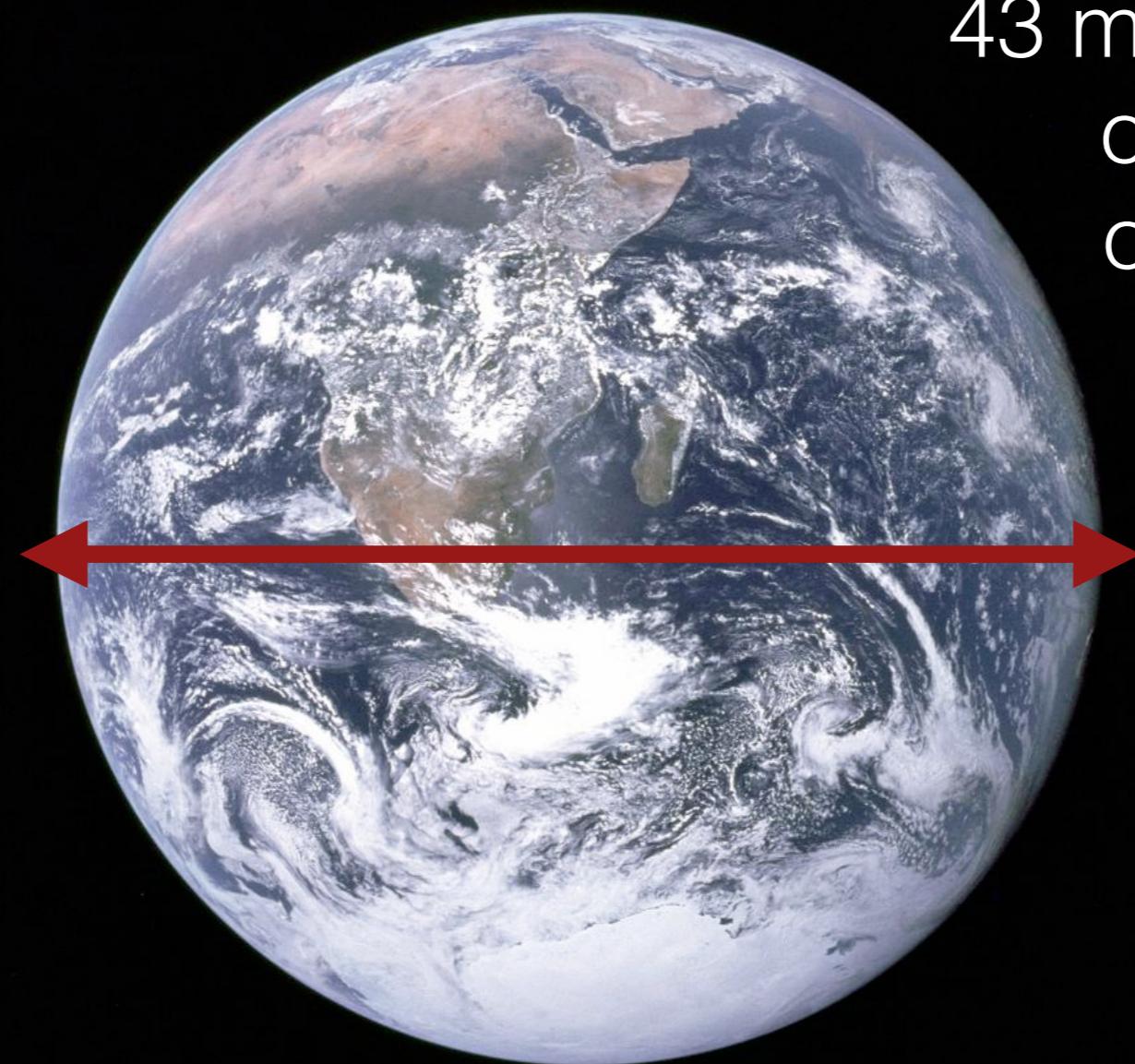


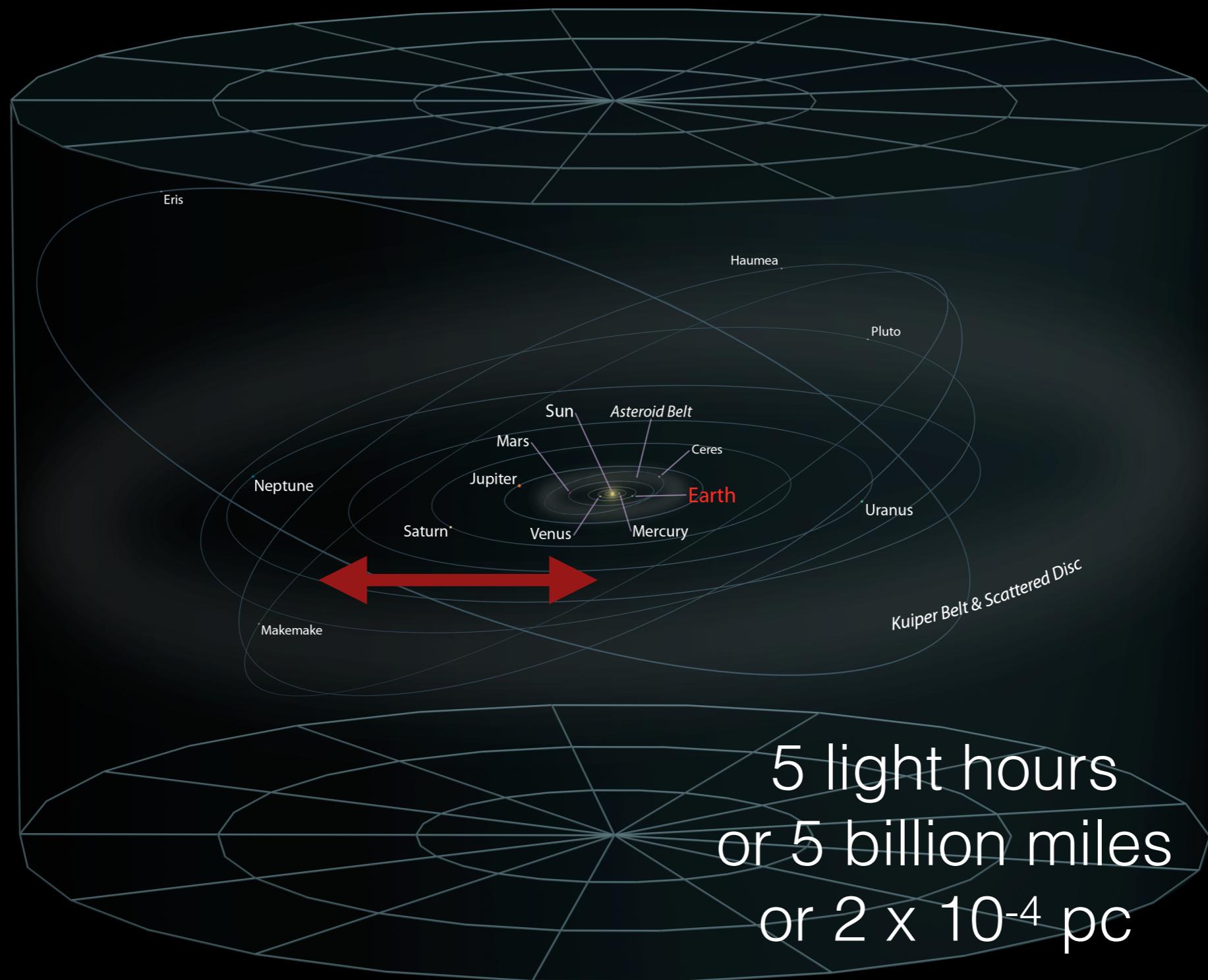
How big is our
Universe?

