From micro to macro :
the story of our unfolding Universe

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Micro Macro

Outline

- The forebears

- The story of light

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- The story of matter ... and anti-matter

- The story of Dark Matter

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- The story of Dark Matter

- There is also Dark Energy

Moving the earth

Archimedes

(440 BC?=year 220 of the Buddha)

A true ancestor of Physics as Mathematical Philosophy

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Laws of lever ...

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Extending the scale of applicability of a physical law : From pebbles to the whole earth

The apple and the Moon

Newton is famous for having discovered the Law of Gravitation. Comparing the fall of the apple with the "falling" of the Moon towards the Earth

"Moon falls 0.0045 ft/sec towards the earth and is 60 earth radii away"

"Speed of an apple at 1 earth radius increases 32 ft/sec in a second"

Unification of the heavenly with the terrestrial
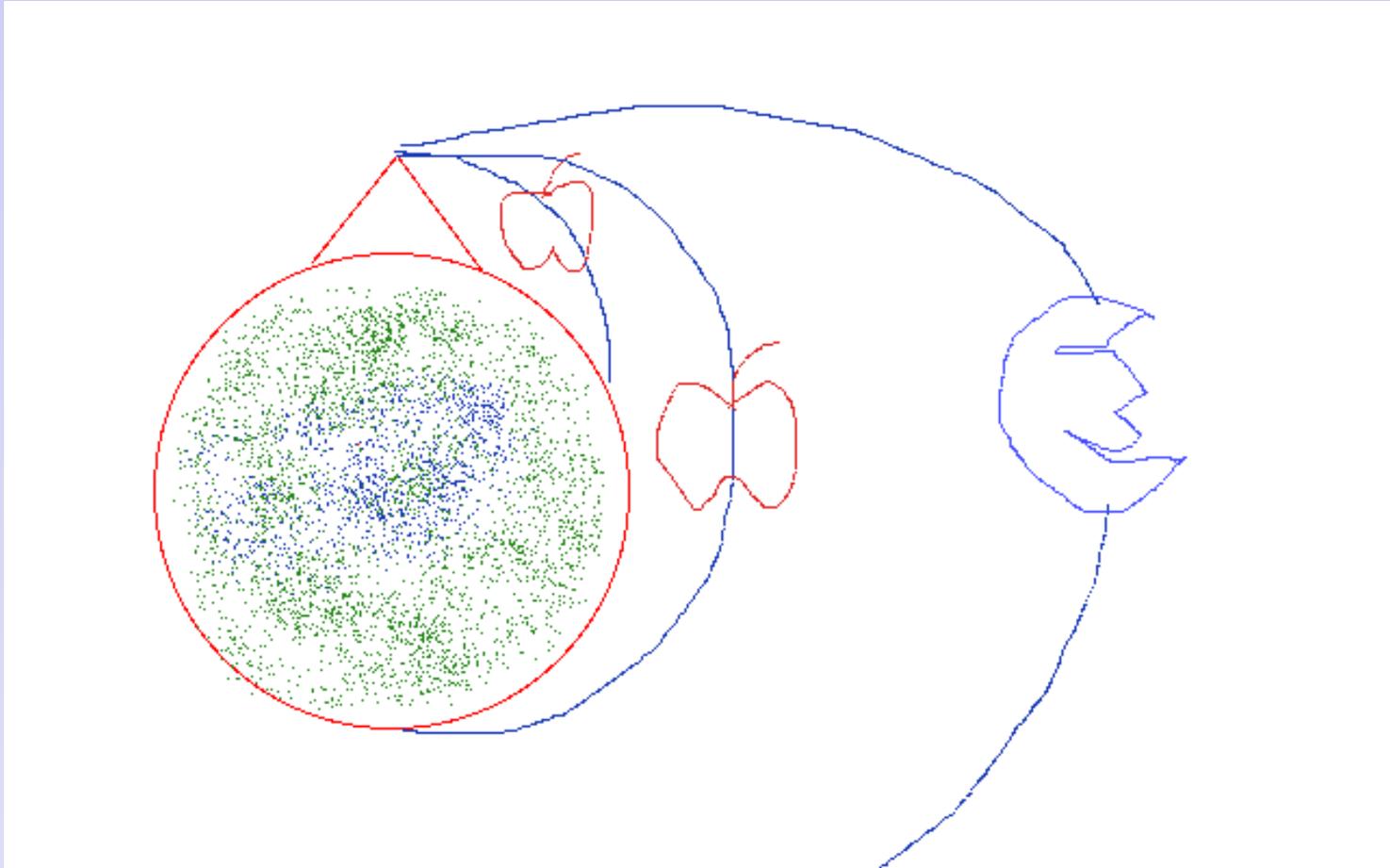
The story of light

The spectrum of sunlight
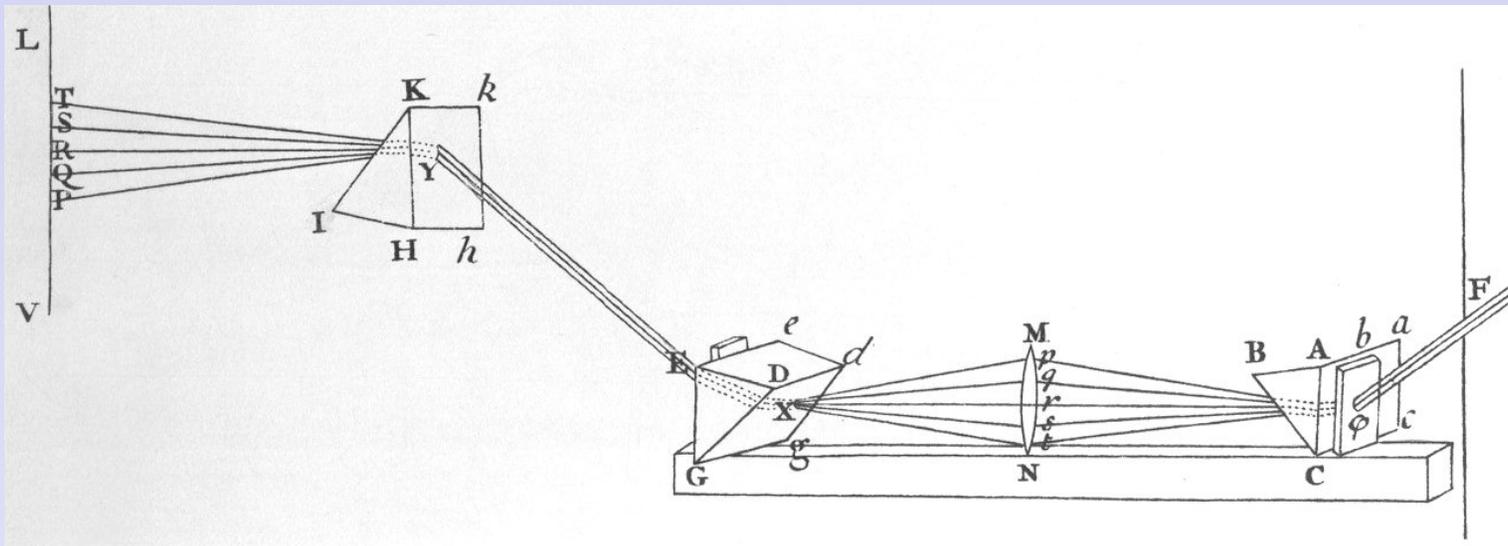
Spectra in the laboratory : glowing metals
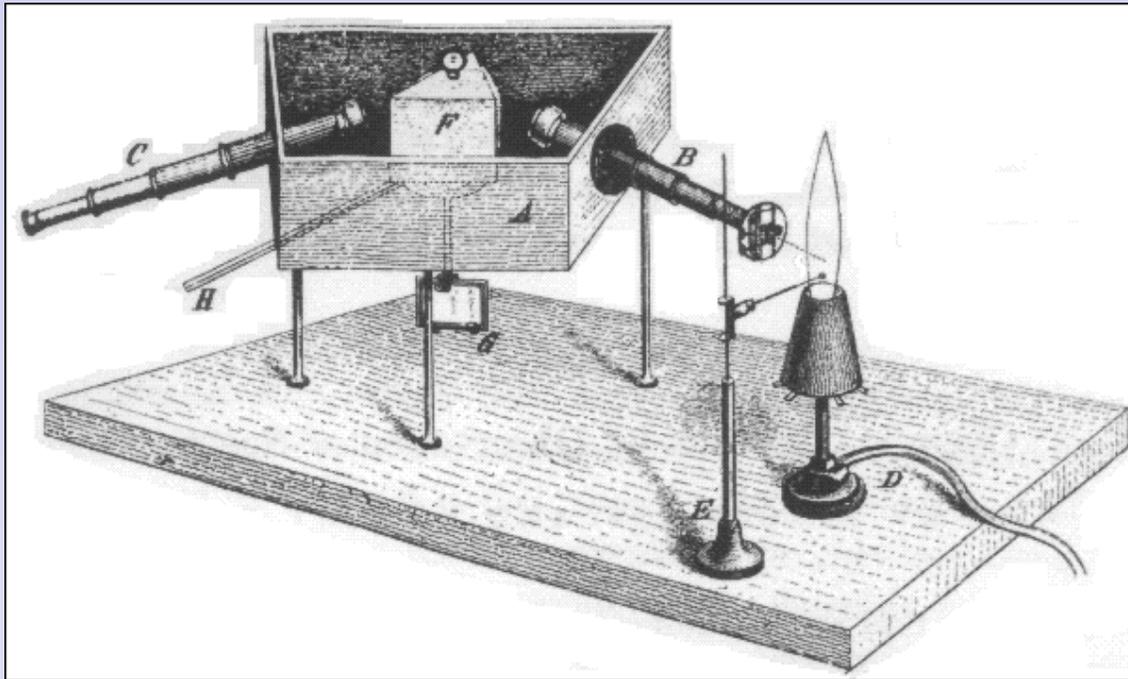

