JSPS Joint Project

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Project title: "Magnetic activities of the Sun and the stars probed by the new-generation oscillation data"

This was a multifaceted project involving collaborators at several institutions. All of the projects involved asteroseismology and the interaction of stellar pulsations with magnetic fields. Sub-projects included:

1. The measurement of the solar radius based on seismic investigation carried out by Dr Masao Takata of the University of Tokyo and Prof. Douglas Gough of the University of Cambridge.
2. An investigation of dynamics in stellar atmospheres based on spectroscopic observations of line profile variations. This was carried out with observations obtained with the Japanese 8-m Subaru Telescope on Mauna Kea, Hawaii, by Profs Donald Kurtz and Hiromoto Shibahashi of the University of Tokyo, and included collaboration with Prof. Hideyuki Saio of Tohoku University and Prof. Simon Jeffery of Armagh Observatory, Northern Ireland.
3. Asteroseismology with high-precision photometry was the major focus of the collaboration between Profs Kurtz and Shibahashi, primarily using data from the NASA Kepler Space Mission, but also using ground-based observations obtained by Kurtz in Chile. The projects under this theme included many collaborators in the UK, Japan and internationally, as can be seen from the papers published.
4. The investigation of magnetic activity of solar-like stars carried out by Dr Takashi Sekii of the National Observatory of Japan working with members of the Birmingham Solar Oscillation network group.

The collaboration between Kurtz and Shibahashi dates back to 1984 when Kurtz was first invited to visit the Department of Astronomy at the University of Tokyo by Shibahashi (neither was a professor then). Over the decades there have been several JSPS and Royal Society fellowships.

Funds awarded:

2.5 million yen /yr x 2yr = 5 million yen
This was used to cover travel to UK for Prof. Shibahashi and Drs Takata and Sekii for research, and also for meetings to Hungary, Australia, France, China and Poland.

Matching funding from the UK:

Profs Shibahashi and Kurtz had a £12000 Royal Society UK-Japan collaboration program award from 2010- 2012

Prof. Kurtz had a £2000 UK JSPS London Furusato Award in 2013

Kurtz visited Japan under these various grants in 2012 July 1-7, November 16-December 1 and 2013 October 3-26, including funding from a JSPS Invitation Fellowship

Prof. Gough visited Japan 2012 November 5-December 19

Results from the collaborations started and continued under this JSPS funding and associated grants include:

1. In collaboration with Kurtz's PhD student, Simon Murphy, we showed that there is no Nyquist frequency limitation to the study of all pulsation frequencies in Kepler Space Mission Long Cadence data. These frequencies are the fundamental data of asteroseismology and this paper opens up thousands of stars to asteroseismic analysis that were previously thought to have insuperable ambiguities. Taking account of the huge cost of the Kepler mission, we say our discovery is important not only in opening a new prospect in scientific achievements but also in financially efficient usage of a resource in big science. Coupled with the results of the next study, this may lead to the discovery of new exoplanets by novel means we developed.

Refereed publication:

Super-Nyquist asteroseismology with the Kepler Space Telescope:
Murphy, Simon J.; Shibahashi, Hiromoto; Kurtz, Donald W., 2013, Monthly Notices of the Royal Astronomical Society (MNRAS), 430, 2986-2998

This work was carried out during joint visits between Japan and the UK funded by a Royal Society UK-Japan International Joint Project for Kurtz and Shibahashi, funded for £11520 for two years, 2010 – 2012, and by the Japan Society for the Promotion of Science (JSPS) Japan-UK Joint Research Program for Shibahashi and Kurtz for two years, 2012-2013.

2. We invented a new method to measure stellar radial velocities directly from photometric light curves by understanding the light travel time effects on the Fourier transform of stellar pulsation signals. This obviates the need for expensive and time-consuming acquisition and measurement of stellar spectra. We showed an example using Kepler Space Mission data of a hierarchical quintuplet stellar system with a pulsating star where we were able to derive the "mass function" to far better precision than a team working with spectra from some of the world's largest telescopes. Our new technique has the capability to detect exoplanets and stellar-mass black holes that are not detectable by other means.

Refereed publication:

FM stars: a Fourier view of pulsating binary stars, a new technique for measuring radial velocities photometrically: Hiromoto Shibahashi and Donald W. Kurtz, 2012, Monthly Notices of the Royal Astronomical Society (MNRAS), 422, 738-752

This work was carried out during joint visits between Japan and the UK funded by a Royal Society UK-Japan International Joint Project for Kurtz and Shibahashi, funded for £11520 for two years, 2010 - 2012.

3. In collaboration with the “UltraCam” team we discovered a new type of pulsating white dwarf star that can elucidate the chameleon-like changes of cooling white dwarf stars from helium to hydrogen to helium atmosphere stars as they cool. These new stars are a probable new class of pulsating white dwarfs that will help to measure of the important thicknesses of the atmospheric hydrogen layer. This work was the successful observational culmination of a theoretical prediction by Shibahashi that such stars should exist. UltraCam is a state-of-the-art UK photometer that we attached to the European Southern Observatory New Technology 3.5-m telescope (ESO NTT) and to the UK Northern Hemisphere Observatory 4-m William Herschel Telescope (WHT) for highly competitive observing time awarded to our consortium with Kurtz as principal investigator.

