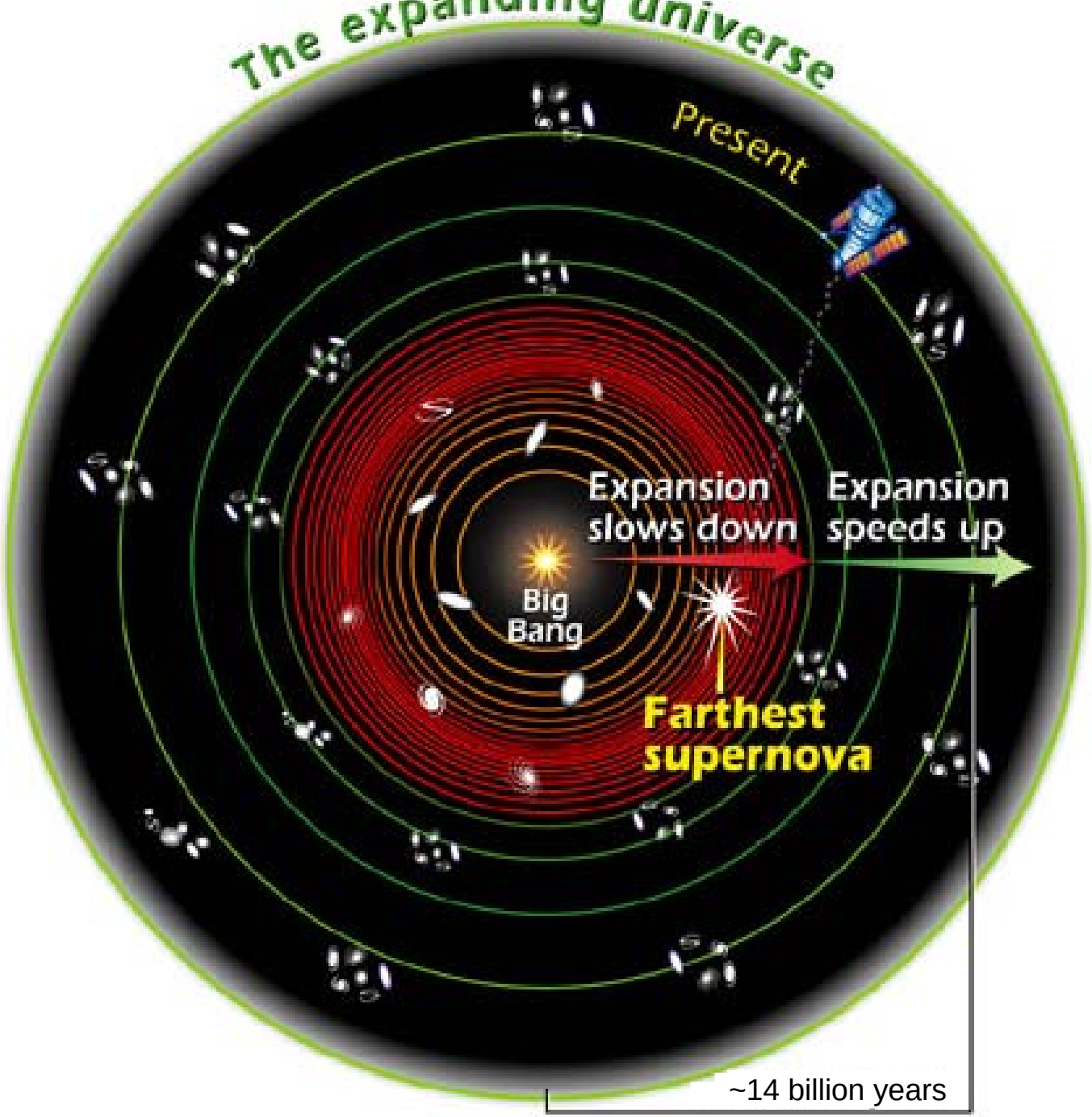
Distant galaxies are receding from us with a speed proportional to their distance

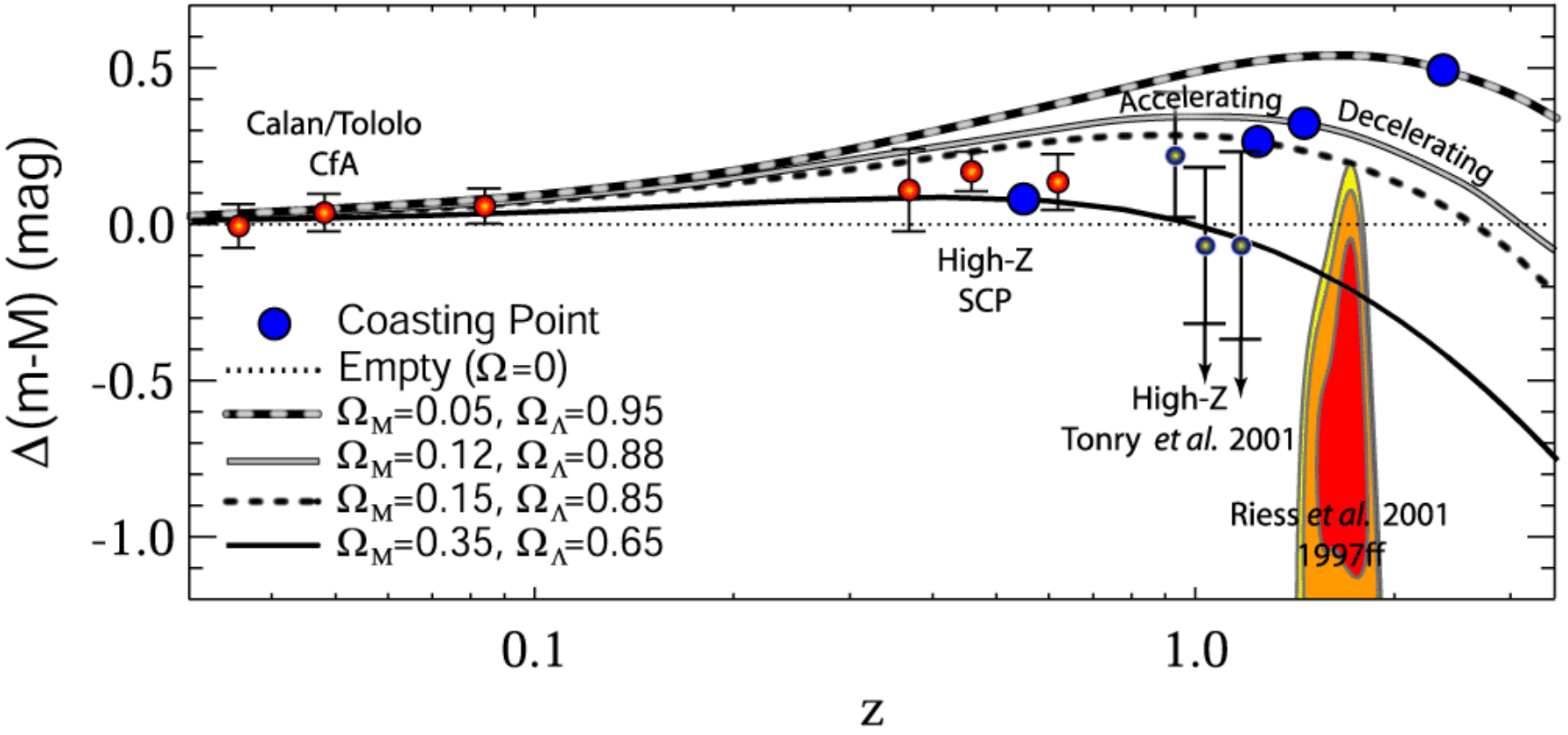


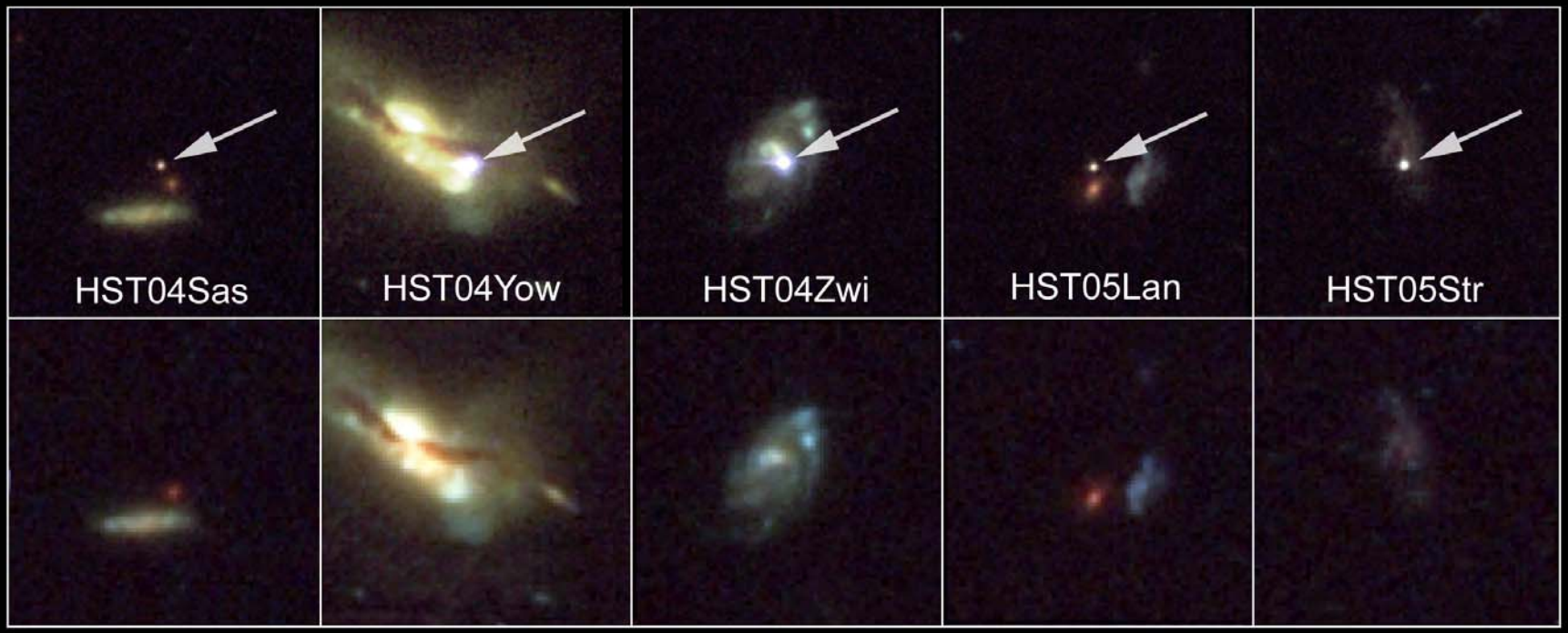
Although Hubble got the expansion law correct, his measurement of the current ***rate*** of expansion was quite wrong, and took many decades to correct.

More recently we have extended the Hubble diagram to great distances, using e.g. Supernovae….




The expanding universe
Present
Expansion slows down
Expansion speeds up
Big Bang
Farthest supernova
~14 billion years


0.5
0.0
-0.5
-1.0
Δ(m-M) (mag)
0.1
1.0
z
Calan/Tololo
CfA
High-Z
SCP
High-Z
Tonry et al. 2001
Riess et al. 2001
1997ff
Accelerating
Decelerating
Coasting Point
Empty (Ω=0)
ΩM=0.05, ΩΛ=0.95
ΩM=0.12, ΩΛ=0.88
ΩM=0.15, ΩΛ=0.85
ΩM=0.35, ΩΛ=0.65



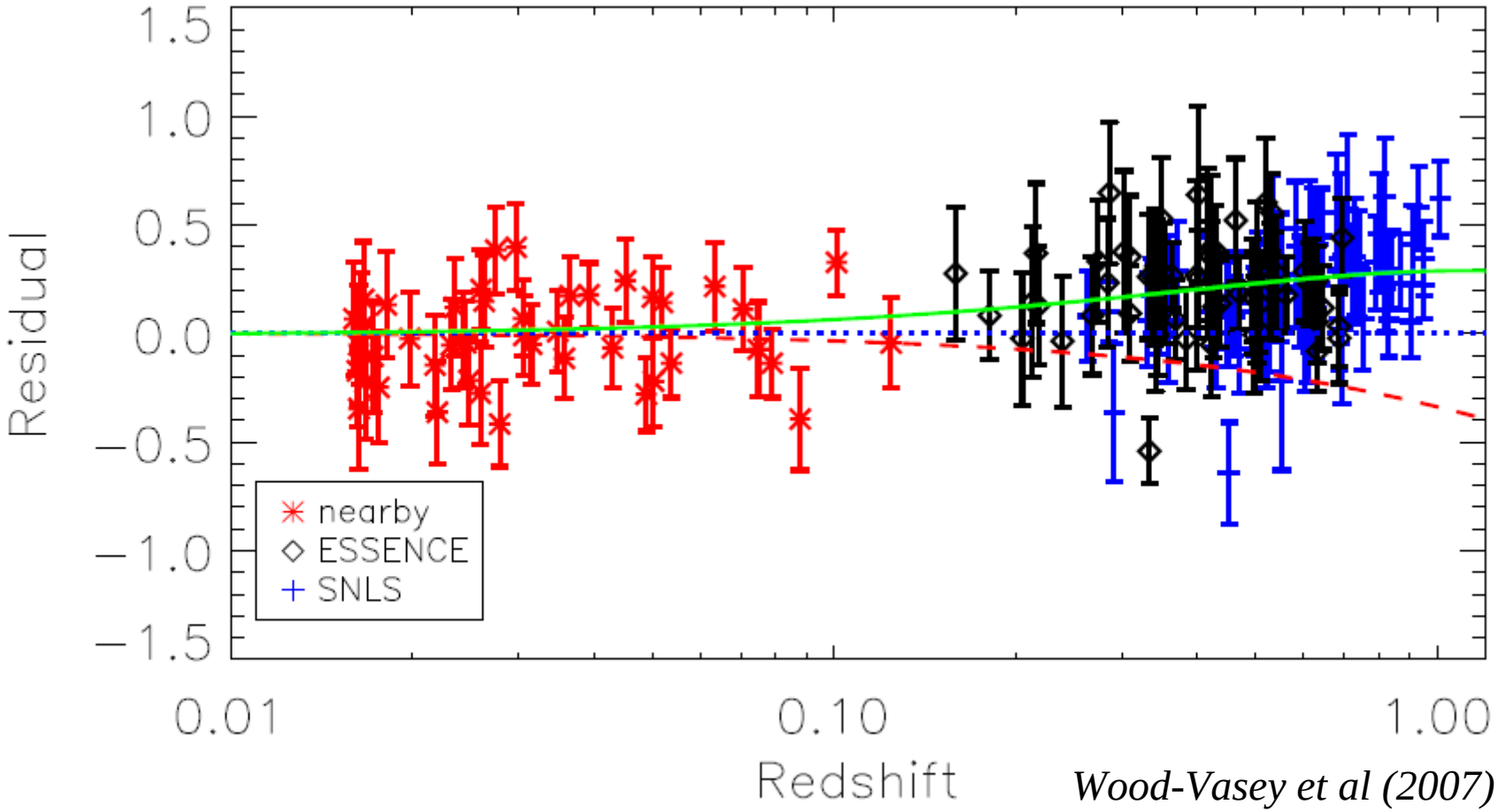
Host Galaxies of Distant Supernovae

Hubble Space Telescope ▪ Advanced Camera for Surveys

NASA, ESA, and A. Riess (STScI)

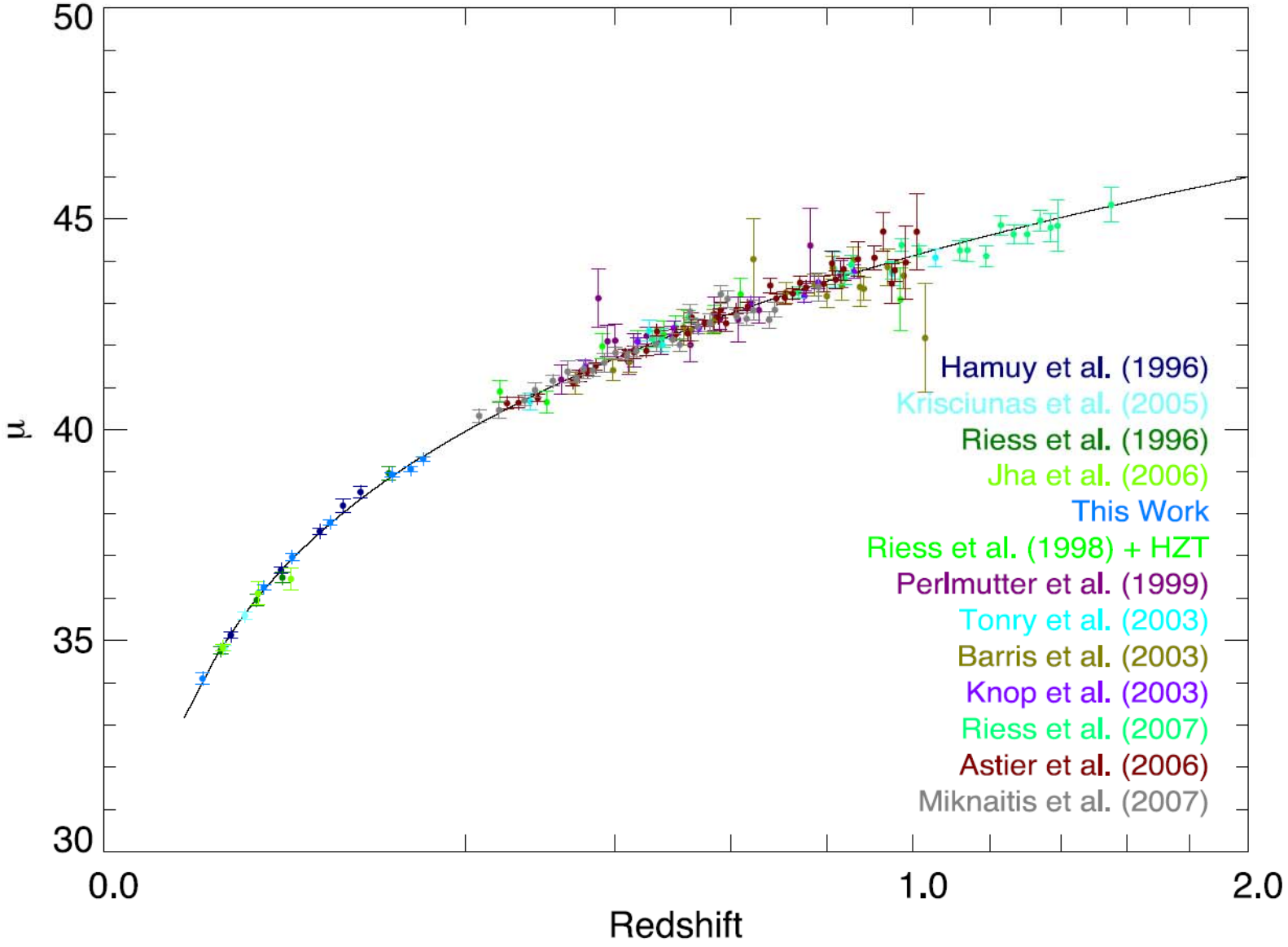
STScI-PRC06-52

Latest results: still speeding up!!!



Wood-Vasey et al (2007)

Latest results: still speeding up!!!

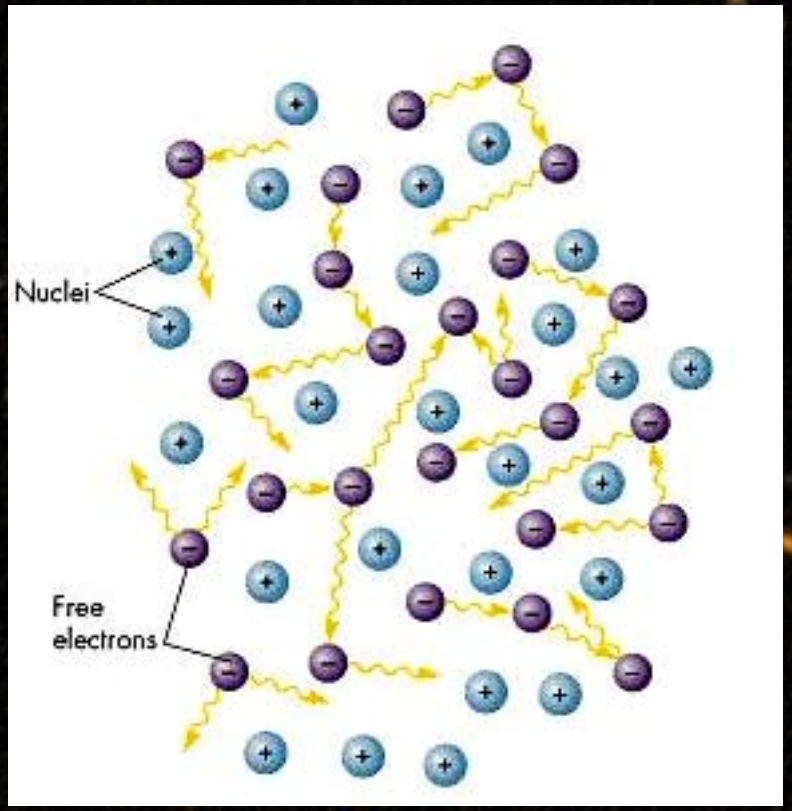


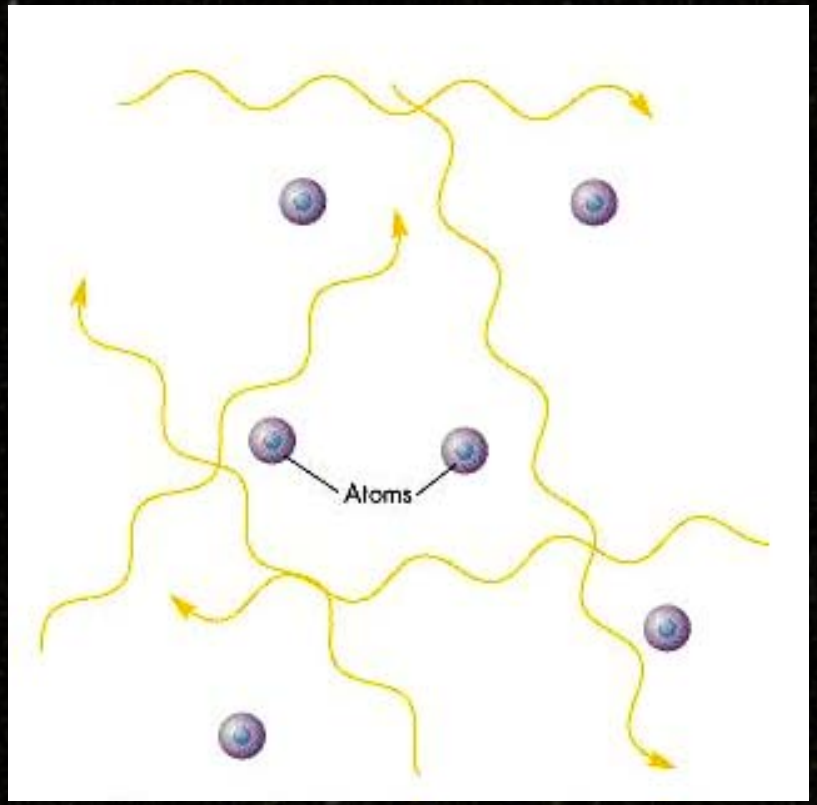
We can measure the shape of the Universe using the cosmic microwave background radiation

Early Universe too hot for neutral atoms

Free electrons scattered light (as in a fog)

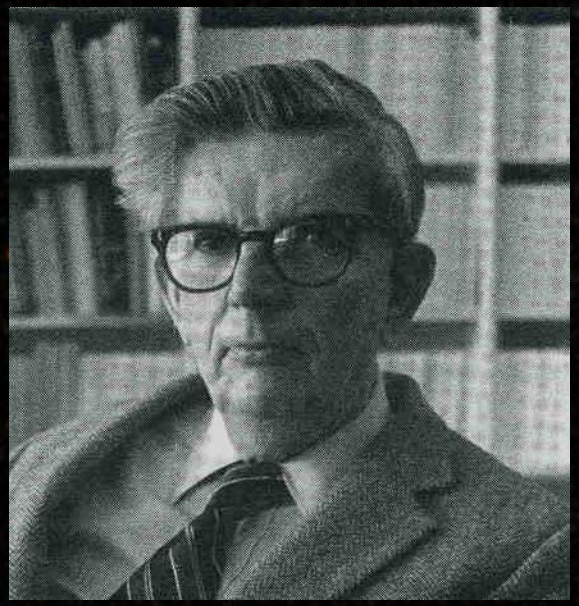
After 380,000 years, cool enough for atoms; fog clears!





Background radiation predicted in 1950s and 1960s by Gamov, Dicke, Peebles.