Spectroscope (1860)
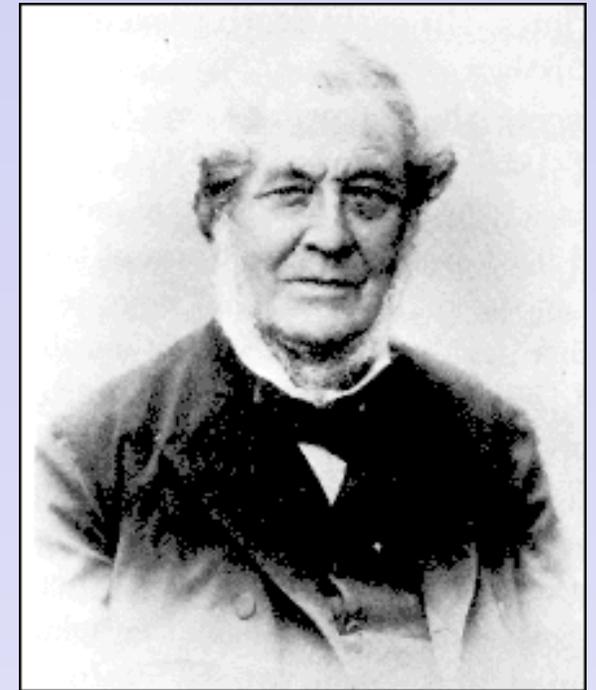
Robert Bunsen

Complementarity of emission and absorption

Hot light source
Cloud of gas
Spectroscope
Continuous spectrum with dark lines
Continuous spectrum
Bright-line spectrum
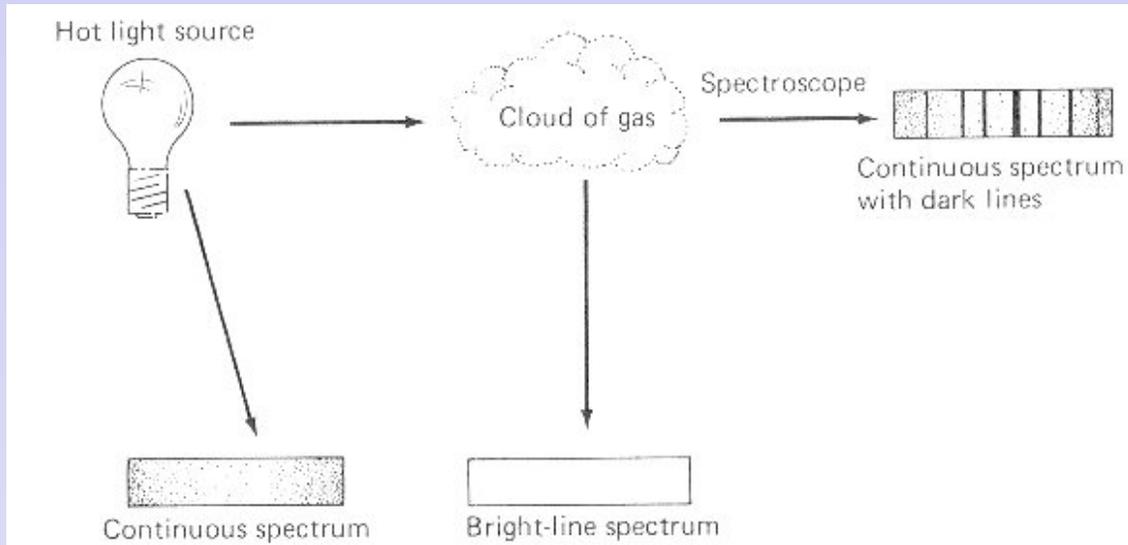
Gustav Kirchoff

Kirchoff's challenge (1859)

To prove that the Emissivity of a glowing substance was a universal function only of its temperature.

More precisely,

$$\frac{\mathcal{E}(\nu)}{A_\nu} \;=\; J(\nu, T)$$

It is necessary to factor out the absorptivity A_ν. Ideal substance for which $A_\nu = 1$ is called Black Body. An enclosure with perfectly reflecting walls (and a small exit hole) is Black Body and is well approximated by a cavity made in a metalic block.

'An act of desperation ...

