# Asteroseismology of massive stars:

# a basic introduction

**Conny Aerts**

*Instituut voor Sterrenkunde, K U Leuven, Belgium*

*http://www.ster.kuleuven.ac.be*

# Introduction

This tutorial concerns the topic of *oscillations* that occur inside stars. Illustrative material can be found on different web pages, some of which are provided as links from our own institute web page accessible at

http://www.ster.kuleuven.ac.be

The recent research domain of *asteroseismology* refers to the study of the internal structure of stars through the interpretation of their oscillation frequency spectra. For one of the early reviews on the topic, we refer to Brown & Gilliland (1994). Essentially, asteroseismologists try to make use of the oscillations to probe the stellar interior, which is not directly observable. The basic principles of asteroseismology are, to a certain extent, similar to those developed and employed by earth seismologists. Asteroseismology relies on advanced mathematical descriptions of oscillations in a three-dimensional body and numerical modelling. It is therefore a prominent example of interdisciplinary science, more precisely of “integrated” physics.

No part of the Universe is more difficult to observe directly than the interior of the stars. The reason why stellar interiors can be probed from the oscillations is that the behaviour of the oscillations is determined uniquely by the properties of the total stellar structure. More particularly, the different oscillation modes of a star penetrate to different depths inside that star and so one is able to study the internal layers from the frequency differences of the modes. Asteroseismology is the only available method to derive in a quasi-direct way the internal structure of the stars with high precision.

The ultimate goal of asteroseismology is to improve the evolutionary models of the stars. The theory of stellar evolution is reasonably well established in a global sense. We know that stars are born out of giant clouds of dust and that they burn hydrogen into helium in their core during 95% of their life. As soon as the central fuel is exhausted, they become red giants and expell their outer layers. Depending on their mass, they end their lifes as white dwarfs or supernovae. This broad picture is derived from, and in agreement with, the observations of many different kinds of stars of different ages. However, the current observations do not allow a confrontation between the theoretical models and real physical properties of the stellar material in the deepest internal layers. The hope is that asteroseismology will lead to significant contributions in this context.

# Basic properties of non-radial oscillations

It is very fortunate that oscillations are excited in almost all types of stars and in many stages of stellar evolution. All classes of oscillating stars known up to the present day are shown in Figure 1. Gautschy & Saio (1996) give a broad overview of the observational characteristics of the oscillations in the different classes, while Gautschy & Saio (1995) highlight the basic theoretical framework to study the oscillations.

The simplest oscillation a star can undergo is a *radial* one. In that case, the star expands and contracts radially and spherical symmetry is preserved during the oscillation cycle. From a mathematical point of view, the differential equation describing the radial displacement is of the Sturm-Liouville type and thus allows eigensolutions that correspond to an infinitely countable amount of eigenfrequencies. The smallest frequency corresponds to the fundamental radial oscillation mode. The period of this mode is inversely proportional to the square root of the mean density of the star. Radial oscillations are characterised by the radial wavenumber $n$: the number of nodes of the eigenfunction between the center and the surface of the star. Well-known radial oscillators are the Cepheids, RR Lyrae stars and Red Giants (see Figure 1).

If transverse motions occur in addition to radial motions, one uses the term *non-radial oscillations.* The oscillation modes are then not only characterised by a radial wavenumber $n$, but also by non-radial wavenumbers $\ell$ and $m$. The latter numbers correspond to the degree and the azimuthal number of the spherical harmonic $Y_\ell^m(\theta, \varphi)$ that represents the dependence of the mode on the angular variables $\theta$ and $\varphi$ for a star with a spherically symmetric equilibrium configuration. The degree $\ell$ represents the number of surface nodal lines, while the azimuthal number $m$ denotes the number of such lines that pass through the rotation axis of the star. The surface pattern of some non-radial oscillations is graphically depicted in Figure 2.

These *Doppler maps* show the radial velocity structure at the stellar surface of a non-radial oscillator at one particular phase of the oscillation cycle. The red parts are moving inwards and cause a redshift in the observed stellar spectrum while the blue parts move simultaneously outwards and give rise to a blueshifted spectrum. Half an oscillation cycle later, the red parts have become blue and vice versa. The white lines in Figure 2 represent the $\ell$ *nodal lines.* The mass elements on these lines do not move during the oscillation cycle.

