

## ECLIPSE MAPPING CODE

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### ABSTRACT

I describe a C code that can read in time series photometry data of a transiting planet host star and produce a two dimensional surface brightness map of it. Using the Nelder-Mead Simplex Algorithm to minimize a chi-squared function, I am able to solve for relative brightness on the surface of the star. This code is meant to be easily extensible to any Kepler object. Planetary transits in the Kepler data allow for higher resolution of this brightness map along the path of the transit.

### 1. INTRODUCTION

#### 2. DESCRIPTION OF THE MODEL

Overall characterization of the necessary pieces of information. This includes terminology, geometry of a star in the general case, input parameters, model flux, limb darkening, and a description of the brightness values for which we are solving.

##### 2.1. Set-up and Terminology

This section should give an overview of the three types of regions in our stellar brightness map: boxes, stripes, and longitudes. It should also describe why each of these types occupies the region of the star that it does.

Figure [CoRoT brightness map]

##### 2.2. Describe the inputs to the program

This section should describe the stellar input parameters, planetary input parameters, and the model input parameters. This will be a relatively short and straightforward section.

##### 2.3. Model flux

This section should describe the general case for  $f_{mod,i}$ . It should also talk about the specific variables,  $V_{i,j}$  and  $b_j$  and motivate the reason for the visibility calculations below. It should describe the timescale for the evolution of starspots and our decision to include "windowing" in our model. And finally, it should give a brief description of the Simplex algorithm.

### 3. VISIBILITY AS A FUNCTION OF TIME

This section should discuss all of the math involved in the visibility profile of a general case star.

#### 3.1. Region Visibilities

This should outline the rationale behind the integral used to calculate the projected surface area of each region. It should show the integral once and then show that for a box and a longitude, the  $\theta$  limits are the only thing that change. It should also discuss the fact that the stripe visibilities are calculated within the Amoeba Algorithm and why (or I should change it in the code).

#### 3.2. Transiting Planet Model

This section should discuss the idea that the planet is nothing more than a blocking of visibility while it is occluding the star. It should explain the basic geometry of this calculation and show the ten different cases involved.

- Figure[Example of a model transit and my model transit]

#### 3.3. Limb Darkening

The final visibility section will outline the limb darkening. Important facts to include are that we use a quadratic limb darkening equation, we include limb darkening both in and out-of-transit, and the specific math behind our calculations for each region (yay for analytically solving things).

##### Note

Everything is done as a function of time over the orbit.

### 4. VALIDATING OUR MODEL

Now that we have properly defined how our model works theoretically, we need to prove that it does work in practice

#### 4.1. What is variable?

Give a description of the parameters that we still can mess with. For example, the number of stripes, number of boxes, and binning cadences both in and out-of-transit.

#### 4.2. Making the model light curves

Describes the process of generating a model light curve and how, in our case, it was intrinsically linked to the stellar and planetary parameters of Kepler 17. It should briefly mention that I use a python script to generate Gaussian noise based on Kepler magnitude noise. It should also outline the list of spot models that we tried and our motivation for doing so.

#### 4.3. Testing Complexity

We have only tested the ability of our program to solve for brightness values in two parameter spaces, complexity of the spots and noise of the light curve.

#### 4.4. Results

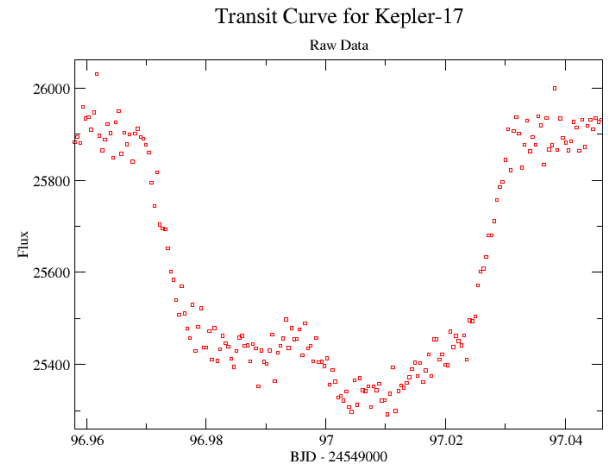
Show plots (RMS, 2d boxes over time, stripes, etc.)

