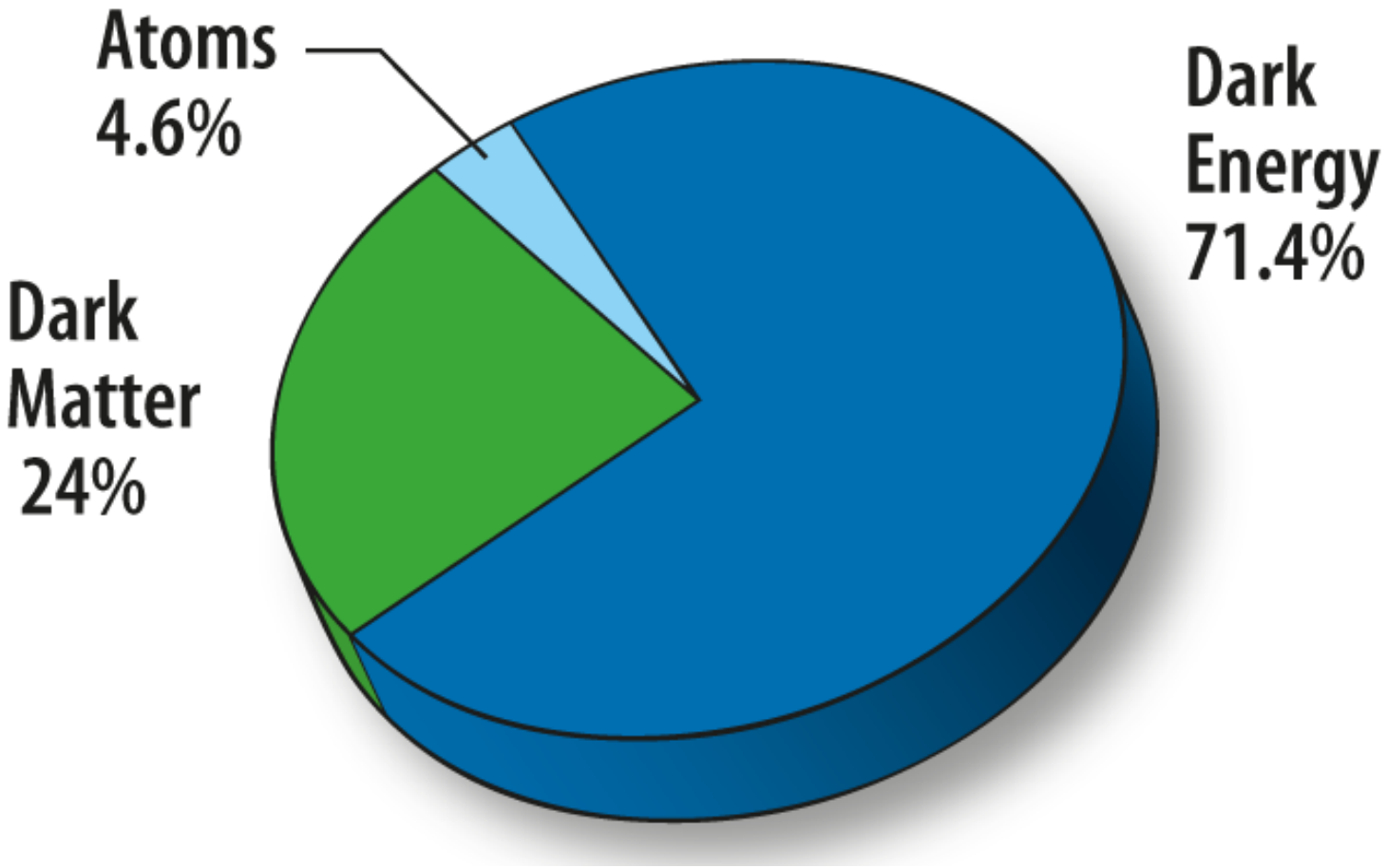
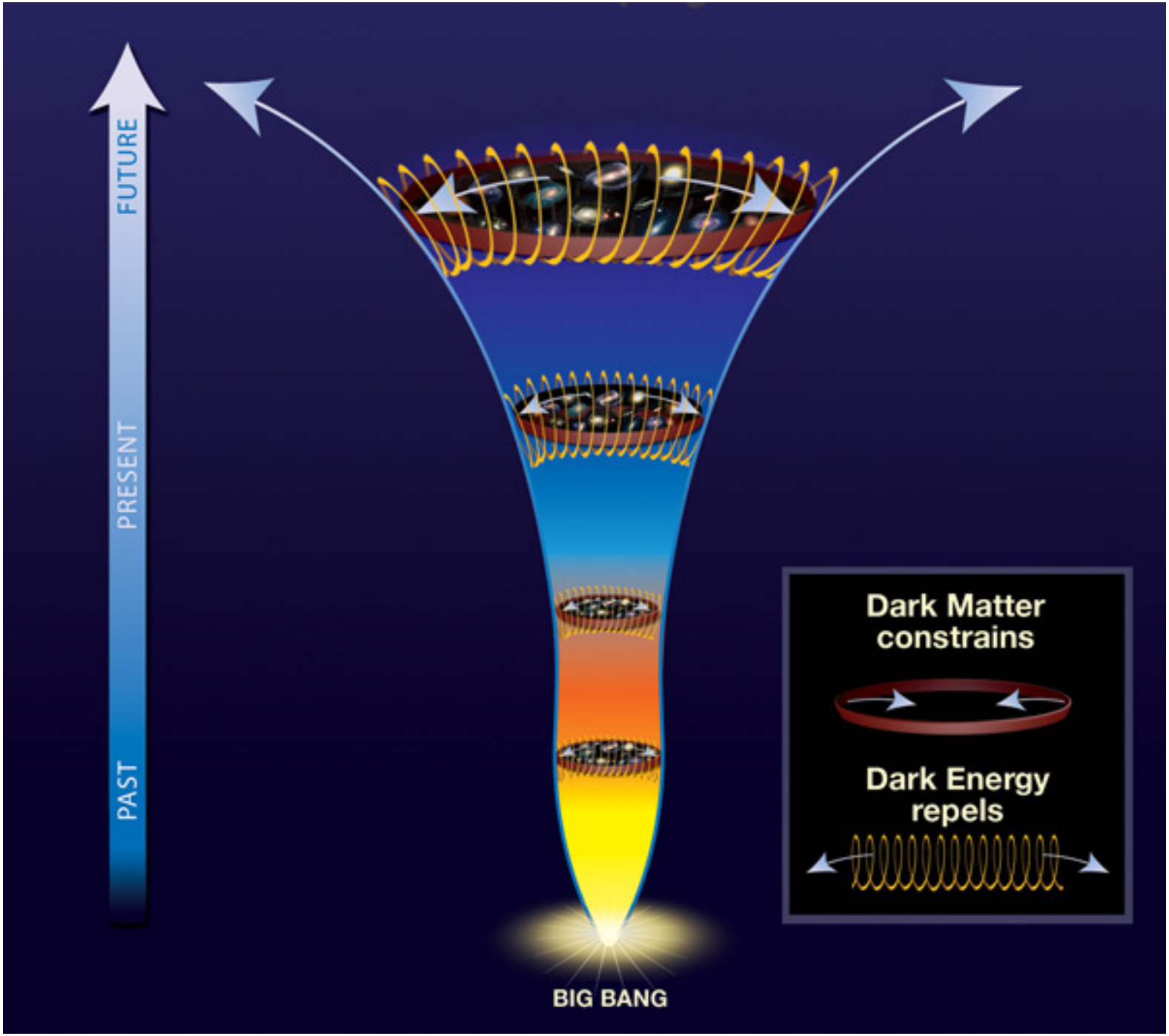
Part 3: The Dark Energy

