Pulsation of Ap Stars

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It has been known for many centuries that one can determine by simple means if a barrel of wine is full, half empty, or – horribile dictu – empty. One knocks against the wall and listens to the echo. Another example of the same technique, but less interesting for the *connaisseur en vin* is given by seismology. Seismographs distributed all over the globe register earthquakes and since they are differently located with respect to an earthquake centre the registrations look different. From a comparison of such registrations geologists have extracted most of our knowledge about the structure and composition of the terrestrial interior. Corresponding experiments were also planned and successfully executed on the Moon and on Mars. Stellar astronomers, however, are not in the lucky position of their colleagues who work in our solar system with the help of satellites. They are limited to stars which pulsate voluntarily. We will not discuss here the question why some groups of stars pulsate and others do not. We shall only mention that pulsating stars have at least one layer in their interior which does not absorb pulsational energy, as is the case for the rest of the star, but produces energy of variable amount and in phase with pulsation. This mechanism keeps the star pulsating as long as this (these) layer(s) exists. Due to stellar evolution, diffusion, magnetic fields, to name only some possible mechanisms, these layers can disappear or undergo substantial changes so that the energy losses due to pulsation cannot be compensated anymore. Damping will result and finally the star will become stable against pulsation.

Damped oscillations are observed sometimes in stars when considerable mass falls onto a stellar surface, coming for example from an accretion disk or from a nearby companion star. X-ray emission usually is the consequence and sometimes additional periodic light variations with a decreasing amplitude are observed – damped oscillations.

To make a long introduction short, the analysis of stellar pulsation is a powerful tool, although a very complex one, for investigating stellar structures. Pulsation is one of the very few mechanisms which allow us to check the validity of theories of stellar structure with direct measurements. On these grounds, astronomers working in the field of chemically peculiar stars of the upper main sequence (so-called Cp stars, stars with spectral type ranging from late B to early F, also known as Ap stars) were excited when news spread a few years ago that some Cp stars definitely pulsate. Periods between 6 to 15 minutes and amplitudes of a few thousandths of a magnitude were observed.

Photometric and spectroscopic instabilities on time scales of minutes up to a few hours have been reported occasionally since the time the group of Ap stars was formally established. Karl Rakosch was one of the first in this field with a publication from the Lowell Observatory in 1963. However, evidence was not convincing at that time. This situation improved when J. Percy, in 1973, started a survey for pulsation in some Ap stars, which later was followed by more extensive studies by D. Kurtz in South Africa and by W. Weiss and H. Schneider at ESO and currently at Mauna Kea Observatory in Hawaii.

Before we continue, we should probably briefly comment on the nature of the peculiarity of Cp stars. A more detailed discussion of the characteristics of this group can be found in another article in this journal (H.M. Maitzen and W.W. Weiss: 1977, *The Messenger,* No. 11, p. 18). Cp stars differ from normal stars of comparable temperature and gravity in an overabundance of Rare Earth elements, Strontium and Iron group elements, among others. Cp stars rotate abnormally slow, reveal a spotty element distribution in their atmosphere, and frequently have a measurable surface magnetic field.

Besides the commonly used grouping of Cp stars into Si stars, Cr-Eu-Sr stars, He-weak stars, to name only some of the subgroups, it seems to be possible to distinguish Cp stars also according to their pulsational characteristics.

Pulsationally Stable Cp Stars

The Cp stars of this group are stable against pulsation or at least have amplitudes which are undetectable by standard photometric techniques.

This group comprises the vast majority of Cp stars.

