# OTHER GROUNDBASED OBSERVATIONS

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ABSTRACT

There are still roles to be played for modest ground-based observational programs in these days of big space experiments and ground networks (SOI/MDI, GOLF, VIRGO, GONG). Some of these roles are for niche observations not part of the goals of the big projects or not necessarily done well by them. SOI/MDI will have excellent capabilities to observe short wavelength oscillations. However, it may not be observing long enough to give information about the solar cycle, leaving an opening for programs making synoptic observations of high-degree modes. For similar reasons, long term observations of low-degree modes can also make important contributions. Another area that the big projects may miss is at high temporal frequencies. Another role that modest ground-based programs will play is as a testbed for new techniques and instrumentation. The large programs in general must use proven technologies in a relatively conservative approach. New approaches must first be tried out on a modest scale, to see if they can be useful. If twenty-four hour coverage is required, the South Pole is a good possibility for a testing site. Alaska is another possibility with 19-hour coverage and much easier logistics. Some of the programs have been run for many years and the systematic errors are well understood. It will be advantageous to compare the results of the new experiments with the older ones to look for systematic errors.

Keywords: helioseismology, ground-based, observations.

## 1. THE PROGRAMS

In Table 1 is a list of the ongoing observational programs. As this is a forward-looking review, programs that are no longer observing, such as the Big Bear program and HAO's Fourier Tachometer, are not discussed. Each of the programs will be discussed in turn.

Table 1: The ongoing groundbased observing programs (other than GONG). The first column is an identifier for the program, the second is an organization(s) associated with the project (if the number is small), and the third is the spatial frequency range covered by the program (inter. is short for intermediate). The order is oldest first. BISON is the Birmingham Solar Oscillation Network. IRIS stands for International Research on the Interior of the Sun. POI stands for *P*-Mode Oscillation Imager. HLH is the High-$l$ Helioseismometer. LOWL is the Low Degree instrument. LOI is the Luminosity Oscillations Imager. TON is the Taiwanese Oscillation Network.

| Identifier | Organization | $l$ Range |
|---|---|---|
| BISON network | Univ. of Birmingham | low |
| Low degree obs. | Crimean Observatory | low |
| Low degree obs. | Stanford Univ. | low |
| Tenerife group | IAC | low |
| South Pole | Bartol/NSO/NASA | inter.-high |
| Mt. Wilson | USC/UCLA | inter.-high |
| IRIS network | Univ. of Nice | low |
| POI | Univ. of Hawaii | inter.-high |
| HLH | NSO/NASA | inter.-high |
| LOWL | HAO | low-inter. |
| Ground LOI | ESA | low |
| TON | Univ. of Taiwan | inter.-high |

### 1.1 BISON (Birmingham Solar Oscillation Network)

This, the oldest of observational programs, is currently one the most active (Elsworth *et al* 1995[18]). The Sun is observed in integrated light with a potassium resonance scattering device. The Tenerife site started operation in 1974. Multiple station operation started in 1981 and six stations have been operating since 1992. It is expected to be able to get 70-80% coverage with the current configuration.

This group has been very active scientifically in recent years. Elsworth *et al* 1994[14] found the temporal frequency variation of the solar cycle effect on mode frequencies at low degree. Measurements of rotational splitting of $l = 1, 2$ were extended down to 1.4 mHz (Elsworth *et al* 1995[15]). They find the relatively low value of 440 $\pm$ 10 nHz. Elsworth *et al* 1995[16] measured the separation of the $l = 0/2$ mode pairs. Their results support a model that includes Helium settling in the core. It was confirmed that the strengths of modes are described by $\chi^2$ with two degrees of freedom (Elsworth *et al* 1995[17]).

One of the great triumphs of helioseismic networking is shown in Fig. 1, a small portion of a spectrum of four months of data with 70% coverage. The spectrum shows an $l = 0/2$ pair of modes. The temporal sidebands, not clearly visible, should be present at only the 3% level. In the past it has been relatively difficult to measure the $l = 0/2$ separation because its value is so close to the day-night sideband offset of 11.57 $\mu$Hz. From this figure, it is clear that the separation measurement should not be limited by the sidebands.