The Earth

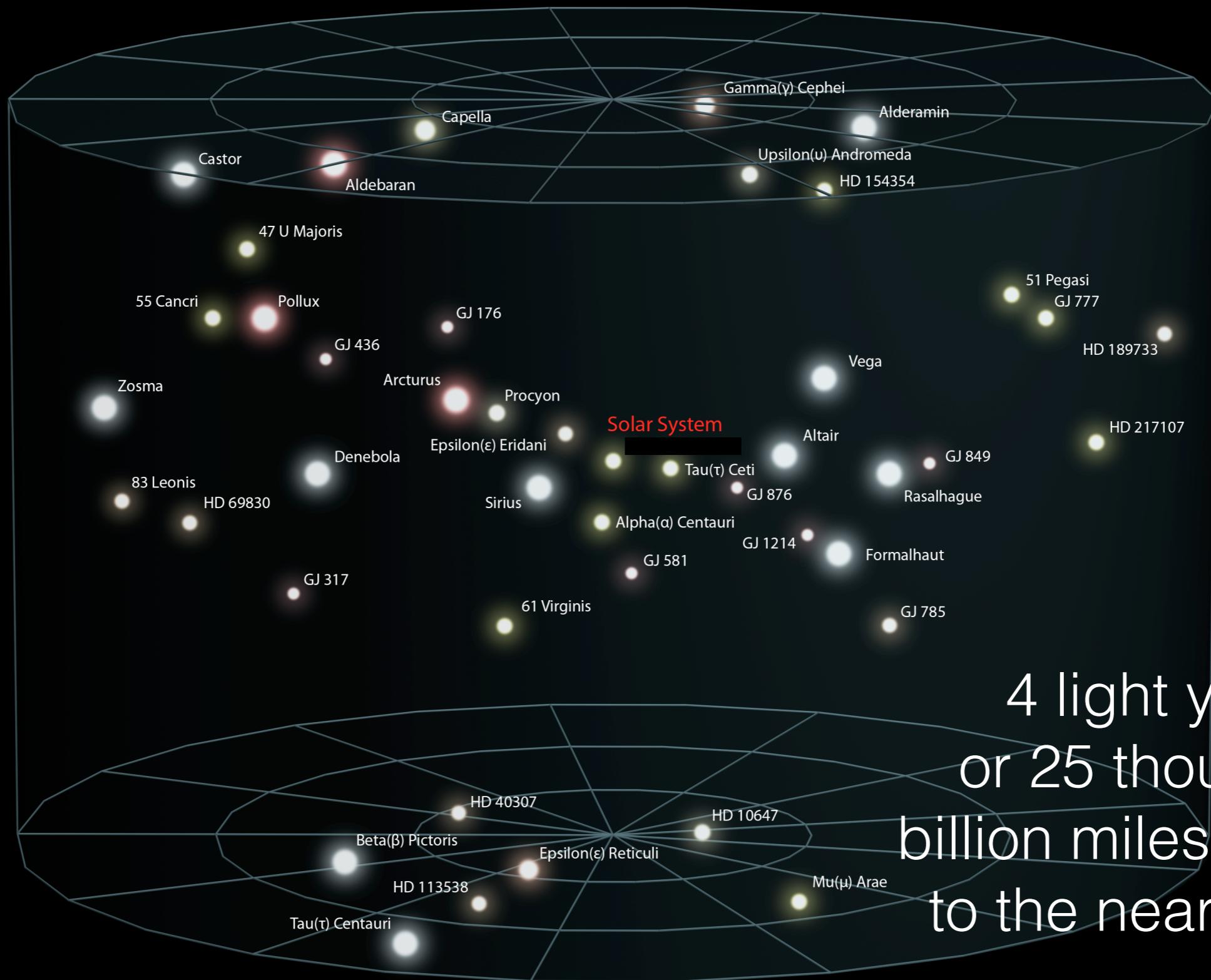


43 milli-light seconds
or 8000 miles
or 4×10^{-7} pc

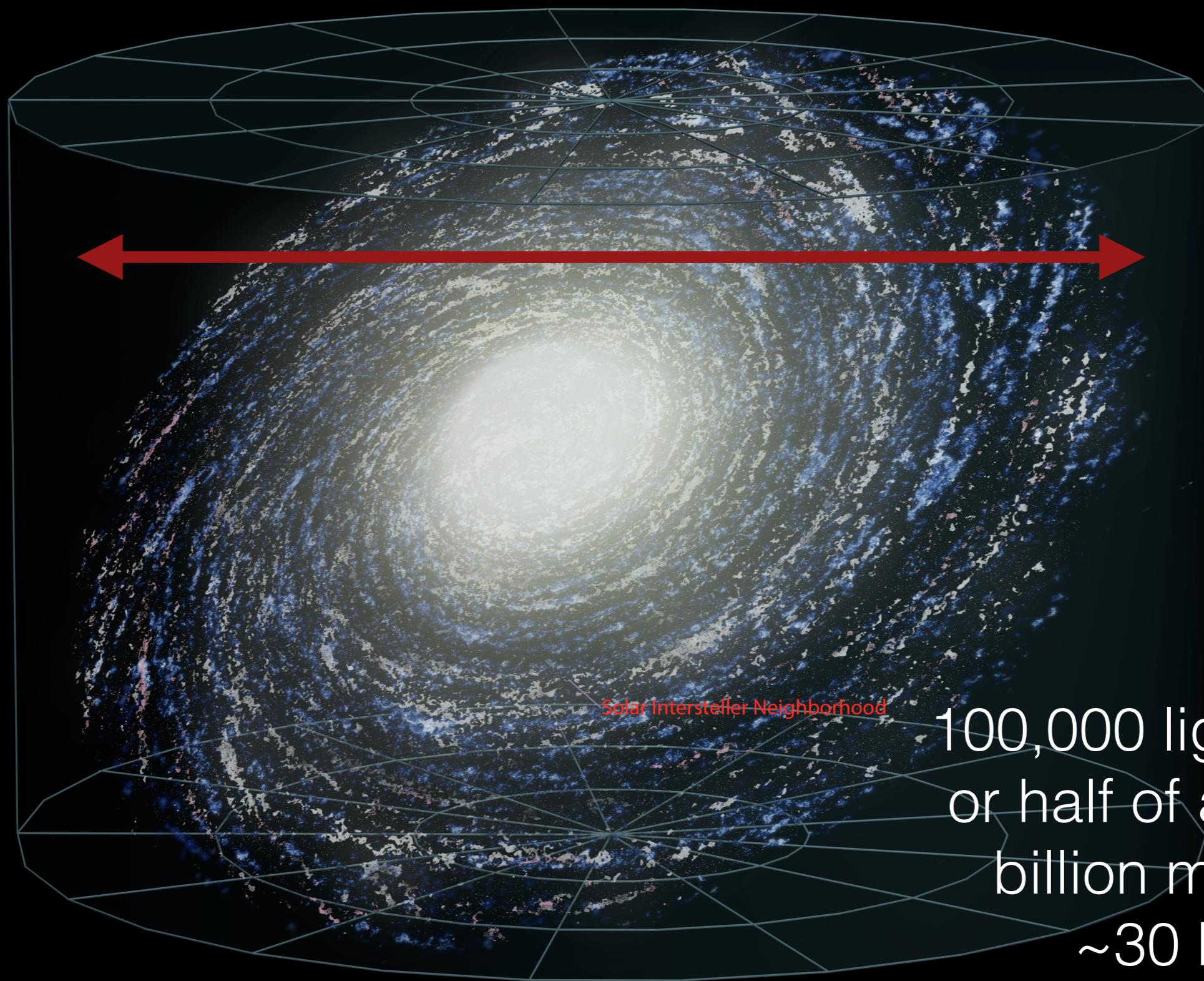
The Solar System

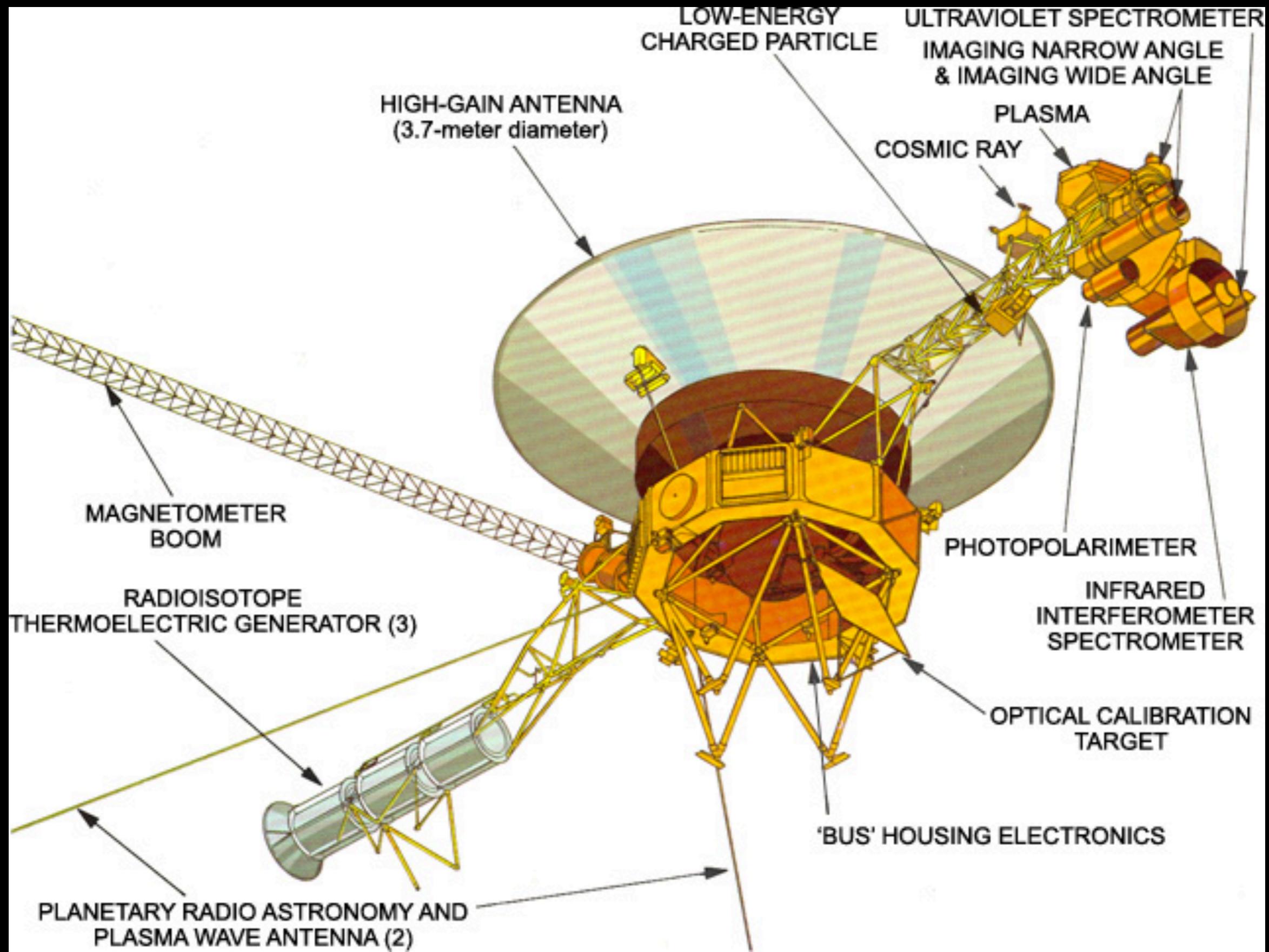


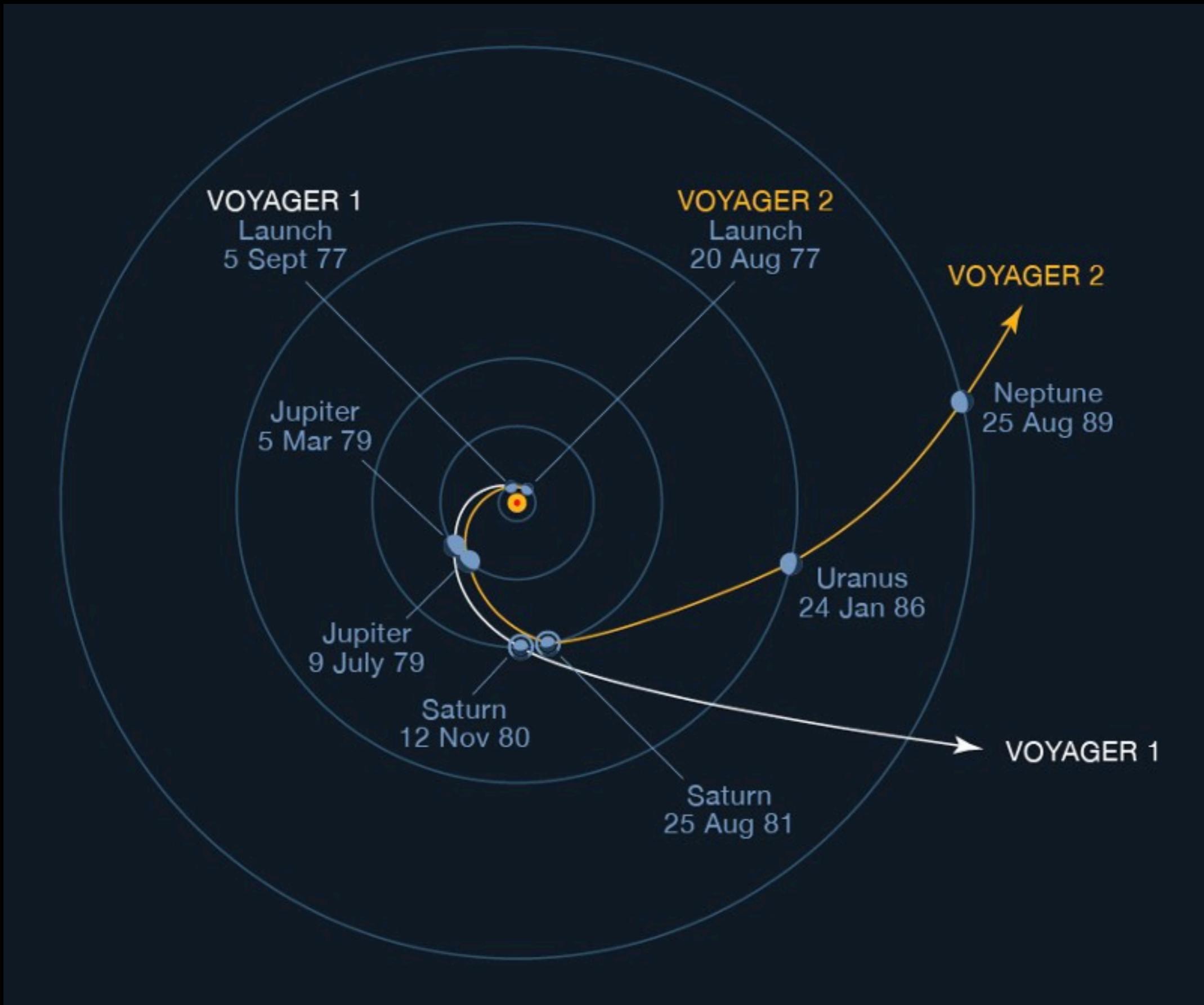
Nearby Stars

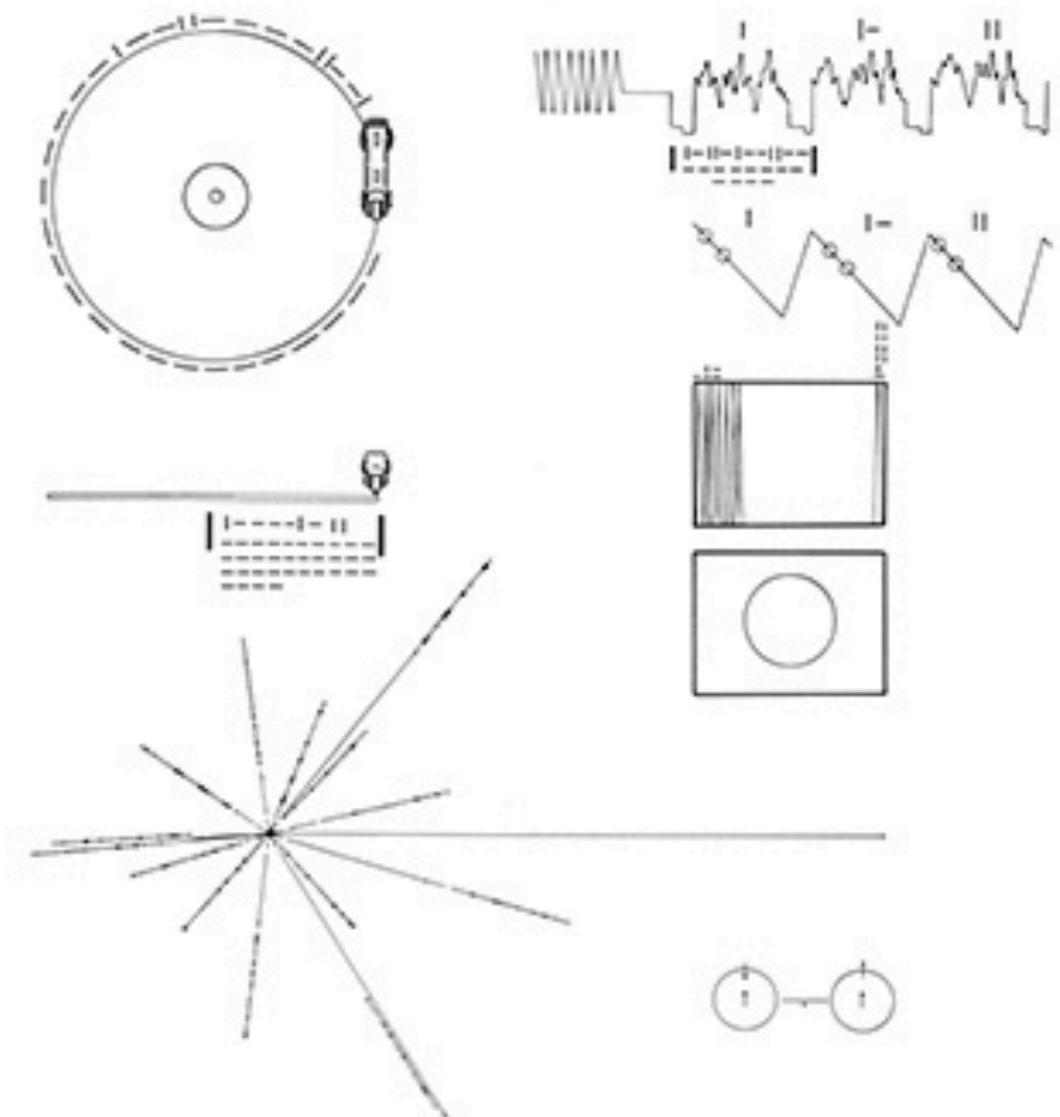
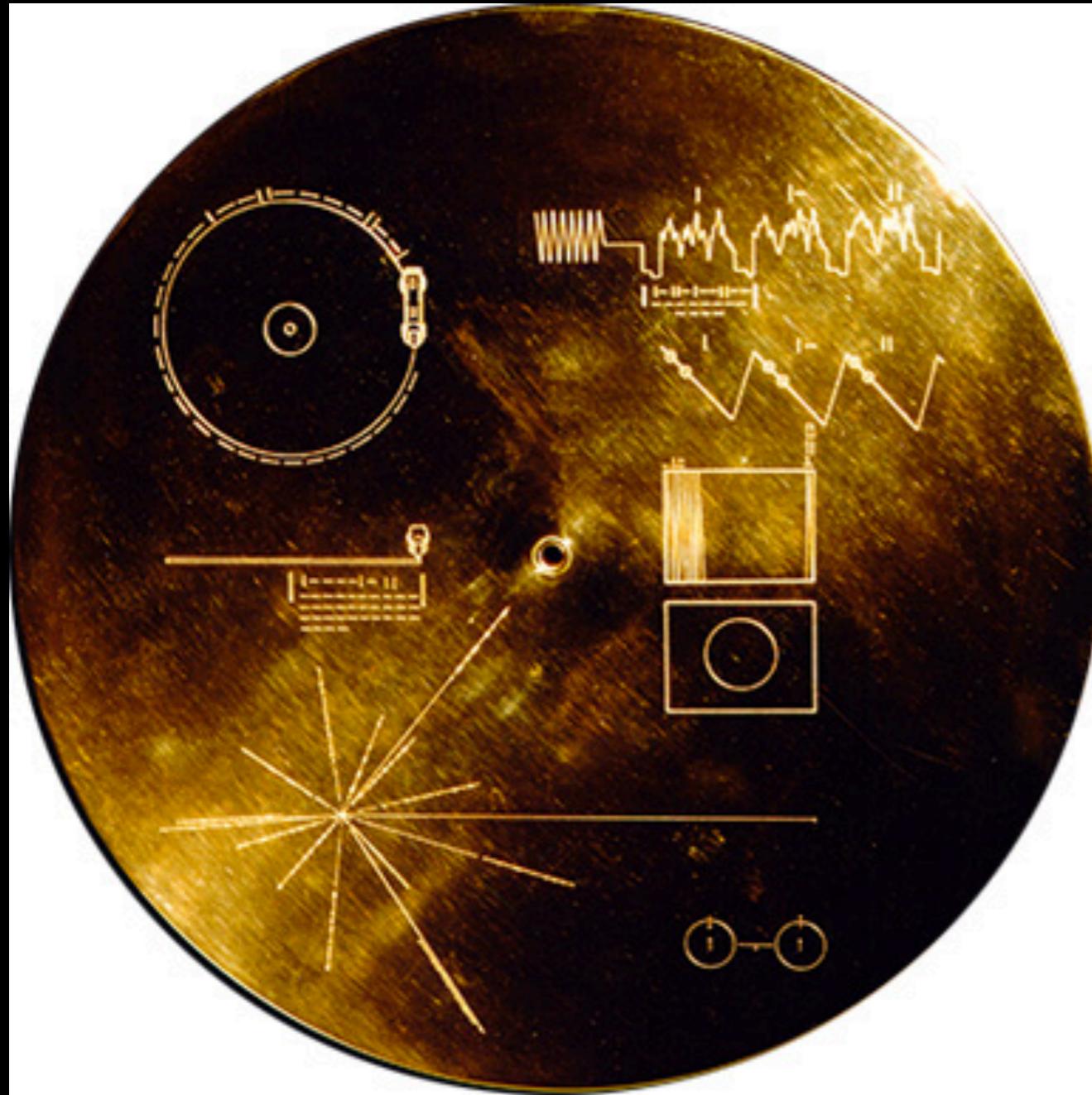


