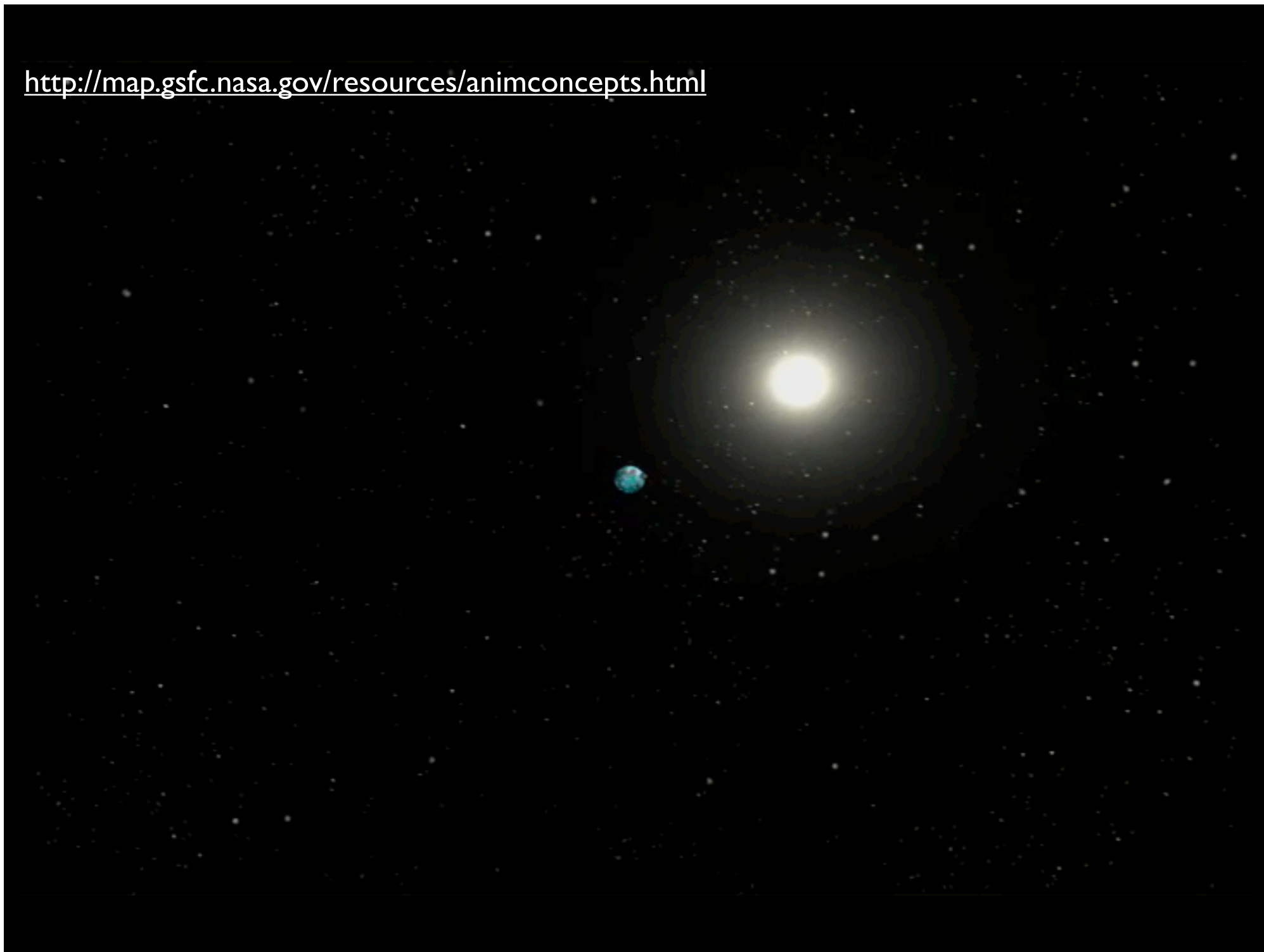
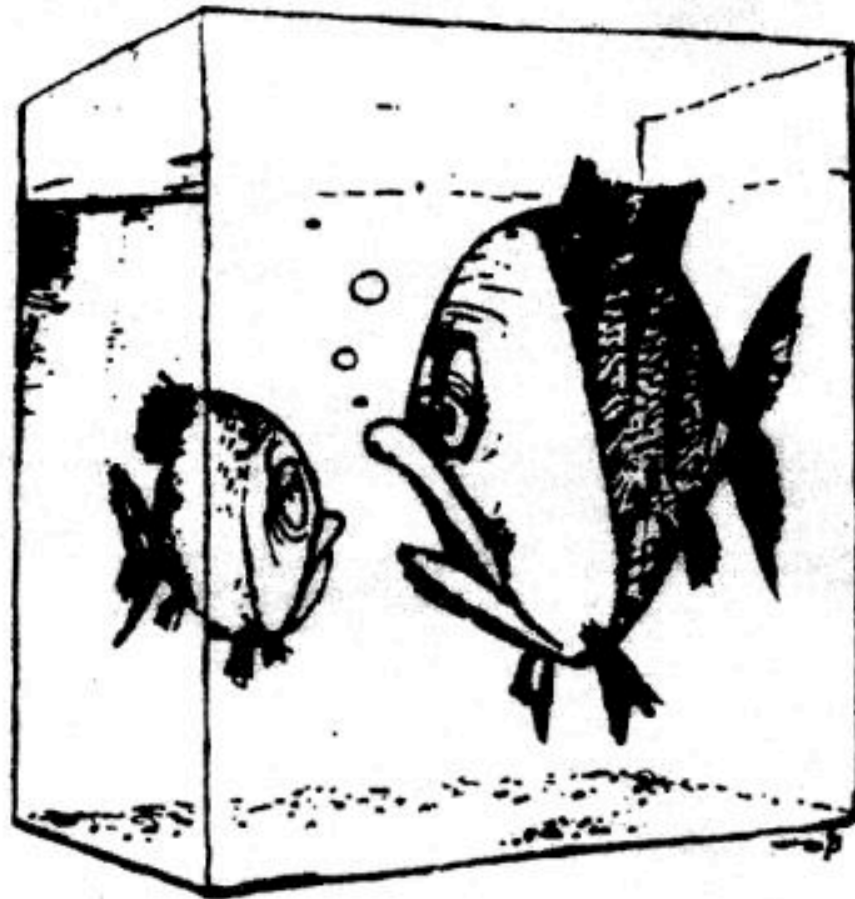


What is the  
Universe made of?

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

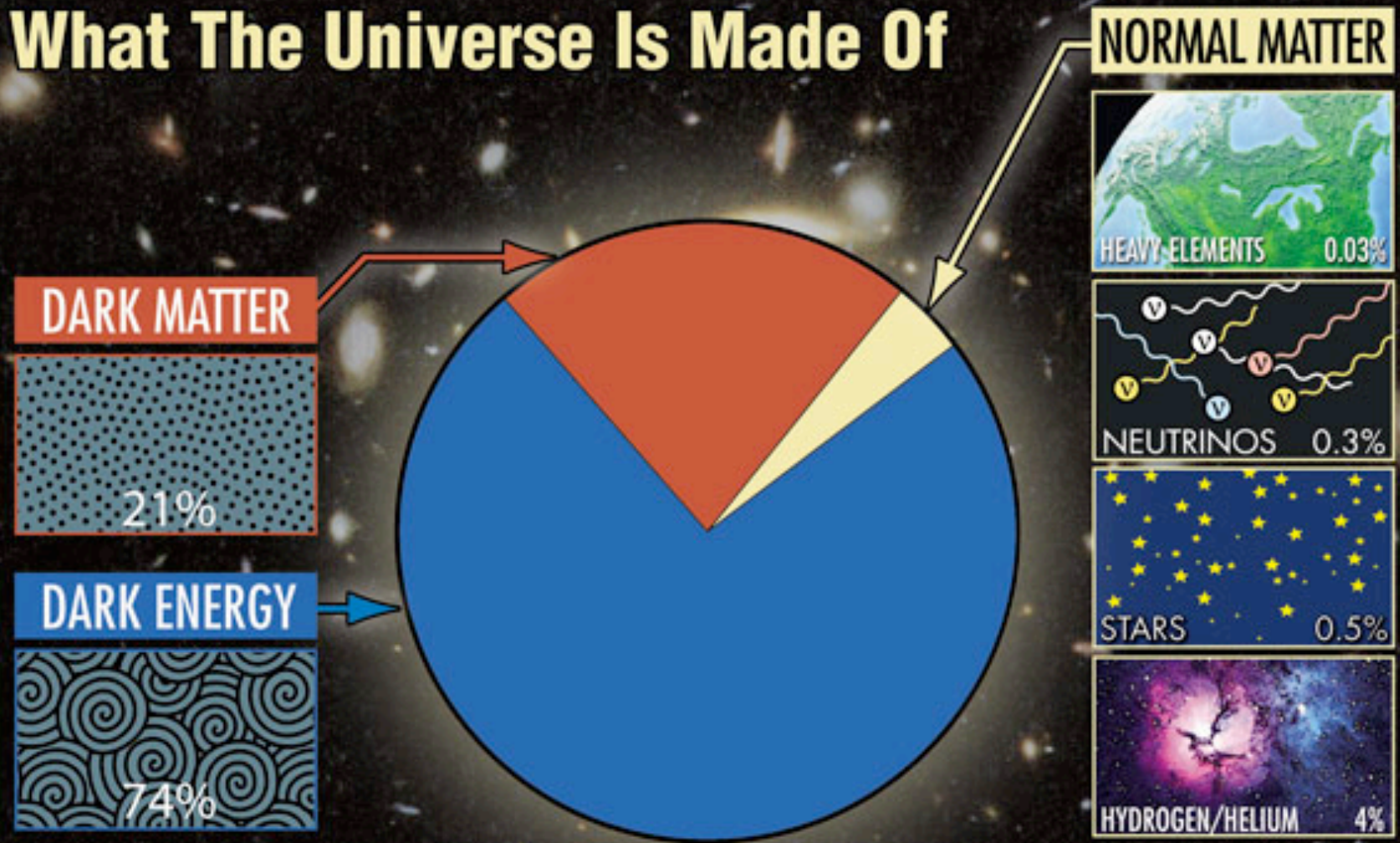






*'The universe, my  
son, is a large  
tank full of water*

# What The Universe Is Made Of



# The problem of dark matter



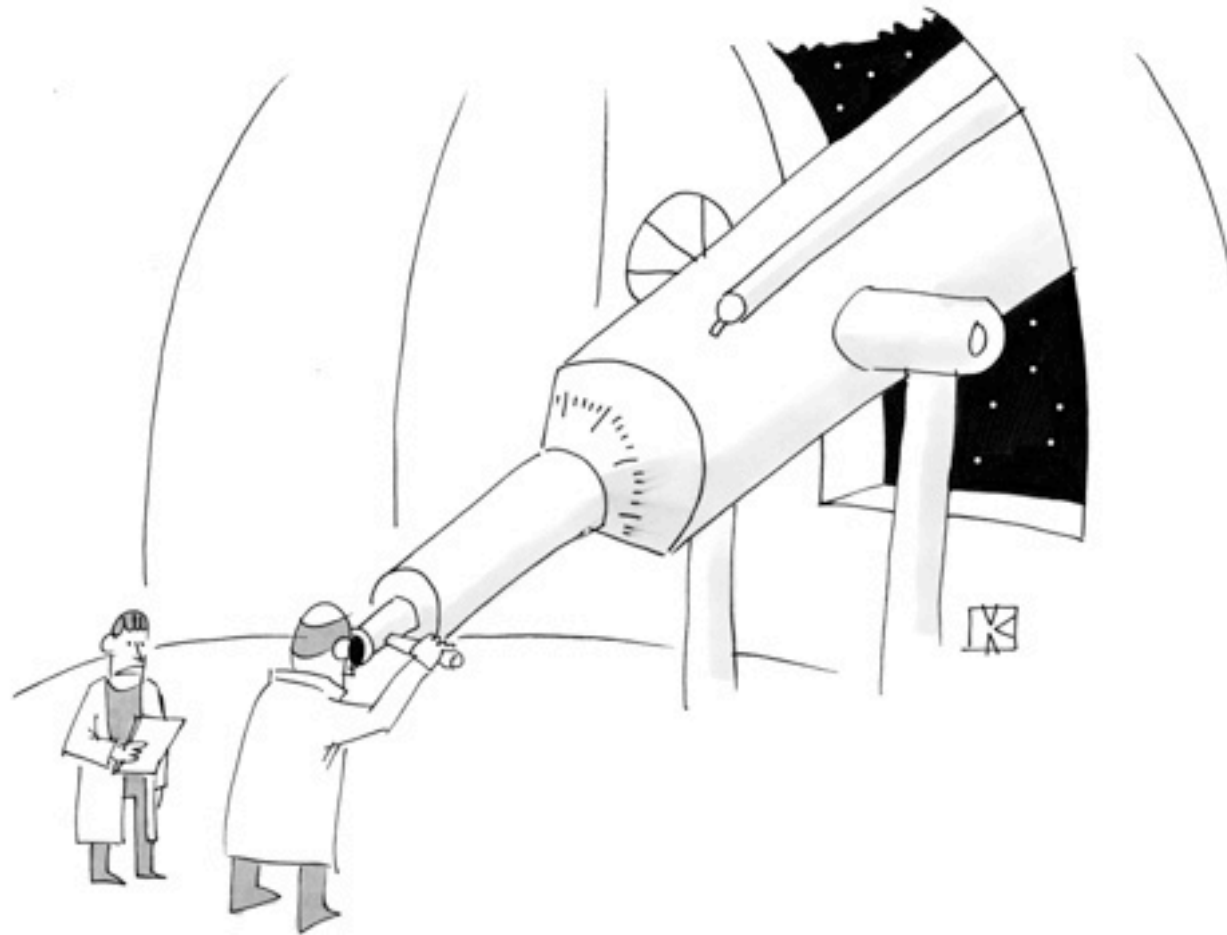
# The problem of dark matter



# The problem of dark matter

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*“That isn't dark matter, sir—you just forgot to take off the lens cap.”*



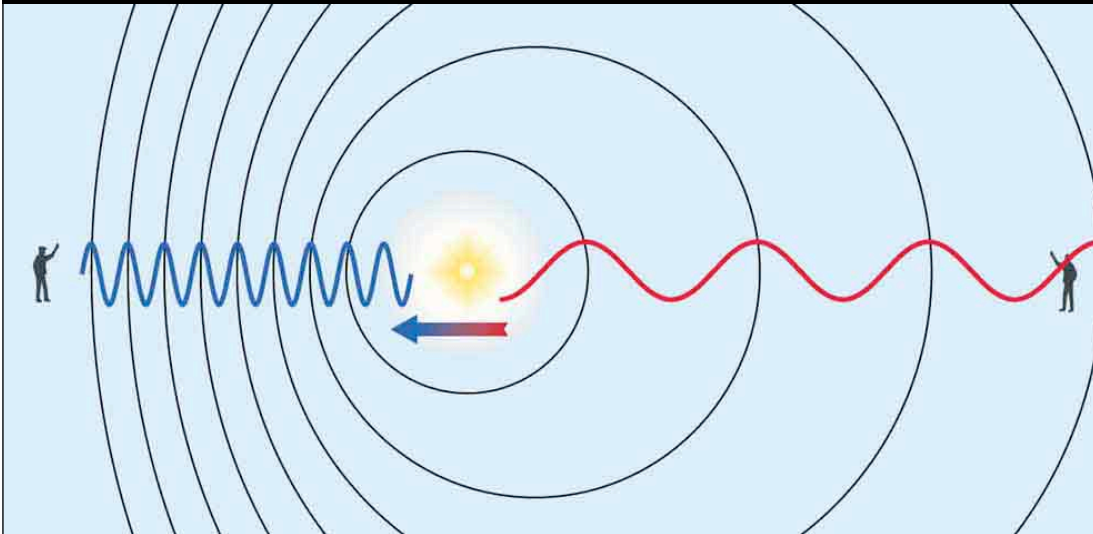
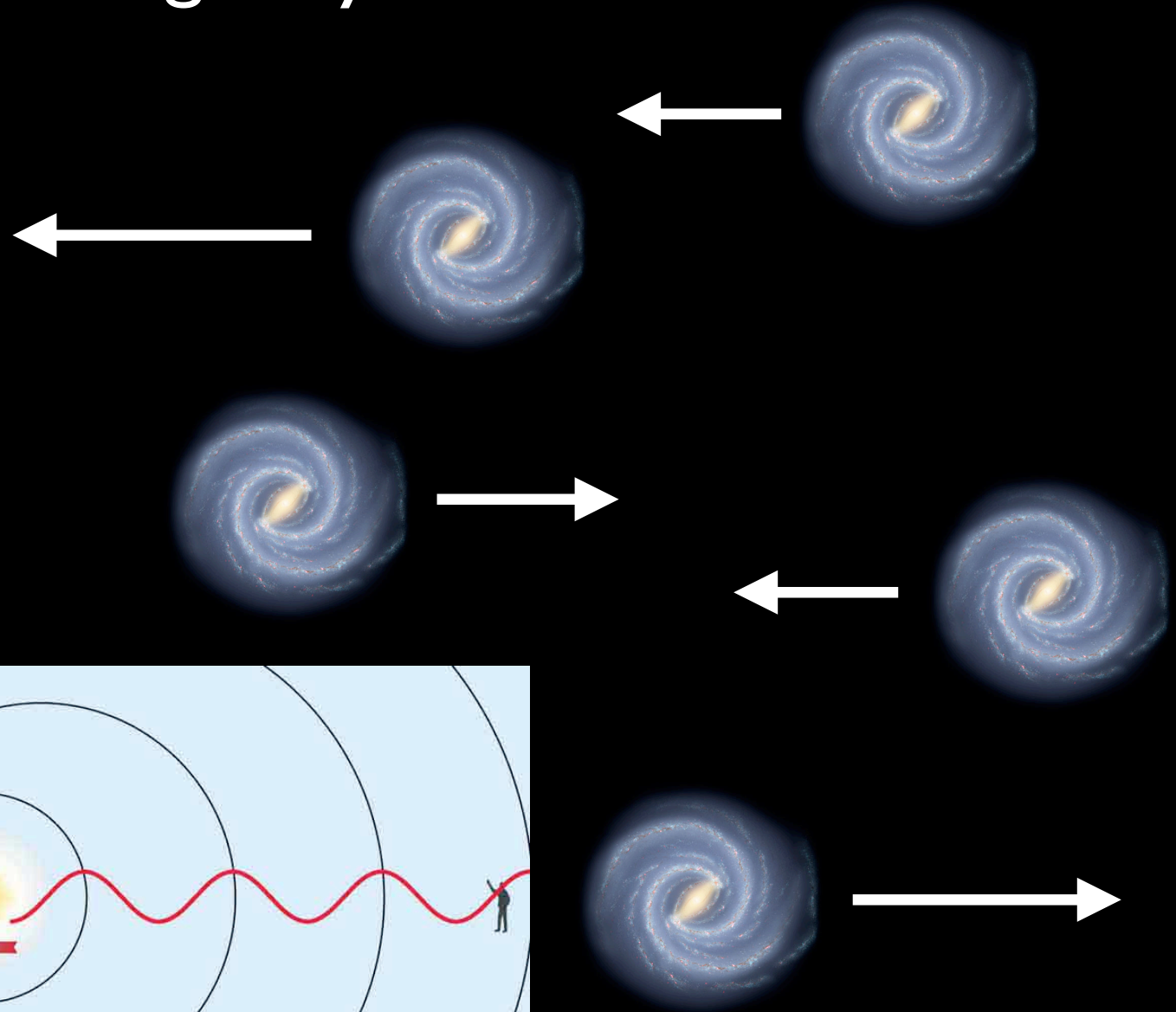
# Galaxy groups



