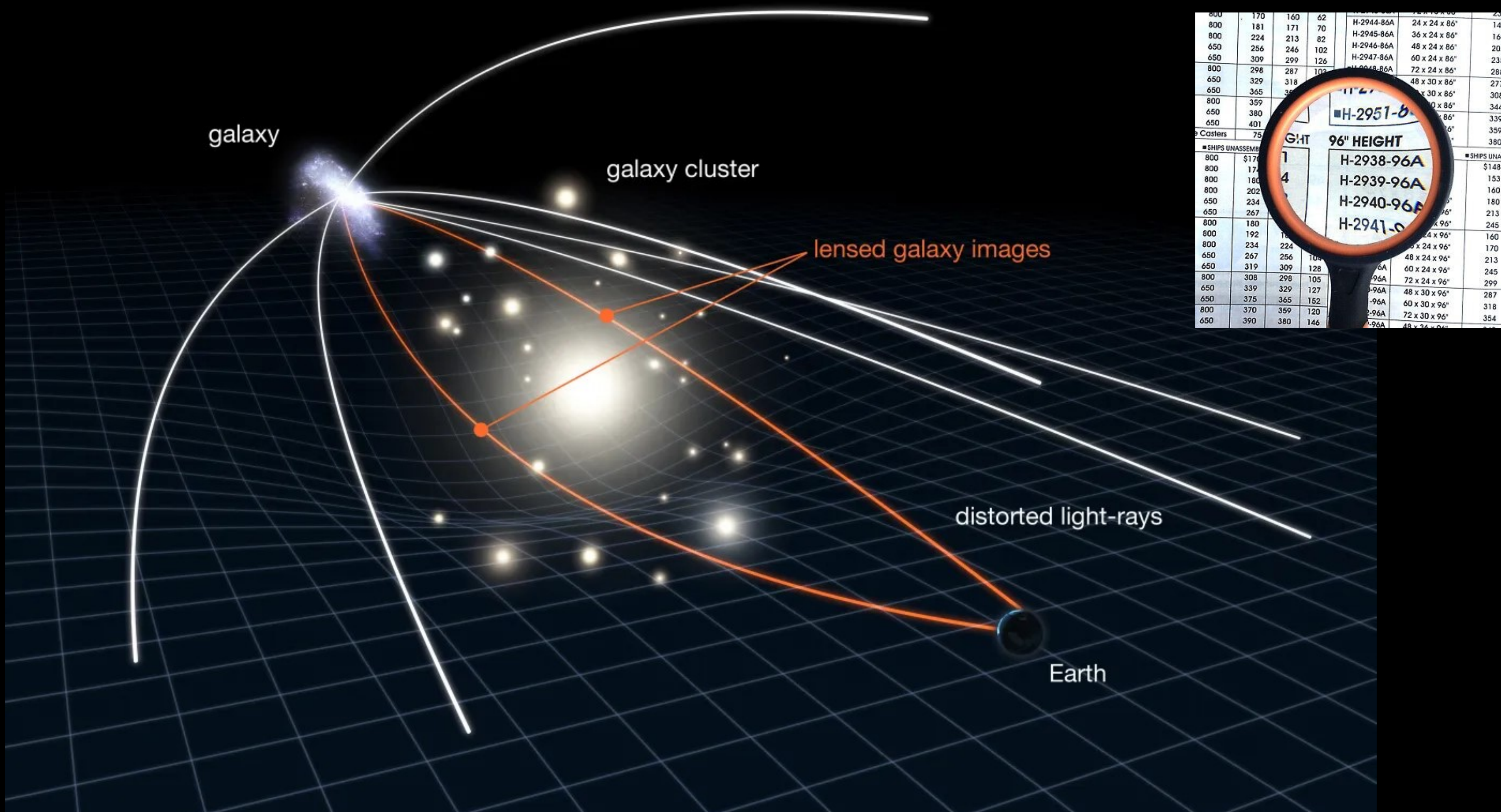
Latest News from the Early Universe and the Solar System

Lecture 3: DESI Experiment and Solar System Probes

OLLI Spring 2024

Cathrine Blom

Not only do stars bend light, galaxies and galaxy clusters bend light even more. Light-bending acts like a magnifying glass.



The light from a background galaxy is deflected and brightened by the foreground cluster's strong gravitational field. The bigger the galaxy cluster, the brighter the image of the background galaxy.

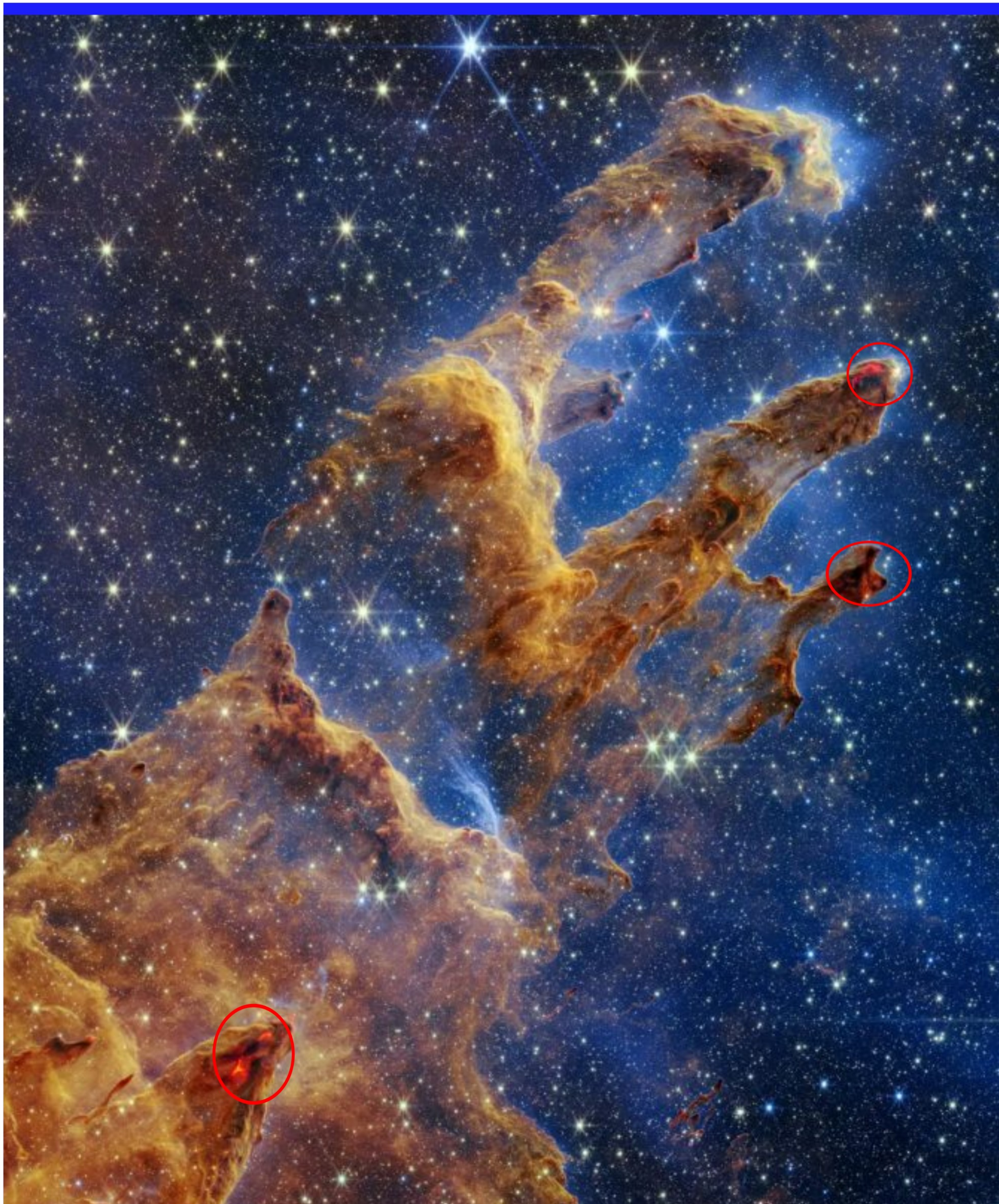
Oldest black hole detected so far,
400 million years after the Big Bang.

The galaxy GN-z11, a very bright infant galaxy seen here as it was 13.4 billion years ago, contains a 1.6 mill. solar mass black hole - a quasar - gobbling matter around it.

Open question: How can such an enormous black hole have formed at the end of the Dark Ages, just 400 million years after the Big Bang?

The galaxy GN-z11 is surrounded by hydrogen and helium gas

Could its stars be made from hydrogen and helium only?
Have we detected the first Population III stars – stars made from primordial matter?



James Webb Space Telescope, 2022

Stellar Nurseries

The Pillars of Creation seen in infrared light. Red areas are star forming regions where very hot, newborn stars release ultraviolet light. The light ionizes the surrounding clouds causing them to break up and disappear.

JuMBOs = Jupiter Mass Binary Objects = new gaseous planets:

0.6 – 13 x size of Jupiter, very wide orbits (20,000-80,000 years)

200 times the distance between Earth and the sun

temperature 1000 – 2300 F, about 1 million years old.

How did they form? Where did they originate?

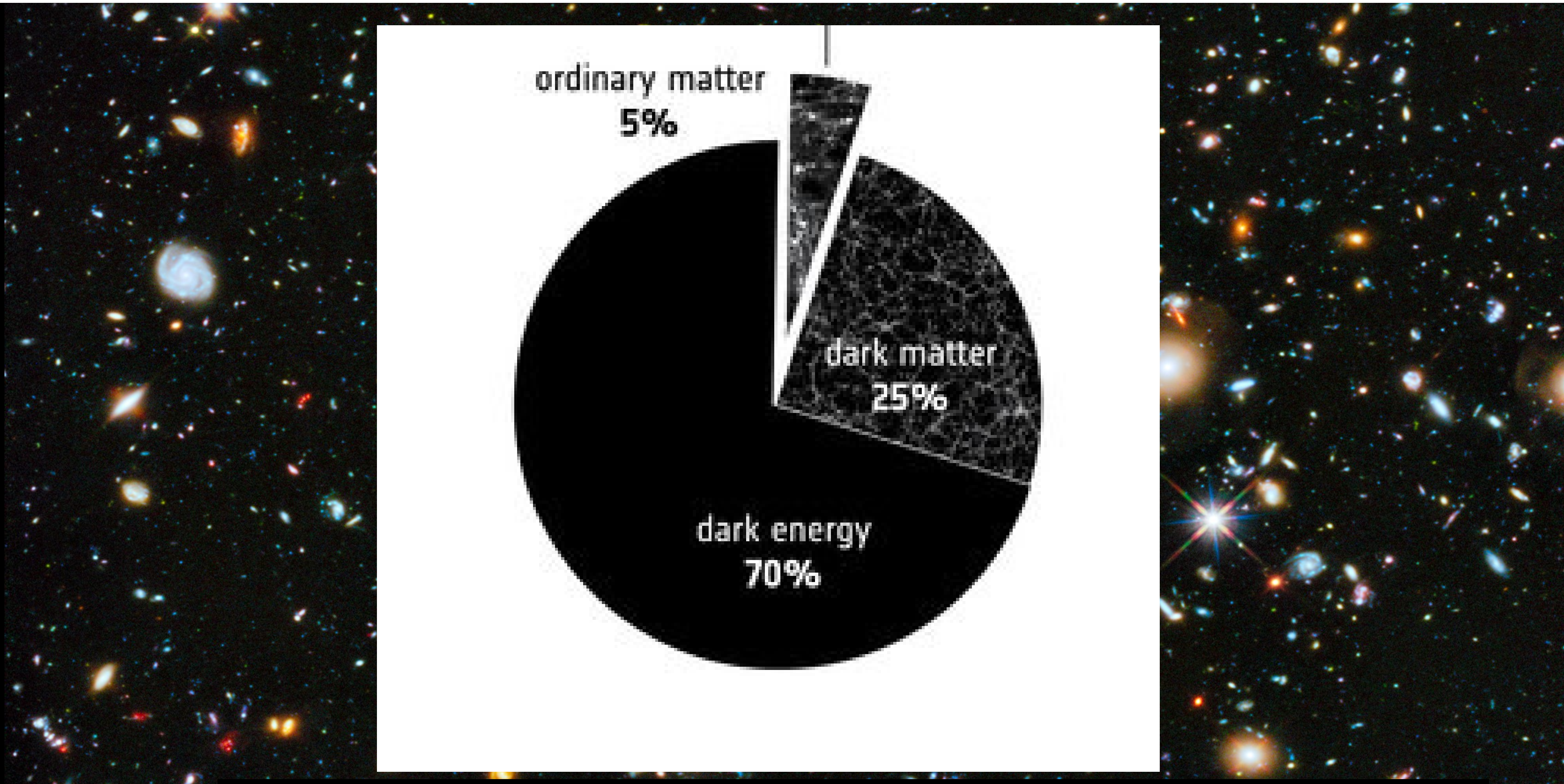
No existing theoretical explanation.

The Expansion of the Universe: Dark Energy and the DESI Experiment


There are about 100 billion galaxies in the observable Universe
Each galaxy contains about 100 billion stars
The galaxies have been moving away from one another from the Big Bang 13.8 billion years ago
The Universe is HUGE

The 100 billion galaxies, containing about 100 billion stars, plus gas and dust account for around 5% of the mass of the Universe. THE REST UNKNOWN:

DARK MATTER AND DARK ENERGY



Dark Matter holds the Universe together,

Dark Energy decides its destiny

Einstein, 1917, realizing that all the stars attract each other through gravity, asked

Why doesn't the Universe collapse?

To stop the Universe from eventually collapsing, Einstein proposed that all of space is infused with a constant amount of extra energy -- which has negative pressure and pushes outwards – the cosmological constant (labelled by the Greek letter Lambda (Λ)

He later called this his greatest blunder.

Edwin Hubble, 1929: The Universe is expanding!

