Evidence of a Neptune-sized Planet in the ρ^1 Cancri System

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ABSTRACT

Reanalyzing published data, I find evidence of a Neptune-sized planet in the ρ^1 Cancri system with a period near 261 days and a mass approximately 1.8 times the mass of Neptune.

Subject headings: planetary systems — stars: individual(ρ^1 Cancri)

1. Introduction

A number of planets have been found around ρ^1 Cancri (= ρ^1 Cancri A = 55 Cancri 1 = HD 75732 = HIP 43587 = HR 3522; (Marcy, et al. 2002)). The first planet (ρ^1 Cancri b) that was detected has a period near 14.67 days (Butler, et al. 1997), and $M \sin i \approx 0.78 M_J$, where M_J is the mass of Jupiter. This was followed by the detection of a long period planet (ρ^1 Cancri d) with period near 14 years and $M \sin i \approx 3.5 M_J$ (Marcy, et al. 2002). In the same paper evidence was presented of a third planet (ρ^1 Cancri c) with an intermediate period near 44.3 days and $M \sin i \approx 0.22 M_J$. These mass estimates presume a stellar mass of $0.95 M_\odot$ (Marcy, et al. 2002; McArthur, et al. 2004). Finally, evidence of a fourth planet (ρ^1 Cancri e) with a period near 2.8 days and $M \sin i \approx 0.045 M_J \approx 0.82 M_N$ (M_N is the mass of Neptune) has been presented (McArthur, et al. 2004). In this letter I raise doubts concerning the existence of the 2.8 day planet, and present evidence of a new Neptune-sized planet with a period near 261 days and $M \sin i \approx 1.8 M_N$.

2. Observations and Method

I use the three sets of published radial velocity data for the star ρ^1 Cancri: the Lick data (Marcy, et al. 2002), the OHP data (Naif, et al. 2004) and the HET data (McArthur, et al. 2004). The data are shifted to have consistent radial velocity origins using the constants provided by McArthur, et al. (2004).

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Periodicities in the radial velocity data are identified simply by fitting a sinusoid of presumed period to the data using weighted least squares and plotting the resulting χ^2 of the fit versus the period. A dip in χ^2 indicates a periodicity. This method is equivalent to the Lomb-Scargle periodogram for weighted data (Lomb 1976; Scargle 1989).

If the data warrant it, the fit can be refined by fitting a Keplerian orbit or simultaneously fitting a number of Keplerian orbits. I fit for the Keplerian orbit parameters and the radial velocity semiamplitude (K) using the Nelder-Mead downhill simplex method. By repeatedly restarting the nonlinear fit (reextending the simplex), some local minima can be averted.

A previous attempt to fit the ρ^1 Cancri system with a fully interacting n-body dynamics did not show substantial improvement of the fit (reduction of χ^2) over the fits to simple noninteracting Keplerian orbits. I stick to Keplerian fits here.

In McArthur, et al. (2004), the Lick and HET data were used to fit for the longest period planet, but only the HET data were used in the fits for the remaining planets. Here I use all the available data for all the fits for all the planets.

Using all the available data new Keplerian fits for planets ρ^1 Cancri d, b, and c have been made. I fit for the planets d and b (the two with the strongest signals) simultaneously. The fit for planet c was made after the first two were subtracted from the data.

3. Is the 2.8 day signal a planet?

The periodogram of the HET data shows a signal near 2.808 days that has been interpreted as a Neptune-sized planet (McArthur, et al. 2004). The period of this signal has a curious relationship to the period, 43.93 days, of ρ^1 Cancri c. In particular, the relationship

$$\frac{1}{2.808} \approx \frac{1}{3} + \frac{1}{43.93}$$

is valid to four digits. This raises concern that the 2.8day signal might be an alias of the 43.93 day planet. Note that aliases of the planetary signals appear near 1 day. This might be due to periodic differences in the quality of data near dawn or dusk. However, there is no apparent reason for an alias to be related to a 3 day period.

