Rotation of the universe, Gödel and Cosmology

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بسم الله الرحمن الرحیم

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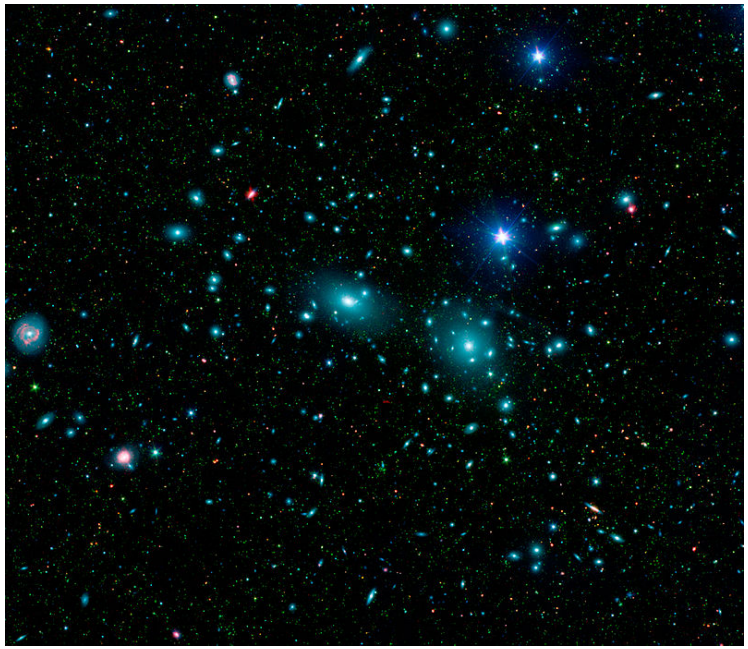
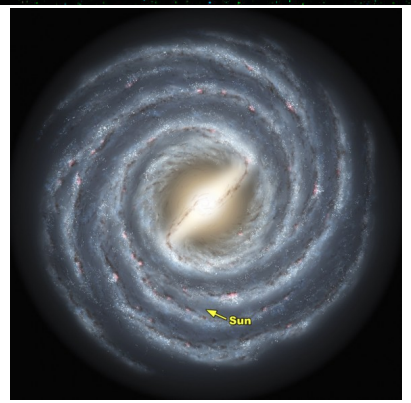
- **Plato**: Heavenly objects only take up perfect motion
  $\rightarrow$ circular motion with uniform speed

- **Aristotle**: Earth sits still at the center of the universe
  $\rightarrow$ A finite, rotating universe; human is unique (geocentric theory)

- **Copernicus**: Stars and the sun are fixed; Earth and other planets orbit around the sun(Heliocentrism)

- **Galileo**(100 years after Copernicus) : He was able to use this telescope to prove the truth of the Copernican system of heliocentrism




Sun

Everything spins:

- Sun rotates once every $\sim$ 25 days.
- Jupiter rotates once every $\sim$ 10 hrs.
- Milky Way is rotating, with period $\sim$ 220 MYr at Sun's orbit

A fundamental question:

How did all these rotary motions come into being?

E.T. Whittaker, *Spin in the universe*, Yearbook of Roy. Soc. Edinburgh, 5-13, (1945):

"**Rotation is a universal phenomenon**; the earth and all the other members of the solar system rotate on their axes, the satellites revolve round the planets, the planets revolve round the Sun, and the Sun himself is a member of the galaxy or Milky Way system which revolves in a very remarkable way. **How did all these rotary motions come into being?** What secures their permanence or brings about their modifications? And what part do they play in the system of the world?"

Edmund Whittaker

Existing answers:

Ozernoy, L. M., and Chernin, A. D.,
Astron. Zh., **45**, 1137, (1968):

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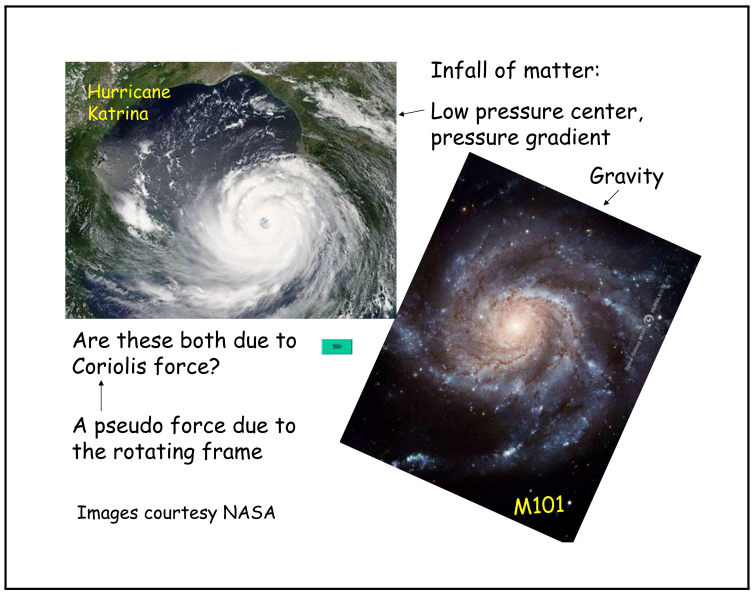

Gamow G., Nature, 158, 549, (1946):

LETTERS TO THE EDITORS

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Rotating Universe ?

ONE of the most mysterious results of the astronomical studies of the universe lies in the fact that all successive degrees of accumulation of matter, such as planets, stars and galaxies, are found in the state of more or less rapid axial rotation. In various cosmogonical theories the rotation of planets has been explained as resulting from the rotation of stars from which they were formed. The rotation of stars themselves (in particular that of *B*-stars) can be presumably reduced to their origin from the rotating gas-masses which form the spiral arms of various galaxies. But what is the origin of galactic rotation ?

