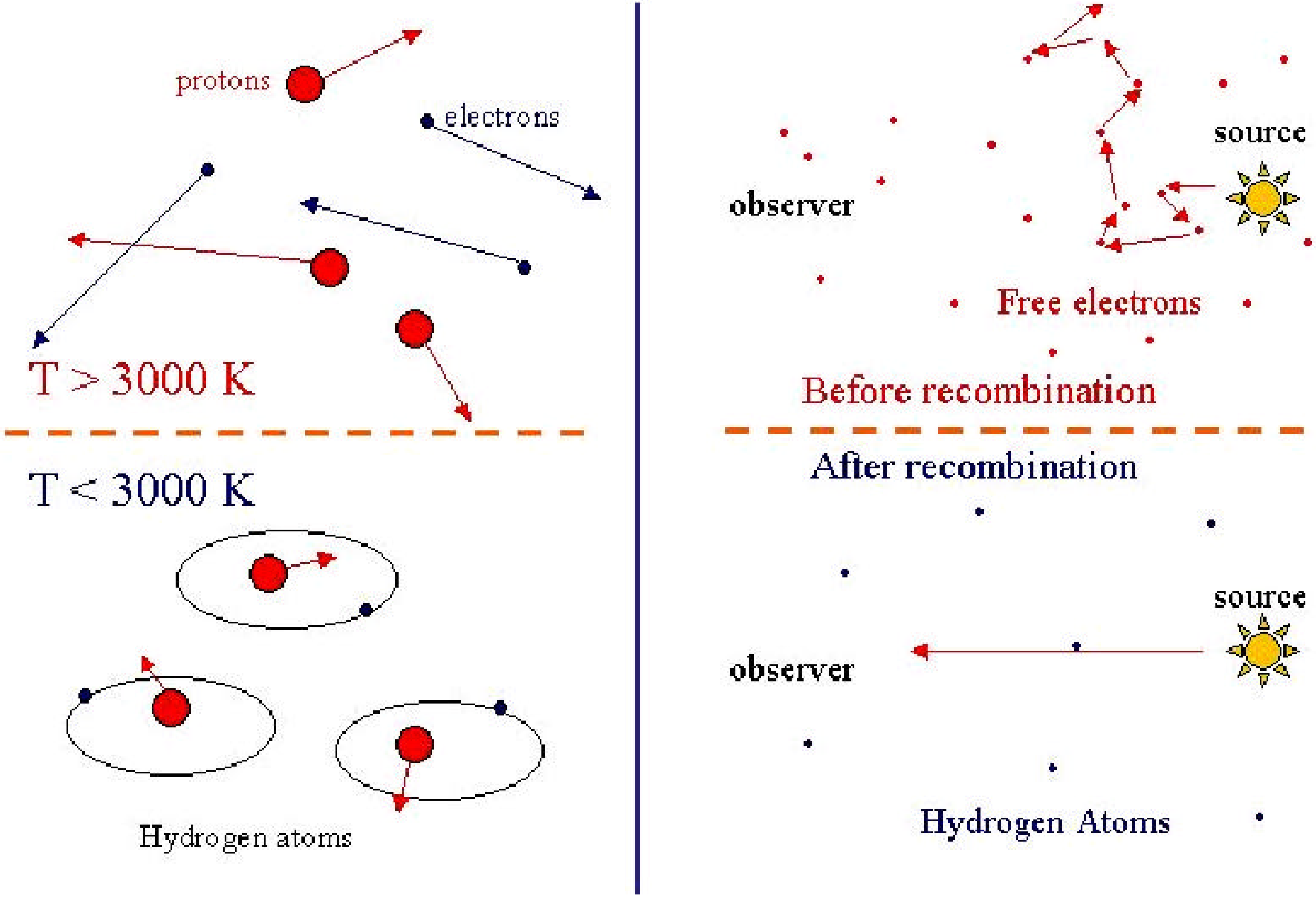
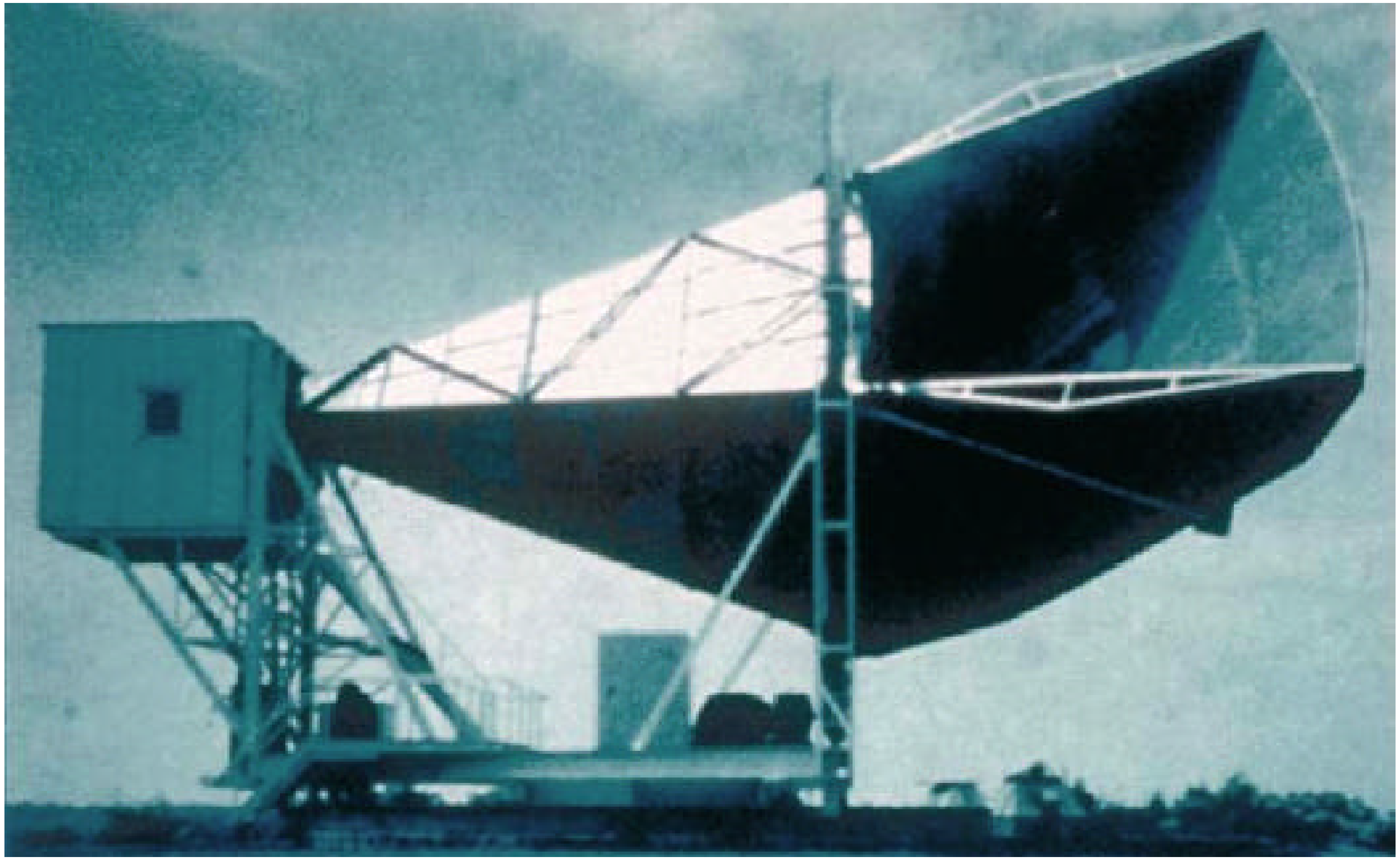
End of Opaque Universe



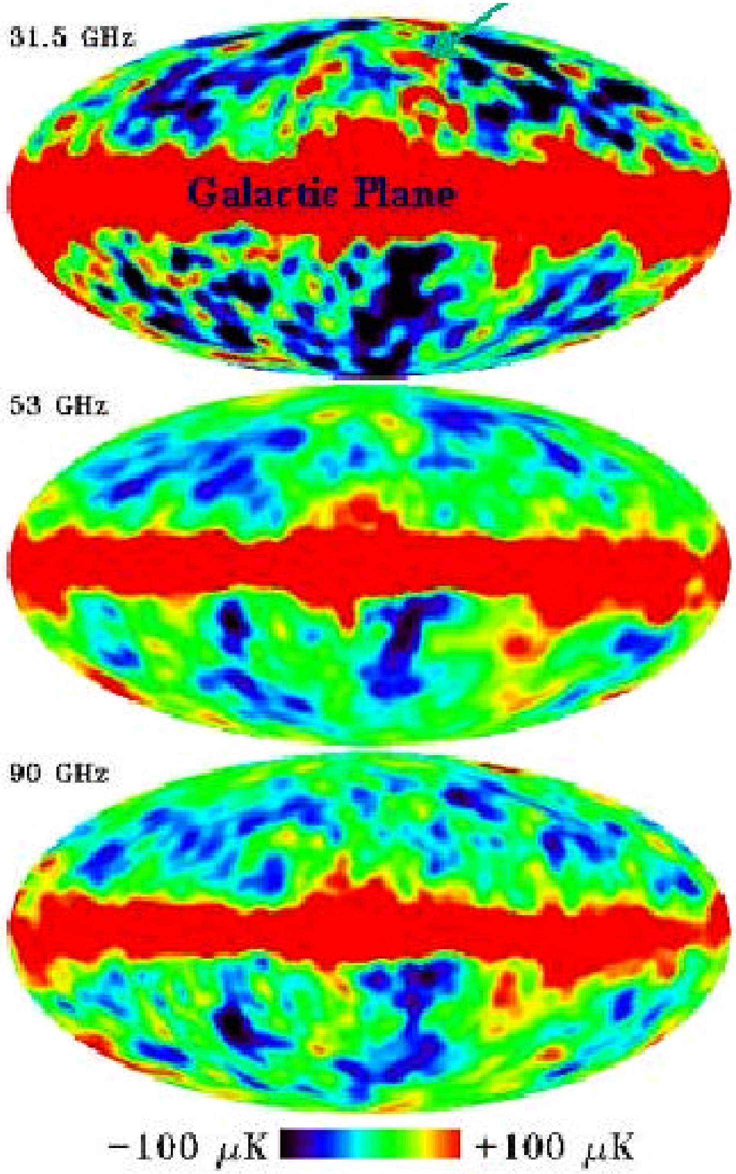
After recombination universe becomes transparent.

