Geometry and quantum mechanics

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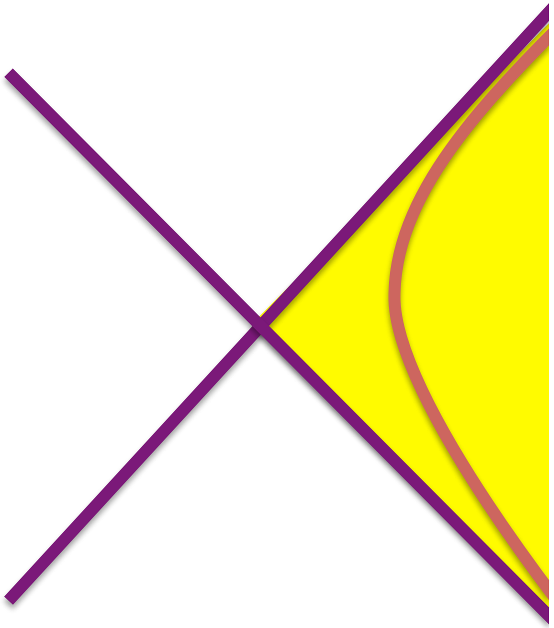
IAS

Strings 2014

Vision talk

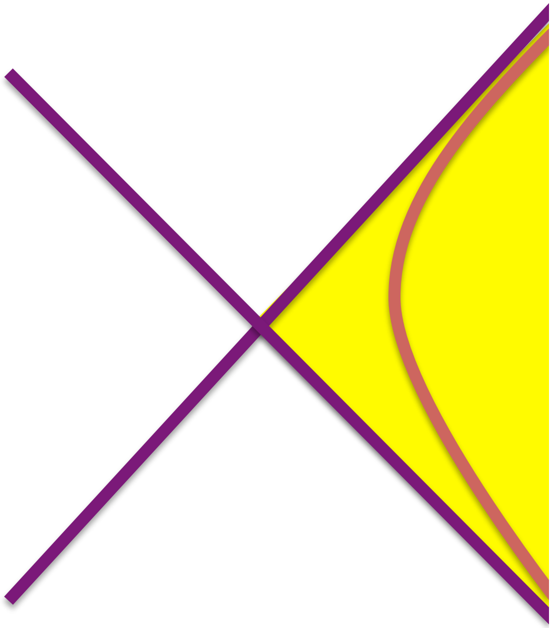
QFT, Lorentz symmetry and temperature

- In relativistic quantum field theory in the vacuum.
- An accelerated observer sees a temperature.
- Quantum effect



- Due to the large degree of entanglement in the vacuum.

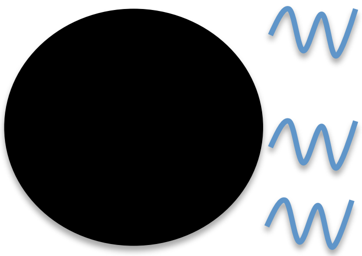
- Interesting uses of entanglement entropy in QFT: c, f theorems.



Geometry & thermodynamics

Geometry → thermodynamics

- With gravity:
- Hawking effect. Black holes → finite temperature.
- We understand in great detail various aspects:
- BPS counting of states with exquisite detail.
- 2nd Law
- Exact description from far away. (Matrix models, AdS/CFT)



- We understand the black hole in a full quantum mechanical way from far away.

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- Going inside:

Quicksand

Thermodynamics → geometry ?

- How does the interior arise ?
- Without smoothness at the horizon, the Hawking prediction for the temperature is not obviously valid any more. (MP assumes ER → EPR)
- Is there an interior for a generic microstate ?
- What is the interpretation of the singularity ?

Litmus test for your understanding of the interior

Popular view

- The interior is some kind of average.

- Mathur, Marolf, Wall, AMPS(S): not as usual. The interior is not an average quantity like the density of a liquid or the color of a material.

$$\langle o_i \rangle = \langle M | O_i^{out} | M \rangle$$

- Fixed operators
- Observer is ``outside'' the system.

Prediction

Prediction

- We will understand it.
- It will be simple.
- Implications for cosmology.

- A specially solvable string theory example will be key.
- We can have it all: unitarity from the outside and a reasonably smooth horizon for the infalling observer.

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- We can have it all: unitarity from the outside and a reasonably smooth horizon for the infalling observer.