I had to obtain a positive result, under any circumstances and at whatever cost'

Planck, in 1931, recalling his situation in 1900

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In October 1900 on a Sunday afternoon visit by the Rubens to the Plancks, Heinrich Rubens informs Planck that most likely,

$$\rho \propto T \qquad \text{for } \nu \to 0$$

It seems this was the remark which electrified Planck into arriving

at the law

$$\rho(\nu, T) = \frac{8\pi\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1}$$

DISCOVERY OF COSMIC BACKGROUND
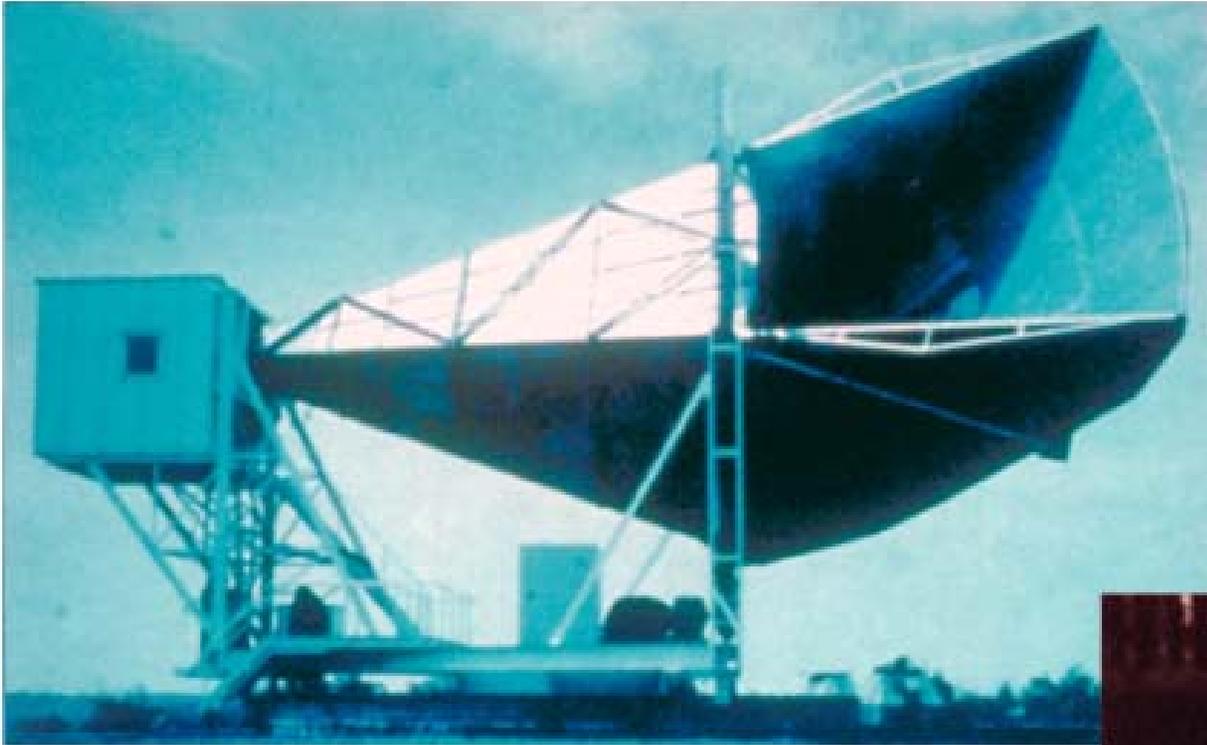


Microwave Receiver
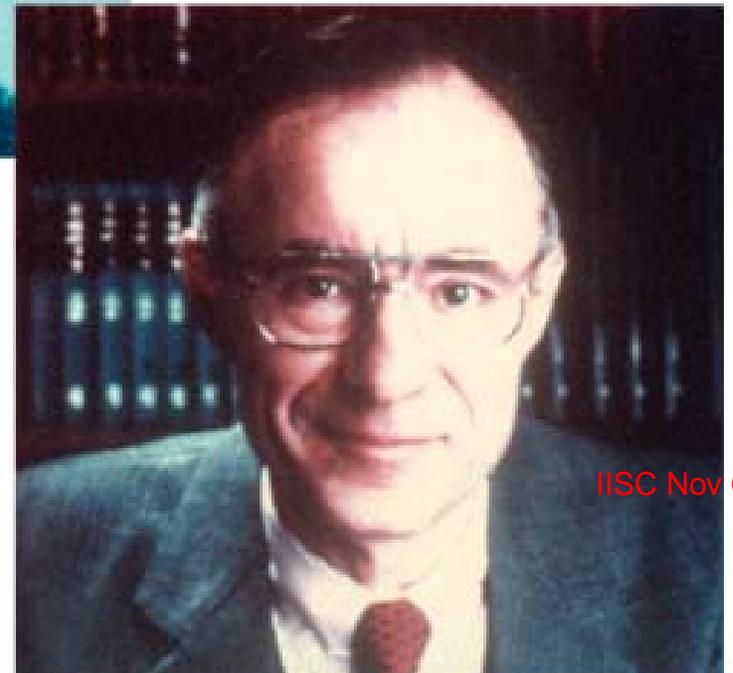
The spectrum of the Big Bang Universe (CMBR)
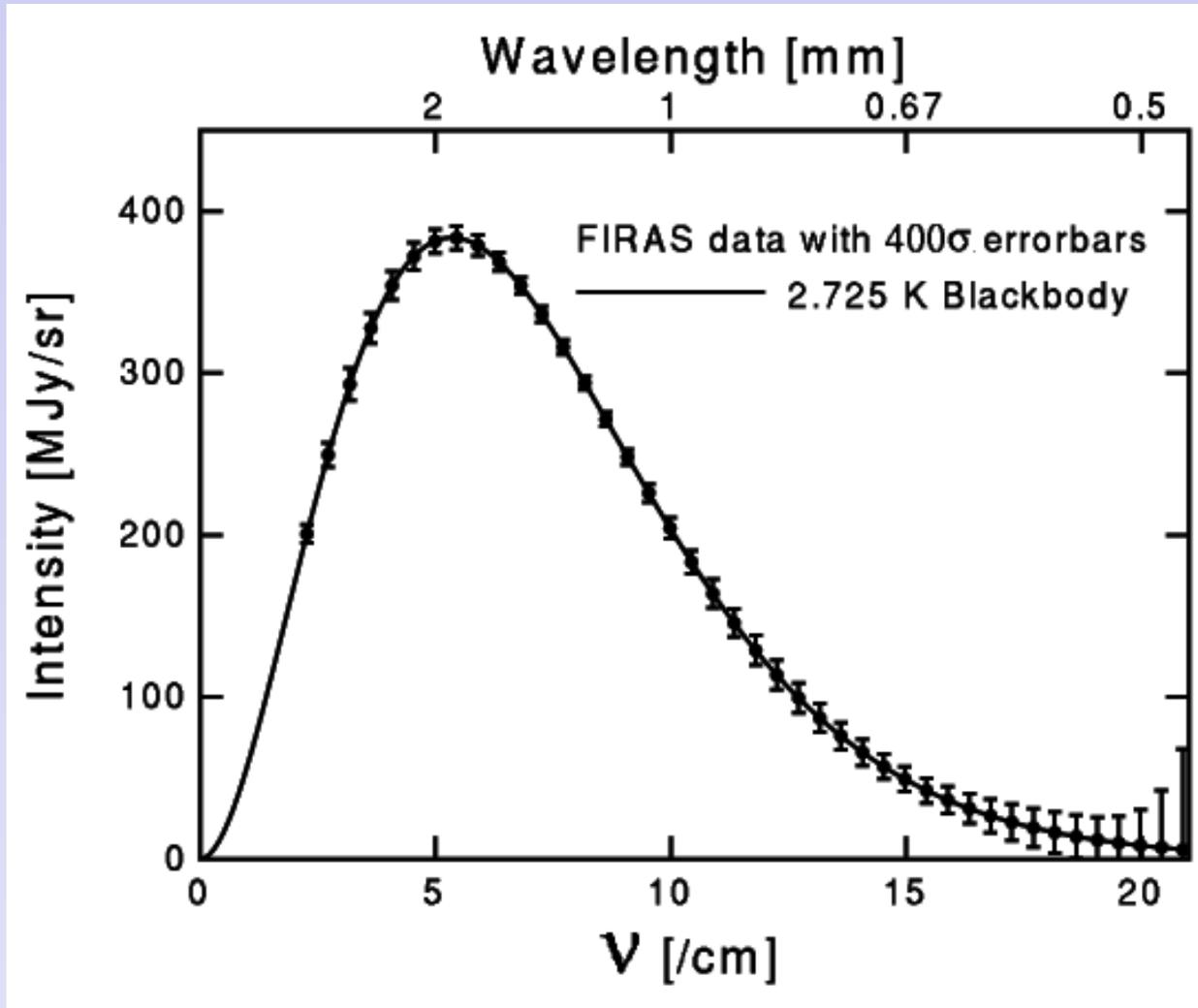
The Big Bang