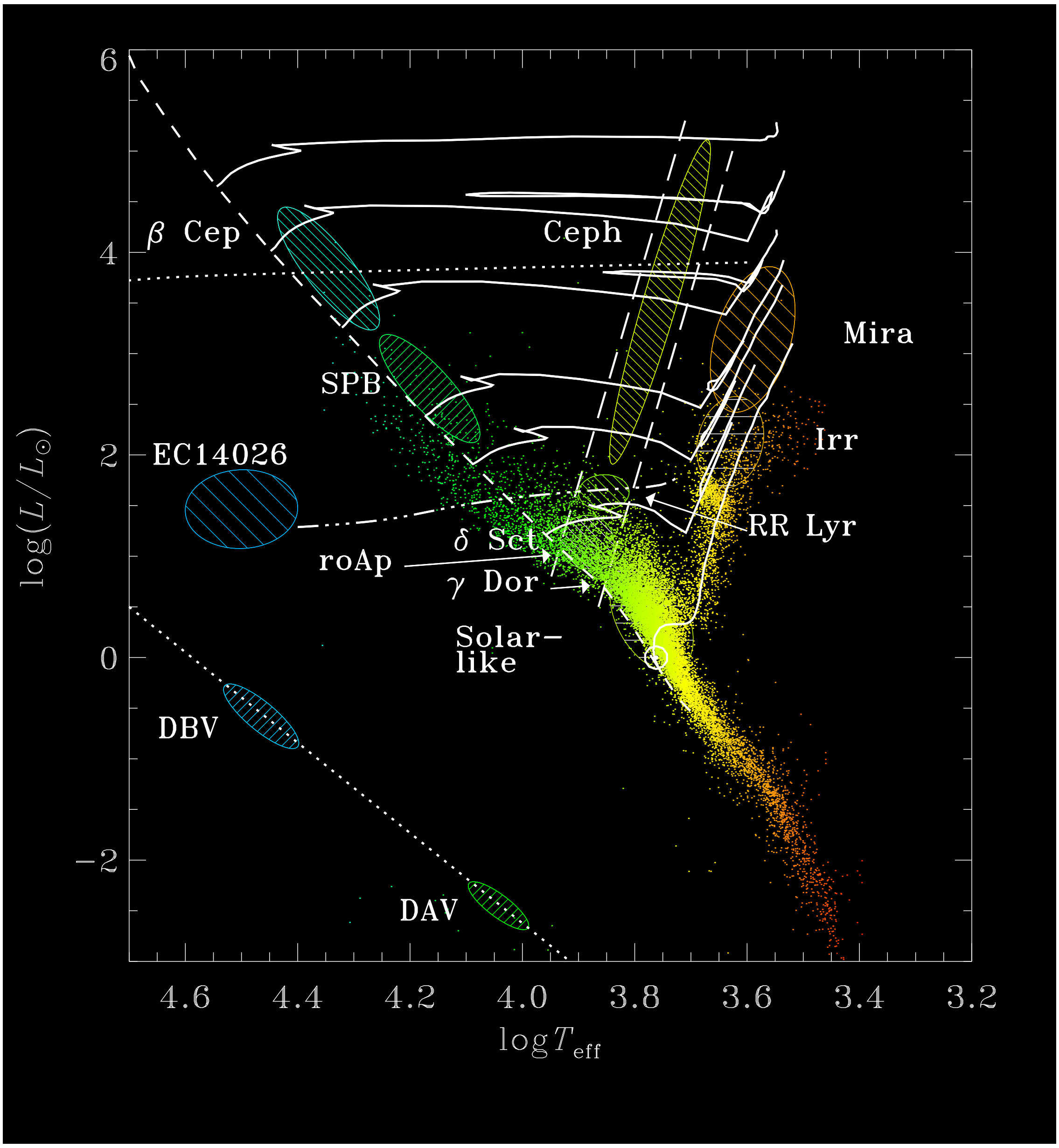

Figure 1: Schematic representation of the different classes of oscillating stars in the Hertzsprung-Russell diagram in which the stellar luminosity is plotted against the surface temperature of the stars. The dashed line indicates the "main sequence". All stars in this stage of evolution are relatively young and burn hydrogen in their core. Along the main sequence many different classes of non-radial oscillators occur, from the low-mass solar-like stars up to the massive $\beta$ Cep stars. To the right, we find classes of oscillating stars along the horizontal and red-giant branch. These stars burn helium in their core. All classes of non-radial oscillators to the lower left of the main sequence are evolved stars that have reached the stadium of (pre-)white dwarfs. They no longer have nuclear burning and are condemned to cool. The full lines in the figure are the evolutionary tracks for stars with different initial masses (Figure taken from Favata et al., 2000).