Low-harmonic Radially Pulsating Cp Stars

This group resembles the long known δ Scuti-type stars. But let us first comment a little bit on the technical terms. The simplest pulsation we can imagine is the radial mode. Like a balloon which is attached to a bicycle pump with a broken valve, the star grows larger and collapses periodically. Eddington found already in the early years of theoretical investigations of stellar interiors a simple first order approximation for the period of radially pulsating stars,

$$P = Q\,(M/M_\odot)^{-1/2}(R/R_\odot)^{3/2},$$

with Q being called the pulsation constant ($Q \sim 0.03$ for δ Scuti stars). The period essentially corresponds to the time a star needs to adjust to hydrostatic equilibrium. Periods between 1.5^h and 2^h can be expected for a main-sequence A-type star.

However, it is possible that pulsation modes can also be excited so that one or more shells at certain distances from the stellar core do not participate in periodic movements, in other words, where matter is at rest. These shells are called, in analogy to acoustics, *nodes.*

Depending on the number of nodes we speak of first, second, etc. harmonics (or overtones). The pulsation period decreases if a star is pulsating in a higher overtone. The period ratio between the fundamental and first harmonic for Cepheids is, for example, about 0.77. Model calculations show that the fundamental-mode solution is primarily determined by the properties of the star about 3/4 of its radius away from the core. This means that the period of the fundamental mode is determined primarily by conditions in the central regions where most of the mass is located. Interestingly, Ap stars differ from normal stars mostly just in the very outer parts of their envelope.

These considerations in mind, astronomers interested in the stability of Cp stars were testing primarily in the period range of 1 to 3 hours. And indeed, at least 4 stars with an Ap classification are known meanwhile to pulsate in a low harmonic radial mode. HD 4849 was discovered in 1978 by Weiss during one of the ESO surveys ($P = 1.2^h$) and HD 10088 ($P = 1.5^h$) in 1982 at the Mauna Kea Observatory. HD 3326 and HD 185139 were discovered in 1981/82 by Kurtz. HD 11503 (γ Ari), HD 108945 (21 Com) and HD 224801 were found earlier to be possible pulsating stars, but different observers do not agree on the

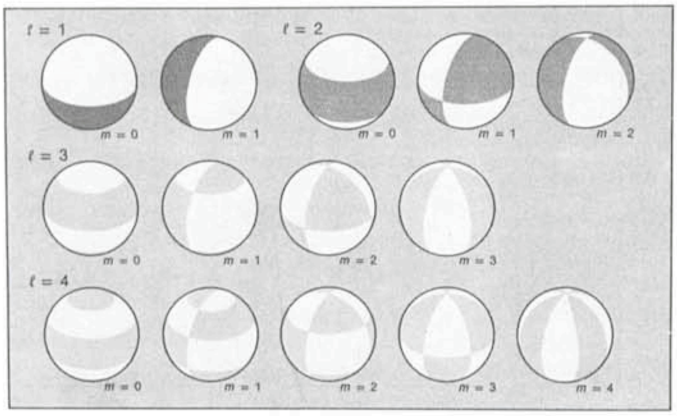

Fig. 1: *Non-radial pulsation modes (Winget and Van Horn,* Sky & Telescope, ***64,*** *216, 1982; by permission of the Sky Publishing Corporation).*

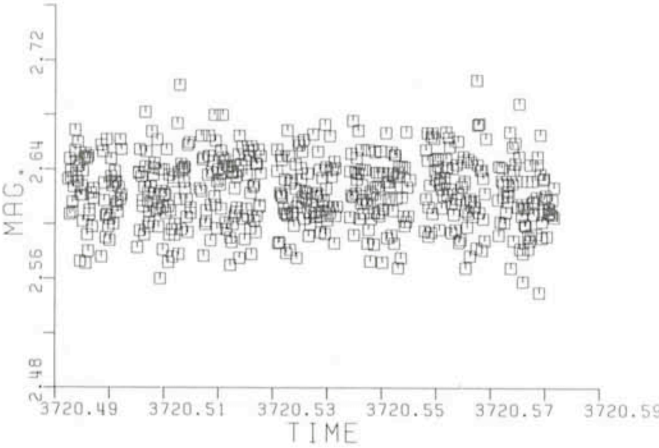

Fig. 2: *β photometry of HD 101065 (Weiss and Kreidl,* Astronomy and Astrophysics, ***81,*** *59, 1980).*

evidence of pulsation. For all the stars mentioned, there is a definite need for more detailed spectroscopic investigation. It has to be quantitatively established to what degree these stars are chemically peculiar, or if they are just extreme δ Scuti stars. Unfortunately, this group of variables populate the same temperature and gravity domain as do the pulsating Cp stars. More and better photometry is also required to determine the complete pulsation-frequency spectrum. The latter would allow a critical discussion of the pulsation modes.

