ASSISTING EXTRASOLAR PLANETARY DETECTION THROUGH THE DETERMINATION OF STELLAR SPACE ORIENTATIONS

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ABSTRACT. Various methods outlined for indirect planetary detection would greatly benefit (in some cases require) the determination of the planetary orbital plane, which is theoretically equivalent to the stellar equatorial plane. Determining the stellar space orientation, therefore, would greatly benefit extrasolar planetary detection.

We utilize stellar rotation periods determined from short-term variations in CaII H&K sunspot emission combined with both stellar radii measurements and Doppler broadened spectral line profiles to get the stellar inclination to the line of sight.

The clocklike, on the plane-of-the-sky component determination utilizes the concentration of sunspot associated plage areas at central stellar latitudes when viewed in CaII H or K emission. One can perform CaII H&K emission speckle interferometry to measure the clocklike angle of this stellar CaII H&K emission band, modeling it as an elliptical intensity distribution. Both components should be determinable to within ten degrees for at least resolvable fifth magnitude stars.

Applications and Methods

As the previous papers have pointed out, among the major approaches to the detection of extrasolar planetary systems is the detection of effects produced by such a system on its parent star. These include detection of proper motion wobbles or small, periodic Doppler shifts in a star due to the gravitational influence of any unseen planetary companion(s). Other methods include the detection of a photometric drop in the stellar luminosity due to the transit of a planet[1]. Taking our solar system as a model, along with preliminary observations of what may be proto solar systems and theories of solar system formation in general, it is expected that planetary systems would form in or very near the equatorial plane of the star. Thus, it would seem that the determination of the stellar space orientation could closely approximate the determination of the planetary plane.

Finding the orientation of a star in space would, first of all, allow the extrasolar planetary observer to determine which method to use on a stellar system. If the stellar pole is inclined toward the

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observer then a proper motion method should be applied. On the other hand, if the pole is perpindicular to the line-of-sight then radial velocity variations should be looked for. In addition, the projected components of both of these observations could be resolved and the true magnitude of the variations can be determined. In the case of a planetary system having two or more planets, the resolution of the stellar wobble about the barycenter could be very difficult to determine uniquely whereas knowing the planetary plane would immediately allow the orbital parameters of the system to be established.

The photometric method greatly benefits from this determination as one could then choose which stellar systems are inclined favorably for the transit of a planetary companion to occur in the line-of-sight. This would reduce the expected observing time for the detection of such a transit (assuming the continuous observing of at least two thousand stars) from, at most, one a year, to at least, one a day!

Intrinsic stellar pulsation components would also be separable from external body gravitational effects, and the magnitude of the deviations would highly constrain the expected mass or masses of the planetary bodies around the star.

How, then, can one determine the space orientation of a star? We will separate the stellar orientation into two components: a) the inclination to the line-of-sight and b) the clocklike, on the plane-of-the-sky component.

To determine the inclination to the line-of-sight one can utilize the stellar rotation periods determined from CaII H&K sunspot emission[2]. Late-type stars, like the Sun, have sunspot, (or starspot) cycles which can be detected by observing the presence of an emission feature in the usual absorption band of CaII H and K lines. While long-term variations in this feature have allowed the determination of sunspot cycles for other stars, short-term variations - due to the asymmetric distribution of the starspot features on the eastern and western hemispheres alternately displayed toward the observer have allowed the stellar rotation periods (P) to be determined.

This can be combined with stellar radii measurements (r), determined from various techniques, to give the true rotational velocity of the star[3]. Dividing this into the projected rotational velocity determined from Doppler broadened spectral line profiles (V sin i) then gives the inclination to the line-of-sight component of the star's space orientation according to the equation:

$$i = \arcsin \frac{V \sin i}{2\pi r/P} \qquad (1)$$

The clocklike component of stellar space orientations can be determined, it turns out, by using the characteristics of a star when viewed in CaII H&K emission. Sunspot associated plage areas on the Sun, which are responsible for the CaII H&K emission, can be seen (like sunspots) to be confined to the equatorial regions of the Sun. Thus viewing the Sun in CaII H&K emission one sees a distinct equatorial "sash"[4].

