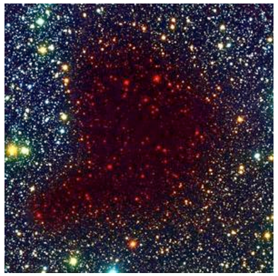
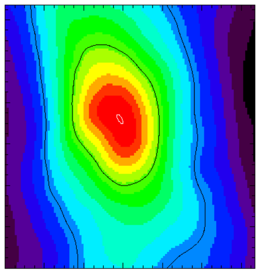
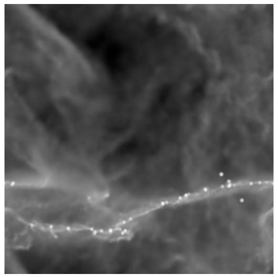
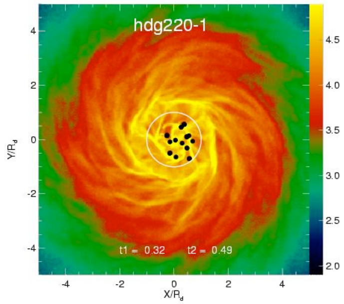
First star formation





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thanks to ...

... people in the group in Heidelberg:

Richard Allison, Gabriel Anorve, Christian Baczynski, Erik Bertram, Frank Bigiel, Paul Clark, Gustavo Dopcke, Jayanta Dutta, Philipp Girichidis, Simon Glover, Lukas Konstandin, Faviola Molina, Milica Micic, Mei Sasaki, Jennifer Schober, Rahul Shetty, Rowan Smith

... former group members:

Robi Banerjee, Ingo Berentzen, Christoph Federrath, Thomas Greif, Thomas Peters, Dominik Schleicher, Sharanya Sur

... many collaborators abroad!

Deutsche Forschungsgemeinschaft DFG

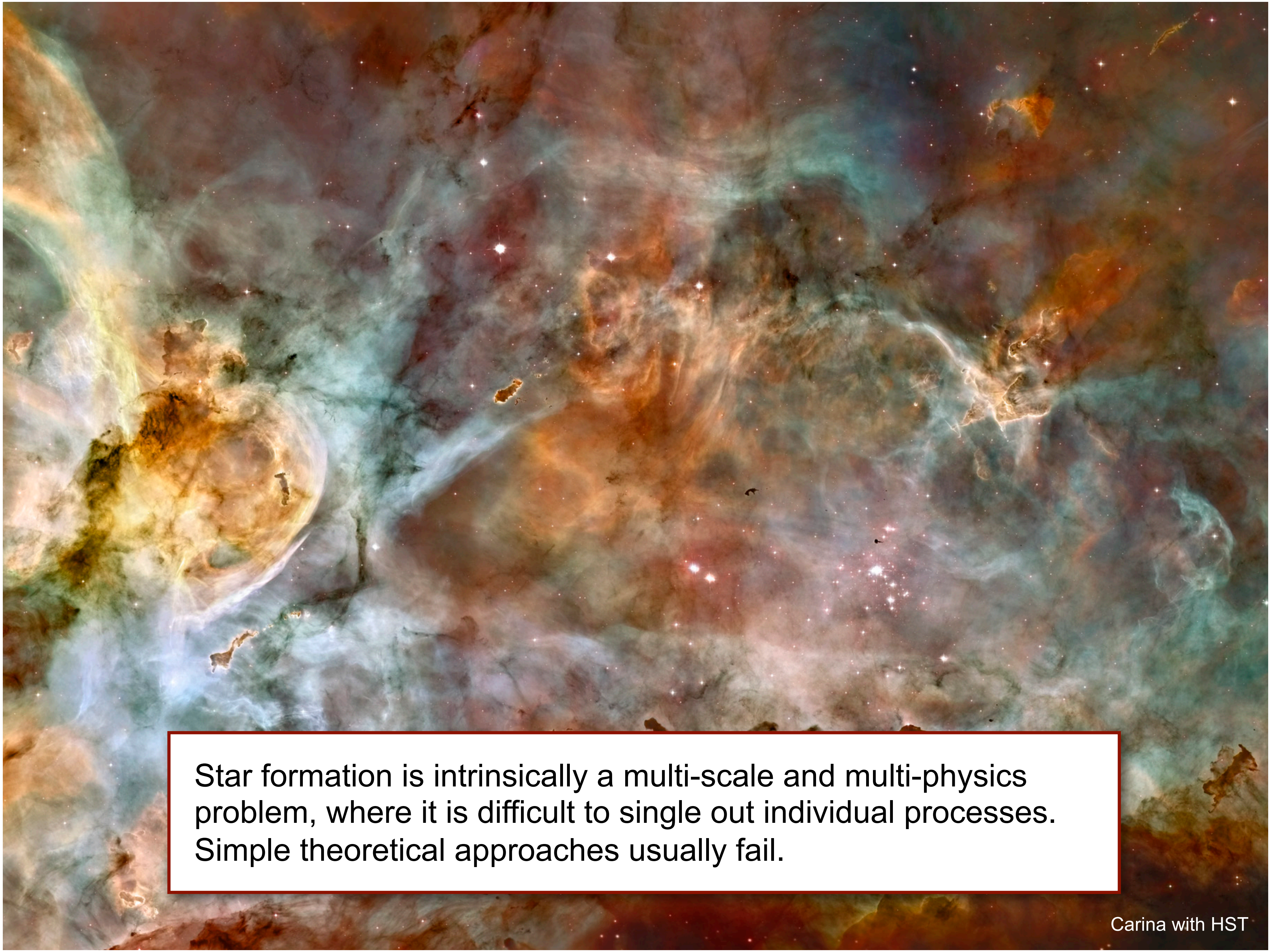
Emmy Noether-Programm Deutsche Forschungsgemeinschaft DFG

ASTRONET

LANDESSTIFTUNG Baden-Württemberg

HGSFP

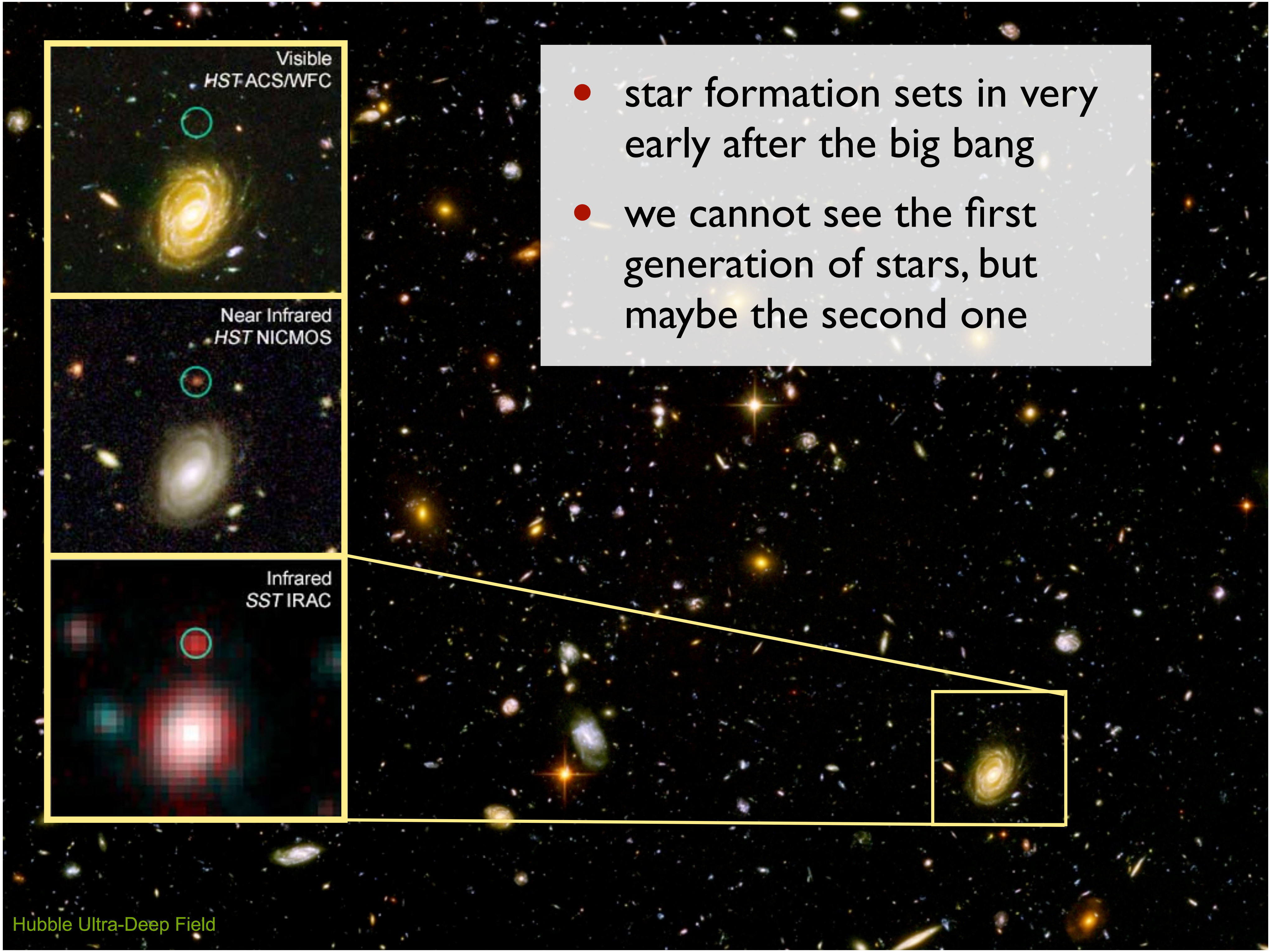
IMPRS



Star formation is intrinsically a multi-scale and multi-physics problem, where it is difficult to single out individual processes. Simple theoretical approaches usually fail.

