Global solar and stellar coronal seismology

The possibility of using waves propagating in solar atmospheric plasmas to infer quantities impossible to measure (magnetic field, transport coefficients, fine structuring, etc.) became a reality after high cadence observation of oscillatory motion was made possible by space and ground-based telescopes. These observations combined with theoretical models allow to develop a new branch of solar physics called *coronal seismology*.

Pioneering studies by Uchida (1970), Roberts, Edwin and Benz (1984), Aschwanden et al. (1999) and Nakariakov et al.(1999), have formed the basis of a very promising and exciting field of solar physics. Traditionally, the terminology of coronal seismology was used mainly to describe the techniques involving waves propagating in coronal loops. Since then, this word has acquired a much broader significance and the technique is generalised to acquire information about the magnetic solar atmosphere (De Pontieu,Erdelyi and James, 2004; Erdelyi, 2006). Coronal seismology uses waves which are localized to a particular magnetic tructures, therefore it would be necessary to label these seismic studies as *local coronal seismology*. After the discovery of large-scale wave-like disturbances, such as EIT waves, X-ray waves, etc., it became necessary to introduce a new terminology, i.e. *global coronal seismology* where the information is provided by global waves propagating over very large distances, sometimes comparable to the solar radius. Although this may seem a separate subject, in reality these two aspects of coronal seismology are very much linked. A global wave generated by sudden energy releases (flares, CMEs) can interact with active region loops or prominences and localized loop or prominence waves and oscillations are emerging so, there must be a link between the generating source and flare-induced waves in coronal loops.

Global waves have been known since the early 1960 Although it is still not known how the release of energy and energized particles will transform into waves, today it is widely acceptedthat these disturbances are similar to the circularly expanding bubble-like shocks after atomic bomb explosion or shock waves which follows the explosion of a supernova. Thanks to theavailable observational facilities, global waves were observed in a range of wavelengths in different layers of the solar atmosphere. A pressure pulse can generate seismic waves in the solar photosphere propagating with speeds of 200-300km/s (Kosovichev and Zharkova, 1998; Donea et al. 2006). Higher up, a flare generates very fast super-alfvenic shock waves known as Moreton waves (Moreton and Ramsey, 1960), best seen in the wings of Halpha images, propagating with speeds of 1000-,2000 km/s. In the corona, a flare or CME can generate an EIT wave (Thompson et al., 1999)first seen by the SOHO/EIT instrument or an X-ray wave seen in SXT (Narukage et al., 2002). There is still a vigourous debate how this variety of global waves are connected (if they are, at all). Co-spatial and co-temporal investigations of various global waves have been carried out but without a final widely accepted result being reached.

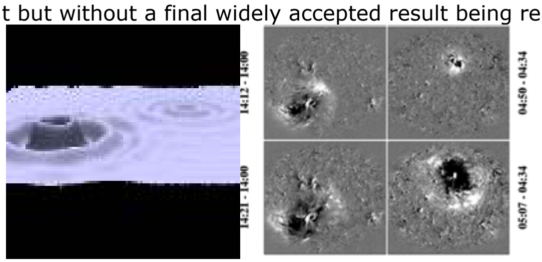

Fig. 1. Simulation model fore EIT propagation wave and observational images 1997 event

Properties and characteristics of EIT waves

Unambiguous evidence for large-scale coronal impulses initiated during the early stage of a flare and/or CME has been provided by the Extreme-ultraviolet Imaging Telescope (EIT) observationsonboard SOHO and by TRACE/EUV. EIT waves propagate in the quiet Sun with speeds of 250-400 km /s at an almost constant altitude. At a later stage in their propagation EIT waves can beconsidered a freely propagating wavefront which is observed tointeract with coronal loops (Wills-Davey and Thompson, 1999). Using TRACE/EUV 195 A observations, Ballai, Erdelyi and Pinter (2005) have shown that EIT waves (seen in this wavelength) are waves with average periods of the order of 400 seconds. Since at this height, the magnetic field can be considered vertical, EIT waves were interpreted as fast MHD waves.

The observations of EIT waves propagating in the solar corona allowed us to shed light on some elementary properties of coronal global EIT waves, however, the available observational precision does not permit us yet to determine more characteristics of these waves.

