Solar Atmospheric Metrology using Prominence Seismology

J. L. Ballester[1], I. Arregui[2], R. Oliver[1], J. Terradas[1], R. Soler[1], M. Goossens[3]

[1]Solar Physics Group
Universitat de les Illes Balears
Palma de Mallorca (Spain)

[2]Instituto de Astrofísica de Canarias
La Laguna (Spain)

[3]Centre for Mathematical Plasma Astrophysics
KULeuven (Belgium)

Solar Metrology: Needs and Methods
Paris, 7 – 9 October 2015

Introduction

- Metrology is "the science of measurement, embracing both experimental and theoretical determinations....in any field of science ...." (Bureau International des Poids et Mesures, Sèvres)
- Magnetohydrodynamic (MHD) Seismology: Method of remote diagnostics of plasma structures combining observations of oscillations with an interpretation in terms of MHD waves. Similar to helioseismology, but only local diagnostics of the structures (Local seismology)
- Solar Atmospheric Seismology, based on MHD seismology, is supported by observations providing us with strong evidence about the presence of oscillations and waves in magnetic structures

Introduction

- Metrology is "the science of measurement, embracing both experimental and theoretical determinations....in any field of science ...." (Bureau International des Poids et Mesures, Sèvres)
- Magnetohydrodynamic (MHD) Seismology: Method of remote diagnostics of plasma structures combining observations of oscillations with an interpretation in terms of MHD waves. Similar to helioseismology, but only local diagnostics of the structures (Local seismology)
- Solar Atmospheric Seismology, based on MHD seismology, is supported by observations providing us with strong evidence about the presence of oscillations and waves in magnetic structures

Introduction

- Metrology is "the science of measurement, embracing both experimental and theoretical determinations....in any field of science ...." (Bureau International des Poids et Mesures, Sèvres)

- Magnetohydrodynamic (MHD) Seismology: Method of remote diagnostics of plasma structures combining observations of oscillations with an interpretation in terms of MHD waves. Similar to helioseismology, but only local diagnostics of the structures (Local seismology)

- Solar Atmospheric Seismology, based on MHD seismology, is supported by observations providing us with strong evidence about the presence of oscillations and waves in magnetic structures

Introduction

- Aim of Solar Atmospheric Seismology: To determine difficult to measure physical parameters like Alfvén speed, magnetic field strength, inhomogeneity scales, etc., of magnetized solar atmospheric structures

- In this talk, using Prominence Seismology, I would like to show you, in a pedagogical way, three examples of the determination of (a) Alfvén speed and non-dimensional thickness of transition layer; (b) lower bounds of Alfvén speed; (c) longitudinal density profile, in solar filament fine structures

- Our seismological tools are: (a) Observations of small amplitude oscillations in filament threads; (b) Theoretical interpretation of the observed oscillations in terms of a kink MHD wave; (c) Resonant absorption as damping mechanism

Introduction

- Aim of Solar Atmospheric Seismology: To determine difficult to measure physical parameters like Alfvén speed, magnetic field strength, inhomogeneity scales, etc., of magnetized solar atmospheric structures

- In this talk, using Prominence Seismology, I would like to show you, in a pedagogical way, three examples of the determination of (a) Alfvén speed and non-dimensional thickness of transition layer; (b) lower bounds of Alfvén speed; (c) longitudinal density profile, in solar filament fine structures

- Our seismological tools are: (a) Observations of small amplitude oscillations in filament threads; (b) Theoretical interpretation of the observed oscillations in terms of a kink MHD wave; (c) Resonant absorption as damping mechanism

Introduction

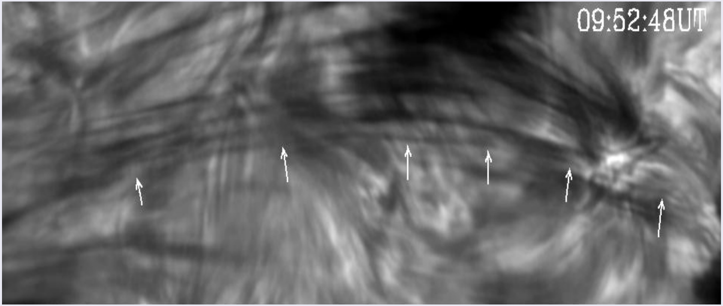
- Aim of Solar Atmospheric Seismology: To determine difficult to measure physical parameters like Alfvén speed, magnetic field strength, inhomogeneity scales, etc., of magnetized solar atmospheric structures

