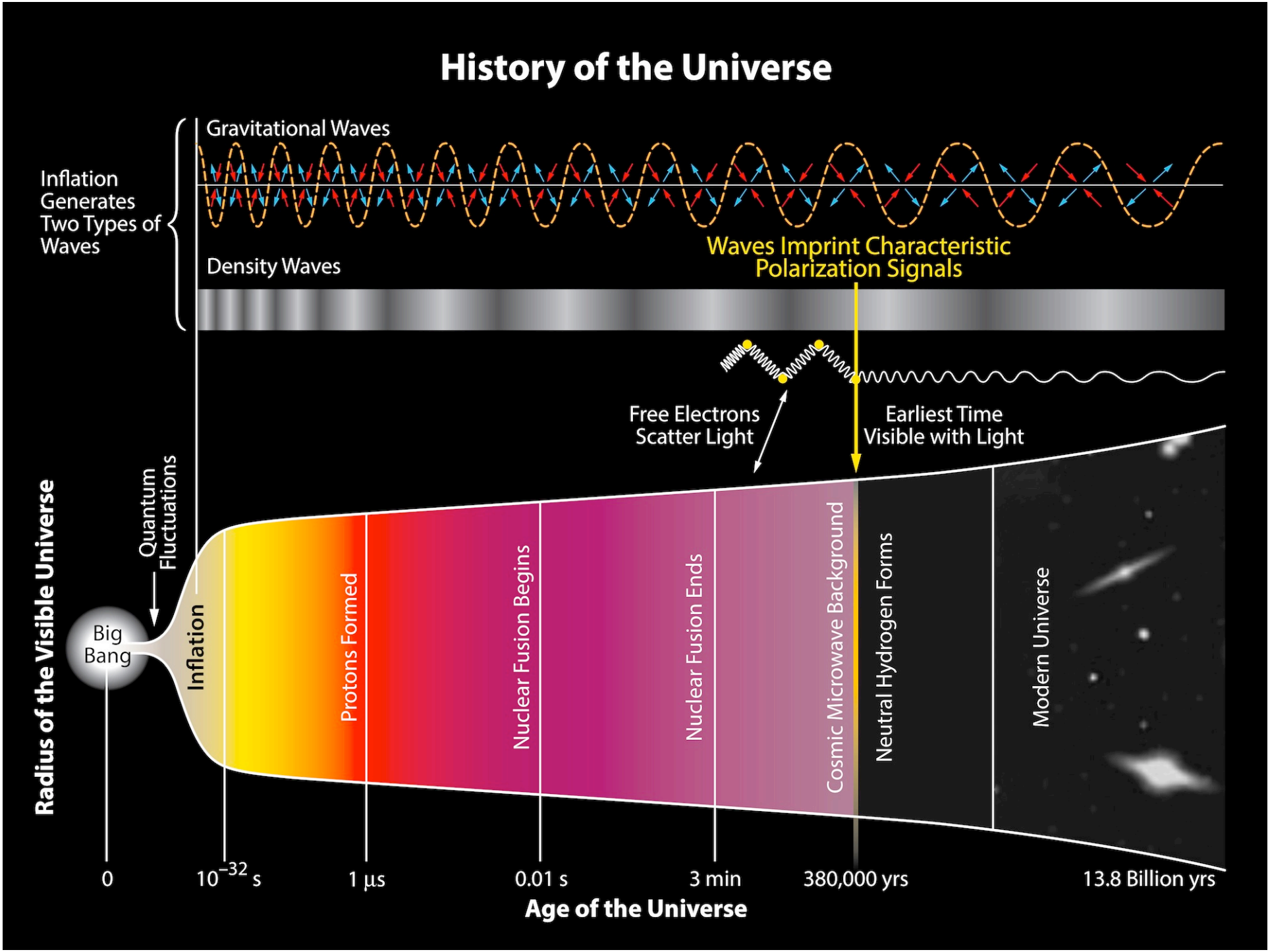
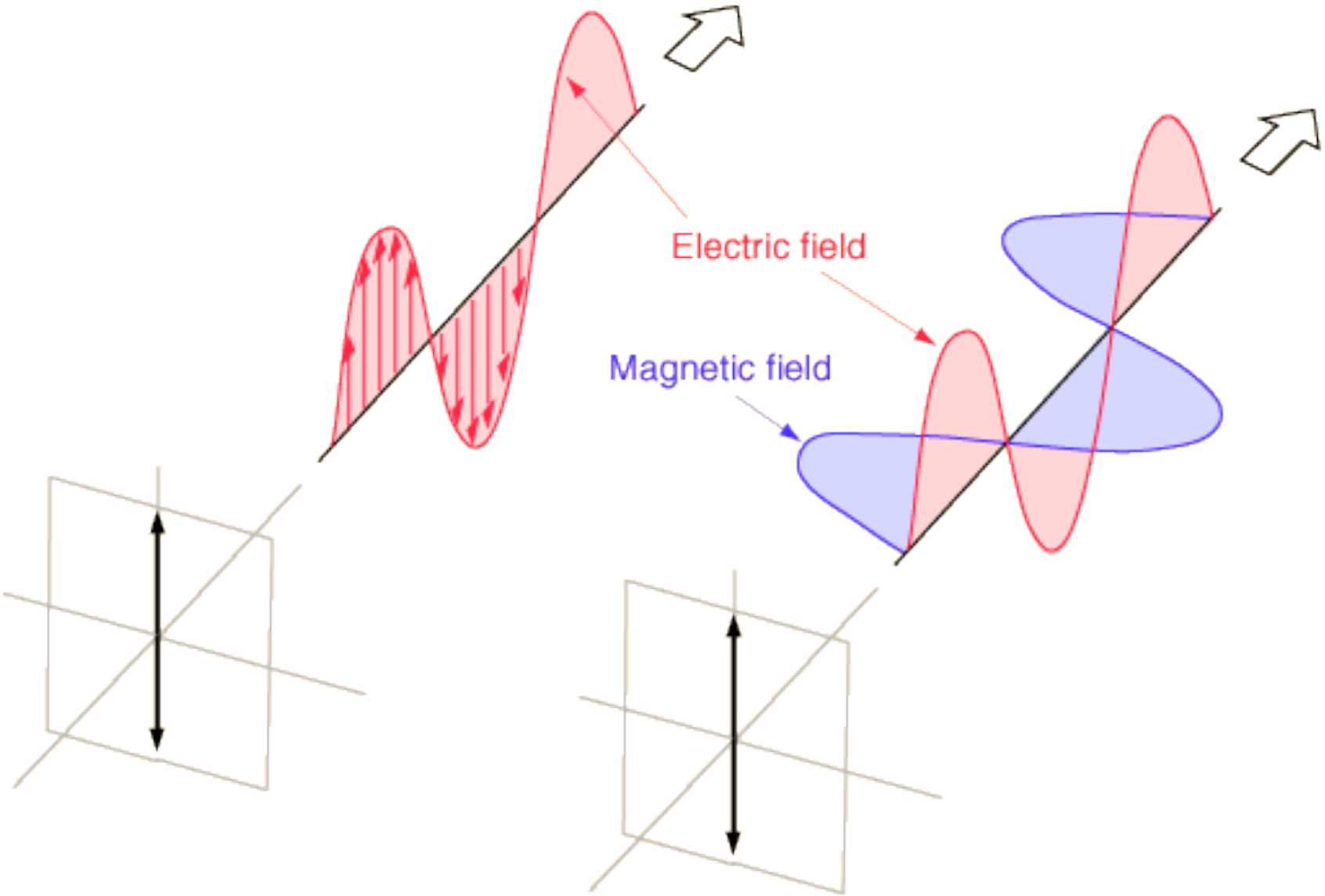
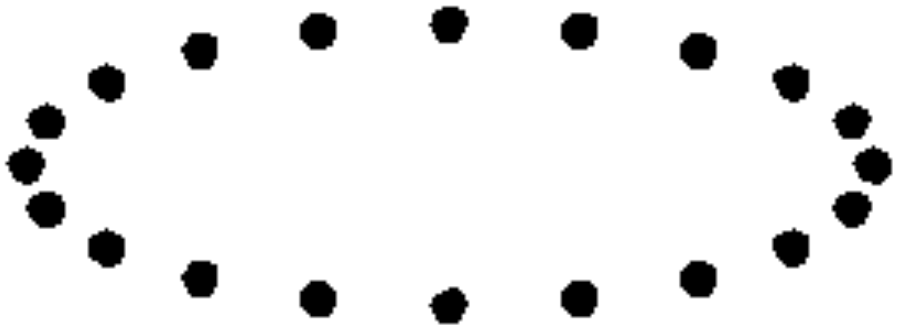
# Life in the Universe
# Latest Discoveries and Class Summary