See photons as Cosmic Microwave Background Radiation redshifted by 1000 to 2.7K

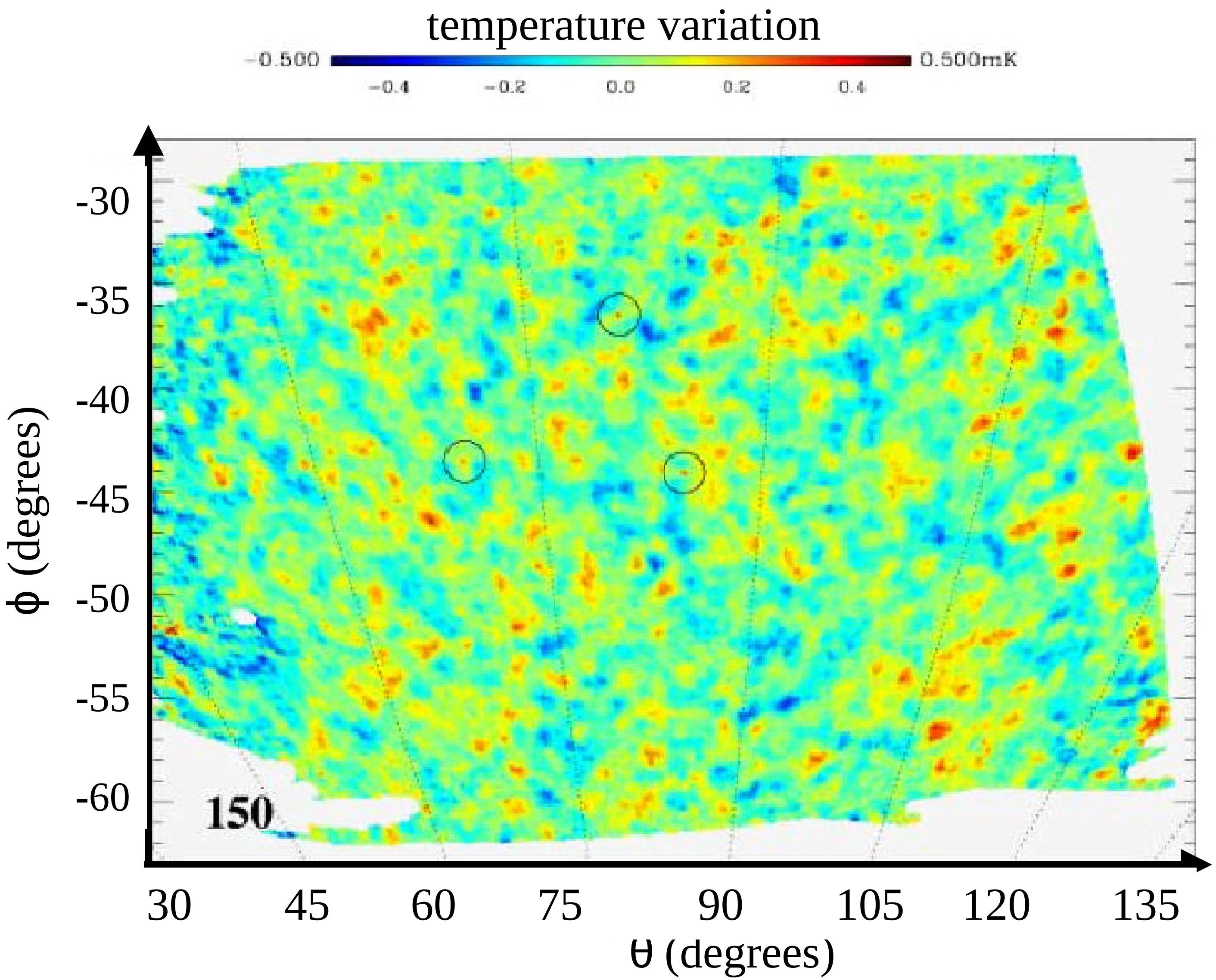
Penzas and Wilson Discovery of Cosmic Microwave Background



Cosmic Microwave Background Radiation

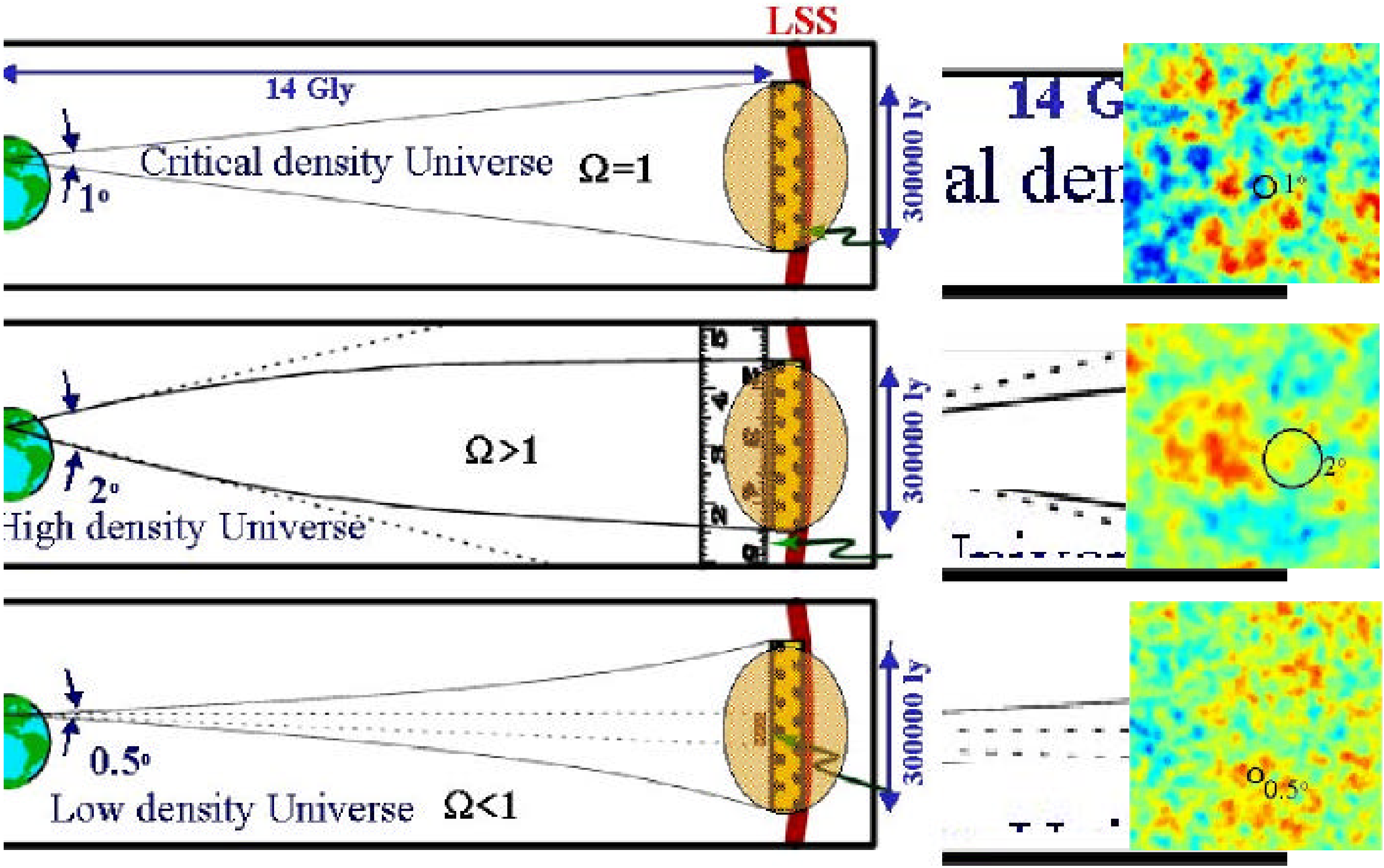


Cosmic Microwave Background Radiation

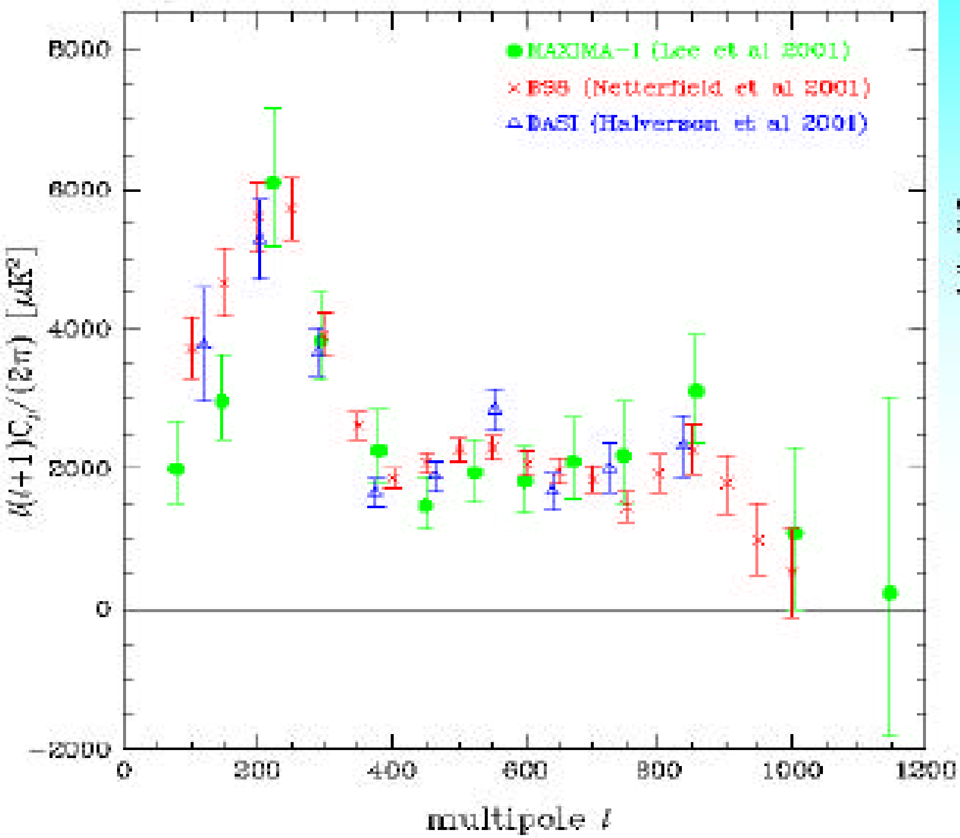


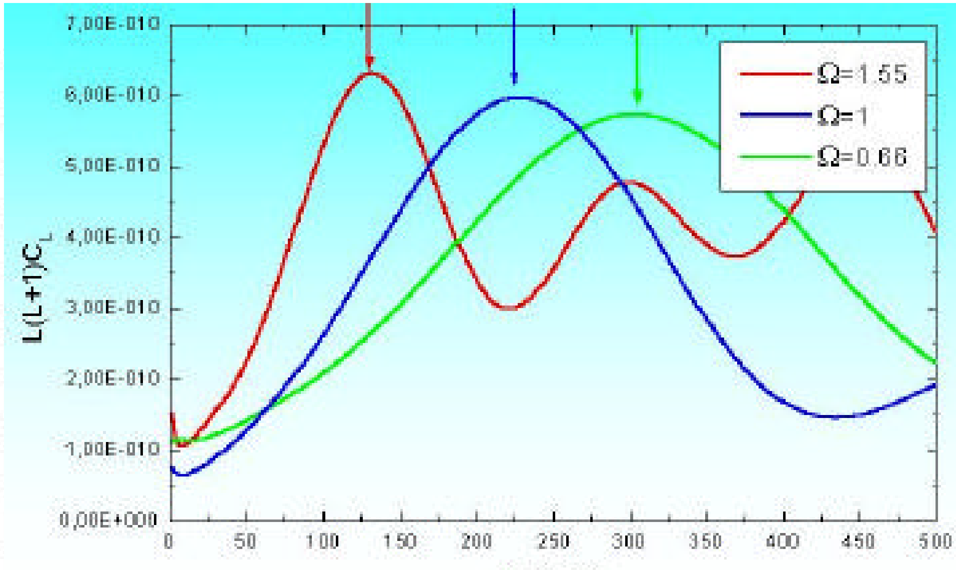
Analyse angular distribution to see typical variation scale