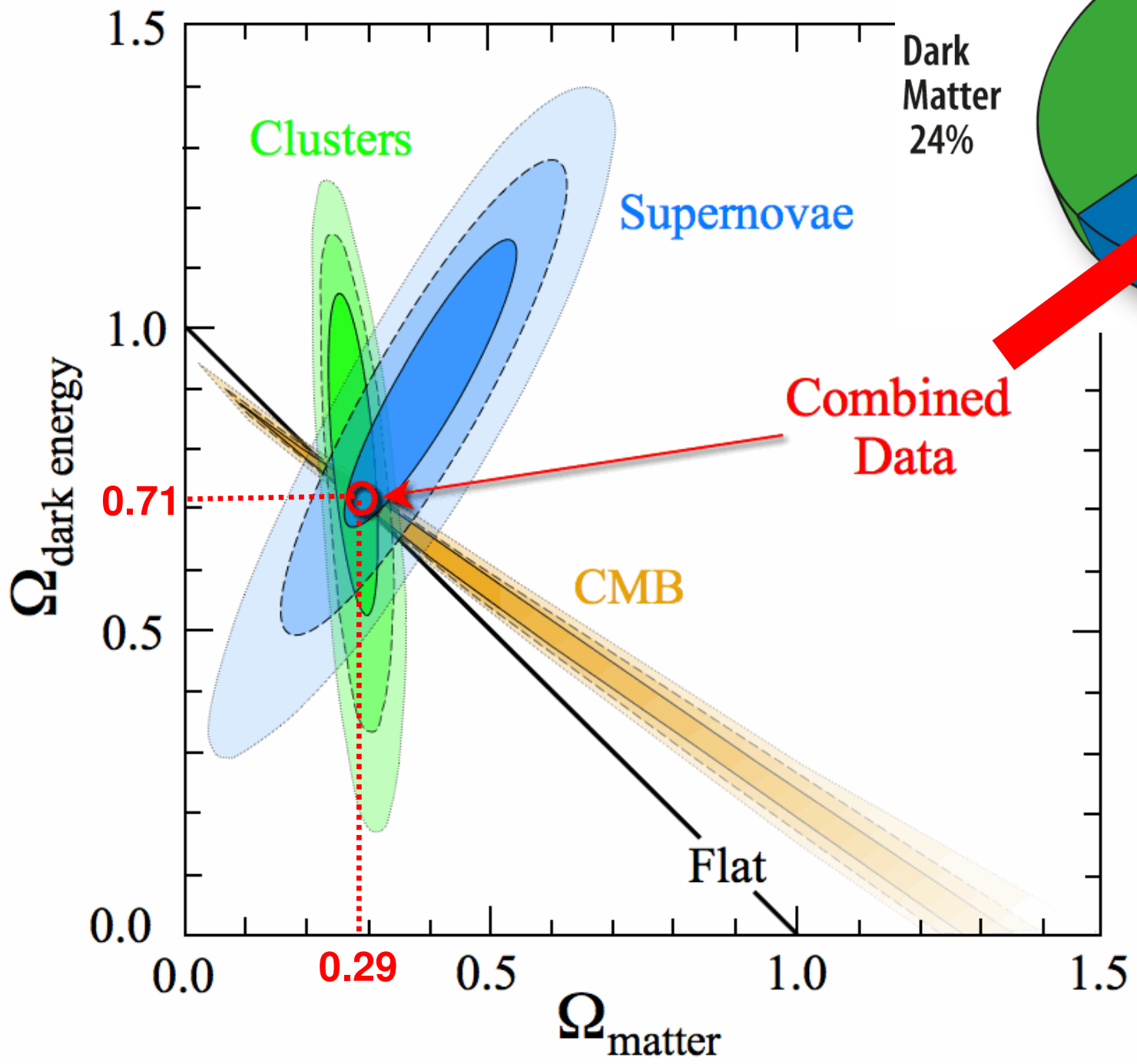


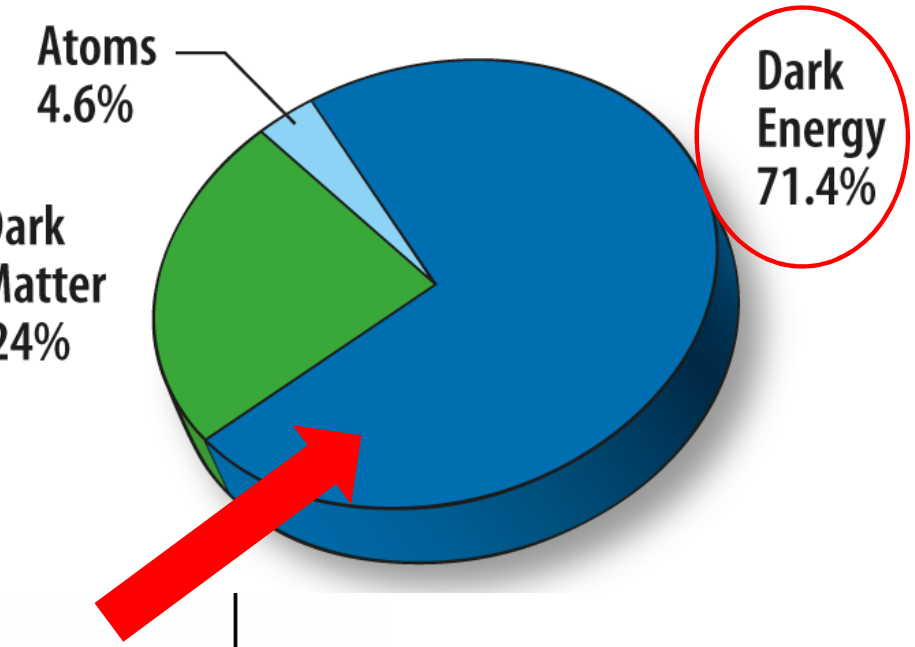
What is the dark energy?



http://www.wired.com/2008/12/dark-energy-ein/

How much dark energy?





www.hep.ucl.ac.uk

Dark energy theory # 1

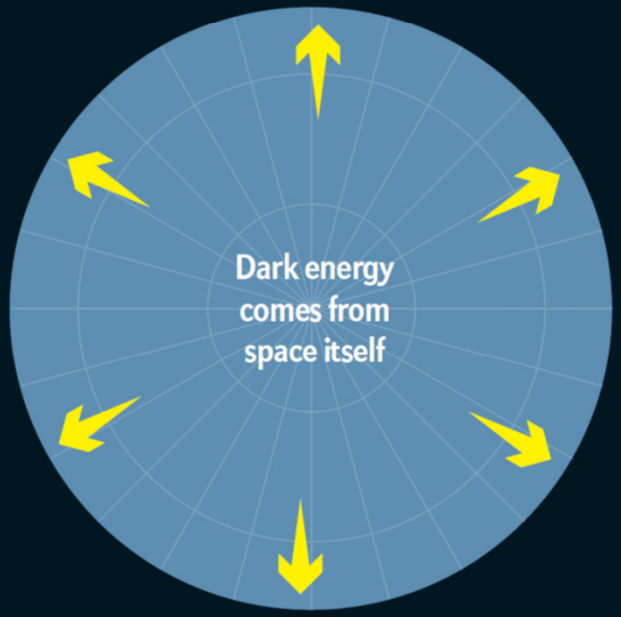
Dark Energy Possibilities and Potential Futures

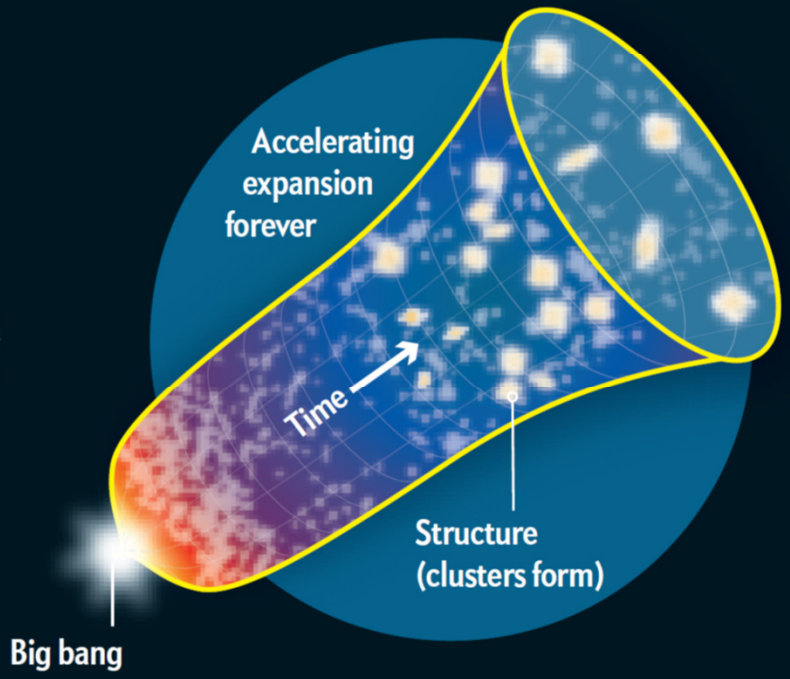
Dark energy is scientists' name for whatever is causing the expansion of the universe to accelerate. Explanations for dark energy fall into three main categories: it may be an unchanging energy arising from empty space (an idea called the cosmological constant) or a varying energy stemming from a field pervading the universe (quintessence). Or dark energy may not exist at all—in that case, gravity would act differently than thought on cosmic scales.

MODEL → FUTURE

Cosmological Constant

If the vacuum of empty space has an inherent energy, it may push the universe to expand. The strength of such an energy would be constant through time and would act just like the cosmological constant term Albert Einstein added to, and later removed from, his equations of general relativity.





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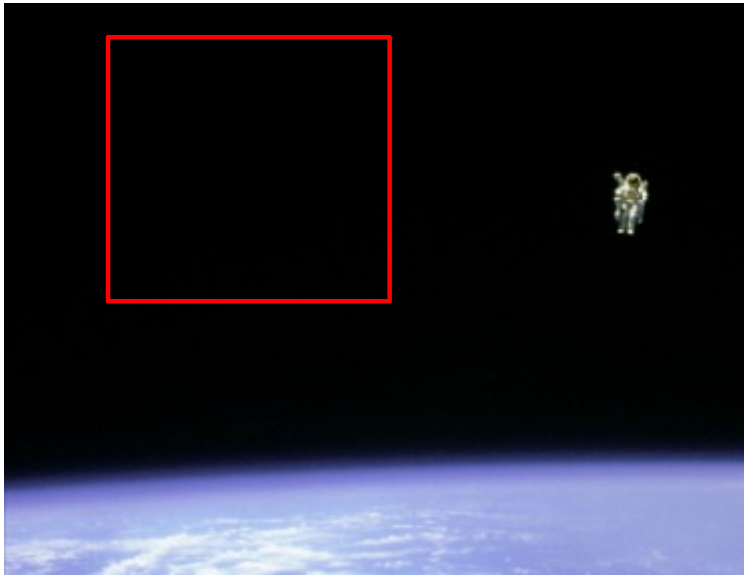
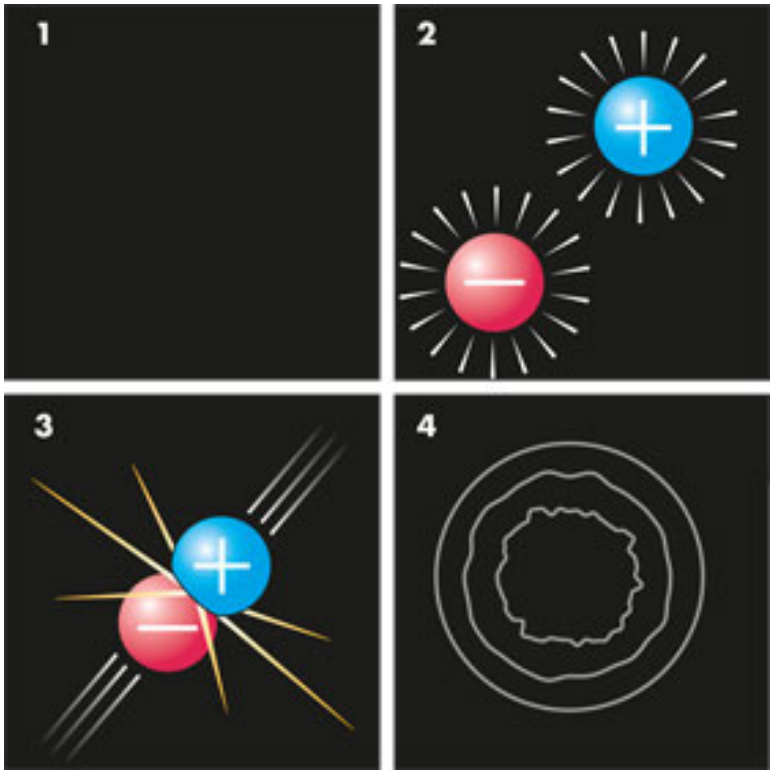


Vacuum is not just “nothing”!

