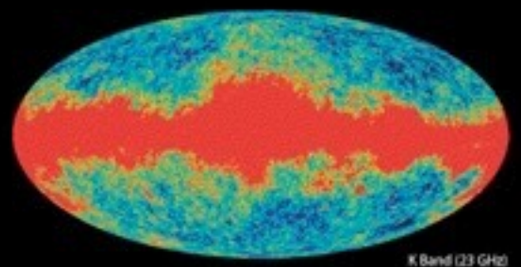
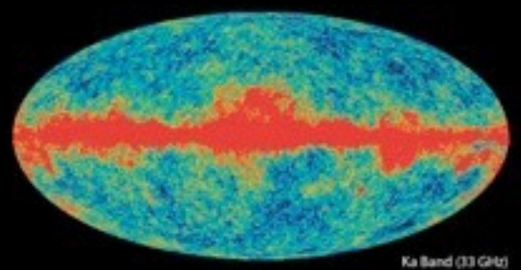
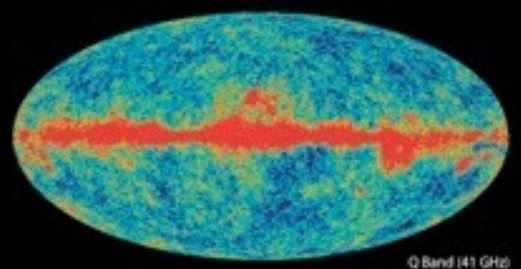
Galaxies: A Universe of galaxies

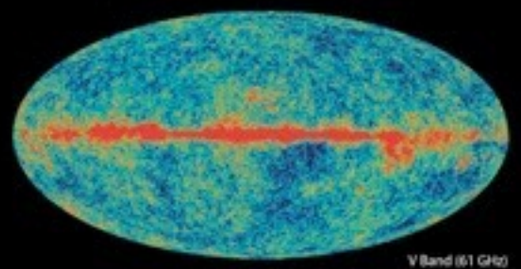
ASTR 505

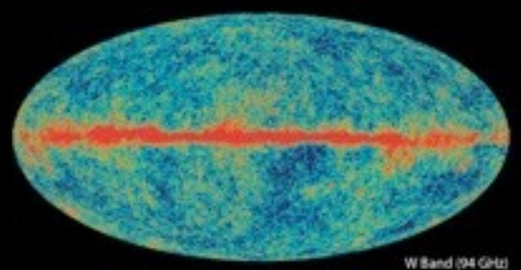
Wilkinson Microwave Anisotropy Probe (WMAP)


K Band (23 GHz)

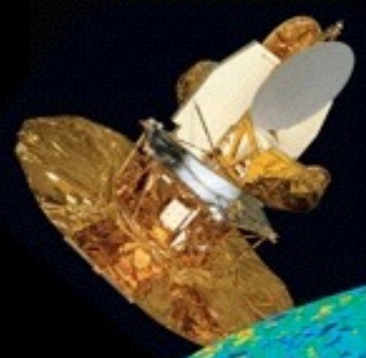

Ka Band (33 GHz)

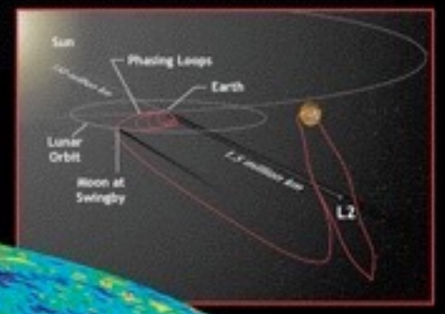

Q Band (41 GHz)

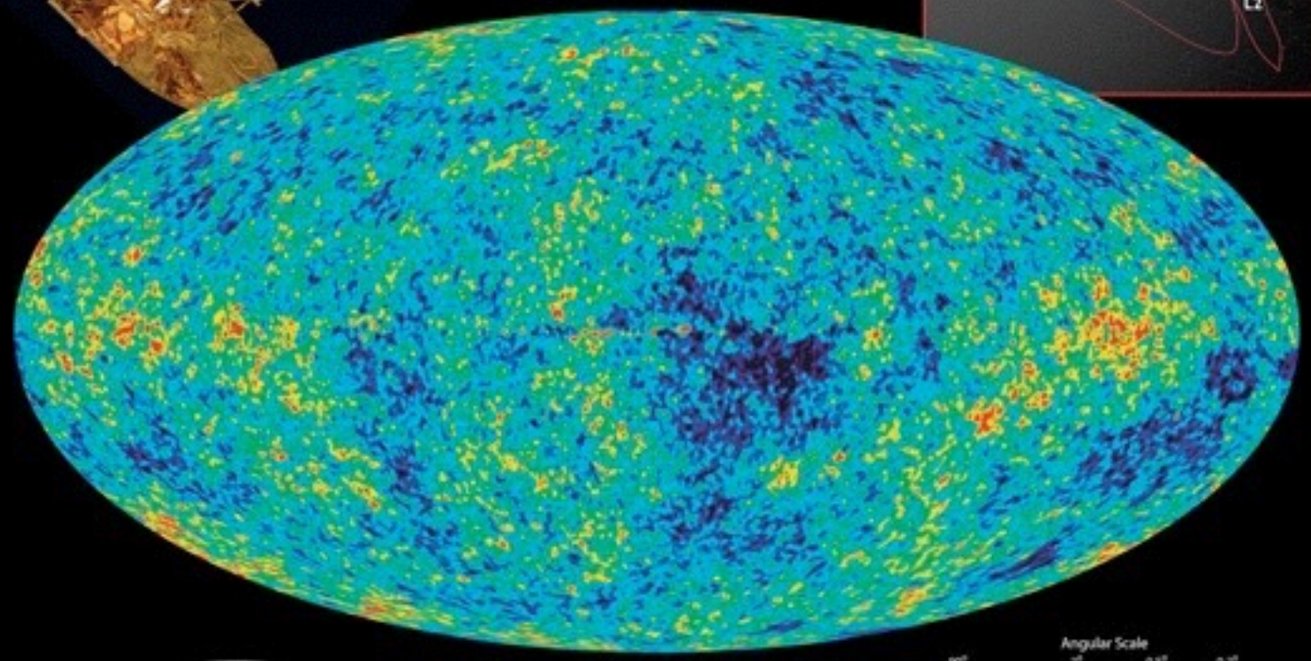

V Band (61 GHz)

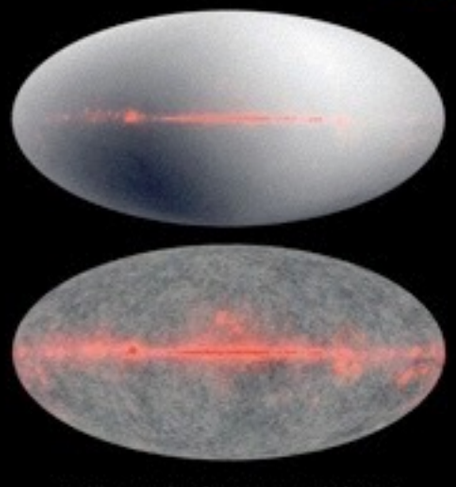

W Band (94 GHz)

WMAP Full-sky Maps

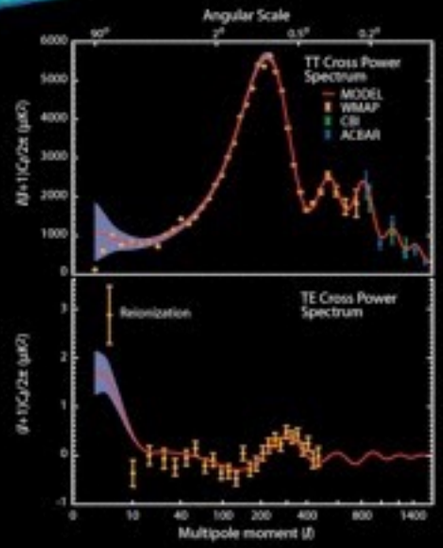


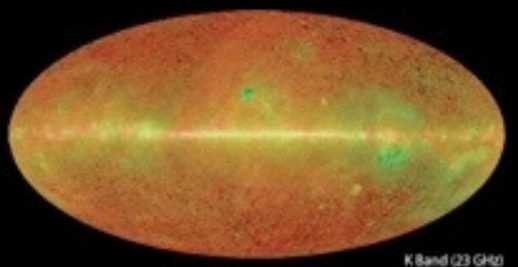


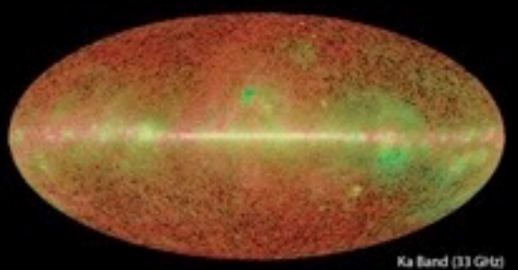




WMAP Foregrounds vs. Cosmic Microwave Background
Red=Q band Green=V band Blue=W band




K Band (23 GHz)


Ka Band (33 GHz)


Q Band (41 GHz)


V Band (61 GHz)


W Band (94 GHz)

WMAP Foregrounds
Red=Synchrotron Green=Free-Free Blue=Thermal Dust

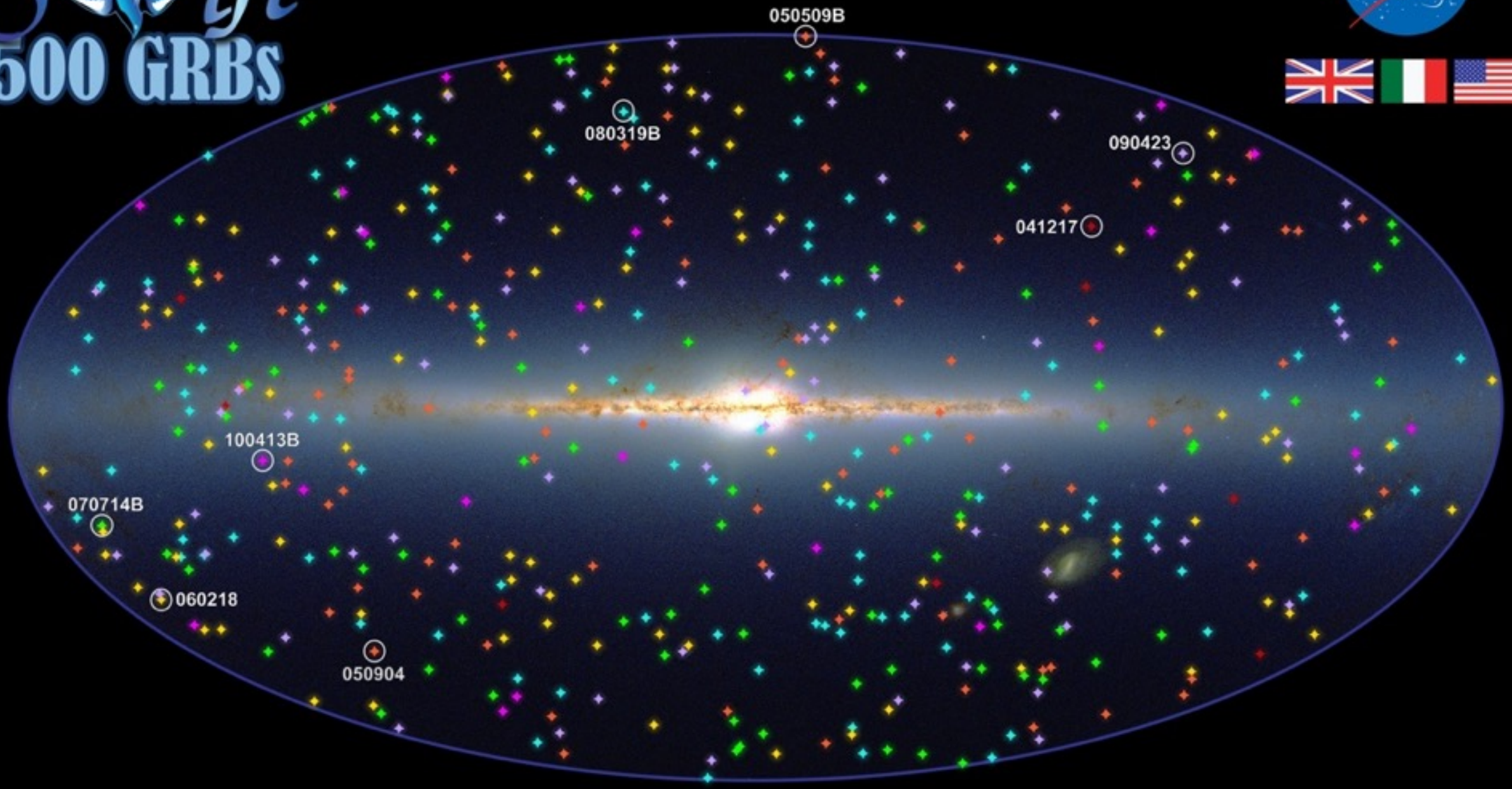
Goddard Space Flight Center • Princeton University • University of Chicago • UCLA • University of British Columbia • Brown University
http://map.gsfc.nasa.gov • http://lambda.gsfc.nasa.gov