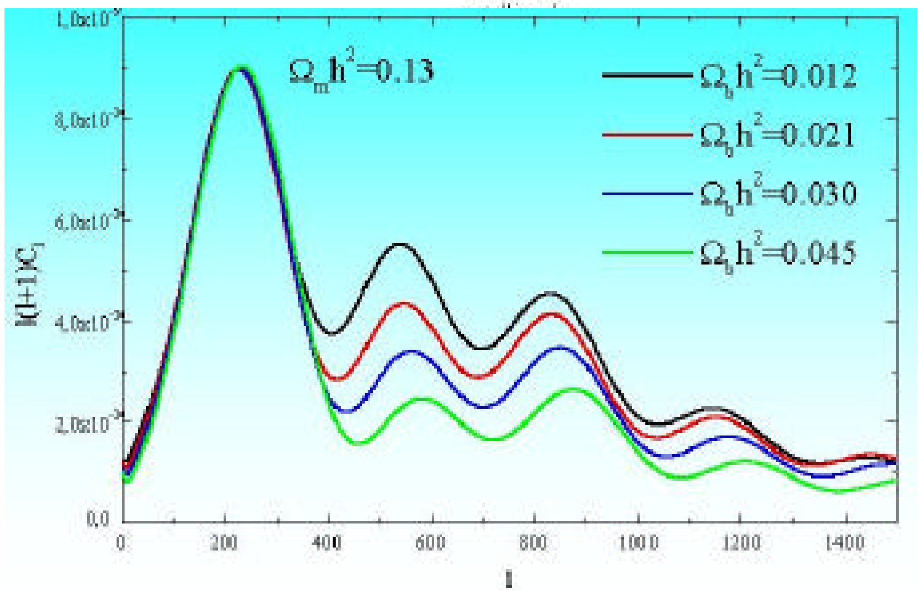
Measure Scale of CMBR Fluctuations



CMBR Data Analysis



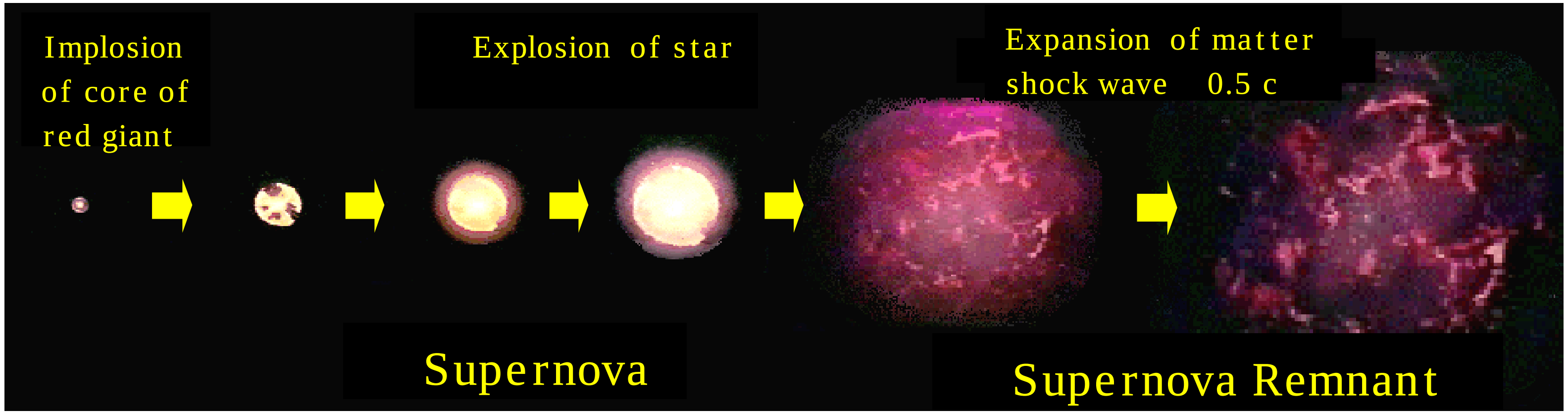


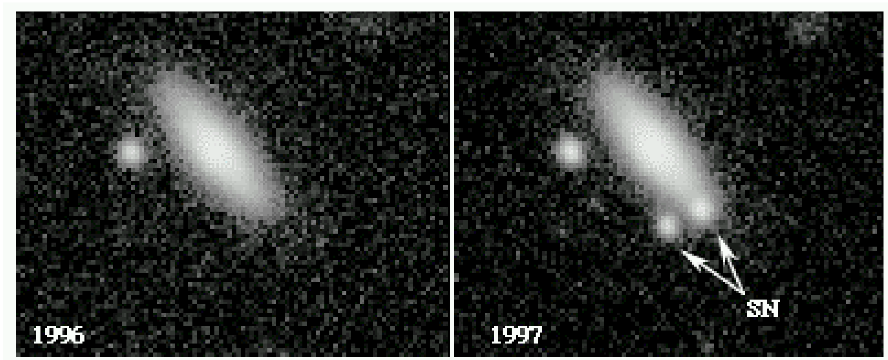


location of first peak: $\Omega_{total} \sim 1$

amplitude of other peaks sensitive to Ω_{baryon}

Supernova Type 1a





⇒

→ π

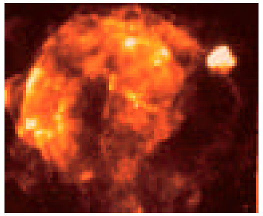
→

SuperNovae observed in our galaxy

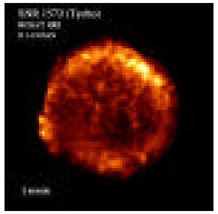
Date	Remnant	Observed
352 BC		Chinese
185 AD	SNR 185	Chinese
369 ?		Chinese
386		Chinese
393	SNR 393	Chinese
437 ?		
827 ?		
902 ?		
1006	SN1006	Arabic, ...
1054	Crab	Chinese,..
1181	3C58	Chinese,..
1203 ?		
1230 ?		
1572	Tycho	Tycho Brahe
1604	Kepler	Johannes Kepler
1667	Cas A	not seen ?