Discovered in 1965 by Penzias and Wilson



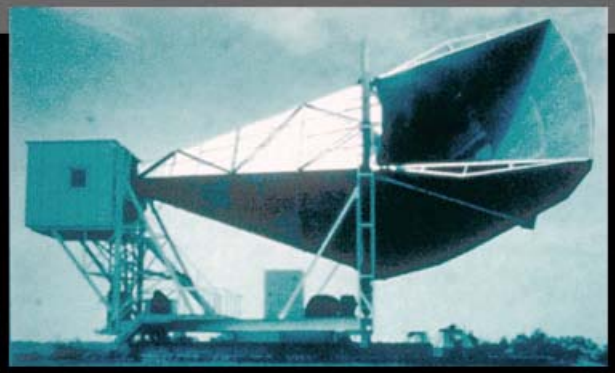
Robert Dicke

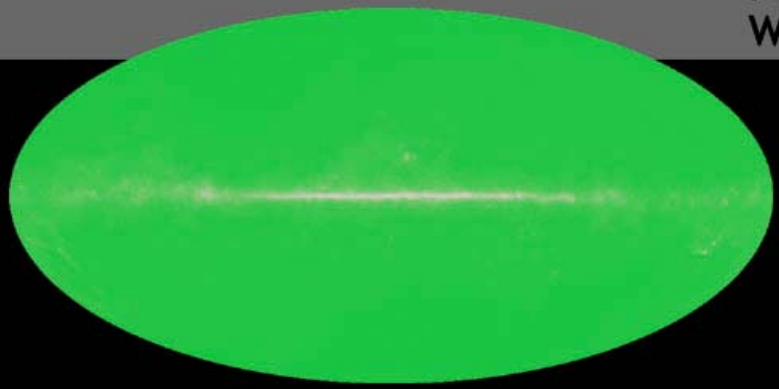
Arno Penzias and Robert Wilson

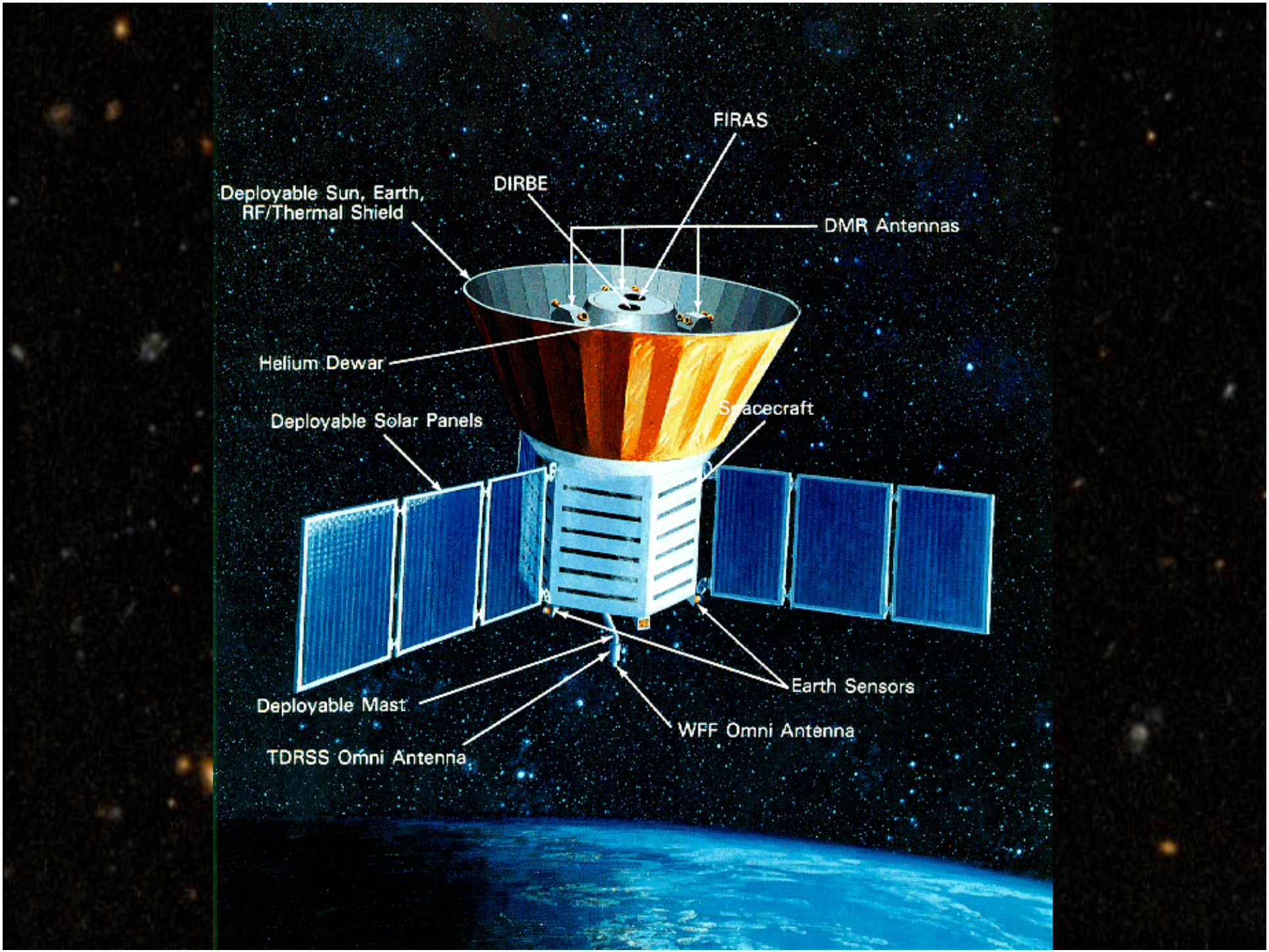
Jim Peebles

1965

Penzias and Wilson

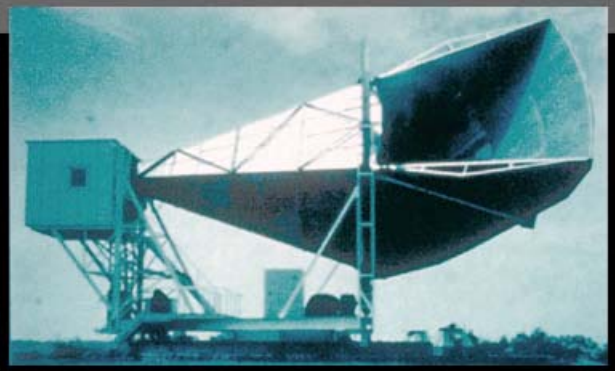


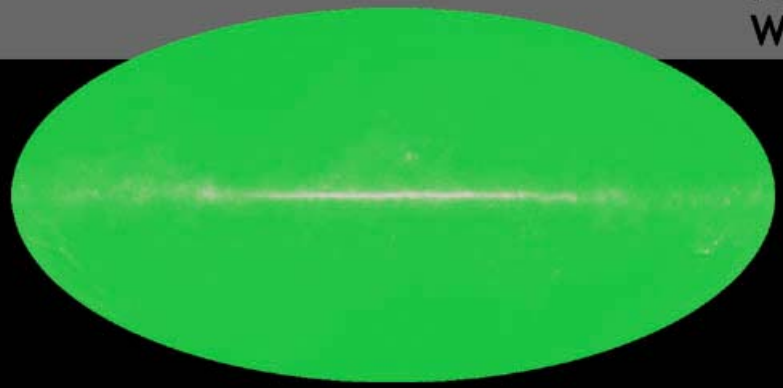



FIRAS
DIRBE
Deployable Sun, Earth,
RF/Thermal Shield
DMR Antennas
Helium Dewar
Deployable Solar Panels
Spacecraft
Earth Sensors
Deployable Mast
WFF Omni Antenna
TDRSS Omni Antenna

1965

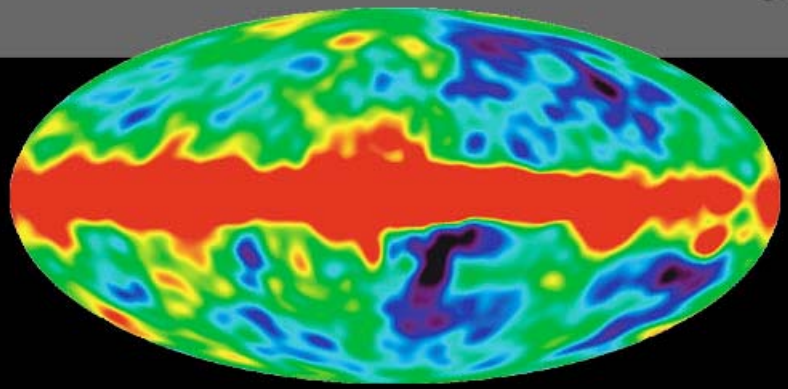
Penzias and Wilson

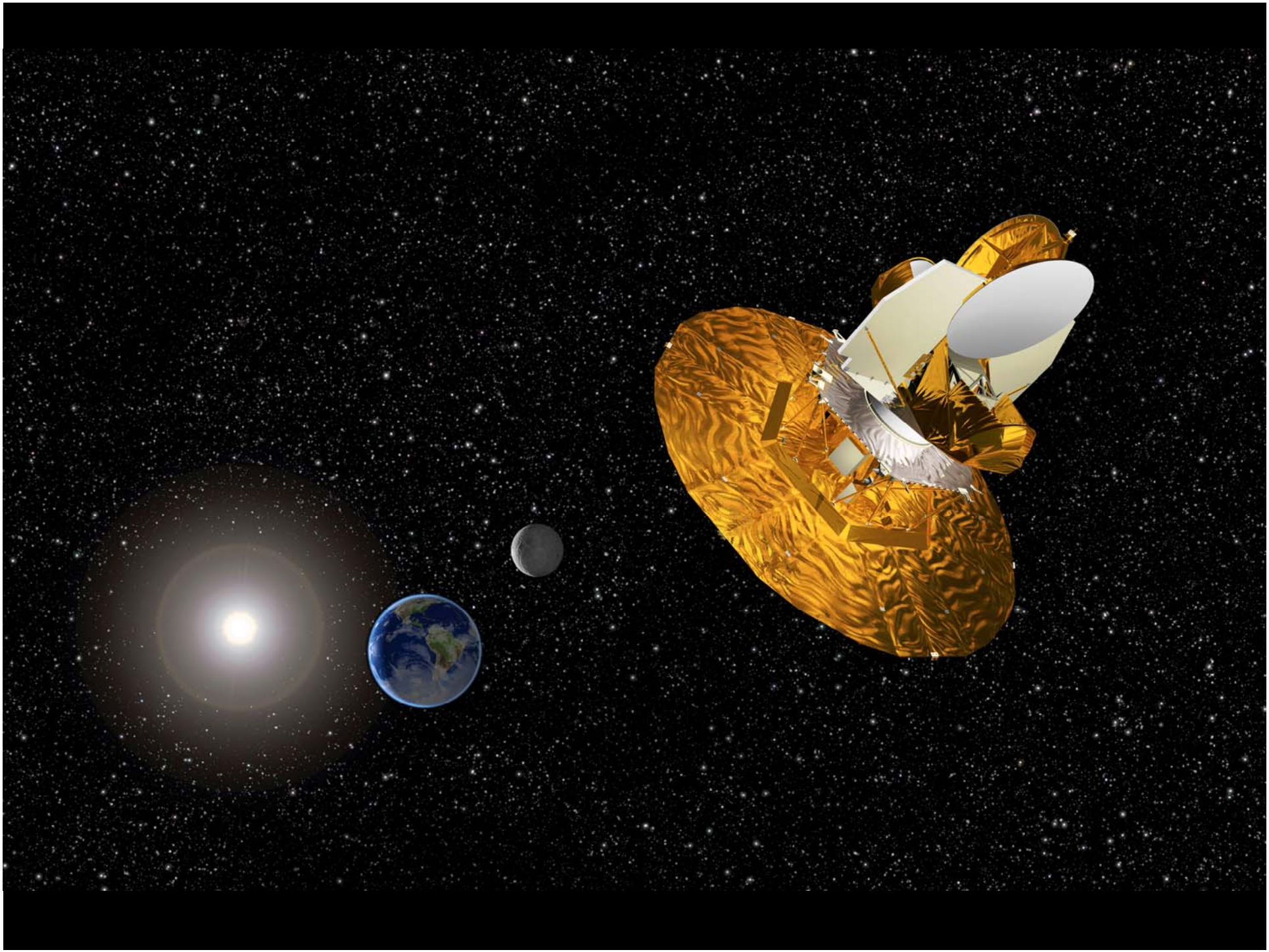




1992

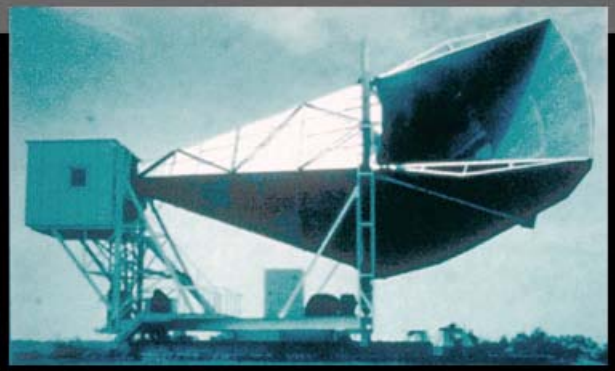
COBE

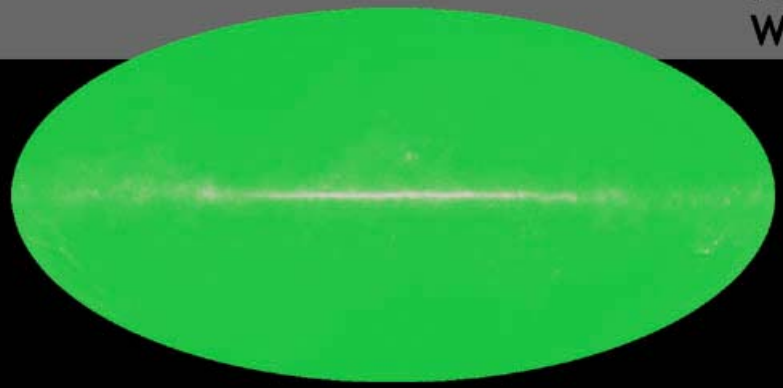




1965

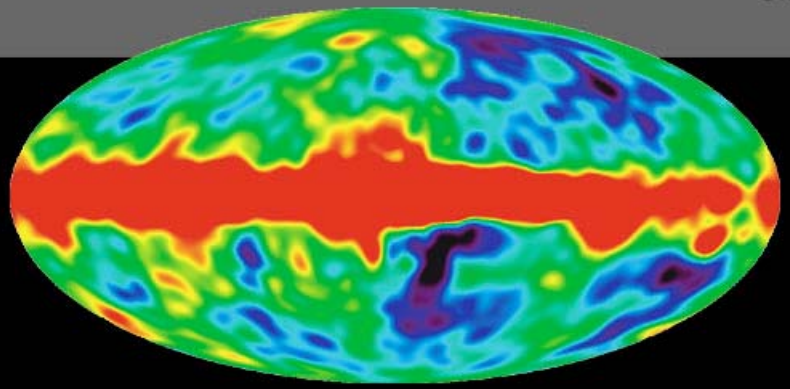
Penzias and Wilson





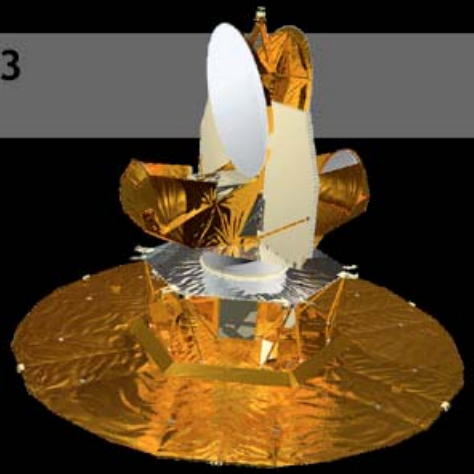
1992

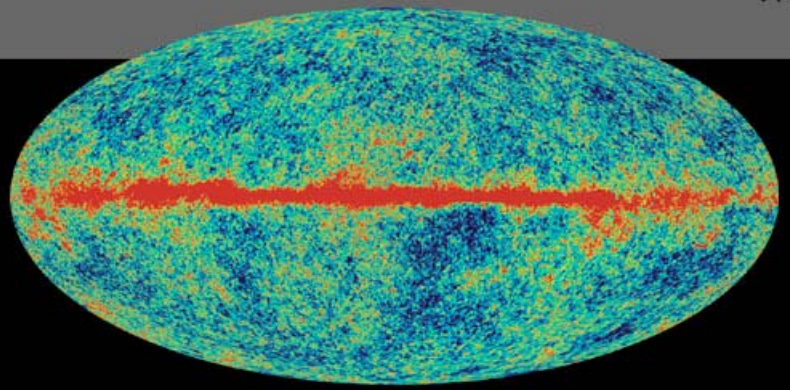
COBE



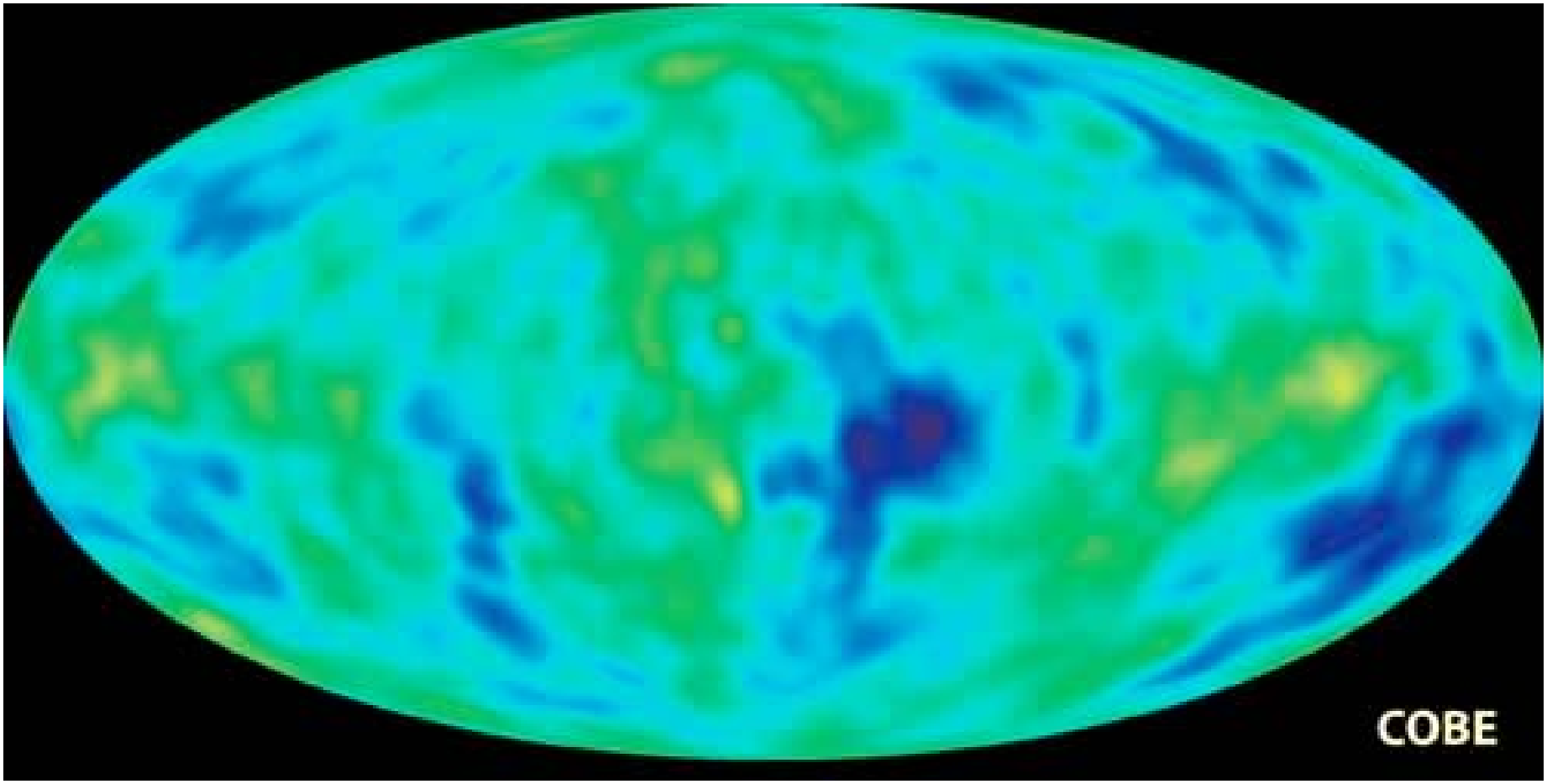
2003

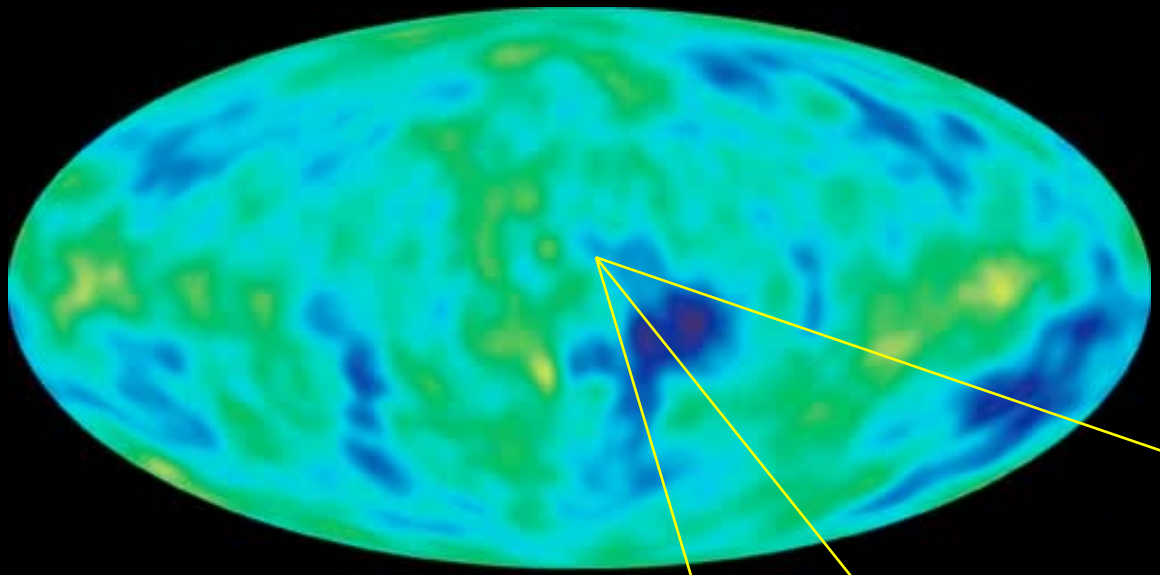
WMAP



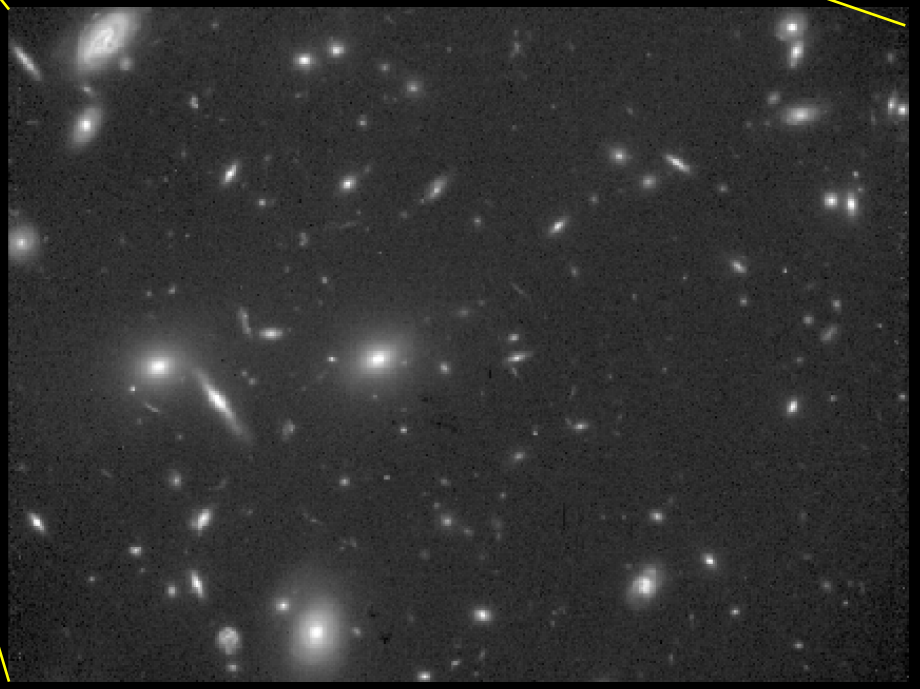


CoBE map of temperature across the sky

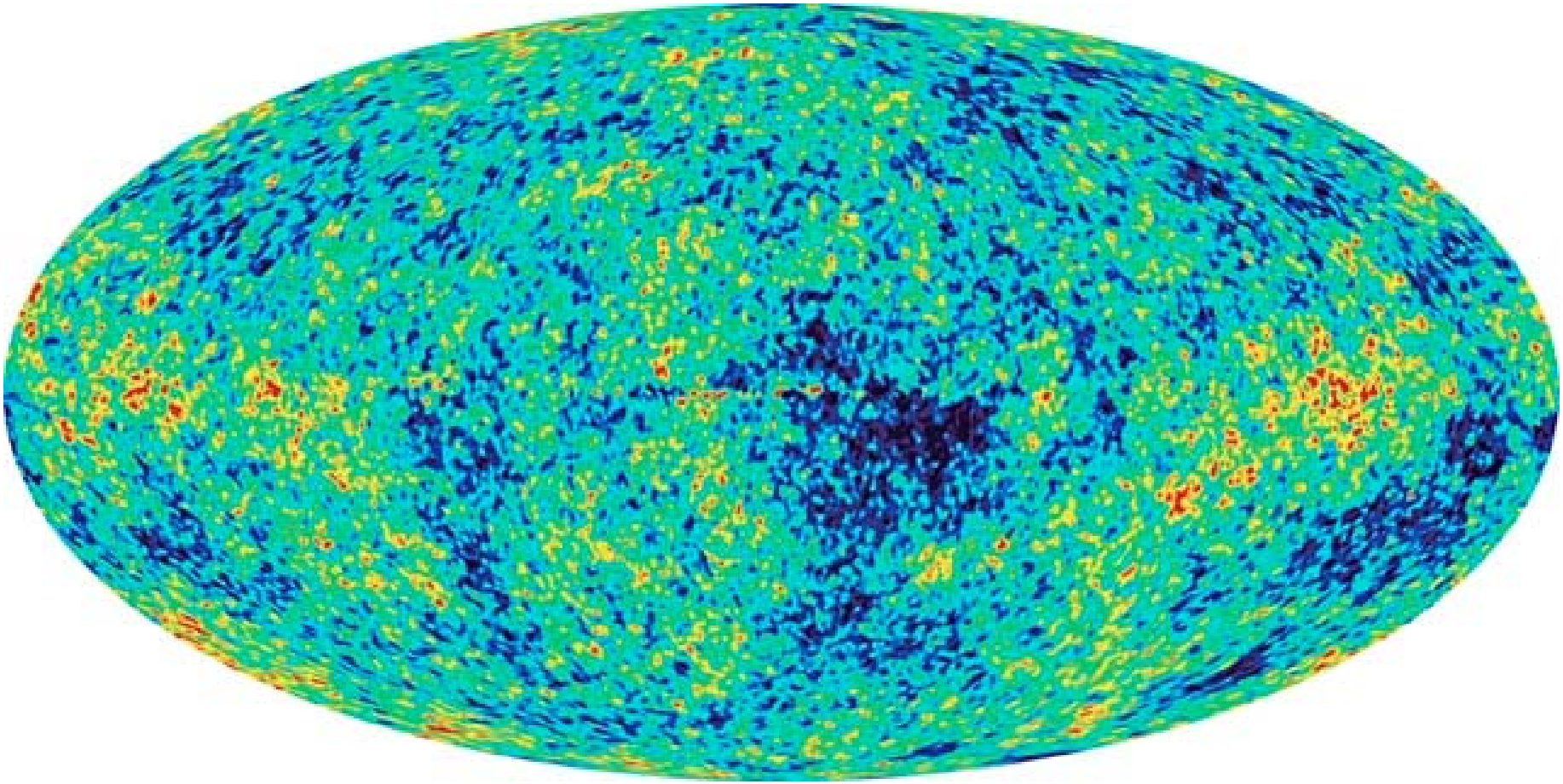




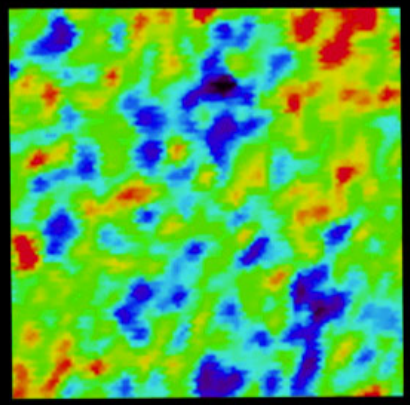
CMBR ‘ripples’ are the seeds of today’s galaxies

