The History of Light: How Stars formed in Galaxies

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Where does the (visible) light in the Universe come from?

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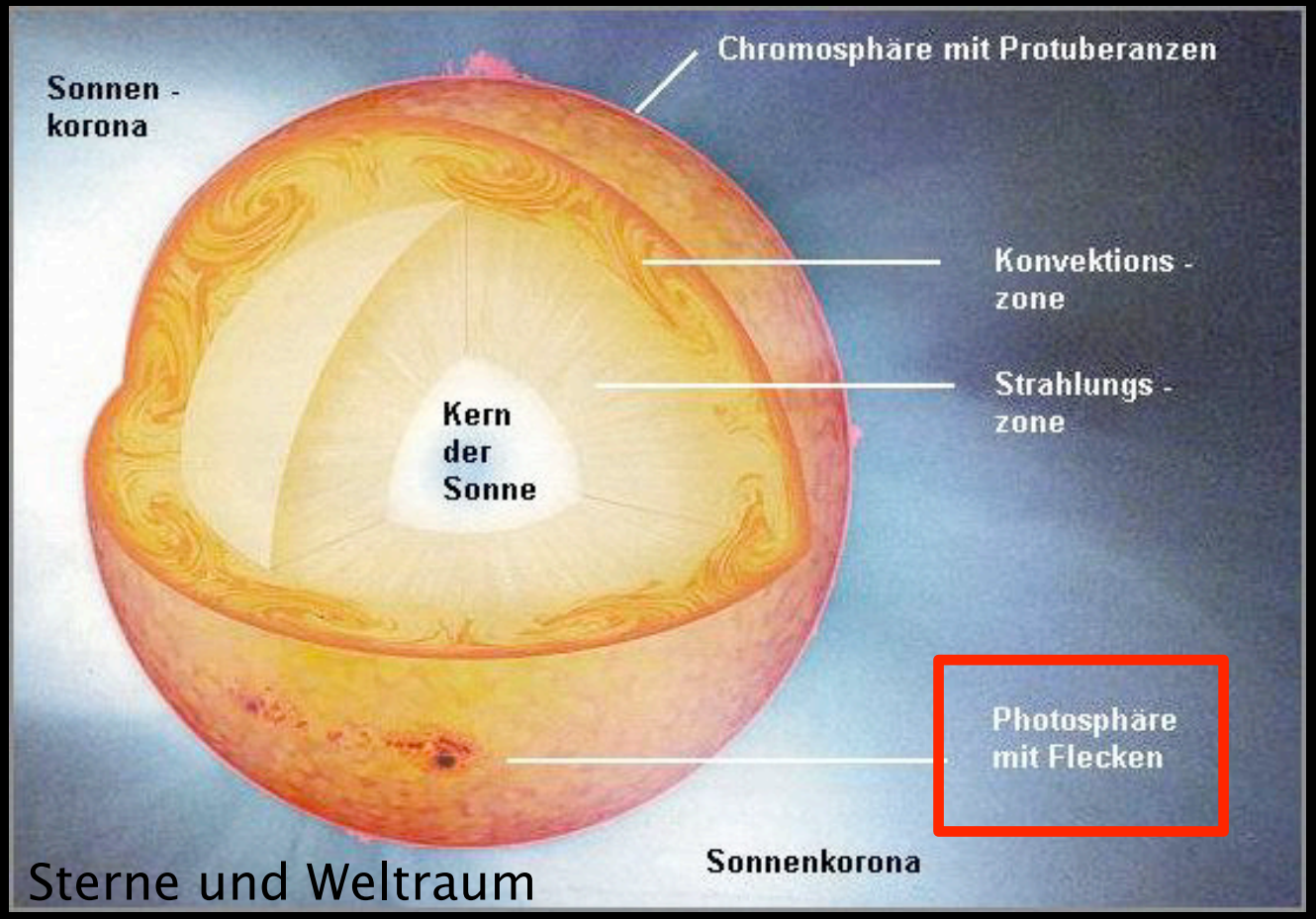


Mostly stellar photospheres

Where do the stars come from?

1) Where, when and how were they born?

2) Why is that important to know?

3) How can we observe and model the history of star birth?

