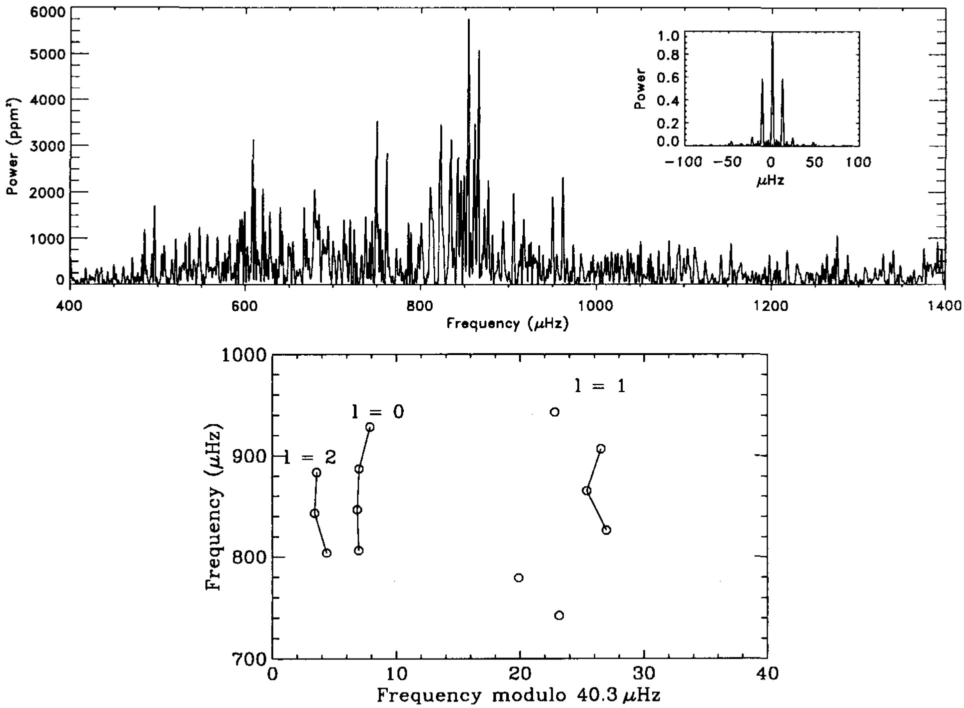

Figure 1. Solar-like oscillations in η Boo.

tions. Similar observations of the daytime sky show the five-minute solar oscillations at the expected frequencies (Kjeldsen *et al.*, 1994).

13. roAp stars (D. Kurtz and P. Martinez)

Among the A stars there is a subclass of peculiar stars, the Ap stars, which show strongly enhanced spectral lines of the Fe peak, rare earth and lanthanide elements. These stars have global surface magnetic fields several orders of magnitude larger than that of the Sun, 0.3 to 30 kGauss is the measured range. For stars with the strongest magnetic fields, the spectral lines are split by the Zeeman Effect and the surface magnetic field strength can be measured. Generally, though, the magnetic fields are not strong enough for the magnetic splitting to exceed other sources of line broadening. In these cases residual polarization differences between the red and blue wings of the spectral lines give a measure of the effective magnetic field strength – the integral of the longitudinal component of the global magnetic field over the visible hemisphere, weighted by limb-darkening. In the Ap stars the effective magnetic field strengths vary with rotation. This is well understood in terms of the oblique rotator model in which the magnetic axis is oblique to the rotation axis, so that the magnetic field is seen from varying aspect with rotation.

The rapidly oscillating Ap (roAp) stars are cool magnetic Ap SrCrEu stars which pulsate in high-overtone, low-degree ($n >> l$) p modes with periods which range from just under 6 minutes to about 16 minutes (the upper limit is poorly defined). The amplitudes of the light variations are observed to be 0.05 mmag to a few mmag. Thus, these stars have pulsation modes similar to the low degree modes seen in the Sun, but with amplitudes three to four orders of magnitude larger.

