Before the Big Bang? Penrose's Conformal Cyclic Cosmology

Pawel Nurowski

Mathematics GTIIT
and
Center for Theoretical Physics
Polish Academy of Sciences

Mathematics Colloquium
Shantou, 16.04.2021

Two fundamental facts about observational cosmology

- Our Universe **had a beginning**.This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. Moreover, the measurments of **cosmological constant**, obtained by calibrating cosmological distances using certain type of **supernovae**, show that it **will be expanding forever**. Cosmological constant is **positive**.

Two fundamental facts about observational cosmology

- Our Universe **had a beginning.**This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. Moreover, the measurments of **cosmological constant**, obtained by calibrating cosmological distances using certain type of **supernovae**, show that it **will be expanding forever**. Cosmological constant is **positive**.

Two fundamental facts about observational cosmology

- Our Universe **had a beginning**.This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. Moreover, the measurments of **cosmological constant**, obtained by calibrating cosmological distances using certain type of **supernovae**, show that it **will be expanding forever**. Cosmological constant is **positive**.

Two fundamental facts about observational cosmology

- Our Universe **had a beginning**.This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. Moreover, the measurments of **cosmological constant**, obtained by calibrating cosmological distances using certain type of **supernovae**, show that it **will be expanding forever**. Cosmological constant is **positive**.

Two fundamental facts about observational cosmology

- Our Universe **had a beginning**.This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. Moreover, the measurments of **cosmological constant**, obtained by calibrating cosmological distances using certain type of **supernovae**, show that it **will be expanding forever**. Cosmological constant is **positive**.

Two fundamental facts about observational cosmology

- Our Universe **had a beginning**.This beginning is called the **Big Bang**.
- Our Universe, as observed now, **is expanding**. Moreover, the measurments of **cosmological constant**, obtained by calibrating cosmological distances using certain type of **supernovae**, show that it **will be expanding forever**. Cosmological constant is **positive**.

Copernican principle

- Universe is the same **everywhere in space** (Copernicus) and is the same **in every direction** (Friedman/ Lemaître/ Robertson/ Walker).
- Friedmann used the **Einstein equations** (with cosmological constant equal to zero) to get a model compatible with these assumptions.
- We have only **three models**.

Copernican principle

- Universe is the same **everywhere in space** (Copernicus) and is the same **in every direction** (Friedman/ Lemaître/ Robertson/ Walker).
- Friedmann used the **Einstein equations** (with cosmological constant equal to zero) to get a model compatible with these assumptions.
- We have only **three models**.

Copernican principle

- Universe is the same **everywhere in space** (Copernicus) and is the same **in every direction** (Friedman/ Lemaître/ Robertson/ Walker).
- Friedmann used the **Einstein equations** (with cosmological constant equal to zero) to get a model compatible with these assumptions.
- We have only **three models**.

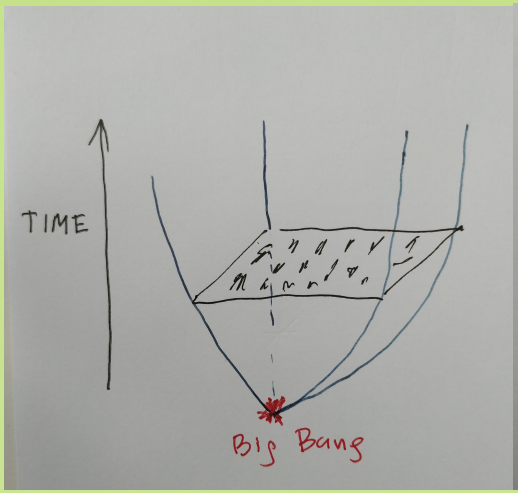
Copernican principle

- Universe is the same **everywhere in space** (Copernicus) and is the same **in every direction** (Friedman/ Lemaître/ Robertson/ Walker).
- Friedmann used the **Einstein equations** (with cosmological constant equal to zero) to get a model compatible with these assumptions.
- We have only **three models**.

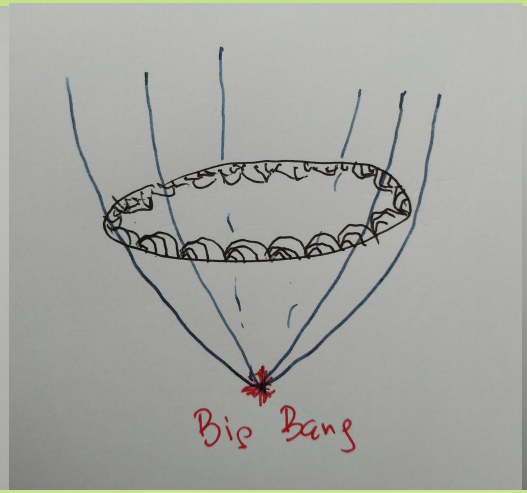
Copernican principle

- Universe is the same **everywhere in space** (Copernicus) and is the same **in every direction** (Friedman/ Lemaître/ Robertson/ Walker).
- Friedmann used the **Einstein equations** (with cosmological constant equal to zero) to get a model compatible with these assumptions.
- We have only **three models**.

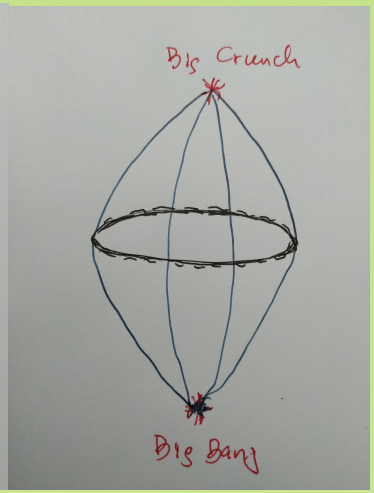
Friedman: three models of cosmology satisfying Copernican principle



$K = 0$

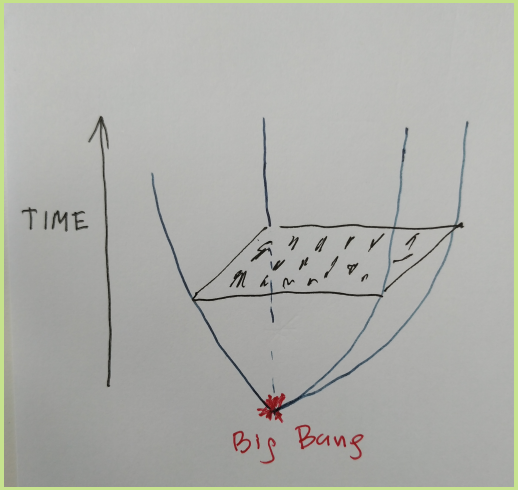


$K < 0$

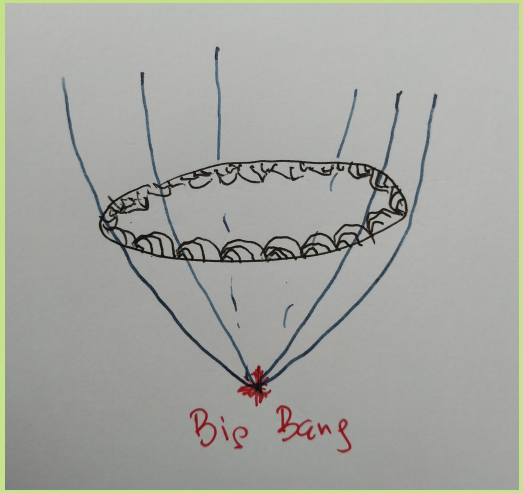


$K > 0$

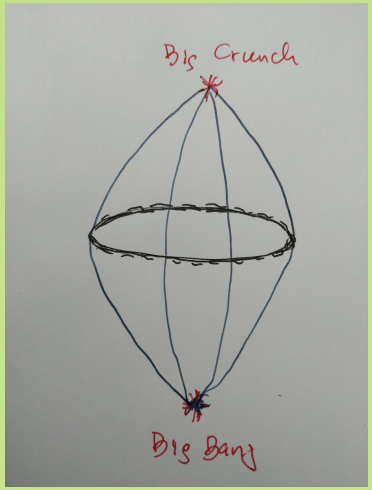
Friedman: three models of cosmology satisfying Copernican principle



$K = 0$

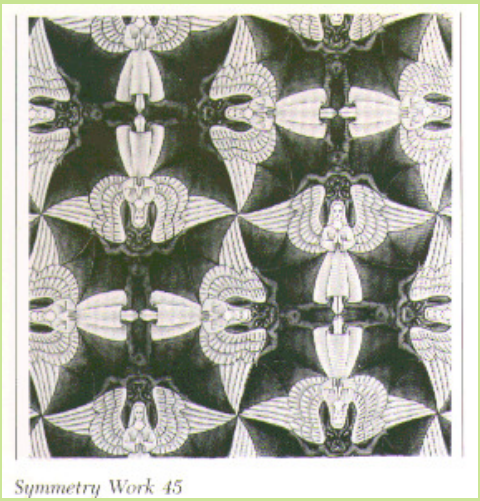


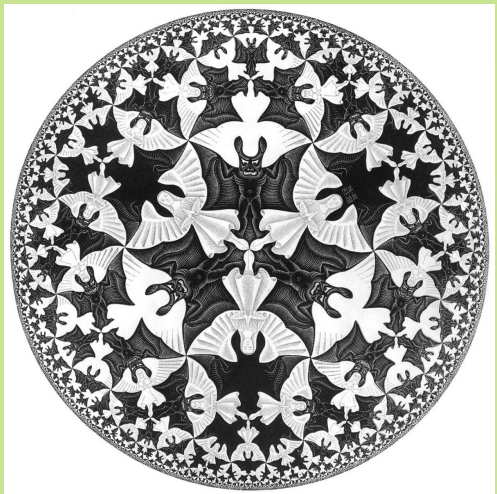
$K < 0$



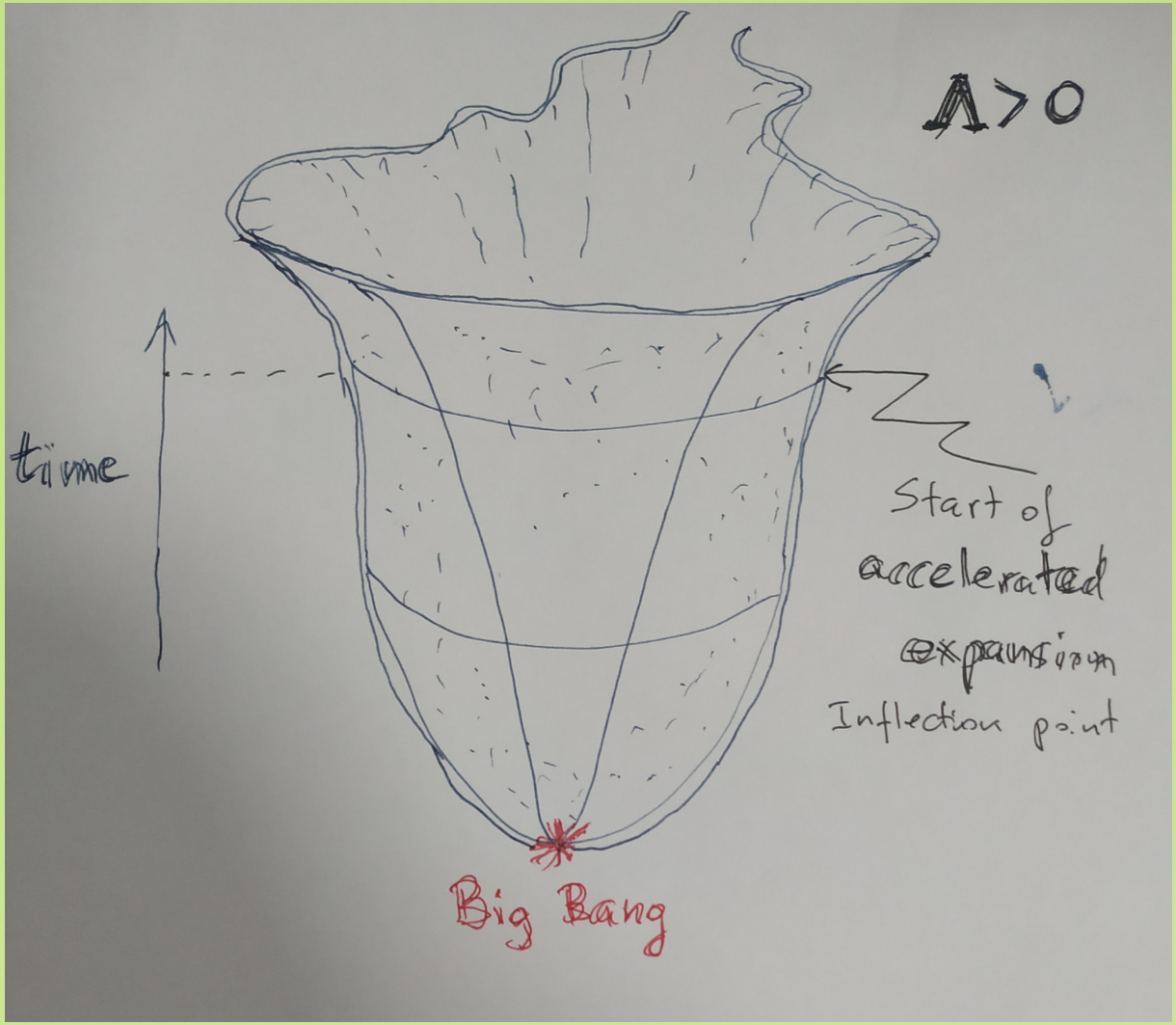
$K > 0$

Three types of Riemannian geometries:





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



Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box.** It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

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, which is called **entropy**. The **second law of thermodynamics** says that the entropy of an isolated system does not decrease with time. For example, **a gas compressed to a small volume in a corner of a box** container, will evolve from this very special configuration, and **after some time will be** in a stage in which **all the gas particles are quite uniformly distributed in the box**. It tends to the **stage of maximal entropy**.

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous.** As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models.**
- Another way was to try to find explanations of this fact **before the Big Bang.** (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

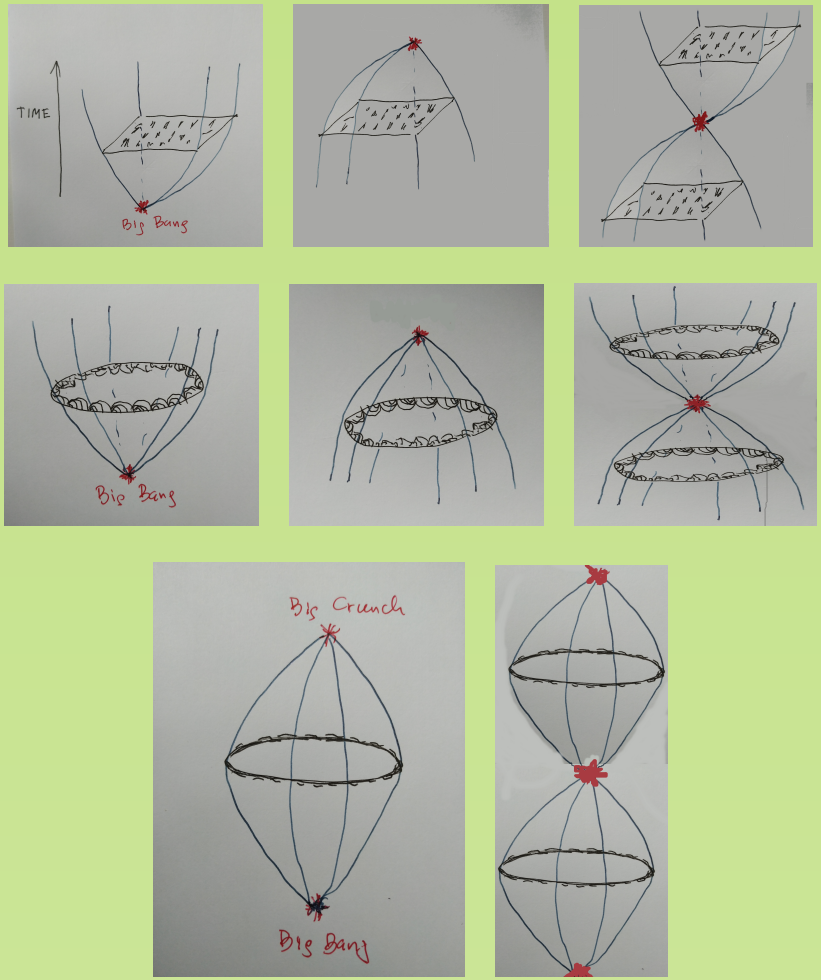
Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Troubles with the initial stage of the Universe

- Applying the Second Law to the **Universe**, we conclude that it should be more and more random during its evolution. 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 **extremally homogeneous**. As the Universe was **in a** totally random **stage of maximal entropy**.
- One way of resolving this conundrum was to introduce (quite ad hoc) **inflationary cosmological models**.
- Another way was to try to find explanations of this fact **before the Big Bang**. (e.g. the Italian physicist Gabriele Veneziano who considered string theory based 'pre-Big Bang scenarios' to replace inflation).

