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THE SPACE BONUS

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ABSTRACT We will discuss the opportunities opened by space experiments to make measurements that cannot - or only marginally - be made from ground.

THE ADVANTAGES OF SPACE EXPERIMENTS

- Time base of uninterrupted data sets
- Uninterrupted data sets
- No atmospheric noise
- Thermal and noise stability
- Unlimited Access to electromagnetic spectrum
- Experimental science (comet probes, planetary explorer missions, etc.)
- Microgravity

From the list above the first four are particularly important for high quality asteroseismic data. The time base of a data set, expressed for example as number of observed cycles, determines the frequency resolution. For ground based observations, this time base is frequently limited by day/night cycles, and changing seasons. Properly chosen orbits allow a space borne experiment to overcame these limits almost entirely.

Figure 1 illustrates the influence of the time base on the frequency resolution for the pulsating CP2 star HR 1217. A frequency analysis of photometric data (Kurtz et al., 1989), indicates that HR 1217 probably pulsates with at least 6 frequencies. There is strong evidence that rotational side lobes have also been observed. These 21 frequencies (presented in Figure 10 of their paper) were used to compute synthetic data which cover different number of cycles. The corresponding frequency spectra are presented in the insert of our Figure 1. The main figure presents an exanded view of the spectrum, centered on the group of frequencies around 229.3 c/d (2.65 mHz). At least 20000 cycles have to be observed for a full frequency resolution which is determined by $\Delta\nu \approx 1/(P \cdot n)$, where P is the pulsation period and n the number of continuously observed cycles. As we have learned in this conference, frequency resolutions of the order of a μHz are needed to answer certain questions concerning the structure and evolution of stars. Very long and homogeneous data sets, spanning up to several years, are required to achieve this extreme high resolution in frequency.

But it is not enough to obtain a long time strings. Gaps in the data cause a problem for the interpolation of harmonic functions, because the number of cycles which have not been observed can only be estimated. Hence, harmonic functions with different frequencies can be fitted equally well through the same data set.

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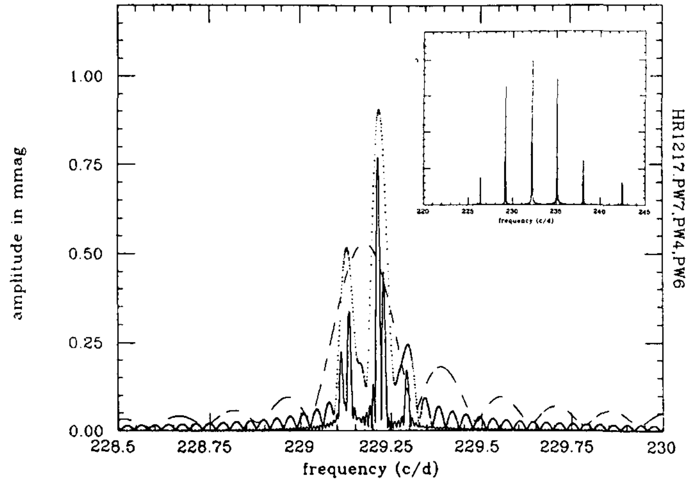

Figure 1: Increasing frequency reolution for data sets with 1500 (dashed line), 6000 (dotted line) and 25000 (full line) cycles.

The spectral window, also called window function, is usually presented to illustrate this ambiguity of frequency solutions, called aliasing. Figure 2 gives an example for spectral windows as a function of the duty cycle. The simulations are based on noise free data of one sinusoidal cycle. Obviously, a duty cycle close to 100% is desirable in order to eliminate ambiguities in the identification of intrinsic frequencies.