Carina with HST


HH 901/902 in Carina with HST



- star formation sets in very early after the big bang
- we cannot see the first generation of stars, but maybe the second one

How do we know the initial conditions of first star formation?

From determining the cosmic expansion rate.

From measuring the cosmic microwave background.

From cosmic nucleosynthesis.

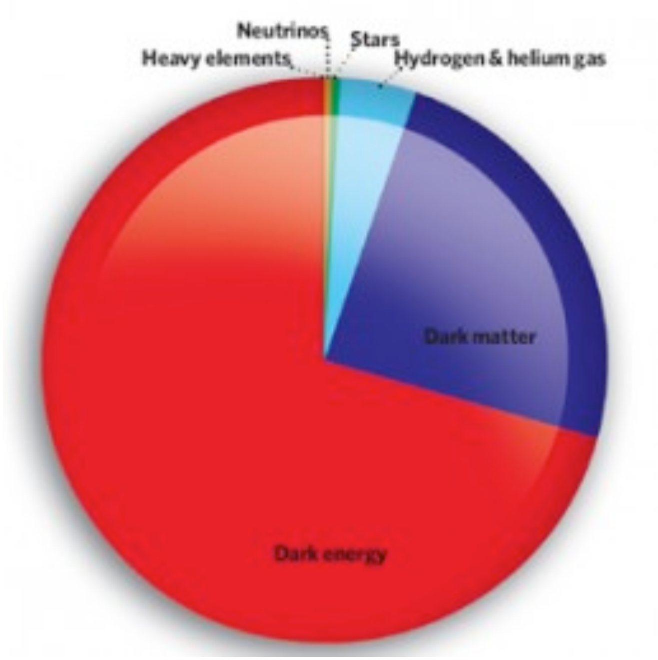
Energy density in universe

Dark Energy

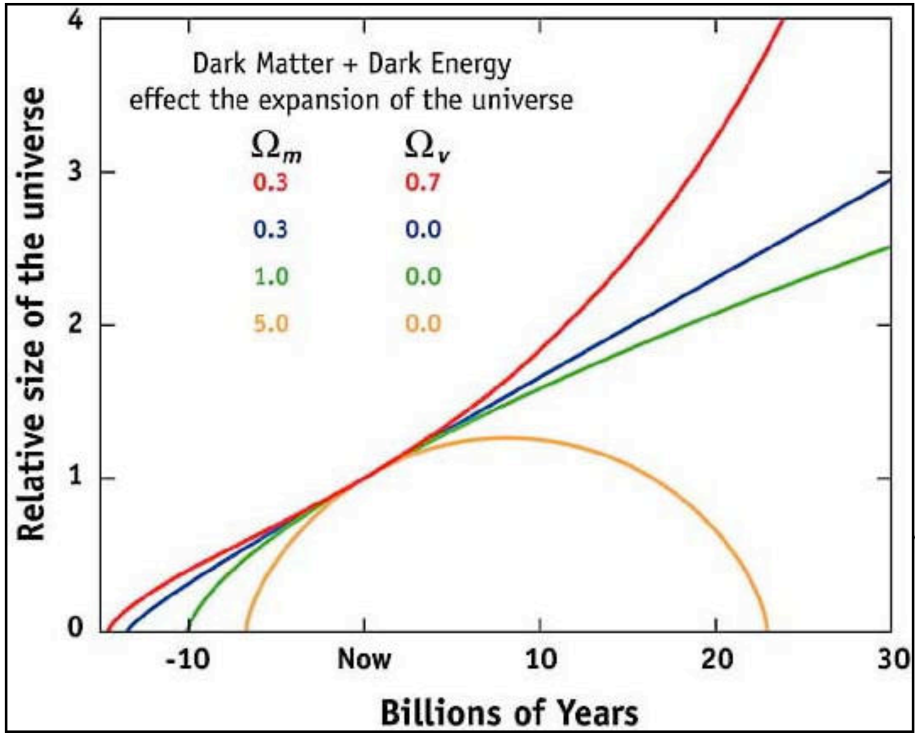
Dark Mater

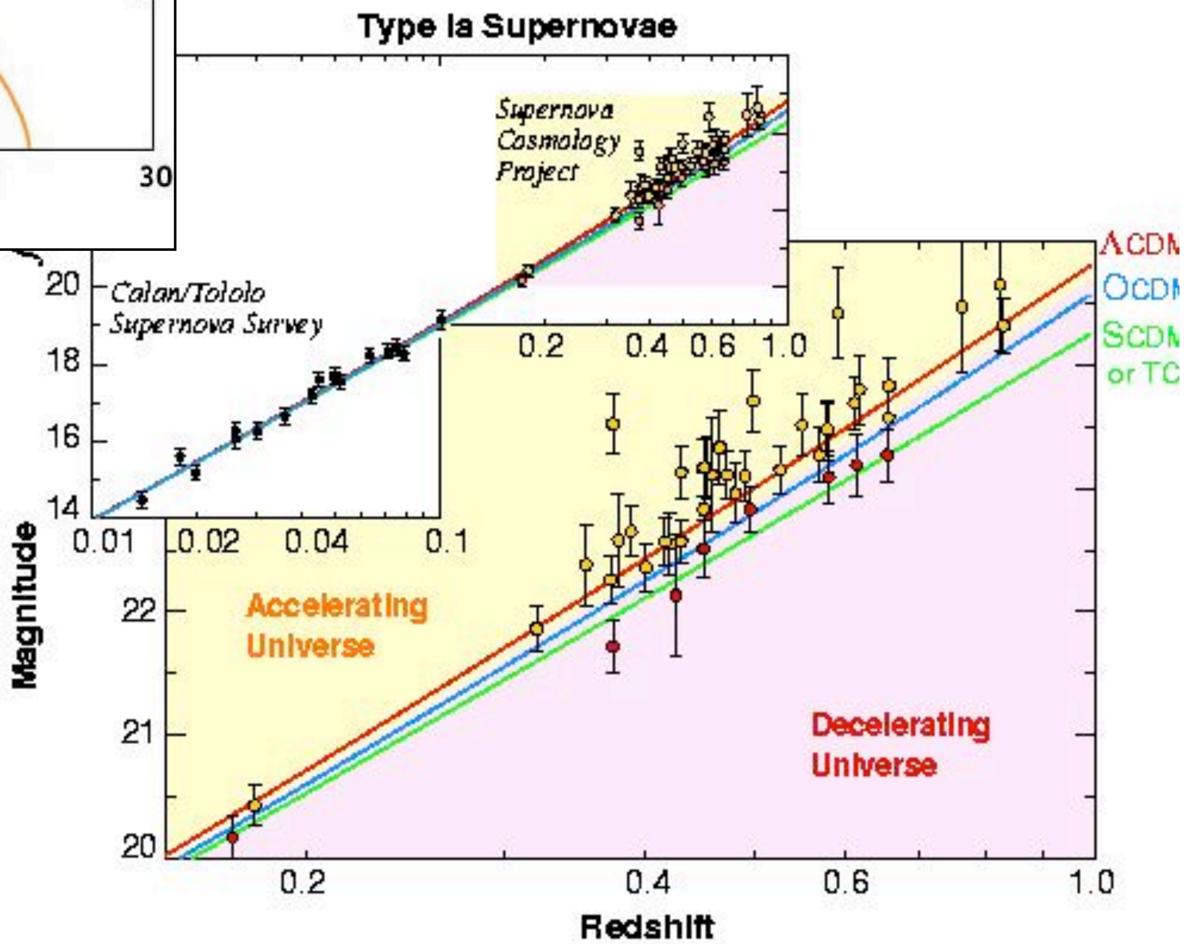
Baryonic (visible) material
- -- Gas
- -- Stars