If, according to the current theories, we consider the galaxies as the result of gravitational instability of the originally uniform distribution of matter in space, we will find it very difficult to understand why such condensations are in most cases found in the state of rather fast rotation. In fact, on the basis of statistical distribution of angular momentum, we would rather expect such condensations to show no more rotation than the water droplets in a fog formed from oversaturated vapour. Barring the possible explanation of the rotation of galaxies on the basis of the alleged irregular turbulent motion of the masses of the universe, we can ask ourselves whether it is not possible to assume that *all matter in the visible universe is in a state of general rotation around some centre located far beyond the reach of our telescopes ?*

The answer to such, at first sight fantastic, question need not wait until much larger telescopes shall have been built. It can be, in fact, settled by present means of observation. We know that the rotation of the stars of our system around the galactic centre can be proved by the study of the so-called Oort-effect in the radial velocities of comparatively near stars. In fact, due to the phenomenon of differential rotation, the mean radial velocities of stars located along the galactic plane show a double-sine periodicity with nodal axes directed parallel and perpendicular to the line connecting the sun with the centre of rotation. Thus if the realm of galaxies as seen through Mt. Wilson telescope represents only a small part of a much larger system (a 'super-galaxy' in the super-Shapley sense) rotating around a distant centre, careful observations of mean radial velocities of galaxies located in different regions of the sky should reveal similar periodicity.

The existence of this effect would prove general rotation of the universe and indicate the direction towards the rotation centre without, however, giving us its distance. Thus, it seems that the answer

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- We can ask ourselves whether it is not possible to assume that **all matter in the visible universe is in a state of general rotation around some centre located far beyond the reach of our telescopes?**

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- In the language of the general theory of relativity such a rotating universe can be probably represented by the group of anisotropic solutions of the fundamental equations of cosmology.

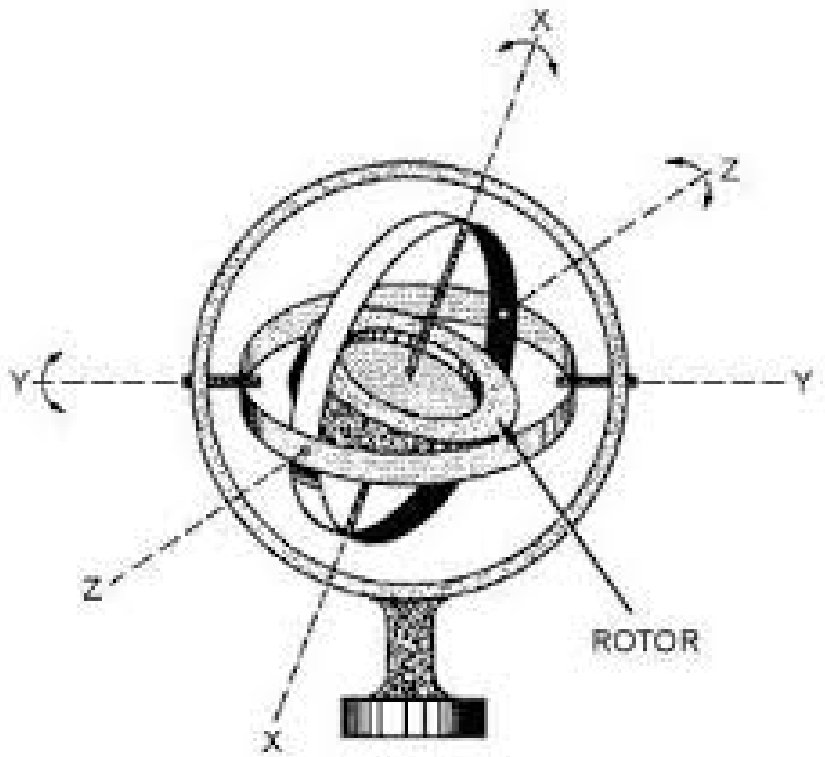
Is our Universe Rotating?

Whether our Universe is rotating is a question for measurements, not theory.

Measurements can never prove that the rotation is exactly zero. As it is, there is no certain evidence that our Universe rotates.

Let's have a look at the upper limits.

Observational methods:



- Solar system observations
- CMB constraints

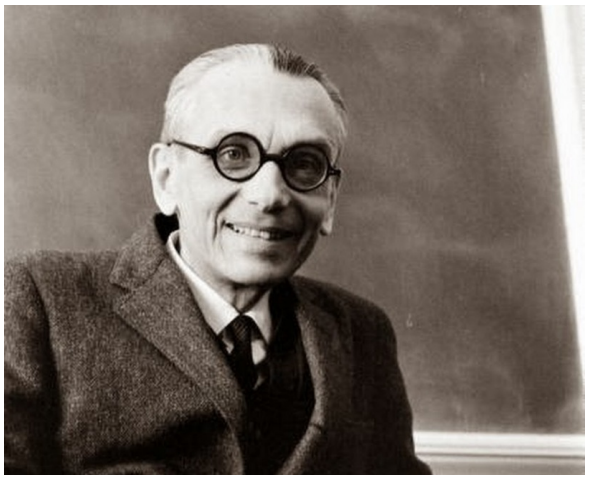
CMB constraints:

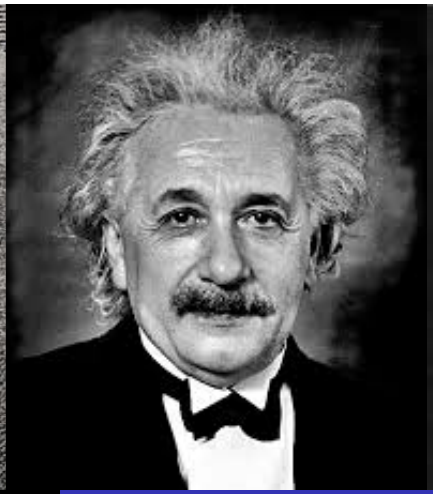
Closed universe	Hawking(1969)	$< 10^{-14} - 7 \times 10^{-17} \mathrm{rad/yr}$
Open universe	Hawking(1969)	$< 2 \times 10^{-17} \mathrm{rad/yr}$
Flat universe	Barrow et al. (1985)	$< 1.5 \times 10^{-15} \mathrm{rad/yr}$

Gödel's motivations: Philosophy, Birthday, Letter

Kurt Gödel: The greatest logician since Aristotle

(Yourgrau P. Gödel meets Einstein (1999).)