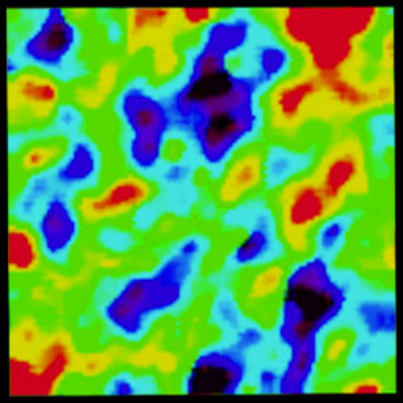


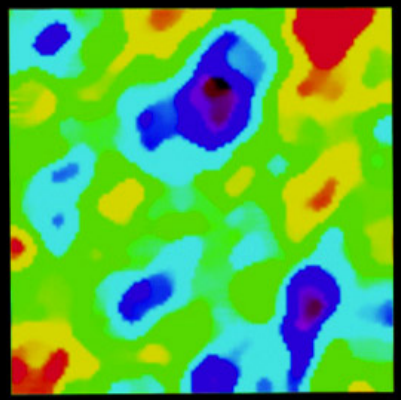
Galaxy formation is highly sensitive to the pattern, or power spectrum, of CMBR temperature ripples

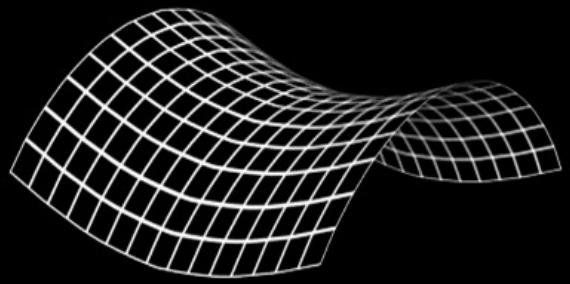


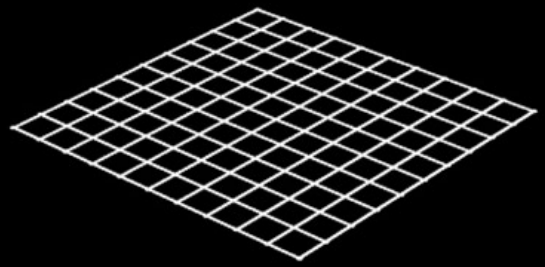
GEOMETRY OF THE UNIVERSE

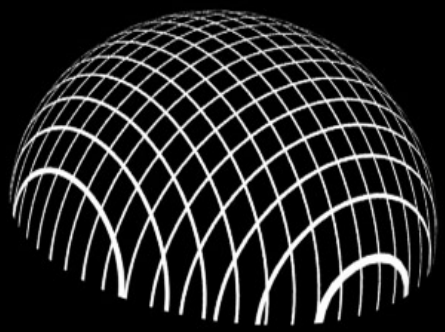








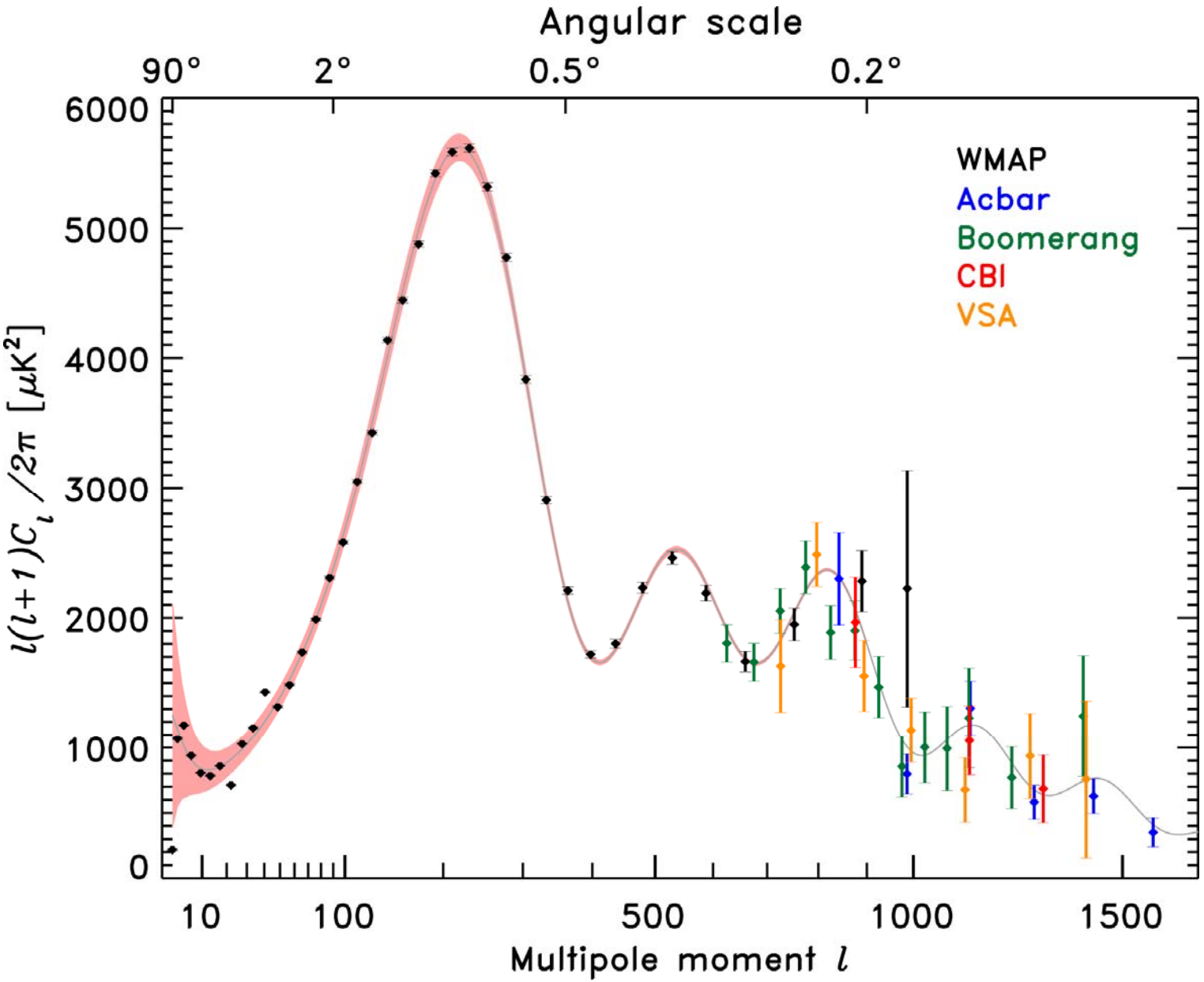




OPEN

FLAT

CLOSED


Angular scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ [μK^2]
WMAP
Acbar
Boomerang
CBI
VSA
10
100
500
1000
1500
Multipole moment l

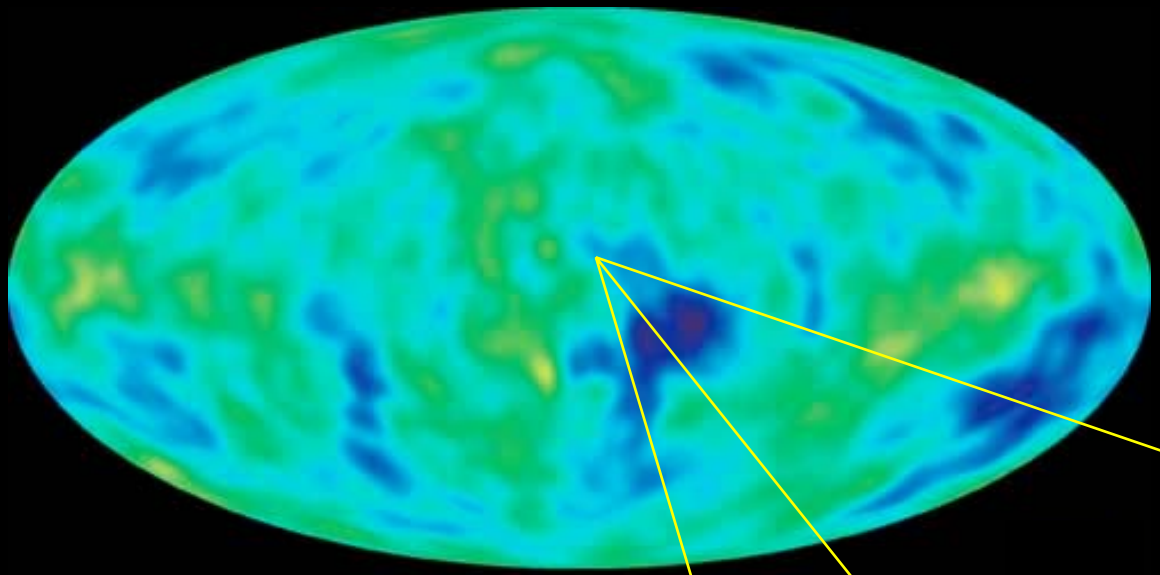
Summary:

The shape of the Universe is FLAT

The Universe will continue to expand for ever

The expansion is accelerating


The future of the Universe?
No
Big Crunch!!!



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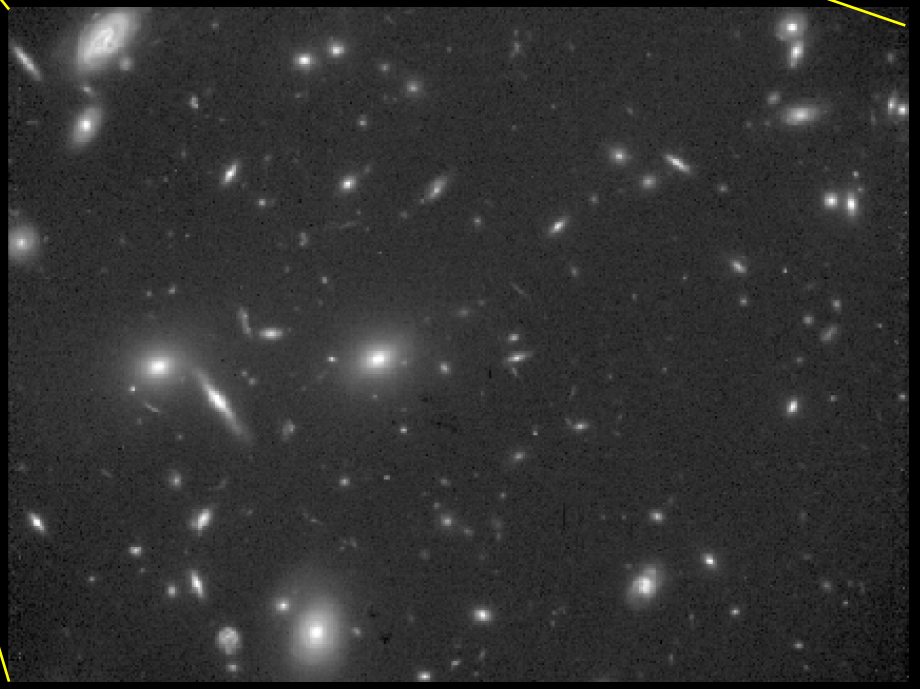

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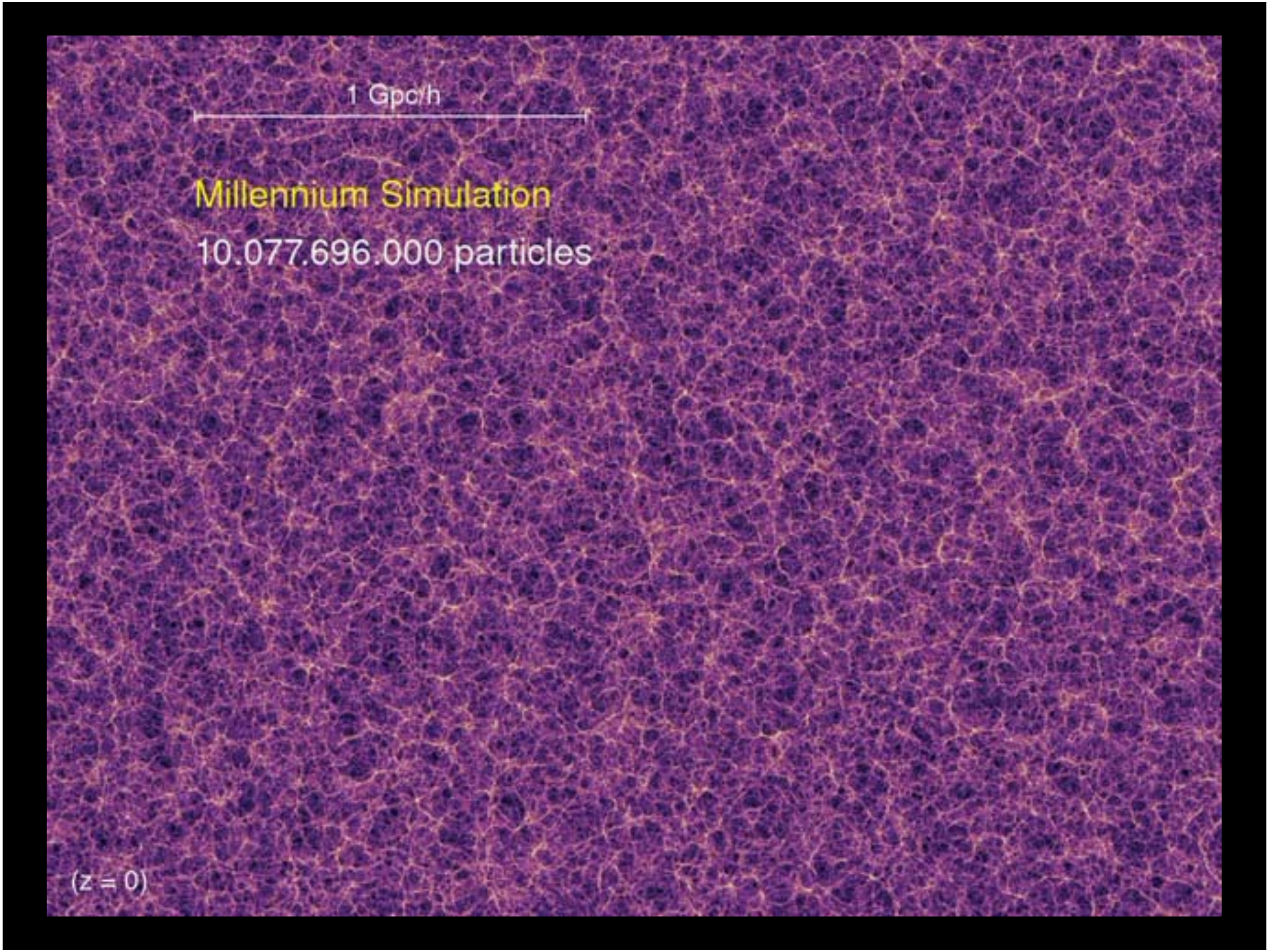
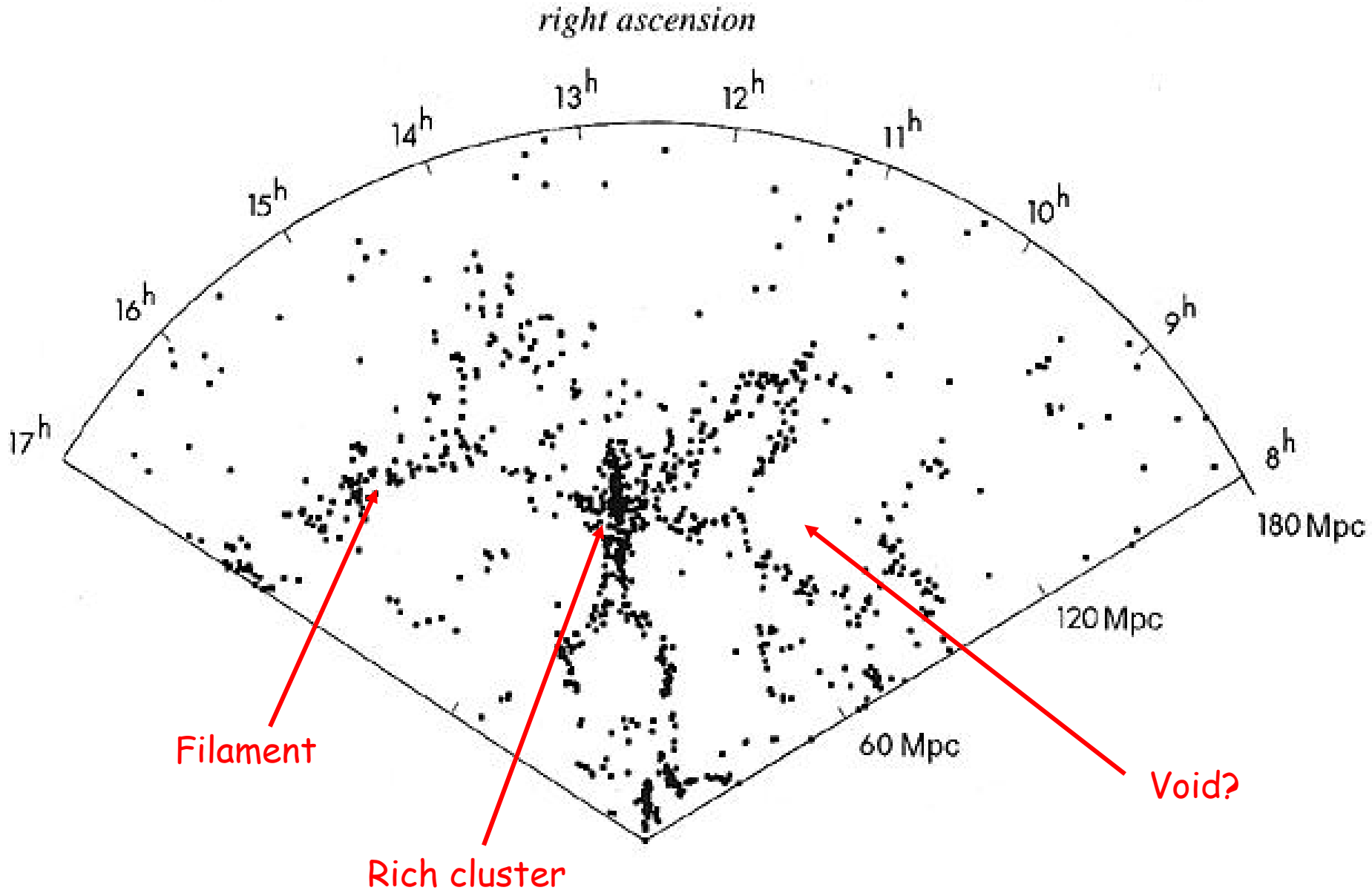
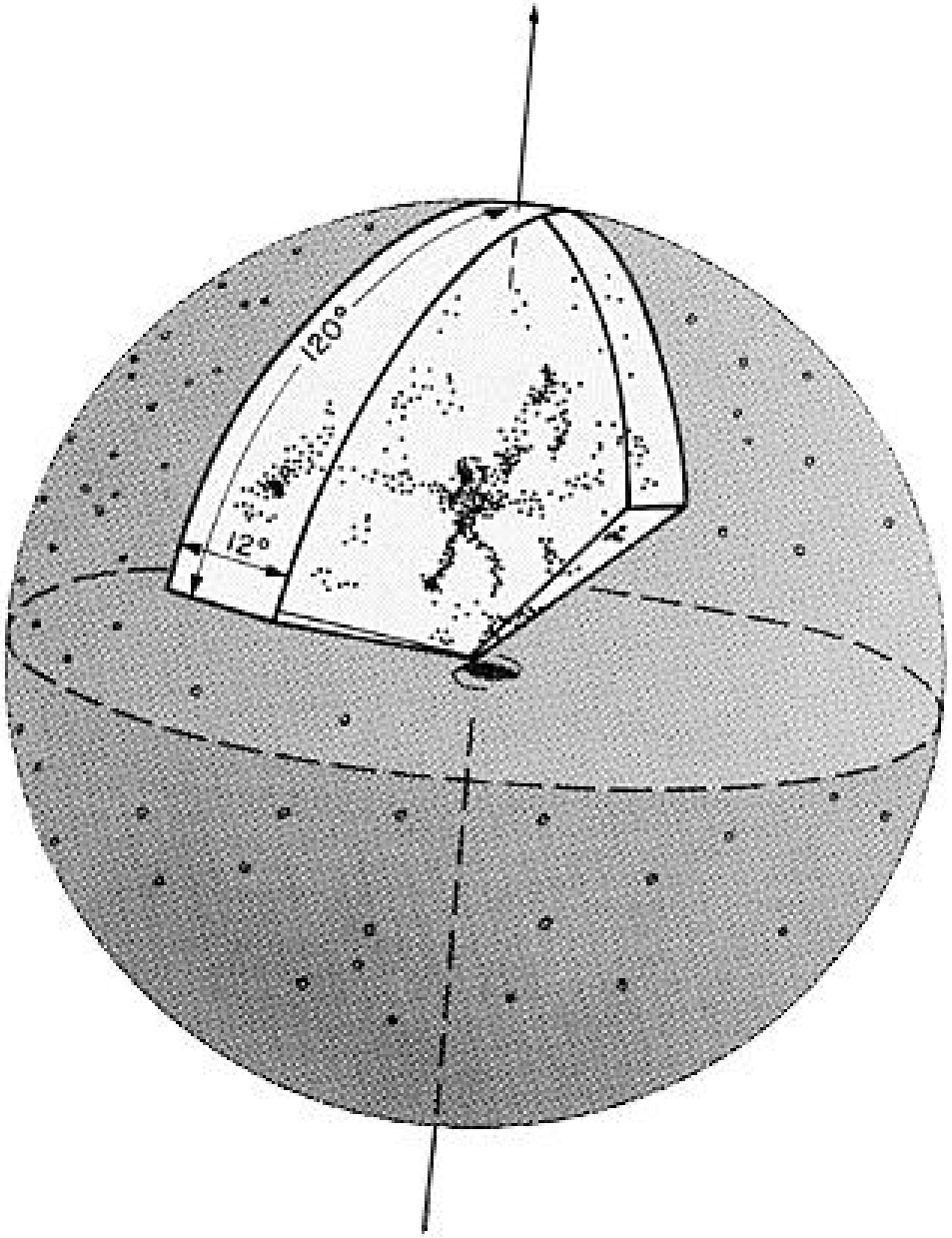
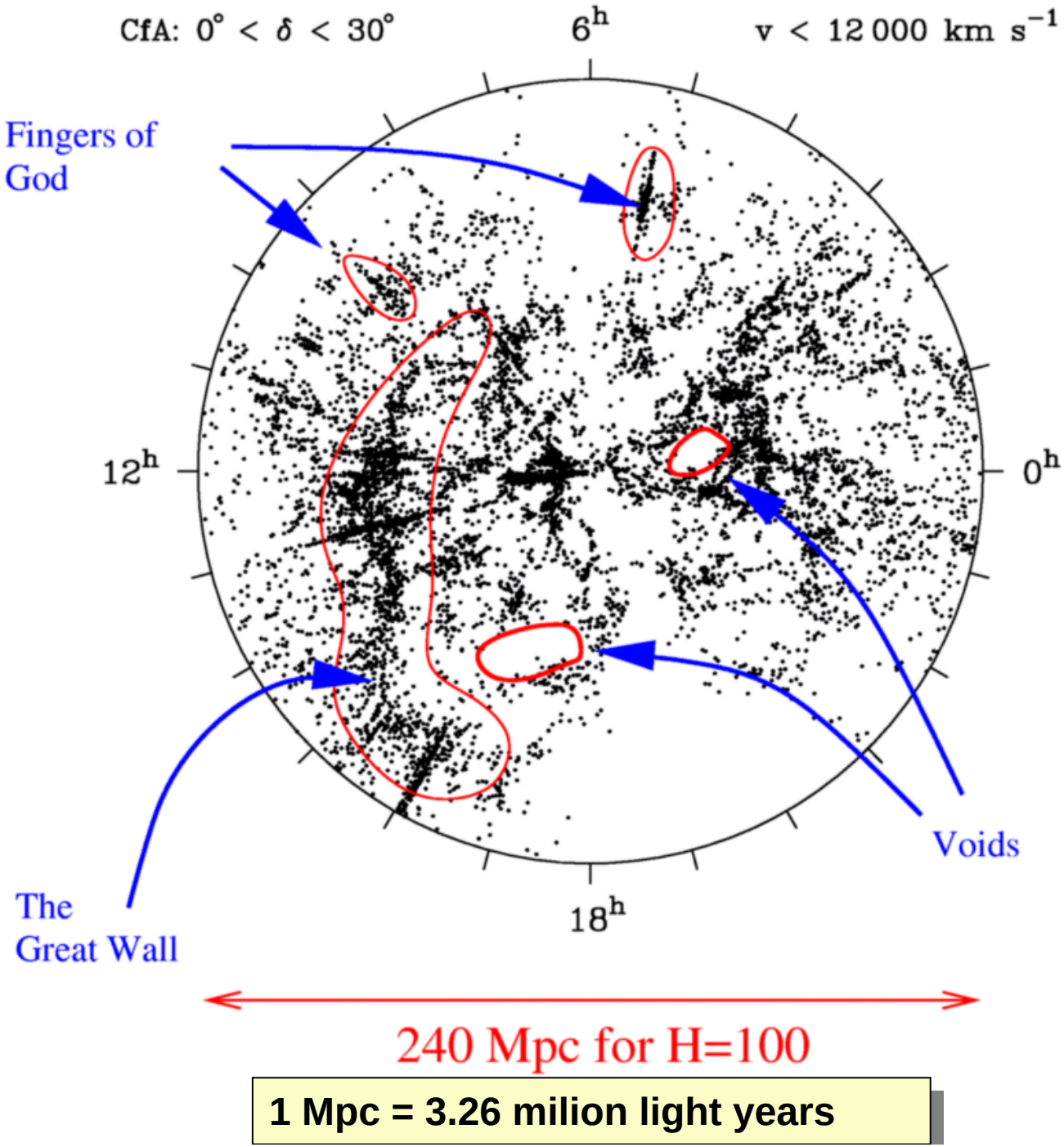

1 Gpc/h
Millennium Simulation
10.077.696.000 particles
(z = 0)


right ascension
13h
12h
14h
11h
15h
10h
16h
9h
17h
8h
180 Mpc
120 Mpc
60 Mpc
Filament
Rich cluster
Void?

