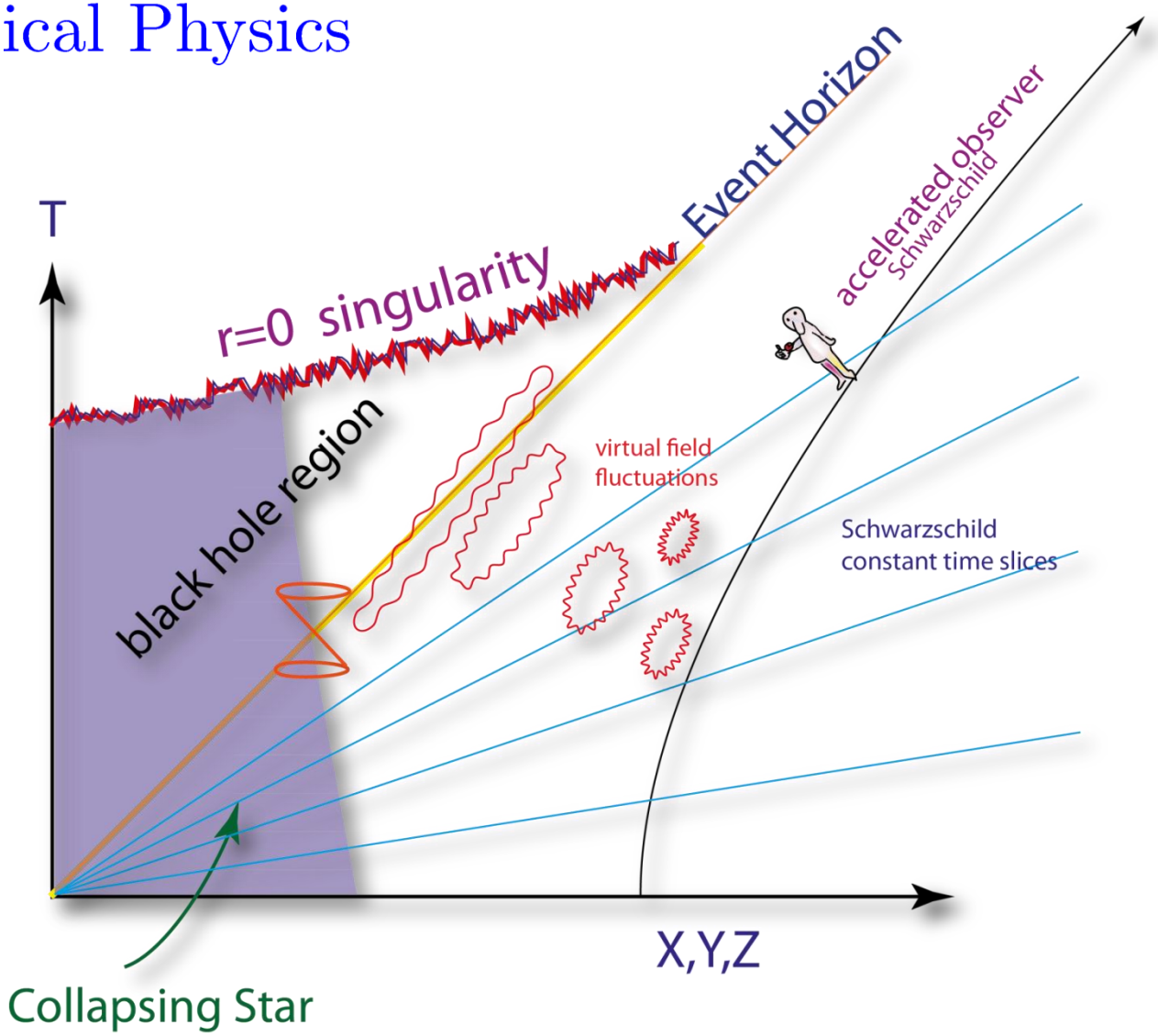
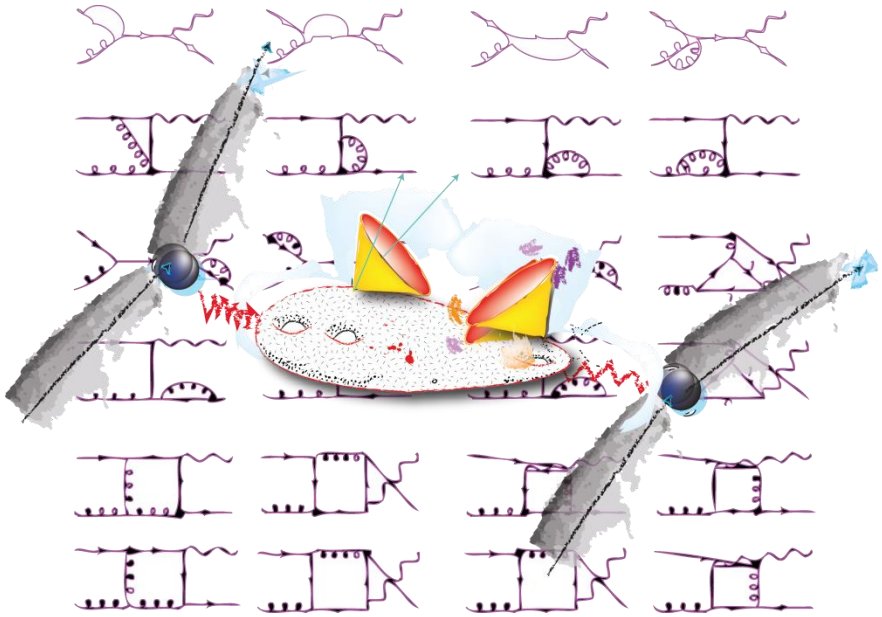
General Relativity, Geometry, Quantum Field Theory: Exploring Connections Between Advanced Mathematics & Theoretical Physics