Miscellaneous

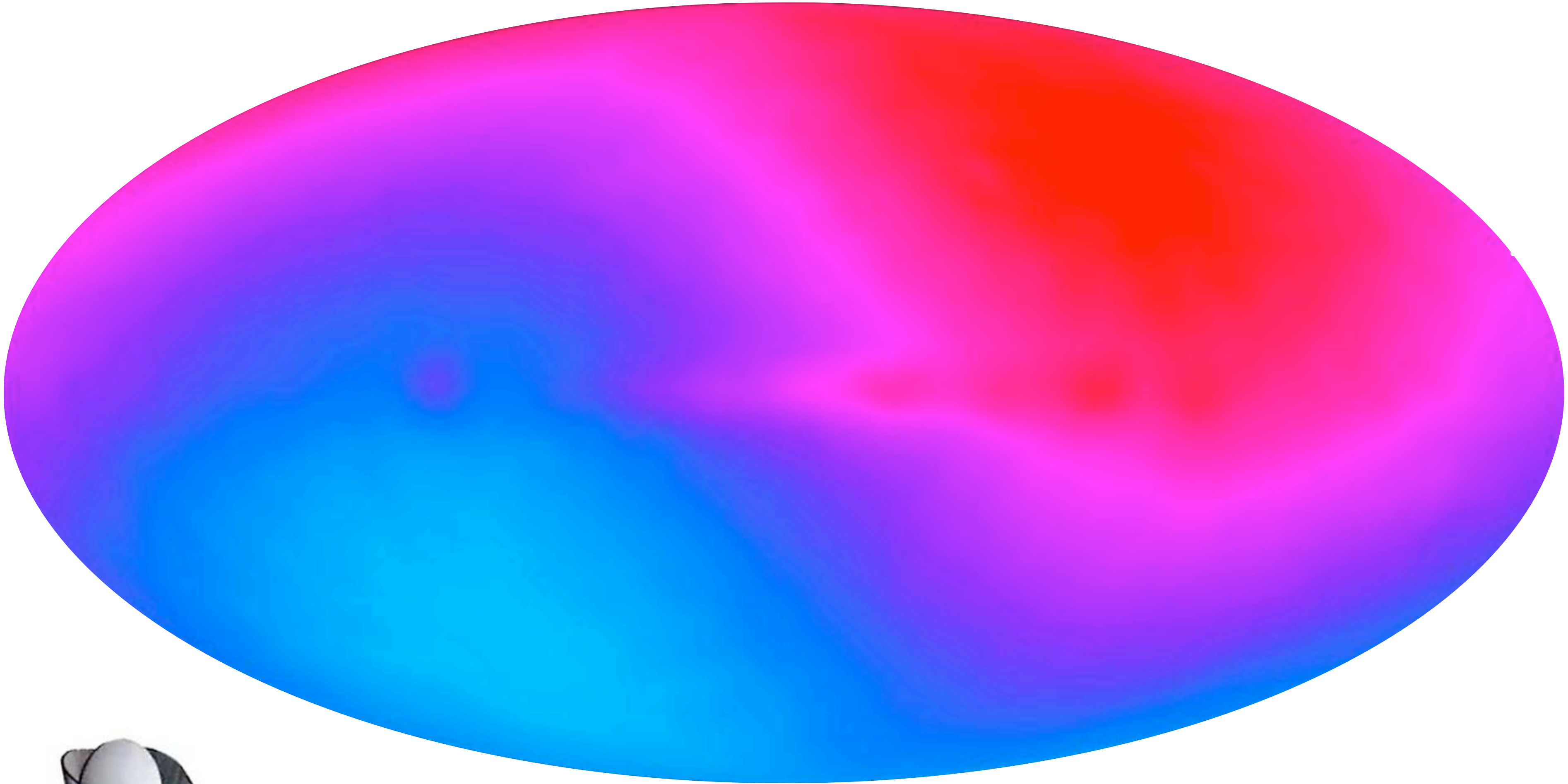


Expansion of the Universe

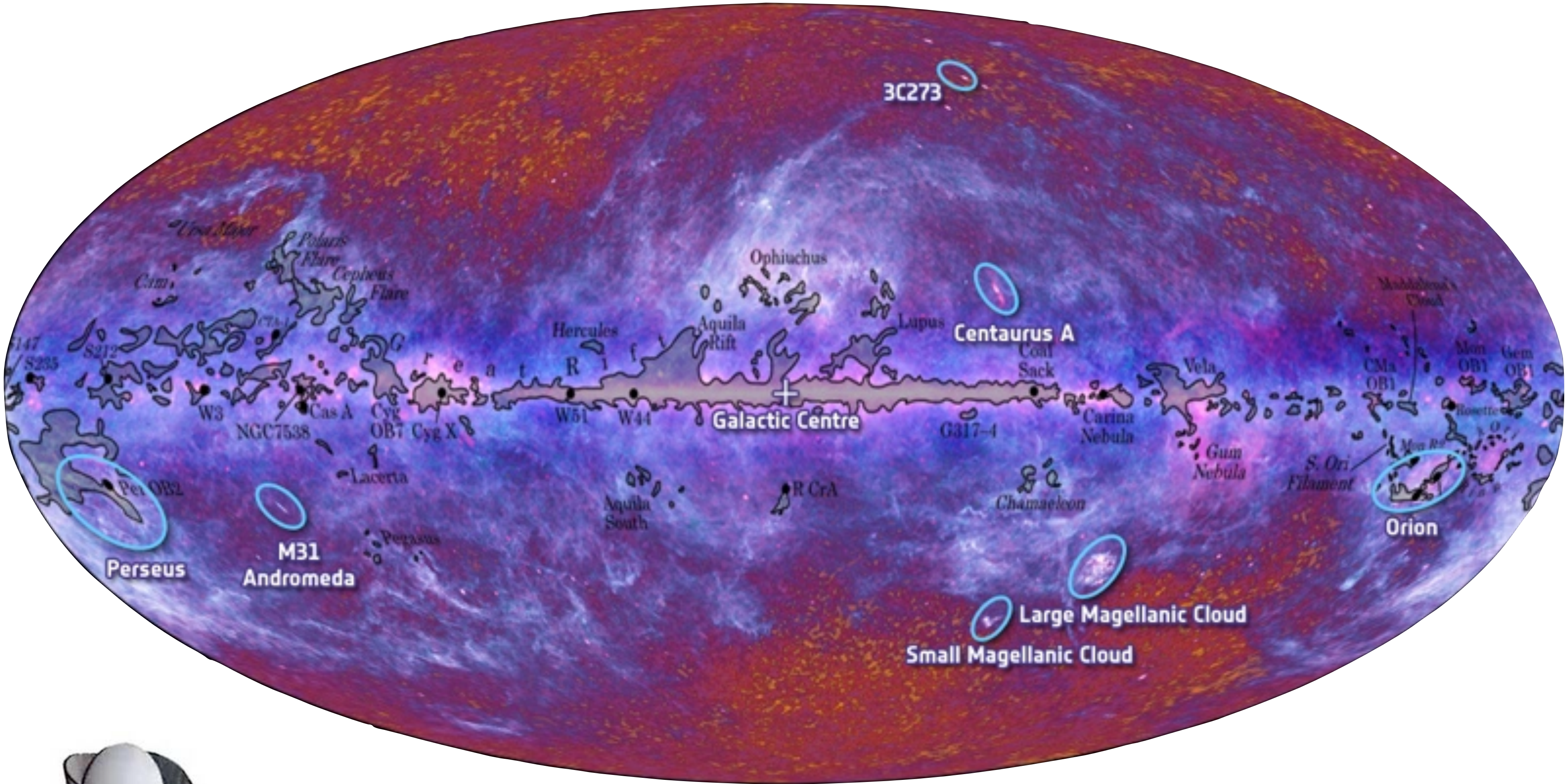




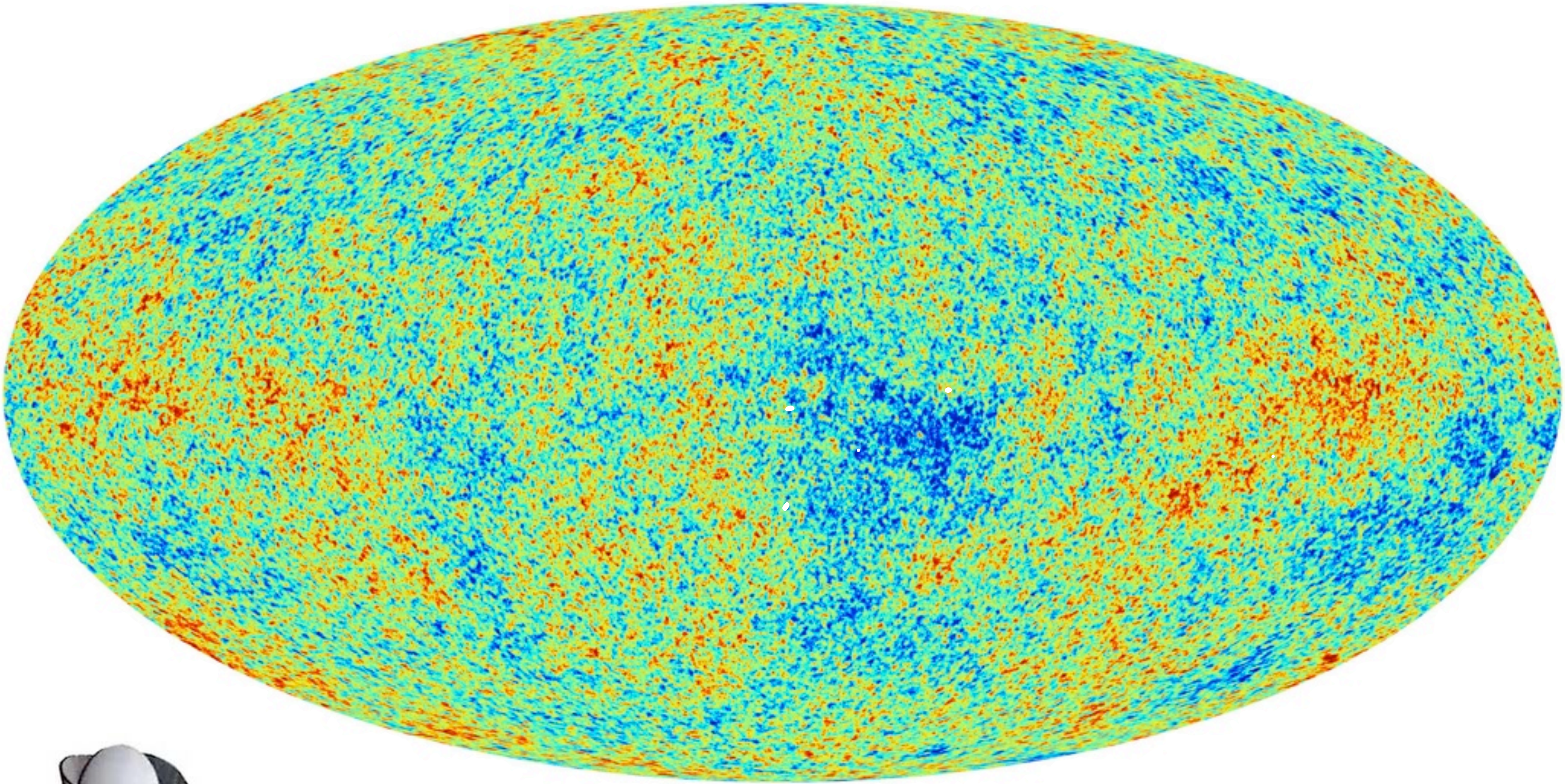
Saul Perlmutter, Brian P. Schmidt, Adam G. Riess



