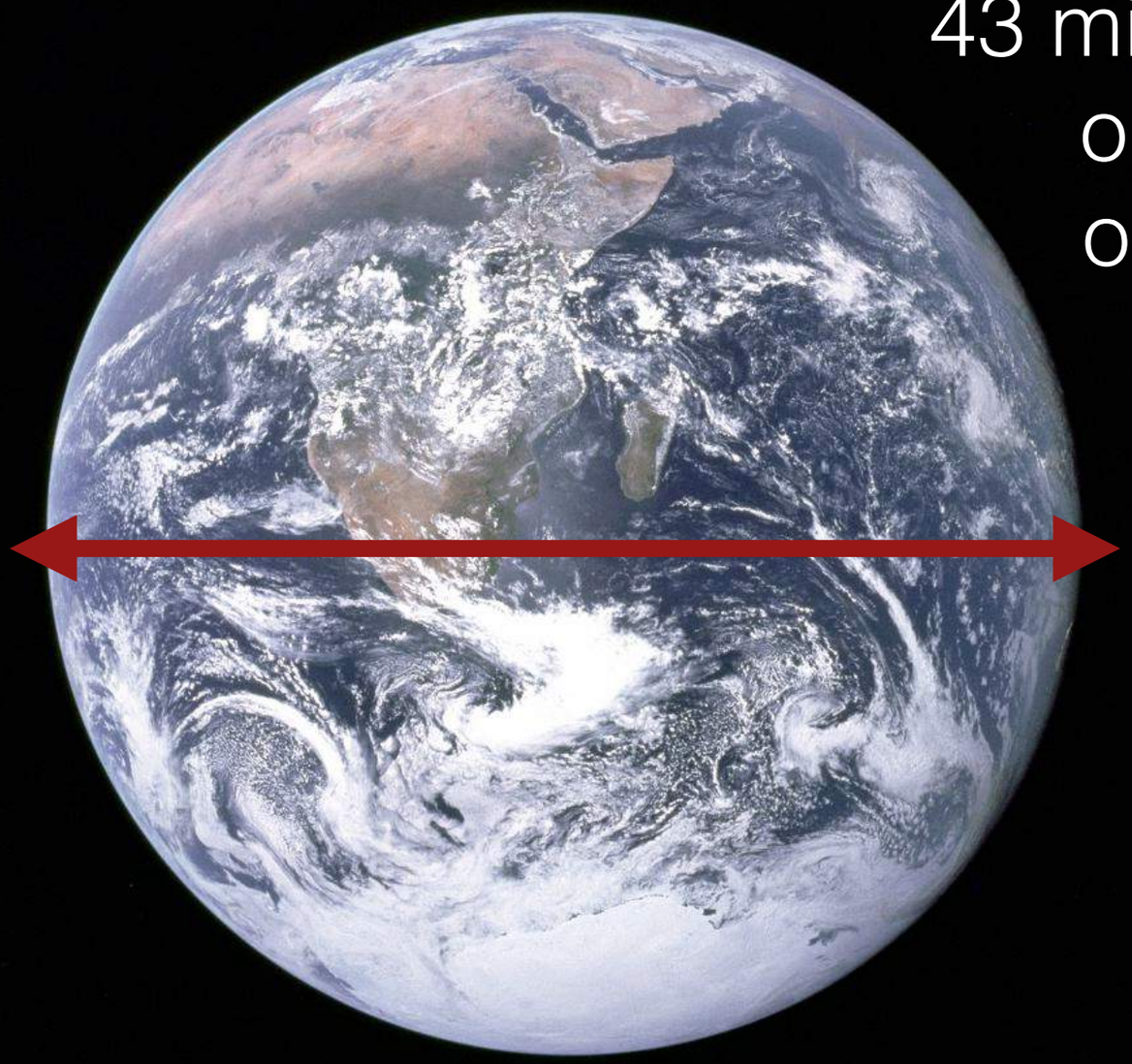
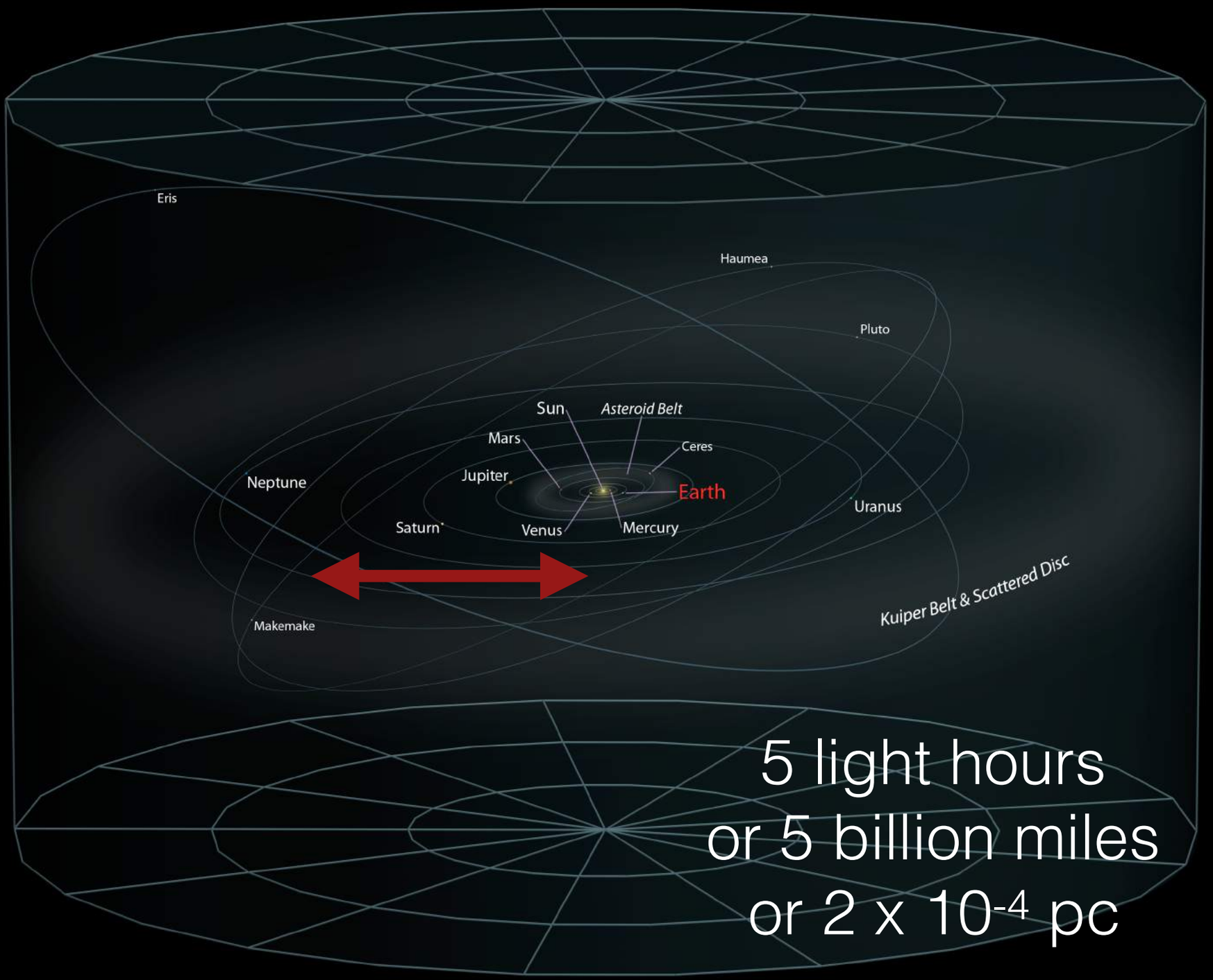
How big is our Universe?

The Earth



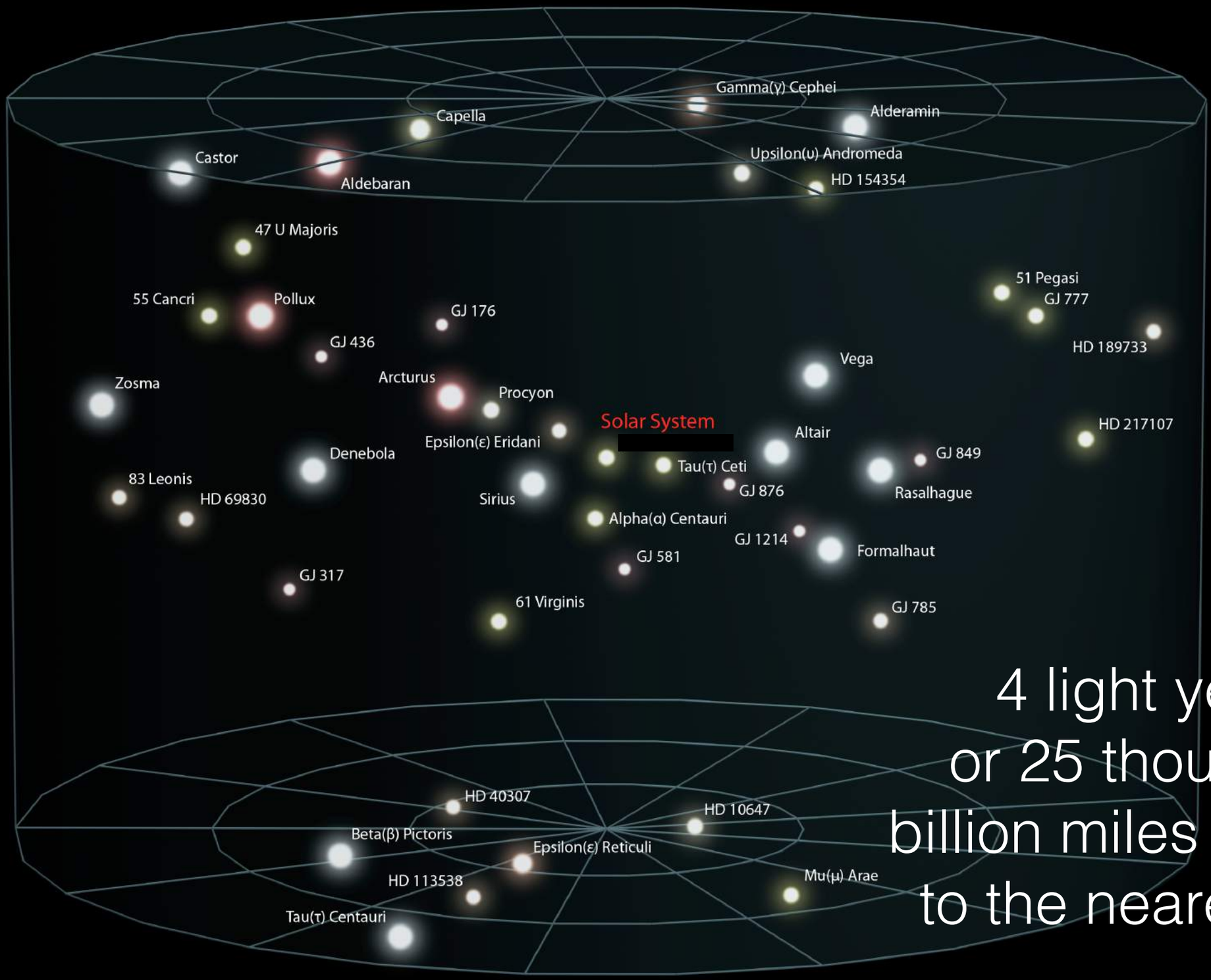
43 milli-light seconds
or 8000 miles
or 4×10^{-7} pc

The Solar System



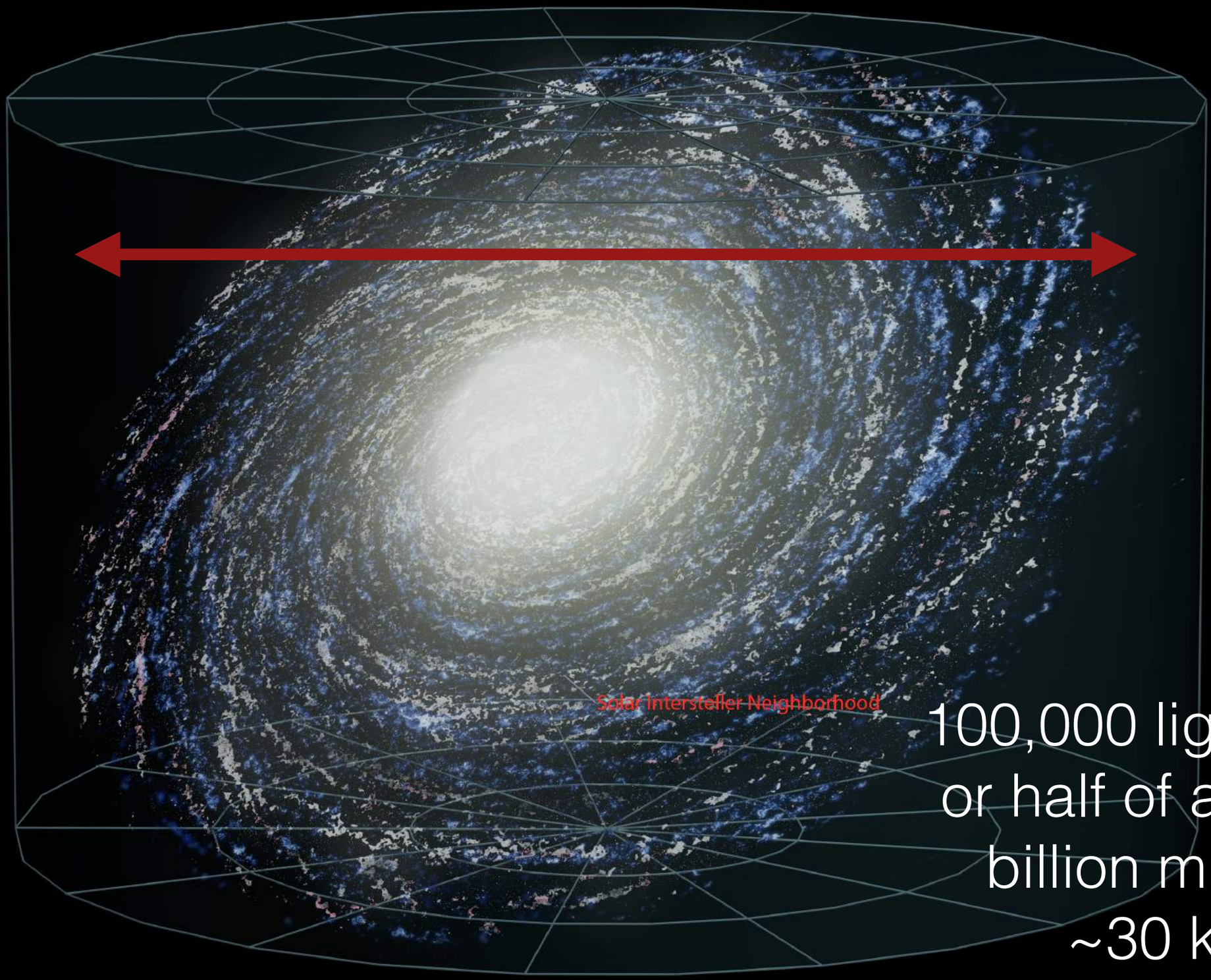
5 light hours
or 5 billion miles
or 2×10^{-4} pc

Nearby Stars

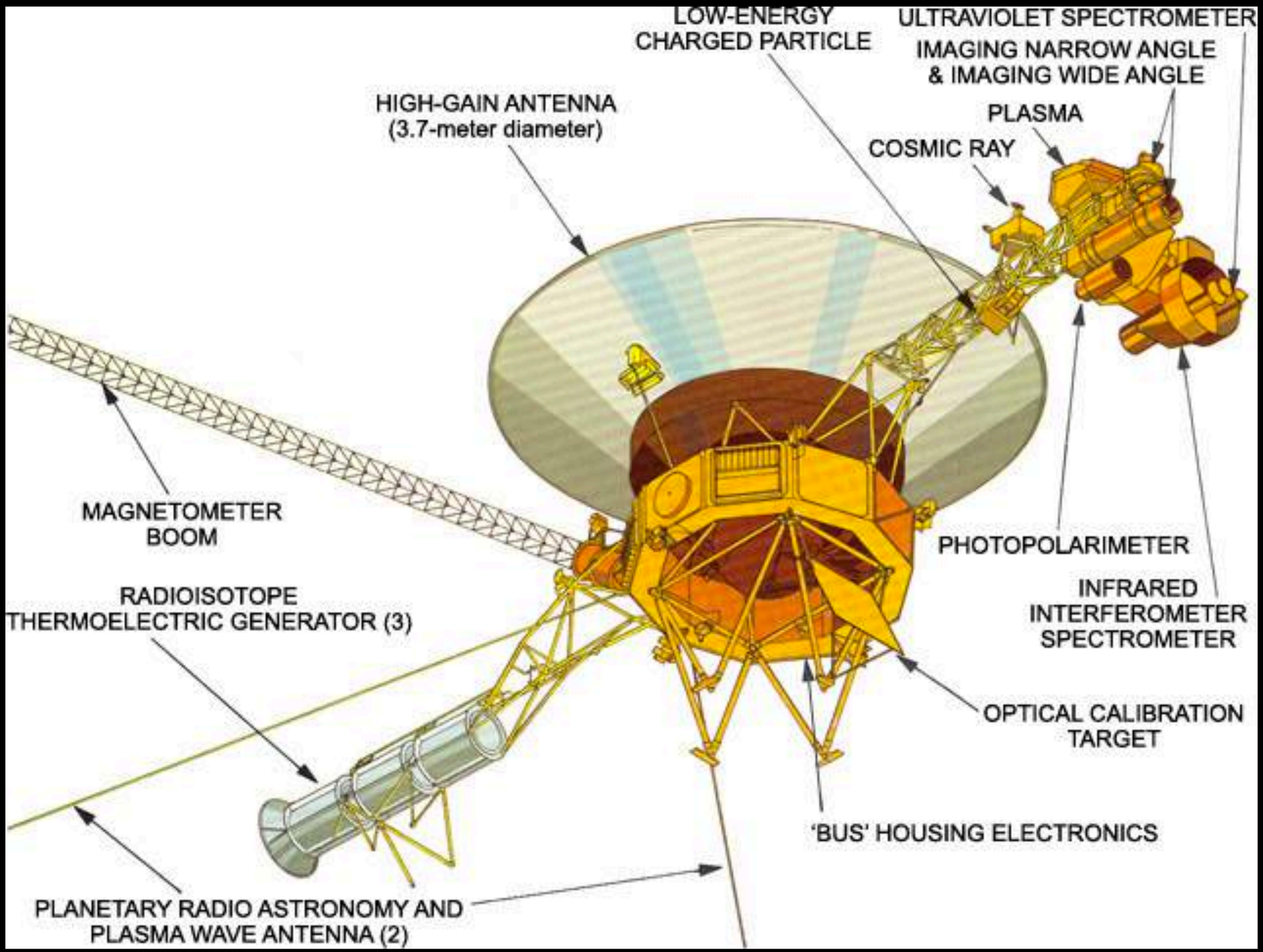


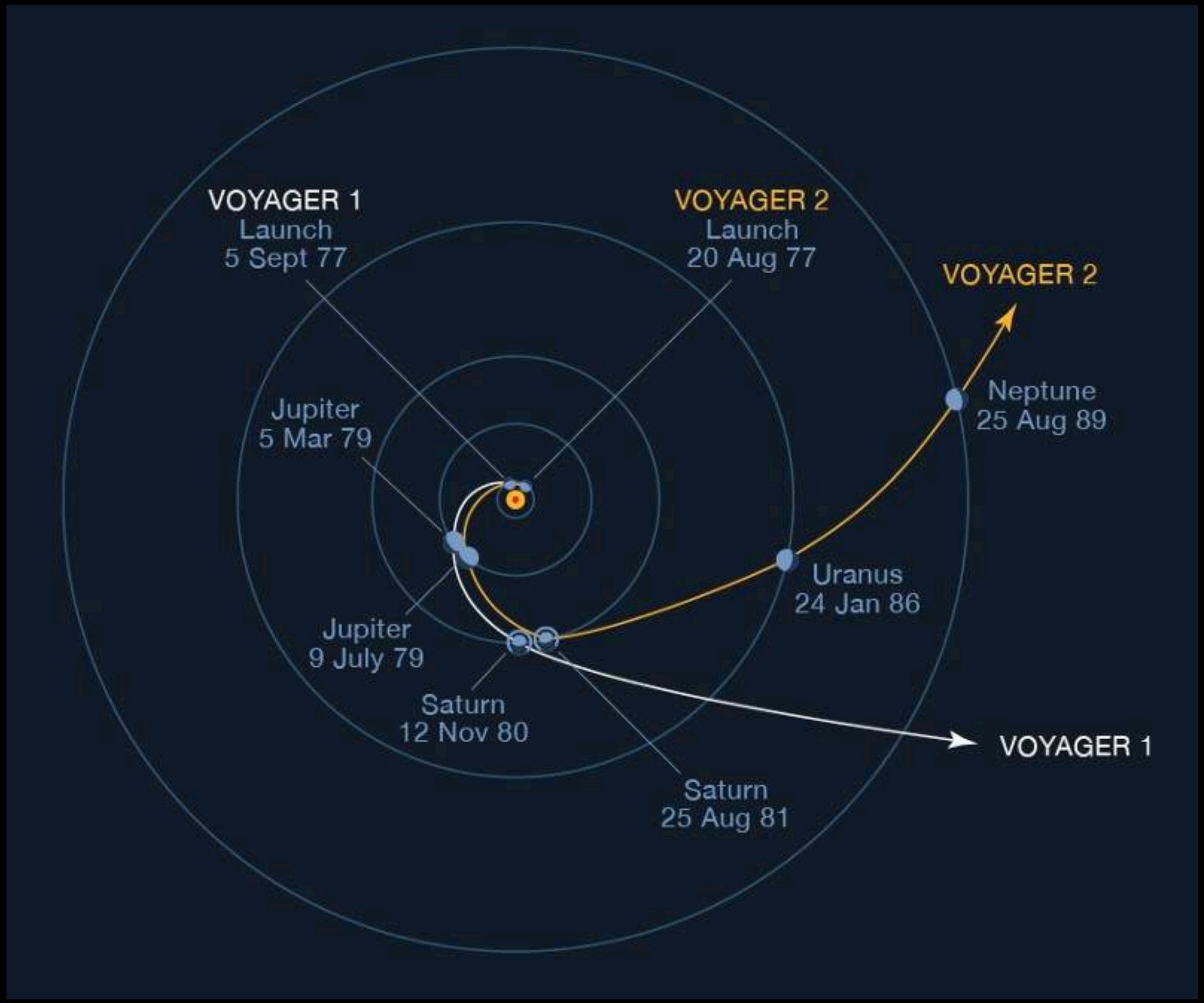
4 light years
or 25 thousand,
billion miles or ~1pc
to the nearest star