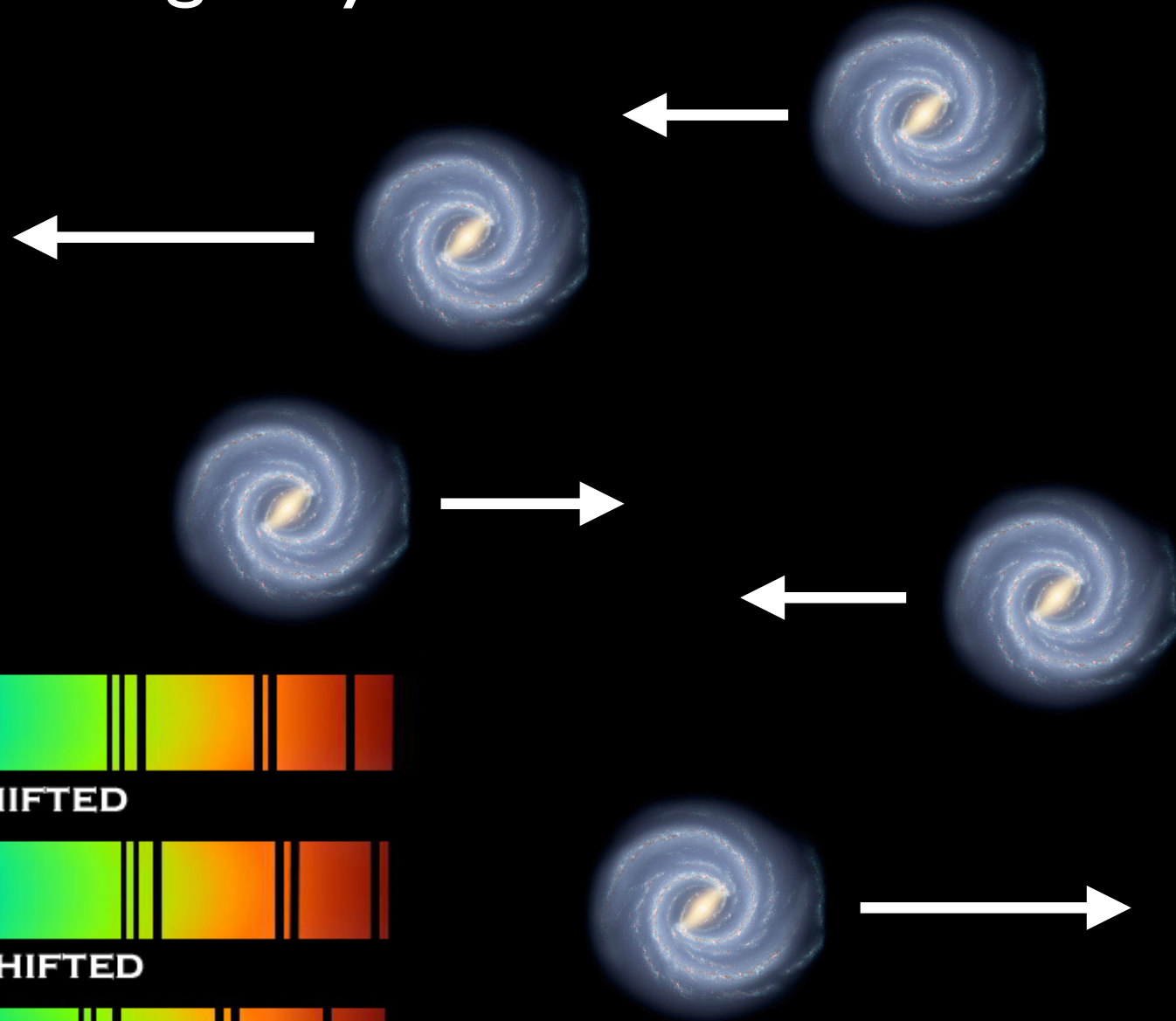
# Dark matter in galaxy clusters



# Dark matter in galaxy clusters



# Dark matter in galaxy clusters



UNSHIFTED

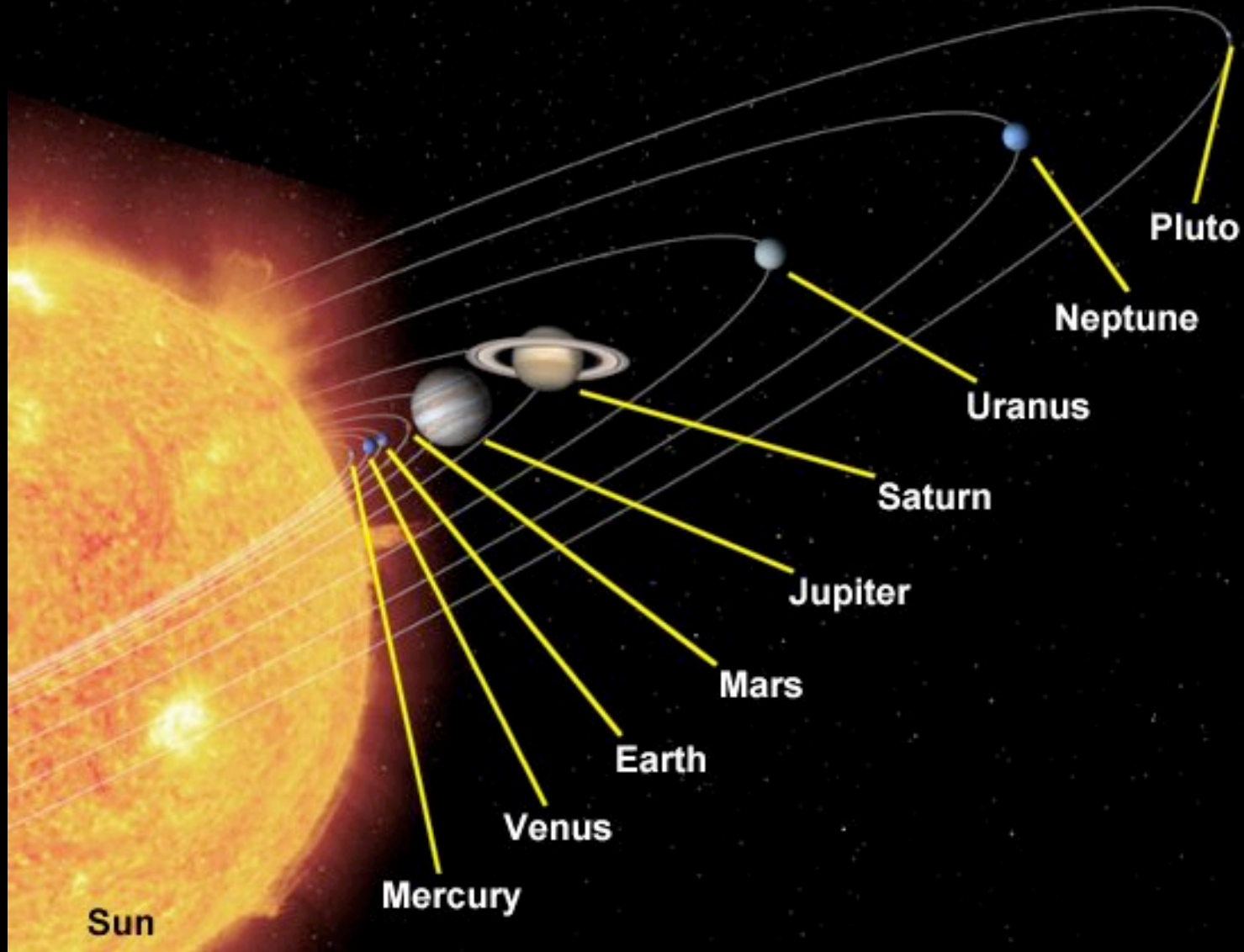


REDSHIFTED

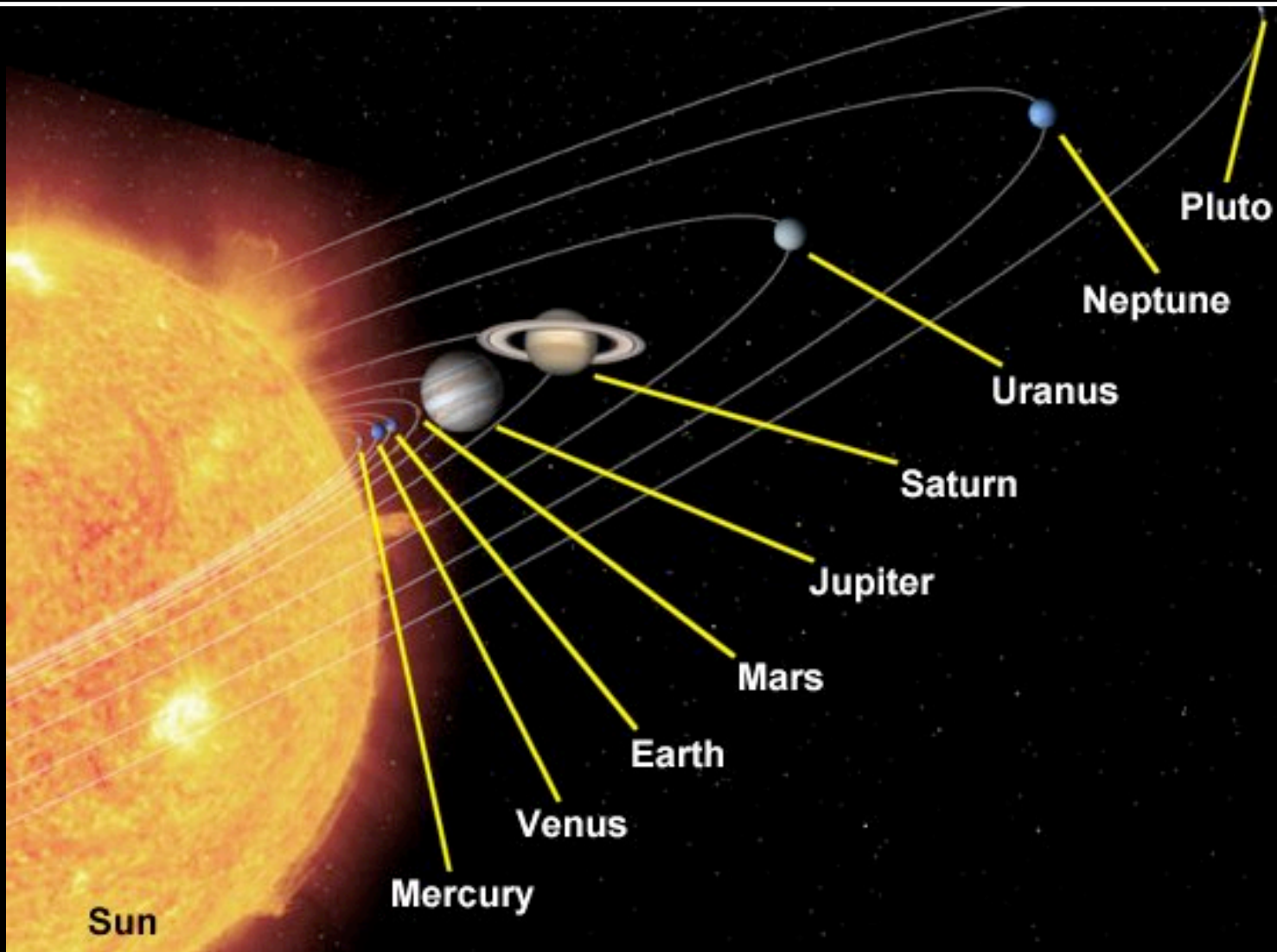


BLUESHIFTED

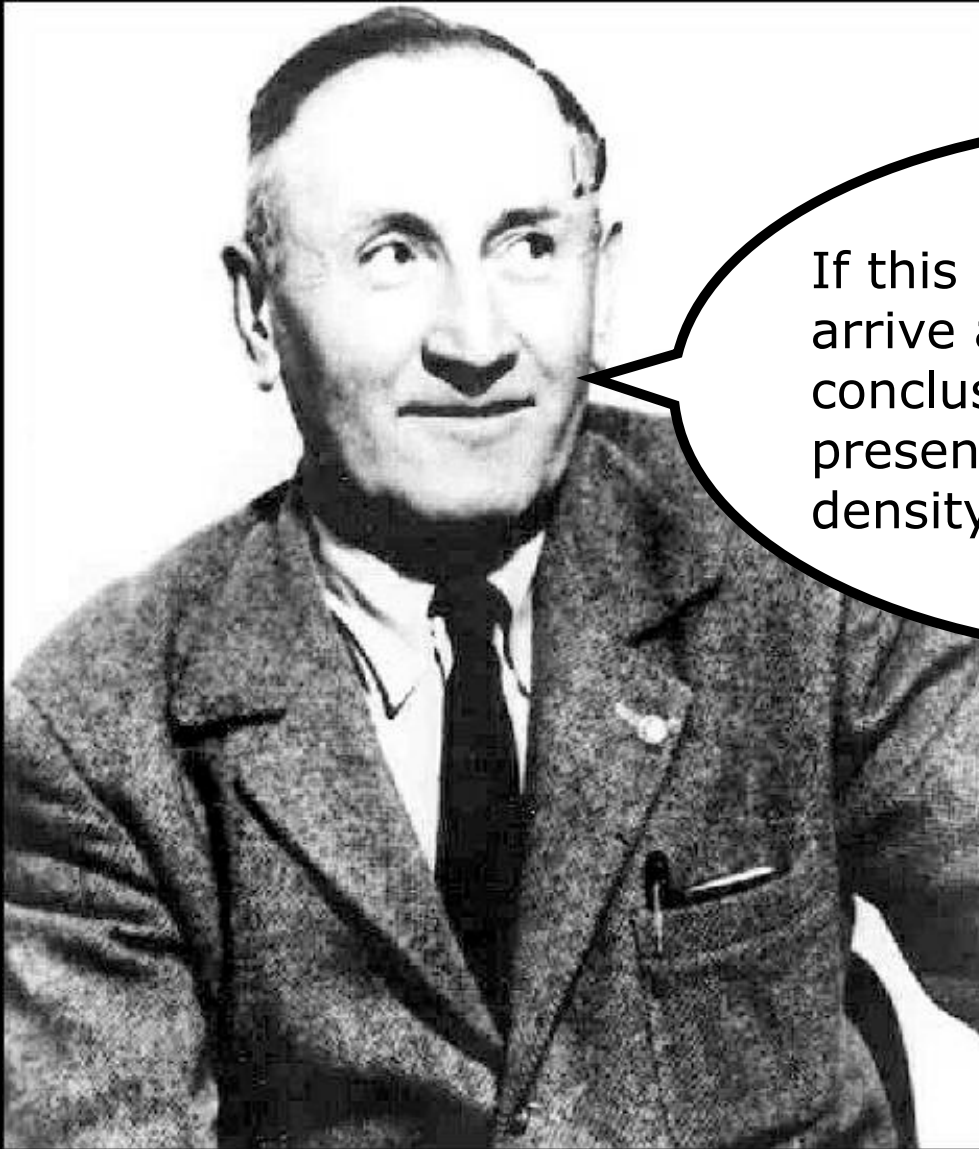
# Relating motion to gravitational mass!



Just remember that you're standing on a planet that's evolving  
And revolving at nine hundred miles an hour,  
That's orbiting at nineteen miles a second, so it's reckoned,  
A sun that is the source of all our power.



# Dark matter in galaxy clusters



If this is confirmed, we would arrive at the astonishing conclusion that dark matter is present with a much greater density than luminous matter

Fritz Zwicky , 1933

Dark matter is the glue holding  
together clusters of galaxies





# Dark matter in galaxy clusters



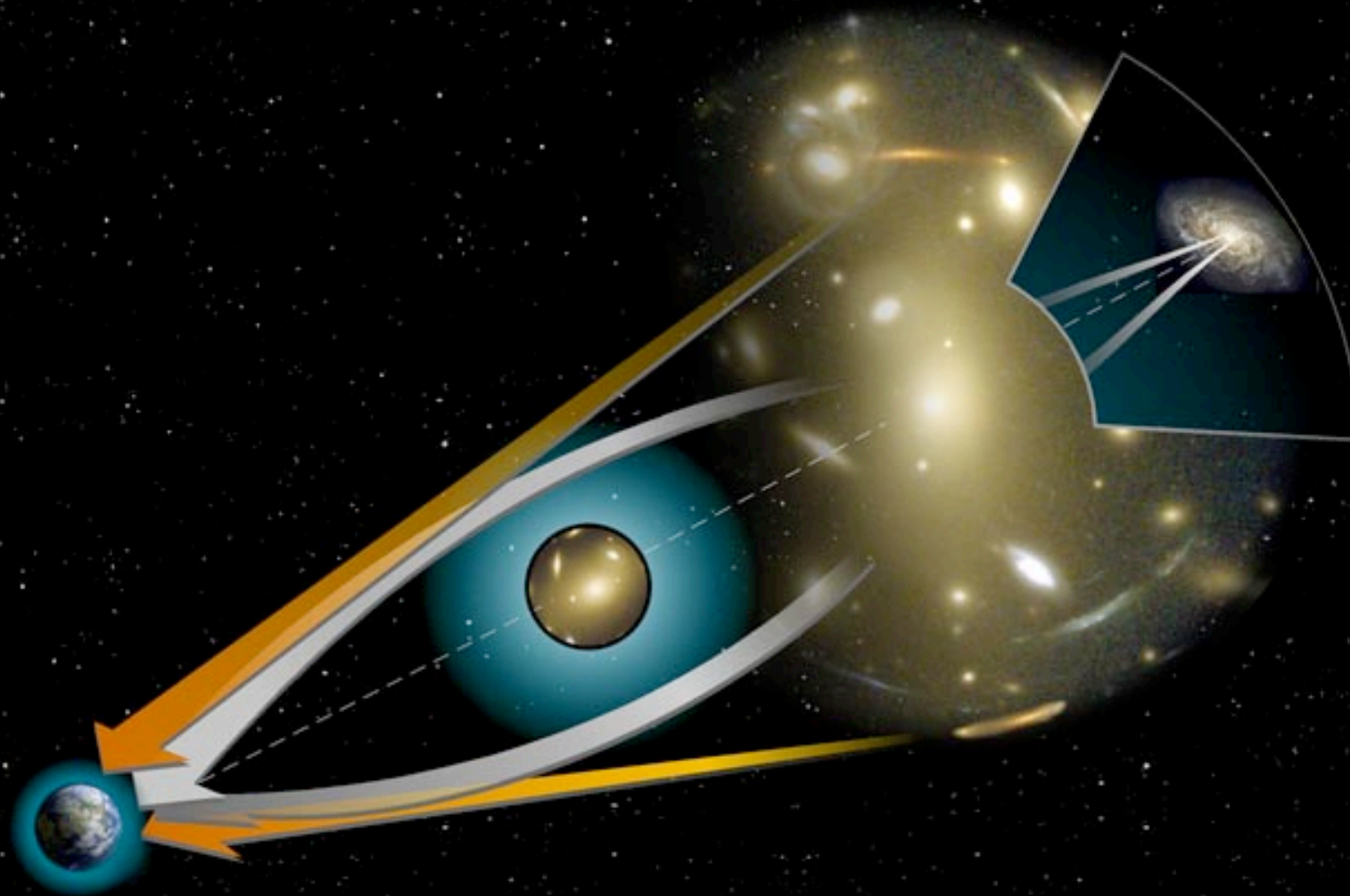
Every evening, I come home tired and have just enough energy to fill out the endless tax forms, to pay bills, not to let my house neglected and to hear the radio concert for an hour