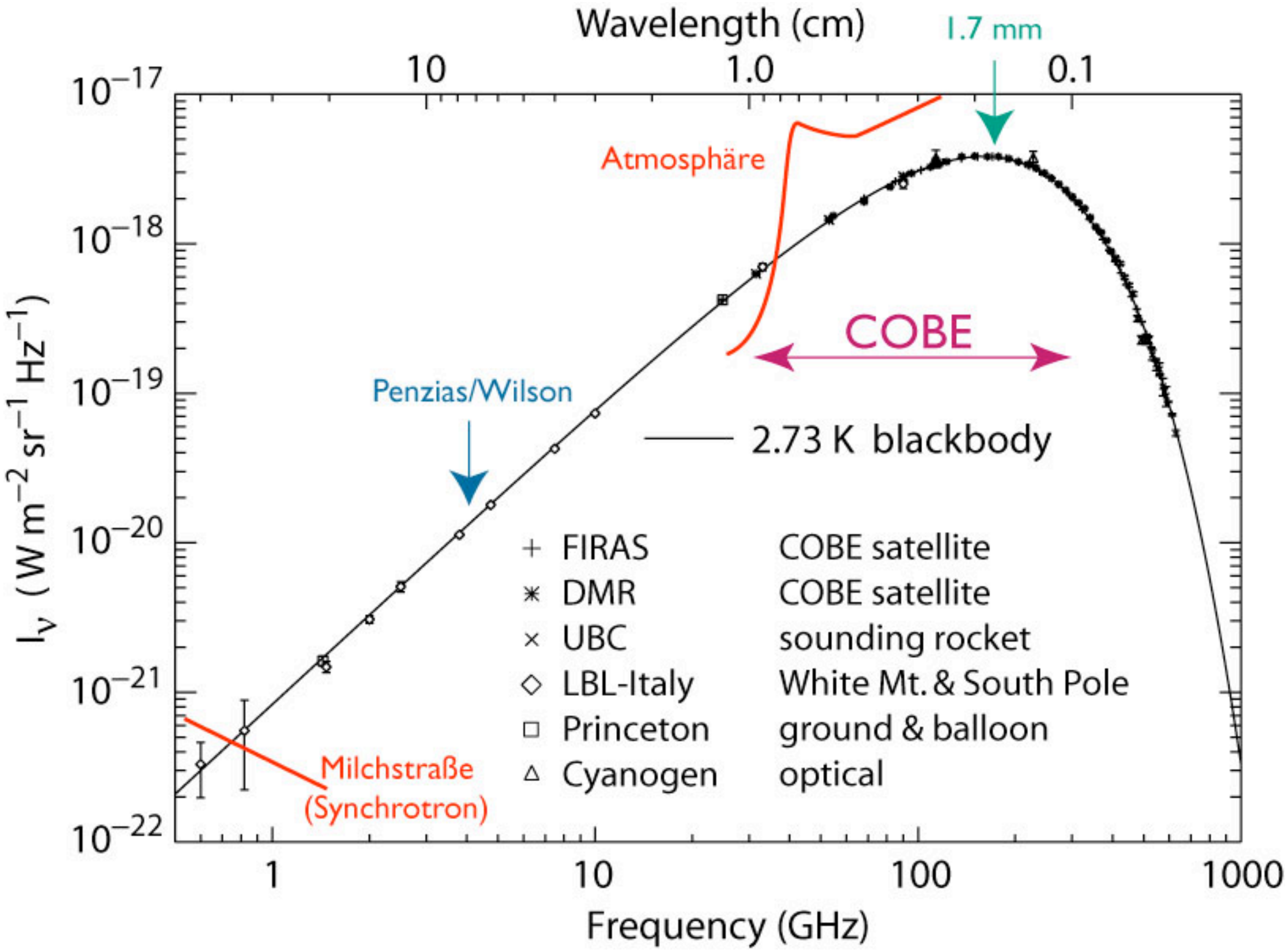
Planck satellite: total flux



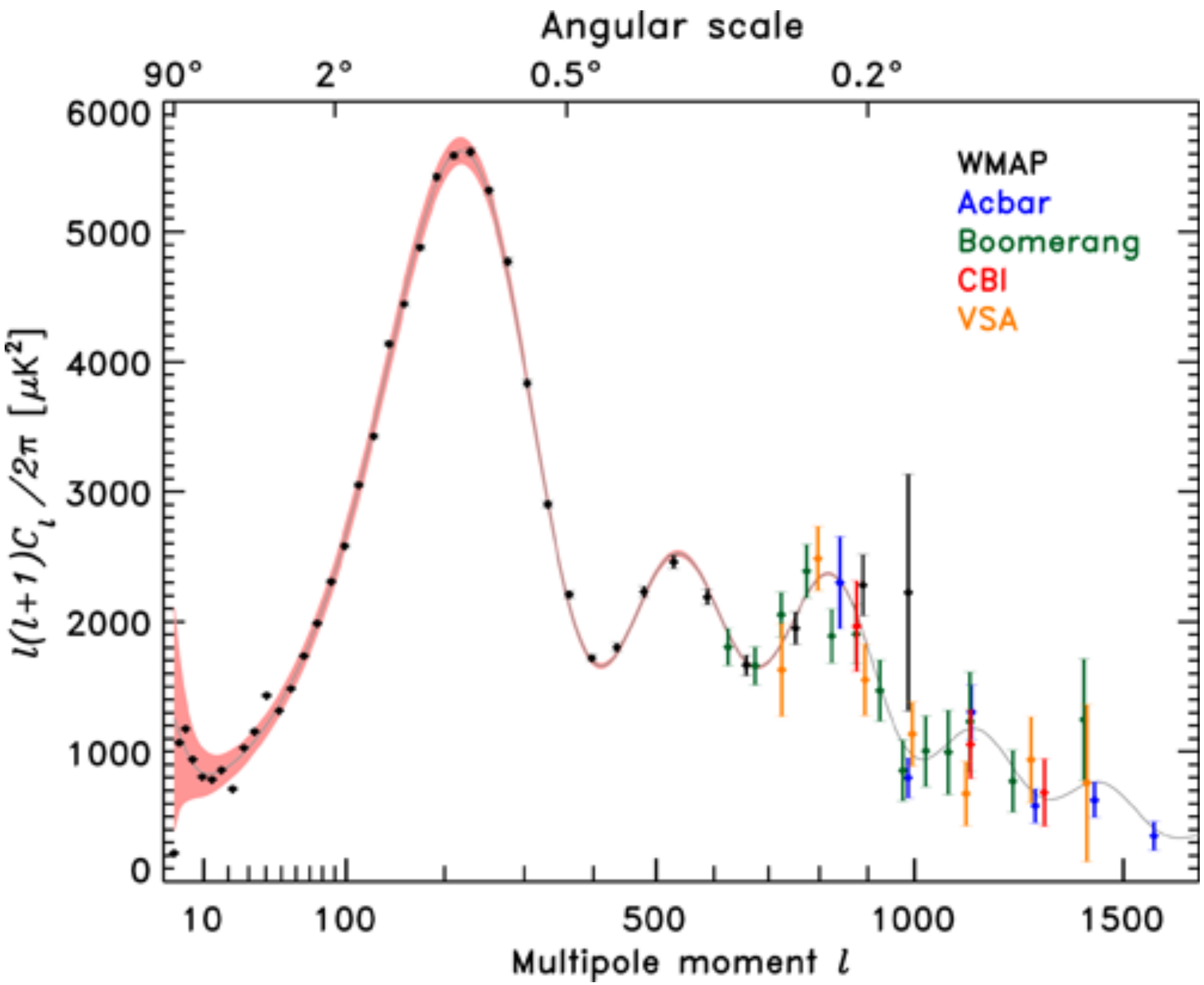
Planck satellite: Galactic foregroud emission