We have a kind of duality between bulk geometry and the microstates.

In dualities, contradictions arise because we are not being careful enough.

``subtle is the Lord, but not malicious''.

Complexity theory

Fuzzballs/ firewalls

State dependence

ER = EPR

Non-locality

- We need to understand better the emergence of the outside. Even without a black hole.
- Local physics in the bulk from the boundary theory.

- Is a purely classical phenomenon.
  - Large N. Bulk emerges as we vary λ.

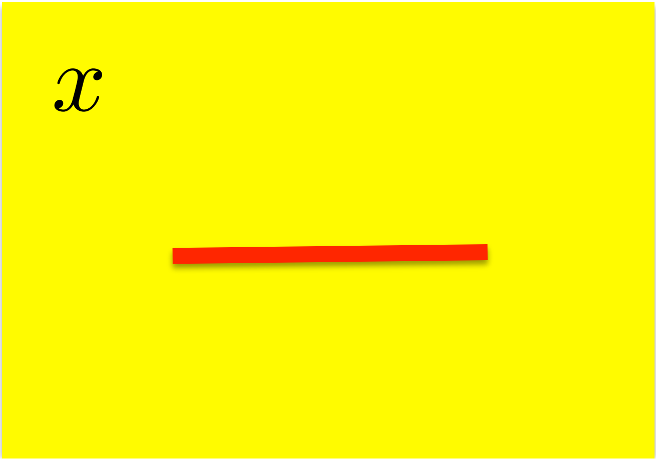
Example

- Matrix integral

$$\int DMe^{-Tr[M^2]}$$

$$\langle Det(M-x)\rangle \sim e^{N\varphi(x)}$$

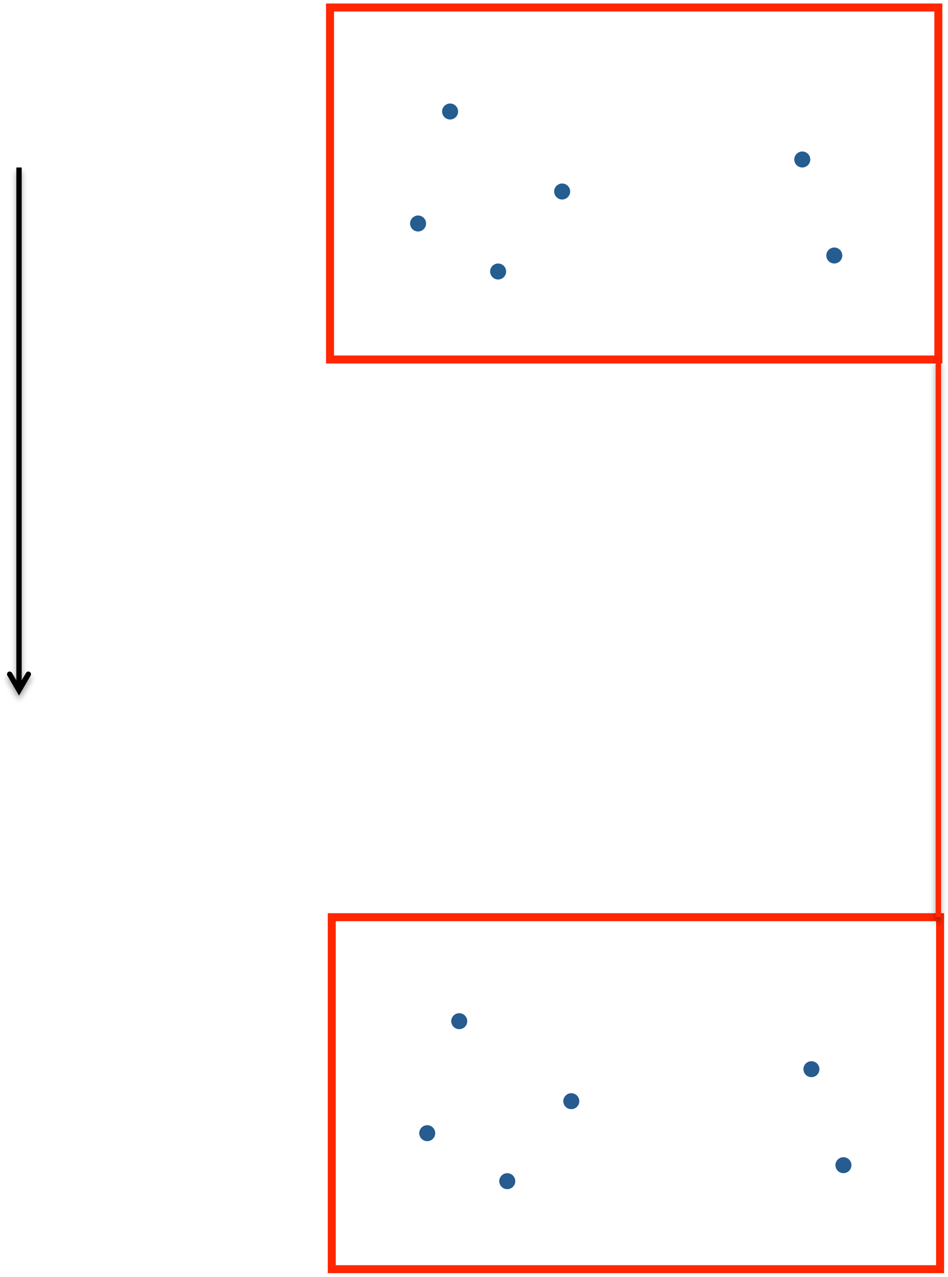
$$y^2 = 1 - x^2$$



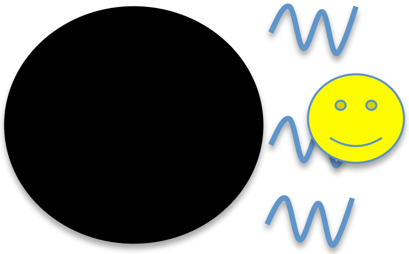
Importance of observer

- Observer as part of the system.
- Only required to reproduce what the observer can see.

Gravitational field and thermodynamics



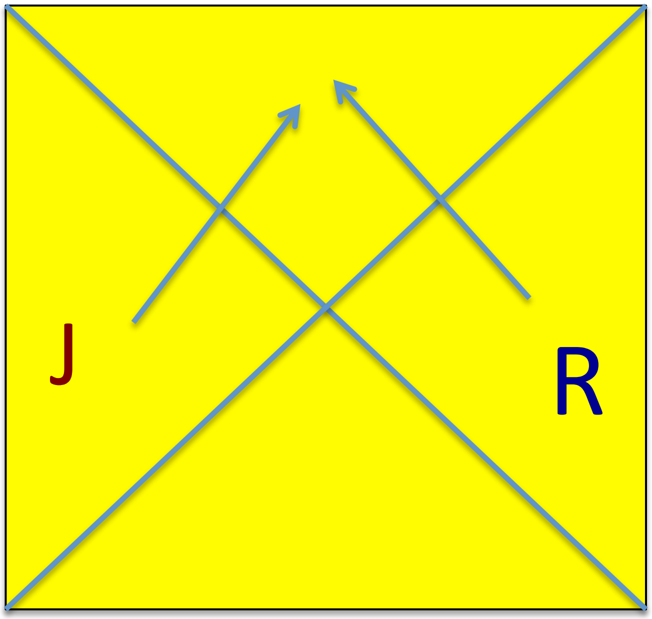
$$S(\rho|\rho_{vac}) = \Delta K - \Delta S \geq 0$$



- This is also the increase in the black hole entropy after the process.
- The measurements in the interior might be related to the approach to equilibrium.
- Speculation: Statistical significance of any measurement is not greater than

$$p > e^{-S}$$

Emergence of space from entanglement, ER = EPR



Is this correct ?
For this case?
In general ?

Is a smooth spacetime generic ?

Is it fine tuned ?

Emergent time → emergent QM

Spacetime and quantum mechanics

Spacetime and quantum mechanics

- Quantum mechanics of spacetime: is irrelevant and unmeasurable ?

Spacetime and quantum mechanics

- Quantum mechanics of spacetime: is irrelevant and unmeasurable ?
- Wrong!

- → shape of our spacetime at long distances determined by quantum fluctuations. (inflation)
- Through Hawking radiation from the cosmological horizon.
- Generic prediction of inflation !

- → shape of our spacetime at long distances determined by quantum fluctuations. (inflation)
- Through Hawking radiation from the cosmological horizon.
- These fluctuations are crucial to our existence!

