



Four fabulous facts about the Universe

COSMOLOGY MARCHES ON



Getting our bearings : how big is the Universe?

Getting our bearings : how big is the Universe?

The Earth

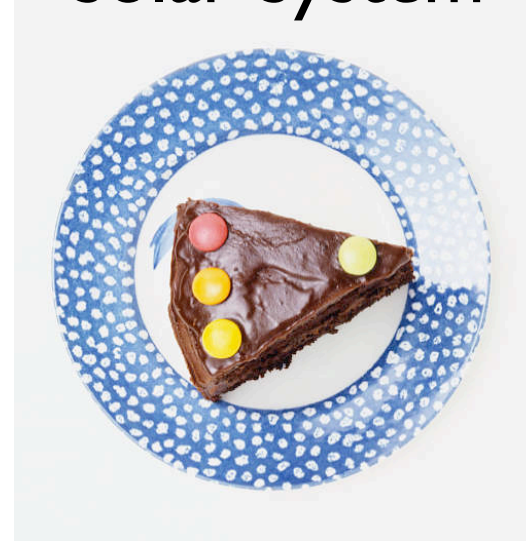


Getting our bearings : how big is the Universe?

The Earth

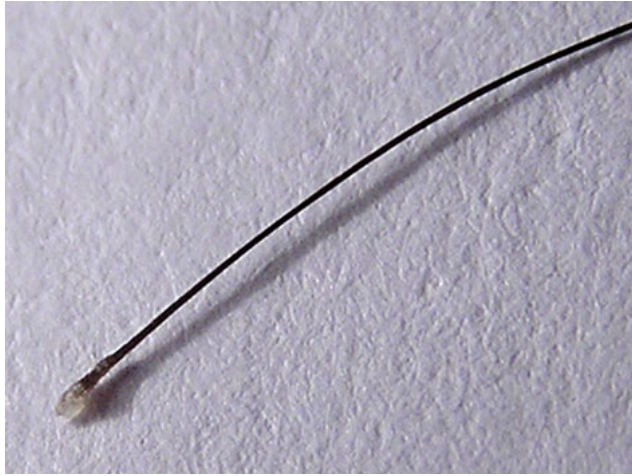


Solar System

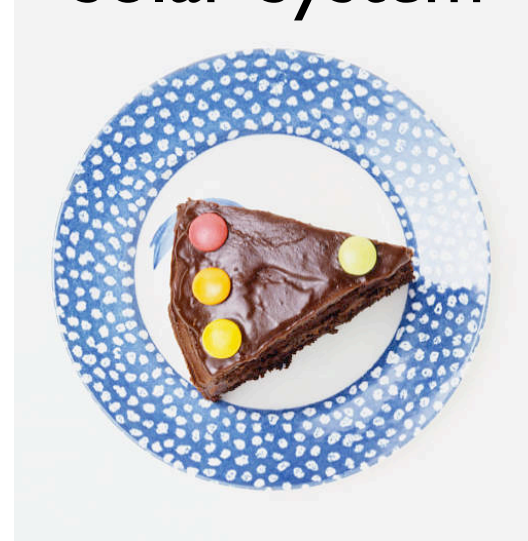


Getting our bearings : how big is the Universe?

The Earth



Solar System

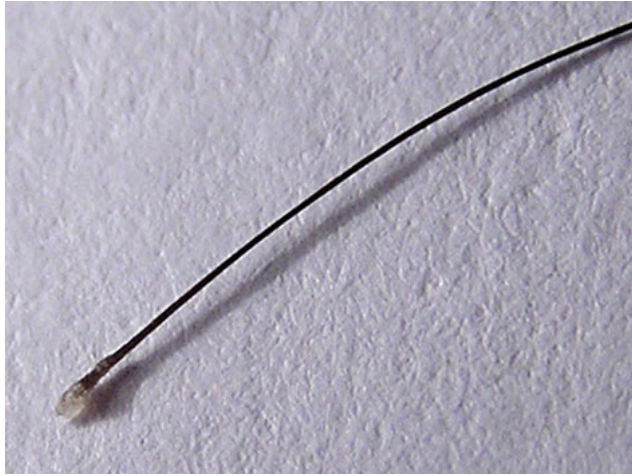


Milky Way Galaxy



Getting our bearings : how big is the Universe?

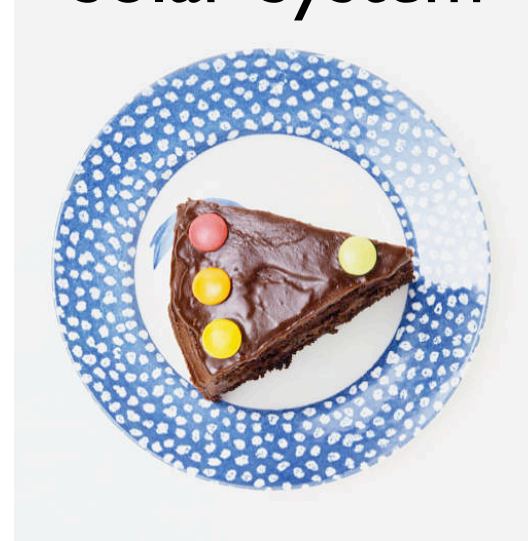
The Earth



Milky Way Galaxy



Solar System



The observable Universe

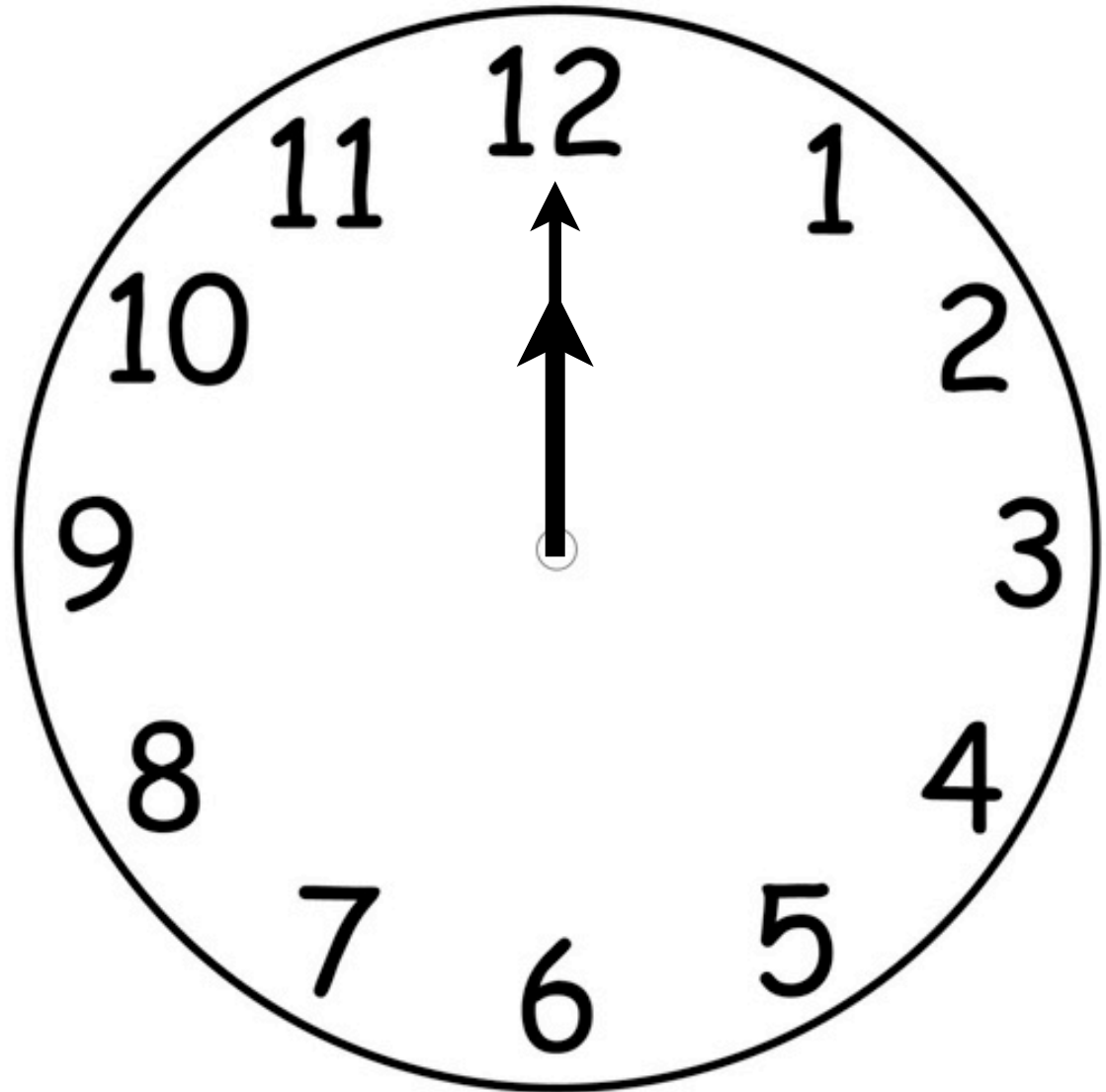


Getting our bearings : how big is the Universe?

<http://map.gsfc.nasa.gov/resources/animconcepts.html>

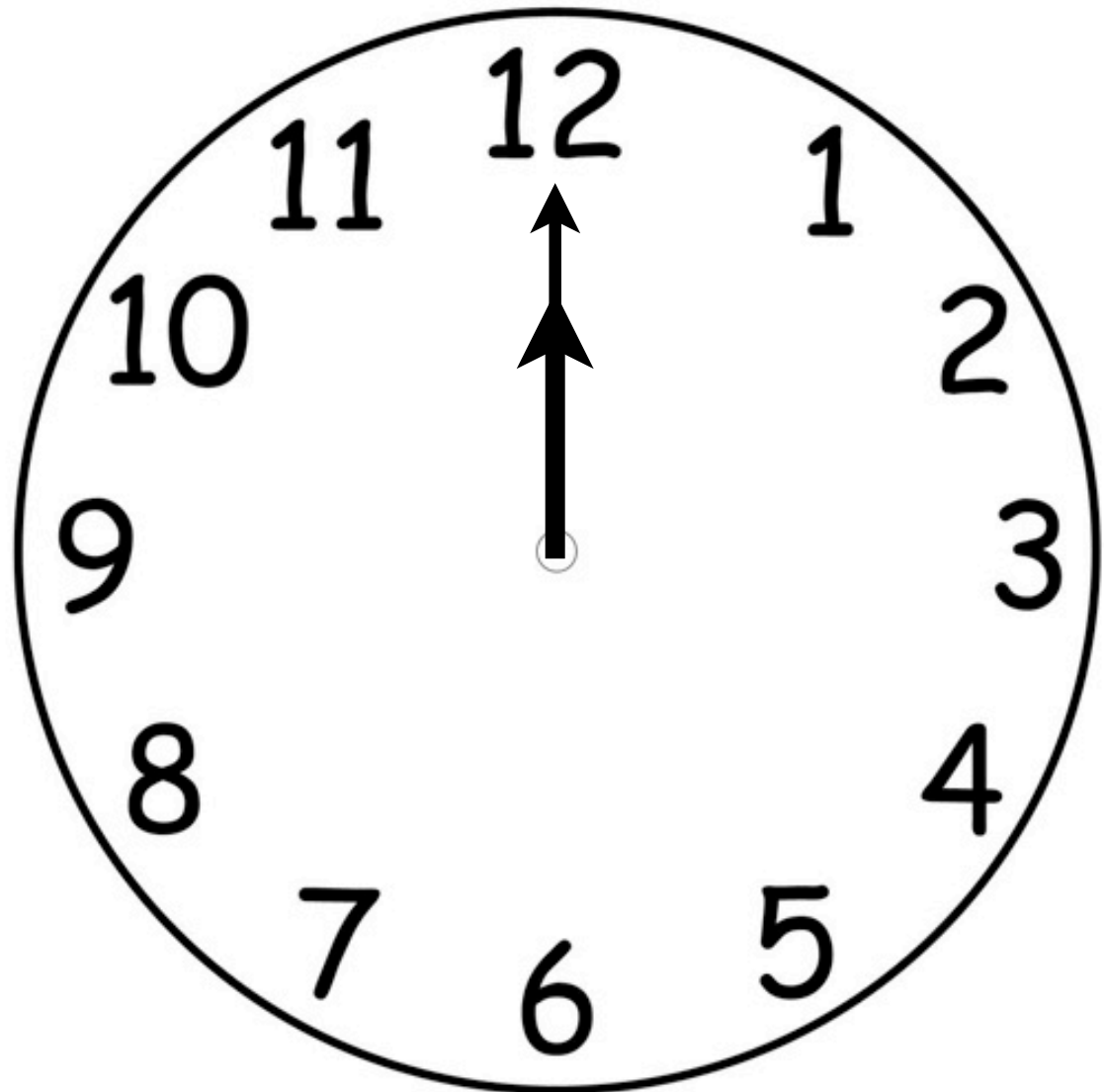


Getting our bearings : how old is the Universe?



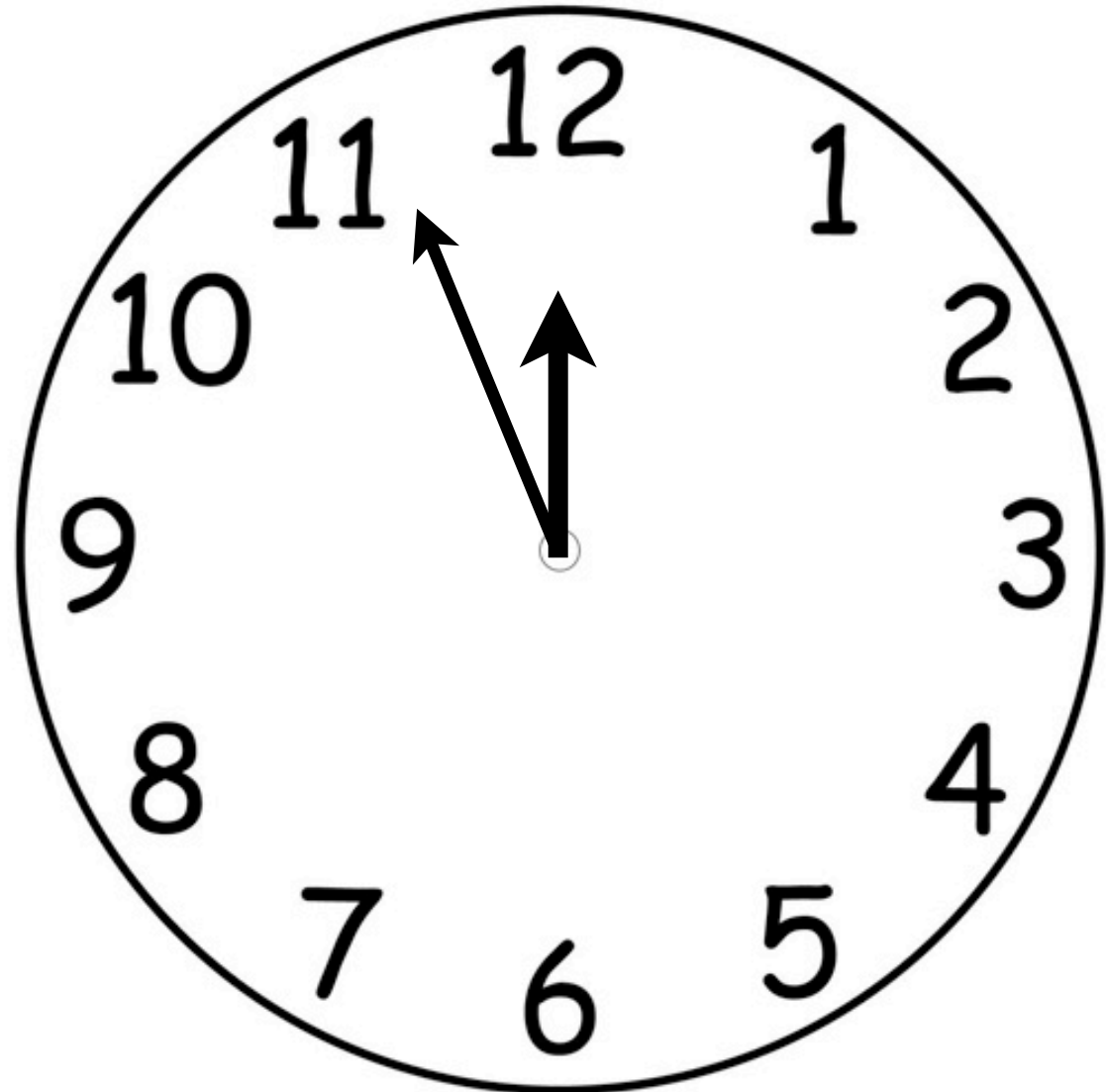
Getting our bearings : how old is the Universe?

My lifetime ...
(31 yrs)



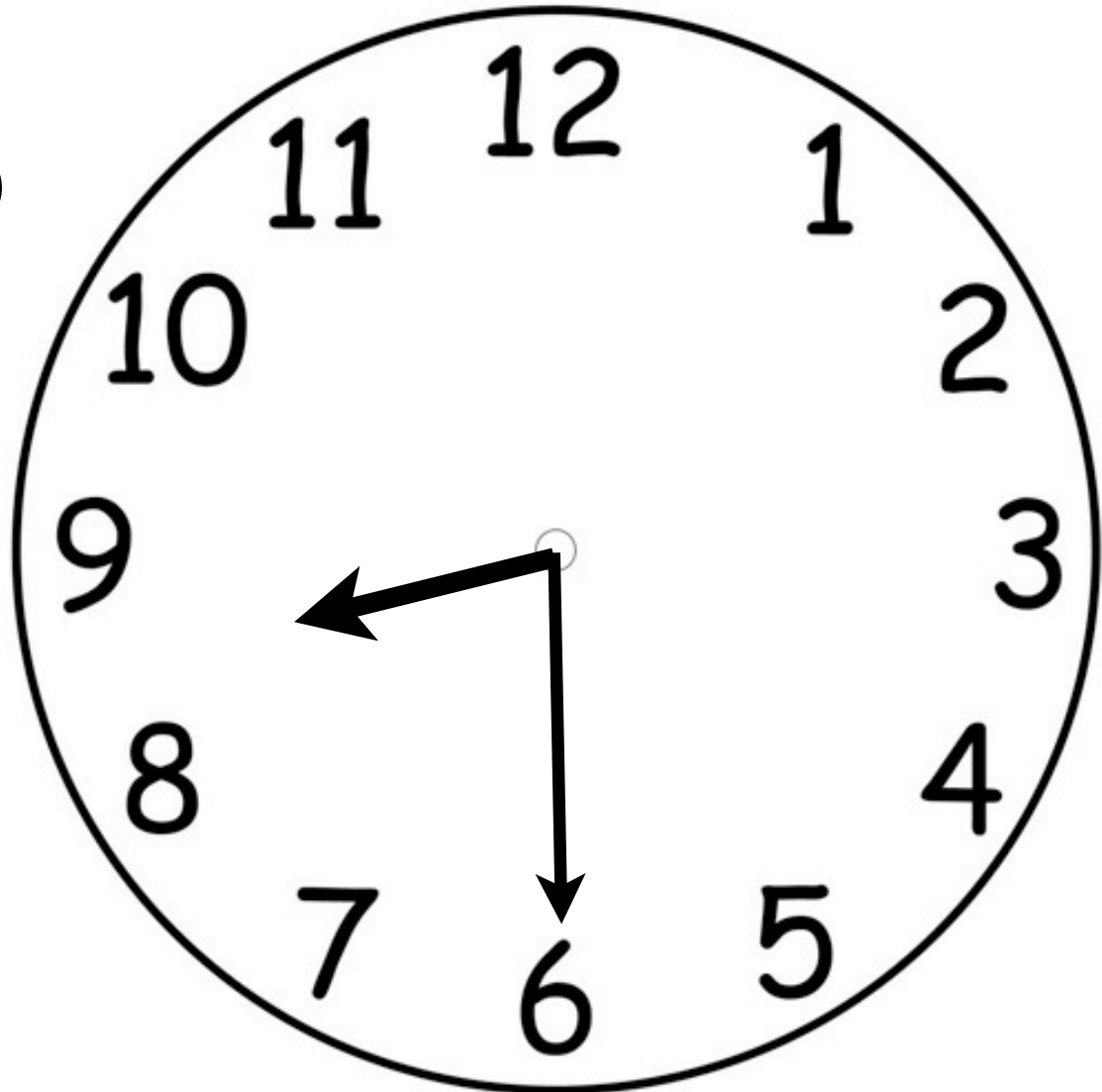
Getting our bearings : how old is the Universe?