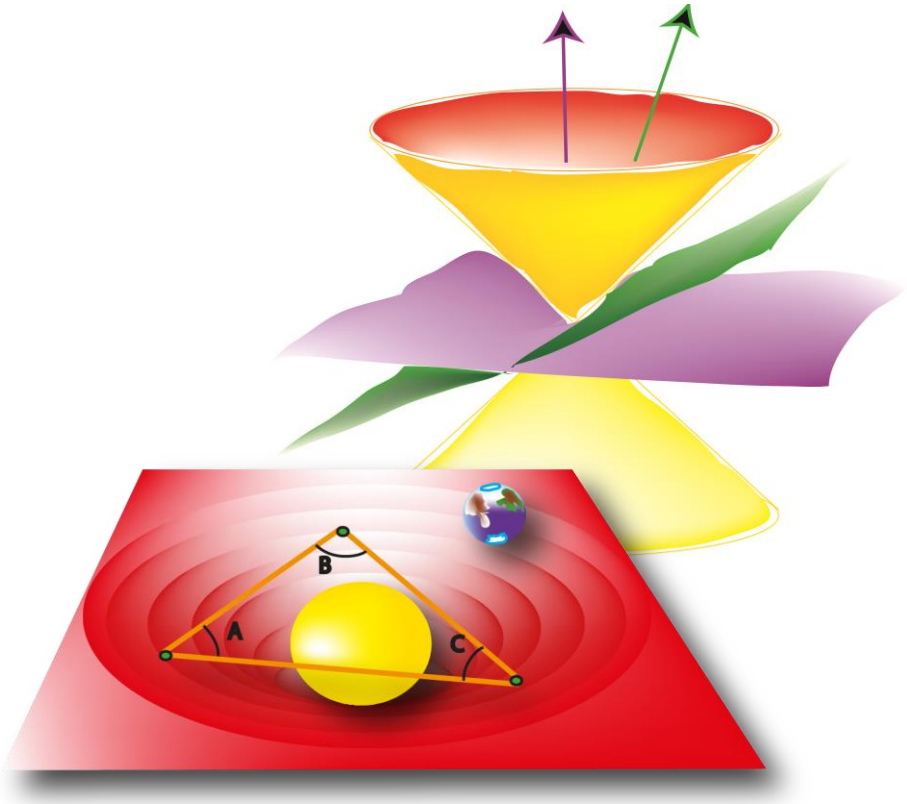


The two major conceptual revolutions in '900 Physics:

- **Quantum theory**



- **Special and General relativity**

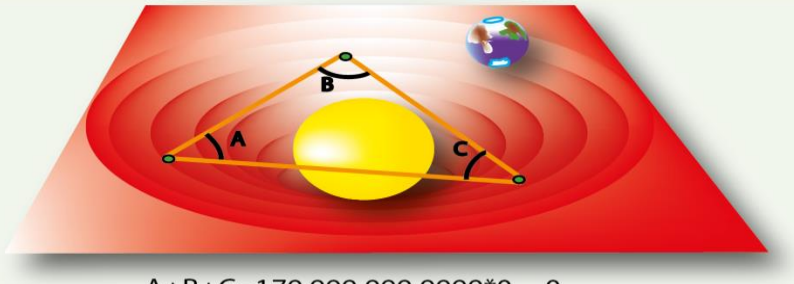


Strikingly different and accurate pictures of Physical Reality

Quantum evolution produces probability amplitudes rather than specific trajectories.

