PhoDyMM: The PhotoDynamical Muli-planet Model

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Introduction

As the study of exoplanets has developed, new observational constraints have illuminated the formation and evolution of planetary systems. Among these observations, the true distributions of planetary mass, radius, and density are at the forefront. The Kepler Space Telescope has provided an enormous wealth of data on the exoplanet radius distribution as well as mass measurements through the detection of planet-planet dynamical interactions.

PhoDyMM

The planet-planet interactions have typically been characterized with Transit Timing Variations (TTVs). However, TTVs tend to either be ignored or analyzed independently from the lightcurve. A more self consistent approach is to use photodynamical modeling. This method uses an n-body integrator to produce synthetic lightcurves given a set of stellar and planetary parameters. Photodynamical models allow for the greatest amount of inference from lightcurve data and enables the study of small planets even when they do not exhibit visible transits.

To support photodynamical modeling, we have developed the PhotoDynamical Multiplanet Model which combines a phtodynamical model with a Differential Evolution Markov Chain Monte Carlo (DEMCMC) algorithm for Bayesian parameter inference. This allows us to construct posterior distributions for parameters of interest such as the mass, radius, and orbital elements of the Kepler systems.

An additional strength of PhoDyMM is its flexibility. It was built to handle systems with an arbitrary number of planets allowing it to analyze the data from all of the Kepler multis in a self-consistent manner.

Testing

We have used synthetic systems to test PhoDyMM and have found that planetary density is relatively robust to stellar uncertainty.

Additional testing is also being performed in order to analyze how PhoDyMM scales with the number of planets, walkers, and steps