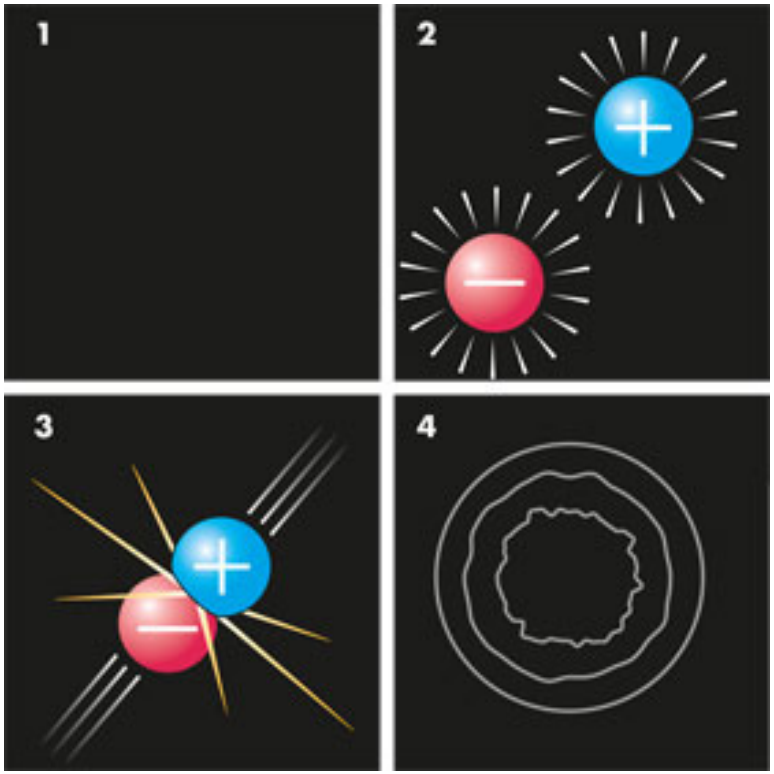
In quantum physics a vacuum is not “nothing”.

It is teeming with pairs of “virtual” particles and antiparticles that spontaneously appear and annihilate one another within a tiny fraction of a second.



1. Empty space.
2. Two particles suddenly appear.
3. Particles ram together and annihilate each other.
4. They leave ripples of energy through space

http://hetdex.org/dark_energy/what_is_it/vacuum_energy.php



Why vacuum fluctuation do not violate the law of energy conservation?

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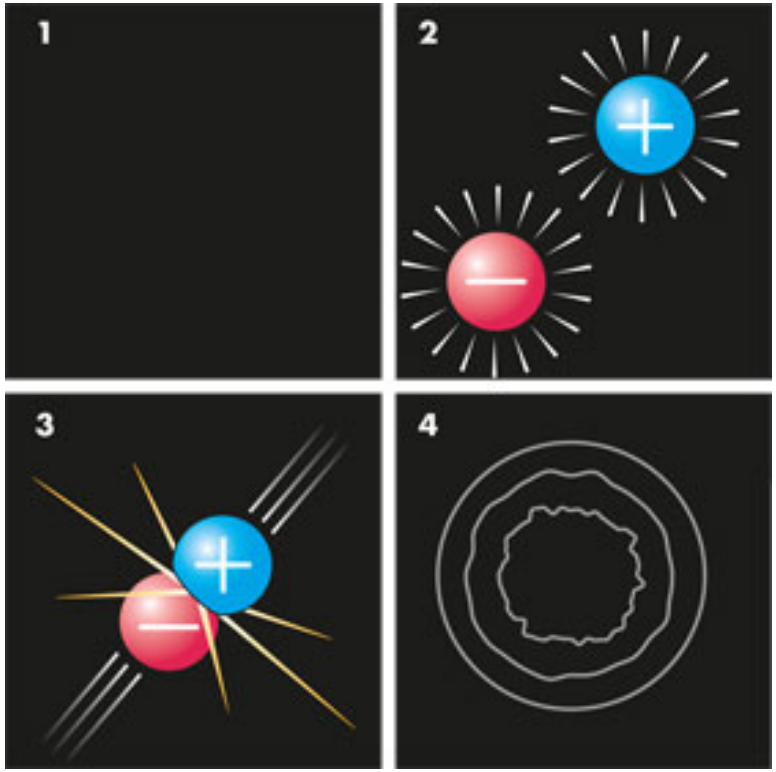
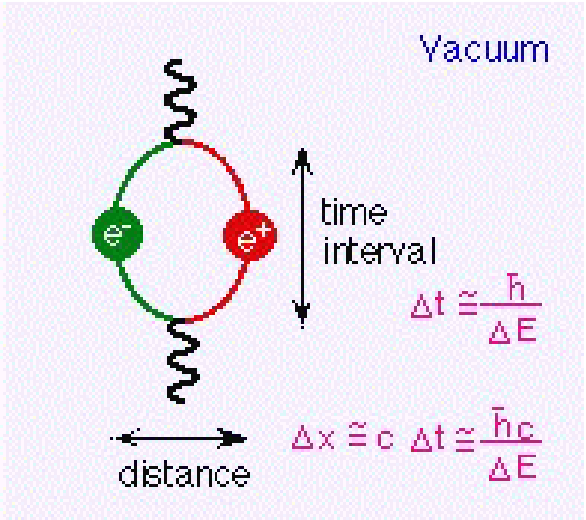


Uncertainty principle

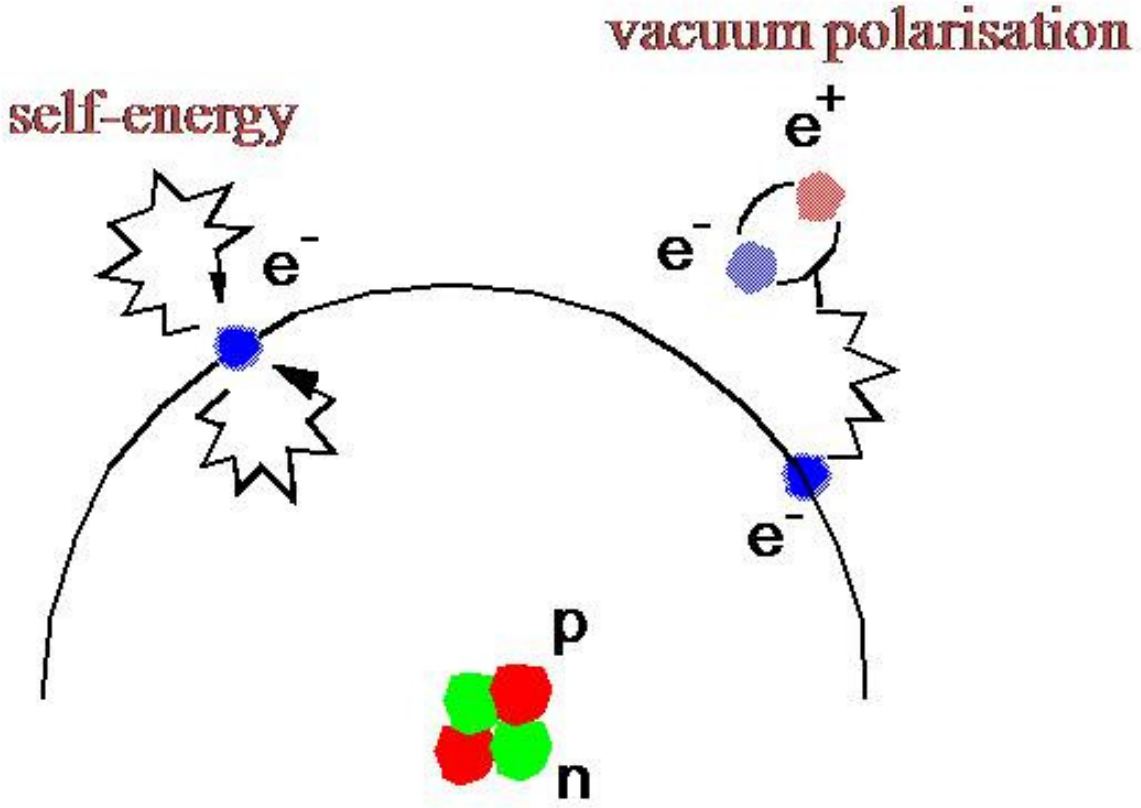
$$\Delta E \Delta t \geq \frac{\hbar}{2}$$



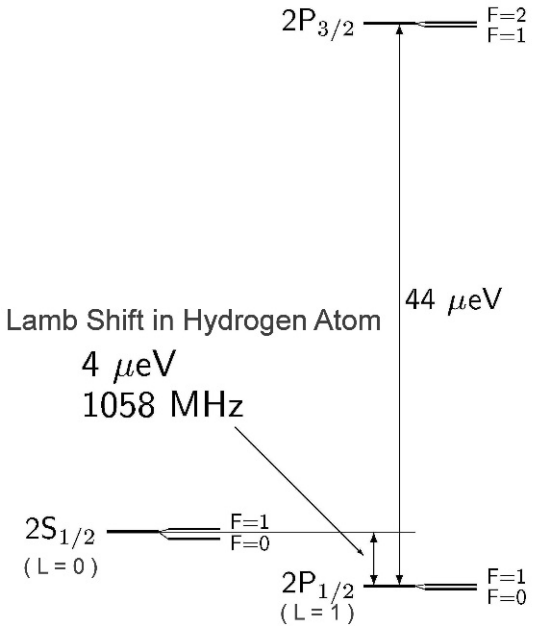
http://www-jlc.kek.jp/hep/hep-c8-e.html

Experimental confirmations that vacuum is not “empty”: Quantum electrodynamics (QED) is a very well tested theory!

Lamb shift – **shift of atomic energy levels** is caused by interactions between vacuum fluctuations and atomic electrons.



