PROSPECT FOR STELLAR SEISMOLOGY ON BOARD AN INTERPLANETARY SPACECRAFT

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ABSTRACT. We describe a stellar seismology photometric experiment which we have proposed to embark on-board the interplanetary vehicles belonging to the VESTA mission (France - USSR mission towards Mars and the asteroids belt, to be launched about 1994). The objective is to use the cruise time to obtain long, uninterrupted observations of the white light fluctuations in a few late-type stars, with a view to the detection of global non-radial modes at the level 10^{-5} to 10^{-6} mag. We have performed a design-study of the instrumentation, formed by a 5 cm spherical collector, working in two spectral bands 1500 A wide, with two photomultipliers as detectors. Advantages and difficulties of the system are briefly discussed.

1. WHY STELLAR SEISMOLOGY FROM SPACE ?

Stellar seismology observations performed with ground-based instruments suffer from several limitations : (i) If one measures Doppler velocity fluctuations, limits are imposed by photon noise, therefore by the size of the collectors (Fossat, 1984), and by the broadening of lines due to the rotation velocity of stars (Mangeney

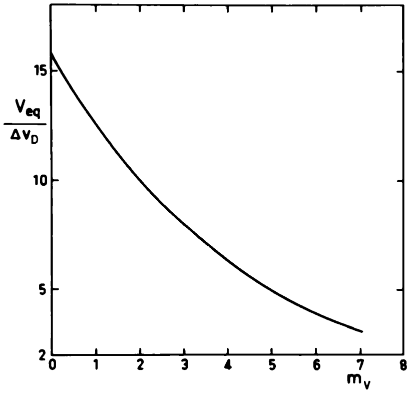

Fig. 1. Doppler shift fluctuations : critical equatorial velocity such that 1 month observing time is requested with a 1 m telescope, $\lambda / \Delta\lambda = 10^5$, to reach $\delta V_{rms} = 10$ cm s^{-1} on a solar type star (we used P. Connes,1985, estimates of the performances for an optimized absolute accelerometer). The graph gives $V_{eq}/\Delta v_D$ versus visual magnitude m_V, with Δv_D = Doppler width of the line.

J. Christensen-Dalsgaard and S. Frandsen (eds.), Advances in Helio- and Asteroseismology, 549–553.

and Praderie, 1984, and Fig. 1). (ii) Intensity fluctuations in narrow spectral bands, such as the Ca II K line emission are potentially a better tool (Noyes et al., 1984 ; but also see Harvey, this volume). This type of measure is however restricted to solar-type stars. (iii) Observations of intensity fluctuations in white light are hampered mainly by variations in the earth atmosphere transparency (Deubner and Isserstedt, 1983 ; Fossat, 1984). Photometric observations from space are clearly unaffected by this effect and appear to be the only practical way to detect oscillations in stars with a large variety of rotation rates and without restrictions to solar-type stars.
In what follows we describe a project for a test experiment, which is characterised by its small scale and lack of instrumental sophistication.

2. A PROPOSED EXPERIMENT ON AN INTERPLANETARY SPACECRAFT

The goal is to detect coherent global oscillations with white light amplitudes as low as 10^{-5} to 10^{-6} mag. That this level is the one to seek is ascertained by the SMM satellite irradiance measurements of the sun performed by Woodard and Hudson (1983).
The concept for the experiment proposed is presented in Fig. 2. The instrumentation comprises two subsystems :
- A photometric subsystem including an off-axis 5 cm diameter spherical mirror (f = 25 cm). A reflecting diaphragm is located in the focal plane, with a hole of diameter d and the possibility of measuring the parasitic signal due to the varying background created by weak neighbouring stars entering or leaving the field due to pointing variations. A Fabry mirror forms the image of the entrance pupil on two detectors through a dichroic filter. The two detectors (PMT) detect two wide band (1500 A) spectral ranges.
- An internal pointing subsystem, coaligned with the main photometric device, and with a multi-anode PMT as a detector.

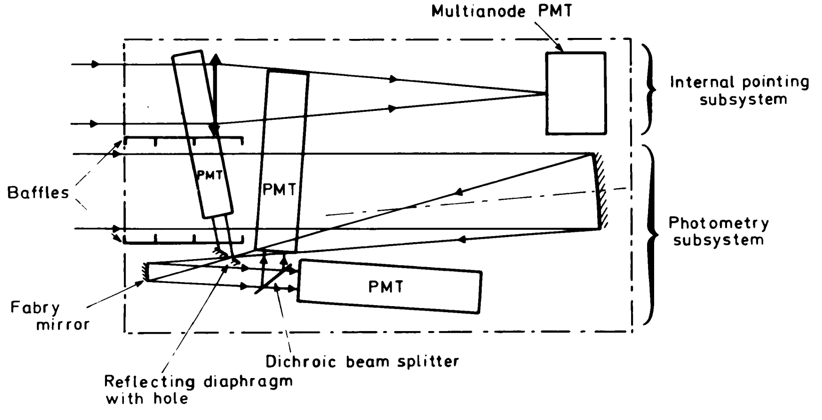

Fig. 2. Design of the seismology experiment.

The proposed instrumentation is adapted to the vehicles which are destined carry it, namely those belonging to VESTA, a dual interplanetary space mission going to planet Mars in 9 months, then to the asteroid belt in 4-5 years. Long observing sequences are possible during the cruise phase of the mission, providing at the same time the temporal resolution requested (better than 0.1 μHz) and the final photometric precision (due to photon statistics).
Typical observing times necessary to detect oscillations with a noise level of 10^{-6} mag for stars of magnitude V are given in Fig. 3.
Since not much room is available for this experiment on spacecrafts with other major scientific objectives, the proposed telescope is small, hence the test experiment will be limited to the observation of a few bright stars.
Since the pointing of the spacecraft is insufficient (± 1°), we need to compensate by an internal sensor and an actuator, to acquire a precision better than 0°.1 in two axes.

