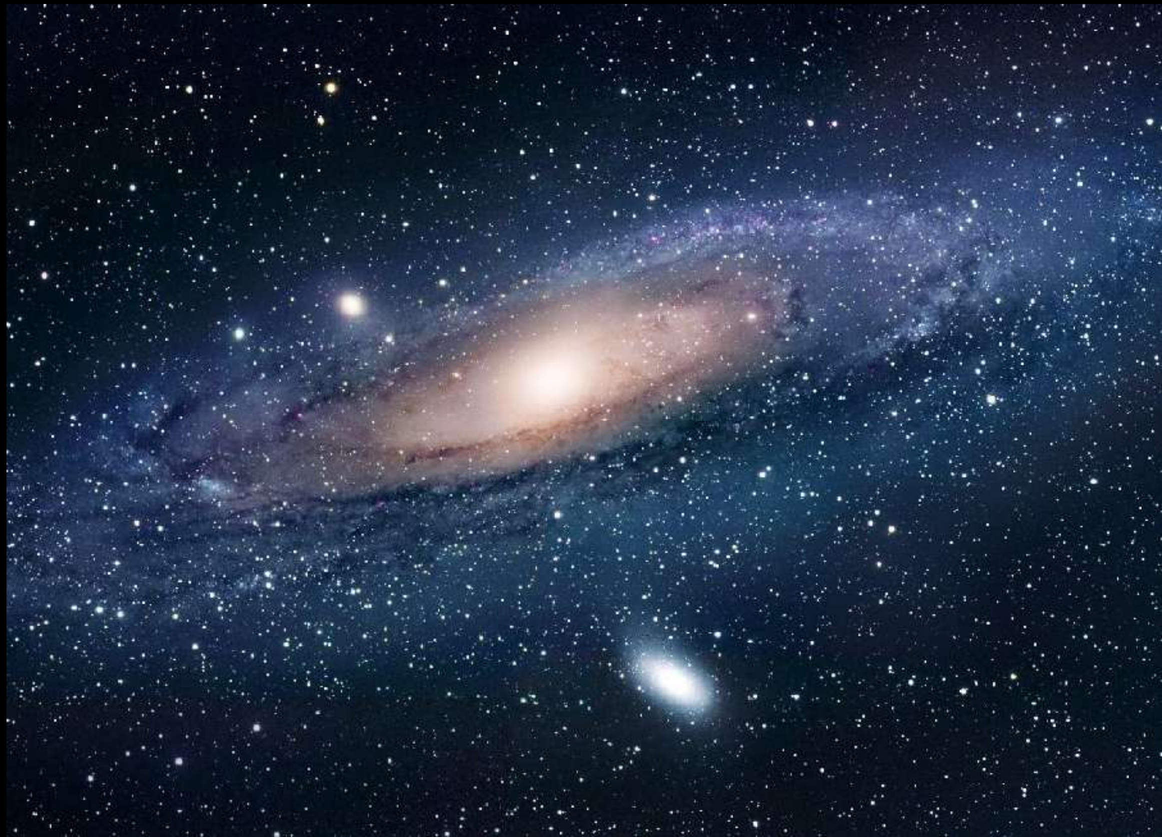
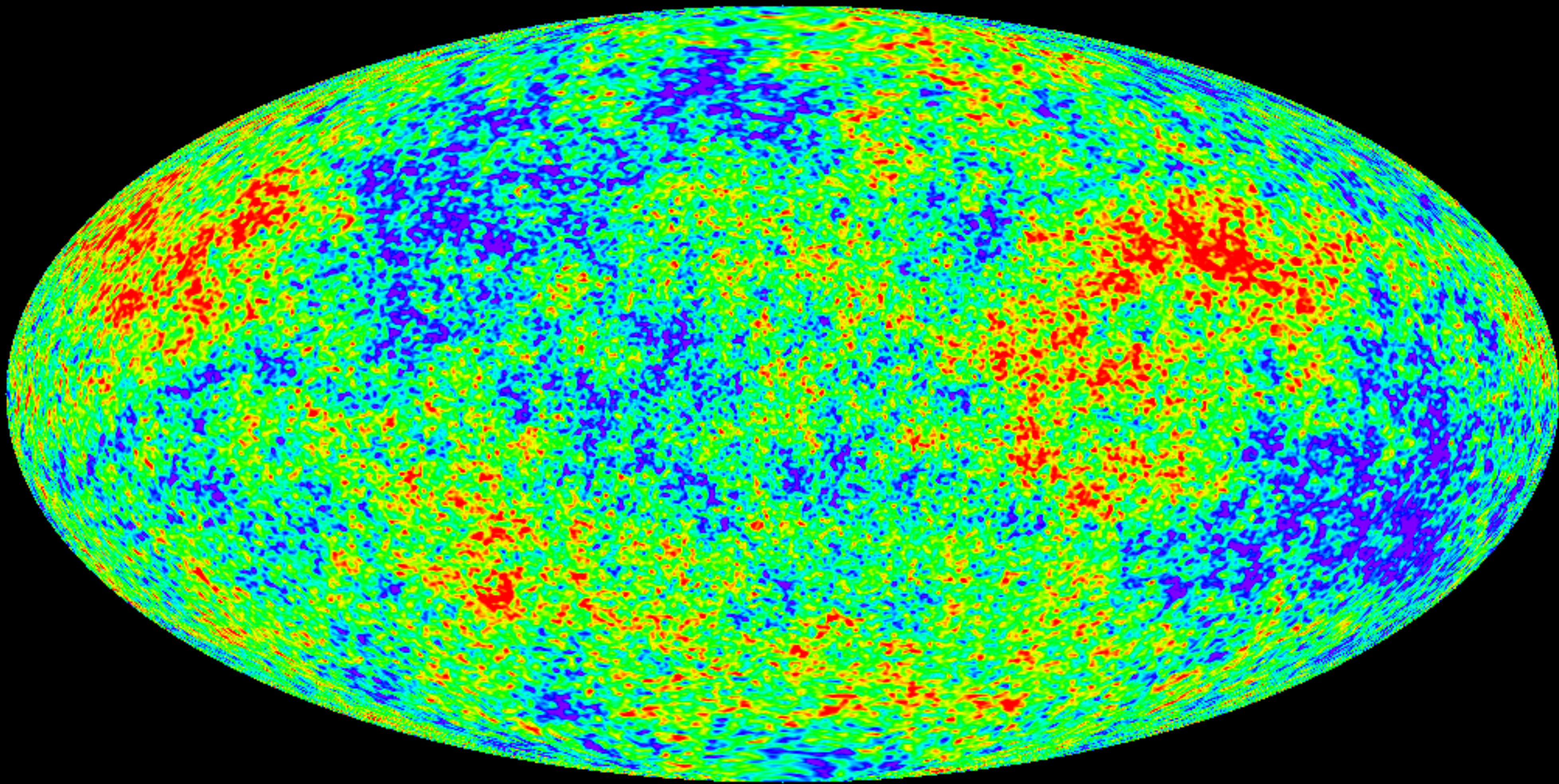
Origins: The universe to intelligent life and everything in between



Christopher J. Conselice
(University of Manchester)

Cosmic Background Radiation – early structure



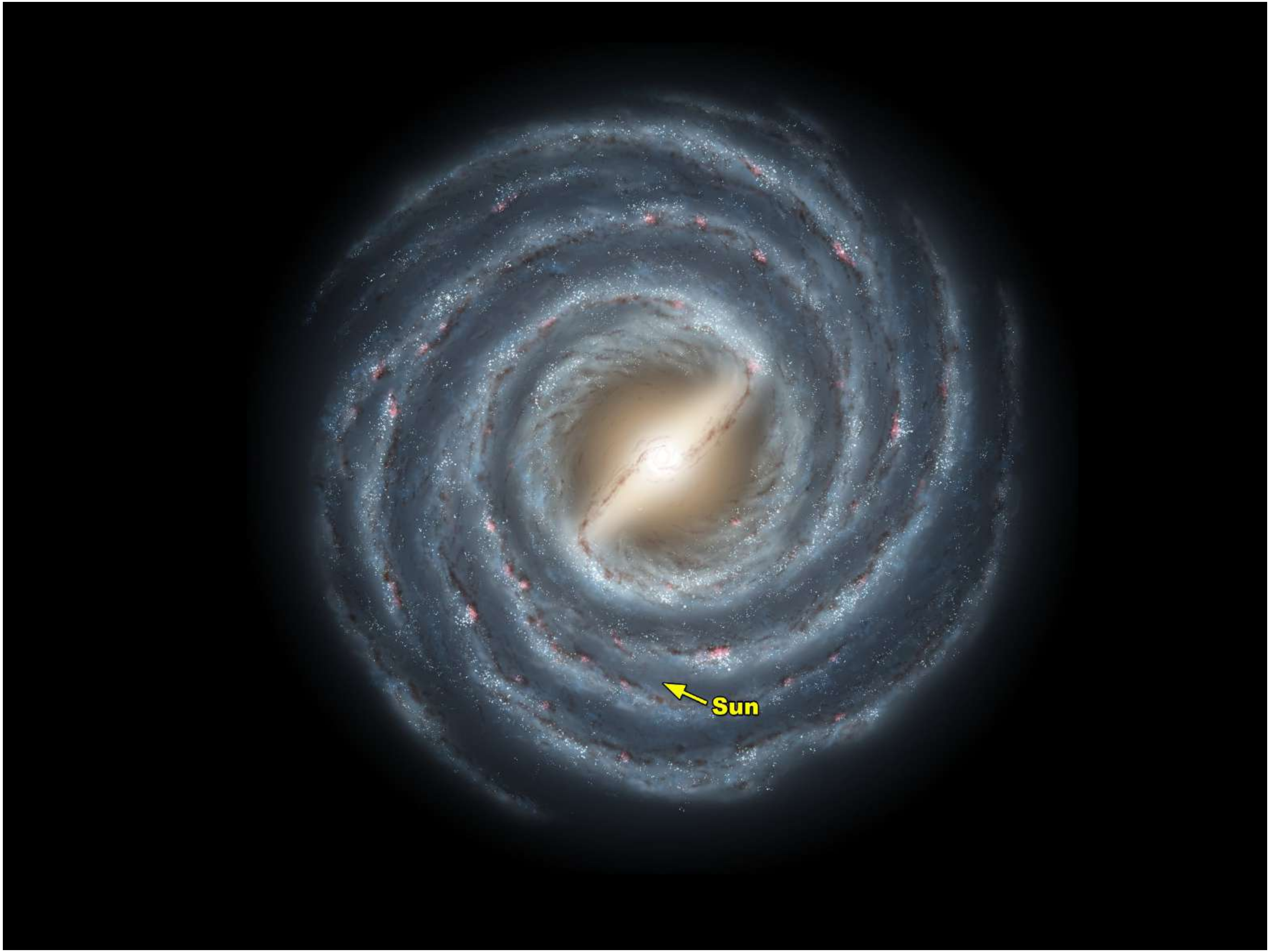
300,000 years after the big bang

Properties from Cosmology

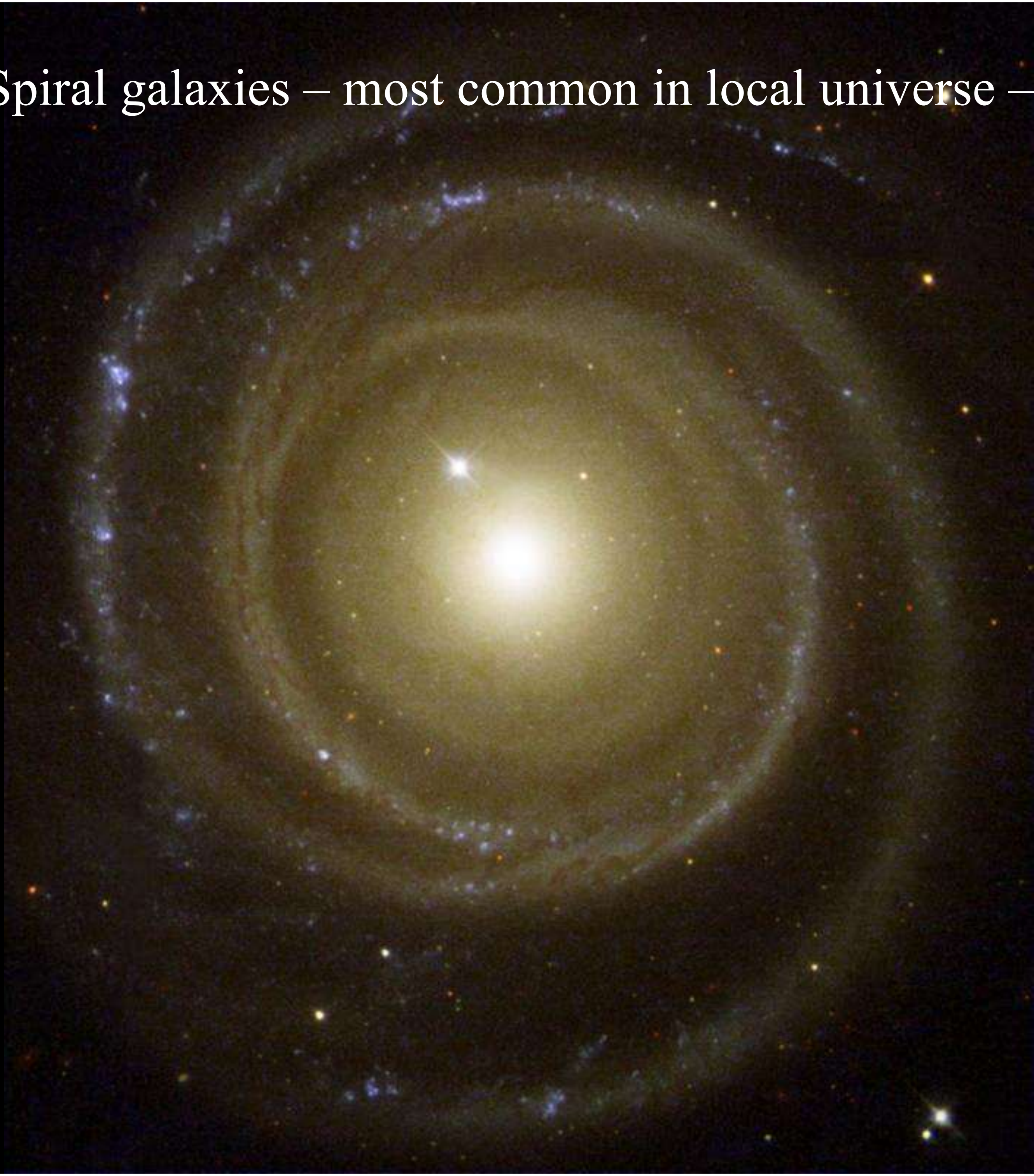
- Age of Universe 13.7 Byr (2%)
- Atoms
- Dark matter
- Dark energy
- Flatness

- Hubble constant (km/s/Mpc) 71 (6%)
- Photon/proton ratio 1.6×10^9 (5%)
- Time of first stars 180 Myr (50%)
- Time of MWB 380,000yr (2%)

The Milky Way Galaxy

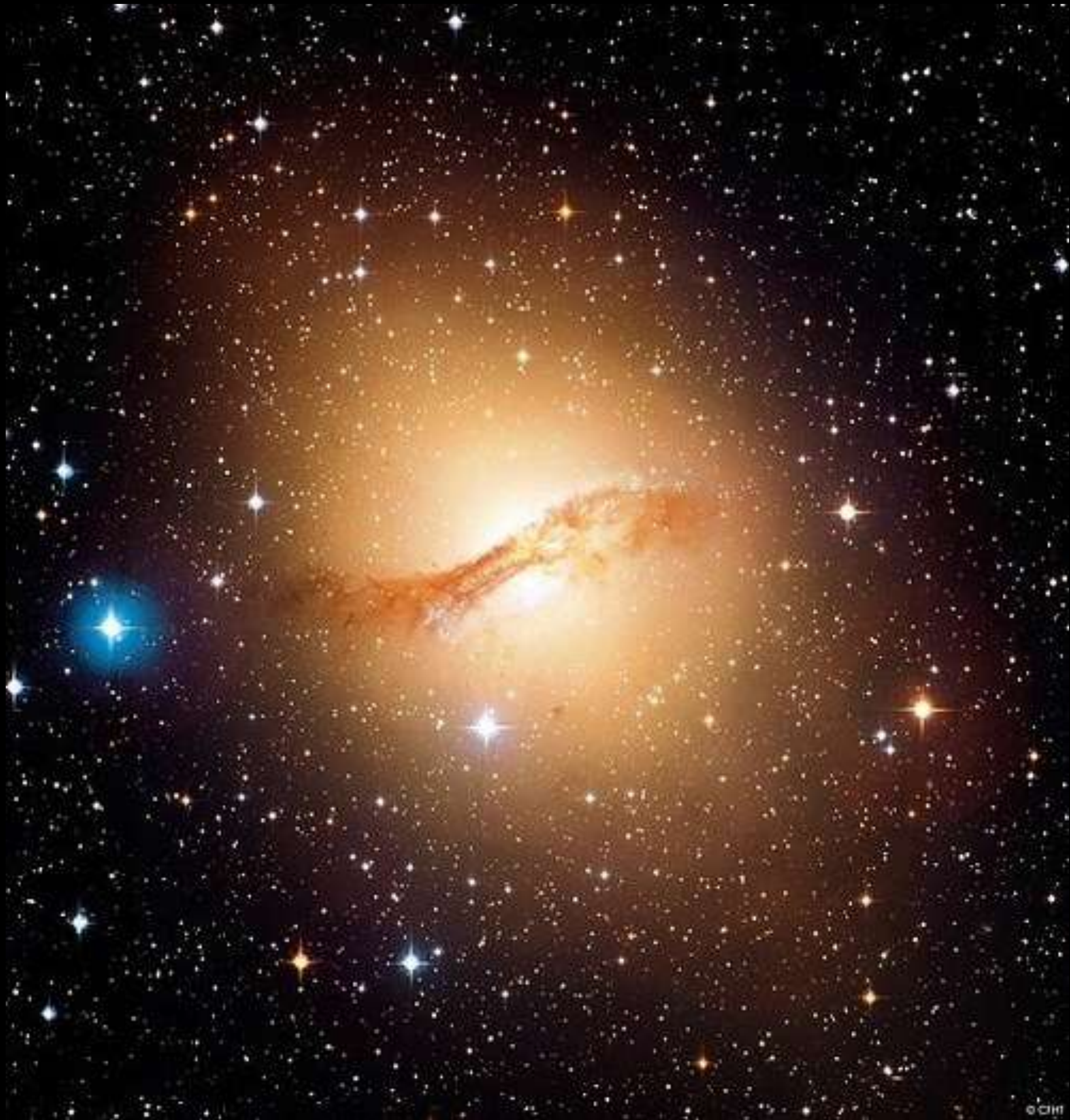

Sun

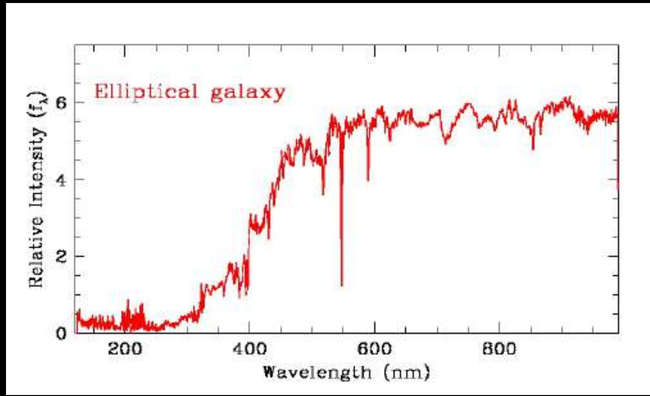
Spiral galaxies – most common in local universe – 70%

