mentionnée ci-dessus. La raie K de Ca II a un profil complexe avec deux et parfois trois composantes en absorption. Ces composantes varient avec le temps de façon différente et en particulier sont modelées avec des périodes distinctes, comme le montre l'analyse faite à l'aide de programmes mis au point pour ce type de recherche (périodogramme, algorithme CLEAN, minimisation de dispersion de phase). Ici nous obtenons 35 et 50 h. Ceci peut se comprendre si les diverses composantes se forment à des endroits distincts dans le vent de l'étoile.

Nous avons interprété cette modulation rotationnelle comme étant due à l'alternance sur la ligne de visée de jets lents et de jets rapides. Par analogie avec ce que l'on connait du vent solaire, on peut penser que cette structure est reliée à un champ magnétique de surface. Dans ce cas, les questions que l'on se pose sont nombreuses: ce champ magnétique est-il la clef des phénomènes actifs dans ces étoiles, comme c'est le cas pour le soleil? Est-il fossile ou produit par l'étoile, et comment? Comment ce champ magnétique et l'activité qui s'y rattache évoluent-ils pendant la contraction de l'étoile vers la séquence principale? Peut-on bâtir un schéma cohérent de l'évolution de l'activité et des champs magnétiques pour les étoiles de cette masse, incluant les étoiles de Herbig, les étoiles A normales de la séquence principale et les étoiles Ap?

L'observation de la modulation rotationnelle des raies dans les étoiles Ae/Be de Herbig présente donc un intérêt important. Il reste maintenant à trouver comment ce phénomène dépend des paramètres stellaires comme la masse et l'âge, en observant de la même façon d'autres membres de la classe. L'observation de cette modulation rotationnelle nécessite l'obtention d'un grand nombre de spectres à haute résolution (30000) ayant un rapport $S/B > 50$, de façon la plus continue possible car la période de rotation de ces étoiles est comprise entre 1 et 2 jours. Des observations multi-sites sont nécessaires pour une bonne couverture en phase. Elle nécessite également une instrumentation performante car les prochains objets à observer ont une magnitude comprise entre 10 et 13.

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Seismological Study of Procyon and Arcturus

Seven nights have been granted in 1989 to the Asteroseismology Program, February 13 to 20. Two stars have been observed, Procyon and Arcturus, the rule of the game being to find extremely small amplitude radial and slightly non-radial velocity oscillations.

Asteroseismology

These oscillations, the excitation mechanism of which is still unclear but presumably due to stochastic interaction with the subphotospheric convective layers, are acoustic resonant modes trapped between a reflection at the stellar surface and a refraction very deep in the stellar core. Being present in most of the stellar body, they can be used as a probe of the internal structure. The well known success of helioseismology is due to the fact that many such eigenmodes can be identified and measured with high accuracy, making it possible to use inverse techniques to reconstruct and improve the solar model. This success has made very attractive the possibility of obtaining at least partly the same kind of information on other stars. The problem for the observer is to detect as many different eigenmodes as possible. They will be as many constraints on the stellar model.

For instance, two independent asteroseismological parameters, the fundamental frequency and the gradient of the sound speed in the core, represent the initial information that we are looking for. These two parameters are independent to a large extent because one is an integral along the stellar radius, in which the main contribution is in the external layers, and the other one is an information related to the stellar core. As such, they have been used by theorists to build a diagram which can be regarded as having an importance comparable to the one of the HR diagram. And obviously, any more seismic information will come on top of that.

This is a major difference with the study of most so-called classical variable stars. Most of those stars exhibit only one or two modes. The only stars known to oscillate with a significantly larger number of modes with observable amplitudes are the Ap stars. They display photometric relative variations of the order of 10^{-3} per mode, or more, which are easily accessible in a good photometric sky. For other types of stars, the expected photometric amplitudes are much smaller. In the case of solar type stars, the amplitude per mode is rather in the micromagnitude range, which cannot be detected from the ground, even in the best possible mountain sites.

