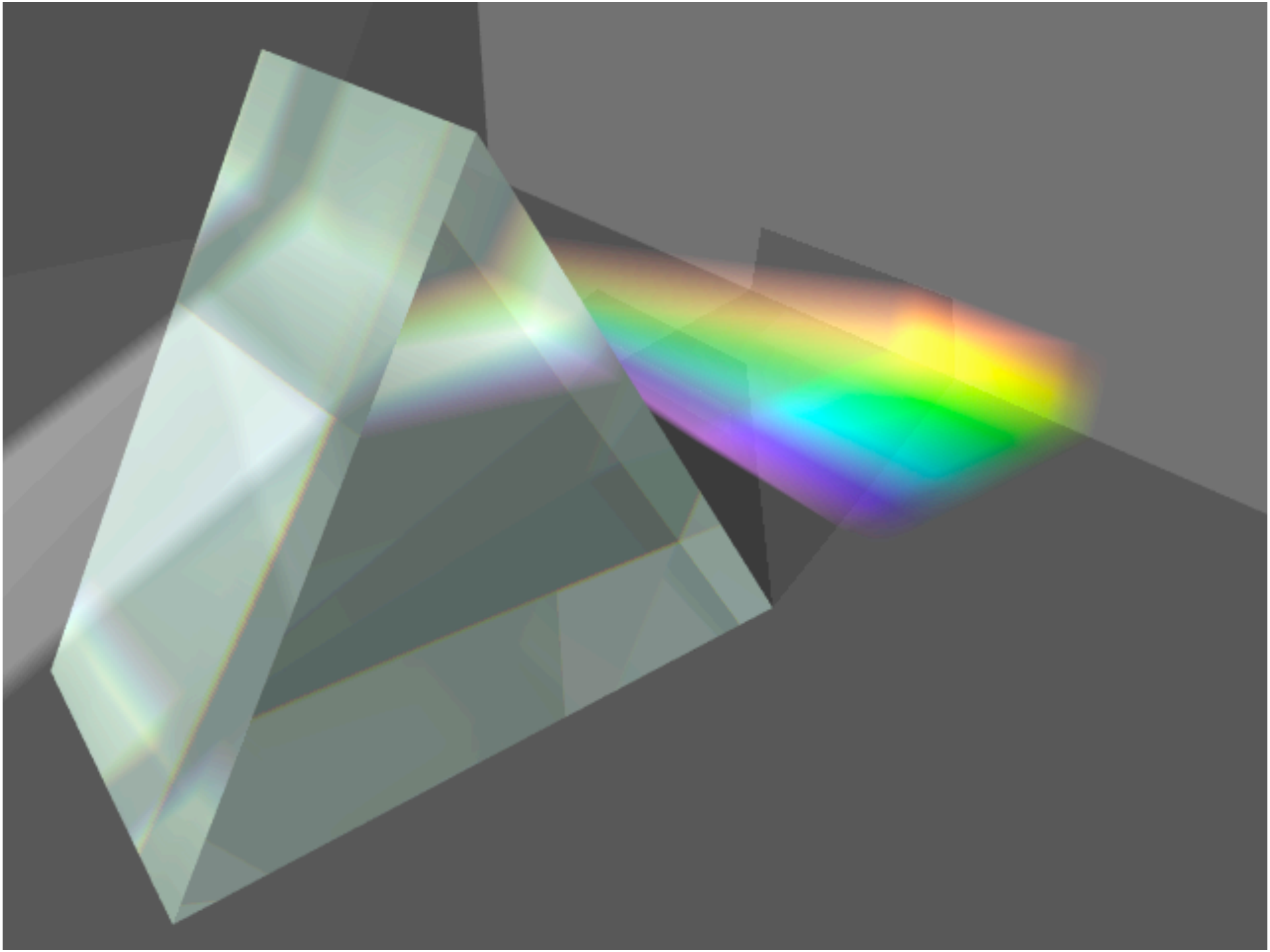
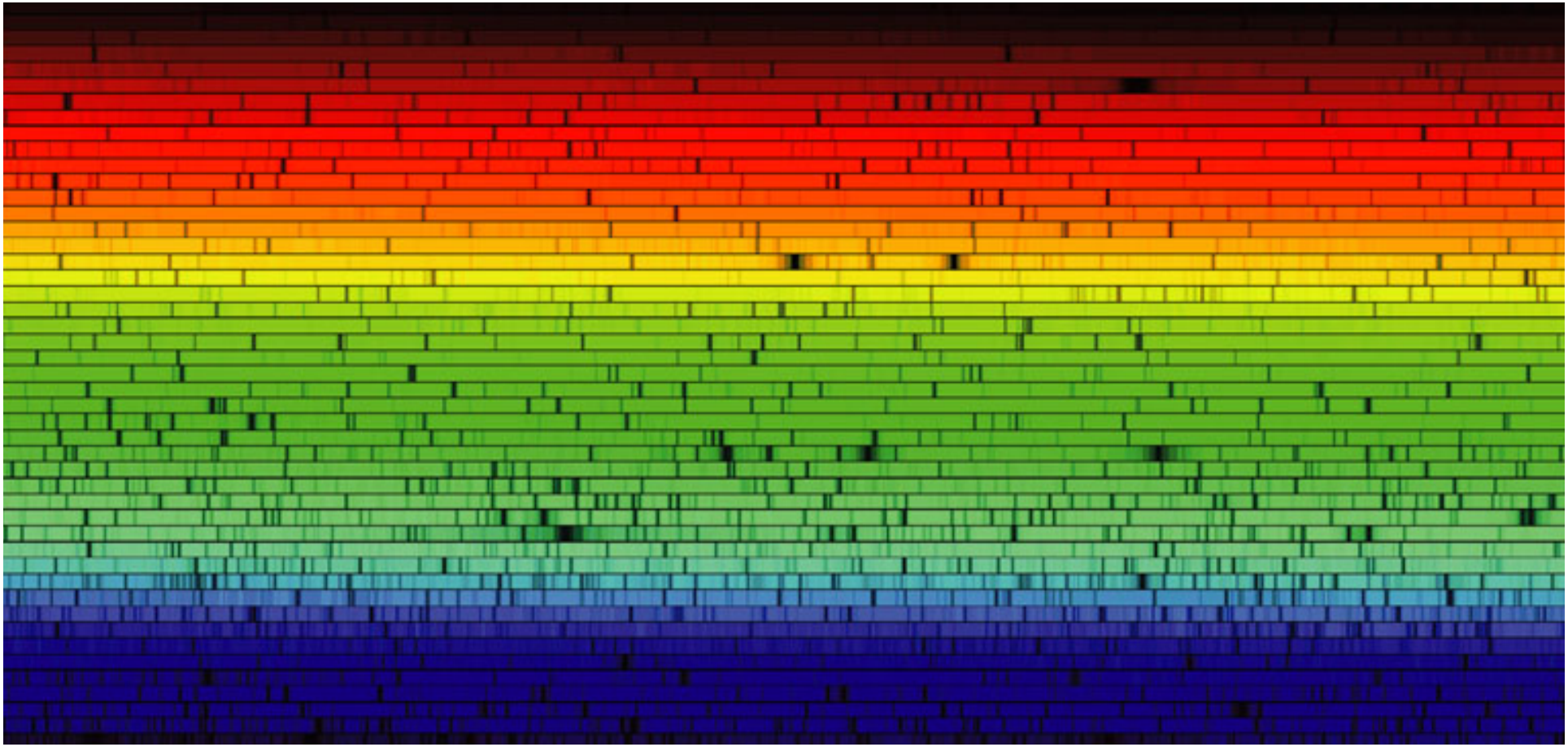
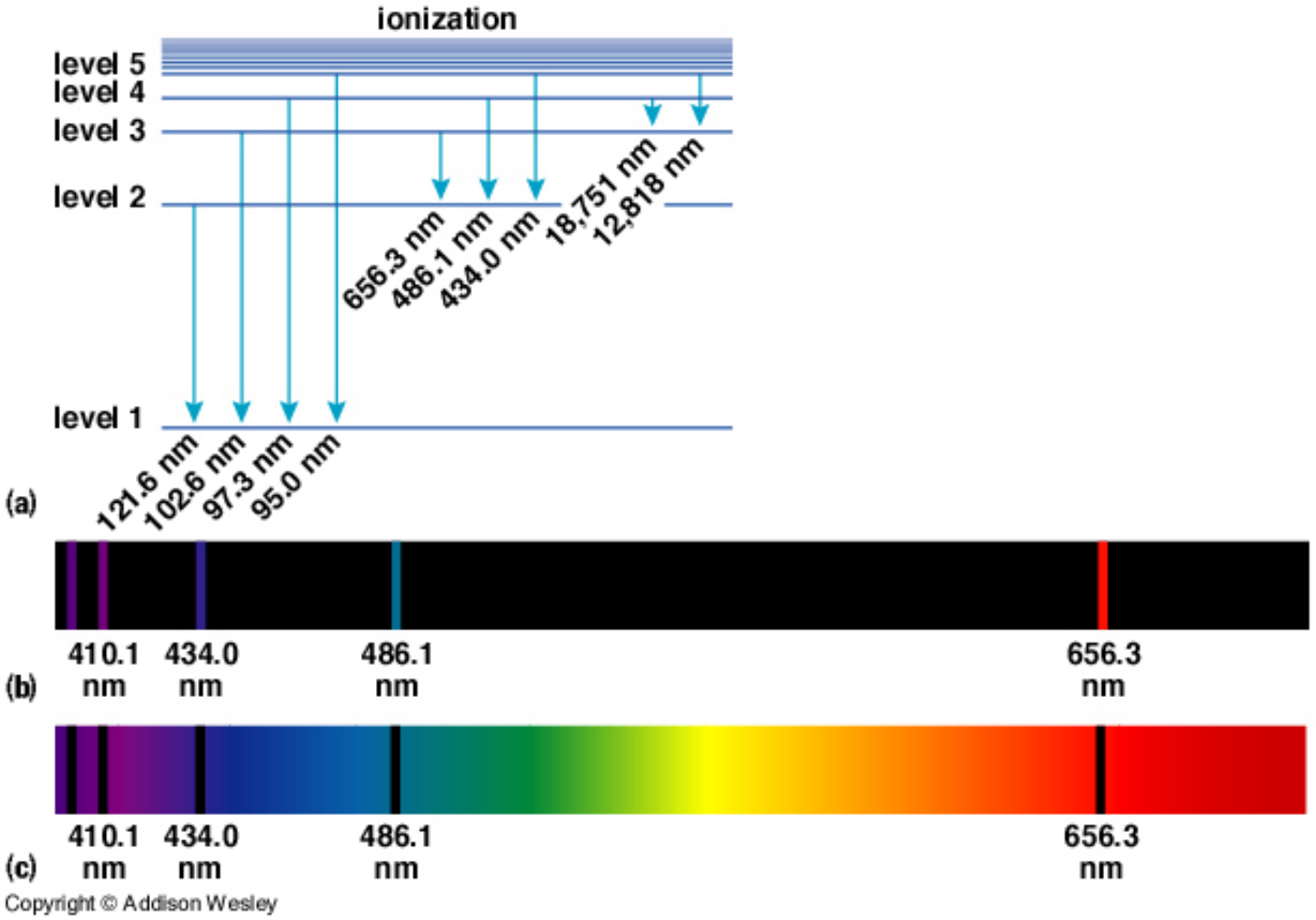
The Big Bang Theory & Expansion of the Universe



Example: the Sun's Spectrum



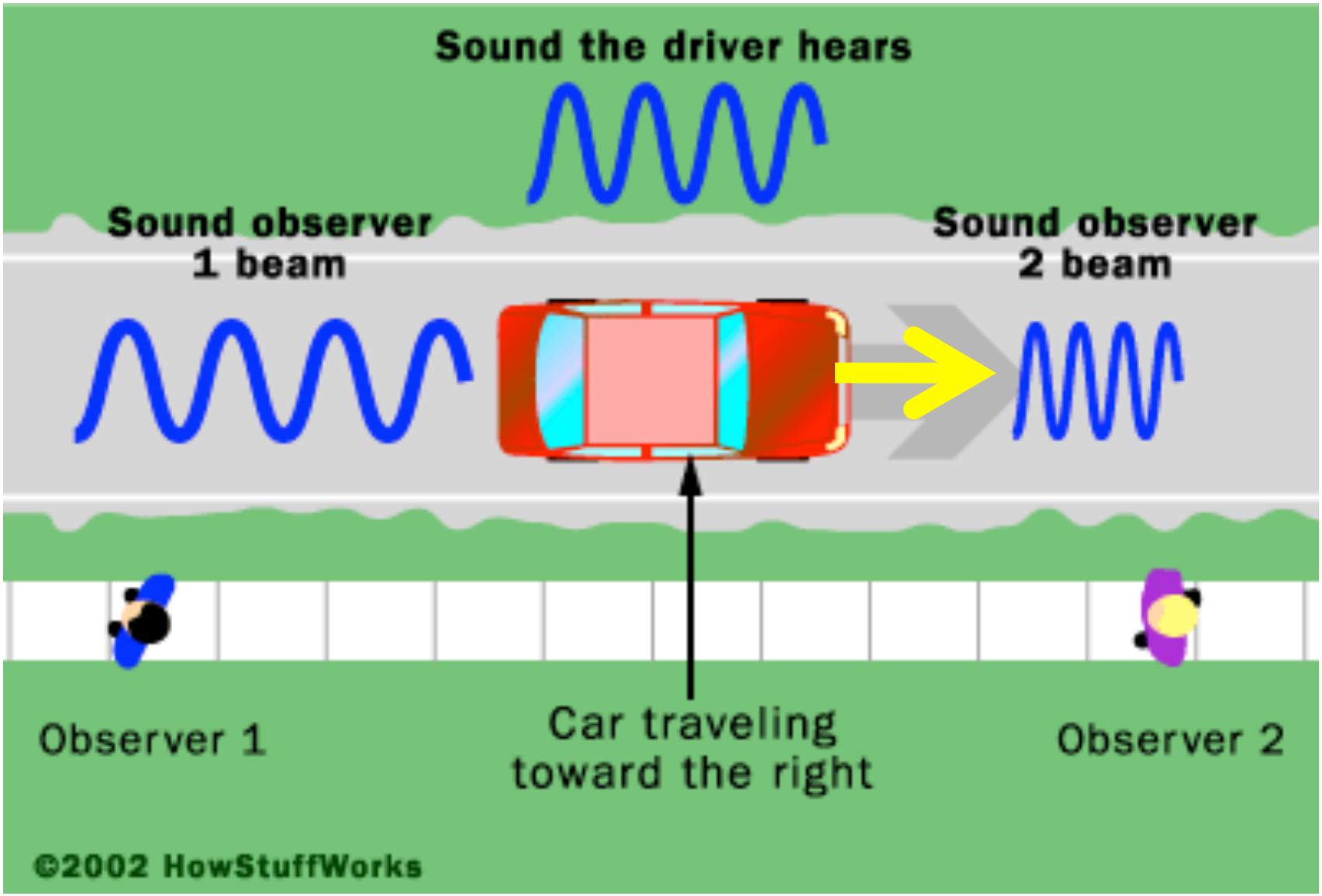
Distinct energy levels lead to distinct emission or absorption lines.



