Gravitational Microlensing

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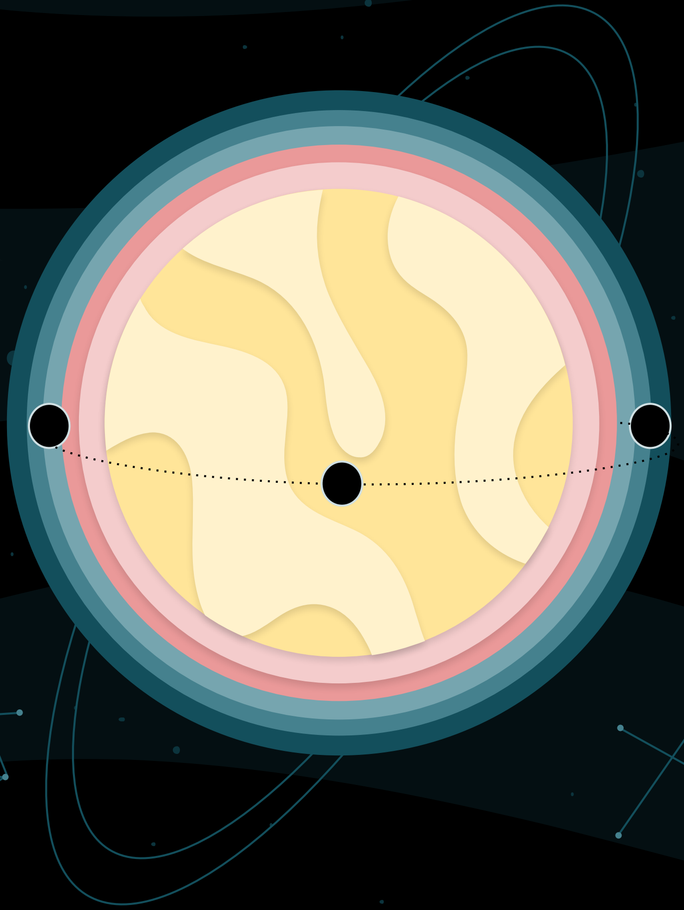


What is the research presentation about?

We are basically taking three Microlensing Events, and fitting them to a model. Our steps are as follows:

- Pick 3 random events from the OGLE Database
- Check the parameters from the Paczynski Model and optimize them (Remember Practical 5?)
- Fit the Paczynski Model (with those parameters) to those events and visualize it
- Run MCMC analysis to check the range of variability
- Analyze bias, quantification and residuals
- Conclusion

What is Microlensing and why is it important?

Gravitational Microlensing occurs when a massive body (the lens) passes in front of a source of light from our perspective on Earth, causing a distortion in brightness for the duration of the event. These massive objects can vary from other massive stars to point-mass objects. Such astrophysical phenomenons are detected and recorded by OGLE EWS (Optical Gravitational Lensing Experiment Early Warning System). The recorded data sets allow for the creation of fit-curves using the Paczynski Model, which will allow calculations to additional information about the event.