Extinction of the dinosaurs ...
(65 million yrs)



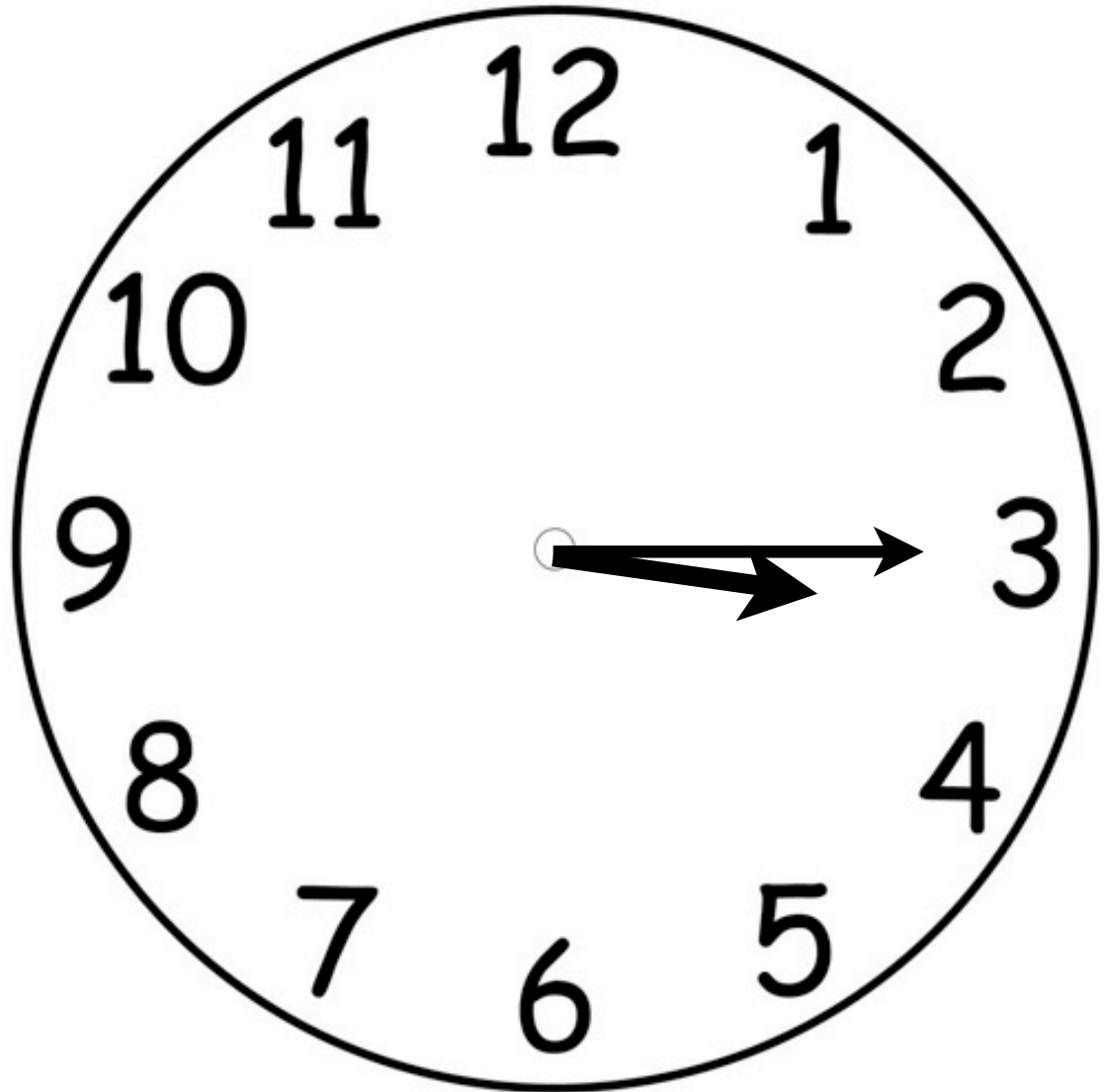
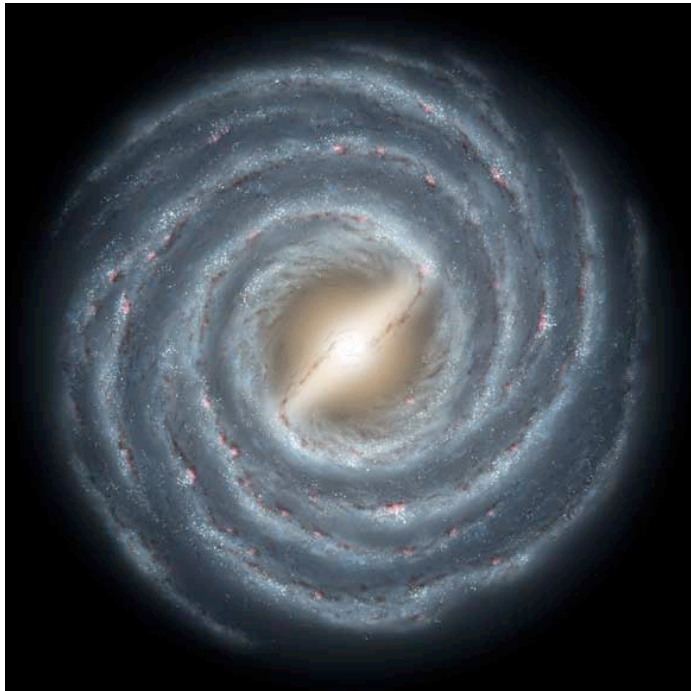
Getting our bearings : how old is the Universe?

Formation of the
solar system ...
(approx. 4 billion yrs)



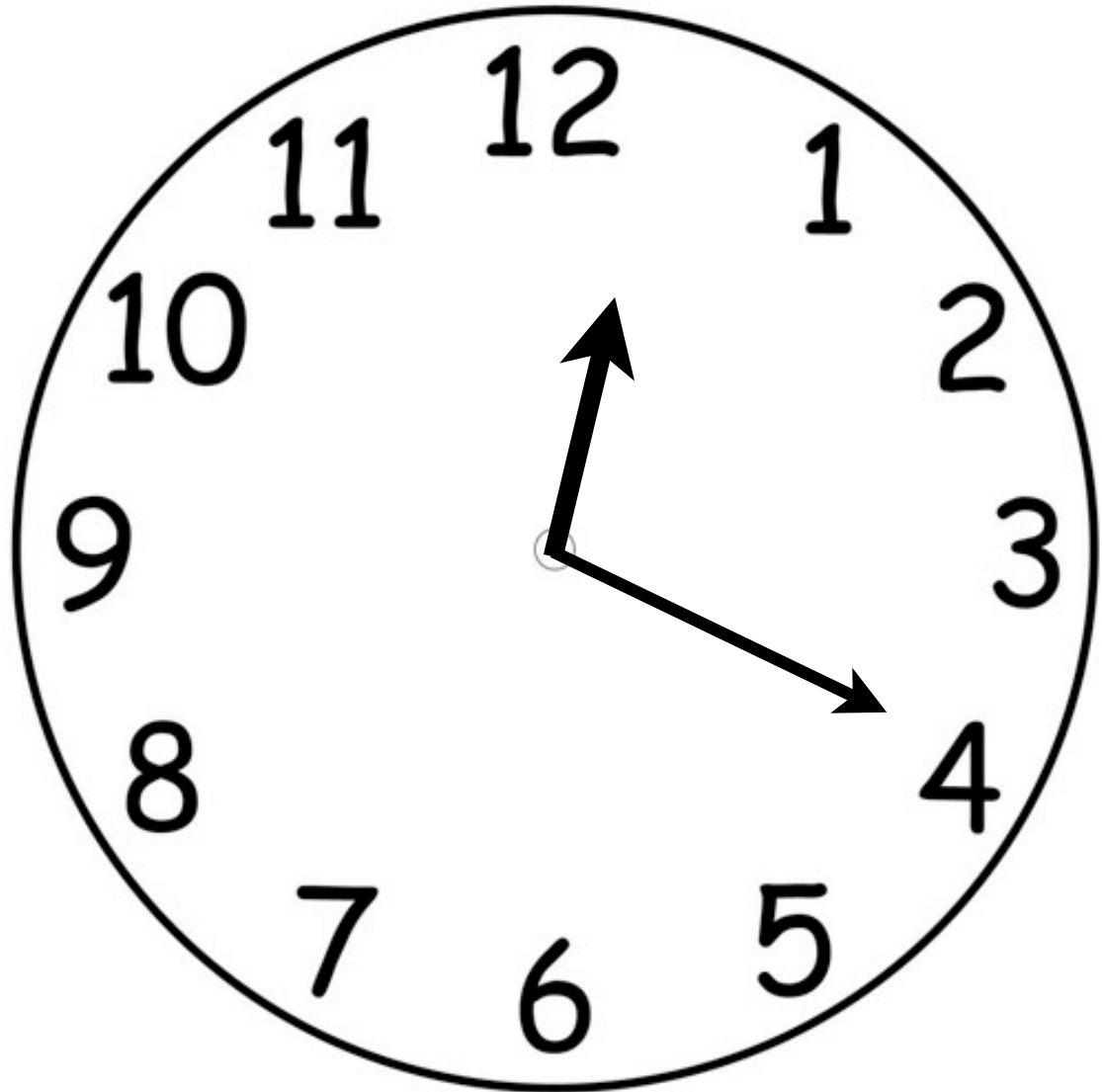
Getting our bearings : how old is the Universe?

Formation of our galaxy ... (approx. 10 billion yrs)



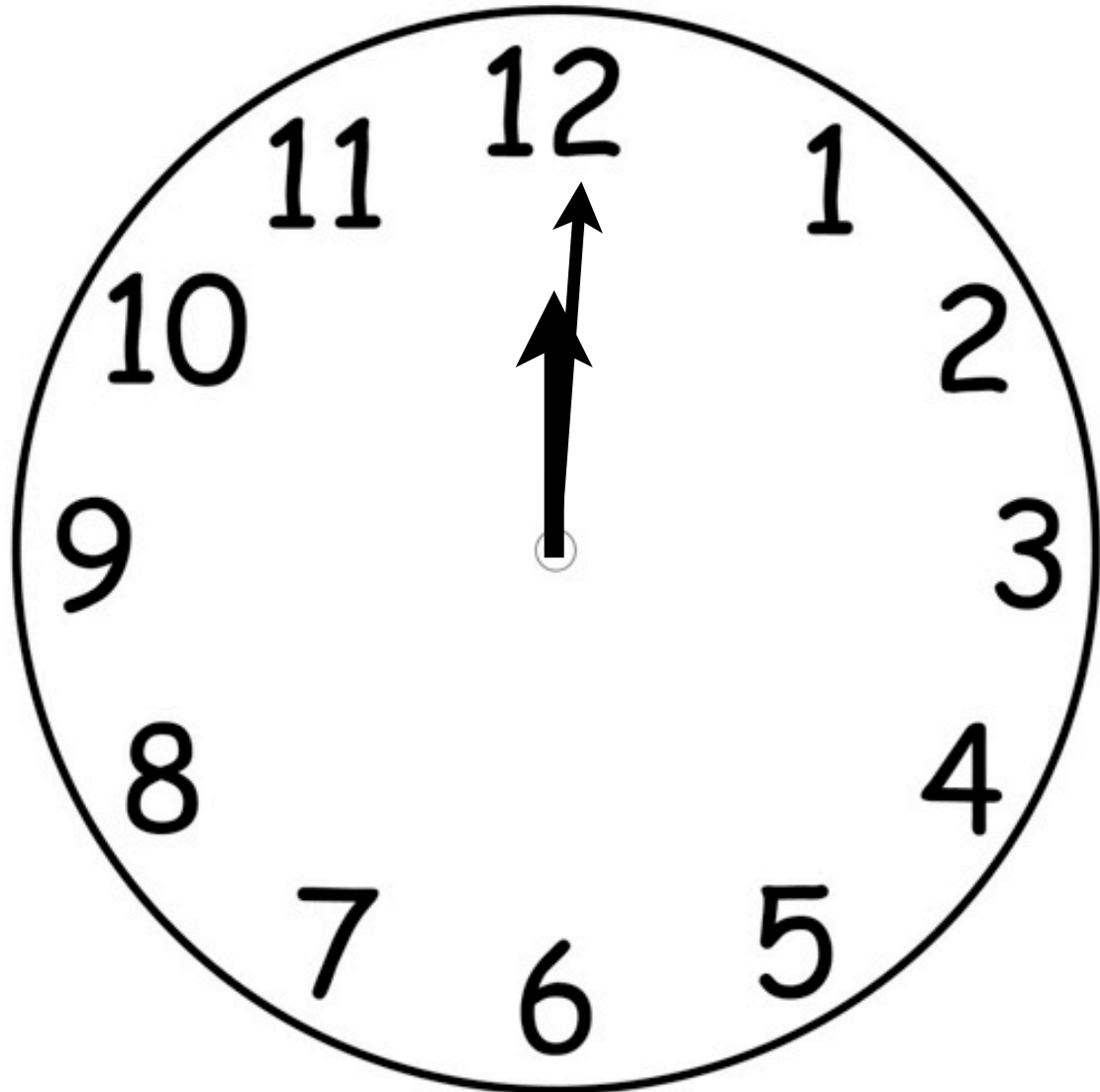
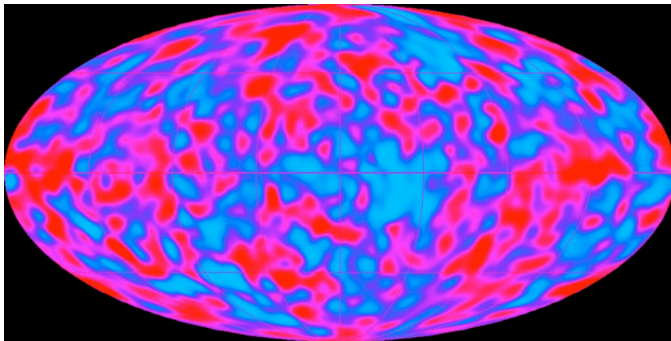
Getting our bearings : how old is the Universe?

Formation of first stars ... (approx. 13.3 billion yrs)



Getting our bearings : how old is the Universe?

The first light we
can detect (13.7
billion yrs)



Four fabulous facts about the Universe

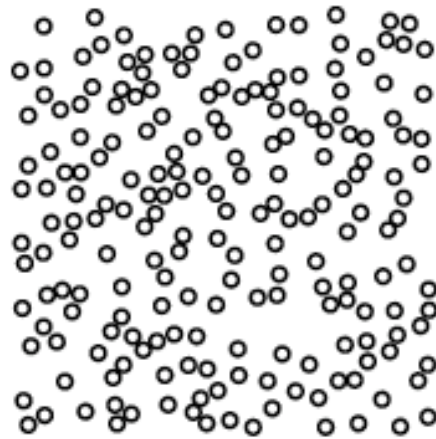


(I) The Universe is expanding

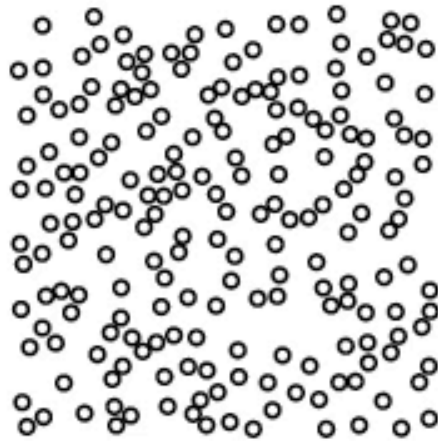
<http://snap.lbl.gov/multimedia/animations/>



(I) The Universe is expanding



(I) The Universe is expanding



(2) The Universe is a time machine



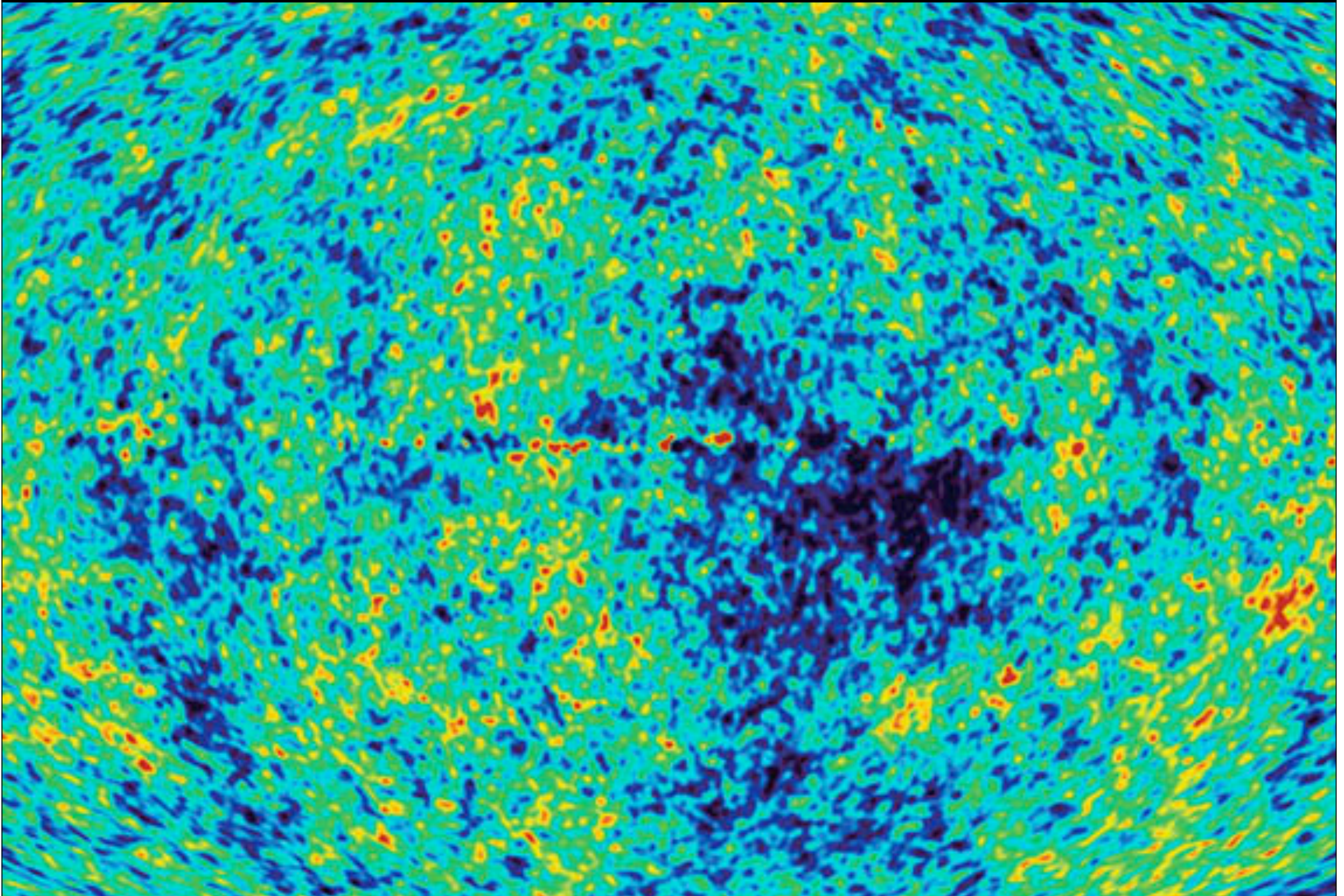
Useful fact:
Light travels at
300,000 km/s

(2) The Universe is a time machine

<http://hubblesite.org/newscenter/archive/>



(3) The Universe was much hotter in the past



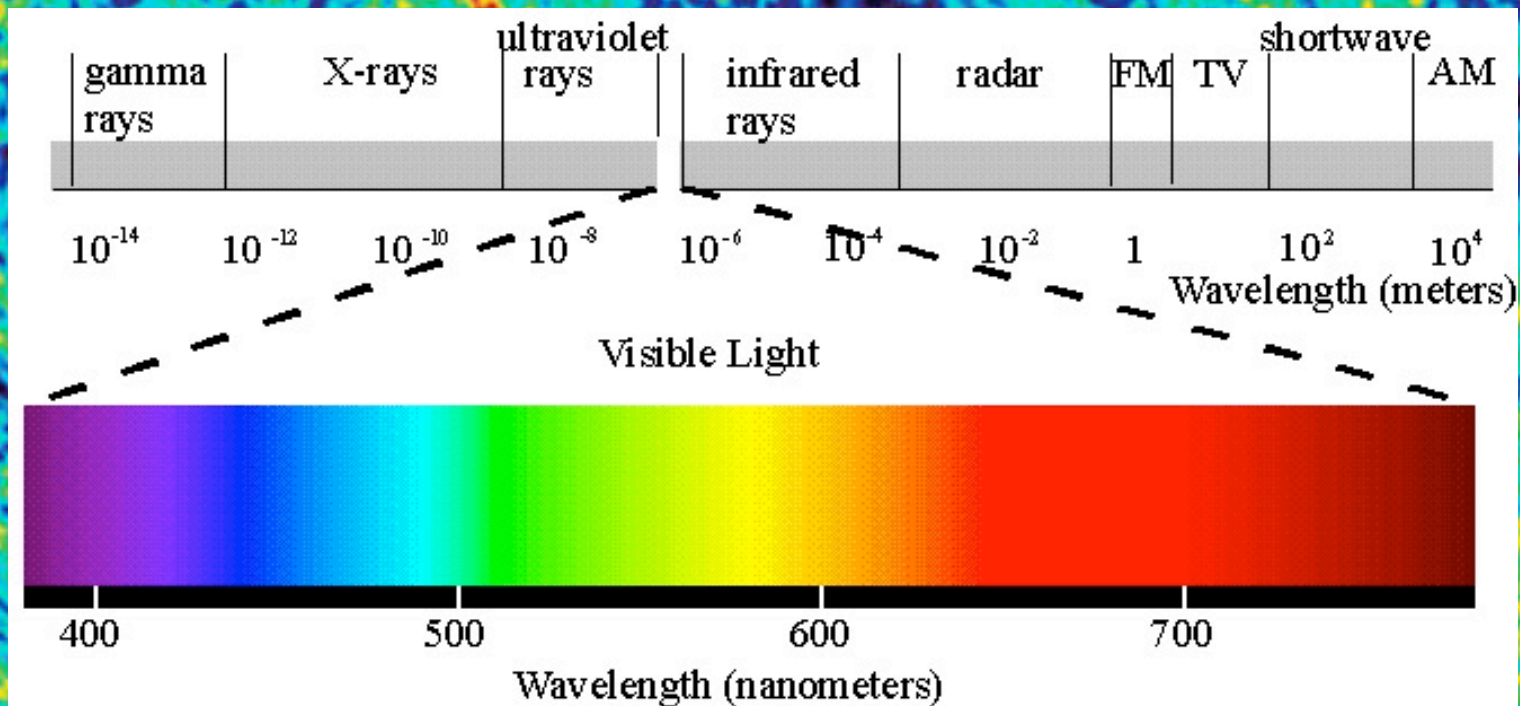
(3) The Universe was much hotter in the past

A full-page image of the Cosmic Microwave Background (CMB) radiation. It is a complex, grainy pattern of colors representing temperature fluctuations across the universe. The colors range from dark blue (cooler) to red and yellow (warmer). A large, dark blue region is visible in the upper right quadrant, while other areas show a mix of blue, cyan, and yellow. The overall appearance is that of a noisy, textured field.

