CSAM: Project summary

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The project aims to further our understanding of magnetohydrodynamical (MHD) waves in the solar corona and the upper layers of the solar interior and specifically addresses the coupling between the waves at the solar surface and in the corona. Within the local helioseismology community it is becoming widely accepted that magnetic fields should be taken into account when inverting the seismological data to infer local properties of the solar plasma. While the local helioseismic techniques have reached a fairly advanced stage they are predominantly based on purely hydrodynamical models. In the coming years, the inclusion of magnetic effects in the local helioseismic techniques is likely to become an important issue. Meanwhile, the emerging field of coronal seismology uses, compared to local helioseismology, simple models and methods often based on the analysis of a single eigenmode of the structure. As current and future space missions boost the data available for coronal seismology, the development of more advanced tools suitable for coronal seismology is a necessity. However, the construction of techniques for coronal seismology analogous to those used in local helioseismology is not straightforward, as it inevitably involves the inclusion of magnetic fields and is complicated by the inherent 3D structure of the coronal magnetic fields and line of sight integration effects.

The project has focused on a number of specific topics explicitly exploiting the expertise of both the fellow and the outgoing host.

The first involves a common theoretical framework in which both the scattering of p-modes by sunspots (a subject of local helioseismology) and the eigenmodes of coronal loops (a subject from coronal seismology) can be described. It thus unites two models which are fundamental to the two distinct disciplines and is thus well addressing the aims of the project. The clear message from this analysis is that while being two methods with a different methodology, in general the two cannot strictly be separated. The model is very promising towards applications as it has the potential to be also and especially of use to assess the coupling between the oscillations at the photospheric level and in the corona.
While the conceptual framework that it provides is surely instructive and illuminating, some mathematical complication has been hampering the implementation of the model in a practical application. That complication was eventually overcome and brought back to the complications involved in taking functions of matrices where the matrices are not Hermitian. Our present practical implementation relies on the Schur-Parlett recurrence for that purpose.
Of immediate practical importance is the clarification with respect to the well known modes in slender flux tubes: sausage modes and kink modes. In particular it is shown convinc-

ingly that the equation for the kink mode derived by Spruit (1981, A&A 98, 155-160) is erroneous. Under certain conditions the equation by Spruit leads to a Klein-Gordon equation meaning that energy in the kink modes can only travel from the photosphere to the corona provided the frequency is above a certain cut-of value. However, such cut-of does not appear in the correct equation and hence (in as far as the simplifying conditions are justified) kink modes (as Alfvén modes) can propagate towards the corona. It remains to be investigated how much energy might be transmitted and reflected under more general conditions.
A second practical example is the extension of the multiple scattering formalism for ensembles of flux tubes to longitudinally stratified tubes.

Another topic involves the application of generalized ray tracing theory, as developed by the outgoing host institution in the context of local helioseismology, to the problem of resonant absorption. Resonant absorption is a concept overwhelmingly present in coronal seismology studies but is at present absent in the developed ray tracing methods. A model problem with a constant magnetic field and a density varying perpendicular to the magnetic field was investigated, representing the simplest model where resonant absorption is known to occur and which seemed suited for application of a ray tracing method. The results are both encouraging and discouraging. Encouraging, is the fact that the problem can clearly be treated in the sense of a generalized ray tracing method, where conversion between wave types happens at the location where two distinct ray paths approach each other. This has been clearly shown by building wave packets from the obtained normal modes and evolving these in time (an idea that was a fundamental theme in the project proposal). Comparison with the ray paths obtained by ray tracing is near perfect. However, somewhat discouraging, the estimates of the energy exchange between the waves which are build on a theoretical treatment by Tracy, Kaufman and Brizard (2003, Physics of Plasmas, 10, 2147) seem to be erroneous. It is concluded that the overall problem can indeed be addressed from a ray tracing perspective but the computation method for the transmission coefficients is inadequate in the present configuration and needs to be amended.