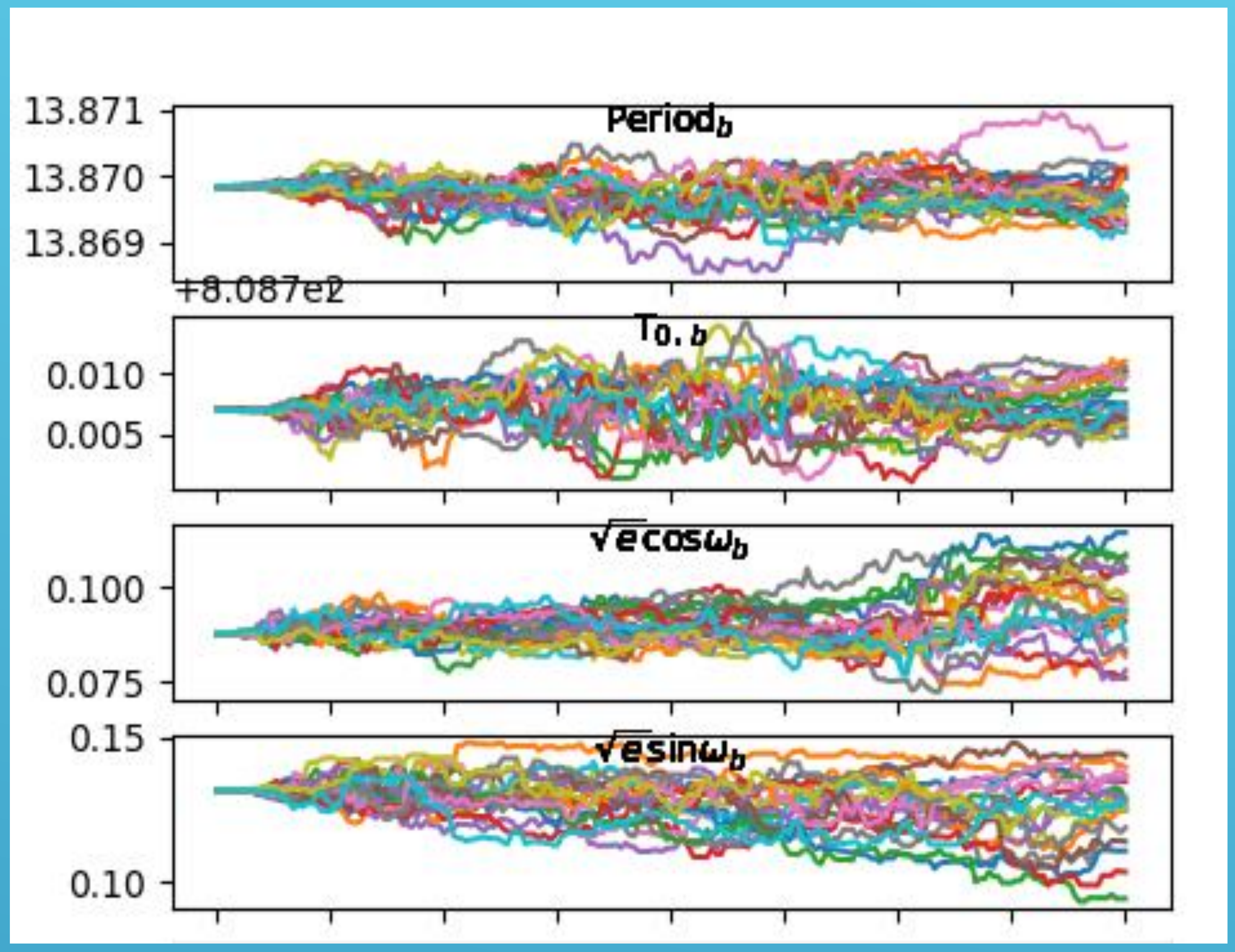

Figure 1: Partial walker plot from PhoDyMM analysis of Kepler 36 with 20 walkers and 1001 steps. While the walkers have not converged, they are adequately sampling the parameter space without getting "lost" **.**

PhoDyMM is publically available at https://github.com/dragozzine/PhoDyMM.git

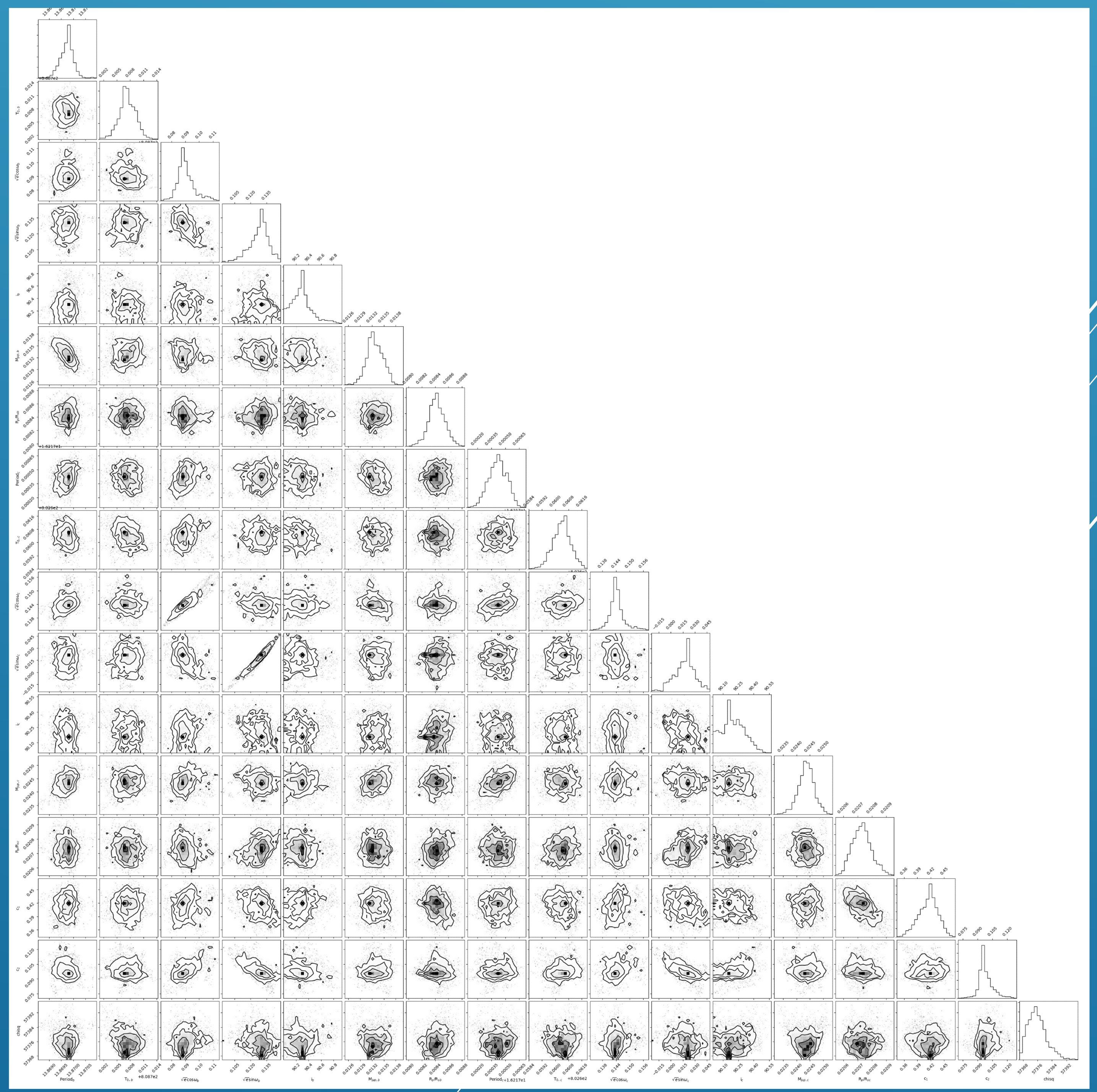

Figure 2: Corner plot form the same PhoDyMM run as in Figure 1. As can be seen from the plot, even with a short run, PhoDyMM can return posterior distributions that match accepted values for well understood systems.