Therefore, the ground based approach to asteroseismology is the precise radial velocity measurement. It has already been successfully used in helioseismology. The

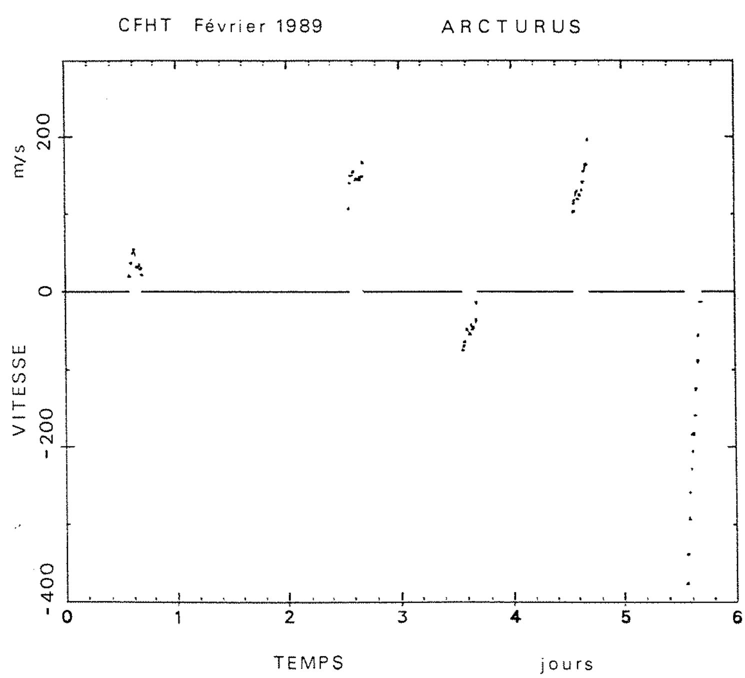

Figure 9: Radial velocity of Arcurus measured at CFHT during 5 nights in February 1989. Orbital and spin motions of the earth have been substracted.

principle is the measurement of the Doppler shift of the stellar atomic Fraunhofer lines. Because the very small amplitudes, the line shifts to be measured are an extremely small fraction of the natural linewidth. A consequence is that the measurement is still a photometric measurement. It takes advantage of an amplification coefficient due to the sharp slope of the line profile, where a very monochromatic filter is used. Typically, the photometric variations to be detected are 10 times larger, and moreover they can use the nearby continuum of the stellar spectrum as a reference. Such a measurement becomes, in principle, feasible.

Our group at Nice, with a long helioseismological experience, has developed an instrument devoted to stellar seismology for solar-type stars, using the spectroscopic principle of atomic sodium optical resonance. This instrument acts as a very narrow filter of about 0.1 Å bandwidth, and an obvious consequence of this very narrow spectral band is that it is drastically limited by the photon statistics and can be used only with large optical collectors. On the other hand, it offers, relatively easily, the required spectral stability making possible high-accuracy measurements.

Procyon Seismology

A prototype of our instrument was tested in 1983 and 1984 on the two 3.6-meter telescopes of La Silla and CFHT. These initial campaigns made possible to obtain the first detection of oscillations on two solar-type stars: Alpha Centauri A and Procyon.

A second version of the instrument, improved in performance and reliability, has since been developed. Two campaigns of observations on Procyon have been organized, the first one in February 1988, and the last one being the presently reported one.

Procyon is an F5 dwarf of about 1.5 solar mass. The equivalent of the solar 'five minute' oscillations are supposed to lie in the 10 to 15 minute period range with possibly larger amplitudes due to a different structure of its convective zone. The oscillations detected in 1984 were in good agreement with these expectations, with periods ranging between 10 and 25 minutes and maximum amplitudes of about 70 cm/s. Unfortunately (for the ease of detection) the amplitudes found in the 1-2 mHz range in 1988 were significantly less than those values, and appear to be lower in 1989. With the lack of a good theory for the excitation mechanism we have no explanation for the amplitude decay in five years. It may be a magnetic cycle effect. If the typical damping and excitation characteristic times are of the order of a few days, it may also be that a few days of observations provide quite different amplitudes from year to year just because the measured signal is not stationary enough.