The periodogram near the 2.808 day signal shows a single peak when only the HET data are used. However, when all the available data are used the 2.8 day signal is split into a doublet (see Fig.1). For this figure the signals for the first three planets (ρ^1 Cancri d, b, and c) are first subtracted. The periods of the doublet lines are 2.7957 days and 2.8175 days. The average of these two periods is 2.807 days and the splitting between them corresponds to a period of 361.3 days, roughly a year. There is no significant signal at 2.808 days. Note that if the two sinusoids that fit the two peaks of the doublet are subtracted, the periodogram of the resulting data shows no signal in this interval. The lack of signal near 2.808 days is evidence against the existence of a 2.808 day planet.

4. A new Neptune-sized planet

After subtraction of the signal for planets *d*, *b*, and *c*, the resulting data are fit with the weighted least squares method. The resulting plot of χ^2 versus period (see Fig.2) shows a number of signals. The four most significant are near 1.03, 2.8, 1.55, and 260 days. The signal near 1.032 days is presumably an alias, but its origin is not clear. Perhaps it is an alias of the period of full moon. The signal near 1.55days is apparently an alias of the 2.8 day signals; it disappears when those are subtracted.

The best fit sinusoid to the dip near 260 days has a period of 257.8 days, before subtracting the doublet signal near 2.8 days, and a period of 261.2 days, after subtracting the doublet. The radial velocity semiamplitude in the latter fit is $K = 3.15$m/s. Interpreting this signal as a planet, this corresponds to a mass of $1.8 M_N$ (assuming a stellar mass of $0.95 M_\odot$).

The data folded on this period are very noisy (Fig.3). Nevertheless, a sinusoidal component can be seen. The best fit sinusoid is plotted with the folded data. To more clearly pull out the sinusoid, the folded data were binned into 10 bins of roughly equal number. The data in each bin were averaged and the standard deviation of those averages was computed (Fig.4).

It is not clear that the data warrant a Keplerian fit. Keplerian fits to noisy data tend to find large eccentricities, which artificially distort the fitted curve to match irregularities in the data (i.e. the data are over-fit). A Keplerian fit to this data indeed shows a large eccentricity of 0.51.

As a test of the statistical significance of this dip in χ^2 the following numerical experiment was carried out. I generated simulated data with gaussian random errors with the times for the simulated data the same as for the actual data. The size of the errors was chosen to give a χ^2 roughly equal to that observed without a dip. I then fit sinusoids to the data, limiting attention to the interval between periods of 100 and 1000 days, and formed the ratio of the minimum χ^2 to the maximum χ^2 found. For the actual data, which has a dip near 261 days, this ratio is 0.918. After 1000 simulated trials, the ratio of minimum to maximum χ^2 never got as low as 0.918. I therefore estimate that the false alarm probability that the observed dip near 261 days is a statistical artifact is less that 1 part in a 1000.

I performed a second numerical experiment like the first, but with different errors. Instead of using gaussian random errors I used the residuals in the data after the 261 day planet signal was subtracted. These errors were scrambled and assigned randomly to the times of the original data. As before I fit sinusoids to the data, limiting attention to the interval between periods of 100 and 1000 days, and formed the ratio of minimum χ^2 to the maximum χ^2 found. After 1000 different scramblings of the data residuals, the ratio of χ^2s never got as low as for the actual data. This confirms the above estimate that the false alarm probability that the observed dip near 261 days is a statistical artifact is less than 1 part in a 1000.

The latter experiment was extended to 23,000 different scramblings of the residuals. Fitting these as before, 17 had a ratio of minimum to maximum χ^2 lower than for the actual data. Thus I estimate that the false alarm probability that the observed dip near 261 days is a statistical artifact is about 0.0007. Marcy, et al. (2005) suggested, as a benchmark, that a planet detection should have a false alarm probability less than 0.01.

5. Conclusion

The recently announced Neptune-size planet with a period near 2.8 days may be an alias. But there is evidence for another planet in the published data. The period of this planet is near 261 days; its mass is about $1.8 M_N$.