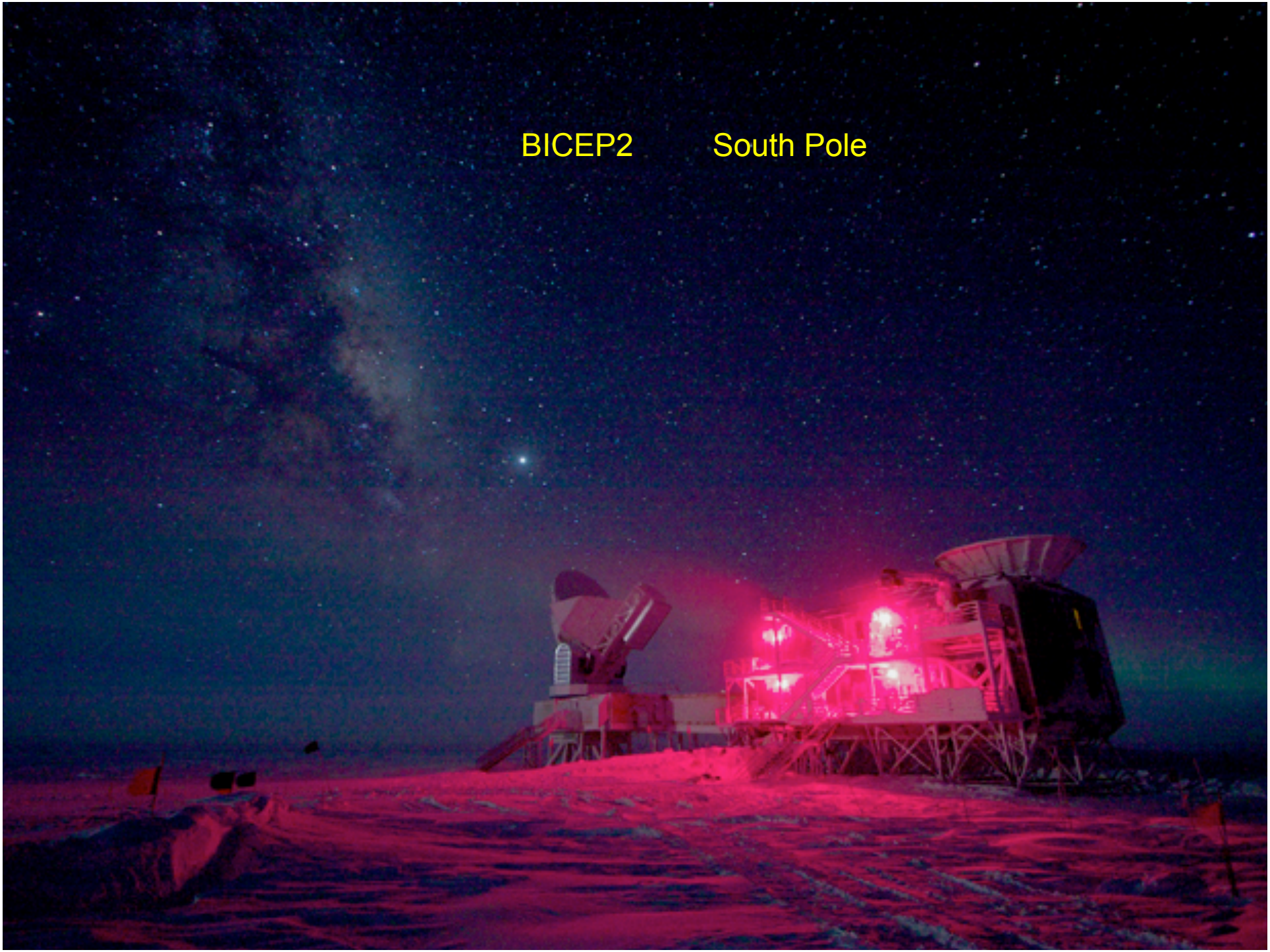

History of the Universe
Gravitational Waves
Inflation Generates Two Types of Waves
Density Waves
Waves Imprint Characteristic Polarization Signals
Free Electrons Scatter Light
Earliest Time Visible with Light
Quantum Fluctuations
Big Bang
Inflation
Protons Formed
Nuclear Fusion Begins
Nuclear Fusion Ends
Cosmic Microwave Background
Neutral Hydrogen Forms
Modern Universe
Radius of the Visible Universe
0
10−32 s
1 µs
0.01 s
3 min
380,000 yrs
13.8 Billion yrs
Age of the Universe

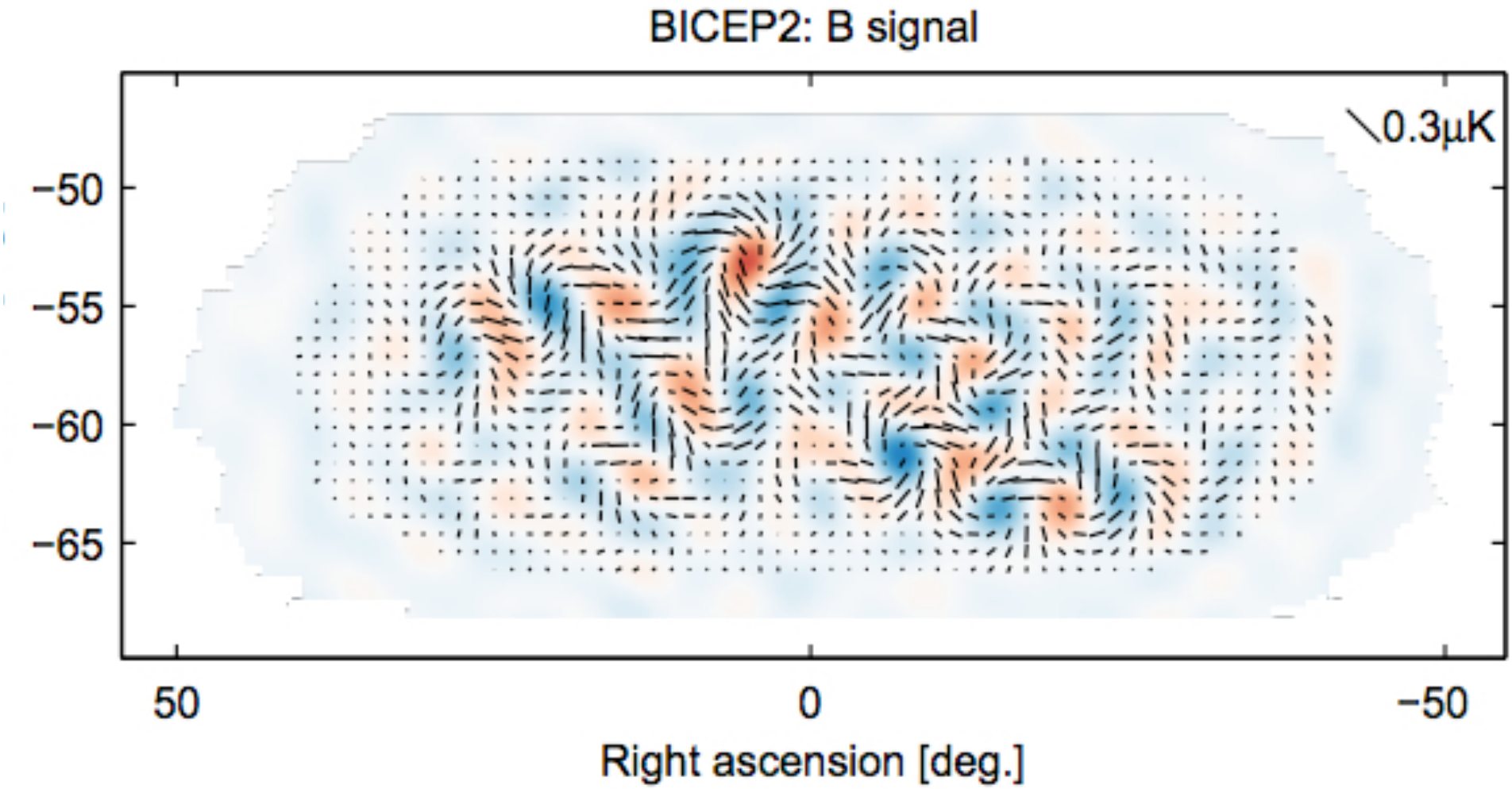
# Polarization of Light



# Passage of Graviational Wave

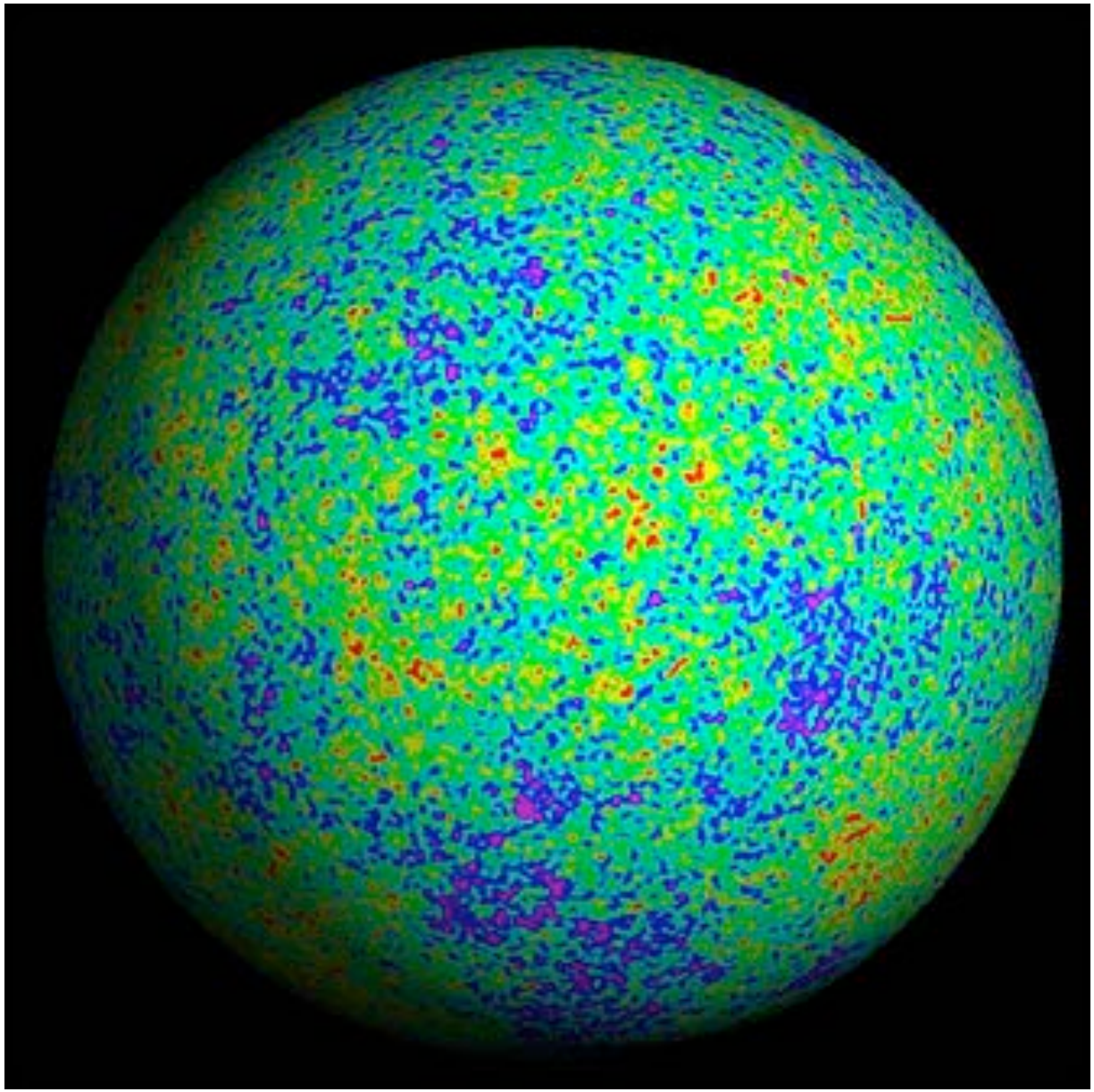



BICEP2
South Pole


BICEP2: B signal
0.3μK
−50
−55
−60
−65
50
0
−50
Right ascension [deg.]