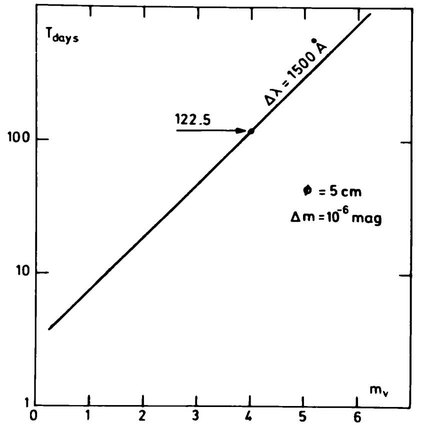

Fig. 3. Exposure time needed to reach a photon-noise of 10^{-6} mag with a device such as shown in Fig. 2, versus the visual magnitude of the star m_V.

3. IMPORTANT REMARKS

In order to reach the photon noise level on the stellar signal, we need :
- A perfect control of the PMT's and of the acquisition electronics.
A maquette built in Meudon (a stable fluorescent radioactive source + 2 PMT's working in photon counting mode) has been studied for continuous periods of time allowing in principle to obtain the photon noise limit ($N=10^{-6}$ cts/sec, T ~ 10 days).
Then a weak modulated signal (LED) was superimposed over the main source signal (amplitude 10^{-4}). See feature A on Fig. 4.
To calibrate the noise level, a numerical sine wave signal is introduced in the data treatment. See feature B on Fig. 4.
The noise power is ~ 10^{-3} after 5 days, which allows a 3 σ detection of 2.5 10^{-6} mag.
- A control of the main stellar signal contamination by faint stars entering the diaphragm in focal plane (Fig. 2).
The size of the diaphragm is determined by the aberration image (± 2' for the chosen optics) and by the pointing stability (± 6' is

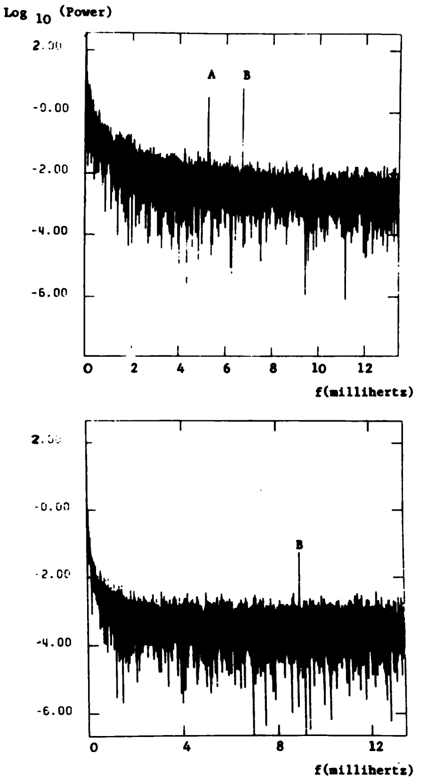

Fig. 4. Power spectrum of the counts/sec measured by a photomultiplier looking at a strongly attenuated radioactive source. a) In the upper panel the light coming from a modulated "LED" has been added with a relative amplitude ~ 10^{-4} mag (peak A); a numerical sinusoidal signal of amplitude 10^{-5} has been added to the total experimental signal for purpose of calibration (peak B), with a relative amplitude of 2.5 10^{-4} mag. b) In the lower panel, same as above but without the "LED"; the numerical signal has a relative amplitude of 2.5 10^{-5} mag (peak B). The total duration of the experiment was T ~ 5 days and the average count rate ~ 10^6 counts/sec.

expected, in the worse case). Therefore the diameter d=16' in the present design.

Because of this, the stellar signal will be modulated with harmonics of the depointing frequency. The parasitic signal will depend on the crowding of the 16' field, hence of the galactic latitude b of the field observed.

We first choose fields containing one bright star with $3 < V < 4$ and no weak stars with $V < 12$ in ± 8'.

An analytical estimate of the contamination effect of stars weaker than V = 12 gives the results presented in Table I.

TABLE I
Relative contribution of background stars referred to a target with V = 4, as a function of galactic latitude (with density of stars per sq. degree taken from Allen 1983).

V of Background stars	Galactic Latitude b = 0°	b = 90°
12	10^{-4}	10^{-5}
14	10^{-4}	7 10^{-6}
16	9 10^{-5}	4 10^{-6}

https://doi.org/10.1017/S0074180900158681 Published online by Cambridge University Press

This estimate was done assuming optics yielding a uniform field. One solution consists in using optics which degrade the image quality on the edges of the diaphragm (this solution has not yet been studied). For such a test experiment, it is very critical that : (i) The internal pointing is improved, and (ii) Targets near the galactic pole are observed.

4. HOW MANY STARS TO OBSERVE ?

We performed a systematic search for fields comprising only one bright ($3 < V < 4$) F, G or K star with the following prescriptions :
- No other bright ($V < 4$) star at less than $\pm 2°$.
- No star $V < 12$ in $\pm 8'$ around the bright target.
- $|b| > 45°$.

It follows that only a few fields are possible.
The VESTA mission is under USSR-FRANCE study. In the typical payload, a stellar seismology experiment is considered. It would fly in double, on each of the soviet vehicles going to Mars. In 9 months, at least 4 stars can be observed.

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