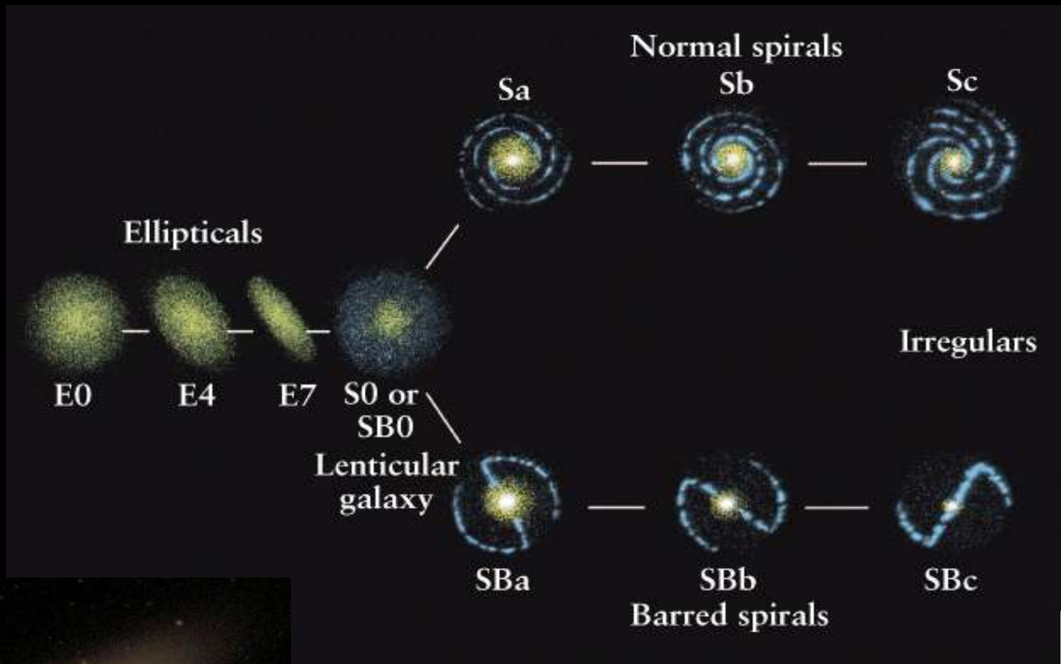


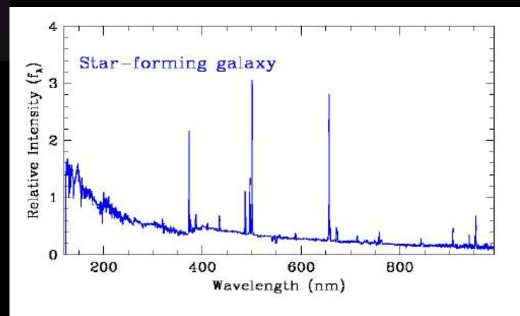
Elliptical galaxies 25% of nearby population and typically the most massive galaxies

Example of nearby massive galaxy

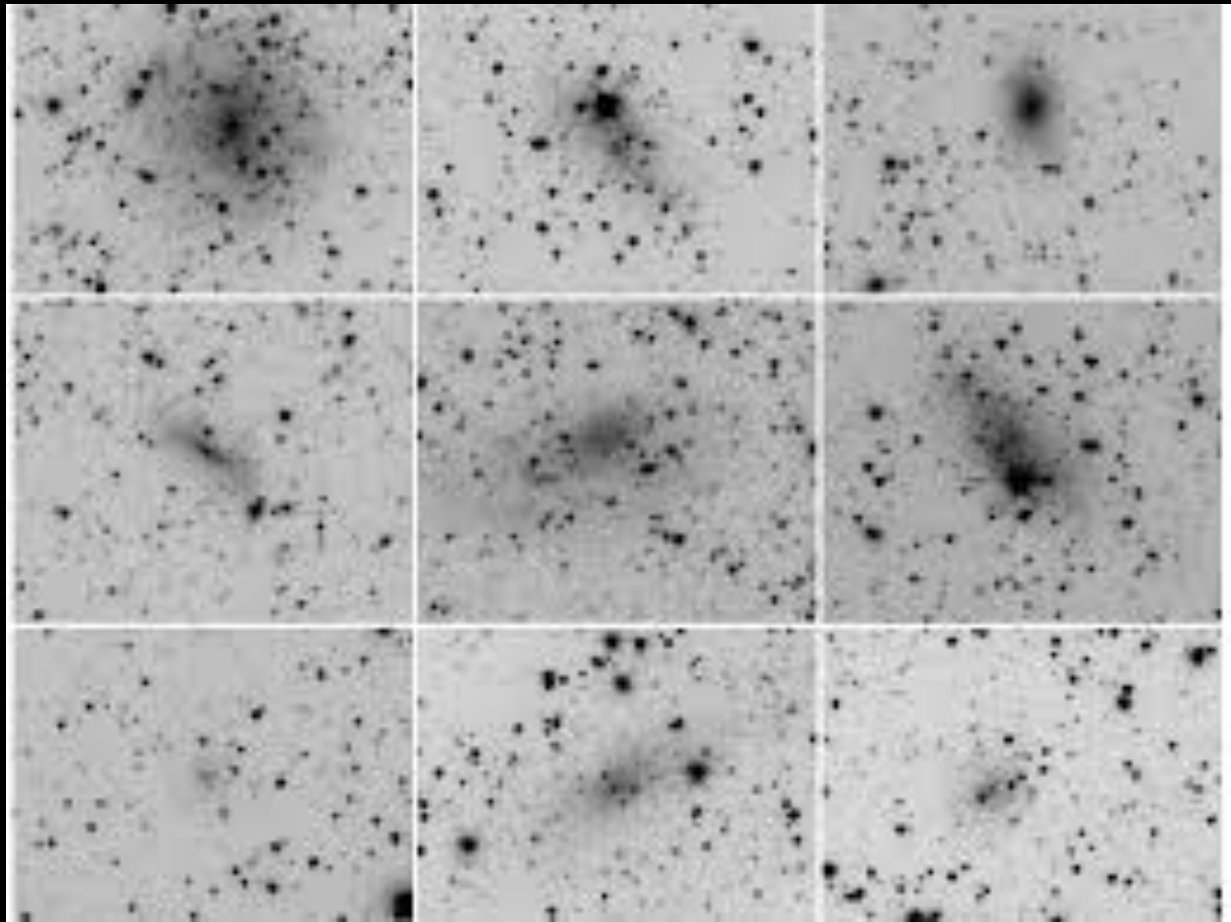

© CFHT

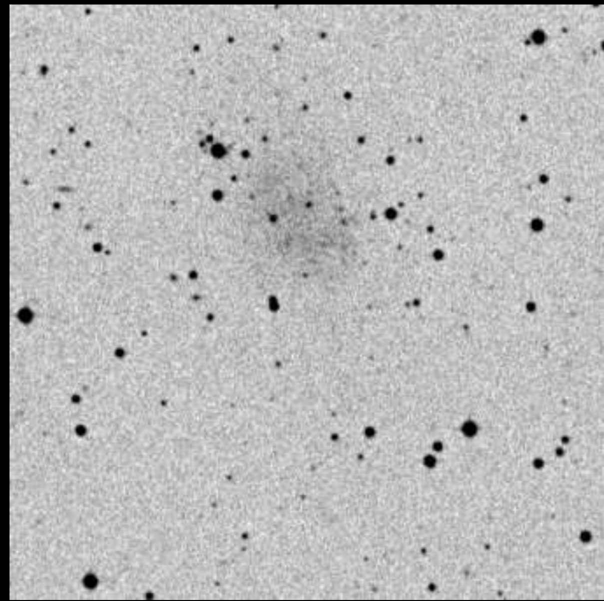

Elliptical galaxy
Relative Intensity (f_λ)
0
2
4
6
200
400
600
800
Wavelength (nm)


Normal spirals
Sa
Sb
Sc
Ellipticals
E0
E4
E7
S0 or SB0
Lenticular galaxy
Irregulars
SBa
SBb
SBc
Barred spirals

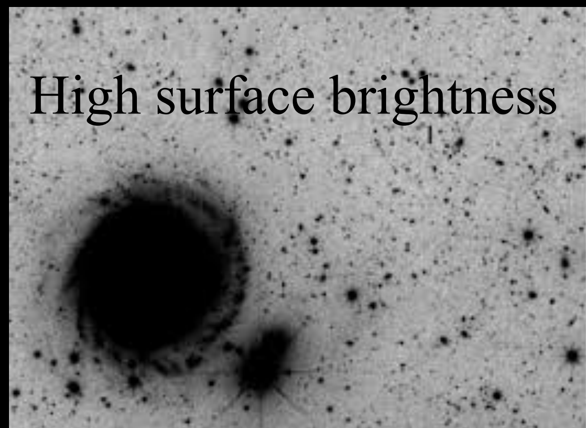

Star−forming galaxy
Relative Intensity (f_λ)
0
1
2
3
4
200
400
600
800
Wavelength (nm)

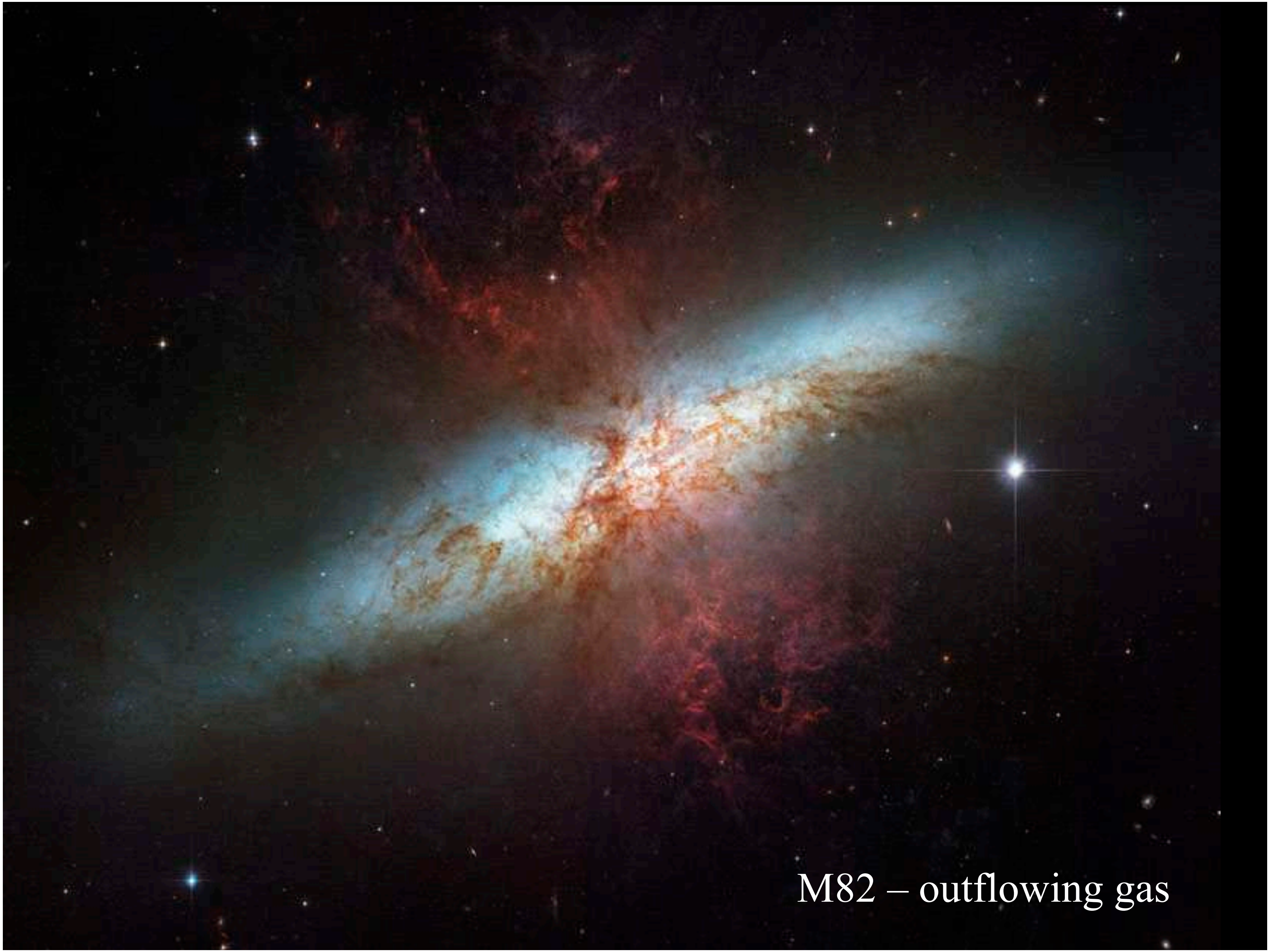
Edwin Hubble (1889-1953)





