El UNIVERSO

expansión acelerada

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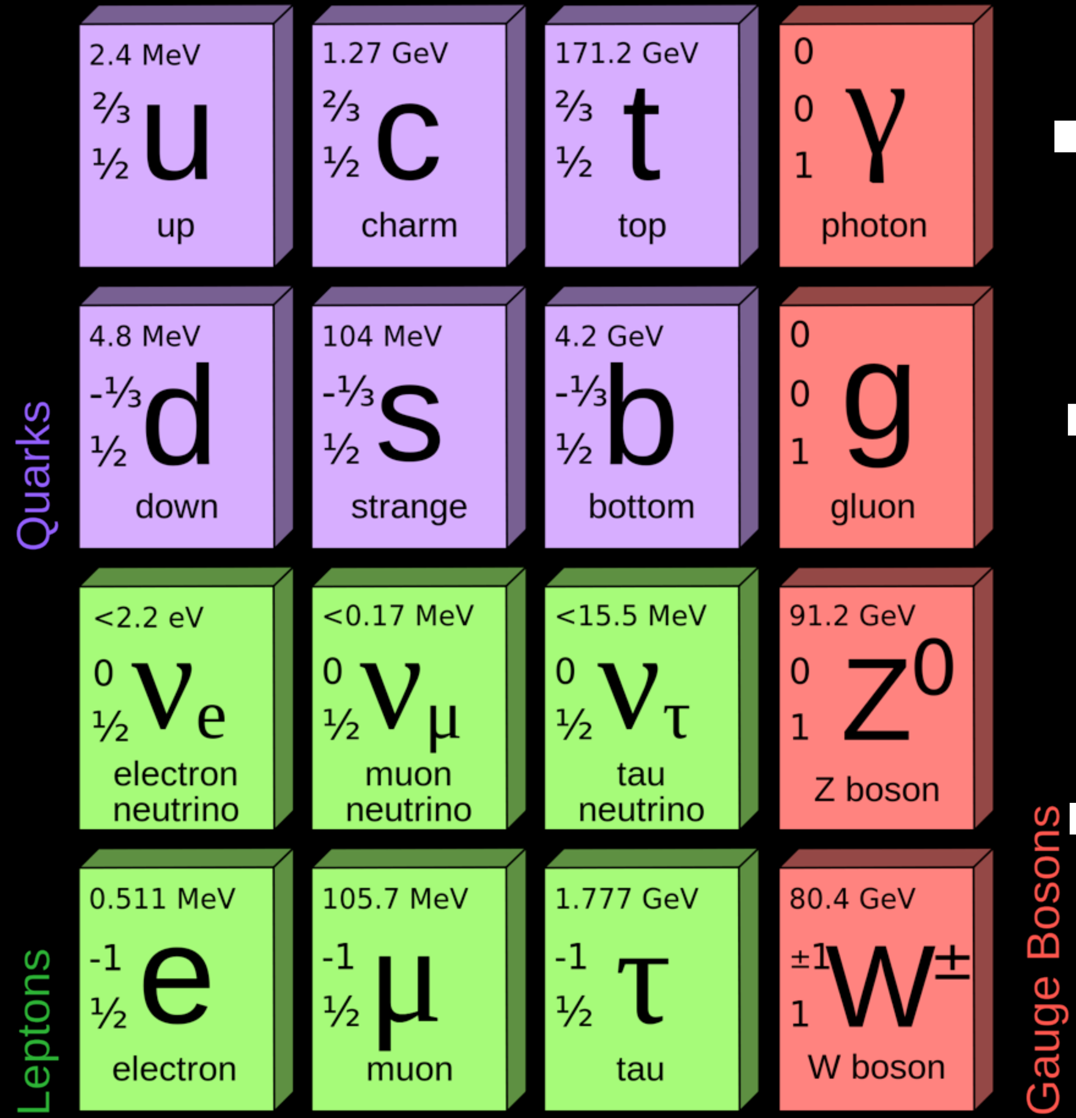
Universitat de València