The Milky Way

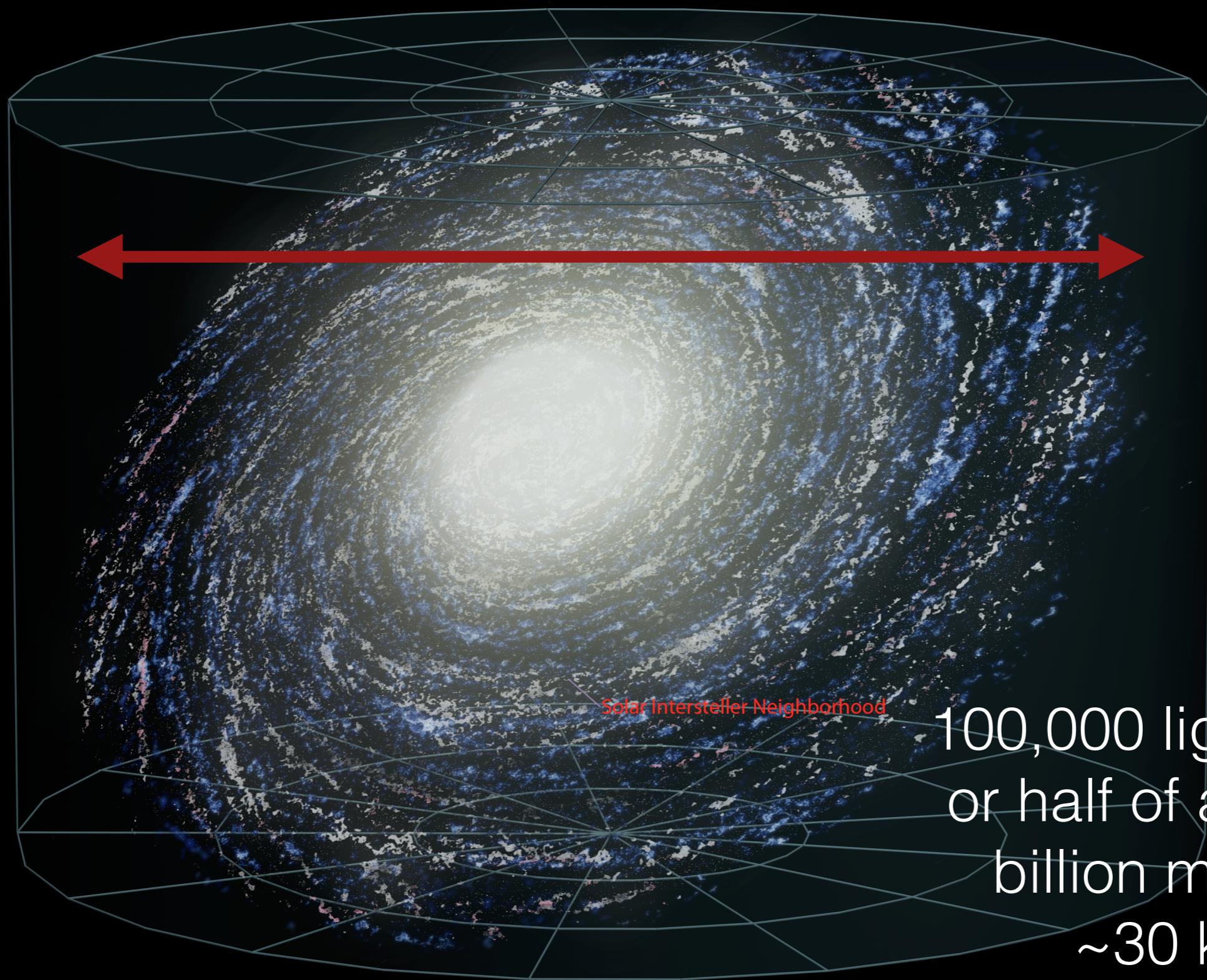




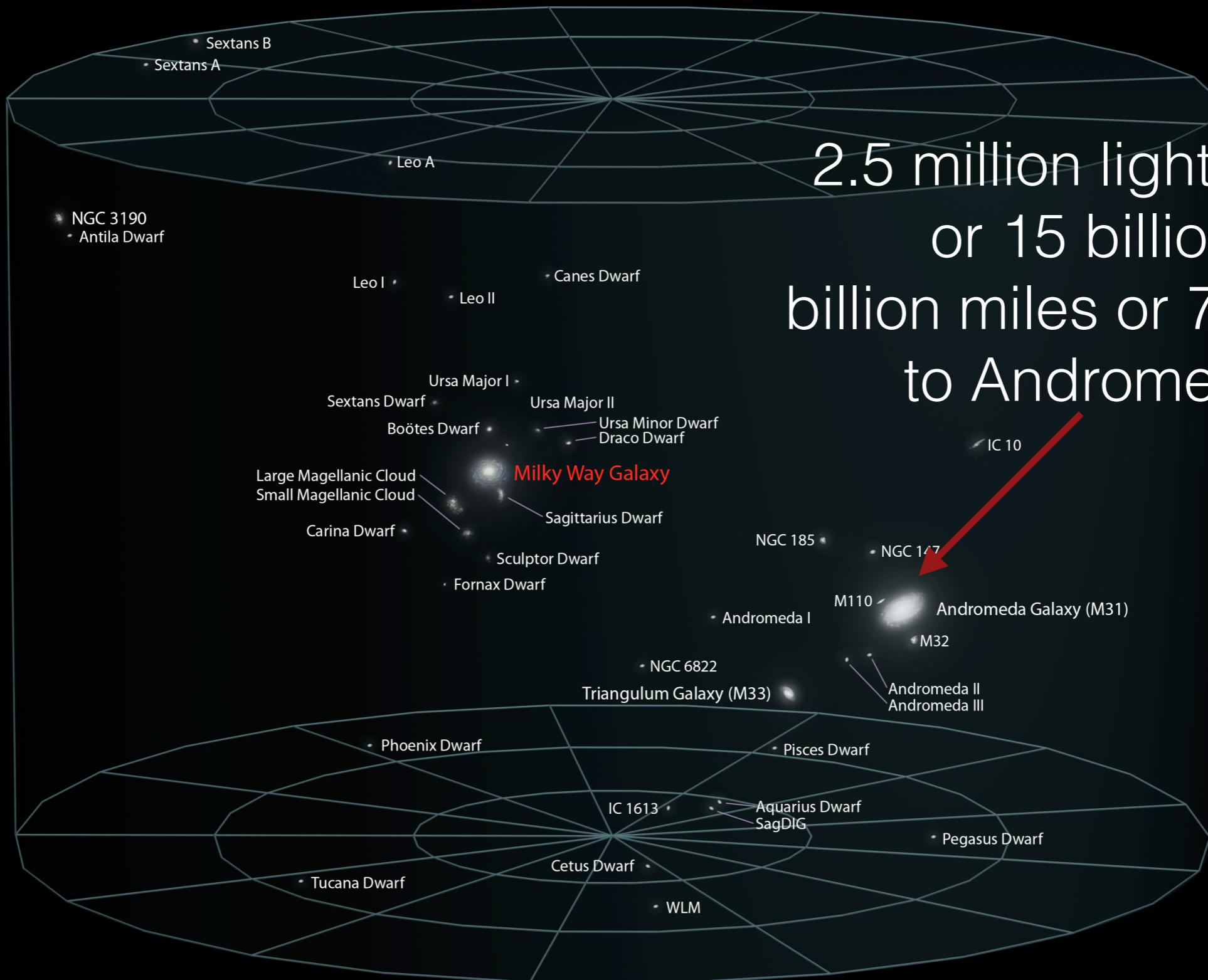




The Milky Way

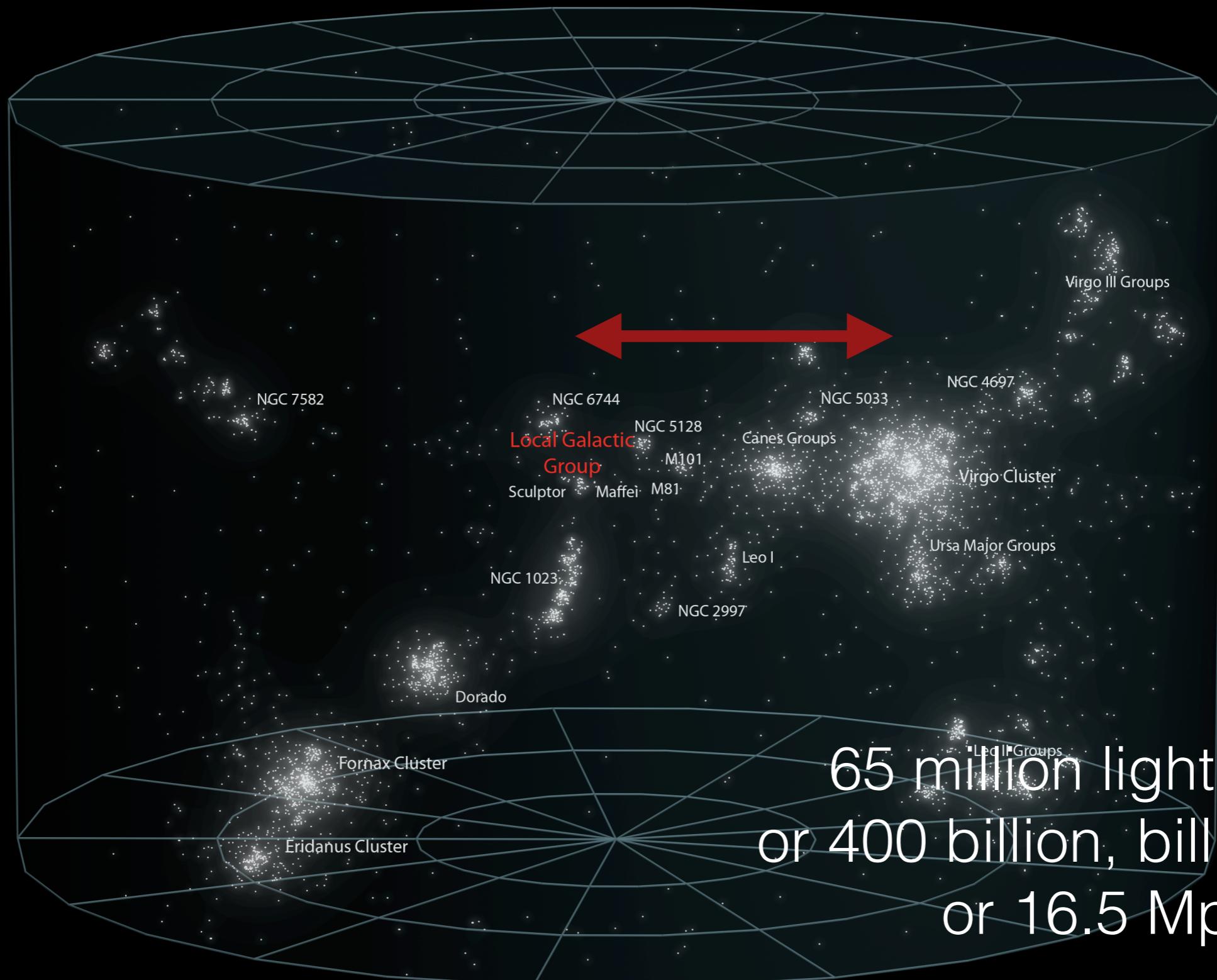


The Local Group

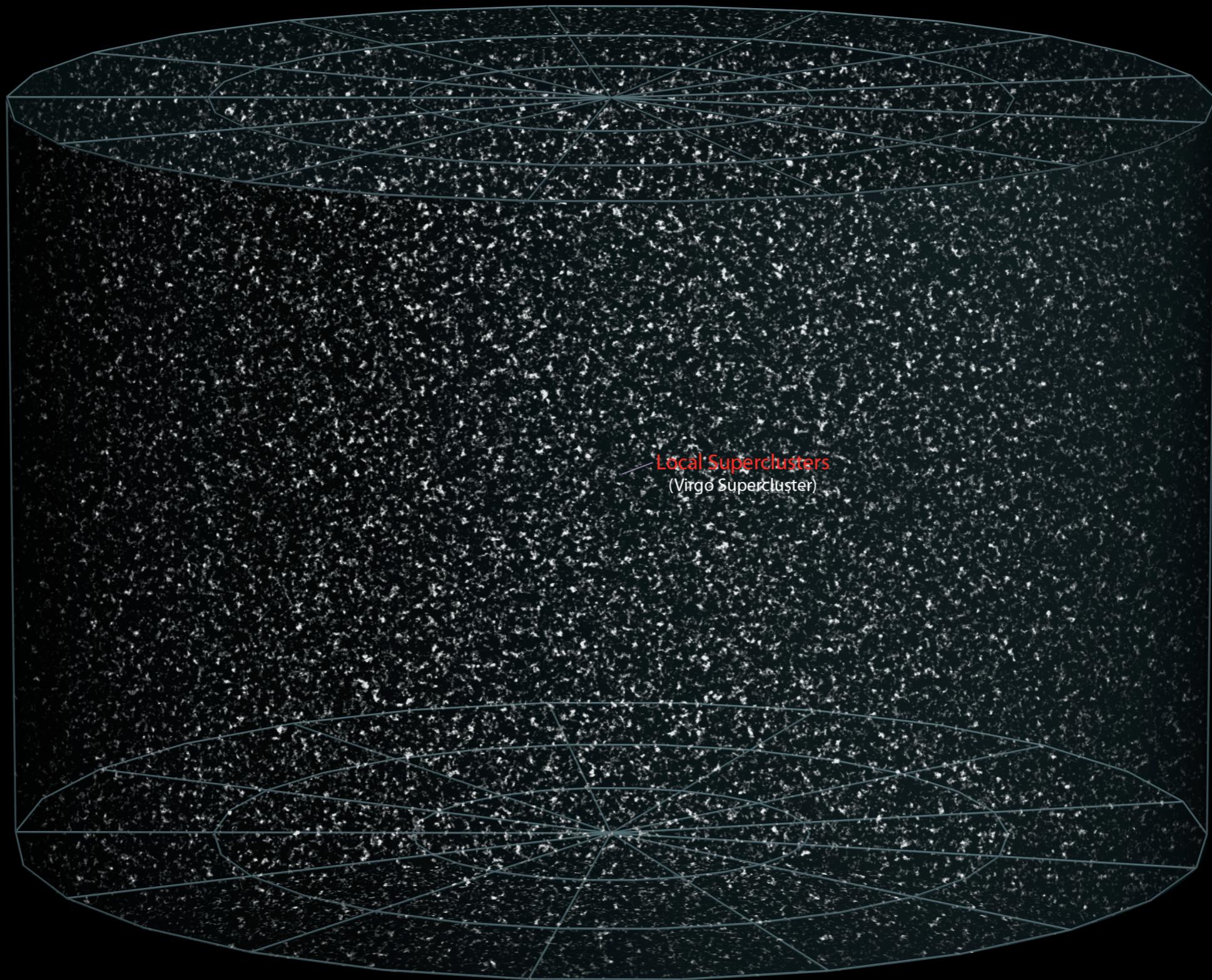


2.5 million light years
or 15 billion,
billion miles or 780 kpc
to Andromeda

Virgo Supercluster



We are just one of many

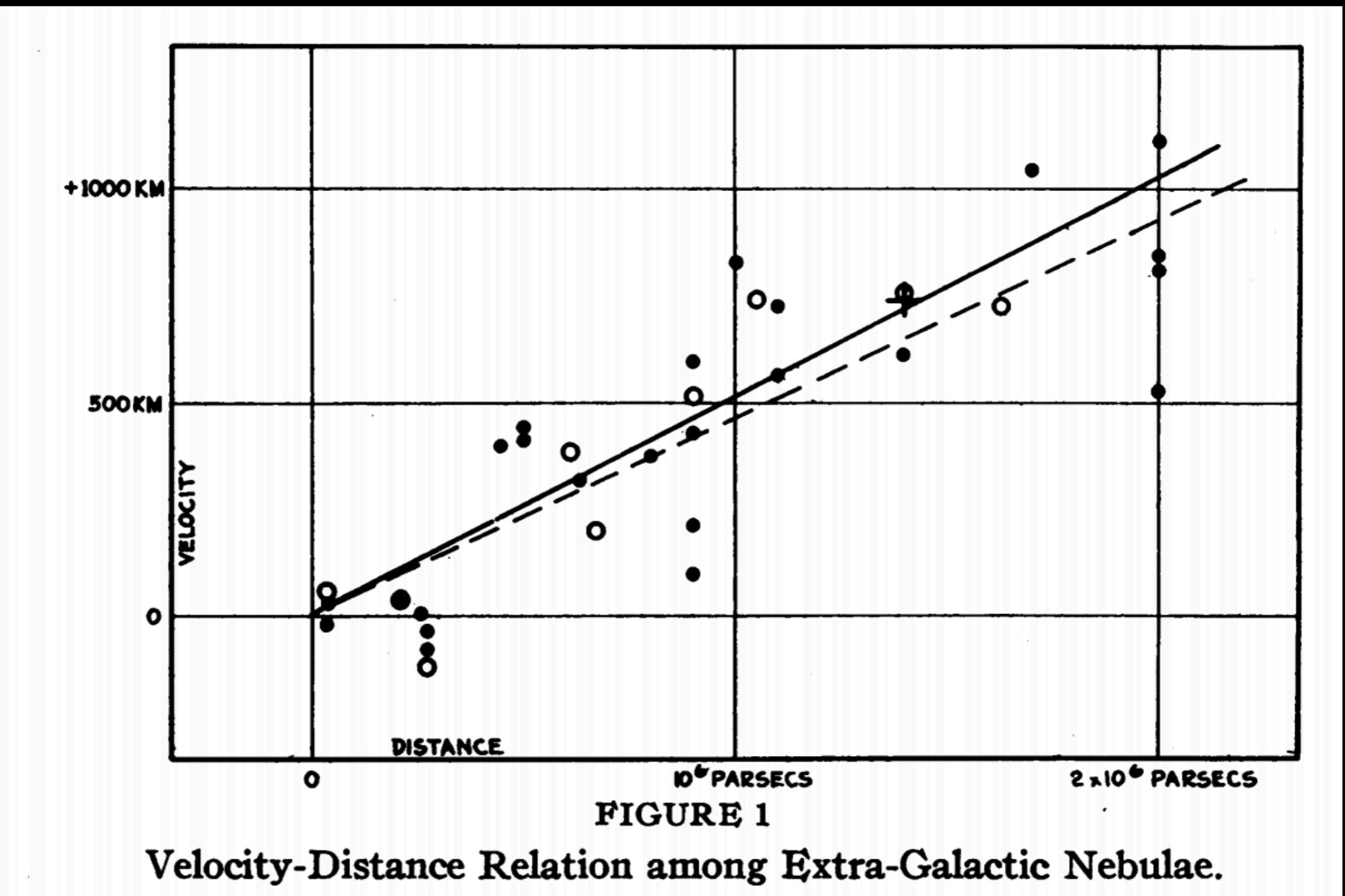




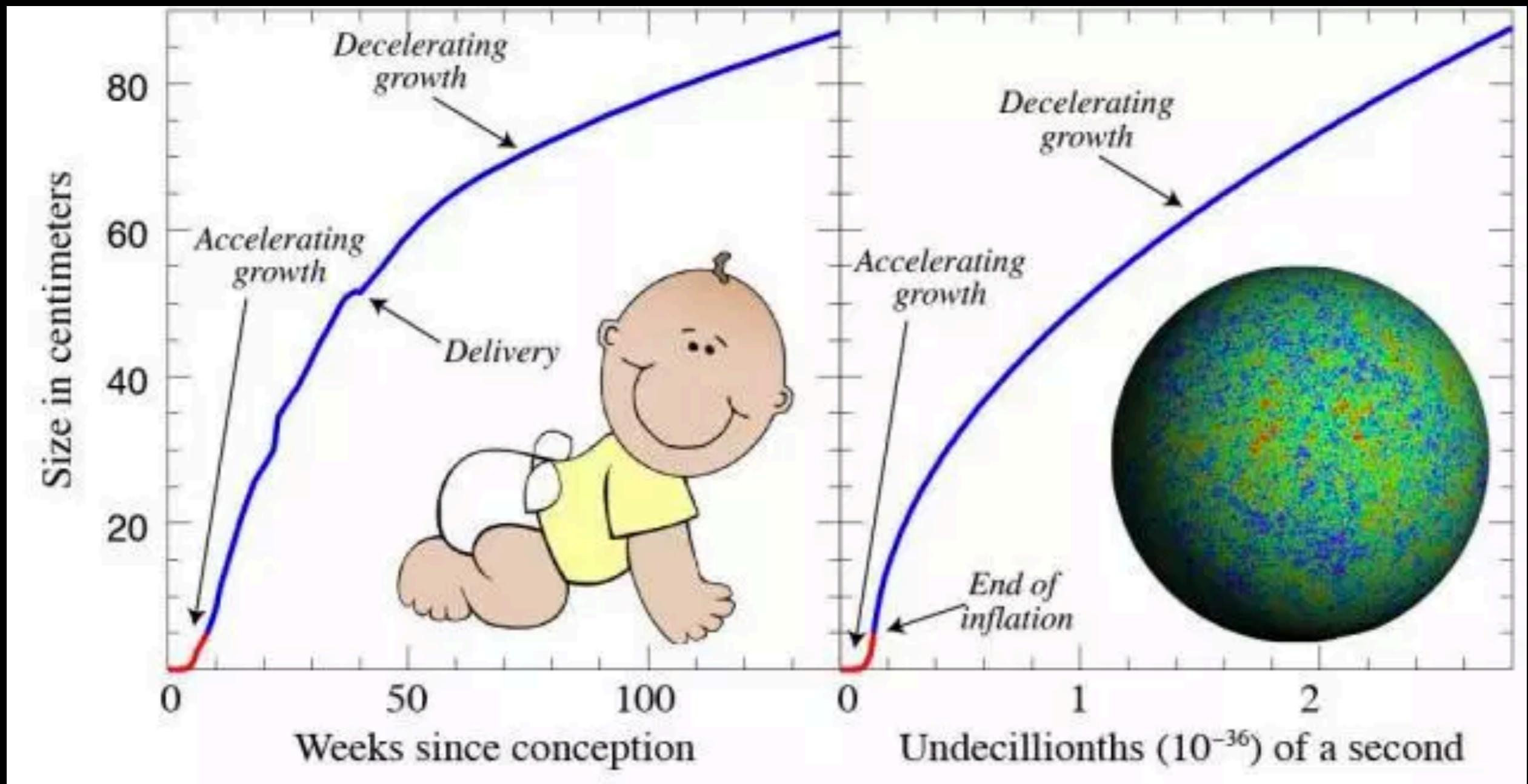


MONGABAY.COM





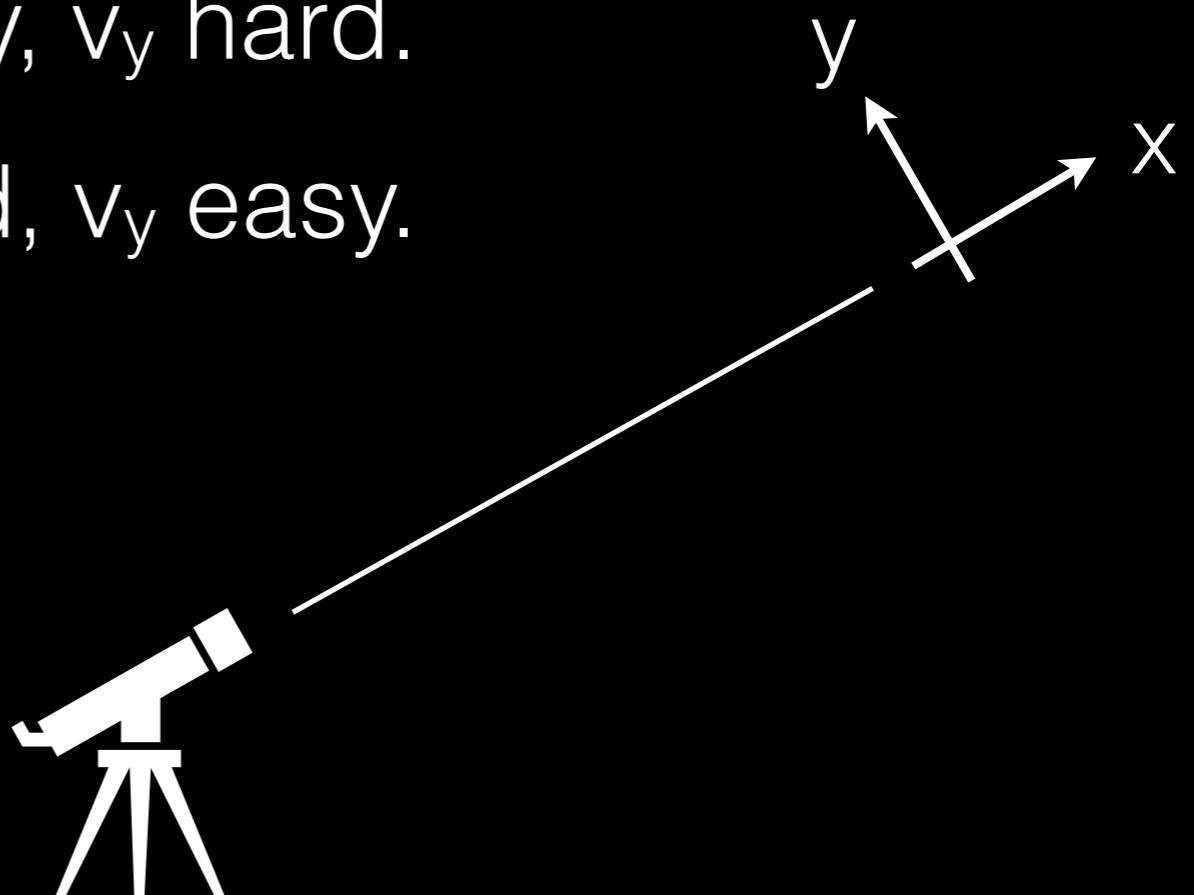
Hubble (1929)



Our Mathematical Universe by Max Tegmark

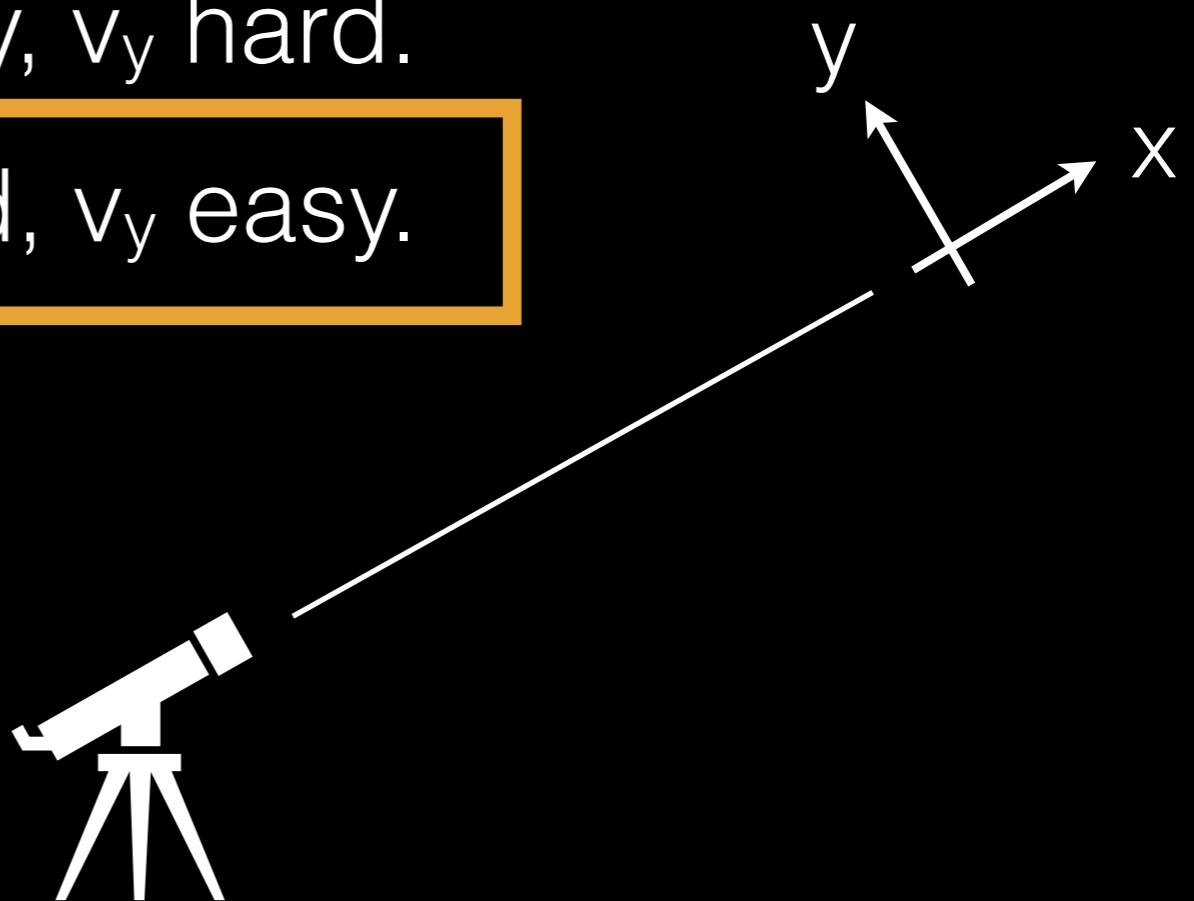
Which of components of a distant galaxy's position and velocity are easy/hard to observe?

- 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.

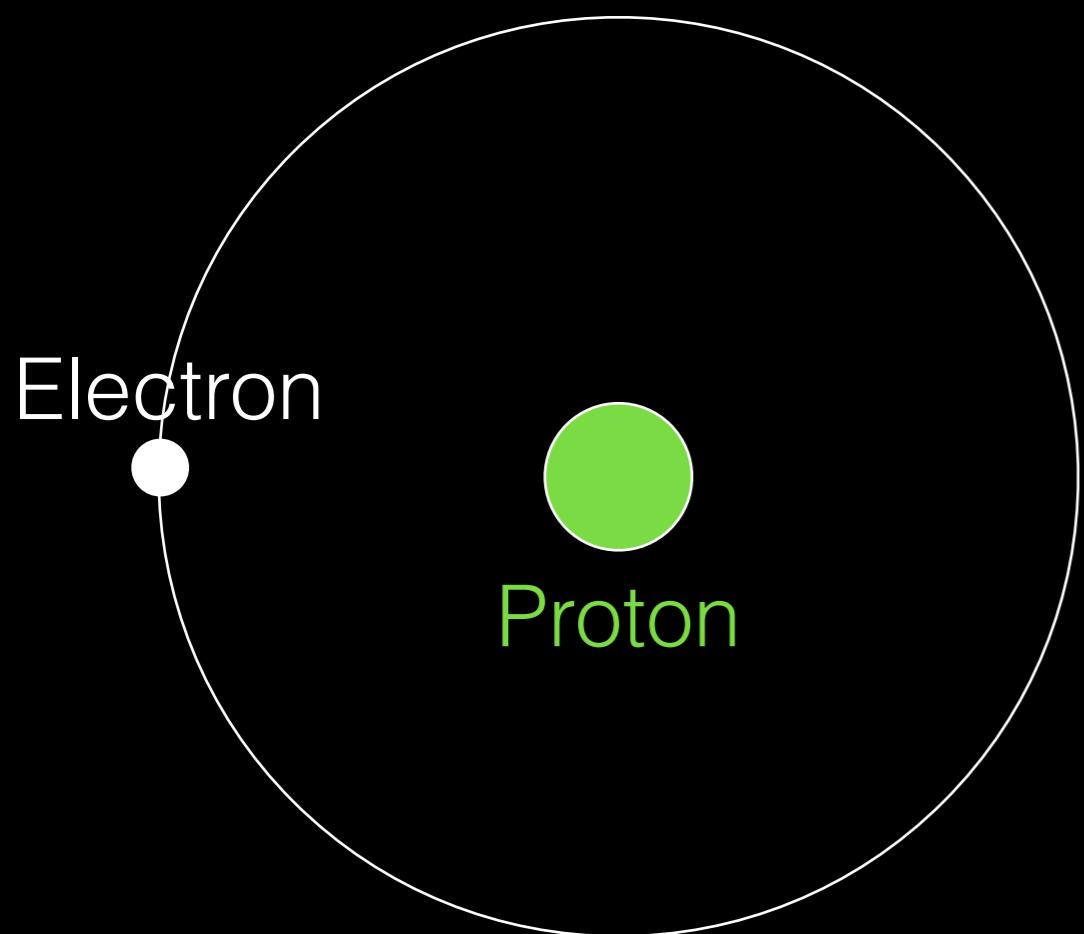


Which of components of a distant galaxy's position and velocity are easy/hard to observe?

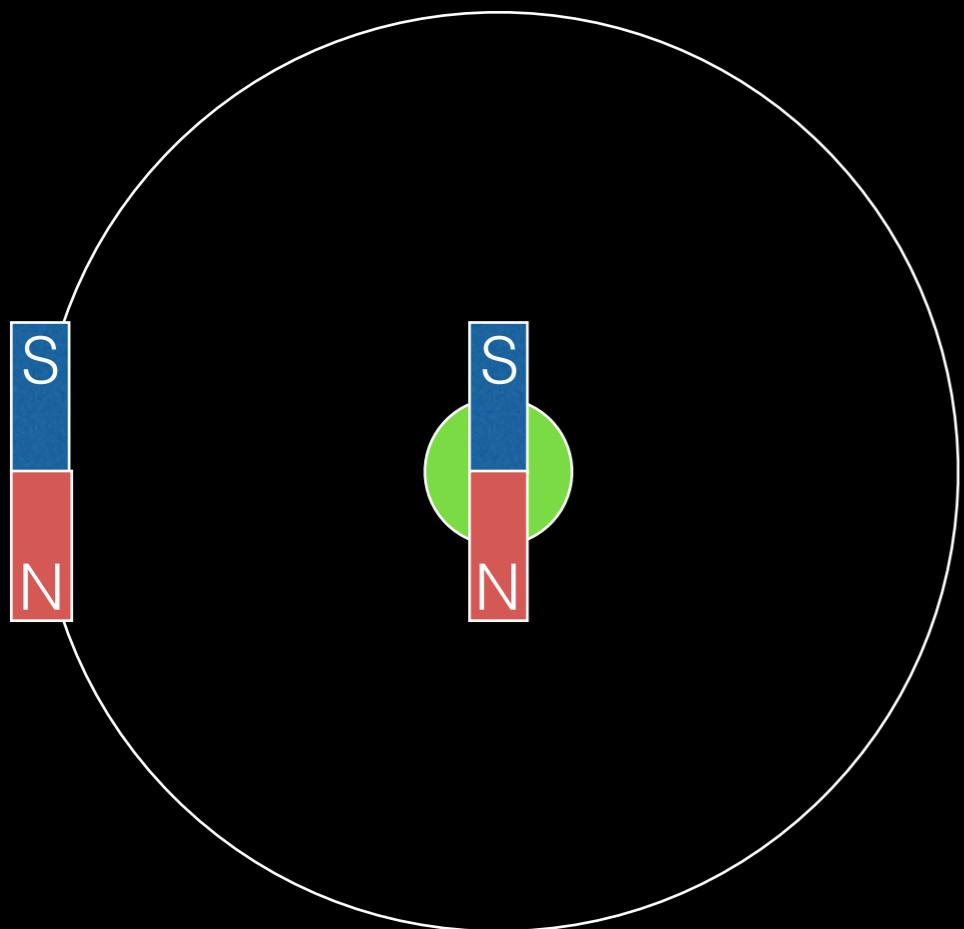
- A. d_x easy, d_y hard; v_x easy, v_y hard.
- B. d_x easy, d_y hard; v_x hard, v_y easy.
- C. d_x hard, d_y easy; v_x easy, v_y hard.
- D. d_x hard, d_y easy; v_x hard, v_y easy.



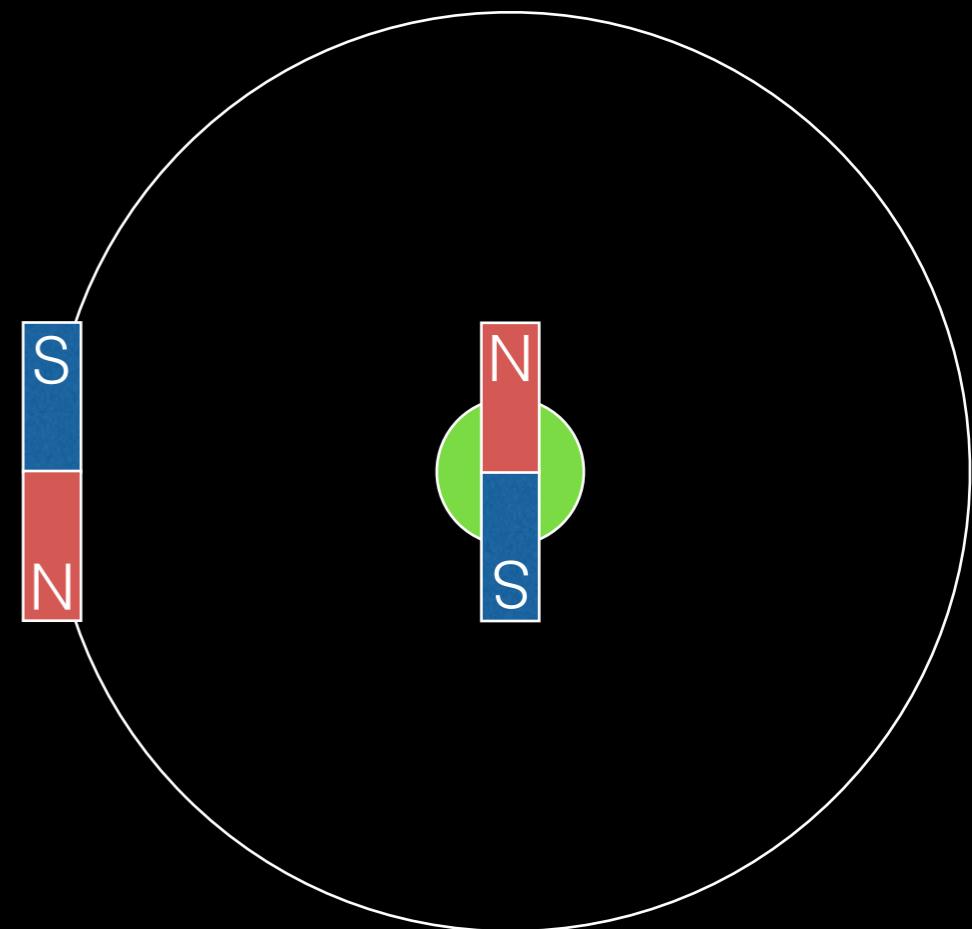
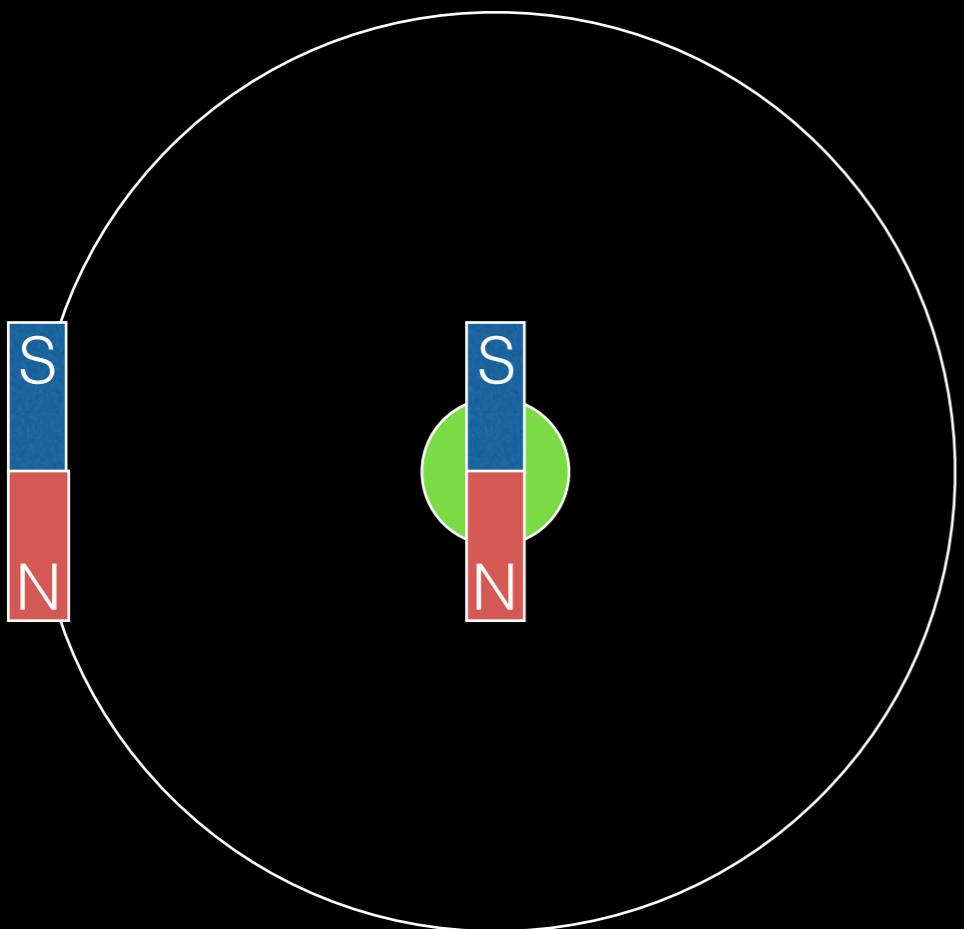
Hydrogen atoms emit radio waves with 21cm wavelengths



