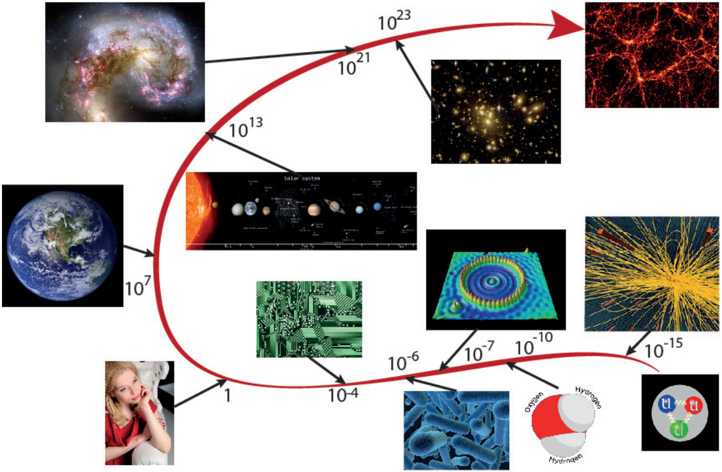
The mysterious beginnings of Everything

Kasia Rejzner

27.01.2016

Life, the Universe and Everything



1 Large
- Spacetime in special relativity
- Spacetime in general relativity

2 Small

3 Everything

Physics at high velocities

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- Special relativity is a theory proposed in 1905 by Albert Einstein in the paper *On the Electrodynamics of Moving Bodies*.
- As the name of the paper suggest, the motivation was to make Electrodynamics compatible with Mechanics. This turned out to be impossible within Newton's theory.

Universe at large scales

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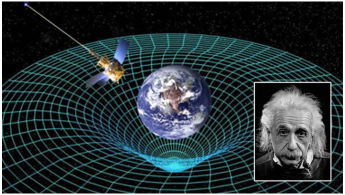

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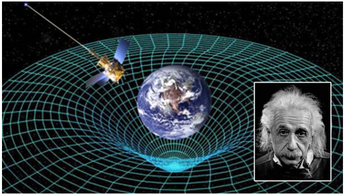

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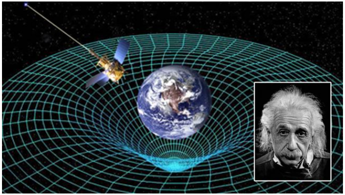

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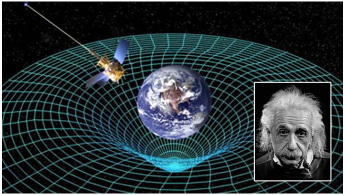
- The structure of spacetime influences the motion of observers.
- Moreover, spacetime *itself* is dynamical and subject to certain equations (Einstein's equations).



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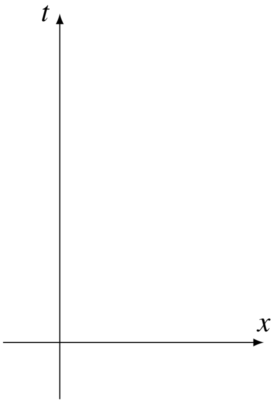

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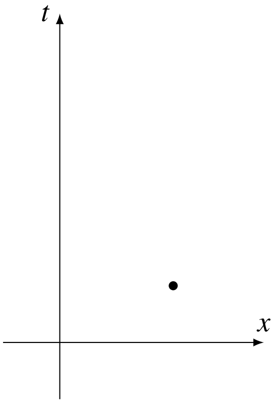

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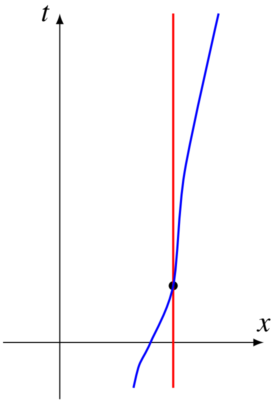

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- Wether we move or stand still, we can describe our position in space and time by drawing a curve in the spacetime diagram.