Atempts of glueing cosmological models: Friedman Universes



This does not work in the real Universe!

There is **gravity** in the real Universe, and it initiates proces of clamping of the matter, first in **stars**, then **galaxies**, and eventually in **black holes.** Black holes create **essential singularities** in the Universe**. Penrose** got the Nobel Prize in Physics in the year 2020, for proving that such objects will be created in practically any reasonable spacetime. Reversing the time in the Universe filled with black holes, would produce a **horrible** Big Crunch singularity!

This does not work in the real Universe!

There is **gravity** in the real Universe, and it initiates proces of clamping of the matter, first in **stars**, then **galaxies**, and eventually in **black holes.** Black holes create **essential singularities** in the Universe. **Penrose** got the Nobel Prize in Physics in the year 2020, for proving that such objects will be created in practically any reasonable spacetime. Reversing the time in the Universe filled with black holes, would produce a **horrible** Big Crunch singularity!

This does not work in the real Universe!

There is **gravity** in the real Universe, and it initiates proces of clamping of the matter, first in **stars**, then **galaxies**, and eventually in **black holes.** Black holes create **essential singularities** in the Universe. **Penrose** got the Nobel Prize in Physics in the year 2020, for proving that such objects will be created in practically any reasonable spacetime. Reversing the time in the Universe filled with black holes, would produce a **horrible** Big Crunch singularity!

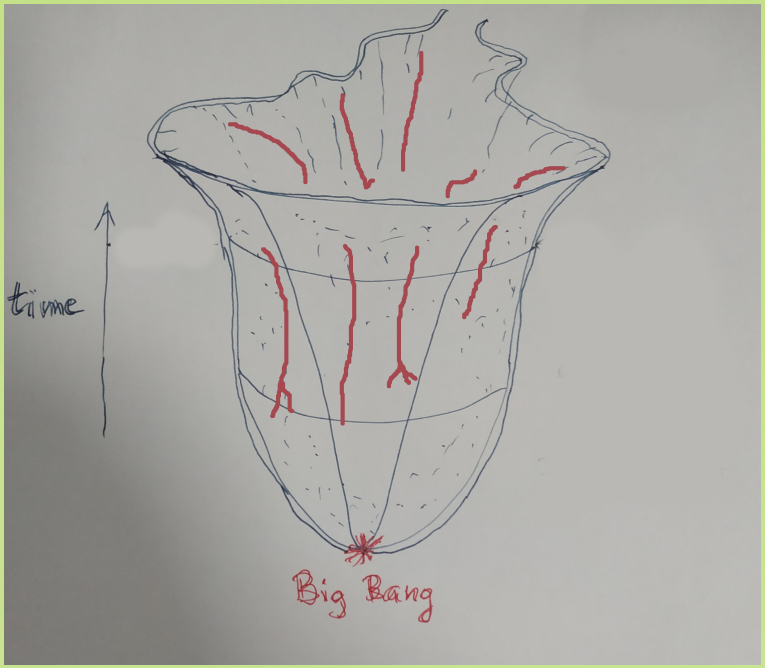
This does not work in the real Universe!

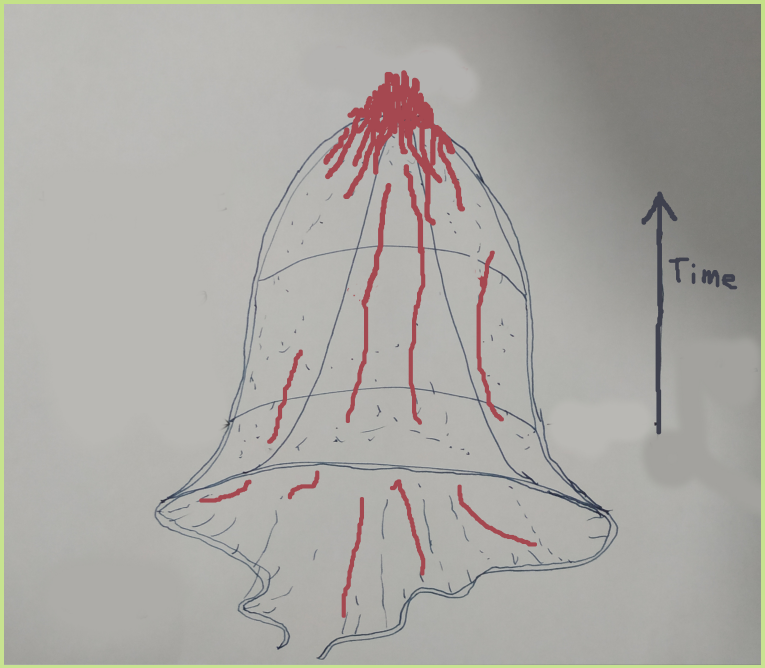
There is **gravity** in the real Universe, and it initiates proces of clamping of the matter, first in **stars**, then **galaxies**, and eventually in **black holes**. Black holes create **essential singularities** in the Universe. **Penrose** got the Nobel Prize in Physics in the year 2020, for proving that such objects will be created in practically any reasonable spacetime. Reversing the time in the Universe filled with black holes, would produce a **horrible** Big Crunch singularity!

This does not work in the real Universe!

There is **gravity** in the real Universe, and it initiates proces of clamping of the matter, first in **stars**, then **galaxies**, and eventually in **black holes**. Black holes create **essential singularities** in the Universe. **Penrose** got the Nobel Prize in Physics in the year 2020, for proving that such objects will be created in practically any reasonable spacetime. Reversing the time in the Universe filled with black holes, would produce a **horrible** Big Crunch singularity!

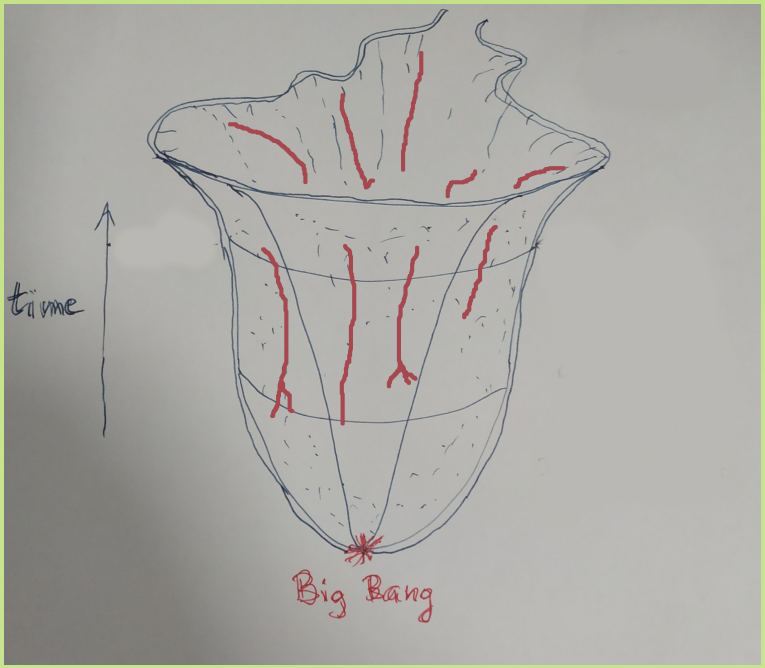
Reversing the time in the Universe with black holes

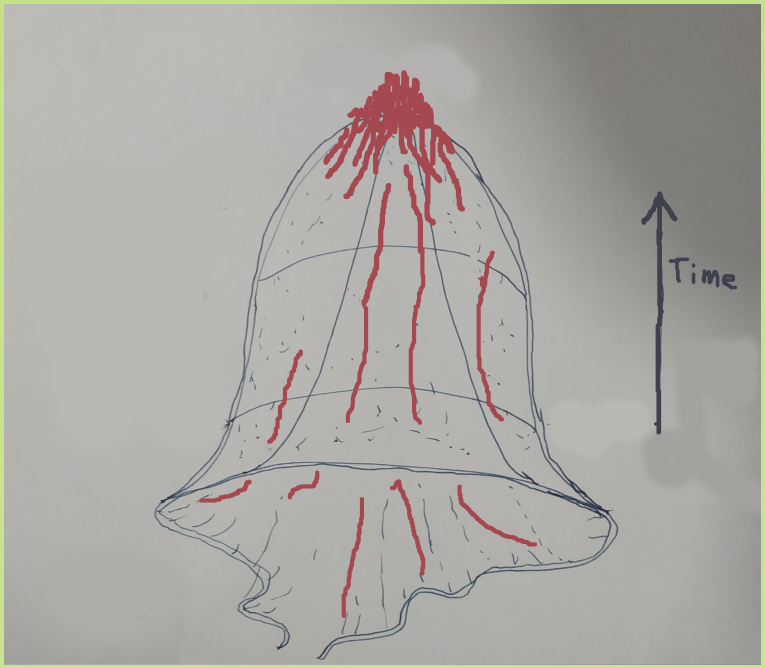




All our knowledge (the theory and observations) tells us that the singularity at the beginnig of our Universe is **extremely simple**! It is much much **simpler** than a singularity of **any black hole**. Nothing saying about comparison of it to the singularity in which many black holes are squized to death at the Big Crunch!

Reversing the time in the Universe with black holes



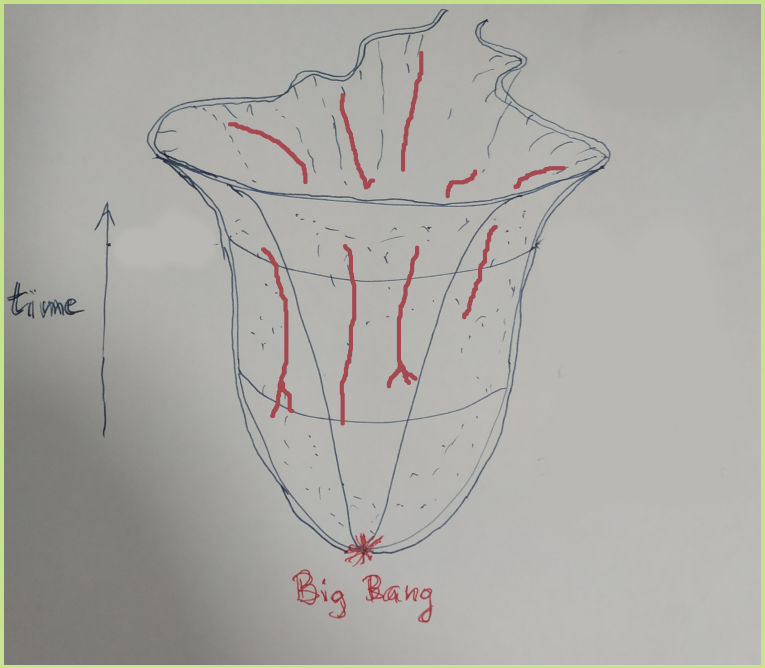


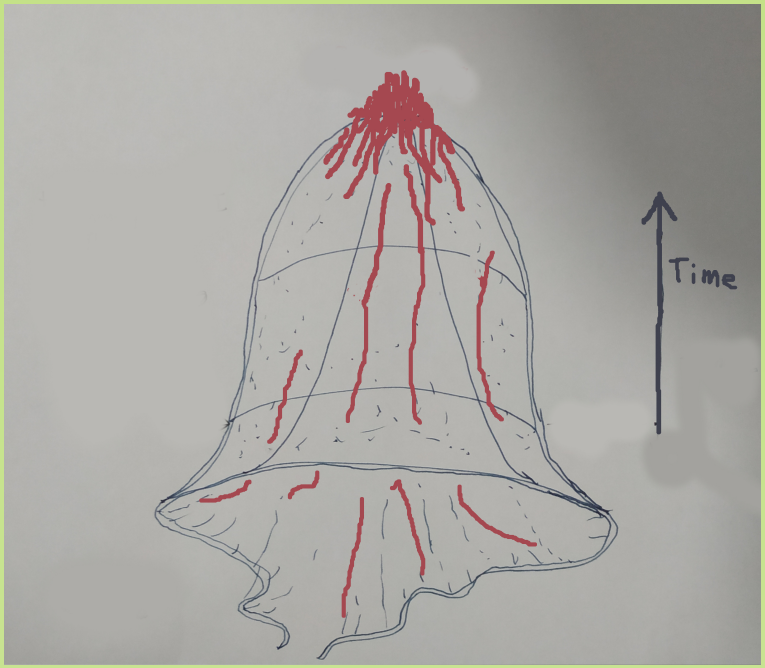
All our knowledge (the theory and observations) tells us that the singularity at the beginnig of our Universe is **extremely simple**!

It is much much **simpler** than a singularity of **any black hole**.

Nothing saying about comparison of it to the singularity in which many black holes are squized to death at the Big Crunch!