# Describing Brightness Variations on Sphere

Cosmic Microwave Background



# Spherical Harmonics

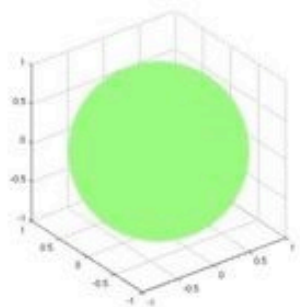
$\ell = 0$

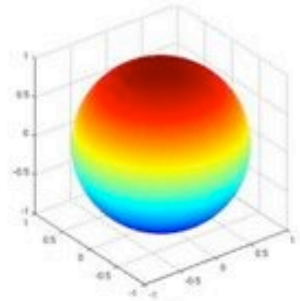
$\ell = 1$

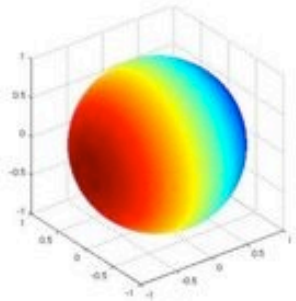
$\ell = 2$

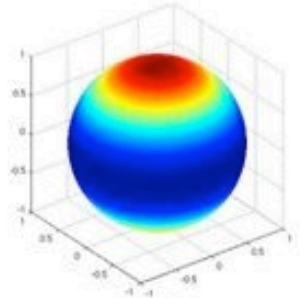
$\ell = 3$

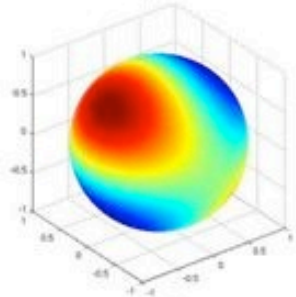
$$\cos(m\phi)\ P_\ell^m(\cos\theta)$$