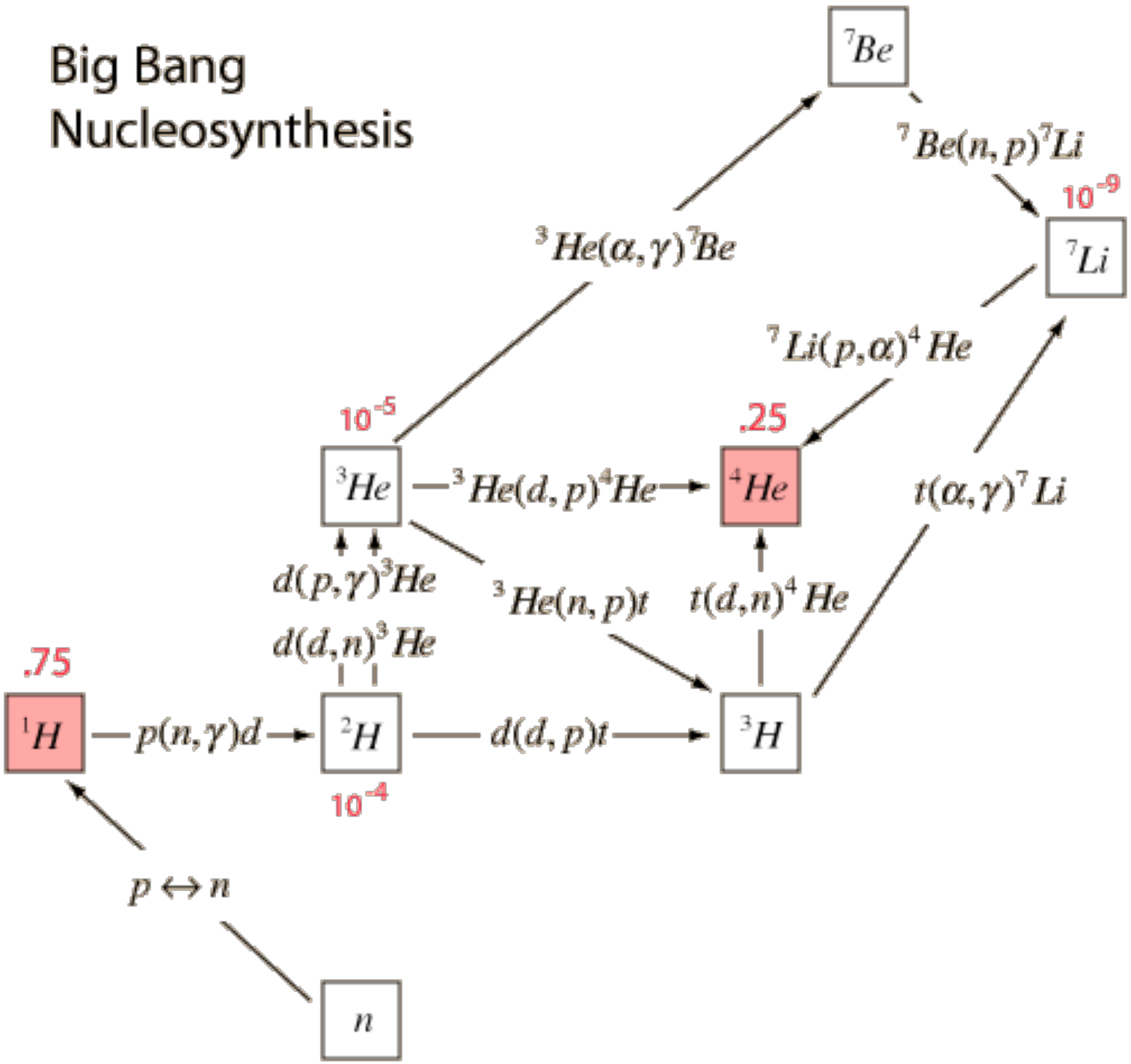
Planck satellite: Cosmic microwave background

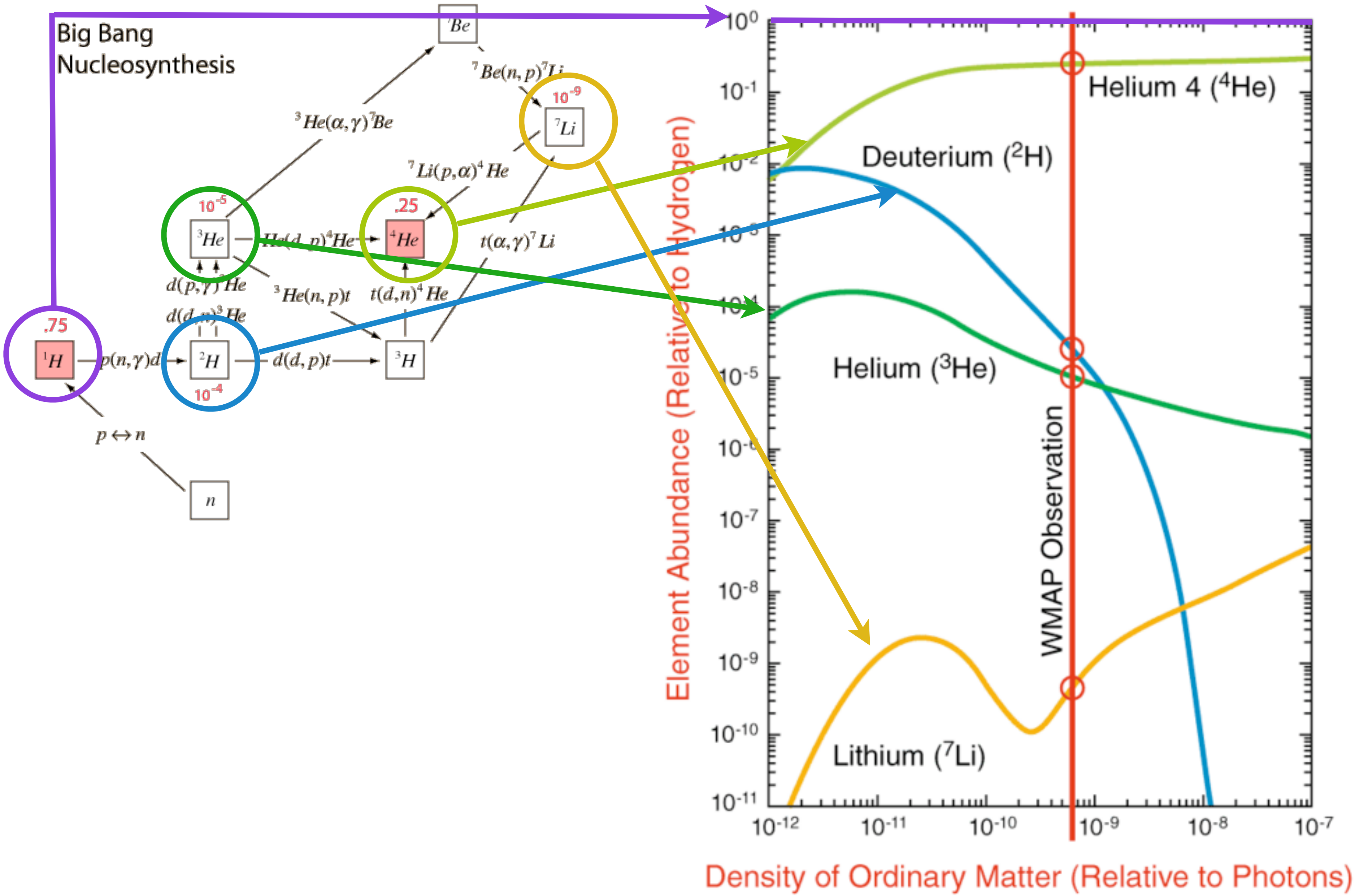


Wavelength (cm)
10
1.0
0.1
1.7 mm
Atmosphäre
COBE
Penzias/Wilson
2.73 K blackbody
FIRAS COBE satellite
DMR COBE satellite
UBC sounding rocket
LBL-Italy White Mt. & South Pole
Princeton ground & balloon
Cyanogen optical
Milchstraße
(Synchrotron)
I_ν (W m^{-2} sr^{-1} Hz^{-1})
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
1
10
100
1000
Frequency (GHz)


Angular scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
WMAP
Acbar
Boomerang
CBI
VSA
l(l+1)C_l /2π [μK²]
10
100
500
1000
1500
Multipole moment l