Hubble discovered that all the galaxies are **moving away from each other.** The further away they are, the faster they move (Hubble's law)

→ The universe is expanding, i.e., space itself is increasing in size just like a balloon being blown up

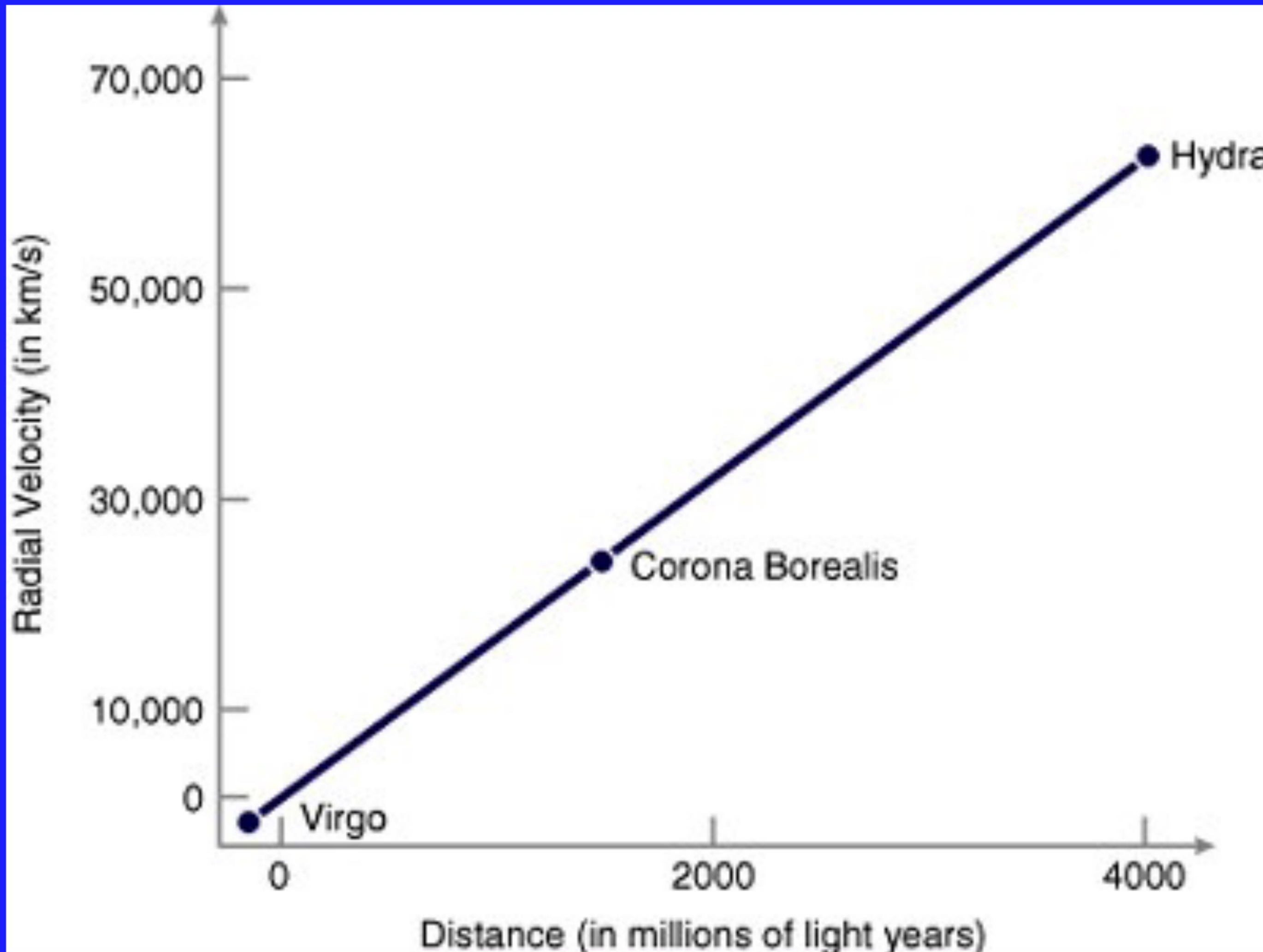
→ The universe has no center

Think of the Universe as living on the surface of an expanding sphere

The Universe has no center and space itself is expanding (There is no space “outside” or “inside” the balloon)

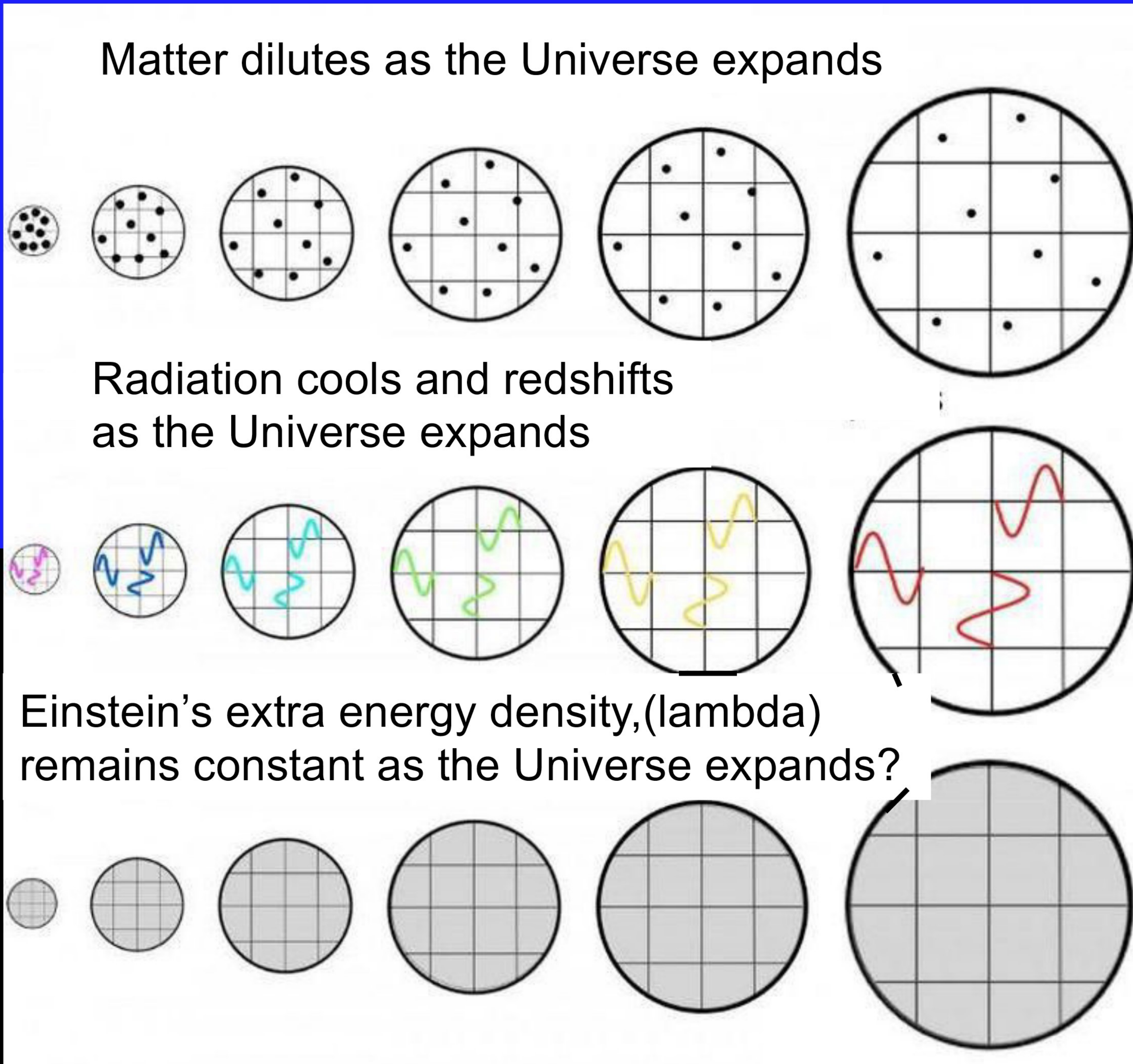

THEEDGE OF
UNIVERSE
I Love YOU
IT'S A
Happy Birthday!

Hubble's Law



Therefore: The Universe must have had a beginning.

The expansion of the Universe is the prime piece of evidence supporting the Big Bang



Galaxies move apart from each other

Universe has cooled down to 2.7^{o}K

Einstein’s energy Lambda stays constant

Fast forward to 1965:

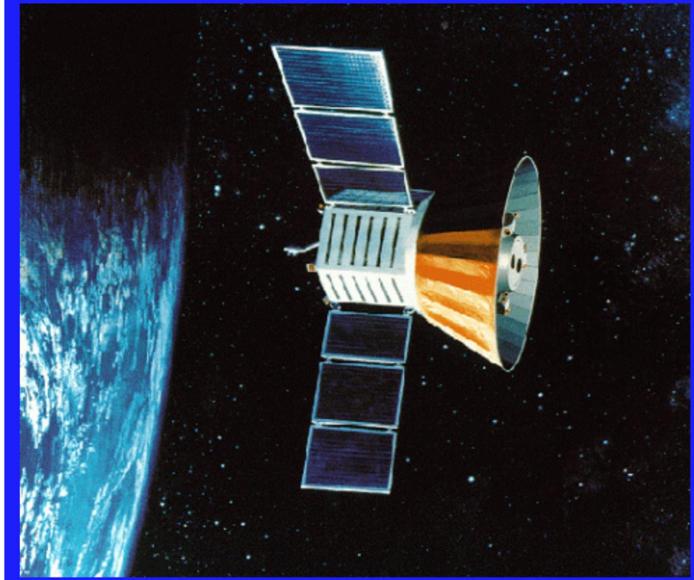
In July of 1965, Arno Penzias and Robert Wilson, testing antennas at Bell Telephone Labs, found

* radiation coming uniformly from all directions of the sky
* the same day and night
* free of seasonal variations

Time ----->

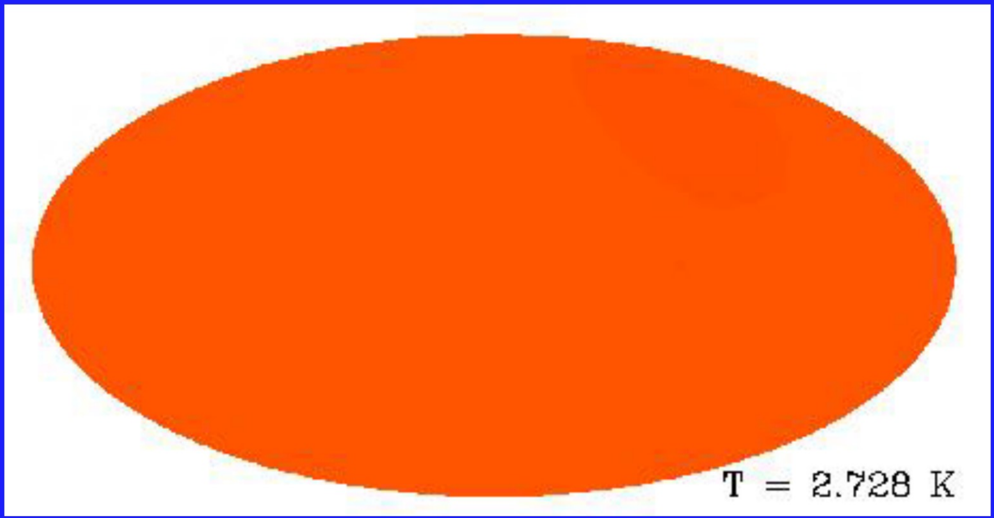
They had found the ***leftover heat*** from the Big Bang, cooled down from a trillion degrees at one second to about to 2.7 K degrees = - 454 F now.

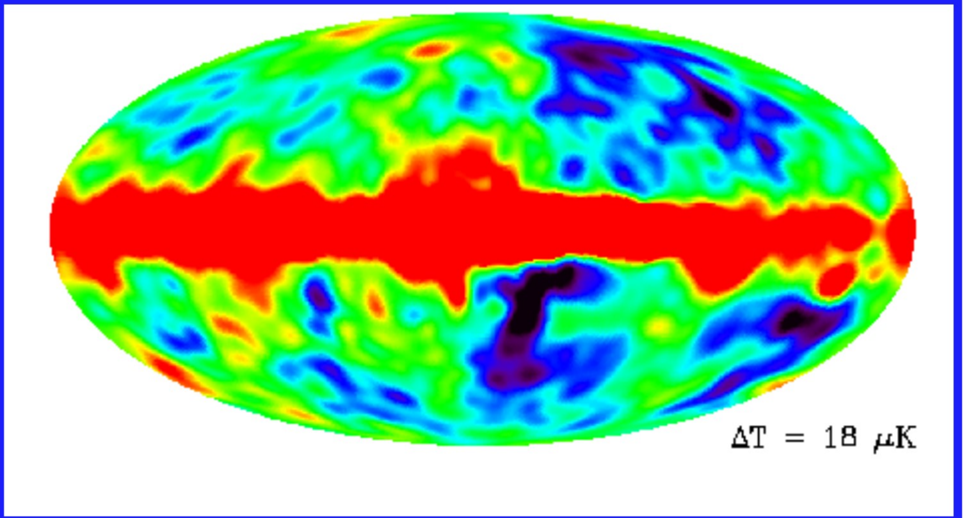
Cosmic Microwave Background Radiation



In 1989, COBE (Cosmic Background Explorer) was launched to measure the Cosmic microwave background radiation from 0 to 4 K (- 460 F to - 450 F) in all directions in the sky.

No matter which direction in the sky COBE looked, the temperature was the same (isotropic). Only tiny variations.

