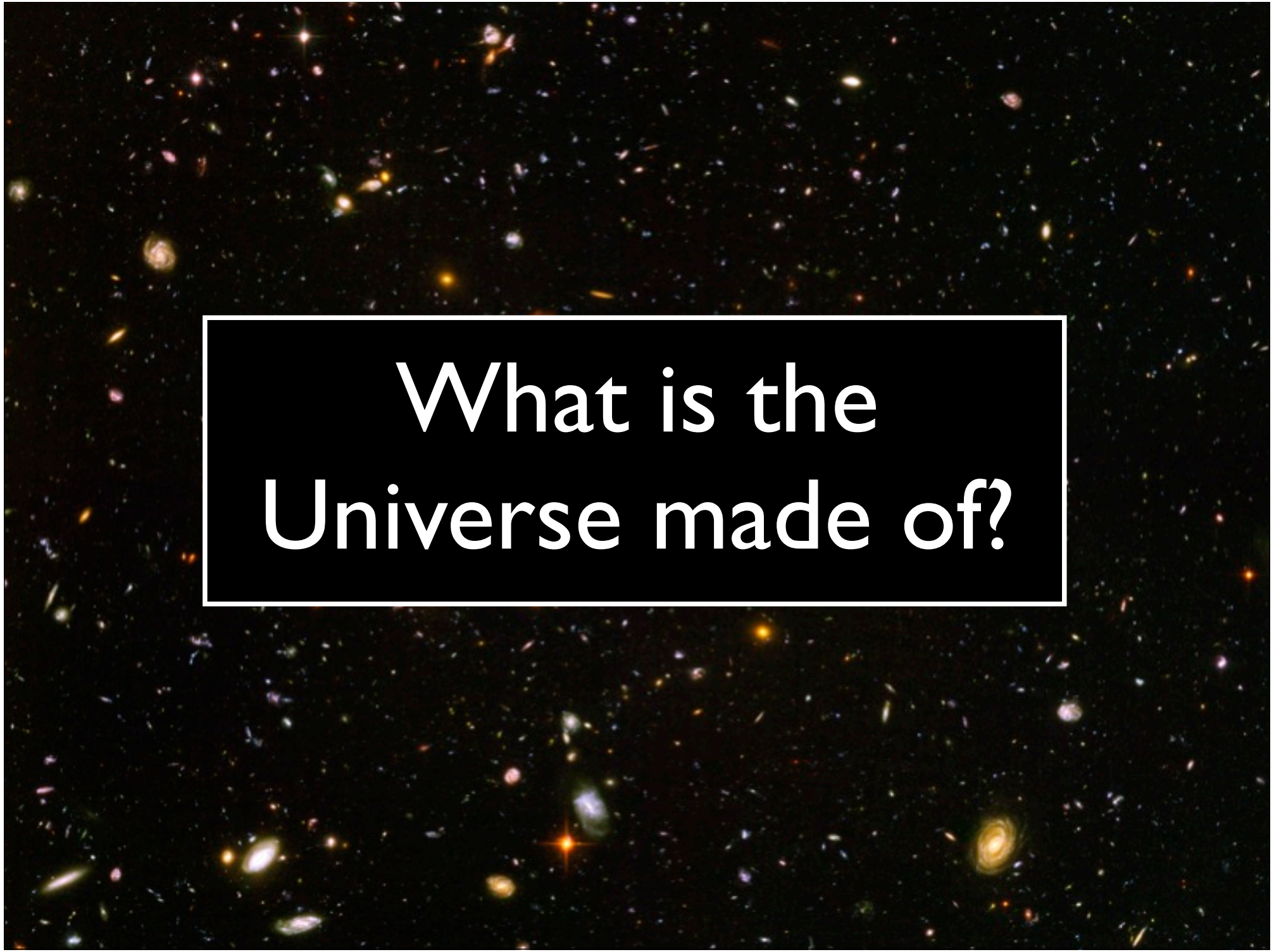
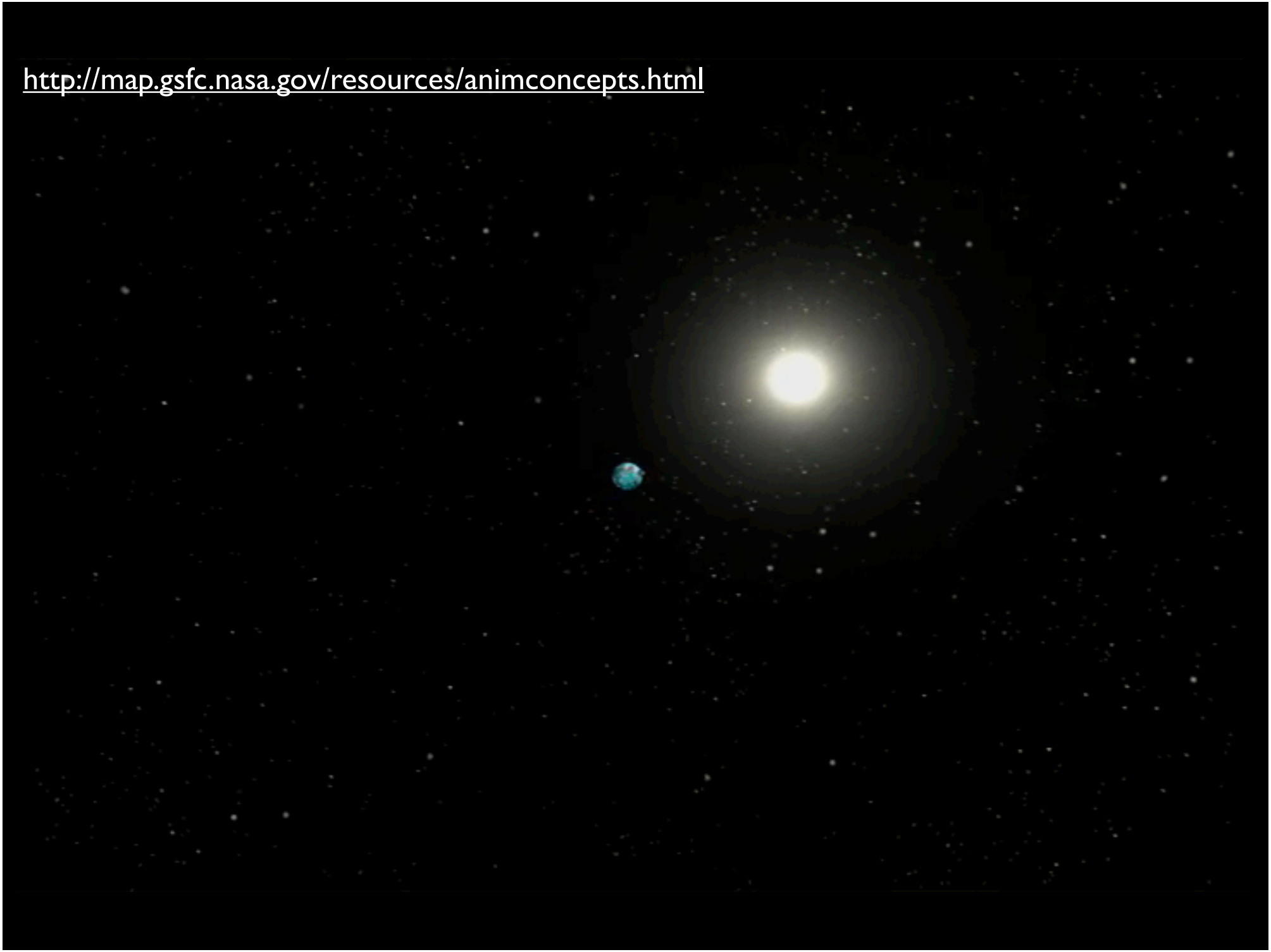
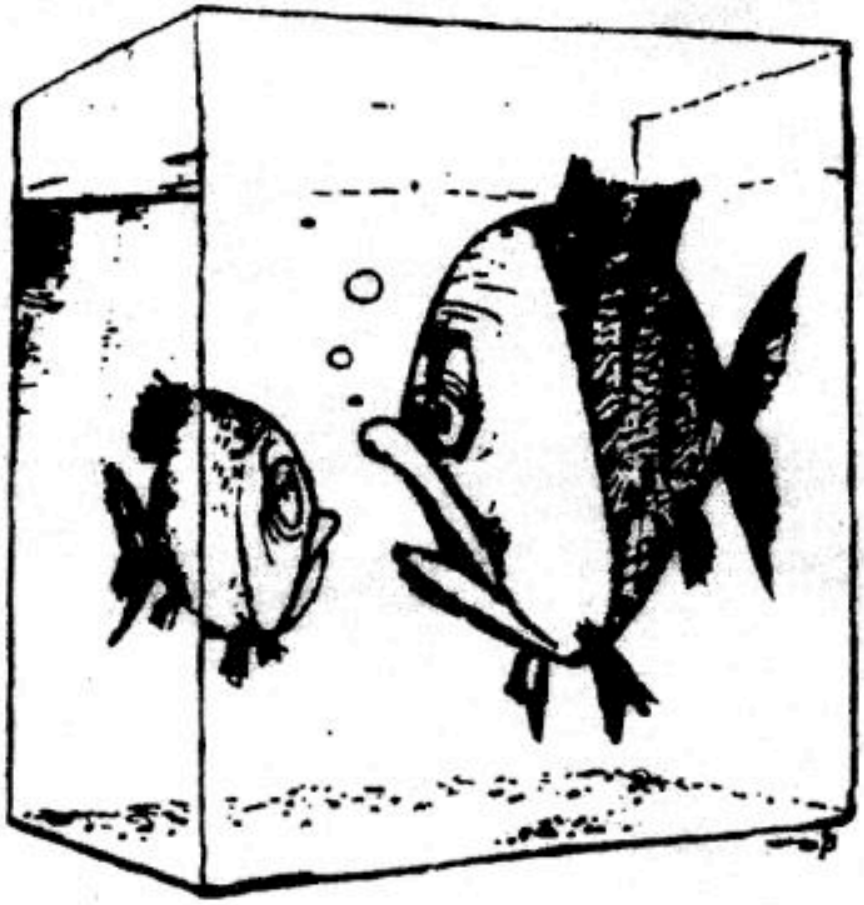
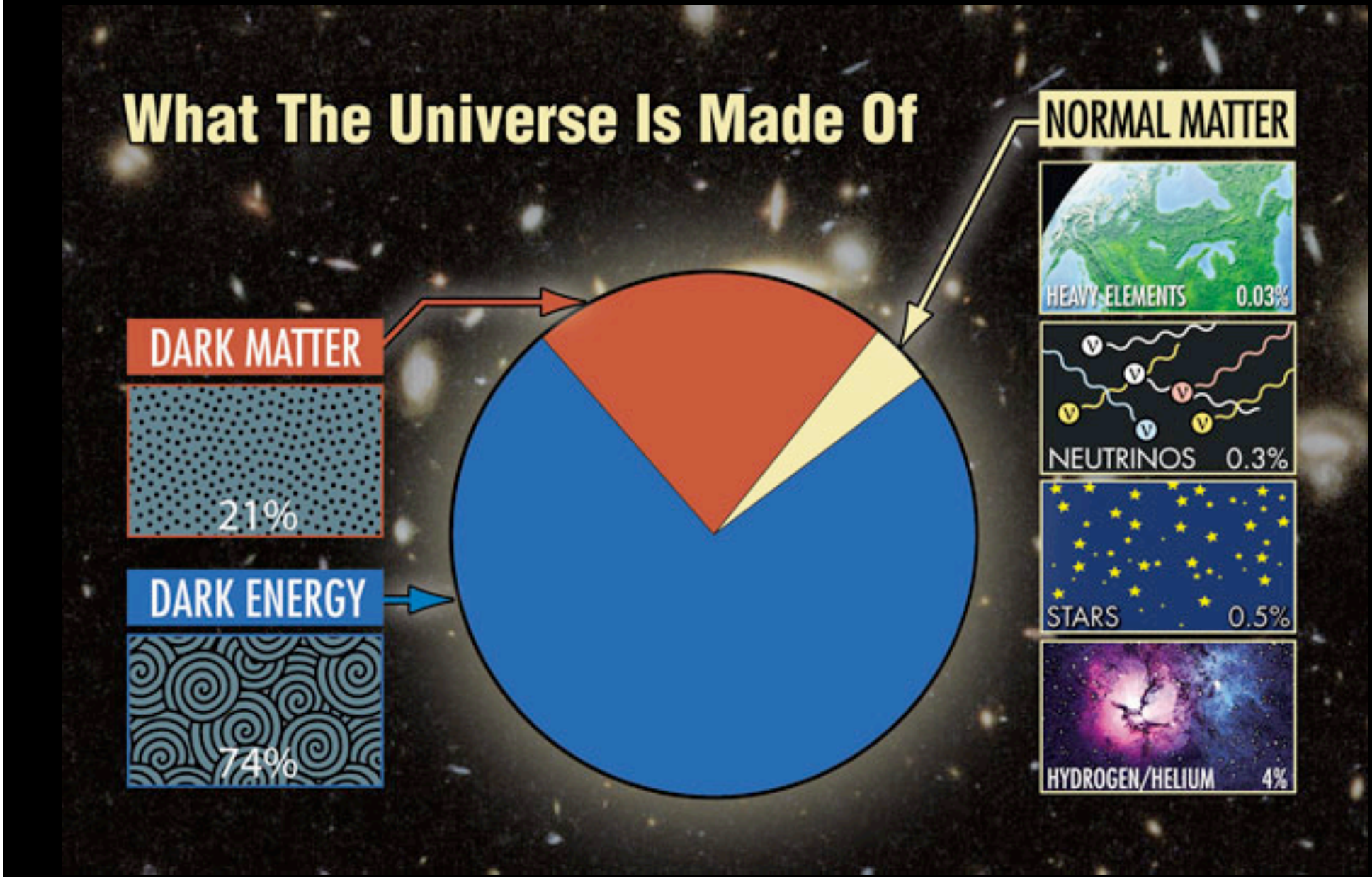

What is the
Universe made of?


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

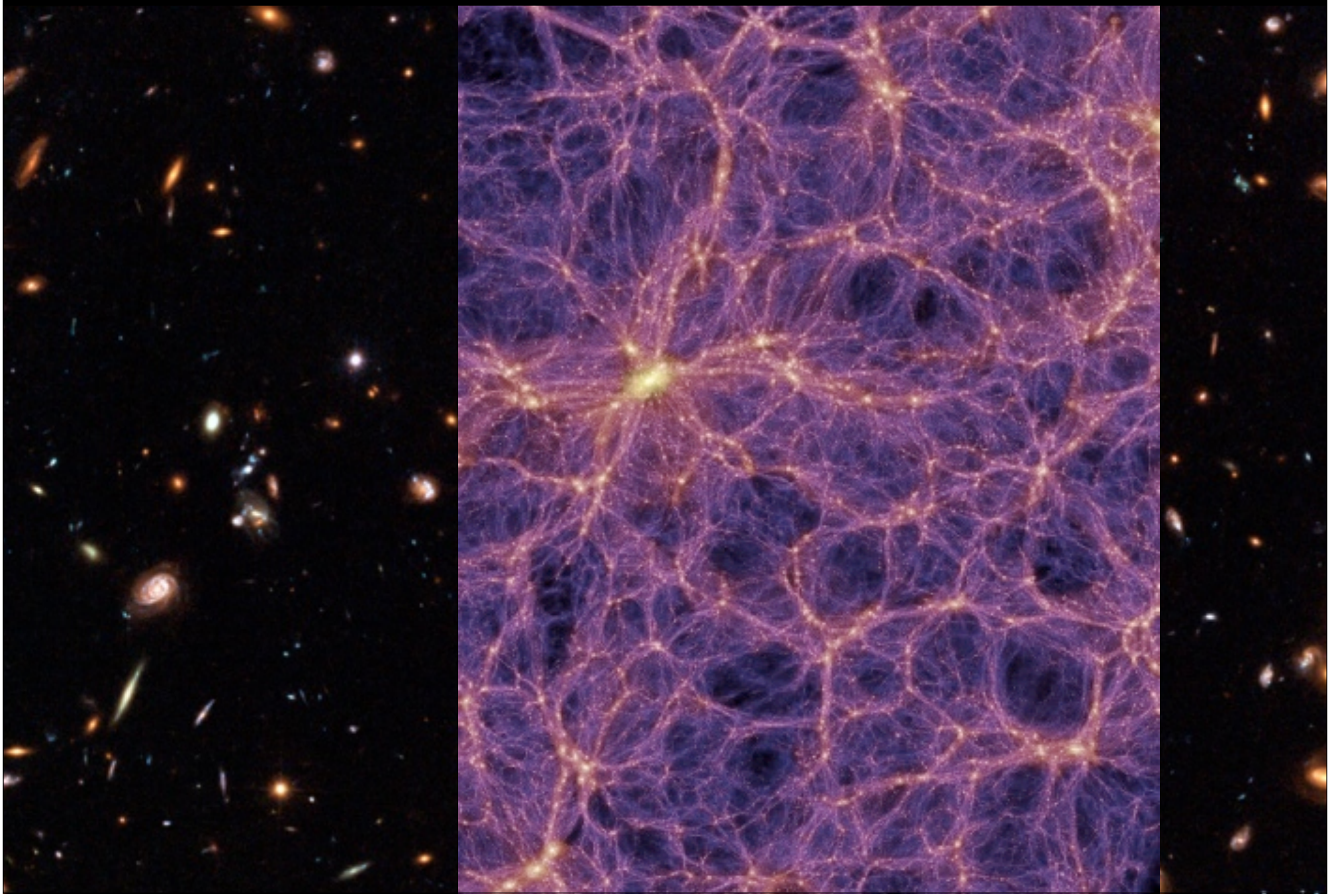


'The universe, my son, is a large tank full of water


What The Universe Is Made Of
NORMAL MATTER
HEAVY ELEMENTS 0.03%
NEUTRINOS 0.3%
STARS 0.5%
HYDROGEN/HELIUM 4%
DARK MATTER
21%
DARK ENERGY
74%