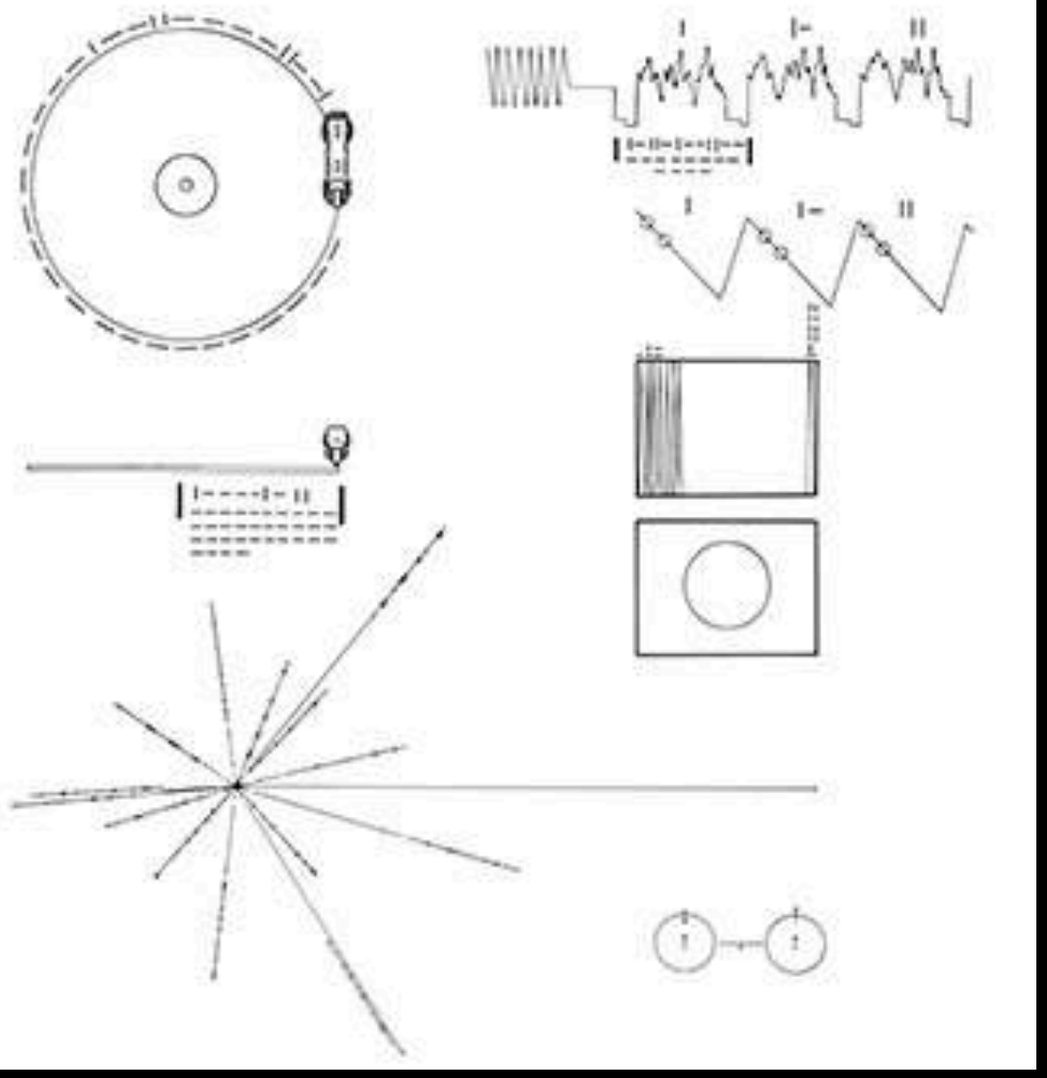
The Milky Way



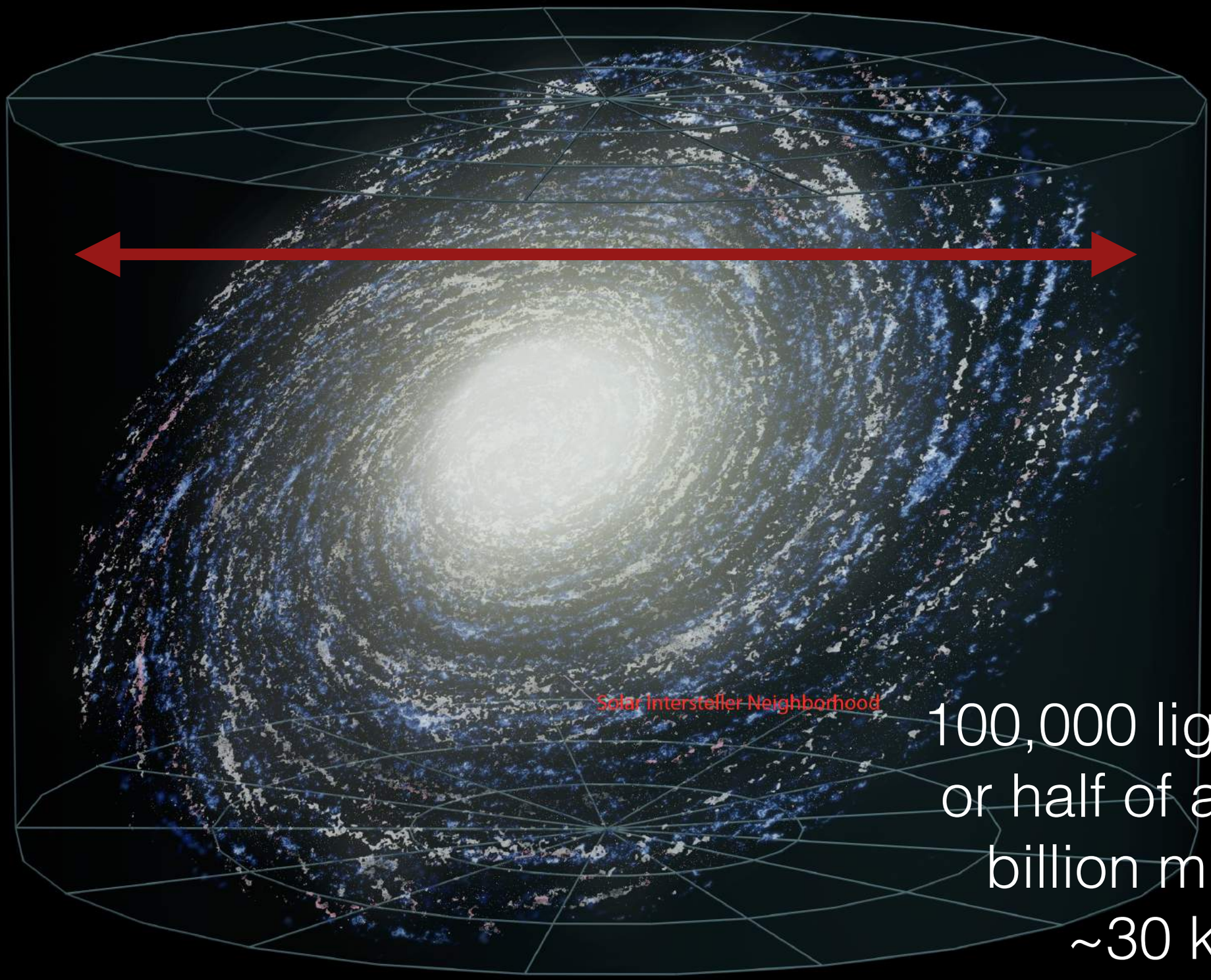
100,000 light years
or half of a billion,
billion miles or
~30 kpc


LOW-ENERGY
CHARGED PARTICLE
ULTRAVIOLET SPECTROMETER
IMAGING NARROW ANGLE
& IMAGING WIDE ANGLE
HIGH-GAIN ANTENNA
(3.7-meter diameter)
PLASMA
COSMIC RAY
MAGNETOMETER
BOOM
PHOTOPOLARIMETER
INFRARED
INTERFEROMETER
SPECTROMETER
RADIOISOTOPE
THERMOELECTRIC GENERATOR (3)
OPTICAL CALIBRATION
TARGET
'BUS' HOUSING ELECTRONICS
PLANETARY RADIO ASTRONOMY AND
PLASMA WAVE ANTENNA (2)


VOYAGER 1
Launch
5 Sept 77
VOYAGER 2
Launch
20 Aug 77
VOYAGER 2
Neptune
25 Aug 89
Jupiter
5 Mar 79
Uranus
24 Jan 86
Jupiter
9 July 79
Saturn
12 Nov 80
VOYAGER 1
Saturn
25 Aug 81

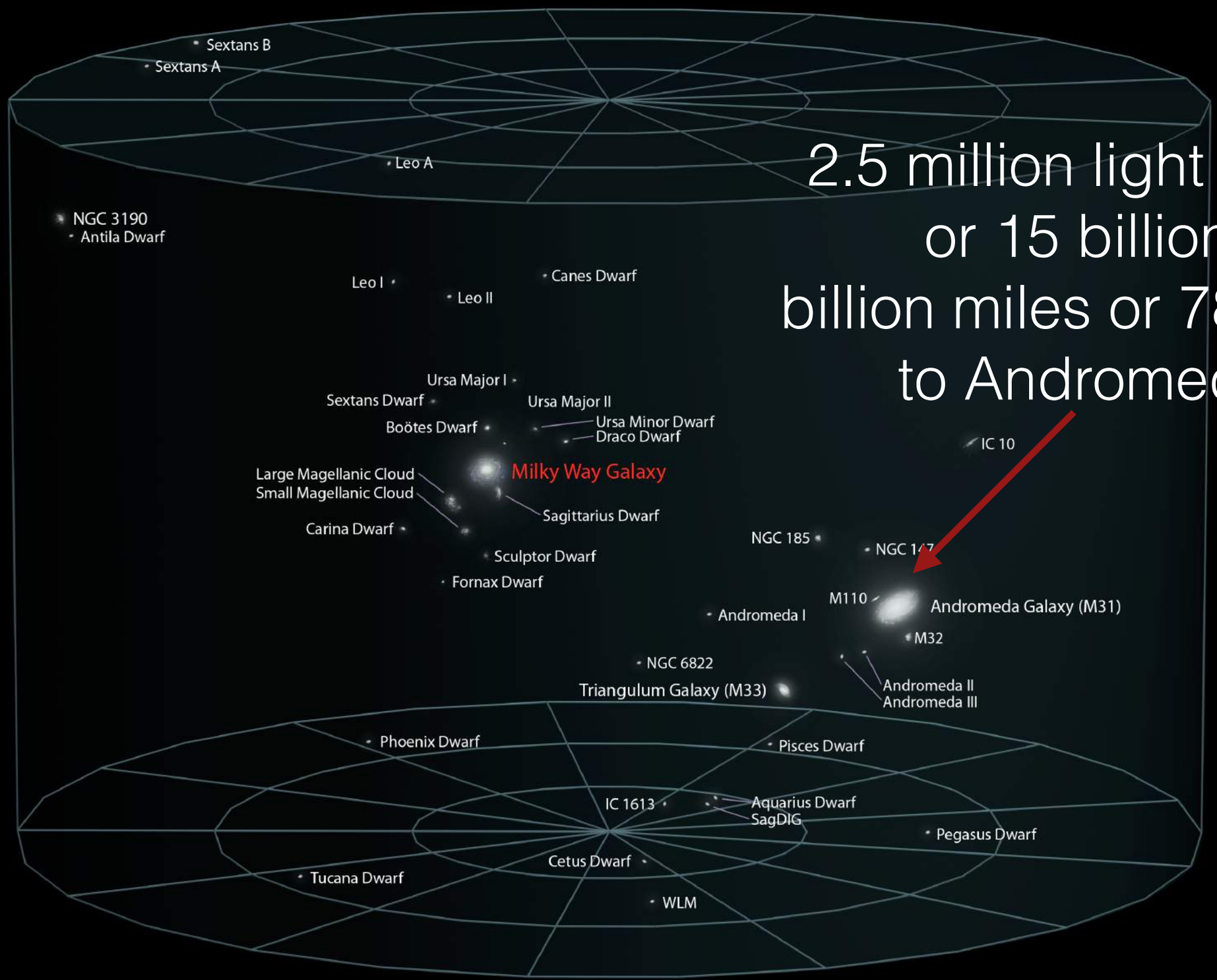


The Milky Way



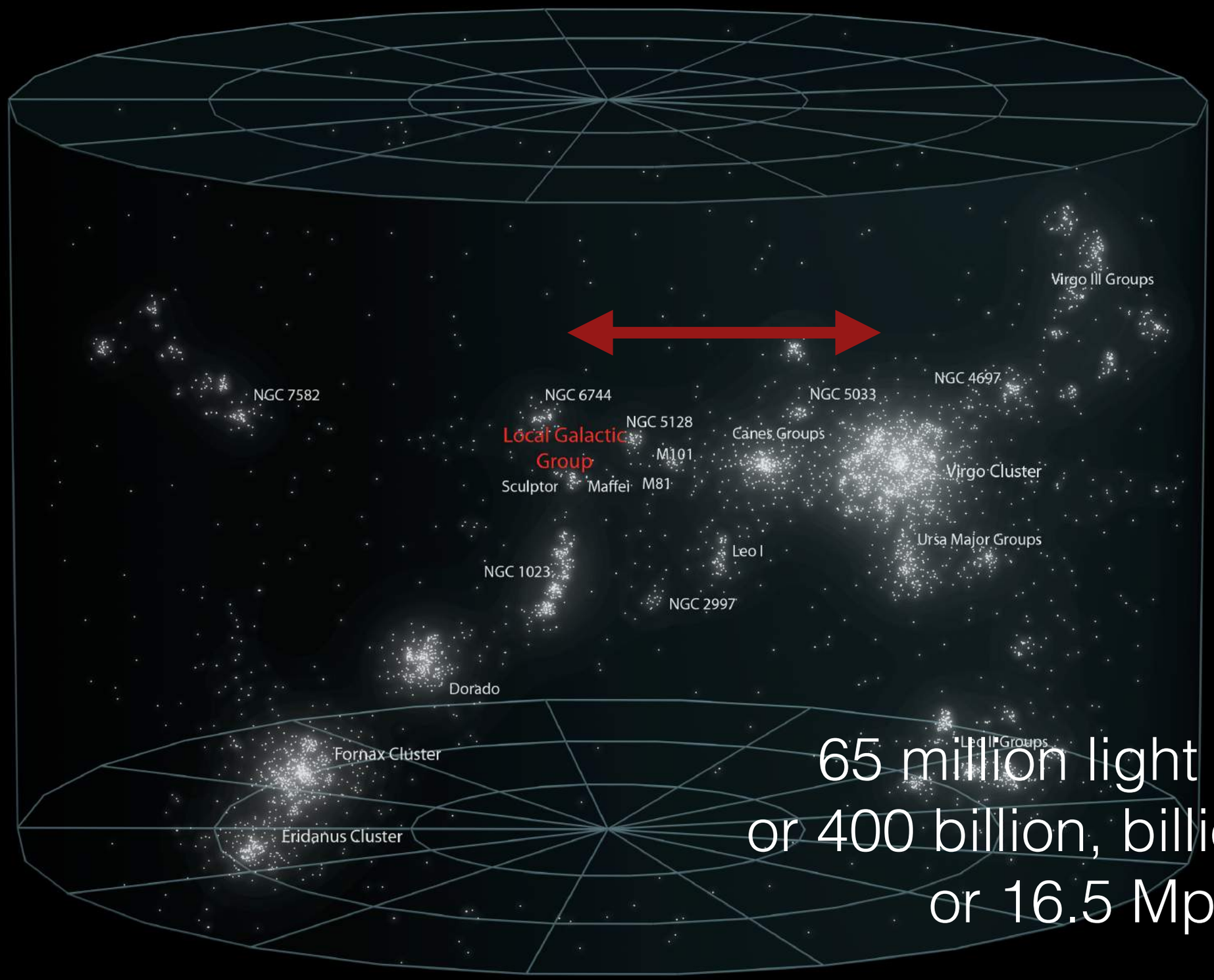
100,000 light years
or half of a billion,
billion miles or
~30 kpc