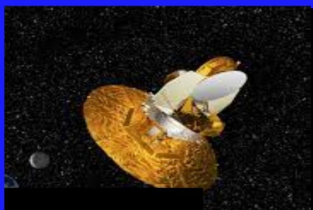


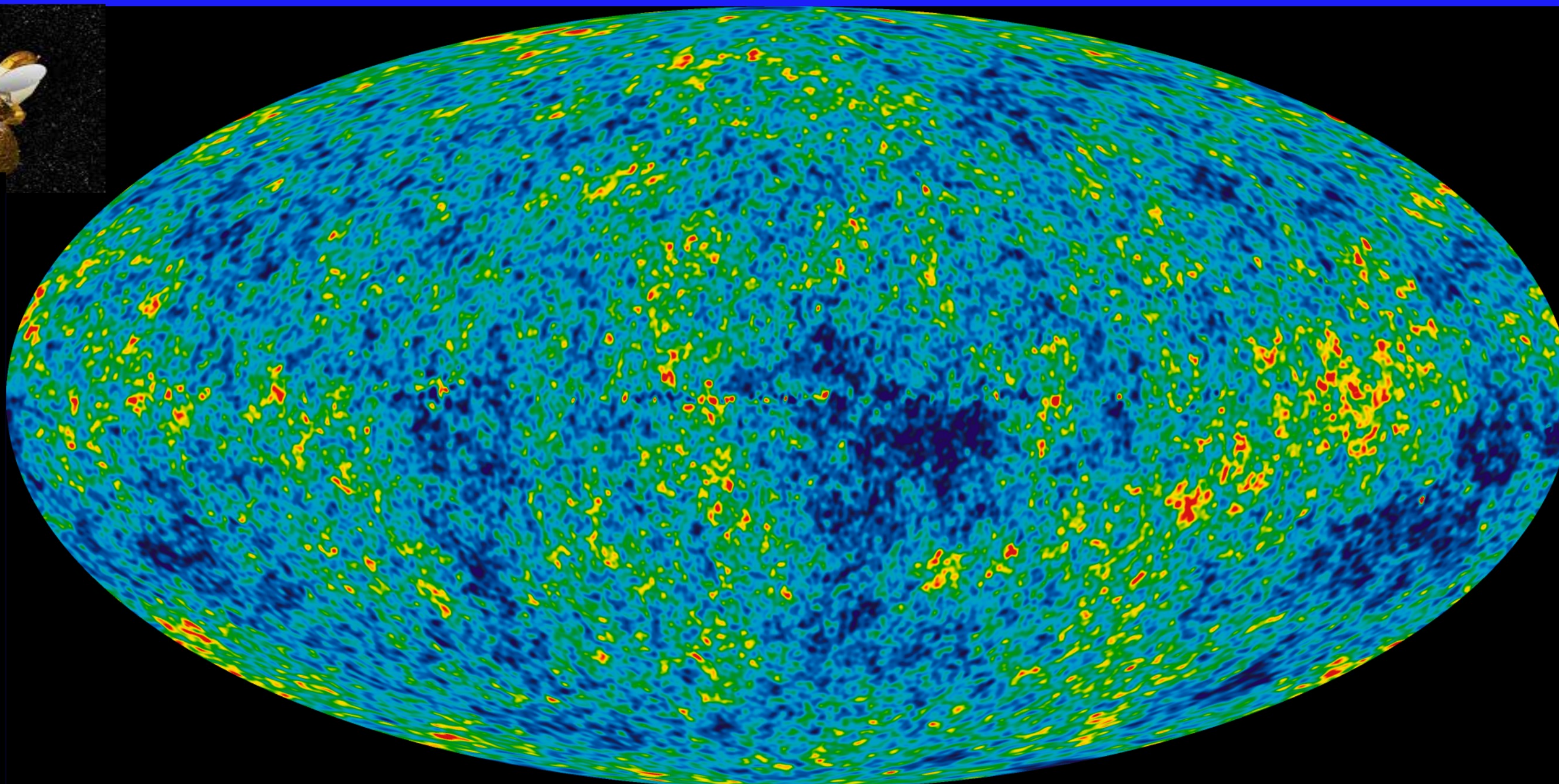


Temperature = 2.728 K

10/millionth of a degree variations

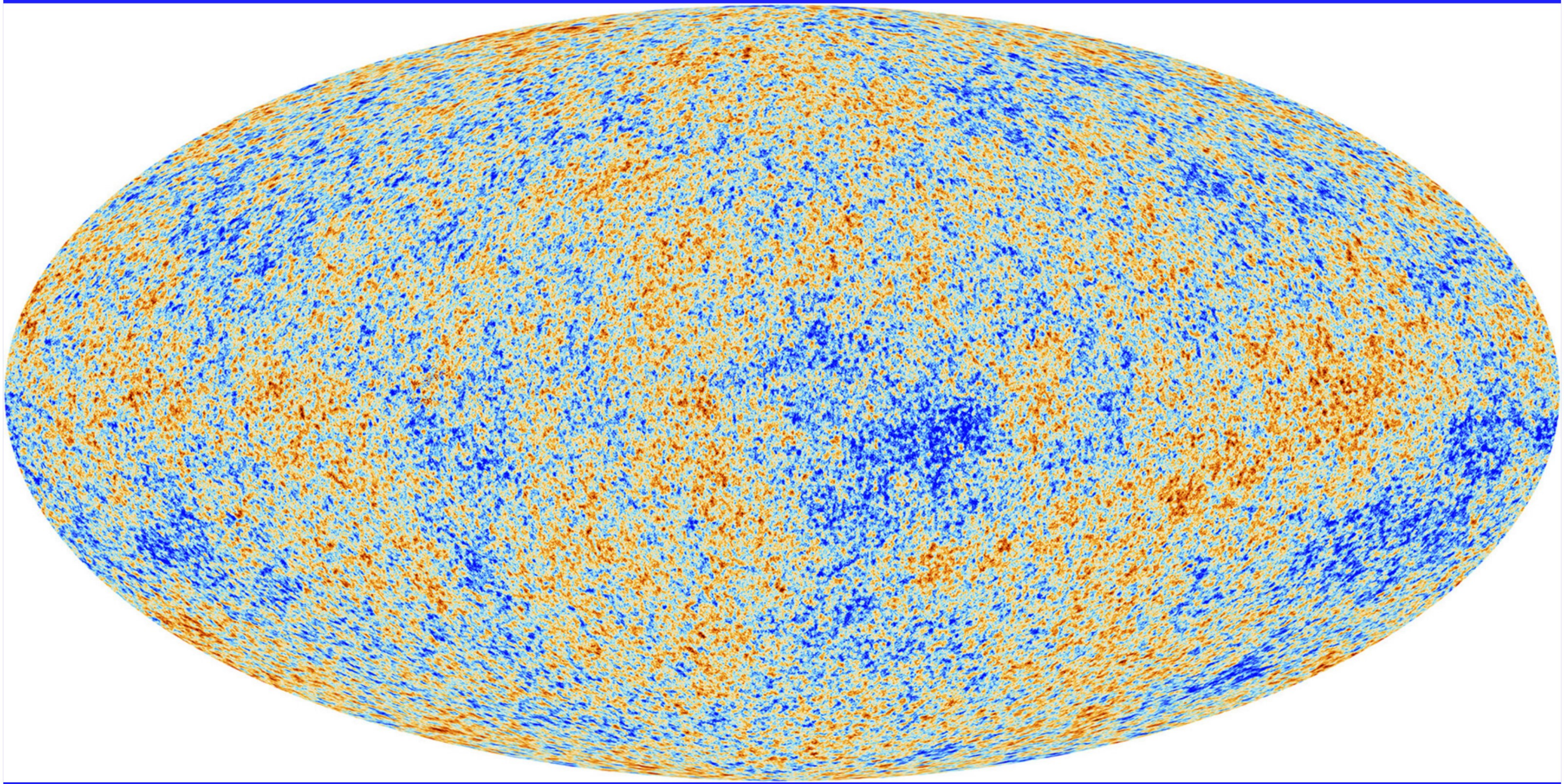
In 2001: Wilkinson Microwave Anisotropy Probe (WMAP)





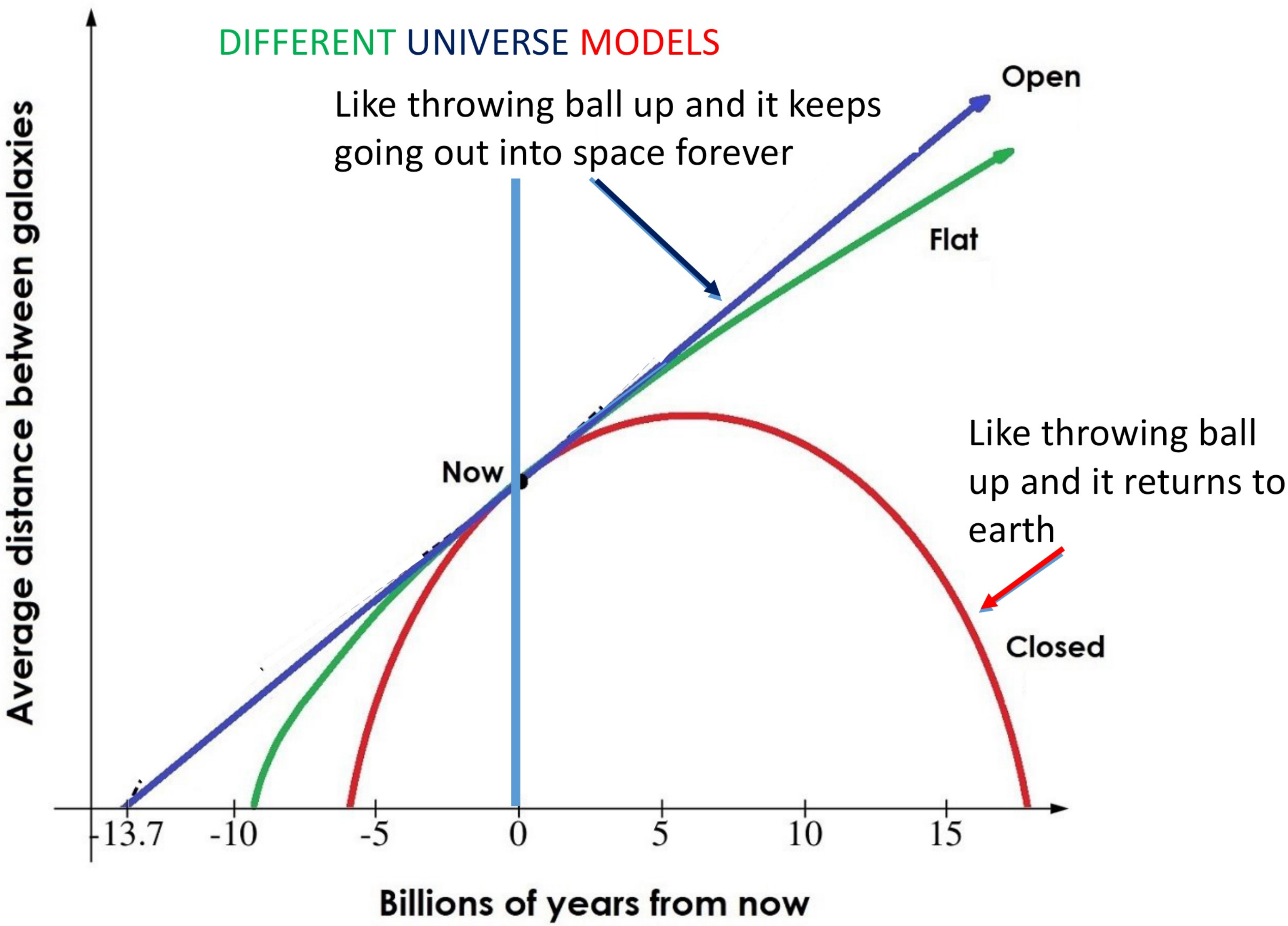
Picture of the infant universe 13.7 billion years ago created from five years of WMAP data. The color differences are slight temperature differences: red warmer and blue cooler by about 0.0002 degrees K. The warmer areas (higher density) grew into stars, galaxies, and galaxy clusters over time.

In 2018: Planck satellite



Plank’s picture of the infant universe. It measured temperature differences down to two parts in a million.

Is the Universe slowing down or will it expand forever?



Fast forward to 1997:

Two collaborations set out to check the expansion of the Universe

Their guess, the expansion would be slowing down, like a ball thrown up slows down.

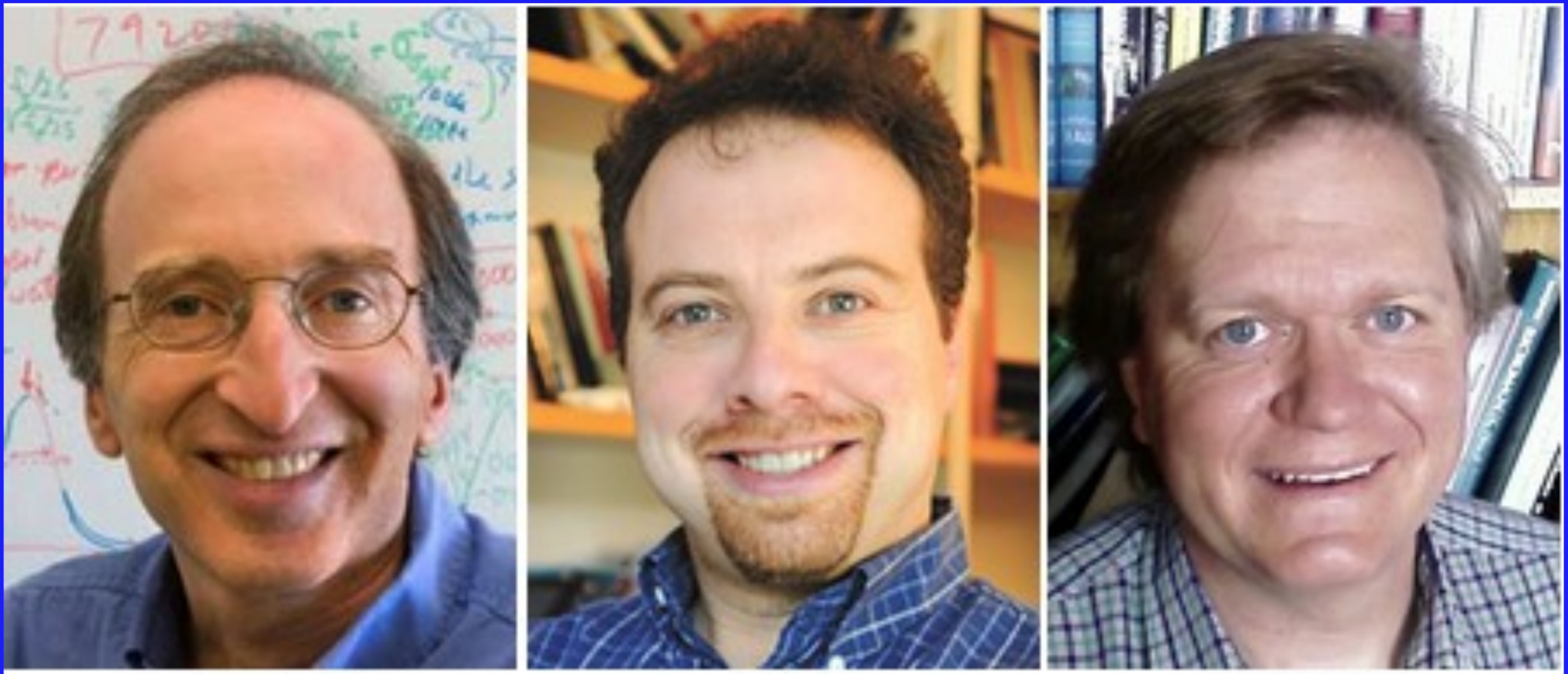
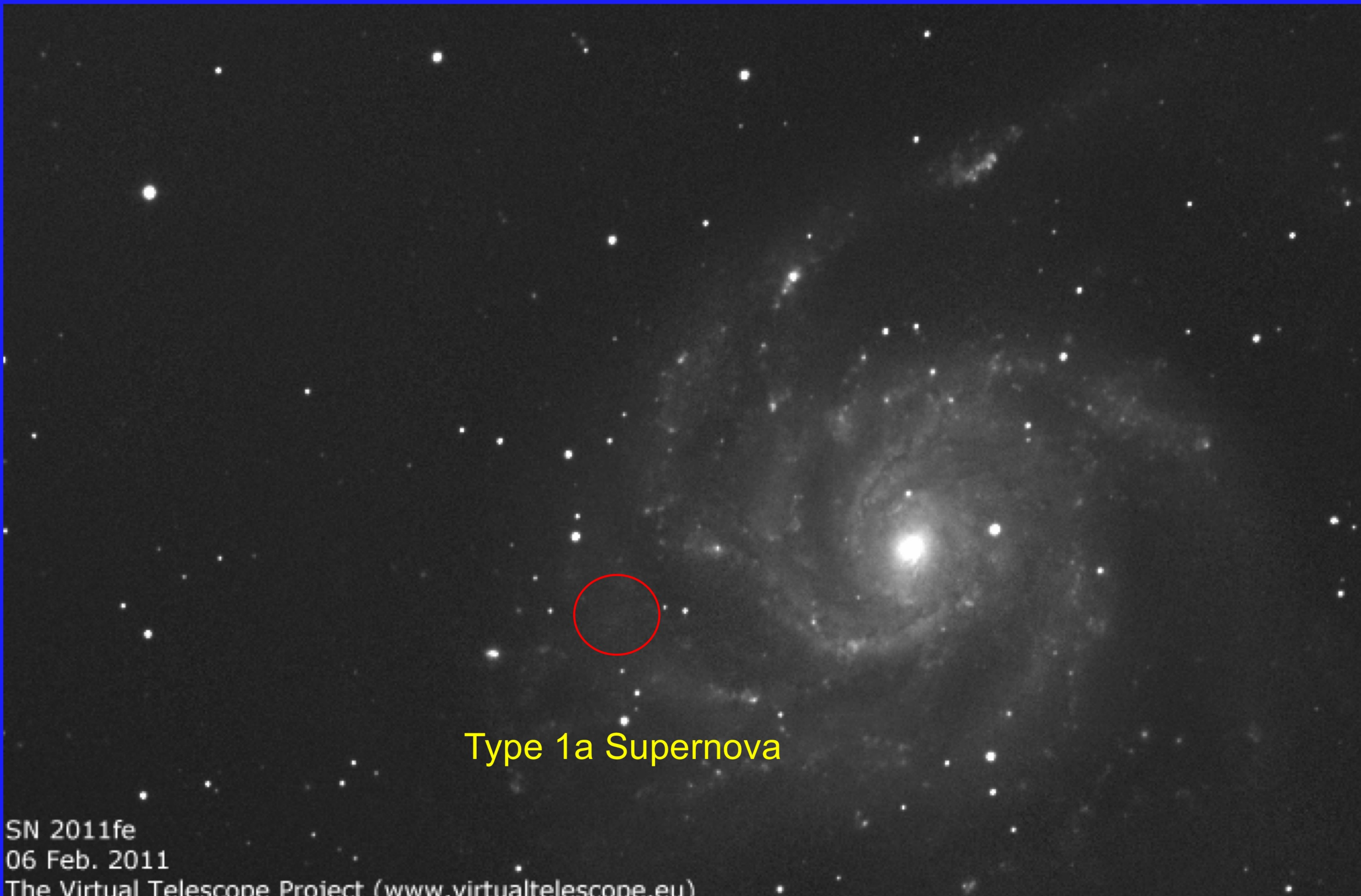


Image Credits (left to right): Roy Kaltschmidt, LBNL; Homewood Photography; Research School of Astronomy and Astrophysics, Australian National University

How did they see that the universe is expanding?

