Before the Big Bang? Penrose's Conformal Cyclic Cosmology

Pawel Nurowski

Center for Theoretical Physics
Polish Academy of Sciences
and
Guangdong Technion
Israel Institute of Technology

Nara Women's University
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Two fundamental facts about observational cosmology

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- Our Universe **had beginning**.This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. The main observational **parameter deciding about the nature of this expansion** is called the **cosmological constant**. Observations show, that this constant is very small but nonzero and **positive**. This in particular means that the Universe **will expand forever**.

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Copernican principle

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- Universe is the same **everywhere in space** (Copernicus) and is the same **in every direction** (Friedman/ Lemaître/ Robertson/ Walker).
- To get **possible models of the Universe compatible with these assumptions** Friedman used **Einstein's equations** of General Relativity Theory.
- He assumed that the **cosmological constant is zero** and has shown that there are **only three possibilities**.

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Friedman: three possible cosmologies satisfying Copernican principle

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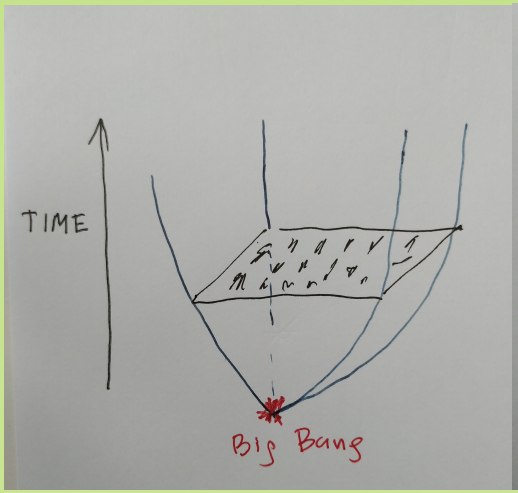
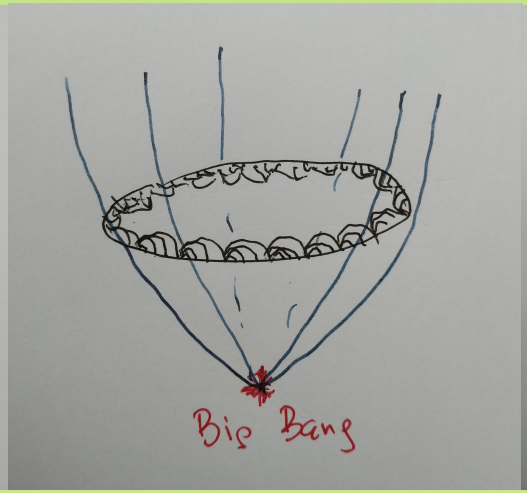


$K = 0$



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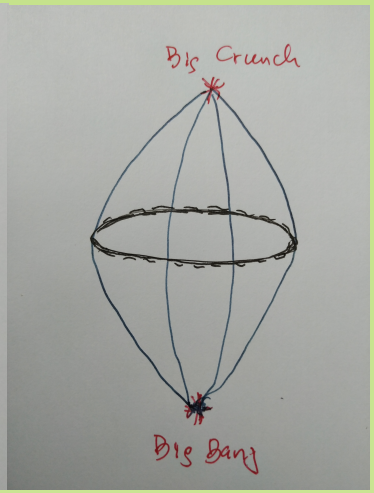

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Friedman: three models of cosmology satisfying Copernican principle

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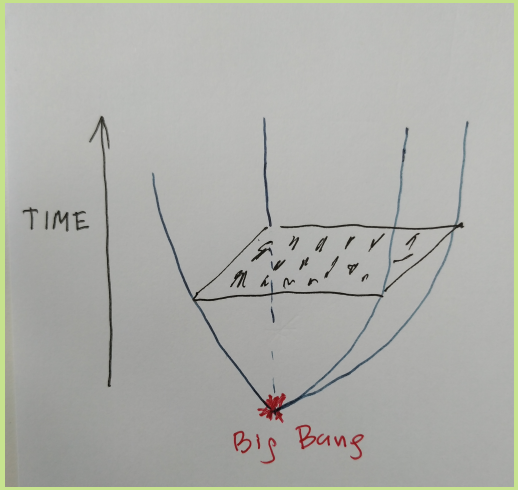

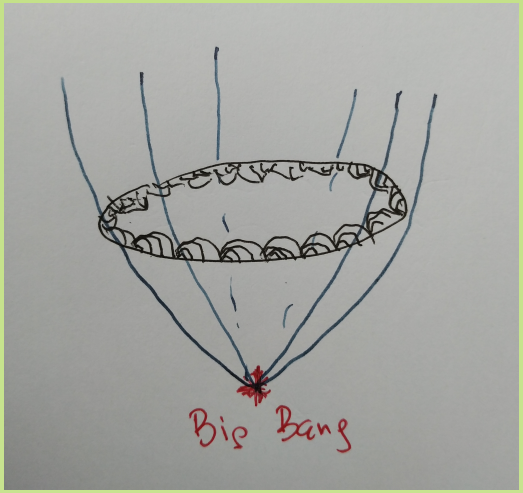

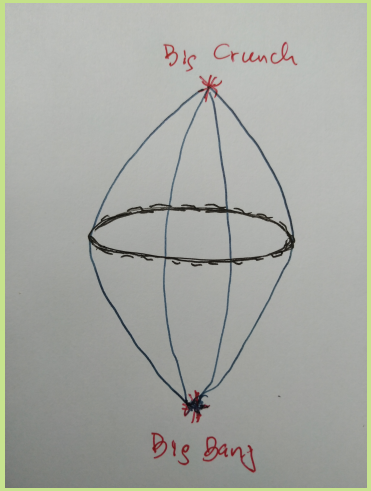

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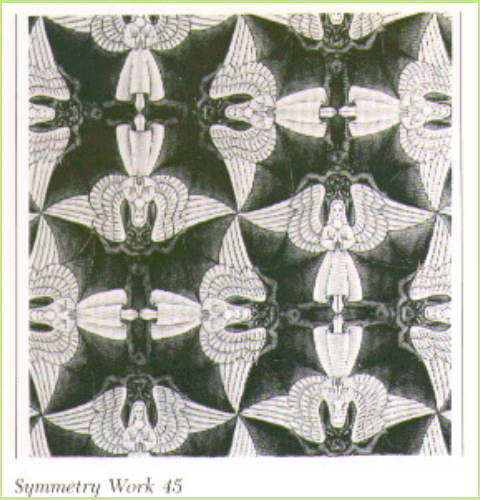
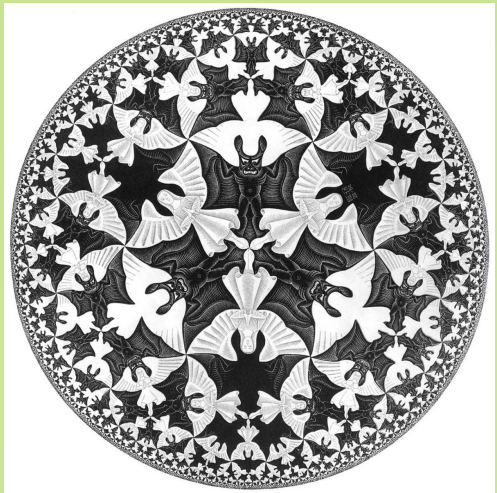
Three types of Riemannian geometries:





If there is a positive cosmological cosntant the picture is a bit different

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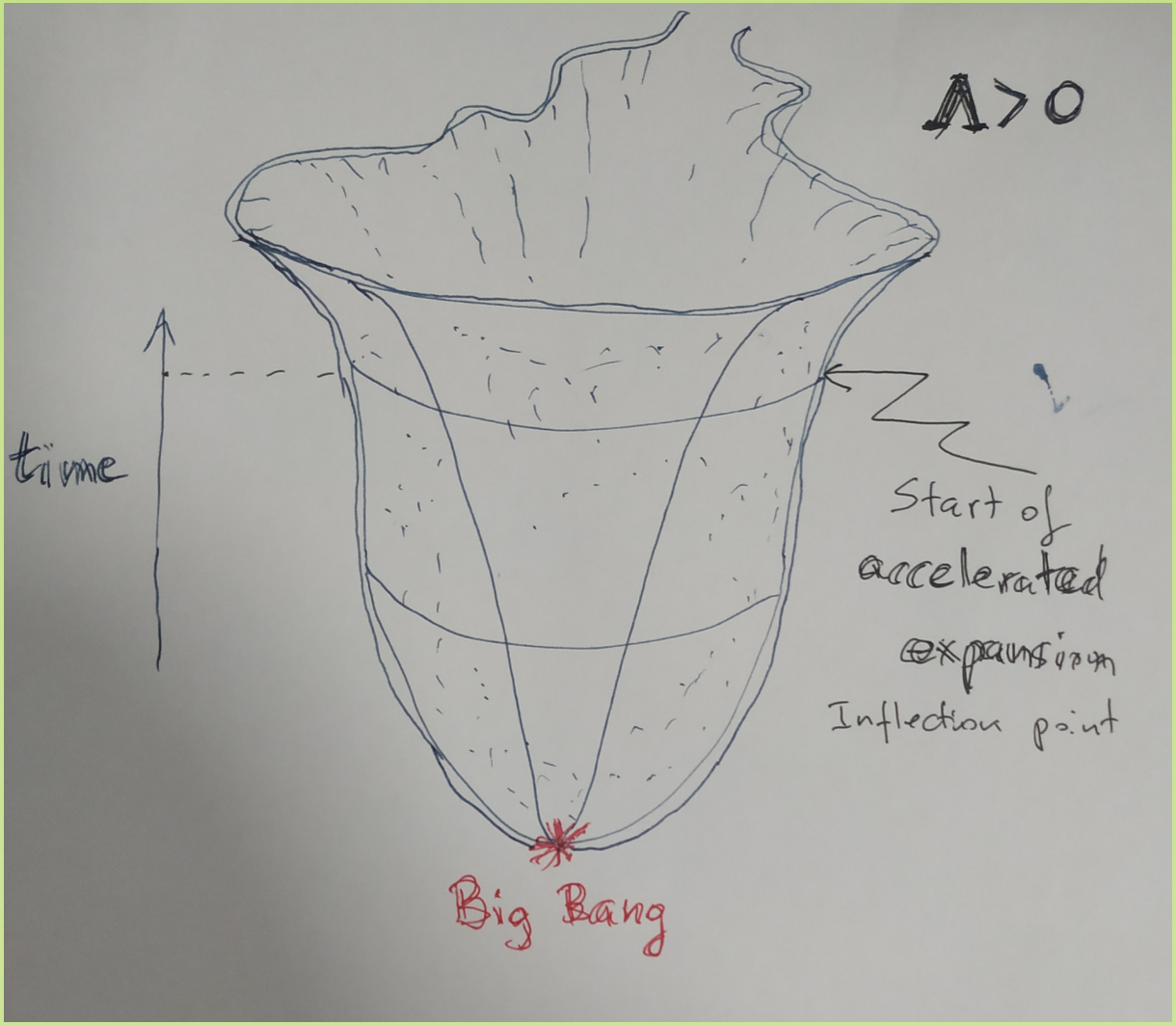

These standard models Universe have a number of difficulties

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I will mention only one. This is related to the **Second Law of Thermodynamics**.

- A closed physical **system evolves** in a way such that it is more and **more random**. Physicists have a notion that measures this randomness. It is called **entropy**.
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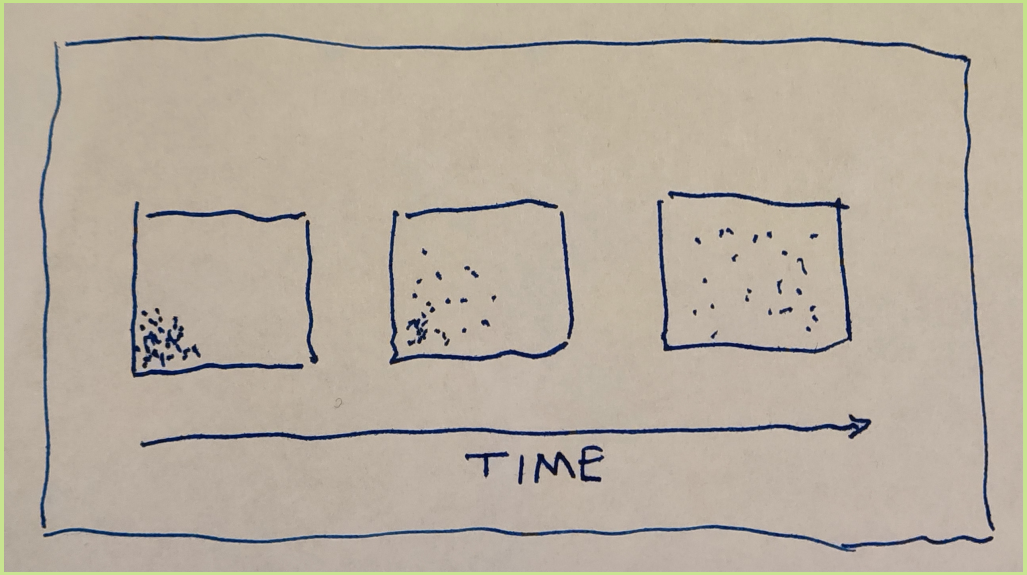

- For example, **a gas compressed to a small volume in a corner of a box** will evolve from this very special configuration, and **after some time will be** in a stage in which **all its particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

