SUMMARY OF THE WORKSHOP ON STRONG MAGNETIC FIELDS AND NEUTRON STARS

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1 How to Summarize the Workshop ?

When asked by the Organizers to prepare a summary of the Havana Workshop I gladly accepted the request and readily started to review all the material presented along the five day sessions. Soon I had realized the difficulty of the task, mainly because in spite of the apparently narrow scope of the title, the presentations and discussions led to much wider subjects all deeply connected. To quantify this difficulty I have written an heuristic equation expressing it in terms of the Workshop language, which reads

$$P\left[\int \begin{pmatrix} variety\ of\ complex\ topics\ of \\ QFT,\ RNP,\ Ap.\ \&\ Cosmology \end{pmatrix} d[Myself]\right] = \begin{matrix} Non-renormalizable \\ divergent\,task \end{matrix} .$$

Nevertheless, a bold attempt has to be made to describe these exciting developments proposed by the participants. With all these caveats, the questions tackled by the speakers follow.

2 To B or not to B, and Related Topics

The importance of the magnetic field in astrophysics, and in compact stars in particular, has been recognized for several decades. An ever-increasing value of the "maximal" values considered have been also inflationing whenever observations indicated a new record. For example, magnetic fields of strength $\sim 10^{12}\,G$ were the top choice just 15-20 years ago. Today (2003) the refined observations have leaded to considered the reality of magnetic fields 1000 times as strong, well above the well-known Schwinger limit $\sim 4.4\times 10^{13}\,G$. What is the physical behavior of bulk matter in this regime? Which are the derived transport and structural properties? Which is the ground state ater all? These are difficult questions to which no definitive answer is available as yet. Talks addressed the spectra of e^- and n, p in this regime, the first being of interest for the theory of neutron star atmospheres (and possibly white dwarfs); while the latter may constitute the bulk of compact stars. The word

"may" refers to the caveats about the appearance at relatively low densities of the deconfined QCD phase, which has been studied in a strong magnetic field elsewhere. The overall message is that new phenomena is expected (*not* just a scaled-up version of the small-field physics) to alter dramatically the features of neutron stars. Let us revisit some of them discussed during the event.

As already mentioned, super-Schwinger fields are important for NS atmospheres and may be important for WD interiors depending on the strength of the field as a function of depth. Espinoza showed us some general results for the electron gas useful for the modelling. Questions about the very origin of WD magnetic fields, and particularly the existence of a reason to limit the observed fields to $\sim 10^9 G$ are still unknown. Riesengger suggested that the flux is very much the same for magnetic WD and NS, as well as for peculiar A/B upper main sequence stars in his "magnetic strip tease" model. Nevertheless, and quite independent of its origin, it is quite clear that the study of external (magnetospheric for NS) physics would need a better understanding of quantum processes there (Shabad) and disentangling them from the complex path that generates radiation ultimately observed (Quiao). Completely new physical phenomena may show up (like catalyzed axion decay, Horvath and neutrino pair production, Pacheco and Regimbau) and need to be studied in detail, because they may make an essential difference for the forthcoming detectors.

On the other hand, the behavior of nucleons in superstrong magnetic fields (naturally expected to be quantized at $(m_n/m_e)^2 \sim 10^6$ times the value of the Schwinger field for electrons) has attracted the attention during the Workshop, since not only effects on the kinetic part of the energy have been calculated (Pérez Rojas, Pérez Martínez, Mosquera Cuesta, Goyal); but also the vacuum seems to present a complicated behavior in response to such a large field (Rodríguez). The issue of a fundamental instability of matter induced by the magnetic field is very relevant to the observations of magnetars, and claims against their neutron nature have been issued. We feel that this is a promising avenue for research, since many quantum effects have to be properly evaluated, and their combined effects on the self-gravitating stars addressed. Ultimately, there *must* be an upper limit to the magnetization of a star (around the virial value ?), but it is unclear as yet if this highest value is really relevant for actual stars.

Moderate ($\leq 10^{12}\, G$) fields have also attracted a lot of attention, and posed their own "classical" problems to solve. Reisenegger reviewed what is presently known about the origin and evolution of "standard" (i.e. up to $10^{12}\, G$) fields. In addition, the issue of r-mode instabilities has been revisited and concluded that newborn NS are not as strong sources as once expected, although the instability may be relevant to understand the evolution of ms pulsars accelerated in binary systems. Other (already classical) subjects were already addressed. Particularly, the big efforts undertaken to systematically evaluate hadronic models of the supranuclear equation of state were extensively discussed by Vasconcellos and Dillig. The connection of this regime with laboratory hadronic physics can not be overemphasized, especially the quest for an appropriate description of the QCD vacuum immediately

above the saturation density. While it is frequently argued that this is the relevant regime for NS, it must be acknowledged that many theories predict the onset of the deconfined phase at relatively low densities, and even absolutely stable phases like the celebrated "strange matter". If so, it may be possible to model compact stars using quark degrees of freedom, notably 2SC and CFL phases recently discussed in the literature (Horvath). Again, it is mainly the behavior of the vacuum which should tell us which way to go.

A subject particularly forgotten in the literature, but revived recently and possibly relevant to some high-energy phenomena, is the existence of *charged* compact objects. Mosquera Cuesta discussed a model of a black hole that becomes charged because of charge flux to an extra dimension; while Malheiro has raised questions on compact stellar structure with a net charge. There is no clear evidence for such objects as yet, but in any case, examination of these problems may prove an interesting fruitful exercise in theoretical astrophysics.

Last, but not least, the Workshop benefited from a full session devoted to cosmological issues. Goyal discussed how cosmological QCD dynamics may have left massive remnants with asteroidal masses, the so-called "quark nuggets". Contrary to earlier beliefs, it can be now stated that if stable nuggets form they may be able to survive evaporation/boiling down to $\sim MeV$ temperatures. The Las Villas group participants (Cárdenas, González, Quirós and Leiva) have shown the results of their cosmological model involving a dynamical quintessence field and cosmological constant, discussing the consistency with type Ia supernovae observations. This type of tentative approach is important if one has ever to understand the interplay between the content of the universe and related quantum field quantities, likely the cosmological constant itself.

3 Highlights

As expected, and also confirmed in other occasions, Cuba itself proved to be an unique cultural and touristic experience far beyond the limits of the Workshop (notably the trip to Tarará beach, among others). Some highlights may be awarded not with the conventional "stars", but rather with some of the most typical excellence products of the island (the Cohiba), here promoted to the status of qualifier.

In my opinion, the ample time devoted to round tables each day, in which participants openly exposed their points of view, was the most remarkable highlight of the Workshop. Following the standard nomenclature, round tables are given the 5 Cohibas rate.

The worst rate (probably a few negative Cohibas) was awarded to the forced last-minute absence of several participants and invited speakers due to a very unfavorable international situation that reflected on one of the most ancient globalized human enterprises, science. We all lost to some extent, but will not give up our own way of setting collaboration and exchange of ideas, as a kind of Le Chatelier

reaction to devastating conflicts that isolate nations and people.

As a concrete example of the last statement, an international Latin-American network of high-energy physics and astrophysics has been discussed and launched during the Workshop. Hopefully, the number of Cohibas awarded to this effort will grow with time and allow a fluid exchange of researchers/students and joint experimental ventures.

On behalf of the participants I offer a big clap for Hugo, Aurora, Herman, Zochil, Betty, Armando, María, Joanna and Eloísa for their work. Thank you all and see you in the next Caribbean Workshop !