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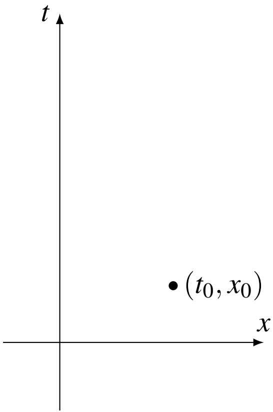

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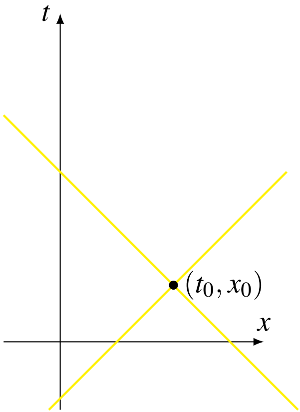

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- On the spacetime diagram, we can draw at each point two lines (a cone) representing $|x - x_0| = |t - t_0|$, which limits the region of spacetime accessible from that point. This object is called the lightcone with apex (t_0, x_0).

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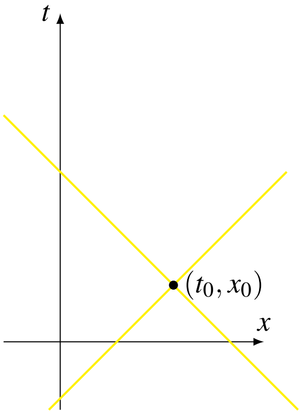

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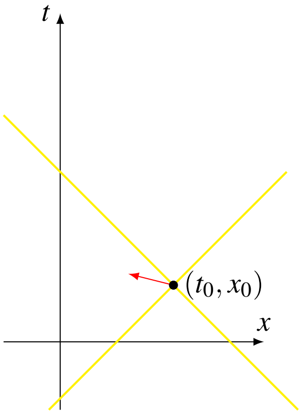

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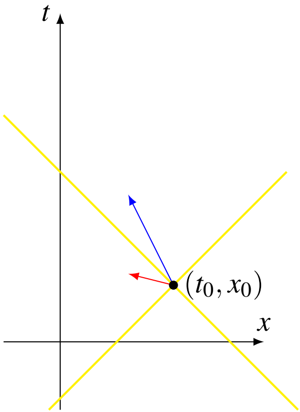

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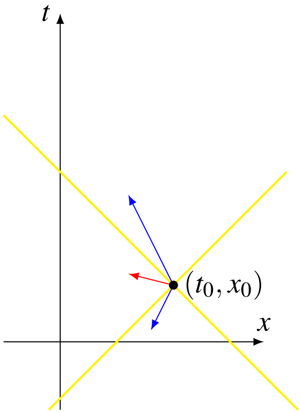

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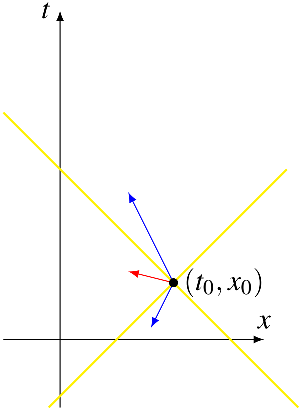

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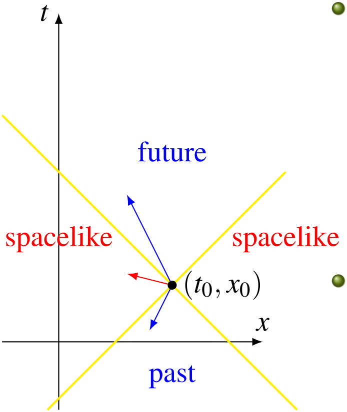

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- This way we divide the spacetime into regions that are in the future of (t_0, x_0), in its past, or are spacelike to (t_0, x_0).

Space and time

- To summarize: in special relativity at each point (t_0, x_0) the lighcone is described by the equation $|x - x_0| = |t - t_0|$, or equivalently $(t - t_0)^2 - (x - x_0)^2 = 0$.

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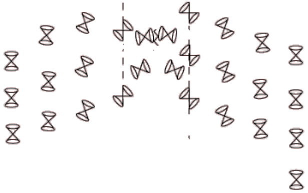

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- in general relativity we want to keep the idea of the lightcone, but the equation describing the lighcone changes from point to point. Lighcones at different points can be tilted and twisted, so observers at different points have different ideas what is future, past or spacelike.

Mathematical description of spacetime

- In our toy model the spacetime is 2 dimensional and is simply $\mathbb{R}^2$ (the plane). Directions are described by 2-dimensional vectors, which are represented as columns of numbers: $\vec{v} = \begin{pmatrix} v_0 \\ v_1 \end{pmatrix}$ and we denote $\vec{v}^T = \begin{pmatrix} v_0 & v_1 \end{pmatrix}$.

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- This has a geometrical interpretation in terms of the Minkowski metric, which is (in our example) a 2 by 2 matrix $g = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$, so that $\vec{v}^T g \vec{v} = v_0^2 - v_1^2$.