One of the un-answered problems related to EIT waves is connected to their propagation. The core of the problem resides in the lack of detection of an EIT wave with every flare or CME. This could be explained partly by the poor temporal resolution of the SOHO satellite (the only satellite giving full-disk EUV images at the moment) where frames are available with a low cadence, therefore EIT waves generated near the limb simply cannot be recorded. In general, EIT waves seen by SOHO are generated by sources which are located near the centre of the solar disk. EUV images provided by TRACE are much better to use, although the field of view of this instrument is limited. Since EIT waves propagate over a large area of the solar surface (at a certain altitude) they are dispersive.

Other ingredients to be considered are the stratification of the medium and the inhomogeneous character of the plasma. All of these factors influence the propagation of coronal EIT waves.

Another plausible explanation for the absence of EIT waves associated with every flare or CME might be that EIT waves diffuse very rapidly, i.e. they become evanescent in a short time after their launch. This means that only those EIT waves could be observed which propagate as guided (trapped) waves. The MHD equations in a gravitationally-stratified plasma Marcu (2006), allows as asolution the magnetoacoustic/ magnetogravi-tational waves of growing amplitude with time (upward propagating waves) and decreasing amplitude with time (downward propagating waves). Trapped EIT waves might arise as a combination of magnetoacoustic and magnetogravitational waves propagating in opposite directions. Further investigations of the possibility of trapping spherical waves in a dissipative medium are needed.

Interaction of EIT waves with other coronal magnetic entities

According to the classical picture, EIT waves collide with coronal loops resulting in a multitude of modes generated in loops either in the form of standing oscillations or propagating waves. Both types of waves have the general property that they decay very rapidly in a few wavelengths or periods (see e.g. Nakariakov et al., 1999; Aschwanden et al., 2002). This damping was later used to diagnose the magnetic field inside coronal loops (Nakariakov et al., 1999), transport coefficients for slow waves or global fast waves, sub-structuring, heating function, etc.

In coronal loops we consider only the transversal generation of waves, i.e. waves and oscillations are triggered by the interaction of EIT waves and coronal loops. From the EIT wave point of view, a coronal loop (similar to an active region or coronal hole) is an entity with a stronger magnetic field (at least one order of magnitude) than the medium in which they propagate (quite Sun). Therefore, beside transferring energy to coronal loops, EIT waves can be scattered, reflected, and refracted (Terradas and Ofman, 2004).

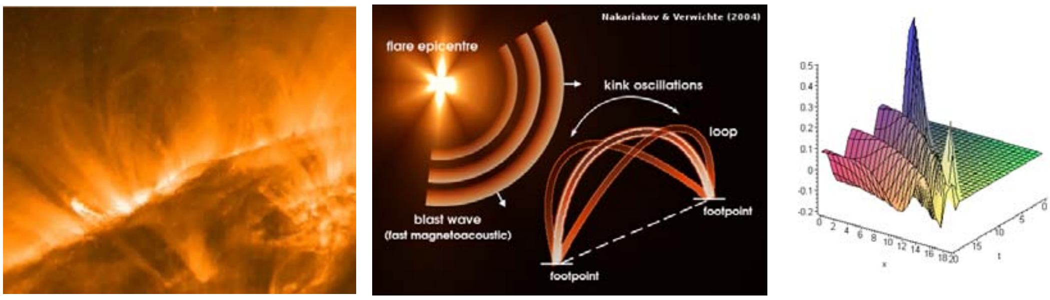

Fig2. Interaction of EIT waves with coronal loops, generation mechanism of loop oscillations

Without claiming completeness, we can draw a few conditions that could influence the appearance of coronal loop oscillations:

- height of the loop: since EIT waves propagate at certain heights in the solar corona, it is likely that not all loops will interact with the global waves. Schrijver, Aschwanden and Title(2002) pointed out that only those loops will be affected by EITwaves whose heights exceed 60-150 Mm.
- the height of the interaction between EIT waves and coronal loops: this factor simply means that it is easier to generate oscillations in a loop if the interaction point between the EIT wave and coronal loop is closer to the apex of the loop rather than the footpoint.
- orientation of the loop: if the front of the EIT wave is perpendicular to the plane of the coronal loop the interaction between the EIT waves and the coronal loop occurs in two points at the same time. If the loop is stiff enough, a standing oscillation can be easily excited. If the front is not perpendicular, the collision between the EIT wave and loops occurs in two points delayed in time by $\zeta = d \cos \alpha / v_{EIT}$, where d is the distance between the footpoints, α is the attack angle, and v_{EIT} is the propagation speed of the EIT wave. In this case,standing modes can be excited only in very special cases.
- distance between the flaring site and coronal loop (or energy of EIT waves): During their propagation, EIT waves are losing energy due to the geometrical damping (dilatation of the front) and due to some physical damping effects. Therefore it might happen that the energy of an EIT wave originating from a distant flare is not enough to dislocate the loop.

