ABSOLUTE ASTRONOMICAL ACCELEROMETRY : A NEW TOOL FOR PLANETARY SEARCHING

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ABSTRACT. Absolute astronomical accelerometry is a new proposed technique specifically optimized to detect small radial velocity changes (i.e. accelerations) of either the Sun or a star ; it is intended for the two problems of stellar seismology and the search for extrasolar planetary systems. In both cases the computed performance is such that positive results should be obtainable in a large number of cases with a moderate size telescope. Essentially the method involves two separate and simultaneous servo loops. In the first a variable path-difference Fabry-Perot interferometer is adjusted so that its bandpasses track the fluctuations of the lines in the stellar spectrum. Then a tunable laser tracks the fluctuations of the FP and one has only to measure the beat frequency from a stabilized laser. The result is absolute i.e. obtained solely in terms of frequencies and the speed of light. All instrumental or spectral characteristics drop out ; no calibration is required. Furthermore the method can be demonstrated to approach closely a so far never computed photon noise limit for radial velocities.

I. INTRODUCTION

Our personal interest in SETI has produced two different but related ouputs. As a week-end activity, we have put into writing some speculations about the cause of the so-called "Great Silence" [1]. Such an undertaking not being enough to keep the scientific pot boiling, the rest of the week was devoted to the more down to earth problem of extrasolar planetary detection. The first proposed solution [2] was a ground-based astrometric system. As far as we know this is the only technique which is fully optimized for this specific problem : the directly measured quantity is the stellar motion itself, and no sky mapping is involved ; unlike in the HIPPARCOS or MAP [3] cases one does not have to measure the star position. Parallaxes are also measurable, relative to either faint stars or galaxies themselves. However HIPPARCOS (which is not relevant to

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extrasolar planet detection because of too short lifetime) will be able to produce far more numerous parallaxes (but not more accurate ones) and, partly as a consequence, our proposal has not been supported at all.

The second approach has been through spectroscopic detection. A dedicated and optimized spectrometer was proposed [4] ; this was based on the principle of the FELLGETT "Radial Velocity Photometer" [5] . No support was found either ; however an essentially similar and almost completed device has just been described [6] ; it is intended indeed for planetary searching.

While the FELLGETT principle did lead to the most efficient RV measuring devices as far as basic photon counting limitations go, their weak point remained systematic errors : these are normally quite large in any grating based system. This deficiency has been the main motivation behind the construction of FABRY-PEROT interferometer systems, e.g. the SERKOWSKI [7] planetary search instrument. There is good hope that in this case systematic errors will be lower indeed, but the photon-noise velocity error (even the merely anticipated one) is distinctly above the already achieved figure for CORAVEL [8] (the most efficient version of the FELLGETT device).

II. DESCRIPTION OF PROPOSAL

In the present paper a new proposal is made, which clearly obsoletes the 6 years old one [4] , while re-using many of the results. Only a very brief description is intended, since a complete one will be found elsewhere [9] , and a summary one in [10] . The new proposal promises on the one hand a large fully computable gain in sensitivity (i.e. reduction of photon-count RMS velocity error), and on the other raises the hope of an important reduction of systematic errors, because of the novel absolute principle of measurement involved. The same principle, christened Absolute Astronomical Accelerometry, leads to two separate instruments. The first is the solar accelerometer, which makes use of a single preselected solar line ; it is relatively simple and inexpensive, hence likely to be tested first, but since it is not relevant to the extrasolar planetary problem, it will not be described here. The second one, or stellar accelerometer, makes use of the entire spectrum across a broad spectral range. As we shall see, its sensitivity comes close to being optimal ; it is high enough to permit the detection of solar-type oscillations on a large number of stars, even with a small telescope. Since helioseismology has been a rapidly expanding field over the last few years, there is presently much interest in getting the same type of information on stars ; hence our stellar accelerometer is aimed not only at the planetary search market, but also at the potential one of stellar seismology.

A large coudé-type spectrograph with an image detector (e.g. a CCD), and making use of crossed dispersion, receives alternately the stellar beam from the telescope, and that from a laboratory white light source which has passed through a variable path difference FP interferometer ; only small variations are needed, such as can be implemented with piezoelectric drives for instance. The CCD output goes straight into a microcomputer, and complete symetry is preserved in the handling of the two spectra ; the one difference is that only a small fraction of the commutator cycle is spent observing the laboratory source, since far more photons are available. We consider two successive observing epochs T_1 and T_2 . Stellar radial velocity has changed from V_1 to V_2, and any spectral feature primarily at wavenumber σ_1 has been shifted by $\delta\sigma_S = \sigma_1 (V_2 - V_1) / c$ Simultaneously, the FP spacing has been changed from t_1 to t_2 , and any feature appearing at the same σ_1 has been shifted by $\delta \sigma_F = \sigma_1 (t_2 - t_1) / t_1$. While the two spectra (stellar and interferometric) are totally unlike each other, these shifts can be made to match precisely, even across a broad spectral range. Then the computer performs two identical and separate operations upon the two spectra ; by comparing the two stellar recordings at T_1 and T_2 on the one hand, and the two recordings from the interferometer beam on the other, two signals respectively proportional to $\delta\sigma_F$ and to $\delta\sigma_S$ are produced ; their difference is used as an error signal, fed back to the interferometer, and cancels. Hence this first servo loop means that from now on the FP bandpasses will track the stellar lines. We note that this has been achieved without passing the stellar light through the interferometer, which would have been harmful since the broad band efficiency of any FP interferometer is at best equal to the inverse of the finesse.