NW-2002-5-032-GSFC

Swift

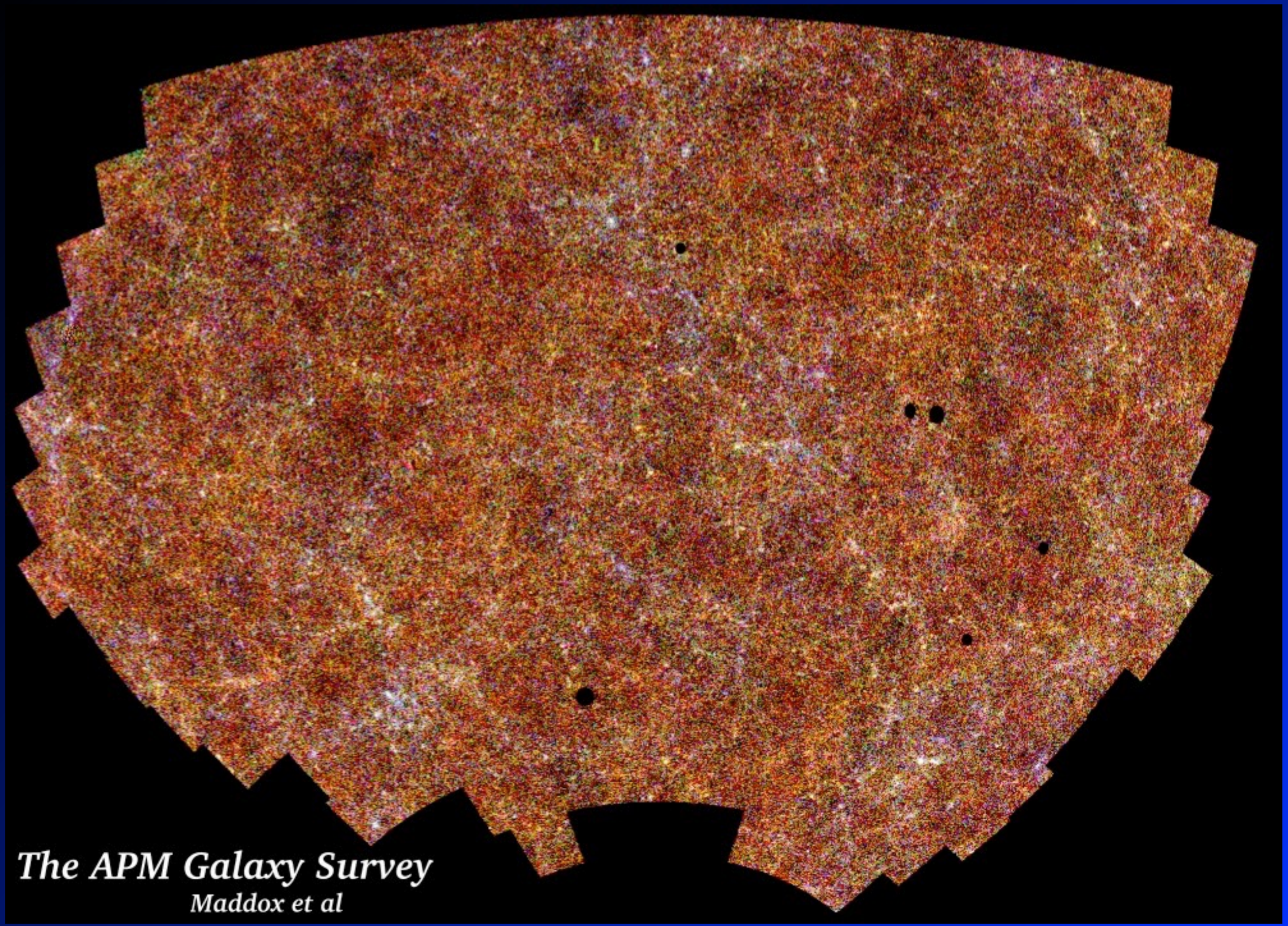
500 GRBs

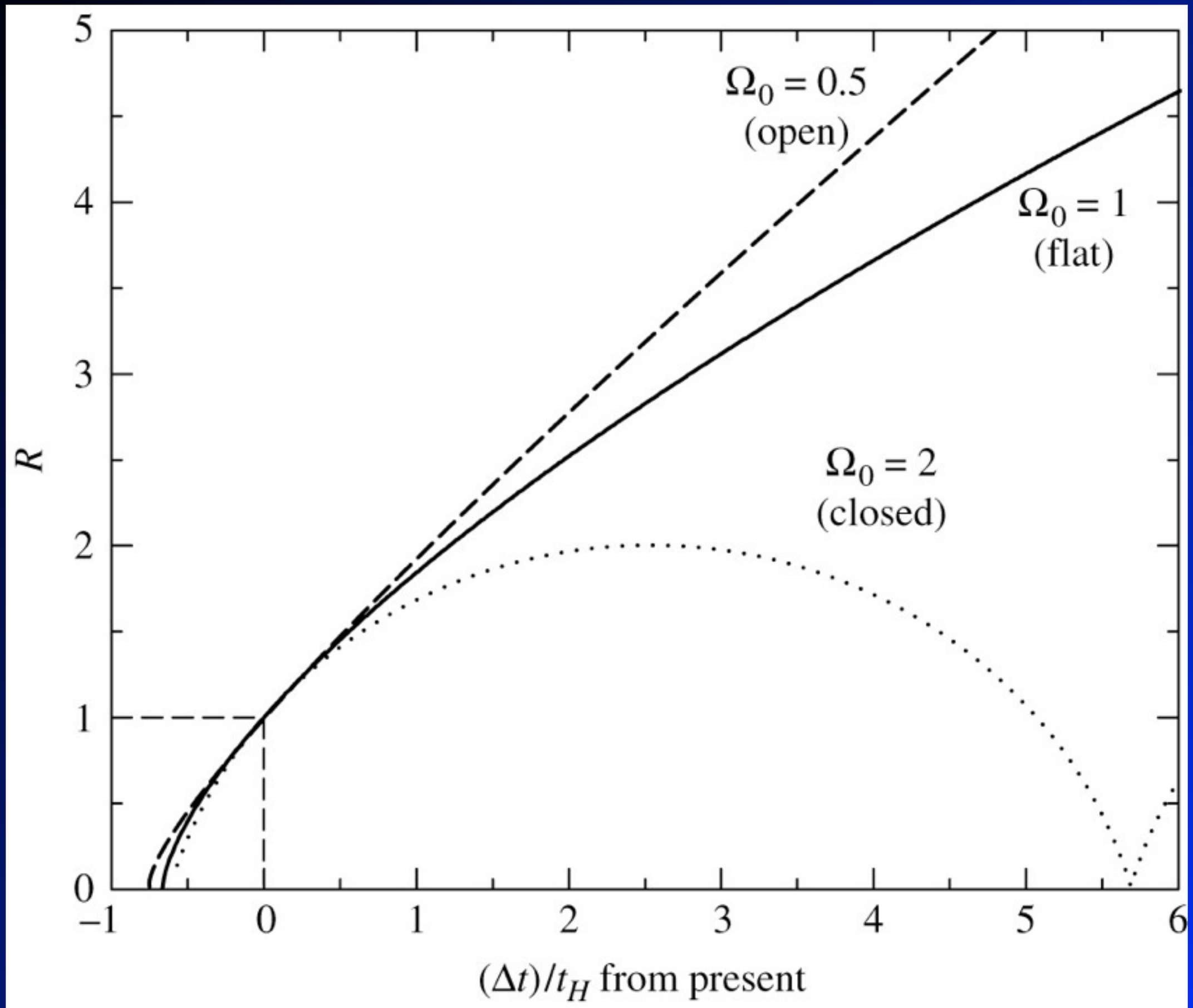
NASA



2004 2005 2006 2007 2008 2009 2010

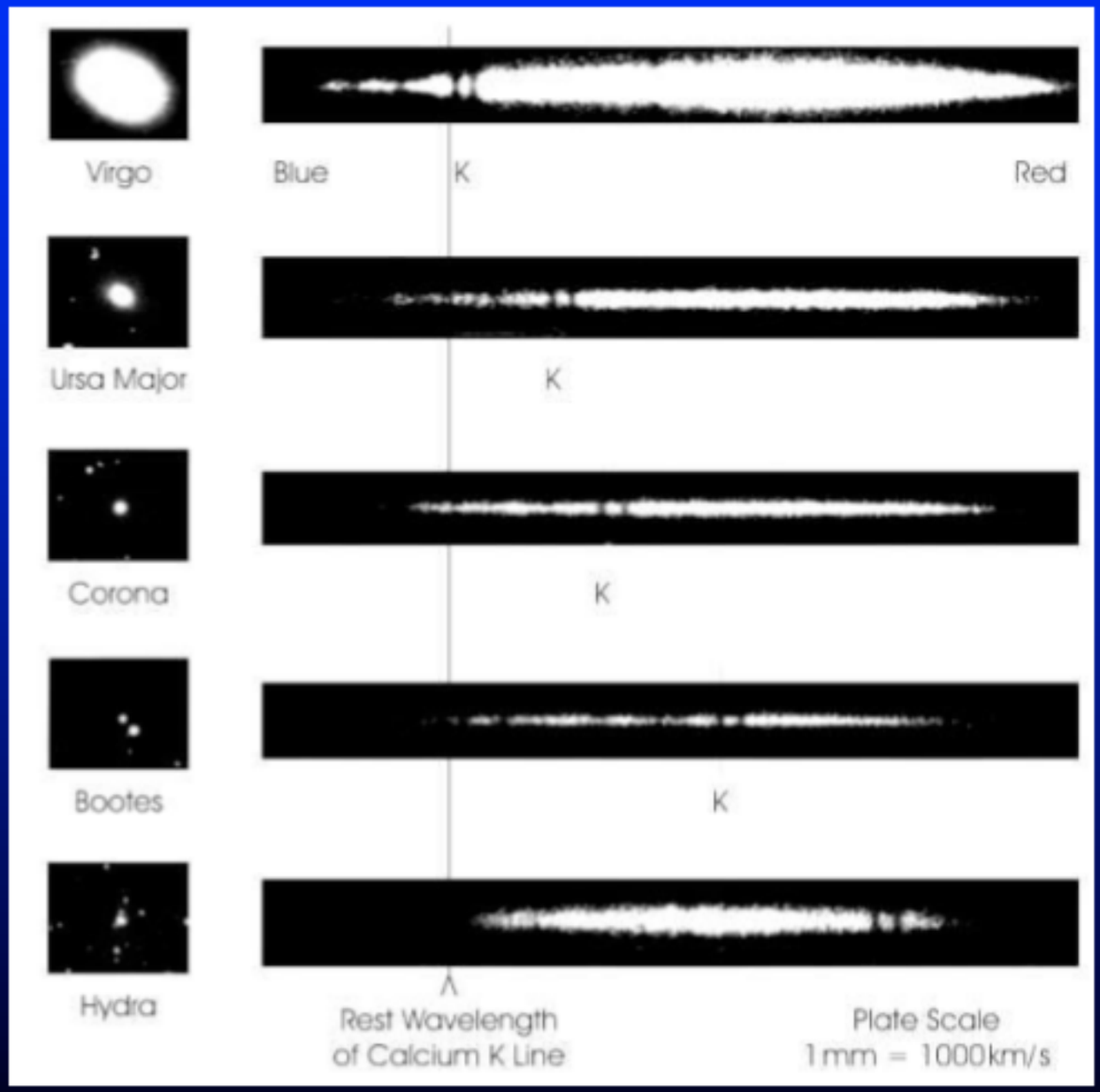
www.nasa.gov/swift


The APM Galaxy Survey
Maddox et al

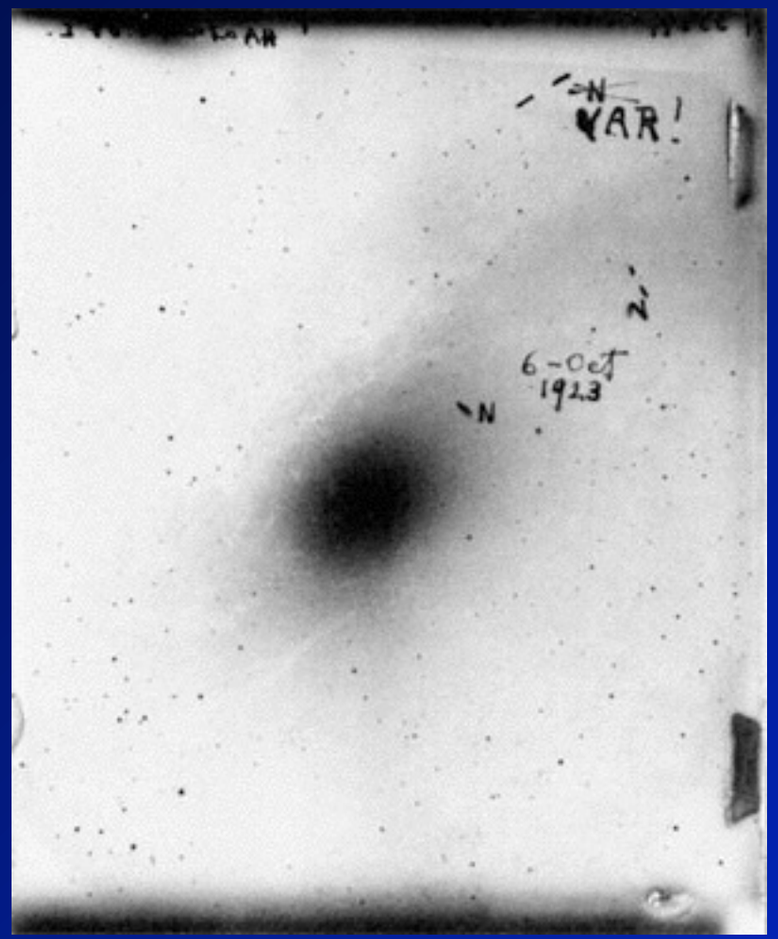

5
4
3
2
1
0
R
$\Omega_0 = 0.5$
(open)
$\Omega_0 = 1$
(flat)
$\Omega_0 = 2$
(closed)
−1
0
1
2
3
4
5
6
$(\Delta t)/t_H$ from present

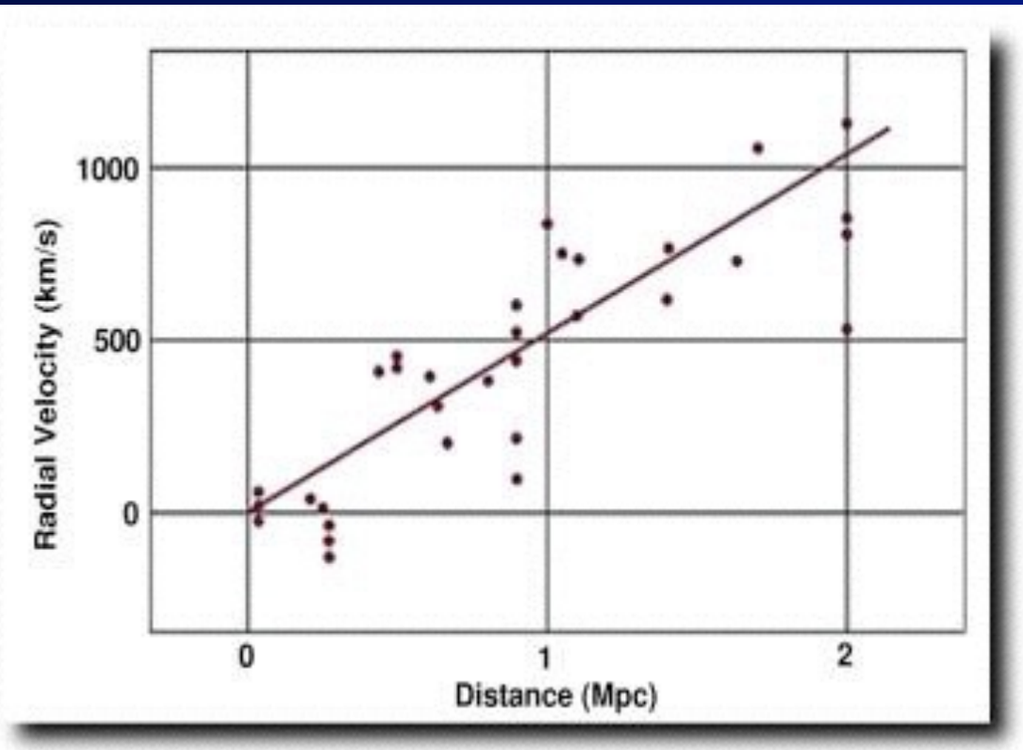
Vesto Melvin Slipher

- Used the Lowell 24” refractor to measure the speeds of approach or recession of galaxies

