Complex systems at Physics Division: cosmology, astroparticles, and matter under extreme conditions.

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Summary: The study of cosmological phenomena has long fascinated scientists, providing a unique testing ground for validating fundamental physical theories. Moreover, challenging studies of matter under extreme and exotic condition found in stars and planetary systems open new routes for applications. Our researches at Unicam focus on: Cosmology, Black Hole Physics, High Energy Astrophysics, Particle Astrophysics and Gravitational Waves, nucleosynthesis, liquid and glasses under extreme planetary conditions.

Cosmology

Late-time Universe: Dark Energy and Dark Matter

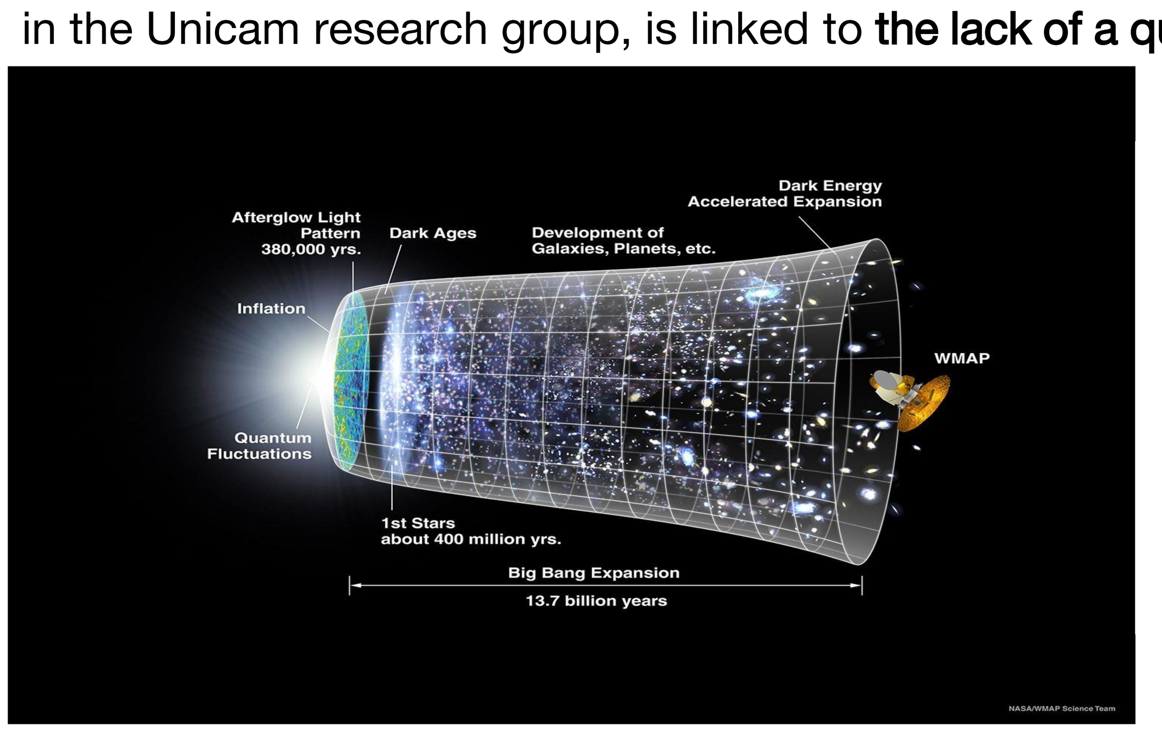
The main constituents that make up our Universe are dark energy (≃68%) and dark matter (≃27%). The first accounts for the late-time cosmic acceleration while the latter unlike ordinary matter, interacts only gravitationally. The scope of the cosmology group at Unicam is to single out the right **dark energy and dark matter models** and to predict how to unify the entire dark sector under the same standards.