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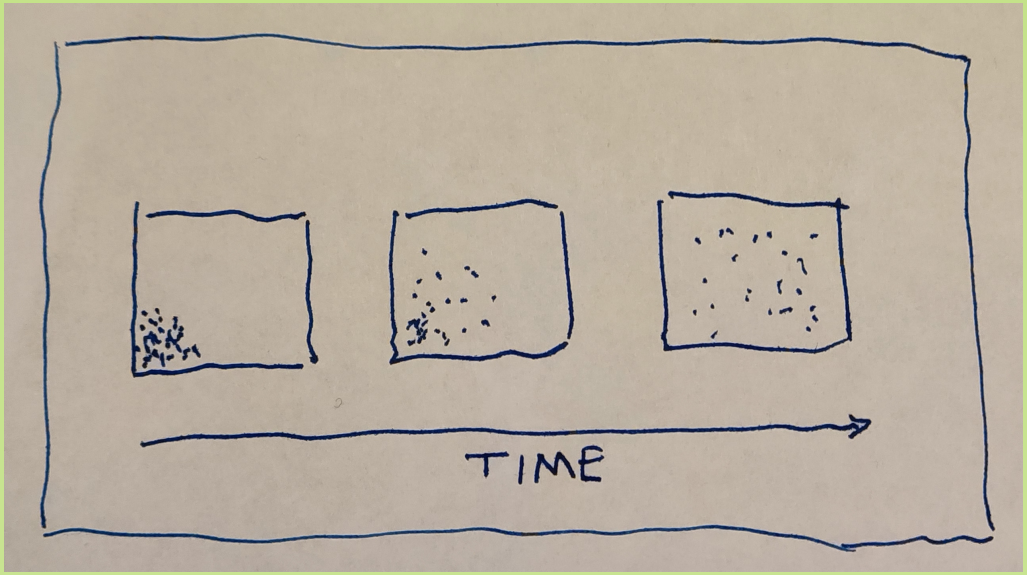

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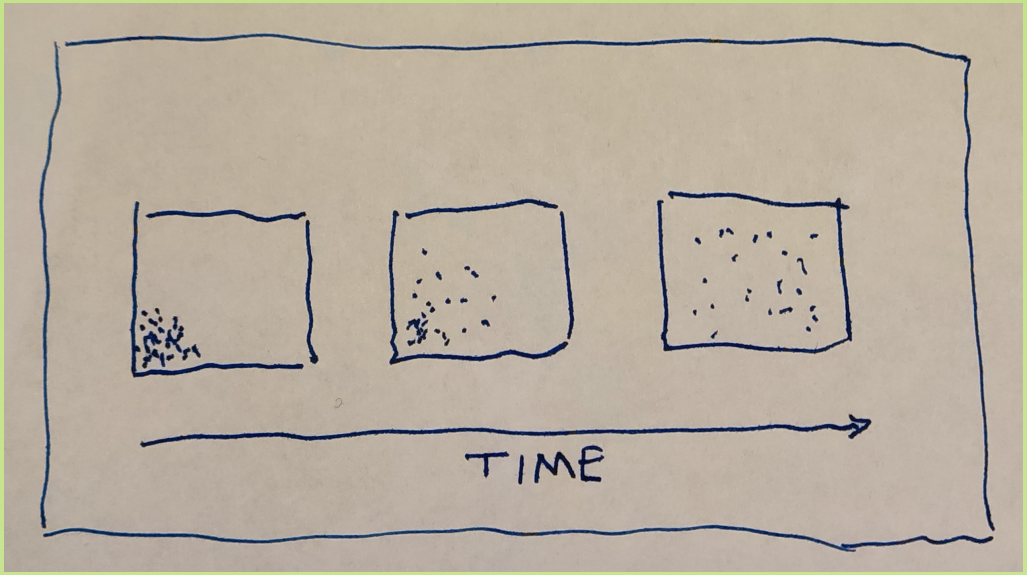

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- Applying the Second Law to the **Universe**, we conclude that it should be more and **more random the older it is**. Going **back in time, it should be** more and **more special**.
- But looking at the earliest 'photograph' of the Universe - the distribution of the temperature of the **Cosmic Microwave Background Radiation** on the Sky - we see that this distribution is **extremly homogeneous**.
- As, **at the begining**, the Universe was **in** the totally random **stage of maximal entropy**.

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- Another possibility is, a bit strange, since the Universe is everything we have, but one can **try to explain** speciality of the initial stage of the Universe by this what has happened **before the Big Bang**.
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Norway grants

How to make a model of pre-Big Bang Universe?

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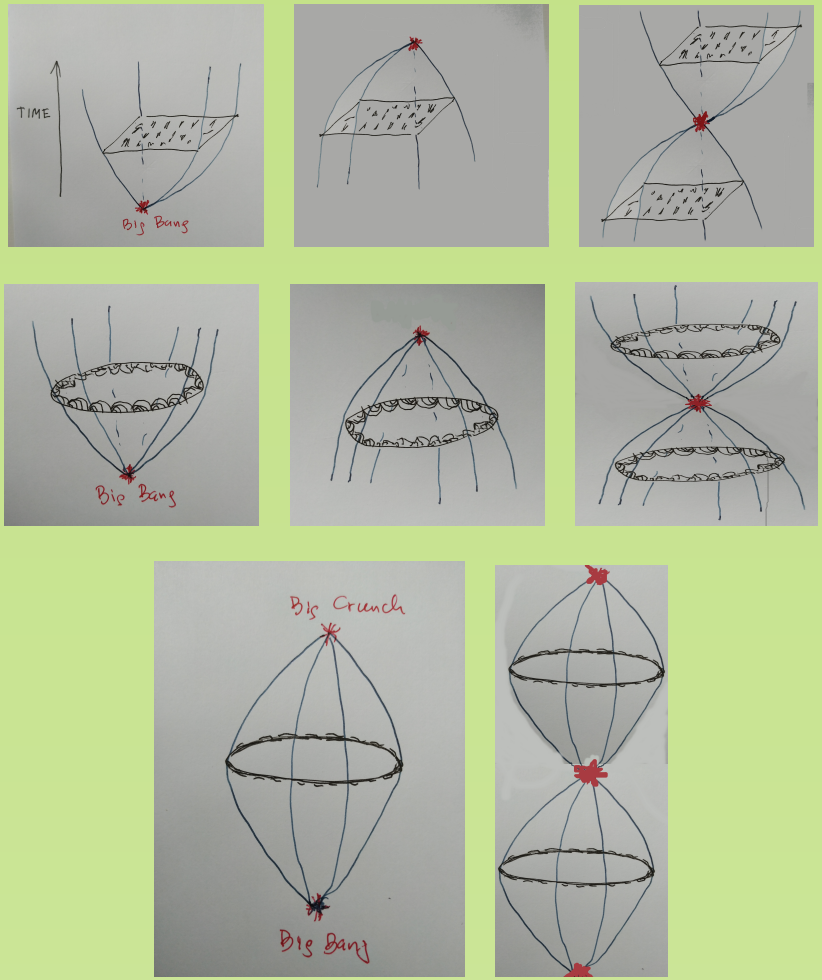

This does not work in the real Universe!

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- There is **gravity** in the real Universe, and it initiates proces of **clamping of matter**, first in **stars**, then **galaxies**, and eventually in **black holes**. Black holes create **essential singularities** in the Universe. Recently **Penrose** got the Nobel Prize in Physics for **proving that such objects will be created in spacetime** practically **in any reasonable theory of gravity**.
- So the **real Universe** is filled with plenty of **black holes**.
- Reversing the time in the Universe filled with black holes, would produce a **horrible** Big Crunch singularity!

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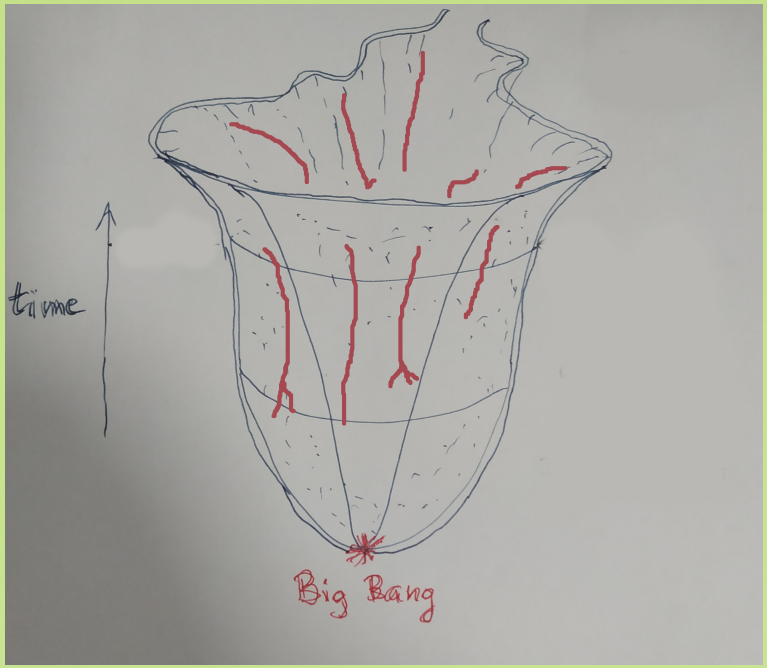

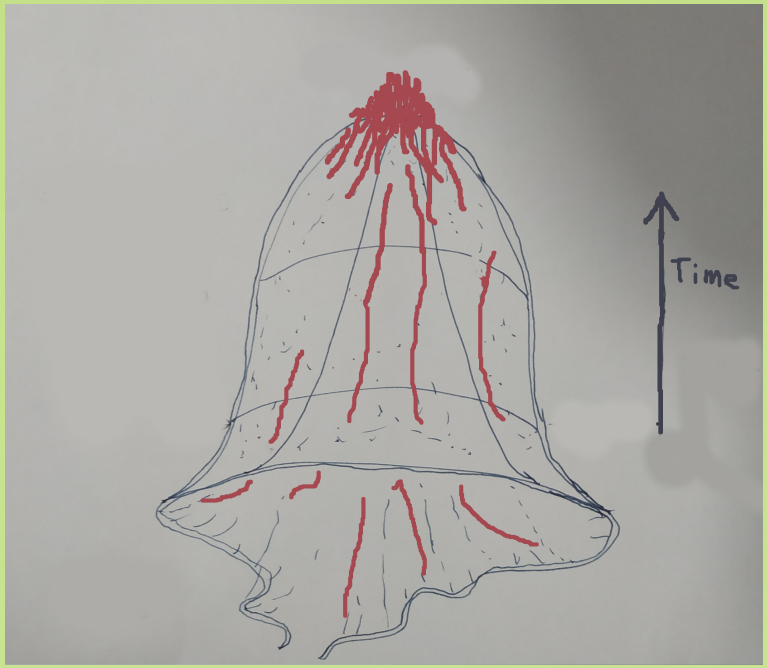

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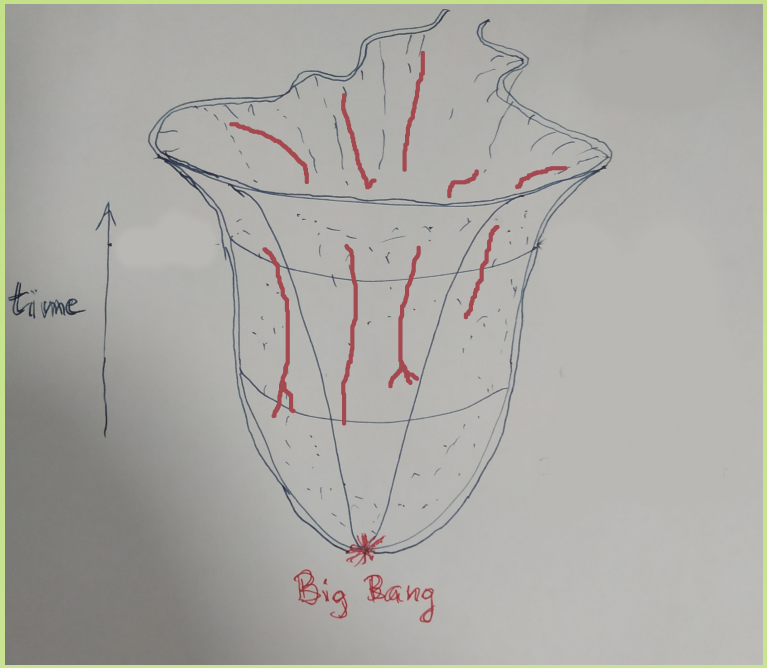