Mathematical description of spacetime

- In 4 dimensions (1 time+3 space) the Minkowski metric is
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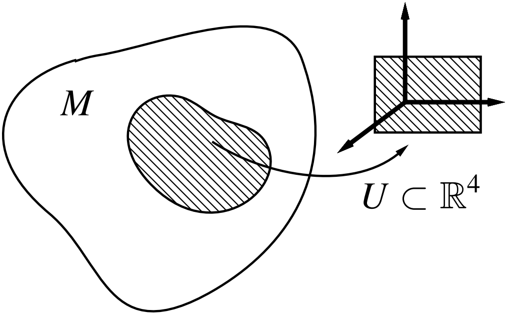
- $\mathbb{M} = (\mathbb{R}^4, g)$ is called the 4-dimensional Minkowski spacetime.
- In spacial relativity (SR), $\mathbb{M}$ is the model of space and time.

Spacetime in general relativity

- In general relativity we replace $\mathbb{R}^4$ with a mathematical structure called a manifold and denoted by M. Locally, i.e. sufficeintly close to each point $P = (t_0, x_0)$, M looks like $\mathbb{R}^4$.



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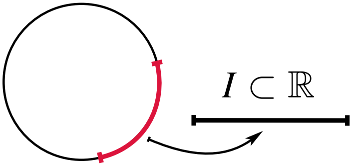
- Simple example of a manifold: a circle. Pieces of a circle look like intervals (pieces of $\mathbb{R}$), so a circle is locally behaving like $\mathbb{R}$.



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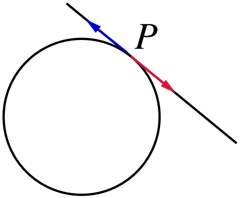

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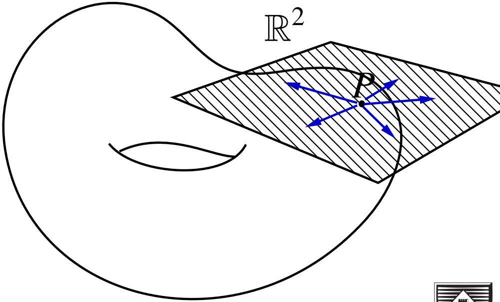

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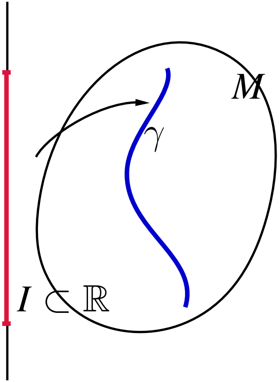
- Again, a direction $\vec{v}_P$ can be spacelike, timelike or lightlike, depending on the value of $\vec{v}_P^T\, g_P\, \vec{v}_P$.
- At each point we can draw a small lightcone, defined by the equation $\vec{v}_P^T\, g_P\, \vec{v}_P = 0$.

Classifications of curves

- A curve $\gamma : \mathbb{R} \supset I \to M$ is

  where $\dot{\gamma}$ denotes the tangent vector.



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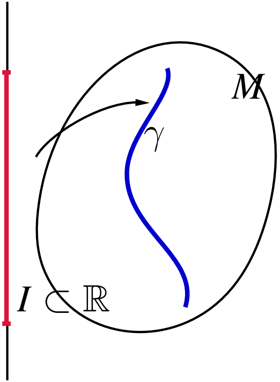

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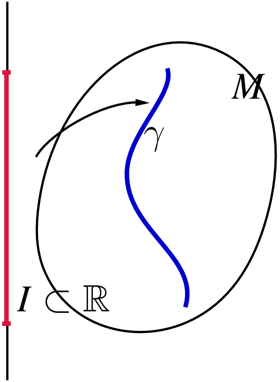

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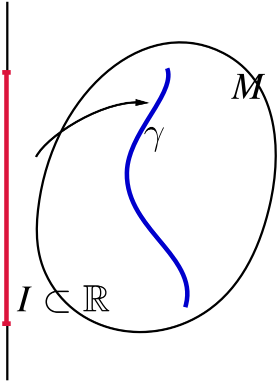

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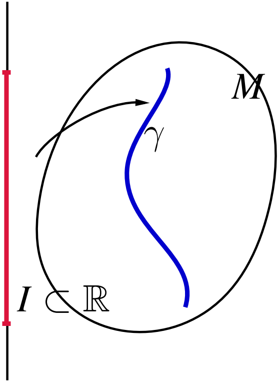

