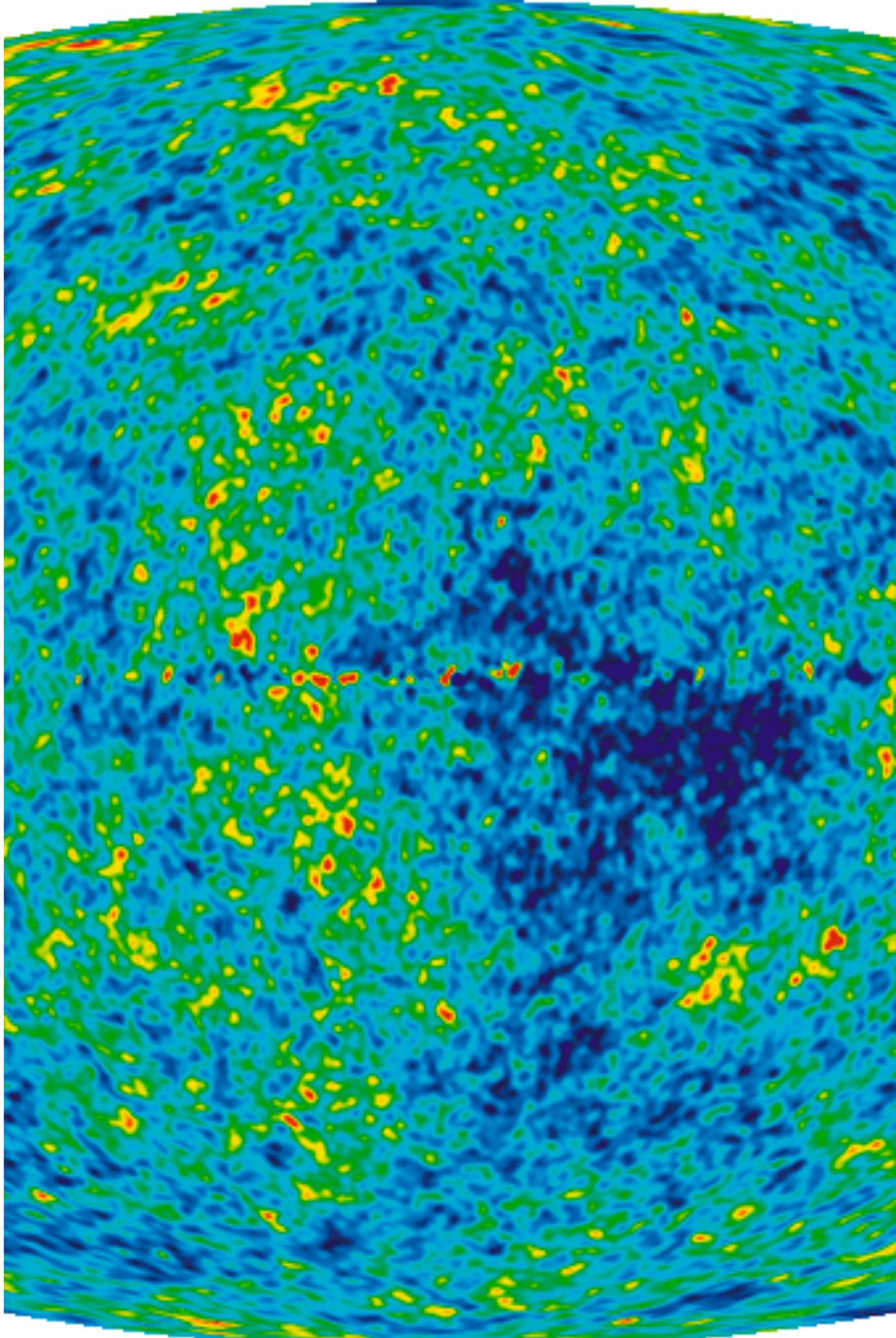
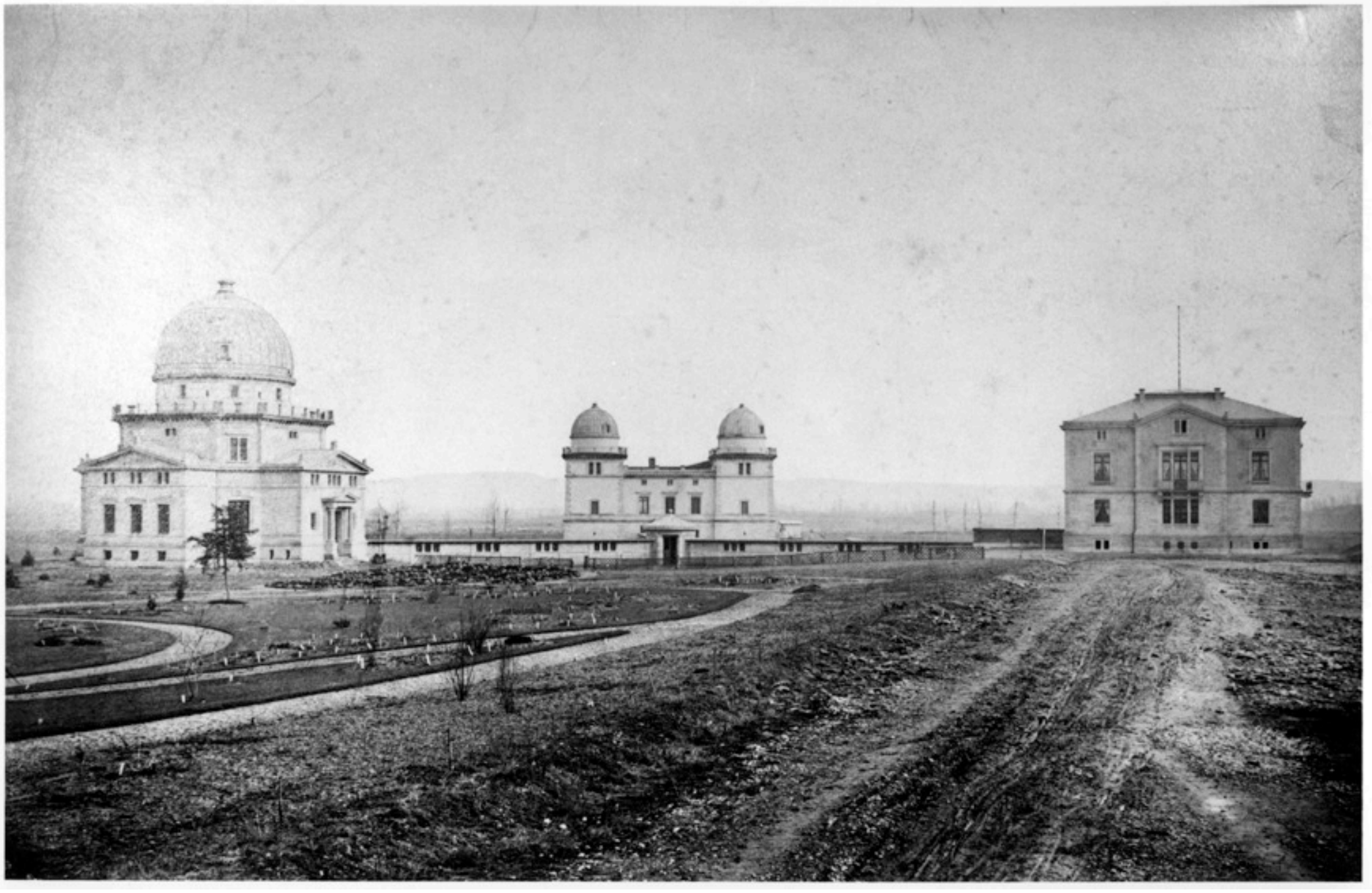
The Cosmological Sky

Dominique Aubert

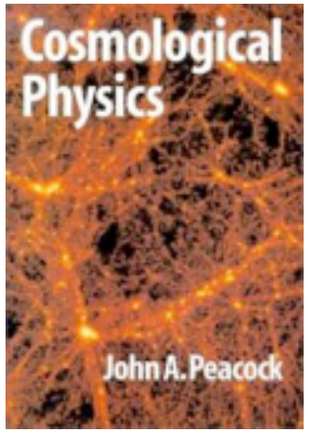


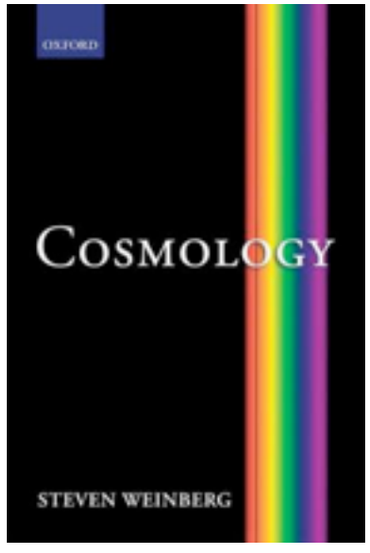
Welcome to the Observatory

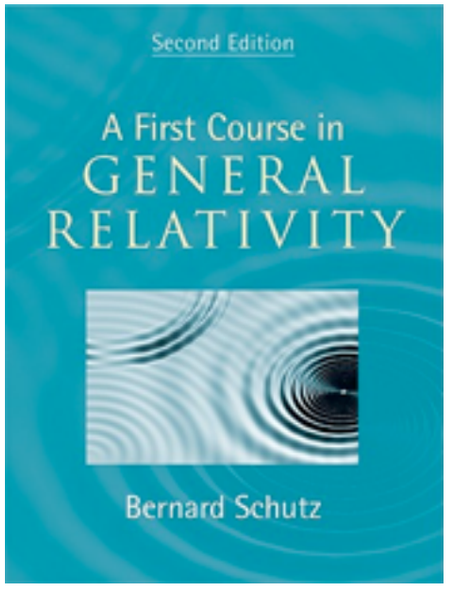


Bibliography

- Ned Wright website :http://www.astro.ucla.edu/~wright/cosmolog.htm
- Wayne Hu website :http://background.uchicago.edu/~whu/
- WMAP Papers : http://map.gsfc.nasa.gov/news/tp_links.html
- IPAC level 5: http://ned.ipac.caltech.edu/level5/
- Cosmological Physics by J. Peacock
- Cosmology by S. Weinberg
- A First Course in General Relativity By Bernard Schutz

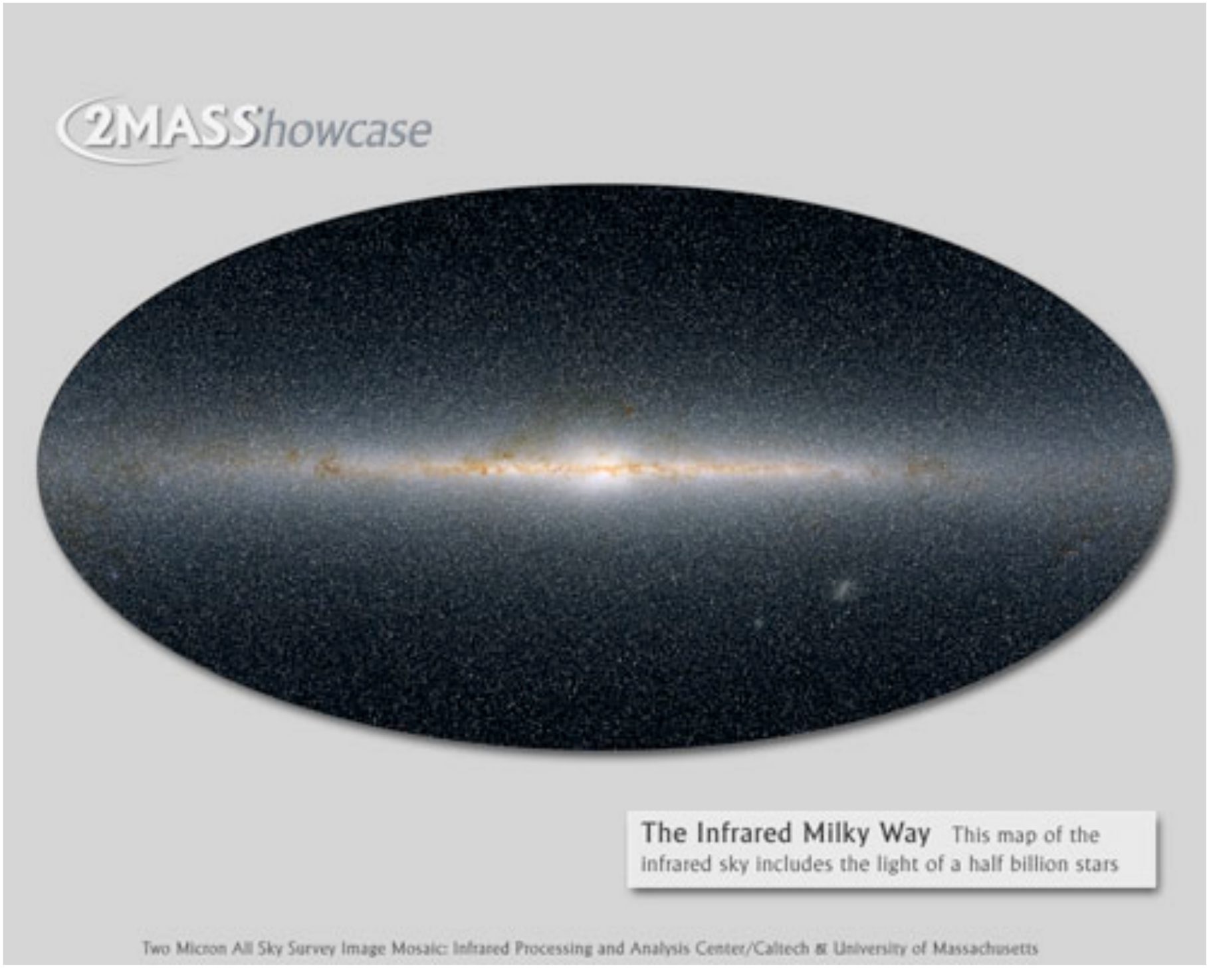




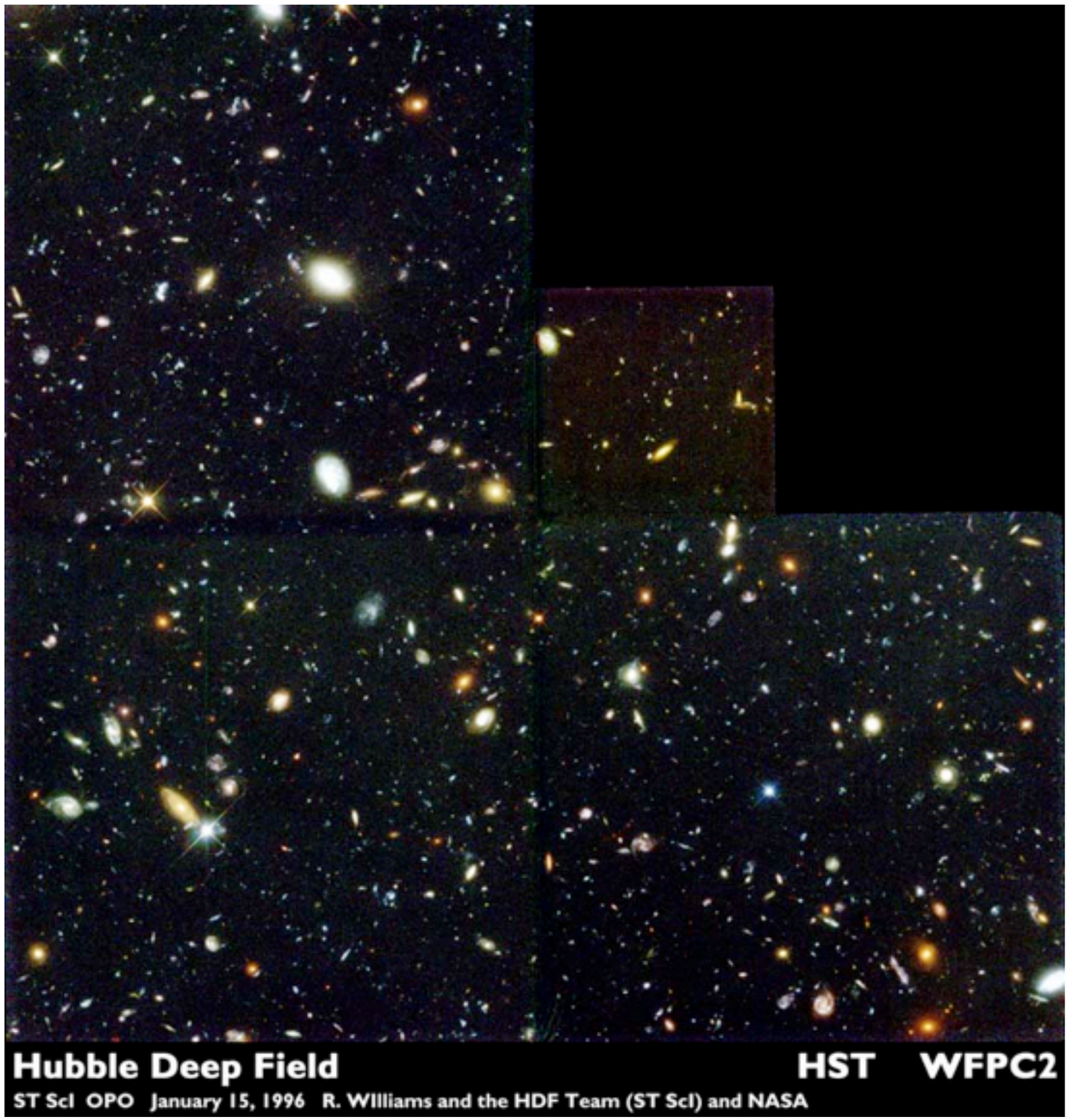


Zooming Out

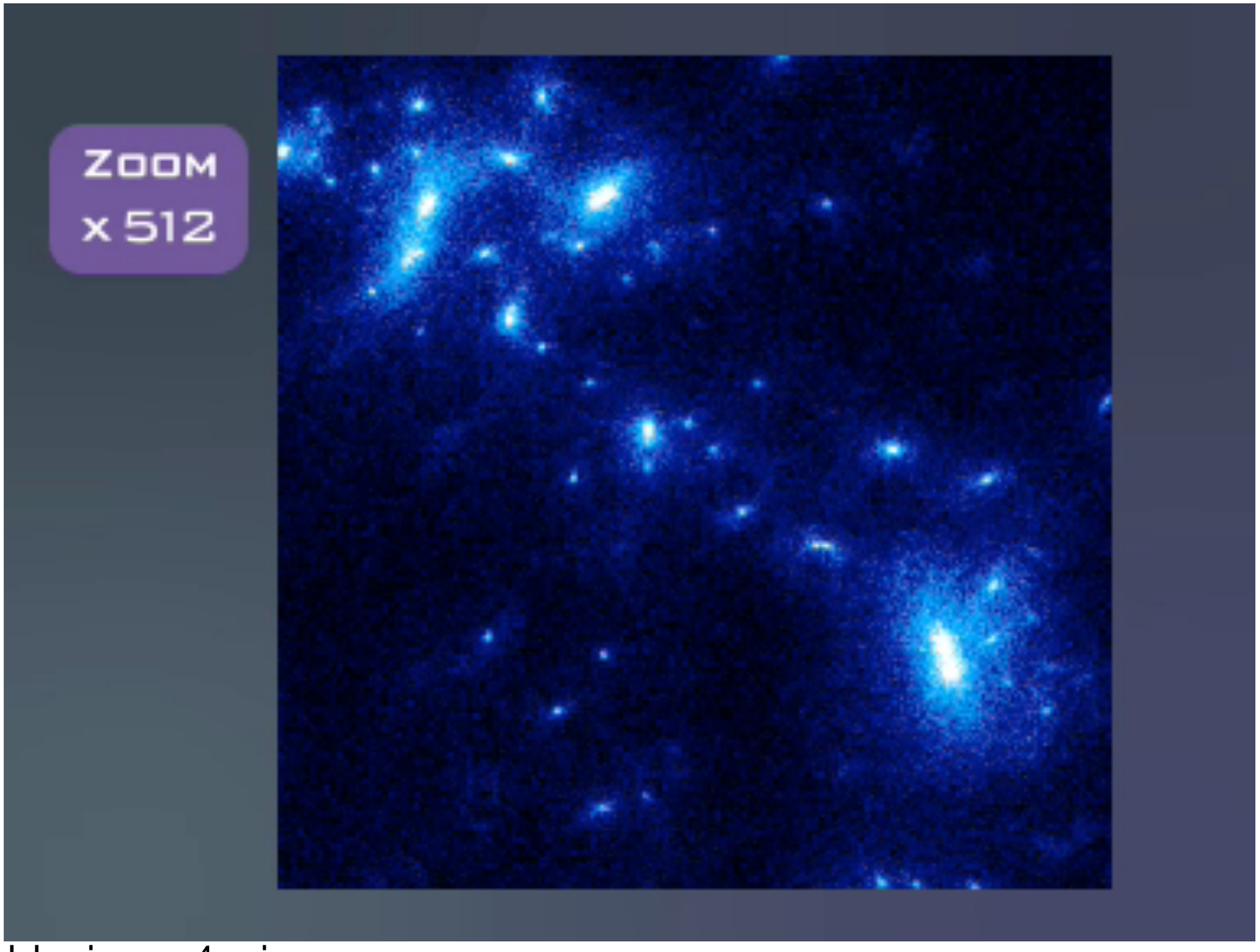
The Galaxy


2MASShowcase
The Infrared Milky Way This map of the infrared sky includes the light of a half billion stars
Two Micron All Sky Survey Image Mosaic: Infrared Processing and Analysis Center/Caltech & University of Massachusetts

HDF


Hubble Deep Field
HST WFPC2
ST ScI OPO January 15, 1996 R. WIlliams and the HDF Team (ST ScI) and NASA

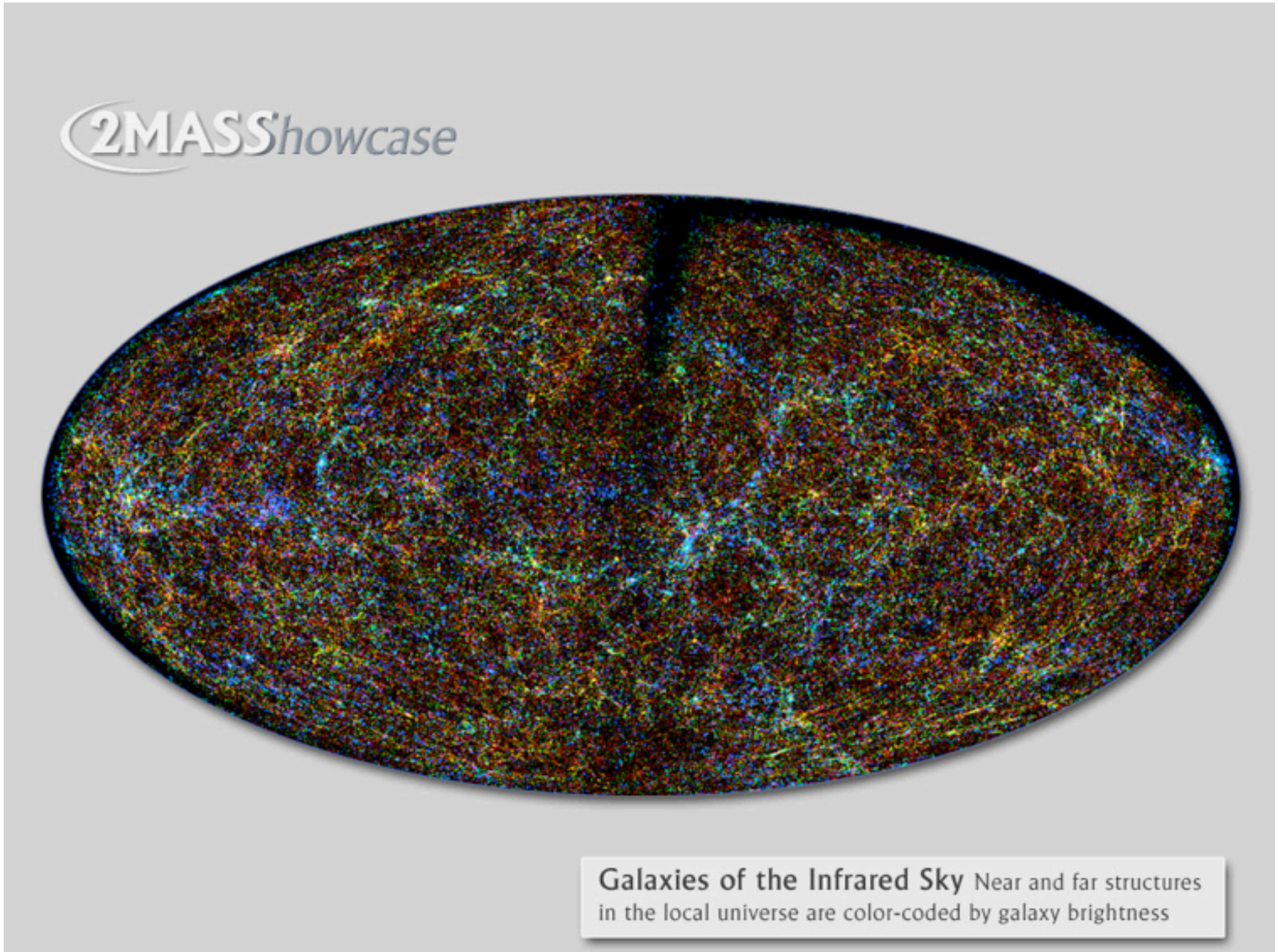
Large Scale Structures : LSS



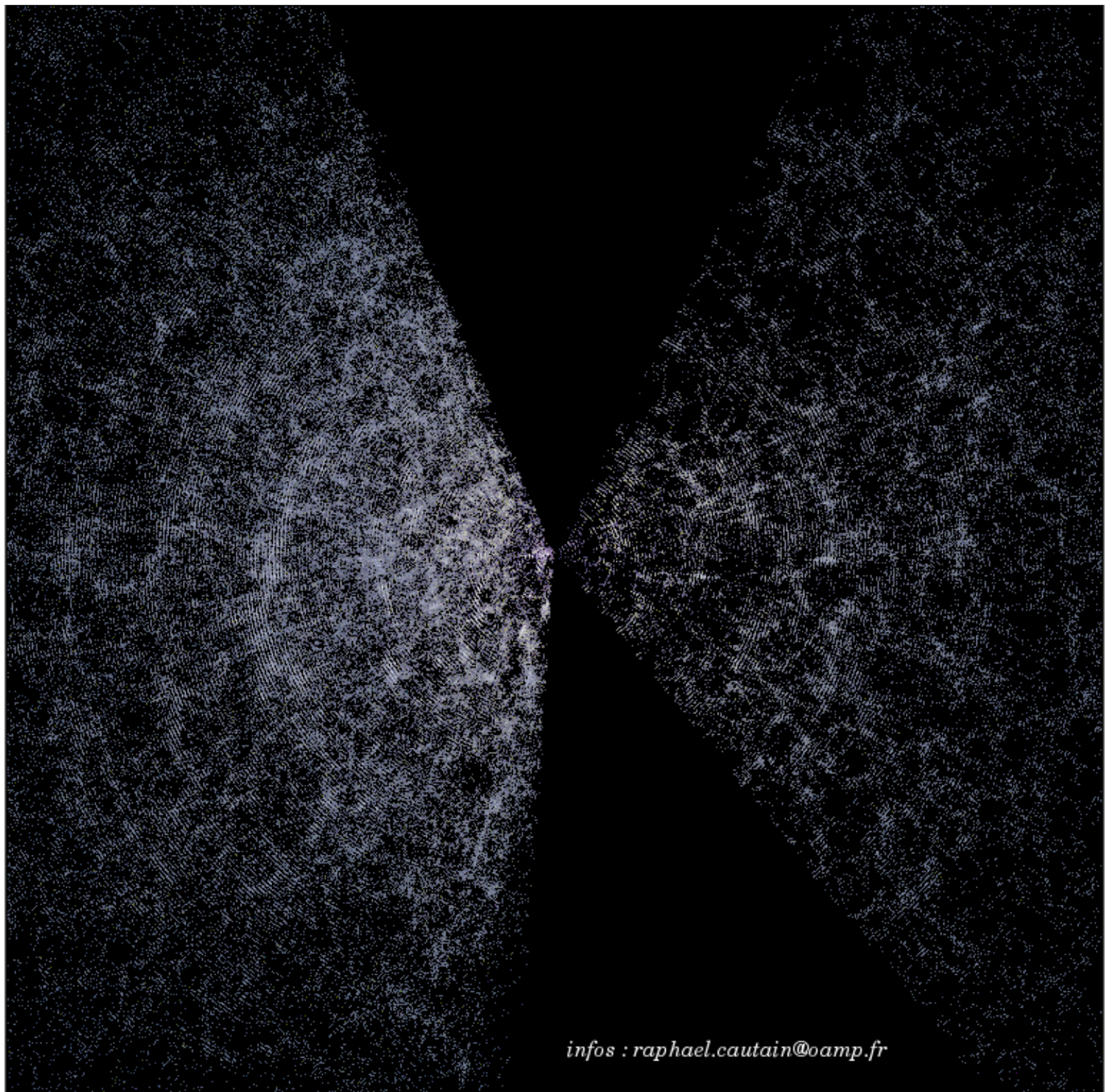
Horizon 4 pi

Credit : Horizon Project

LSS


2MASShowcase
Galaxies of the Infrared Sky Near and far structures
in the local universe are color-coded by galaxy brightness
Two Micron All Sky Survey Image Mosaic: Infrared Processing and Analysis Center/Caltech & University of Massachusetts

LSS

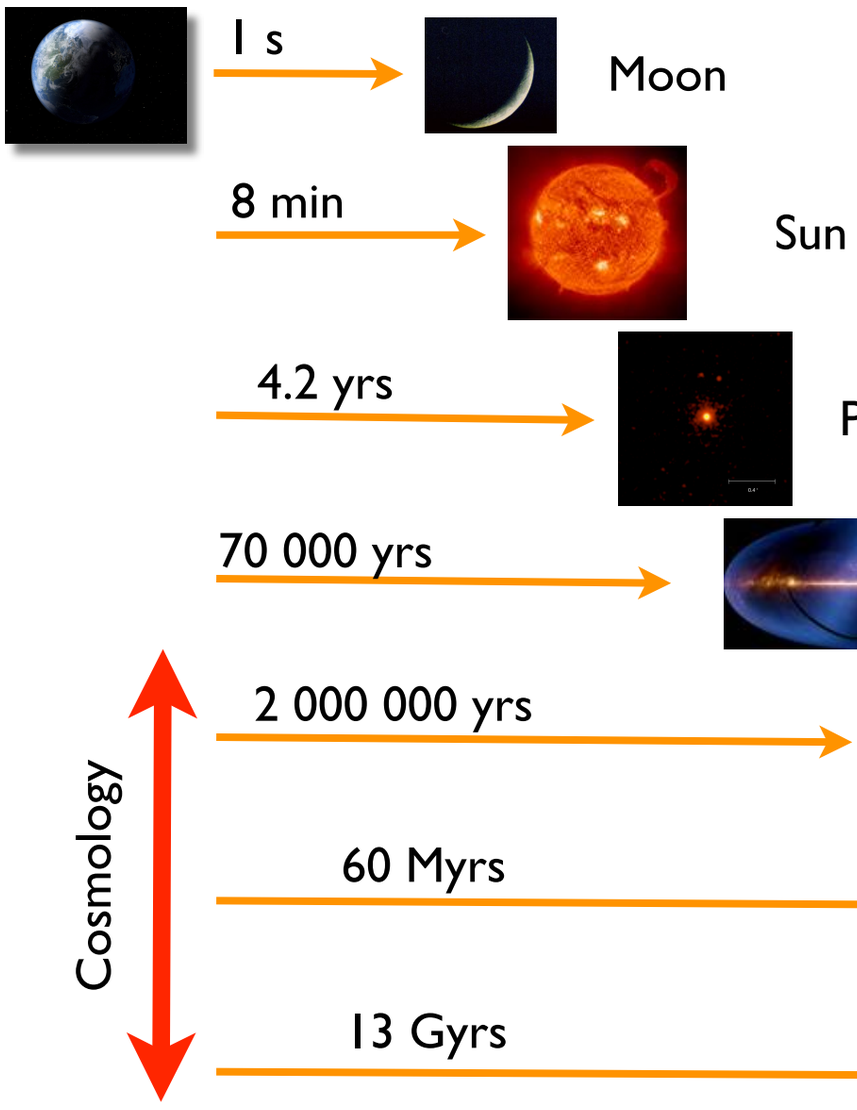


Voids...