SuperNovae Remnants

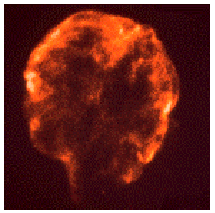
Vela

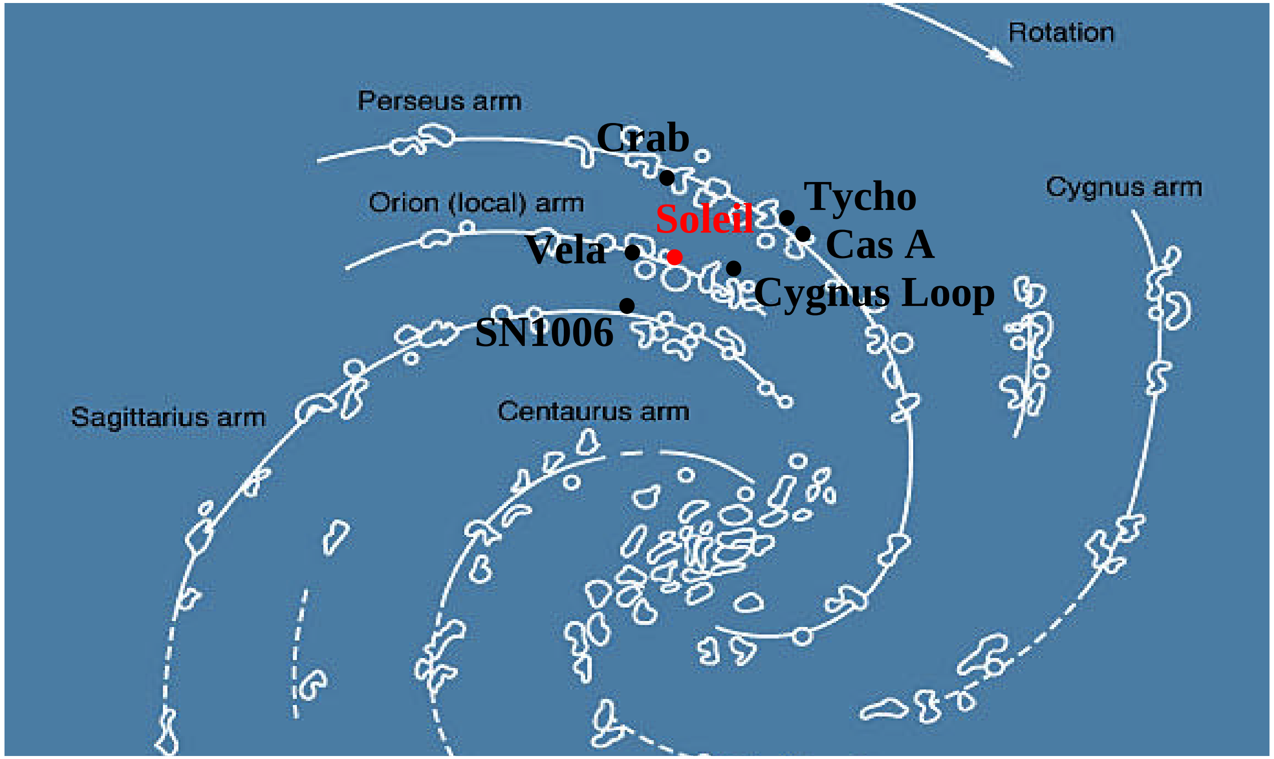


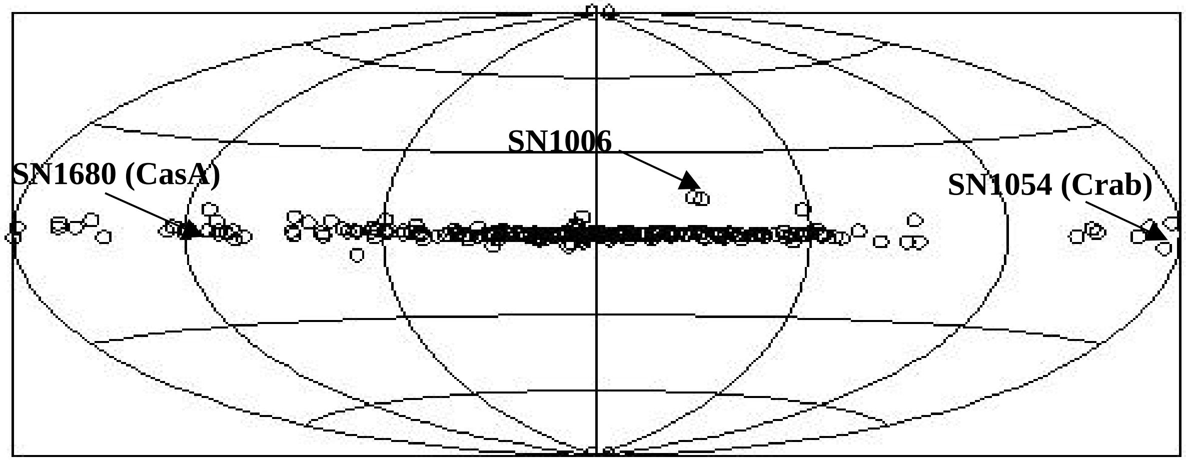
Tycho



Cygnus

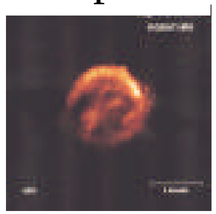




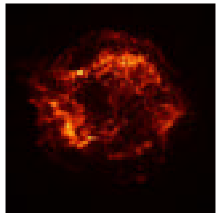


Crab

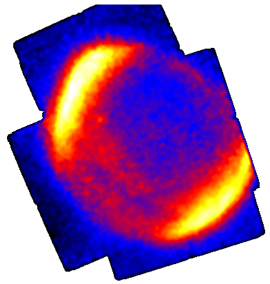
Kepler



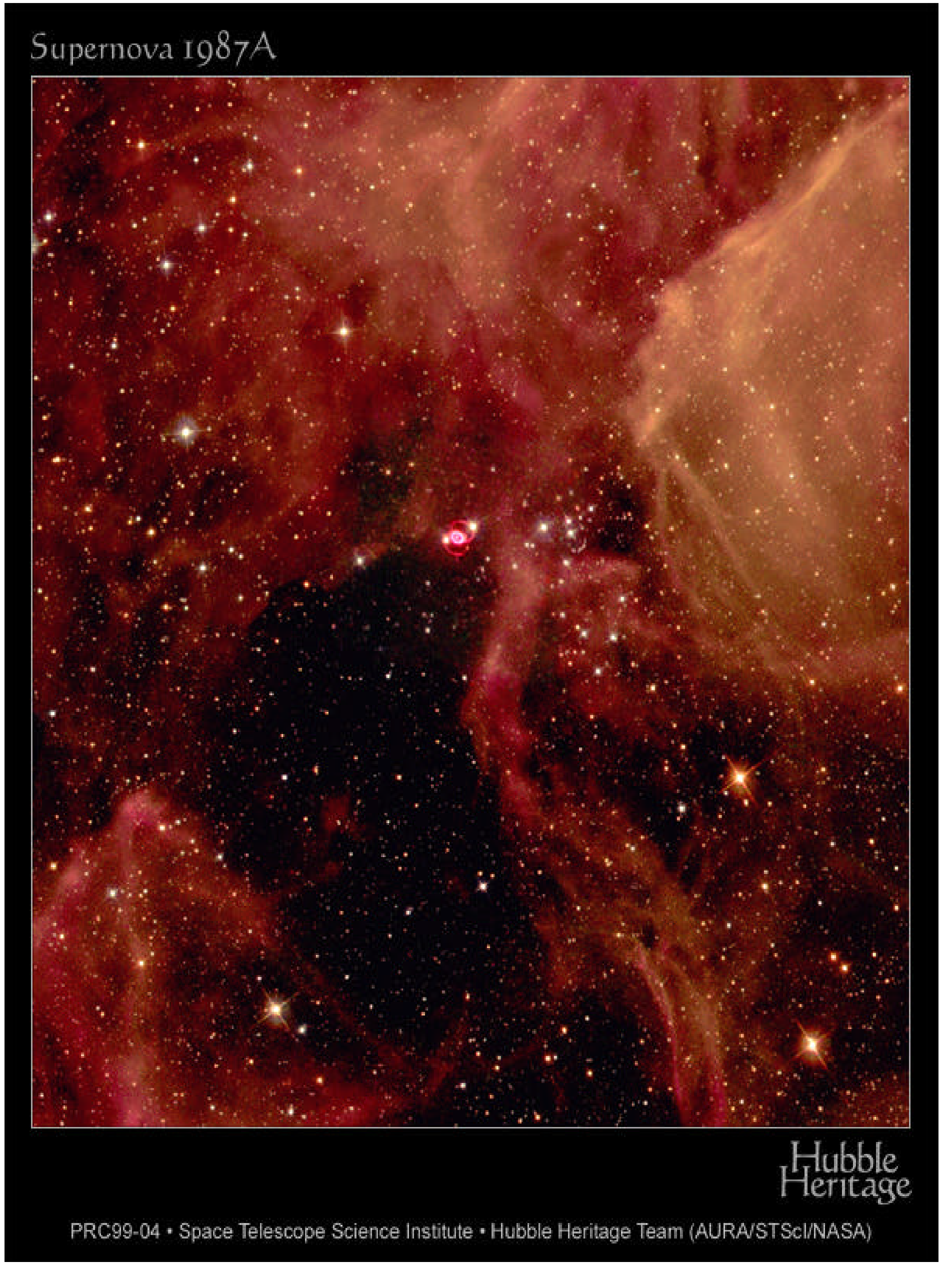
Cas A



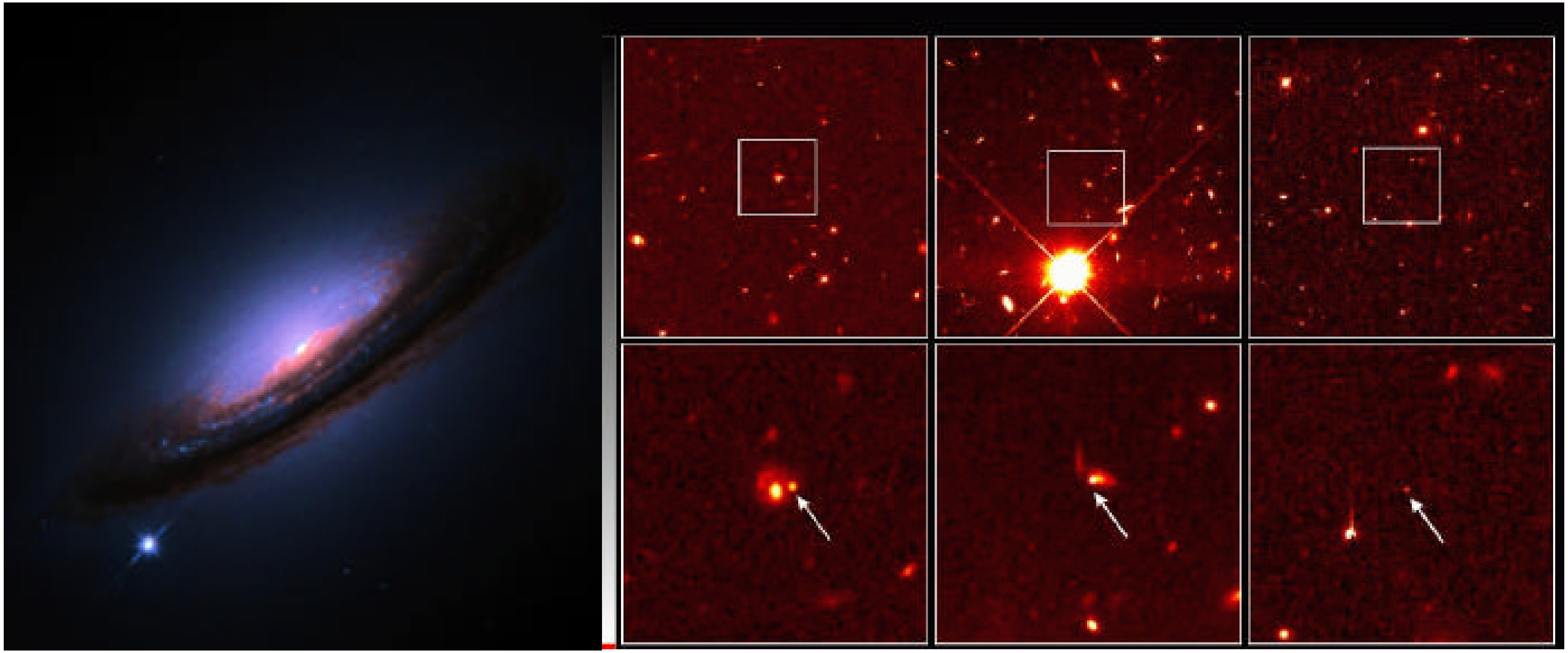
SN1006



Supernova in Large Magellenic Cloud

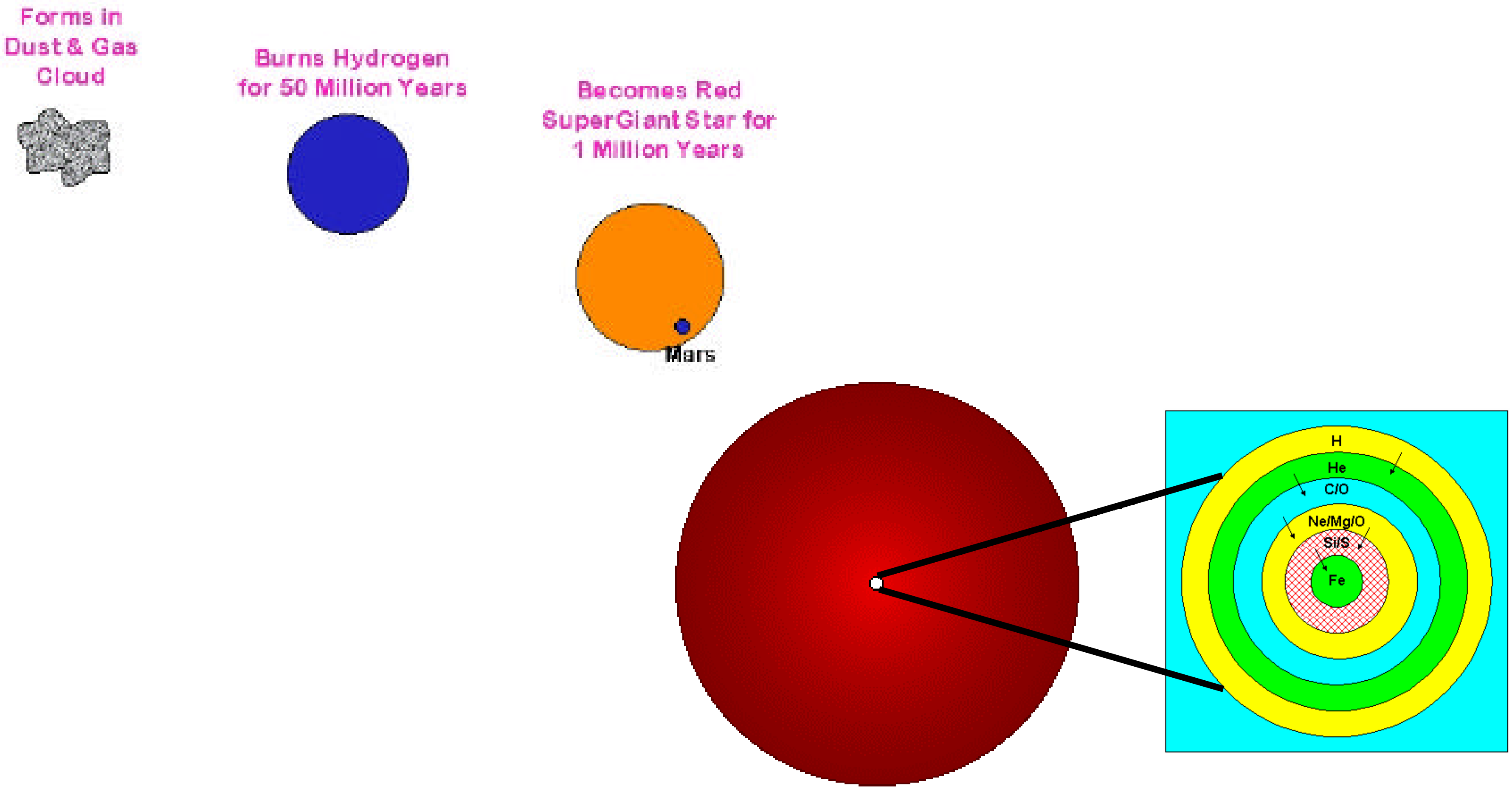


Distant Supernova



Life of big star (> 1,4 M)