We will want to measure, then, stellar radii in CaII H&K emission; the longest axis giving the clocklike orientation of the stellar equator.

Because of the very limited light available in CaII H&K emission, (which, in addition, will vary with starspot cycle), speckle interferometry[5] must be adapted to this measurement of the longest axis of the star when viewed in this very narrow band.

The image of the star in CaII H&K flux can be modeled as an elliptical intensity distribution. Short time exposures (10^{-3} sec) taken of the star in CaII H or K emission can be Fourier transformed using a digital image processing approach. The spacial scales will invert in the Fourier transform image (k - space) and the large scale atmospheric features (the separation between specks in the speckle image) will now become the smaller features, while the small scale features in the speckle image (elongated specks) due to features of the stellar radii will become the large scale features in k - space. Since the wings of the intensity distribution of the Fourier transformed image will decrease with increased deviation from a point source, the equatorial or longest axis will appear most foreshortened. The longest axis of the elliptical intensity distribution in k - space will thus appear rotated 90° to the true equatorial axis of the original speckle image.

Each speck in the Fourier transformed speckle image will be made up of a number of pixels, each with a particular intensity, and from this we can determine the centroid of the ellipse. A longest axis($\hat{n}$) can then be defined at the points about which the perpindicular vector ($\delta\hat{n}$) is symmetric. Assuming Poisson statistics (random walk photons), we can then estimate the accuracy of the determination of the stellar clocklike axis in terms of photon limits. We have the following equation for $\delta\hat{n}$: [6]

$$/\delta\hat{n}/ = N_I\left[\frac{N_s}{NN_pN_e}\right]^{\frac{1}{2}} \quad \text{where,} \qquad (2)$$

N_I = the number of pixels in a configuration space speck, N = the number of photons,

N_s = the number of specks in the image (either space), N_p = the number of pixels, and

N_e = the number of exposures used in the determination of the oblateness axis.

From here we can determine the above photon limits in terms of stellar magnitude with the equation:

$$M = 2.5\log_{10}\left[\frac{\delta\hat{n}}{N_I}\; N_pN_e\; \frac{\Delta\nu}{\nu}\; \frac{QSA\gamma}{N_sE_p}\right] - 26 \quad \text{where} \qquad (3)$$

Q - quantum efficiency = 0.2, S - solar constant = 10^3 watts/m^2,
γ - exposure time = 10^{-3} sec, A/N_s - collecting area over number of specks = 2.5×10^{-4} m^2,
E_p - energy of photons = 2.5 eV, $\Delta\nu/\nu$ - bandpass = $2\text{x}10^{-4}$, $N_p = 10^6$, $N_e = 10^2$, and
$N_I = 10^2$ for reasonable values. For a $\delta\hat{n} = 0.1$ (about 6°) we obtain a corresponding threshold magnitude of 5, although both the number of pixels and number of exposures could easily be extended by an order of magnitude.

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In conclusion then, the determination of the space orientation of stars that are to be searched for evidence of extrasolar planetary systems would appear to be an important, and in some cases, essential operation both in the proposed observational program as well as in the interpretation of results. Present techniques should allow the determination of the space orientation of such candidate stars to within 10^{o} or better.

REFERENCES

1) Black, D.C., 1980, Space Science Reviews 25, 35

2) Baliunas, S.L., et al., 1983, Ap.J. 275, 752

3) Fracassini, M., et al., 1981 Astron. Ap Supp. 45, 145

4) Wilson, O.C., et al., 1981, Sci. Amer. 244,104

5) Labeyrie, A., 1970, Astro. Ap 6, 85

6) Doyle, L.R., Wilcox, T.J., and Lorre, J.J., 1984, Ap.J. Dec.1, 1984

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