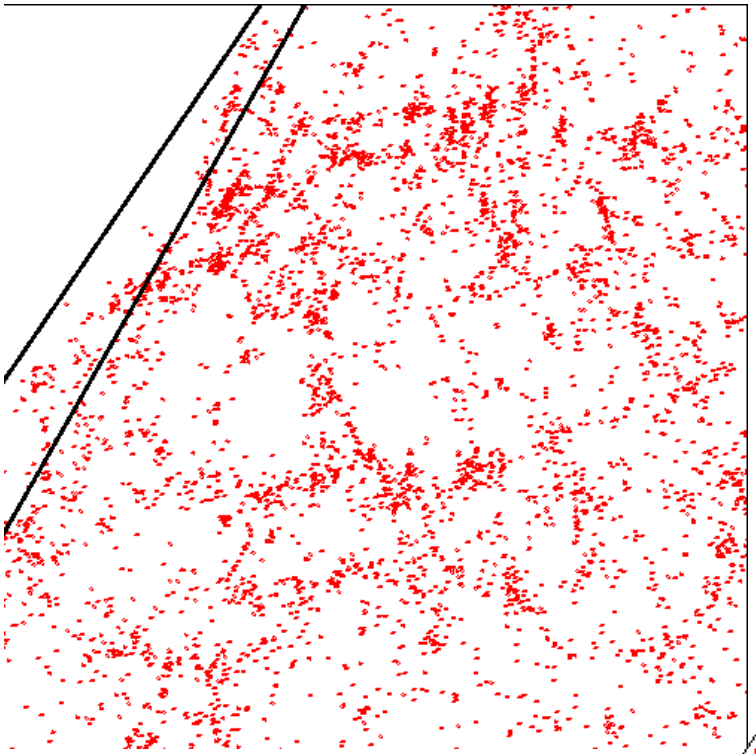

120°
12°

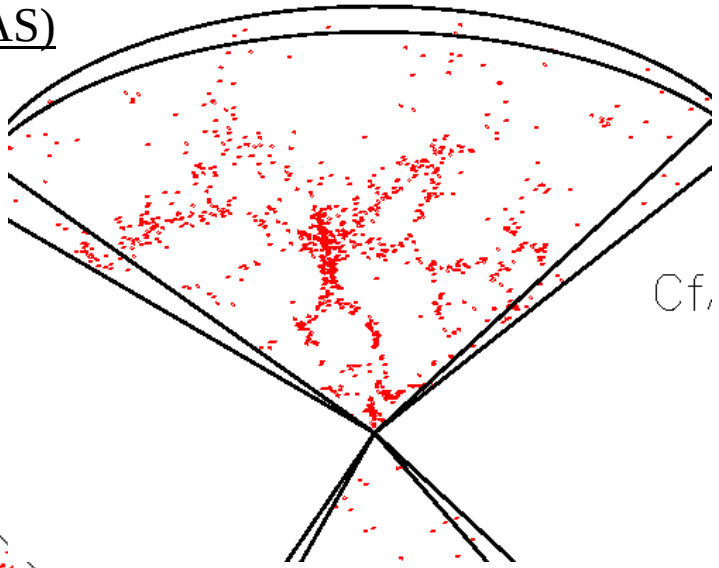


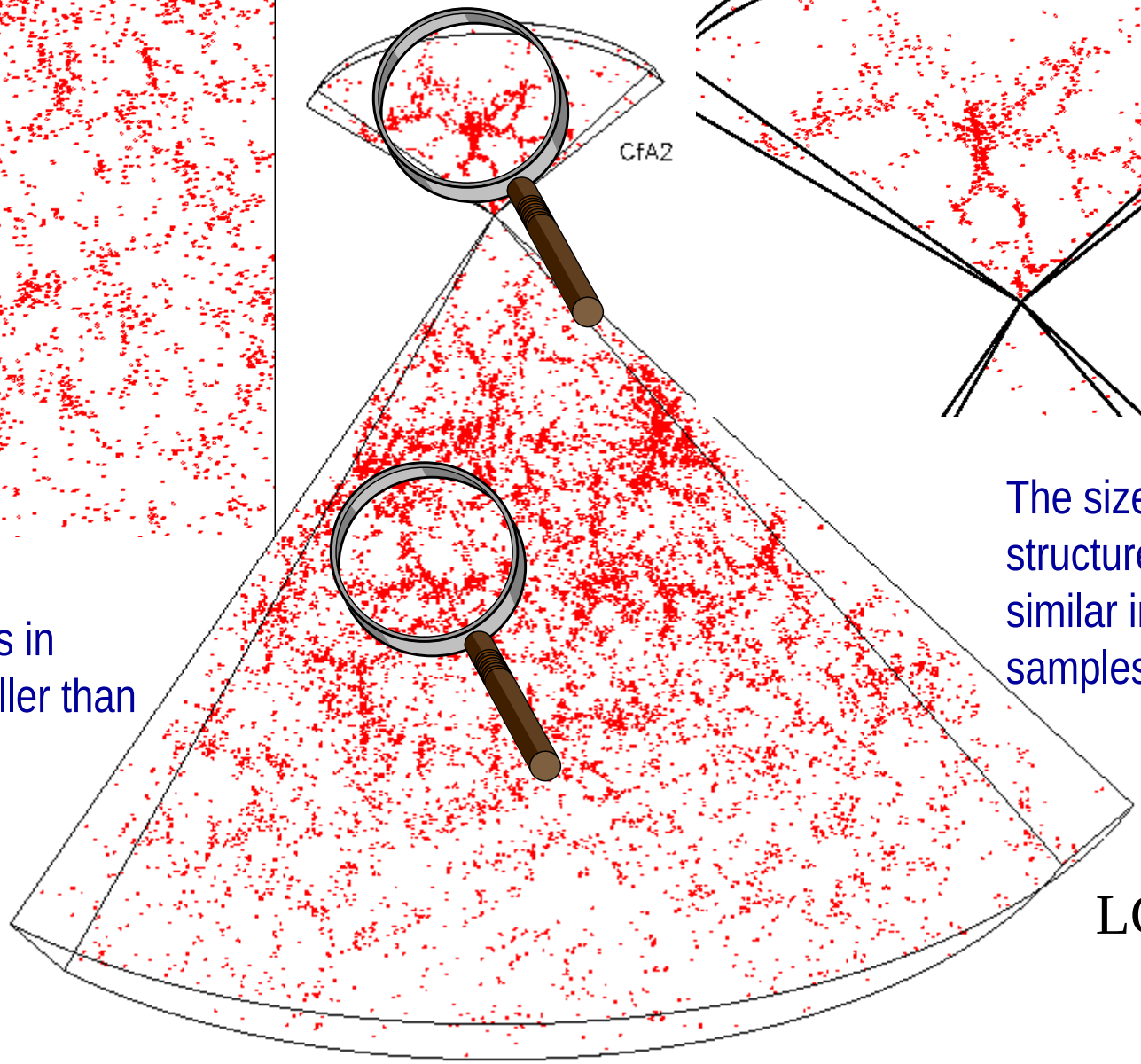
Redshift surveys (mid-1980s)

1 Mpc = 3.26 milion light years

1995 (LAS CAMPANAS)







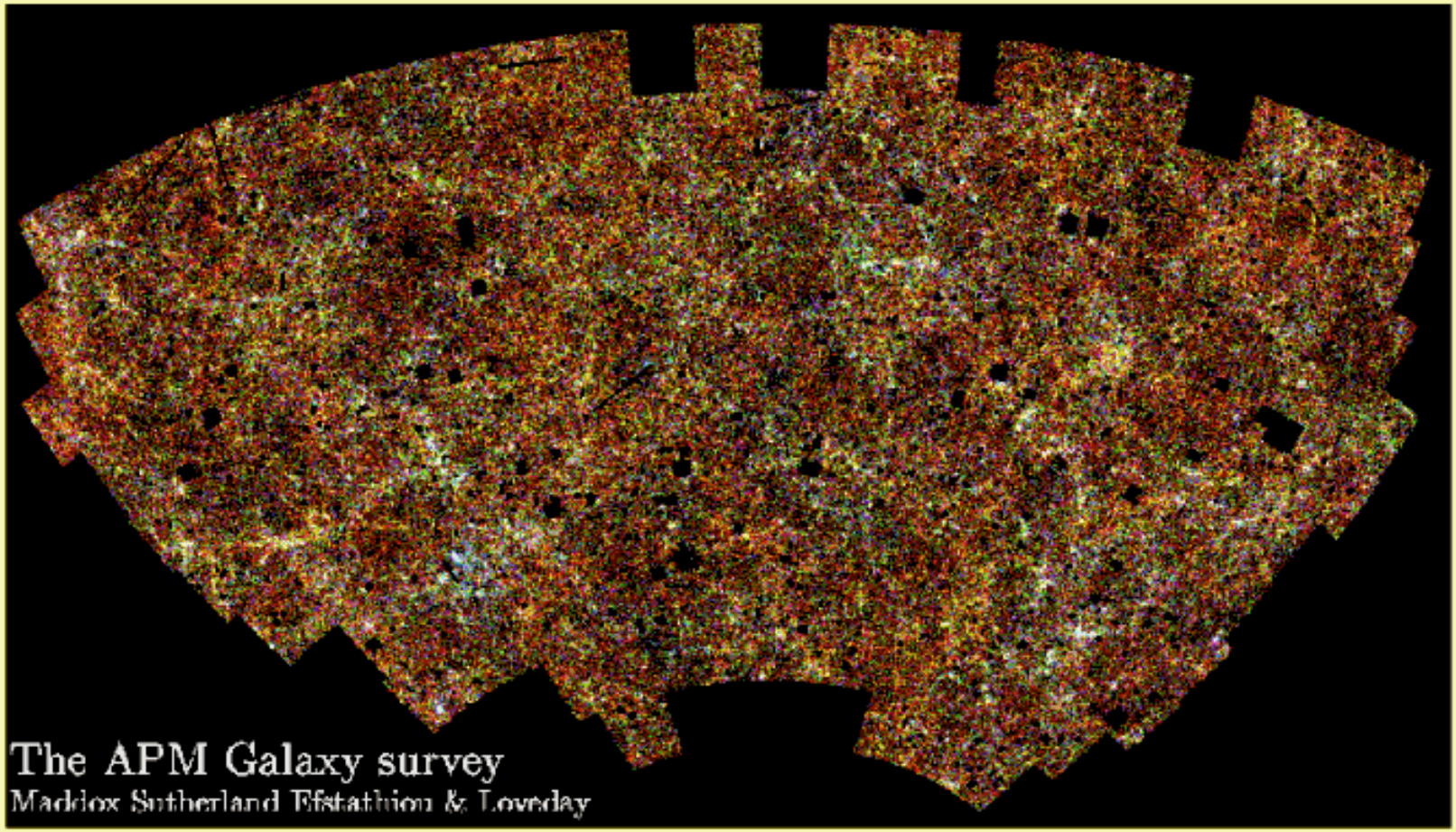
The largest structures in LCRS are much smaller than the survey size

The size of the structures is similar in both samples

LCRS

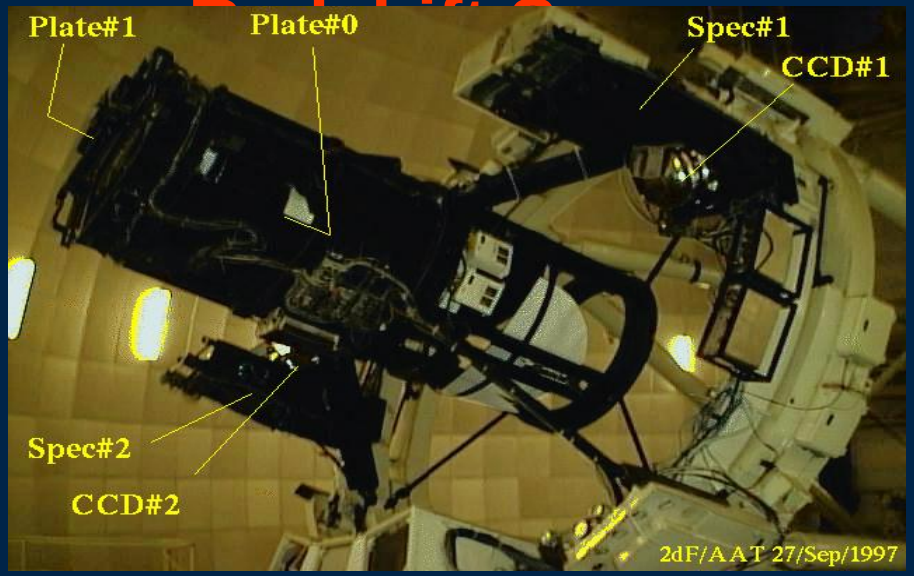
2dFGRS input catalogue

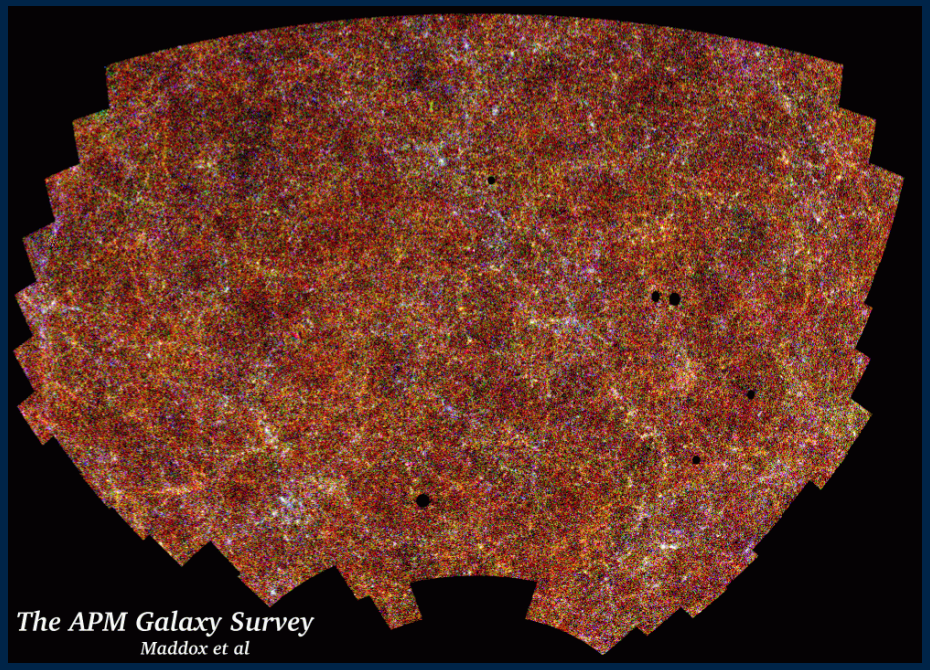
- Galaxies: $b_J \leq 19.45$ from revised APM

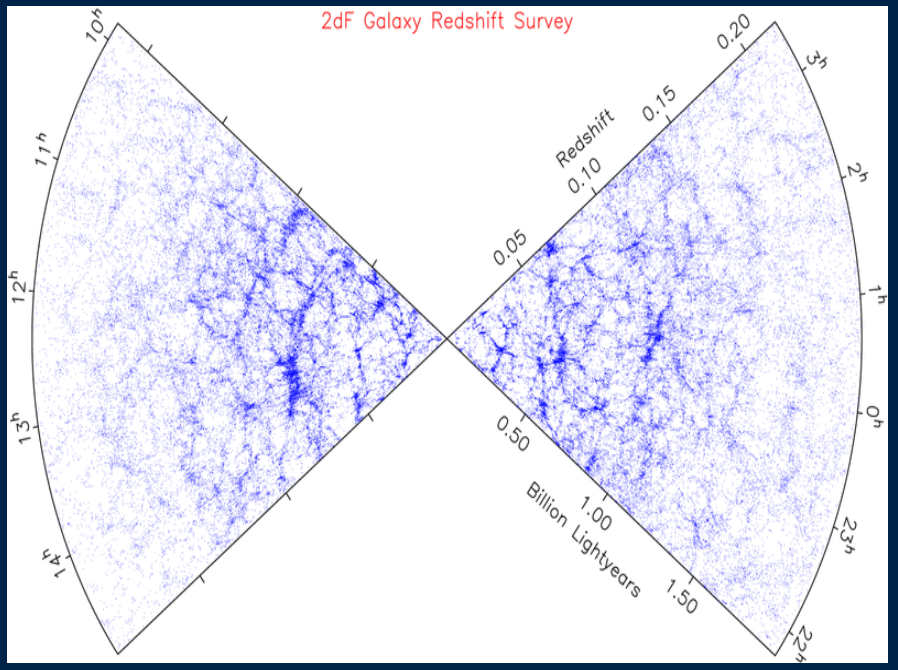


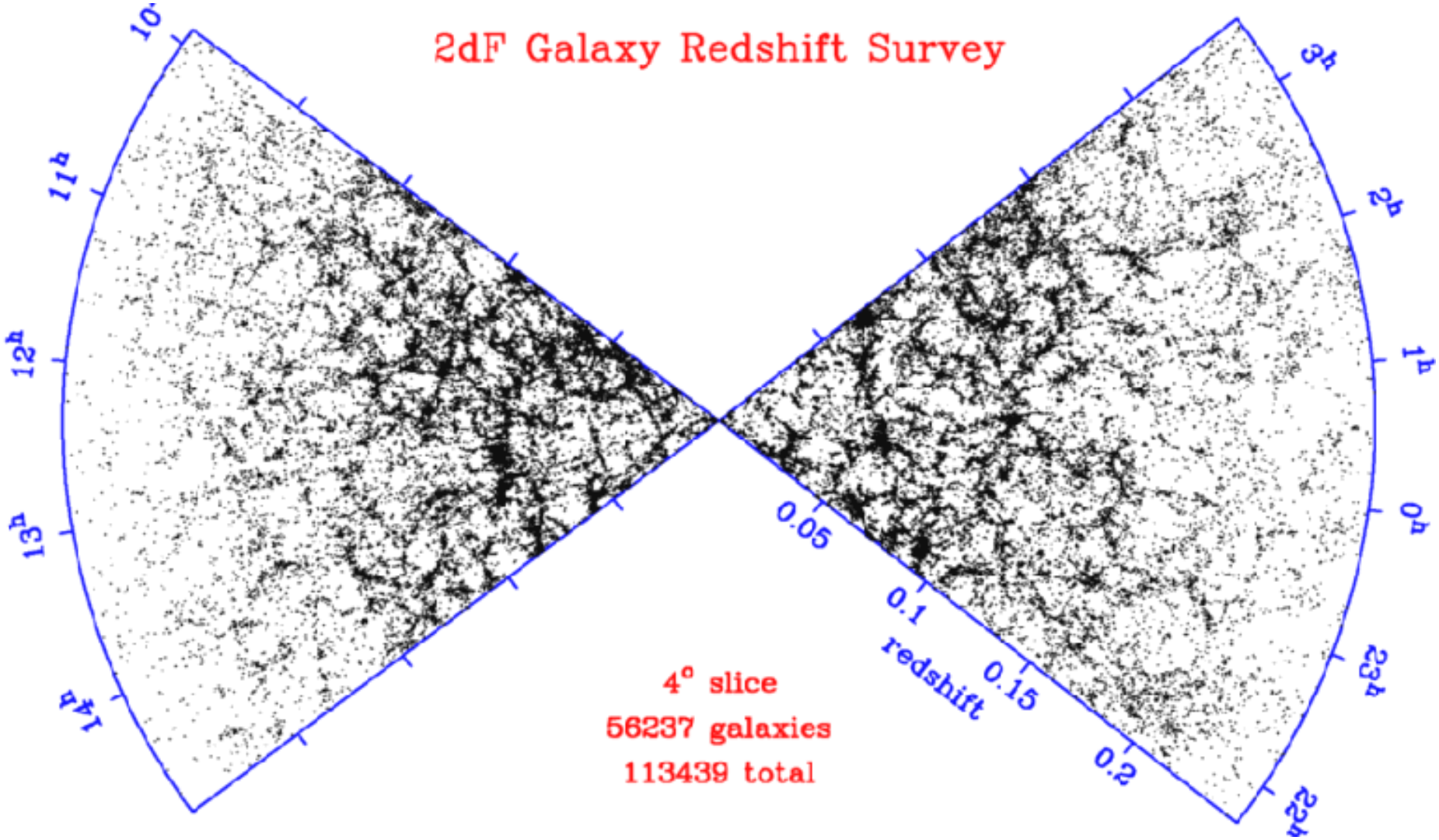
- Total area on sky ~ 2000 deg²
- 250,000 galaxies in total, 93% sampling rate
- Mean redshift <z> ~ 0.1, almost all with z < 0.3

