A COMBINED HIPPARCOS AND MAP STUDY OF THE PROPOSED PLANETARY SYSTEM OF RHO CORONAE BOREALIS

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ABSTRACT

Hipparcos and Multichannel Astrometric Photometer (MAP) (Gatewood 1987) observations of Rho Coronae Borealis independently display astrometric motion at the period of the proposed “extrasolar planetary” companion to the star. Individual least squares fits to each astrometric data set yield independent estimates of the semimajor axis, inclination, and node angle that are in excellent agreement. A combined solution of the Hipparcos and MAP data yields an inclination of 0 .5 degrees, a node at 30 .5 ± 12 .4 and a semimajor axis of 1.66 ± 0.35 mas indicating a companion mass of 0.14 ± 0.05 $M_{\odot}$, over two orders of magnitude greater than the minimum mass for the companion as determined by radial velocity studies. This mass is approximately that of an M dwarf star; the companion cannot be a planetary object.

Subject Headings: Stars: Planetary Systems; Stars: Rho Coronae Borealis; Astrometry

1. INTRODUCTION

High precision radial velocity measurements of Rho Coronae Borealis (rho CrB, Hip 8459, HR 5968) show a small, but periodic, variation indicating the presence of a companion with a minimum mass of approximately 0.001 $M_\odot$ and an orbital period and eccentricity of 39.9 days and 0.13 respectively, (Noyes, et al. 1997). The interpretation of the nature of this and similar low-mass companions is complex and the subject of controversy (e.g. Black 1997, Stepinski and Black 2000), but it is customary for detection papers to announce them as “extrasolar planets.” The increasing sample of low-minimum-mass spectroscopic companions has allowed a number of investigations of their probable nature (eg. Boss 2000). The success of these studies is dependent ultimately upon verification of the companion mass. In many cases this can be done by astrometry, but the size of the astrometric signal is so small that the confirmation of any positive result by a second astrometric study is desirable. Virtually all of the suspect stars are bright enough to be included in the Hipparcos Catalogue. Unfortunately, there are very few high precision astrometric instruments that can be used to observe stars this bright and thus provide confirmation of a Hipparcos result.

2. ASTROMETRIC DATA

The 40 abscissa measurements of rho CrB, contained in the Hipparcos Intermediate Astrometric Data (IAD) (ESA 1997), span more than 28 orbits. Their initial analysis led to the star's inclusion in the Double and Multiple Systems Annex, vol 10, with a suggested period of 80 days and a motion of 2.3 mas (thousandths of an arc second). Hipparcos measurements are neither orthogonal pairs or are they evenly spaced in time. Indeed the angles along which the measurements are made are sometimes clustered with respect to time, thus it is possible that the noted motion is at a multiple of the 39.9 day period derived from the AFOE study (Noyes et al.1998).

The Allegheny Observatory began MAP observations of rho CrB in April of 1999 in order to assess the motion suggested by the Hipparcos result and if confirmed, to determine its period more accurately. The epochs of the observations, which span 11 orbital periods of the SB, and the residuals to a least squares fit to the position, proper motion and parallax of rho CrB are listed on the Observatory's web site at http://www.pitt.edu/~aobsvtry/research.html . Periodogram analysis of the full MAP data set indicated that the astrometric period was indeed near 39 days and not the 80 days suggested in the Hipparcos Catalogue Annex.

To illustrate that the two astrometric data sets affirm the period of the SB orbit, we made a series of statistical fits of the astrometric data to the SB orbital parameters of Noyes, et al. while varying the orbital period. Figure 1 is a plot of the variance of unit weight found for the different periods that were forced on the solution. The Hipparcos variances are shown with a dashed line. The solid line represents the results of a similar series of statistical adjustments to the MAP data that minimized the χ^2 statistics. The MAP variances are scaled to the variance of the Hipparcos data to produce overlying signals. While the 80 day period suggested in the Hipparcos Annex is clearly shown in the Hipparcos data, it is not found in the MAP analysis. (This dramatizes the need for a second astrometric instrument.) Near the period of the SB binary, the MAP data shows the wide dip in the variance that is to be expected with the relatively short span of that data set, discussed below. The split in the bottom of the dip originates in that fact the data was acquired during two periods, of several months duration, separated by a slightly longer period during which the region was inaccessible. The longer span of the Hipparcos data set leads to a sharp decrease in variance at 39.5 days weakly suggesting that the period of the SB orbit could be adjusted slightly.