The Milky Way

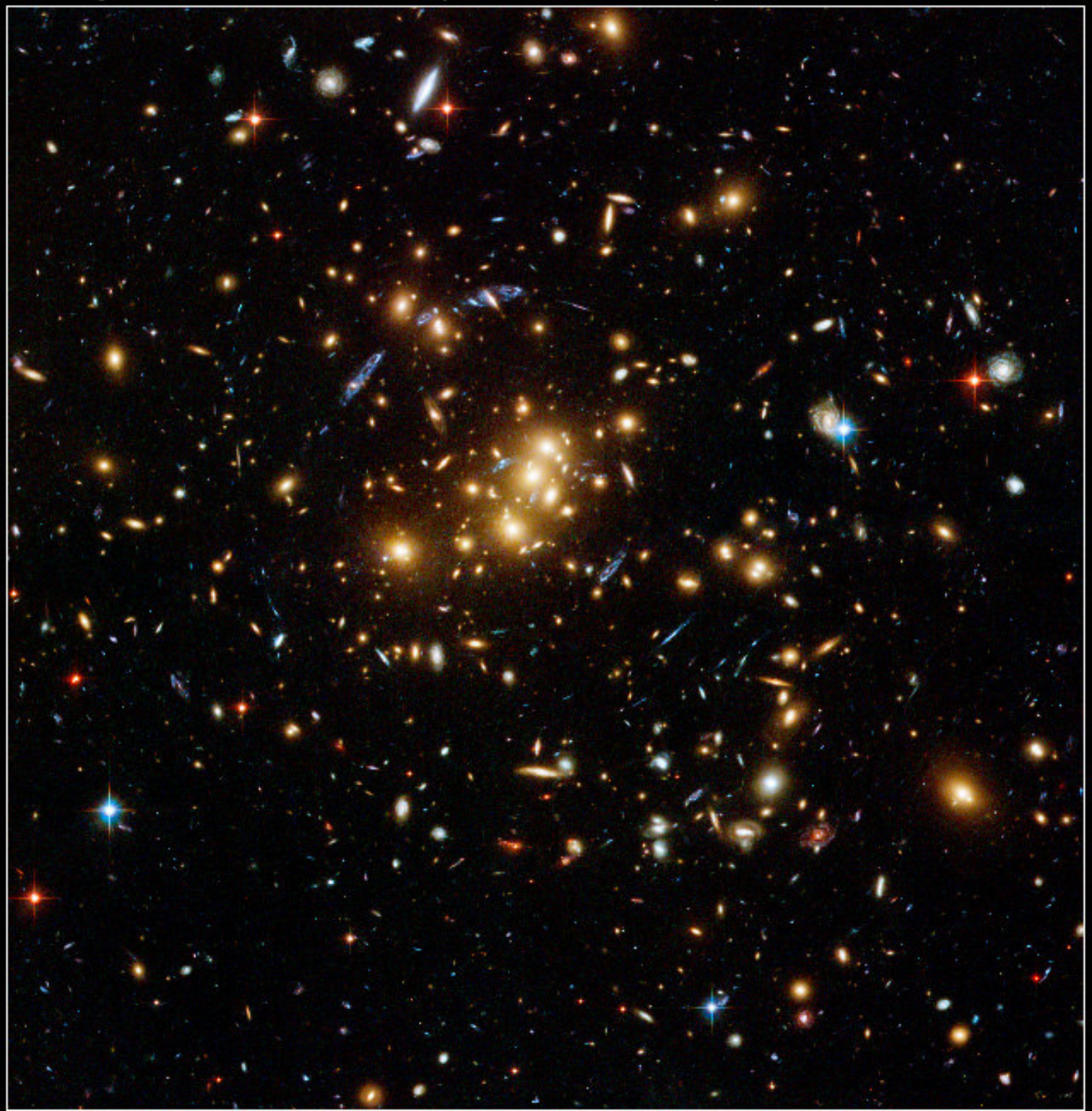
Milky Way

M31 (“Andromeda Galaxy”)

M51 (“Whirlpool Galaxy”)

M104 (“Sombrero Galaxy”)