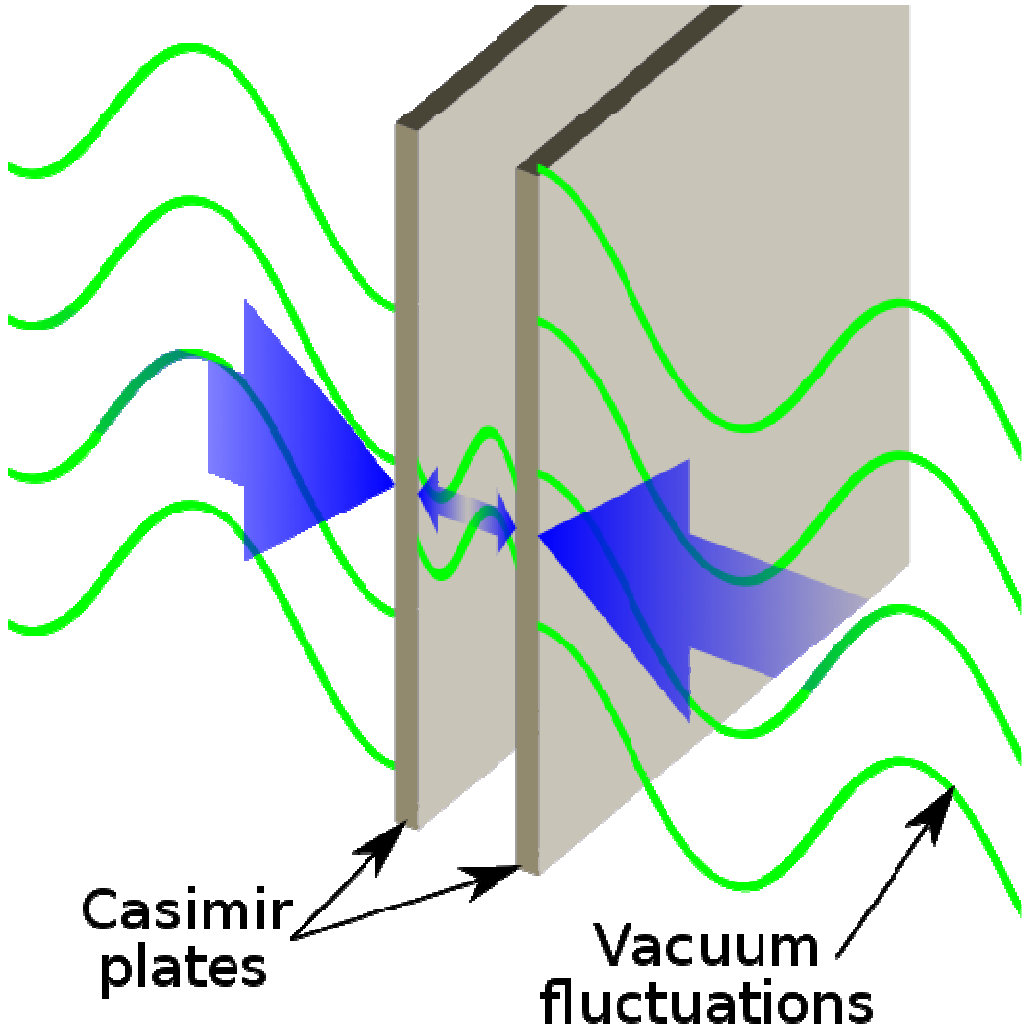
He



http://www.nat.vu.nl/~wimu/QED-Test.html

Casimir effect

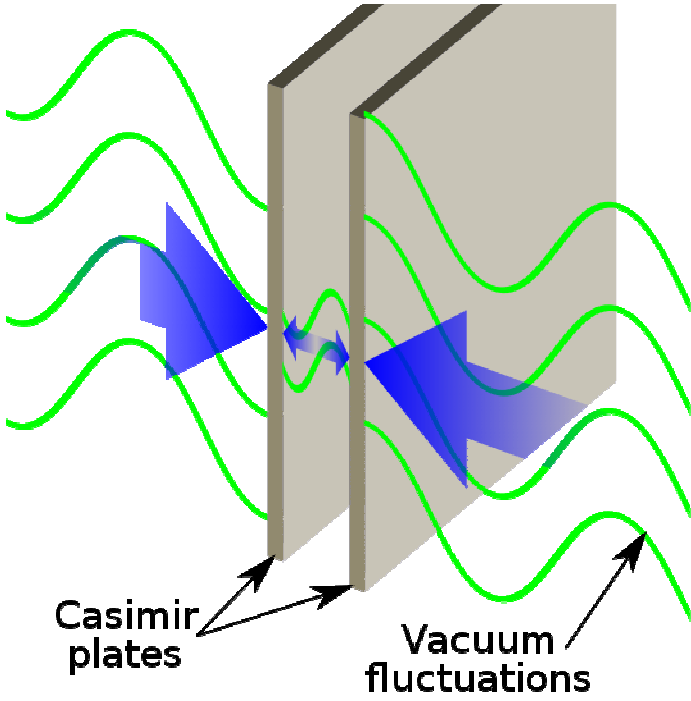
Casimir effect: a small attractive force that acts between two close parallel ***uncharged*** conducting plates in a vacuum. It is due to quantum vacuum fluctuations of the electromagnetic field.



https://en.wikipedia.org/wiki/Casimir_effect

Casimir effect

If we place two mirrors facing each other in a vacuum, some of the “vacuum fluctuation” electromagnetic waves will fit between them, bouncing back and forth, while others will not.

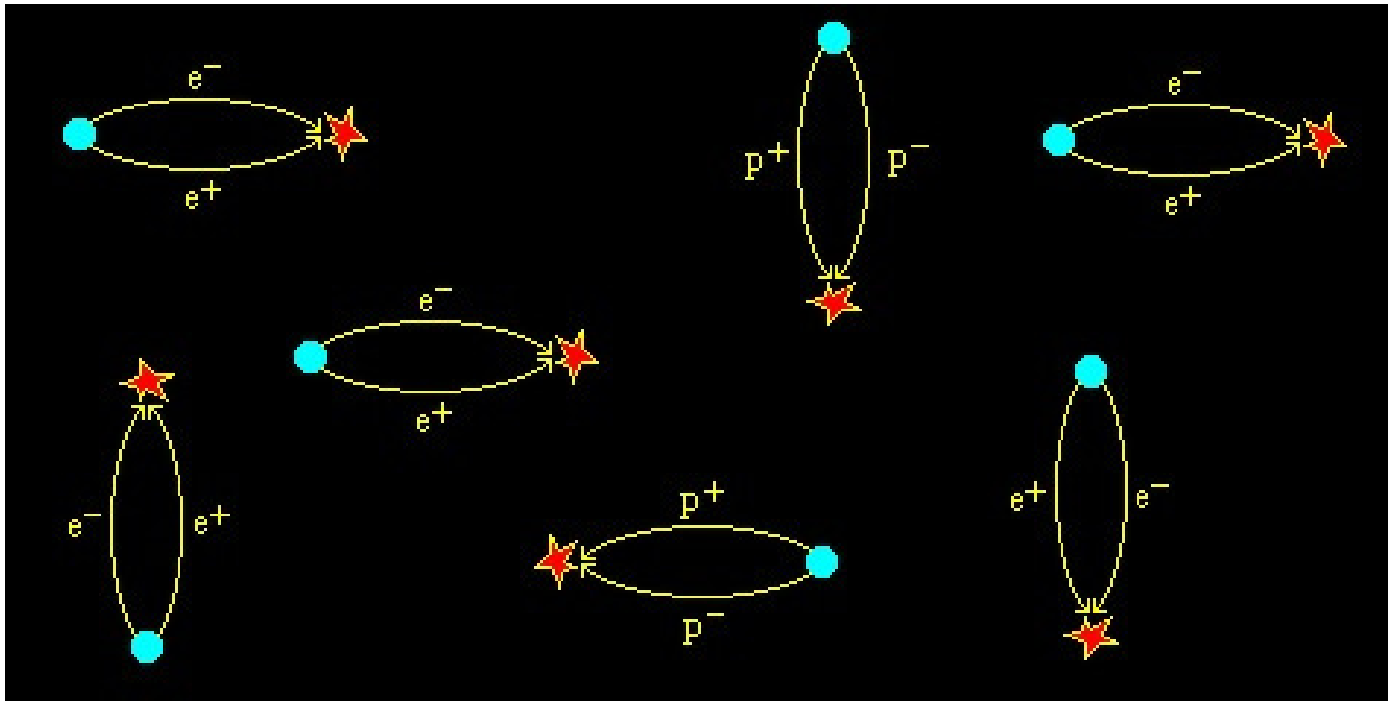


As the two mirrors move closer to each other, the longer waves will no longer fit--the result being that the total amount of energy in the vacuum between the plates will be a bit less than the amount elsewhere in the vacuum.

Thus, the mirrors will attract each other, just as two objects held together by a stretched spring will move together as the energy stored in the spring decreases.

http://www.scientificamerican.com/article/what-is-the-casimir-effec/

Vacuum can act as “repulsive gravity”

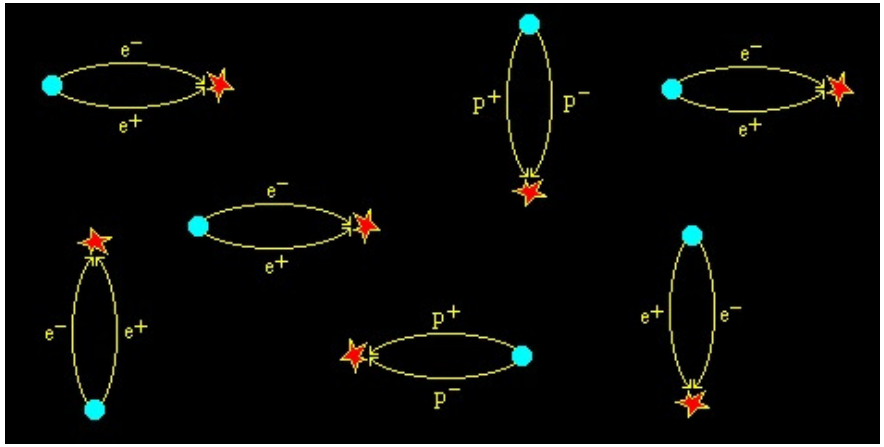


This “sea” of ephemeral particle pairs carries energy, and energy, just like mass, can produce gravity.

Unlike mass, however, energy can create either an attractive or a repulsive gravity, depending on whether its pressure is positive or negative.

Problem with the vacuum energy being the dark energy

Wrong by 120 orders of magnitude!