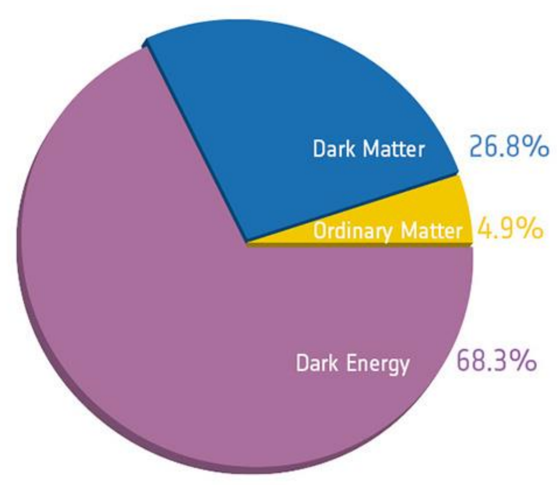
Primordial times: Big-Bang and Inflation

The Big Bang model proposes that the Universe in its early stages was very hot and dense and since then it has been expanding and cooling. Inflation is necessary to solve its problems and involves a phase of accelerated expansion. Among the variety of the topics treated at Unicam, the cosmology group treat **particle production in the inflationary regime.**

Modifying Gravity: Extended theories of gravity

Extended theories of gravity extend general relativity but recover it at local scales. The simplest of these theories generalizes high-order curvature terms by adding inside the action the function $f(R)$ of the Ricci scalar. The study of these theories, in the Unicam research group, is linked to **the lack of a quantum theory of gravity.**





Relativistic Astrophysics

Gamma-ray bursts: The most powerful explosions in the Universe

Gamma-ray bursts are high-energy astrophysical sources essential to probe the Universe up to very high redshifts. This can be done in conjunctions with other probes such as baryonic acoustic oscillations and type Ia supernovae to get constraints on key cosmological parameters. Within the cosmology research group at Unicam, **these data sets are used as cosmological probes to disclose the early-time dynamics of the Universe.**

Black holes and gravitational waves

Black Holes: From standard to exotic objects

Black holes arise as solutions to Einstein's field equations. Understanding these objects could be of utmost importance to reveal potential deviations from general relativity due to effects of quantum gravity that could arise because of their strong gravitational field. At Unicam **we seek new black hole solutions describing exotic objects in the Universe and their accretion disk properties.**

Compact objects: Sources of heavy elements in the Universe

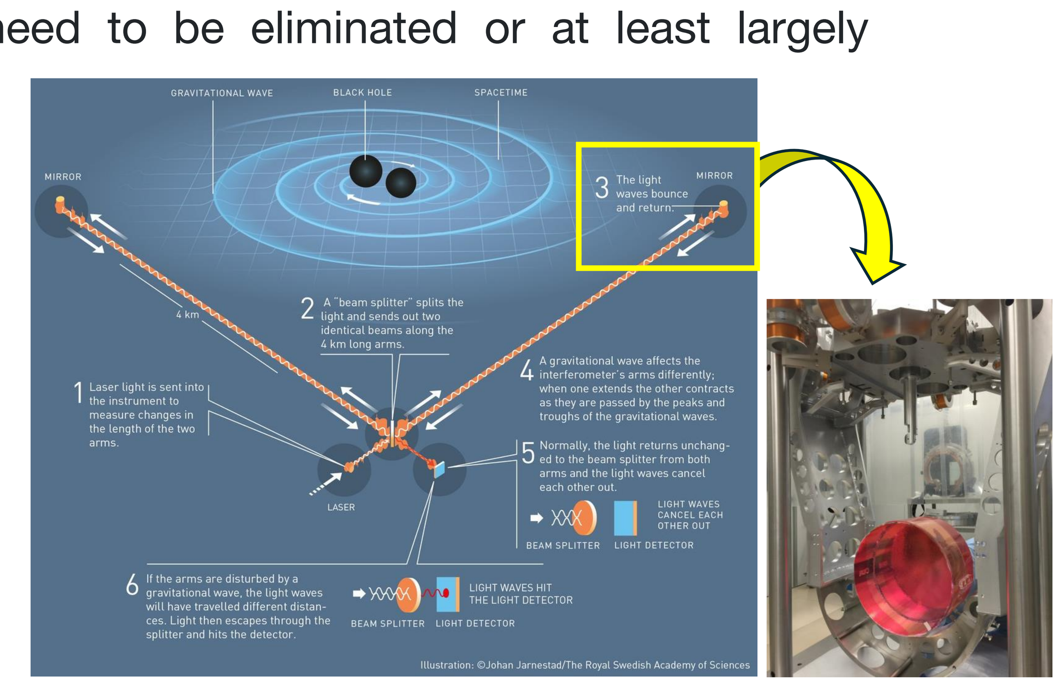
Compact objects are almost the final product of the life cycle of stars. The type of compact object that will arise from the death of the star depends on the final mass of the star, e.g. white dwarfs, neutron stars, black holes, etc. At Unicam we study their **structure, form, life and experimental evidence to characterize the new physics from them.**

Materials and technology for gravitational waves detectors

The high sensitivity needed for observing the tiny space-time variations induced by the passage of gravitational waves through the detector represents a real challenge. Numerous noise sources need to be eliminated or at least largely suppressed.