For most galaxies, the Hydrogen spectrum is shifted into the red. Independent measurements of distances to galaxies and their redshifts revealed a pattern. Edwin Hubble drew a line through this plot.
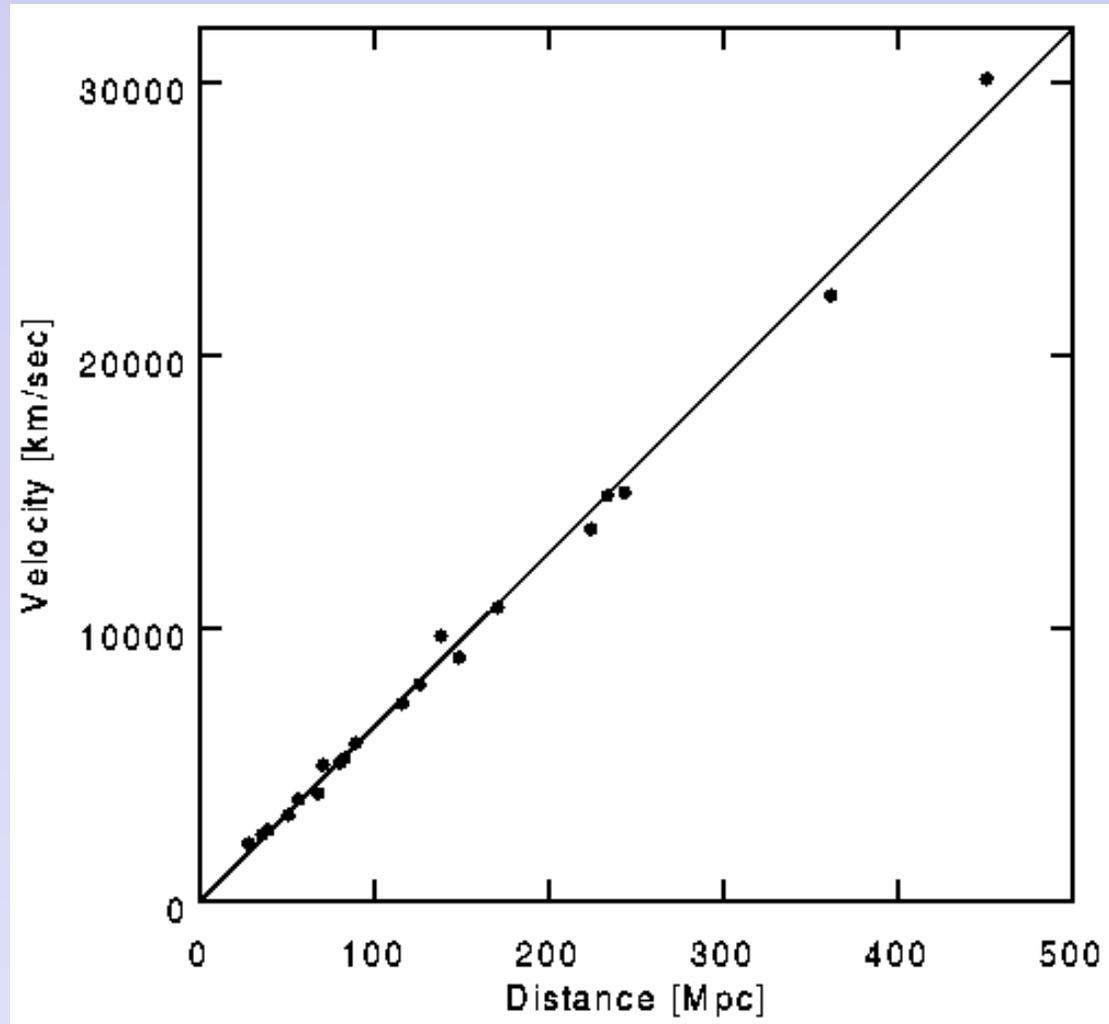
Modern Hubble plot
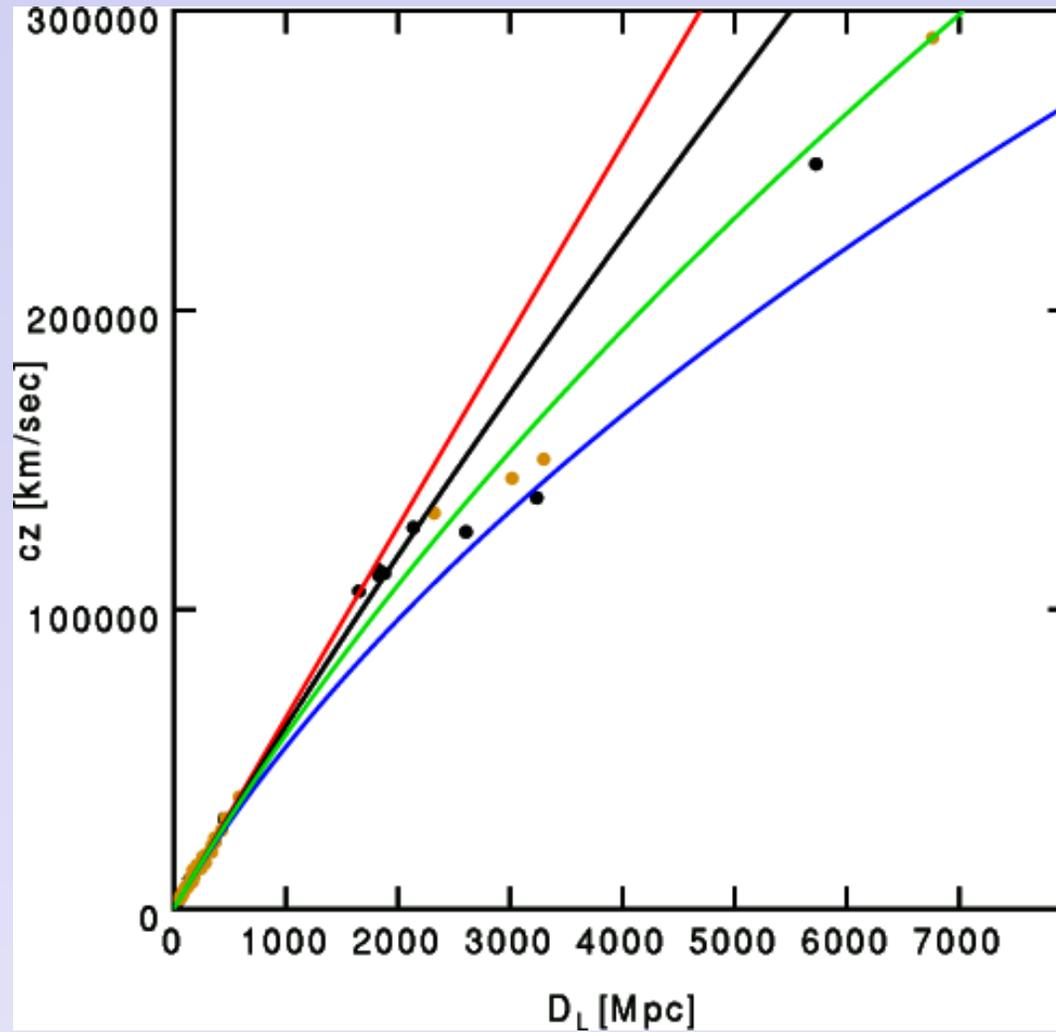
A blast from the remote past