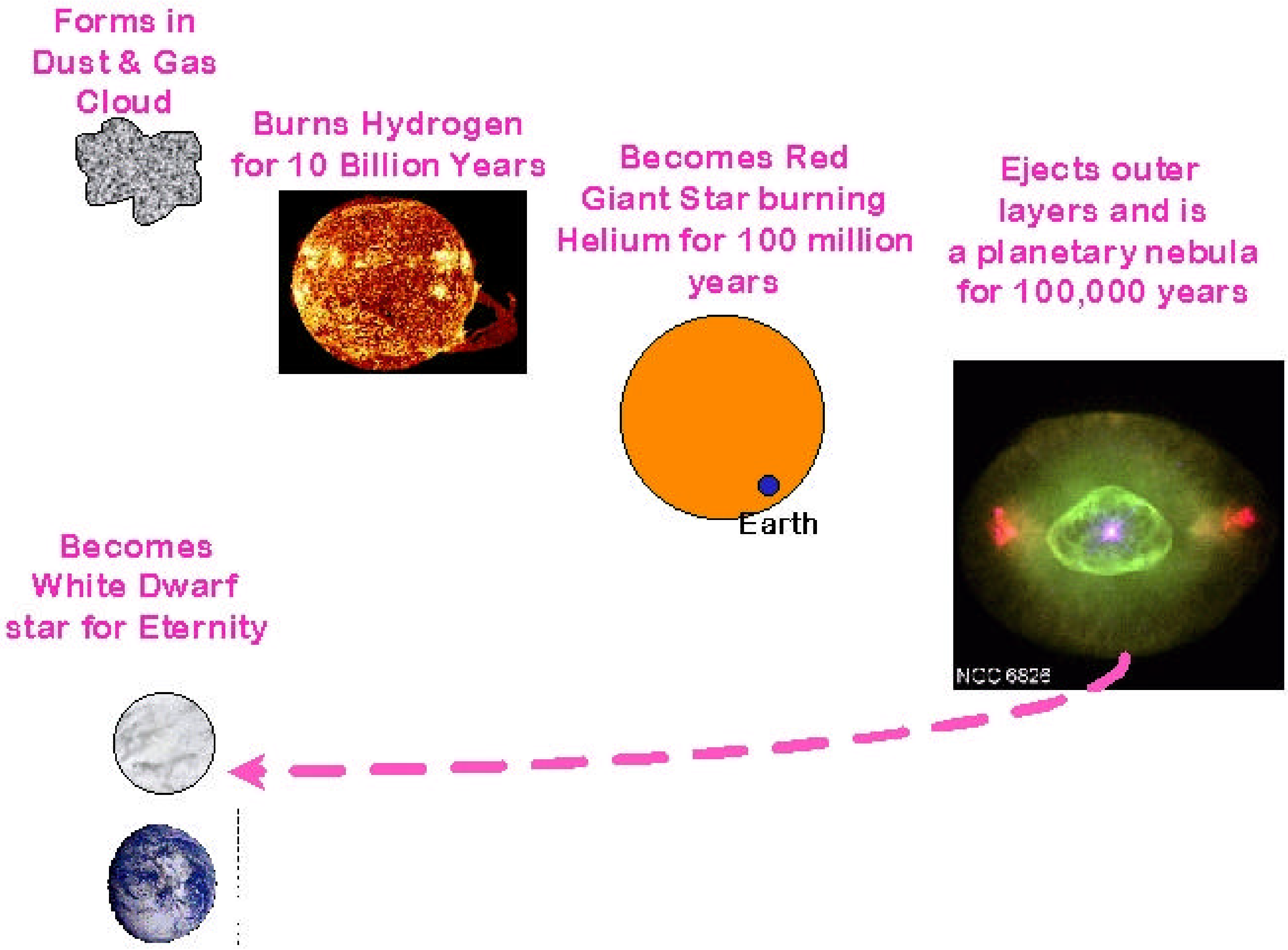
End in Supernovae of type Ib, Ic et II



The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

ESO PR Photo 40f/99 (17 November 1999)

Life of big star (< 1,4 M)

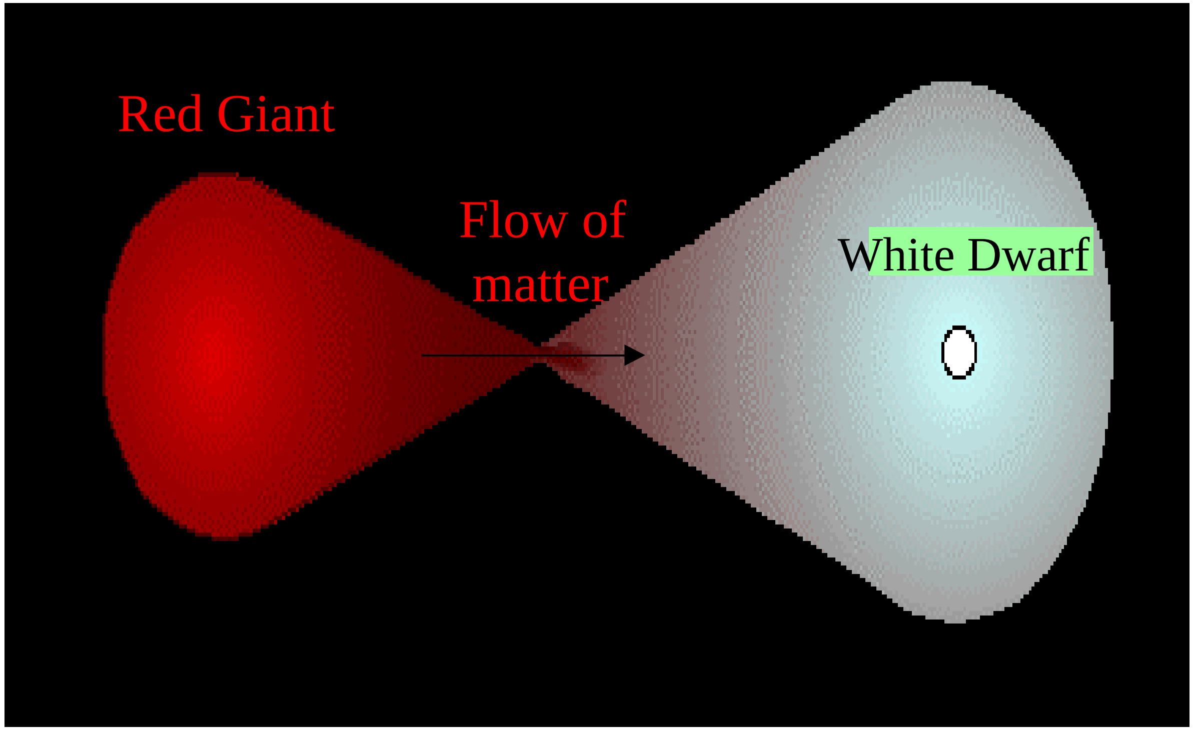


NGC 2392 • "Eskimo" Nebula HST • WFPC2
NASA, ESA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-07

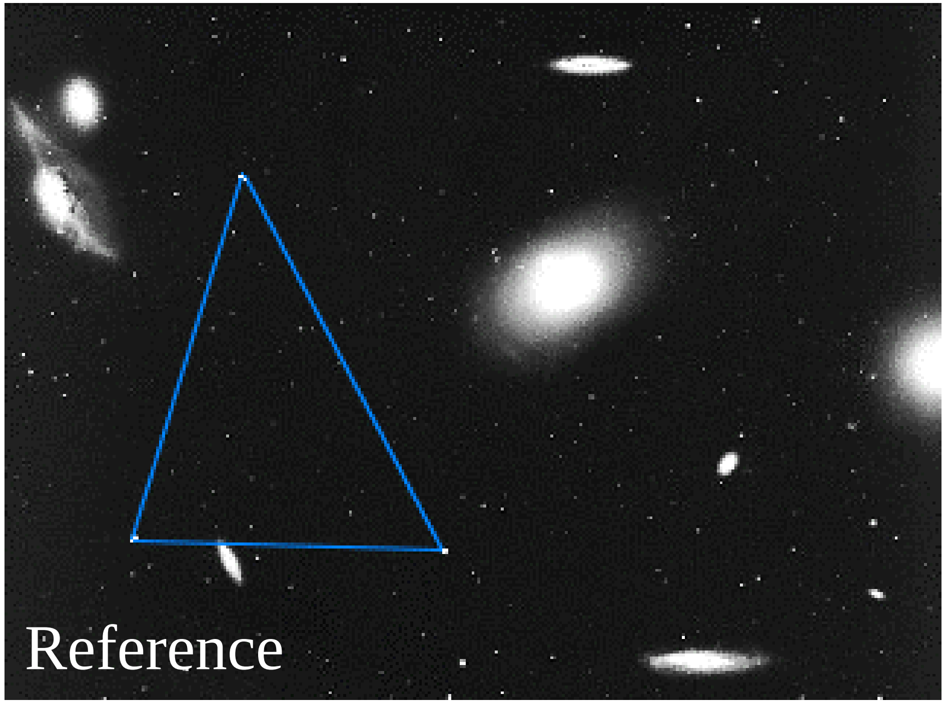
La nébuleuse de la Lyre

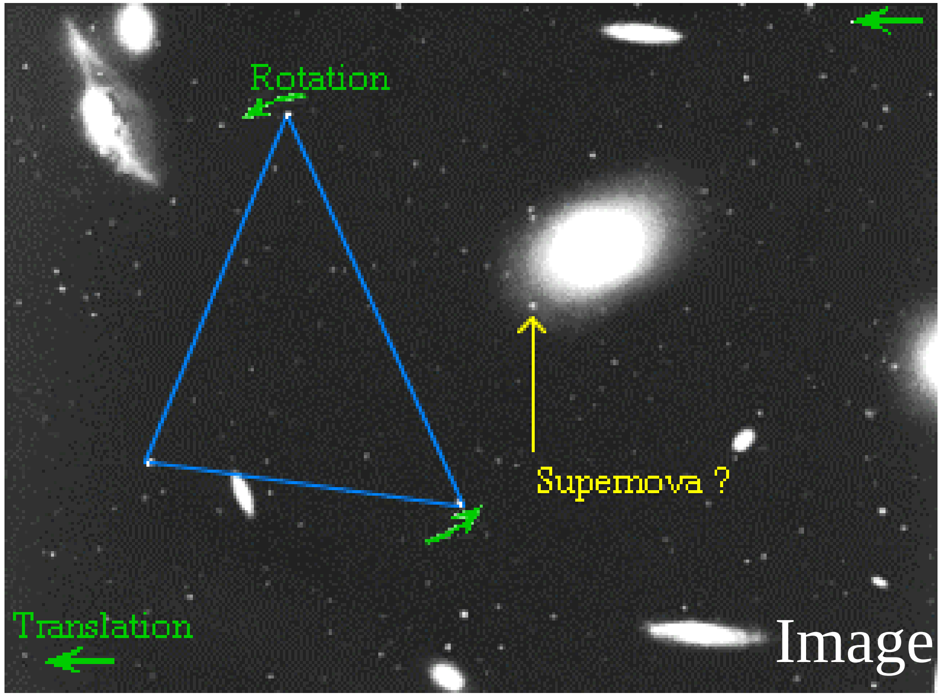
Type Ia supernovae

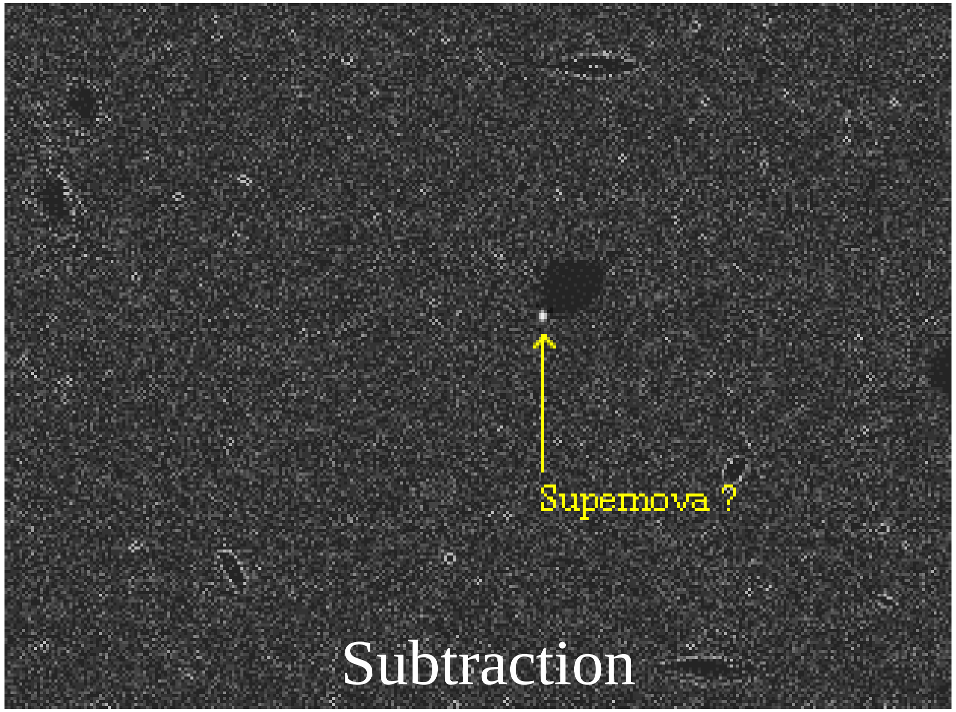
SNe Ia sont which accrete matter from neighbour star in binary system
When the mass achieves the Chandrasekhar mass (~1.4 $M_{ù}$) star collapses to neutron star in supernova explosion.