Emission: atom loses energy

Absorption: atom gains energy

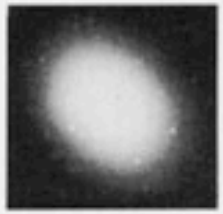
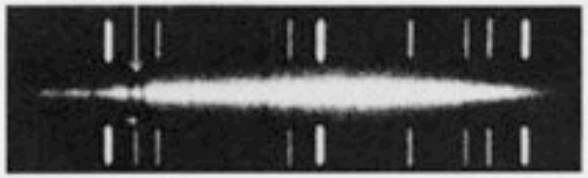
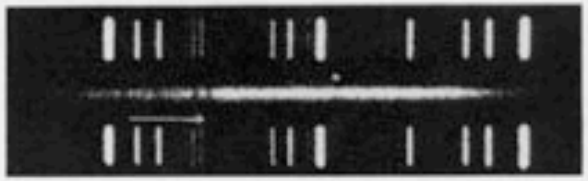
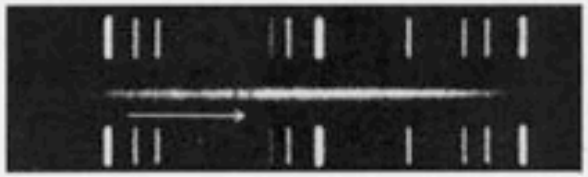
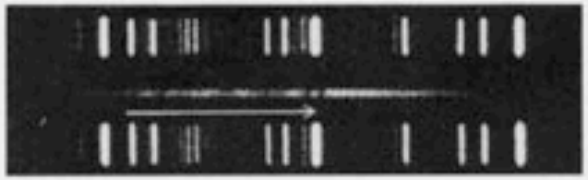
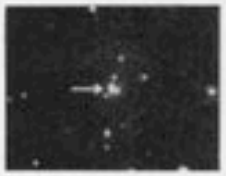
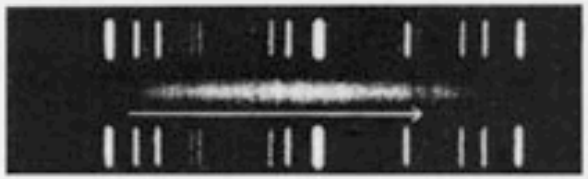
Doppler Shift



Definition : Redshift

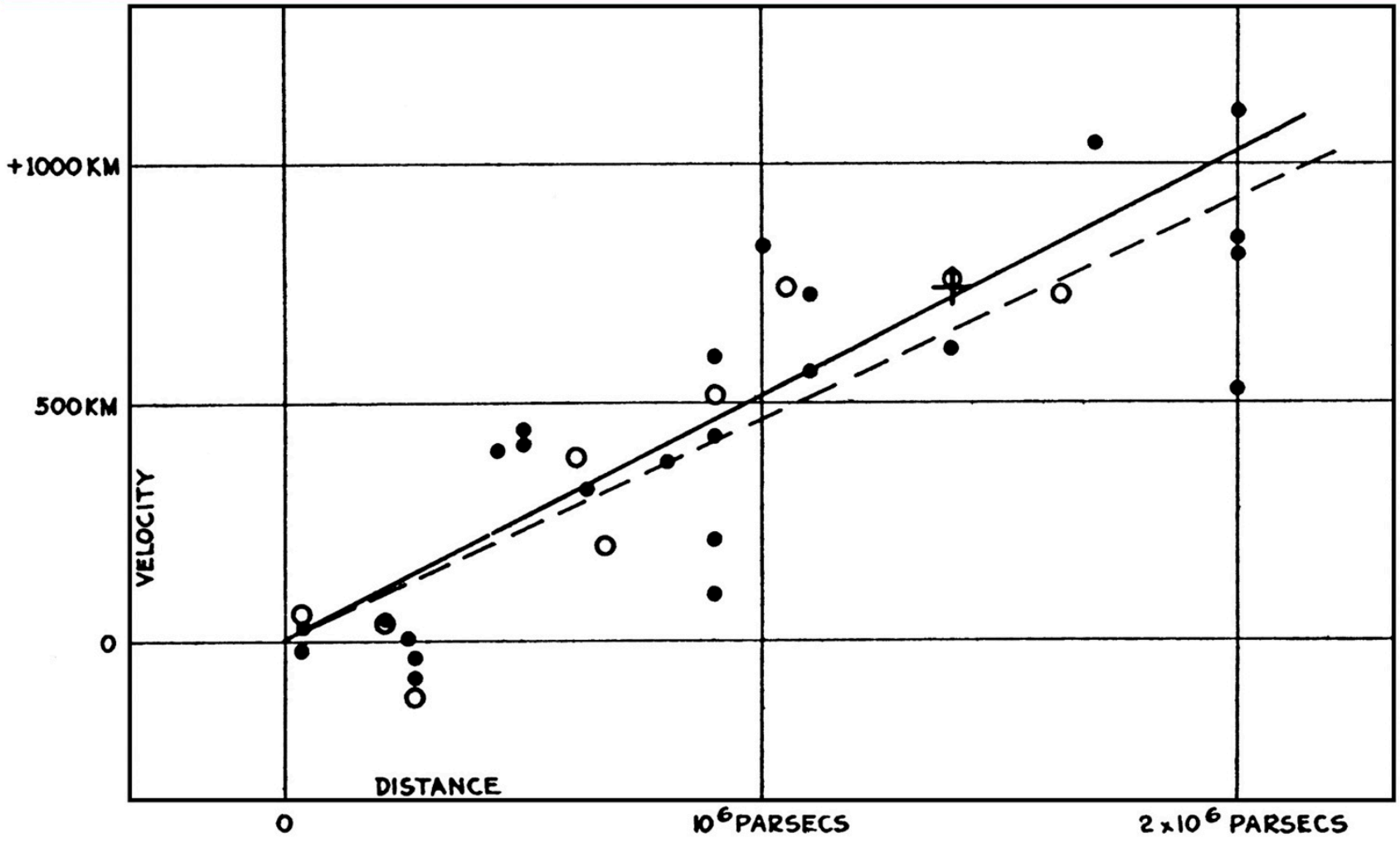
• The measure of the amount a spectral line is shifted in wavelength

Edwin Hubble & Vesto Slipher

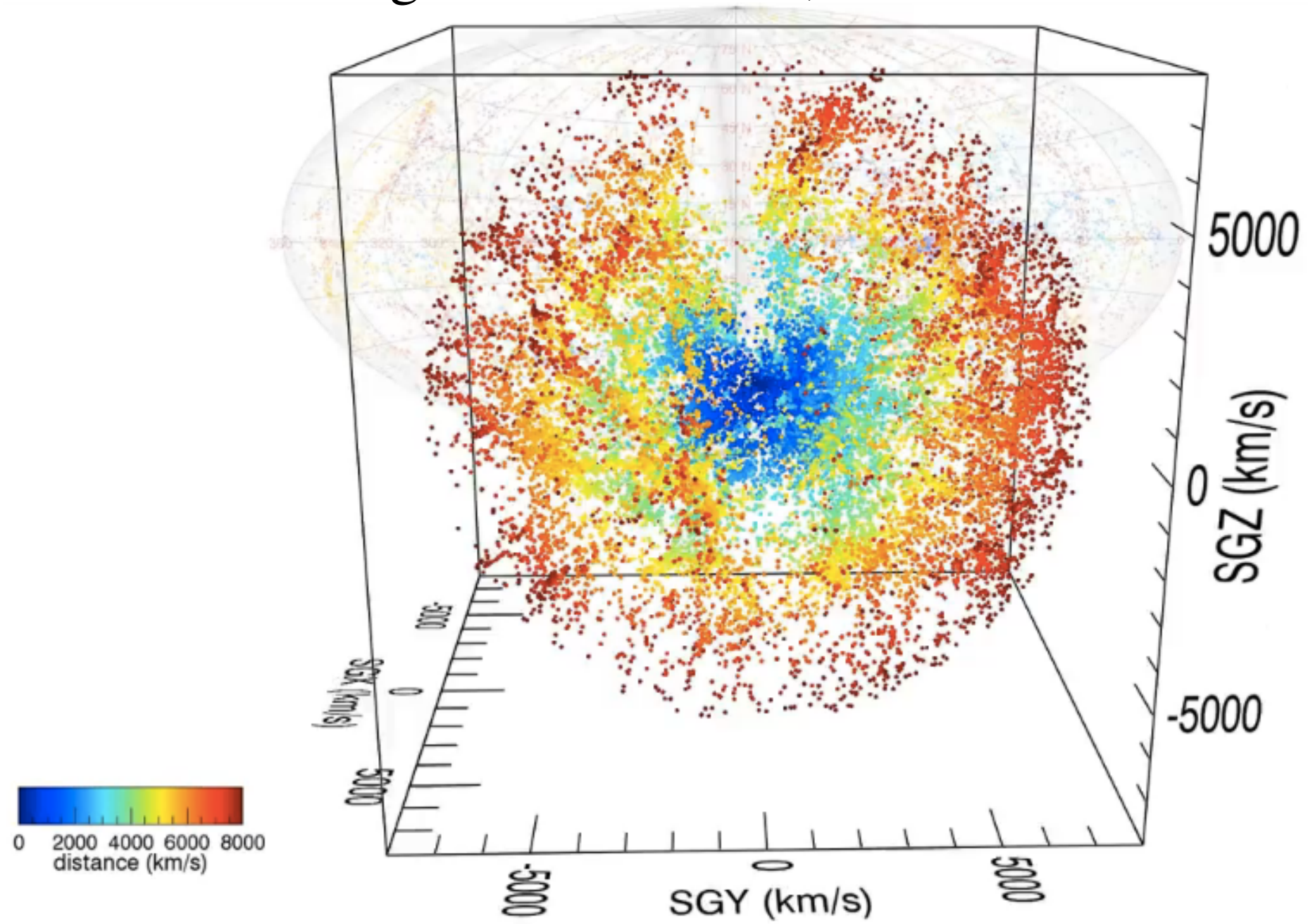
Cluster nebula in	Distance in light-years	Redshifts
 Virgo	78,000,000	 1,200 km s^{-1}
 Ursa Major	1,000,000,000	 15,000 km s^{-1}
 Corona Borealis	1,400,000,000	 22,000 km s^{-1}
 Bootes	2,500,000,000	 39,000 km s^{-1}
 Hydra	3,960,000,000	 61,000 km s^{-1}