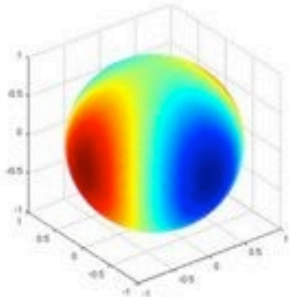


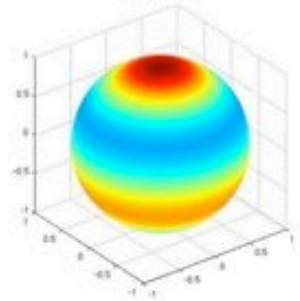


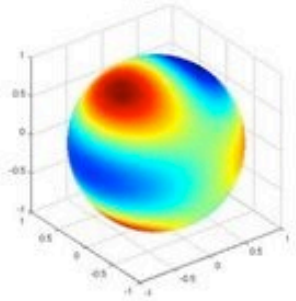


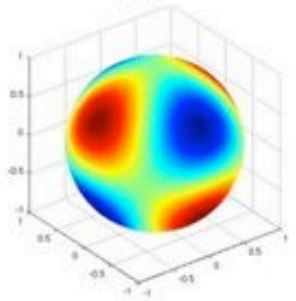


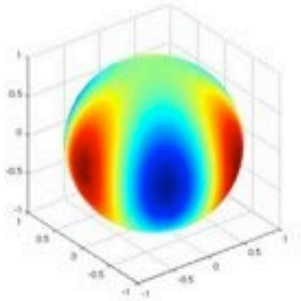










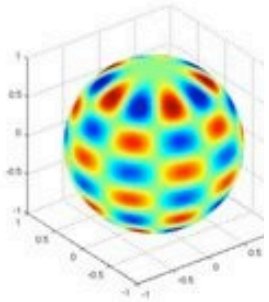


$m = 0$

$m = 1$

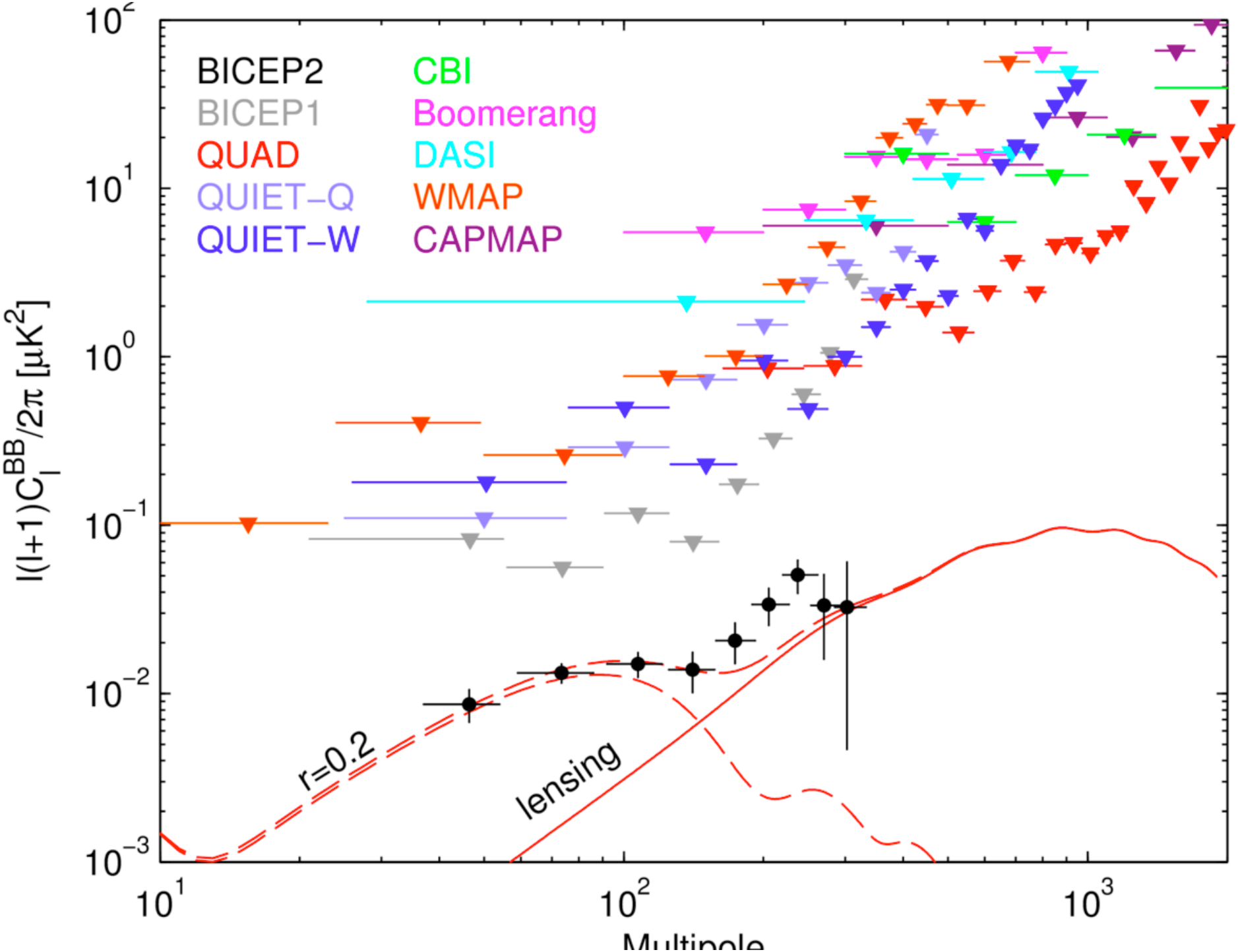
$m = 2$

$m = 3$

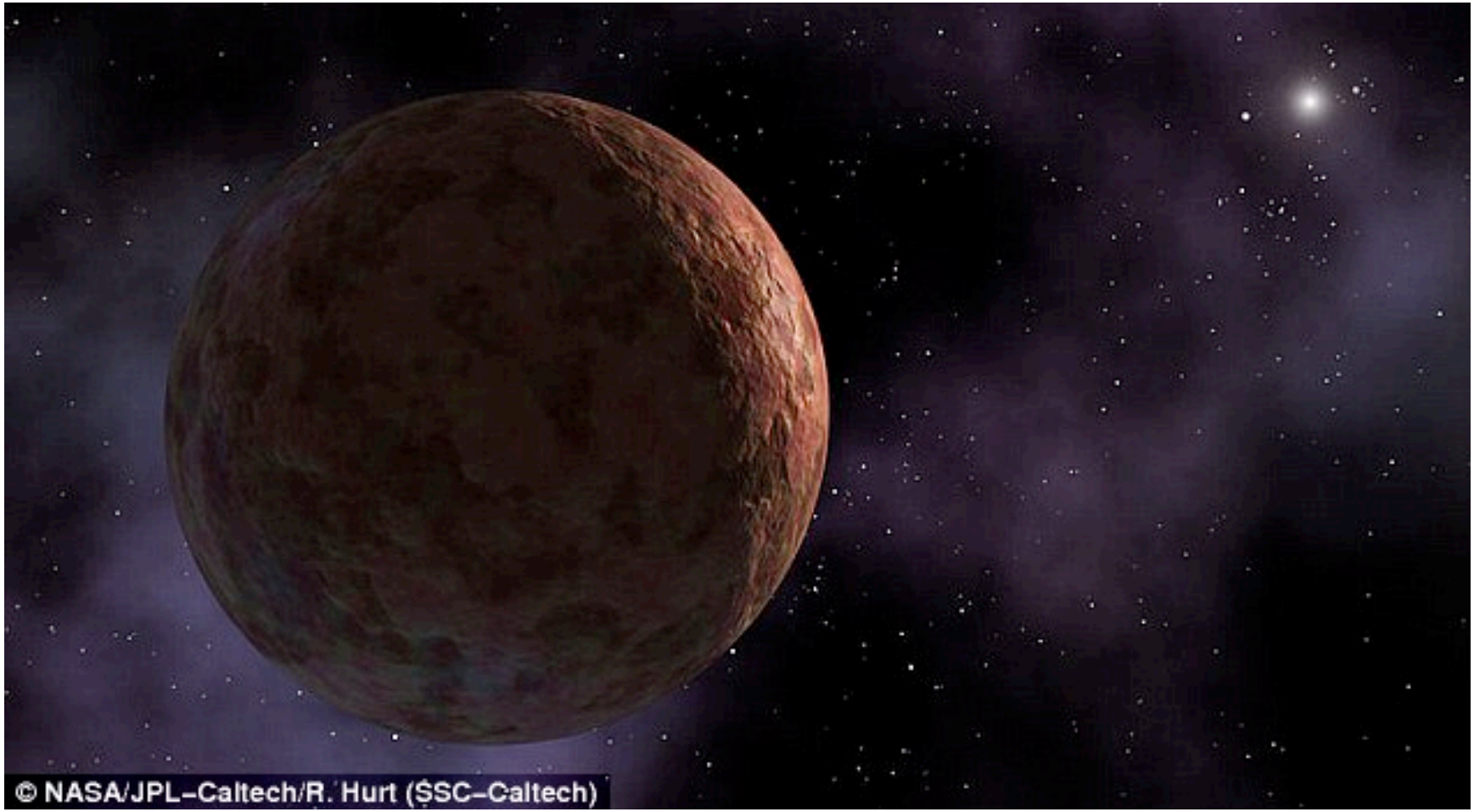


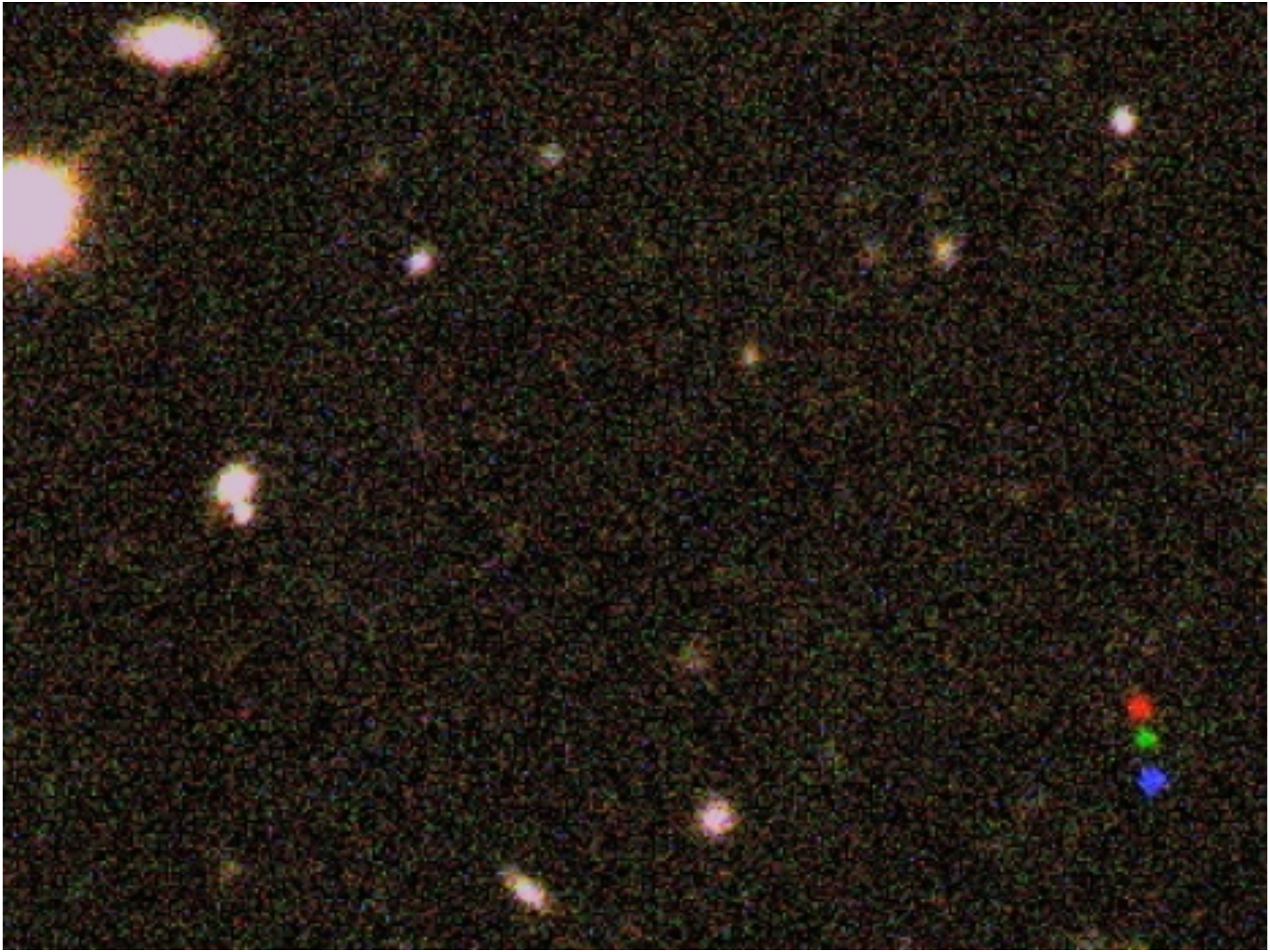