Gödel, Kurt. "An example of a new type of cosmological solutions of Einstein's field equations of gravitation." Reviews of Modern Physics 21.3 (1949):

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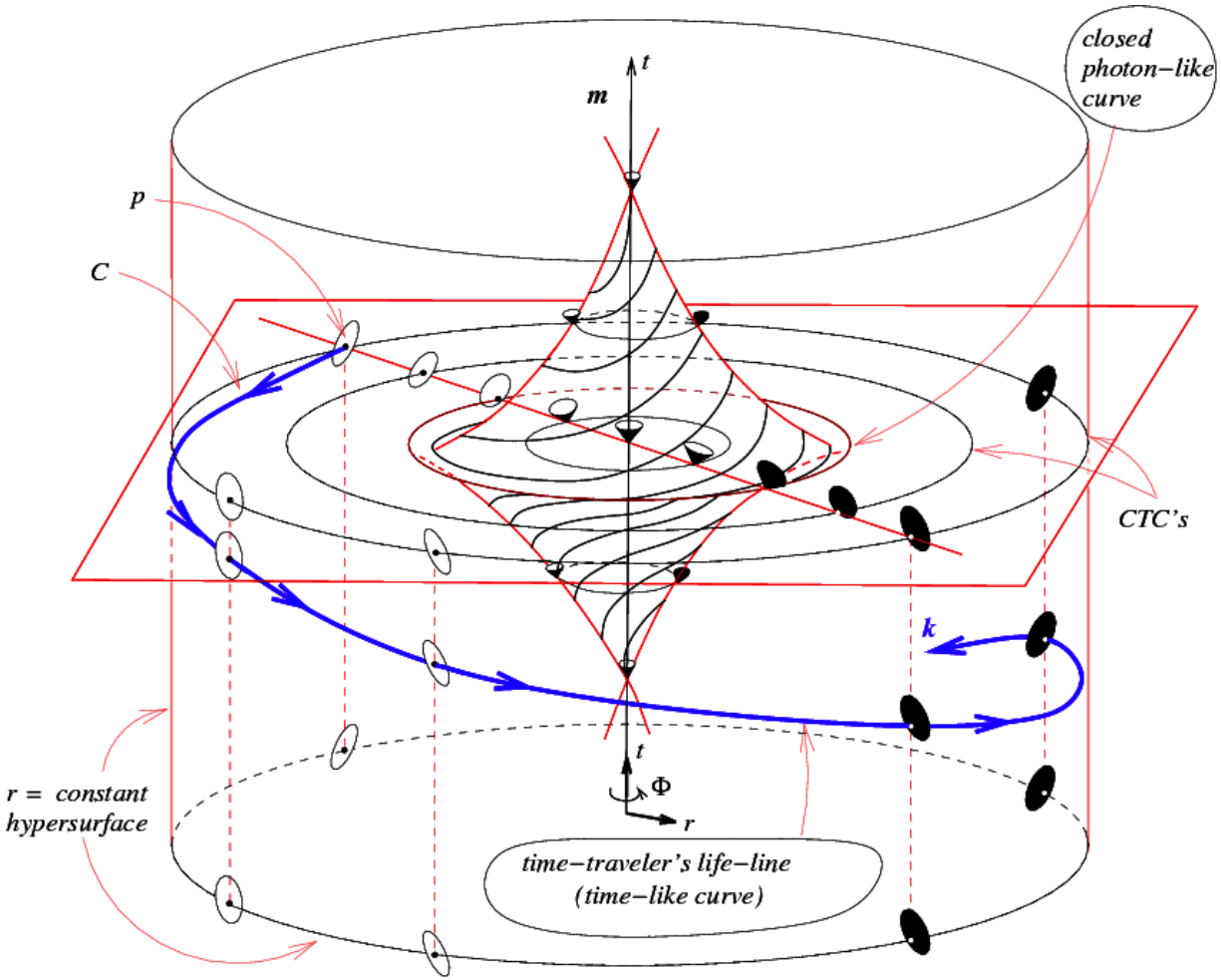
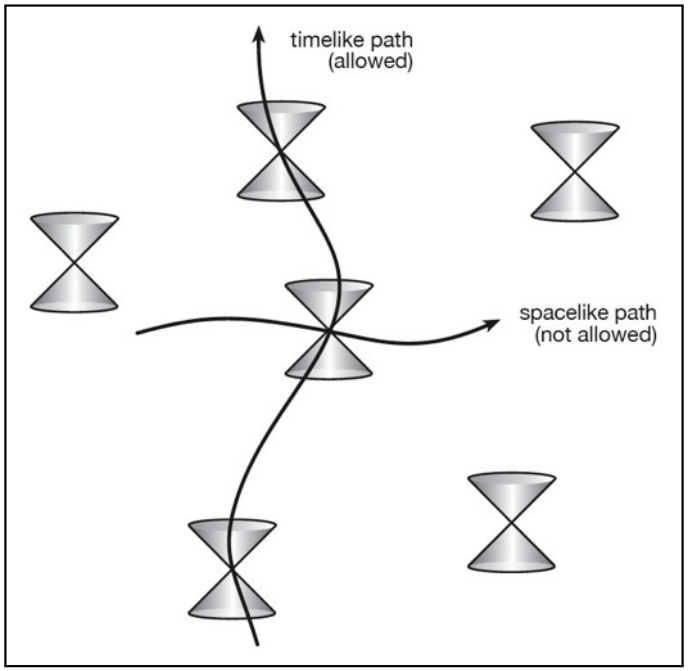
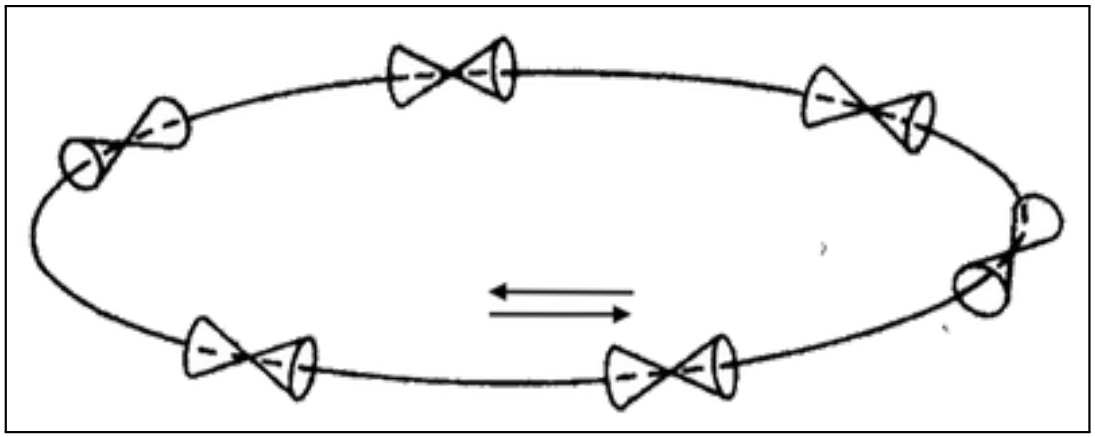
- Matter rotates about every point in space-time with constant angular velocity proportional to the square root of the matter density.
- The source for Gödel geometry is a perfect fluid with a constant density ρ and no pressure $p = 0$

