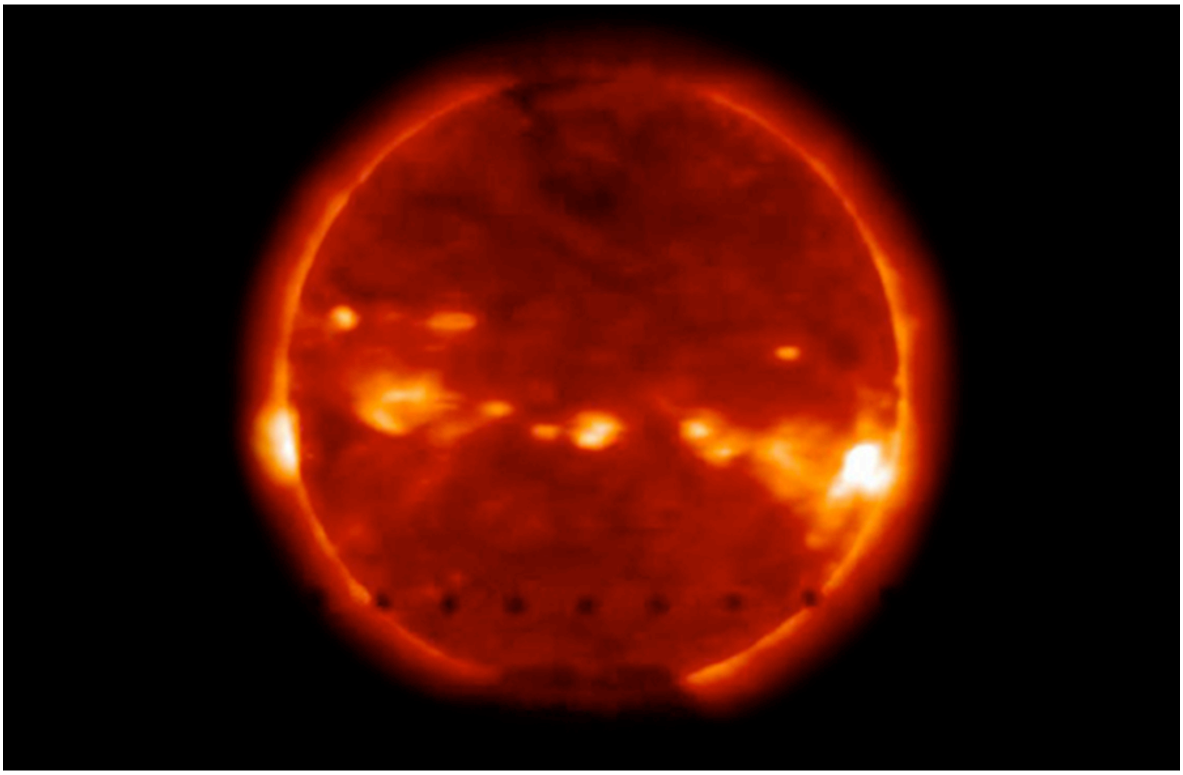

# Planetary transits and stellar variability

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The picture on the previous page is a composite of images taken during the transit of Venus on 8 June 2004 with the Solar X-ray imager (SXI) on the GOES-12 spacecraft. It was produced by the US National Oceanographic and Atmospheric Administration (NOAA) and downloaded from `www.solarviews.com`. It points to one of the main difficulties in detecting transits of a terrestrial planet: the intrinsic variability of late-type stars, a major part of which is due to magnetically induced photospheric features at the base of the X-ray bright coronal loops visible here.

# Summary

Most of the 130 or so exo-planets (planets orbiting a star other than the Sun) known to date, were detected via the radial velocity (RV) method, which relies on the spectroscopic detection of changes in the parent star's radial velocity as it orbits the star-planet system's centre of mass. Another promising method relies on the detection, in stellar photometric time series, of the periodic dips caused by planets as they cross the disk of their parent star: planetary transits.

Many ground-based transit search projects have been operating for several years and are expected to come to fruition soon – a handful of planets detected via their transits have been confirmed already. From the ground, both transit and RV methods are limited to giant planets. Several space-based transit search missions are thus planned to probe the terrestrial and habitable planet regimes. The preparation of data analysis tools for these missions, in particular COROT and *Eddington*, has been the focus of my PhD, with potential application to ground-based data as a secondary objective.

I first developed and tested an algorithm for the automated detection of transits in white noise, a challenge due to the rare, brief and shallow nature of the transits. One of the most important noise sources for future space-based missions is the intrinsic low-amplitude variability of the parent star on timescales of tens of minutes to weeks. I constructed an empirical model of this 'stellar micro-variability' to simulate realistic light curves for a variety of stars, and developed filters to remove micro-variability. Monte Carlo simulations were used to test the performance of these tools alone and in combination, and to identify which types of stars make the most promising targets for *Eddington* & COROT.