Reversing the time in the Universe with black holes

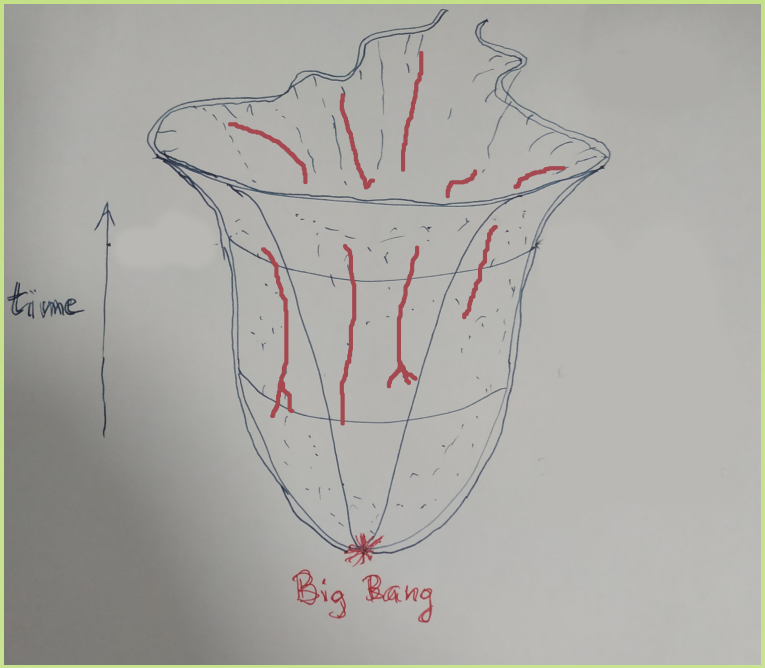


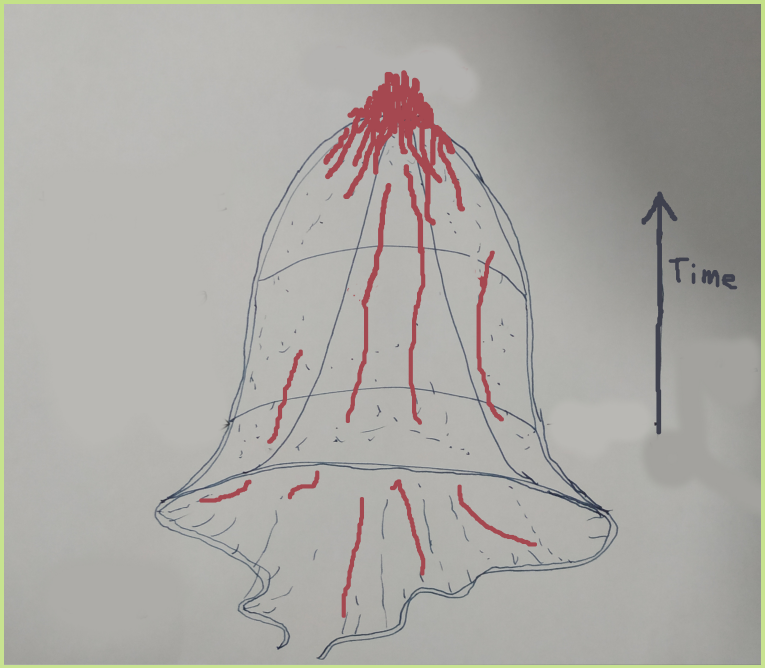


All our knowledge (the theory and observations) tells us that the singularity at the beginnig of our Universe is **extremely simple**! It is much much **simpler** than a singularity of **any black hole**.

Nothing saying about comparison of it to the singularity in which many black holes are squized to death at the Big Crunch!

Reversing the time in the Universe with black holes





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**. Nothing saying about comparison of it to the singularity in which many black holes are squized to death at the Big Crunch!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

Baby Universes: busted!

One physicist wrote once a book, which actually selled very well, proposing 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 '**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; A new born universe should be **conformally flat**; It **is** singular, **but** its singularity at the Big Bang surface is very weak: it involves one function only, its **conformal factor**!

What is then Penrose's answer for 'what was before the Big Bang'?

We need some preparations from the theory of
General Relativity.

Here is the picture from Penrose's Nobel winning article
'Gravitational collapse and spacetime singularities' from 1964:

What is then Penrose's answer for 'what was before the Big Bang'?

We need some preparations from the theory of
General Relativity.

Here is the picture from Penrose's Nobel winning article 'Gravitational collapse and spacetime singularities' from 1964:

What is then Penrose's answer for 'what was before the Big Bang'?

We need some preparations from the theory of
General Relativity.

Here is the picture from Penrose's Nobel winning article 'Gravitational collapse and spacetime singularities' from 1964:

What is then Penrose's answer for 'what was before the Big Bang'?

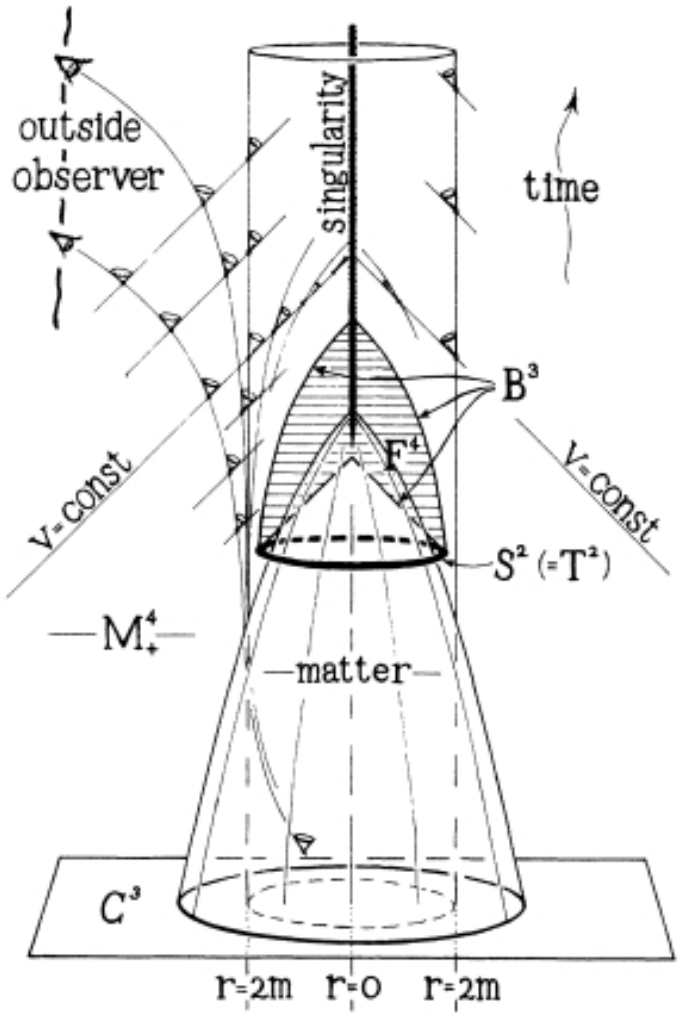


FIG. 1. Spherically symmetrical collapse (one space dimension surpressed). The diagram essentially also serves for the discussion of the asymmetrical case.

What is then Penrose's answer for 'what was before the Big Bang'?

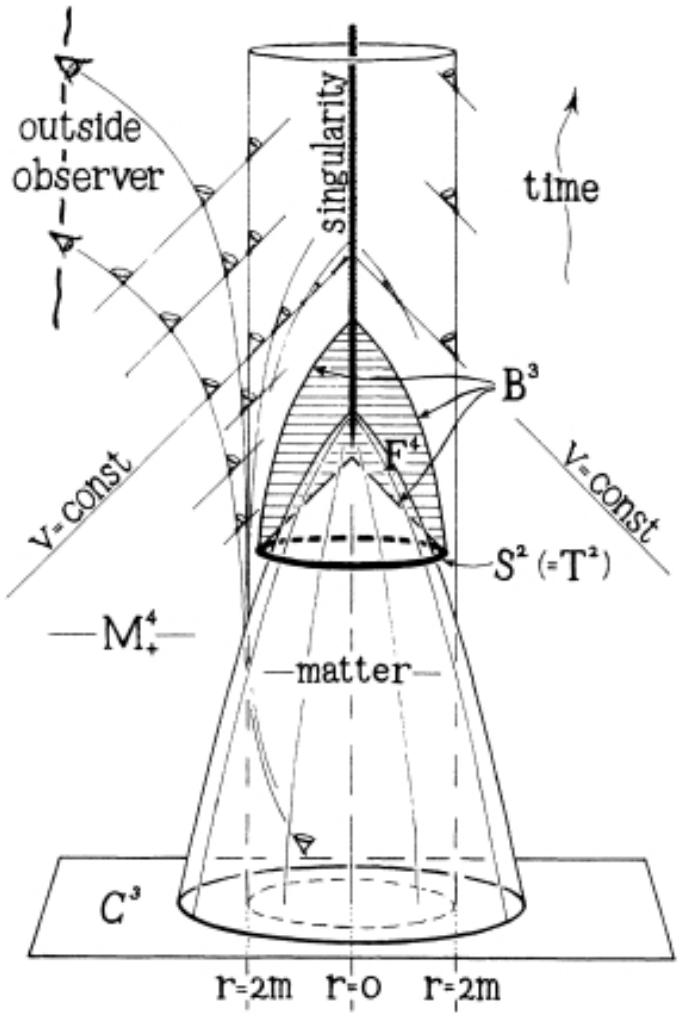
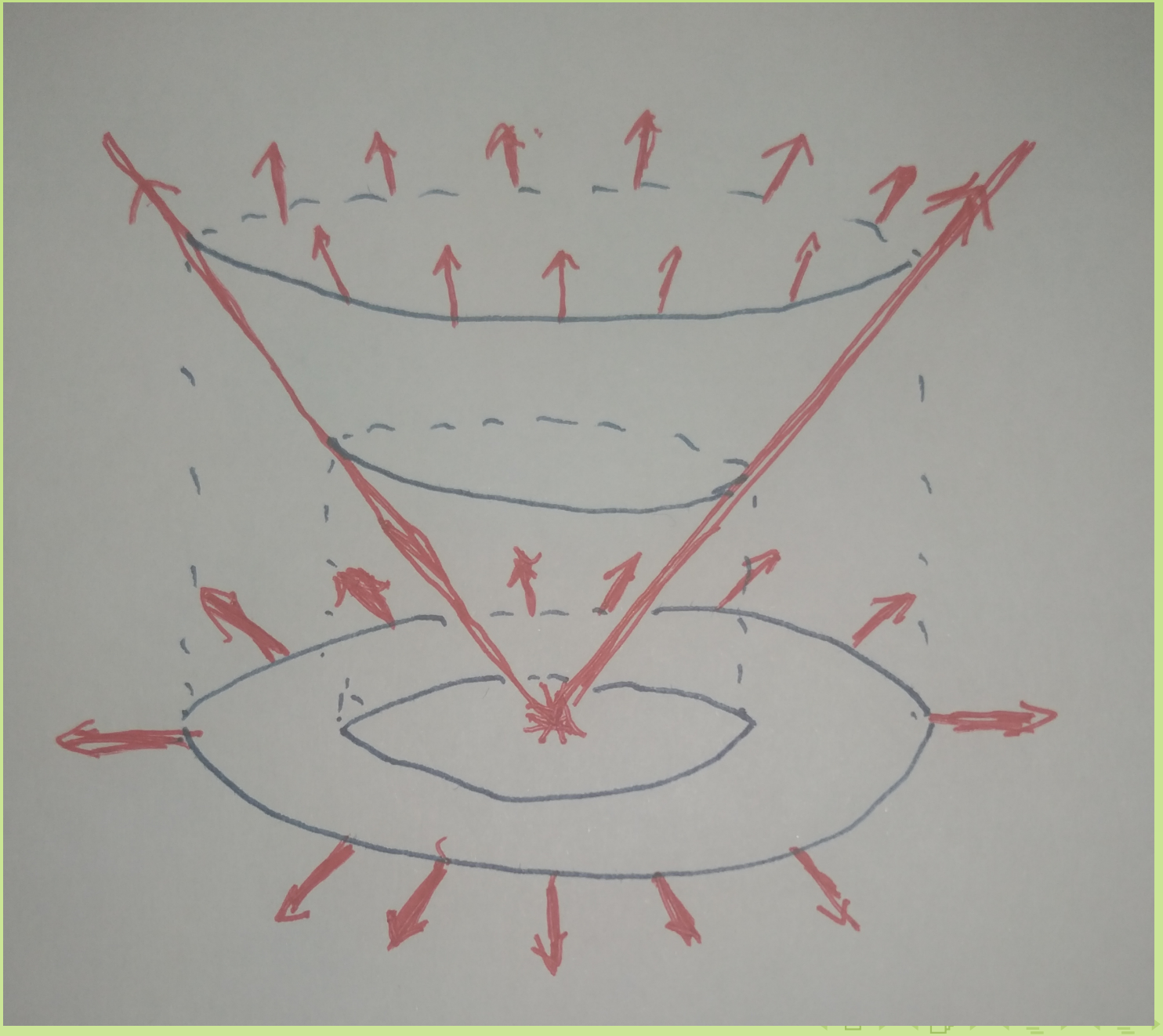


FIG. 1. Spherically symmetrical collapse (one space dimension surpressed). The diagram essentially also serves for the discussion of the asymmetrical case.

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



What is then Penrose's answer for 'what was before the Big Bang'?

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**. The distribution of cones gives us **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 **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.

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**. The distribution of cones gives us **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 **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.

What is then Penrose's answer for 'what was before the Big Bang'?

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**. The distribution of cones gives us **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 **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.

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**.

The distribution of cones gives us **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 **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.

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**. The distribution of cones gives us **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 **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.

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**. The distribution of cones gives us **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 **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.

The **structure of spacetime** is described in terms of the **distribution** of **light cones** on the arena of events called a **manifold**. Knowing how the light cones are distributed, and how they are squized, tilted and deformed on the manifold we have essentially all the information about the spacetime; Well all, except the ability of observers/particles to measure **time**. The distribution of cones gives us **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 **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.

- 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**.

- 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**.

- 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**.

- 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**.

- 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**.

- 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**.

- 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**.

- 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**.

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

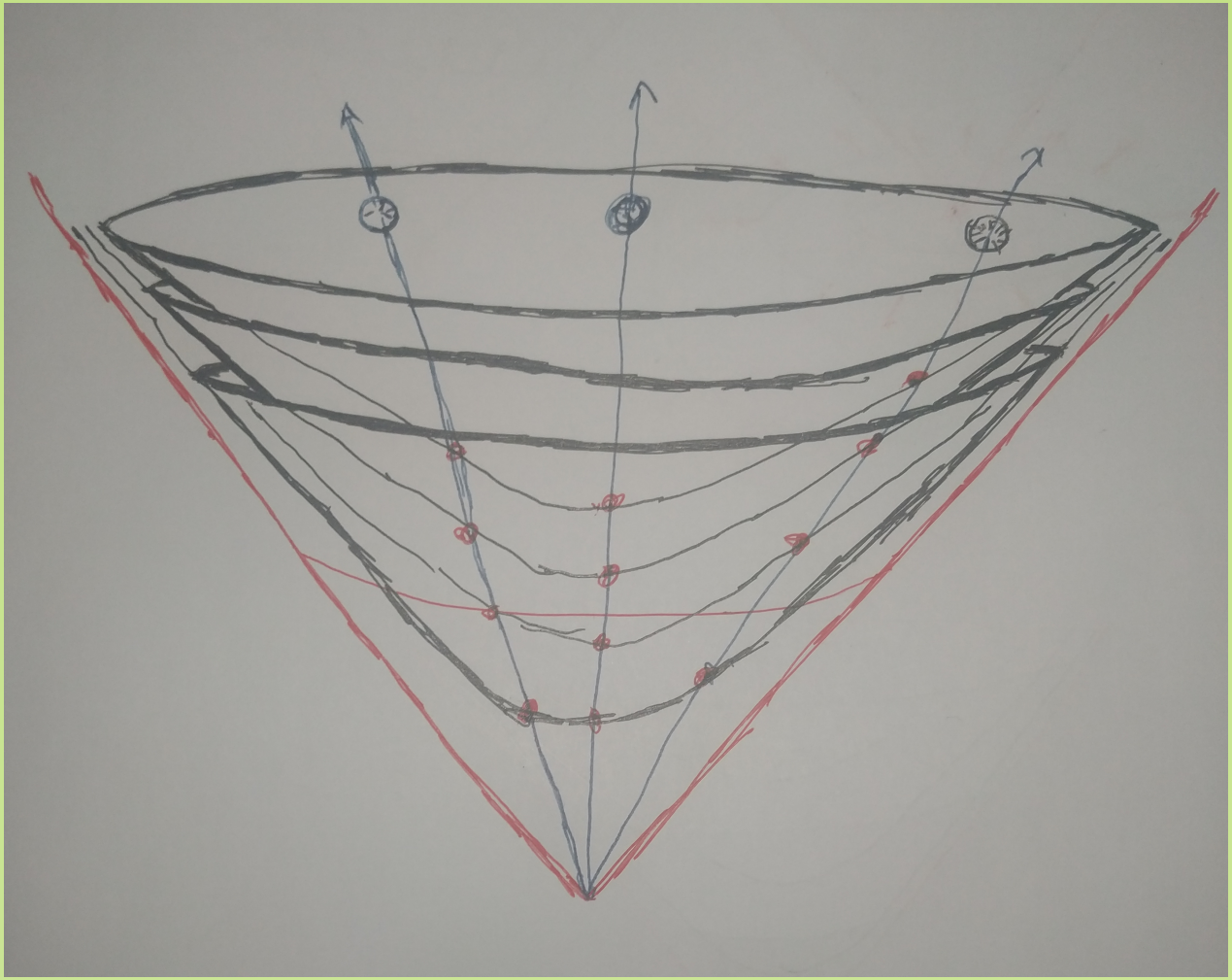
$$E = h\nu \quad \text{(Planck)} \quad \text{and} \quad E = mc^2 \quad \text{(Einstein)}.$$