Filaments...

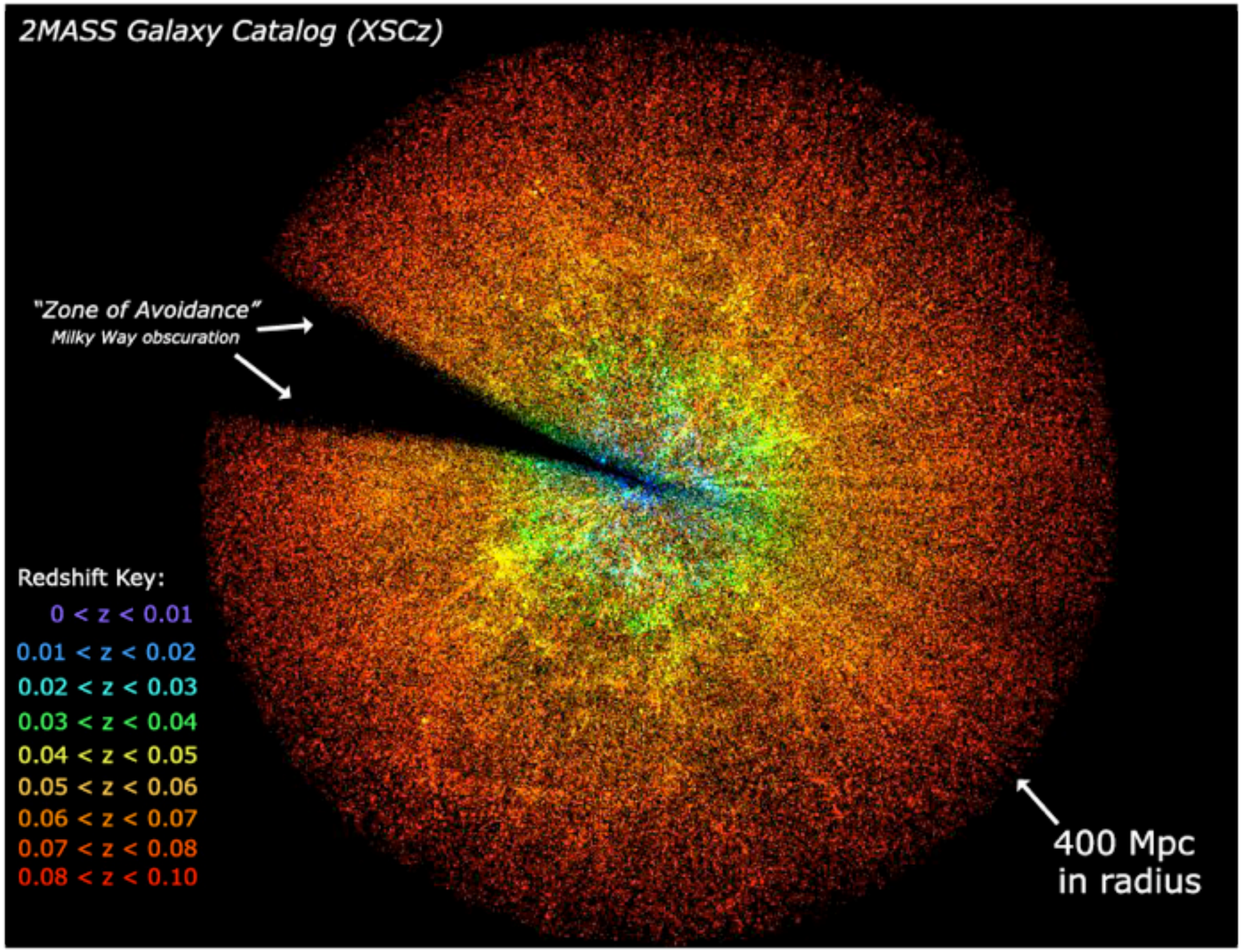
Clusters...

Cosmological distances



How long does it take for light to travel to ...

Universe Expansion



the reddening of light or «redshift» is related to the motion of emitters

Cosmological Principle

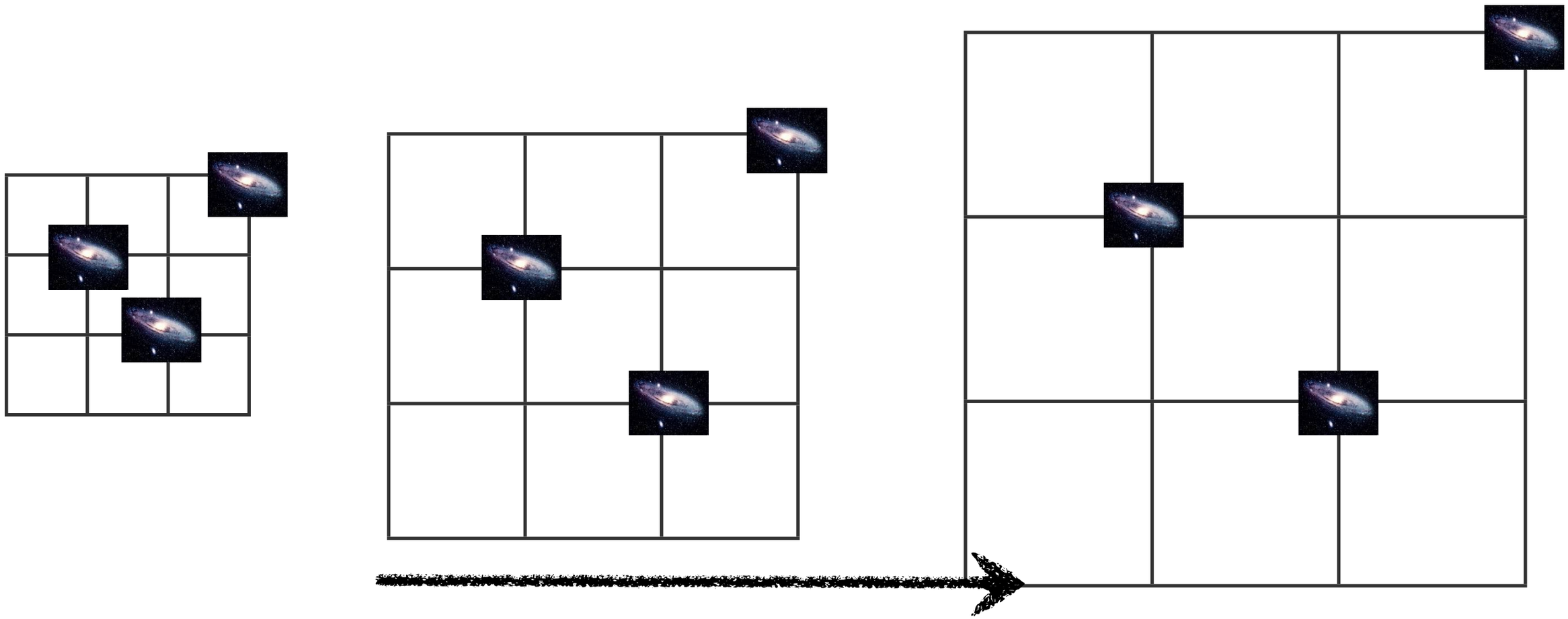
The standard cosmological model assumes :

- the Universe is isotropic and homogeneous (on cosmological scales)
- Gravitation is described by General Relativity (GR)

Extension of the Copernician principle. It leads to:

ΛCDM

Expansion

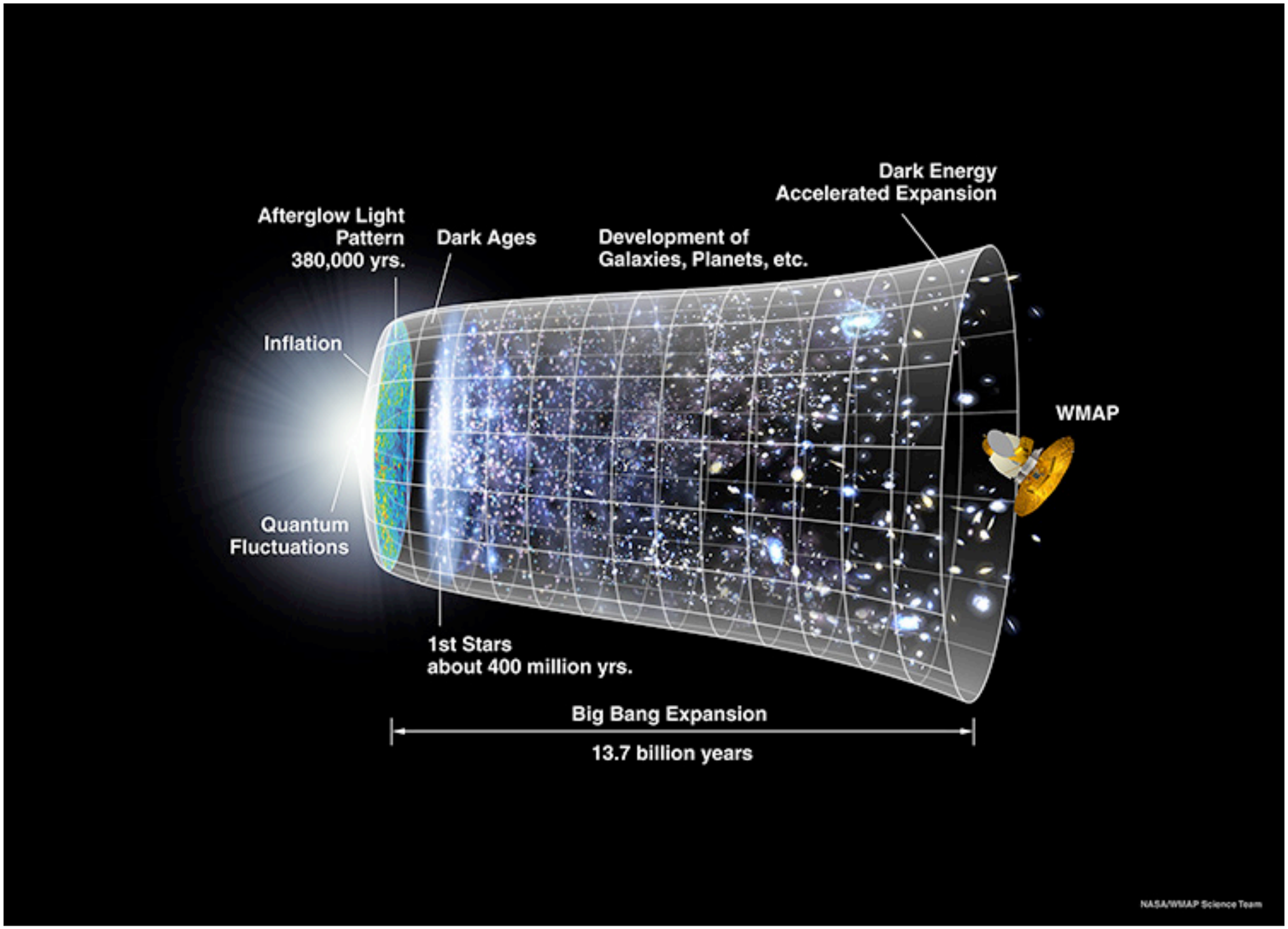


time

as we will discuss later:

- space expands with time
- the Universe temperature decreases with time

History of the Universe



Nasa /WMAP team

The standard model

Table 1
Summary of the Cosmological Parameters of ΛCDM Model[a]

Class	Parameter	*WMAP* Seven-year ML[b]	*WMAP*+BAO+H_0 ML	*WMAP* Seven-year Mean[c]	*WMAP*+BAO+H_0 Mean
Primary	$100\Omega_b h^2$	2.227	2.253	$2.249^{+0.056}_{-0.057}$	2.255 ± 0.054
	$\Omega_c h^2$	0.1116	0.1122	0.1120 ± 0.0056	0.1126 ± 0.0036
	Ω_Λ	0.729	0.728	$0.727^{+0.030}_{-0.029}$	0.725 ± 0.016
	n_s	0.966	0.967	0.967 ± 0.014	0.968 ± 0.012
	τ	0.085	0.085	0.088 ± 0.015	0.088 ± 0.014
	$\Delta^2_{\mathcal{R}}(k_0)$[d]	2.42×10^{-9}	2.42×10^{-9}	$(2.43 \pm 0.11) \times 10^{-9}$	$(2.430 \pm 0.091) \times 10^{-9}$
Derived	σ_8	0.809	0.810	$0.811^{+0.030}_{-0.031}$	0.816 ± 0.024
	H_0	70.3 km s^{-1} Mpc^{-1}	70.4 km s^{-1} Mpc^{-1}	70.4 ± 2.5 km s^{-1} Mpc^{-1}	70.2 ± 1.4 km s^{-1} Mpc^{-1}
	Ω_b	0.0451	0.0455	0.0455 ± 0.0028	0.0458 ± 0.0016
	Ω_c	0.226	0.226	0.228 ± 0.027	0.229 ± 0.015
	$\Omega_m h^2$	0.1338	0.1347	$0.1345^{+0.0056}_{-0.0055}$	0.1352 ± 0.0036
	$z_{\rm reion}$[e]	10.4	10.3	10.6 ± 1.2	10.6 ± 1.2
	t_0[f]	13.79 Gyr	13.76 Gyr	13.77 ± 0.13 Gyr	13.76 ± 0.11 Gyr

Amount of Baryonic matter

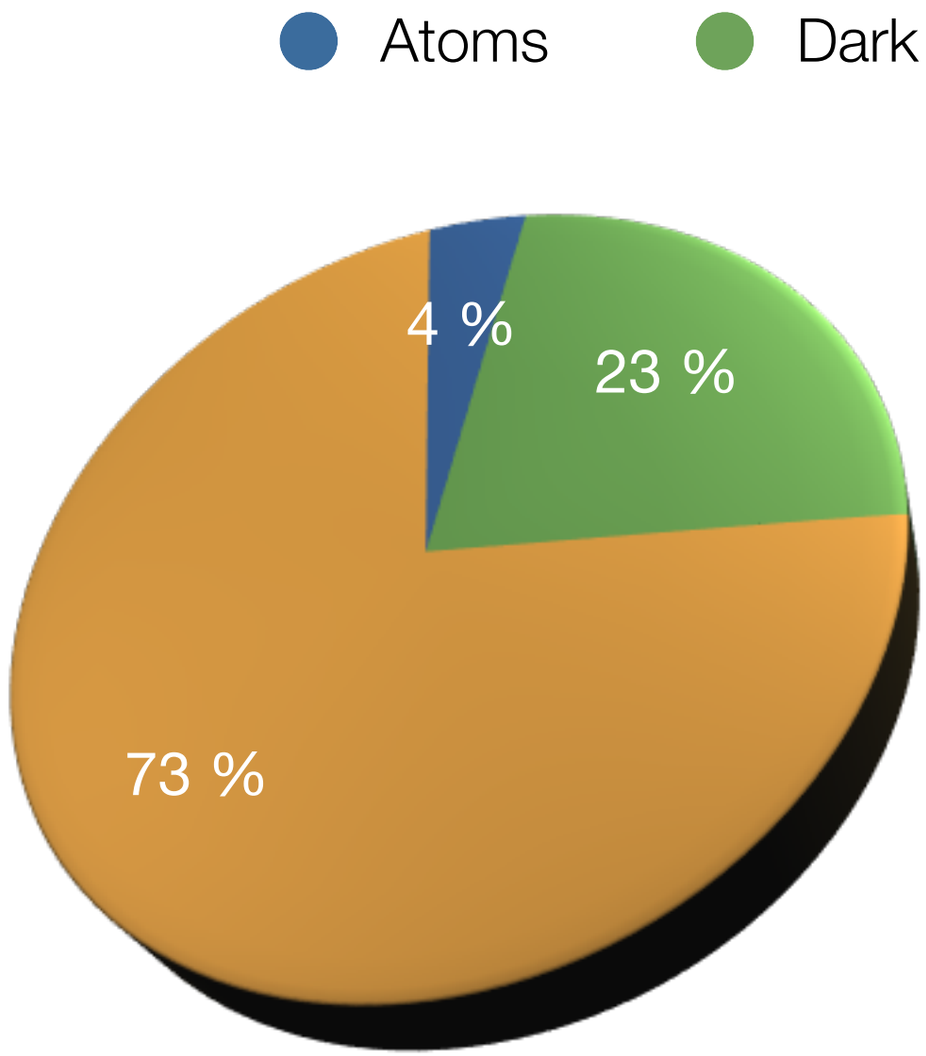
Amount of Dark matter

«Geometrical» distribution of initial seeds

Amount of Dark Energy

Instant of Reionisation

Energetic content of the Universe, today



$$\Omega_\Lambda = 0.73$$

$$\Omega_m = 0.27$$

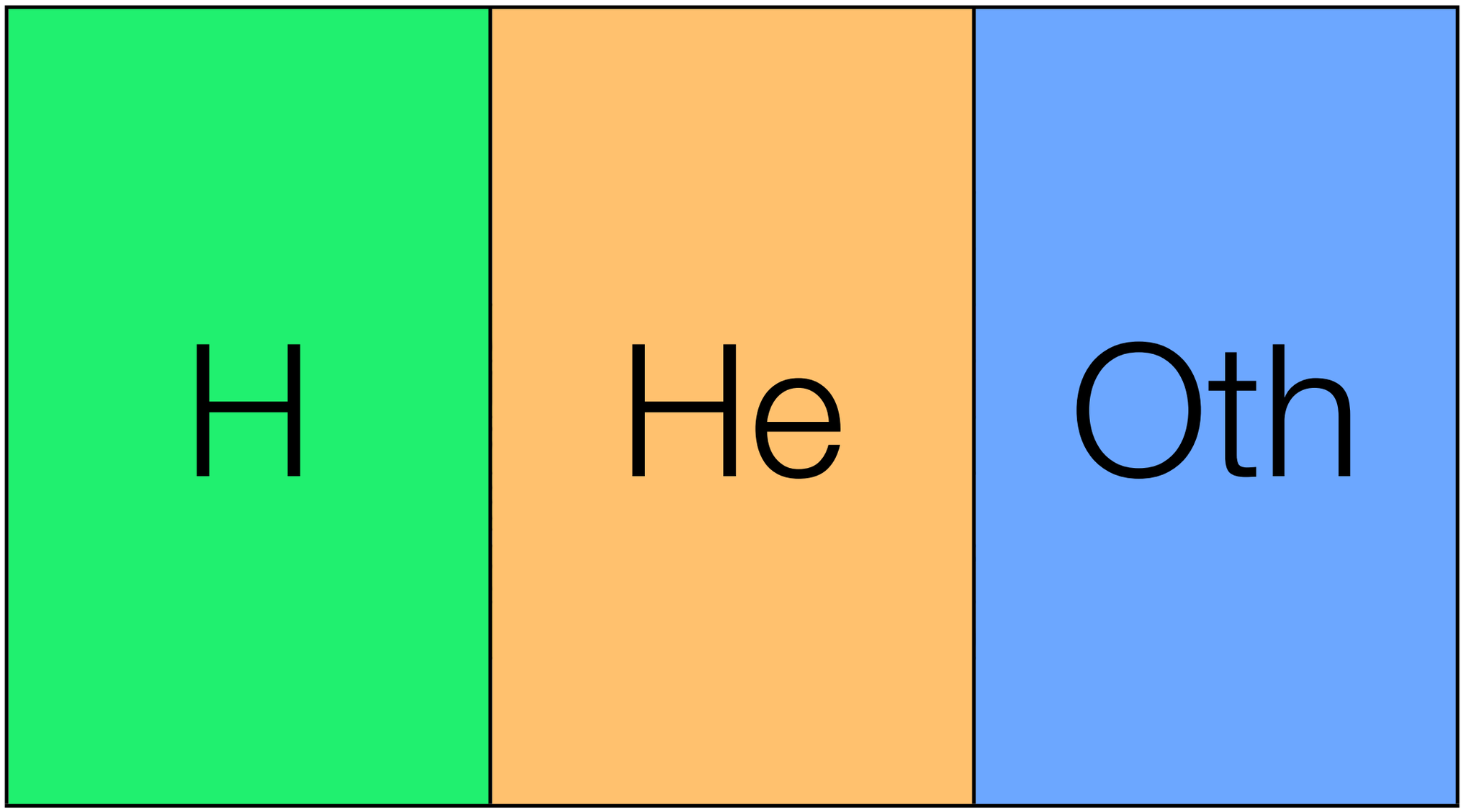
$$\Omega_b = 0.04$$

$$\Omega_r \sim 0.00001$$

$$\Omega_m + \Omega_r + \Omega_\Lambda = 1$$

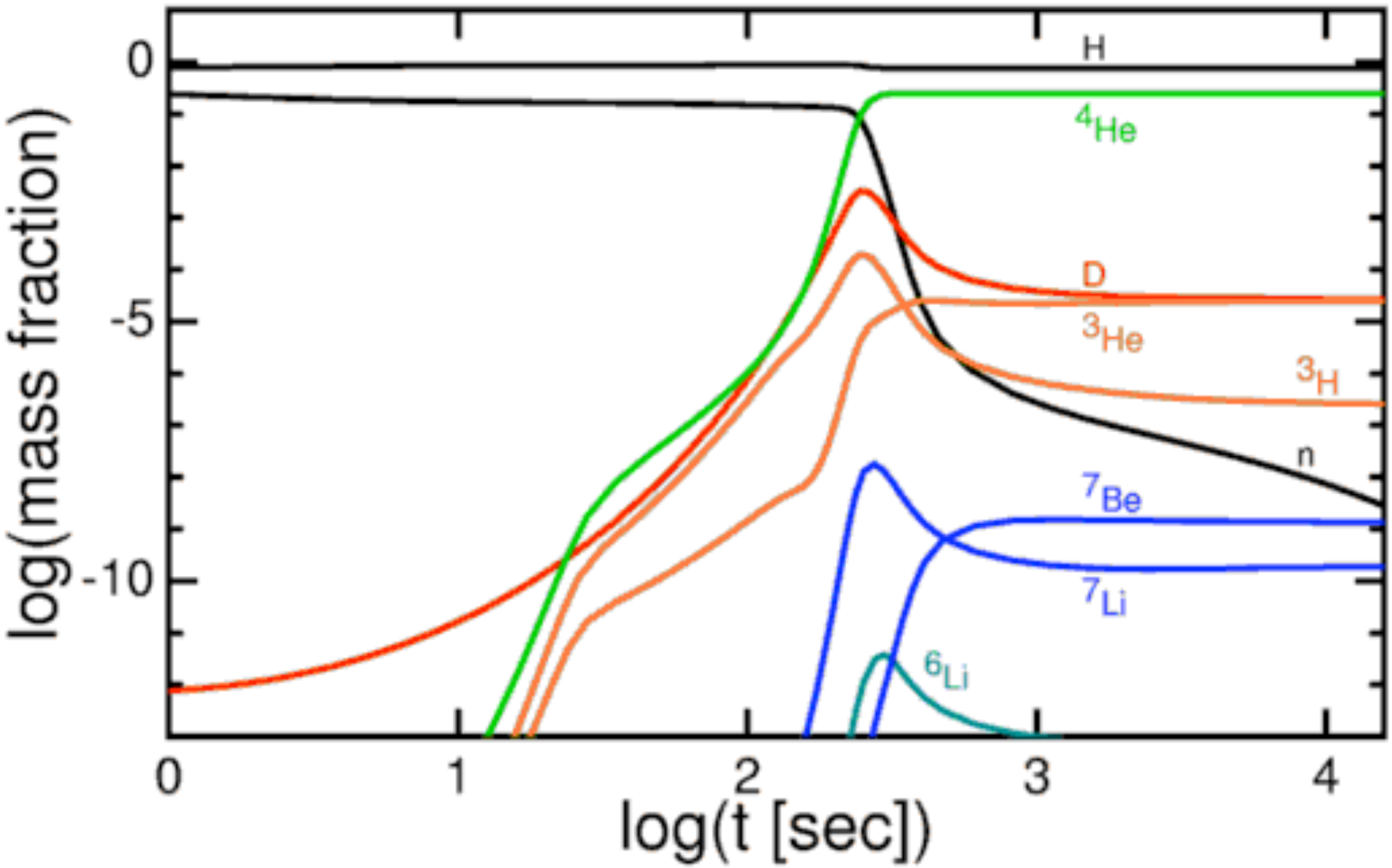
Baryons (or the story of the first 3 minutes)