FUNDACIÓN VALENCIANA DE ESTUDIOS AVANZADOS

21 de Noviembre de 2013



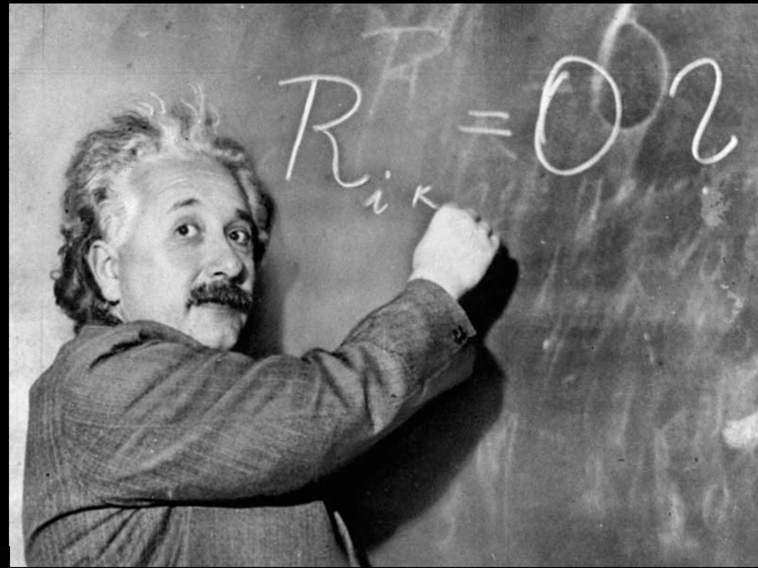
➡ **Electromagnética**

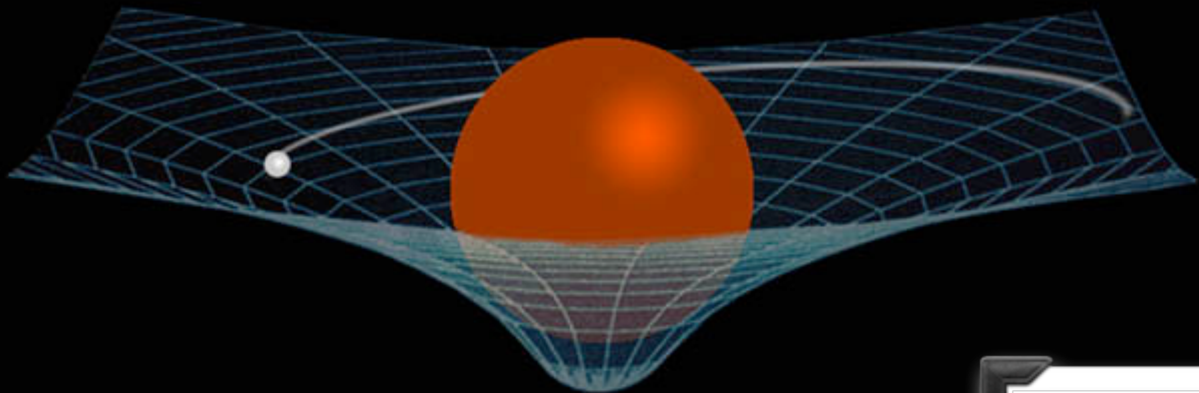
➡ **Nuclear Fuerte**

➡ **Nuclear Débil**

Fuerza Gravitatoria

RELATIVIDAD GENERAL





$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

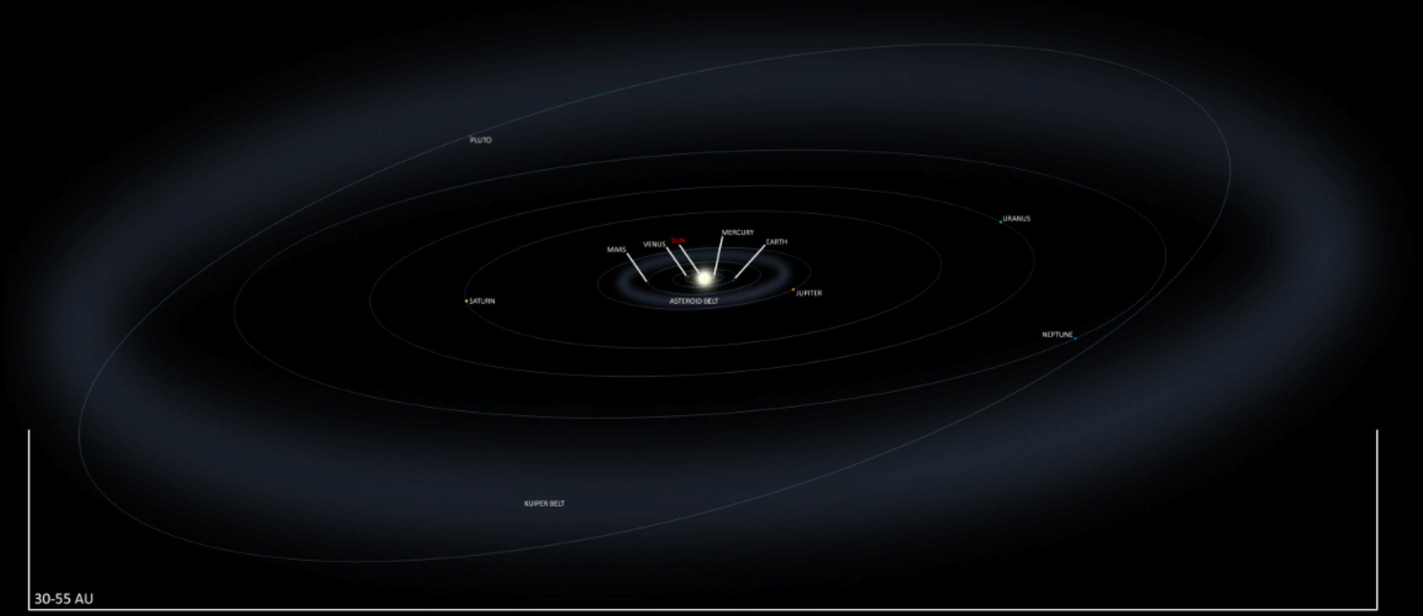
Galaxia de Andrómeda

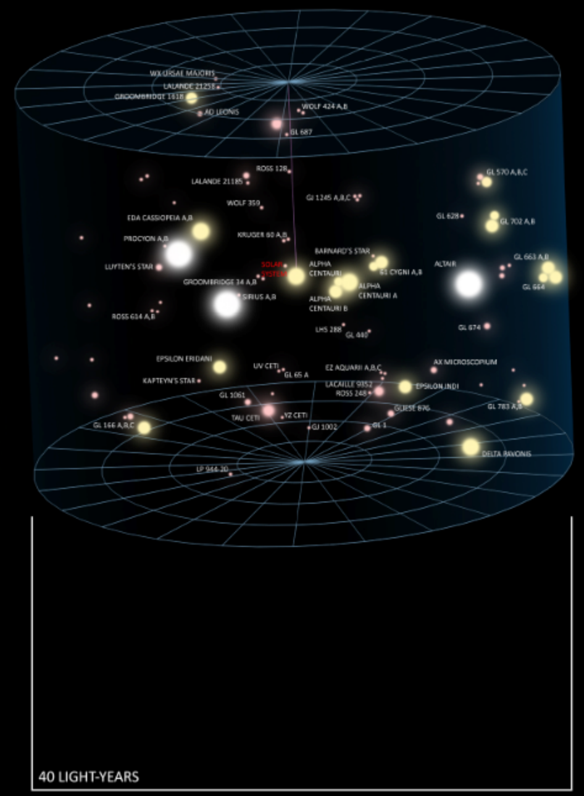
a una distancia de

2,5 millones de años luz

SUN'S NEIGHBORHOOD

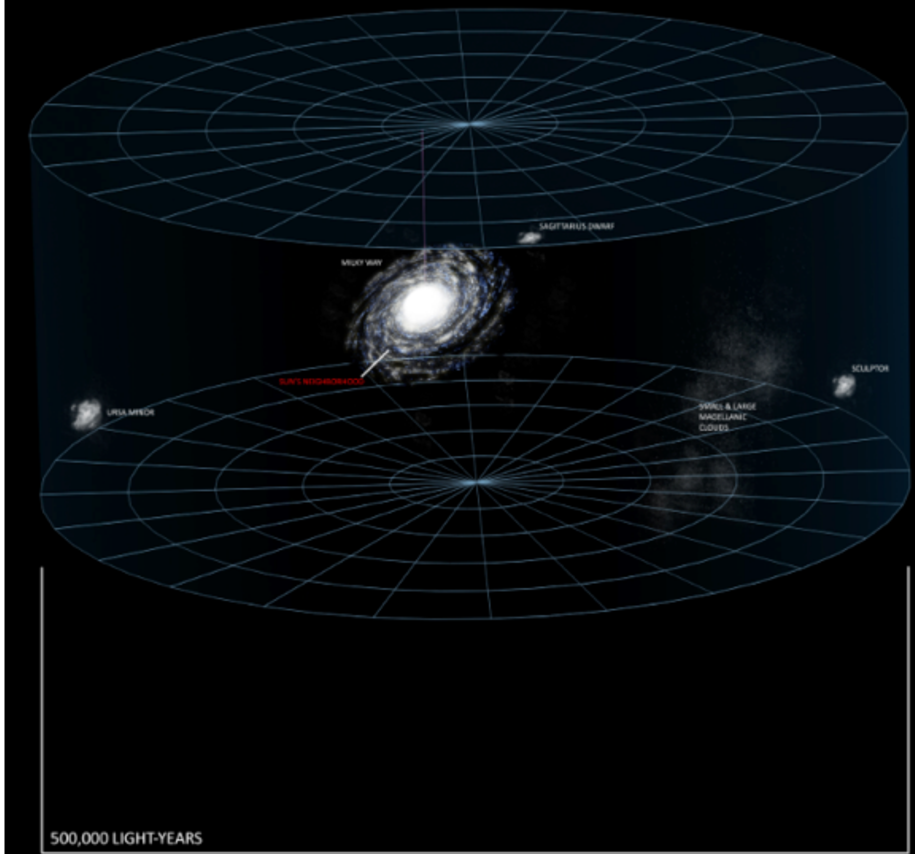
SOLAR SYSTEM

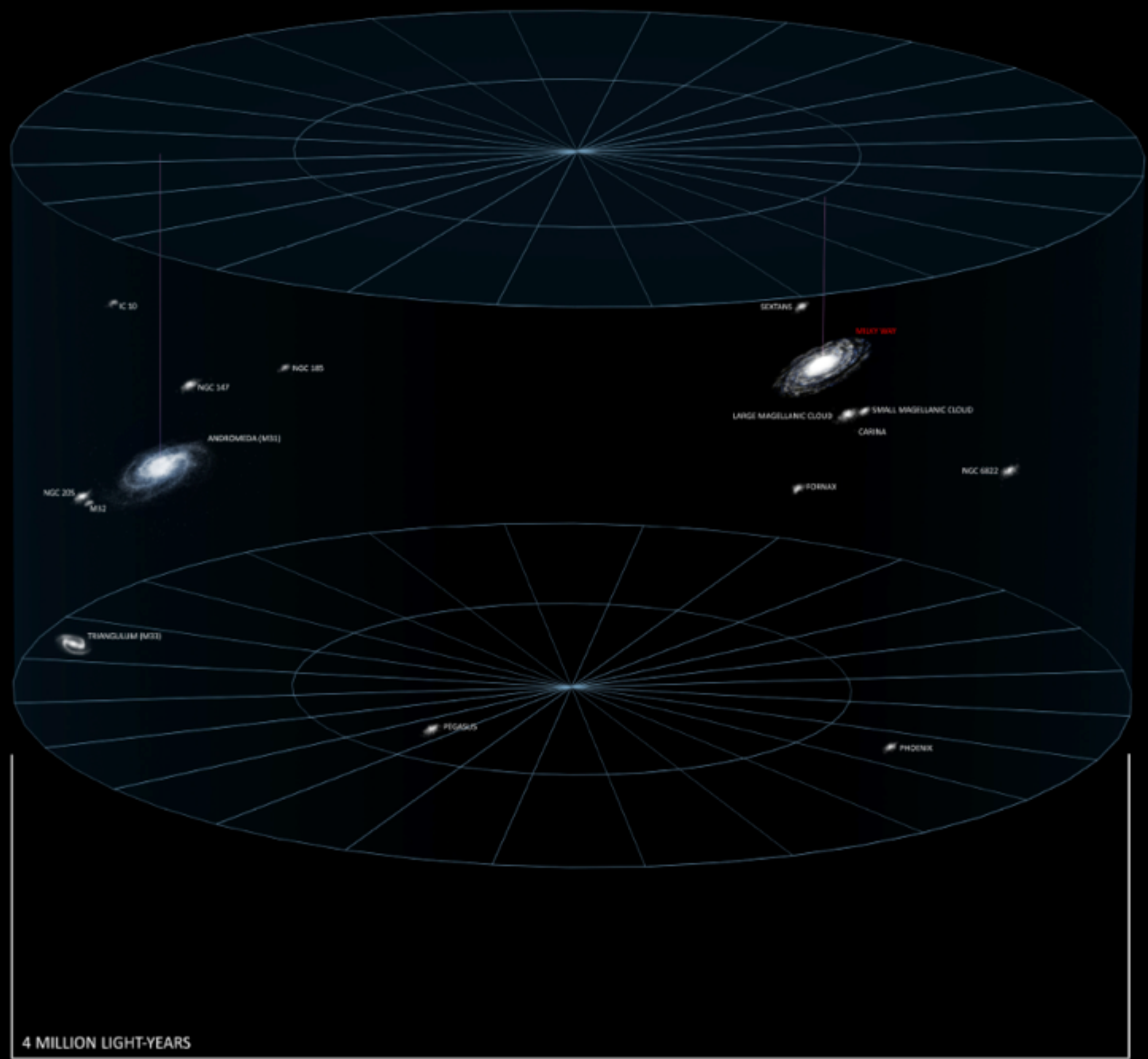




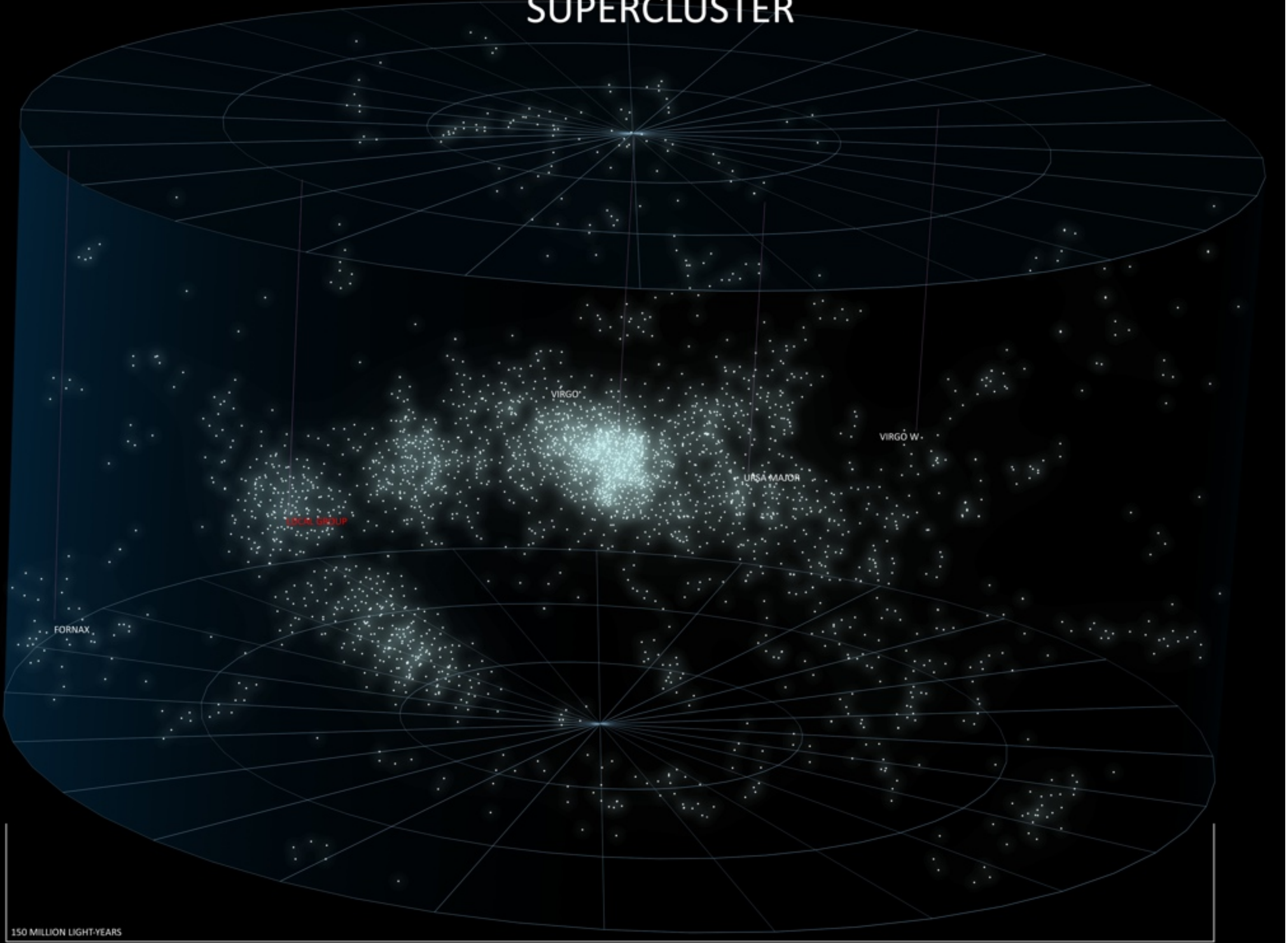
LOCAL GROUP

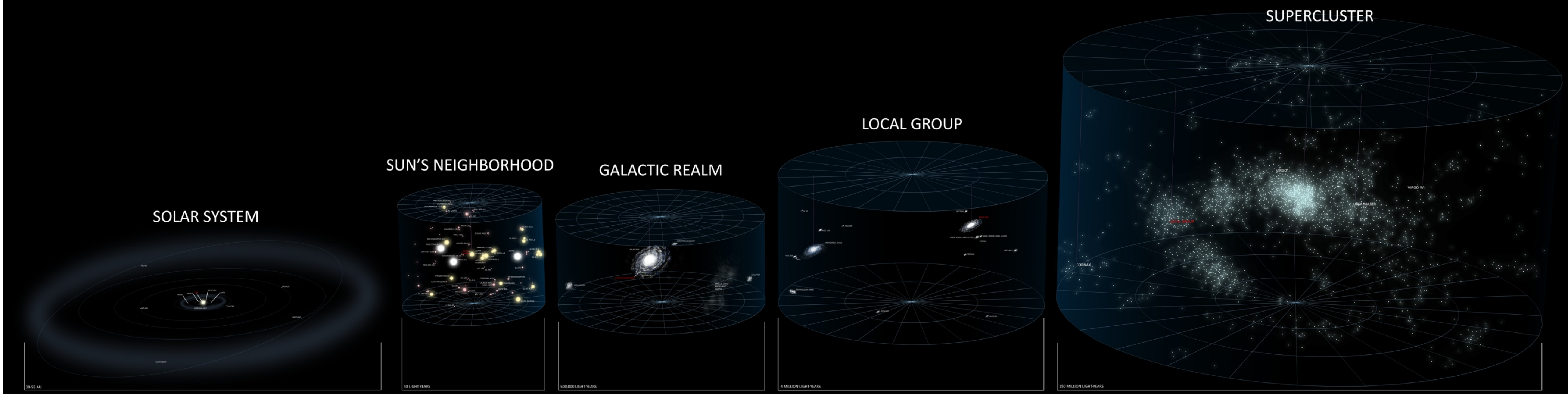
GALACTIC REALM



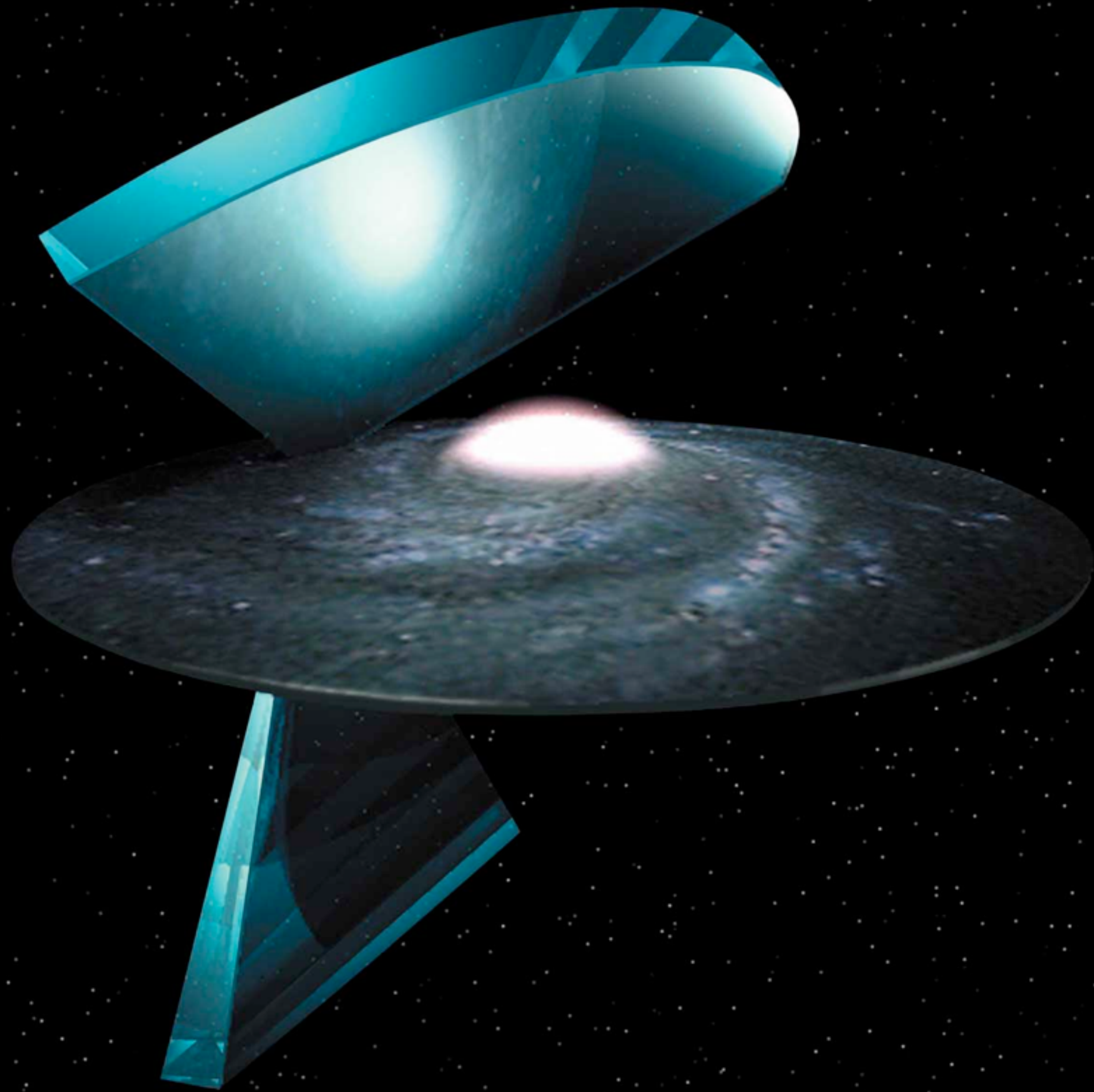


SUPERCLUSTER

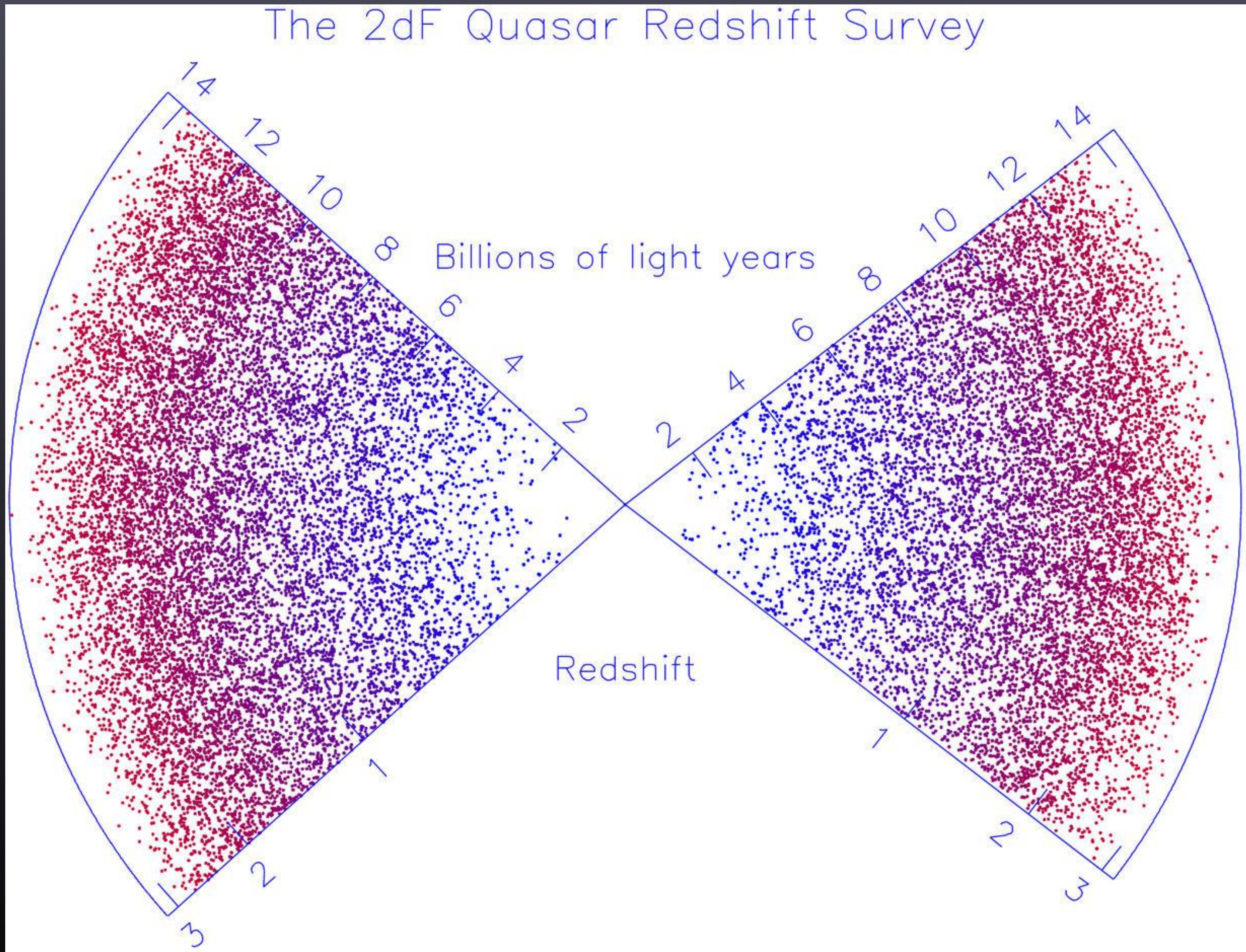



SOLAR SYSTEM
SUN'S NEIGHBORHOOD
GALACTIC REALM
LOCAL GROUP
SUPERCLUSTER
30-55 AU
40 LIGHT-YEARS
500,000 LIGHT-YEARS
4 MILLION LIGHT-YEARS
150 MILLION LIGHT-YEARS

The 2dF Galaxy Redshift Survey



Estructura a gran escala. Isotropía y Homogeneidad



Principio Cosmológico

(Homogeneidad e Isotropía)

↓

Métrica de Robertson-Walker

$$ds^2 = -dt^2 + a(t)^2 \left(\frac{dr^2}{1 - k\,r^2} + r^2\,d\theta^2 + r^2 \sin^2\theta\,d\phi^2 \right)$$

Ecuaciones de Friedmann

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - k\frac{c^2}{a^2}$$

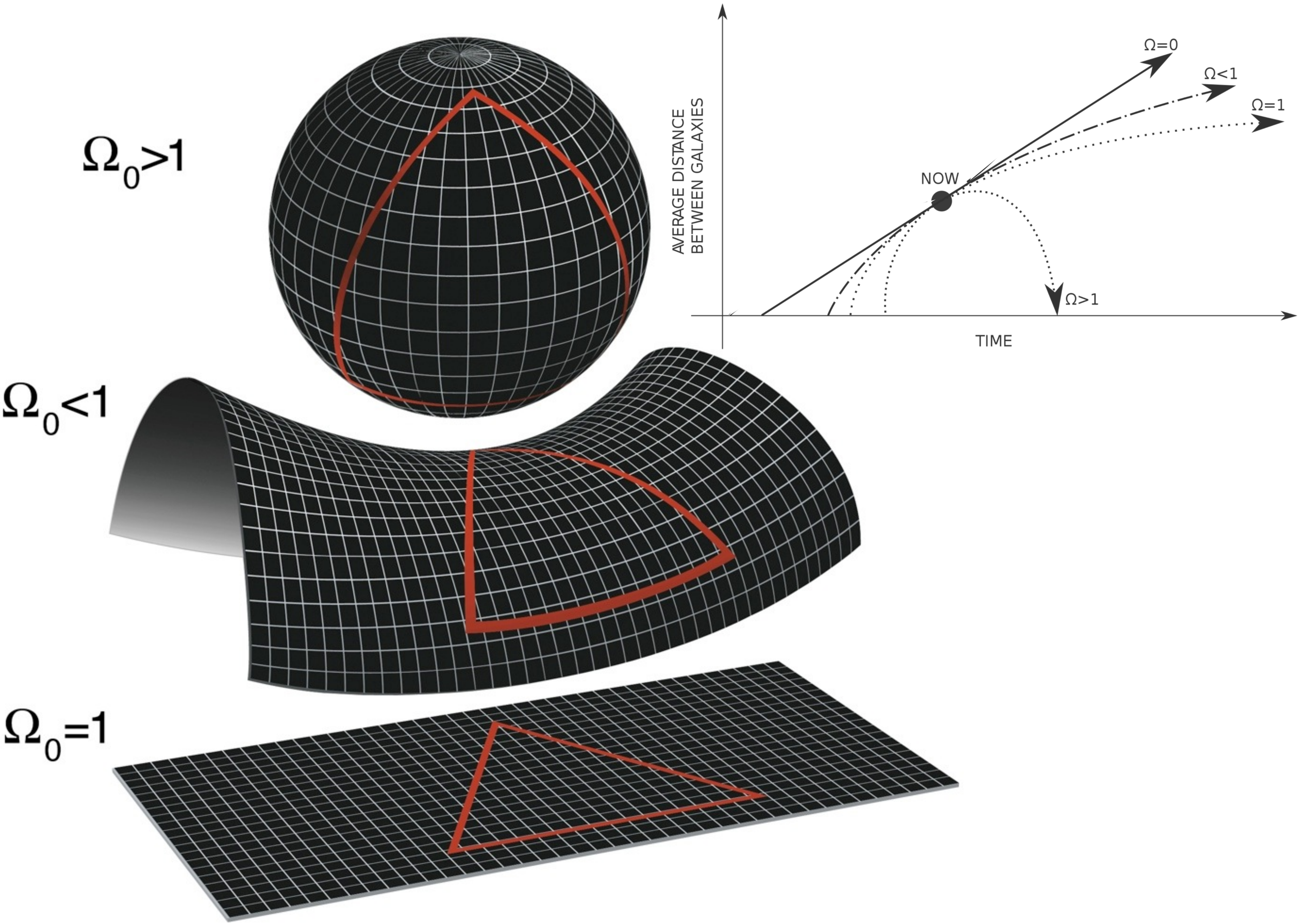
$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\rho$$

Parámetro de densidad

$$\Omega = \frac{\rho}{\rho_c} = \frac{8\pi G\rho}{3H^2}$$

Parámetro de deceleración

$$q = -\frac{\ddot{a}a}{\dot{a}^2} \qquad \left(q_0 = \frac{\Omega_0}{2}\right)$$



$\Omega_0>1$
$\Omega_0<1$
$\Omega_0=1$
AVERAGE DISTANCE
BETWEEN GALAXIES
TIME
NOW
Ω=0
Ω<1
Ω=1
Ω>1

Consecuencias

- ✓ <u>Universo en expansión</u>
- ✓ <u>Radiación de fondo de microondas</u>
- ✓ <u>Nucleosíntesis</u>

A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

BY EDWIN HUBBLE

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON

Communicated January 17, 1929

Ley de Hubble

$$v = H_0\, d$$

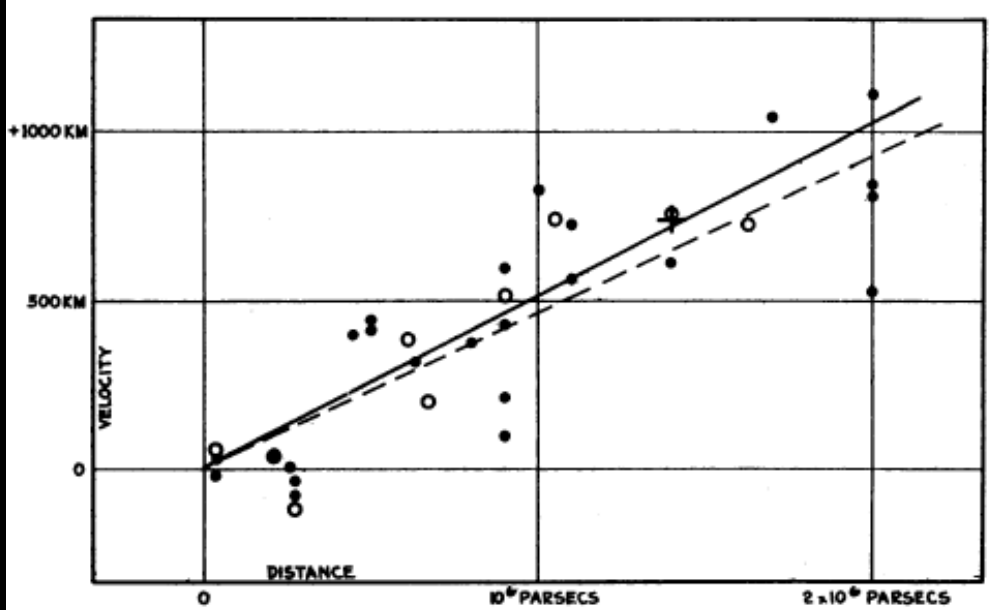
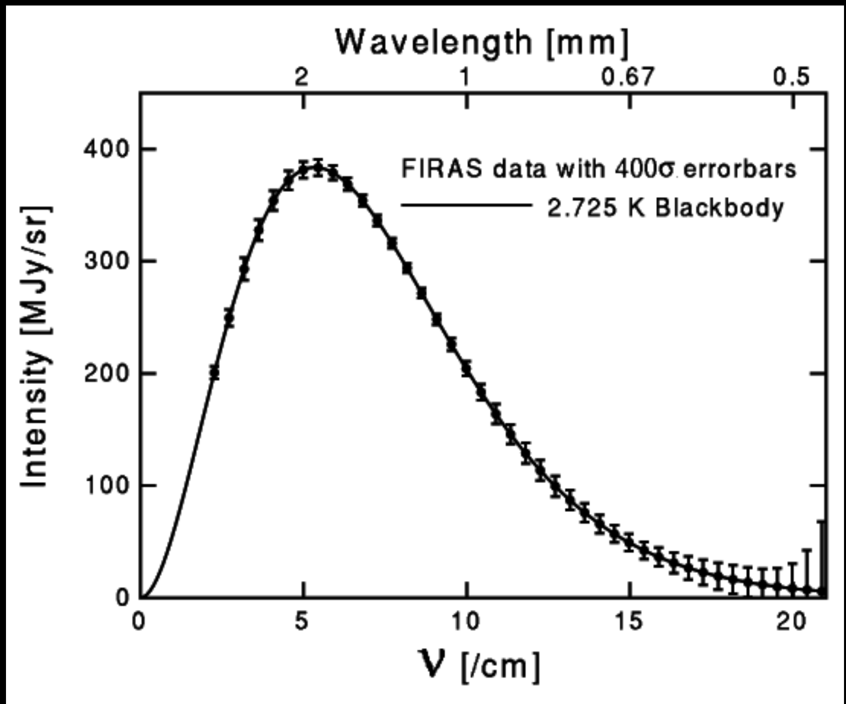


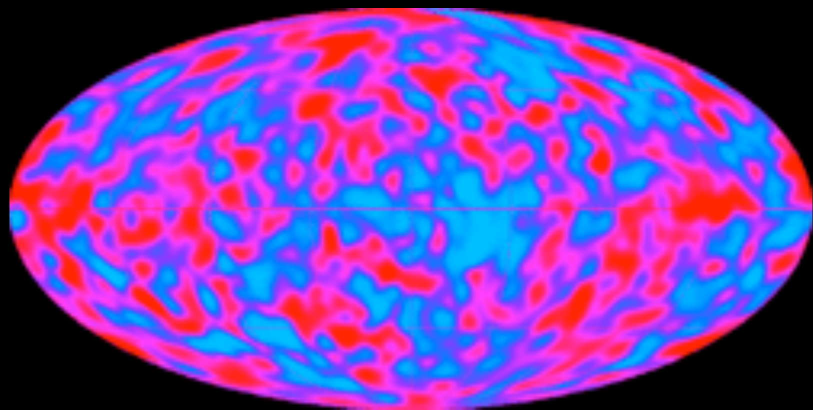
FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