Hubble Law - 1929

Originally H_0 ~ 500 km/s/Mpc



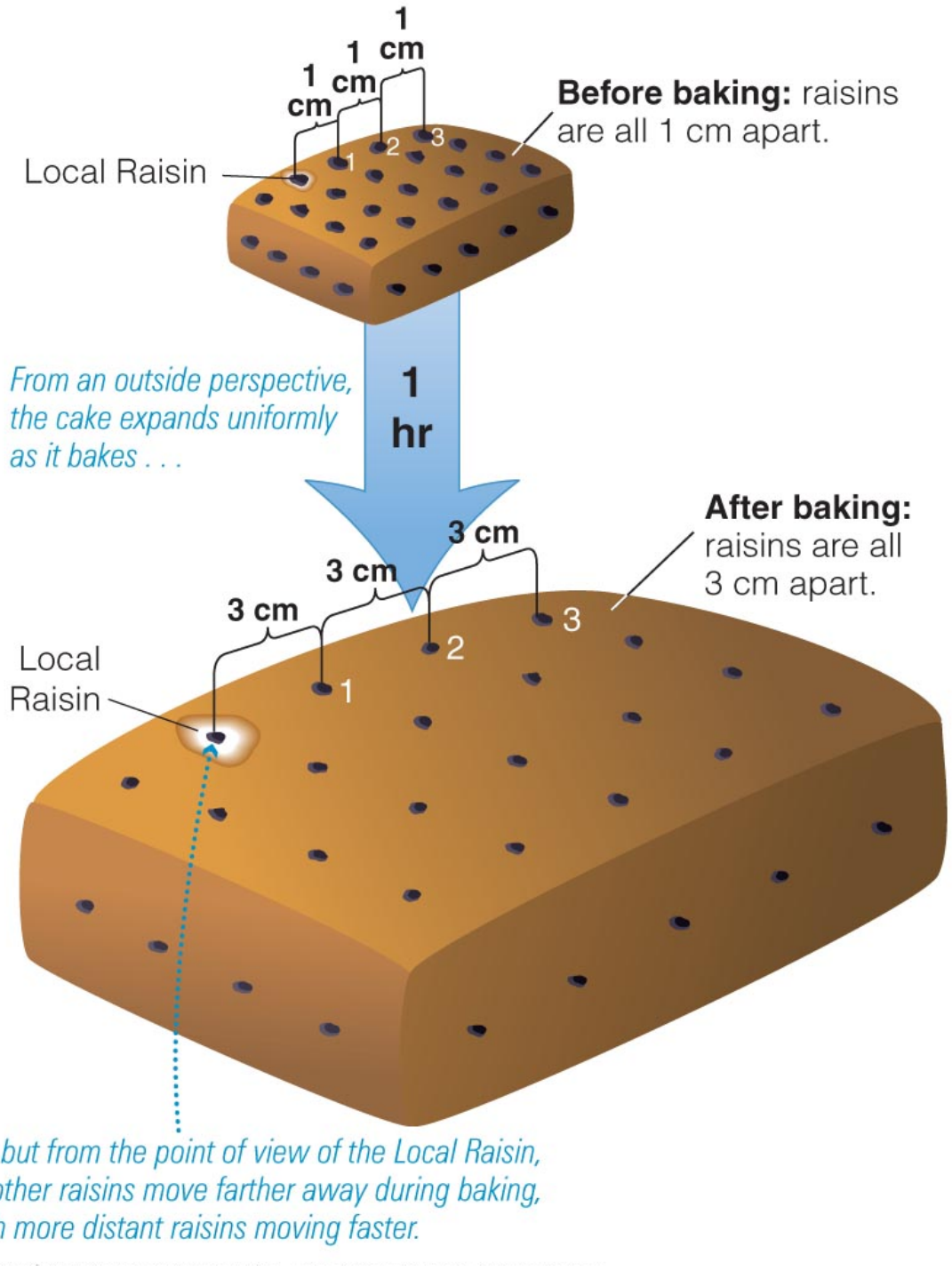
Known galaxies within 8,000 km/s of us



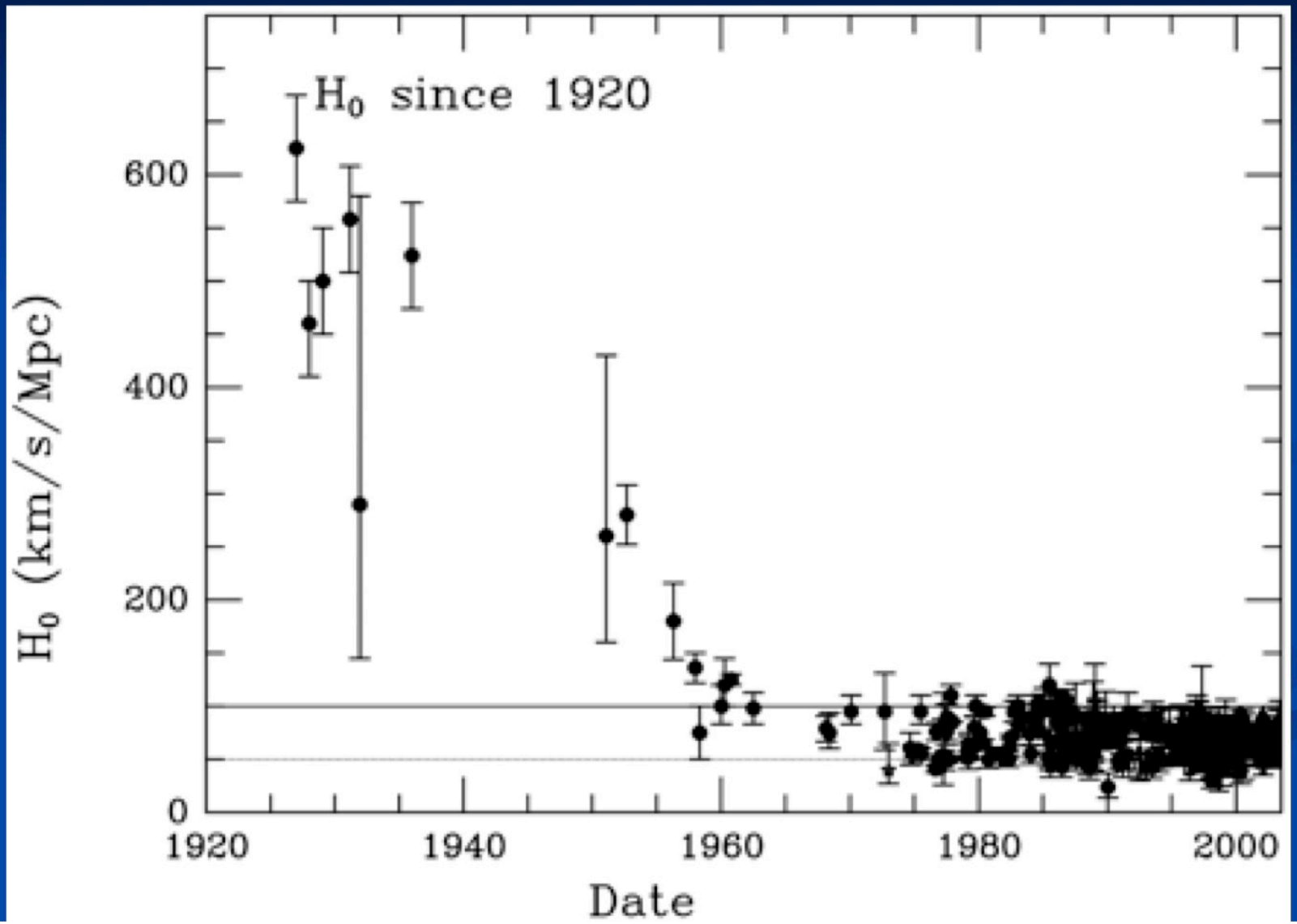
• Galaxies are all moving away from each other, so every galaxy sees the same Hubble expansion, i.e there is no center.

• The cosmic expansion is the unfolding of all space since the big bang, i.e. there is no edge.

• We are limited in our view by the time it takes distant light to reach us, i.e. the universe has an edge in time not space.

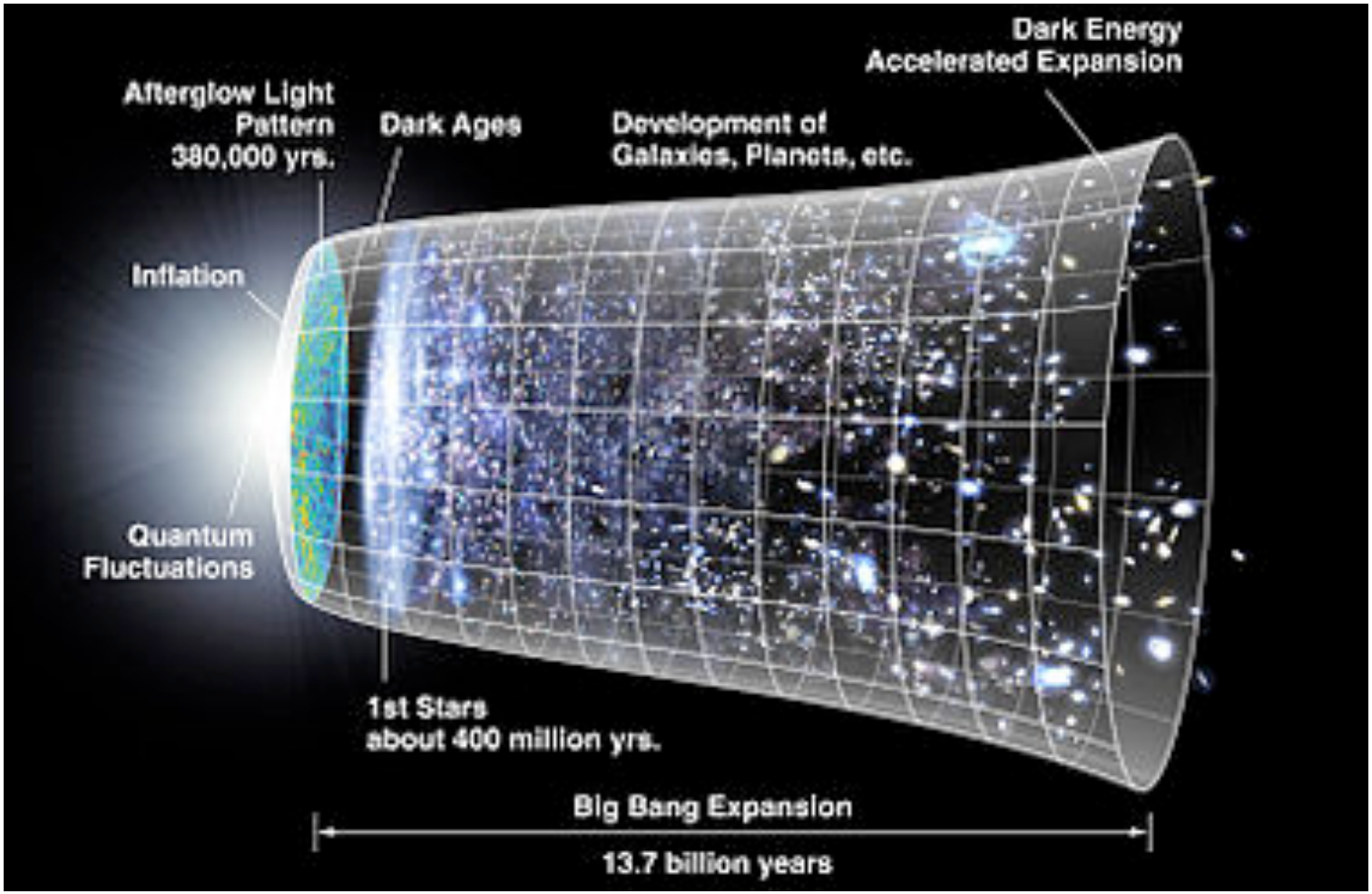


Hubble Constant Determinations

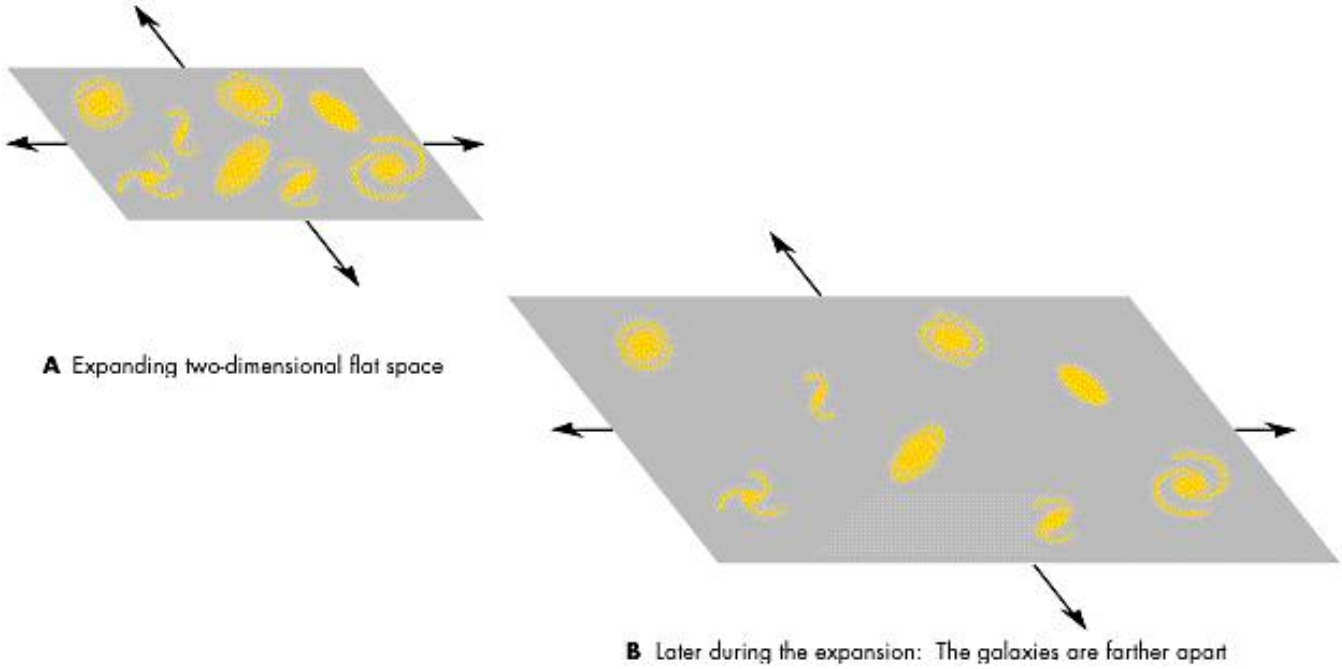


Cosmology: What We Know

1. Redshift – it's cosmic expansion, *not Doppler*



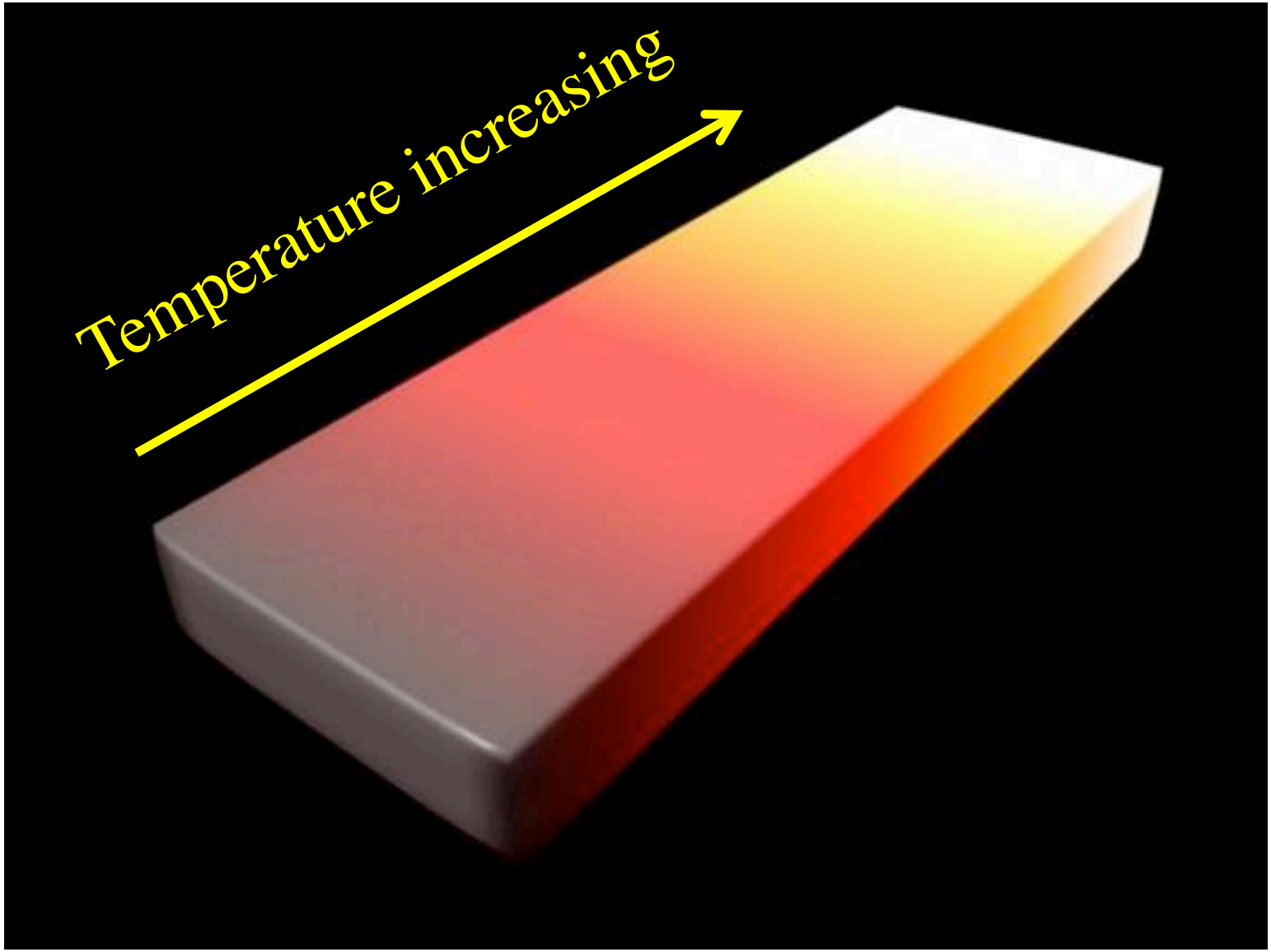
1. If the Universe is expanding, then reversing that expansion (going backwards in time) indicates that the Universe must have been smaller in the past.