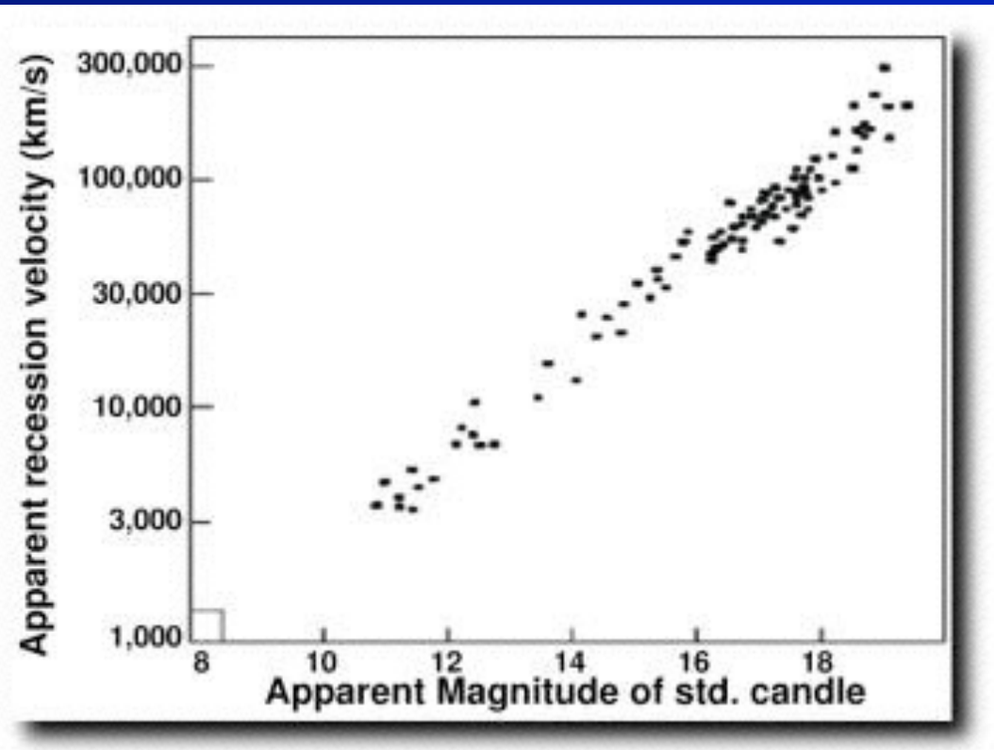


Hubble expansion
v = Hd

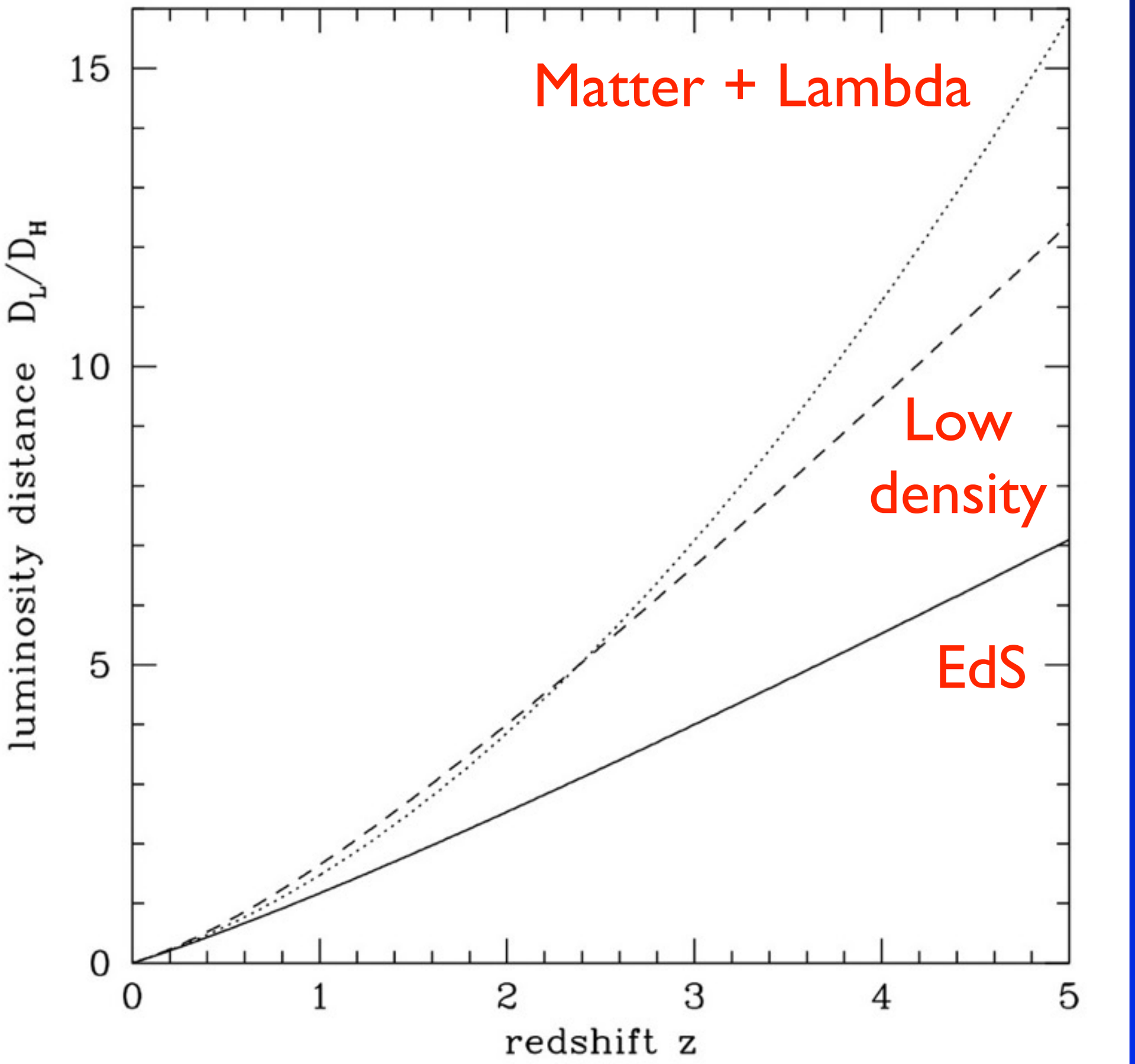


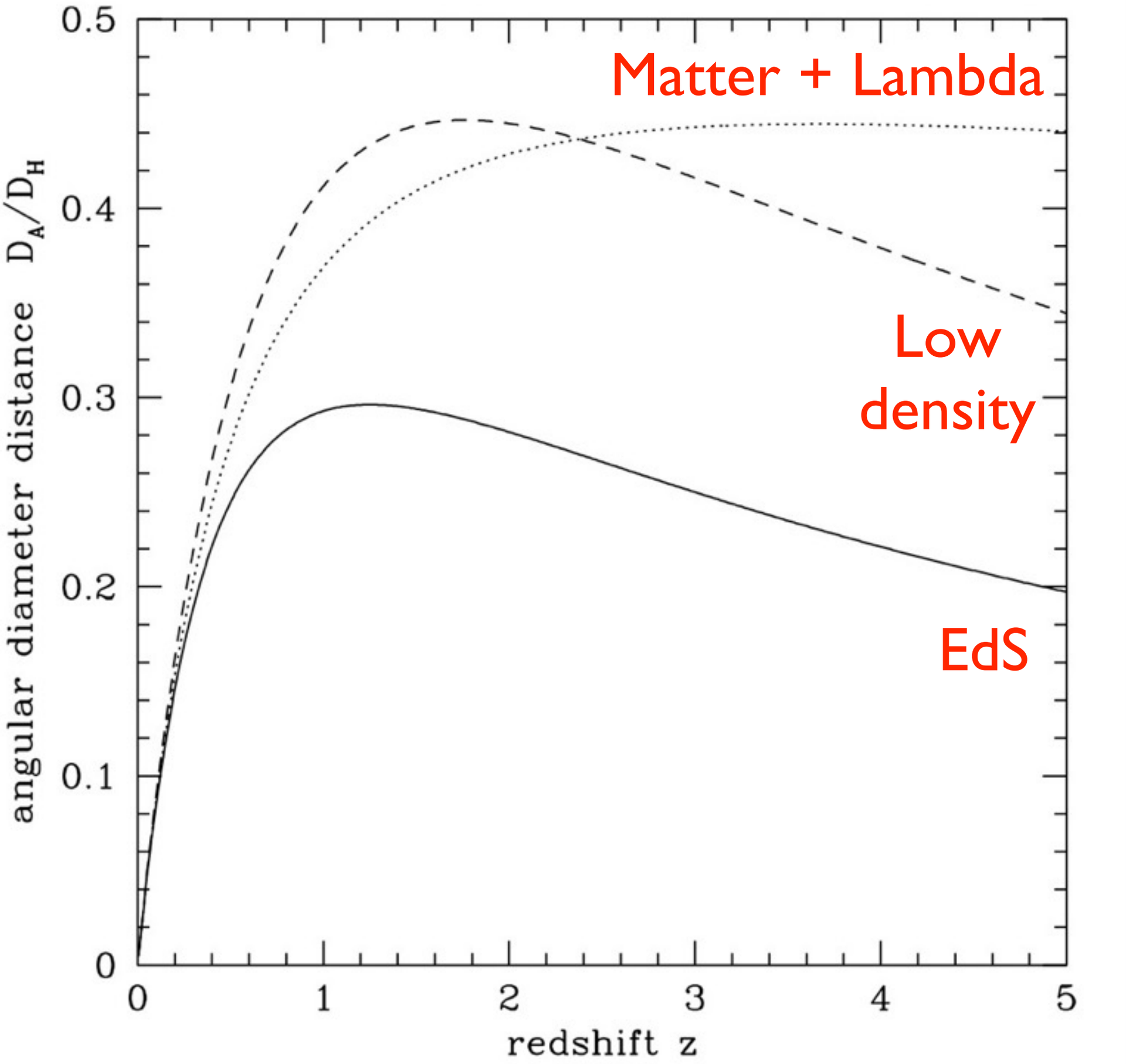


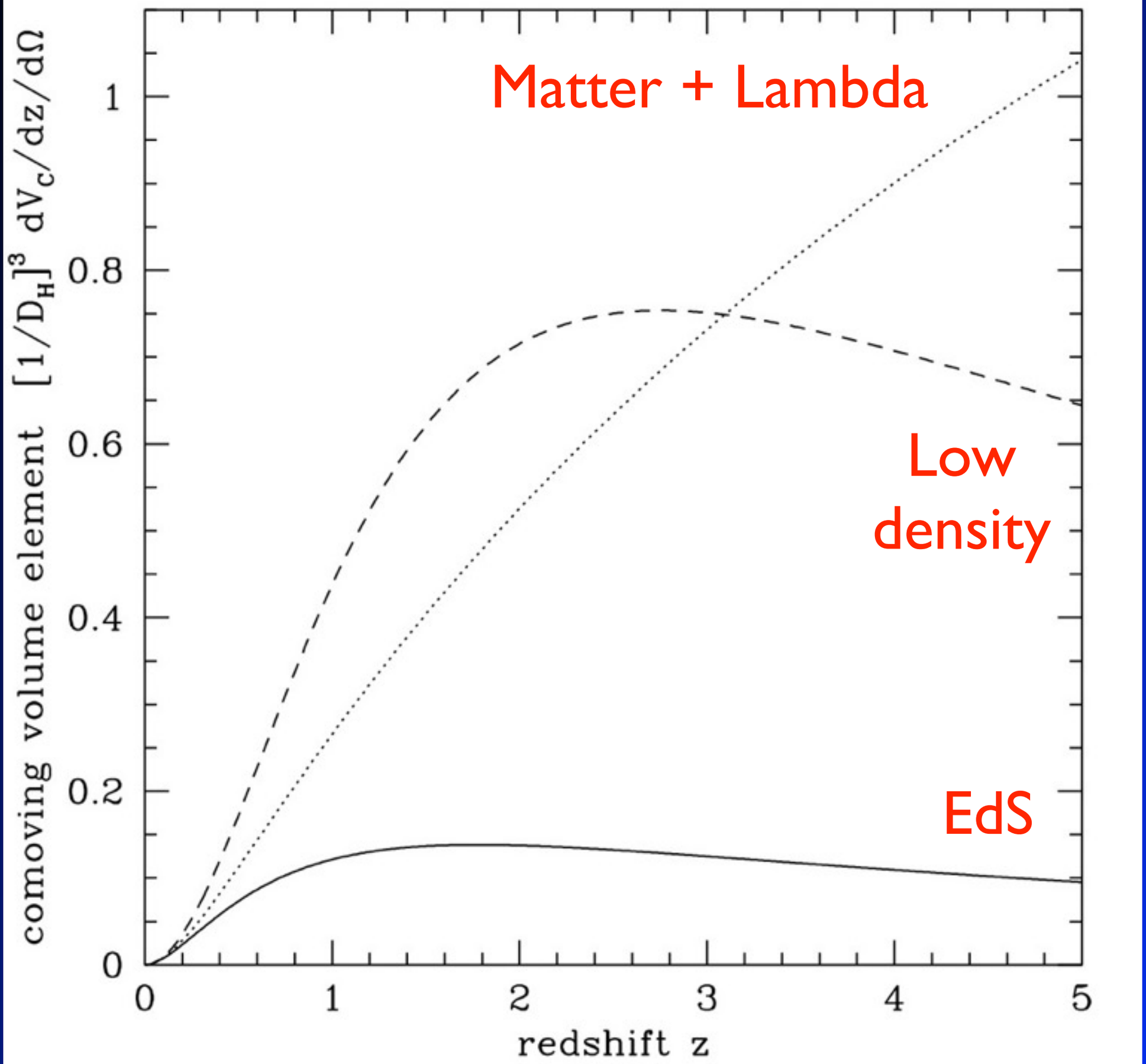
Hubbles' Original Data

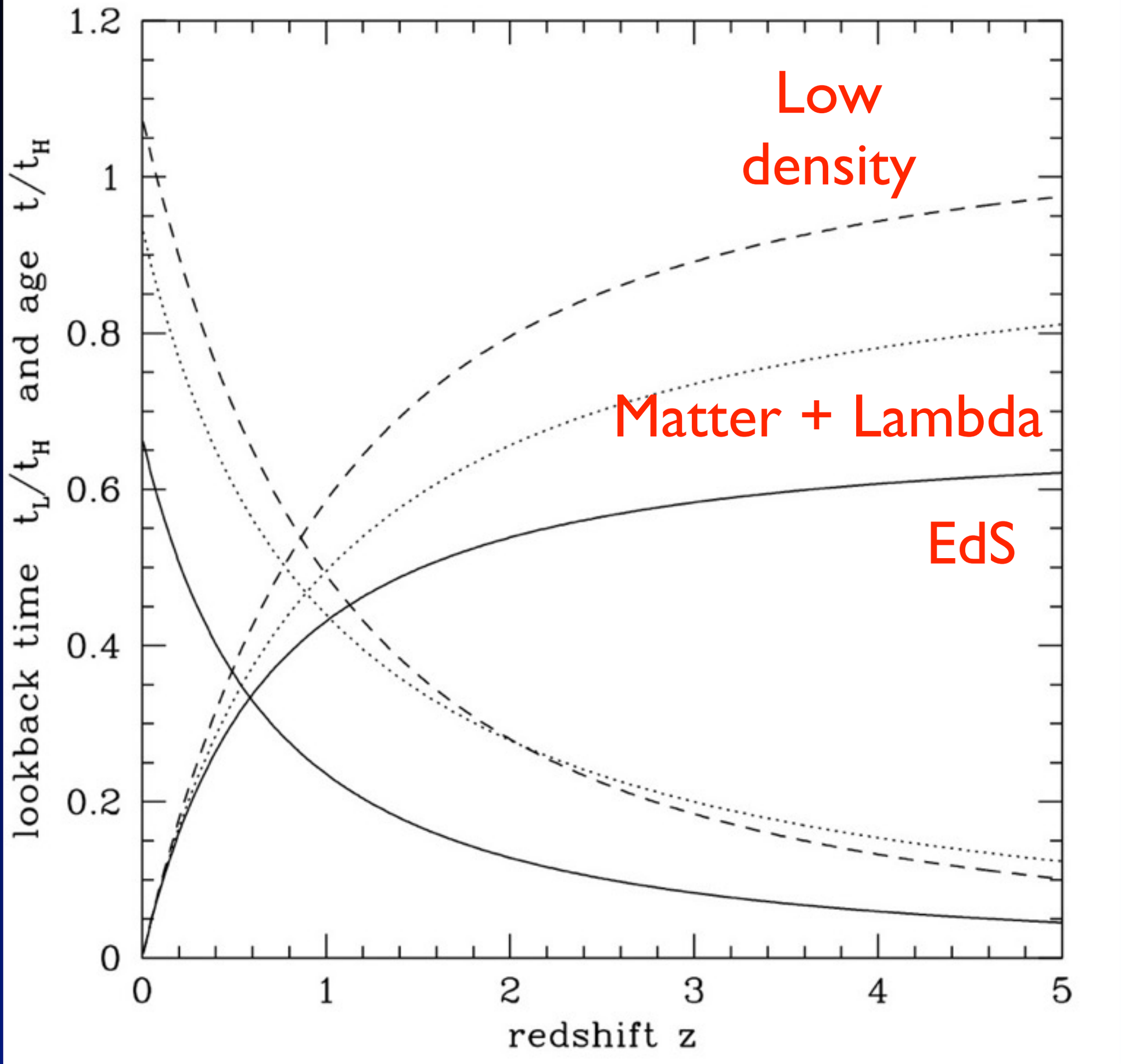