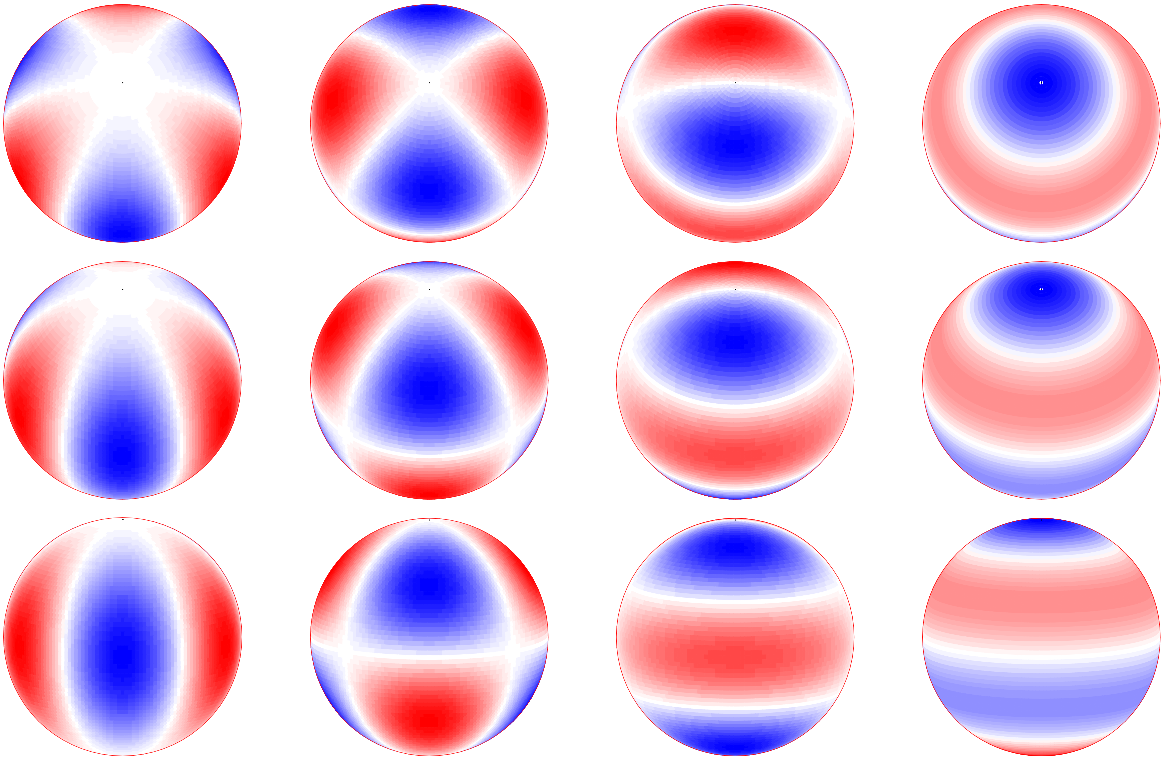

Figure 2: Different examples of non-radial oscillations, seen from a different inclination angle: $i = 30°$ (top row), $i = 60°$ (middle row), $i = 90°$ (bottom row). The velocity field of a non-radial oscillator is represented by a spherical harmonic $Y_\ell^m$. The meaning of the spherical wavenumbers $(\ell, m)$ is visualised. In these examples $\ell = 3$ and $m$ takes values from 0 (right) to 3 (left). The dot indicates the symmetry axis of the oscillation, which corresponds to the rotation axis of the star. The colouring denotes the Doppler shift in an observed spectrum due to the oscillation, i.e. at this particular instance in the oscillation cycle, the red parts are moving towards the stellar center (thus away from the observer) and therefore shift the spectrum to longer wavelengths (redshift) while the blue parts are moving outwards (towards the observer) and result in a shift to shorter wavelengths (blueshift).

Non-radial oscillations can penetrate deeply inside a star. For each oscillation the surface pattern is a continuation of the internal oscillatory behaviour and so the latter can, to a certain extent, be derived from measuring the surface variability. For each surface pattern, a whole series of oscillations with different internal behaviour is possible. This series is characterised by the radial wavenumber $n$, which represents the number of nodal surfaces inside the star in the case of a non-radial oscillation. The latter is thus characterised by three numbers $(n, \ell, m)$ and its frequency $\nu_{n\ell m}$. We point out that the differential equations describing the non-radial oscillations are degenerate with respect to the azimuthal number $m$ when one considers a non-rotating star. Whenever the rotation of the star can be neglected the oscillations are described by $(n, \ell)$ and $\nu_{n\ell}$. The rotation lifts this degeneracy and gives rise to $2\ell + 1$ modes with the same degree $\ell$ but different azimuthal number $m$.