Distant Supernova in the Hubble Deep Field   HST • WFPC2
NASA and A. Riess (STScI) • STScI-PRC01-09

Difference: 1997-1995
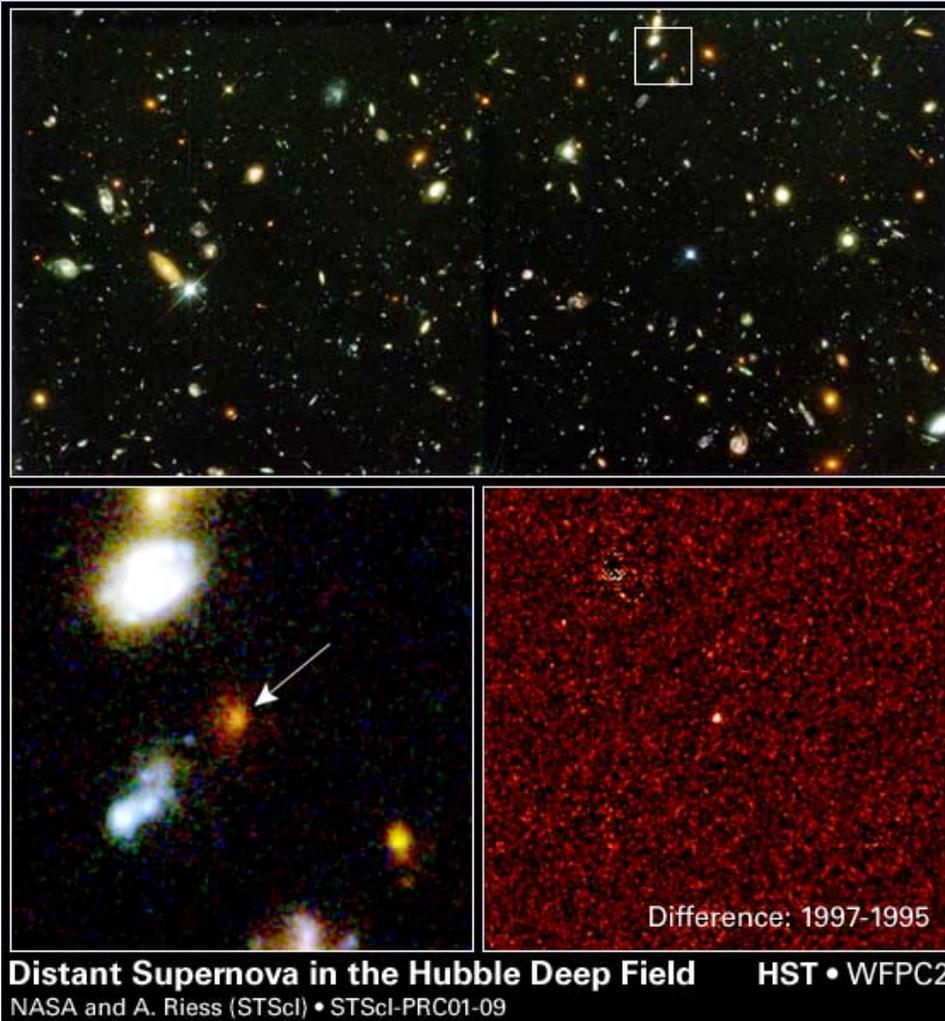
Show movie

[-1cm]The Cosmic Expansion

Extrapolated sequence backwards in time

- Ionised Hydrogen 	 1 eV 	 10^4 K

- Free neutrons and protons 	 1 MeV 	 10^{10} K

- Quark-Gluon plasma 	 1 GeV 	 10^{13} K

- Electroweak scale 	 100 GeV 	 10^{15} K

- Quantum Gravity 	 10^{19} GeV

Neutral H formation $\sim 10^5$ years after the Big Bang

Relic radiation 10^4 K then; 3 K now

Alpher, Bethe and Gamow (1942)

Gravity = curved space-time

General Relativity the theory of the space-time metric

$$ds^2 = dt^2 - R(t)^2 \{\frac{dr^2}{1 + kr^2} + r^2 d\theta^2 + r^2 \sin^2 d\phi^2\}$$

$k = 0$ for flat Universe; $k = \pm 1$ for constant positive or negative curvature

$R(t)$ the Scale factor ... A. A. Friedmann

Equation for R

$$\left(\frac{1}{R}\frac{dR}{dt}\right)^2 + \frac{k}{R^2} = \frac{8\pi}{3}G\rho$$

Equation of state $p = p(\rho)$ required

Radiation dominated Universe :

$$p = \tfrac{1}{3}\rho \Rightarrow R(t) \propto t^{1/2}$$

Matter dominated Universe :

$$p = 0 \Rightarrow R(t) \propto t^{2/3}$$

Book keeping of Cosmic contents

$$H^2 + \frac{k}{R^2} - \Lambda = \frac{8\pi G}{3}\rho$$

where $\rho =$Total energy

another way of writing ...

$$1 + \frac{k}{H^2 R^2} = \Omega_\Lambda + \Omega_\rho$$

✘ Today LHS seems to be 1

  ✘ So in the curvature term, $k = 0$

Current best fit to data

✘ Λ term seems to dominate, $\Omega_\Lambda = 0.7$

✘ But most of ρ is not baryons! Let $\Omega_\rho = \Omega_{DM} + \Omega_B$

   ✘ Baryons contribute only $\Omega_B = 0.03$

   ✘ $\Omega_{DM} = 0.27$ So much is the "Dark Matter"