### 5. APPLICATION OF OUR PROGRAM TO REAL DATA

Kepler 17

## 6. POSSIBLE FIGURES

## 1. Brightness maps



**Figure 1.** One transit from the actual Kepler 17 light curve. You can see the characteristic "bite" out of the transit curve where a starspot is likely occluded.

## 2. Model lightcurve fits

4. CoRoT brightness map

5. Figure showing angles that are discussed

6. Geometry of eclipse path visibility calculations

7. Visibility Plots

8. Stripes over time

9. Boxes over time

10. Errors and residuals

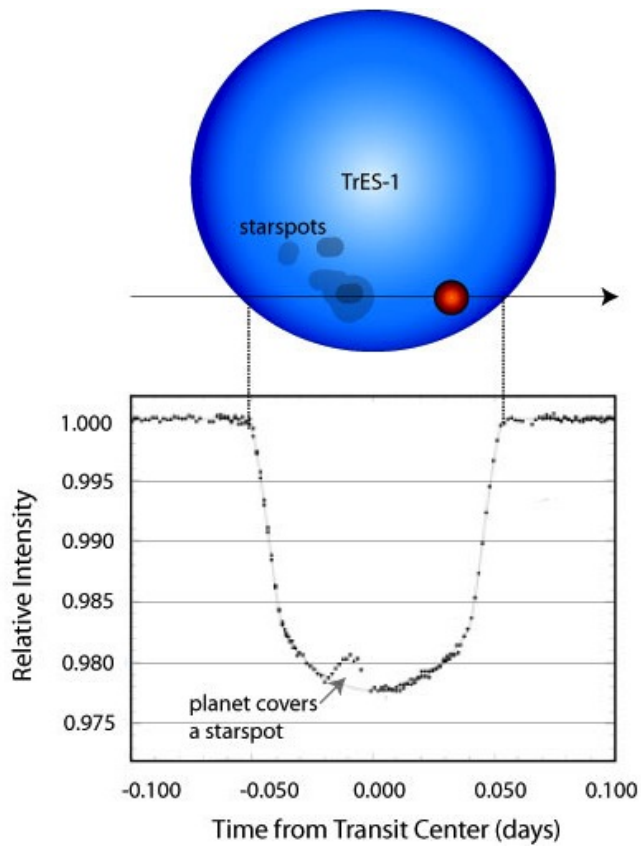
11. Simplex

12. Unbinned vs. binned lightcurves

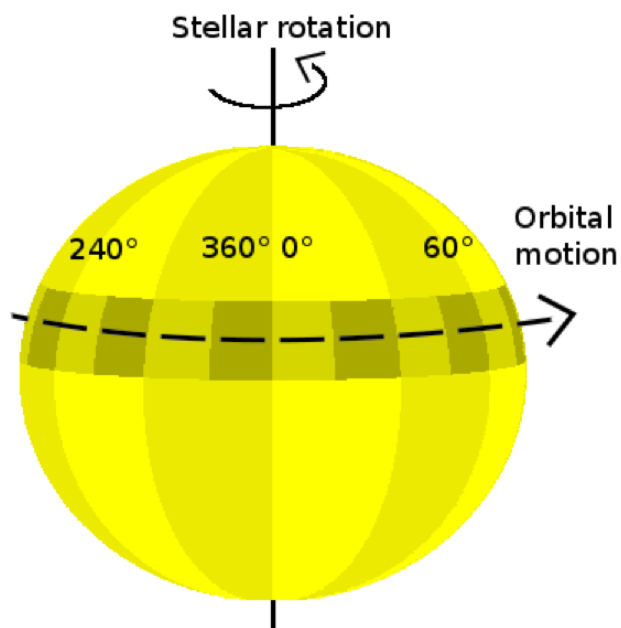
13. Noise in the models

14. ...?

