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Helioseismology: The observations of low degree oscillations of the Sun from the South Pole to SoHO

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Thanks to the pioneer works of F. Deubner, the G. Isaack group at Birmingham, and the observations made at the geographic South Pole by G. Grec, E. Fossat and M. Pomerantz, the "5 min" oscillations of the photosphere discovered earlier by R. Noyes and R. Leighton are understood as spherical modes of oscillation. At that time it was an analytic concept due to P. Ledoux, already applied to stellar oscillations; the asymptotic analysis due to M. Tassoul has been a surprising key to identify the solar acoustical modes.

The travel time of the perturbations related to an oscillatory mode (either acoustical or density fluctuations) is short, in the hour range, giving an immediate picture of the whole Sun. The frequency of a given oscillation mode is an integral data over the solar sphere: a new window is open to study the physics of the deep interior of the Sun, taking into account the helioseismic data. In comparison, the Sun is very opaque for photons (10^6 years of travel time), transparent for neutrinos and gravity field.

The observations are now underway, including measurements of the solar irradiance or of the solar surface velocity, imaging the Sun or observing the whole disk as a star – including the observations obtained with the CrAO tower solar telescope, starting with the work of A. Severny, V. Kotov and T. Tsap.

The analysis of the spherical harmonics implies 3 parameters: the degree l is the number of nodal lines on the sphere, the radial order n is the number of nodes along the radius, the tesseral order m determines the apparent frequency for prograde and retrograde modes of a rotating body.

To observe the Sun as a star, without any imaging, gives access to the modes of low l, from radial modes $l = 0$ to $l = 3$ and with a lower sensivity $l = 4$ and $l = 5$. This talk will give a brief history of those observations.

Devices using the atomic resonance to measure the photospheric Doppler shift have been used all along. For the South Pole observations, the Iris network and the GOLF instrument, the resonant filter is made with sodium vapor. GOLF is now working aboard SoHO since April 1996, with only a relatively short interrupt due to a momentary failure in the spacecraft control: the observation time is now close from the duration of a solar cycle, several additional years of observation are still foreseen.

One objective is to detect gravity solar modes (for which the buoyancy gives the restoring force). So far those modes are not surely detected, even the question of their detectability has not definitive answer.

Another objective is to improve the knowledge of the temporal power spectrum of the acoustical modes (for which the pressure gives the restoring force.) Those modes are randomly excited and damped and obviously the statistical determination is growing as observational time cumulates. On the other hand, the frequency of a given mode varies with the solar magnetic activity, but contains also random variations. There is no detectable correlation between modes. This point is a specially important one for the knowledge of the physics of the solar interior, based on comparison of the observed spectrum and on a spectrum calculated for a solar model.

This solar model describes the variations of the physical properties (as an example: the sound speed) along the radius, it is itself deduced from a model of the solar evolution which determines the chemical composition: so far all computational codes do not include any data about the solar magnetic properties. It is then crucial to determine the p-mode frequency spectrum for a “minimum” magnetic activity Sun, if the ideal “zero” activity is never observed.

Nevertheless, increasing the accuracy of the p-mode frequency spectrum produces stronger constraints on the solar model.

Another point is to study the stability of the resonant cavity of the p-modes over short time scale. That is a new research field of analysis for which I will show very preliminary results.