Two main types of oscillations exist in stars: pressure or p-modes and gravity or g-modes. The p-modes are basically acoustic oscillations for which the restoring force is the pressure force; radial modes can be viewed as a special case of non-radial p-modes with $\ell = 0$. In g-modes, the restoring force is the buoyancy force; such modes have periods that are longer than the period of the radial fundamental mode. The p-modes mainly attain a large amplitude in the outer layers of the star while g-modes have a large amplitude in the deep layers of the star. Therefore, g-modes are by far the most interesting from an asteroseismological point of view. However, the corresponding periods of g-modes are one order of magnitude longer than those of p-modes. For massive main-sequence stars, p-modes have periods of the order of hours, while the periods of g-modes are of the order of days. Hence, multiperiodic oscillations in g-modes result in beat periods of the order of months, while the beat-periods of main-sequence p-mode oscillators are much shorter, from days to weeks.

# Why do stars oscillate ?

The basic properties of oscillation modes are explained in the previous section. However, one needs to have a mechanism that *excites* the modes in the stars. Two types of excitation mechanisms exist. The Sun oscillates in millions of p-modes with velocity amplitudes of the order of cm/s. These modes are caused by the outer convective motions and have lifetimes of the order of weeks to months. Such oscillations are expected in all stars having convective outer layers.

For most of the oscillation classes indicated in Figure 1, however, the modes are *self-excited.* This self-excitation is possible because some layers in the stars turn out to have the potential to act as a heat engine. Such layers are able to trap the energy radiated outwards by the stellar core in a very efficient way during a small contraction of the star, and to release the trapped energy during the subsequent expansion. For this so-called $\kappa$ *mechanism* to work, i.e. for it to be able to make the whole star oscillate, the pertinent layer has to be situated at a suitable position in the star. As a result, oscillations can only be excited when a suitable combination of stellar luminosity, temperature, and chemical composition occurs. For this reason, non-radial oscillations are excited in so-called *instability strips* in the Hertzsprung-Russell diagram (see Figure 1). A recent overview of the excitation of $\kappa$ driven modes along the main sequence can be found in Pamyatnykh (1999).

# Why do we study massive stars ?

We plan to perform asteroseismology of B-type stars some of which oscillate in p-modes while others exhibit g-modes. Interesting oscillating stars in the frame of massive objects are the $\beta$ Cep stars and the slowly pulsating B stars (see Figure 1). In general, B-type stars are massive stars, with masses between 3 and 30 times the mass of the Sun. Stars heavier than roughly 9 solar masses will eventually explode as a supernova at the end of their life. Thanks to such explosions, the interstellar medium is enriched with products of the nuclear burning in the stellar core, i.e. with chemical elements heavier than hydrogen and helium. The stars with initial masses larger than 20 solar masses constantly loose mass during their life due to a strong stellar wind. They also follow a much faster evolution compared to stars with lower masses (see e.g. Maeder & Meynet, 1991).

Our knowledge of the interiors of stars heavier than the Sun is relatively poor, because such stars have large convective and rotational motions in their core leading to mixing of chemical species (see, e.g. Zahn 1991). The main difference with the internal structure of stars with solar-like masses is that the latter have only outer convective layers and that they gradually build up a heavier core. The importance of rotational mixing in massive stars was recently put forward by Maeder & Meynet (2000). Their work clearly points out that we need to know in detail the internal rotation law of massive stars if the aim is to predict their evolution with high accuracy. Since the massive stars are, through their supernova explosion, largely responsible for the nucleosynthesis and the chemical enrichment of our Milky Way, and of the Universe as a whole, it is evident that accurate asteroseismic applications to such supernova-progenitors are much needed.