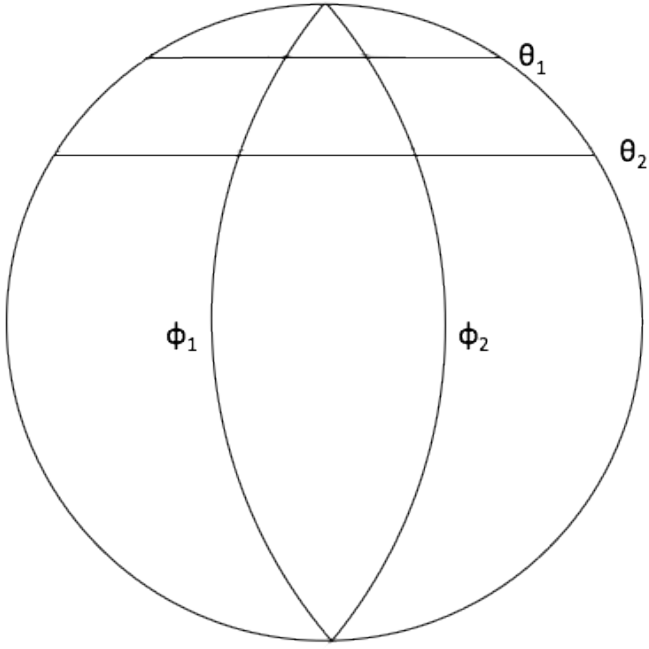
3. Transit starspot bumps (TrES-1 Cartoon)



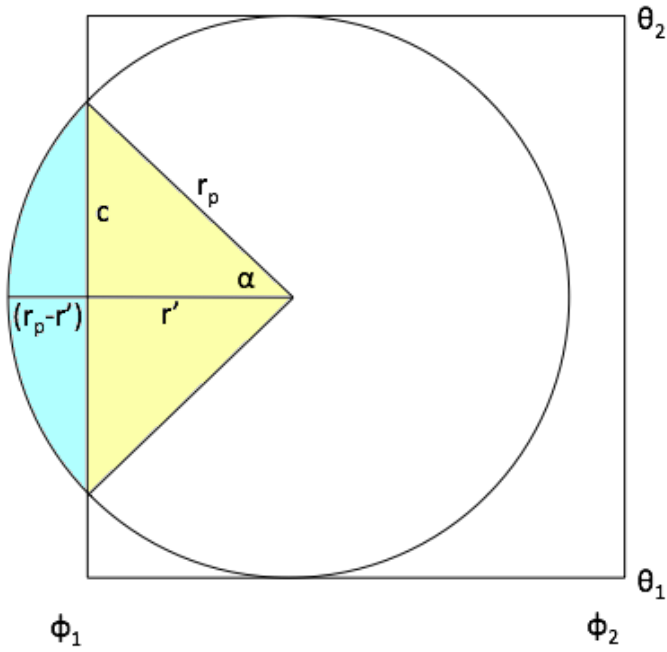
**Figure 2.** A clear illustration of the effect of a starspot on a transit light curve. When the planet blocks the spot it is occluding a relatively less bright region of the star and the effective luminosity increases.



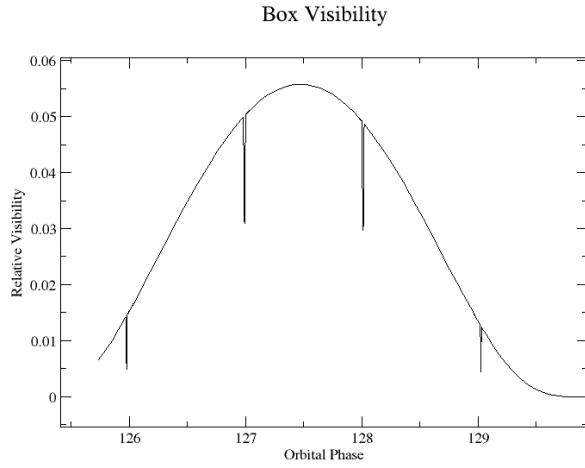
**Figure 3.** Example of a brightness map that is defined by our code. This image was taken from the first paper detailing this technique. It was done specifically on CoRoT 2.



