Applied Doppler Imaging: Can Magnetic Activity of IM Pegasi Affect the Gravity Probe B Mission?

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Abstract. IM Peg is a single-lined, spectroscopic RS CVn binary, with a rapidly rotating ($v \sin i = 27$ km/s), early K-type, giant primary. Magnetic activity of the primary is indicated by dark spots covering $> 15\%$ of the surface. The system is bright in both optical and radio, and was chosen as a guide star for the Gravity Probe B (GP-B) satellite mission. The goal of GP-B is to verify two predictions of Einstein’s theory of general relativity (geodetic effect and “frame dragging”), based on measurements of mean gyroscopic drift with respect to the optical centroid of IM Peg. The requested precision of $0.5 \times 10^{-3}$ arcsec/yr implies that even small shifts of the optical centroid of IM Peg due to surface magnetic activity must be determined. In support of the GP-B mission, we are undertaking an intensive Doppler imaging survey of the primary component of IM Peg, to determine the effect of spot features on its optical centroid. We present an overview of our work for GP-B, and report initial results from this support project, including the first magnetic maps of the IM Peg primary, created using Least-Squares Deconvolution and Zeeman Doppler Imaging.

1. Gravity Probe B and IM Peg

Gravity Probe B (GP-B) is a polar orbiting satellite designed to test with unprecedented accuracy two predictions of Einstein’s theory of general relativity concerning the behavior of gyroscopes in near-Earth space. The larger effect is the geodetic effect, due to the curvature of space near the Earth, which is predicted to cause a $6.6 \text{ arcsec/yr}$ drift of the spin axes of the orbiting gyroscopes in the plane of the polar orbit. Much smaller is the Lense-Thirring, or “frame dragging”, effect due to the rotation of the Earth, which is believed to cause the gyroscopes to drift eastward by $\sim 41 \times 10^{-3}$ arcsec/yr. Both drifts are measured with respect to the optical centroid of IM Peg with which the entire satellite is aligned by means of a guide telescope. More information on GP-B can be found at \url{http://einstein.stanford.edu/}.

The primary of IM Peg (a K2 giant) is a magnetically active star having dark spots on its surface, seen in Doppler images (Berdyugina et al. 2000), covering $15\%$ or more of the surface. In support of the GP-B mission we are undertaking an intensive Doppler imaging survey of the primary component of IM Peg to determine the extent to which spot activity could shift the optical centroid of the star and thus affect the accuracy of the GP-B mission. Thanks to this experiment, IM Peg is becoming one of the best studied magnetically active stars after the Sun.
2. Detection of the Secondary

To provide the optical support to the GP-B mission, high-resolution echelle observations of IM Peg have been obtained almost daily with the 2m Automatic Spectroscopic Telescope (Eaton & Williamson 2004). The technique of Least-Squares Deconvolution (LSD; Donati et al. 1997) was used to combine over 1700 photospheric lines in each echelle spectrum into a high S/N LSD profile. The high S/N enabled the first ever detection of the secondary in this spectroscopic binary (see Marsden et al. 2005). One orbital period of the secondary in these profiles is shown in Fig. 1. From the orbital solution and the LSD profiles of the secondary its stellar properties were determined. The secondary was calculated to have a mass of $1.0 \pm 0.1 M_\odot$, a radius of $1.00 \pm 0.07 R_\odot$, and a temperature of $5650 \pm 200$ K, assuming that it is a main-sequence star.

3. Doppler Imaging

The LSD profiles were also used to produce brightness topologies of the primary with the Doppler imaging code of Donati & Brown (1997). These are shown in Fig. 2. The new Doppler images of IM Peg show the absence of a strong polar cap, in agreement with previously published images by Berdyugina et al. (2000). In addition, most images show that spots tend to be found in two clumps on opposite sides of the star, supporting the idea of long-lived active longitudes on IM Peg. Moreover, it appears that a flip-flop happened in the beginning of 2004. A detailed analysis of the images will be presented in a forthcoming paper.
Figure 2. Maximum entropy brightness image reconstructions for IM Peg from August 2003 to July 2005. The images are polar projections down to -60° latitude with the bold line denoting the equator and the radial ticks outside the plots indicating the phases of observations. The images show spot occupancy, the local relative area occupied by cool spots. Phase 0.0 corresponds to conjunction, with the primary behind the secondary.
4. Zeeman Doppler Imaging

In September 2004, IM Peg was observed at the Anglo-Australian Telescope in left- and right-hand circularly polarized light using the SEMPOL spectropolarimeter (Donati et al. 2003). After combining the signals of over 5500 photospheric lines into LSD profiles, and using the Zeeman Doppler Imaging code of Donati & Brown (1997) we produced brightness and magnetic topologies of the primary, shown in Fig. 3.

The primary of IM Peg shows both positive and negative radial fields at most latitudes. However, positive azimuthal fields appear to be predominant at high latitudes, while negative azimuthal fields are more dominant closer to the equator. This is similar to structures seen on the single early G-type giant HD 199178 (Petit et al. 2004) and on other stars (Donati et al. 2003).

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References