Galaxy Cluster Cl 0024+17 (ZwCl 0024+1652) *HST* • ACS/WFC

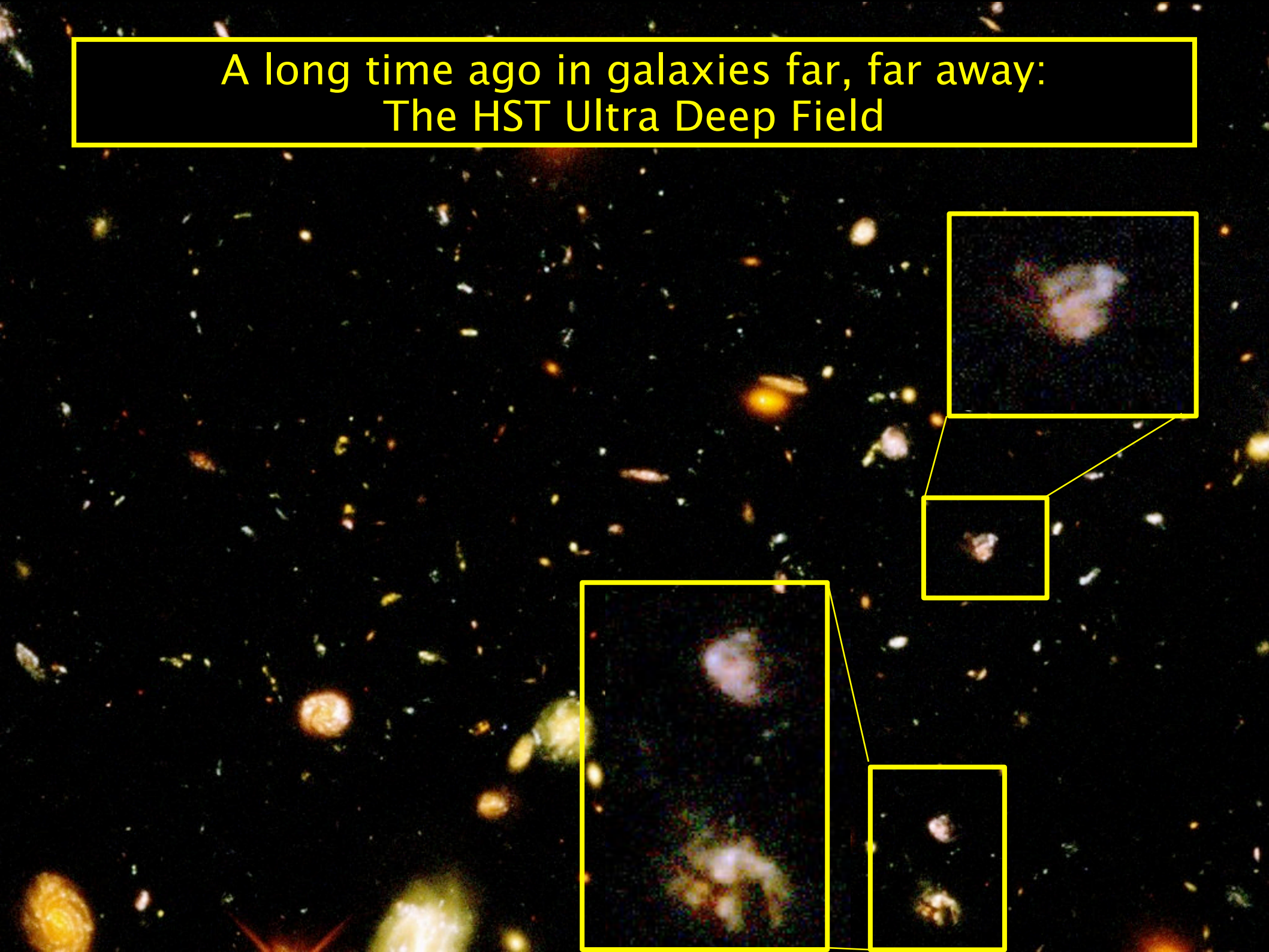


Stars are not evenly distributed in the Universe

They are born, live, and die in Galaxies.

Why is that so?
And where do galaxies come from?