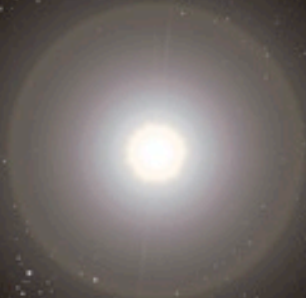
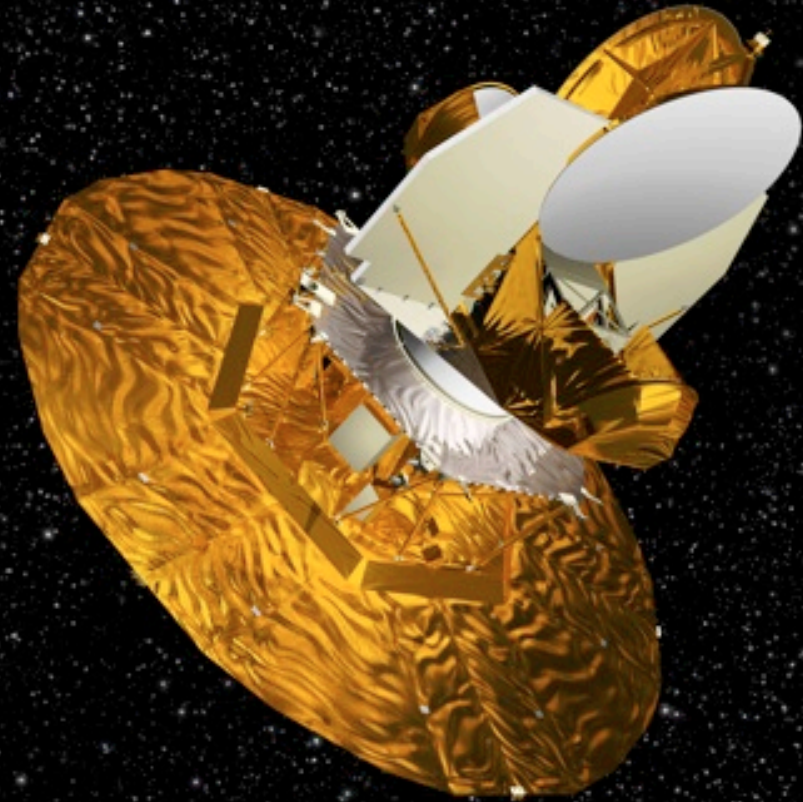
**COSMIC MICROWAVE
BACKGROUND
RADIATION**

(3) The Universe was much hotter in the past

COSMIC MICROWAVE BACKGROUND RADIATION



(3) The Universe was much hotter in the past



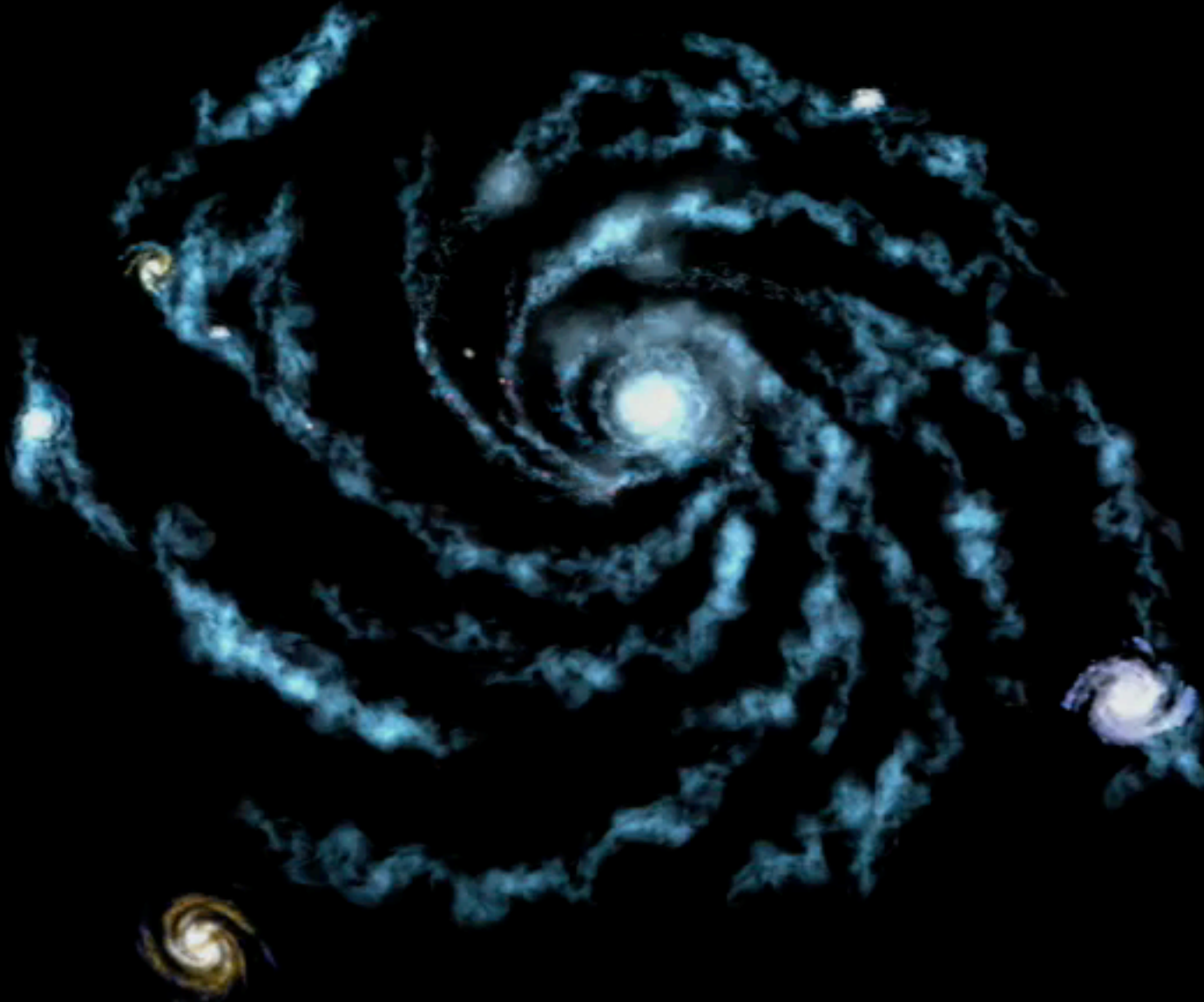
The WMAP satellite

(3) The Universe was much hotter in the past

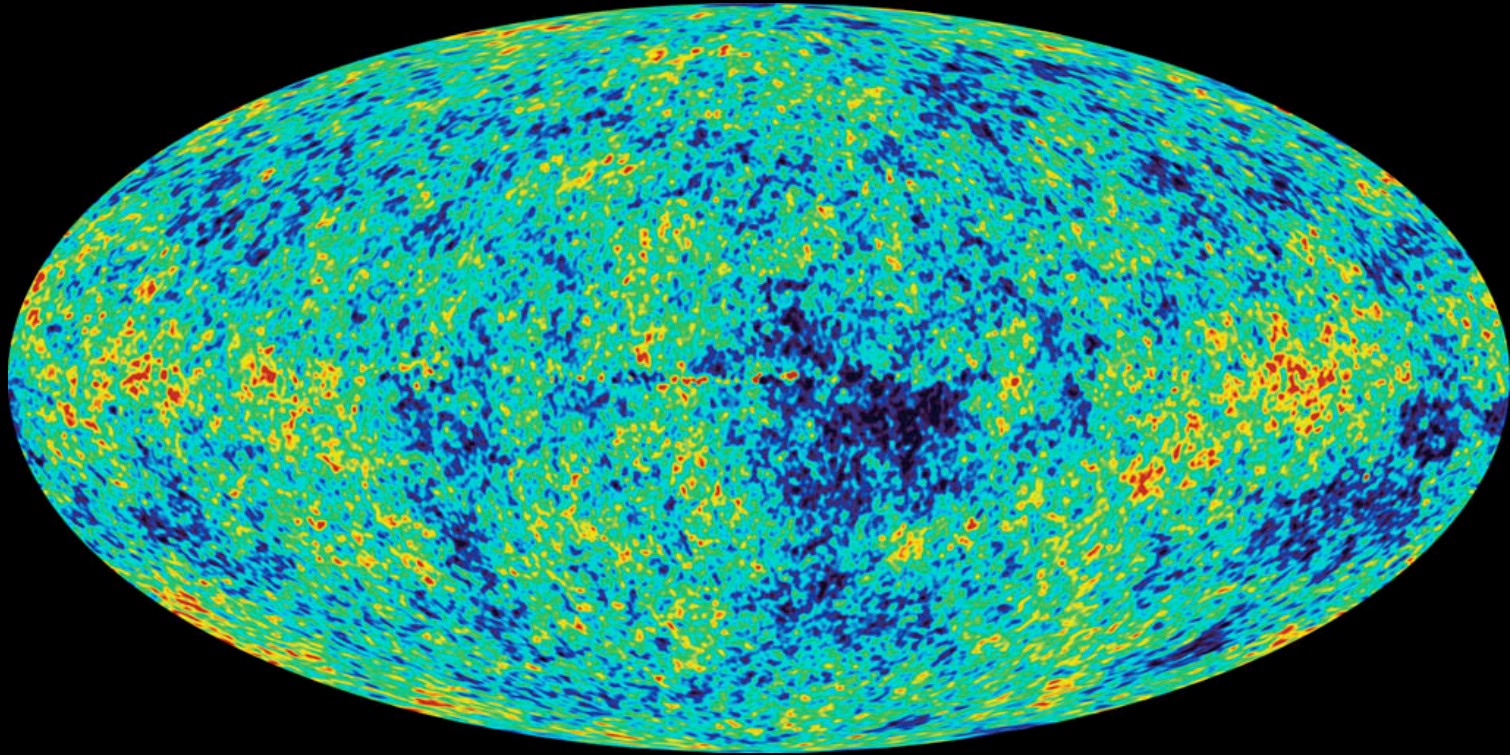


(3) The Universe was much hotter in the past

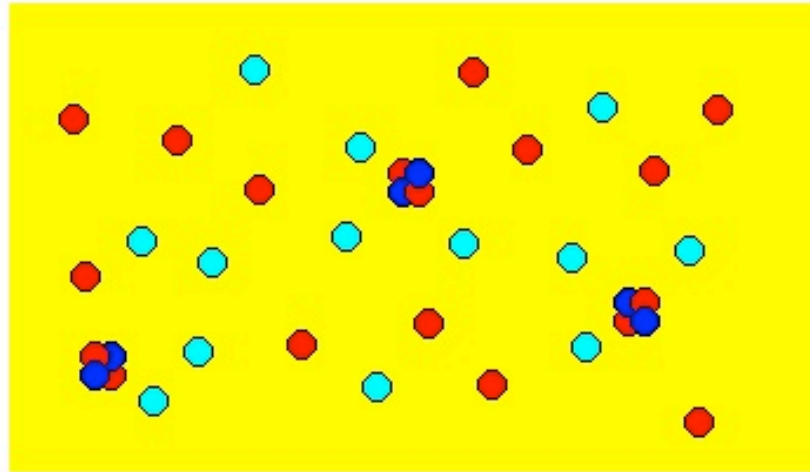
<http://map.gsfc.nasa.gov/resources/animconcepts.html>






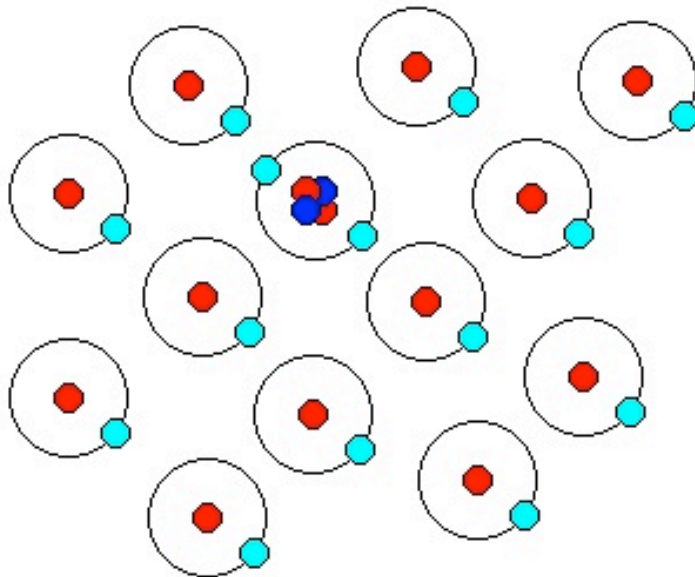
(3) The Universe was much hotter in the past

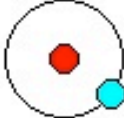
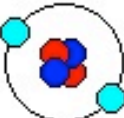