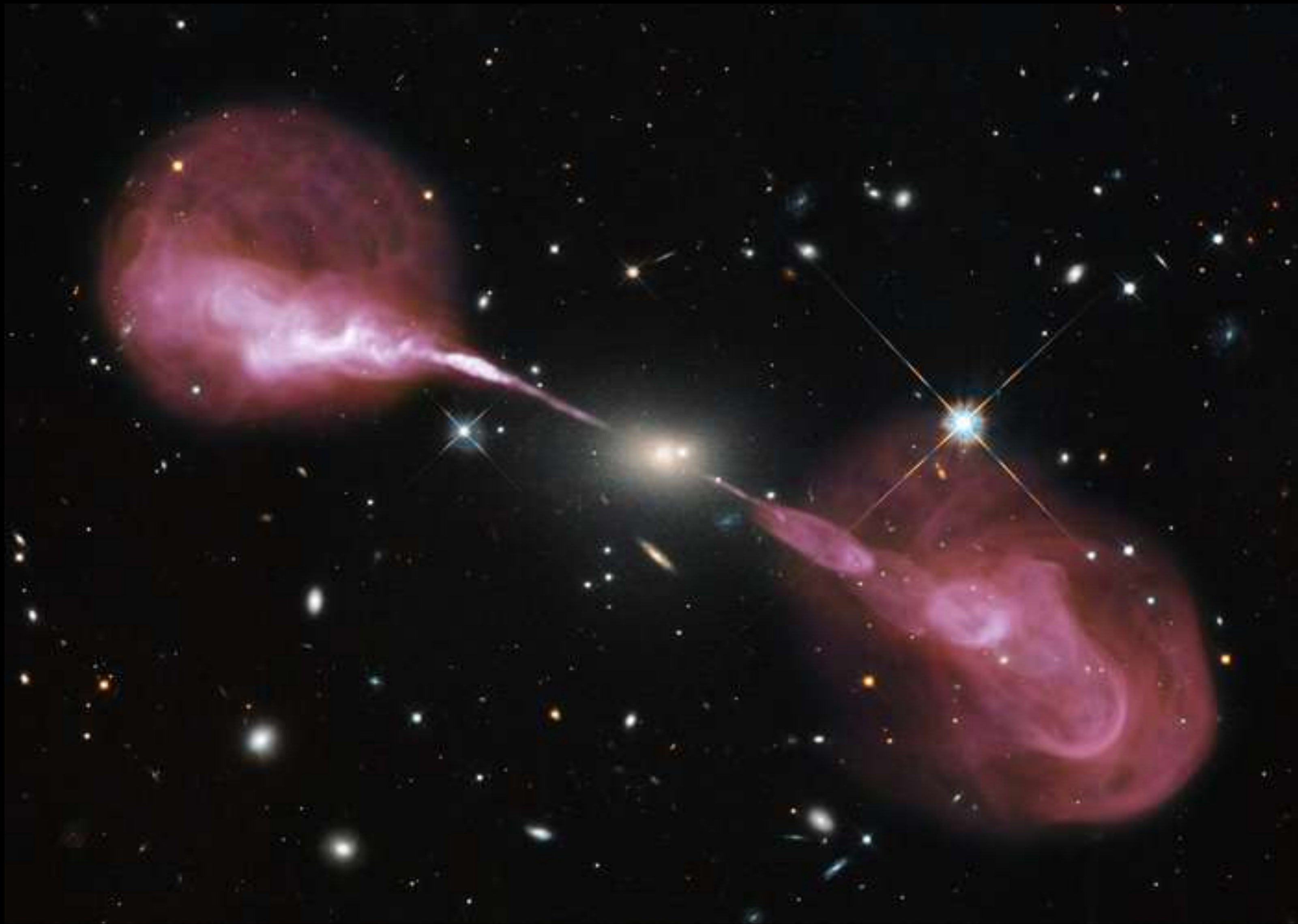
Low surface brightness

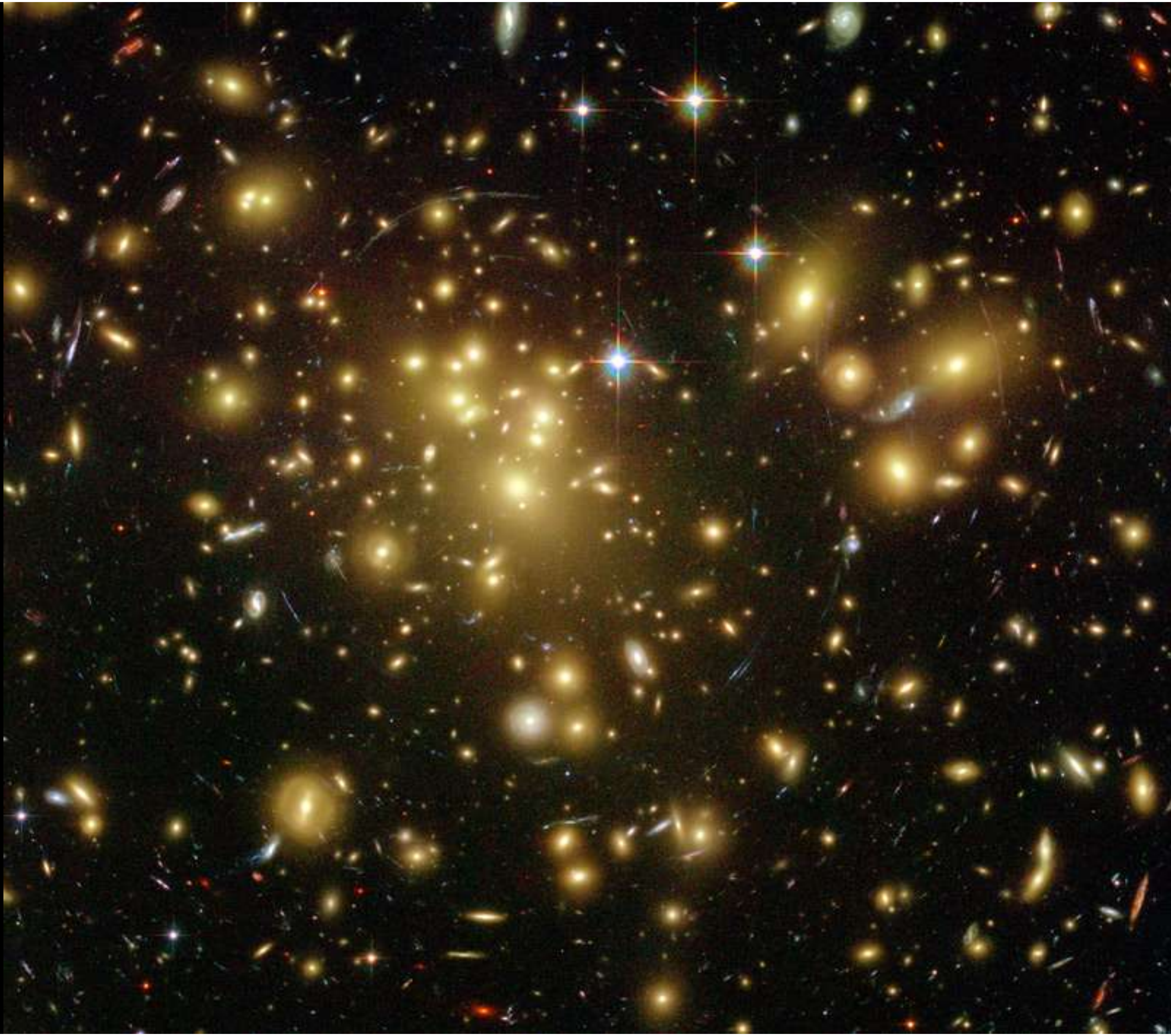


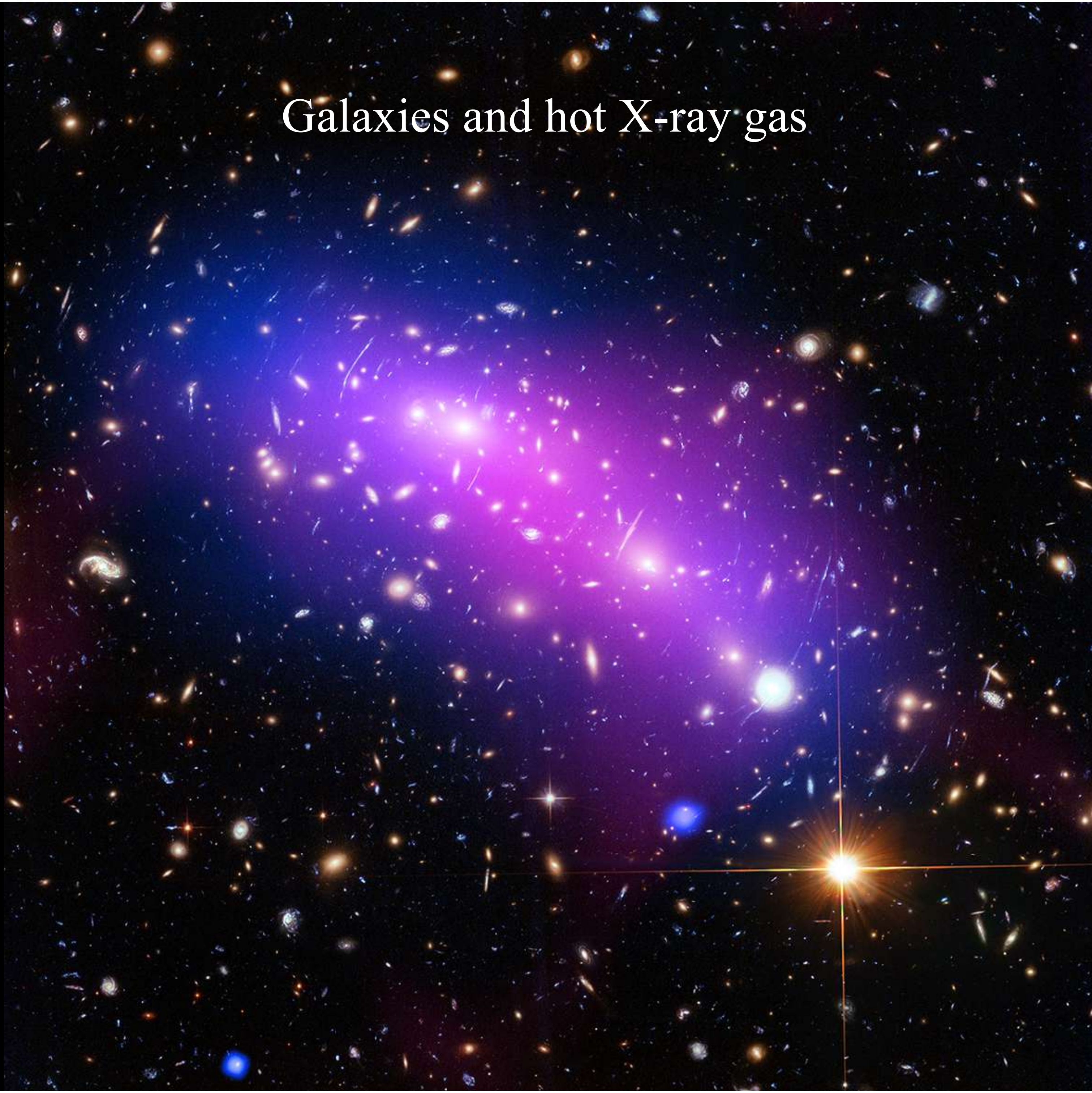


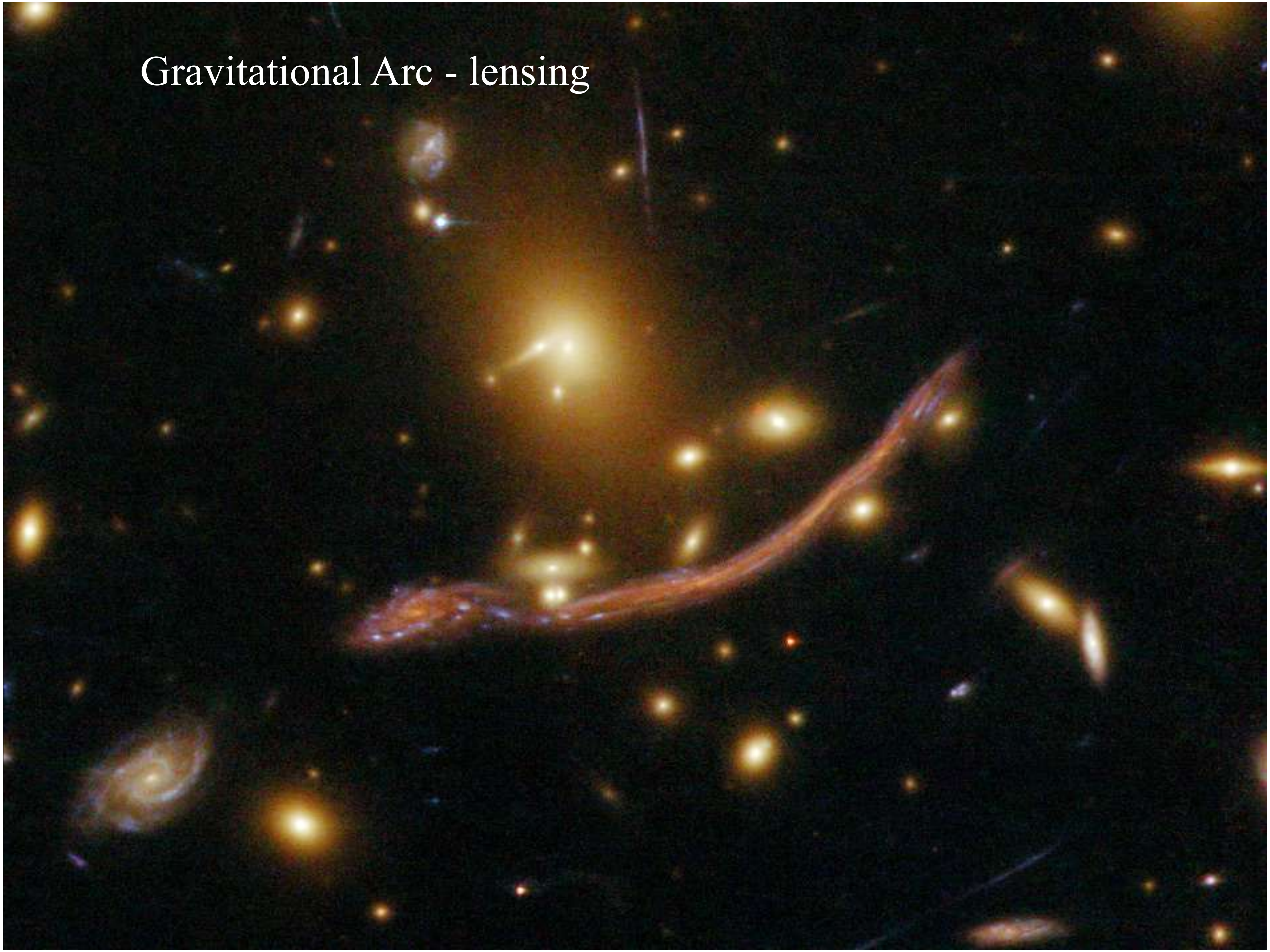
M82 – outflowing gas

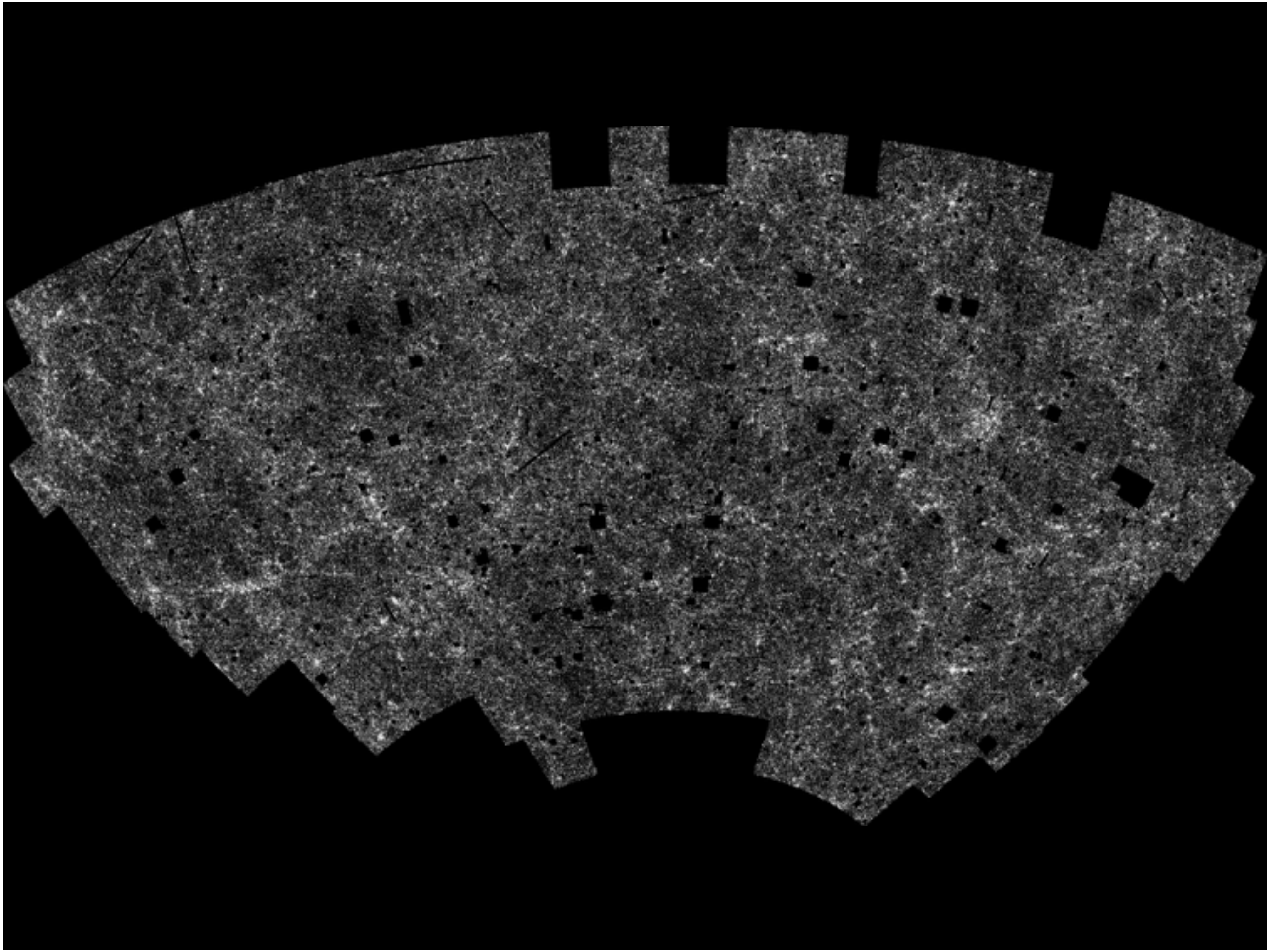
Radio lobes from AGN

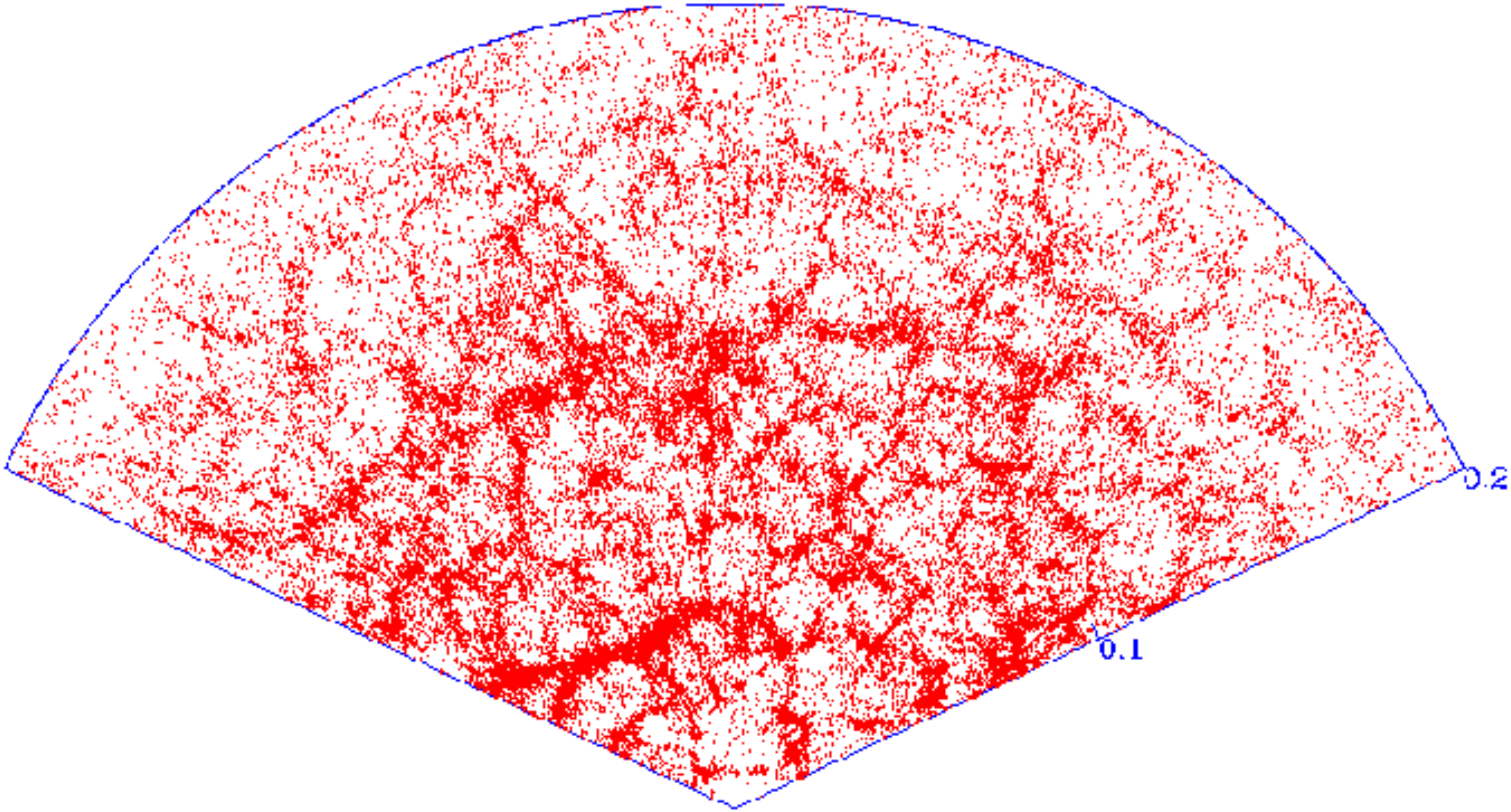