A long time ago in galaxies far, far away: The HST Ultra Deep Field

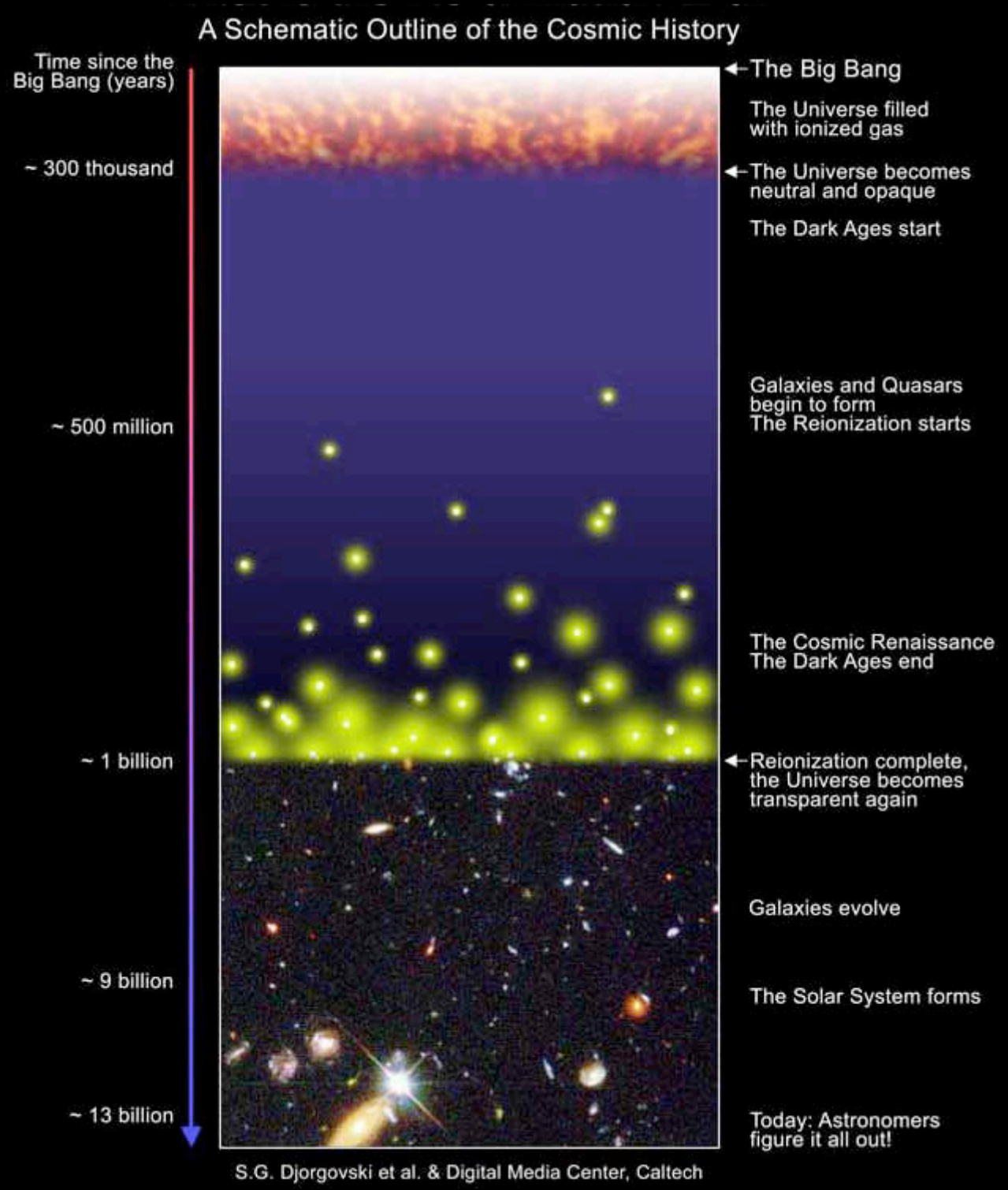


Two immediate results:

I. Galaxies formed at some point in the distant past

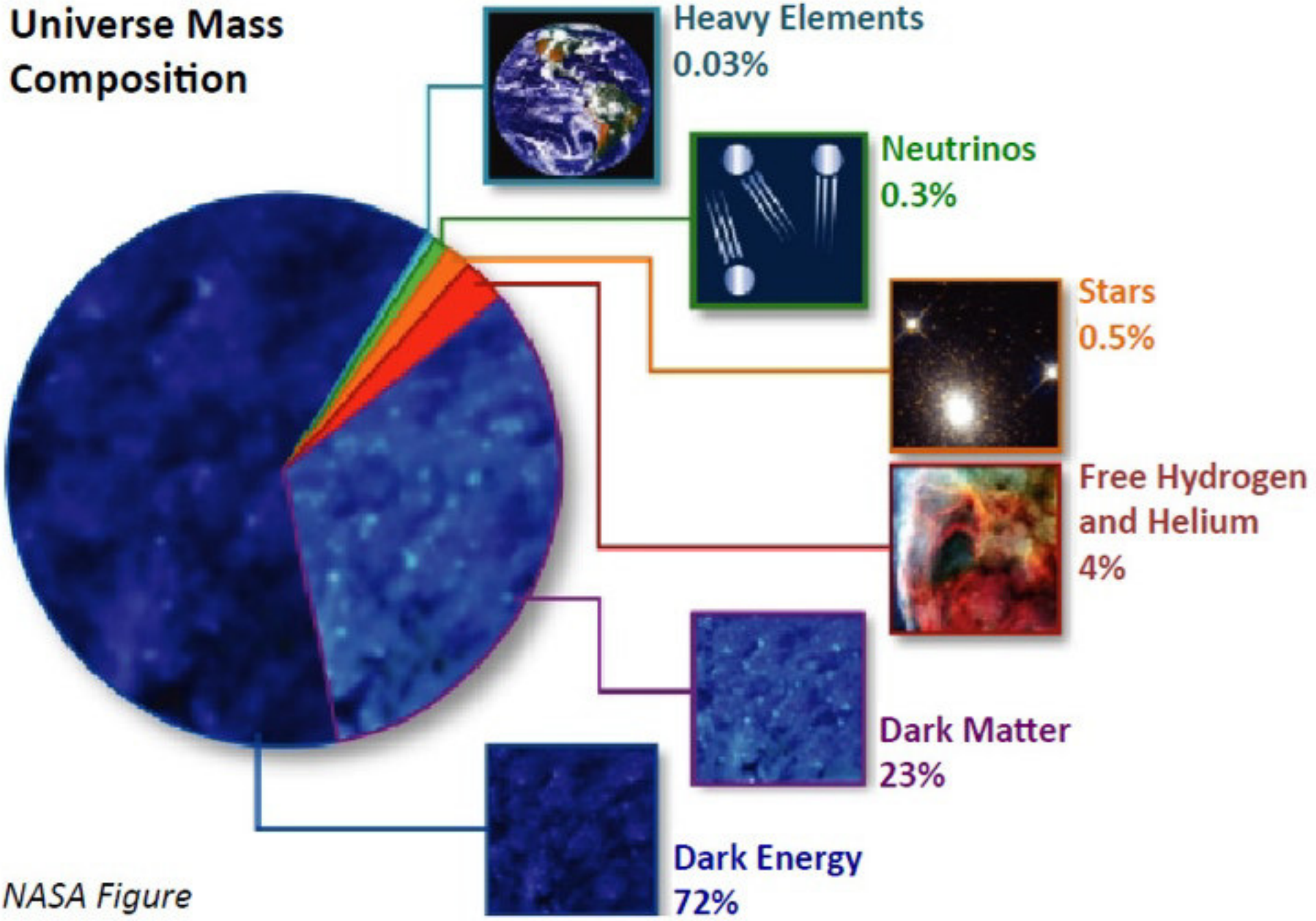
II. Galaxies evolved with time

Where do the Stars and Galaxies come from?