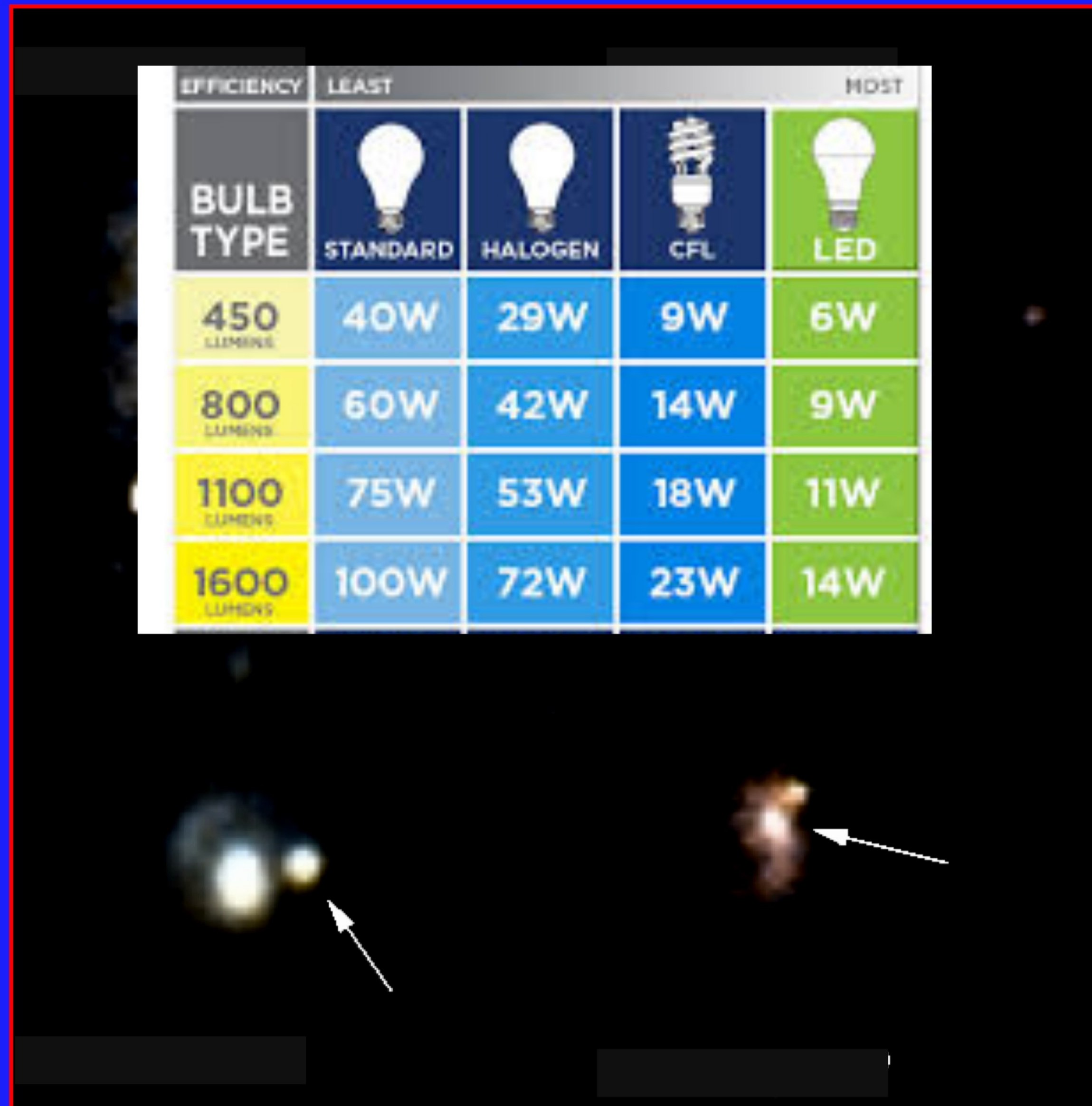


Type 1a Supernova:

A 1.4 Solar Mass thermonuclear bomb: easy to see across the cosmos

Used as a “standard candle” to measure cosmic distances due to all having the same mass and therefore the same absolute brightness

… but rare: some 1 per 100 years per galaxy

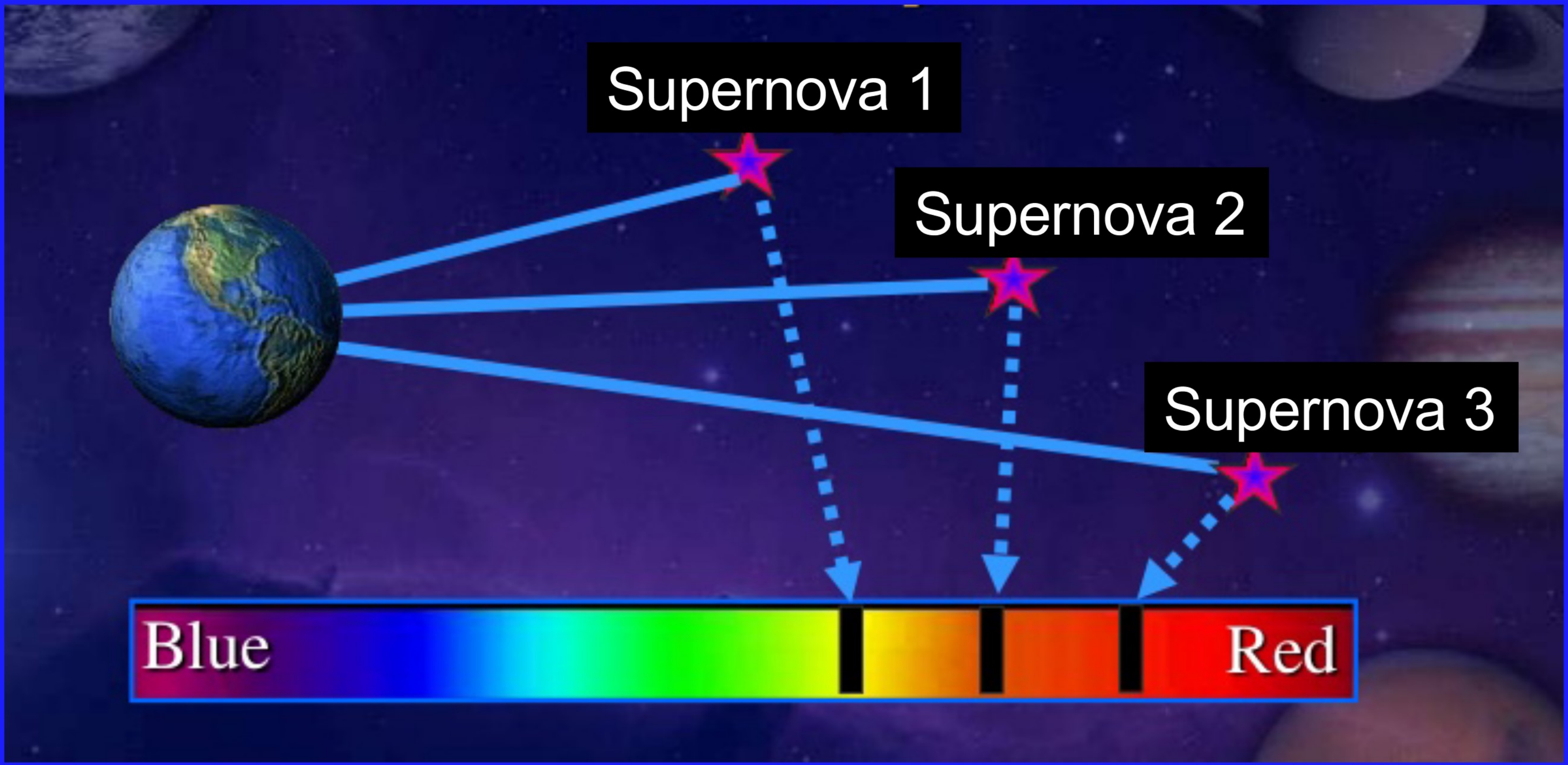


EFFICIENCY	LEAST			MOST
BULB TYPE	STANDARD	HALOGEN	CFL	LED
450 LUMENS	40W	29W	9W	6W
800 LUMENS	60W	42W	14W	9W
1100 LUMENS	75W	53W	18W	11W
1600 LUMENS	100W	72W	23W	14W

Check a lot of galaxies!

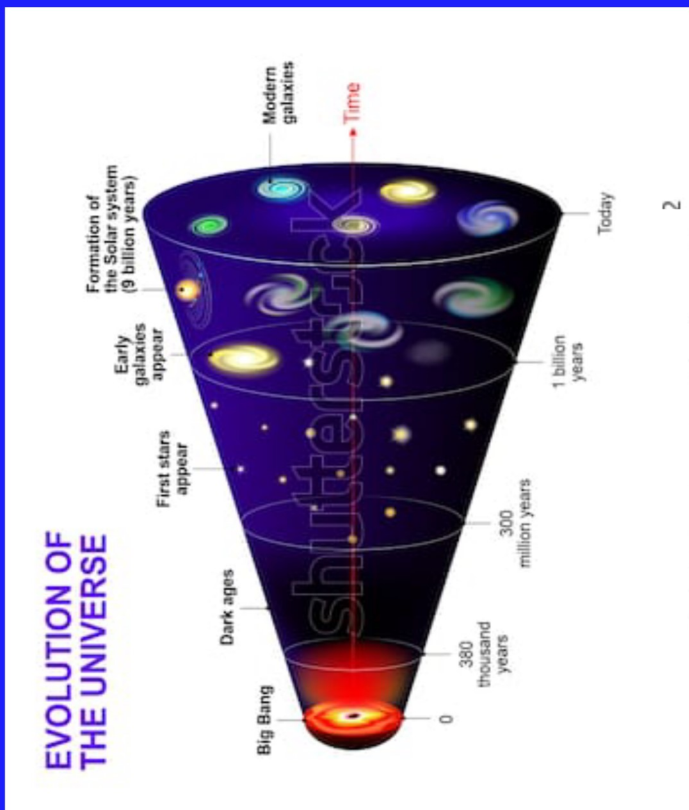
Using the Hubble Telescope they found that

Light from distant supernovae was dimmer than it should be and the redshifts were larger. Therefore the supernovae are further away than expected.

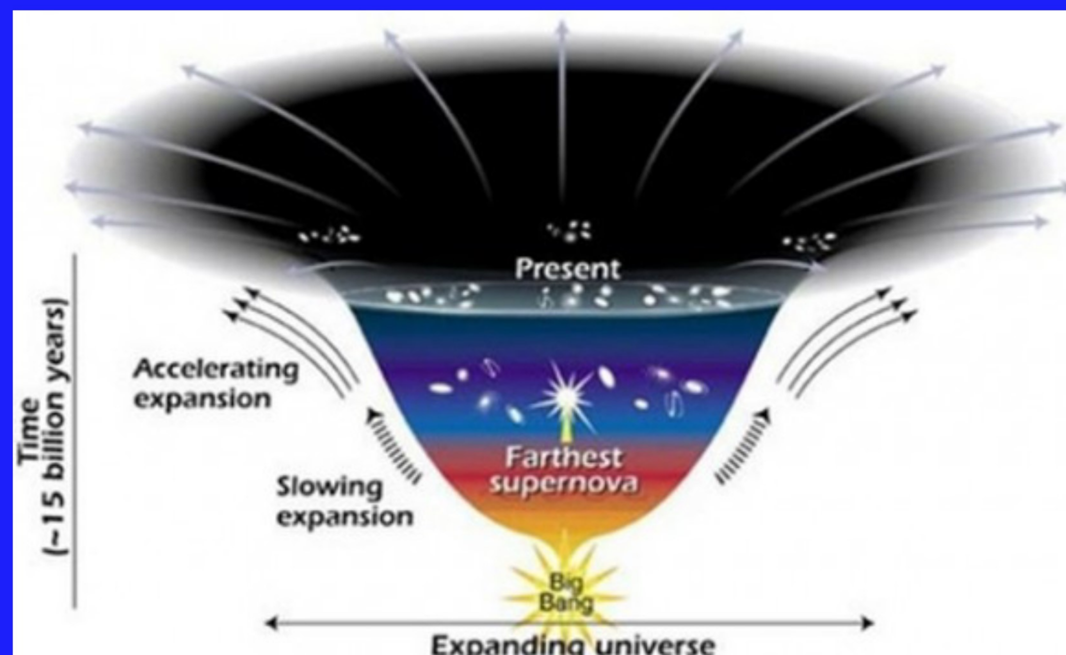


Something is pushing the distant supernovae further away: an unknown force (dark energy) is pushing the Universe apart.