The Local Group



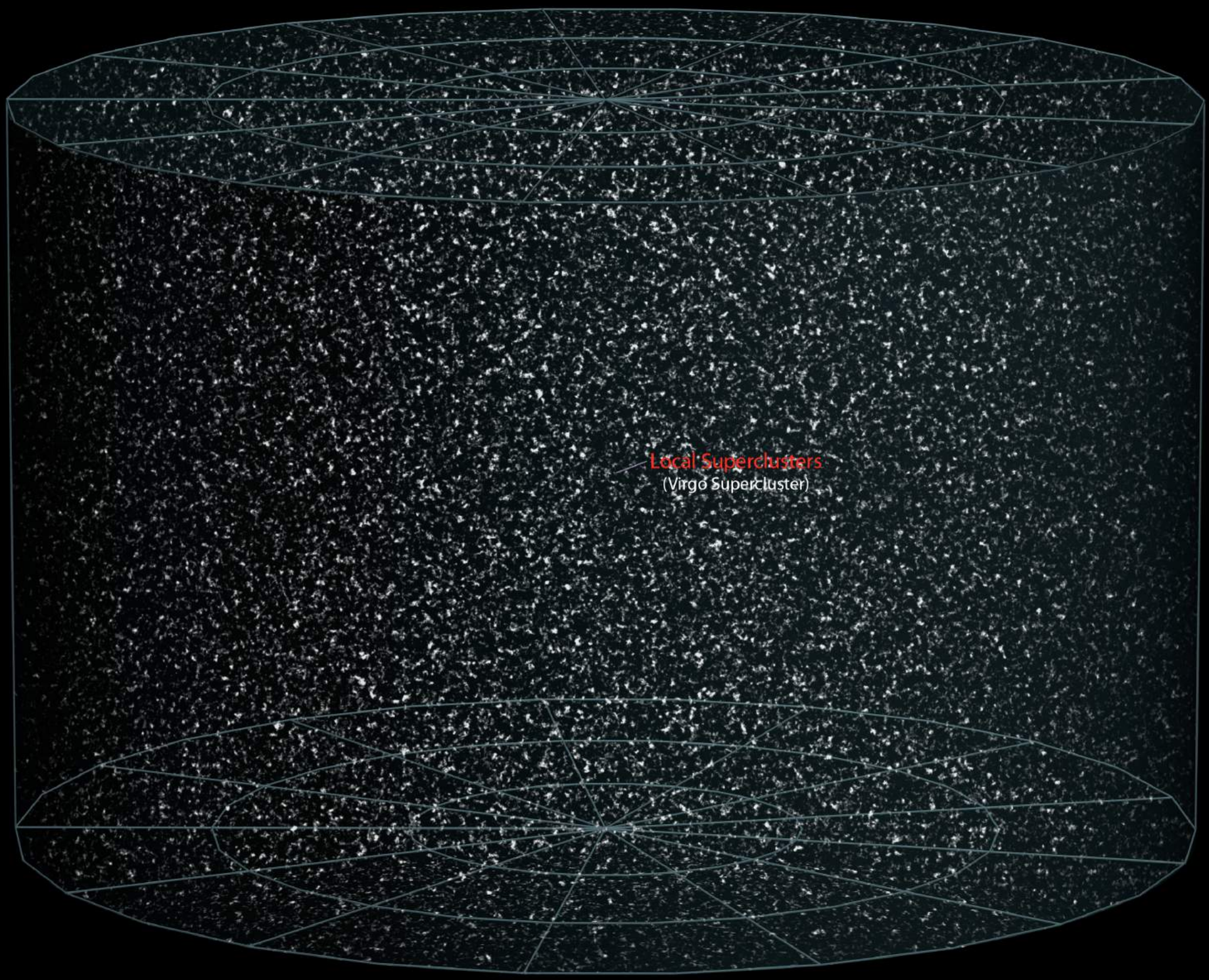
2.5 million light years
or 15 billion,
billion miles or 780 kpc
to Andromeda

Virgo Supercluster



65 million light years
or 400 billion, billion miles
or 16.5 Mpc

We are just one of many




MONGABAY.COM

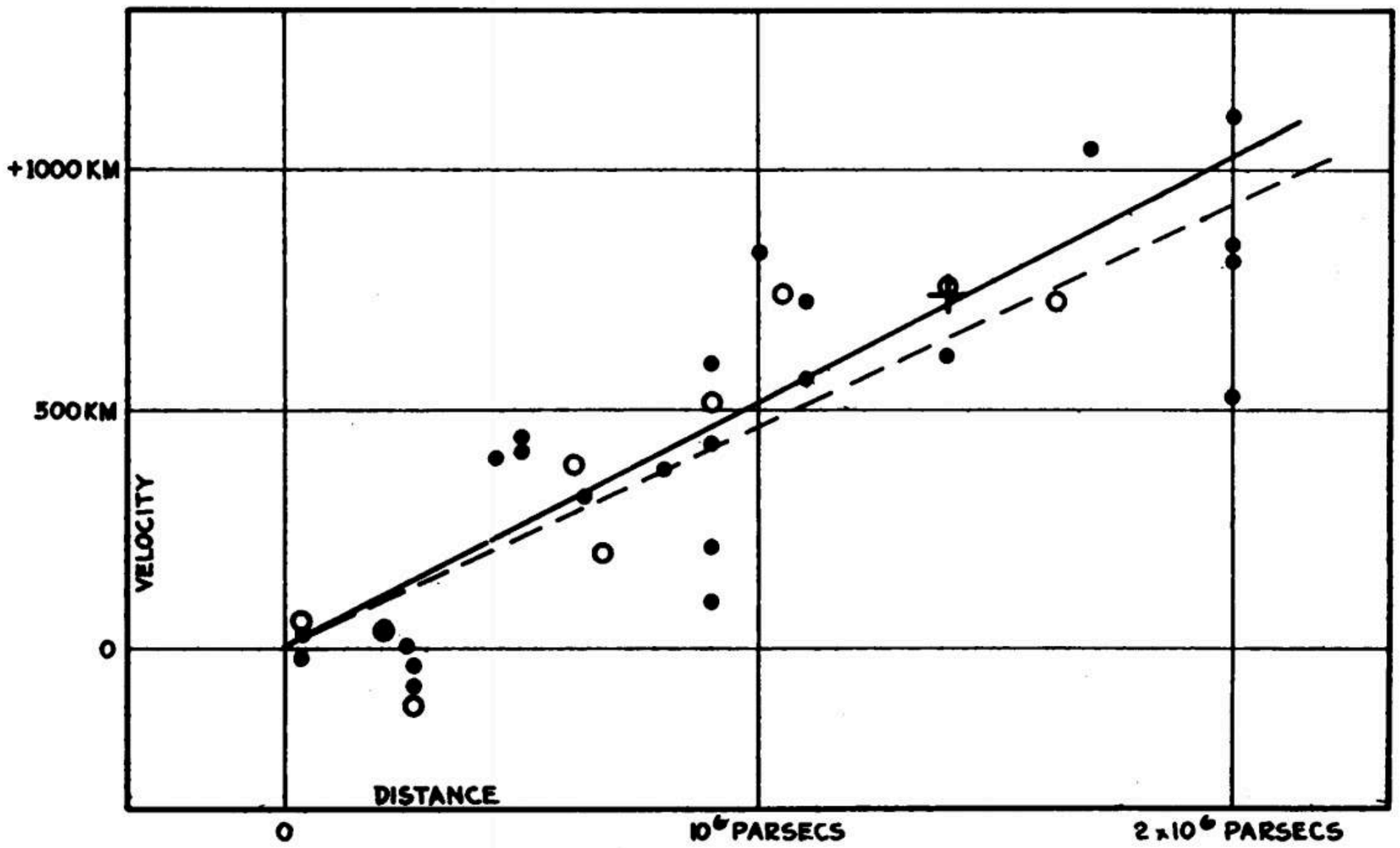
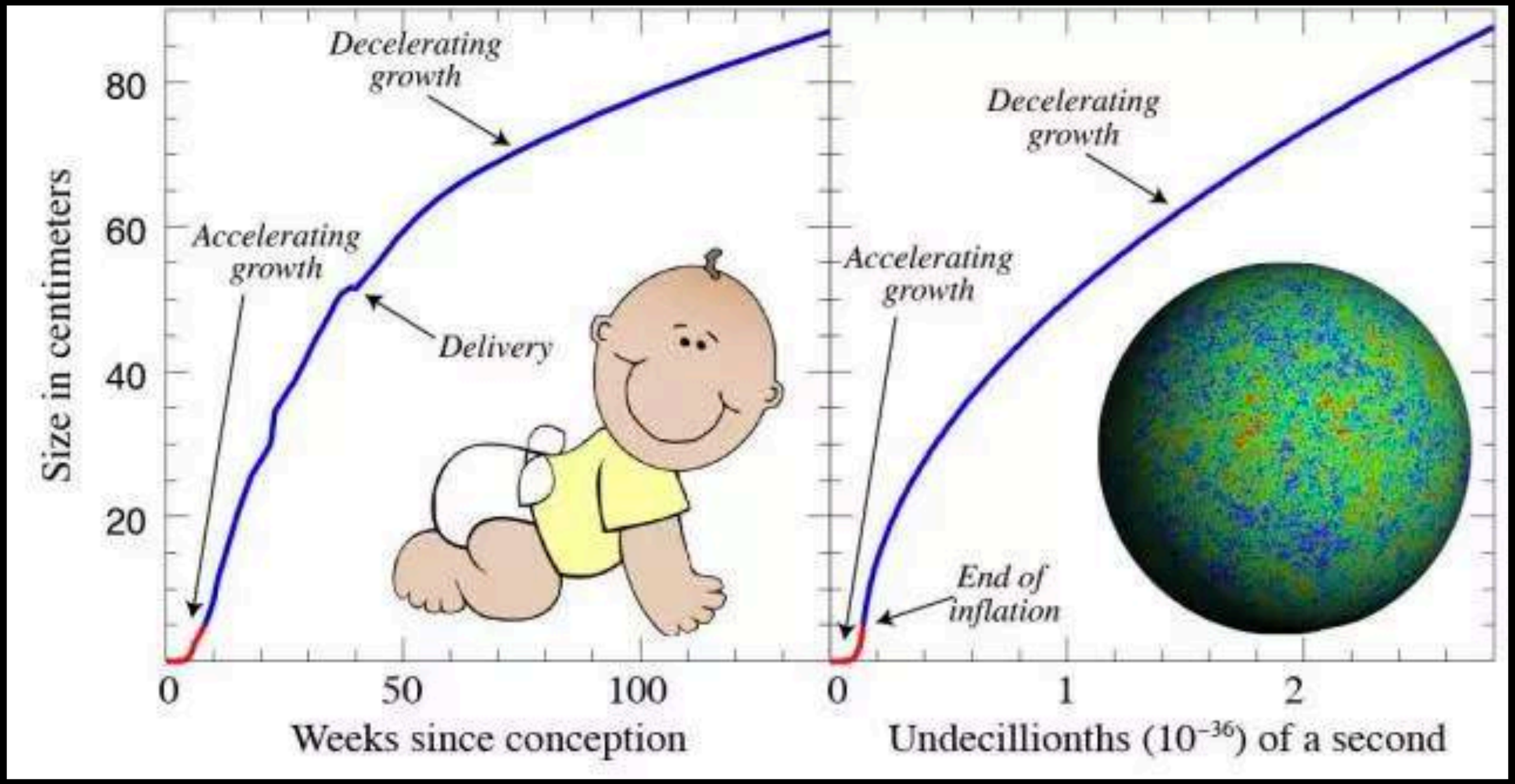


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Hubble (1929)



Our Mathematical Universe by Max Tegmark

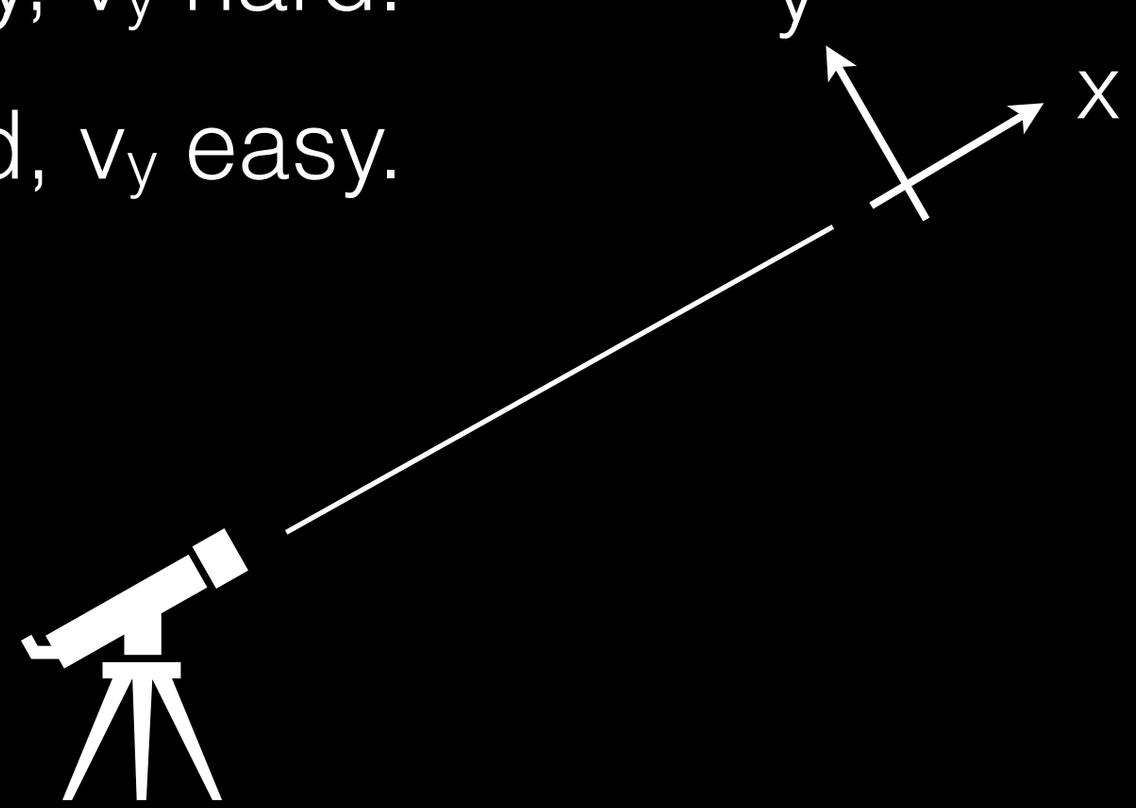
Which of components of a distant galaxy's position and velocity are easy/hard to observe?

A. d_x easy, d_y hard; v_x easy, v_y hard.

B. d_x easy, d_y hard; v_x hard, v_y easy.

C. d_x hard, d_y easy; v_x easy, v_y hard.

D. d_x hard, d_y easy; v_x hard, v_y easy.



Which of components of a distant galaxy's position and velocity are easy/hard to observe?

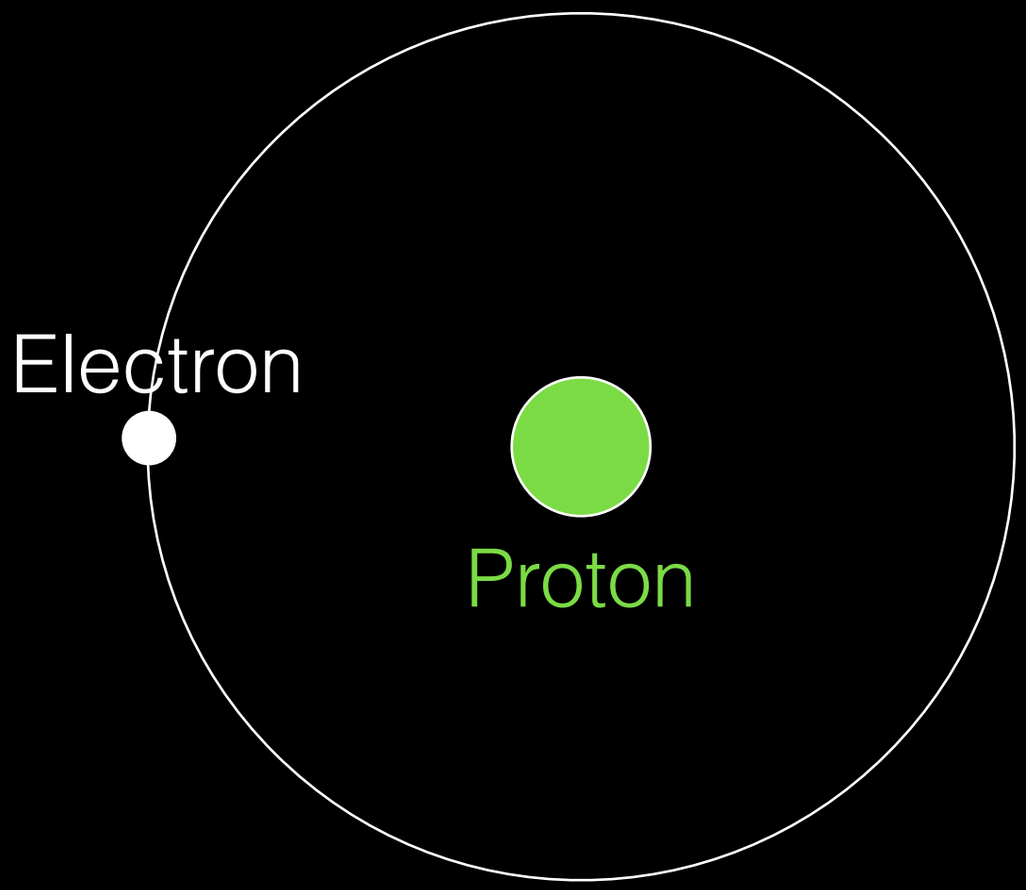
A. d_x easy, d_y hard; v_x easy, v_y hard.

B. d_x easy, d_y hard; v_x hard, v_y easy.

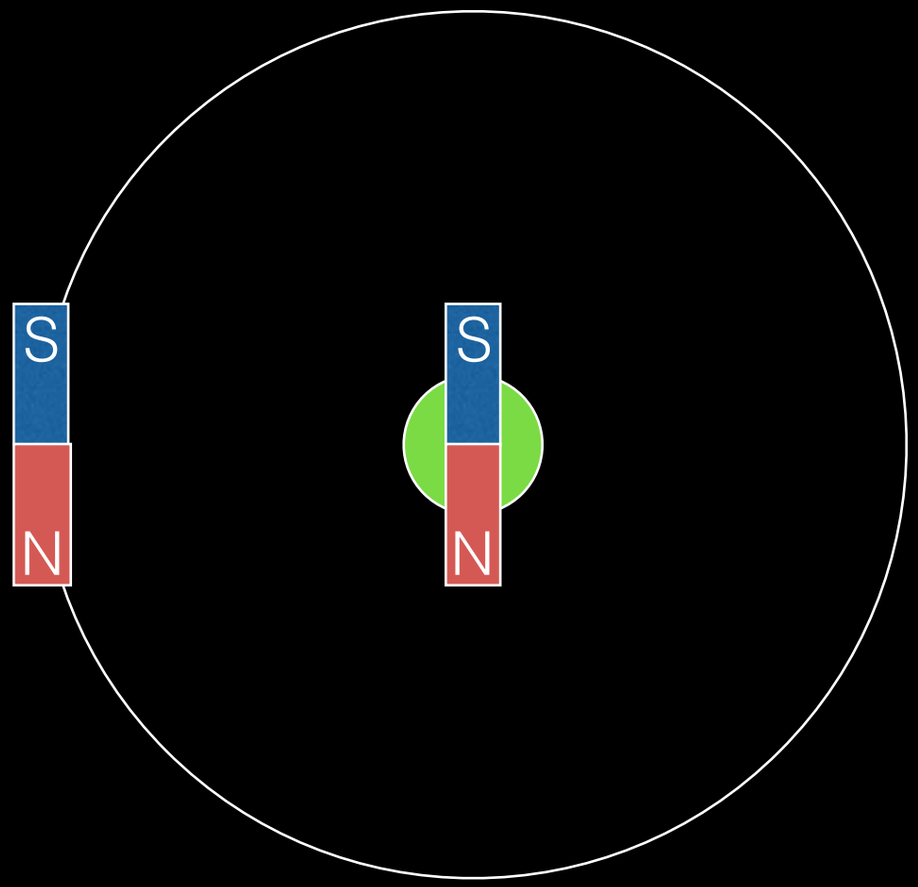
C. d_x hard, d_y easy; v_x easy, v_y hard.

