Contribution ID: **36** Type: **not specified**

Properties of matter at high baryonic density: a fundamental discovery within reach.

Wednesday, 18 June 2014 15:00 (1 hour)

Abstract:
Over the last few years, a strong synergy has been developing among research areas apparently quite separated, offering the possibility to investigate several crucial questions in hadronic and nuclear physics, astrophysics, and gravitational physics from complementary viewpoints. The main goal of this research is to discover the composition of matter at supra-nuclear density, which, in turn, would allow us to map in a more complete way the phase diagram of matter under extreme conditions, by complementing the information at high temperature and low baryonic density that is already investigated in heavy-ion collision experiments at energies larger than about 100 AGeV, such as the ones performed by ALICE at CERN. A few fundamental questions wait to be answered, in particular:

- At which baryonic densities do quarks start to deconfine? Is there at all a deconfinement critical density?
- Is there a critical point in the phase diagram of matter at large densities and temperatures?
- Is Witten's hypothesis about the absolute stability of strange quark matter realized in compact stars?
- Are supernova explosions and gamma-ray bursts associated to phase transitions in dense matter?

These questions are deeply connected with a fundamental problem: at which densities can strange hadrons be produced and what is their impact on the equation of state of matter? The solution of this problem has become extremely urgent after the discovery of compact stars having a mass of at least two solar masses: the so-called "hyperon puzzle"has to do with the difficulties in explaining the stability of very massive stars while taking into account the production of strange hadrons, as requested by the present laboratory data. The solution of this problem, crucial both for nuclear-hadronic physics and for astrophysics, is at the moment unknown and it could indicate that the interaction of strange hadrons is deeply different from what is known at the moment or that deconfined quarks appear at least in the most massive stars.

In order to answer these questions, the collaboration among various research areas is not only useful, but rather essential. The reason is that results obtained only from laboratory experiments or only from X-ray satellites would not be able to address the questions above. For instance, the discovery that Witten's hypothesis is indeed realized in Nature can come only from: a) laboratory experiments revealing at which densities strange hadronic matter starts being formed; b) theoretical studies investigating the implications of strangeness deposition on the stability of matter and, obviously, c) the measurement of masses and radii of compact stars via observations from gravitational-wave detectors and X-ray satellites. Separately, each of these investigations could provide some hints, but cannot give a definitive answer.

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