A Expanding two-dimensional flat space

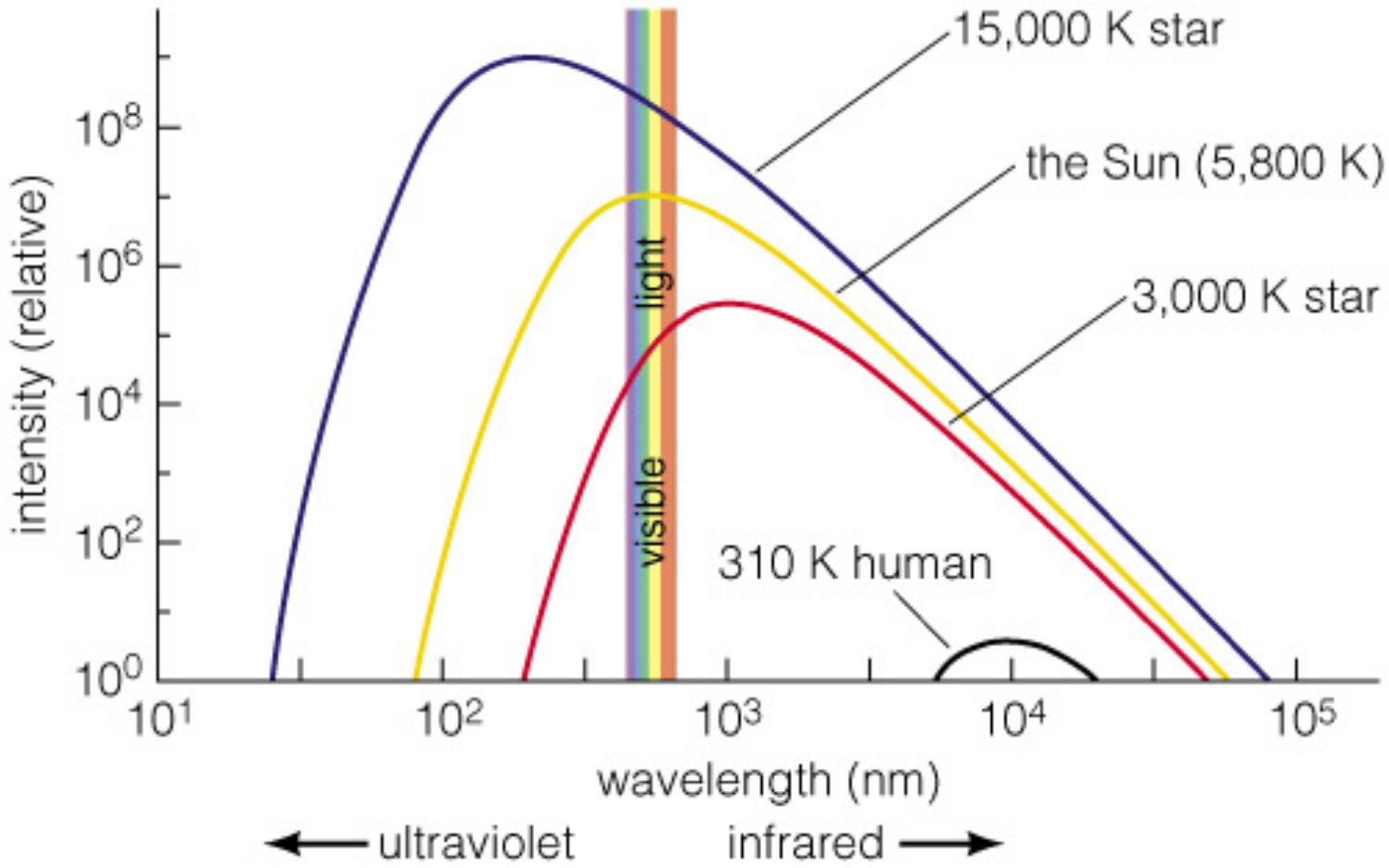
B Later during the expansion: The galaxies are farther apart

Blackbody (Thermal) Radiation

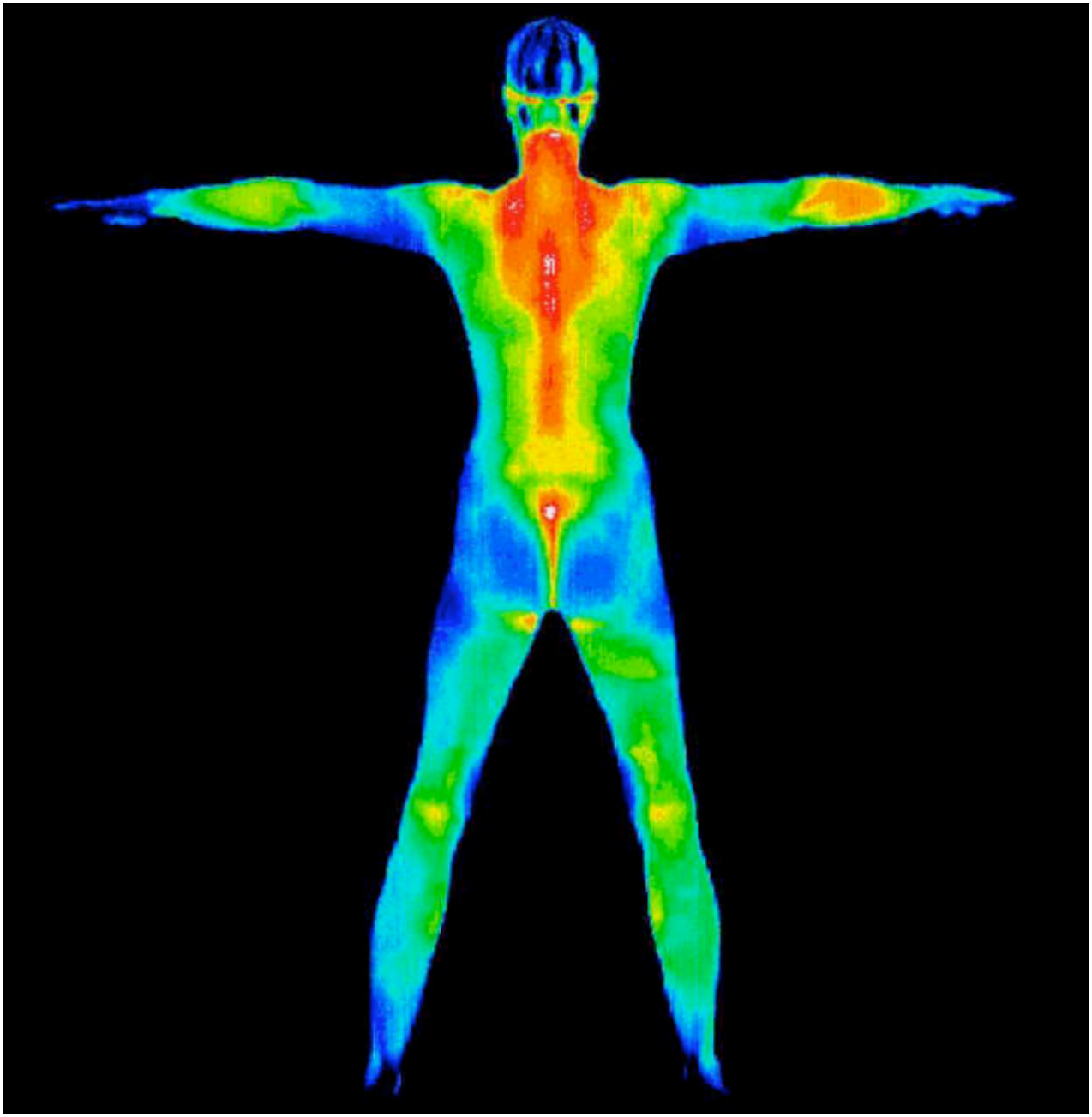


Two Properties of Thermal Radiation:

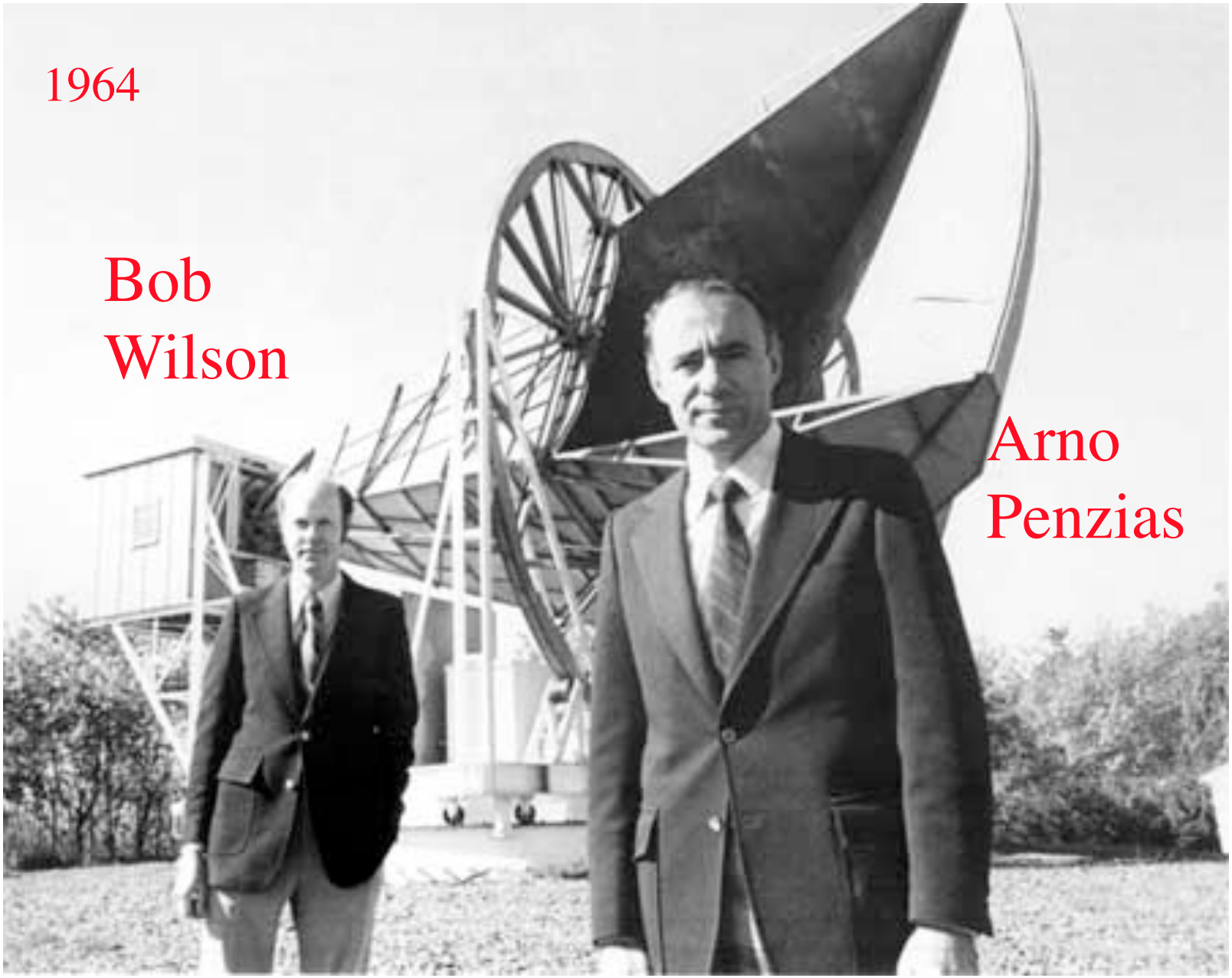
1. Hotter objects emit more light at all frequencies per unit area.
2. Hotter objects emit photons with a higher average energy.



Infrared Light – Human Body Glows!