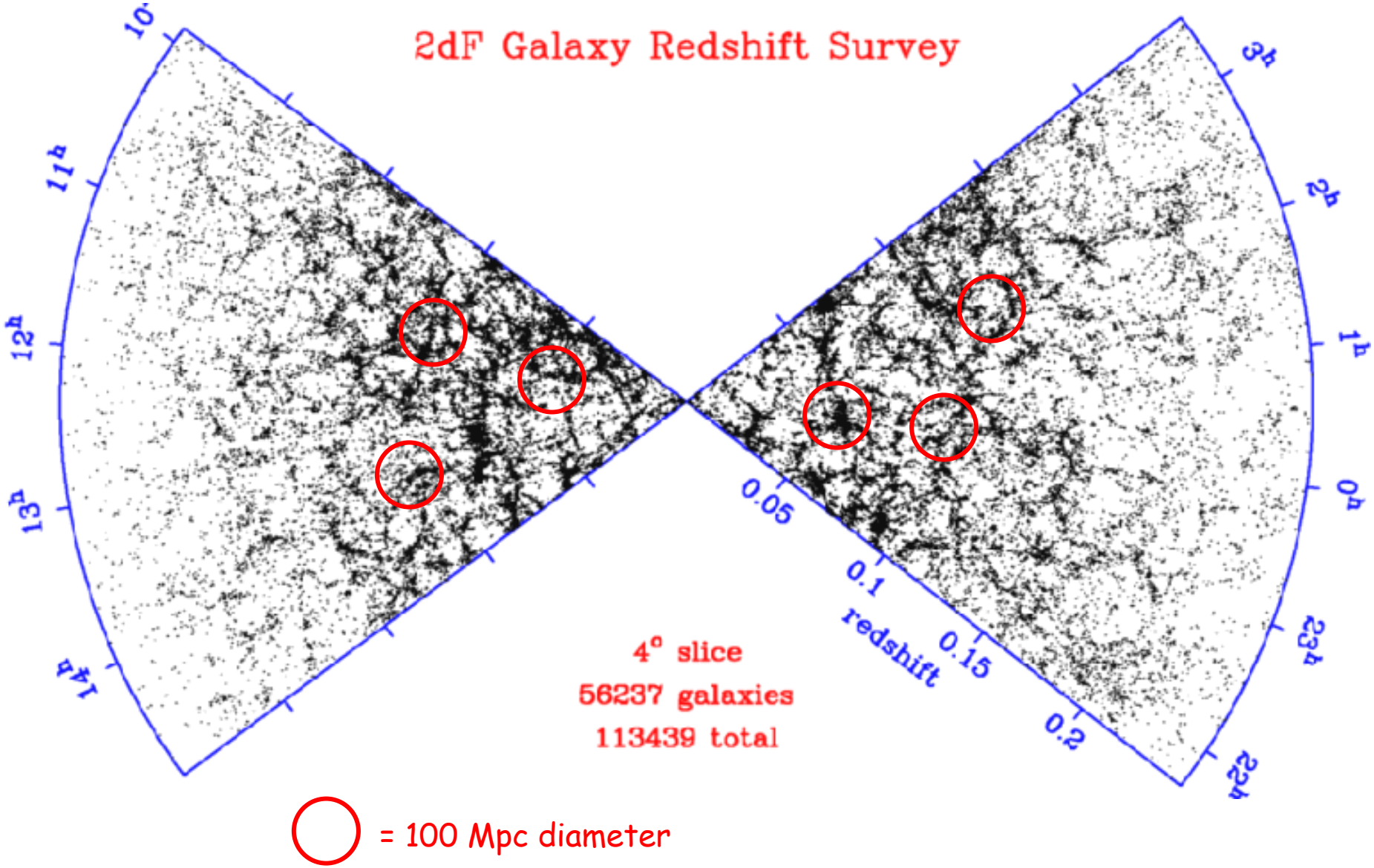
The Two Degree Field Galaxy



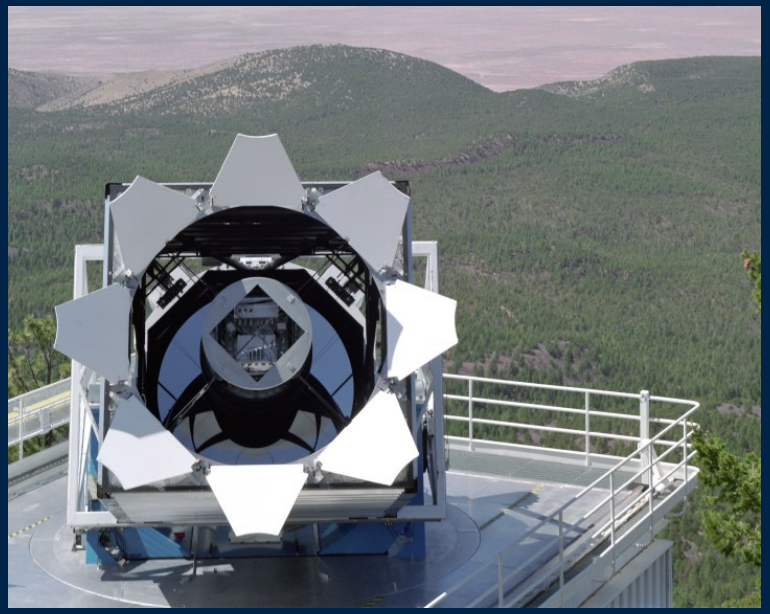


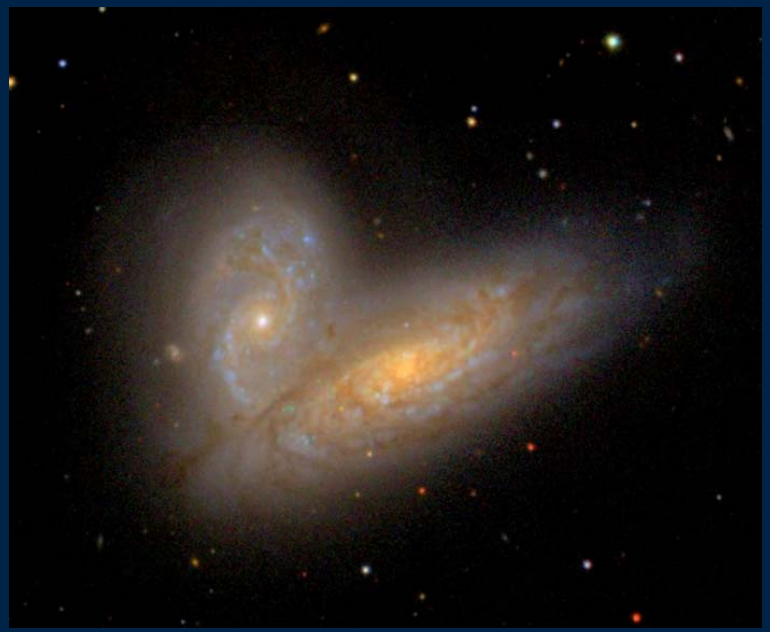


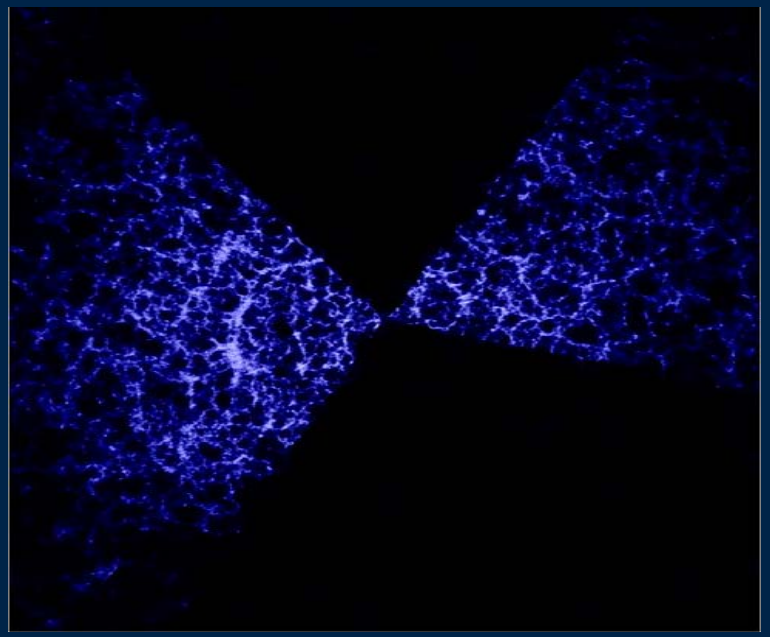

2dF Galaxy Redshift Survey
10h
11h
12h
13h
14h
3h
2h
1h
0h
23h
22h
0.05
0.1
0.15
0.2
redshift
4° slice
56237 galaxies
113439 total

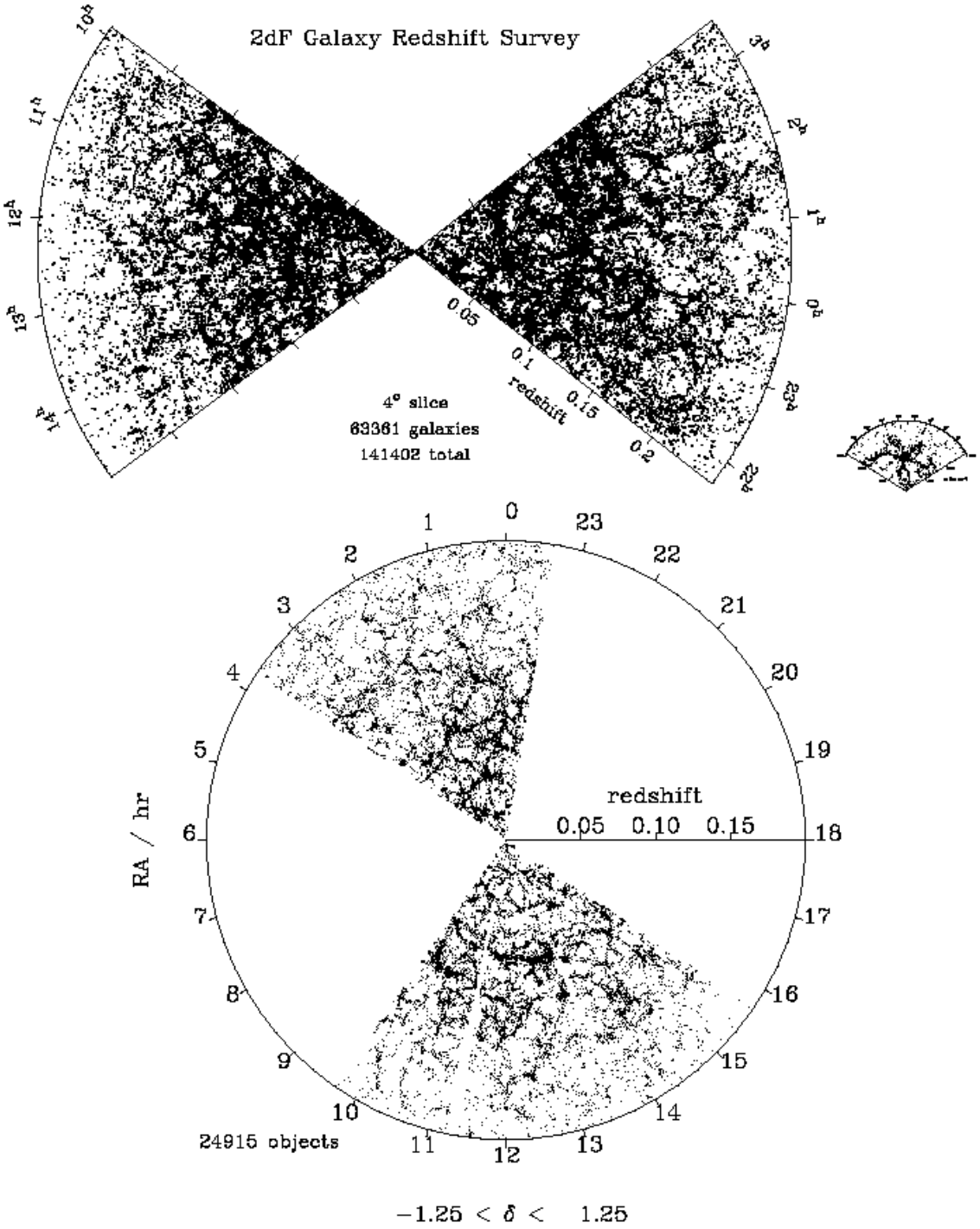

2dF Galaxy Redshift Survey
10h
11h
12h
13h
14h
3h
2h
1h
0h
23h
22h
0.05
0.1
0.15
0.2
redshift
4° slice
56237 galaxies
113439 total
= 100 Mpc diameter

The Sloan Digital Sky (SDSS)

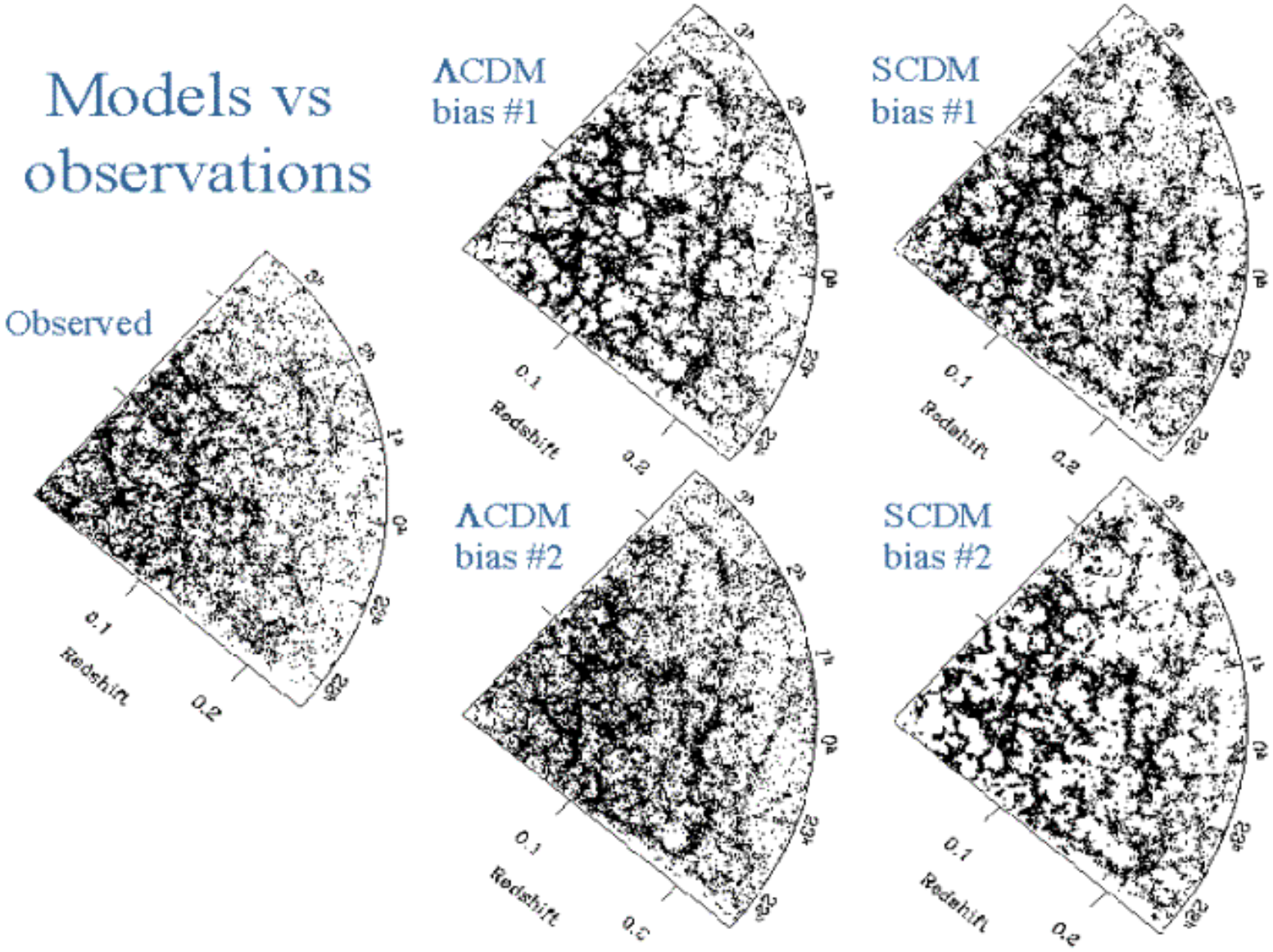




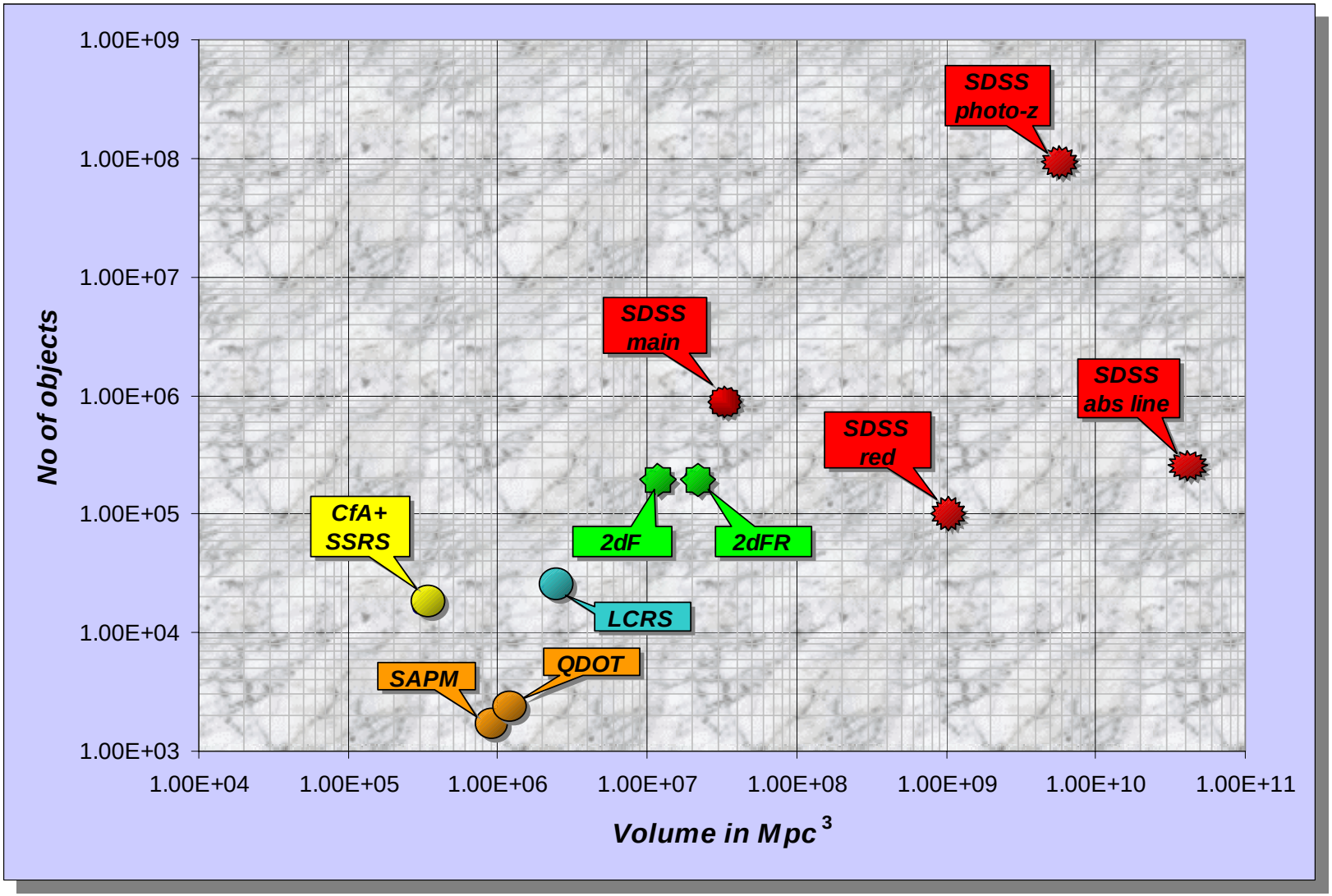



2dF Galaxy Redshift Survey
10h
11h
12h
13h
14h
0h
1h
2h
3h
22h
23h
0.05
0.1
0.15
0.2
redshift
4° slice
63361 galaxies
141402 total
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
redshift
0.05 0.10 0.15
RA / hr
24915 objects
−1.25 < δ < 1.25

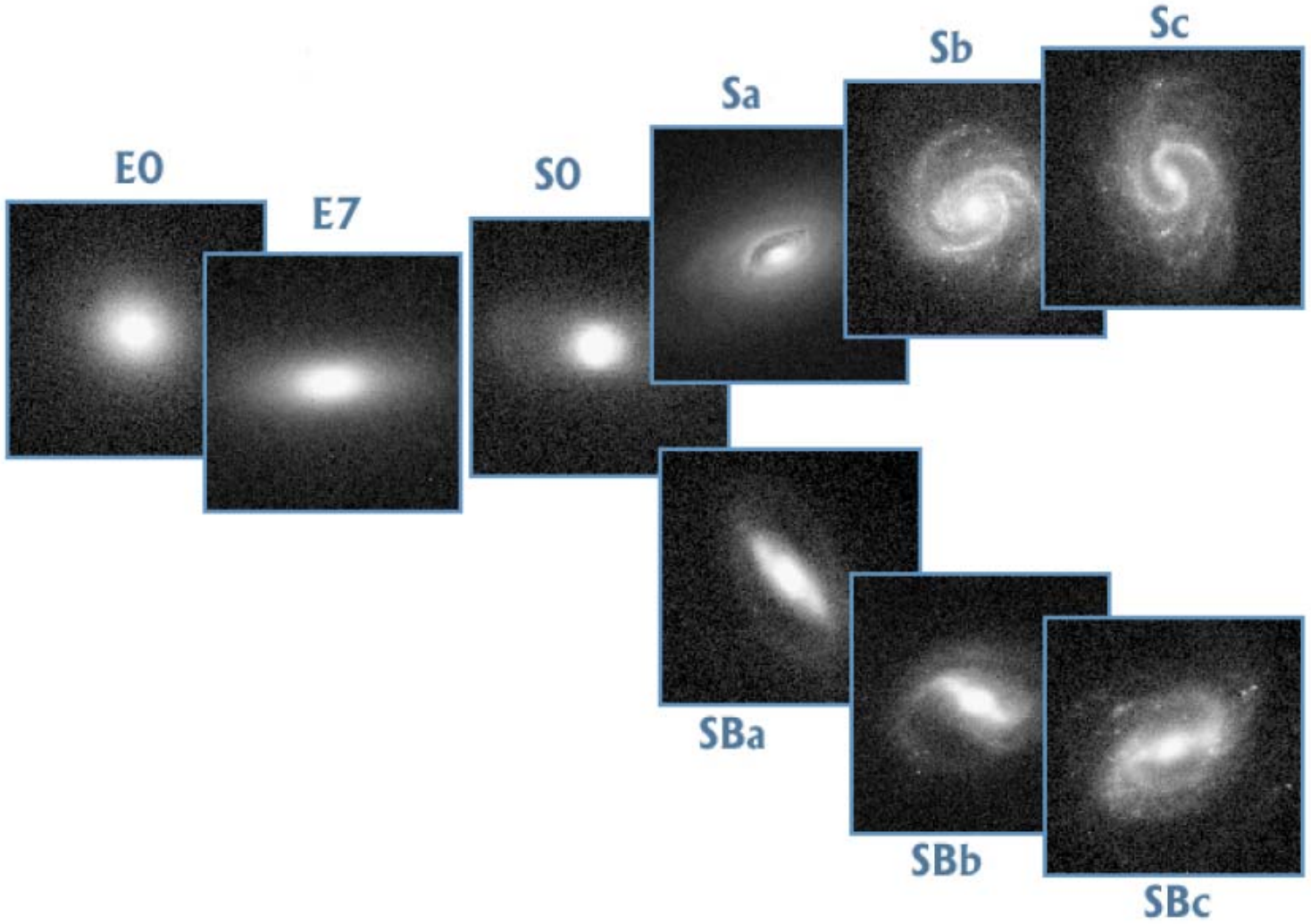
Which simulation model matches the observations?...



Area and Size of Redshift Surveys



We see spiral and elliptical galaxies…

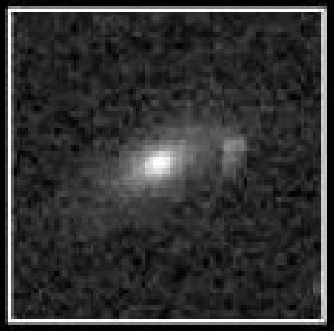
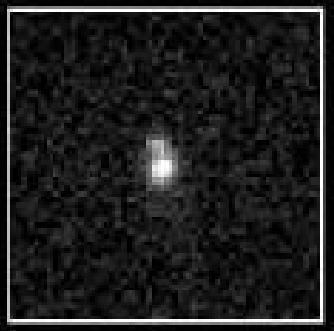


Hubble's tuning fork classification

Age of the Universe

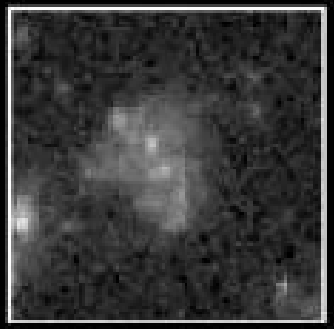
Today: 14 Billion Years | 9 Billion Years | 5 Billion Years | 2 Billion Years



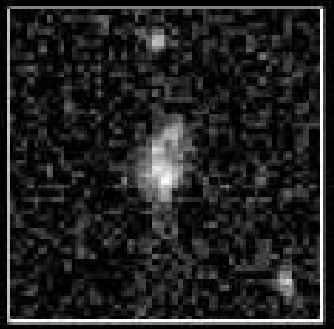



Elliptical





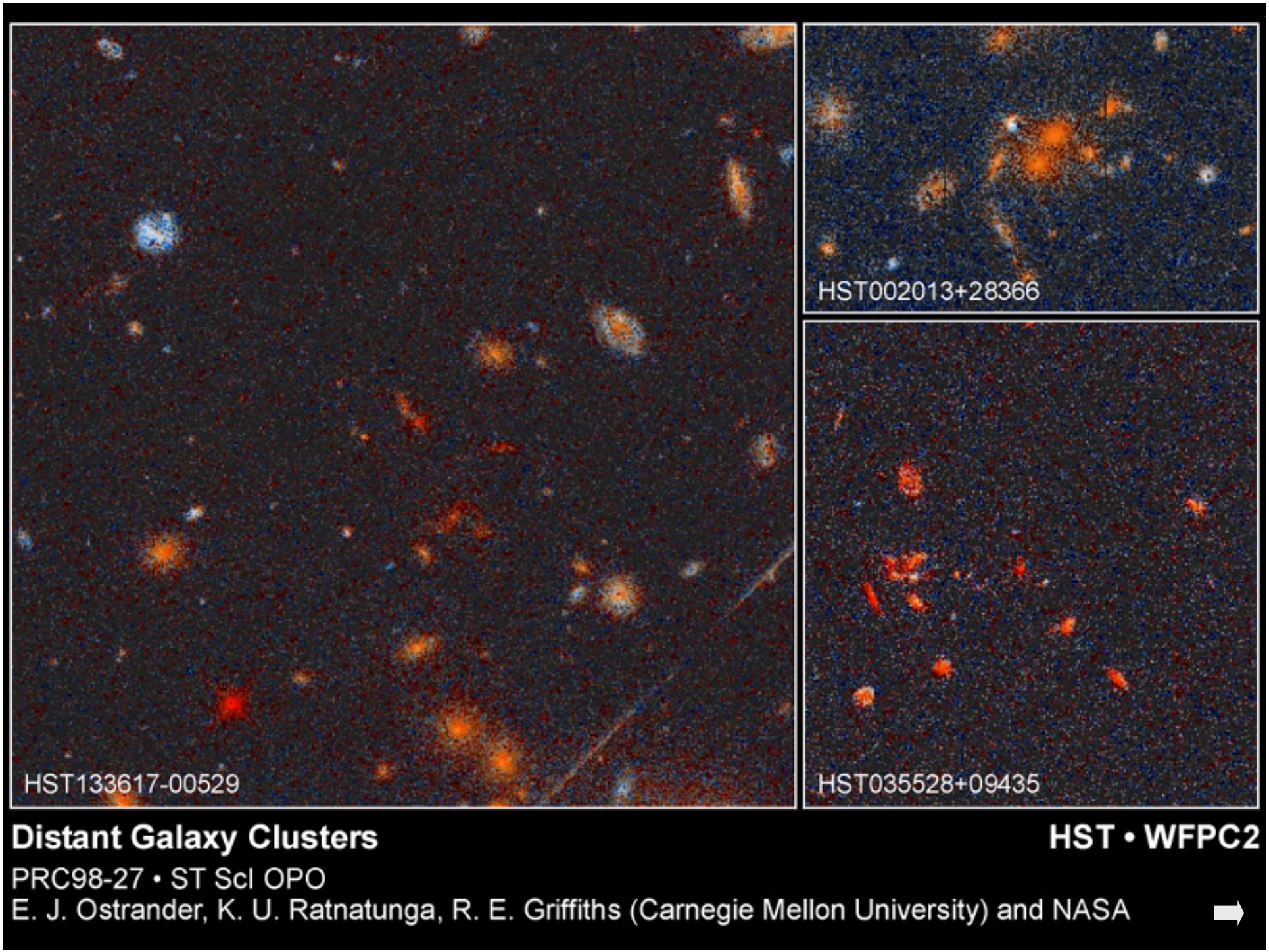




Spiral

Morphological Segregation

Nowadays we find few spiral galaxies in rich clusters. This is thought to be because the spiral disks are disrupted by tidal forces…