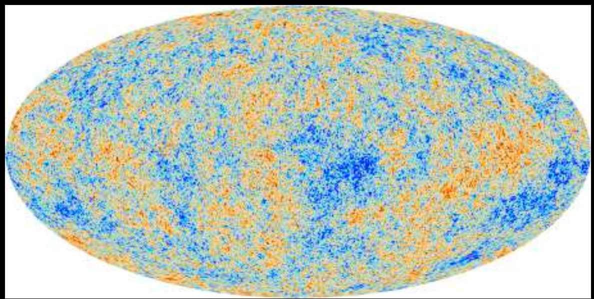

Galaxies and hot X-ray gas


Gravitational Arc - lensing

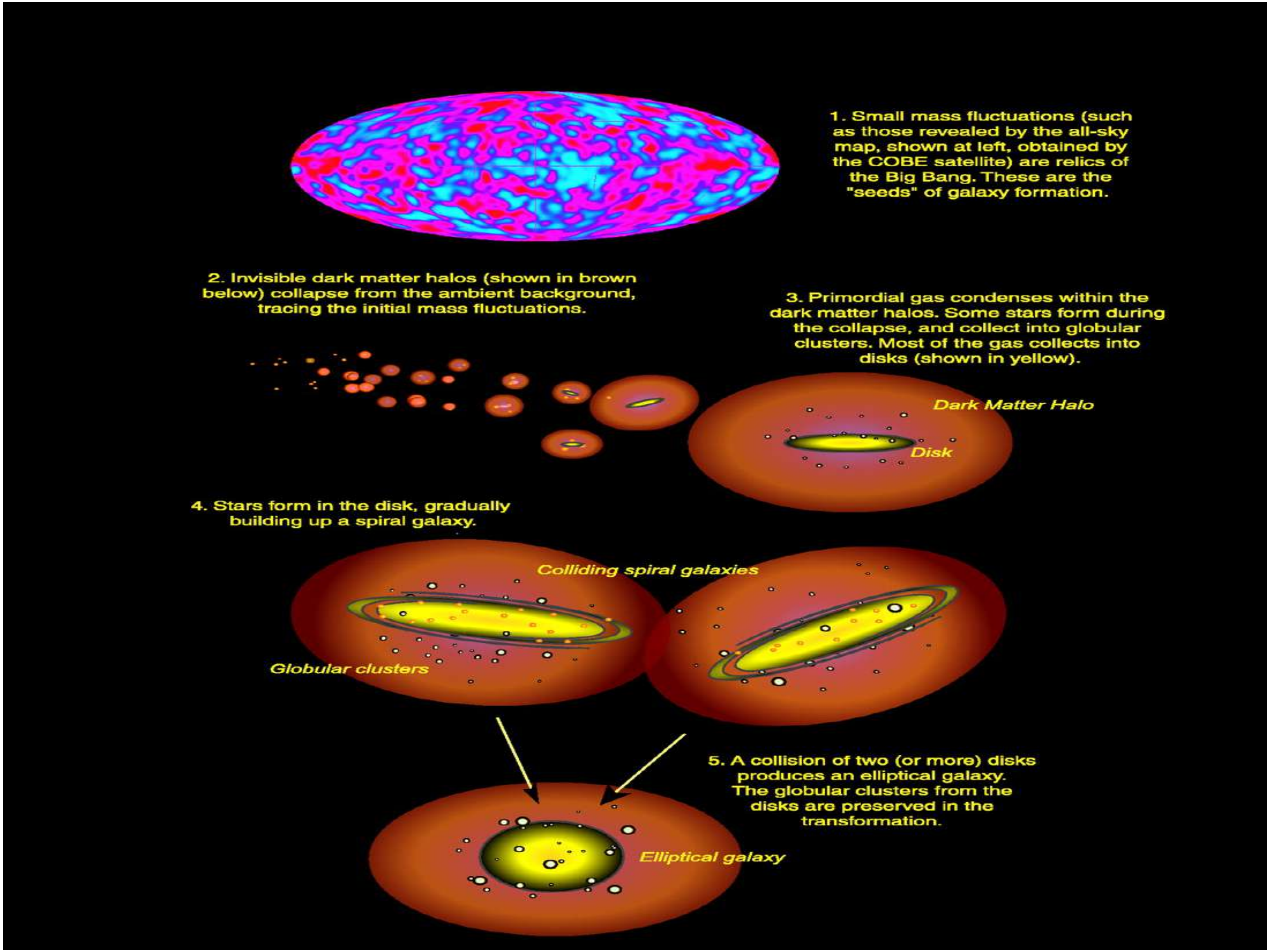


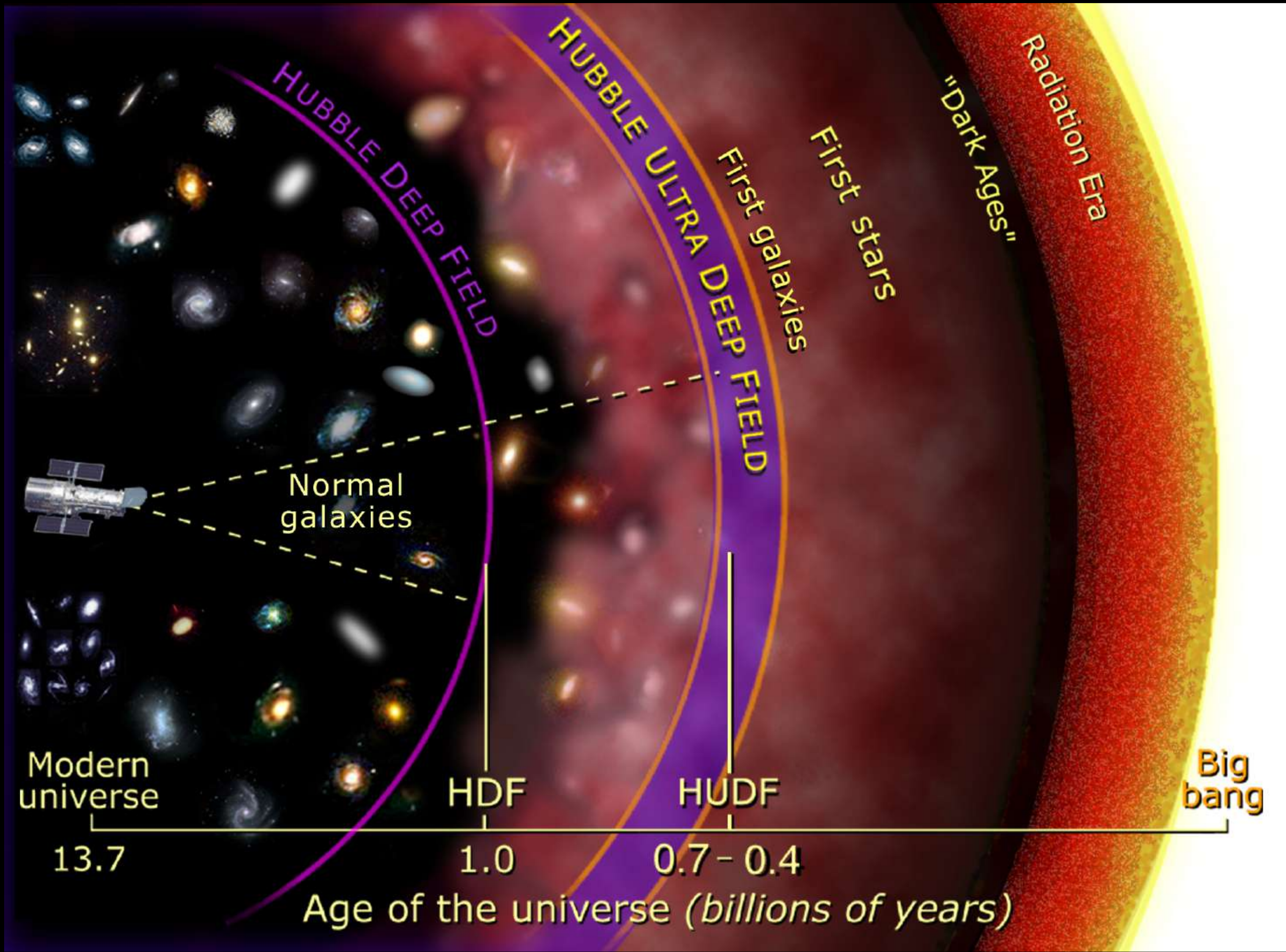

0.2
0.1

How do we get from the early universe to the rich universe of nearby galaxies?

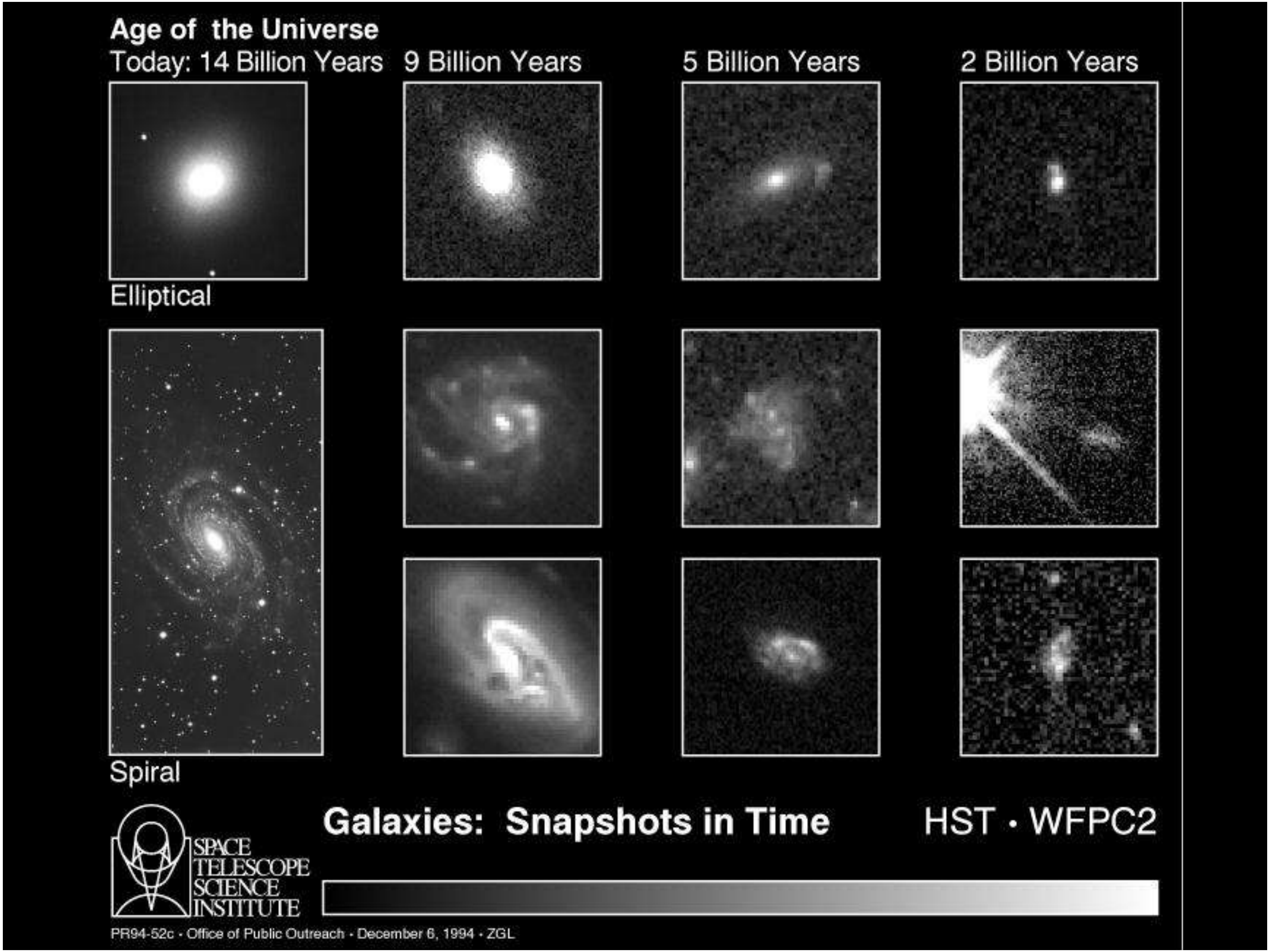


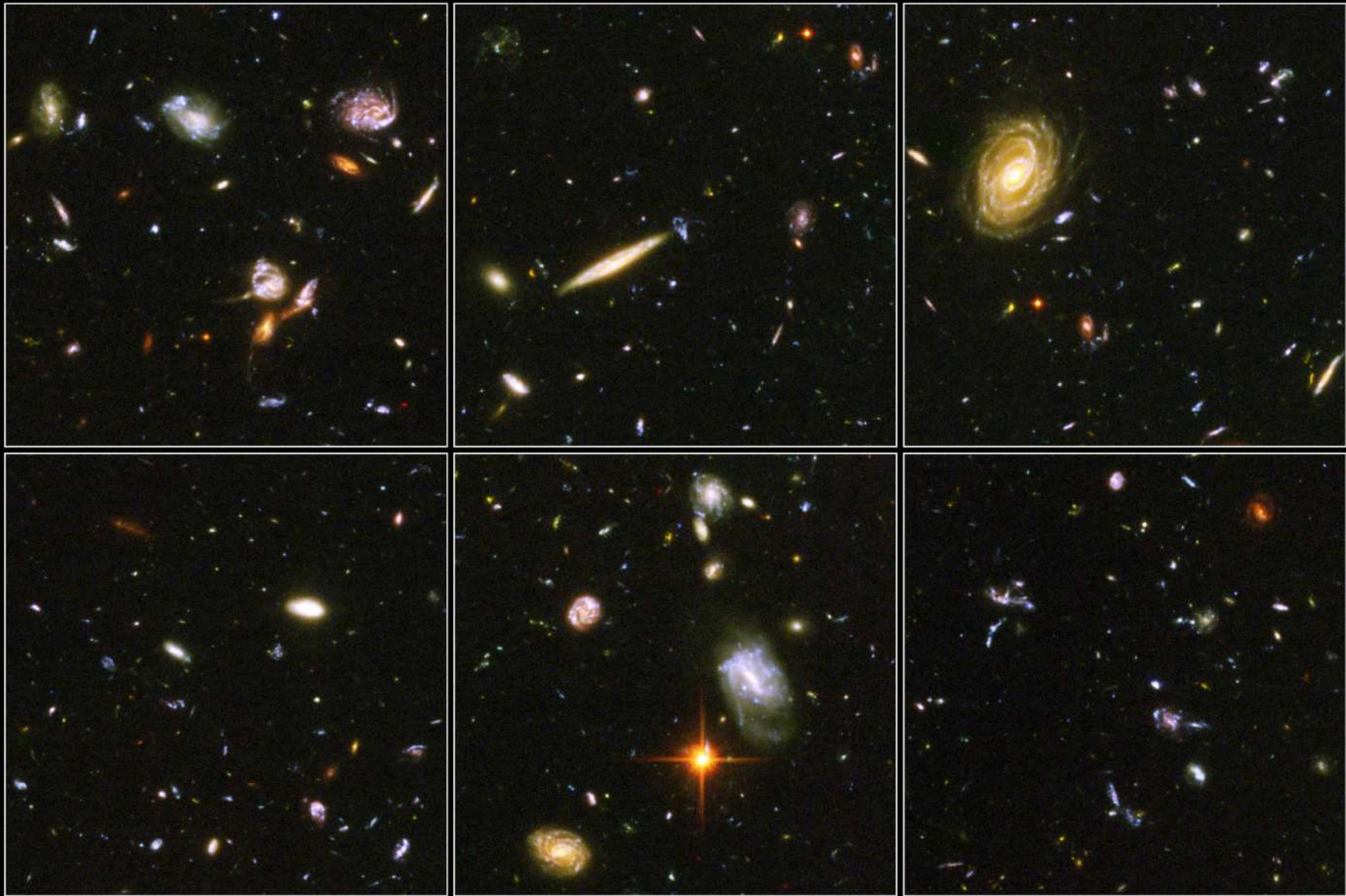
?