Fritz Zwicky

# Gravitational lensing



# Gravitational lensing

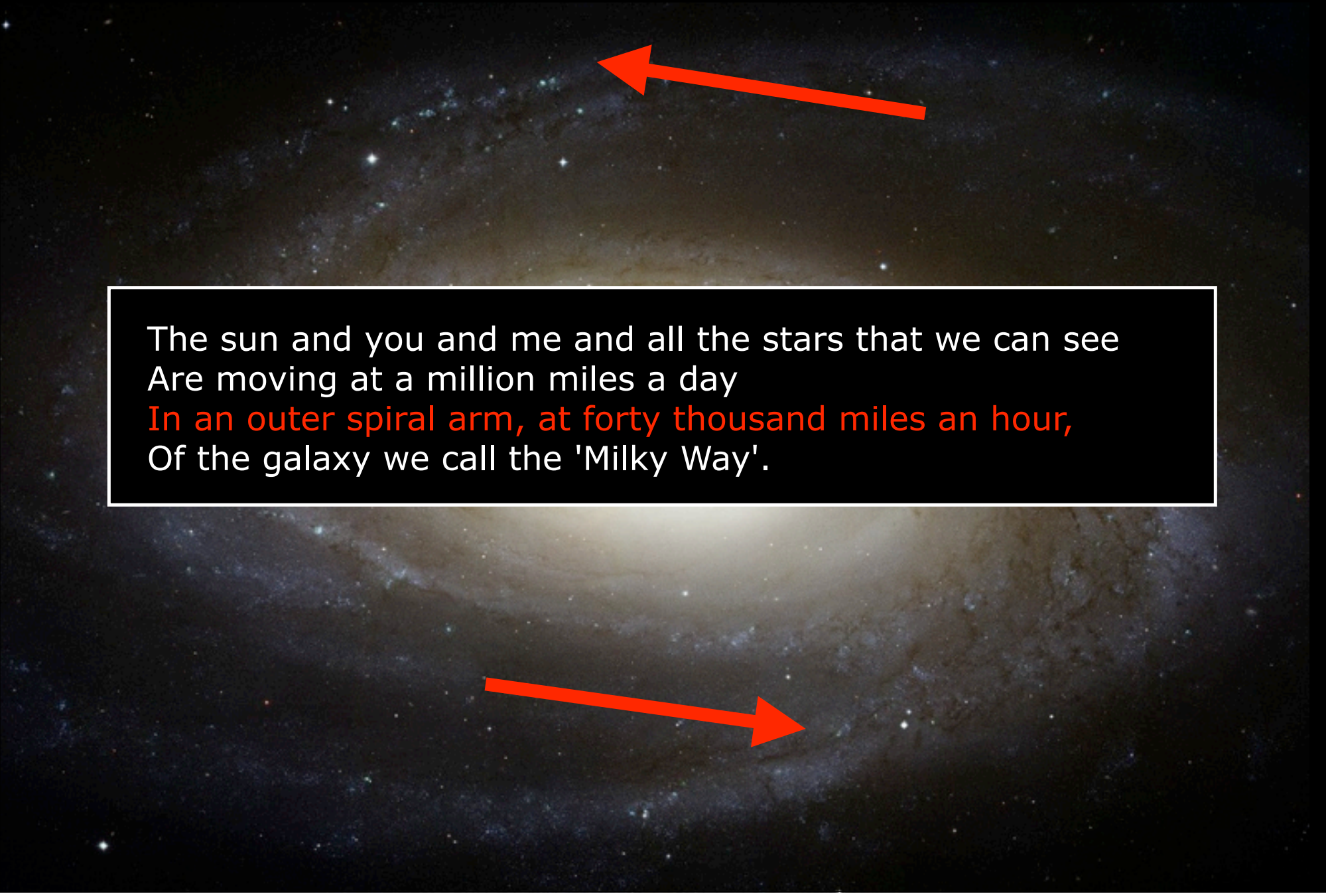


# Dark matter in individual galaxies



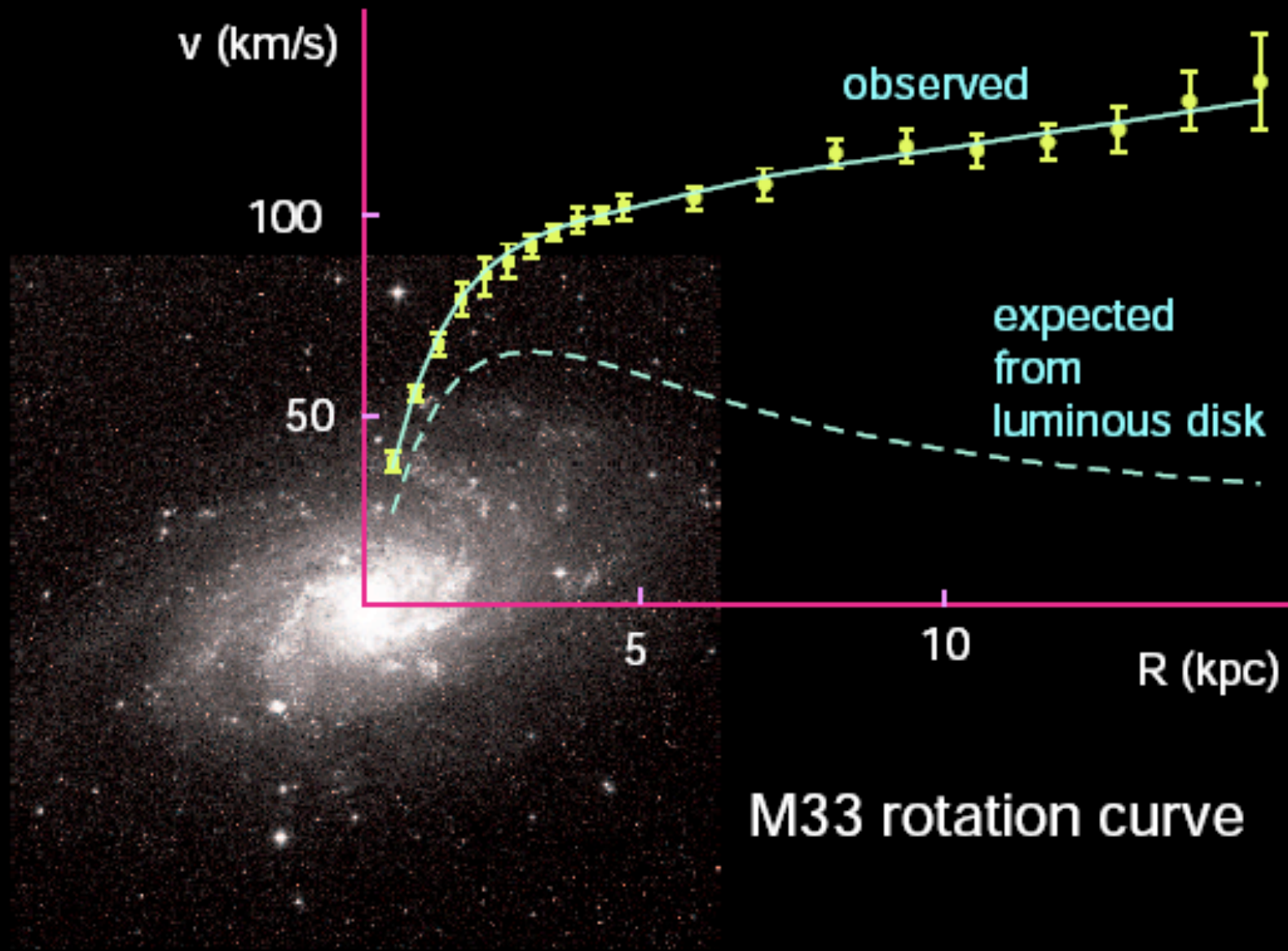
M81


# Dark matter in individual galaxies



The sun and you and me and all the stars that we can see  
Are moving at a million miles a day  
In an outer spiral arm, at forty thousand miles an hour,  
Of the galaxy we call the 'Milky Way'.

# Dark matter in individual galaxies



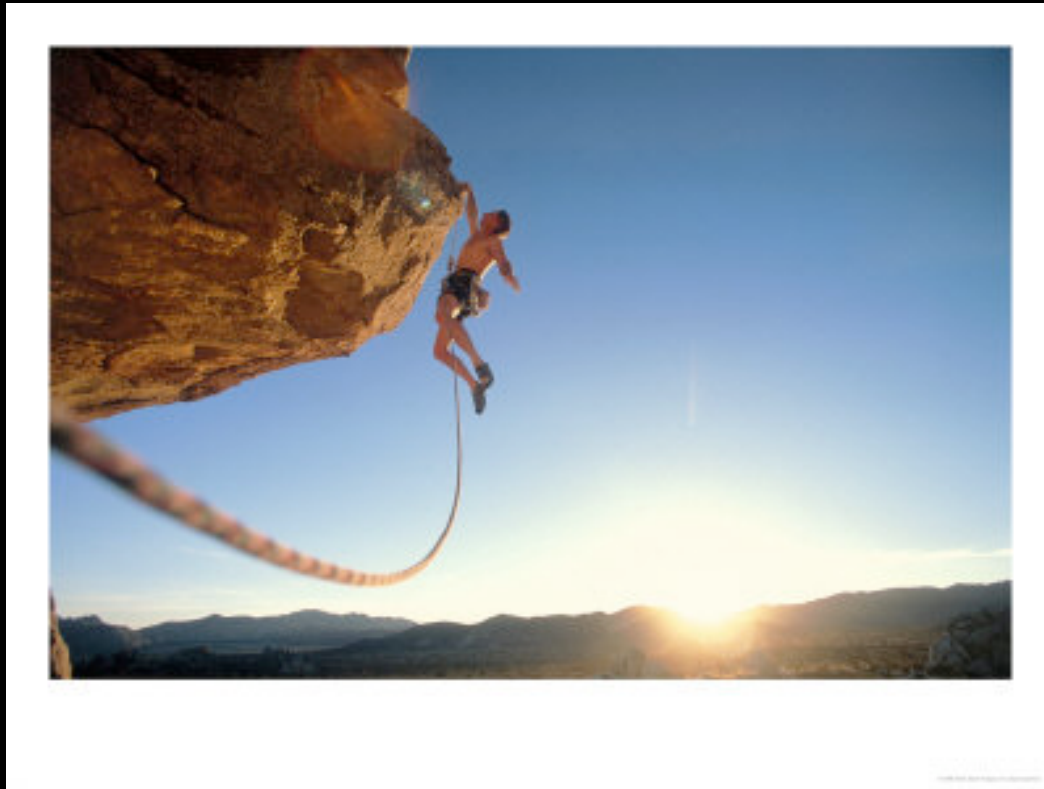


Dark matter is the glue holding  
together individual galaxies

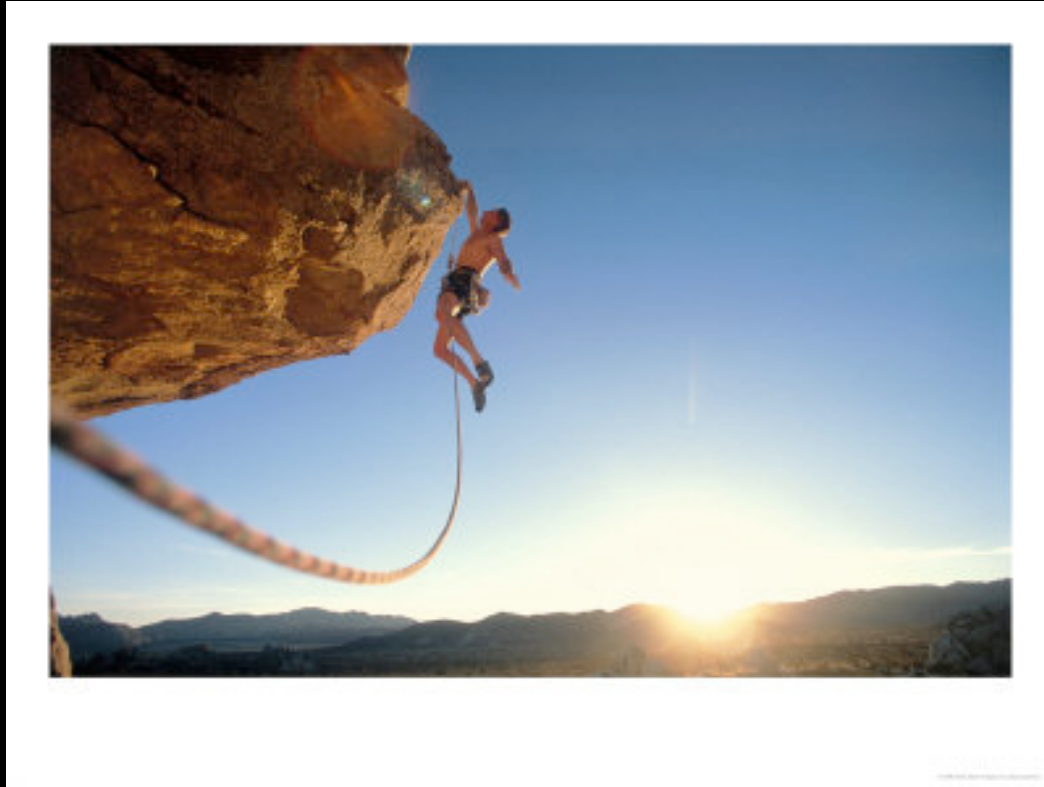
What is dark matter made of?



# What are humans made of?

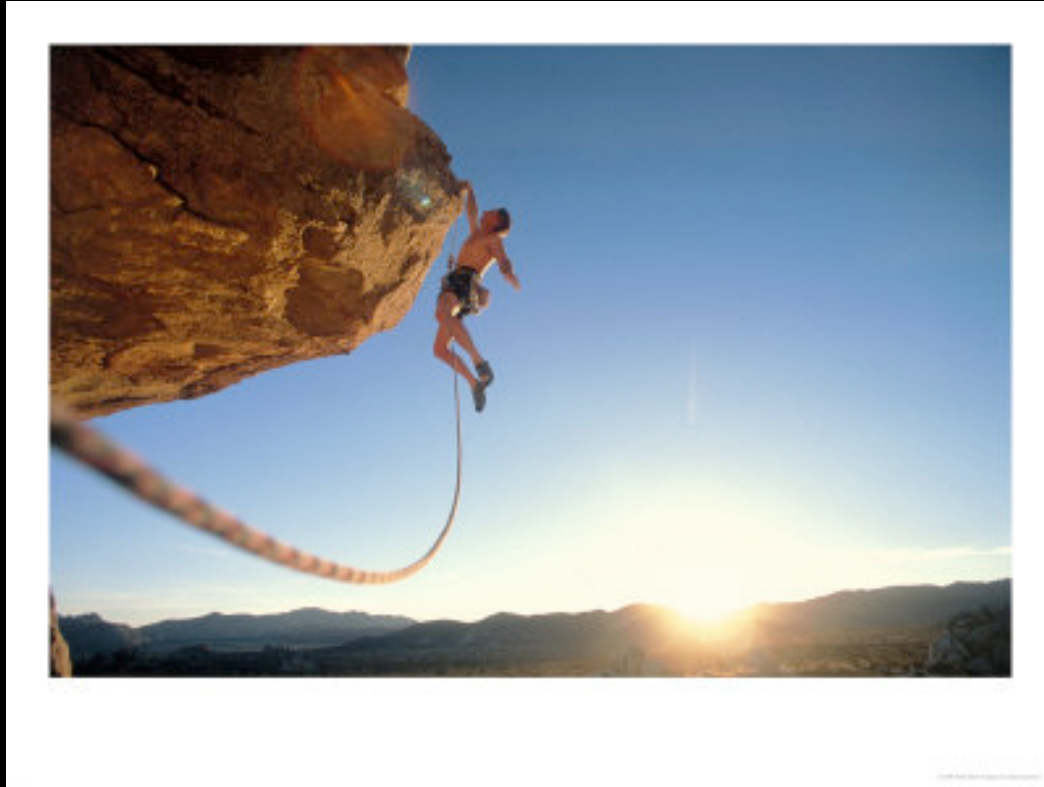


# What are humans made of?



The average human body contains enough: **sulphur** to kill all fleas on an average dog, **carbon** to make 900 pencils, **potassium** to fire a toy cannon, **fat** to make 7 bars of soap, **phosphorus** to make 2,200 match heads, **water** to fill a ten-gallon tank, and enough **iron** to make a 3 inch nail.

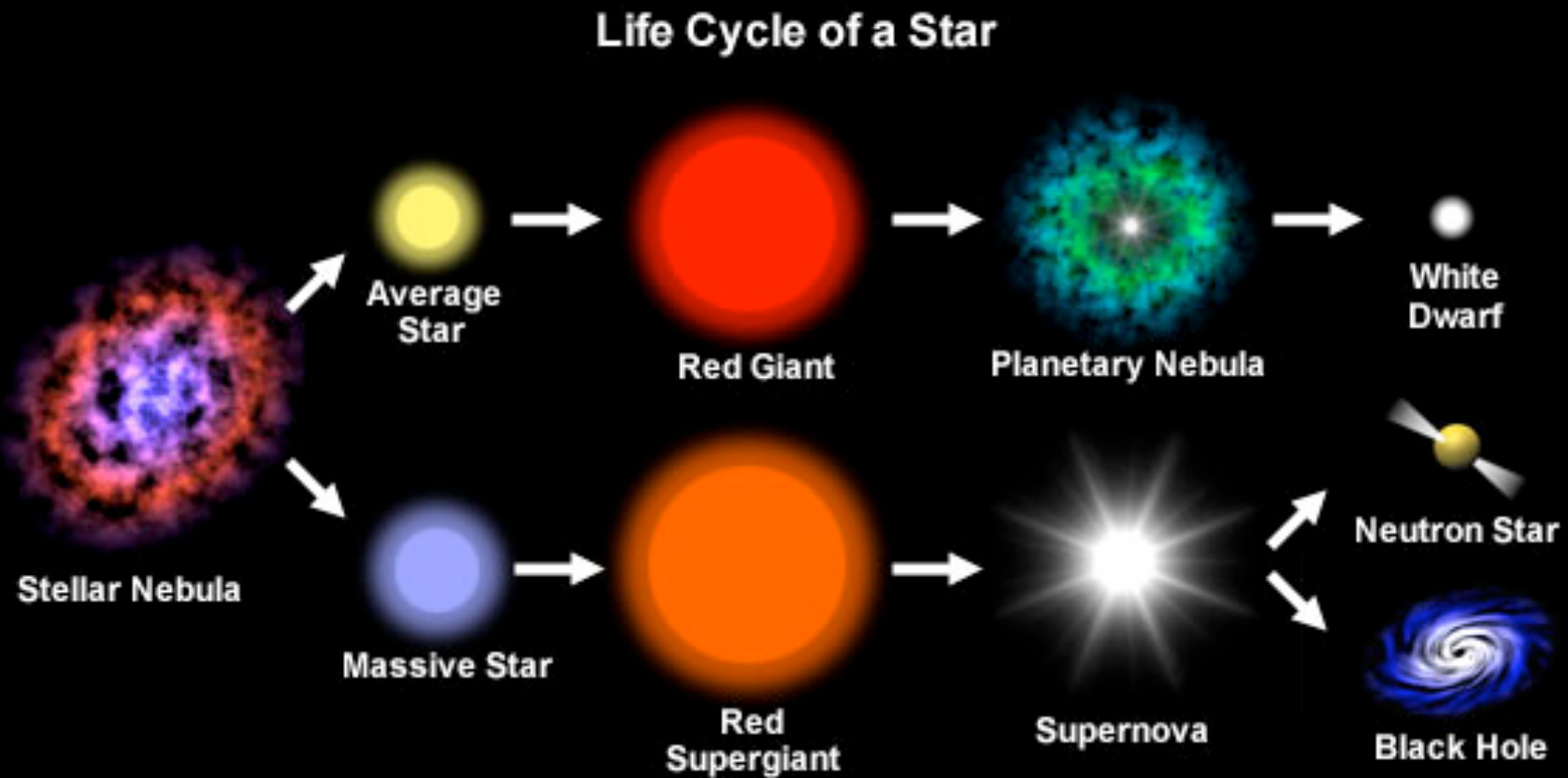
# What are humans made of?



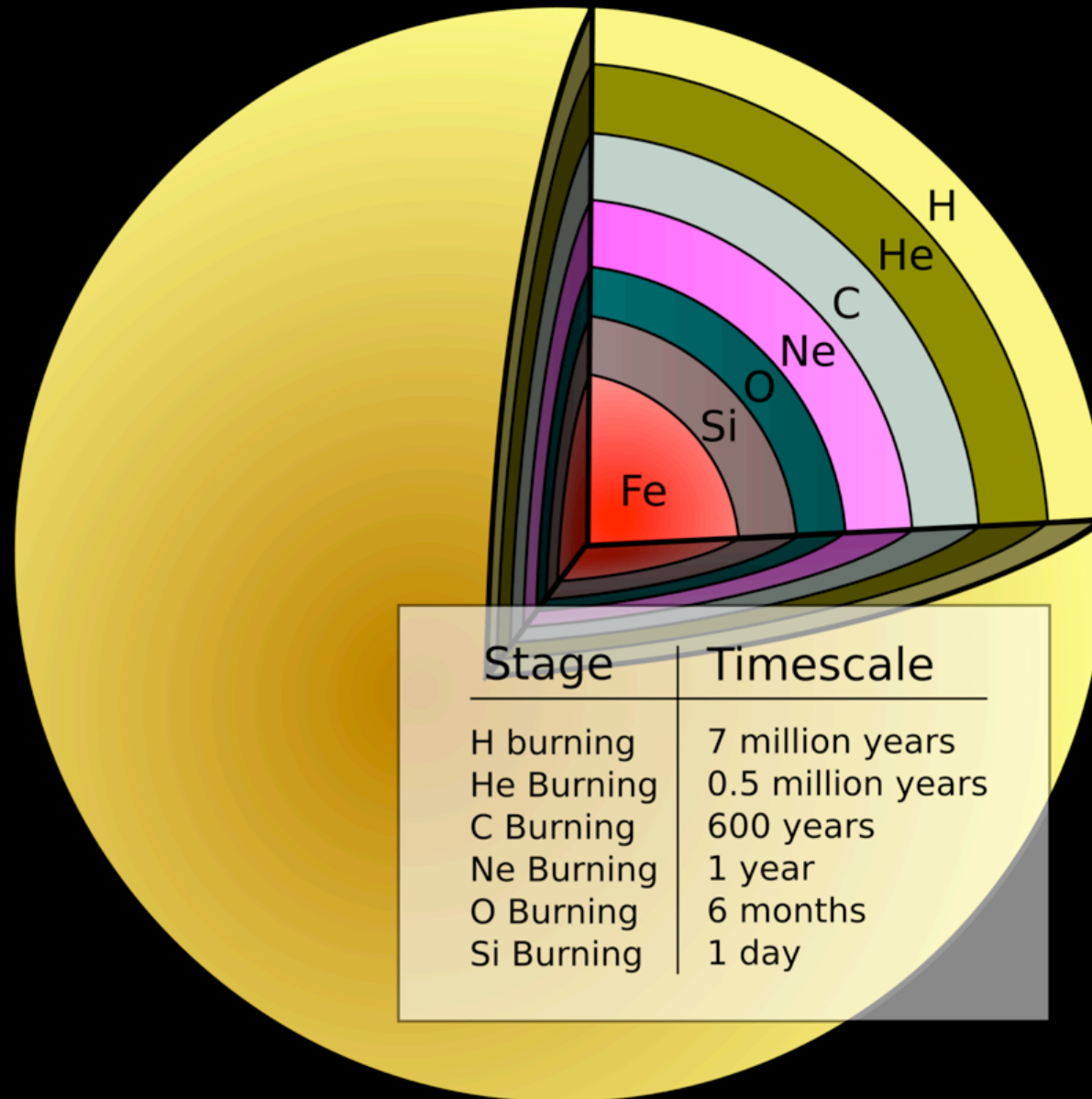
The average human body contains enough: **sulphur** to kill all fleas on an average dog, **carbon** to make 900 pencils, **potassium** to fire a toy cannon, **fat** to make 7 bars of soap, **phosphorus** to make 2,200 match heads, **water** to fill a ten-gallon tank, and enough **iron** to make a 3 inch nail.