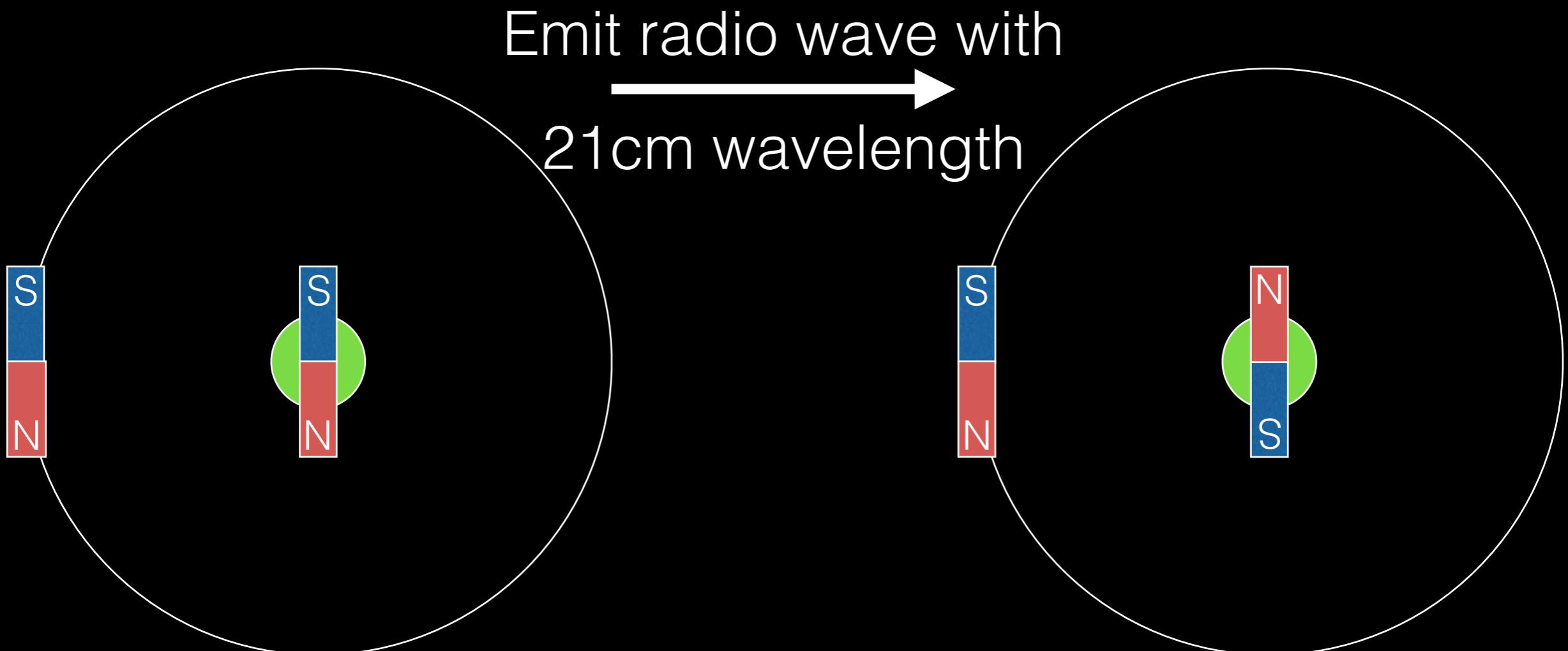
Hydrogen atoms emit radio waves with 21cm wavelengths



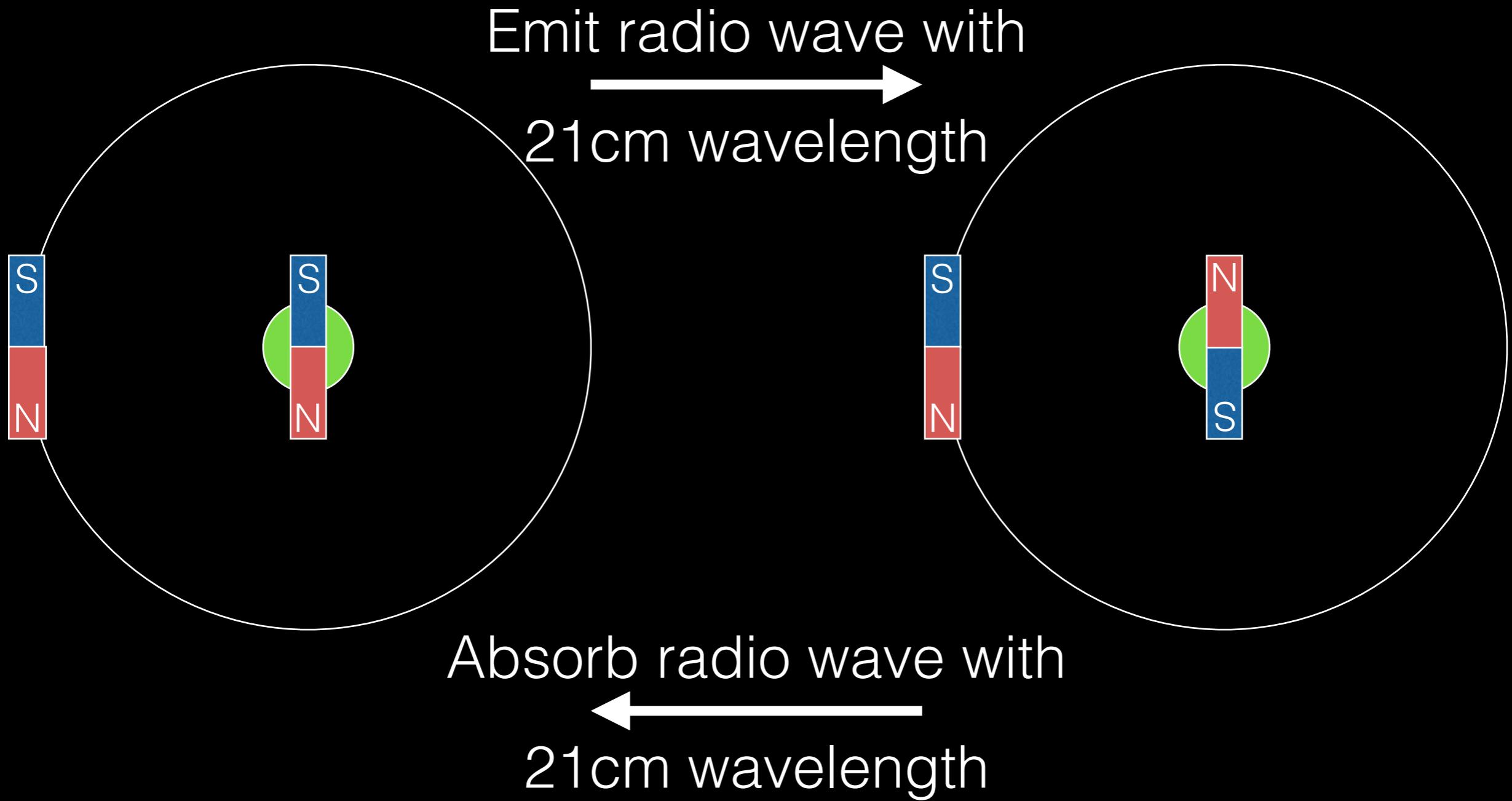
Hydrogen atoms emit radio waves with 21cm wavelengths

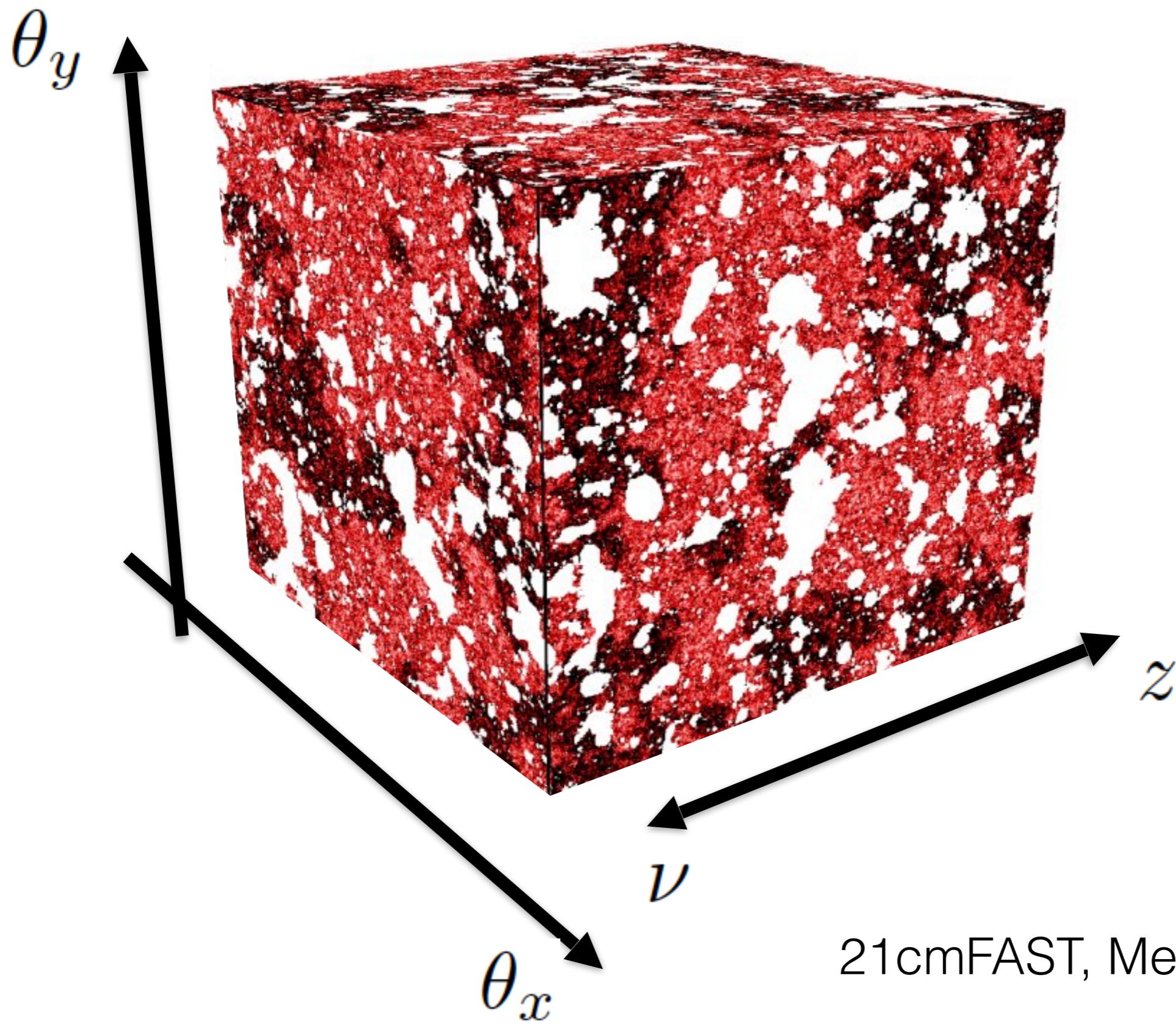


Hydrogen atoms emit radio waves with 21cm wavelengths



Hydrogen atoms emit radio waves with 21cm wavelengths





21cmFAST, Mesinger et al.

The night sky is a time
machine

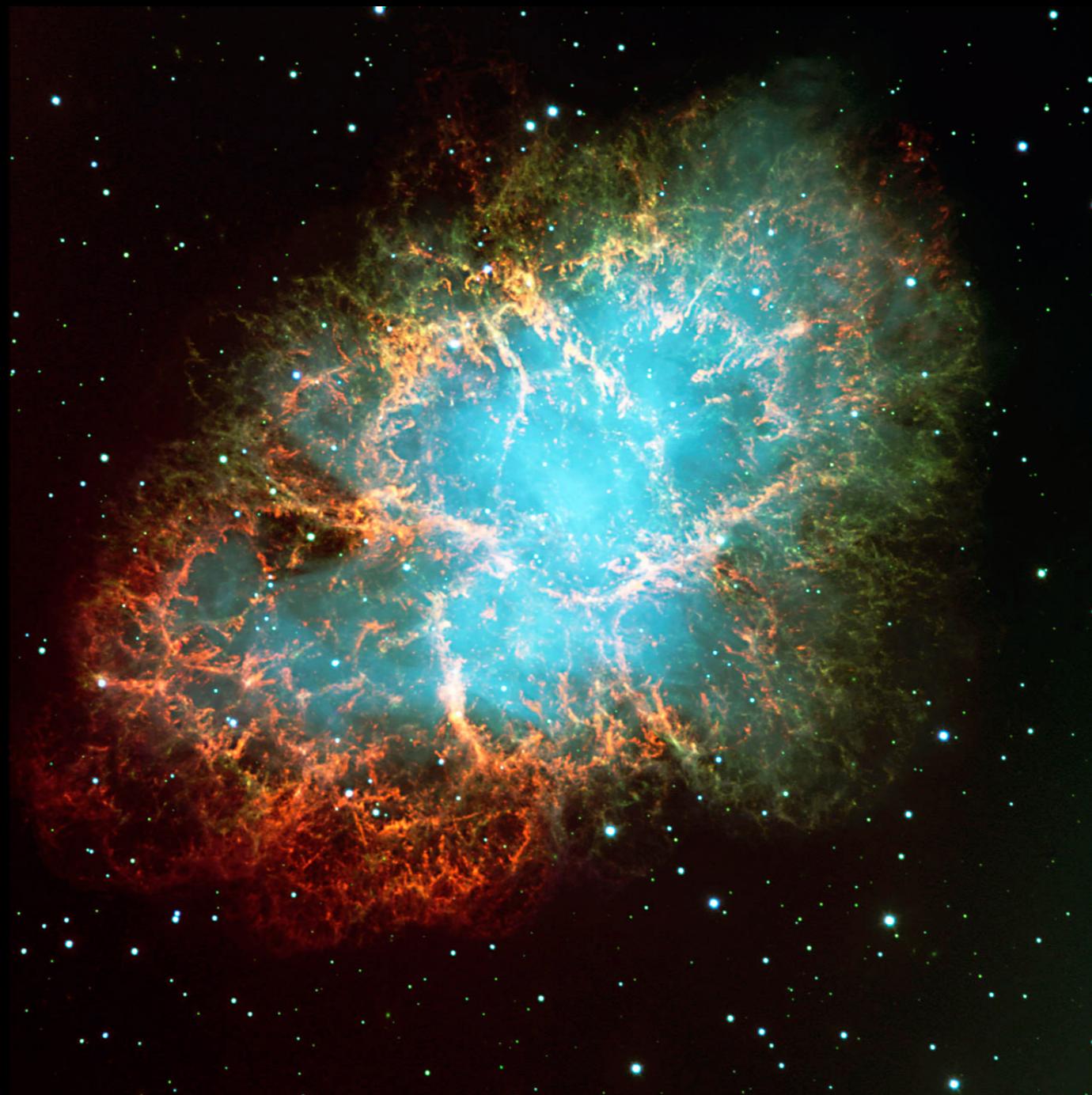
The night sky is a time machine

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

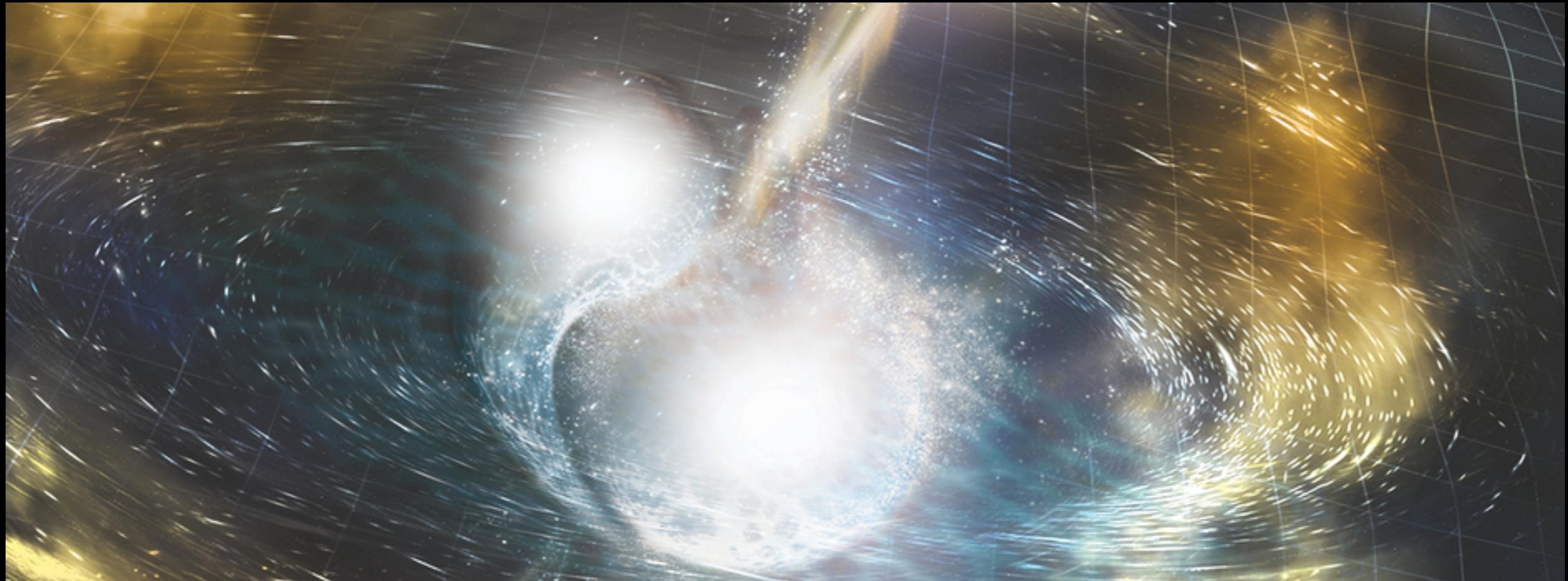
The night sky is a time machine

- 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!