1. Small mass fluctuations (such as those revealed by the all-sky map, shown at left, obtained by the COBE satellite) are relics of the Big Bang. These are the "seeds" of galaxy formation.
2. Invisible dark matter halos (shown in brown below) collapse from the ambient background, tracing the initial mass fluctuations.
3. Primordial gas condenses within the dark matter halos. Some stars form during the collapse, and collect into globular clusters. Most of the gas collects into disks (shown in yellow).
Dark Matter Halo
Disk
4. Stars form in the disk, gradually building up a spiral galaxy.
Colliding spiral galaxies
Globular clusters
5. A collision of two (or more) disks produces an elliptical galaxy. The globular clusters from the disks are preserved in the transformation.
Elliptical galaxy


HUBBLE DEEP FIELD
HUBBLE ULTRA DEEP FIELD
First galaxies
First stars
"Dark Ages"
Radiation Era
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 – 0.4
Age of the universe (billions of years)

High Redshift Galaxies


Age of the Universe
Today: 14 Billion Years
9 Billion Years
5 Billion Years
2 Billion Years
Elliptical
Spiral
Galaxies: Snapshots in Time
HST • WFPC2
SPACE TELESCOPE SCIENCE INSTITUTE
PR94-52c • Office of Public Outreach • December 6, 1994 • ZGL

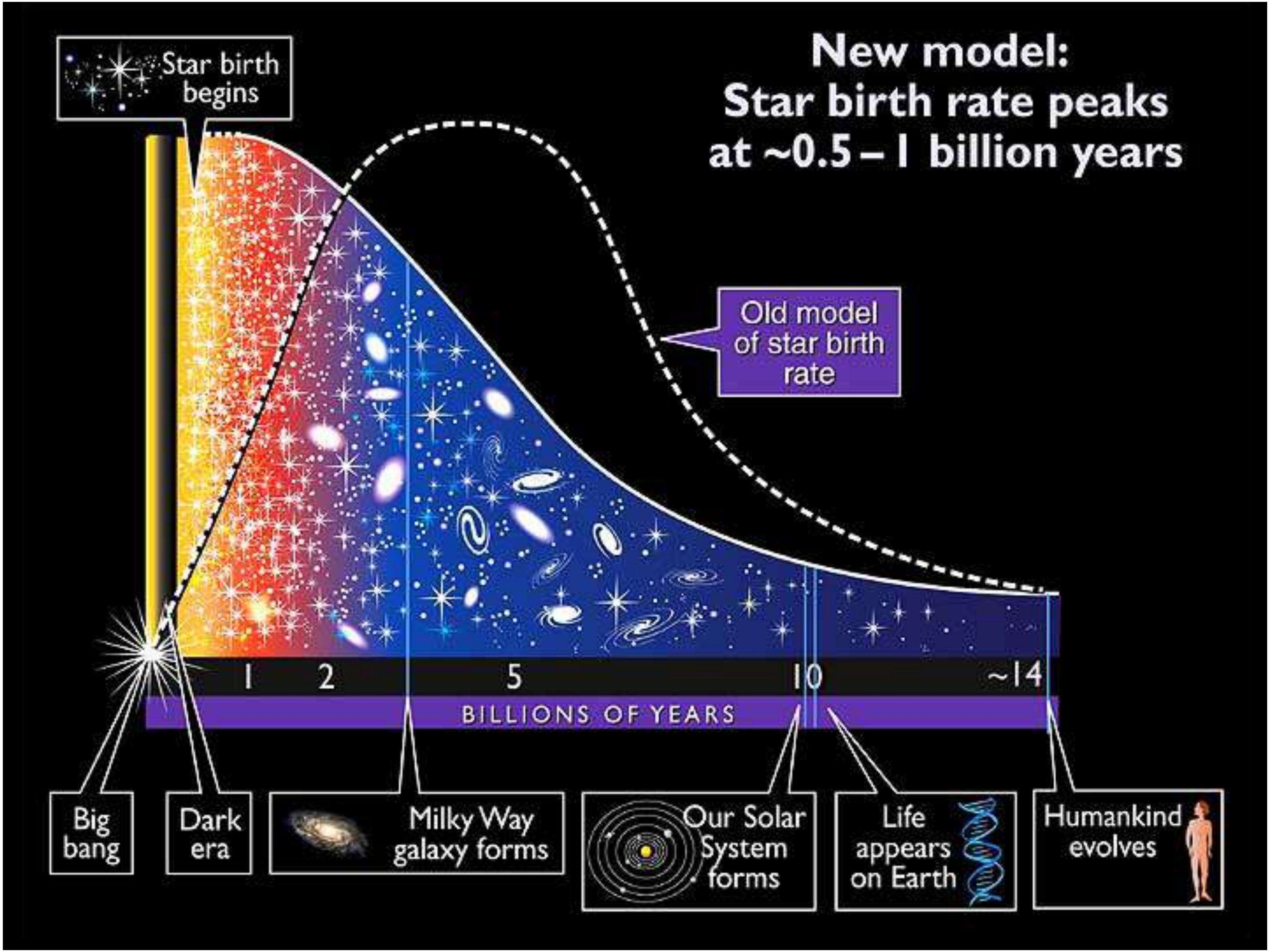


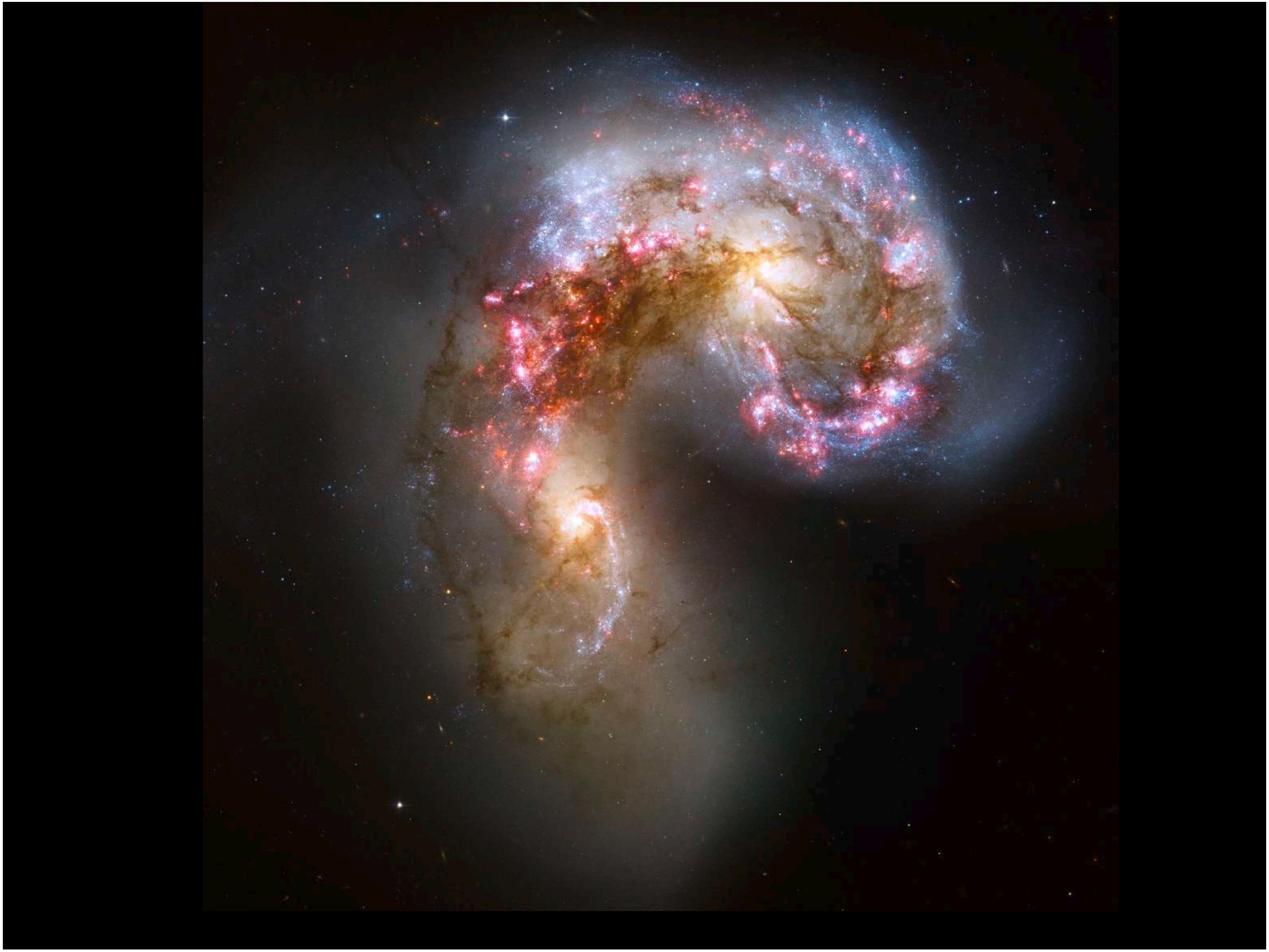
Hubble Ultra Deep Field Details

Hubble Space Telescope • Advanced Camera for Surveys

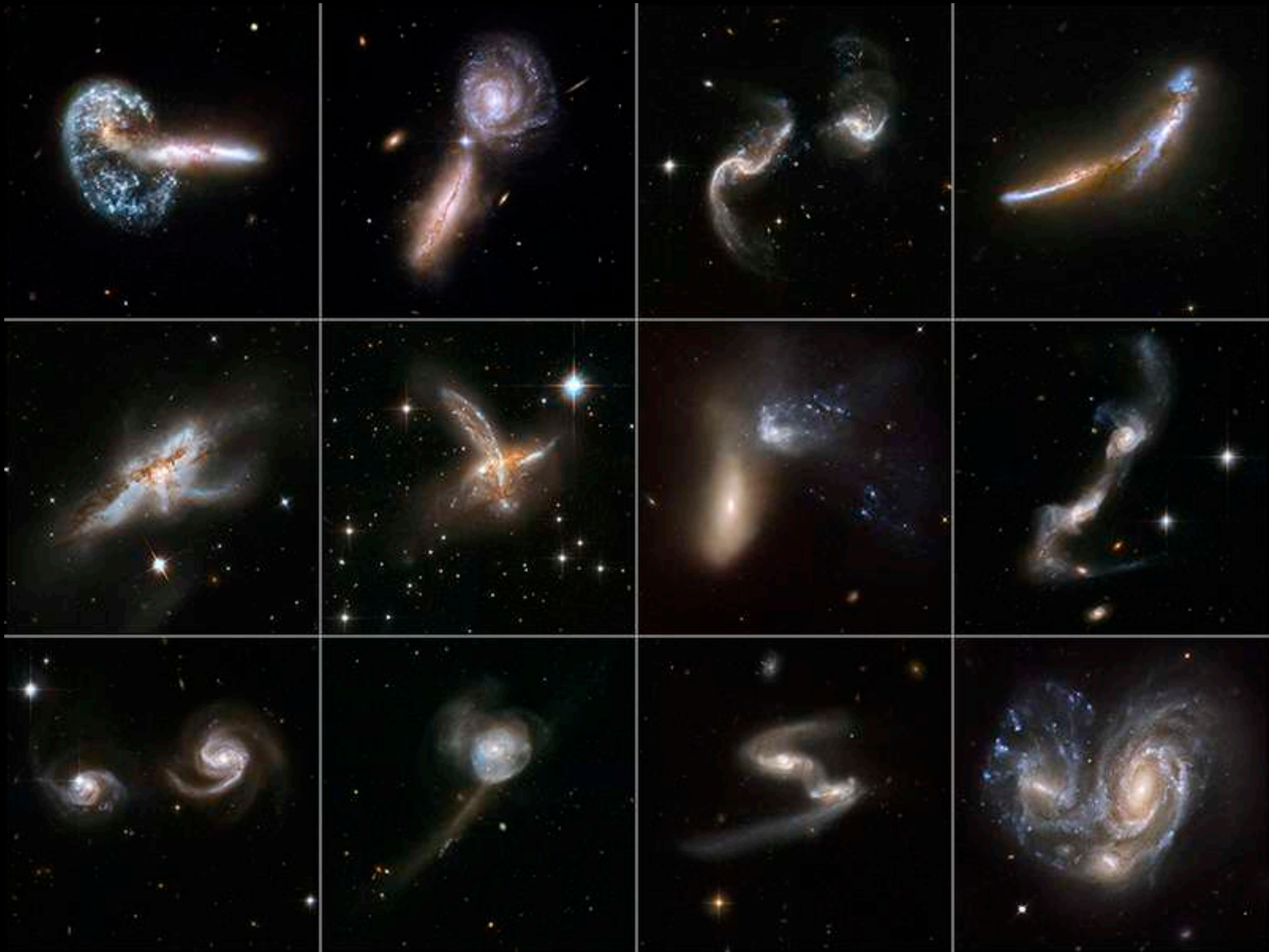
NASA, ESA, S. Beckwith (STScI) and the HUDF Team

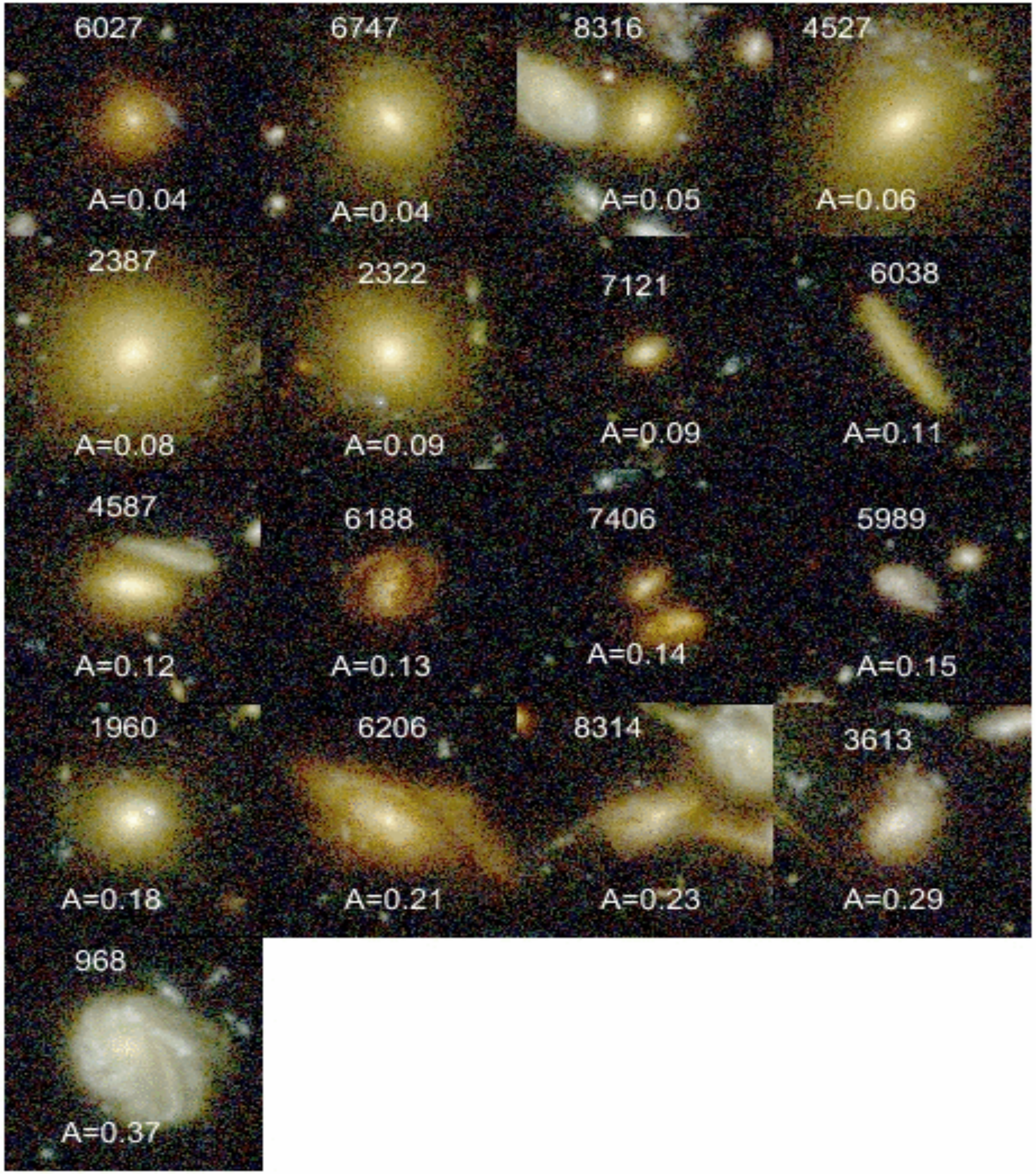
STScI-PRC04-07c


New model:
Star birth rate peaks at ~0.5 – 1 billion years
Star birth begins
Old model of star birth rate
1
2
5
10
~14
BILLIONS OF YEARS
Big bang
Dark era
Milky Way galaxy forms
Our Solar System forms
Life appears on Earth
Humankind evolves