Is there more ?

Flashback: UV catastrophe

- Black body:
- Applying the rules they knew they got an infinite entropy/energy for a black body.
- Solutions:
  - Black body did not have time to equilibrate
  - QM

IR catastrophe

- We can compute the probabilities of curvature fluctuations with l=2, … .
- What about the l=0 mode: spatial curvature of the whole universe ? Is it 10^{-5} or 10^{-3} ?
- Hartle-Hawking : Very highly likely to have positive curvature → disagrees with experiment.

Some authors → out of ``equilibrium’’

- At longer distances quantum effects are probably larger.
- Quantum gravity, properly understood, will likely give a surprisingly simple, non-classical, non-semiclassical explanation.
- This correct answer cannot be easily imagined by me, since I am too used to semiclassical approximations.

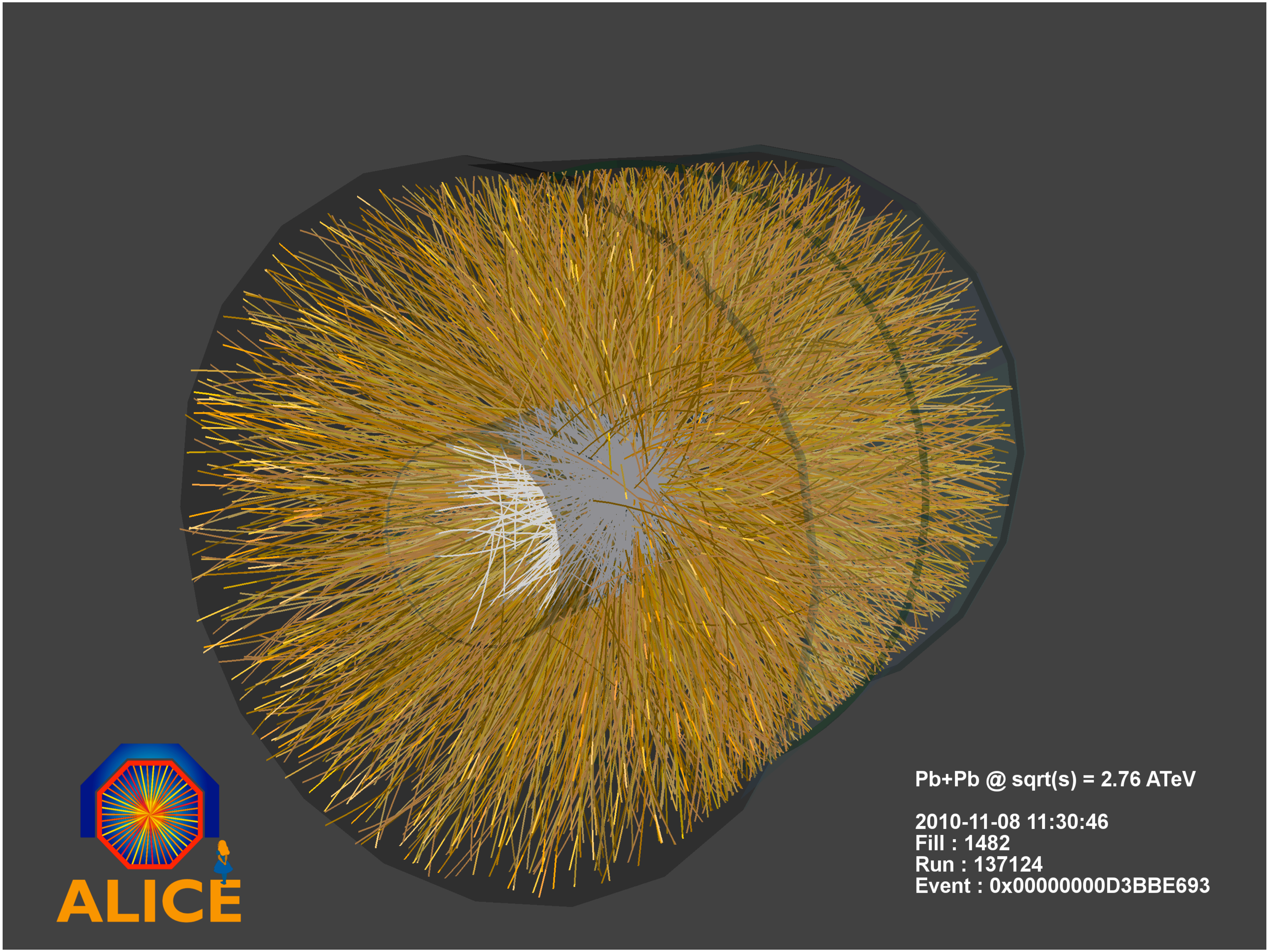
More practical problem

- The Planck scale seems for far away.
- Could we expect to be able to collide gravitons at very high energies ?