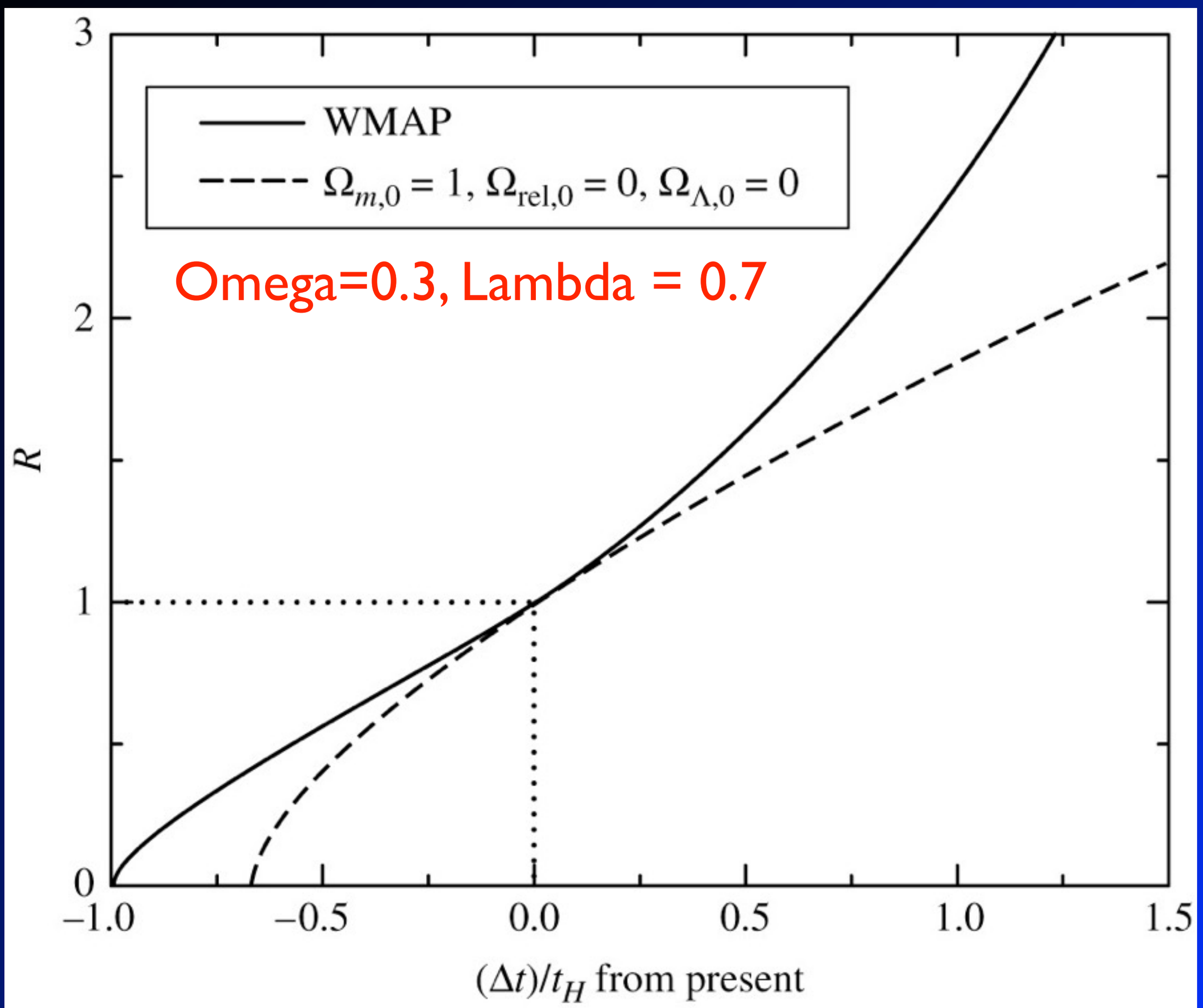
Modern Data

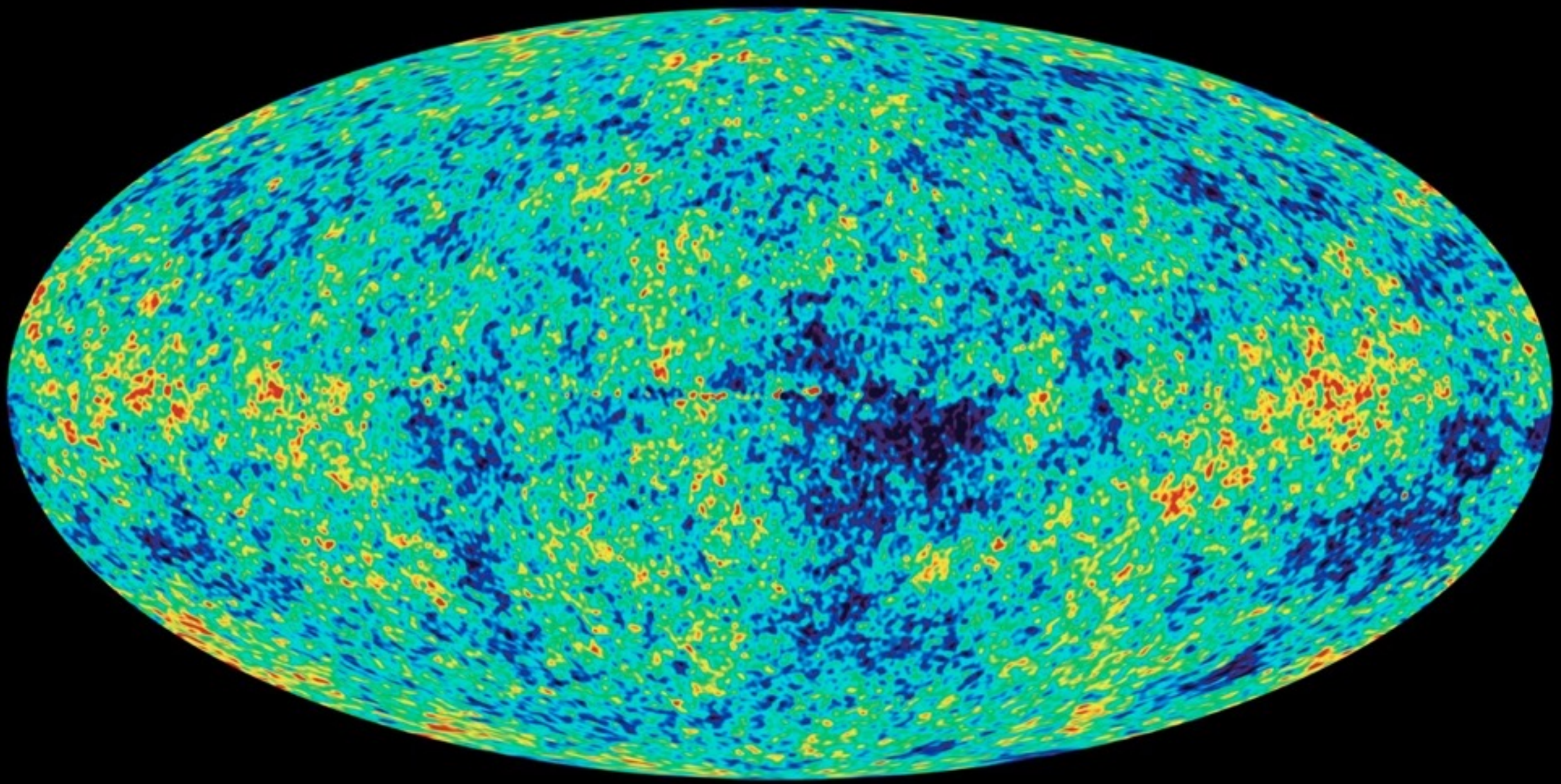

Matter + Lambda
Low density
EdS
luminosity distance D_L/D_H
redshift z
0
5
10
15
0
1
2
3
4
5

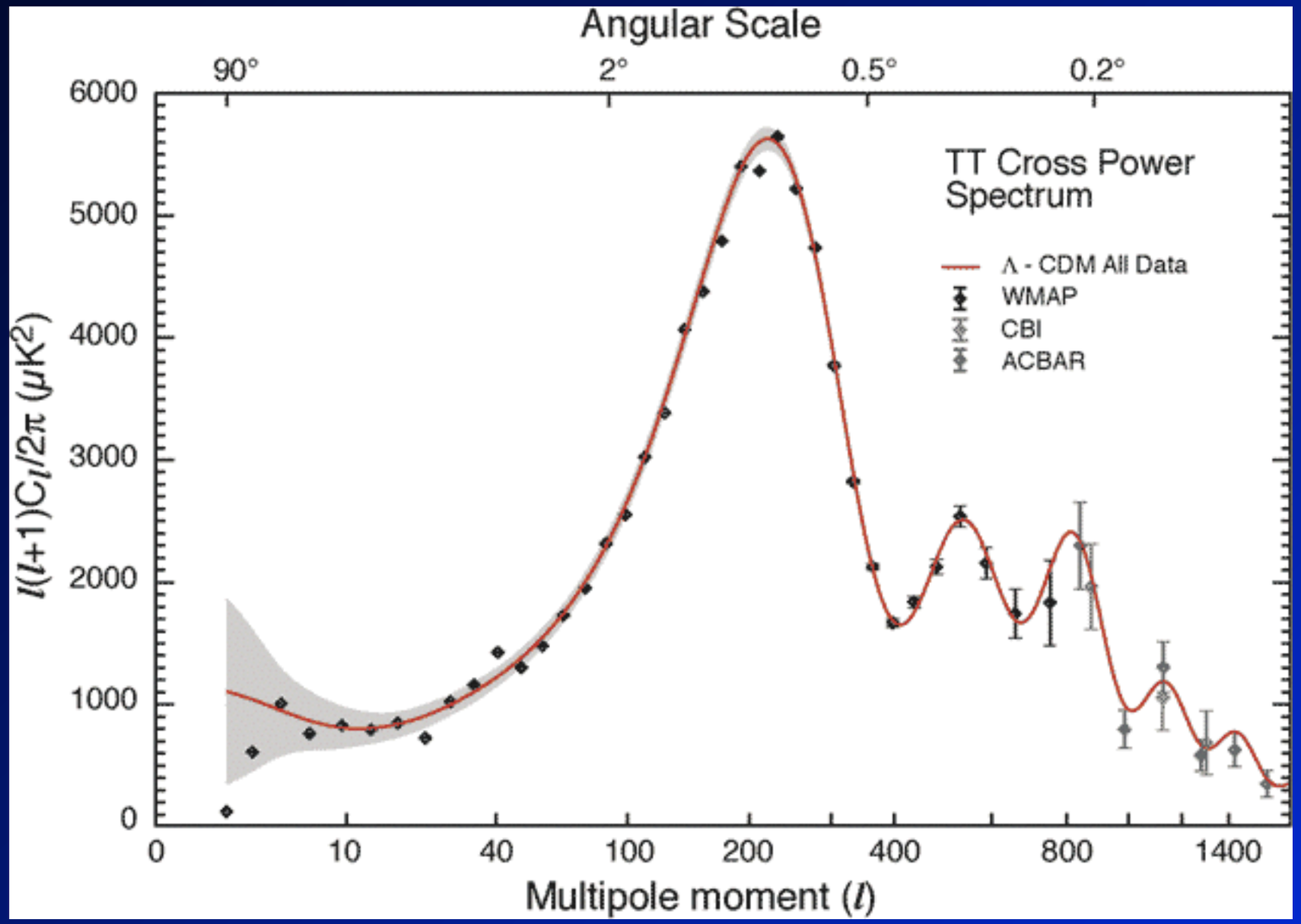

Matter + Lambda
Low
density
EdS