(3) The Universe was much hotter in the past

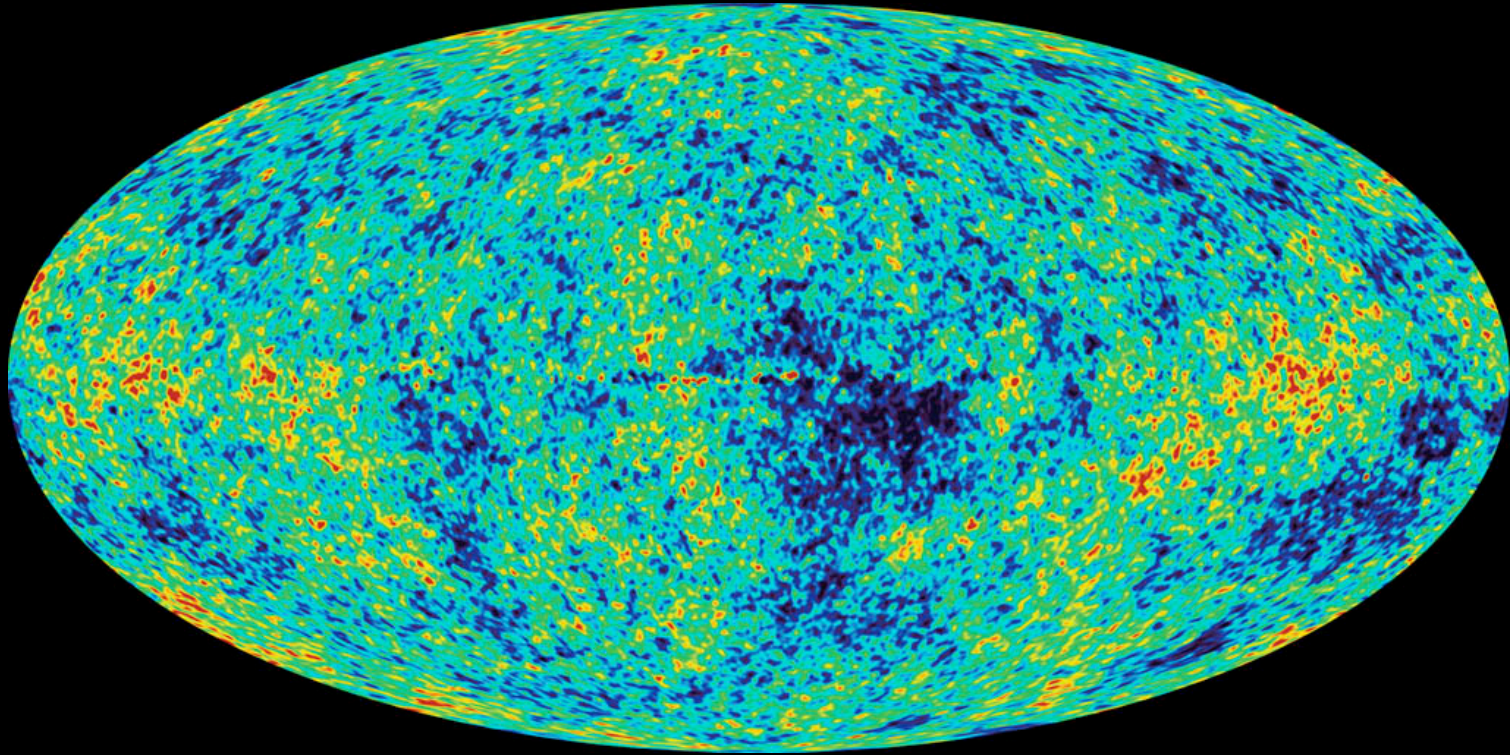


-  electron
-  proton
-  helium nuclei



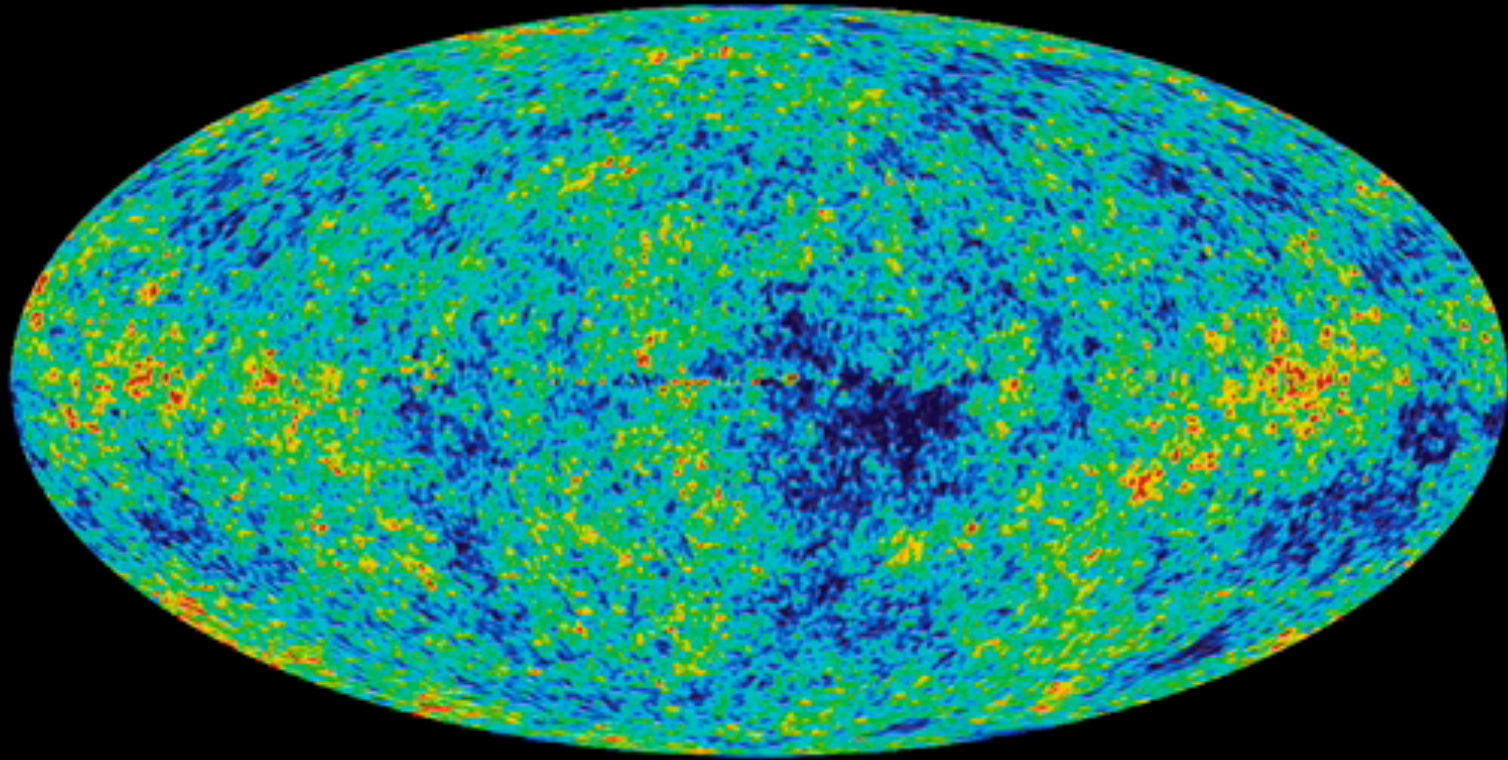
-  hydrogen atom
-  helium atom

(3) The Universe was much hotter in the past

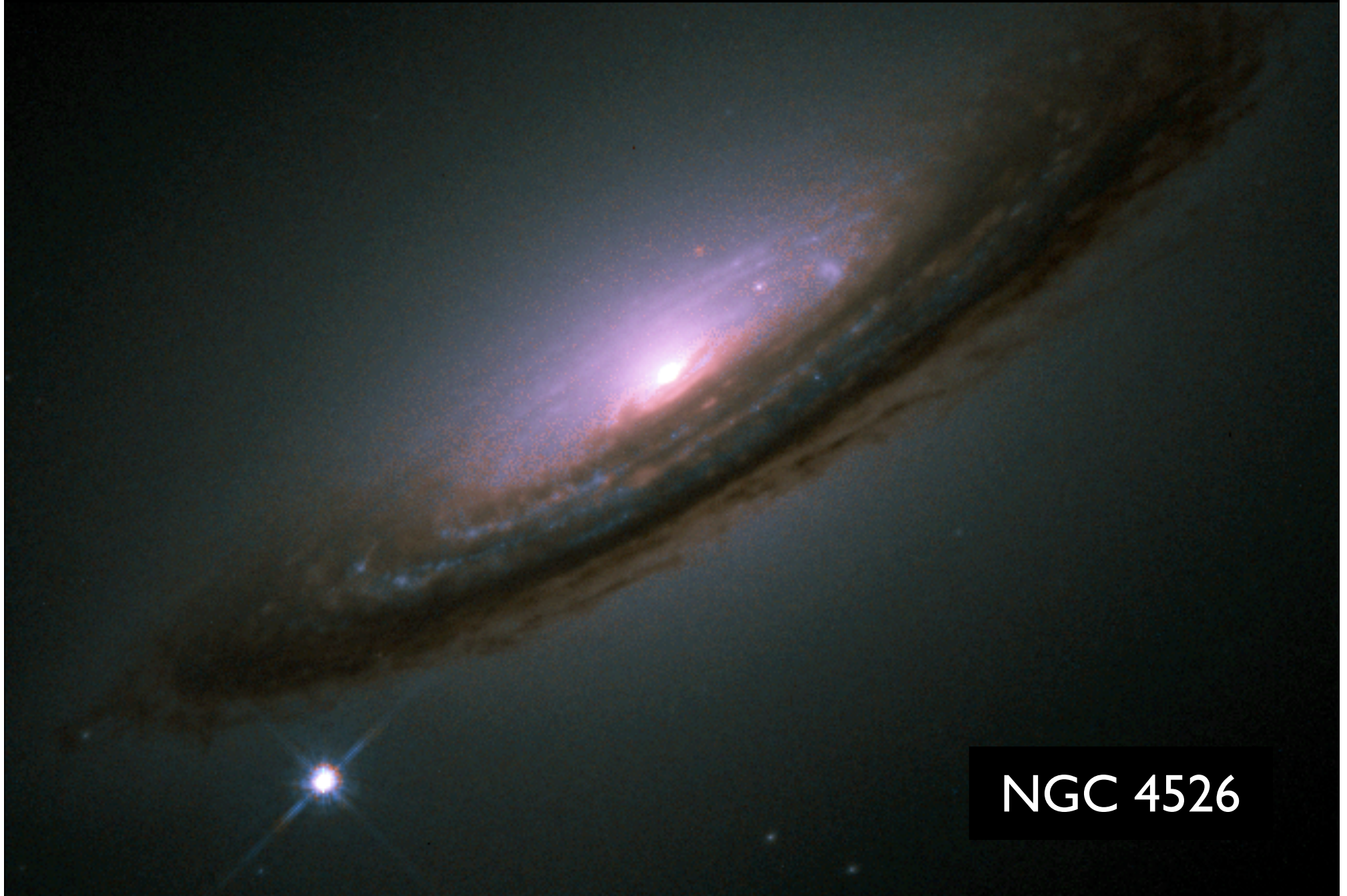


(3) The Universe was much hotter in the past

<http://map.gsfc.nasa.gov/resources/animconcepts.html>

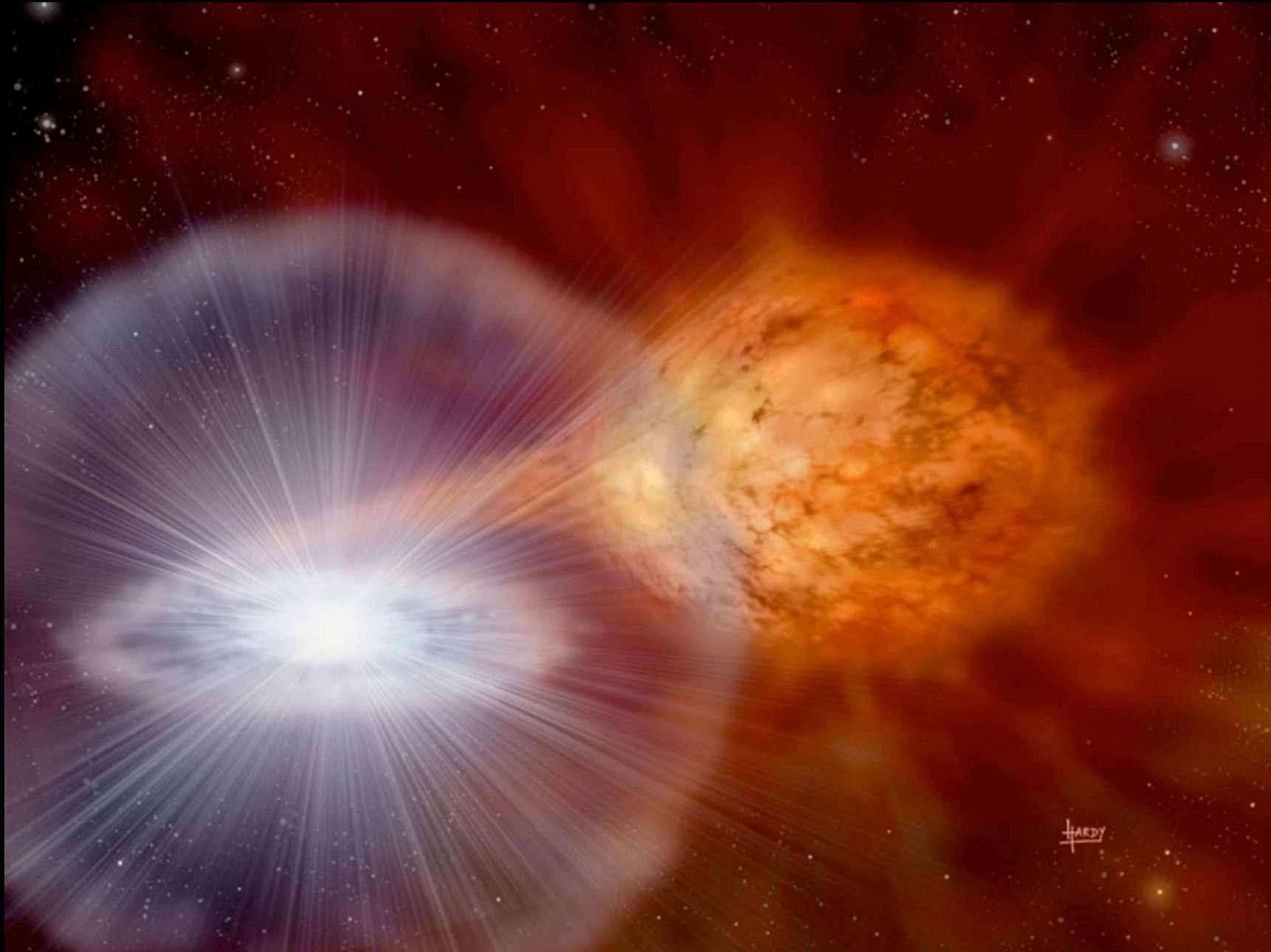


(4) The expansion rate is speeding up



NGC 4526

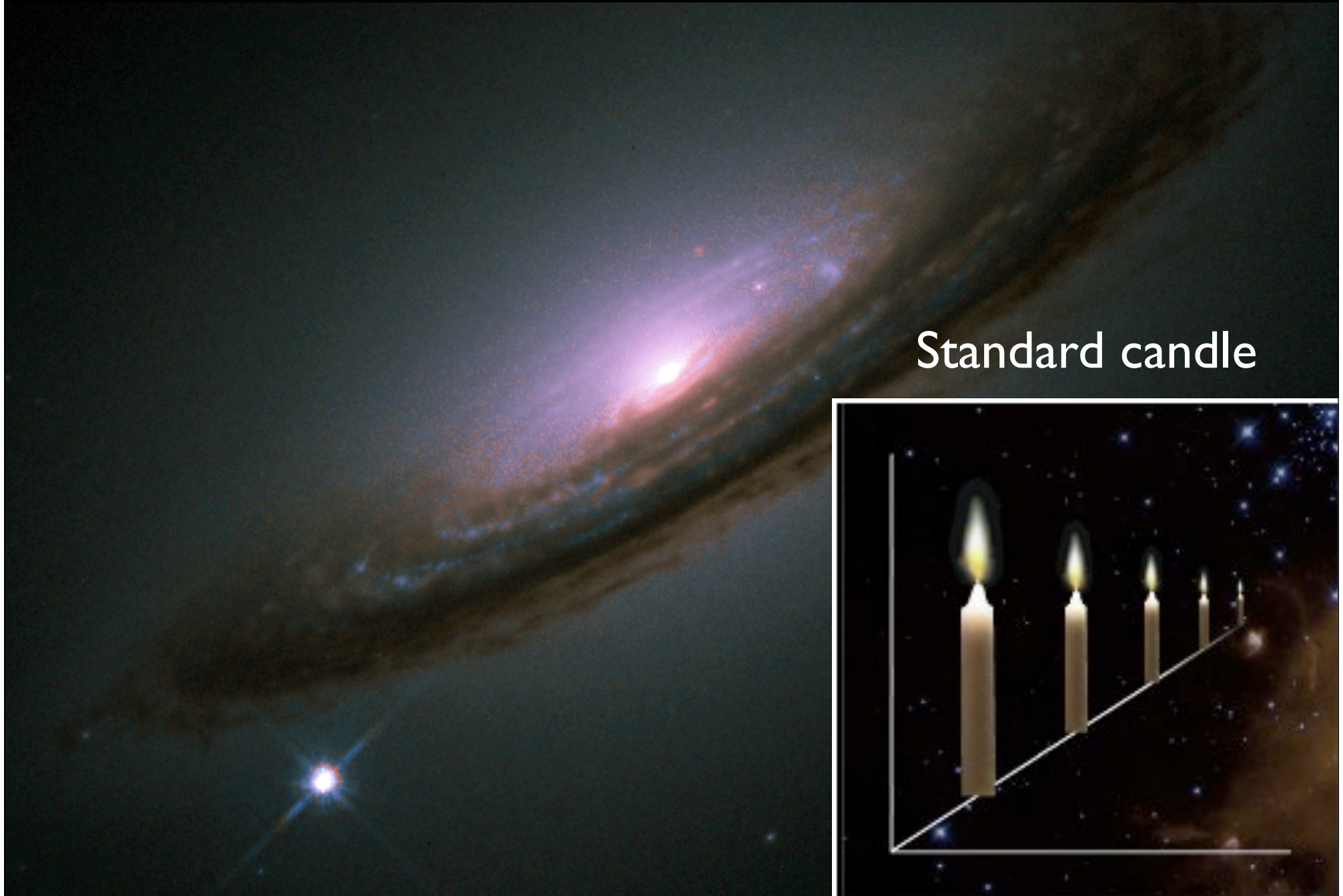
(4) The expansion rate is speeding up



(4) The expansion rate is speeding up

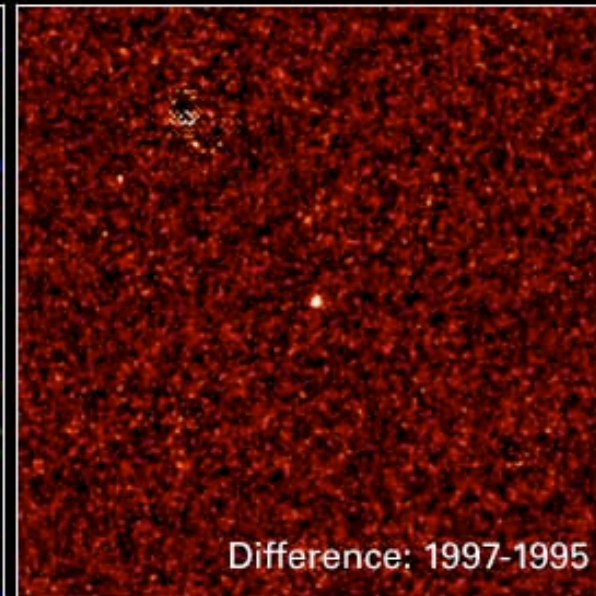
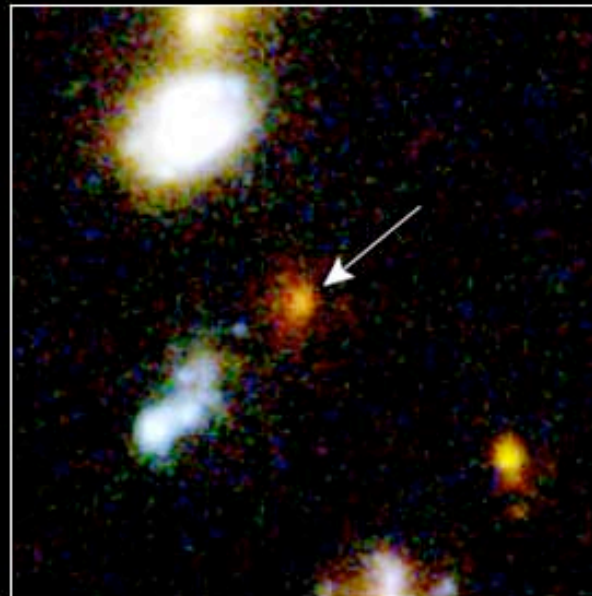
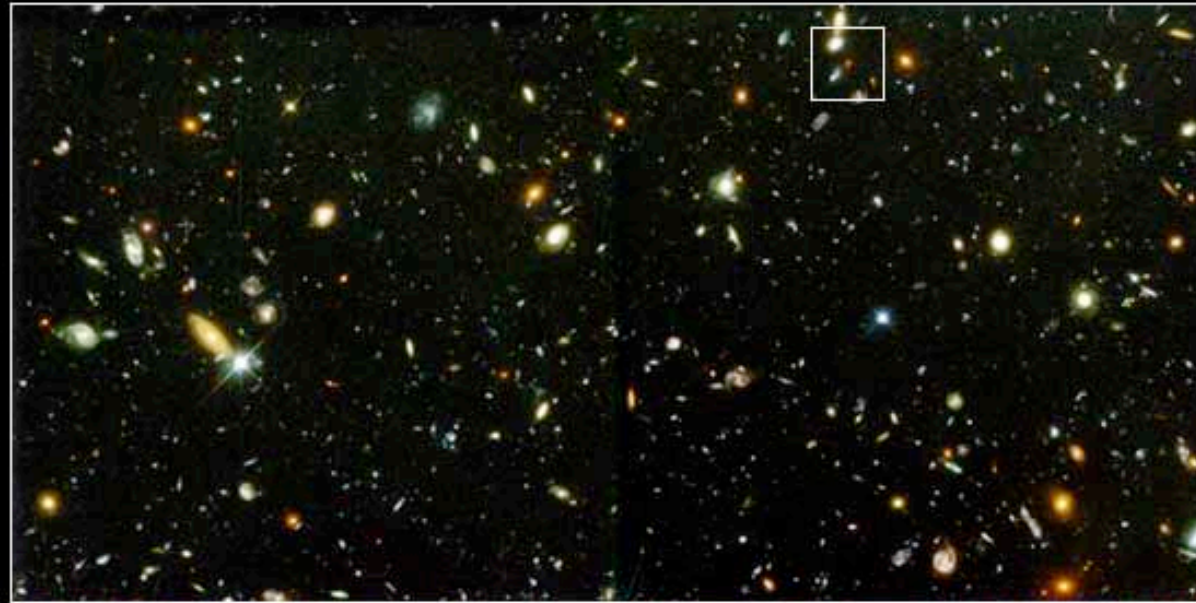


(4) The expansion rate is speeding up



Standard candle

(4) The expansion rate is speeding up

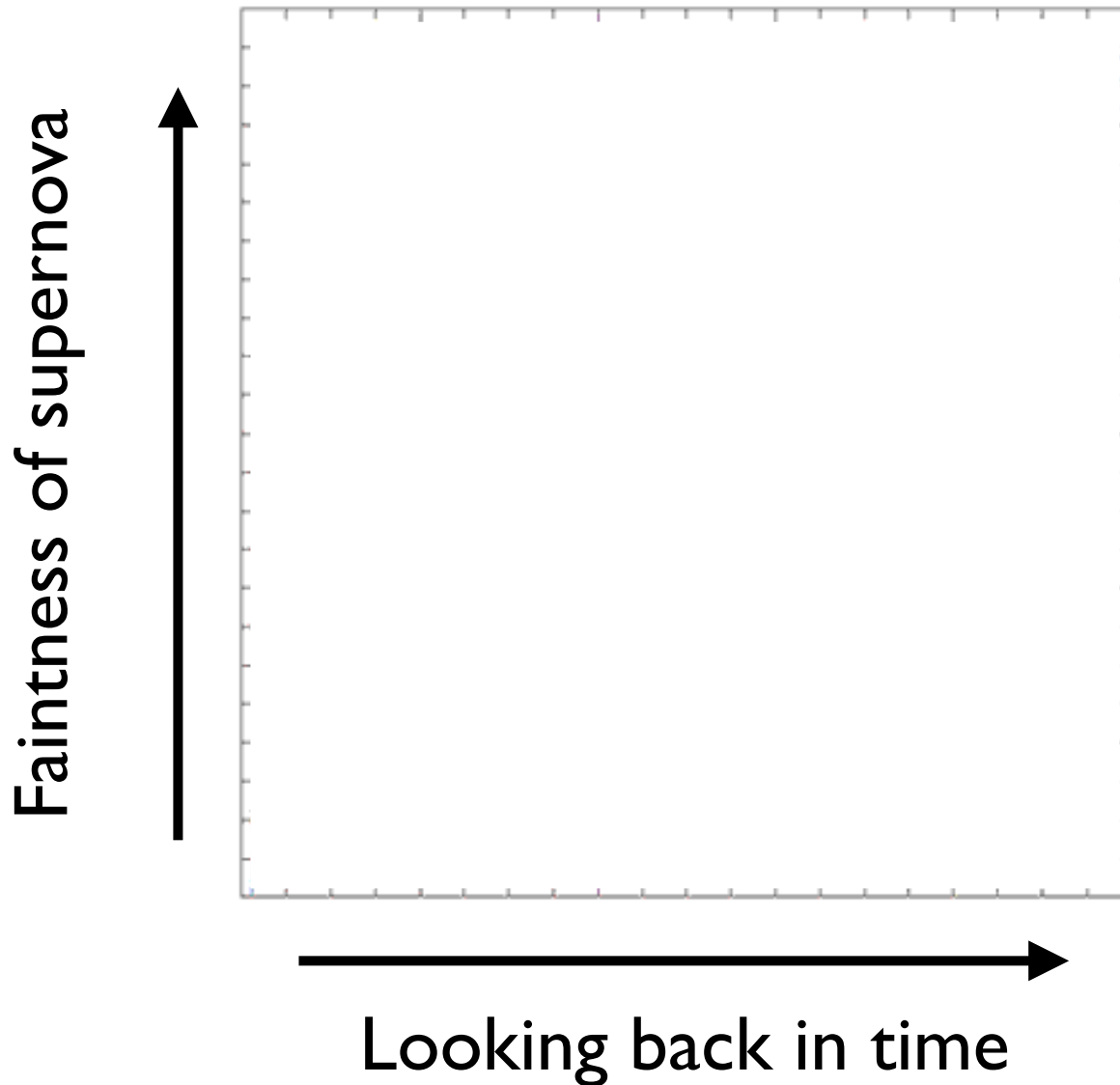


Difference: 1997-1995

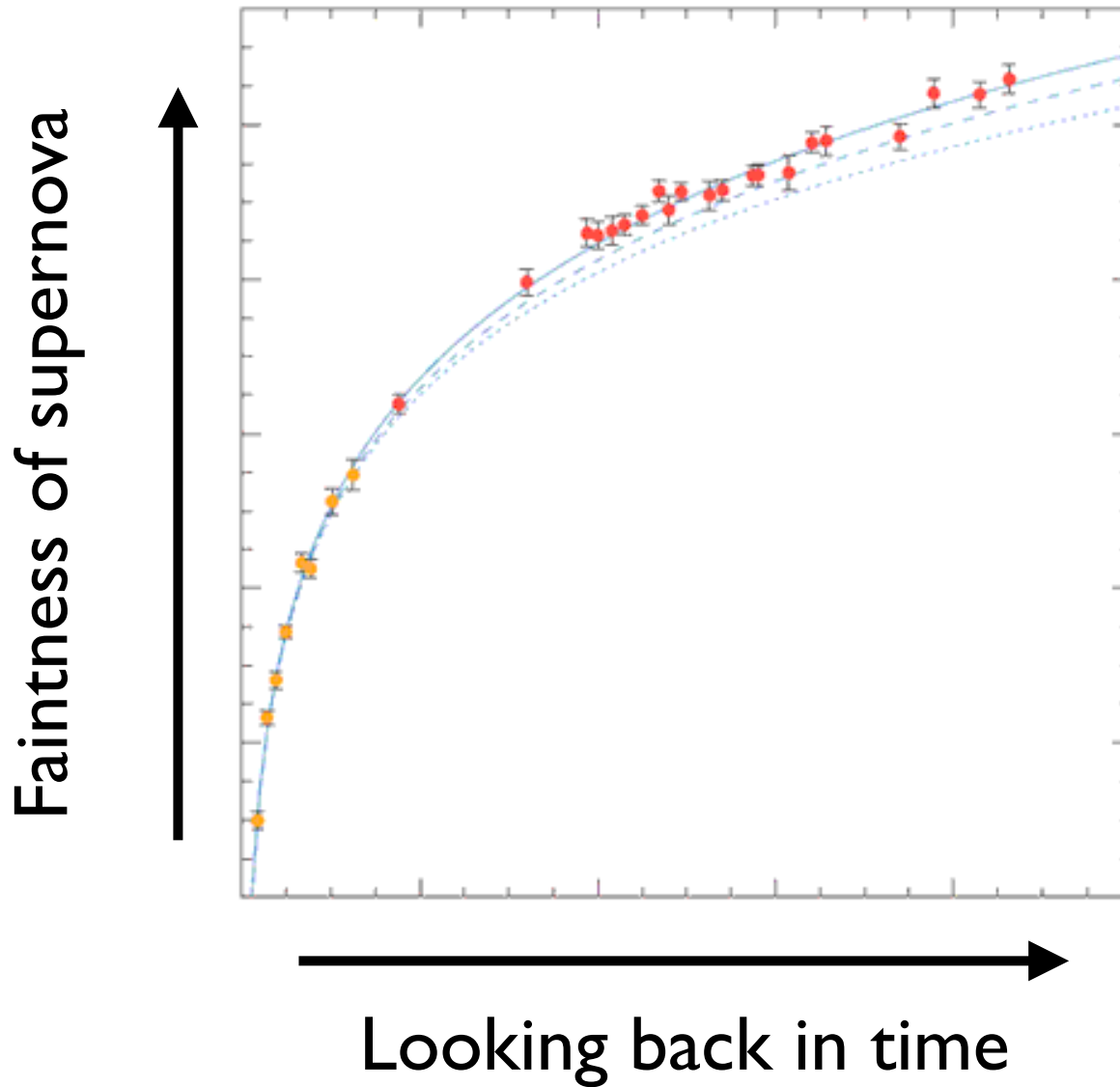
Distant Supernova in the Hubble Deep Field HST • WFPC2