How do we know all this?
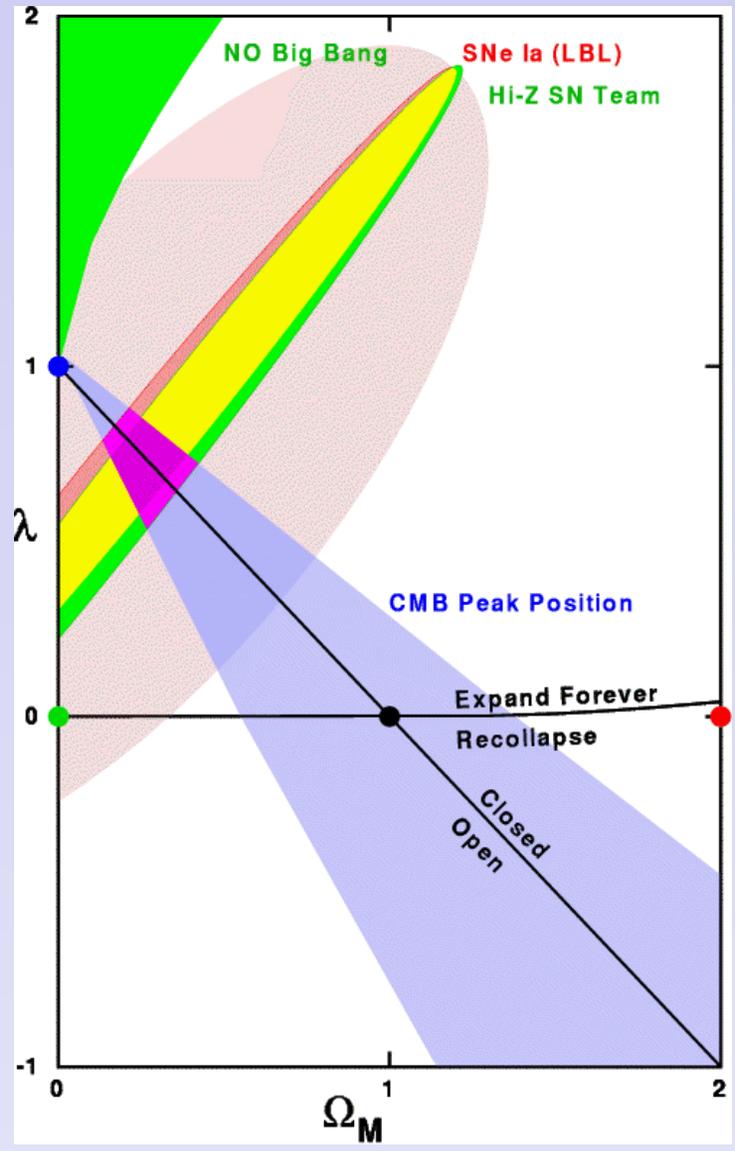
Cosmography : main features

Current parameters of the Universe :

- Expansion rate 71 ± 4 (km/s)/MegaParsec

- Size of the visible Universe 3 GigaParsec

- Age of the Universe 13.7 ± 2 GigaYears

- Age at decoupling $380 \pm 7 \times 10^3$ Year

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Dark Matter and Dark Energy

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CMBR data

ColdDarkMatter : Signature of new physics? Supersymmetry?

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- Anti-hydrogen consisting of anti-proton and positron has been created in the lab. We expect that it will have the exact same Balmer lines, Paschen lines ...

The fundamental force laws are the same for all these examples of matter and anti-matter.

Where *is* all the anti-matter?

As far away as we can see, there is only Hydrogen in the Universe, no anti-hydrogen.

Any anti-protons or positrons violently annihilate to produce high energy radiation.

[Not all particle-anti-particle pairs will annihilate into photons. For this they need to be sensitive to the electromagnetic force. For examples neutrio-anti-neutrino pair can only annihilate directly only into Z^0 gauge bosons, not photons.]

High energy anti-protons are found in cosmic rays reaching the

earth but these can be easily explained as products of violent astrophysical phenomena, not constituents of stable astrophysical objects.

The distribution of large hydrogenic clouds is almost continuous. There seem to be no major empty "corridors" separating matter universe and anti-matter universe.

Micro Macro
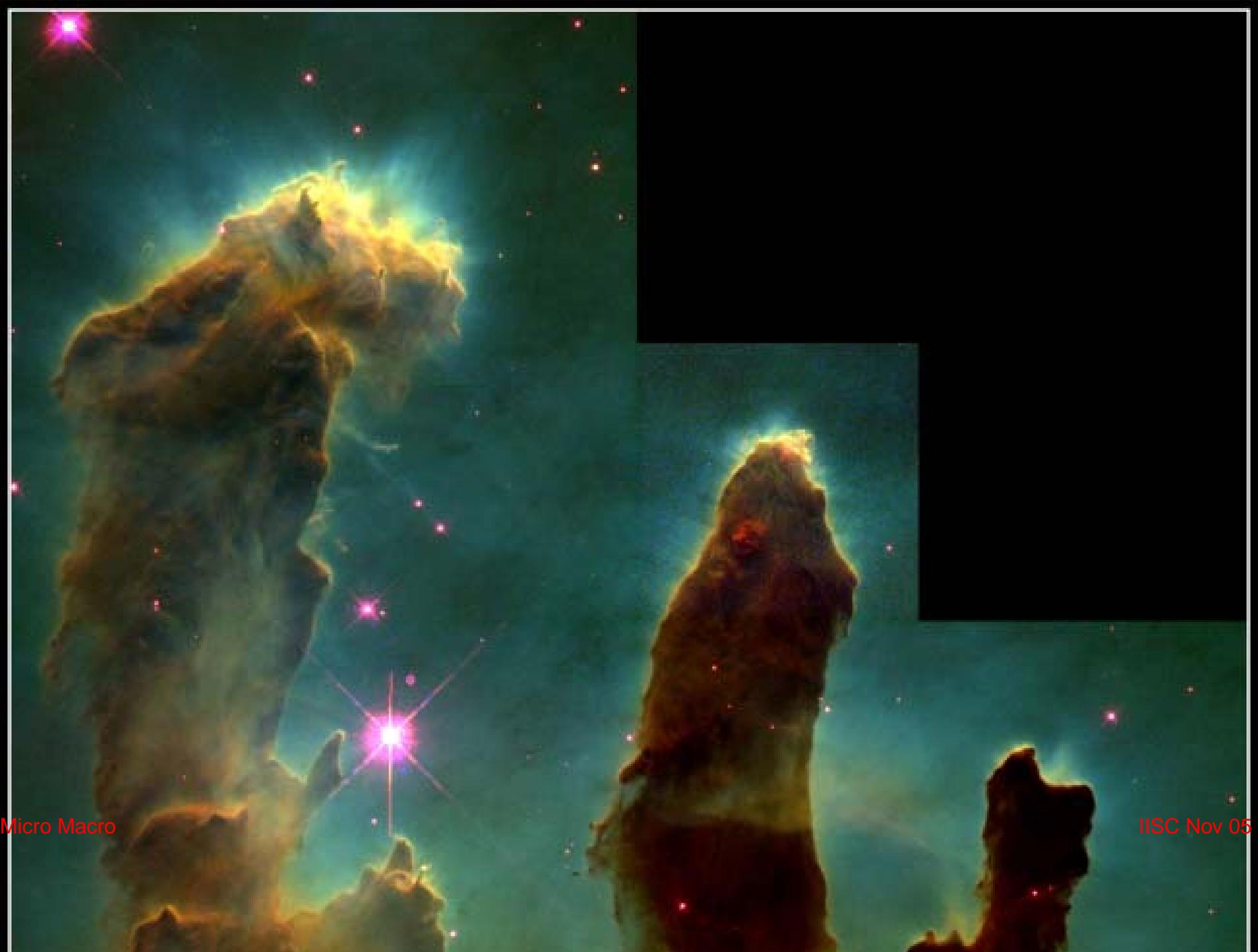
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Micro Macro

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RA

10 h
11 h
12 h
13 h
14 h
15 h

cz (1000 km/s)