D. d_x hard, d_y easy; v_x hard, v_y easy.

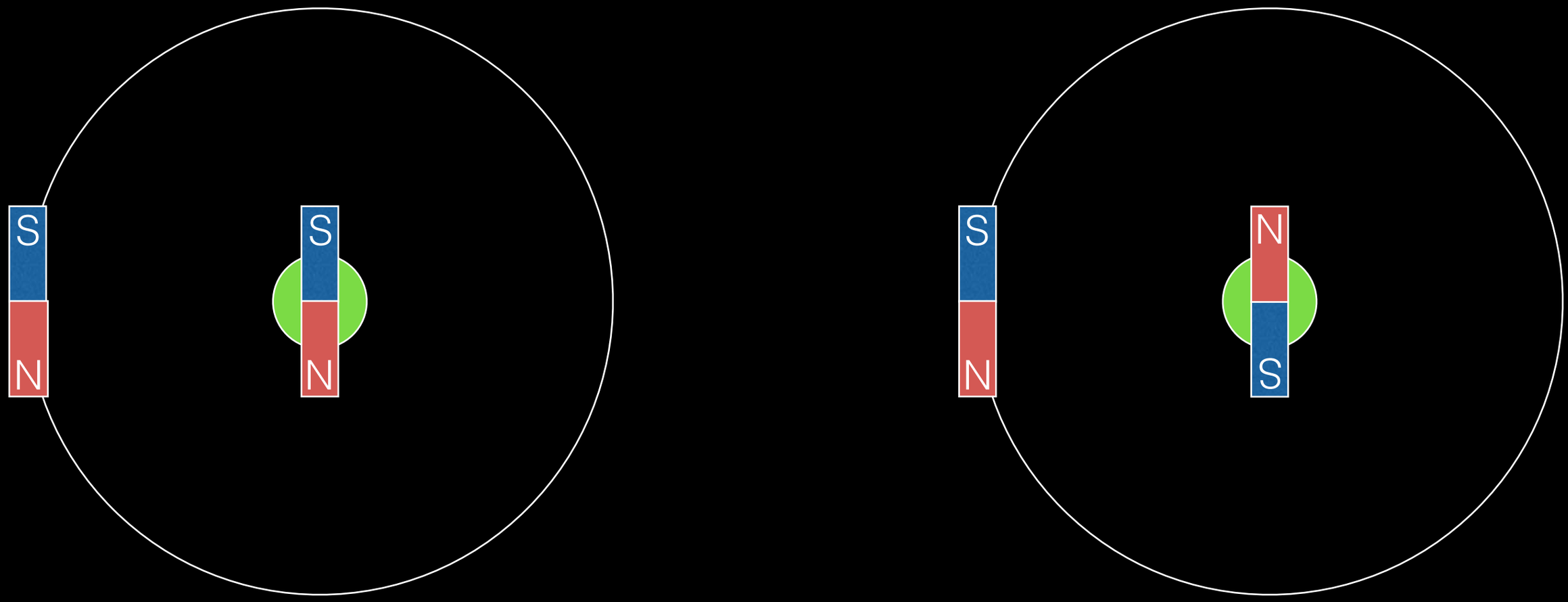
Hydrogen atoms emit radio waves with 21cm wavelengths



Hydrogen atoms emit radio waves with 21cm wavelengths

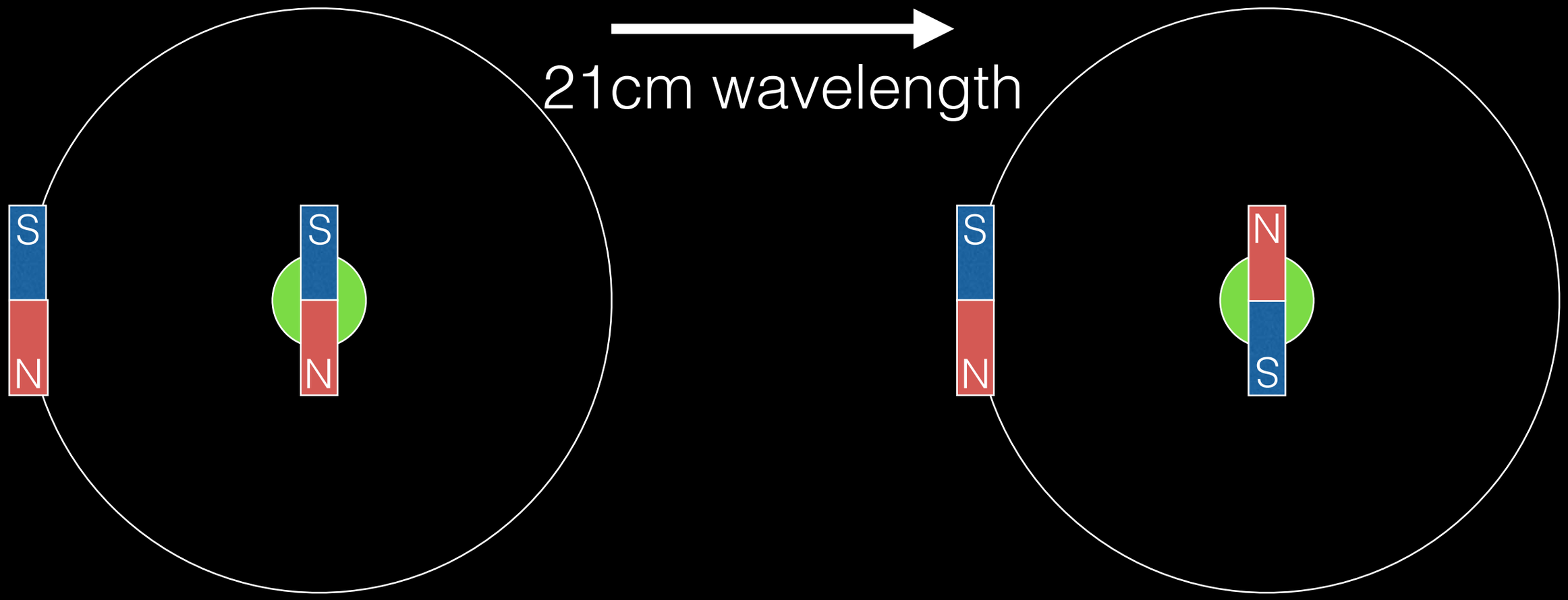


Hydrogen atoms emit radio waves with 21cm wavelengths



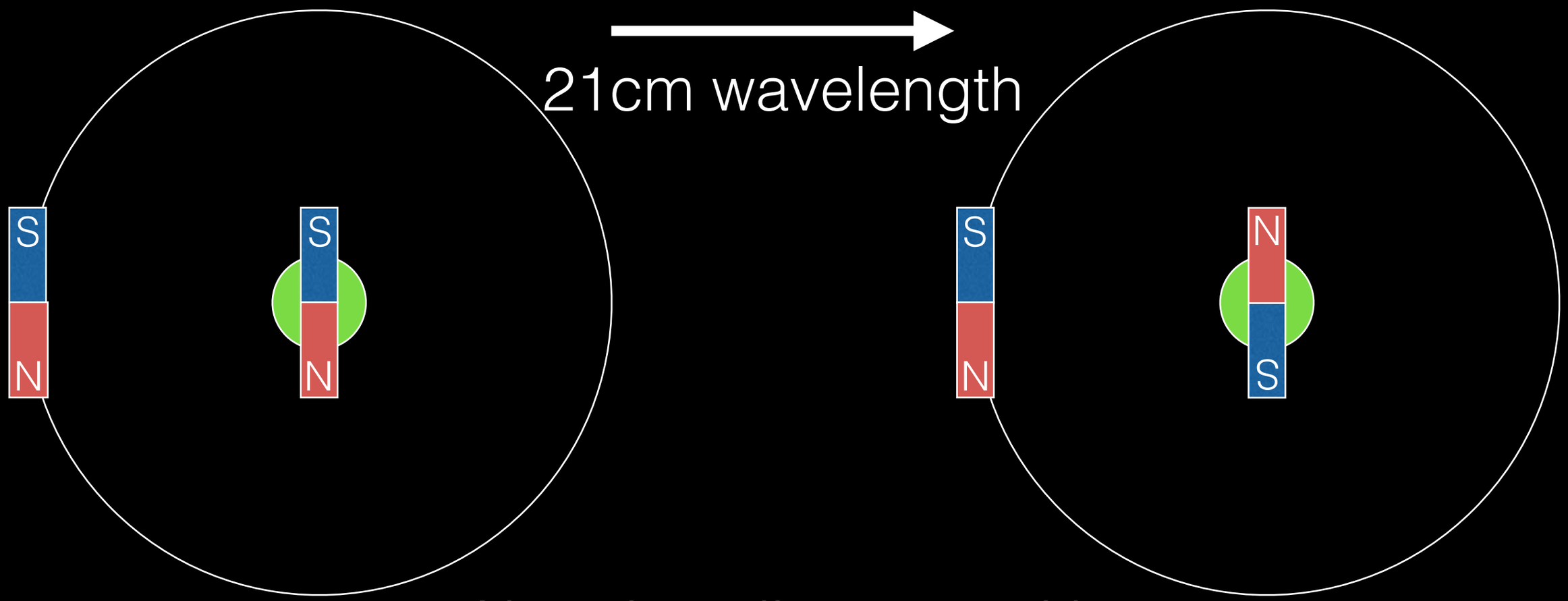
Hydrogen atoms emit radio waves with 21cm wavelengths

Emit radio wave with



Hydrogen atoms emit radio waves with 21cm wavelengths

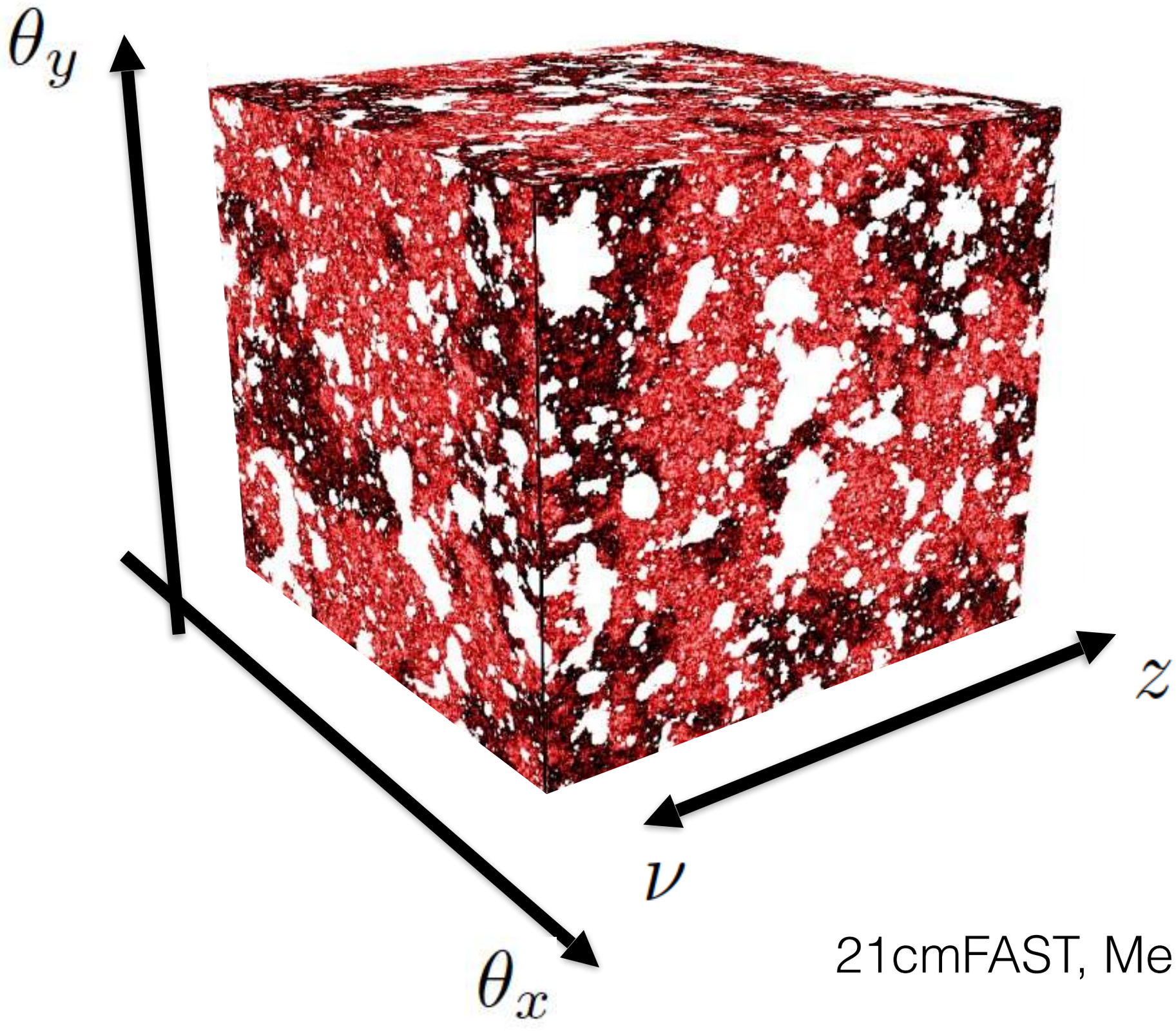
Emit radio wave with



21cm wavelength

Absorb radio wave with

21cm wavelength



21cmFAST, Mesinger et al.

The night sky is a time machine

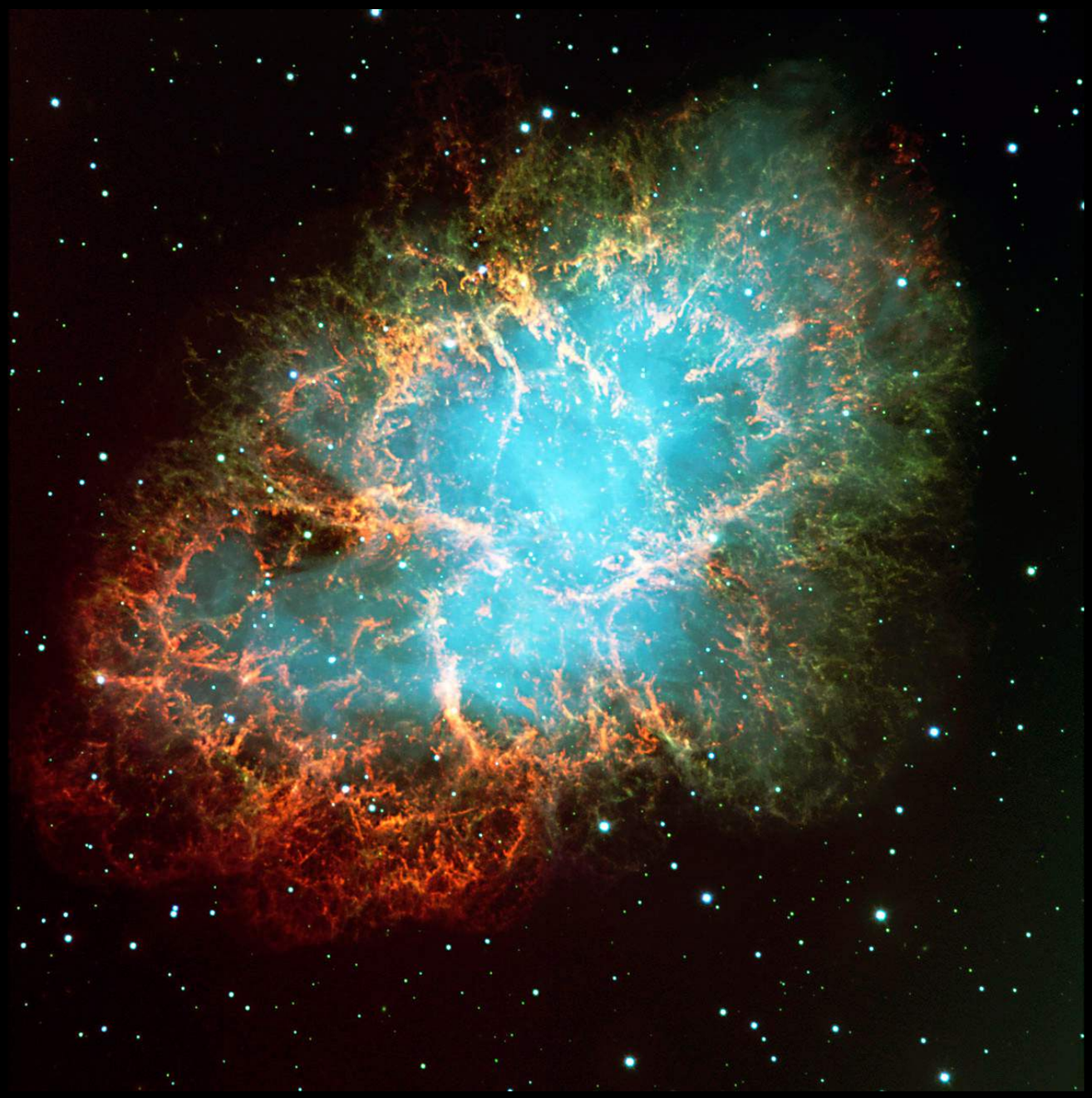
The night sky is a time machine

- Light coming to us from 4 light years away started traveling towards us 4 years ago.

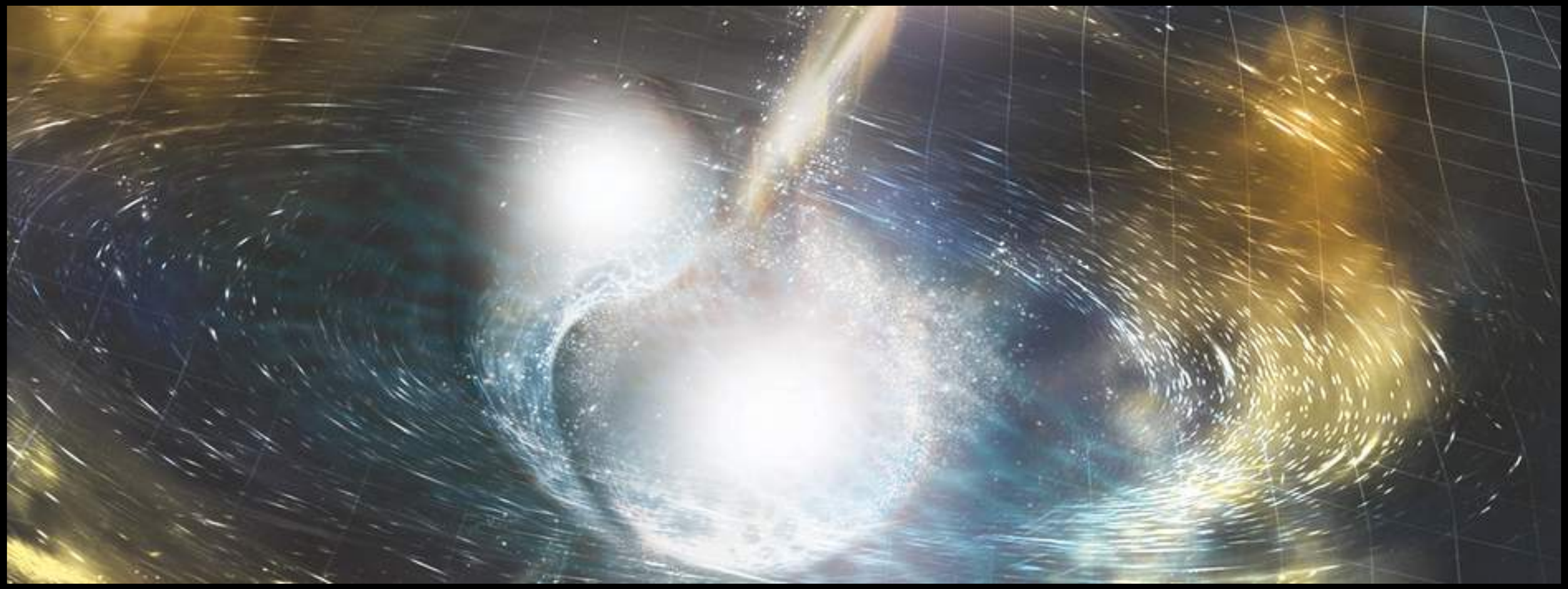
The night sky is a time machine

- Light coming to us from 4 light years away started traveling towards us 4 years ago.
- Light coming to us from 4000 light years away started traveling towards us 4000 years ago.