$$ds^2 = (dt + e^{\sqrt{2}\Omega x/2} dy)^2 - dx^2 - \frac{1}{2} e^{\sqrt{2}\Omega x} dy^2 - dz^2$$



CTCs:





Closed time–like curve

In a closed time–like curve, the world-line of an object through space-time follows a curious path where it eventually returns to the exact same coordinates in space and time that it was at previously.

Gödel's CTCs:

- Gödel metric in cylidricall coordinates is

$$ds^2 = \frac{2}{\Omega^2}[dt^2 - dr^2 - dz^2 + (\sinh^4 r - \sinh^2 r)d\phi^2 + 2\sqrt{2}\sinh^2 r d\phi dt]$$

- If $dt = dz = dr = 0 \Rightarrow ds^2 = \frac{2}{\Omega^2}(\sinh^4 r - \sinh^2 r)d\phi^2$
- This curve is time–like if $\sinh^4 r - \sinh^2 r > 0$ and thus $r > \ln(\sqrt{2}+1)$
- **"Local" time–travel is not possible.** One has to exceed the closed null curve with $r > \ln(\sqrt{2}+1)$

CTCs in Gödel space-time are not geodesics

Kundt, W.: Trägheitsbahnen in einem von Gödel angegebenen kosmologichen Modell. Z. Phys. 145, 611–620 (1956) Chandrasekhar,

S., Wright, J.P.: The geodesics in Gödel's universe. Proc. Natl. Acad. Sci. USA 47,341–347 (1961)

The total integrated acceleration of any closed time–like curve must be at least $\ln(1+\sqrt{5})$

Malament, D.: Minimal acceleration requirements for 'time–travel' in Gödel space-time. J. Math. Phys.26, 774–777(1985)