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

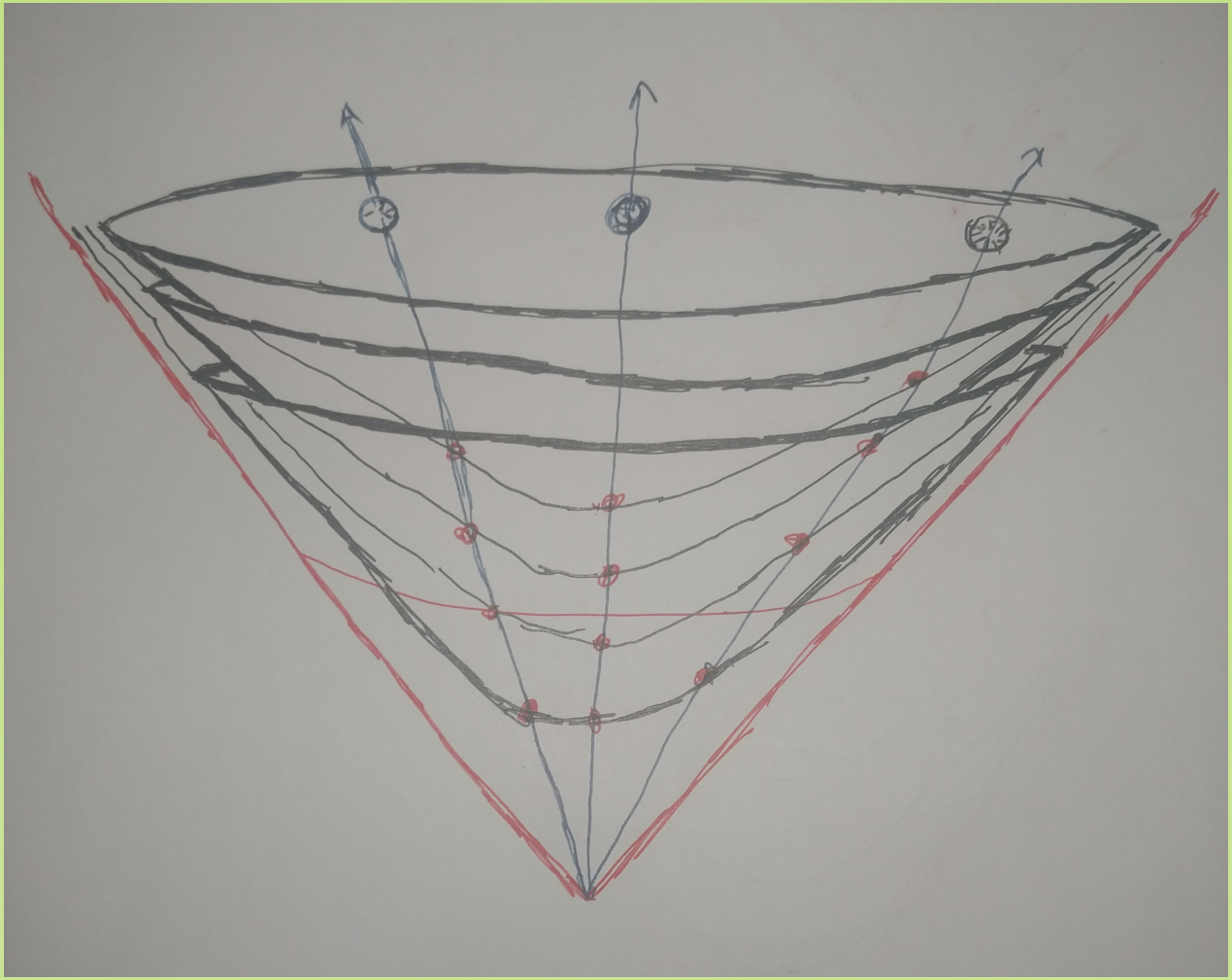
$$T = m^{-1}$$

  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**.

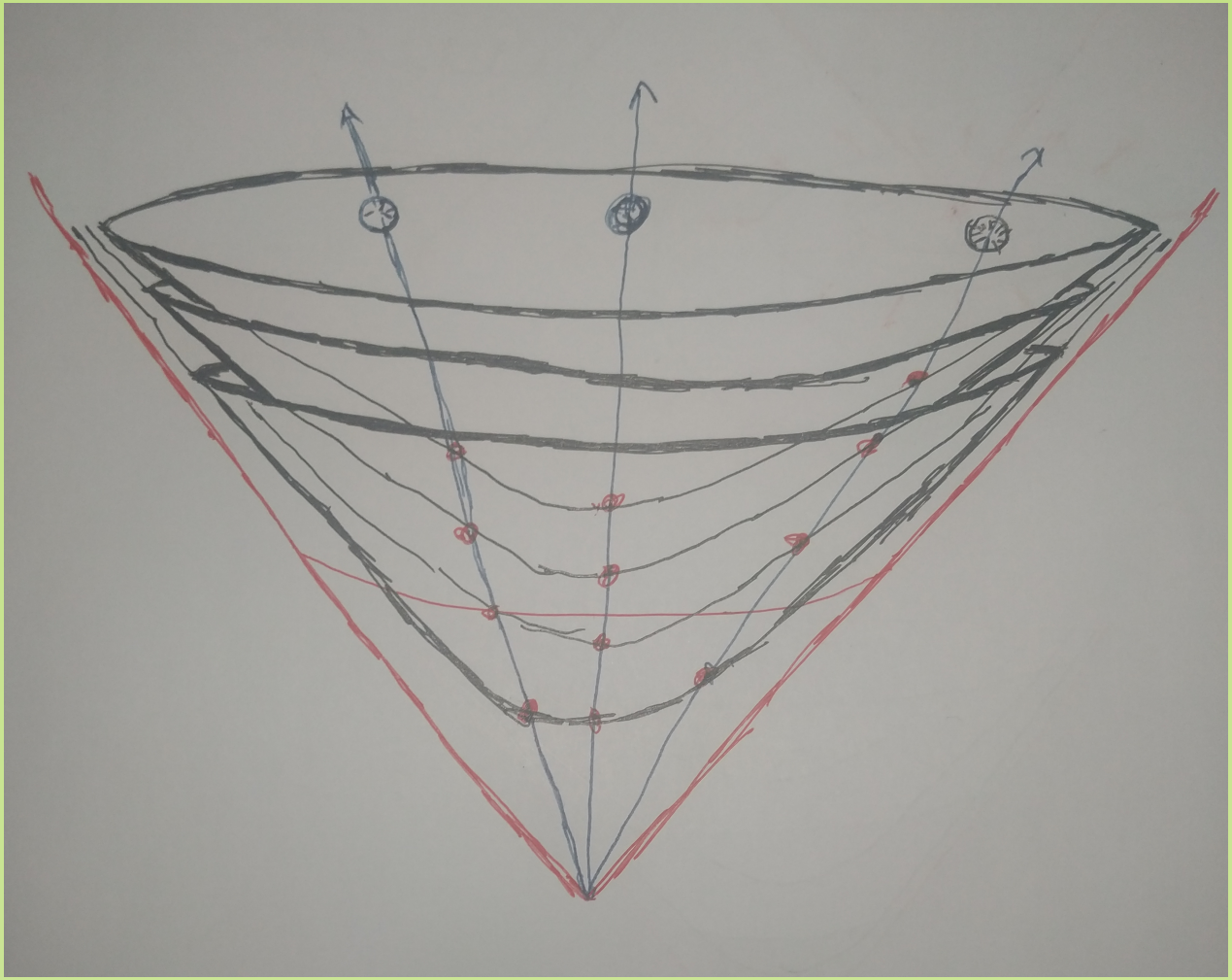
‘What was before the Big Bang’?: measuring time



Photons (massless particles) **do not feel time.** Penrose: it is difficult to bore a photon.

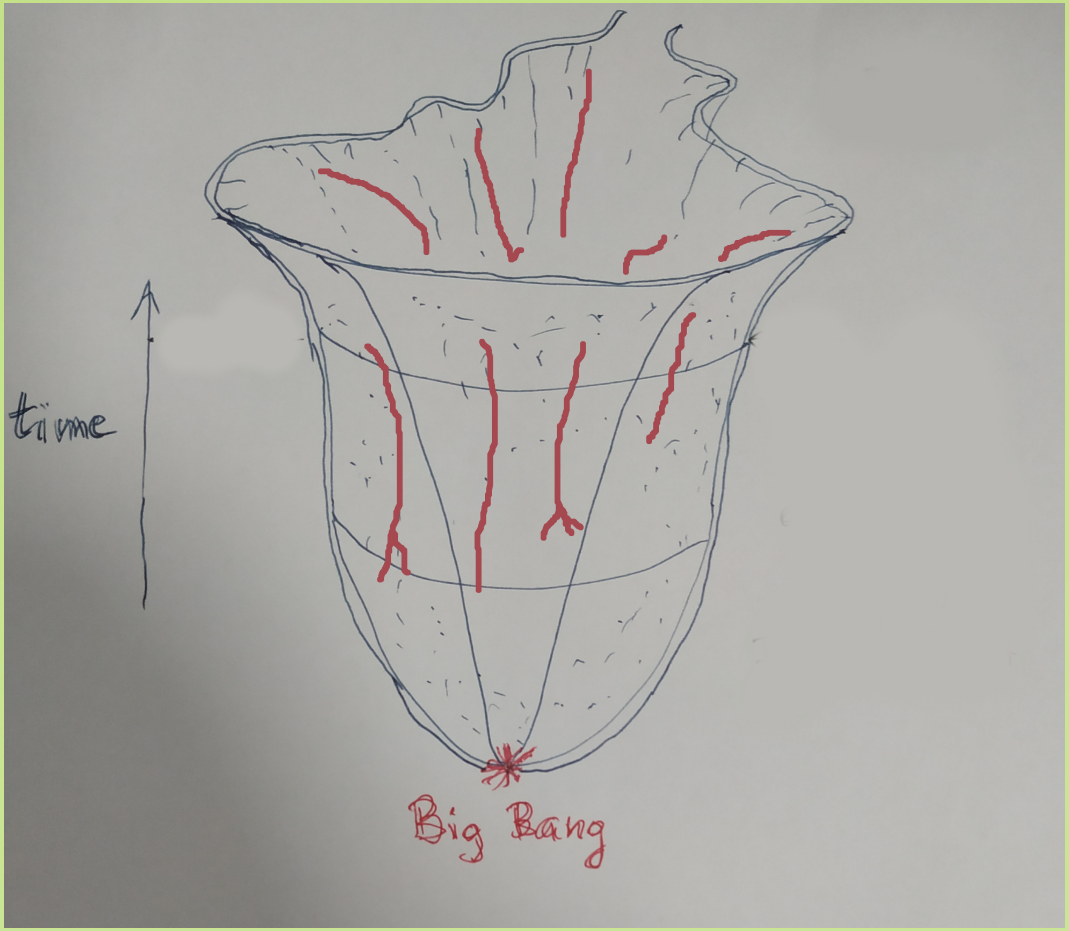


Photons (massless particles) **do not feel time.** Penrose: it is difficult to bore a photon.

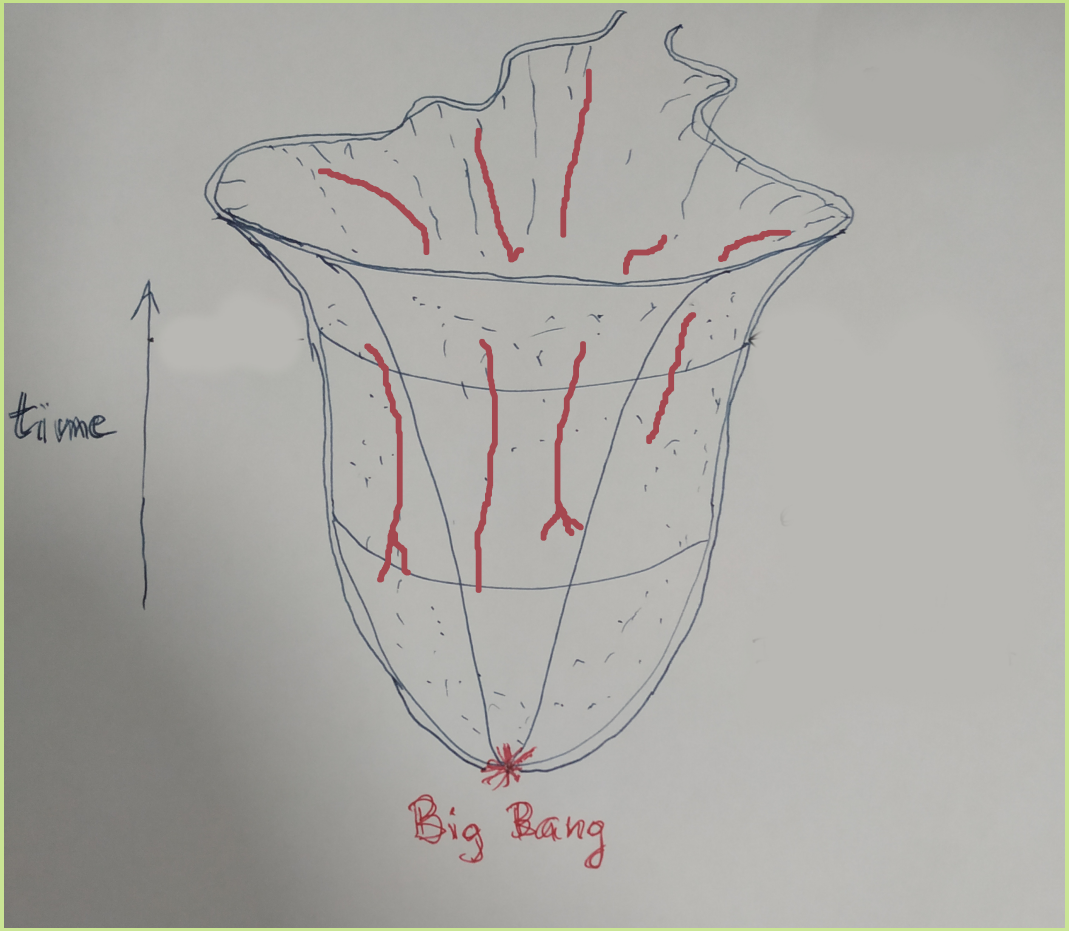


Photons (massless particles) **do not feel time**. Penrose: it is difficult to bore a photon.