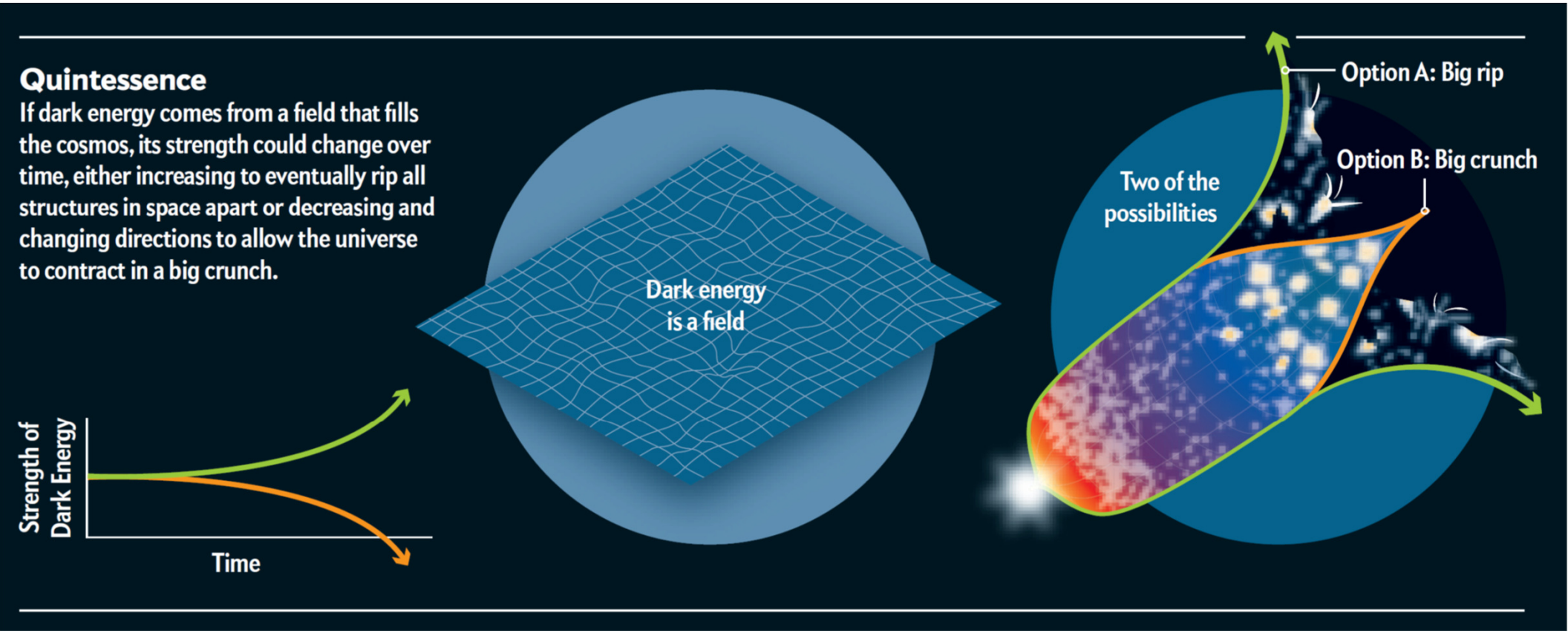


When one naively attempts to sum up the energies over all the presumed quantum states associated with the sea of virtual particles and antiparticles in the vacuum of space, one obtains a value that is more than 120 orders of magnitude larger than the observed sum.

More sophisticated calculations:

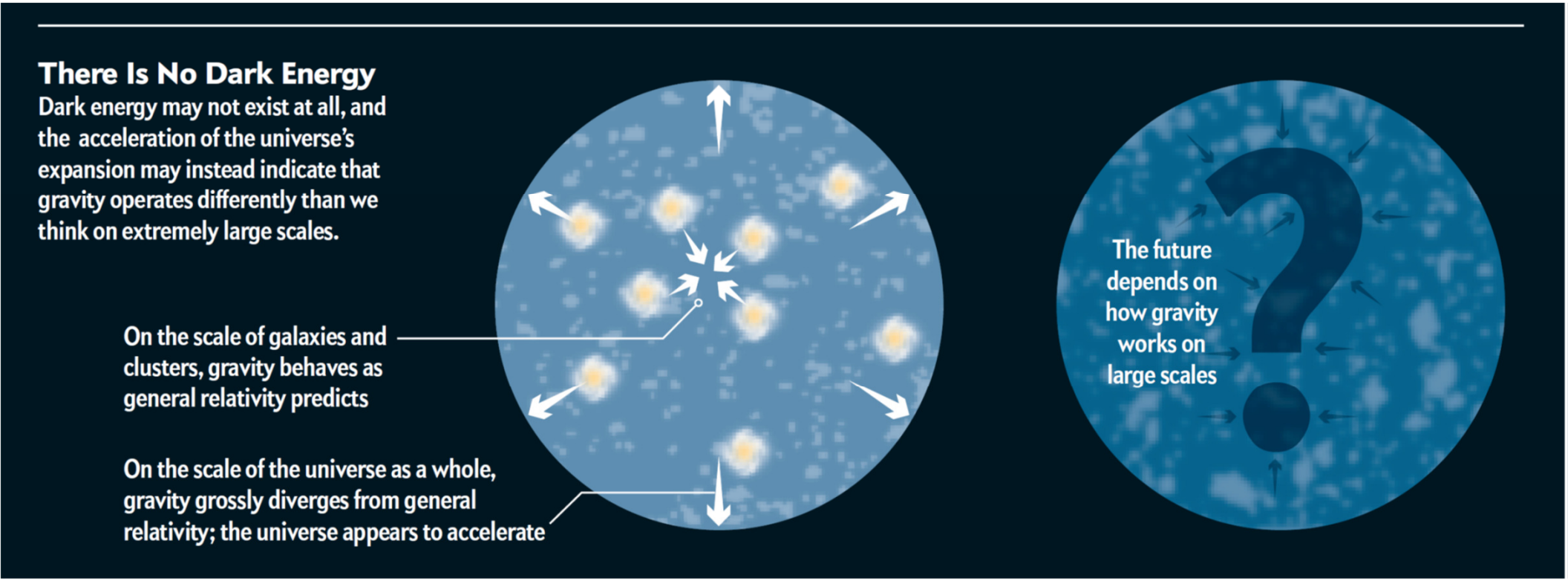
From being wrong by 10^{120} to being wrong by 10^{55}

Dark energy theory # 2
Unknown field



Scientific American **314**, 38 (2016)

Dark energy theory # 3
There is no dark energy.
General relativity is wrong on the large scales



Problem: we can not come up with the other theory that is not conflicting with already known data.

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Dark energy theory # 4
There is no dark energy:
We live in a special place in the Universe

COPERNICAN PRINCIPLE

Human life doesn't have privileged position in the universe, or in the scheme of physics

Andreas Cellarius, *Harmonia Macrocosmica* (1661)

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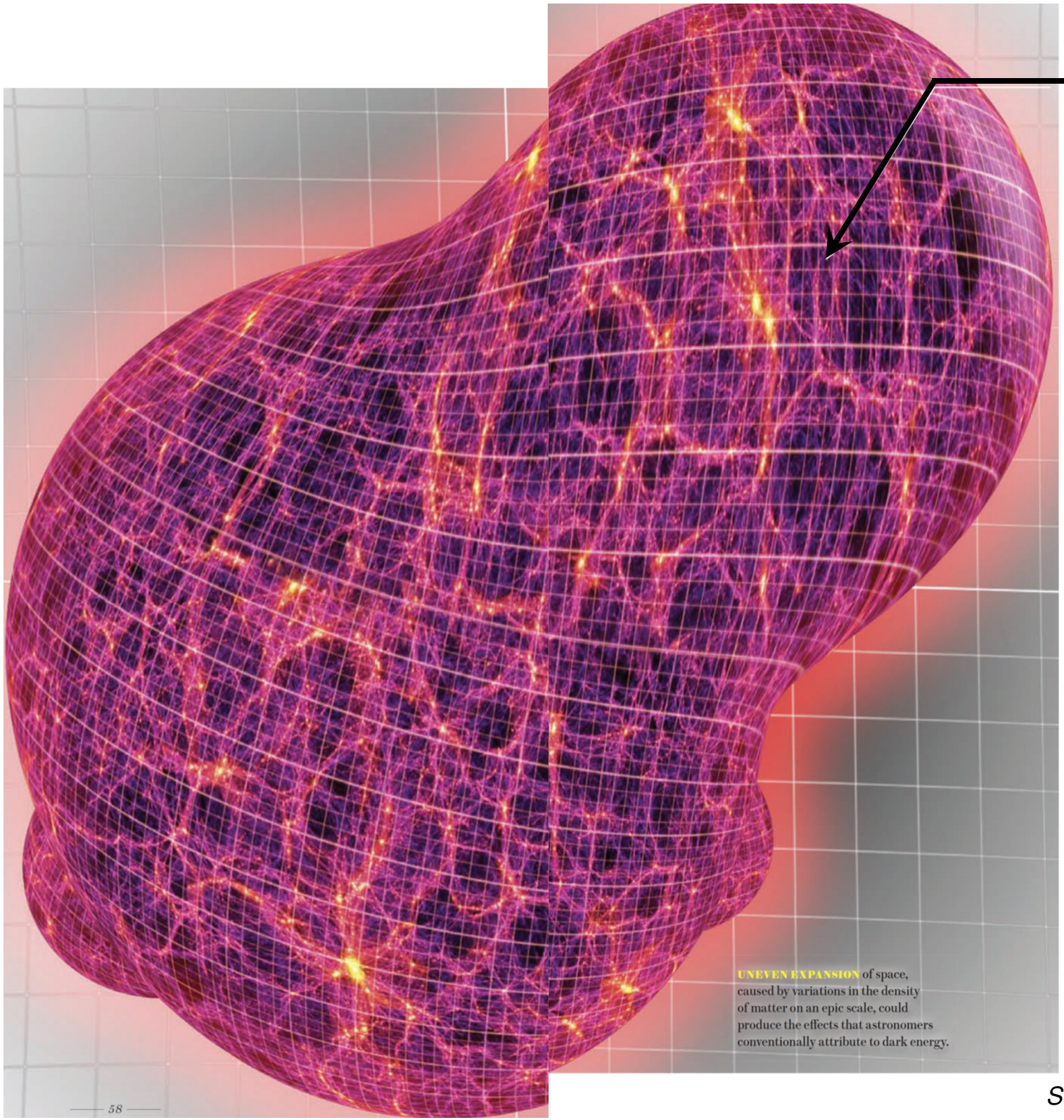

UNEVEN EXPANSION of space, caused by variations in the density of matter on an epic scale, could produce the effects that astronomers conventionally attribute to dark energy.