Big Bang
Nucleosynthesis

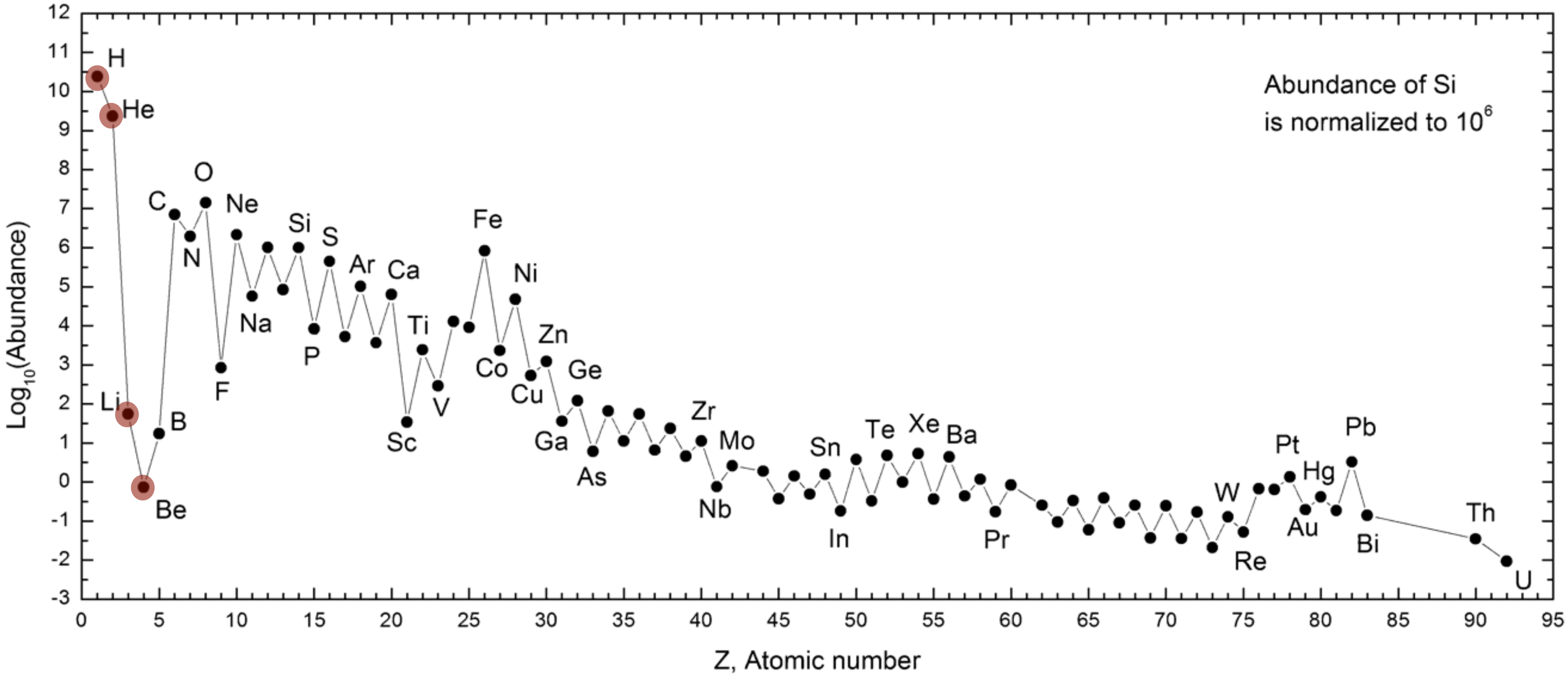




NASA/WMAP Science Team
WMAP101087

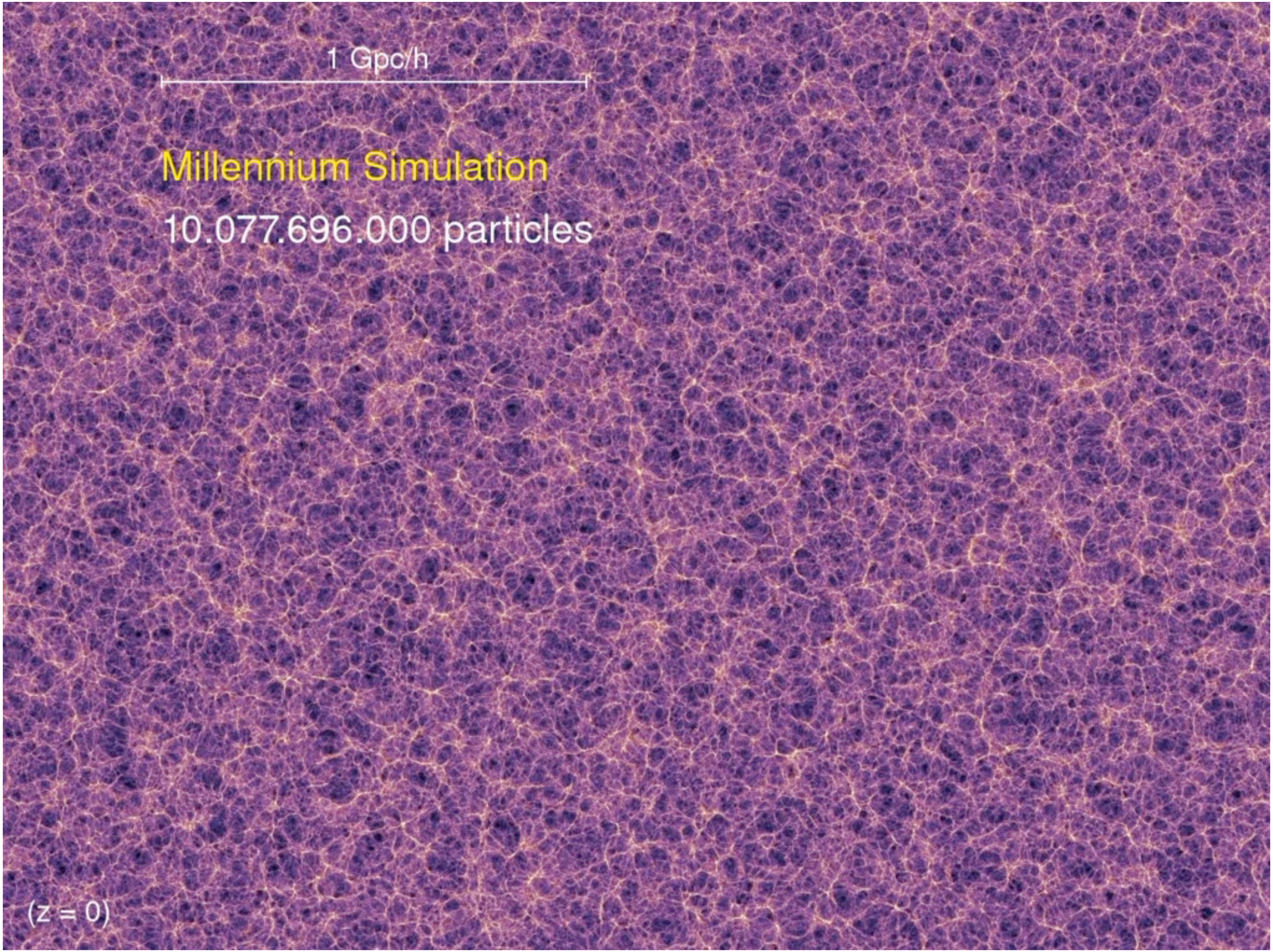
Element Abundance graphs: Steigman, Encyclopedia of Astronomy and Astrophysics (Institute of Physics) December, 2000

Element abundances of gas in solar neighborhod

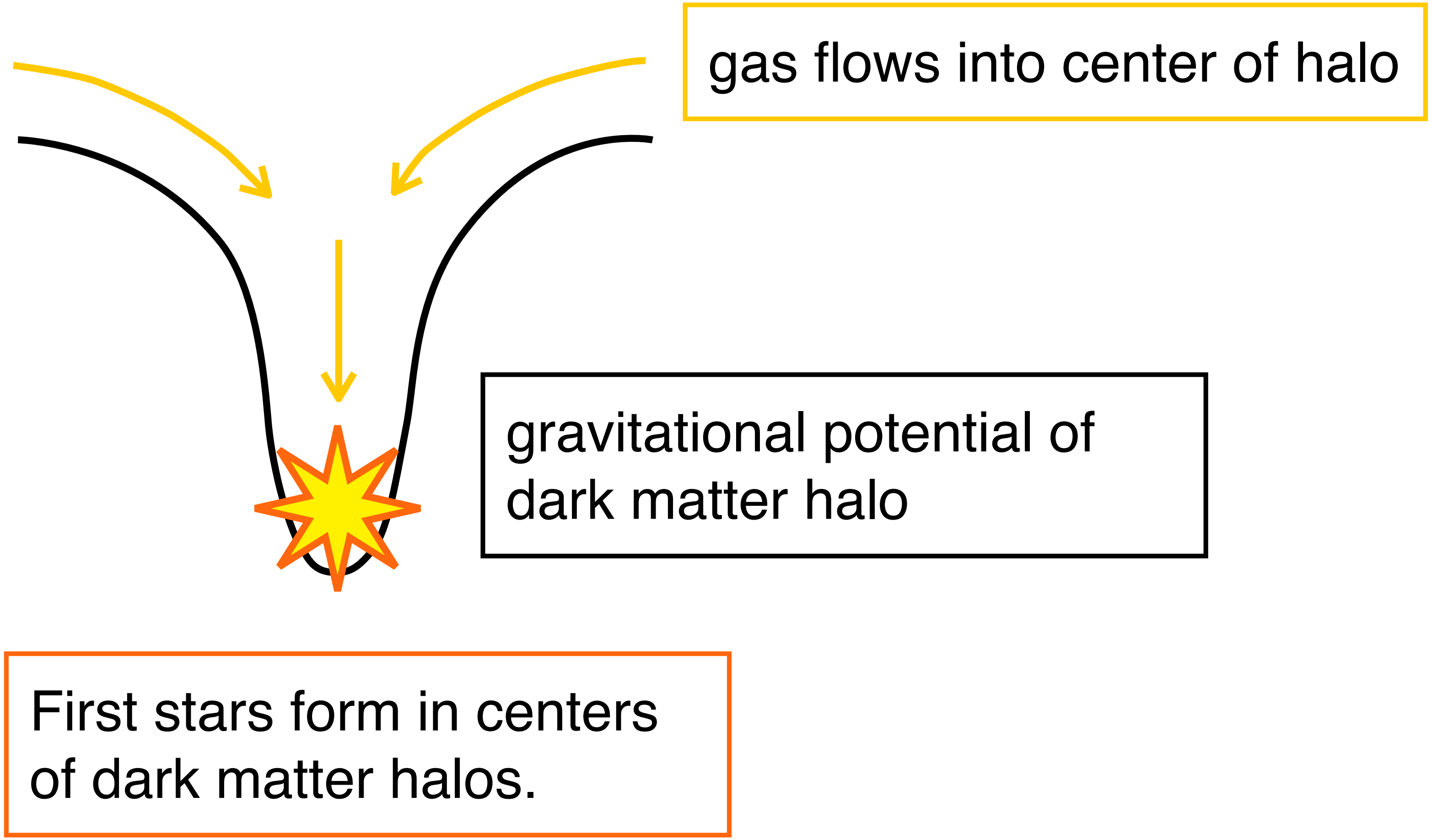


all those elements have been produced in stars

formed in
big bang


1 Gpc/h
Millennium Simulation
10.077.696.000 particles
(z = 0)

Schematic of first star formation



most simple theoretical approach

- *Jeans (1902):* Interplay between self-gravity and thermal pressure
  - stability of homogeneous spherical density enhancements against gravitational collapse
  - dispersion relation:

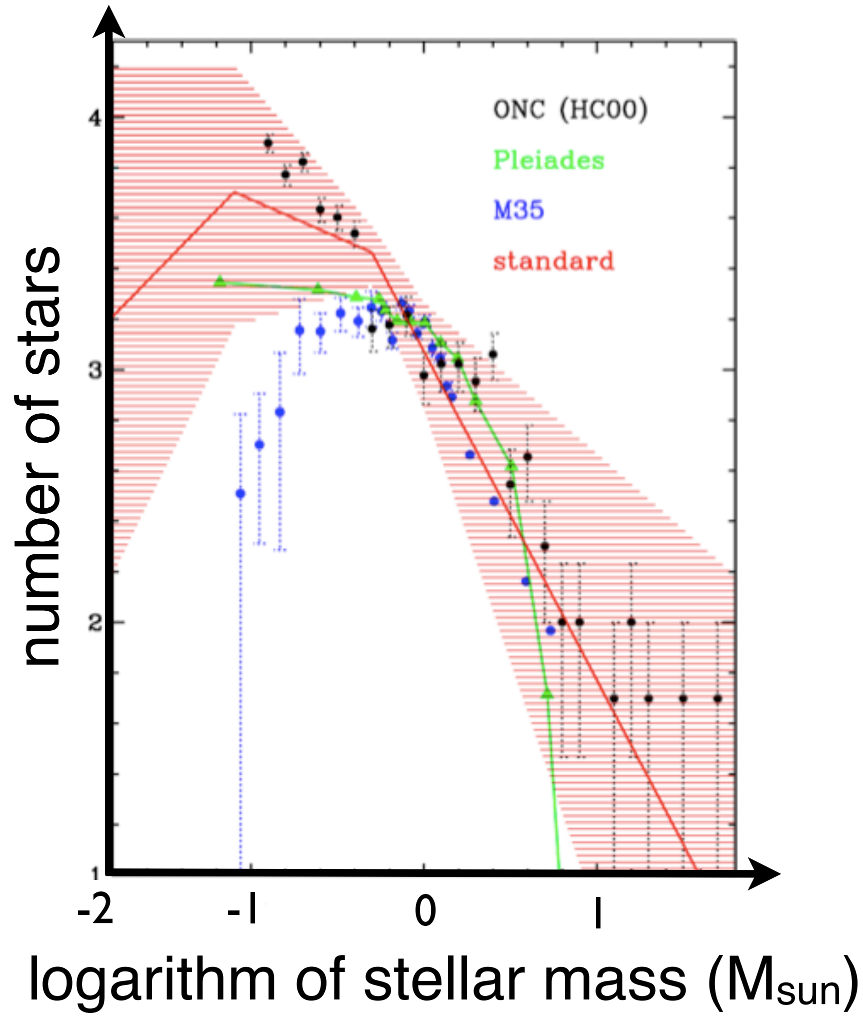
$$\omega^2 = c_s^2 k^2 - 4\pi G \rho_0$$

  - instability when $\omega^2 < 0$
  - minimal mass: $M_J = \frac{1}{6}\pi^{-5/2} G^{-3/2} \rho_0^{-1/2} c_s^3 \propto \rho_0^{-1/2} T^{+3/2}$

Sir James Jeans, 1877 - 1946

Stellar mass function

Stars of Milky Way follow universal mass function

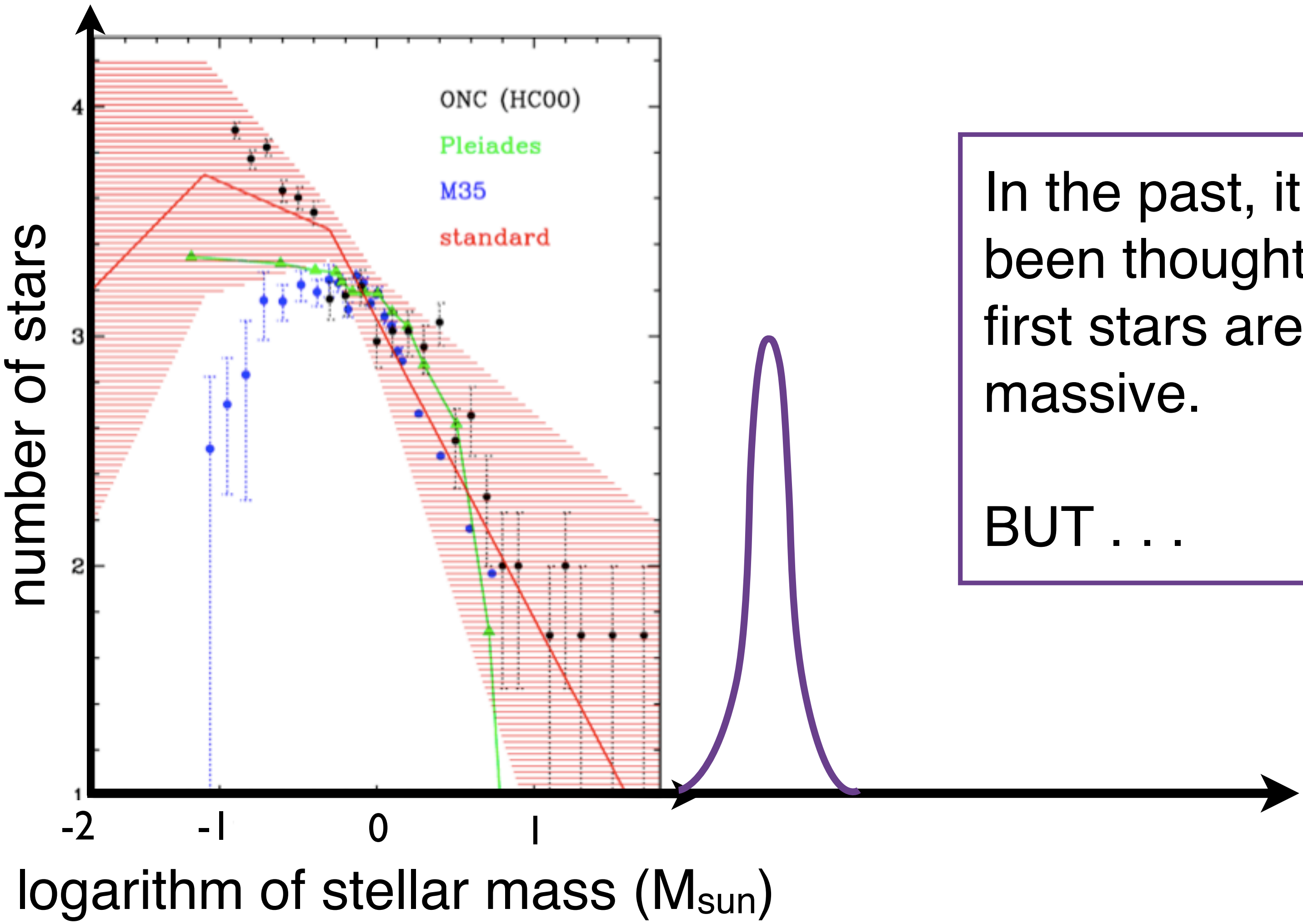


(Kroupa 2002)

Orion, NGC 3603, 30 Doradus
(Zinnecker & Yorke 2007)

Stellar mass function

Stars of Milky Way follow universal mass function



(Kroupa 2002)

In the past, it has been thought that first stars are very massive.

BUT . . .