Yes, we can! (optimistically)

The 10^{14} Gev Cosmological Collider

- We could have a “cosmological collider” with energies up to 10^{14} Gev = H_{bicep} .
- Very weak coupling, 10^{-5} .
- Need to learn to read off the results.



Pb+Pb @ sqrt(s) = 2.76 ATeV

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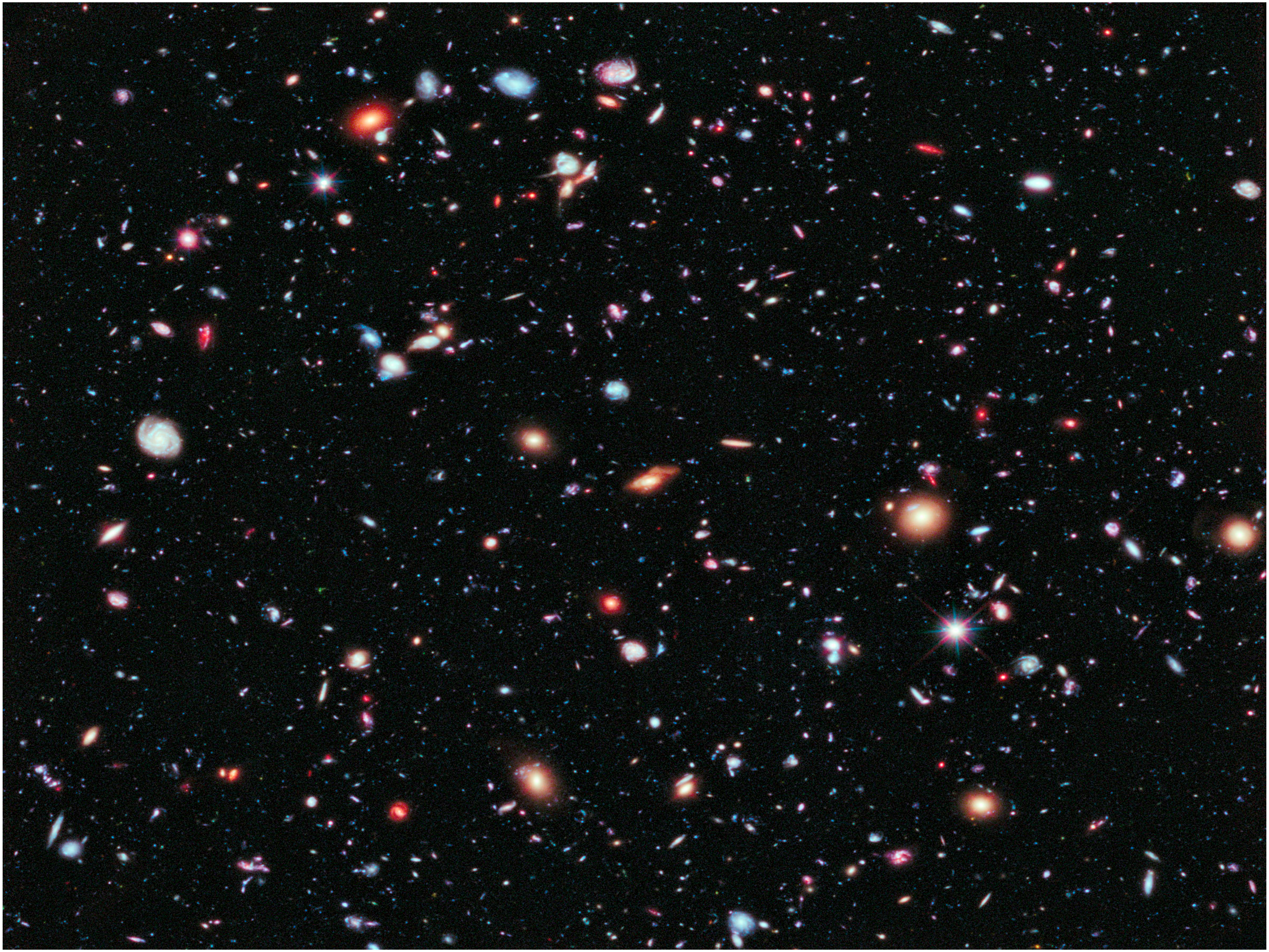
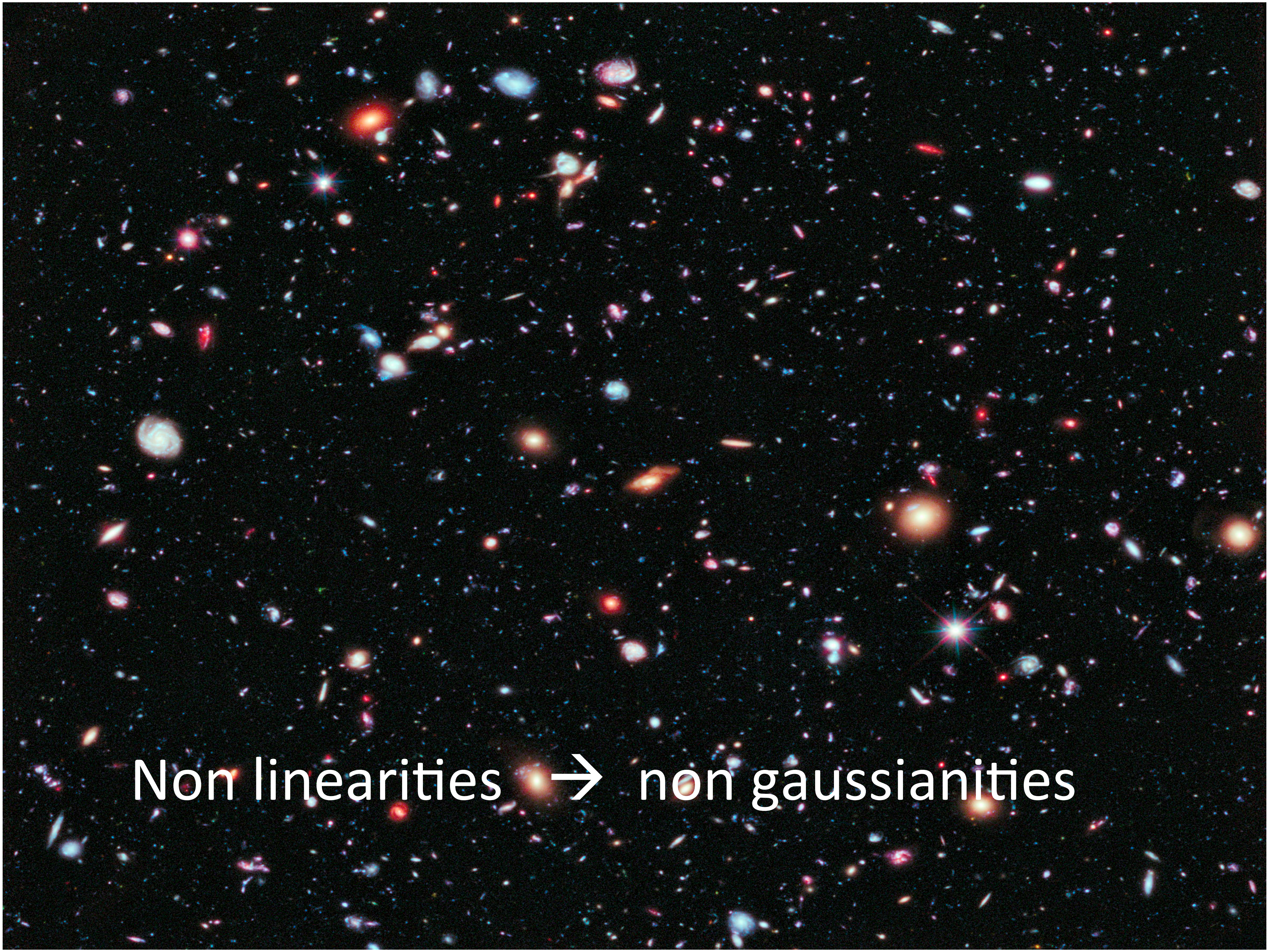
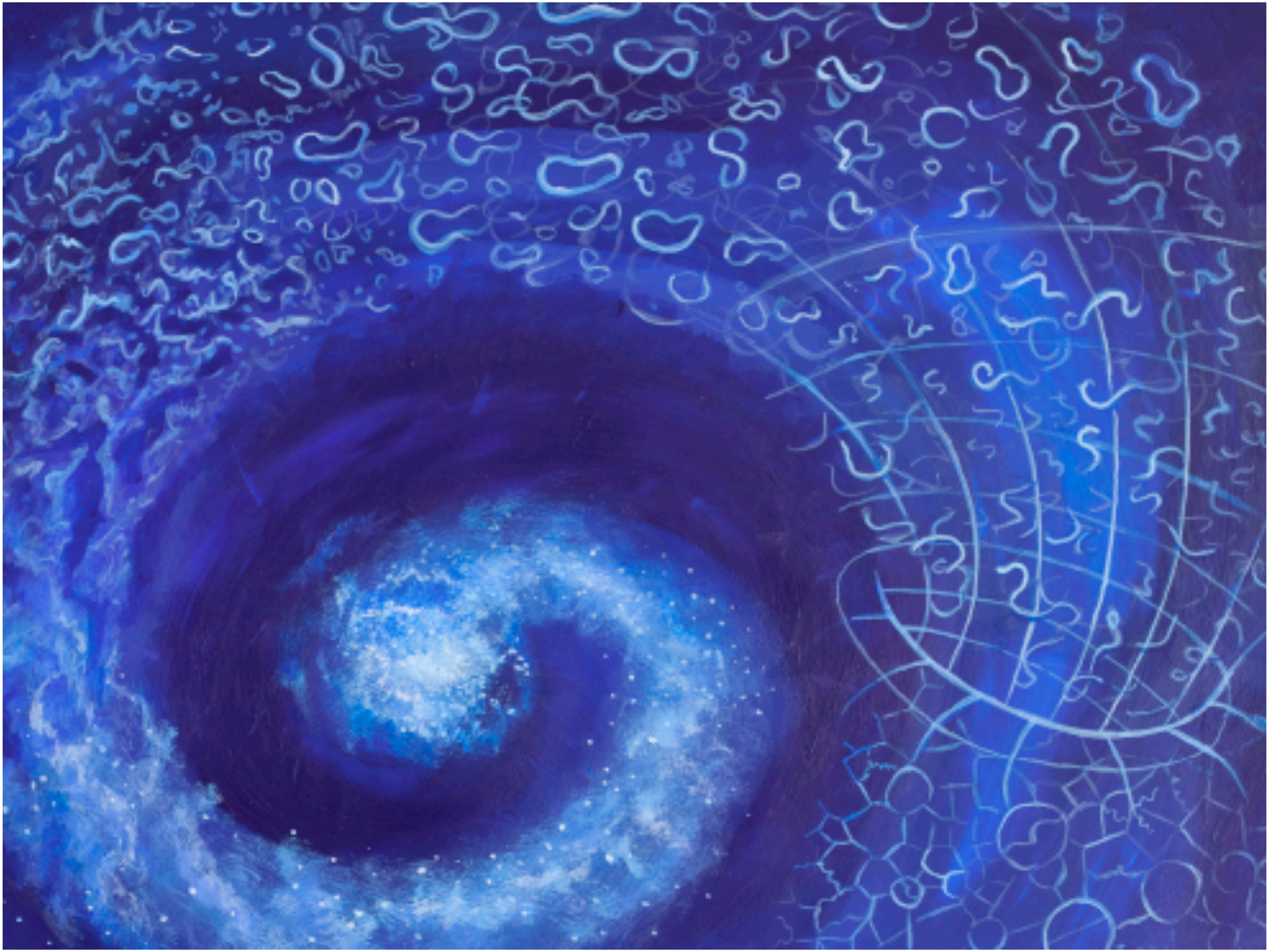




Non linearities → non gaussianities



- The future is coming fast!

What is string theory?

- Solid
- Theoretical
- Research
- In
- Natural
- Geometric
- Structures

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That's all folks!