Light Elements in the Universe



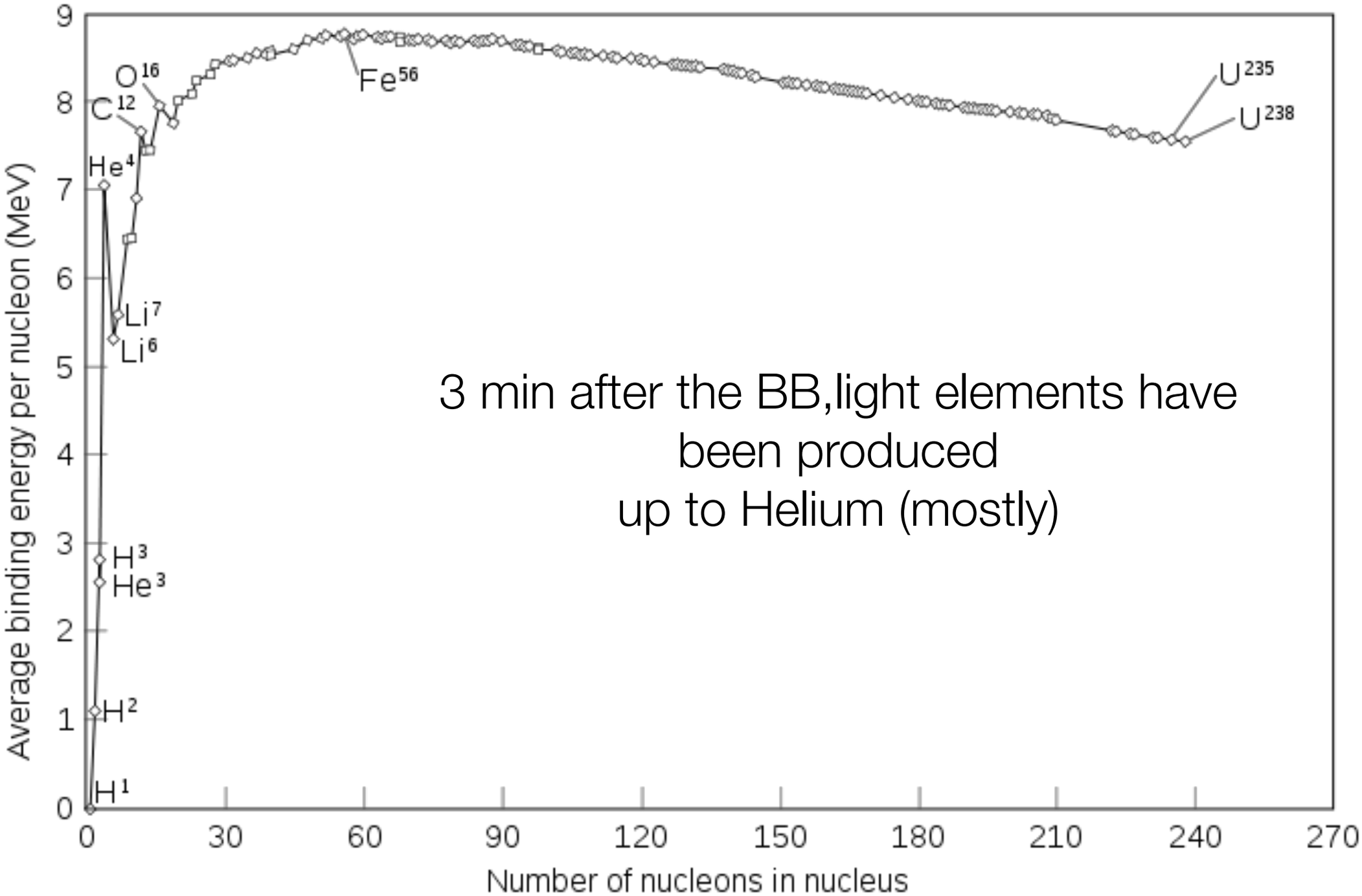
75 % H -- 25% He -- 0% Others (Metals)

BBN



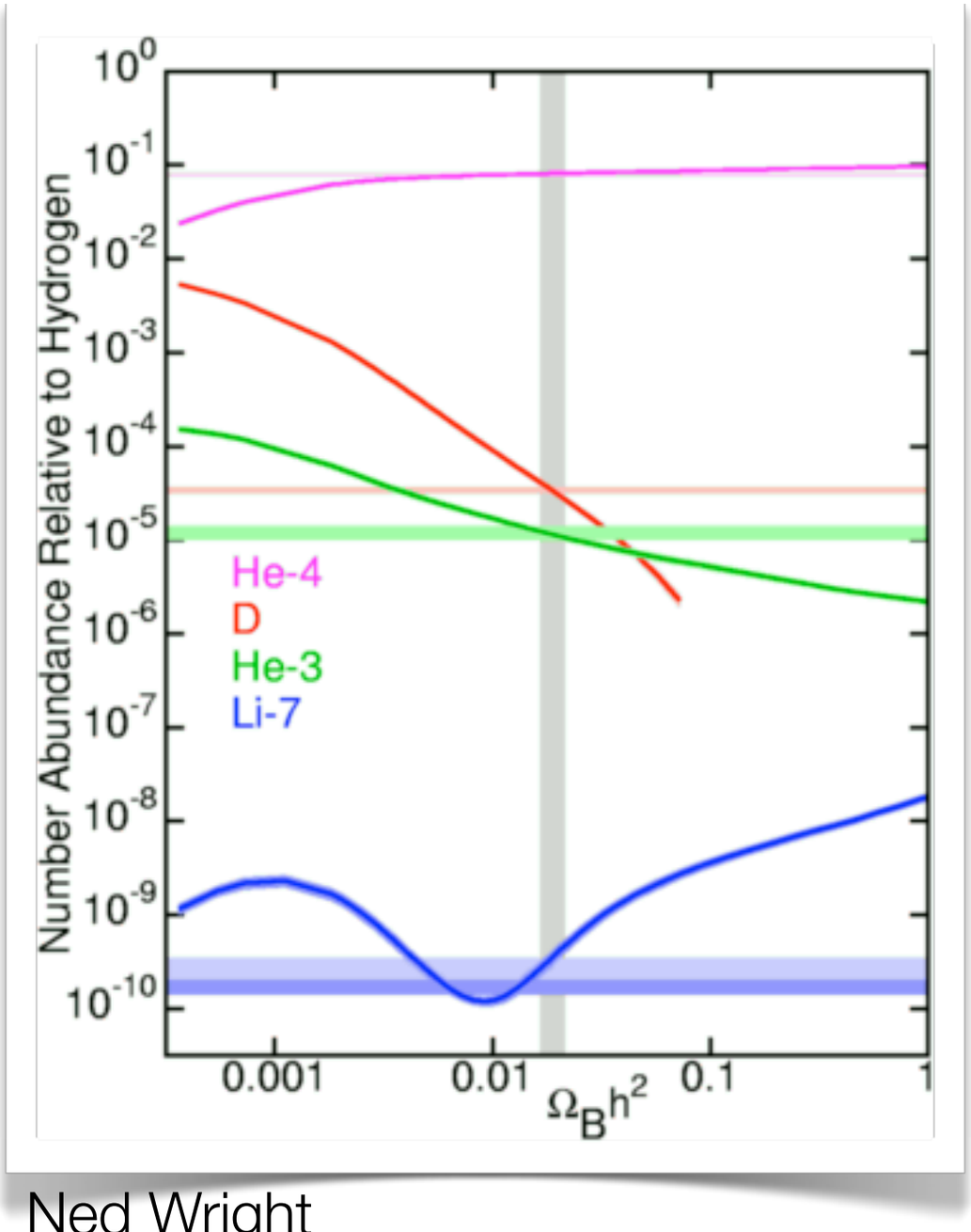
as the Universe cools down Deuterium than Helium can be created

Stability of Nuclei



3 min after the BB,light elements have been produced
up to Helium (mostly)

Big Bang Nucleosynthesis

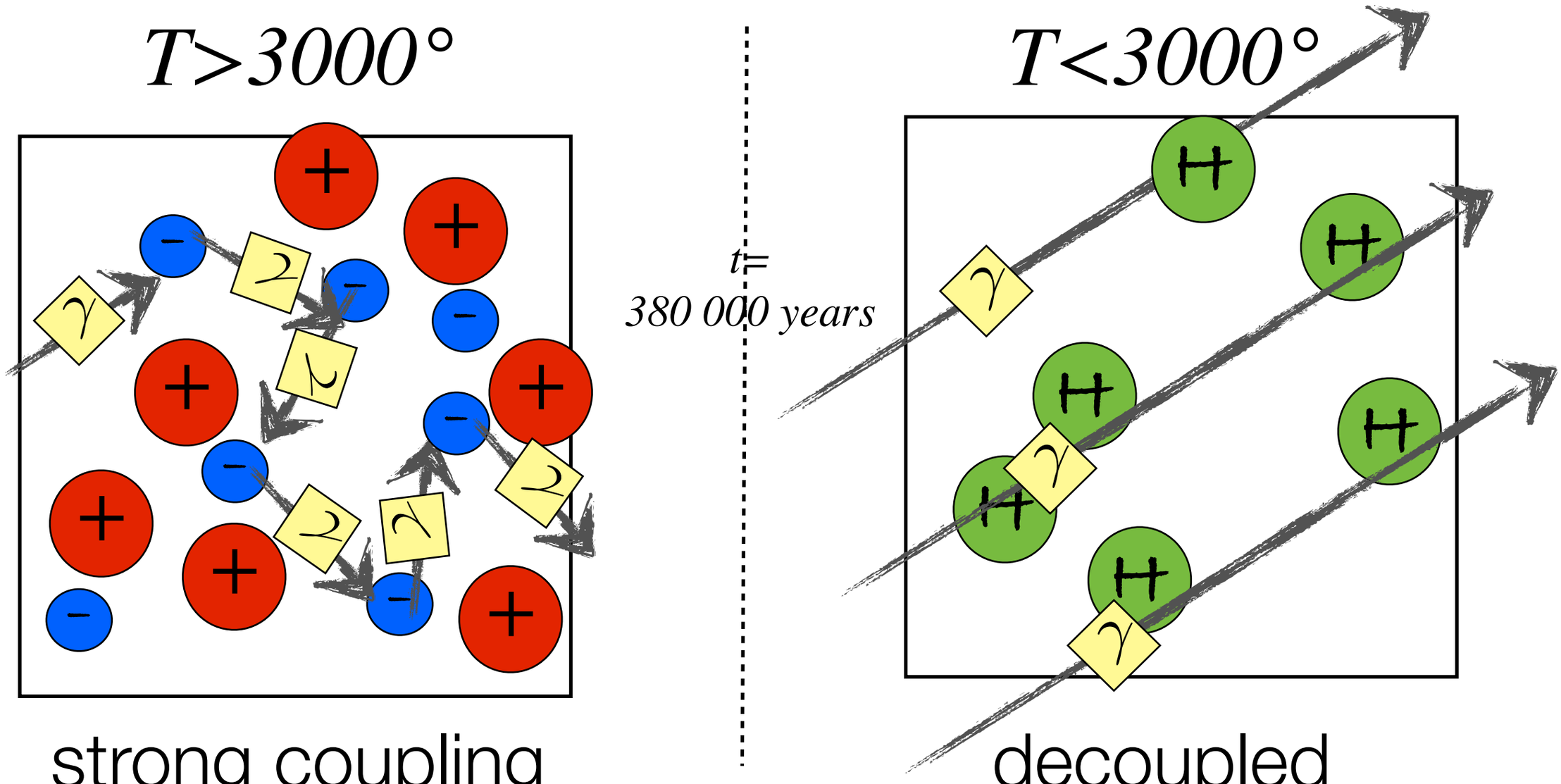


Ned Wright

The total amount of Baryons is constrained by BBN

Light (or the first 400 000 years)

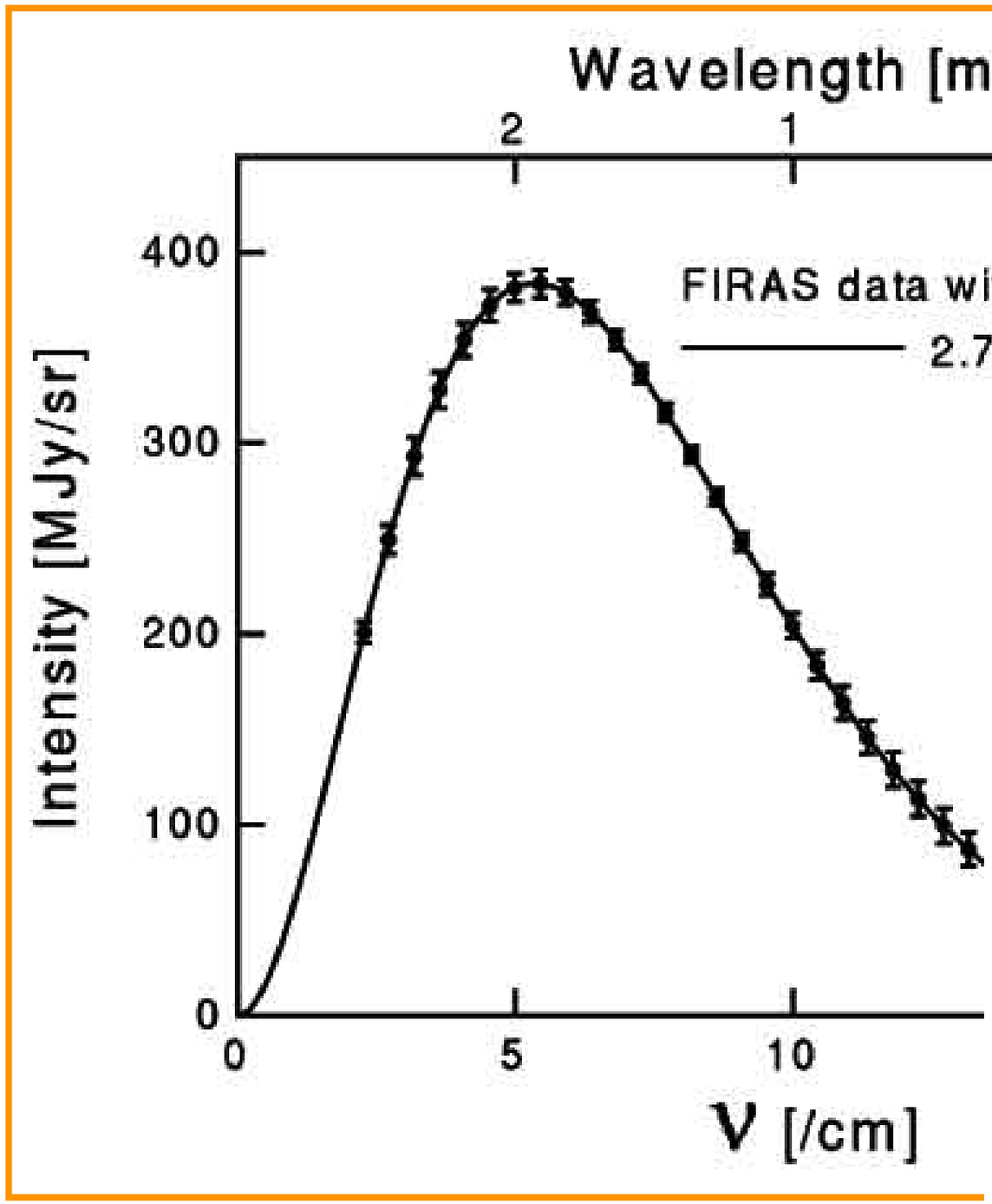
Last Scattering



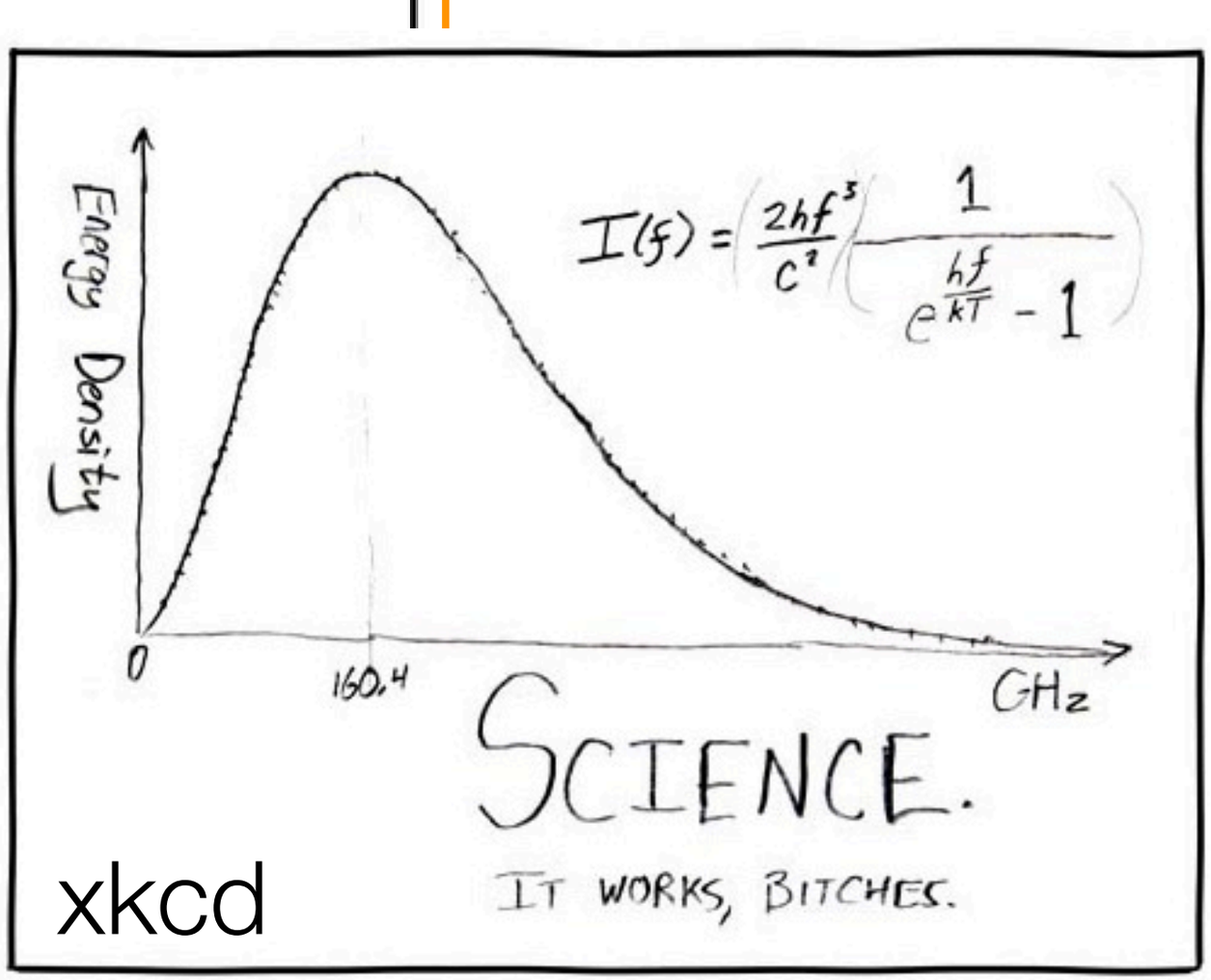
strong coupling
Black Body
opaque medium