NASA and A. Riess (STScI) • STScI-PRC01-09

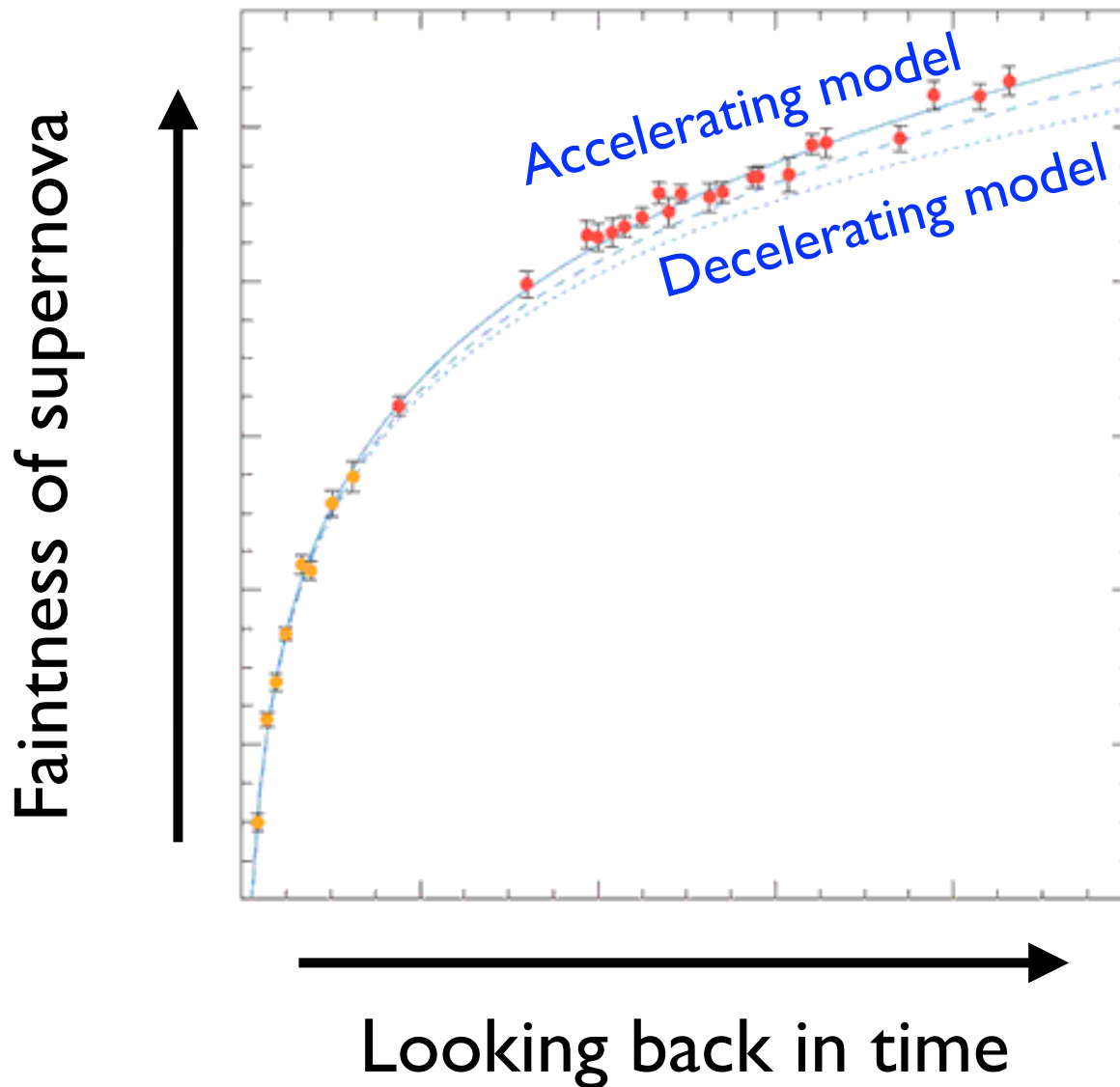
(4) The expansion rate is speeding up



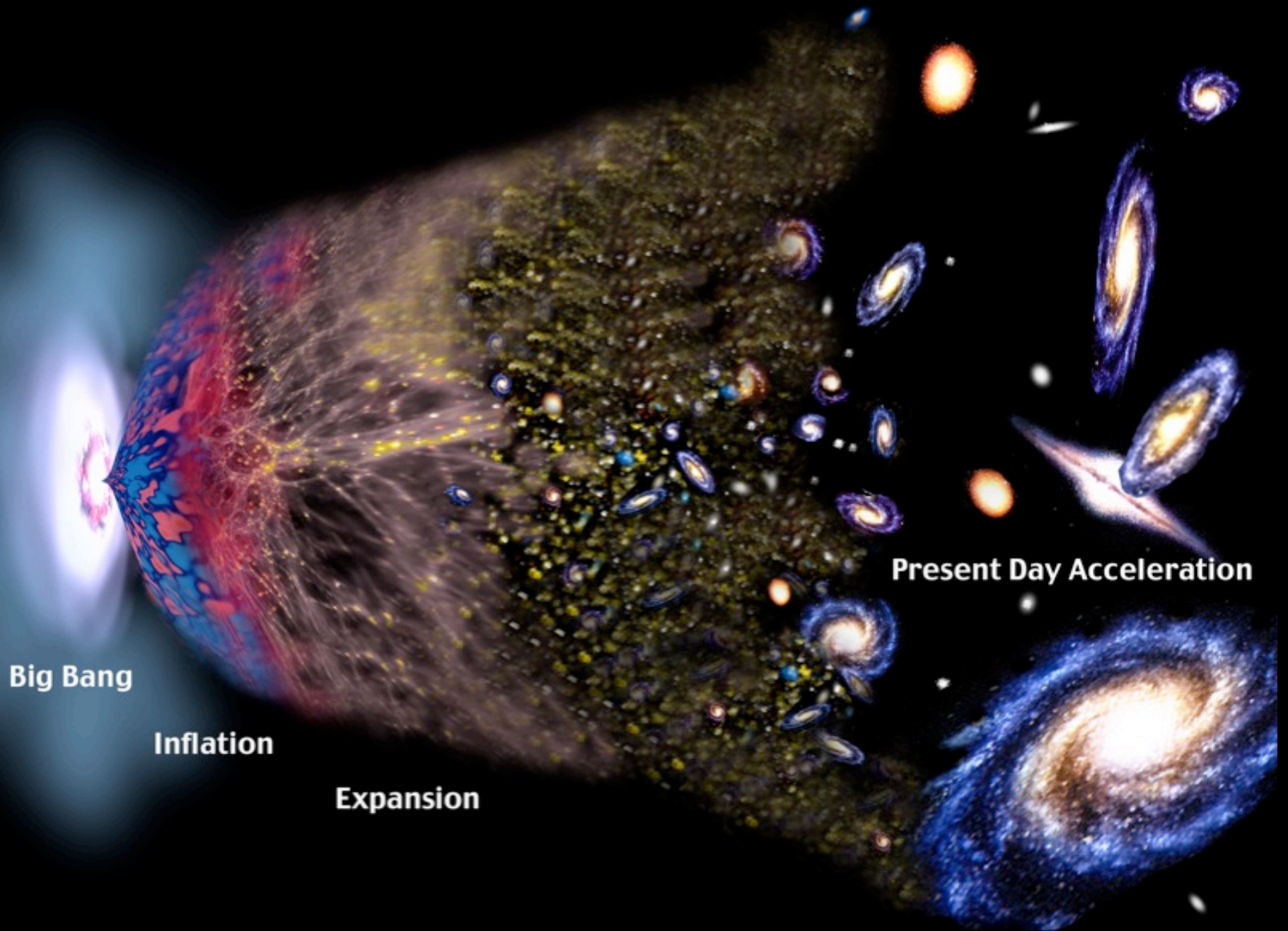
(4) The expansion rate is speeding up



(4) The expansion rate is speeding up



Putting it all together!



Four fabulous facts about the Universe

- The Universe is expanding
- Peering deeper is looking back in time
- The Universe used to be much hotter
- The expansion is speeding up

Cosmology F.A.Q.

Q. What is the Universe expanding into ?

A. We cannot observe anything outside the Universe, as far as we know. Therefore science cannot address this question.

Q. Where is the edge of the Universe ?

A. The whole Universe is infinite in extent and has no edge. The observable Universe - the bit we can see - has a size equal to the distance light can travel since the Big Bang, 13.7 billion years ago.

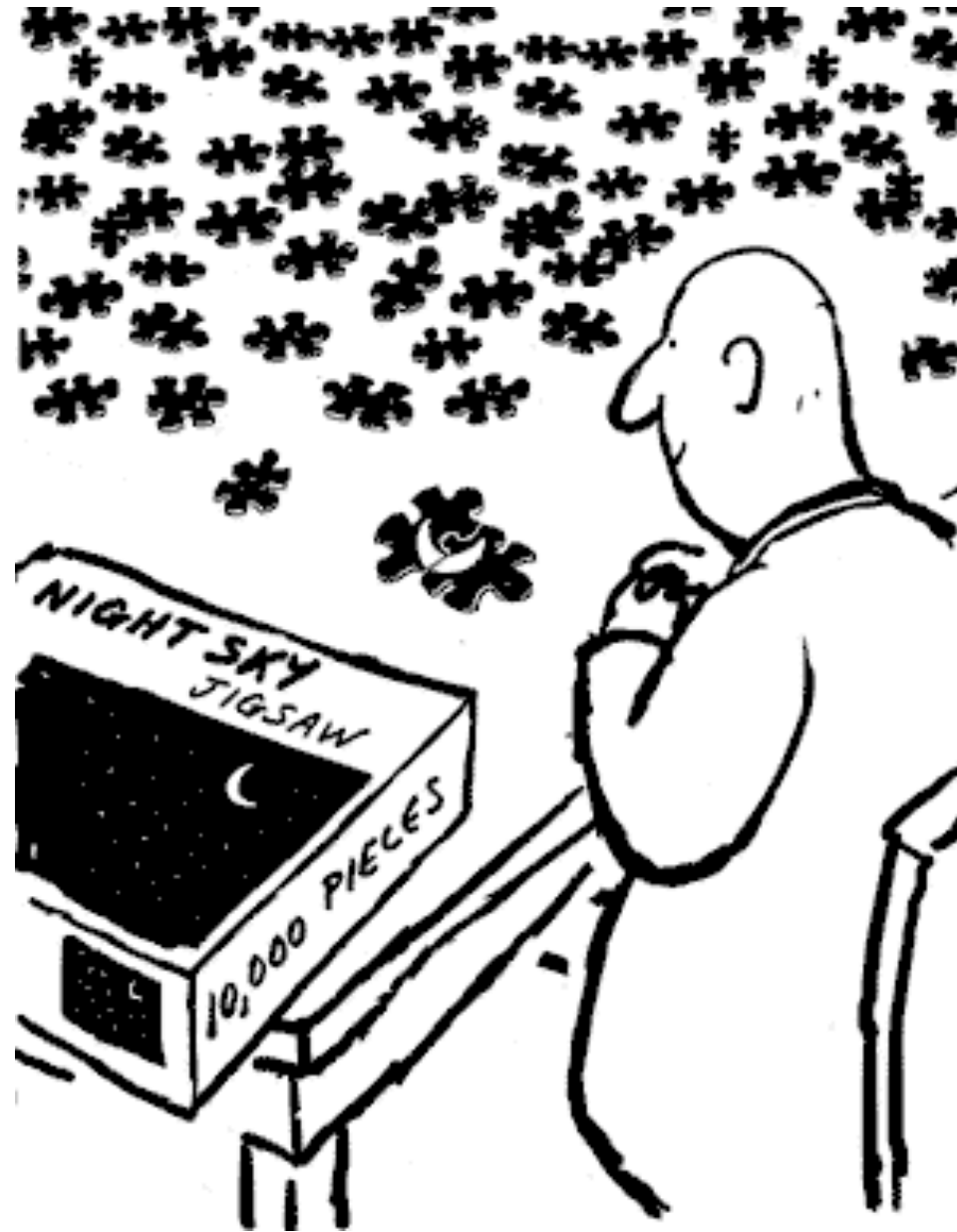
Q. What happened before the Big Bang ?

A. We cannot observe anything before the Big Bang, as far as we know. Therefore science cannot address this question.



Mapping the Universe

What is the Universe made of?

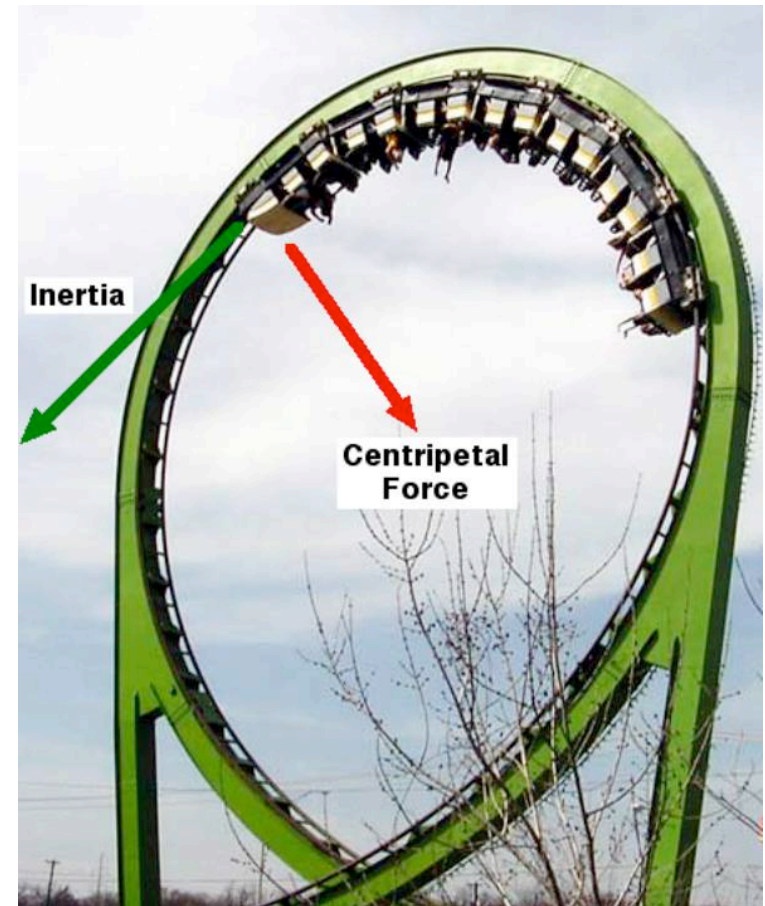
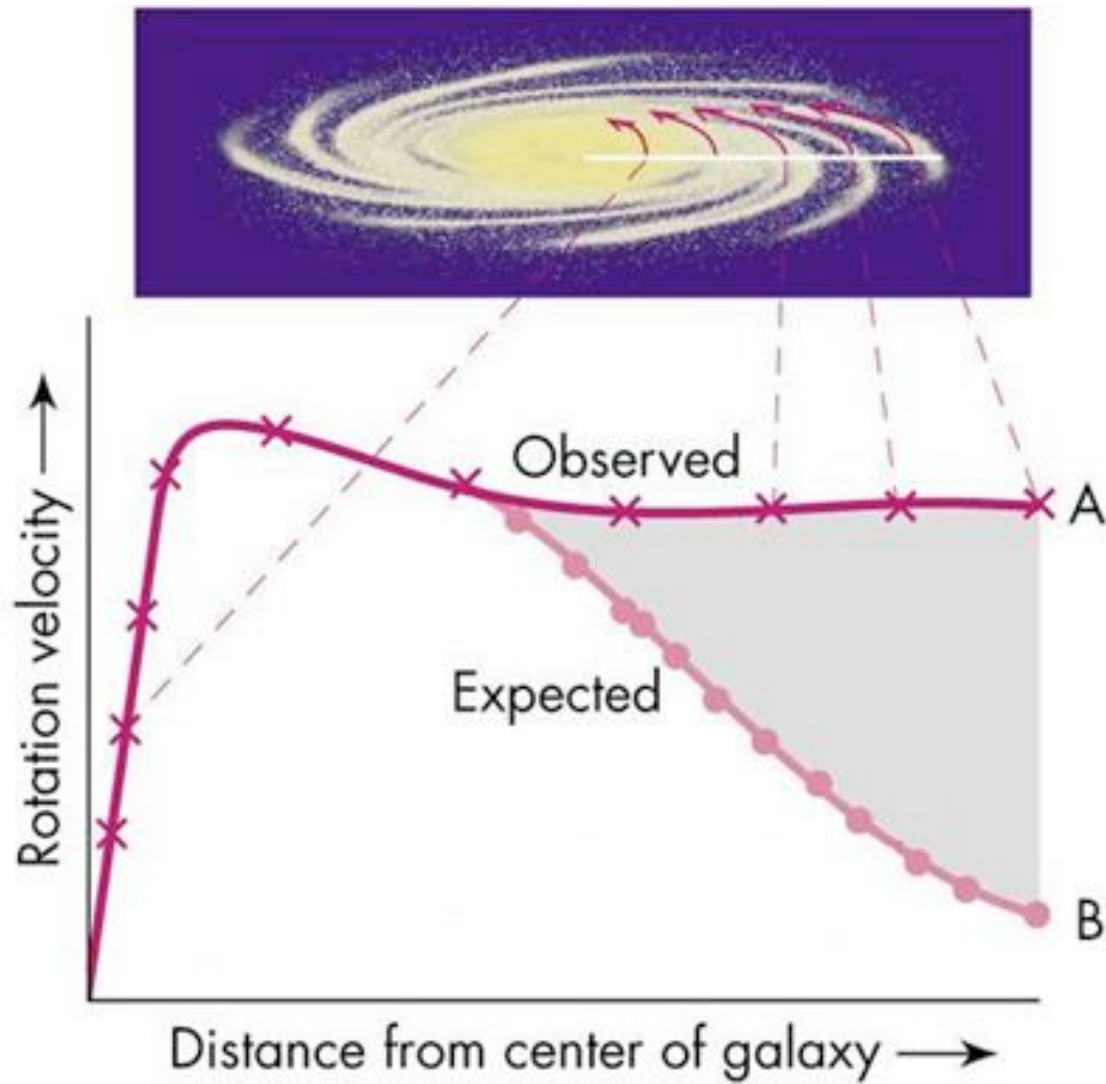