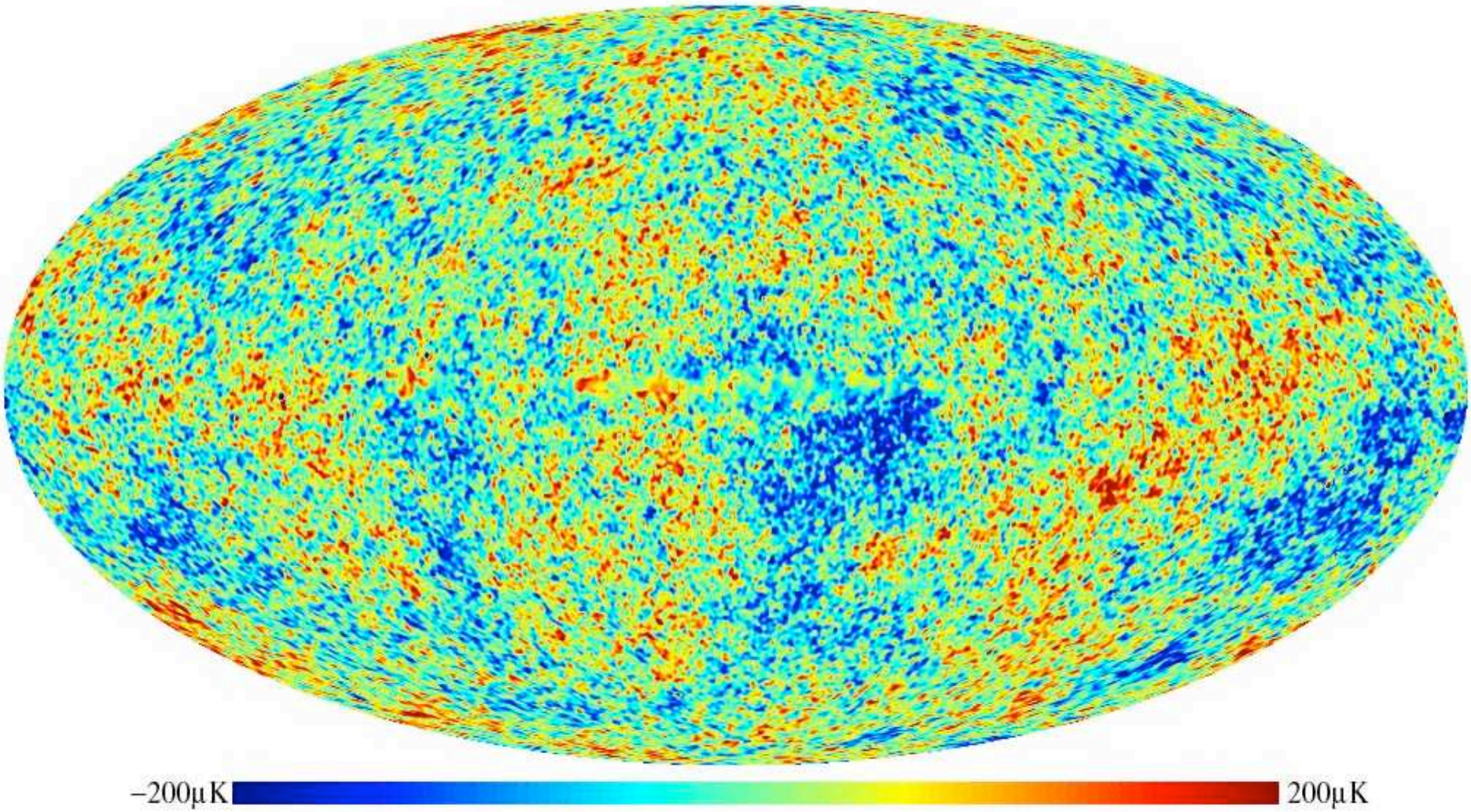


2. Discovery of the Cosmic Microwave Background

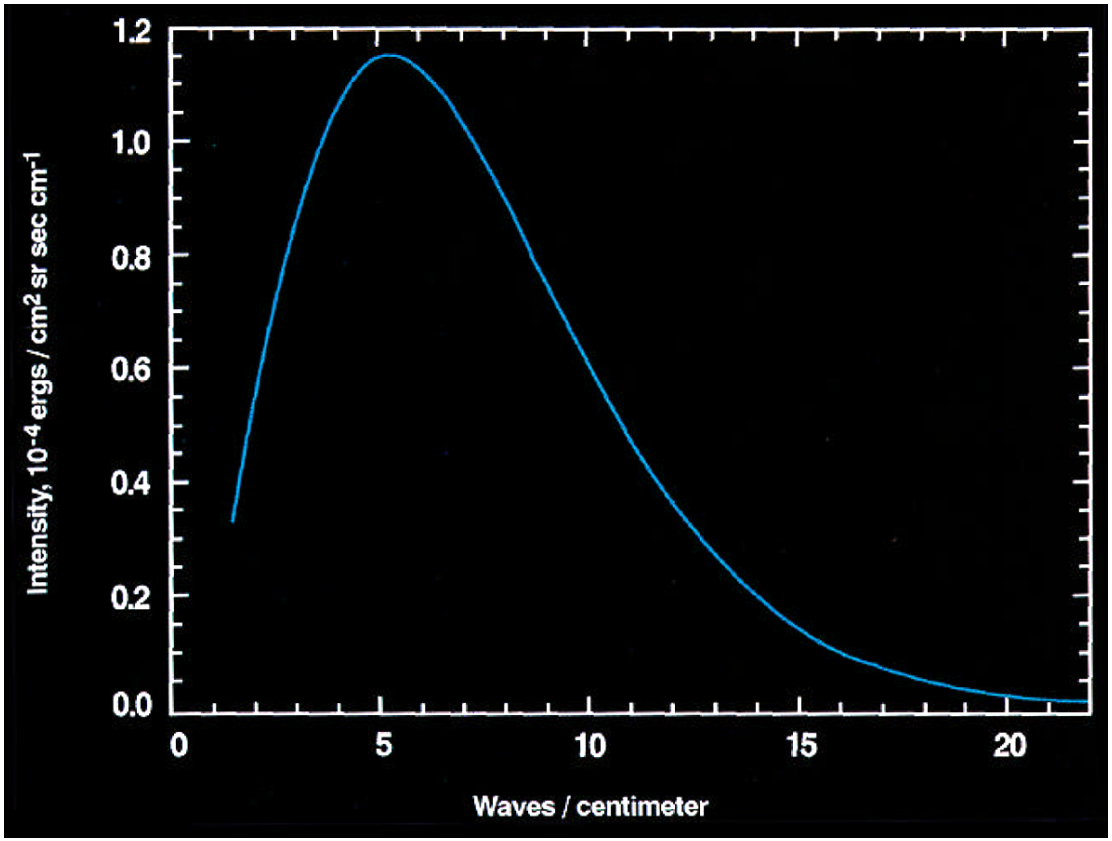


Cosmic Microwave Background: The farthest we can see back…

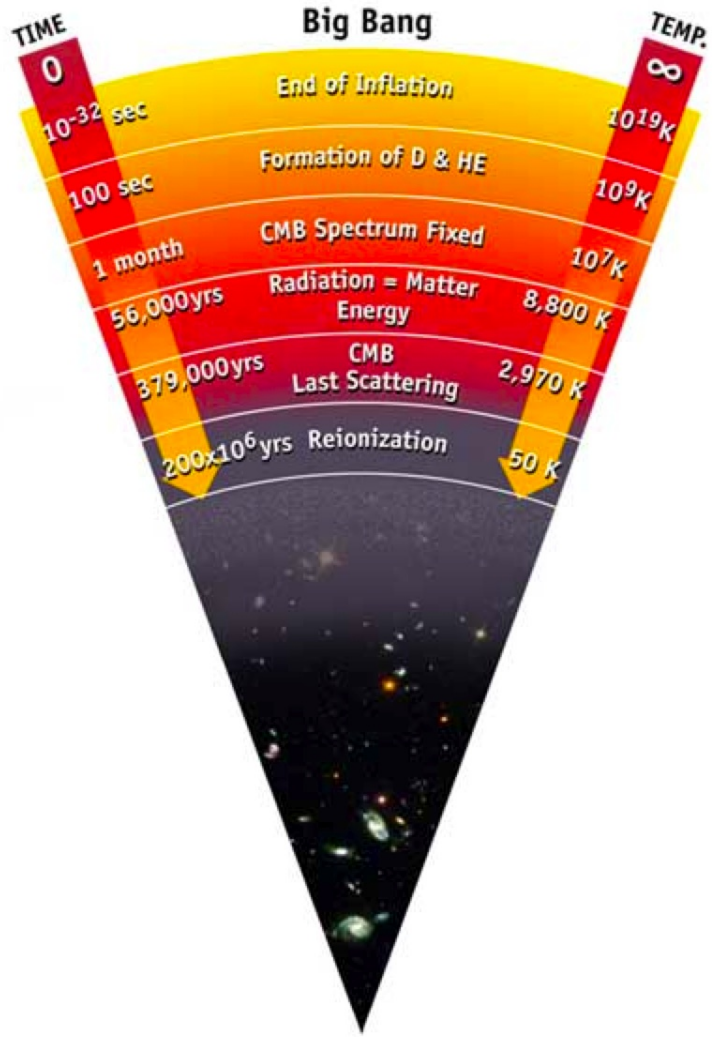
Radiation signature from 300,000 years after the Big Bang



Cosmology: What We Know

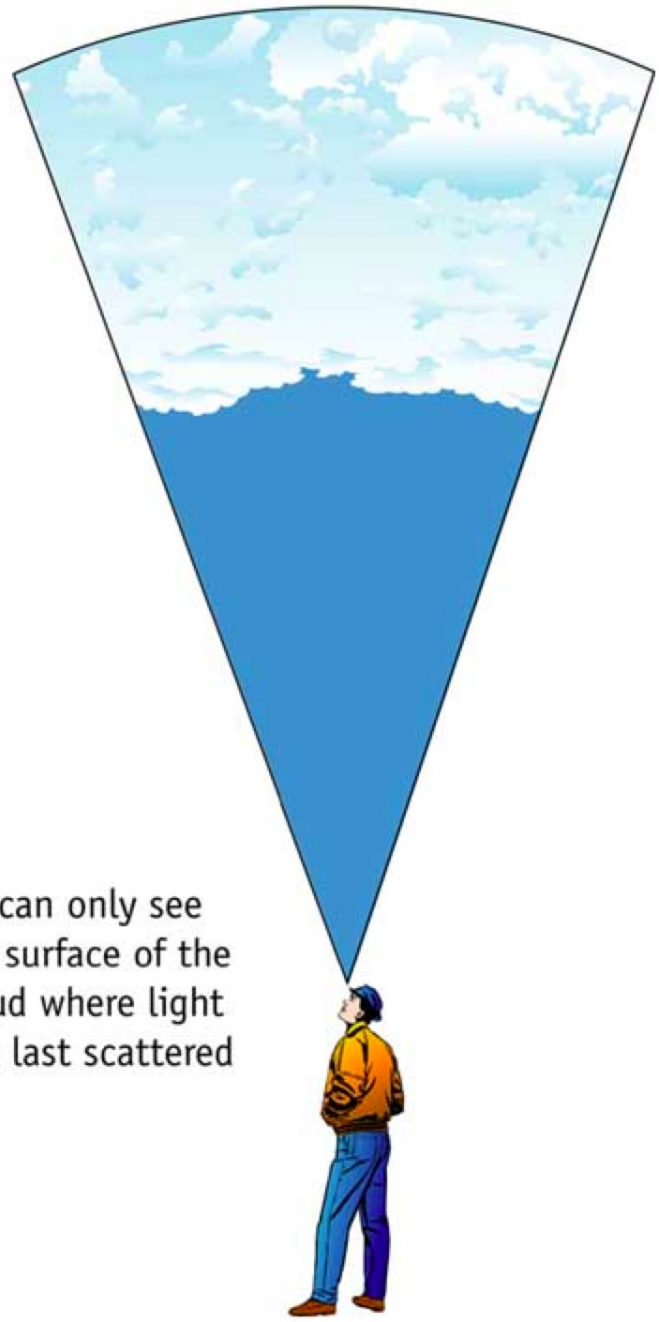


2. Background Radiation – thermal, at 2.73K



PRESENT
13.7 Billion Years after the Big Bang

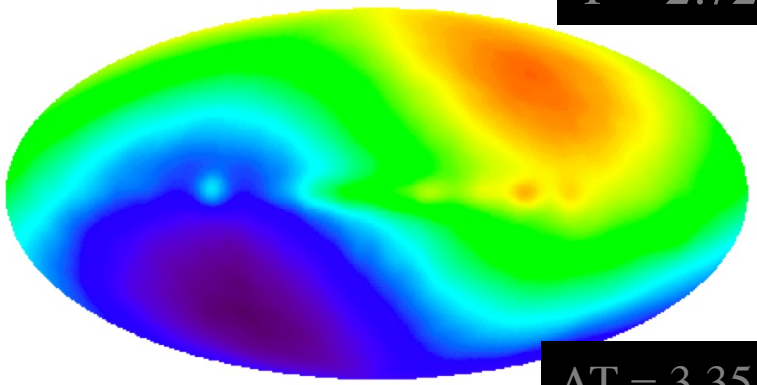
The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.



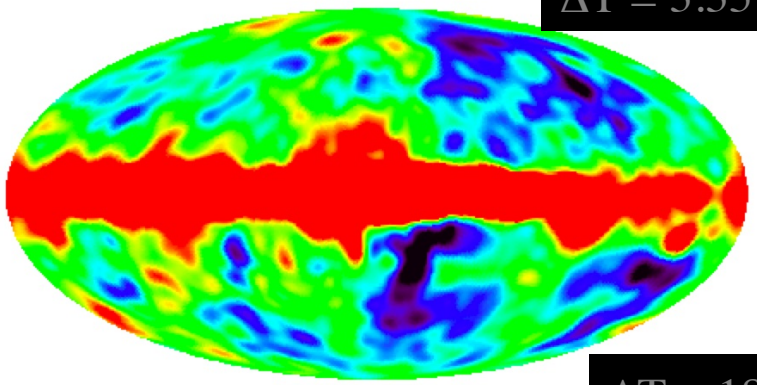
We can only see the surface of the cloud where light was last scattered