60
50
40
30
20
10

Dec

-3°
-6°
-12°

North

11263 galaxies

South

12434 galaxies

10
20
30
40
50
60

-45°
-42°
-39°

4 h
3 h
2 h
1 h
0 h
23 h
22 h
21 h
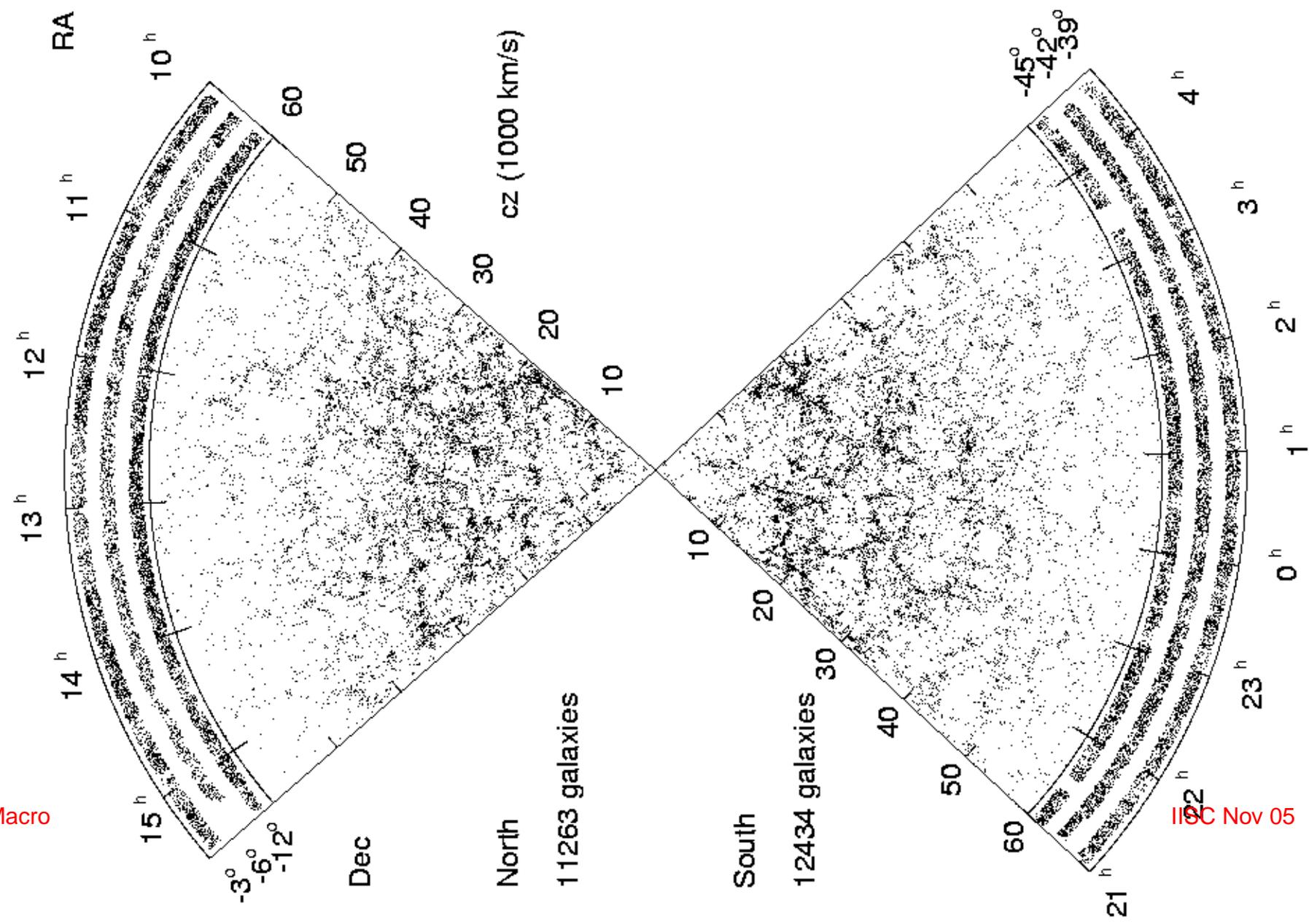
Micro Macro

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The 2dF Quasar Redshift Survey