Dark matter

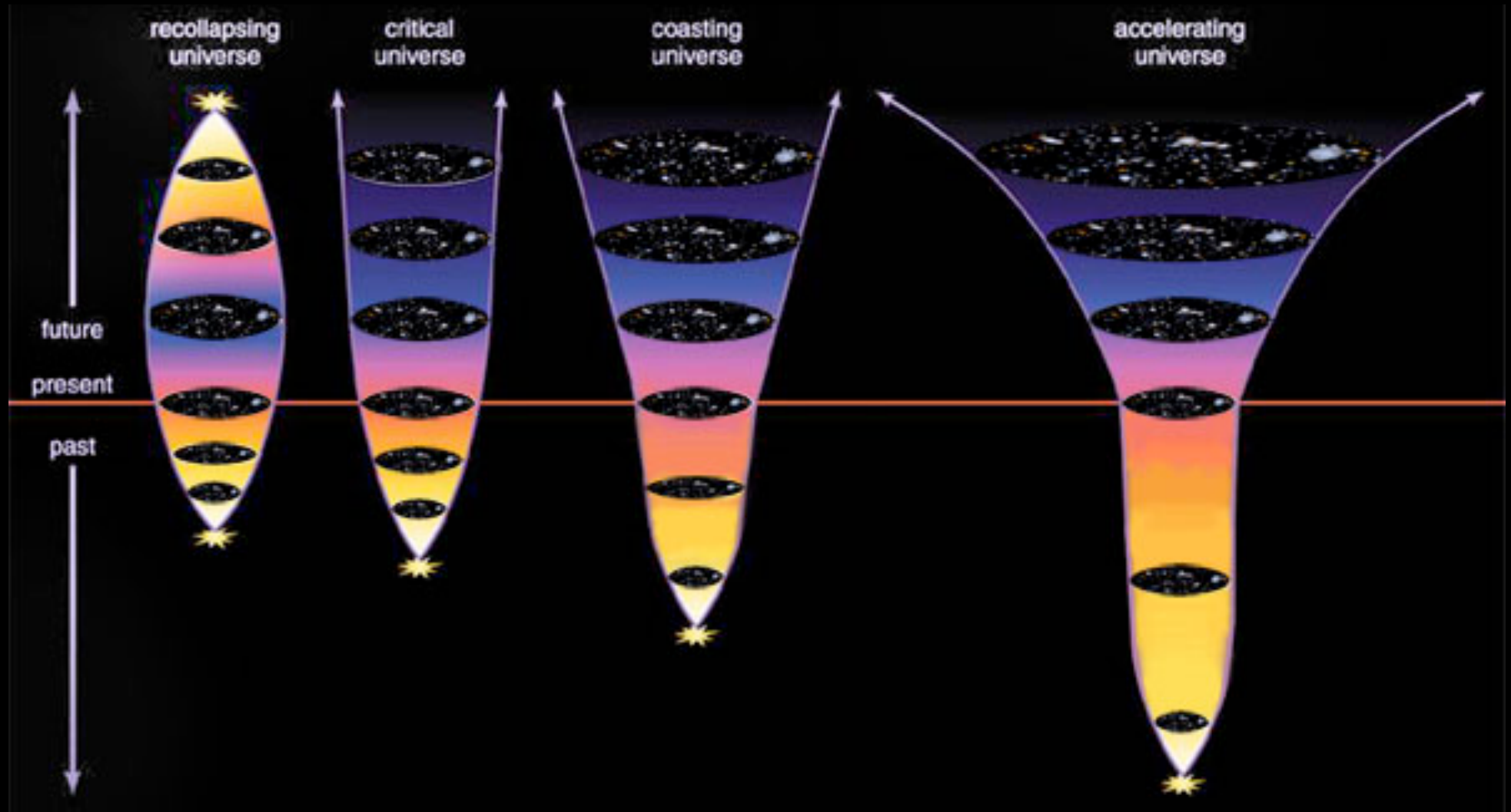


NGC 3370

Dark matter



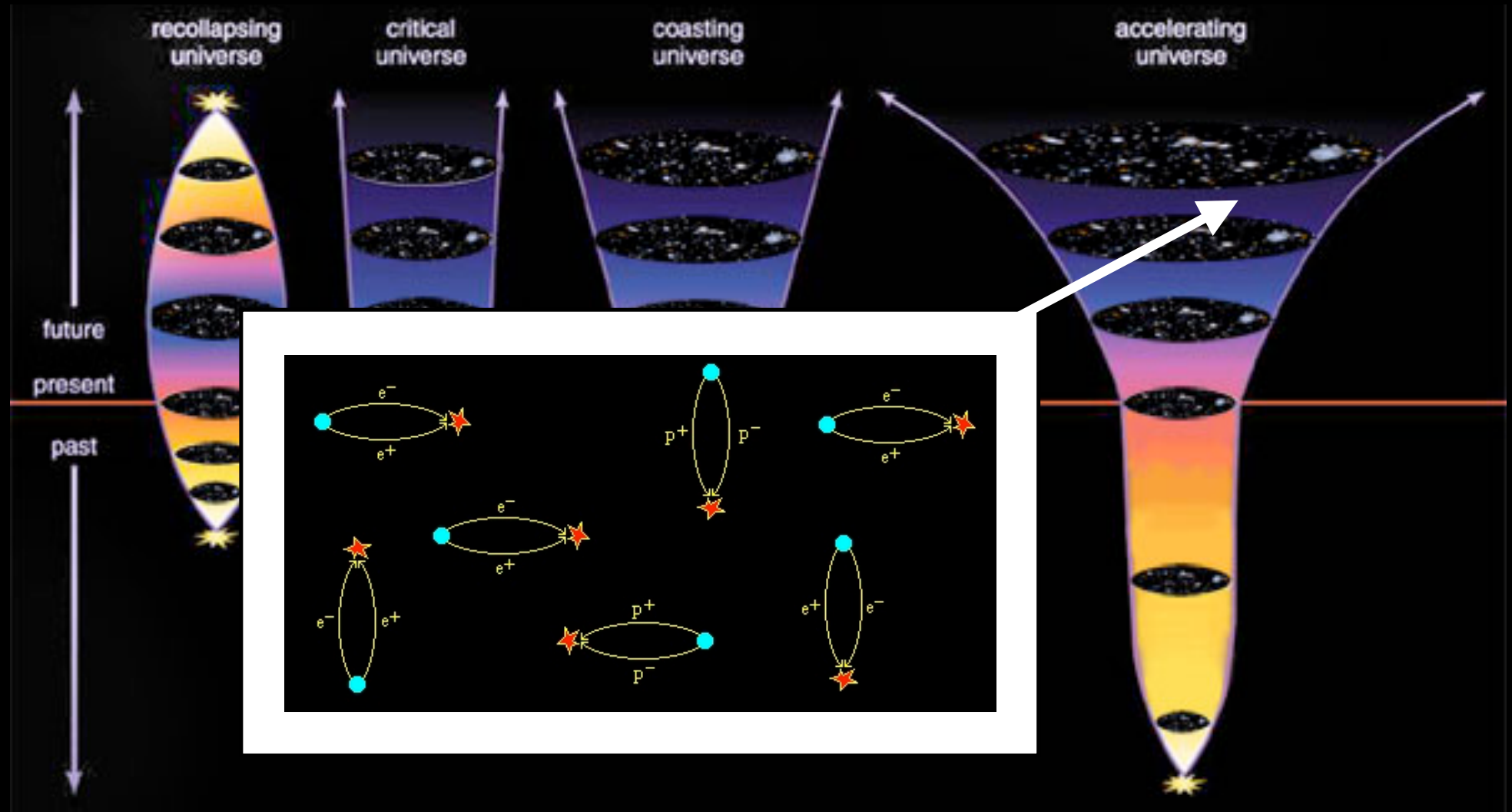
Does that explain everything?



Dark matter
dominates

Dark energy
dominates

Does that explain everything?



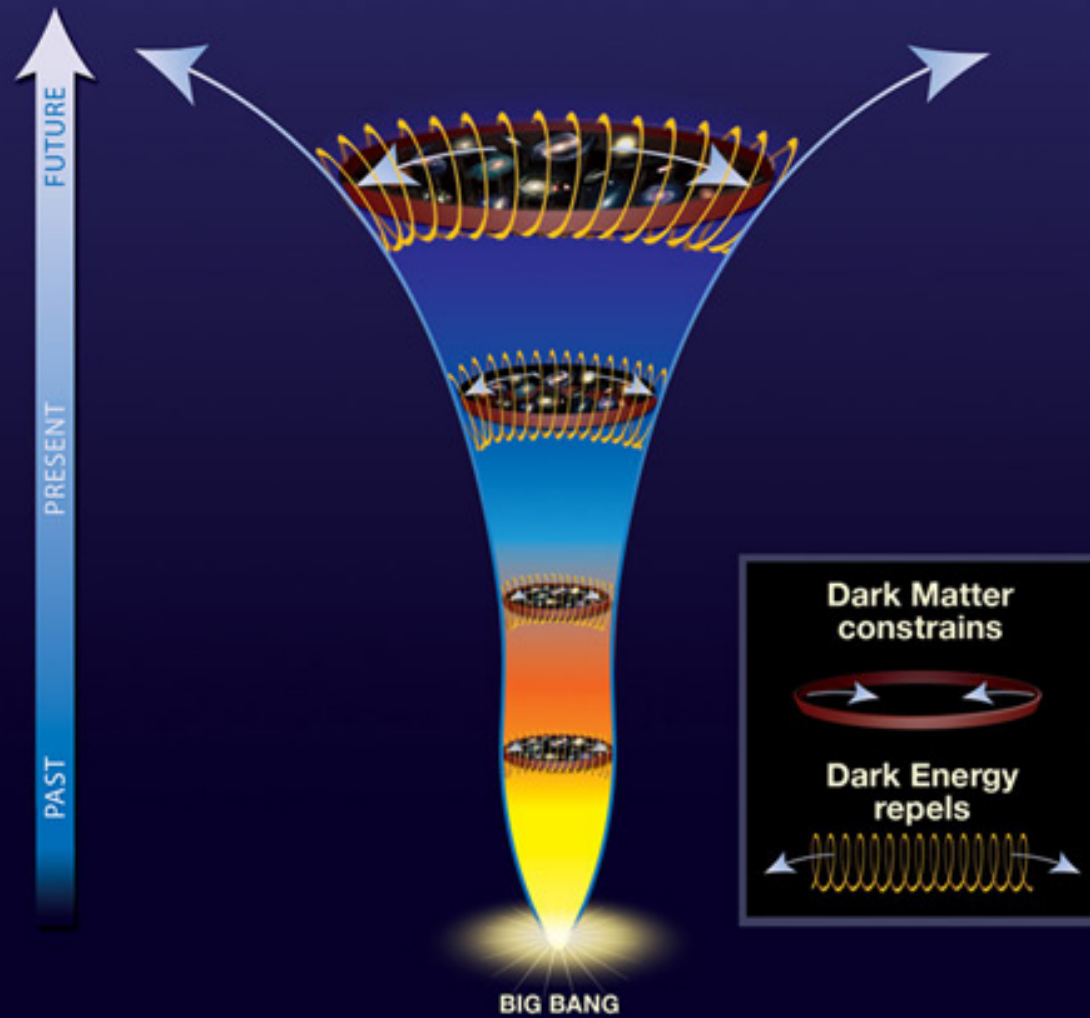
**Dark matter
dominates**

**Dark energy
dominates**

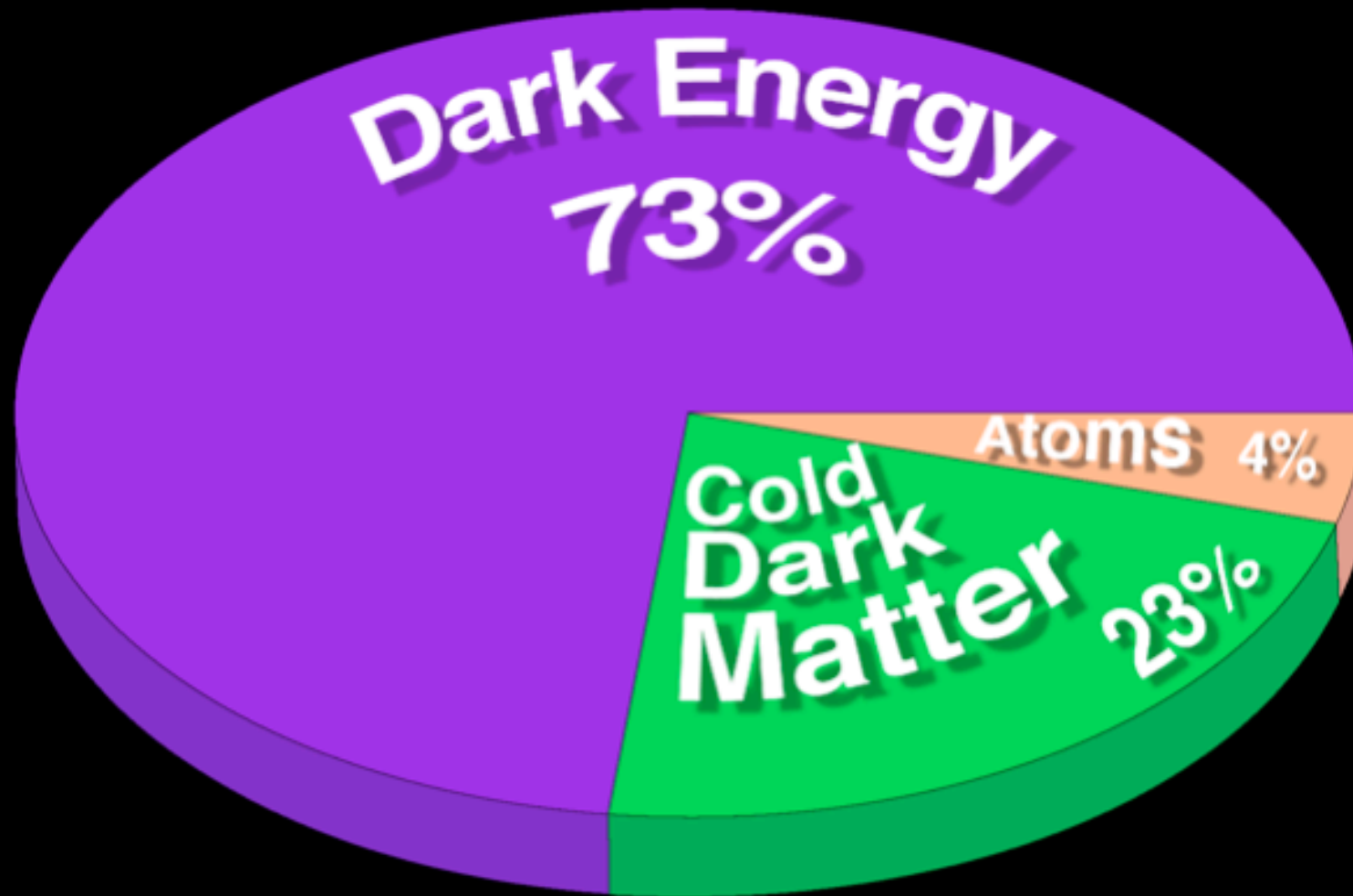
The cosmic tug of war

Cosmic tug of war

The force of dark energy surpasses that of dark matter as time progresses.



What is the Universe made of?



Our own backyard ...



M32

M31

M110

Our own backyard ...

SMC

LMC



Our own backyard ...

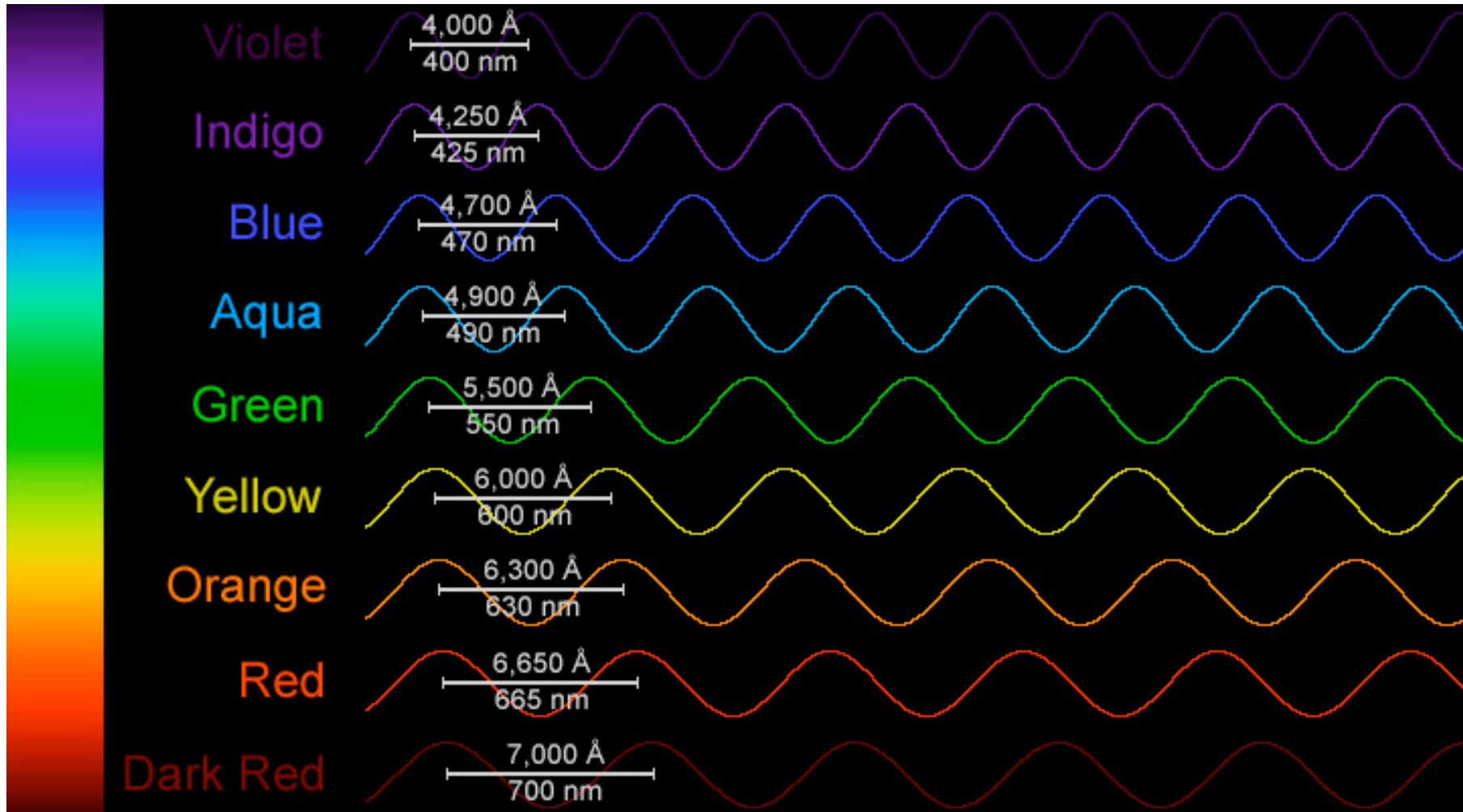
The LOCAL GROUP

Figure 18.17 These are the galaxies of the Local Group, arranged to represent their actual physical relationships to the Milky Way <https://universe.oxfordjournals.org/doi/10.1093/oxfordjournals.oup.com/9780195316000.ch18>



- | | |
|----------------|----------------------------|
| (1) Milky Way | (17) NGC 205 |
| (2) Draco | (18) M32 |
| (3) Ursa Minor | (19) Andromeda I |
| (4) SMG | (20) Andromeda II |
| (5) LMG | (21) Andromeda (M31) |
| (6) Carina | (22) M33 |
| (7) Sextans | (23) LGS 3 |
| (8) Ursa Major | (24) IC 1613 |
| (9) Pegasus | (25) NGC 6822 |
| (10) Sculptor | (26) Sextans A |
| (11) Fornax | (27) Leo A |
| (12) Leo I | (28) IC 10 |
| (13) Leo II | (29) DDO 210 |
| (14) Maffei | (30) Wolf-Lundmark-Melotte |
| (15) NGC 185 | (31) IC 5152 |
| (16) NGC 147 | |

How can we make a map of the Universe?



Useful fact : the amount of redshift of the galaxy light tells us how far away it is

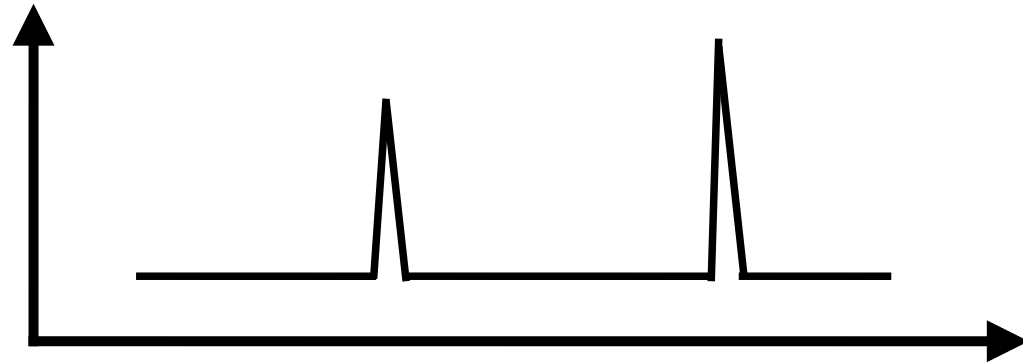
How can we make a map of the Universe?