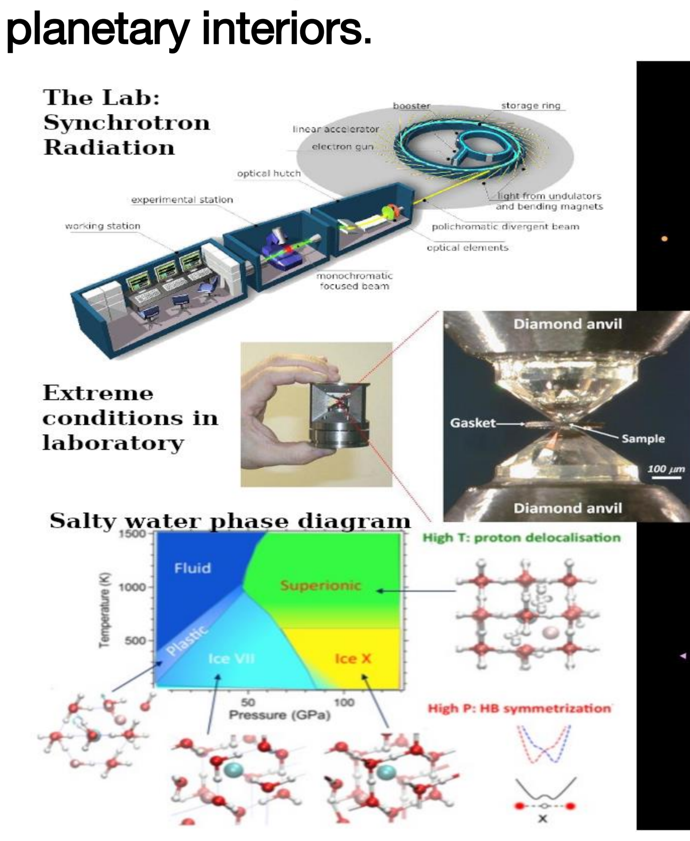
Activities carried out at UNICAM within the Virgo and ET collaborations focus on:

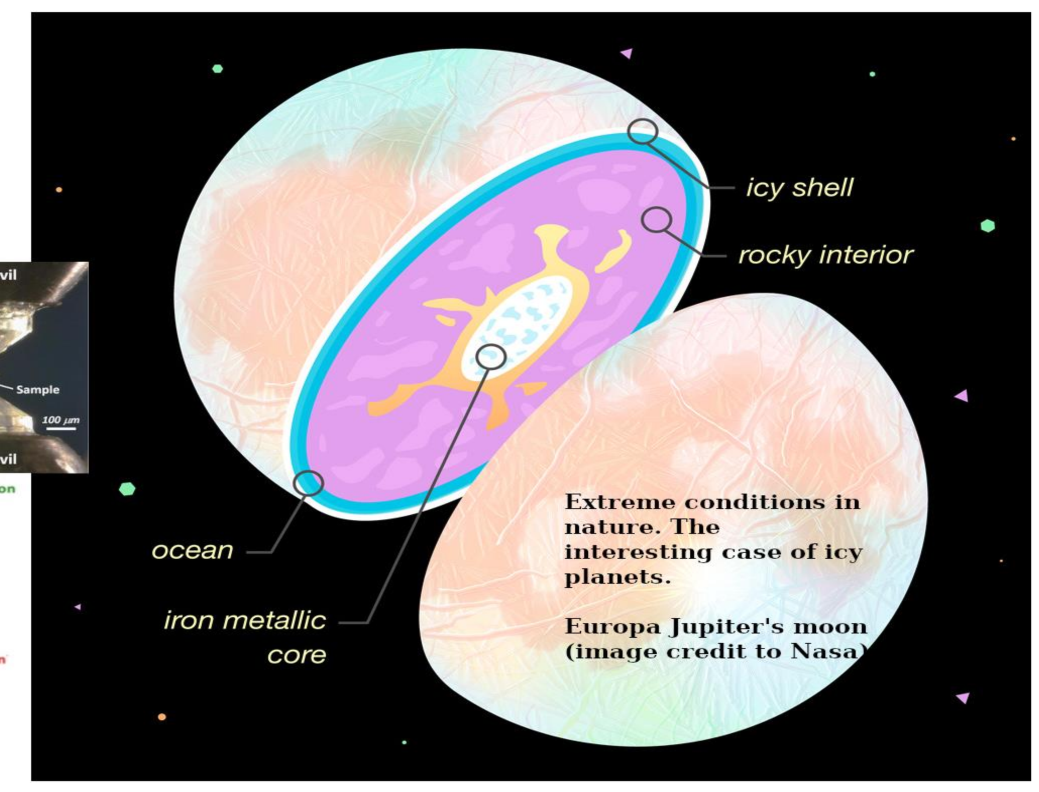
- **design of fiber suspension systems and thermal noise modelling**
- **measurements of mechanical losses**
- **exploring novel solutions for coatings**