decoupled
still a Black Body
transparent medium

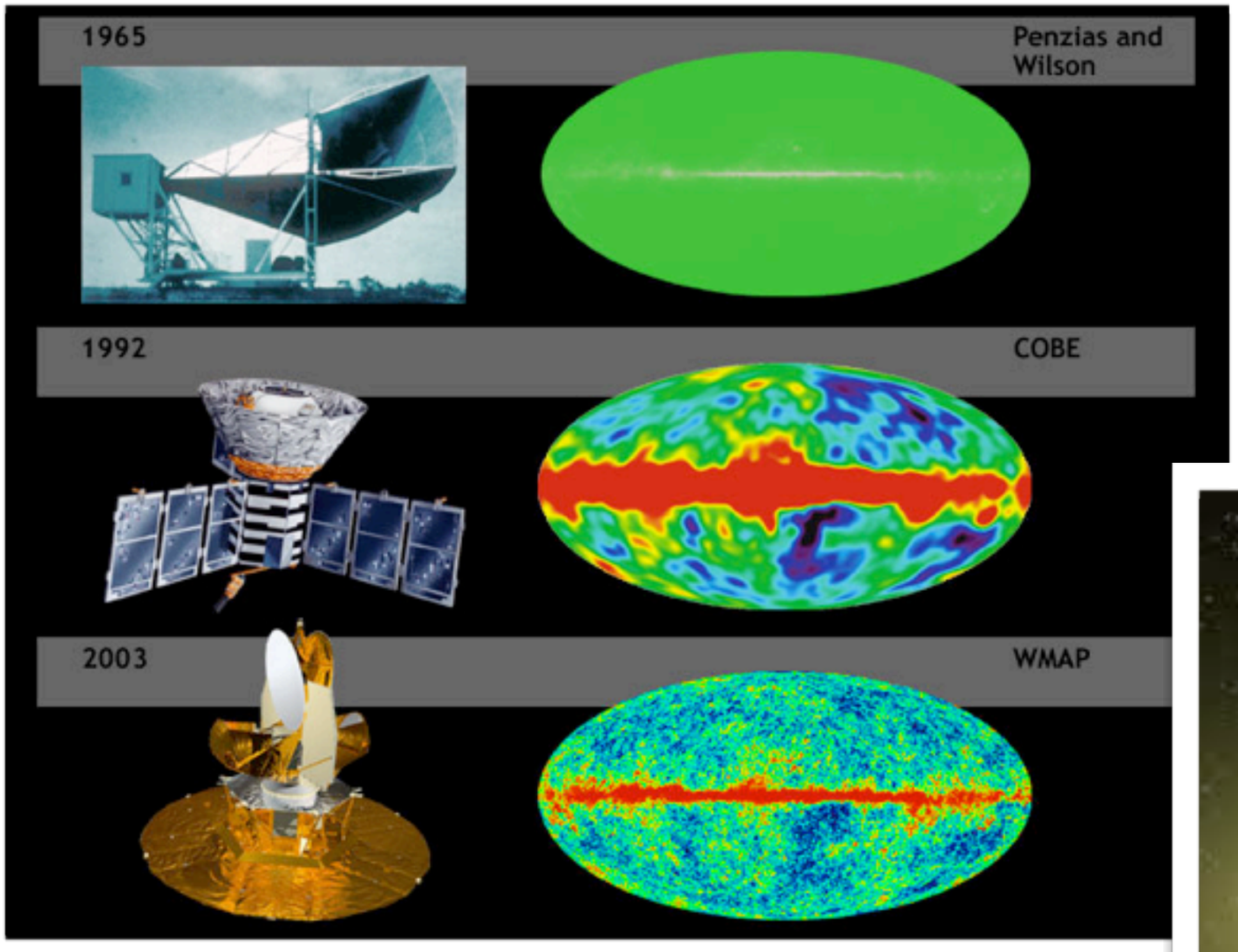
The CMB : the perfect Black Body



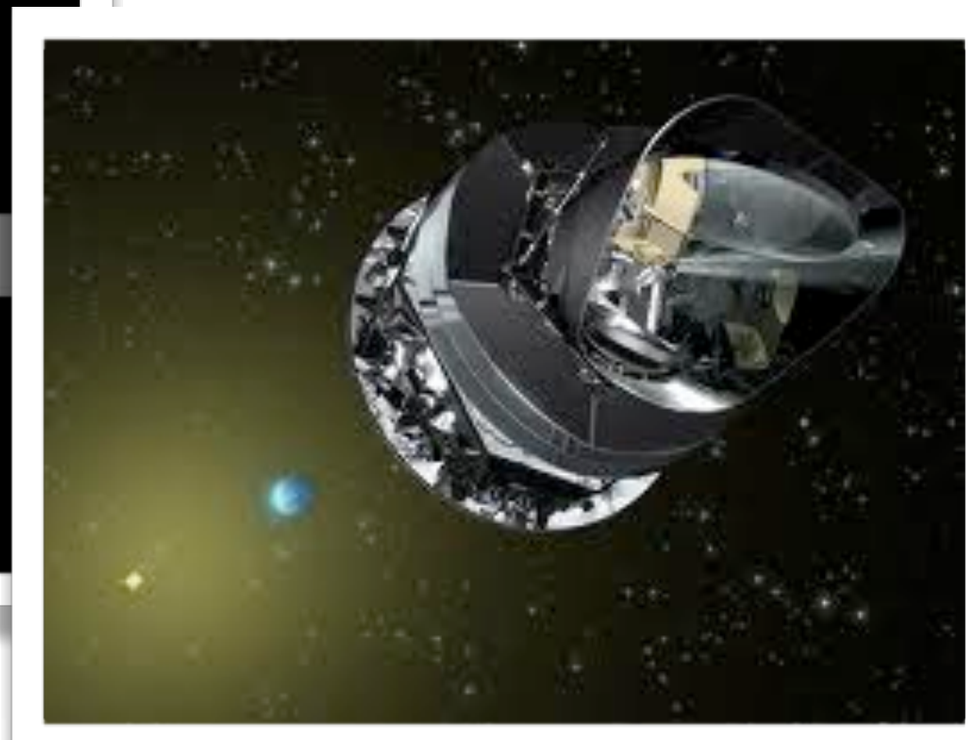
3 K BBody



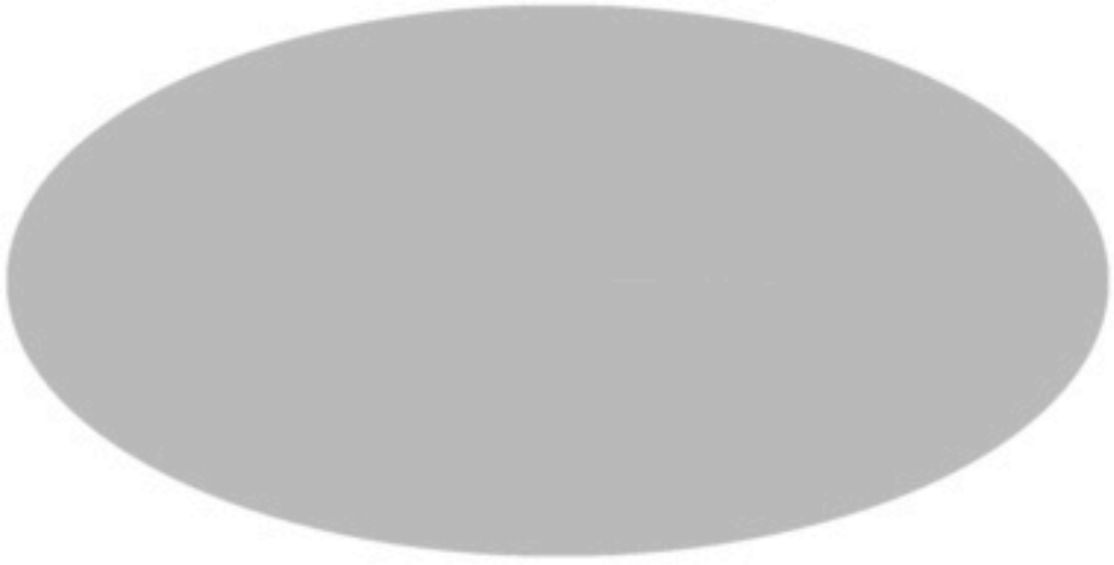
Looking for the CMB

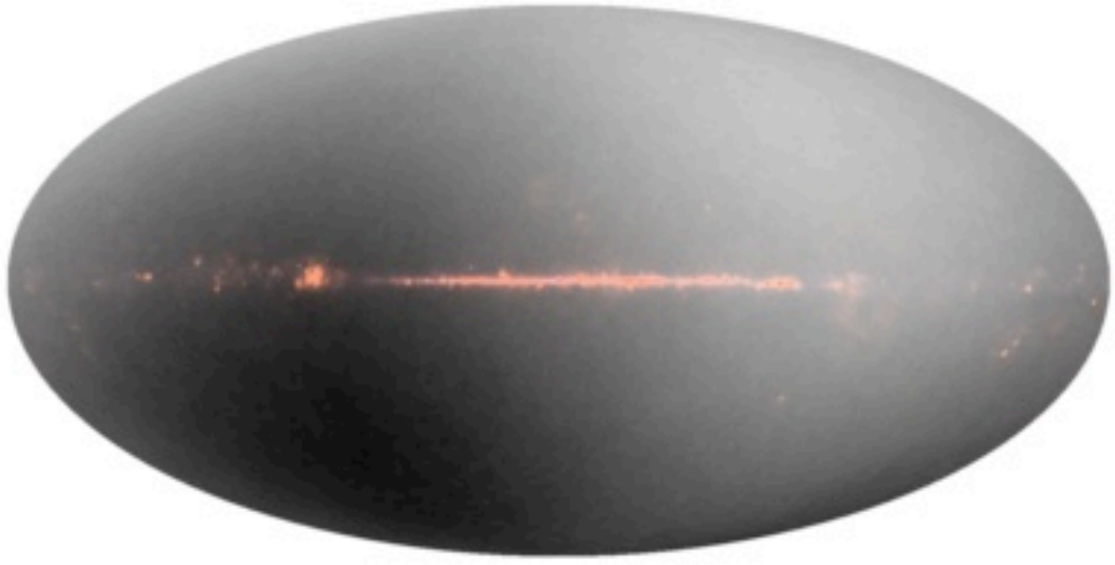


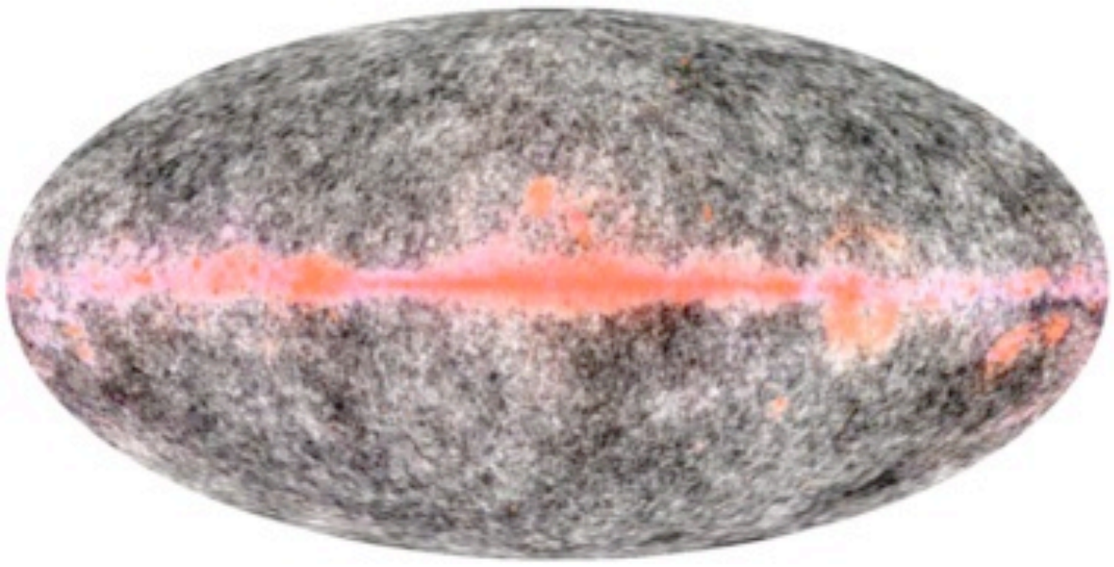
NASA/WMap

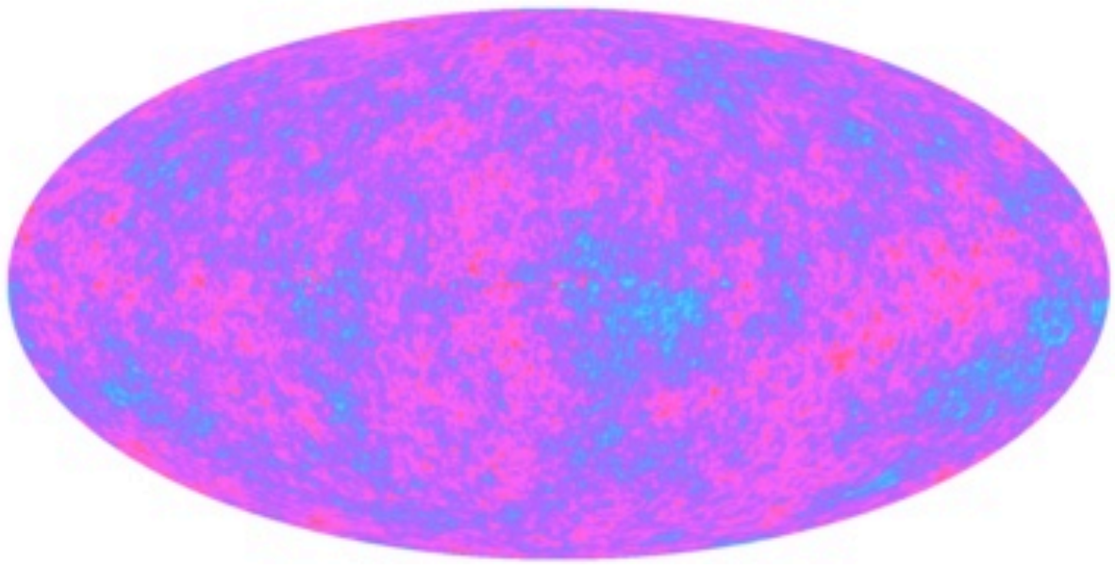


ESA



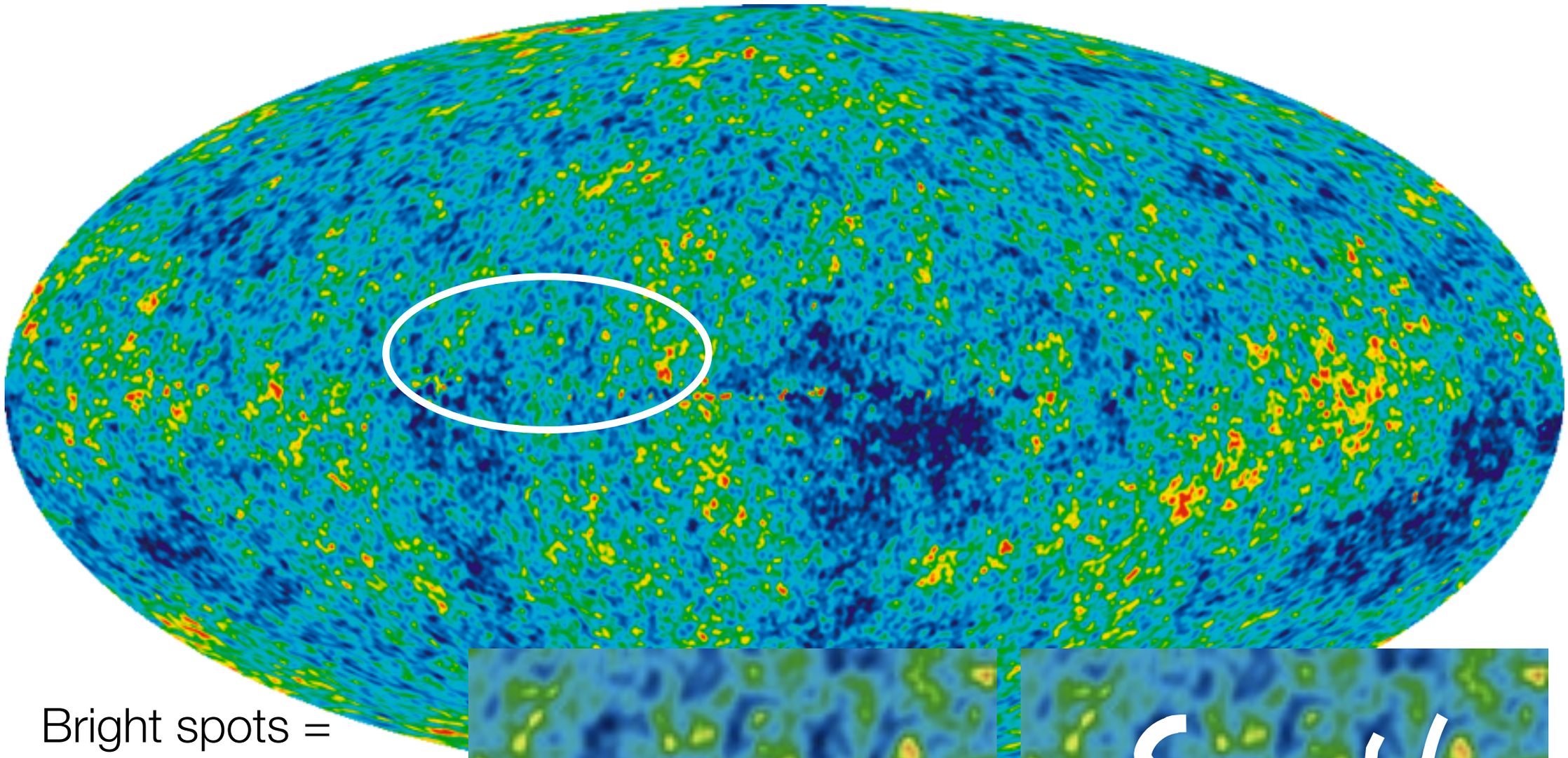






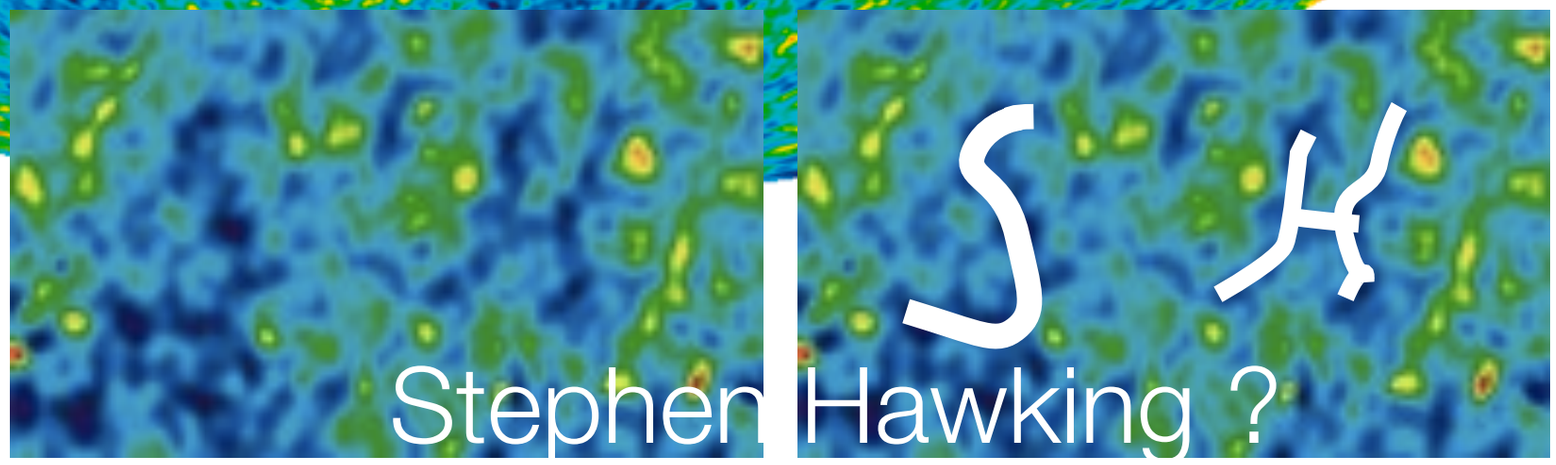
http://www.astro.ucla.edu/~wright/

The CMB

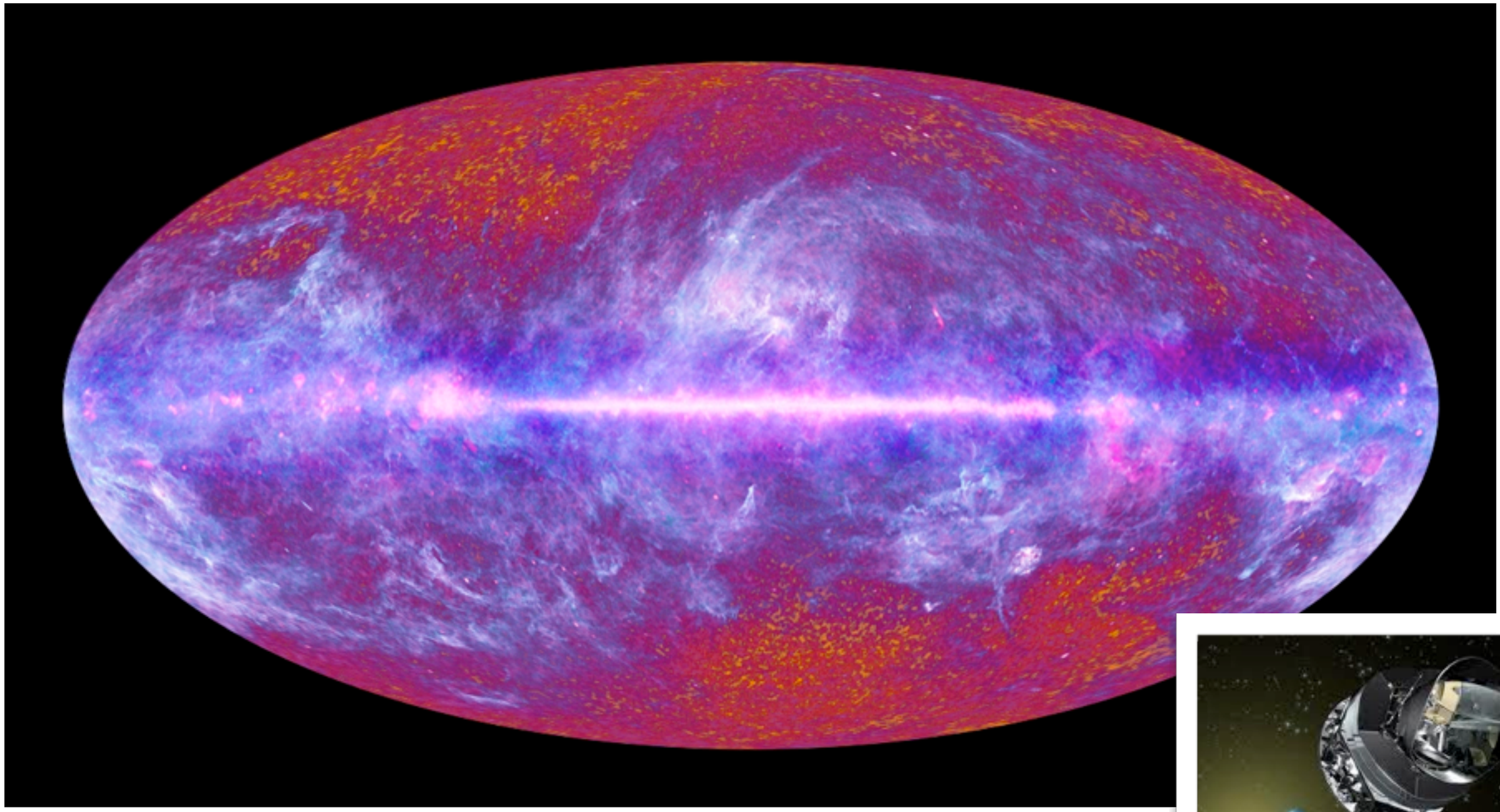


Bright spots =
dense patch

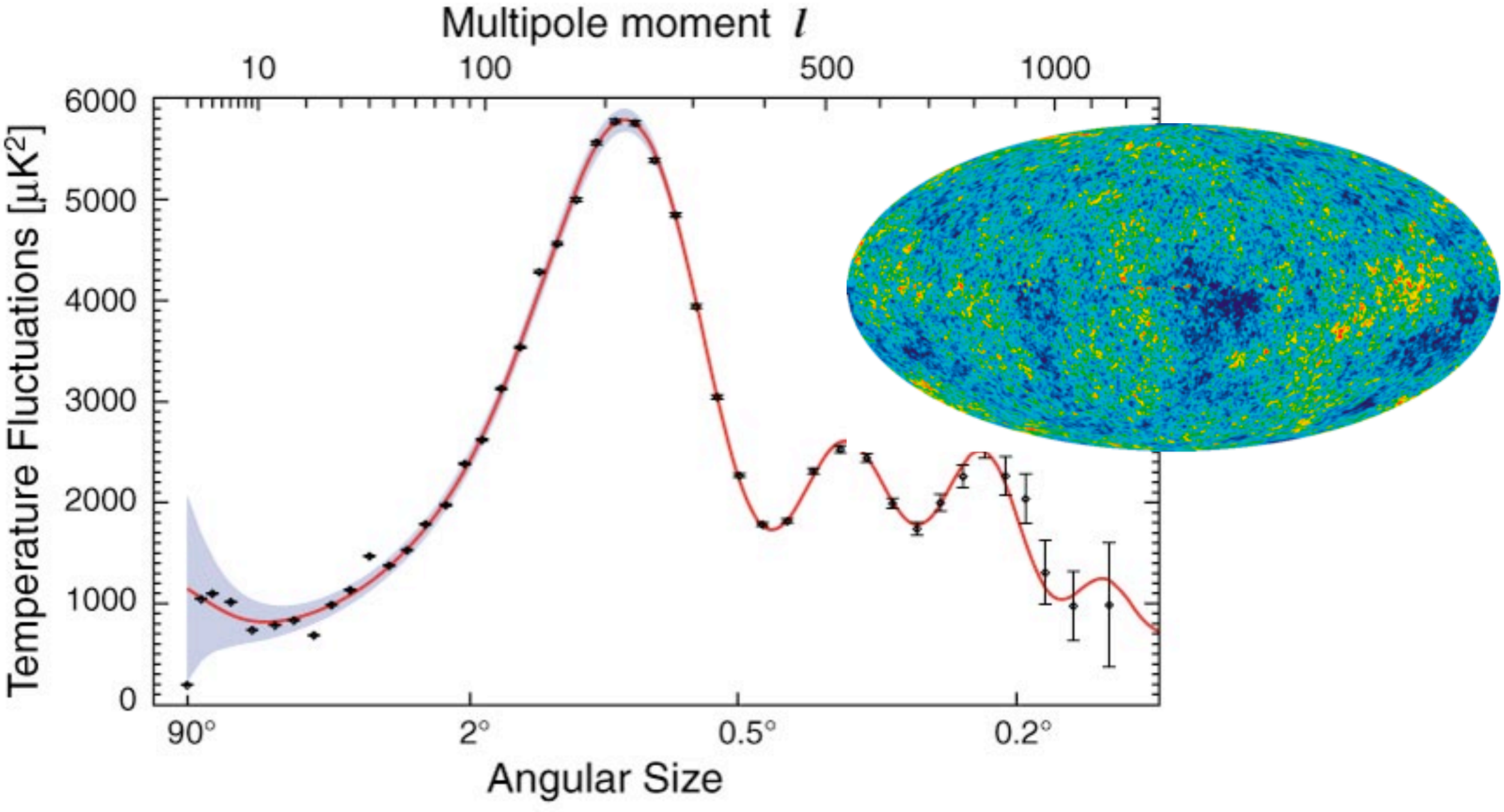
Weak spots =
underdense patch



Waiting for Planck ...

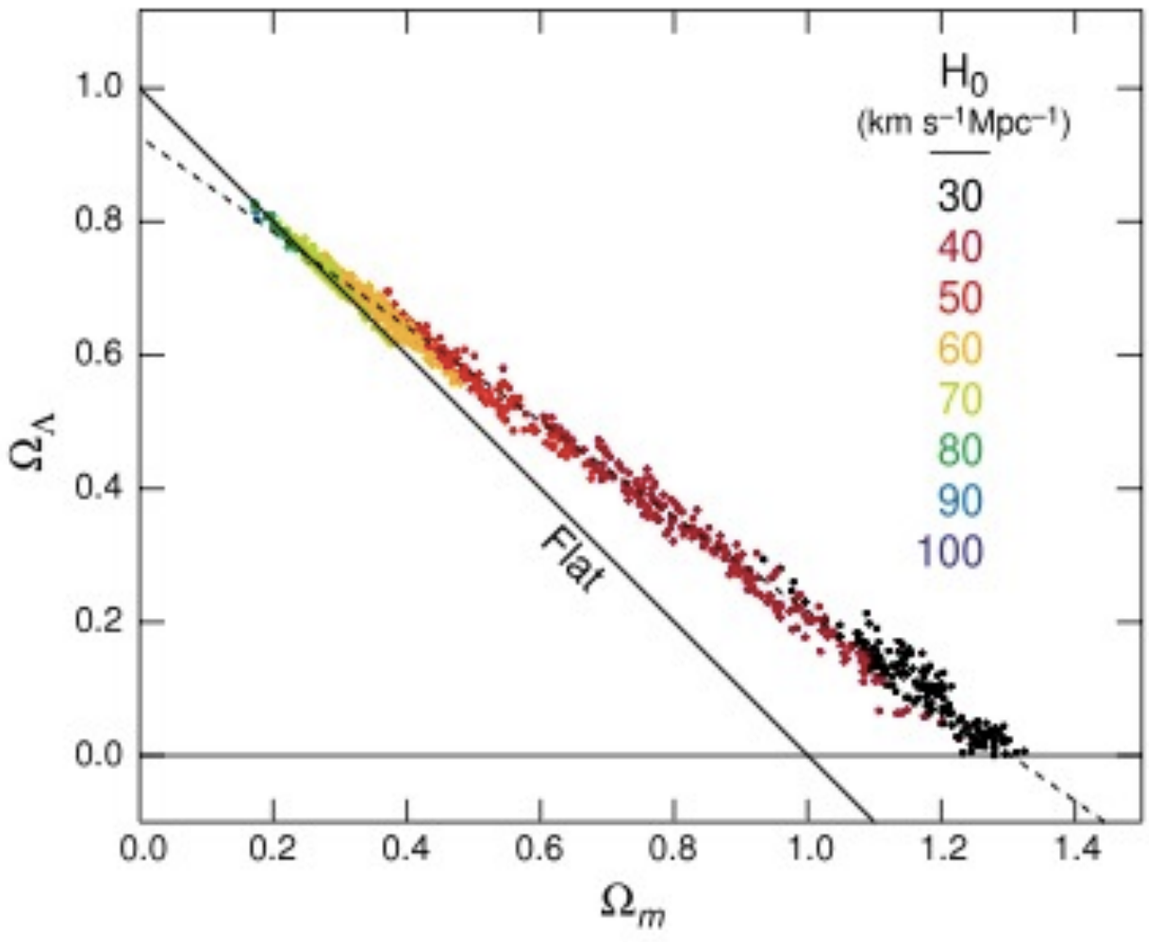


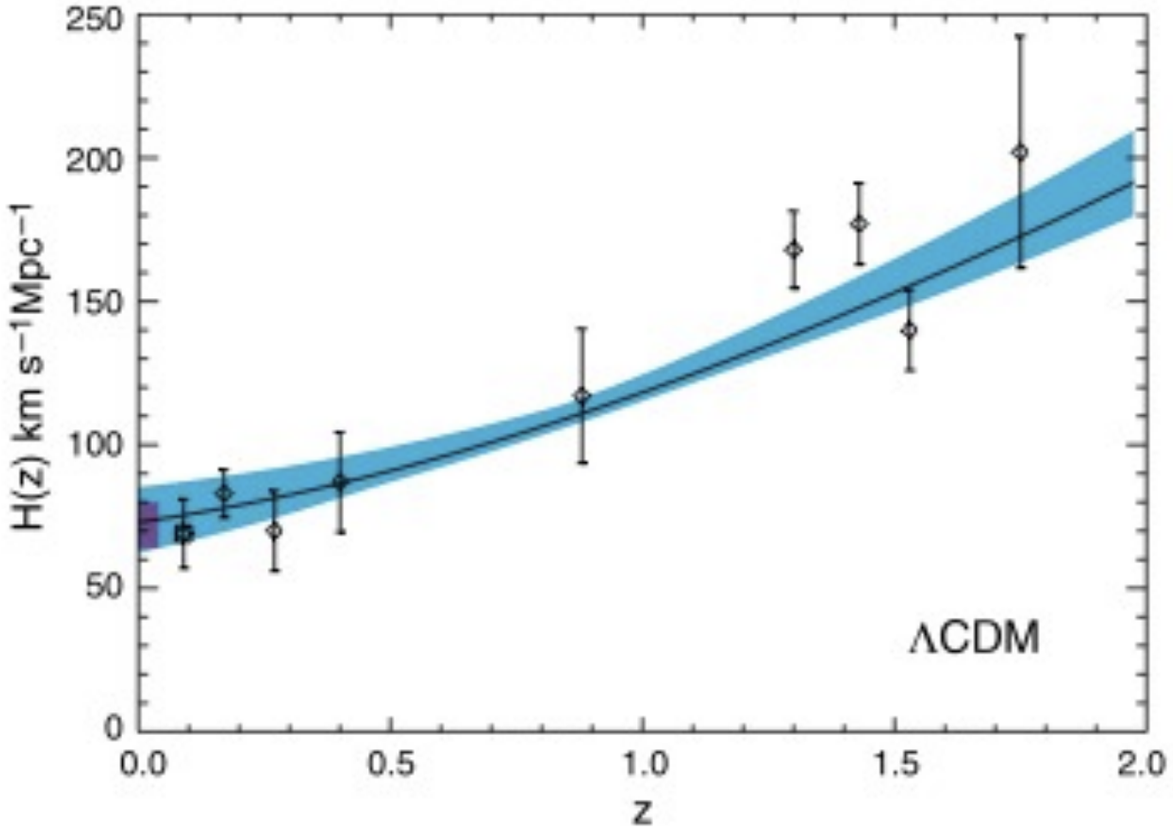
The CMB power spectrum



Describes the relative intensity of «spots» in CMB maps

Flatness of the Universe

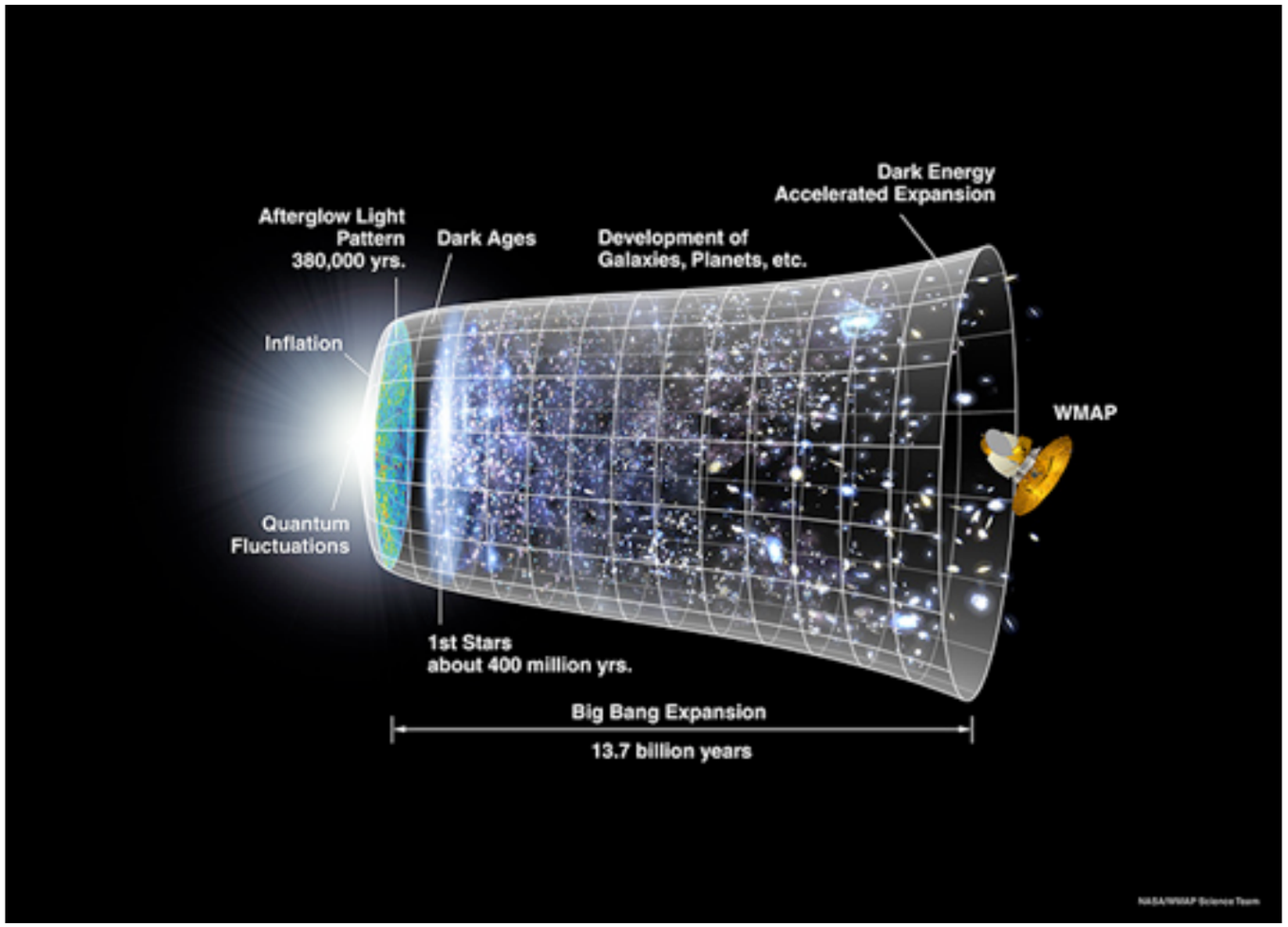




Spergel et al. 2007 (WMAP 3)

Stars & Reionization

The Dark ages



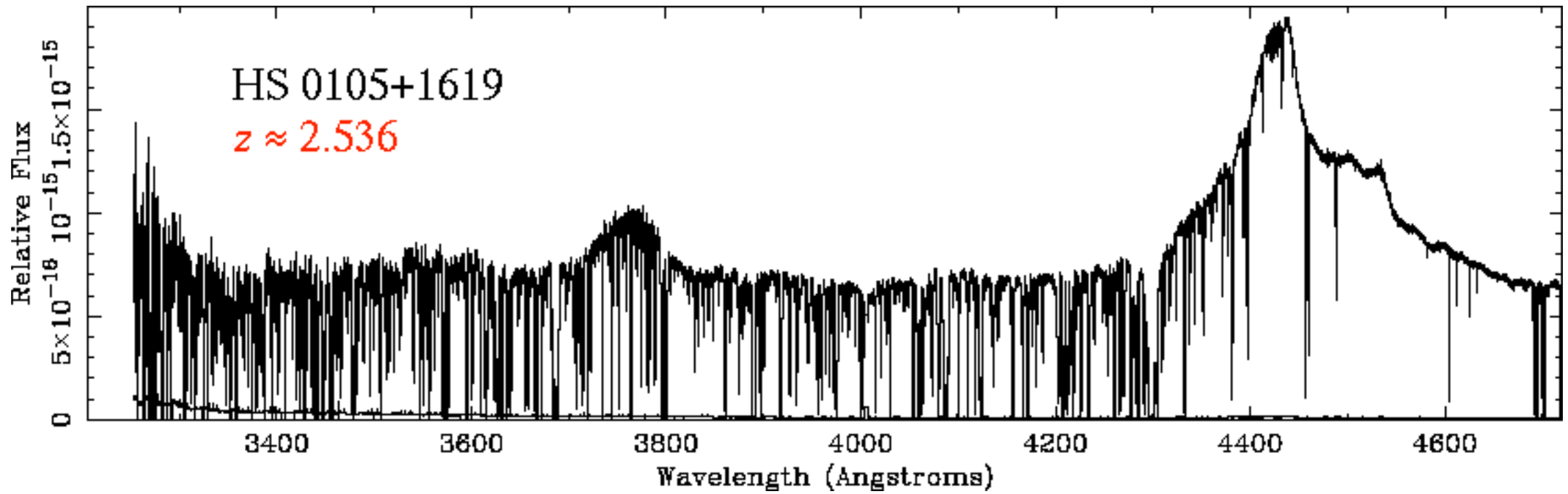
After recombination (t= 380 000 years), light & baryons are decoupled