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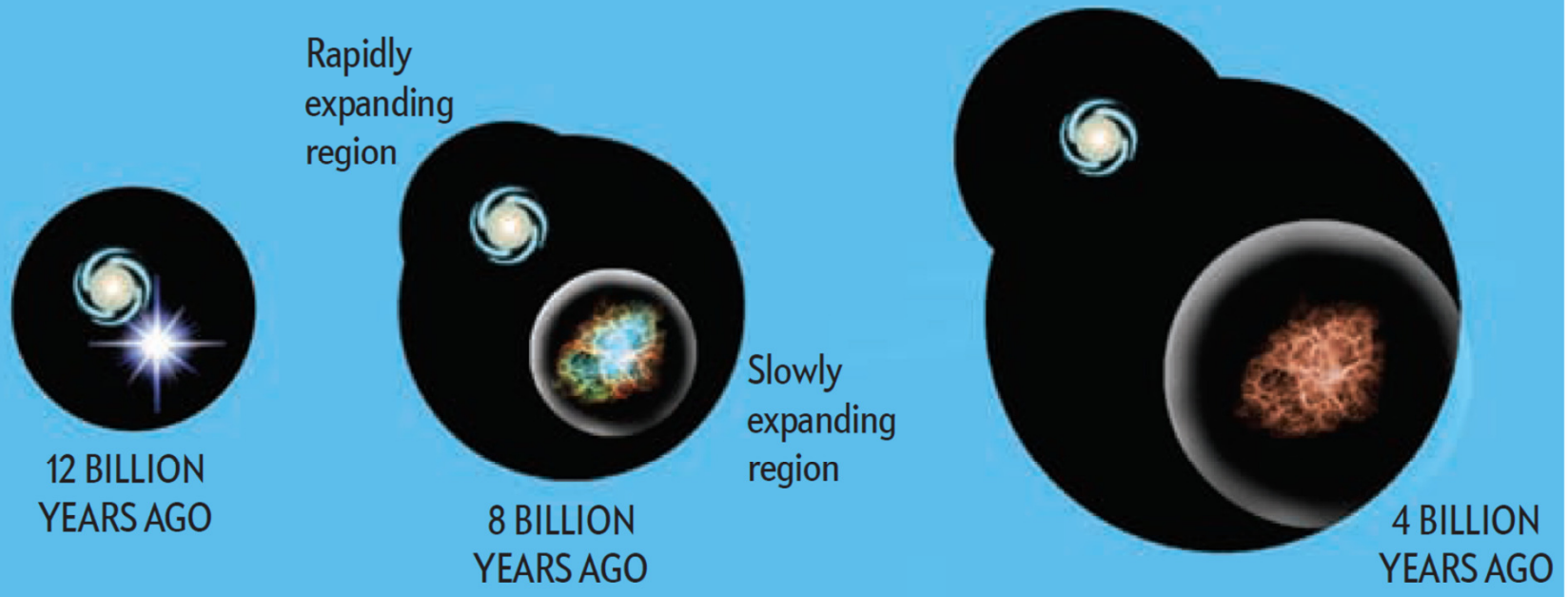
There is no dark energy: we live in a cosmic void

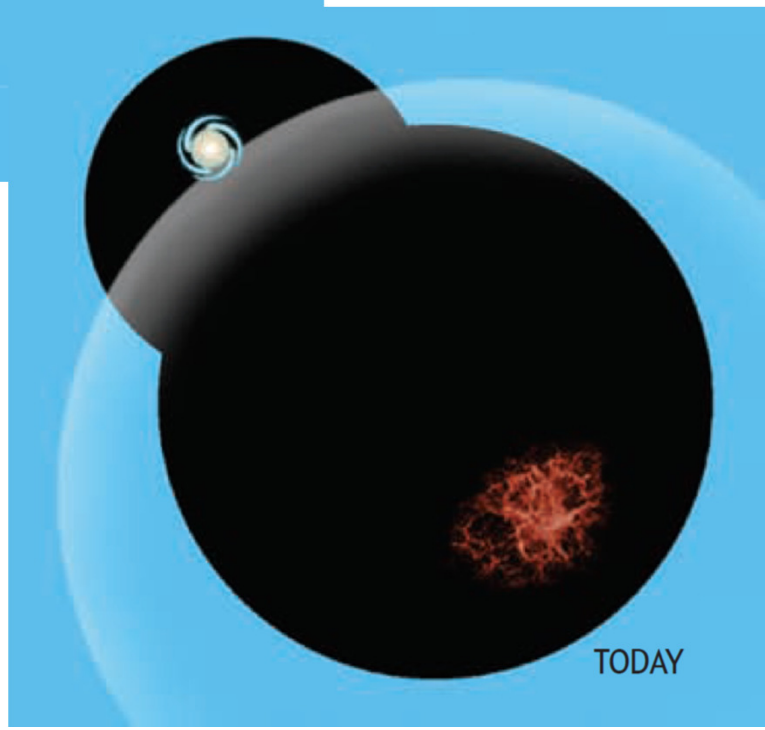
Scientific American **22**, 58 (2013)

Alternatively, perhaps expansion is decelerating but at different rates in different places. If our neighborhood is emptier than other areas, it has less matter to retard the expansion and decelerates less quickly.



As light from a supernova spreads out, it enters zones of increasingly rapid expansion—which has the same effect as cosmic acceleration but without any need for dark energy.

What If Universe is Inhomogeneous (not the same everywhere)?



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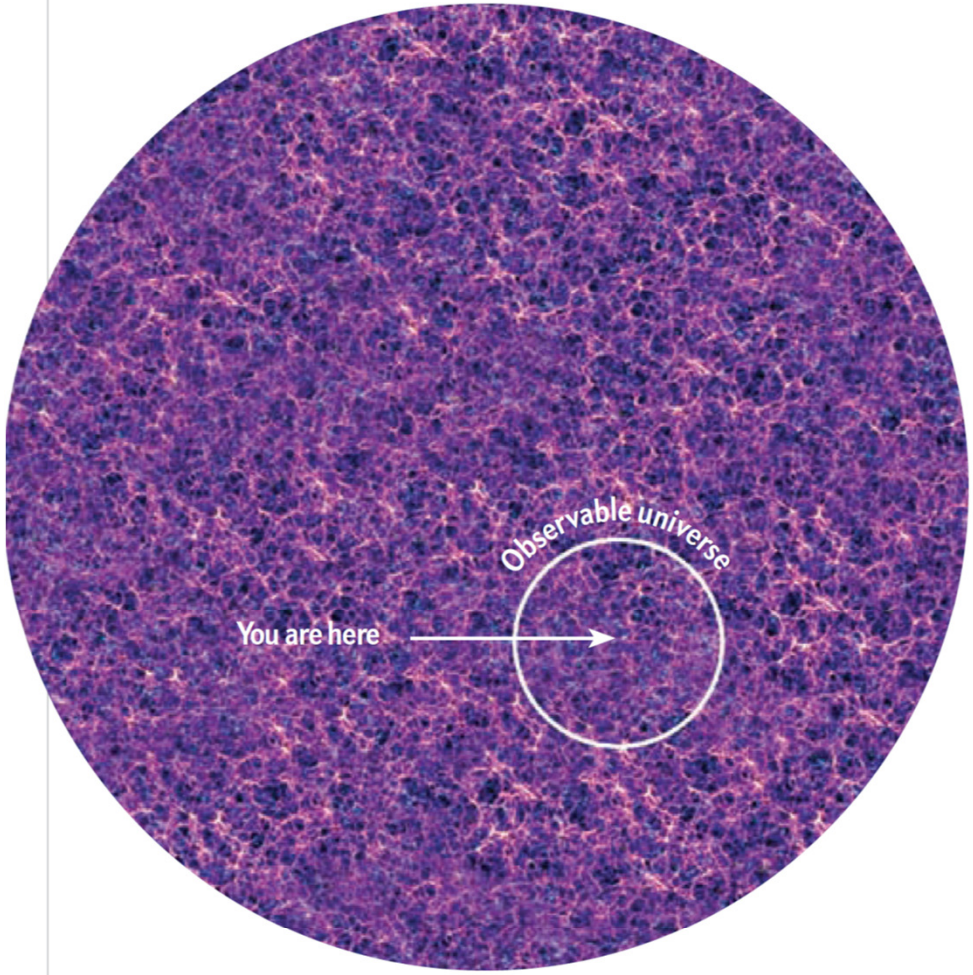
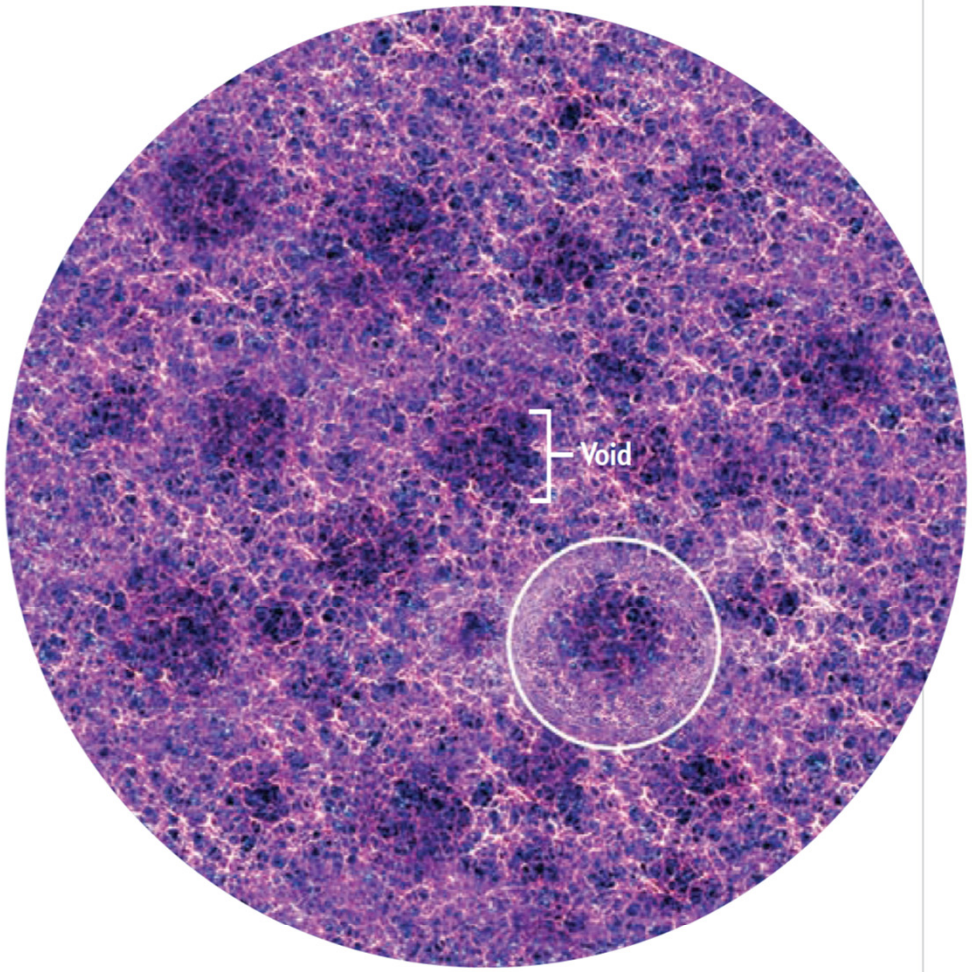
We assume that Universe is homogeneous – the same everywhere on a large scale



Homogeneous Universe: Our Location Is Typical
In the standard view, galaxies are lined up in a spidery pattern, but overall space looks much the same everywhere, and Earth's position is nothing special.