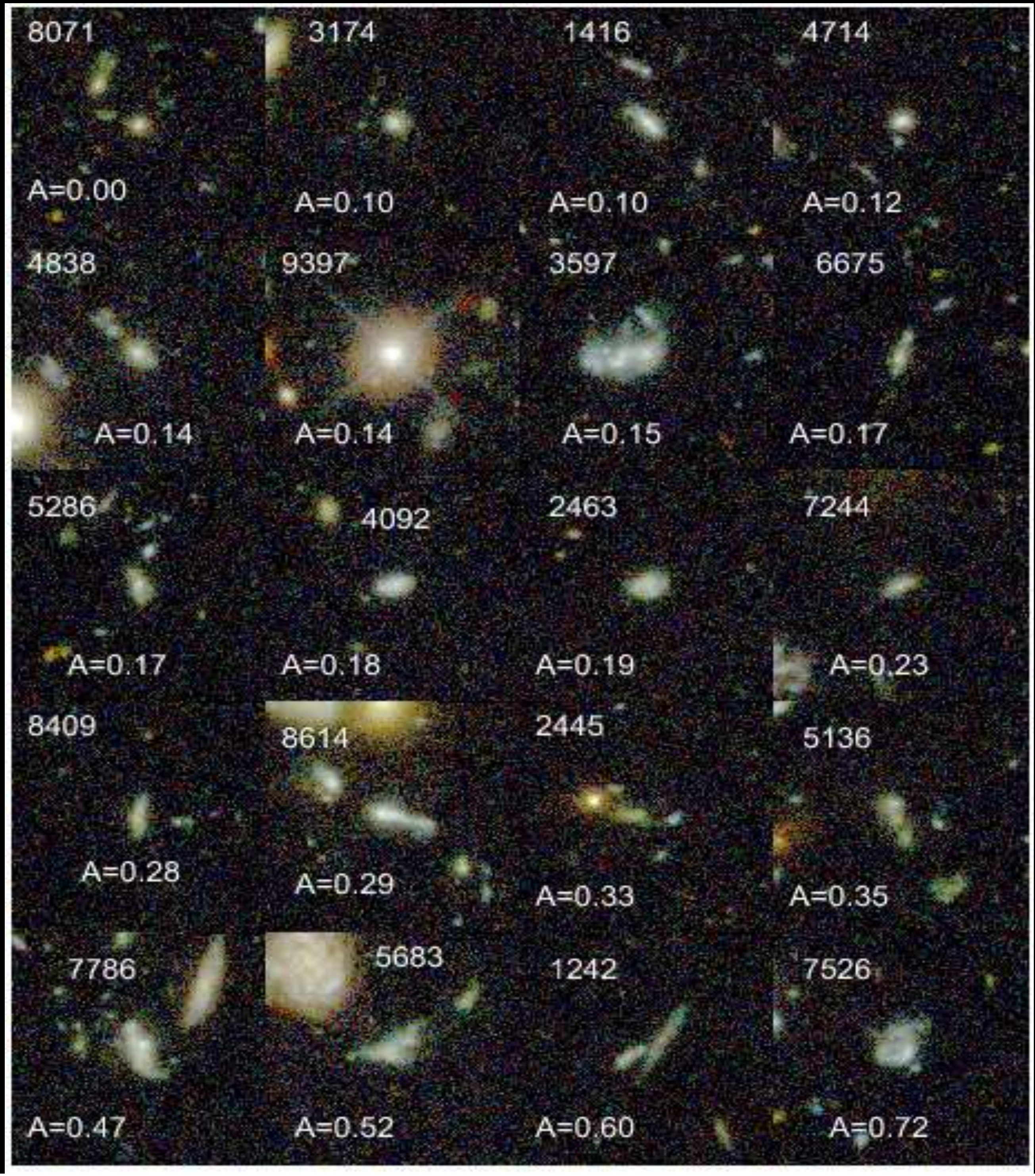


Key goal for galaxy formation studies is role of merging



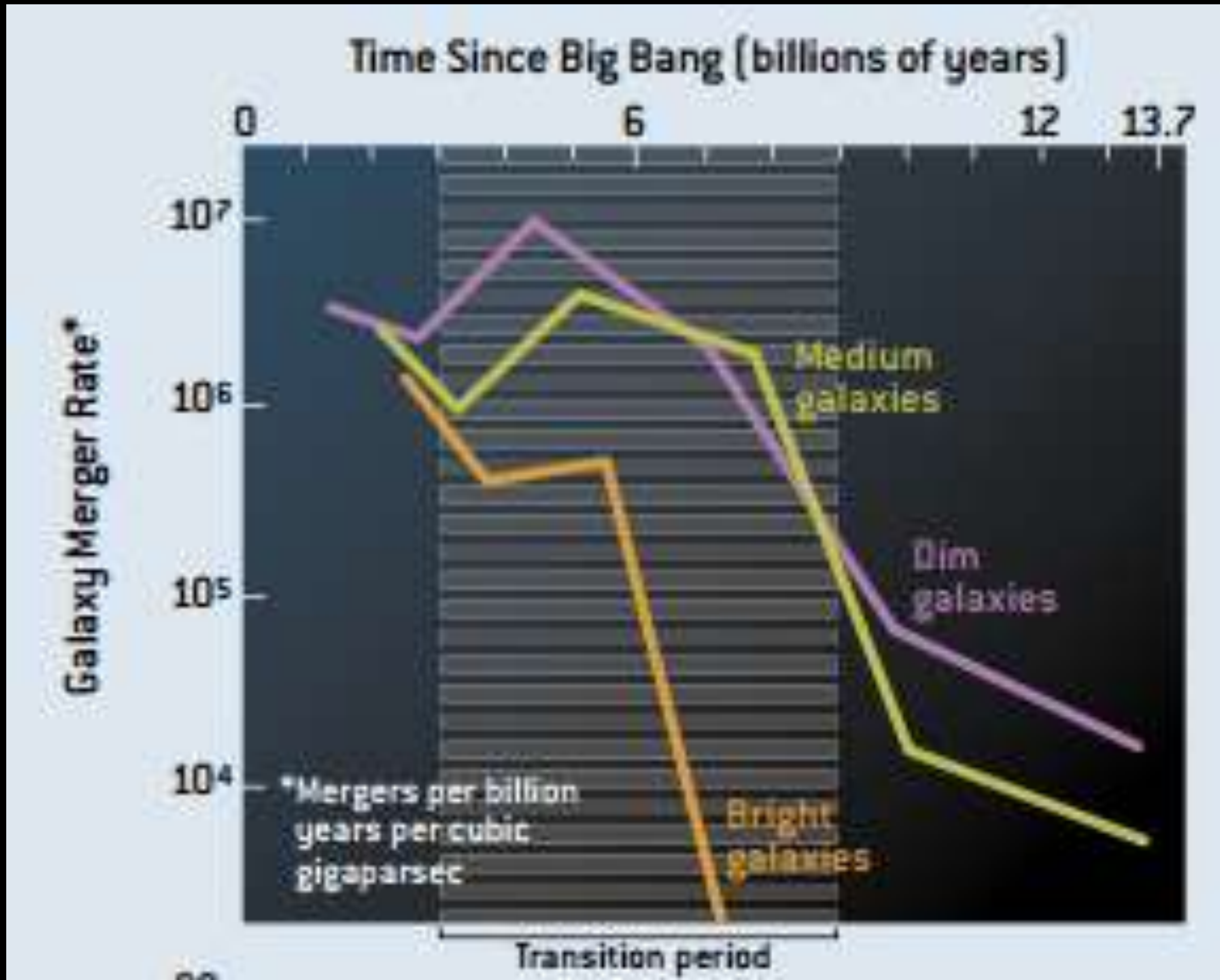


Galaxies in the 2nd half of the Universe's history

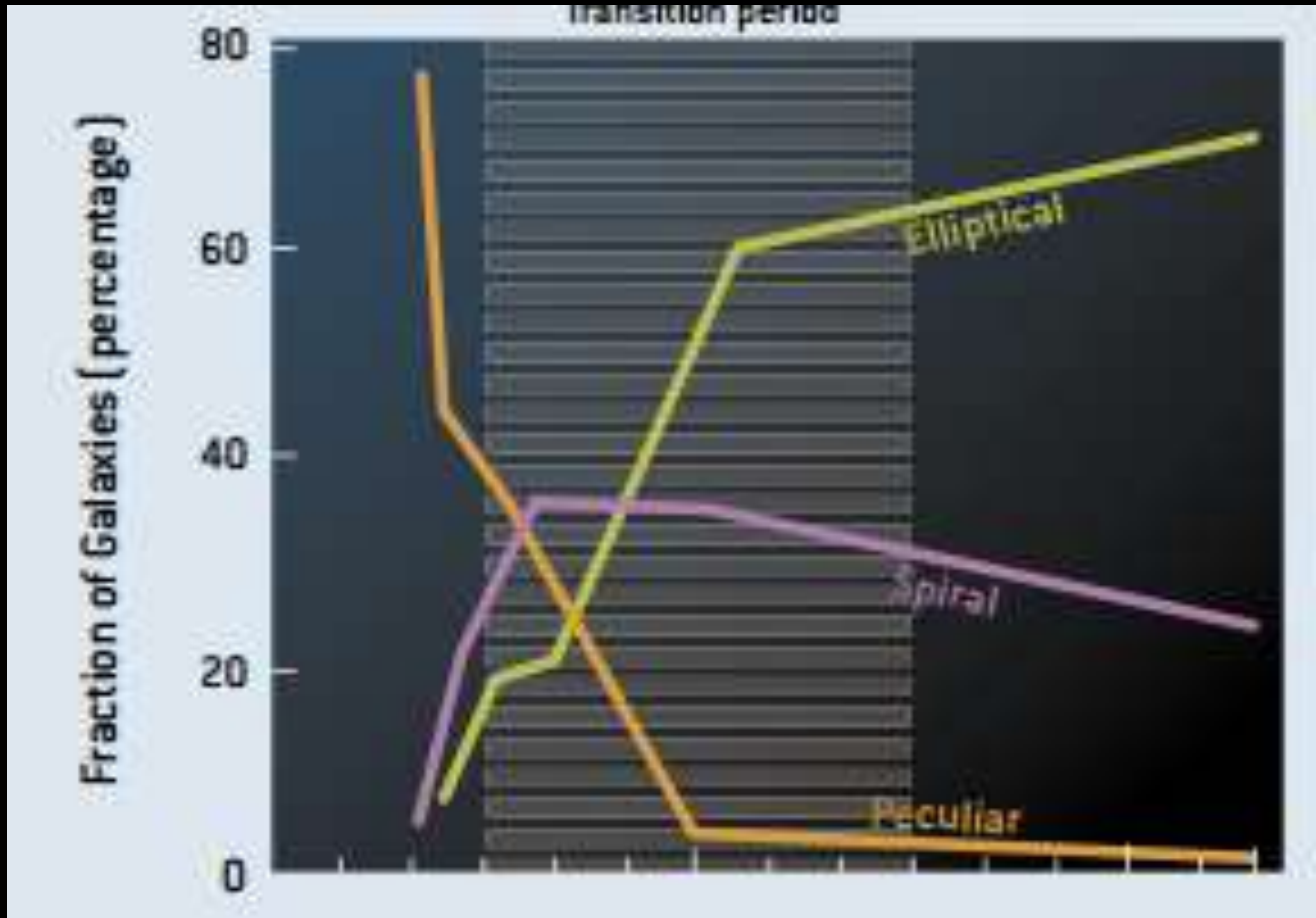


Galaxies in the 1st half of the Universe's history

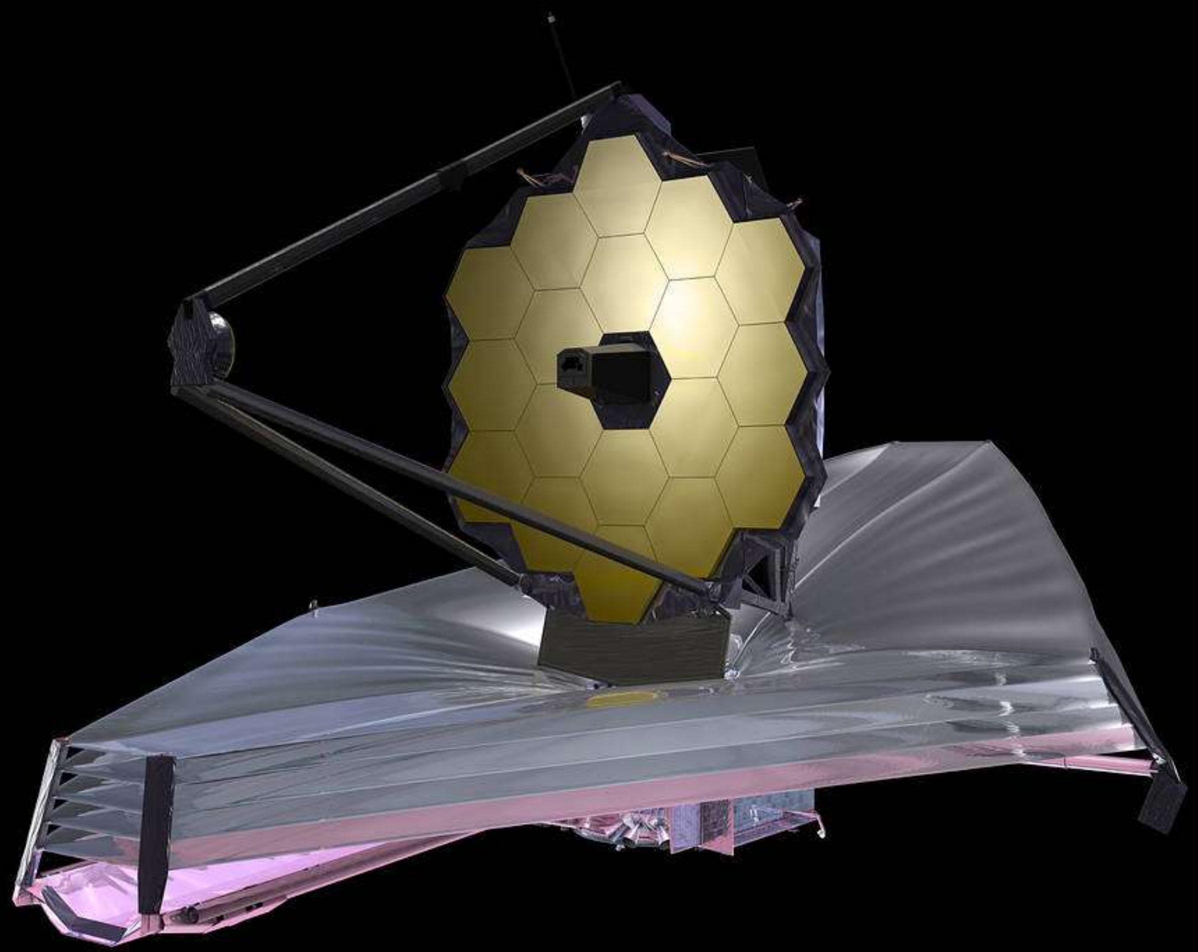
We can now measure the merger rate



And see normal galaxies forming late in the universe's history



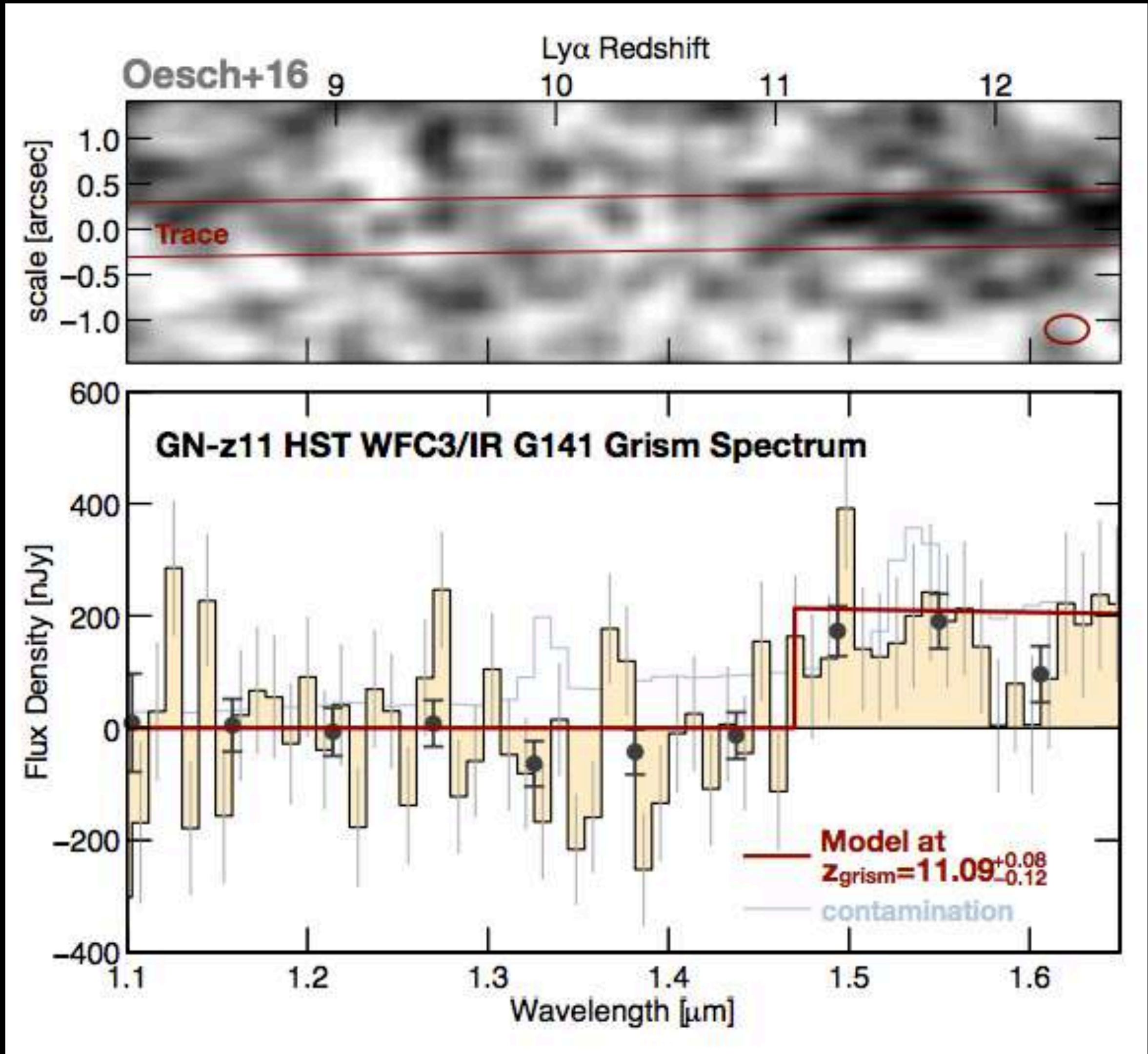
The James Webb Space Telescope



The James Webb Space Telescope

First images released on July 12!