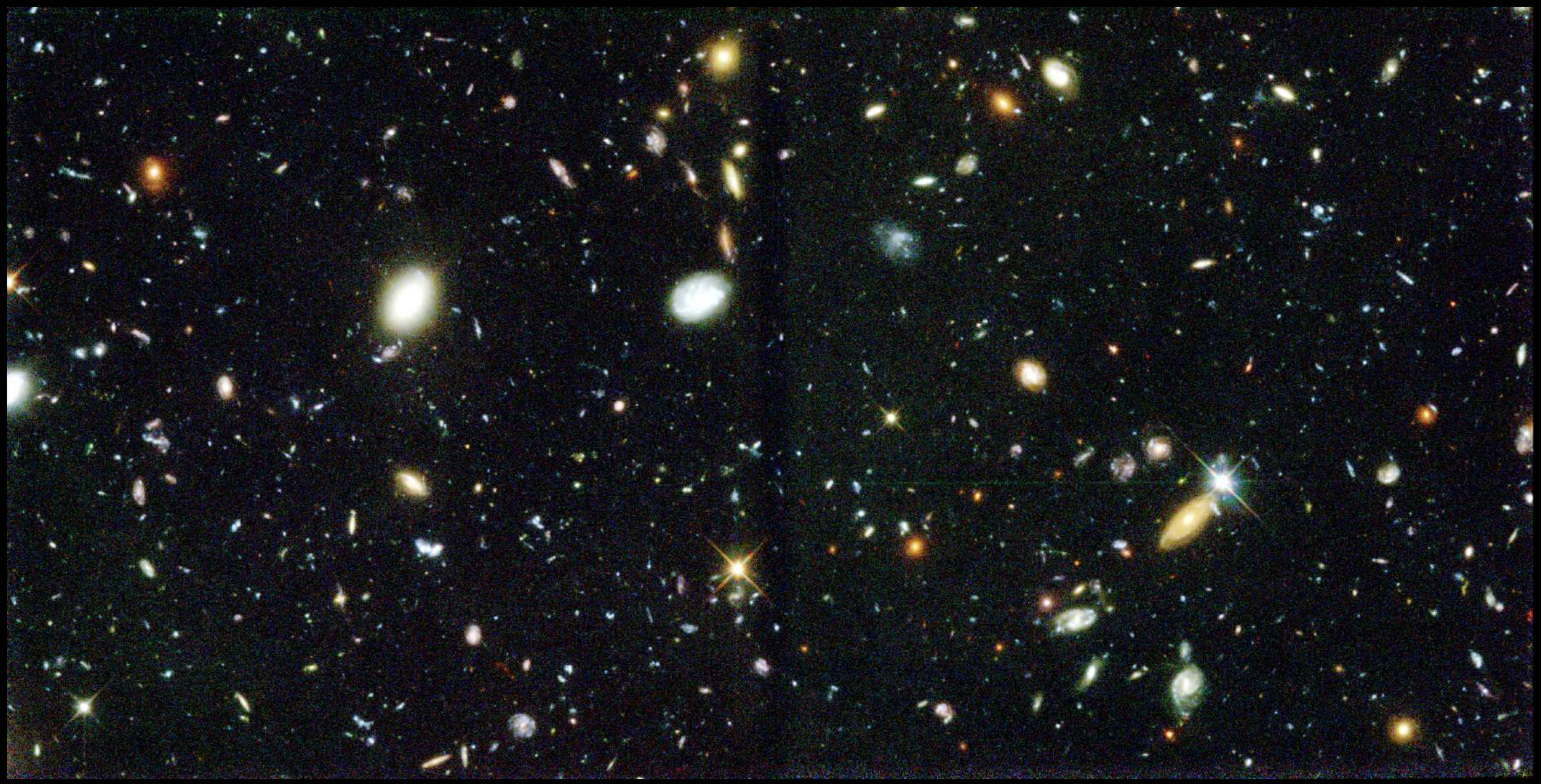
We see the Crab Nebula not as it is today, but as it was 6500 years ago



The neutron star merger that was recently detected happened about 120 million years ago!



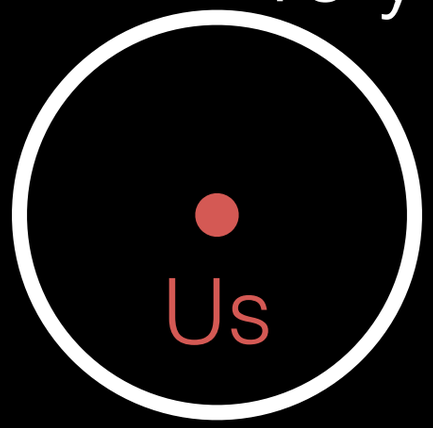
We see distant galaxies not as they are today, but they were billions of years ago



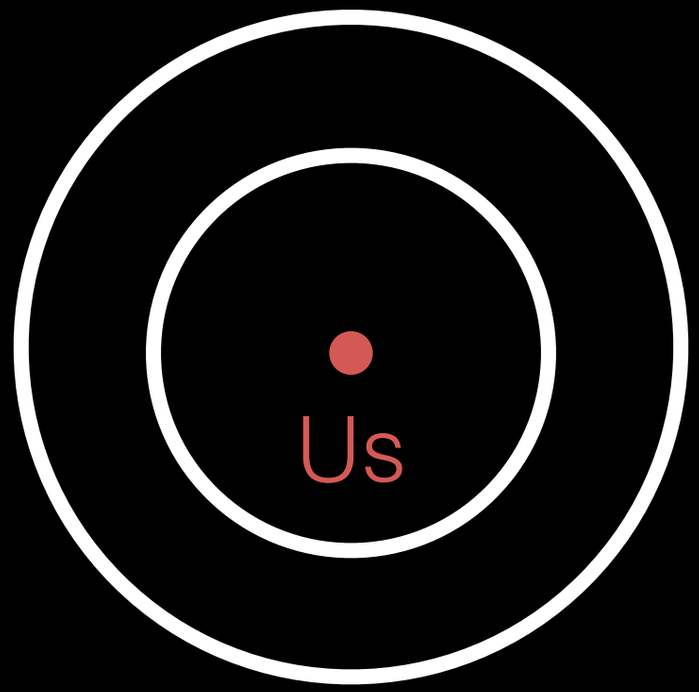
The farther away we look,
the farther back in time
we see

Us

10 years ago



20 years ago



How far back have we looked? How far back **can** we look?

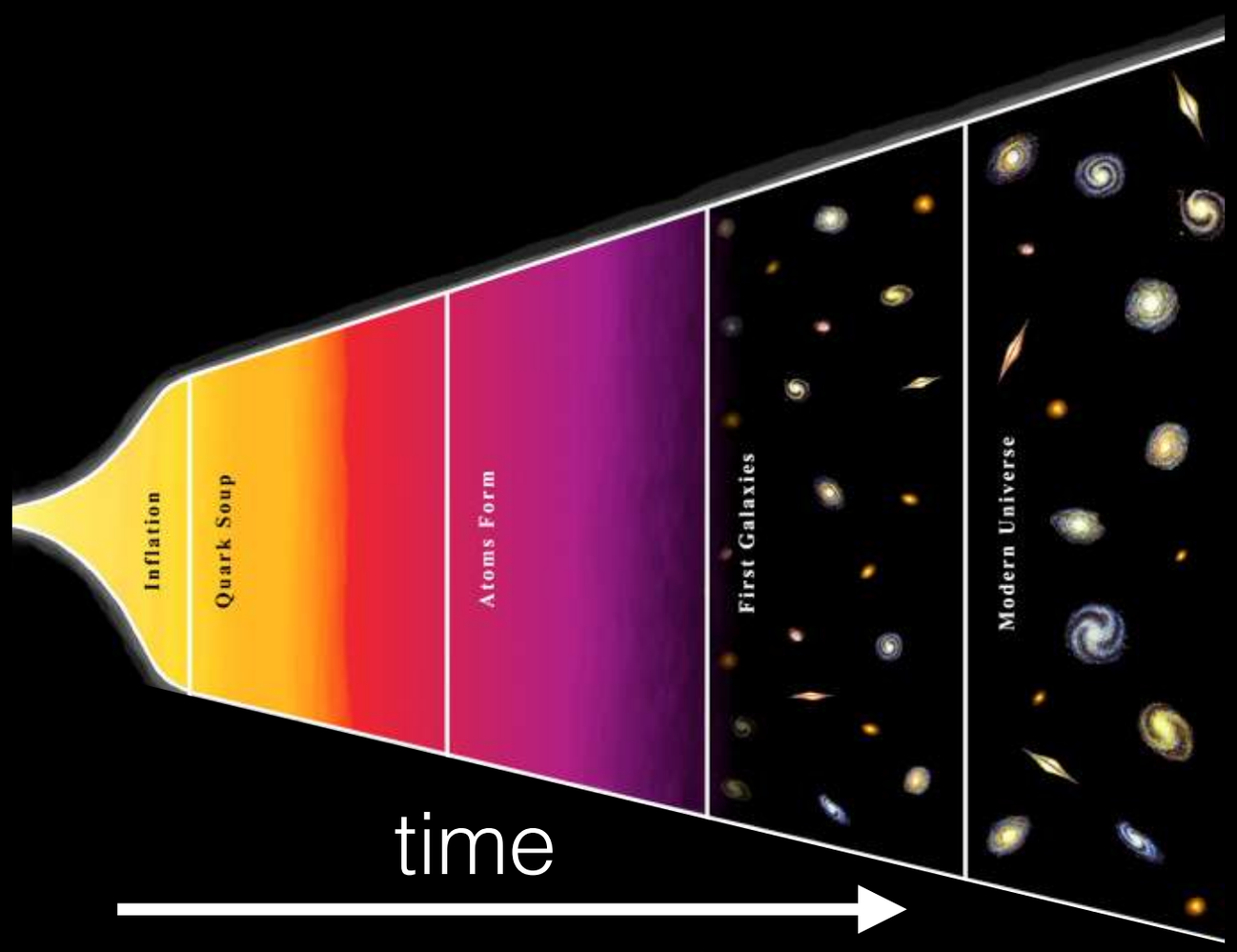
Unobservable Universe: our Universe is not old enough for light to have reached us from out here

13.8 billion years ago

Unobservable Universe: our Universe is not old enough for light to have reached us from out here

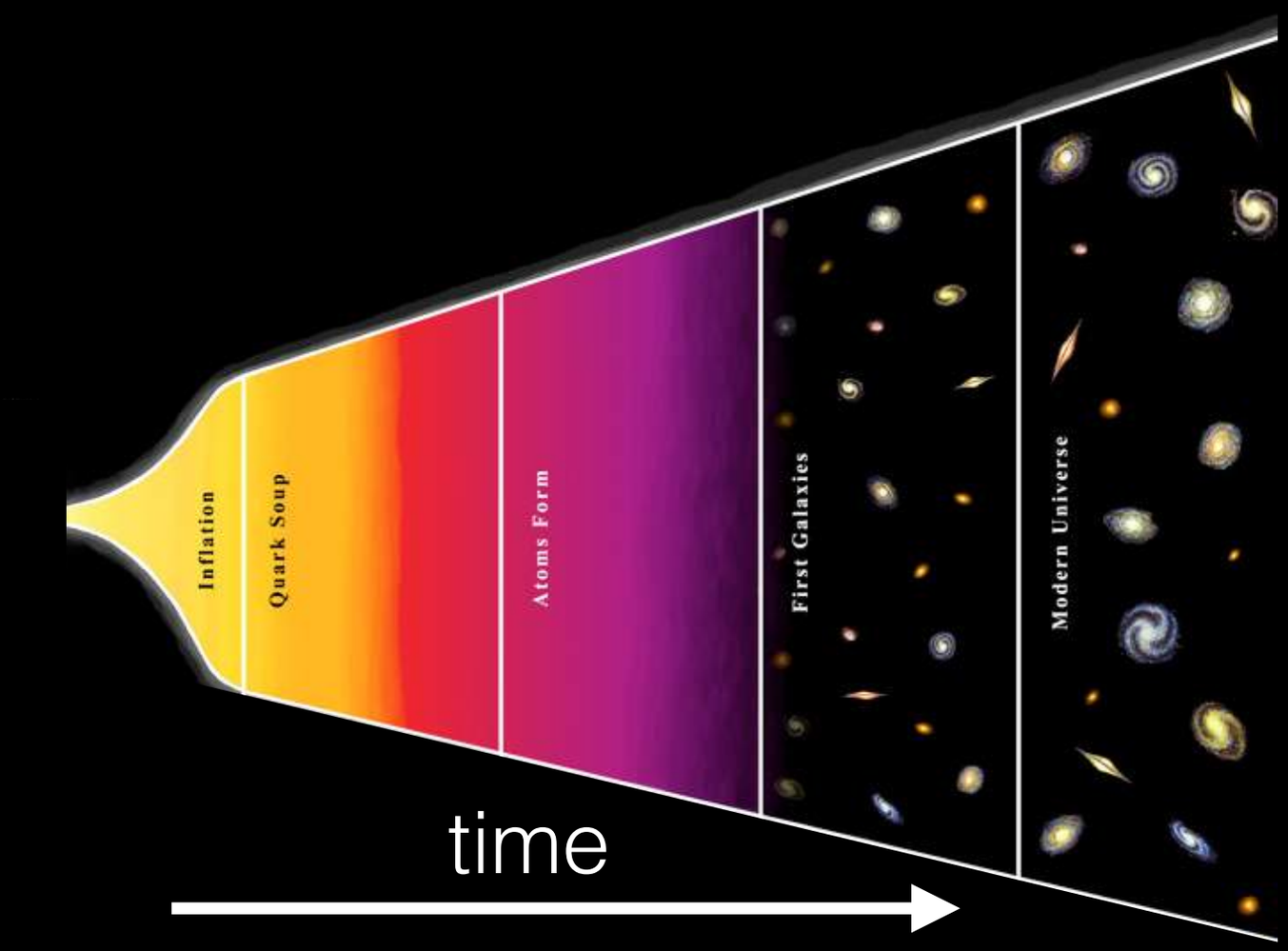
Actual limit we can see. Not 13.8 billion years ago, but 400,000 years after that

Our Universe is expanding, so as we look back in time, we see a smaller, denser, hotter Universe



Us looking far away/back in time

Our Universe is expanding, so as we look back in time, we see a smaller, denser, hotter Universe

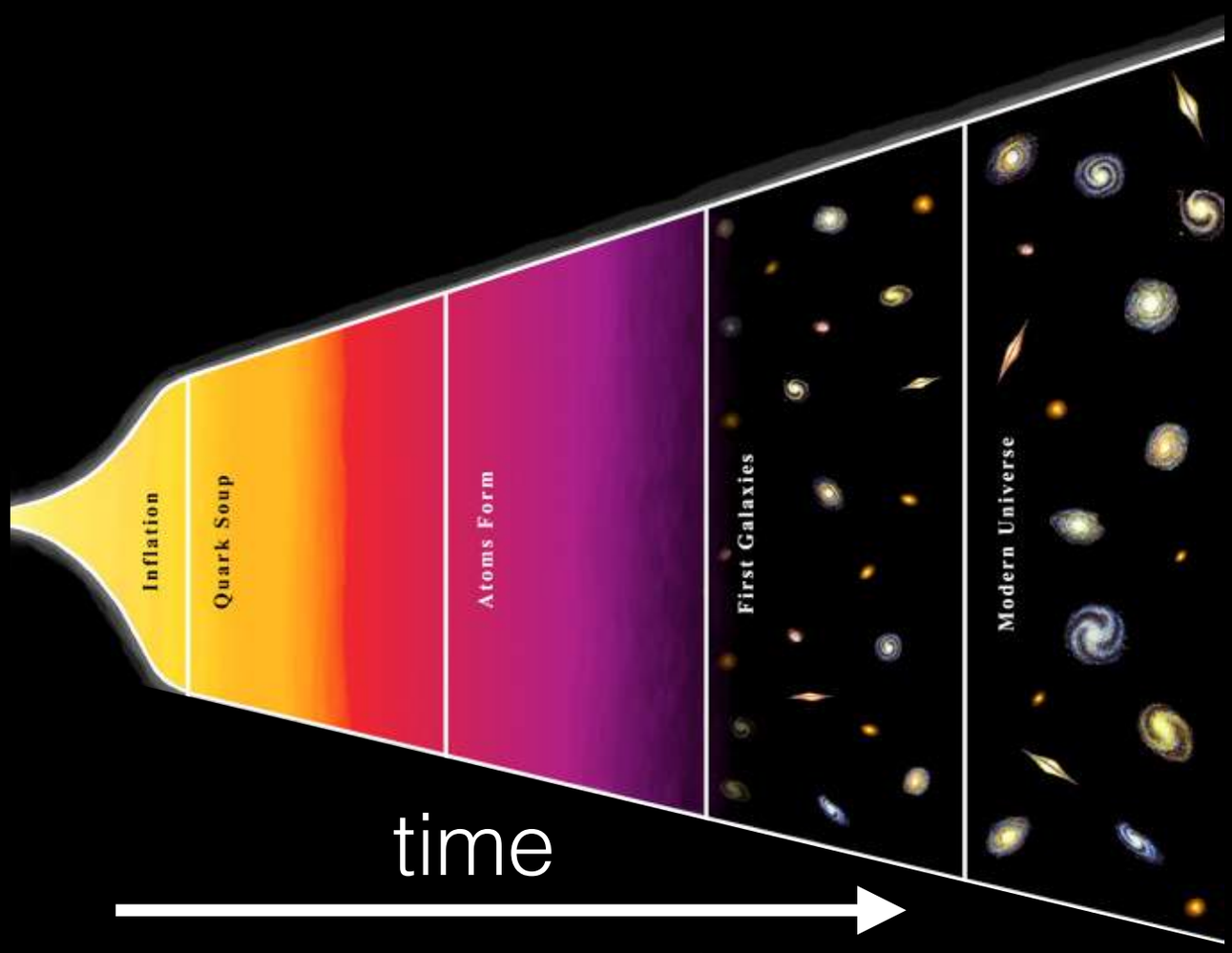


Us looking far away/back in time

Smaller

Larger

Our Universe is expanding, so as we look back in time, we see a smaller, denser, hotter Universe