Time travel

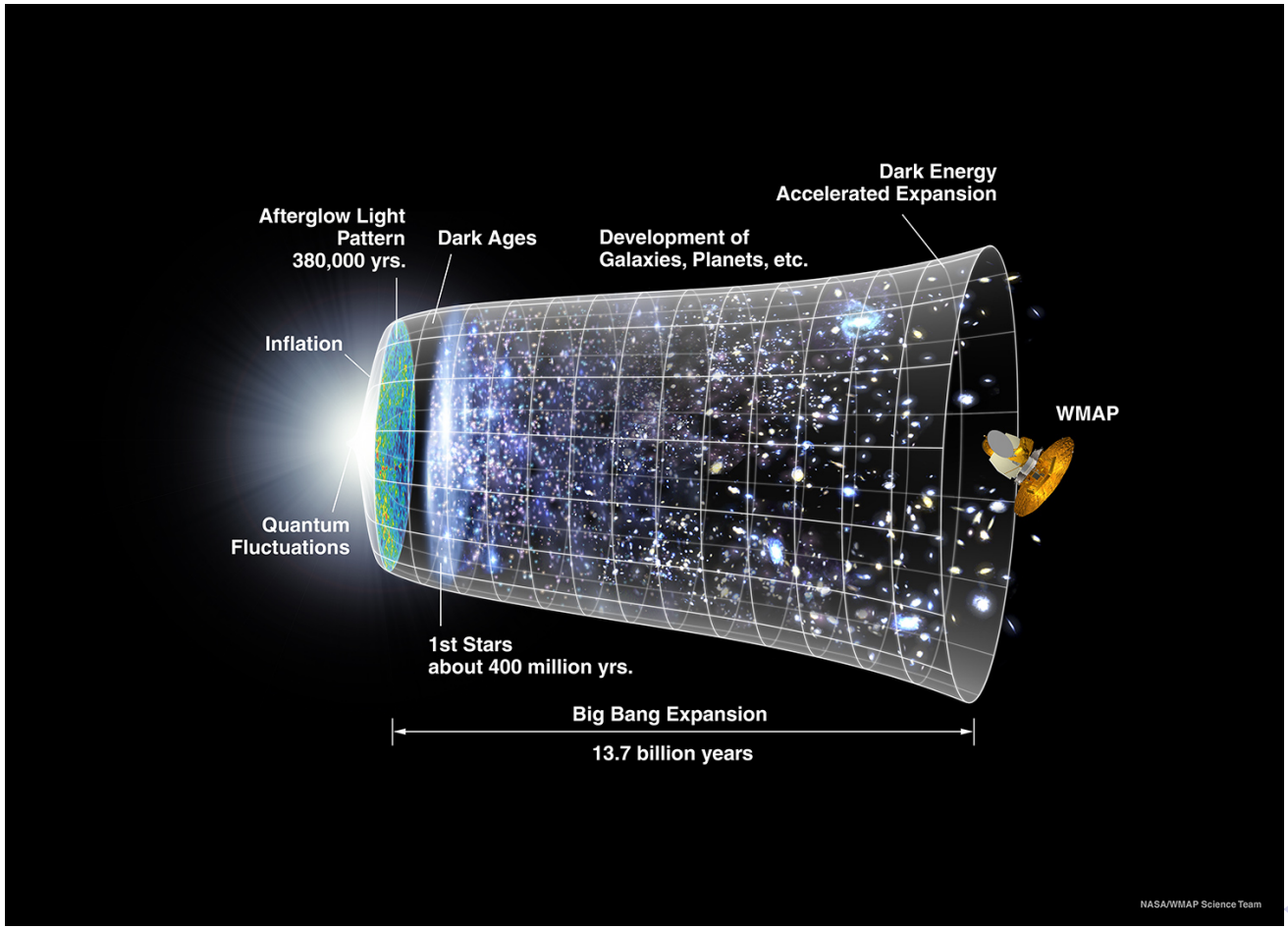
Is Time Traveling Possible in our Universe?

In order to be able to travel to the past, three conditions should be fulfilled:

1. Einstein's General Relativity is a valid description of the universe. **yes**
2. The Universe has a suitable structure probably incorporating sufficiently fast rotation. **Most probably no**
3. The practical difficulties can be overcome. **No way**, **ten billion years is not exactly an easy task.**

The Standard Model of Cosmology

There is no place for the origin of rotation in the Standard Model of Cosmology



Lets see if a cosmological phase transition could be a candidate for the origin of rotation

Cosmological Phase Transition:

Comparing covariant expression for the components of the energy–momentum tensor of a perfect fluid and the energy–momentum tensor of a scalar field makes it clear that a scalar field acts like a perfect fluid with an energy density and pressure given by

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) - \frac{1}{2}\left|\vec{\nabla}\phi\right|^2$$

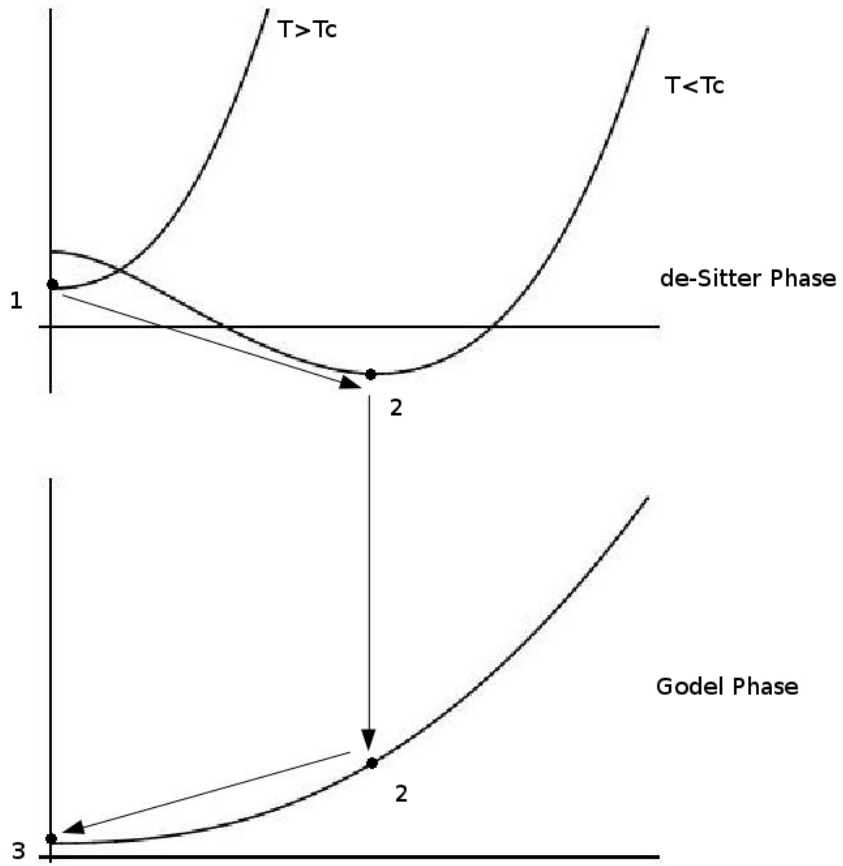
$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) + \frac{1}{2}\left|\vec{\nabla}\phi\right|^2$$

In the minimum of potential, $\dot{\phi}$ is negligible and $\vec{\nabla}\phi = 0$ provided that the field ϕ is spatially constant.