oxygen 43 kg  
carbon 16 kg  
hydrogen 7 kg  
nitrogen 1.8 kg  
calcium 1.0 kg  
phosphorus 780 g  
potassium 140 g  
sulfur 140 g  
sodium 100 g  
chlorine 95 g  
magnesium 19 g  
iron 4.2 g  
fluorine 2.6 g  
zinc 2.3 g  
silicon 1.0 g  
rubidium 0.68 g  
strontium 0.32 g  
bromine 0.26 g  
lead 0.12 g  
copper 72 mg  
aluminum 60 mg  
cadmium 50 mg  
cerium 40 mg  
barium 22 mg  
iodine 20 mg  
tin 20 mg  
titanium 20 mg  
boron 18 mg  
nickel 15 mg  
selenium 15 mg  
chromium 14 mg  
manganese 12 mg  
arsenic 7 mg  
lithium 7 mg  
cesium 6 mg  
mercury 6 mg  
germanium 5 mg  
molybdenum 5 mg  
cobalt 3 mg  
antimony 2 mg  
silver 2 mg  
niobium 1.5 mg  
zirconium 1 mg  
lanthanum 0.8 mg  
gallium 0.7 mg  
tellurium 0.7 mg  
yttrium 0.6 mg  
bismuth 0.5 mg  
thallium 0.5 mg  
indium 0.4 mg  
gold 0.2 mg  
scandium 0.2 mg

# Where do atoms come from?



# Where do atoms come from?

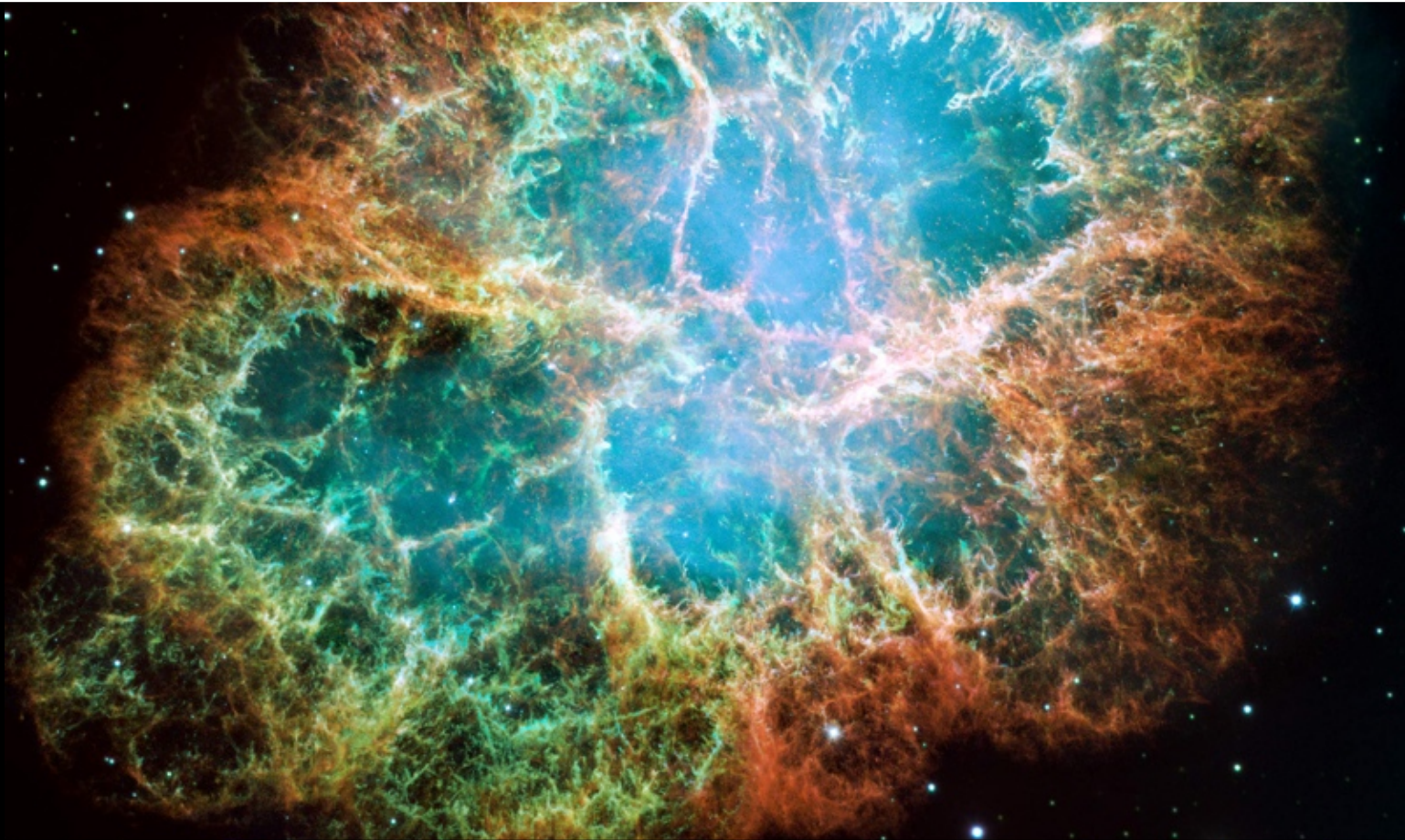


Where do atoms come from?

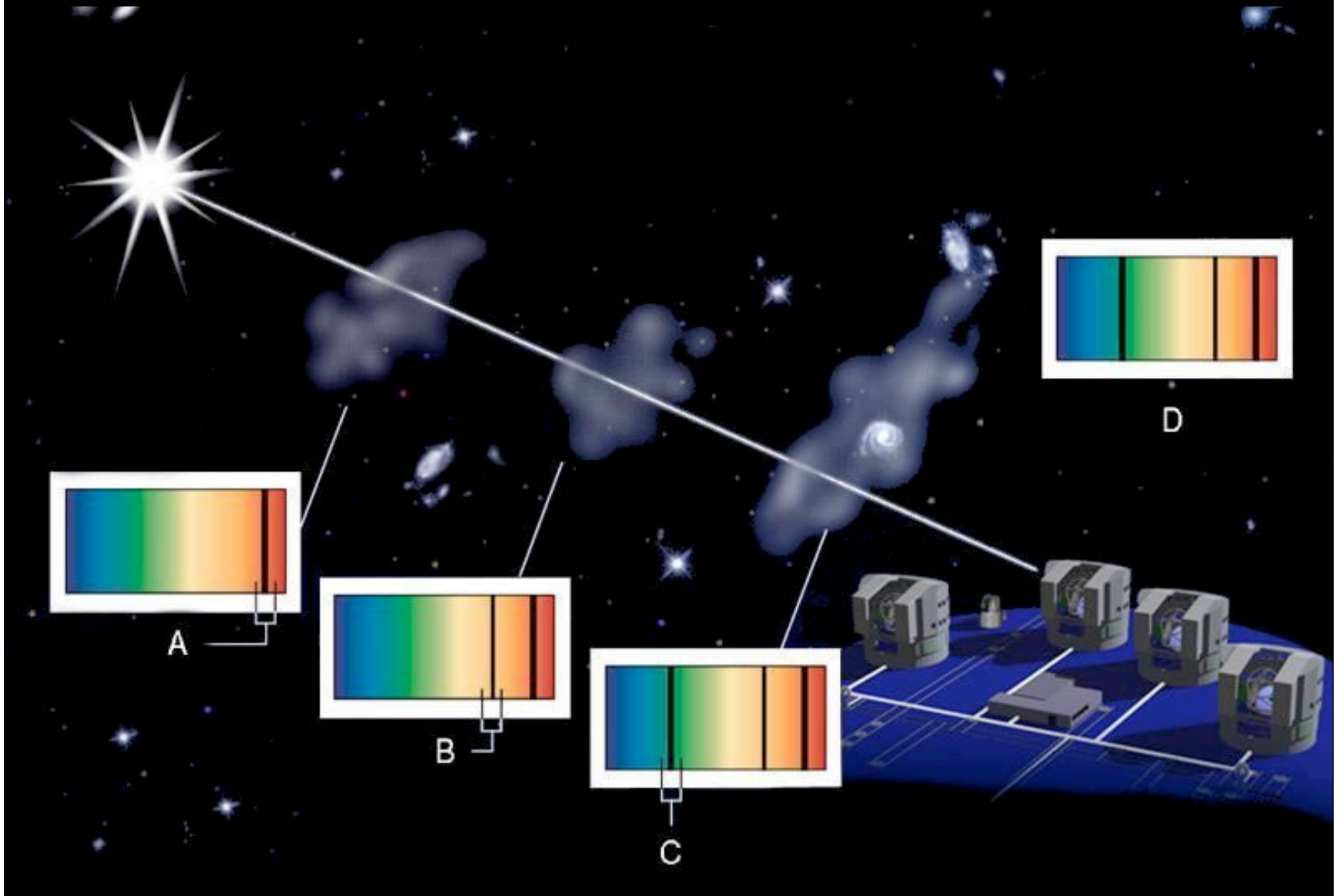


Where do atoms come from?

Nuclear reactions in stars form  
many elements ... but not all!!

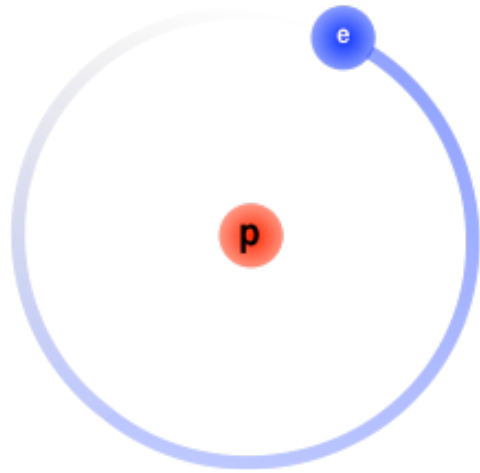


# Stars cannot produce all the atoms !

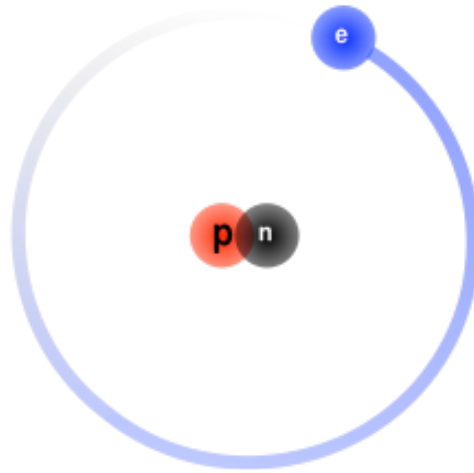




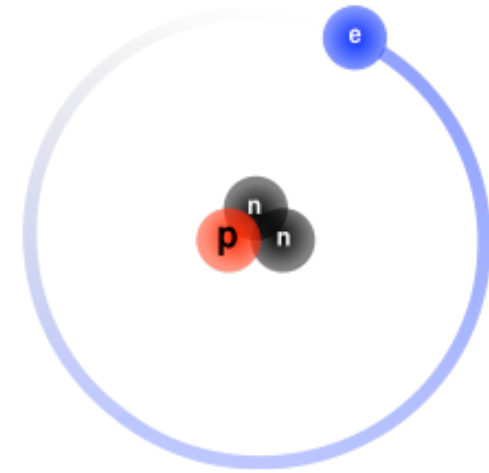
# Stars cannot produce all the atoms !



Hydrogen

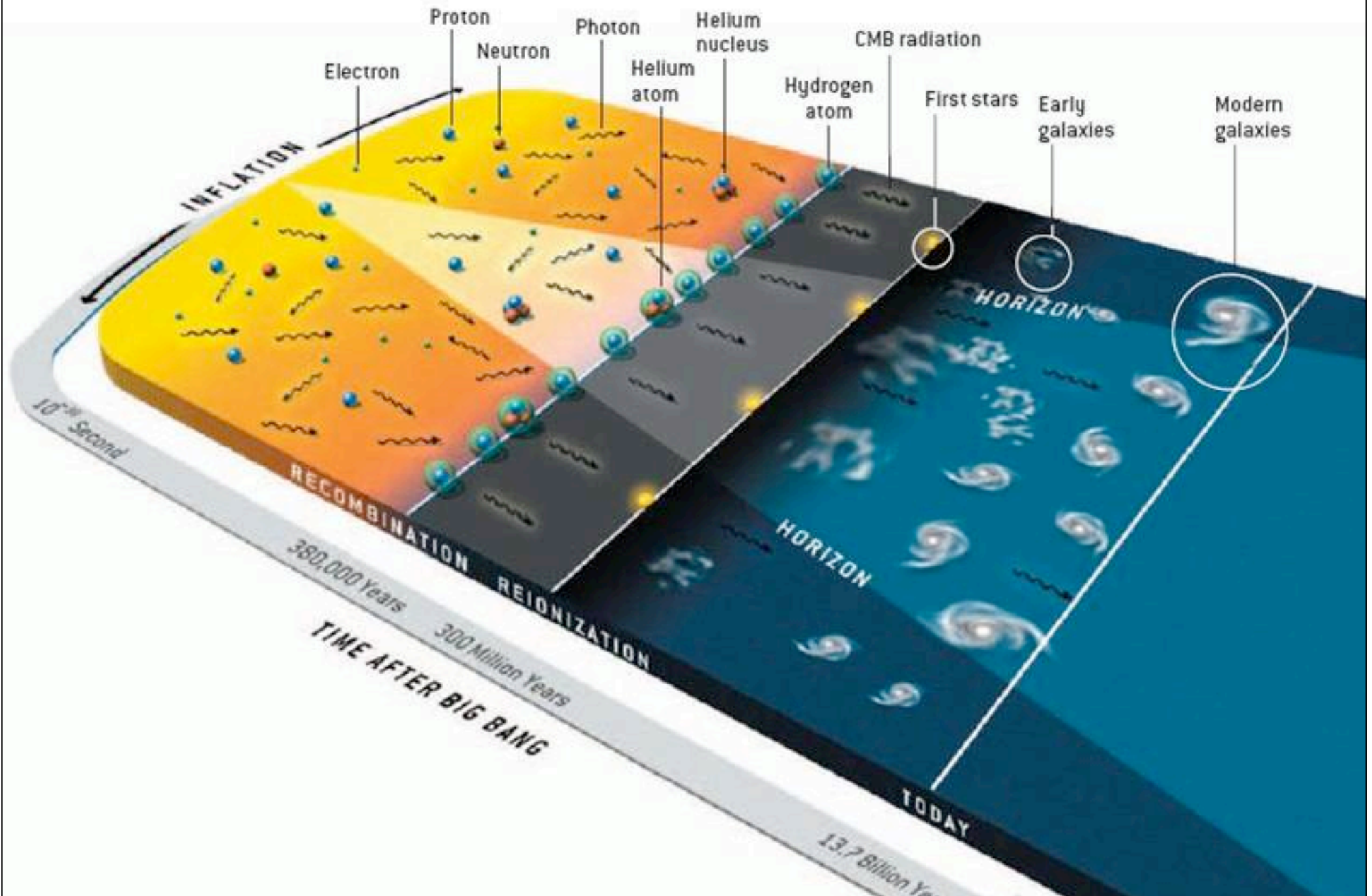


Deuterium

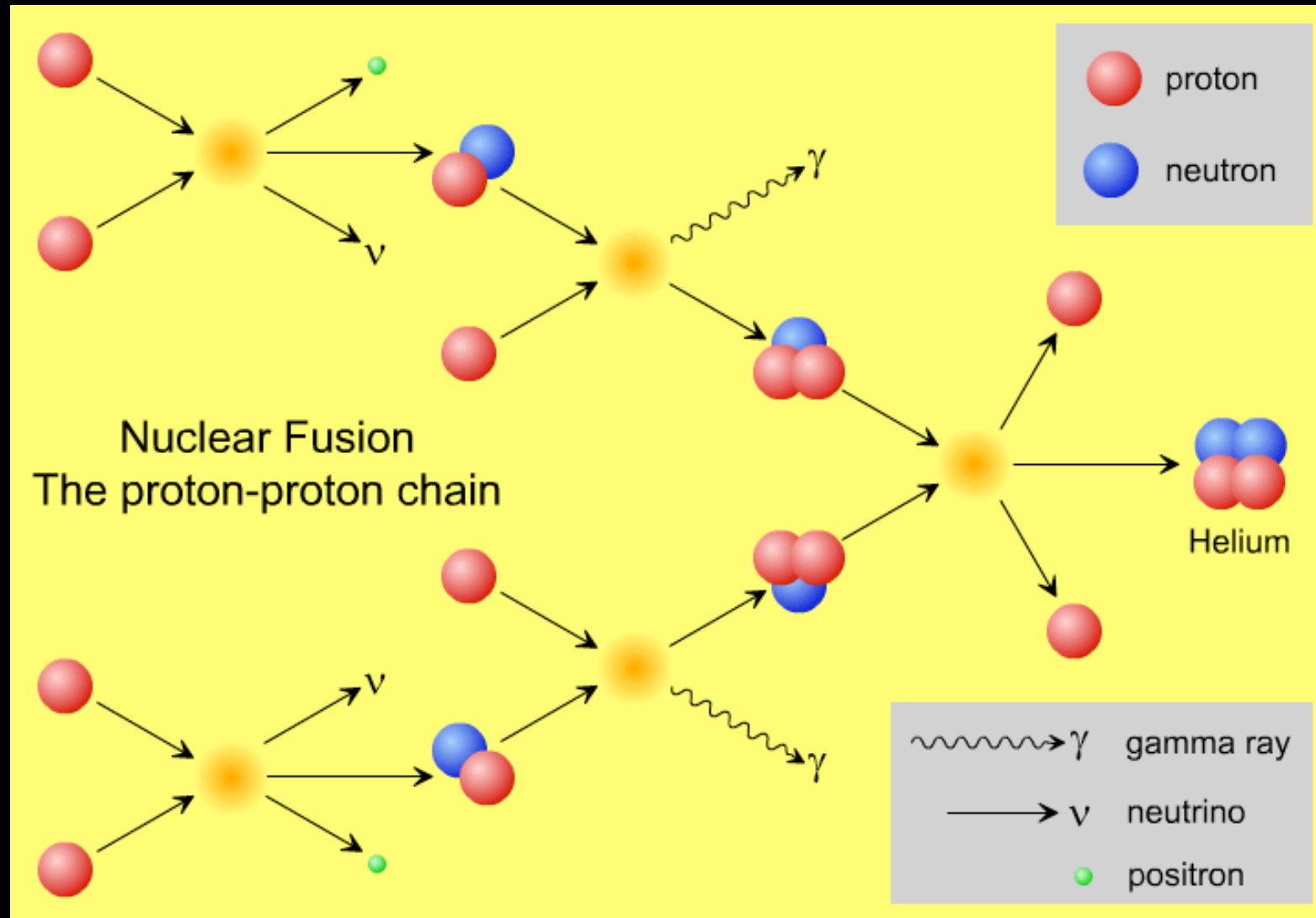


Tritium

# Big Bang nucleosynthesis

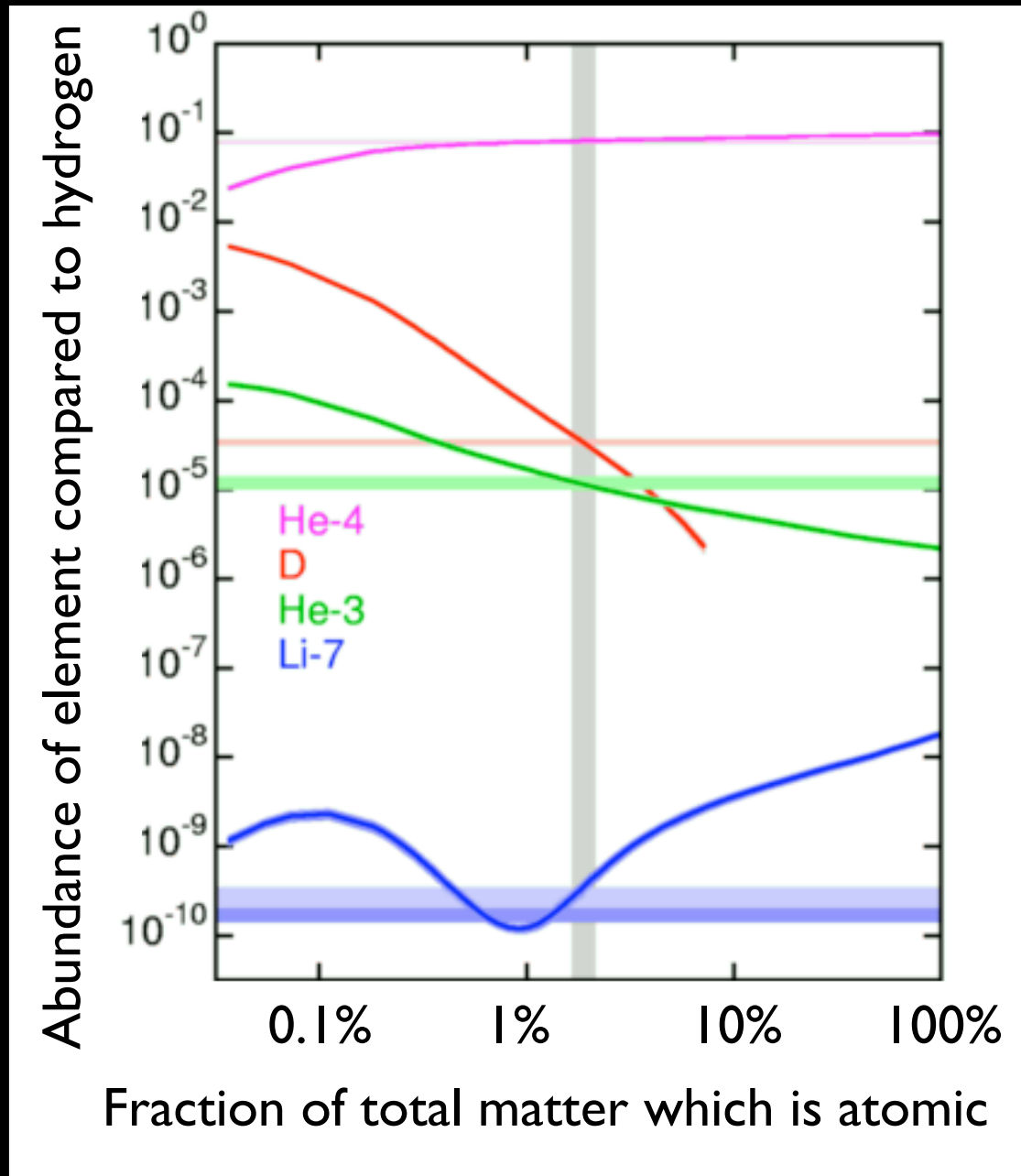


# Big Bang nucleosynthesis

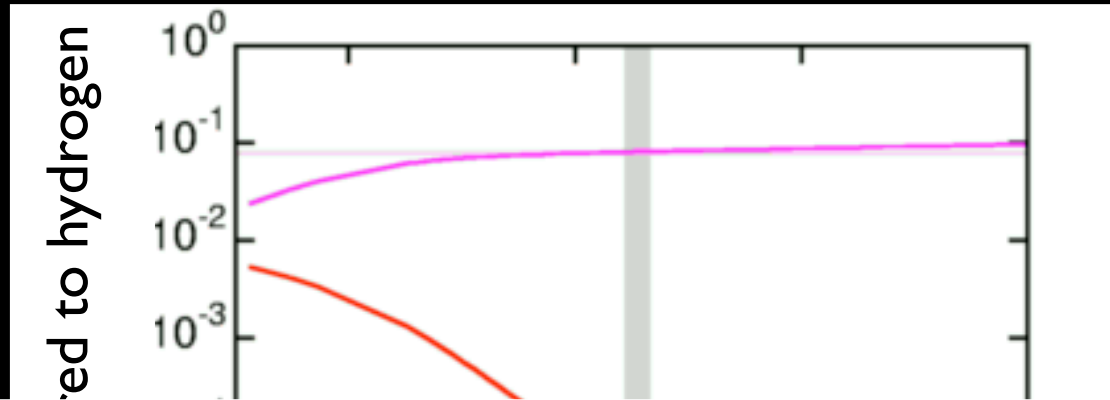


Rate of these reactions depends on atom density!