# History & state of the art

Although very succesful applications of asteroseismology were already obtained from ground-based data of the 3-15 minutes oscillations of the Sun (see e.g. Elsworth et al., 1994 – Birmingham Solar Oscillations Network), the breakthrough in *helioseismology* came from the space data of the Sun obtained with the ESA/NASA satellite SoHO which was launched in 1995 (for more information, see http://sohowww.nascom.nasa.gov/). A part of the Solar frequency spectrum derived from SoHO data is shown in Figure 3. The regular pattern in the peaks is clearly visible. One defines two important quantities derived from such a spectrum: the *large frequency separations* $\triangle\nu_\ell$, which occur between the frequency peaks belonging to modes with wavenumbers $(n,\ell)$ and $(n-1,\ell)$, and the *small frequency separations* $\delta\nu_\ell$ which represent the frequency differences between modes with wavenumbers $(n,\ell)$ and $(n-1,\ell+2)$. The large frequency separation is dependent upon the average density while the small separation is determined by the core composition. It is thus possible to infer the mass of the star, and also the age since the core composition changes as more hydrogen is turned into helium by the nuclear burning. The small frequency separation is, therefore, a measure of the evolutionary state of the star.

The diagnostic properties of solar-like oscillations have been derived in great detail. The seismic studies based on the SoHO data have revealed for the first time the properties of the outer convective layers of the Sun. The outer convection zone of the Sun turns out to be 50% more extended than previously thought. Moreover, the internal differential rotation and mixing in the Sun could be mapped in full detail (see, e.g. Schou et al., 1998). A review on the results of helioseismology is presented by Christensen-Dalsgaard et al. (2000). In the forthcoming decade helioseismic studies will focus on “attention to detail, to extract a new level of precision necessary to isolate subtle properties of the Sun” (Gough, 2000).

The successes of helioseismology have of course led to quite a bit of effort to obtain the same level of precision in other oscillators over the whole mass range. As far as the search of oscillations in other solar-like stars is concerned, clear detections of stochastically excited p-modes were recently found in $\beta$ Hydri (Bedding et al., 2001) and in $\alpha$ Cen (Bouchy & Carrier, 2001). For these stars, the techniques of helioseismology are immediately applicable once the frequency spectrum is well determined, and so we expect quite a bit of progress in the derivation of the internal structure parameters of these types of stars (Gough, 2001).

Other concrete in-depth asteroseismological results, in the sense of probing the internal structure, were obtained for the g-modes in white dwarfs. The latter objects are the compact end-products of stars with initial masses below 9 solar masses. The white dwarfs oscillate multi-

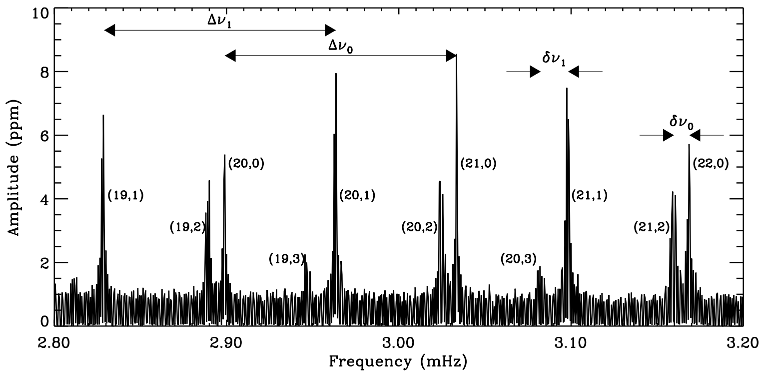

Figure 3: Part of the oscillation spectrum of the Sun for the frequency interval [2.8;3.2]$\mu$Hz derived from the experiment VIRGO onboard SoHO. The amplitude of the oscillations, expressed in ppm (parts per million), is drawn as a function of the oscillation frequency. The highest frequency peaks have amplitudes of a few ppm, which means that the relative change of the luminosity of the Sun due to the oscillations is only a few parts per million (Figure kindly made available by J. Christensen-Dalsgaard).

periodically, in g-modes with periods around 10 minutes. In order to cover the overal beat-period of all the excited modes, a network of telescopes around the Earth equator was set up in the late 1980s: the WET, which stands for Whole Earth Telescope. A WET campaign on the DOV PG 1159-035 allowed Winget et al. (1991) to derive the mass, rotation rate, and internal stratification of this white dwarf with unforeseen precision. Other succesful campaigns on white dwarfs followed later, up to the present day.