The reduction method used is similar to that of Halbwachs et al. (2000) and of Mazeh et al. (1999), the derived astrometric elements being the same. After initial tests indicated that little improvement in the spectroscopic elements could be gained from the astrometic data, the radial velocity elements were simply adopted and not allowed to vary within the constraint of their standard errors. Thus, in addition to the position, proper motion and parallax, only three orbital parameters are to be found from the astrometric analysis: the angle of the node of the orbit on the plane of the sky (Ω), the inclination of the orbit out of the plane of the sky (i), and the angular size of the astrometric semimajor axis (α). The radial velocity study also provides a ratio between the size of the semimajor axis and sin(i). As noted by Halbwachs et al., however, its adoption can lead to some confusion in the interpretation of the standard error of i. We follow their example of excluding this standard error from our results. A measure of the goodness of the fit obtained in this manner is shown in Figure 2 where we indicate how the normalized χ^2 varies with angle i. Note the sharp reduction in the normalized χ^2 at an angle of 0.5 degrees. Also shown in Figure 2, as tick marks just inside the sharp dip in the curve, are the 1-, 2-, and 3-σ confidence levels associated with the best-fit solution. The lowest tick is at the 3-σ level.

Table 1 lists the results of our study. The Hipparcos analysis uses the data of both Hipparcos consortia. Based upon completely independent data and instrumentation, the 1.5 years of MAP data yield results that are in excellent agreement with those of Hipparcos although the standard error of unit weight reflects the faintness of the reference stars for the region around rho CrB. Finally, by combining these two data sets in a single reduction, we obtain an estimate of the semimajor axis of the orbit, namely a = 1.66 ± 0.35 mas, indicating a secondary mass of 0.14 ± 0.05 $M_{\odot}$.

3. DISCUSSION AND CONCLUSIONS

The full MAP data set confirms that the astrometric periodic motion is similar to that of the SB orbital period and not that given in the Hipparcos Annex. Analysis of the Hipparcos data shows that the fit of the SB orbital parameters is actually better than that listed in the Annex for the longer period and that the parameters derived are in excellent agreement with those based on MAP data. A combined Hipparcos/MAP fit to the SB orbital parameters yields a semimajor axis of 1.66 mas, 4.7 times its standard error. This indicates that significant astrometric motion has been detected. The mass of the object that could cause the detected motion must be at least one hundred times the minimum mass of 0.001 M given by Noyes et al. The agreement of the two astrometric instruments, shown in Figure 1, indicates that there is a very high likelihood that they are not only sensing the same signal but that they are sensing a motion with the period of the spectroscopic orbit. The minimum mass is far too small to cause this effect. In the same orbit, the minimum mass would produce a motion of 0.013 mas, far below the detection threshold of any astrometric data set that will become available until the end of this decade.

The inclination of 0.5 degrees obtained from our analysis differs substantially from that obtained by Trilling et al. (2000) who quote a value of 46 degrees. Their estimate is not based on observations linked directly to the companion, but is based upon observations of a circumstellar disk associated with the star. It should be noted that there are two key assumptions involved in the value given by Trilling et al. One is that the disk is circular. This is essential in that the authors use the apparent shape of the disk to derive an inclination. The authors do remark that there is an apparent asymmetry associated with this disk. The source of this asymmetry is unknown (it could be inherent in the disk, or it could be associated with aspects of the observations/data reduction although there is no mention of similar asymmetry in any of the other disks that they detect). A second key assumption is that the disk and planet orbital planes are aligned. Given that the companion is at a distance that is roughly 1/350 the radius of the disk, that assumption is far from firm. Given the above, the inclination given by Trilling et al. must be considered as a model dependent estimate, as contrasted with a direct observation. The value given here is derived directly from observed properties of the companion/star system.

The remarkably small value inclination found in this study, along with a similar small inclination found by Zucker and Mazeh (2000) in the case of HD 10697, and the small inclinations found by Halbwachs et al. (2000) in the analysis of Hipparcos data on the eleven stars with companions that evidenced msini values in the range from 17 to 64 Jupiter masses, suggests strongly that there may be a bias in the sample used by the radial velocity searches. We present further evidence of this bias in a separate paper (Han et al., 2000) assessing all stars with “extrasolar planetary companions” in orbits with periods in excess of ten days.

