FINAL SUMMARY REPORT OF THE PROJECT SOLPROM-SMS (PIEF-GA-2010-274716)

The sub-project A of the SOLPROM-SMS project was devoted to the study of wave propagation, damping, and seismology in the fine structure of solar prominences. There is frequent observational evidence of **transverse oscillations and propagating waves** in threads of both quiescent and active region prominences. Common features of these waves are that the reported periods are usually in a narrow range between 2 – 10 min, that the velocity amplitudes of the oscillatory motions are smaller than 3 km/s, and that the oscillations are typically damped in less than 10 periods. In this sub-project we have investigated the effects of mass flows, resonant absorption, and partial ionization on prominence thread oscillations and seismology. The main conclusions of this sub-project are: (i) the presence of flow modifies the period of the oscillations with respect to the static case and can **significantly affect** the estimation of the transverse inhomogeneity length scale (see Fig. 1); (ii) the wave damping length due to resonant absorption is inversely proportional to the frequency, while that due to ion-neutral collisions is inversely proportional to the **square of the frequency**; (iii) based on their wave properties, the fundamental kink modes can be considered as **surface Alfvén waves**; (iv) an analytical seismological **inversion scheme** for propagating MHD kink waves has been developed. These studies were performed in collaboration with researchers from KU Leuven (Belgium), University of the Balearic Islands (Spain), University of Sheffield (UK), Space Research Institute (Austria), University of St Andrews (UK), and Instituto de Astrofísica de Canarias (Spain). The results of the sub-project A were reported in the following papers:

(1) Soler & Goossens 2011: *Kink oscillations of flowing threads in solar prominences.* Astonomy and Astrophysics, 531, A167
(2) Arregui, Soler, Ballester, & Wright 2011: *Magnetohydrodynamic kink waves in two-dimensional non-uniform prominence threads*. Astronomy & Astrophysics, 533, A60.
(3) Soler, Andries, & Goossens 2012: *Resonant Alfvén waves in partially ionized plasmas of the solar atmosphere*. Astronomy & Astrophysics, 537, A84.
(4) Goossens, Andries, Soler, Van Doorsselaere, Arregui, & Terradas 2012: *Surface Alfvén waves in solar flux tubes*. The Astrophysical Journal, 753, 111
(5) Soler, Ruderman, & Goossens 2012: *Damped kink oscillations of flowing promience threads.* Astronomy & Astrophysics, 546, A82.
(6) Goossens, Soler, Arregui, & Terradas 2012: *Analytic approximate seismology of propagating magnetohydrodynamic waves in the solar corona*. The Astrophysical Journal, 760, 98
(7) Zaqarashvili, Khodachenko, & Soler 2013: *Torsional Alfvén waves in partially ionized solar plasma: effects of neutral helium and stratification*. Astronomy & Astrophysics, 549, A113.

The sub-project B of the SOLPROM-SMS project was devoted to the investigation of various instabilities in solar prominence plasmas. Inspired by the recent high-resolution observations of plasma instabilities in prominences, theoretical analysis of the **Kelvin-Helmholtz, Rayleigh-Taylor, and thermal instabilities** in partially ionized compressible plasmas was performed. Analytic dispersion relations were obtained and parametric studies of the linear stage of the instabilities were done. The results were applied to the case of prominences and the main conclusions are: (i) the threshold flow velocity that can trigger Kelvin-Helmholtz instabilities in prominences becomes **sub-Alfvénic** thanks to the coupling between ionized and neutral species (see Fig. 2), (ii) the growth rate of the Rayleigh-Taylor instability decreases due to ion-neutral collisions, compared to the value in the fully ionized case, and becomes of the **same order of magnitude** as the observed life time of prominence threads, (iii) thermal modes may be unstable in prominence plasmas at **lower temperatures** than predicted in previous works and may affect the evolution of cool plasma condensations. These studies were performed in collaboration with researchers from KU Leuven (Belgium), University of the Balearic Islands (Spain), Royal Observatory of Brussels (Belgium), and Instituto de Astrofísica de Canarias (Spain). The results of the sub-project B were reported in the following papers:

(1) Díaz, Oliver, Ballester, & Soler 2011: *Twisted magnetic tubes with field aligned flow. I. Linear twist and uniform longitudinal field*, Astronomy & Astrophysics, 533, A95.
(2) Soler, Díaz, Ballester, & Goossens 2012: *Kelvin-Helmholtz instability in Partially Ionized Compressible Plasmas*. The Astrophysical Journal, 743, 163.
(3) Díaz, Soler, & Ballester 2012: *Rayleigh-Taylor instability in Partially Ionized Compressible Plasmas*. The Astrophysical Journal, 754, 41.
(4) Soler, Ballester, & Parenti 2012: *Stability of Thermal Modes in Cool Prominence Plasmas.* Astronomy & Astrophysics, 540, A7.

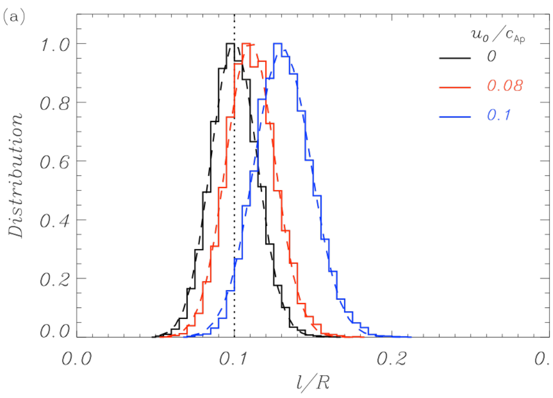

Fig. 1: *Normalized histogram of the seismologically estimated inhomogeneity length scale (l/R) for three values of the flow velocity (indicated within the panel in units of the Alfvén velocity) and a maximum background noise corresponding to 50% of the wave amplitude. Adapted from Soler, Ruderman, & Goossens (2012, A&A 546)*

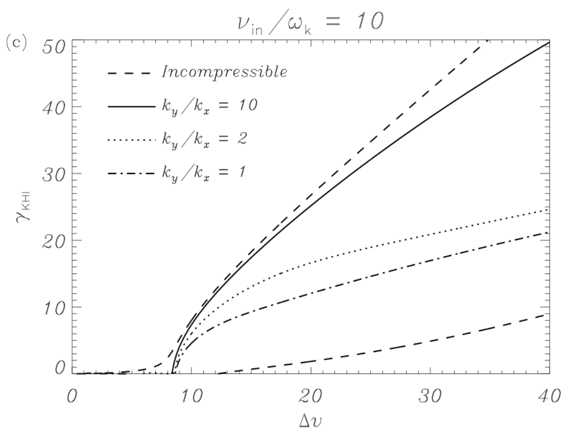

Fig. 2: *Dimensionless Kelvin-Helmholtz instability linear growth rate, γ_{KHI}, as a function of the dimensionless velocity shear at a plasma interface, Δv, for a plasma with ion-neutral collision frequency 10 times larger than the surface wave frequency. Adapted from Soler, Díaz, Ballester, & Goossens (2012, ApJ 749)*

The results of this project have also been communicated in 15 international conferences (**2 invited talks**, 8 oral contributions, and 5 posters).