**Figure 4.** A reference image for the angles that are discussed in relation to the definition of visibility values on the star.



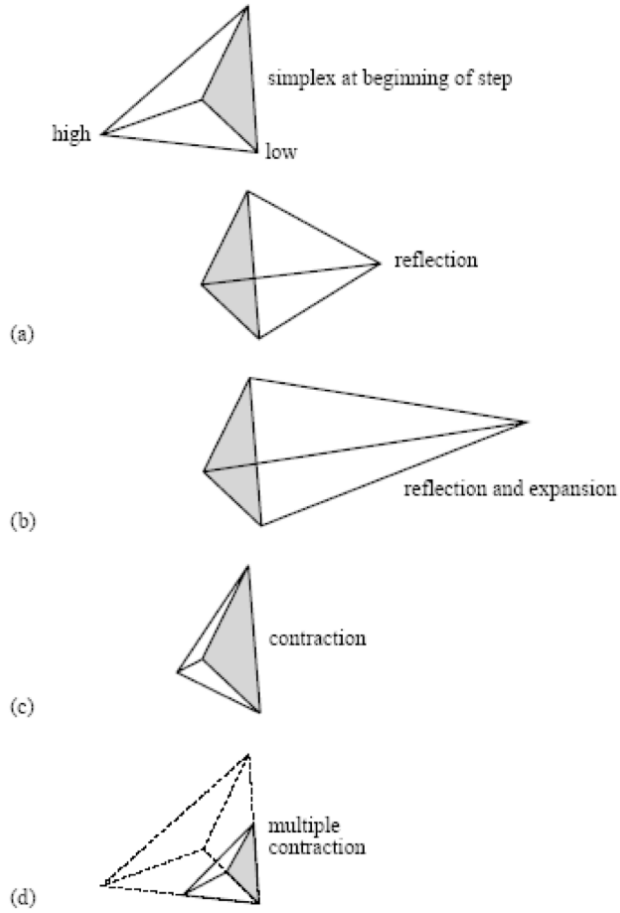
**Figure 5.** A simplified visualization of the geometry used in defining the eclipse path visibility of a system. The blue section is the important area for which we are solving.



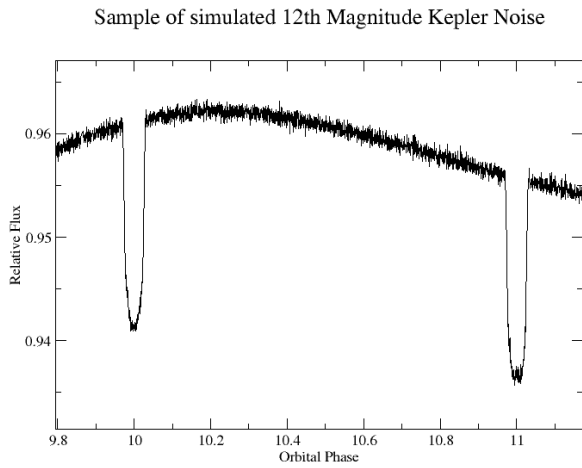
**Figure 6.** The visibility of one box during one window. Note that the transit dips are not full transits, but only a portion of the transit while the planet is in front of that specific region.

images/sum\_vis.png

**Figure 7.** Overall visibilities for a window. The longitudes' visibility values are 1.0. The stripes are the next highest, but do not have transits in them. The boxes are the lowest values.



**Figure 8.** The various operations that a simplex can use to "move downhill" in chi-squared space.



**Figure 9.** Example of Gaussian noise in a model. This particular light curve part is one "window" in our model. It has a simulated noise similar to that of a Kepler 12th magnitude star.