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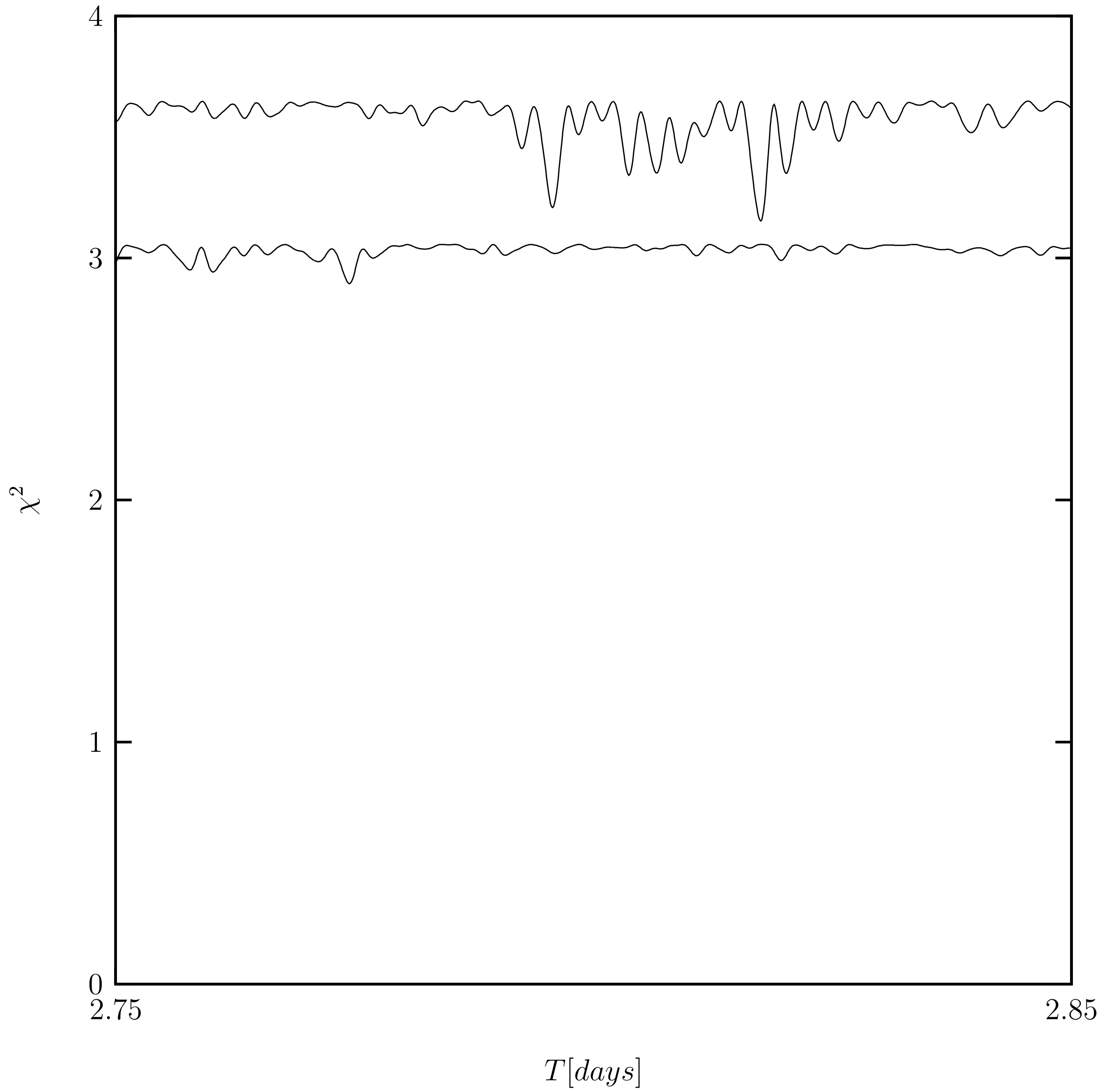

Fig. 1.— The upper curve is the χ^2 for a sinusoidal fit with period T to the radial velocity data with planets d, b, and c subtracted. The lower curve in addition subtracts two sinusoids that are fit to the doublet. The two sinusoids remove the signal in this period interval.