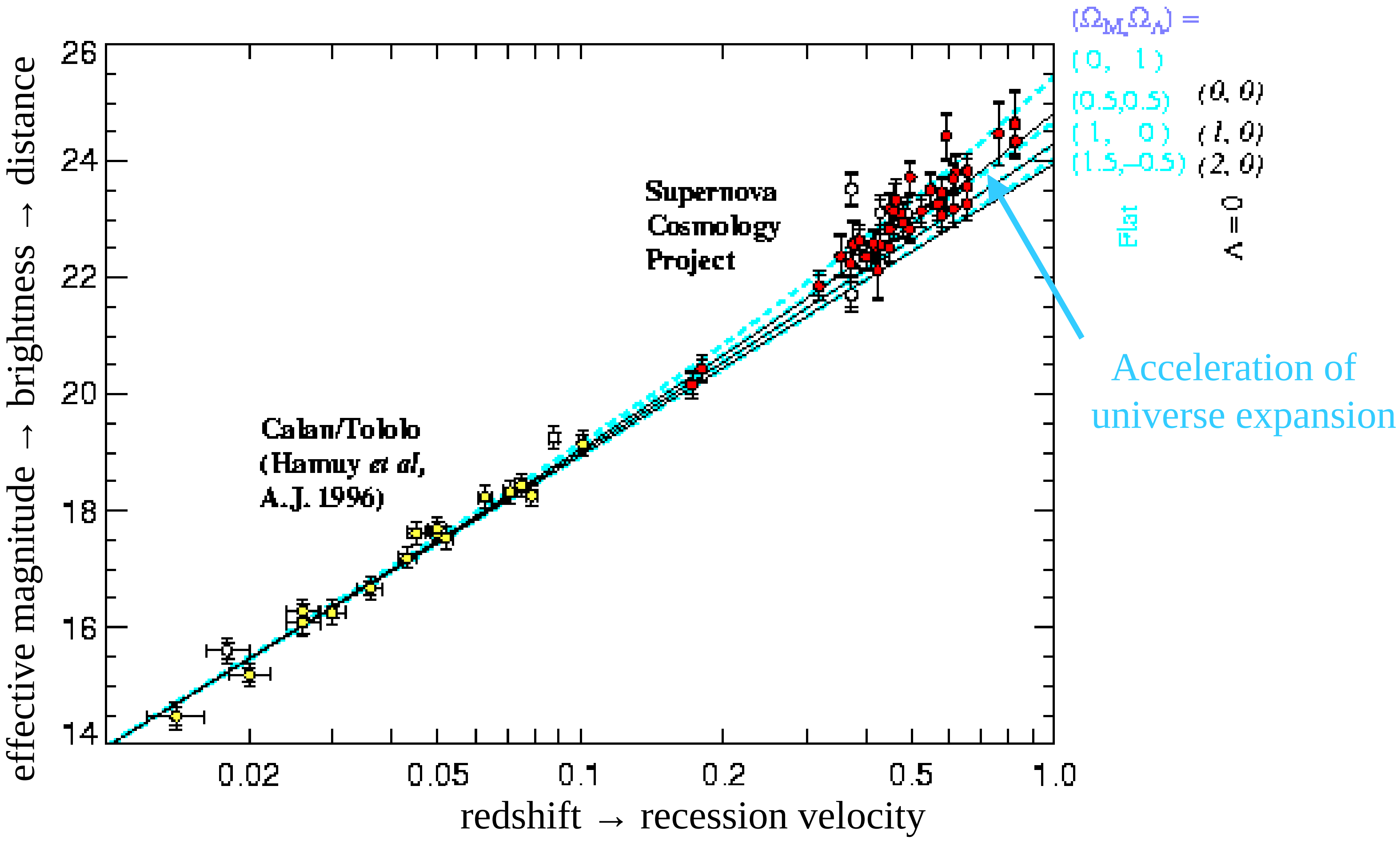
Always same mass so always same luminosity
Standard Candle for measuring universe expansion

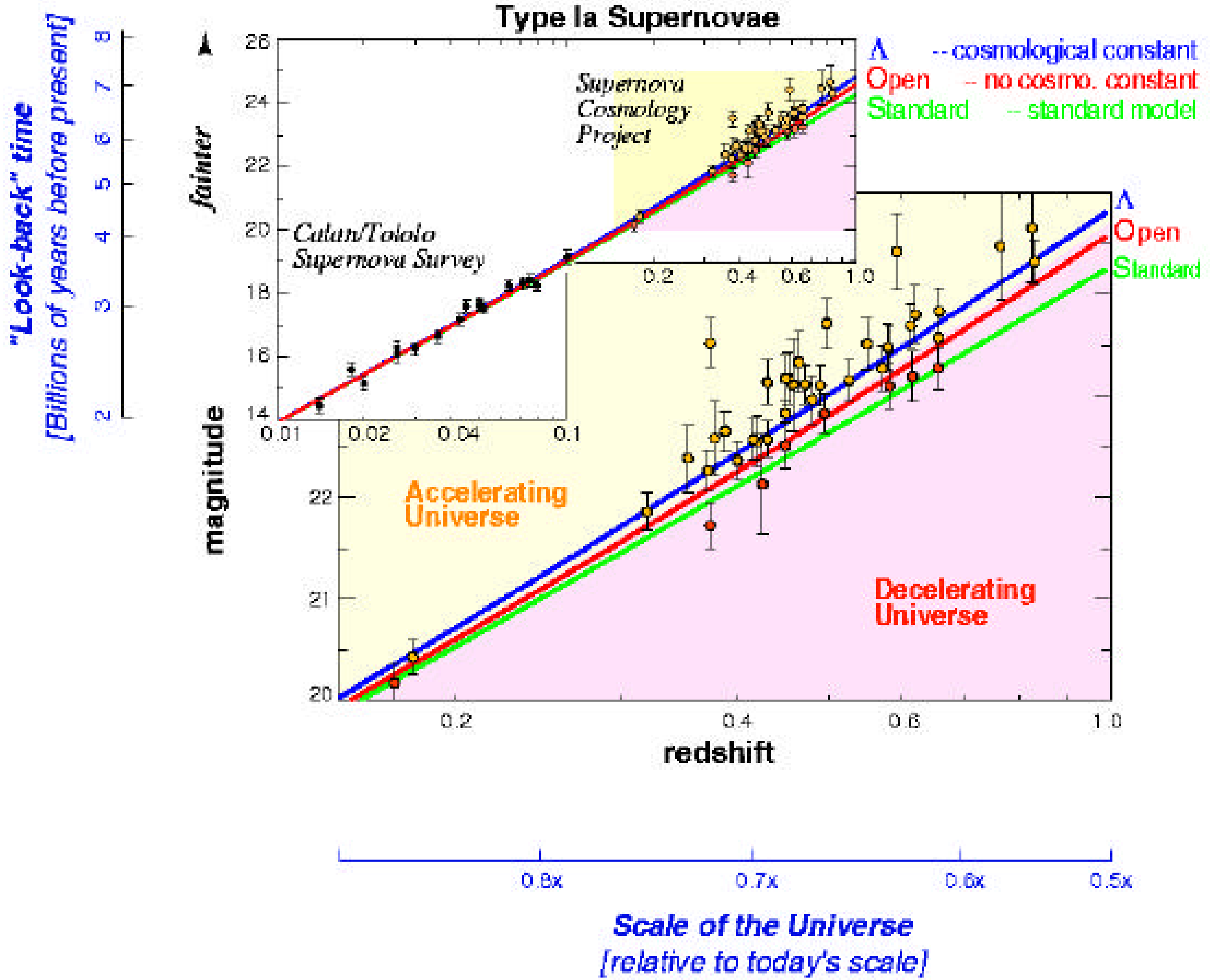

Reference


Rotation
Supernova ?
Translation
Image


Supernova ?
Subtraction

Expansion with Supernova Ia



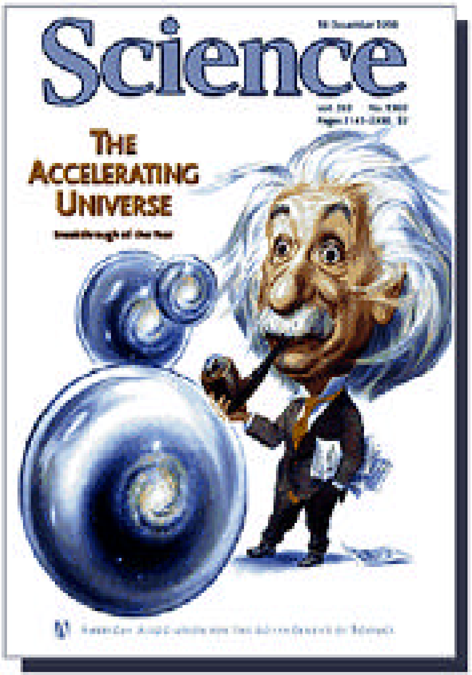


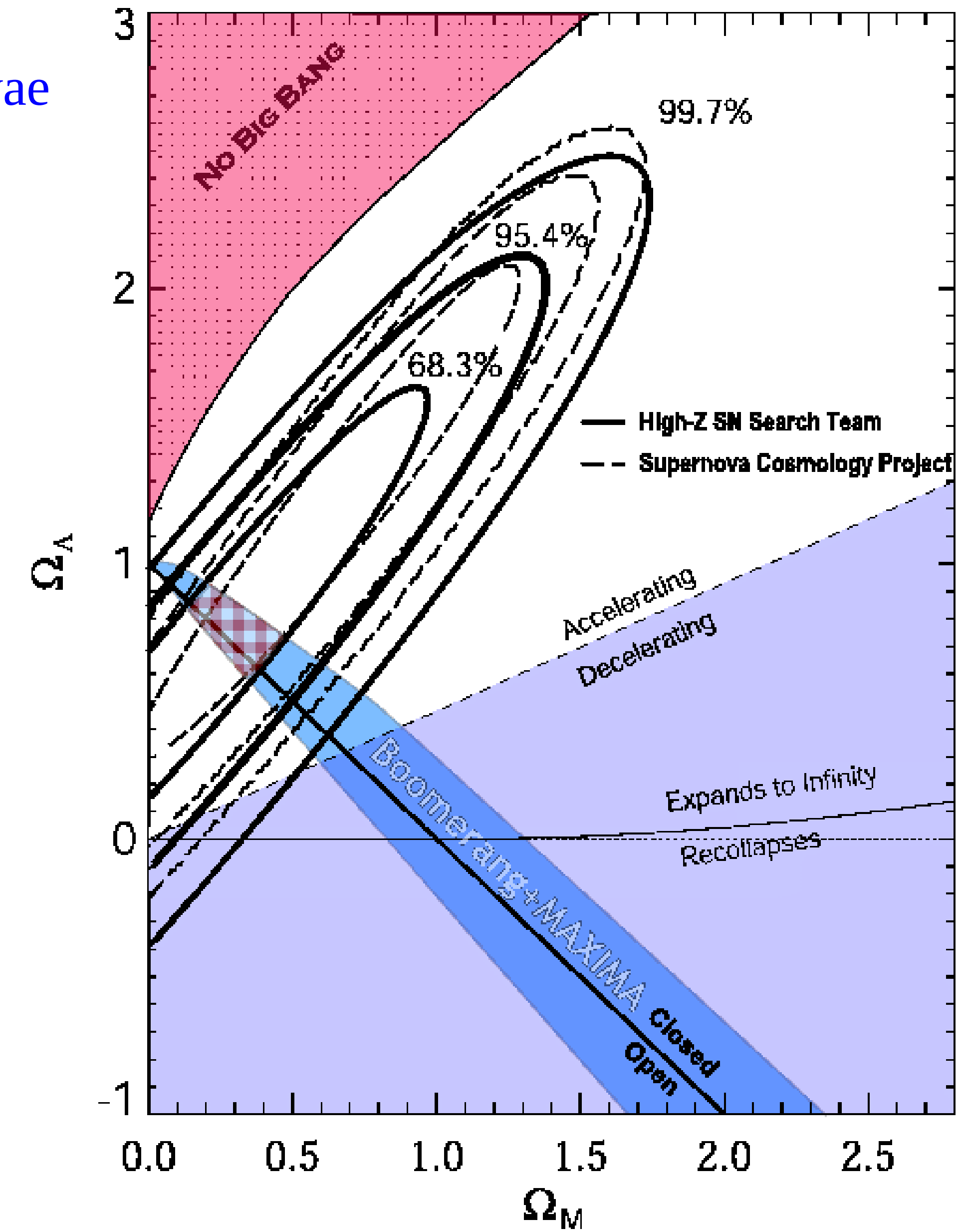
Type Ia Supernovae
Λ -- cosmological constant
Open -- no cosmo. constant
Standard -- standard model
Supernova Cosmology Project
Calan/Tololo Supernova Survey
fainter
magnitude
redshift
Accelerating Universe
Decelerating Universe
"Look-back" time
[Billions of years before present]
Scale of the Universe
[relative to today's scale]
0.8x
0.7x
0.6x
0.5x

In 1998, two teams: High-Z Supernovae and Supernovae Cosmology Project simultaneously annouce non-zero cosmological constant:

$$\Omega_\Lambda = 0{,}72 \pm 0{,}23$$

$$\Omega_M = 0{,}28 \pm 0{,}09$$





So what does it mean?