Gravity is not a force in a rigid Euclidean space. Rather the opposite: it is the manifestation of a dynamical space–time geometry.

THE RELATIVITY LANDSCAPE



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General Relativity

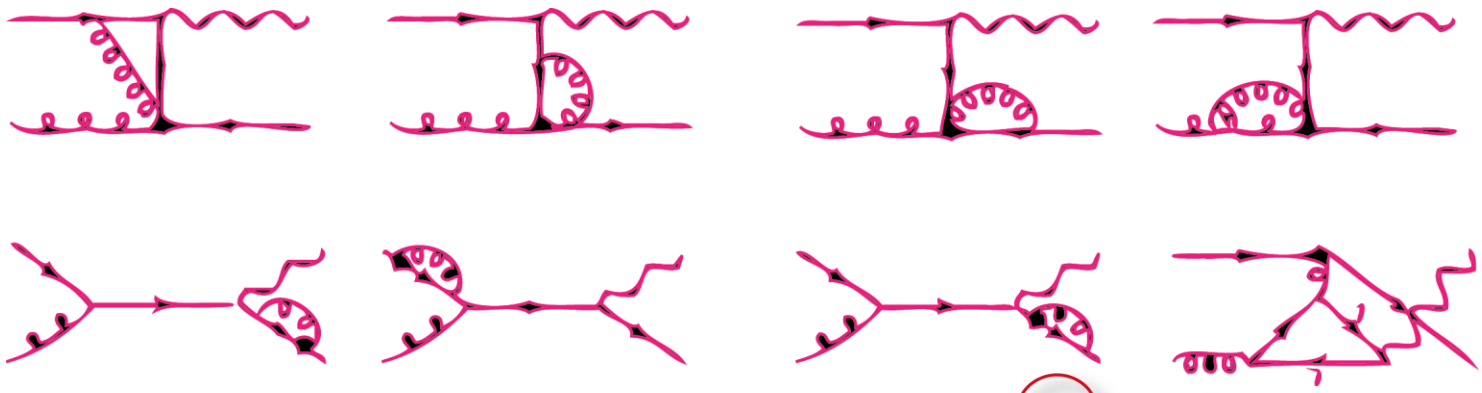
The most accurate framework for Classical Physics

Spacetime is Dynamical & Curved

General Relativity (A. Einstein 1915) is rooted in classical Mechanics: it extends Newton's theory of gravitation and his theory of motion

- The physical roots of GR lie in the analysis (Einstein) of the equality of the inertial and the gravitational mass which is unexplained in Newtonian theory.
- The most fundamental aspect of GR is its geometric nature.
- GR accomplishes a blending of Space, Time and Gravitation in the dynamical geometry of a curved Spacetime.