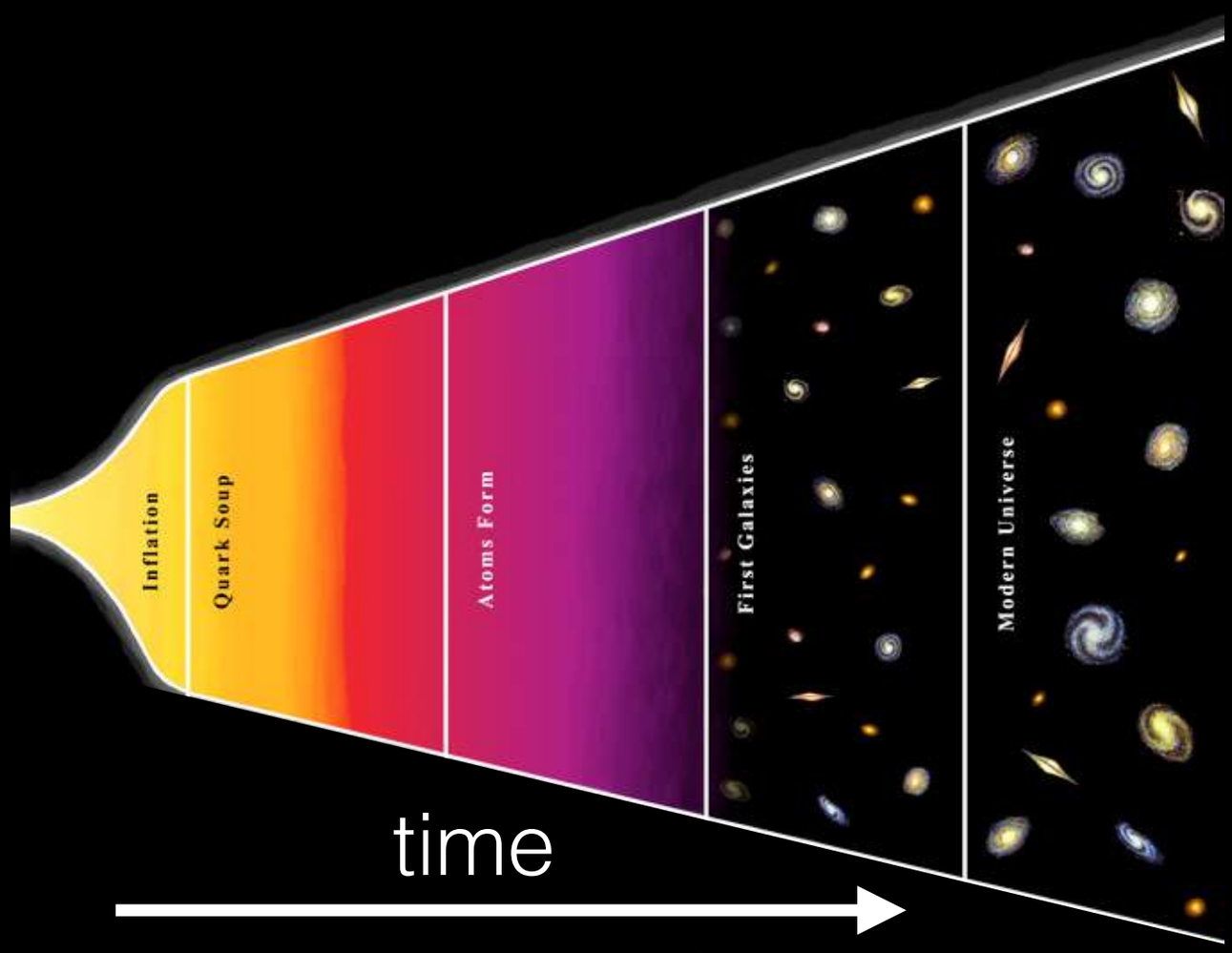


Us looking far away/back in time

Smaller
Denser

Larger
Less dense

Our Universe is expanding, so as we look back in time, we see a smaller, denser, hotter Universe



Us looking far away/back in time

Smaller
Denser
Hotter

Larger
Less dense
Cooler

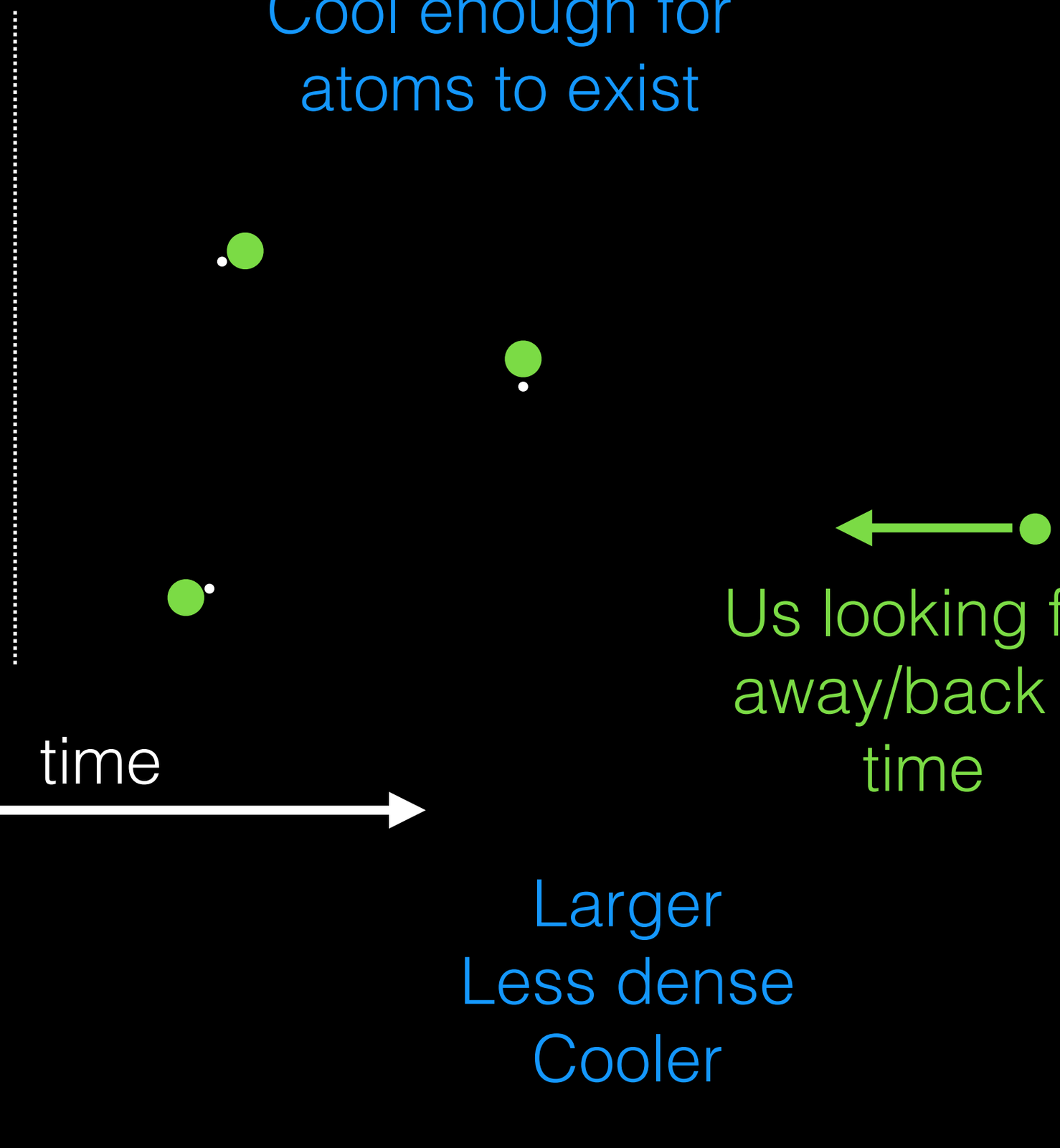
Us looking far away/back in time

time

Smaller
Denser
Hotter

Larger
Less dense
Cooler

Cool enough for atoms to exist



Too hot for atoms to form (plasma)

Cool enough for atoms to exist

Us looking far away/back in time

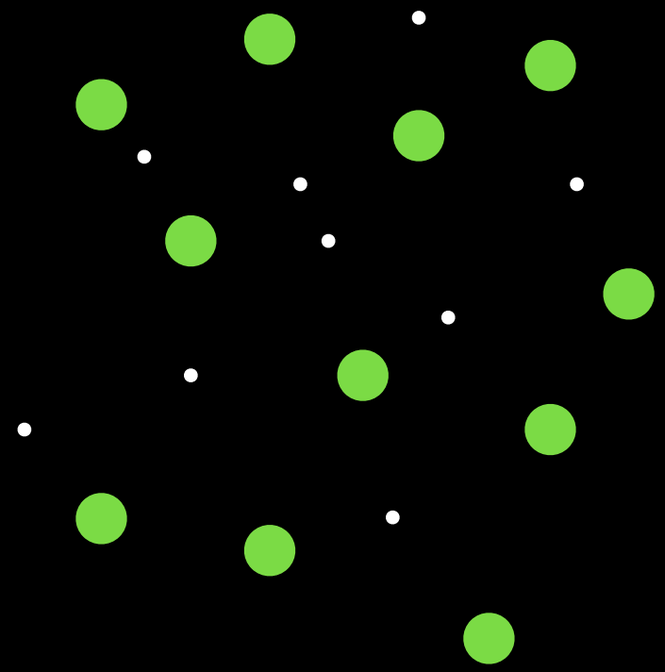
time

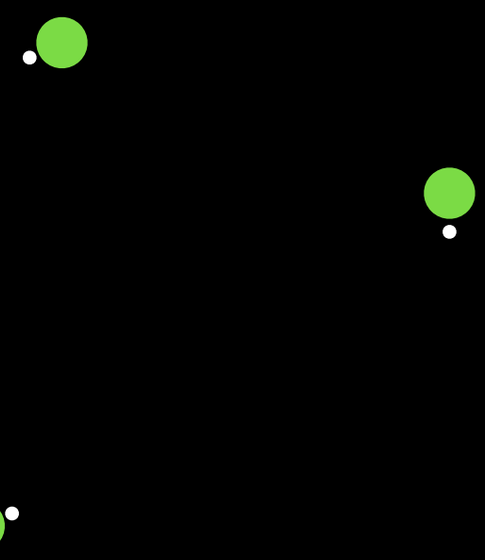
Smaller
Denser
Hotter

Larger
Less dense
Cooler

Too hot for atoms to form (plasma)