Oscillations in g-modes were recently found by South-African astronomers in another group of evolved stars, termed the EC 14026 B-type subdwarfs (sdB) named after their prototype (Kilkenny et al. 1997). These sdB oscillators were, almost simultaneously with their observational discovery, understood theoretically in terms of the $\kappa$ mechanism (Charpinet et al. 1997). The exploitation of the asteroseismological potential of the sdB stars is currently ongoing. While these seismological studies of evolved stars have fine-tuned the evolutionary cooling tracks of such objects, they do not help us to confine the early phases of the evolution of the progenitors of these stars. Such studies thus cannot help us to constrain the internal structure at the main-sequence stage of the stars that will eventually become sdBs and white dwarfs. Let us therefore review the current status of asteroseismology of non-solar-like main-sequence stars.

For more massive stars, the application of asteroseismology is not so straightforward. A prerequisite for such an application is the detection of many oscillation modes and their mode identification, i.e. the knowledge of their wavenumbers $(n, \ell, m)$. The best candidates according to the number of modes detected are the $\delta$ Scuti stars (see Figure 1), which pulsate in p-modes. For some of these stars, more than 30 oscillation frequencies have been detected from multisite campaigns coordinated by the Institute of Astronomy in Vienna (Breger et al., 1999). While early attempts of seismology of such stars were very promising (Goupil et al., 1993), it has become clear that unexplained amplitude and period changes occur in these stars (Breger & Pamyatnykh, 1998).

Moreover the lack of accurate mode identifications, due to the incomplete frequency spectra, limits seismic applications.

The rapidly oscillating Ap (roAp) stars are chemically peculiar stars in the $\delta$ Scuti instability strip with a strong magnetic field. Because of this, their oscillation symmetry axis is not alligned with the rotation axis, but with the magnetic axis. Their oscillations are explained in terms of the oblique pulsator model (Kurtz & Shibahashi, 1986). For a review about the oscillation properties of these stars, we refer to Kurtz (1990). They oscillate in p-modes with periods of the order of minutes. Matthews et al. (1999) recently combined the p-mode eigenfrequency spacings of 12 roAp stars with astrometric space data gathered with the ESA Hipparcos satellite and found that the roAp stars are systematically cooler than expected from ground-based photometry. If their results are correct, then the roAp stars would lie outside the instability strip and the $\kappa$ mechanism cannot cause their oscillations. This "negative" asteroseismic result is important, since it implies a detailed confrontation between the excitation models and the observations.

For the massive B-type main-sequence oscillators, as well as for the recently discovered $\gamma$ Doradus stars, the problem of detecting multiple modes and of identifying them is even more severe, since their oscillation periods are considerably longer. Early attempts to perform seismology of $\beta$ Cep stars were done by Dziembowski & Jerzykiewicz (1996, 1999) and by Shibahashi & Aerts (2000). Again here, the limited number of at most 6 detected modes and problems with mode identification prevent the derivation of internal structure parameters for these massive stars. The only way to make progress in asteroseismology of stars more massive than the Sun is, on the one hand, to lower considerably the amplitude detection treshold of the current instruments and, on the other hand, to obtain uninterrupted time series that cover the overal beat-periods of the oscillations in the stars. This calls for space missions devoted to asteroseismology, which are planned for the near future.

# Expertise at the IvS

Researchers at the Instituut voor Sterrenkunde (IvS) have been observing oscillating B stars for more than 20 years. The publications by Waelkens & Rufener (1985), Waelkens (1991), Heynderickx (1992), and Aerts (2000), e.g., describe the long-term multicolour photometric campaigns of B-type variables and contain frequency spectra of many $\beta$ Cep and slowly pulsating B stars. The excitation of the oscillations in the $\beta$ Cep stars and in the slowly pulsating B stars was understood only recently in terms of the $\kappa$ mechanism (Dziembowski & Pamyatnykh, 1993; Dziembowski et al., 1993; Gautschy & Saio, 1993). The $\beta$ Cep stars oscillate in p-modes with periods of a few hours; the slowly pulsating B stars oscillate in g-modes that penetrate deep into the stellar interior and have periods of 1–3 days.

As already mentioned, one of the key-problems of the astrophysical interpretation of the oscillation spectra of stars more massive than the Sun is the lack of accurate mode identifications for the detected oscillation frequencies. The rich frequency spectra as the one of the Sun and of compact pulsators automatically allow mode identification through the spacings of the frequencies. When only a limited number of modes are detected in the frequency spectra, one has to come up with other means to identify the modes. During the past decade, astrophysicists at the IvS have played a central role in the interpretation of oscillation data of both $\beta$ Cep and slowly pulsating B stars by means of the development and application of *mode identification techniques*.