angular diameter distance D_A/D_H
redshift z
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5

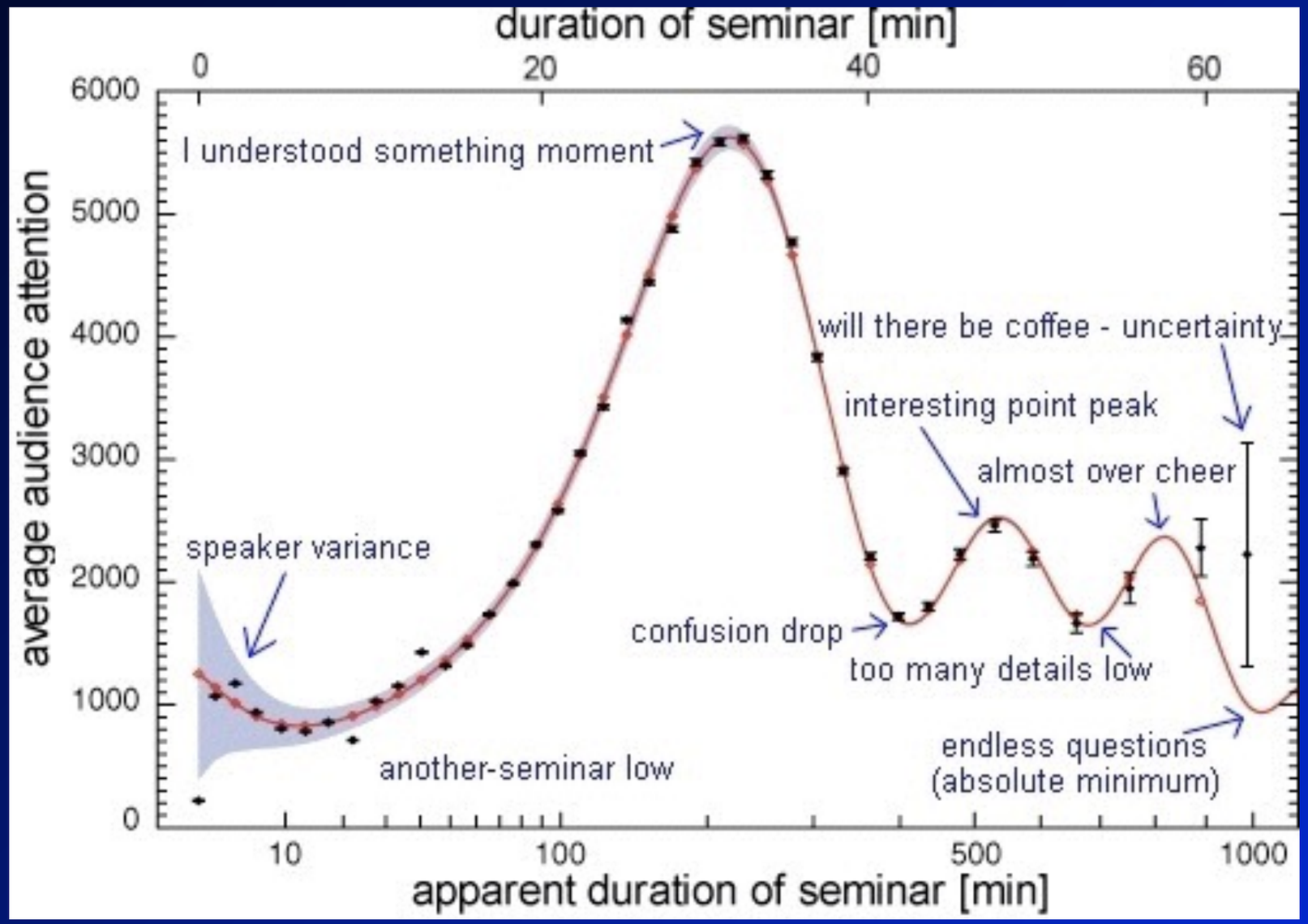

Matter + Lambda
Low density
EdS
comoving volume element [1/D_H]^3 dV_C/dz/dΩ
redshift z
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5