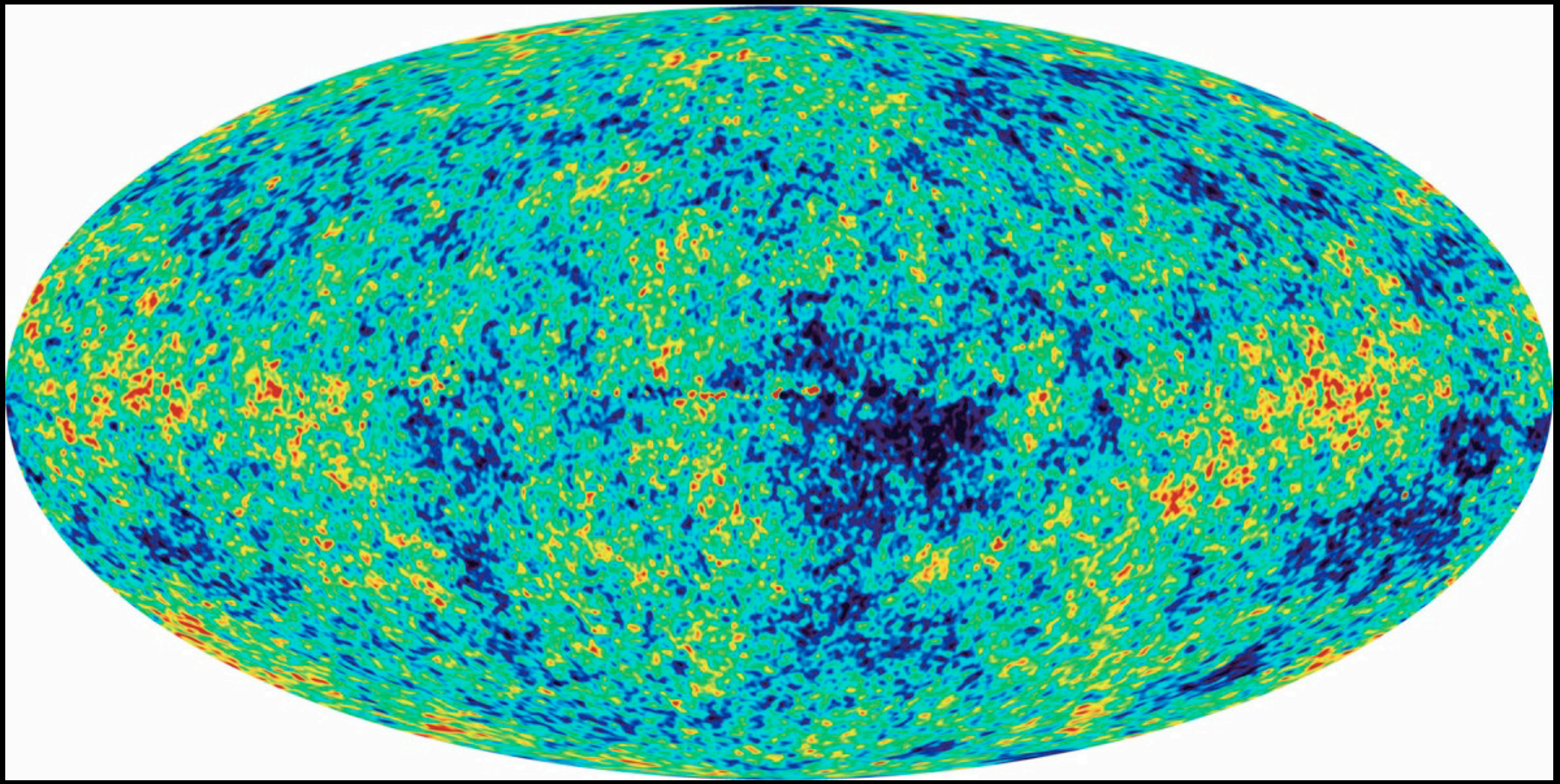


Timeline (very rough)

- Most galaxies have very old stars
- most galaxies started forming their stars some 10-13 Billion years ago,shortly after the beginning of the Universe


Universe Mass Composition
Heavy Elements
0.03%
Neutrinos
0.3%
Stars
0.5%
Free Hydrogen and Helium
4%
Dark Matter
23%
Dark Energy
72%
NASA Figure

The Cosmic Microwave Background,
a baby photo of the Universe when it was just 300,000 years old



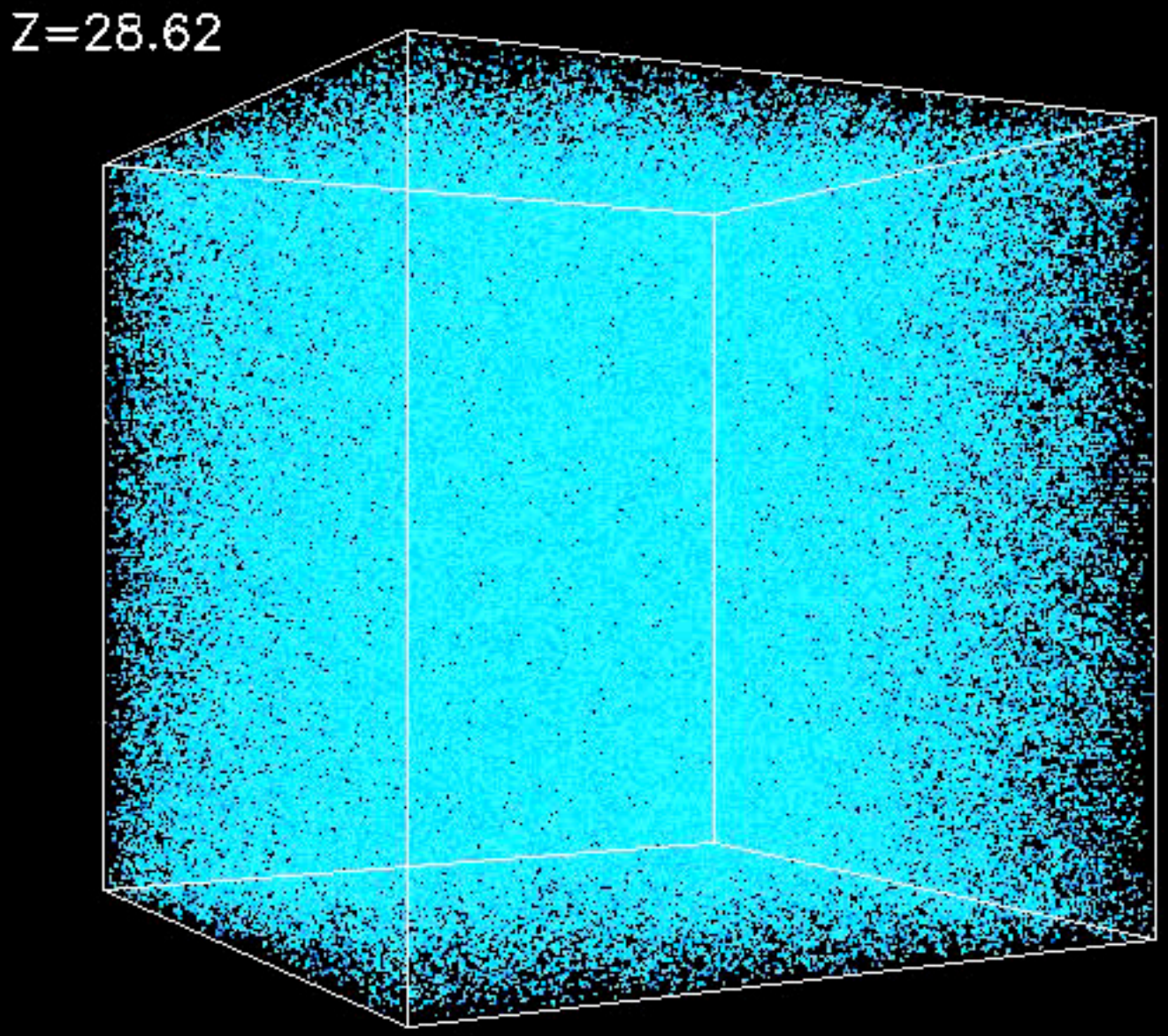
It reveals tiny irregularities;
the density of matter varied by parts in a million