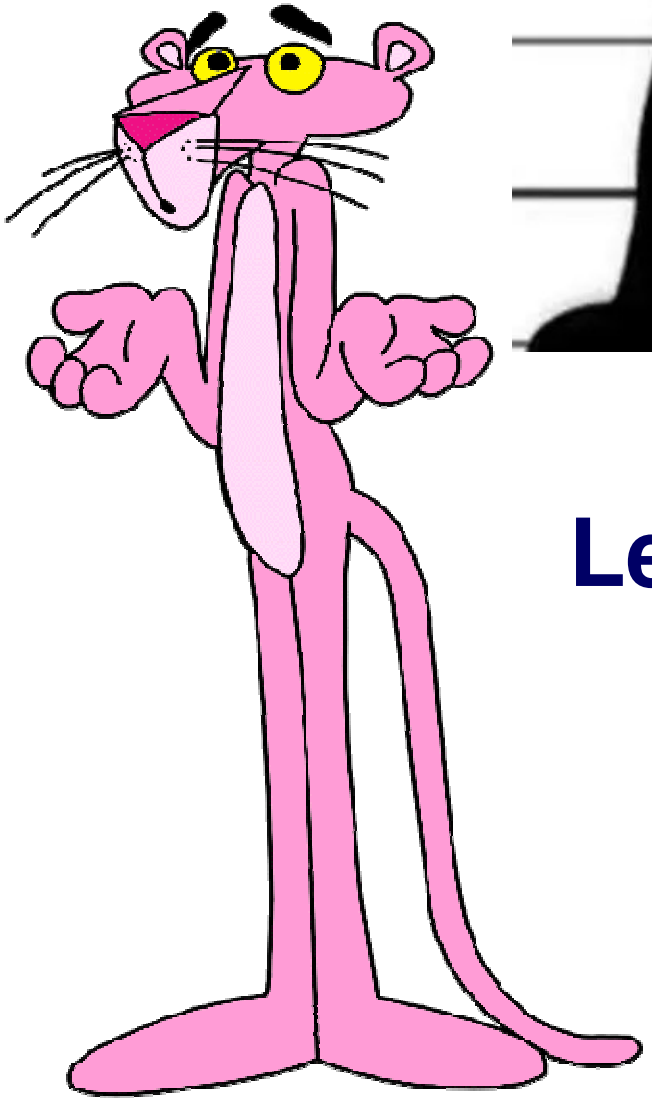


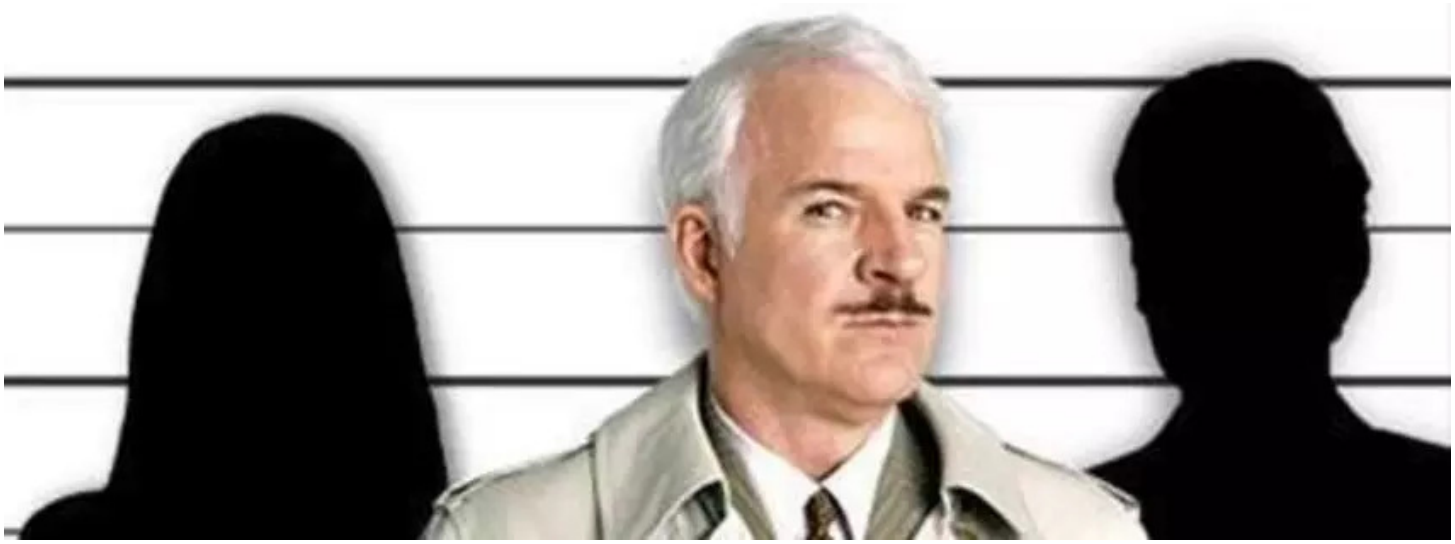
Inhomogeneous Universe: Our Location Is Special
Alternatively, the density of matter could vary on large scales, and Earth may lie at or near the center of a relatively less dense region, or void.

Void has the be close to the size of observable Universe – mostly ruled out.

Scientific American **22**, 58 (2013)

Summary of the current knowledge of what dark energy is:





Inspector Jacques Clouseau

Let me bring you up to speed...

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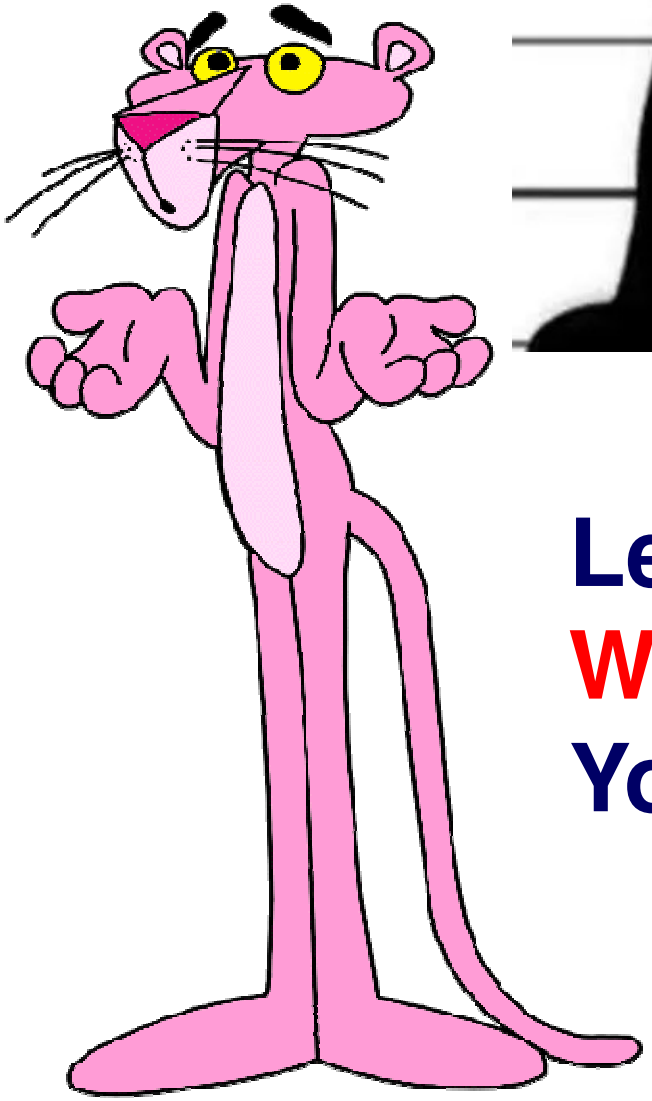
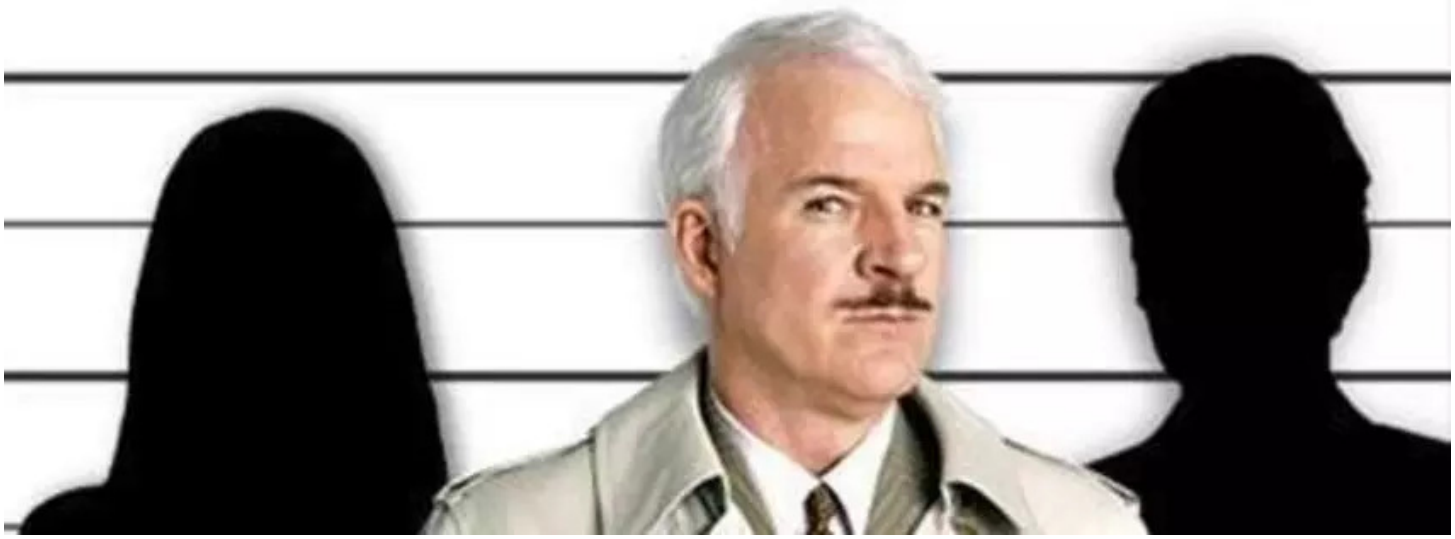




Inspector Jacques Clouseau

Let me bring you up to speed...