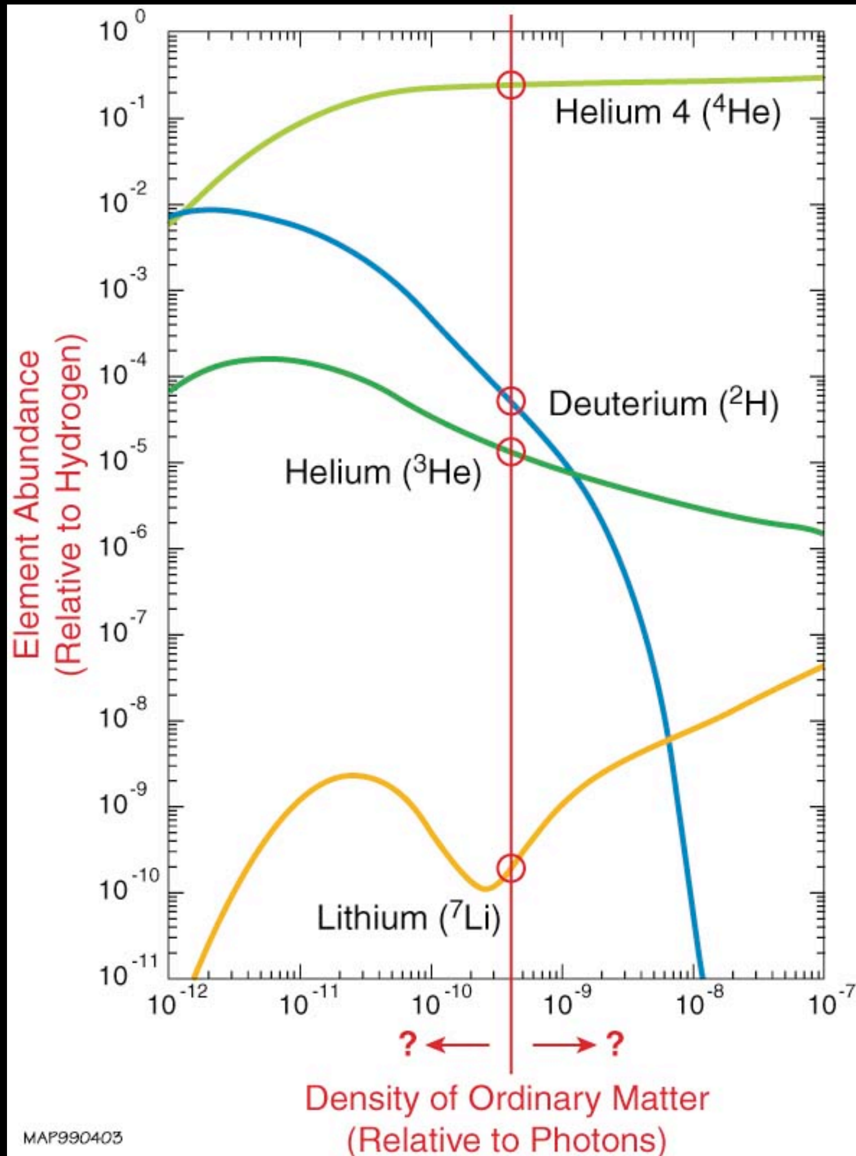
Arno Penzias y Robert W. Wilson descubrieron "accidentalmente" la radiación de fondo en 1965. (Premio Nobel de Física en 1978)

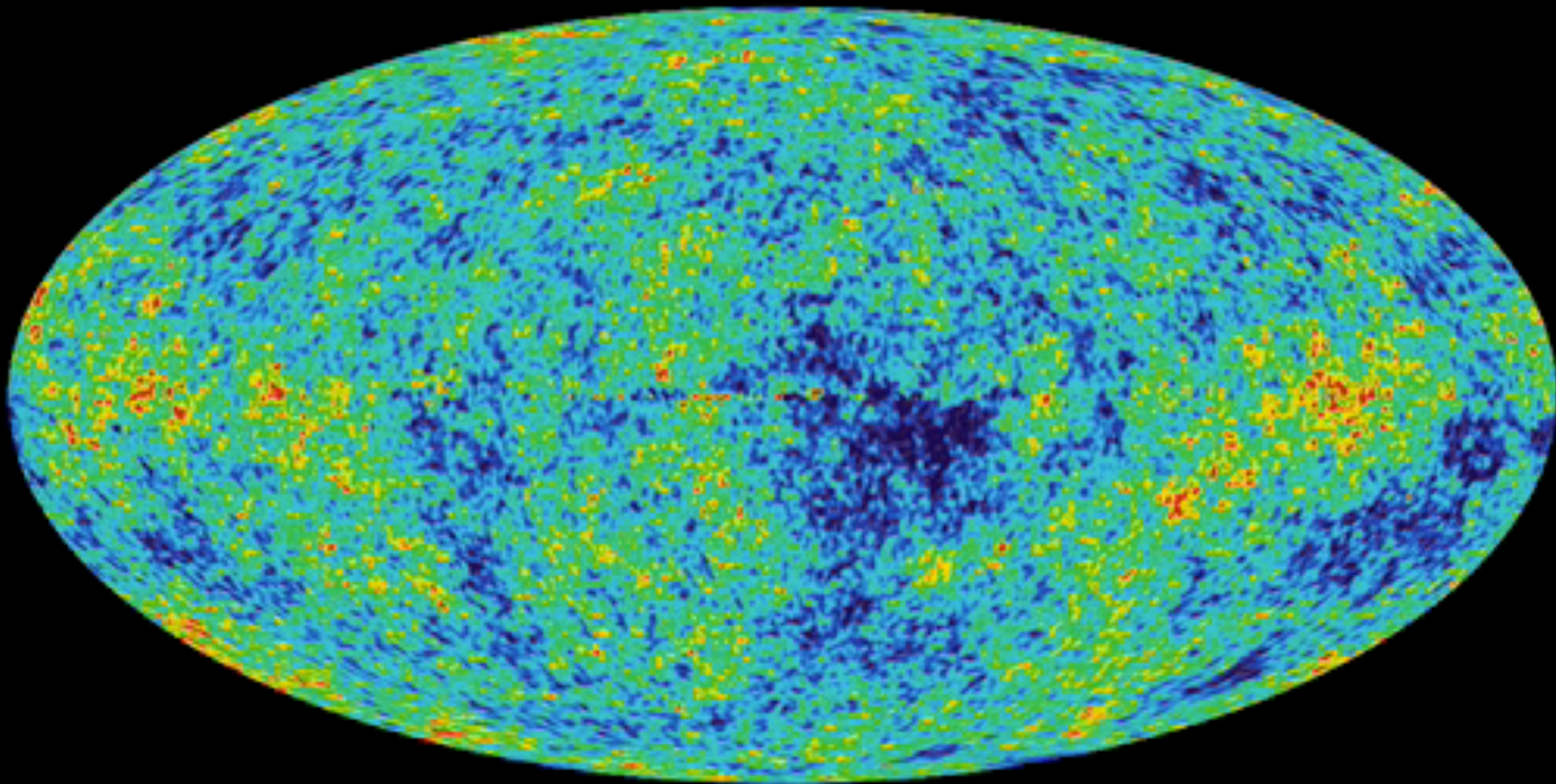


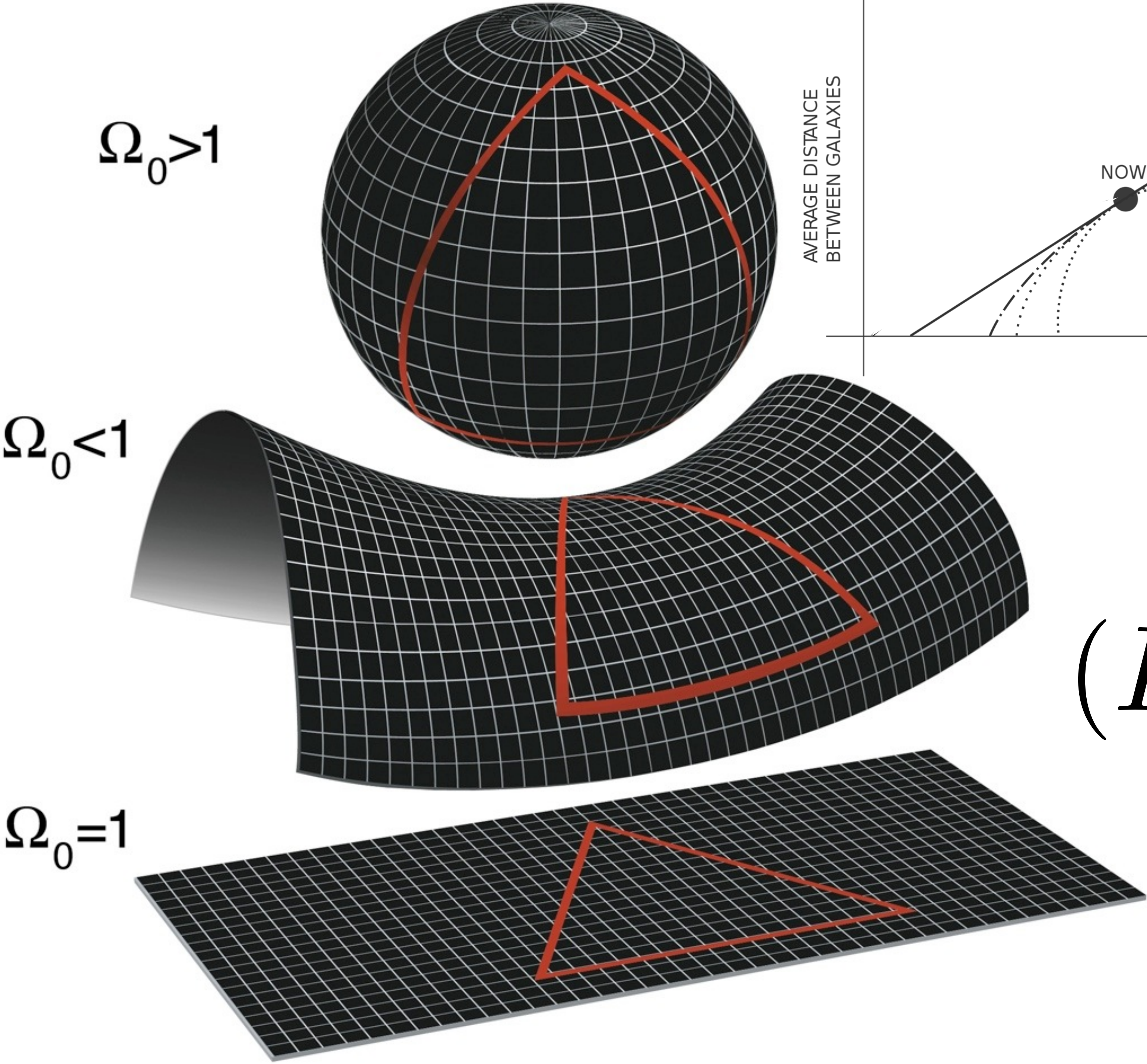
Proyecto COBE (1990's).
John C. Mather y George F. Smoot.
(Premio Nobel de Física en 2006)