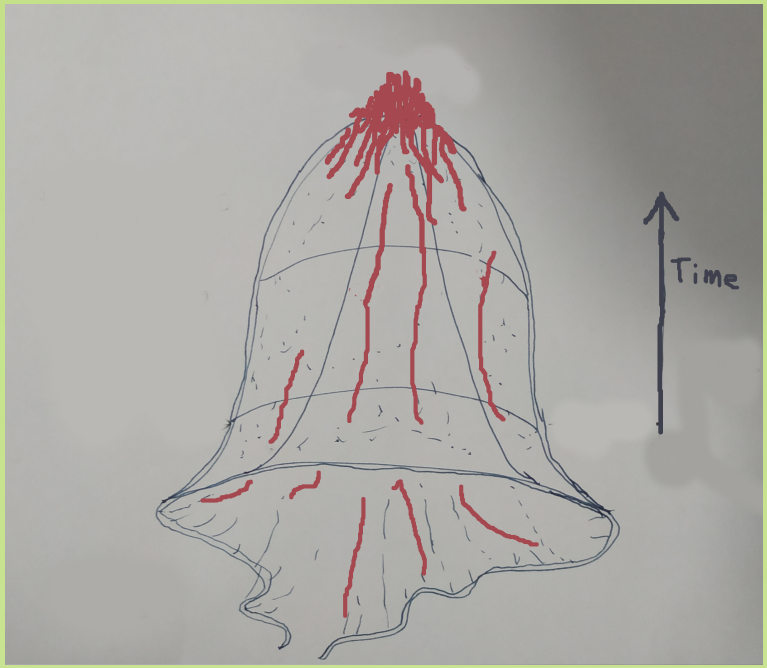

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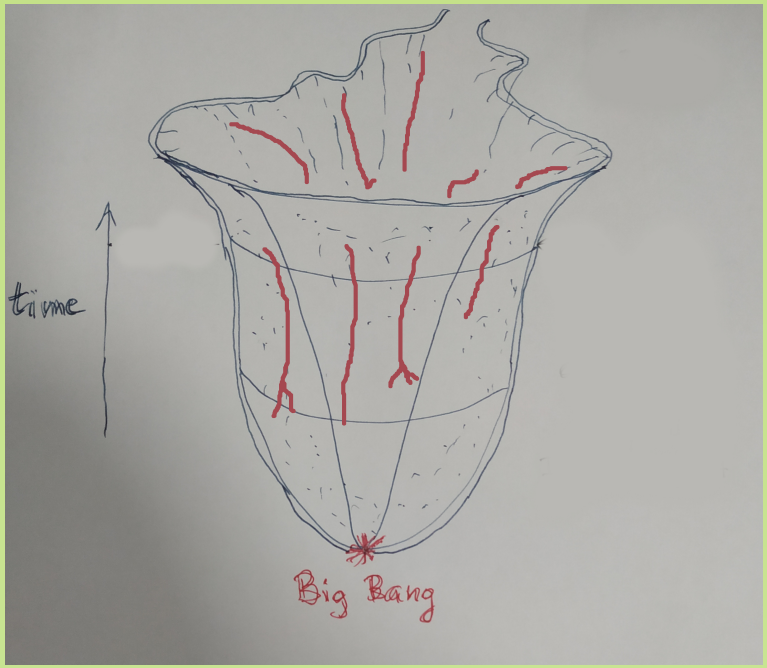

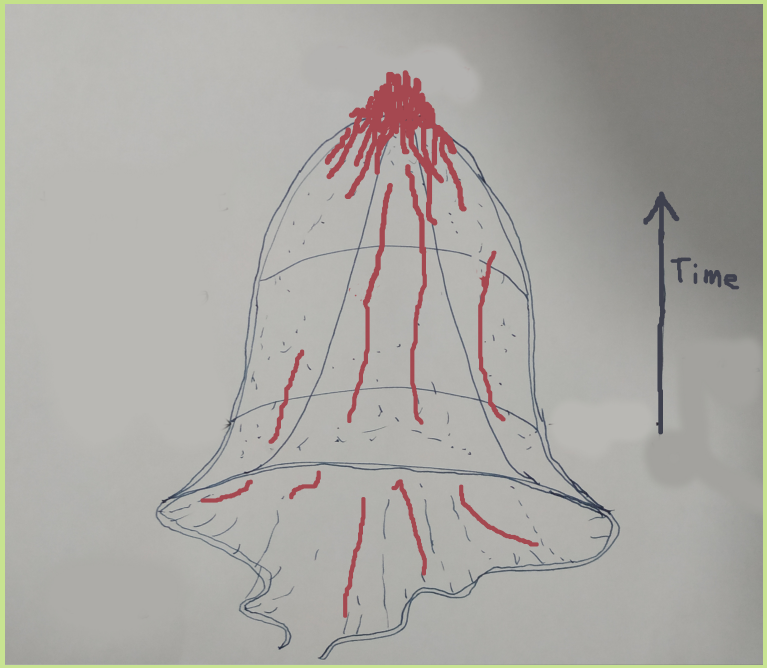

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Reversing the time in the Universe with black holes

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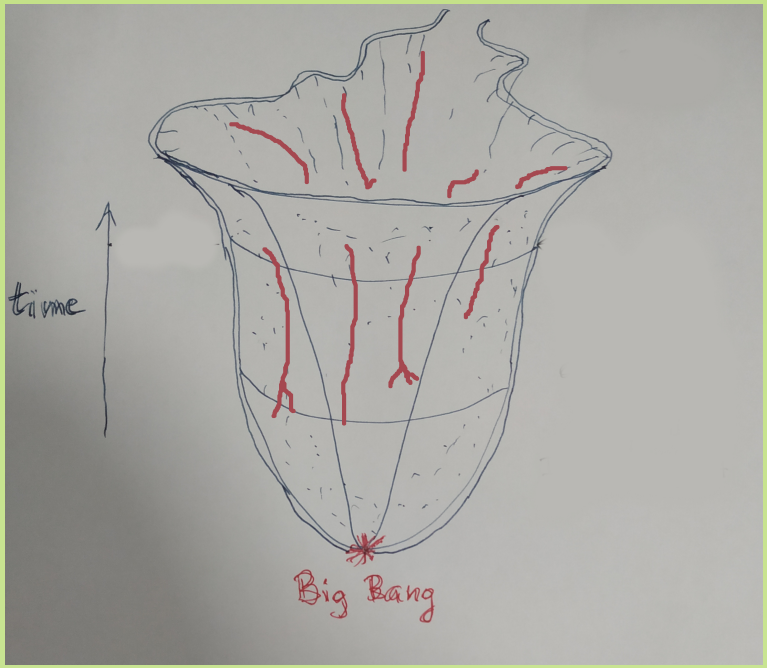

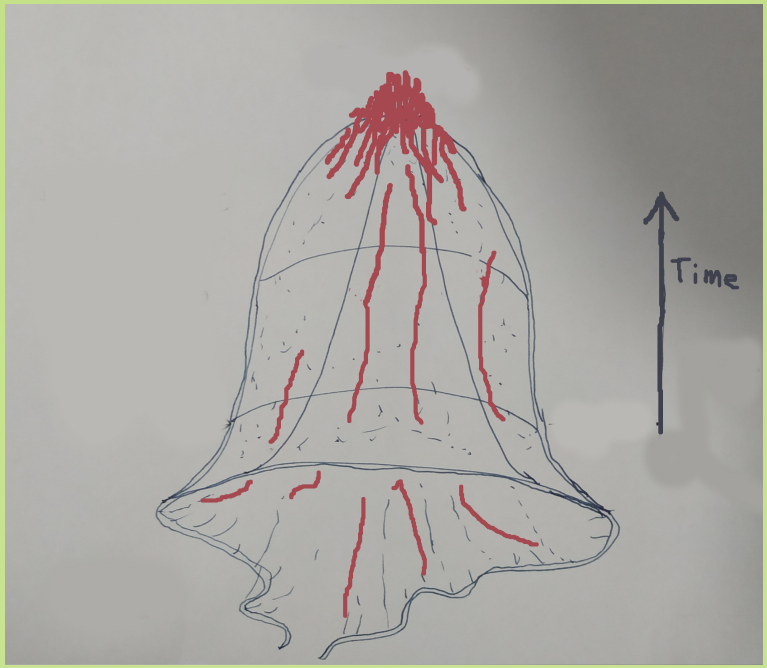

All our knowledge (the theory and observations) tells us that the singularity at the beginnig of our Universe is **extremely simple**! It is much much **simpler** than a singularity of **any black hole**. And imagine the complexity of a singularity produced by zylions of black holes squized to death at the Big Crunch!

Baby Universes: busted!

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There is a respected theoretical physicist, who once wrote a book in which he proposed that everytime when black hole emerges, a new universe is created in the place of its singularity. So his answer to the question '**what was before the Big Bang?**' is: '**there was a black hole**'. In view of this what I just have said it is a **nonsense**: even the simplest black hole, such as Schwarzschild black hole, has a nontrivial singularity; Its conformal curvature is **not** zero; On the other hand, astronomical observations tell us that a new born universe is **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves singularity **in one function only**; in the Universe **conformal factor**!

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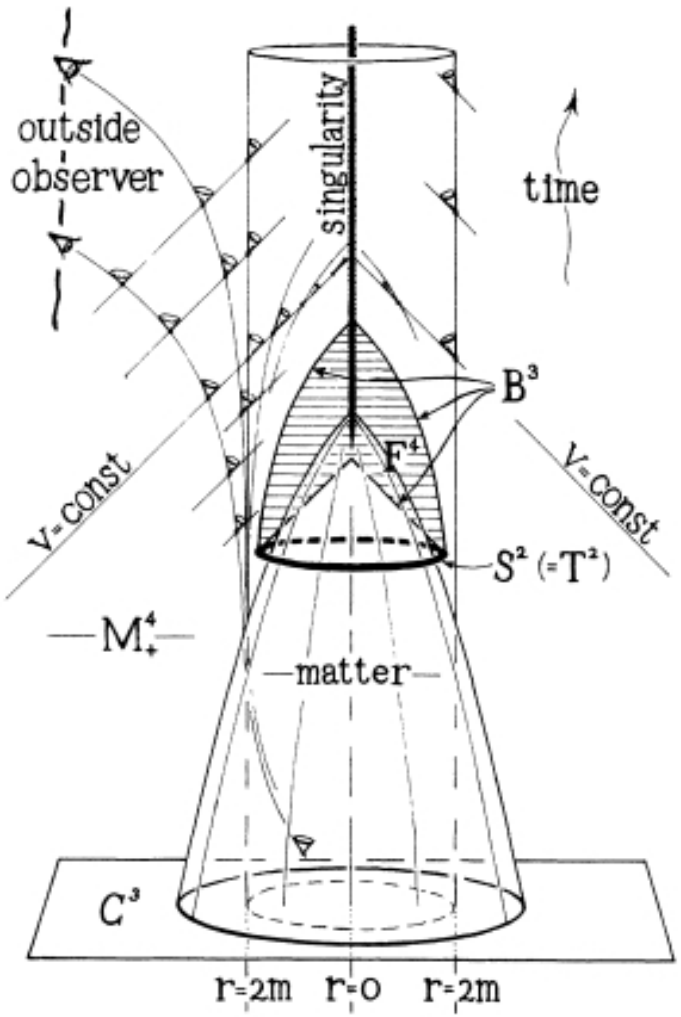

FIG. 1. Spherically symmetrical collapse (one space dimension surpressed). The diagram essentially also serves for the discussion of the asymmetrical case.

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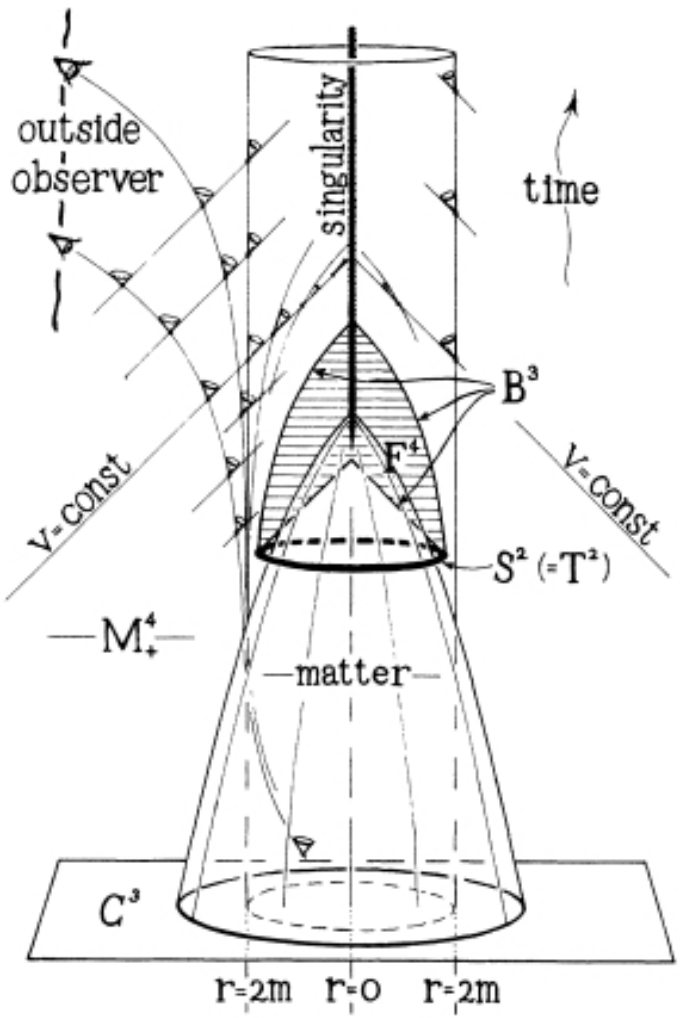

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‘What was before the Big Bang’?: light cones