The aliasing problem due to the day/night cycle is very disturbing for ground based observations. The only way out of this problem is to observe the target star from

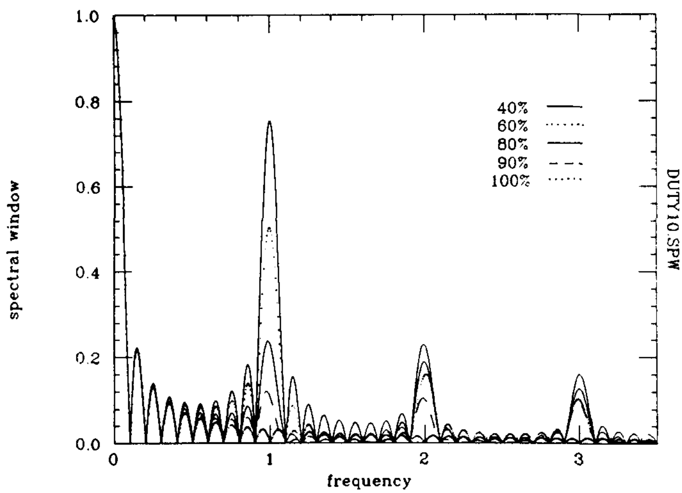

Figure 2: Spectral window for one period as a function of the duty cycle.

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several sites well distributed at various longitudes. There are many difficulties merging data obtained from such international observatory campaigns, including differences in instrumentation and climate. Space borne experiments can be freed from such limitations.

Last, but not least, space experiments do not suffer scintillation noise from the terrestrial atmosphere which usually is the dominant source of noise in recent network data. This noise is well described by a formula given by Young (1967),

$$\sigma_{atm} = 0.08 \cdot D^{-2/3} \cdot X^{1.8} \cdot e^{-h/2000} \cdot t^{\cdot}$$

with the telescope aperture D in cm, sealevel of the observatory h in m, the air mass X and the integration time t (in seconds).

It is a simple exercise to estimate the stellar magnitude for a give telescope where scintillation and photon noise for a ground based observatory network equals the photon noise of a particular space borne photometric instrument. Such a diagram is given in Figure 3. The inclined bold line indicates the magnitude range where a 40 cm space borne telescope (the case of the Large Photometer of PRISMA) gives better photometric data than a network of at least six telescopes, distributed in longitude and which have an aperture of 10 meters, whereas the horizontal bold line indicates the magnitude range for which such a telescope network would give the needed accuracy in less time than the space borne photometer. The basis for figure 3 is a noise level of $\sigma = 10^{-6}$ (right hand side ordinate) and $5 \cdot 10^{-7}$ (left hand side ordinate) in the power spectrum for a star with magnitude *mag(V)* and observed with 100% duty cycle.

For the fainter stars observed by the Large Photometer of PRISMA, the noise level of 10^{-6} (due to photon noise in this case) is achieved in about 30 days. It would need a continuously working 10 m telescope network in order to reduce the scintillation noise to the same level, which would be the dominating noise source for ground based observations. If frequencies have to be determined with comparable accuracy, but in a shorter time (for example to investigate the damping mechanism of modes or to prove chaotic excitation) a dedicated ground based network of 50 m diameter telescopes, or even larger, would be needed to perform the job which PRISMA can do with a 40 cm aperture.

We can conclude that asteroseismic data of phenomena which have to be studied in time scales of weeks and with a precision of 10^{-6} or better cannot be obtained from ground and are therefor a domain of space experiments.

The last properties of space experiments listed at the beginning do not need detailed discussion. Stellar astrophysisists are presently not in the position of having the possibility to perform *hands-on* experiments with stars, contrary to planetary system scientists who have successfully sent a probe to planets, comets and who are doing experiments with the interplanetary medium.

Microgravity experiments may bring important insights in the near future to fundamental physics and hence also to astrophysics. I refer in this context to various space experiments under consideration which are designed to prove far more precisely the validity of the equvivalence principle of the General Relativity Theory than has been possible until now. Another benefit from the microgravity environment in space can come for astrophysics when very larger instruments have to be deployed which would be impossible, or extremely expensive to build on ground (large radio telescopes, interferometers, gravitational wave detectors, e.g.).