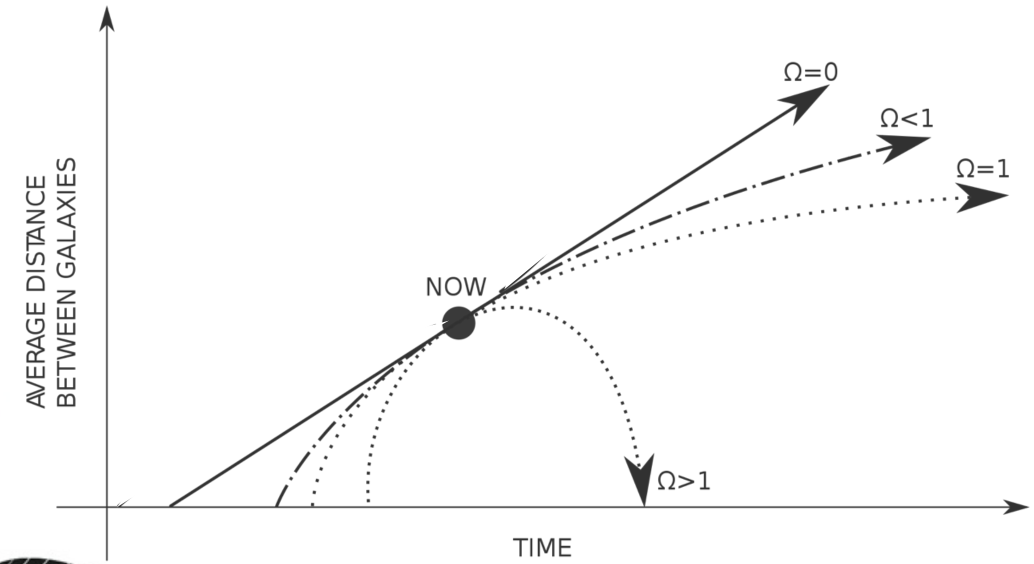


Nucleosíntesis



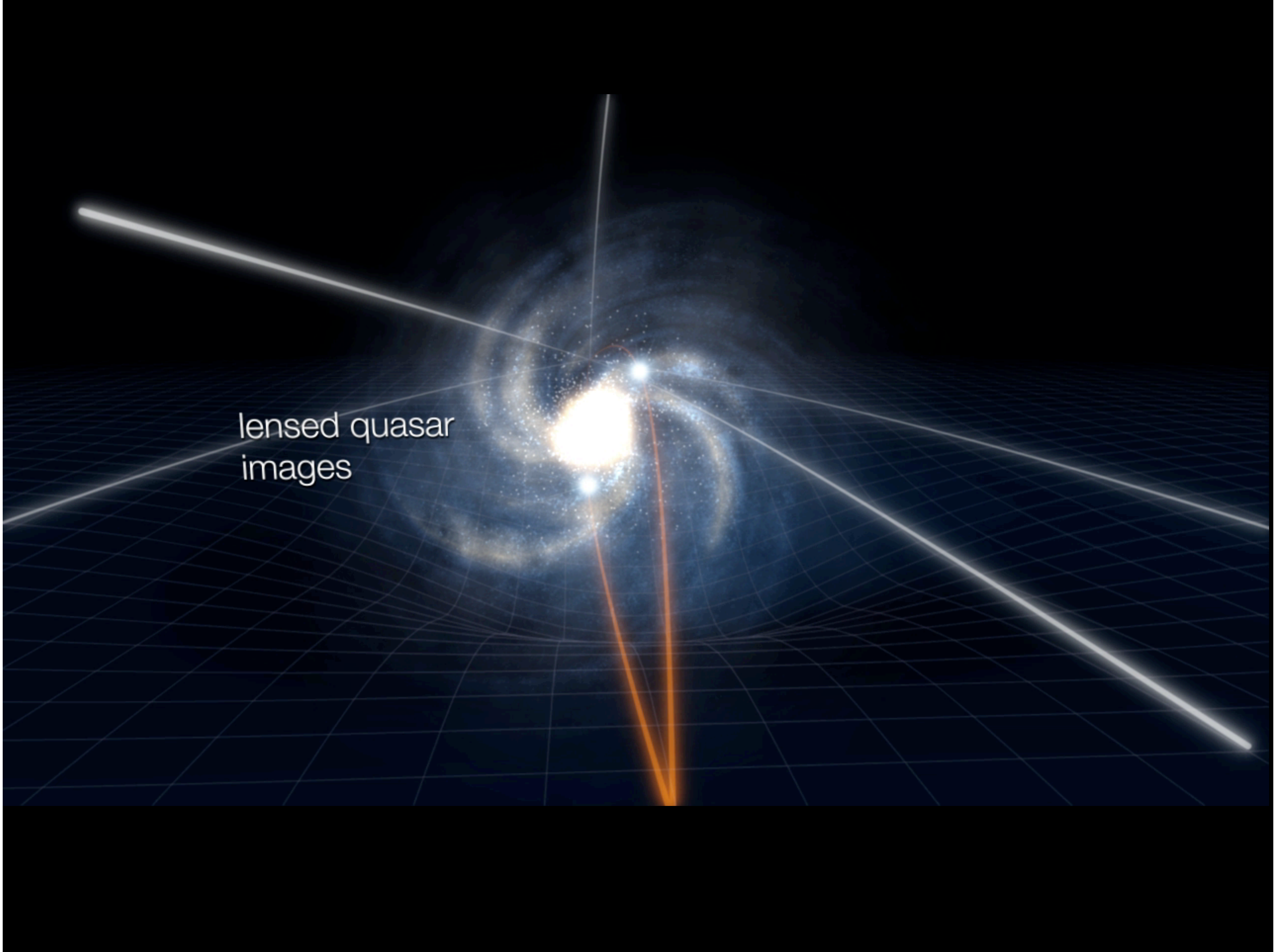



Ω0>1
Ω0<1
Ω0=1

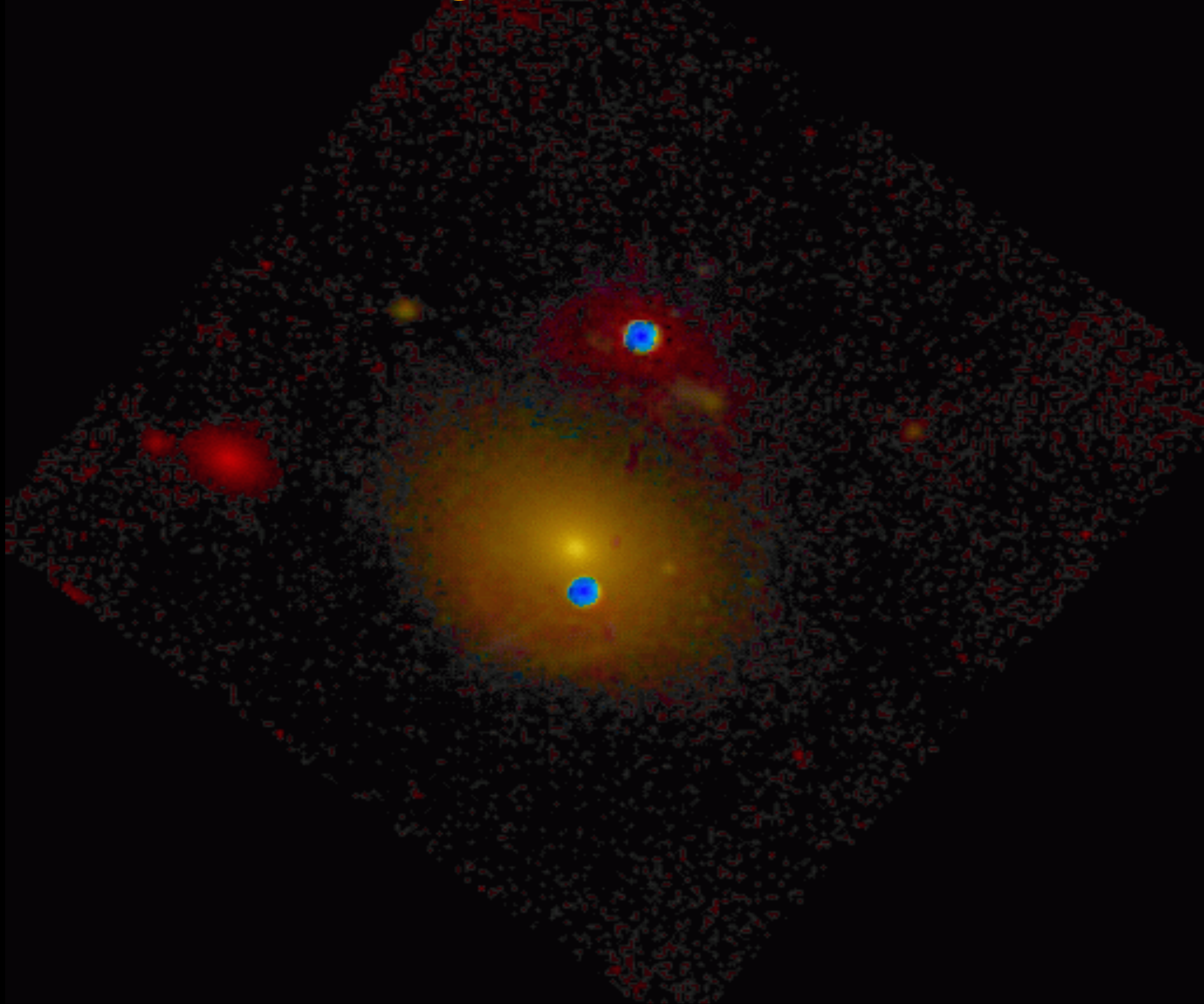

AVERAGE DISTANCE
BETWEEN GALAXIES
TIME
NOW
Ω=0
Ω<1
Ω=1
Ω>1

$$(H_0, \Omega_0)$$

The Sagittarius Dwarf Tidal Stream

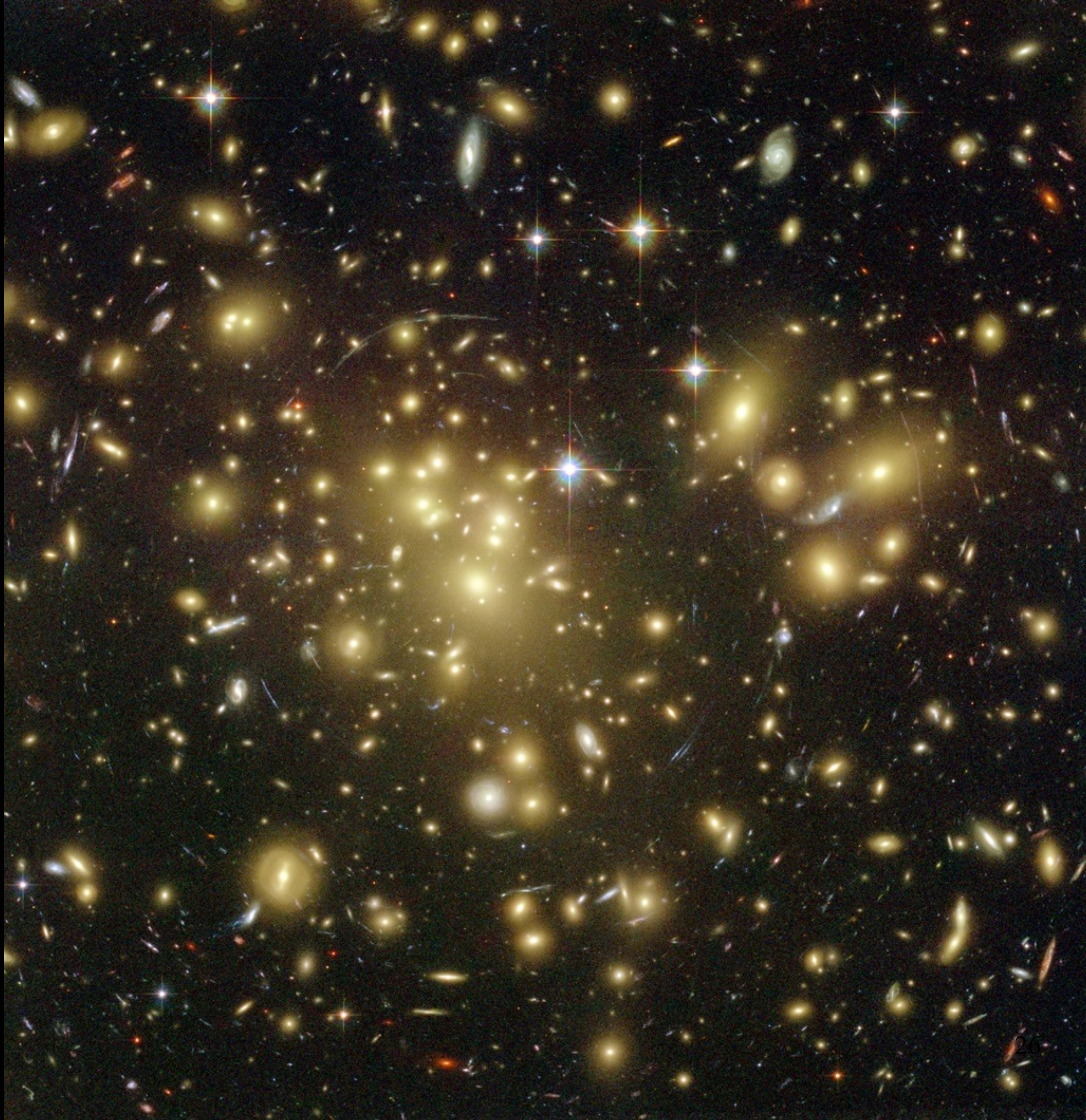

lensed quasar
images

Q0957+561

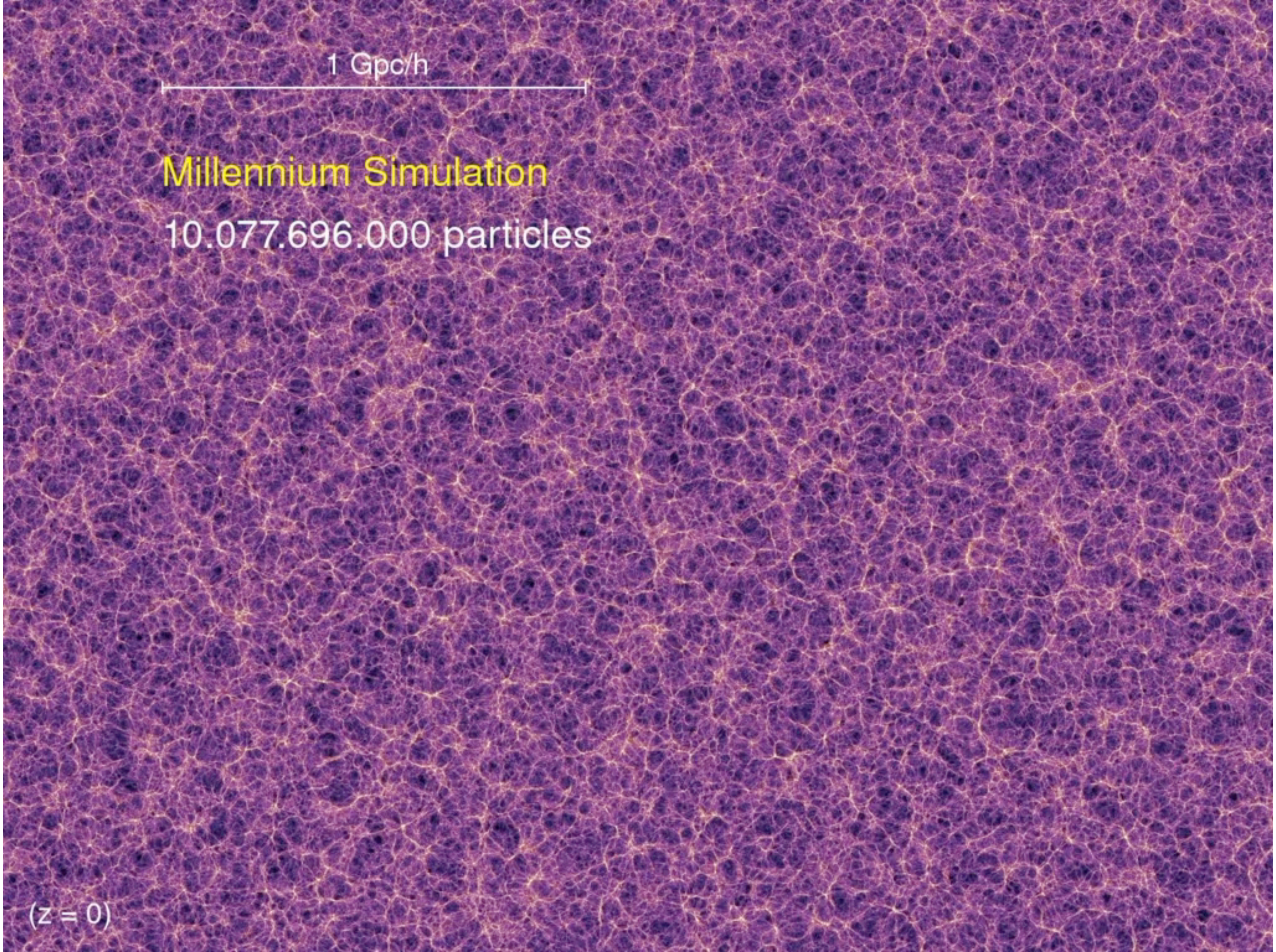


Gravitational Lens in Abell 2218 HST · WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA



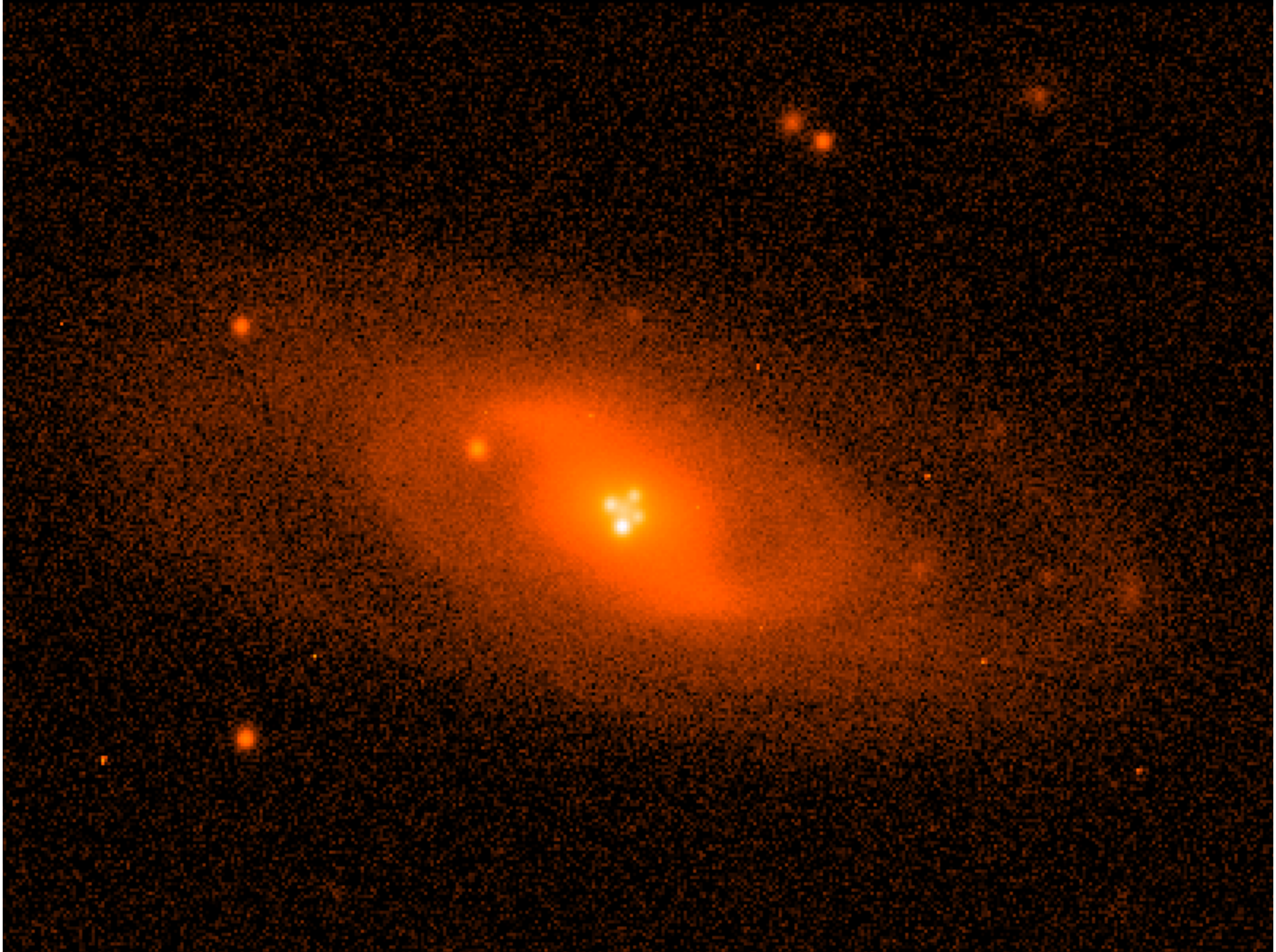
Abell 1689


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

MACHOs vs. WIMPs

Massive Compact
Halo Object

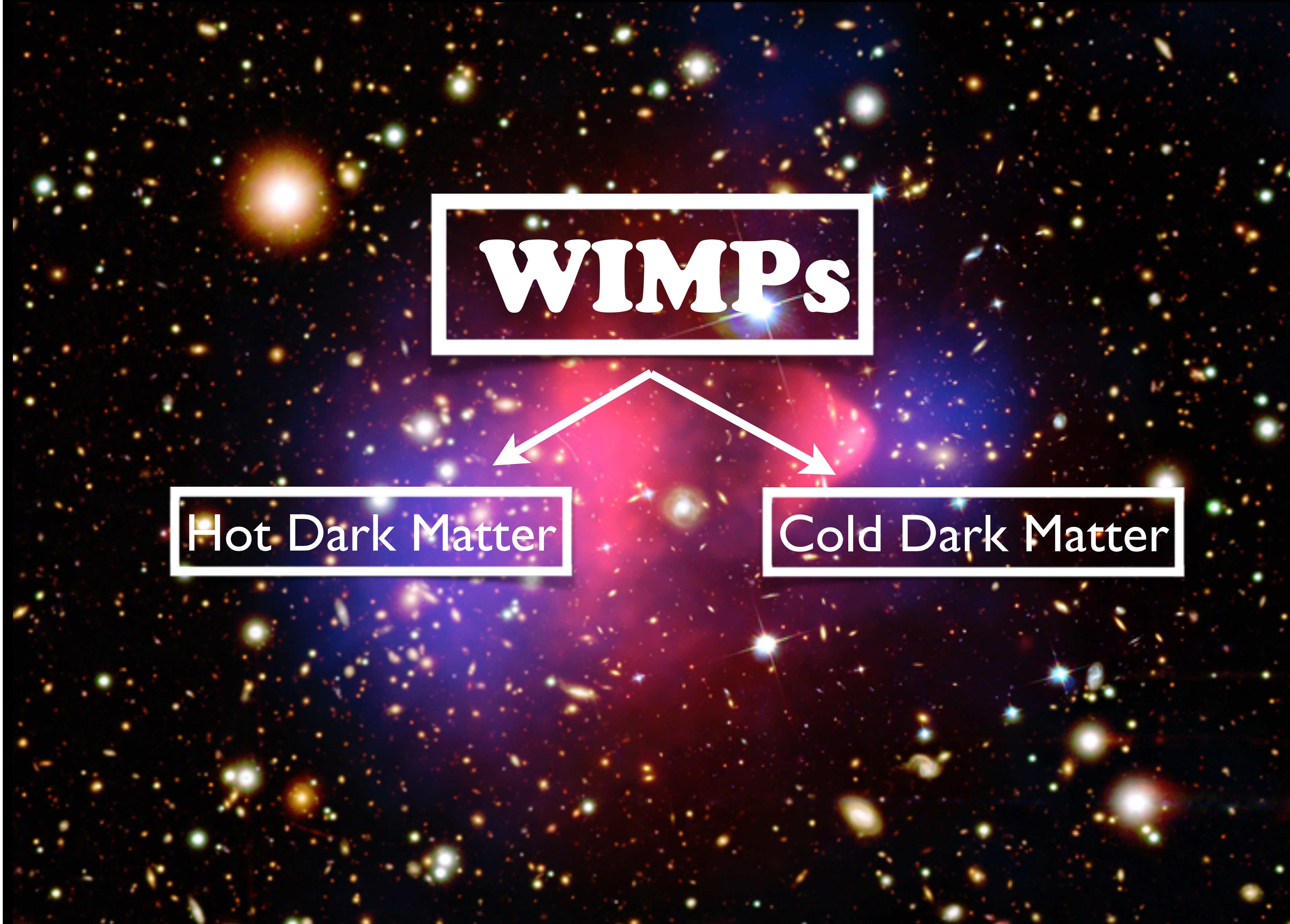
Weakly Interacting
Massive Particle



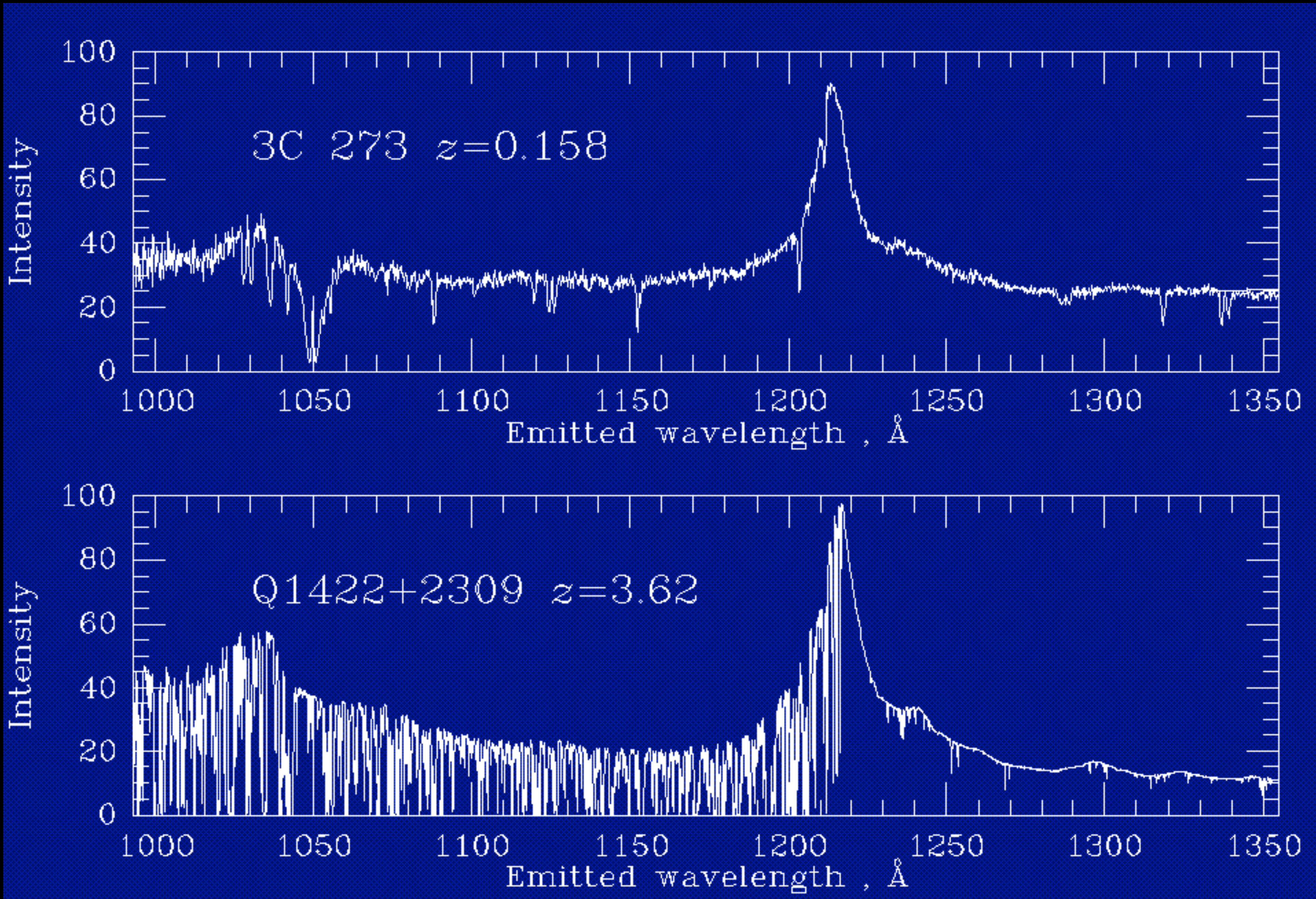
~~MACHOs~~ vs. WIMPs

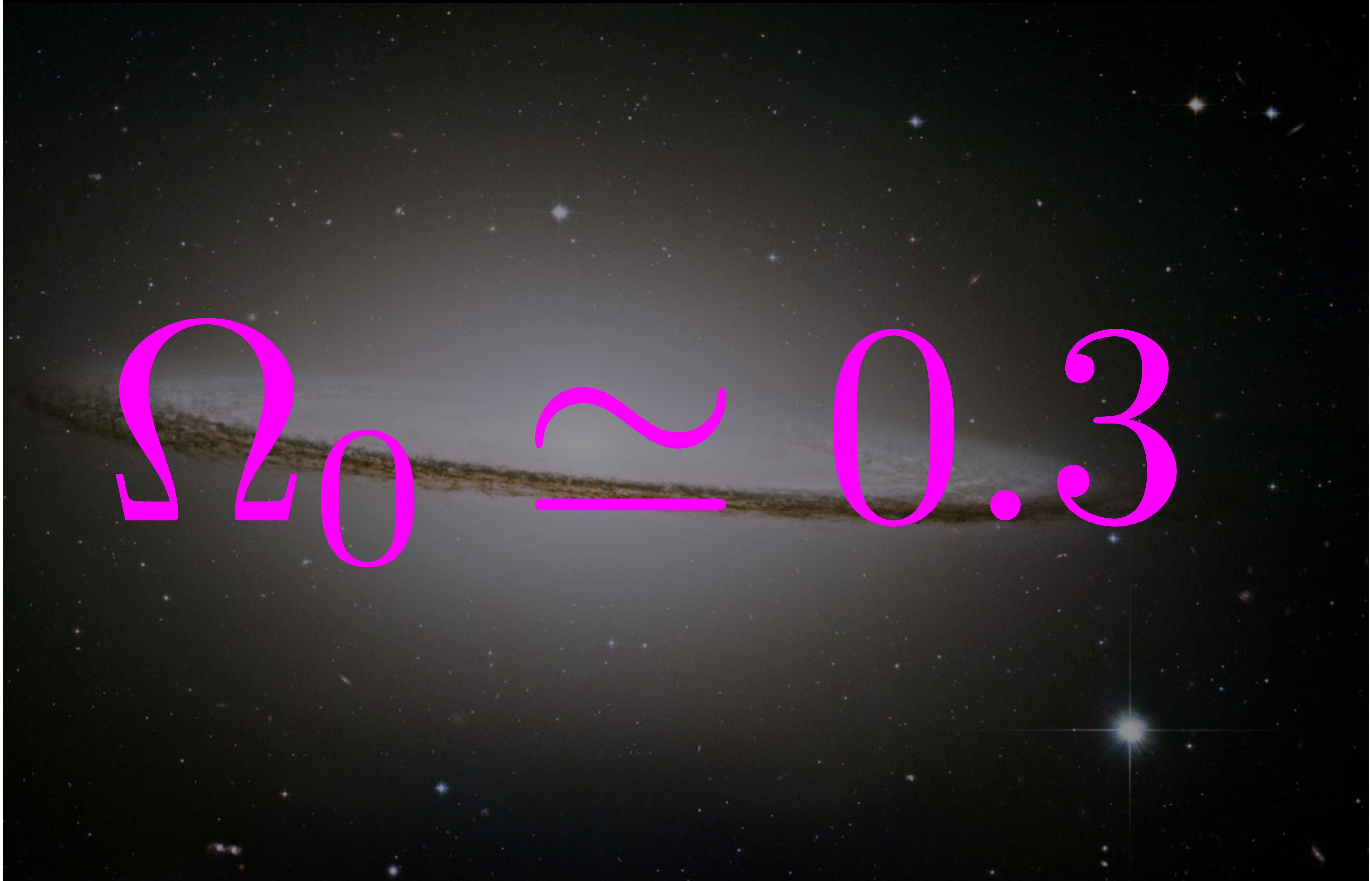
~~Massive Compact Halo Object~~

Weakly Interacting Massive Particle


WIMPs
Hot Dark Matter
Cold Dark Matter

Lyman-alpha Forest





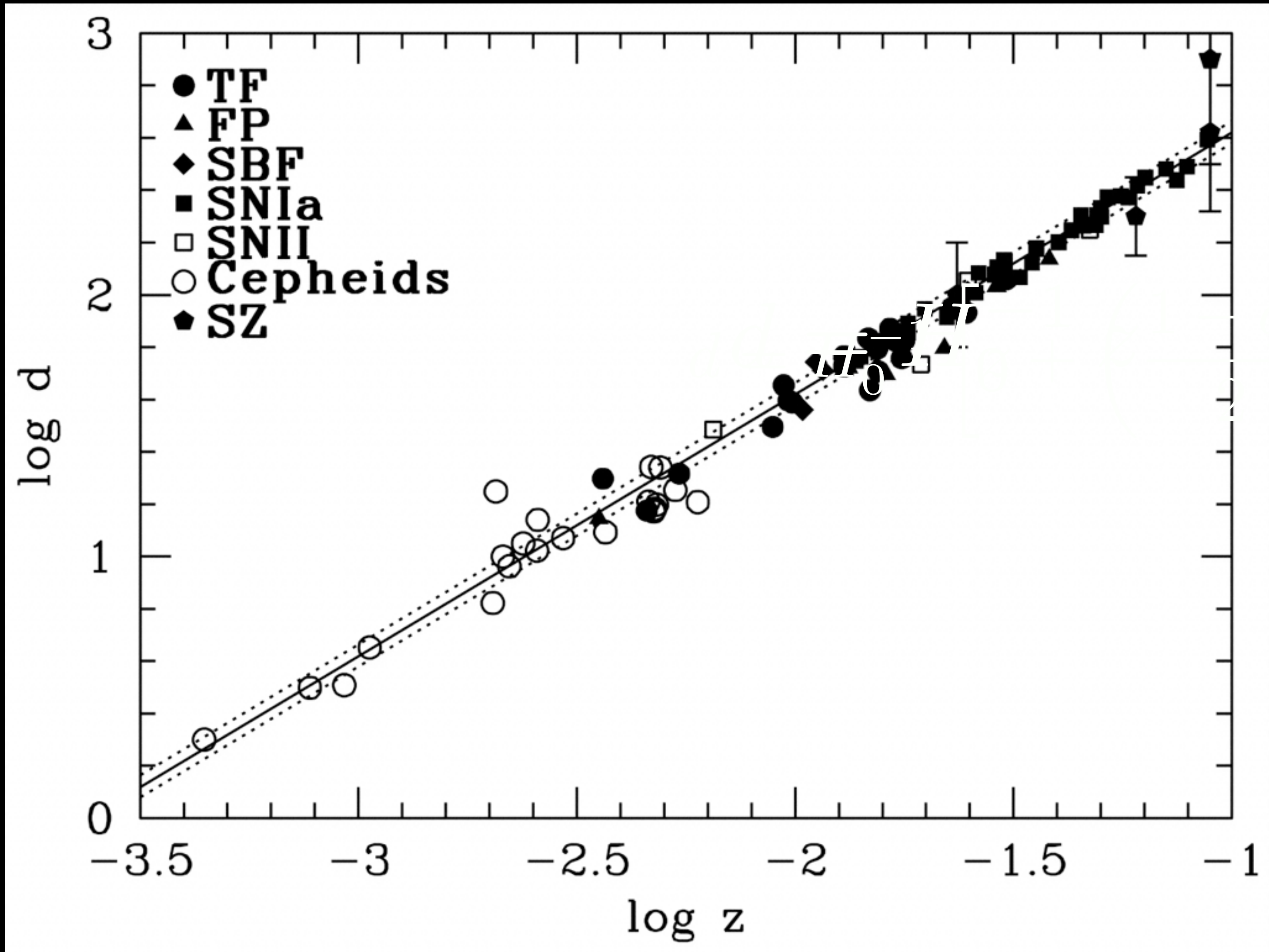
$$\Omega_0 \simeq 0.3$$

Constante de Hubble

$$H_0 = 100\, h\, \mathrm{Km\ s}^{-1}\mathrm{Mpc}^{-1}$$

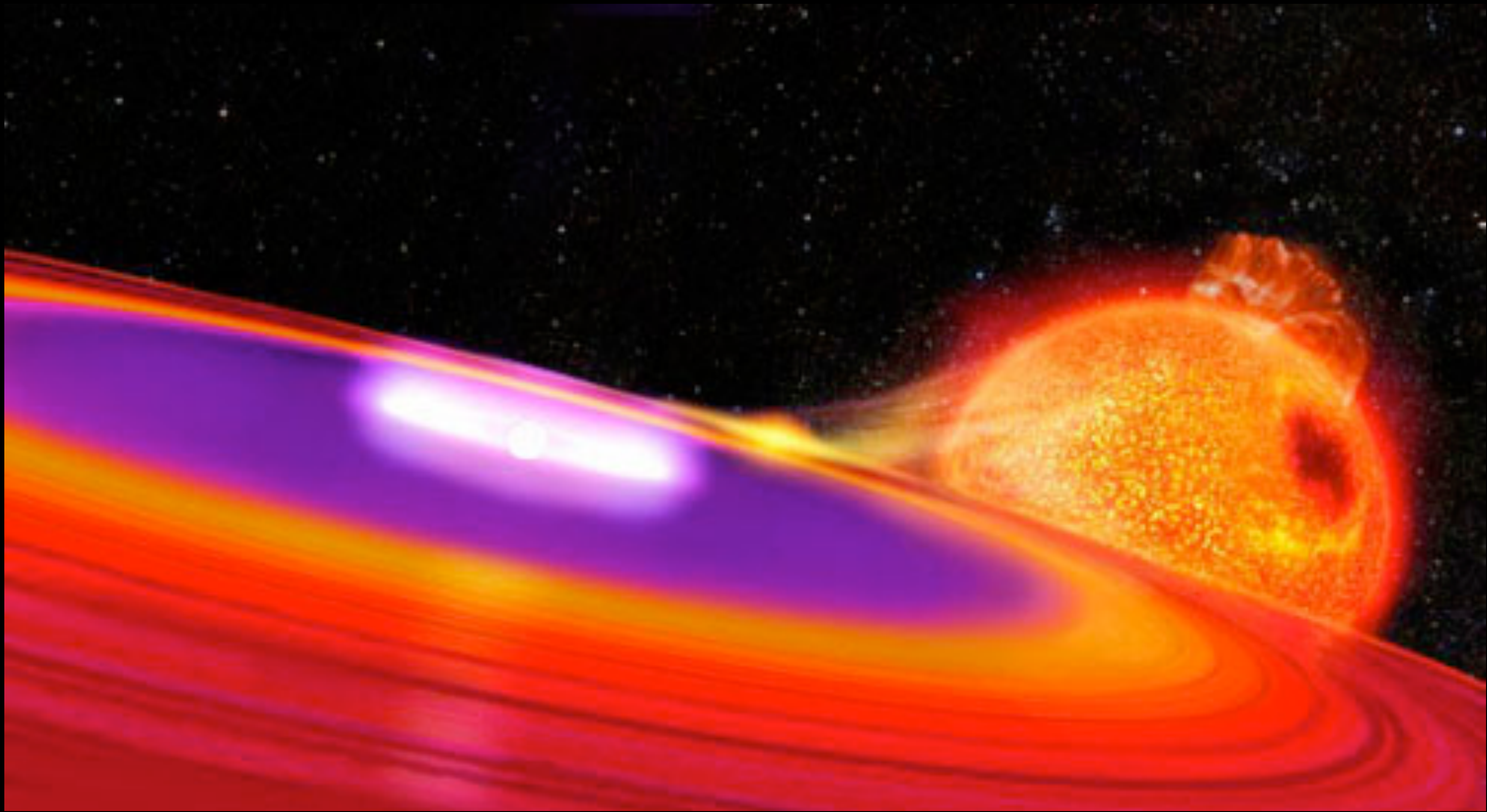
Final Results from the *Hubble Space Telescope* Key Project to Measure the Hubble Constant