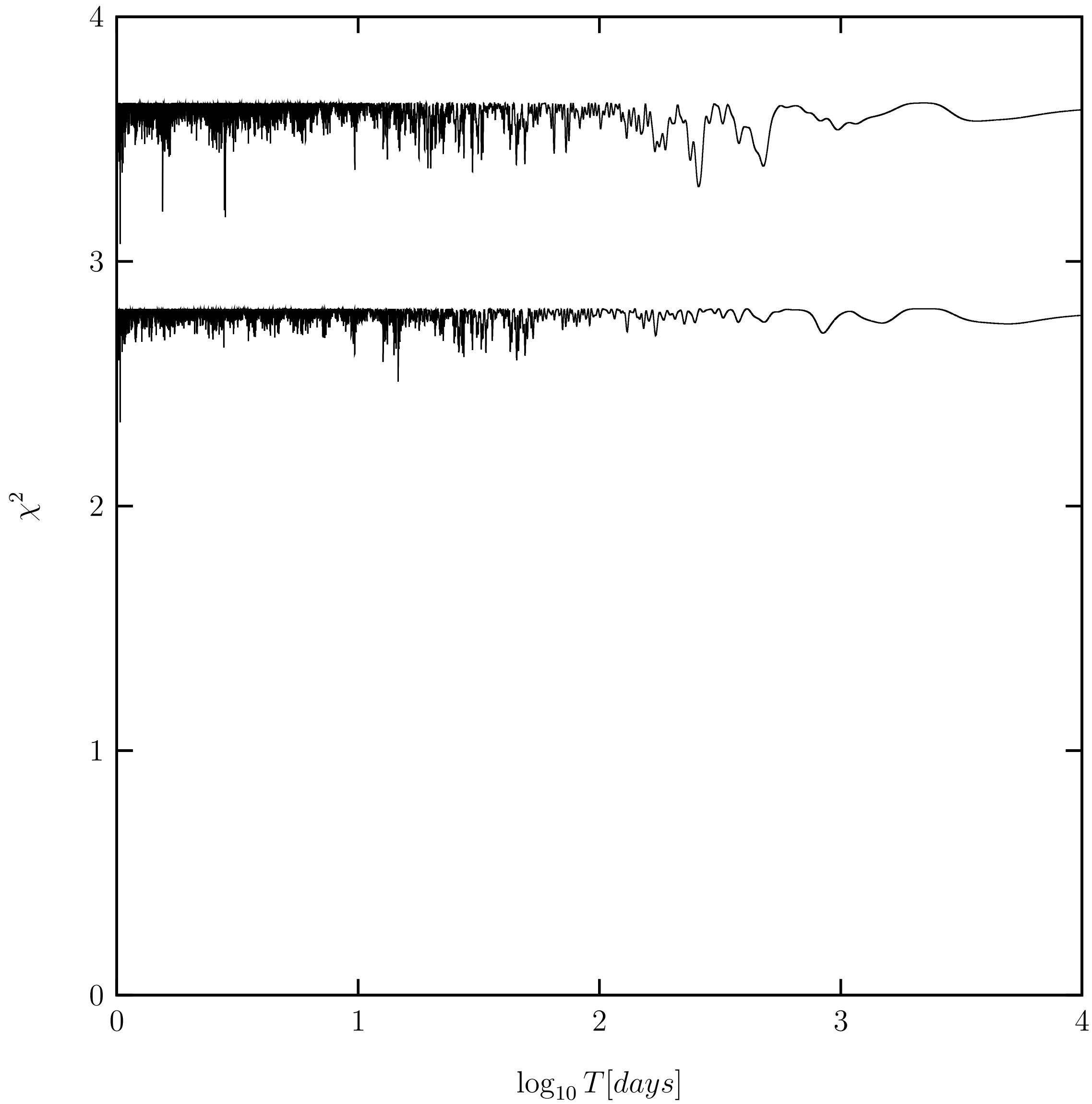

Fig. 2.— The upper curve is the χ^2 versus period T for a sinusoidal fit to the radial velocity data with planets d, b, and c subtracted. There are signals near 1.03, 1.55, and 2.81 days, and a dip near 261 days. The lower curve shows the χ^2 with the two sinusoids representing the 2.8 day doublet subtracted from the data, as well as with a sinusoidal fit to the 261 day signal removed.