Dark Matter is more abundant, dominates gravity:

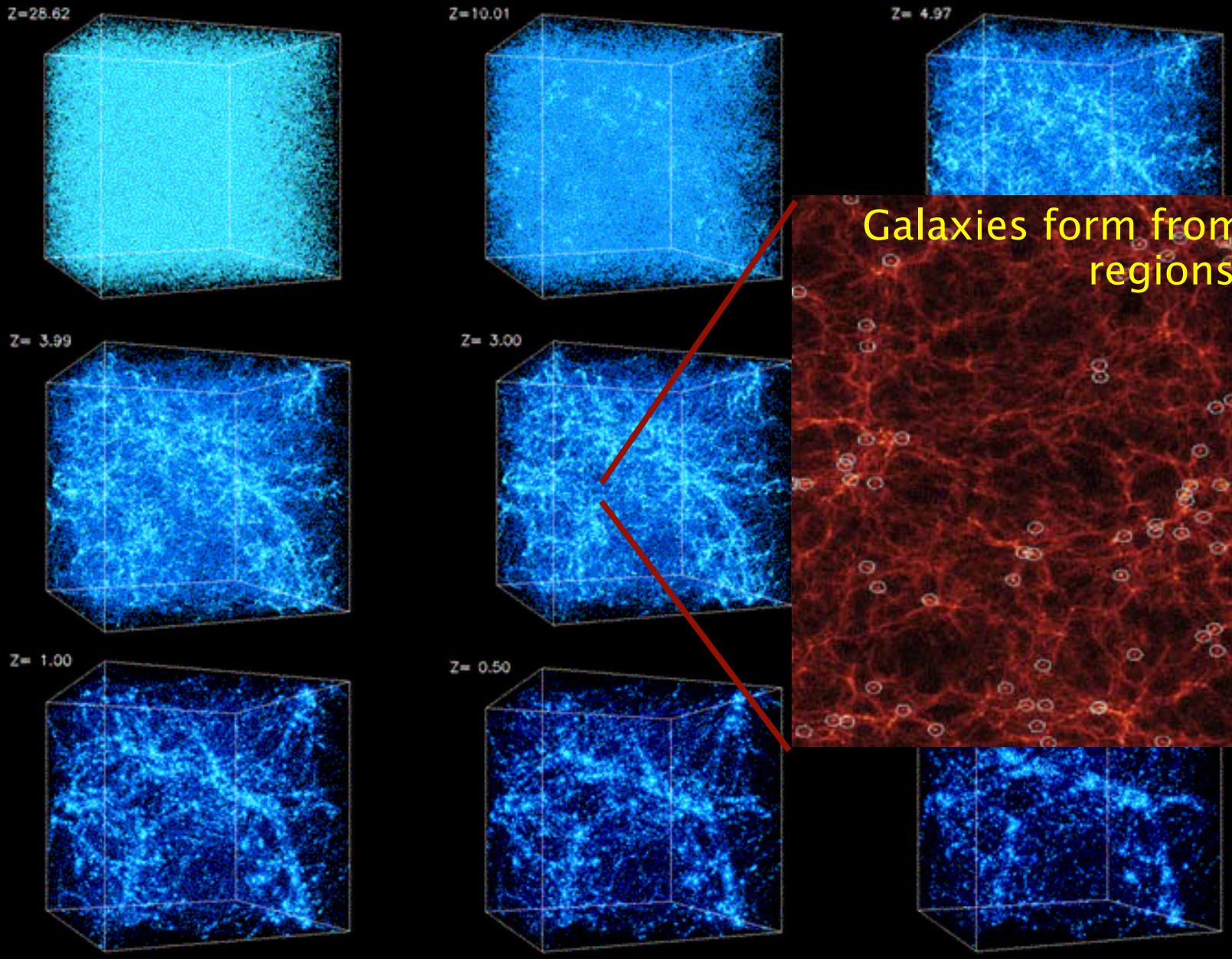
To understand how gravity created structure (galaxies) from the early homogeneous Universe, we need to simulate Dark Matter