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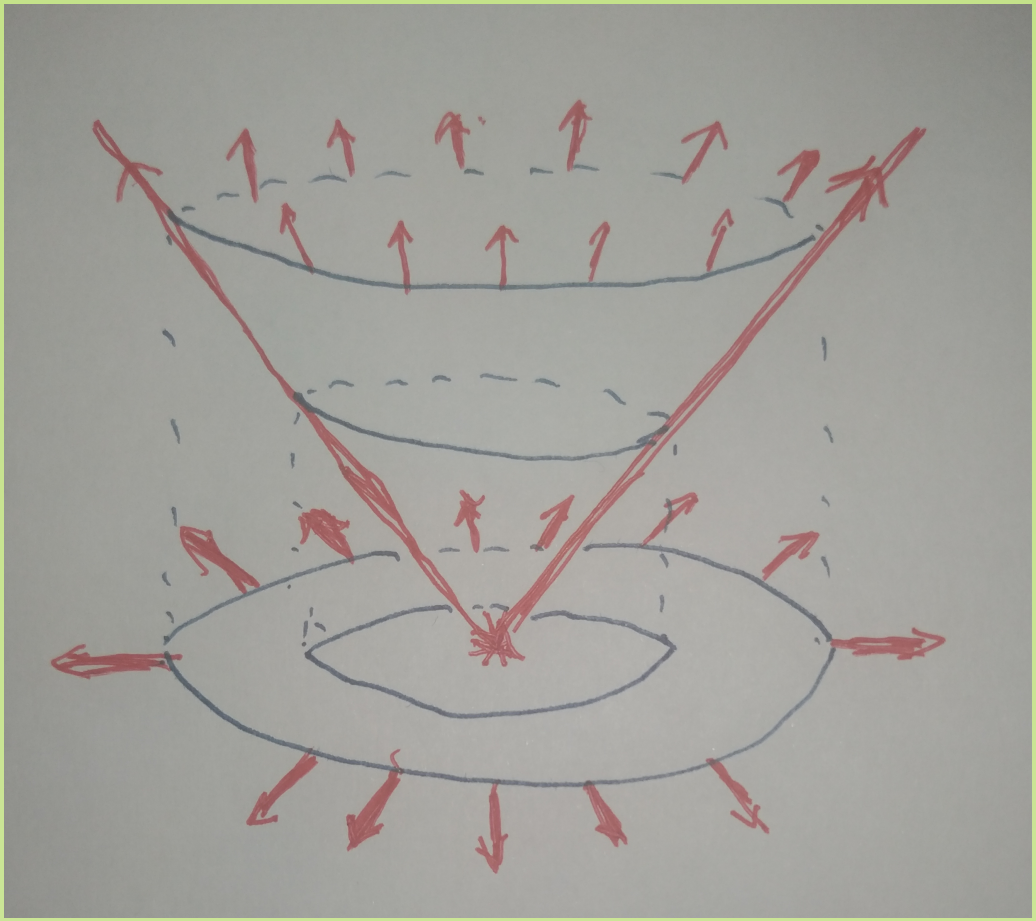

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The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events, called a **manifold**. Knowing how light cones are **distributed**, and how they are **squized**, **tilted** and **deformed** on the manifold we essentially have full information about the spacetime; Well ... the information is full, except one thing: observers/particles have no ability to meassure **time**. The distribution of cones gives **nine** out of **ten** functions defining the spacetime structure. A lot of physics, as for example **physics of massless particles**, such as **photons**, is only depending on the distribution of light cones. In mathematical terms: this physics depends on a **conformal** geometry only, i.e. on a geometry of a metric given **up to a scale**, and not on a more restrictive (pseudo)-Riemannian geometry, where the full metric is needed.

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General Relativity

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- Physical spacetime is a 4-dimensional **manifold** M, equipped with a **Lorentzian metric** g, satisfying **Einstein equations**
$$Einstein(g) + \Lambda g = Matter.$$
- Knowing the metric g satisfying these equations, we have all information about the spacetime. The constant Λ apearing here is the **cosmological constant.**
- The **Universe is a spacetime such that the** $Matter$ **term** on the right hand side of these equations **is specific to the matter content of our Universe.** To know physics in our Universe it is neccessary (but also in principle sufficient) to know the metric g specific to the matter of our Universe.

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- The metric g at every point is a $4x4$ **symmetric matrix.** So at every point it has **ten** components. In other words, to know the metric of the Universe, we must know **ten functions**.
- It turns out that the metric g of our Universe can always be written as $g = \Omega^2 g_0$, where g_0 is a **non**-sinngular metric, i.e. a metric which is **regular near the Big Bang**, and Ω is a **function**, that has **singularity at the Big Bang**.
- It is the g_0 that equips the spacetime with **conformal structure** responsible for the distribution and shapes of light cones. This structure is **regular** and determined by **nine** regular spacetime functions.
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- It turns out that the metric g of our Universe can always be written as $g = \Omega^2 g_0$, where g_0 is a **non**-sinngular metric, i.e. a metric which is **regular near the Big Bang**, and Ω is a **function**, that has **singularity at the Big Bang**.
- It is the g_0 that equips the spacetime with **conformal structure** responsible for the distribution and shapes of light cones. This structure is **regular** and determined by **nine** regular spacetime functions.
- The Big Bang singularity is caused by the **singularity in the scaling function** Ω. One function only!

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- As I said, if the spacetime was equipped only with **conformal class** of g_0 a lot of physics of the Universe could be understood: in particular all the physics of **masless** particles.
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‘What was before the Big Bang’?: measuring time

Pawel Nurowski

- One of the two gratest formulae of 20th century Physics:

$$E = h\nu \quad \text{(Planck)} \quad \text{and} \quad E = mc^2 \quad \text{(Einstein)}.$$

- Combining we get $\frac{\nu}{m} = \frac{c^2}{h} = \text{const}$, or that the time T - the reciprocity of the frequency ν - is

$$T = m^{-1}$$

in physical units $h = c = 1$.

- To measure **time** we need **mass**. An **existence of massive particles** is needed to have the very **notion of time**.

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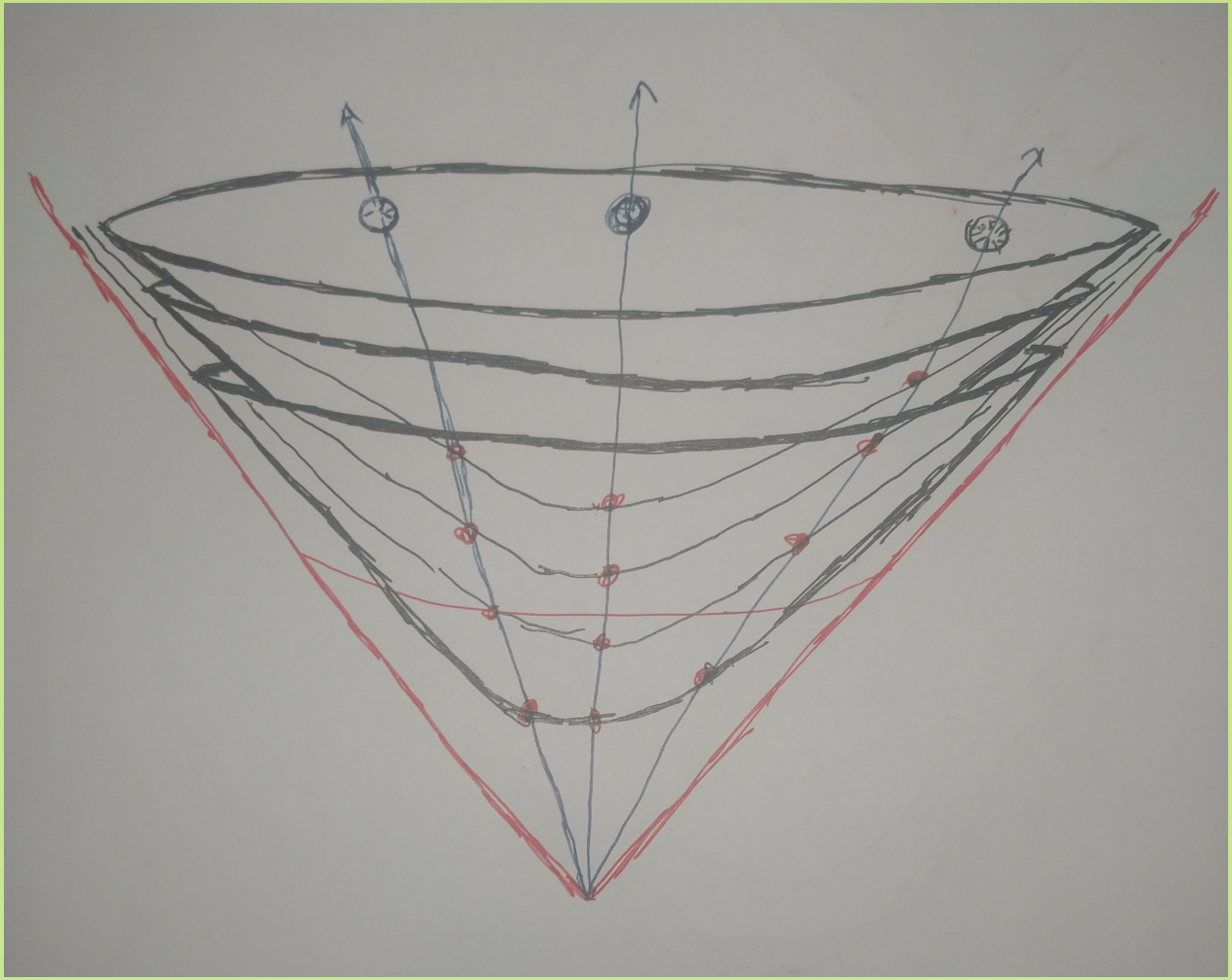

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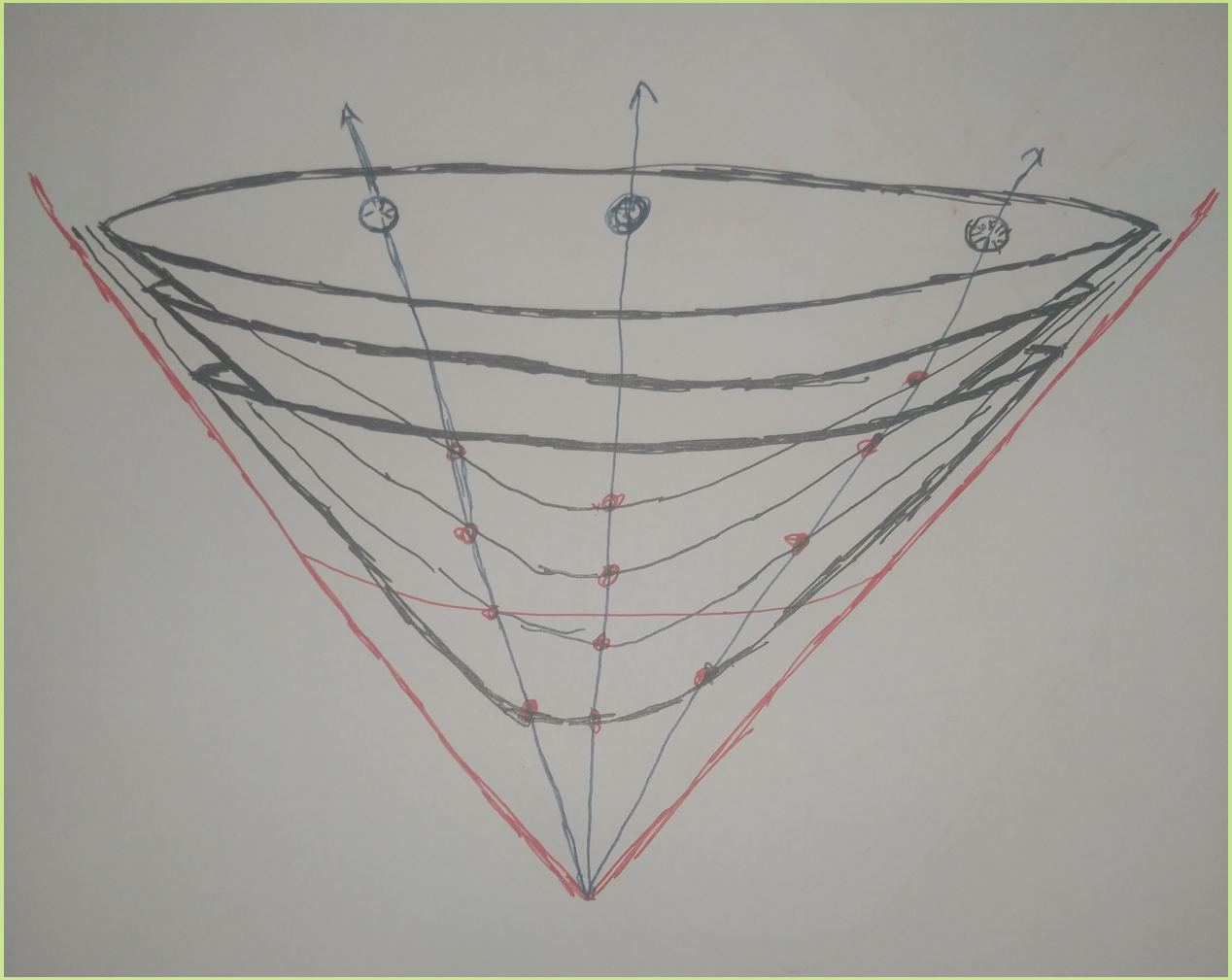