The problem of dark matter

The problem of dark matter

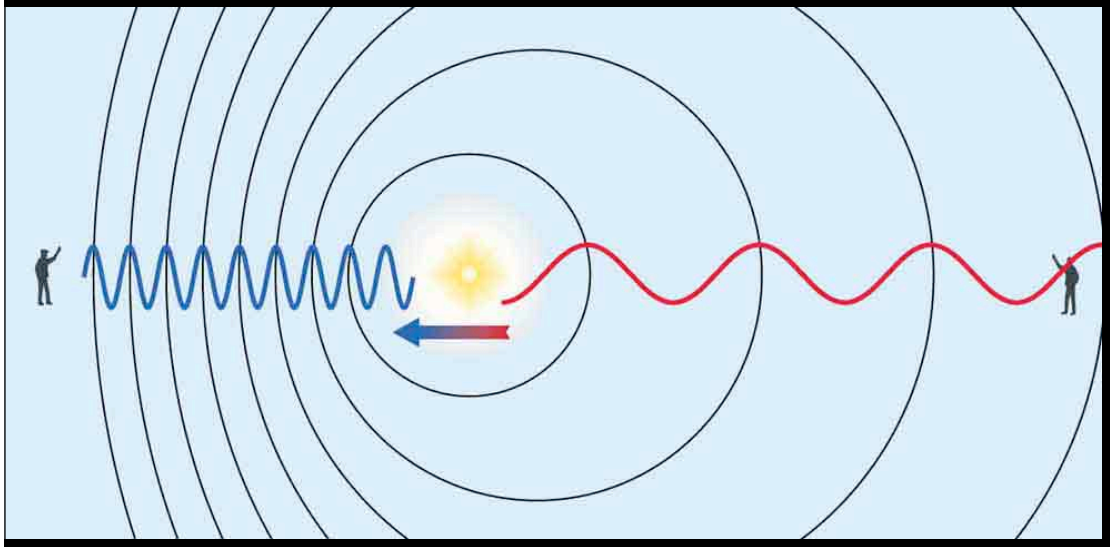


The problem of dark matter

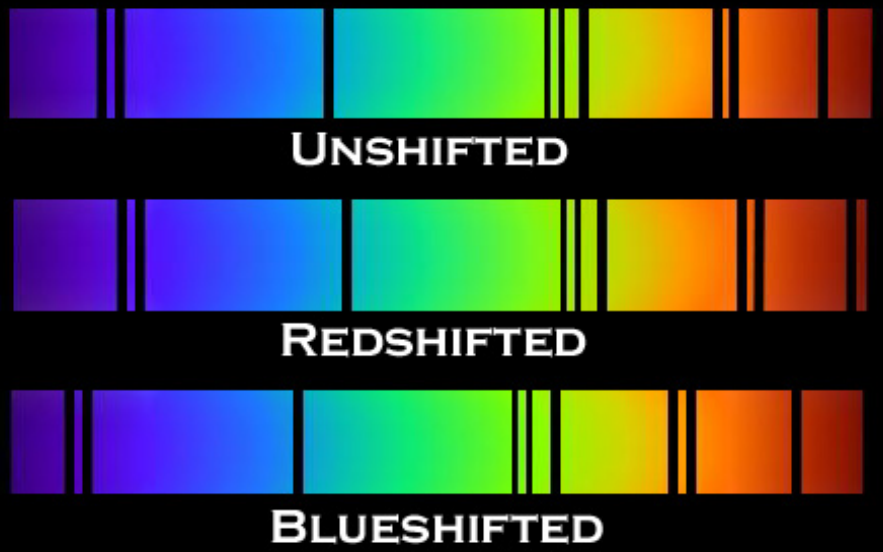
Galaxy groups

Dark matter in galaxy clusters

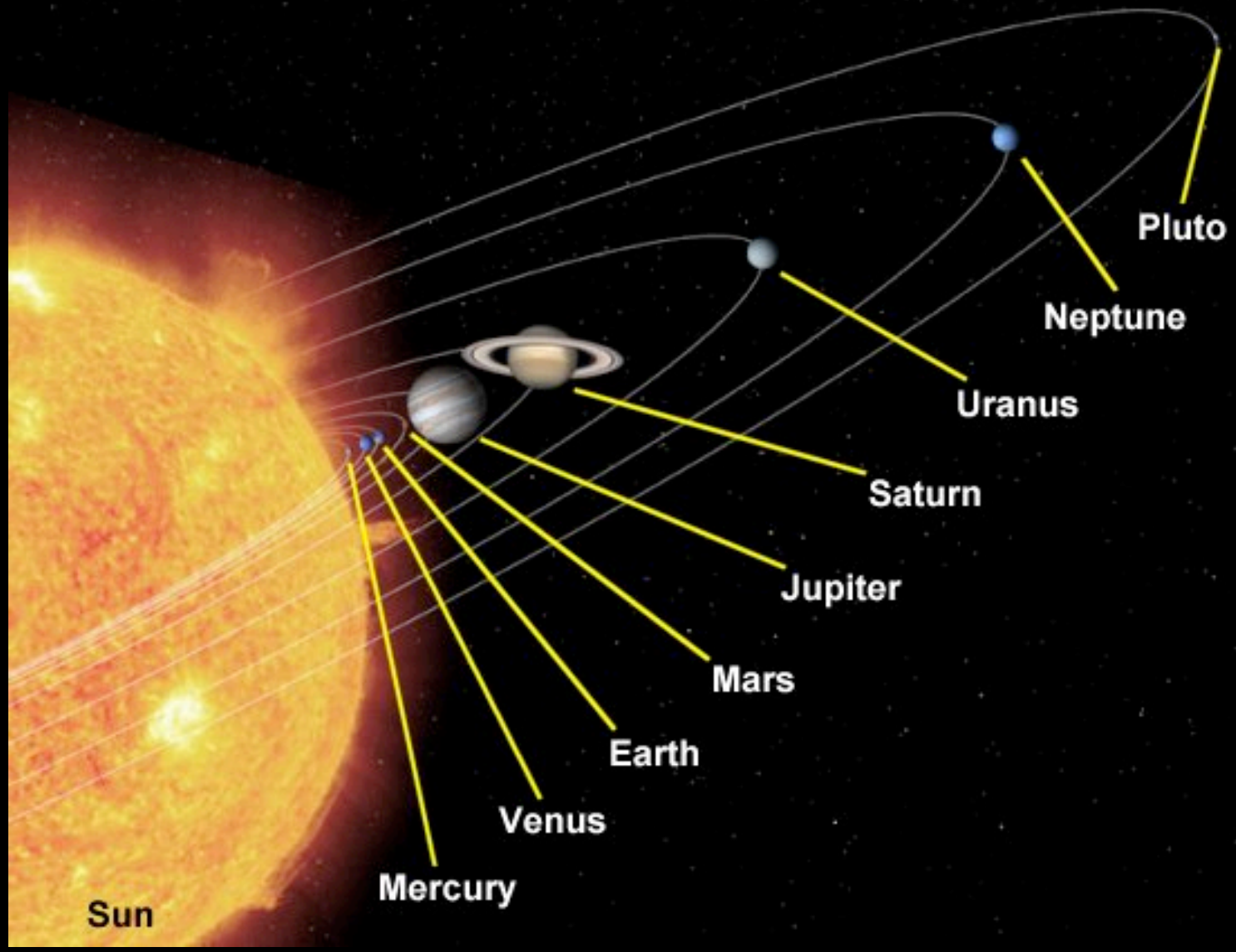
Dark matter in galaxy clusters



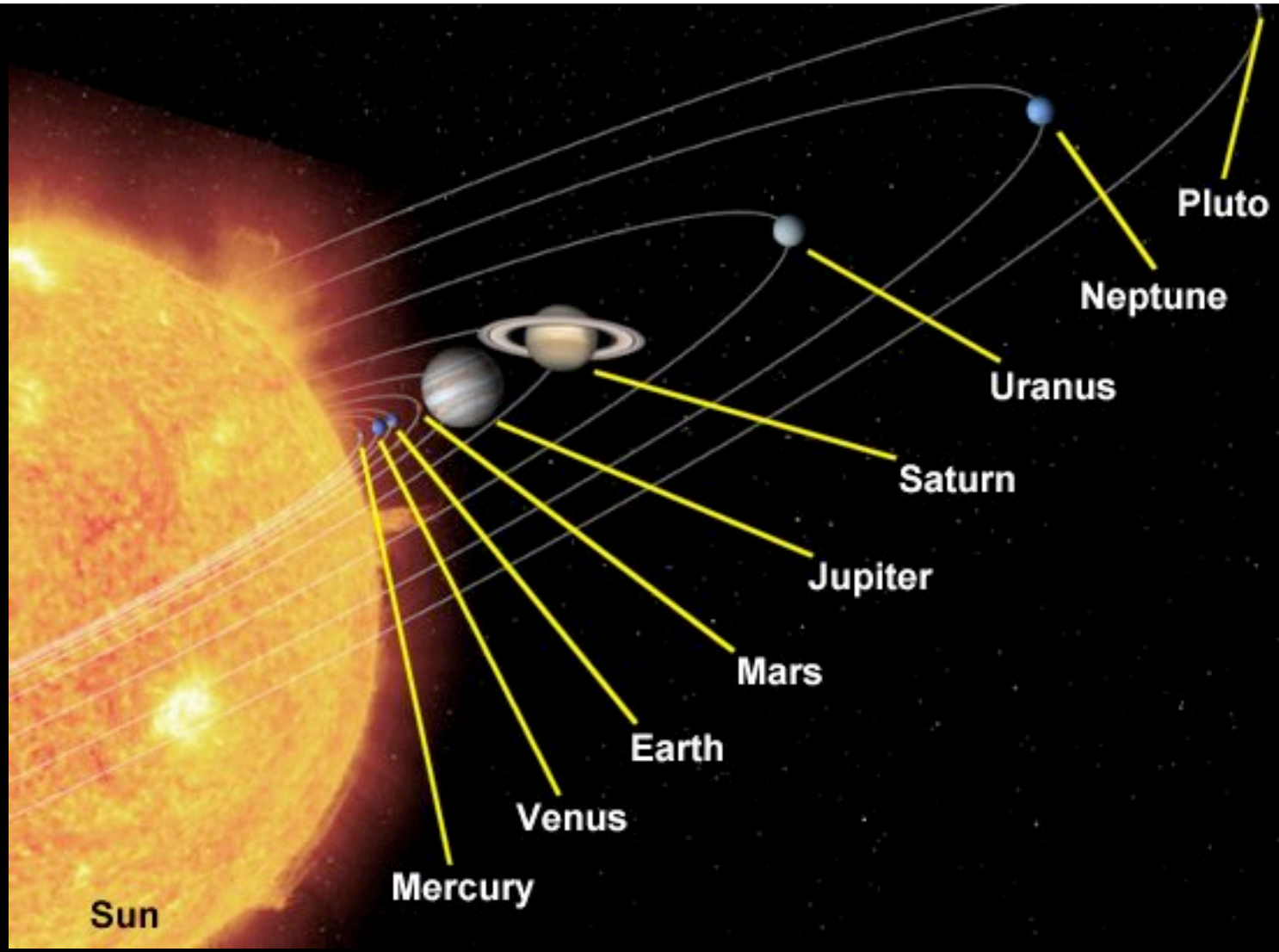
Dark matter in galaxy clusters



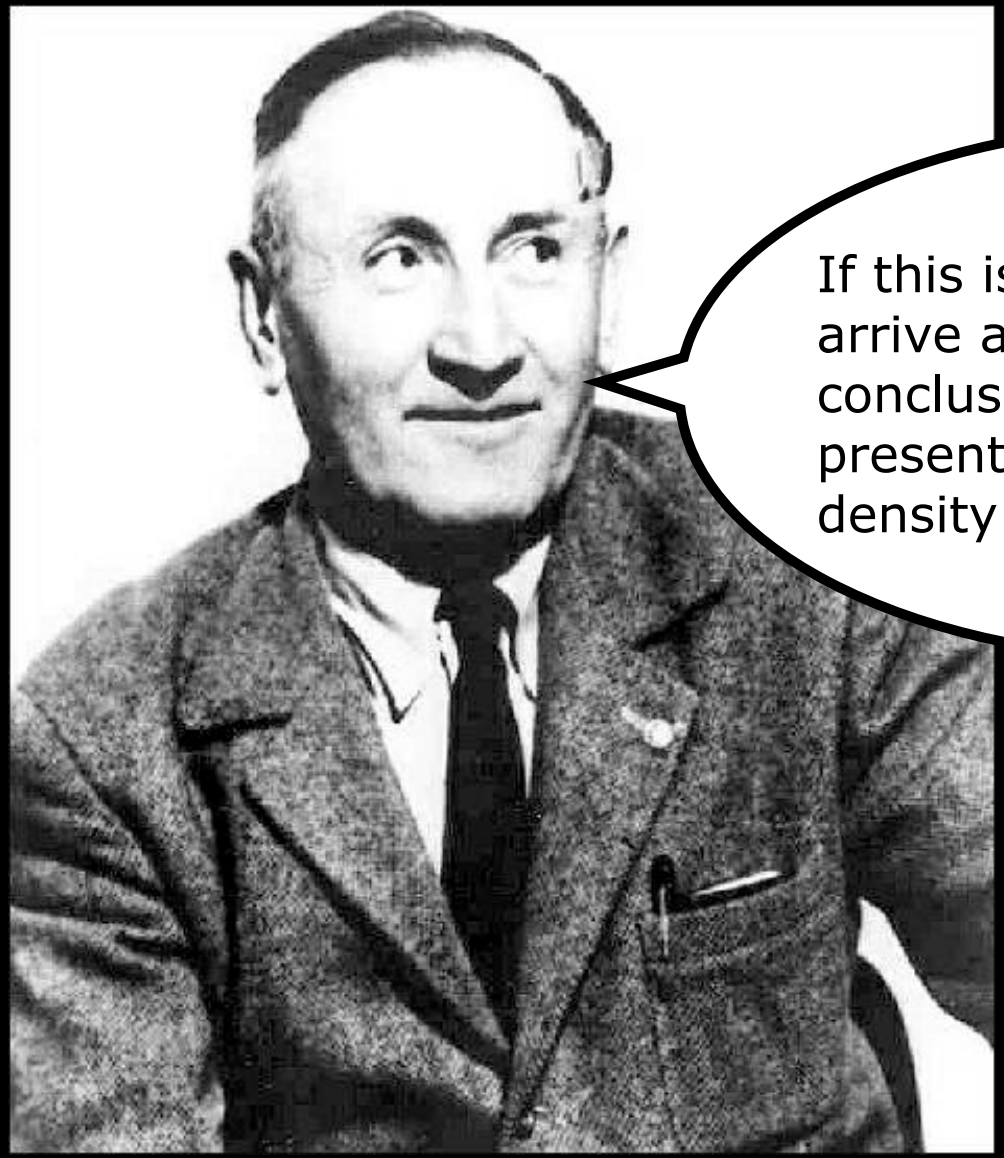
Relating motion to gravitational mass!



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

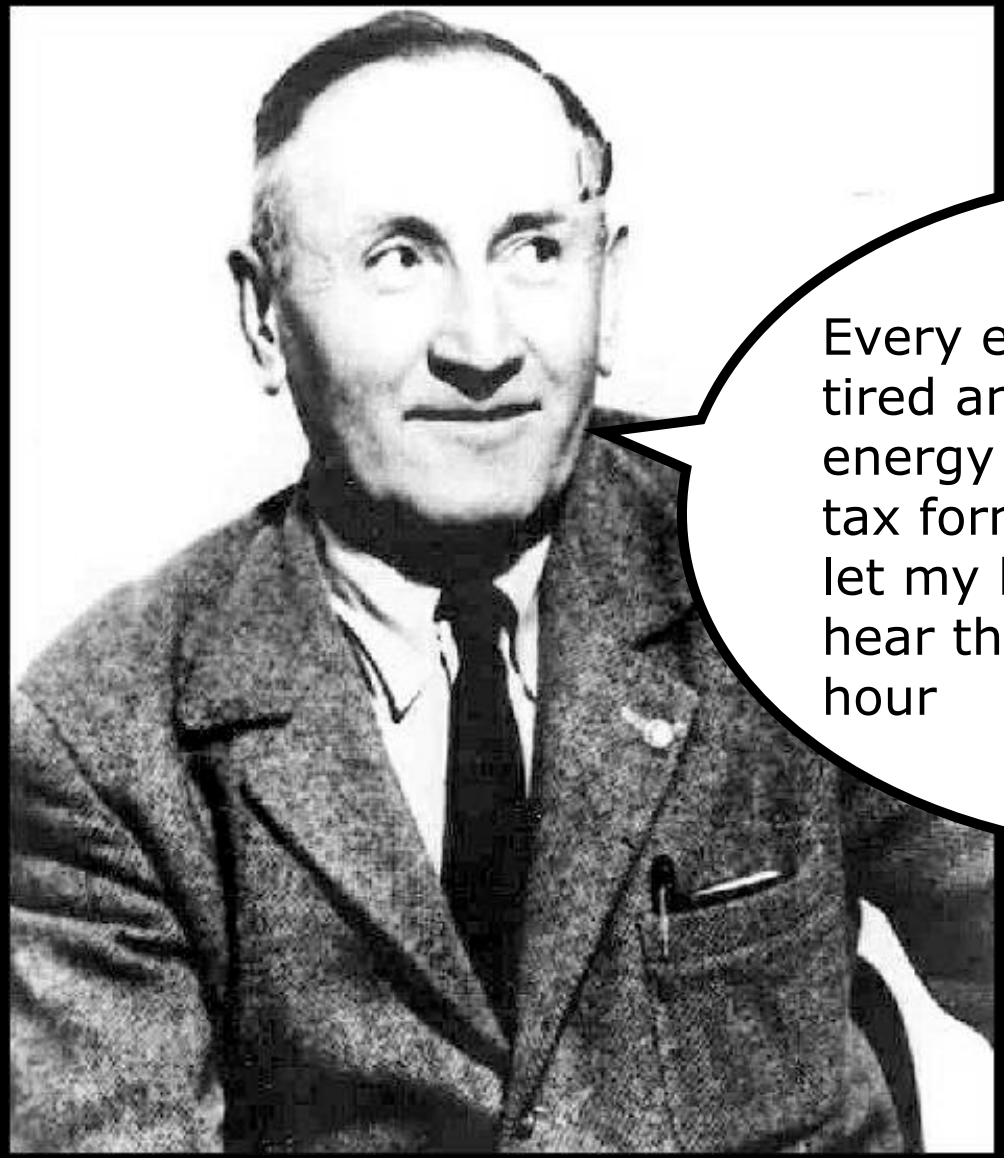


If this is confirmed, we would arrive at the astonishing conclusion that dark matter is present with a much greater density than luminous matter

Fritz Zwicky , 1933

Dark matter is the glue holding together clusters of galaxies

Dark matter in galaxy clusters

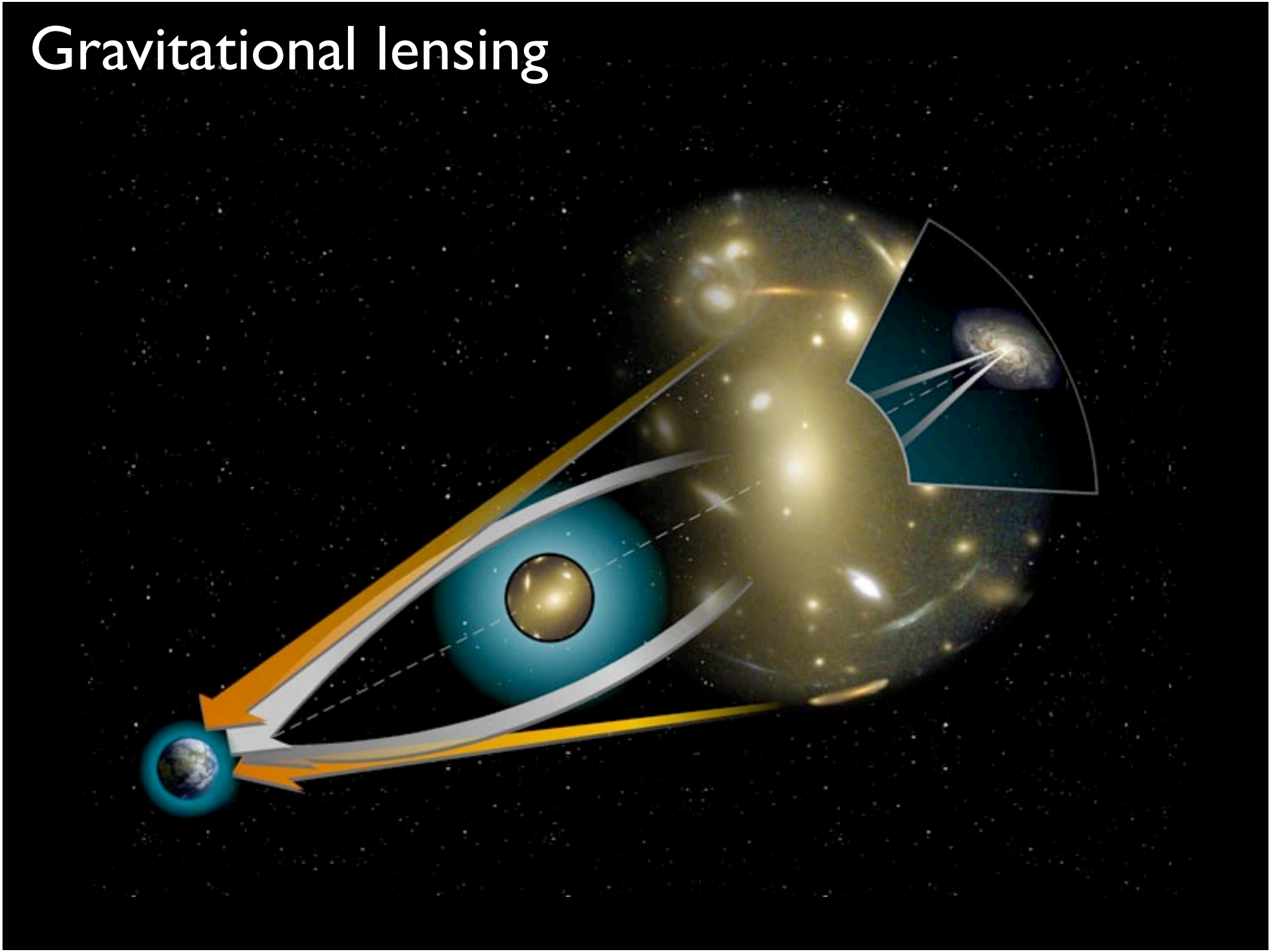


Every evening, I come home tired and have just enough energy to fill out the endless tax forms, to pay bills, not to let my house neglected and to hear the radio concert for an hour