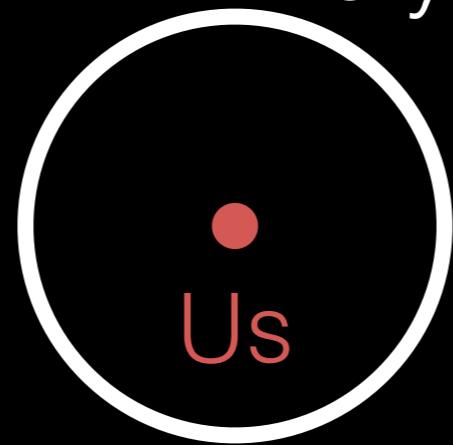
We see distant galaxies not as they are today, but they were billions of years ago



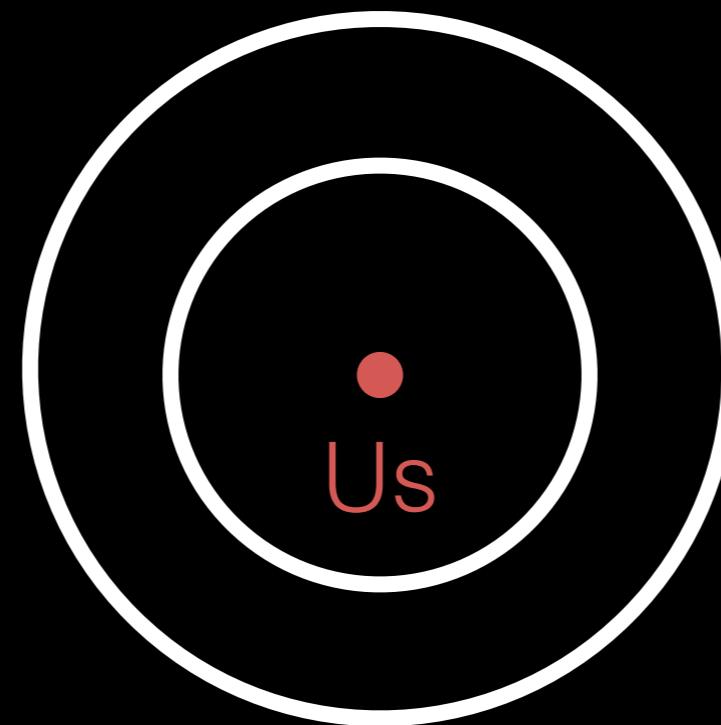
The farther away we look,
the farther back in time
we see

•
Us

10 years ago



20 years ago



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

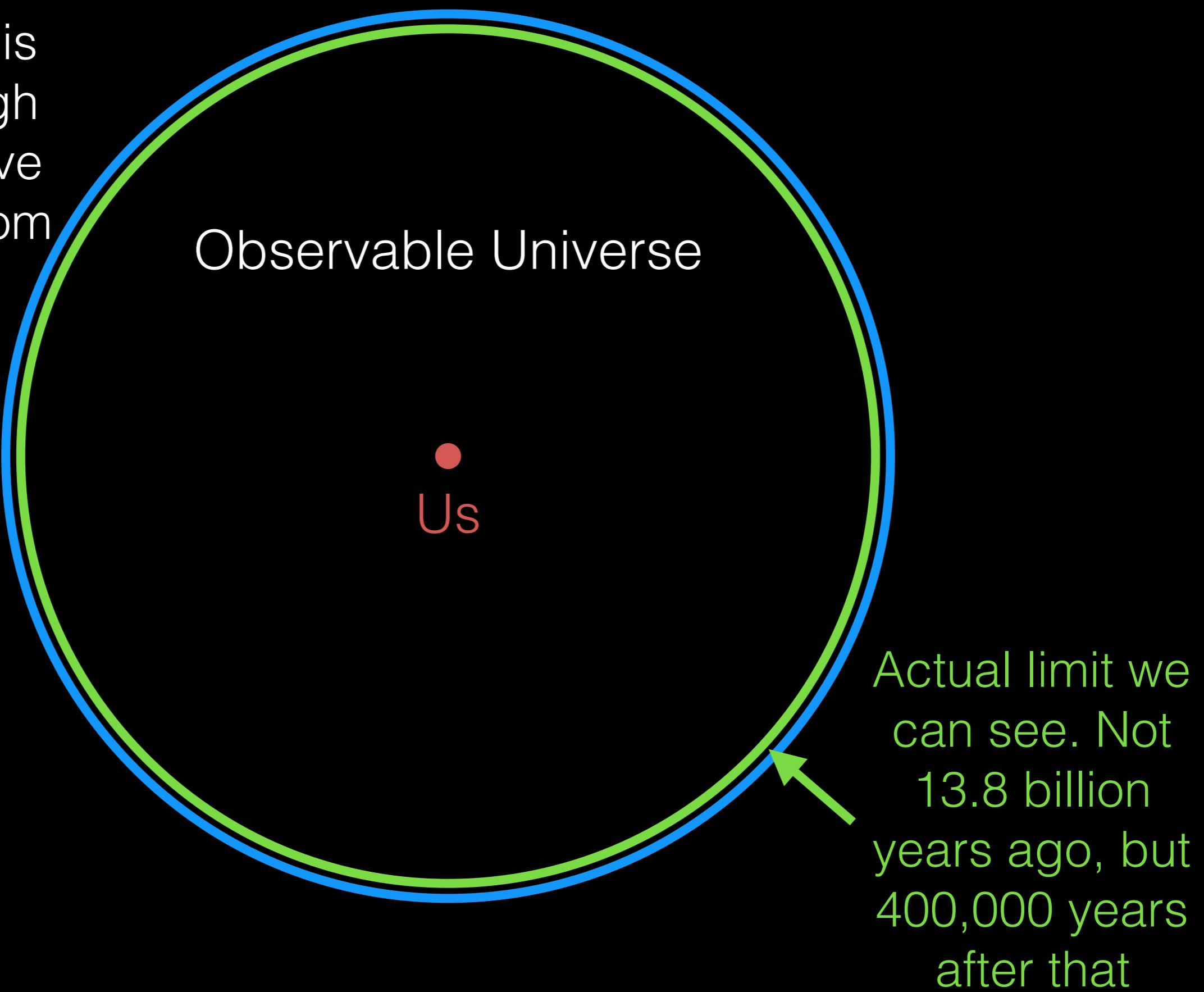
Unobservable
Universe:
our Universe is
not old enough
for light to have
reached us from
out here

13.8 billion years ago

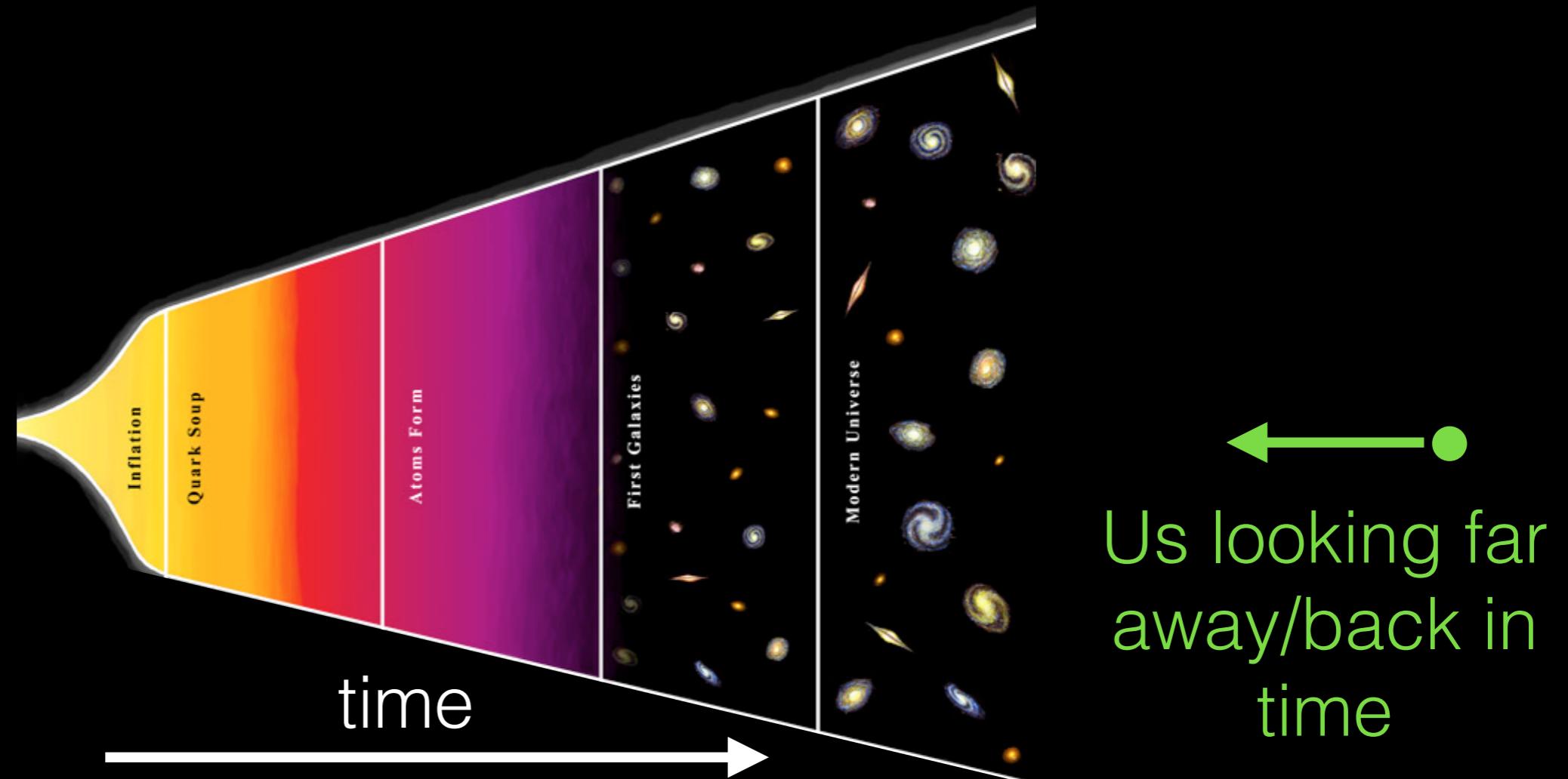
Observable Universe



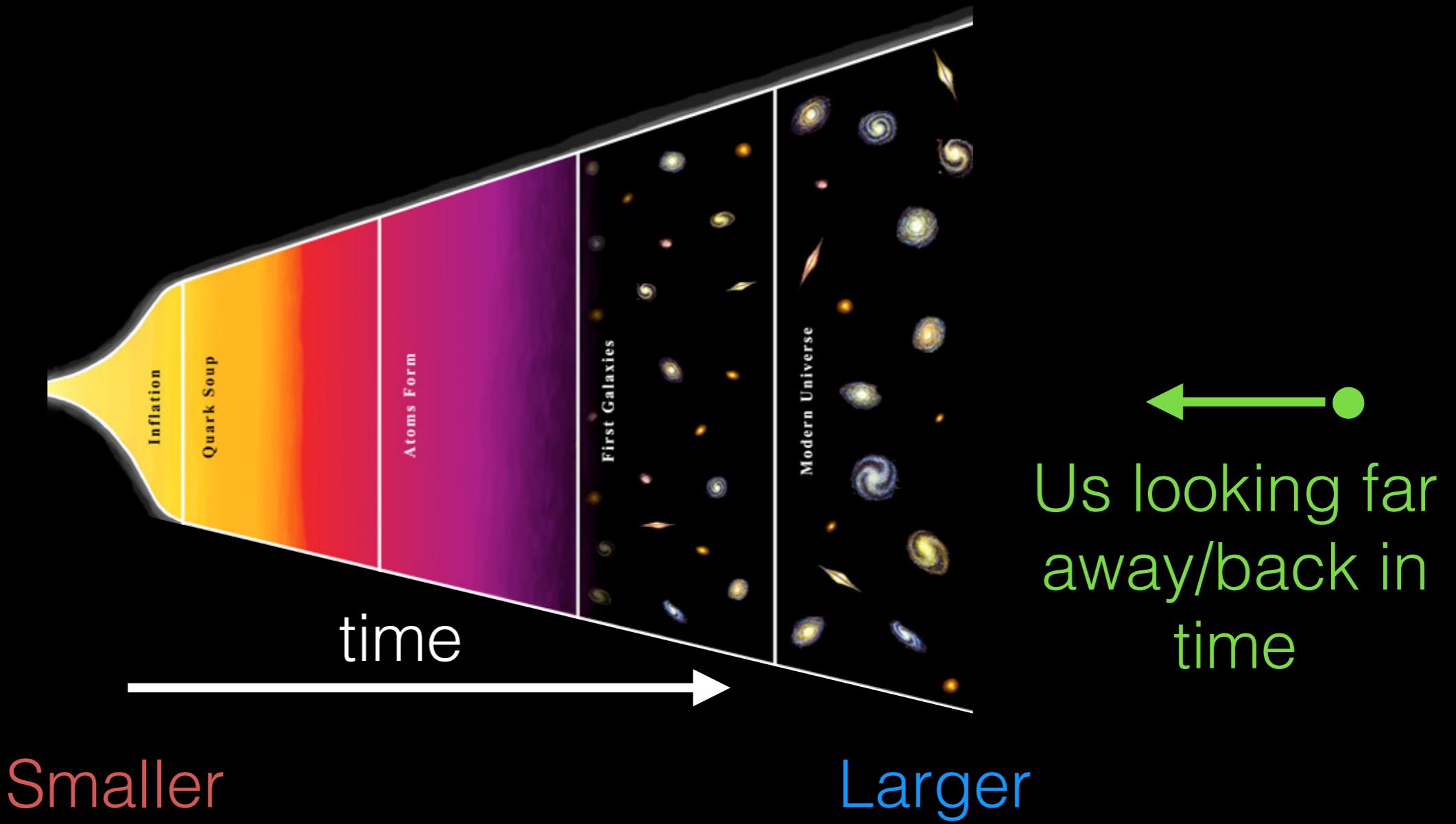
Unobservable
Universe:
our Universe is
not old enough
for light to have
reached us from
out here



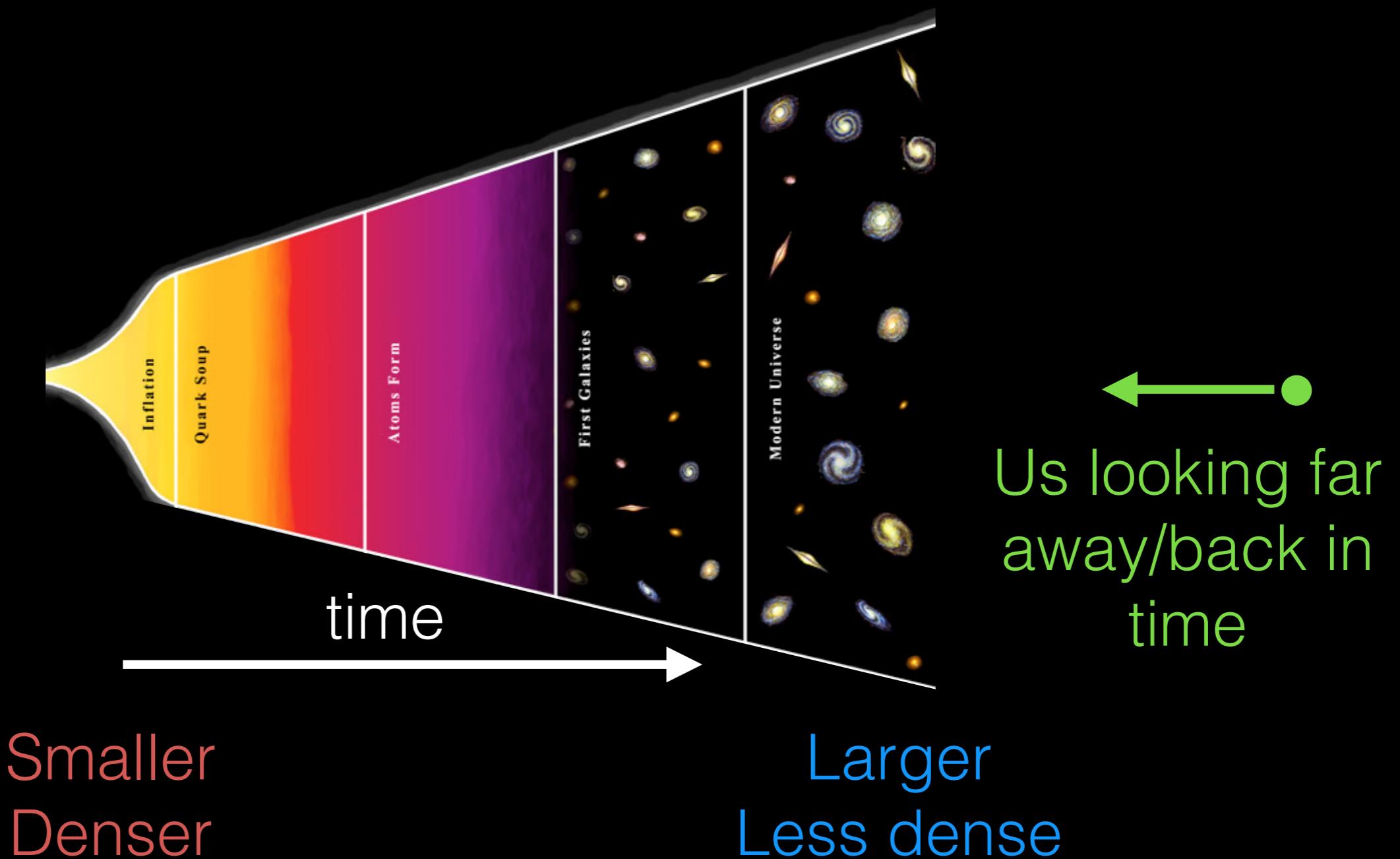
Our Universe is expanding, so as we look back in time, we see a smaller, denser, hotter Universe



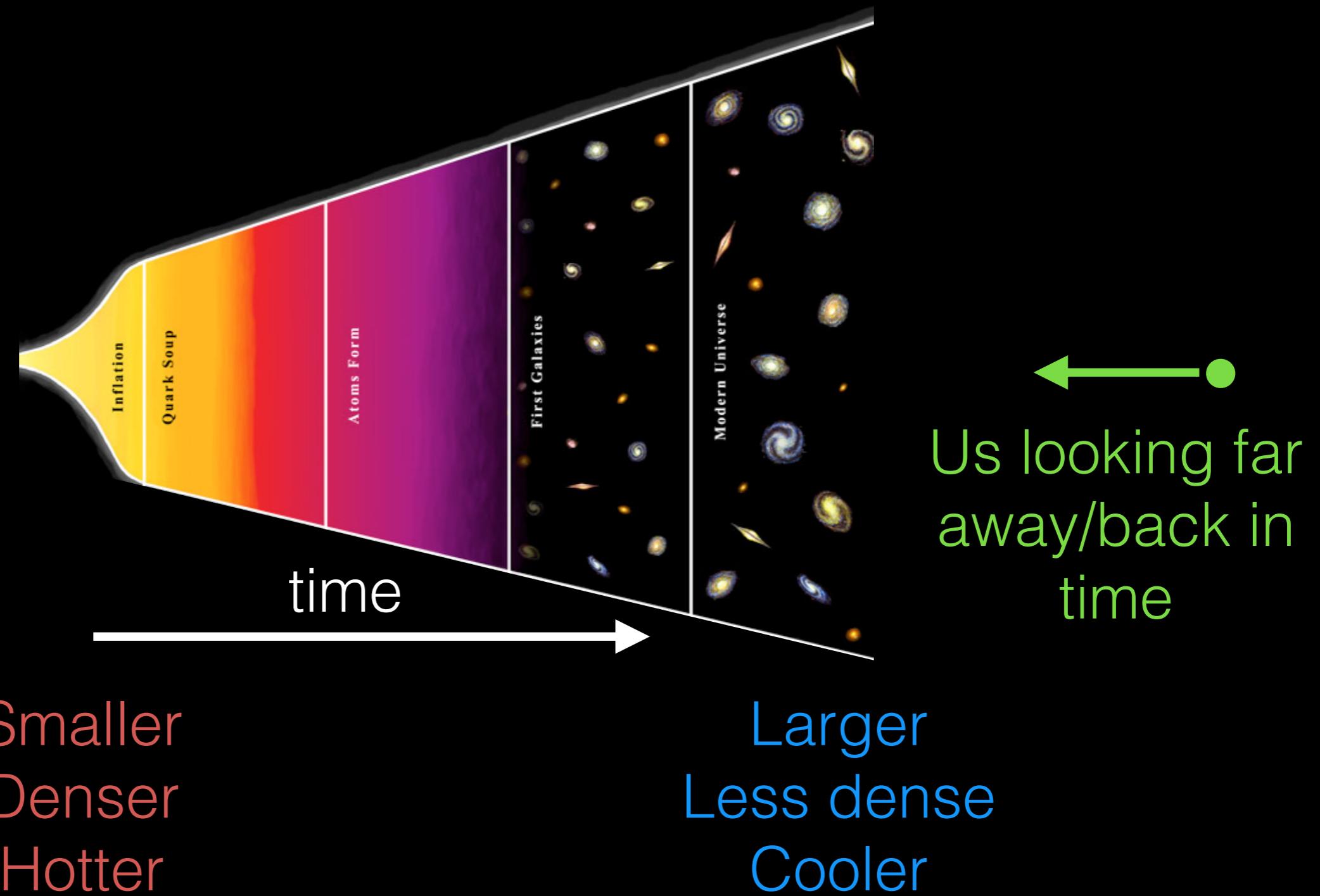
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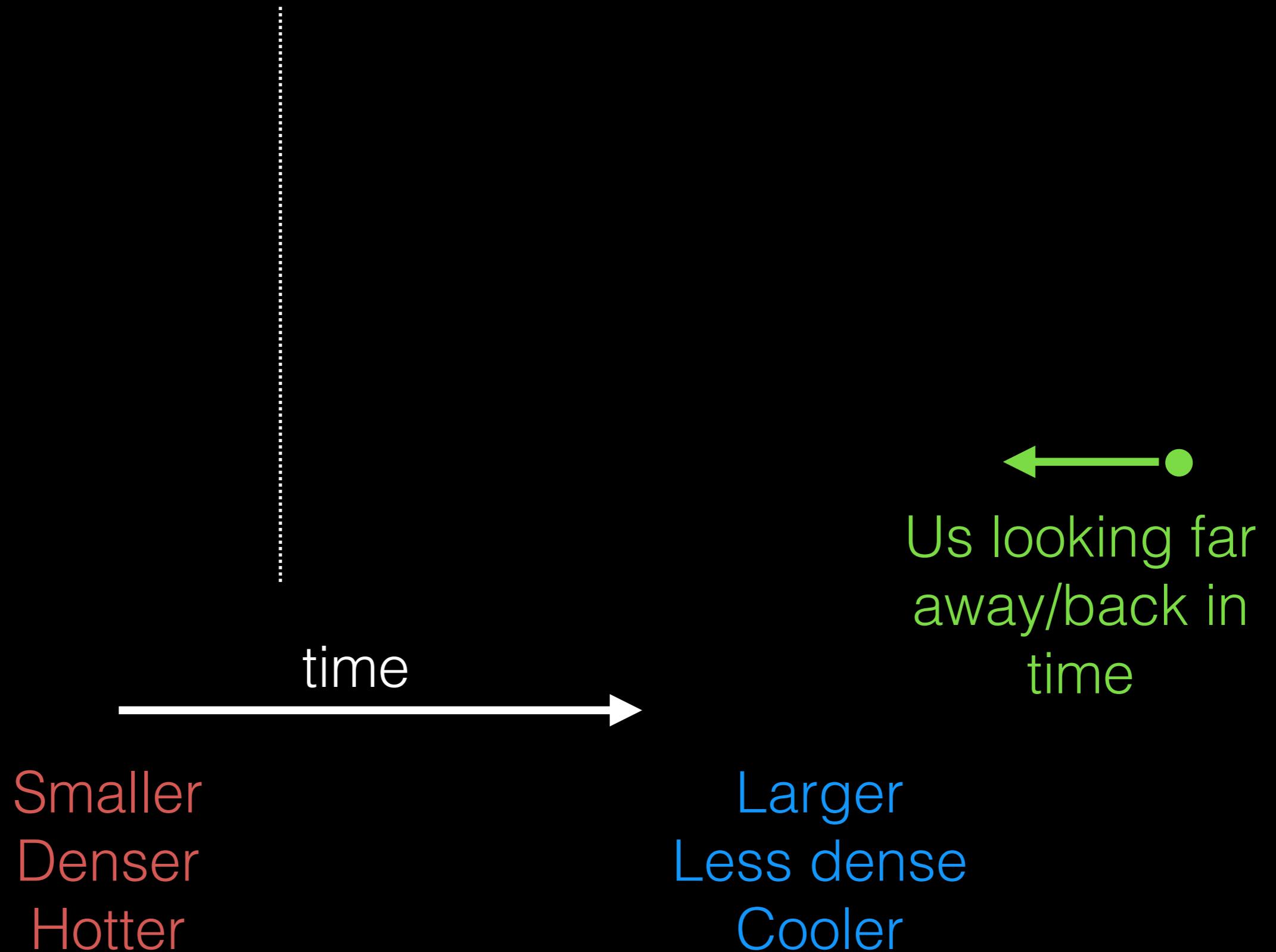