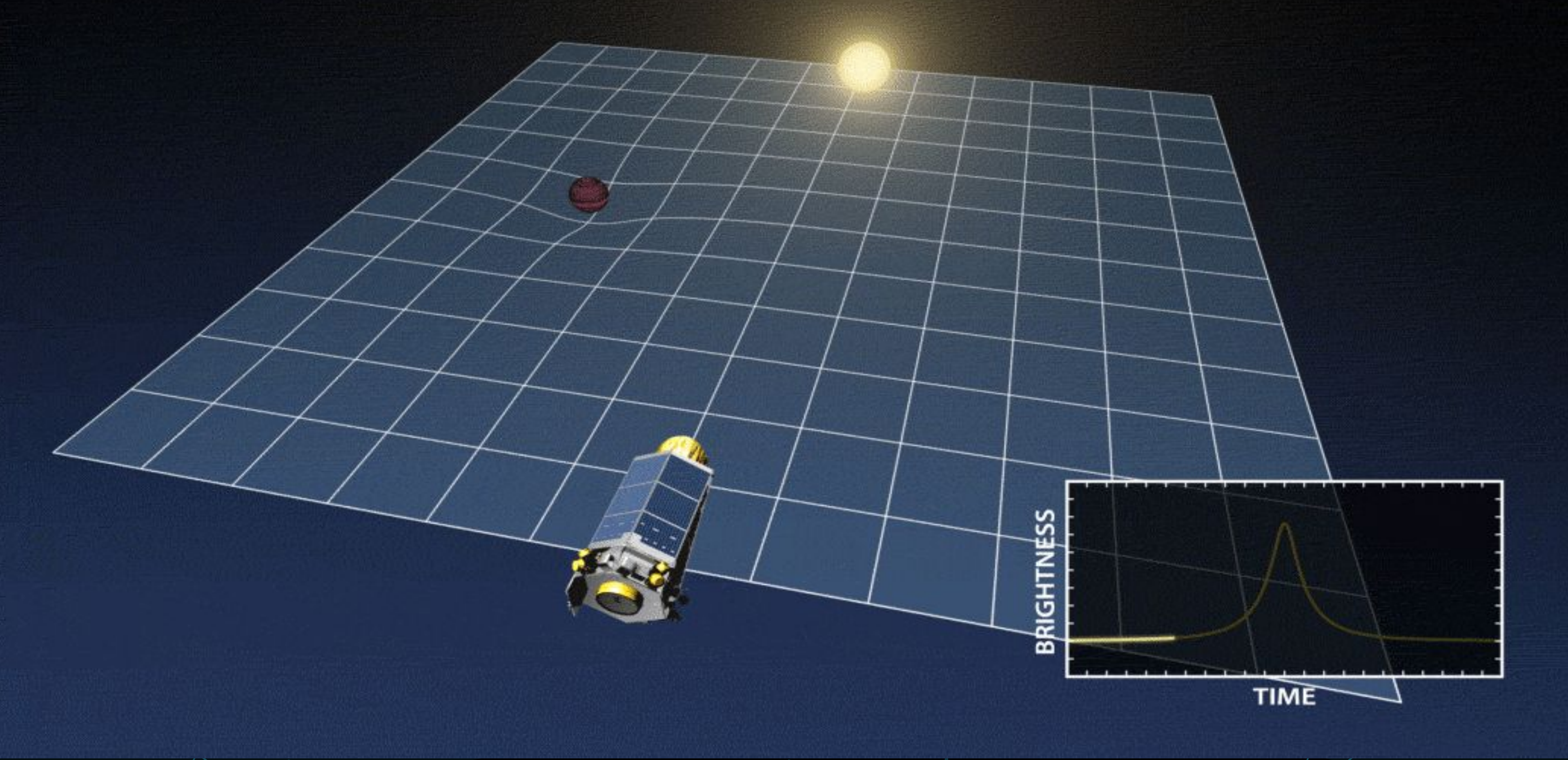


Image credit: NASA Ames/JPL-Caltech/T. Pyle, https://www.jpl.nasa.gov/news/news.php?feature=6314

The Model

The primary model for a microlensing curve* is the Paczynski Light Curve, which is:

$$m(t) = m_{src} - 2.5log_{10}[f_{bl} \cdot A(t) + (1 - f_{bl})]$$

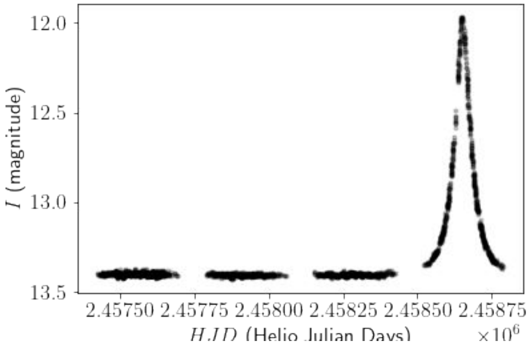
Here, m(t) is the apparent magnitude as a function of time. M_{src} is the baseline magnitude, A(t) is the amplification as a function of time, and f_{bl} is the blend parameter, which tells us what fraction of the brightness is from the background star. The lensing amplification is defined as:

$$A(t) = \frac{u(t)^2 + 2}{u(t)\sqrt{u(t)^2 + 4}} \qquad where \qquad u(t) = \left[u_{min}^2 + \left(\frac{t - t_0}{t_E}\right)^2\right]^{\frac{1}{2}}$$