Lyman-break galaxy at z=11 (few 100 Myr after big bang)



Most distant galaxy (candidate) yet known

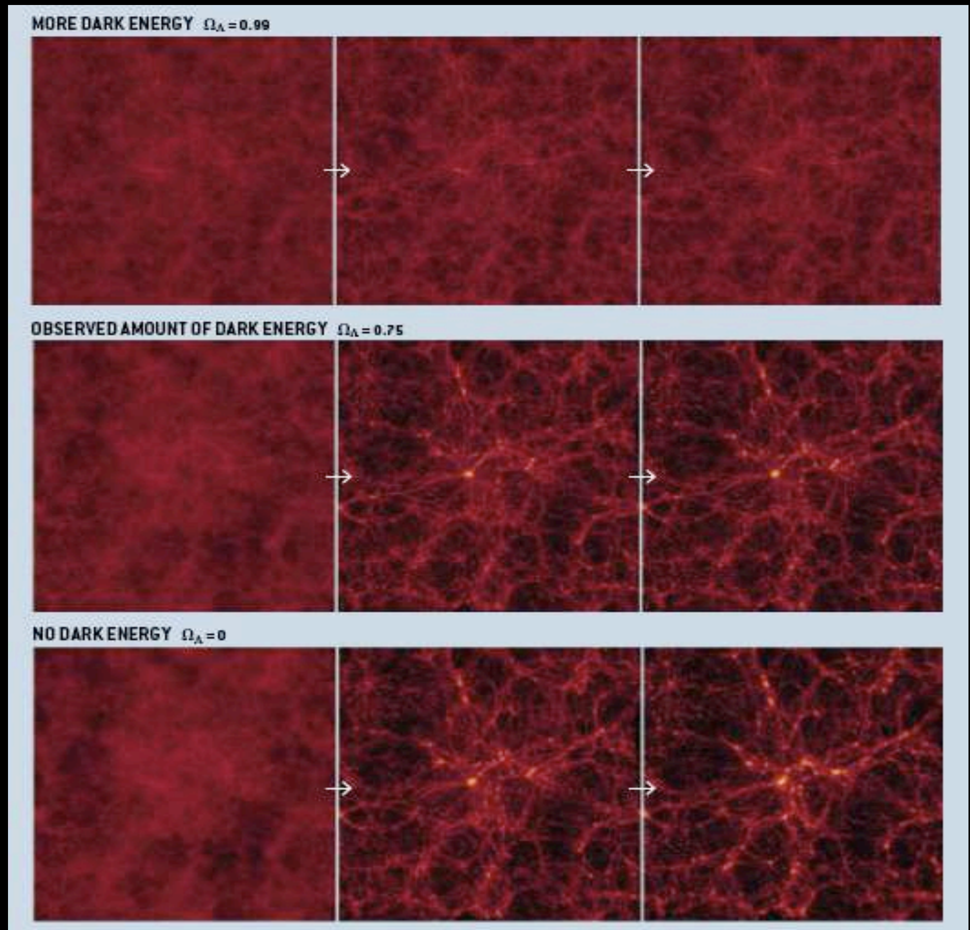
JWST will find many more of these starting in 2022

Oesch+15

Galaxy Merging and Cosmology

High-z

Today



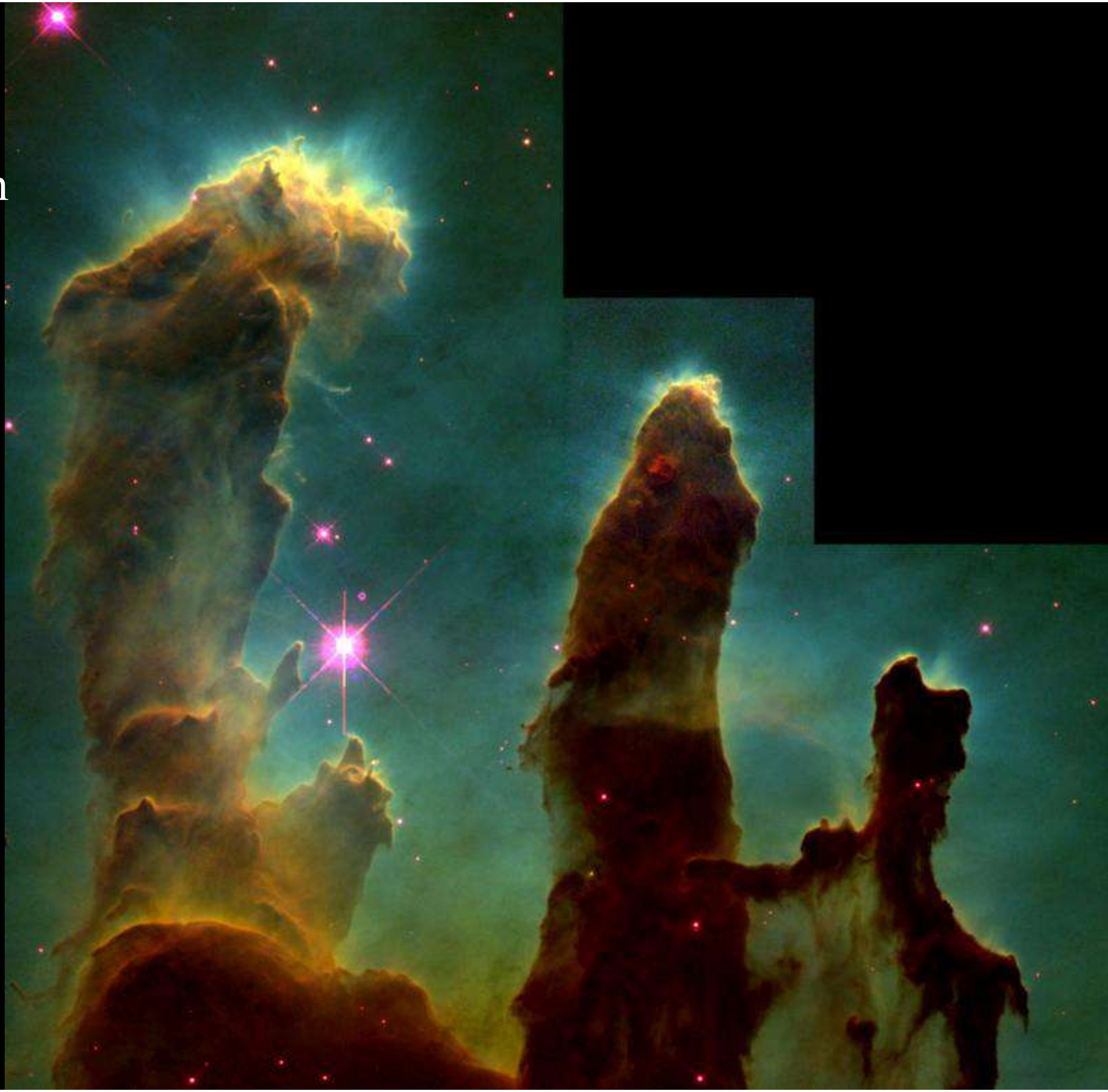
Observations of how structure formation occurs can perhaps help reveal the physical nature of dark energy

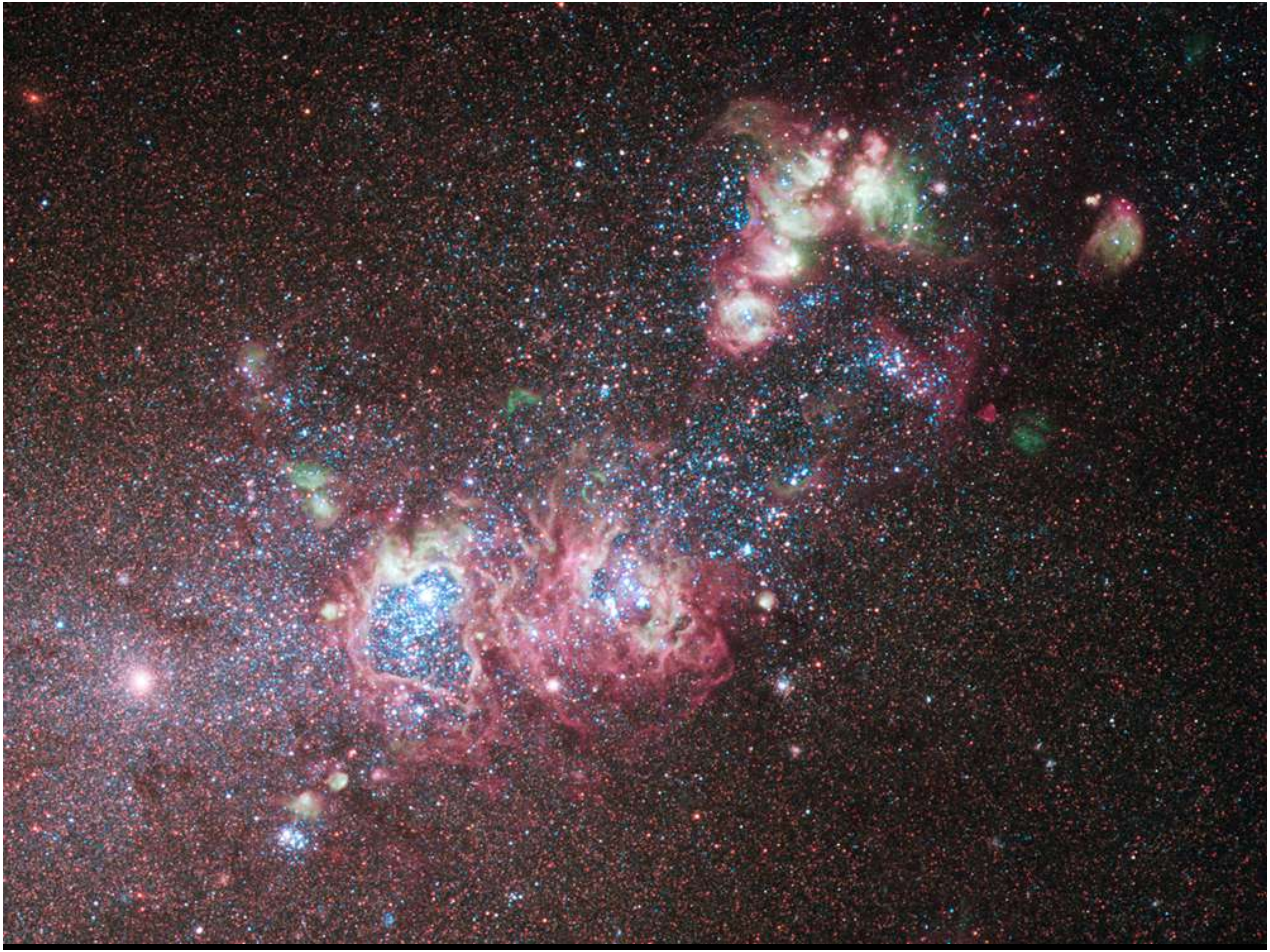
Conselice, Feb 2007 Scientific American

Star formation
In Galaxies

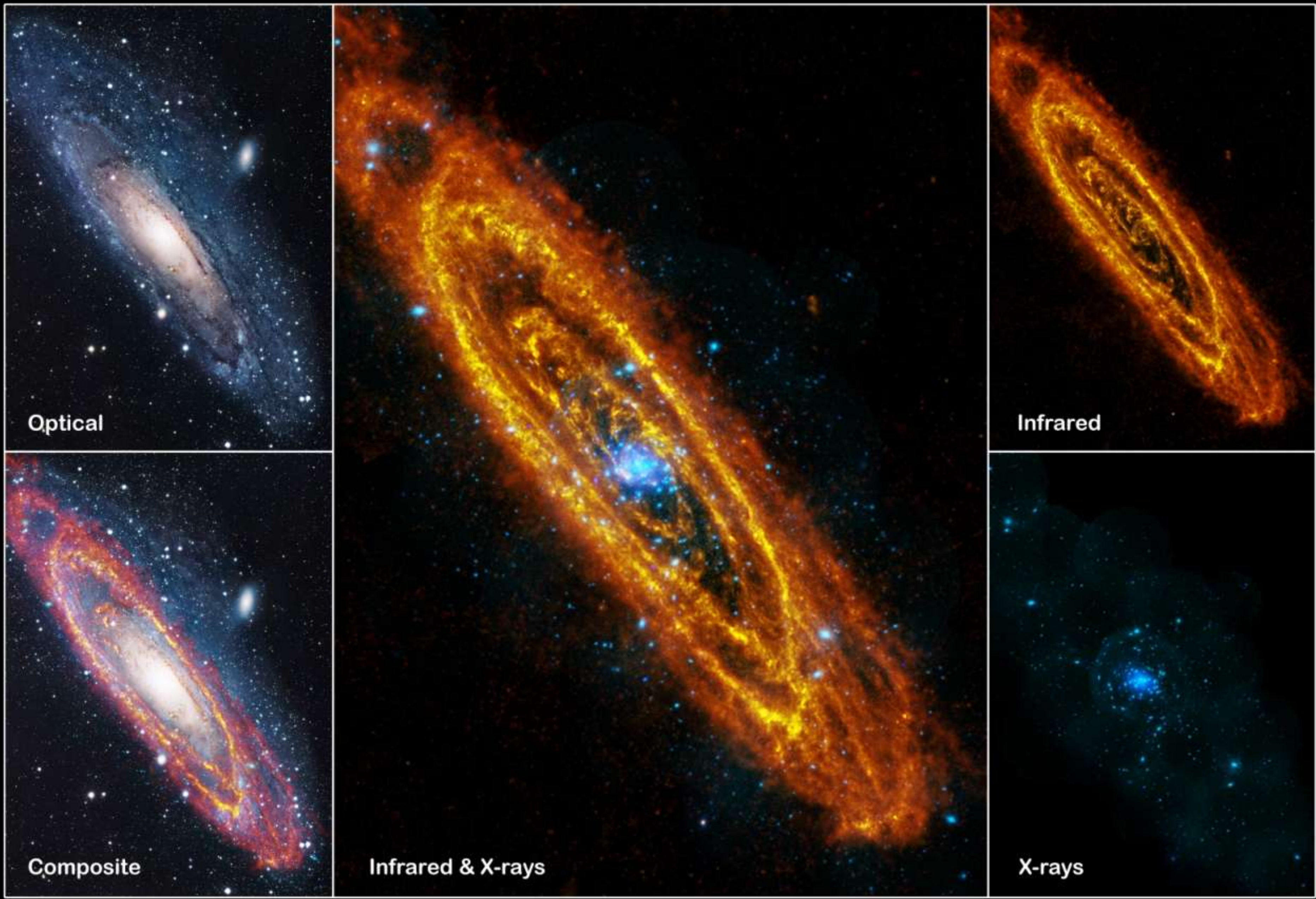
Pillars of
Creation

Gas and
Dust →
Young stars





Heated dust – seen at >5μm



The Formation of life

Classical Calculation

Drake Equation

$$N = R \times f_s \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- R average rate of star formation
- f_s fraction of good stars that have planetary systems
- n_e number of planets aound these stars within an "ecoshell"
- f_l fraction of those planets where life develops
- f_i fraction of living species that develop intelligence
- f_c fraction of intelligent species with communications technology
- L lifetime of the "communicative phase"

Name	Symbol	Pessimistic Value	Optimistic Value
Rate of star formation	R*	7	7
Fraction of stars with planets	fp	80%	100%
Number of earthlike planets per planetary system	ne	0.5	2
Fraction of earthlike planets that evolve life	fl	1%	100%
Fraction of life-bearing planets that evolve intelligent life	fi	1%	100%
Fraction of intelligent species that develop communication technology	fc	50%	100%
Length of time technological civilizations communicate	L	100	10,000
Total number of civilizations in the Milky Way galaxy right now	N	0.014	140,000

Alternative Method

THE ASTROPHYSICAL JOURNAL, 896:58 (18pp), 2020 June 10
https://doi.org/10.3847/1538-4357/ab8225

CrossMark

The Astrobiological Copernican Weak and Strong Limits for Intelligent Life

Tom Westby and Christopher J. Conselice
School of Physics and Astronomy, University of Nottingham, UK
Received 2019 December 4; revised 2020 March 15; accepted 2020 March 17; published 2020 June 15

Abstract

We present a cosmic perspective on the search for life and examine the likely number of Communicating Extra-Terrestrial Intelligent (CETI) civilizations in our Galaxy by utilizing the latest astrophysical information. Our calculation involves Galactic star formation histories, metallicity distributions, and the likelihood of stars hosting Earth-like planets in their habitable zones, under specific assumptions which we describe as the Astrobiological Copernican Weak and Strong conditions. These assumptions are based on the one situation in which intelligent, communicative life is known to exist—on our own planet. This type of life has developed in a metal-rich environment and has taken roughly 5 Gyr to do so. We investigate the possible number of CETI civilizations based on different scenarios. At one extreme is the Weak Astrobiological Copernican scenario—such that a planet forms intelligent life sometime after 5 Gyr, but not earlier. The other is the Strong Astrobiological Copernican scenario in which life must form between 4.5 and 5.5 Gyr, as on Earth. In the Strong scenario (under the strictest set of assumptions), we find there should be at least 36^{+175}_{-32} civilizations within our Galaxy: this is a lower limit, based on the assumption that the average lifetime, *L*, of a communicating civilization is 100 yr (since we know that our own civilization has had radio communications for this time). If spread uniformly throughout the Galaxy this would imply that the nearest CETI is at most $17{,}000^{+33{,}600}_{-10{,}000}$ lt-yr away and most likely hosted by a low-mass M-dwarf star, likely far surpassing our ability to detect it for the foreseeable future, and making interstellar communication impossible. Furthermore, the likelihood that the host stars for this life are solar-type stars is extremely small and most would have to be M dwarfs, which may not be stable enough to host life over long timescales. We furthermore explore other scenarios and explain the likely number of CETI there are within the Galaxy based on variations of our assumptions.