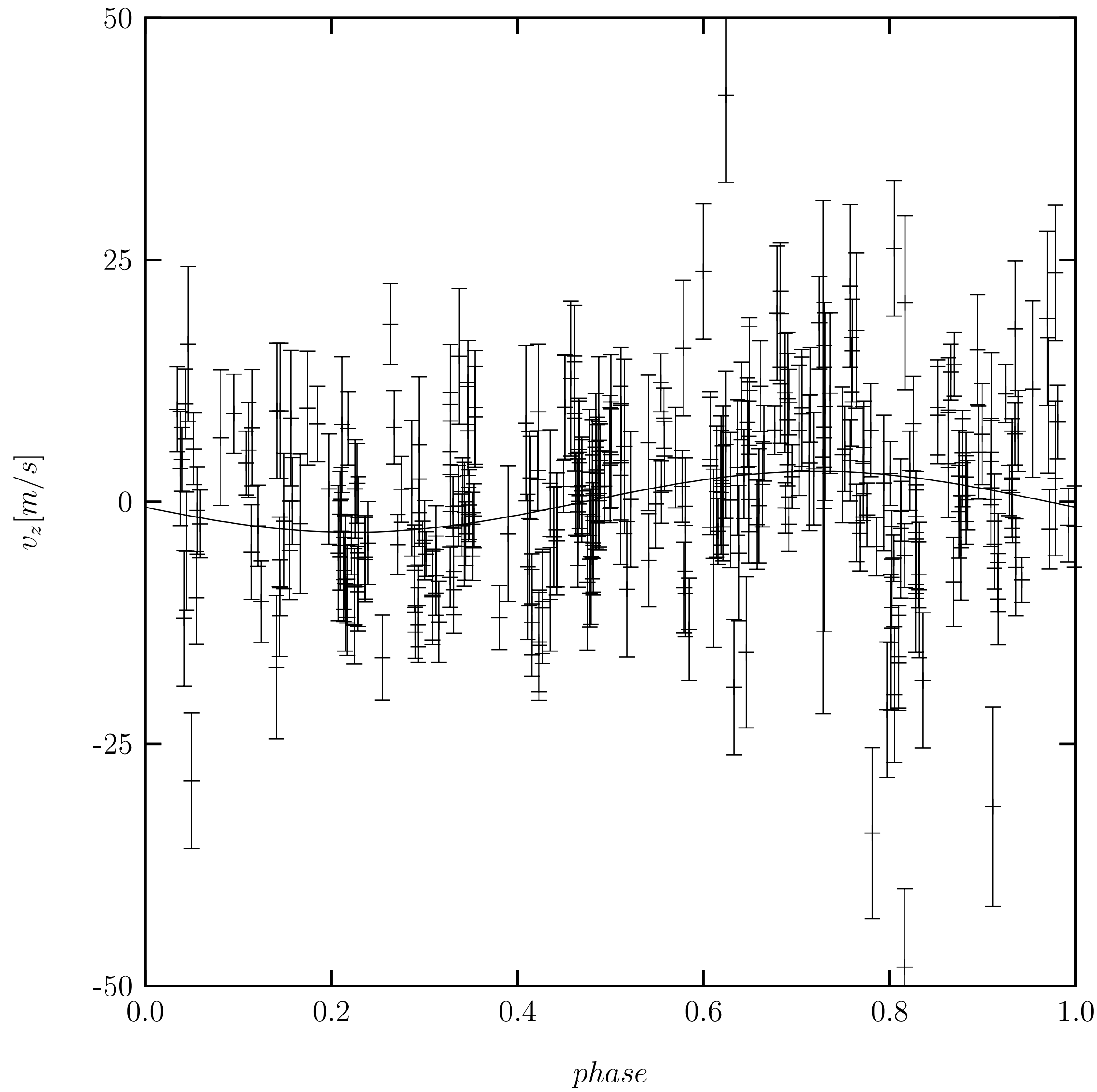

Fig. 3.— The radial velocity data are folded on the orbital period of the 261.2 day planet. Planets *d*, *b*, and *c* have been subtracted, as well as the sinusoidal fits to the 2.8 day doublet. The data are noisy but a sinusoidal component is apparent. The curve is the best fit sinusoid, which has a semiamplitude of 3.15 m/s.