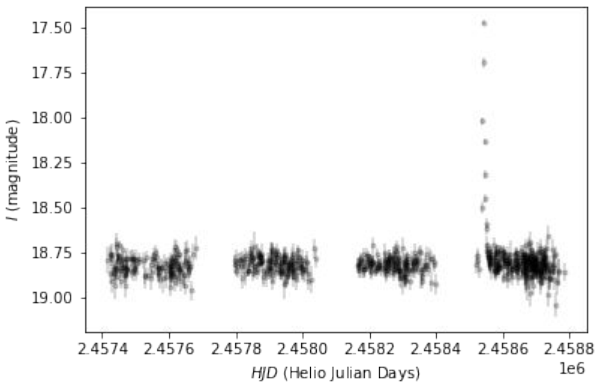
Here, u(t) is the alignment (the projected distance) of the source from the lens as a function of time. u_{min} is the is the minimum distance (also called the impact parameter). t_0 is the time when the light curve reaches its peak, and t_E is the Einstein time scale for the event. Some models and research papers use τ and t_E interchangeably.

Picking Datasets

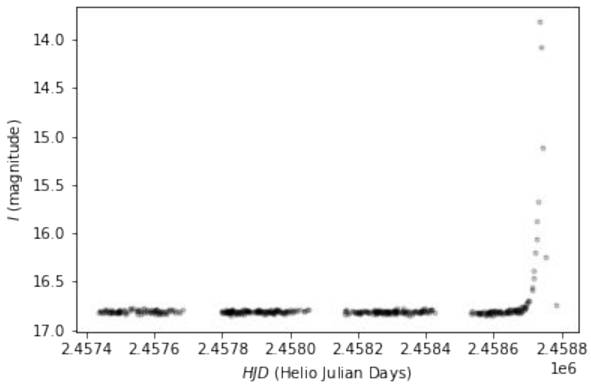
Choose 3 events randomly. We used a random number generator between 0 and 1526 and we got 148, 164 and 1307. Here's what they look like:



BLG 148



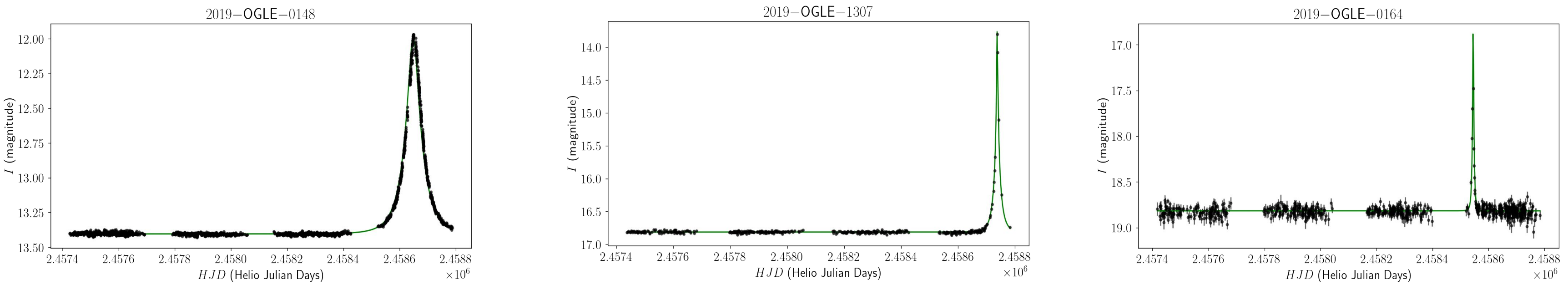
BLG 164

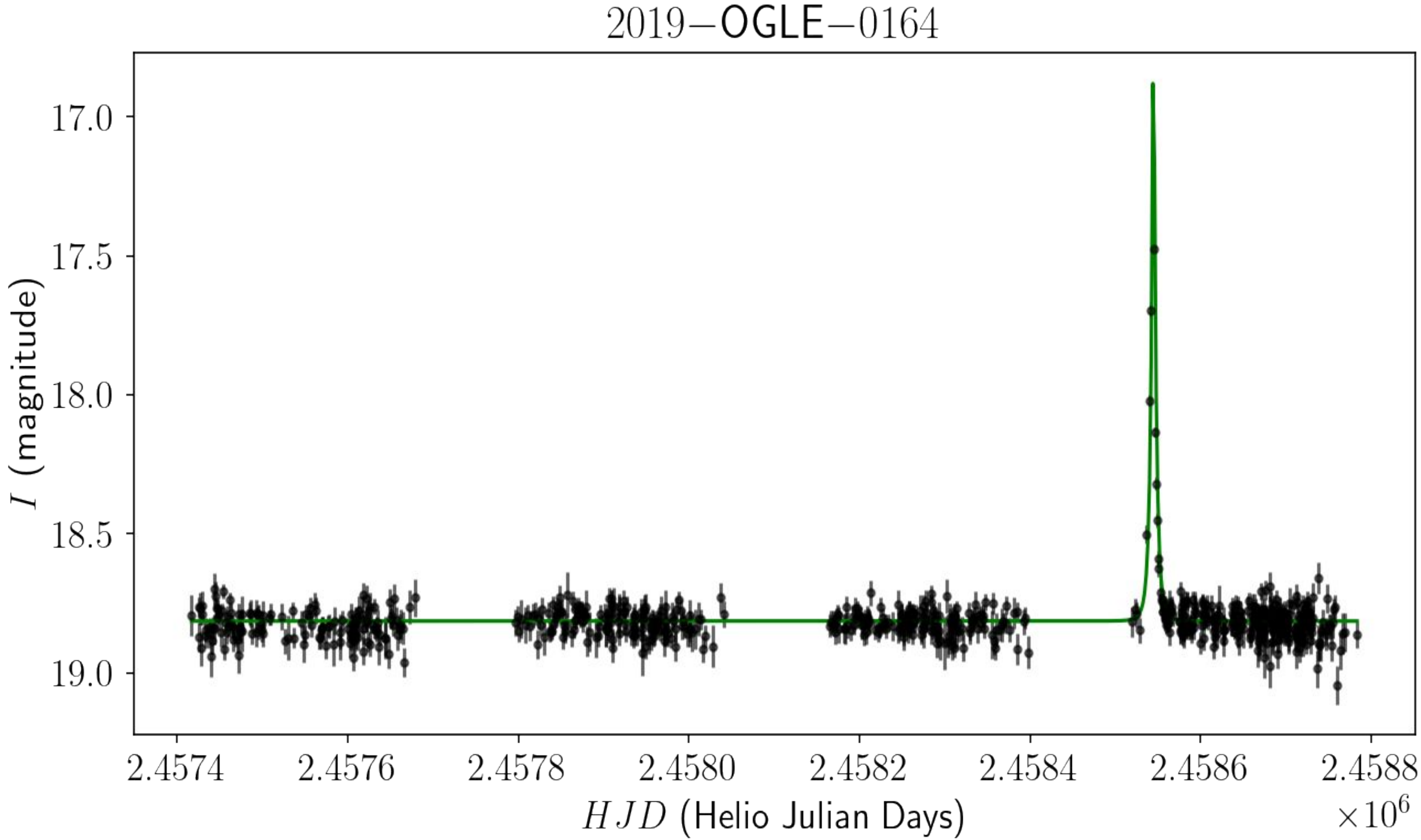


BLG 1307

Model Fitting

After optimizing the parameter values from the OGLE database, we fit the Paczynski Model to the data:

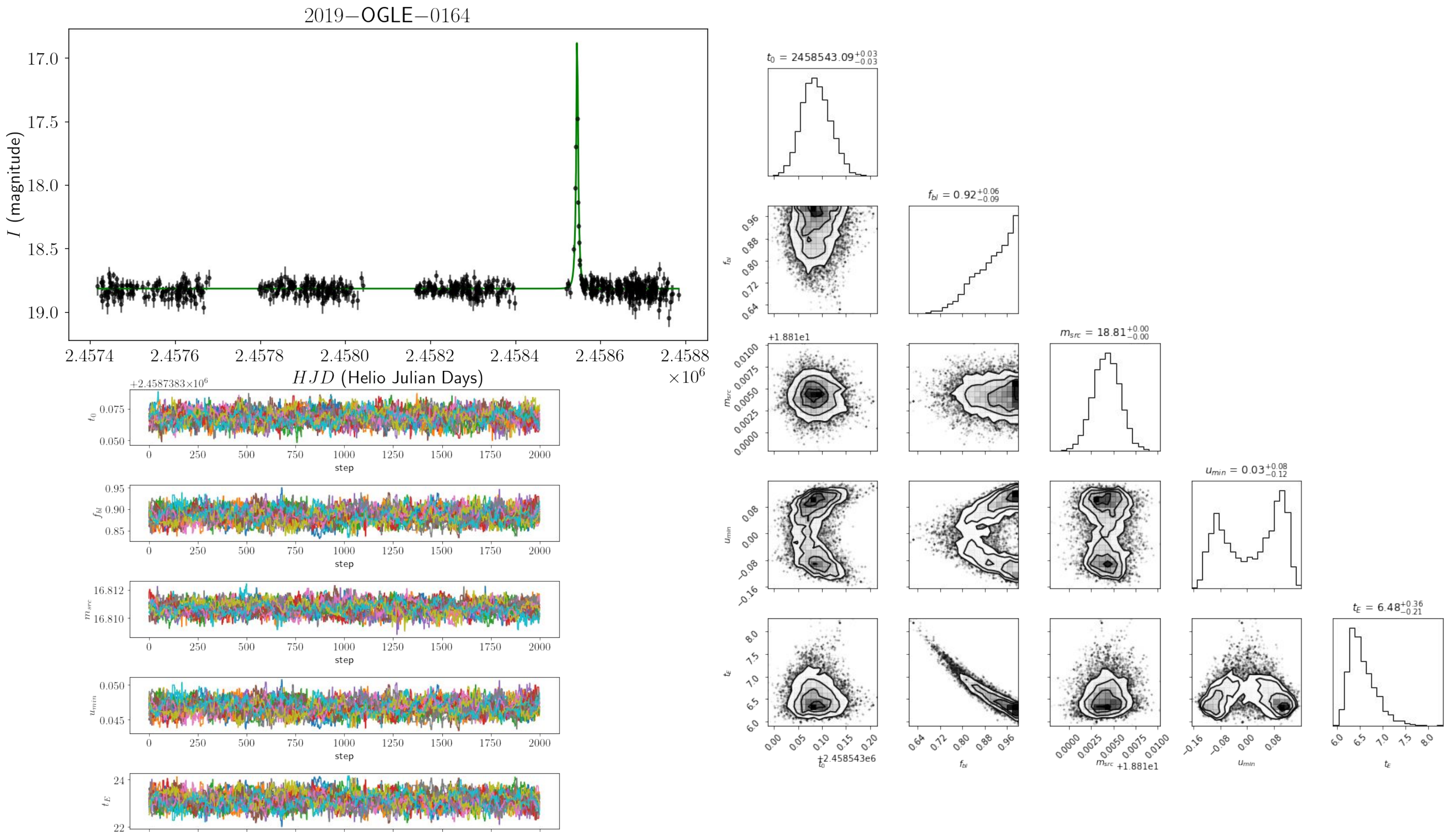




2019−OGLE−0164
17.0
17.5
18.0
18.5
19.0
I (magnitude)
2.4574
2.4576
2.4578
2.4580
2.4582
2.4584
2.4586
2.4588
HJD (Helio Julian Days)
×10^6