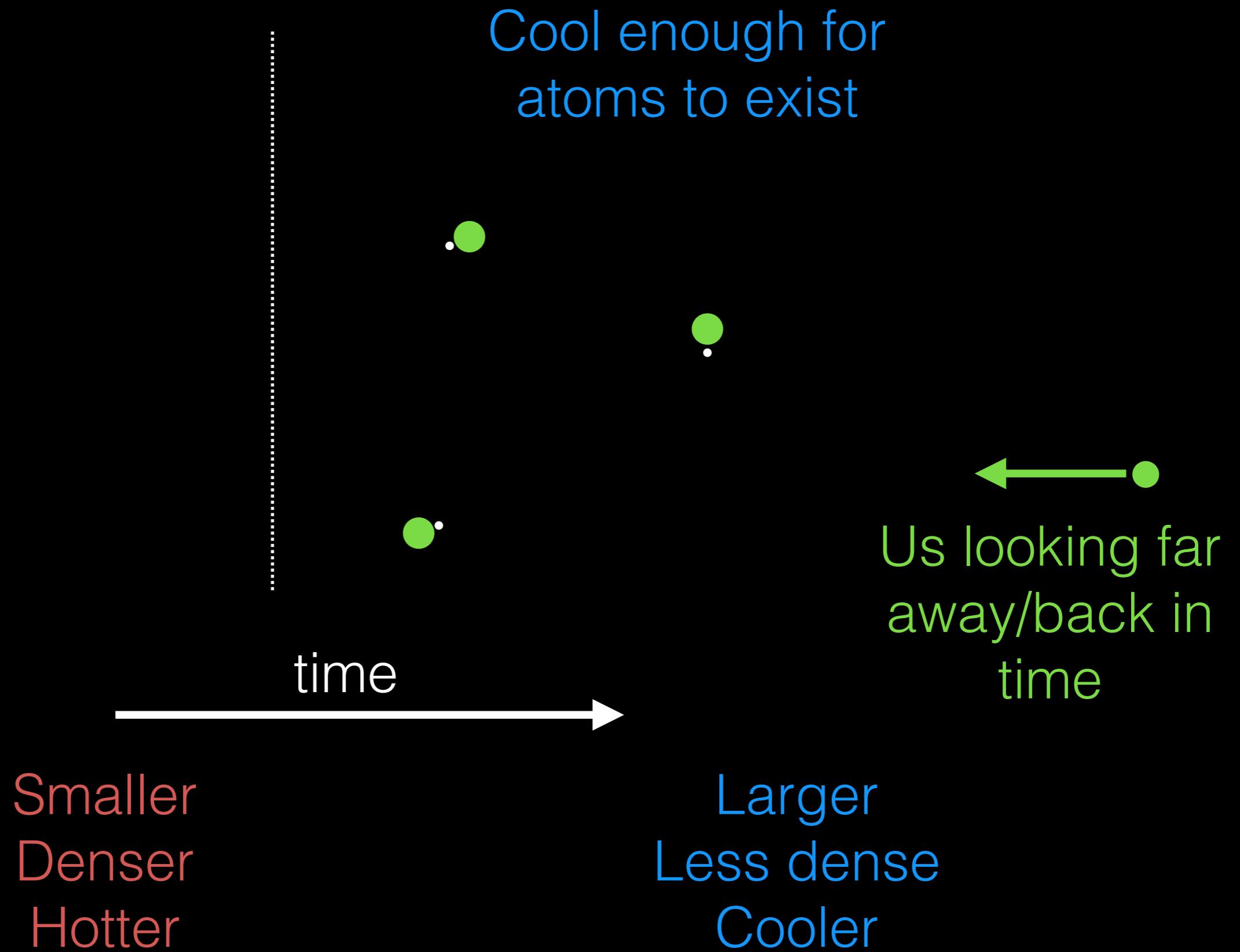
Our Universe is expanding, so as we look back in time, we see a smaller, denser, hotter Universe



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

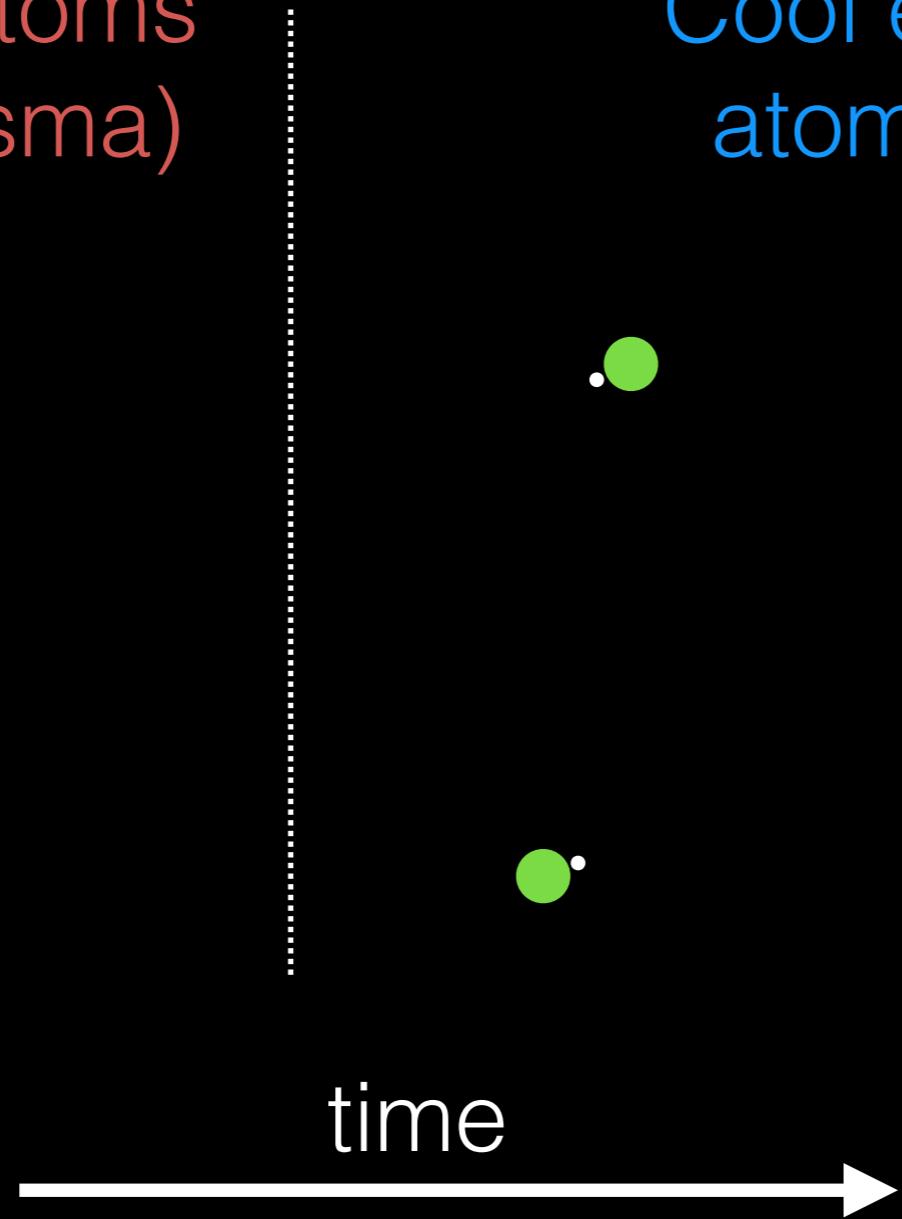






Too hot for atoms
to form (plasma)

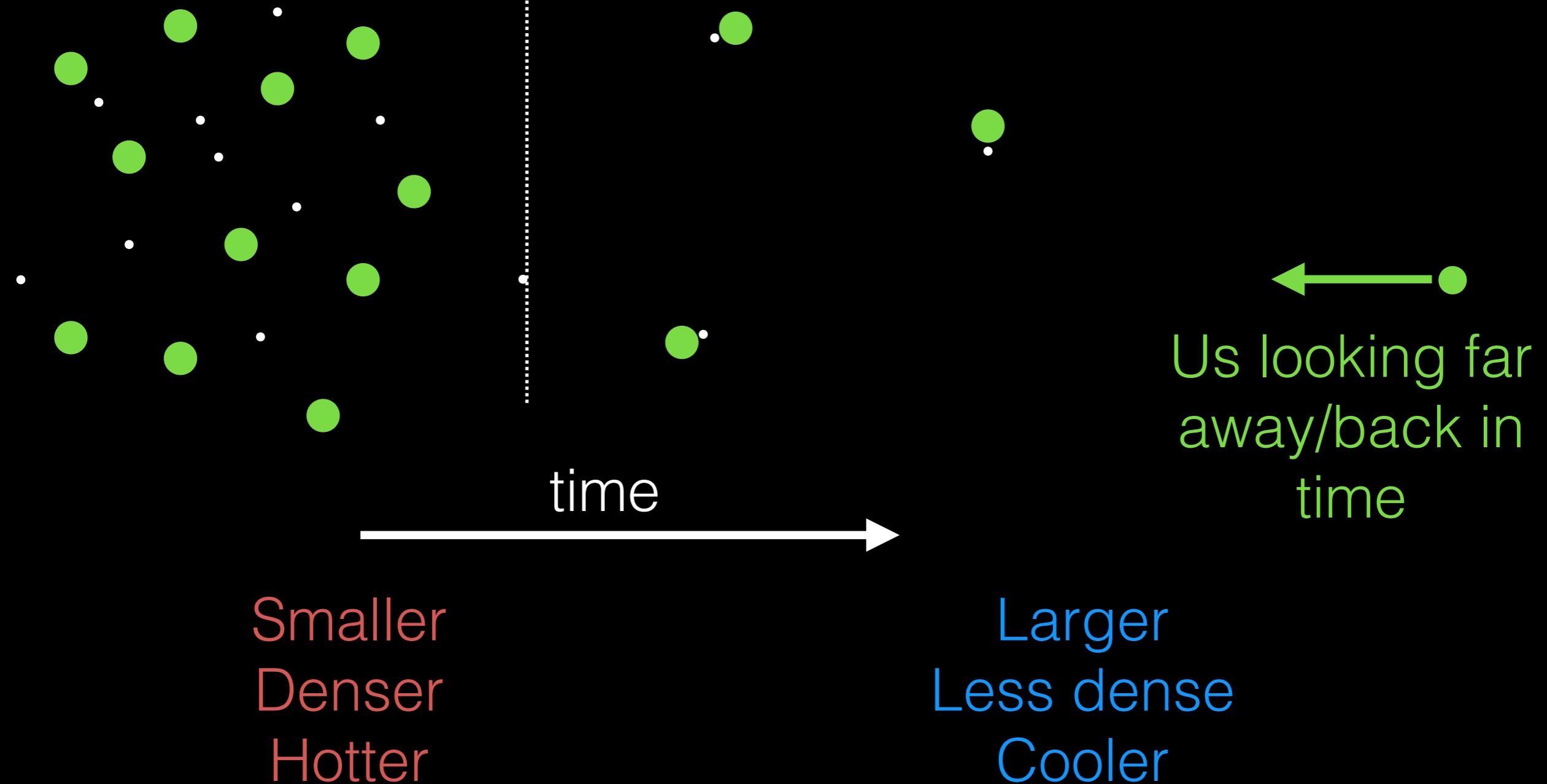
Cool enough for
atoms to exist



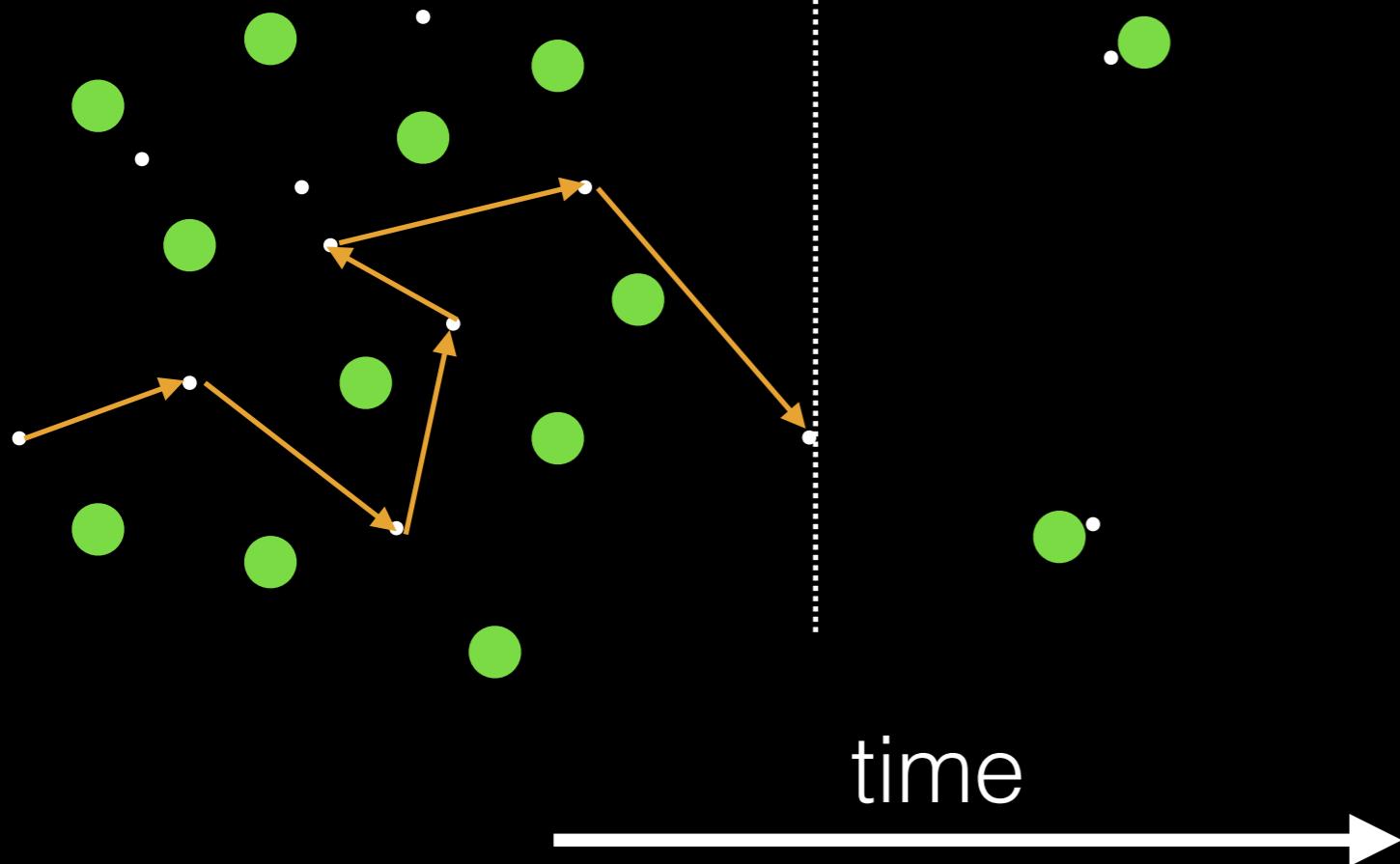
Us looking far
away/back in
time

Too hot for atoms
to form (plasma)

Cool enough for
atoms to exist



Too hot for atoms
to form (plasma)
Not transparent



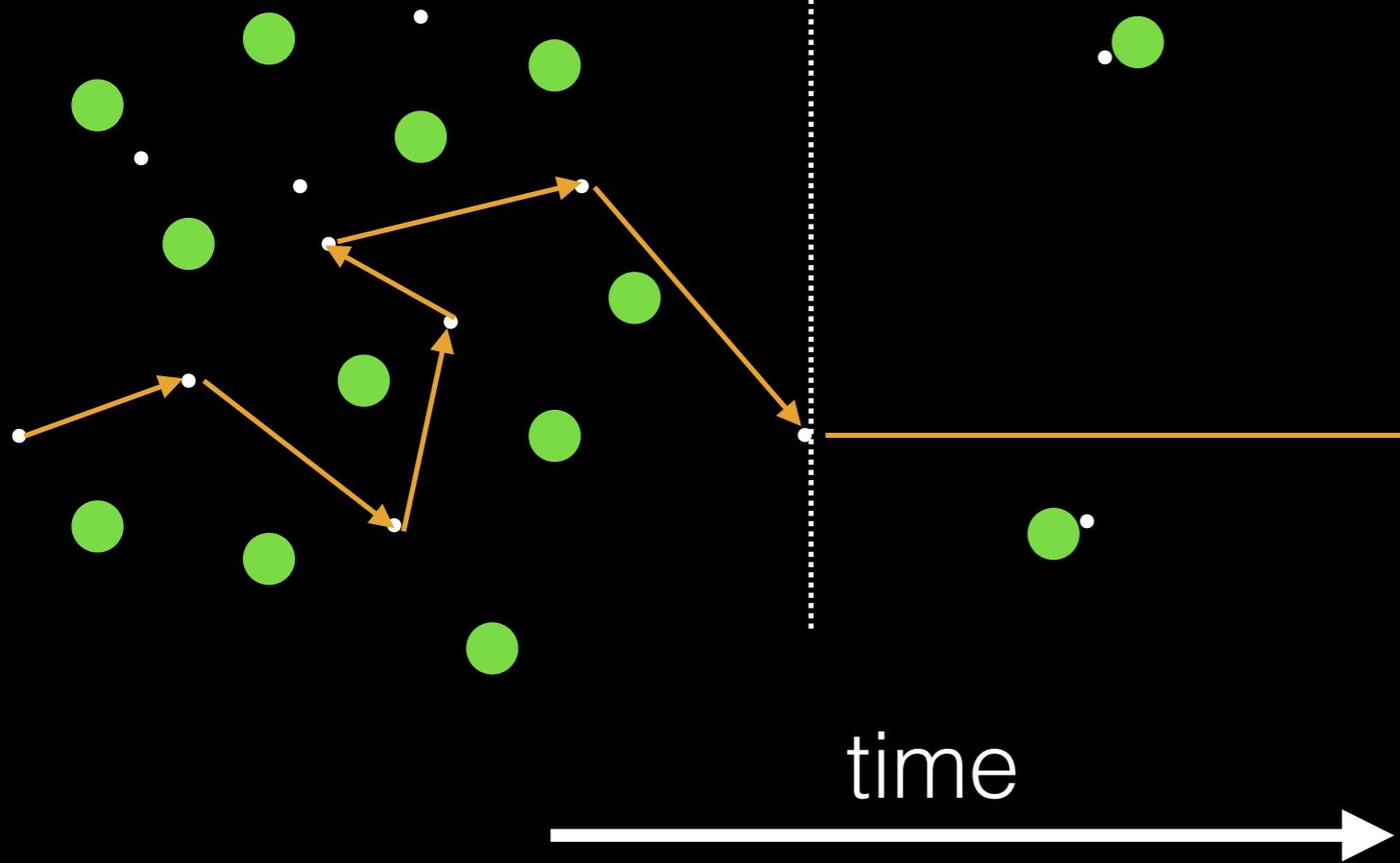
Smaller
Denser
Hotter

Cool enough for
atoms to exist

Larger
Less dense
Cooler

Us looking far
away/back in
time

Too hot for atoms
to form (plasma)
Not transparent

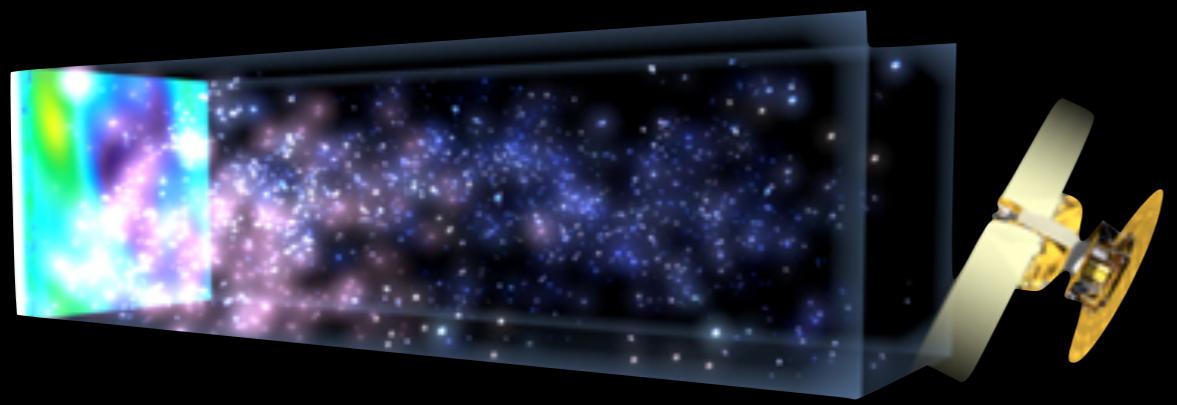


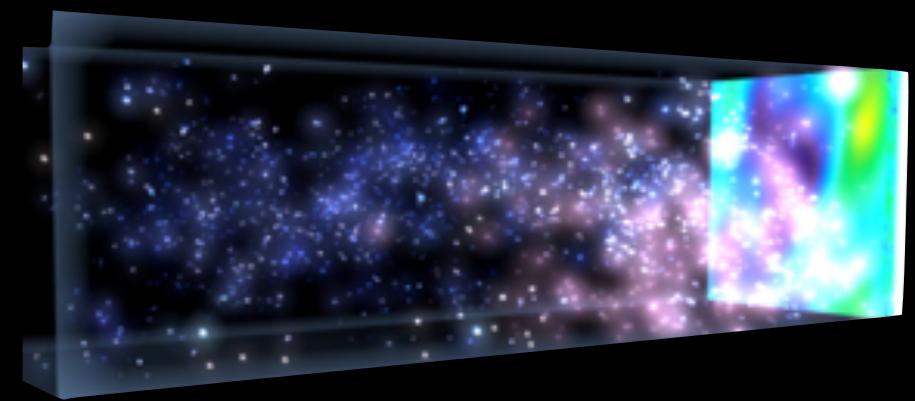
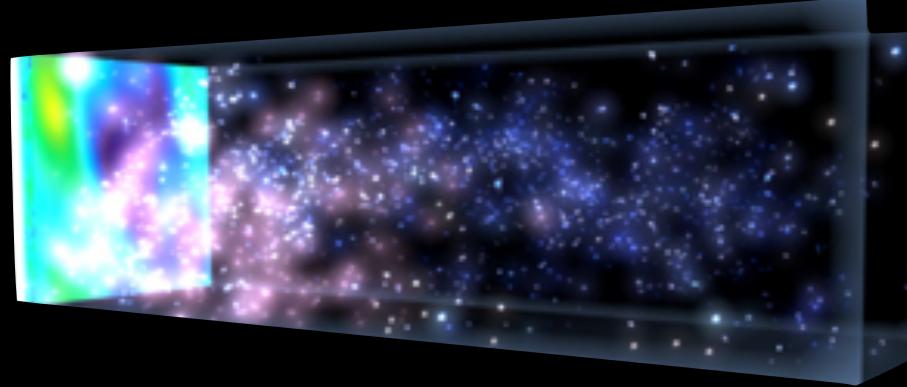
Smaller
Denser
Hotter