How can we make a map of the Universe?



Amount of light



Blue light

Red light

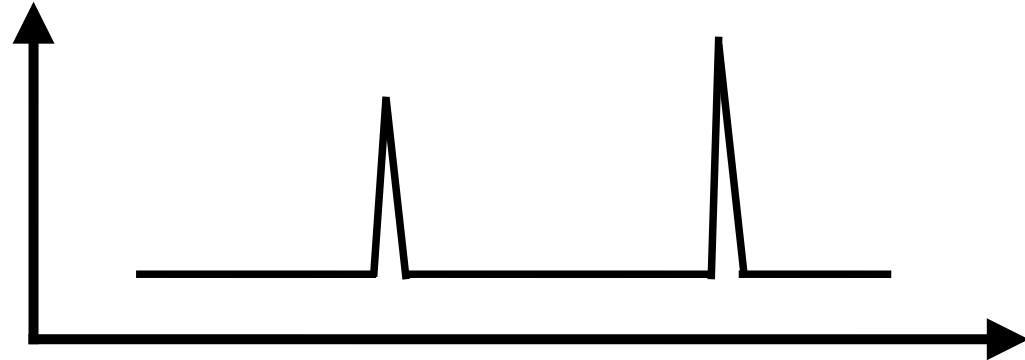
How can we make a map of the Universe?



Move further away...



Amount of light



Blue light

Red light

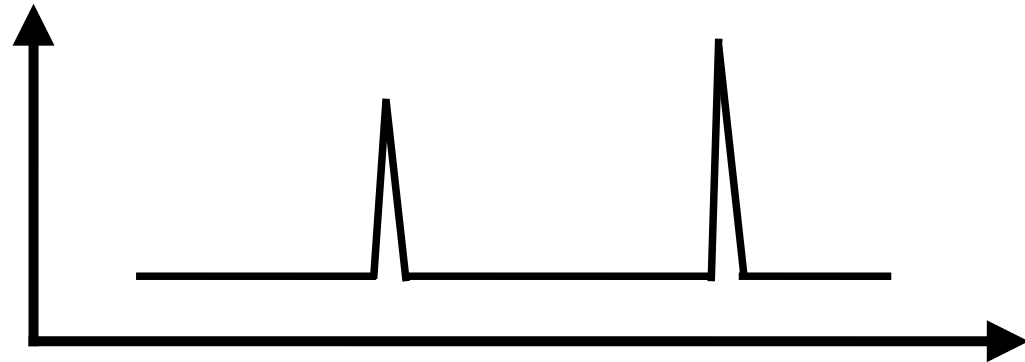
How can we make a map of the Universe?



Move further away...



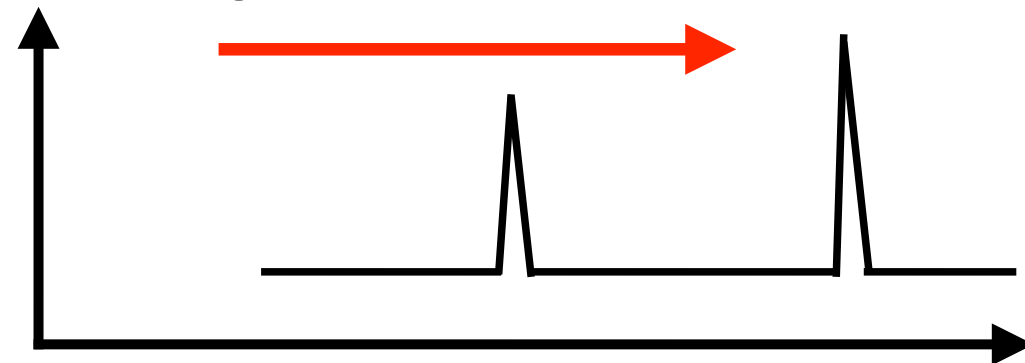
Amount of light



Blue light

Red light

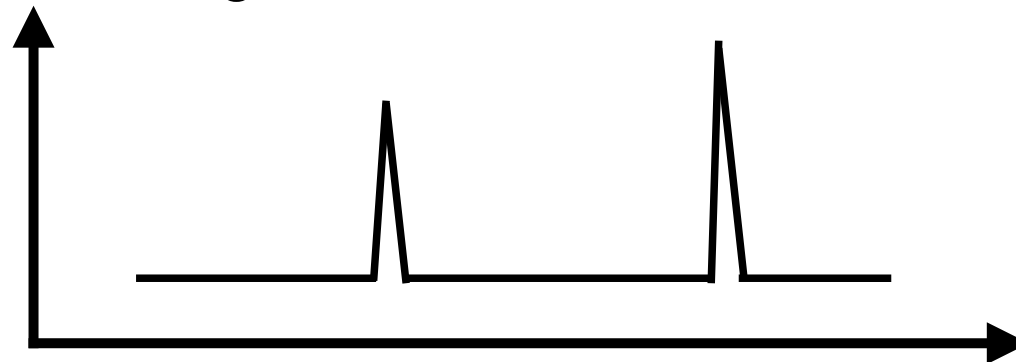
Amount of light



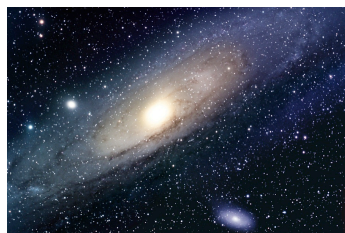
How can we make a map of the Universe?



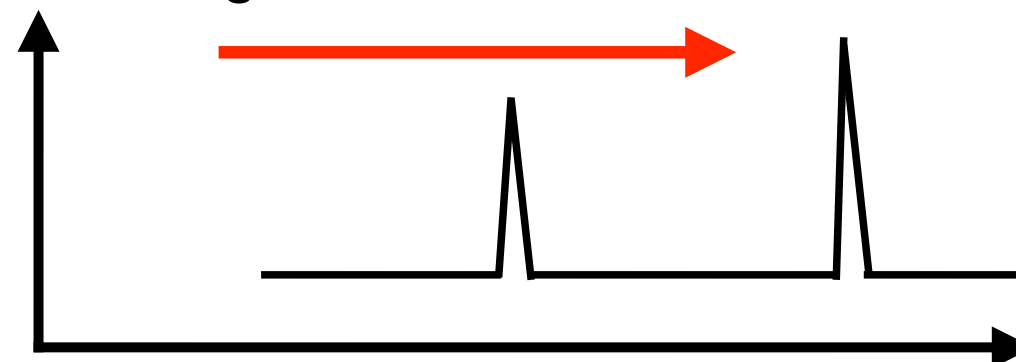
Amount of light



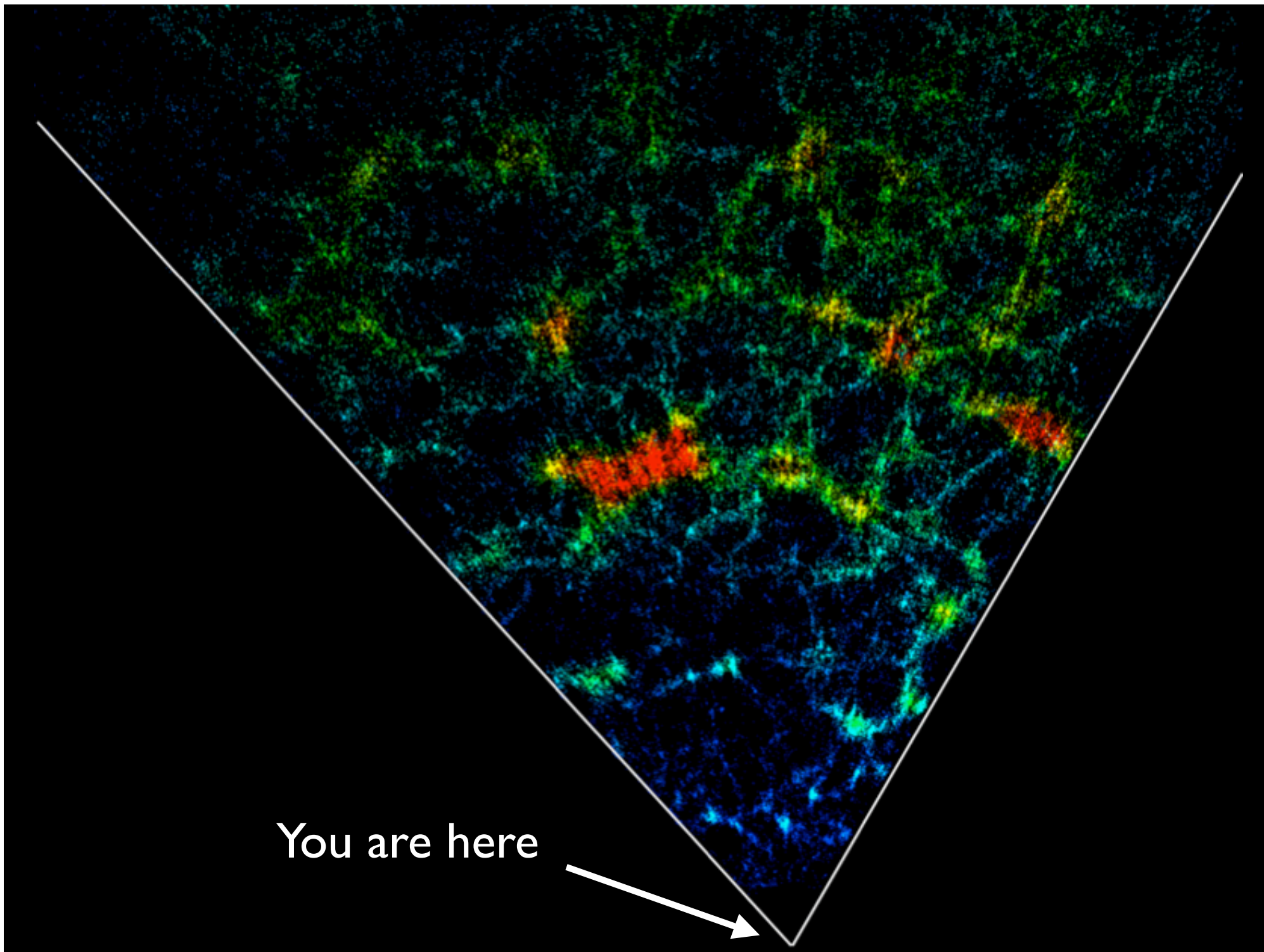
Move further away...



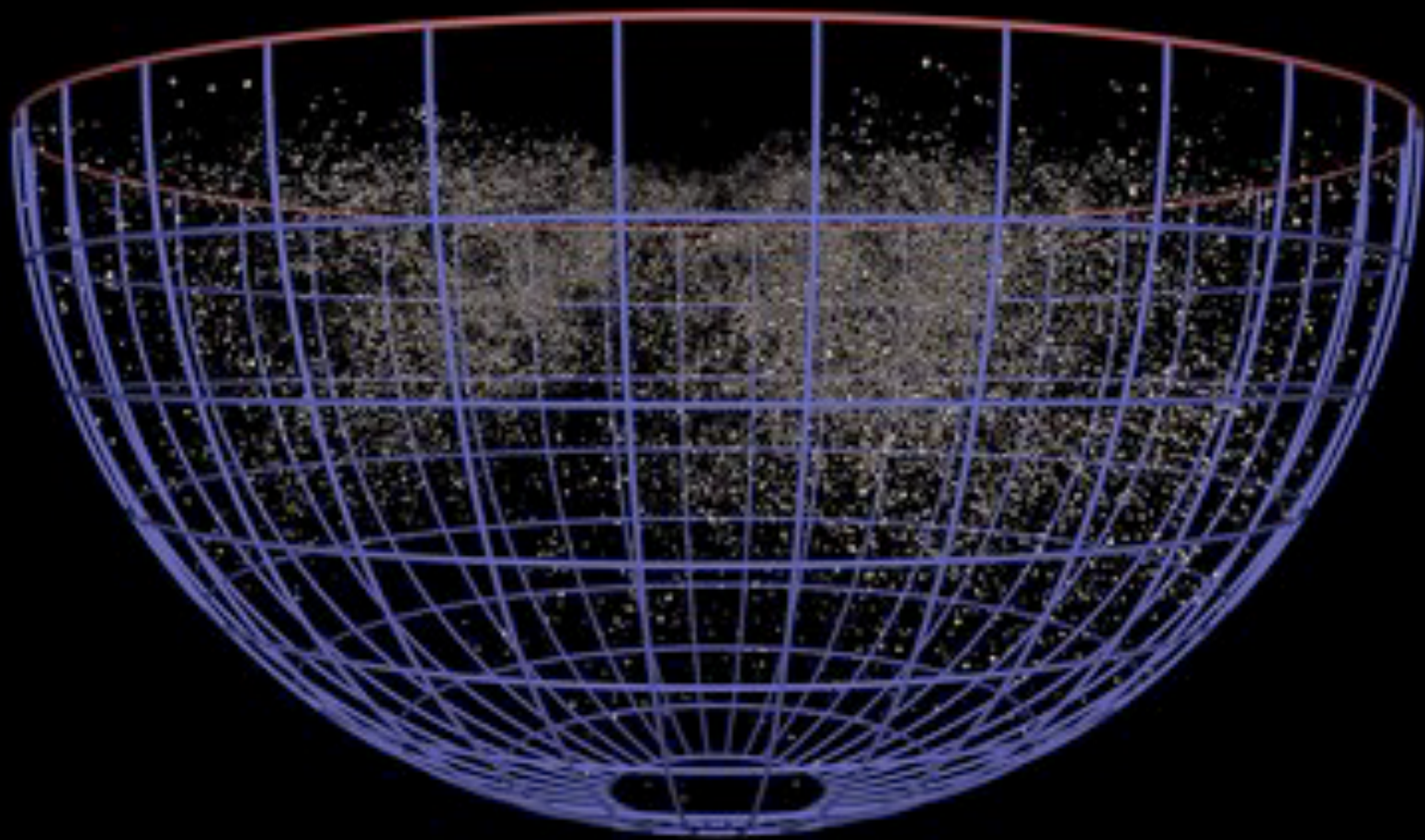
Amount of light



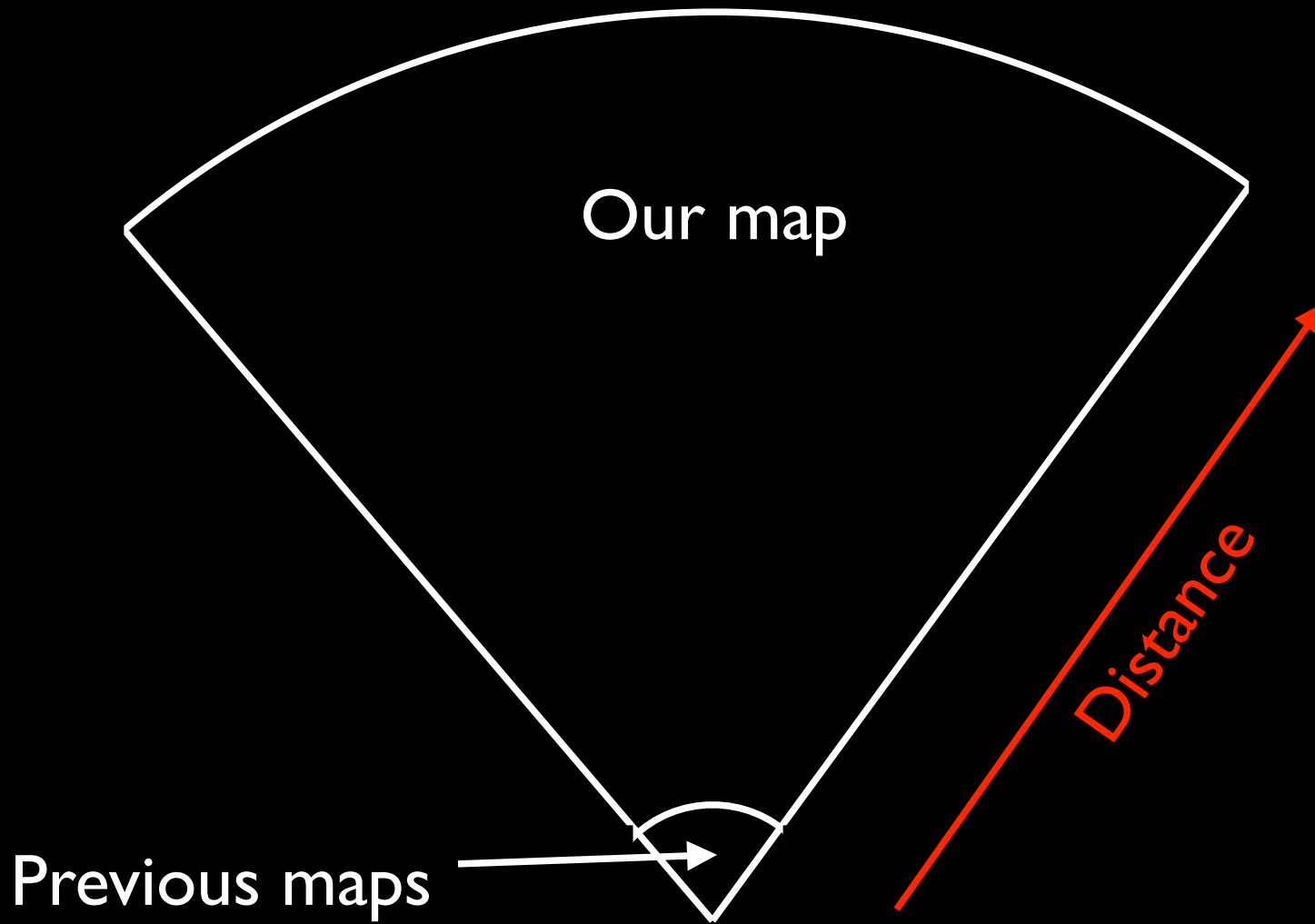
Shift in spectrum of galaxy tells us how far away it is