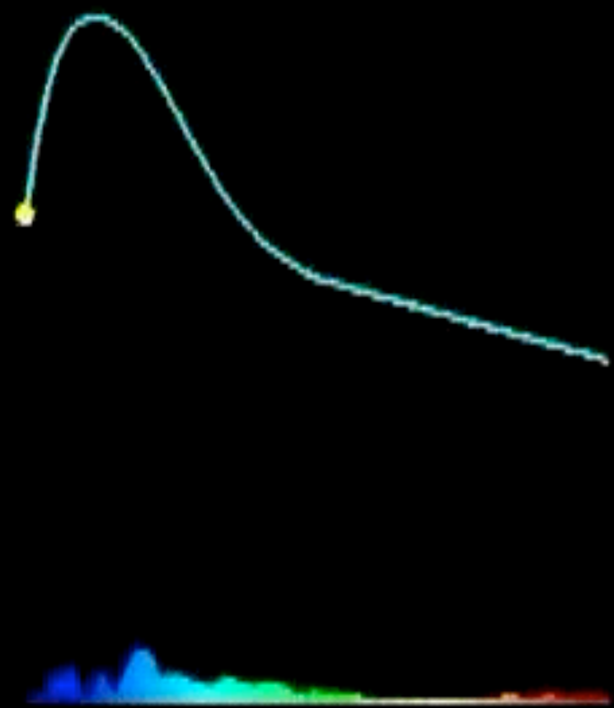
Wendy L. Freedman et al. 2001



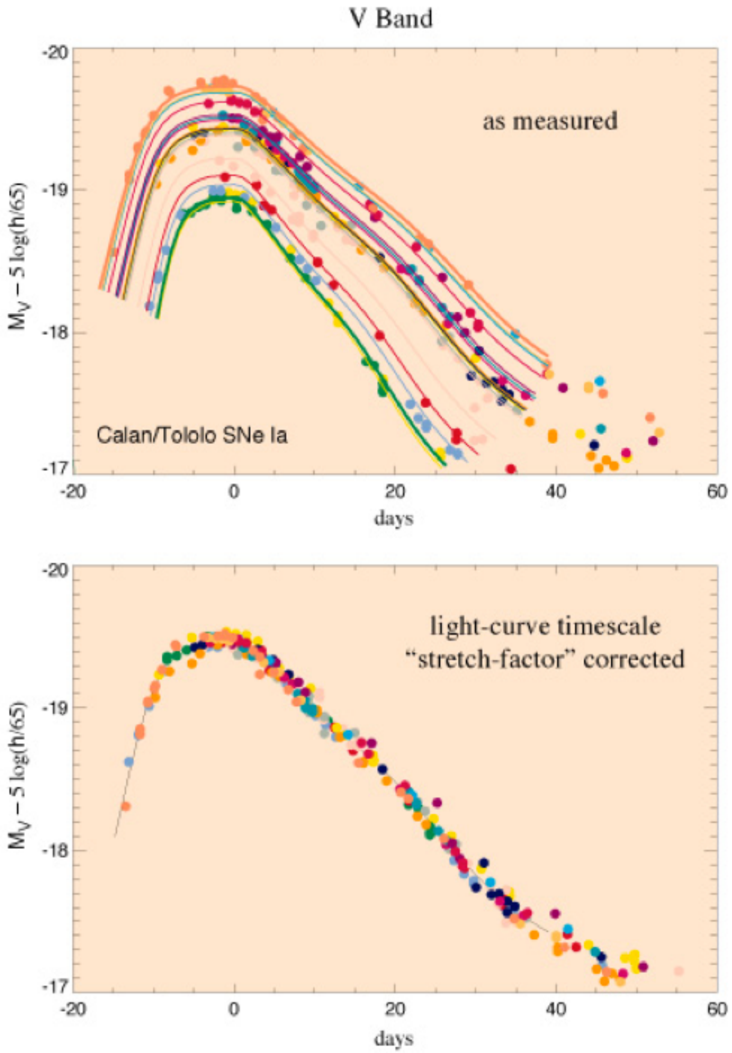
$H_0 = 72 \pm 8$ km s^{-1} Mpc^{-1}

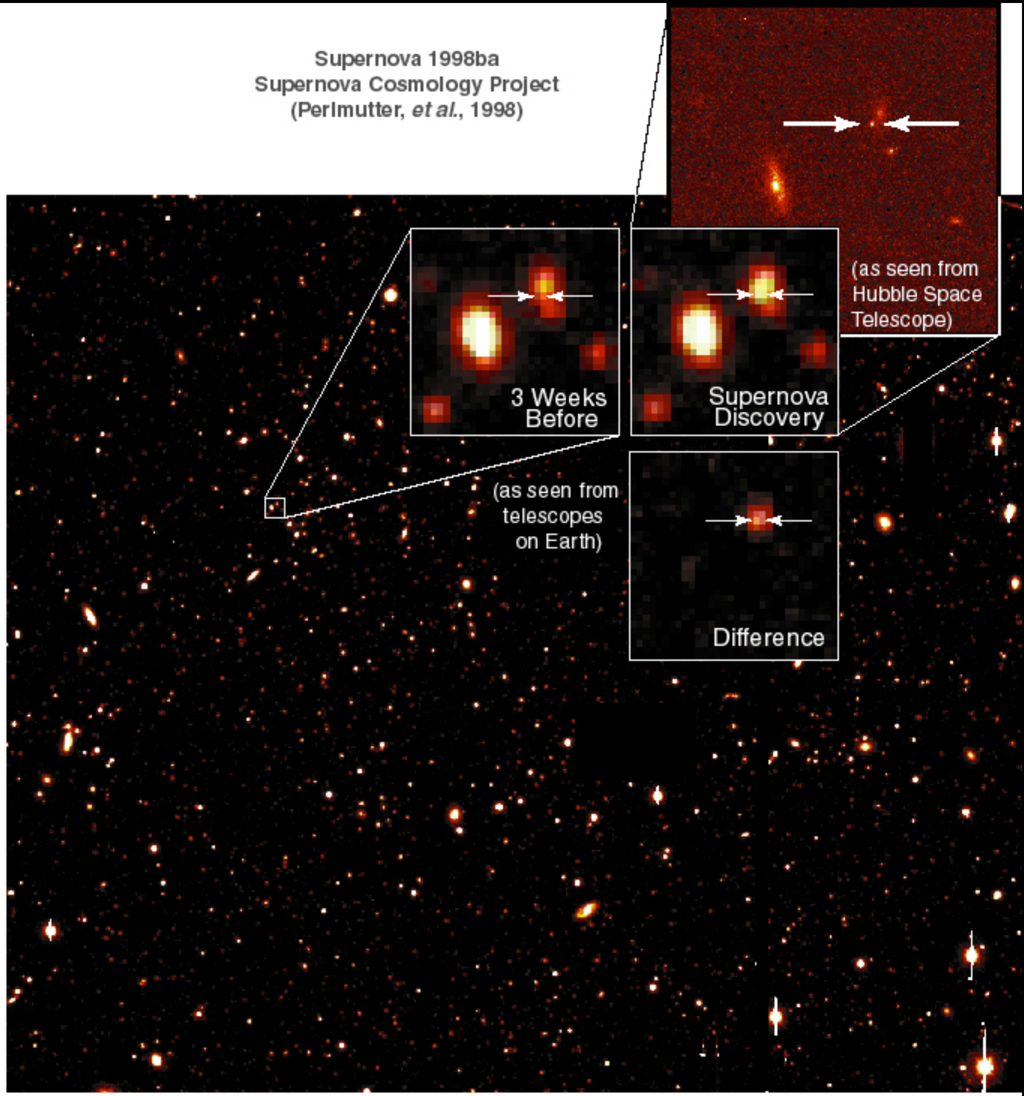
Supernovas Tipo Ia



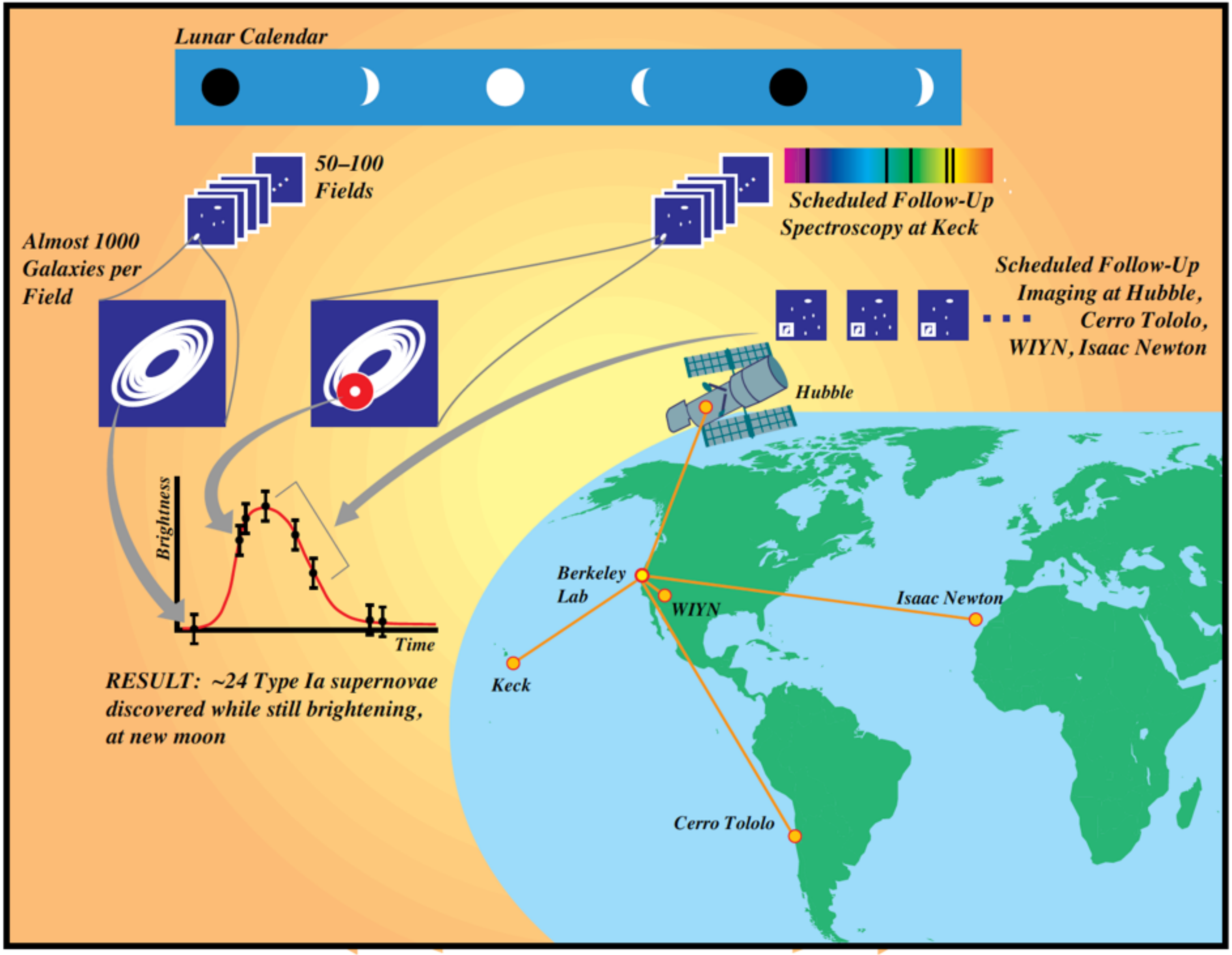



Low Redshift Type Ia Template Lightcurves



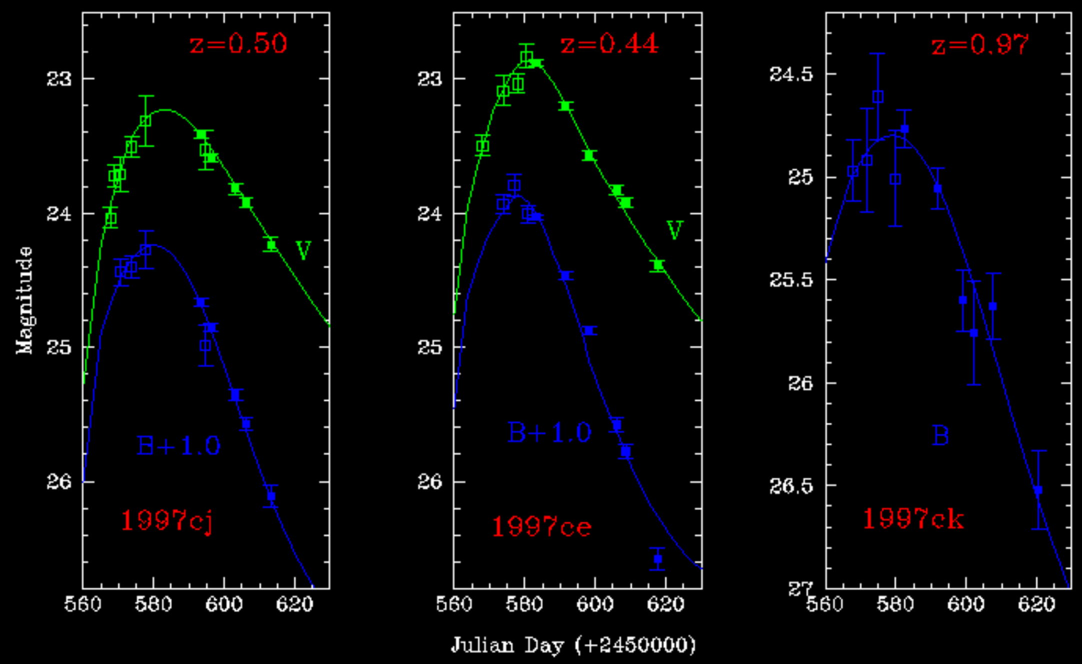


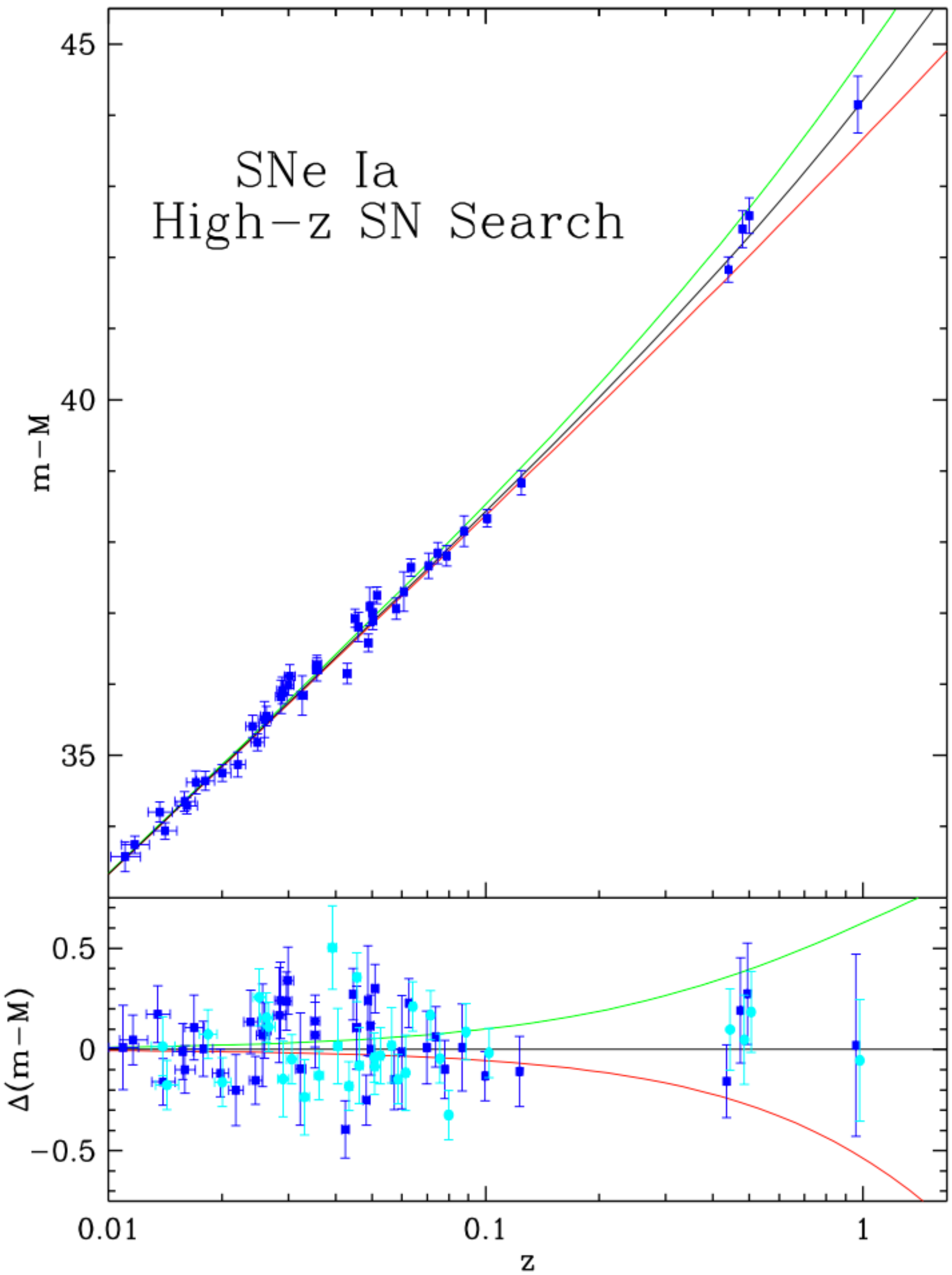
Strategy



Perlmutter, *et al.*, in **Thermonuclear** *Supernovae*, NATO ASI, v. 486 (1997)

Explosiones de supernovas a alto redshift





AAS Meeting
January 6-10, 1998
Washington, D.C.

$$d = H_0^{-1}\left[z + \left(\frac{1-q_0}{2}\right)z^2 + ...\right]$$

$$q_0 \sim -0.1$$

$$R_{\mu\nu} - \frac{1}{2} R \, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$R_{\mu\nu} - \frac{1}{2} R \, g_{\mu\nu} + \Lambda \, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$\left(\rho_\Lambda = \frac{\Lambda \, c^4}{8\pi G}, \quad p_\Lambda = -\rho_\Lambda \right)$$

Ecuaciones de Friedmann

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - k\frac{c^2}{a^2} + \frac{\Lambda}{3}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\rho + \frac{\Lambda}{3}$$

Parámetros de densidad

$$\Omega_m = \frac{\rho_0}{\rho_c} = \frac{8\pi G \rho_0}{3H_0^2}$$

$$\Omega_\lambda = \frac{\Lambda}{3H_0^2}$$

Parámetro de deceleración

$$q = -\frac{\ddot{a}a}{\dot{a}^2} \quad \left(q_0 = \frac{\Omega_m}{2} - \Omega_\lambda\right)$$

THE ASTRONOMICAL JOURNAL, 116:1009–1038, 1998 September

OBSERVATIONAL EVID

ADAM G. RIESS,[1] ALEXEI V
PETER M. GARNAVICH,[2] R
B. LEIBUNDGUT,[6] M. M
R. C

We present spectral and
range $0.16 \leq z \leq 0.62$. The l
relations between SN Ia l
High-z Supernova Search T
supernovae and a set of 34
logical parameters: the Hub
vacuum energy density, Ω_Λ)
The distances of the high-re
density ($\Omega_M = 0.2$) universe
subsamples, and prior cons
logical constant (i.e., $\Omega_\Lambda >$
constraint on mass density
consistent with $q_0 < 0$ at th
confidence levels, for two di
0.2, results in the weakest d
For a flat universe prior (Ω
and 9 σ formal statistical si
matter (i.e., $\Omega_M = 1$) is form
methods. We estimate the d
tainties in the current Ceph
atic error, including prog
perturbations in the expans
these effects appear to recon

Key words: cosmology: obs

THE ASTROPHYSICAL JOURNAL, 517:565–586, 1999 June 1

MEASUREMENTS OF Ω AND Λ FROM 42 HIGH-REDSHIFT SUPERNOVAE

S. PERLMUTTER,[1] G. ALDERING, G. GOLDHABER,[1] R. A. KNOP, P. NUGENT, P. G. CASTRO,[2] S. DEUSTUA, S. FABBRO,[3]
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AND
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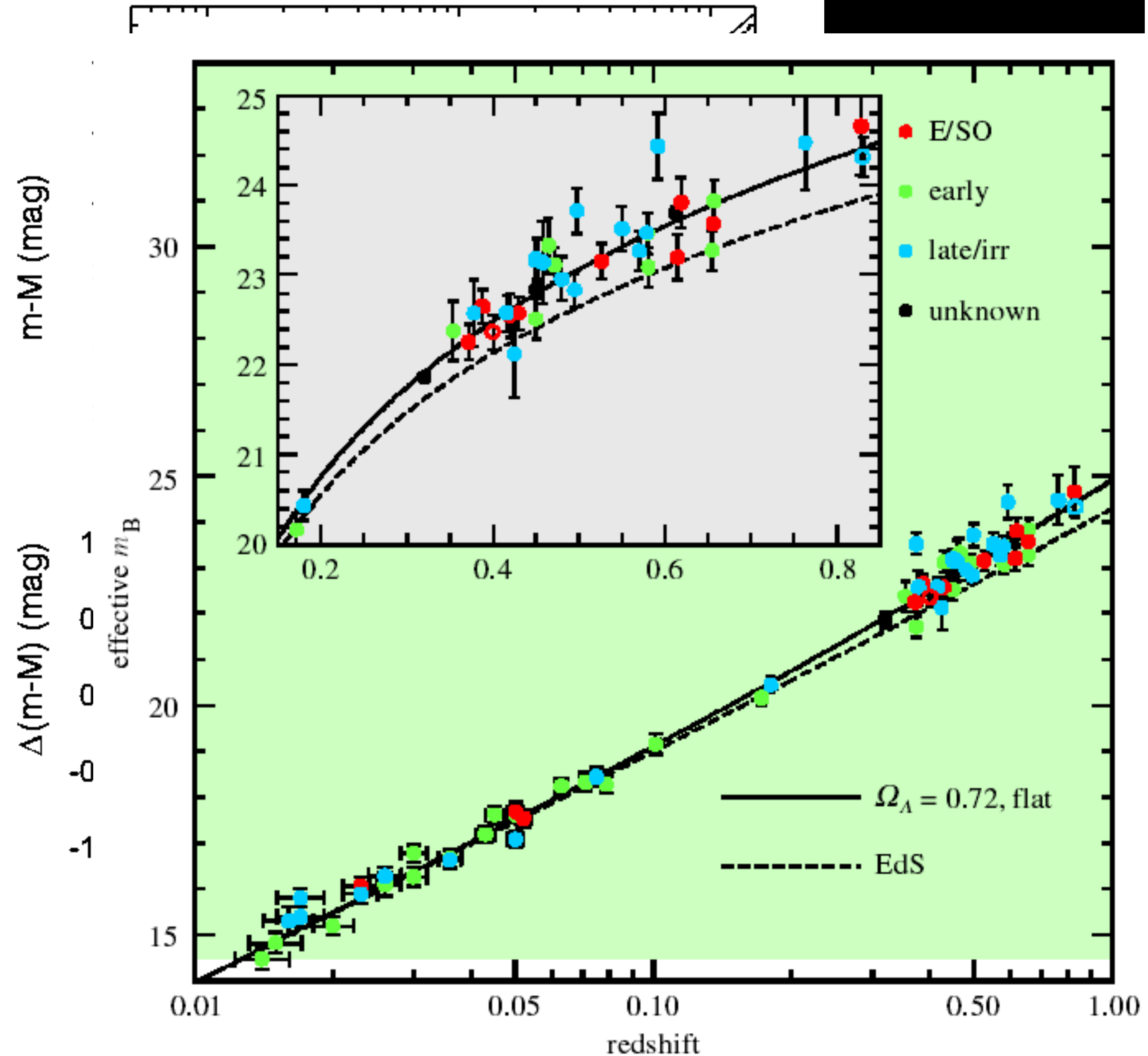
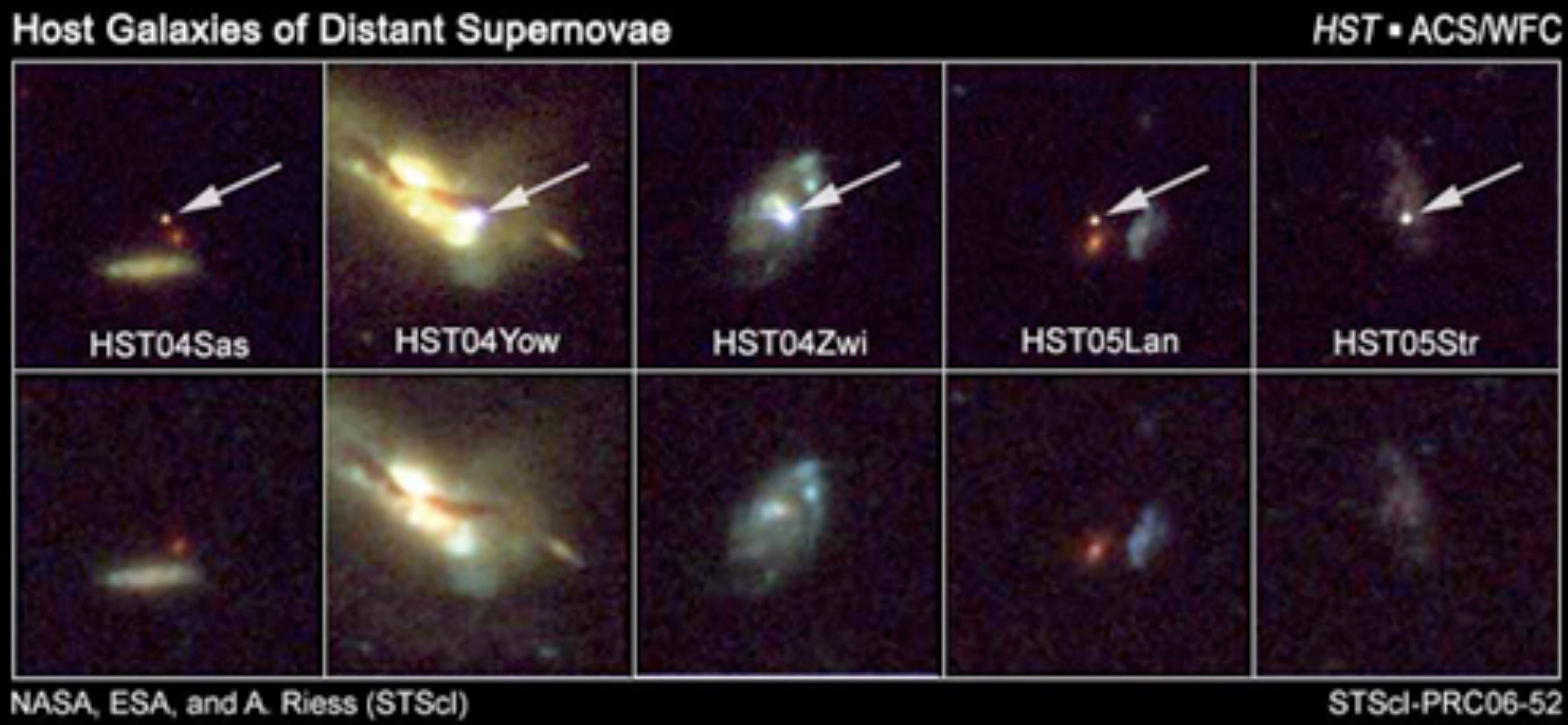
University of New South Wales, Sydney, Australia
(THE SUPERNOVA COSMOLOGY PROJECT)
Received 1998 September 8; accepted 1998 December 17

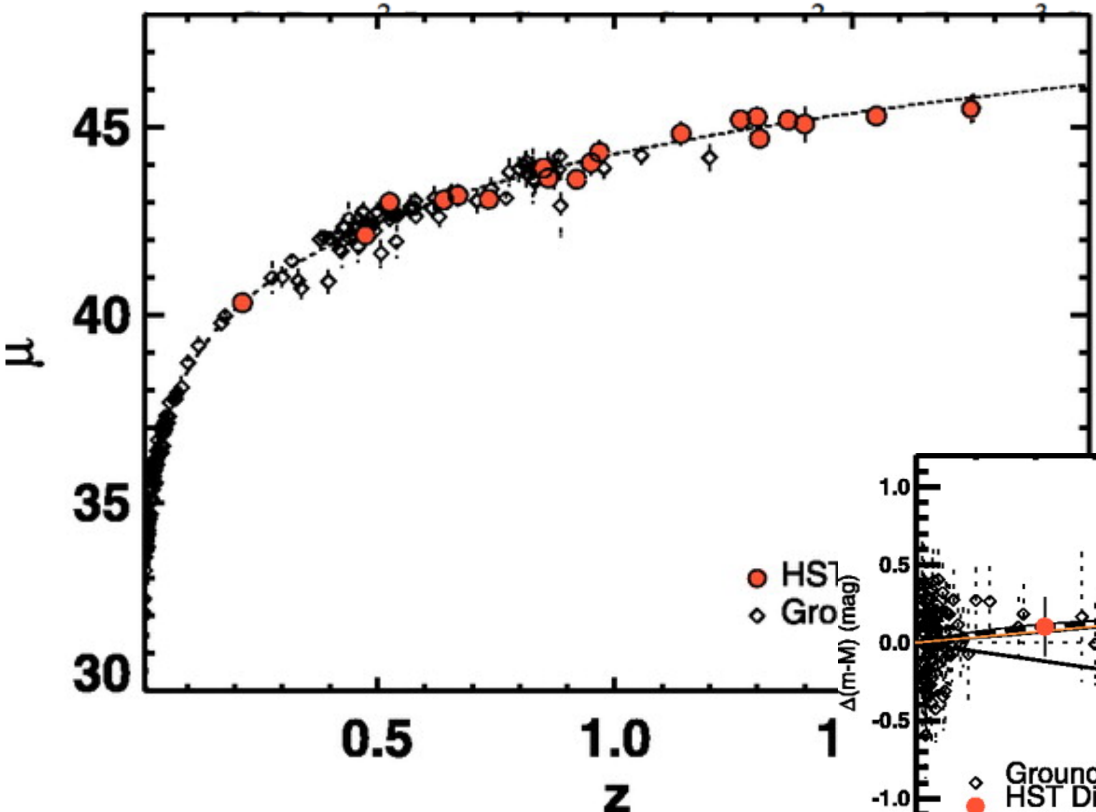
ABSTRACT

We report measurements of the mass density, Ω_M, and cosmological-constant energy density, Ω_Λ, of the universe based on the analysis of 42 type Ia supernovae discovered by the Supernova Cosmology Project. The magnitude-redshift data for these supernovae, at redshifts between 0.18 and 0.83, are fitted jointly with a set of supernovae from the Calán/Tololo Supernova Survey, at redshifts below 0.1, to yield values for the cosmological parameters. All supernova peak magnitudes are standardized using a SN Ia light-curve width-luminosity relation. The measurement yields a joint probability distribution of the cosmological parameters that is approximated by the relation $0.8\Omega_M - 0.6\Omega_\Lambda \approx -0.2 \pm 0.1$ in the region of interest ($\Omega_M \lesssim 1.5$). For a flat ($\Omega_M + \Omega_\Lambda = 1$) cosmology we find $\Omega_M^{\rm flat} = 0.28^{+0.09}_{-0.08}$ (1 σ statistical) $^{+0.05}_{-0.04}$ (identified systematics). The data are strongly inconsistent with a $\Lambda = 0$ flat cosmology, the simplest inflationary universe model. An open, $\Lambda = 0$ cosmology also does not fit the data well: the data indicate that the cosmological constant is nonzero and positive, with a confidence of $P(\Lambda > 0) = 99\%$, including the identified systematic uncertainties. The best-fit age of the universe relative to the Hubble time is $t_0^{\rm flat} = 14.9^{+1.4}_{-1.1}(0.63/h)$ Gyr for a flat cosmology. The size of our sample allows us to perform a variety of statistical tests to check for possible systematic errors and biases. We find no significant differences in either the host reddening distribution or Malmquist bias between the low-redshift Calán/Tololo sample and our high-redshift sample. Excluding those few supernovae that are outliers in color excess or fit residual does not significantly change the results. The conclusions are also robust whether or not a width-luminosity relation is used to standardize the supernova peak magnitudes. We discuss and constrain, where possible, hypothetical alternatives to a cosmological constant.


m-M (mag)
Δ(m-M) (mag)
30
25
20
15
1
0
0
-0
-1
effective m_B
25
24
23
22
21
20
0.2
0.4
0.6
0.8
E/SO
early
late/irr
unknown
Ω_Λ = 0.72, flat
EdS
0.01
0.05
0.10
0.50
1.00
redshift


Host Galaxies of Distant Supernovae
HST ▪ ACS/WFC
HST04Sas
HST04Yow
HST04Zwi
HST05Lan
HST05Str
NASA, ESA, and A. Riess (STScI)
STScI-PRC06-52

TYPE Ia SUPERNOVA DISCOVERIES AT $z > 1$ FROM THE *HUBBLE SPACE TELESCOPE*: EVIDENCE FOR PAST DECELERATION AND CONSTRAINTS ON DARK ENERGY EVOLUTION[1]



ANO CASERTANO,[2] HENRY C. FERGUSON,[2] BAHRAM MOBASHER,[2]
VEIDONG LI,[5] RYAN CHORNOCK,[5] ROBERT P. KIRSHNER,[4]
[2] MARIO LIVIO,[2] MAURO GIAVALISCO,[2]
ÍTEZ,[8] AND ZLATAN TSVETANOV[8]