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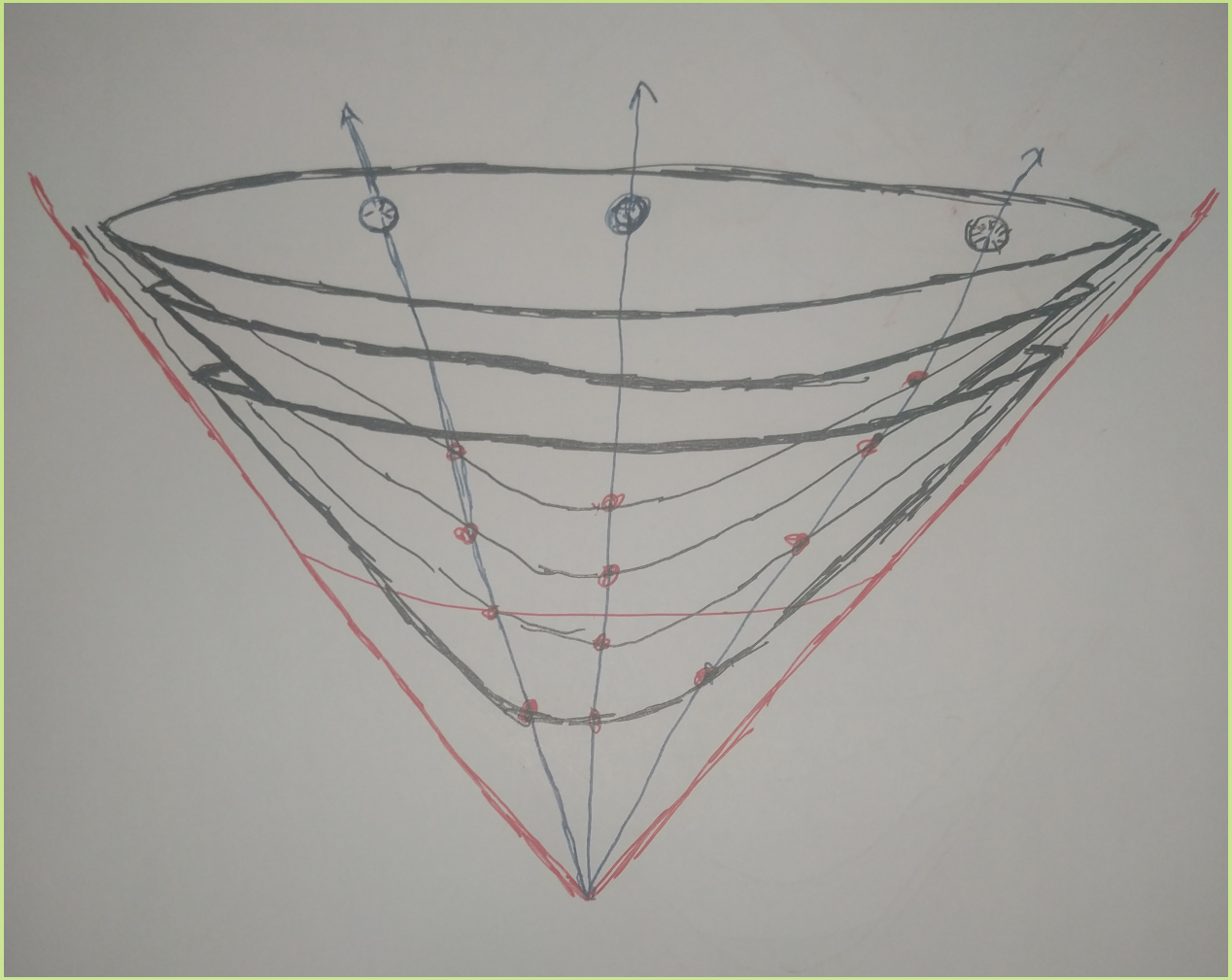

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‘What was before the Big Bang’?: the importance of positivity of Λ

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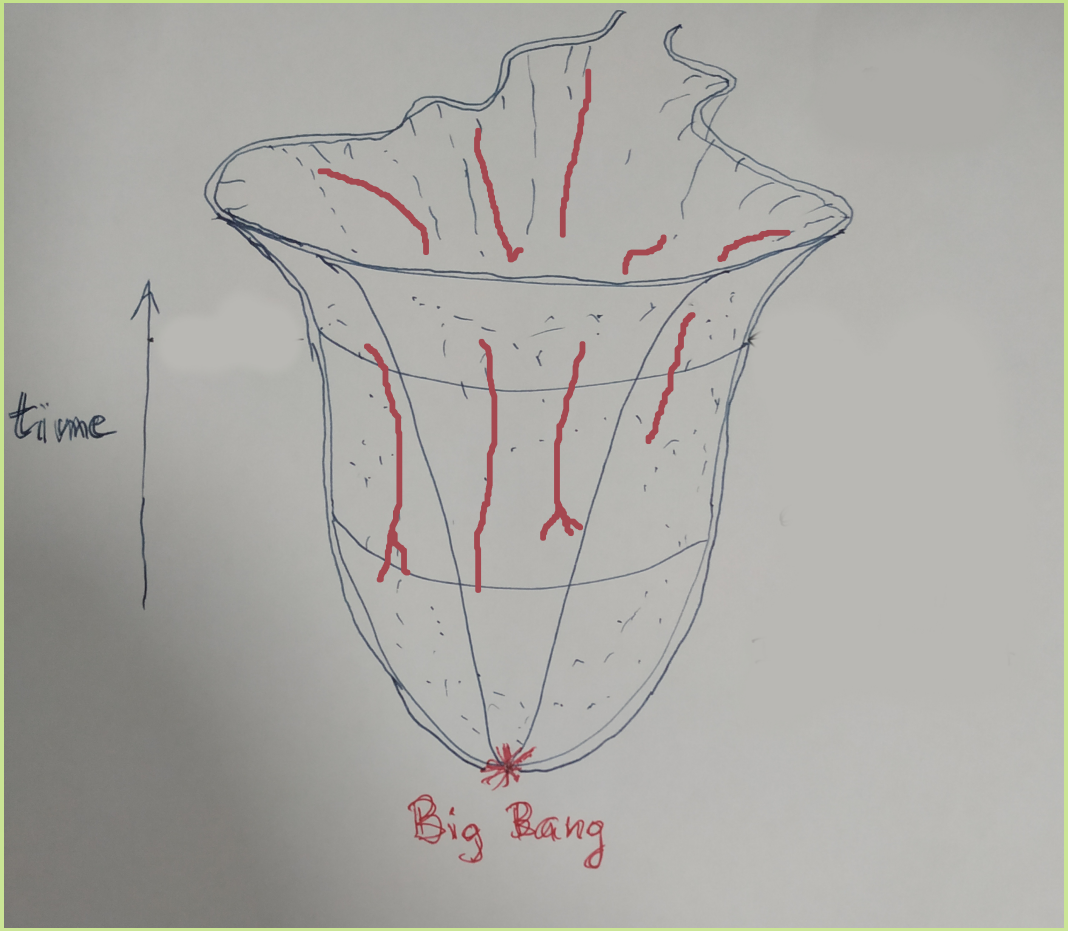

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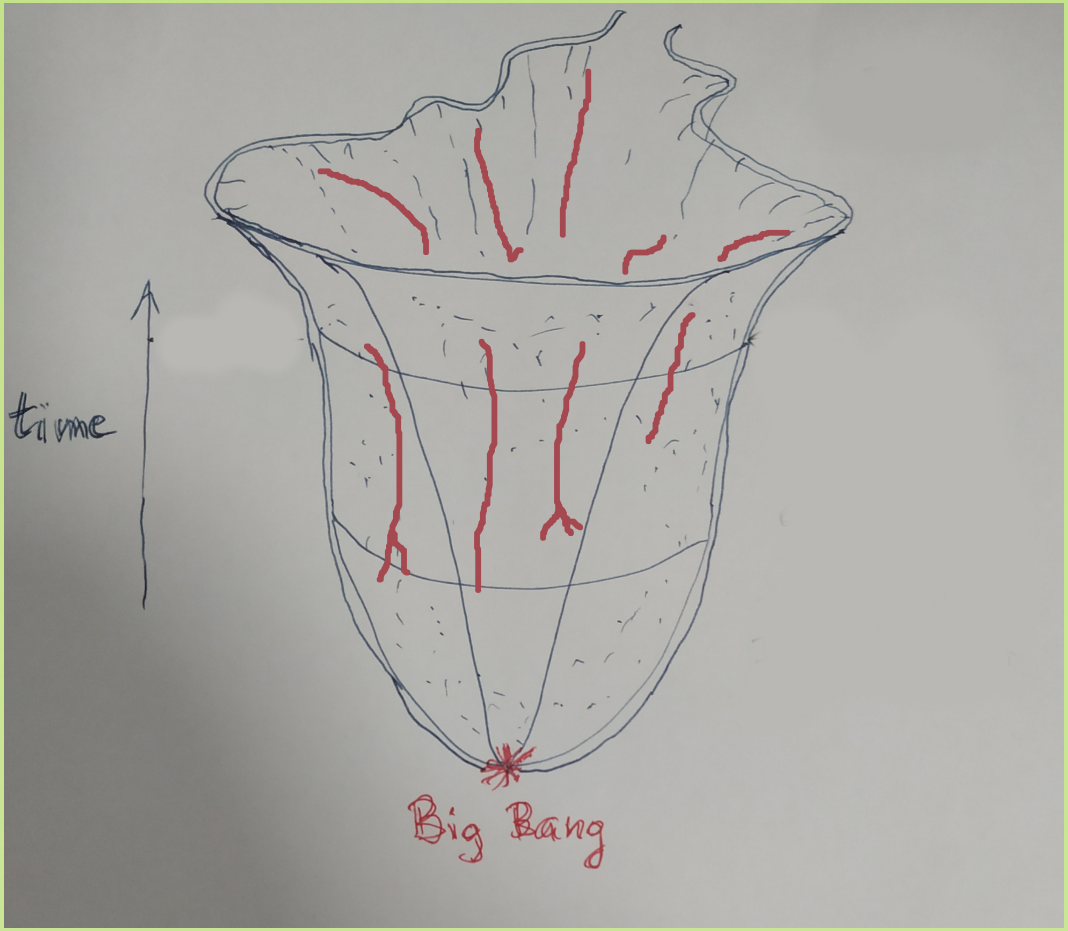

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- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
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- In this regime the Univese will be **conformally flat**, conformal to the **deSitter spacetime**.
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‘What was before the Big Bang’?: Penrose’s main argument

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- The Universe at its late stage of evolution will be equipped with **conformal geometry** only. The full information about its spacetime metric will be **mutilated** by imposibility of determining the **conformal factor** of the metric.
- The **conformal structure** of the Universe at his very late stage of evolution - mathematicians say: **assymptotically** - will be **flat**. And the ‘final’ hypersurface of the dying Universe - the **null infinity** - the **set where all the null geodesics ends in the future** - will be **spacelike** due to the **positivity of** Λ.
- Note that the Universe at its **very early stage** of evolution is **also conformally flat**!
- Well, there is a **Big Bang singularity** there, but the only **function that is singular** in the spacetime metric is in the metric **conformal factor**. Particular choice of a conformal factor in a **conformal geometry** is what reduces it to the **geometry with a metric**. From the point of view of **conformal geometry** a choice of conformal factor is one of the **coordinates** on the structure, and singularity in it, is caused by a **wrong choice of one of the coordinates** rather, then geometric.
- If we **strip off the conformal factor** from the spacetime **metric of the Big Bang** it becomes **flat**, and the **hypersurface** of the **Big Bang** will be **spacelike**.
- So the **hypersurface of the Big Bang of The Univesre** is **conformally flat and spacelike** preatty much **the same as the last hypersurface of the dying Universe**!
- Penrose: **IDENTIFY THEM**!!!

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A 4-dimensional spacetime M is equipped with a **conformal structure** $[g_0]$ if it is equipped with a class of metrics g_0 of signature $(-,+,+,+)$ such that two metrics g_0 and g are in the same class if and only if there exists a function Ω such that $g = \Omega^2 g_0$. The function Ω is called a conformal factor for g. It is this structure on M which **determines and is determined** by the distribution of light cones in M.

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‘What was before the Big Bang’?: Three conformal tricks

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- By chosing conformal factor Ω in a way such that it **tends to zero** when the **space infinitely expands** we can make the size of the space **finite. Conformal squash down.**
- By chosing conformal factor Ω in a way such that it **tends to infinity** when the **space shrinks to zero** we can make the size of the space **finite. Conformal stretching**.
- One can still choose a conformal factor compatible with the other two choices, so that **the entire time of the Universe** is **strached to a closed interval**!
- These mathematical tricks of **passing from one spacetime** to **a conformally equivalent one** with **compact boundary** are called **conformal compactifications**.

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‘What was before the Big Bang’?: conformal tricks - the result

