Scientific report for the CompStar exchange visit: 'The nonlinear evolution of magnetic instabilities in neutron stars'

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1 Summary of visit

This scientific report is a summary of my exchange visit from the Albert Einstein Institute to the University of Southampton, from January to June 2011. The main goal of the visit was to investigate magnetic equilibrium configurations of neutron stars and their stability, calling upon expertise and resources from both the AEI and Southampton. The intention has been that this exchange visit will help to build stronger collaboration between the two institutions.

During the visit I was chiefly engaged in work on two projects. The primary one was to study the development of magnetic instabilities in stars, using the nonlinear relativistic MHD code `WhiskyMHD` developed at the AEI. My collaborators (Riccardo Ciolfi, Gian-Mario Manca and Luciano Rezzolla) and I showed that an instability of poloidal magnetic fields — already known from perturbative studies — develops into a nonlinear regime where it causes large-scale rearrangement of the star's magnetic field. The resulting configuration contains poloidal and toroidal components and appears to be more stable, from our simulations. Accompanying this rearrangement is an excitation of the star's fundamental oscillation mode and consequent emission of gravitational radiation. This emission may occur after magnetar giant flares, and interestingly results in a long-duration signal rather than just a burst. This represents an interesting source for third-generation gravitational-wave detectors.
To conclude this project, I returned to the AEI for a week (16/05/2011-20/05/2011) during the period of my exchange visit. In addition to my direct collaboration with colleagues from the AEI I have benefited from the input of the Southampton group, especially Ian Jones, in discussions on the more physics-related aspects of the project.

The second project involved studying equilibrium configurations of 'two-fluid' stratified neutron star models, with superfluid neutrons and magnetised protons. This is a more realistic model than the single-fluid, barotropic models of magnetised stars considered by most studies to date. The Southampton group has considerable experience in this direction, so being based there while working on this project has been very useful.
For the case of stars with purely toroidal magnetic fields we were able to treat the full problem of superfluid neutrons and type-II superconducting protons, which is the situation predicted to occur in many real neutron stars. In the normal-MHD stratified case, we found that the toroidal component in mixed poloidal-toroidal magnetic fields may be larger than in the barotropic case, which may have implications for the stability of these stars. Another main result from this work was calculating the magnetic distortions of neutron stars with superconductivity. These may be significantly larger than for magnetic fields in standard MHD; in turn, this leads to a larger possible gravitational-wave emission from this magnetic asymmetry.

In addition, I have begun work on a third project with members of the Southampton group (chiefly Ian Jones): investigating the stability and oscillation-mode spectra of neutron stars

with mixed poloidal-toroidal magnetic fields, using a linearised time-evolution code. This would be a complementary study to the primary project of this exchange visit, allowing us to see how large a toroidal component is required to remove poloidal-field instabilities. In addition, this project is motivated by the observations of magnetar QPOs. We will be able to gauge the effect of different field configurations on the oscillation spectra of magnetars, and hopefully come closer to understanding which modes we observe in magnetar QPOs. If some of the QPOs represent modes of the fluid interior, we would have a possible probe of the interior physics of neutron stars. I plan to continue collaboration with the Southampton group, particularly on this project, in the coming months.

2 Publications resulting from the grant

1. Ciolfi R., Lander S.K., Manca G.M. and Rezzolla L., *Instability-driven evolution of poloidal magnetic fields in relativistic stars*, arXiv:1105.3971, accepted for publication in ApJ letters
2. Lander S.K., Andersson N. and Glampedakis K., in preparation
3. Lander S.K. and Jones D.I., in preparation