THE QUANTUM FIELD THEORY LANDSCAPE

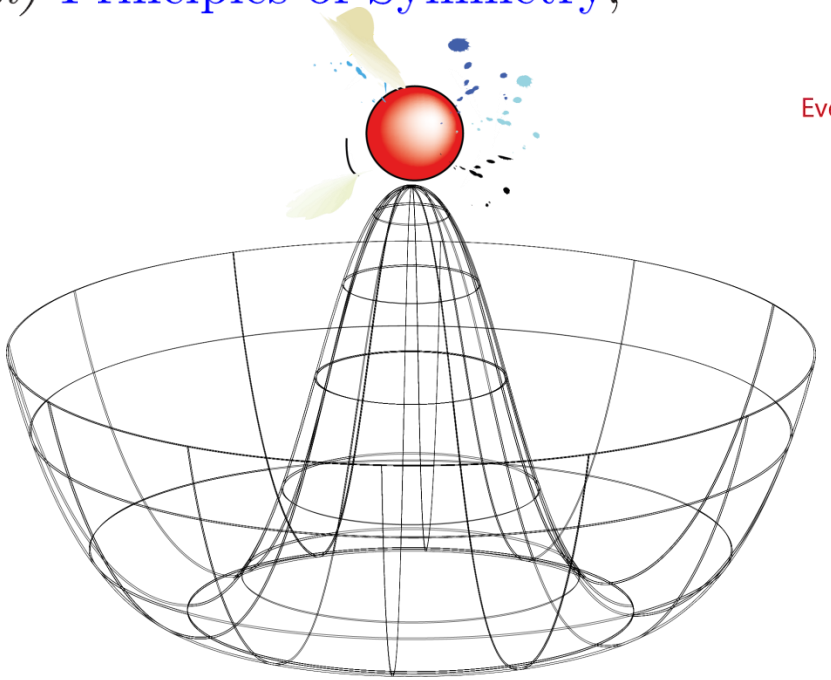


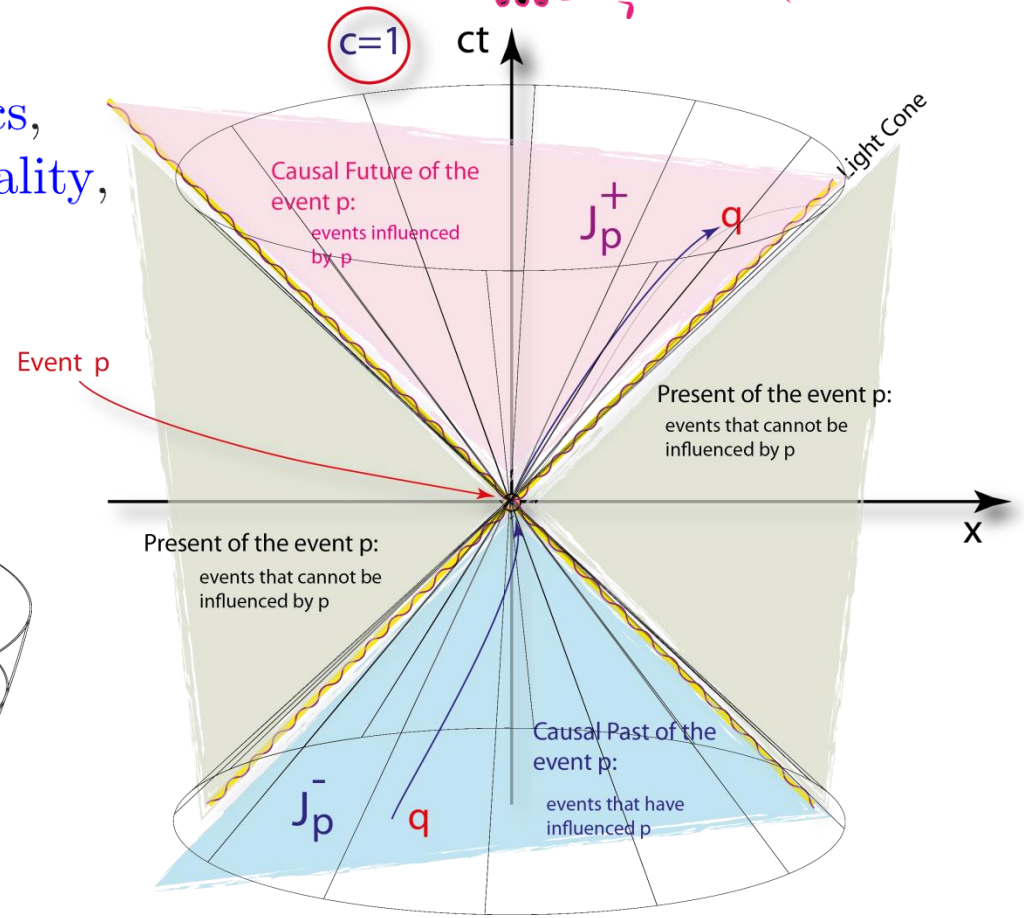
QFT is based on the:

(i) Principles of Quantum Mechanics,

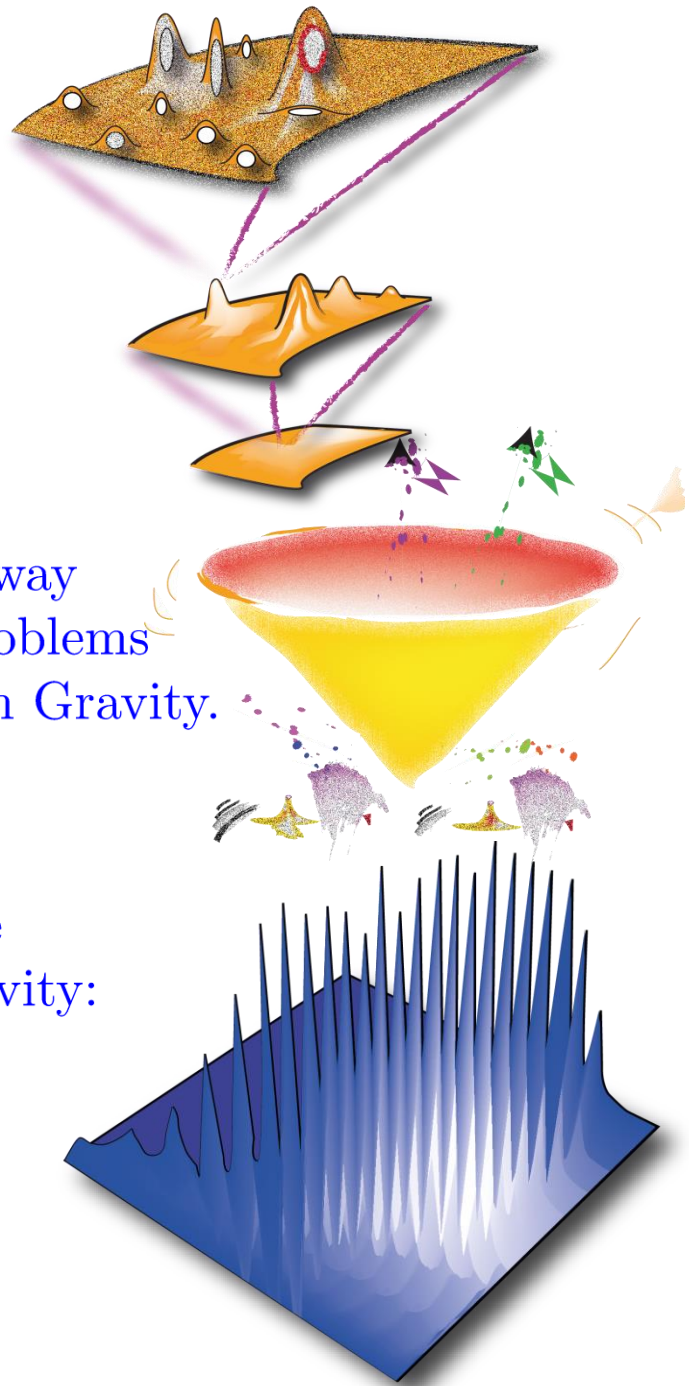
(ii) Principles of Locality and Causality,

(iii) Principles of Symmetry,





QFT is unable to incorporate Gravity as a fundamental theory because it is unclear how to implement *(ii)* (locality) and *(iii)* (symmetry) when the spacetime is a dynamical arena rather than a fixed backround:

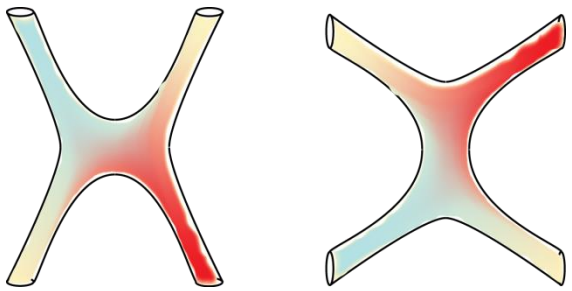


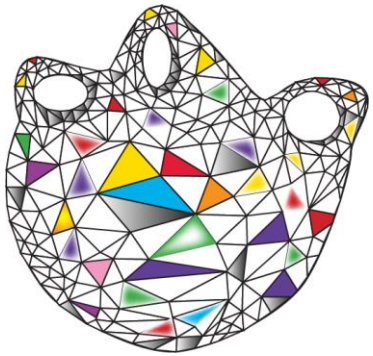
- In General Relativity there is no invariant local way to specify the spacetime position of an event: problems in characterizing **local observables** in Quantum Gravity.