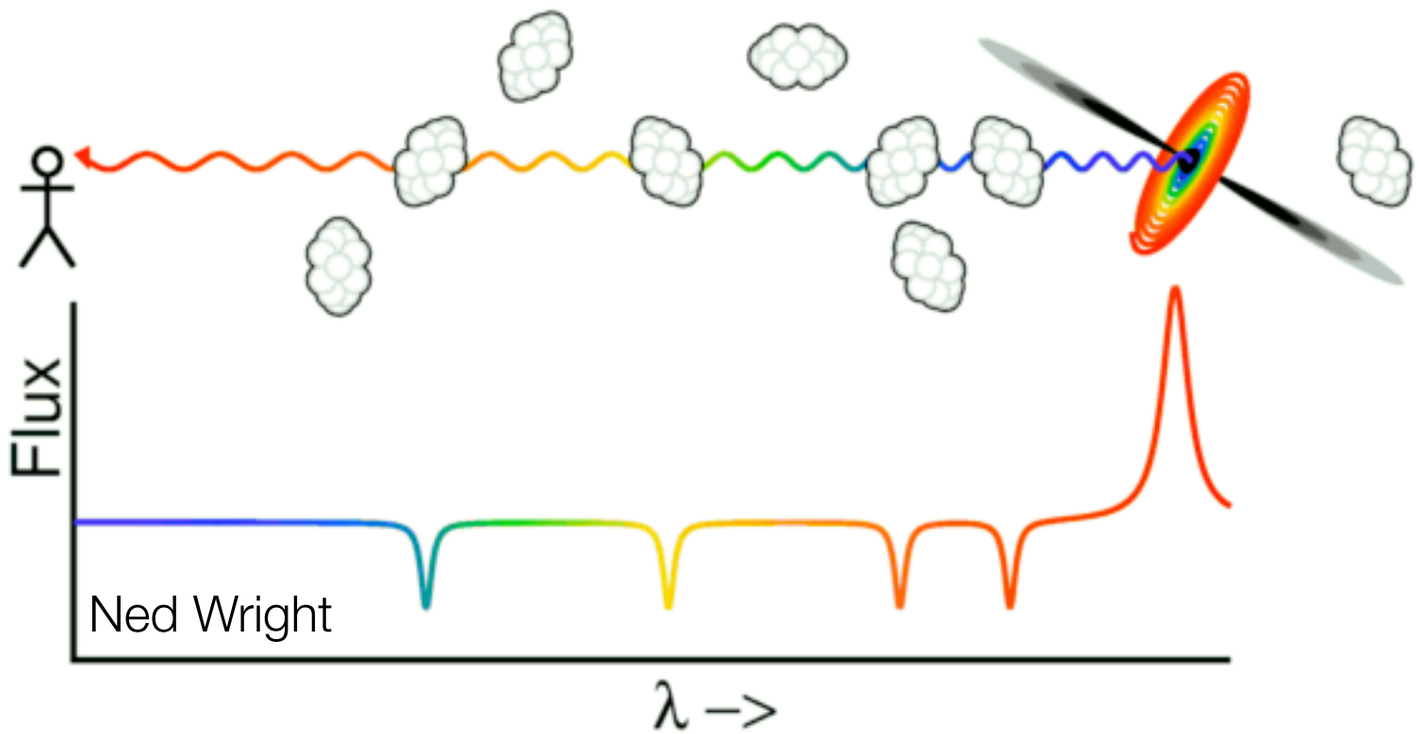
Neutral Gas cools down and collapses because of gravity

Roughly 200 Myrs after the BB, the density is large enough to convert hydrogen into stars

In between, no light is produced, the so-called Dark Ages

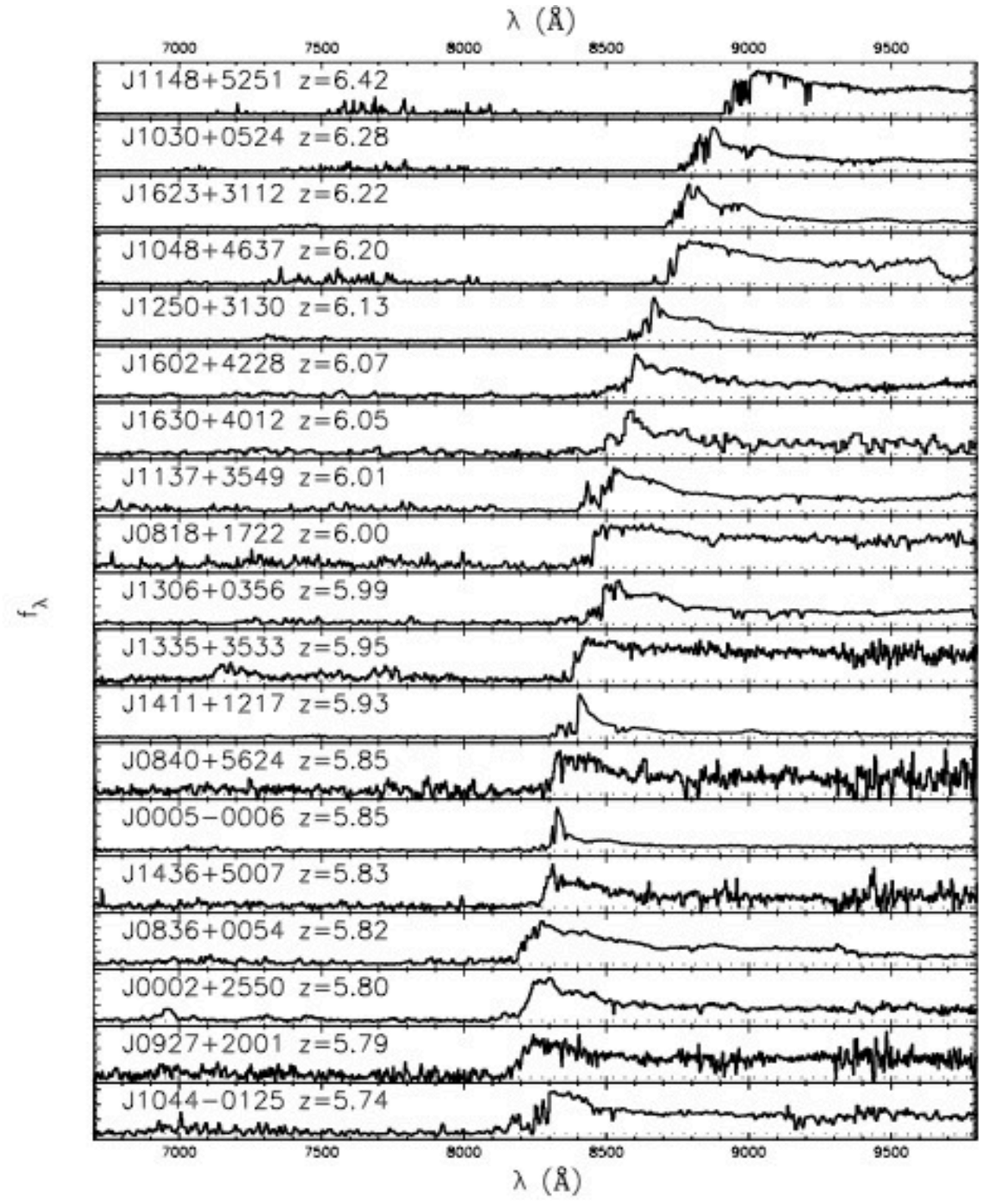
Lyman Alpha Forest





when looking at distant objects (e.g. quasars) neutral intergalactic gas produce aborption features along the line of sight

Gunn-Peterson Through

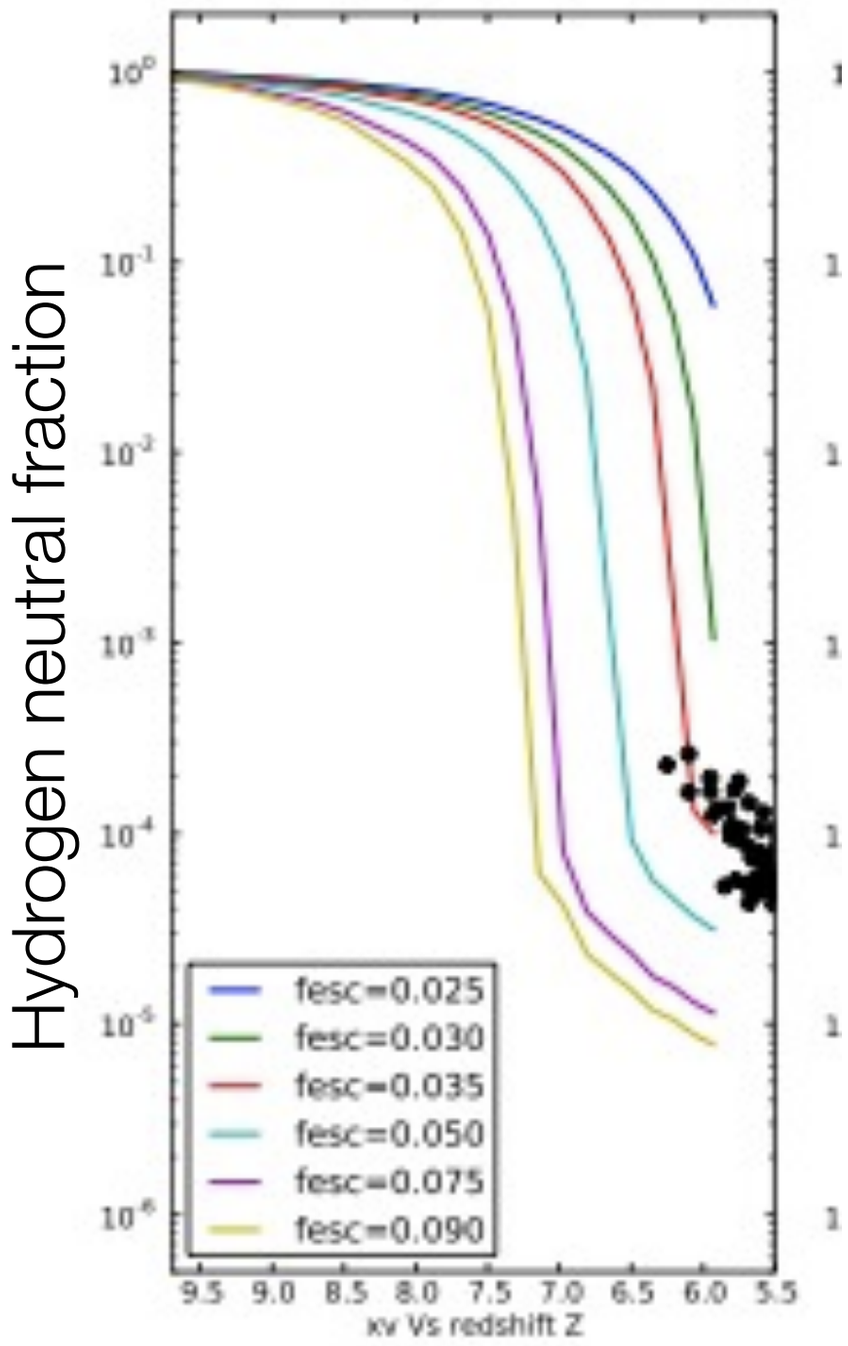


@ z>6 (1Gyr), spectras can be fully absorbed

no neutral windows with transmission

the Universe should be fully neutral at these times

Reionisation



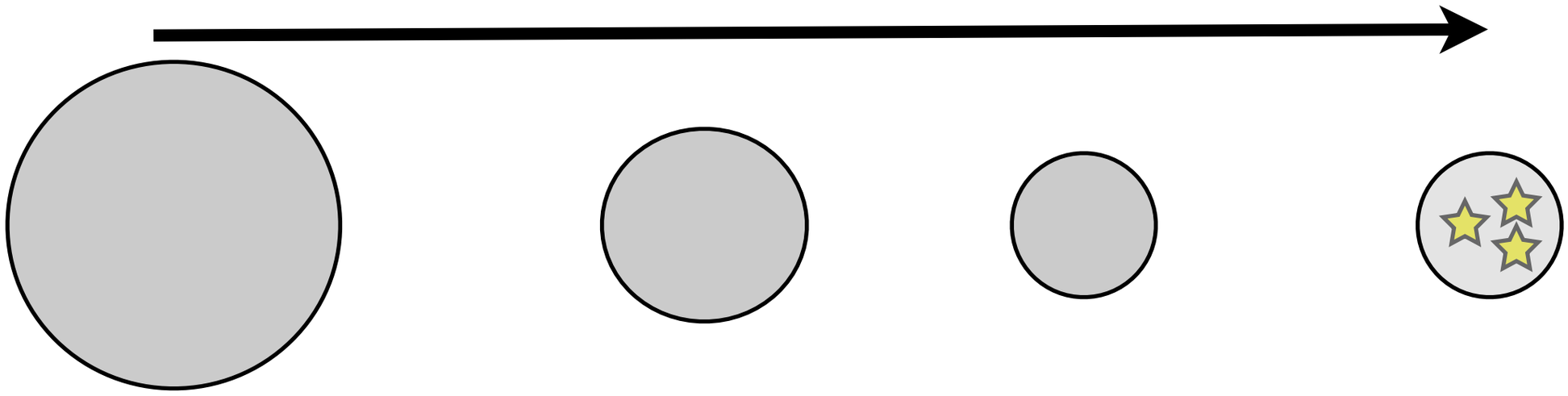
t=380 000 years: ionised -> neutral

t=1Gyr : neutral ->ionised

The Universe becomes ionised again:
The Reionisation

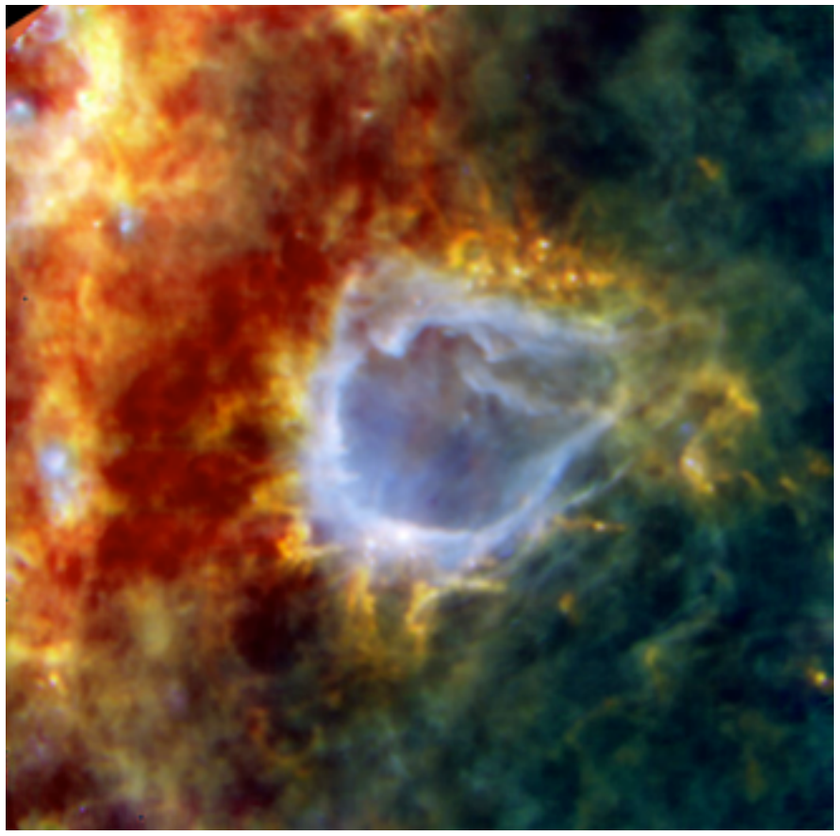
What happened ?

First Stars



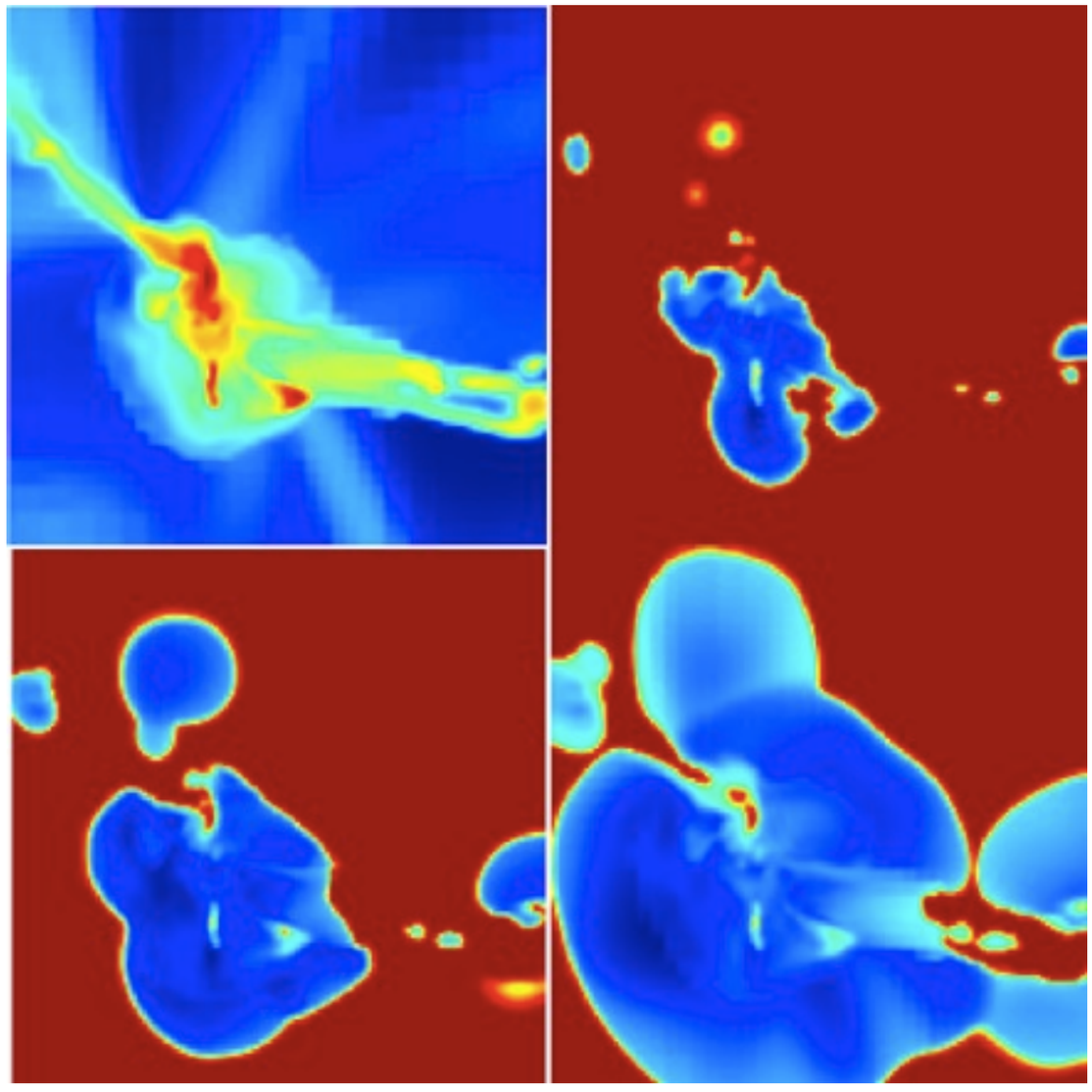
First Stars are expected to be metal-free, massive, and strong UV emitters

They appear in a gaseous environment



ESA/PACS/SPIRE/HOBYS Consortia

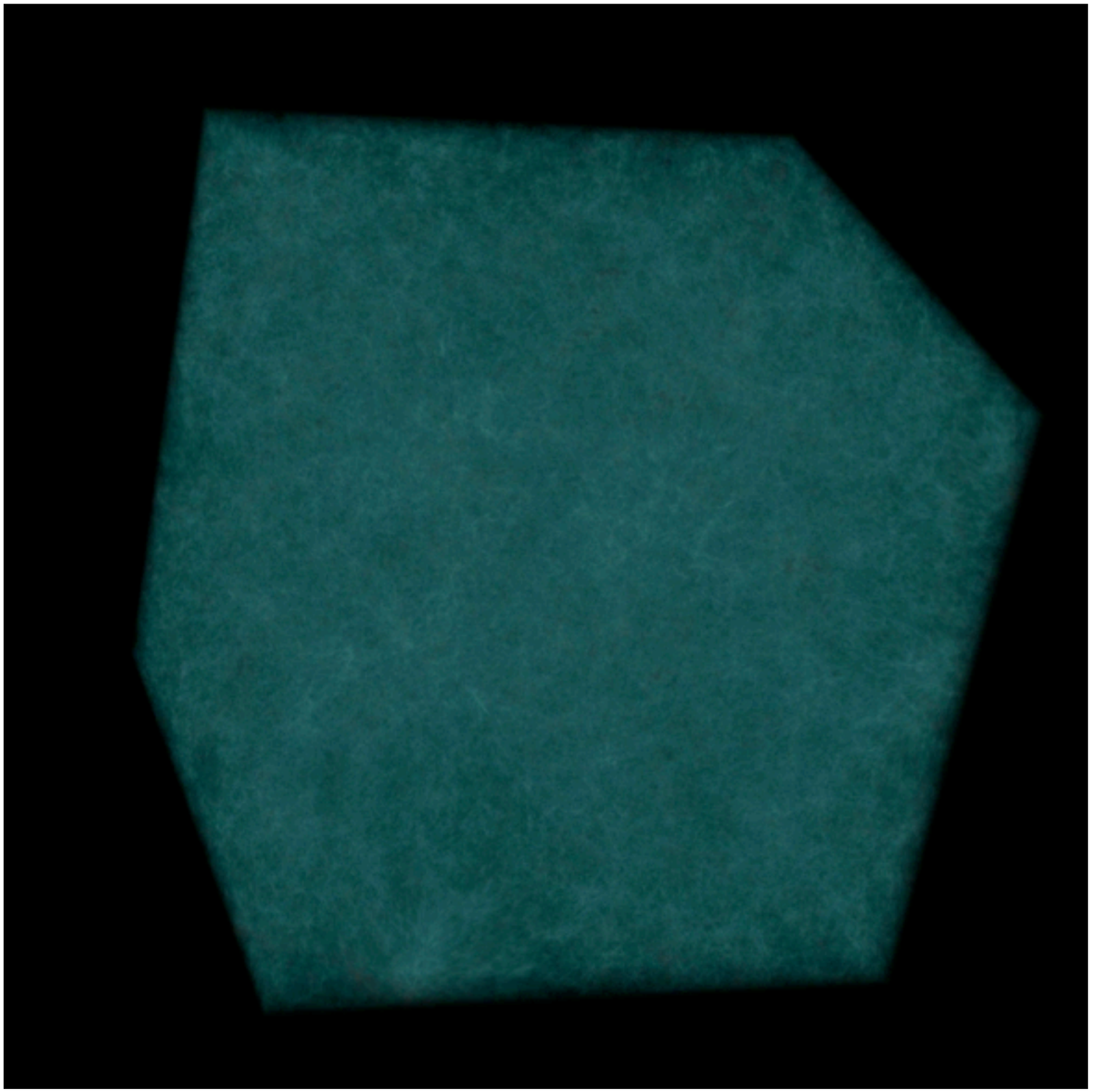
HII Regions



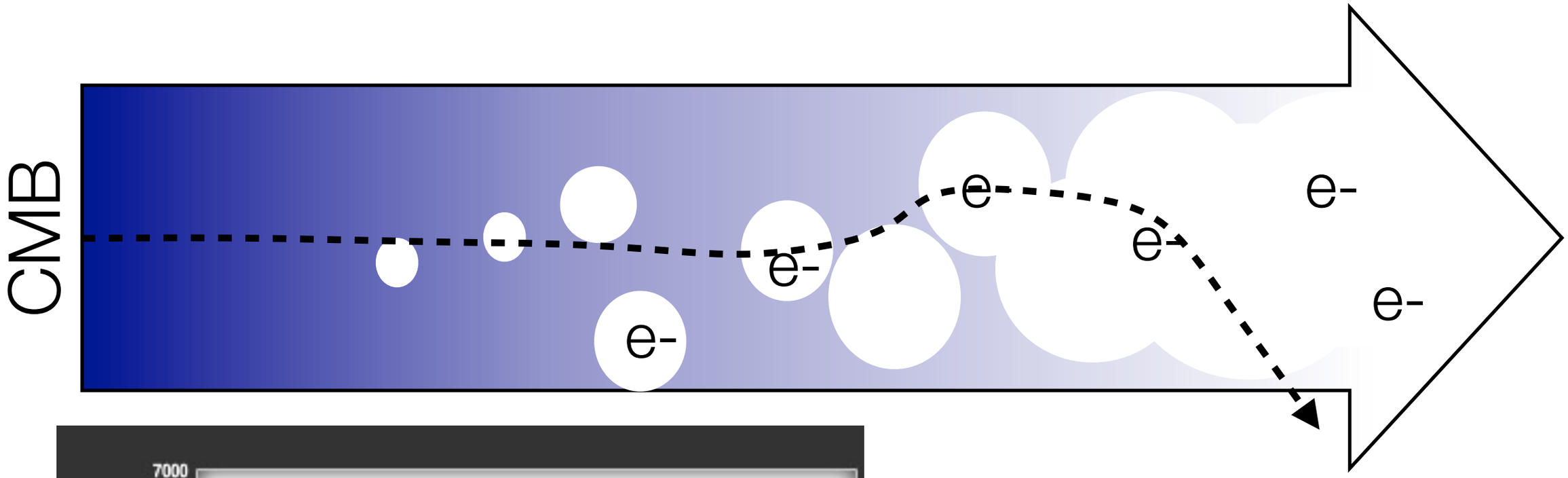
The new stars ionise their surroundings with their UV emission

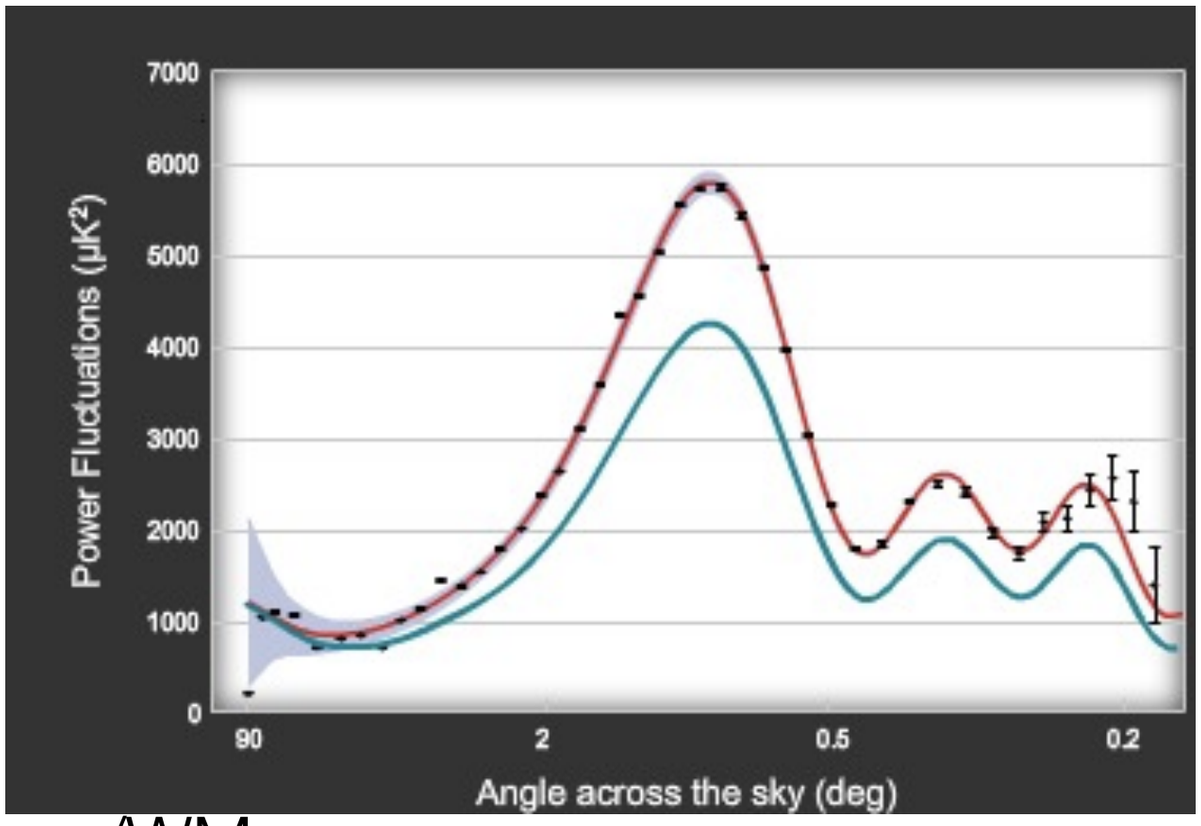
This process operates in the whole Universe

