MULTIPLEXED INTERFEROMETRIC STELLAR OSCILLATION SPECTROMETRY - MISOS.

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Abstract. Interferometric spectrometry techniques for measuring stellar oscillations have been developed at Imperial College, resulting in two separate interferometers, the Michelson and the Fabry-Perot based instruments. They have both been used on large telescopes; the Michelson instrument to search for oscillations in solar-type stars and the Fabry-Perot instrument to measure oscillations in δScuti-type stars. So far there has been only marginal evidence for solar-type oscillations, including our observations of εCyg with ~1ms^{-1} precision. In order to increase the significance of future observations we are currently improving both instruments and aim to achieve a ten-fold increase in precision, i.e. ~10cms^{-1}, by using up to 100 separate spectral lines simultaneously. Such an improvement will allow us to continue the search for solar-type oscillations.

1. INTRODUCTION

The search for oscillations in Solar-type stars, analogous to the solar 5 minute p-modes, has so far not produced convincing evidence for their existence. Our knowledge of the 5-minute oscillations is based on the Sun, which, observed as a star, shows modes of degree l≤3 and amplitudes of ≤15cms^{-1}.

The claim of Fossat et al (1985) to have detected a mode spacing on Procyon is based on data with a signal-to-noise ratio (SNR) of barely unity. Similarly, the ISOS data on εCyg have a precision of 68cms^{-1} and a claim for the detection of a mode spacing cannot be confidently made.

In this paper we describe an improvement to the ISOS technique that will eventually allow us to achieve noise levels of <10cms^{-1} and we present preliminary laboratory test results.

2. THE ISOS INSTRUMENTS

At present the ISOS instruments measure the changes in position of a single stellar absorption line and hence the changes in radial velocity.

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With the Michelson ISOS, this is done by measuring, at constant path difference, the changes in the intensities, C and D, measured at the two complementary output ports. The path difference is held constant (with respect to a standard wavelength) at a value which maximises the changes in intensity for a given change in radial velocity. Changes in the ratio r=C-D/C+D are then proportional to changes in radial velocity. Using a reference wavelength removes any thermal or mechanical drifts, the solid construction provides stability and facilitates field compensation and rapid beam swapping averages the optical paths, detectors and electronics. For a full description of the ISOS instruments see Reay et al (1986).

2.1. Accuracy On Solar-type Stars.

Both instruments are shot-noise limited, i.e. the noise depends on the number of photons counted and the sensitivity of the instrument to changes in radial velocity. For the Michelson, the noise level is 68cms^{-1}, in the power spectrum (smoothed to 0.2mHz), when observing a solar-type star (ϵCyg ($2^{m}.46$)) on a 2.5m telescope for 3 nights. Recent Michelson results are presented in Pietraszewski et al (1985).

Using a 4.2m telescope and a 0^{m} star would provide an increase in flux of ~25 times and a noise level of ~14cms^{-1}. Even such a noise level is not enough to distinguish clearly the p-mode envelope in the amplitude spectrum. Similar accuracy is intrinsically possible with the Fabry-Perot instrument.

2.2. Reduction of Data.

The reduction of data is plagued with the problems of side lobes due to the daytime gaps in the data. Computing the power spectrum of a section of a power spectrum (ordinates proportional to velocity^4) exaggerates random features to the point that they appear significant. Simulations show that there is a 50% probability of obtaining a significant-looking peak in the power spectrum of the power spectrum. Until the data is precise enough to show p-modes in the amplitude spectrum, the uncertainty of detection in the second power spectrum will remain.

3. IMPROVING THE ACCURACY - USE OF MANY LINES.

Without using many lines the only way to improve measurement accuracy is to observe for longer, or increase the telescope size, or both; this, however, can only improve the accuracy by small factors.

To benefit fully from using many lines with the ISOS technique the individual line signals must be added coherently. This gives an overall increase in SNR proportional to the square root of the number of lines, N. It is, therefore, possible to increase the SNR by a factor of ~10 when using up to 100 lines provided by a standard spectrograph along individual optical fibres (figure 1). There would be no increase in SNR if the signals from the lines were added randomly as both signal and noise would increase in proportion to $\sqrt{N}$.