$\ell = 10$

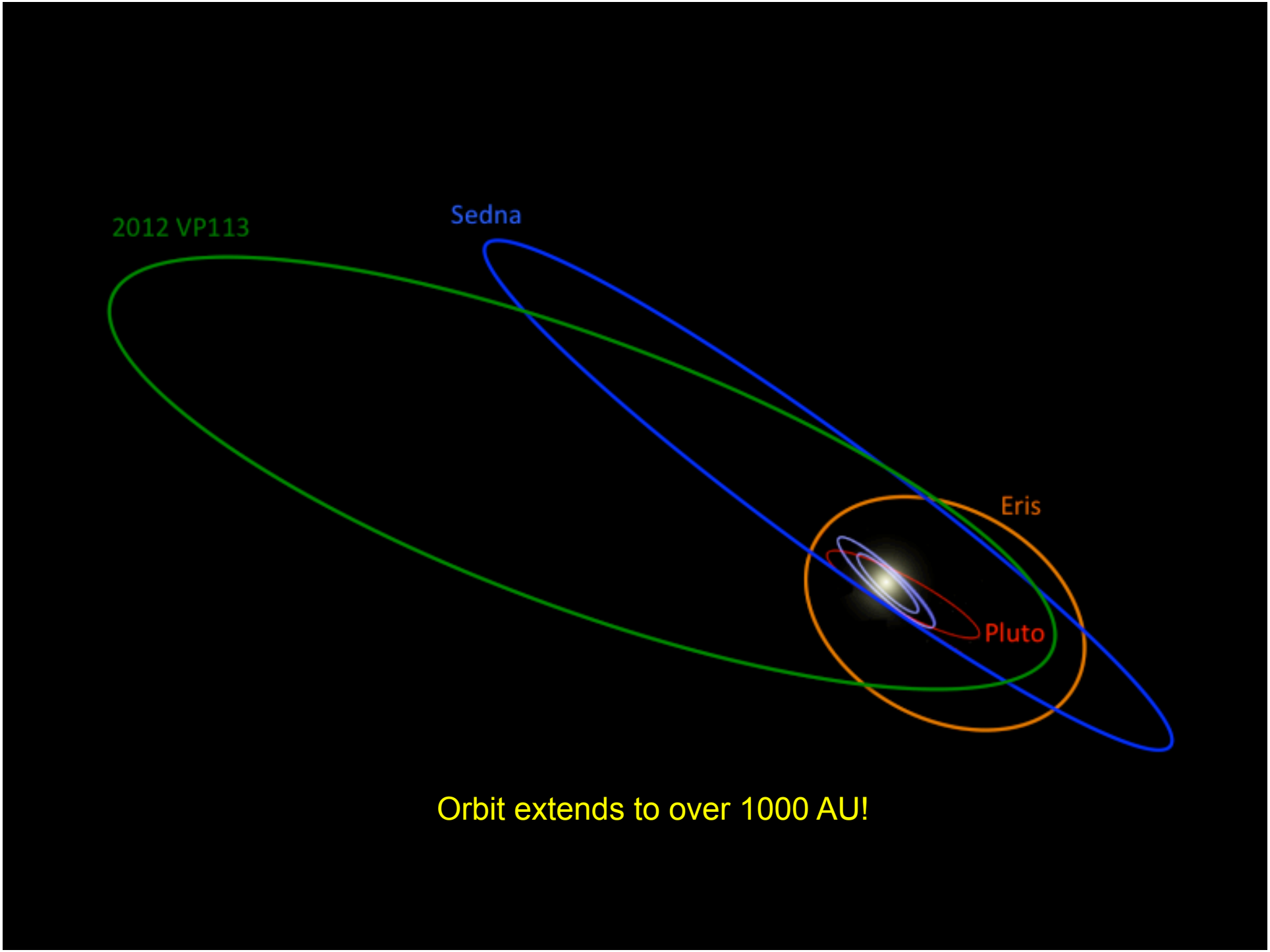
$m = 5$

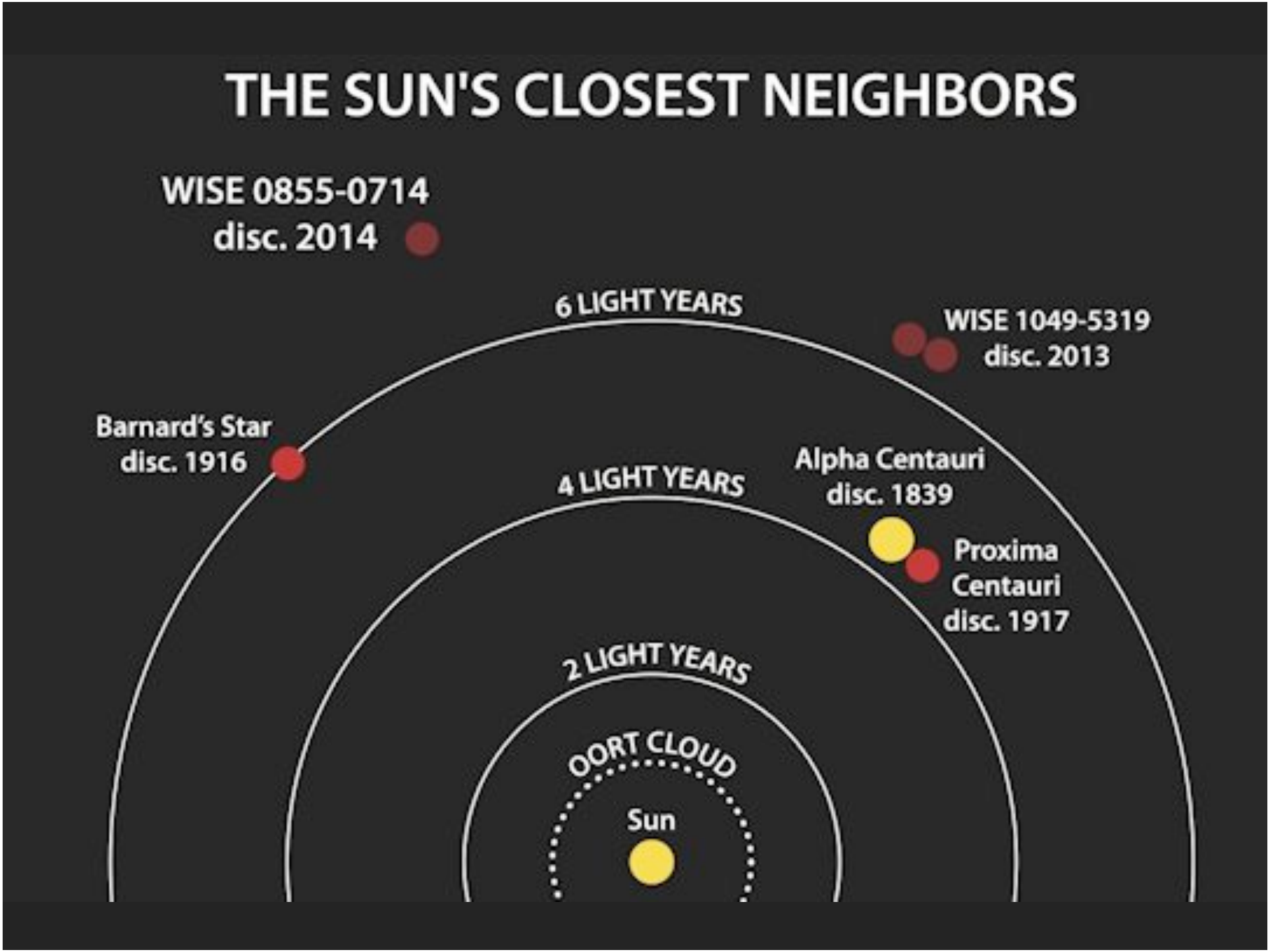

BICEP2
BICEP1
QUAD
QUIET–Q
QUIET–W
CBI
Boomerang
DASI
WMAP
CAPMAP
r=0.2
lensing
$l(l+1)C_l^{BB}/2\pi$ [$\mu K^2$]
Multipole
$10^{1}$
$10^{2}$
$10^{3}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$

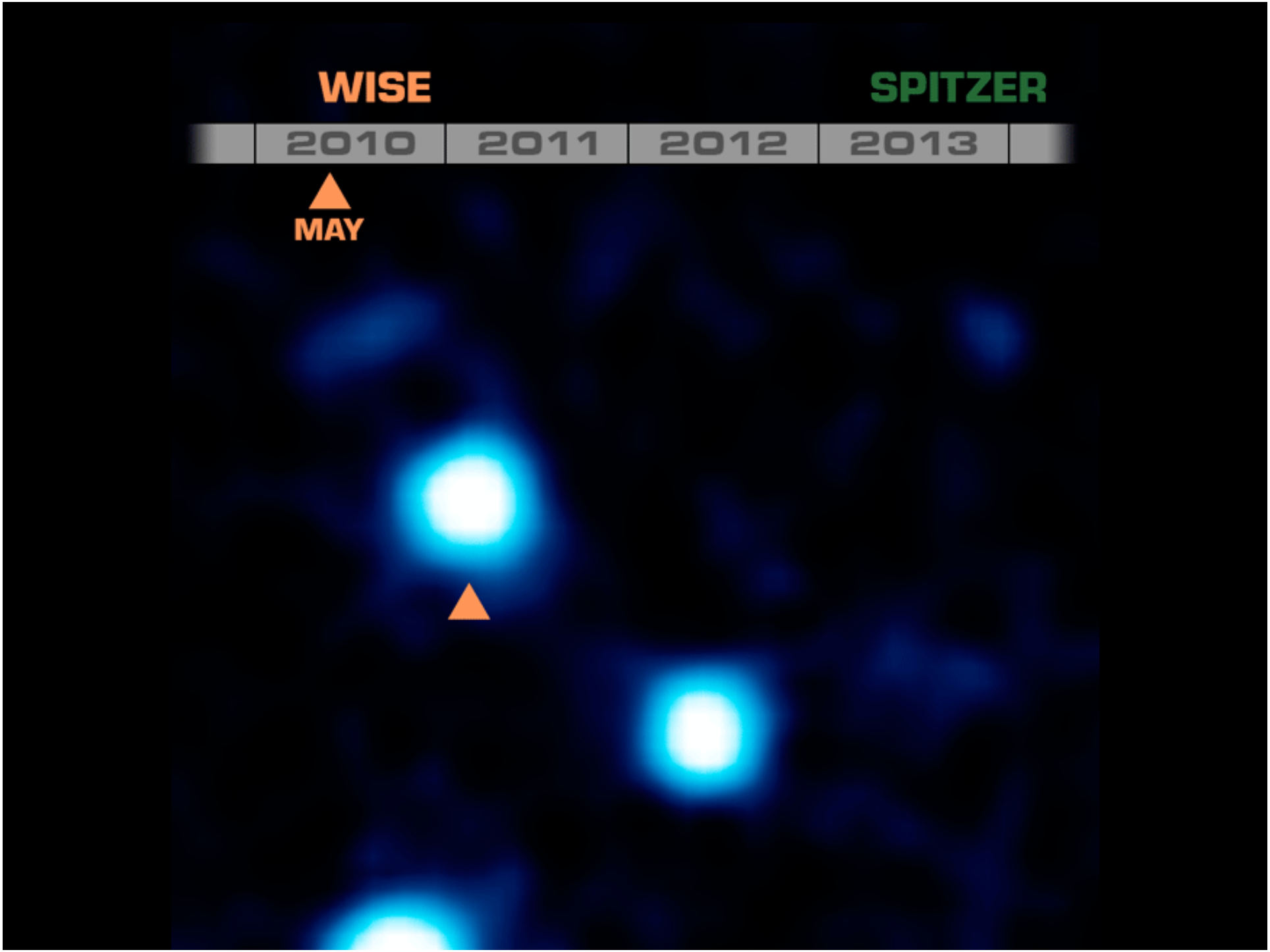
# A New Distant Dwarf Planet in Our Solar System : “VP113”