One mode identification method is based on multicolour photometric data. It essentially comes down to comparing the amplitudes of the modes at different wavelengths. This allows one to constrain the degree $\ell$ of the pulsation modes. This method was introduced by Dziembowski (1977) and refined by Stamford and Watson (1981), Watson (1988), and Heynderickx et al. (1994). The latter authors have made a thorough study of a large group of $\beta$ Cep stars for which they determined the degree of the pulsation modes. Photometric observations remain the best ones suited to study long-period oscillations, because they can be obtained with small telescopes, which are available on longer time scales.

The introduction of high-resolution spectrographs with sensitive detectors some 15 years ago has had an enormous impact on the field of mode identification. Spectroscopic data offer a very detailed picture of the oscillations. Indeed, the velocity field caused by the non-radial oscillation(s) (see Figure 2) leads, through the Doppler effect, to periodic variations in the profiles of spectral lines. Observations of such line-profile variations require large telescopes and sophisticated instrumentation. Methodologically, the largest problem to overcome when identifying modes is that the theoretical model contains many free parameters, among which $(n, \ell, m)$. Especially the infinite amount of candidate modes is a problem when constructing identification techniques and it often keeps the predictive power of the methods low. This is in particular the case for the methods that are based on a trial-and-error principle. Quantitative methods are better to obtain a reliable mode identification. Aerts et al. (1992) have developed and applied such a quantitative mode identification technique, which is based on the first velocity moments of the line profiles. This new methodological work was improved by Aerts (1996). The discriminant code programmed by Aerts (1996) can be retrieved from the web page of our institute. Overviews of the currently available mode identification methods were presented by Aerts (1994) and Aerts & Eyer (2000).

The group of the slowly pulsating B stars was significantly increased by an analysis of photometric observations of variable B-type stars discovered by the astrometric space mission HIPPARCOS, which was launched in 1989 and gathered data during some 3 years (Waelkens et al., 1998). The task of classifying these new variables was commited to the IvS by the HIPPARCOS team, in view of our expertise in oscillating B-type stars. Aerts et al. (1998) subsequently found and classified 14 new $\gamma$ Doradus stars from the HIPPARCOS data. These stars form a relatively new class of non-radial g-mode oscillators with periods of the order of days that was discovered only recently (see Figure 1) and of which only 11 members were known before our work. In the meantime, several additional new candidates were found.

Finally, the IvS has a long tradition of theoretical studies of non-radial oscillations, with special emphasis on asymptotic representations of non-radial oscillations (e.g. Smeyers et al., 1995) and theoretical developments of non-linear non-radial oscillations (e.g. Van Hoolst, 1994). Asymptotic theories often form the basis of inversion methods and will be of importance for asteroseismology of B stars.

# The use of data from space

Since precise knowledge of the internal processes in stars has broad applications, from stellar evolution to cosmology, a large emphasis is currently put on seismological studies. It has become evident that the opportunity to use high temporal-resolution data from space would imply an enormous step forward for asteroseismology. One specific advantage of having time series of space data is that the latter do not suffer from a night-and-day rythm. This is particularly important for stars more massive than the Sun because their oscillation periods are much longer than a few minutes. Indeed, they typically have periods of the order of hours to days, which are hard to find in ground-based data because of the inherent artificial period of a day in the observation time series. Another, and even more important advantage is that the scintillation noise induced by the Earth atmosphere does no longer limit the detection treshold to the current level of millimagnitudes.

## WIRE and MOST: asteroseismic pioneers

The NASA Wide-Field Infrared Explorer (WIRE) was launched 4 March 1999. The satellite was designed for a four-month infrared survey at 12 and 25 $\mu$m. The primary science instrument on WIRE failed due to the loss of coolant shortly after launch. The rest of the satellite, however, continued to function perfectly and other use of the onboard instruments became possible. Soon after the report on the failure of the main mission of the satellite, it was realised by D. Buzasi (US Air Force Academy) that the WIRE star tracker with a diameter of 5.2 cm could be used as an optical wide band photometer suitable for asteroseismology and variable star studies in general. Asteroseismology observations began on 30 April 1999 and were temporarily terminated on 30 September 2000. During that time, 28 objects were observed primarily as asteroseismology targets and an additional 10 were observed for other projects. The asteroseismology target list was designed as a survey and thus spans all spectral types. The preliminary results of the asteroseismological program with the star tracker of the WIRE satellite are extremely promising. For many known oscillators spanning the complete Hertszprung-Russell diagram, ground-based results could be confirmed and in a few cases already be extended. The latter is the case for the $\beta$ Cep star $\beta$ Crucis, of which astronomers at the IvS were allowed to use the NASA WIRE data. For an overview of the current status of the WIRE results we refer to Cuypers et al. (2002). With a better understanding and correction for the orbit related features, the limits of detection of periodicities in WIRE data will be pushed further. Since all this has been done with a mission that was not at all optimized for asteroseismology and had no powerful instruments, these results show only a tiny fraction of what will be the outcome of the fully adapted asteroseismological missions now in preparation. Meanwhile, WIRE is observing again.