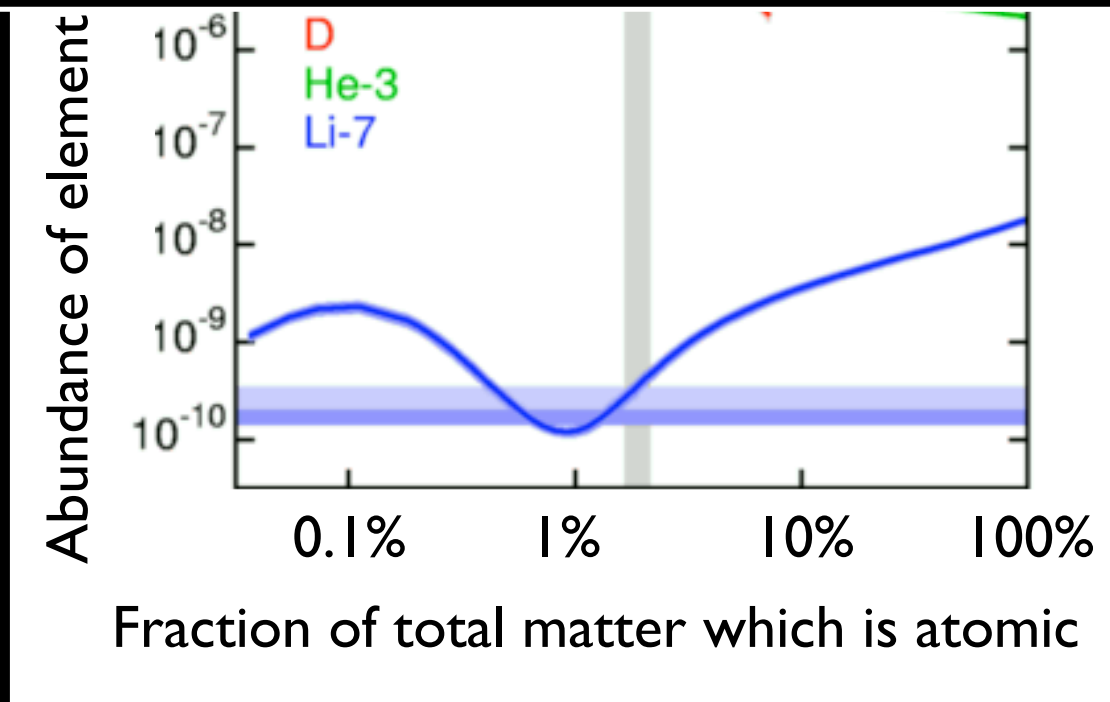
# Big Bang nucleosynthesis



# Big Bang nucleosynthesis



Dark matter is made up of exotic particles!

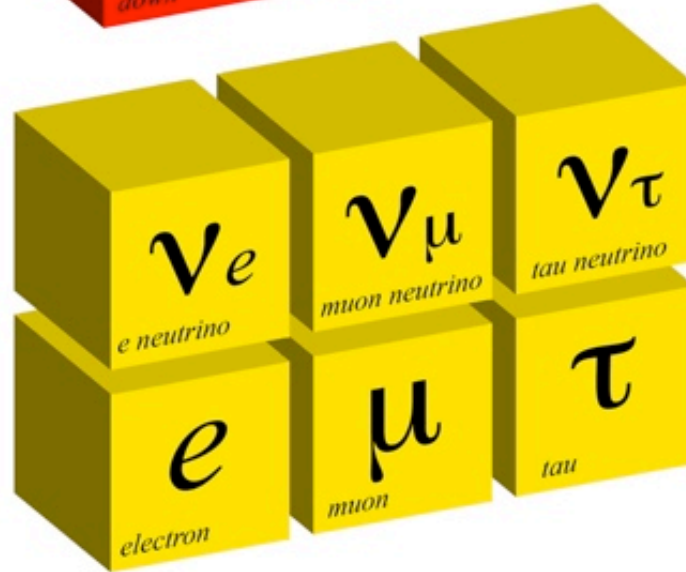


# Fundamental Particles of the Standard Model

Quarks



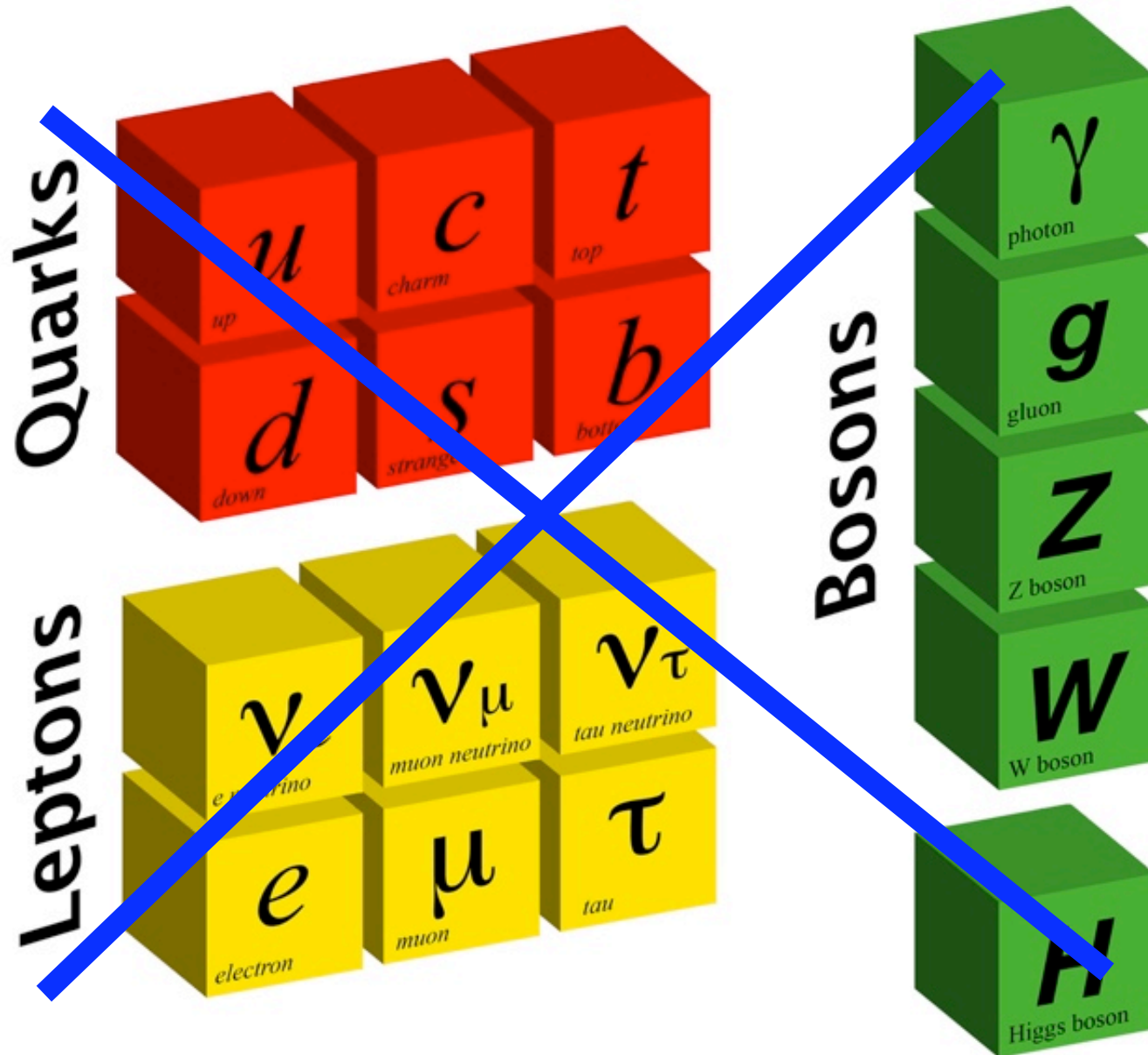
Leptons



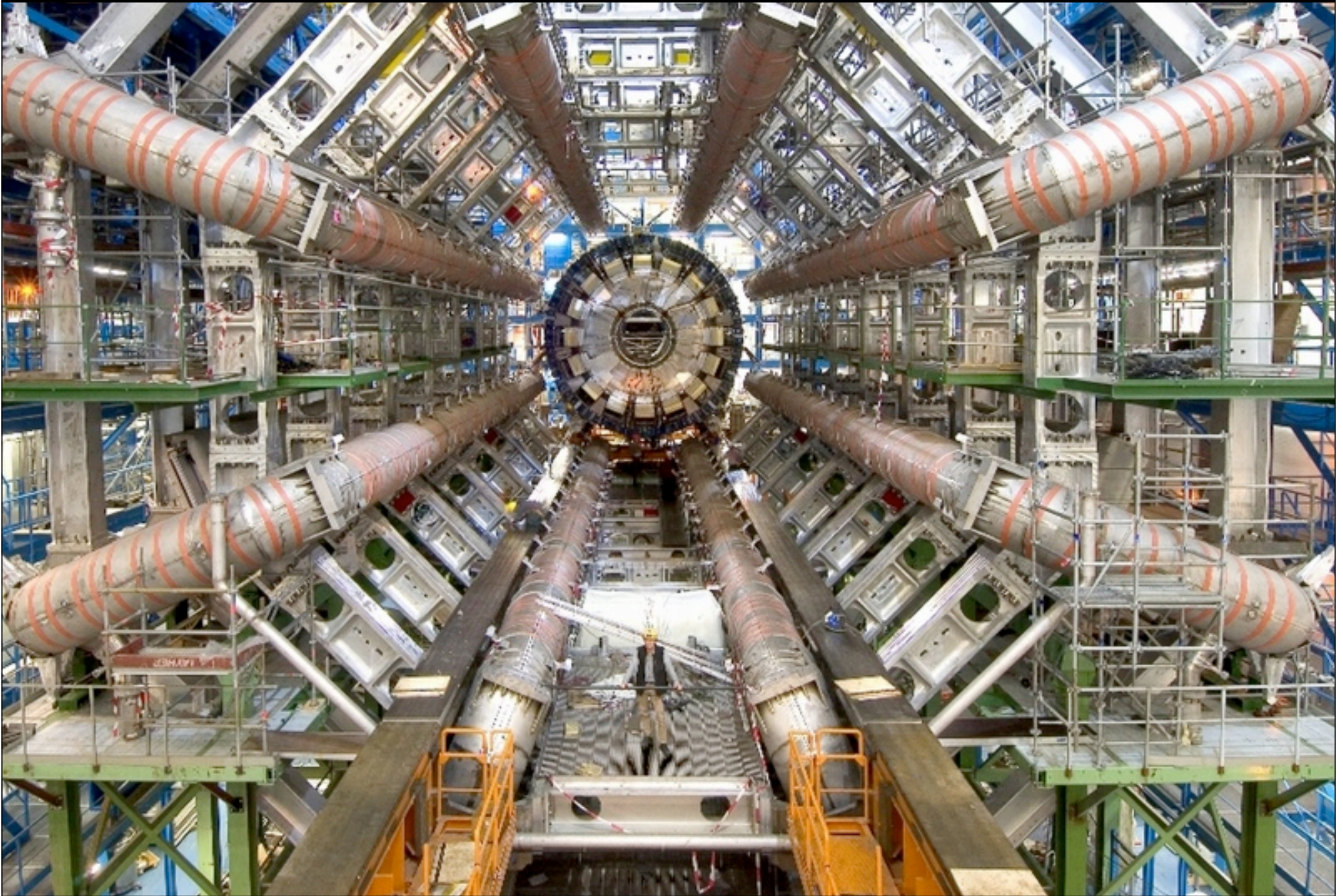
Bosons



# Fundamental Particles of the Standard Model

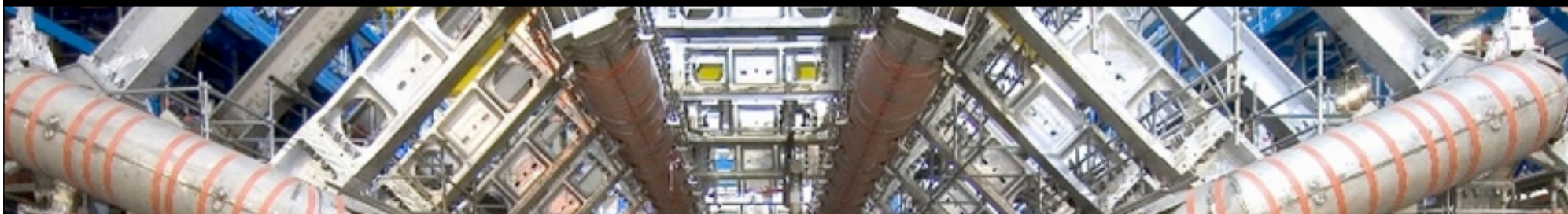


# Particles beyond the standard model

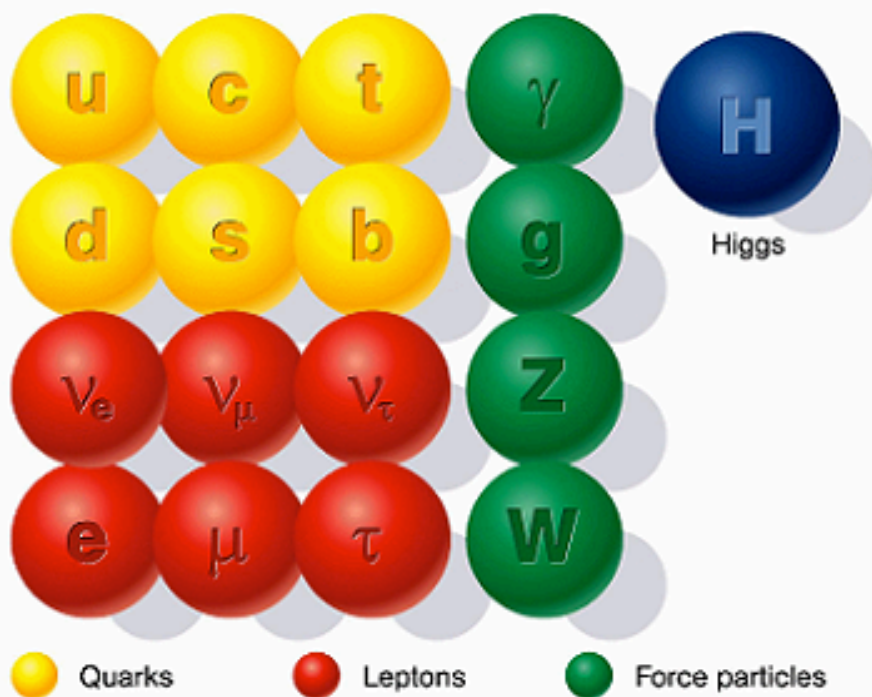




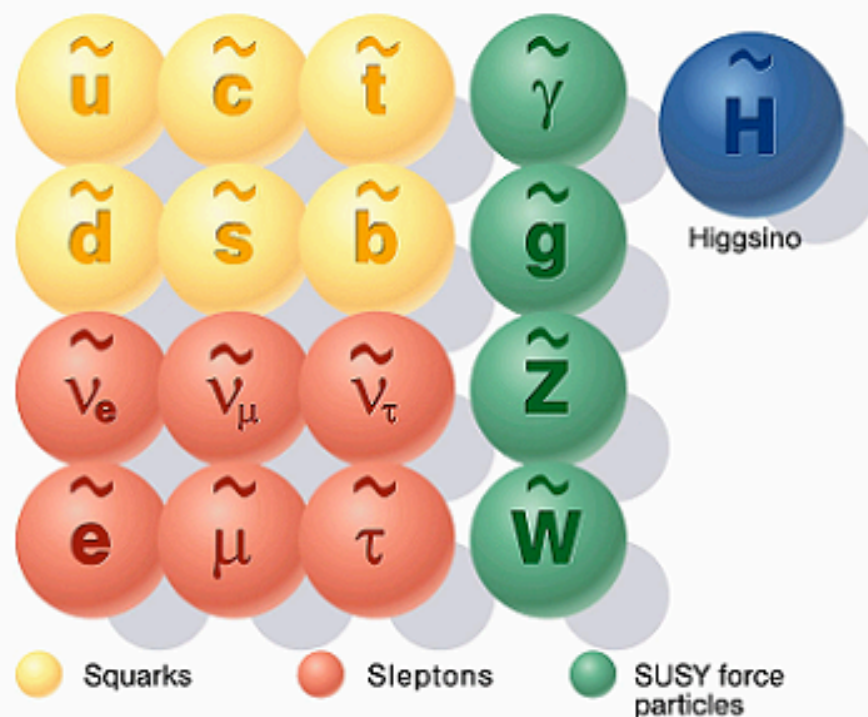
# Particles beyond the standard model



## Standard particles



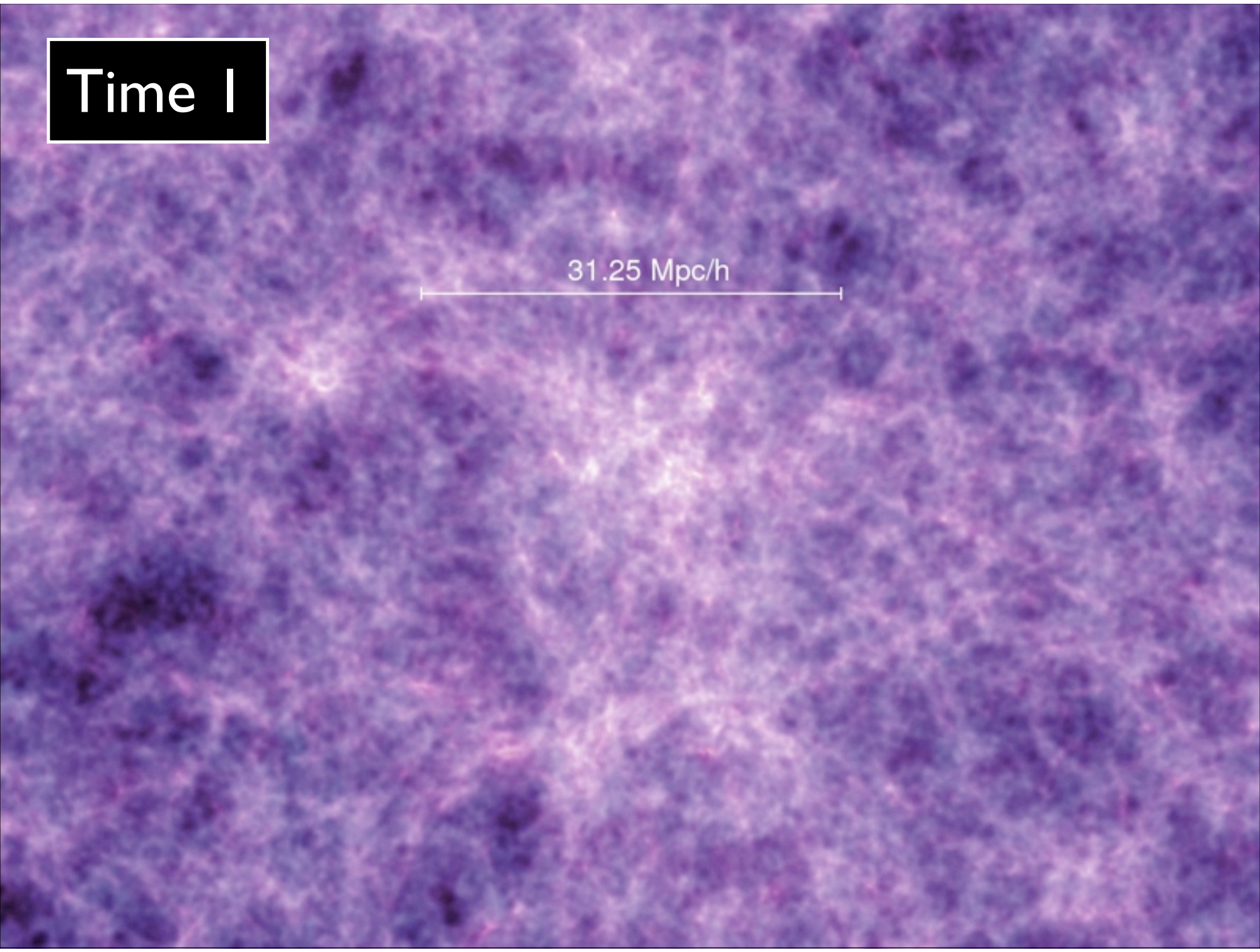
## SUSY particles



What is dark matter made of?