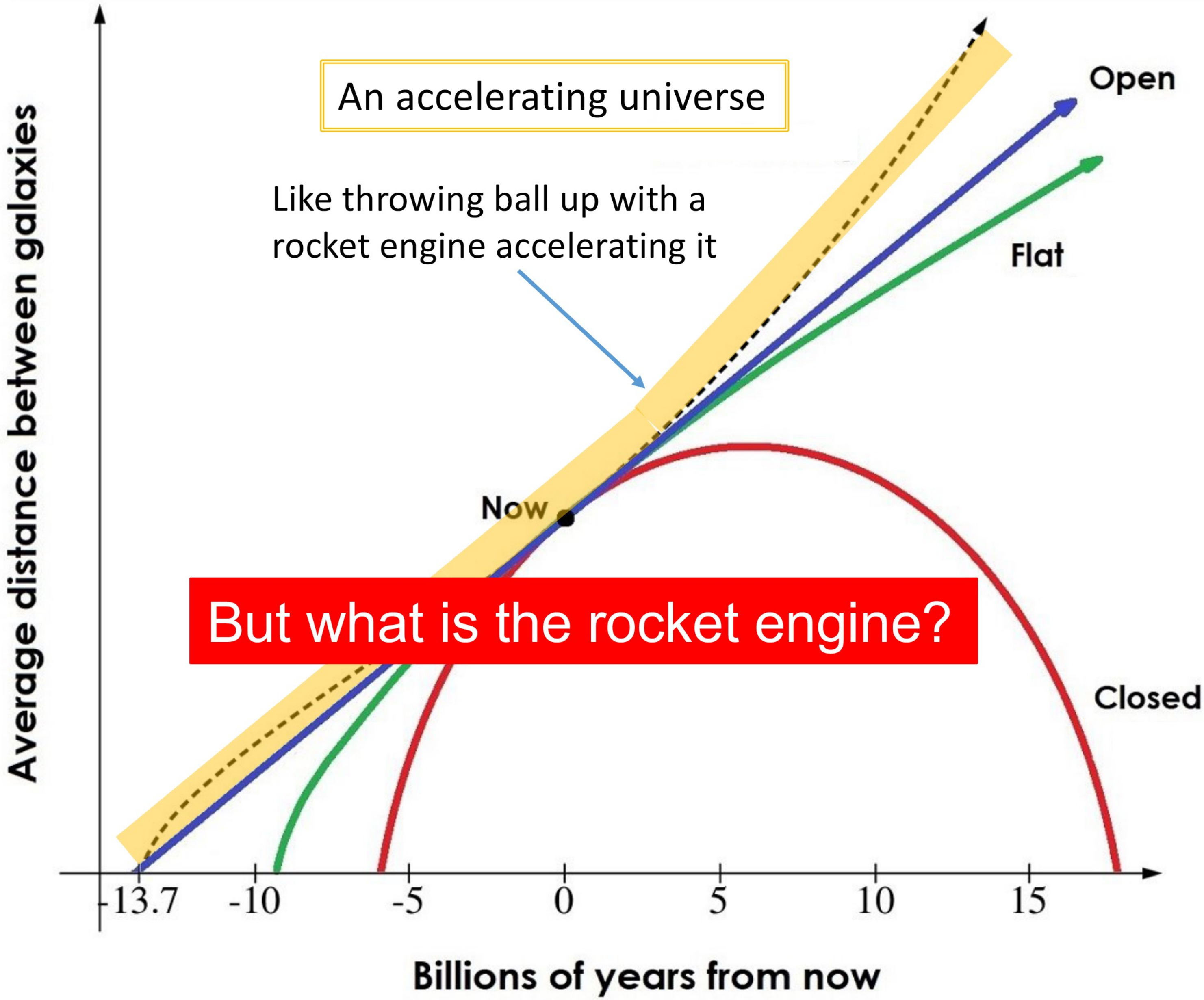
Instead of this Universe:



we have this:



ONE OF THE BIGGEST SURPRISES OF THE 20TH CENTURY:



Based on their data, the two teams concluded that the Universe is dominated by a new ingredient, some previously unknown “Dark Energy” that makes the Universe expand. In addition, the new ingredient is totally dominating the Cosmos. What is it?

30 years later, we still don’t know!

What DO we know about Dark Energy?

* Dark Energy pushes while gravity pulls

* It is an "anti-gravity" force that fills the Universe with negative pressure so space is stretched and matter is spread out over larger and larger distances

* Dark Energy became significant about 3.3 billion years ago

* Distributed evenly throughout space.
  Is it constant in time?

The Dark Energy Spectroscopic Instrument (DESI)

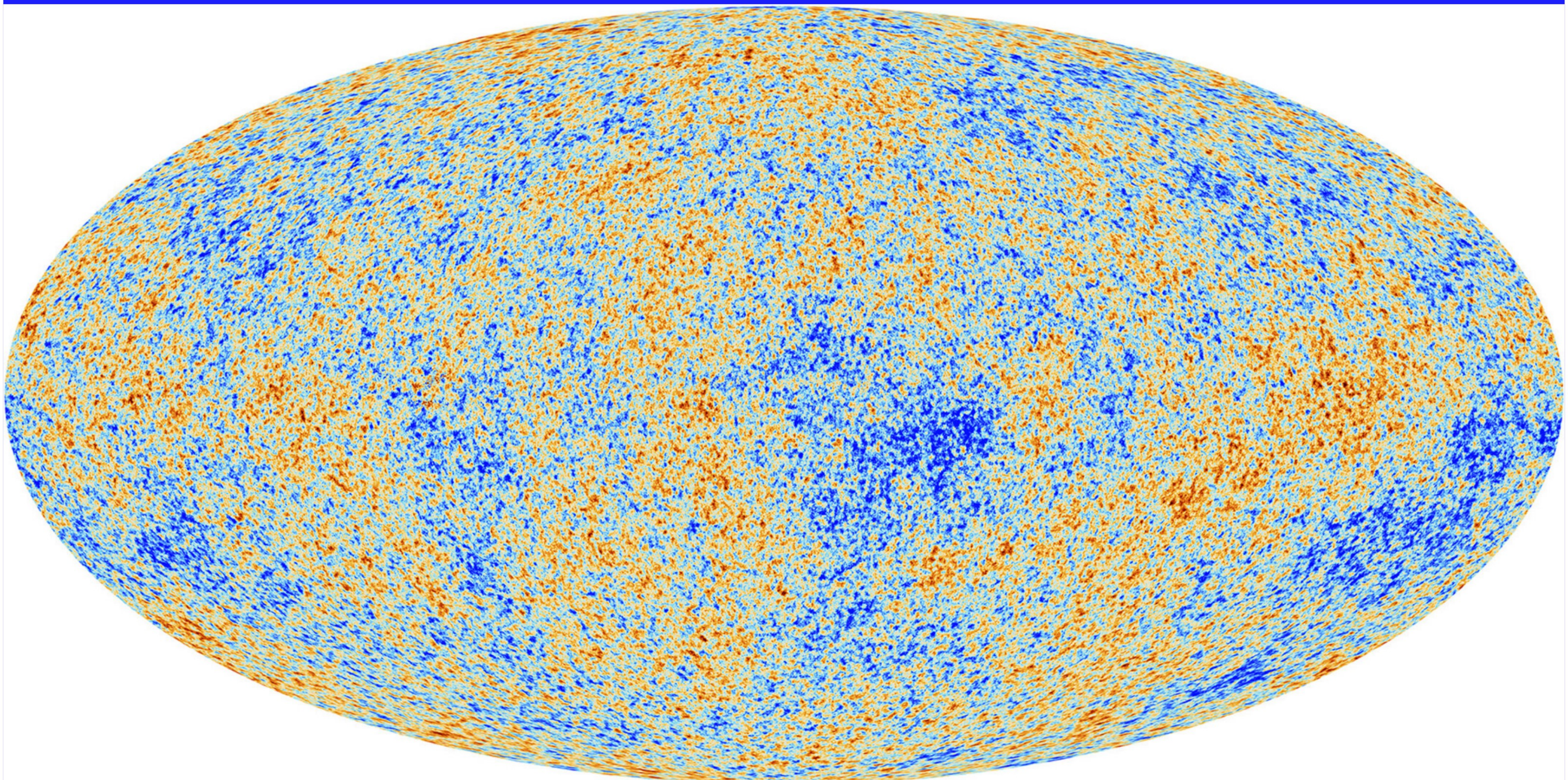
DESI is measuring the effect of **dark energy** on the expansion of the universe to find out whether it is constant over time. It does this by measuring redshifts and other properties of tens of millions of galaxies and quasars, and constructing a 3D map spanning the Universe out to 12 billion light years from Earth -- that is, 1.8 billion years after the Big Bang.

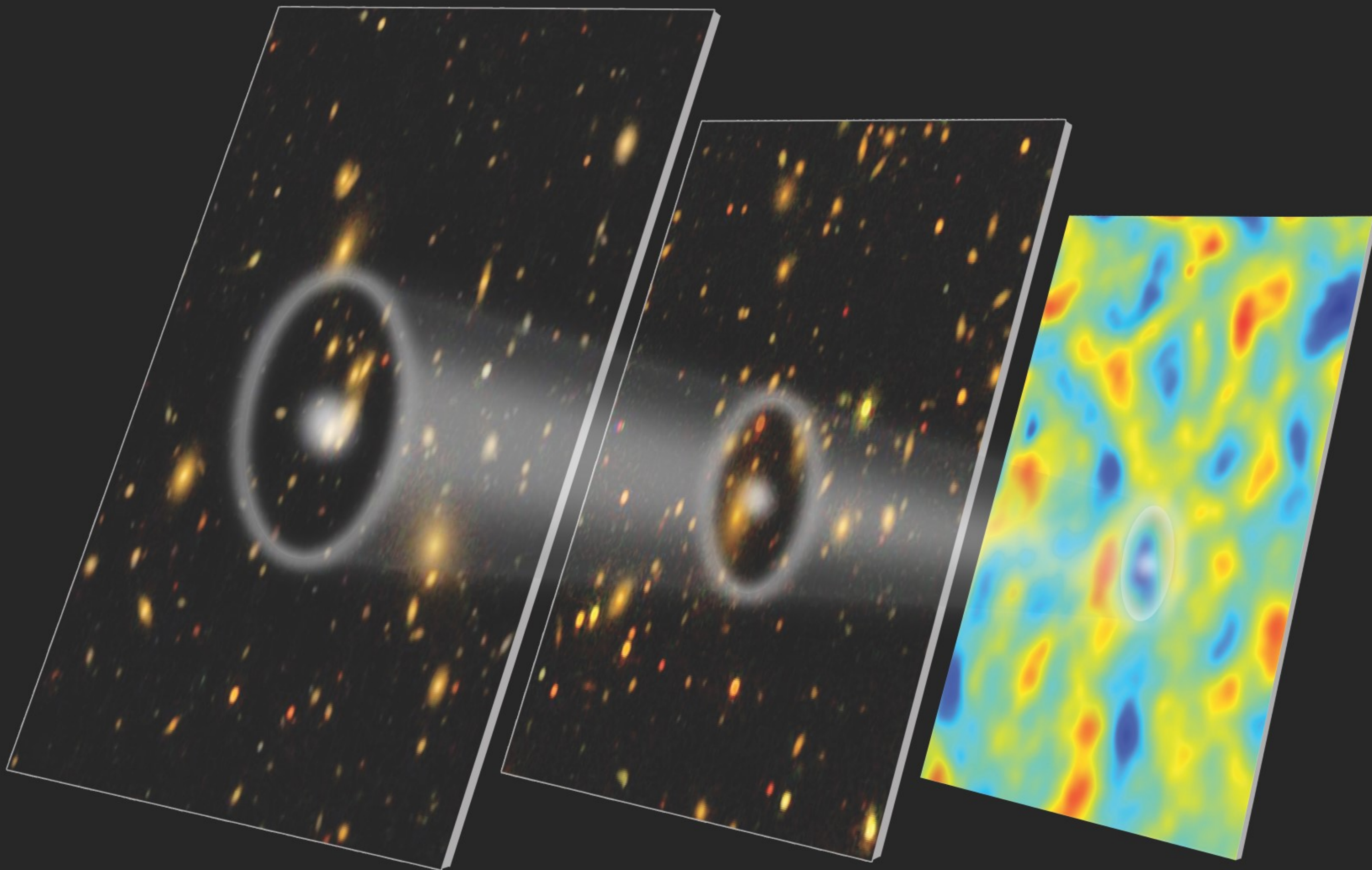
DESI will obtain 40 million redshifts over its five year survey.

DESI is mounted on the 4-meter (13 ft) Mayall Telescope at Kitt Peak National Observatory outside Tucson, Arizona

DESI EXPERIMENT SETUP

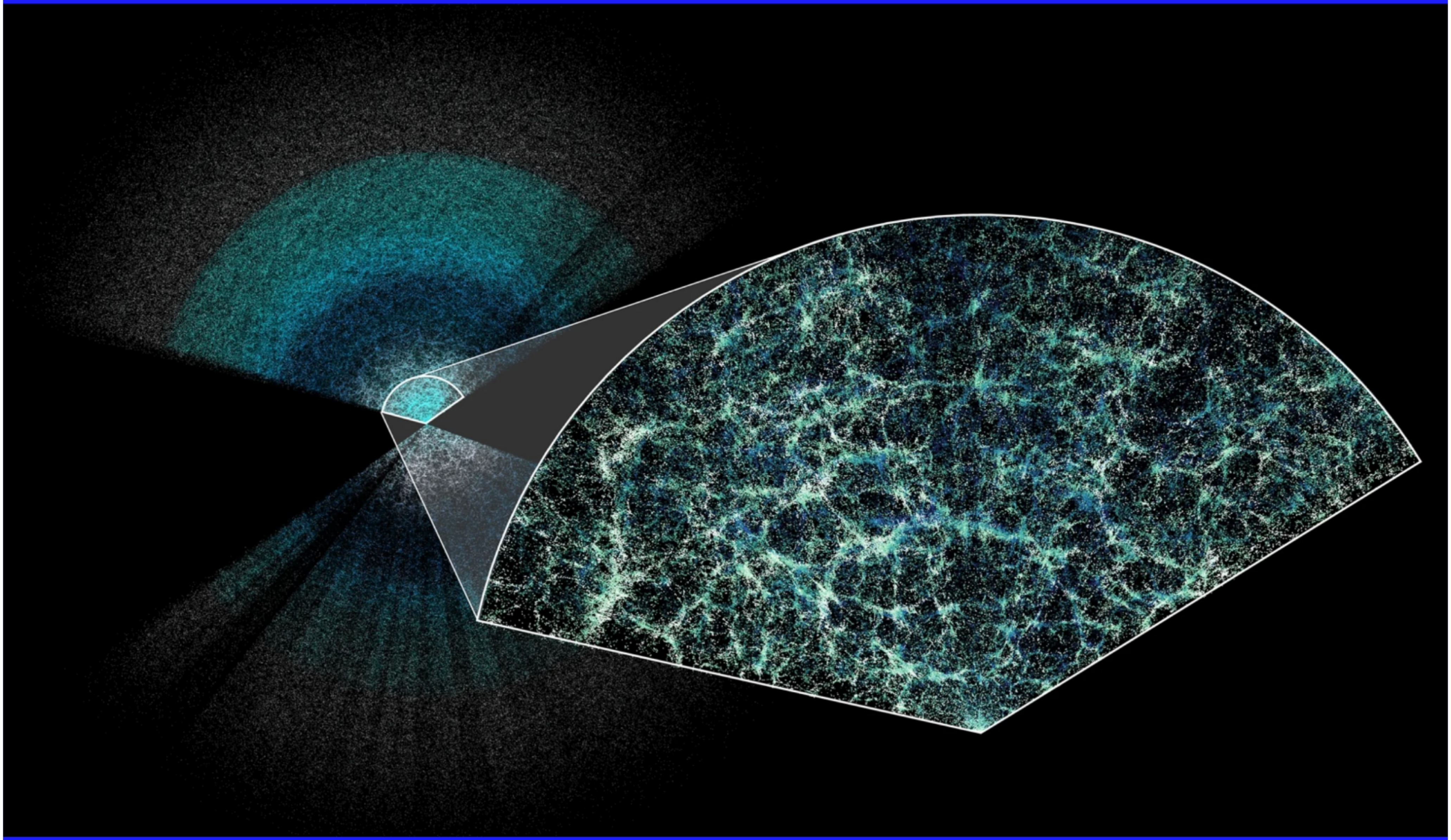
Planck satellite's picture of the infant Universe