The last phase transition of the Universe



Reionisation & CMB





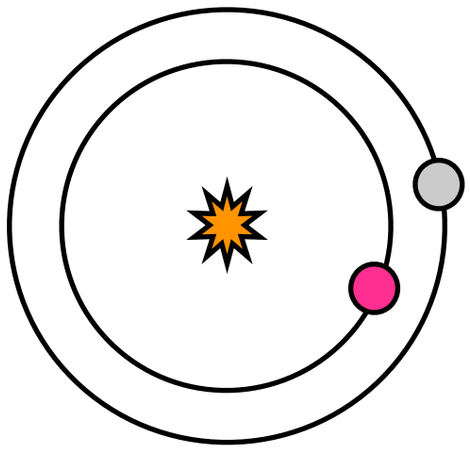
Nasa/WMap

The electrons released by reionisation will scatter CMB photons

it reduces the amplitude of fluctuations

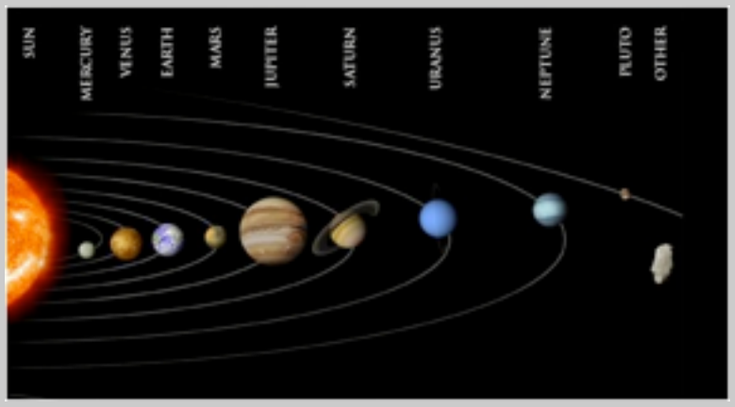
Matter (or the story of the first 8 Gyrs)

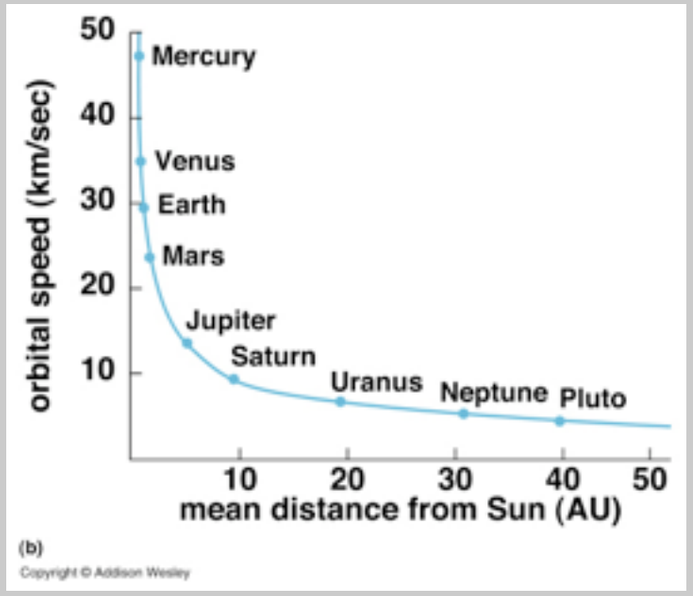
Mass & Rotation



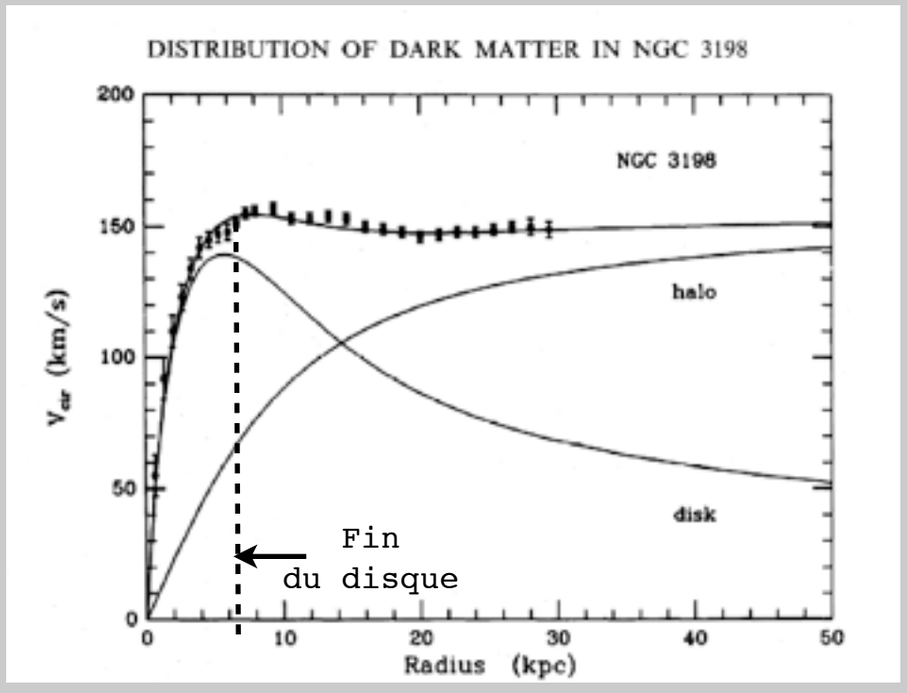
velocity of ● < velocity of ●

velocity depends on :
- the radius of the orbit
- the mass enclosed in the orbit





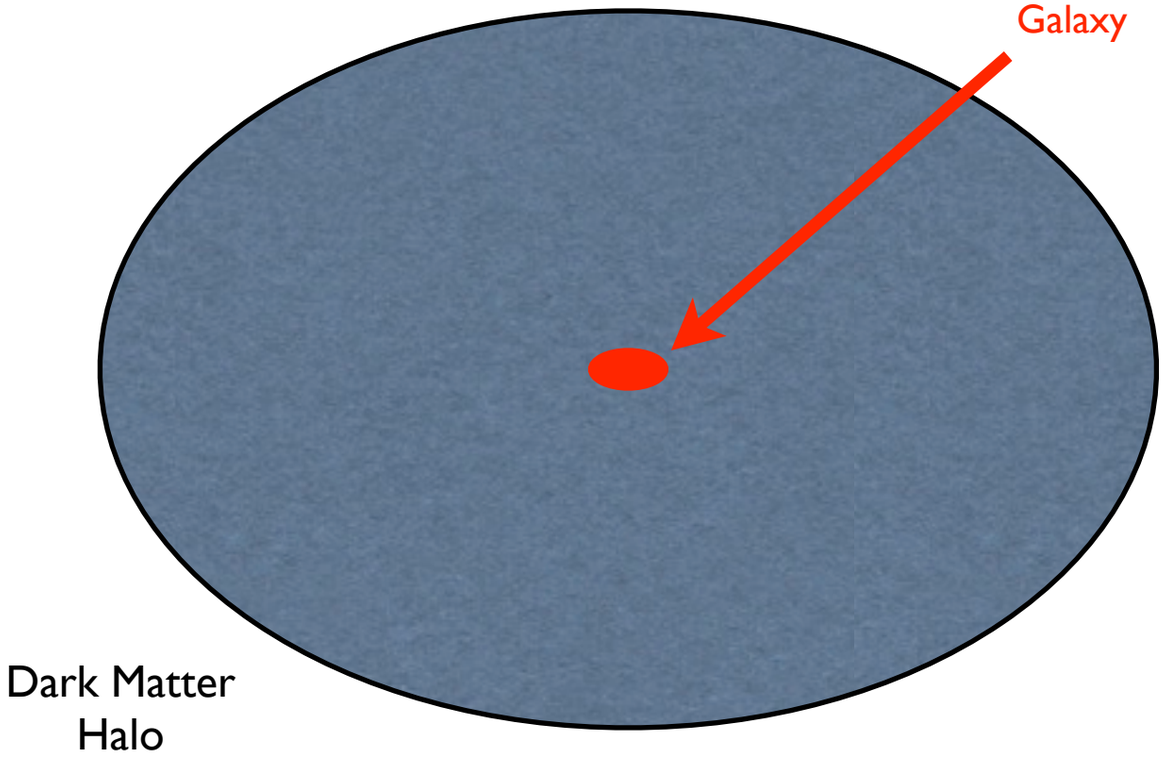
Rotation Curve of Galaxies



@ large distance, velocities are larger than expected

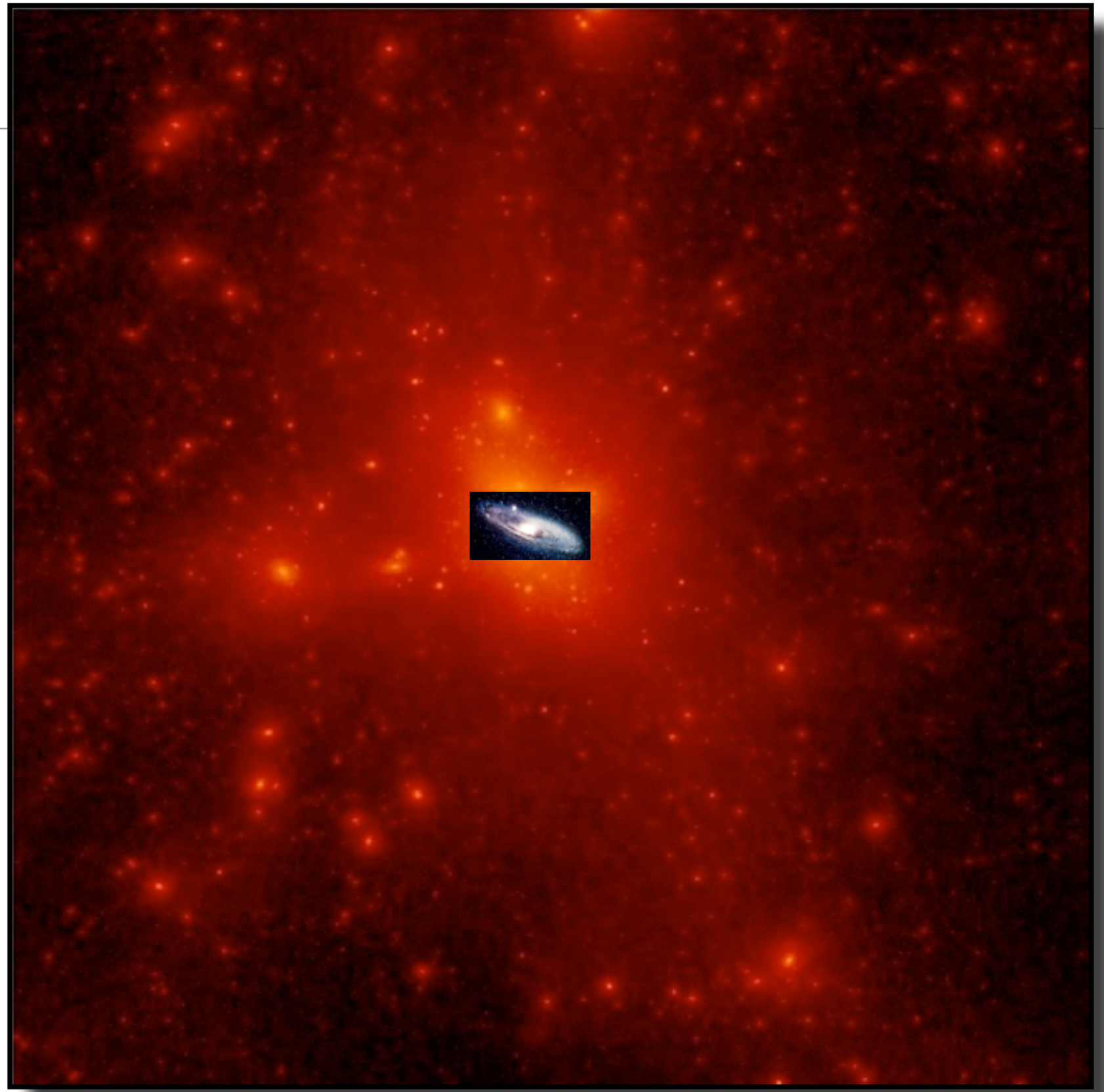
Dark Matter Haloes

Distant gas goes faster than expected.
The amount of central mass is larger than observed

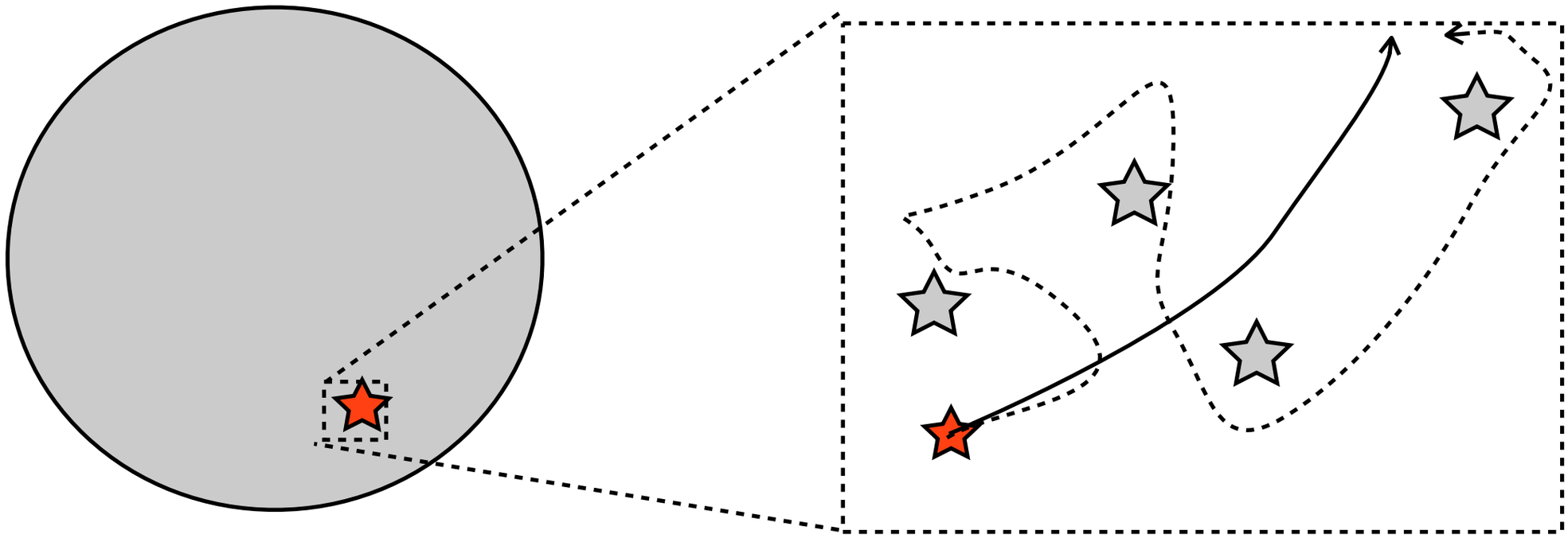


<u>Dark Matter:</u>
gravitation only

~90% of the mass

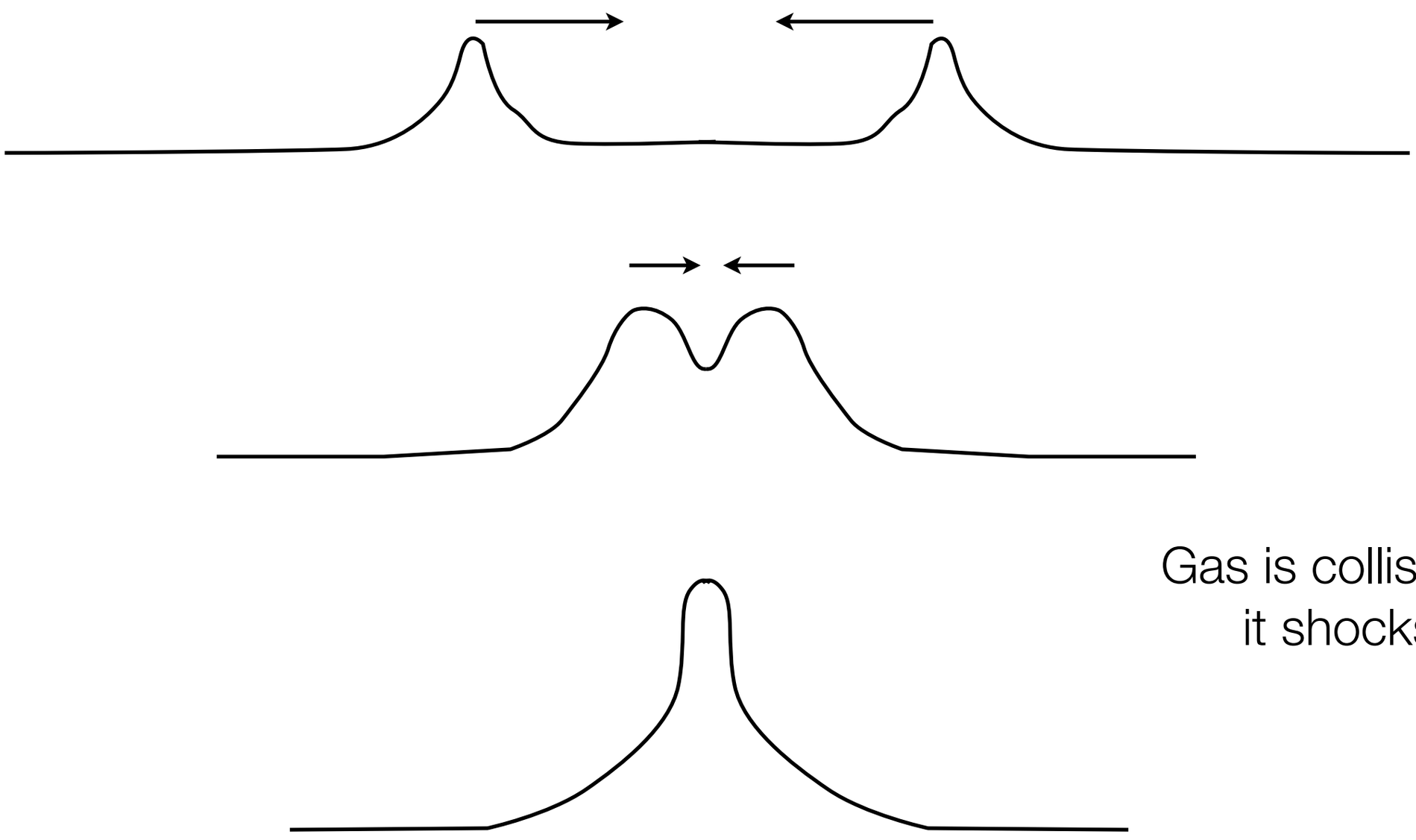


Collisionless Dark matter



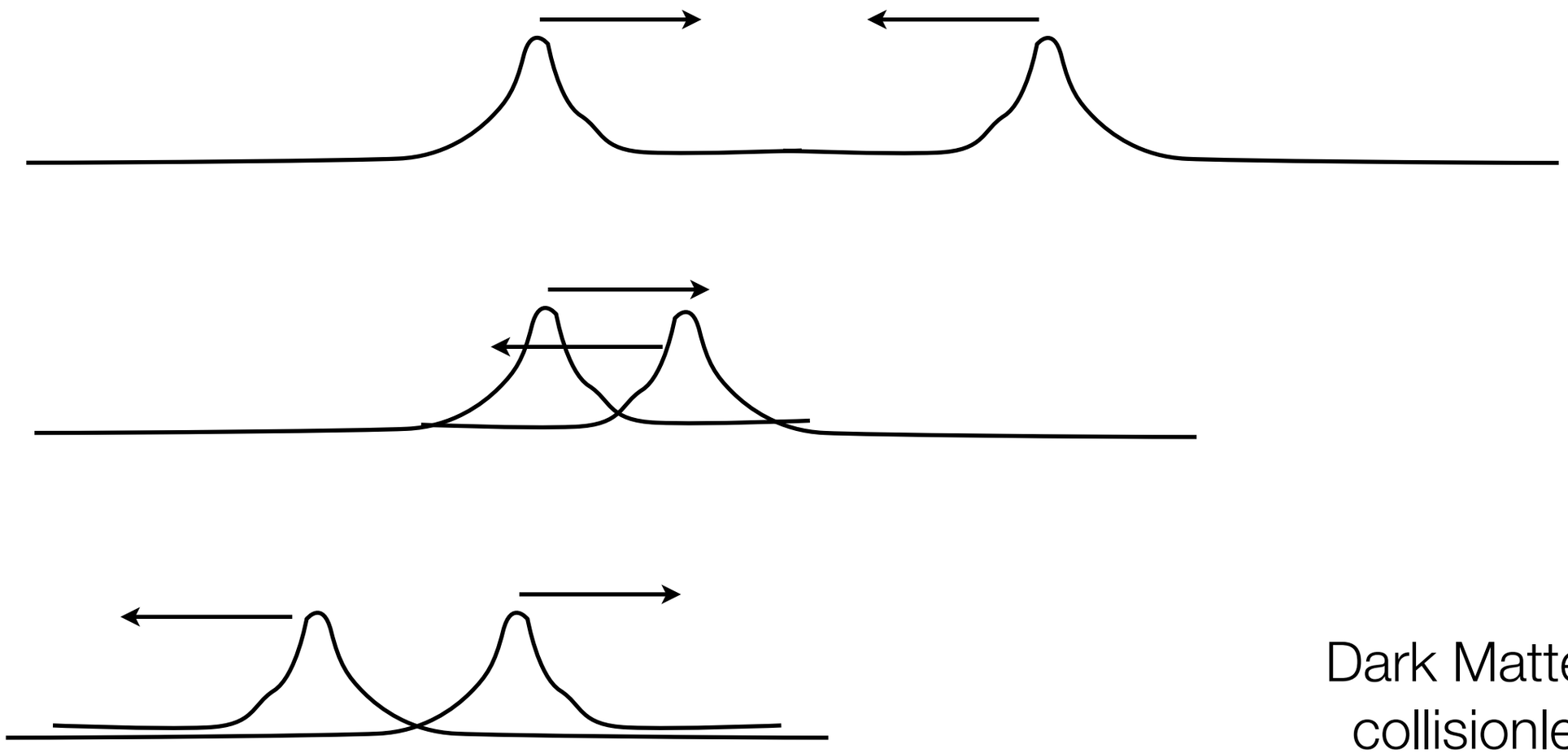
A dark matter particle is weakly influenced by its neighbors

Collisional Matter

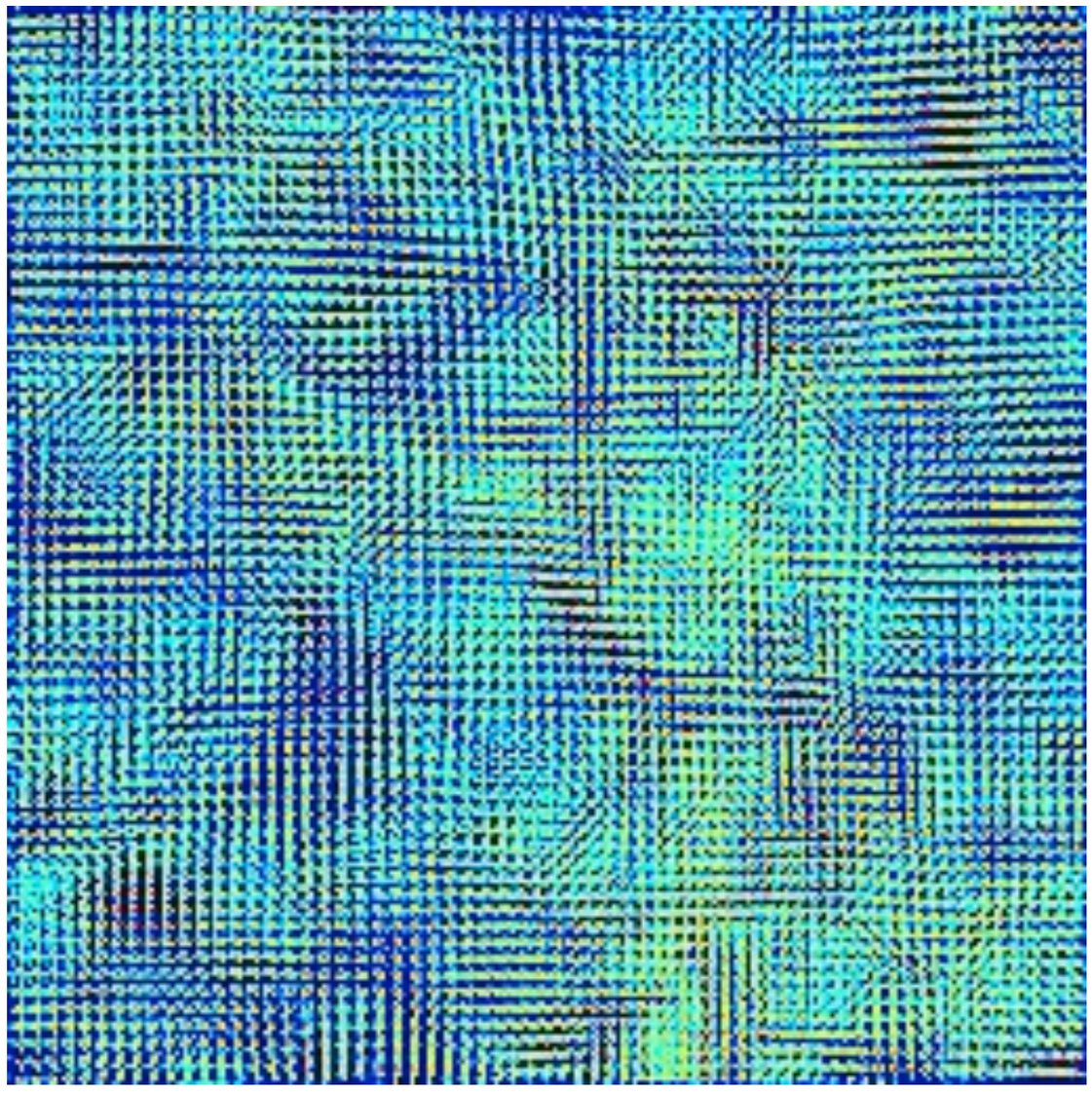


Gas is collisional
it shocks

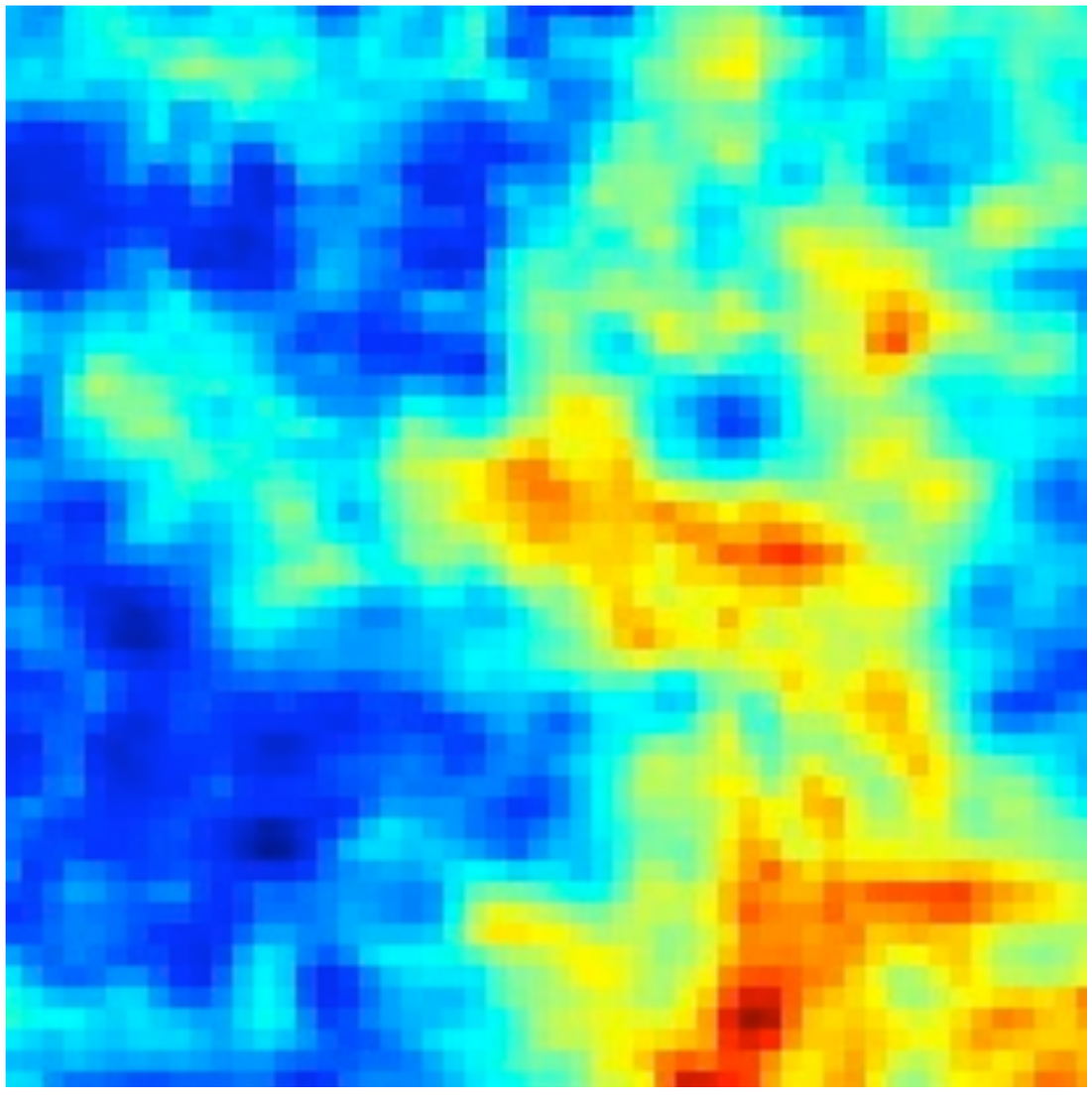
Collisionless Dark Matter



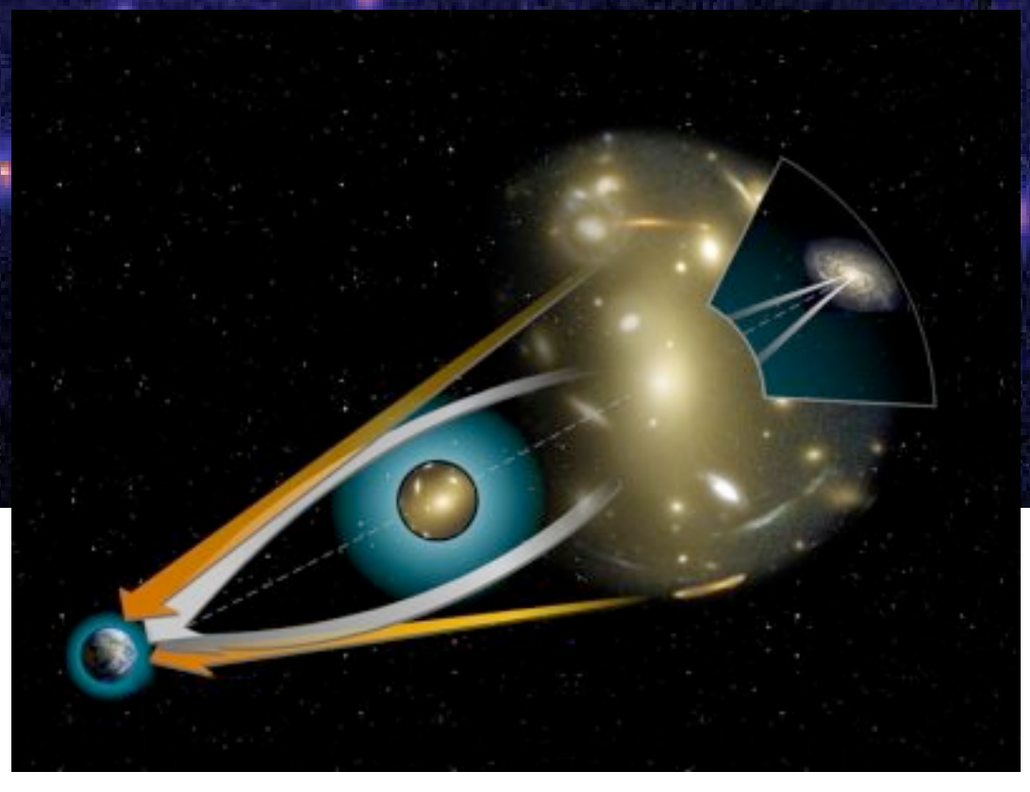
Dark Matter is collisionless
Almost no collisions