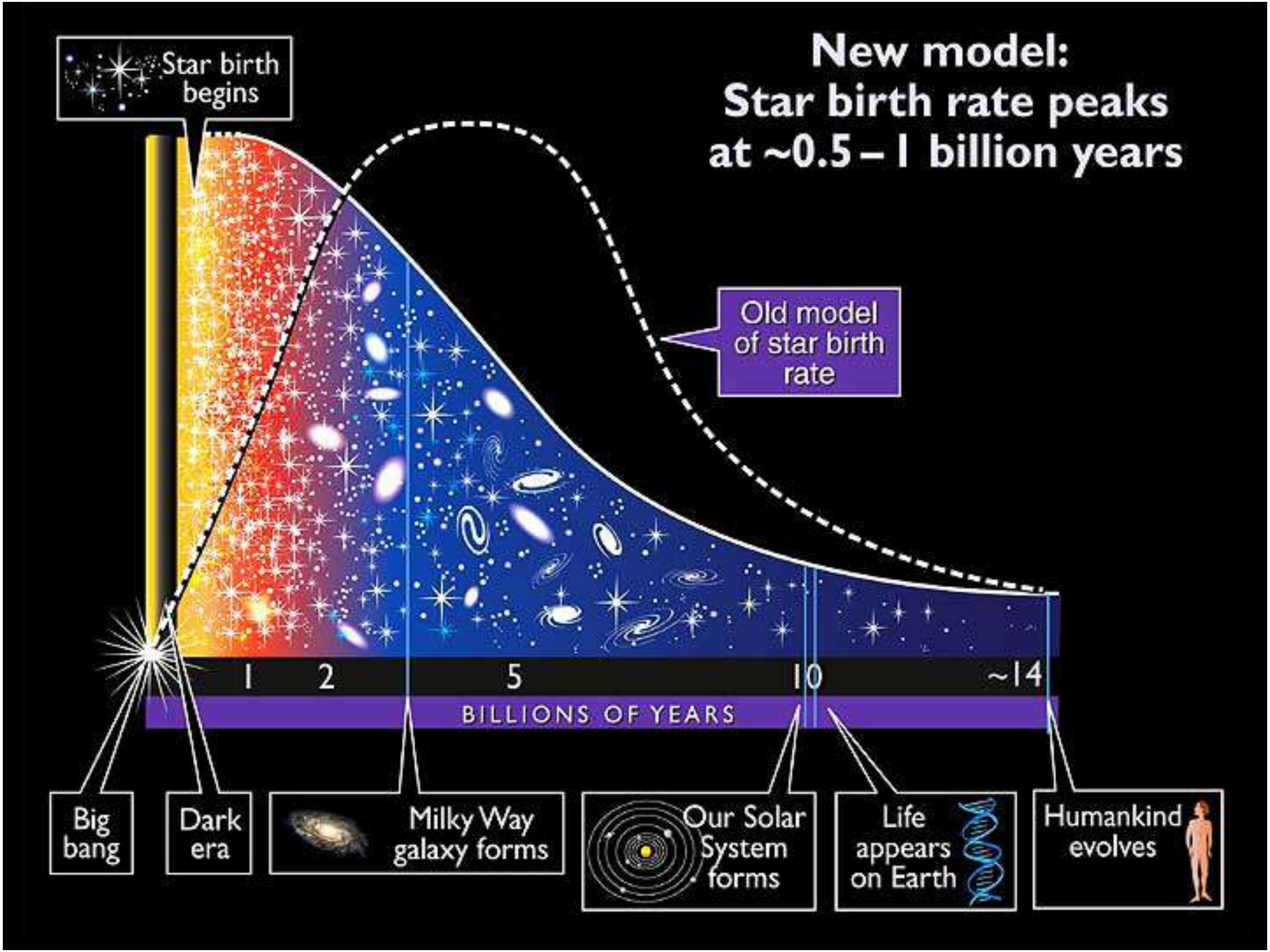
Unified Astronomy Thesaurus concepts: Astrobiology (74); Astrostatistics (1882); Milky Way Galaxy (1054); Metallicity (1031); Stellar abundances (1577); Star formation (1569); Habitable planets (695); Exoplanet astronomy (486); Exoplanets (498)

Astrobiological Copernican Method

Answers question by finding similar formation histories as Earth

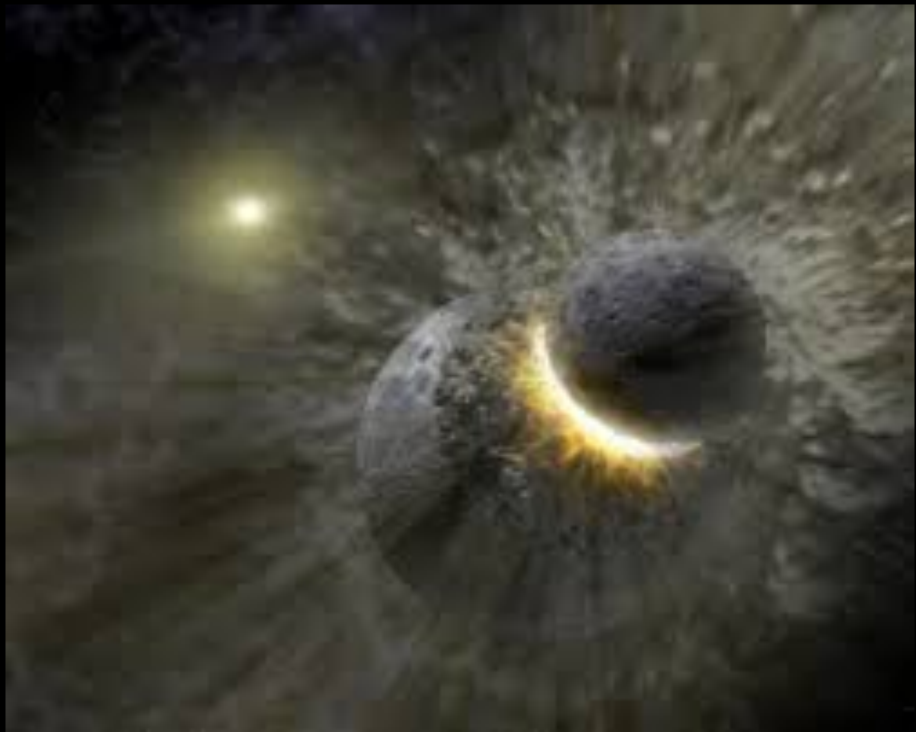
Star formation

Most necessary requirement – produces metals



New model:
Star birth rate peaks at ~0.5 – 1 billion years
Star birth begins
Old model of star birth rate
1
2
5
10
~14
BILLIONS OF YEARS
Big bang
Dark era
Milky Way galaxy forms
Our Solar System forms
Life appears on Earth
Humankind evolves

Planet formation

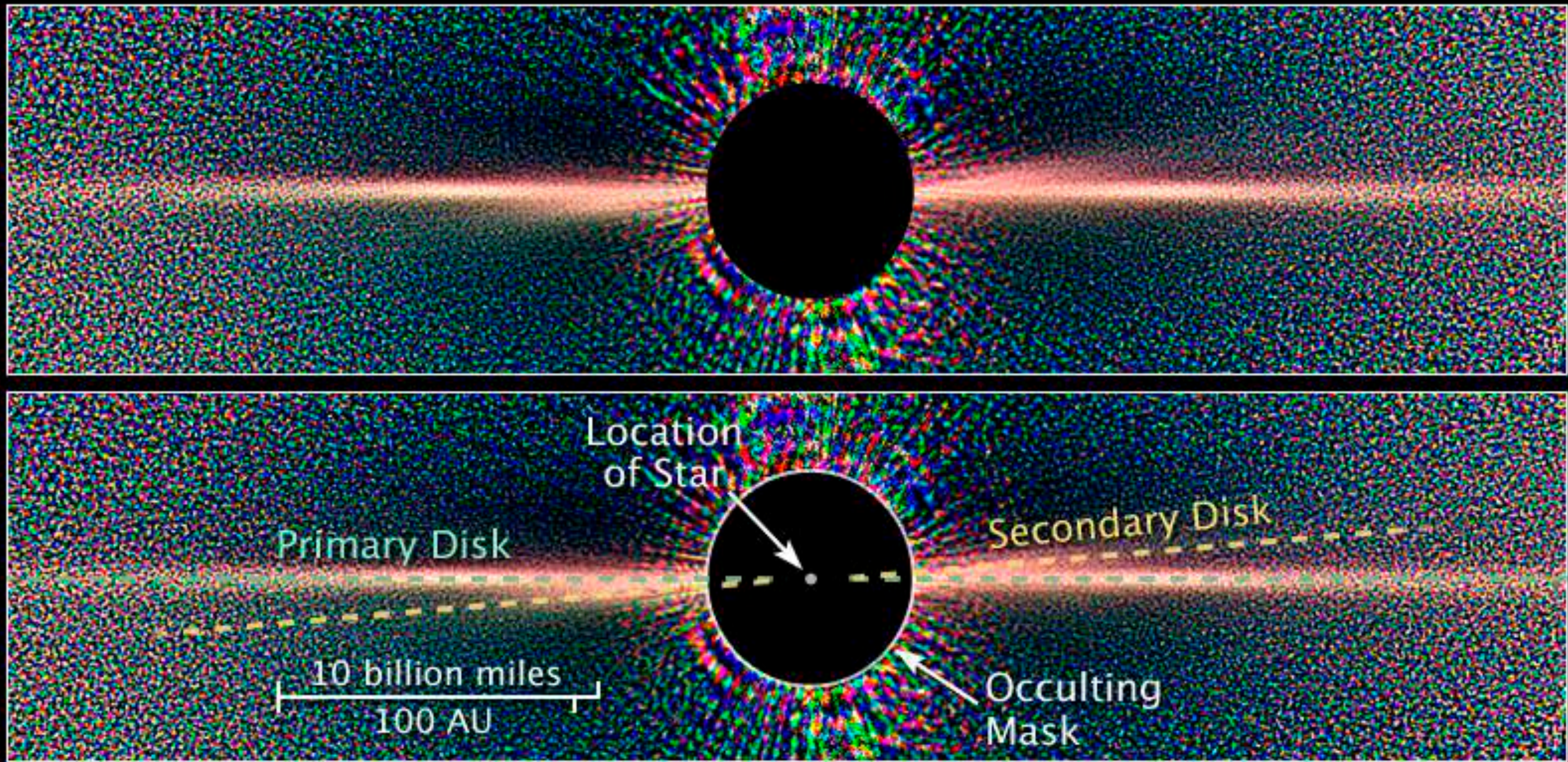


Need heavy metals – carbon, oxygen, etc to form

Can observe formation in progress

Beta Pictoris

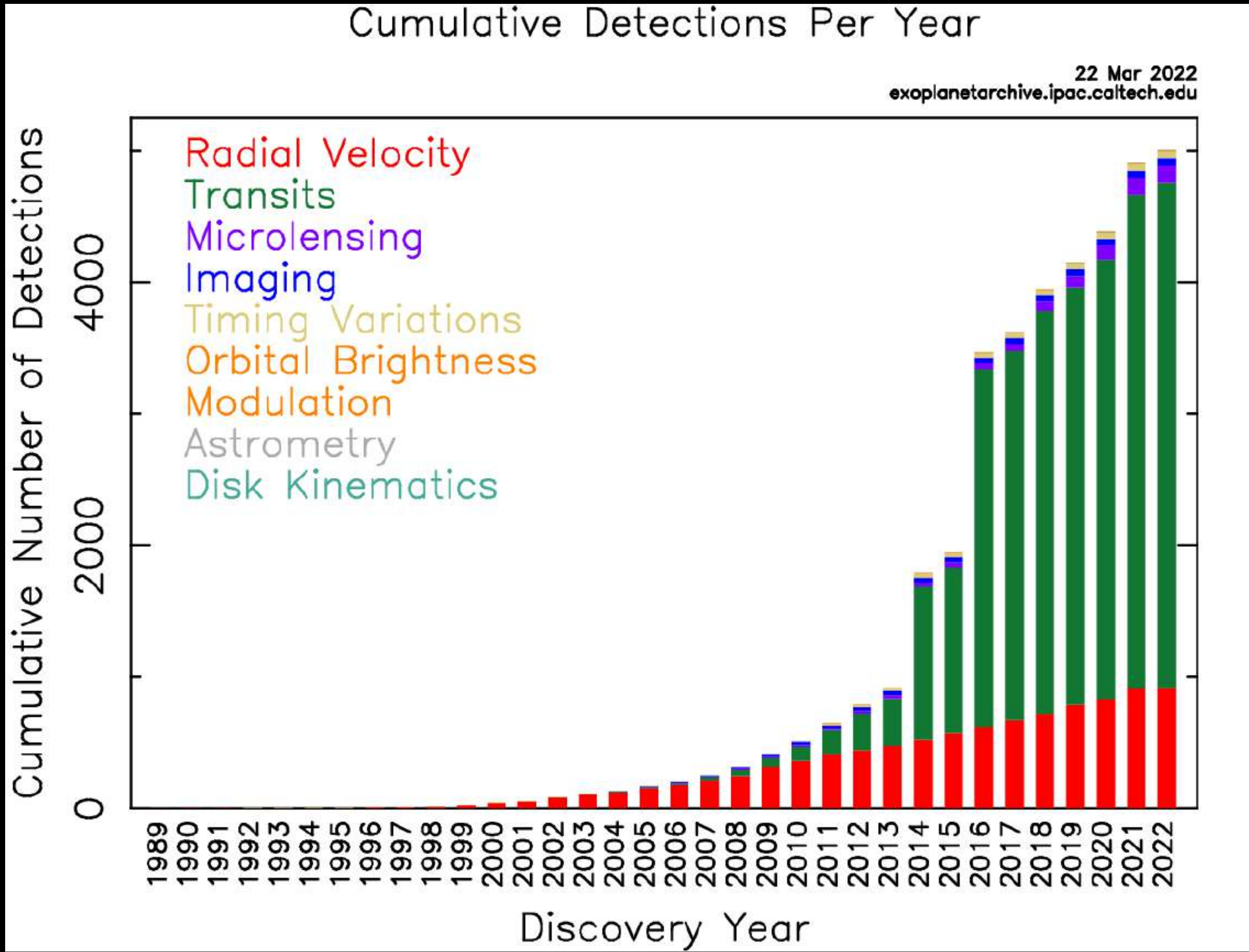
Hubble Space Telescope ▪ ACS/HRC



NASA, ESA, and D. Golimowski (Johns Hopkins University)

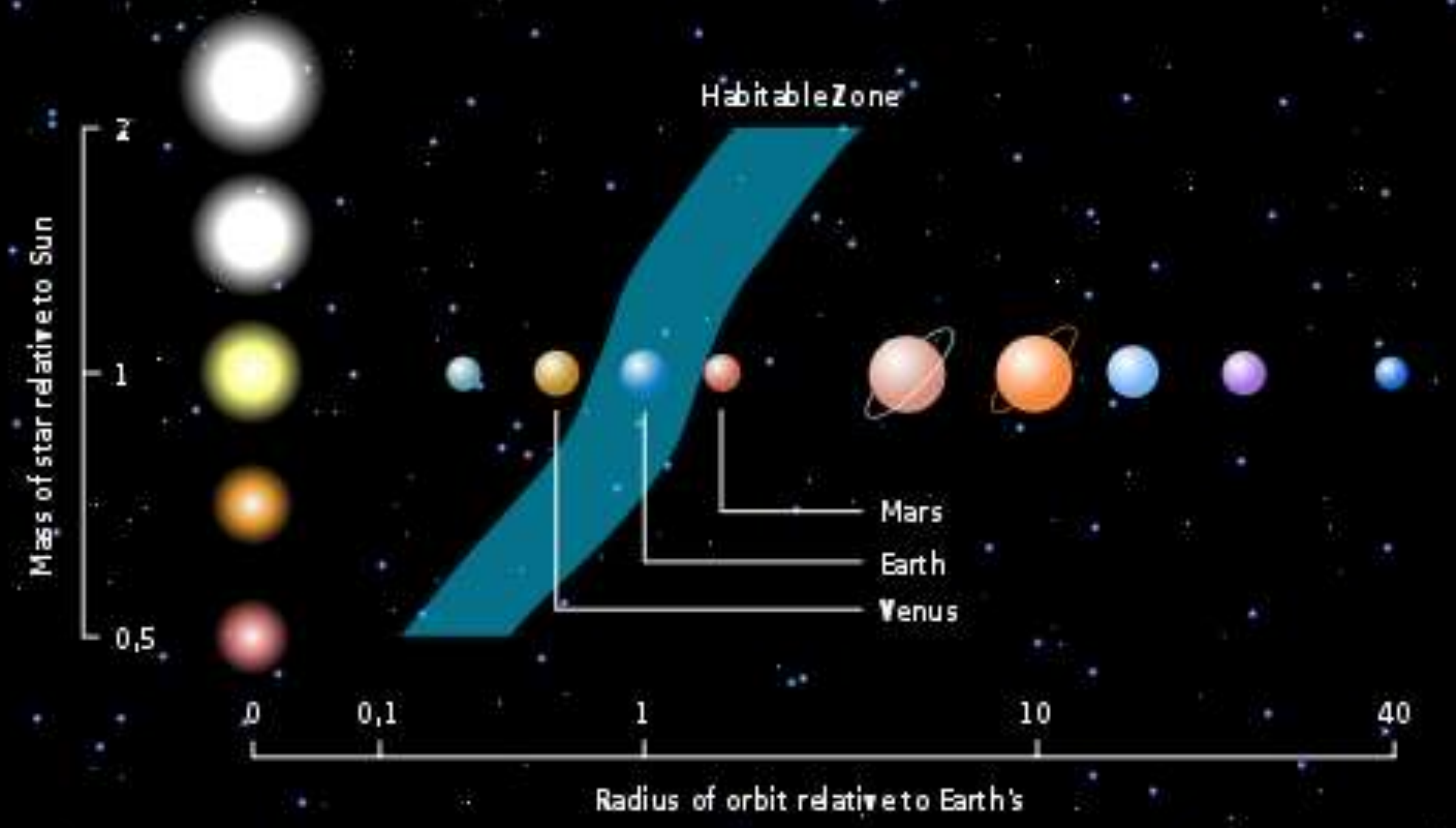
STScI-PRC06-25

How many exoplanets are there? Every year sees more and more



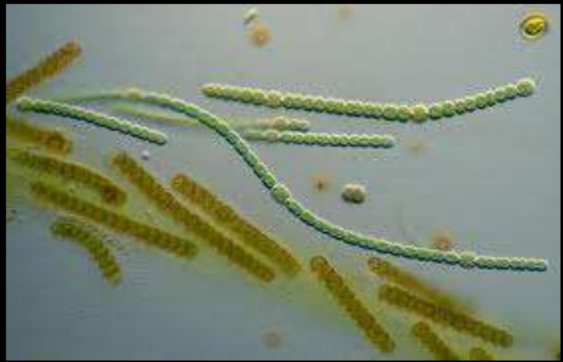
Fraction of stars with plants = 15%

Habitable Zone around a planet – where life can thrive



The galactic habitable zone?

First Life



4 Billion years ago

Human Life

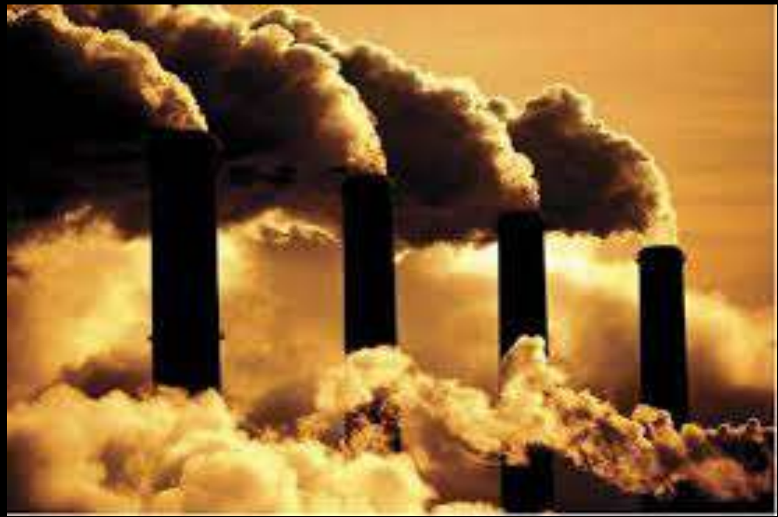
300,000 years ago

Communicating Intelligent Life

Today

Technical civilization on earth – 100-200 Years old

Life time of our civilization?



Result

Number of civilizations in galaxy with communication is >

¼ life-time of civilizations

So at least 36 civilizations in galaxy