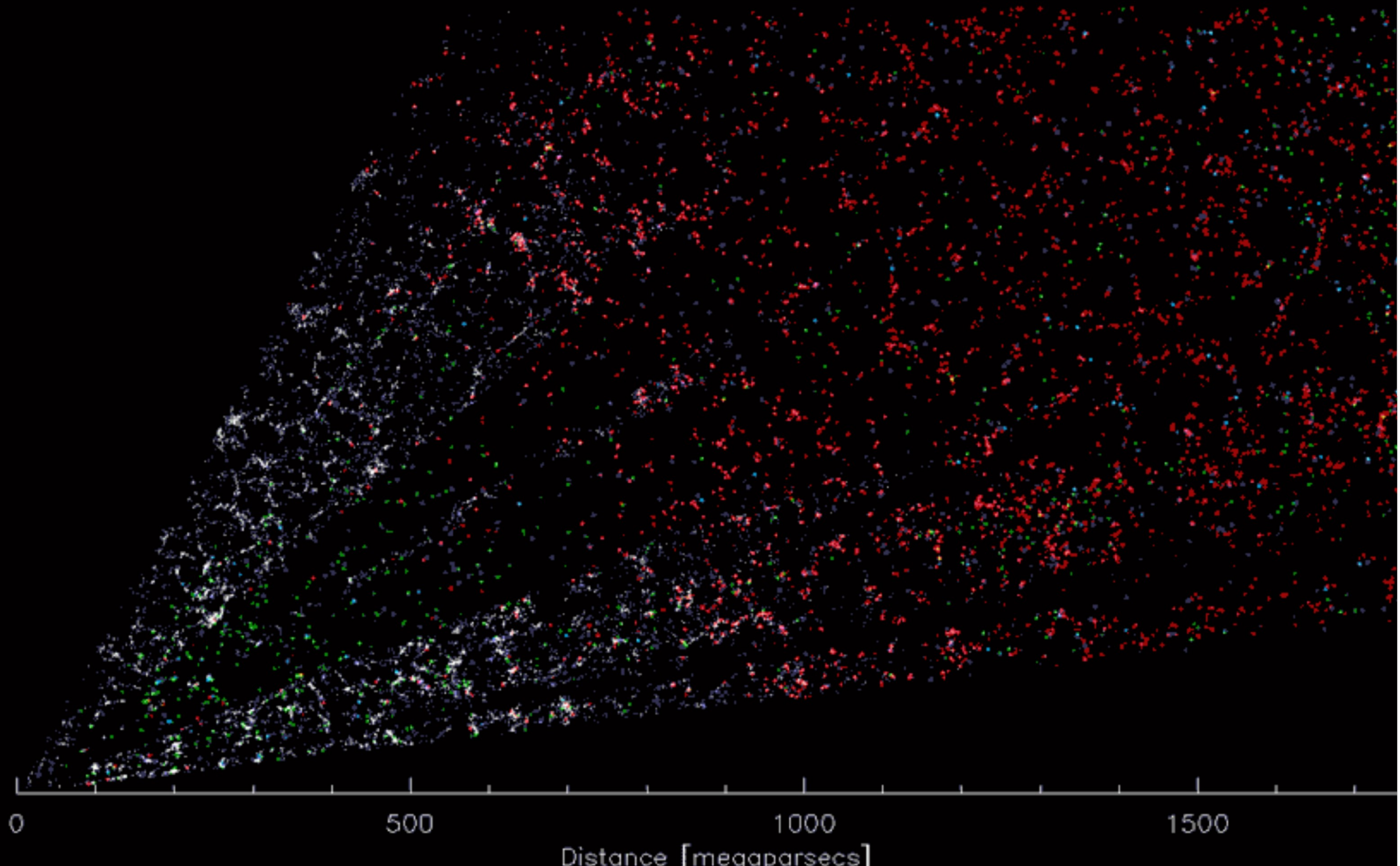


Galaxy map 3.8 billion years ago
Galaxy map 5.5 billion years ago
CMB 13.7 billion years ago

Earth is at the center of this thin slice of DESI's 3D map of the Universe and magnifies the distribution of 7.5 million galaxies and voids as far back as 12 billion years ago.



Galactic redshifts at different angles up to 5 billion light years



5 billion light years

New Results from DESI as of April 2024:

Dark Energy may be weakening

** DESI, combining its results with recent supernova data, is giving first hints that Dark Energy is varying in time – not constant!

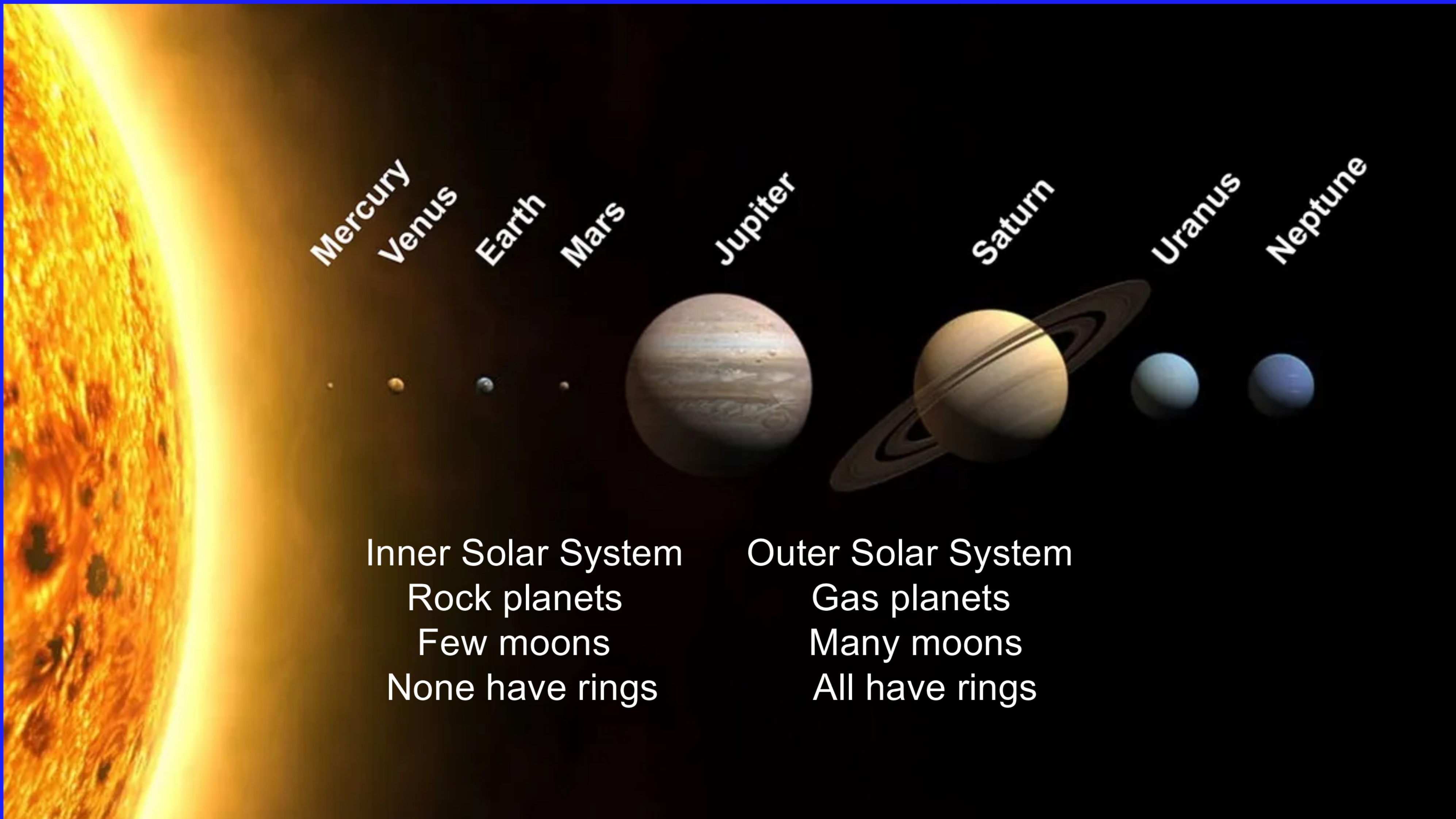
** The expansion of the Universe is slowing down or “thawing.”

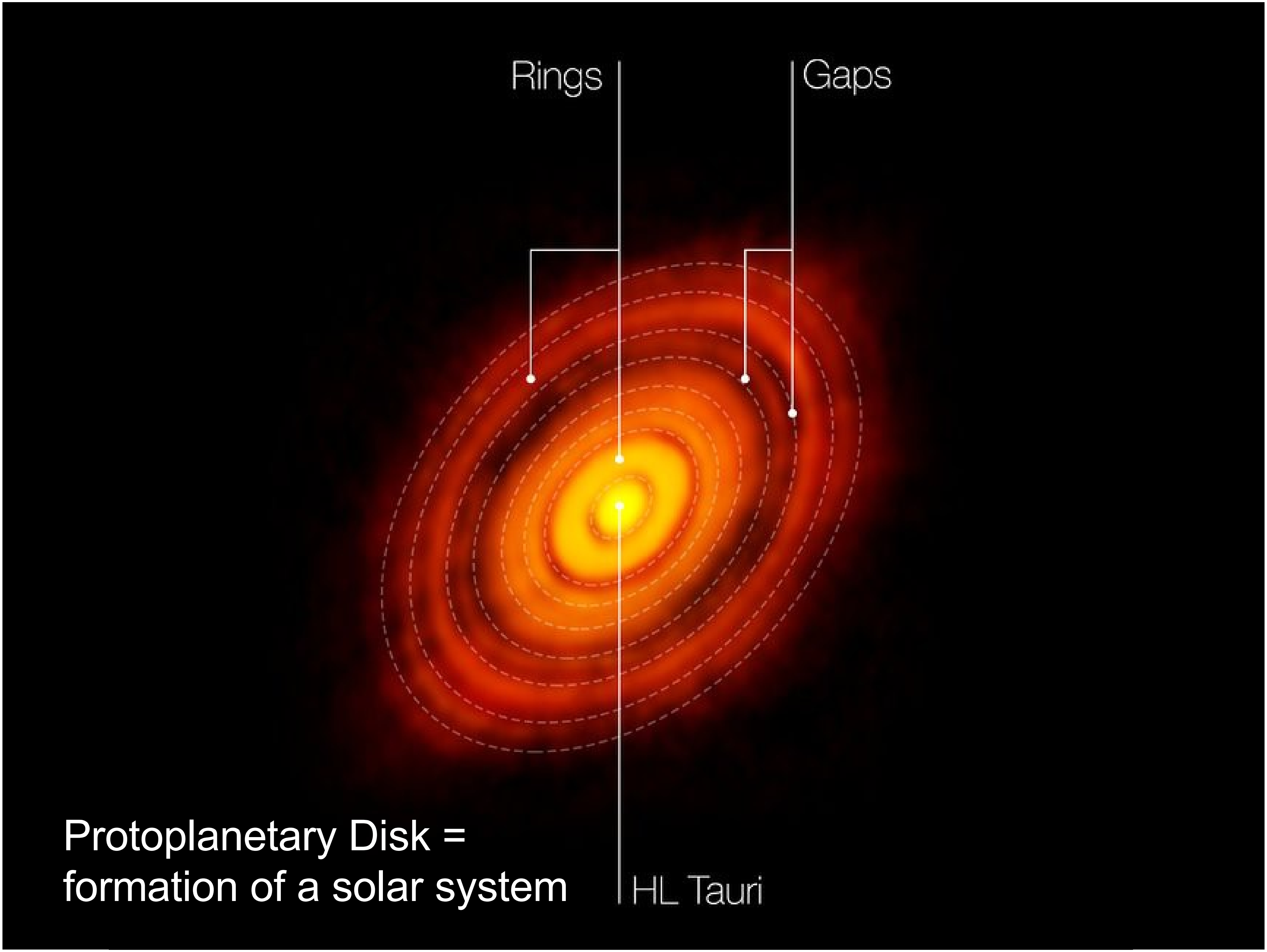
** Dark Energy may have reached maximum strength about 3 billion years ago, weakening now and into the future.

** Should know more at the end of this year.

STAY TUNED!!