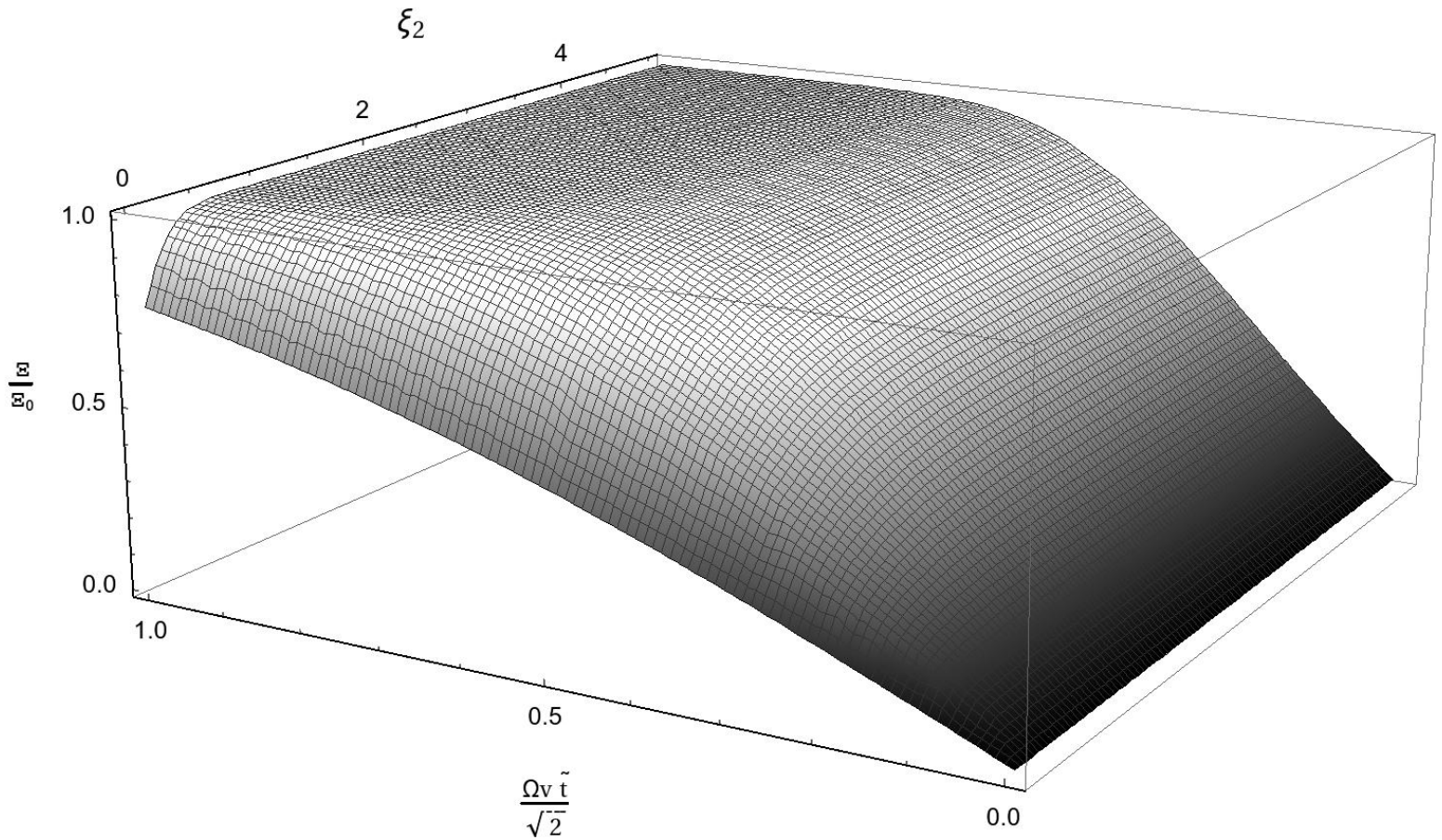
These assumptions yield an equation of state of $p_\phi = -\rho_\phi$, thus $V(\phi)$ acts as an effective cosmological constant.

A proposed Scenario(to appear in PRD):