You are here



A new and larger map

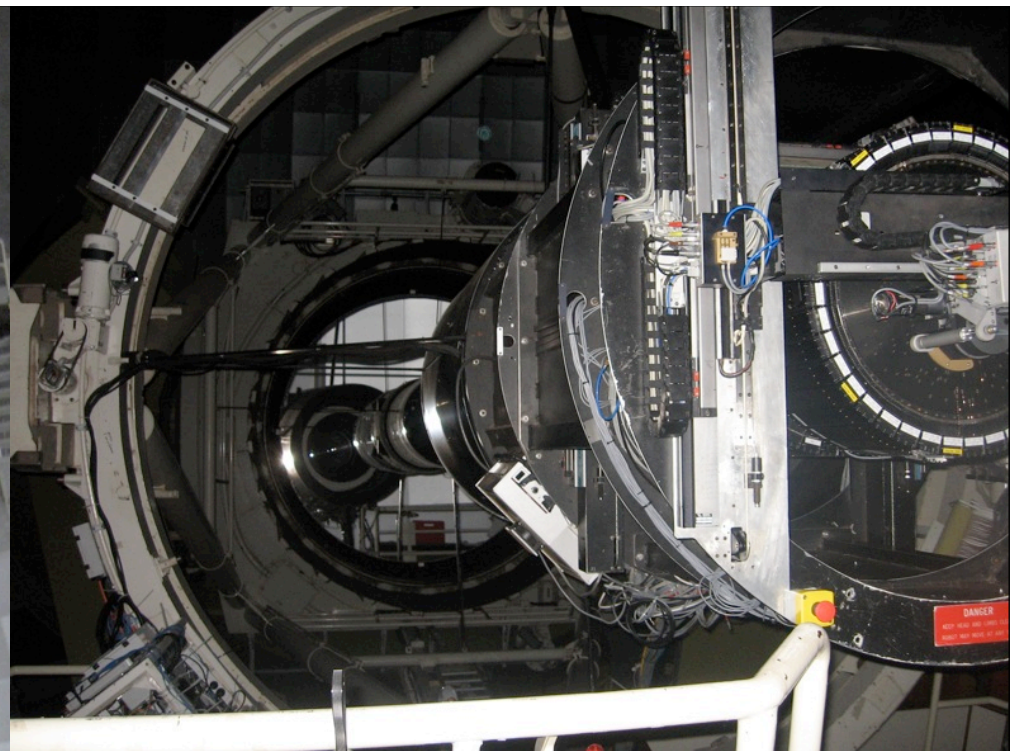


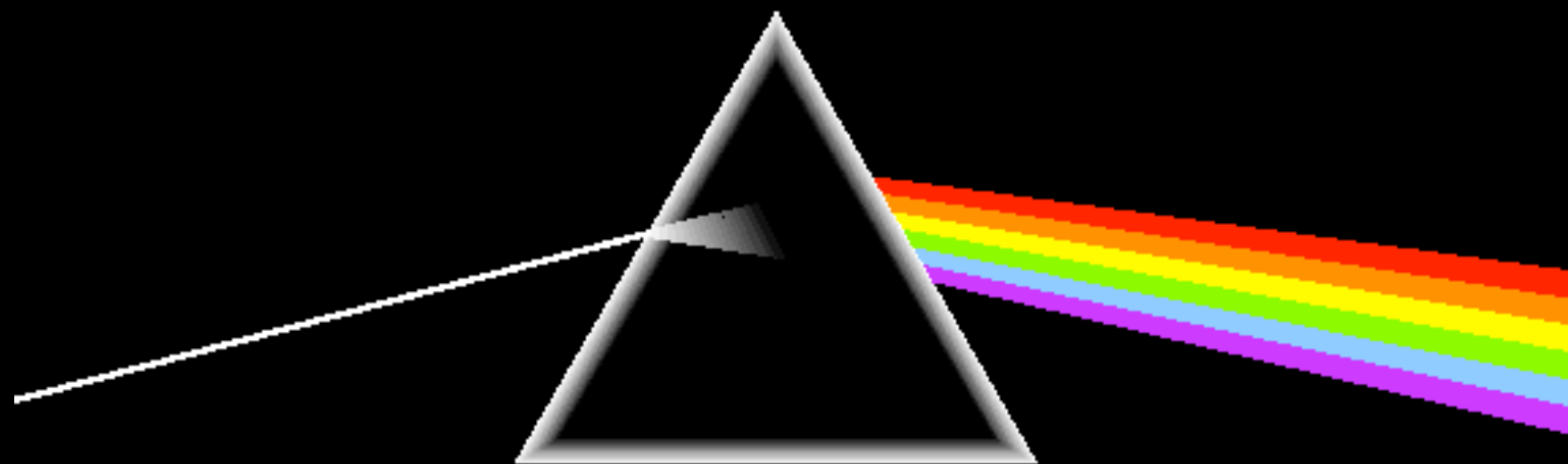


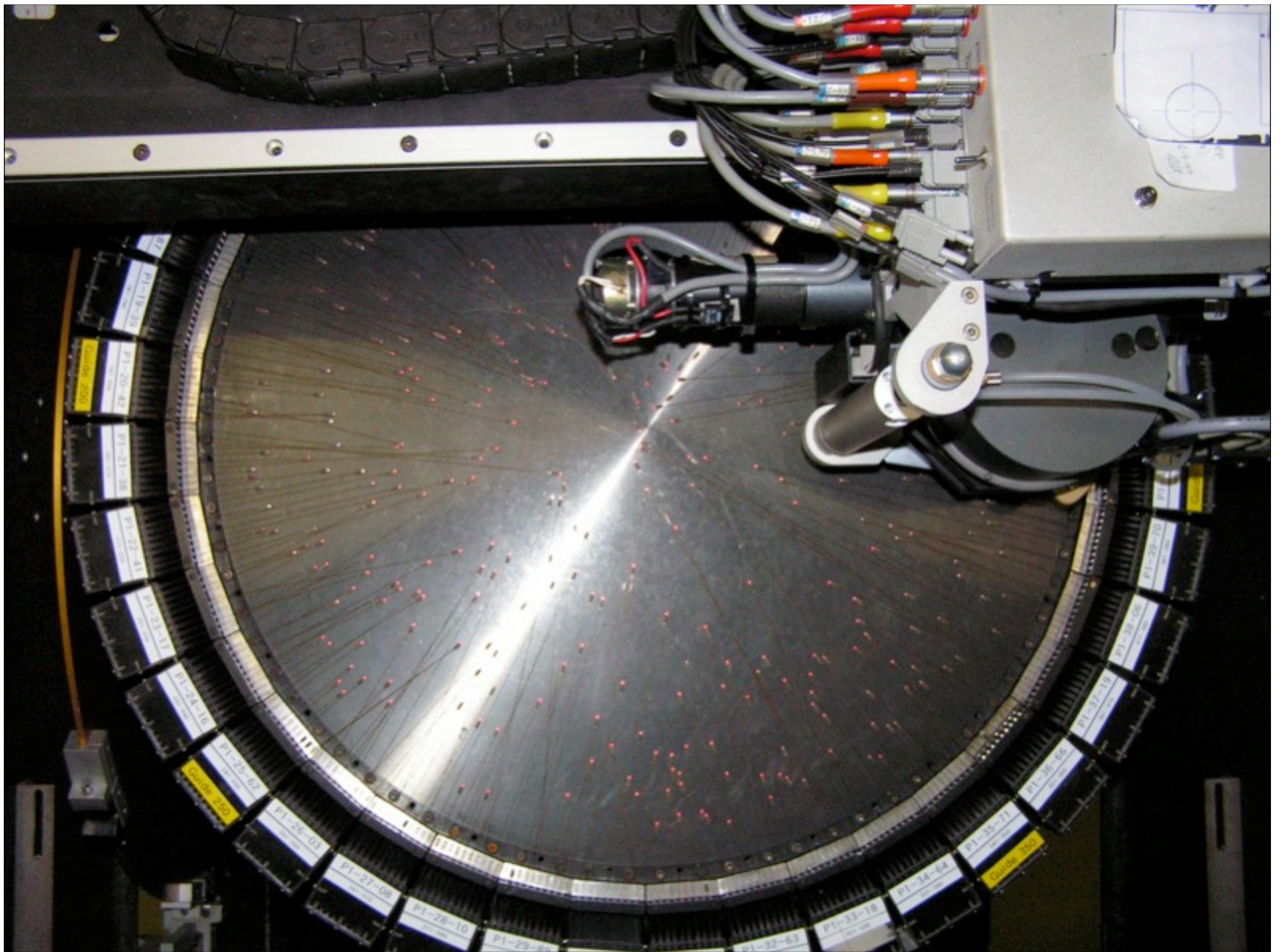


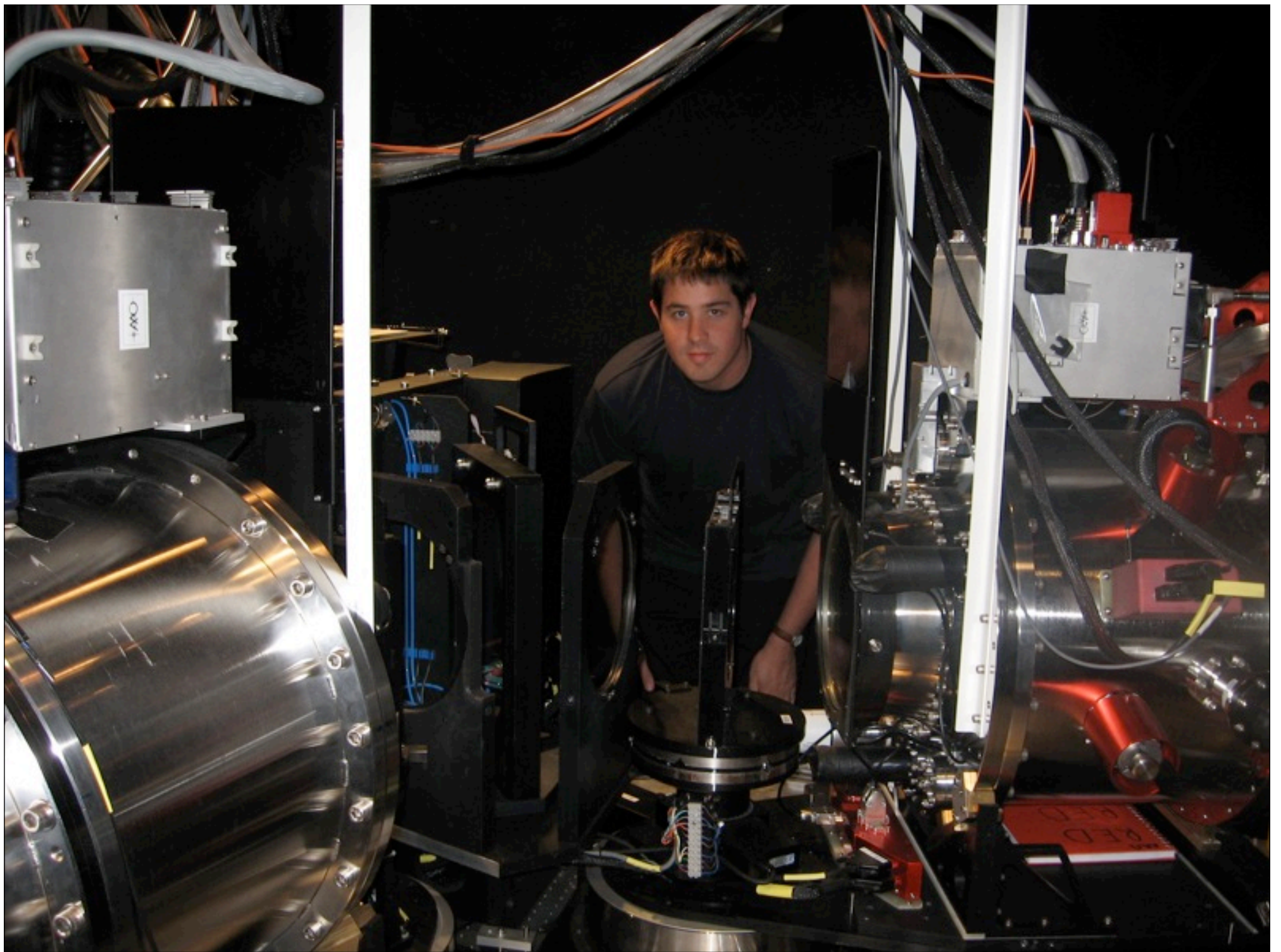












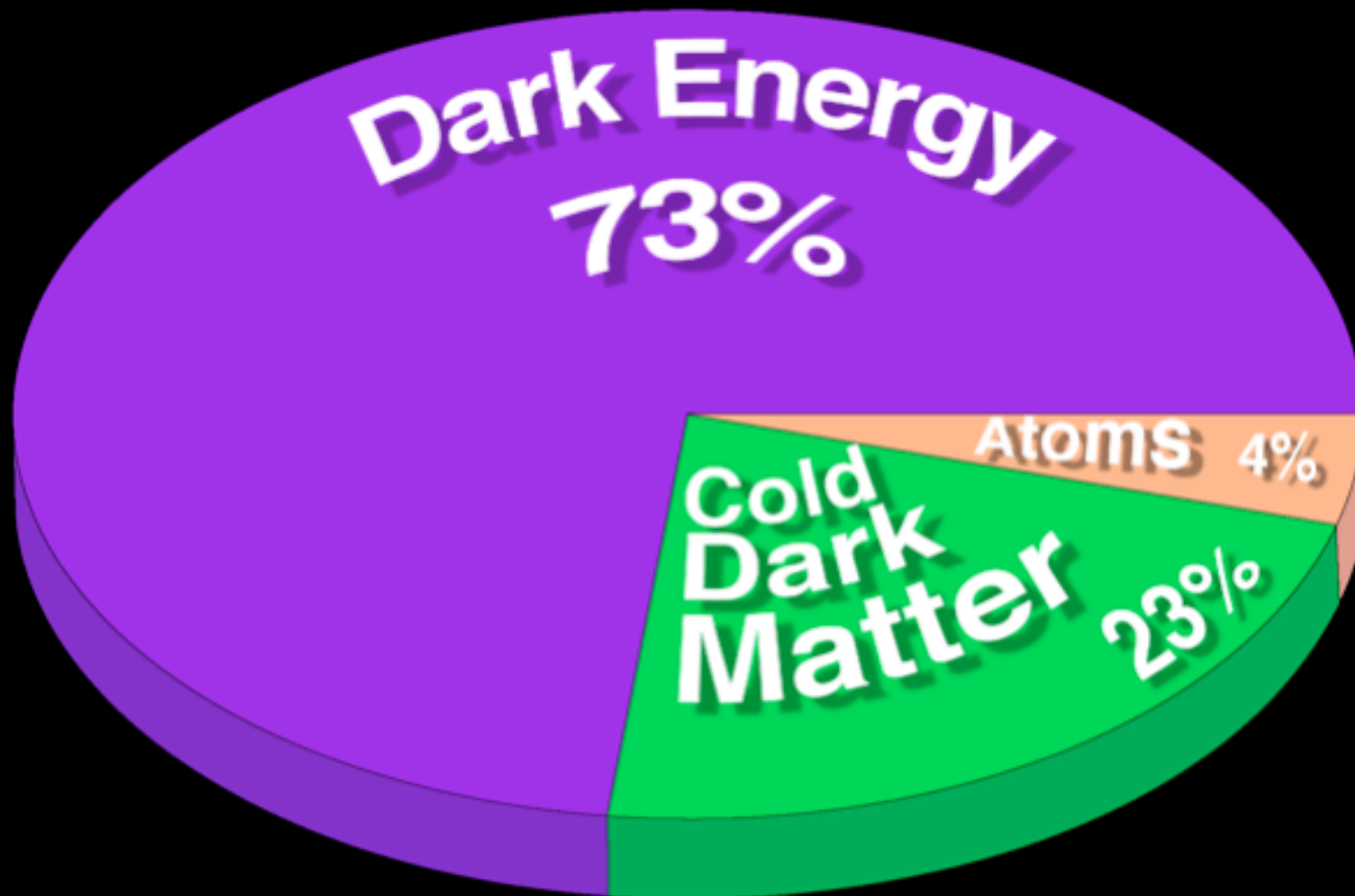




5

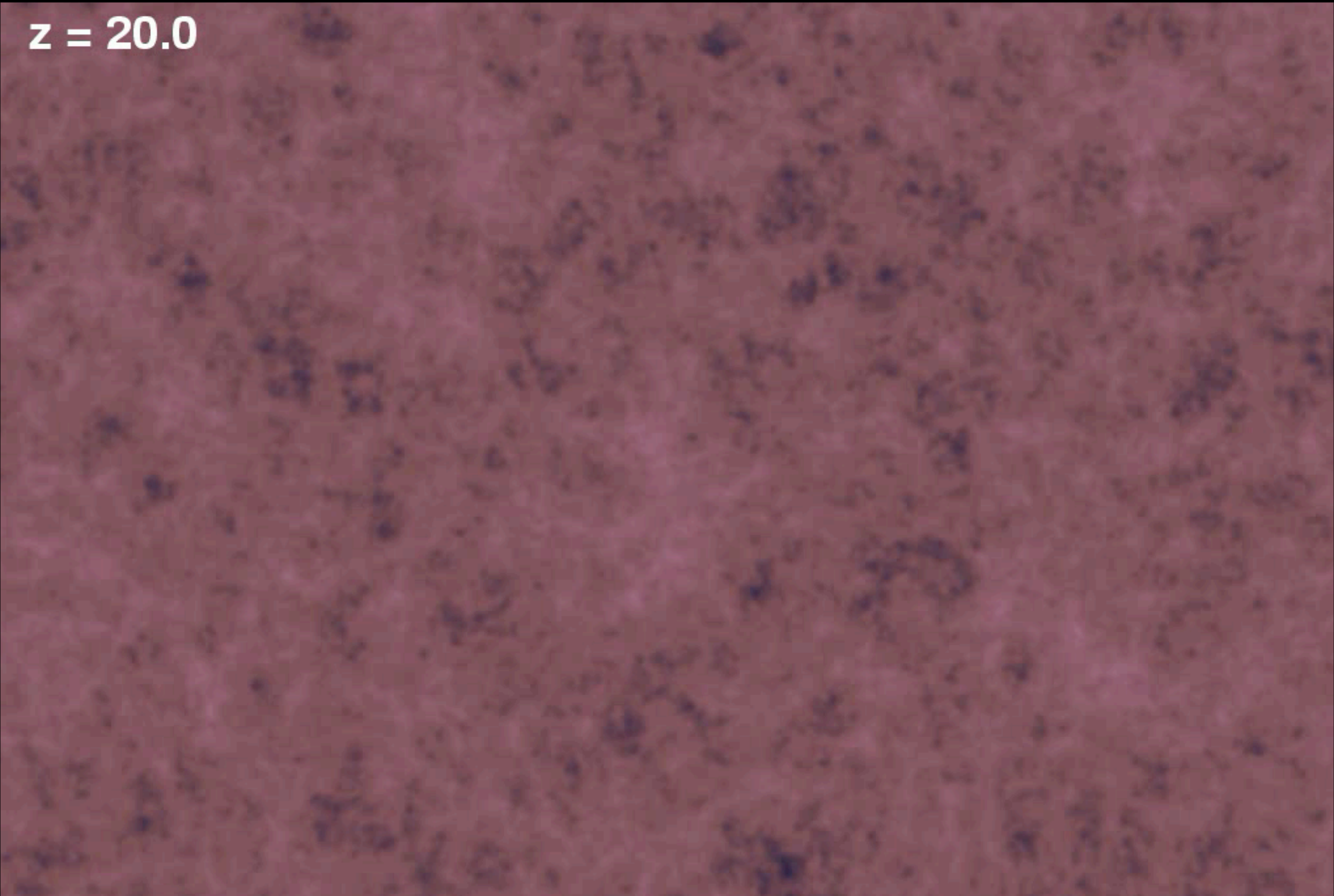
WARNING
IN CASE OF
FIRE
DO NOT USE
LIFT





The Universe inside a computer ...

$z = 20.0$

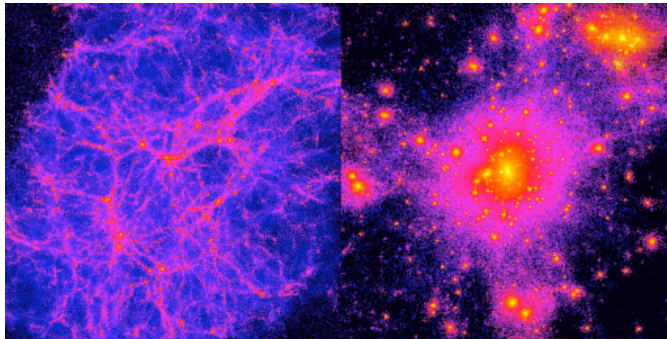
The image displays a simulated view of the universe at a high redshift of $z = 20.0$. The field is filled with a dense population of small, faint, reddish-brown and blueish spots, representing the early stages of galaxy formation. The overall appearance is a noisy, textured field of light against a dark background, characteristic of a high-redshift galaxy survey.

The Universe inside a computer ...

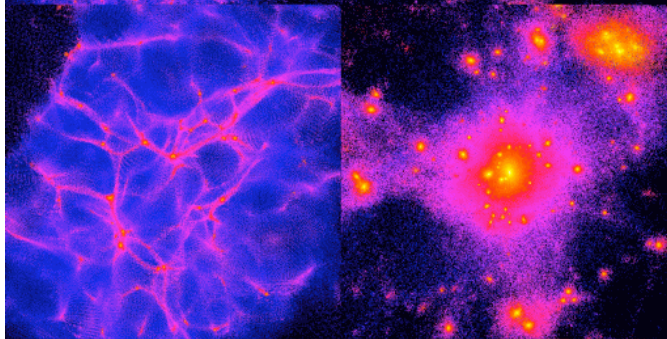
Dark matter?

Dark energy?

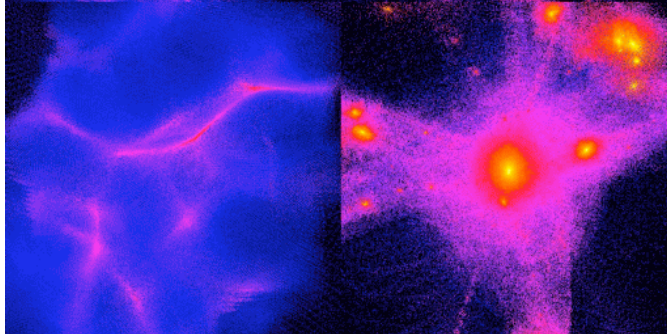
Cold



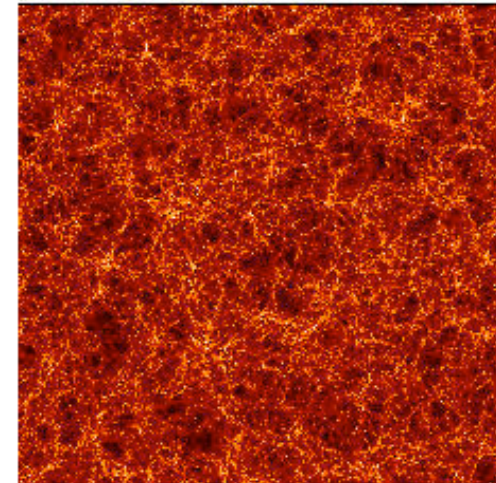
Warm



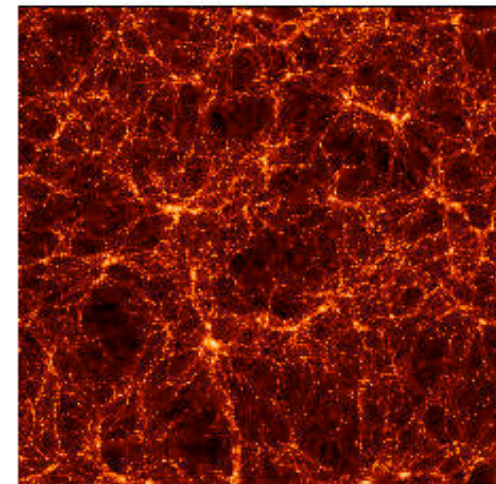
Hot



Yes



No



Mapping the Universe

- The redshift of a galaxy tells us how far away it is
- The patterns in the galaxy map tell us about the properties of dark matter and dark energy

Thank you for coming !