Matter under extreme conditions

The XAS group at Unicam has a longstanding activity in studying properties of disordered matter under high pressure and high temperature conditions using different advanced techniques in connection with world-classsynchrotron-radiation facilities. The recent PRIN project E-ICES aims **to study the exotic properties of gas and ions filled ices under extreme conditions, typical of several planetary interiors.**

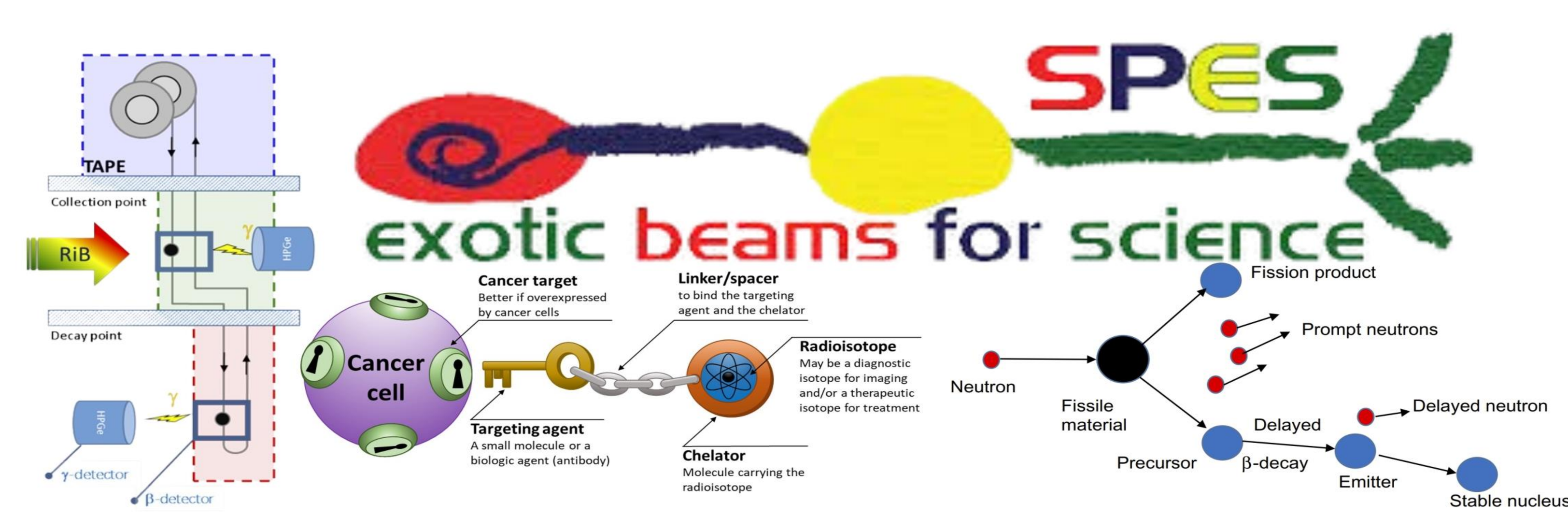




Nucleosynthesis

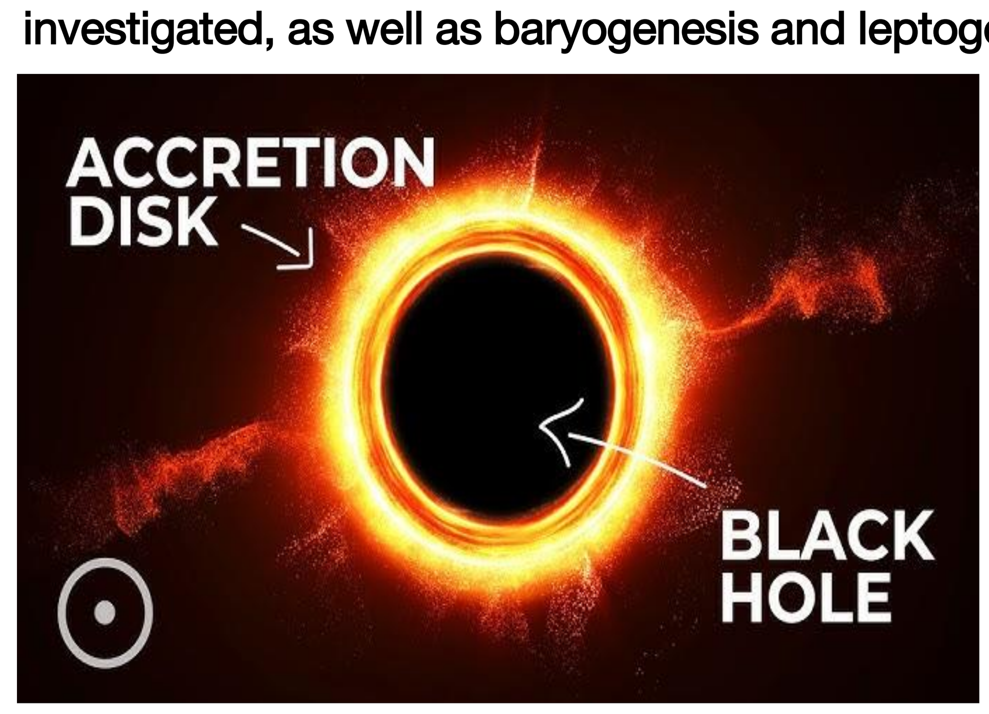
The SPES Project: From the Stars, an Hope for the Future

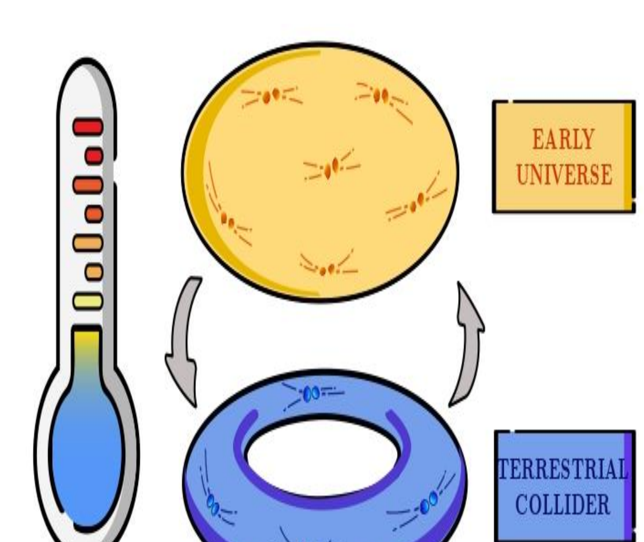
Unicam Physics Section is involved in the INFN's SPES project, at Laboratori Nazionali di Legnaro (Padua). The goal is to induce fission in 238-Uranium using high-intensity proton beams, at energy of 70 MeV. The radioactive ion beams (RIBs) are selected using the Atomic Vapor Laser Isotope Separation (AVLIS) techniques and implanted onto a tape to study the β^{-}decays. The studies are crucial in nuclear medicine and reactor controls. This process allows **the production in the laboratory of exotic species that are typically found only in Stars, particularly in Supernovae.**



High energy Astrophysics

The idea that the early Universe was a hot and dense soup of particles is rooted in observing that our Universe is nowadays expanding. Hence, going back towards earlier times, its size had to be much smaller and the energy density much higher. The early Universe worked as a factory for the light elements originating from thermal collisions between protons and neutrons making it a thermal collider. However, it is not clear how to explain a wide class of open questions, like the existence of dark matter and the primordial matter-antimatter asymmetry. At Unicam, **novel particles and interactions present in the early Universe, are investigated, as well as baryogenesis and leptogenesis.**





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