Examiner's report on the Doctoral thesis of Gabriel Török

This thesis deals with the kilohertz quasi-periodic oscillations (QPOs) seen in the X-ray fluxes coming from disc accretion flows onto neutron stars and black holes. The work presented consists of reprints of fourteen papers published in refereed journals and also three other papers, prefaced by a systematic extended introduction which puts the work in context and links together the material in the papers.

The work divides basically into two sub-sections: one dealing with cases where kilohertz QPOs are seen in black-hole sources and the other dealing with cases where the compact object concerned is a neutron star. In both types of source, the QPOs are typically seen at two related frequencies, appearing as "twin peaks" in the power density spectrum. The phenomenology is rather different in the two cases but also has some striking similarities which are investigated in detail here. The question of whether a similar mechanism is involved in both cases has been a subject of lively debate in the literature. Various models have been proposed to explain the observed effects: the emphasis here is on the orbital resonance model of Kluzniak & Abramowicz but there is also a comparative discussion of the other proposals.

In the black-hole sources, one sees a characteristic 3:2 ratio between the QPO frequencies, which is interpreted in the orbital resonance model as being associated with a parametric resonance between vertical and radial epicyclic modes. On this picture, the oscillations for a given central object would occur at a very precise location in the accretion disc at which the resonance condition is satisfied. The kilohertz QPO observations involve stellar mass objects, but similar QPOs (at lower frequencies) may also be expected to occur for active galactic nuclei and have indeed been seen for Sagittarius A*, the supermassive black hole at the centre of our own galaxy. For that, a number of QPO frequencies have been observed, including ones having a 3:2 frequency ratio but also ones with other frequency ratios which are interpreted in terms of forced resonances. For these, one requires a forcing mechanism and it has been suggested that this might be provided by the "Aschenbach effect", which is related to the fact that for very rapidly rotating black holes, the profile of linear azimuthal velocity in the disc is not typically monotonically decreasing as would usually be the case, and this non-monotonic behaviour is associated with a certain characteristic frequency. The mechanism for this producing the forced oscillations remains somewhat obscure, however. All of these issues are discussed in detail in the thesis with many new contributions. From the models, it is possible to make estimates of the black-hole spin which is interesting to do but turns out to be problematic since conflicting values of the spin are found in some cases when using different methods of estimation. This is also discussed in the thesis.

For the neutron-star sources, the situation is more complicated than for those with black holes. One still does see twin-peak QPOs with frequency ratios clustering at the characteristic 3:2 value but there is a spread around this and also, these systems are variable and often only one peak is seen at a time. For a given source, the twin frequencies typically follow a linear relationship (which can be explained within the orbital resonance model); the slopes of the linear laws are different for the different sources and there is an anti-correlation between the slope and the intercept. All of the linear relationships pass through a special point giving a frequency ratio of 3:2 and with particular values for the upper and lower frequencies. Much of this is explainable in terms of the orbital resonance model but there are some features which remain elusive and some of the interpretation is controversial. The thesis contains an account of all this, again with many original contributions. A particular point, which is maybe the most striking result of the thesis, concerns the behaviour of the amplitude difference between the twin peaks as a function of the frequency ratio. The candidate's analysis of the observational data has shown that the amplitude difference changes sign at the special 3:2 frequency ratio, and also at another special frequency ratio 5:4. The lower frequency peak has smaller amplitude for frequency ratios greater than 3:2 but then becomes the dominant one on passing 3:2 and this continues until the 5:4 ratio is reached when the amplitudes again become equal. This is a striking behaviour which is clearly saying something fundamental about how the process works and it has attracted a lot of attention from top experts in the field.

The subject matter of the thesis is extremely interesting, casting new light on processes occurring in rather strong-field regions near to the surface of neutron stars and black holes. In this work, the candidate has demonstrated expertise both with data handling and with the theoretical aspects of the project and has made contributions which are certainly substantial at an international level. The amount of original work presented here is impressive. I have no hesitation in recommending that the thesis should be approved for award of the Doctoral degree. I am looking forward to discussing various aspects of it with the candidate in person but this will not change my recommendation.

John Miller

Trieste, 10th September 2008