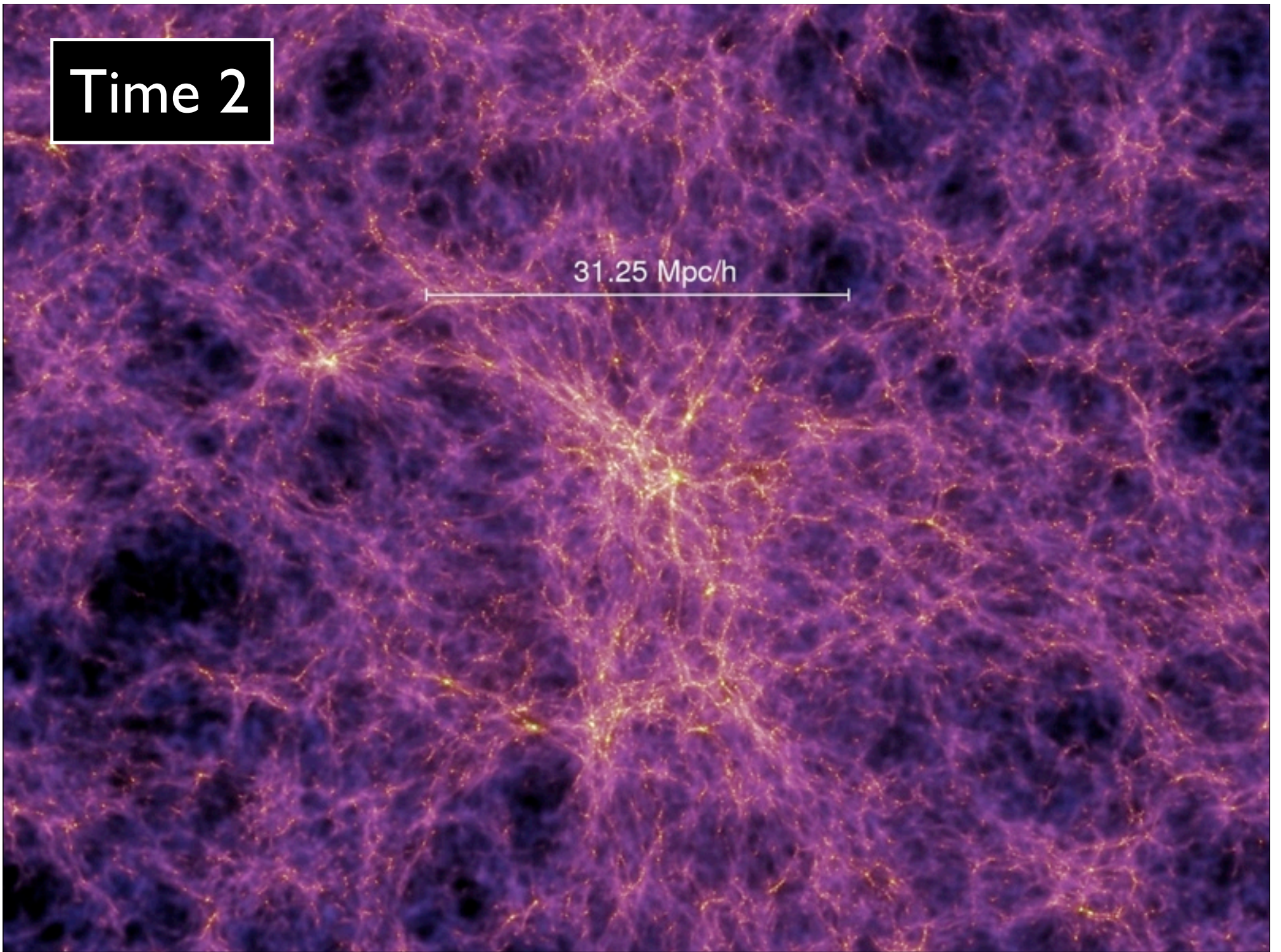
Time 1

31.25 Mpc/h

A visualization of the cosmic web at Time 1, showing a complex network of dark matter filaments and clusters. The filaments are represented by thin, interconnected lines of varying thickness and color, ranging from light purple to dark blue. The background is a dense, textured field of these filaments, with some brighter, more prominent structures. A horizontal scale bar is positioned in the upper-middle part of the image, consisting of a white line with vertical end caps, labeled "31.25 Mpc/h".

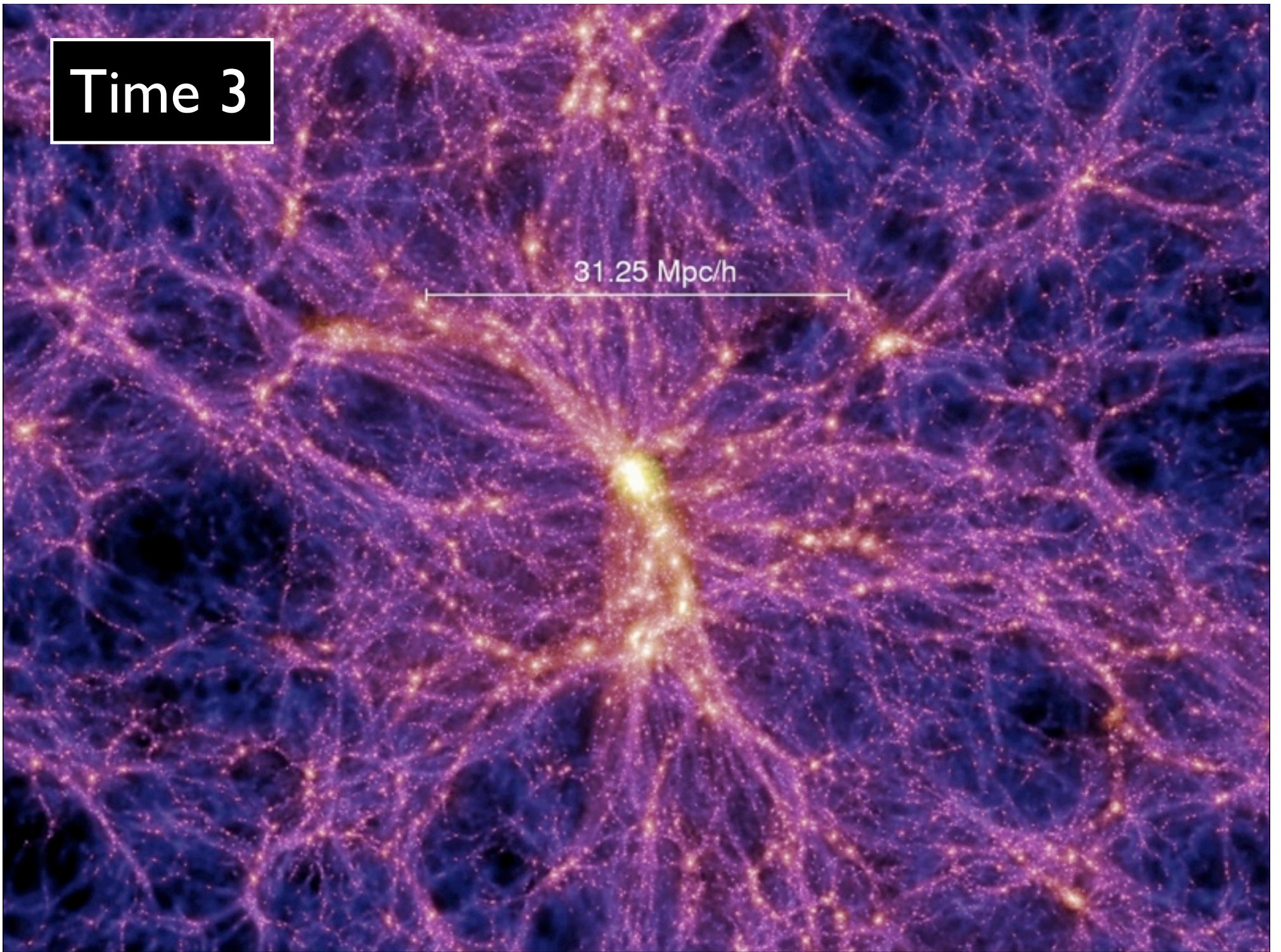
Time 2

31.25 Mpc/h



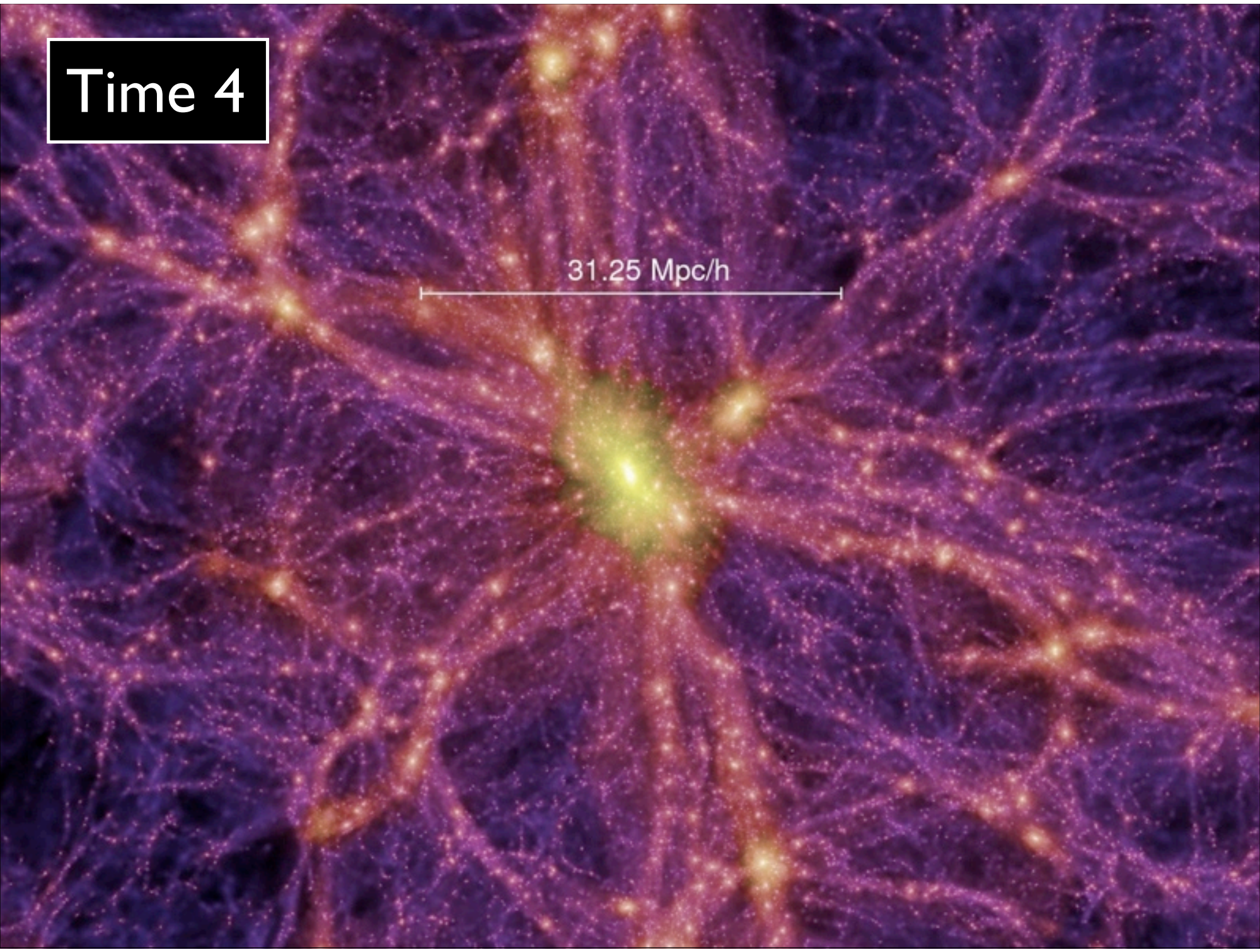
Time 3

31.25 Mpc/h

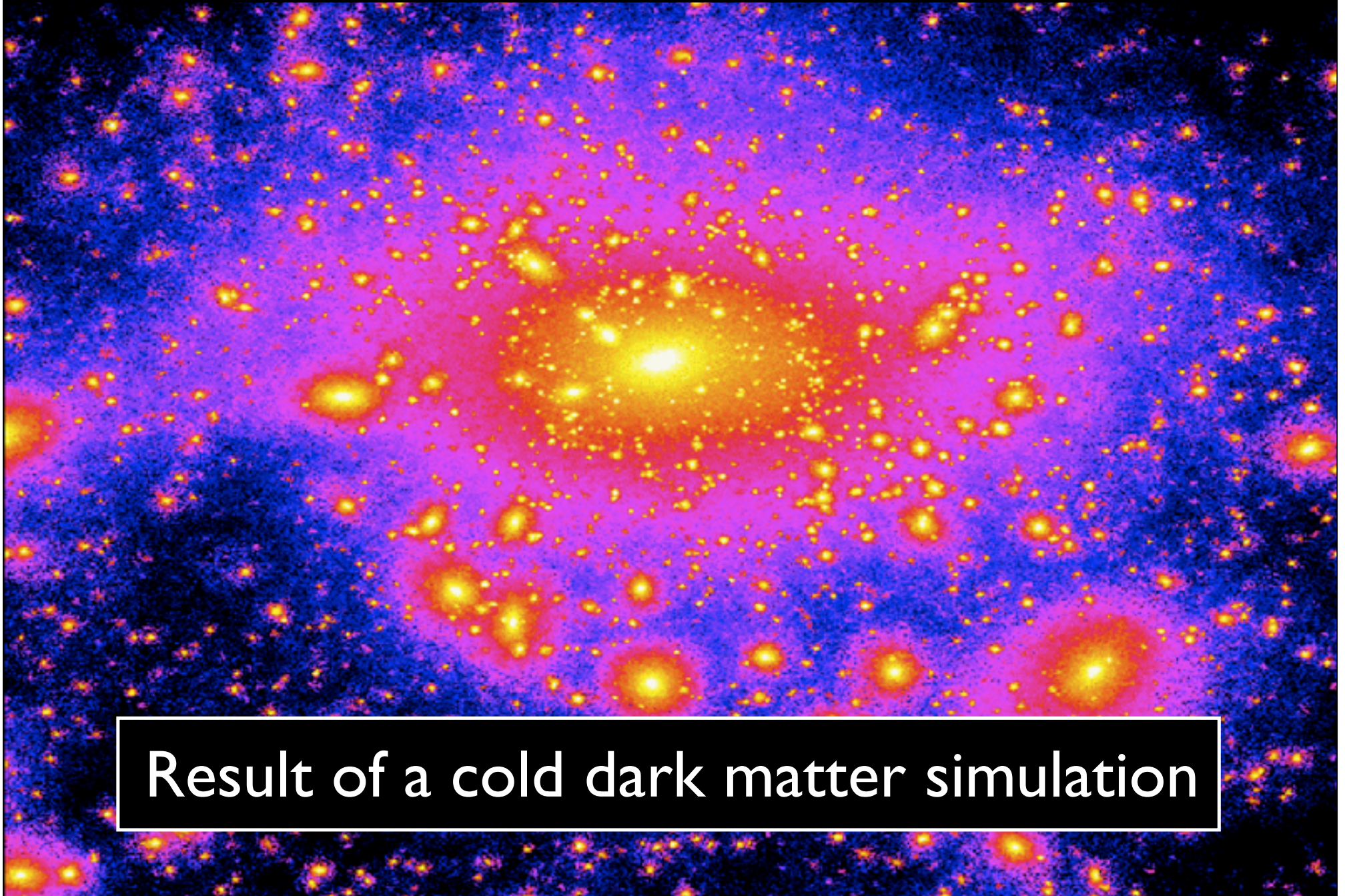


Time 4

31.25 Mpc/h

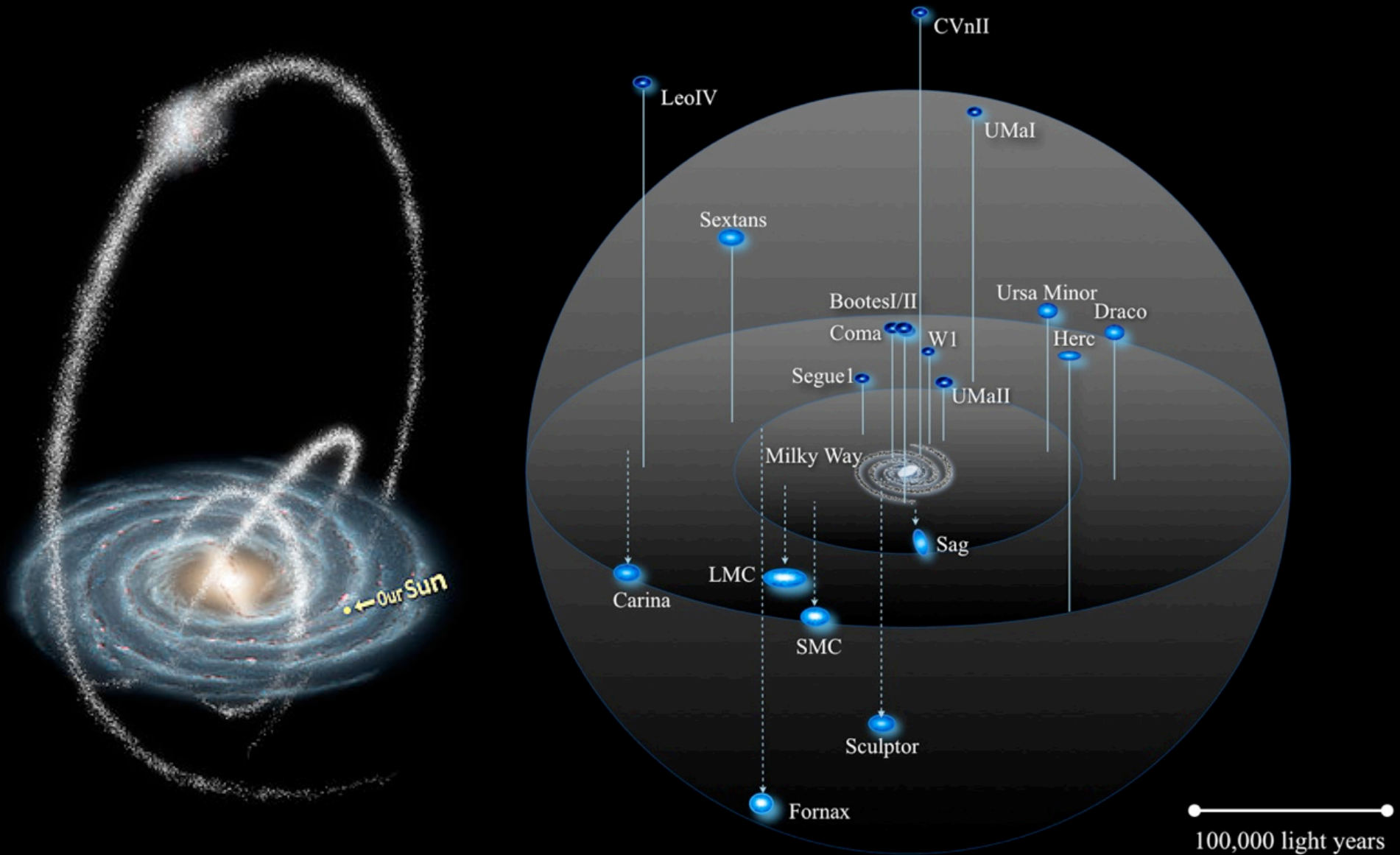
A visualization of the cosmic web at a specific time, labeled "Time 4". The image shows a complex network of filaments and nodes. The central region is dominated by a bright, yellowish-green cluster of galaxies. From this central hub, several major filaments extend outwards, forming a cross-like pattern. These filaments are composed of numerous smaller, purple and orange-red galaxy clusters and individual galaxies. The background is a dense field of purple and blue points, representing the overall distribution of matter. A horizontal scale bar is positioned in the upper-middle part of the image, with the text "31.25 Mpc/h" above it, indicating the physical distance represented by the length of the bar.