Measuring the Cosmic Microwave Background

T = 2.725 K

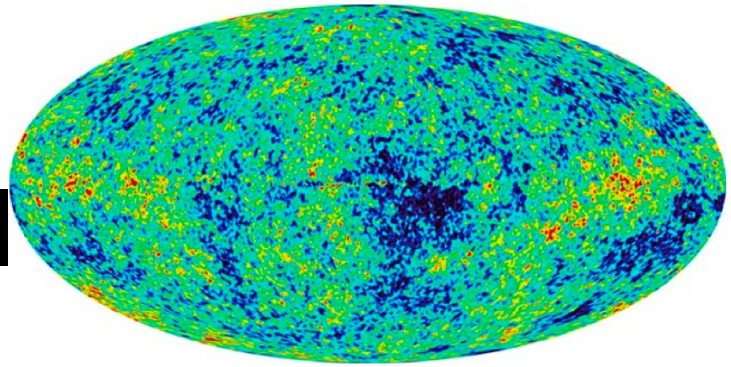


ΔT = 3.35 mK



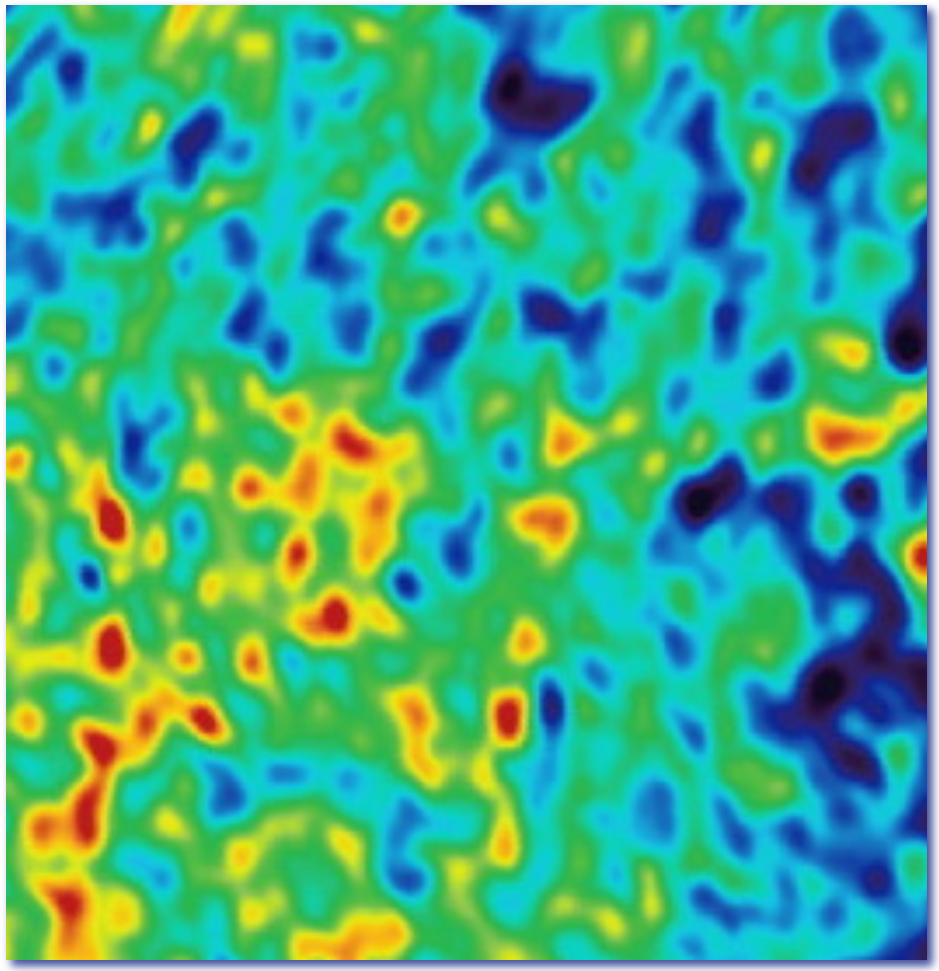
ΔT = 18 μK

WMAP

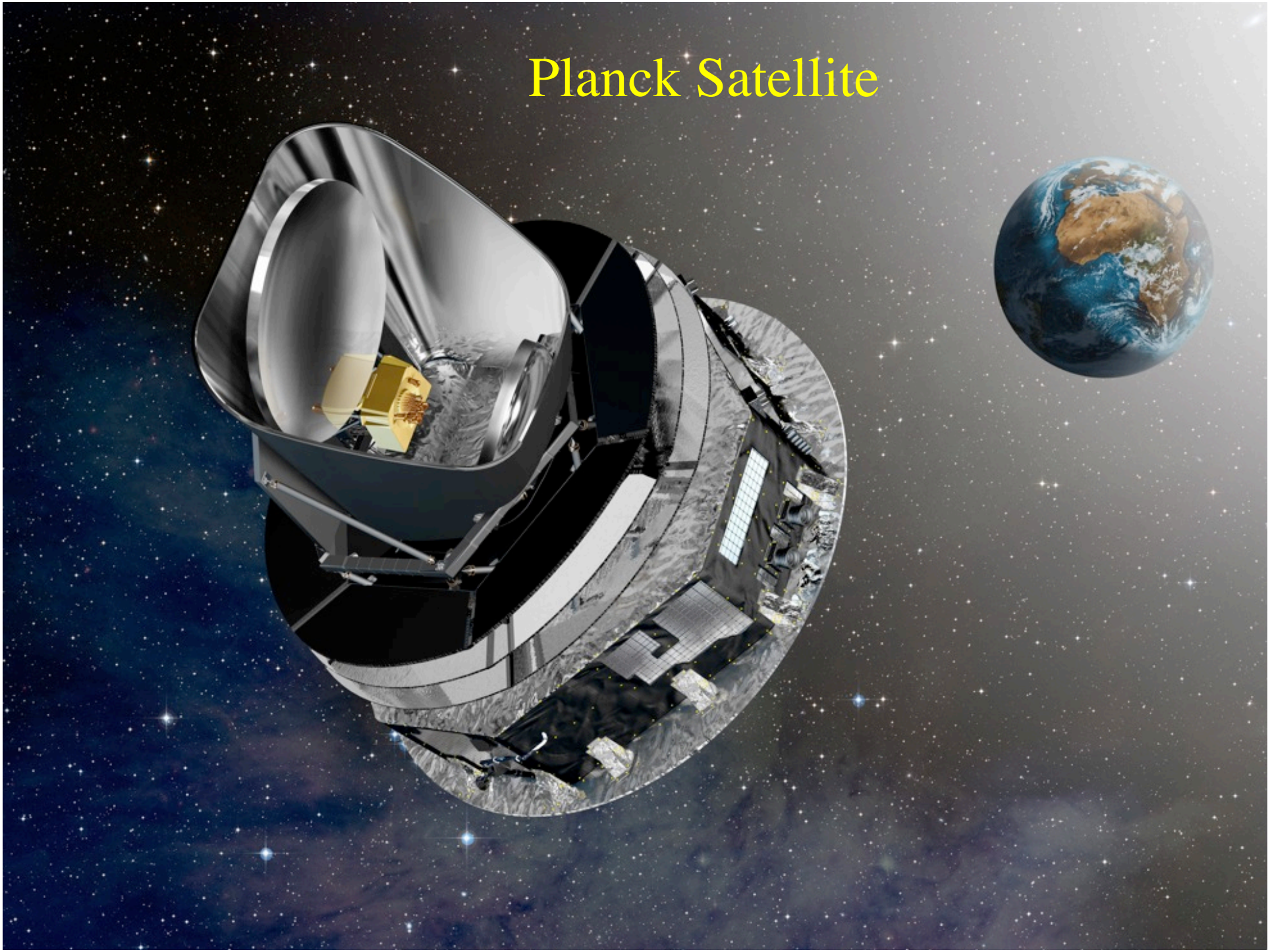


ΔT = 18 μK

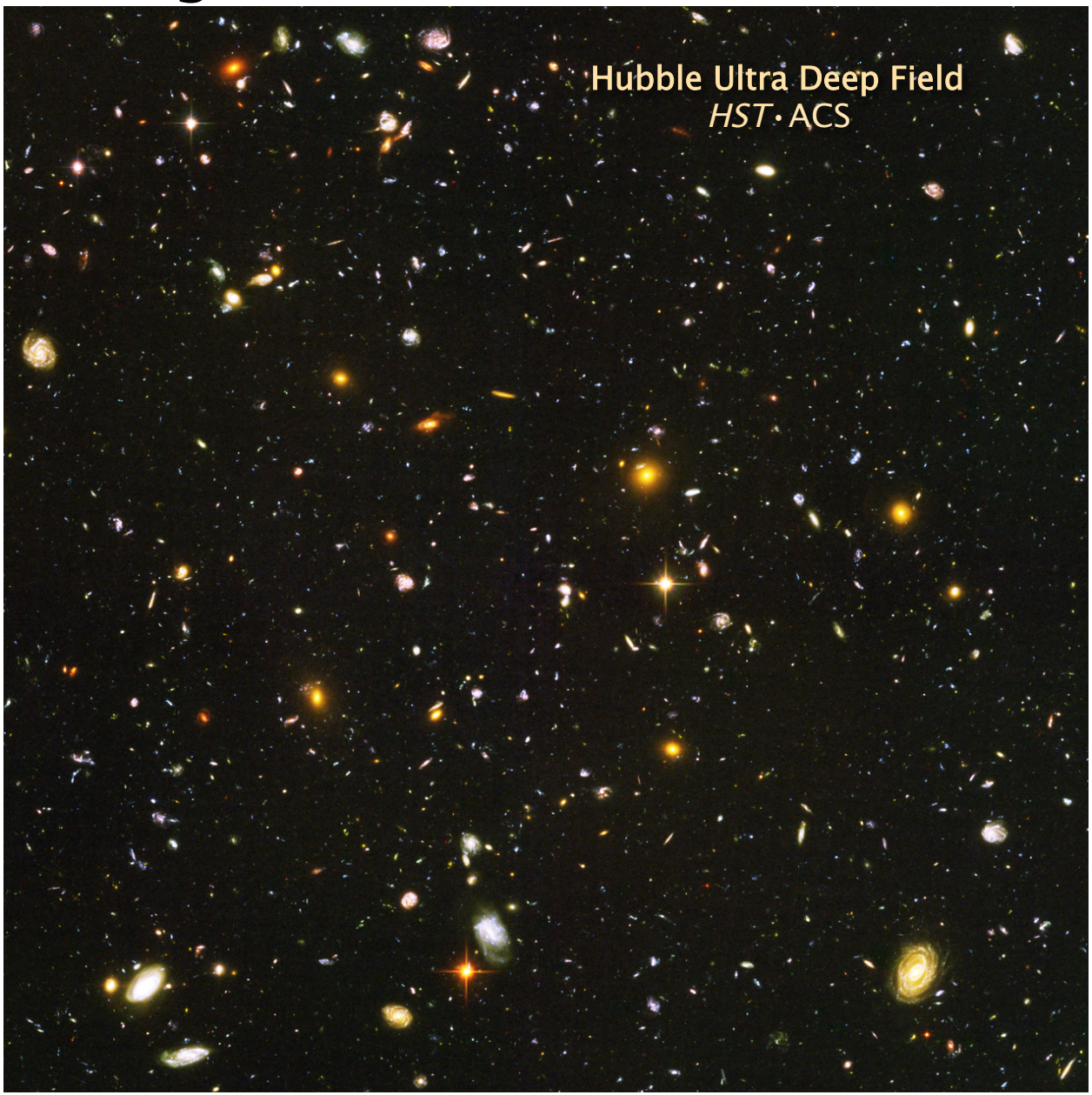
An image of quantum fluctuations blown up to the size of the universe

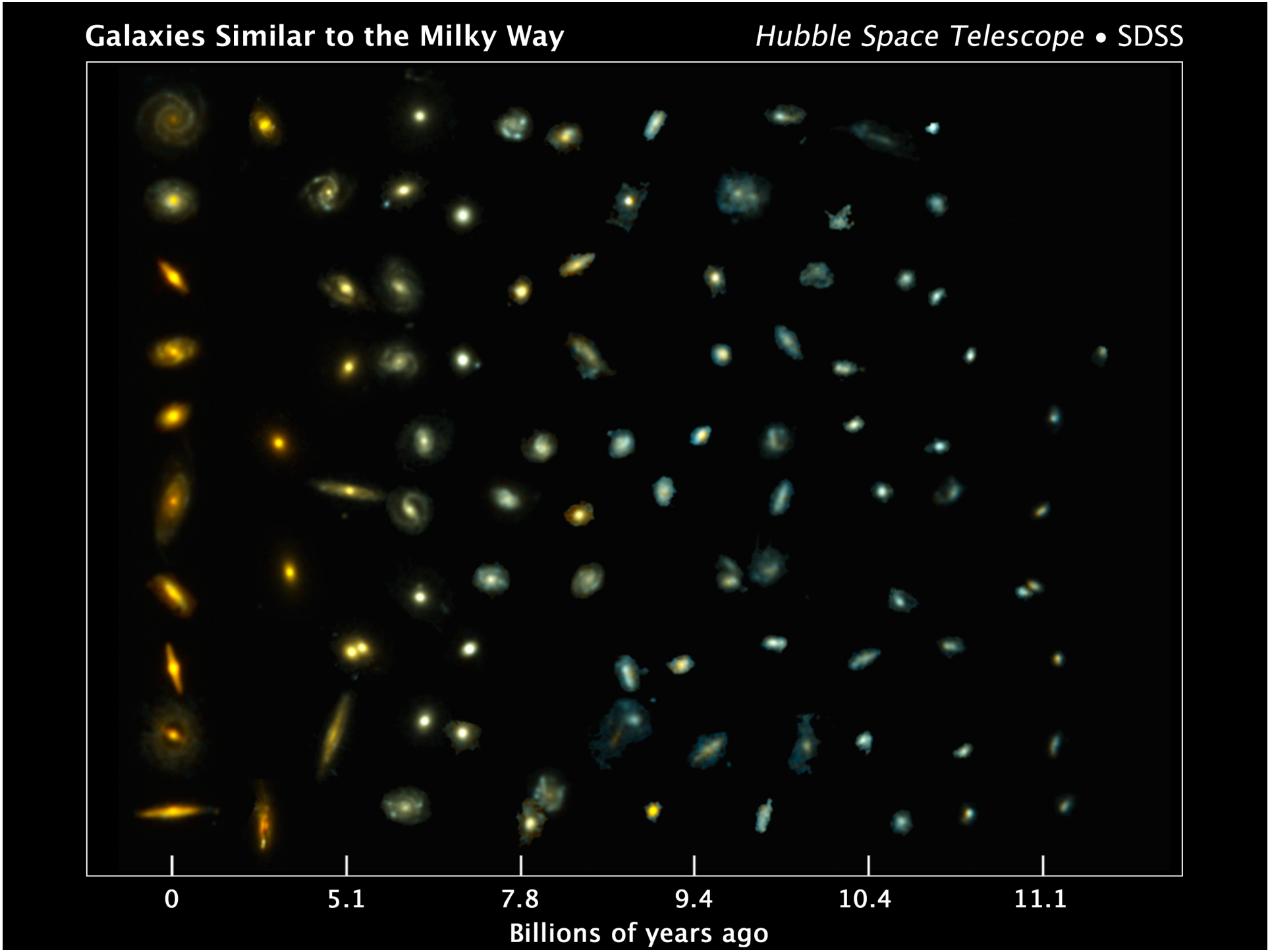


Planck Satellite



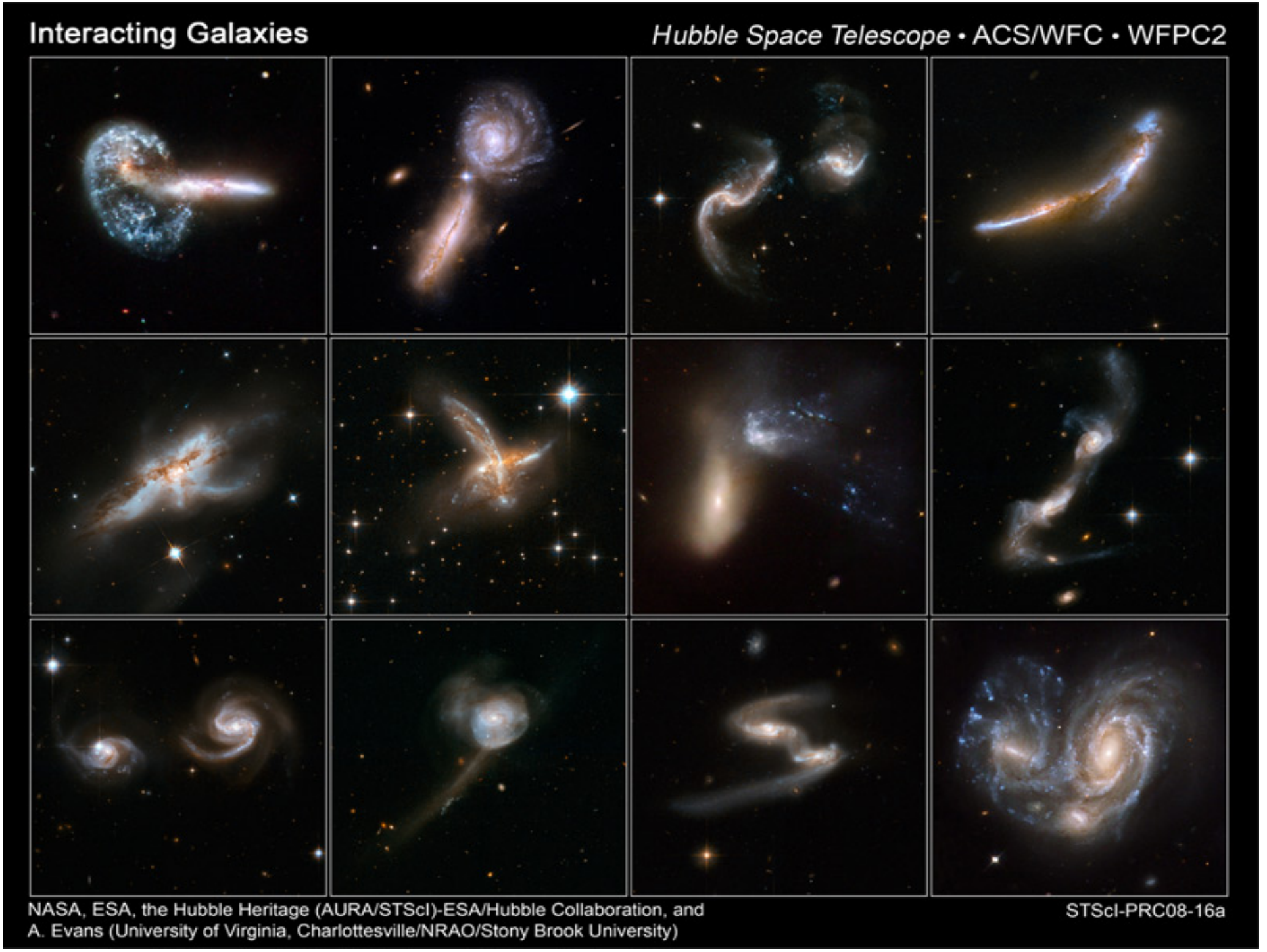
3. Galaxies in past look younger (smaller and more irregular)




