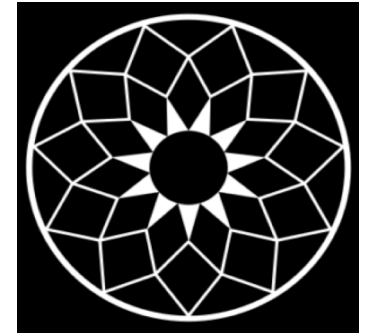


XXV SIGRAV Conference
SISSA Trieste, 4-8 September 2023



Lessons from gravitational physics and beyond: how can we rethink space, time and causal order?

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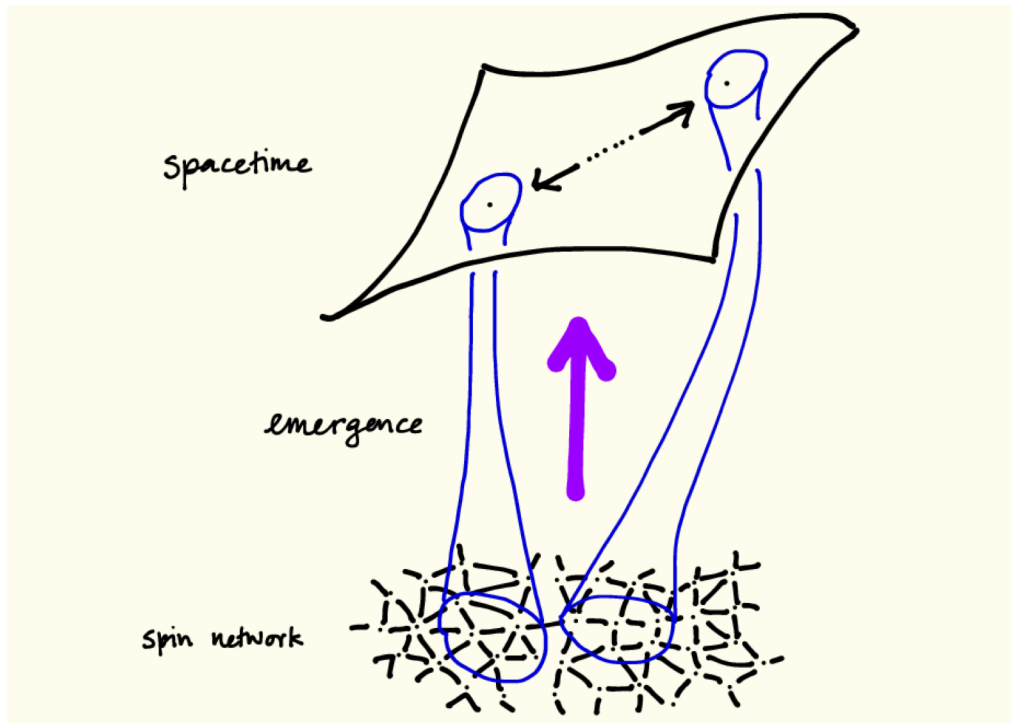
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PROTEUS (SHAPESHIFTER) «Paradoxes and Metaphors of Time in Early Universe(s)»



Quantum gravity and its conceptual challenges



Theories of quantum gravity propose that time (and space) may be emergent from something more fundamental.

PROTEUS has dealt with the questions that arise when trying to understand those claims.

RQ13-15 Questions concerning what we mean with «emergence of time».

RQ16-18 Questions regarding details about this emergence, e.g., relation with space, causality, and direction of time.

Some results of the ERC PROTEUS..