High-harmonic, Non-radially Pulsating Cp Stars

In contrast to the δ Scuti-type pulsating Cp stars, the third group of Cp stars is better defined and their observed properties are well established. However, from the point of view of a theoretician they are even more difficult to understand.

But let us first clarify again some terms. Fig. 1 illustrates the situation for the lowest non-radial modes (l = 1 to 4). We see that not only nodal spheres are possible inside a star, but also nodal lines at the surface; i.e. regions which are at rest. The other non-radial mode parameter m characterizes the position of those nodal lines in the case of a star that is not completely centrally symmetric, but, for example, is rotating. The third integer parameter describing a non-radial mode is n and specifies the radial harmonics of the pulsation, similar to the already discussed case of radially overtone pulsation.

In fig. 1 areas which move in the same direction are shaded in the same tone. It becomes evident that non-radial modes can only be observed for distant stars (the sun is a special case), if l is a small number. Otherwise the light and radial velocity variations of different areas are cancelled or at least their observable effect is buried in the noise of the measurements.

In an interesting paper, D. Kurtz published the discovery of 12.2 min pulsations of HD 101065. This star is also called Przybylski's star since it was this astronomer who found extremely peculiar abundances for this star, making HD 101065 peculiar even in the group of peculiar stars. Kurtz interpreted the short period as a result of a non-radial (l = 2) high overtone (n = 15) mode. A few weeks after the announcement of Kurtz's discovery, W. Weiss had the opportunity of using the Danish Hβ photometer during some non-photometric nights and accumulated over 500 β values of Przybylski's star (fig. 2). Although HD 101065 is a faint object (B = 8.8 mag) considering the narrow filters and a 50 cm telescope, variations of the β index with a period of 12.5 minutes and an amplitude of 0.007 mag (fig. 3) could be detected, despite the poor signal-to-noise ratio. These observations clearly demonstrate the limits of the technique. The β amplitude together with the B and V measurements published by Kurtz cannot be interpreted as pure temperature variations. Additional gravity variations are required. The observations are therefore consistent with a pressure wave travelling through the atmosphere.