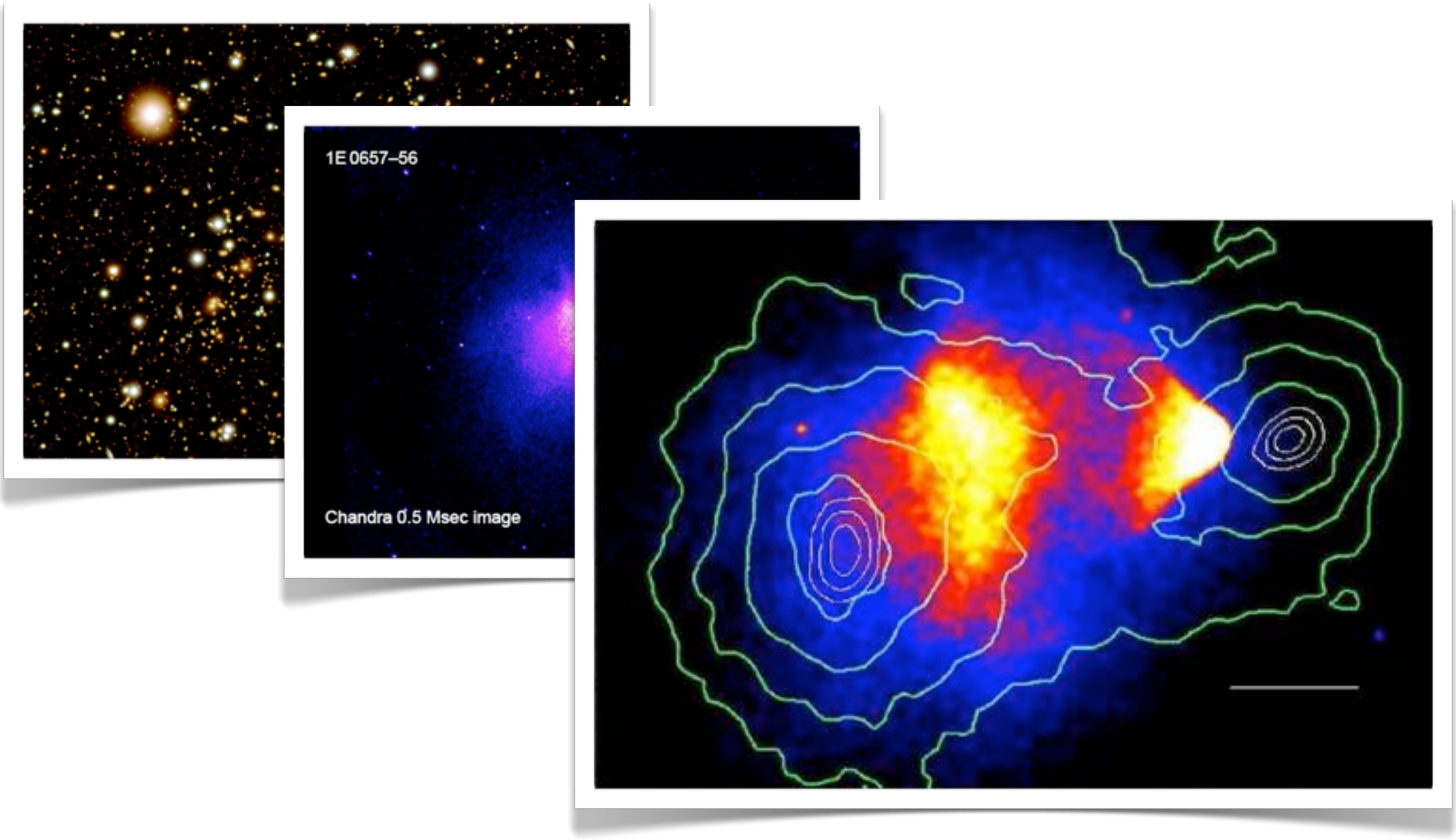
Dark Matter



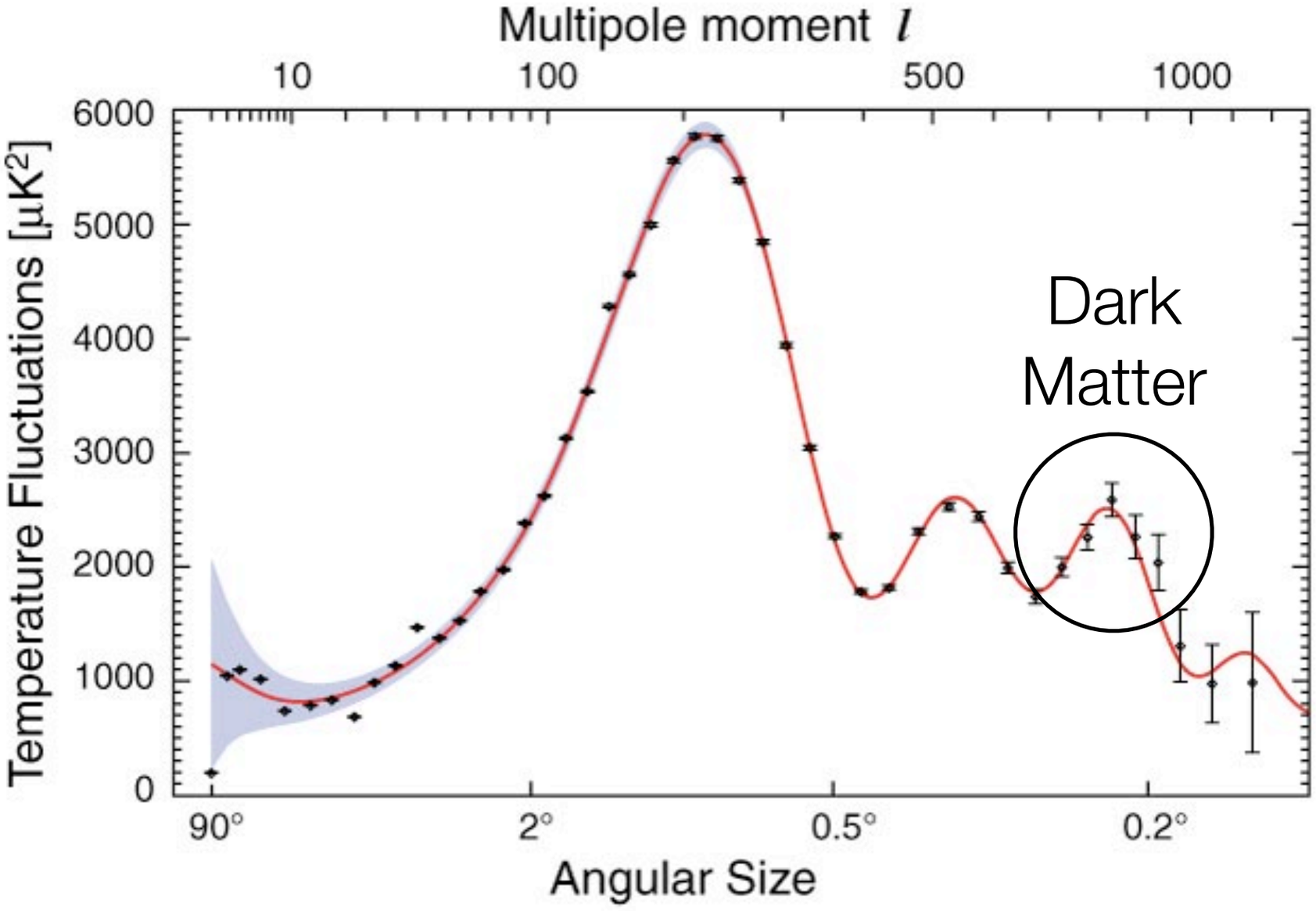
Gas



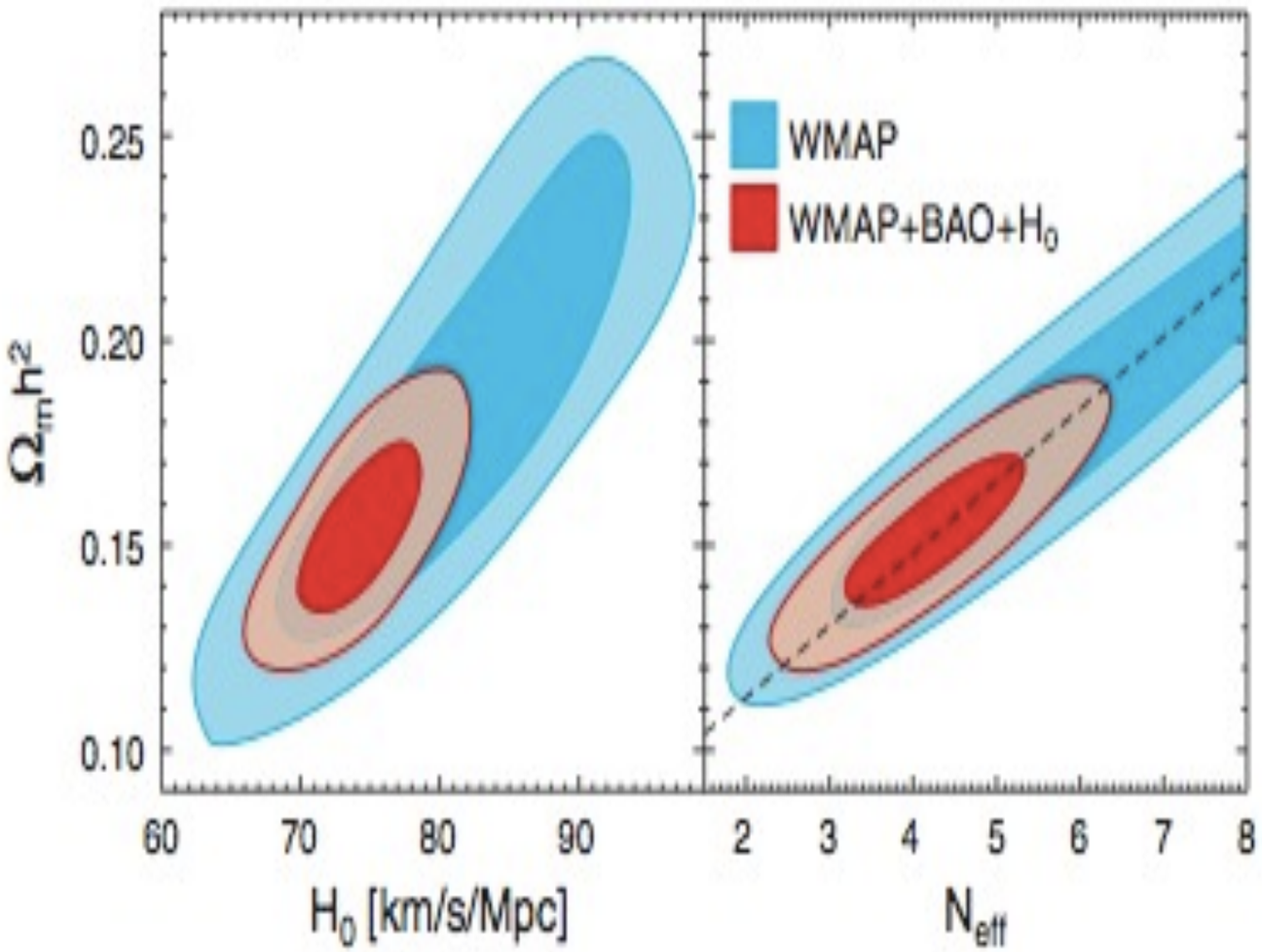
Invisible Matter

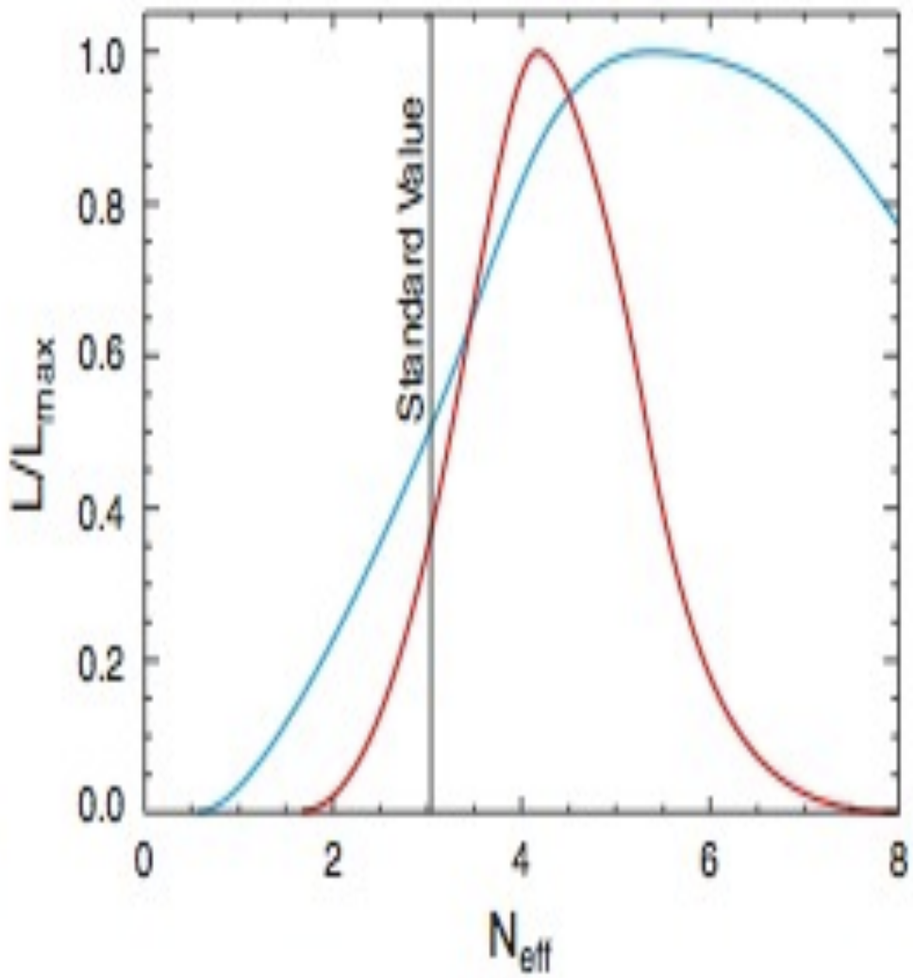


DM in CMB

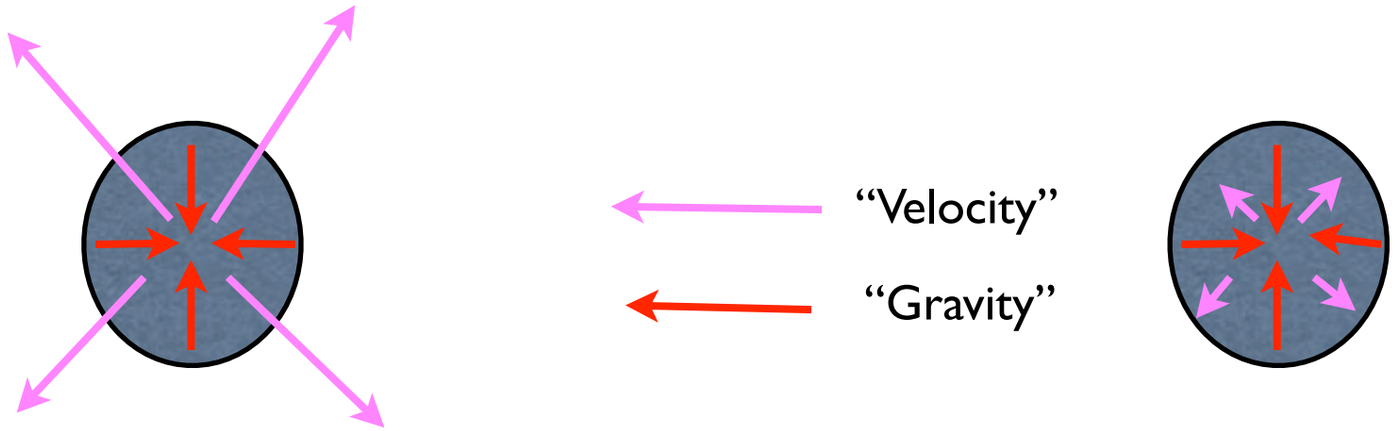

Multipole moment l
10
100
500
1000
6000
5000
4000
3000
2000
1000
0
Temperature Fluctuations [μK²]
90°
2°
0.5°
0.2°
Angular Size
Dark
Matter

Number of relativistic species





Nature of DM



Hot Dark Matter

Cold Dark Matter

Some candidates

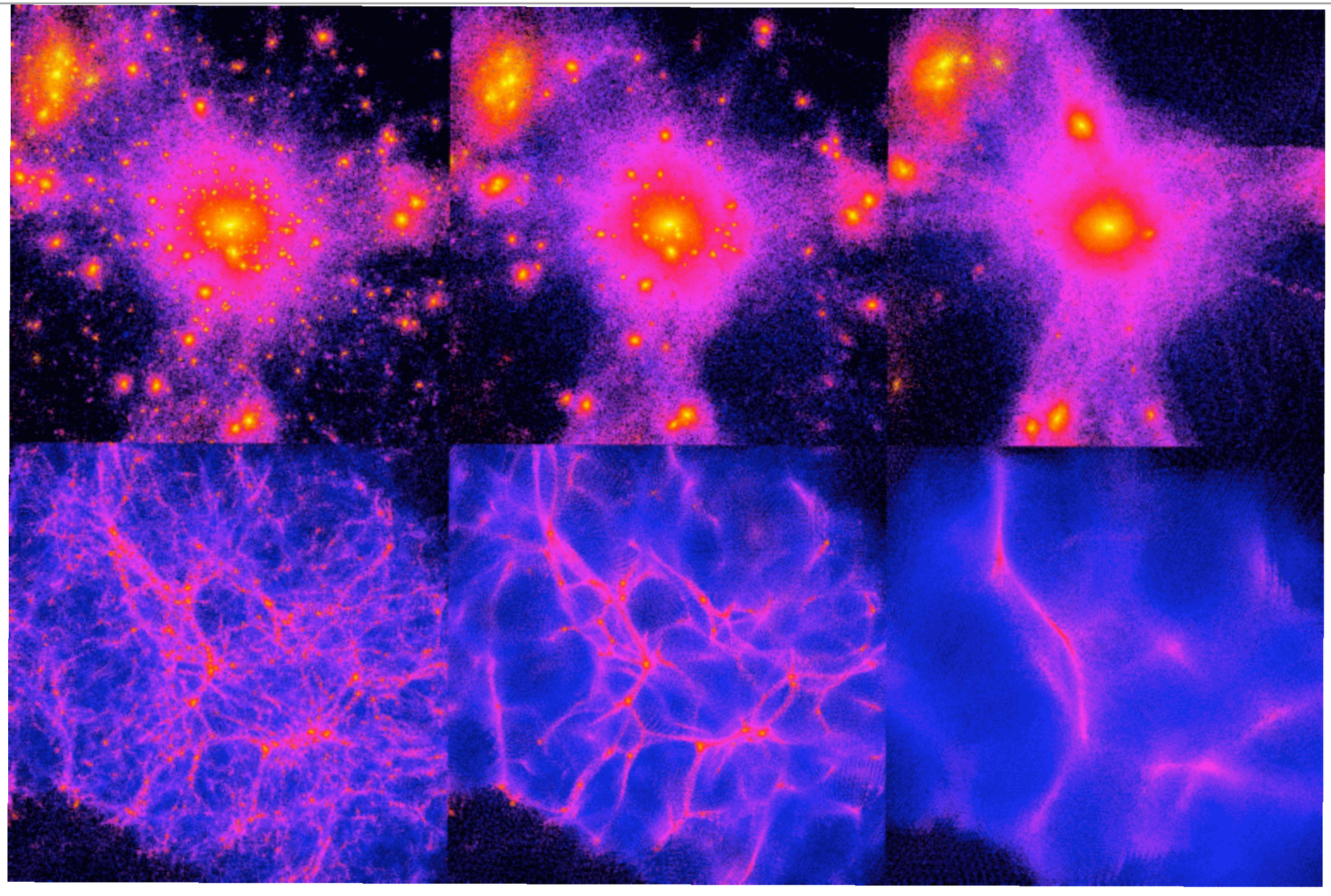
-Neutrinos ? Sterile Neutrinos ?

- Cold Gas

- Supersymmetric particle

- Modified Gravity Beyond Einstein?

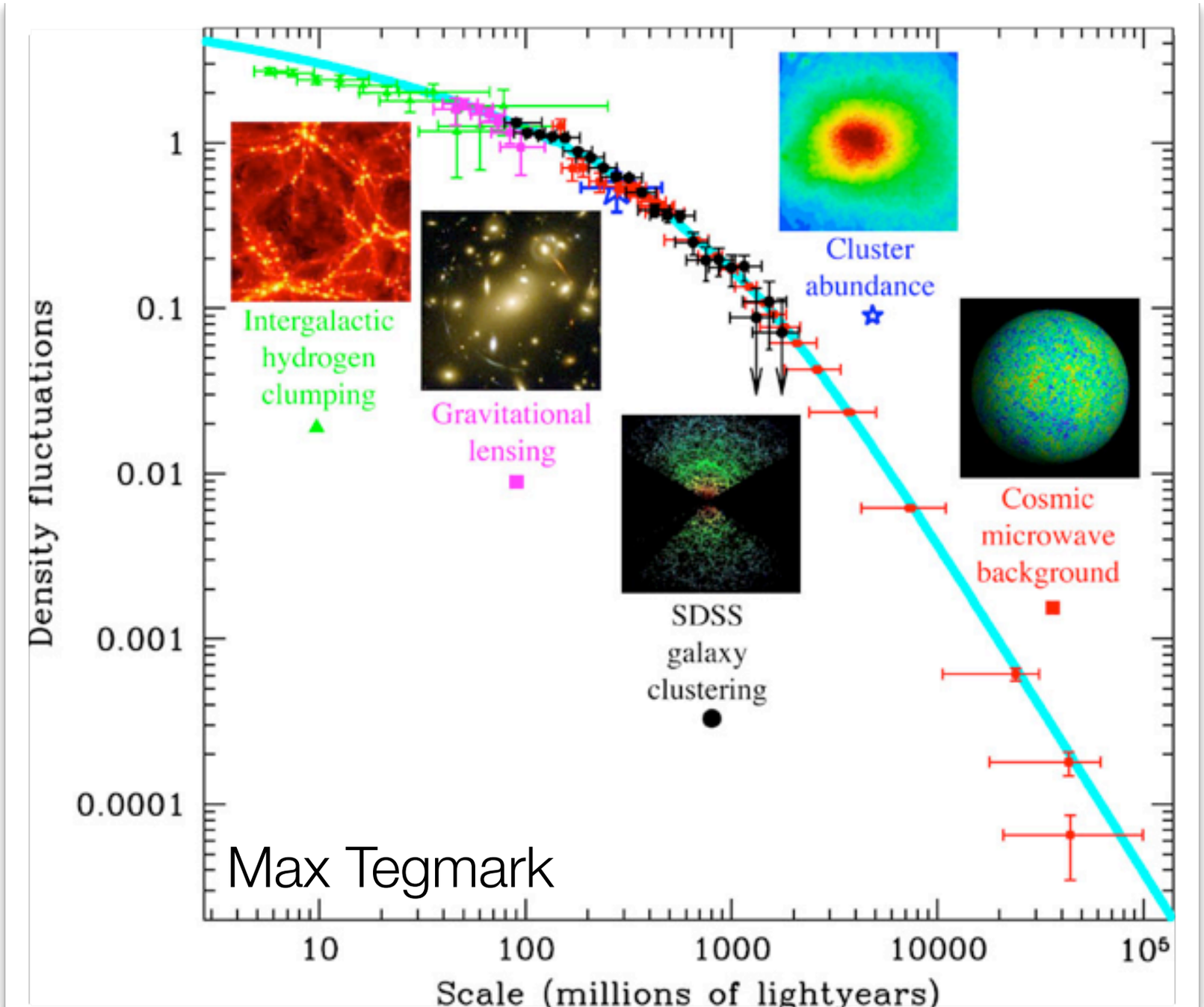
Warm Dark Matter Vs Cold Dark Matter



Ith Zurich

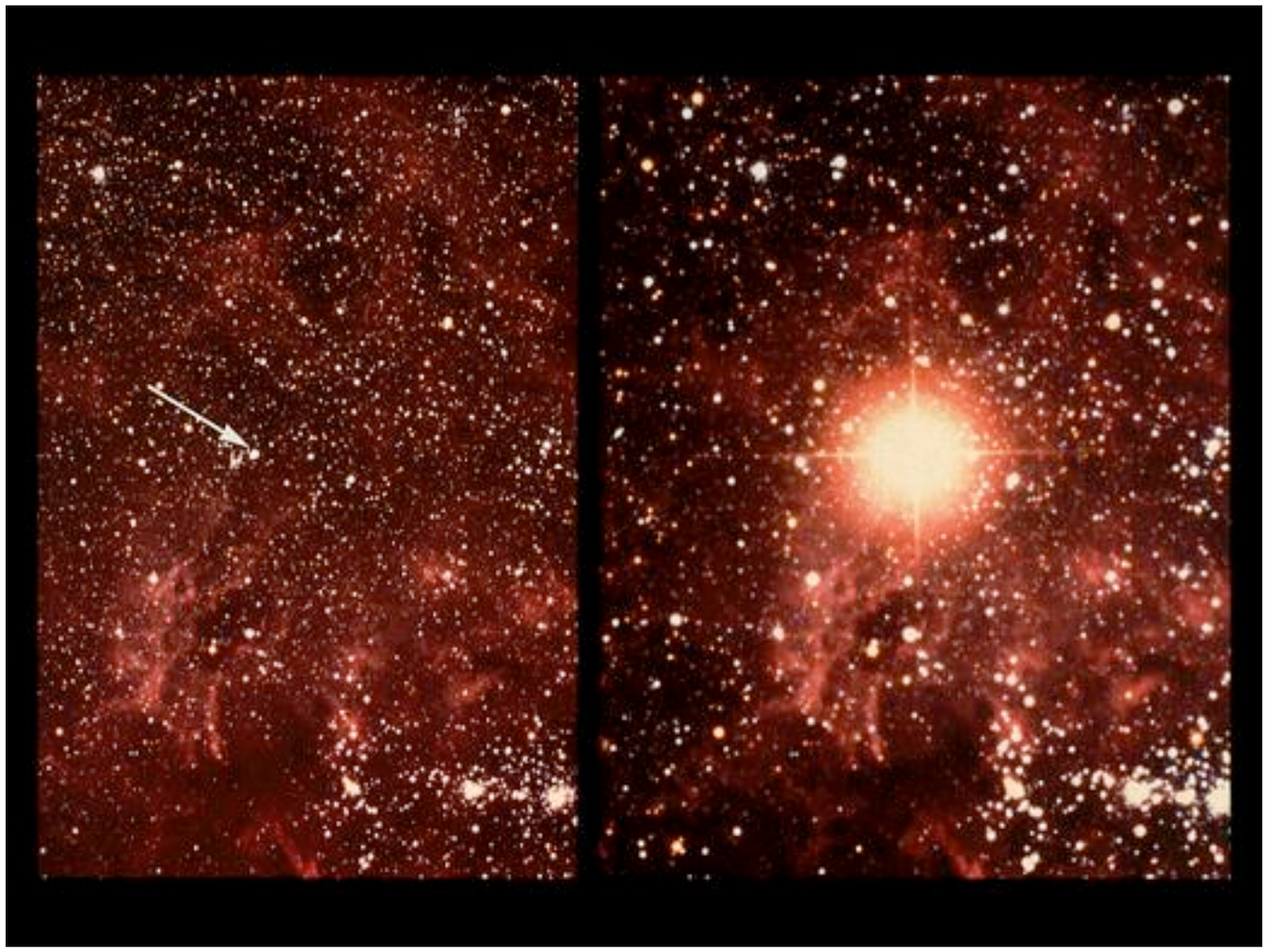
Small scales are suppressed in WDM

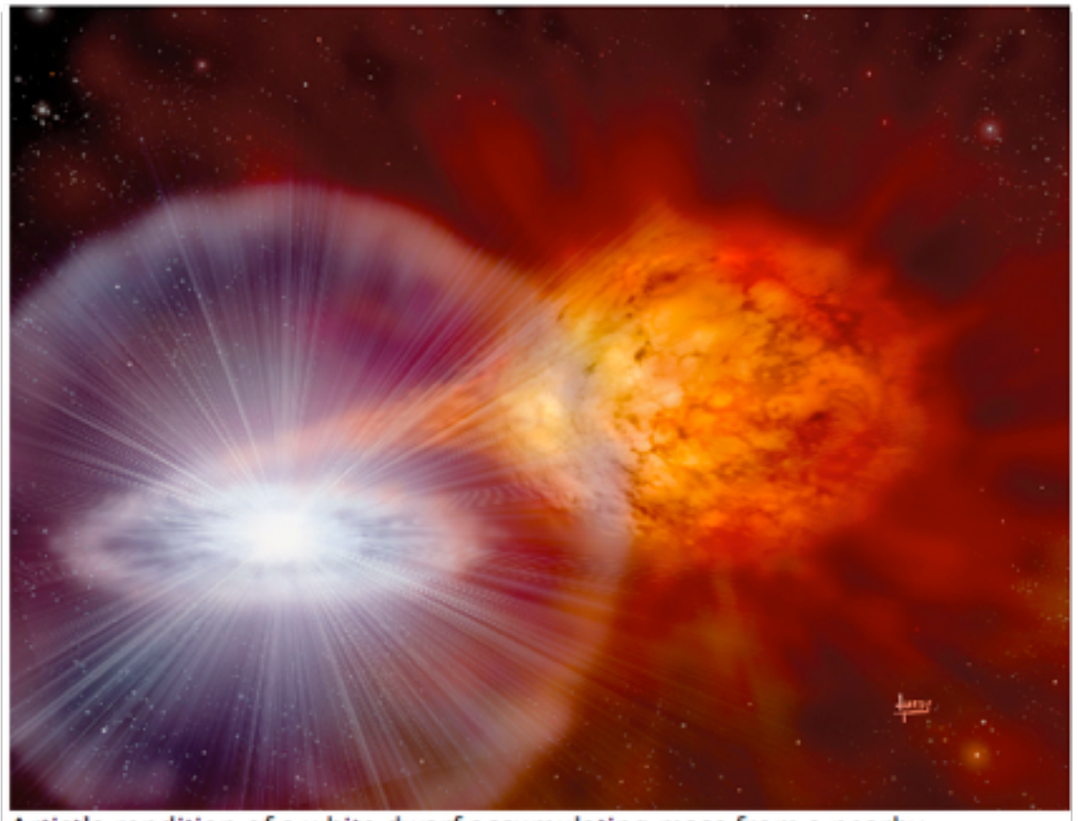
LSS and Dark Matter



Vacuum (or the story of the last 5 Gyrs)