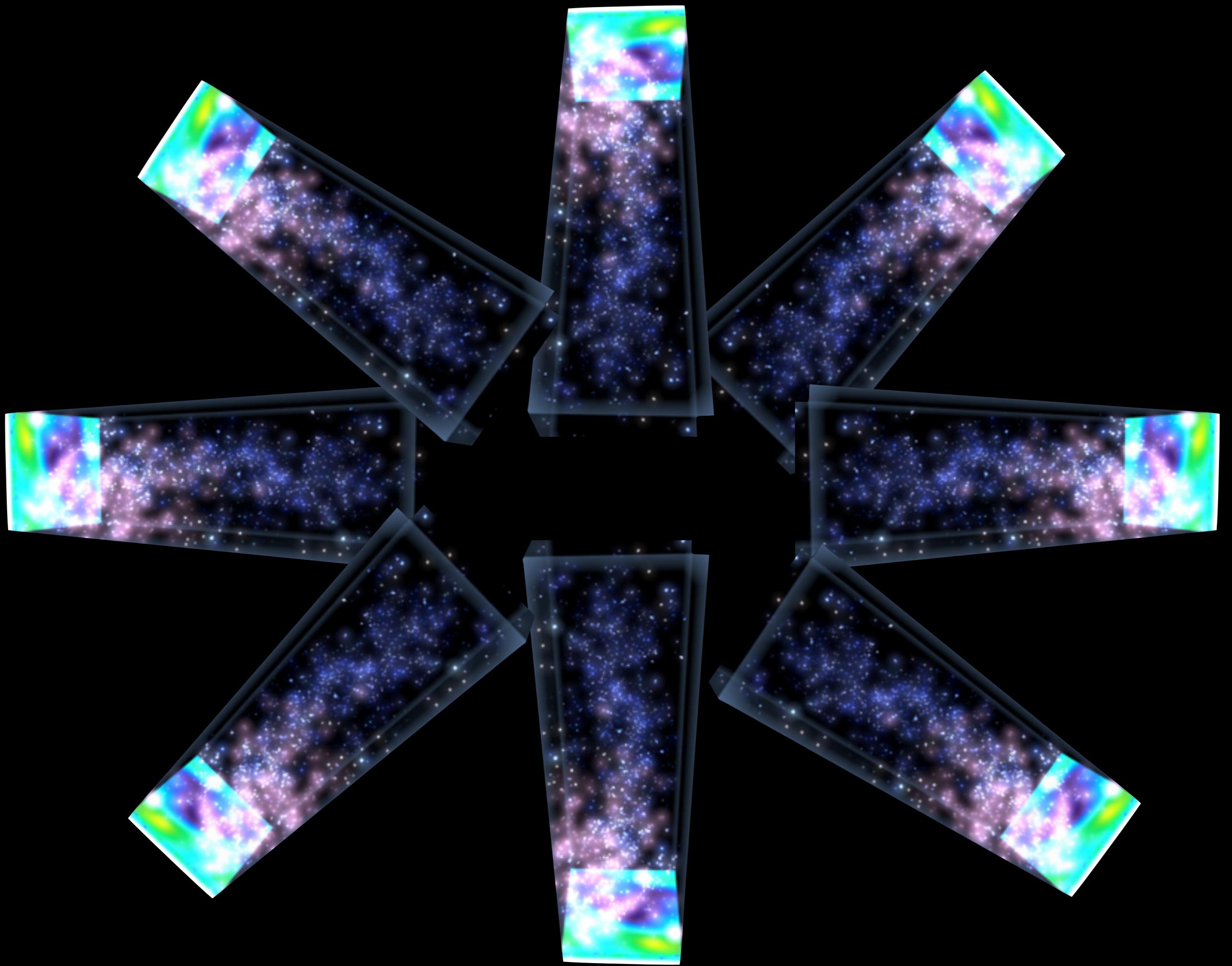
Cool enough for
atoms to exist
Transparent

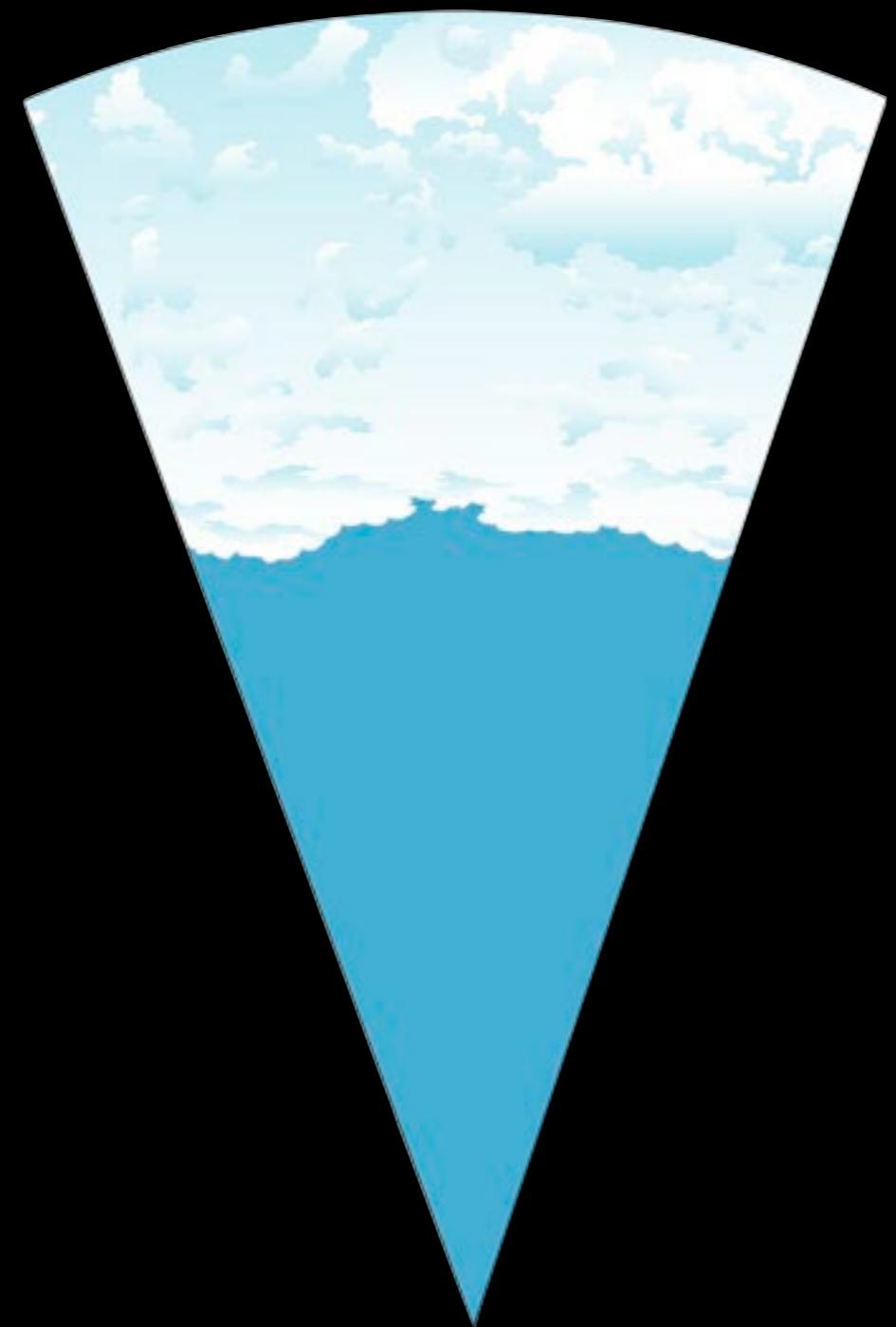
Larger
Less dense
Cooler

Us looking far
away/back in
time

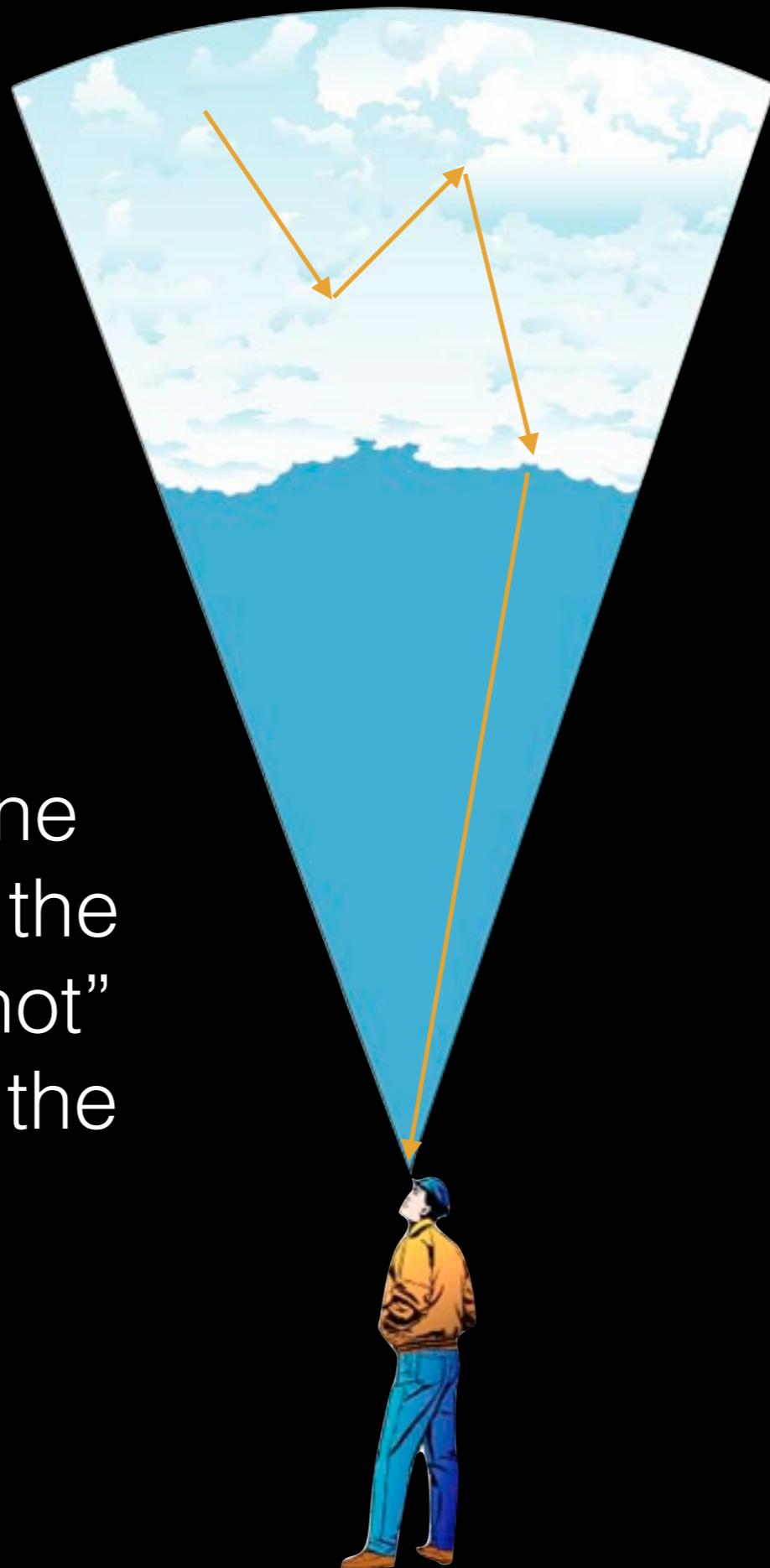




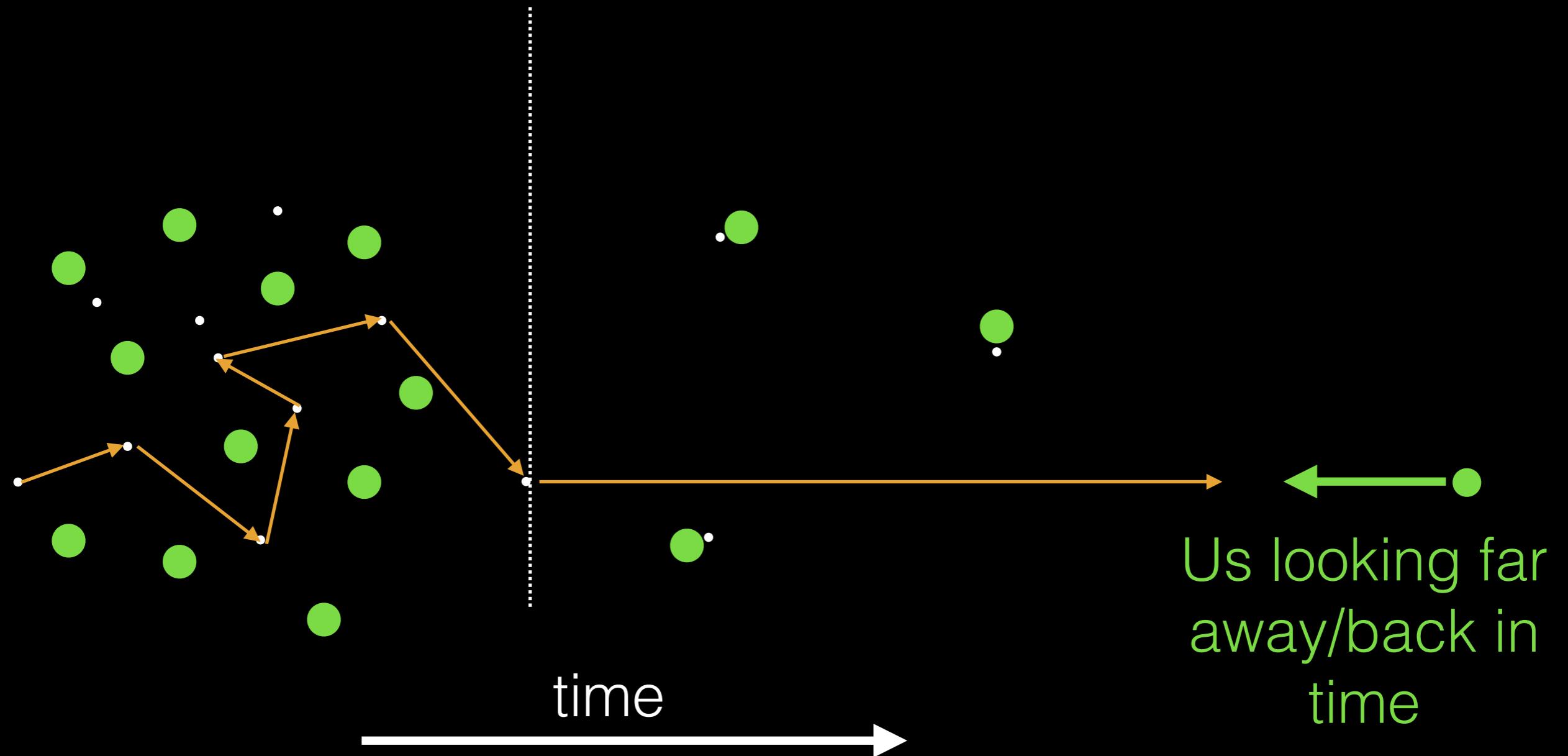




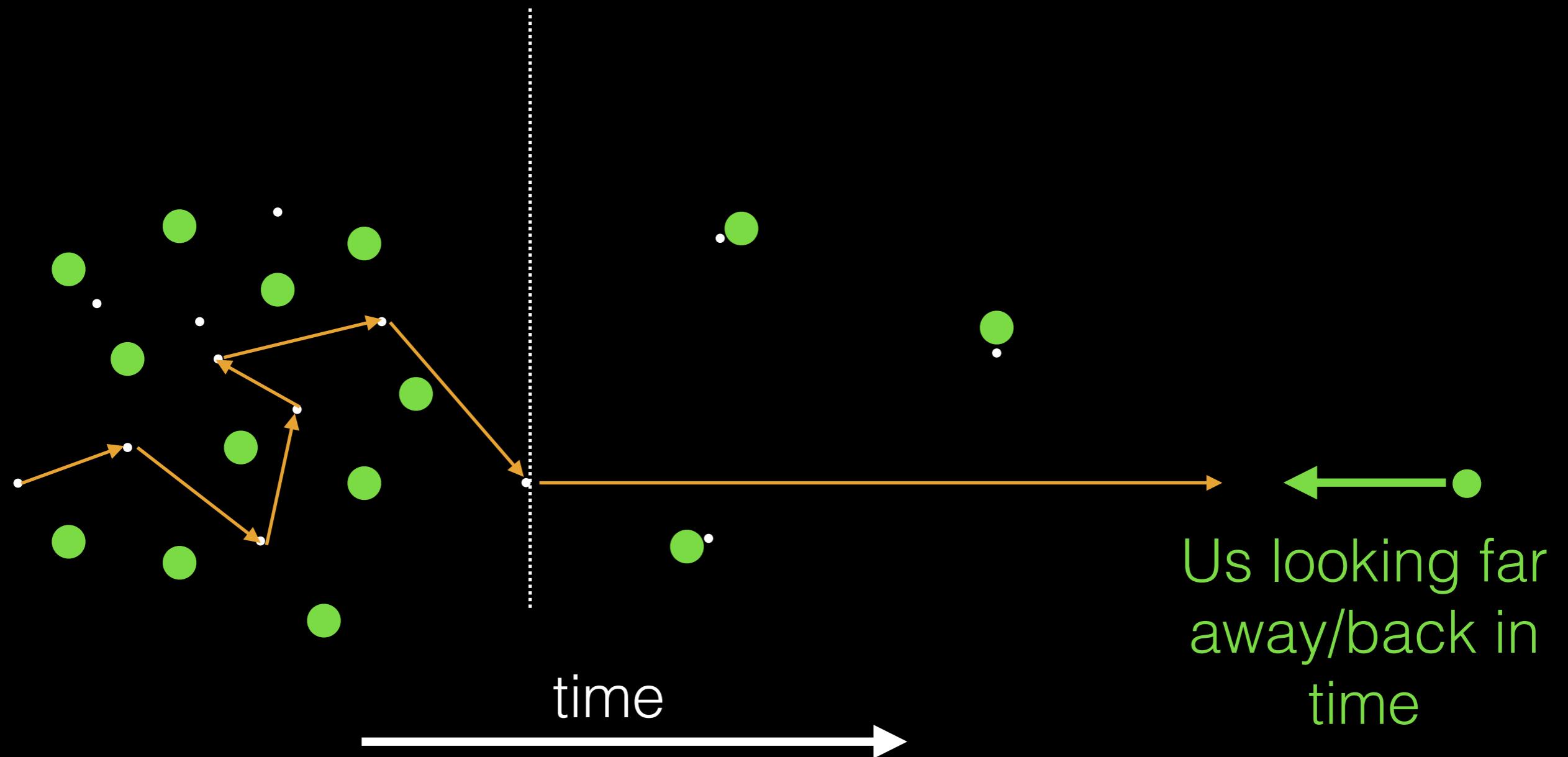
We see an outline
of the surface of the
cloud, a “snapshot”
of the exterior of the
cloud



400,000 years

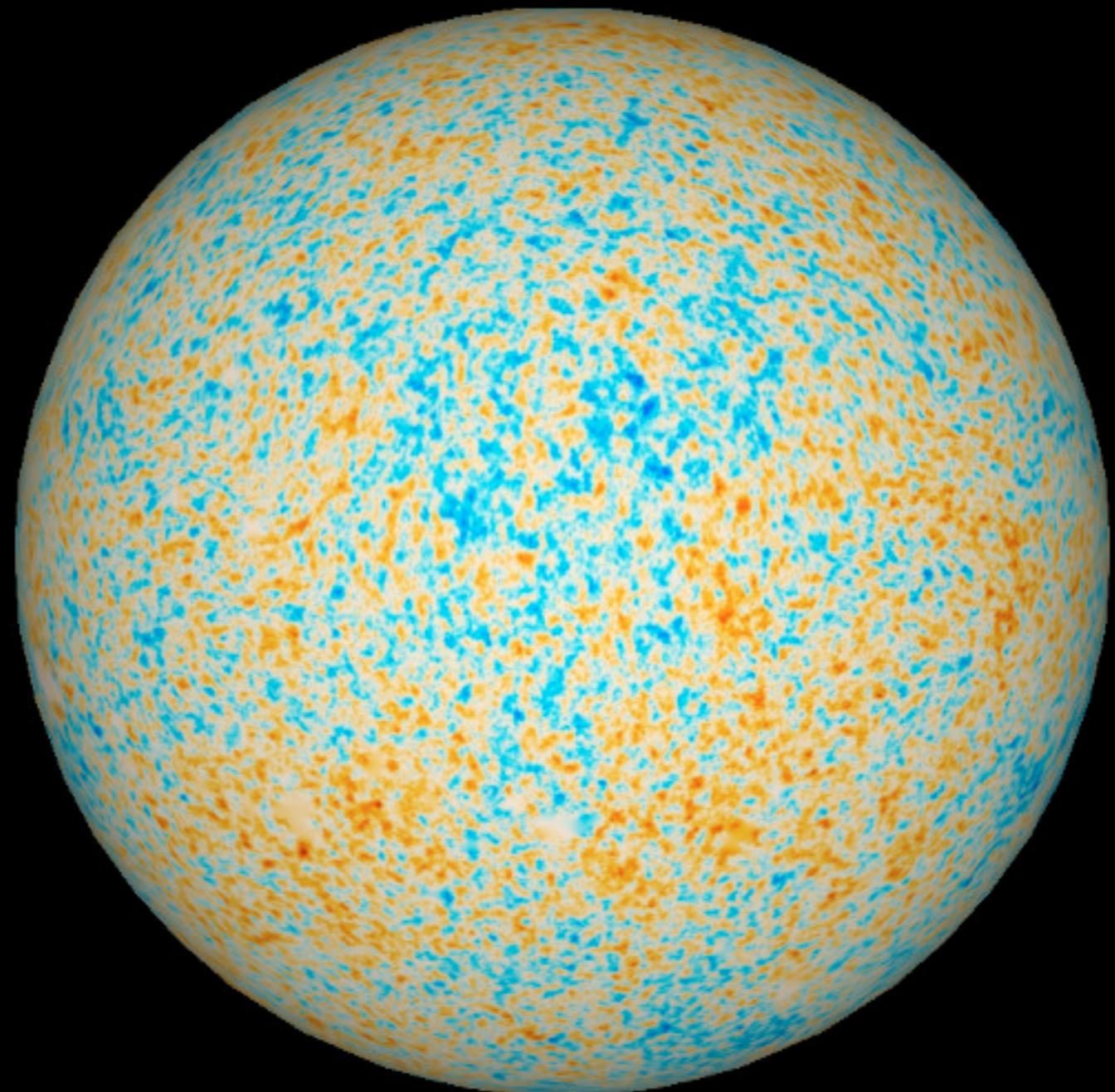


400,000 years



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

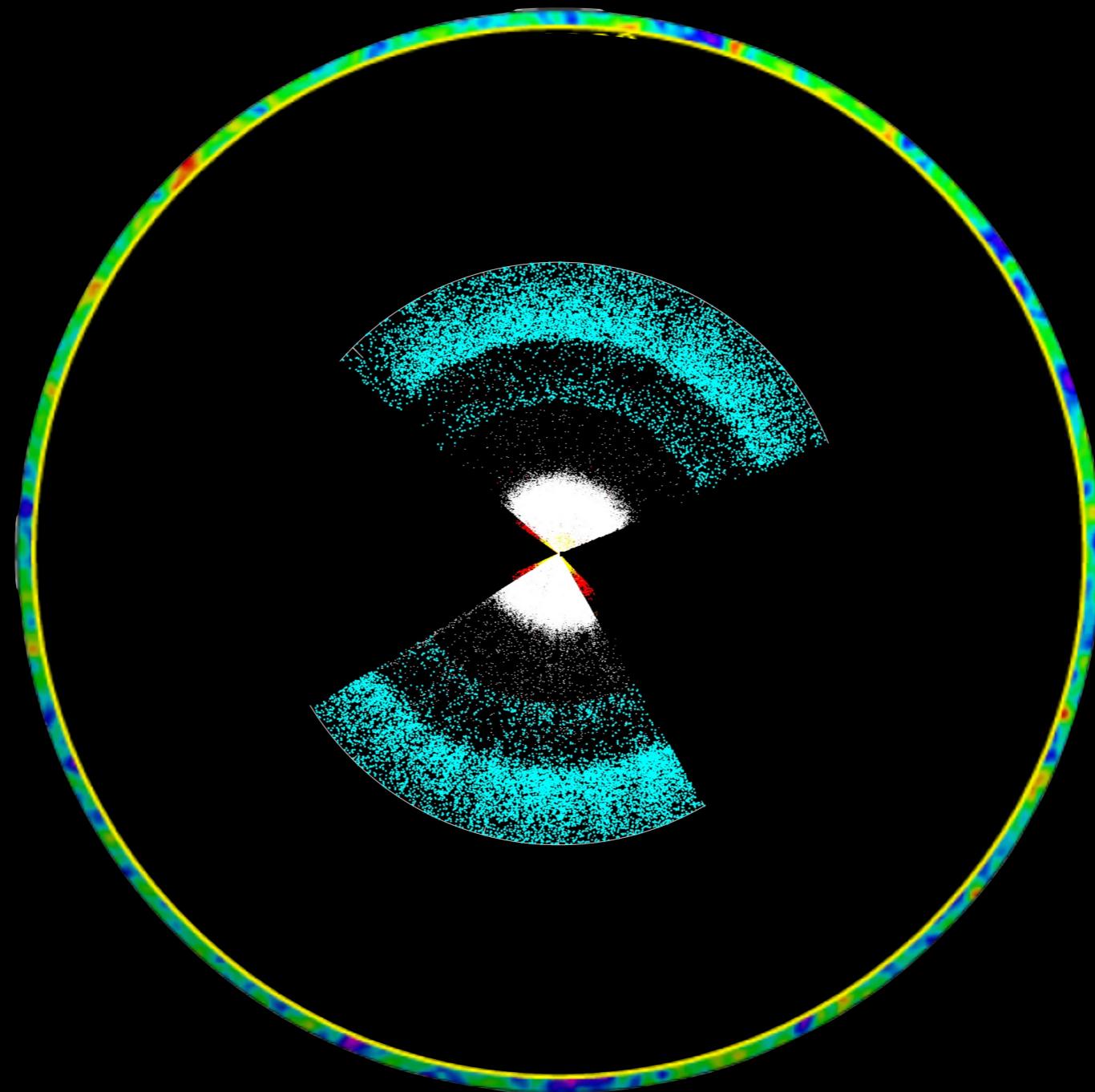
The Cosmic Microwave Background provides a snapshot of our baby Universe