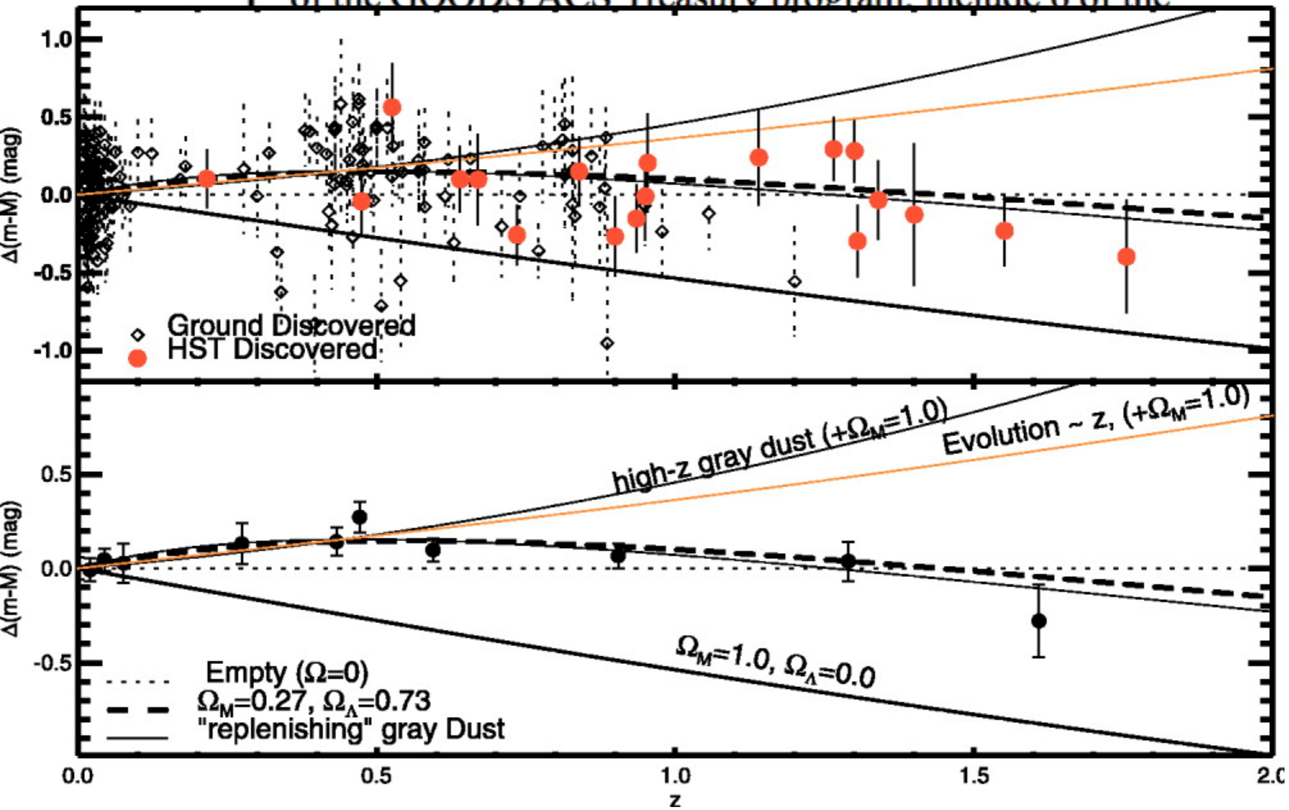
ccepted 2004 February 16

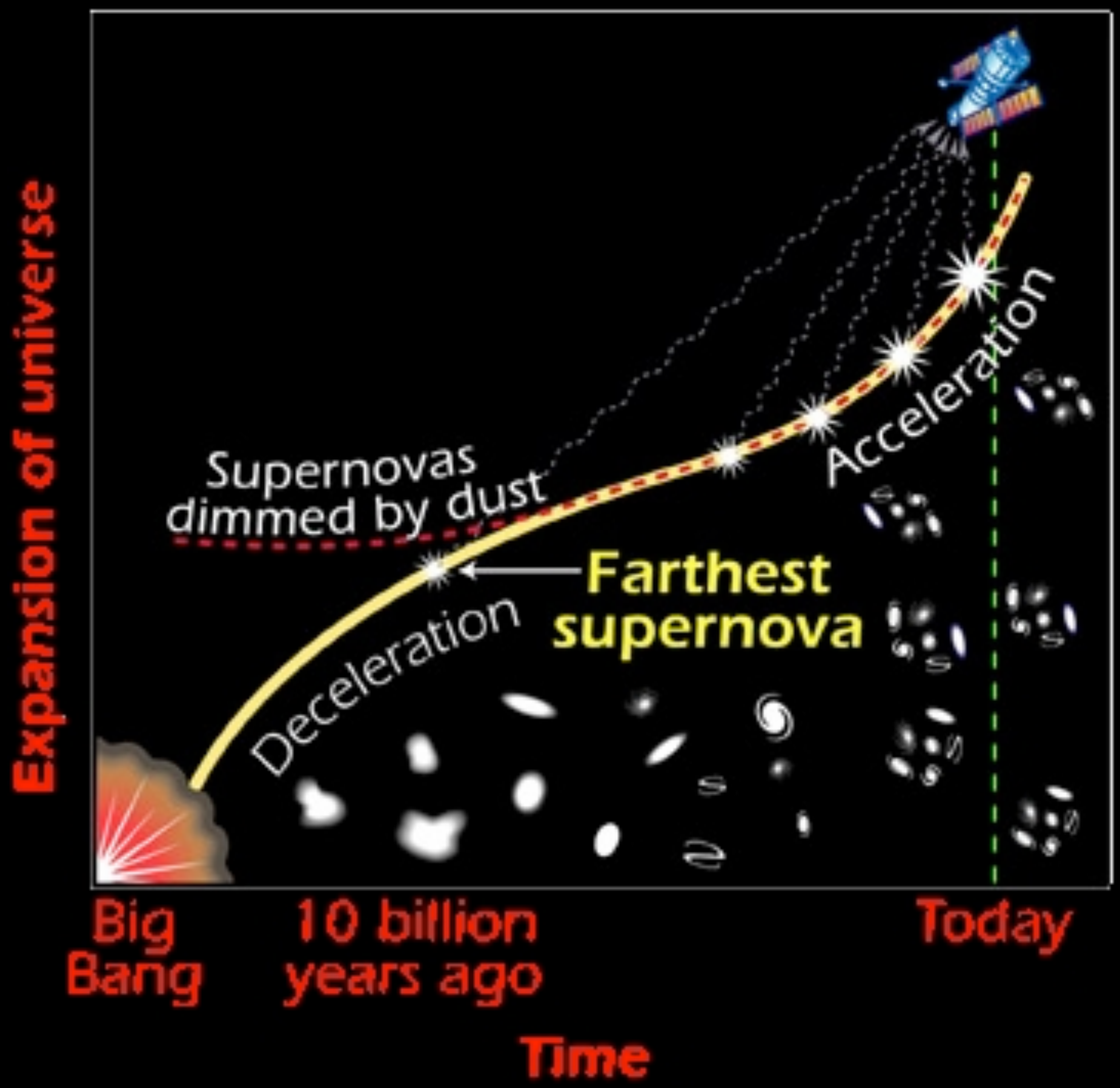
ACT

with the *Hubble Space Telescope* (*HST*) and have used
deceleration that preceded the current epoch of cosmic
of the GOODS ACS Treasury program, include 6 of the

$\Omega_M = 0.29 \pm^{0.05}_{0.03}$ (equivalently, $\Omega_\Lambda = 0$
cosmic microwave background and la
confidence level) for an assumed static
recent equation of state of dark energy
the first estimates and twice as preci
are consistent with the static nature o
$dw/dz = 0$) and are inconsistent with v
dark energy for the fate of the univers

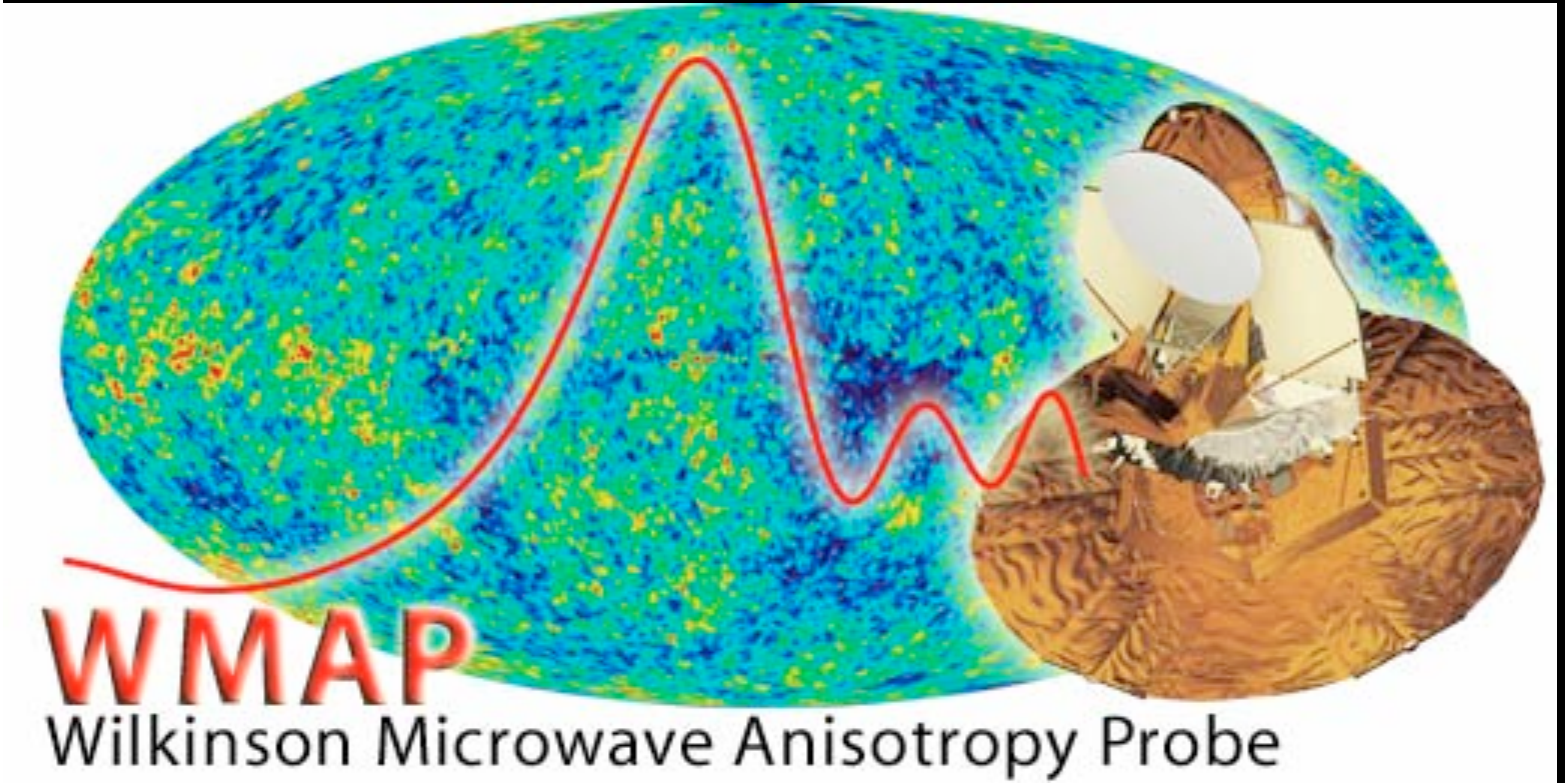
Subject headings: cosmology: observa
supernovae: general

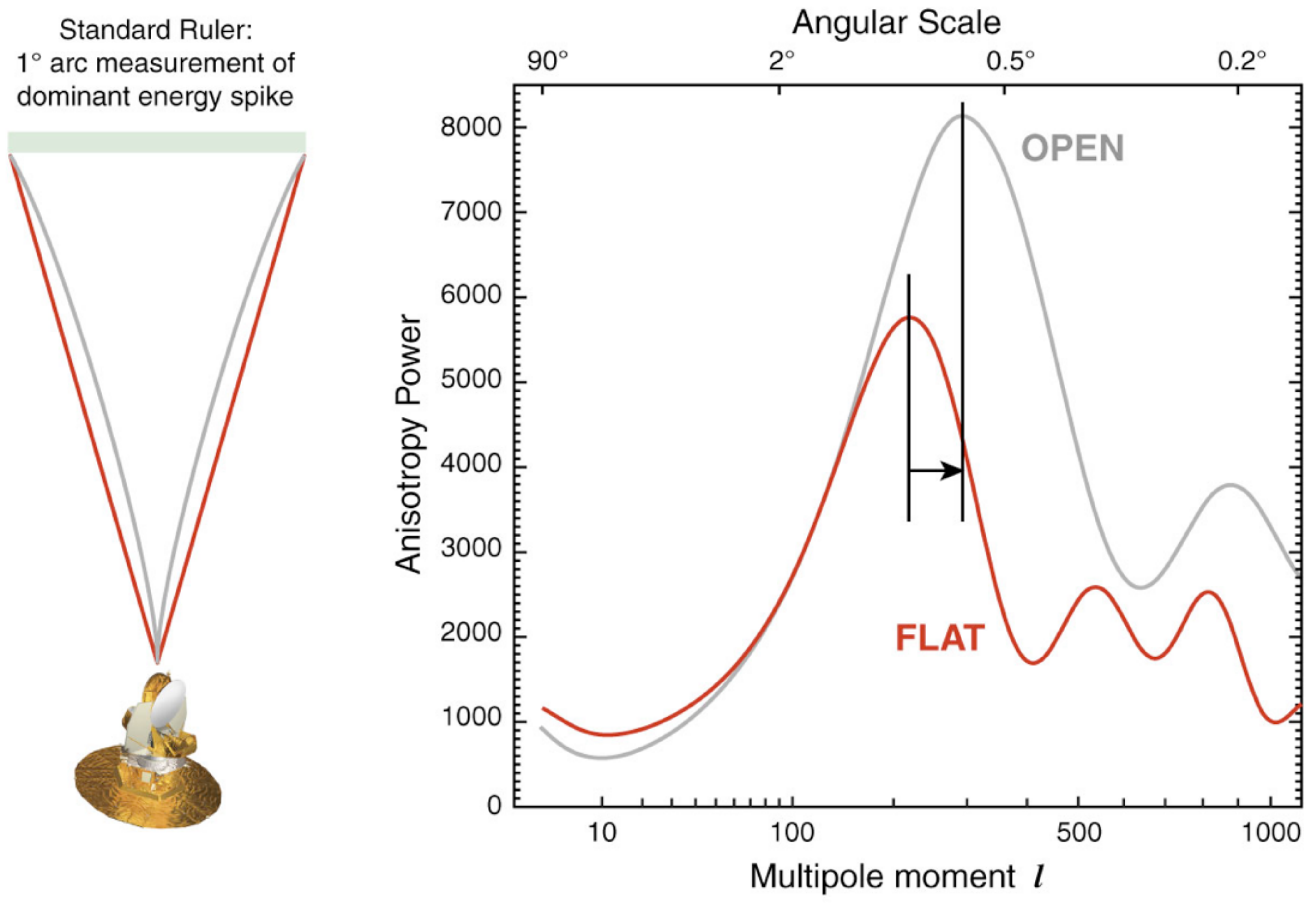


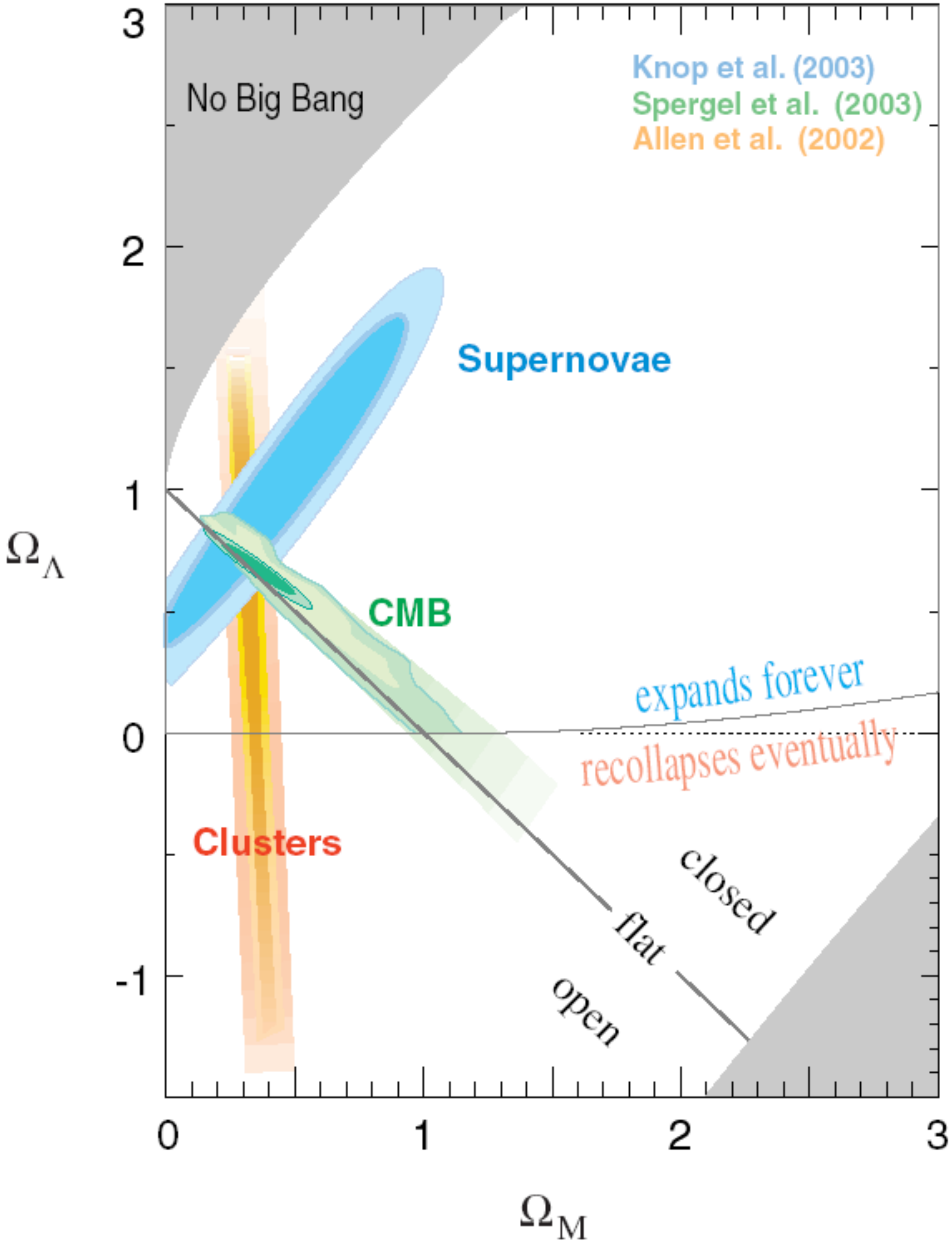


$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\rho + \frac{\Lambda}{3}$$

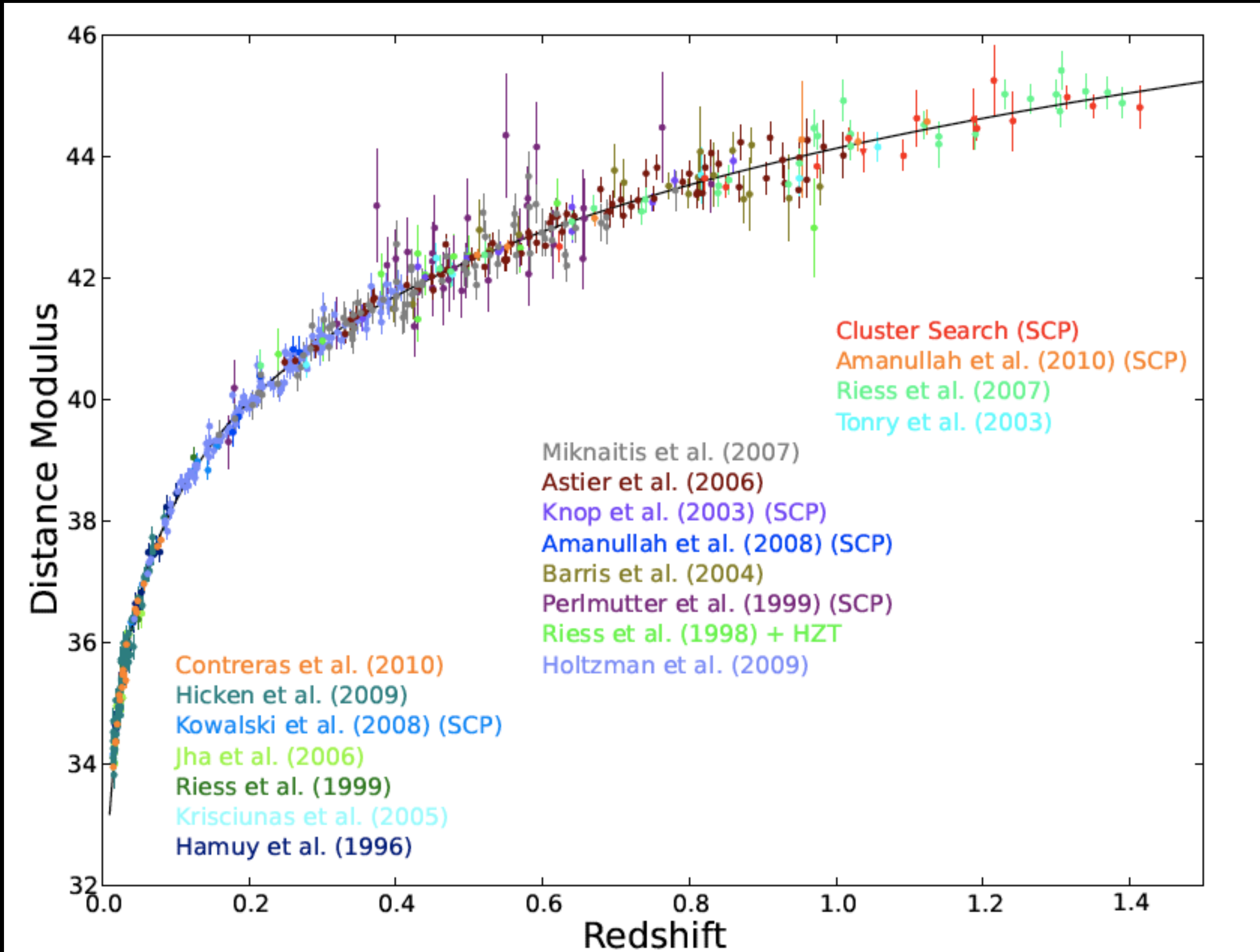
$$q_0 = \frac{\Omega_m}{2} - \Omega_\lambda$$