Distant Galaxy Clusters **HST • WFPC2**

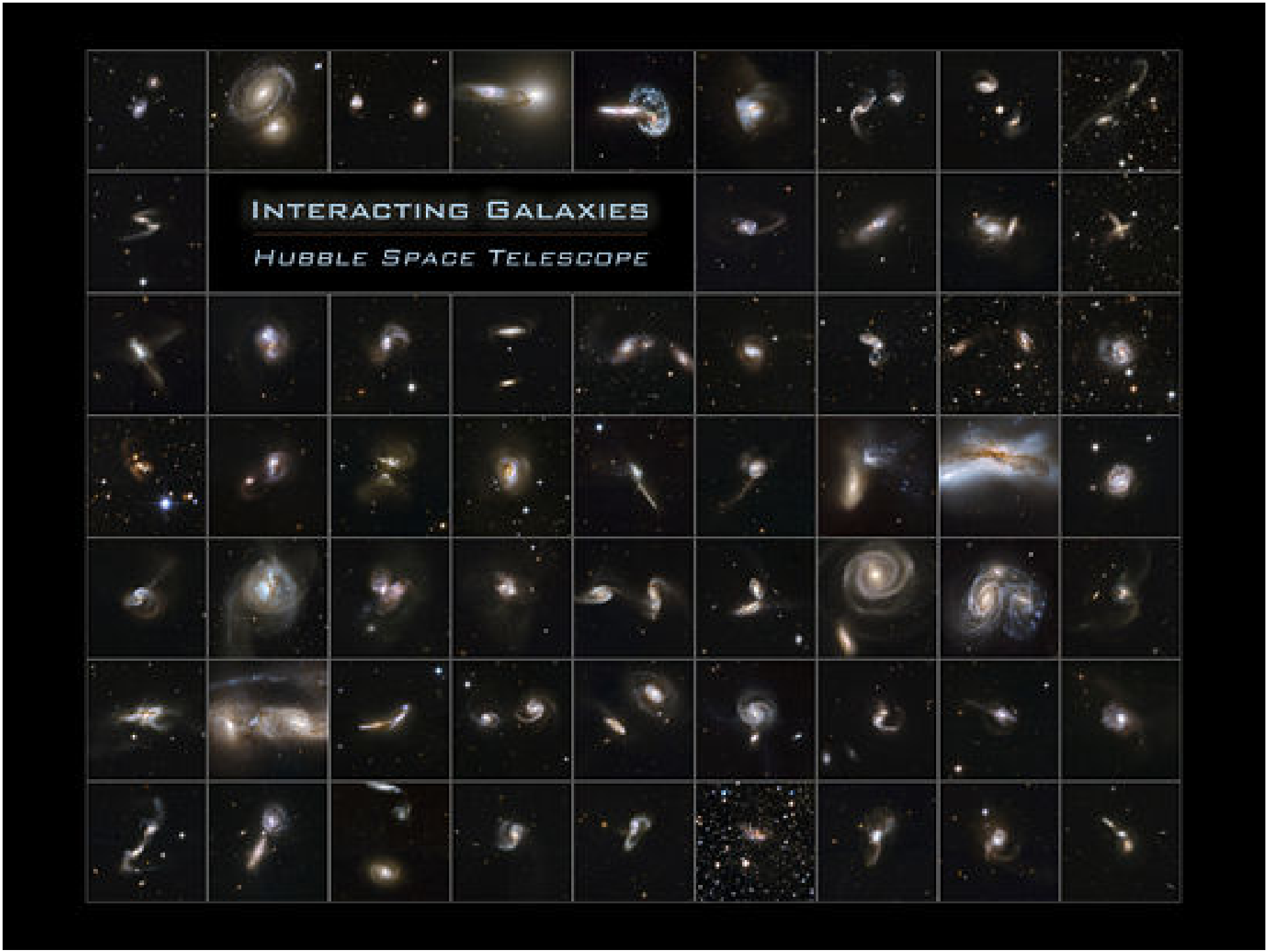
PRC98-27 • ST ScI OPO

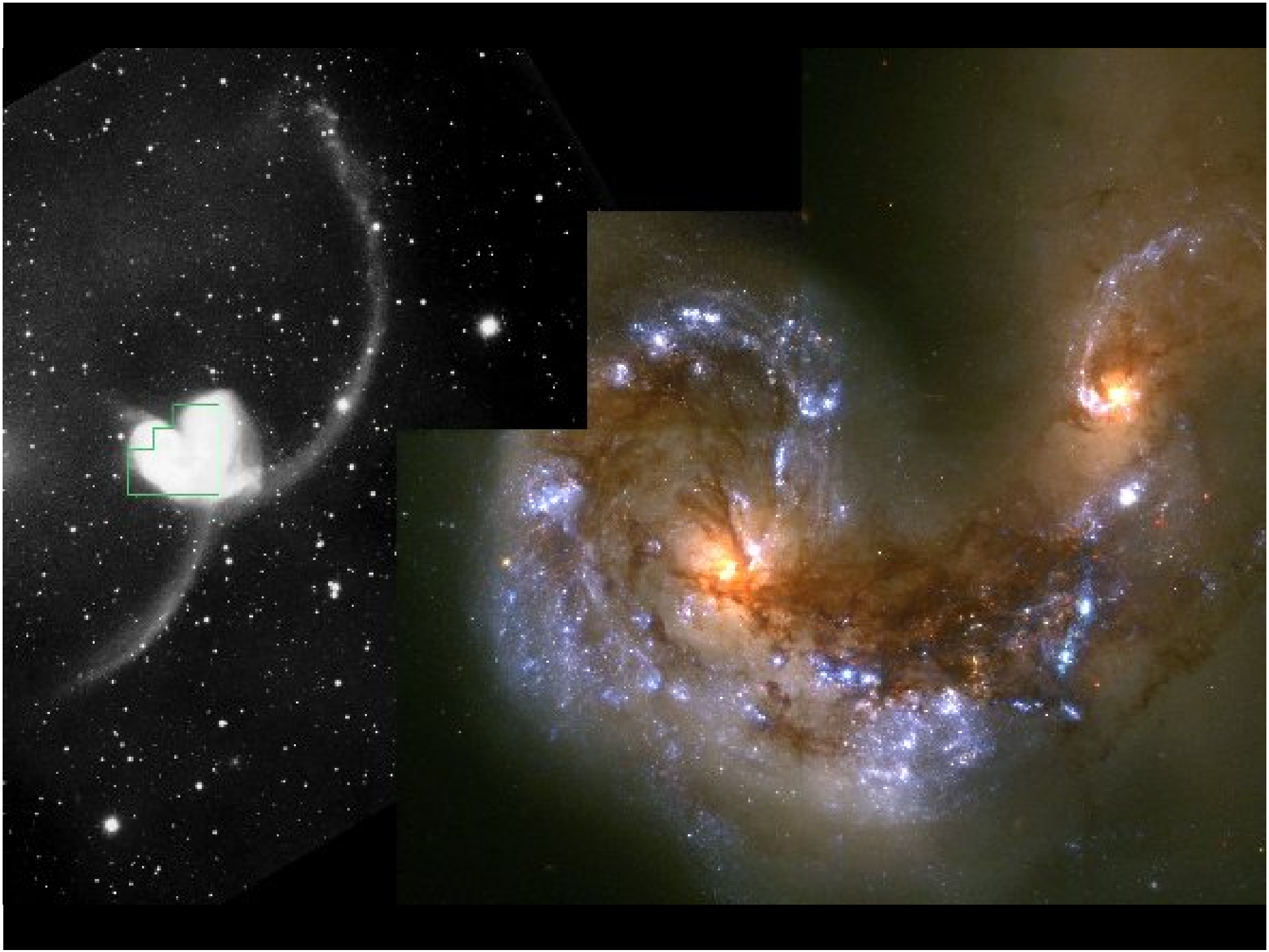
E. J. Ostrander, K. U. Ratnatunga, R. E. Griffiths (Carnegie Mellon University) and NASA

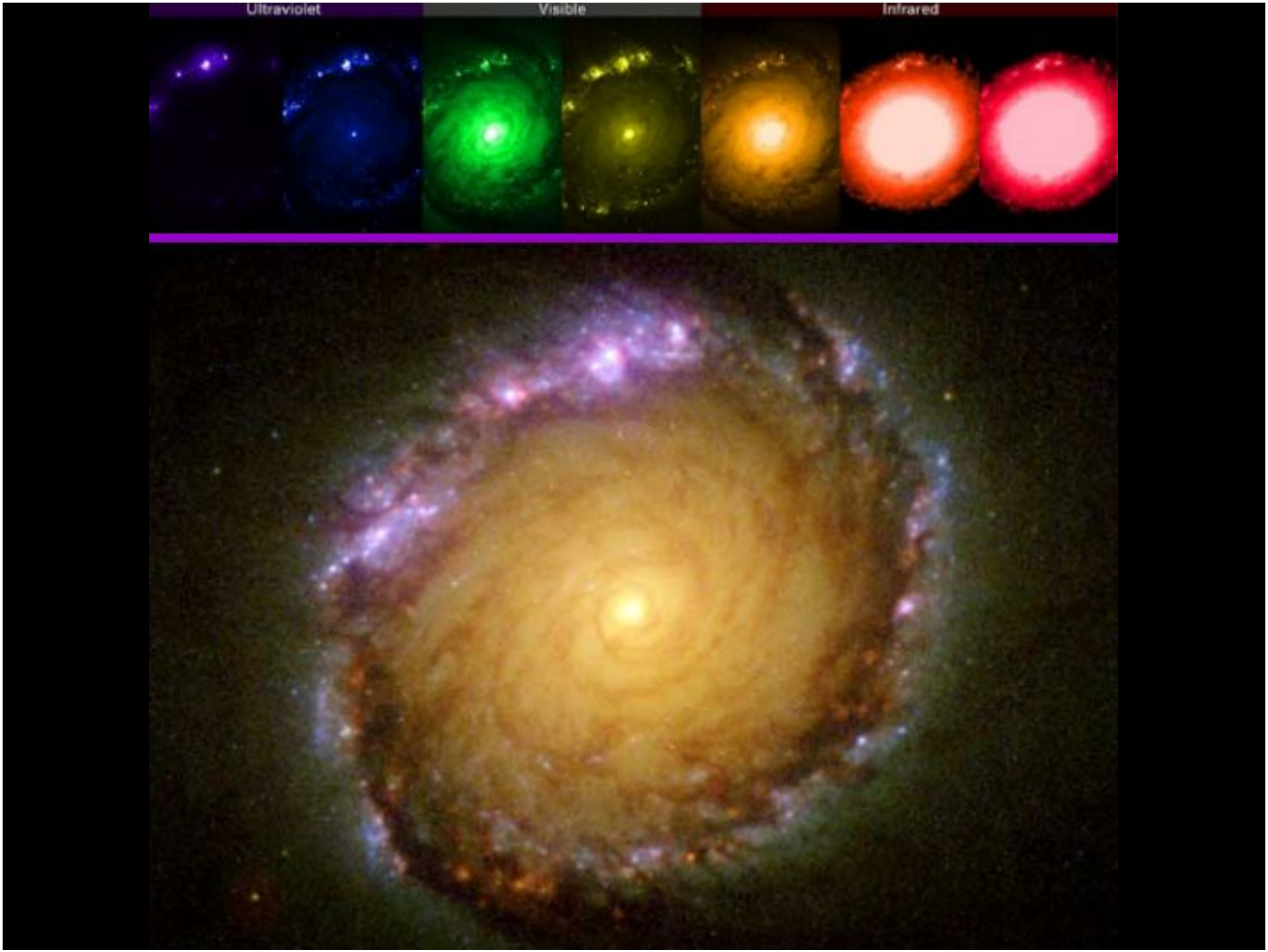
Morphological Segregation

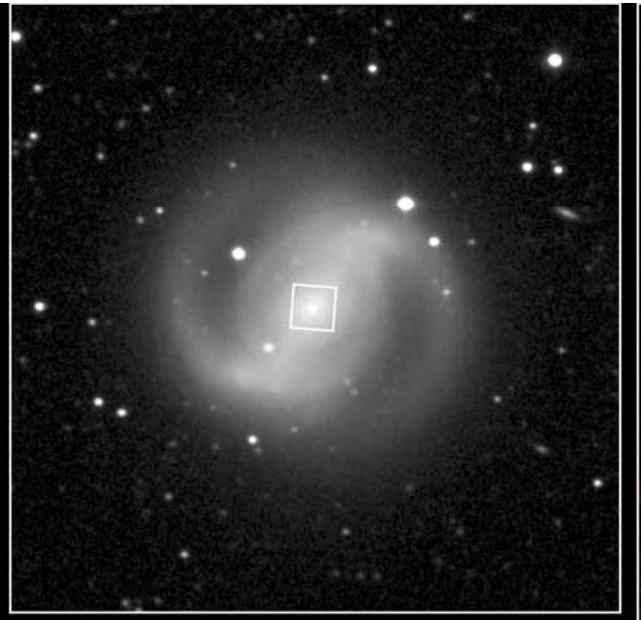
Nowadays we find few spiral galaxies in rich clusters. This is thought to be because the spiral disks are disrupted by tidal forces…

…Conversely, many ellipticals (and some spirals) may have formed from galaxy **mergers**.

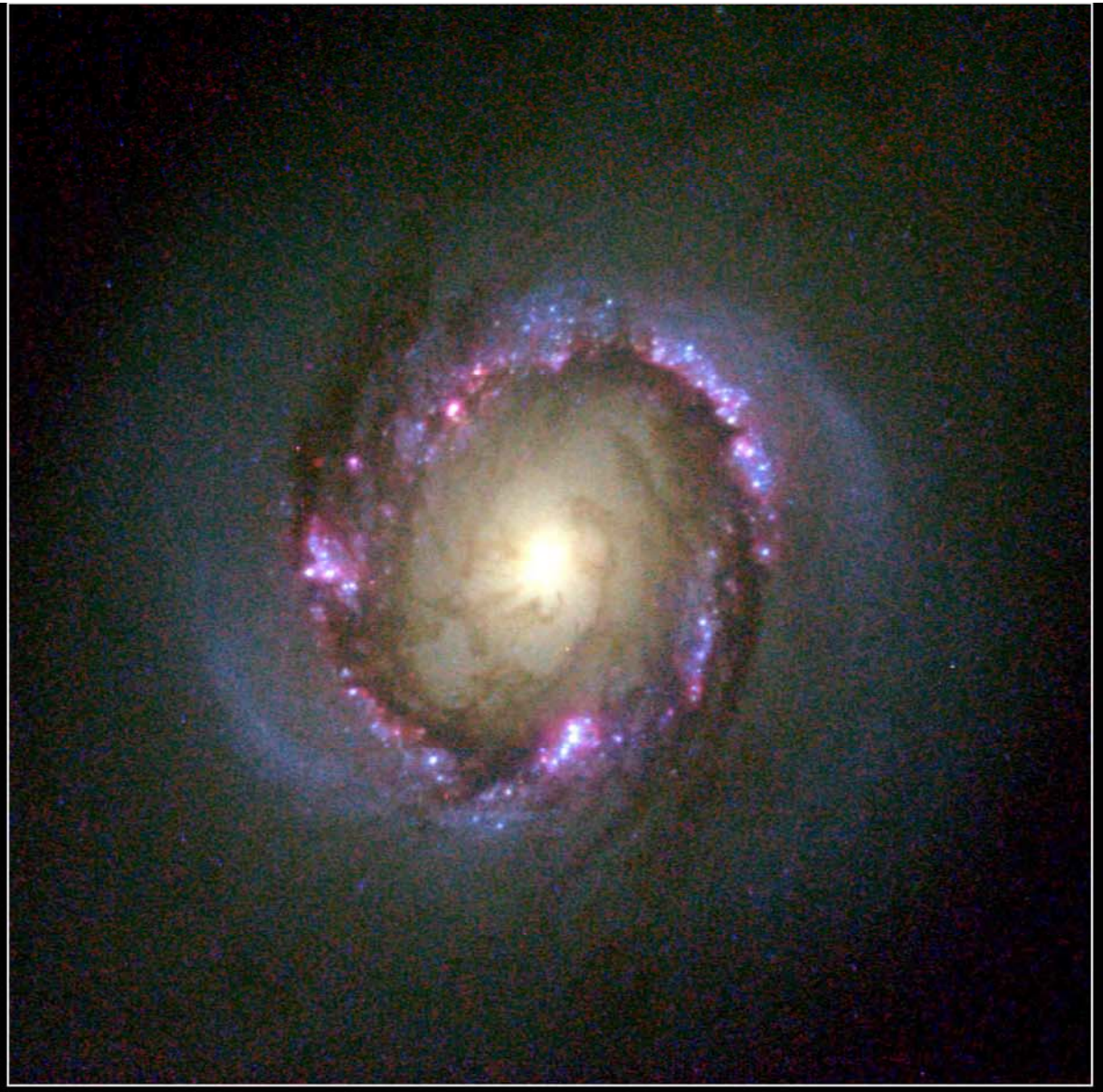

INTERACTING GALAXIES
HUBBLE SPACE TELESCOPE




Ultraviolet
Visible
Infrared



McDonald Observatory

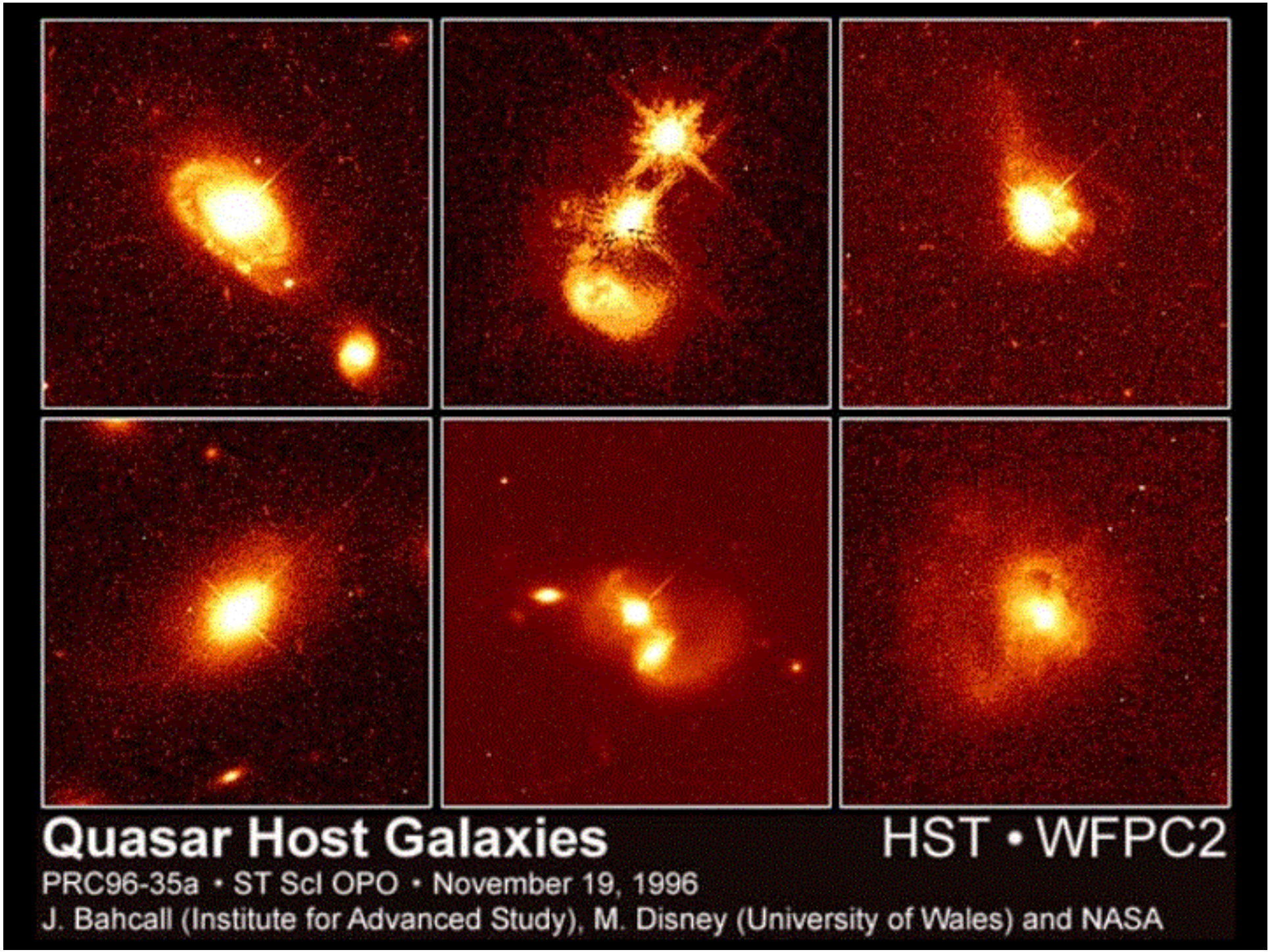


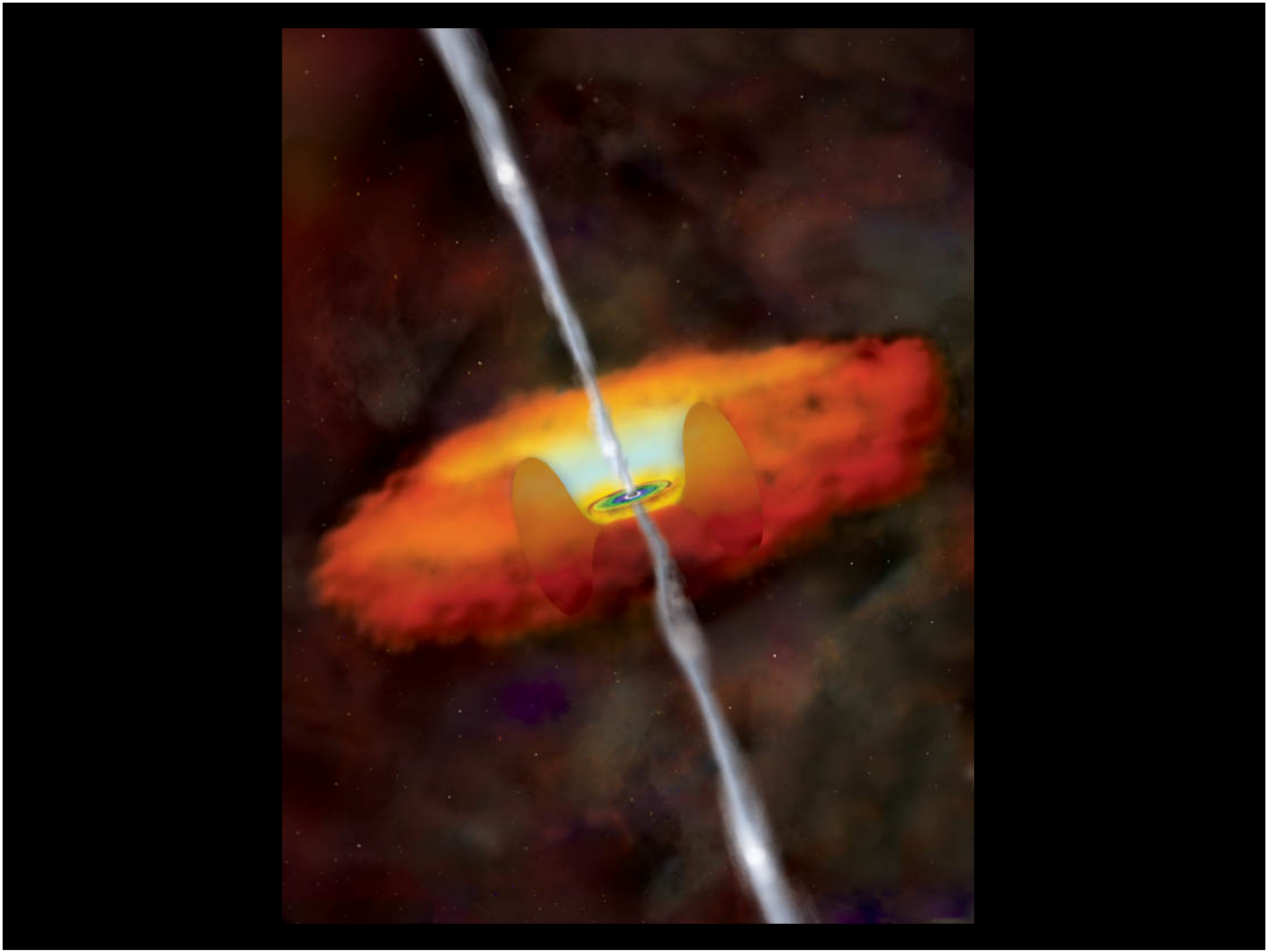
HST

Galaxy NGC 4314 • Nuclear-Ring

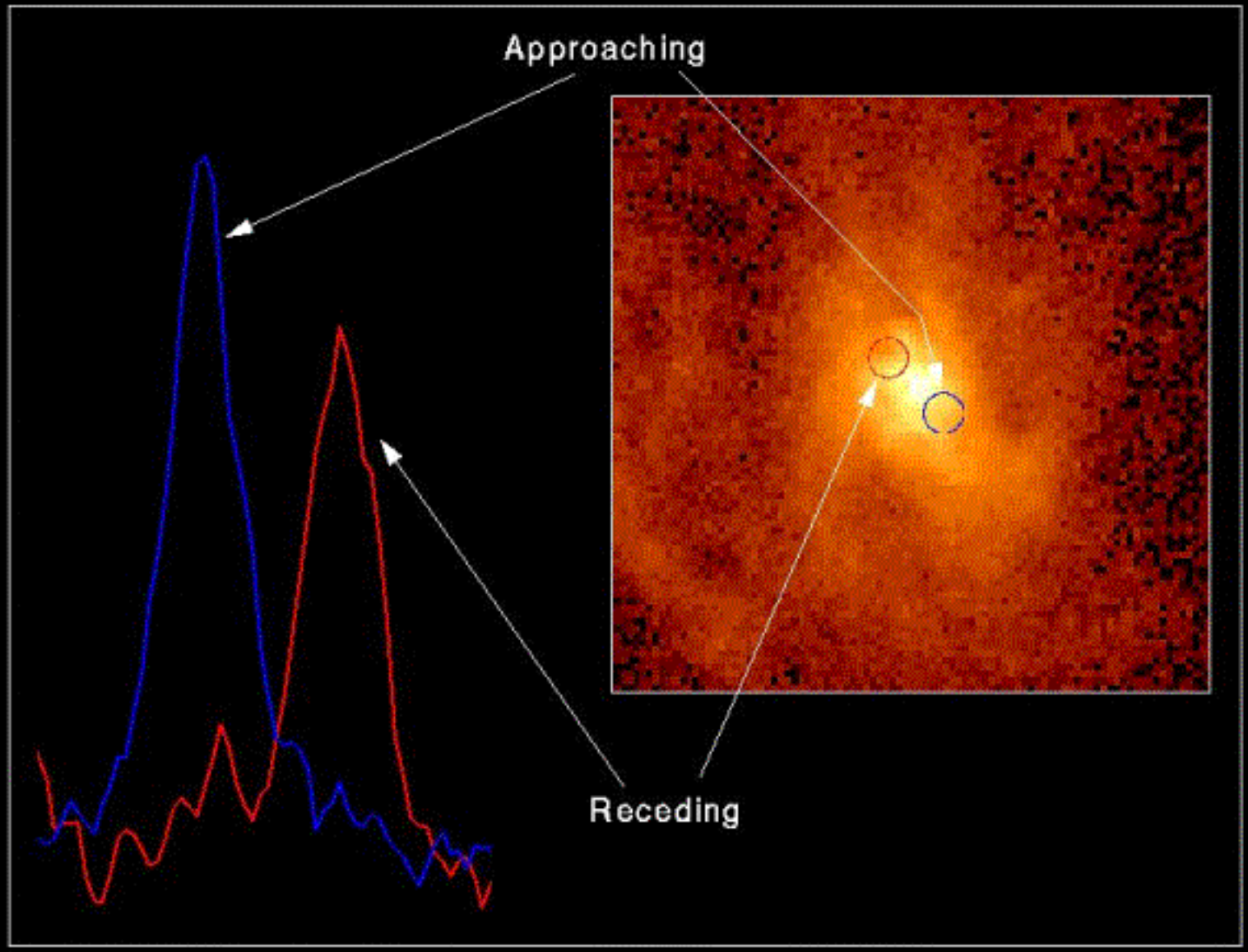
Hubble Space Telescope • Wide Field Planetary Camera 2