Fritz Zwicky

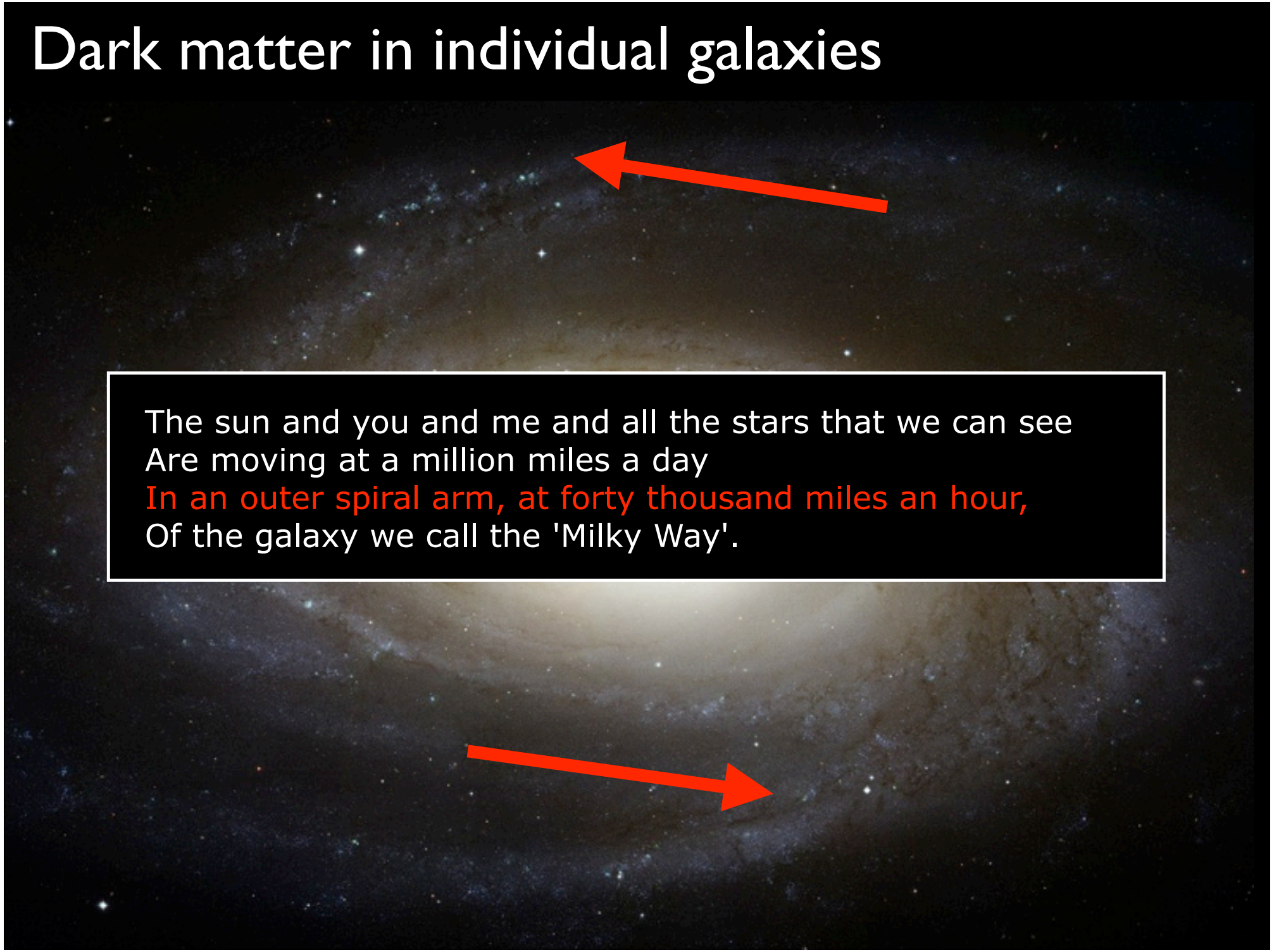
Gravitational lensing

Gravitational lensing



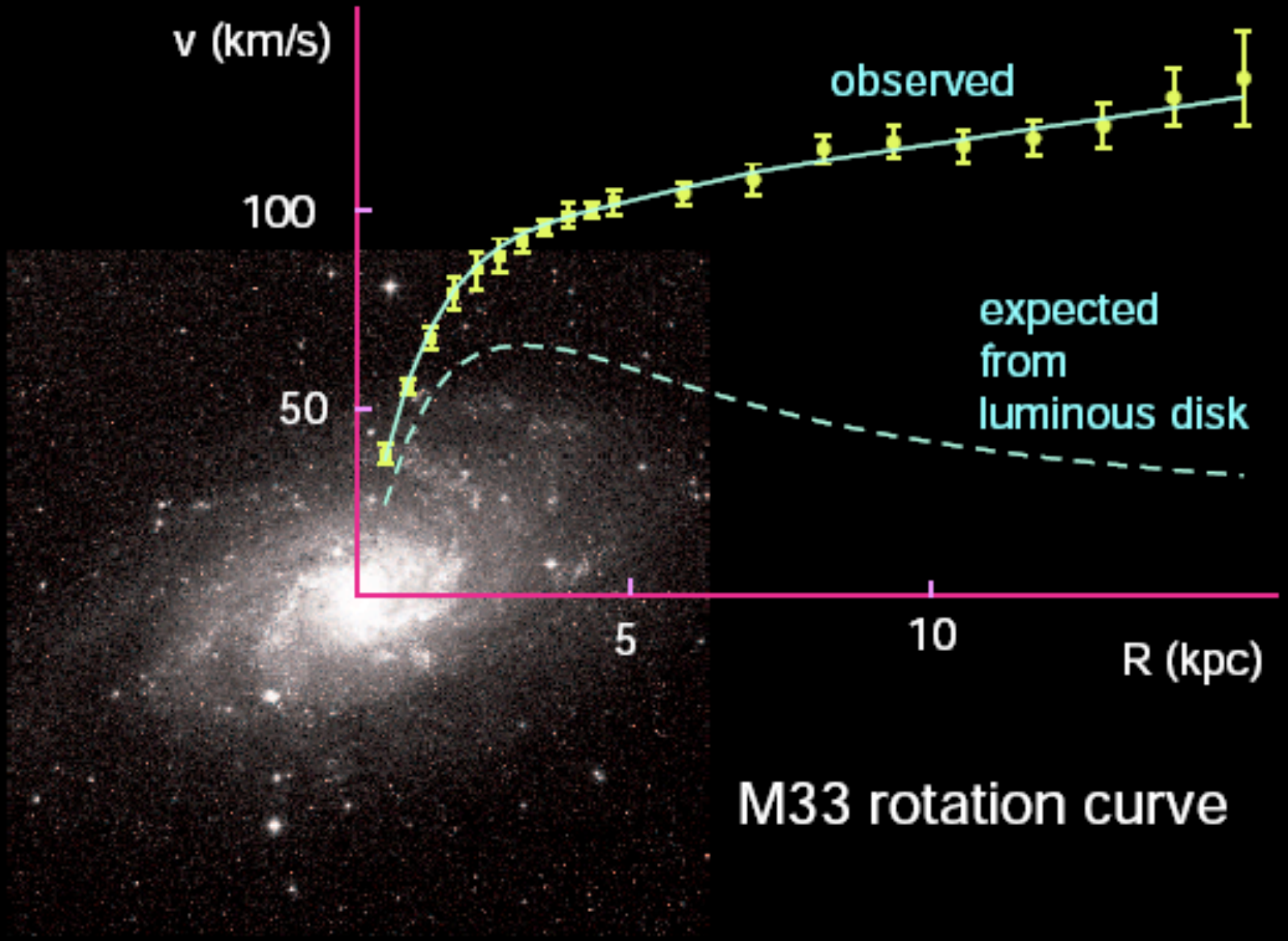
Dark matter in individual galaxies

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?

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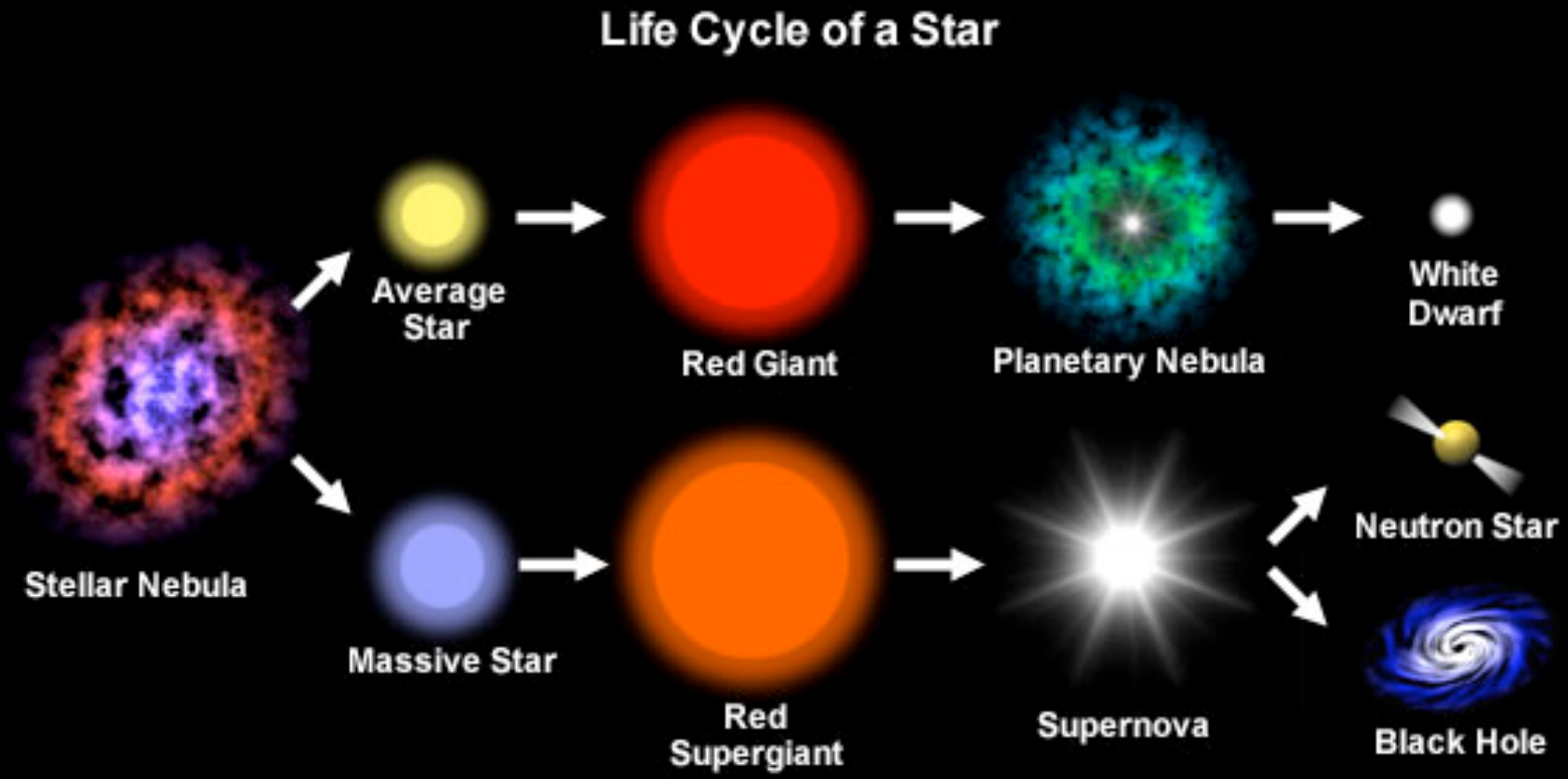
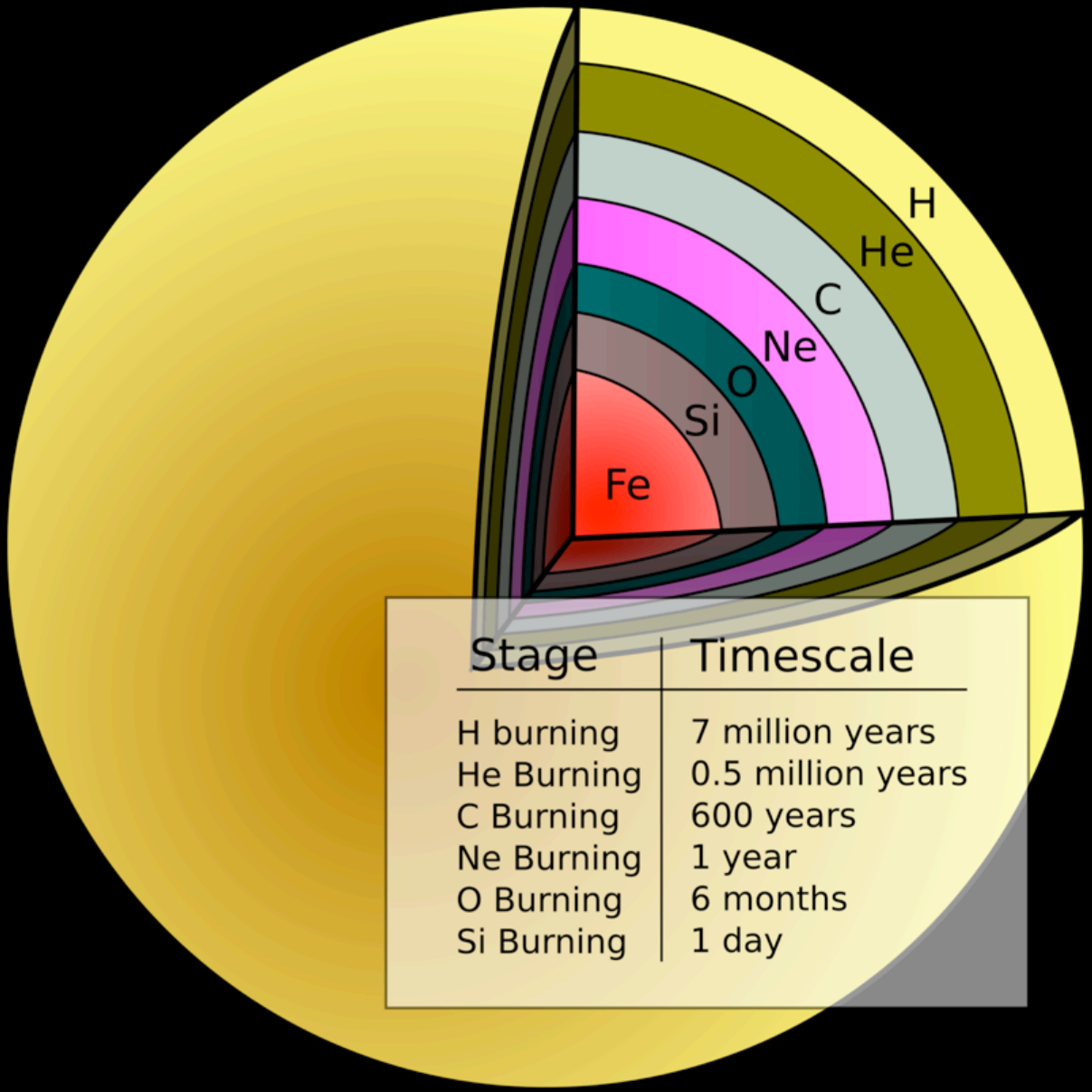
oxygen 43 kg
carbon 16 kg
hydrogen 7 kg
nitrogen 1.8 kg
calcium 1.0 kg
phosphorus 780 g
potassium 140 g
sulfur 140 g
sodium 100 g
chlorine 95 g
magnesium 19 g
iron 4.2 g
fluorine 2.6 g
zinc 2.3 g
silicon 1.0 g
rubidium 0.68 g
strontium 0.32 g
bromine 0.26 g
lead 0.12 g
copper 72 mg
aluminum 60 mg
cadmium 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
lanthanium 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?

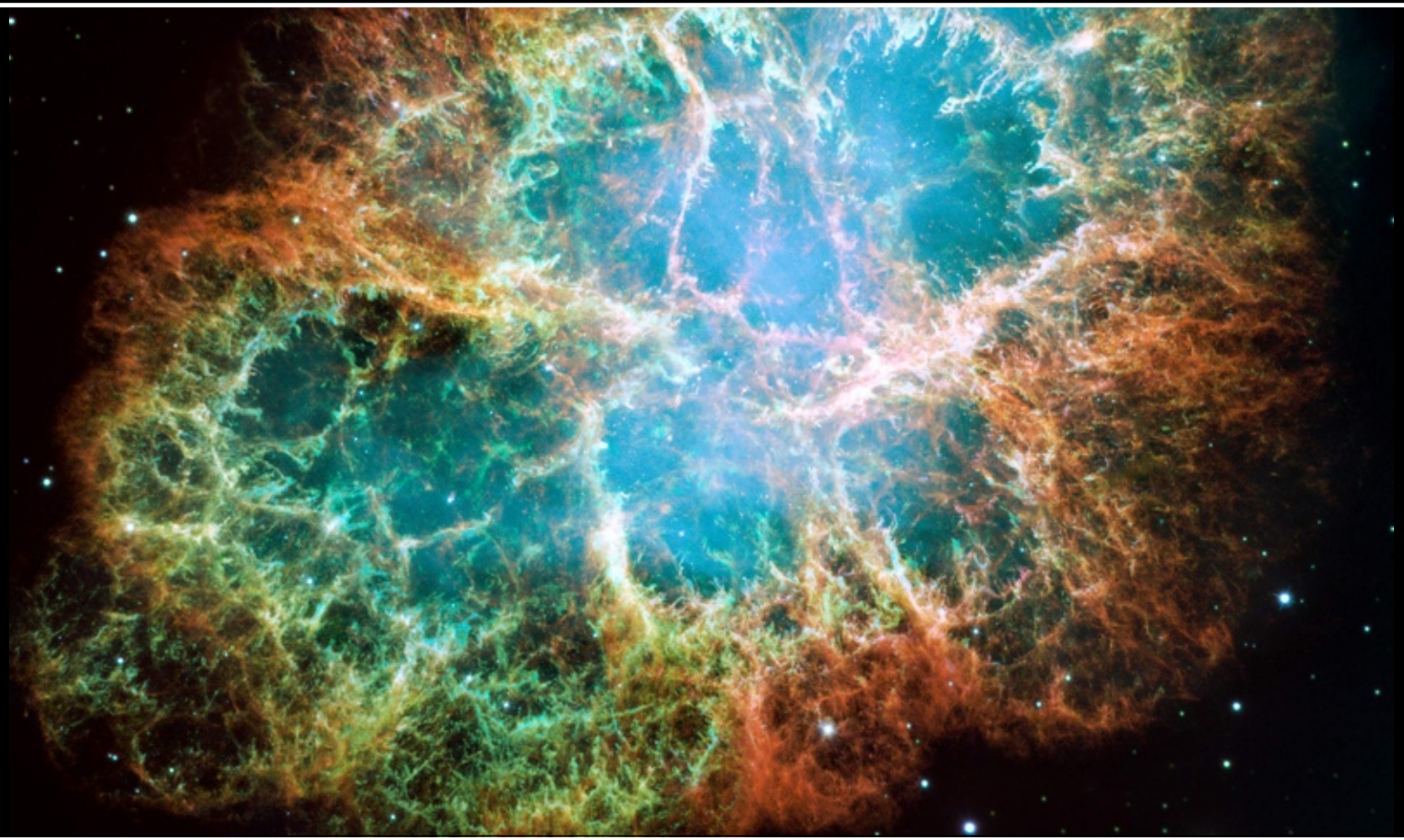


Stage	Timescale
H burning	7 million years
He Burning	0.5 million years
C Burning	600 years
Ne Burning	1 year
O Burning	6 months
Si Burning	1 day