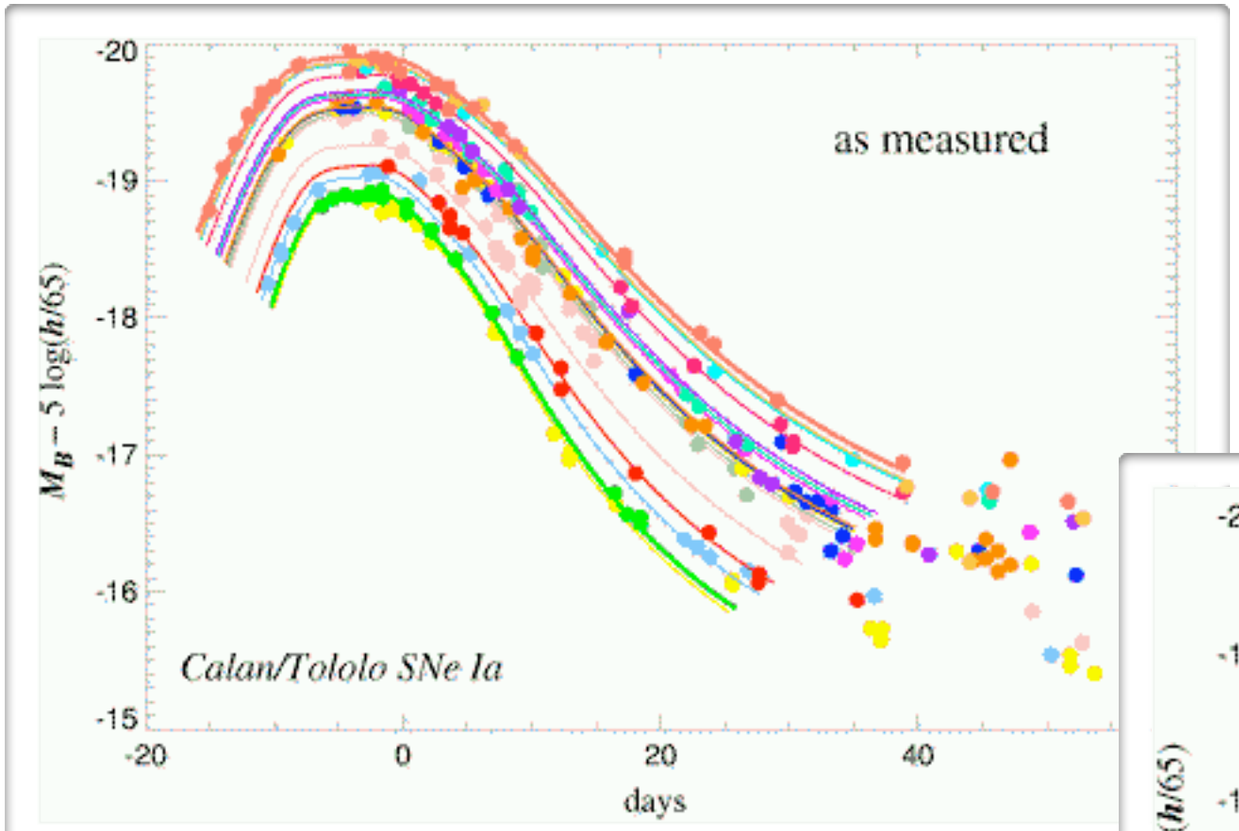
SN IA

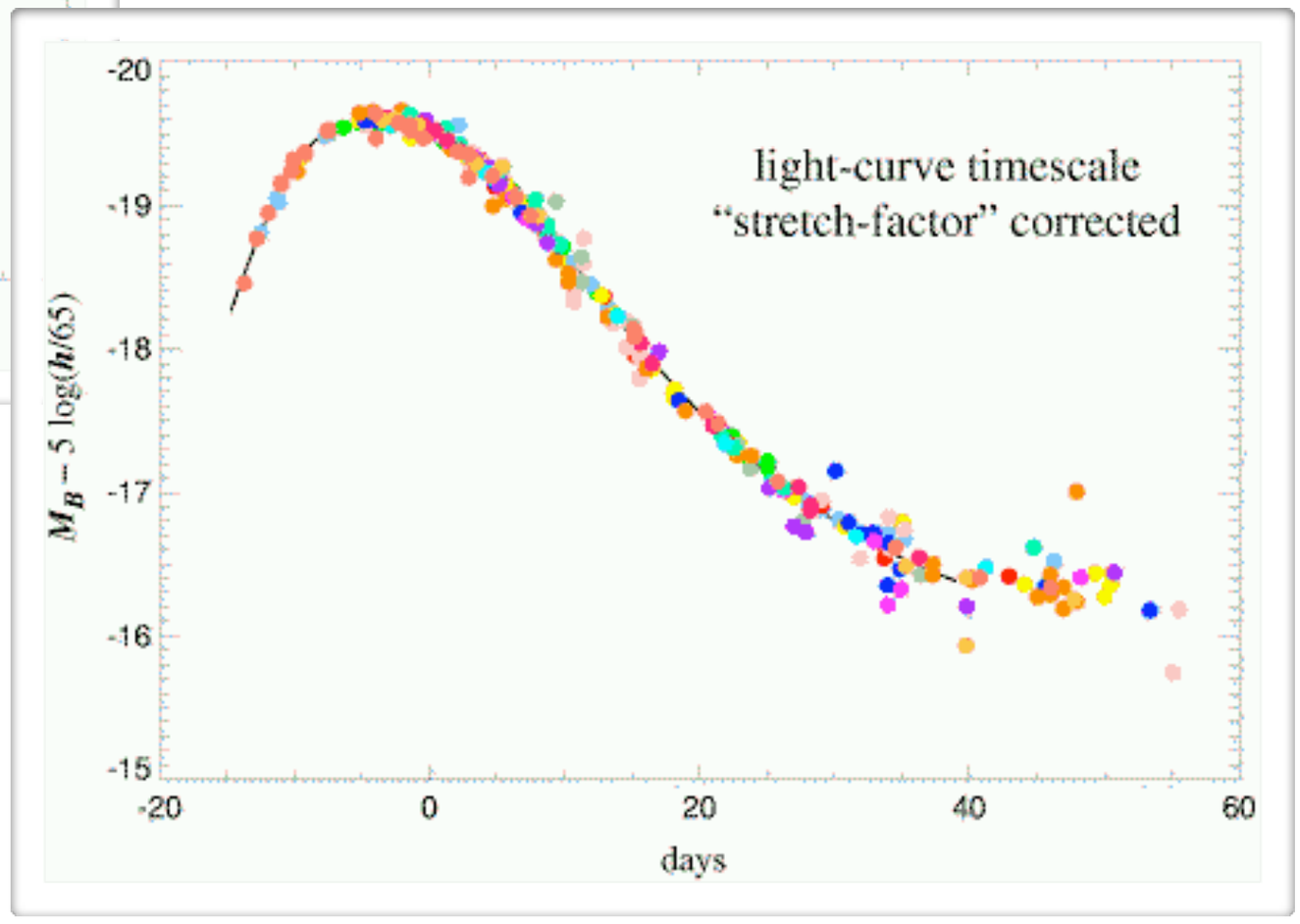




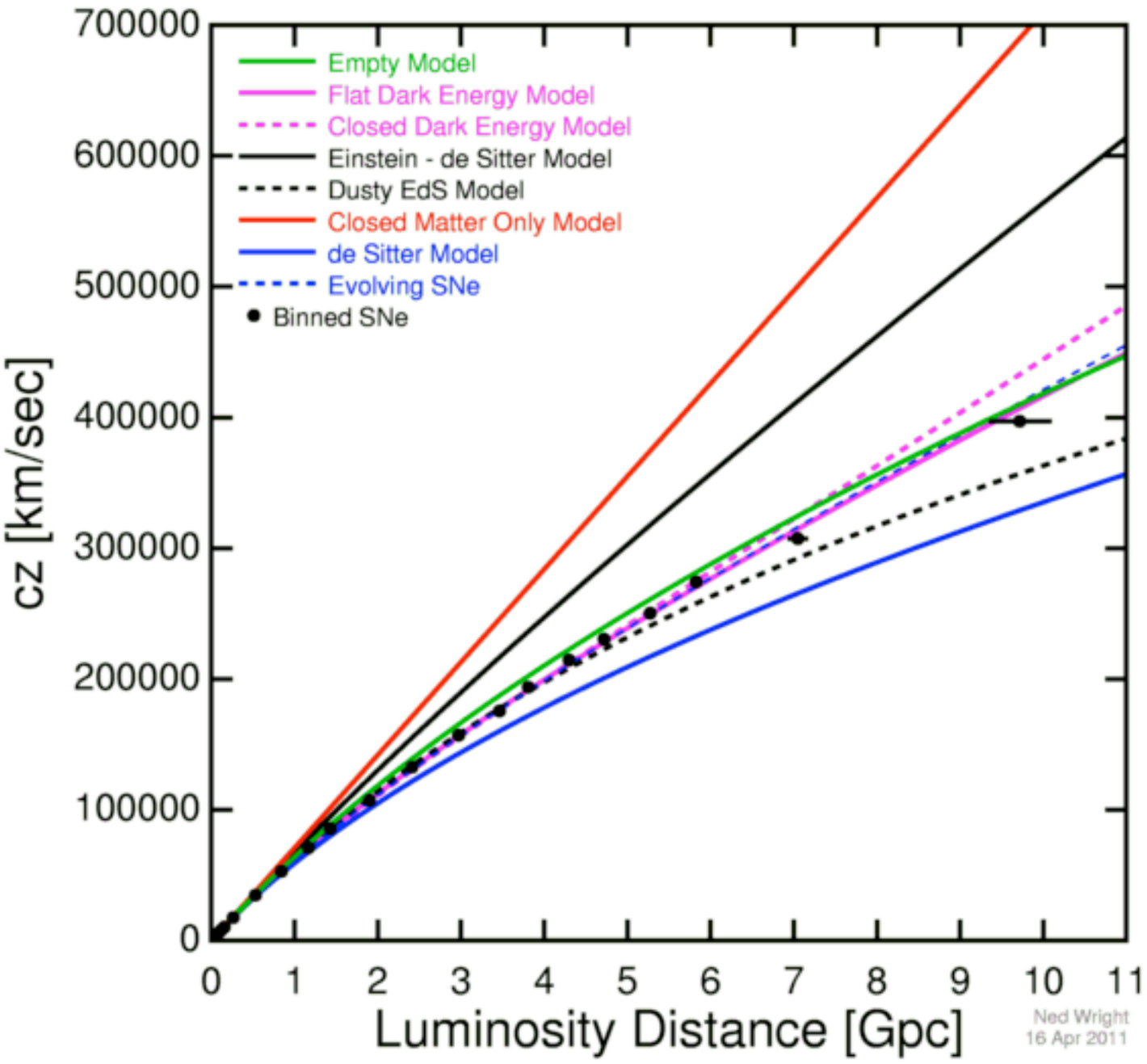
Artist's rendition of a white dwarf accumulating mass from a nearby companion star. This type of progenitor system would be considered singly-degenerate.

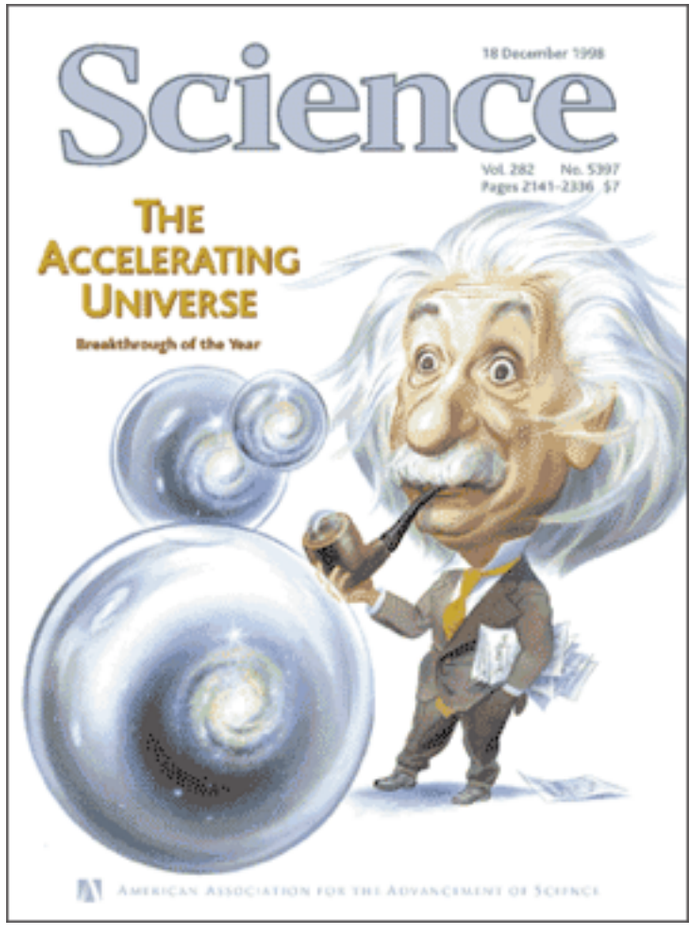
SN Light Curves





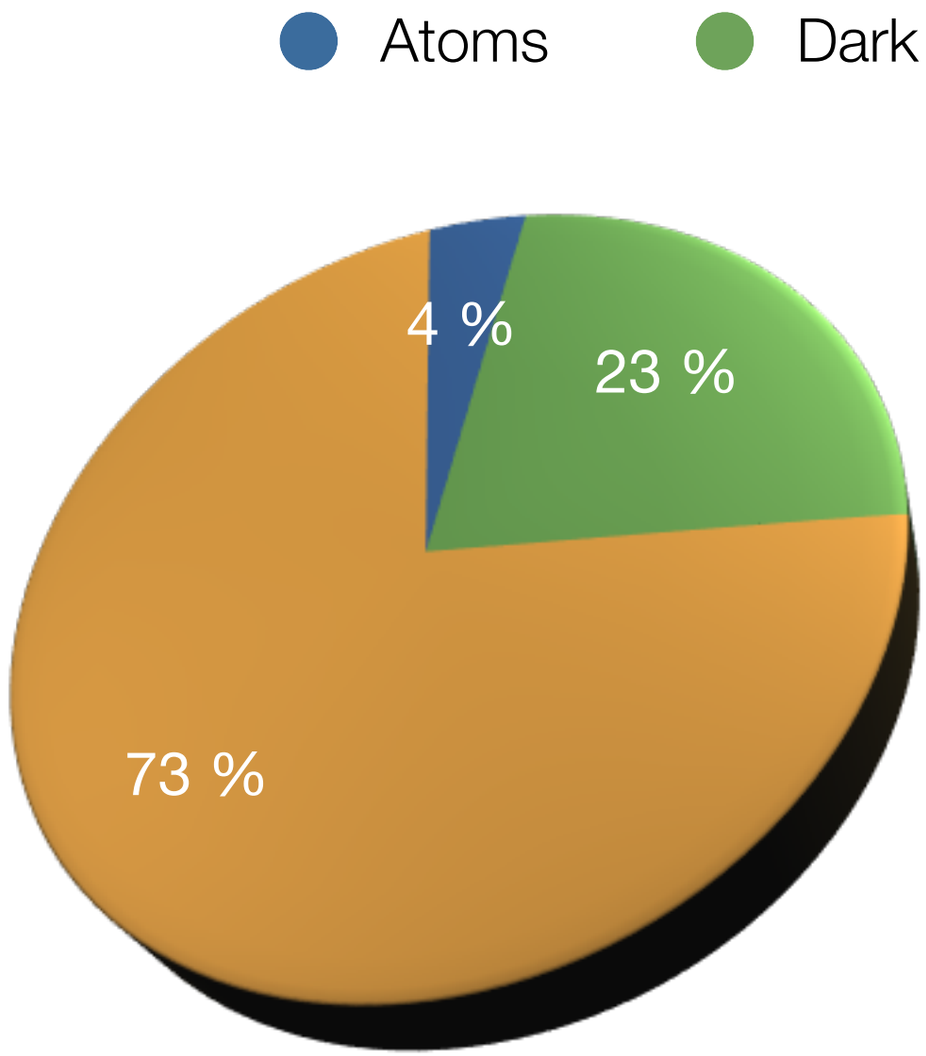
SN





Ned Wright

Energetic content of the Universe, today



$$\Omega_\Lambda = 0.73$$

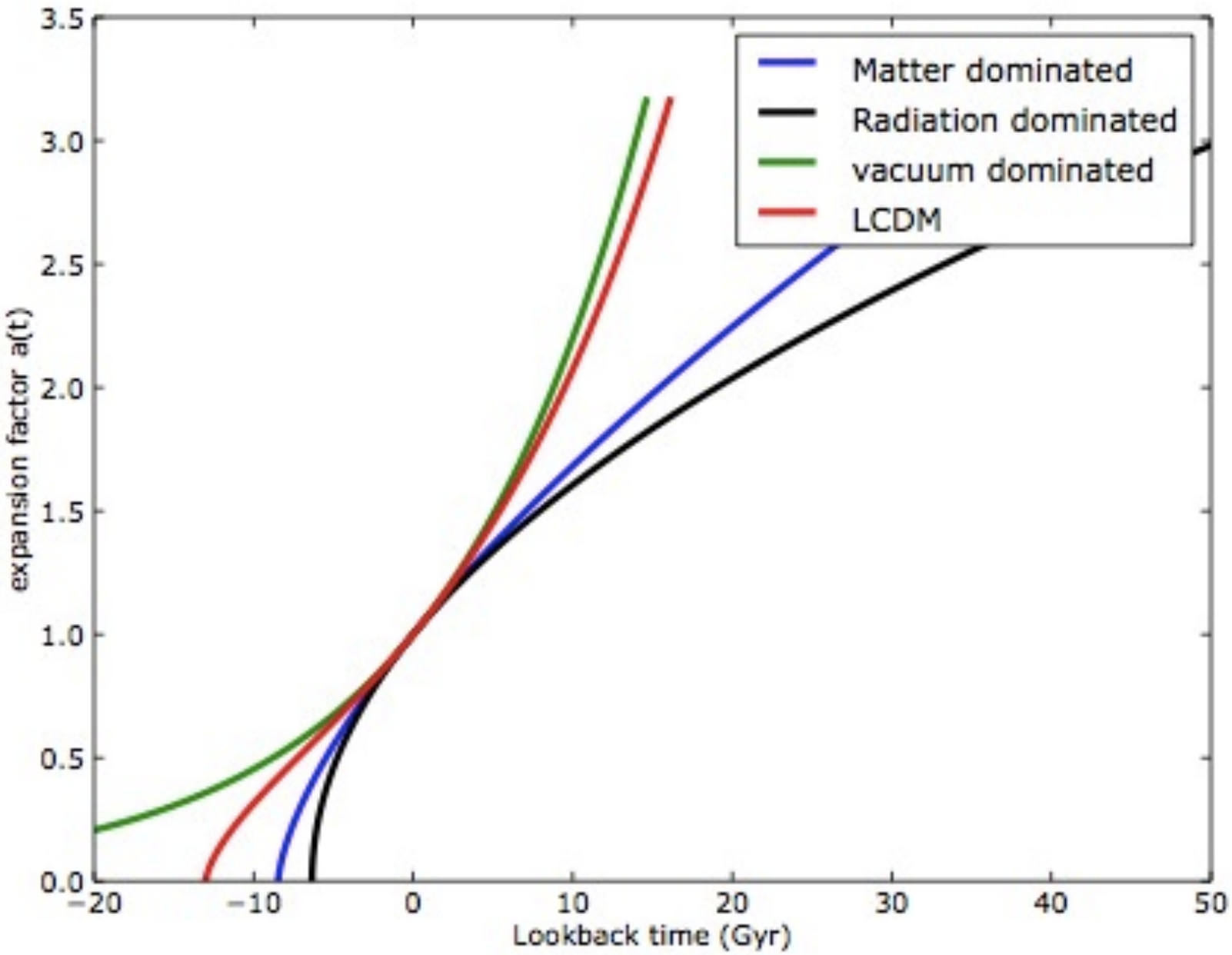
$$\Omega_m = 0.27$$

$$\Omega_b = 0.04$$

$$\Omega_r \sim 0.00001$$

$$\Omega_m + \Omega_r + \Omega_\Lambda = 1$$

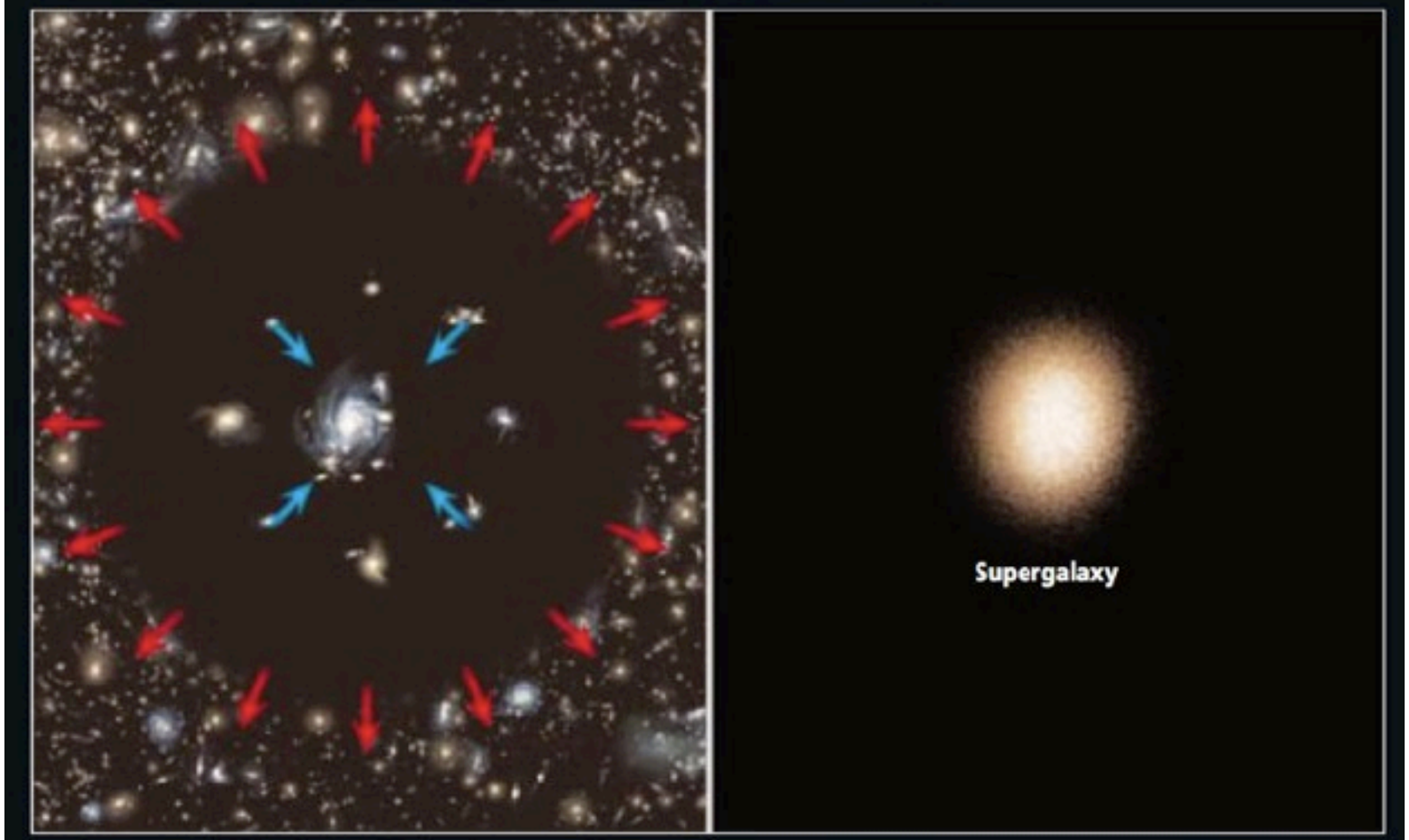
From energy to expansion



Big Rip

THE APOCALYPSE OF KNOWLEDGE

The accelerating cosmic expansion is beginning to undermine the three observational pillars of the big bang theory: the motion of galaxies away from one another, the cosmic microwave background radiation, and the relative quantities of light chemical elements such as hydrogen and helium.



TODAY all three pillars are prominent. We see distant galaxies recede from us (*red arrows*) as nearby ones pull tighter (*blue*); background radiation suffuses space; and cosmic gas largely retains the chemical mix produced early in the big bang.

BILLIONS OF YEARS LATER nearby galaxies have merged and distant ones have receded from view. The background radiation is undetectably dilute. Multiple generations of stars have contaminated the original chemical mix.

To Conclude

Cosmological Principle ?

The standard cosmological model assumes :

- the Universe is isotropic and homogeneous (on cosmological scales)
- Gravitation is described by General Relativity (GR)

In order to get rid of DM and DE one may (see B. Famaey talk):

- relax the assumption of isotropy or homogeneity
- assume that GR is only an effective theory

Otherwise:

ΛCDM