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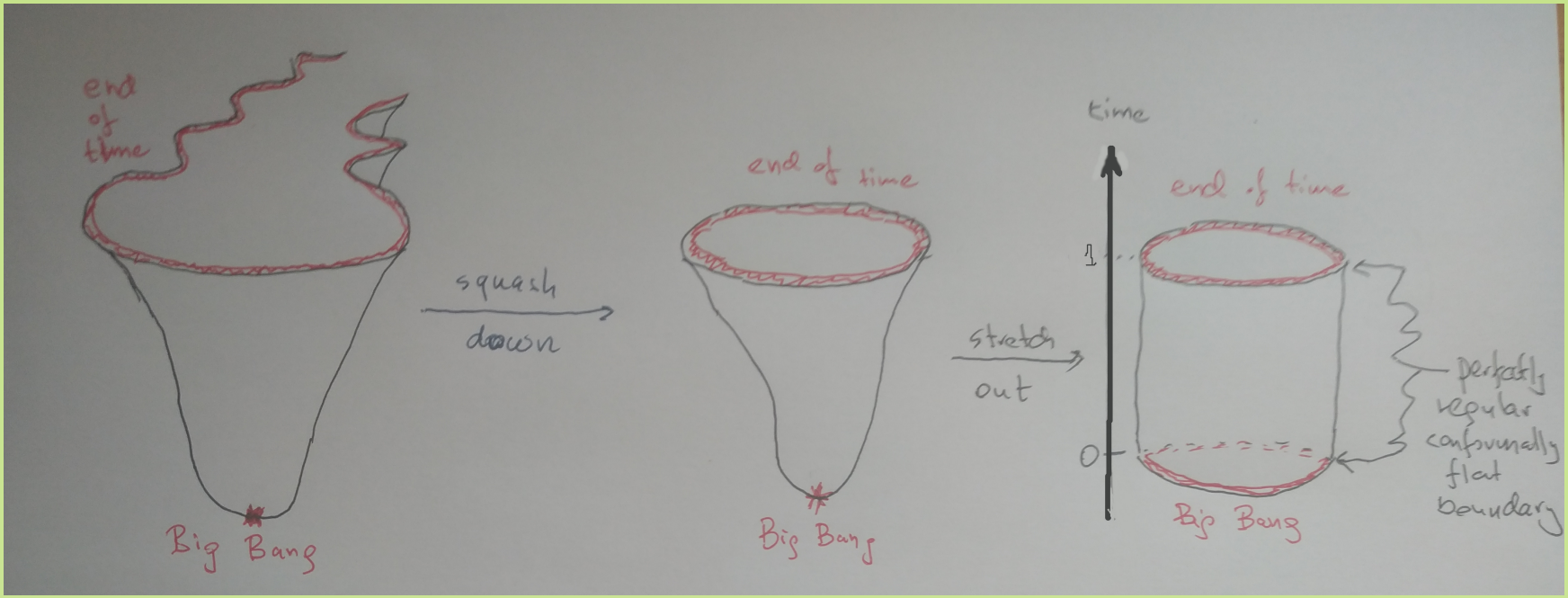
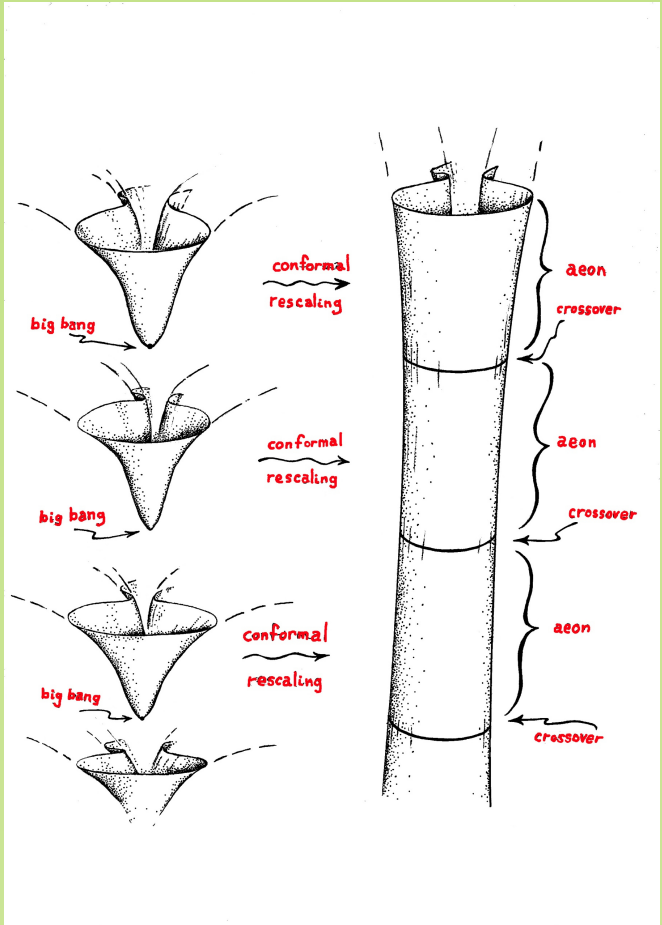


‘What was before the Big Bang’?: Conformal Cyclic Cosmology

Pawel Nurowski



Penrose's Conformal Cyclic Cosmology

Pawel Nurowski

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** boundaries. Each eon has two boundaries: one in the past, and one in the future. The **Weyl tensor** of the metric on each boundary **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along the boundary in the future **of the past eon**, and the boundary in the past **of the present eon**.

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Penrose's Conformal Cyclic Cosmology

Pawel Nurowski

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Penrose's eons

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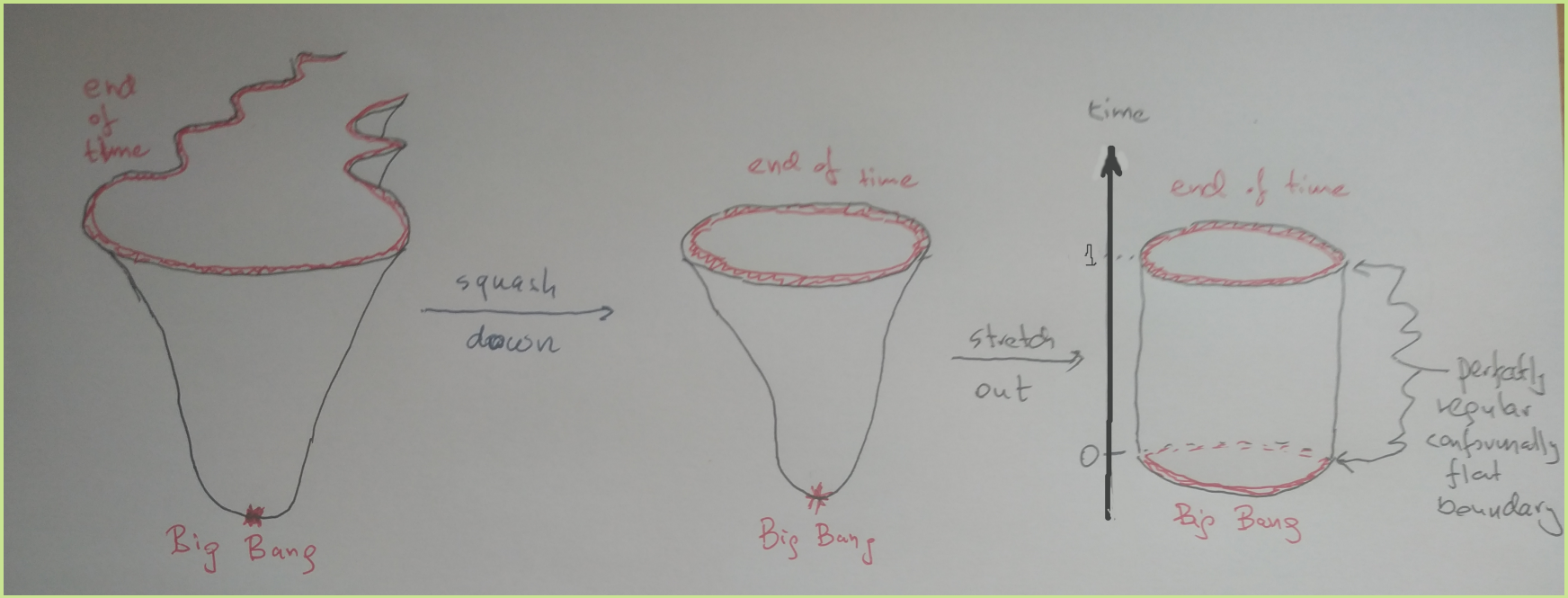
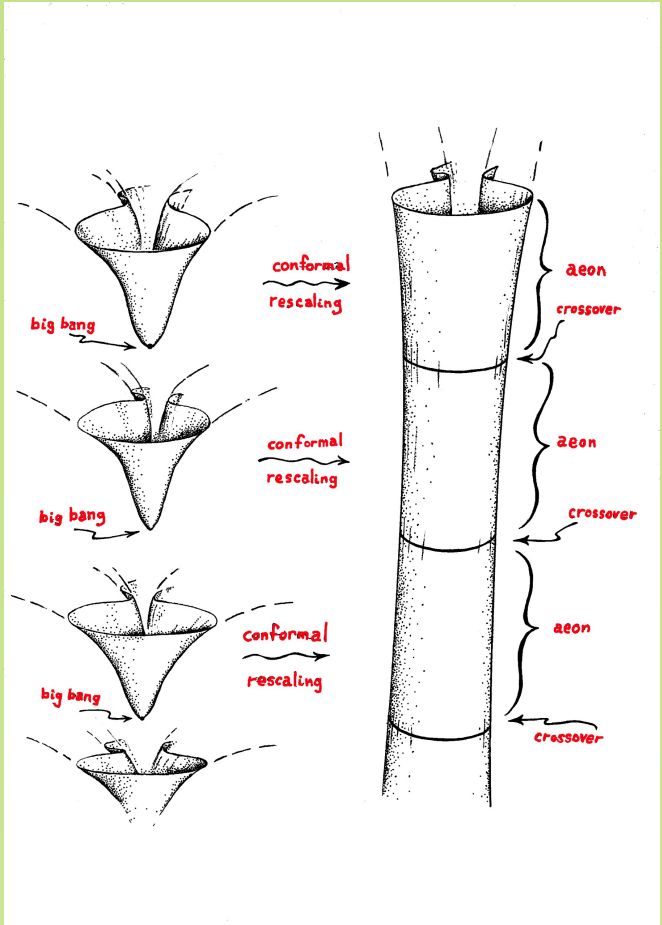


Norway grants

Penrose's eons

Pawel Nurowski



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Penrose's Conformal Cyclic Cosmology: is it true?

Pawel Nurowski

CAN WE SEE IT?

CAN WE SEE IT?

Penrose's Conformal Cyclic Cosmology: photons dont die!

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- **Standard cosmology**: physics of spacetime is related to the geometry with a Lorentzian metric $g = \Omega^2 g_0$.
- **Penrose's CCC**: physics of spacetime near Big Bang is related to the conformal geometry $[g_0]$.
- There is a class of intrinsically defined **geometric objects** in **Lorentzian geometry** that **are the same** in the weaker **conformal geometry**.
- One of them are **null geodesics**.
- In General Relativity Theory they model **worldlines of massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
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Penrose's Conformal Cyclic Cosmology: circles in the CMBR maps

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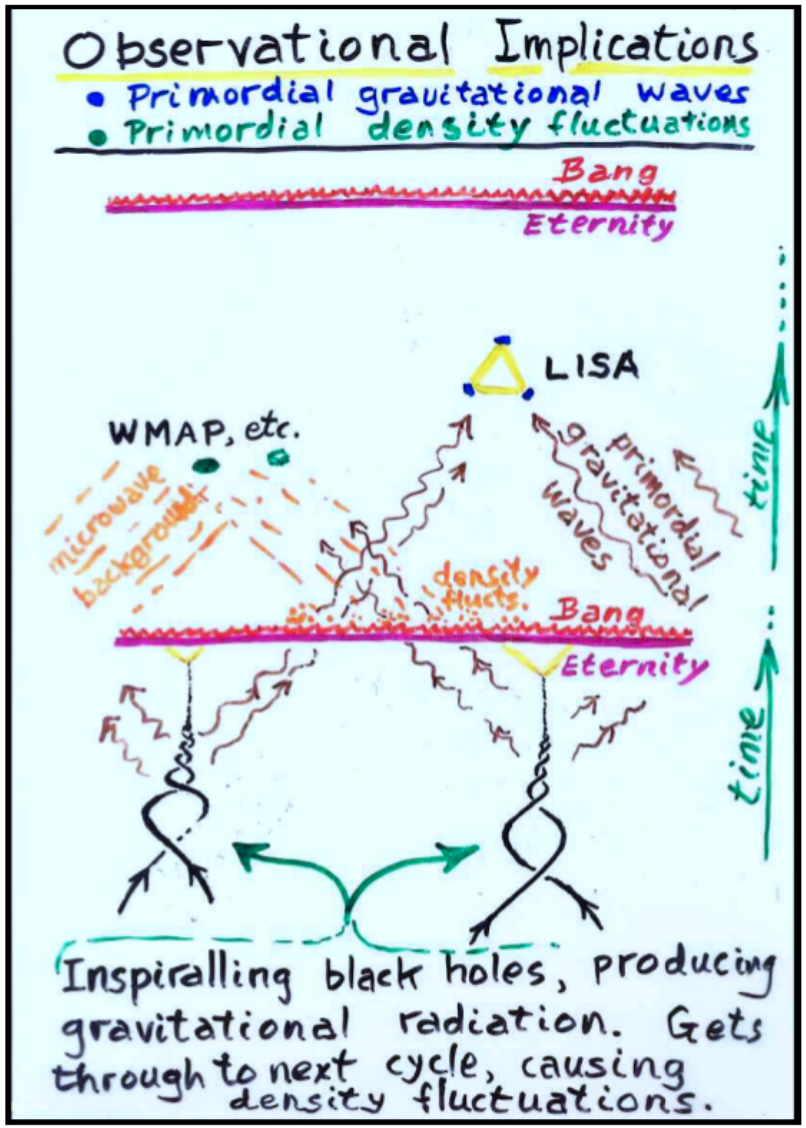

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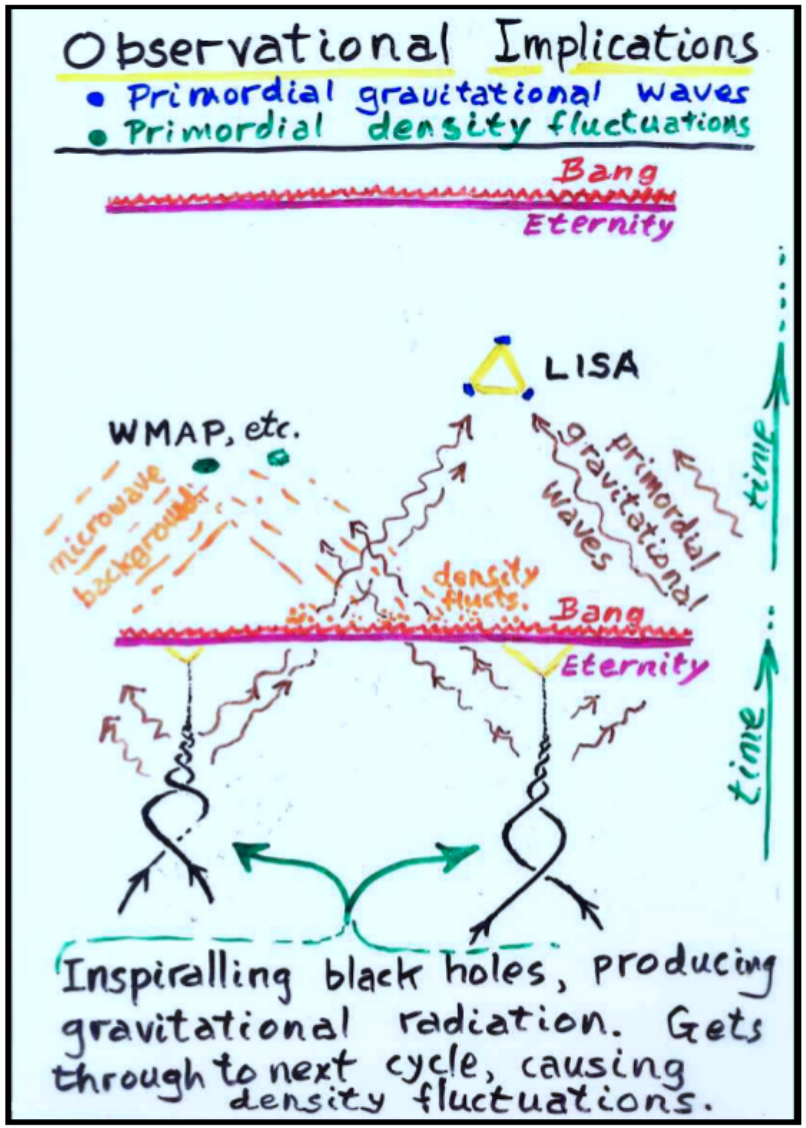