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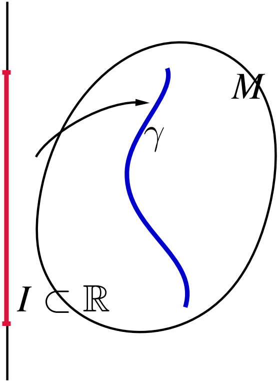
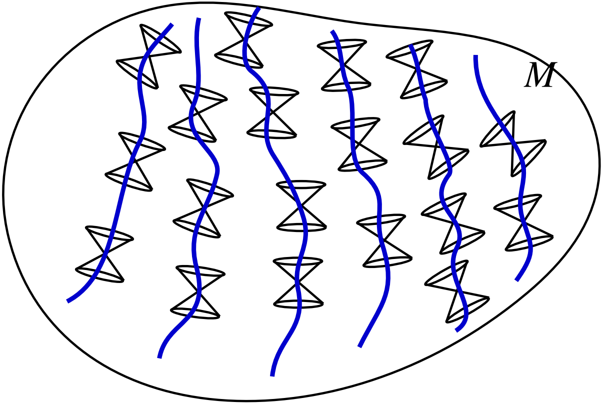


An important principle of general relativity states that observers can move only on timelike curves, so the causal structure given by the metric “tells particles where to go”.

Timelike curves in GR



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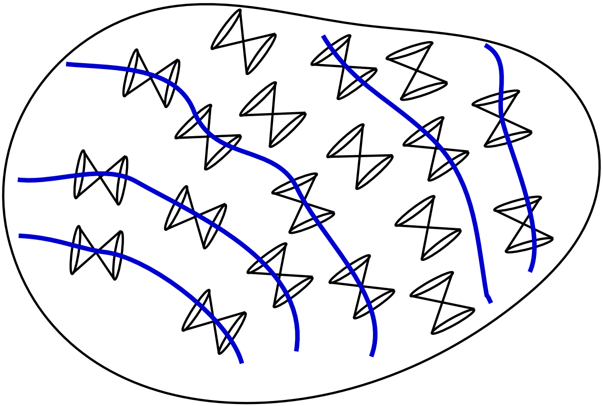

How matter influences the spacetime

- The dynamics of spacetime and matter is given by the Einstein's equations:
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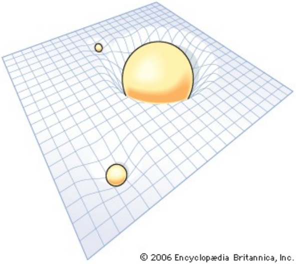

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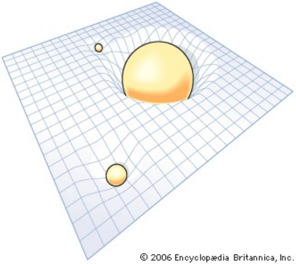

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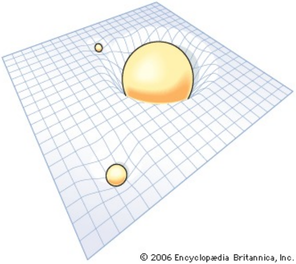

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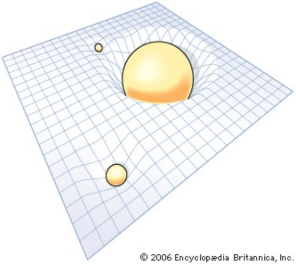

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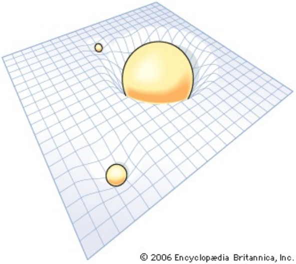
- G is the gravitational constant and c is the speed of light.
- The change of spacetime influances the matter, but also change of the matter influences the curvature of spacetime!