- Two senses of emergence:

- 1) Emergence as a process: Geometrogenesis in GFT

- Mozota Frauca, A. (2023). “Geometrogenesis in GFT: an analysis”. <https://arxiv.org/pdf/2307.11805.pdf>
- Forgione M. (2023) Group Field Theories and Phase Transitions: Revisiting the Problem of Spacetime Emergence. <https://philpapers.org/archive/FORGFT.pdf>

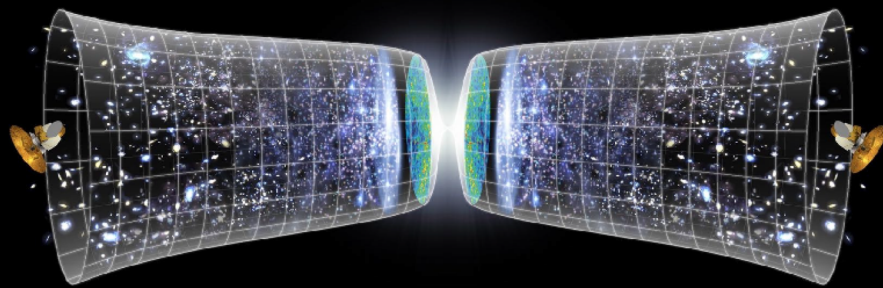
- Gabbanelli L. & De Bianchi S., Cosmological implications of the hydrodynamical phase of group field theory, Gen.Rel.Grav. 53 (2021) 66
- De Bianchi S. & Gabbanelli L. (2023) Re-thinking geometrogenesis: instantaneity in Quantum Gravity scenarios, Phys.: Conf. Ser. 2533, 012001

- 2) Emergence in the sense of “surprising supervenience”: Fundamental aspect of time as ordering of events.

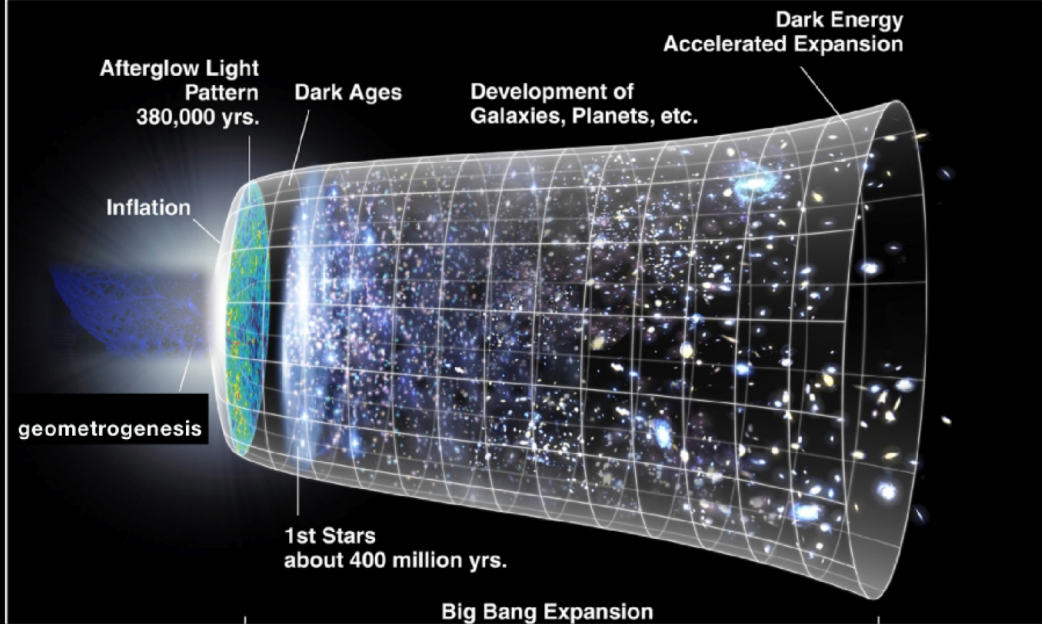
- Mozota Frauca, A. (2024). “Time is order”. Forthcoming in Time and timelessness in fundamental physics and cosmology (Springer)

Critical assessment of how spacetime emergence is supposed to be achieved in QG: problem of time raises worries about this:

- Mozota Frauca, A. (2023). “Reassessing the problem of time of quantum gravity”. Gen. Rel. Grav. 55(1), 21.
- Mozota Frauca, A. (2023). “The problem of time for non-deparametrizable models and quantum gravity,” forthcoming in the Post-Graduate SILFS 2022 volume (College Publications).