Outcome depends strongly on the structure/geometry of the Universe and the content of Dark Matter

Supercomputer simulations of Dark Matter: Gravity grows the initial density perturbations, structure forms

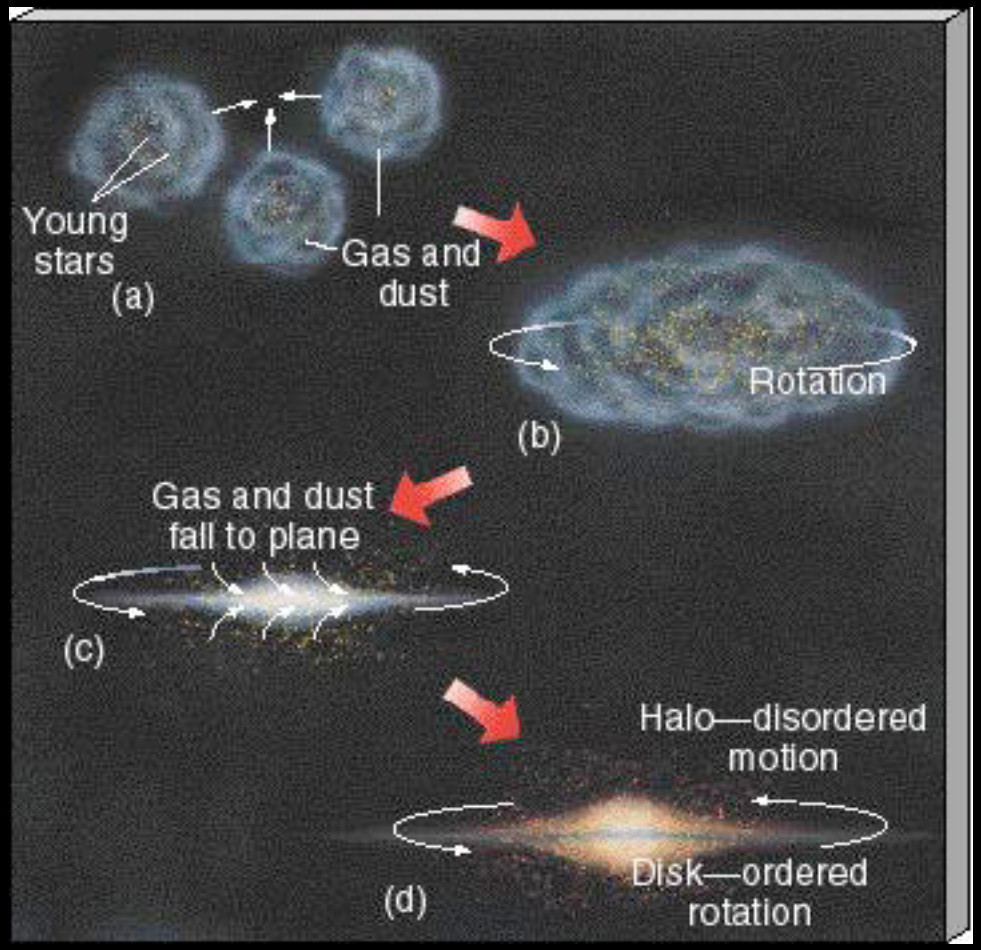


Gravity grows a "Cosmic Web" of Dark Matter – voids, filaments, clusters of clumps that host galaxies



Simulation: A.Kravtsov

Luminous matter, Formation gas disk and stars:



Luminous matter (gas!) is viscous, and heated as it falls into dark matter halos; then heat is radiated away–gas cools–contracts

angular momentum is conserved–>spin–up of rotation ("figure skater") – fast rotating disk

energy in turbulent/random motions (perpendicular to disk) is dissipated (viscosity–>friction–>heating –>heat is radiated away)
–> motions perpendicular to ordered rotation disappear

–>cold, dense gas disk –> STARS

Recap: From Dark Matter to Stars

1) The Universe contains mostly Dark Matter

2) Tiny irregularities in the Dark Matter density in the early Universe grew rapidly through gravity

3) Gas fell into the resulting Dark Matter clumps/"halos" (galaxies) and formed cold, dense gas disks

4) Stars are born and live in galaxies because they need cold, dense gas to form