Low
density
Matter + Lambda
EdS
lookback time t_L/t_H and age t/t_H
redshift z
0
0.2
0.4
0.6
0.8
1
1.2
0
1
2
3
4
5


WMAP
$\Omega_{m,0} = 1, \Omega_{\mathrm{rel},0} = 0, \Omega_{\Lambda,0} = 0$
Omega=0.3, Lambda = 0.7
R
3
2
1
0
−1.0
−0.5
0.0
0.5
1.0
1.5
$(\Delta t)/t_H$ from present




Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
TT Cross Power Spectrum
Λ - CDM All Data
WMAP
CBI
ACBAR
0
10
40
100
200
400
800
1400
Multipole moment (l)

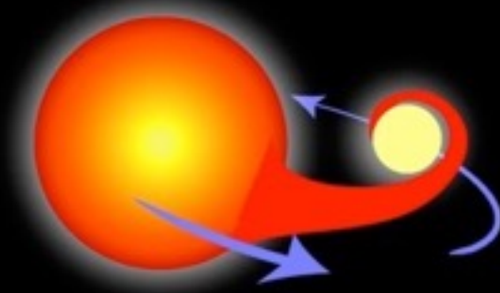

duration of seminar [min]
0
20
40
60
6000
5000
4000
3000
2000
1000
0
average audience attention
I understood something moment
will there be coffee - uncertainty
interesting point peak
almost over cheer
speaker variance
confusion drop
too many details low
endless questions
(absolute minimum)
another-seminar low
10
100
500
1000
apparent duration of seminar [min]


SN 2005df
SN 2006bp

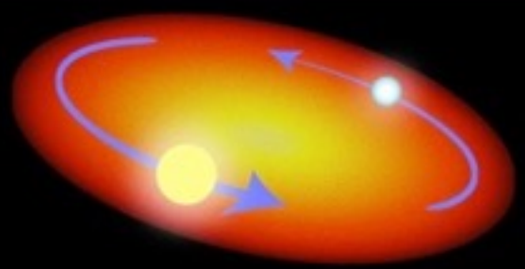
The progenitor of a Type Ia supernova

Two normal stars are in a binary pair.

The more massive star becomes a giant...



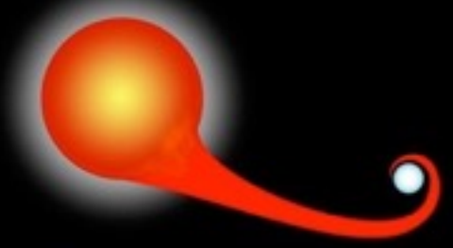
...which spills gas onto the secondary star, causing it to expand and become engulfed.



The secondary, lighter star and the core of the giant star spiral inward within a common envelope.

The common envelope is ejected, while the separation between the core and the secondary star decreases.

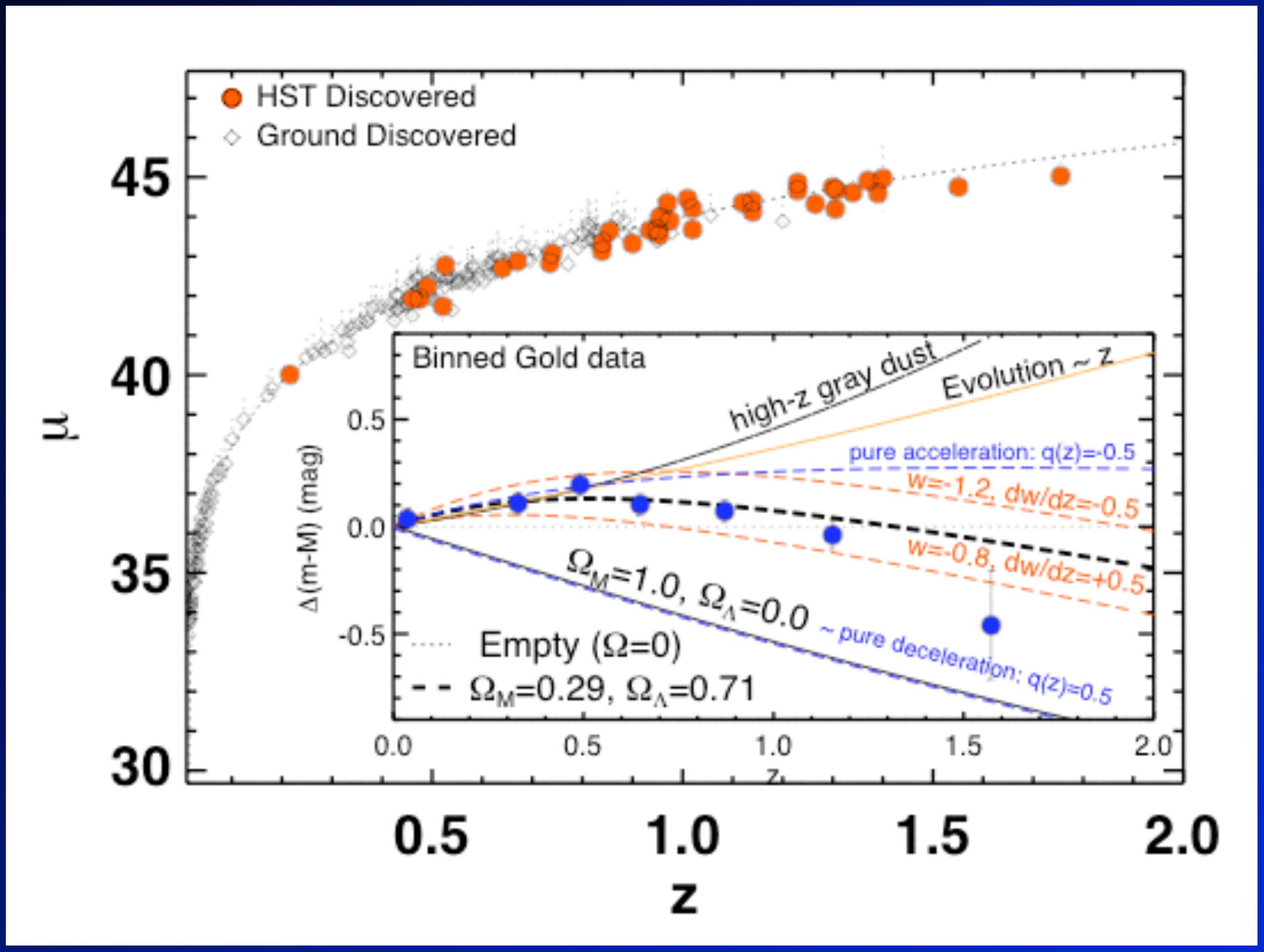
The remaining core of the giant collapses and becomes a white dwarf.