The upsetting result is that despite having a quite better instrument providing a lower noise level, we could not obtain a better signal to noise ratio during the last two campaigns. It also makes the comparison Fourier spectra of different data sets more complex. It has to be done carefully, however, to test the reliability of the detected individual peaks, which presumably correspond to individual stellar oigenmodes. This new (May 09, 1989) analysis is still not finished and will take a few more months. However, some preliminary indications are already firmly established. The first seismic parameter detected in 1984 (namely the pseudo-equidistance of the frequencies of successive harmonics, which is a first approximation of the fundamental frequency of the star) is confirmed. There are also possibly larger amplitude oscillations at longer periods, near one hour. But because the instrumental noise also increases with increasing period, these are not so firmly established yet.

Recently, another very preliminary result has been privately reported by T. Brown, who measured Procyon oscillations with a standard coudé spectrograph and a double fiber optics feed, one for the star and the second for a reference absorption cell. He reported some power significantly above the surrounding noise in the 15 minute range with a maximum peak amplitude of the order of 70 cm/s. These two values are very similar to the ones we obtained in 1984, and we are anxiously waiting for a more detailed analysis of this data set, which could hopefully confirm our seismological parameter.

It can be concluded from Procyon data that stellar seismology is certainly possible on solar-type stars, which very probably are oscillating, as the sun, with many different modes. It is also fair to say that the observational problem is difficult. It requires long sequences of data with large collectors, where the observing time is quite 'expensive', and it will also require one more iteration in the instrument sensitivity improvement if we want not to be limited to the just significant detection of stellar modes, without detail, on only two bright stars.

Arcturus Seismology

Arcturus is a very different star, a K0 red giant. Its periods of oscillation are consequently expected to be much larger. In fact, one oscillation has already been reported, with a period of 1.04 days and a large amplitude of the order of 100 m/s. The amplitude is large enough for easy detection, but the period, not much shorter and not much longer than one day is very 'uncomfortable' for Fourier analysis. If we take everything proportional in the comparison with the solar 5-minute oscillation we can conclude that a few year of continuous data will be necessary on Arcturus in order to resolve all useful individual modes. We can also hope that the Arcturus excited acoustic spectrum is broader than the solar one, and that some oscillations at periods shorter than one day can be detected, even though with smaller amplitudes.

Our instrument as it stands now has not been optimized for such a long period range. It still has a good sensitivity, but using two different detectors for the monochromatic and the reference channel, it has no guaranteed long term stability. Moreover, we observed Arcturus only during 3 hours each night (at the end of the run on Procyon, until the sunrise).

Assuming the absence of long period variations in the Procyon stellar signal, we have used this signal for the calibration of the instrument sensitivity during each night. The extrapolation of this slowly varying calibration during the following three hours, during the Arcturus observation, made possible to detect highly significant variations of the Arcturus radial velocity from night to night, with peak to peak amplitudes of the order of 400 m/s.

Clearly, these variations do not manifest the presence of a single mode frequency. A Fourier analysis of this data shows a large number of peaks, each one of which exhibits lots of sidelobes, due to periodicity of the data set. A CLEAN algorithm has been performed in order to try to identify the different frequencies. Most are harmonics of one day. At the present level of this analysis (unfinished), no confirmation of a previously reported frequency has been possible. It can be said, however, that individual periods will probably not be identified with this data set because they are so close to one day.

What's Next

Two different types of stars are now being investigated by asteroseismologists: α Centauri, Procyon, and ε Eridani on one hand, and Arcturus on the other.