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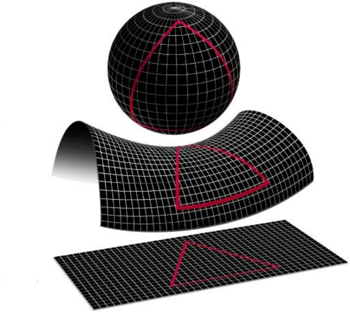

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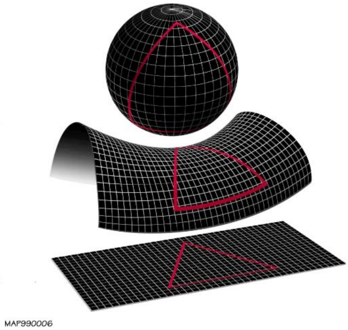

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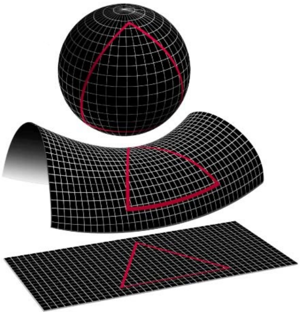

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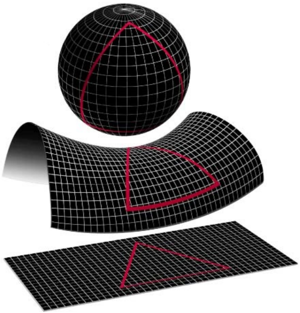
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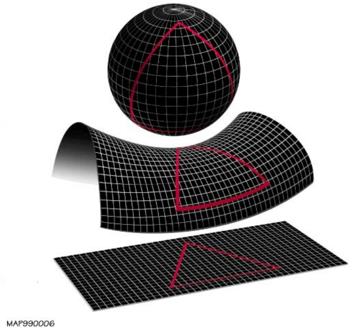

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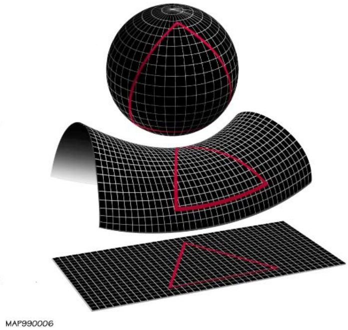

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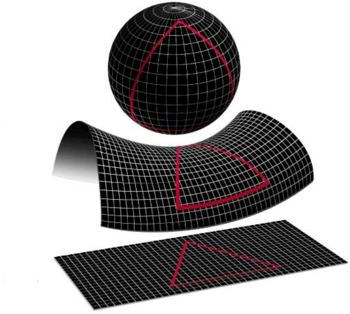
- The metric is (in block diagonal form) $g(t, \underline{x}) = \begin{pmatrix} 1 & 0 \\ 0 & -a(t)^2 h(\underline{x}) \end{pmatrix}$, where h is the standard metric on Σ, and a is a smooth positive function on I.



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   - Spacetime in general relativity
2. Small
3. Everything

Universe at small scales

- How does a particle physicist learns how things work?

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- Works with vases and protons, but doesn't quite work with Universes...

Quantum Field Theory

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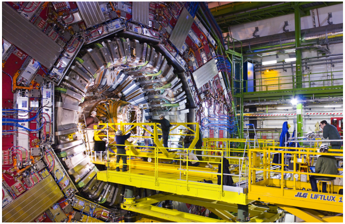

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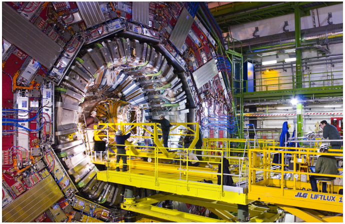

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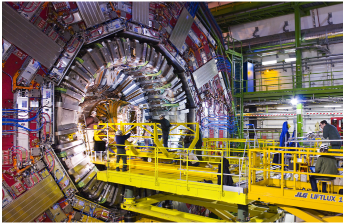

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- What happened at the very beginning of the Universe is quite mysterious.

The Answer to the Ultimate Question of Life, The Universe, and Everything is...

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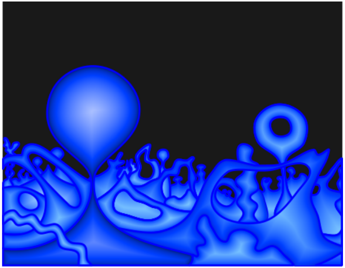

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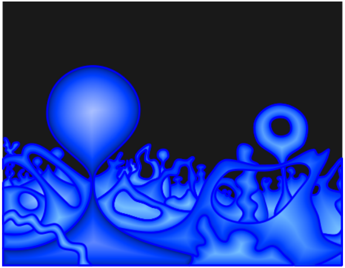

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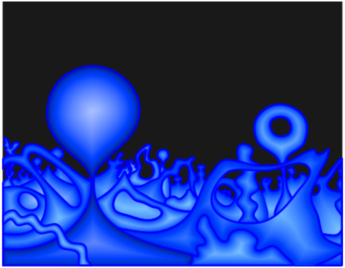