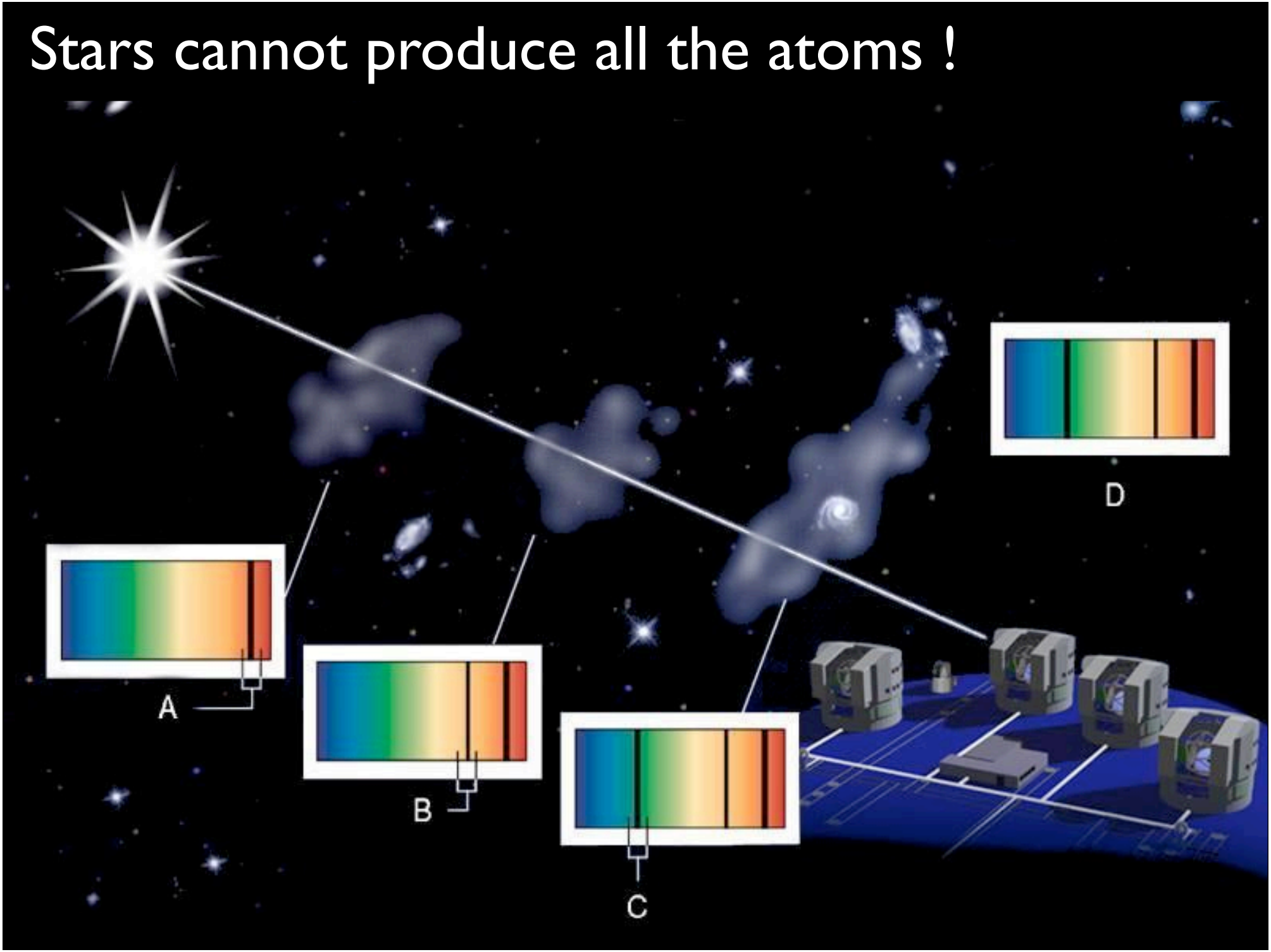
Where do atoms come from?

Where do atoms come from?

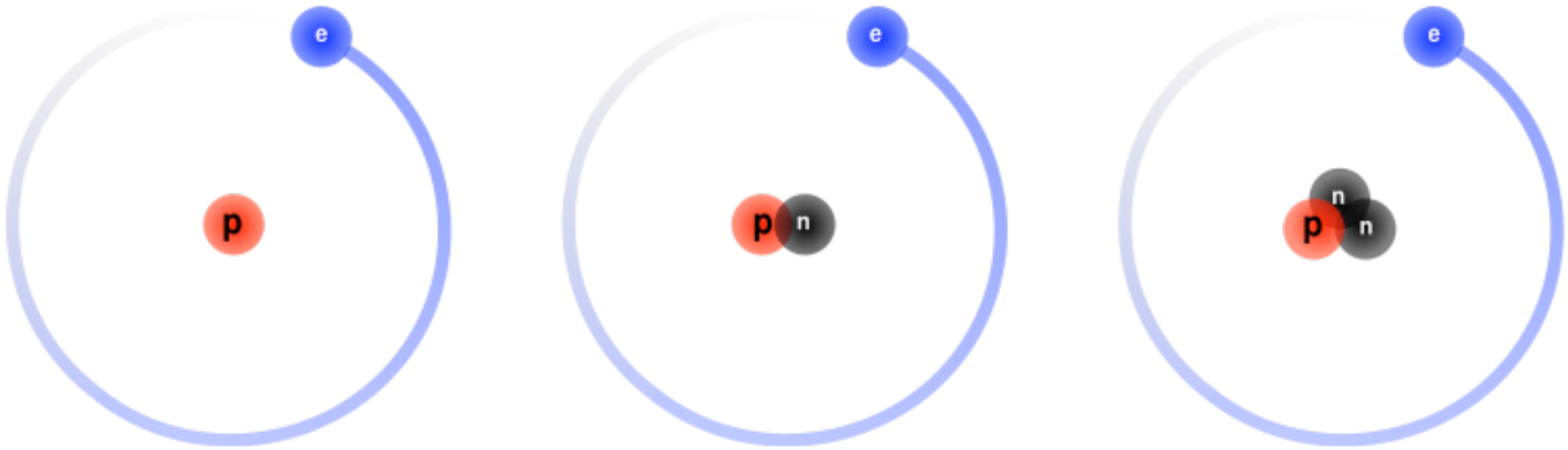
Nuclear reactions in stars form many elements ... but not all!!



Stars cannot produce all the atoms !

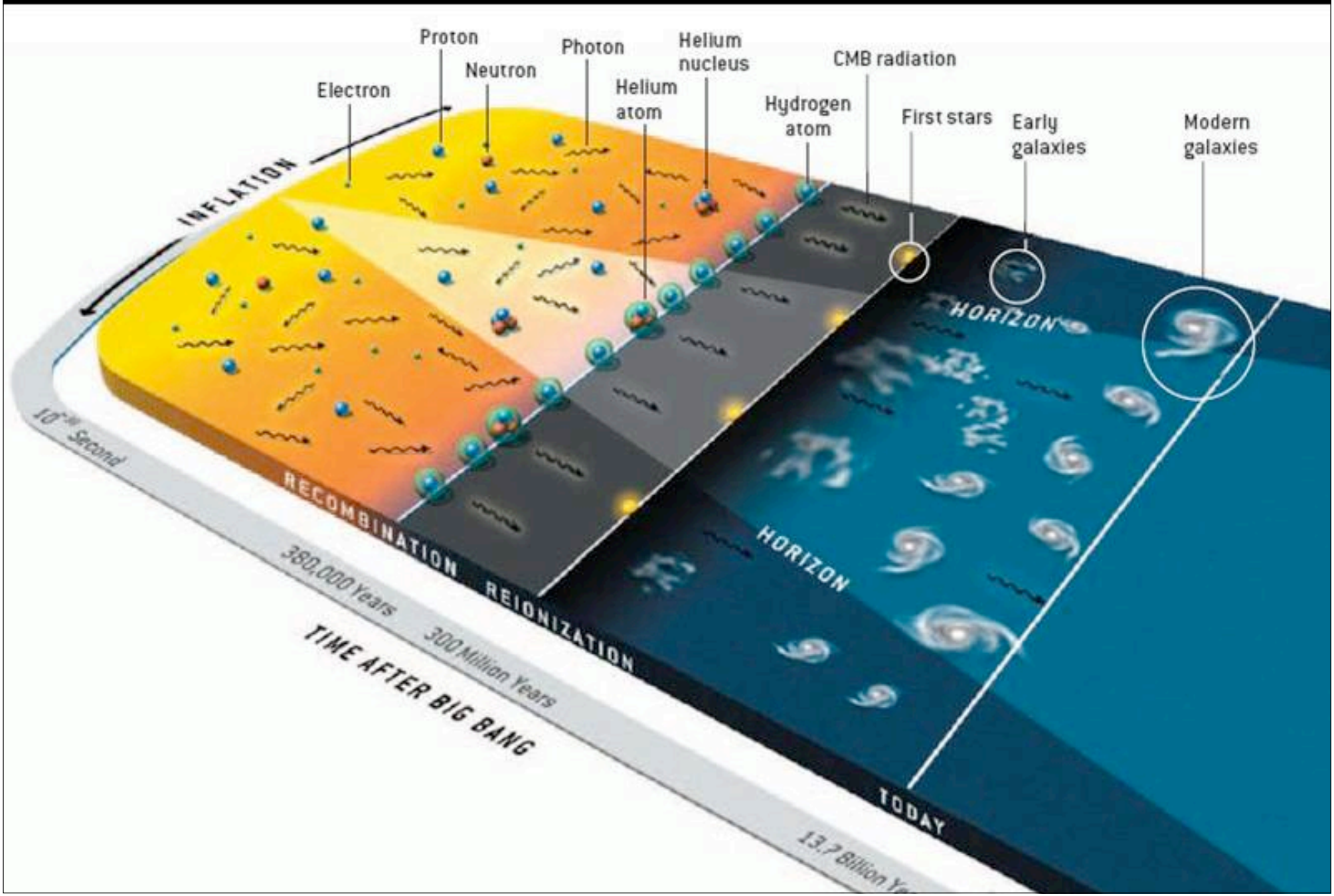


Stars cannot produce all the atoms !

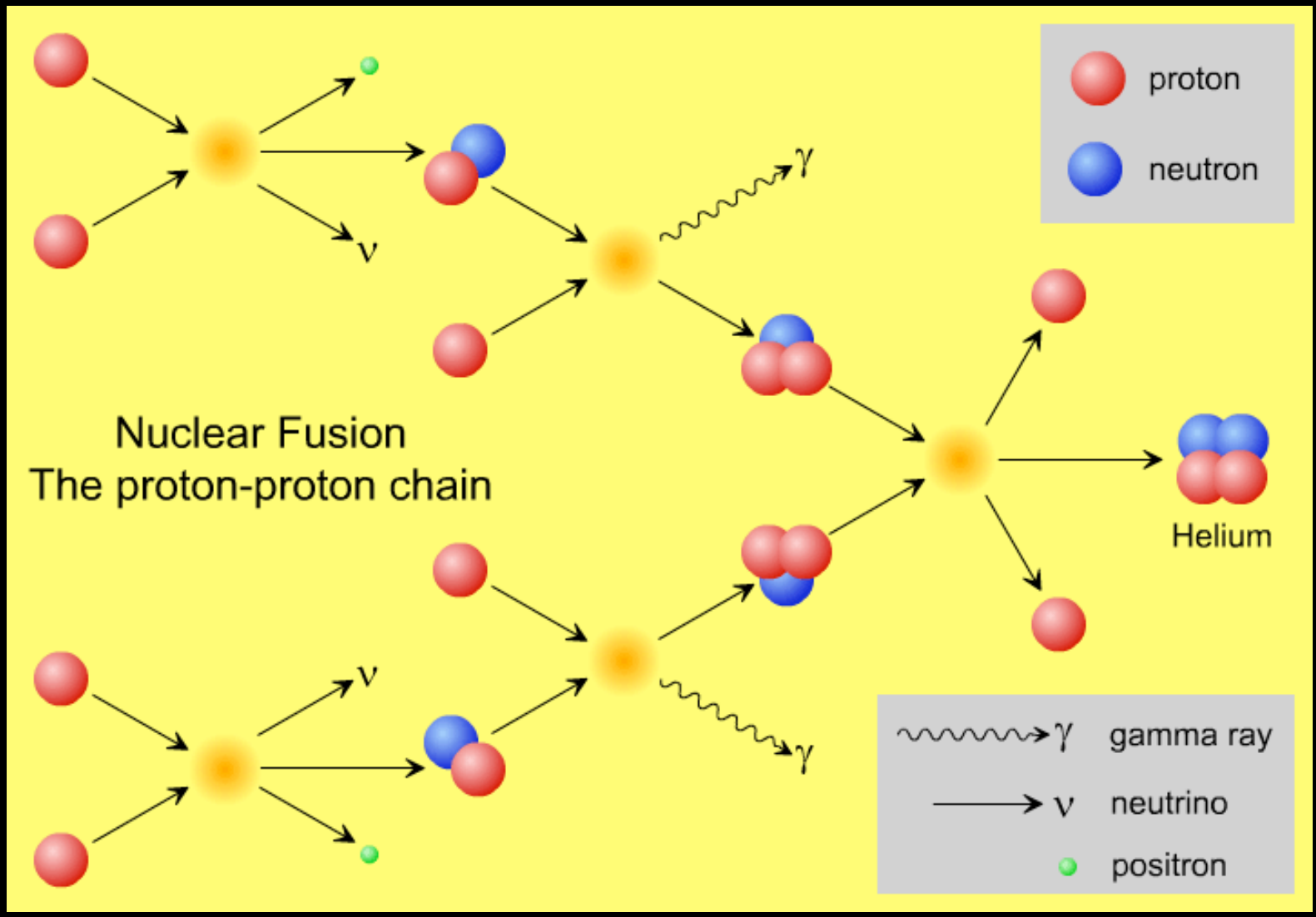


Hydrogen Deuterium Tritium

Big Bang nucleosynthesis

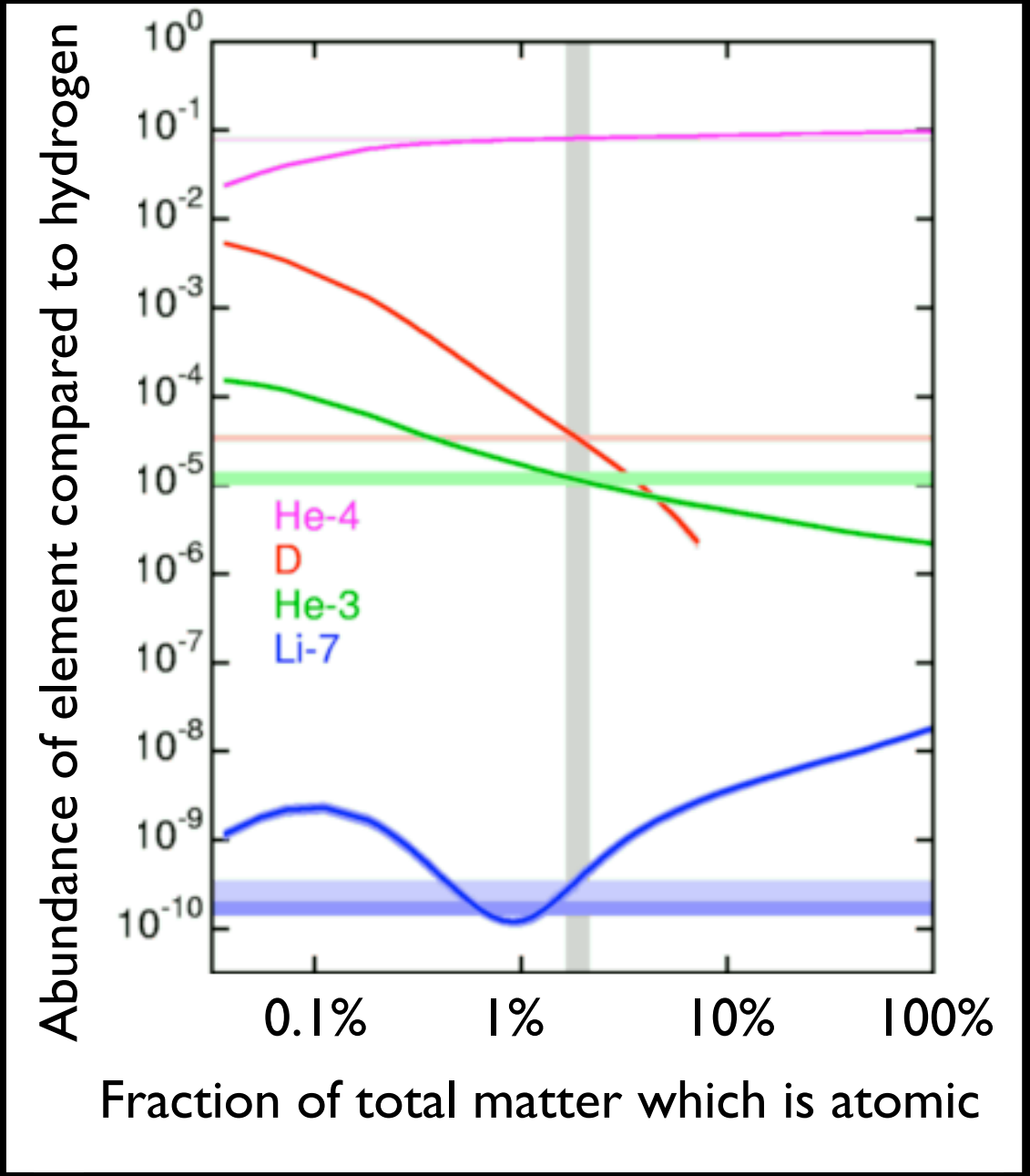


Big Bang nucleosynthesis

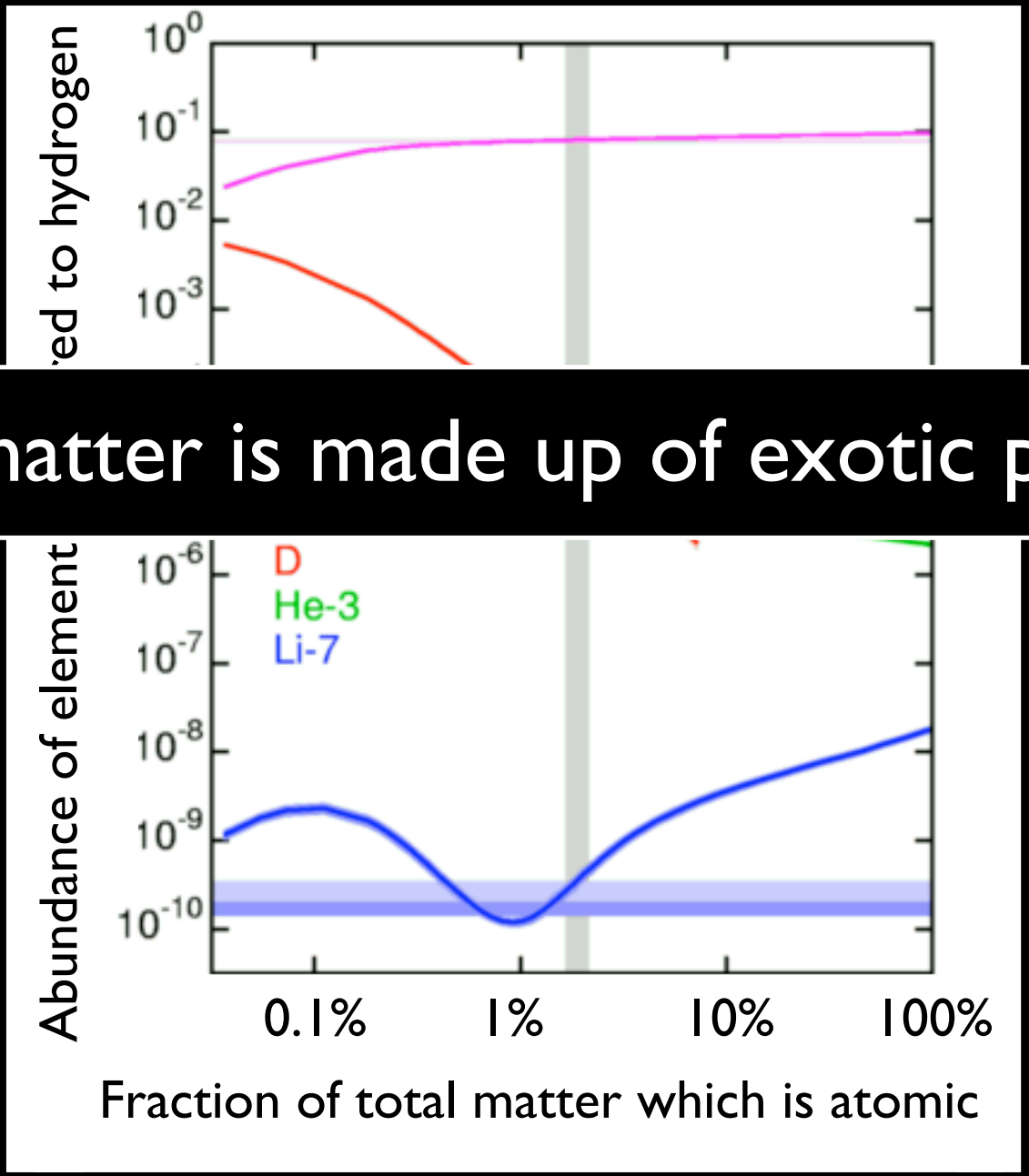


Rate of these reactions depends on atom density!