The algorithms' performance was tested against that of others by participating in the COROT transit detection blind exercise, in which a number of groups from across Europe applied their algorithms to a set of simulated light curves of content known only to a game master. A transit search was also performed in 5 nights of data obtained in 2003 by the UNSW transit search team using the 0.5 APT telescope in Siding Springs Observatory in the field of open cluster NGC 6633. and a handful of transit candidates with depths below 50 mmag were identified.

# Declaration

I hereby declare that this thesis entitled *Planetary transits and stellar variability* is not substantially the same as any that I have submitted for a degree, diploma or other qualification at this or any other university. This thesis is less than 60 000 words in length. Parts of this thesis were published in the following articles and conference proceedings:

- *Practical planet prospecting*
  Aigrain, S., Irwin, M., 2004
  Monthly Notices of the Royal Astronomical Society, vol. 350, pp. 331–345.
- *Characterising stellar micro-variability for planetary transit searches*
  Aigrain, S., Favata, F., Gilmore, G., 2004
  Astronomy & Astrophysics, vol. 414, pp. 1139–1152.
- *Impact of stellar micro-variability on* Eddington*'s planet-finding capability*
  Aigrain, S., Favata, F., Gilmore, G., 2004
  in 'Stellar structure and habitable planet finding', $2^{nd}$ *Eddington* Workshop, ed. F. Favata & S. Aigrain, ESA SP-538, pp. 215–224.
- *Detecting planetary transits in the presence of stellar variability. Optimal filtering and the use of colour information*
  Carpano, S., Aigrain, S., Favata, F., 2003
  Astronomy & Astrophysics, vol. 401, pp. 743–753
- *The Frequency Content of the VIRGO/SoHO Light Curves: Implications for Planetary Transit Detection from Space*
  Aigrain, S., Gilmore, G., Favata, F., Carpano, S., 2003
  in 'Scientific Frontiers in Research on Extrasolar Planets', ed. D. Deming & S. Seager, ASP Conference Series, vol. 294, pp. 441–444.
- *Bayesian detection of planetary transits. A modified version of the Gregory-Loredo method for Bayesian periodic signal detection*
  Aigrain, S., Favata, F., Gilmore, G., 2002
  Astronomy & Astrophysics, vol. 395, pp. 625–636.
- *A Bayesian algorithm for the detection of planetary transits*
  Aigrain, S., Gilmore, G., Favata, F., 2001
  in 'Techniques for the detection of planets and life beyond the solar system', $4^{th}$ Annual ROE Workshop, ed. W. R. F. Dent, p. 8.

This thesis is essentially my own work. However, some of the work presented therein was done in collaboration with others, as detailed below:

- Chapter 2
  The Bayesian algorithm presented in Section 2.1 is essentially my own work but benefited from regular discussions with and advice from F. Favata throughout its development and testing. The box-shaped transit finder was developed in collaboration with M. Irwin. Its implementation and initial testing were carried out in parallel by both of us, though the final Monte Carlo tests are my own work.
- Chapter 3
  The work presented in this Chapter is essentially my own, but benefited from regular discussions with F. Favata and G. Gilmore, and comments from A. Lanza.
- Chapter 4
  The starting point for the work presented in this chapter was the optimal filter described in Carpano et al. (2003), which was developed by S. Carpano with contributions from F. Favata and myself. The filters presented in this Chapter were developed in collaboration with M. Irwin, their implementation and testing being carried out in parallel by both of us.
- Chapter 5
  The work presented in this chapter is essentially my own but benefited from discussions with F. Favata, G. Gilmore and M. Irwin, as well as with M. Auvergne for the COROT simulations.
- Chapter 6
  This Chapter describes the COROT blind exercise, which was carried out by a collaboration led by C. Moutou with the following participants besides myself: M. Auvergne, P. Barge, D. Blouin, R. Cautain, A. R. Erikson, V. Guis, P. Guterman, M. Irwin, A. F. Lanza, F. Pont, H. Rauer, H. Voss and S. Zucker. Sections which describe work that was not my own were included when deemed necessary to place my work in context. The contents of Section 6.1 are the result of discussions between all the participants. The contents of Section 6.2 are primarily the work of others except for Subsection 6.2.3 which describes two sets of stellar light curves, one simulated by myself and one by A. Lanza. Section 6.3 contains work carried out by myself in collaboration with M. Irwin, except for Subsection 6.3.2, which summarises the methods used by the other participating teams for comparison. The contents of Sections 6.4 and 6.4.3.1 are essentially my own although they benefited from discussions with M. Irwin.

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