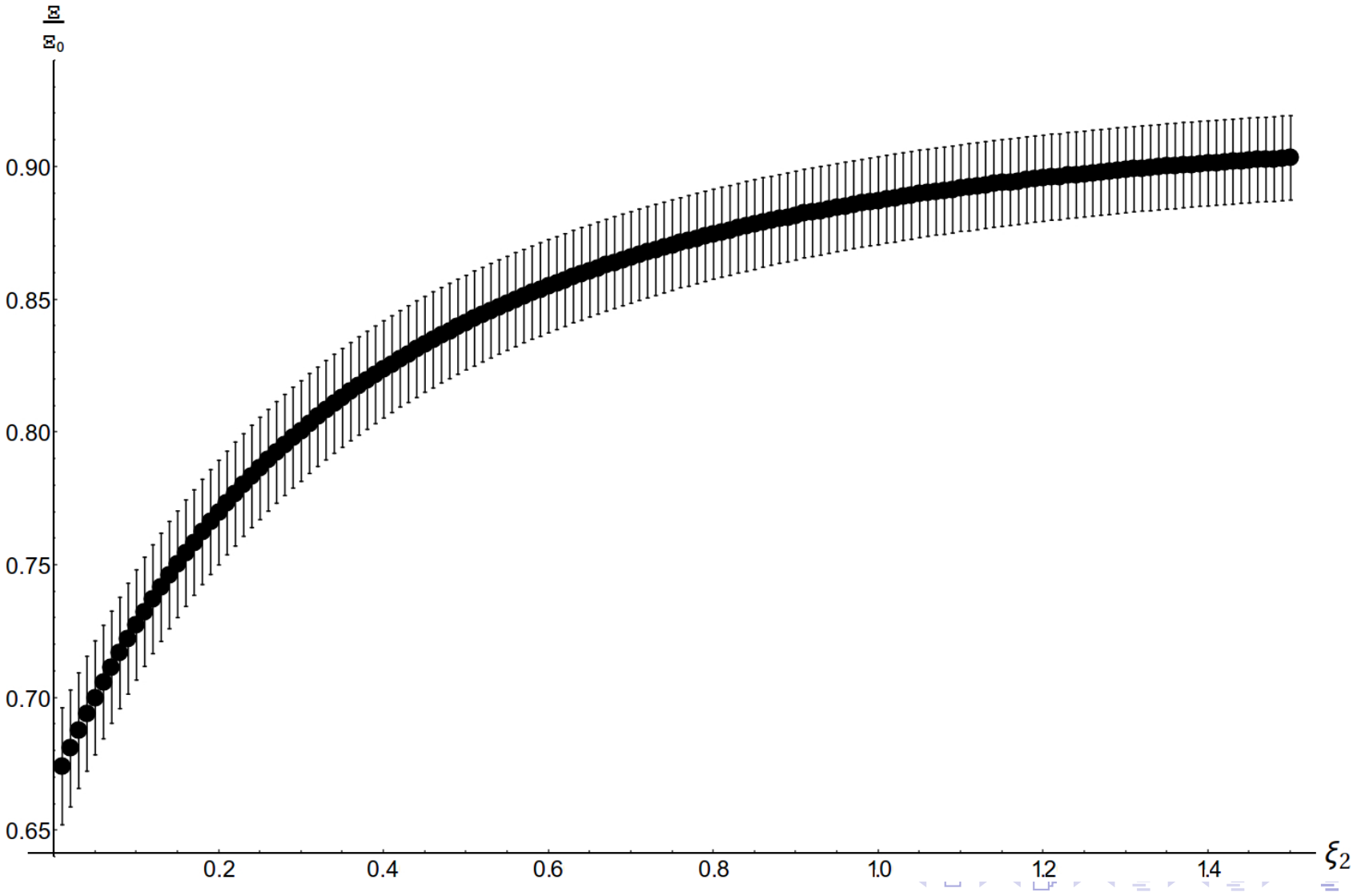
1. First, V_{eff} acts like a positive cosmological constant which is much larger than the dust density ($V_{\text{eff}} \gg \rho_{\text{dust}}$) leading to de-Sitter space-time.
2. Second, V_{eff} plays the role of a negative cosmological constant and equal to $-\rho_{\text{dust}}/2$ to have Gödel space-time.
3. Finally the scalar field should roll such that the universe arrives at de-Sitter space-time again.