WMAP
Wilkinson Microwave Anisotropy Probe


Standard Ruler:
1° arc measurement of
dominant energy spike
Angular Scale
90°
2°
0.5°
0.2°
OPEN
FLAT
Anisotropy Power
8000
7000
6000
5000
4000
3000
2000
1000
0
10
100
500
1000
Multipole moment l

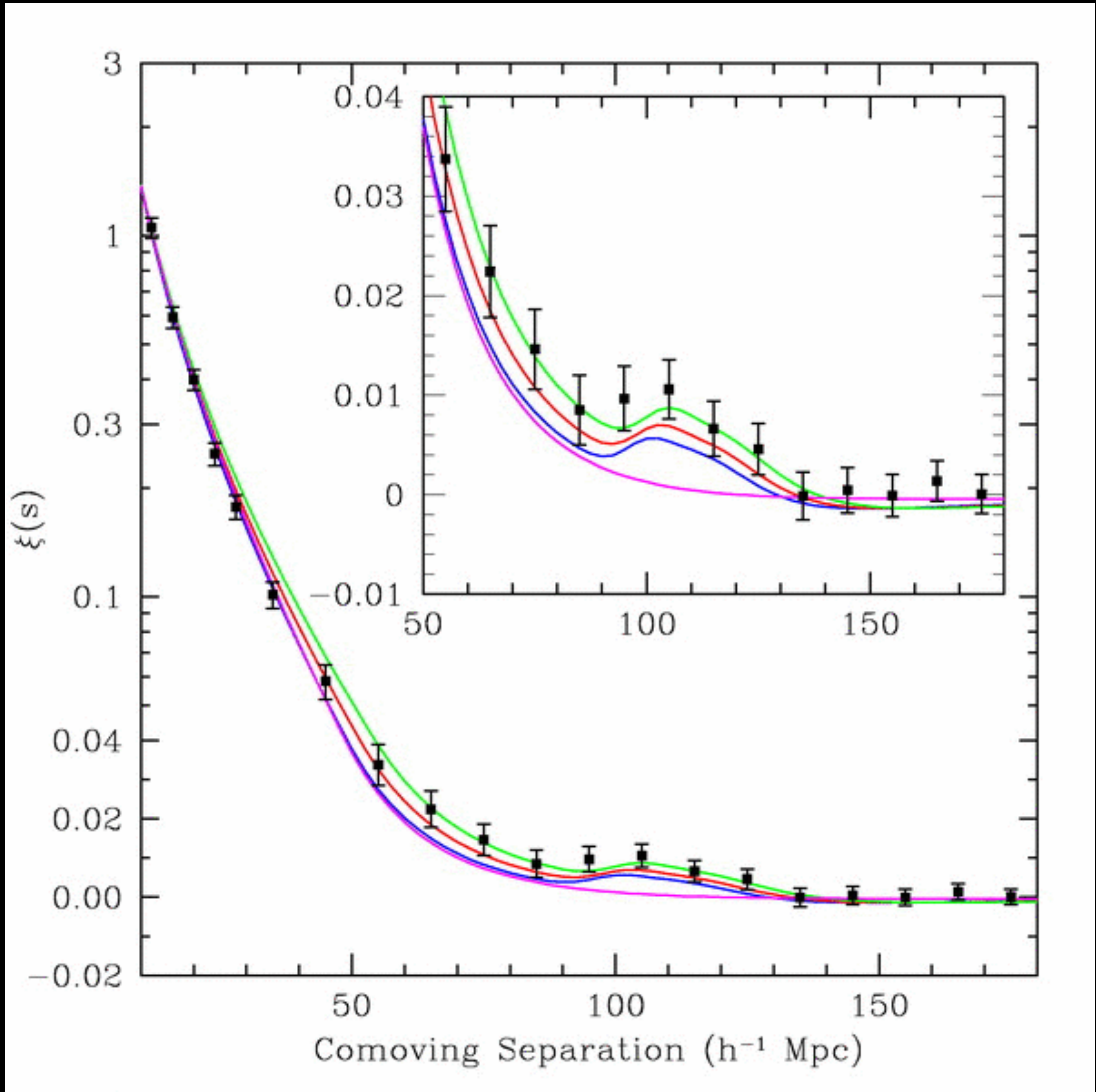


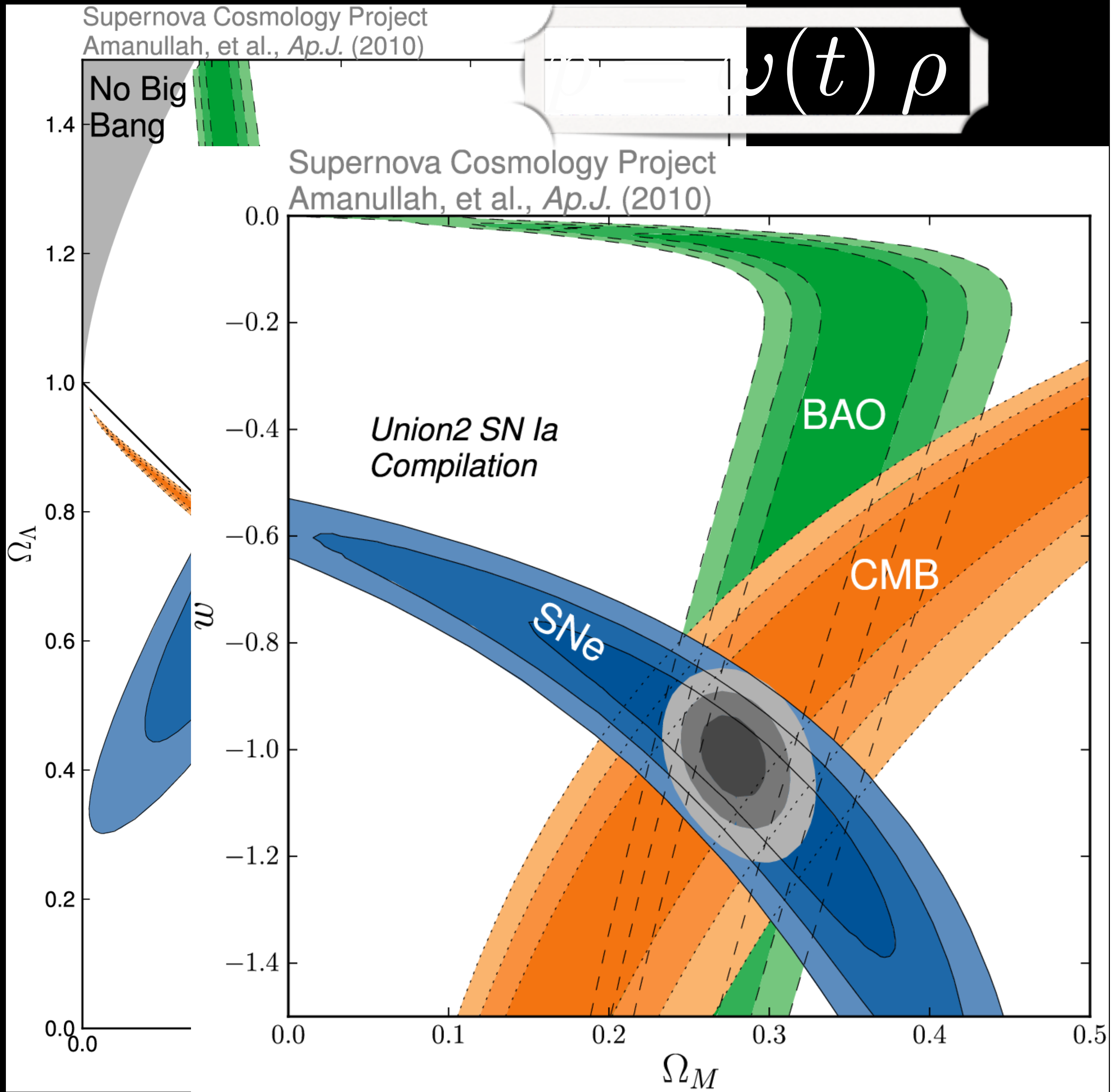
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
Ω_Λ
Ω_M
3
2
1
0
-1
0
1
2
3



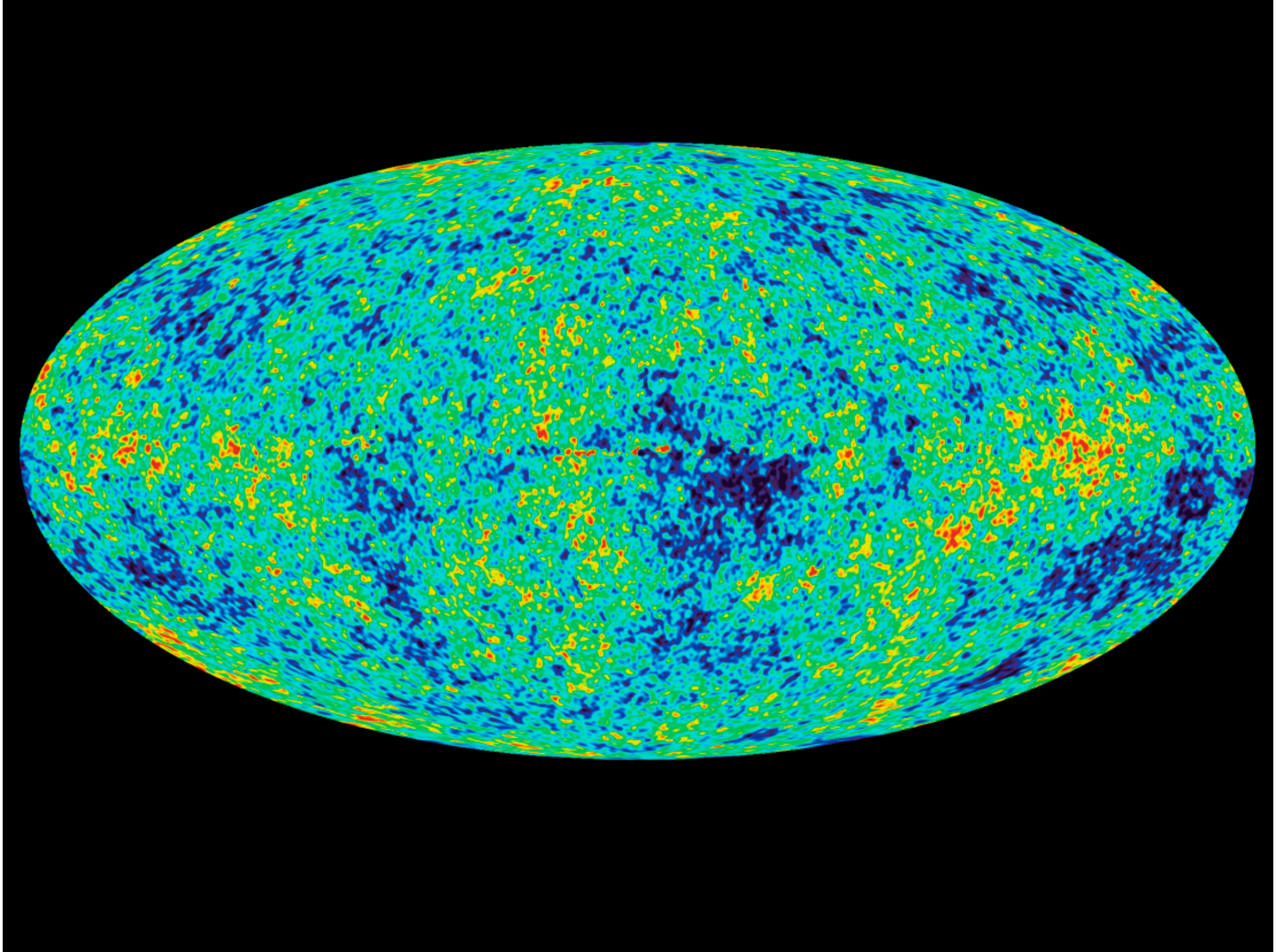
Distance Modulus
Redshift
46
44
42
40
38
36
34
32
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Cluster Search (SCP)
Amanullah et al. (2010) (SCP)
Riess et al. (2007)
Tonry et al. (2003)
Miknaitis et al. (2007)
Astier et al. (2006)
Knop et al. (2003) (SCP)
Amanullah et al. (2008) (SCP)
Barris et al. (2004)
Perlmutter et al. (1999) (SCP)
Riess et al. (1998) + HZT
Holtzman et al. (2009)
Contreras et al. (2010)
Hicken et al. (2009)
Kowalski et al. (2008) (SCP)
Jha et al. (2006)
Riess et al. (1999)
Krisciunas et al. (2005)
Hamuy et al. (1996)

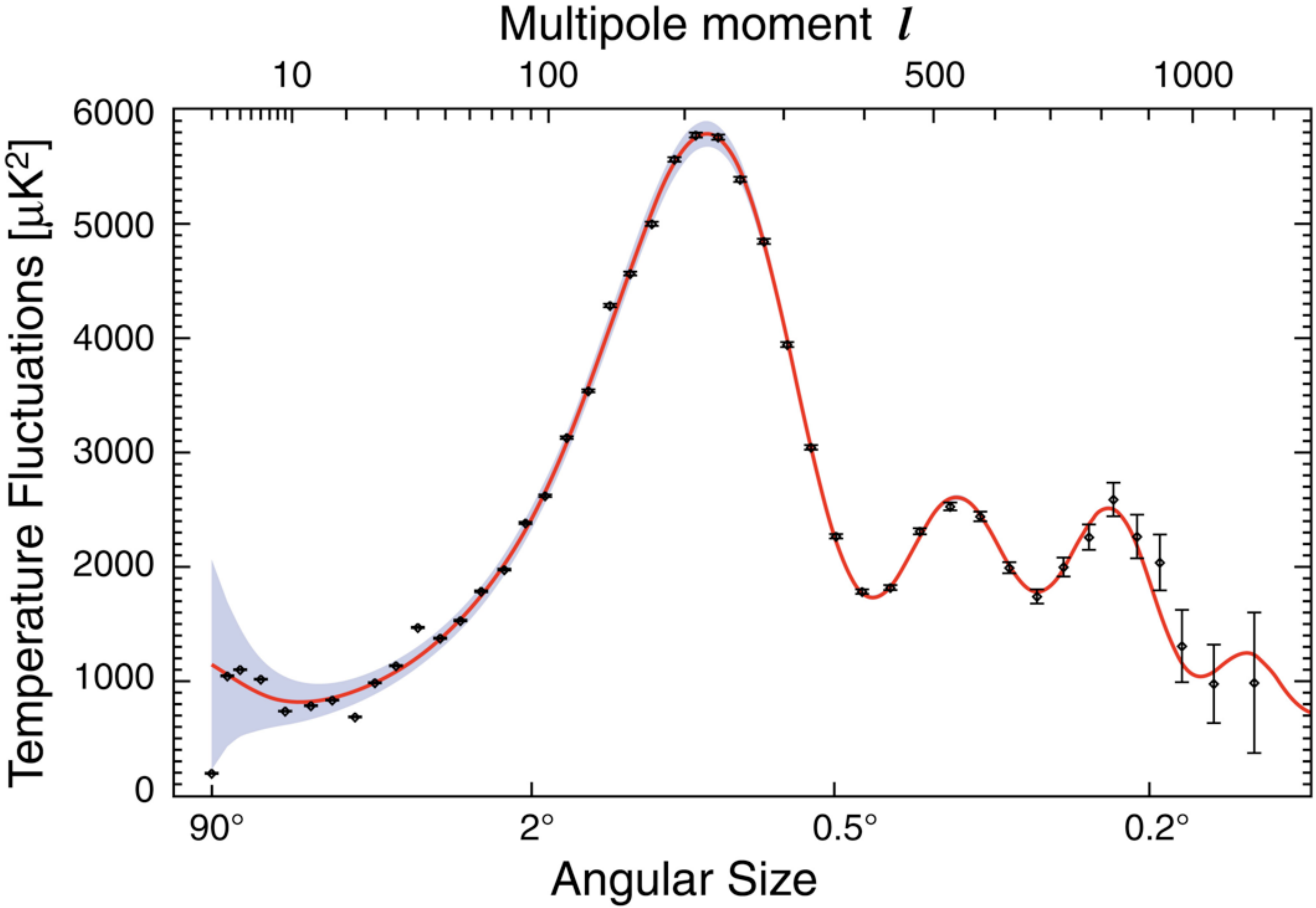
"Baryon Acoustic Peak"





$p = w(t)\,\rho$
Supernova Cosmology Project
Amanullah, et al., Ap.J. (2010)
No Big Bang
Ω_Λ
Supernova Cosmology Project
Amanullah, et al., Ap.J. (2010)
Union2 SN Ia Compilation
BAO
CMB
SNe
w
Ω_M



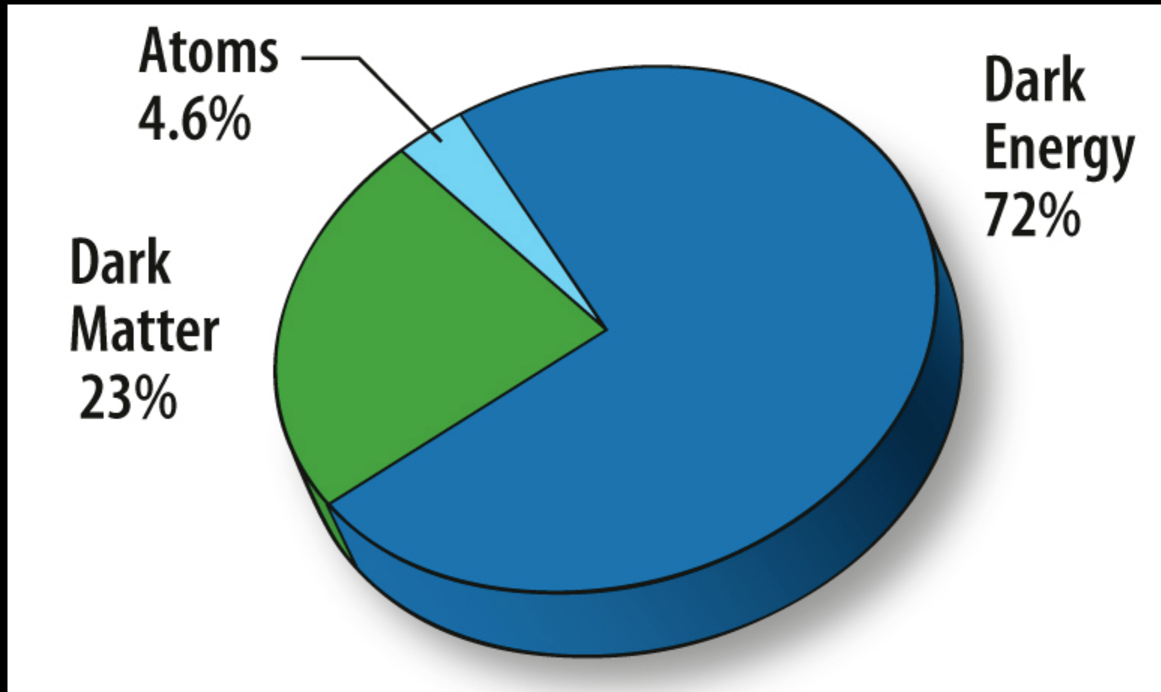

Multipole moment l
10
100
500
1000
6000
5000
4000
3000
2000
1000
0
Temperature Fluctuations [μK²]
90°
2°
0.5°
0.2°
Angular Size

Flat-ΛCDM WMAP+BAO+H0

$$\Omega_b = 0.0456 \pm 0.0016$$

$$\Omega_{dm} = 0.227 \pm 0.014$$

$$\Omega_\lambda = 0.728^{+0.015}_{-0.016}$$



$$\Omega_{tot} = 1.002 \pm 0.006$$