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



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



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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

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

- Positive cosmological constant Λ means that **Universe will expand forever**
- It will be that old that stable particles, such as protons will decay (10^{34} years), will be that old that even **supermassive black holes** will Hawking-evaporate (google years $\sim 10^{100}$ years), all masses vanish, **only massless particles remain**.
- Universe **will loose the notion of time**!
- Out of the **10** functions defining spacetime structure of the Universe, only **9** will remain.
- Universe will pass from the phase of being equipped with the geometry of a **metric** into the phase when it is equipped with the **conformal geometry only**. The phase of a **conformal** Universe will start. Penrose: very boring era!
- From this moment the Universe will still live infinitely long aproaching asymptotically the **conformally flat** deSitter spacetime.
- Because of the positive cosmological constant **conformal boundary** of the Universe - the hypersurface where all the light rays (and other **null geodesics**) tend to - will be **spacelike**.
- Note, that if Λ **was not strictly positive** - the conformal boundary of the Universe, its end, **would not be spacelike**.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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.

‘What was before the Big Bang’?: Penrose’s main argument

- 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**!!!

- 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**!!!

- 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**!!!

Definition

A 4-dimensional spacetime M is equipped with a **conformal structure** $[g]$ if it is equipped with a class of metrics g of signature $(-,+,+,+)$ such that two metrics g and $\check{g}$ are in the same class if and only if there exists a function Ω such that $\check{g} = \Omega^2 g$. 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.

Definition

A 4-dimensional spacetime M is equipped with a **conformal structure** $[g]$ if it is equipped with a class of metrics g of signature $(-,+,+,+)$ such that two metrics g and $\check{g}$ are in the same class if and only if there exists a function Ω such that $\check{g} = \Omega^2 g$. 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.

Definition

A 4-dimensional spacetime M is equipped with a **conformal structure** $[g]$ if it is equipped with a class of metrics g of signature $(-,+,+,+)$ such that two metrics g and $\check{g}$ are in the same class if and only if there exists a function Ω such that $\check{g} = \Omega^2 g$. 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.

Definition
A 4-dimensional spacetime M is equipped with a **conformal structure** $[g]$ if it is equipped with a class of metrics g of signature $(-,+,+,+)$ such that two metrics g and $\check{g}$ are in the same class if and only if there exists a function Ω such that $\check{g} = \Omega^2 g$. 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.

- 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**!

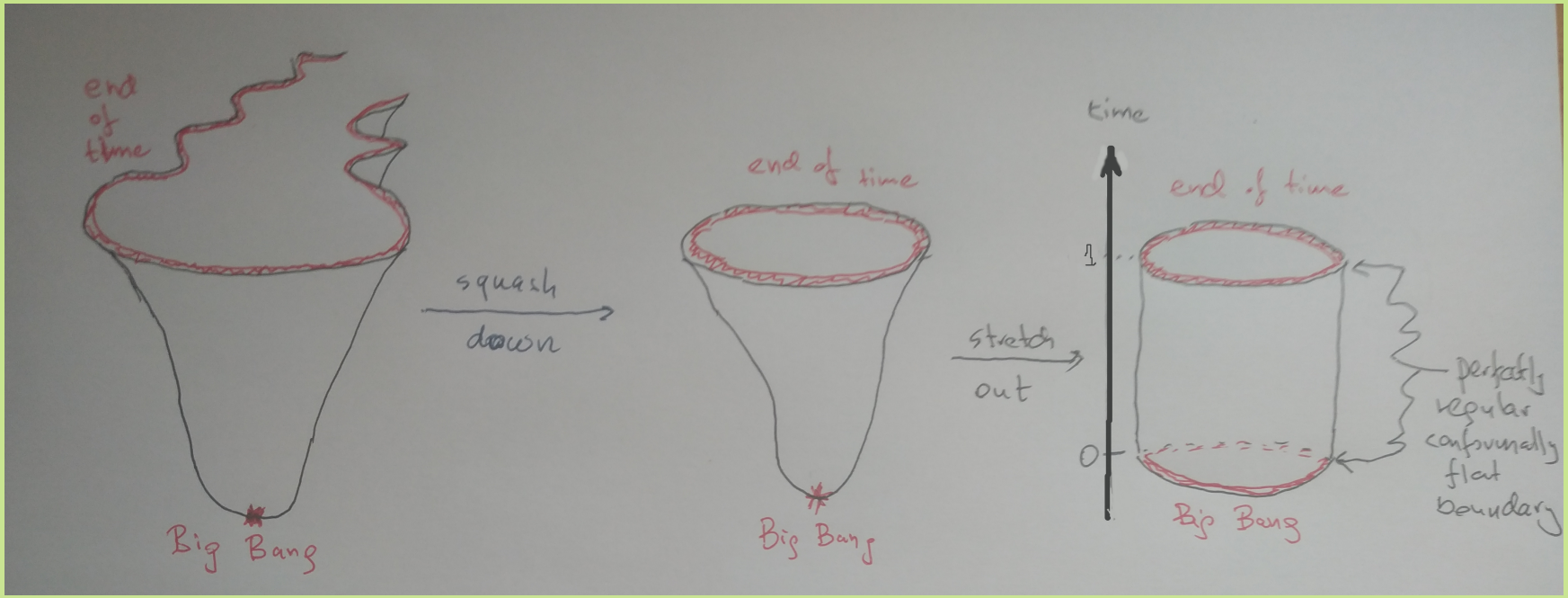
- By chosing conformal factor Ω in a way such that it **tends to zero** when the **space infinitely expands** we can make the size of the space **finite**. **Conformal squash down**.
- By chosing conformal factor Ω in a way such that it **tends to infinity** when the **space shrinks to zero** we can 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**!

- 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**!

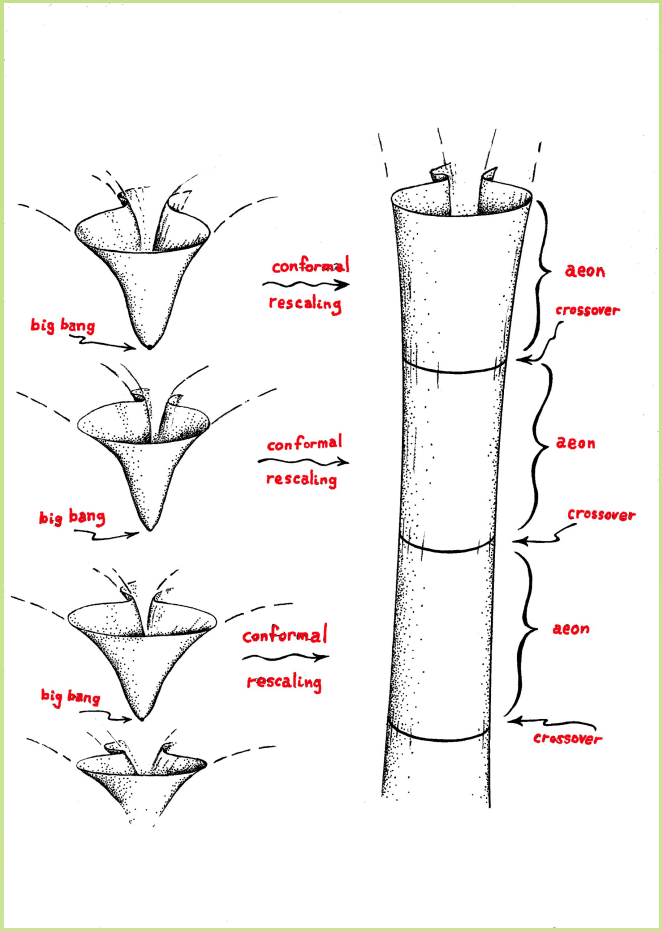
- By chosing conformal factor Ω in a way such that it **tends to zero** when the **space infinitely expands** we can make the size of the space **finite**. **Conformal squash down**.
- By chosing conformal factor Ω in a way such that it **tends to infinity** when the **space shrinks to zero** we can 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**!

- 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**!

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



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



Penrose's Conformal Cyclic Cosmology

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

Penrose's Conformal Cyclic Cosmology

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the metric on each $\mathscr{I}$ **is zero**.
- **DISCLAIMER**:
- *CCC* says **nothing** about this what is the physics in a given eon when the physical age of it **is normal**; **normal** meaning that eon is neither **too young** nor **too old**. *CCC* tells what is going on when an eon is **either about to die, or had just been born**.
- In particular, *CCC* does **not** require that the eons have the same history! It is Conformal Cyclic Cosmology, and **not** Conformal Periodic Cosmology!

Penrose's Conformal Cyclic Cosmology

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

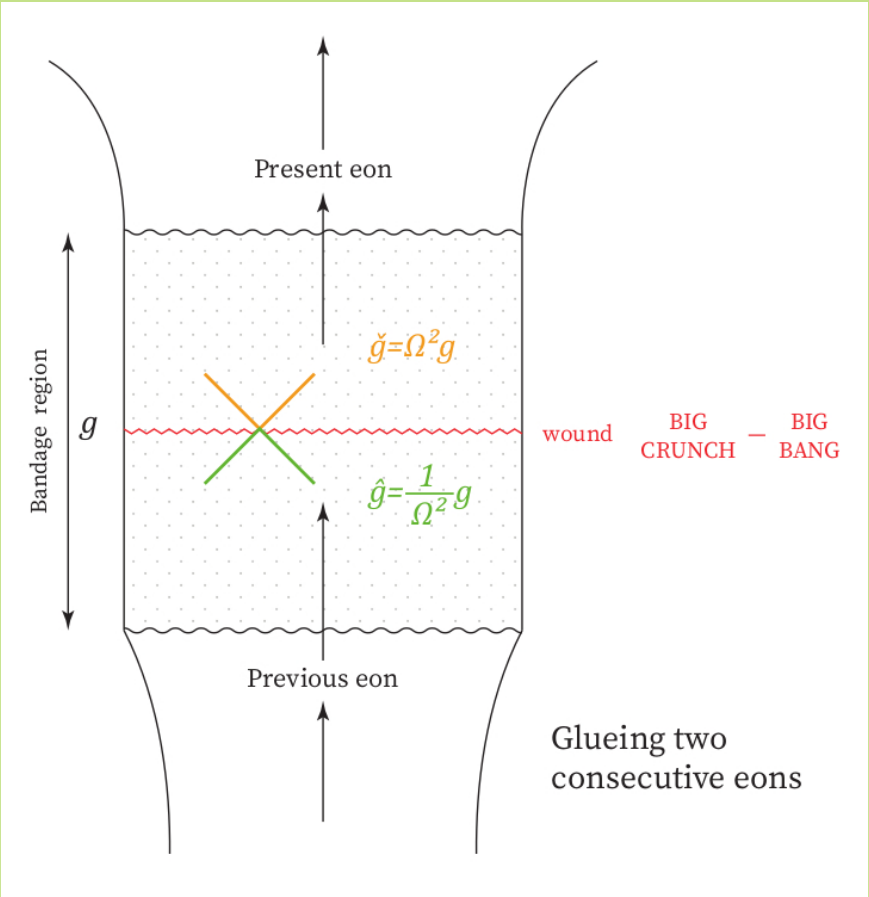
- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

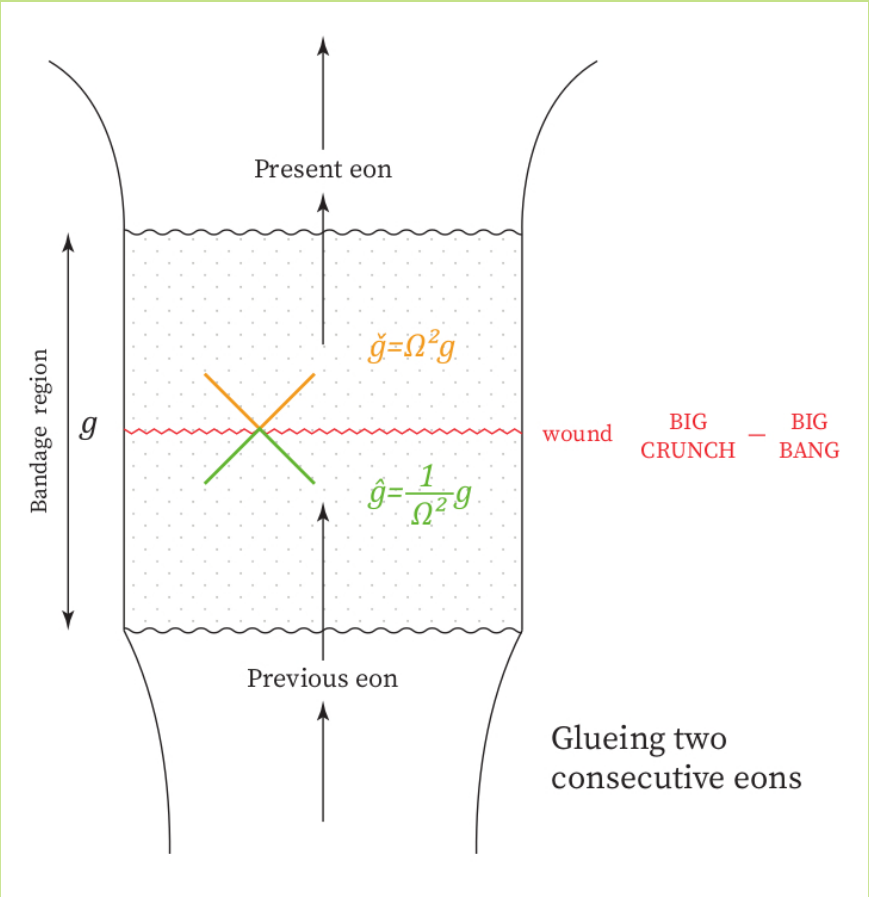
- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

- The Universe consists of **eons**, each being a **time oriented** spacetime, whose **conformal compactifications** have **spacelike** $\mathscr{I}$. The **Weyl tensor** of the 4-metric on each $\mathscr{I}$ **is zero**.
- Eons are ordered, and the **conformal compactifications** of consecutive eons, say **the past one** and **the present one**, are **glued together** along $\mathscr{I}^+$ **of the past eon**, and $\mathscr{I}^-$ **of the present eon**.
- The **vicinity of the matching surface** (the **wound**) of the past and the present eons – this region Penrose calls **bandaged region** for the two eons – is equipped with the following **three metrics**, which are **conformally flat** at the wound:
  - a Lorentzian metric g which is regular everywhere,
  - a Lorentzian metric $\check{g}$, which represents the physical metric of the **present eon**, and which is **singular** at the wound,
  - a Lorentzian metric $\hat{g}$, which represents the physical metric of the **past eon**, and which **infinitely expands** at the wound.

Penrose's Conformal Cyclic Cosmology: bandage region



Penrose's Conformal Cyclic Cosmology: bandage region



- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there.** Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there.** Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\breve{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\breve{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\breve{g}$ **in the present eon** is a **physical metric there.** Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\breve{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that

  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there.** Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there.** Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there.** Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there**. Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there**. Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there**. Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there**. Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

- In a bandage region, the **three metrics** g, $\check{g}$ and $\hat{g}$, are **conformally related** on their overlaping domains.
- How to make this relation specific is debatable, but Penrose proposes that
  $\check{g} = \Omega^2 g$, and $\hat{g} = \frac{1}{\Omega^2} g$, with $\Omega \to 0$ on the wound.
- The metric $\check{g}$ **in the present eon** is a **physical metric there**. Likewise, the metric $\hat{g}$ **in the past eon** is a **physical metric there**.
- Of course, the metric $\check{g}$ **in the present eon**, and the metric $\hat{g}$ **in the past eon**, as **physical spacetime metrics**, **should satisfy Einstein's equations** in their spacetimes, respectively.

