HIGH RESOLUTION SPECTROGRAPH NEEDS FOR STELLAR SEISMOLOGY

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1. INTRODUCTION.

There are two ways to become a famous observing astronomer: 1) by discovering something new and exciting, 2) by detecting a phenomena, which has been predicted, but not observed before.
Observing stellar oscillations belongs to the second category. Indications are around, that solar type stars do oscillate, but there is still a lot of uncertainty, so that nobody can claim to have a 100% solid identification of oscillations in a solar-type star.
The prospects for improving the understanding of stellar structure and evolution have been discussed by Christensen-Dalsgaard (1987) and by Däppen (1988).

2. WHAT ARE WE LOOKING FOR?

The signals that one should observe are shortly described in Table I.

TABLE I

Characteristic amplitudes of acoustic oscillations.

	Sun	F0 V star
Velocity	15 cm/s	40 cm/s
Intensity	3.5×10^{-6}	6.5×10^{-6}
Typical Period	300 s	350 s
Frequency Spacing	137 μHz	96 μHz

Clearly we are dealing with very small amplitudes, which can only be measured with carefully designed instruments.
Let me concentrate on techniques for observing oscillations from the ground. It might be possible to do such measurements with a photometer using differential photometry (Harvey et al.,1987), but generally the instruments

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proposed for doing efficient observations integrate a high resolution spectrograph (HRS) into the design. One can think of a stellar seismometer as consisting of three parts:

Image stabilizer and scrambler with large entrance aperture and (long) narrow exit slit

Very stable HR spectrograph with (or without) wavelength calibration and wide spectral coverage

Two-dimensional low noise, very stable detector, with fast readout and large dynamic range

The first critical element brings the light from the telescope to the HRS. It will almost certainly consist of one or more optical fibers, which scramble the light and bring the light to a more convenient location for a spectrograph than close to or attached to the telescope. Some additional image stabilization could be needed and reimaging might be necessary to match the entrance aperture of the spectrograph.

Secondly one must have a very stable spectrograph, either inherently by eliminating internal turbulence and temperature drifts, or by calibration by a very stable reference source. To reach as low as the amplitudes observed in the Sun, a reference source is probably a necessity.

The detector must have low noise, so that readout noise does not dominate. It must be extremely stable with no change in sensitivity or zero point drift. The Reticon detector at the CES at ESO does not have that stability (Frandsen, 1987). A two dimensional detector is required to have access to several echelle orders and cover a wide spectral range. One needs to record as many photons as possible. Otherwise measurements are restricted to a few very bright stars.

3. TIME REQUIRED TO GET SATISFACTORY S/N RATIOS.

In one echelle order there are close to 20 useful lines, that are not awfully blended (Frandsen, 1987). The gradient of f.ex the K D1 line has a large value only over a range of 0.05Å, so that one can define a typical spectral element of that size. The maximum gradient will for a non-rotating star be given in velocity units by

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$$\frac{d\log I}{dv} \approx 0.4(km/s)^{-1}$$

This means, that a velocity amplitude of 1 m/s corresponds to an intensity change of

$$\frac{\Delta I}{I} \approx 4 \times 10^{-4}$$

Let us now assume, we have a 3.6m telescope at our disposal and the total instrumental efficiency is 1%, and we are observing a m_V=0.0 star. Then the number of photons recorded is

$$N \approx 4 \times 10^4 photons/s$$

If more than one line is used simultaneously, the equivalent bandwidth will be ≈1Å for one echelle order. The observing times required for a moderate S/N≈4 is listed in Table II.

TABLE II

Observing time(seconds) for a S/N ~ 4.

Technique	t(1m/s)	t($V_\odot$)
Doppler shift 1 linewing	150	5400
Doppler shift 10 lines	35	1200
Intensity 60Å band	150	5400

If we instead try to observe the intensity change in the line cores, the typical equivalent bandwidth is 5Å. The signal one expects for the Sun is two times the continuum changes (Frandsen, 1984, Stebbins and Goode, 1987). The amplitude will be around 7×10^{-6} for the Sun. The number of photons recorded within the line cores is

$$N \approx 4 \times 10^6 photons/s$$

The last row in Table II is for this case.

A velocity measurement is the most demanding technique considering the stability of HRS and the entrance element. Intensity studies of line cores is more vulnerable to detector flaws. Roughly speaking the accuracy required on time scales appropriate for stellar oscillations can be defined as in Table III.

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TABLE III

Requirements for a seismometer.

	velocity	intensity
Velocity stability	10 cm/s	1 m/s
Detector/bias stability	10^{-3}	10^{-4}

The stability is for timescales around 5 minutes.
Bias stability describes zero point drifts.
Detector stability problems are changes in sensitivity, nonlinearities, hysteresis etc.

4. CONCLUSION.

If a very stable spectrograph can be constructed, it is more efficient to observe Doppler shift, because the related intensity changes will be the largest. To use telescope time efficiently several echelle orders should be observed with a two-dimensional detector, and to secure a high duty cycle fast readout should be possible. If a very stable detector is available, but no spectrograph, that satisfies the requirements of Table III for measuring Doppler shifts, a reasonable decision could be to measure line core changes. Ideally one should be able to derive both velocity and intensity oscillations from the observed spectra, which would give some additional information about amplitude ratios and phase delays of the oscillations.

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DISCUSSION

FOING How does the stability of such a spectroseismometer compare to that of a resonance cell? Or of a CORAVEL type instrument? What is the gain in S/N of a v measurement brought by the image stabilization, apart from the photon collection?

FRANDSEN A seismometer would probably use a resonance cell or Fabry-Perot filter to calibrate instrumental drifts, so the stability would be comparable to a resonance cell. A CORAVEL has no scrambling of the image and not the stability to be used as a seismometer. Without elimination of the effects of seeing, oscillation measurements are impossible at solar amplitude levels.

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