### 1.2 Crimean low degree program

In this program, the velocity of a large area near the disk center is subtracted from the signal for the whole disk. Mostly low frequency oscillations are studied, in particular the 160 minute oscillation. The program has been active for more than twenty years (Kotov *et al* 1995[32]).

### 1.3 Stanford low degree program

This program has been active for about twenty years (Scherrer *et al* 1993[49]. Similar to the Crimean program, the difference of a circular area at disk center and an outer annulus is measured. Much effort has been expended to observe the 160-minute oscillation [49] and other low-frequency modes (Henning & Scherrer 1988[27]). The five-minute $p$ modes have also been studied (Henning & Scherrer 1986[26]). The observations are done only in the summer months and are continuing.

### 1.4 Tenerife group

The group at Tenerife of the IAC has used the data from the Tenerife BISON site to study with considerable success a variety of effects detectable in low-degree oscillations. The solar cycle variation of $p$-mode frequencies is seen clearly in their data (Régulo *et al* 1994[42],

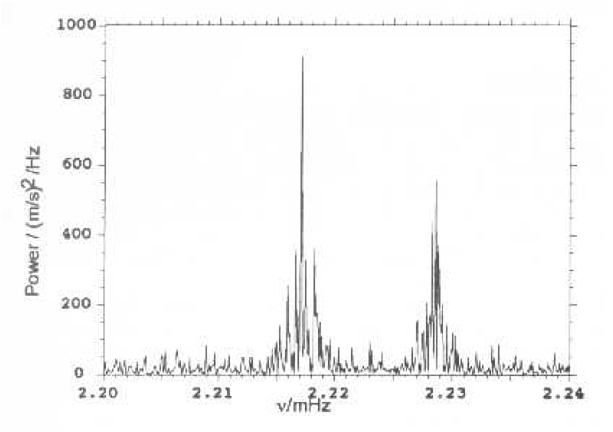


Figure 1: An $l = 0/2$ pair of modes. From Elsworth *et al* 1995[16].

Pallé *et al* 1995[37]). Pallé *et al* 1995[38] have found the background velocity spectrum to vary over the solar cycle, with most of the spectrum being higher near sunspot maximum. Weak evidence for a changing core rotation with the solar cycle has been found (Jiménez *et al* 1995[30]).

In addition to studying the single site BISON data, this group uses other data obtained at Tenerife. Some modes with odd $l+m$ have been observed with a new spectrometer (Eff-Darwich *et al* 1995[19]). Pallé *et al* 1993[36] have developed a calibration procedure for the IRIS data. With the installation of a GONG instrument on Tenerife, this group is also starting to do imaging helioseismology (Patrón *et al* 1995[40]), in which ring diagrams are measured to look for subsurface flows.

### 1.5 South Pole

Of course, one of the ways to remove the deleterious effects of the day-night cycle is to observe in polar regions and this has been the method of the Bartol/NSO/NASA collaboration. Five expeditions to the Antarctic (1981-2, 1987, 1988, 1990-1, 1994-5) with instruments with increasing spatial and temporal nyquist frequencies have produced some data. The oscillations have been observed in the $Ca^+$ K-line.

The spectra from these observations are relatively clean compared with velocity observations from a single site at mid-latitudes, both because of the high temporal coverage with random gaps and the ability to see the oscillations closer to the limb leading to greater spatial mode resolution. This has led to some of the narrowest line width measurements to date (Jefferies *et al* 1991[28]) and to the first measurements of power spectral line asymmetry (Duvall *et al* 1993[11]). The use of the brightness signal of the $Ca^+$ K-line has made observing at high temporal frequency very fruitful (Duvall *et al* 1991[10], Kumar *et al* 1994[33]). It also made possible the detection of the 3-min chromospheric oscillations as a feature in the power spectrum background (Harvey *et al* 1993[24]).