CAN WE SEE IT?

CAN WE SEE IT?

Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

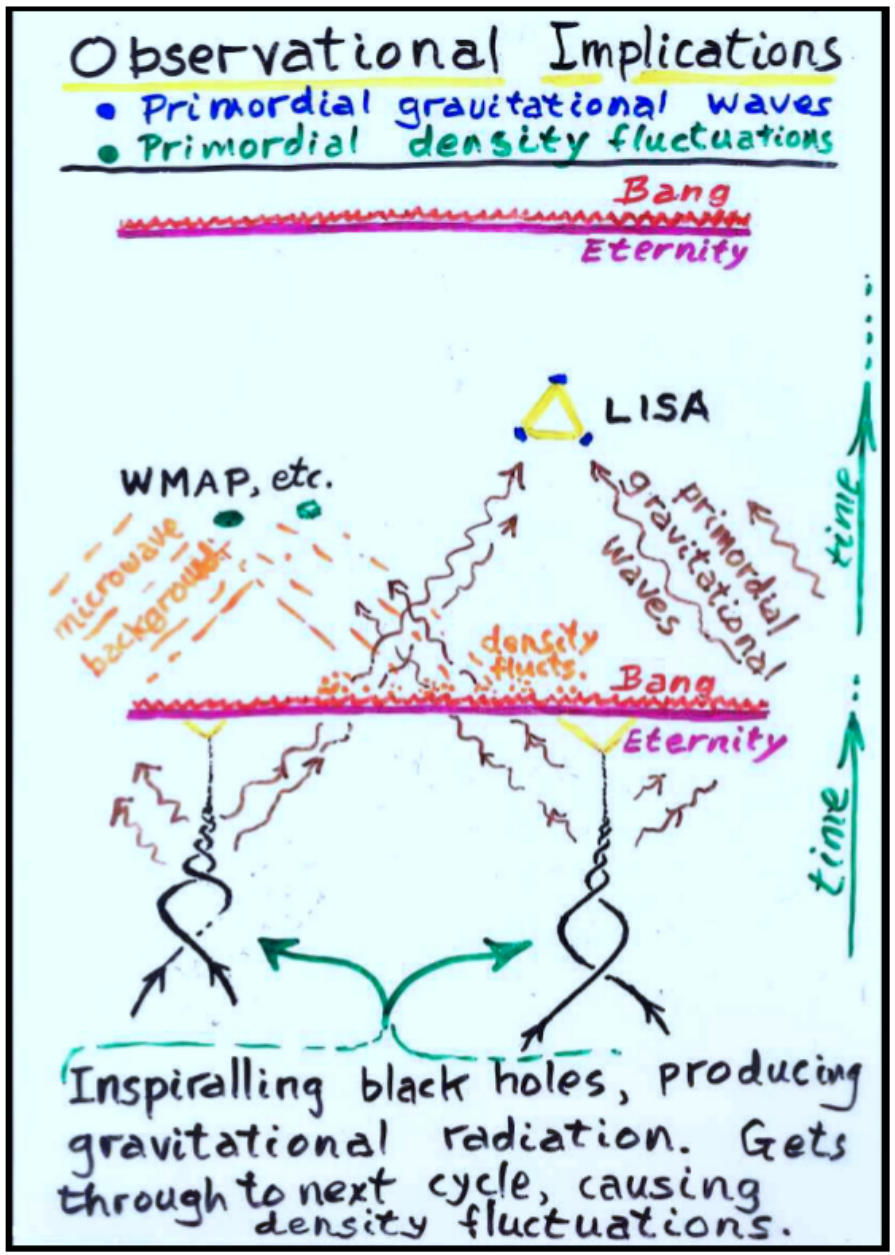
Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

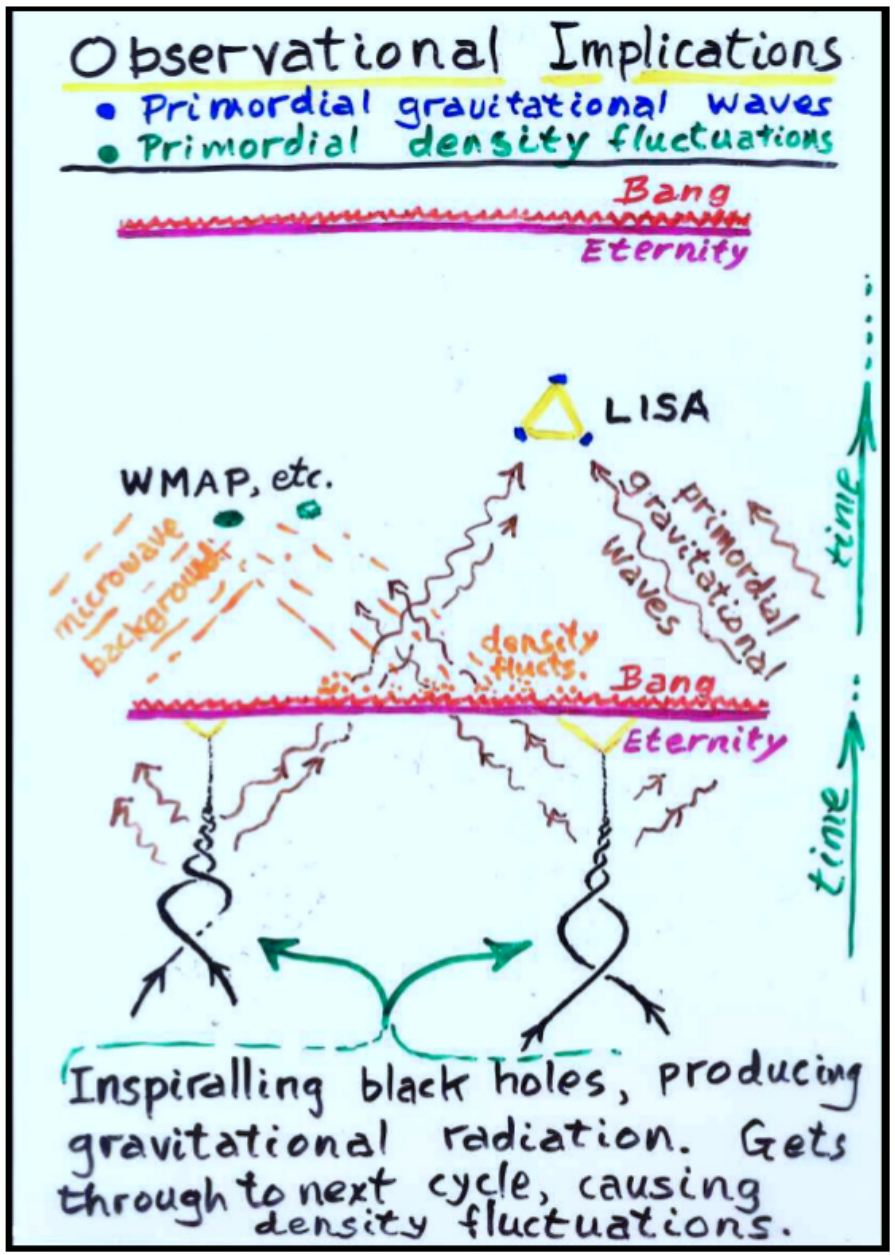
Penrose's Conformal Cyclic Cosmology: photons dont die!

- There is a class of intrinsically defined **Lorentz-metric-geometric-objects** that are also **conformal-geometric-objects**.
- Even if the conformal factor of the metric is not defined - as in the case of bare conformal geometry - they are good objects of conformal geometry.
- These, in particular, are **null geodesics**.
- In General Relativity Theory they model **worldlines of the massless particles**. Such as **photons**.
- So photons, and more generally **radiation** carried by **massless particles**, have no obstacles to traverse the boundaries of eons!
- In principle we could see photons from the previous eon!
- Crazy idea because...

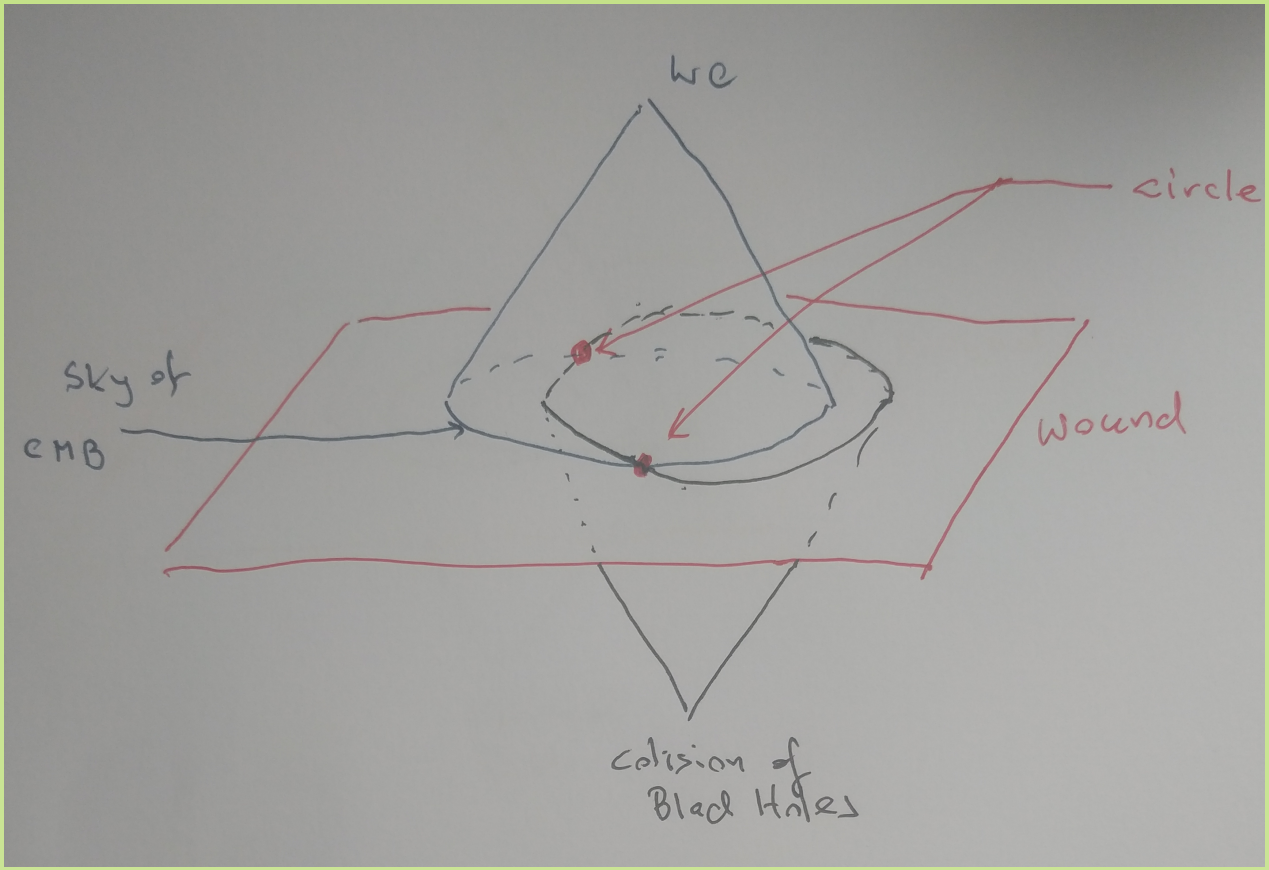
Penrose's Conformal Cyclic Cosmology: circles in the CMBR maps



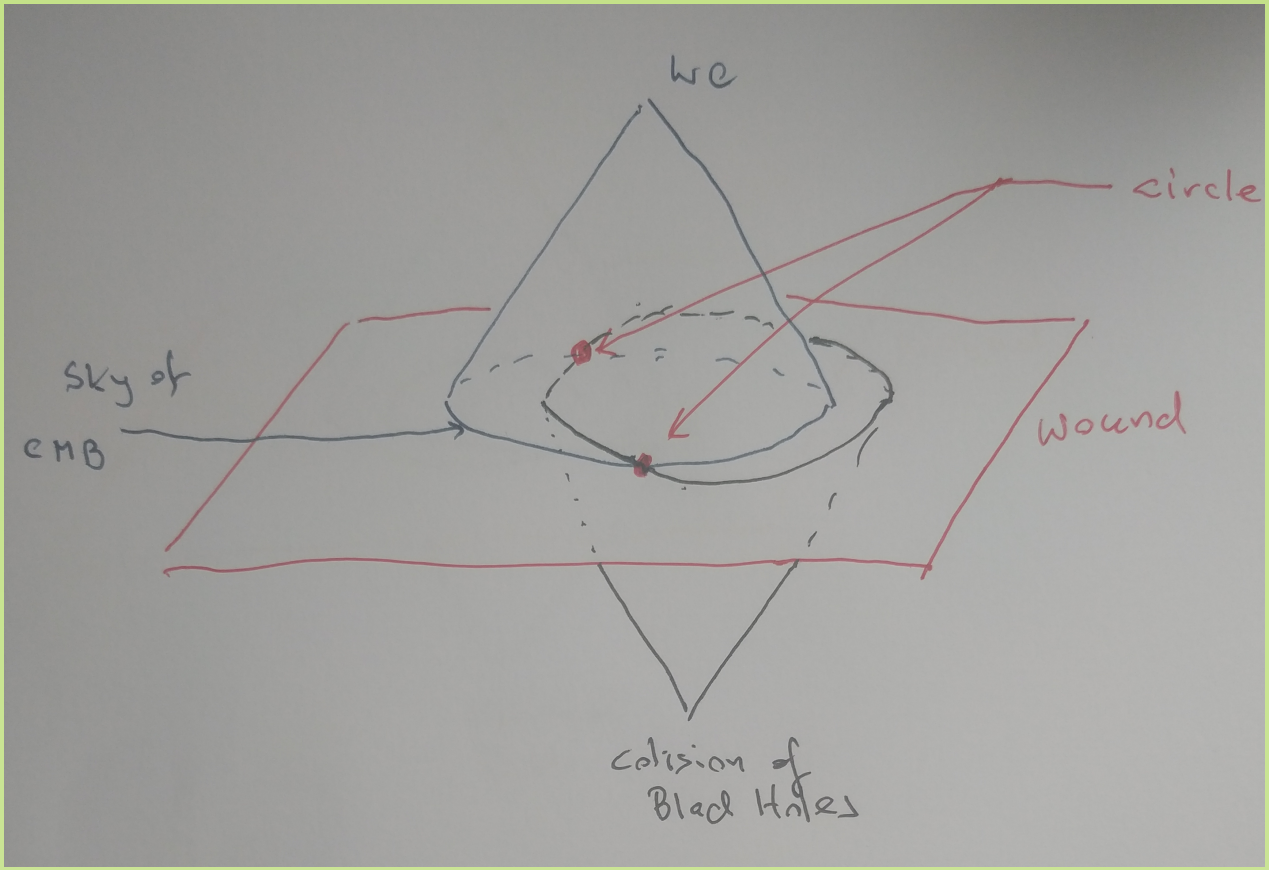
Penrose's Conformal Cyclic Cosmology: circles in the CMBR maps