Big Bang nucleosynthesis

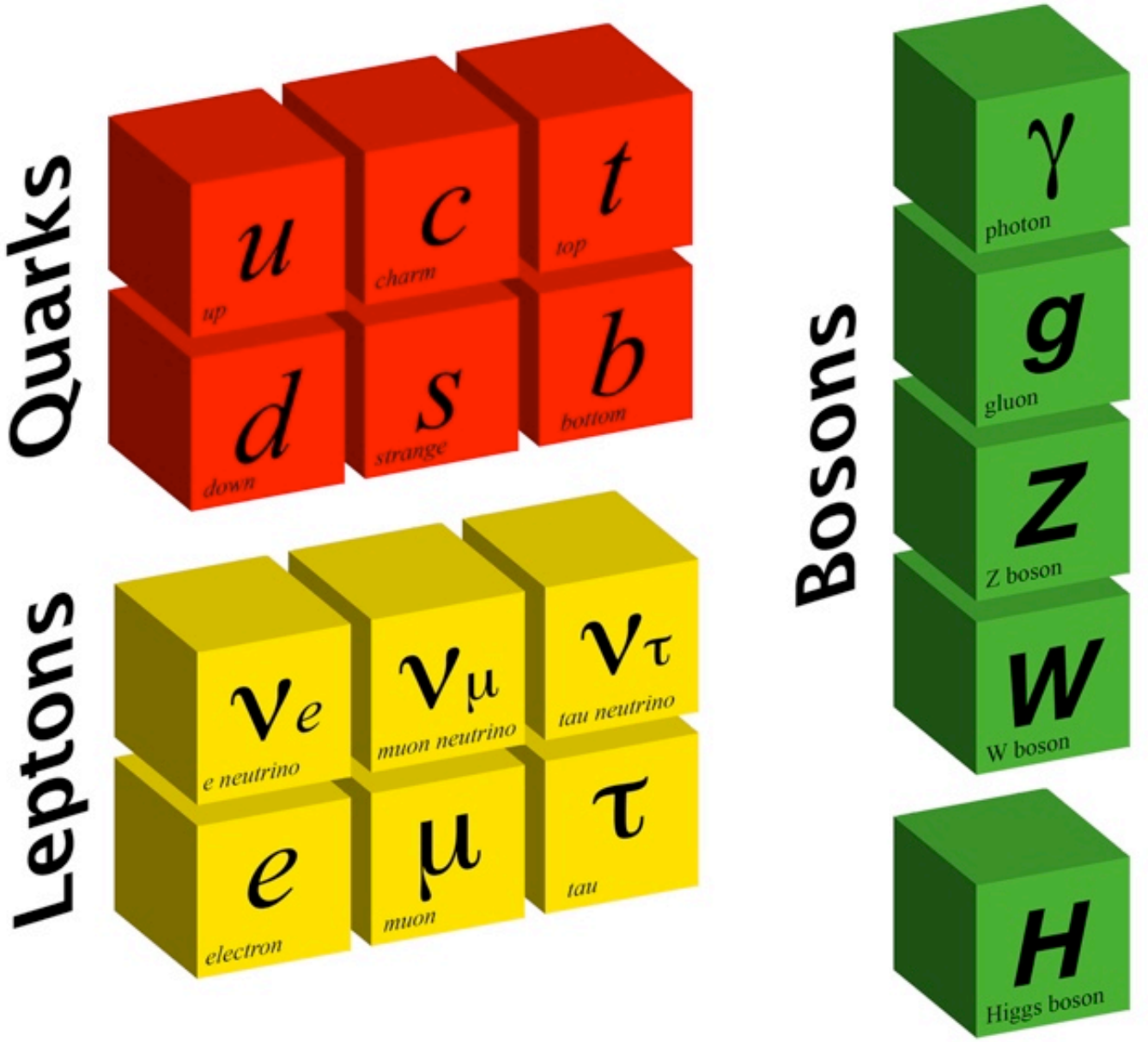


Big Bang nucleosynthesis

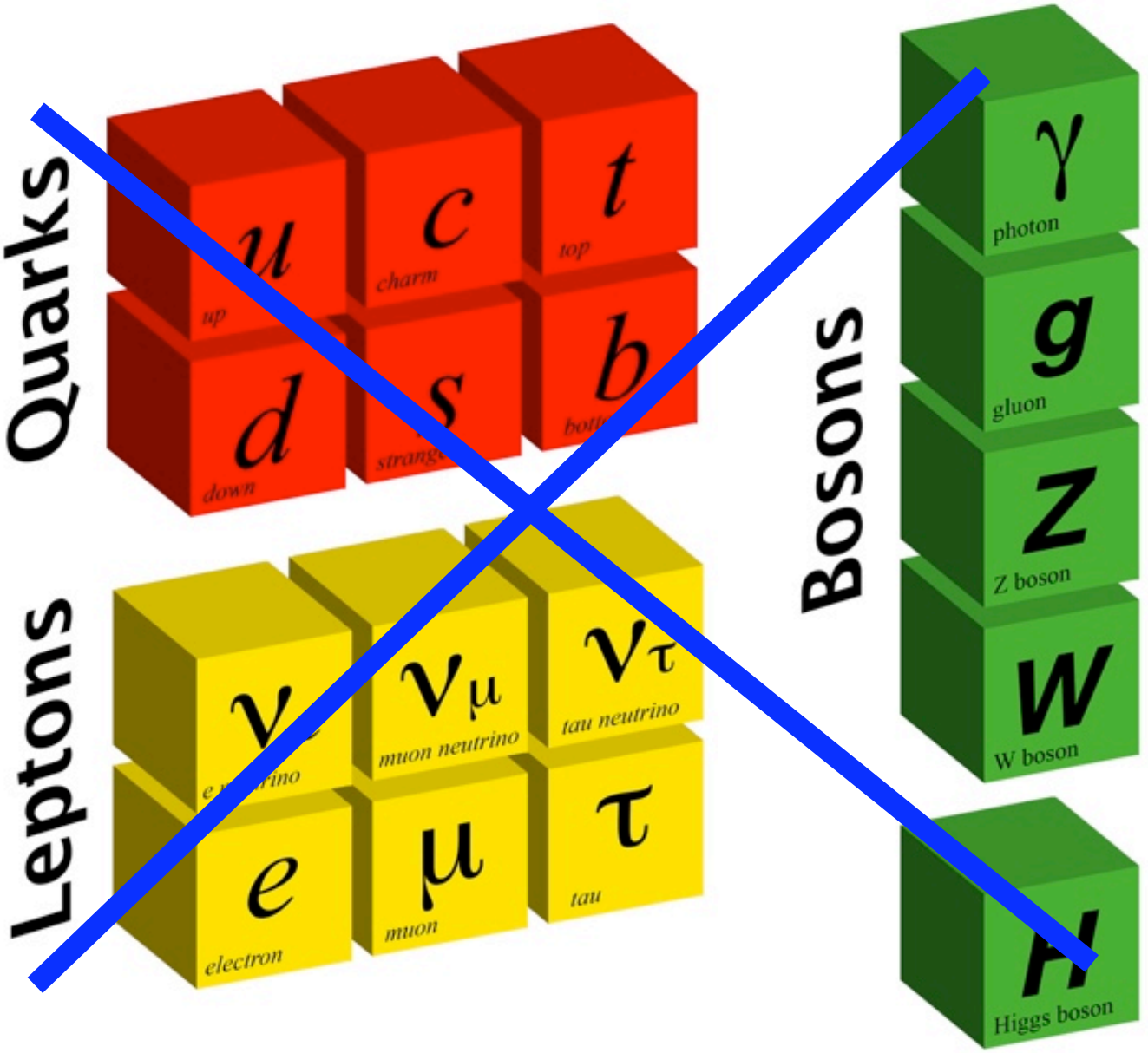


Dark matter is made up of exotic particles!

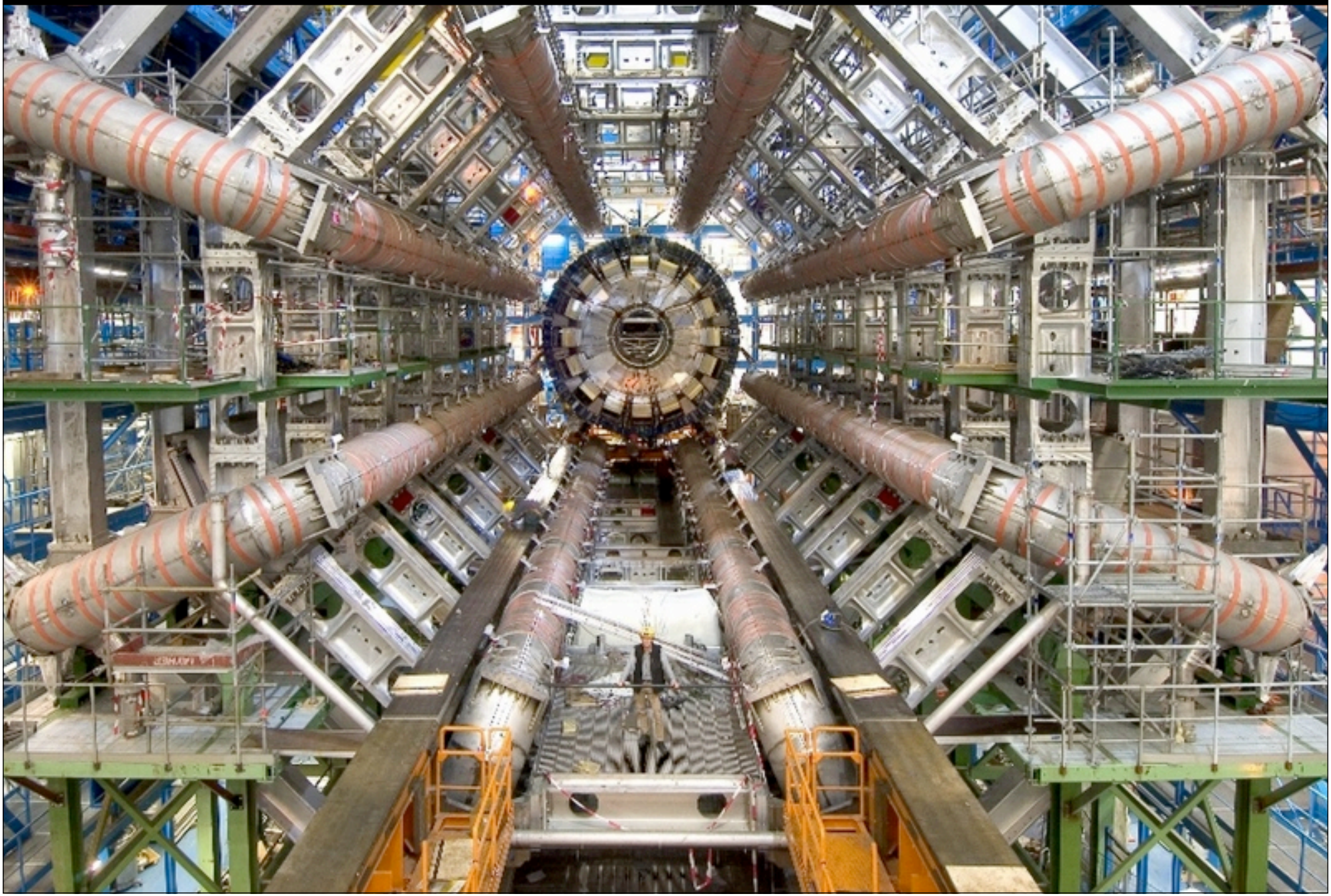
Fundamental Particles of the Standard Model



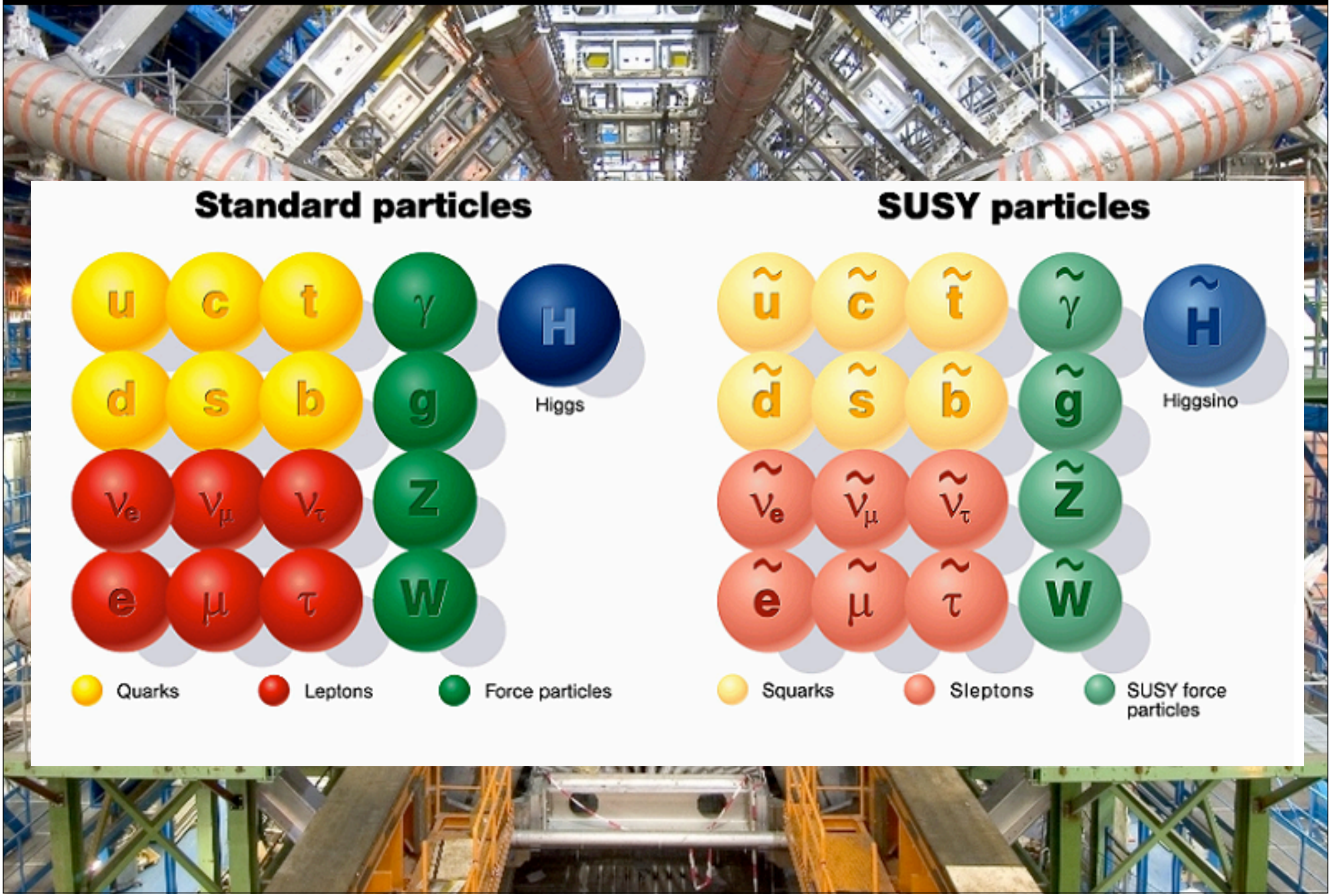
Fundamental Particles of the Standard Model