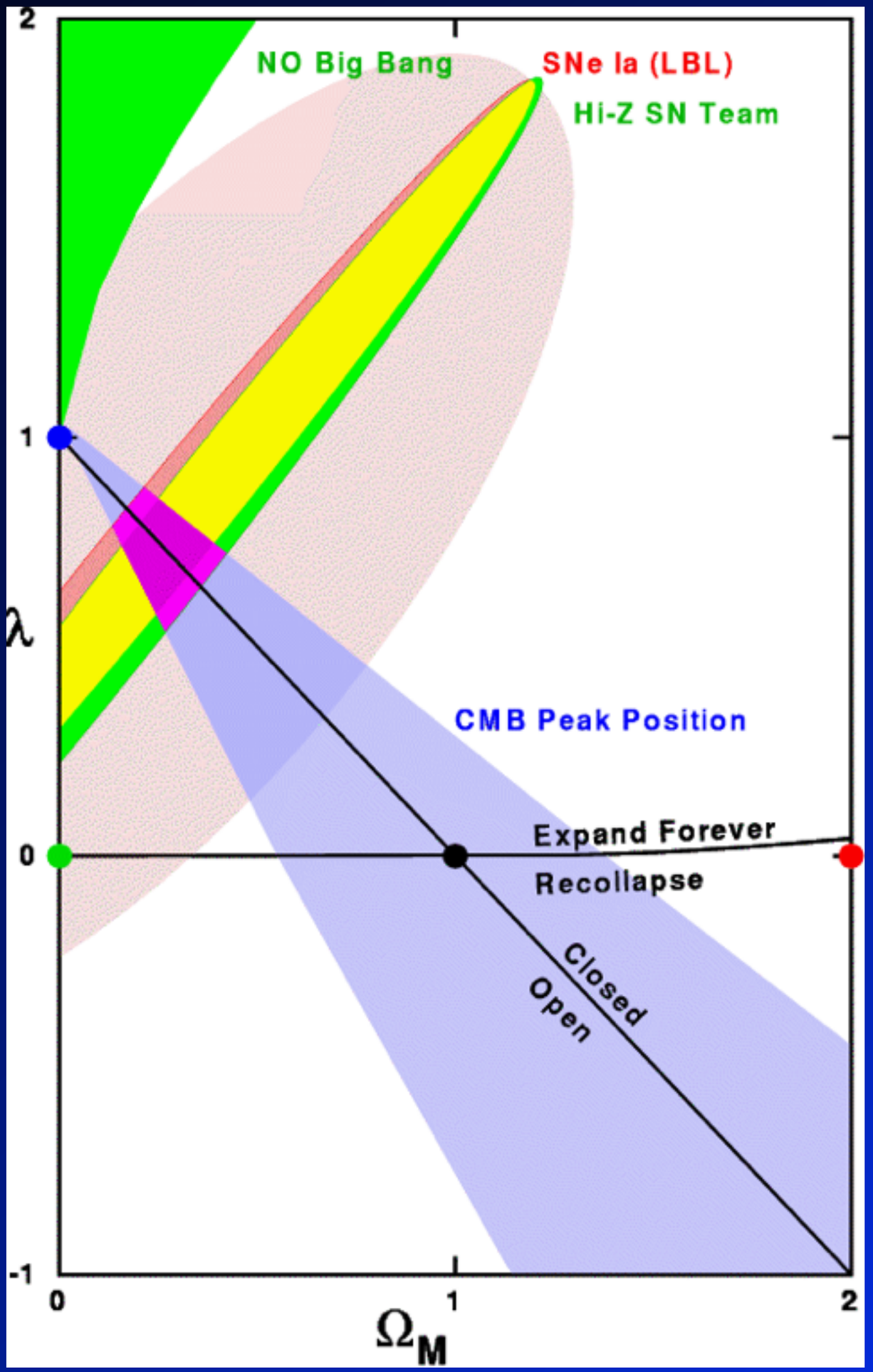


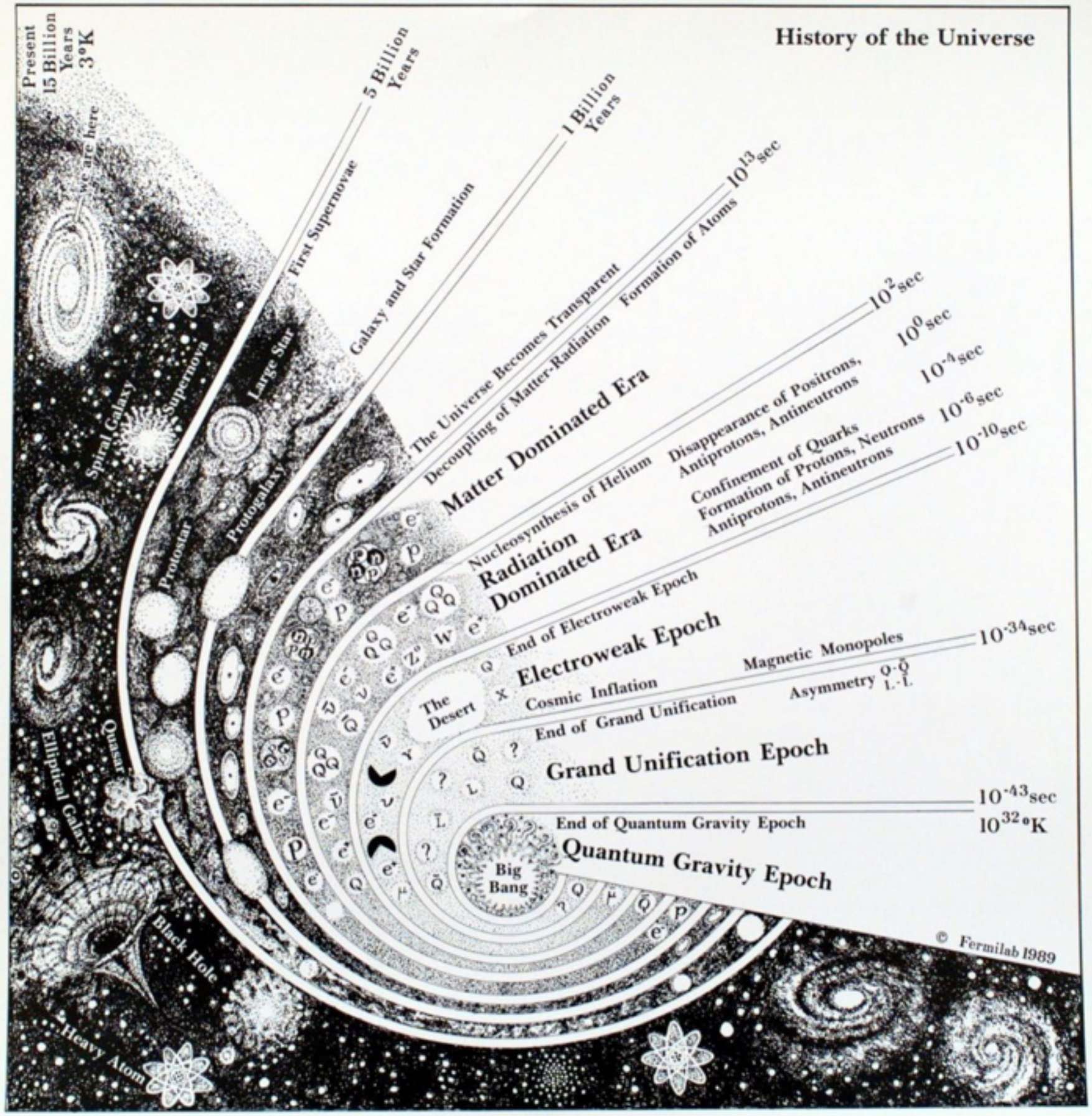
The aging companion star starts swelling, spilling gas onto the white dwarf.

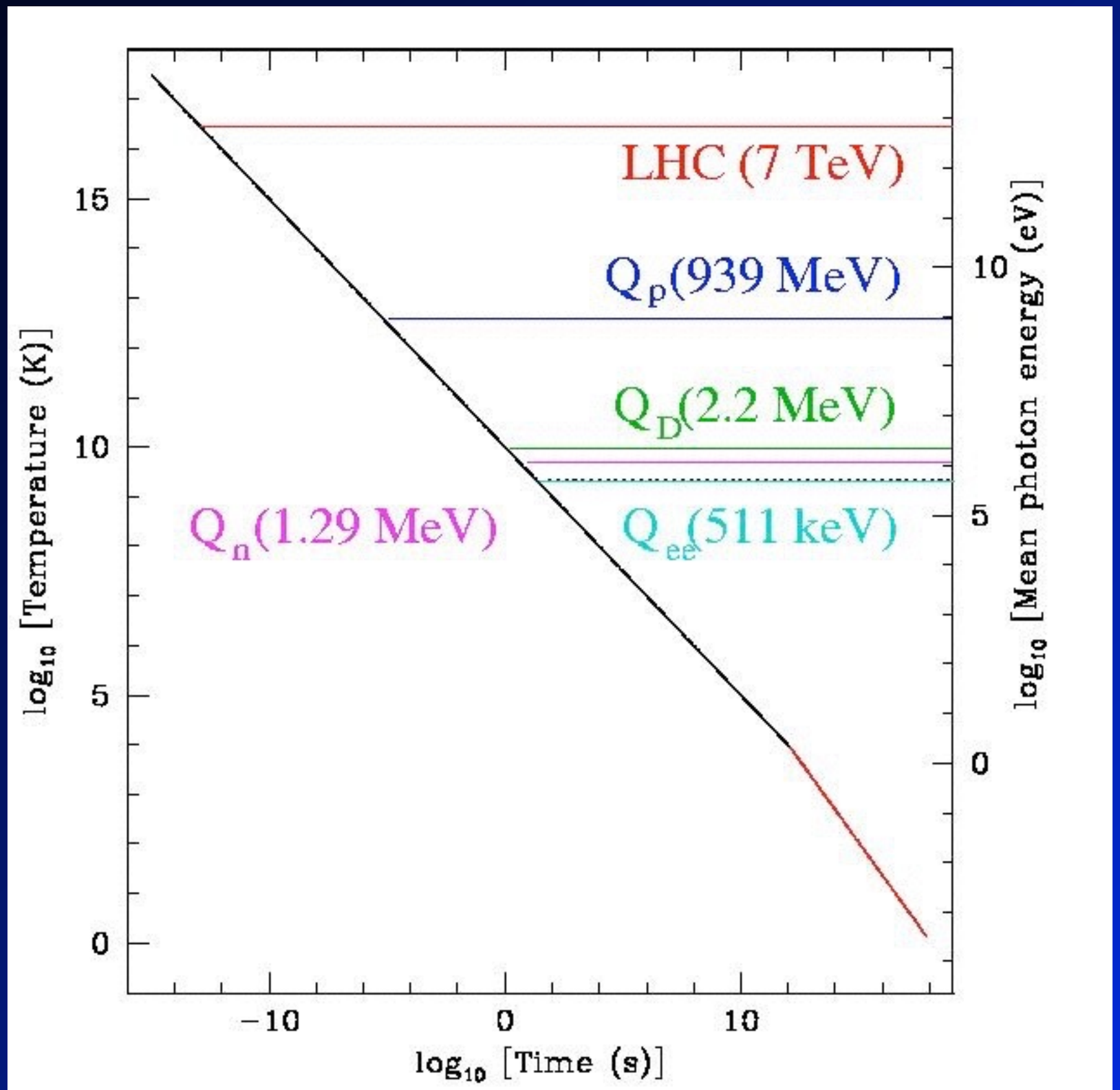
The white dwarf's mass increases until it reaches a critical mass and explodes...

...causing the companion star to be ejected away.

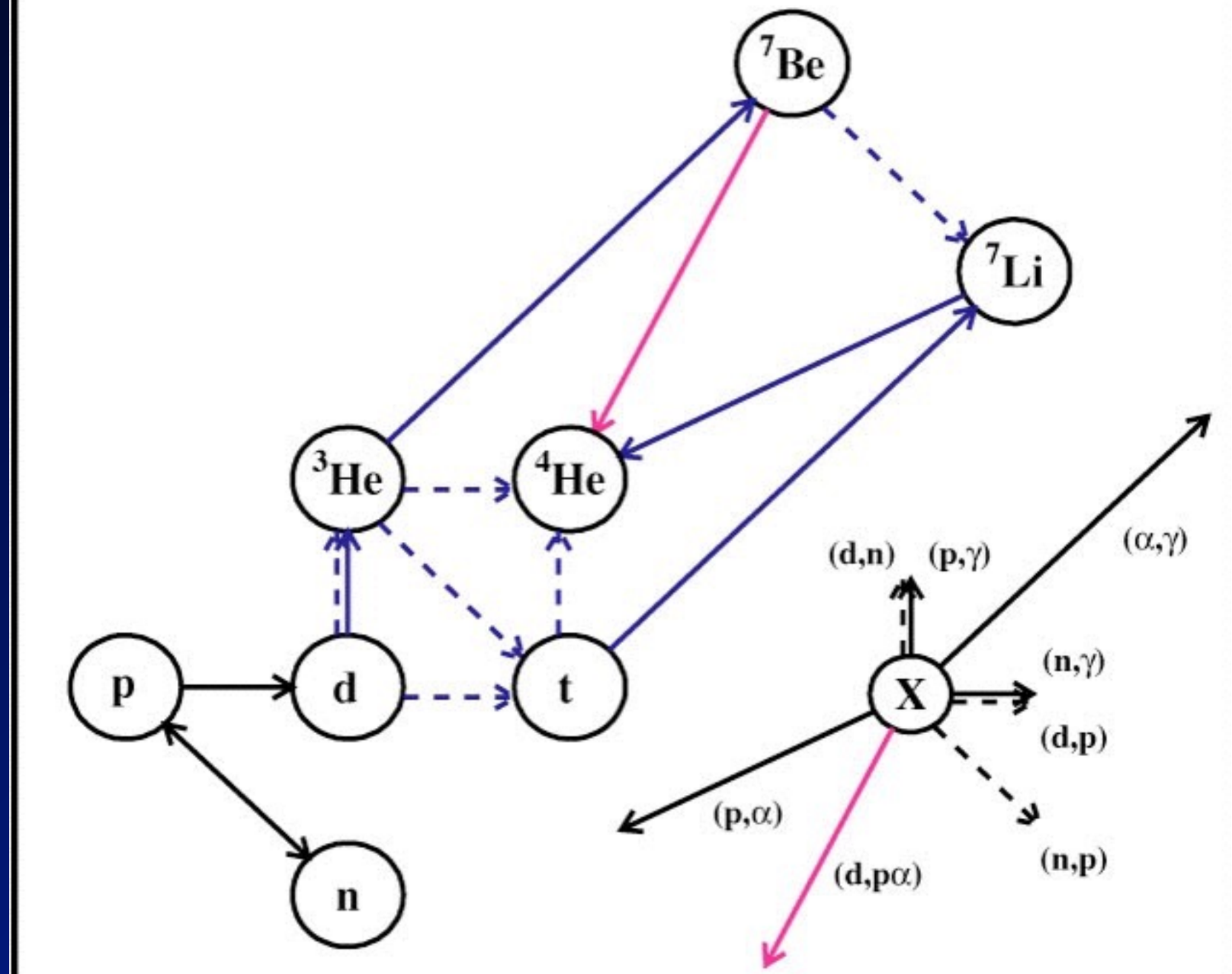

HST Discovered
Ground Discovered
μ
45
40
35
30
0.5
1.0
1.5
2.0
z
Binned Gold data
Δ(m-M) (mag)
0.5
0.0
-0.5
0.0
0.5
1.0
1.5
2.0
z
high-z gray dust
Evolution ~ z
pure acceleration: q(z)=-0.5
w=-1.2, dw/dz=-0.5
w=-0.8, dw/dz=+0.5
Ω_M=1.0, Ω_Λ=0.0 ~ pure deceleration: q(z)=0.5
Empty (Ω=0)
Ω_M=0.29, Ω_Λ=0.71