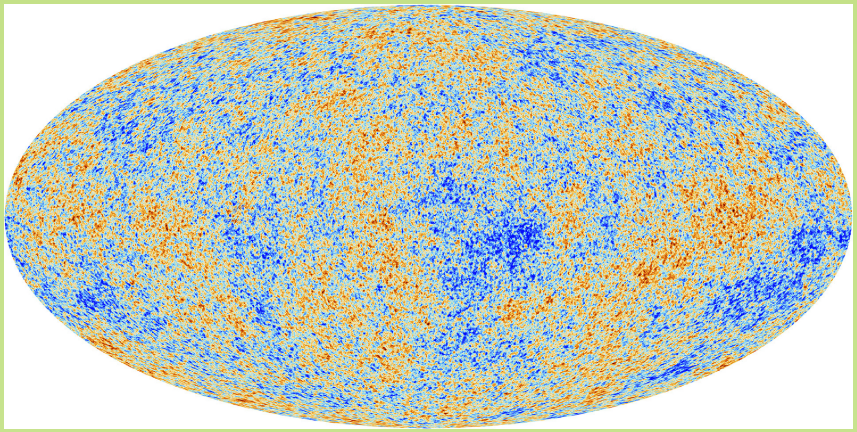
Penrose's Conformal Cyclic Cosmology: circles in the CMBR maps



Penrose's Conformal Cyclic Cosmology: circles in the CMBR maps

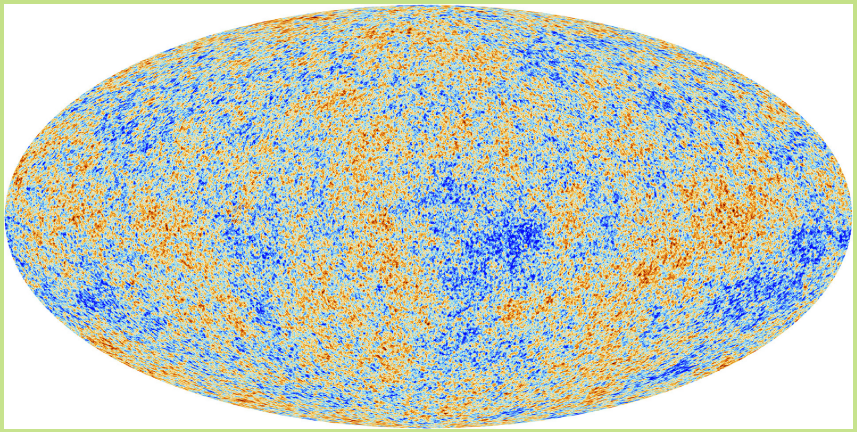


Penrose's Conformal Cyclic Cosmology: circles in the Planck maps?



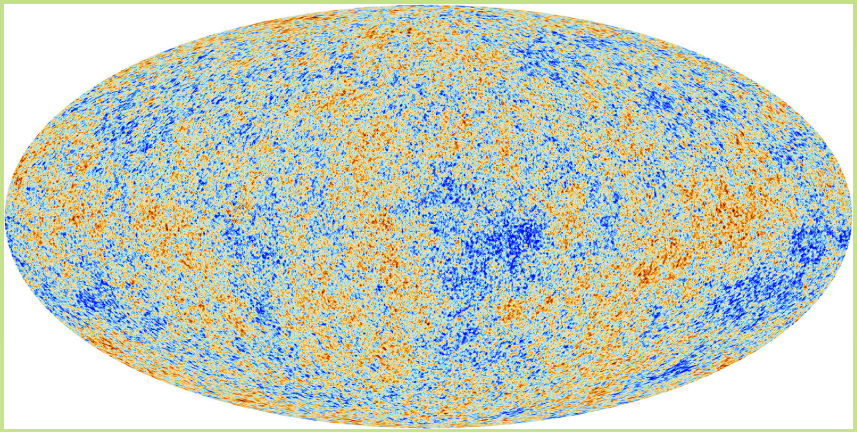
We attemeted to answer this questionfirst in a team of **Krzysztof Meissner**, **Blazej Ruszczycki** and myself (WMAP data), and then with **Daniel An**, **Krzysztof Meissner** and myself (PLANCK data). Later on, we did different analysis of the PLANCK data in the team of **Daniel An**, **Krzysztof Meissner**,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

Penrose's Conformal Cyclic Cosmology: circles in the Planck maps?

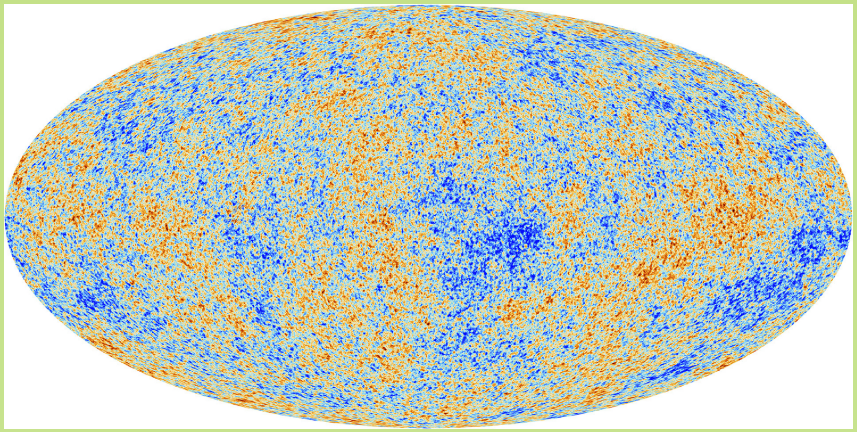


We attemeted to answer this questionfirst in a team of **Krzysztof Meissner**, **Blazej Ruszczycki** and myself (WMAP data), and then with **Daniel An**, **Krzysztof Meissner** and myself (PLANCK data). Later on, we did different analysis of the PLANCK data in the team of **Daniel An**, **Krzysztof Meissner**,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

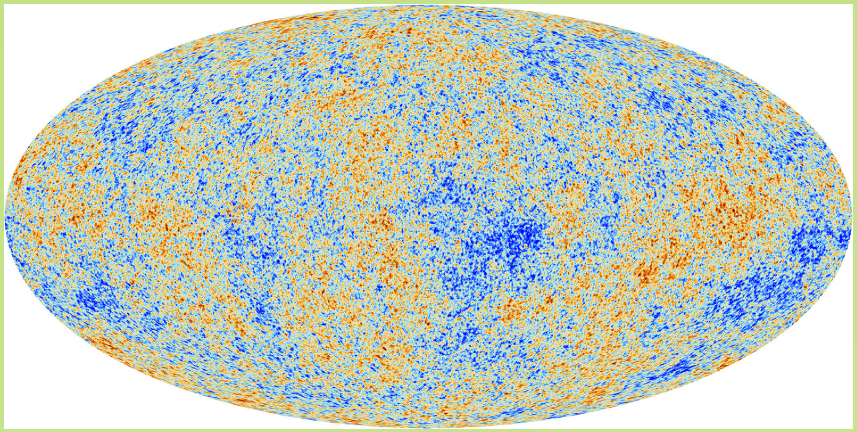
Penrose's Conformal Cyclic Cosmology: circles in the Planck maps?



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).

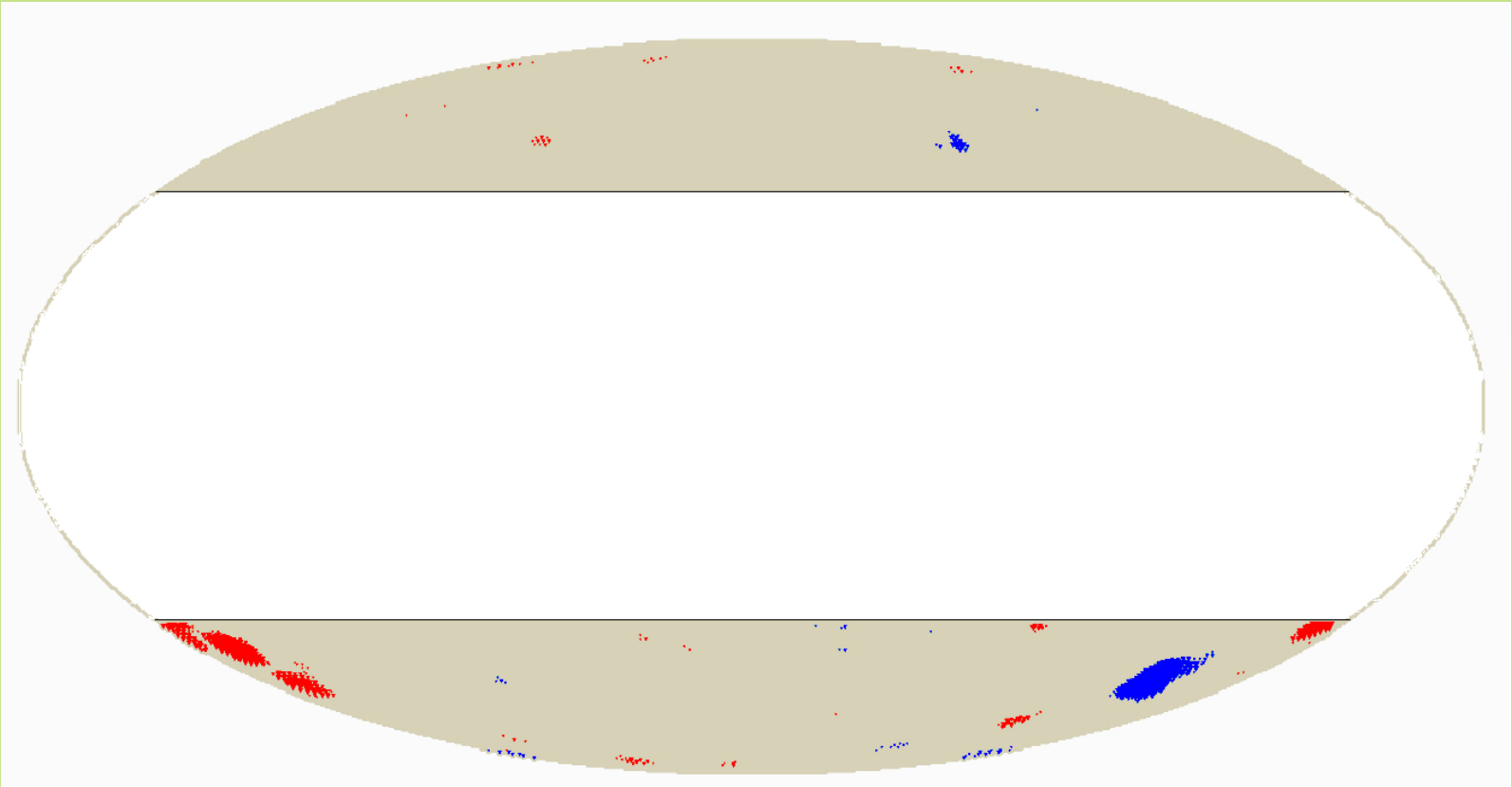


We attemeted to answer this questionfirst in a team of **Krzysztof Meissner**, **Blazej Ruszczycki** and myself (WMAP data), and then with **Daniel An**, **Krzysztof Meissner** and myself (PLANCK data). Later on, we did different analysis of the PLANCK data in the team of **Daniel An**, **Krzysztof Meissner**,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

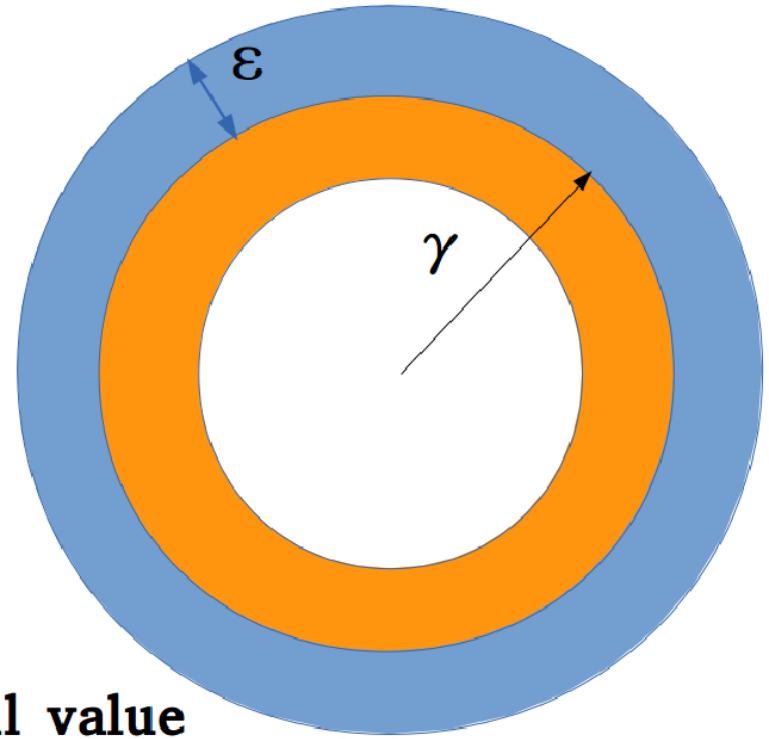


We attemeted to answer this questionfirst in a team of **Krzysztof Meissner**, **Blazej Ruszczycki** and myself (WMAP data), and then with **Daniel An**, **Krzysztof Meissner** and myself (PLANCK data). Later on, we did different analysis of the PLANCK data in the team of **Daniel An**, **Krzysztof Meissner**,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

Exclusion of the Milky Way belt



Ring definition



Integral value
= Inner Avg Temp – Outer Avg Temp

Overlap integrals

- Then

$$I_{(\epsilon,\gamma_k)}(\theta^i,\phi^i) = \sum_{M_-} \frac{\Delta T_m}{N_-} - \sum_{M_+} \frac{\Delta T_m}{N_+}$$

- The first sum runs over all points that belong to the inner circle (between $\gamma - \epsilon$ and γ) and the second sum runs over the outer circle (between γ and $\gamma + \epsilon$)

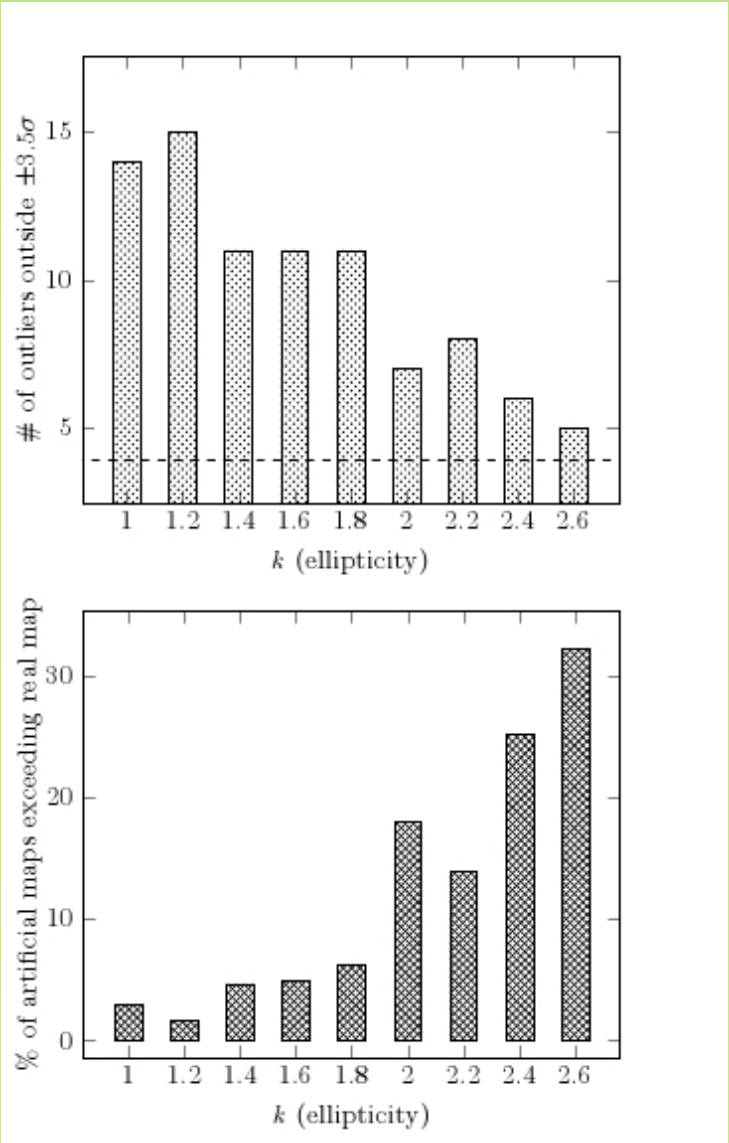
Procedure

- 300 artificial maps have been created
- the overlap integrals for each γ and each ϵ were calculated around 960 points on the real maps (WMAP: W2; Planck: masked, noise cleaned 100 GHz) and all artificial maps (with $k = 10$ grid approximately 12 million points).
- the same was done for nonvanishing ellipticity κ: $\kappa = 1.2$–2.6