Cool enough for atoms to exist





Us looking far away/back in time

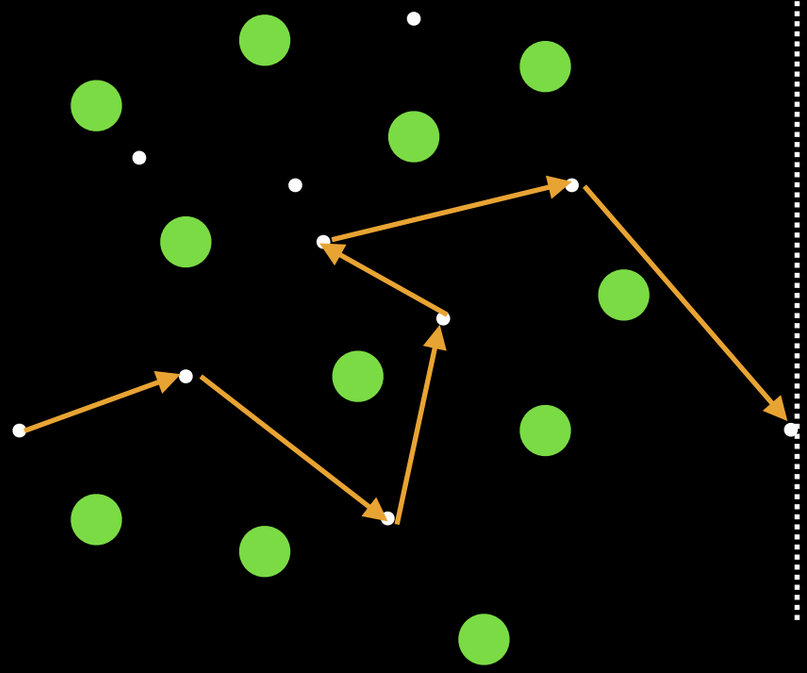
time

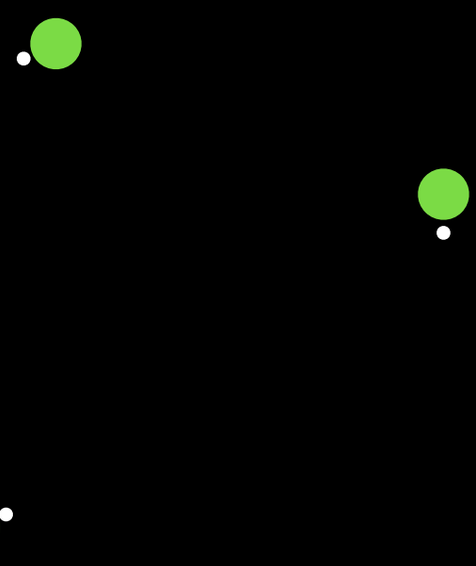
Smaller
Denser
Hotter

Larger
Less dense
Cooler

Too hot for atoms to form (plasma) Not transparent

Cool enough for atoms to exist





Us looking far away/back in time

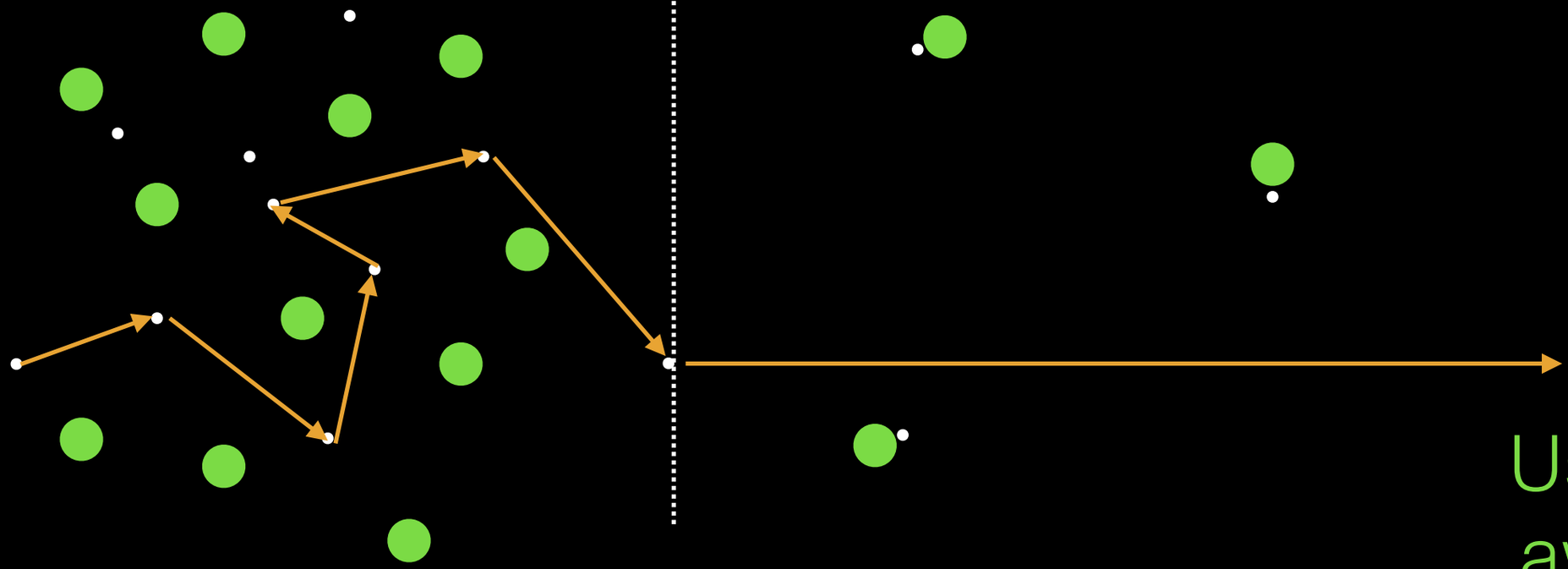
time

Smaller
Denser
Hotter

Larger
Less dense
Cooler

Too hot for atoms to form (plasma)
Not transparent

Cool enough for atoms to exist
Transparent

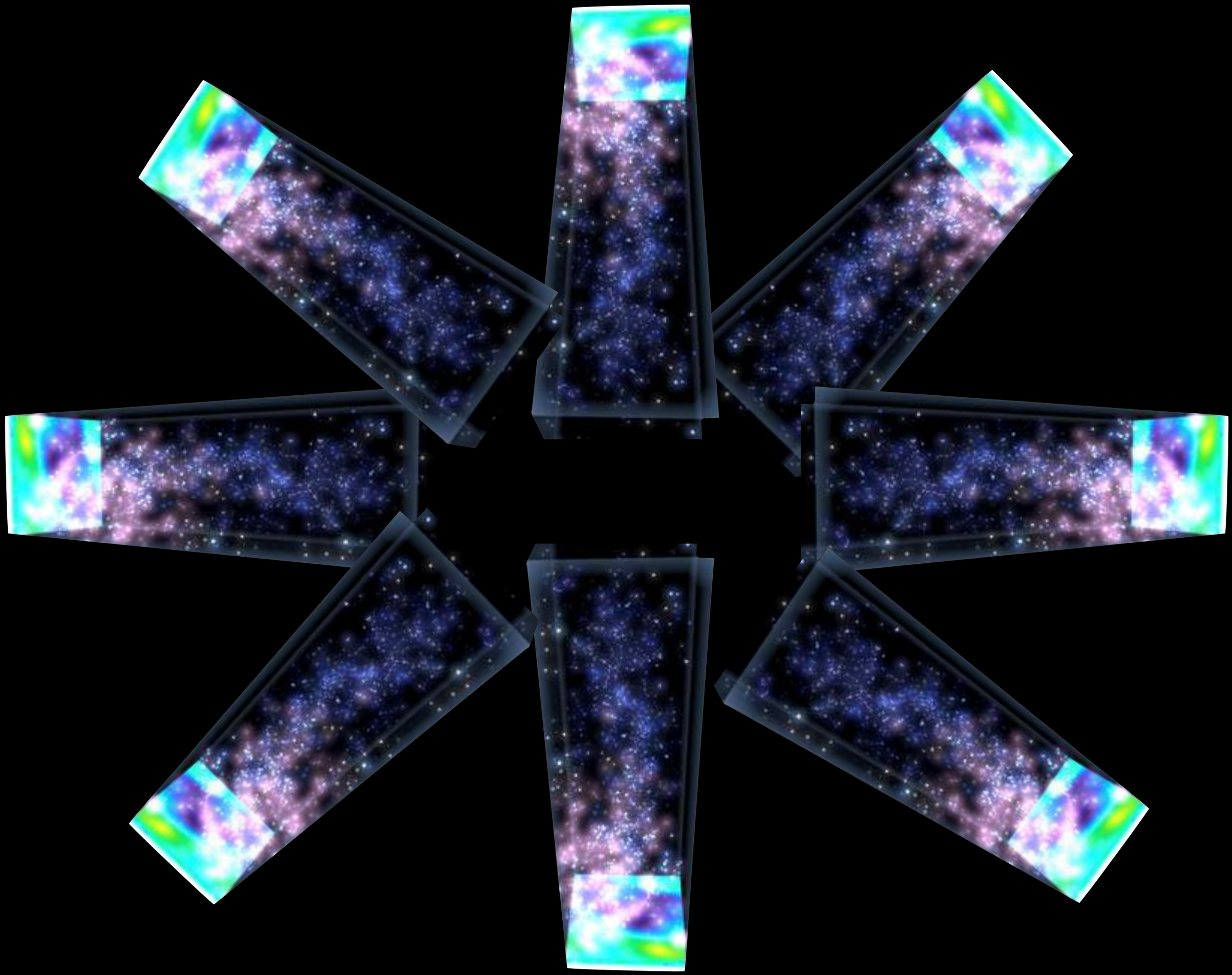


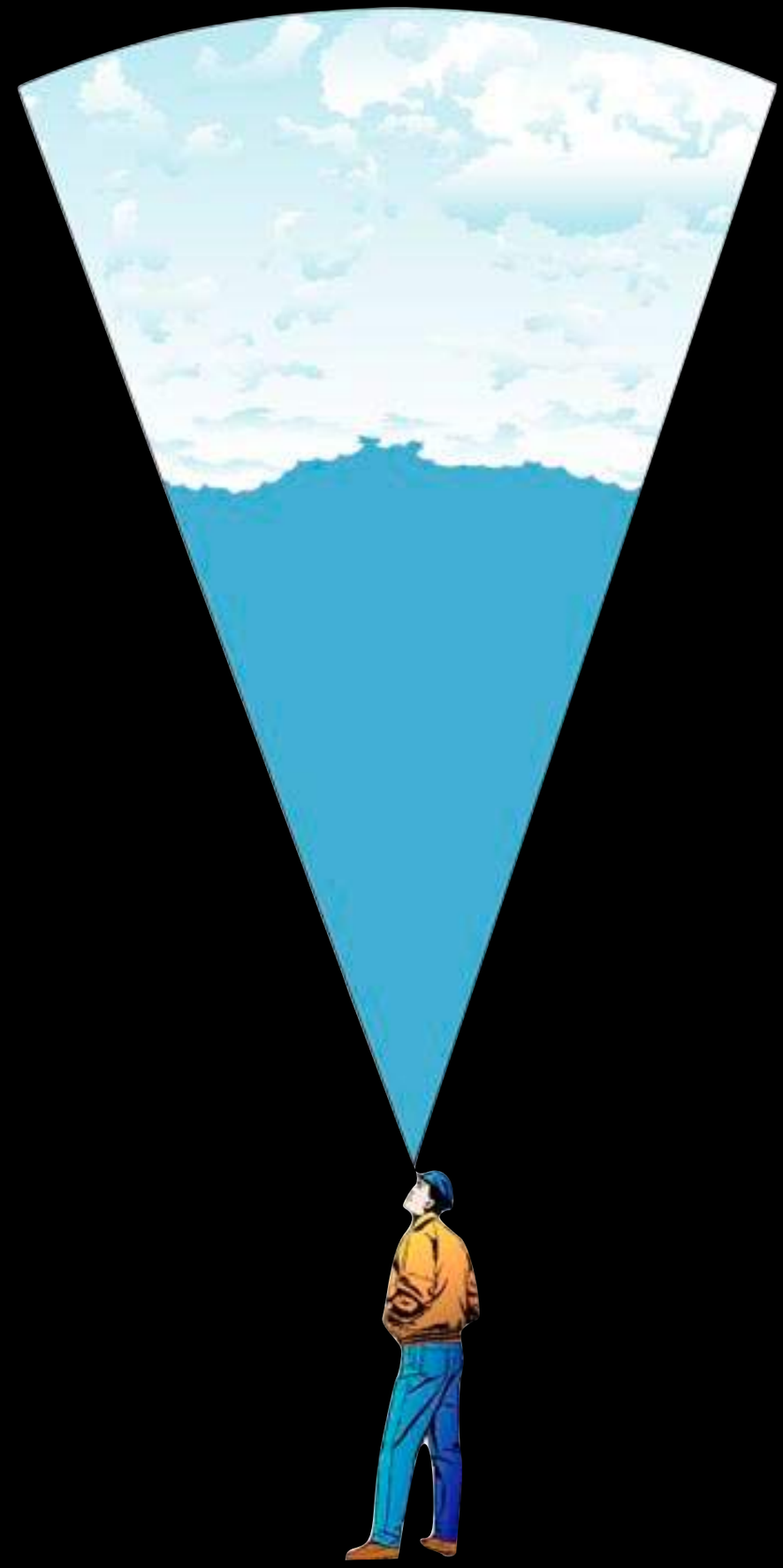
Us looking far away/back in time

time

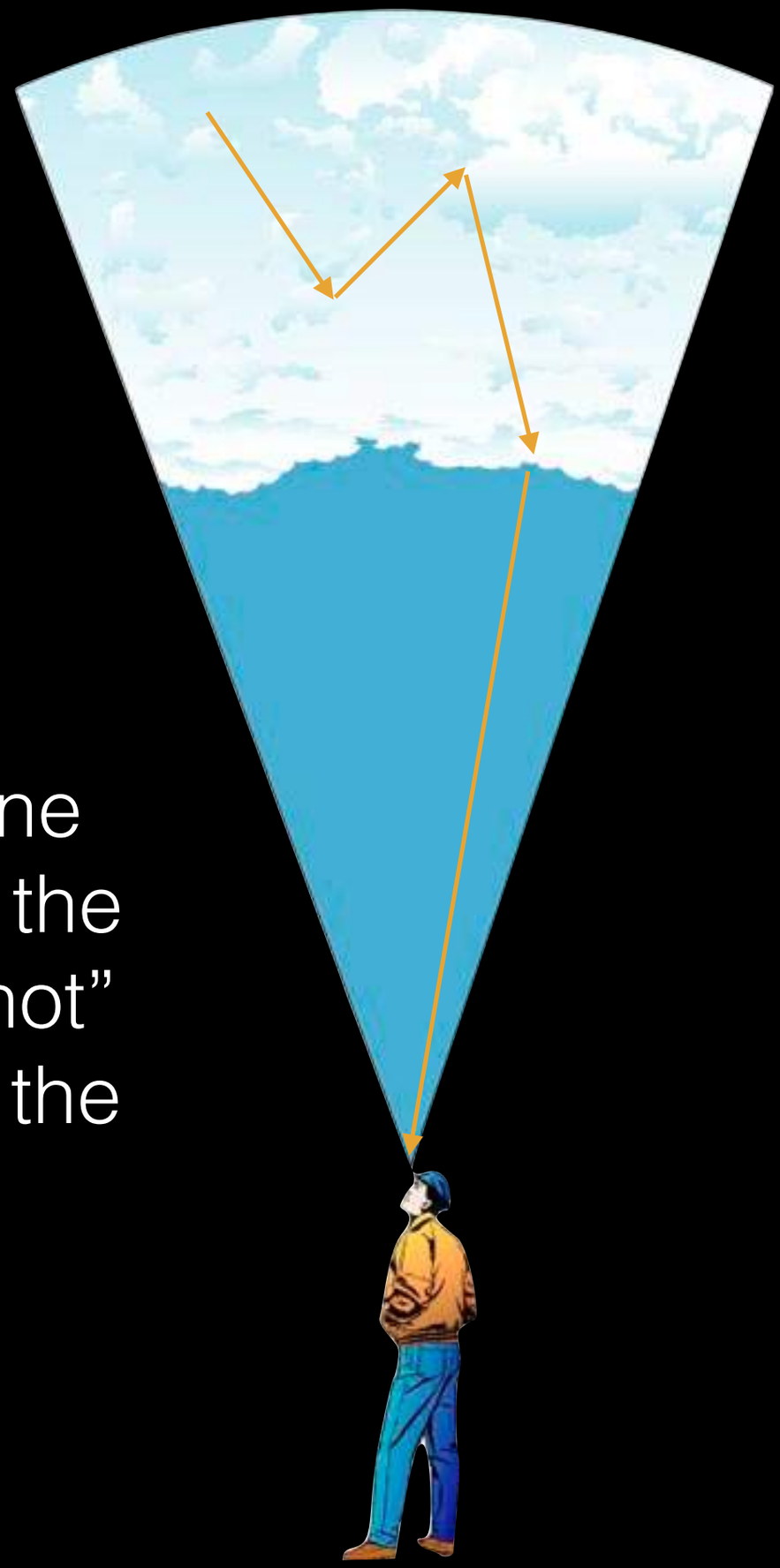
Smaller
Denser
Hotter

Larger
Less dense
Cooler

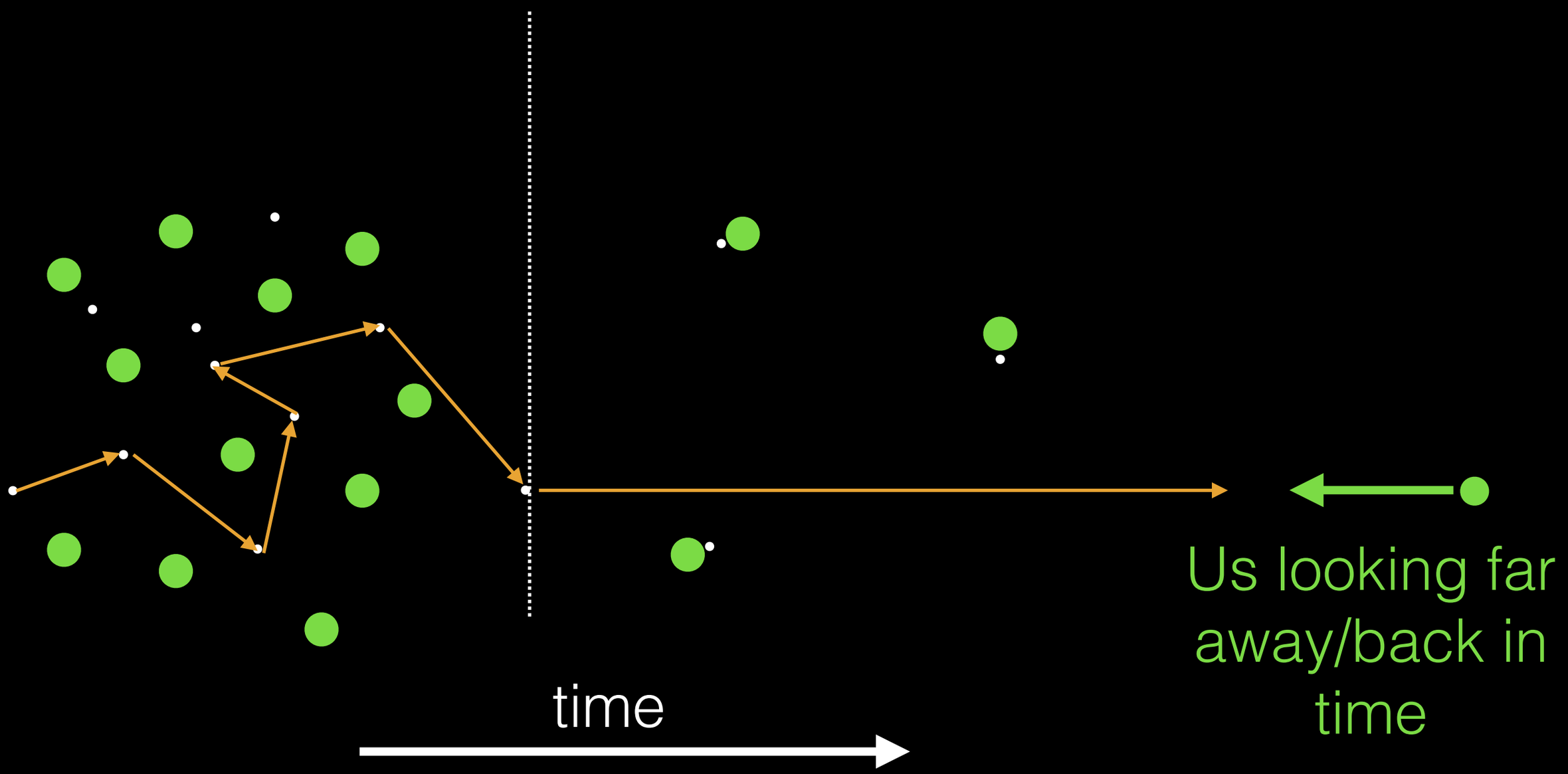




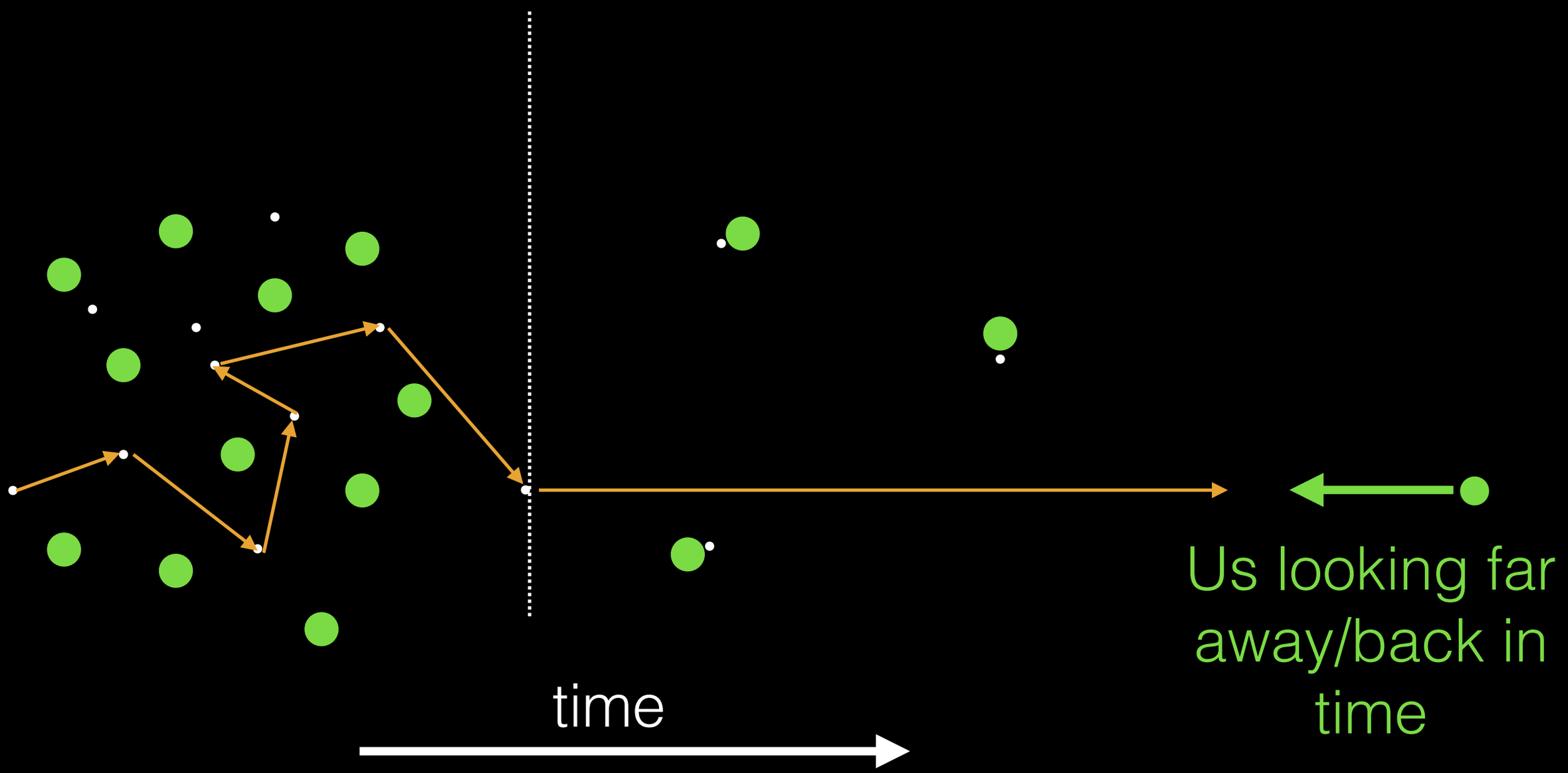
We see an outline of the surface of the cloud, a “snapshot” of the exterior of the cloud



400,000 years

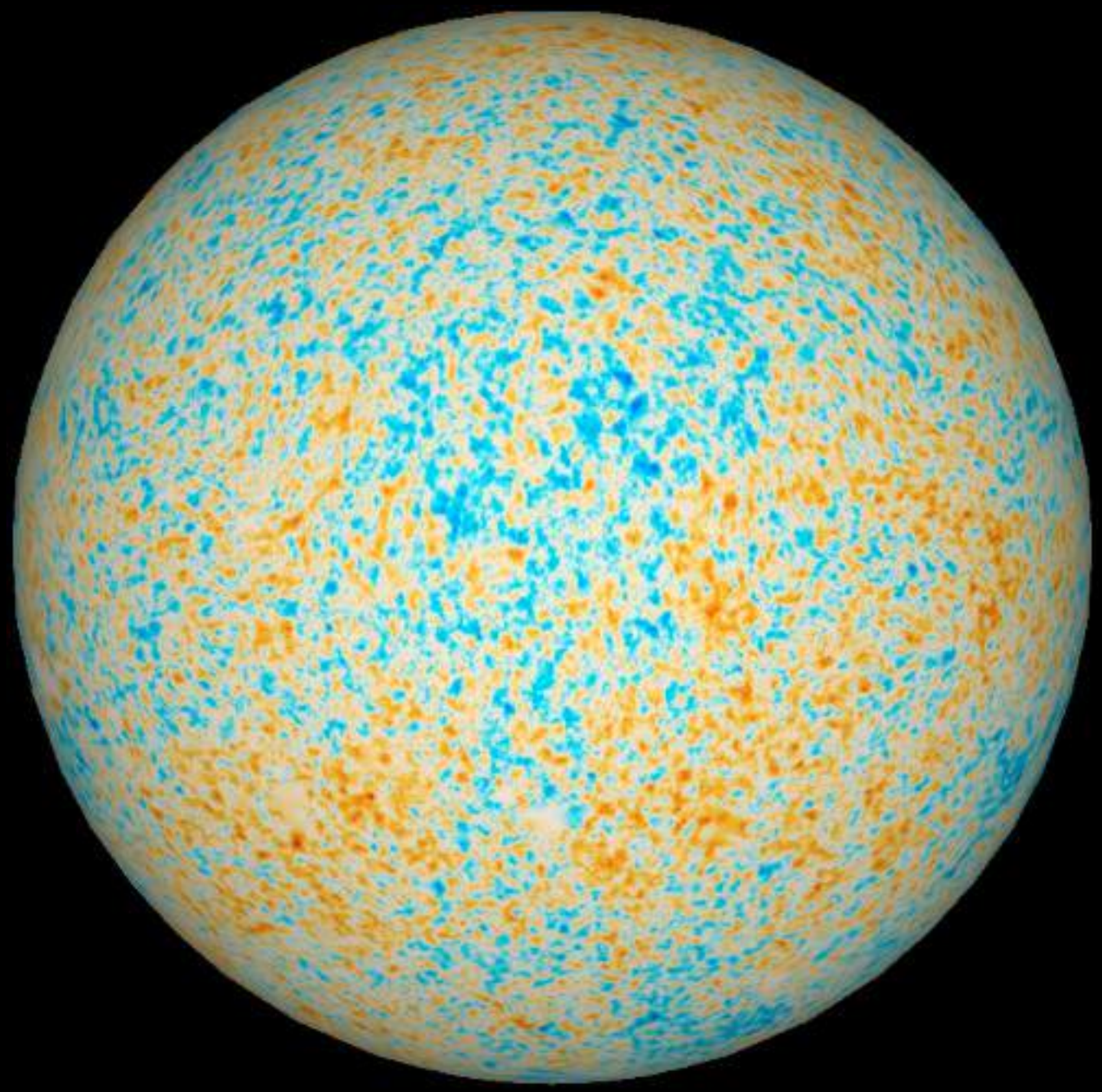


400,000 years



We see a snapshot of our Universe when it was only 400,000 years old. A mere baby!