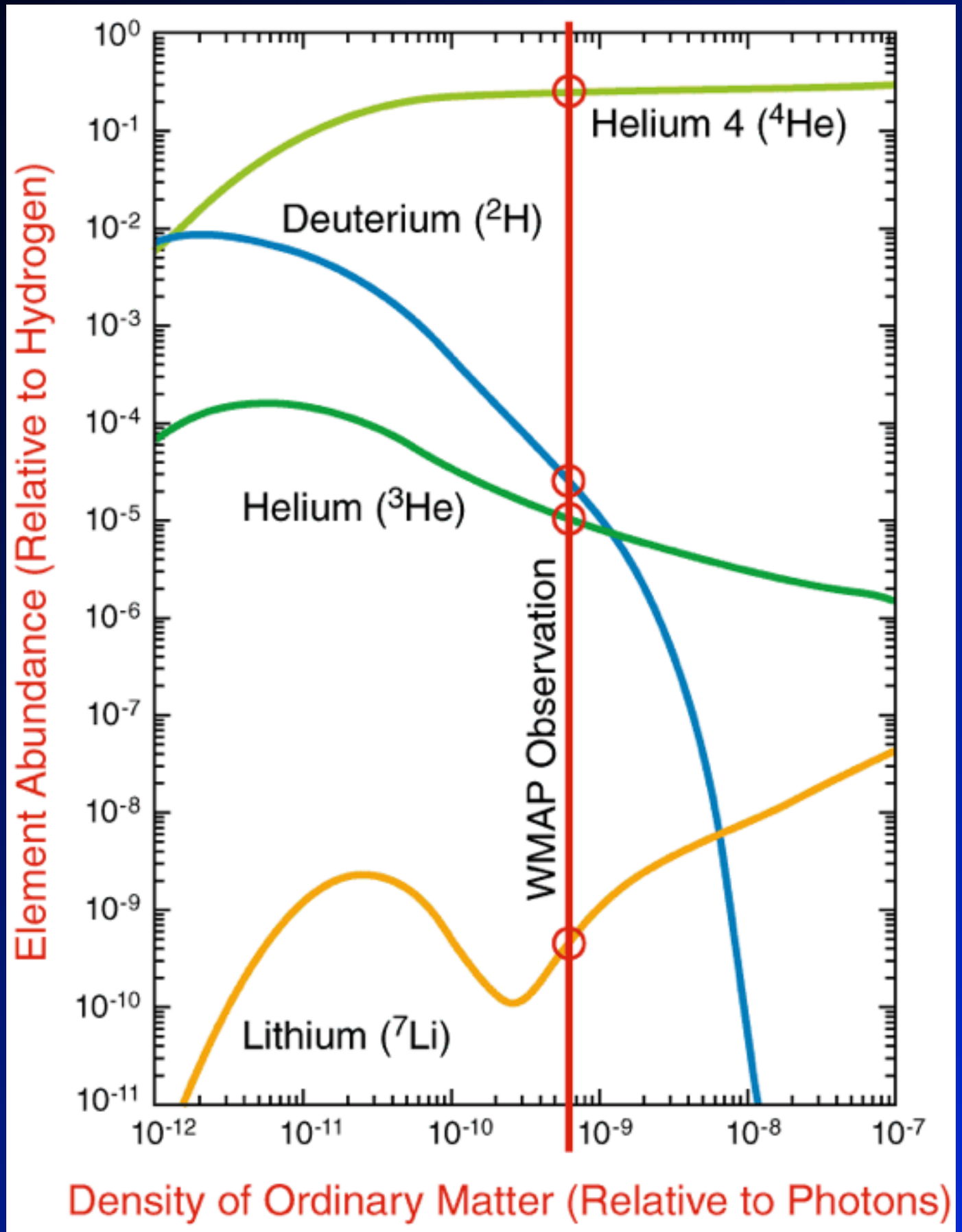

NO Big Bang
SNe Ia (LBL)
Hi-Z SN Team
CMB Peak Position
Expand Forever
Recollapse
Closed
Open
λ
2
1
0
-1
0
1
2
Ω_M


History of the Universe
Present
15 Billion
Years
3°K
we are here
5 Billion
Years
1 Billion
Years
10^{13}sec
10^{2}sec
10^{0}sec
10^{-4}sec
10^{-6}sec
10^{-10}sec
10^{-34}sec
10^{-43}sec
10^{32}°K
Spiral Galaxy
Supernova
Large Star
Protostar
Protogalaxy
First Supernovae
Galaxy and Star Formation
The Universe Becomes Transparent
Decoupling of Matter-Radiation
Formation of Atoms
Matter Dominated Era
Nucleosynthesis of Helium
Disappearance of Positrons, Antiprotons, Antineutrons
Confinement of Quarks
Formation of Protons, Neutrons Antiprotons, Antineutrons
Radiation Dominated Era
End of Electroweak Epoch
Electroweak Epoch
The Desert
Cosmic Inflation
Magnetic Monopoles
End of Grand Unification
Asymmetry
Grand Unification Epoch
End of Quantum Gravity Epoch
Quantum Gravity Epoch
Big Bang
Quasar
Elliptical Galaxy
Black Hole
Heavy Atom
© Fermilab 1989


LHC (7 TeV)
Q_p(939 MeV)
Q_D(2.2 MeV)
Q_n(1.29 MeV)
Q_{ee}(511 keV)
15
10
5
0
−10
0
10
$\log_{10}$ [Temperature (K)]
$\log_{10}$ [Mean photon energy (eV)]
$\log_{10}$ [Time (s)]

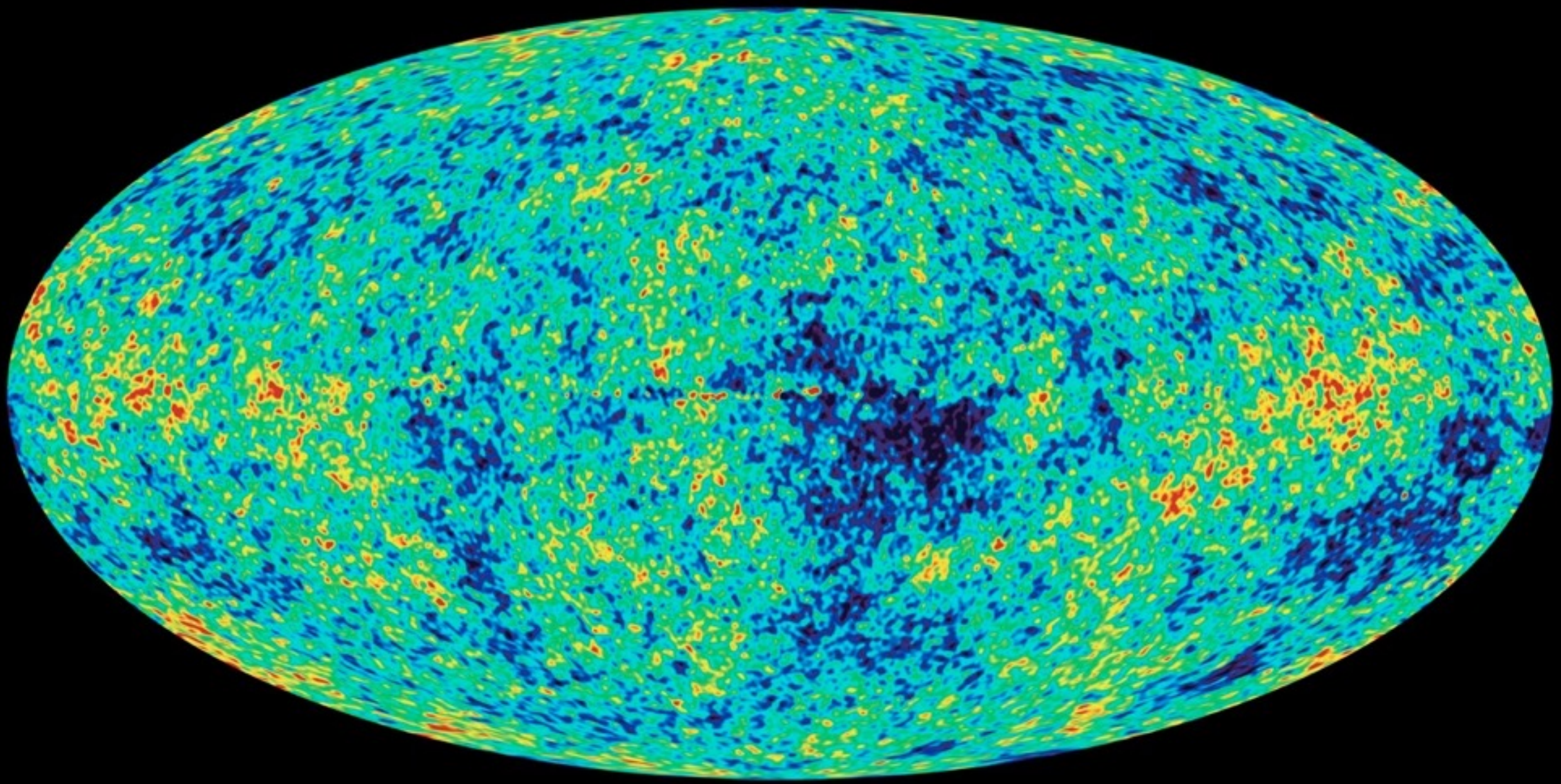
BBN Reaktionsschema

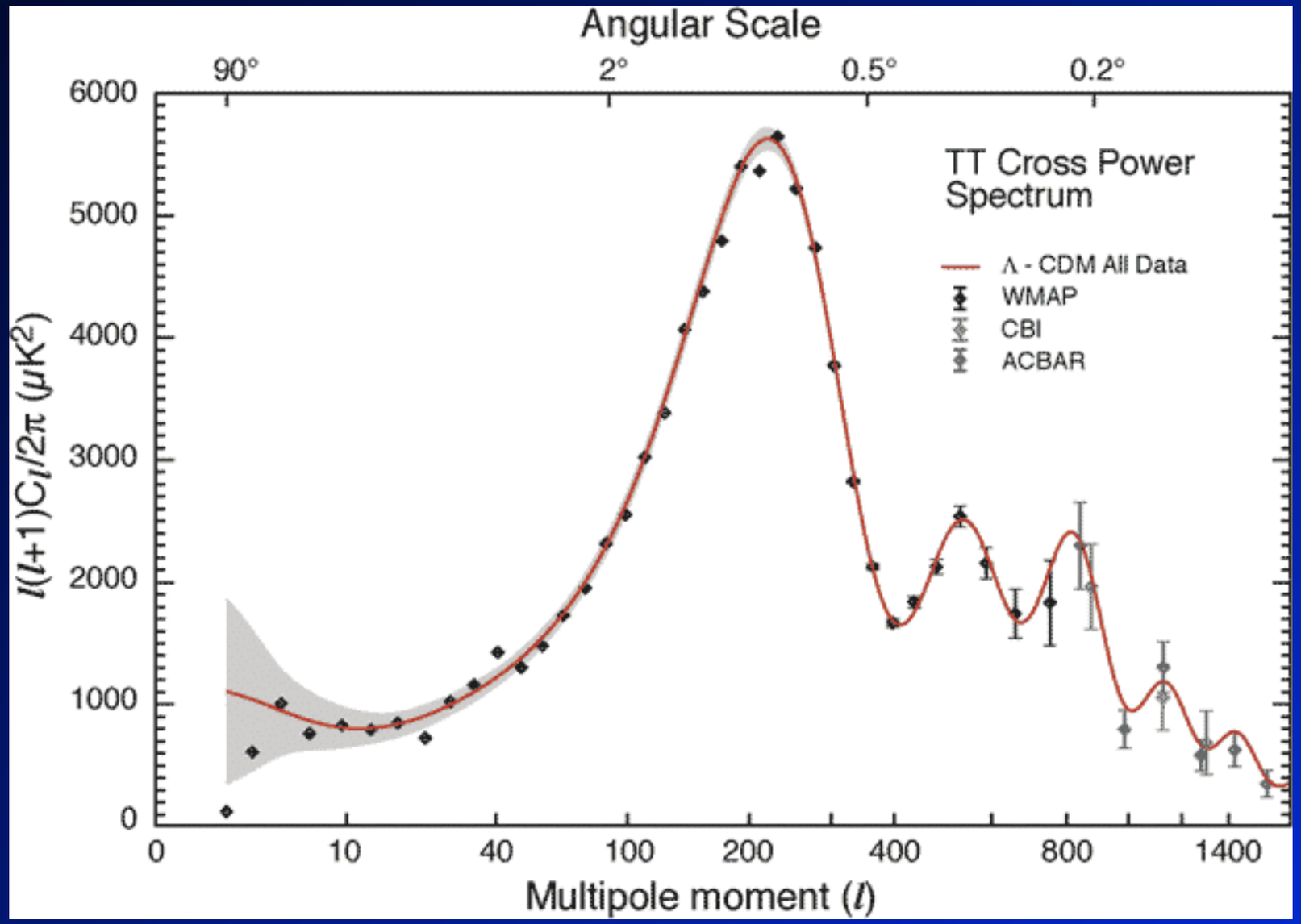




NASA/WMAP Science Team
WMAP101087

Element Abundance graphs: Steigman, Encyclopedia of Astronomy and Astrophysics (Institute of Physics) December, 2000




Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
TT Cross Power Spectrum
Λ - CDM All Data
WMAP
CBI
ACBAR
0
10
40
100
200
400
800
1400
Multipole moment (l)