A major difference from the Sun, however, is that the pulsations in the roAp stars are dominated by the strong global magnetic fields of the Ap stars. The pulsation amplitude is modulated with rotation in phase with the magnetic field modulation. This amplitude modulation of the light curves of the roAp stars can be described by the oblique pulsator model which assumes that the pulsation and magnetic axes are aligned and are oblique to the rotation axis; the rotational modulation of the light variations is caused by the varying aspect of non-radial pulsation modes.

HR 1217 (HD 24712) is probably the best known of the roAp stars to helioseismologists. It shows five pulsation frequencies with alternating spacings of 33.3 μHz and 34.7 μHz and a sixth frequency separated from the others by 1.5 times those spacings suggestive of even- and odd-l modes of high overtone. There is a problem with this interpretation, though. Rotational sidelobe frequencies generated by the amplitude modulation with the rotation cycle are more easily understood if all of the modes are dipole modes, but then the highest frequency is inexplicable. Also, consecutive overtones of $l = 1$ would not be expected to show the alternating spacing. Since the two interpretations have significantly different values of $\delta\nu_0$, the inverse sound travel time across the diameter of the star, the parallax measured by HIPPARCOS may be able to distinguish between them by providing an accurate luminosity.

Several other roAp stars have already been observed to have multiple pulsation modes. The most complex of them is HD 60435 which pulsates in many modes with a basic spacing of 26 μHz. Many of the roAp stars have modes with lifetimes as long as they have been observed - over a decade in some cases. But the lifetimes of the modes in HD 60435 are less than the rotation period of 7.6793 d. It is not known why some of the stars should have modes with lifetimes of only days and others modes with lifetimes greater than a decade.

It is also not known what the mode selection mechanism is. This problem

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is much more complicated that in the Sun. In particular, some of the stars pulsate in multiple modes which are not consecutive overtones; intermediate modes are missing, or have undetectable amplitude. An extreme case of this is HD 217522. Between 1982 and 1989 (when the star was not observed) the principal frequency changed by 15 μHz; in 1989 a mode which was undetectable in 1982 appeared separated by 802 μHz from the principal frequency. Since $\delta\nu_0$ is in the range of 20 to 80μHz for the roAp stars, there are many intermediate overtones not excited in this star. We have looked at HD 217522 again in 1993 and find it unchanged from 1989.

HD 119027 has five pulsation modes with frequencies separated by about 26 μHz consistent with alternating even- and odd-l modes. HD 203932 has four pulsation modes with nearly equal spacing of about 33 μHz. Most of the studies of these stars have been limited to single-site observations, or, at best, a short multi-site campaign. What is needed are much more extensive multi-site observations.

New multi-site observations of α Cir show that its principal pulsation mode is a pure oblique dipole mode with a frequency of 2442 μHz. A rotationally split triplet shows the rotation period to be $P_{rot} = 4.4790 \pm 0.0001$ day. Four low-amplitude secondary frequencies are present with separations that are multiples of 25 μHz suggesting that $\delta\nu_0 = 50$ μHz. The asteroseismological luminosity inferred from this agrees with the luminosity determined independently from the parallax.

An interesting new result for the roAp stars is that many of them show frequency variability on a time scale of months to years. This variability appears to be cyclic and has an amplitude similar to that seen in the Sun over the solar cycle of about 0.1 mHz. We have suggested that this may be evidence for magnetic cycles in Ap stars, but that is theoretically difficult to understand, since the Ap stars are rigid rotators without extensive surface convection zones.

The cyclic frequency variability, the seismology, the geometric information contained in the frequencies, the mystery of the pulsation mechanism, the unknown overtone and degree selection mechanisms, the extreme abundance peculiarities, and other properties of the roAp stars make them fascinating subjects to study.

14. Asteroseismology of white dwarf stars (R.E. Nather)

Perhaps the hardest scientific problems to solve are those most scientists believe have already been solved, but which have not. Any model we make of an astronomical process is doomed to be incomplete at some level; the "broad–brush" picture of stellar structure and evolution is often accepted as a solved problem, but in fact many discrepancies exist between our models

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