Scientific report

May 24, 2010

Purpose of the visit

The aim of this visit was to benefit from the experience of working with the Oxford astrophysics staff members having interests closely related to my project. In particular Jocelyn Bell-Burnell has a wide experience of the physics of neutron stars and pulsars, Philipp Podsiadlowski is an expert on stellar evolution leading to compact object formation and the physics of compact objects and Alex Schekochihin has wide experience in plasma physic issues associated with compact objects. The visit has been facilitated by the presence there for part of the time of my ex thesis advisor John Miller.

There were two scientific projects to be developed and both aims at advancing current understanding of the role of magnetic fields in neutron star (NS) astrophysics. They are: a) study of dynamo mechanisms in proto-NSs (PNSs) and their role in determining the birth magnetic field of NSs, and b) study of magnetic field distortions in the accretion process around magnetised NSs and their consequences in the determining the NS spin history.

On returning to SISSA, I will give a seminar about these research topics at ICTP, during the Celebration of the 65th Birthday of Prof. Marek Abramowicz. Furthermore I will share my experience with the rest of the staff of the Astrophysics and Astroparticle sectors, mainly through seminars and active participation in the compact object group meetings, which take place monthly.

Description of the work carried out during the visit

As regards project “a” (i.e. the study of dynamo mechanisms in PNSs and their role in determining the birth magnetic field of NSs), I have considered an axisymmetric model of PNS and have simulated the amplification of the magnetic field through a mean field dynamo. Before the beginning of the visit I have had worked on the numerical code and produced a new version of the ZEUS-MP code (a public domain parallel code for solving MHD equations).

During the visit I have first finalized the model, by specifying the angular and radial profile of the angular rotation of the PNS, and then defined the region of the parameter space (which is three dimensional) to be analyzed. I have also developed some additional visualization routines in IDL to analyze the data. Finally I have run some numerical simulations (on the SISSA cluster) with which I was able to produce three 2D sections of the phase space. I have then started the physical analysis of these results. I have also had the opportunity of discussing them with Dr. Silvia Zane at the Mullard Space Science Laboratory (MSSL), department of the University College London (UCL). This work is still ongoing and I will continue it with prof. Roberto Turolla in Padova.

For the study of magnetic field distortions in the accretion process (project “b”), I had already addressed the distortions of the poloidal field lines in a previous work and had started the analysis of the toroidal one. During the visit I have continued this work both by finalizing the publication of a paper on the previous analysis and by doing the new analysis on the toroidal component.

In particular I have completed the definition of the model by finding appropriate boundary conditions and choosing a physically plausible profile of the angular velocity of the plasma in the disc. Furthermore

the numerical code for solving the ϕ component of the induction equation has been completed (with the addition of some ghost zones for a better treatment of the boundaries) and fully tested. After that a numerical solution has been obtained, I have worked on the analysis of the results. These have been discussed with the Oxford staff members during a seminar that I have held there and also with prof. Kinwah Wu at MSSL (UCL).

Finally, I participated in a meeting of the IOP (Institute of Physics) in London about "current and future challenges in gravitational physics". A series of talks have been given on the current status of gravitational physics research: overview by Professor Bernard Schutz (Albert Einstein Institute, Golm); gravitational waves by Dr Stephen Fairhurst (Cardiff); cosmology and gravitation by Dr Kazuya Koyama (Portsmouth); and AdS/CFT correspondence and relativistic fluids by Dr Mukund Rangamani (Durham).

Description of the main results obtained

For the project about the dynamo, my preliminary results show two interesting features. The first is that they seem to confute the idea, suggested by some authors in literature and confirmed in my previous 1D model, of having a minimum period such that every PNS rotating faster than that triggers the dynamo action, regardless of the differential rotation. The second feature regards the supercritical regime, i.e. when C_α (the dynamo number associated to the α-effect) is larger than the critical value. I have seen that in some regions of the parameter space the dynamo is switched off, i.e. even above the critical value there can be some regions where the field is damped. Therefore the final intensity of the magnetic field will not be monotonic with C_α.

As regards the distortions of the magnetic field in accretion discs around NSs, I have completed the analysis by calculating also the toroidal component of the field. I have found that it is very different from the profile obtained in the analytic model developed in the 80's and widely cited even nowadays. In particular my results suggest that B_ϕ has a fully two dimensional structure and that it does depend very much on the deviations away of the poloidal component of the magnetic field from a pure dipole. Therefore we see the break down of two of the most common approximations: (1) using the thin disc approximation and the vertical averaging approach to neglect some terms of the induction equation and (2) assuming the poloidal component of the magnetic field to be dipolar-like.

Future collaboration with host institution

The study of magnetic field distortions in the accretion process around magnetised NSs and their consequences in the determining the NS spin history will be for sure subject of a further collaboration. The results obtained so far are very interesting and can have important consequences on the calculation of the spin history of the accreting NSs. In fact, all of the models for calculating the magnetic torque exerted on the star follow the old analytic model and we have suggested an improvement of these models.

Projected publications/articles resulting or to result from the grant

The main publications to result from this grant are the ones for the distortion of the magnetic field of the NS inside the surrounding accretion disc. The one with the analysis of the poloidal component is expected to be published in a month and by the end of June the one with the analysis of the toroidal component is expected to be submitted.

As regards the study of dynamo mechanisms in PNSs and their role in determining the birth magnetic field of NSs, additional work is still needed, both in doing some more numerical calculations (so to span a wider region of the phase space) and in understanding the physics behind the new features that we are seeing. I expect to have a draft not before 3 months.