- In this talk, using Prominence Seismology, I would like to show you, in a pedagogical way, three examples of the determination of (a) Alfvén speed and non-dimensional thickness of transition layer; (b) lower bounds of Alfvén speed; (c) longitudinal density profile, in solar filament fine structures

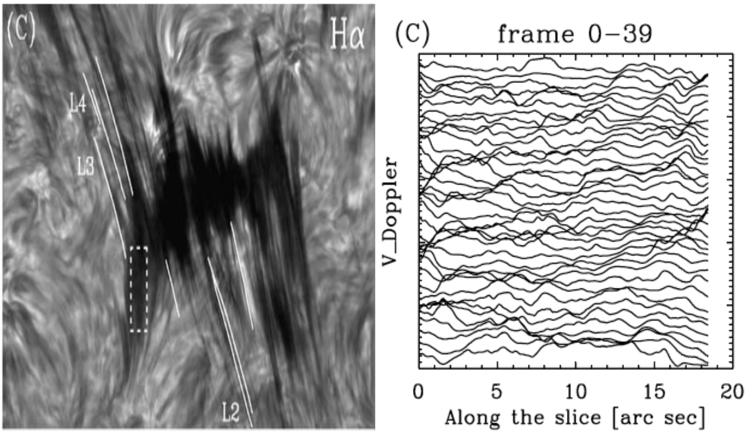
- Our seismological tools are: (a) Observations of small amplitude oscillations in filament threads; (b) Theoretical interpretation of the observed oscillations in terms of a kink MHD wave; (c) Resonant absorption as damping mechanism

Filament threads

- Quiescent and Active filaments are formed by a myriad of fine structures which seem to be field aligned, outlining magnetic flux tubes (Engvold, 1998; Lin, 2004; Lin et al. 2005, 2007; Engvold, 2007; Martin et al. 2008)
- Filament threads are cold plasma condensations occupying a segment of a much longer magnetic tube (Lin, 2004; Okamoto et al. 2007)
- Flowing threads observed in $H\alpha$, CaII, UV and EUV observations

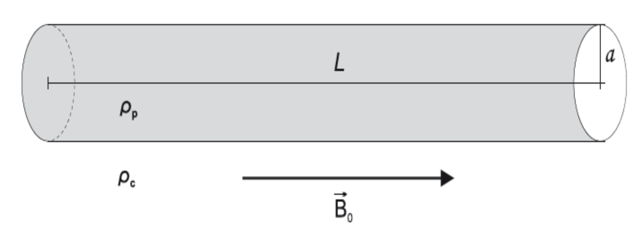


Oscillations in filament threads



- Small amplitude (~ 3 km/s), short-period ($2-10$ min), transverse oscillations, with damping times of the order of a few periods ($\tau_D/P < 10$) observed (Lin, 2004; Lin et al. 2005, 2007; Lin et al. 2009; Okamoto et al. 2007; Ning et al. 2009)

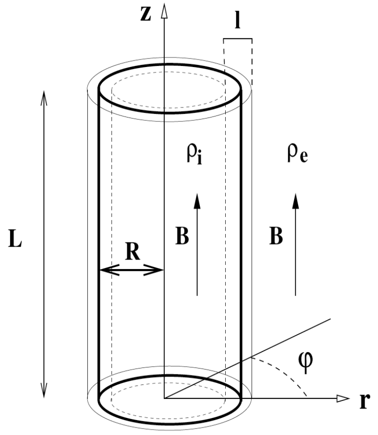
- MHD kink mode of a magnetic flux tube
- Kink waves (Almost incompressible): $\rho' \simeq 0$, Periods: $1 - 14$ min

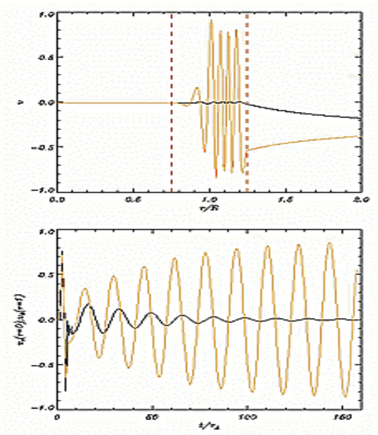


(Movie by J. Terradas)

Damping mechanism: Resonant absorption

- Damping mechanism: Resonant absorption (GIF by J. Terradas)



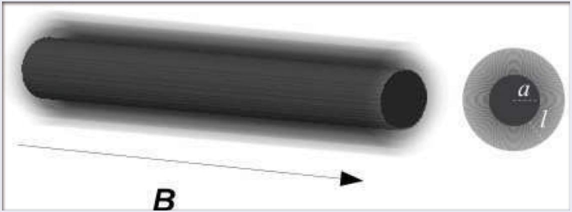


- Resonant damping offers a good explanation for the damping of threads oscillations ($\frac{\tau_D}{P} < 10$)