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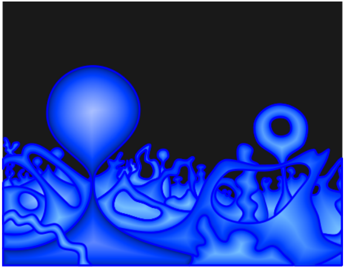

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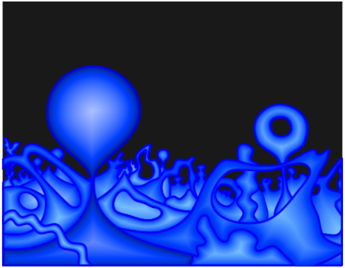

Possible approaches

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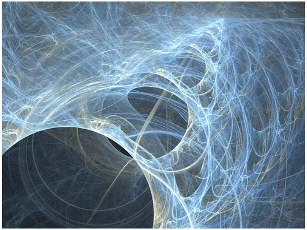

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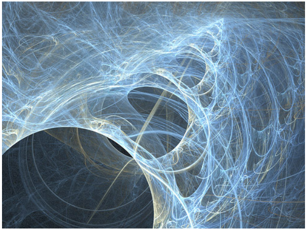

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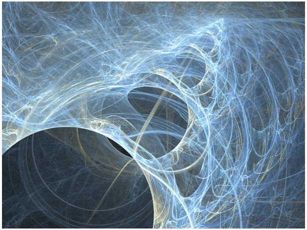

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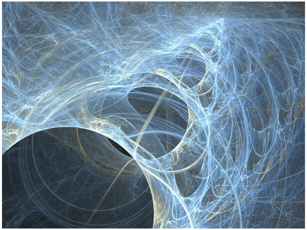
- Instead of a Theory of Everything we want a Theory of Something…



Take one: QFT on curved spacetimes

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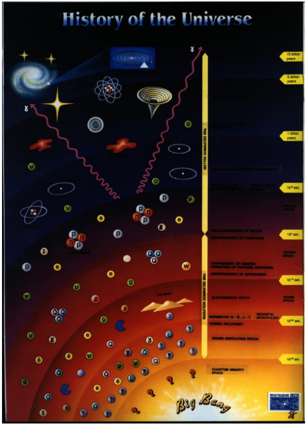

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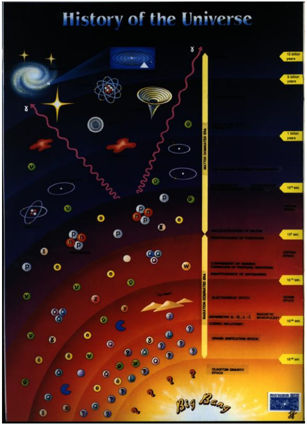

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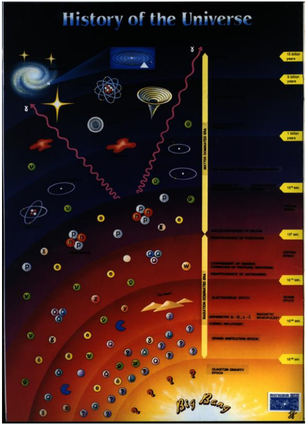

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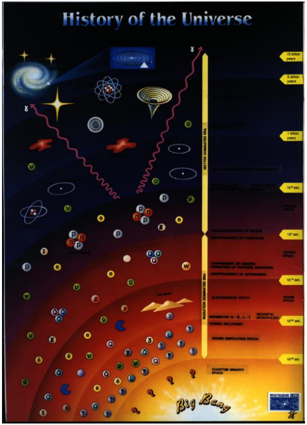

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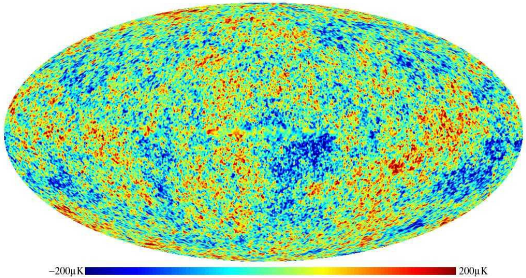
- Already in this approximation one can study phenomena like inflation and try to explain fluctuations of the cosmic microwave background (CMB) radiation.



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- CMB carries information about how the Universe looked like when it exited the inflation phase.

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- Can we see signatures of quantum gravity in CMB or elsewhere?

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- We are getting one more step closer to the beginning of the Universe and Everything...

Some literature

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Thank you for your attention!