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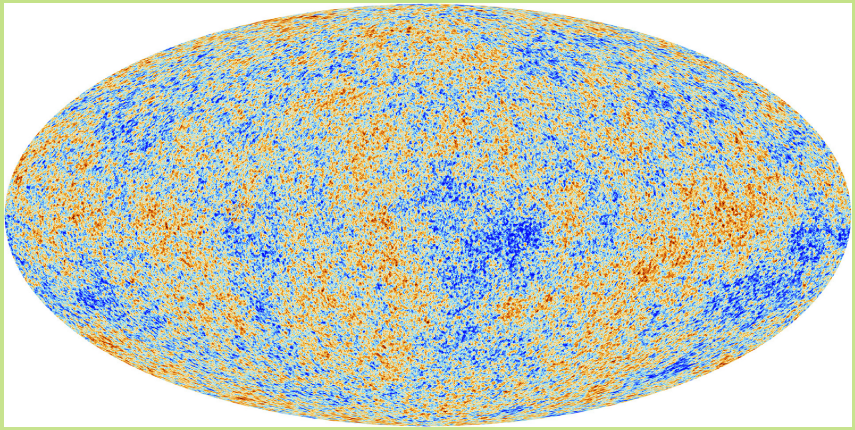

We attemeted to answer this questionfirst in a team of **Krzysztof Meissner**, **Blazej Ruszczycki** and myself (WMAP data), and then with **Daniel An**, **Krzysztof Meissner** and myself (PLANCK data). Later on, we did different analysis of the PLANCK data in the team of **Daniel An**, **Krzysztof Meissner**, **Roger Penrose** and myself (Hawking points).

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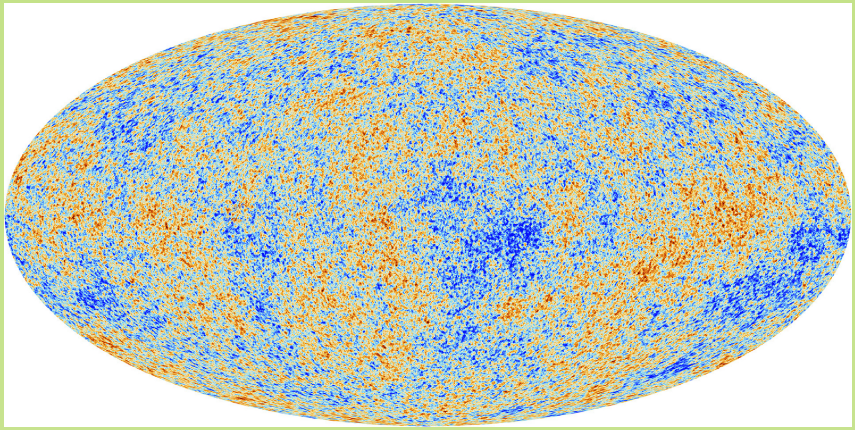

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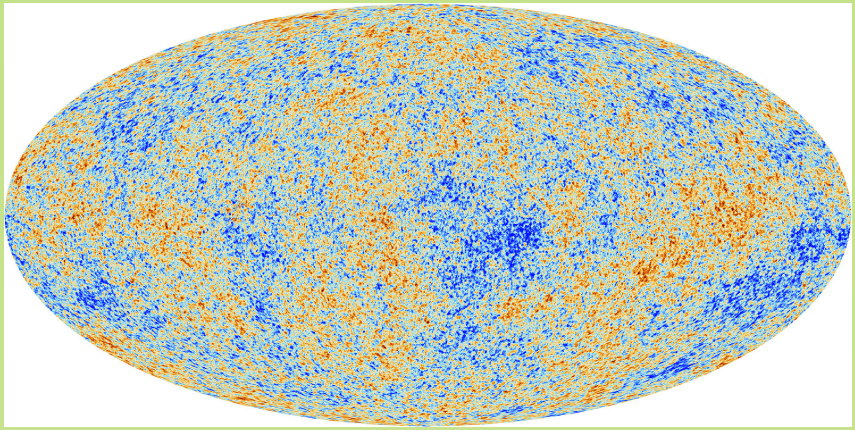

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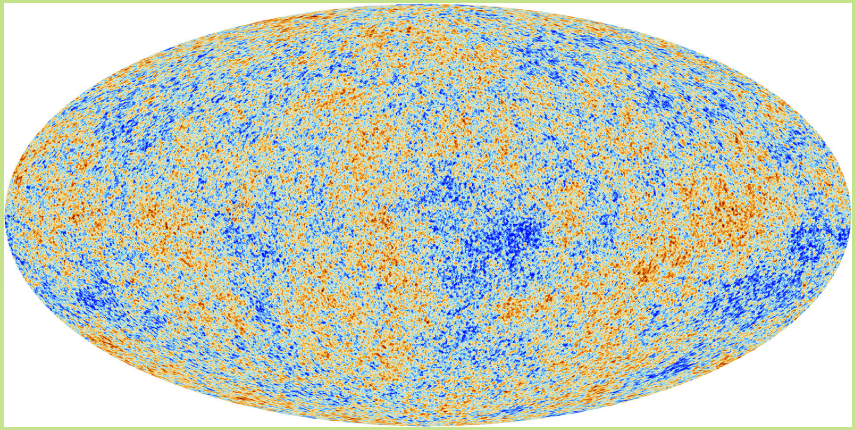

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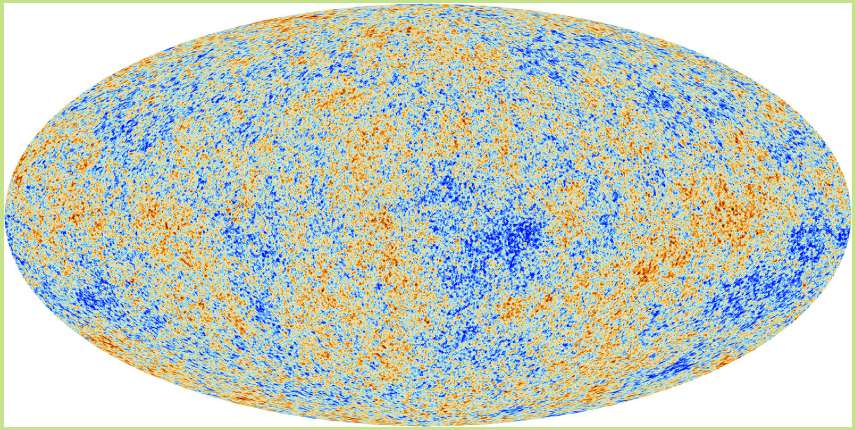

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Ring definition

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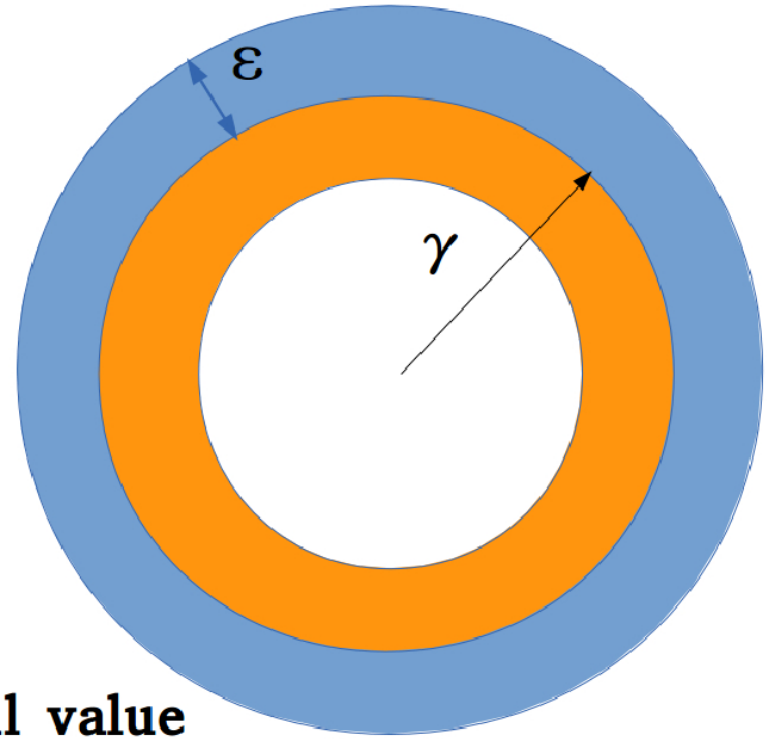

Integral value
= Inner Avg Temp – Outer Avg Temp

Exclusion of the Milky Way belt

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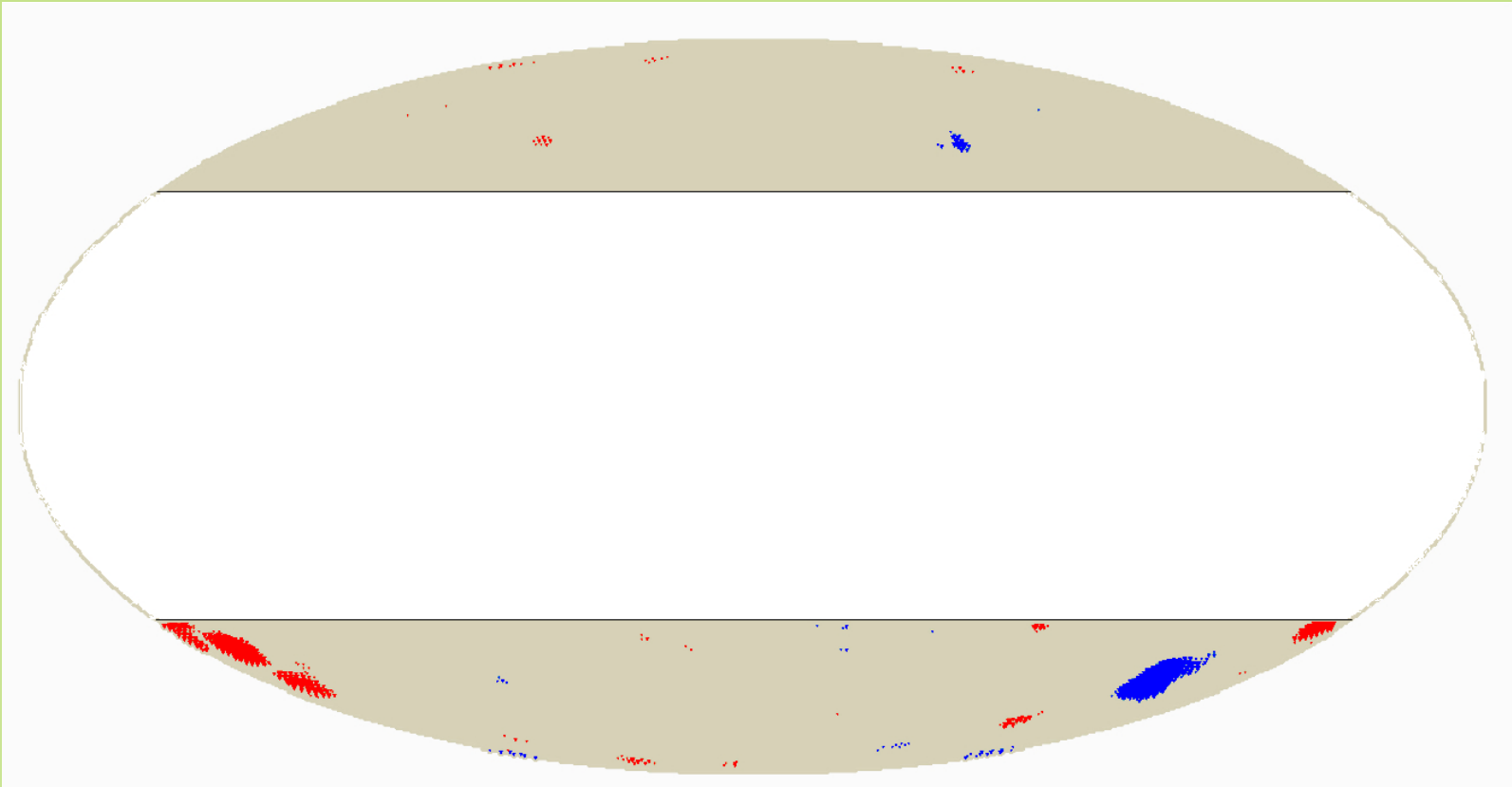