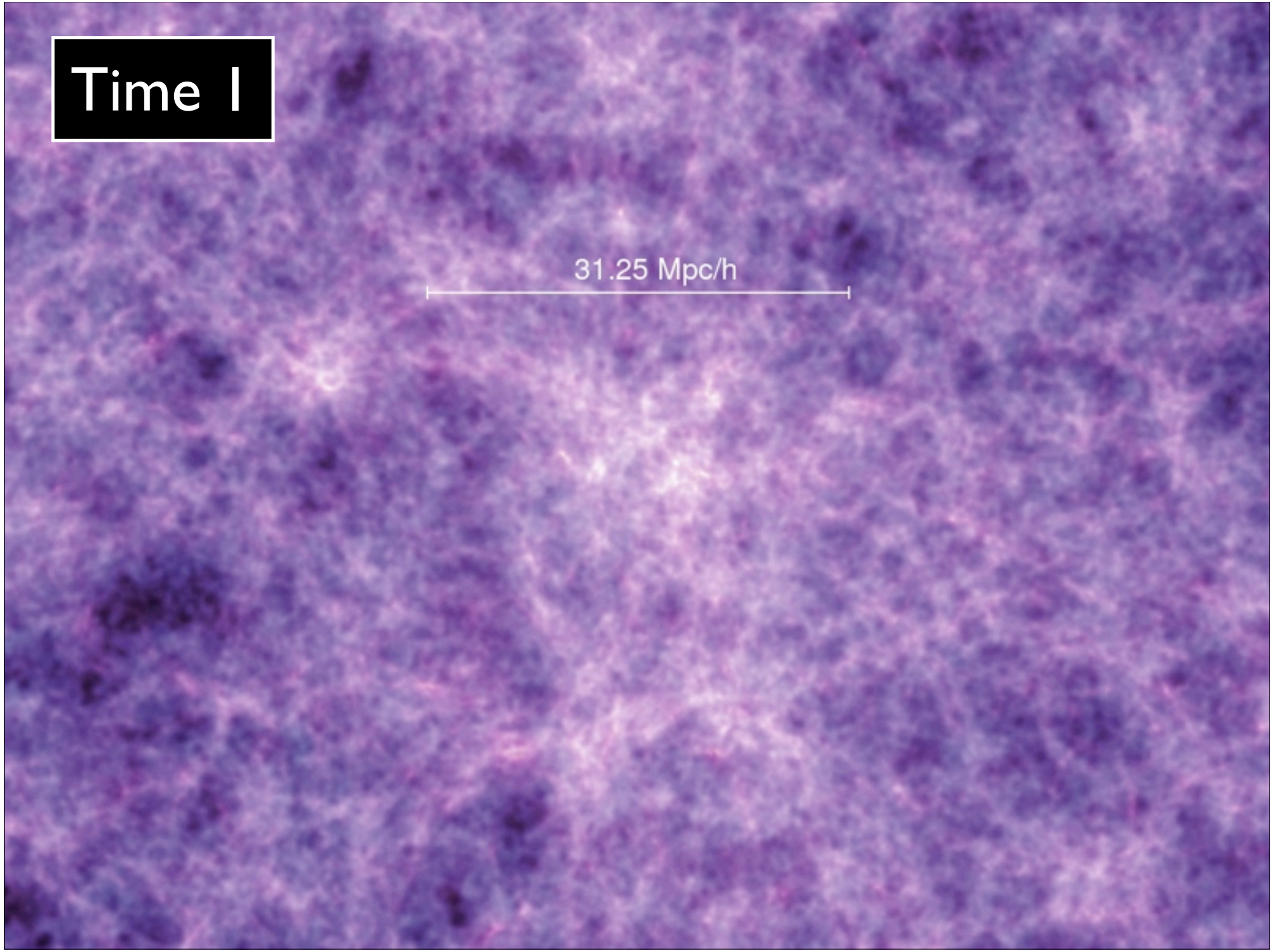
Particles beyond the standard model

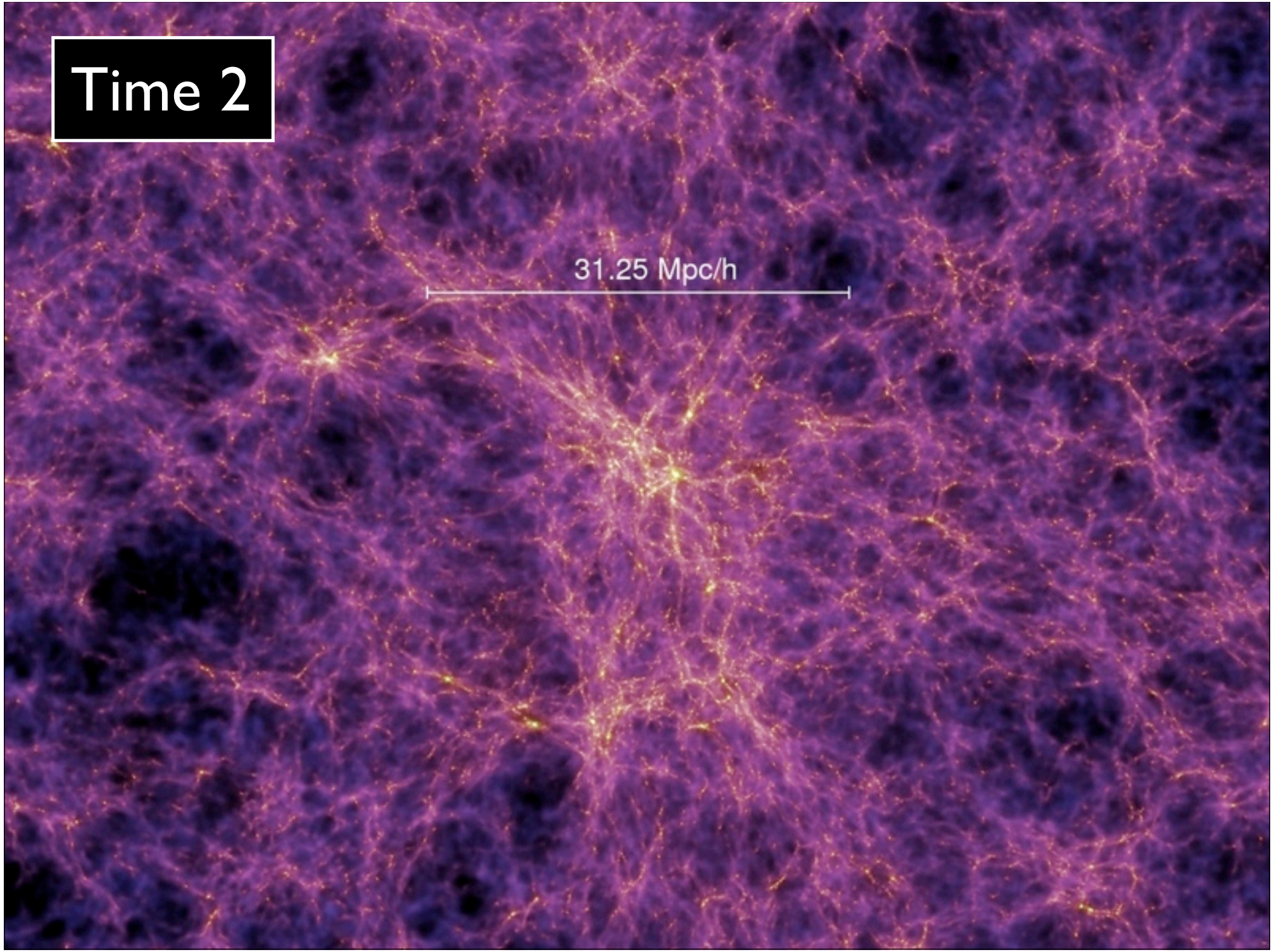


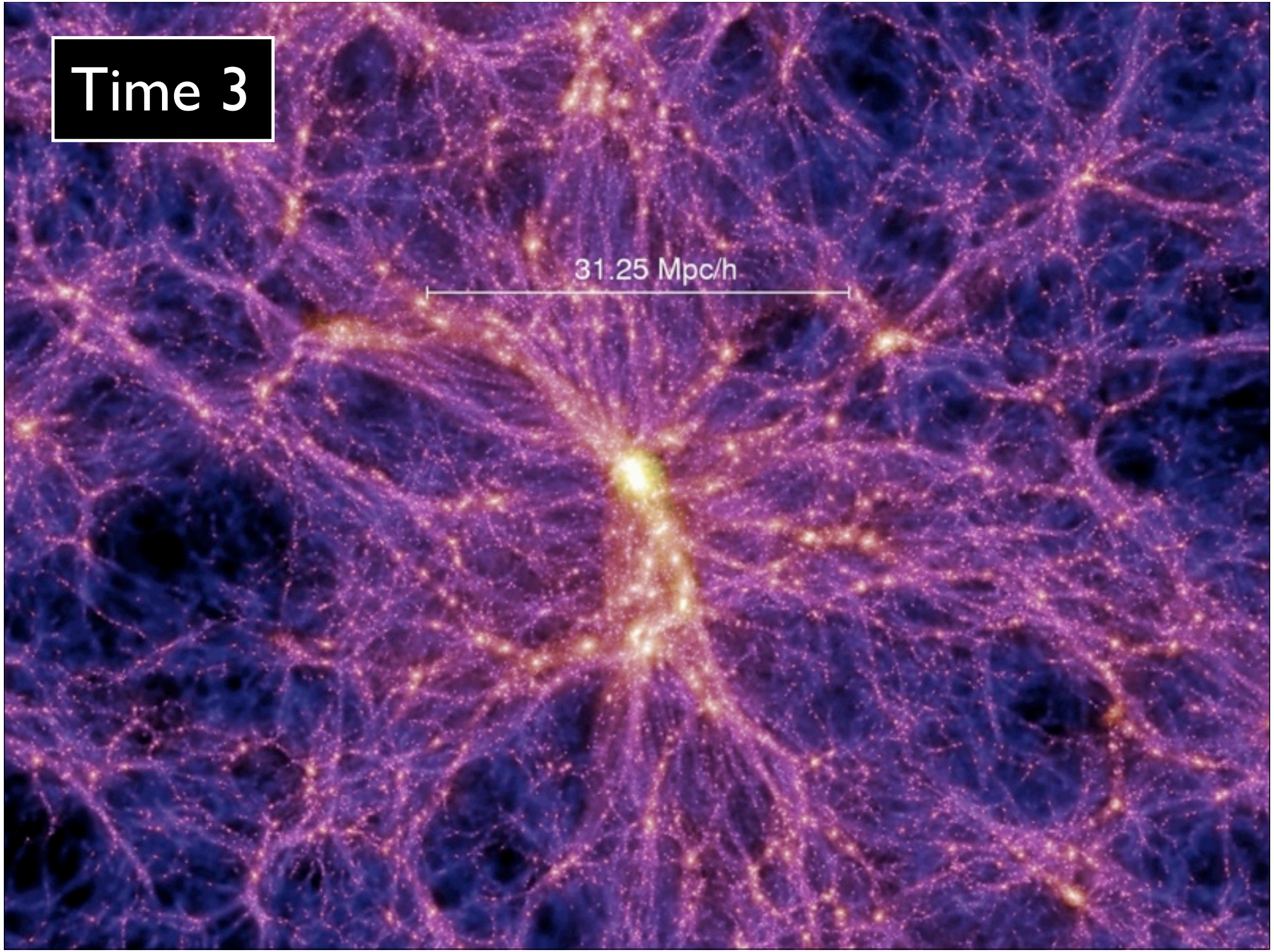
Particles beyond the standard model

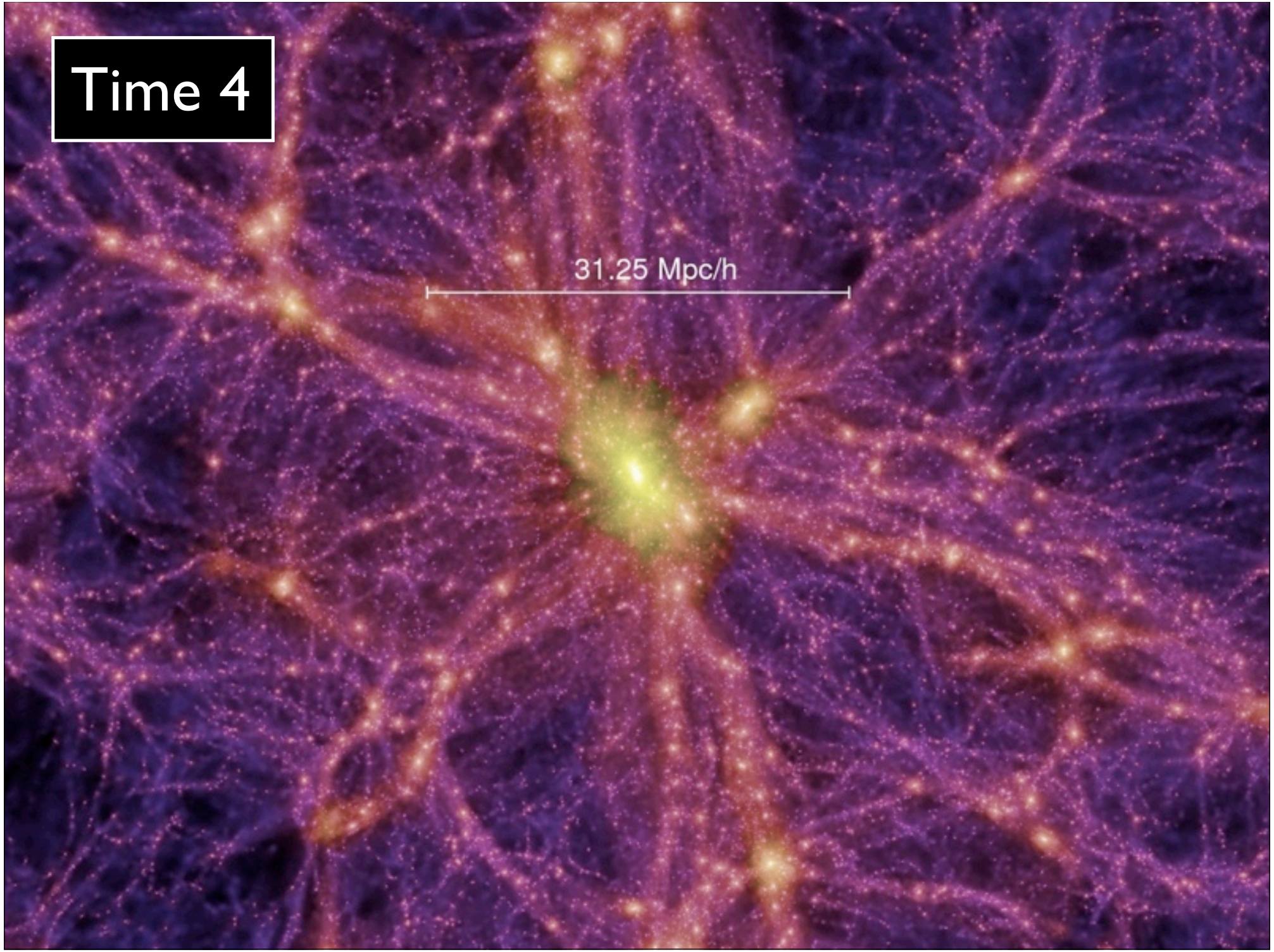


What is dark matter made of?

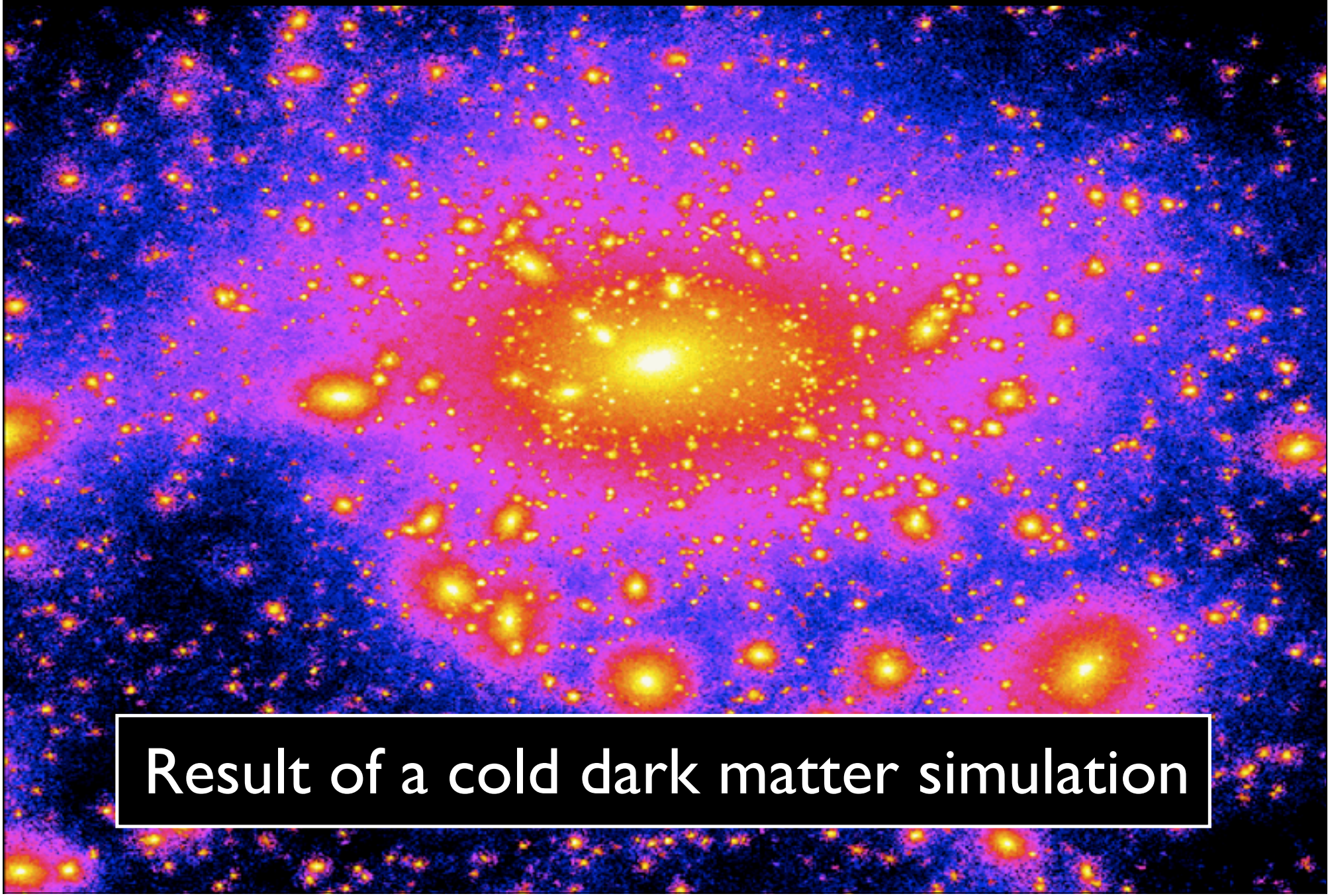

Time 1
31.25 Mpc/h


Time 2
31.25 Mpc/h


Time 3
31.25 Mpc/h

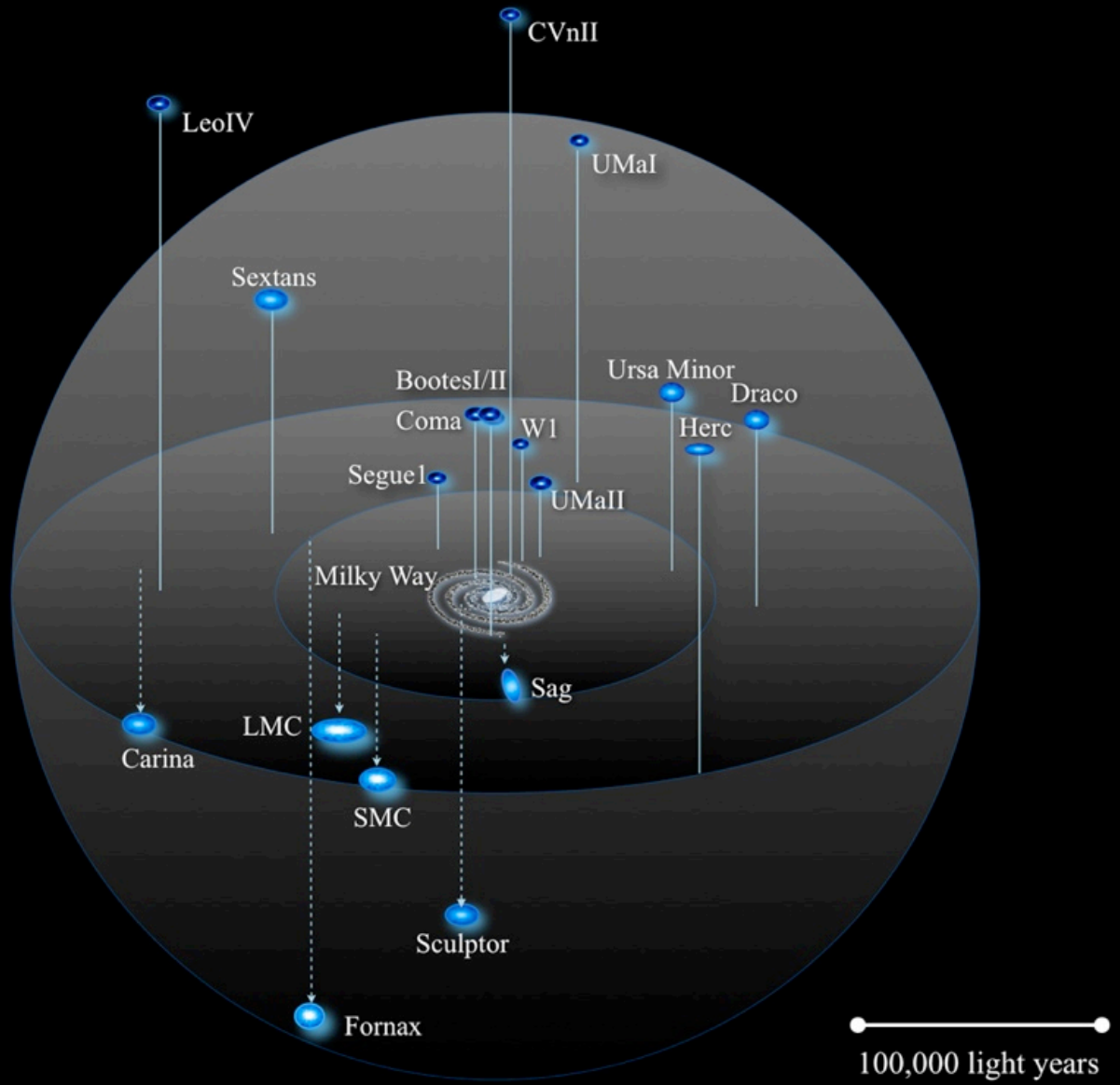

Time 4
31.25 Mpc/h

What are the properties of dark matter?