A second and independant servo loop has been simultaneously operating. A tunable laser beam passes through the interferometer and falls on a separate receiver ; a second error signal is generated and fed back to the laser ; then the laser line tracks the corresponding FP bandpass. At this stage a problem in the realm of incoherent optics (measuring Doppler shifts from a broad band source) has been transferred into that of coherent optics. The rest is easy : one mixes the laser beam with that of a stabilized laser, generates beats and measures the beat frequency. All the second loop and beat generation part of the proposal is standard laser technology. The final result is $V_2 - V_1 = c\ (\Delta N_2 - \Delta N_1) / (N_0 + \Delta N_2)$ where ΔN_1 , ΔN_2 are the beat frequencies at T_1 and T_2 (the sole output from the experiment), and N_o the stabilized laser frequency.

Altogether we have performed a measurement of the velocity change $V_2 - V_1$, but we are unable to get either V_2 or V_1 : the device is truly an accelerometer. Furthermore it is an absolute one : all instrumental or spectral characteristics have dropped out ; the result is independant of line profiles or positions, FP spacing or adjustment errors, of spectrometer resolution, instrumental line shape, distortions within the field etc... (all of these factors affect the two spectra in precisely identical fashion). Unlike in the standard procedure where one uses a FP channeled spectrum to calibrate the field of a grating spectrometer, here we do not have to measure line positions and not even line shifts : the entire (spectrometer-CCD-computer) system operates merely as a null checking device.

A separate and remarkable property of the system is that it can be demonstrated to approach closely a so far never computed limit to the sensitivity of all RV measurements when basic photon count considerations are brought in. The derivation is straightforward : one merely considers that any infinitesimal slice $d\sigma$ in the stellar spectrum does provide an elementary RV measurement ; then one optimally weighs all of them and compounds the results through integration over a wide spectral range. With a 1 m telescope, and 1 h of integration, using available CCD detectors and a fully studied spectrometer, the photon noise limit gives $\Delta V_{RMS} = 1$ m/s for a $m_V = 10$ solar type star. Detector noise is negligible up to at least $m_V = 7$; hence both stellar seismology and planetary detection become feasible for a large number of stars.

Hence the main feature of the technique is that it does combine the high sensitivity arising from near optimal use of the available photon flux with the high precision we may expect from the absolute principle of measurement involved ; however, while the first point has been fully demonstrated (in [9]), the second can only be established by actual experiments, and no figure for the residual systematic errors should be given now. There is yet another advantage, highly relevant to planetary searching. An often-voiced objection to the spectroscopic method of planetary detection is that slow quasi-periodic changes in the stellar atmosphere may masquerade as stellar CG motions. However the objection is still not based on any actual observations ; even for the Sun such a phenomenon is not known because we do not have adequate accuracy measurements of line motions over long periods of time (our solar accelerometer would be particularly appropriate to the problem). As seen with our stellar accelerometer the situation will be as follows. Should the putative stellar atmosphere motions induce solely a wholesale and uniform Doppler shift of all spectral lines together, there is clearly nothing we can do about it : we cannot separate the result from planetary action. However such a clear cut situation is relatively unlikely ; actual changes will more probably affect also line intensities and profiles, and also differ for different classes of lines. Since our device measures the full spectrum at all epochs, all these fluctuations are automatically recorded and preserved for a posteriori analysis. We may hope that in this way any long period term may be ultimately attributed either to stellar effects or to the presence of a planet. Such a separation is not possible with any device using only one line or a small spectral range, nor indeed with the FELLGETT correlation meter which does make use of all lines in a broad range, but has only one detector, hence a single ouput information channel.

We believe that the combination of these three advantages implies that successful spectroscopic detection of planets becomes more likely. Moreover, the great astrophysical importance of stellar seismology means that a near optimal technique specifically tailored to accelerations such as ours purports to be, will have to be tried sooner or later ; this seems unavoidable. Then, serendipitous planetary discovery may come as a consequence.

III. CONCLUSION

The present Conference shows some paucity of efforts in the planetary search field compared to that of SETI. One notices the absence of reports on either actual performance or ultimate limitations of the few methods being presently tried. This is particularly true of the greatest instrumental wonder of the age : the Space Telescope, now frequently touted as the possible solution both for direct detection, through the faint object camera, and astrometric detection through the guiding system. This situation must be contrasted with the effort and ingenuity going into SETI. The wide band radio analysers under development are technologically brilliant ; they may well prove useful to radio astronomy or even to altogether different sciences. Will they detect intelligent life indeed ? We suspect they may do nothing of the kind because of some naivety in the underlying assupmtions, which are much too heavily biased by our available technology ; we have tried to argue that point in [1] . Let us then stress the importance of a balanced program, so far sorely lacking. Why is planetary searching rather neglected ? Admittedly, the problem is an ancient one, and has been talked about for too long without any clear results ; which only means that technology has been so far inadequate. But that may well be no longer true ; the precision increases required (at least for the astrometric/spectroscopic indirect methods) are relatively modest. And, unless present astrophysical thinking is grossly wrong, those planets are lying there, just waiting to be detected. Which is more than anyone can say about ETI.

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