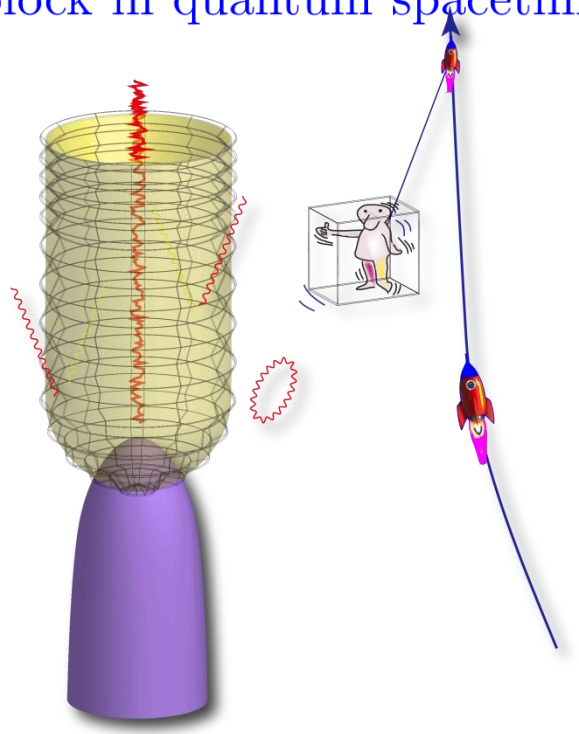
- QFT has **too many degrees of freedom** to be able to address the quantization of general relativity: highly energetic fluctuations $\longmapsto$ distruptive fluctuations in spacetime geometry.

A generalization of QFT is necessary in order to quantize the gravitational field:

- QFT on curved spacetimes
- String theory...
- Duality between gravity and gauge theory: The holographic principle...
- General relativity as an effective theory...Do we really need to quantize it?
- *Discrete nature* of Planckian spacetime?...
- Quantum Angular momentum as a building block in quantum spacetime geometry
- ...New ideas...new unexpected applications...







These are some of the topics addressed by our group:

- M. Carfora: *Elettrodinamica e Relatività* (L e LM);
  Relatività Generale (LM)
- A. Marzuoli (Dip. Matematica); *Meccanica Razionale e Analitica* (L);
  Teoria dei Sistemi Dinamici (LM)
- C. Dappiaggi: *Metodi Matematici II* (L);
  Gruppi e Simmetrie Fisiche (LM);
  Mathematical Introduction to Quantum Theory (Dott);
  Mathematical Introduction to Fluid Dynamics (IUSS)
- Hugo Ferreira (Post-Doc INFN)
- Nicolò Drago (Post-Doc Unipv)

Current Ph. D. Students:

- Samuel Rutili (Dappiaggi)
- Francesco Bussola (Dappiaggi)
- Barbara Giunti (Mat), (Marzuoli)

Recently Minted Ph.D.s :

- Gabriele Nosari (Dappiaggi)
- Marco Benini (Dappiaggi)
- Simone Murro (Regensburg), (Dappiaggi)

Research topics & international collaborations:

- *Relativistic Cosmology and Dark Energy*
  (M. Carfora, collaboration with Thomas Buchert (Lyon)
  awardee of the Advanced ERC Grant *arhtUs*: advances in the
  research on theories of the Dark Universe (2017)
  https://cqgplus.com/2016/01/20/
  the-universe-is-inhomogeneous-does-it-matter/)

- *Renormalization Group (QFT), Ricci Flow,*
  Quantum Gravity, Mathematical GR
  (M. Carfora, collaborations with Christine Guenther
  and Justin Corvino, USA)

- *Topological QFT and Quantum Computation*
  (A. Marzuoli, collaborations with M. Rasetti (ISI, New York and Torino),
  E. Aquilanti (Perugia), M. Loebl (Praga))

- *Geometrical and Topological methods in (big) data analysis*
  (A. Marzuoli and M. Carfora, collaboration with M. Rasetti (ISI))

- *QFT on curved Spacetimes and its applications*,
  (C. Dappiaggi, collaborations with K. Fredenhagen, C. Bär,
  D. Vassiliev, F. Finster, A. Schenkel, C. Herdeiro, J. Yngvason)

Our Mathematical Physics Group provides an opportunity for experimentation in a focused and intelligent learning environment, developing mathematical abilities as well as strengthening theoretical physics skills . We welcome students with:

- Communicative zeal
- beautiful mathematical articulation
- focused research energy