Dr. BRYNMOR HASKELL
"The role of pinning in superfluid neutron star oscillations"
COMPSTAR GRANT FINAL SCIENTIFIC REPORT

Purpose of the visit:

The purpose of this visit was for me to lay, together with Prof. Pizzochero, the foundations for the incorporation of realistic pinning models in multifluid hydrodynamics.
This ambitious goal requires both a deep understanding of the microphysical aspects of vortex pinning in the crust, in which the group in Milan are experts, and a grasp of multifluid hydrodynamics in Neutron Star interiors, which is my own area of expertise.
This is an essentially new project as, even though considerable work has been done on superfluid neutron star dynamics, very little effort has been devoted to incorporating realistic pinning forces in hydrodynamical models.
It is clearly time to fill this scientific gap as such models are required not only to explain present electromagnetic observations of neutron stars (in particular to understand pulsar glitches, but also in the study of the QPOs in magnetar flares), but will also be necessary for future gravitational wave observations.

Work carried out and main results:

During my stay in Milan I have first of all acquainted myself with the microphysical aspects of pinning and the assumptions that underly the calculation of the *pinning energy per unit length*, which is the relevant quantity if one is to study global dynamics. Together with prof. Pizzochero I have then focused on how to incorporate realistic values for the pinning forces in large scale hydrodynamic calculations for two problems: the oscillations of a two component superfluid neutron star and that of pulsar 'glitches', i.e. sudden jumps in the observed rotation rate.
We shall discuss the second problem first, as it is probably the strongest motivation for the study of pinning in neutron star crusts. It is in fact thought that the neutron vortices in the crust are 'pinned' to the nuclei, thus not allowing the superfluid component to slow down with the charged component, which is subject to an electromagnetic spin-down torque. When the lag between the two components becomes too large the vortices "unpin" and there is a sudden transfer of angular momentum to the crust, which gives rise to the observed "glitch".
Models to date have always failed to give quantitatively correct predictions for the scale of a glitch (usually several orders of magnitude too large), but the recent results of Donati & Pizzochero (2006) and Grill & Pizzochero (in preparation) have shown that the pinning force per unit length is much weaker than previously believed, which could produce a glitch of the right order of magnitude.
On my suggestion Dr.Trevor Sidery, who is also an expert on pulsar glitches and currently in Sabanci University, Istanbul, was invited to Milan in November and together we have begun to work on a simple hydrodynamical glitch model, incorporating pinning forces.
In particular we have estimated in which region of the star vortices which unpin can then re-pin, using realistic estimates for the dissipative drag force that acts between the two superfluid components. In fact it is the drag force due to Kelvin excitations in the crust that brings neutrons and protons back to co-rotation after the superfluid has unpinned, and gives rise to the rapid spin-up on a time scale of less than two minutes.

We are now focusing on how to translate the expression for the torque in terms of vortex density to an expression in terms of global properties of the fluid, and the results will be presented in a forthcoming publication (Haskell, Sidery & Pizzochero, in preparation).
As regards the first problem, that of superfluid neutron star oscillations, together with Prof. Pizzochero have proposed a prescription for the mutual friction coefficients that would be needed in the strong pinning case. However the cylindrical nature of the pinning forces make the analytical treatment of oscillation modes on a spherical background considerably complicated, while it is quite easily implemented in the two-dimensional time evolutions the applicant has worked on in Southampton. I have already discussed the application to the code with Andrea Passamonti and Nils Andersson, and plan to focus on this now that I have returned to Southampton. I expect that such a code will also help to validate the analytic glitch models that have turned out to be the focus of my stay in Milan.

Future collaboration with the host institution:

I will continue my collaboration with Prof. Pizzochero, first of all by reporting my progress at the COMPSTAR workshop in Caen in February 2010, and then with a further visit to Milan which is planned for the spring of 2010.

Projected publications resulting from the grant:

There is currently one article in preparation (Haskell,Sidery and Pizzochero, in preparation) directly resulting from the grant, and a further publication in collaboration with A.Passamonti and N.Andersson is expected in the following months.
Furthermore, during my stay in Milan, the applicant has also worked on the following publications:
(Haskell & Andersson, in preparation)
(Andersson, Haskell & Comer, in preparation)

Further comments:

During my stay in Milan I gave a talk at the INAF-sezione di Milano, on the 26/11/2009 with the title: “Gravitational Wave emission mechanisms in accreting systems”