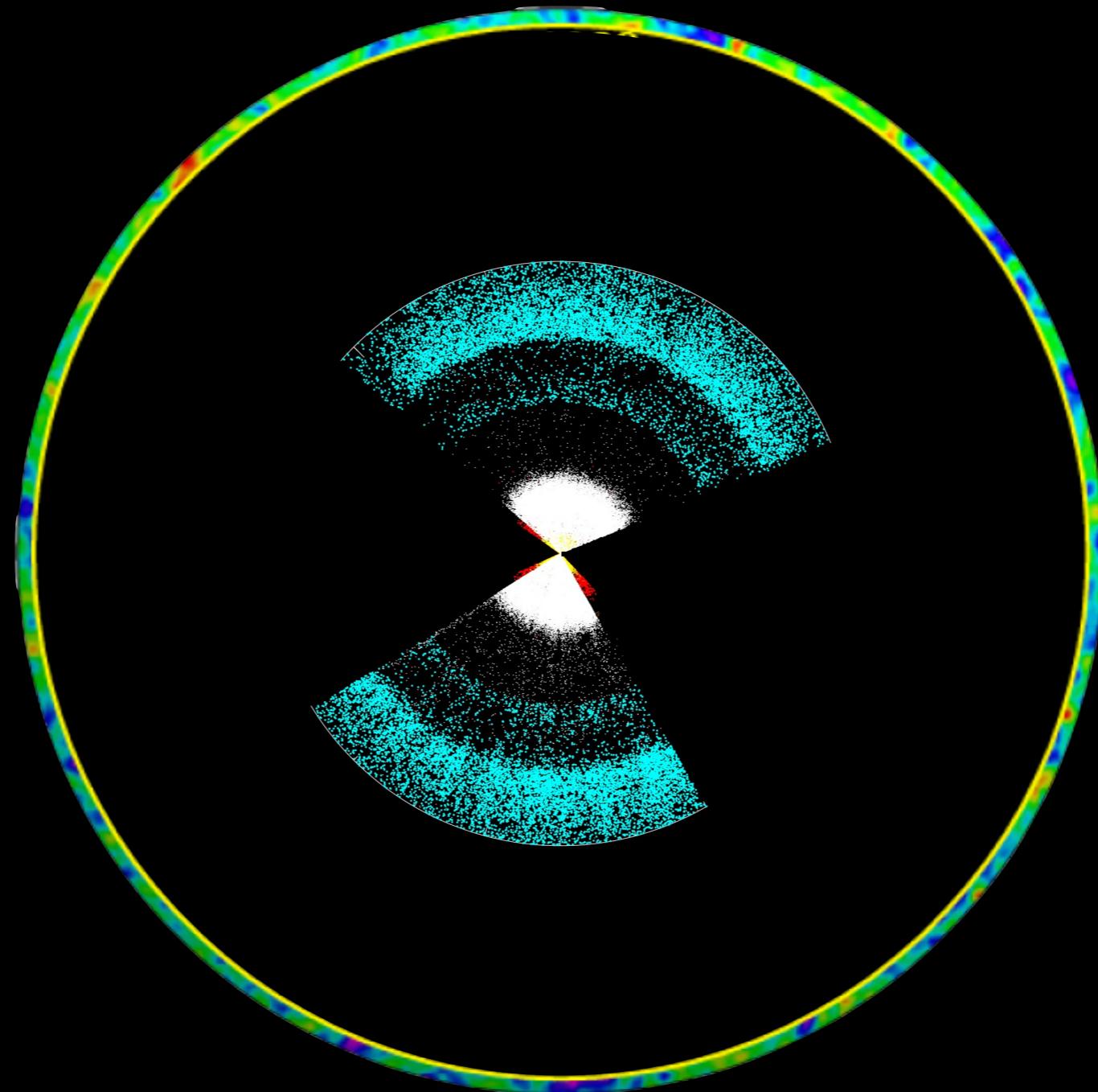
Alvarez et al. (2009)

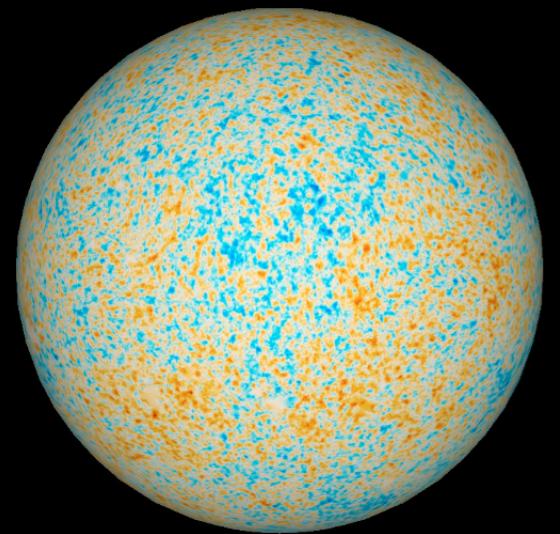
What about the real
thing?

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

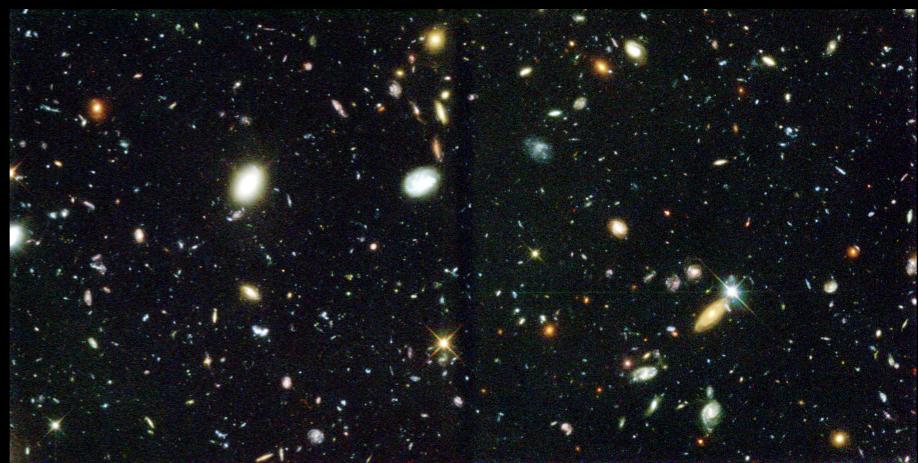




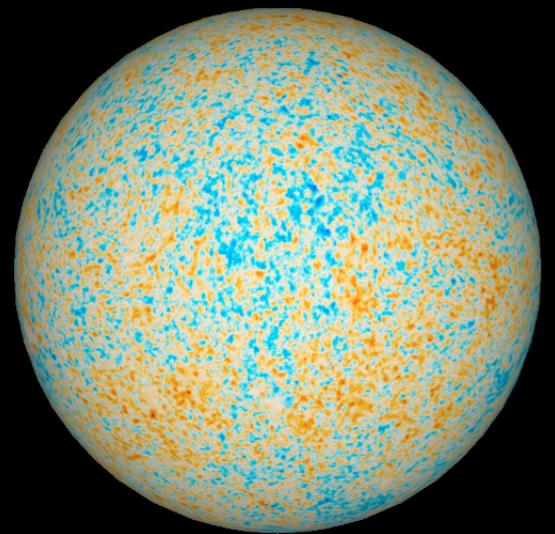
Baby Universe

?

Time

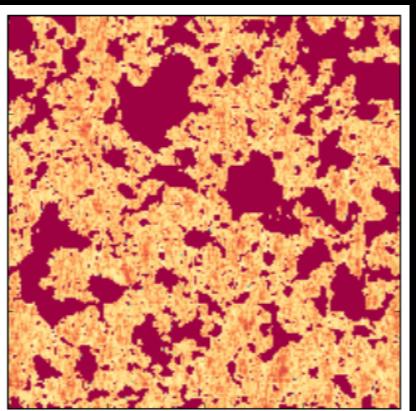


Mature Universe

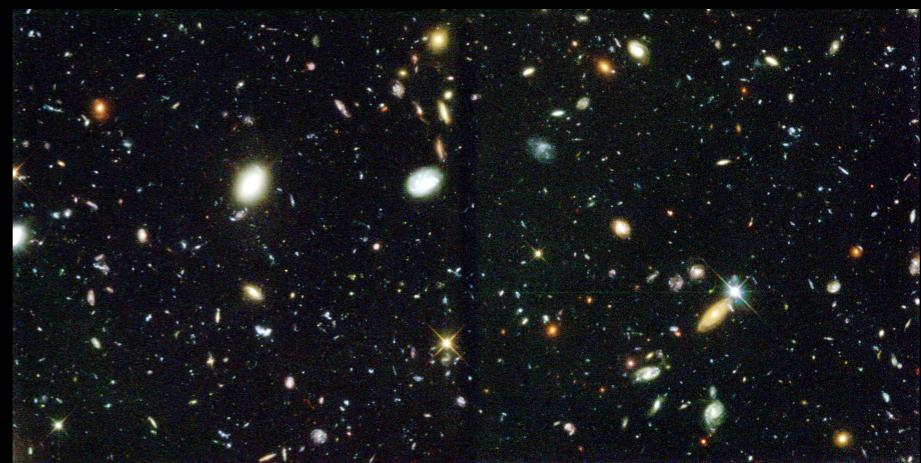


Baby Universe

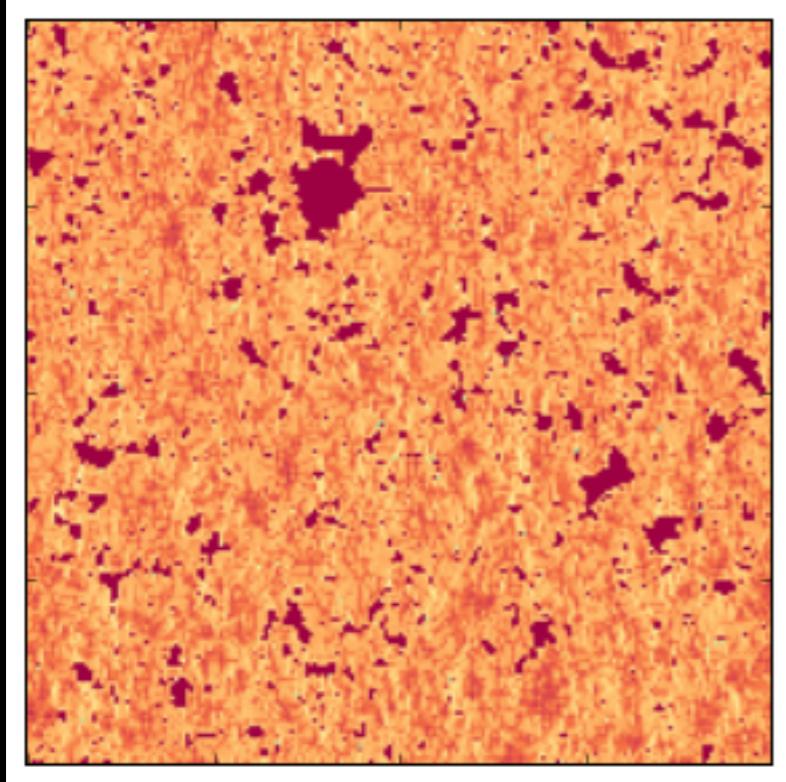
Reionization?



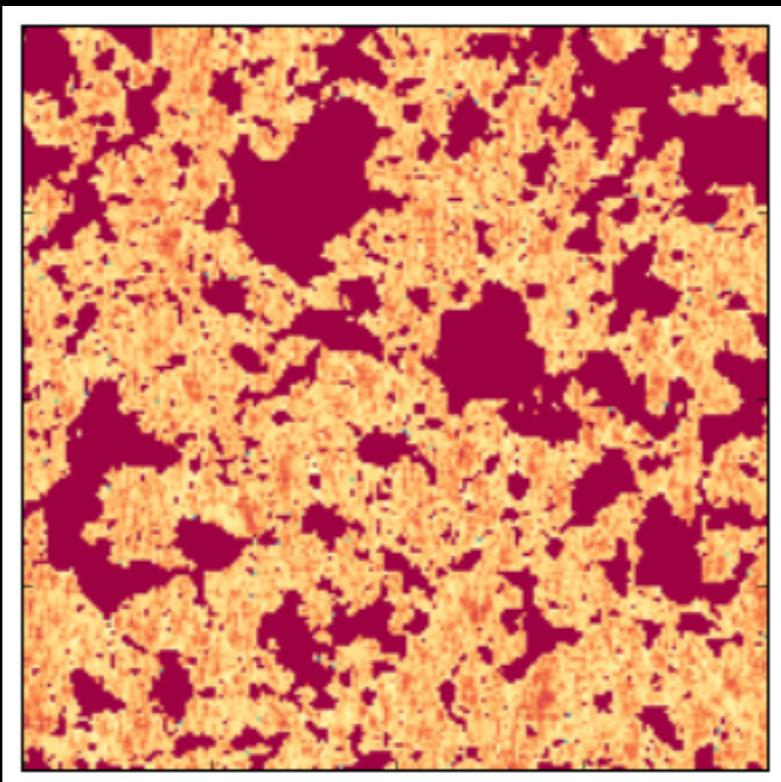
Time



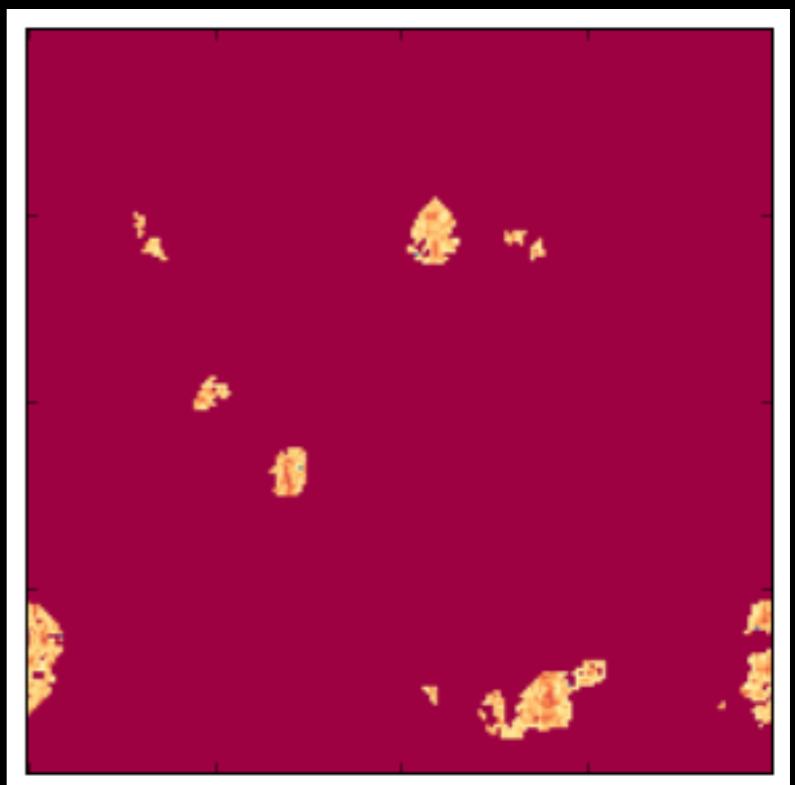
Mature Universe



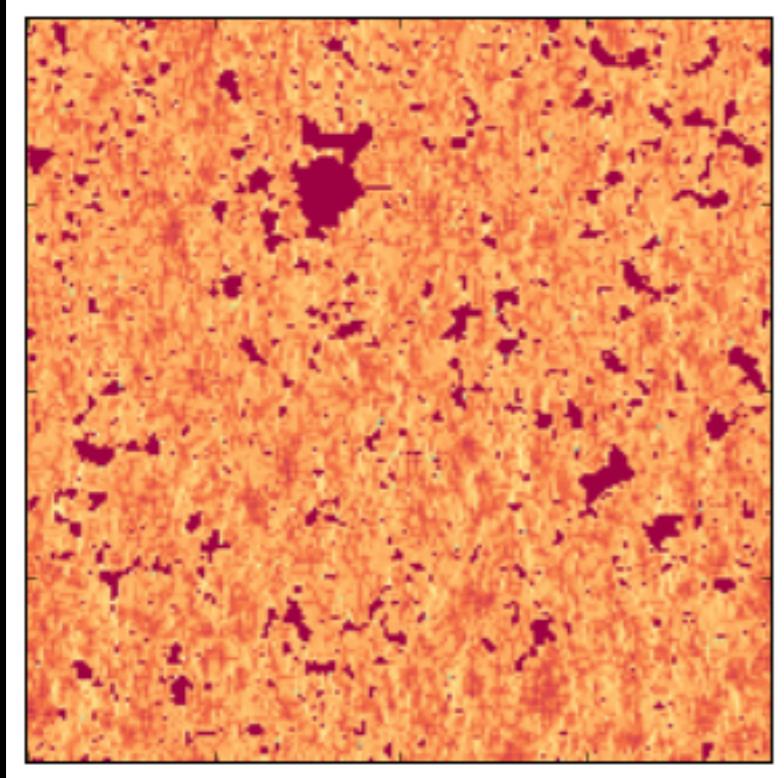
Beginning of
reionization



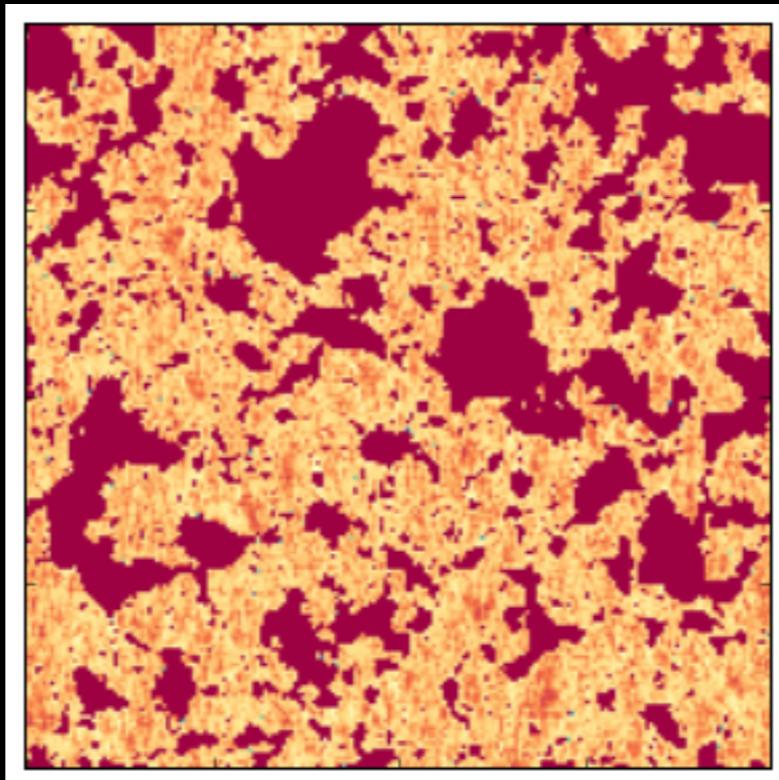
Middle of
reionization



End of reionization



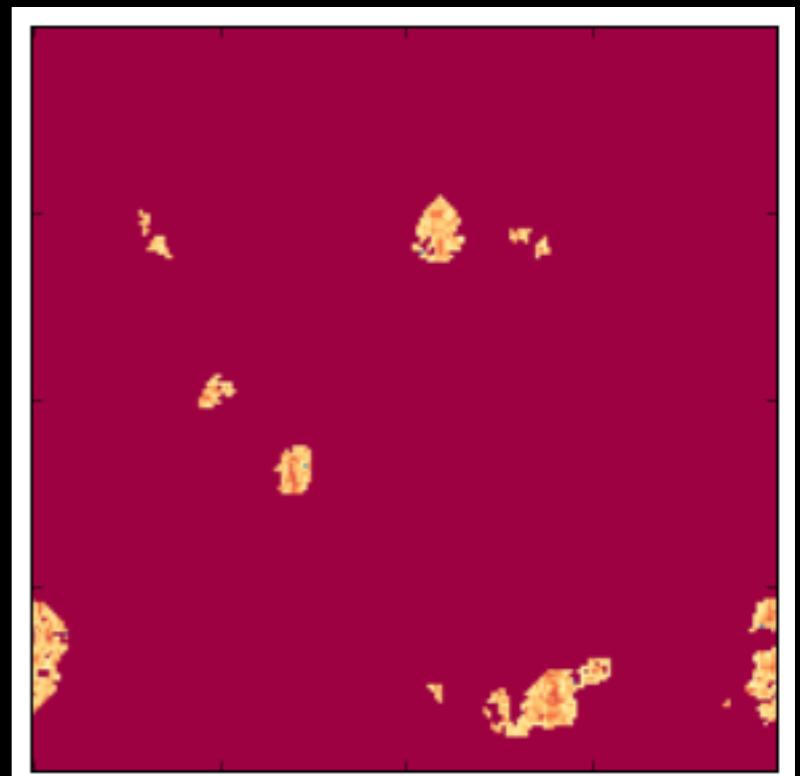
Beginning of
reionization



Middle of
reionization

How did the first
galaxies affect their
environments?

What was the nature
of the first galaxies?



End of reionization