Galaxies Similar to the Milky Way
Hubble Space Telescope • SDSS
0
5.1
7.8
9.4
10.4
11.1
Billions of years ago

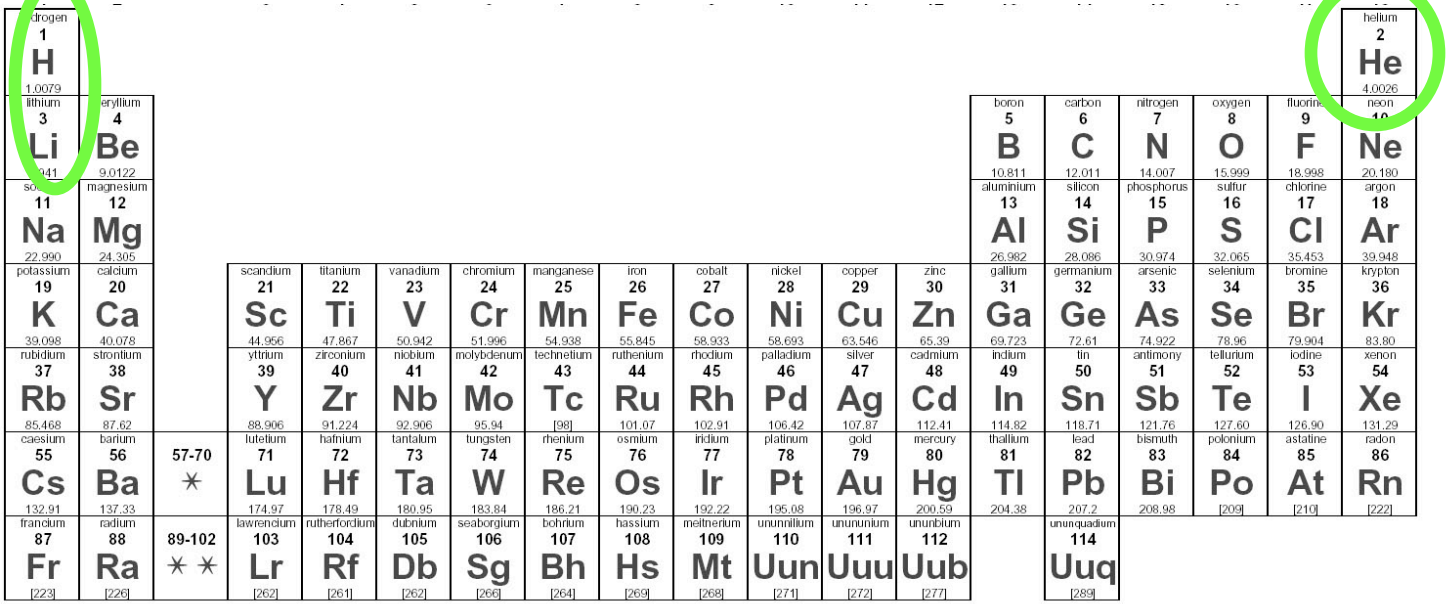
Galaxy Formation Simulation

Courtesy Charlotte Christensen

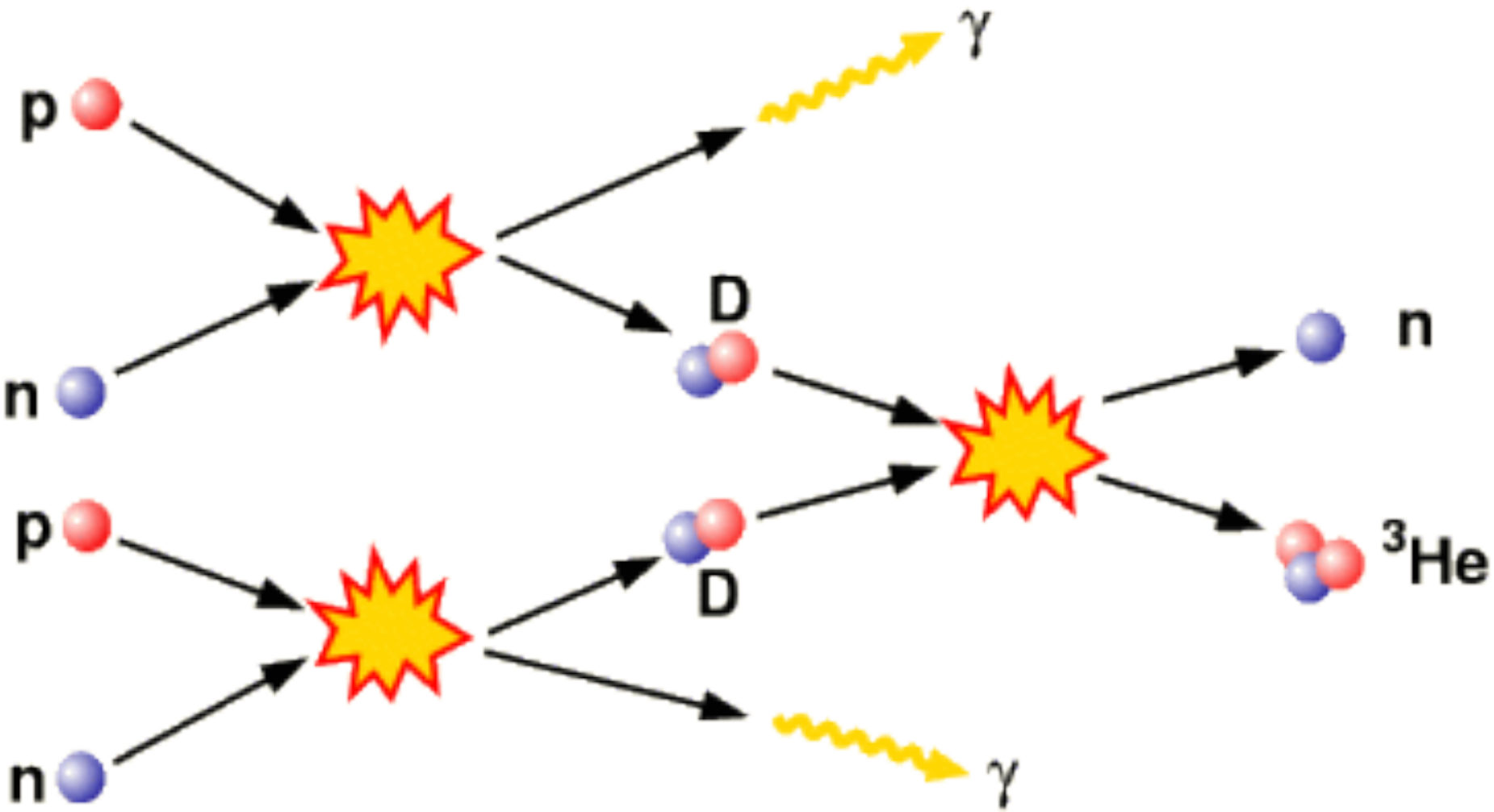

Interacting Galaxies
Hubble Space Telescope • ACS/WFC • WFPC2
NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and
A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)
STScI-PRC08-16a

4. Abundance of the Lightest Elements

The lightest elements — hydrogen, helium, and a smattering of deuterium (heavy hydrogen isotope) and lithium — were from the big bang itself, produced by fusion in the first three minutes when the universe was as hot as the core of a star like the Sun!

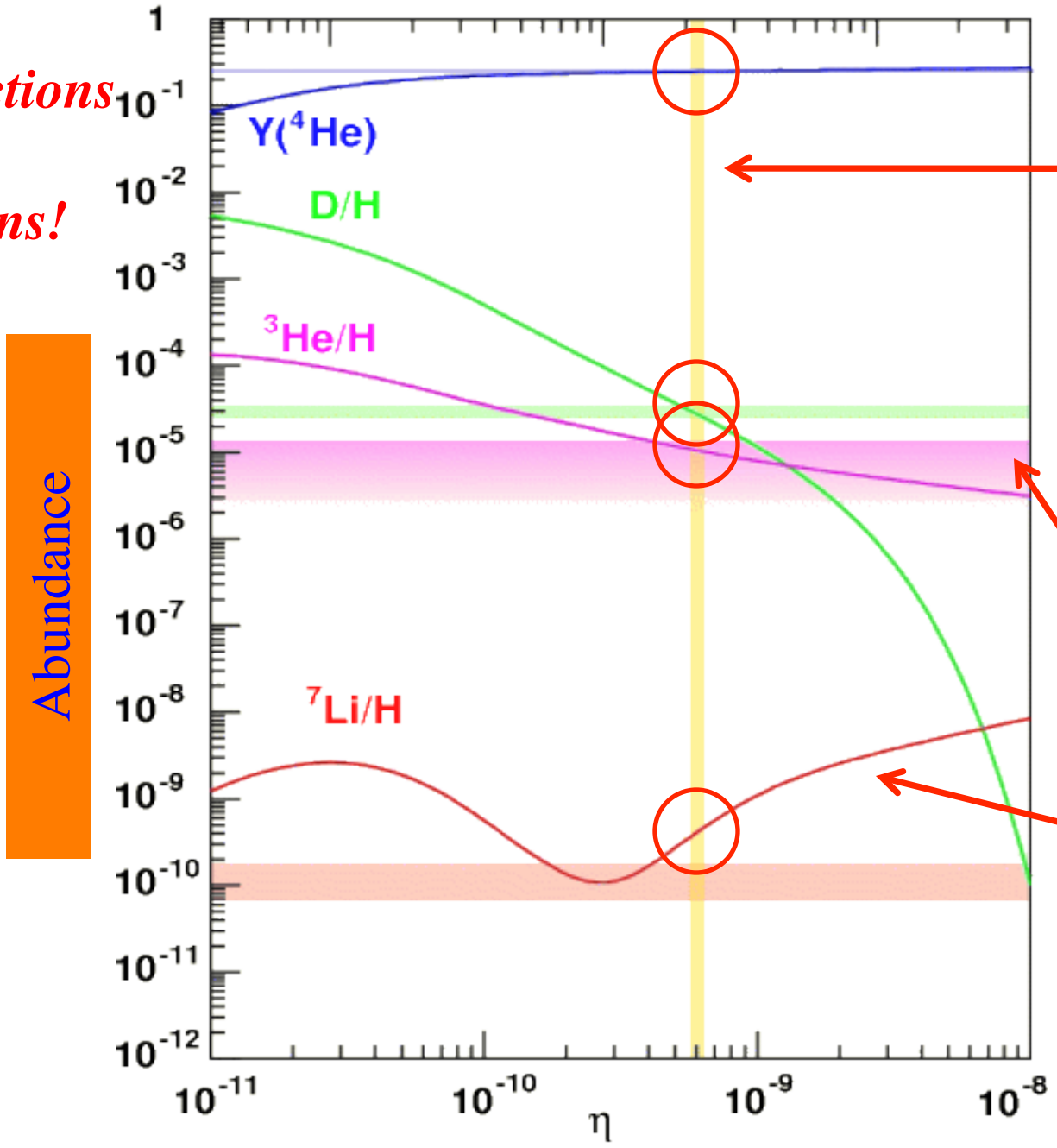


Big Bang Fusion



Nuclear fusion in first 3 minutes

The predictions match observations!