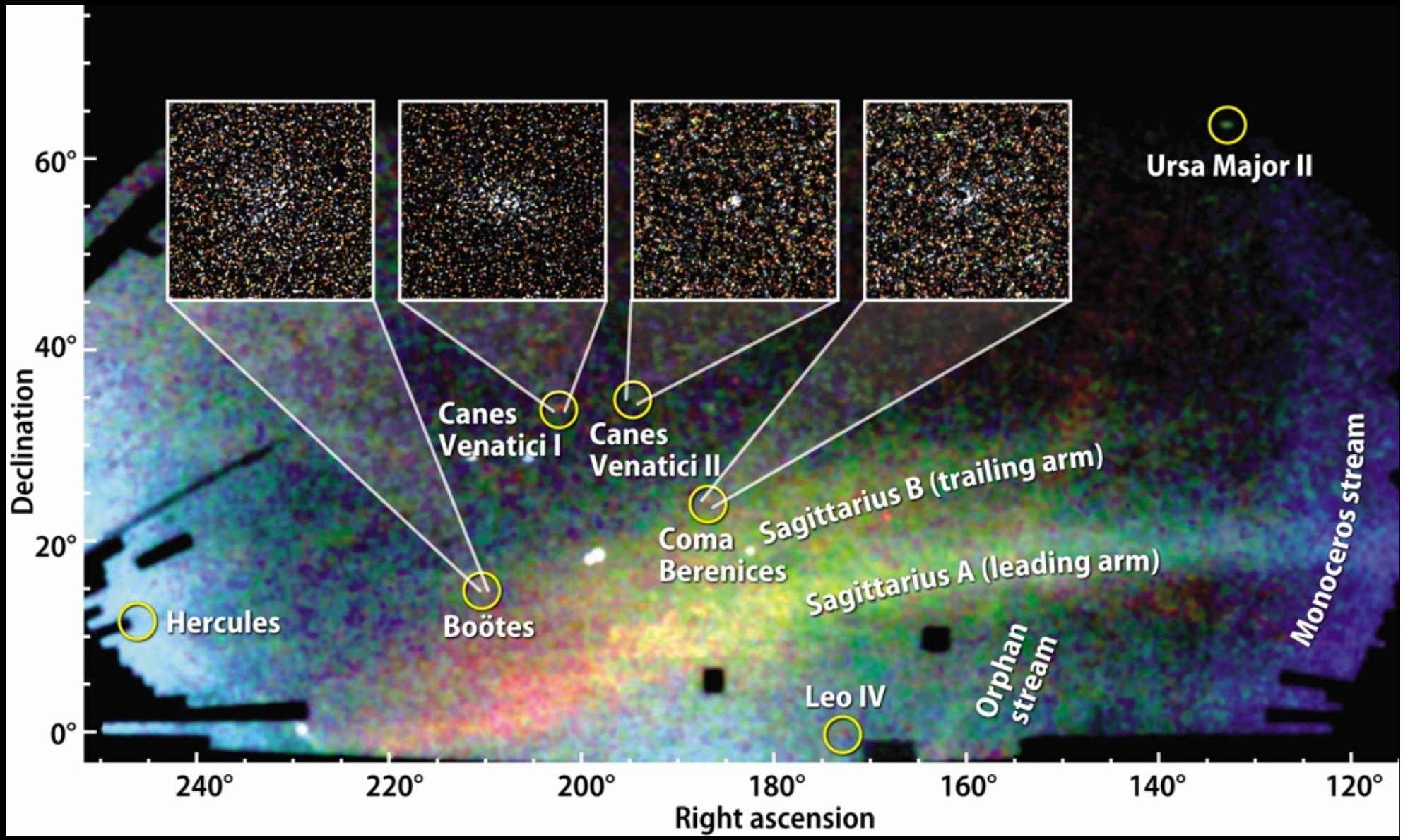


Result of a cold dark matter simulation

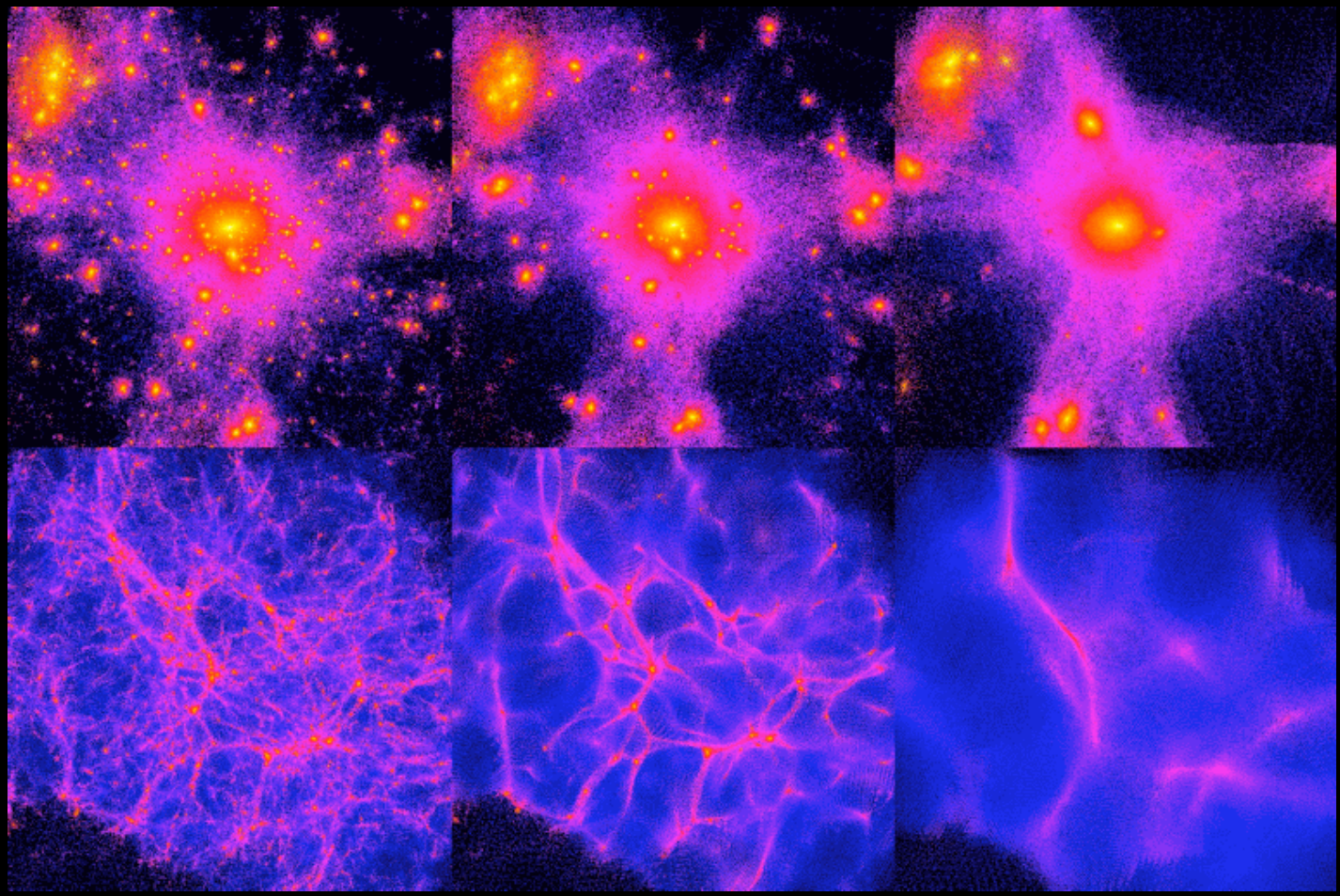
Where are the dwarf galaxies?



Where are the dwarf galaxies?

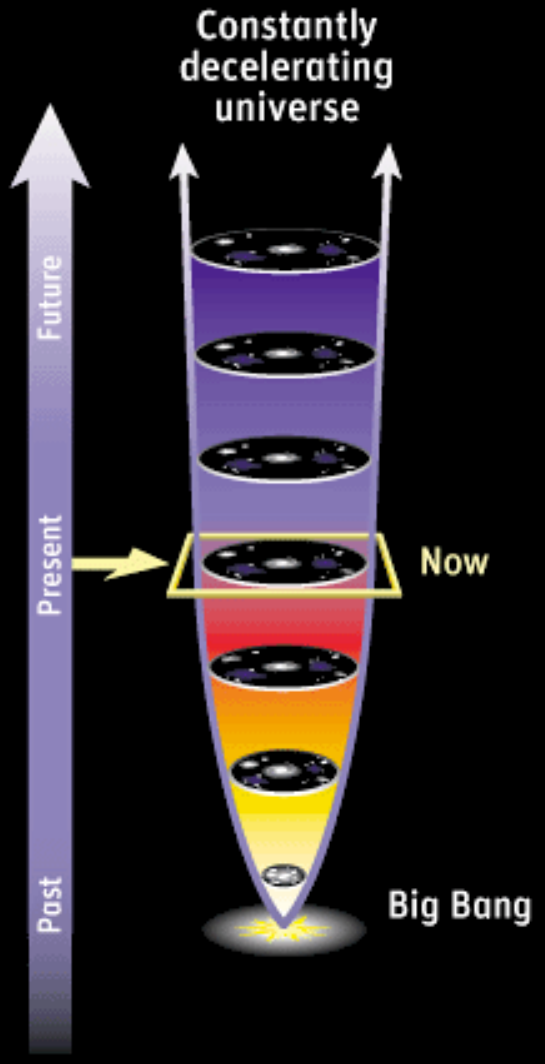


Cold Warm Hot



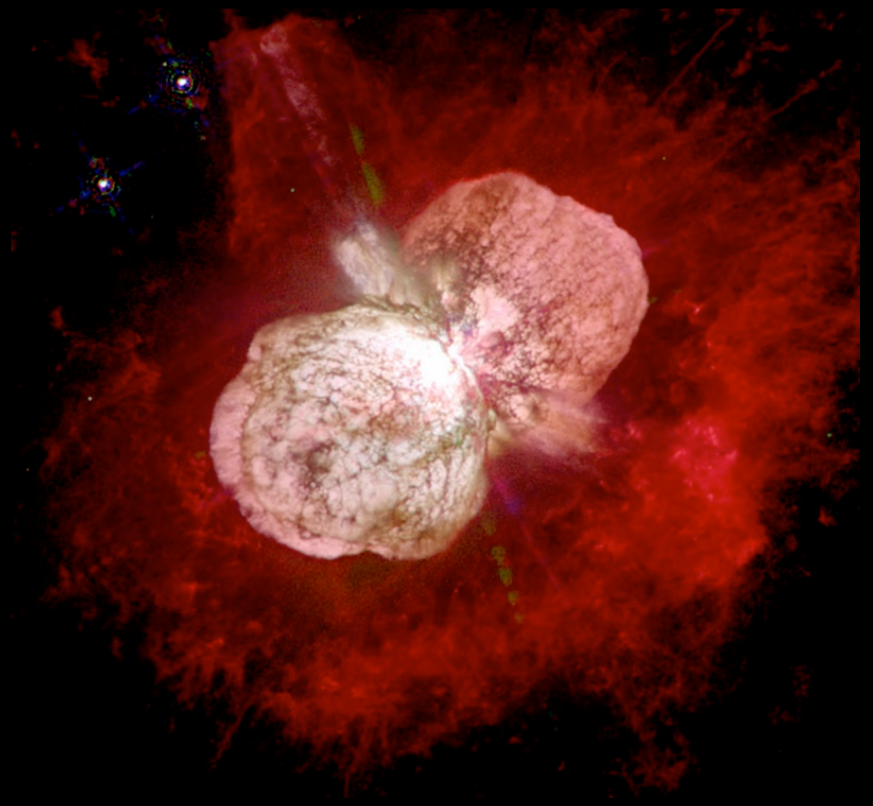
Dark matter is made up of cold particles!