Billions of light years

Redshift
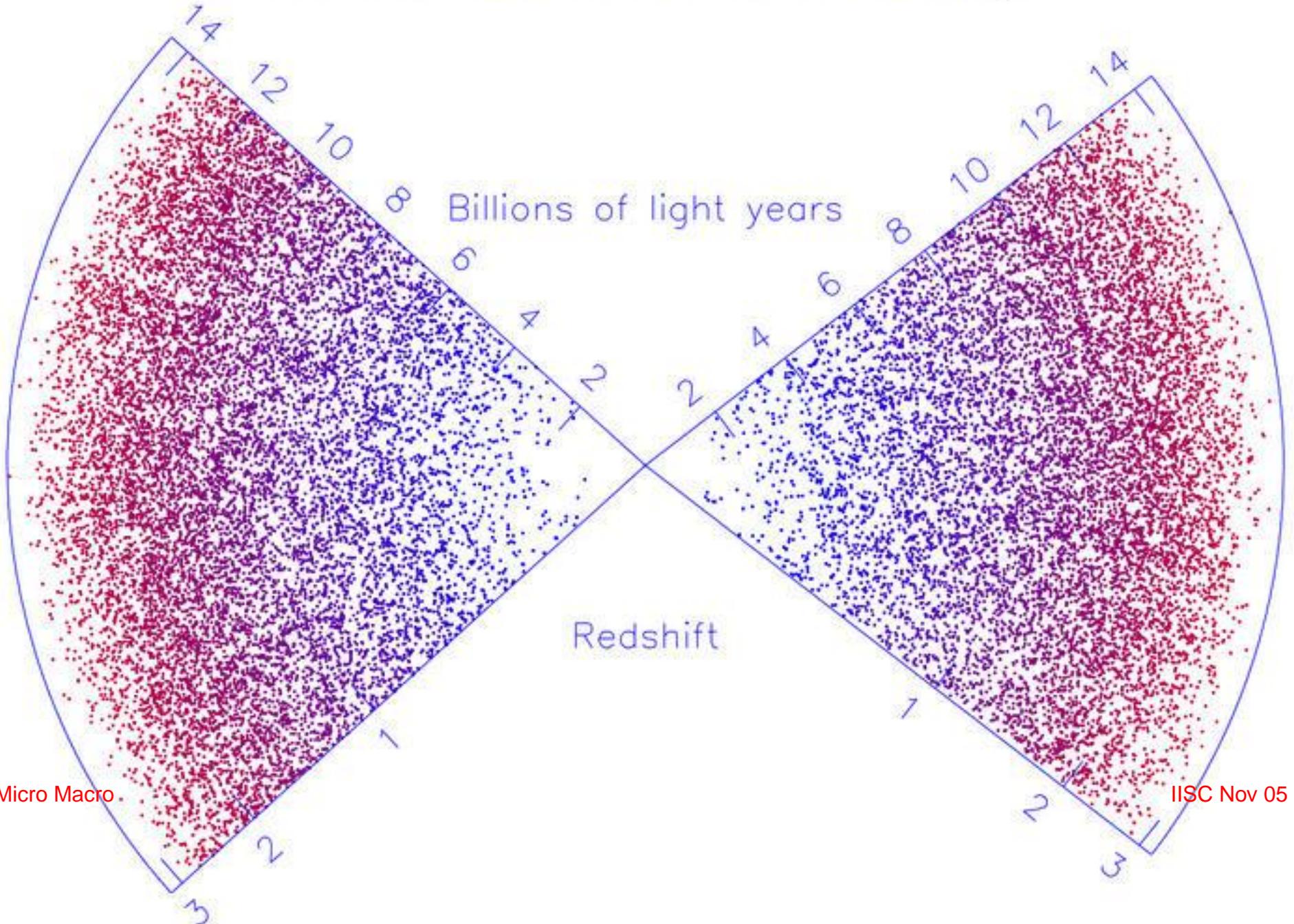
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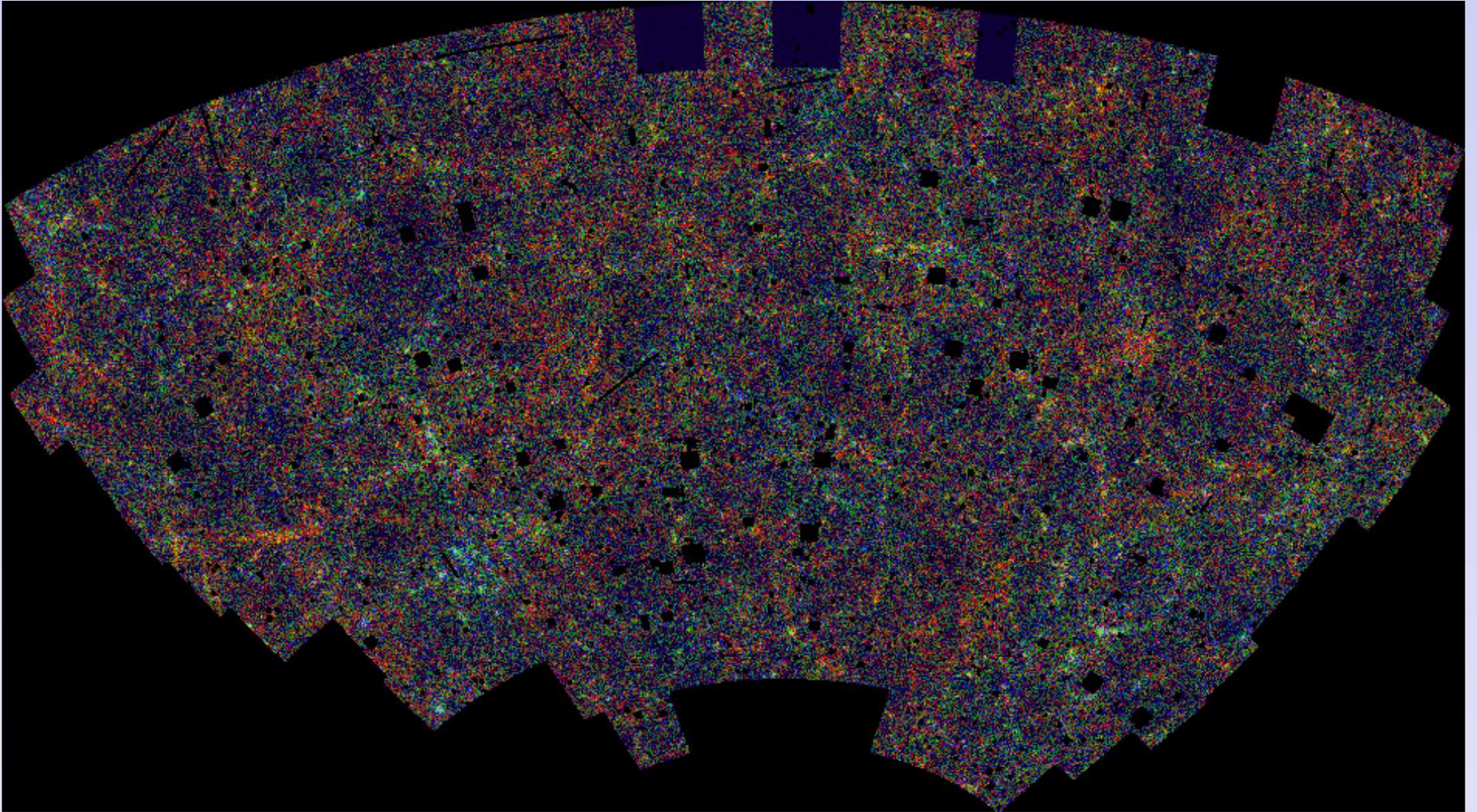
Dynamical explanation for asymmetry

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It may be these that motivated Andrei Sakharov to come up with a specific model

1. Baryon number violation $\not{B}$

$$X \rightarrow q\,q \qquad \Delta B_1 = 2/3$$
$$ \bar{q}\,\bar{\ell} \qquad \Delta B_2 = -1/3$$

2. Charge conjugation violation $\not{C}$

$$\mathcal{M}(x \rightarrow q\,q) \neq \mathcal{M}(\bar{x} \rightarrow \bar{q}\,\bar{q})$$

3 CP violation

$$r_1 = \frac{\Gamma_1(x \to qq)}{\Gamma_1 + \Gamma_2} \neq \frac{\bar{\Gamma}_1(\bar{x} \to \bar{q}\bar{q})}{\bar{\Gamma}_1 + \bar{\Gamma}_2} = \bar{r}_1$$

4 Out of equilibrium conditions
Reverse reactions become unfavorable

... out-of-equilibrium conditions to be provided by the cosmic fireball

The challenge to microphysics

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Example of another such number, not so time honored, is Lepton number.

Classic reaction is neutron decay

$$n \rightarrow p\,e^-\,\bar{\nu}_e$$

Many experiments suggest that the neutrino escaping in this decay has to be anti-electron neutrino, thus keeping Lepton number L zero on both sides of equation; Baryon number B is unity on both sides.

In accelerator experiments, even individual Lepton numbers L_e, L_μ and L_τ are conserved.

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LowEnergy solution : This is low compared to high !!! It means at
the energies of 100proton massess. This is the scale
of Weak nuclear force.

MediumEnergy solution : Moderately heavy neutrinos .... can

violate Lepton number, which later later produces Baryon number by Low Energy method.

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[Note, the age of the Universe is about 14 billion years so we could be sure not a single low energy dcay occure in its entire history. However the intended B violating interactions would be much more rapid at very high energies 10^{14}GeV].

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Summary : The High Energy solution to B asymmetry problem, even if correct seems difficult to verify.

The Low Energy solution

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✘ Not sufficient CP violation in Standard Model.

Of course, many alternatives exist, all quite conclusive according to their authors, but none uniquely distinguished.

Medium Energy solution

With the knowledge as of 1998 of tiny masses 10^{-1}-10^{-2}eV of neutrinos we have strong suspicion that there are lost brothers living at medium to high energies.
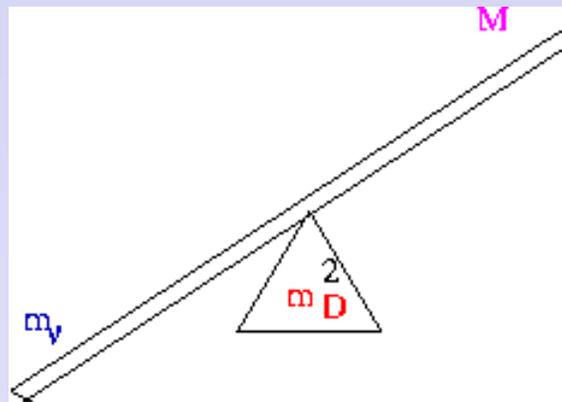
Quantum Field Theory permits such a possibility.

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Overall this route via Leptogenesis is now most favoured, assuming see-saw is the exlplanation for the ultra-light neutrino masses.

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- If we have not misunderstood the matter-anti-matter asymmetry puzzle, its solution alsolies in microphysics; again can point to possible unification schemes.