A three-day sequence with very good coverage was analyzed by Braun *et al* 1992[6] to measure phase shifts of waves traveling outward from a sunspot relative to inward waves. This particular sequence was also used for the first detection of mode-coupling by a sunspot (Braun 1995[7]). Although it could have been discovered in anyone's imaging data, the initial studies of time-distance helioseismology were done with South Pole data (Duvall *et al* 1993[12], Jefferies *et al* 1994[29], Duvall 1995[13]).

### 1.6 Mt. Wilson program

The Mt. Wilson program has been running since 1984 with spatial resolution increasing over the years from a 256x256 detector to 1000x1000. The oscillations are observed in velocity using a magneto-optical filter in the sodium line.

This program has plenty of data to contribute significantly to the study of the solar cycle variations of $p$-mode frequencies (Rhodes *et al* 1993[43], Rhodes *et al* 1995[44]). For the intermediate degrees, they have found variations in agreement with the Big Bear results. At higher degrees, they are breaking new ground with apparent changes opposite in sense to the intermediate degree results[44]. The sense of the 3 mHz, low and intermediate degree solar cycle effect is for increased solar activity to cause increases in mode frequencies. The opposite effect at high degrees is in the same sense as the effect found at high (5.4 mHz) temporal frequencies by Ronan *et al* 1994[48].

Internal rotation has also been studied extensively with the Mt. Wilson data (Korzennik *et al* 1995[31]). Because of the higher degrees included in the rotation inversions, it is possible to carry out the inversions closer to the surface than most other attempts. In addition to the straight helioseimic observations, there are also other observations at the Mt. Wilson 150 foot tower that are relevant. Ulrich *et al* 1993[55] have used line profile measurements to model the effect of active regions on integrated sunlight oscillation measurements. Henney and Ulrich 1995[25] are developing a technique to use Mt. Wilson magnetograms to determine the image orientation of the SOI/MDI images on SOHO.

There are plans to install two more instruments to make a three-station network. These instruments would be at the Crimean Observatory and in Kazakhstan. This is a new network for studying intermediate and high degree modes (Rhodes *et al* 1995[45]). They hope to be running before the end of 1995.

### 1.7 IRIS network

The IRIS (International Research on the Interior of the Sun) network is based on observations of integrated light using a sodium cell optical resonance spectrophotometer. There are instruments at six sites around the globe. Data was obtained with pretty good coverage for four month intervals in the years 1990, 1991, and 1992. The status of the network was summarized recently by Fossat 1995[21]. There have been a series of IRIS workshops with published proceedings (*e.g.* Gough and Roxburgh, 1994[22]). Some data calibration issues have been examined by Pallé *et al* 1993[36]. Some interesting approaches to minimize the effect of the remaining gaps and to combine the multi-station data optimally are being developed (Pantel and Fossat 1995[39]. The possibility of a rapidly rotating core is still present from IRIS rotation results (Loudagh *et al* 1993[35], Fossat *et al* 1995[20]).

### 1.8 POI (P-mode Oscillation Imager)

The POI is an imaging system observing the $Ca^+$ K-line. It is normally used on Haleakala but was taken to Alaska for two observing seasons during the long days of Arctic summer. The use of Alaska as an observing site was described by LaBonte *et al* 1995[34]. It does seem possible to get good coverage during May-June at the Fort Yukon site. Intermediate degree $p$-mode splittings near solar maximum were analyzed by Ronan & LaBonte 1994[47]. The ability of the $Ca^+$ K-line observations to readily observe the high temporal frequencies was exploited by Ronan & LaBonte 1993[46]. They were able to observe the frequencies of features above the acoustic cutoff frequency up to 9 mHz. The first measurements of solar cycle variation at high temporal frequency were reported by Ronan *et al* 1994[48]. By comparing with South Pole data from lower solar activity, they found a large decrease in mode frequency ($\sim 10\mu$Hz) near the peak of the acoustic frequency (5.4 mHz) associated with high solar activity. Observations are continuing in this program.