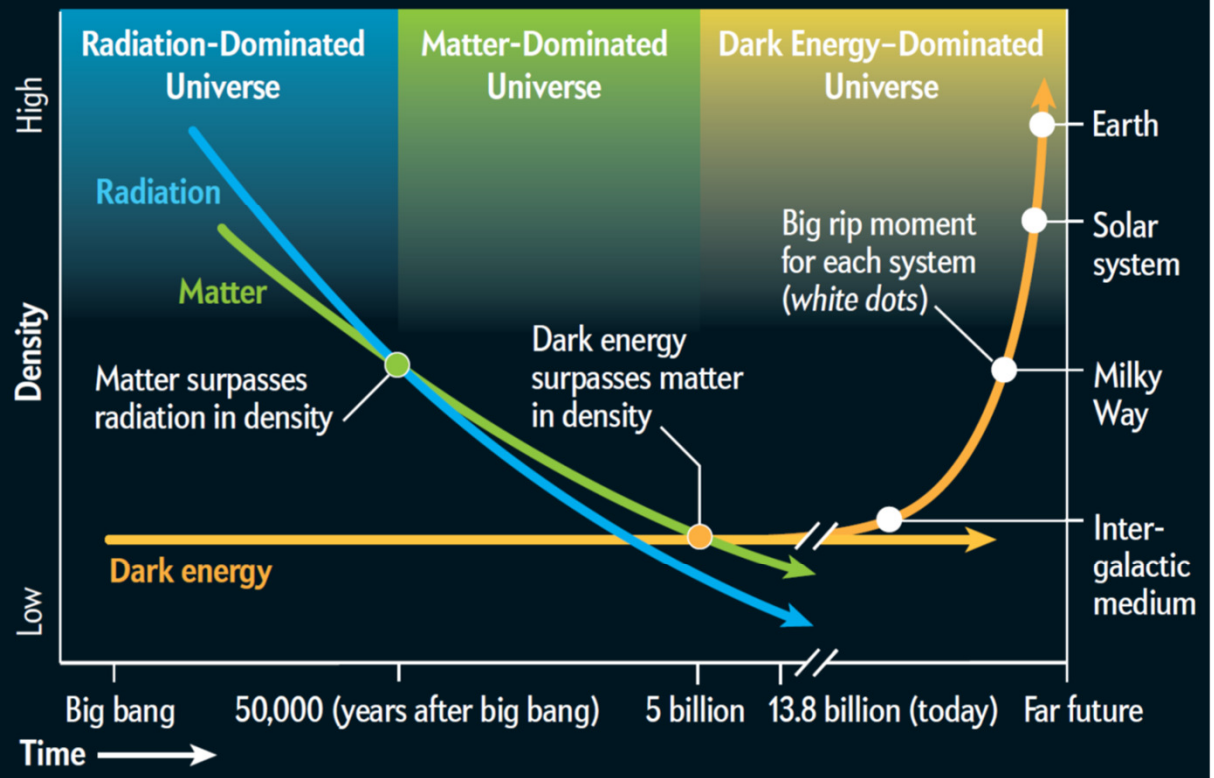
We know nothing.

You are now up to speed.

WHY DARK ENERGY MATTERS

Cosmic Control

Because dark energy is denser in space than any other constituent of the universe, it exerts the dominant influence on the cosmos and will therefore control its fate. Dark energy was not always on top, though: the other ingredients of the universe—radiation (light) and matter (including atoms and regular matter as well as invisible dark matter)—were dominant when the universe was young and small, and they were packed tightly in space. As the universe expanded over time, matter and radiation spread out, and dark energy overpowered them. If the density of dark energy increases, it may become so powerful that it rips apart all structures in space.



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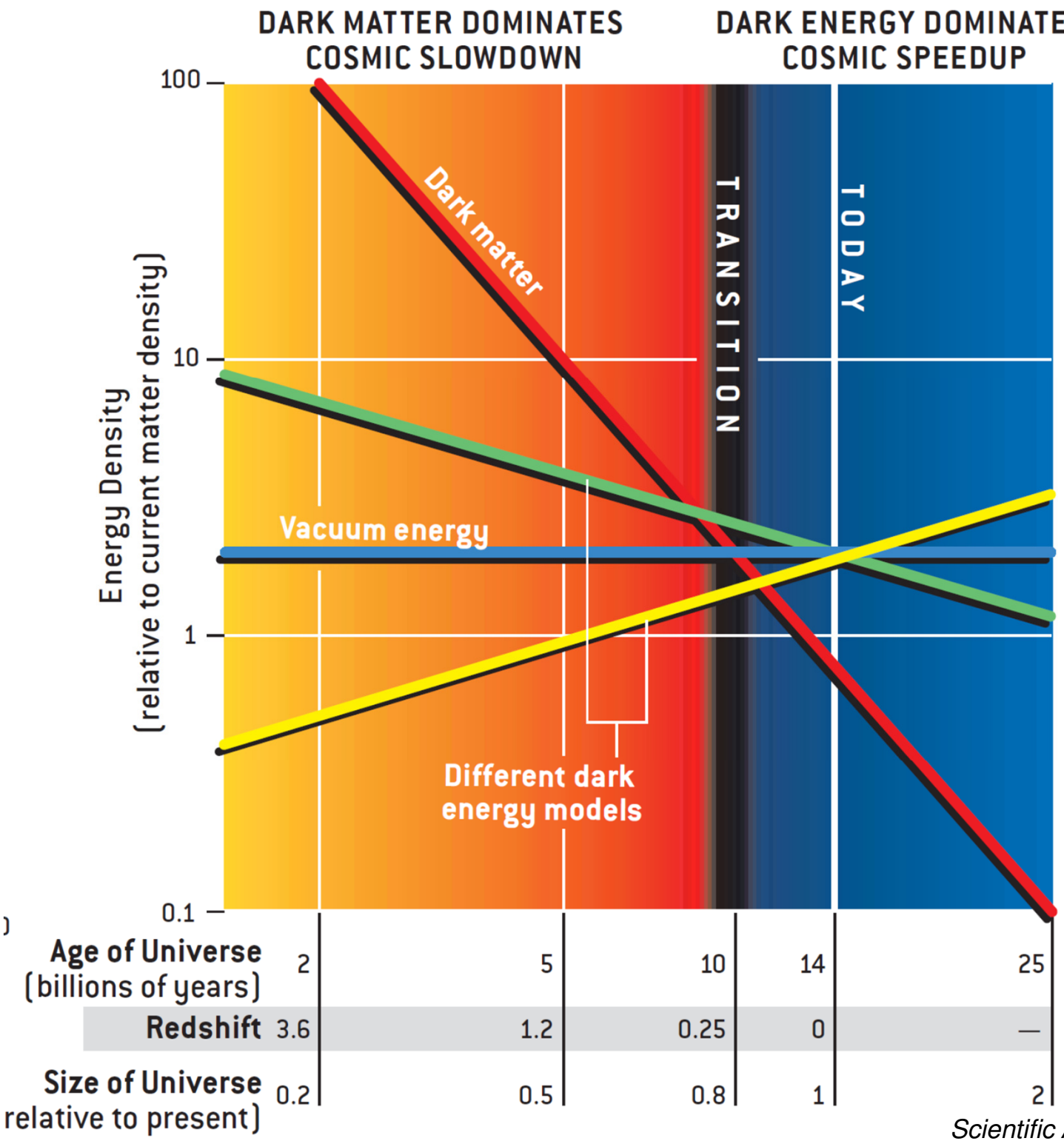
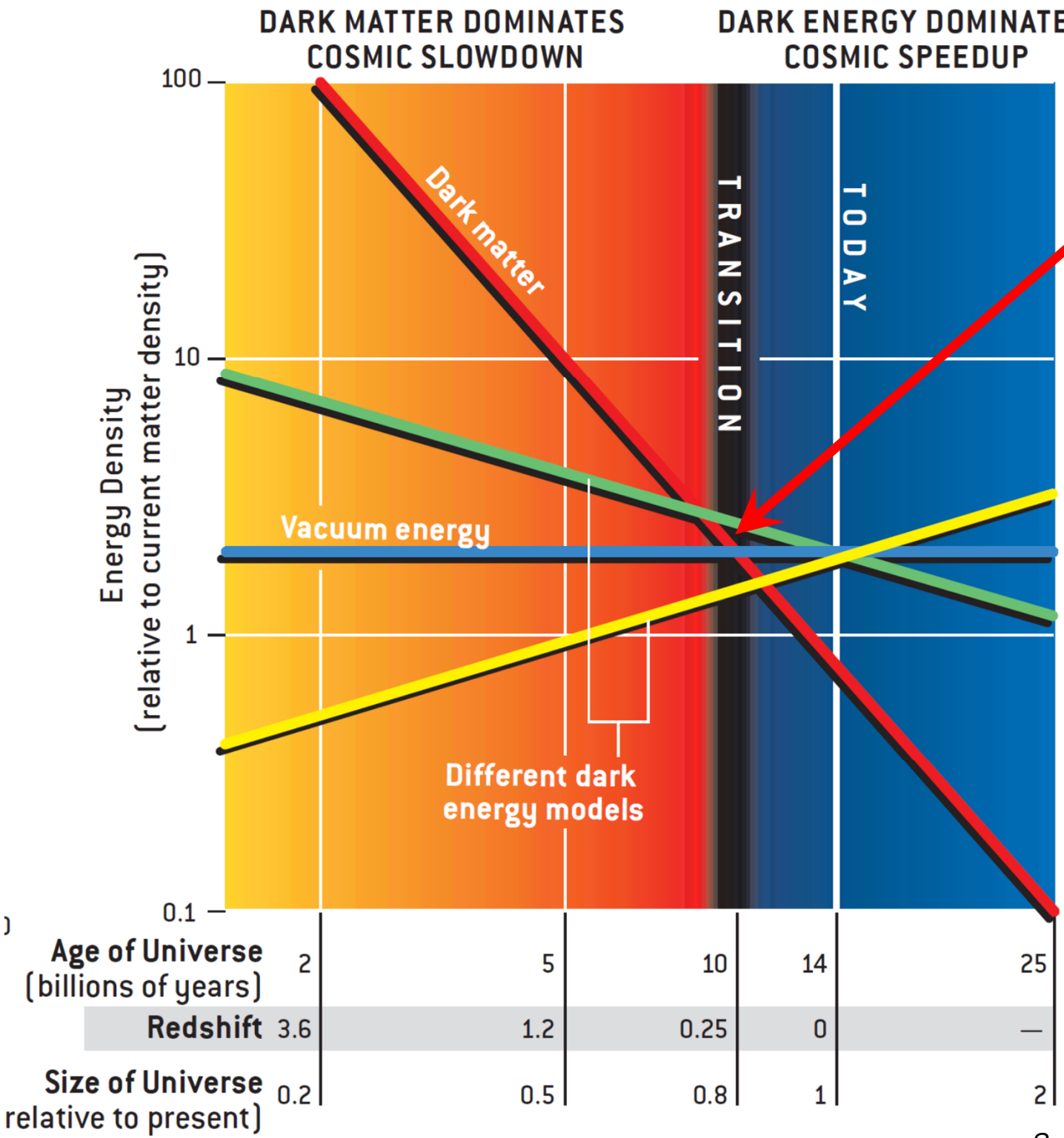


Scientific American **290**, 62-67 (2004)



Learn more about the transition point to let more about the dark energy.

Scientific American **290**, 62-67 (2004)

Need more data to learn more about the nature of dark energy!