WMAP measured this ratio of matter/ photons

Horizontal bands are observed abundances

Solid lines are theory predictions

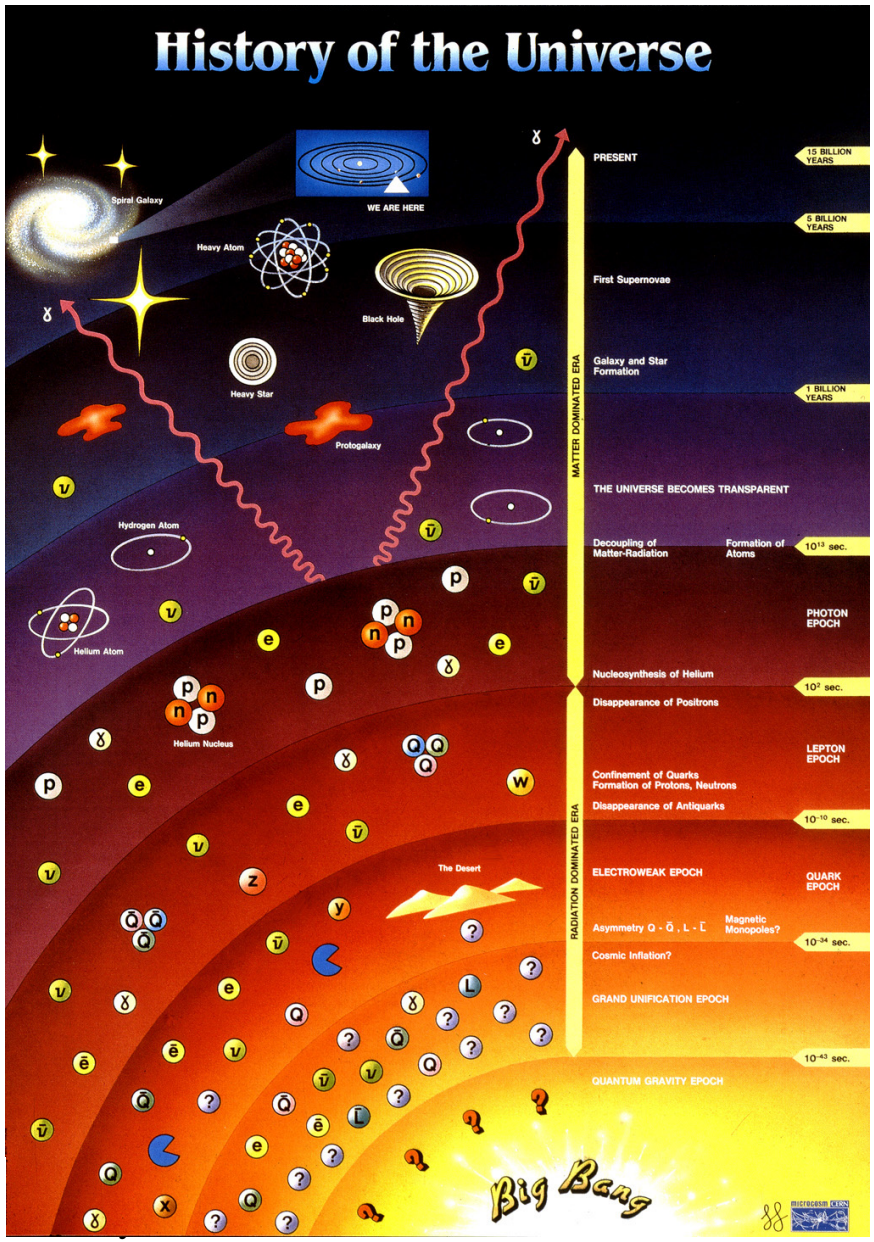
Status of the Big Bang

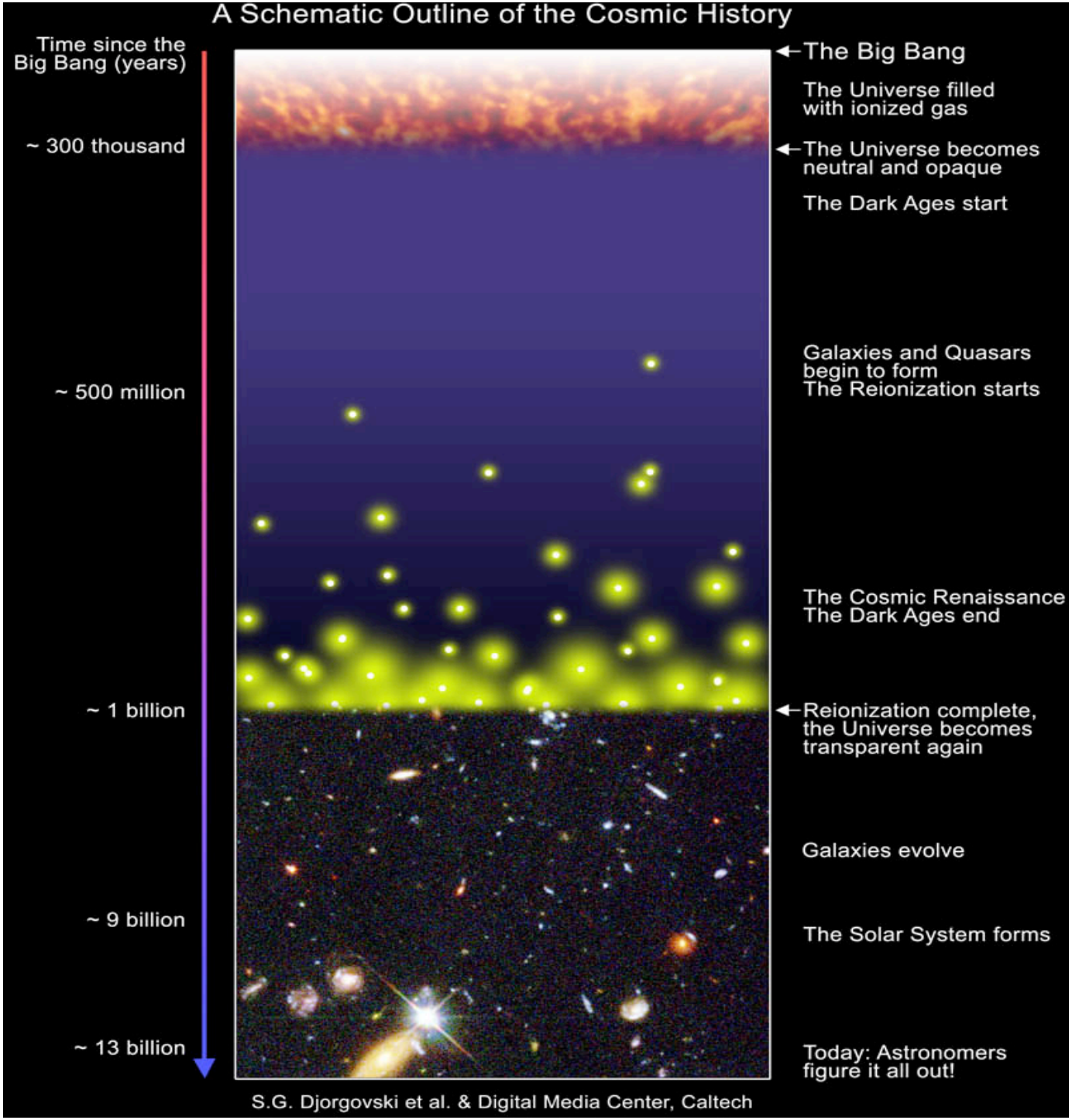
There is evidence for expansion, and the universe was hotter and denser in the distant past.

The microwave background and the helium abundance cannot easily be explained in any other way.

There are hundred of thousands of big bang photons in every breath you take: the big bang is all around us.

It is a theory, but a theory with a web of evidence to support it. The theory is mute about the cause of the cause.

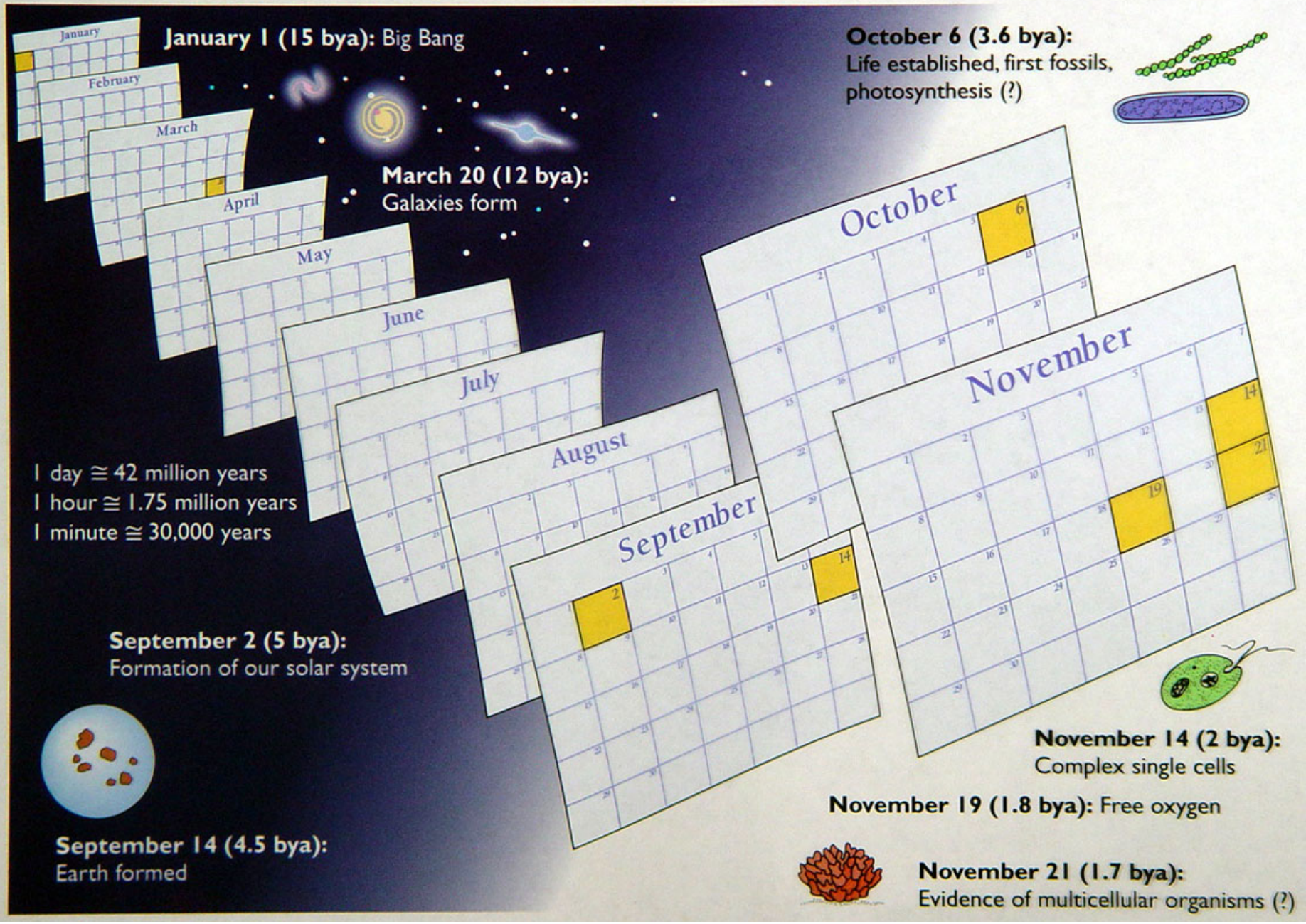



A Schematic Outline of the Cosmic History
Time since the Big Bang (years)
~ 300 thousand
~ 500 million
~ 1 billion
~ 9 billion
~ 13 billion
The Big Bang
The Universe filled with ionized gas
The Universe becomes neutral and opaque
The Dark Ages start
Galaxies and Quasars begin to form
The Reionization starts
The Cosmic Renaissance
The Dark Ages end
Reionization complete, the Universe becomes transparent again
Galaxies evolve
The Solar System forms
Today: Astronomers figure it all out!
S.G. Djorgovski et al. & Digital Media Center, Caltech

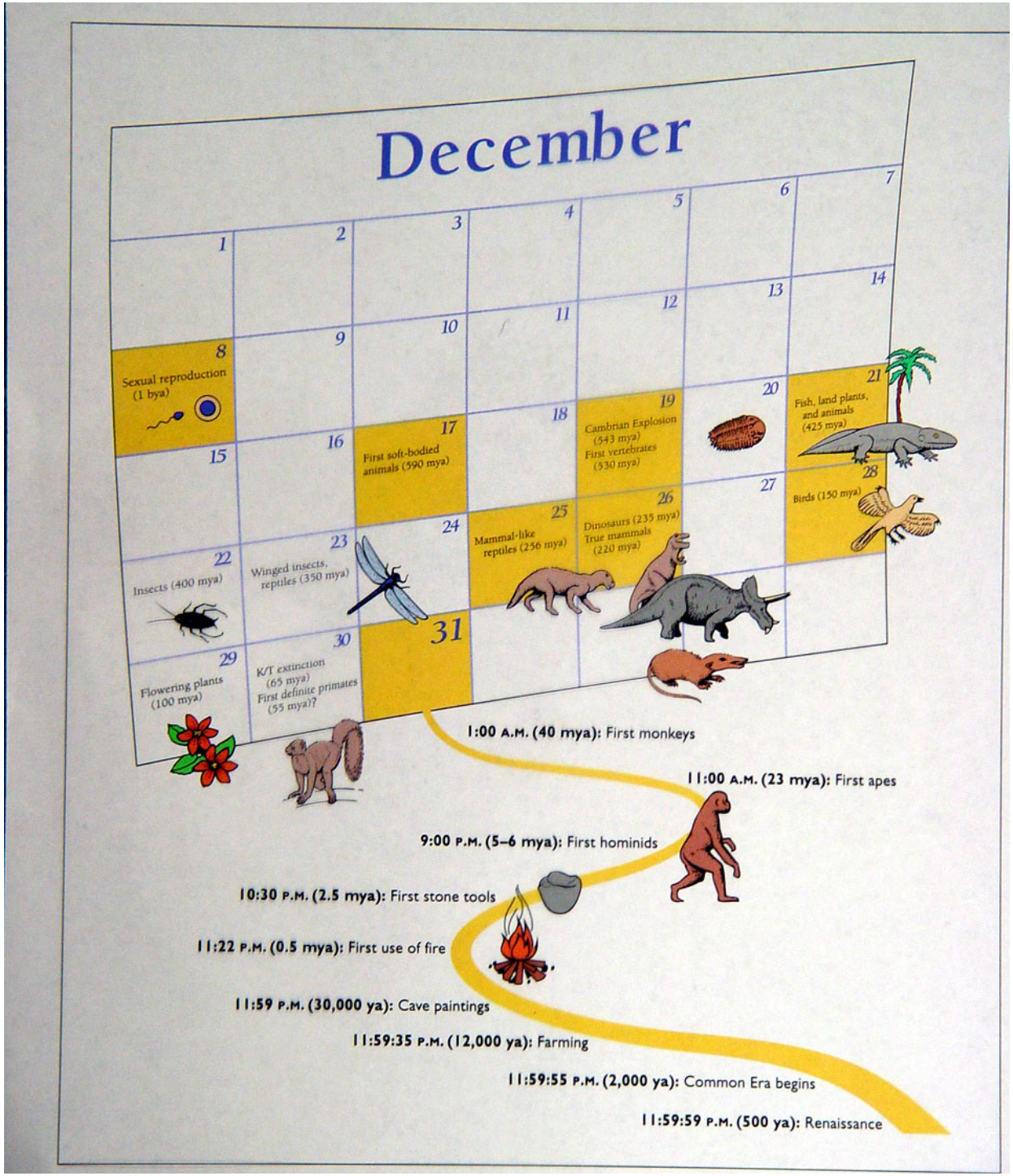
How do our lifetimes compare to the age of the Universe?

- The Cosmic Calendar: a scale on which we compress the history of the universe into 1 year.
- This is a time scale model where 14 billion years equals 1 year, i.e. 14,000,000,000:1.
- Our lives would scale similarly, so 80 years goes down by a factor of 14 billion too.
- In the scale model, a human life is about 2 tenths of a second!

The Cosmic Calendar: January-November



Now home in on the more recent span of the history of life and of humans and civilization



The Raw Material for Astrobiology

- **Space:** the potential habitable worlds around ten thousand billion billion stars; ours is just one.
- **Time:** a cosmic history of nearly 14 billion years; life took less than ½ billion years to start here.

"If they not be inhabited, what a waste of space."

Thomas Carlyle, Scottish Essayist (1795-1881)