PRC98-21 • June 11, 1998 • ST ScI OPO • G. F. Benedict (University of Texas) and NASA


Quasar Host Galaxies
HST • WFPC2
PRC96-35a • ST ScI OPO • November 19, 1996
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA



Spectrum of Gas Disk in Active Galaxy M87



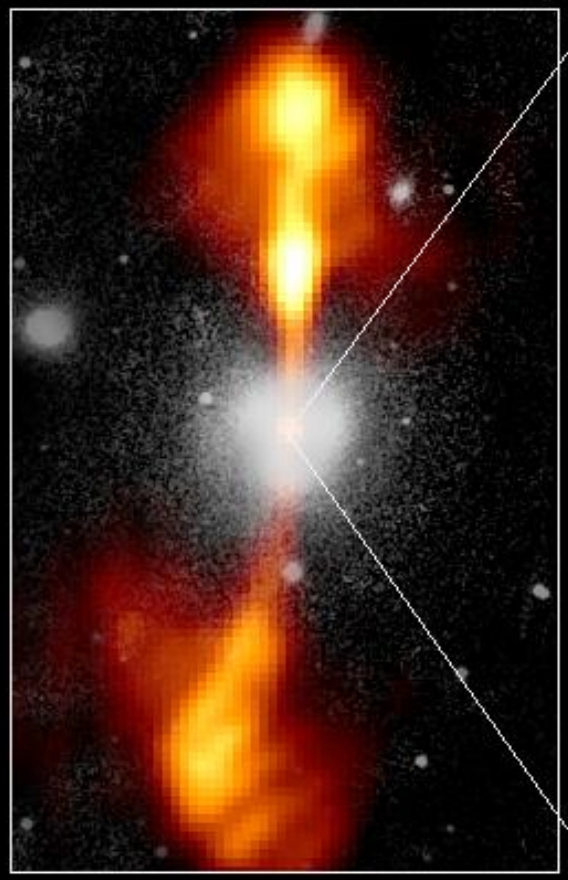
Hubble Space Telescope • Faint Object Spectrograph

Core of Galaxy NGC 4261

Hubble Space Telescope

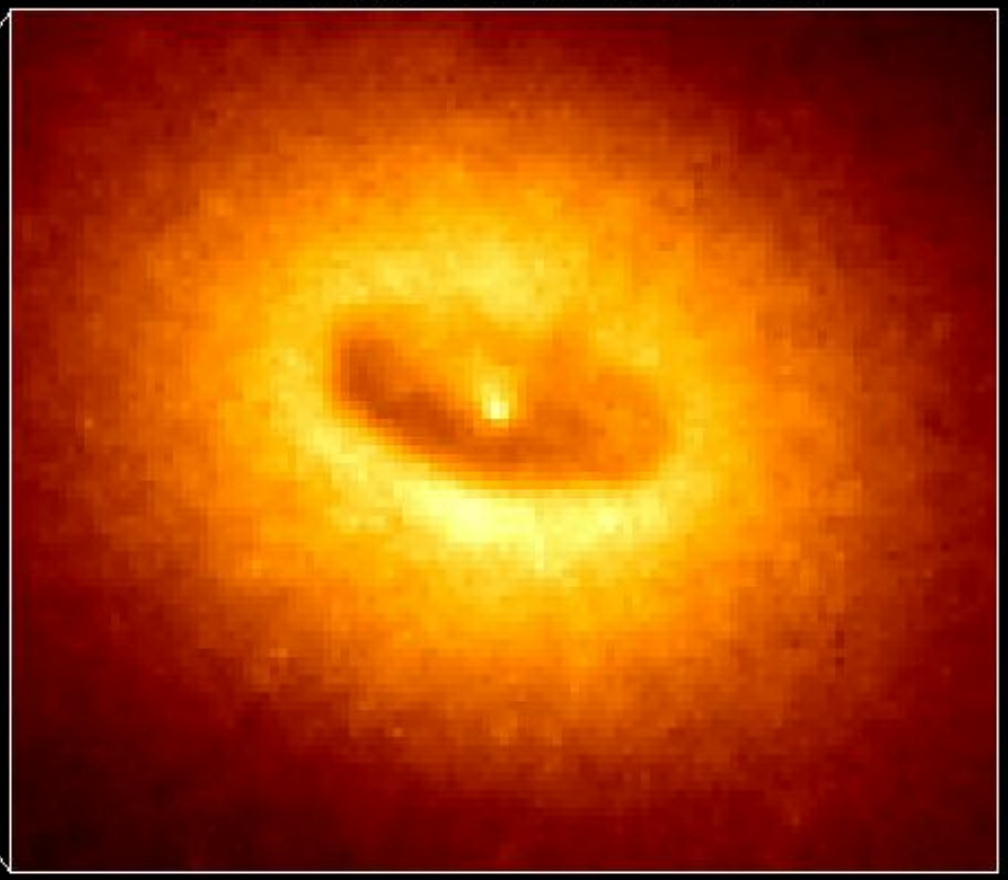
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image