First Example: Seismology of filament threads using period and damping time (Arregui et al. 2008)

1D Model for a single thread

- Static equilibrium, no gravity, pressure-less flux tube, uniform magnetic field, 1D density enhancement
- Mean radius a; thickness of transition layer l; filament plasma density ρ_f, coronal plasma density ρ_c, density contrast $\zeta = \frac{\rho_f}{\rho_c}$



Seismology of filament threads using period and damping time

Inverse problem

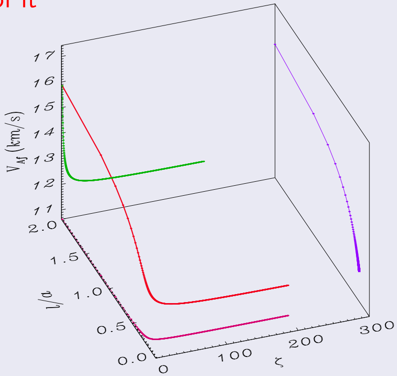
- Construct the model from the observed frequencies (like Helioseismology)
- No assumption on particular values for parameters

$$P_{obs} = P(k_z, \zeta, l/a, V_{Af})$$
$$(\frac{\tau_d}{P})_{obs} = \frac{\tau_d}{P}(k_z, \zeta, l/a)$$

- We use the analytical expressions in the TTTB approximation ($k_z a << 1$; l/a $<< 1$) to invert the problem (Goossens et al. 2008)
- $P = \frac{\sqrt{2}}{2} \frac{\lambda}{V_{Af}} \left(\frac{\zeta+1}{\zeta}\right)^{0.5}, \quad \frac{\tau_D}{P} = \frac{2}{\pi} \frac{a}{l} \frac{\zeta+1}{\zeta-1}$
- Knowing λ, we have two observed quantities $(P, \frac{\tau_d}{P})$ and 3 parameters $(\zeta, l/a, V_{Af})$
- Observed periods and damping times can be reproduced by infinite number of models

Seismology of filament threads using period and damping time

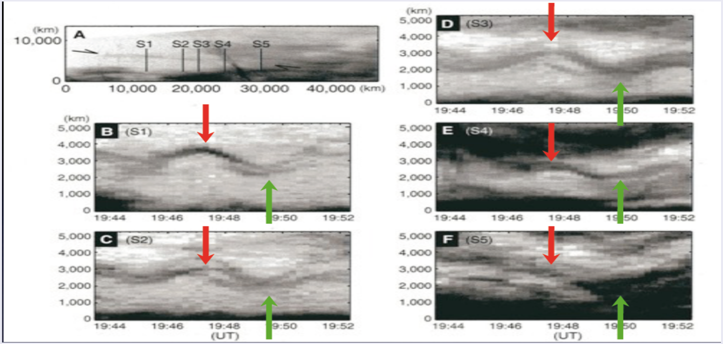
- Inversion in prominence threads:1D model (Arregui & Ballester, 2011)
- $P = 3$ min; $\tau_d = 9$ min; $\lambda = 3000$ km (Lin et al. 2007)
- $V_{Af} = 11.3\ km/s; l/a \approx 0.21$
- For realistic values of the density contrast, period and damping rate are independent of it



Second Example: Seismology of flowing and oscillating filament threads (Terradas et al. 2008)

- Observations with SOT at Hinode. 396.8 nm (Ca II-H line); T $<$ 20,000 K (Okamoto et al. 2007)
- Dark material flowing and oscillating (Six threads). Coexistence of waves and flows

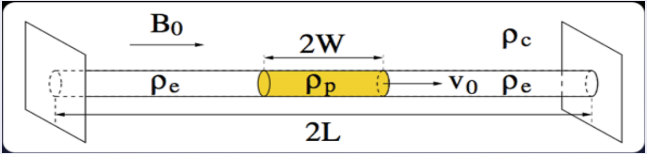
Seismology of flowing and oscillating prominence threads



- Dark material flowing and oscillating. Oscillation syncronous along entire length
- S1-S5 different positions along thread's length
- Maximum and minimum amplitudes occur at nearly the same time for all locations