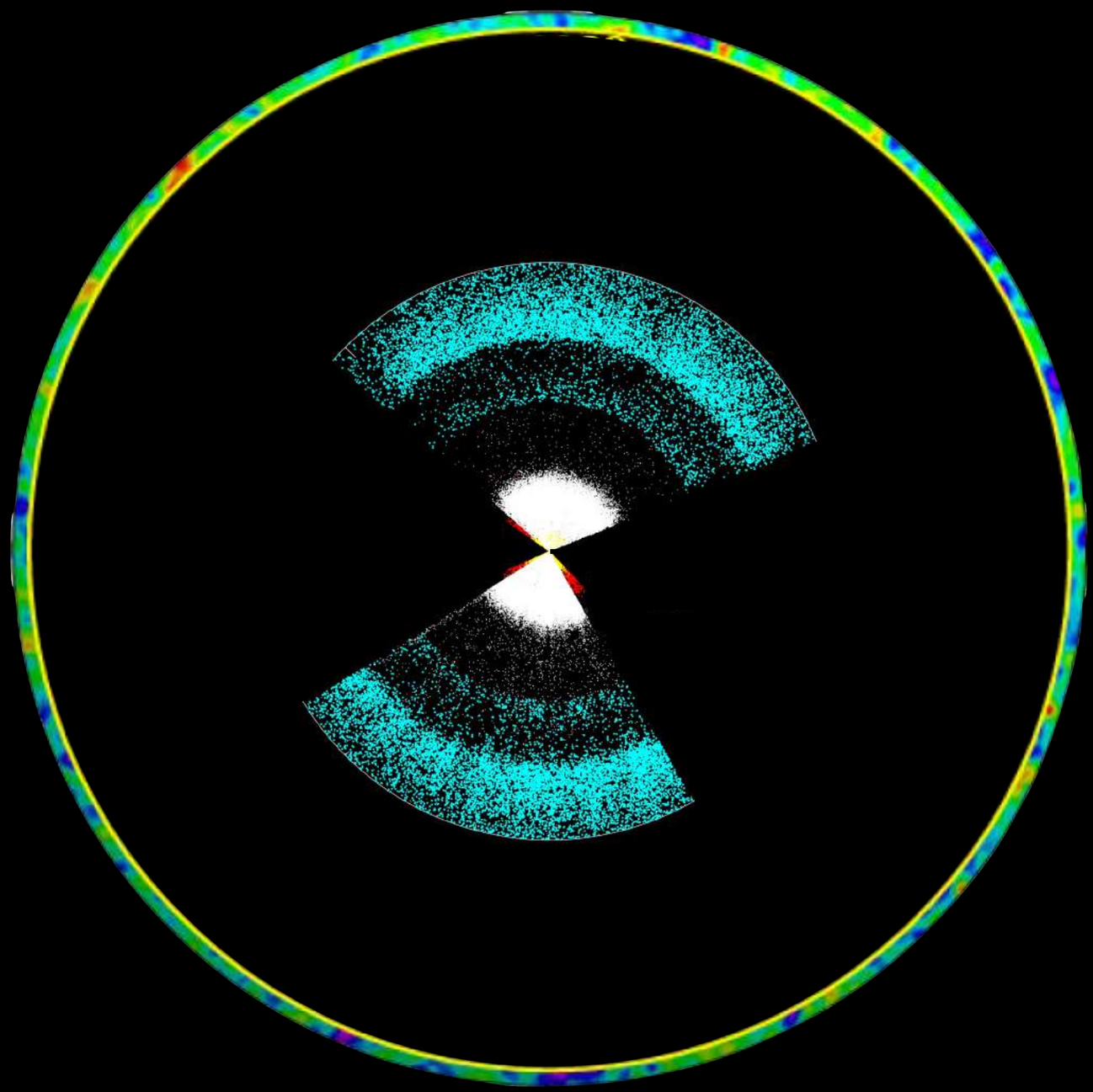
The Cosmic Microwave Background provides a snapshot of our baby Universe



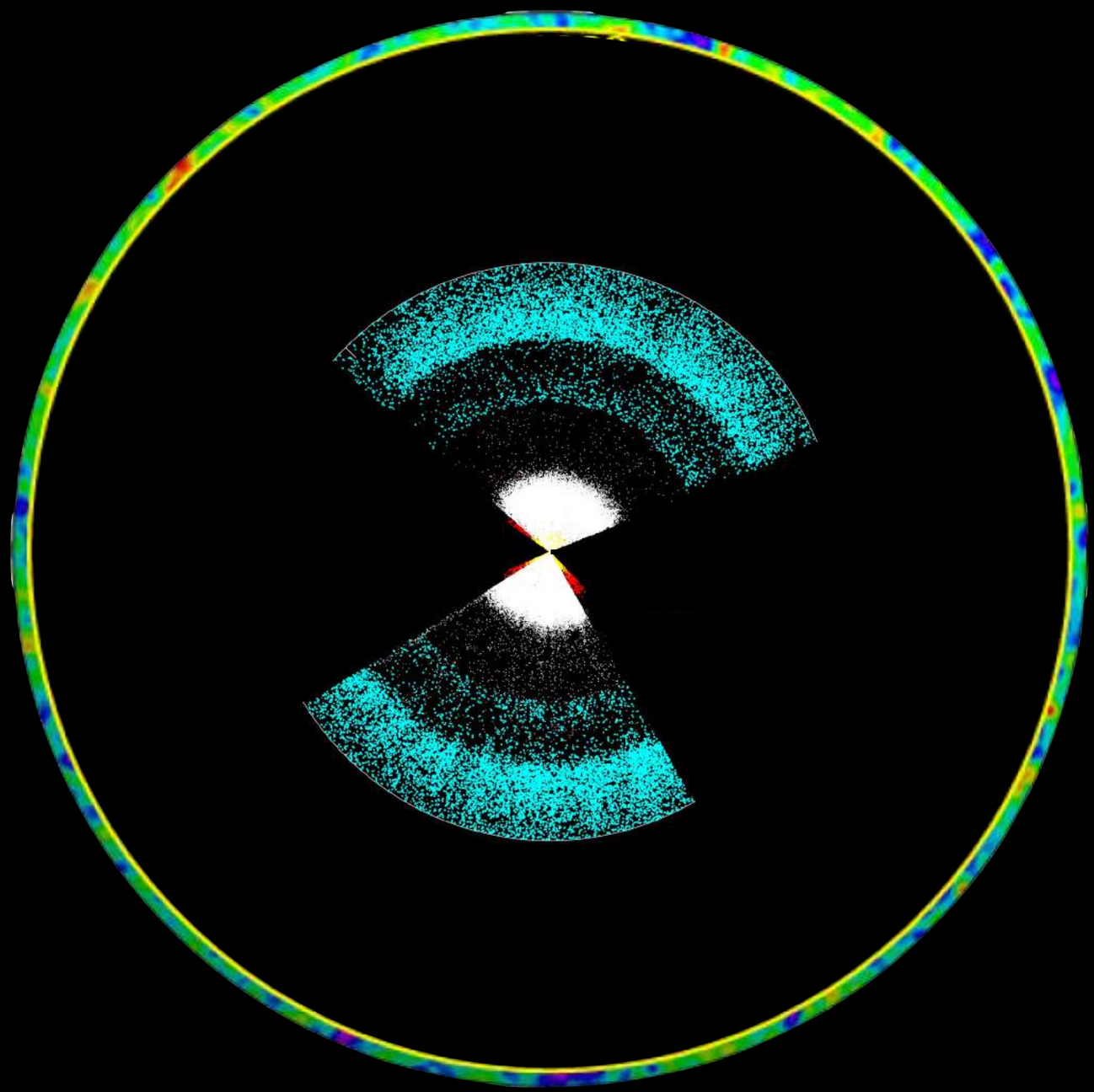
Alvarez et al. (2009)

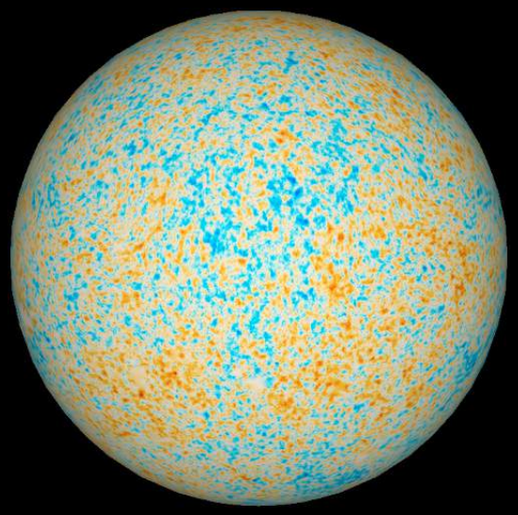
What about the real thing?

We have yet to observe most of the observable Universe



We have seen our grown-up Universe, our baby Universe, but not our Universe as it was growing up

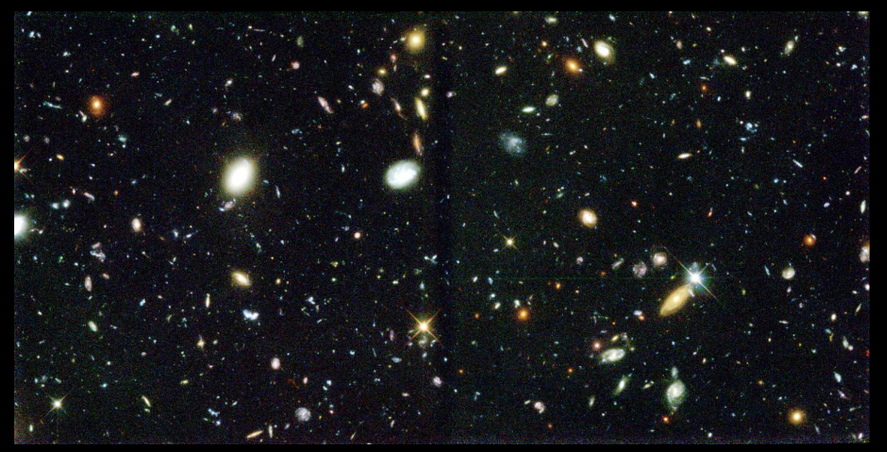




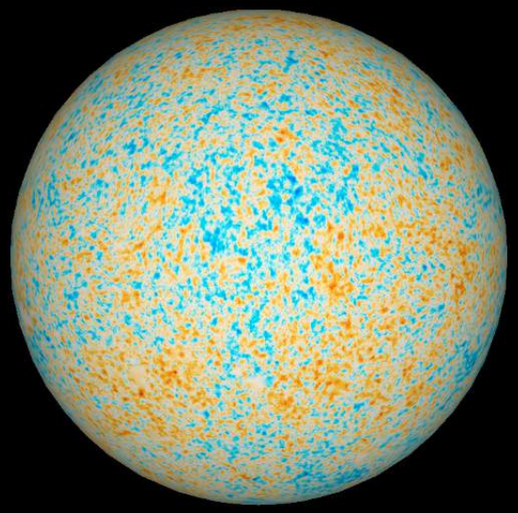
Baby Universe

?

Time

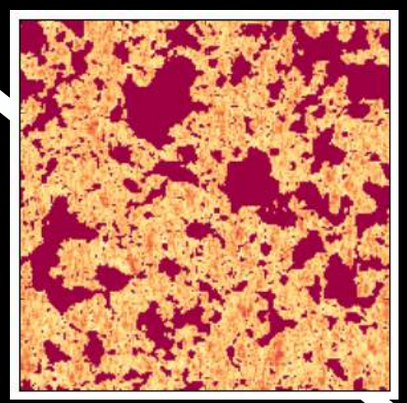


Mature Universe

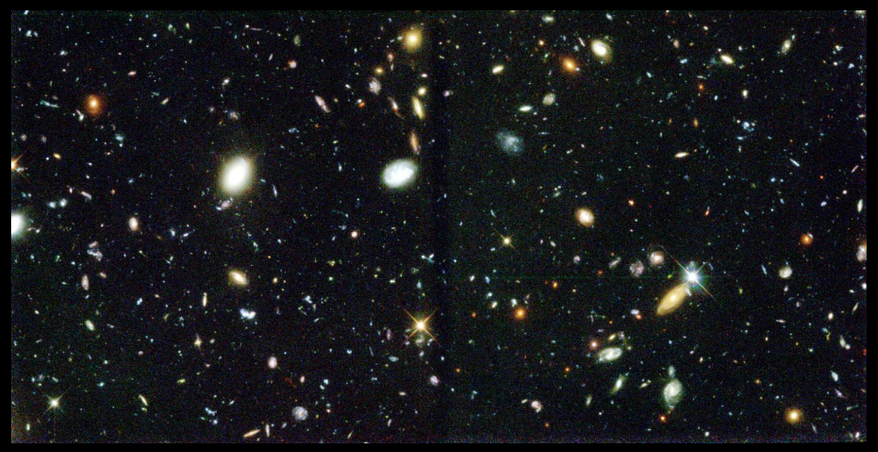


Baby Universe

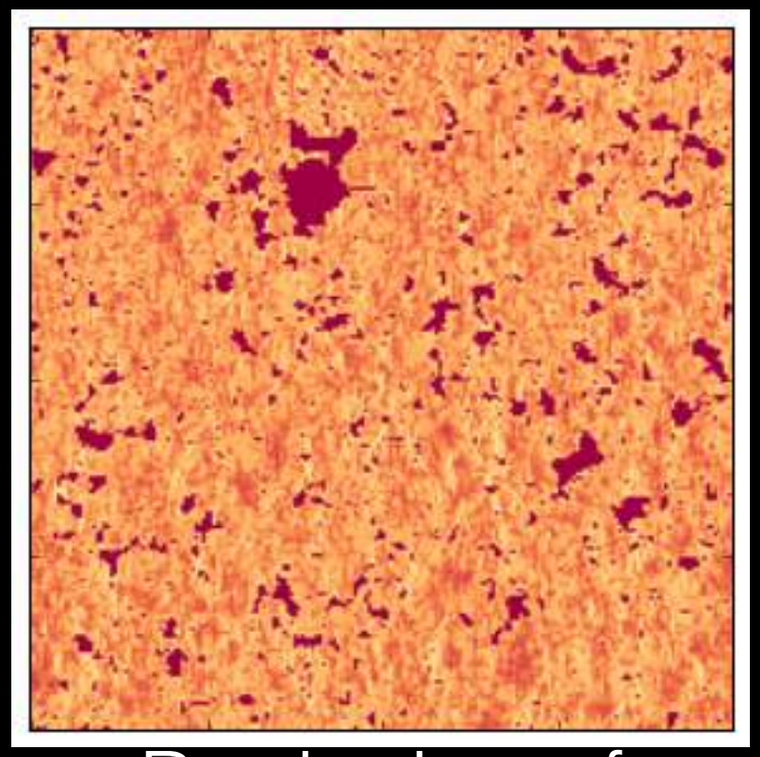
Reionization?



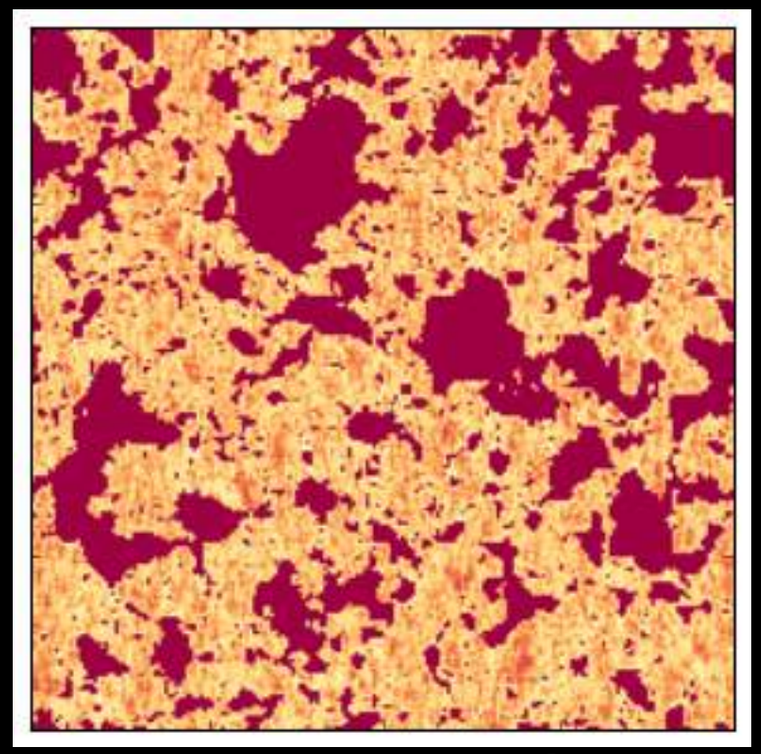
Time



Mature Universe



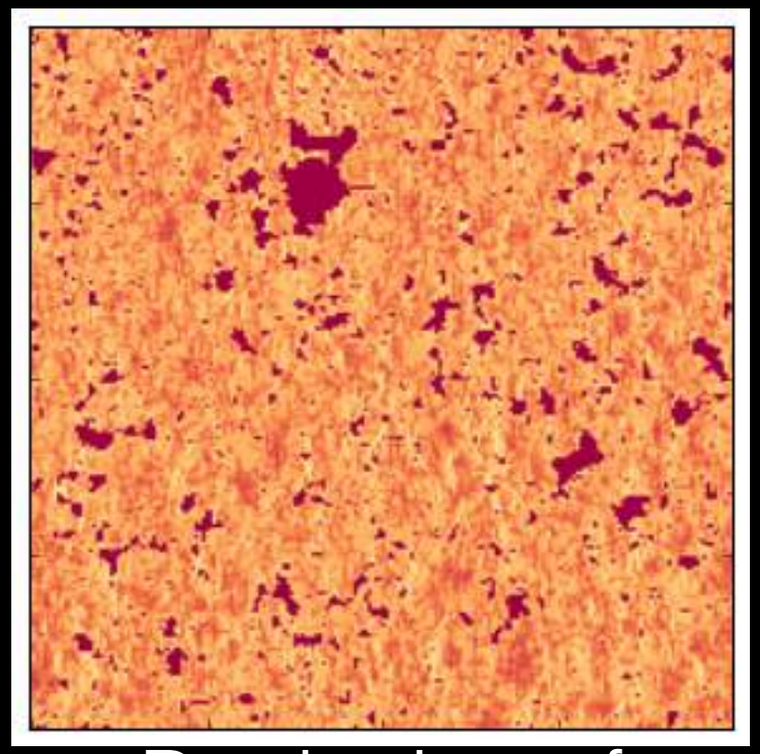
Beginning of reionization



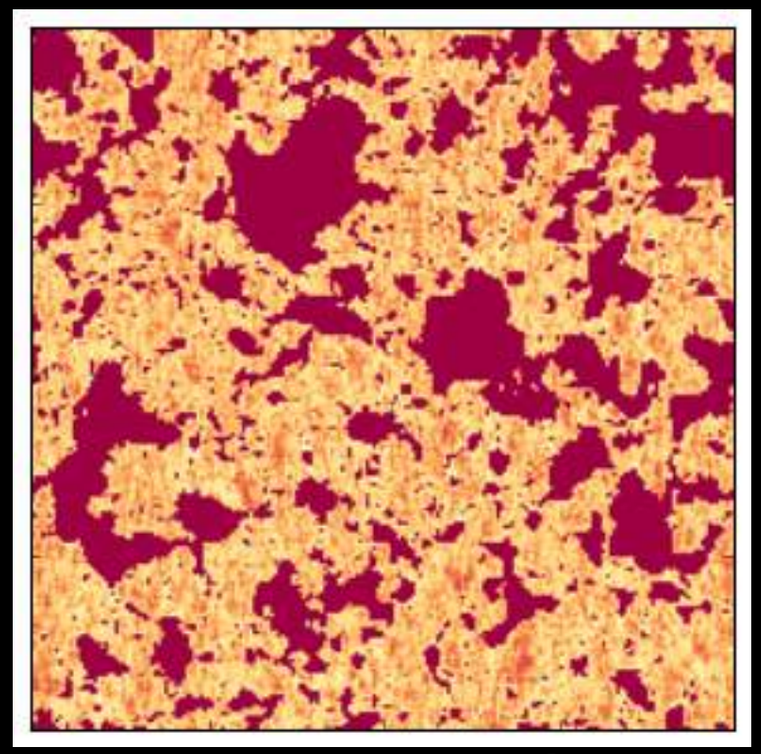
Middle of reionization

End of reionization

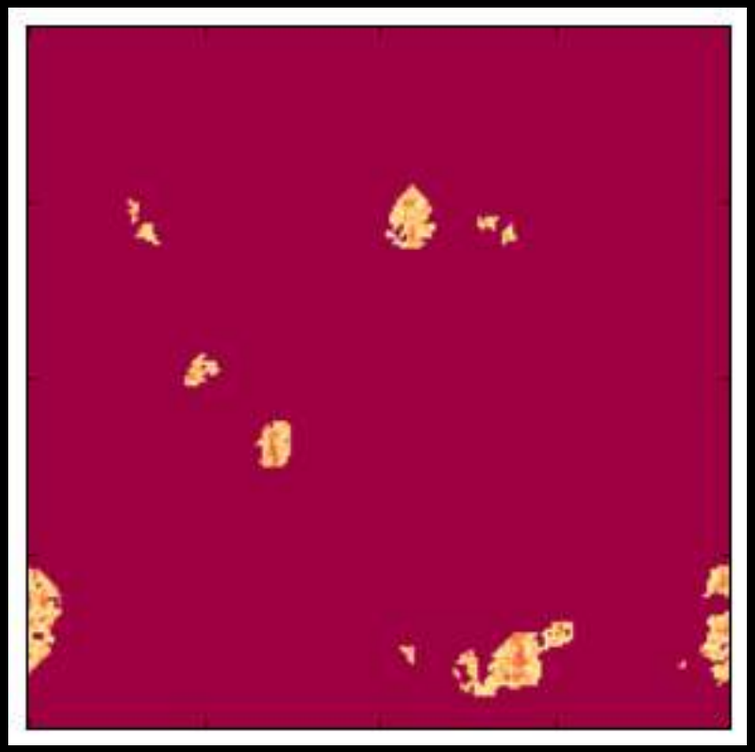
What was the nature of the first galaxies?



Beginning of reionization



Middle of reionization



End of reionization

How did the first galaxies affect their environments?