For both stars, we think it is time now to organize joint effort observations. For the short period stars, the instrument used by Brown, our 'Cacciani cell' and the sodium cell developed by Cacciani himself, at least, can do the job with similar sensitivities. On Arcturus, with larger amplitudes, all optical resonance instruments could be used including the potassium cell of Isaak. Our present instrument has to be made more 'absolute' by an optical modulation in order to use the same detector on the two channels. This can be made without losing photons, and will be the next improvement implemented during the coming year.

Before going to space where very precise broadband photometry will be feasible, the future of asteroseismology on the ground will certainly include a few joint campaigns of a few teams on a few bright stars. Several other projects of promising instruments have been presented in several recent international conferences. We all sincerely hope that they will soon provide comparable sensitivities and may be then asteroseismologists working on the observing side will be able to give many eigonmode frequencies to asteroseismologists working on the theoretical side.

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DIRECTORS' CORNER

IR Working Group — *Summary of the Report*

As described in the previous issue of the Bulletin, an IR Working Group was established by the Scientific Advisory Council to prepare a report on:

1. status of IR array development and use in our three communities and elsewhere,
2. improvements needed to CFHT facilities to better exploit IR cameras, and
3. a possible facility camera for CFHT.

The group presented its final report at the User Meeting in Meudon. The highlights are summarized below. A copy of the complete report can be obtained by writing to CFHT headquarters in Waimea c/o the Director.

The first part of the report described three IR cameras that are either currently in use or soon will be in use as visitor instruments at CFHT. The first of these is CIRCUS, which employs a 32x32 InSb CID array for imaging in the 1-5 µm region. CIRCUS is described in much more detail in Info Bulletin No. 19 and in its User Manual which is available from Daniel Rouan at Meudon. Although originally a purely visitor instrument, CIRCUS is now available on a limited basis to anyone who applies to use it. So far, we have not turned anyone down for non-scientific reasons. The second camera discussed is the 10-µm cousin of CIRCUS, which has been funded by INSU and developed as a joint effort of CEN-Saclay and Obs. de Lyon. It employs a 32x32 Si:Ga array designed for ground-based (high-background) work in the 10-µm window. The camera will have its first run at CFHT in November. It is planned to replace the array with a 64x64 version in 1990. The third camera is a project of Daniel Nadeau and co-workers at Université de Montréal. Construction is just getting underway. A Rockwell 128^2 HgCdTe chip will be used, sensitive from 1-2.5 µm. A read noise of 60-80 e^- is expected — 20 times lower than that of CIRCUS. Daniel has designed the system to be compatible with CFHT's new HP9000-based data acquisition environment. He hopes to be operational in 1990.

The second part of the report assesses array development in France and the U.S.A. In France, a consortium known as SOFRADIR is producing HgCdTe arrays bonded to CCD readouts. The prospects appear good for a 128^2 device in the near future and 256^2 later. LETI/LIR has developed the 32x32 Si:Ga array mentioned above, and this will be followed by a 64x64 version. In the U.S.A., both Santa Barbara Research Center (SBRC) and Rockwell are producing arrays suitable for astronomy in the near IR. SBRC uses InSb and Rockwell concentrates on HgCdTe. In both cases direct readout (DRO) multiplexors are used. We can expect to have 256^2 arrays available within the next couple years with read noise below 100 e^-.

The third section of the report addresses the issue of the IR secondary mirror. The current f/36 mirror has two principal defects: a turned down edge which produces a halo component in the point spread function comprising ~15% of the total light, and a diameter somewhat smaller than ideal. The latter derives from the original requirement of an 8-arcminute background-free field, which is much larger than needed. As a result, the illuminated primary diameter is only 3.36 m. The Working Group wrestled with the question of whether to retain the chopping capability. The strongest potential need is for 10 µm work, and it is still too soon to know for certain whether chopping is required at this wavelength. After considering all the aspects, the group recommends that a new mirror be obtained which is slightly larger than the current one (4 arcminute field) and which has optical quality at least as good as the primary. The new mirror