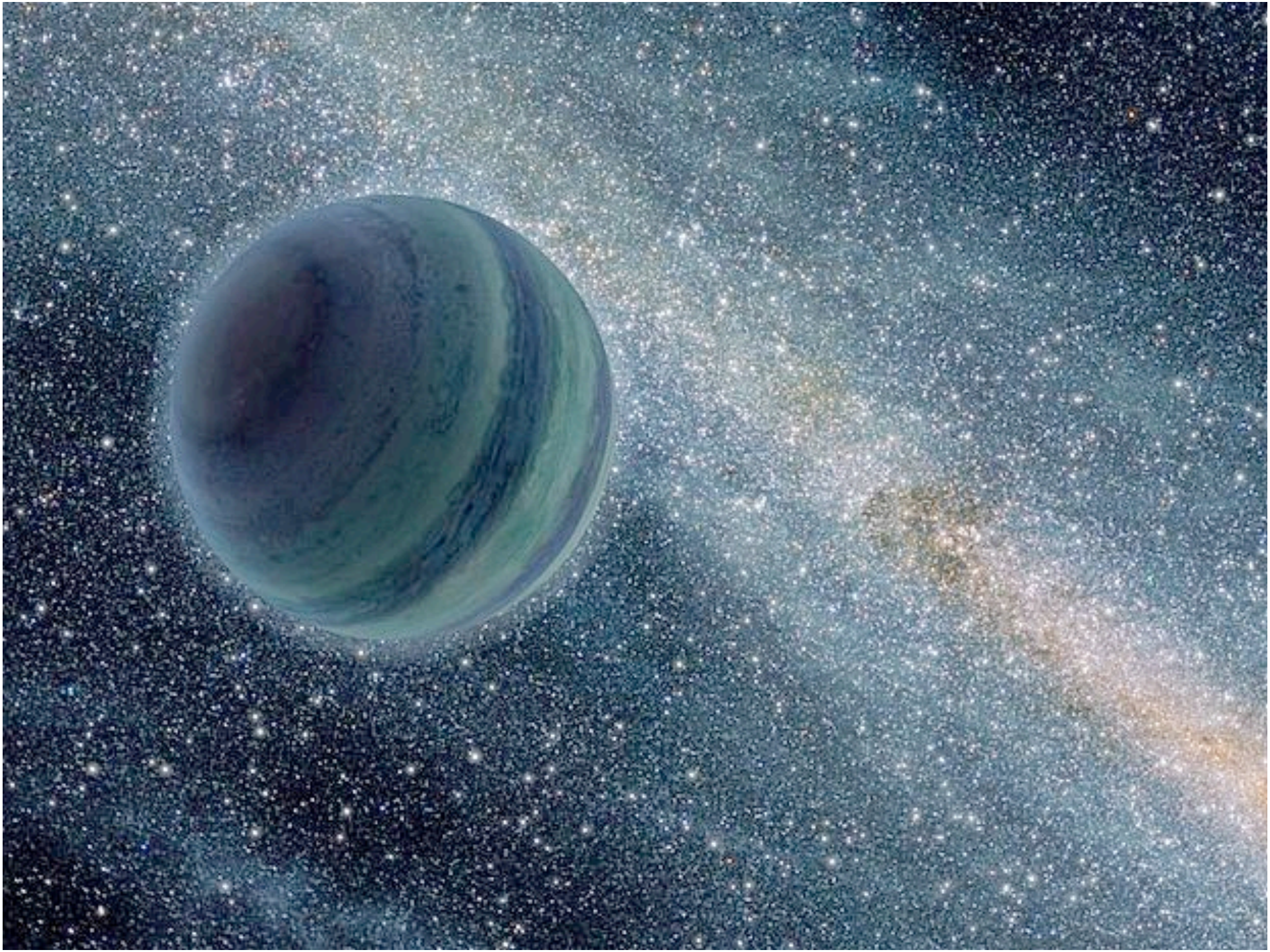




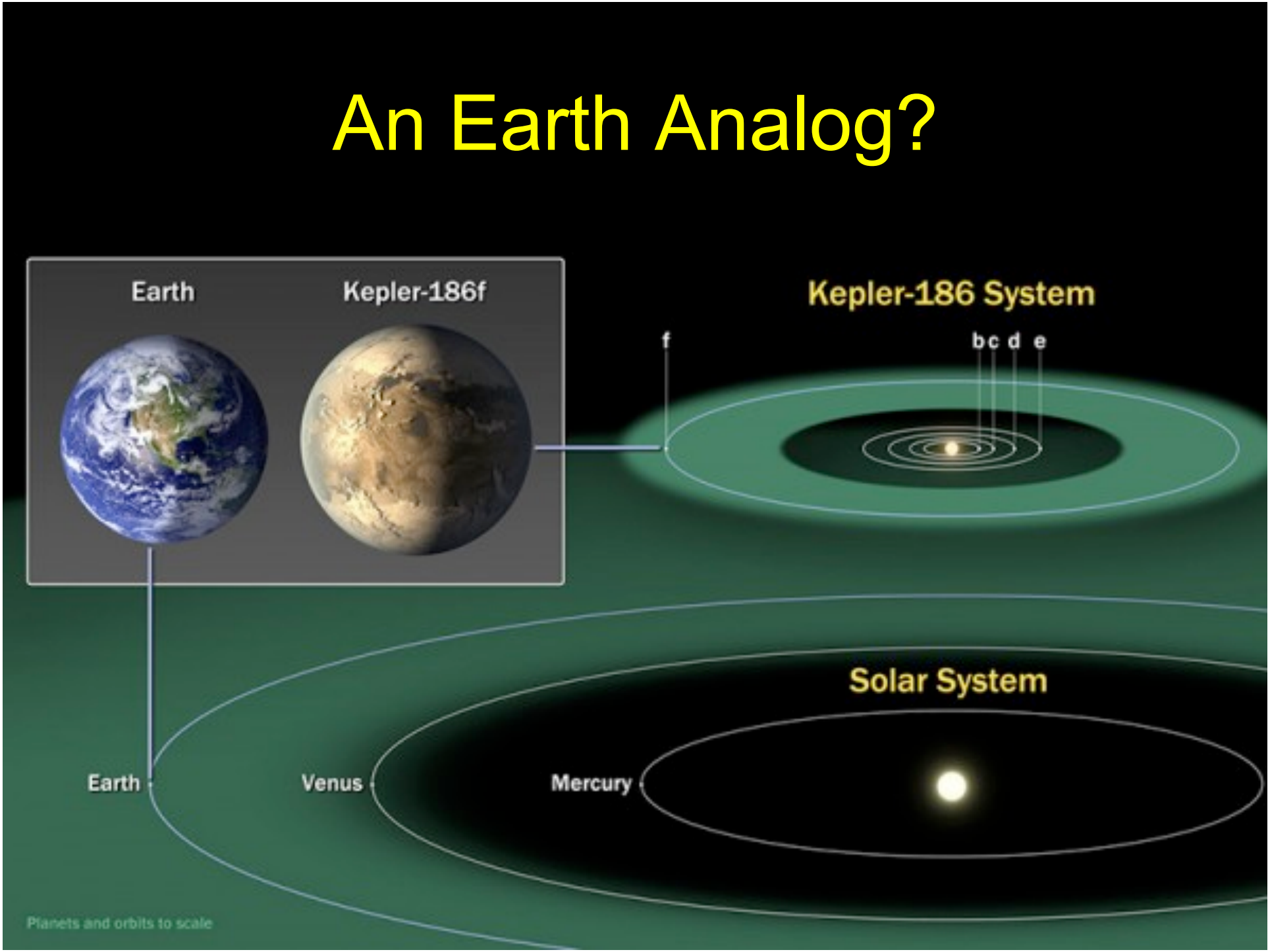

2012 VP113
Sedna
Eris
Pluto
Orbit extends to over 1000 AU!


THE SUN'S CLOSEST NEIGHBORS
WISE 0855-0714
disc. 2014
6 LIGHT YEARS
WISE 1049-5319
disc. 2013
Barnard's Star
disc. 1916
4 LIGHT YEARS
Alpha Centauri
disc. 1839
Proxima
Centauri
disc. 1917
2 LIGHT YEARS
OORT CLOUD
Sun

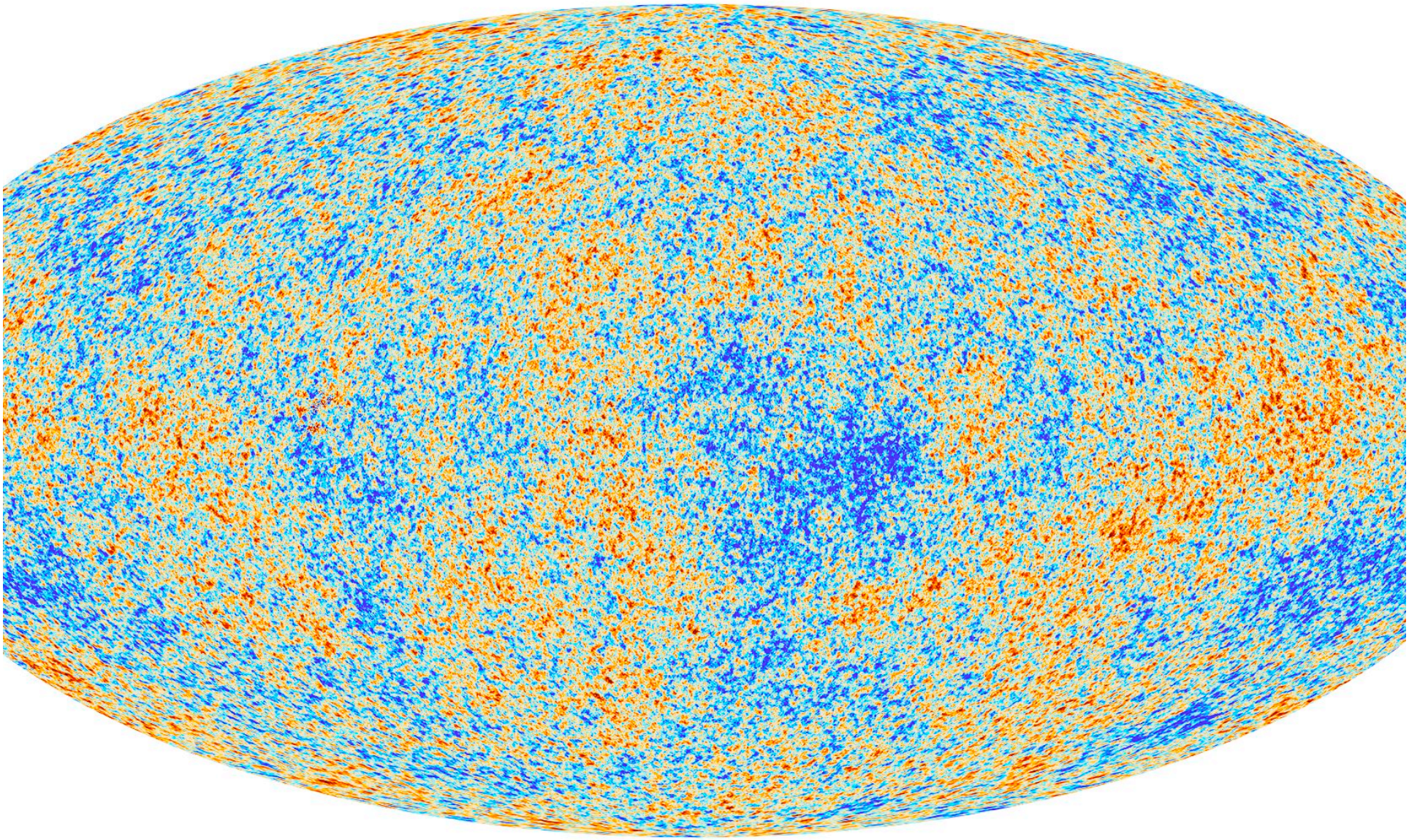

WISE
SPITZER
2010
2011
2012
2013
MAY



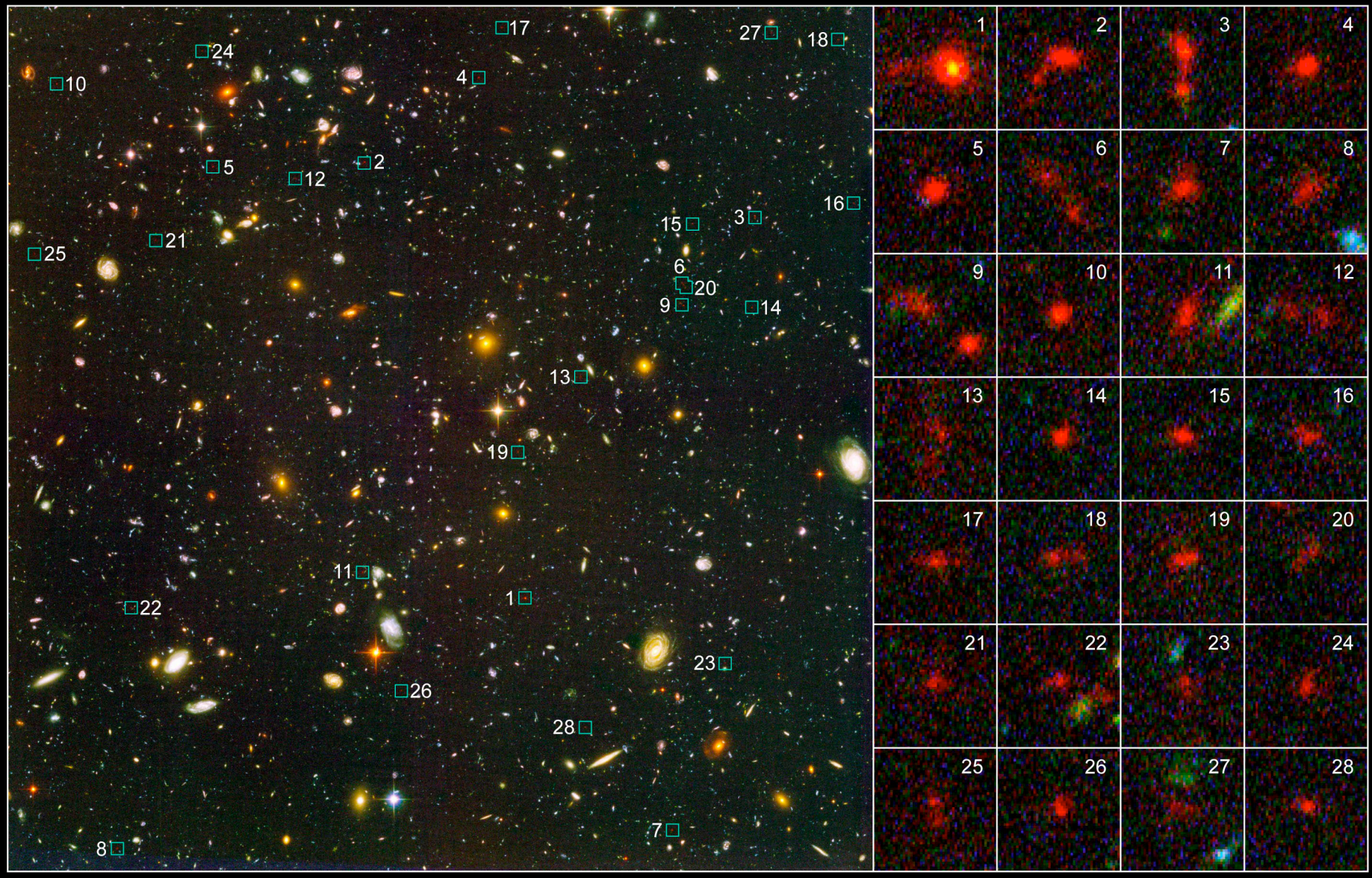
# An Earth Analog?