- radius of the loop and the density contrast (or Alfven speed contrast): a massive loop is much harder to dislocate thana thin loop. The ratio between the densities in the loop and its environment is known to influence the amplitude of oscillations.

The interaction models estimate the magnetic field of the coronal loops with magnetic thin tubes (tube radius<< any other dimension from the system) and it is considered than during the entire propagation the environment (medium) is in hydrostatic equilibrium. In the collisional process the force generated by the EIT wave will be compensated by the elastic force represented by the magnetic tension and the inertia of the fluid element which must be misplaced (Ryutov and Ryutova 1975). The wave generation dynamics in the coronal loops, as a result of the interaction between the global wave and the loop, is described by a Klein-Gordon equation, whose solution in the context of the MHD solar waves was initiated by Rae and Roberts (1982), Hargreaves (2005), Ballai, Erdely si Hargreaves (2006). The solution found are specific to the dispersive waves (waves with low wavelength and which are fast propagated) with low group speed, having a maxim dependent of the ratio between the tube density and the density of the environment. The waves described can propagate only if their frequency is higher than the cutt-off frequency ((at v_A=1000km/s, ω>0.11mHz or the period < 150 minutes).

Terradas, Oliver and Ballester (2005) have studied the same problem of interaction, but in the approximation $\beta \rightarrow 0$, they established that the coronal loop is decreasing asimptothyc as $t^{-1/2}$.

Ballai, Erdely and Hardegraves (2006), are explaining the transfer of the energy from large scale to the lower ones, introducing an additional dissipative term (resonant absorbtion ≡proportionally with the Alfyen)speed gradient) and analising a Klein-Gordon-Burgers equation (asymptotic analysis) and demonstrate that waves posses a spatial and temporal damping with proportional attenuation $t^{-3/2}$.

Another important factor is the energy of the EIT waves. Recent Ballai,, Erdely and Pinter (2006) managed to find ,using the energy conservation law, the minimum value of the EIT wave energy capable to produce oscillations of the coronal loops (dimension order $3x10^{17}$-$3x10^{18}$J for loops with wavelength 60-500 Mm and radius 1-10 Mm).

Determination of magnetic field values

Observations show that EIT waves propagate in every directionalmost isotropically on the solar disk, therefore we can reasonably suppose that they are fast magnetoacoustic waves (FMWs) propagating in the quiet Sun perpendicular to the vertical equilibrium magnetic field. The representative intermediate line formation temperature corresponding to the 195 A wavelength is $1.4x10^6$ K. The sound speed corresponding to thistemperature is 179 km/s. Since the FMWs propagate perpendicular to the field, their phase speed is approximated by $(c_S^2+v_A^2)^{1/2}$.

The propagation height is an important parameter as a series of physical quantities (density, temperature, etc.) in the solar atmosphere have a height dependence. Given the present status of research on the propagation of EIT waves, there is no accepted value for the propagation height of these waves. For a range of the plasma parameters we can derive average values for the magnetic field by considering the propagational characters of EIT waves. Therefore, we study the variation of various physical quantities with respect to the propagation height of EIT waves.

We recall a simple atmospheric model developed by Sturrock, Wheatland and Acton (1996) to calculate the temperature profile above a region of the quiet Sun, where the magnetic field is radial, quantity weakly dependent on pressure and atmospheric composition; for the solar corona a value of 10^{-6}(in cgs units) is appropriate (Nowak and Ulmschneider, 1977). Assuming a model atmosphere in hydrostatic equilibrium we obtain that the number density based on the temperature profile Having the variation of densitywith height and the value of Alfven speed deduced from the phase speed of EIT waves, we can calculate the magnetic field.

For an average value of EIT wave speed of 300 km/s propagating at 0.05 solar radius above the photosphere we find that the magnetic field is 1.8 G. If we apply Br^2=const.,

i.e.the magnetic flux is constant, we find that at the photospheric level the average magnetic field is 2.1G which agrees well with the observed solar mean magnetic field (Chaplin et al. 2003).