1. Decaying Λ or Quintessence: the existence of a scalar field with a suitable potential which is so tuned to allow the field to be subdominant in the early Universe, yet emerge today slow rolling with a negative equation of state. There are many models on the block for this now, none of them are particularly well motivated from a particle physics point of view.

2. Quantum fluctuations: Perhaps for some reason, not yet understood, there has always been a vacuum energy of this magnitude.

3. Phase transition: perhaps we are currently hung up in a metastable vacuum which has a non-zero energy density, and will one day decay to the true vacuum.

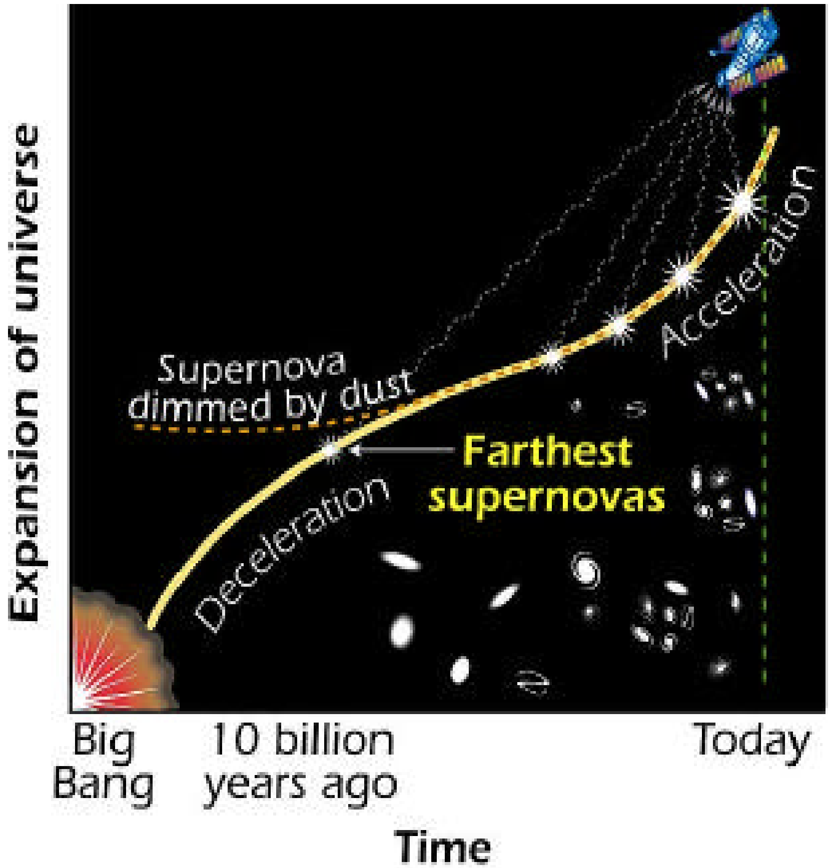
4. The existence of solid dark matter uniformly distributed throughout the Universe, such as a tangled network of cosmic strings produced at a phase transition in the Early Universe.

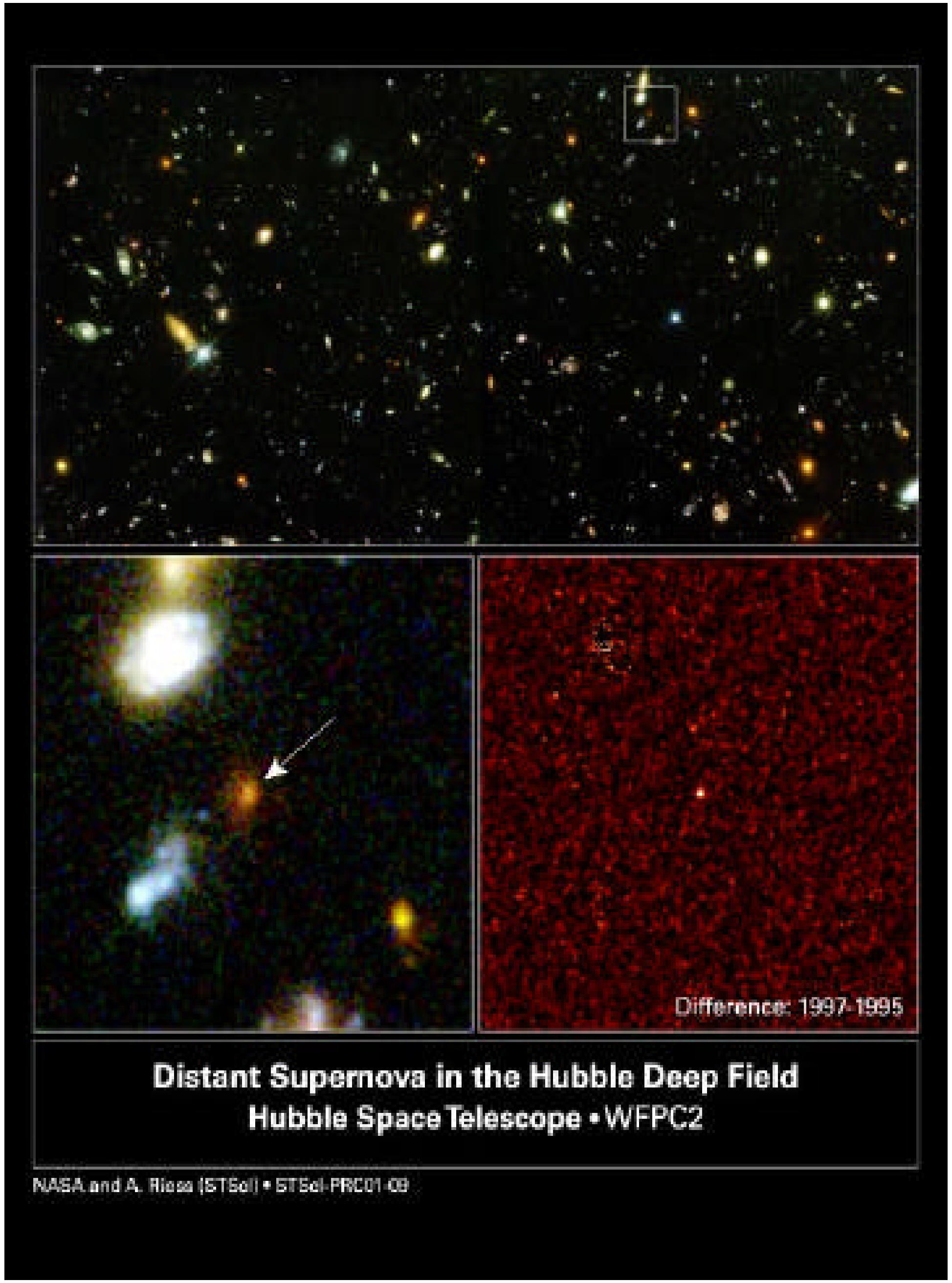
5. We are barking up the wrong tree and there are astrophysical processes taking place concerning the evolution of high red shift supernovae that we do not yet understand, and when we do, this interpretation of the data will vanish.

6. The data is wrong.

(due to E. Copeland, a theorist)