# Cosmic Microwave Background ~ 300,000 years



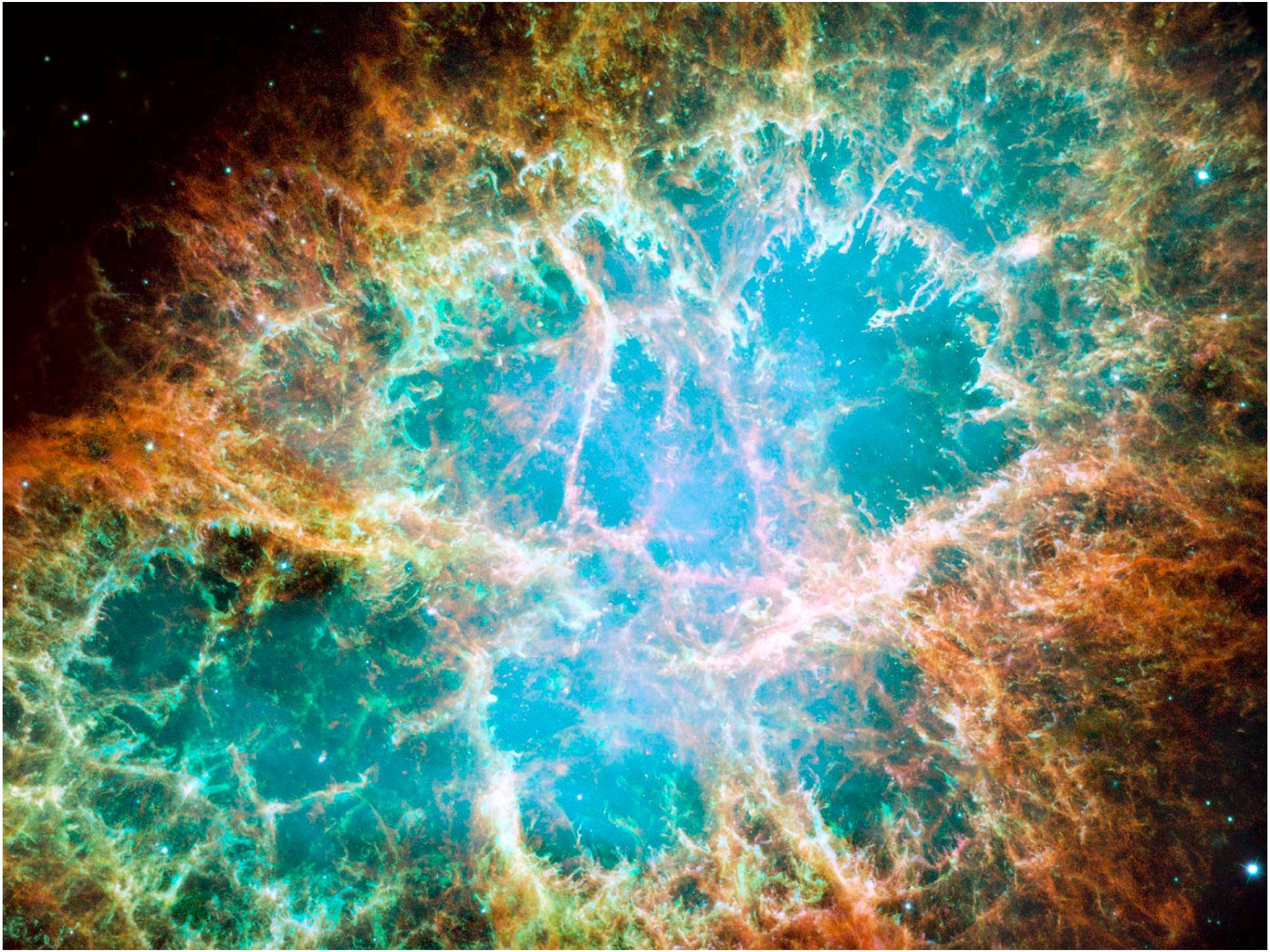

First stars formed after ~ few 100 million years

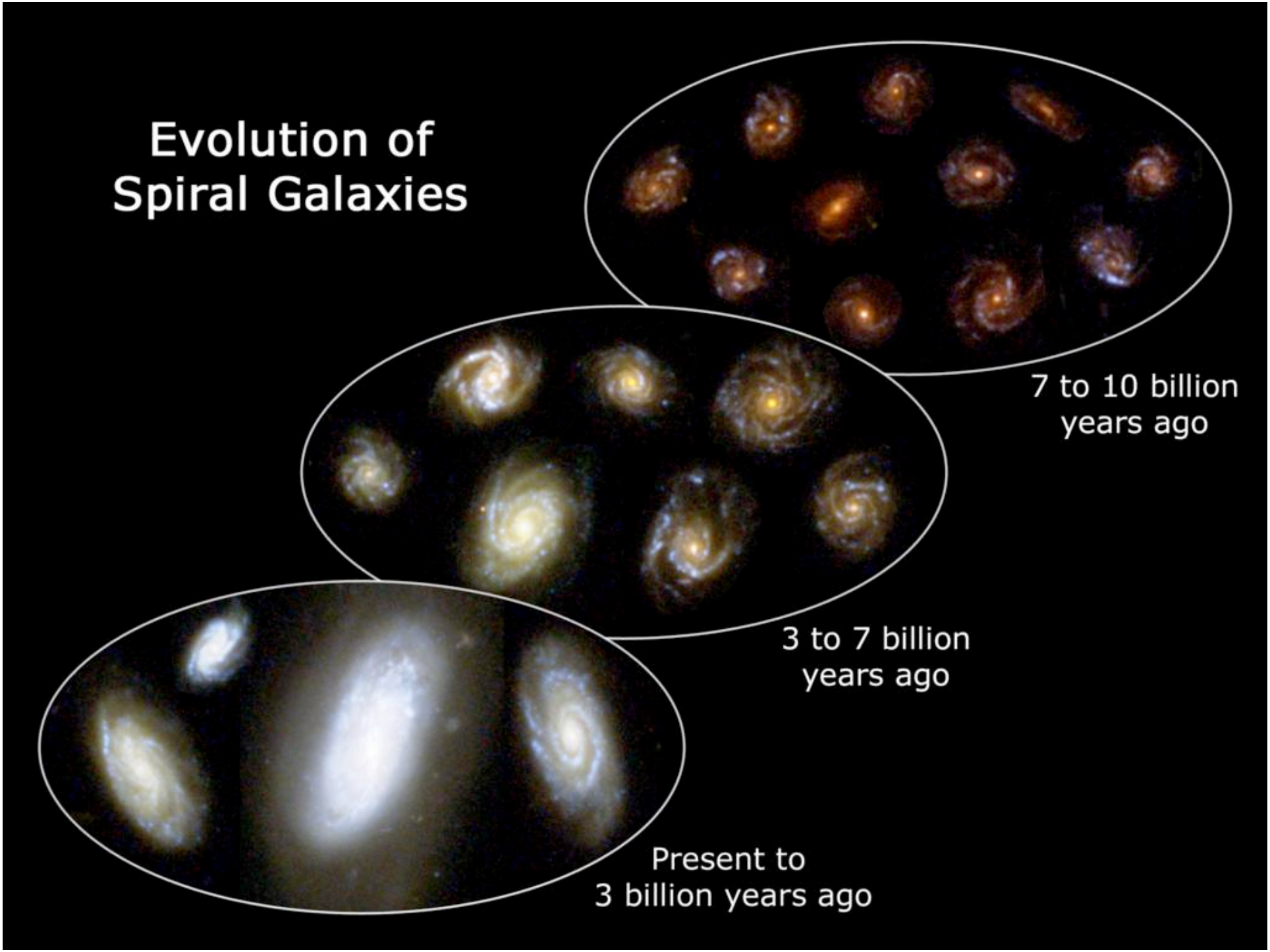



# Distant Galaxies in the Hubble Ultra Deep Field

Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, R. Bouwens and G. Illingworth (University of California, Santa Cruz)




Evolution of
Spiral Galaxies
7 to 10 billion
years ago
3 to 7 billion
years ago
Present to
3 billion years ago