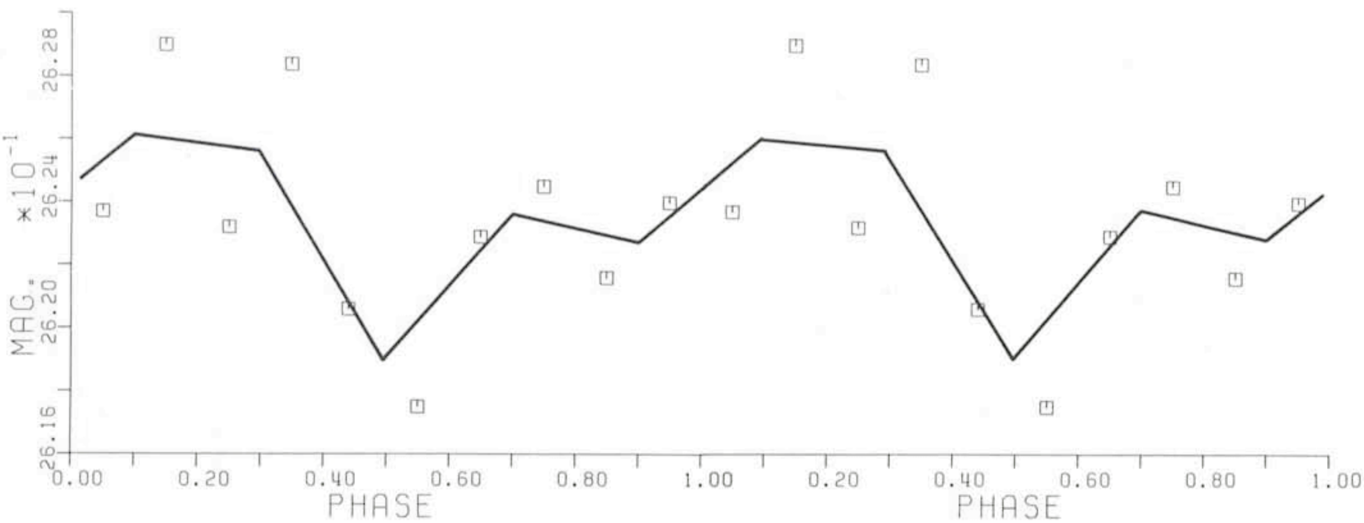

Fig. 3: *Light curve of HD 101065 in Hβ (Weiss and Kreidl,* Astronomy and Astrophysics. ***81,*** *59, 1980).*

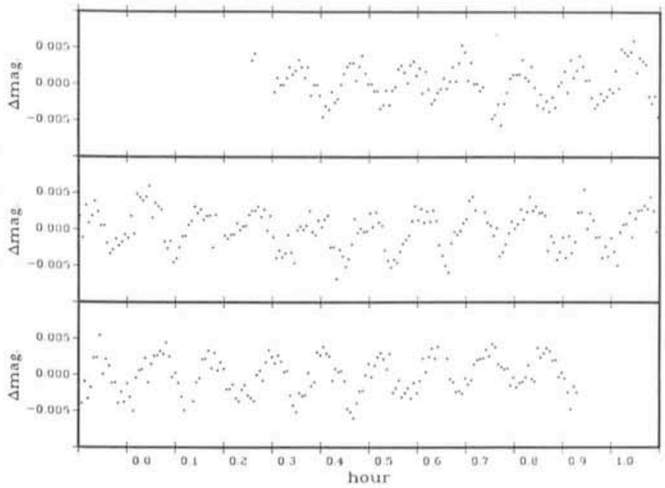

Fig. 4: *Pulsations of HD 128898 observed at La Silla with the 90 cm Dutch telescope, in the Walraven B band.*