Credits: D.Oriti (2018)
<https://arxiv.org/pdf/1811.12458.pdf>



According to some QG approaches we encounter a conceptual difficulties in understanding the transition from a classical universe to another (Big Bounce) or **from a non-geometric to a geometric phase** (Geometrogenesis)

SOLUTION: New concept to think of a-chronic transition: INSTANTANEITY

PROBLEM:
In both scenarios temporality does not play any role in the transition

Atemporality and its structure(s)

Instantaneity is one kind of atemporality (different from proto-time) to which ordering of succession cannot be attributed, but implies **atemporal ordering and possesses a structure**

➤ (order is not ordering: temporal order can arise from atemporal ordering)

Co-presence Postulate: two opposite states are admitted in an undistinguishable region (“Bob and Alice can sit on the same chair at the same time, because there is no chair and no time”)

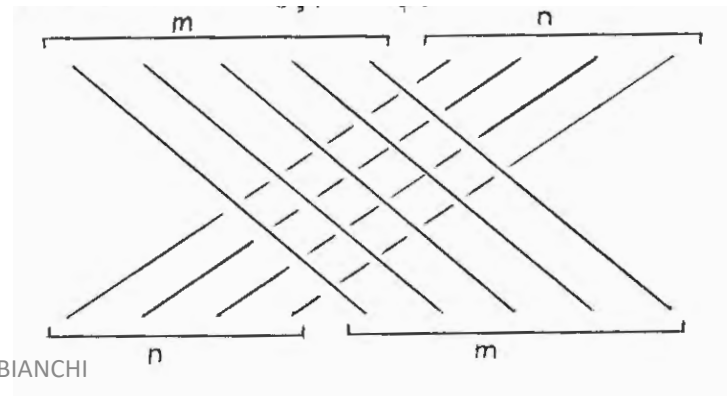
Postulate of Exclusion: all degrees and subsets of the opposite states are excluded from within their respective state and under their respective state (‘Lock-in’ mode, to ‘unlock’ there must be a switch or a twist producing local length)

Instantaneity and its structure(s)

- Co-presence postulate: analogy with entanglement
- Postulate of Exclusion: analogy with Drinfeld twist of braided Hopf algebras (relevant in Non-Commutative Geometry) and monoidal category theory. E.g. A braiding c for the monoidal category \mathbb{B} can be defined as

$$c = c_{m,n} : m + n \rightarrow n + m$$

Diagram for $c_{5,4} \in \mathbb{B}_9$



Rethinking space, time and causal order

Characters of instantaneity:

➤ Change without time:

- Changes at instantaneity are deformations of the group transformation (instantaneity acts as if it were a mapping through invertible elements, i.e. a Drinfeld twist)
- These changes are to be understood as switches or cyclic flips that do not occupy space at time t , they only produce non-local length (lock-in mode).

➤ Atemporal ordering:

- undefined causal order or different types of causality (e.g. correlations that violate causal inequalities in Quantum switch)
- What is the factor breaking the 'lock-in mode'? De Bianchi & Gabbanelli (2023): depends on values assumed by the Ginzburg parameter Q within the L-G mean field theory

➤ Non-locality (strong)

COSMOS

History and Philosophy of Cosmology Network

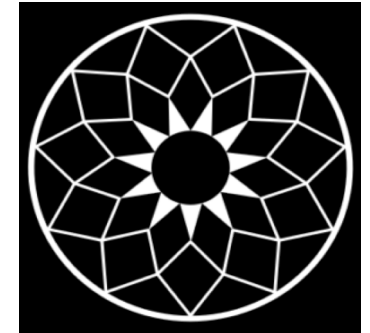


On-going Collaborations:

- **The History Philosophy Culture Working Group of the Next Generation Event Horizon Telescope Collaboration**
- **CosmoVerse (COST action)**
- **ERC project COSMO-MASTER**
- Monthly Newsletter
- Public Outreach
- Astronomical observations INAF (Brera Observatory)
- Excellence in the BA program

**H&PC Conference Launched (biennial)
2022; 2024...in Milan**

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THANK YOU!



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