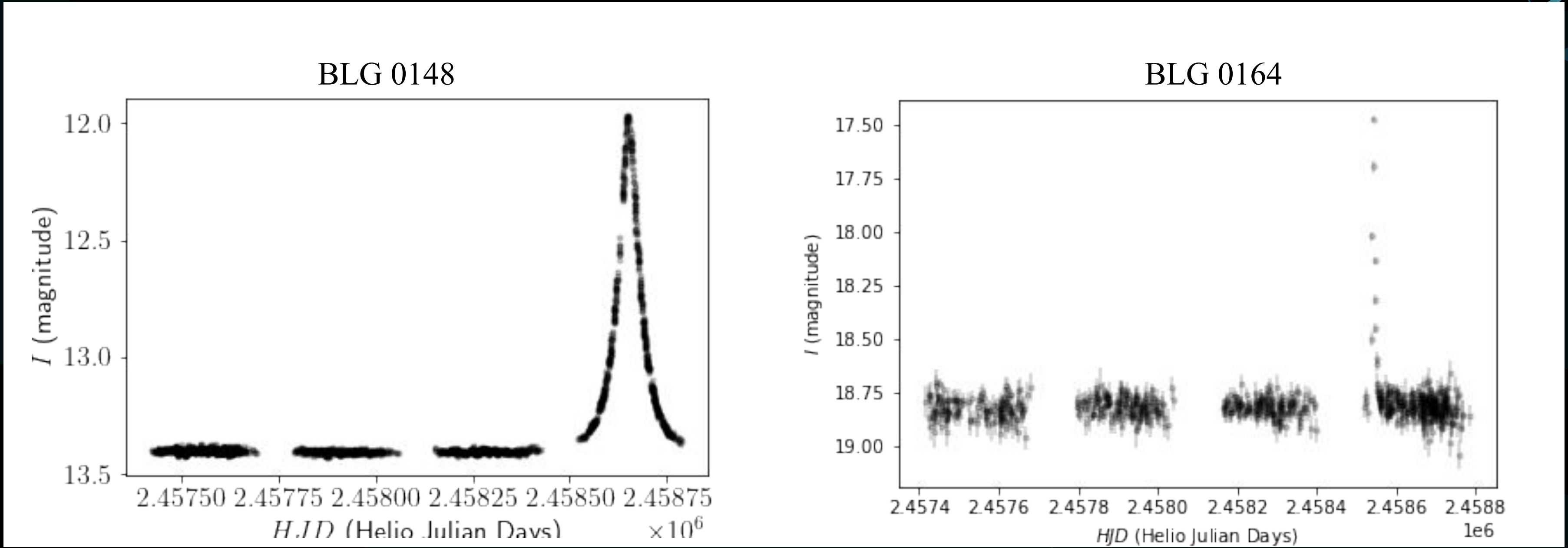
Running MCMC Analysis

We ran Markov Chain Monte Carlo Analysis to check for variability in the probability distribution of the parameters. We used a likelihood function, and a prior function. This is important because we have some prior knowledge about some parameters. For example, f_{bl} has to be constrained between 0 and 1 since it is a fraction. We then used 20 walkers with 400 burn in steps and ~2000 main run steps to extrapolate the 5 parameters from the fitted data.



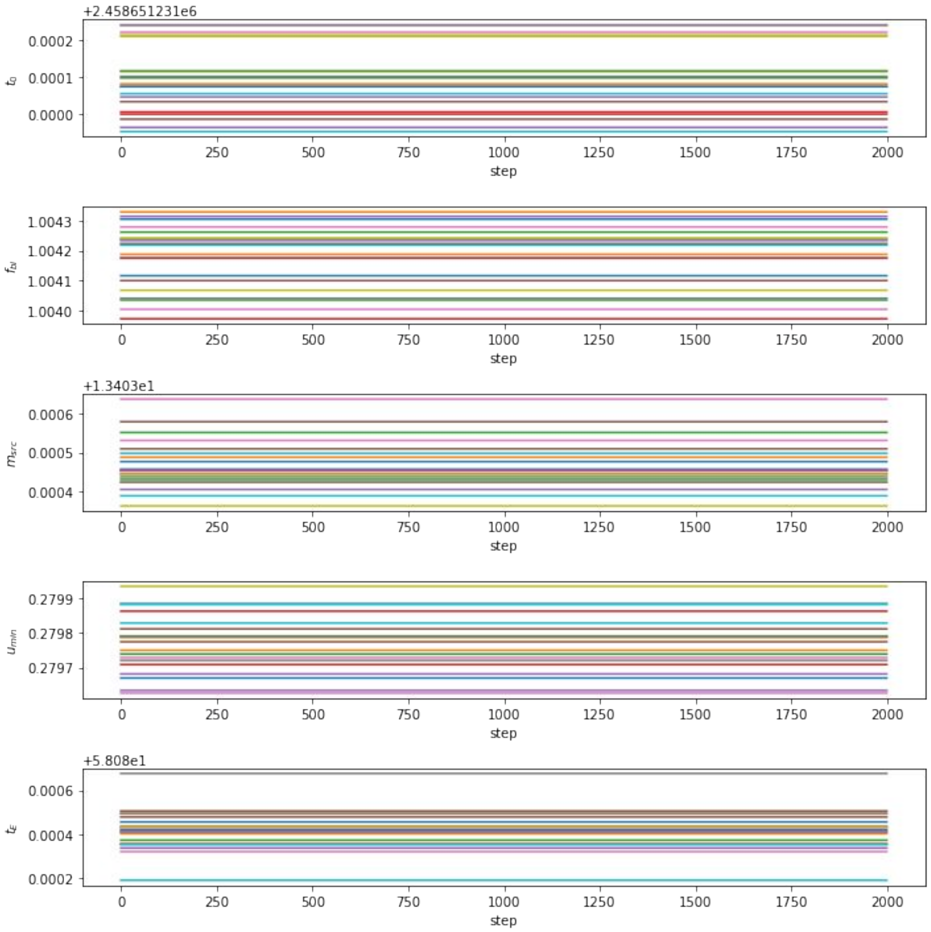
2019−OGLE−0164
I (magnitude)
HJD (Helio Julian Days)
×10^6
step
t_0 = 2458543.09 +0.03 −0.03
f_bl = 0.92 +0.06 −0.09
m_src = 18.81 +0.00 −0.00
u_min = 0.03 +0.08 −0.12
t_E = 6.48 +0.36 −0.21
+2.458543e6
+1.881e1