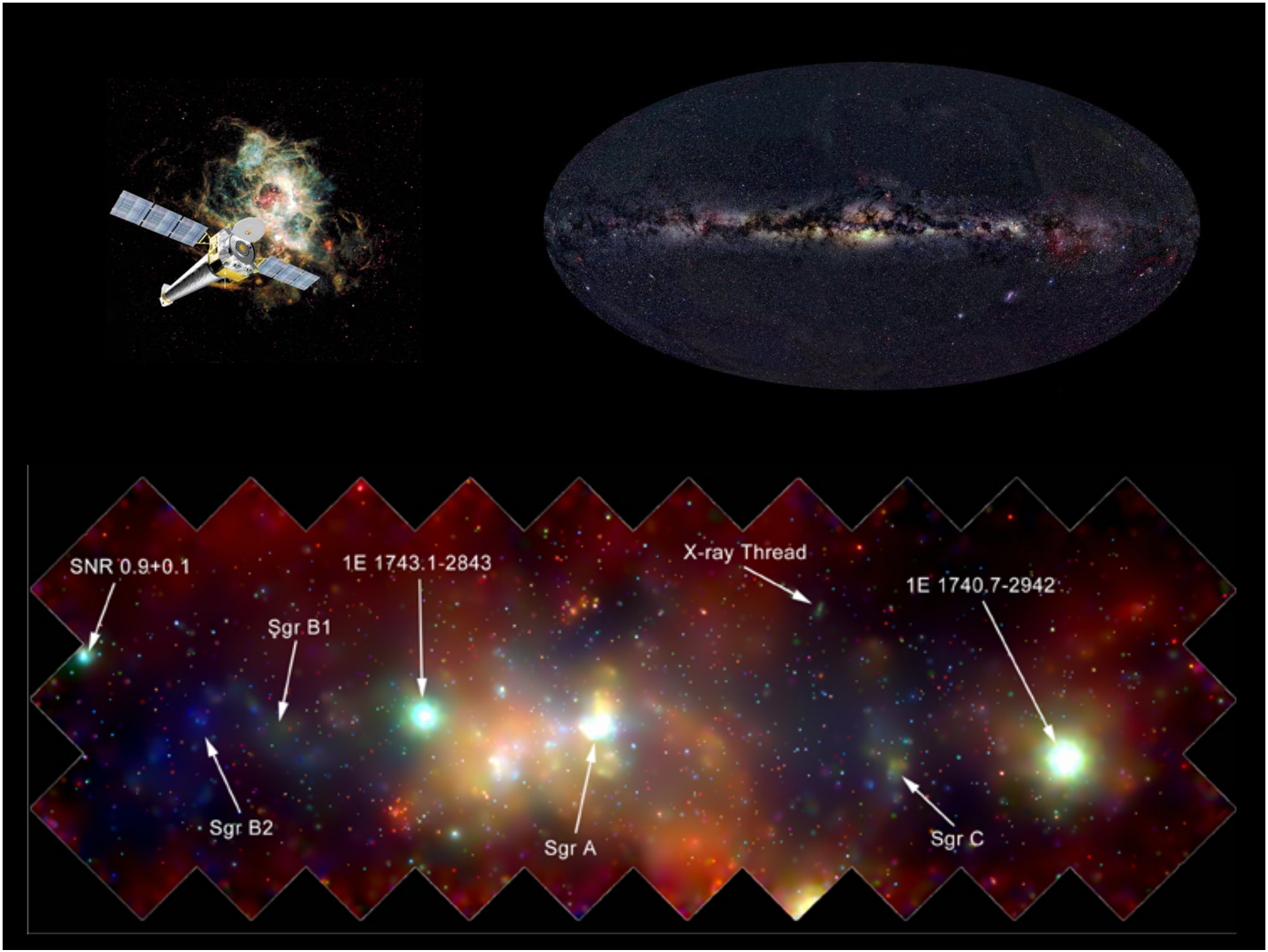


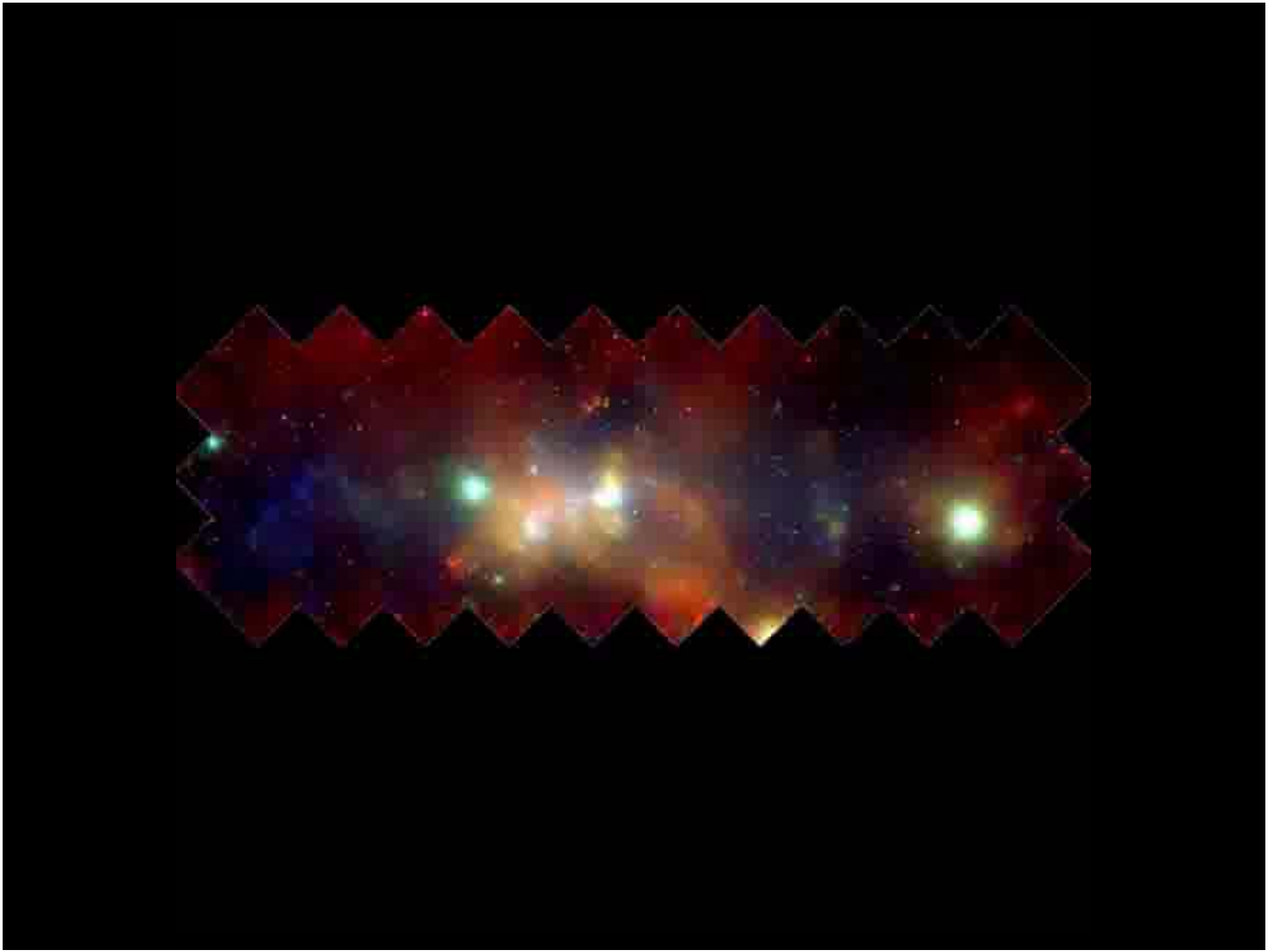
380 Arc Seconds
88,000 LIGHT-YEARS

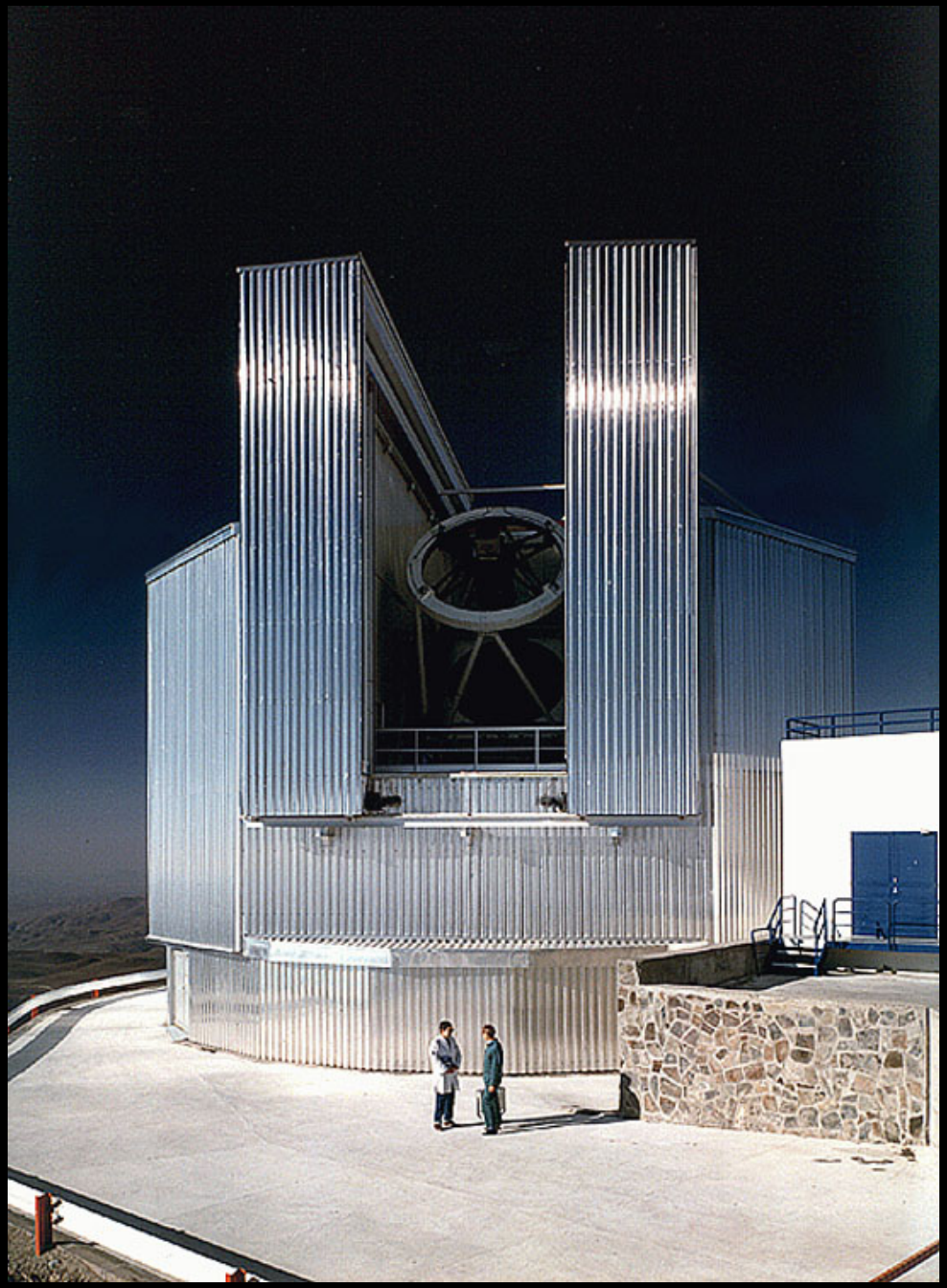
HST Image of a Gas and Dust Disk

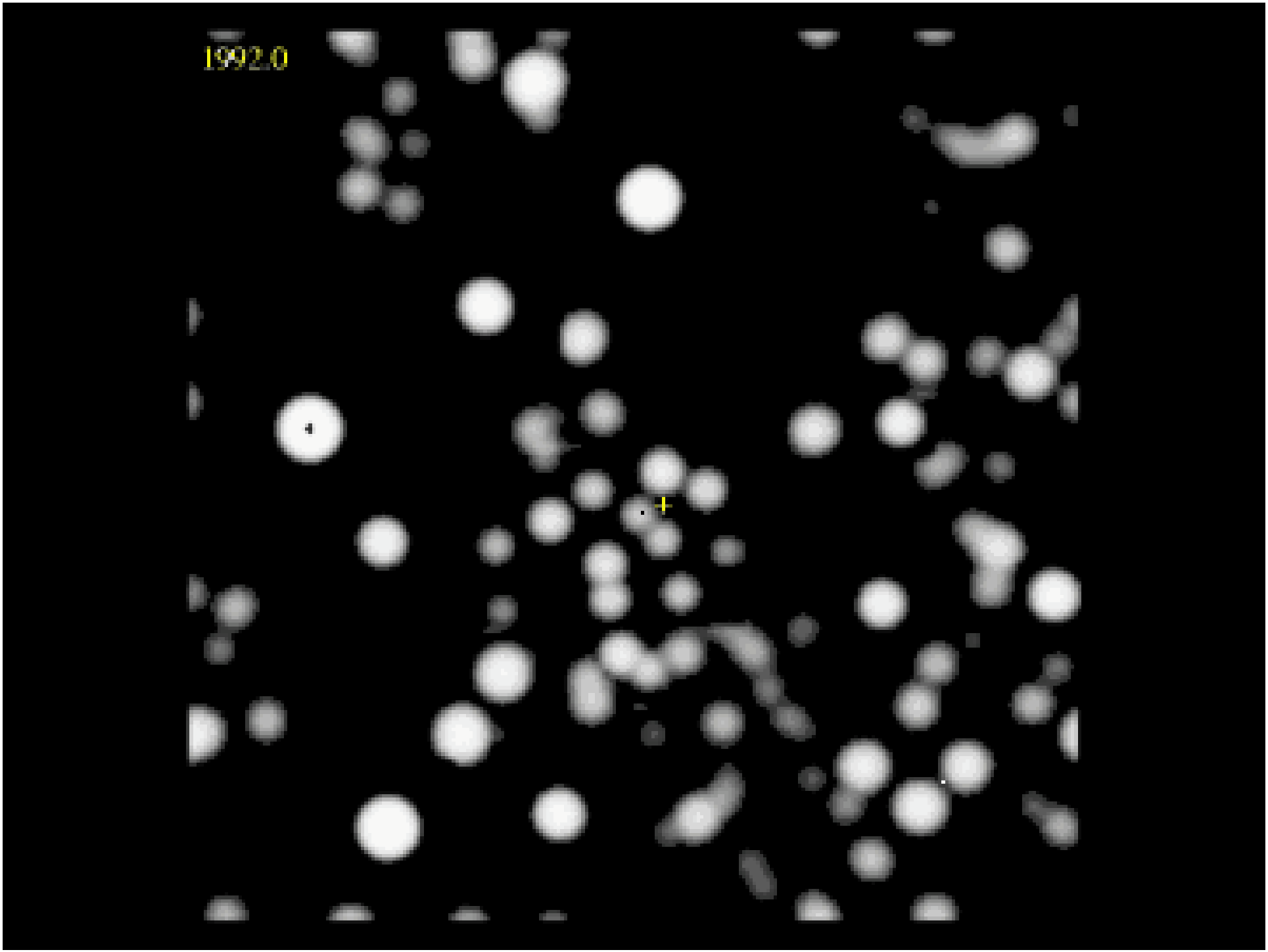


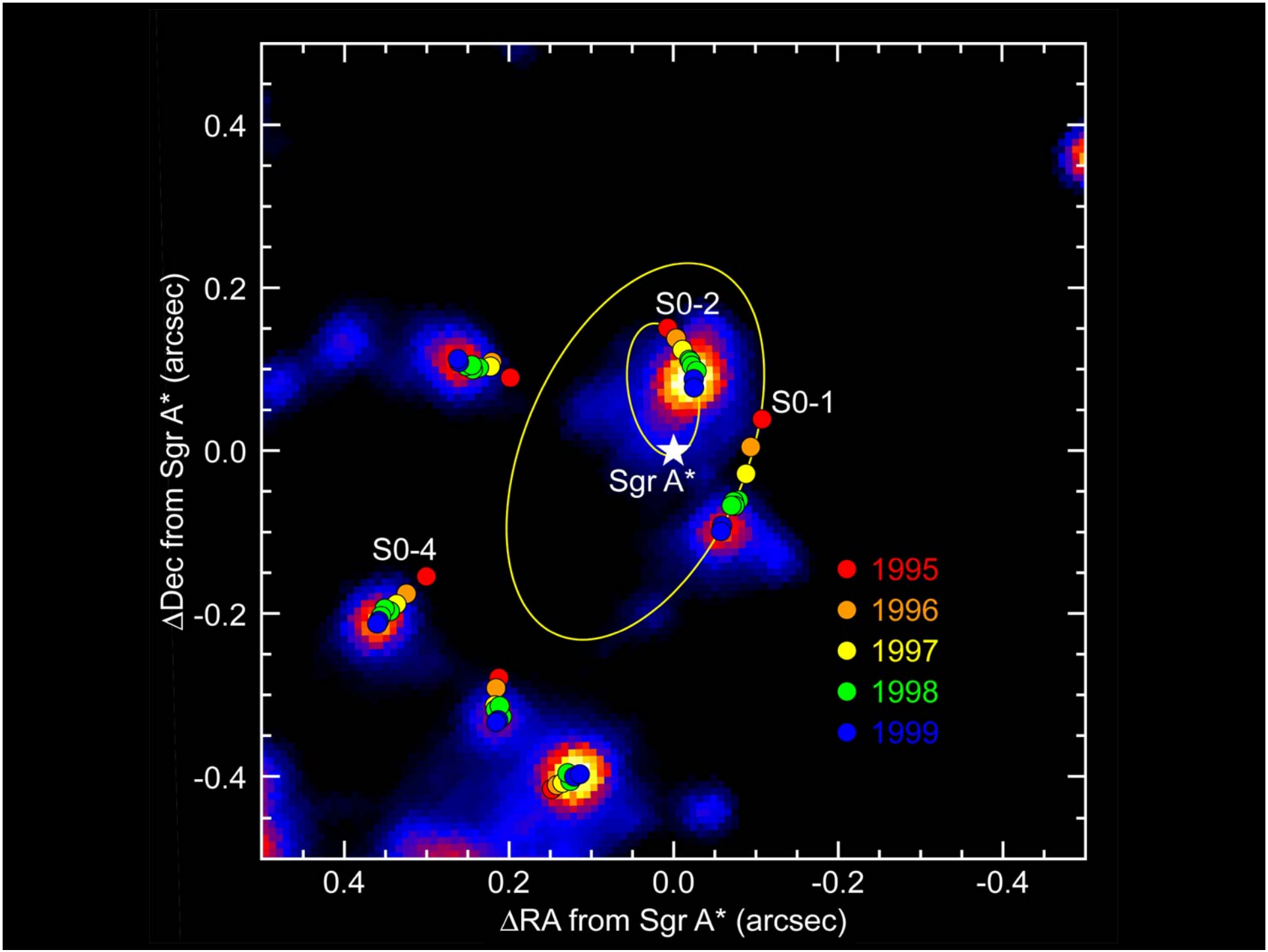
1.7 Arc Seconds
400 LIGHT-YEARS

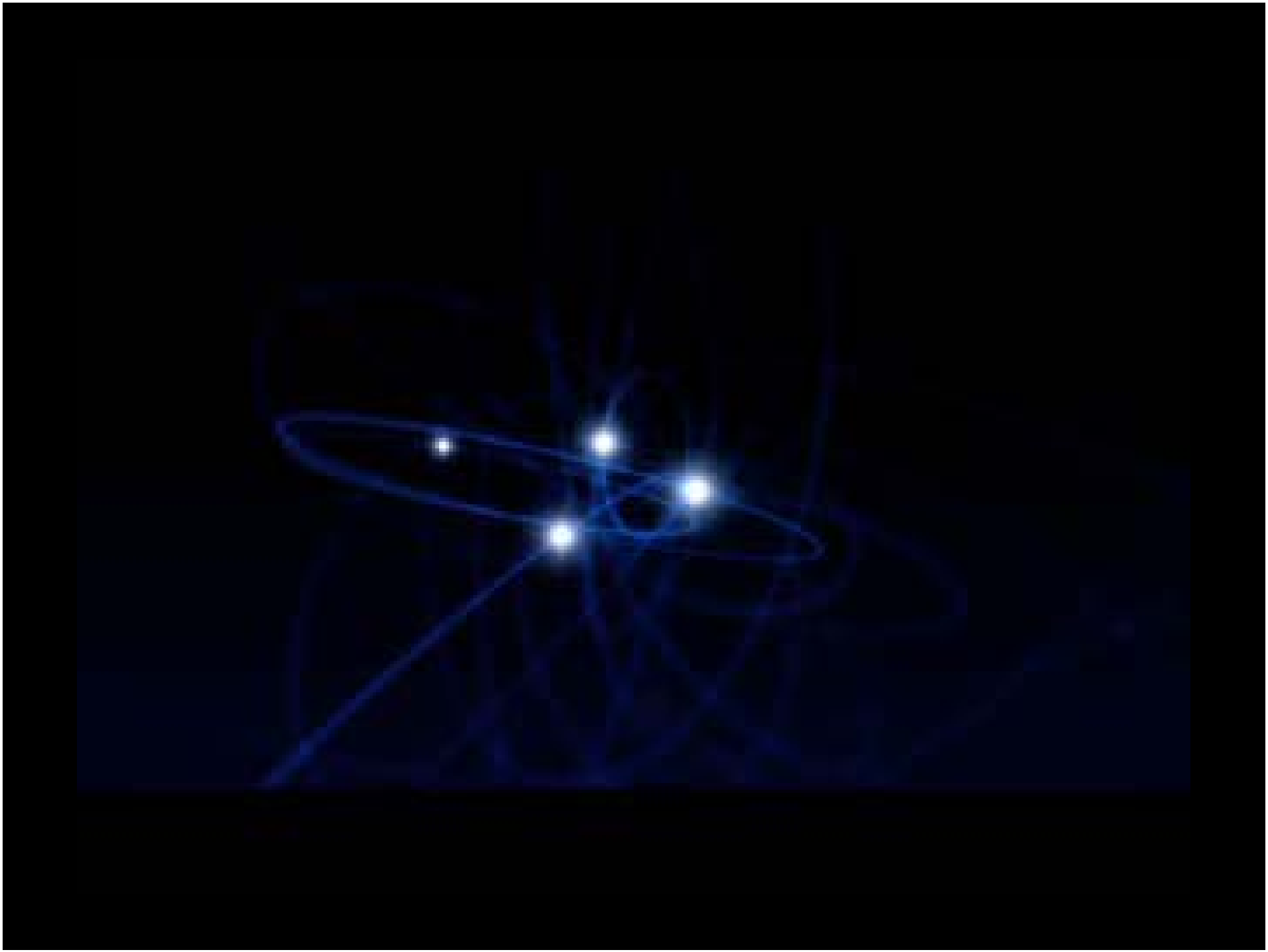

SNR 0.9+0.1
1E 1743.1-2843
X-ray Thread
1E 1740.7-2942
Sgr B1
Sgr B2
Sgr A
Sgr C

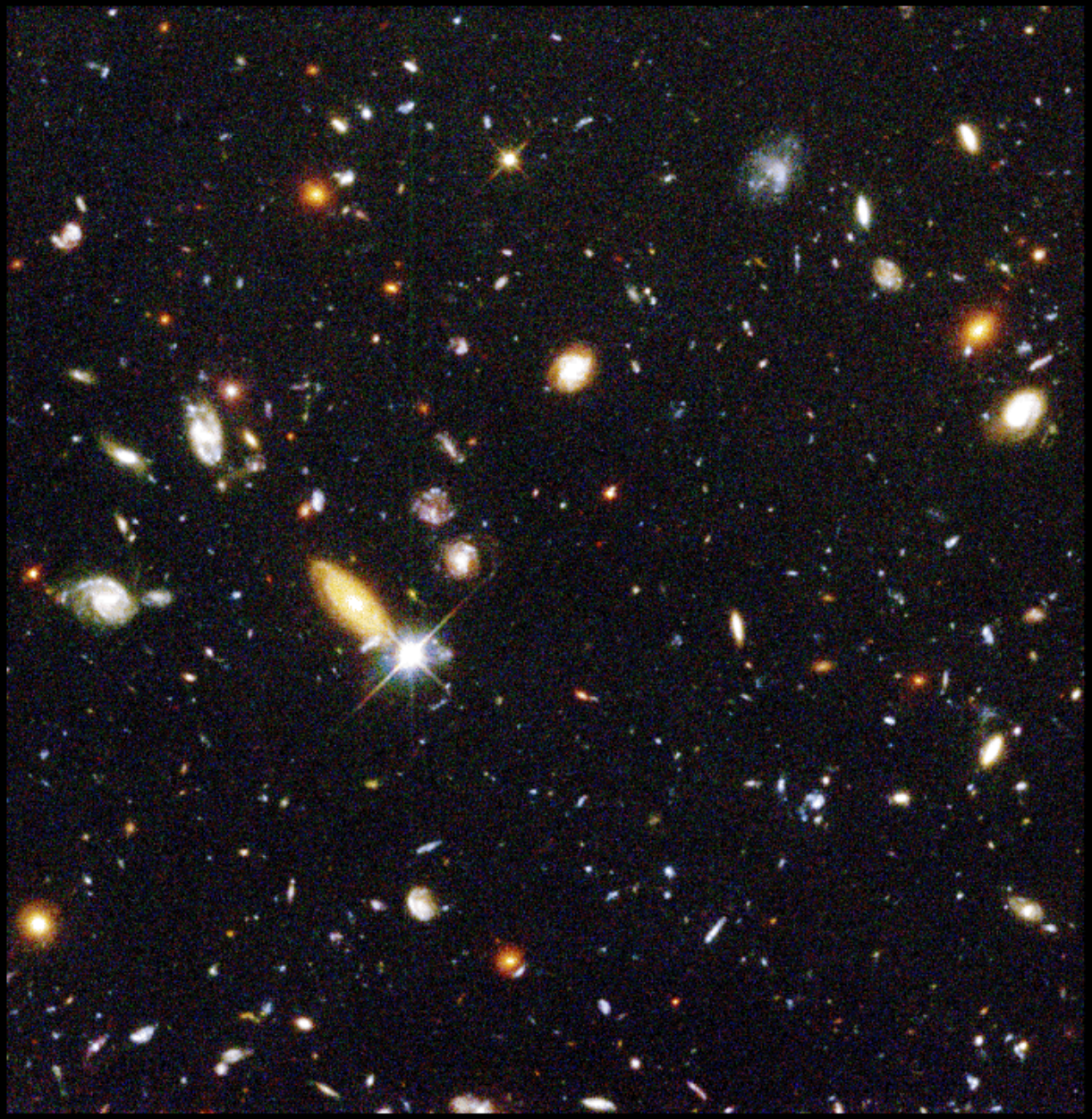





1992.0


0.4
0.2
0.0
-0.2
-0.4
ΔDec from Sgr A* (arcsec)
0.4
0.2
0.0
-0.2
-0.4
ΔRA from Sgr A* (arcsec)
S0-2
S0-1
Sgr A*
S0-4
1995
1996
1997
1998
1999

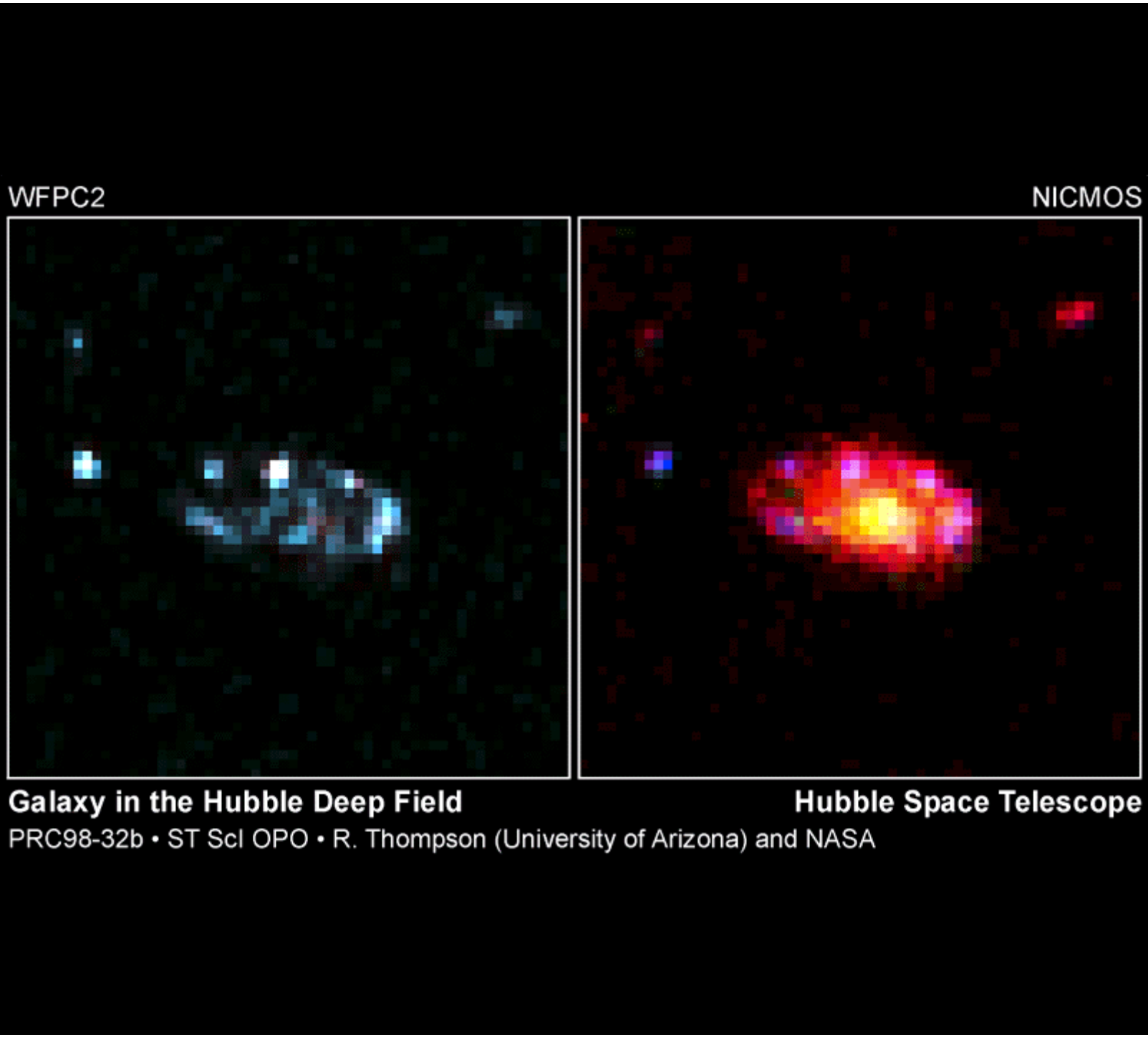


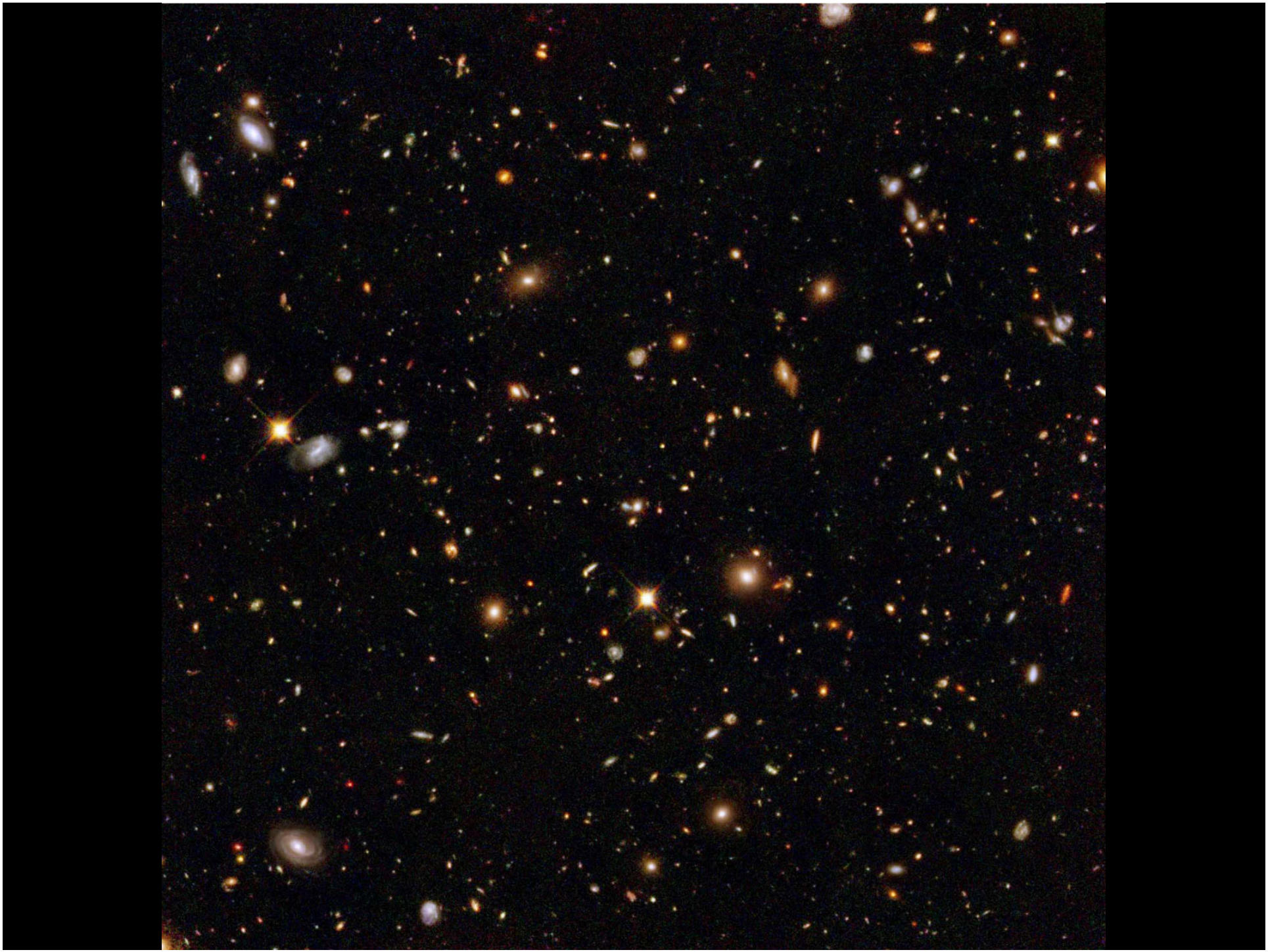


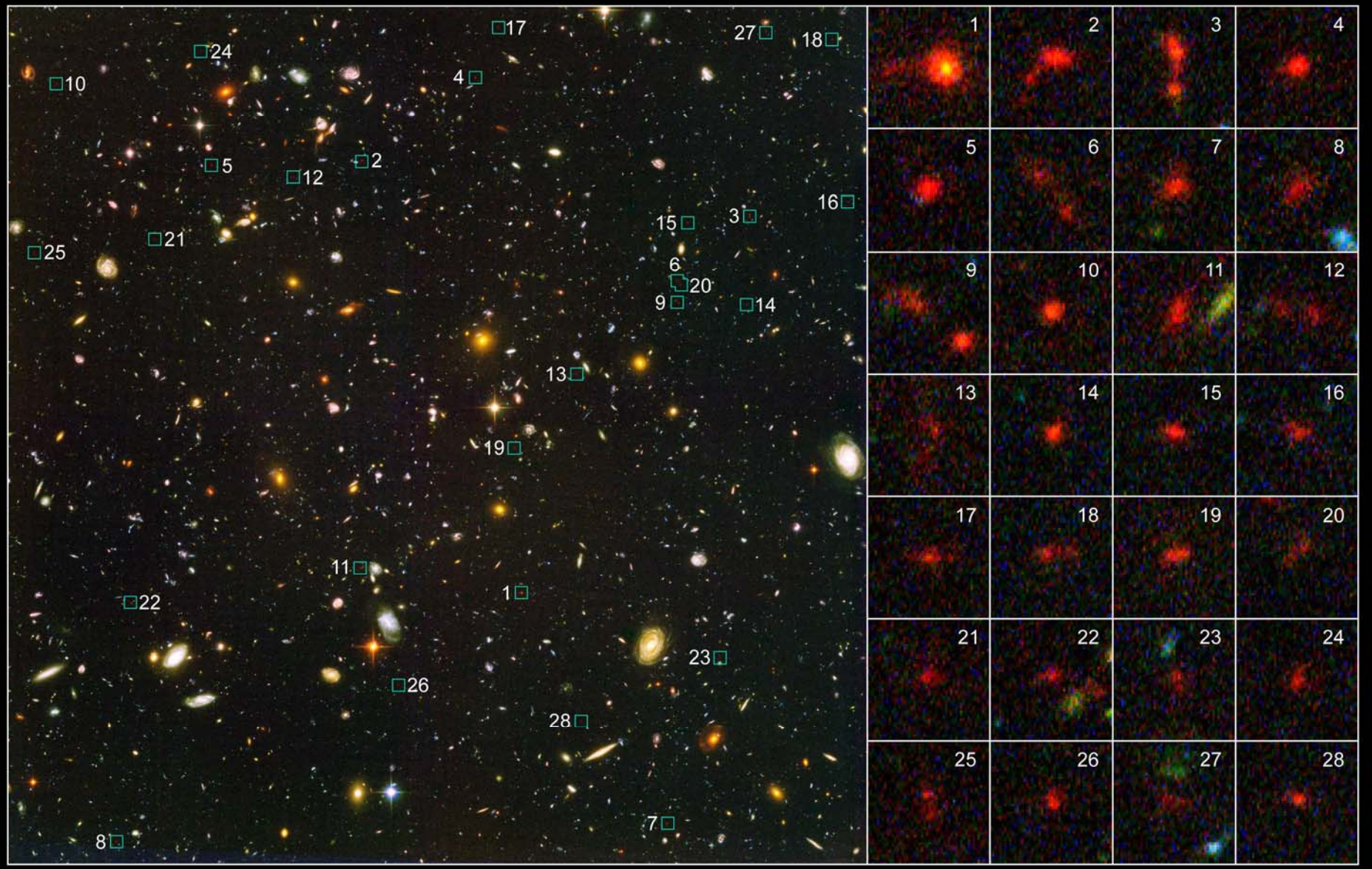
Hubble Deep Field HST • WFPC2

PRC96-01a • ST ScI OPO • January 15, 1996 • R. Williams (ST ScI), NASA


Night Sky


WFPC2
NICMOS
Galaxy in the Hubble Deep Field
Hubble Space Telescope
PRC98-32b • ST ScI OPO • R. Thompson (University of Arizona) and NASA

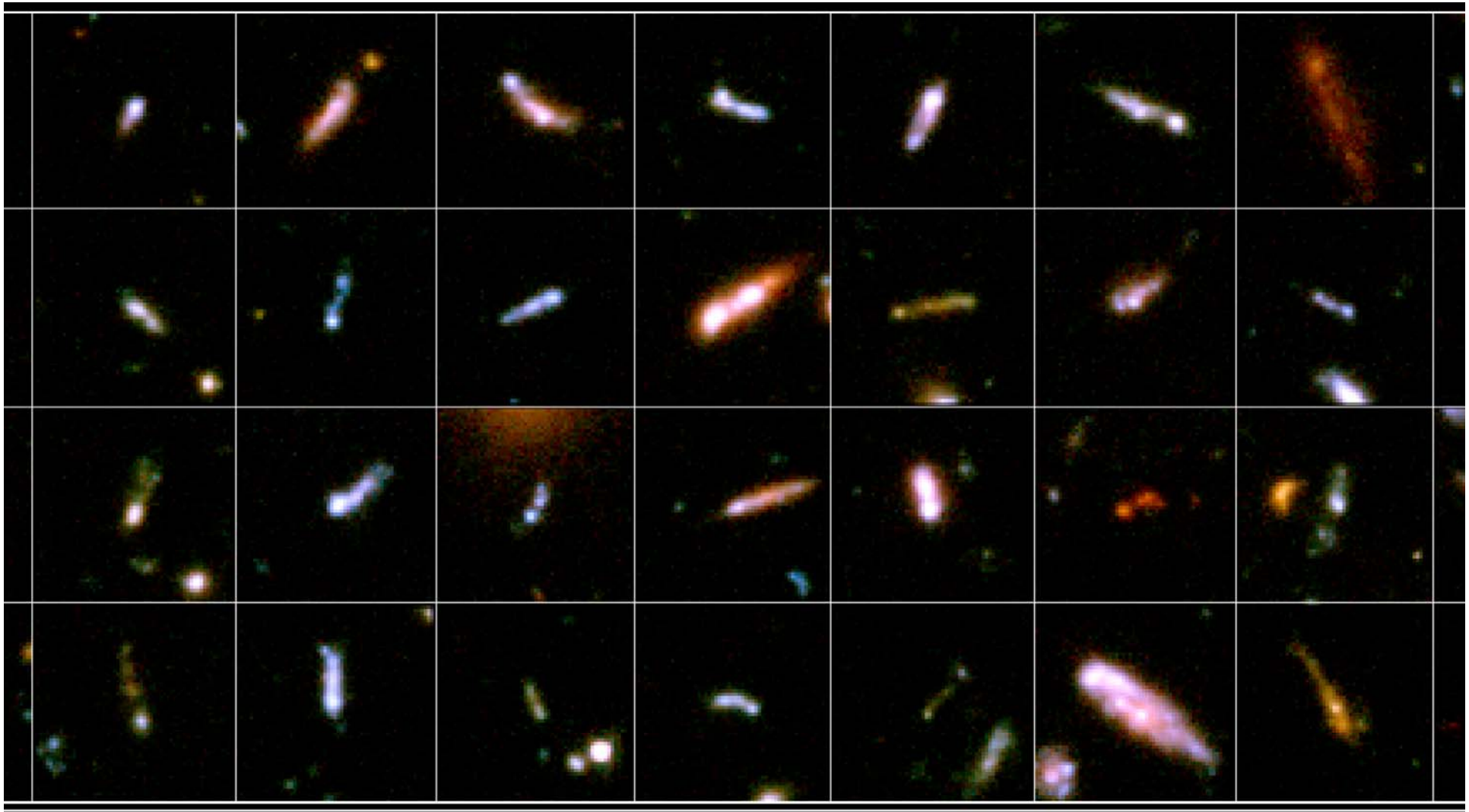




Distant Galaxies in the Hubble Ultra Deep Field

Hubble Space Telescope • Advanced Camera for Surveys

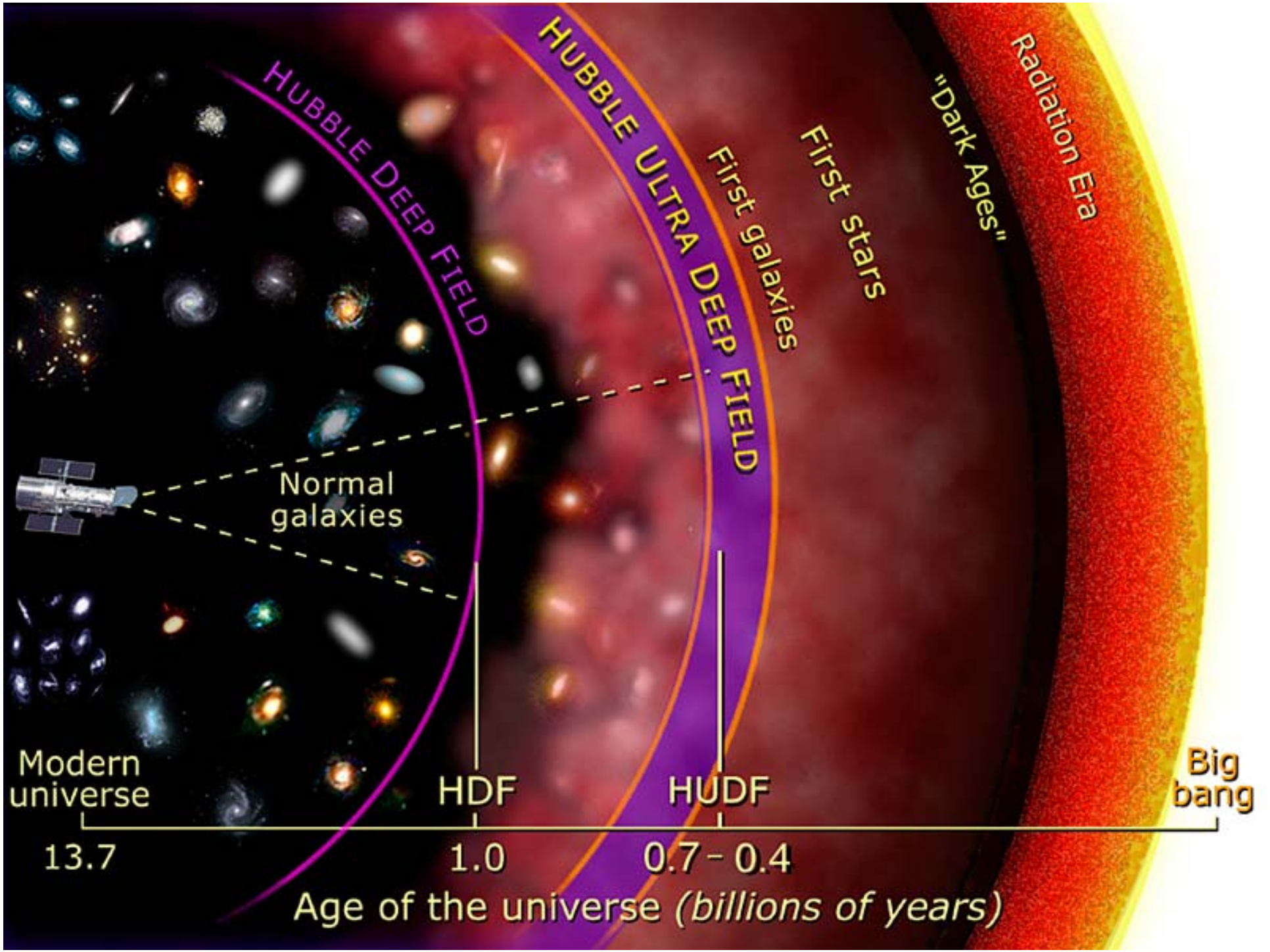
NASA, ESA, R. Bouwens and G. Illingworth (University of California, Santa Cruz)



“Tadpole” Galaxies in the Hubble Ultra Deep Field

Hubble Space Telescope ▪ ACS/WFC

A. Straughn, S. Cohen and R. Windhorst (Arizona State University), and the HUDF team (STScI)


HUBBLE DEEP FIELD
HUBBLE ULTRA DEEP FIELD
First galaxies
First stars
"Dark Ages"
Radiation Era
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 - 0.4
Age of the universe (billions of years)