Seismology of flowing and oscillating filament threads

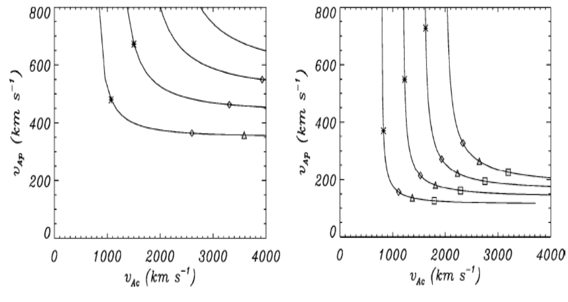
- Interpretation: Transverse kink wave in a magnetic flux tube with a flowing thread (Erdélyi & Fedun 2007; Terradas et al. 2008)



- First, flow not taken into account and from the dispersion relation $f(v_{Ac}, L, W, \zeta, \Omega) = 0$, knowing W, and estimating L, for different values of ζ the coronal Alfvén speed can be determined,
- Since it is related with the thread Alfvén speed through the density contrast ($v_{Ac} = \zeta^{0.5} v_{Af}$), this quantity can be obtained

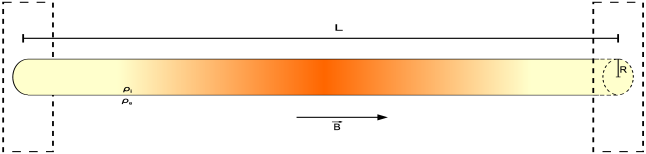
Seismology of flowing and oscillating filament threads

- Curves for $L = 100, 150, 200, 250\ Mm$; Symbols for $\zeta = 5, 50, 100, 200$

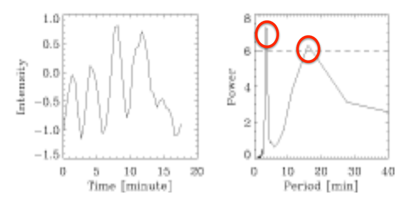


- Unique relation between pair prominence thread and coronal Alfvén speeds for each pair of L,ζ. Lower bound for Alfvén speed in threads
- Next, when measured flow velocities are included, they have a very small impact on the kink mode period and, therefore, on the inferred thread Alfvén speeds

Third Example: Seismology of filament threads using multiple-modes (Soler et al. 2014)

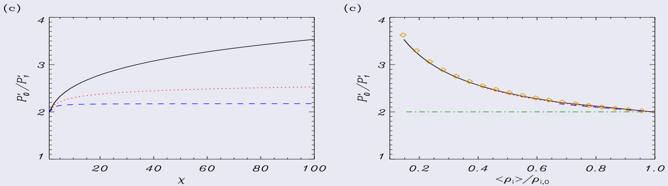


- The ratio of the fundamental mode period to that of its first overtone (P_0'/P_1') has also been used as a seismological tool (Andries et al. 2005). In a homogeneous flux tube the ratio is equal 2
- There are some hints of the second period in some observations (Lin et al. 2007)



Third Example: Seismology of filament threads using multiple-modes

- 2D eigenvalue problem for kink oscillations solved for different longitudinal density profiles



- Empirical equation: $\frac{\langle \rho_i \rangle}{\rho_{i,0}} \approx (\frac{P_0'}{P_1'} - 1)^{-2}$, independent from a specific density profile. $\langle \rho_i \rangle$, $\rho_{i,0}$ = average and central internal density, resp.
- This equation can be used to seismologically estimate the ratio on the LHS using observations of P_0'/P_1'
- Using Lin et al. (2007), $P_0' = 16$ min, $P_1' = 3.6$ min, then, $\frac{P_0'}{P_1'} = 4.44$, and $\frac{\langle \rho_i \rangle}{\rho_{i,0}} \approx 0.084$, strong density gradient along the thread!!

Conclusions

Conclusions

- MHD Seismology is based on evidence of MHD waves and oscillations in magnetized plasma structures of the solar atmosphere, together with, still, highly idealized theoretical models. Therefore, it is still a young science
- All the main assumptions are in the details of the models
- Constrained values for physical parameters (Alfvén speed, non-dimensional thickness of transition layer, density inhomogeneity) in filament fine structures can be obtained

References

References

- Arregui, I., Oliver, R., Ballester, J. L.: Prominence Oscillations. Living Reviews in Solar Physics, 9, 2, 2012
- Arregui, I., Terradas, J., Oliver, R., Ballester, J. L.: Damping of fast magnetohydrodynamic oscillations in quiescent filament threads. The Astrophysical Journal Letters, 682, L141, 2008
- Soler, R., Goossens, M., Ballester, J. L.: Prominence seismology using the period ratio of transverse thread oscillations. Astronomy and Astrophysics (submitted)
- Terradas, J., Arregui, I., Oliver, R., Ballester, J. L.: Transverse oscillations of flowing prominence threads observed with HINODE. The Astrophysical Journal Letters, 678, L153, 2008