EIT waves considered as fast MHD waves can also be used to determine the value of the radial component of the magnetic field at every location allowed by the observational precision. In this way, using the previously cited TRACE observations we can construct a magnetic map of the quiet Sun (see Figure 3), in other words EIT waves can serve as probes in a magnetic tomographyof the quiet Sun.

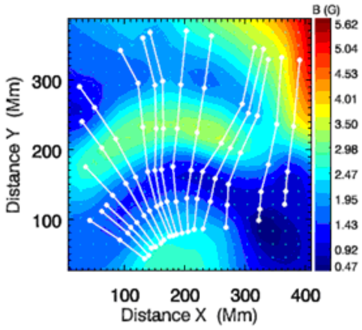

Fig.3 Magnetic map of the quite Sun obtained using EIT wave observed by TRACE/EUV in 195 A

If points are joined across the lines, we will obtain the location of the EIT wavefront. In conclusion, EIT waves propagating in the solar corona exhibit a wide range of applicabilities for plasma and field diagnostics. The fact that during their propagation EIT waves cover a large area of the solar surface (in the coronal) allows us to sample the magnetic field in the quiet Sun. EIT waves could serve as a link between eruptive events and localised oscillations, e.g. loop oscillations could be studied in a much broader context. Using a simple model we found that the minimum energy an EIT wave should have to produce a detectable loop oscillation is in therange of \$$10^{16}$-$10^{19}$ J. espite of the lack of high precision observations, EIT waves show a great potential for magneto-seismology of the solar corona.

The modeling of the orbital period modulation phenomenon in the binary system Y Leonis

The actual stage of the knowledge on the binary system Y Leonis

The eclipsing binary system Y Leonis (HIP 47178) is an Algol type binary system A3 + KIV/K5 EA/SD (Giuricin et al., 1980, 1983; Svechnikov, 1986). The studies on variability of its orbital period emphasized its complexity. Thus, it displays secular changes, irregular, and also periodic variations of the orbital period. The physical mechanisms supposed to be involved were the mass transfer and mass loss (Chis & Pal, 1964; Svechnikov et al., 1970; Svechnikov & Surkova, 1972; Chis, 1976; Chis, 1988) and the presence of a third body in the system (Ghezloun & Svechnikov, 1975). Being given the physical features of the binary system Y Leonis, this was recently included in a target list of eclipsing binaries for searching extrasolar Trojan planets (Caton et al., 2001; Davies et al., 2001). In a recent, preliminary investigation of the orbital period variability of Y Leonis (Pop, 2005), we emphasized, using an observational data set with a time base of 94.9 years, it's extremely intricate behavior. Thus, the $O-C$ curve describing the orbital period variation consists in the following components: (i) a secular variation explainable through the presence of mass transfer in the system, (ii) four periodic components having the following periodicities: 85.2, 8.606, 7.781, and 6.375 years, and (iii) a low level stochastic variability phenomenon of the orbital period, probably related to the mass transfer occurring in the system.

Having in view the preliminary conclusions the study proposed by us has the following goals:

1. The determination of a theoretical model of type *polynomial trend + multiperiodic term* which is able to give an accurate description of the existing observational data, taking into account the statistically significant periodicities;
2. The interpretation of the detected periodicities on the basis of the hypothesis of the existence of one or more stellar/planetary companions and that of the cyclic magnetic activity in the secondary component of Y Leonis binary system;
3. To obtain the light curve of this eclipsing binary system using our own high temporal resolution CCD observations, in the Johnson-Cousins UBVRI photometric system. The improvement of the theoretical model established by us using the new times of minimum light obtained by us.

The preliminary data processing methodology of the minimum light times as well as that of modelling of the $O-C$ curve is described in our previous papers: Pop (1999a, b; 2000), Pop et al. (2003), and Pop & Barbosu (2006). The modelling of the $O-C$ curve uses a high degree of generality semi-empirical model, consisting of a secular trend described by an arbitrary degree polynomial, and a multiperiodic term, resulted from the superposition of an arbitrary number of truncated Fourier series, coresponding to the periodicities detected in the analyzed time series. The detection process is performed using the amplitude spectrum analysis, using Kuschnig's et al. (1997) method, and that based on the bootstrap resampling technique (Pop & Roman, 2007; Pop, 2007b). The main advantge of this last method consists in the lack of any hypothesis on the statistical distribution of the observational noise.