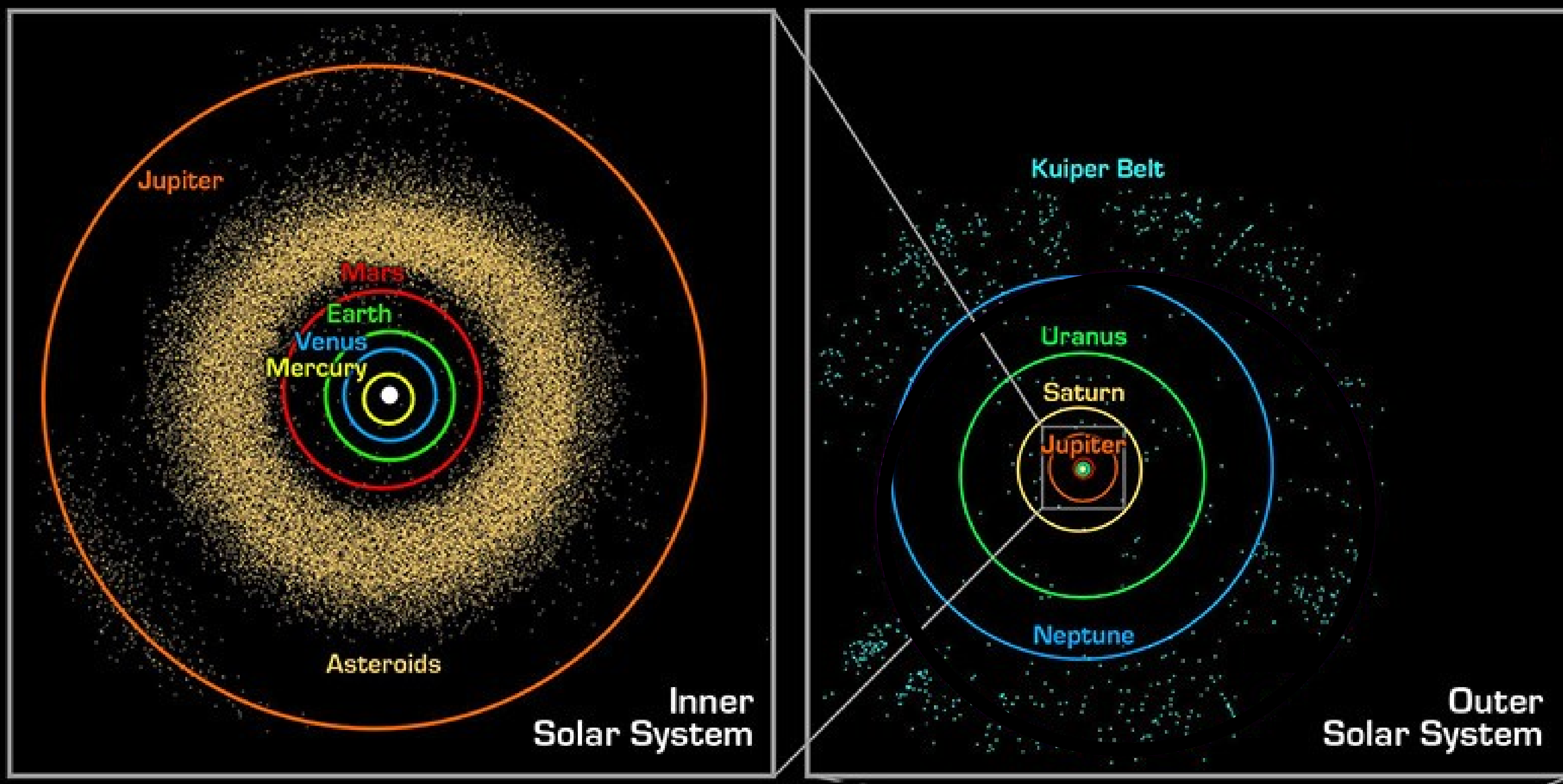
Probing the Solar System



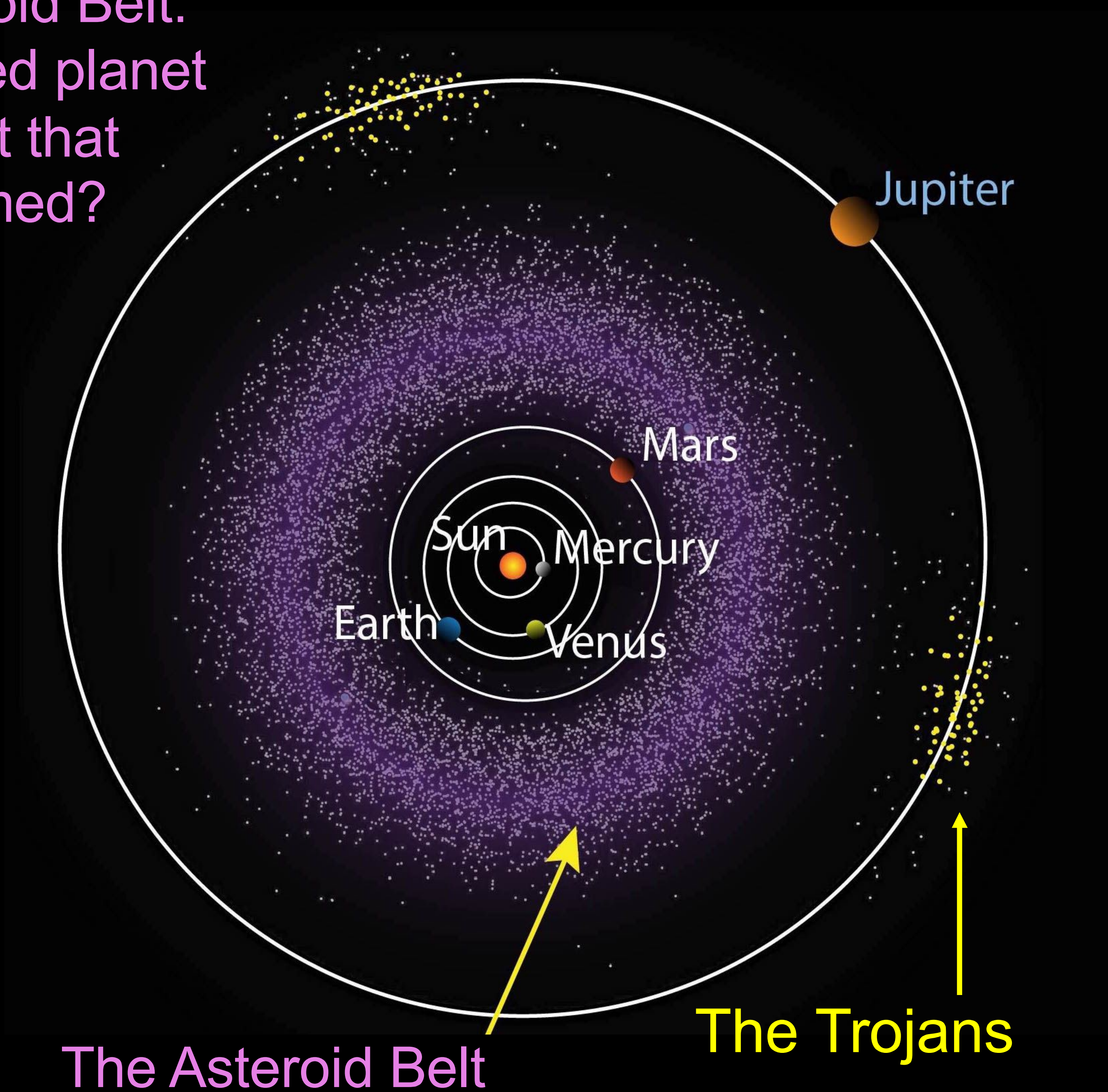


Rings
Gaps
HL Tauri
Protoplanetary Disk =
formation of a solar system

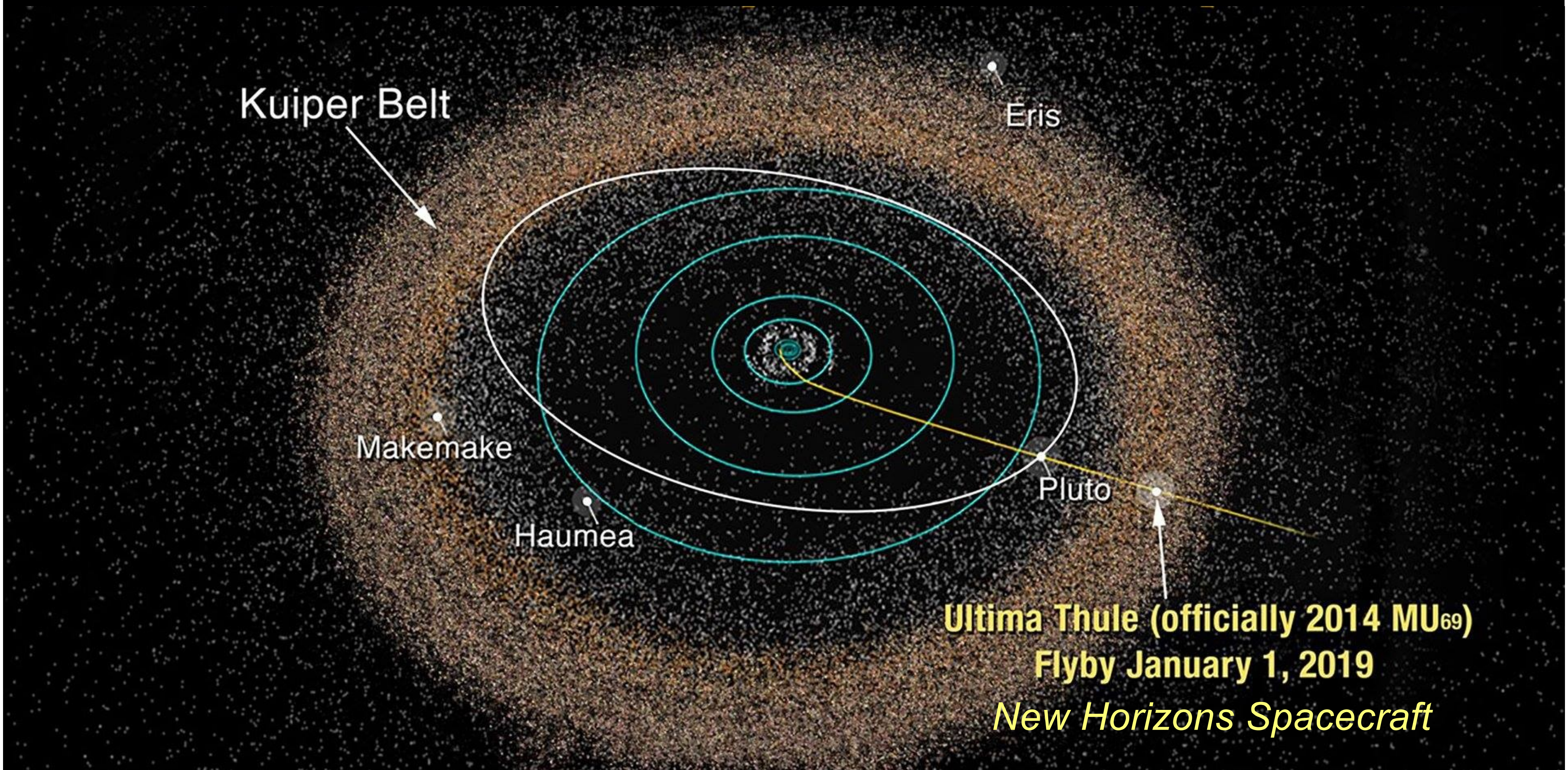
The Solar System is filled with “leftovers” from the formation of the Planetary System

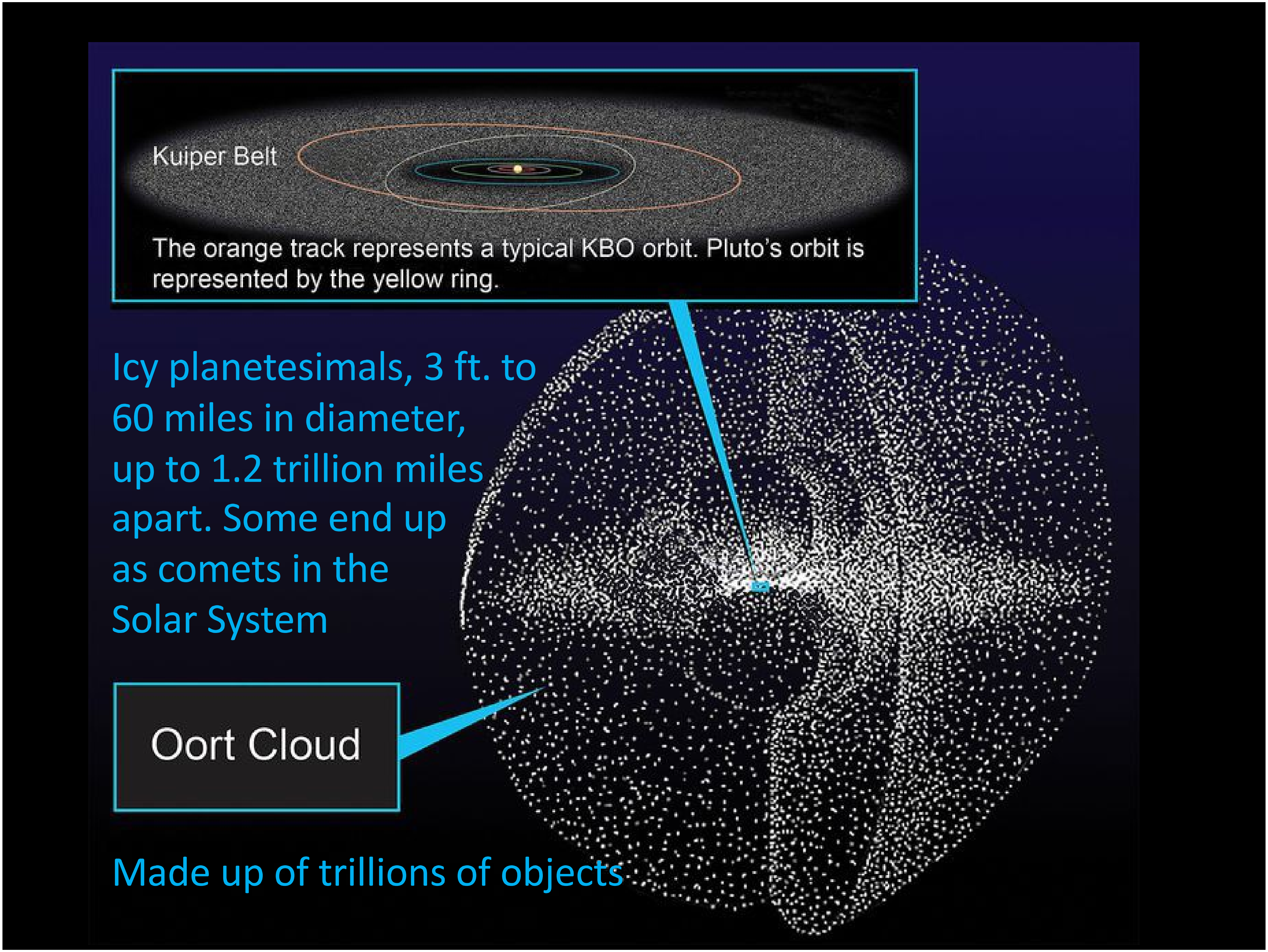


The Asteroid Belt: a destroyed planet or a planet that never formed?

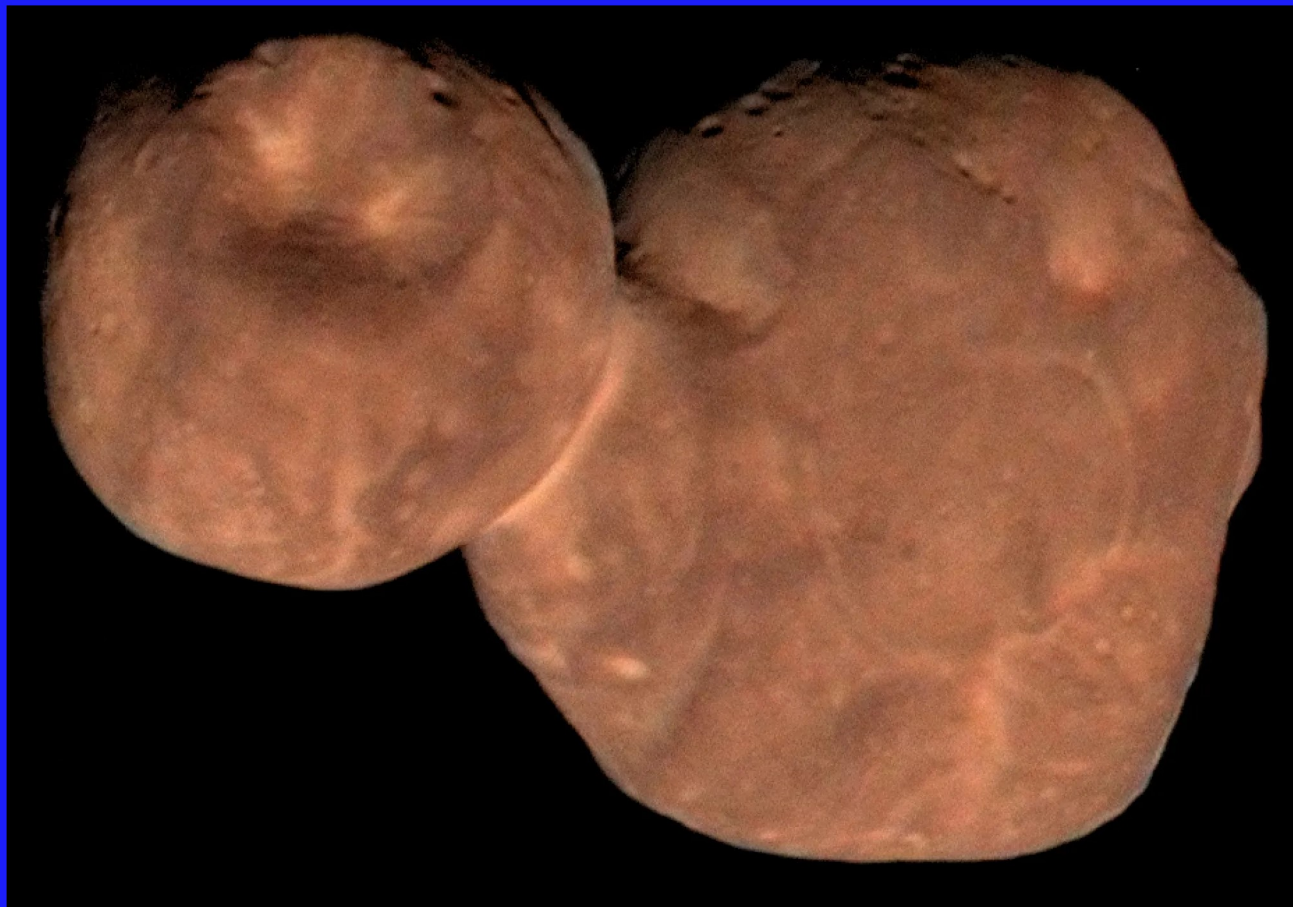


The Kuiper Belt: a destroyed planet or a planet that never formed?




