

Forward modelling: revolutionising coronal seismology

Tom Van Doorselaere

Scientific results

- *Development forward modelling code:* In the initial period of the fellowship, I have concentrated my efforts in the development of a forward modelling code. At the moment, it can calculate the spectral emission from coronal structures. In particular, I have concentrated on the frequently observed FeIX 171 and the FeXII 195 lines. The code is currently written in IDL. However, future development may focus on the rewriting the code in Fortran to allow for parallelisation. Other future inclusions are the modelling of broad band emission (for imaging instruments, such as SDO) and gyrosynchrotron emission (for radio telescopes). **(part of aim 1)**
- *Forward modelling of the slow wave and sausage wave:* This part of the project is in collaboration with Marcin Gruszecki and Valery Nakariakov (University of Warwick). MG has produced numerical models for slow waves and fast waves in stellar coronae. I have used the forward modelling code to calculate the spectral emission from these modes. It is found that, for coarse resolution, the sausage mode is hardly observable as intensity oscillations, because the intensity oscillations are compensated by line-of-sight integration. Because of the slightly off-angle (compared to the magnetic field) propagation speed of the slow wave, neighbouring field lines also start to oscillate, resulting in an observational broadening of the spectral line. Papers on these topics are under preparation. **(part of aim 2)**
- *Transverse oscillation eigenfunction in a torus model:* I have revisited the model I have constructed for plasma oscillations in an over-dense torus. In a previous paper, I concentrated on the frequencies alone, which were shown not be influenced by the curvature. However, here I focus on the eigenmodes of the oscillations that do experience a strong influence. I show that the modes are modified to include other azimuthal mode numbers. This is crucial, because it introduces a compressional component to the transverse mode (which cannot be obtained from cylindrical models). It is the conjecture that this compressional component may be responsible for observed intensity oscillations during transverse oscillations. At the moment, I am stuck at a numerical problem in solving the differential equations. Several solutions have been suggested. **(part of aim 2)**
- *Analysis of LYRA data:* I have taken the lead in the analysis of LYRA observations from the PROBA2 satellite, in a collaboration with the Royal Observatory Belgium. We have detected two periodicities in a flaring light curve, in a distinctly different frequency range. This led us to believe that both a slow and fast sausage mode were observed. We have made a model for such waves in a cylinder, and computer their periods. We have used those calculations to infer the plasma-beta in a flare, and the oscillation modes. This is the first time the plasma-beta in a flare has been measured. Although this technique has been applied to a solar flare, it is easily transferred to the seismology of a stellar flare. **(part of aim 3)**
- *Calculation of vorticity of kink mode:* In 2008, I pointed out that observations of transverse waves should be interpreted in terms of kink waves. However, Goossens et al. (2009) have shown that kink modes have a large Alfvén character. In this work, we show that the kink mode indeed has a delta-function of vorticity around the boundary of the cylindrical structure, which is smeared out with smoother density profiles. We have also calculated

the evolution of the fast body modes as the density contrast between the coronal loop and the external plasma goes to 1 (a homogeneous plasma). I have shown that in this case, the fundamental radial fast modes are converging to the Alfvén mode, and the radial overtones are converging to the fast modes. This makes a clear distinction in the character of the fundamental modes and overtones, and clarifies why their behaviour in the dispersion diagram is so different. **(part of aim 2)**

As can be seen above, I have made a huge progress in the execution of the project, although only one third of the time has been utilised.

Publications

1. Sausage oscillations of a cylindrical plasma non-uniformity, Gruszecki M., Nakariakov V.M., and Van Doorselaere T., 2012, A&A, submitted
2. LYRA observations of two oscillation modes in a single flare, Van Doorselaere T., De Groof A., Zender J., Berghmans D., and Goossens M., 2011, ApJ, vol. 740, pp. 90
3. Nonlinear long-wavelength torsional Alfvén waves, Vasheghani Farahani S., Nakariakov V.M., Van Doorselaere T., and Verwichte E., 2011, A&A, vol. 517, pp. A29
4. The first measurement of the adiabatic index in the solar corona using time-dependent spectroscopy of Hinode/EIS observations, Van Doorselaere T., Wardle N., Del Zanna G., Jansari K., Verwichte E., and Nakariakov V.M., 2011, ApJL, vol. 727, pp. L32

Added value for project and host institute

The Return Grant of Belspo was applied for in connection with the PRODEX project of the host institute (Centre for Plasma Astrophysics, Mathematics Department, K.U.Leuven). The PRODEX project was designed to exploit the data from recently launched space missions studying the solar corona, such as PROBA2, STEREO, Hinode and SDO. This Return Grant has made progress in the modelling of oscillations, specifically in the explanation of the intensity variations during transverse oscillations as observed by SDO. Furthermore, the largest success of this project was in the collaboration with the Royal Observatory Belgium (publication 2), in the analysis of oscillations in a flare observed by LYRA on board PROBA2. The detection of two periodicities in the light curve allowed for the measurement of the plasma-beta in the flare. This has given a huge boost to the further studies of oscillations in flares with PROBA2.

Integration researcher in Belgium

I have integrated very well in the host institute. In fact, thanks to the Return Grant, I have also obtained the large Odysseus funding from the FWO-Vlaanderen. This prestigious grant is given to young, promising researchers to establish their own research group in Belgium. It also comes with a tenure-track position in the host group. This shows that I have very well integrated in the host institute, and ensured a long stay as an independent researcher in Belgium. In that respect, the Return Grant has been an enormous success.