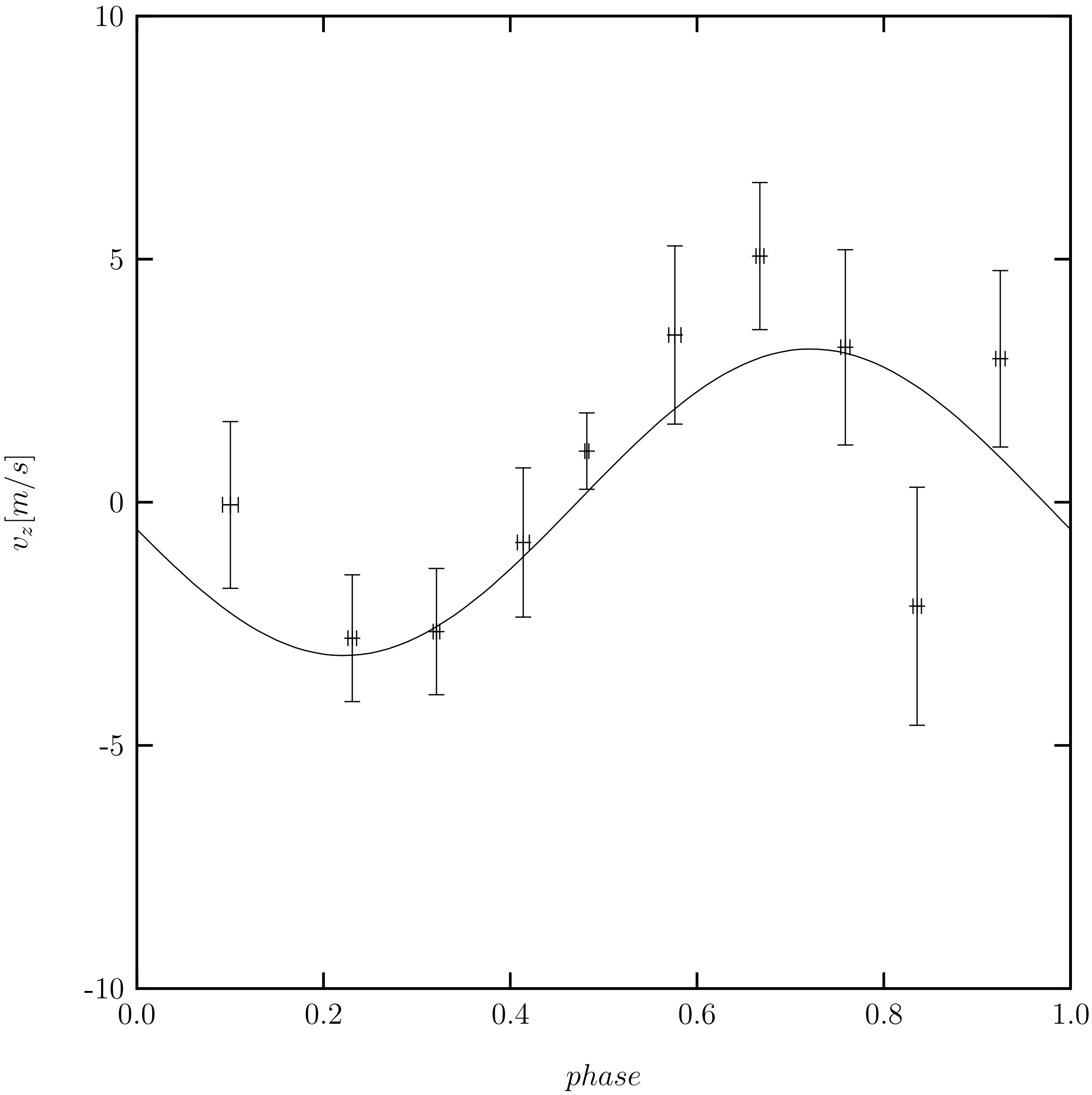

Fig. 4.— The folded data, after subtracting planets *d*, *b*, *c*, and the doublet, were grouped into 10 bins of nearly equal size and averaged. The averages and the standard deviations in those averages are plotted. The curve is the same best fit sinusoid as in Fig.3.