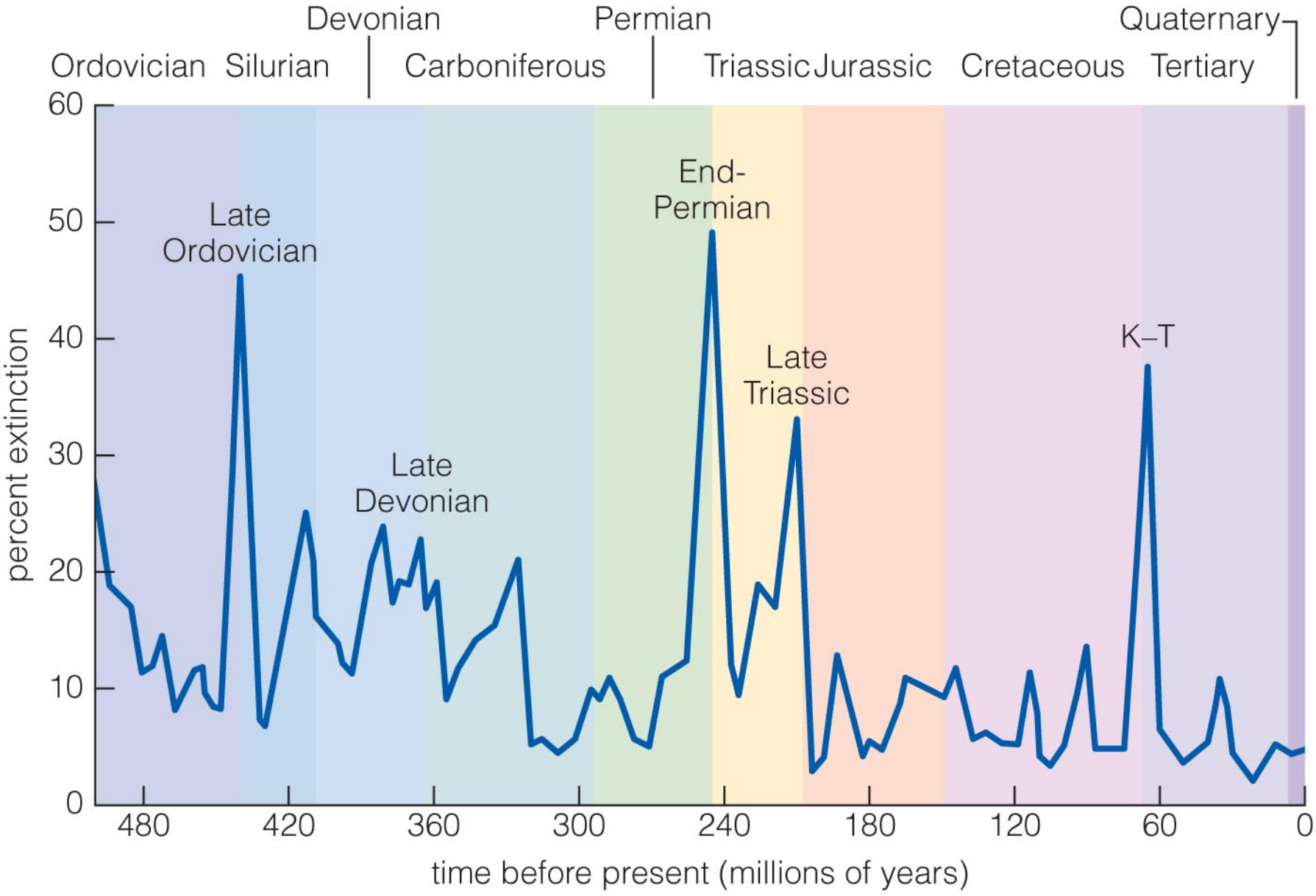
Earth ~4.5 billion years ago


~9.3 billion years after Big Bang

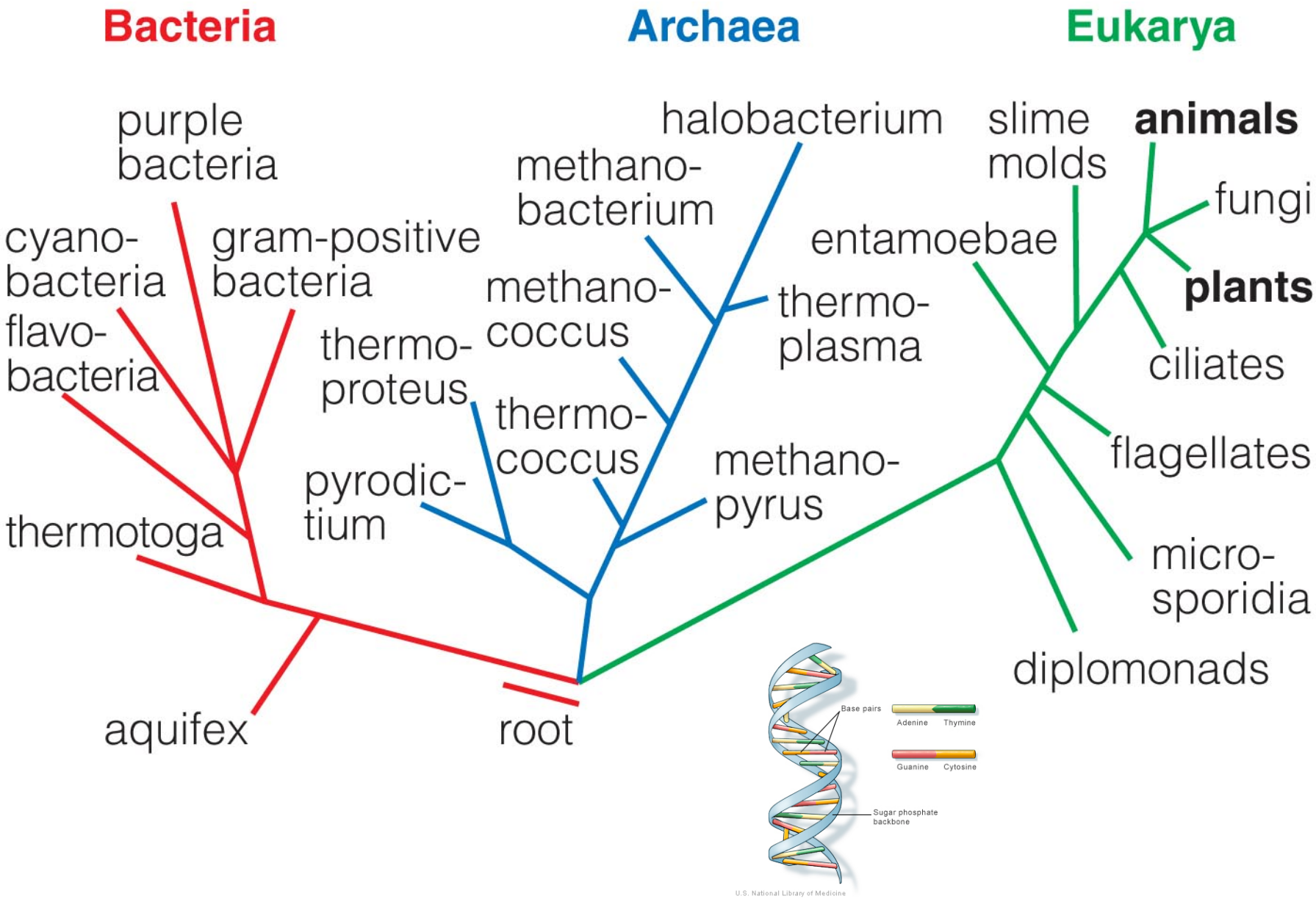
# Earth had life within at least ~700 million years of formation

# After 4 billion years of evolution – the Cambrian Explosion

# Extinction History last 500 million years

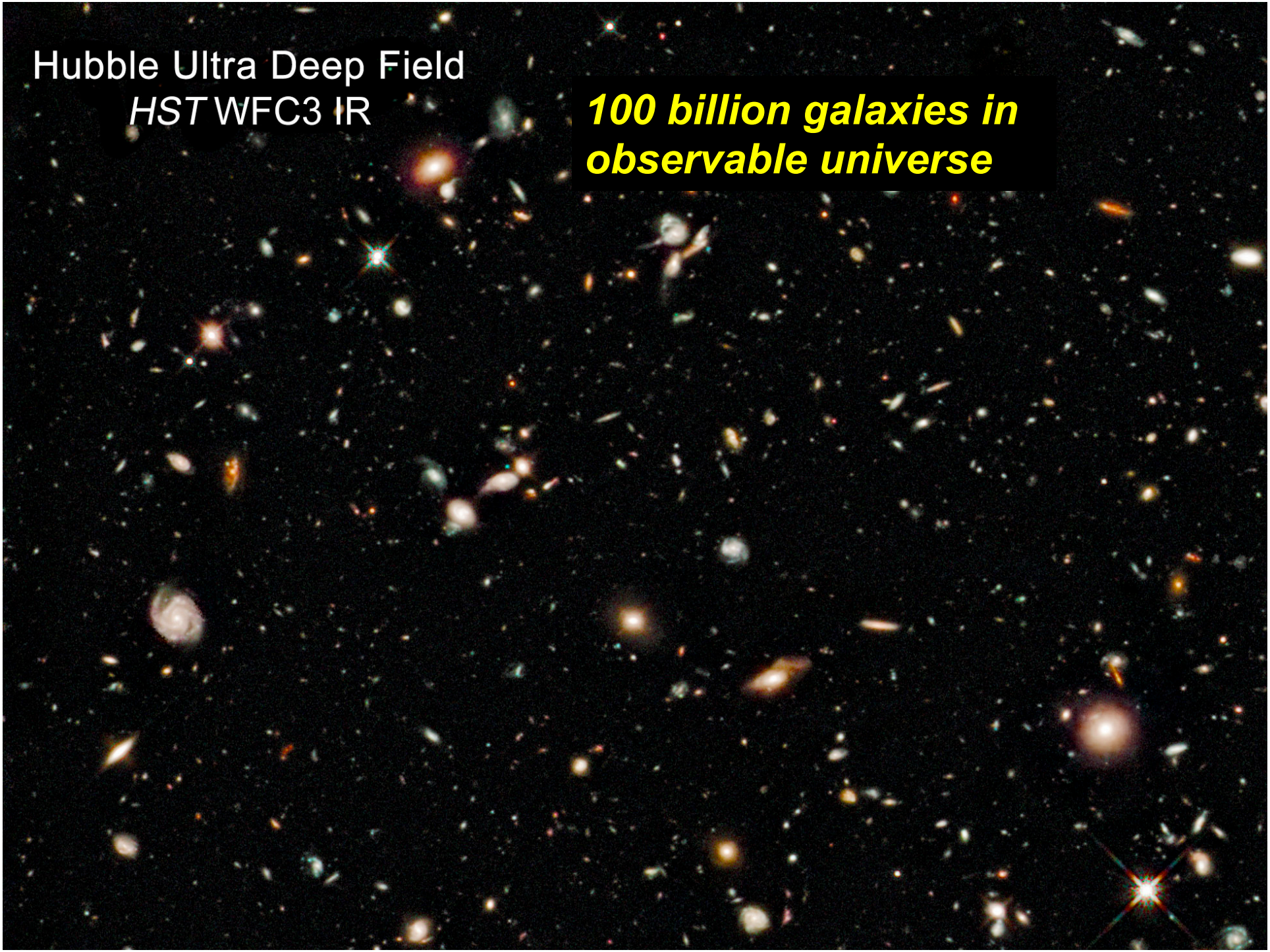


# The Modern Tree of Life




Sea Vents
Yellowstone Hotsprings
Antarctica Subglacial Lakes
Atacama Desert


ω (Omega) Centauri
HST WFC3/UVIS
400 billion stars w/ ~ 1 billion+ terrestrial planets in Habitable Zones in our Galaxy


Hubble Ultra Deep Field
*HST* WFC3 IR
***100 billion galaxies in observable universe***