One final puzzle : dark energy

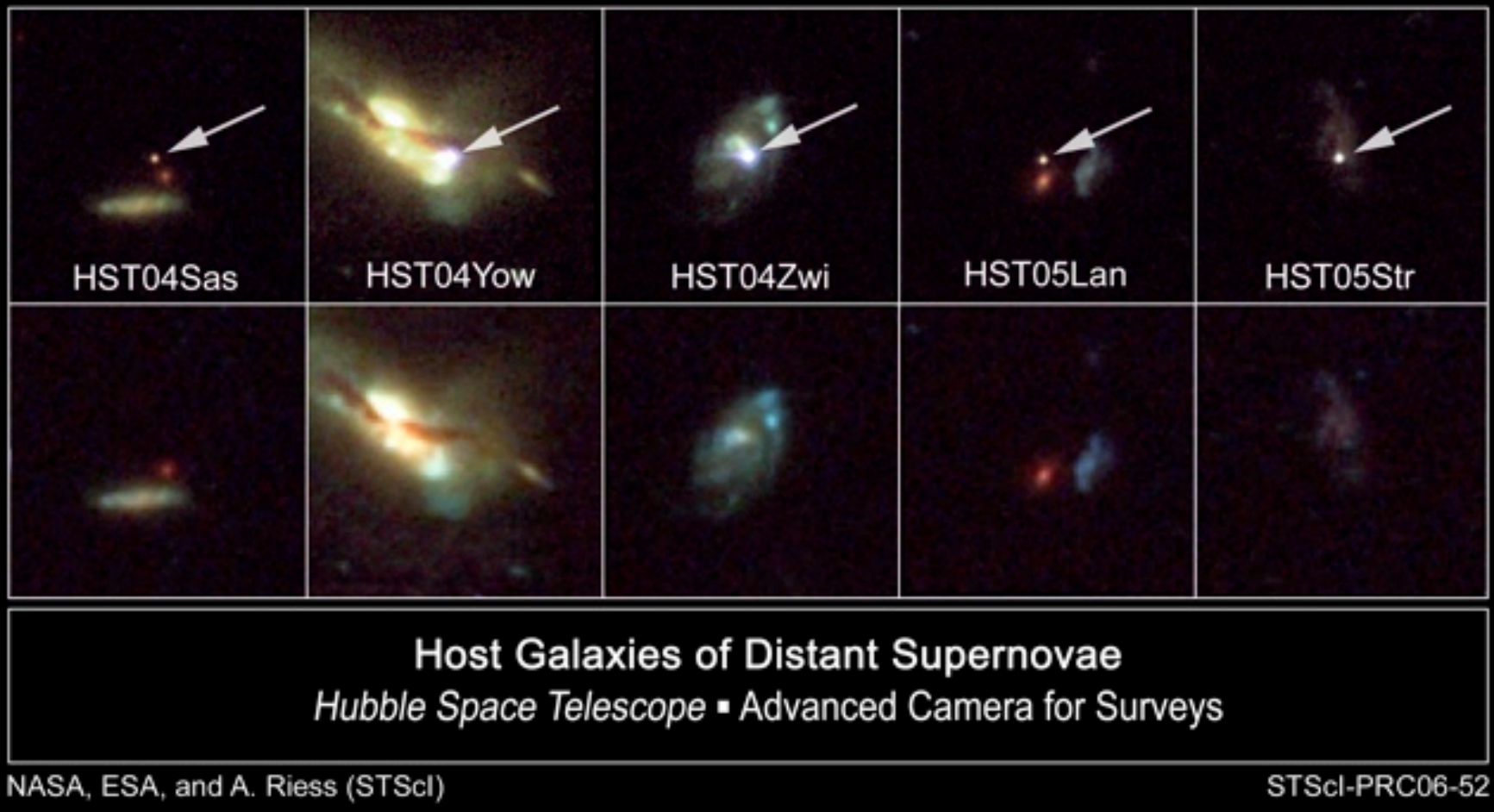


The cosmic expansion should slow down because of the pull of gravity

Supernovae : cosmic beacons

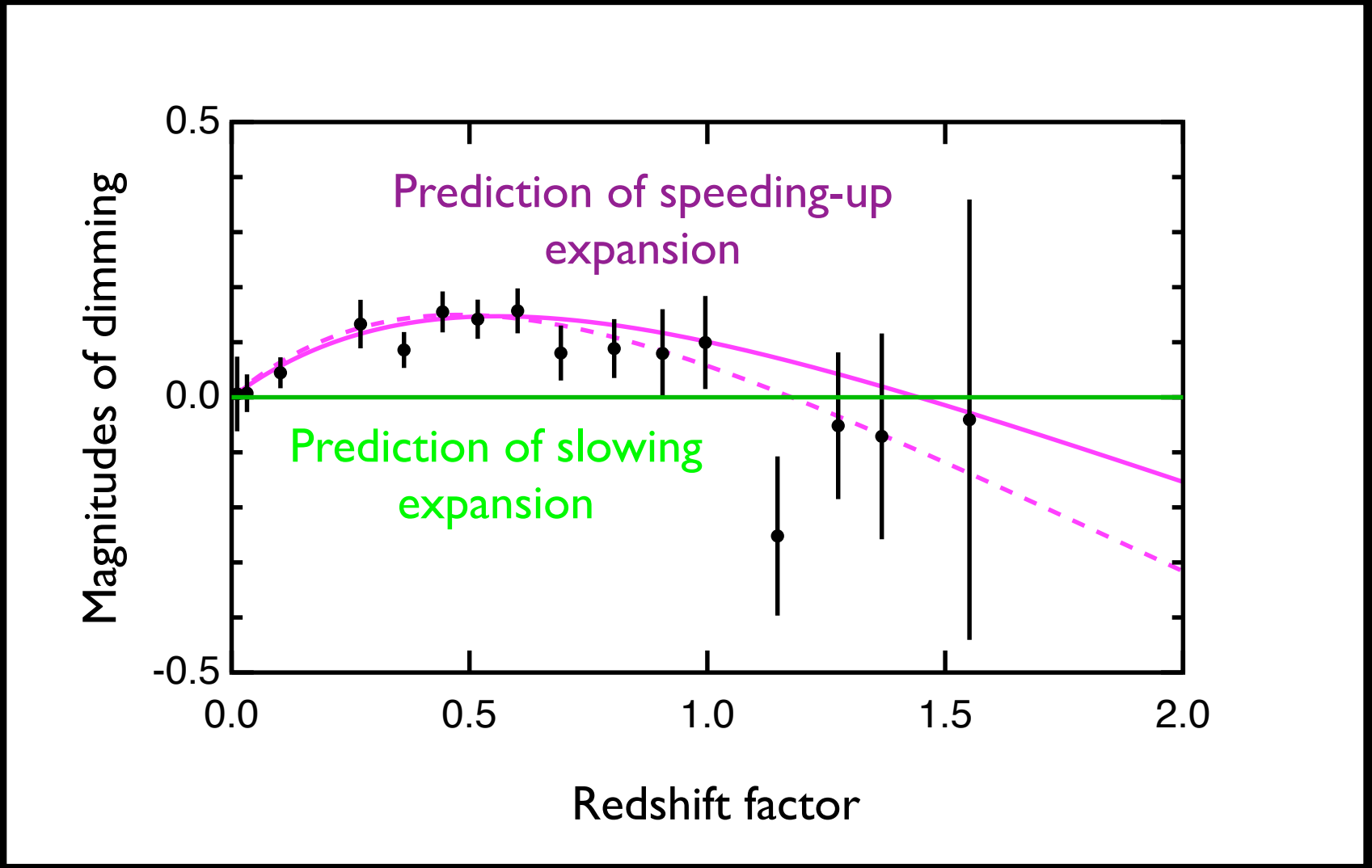


Supernovae : cosmic beacons

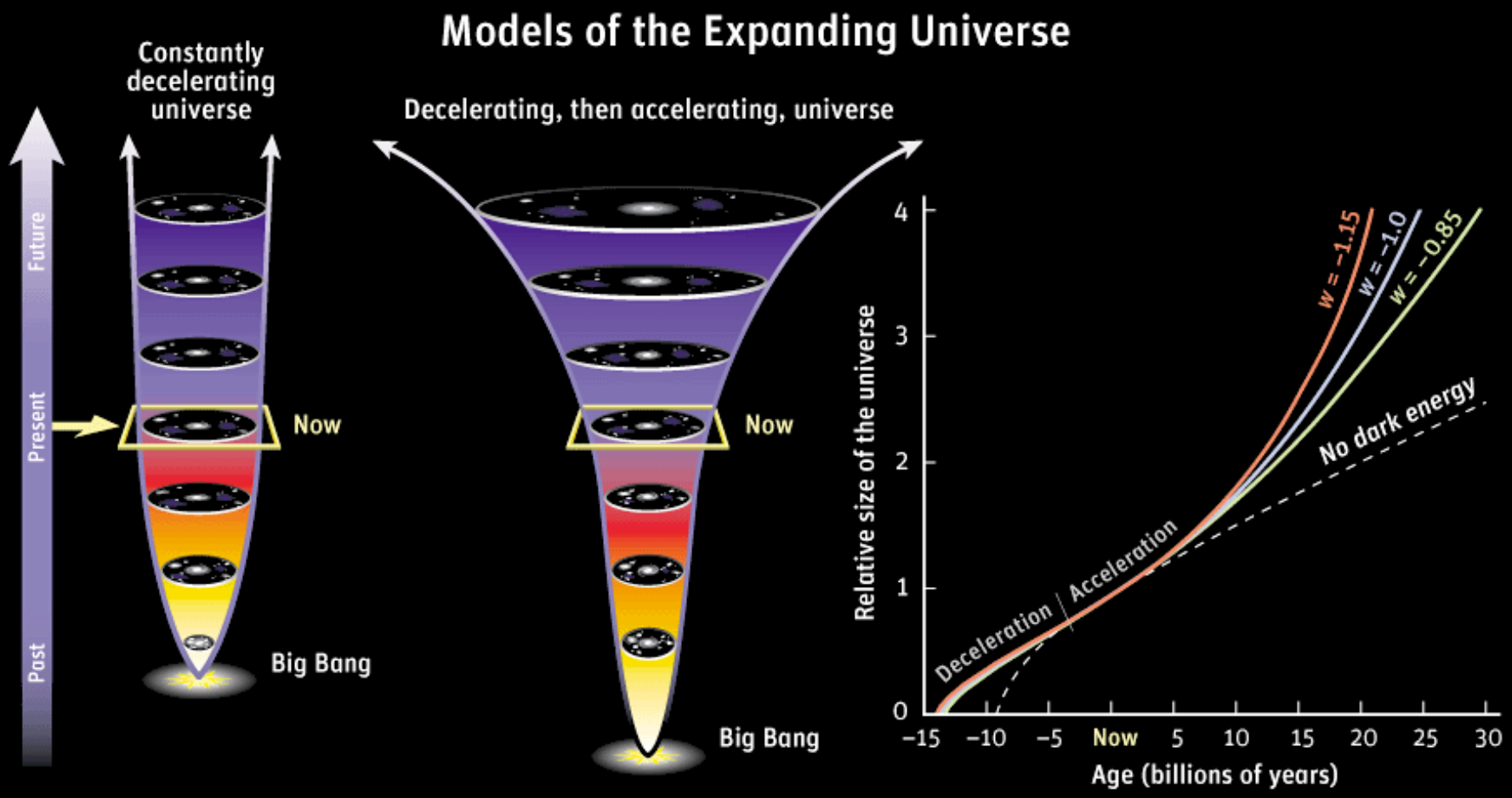


Supernovae : cosmic beacons

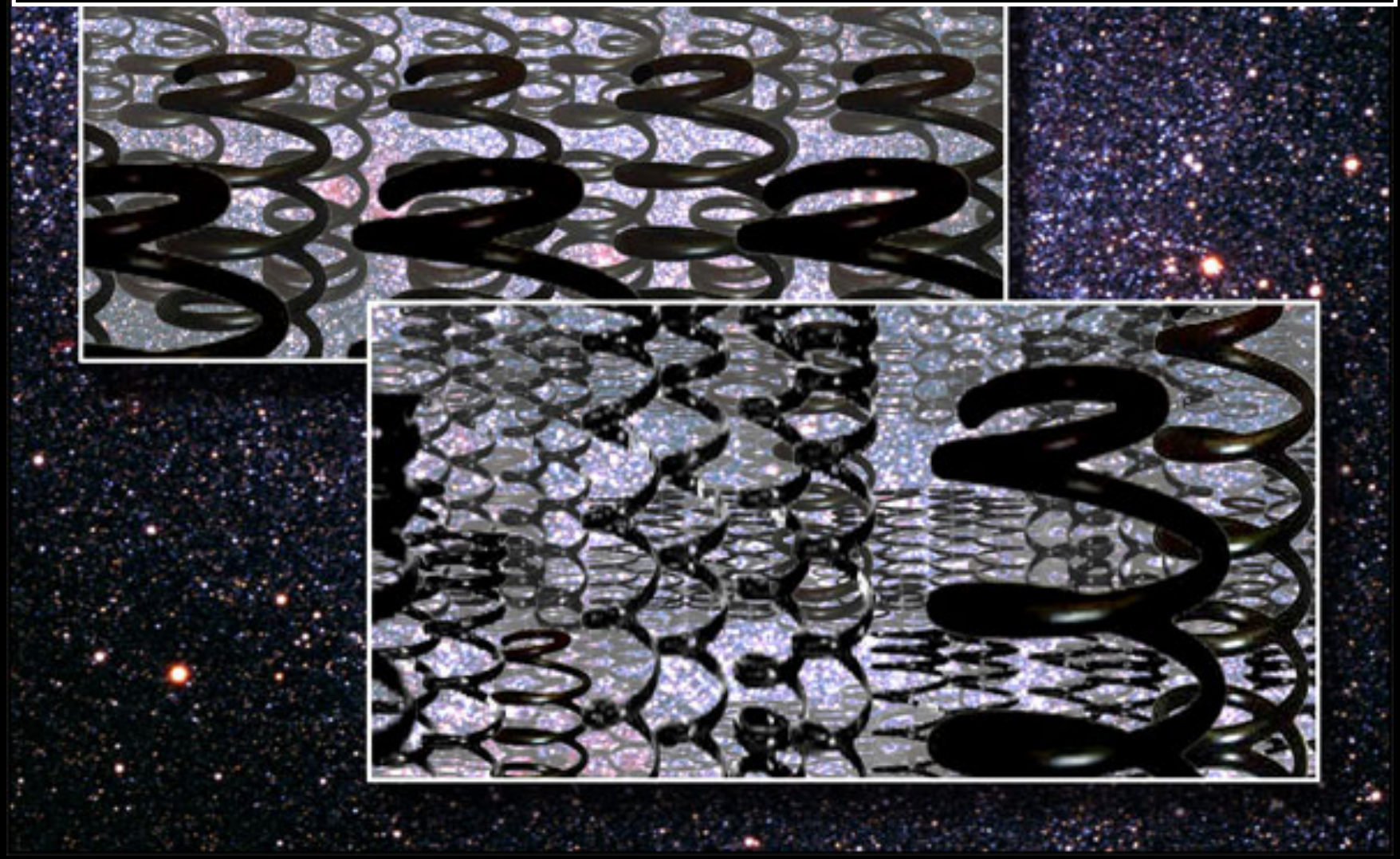
Supernovae : cosmic beacons

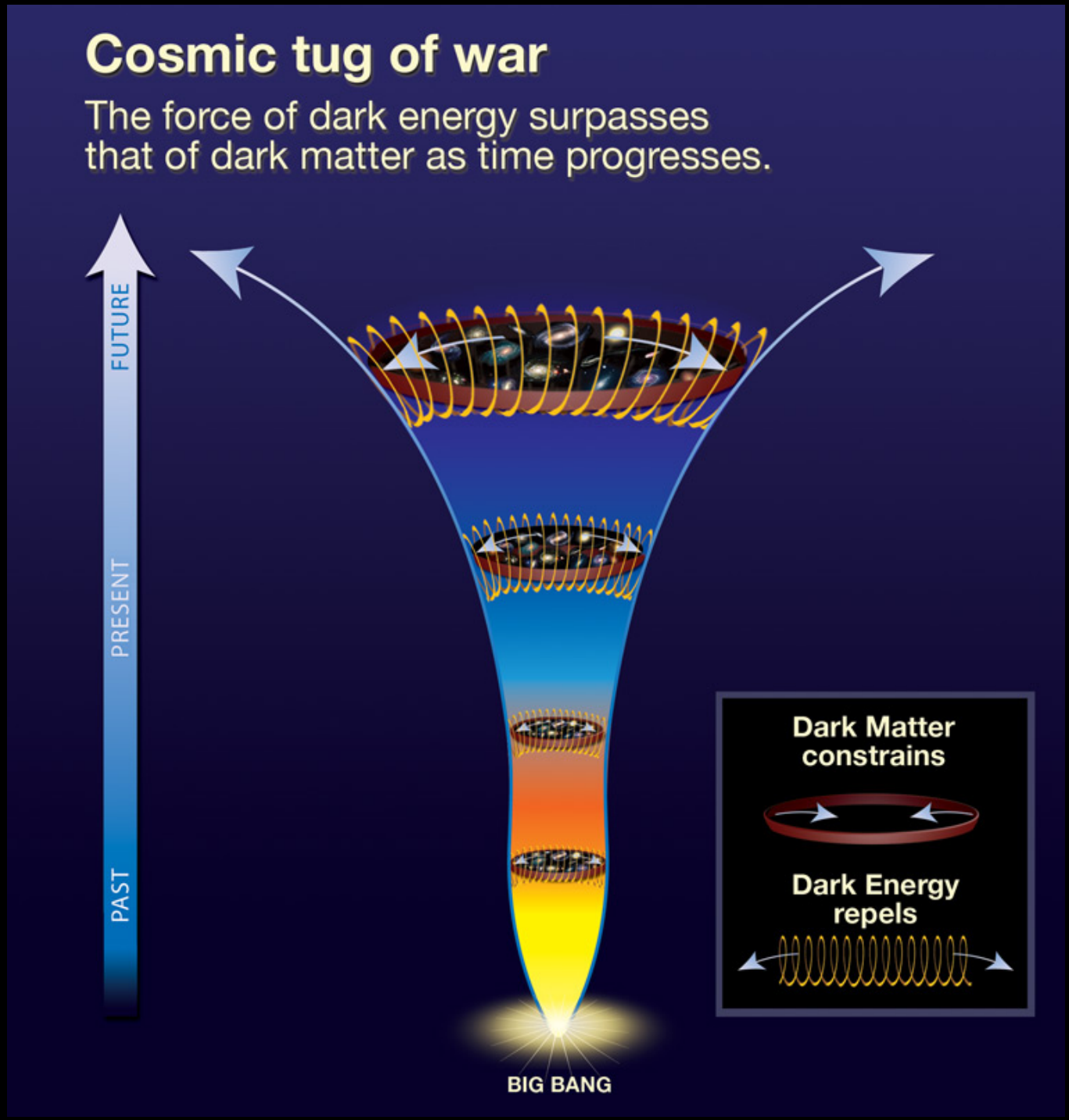


The expansion of space is speeding up!

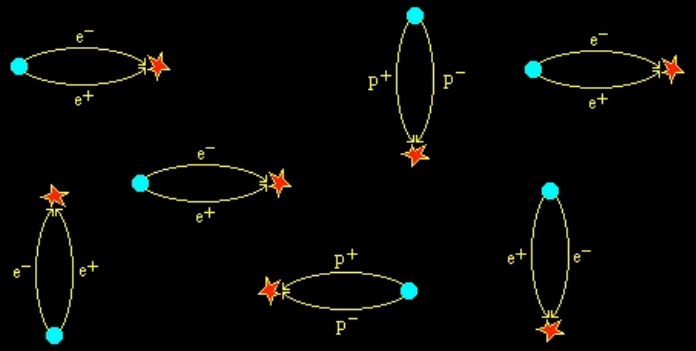


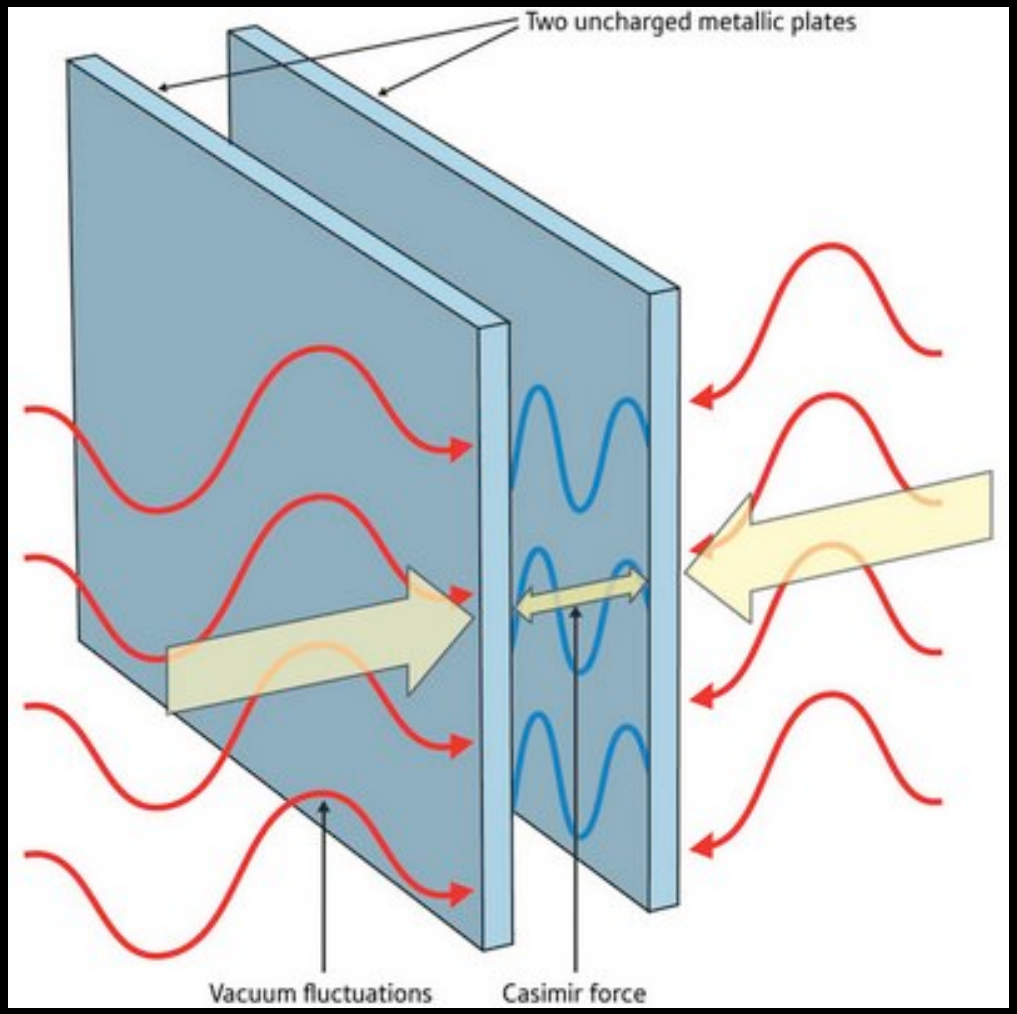
Dark energy is the springs driving the cosmic expansion




Cosmic tug of war
The force of dark energy surpasses that of dark matter as time progresses.
FUTURE
PRESENT
PAST
BIG BANG
Dark Matter constrains
Dark Energy repels

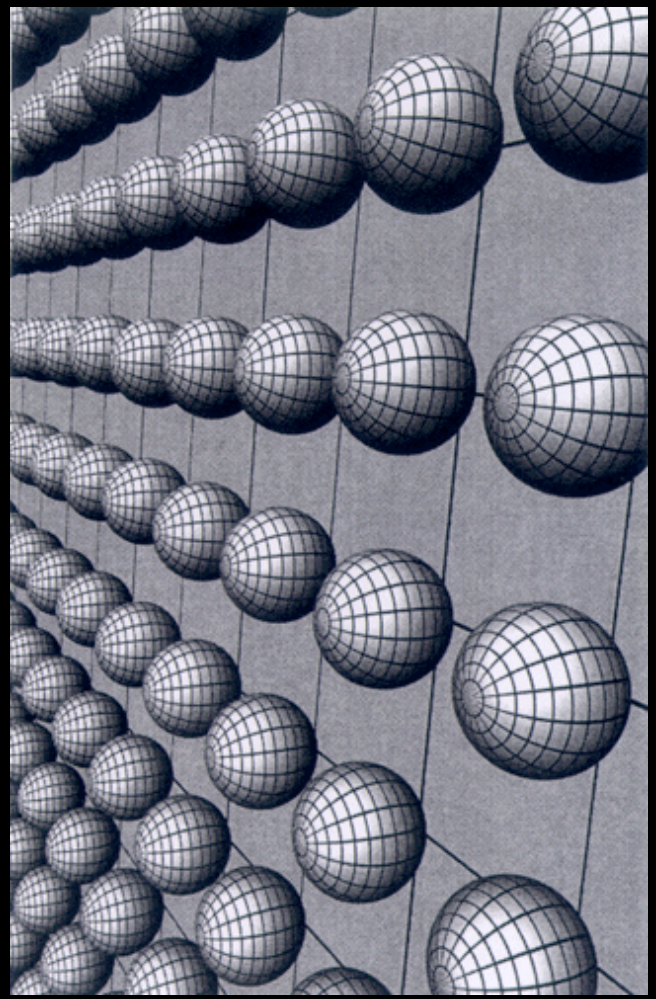
What is dark energy?

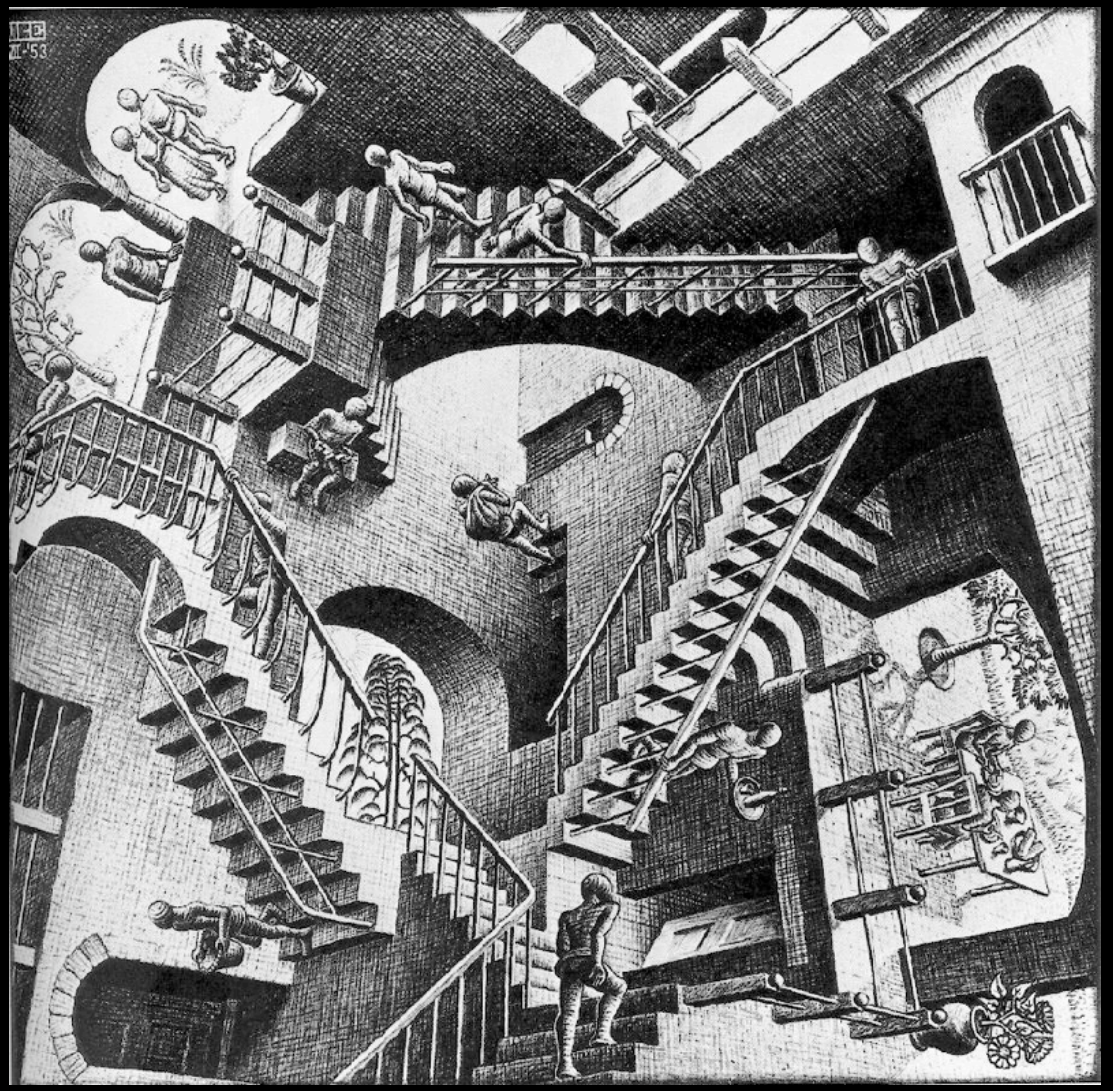




Fluctuations in the quantum vacuum?

What is dark energy?





Extra dimensions of space?

Summing up …