# What are the properties of dark matter?



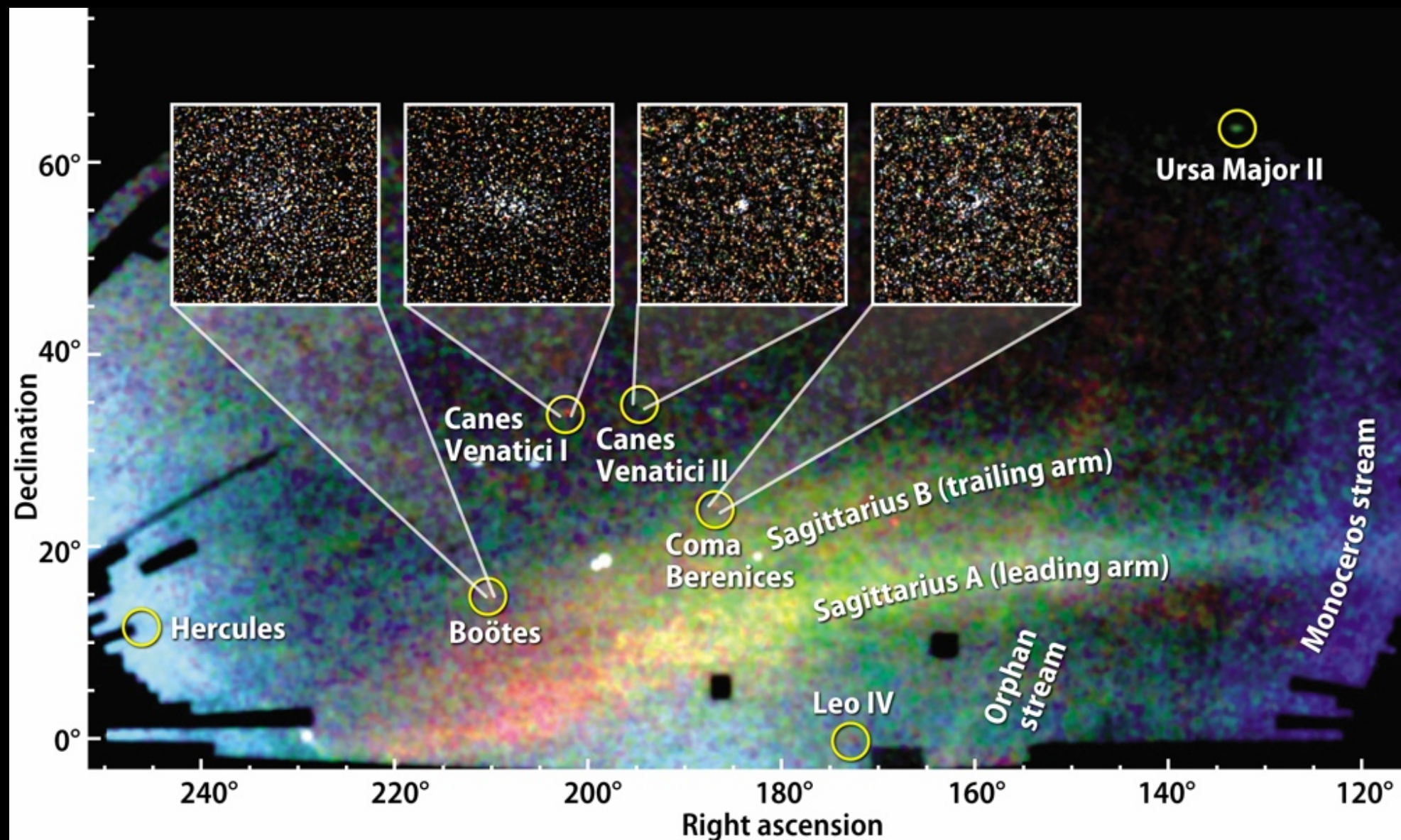
Result of a cold dark matter simulation

# Where are the dwarf galaxies?





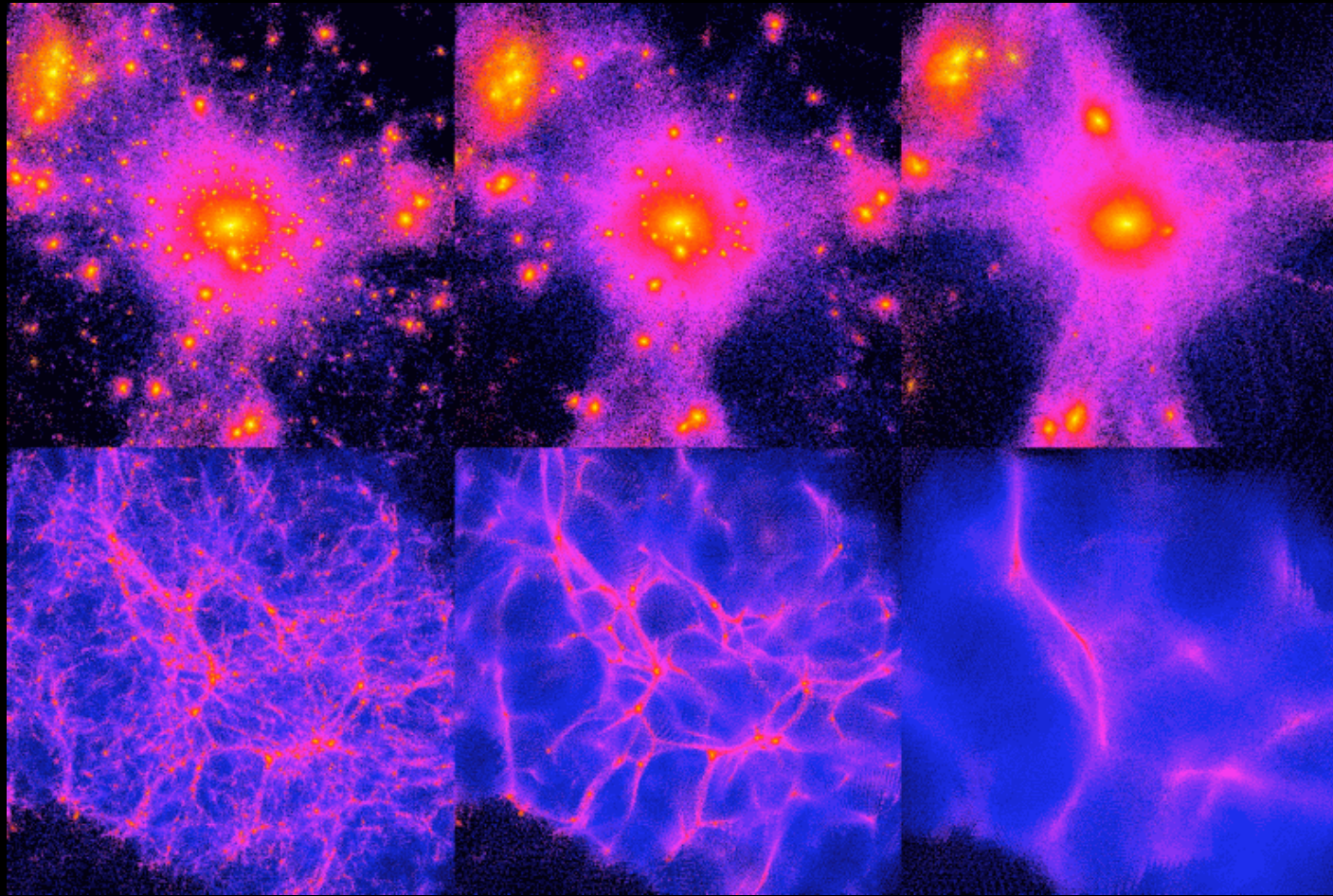
# Where are the dwarf galaxies?



Cold

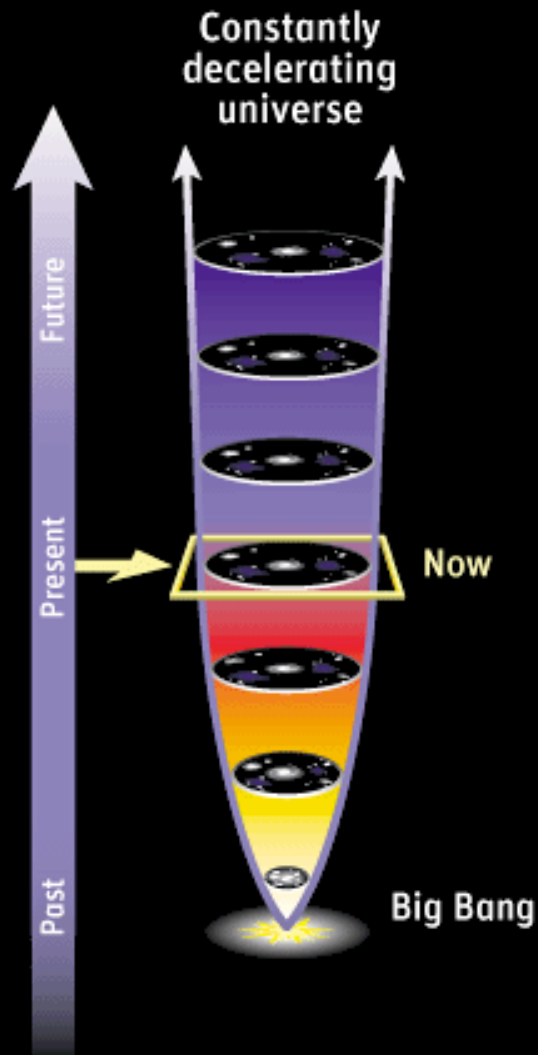
Warm

Hot



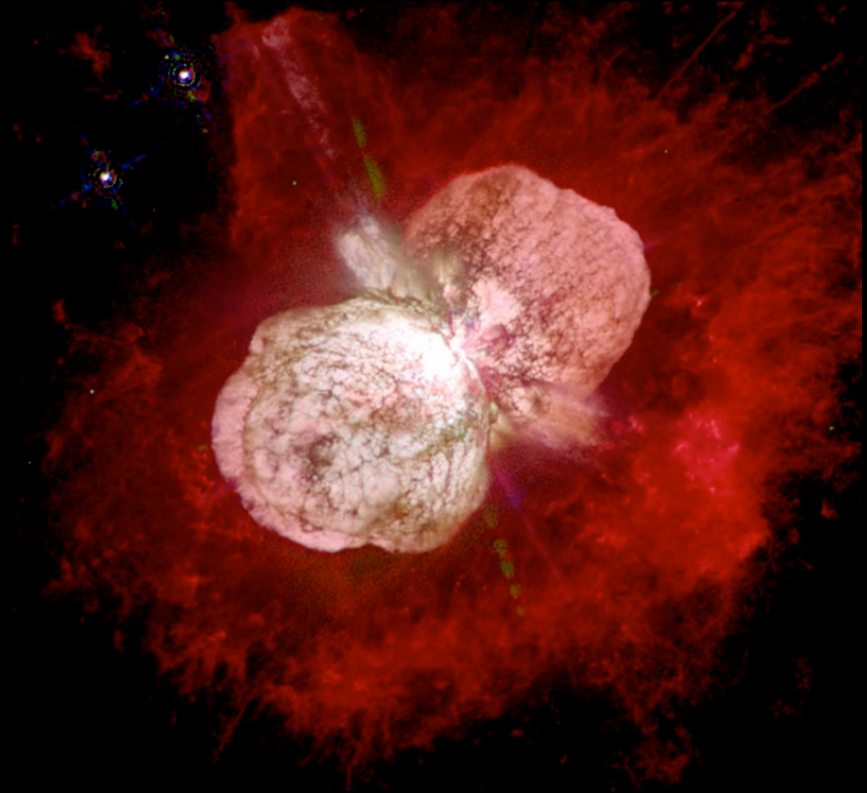
Dark matter is made up of cold particles!