Kuiper Belt
The orange track represents a typical KBO orbit. Pluto's orbit is represented by the yellow ring.
Icy planetesimals, 3 ft. to 60 miles in diameter, up to 1.2 trillion miles apart. Some end up as comets in the Solar System
Oort Cloud
Made up of trillions of objects

Ultima Thule: the farthest and most primitive object ever explored



New Horizons mission

A *contact binary,* 22 miles long, 4 billion miles away, photographed by *New Horizons Spacecraft* in 2019

Ultima Thule meaning *a* distant unknown region; the extreme limit of travel and discovery.

Space travels: The Rosetta Mission to Comet 67P

The Rosetta spacecraft mission

* Rosetta spacecraft named after the Rosetta Stone

* Philae, landing probe, named after the Philae Obelisk (In Egypt)

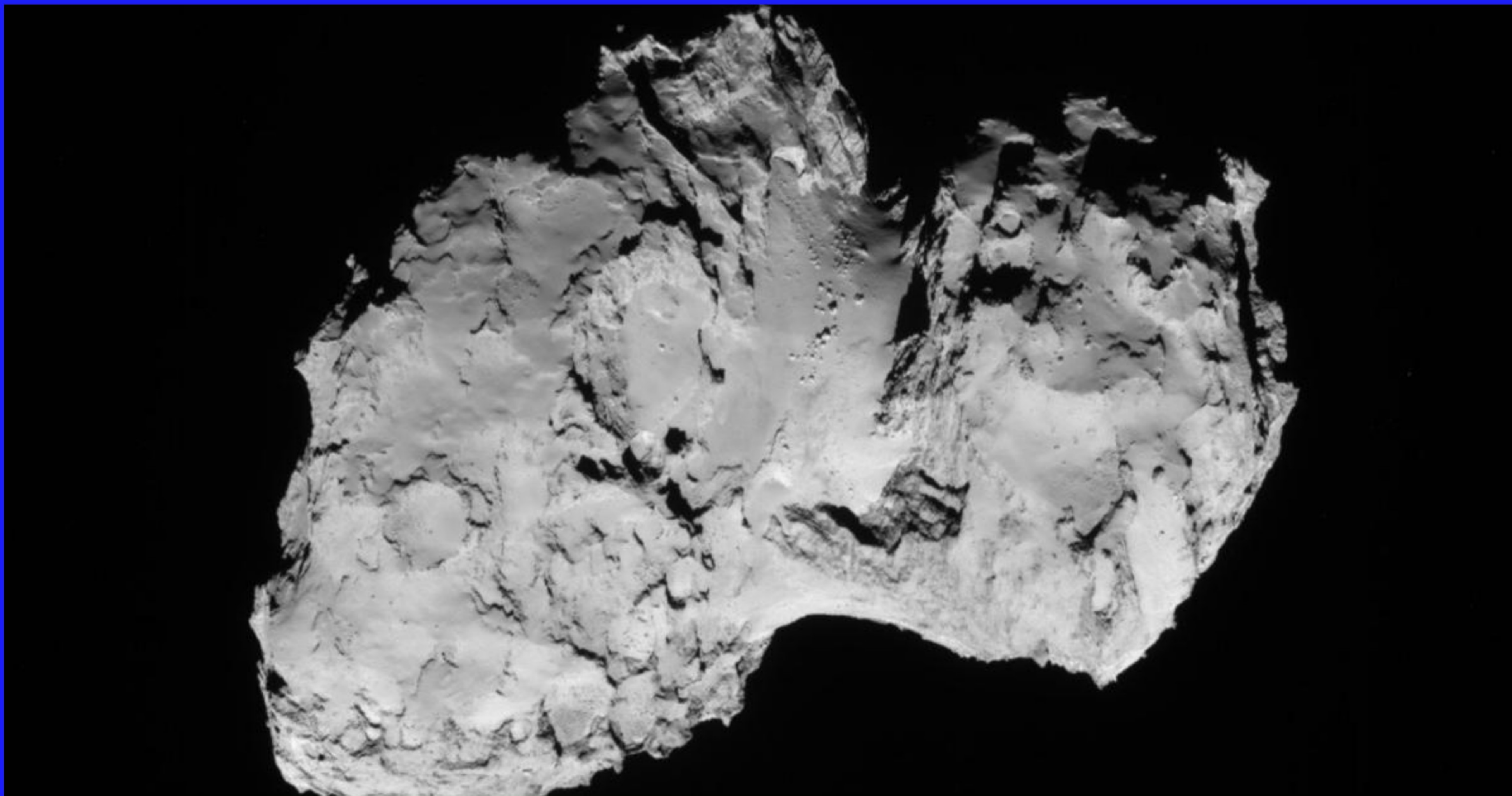
* **12 year long mission,** began in 2004, to **Comet 67P** to measure its characteristics and land a probe on the comet's surface.

* Reached destination in August 2014. Philae touch-down in November. Due to weak gravity (comet only **2.5 mi. long**) it bounced off the surface twice before settling next to a shady rock., It managed to send just a few days' worth of data over the course of more than 21 months..

* The Rosetta spacecraft followed the comet through its closest approach to the Sun and back again into the Solar system.
Its mission ended on September 30, 2016

Elements and chemical compounds found in comets and asteroids

* *Comet 67P*: Water vapor, heavy water, molecular oxygen, carbon dioxide, argon, hydrogen sulfide, hydrogen cyanide, ammonia (H_2O, D_2O, O_2, CO_2, Ar, H_2S, HCN, NH_3.)



The *Itokawa* asteroid, 1,100 feet in diameter, is located in the the Asteroid Belt. The Japanese spacecraft probe, *Hayabusa,* landed on the asteroid in 2019. Made of silicates and nickel-iron. Exposed to many collisions and heated up to 800^0 C = 1500^0 F. Came from parent body, size 12 miles.

Solar wind and galactic cosmic rays will ultimately break it up.

Ryugu, *dragon palace,* near-Earth asteroid (Hayabusa 2)

Studies of the *Ryugu* samples show that the asteroid is very old and formed near Neptune. Ryugu's top layer (regolith) contains abundant water-rich minerals, organic matter, and minerals that formed at high temperatures in the solar nebula more than 4.5 billion years ago.

The chemical compound *uracil*, one of the building blocks of RNA, was in the asteroid sample -- strongest evidence yet that the organic building blocks for life on Earth were formed in space.

Bennu, near-Earth asteroid

OSIRIS-REx : The first U.S. mission to collect a sample from an asteroid

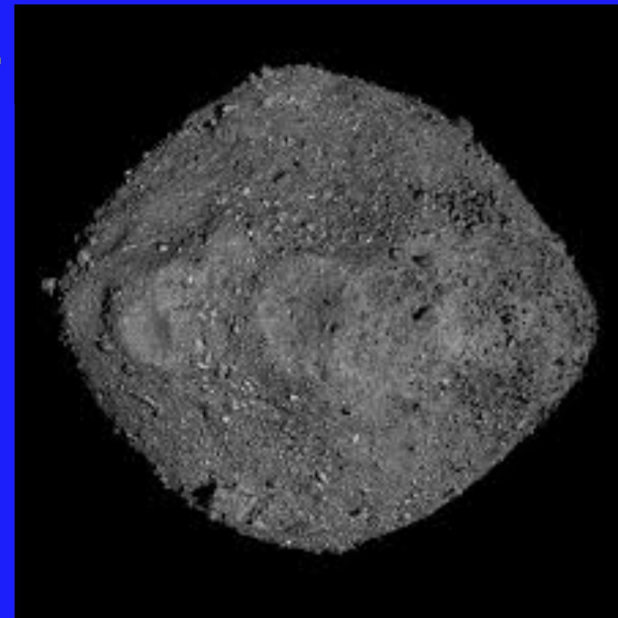
Asteroid *Bennu* samples contain water locked up in minerals like clays and are also rich in carbon, nitrogen, sulfur, and phosphorous.

Phosphate links the nucleotides, the chemical building blocks of DNA together.

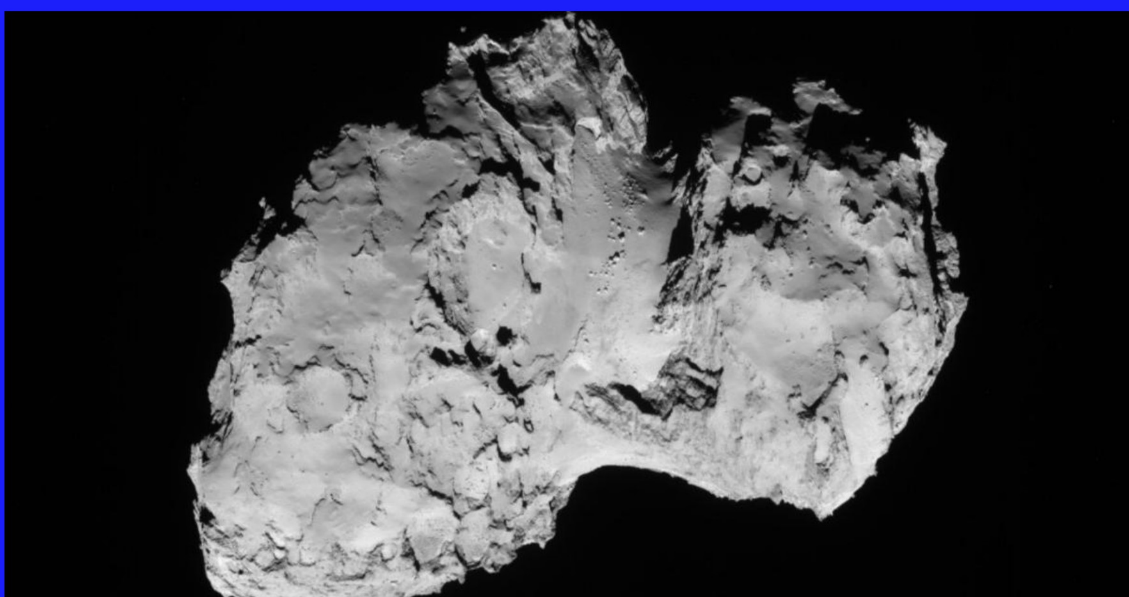
Saturn's moon Enceladus, which has water geysers, also contains phosphates.

Asteroids and comets visited by spacecrafts.
Two are contact binaries.

Itokawa, Asteroid Belt



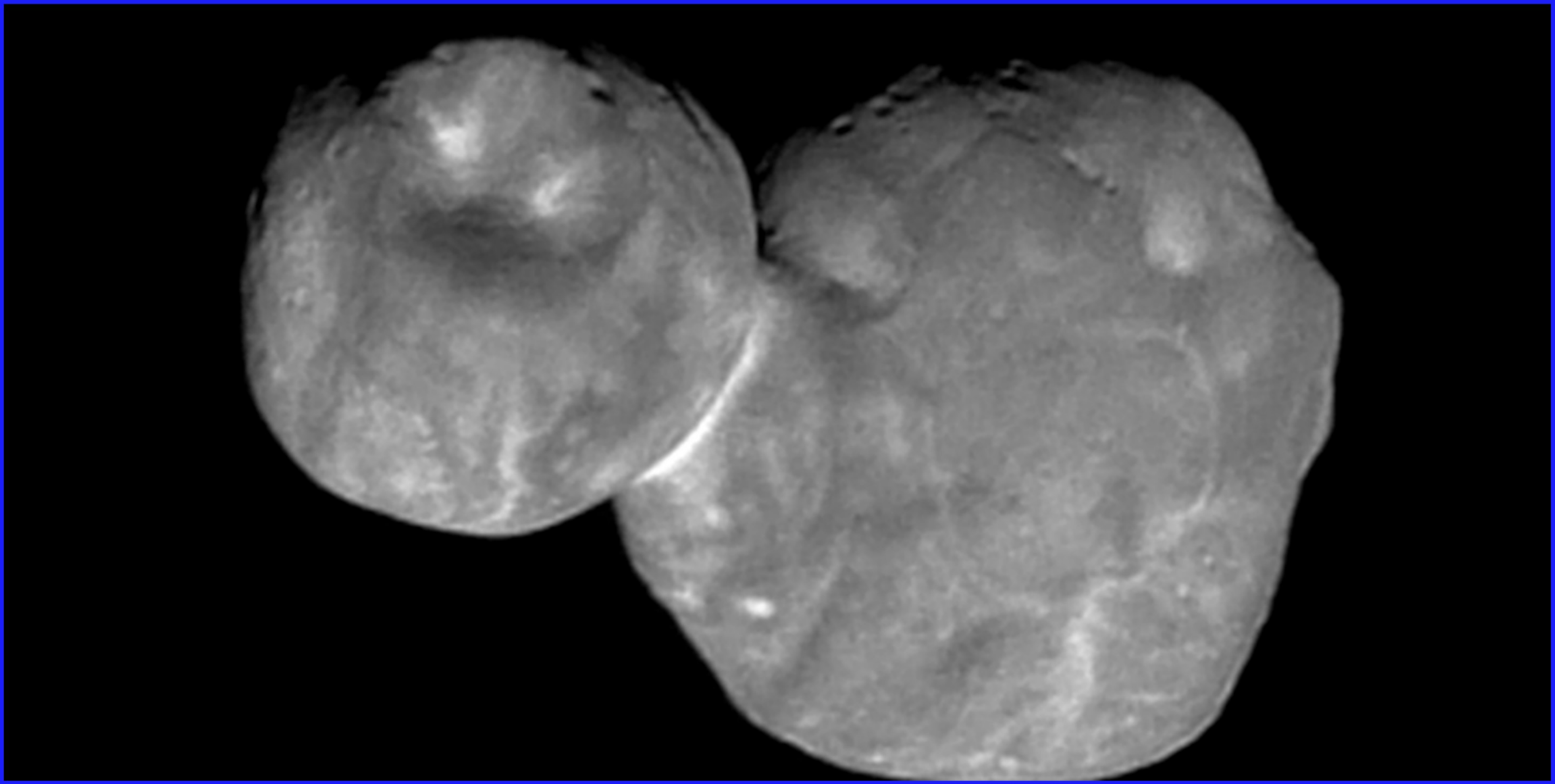
Bennu, near-Earth asteroid



Comet P67, near-Earth comet

Ryugu, near-Earth asteroid

Ultima Thule



A distant unknown region; the extreme limit of travel and discovery.

THANK YOU