Supernova at z≈1.7

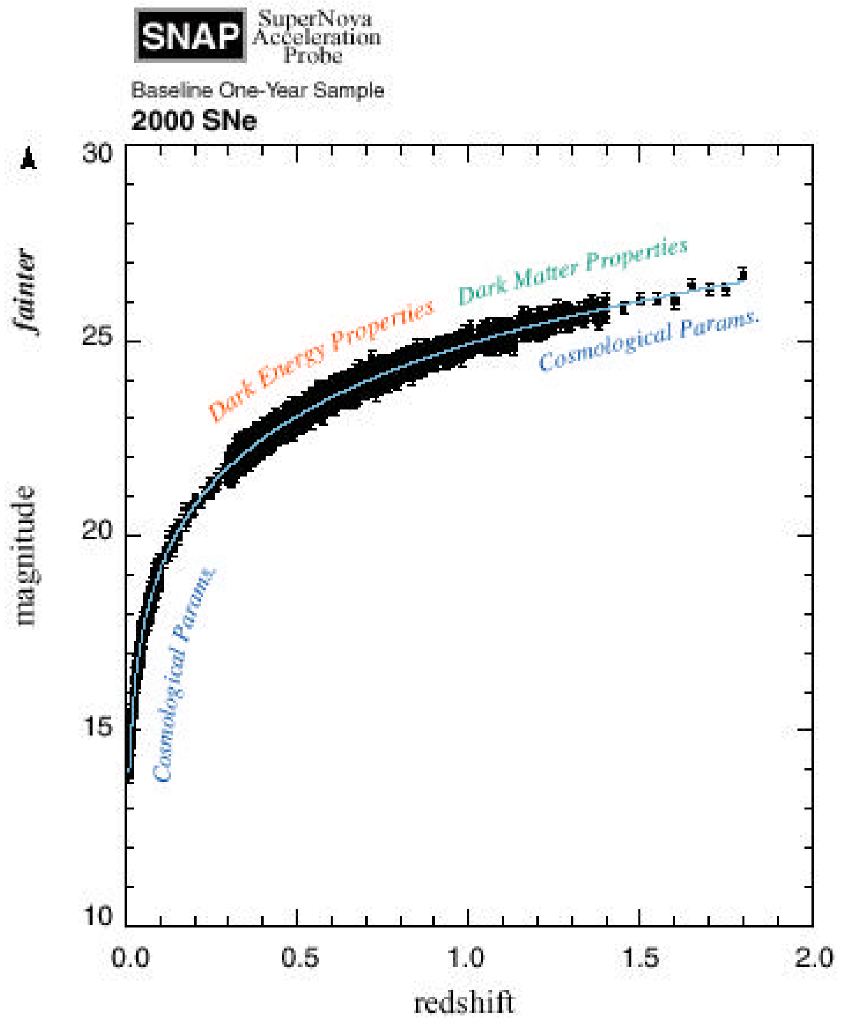




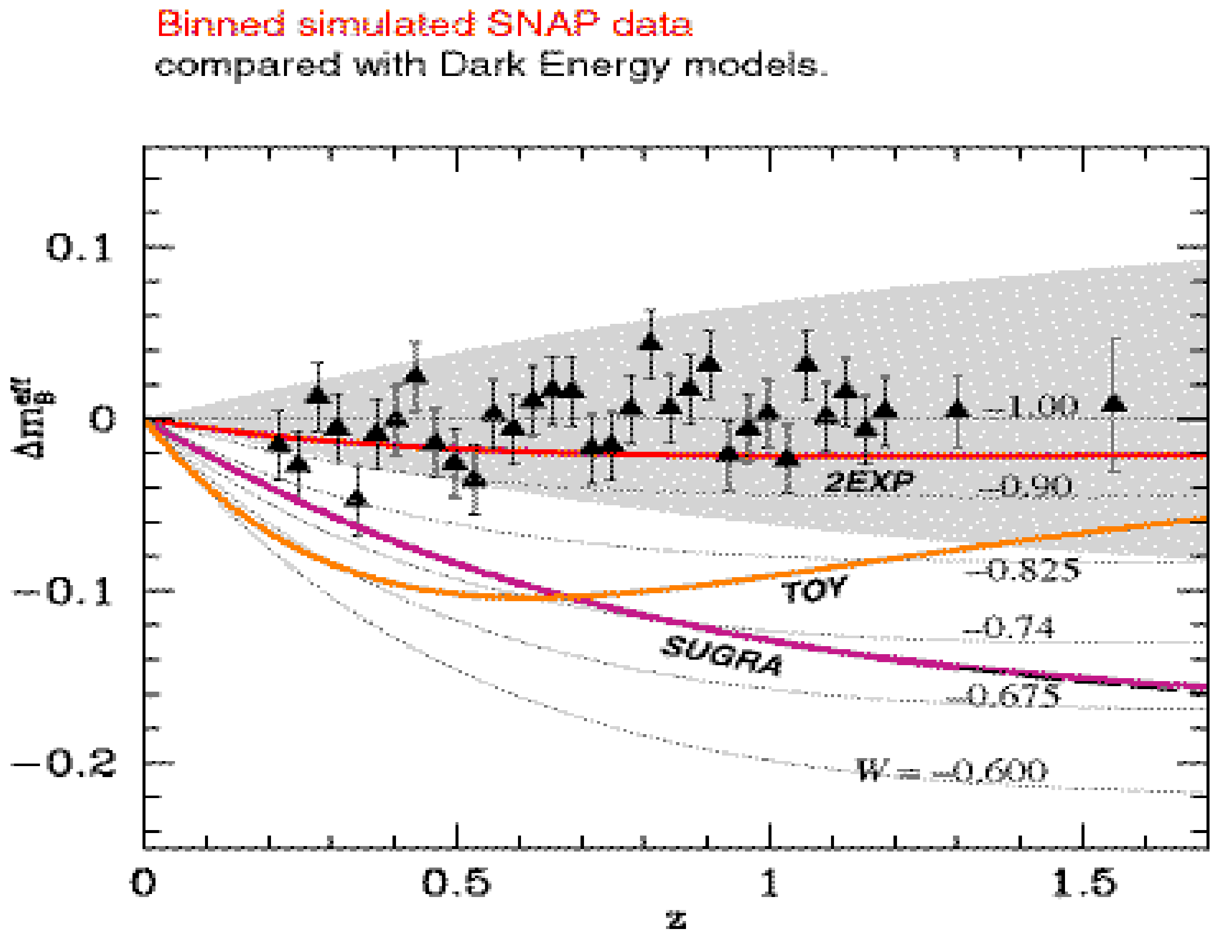
Future Project: SNAP

- 2500 SNe Ia per year with $z < 1.7$
- Study Equation of state $w = p_w/\rho_w$

Assuming:	Planned 1-year baseline statistical and systematic uncertainty on... Ω_M stat	Ω_M sys	Ω_Λ or $\Omega_{d.e.}$ stat	Ω_Λ or $\Omega_{d.e.}$ sys	w stat	w sys	stat	sys
$w = -1$	0.02	0.02	0.05	<0.01				
$w = -1$, flat			0.01	0.02				
$w = const.$, flat			0.02	0.02	0.05	<0.01		
Ω_M known, $w = const.$					0.02	<0.01		
Ω_M known, $w(z) = w + w'z$					0.08	<0.01	0.12	0.15



Understanding Nature of Dark Energy

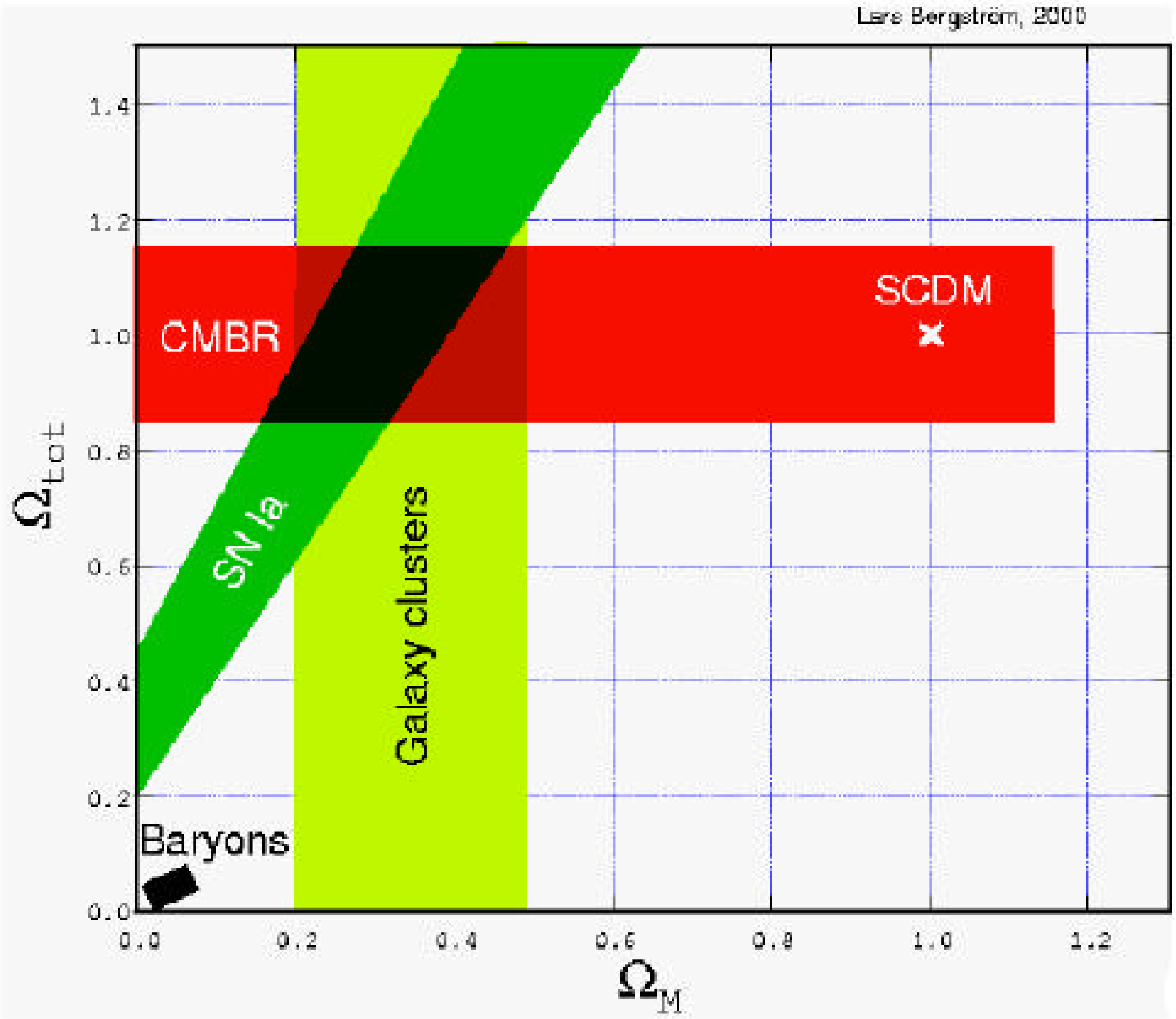


Weller & Albrecht (2000)

Evidence for Matter Density

Combined Data

Cosmic Microwave Background Radiation, Supernova 1a, Galaxy clusters and BBN



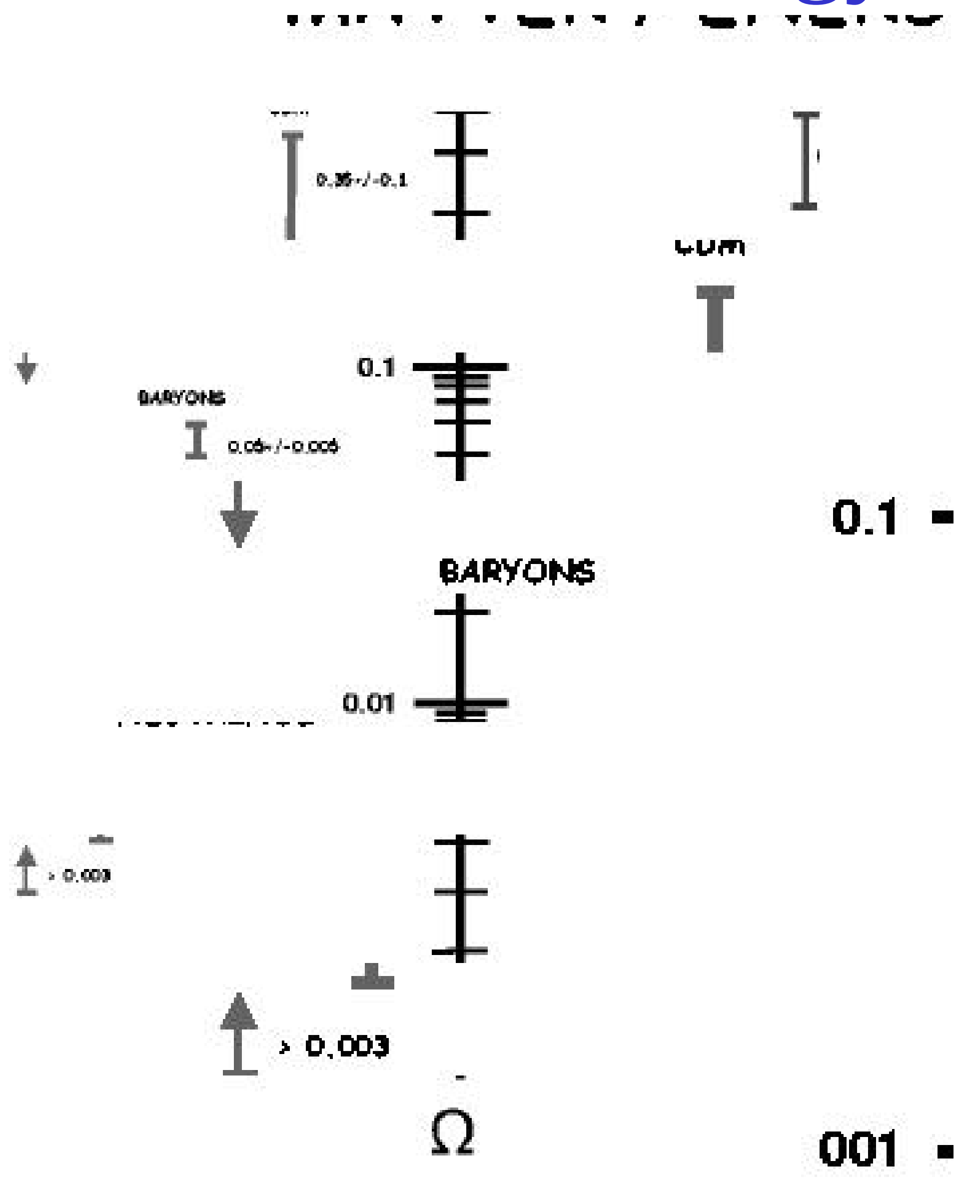
$\Omega_{tot} = \rho_{total} / \rho_{critical}$

critical density
for flat universe
$\rho_{critical} = 3H^2/8\pi G_N$

H = h . 100 km/s/Mpc

$\Omega_M = \rho_{matter} / \rho_{critical}$

Matter/Energy in the Universe



$\Omega_{total} = \Omega_M + \Omega_\Lambda$ 1

matter dark energy

Matter:

$\Omega_M = \Omega_b + \Omega_\nu + \Omega_{CDM}$ 0.4

baryons neutrinos cold dark matter

Baryonic matter :

Ω_b 0.05

stars, gas, brown dwarfs, white dwarfs

Neutrinos:

Ω_ν 0.003

if M(ν) 0.1eV as from oscillations

Cold Dark Matter :

Ω_{CDM} **0.3**

WIMPS/neutralinos, axions