PHY340 Data Analysis Feedback:

Group A02 doing Problem A2

# Data Analysis

The data analysis seems to have been carried out well, although the fitting procedure is not well explained: “using Python’s inbuilt ‘curve fit’ function” does not constitute an explanation! You need to explain *what* you are doing, not *how* you are doing it: the method, not the tool. This is because readers wishing to repeat your analysis may not be Python users. What curve\_fit does can be extracted from its entry in the SciPy reference manual: it uses the Levenberg-Marquardt algorithm in a non-linear least squares fit. There are many possible references for Levenberg-Marquardt: the Wikipedia entry gives the original papers by Levenberg and Marquardt and a number of secondary references. It is worth being specific here, because different χ2 minimisa­tion methods have different strengths and weaknesses: L-M is reasonably robust to poor star­ting values (good) but can be slow (not so good), and will get trapped in local minima if these exist and the starting parameter values are not well chosen (not good, but a common problem).

As the limb-darkening fit is a generalisation of the fit without limb darkening (if you set *cλ* = 0 in equations 13 and 14, you recover equations 10 and 12), direct comparison of χ2 is not really the correct procedure: you should actually use the F-test, as discussed in the lectures. This is be­cause some of the variance in the data (the part outside the eclipse, and the middle of the slope) is common to both fits, so the χ2 values are not independent.

There are some minor bugs in your code, so the limb-darkening fit is not quite right, but it does not look too far off. In comparing your results with literature values, you have made an odd choice of source for the planetary radius: the Extrasolar Planets Encyclopaedia quotes Hoyer et al. (2013), giving 1.395±0.022 *R*J: this is clearly a much more precise value than 1.33±0.16 from Petrucci et al. (2013). Another high-precision result is Nikolov et al. (2012), 1.413±0.020 *R*J. Neither Hoyer et al. nor Nikolov et al. is in agreement with your result, but both use a quadratic limb-darkening law in preference to the linear law adopted in your fit, which may go some way to explaining this difference. You should note that the errors you quote are statistical only, i.e. they are the formal errors on your fit parameters: there are also systematic errors coming from the choice of model to fit.

Since you took your radial velocity measurements from Husnoo et al. (2012), it is slightly odd that you go out of your way to say, in the caption to figure 7, that “a sinusoid is a good fit to the data”, when Husnoo et al. go out of their way to say, in the caption to their figure 6, that it isn’t (“It is clear that a signal is present in the residuals…We attempt to correct for this by repeating our calculations with a linear acceleration term in the model”); they also find that a slightly eccentric orbit is preferred, though a circular orbit is not excluded (*e* = 0.004±0.003). You seem, therefore, to be slightly misrepresenting your source on this point.

Equation 16 does not appear to be the correct equation for determining the radius of the planet in the case where limb darkening is included, since it implicitly assumes that there is *no* limb darkening. If there is limb darkening, then the planet blocks out proportionately more of the light from the star when it is closer to the star’s centre.

For the simple case of a central eclipse (i.e. inclination 90°), we can work out what fraction of the star’s light is blocked by the planet by integrating $B\_{λ}(r)$ from 0 to *Rp*, and comparing with the same integral between 0 and *Rs*. This integral can be done analytically but is a bit messy. I did a simple numerical integration and concluded that for this case your quoted occultation minimum of 0.9713±0.0007 corresponds to a planetary radius of 1.418±0.024 *R*J. This is very close to the literature values, and demonstrates that neglecting limb darkening is very probably the cause of your disagreement. You really should have been able to work this out. (The true inclination is not 90°, but *Bλ* is quite flat out to *r*/*Rs* ≃ 0.6, so this estimate may well be fairly good.) However, the value of *Rp* you should actually quote is the value returned by your fit to the light-curve; you do mention this in the conclusion, but oddly not where you present the fit.

Average grade for this section: 31.75/50

# Data Presentation

The figures presenting the data (figures 7, 8 and 9) are generally satisfactory, though the contrast of green fitted line on blue data points is not very good (a yellow or orange line would probably have been better), and the captions could be more informative (it would be helpful to include the actual numerical values of the fitted parameters). Some of the diagrams illustrating the theory are rather unclear, though: in particular, “asin(wt)” is naturally read as arcsin(wt), whereas what you actually mean is $a\sin((ωt))$ (note that *ω* and *w* are entirely different symbols; also note that you never actually define *ω*).

Numbers are generally quoted to appropriate precision, though not always in the most appro­priate units (planetary radii are quoted in units of Jupiter’s radius if giants, and of Earth’s radius if small, and angles in radians are, to put it mildly, not intuitive; so, for example, on page 5 the fitted radius should be 1.518±0.003 *R*J, and the inclination 85.82°±0.05°). As noted earlier, you should specify that these are statistical errors from the fit only, and do not include systematics due to model dependence.

Average grade for this section: 19.1/30

# Style

The style is generally good, with good use of citations, though the report is a bit too terse: it could have done with more explanation in places. Equations should always be properly intro­duced: equation 11 simply appears from nowhere (it should really come directly after equation 5, which is, I think, the first place that *d*(*t*) is used, and it should be followed by definitions of *t* and *ω*). There are a few typos, such as a missing space in the line before equation 5, and some unwanted capital letters and paragraph indentations after equations (when in fact the text is part of a continuing sentence). You do not seem to understand the word “prediction”: in section 4, you most certainly are *not* “predicting” the transit light-curve, you are attempting to *fit* it (you could only *predict* it if you had pre-existing knowledge of the planet’s radius and orbital inclina­tion).

The conclusion is a bit woolly: for example, you should discuss why your reported error on the planet’s radius is so much smaller than the value from the literature (answer: because you are only reporting the error from the fit, when the dominant source of error is surely the uncer­tainty in what model to adopt—e.g. linear versus quadratic limb darkening law, assumed radius of star, etc.). It would also be worth quoting the probabilities associated with your χ2 values (there is a Python function that will give you this): often, a reduced χ2 value of 1.70 would be quite reasonable, which is at odds with the poor visual appearance of the fit without limb dar­kening—I think the explanation is that the fit has a very large number of degrees of freedom, which makes the χ2 distribution very narrow. In short, your conclusion does not do enough concluding: it is mostly a straight summary of your results, with very little serious discussion.

Also note that discussion in scientific papers should be *quantitative*: it is not enough to say that your result “does not agree particularly well with” a published value—you should quote a confi­dence level, or at least a number of standard deviations. In fact, for the value of *Rp* that you quote, the disagreement is not significant, although this is mainly because you are not quoting the best published value!

Average grade for this section: 12.8/20