Location of possible circles

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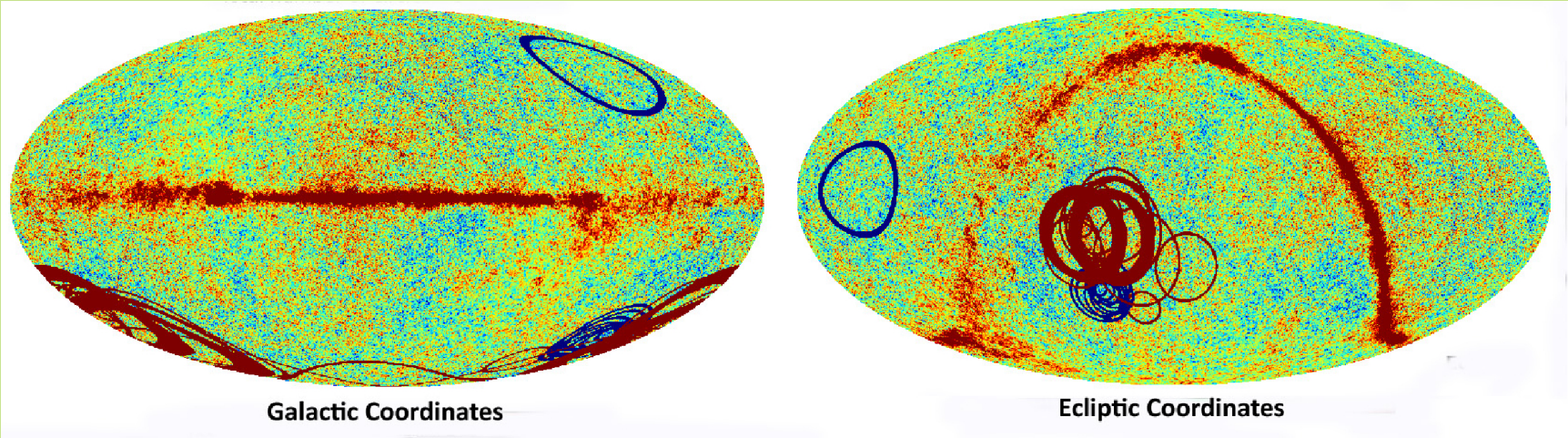

Location of possible circles $\epsilon = 0.08$

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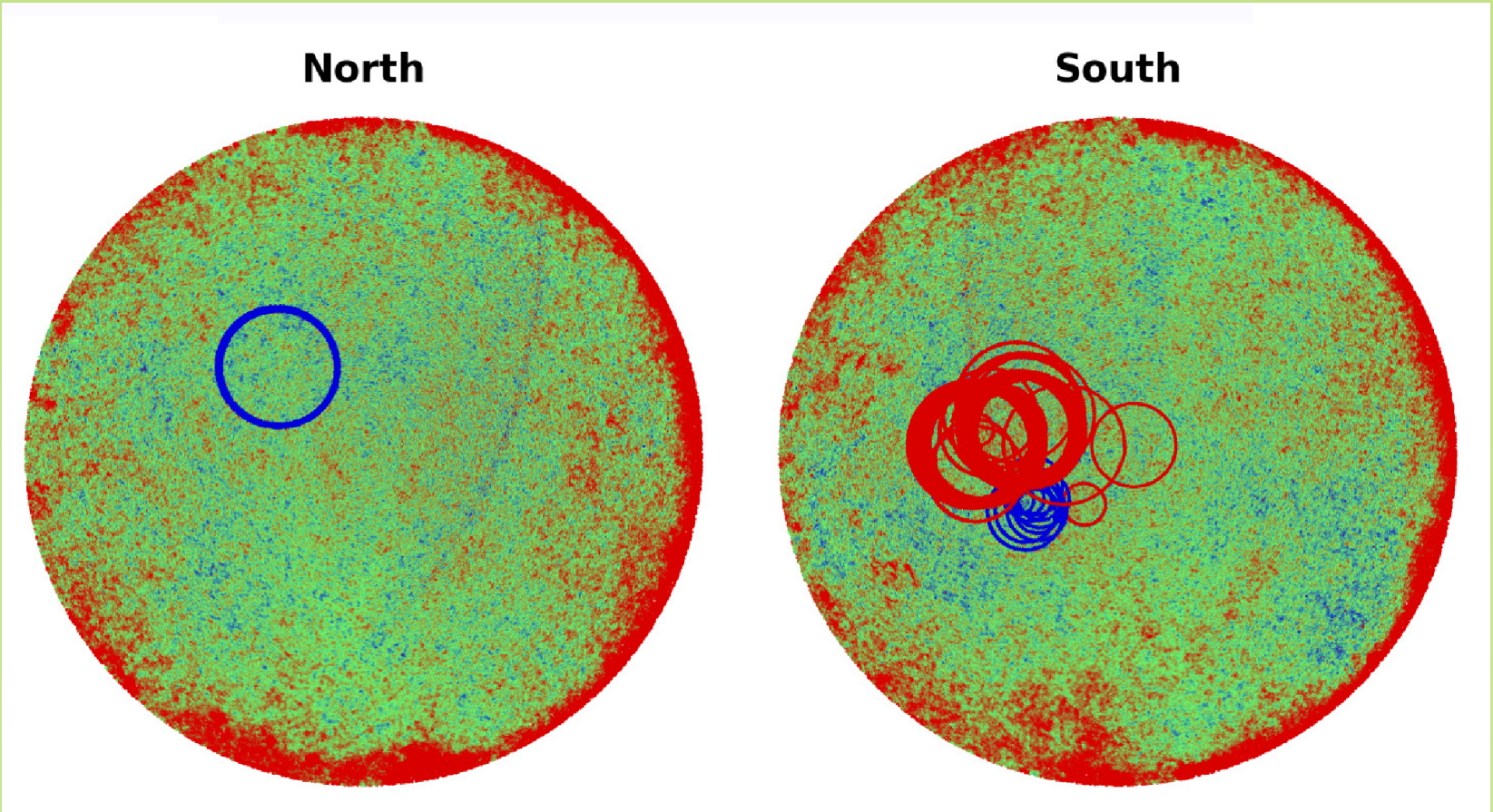

Location of possible circles $\epsilon = 0.04$

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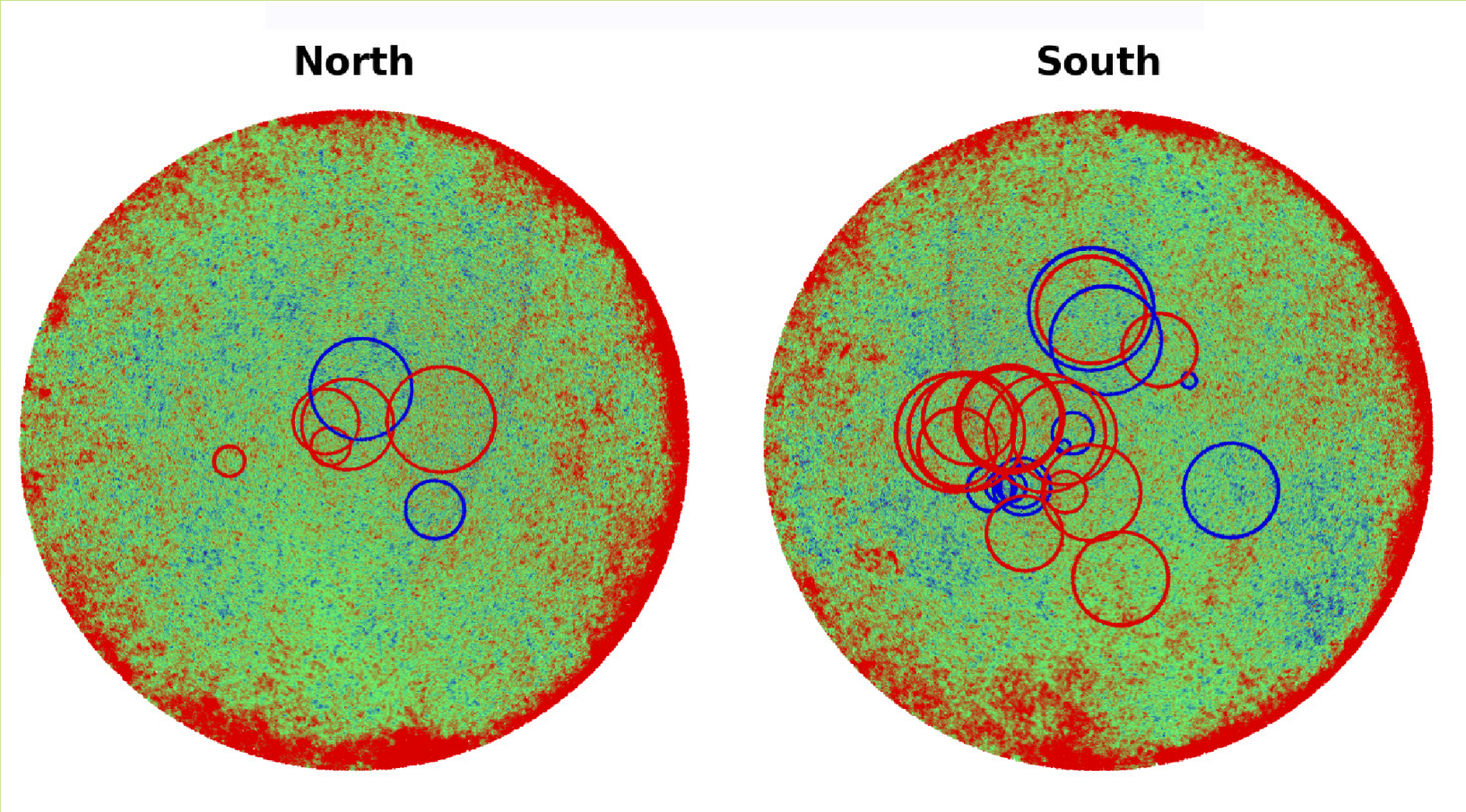

Location of possible circles $\epsilon = 0.02$

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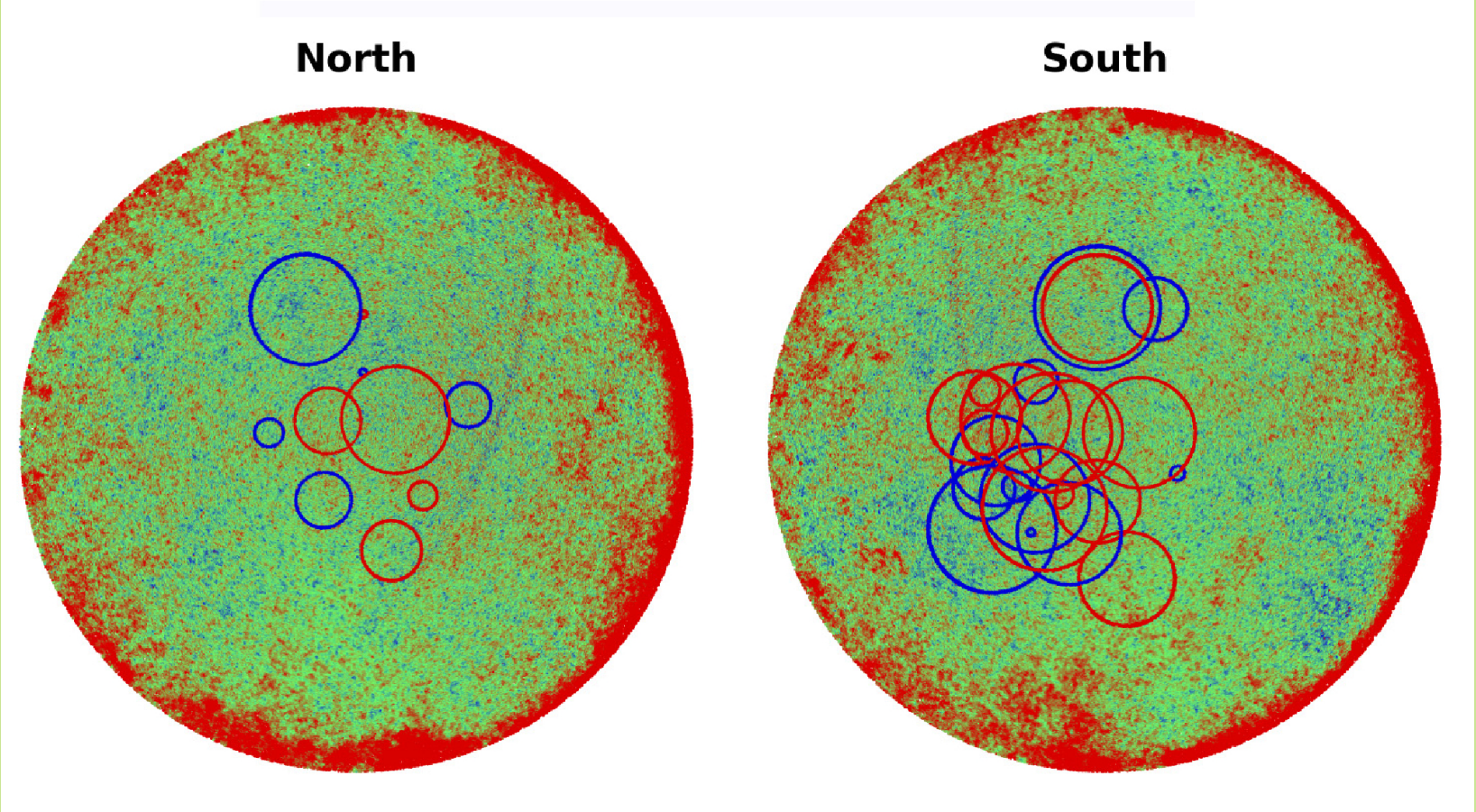

THANK YOU!