Refereed publication:

Hot DAVs: a probable new class of pulsating white dwarf stars*:* D. W. Kurtz, H. Shibahashi,
V. S. Dhillon, T. R. Marsh, S. P. Littlefair, C. M. Copperwheat , B. T. Gaensicke and S. G. Parsons, 2013, Monthly Notices of the Royal Astronomical Society (MNRAS), tmp, 1215

The above work was an advance on our first refereed publication on this subject:

A search for a new class of pulsating DA white dwarf stars in the DB gap: D. W. Kurtz, H. Shibahashi, V. S. Dhillon, T. R. Marsh and S. P. Littlefair, 2008, Monthly Notices of the Royal Astronomical Society (MNRAS), 389, 1771-1779

This first paper was the result of the observational campaigns led by Kurtz that were motivated by Shibahashi’s theoretical prediction of the existence of the new class of pulsators:

The DB gap and pulsations of white dwarfs*:* Shibahashi, H., 2005, Shibahashi H., 2005, in Alecian G., Richard O., Vauclair S., eds, EAS Publ. Q26 Ser. Vol. 17, p. 143

This work was carried out during joint visits between Japan and the UK funded by a Royal Society UK-Japan International Joint Project for Kurtz and Shibahashi, funded for £11520 for two years, 2010 - 2012. This was the primary project for this grant.

4. We have worked together for more than 25 years on studies of the rapidly oscillating Ap (roAp) stars. Kurtz discovered this class of stars in the early 1980s, and Shibahashi led many theoretical developments in our understanding of pulsation in the presence of strong magnetic fields.

Using the unprecedented precision of the Kepler Mission data we discovered an roAp star, KIC 10195926, in the Kepler field and used a study of its pulsations to show for the first time that the influence of the strong, global magnetic field and the influence of rotation combine to give rise to different pulsation axes for different modes. Prior to Kurtz's discovery of the roAp stars it was thought that pulsating stars had pulsation axes coincident with their rotation axes. Kurtz showed that the pulsation is along the magnetic axis, which is oblique to the pulsation axis in these stars in 1982, then Shibahashi, in collaboration with Hideyuki Sao (Tohoku University and University of Tokyo) and Masao Takata (University of Tokyo), developed and expanded our theoretical understanding of this. Later work by Wojtek Dziembowski (Warsaw) and Lionel Bigot (Nice) predicted the possibility that mode axes could be different for different modes, and with this work we confirmed that prediction. We also discovered a low frequency close to half the rotational frequency of the star that we modelled as a first-ever observation of a toroidal pulsation mode seen in a star. This novel idea is still to be tested.

Refereed publication:

***The first evidence for multiple pulsation axes: a new rapidly oscillating Ap star in the Kepler field**, KIC 10195926:* D. W. Kurtz, M. S. Cunha, H. Saio, L. Bigot, L. A. Balona, V. G. Elkin, H. Shibahashi, I. M. Brandao, K. Uytterhoeven, S. Frandsen, S. Frimann, A. Hatzes, T. Lueftinger, M. Gruberbauer, H. Kjeldsen, J. Christensen-Dalsgaard and S. D. Kawaler, 2011, Monthly Notices of the Royal Astronomical Society (MNRAS), 414, 2550-2566

5. One of the brightest of the roAp stars discovered by Kurtz, the naked-eye star gamma Equulei, shows spectral line variations that had been interpreted as arising from rotational non-radial modes. But the star is known to have almost no rotation - it takes about one century to rotate once - hence the rotational explanation cannot be correct. We developed a model of supersonic pulsational shock waves that gives spectral line variations in good agreement with the observations. This is a realm of astrophysics - supersonic pulsations in stars - that is not previously well studied.

Refereed publication:

Shock Waves and Line-Profile Variation in roAp Stars: Hiromoto Shibahashi, Douglas Gough, Donald W. Kurtz, Eiji Kambe, 2008, Publications of the Astronomical Society of Japan (PASJ), 60, 63-76

6. The rapidly oscillating Ap (roAp) stars are unique. They have strong, global magnetic fields up to 25 kG, they have exceedingly peculiar spectra as the result of atomic diffusion, and they pulsate in high overtone acoustic modes. As a consequence these stars provide the most visible test of atomic diffusion - radiative levitation and gravitational settling of elements - processes that are part of the theory of the standard solar model, white dwarf structure, globular cluster lifetimes, and pulsational driving in several classes of stars.