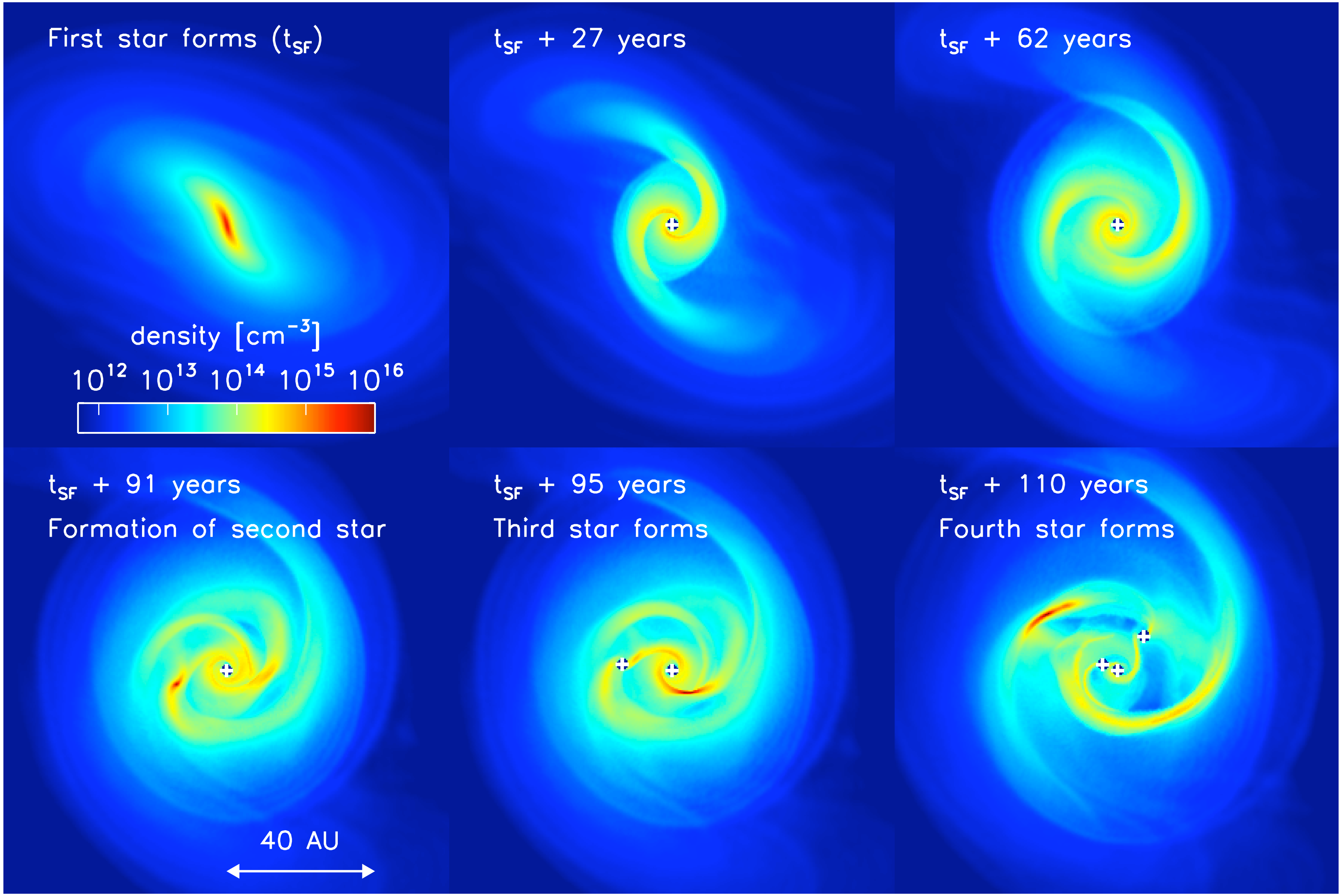
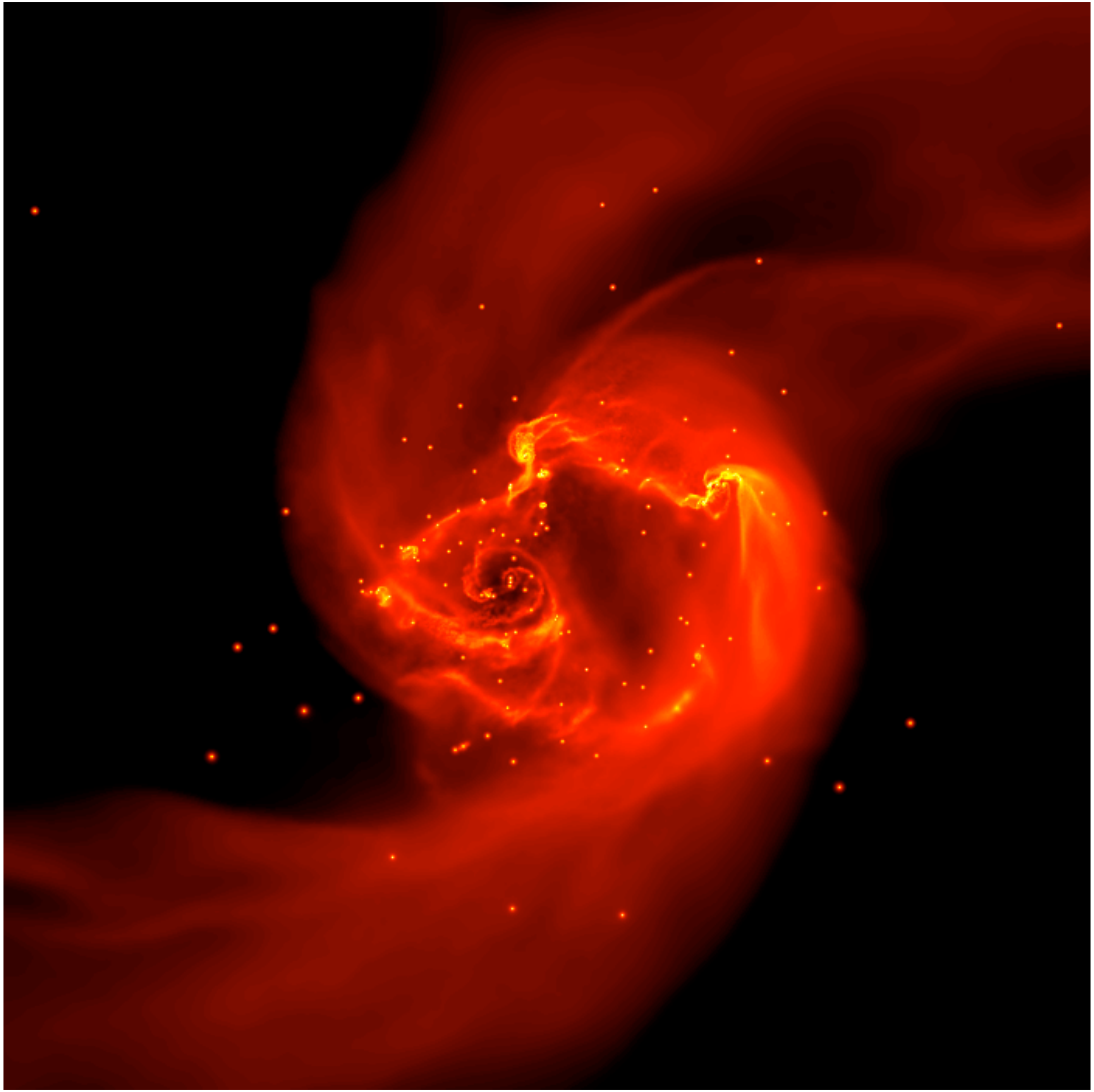


Figure 1: Density evolution in a 120 AU region around the first protostar, showing the build-up of the protostellar disk and its eventual fragmentation. We also see 'wakes' in the low-density regions, produced by the previous passage of the spiral arms.

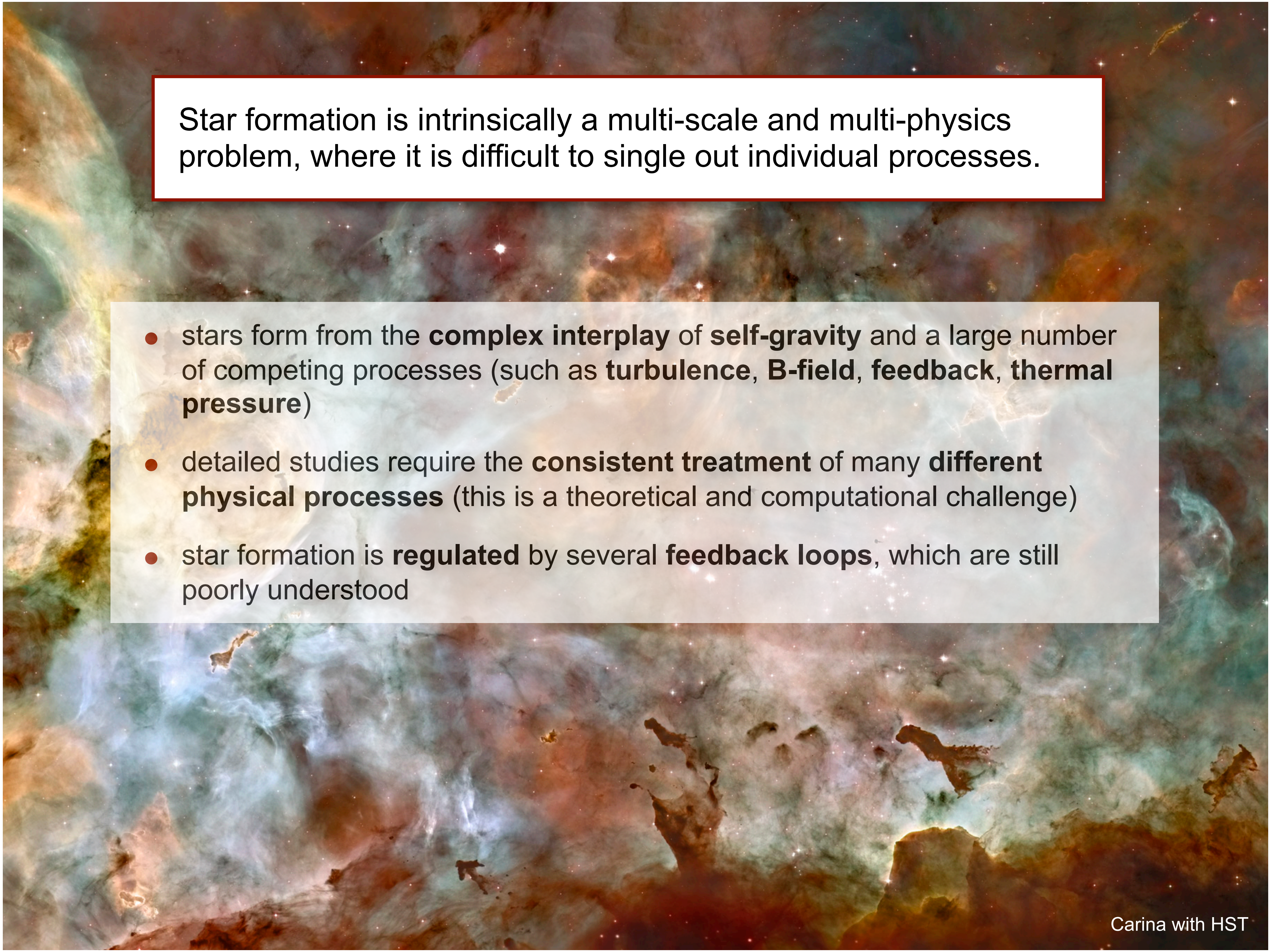
(Clark et al. 2011b, Science, 331, 1040) the first star cluster



(Clark et al. 2008)

Star formation is intrinsically a multi-scale and multi-physics problem, where it is difficult to single out individual processes.

- stars form from the **complex interplay** of **self-gravity** and a large number of competing processes (such as **turbulence**, **B-field**, **feedback**, **thermal pressure**)
- detailed studies require the **consistent treatment** of many **different physical processes** (this is a theoretical and computational challenge)
- star formation is **regulated** by several **feedback loops**, which are still poorly understood



Carina with HST

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First star formation is no different!

Carina with HST


PPVI comes to Heidelberg
in summer 2013
... hope to see you there!!!