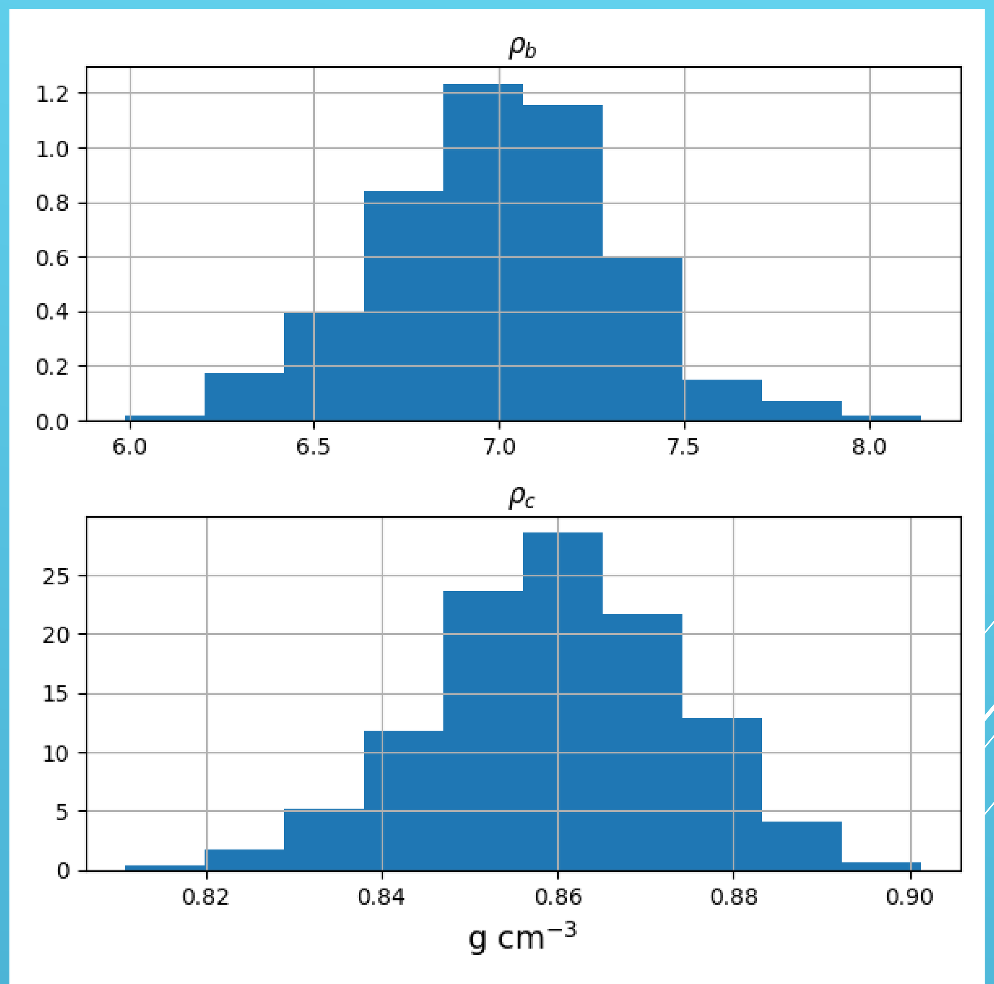

Figure 3: Density posterior distribution for Kepler 36 b and c again from the same PhoDyMM run as Figures 1 and 2.

Results

We are pleased with the progress that has been made towards accomplishing the goal of running PhoDyMM on all of the Kepler multis. From the tests targeting the performance of PhoDyMM, we have found that the code scales well with the number of walkers times the number of steps.

A small run of ~200 systems was executed. Each system ran on 20 cores and was set to have 100 walkers take 1001 steps. From this test we found that approximately 90% of the systems were able to complete the DEMCMC analysis within the four hour time limit given to them. This is an important result as it gives insight into the tractability of the problem of analyzing the multis with PhoDyMM.

With these results in mind, we are confident that as we move forward and execute runs with many more steps on all the multis, we will be able to complete the analysis within a realistic amount of time.

Future Work

While PhoDyMM has already been used in multiple papers on specific systems, we are working to increase the level of automation in order to make running PhoDyMM on multiple systems simpler.

We are also working towards running PhoDyMM on all the Kepler multis, after which we will be able to produce posterior distributions for the masses of these planets. This will then allow us to create an exoplanet mass-radius distribution.