The Canadian MOST (Microvariability and Oscillations of STars) will be the first space mission fully devoted to asteroseismology. It is Canada's first space mission. MOST consists of a 15cm telescope and is designed to return unprecedented photometric precision as low as a micromagnitude for very bright stars. MOST will monitor stars for about 6 weeks continuously. The prime targets of MOST are solar-type stars, roAp stars, $\delta$ Scuti stars, and Wolf-Rayet stars. The launch of MOST is foreseen for the end of 2002. MOST will open the field of space asteroseismology, although it will observe only a very limited number of very bright targets.

## Our involvement in future European space missions

The recent succes of helioseismology led to the financial approval of two European space missions devoted to asteroseismology. It concerns the MONS (Measuring Oscillations in Nearby Stars) mission on the satellite Rømer, which is a Danish-led mission, and COROT (COnvection, ROtation and planetary Transits), a French-led mission. The missions are in full preparation at present, with launches foreseen in 2004/5 and lifetimes of about two years. The two missions are very complementary in design and observation strategy, and moreover focus on different types of prime target stars.

MONS consists of a telescope with a diameter of 32cm, two star trackers and a field monitor. A single CCD detector will collect the infalling light. Essentially, the observations will be done in the same way as those obtained in the framework of campaigns of time-resolved CCD photometry from the ground (Kjeldsen & Frandsen, 1992). Most of the MONS targets will be observed during about 30 days continuously. MONS will primarily study the oscillations of some 20 solar-type stars, but will also observe a few selected massive stars. C. Aerts leads the B-star Group of the MONS mission and is as such responsible for the selection of the B-type stars for the MONS camera. A total of 2 months of observing time was allotted to her for the observation of B-type pulsators. The MONS field monitor and star trackers will observe the oscillations of hundreds of stars across the Hertzsprung-Russell diagram. Although these data will have a lower level of precision, their continuous monitoring with optimized instruments will reveil a wealth of information compared to current ground-based data.

COROT, on the other hand, has a telescope with a diameter of 27 cm, and 4 CCDs in the focal plane two of which will be devoted to asteroseismology. COROT will monitor several tens of stars in total in 5 fields, each of which will be pointed at during 5 months. The COROT data will be of very high precision are thus very well suited to study the signatures of convection and internal rotation. Additionally, some stars in other fields will be explored during 10 – 20 days. The two other CCDs of COROT will detect light variations of about thirty thousand faint stars with the goal to detect photometric transits of planets in front of their parent star. COROT has thus two very different main science goals.

For both MONS and COROT the accuracy of the photometric data will be at micromagnitude level (we recall that the current optimal ground-based data reach only millimagnitude level). In view of their different goals, the orbital planes of MONS and COROT are quite different. The programmatics of both missions are also completely different.

Belgium is a partner in both missions, and provides financial support for part of the instrumental hard- and/or software. We therefore plan to make optimal use of the unique opportunity to work on high time-resolution high-quality photometric space data of massive oscillating stars. In order to coordinate all Belgian efforts in asteroseismology, C. Aerts has created the *Belgian Asteroseismology Group (BAG)* (see http://www.ster.kuleuven.ac.be/∼conny/bag.html for more information and the BAG activities).

Preparatory and additional follow-up ground-based data are necessary for some targets. This is particularly the case for massive stars since their physical properties such as temperature, mass, chemical composition, and luminosity are not well known. Moreover, they have long beat-periods some of which cannot be covered completely by the space missions. In this context, the Leuven Mercator telescope (see http://www.mercator.iac.es/) will be operated by all the members of the IvS as a support instrument for MONS and COROT whenever appropriate. Asteroseismology was one of Mercator's prime science objectives when the plans for this telescope were designed many years ago. Mercator is operational since June 2001 and observations of non-radial oscillations are continuously being performed. It is therefore a very happy circumstance that we are involved in the space missions devoted to what even a cosmologist highlights as one of the two important topics in astrophysics in the new millennium (Longair, 2001).

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