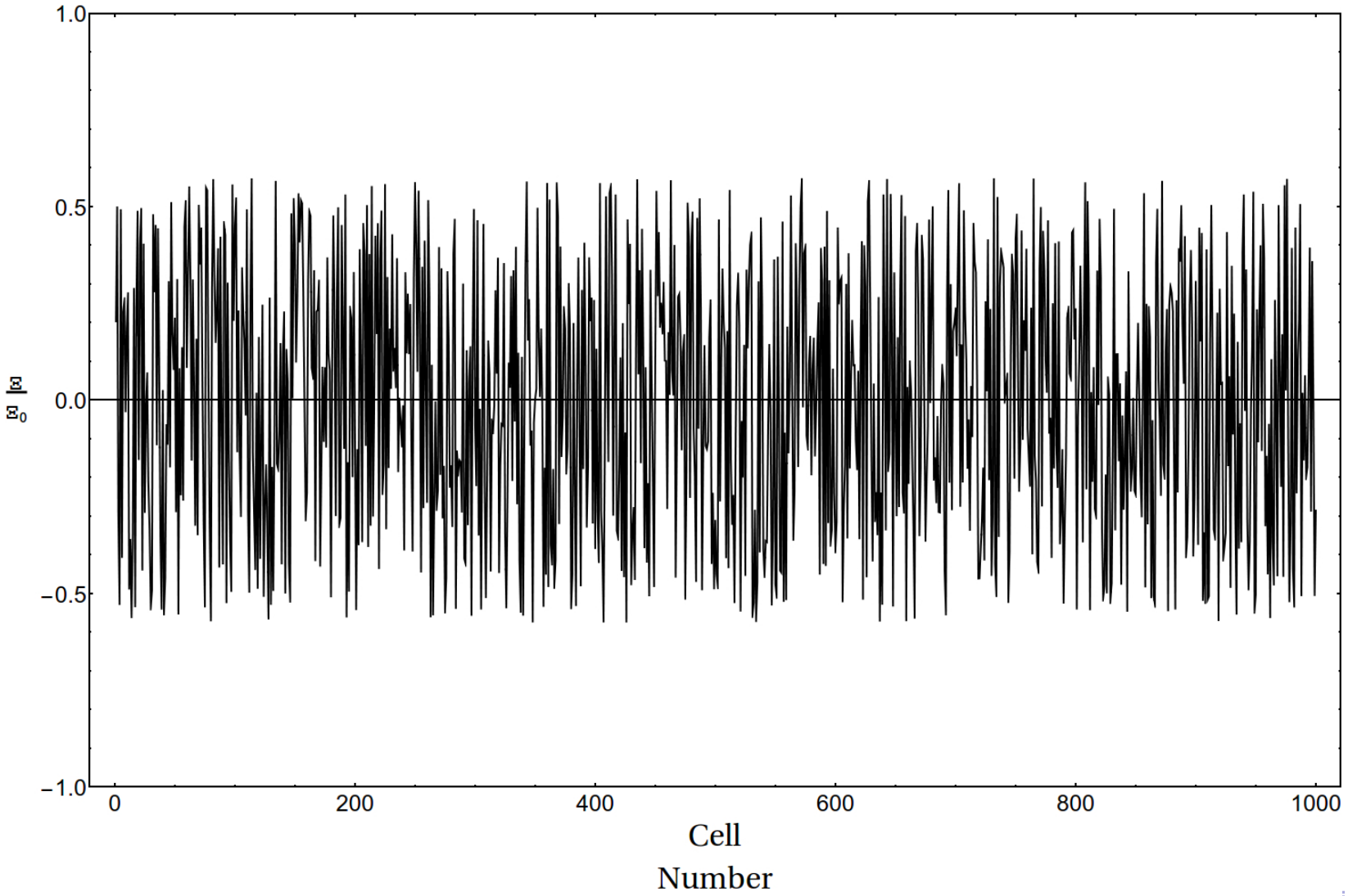
Induced rotation profile

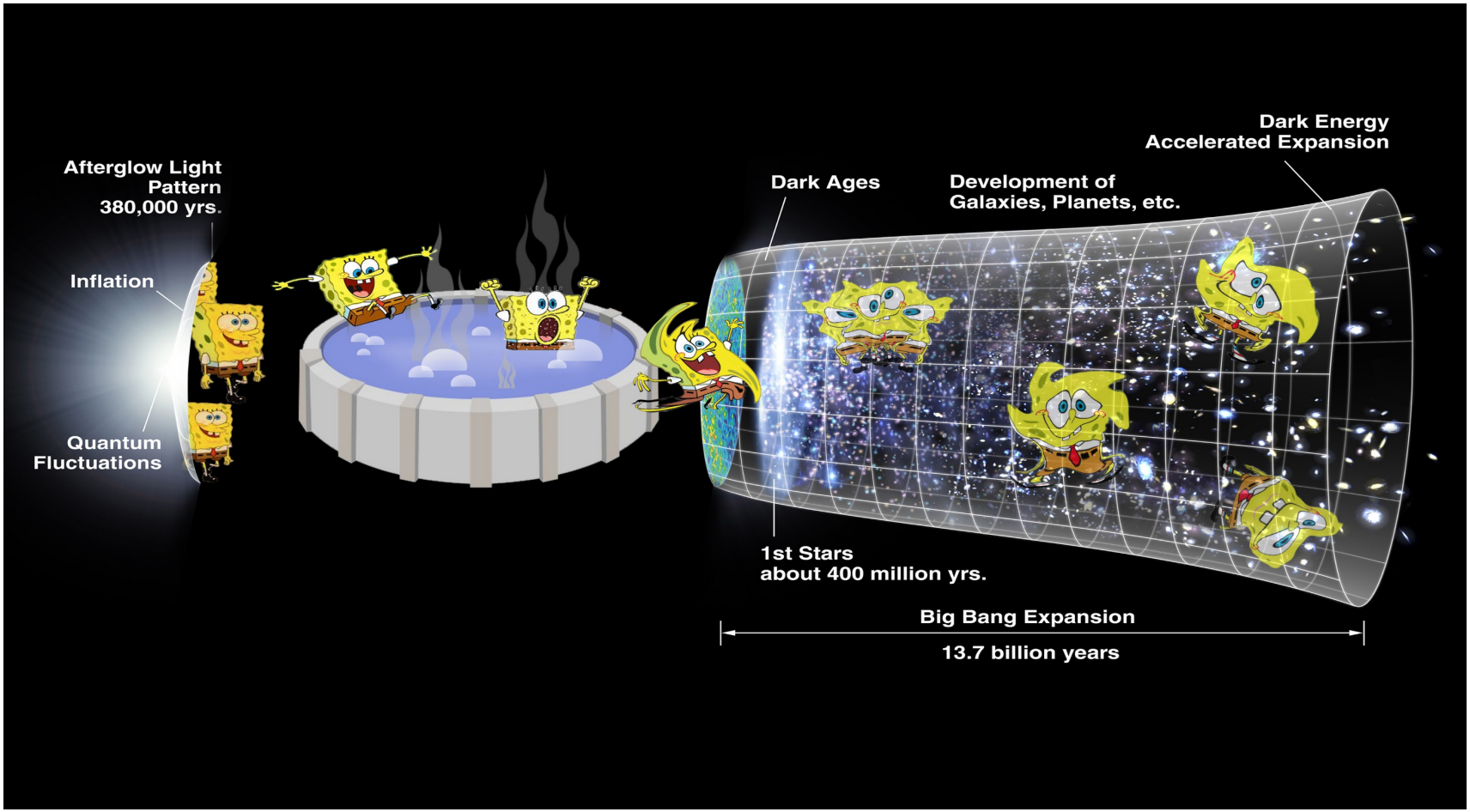


Induced rotation for a local congruence of particles



Computer simulation of the global induced rotation




Afterglow Light Pattern 380,000 yrs.
Inflation
Quantum Fluctuations
Dark Ages
Development of Galaxies, Planets, etc.
Dark Energy Accelerated Expansion
1st Stars about 400 million yrs.
Big Bang Expansion
13.7 billion years

Summary

The origin of rotation

Rotation is essential for the stability of celestial bodies and its origin is an important issue in cosmology. There are number of ways in which physicists have tried to justify how the rotation has been started in the universe, but non of them is the final solution to the problem.

Gödel universe

Following Gödel, we can interpret the dust particles as galaxies, so that the Gödel solution becomes a cosmological model of a rotating universe. Besides rotating, this model exhibits no Hubble expansion, so it is not a realistic model of the universe in which we live.
But still we can use the Gödel metric in our General Relativity computations.

J. Ellis and K. A. Olive, Nature 303, 23 (1983):

Inflation model: exponential expansion of the universe dampens out any initial rotation

Cosmological phase transition

A de-Sitter–Gödel–de-Sitter phase transition can provide a scenario which explains the origin of rotation in the framework of the standard model of cosmology. Such a scenario may be possible in the framework of the standard model of cosmology. The model may be extended to other space–times and fields (like vector, spinor and tensor fields) to get closer to an exact enough expression for the universal rotation.

Q: How many general-relativity theoreticians does it take to change a light bulb?

A: Two. One to hold the bulb and one to rotate space!

*********Thank You*********