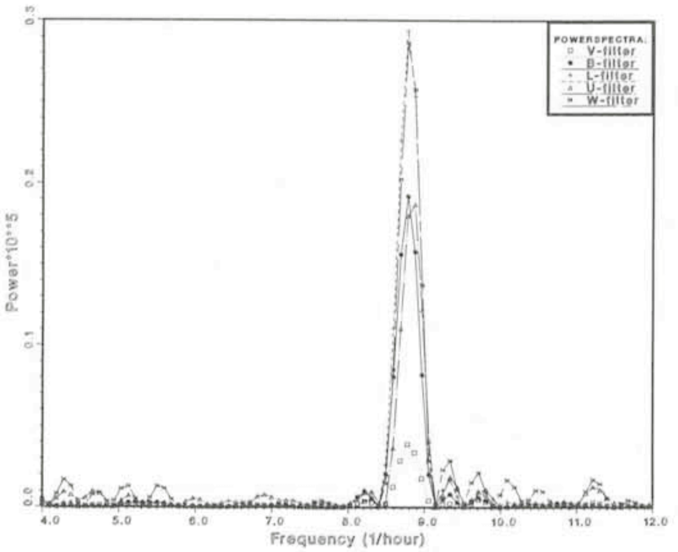

Fig. 5: *Power spectra for HD 128898 for all 5 Walraven colours.*

Another non-radially pulsating Ap star, also discovered by Kurtz, could be observed at ESO: HD 128898. The Walraven VBLUW photometer was used at the Dutch 90 cm telescope at La Silla. During an observing run of 24 nights in June 1982 we were lucky to observe HD 128898 during 3 of the total 20 clear hours of the entire run (it can be very depressing down there in Chile, sometimes!). We got excellent light curves in all colours and we present the B measurements in fig. 4. They are not typical, they are the best ones. A synopsis of the power spectra for all 5 colours is given in fig. 5. The light amplitudes are clearly a function of the wavelengths and we observed the same frequency in all five channels – as expected. Currently we are preparing a paper on these data which hopefully will allow us to specify the mode of pulsation by comparing theoretically determined phase-shifts for colours with our observations.

The other members of this third group of Cp stars were also all discovered by Kurtz and are: HD 24712, HD 60435, HD 83368, HD 137949, HD 201601 and HD 217522. Kurtz proposed a simple model which looks very plausible, but unfortunately, is contradicted by theoreticians. His model is called the *oblique pulsator.*

For this model, the axis of pulsation is aligned with the magnetic field axis. Therefore a maximum amplitude should be observed when looking at the magnetic pole and no pulsation at all when looking at the magnetic equator. This picture corresponds exactly to what we observe. The pulsation amplitude is modulated by the stellar rotation. Secondary frequency peaks are observed in the power spectra relative to the main pulsation frequency and are separated by almost exactly the stellar rotation frequency. But here come the theoreticians. For an observer moving with the rotating star, Coriolis forces perturb the dynamics of the oscillations which lead to a precession of the pulsation axis. Consequently, the frequency splitting should not correspond exactly to the rotation frequency, but should be slightly larger. However, their very crude model calculations also predict to first order that the axis of pulsation should *not* be aligned with the magnetic field.

This time the observational evidence is very strong and different observers agree surprisingly well – at least in the eyes of somebody who has been working in this field already for some time. So we can relax and mumble, "Too bad for the theoreticians!" Can we really relax? Definitely not. More and better determined power spectra are necessary. Reliable abundance determinations and magnetic field measurements are lacking for most of the stars mentioned in this article and simultaneous light- and velocity measurements would considerably ease the difficult task of oscillation-mode determination.

And still more questions are in the air: Why do we observe such high overtones and only very few of them? Is the pulsation axis always aligned with the magnetic axis? Does the magnetic field, a density discontinuity or some other effect trap selected modes? How do rapid oscillations correlate with T_{eff}, log g, v·sin i, H_{eff}, i, β and Z?

There are lots of problems, but lots of exciting results can be expected. Why is not one of the telescopes on La Silla completely devoted to Ap star research?

Workshop on ESO's Very Large Telescope

A workshop on the subject of Very Large Telescopes (VLT) took place at the Institut d'Etudes Scientifiques de Cargèse (Corsica): it was attended by about forty invited participants. During three and a half days (May 16–19, 1983) the following topics were presented and discussed: scientific objectives for galactic and extragalactic research; instrumental requirements and possibilities (different wavelength regions, auxiliary instrumentation, detectors, interferometry, etc.); ESO's New Technology Telescope as a precursor to the VLT; projects existing outside ESO; ESO's VLT studies and options; site selection; general discussion. While it was undoubtedly too early to come to definite technical conclusions, a number of points were clarified and it was absolutely clear that there does exist a strong support on the part of the scientific community in Europe for the idea of a VLT. The workshop was followed in Cargèse by a meeting of ESO's Scientific and Technical Committee which strongly recommended the setting up of a group of persons whose activities will be entirely devoted to the VLT. Such a recommendation was endorsed by the Council on June 6: a VLT project group will thus be created so that technical studies, site surveys, etc. are to begin in the very near future.

The proceedings of the Cargèse VLT workshop are presently in press and their publication is scheduled for September 1983.

J.-P. Swings