Because of radiative levitation of rare earth elements and magnetic spots on the roAp stars, it is possible to study their atmospheric structure in three dimensions as can be done for no other star but the Sun. In this study we obtained simultaneously three nights of telescope time on the European Southern Observatory 8-m Very Large Telescope (ESO VLT) in Chile and the Japanese 8.2-m Subaru Telescope in Hawaii. Observing time on both telescopes is exceedingly competitive: Time on the VLT is oversubscribed by a factor of 6, and on Subaru by a factor of 10. Kurtz's postdoc Lars Freyhammer observed on the VLT and Kurtz on Subaru for this project. We showed both surface and depth structure in the elemental abundances and the pulsational mode, including the first-ever demonstration of "hydrogen spots", a novel idea for stars that are 90% hydrogen. We found running wave patterns in the spectral line profiles similar to those seen in Gamma Equulei (see project 5 above). This UK-Japan collaborative study took several years to bring to fruition, as a consequence of the extremely competitive environment of telescope time allocation on two of the world's largest optical telescopes.

Refereed publication:

A 3-D study of the photosphere of HD 99563: I. Pulsation analysis: L. M. Freyhammer, D. W. Kurtz, V. G. Elkin, G. Mathys, I. Savanov, W. Zima, H. Shibahashi and K. Sekiguchi, 2008, Monthly Notices of the Royal Astronomical Society (MNRAS), 414, 2550-2566

7. V652 Herculis is a helium star that stellar models of Simon Jeffery (Armagh Observatory, UK) and Hideyuki Saio (Tohoku University) have shown is the result of the merger of two helium atmosphere white dwarf stars, which are themselves the stripped cores of red giant stars. This is an extreme helium star. V652 Her pulsates with a period of 2.5 hours, accelerating from 0 to 70 km per second in a mere 15 minutes, reaching velocities that may be as high as Mach 8. This is the most extreme example of supersonic pulsation. We successfully were awarded two nights on the Japanese 8.2-m Subaru telescope for this project. As explained for project 6 above, this telescope time is oversubscribed by a factor of 10. We held a workshop in Armagh in March 2013 for three days and are close to our first refereed publication for this star. It is a surviving example of the kind of white dwarf merger that ends in supernovae for more massive white dwarfs. It is the most remarkable example of supersonic pulsation, and we have 3-minute time resolution of the shock wave racing out through the stellar atmosphere during the acceleration phase. This project is pushing the extreme limits of stellar pulsation physics.

Publication:

Establishing Shock Diagnostics in the Pulsating Extreme Helium Star V642 Herculis, Jeffery, C.S., Shibahashi, H., Kurtz, D.W., Elkin, V., Montañés-Rodríguez, P., & Saio, H., ASP Conf Ser., 479, 369-376, 2013.12

Ongoing and Future work:

As a consequence of Kurtz's last visit to Japan in October 2013, we have made fundamental new discoveries. Once concerns the rotation of the interiors of stars, and our paper has been submitted. Here is the abstract:

Asteroseismic measurement of surface-to-core rotation in a main sequence A star, KIC 11145123

Donald W. Kurtz, Hideyuki Saio, Masao Takata, Hiromoto Shibahashi, Simon J. Murphy, Takashi Sekii

We have discovered rotationally split core g-mode triplets and surface p-mode triplets and quintuplets in a terminal age main sequence A star, KIC 11145123, that shows both delta Sct p-mode pulsations and gamma Dor g-mode pulsations. This gives the first robust determination of the rotation of the deep core and surface of a main sequence star, essentially model-independently. We find its rotation to be nearly uniform with a period near 100 d, but we show with high confidence that the surface rotates slightly faster than the core. A strong angular momentum transfer mechanism must be operating to produce the nearly rigid rotation, and a mechanism other than viscosity must be operating to produce a more rapidly rotating surface than core. Our asteroseismic result, along with previous asteroseismic constraints on internal rotation in some B stars, and measurements of internal rotation in some subgiant, giant and white dwarf stars, has made angular momentum transport in stars throughout their lifetimes an observational science.

We also have many other papers in press and in preparation from other discoveries made using Kepler Mission data during that visit, and in the expanding collaborations that we have built, thanks to the JSPS funding.

A JSPS Fellowship has been awarded to Prof. Shibahashi for Prof. Kurtz to visit Japan in December 2014 - January 2015.

Pictures:

Tokyo (from the left):Prof. Donald Kurtz, Prof. Douglas Gough and Mrs Roseanne Gough, Prof. Hiromoto Shibahashi

Tokyo Tempura Dining (from the left): Prof. Hiromoto Shibahashi, Prof. Donald Kurtz, Dr Keiko Sekiguchi, Prof. Kazuhiro Sekiguchi (Director, Office of International Relations, National Astronomical Observatory of Japan)

Yokohama Dining:
Left: Prof Hiromoto and Mrs Minako Shibahashi
Right: Prof. Donald Kurtz and Dr Masao Takata

Armagh(from the left): Dr Vladimir Elkin, Prof. Hideyuki Saio, Prof. Simon Jeffery, Prof. Hiromoto Shibahashi, Prof. Donald Kurtz

Roscoff (from the left): Prof. Donald Kurtz, Mrs June Kurtz, Mrs Minako Shibahashi, Prof. Hiromoto Shibahashi, Prof. Douglas Gough