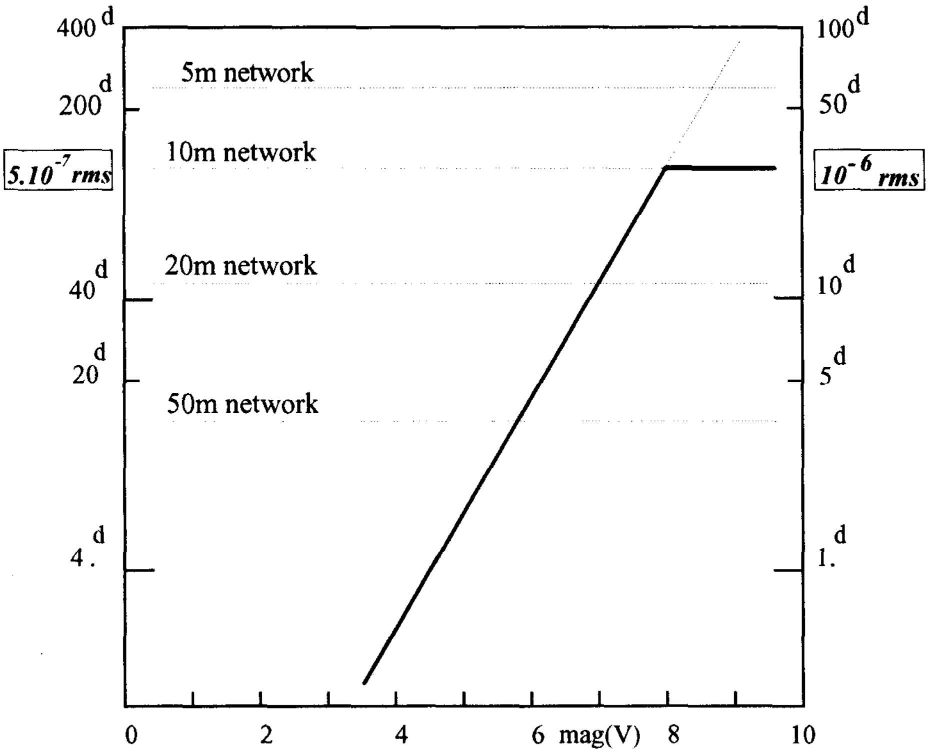

Figure 3: Comparison of a space borne 40 cm photometric telescope with ground based telescope networks in the 10 m size class.

The last aspect of space experiments listed here has been already widely used in the past by the astrophyiscs community. There is no need to dwell more on the enormous amount of new scientific insights which has been gained from this side. The investigation of stellar activities located in various optical depths cannot be done without having access to the UV and X-ray region of the electromagnetic spectrum (see also C. Catala, this volume).

ASTEROSEISMOLOGY FROM SPACE

EVRIS will be the first true space experiment devoted to asteroseismology and is described in this volume (Baglin et al., 1992). During the cruise phase of nearly 300 days on the MARS-94 space probe, EVRIS will continuously monitor about 15 bright target stars with a single-channel photometer. A photon statistics limited noise level of few 10^{-6} will allow astroseismic investigations of solar type stars for the first time. But, as described by Baglin et al. (1992, op. cit.), stars other than of solar type will also be observed.

A considerably larger and more sophisticated instrument, PRISMA, will benefit from the experience gained from EVRIS and will push the limits of observational astrophysics even further. In addition to the unique possibilities for asteroseismology, PRISMA will simultaneously monitor stellar activities by spectrometric and photometric means, from the optical to the near XUV spectral region. PRISMA is descibed also in this volume (Appourchaux et al., 1992).

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Appendix:

Cost estimate for building a dedicated network of six identical 10 m telescopes, of which four telescopes can be set up at already existing sites, where for two other telescopes such sites will have to be developed. The estimate is based on discussions with M. Tarenghi and on published data.

The cost for building one 8m telescope for KPNO was estimated to about 70 M$, one additonal copy for CTIO would cost 60 M$ (NOAO newsletter). The cost for the first Keck 10m telescope was about 93 M$, the estimate for the copy is the same (Physics Today). The Japanese 7.5m telescope will cost about 300 M$, but this instrument is fully developed and built by industries.

No.	item	M $
1	6x10 telescopes (including duplication bonus)	500
2	Headquater building, hardware	5
3	HQ salaries per year	16
4	HQ expenses per year	16
5	development of 2 new sites	40
6	6 sites, installation	180
7	sites, operation per year (10-15 people per site for installation during 2 years, 6-8 peoples to run each site)	60
8	Detector development (2 per telescopes)	20

To set up a working observatory network at six excellent sites will therefor cost about 745 M$ (budget items 1, 2, 5, 6, 8). The costs to run this network for two years can be estimated to 184 M$ (items 3, 4, 7).

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