# One final puzzle : dark energy

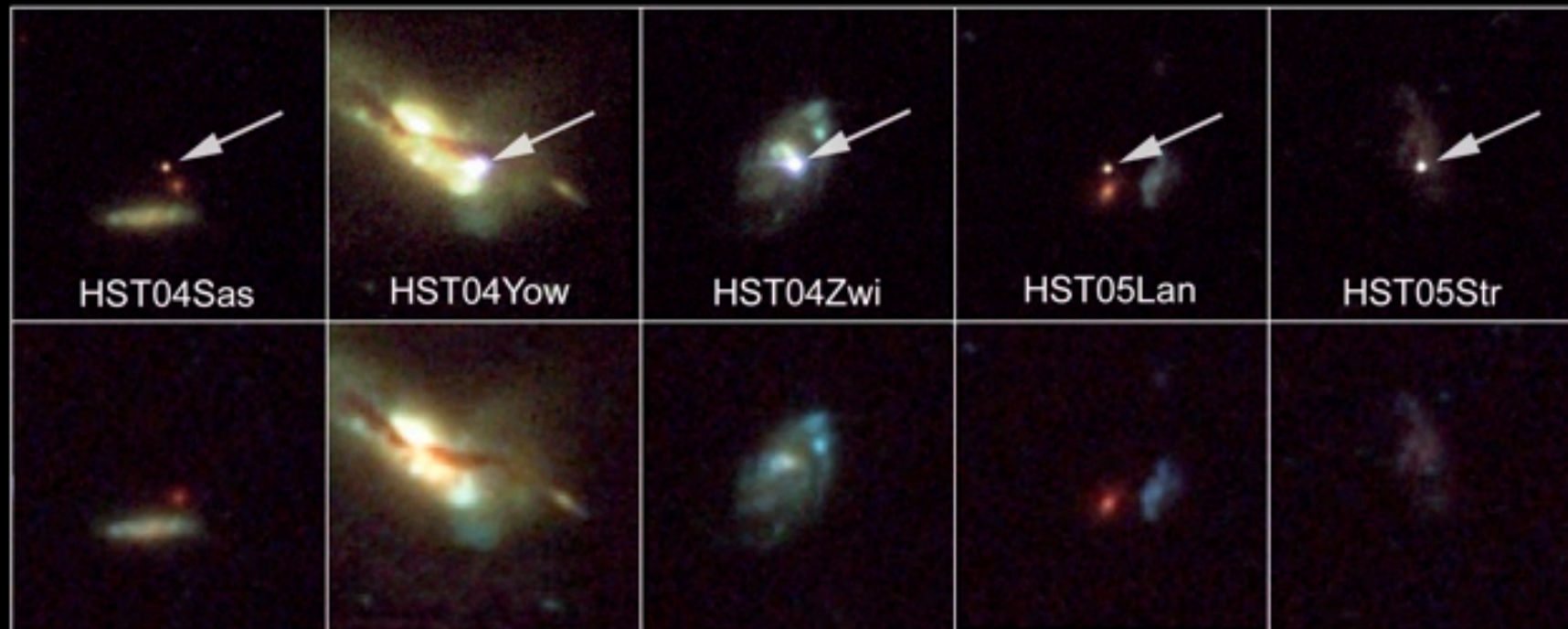


The cosmic expansion should slow down because of the pull of gravity

# Supernovae : cosmic beacons



# Supernovae : cosmic beacons

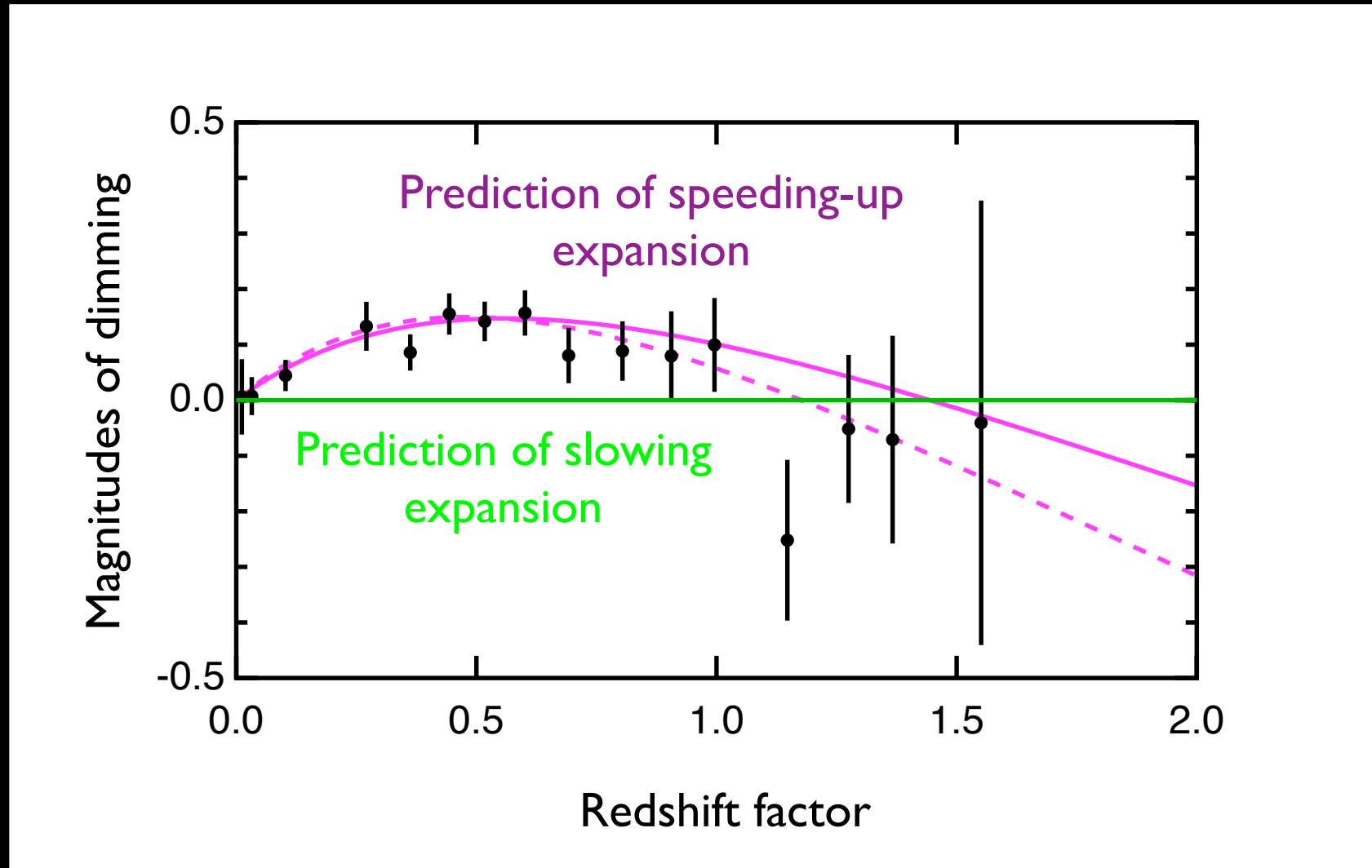


**Host Galaxies of Distant Supernovae**  
*Hubble Space Telescope* ■ *Advanced Camera for Surveys*

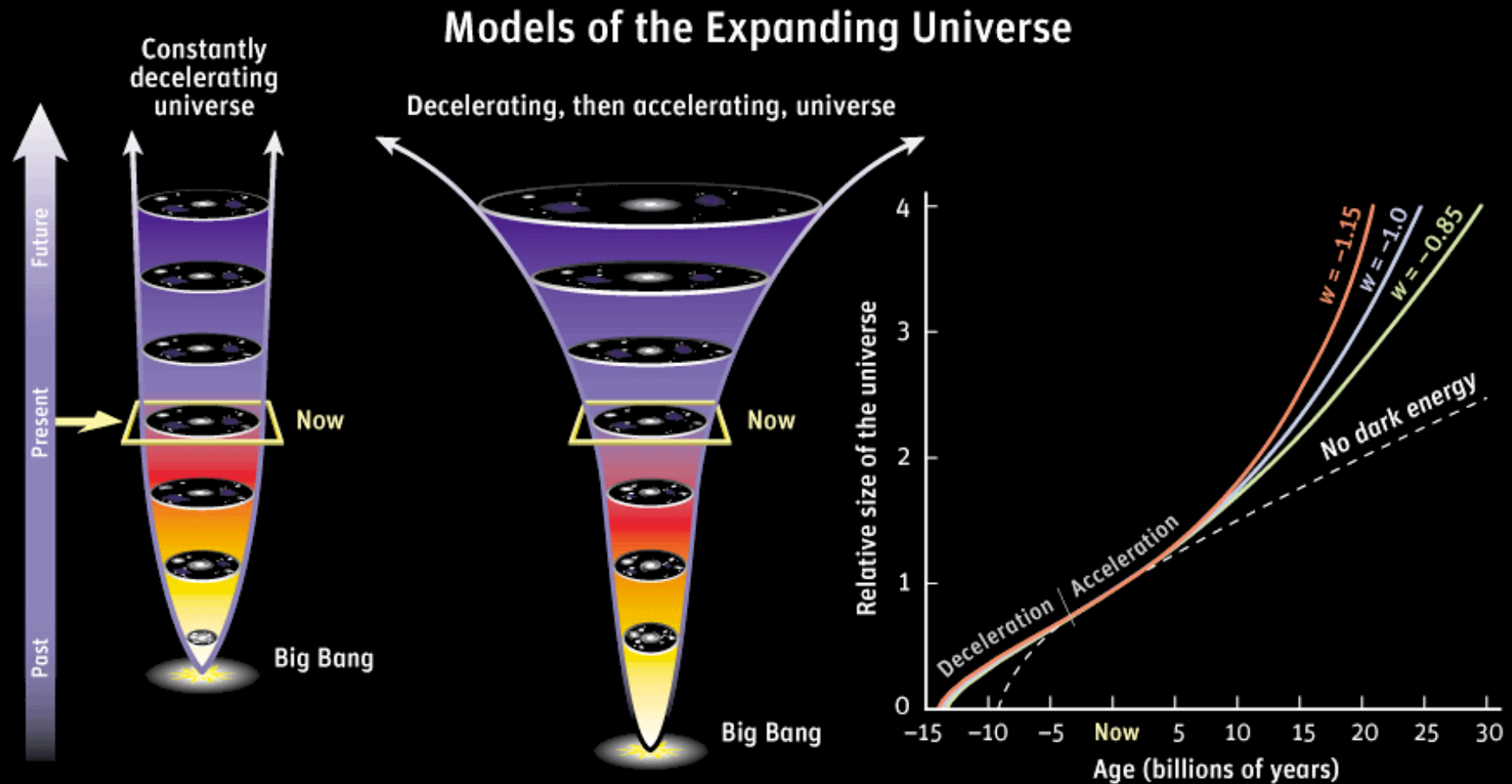
# Supernovae : cosmic beacons



# Supernovae : cosmic beacons

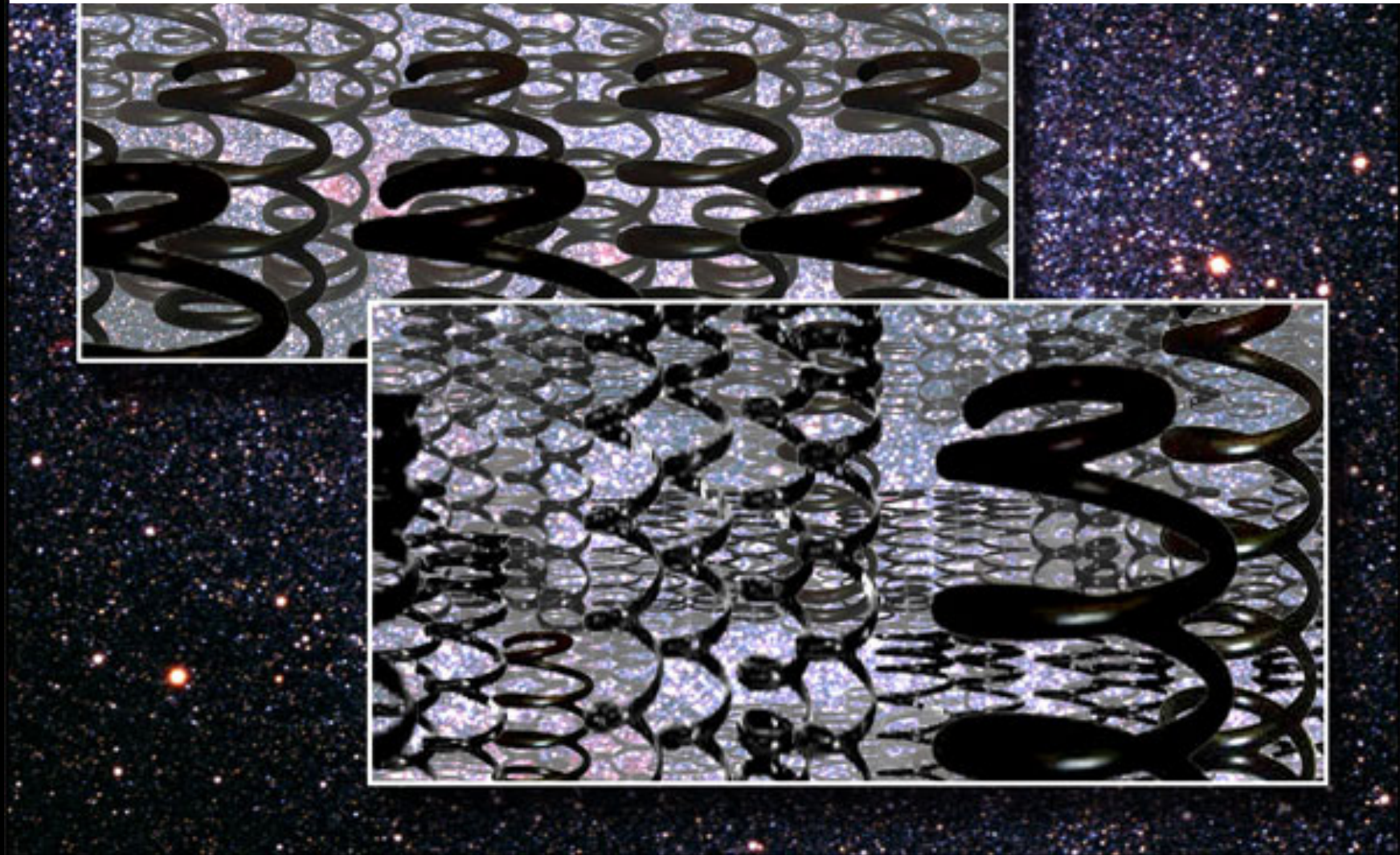


# The expansion of space is speeding up!



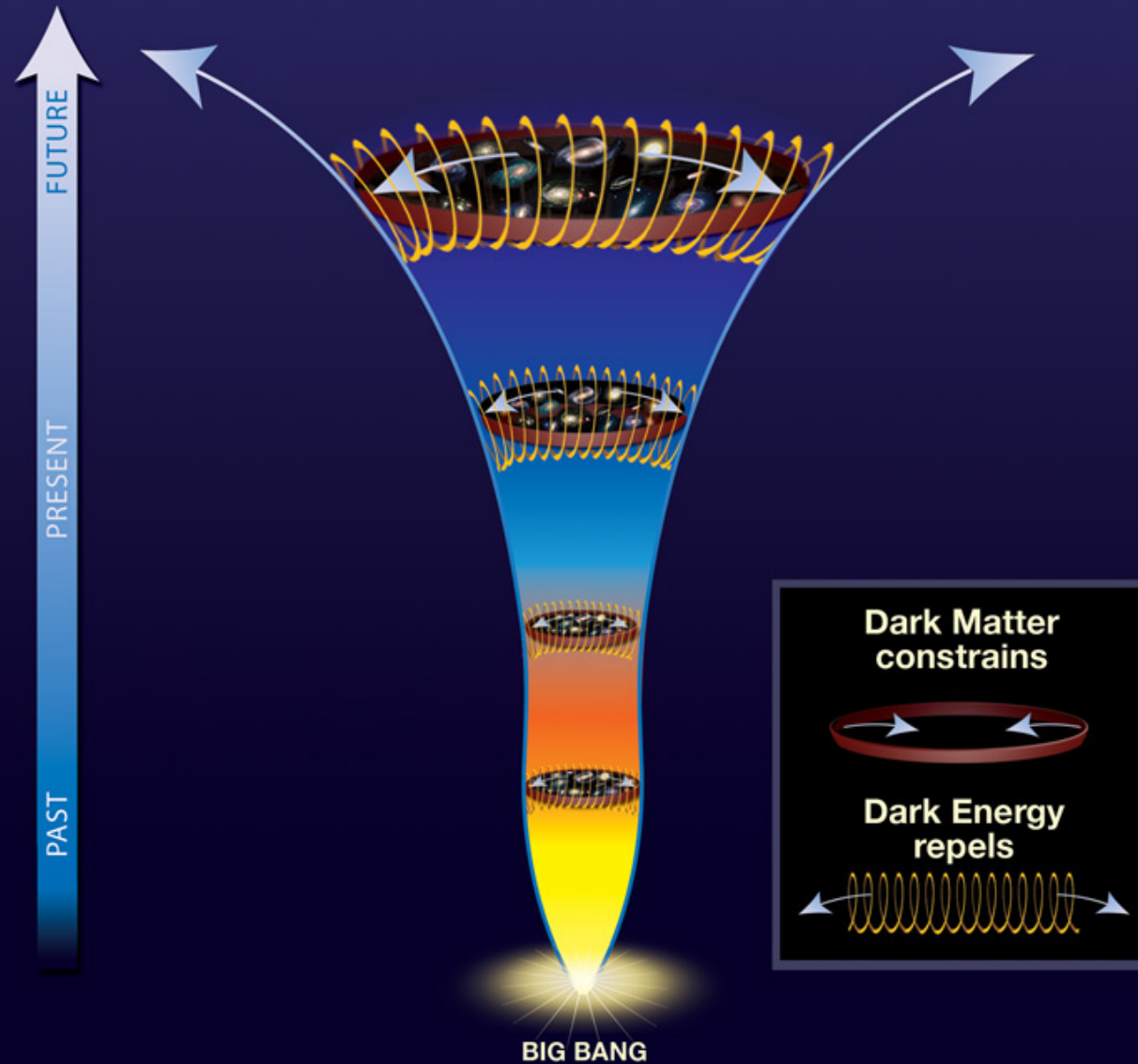


Dark energy is the springs driving  
the cosmic expansion

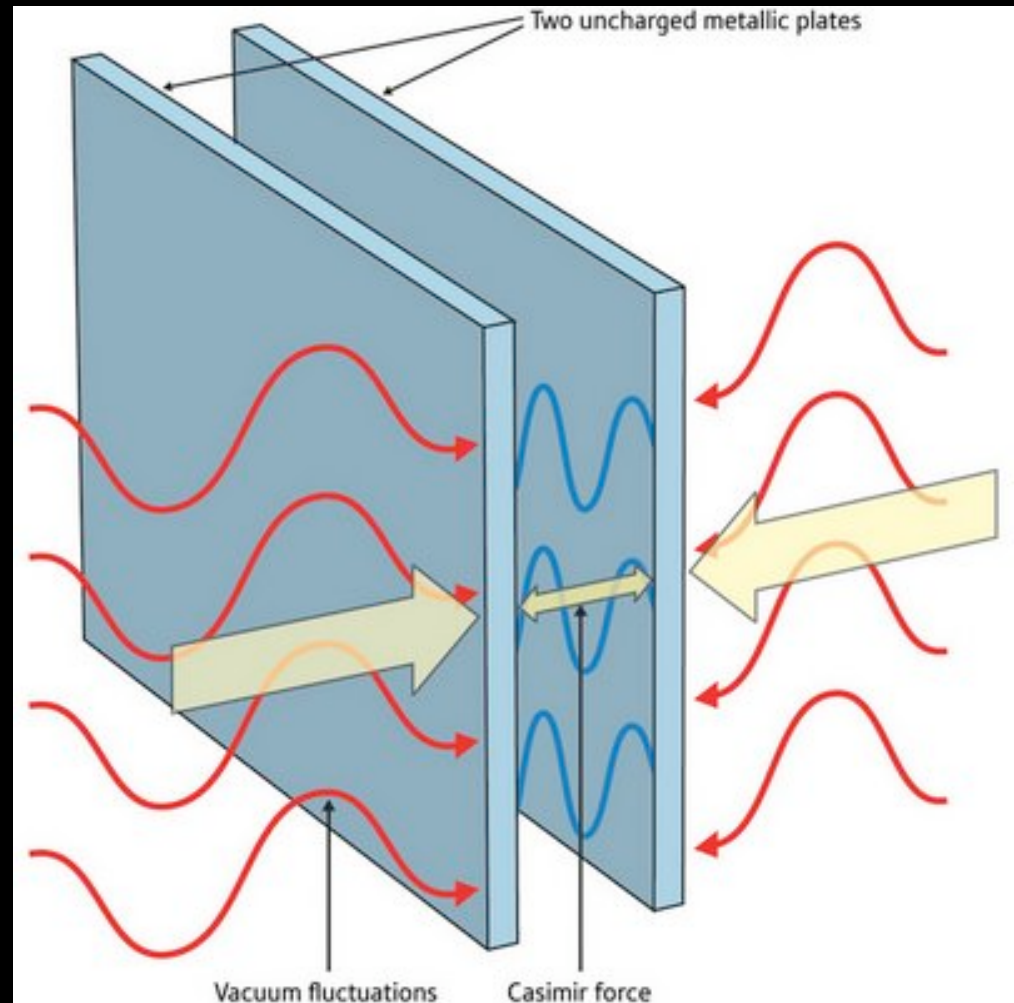
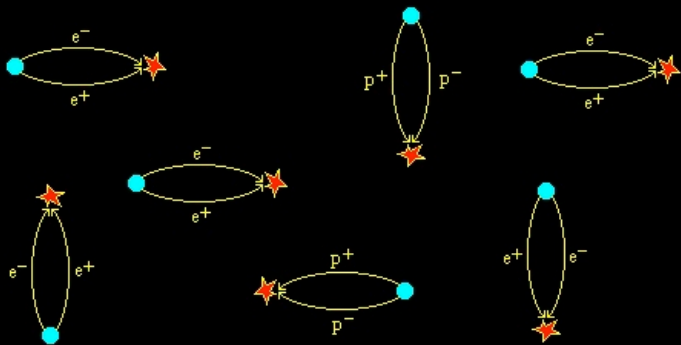
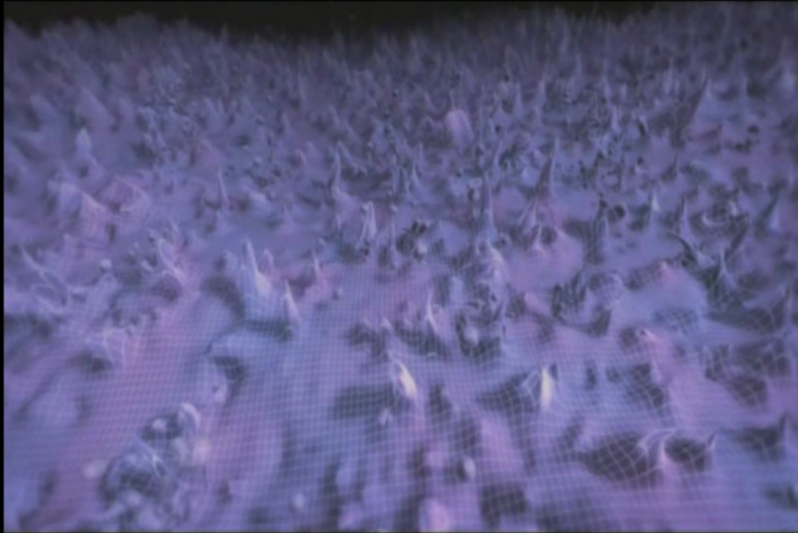


# Cosmic tug of war

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

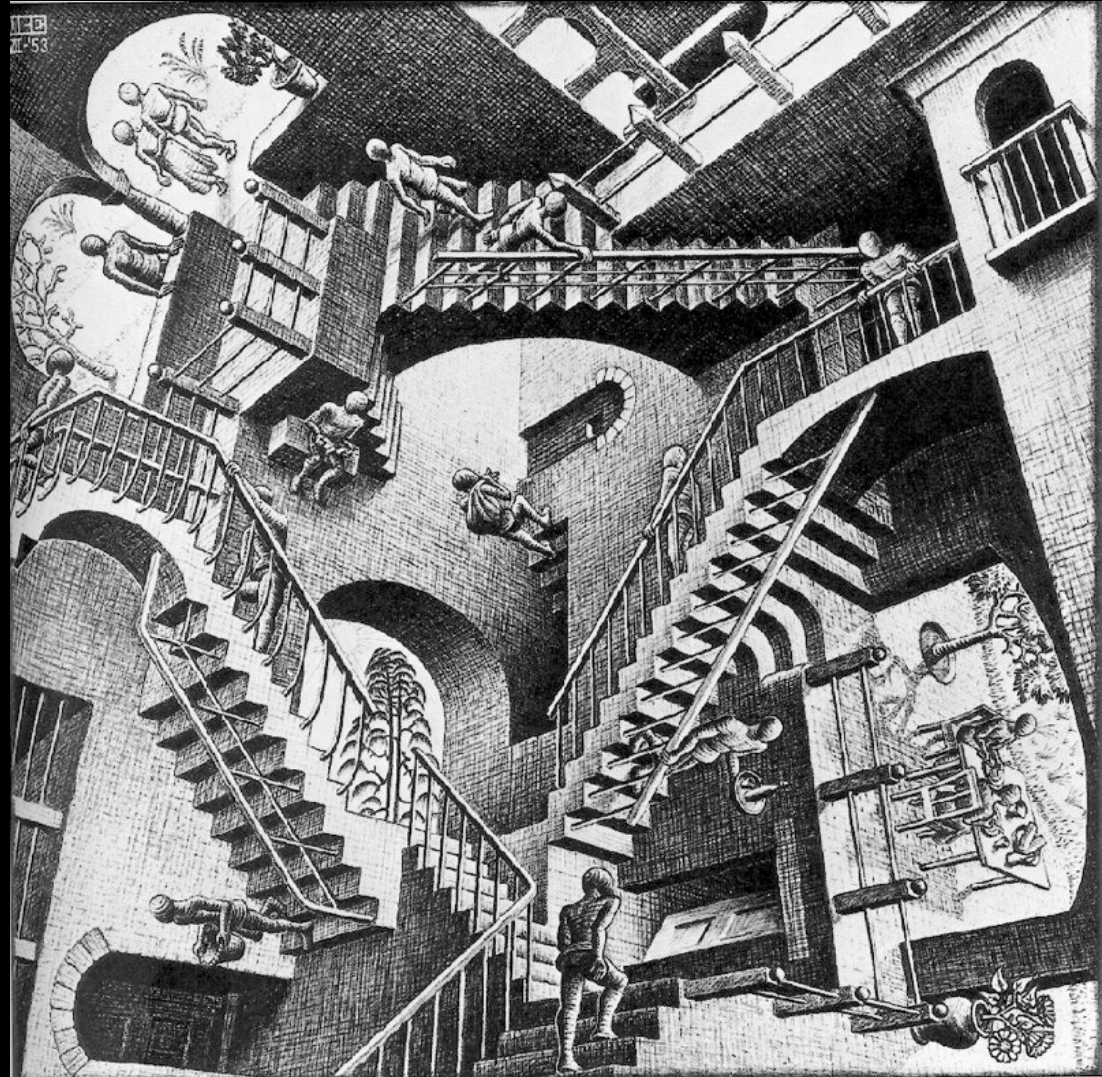
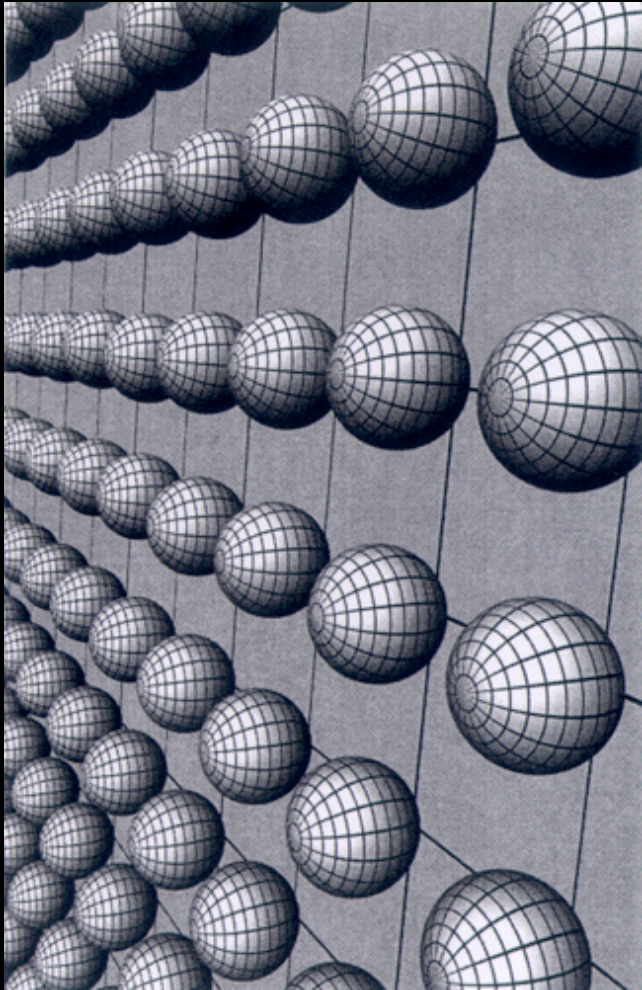


# What is dark energy?



Fluctuations in the quantum vacuum?

# What is dark energy?



Extra dimensions of space?

Summing up ...