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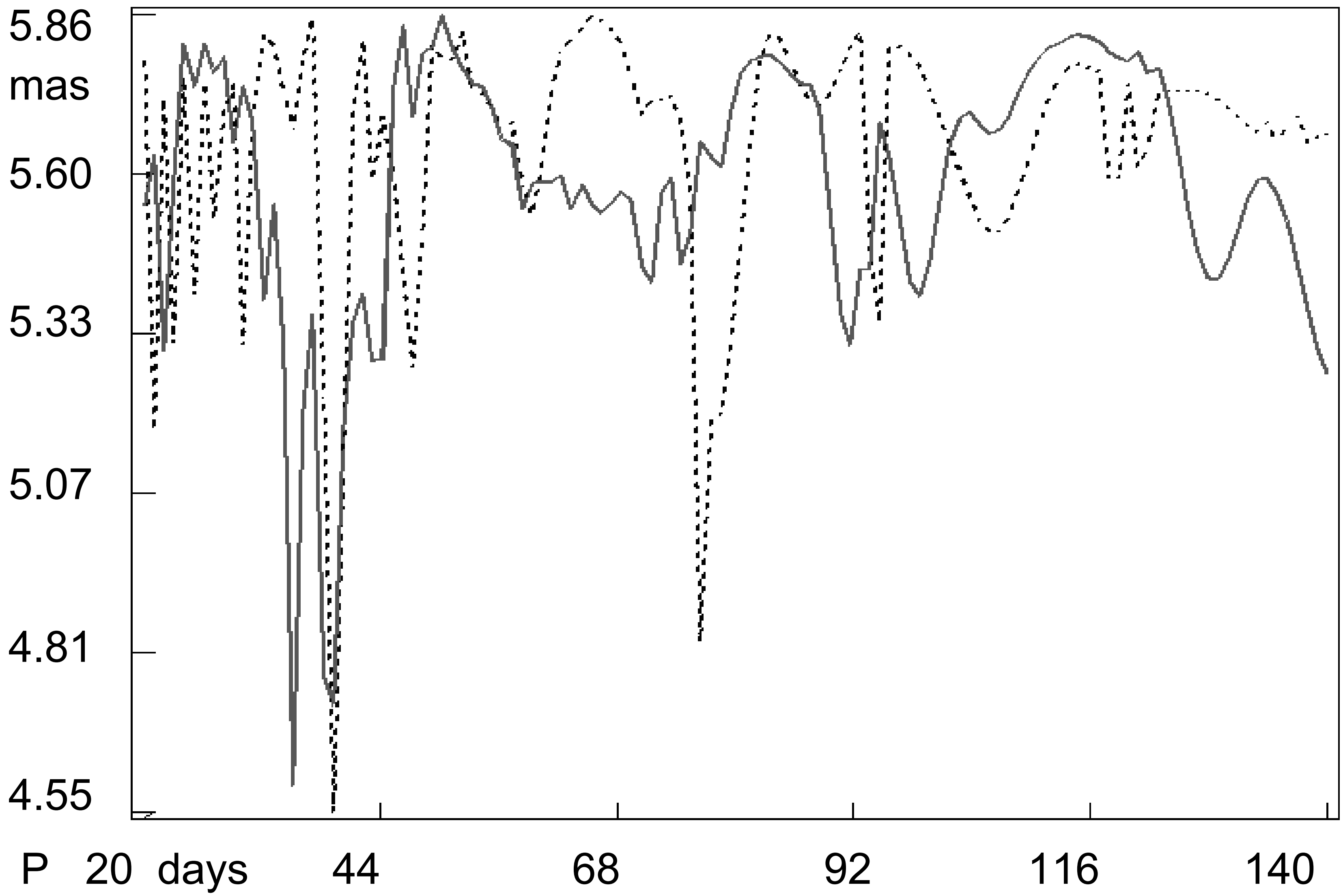
TABLE 1

Astrometric Orbital Elements of ρ CrB

element	unit	Hipparcos	MAP	Hipparcos+MAP
α	mas	1.62 ± 0.44	2.03 ± 0.76	1.66 ± 0.35
Ω	degrees	45.9 ± 16.3	2.4 ± 21.5	30.5 ± 12.3
i	degrees	0.49	0.39	0.48
σ_1	mas	2.19	5.38	2.21

Fig. 1. - Hipparcos (dashed line) and MAP variance, in mas, plotted against possible orbital periods, P, in days. The best fit is at the period of the proposed planetary companion.