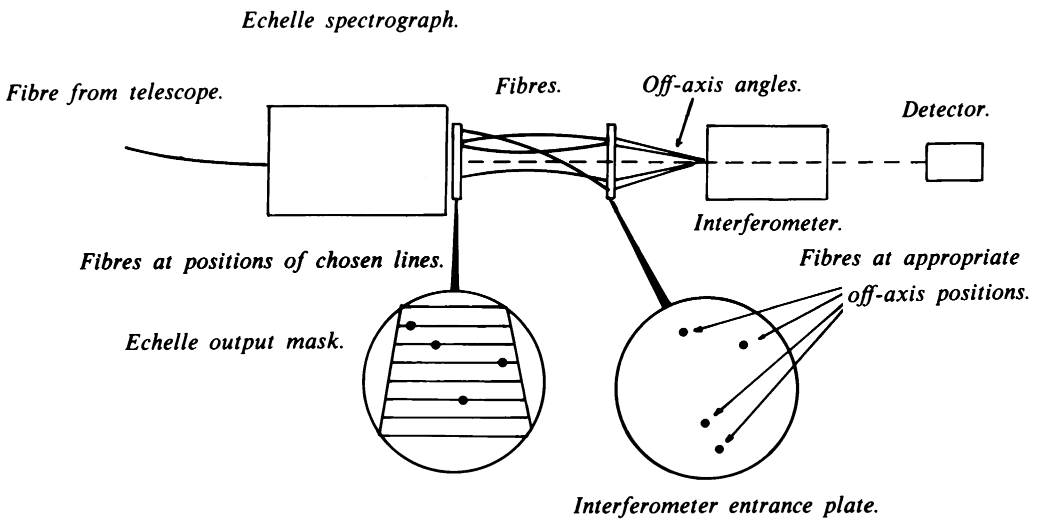

Figure 1. Multi-lining a general MISOS instrument with 4 fibres.

3.1. Multi-lining The Fabry-Perot.

With the etalon at constant gap it is possible to vary the transmitted wavelengths by positioning an input optical fibre at different off-axis angles ($n\lambda=2\mu t\cos\theta$). Hence by individually positioning fibres carrying monochromatic light in this way, it is possible simultaneously to measure the radial velocity shift of the combined lines, (each from a different order). For there to be no loss of resolution with off-axis angle it is necessary to stay within the 'off-axis Jaquinot criterion': $n\delta\lambda=-2\mu t\sin\theta\delta\theta$. This also limits the diameter of the fibres used.

3.2. Multi-lining the Michelson.

At first sight it would seem impossible to use many lines in a field-widened Michelson since it should be insensitive to changes in input angle. However, the cube corners allow a controlled change in the phase of fringes with input angle to be established, despite the field-widening. Moving the apex of one cube corner by a distance δx from the image of the apex of the other cube corner (normal to the beam) introduces a change in phase, $\delta\phi$, with angle θ where $\delta\phi=2\delta x\sin\theta$. Thus the fringes from individual lines can be added coherently by placing optical fibres at the appropriate off-axis angles at the input of the partially field-widened Michelson. The $\cos^2$ fringes of the Michelson also allow for some misalignment of the fibres. Fringes from each line will contribute 95% to the signal even when about 30° out of phase.

Figure 2 shows the effect of introducing 3 separate emission lines at different input angles to the Michelson. Scanning the path difference through ~5 orders clearly shows the lines, Cd λ5085 and λ6438 and Hg λ5461, adding. The relative positions of the fibres determine in which

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order the maximum fringe amplitude occurs.

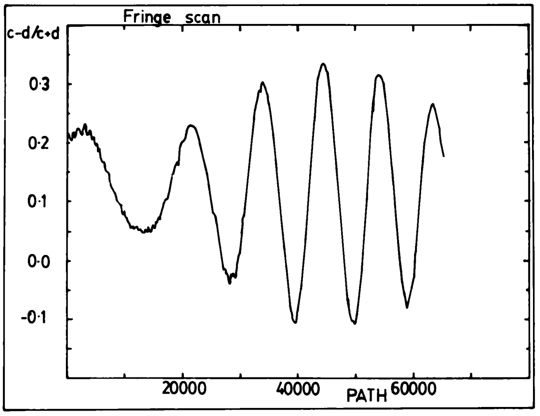

Figure 2. Testing the multiplex properties of the Michelson ISOS.

4. CONCLUDING REMARKS.

The search for solar-type p-mode oscillations in other stars has to be continued at levels of precision not currently available in order to produce the accuracy of data required for comparison with theoretical models.

Even if the behaviour of other stars differs from that of the Sun and, for example, Procyon proves to have 1-2ms^{-1} amplitude oscillations as claimed by Fossat et al (1985), higher accuracy is still needed to reveal these oscillations in the velocity amplitude spectrum.

It is difficult to improve alkali metal vapour methods since they are tied to a single line. However, more efficient use of the spectrum is possible in the ISOS instruments (and the proposed method of Connes (1985)) and it is possible to increase the precision by up to an order of magnitude.

We believe that the work being done at Imperial College will shortly produce reliable detections of solar-type oscillations in other stars and open the door for true asteroseismology.

5. REFERENCES.

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