### 1.9 High-$l$ helioseismometer (HLH)

This is an instrument that was used at the South Pole during the 1990-1 and 1994-5 observing seasons. It was installed on Kitt Peak with some additional guiding equipment to make long term observations of high degree frequencies and to study local helioseismology. Because of the large quantities of data involved, it was decided to normally observe only 4-5 days per month except for special campaigns. Observations began in March 1993. There was a special campaign in June 1994 in which almost one month of data was obtained. A sequence of four clear days (June 1993) has been studied in detail to make measurements of the mode frequencies and get limits on systematic errors (Bachmann *et al* 1995[4], [5]). This data is also being used to obtain ring diagrams (Haber *et al* 1995[23]).

### 1.10 LOWL program

The LOWL program uses an instrument optimized to measure the oscillations of low degree with imaging. A potassium magneto-optical filter is used and both wings of the line are observed simultaneously. That such an instrument from a single site could contribute significantly to our knowledge of the deep interior was argued by Veitzer *et al* 1993[56]. In principle, an imaging instrument has the advantage of being able to cleanly separate the prograde and retrograde modes, in contrast to the integrated sunlight measurements which do not. In order to take advantage of this, however, requires that the instrument be extremely stable, as stable as the integrated sunlight instruments. The initial spectra suggest that the instrument is very stable (Tomczyk 1995[52]). The instrument has been described by Tomczyk *et al* 1995[53].

Some very encouraging initial rotation results were presented by Schou & Tomczyk 1995[50]. Inversions that determine the rotation down to 0.2 $R_\odot$with an uncertainty of 5% were presented by Tomczyk *et al* 1995[54]. The plan is to observe with this instrument as long as it is useful. Observations began in Feb. 1994 and continue each day.

### 1.11 Ground LOI instrument

The LOI (Luminosity Oscillations Imager) is a part of the VIRGO instrument to fly aboard the SOHO spacecraft. It will observe a low-resolution image of the Sun and make oscillation measurements from the brightness signal for $l < 7$. The Qualification Model of the instrument has been installed at Tenerife and began observations in May 1994. The idea for the instrument was first discussed by Andersen *et al* 1988[1] and some details of the design by Appourchaux and Andersen 1990[2]. Rotational splittings and mean frequencies for $l = 2 - 5$ for the first 163 days of observations were presented by Appourchaux *et al* 1995[3]. Their results would seem to imply a core rotating at approximately the surface rate.

### 1.12 TON (Taiwanese Oscillation Network)

The TON currently has three instruments around the globe and has plans for six. The instruments observe the $Ca^+$ K-line with a large format CCD (image diameter 1000 pixels) with considerable similarity to the POI and HLH instruments. The current state of TON was summarized recently by Chou *et al* 1995[8]. Continuing observations with the three-site network began in October 1994. It is planned to study structure, rotation, sunspot helioseismology, local helioseismology, and ring-diagram analysis.

## 2. CONCLUSIONS

The impression one gets from the previous section is of a very active, vital field of study which is still expanding rapidly. And of course, the big projects were not even discussed.

Three new programs started observations during 1994 (LOWL, ground LOI, and TON). The standards for a new program are very high. The first results from the ground LOI covered a 163-day interval and included detailed analyses of mode frequencies and rotational splittings (Appourchaux *et al* 1995[3]). This might be compared with the first reported intermediate-degree mode frequencies (Duvall & Harvey 1983[9]), which used just four days of observation. The first results from the LOWL included rotational inversions of three months of data (Tomczyk *et al* 1995[54]). On the other hand, some aspects of starting a new program are much easier, *e.g.* a sophisticated analysis package (GRASP) is available from the GONG project (Pintar *et al* 1988[41]). GRASP is being used by the TON to do some of its data analysis (Chou *et al* 1995[8]).

Where are these programs most likely to make their greatest contributions in coming years? It would seem most likely that the long term study of the connection of solar activity to the oscillations at low and high degrees will be one area. Another area is at high temporal frequencies. It is clear that with all the effort going into these programs (and the big ones) that there will be plenty of data for all to analyze in coming years.

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