Fig. 2. - Normalized χ^2 statistics as a function of the inclination, constrainted by $a_1\sin(i) = 0.014$ mas. Tick marks just to the right of the strong dip in the curve indicate, from top to bottom, the 1-, 2-, and 3-σ confidence levels.



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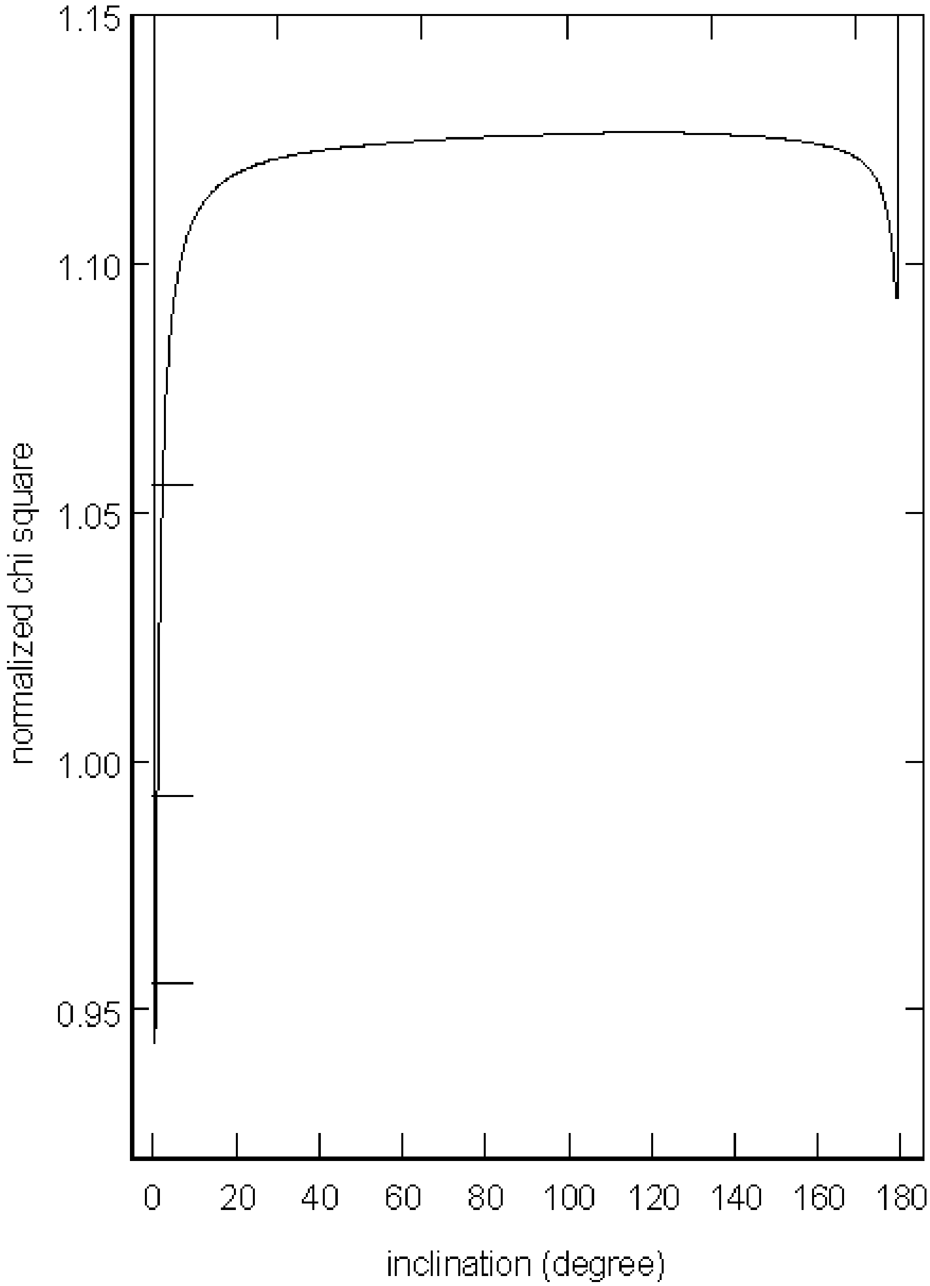
mas
5.60
5.33
5.07
4.81
4.55
P 20 days
44
68
92
116
140


1.15
1.10
1.05
1.00
0.95
normalized chi square
0
20
40
60
80
100
120
140
160
180
inclination (degree)