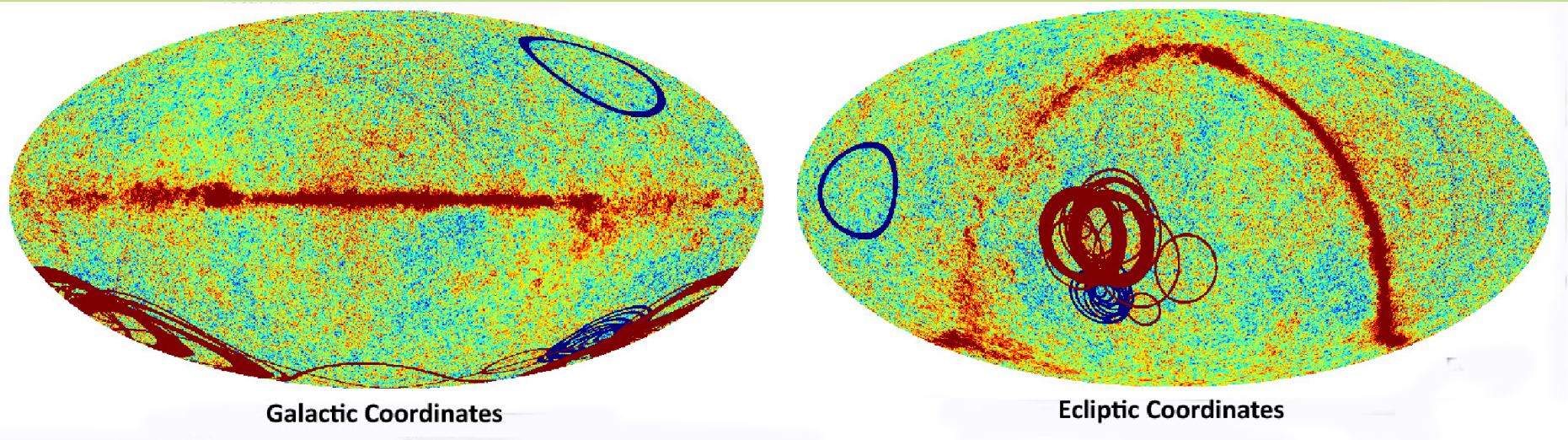
Results I

- for each γ and each ϵ the extremal values (positive and negative) of the overlap integrals for circles were found for the real map
- the same was done for nonvanishing ellipticity κ: $\kappa = 1.2$–2.6 (ellipses oriented in polar coordinates)
- it was determined how many artificial maps have extremal values more positive (more negative) than the extremal values on the real map
- histograms were generated

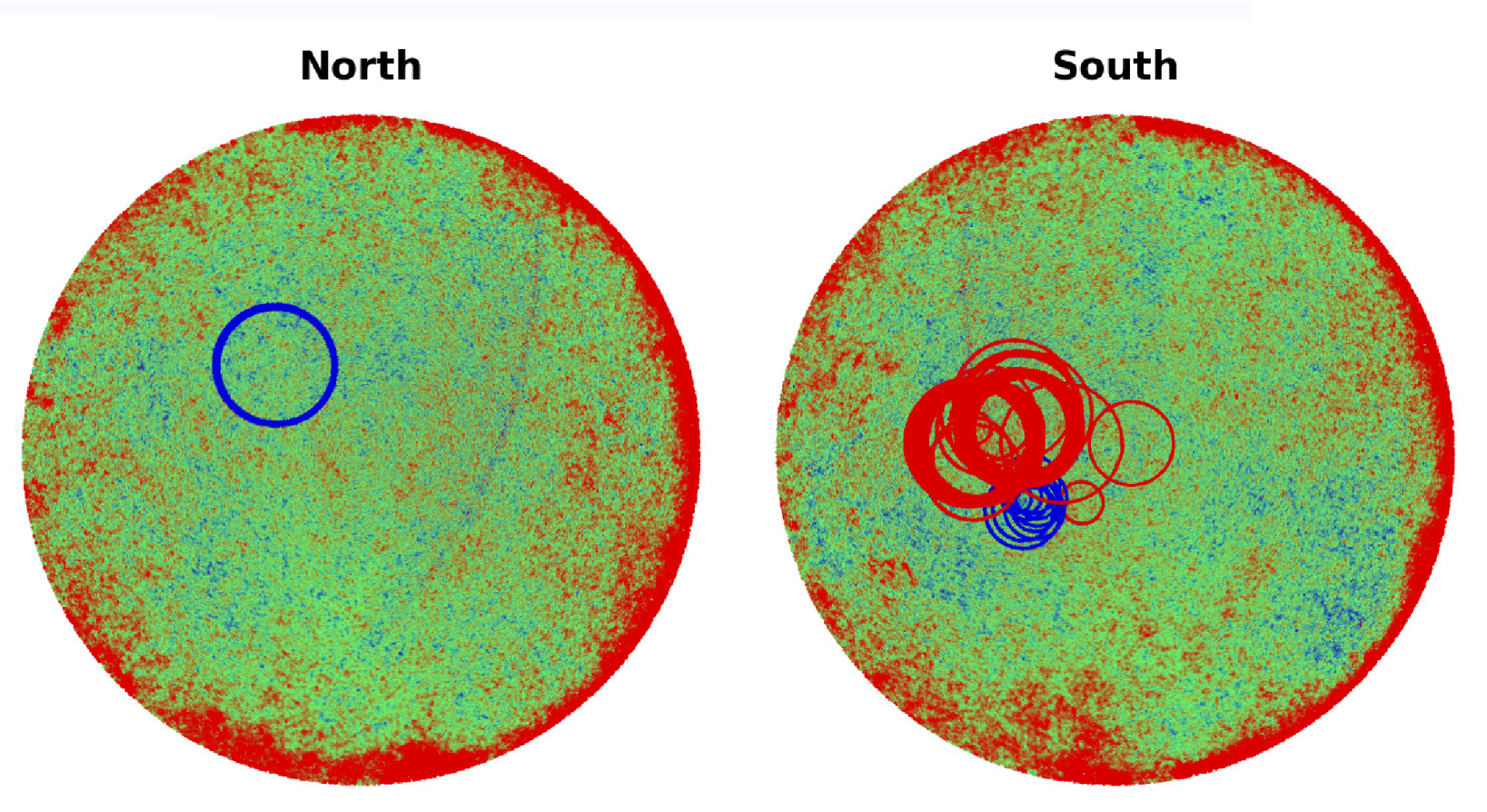
Histogram for $\gamma = 0.3,\ \epsilon = 0.08$



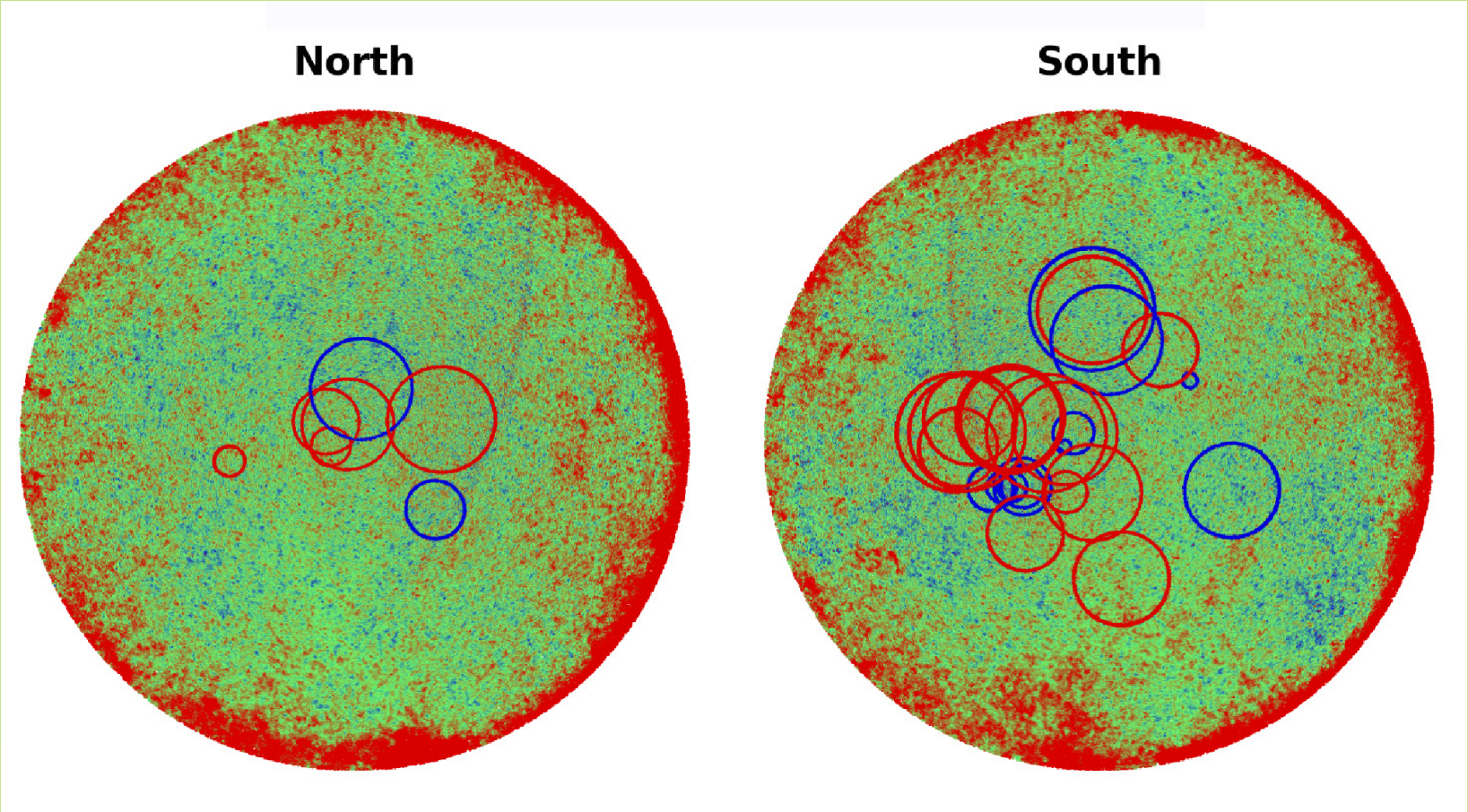
Location of possible circles



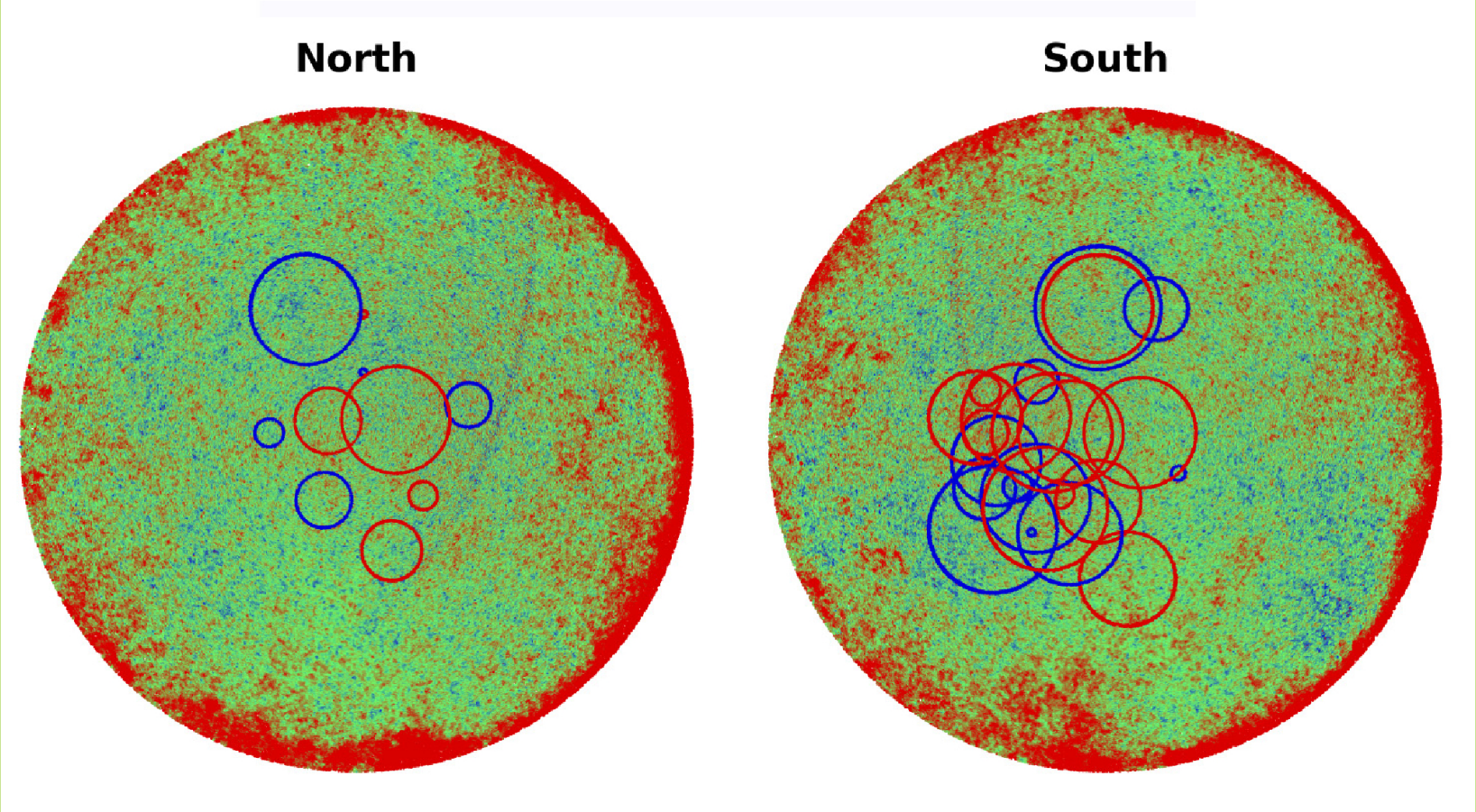
Location of possible circles $\epsilon = 0.08$



Location of possible circles $\epsilon = 0.04$



Location of possible circles $\epsilon = 0.02$



THANK YOU!