Clean vs Messy Data

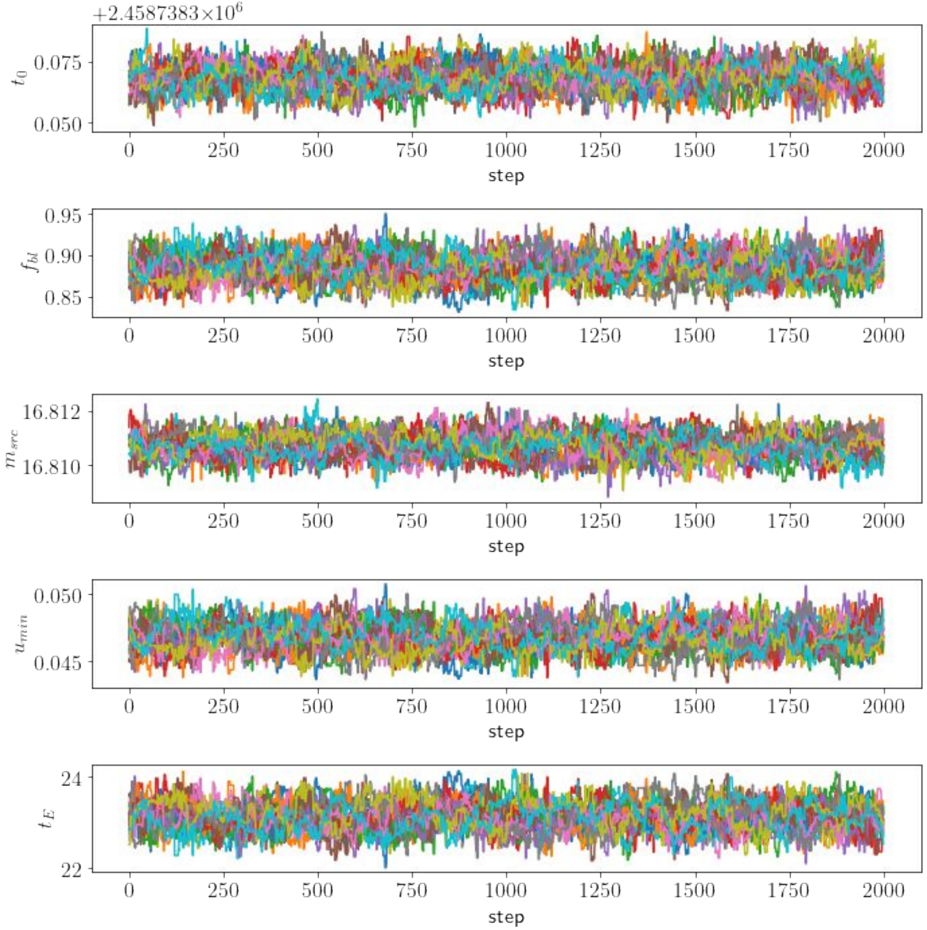


We see from the plots that the observed data points BLG 0148 is much cleaner than BLG 0164. Here ‘clean’ means it has less variability and has more consistency. How does this affect MCMC?

Walkers plot for BLG 0148



Walkers plot for BLG 0164



Clean vs Messy Data - Conclusion

- Since we are measuring data from far away, there will always be a limitation with the instruments used to record the data
- Astrophysical phenomena are prone to variability and natural flexibility
- The model, Paczynski Lightcurve, can handle noise and still output reasonably well parameters
- Cleaner datasets are more favorable

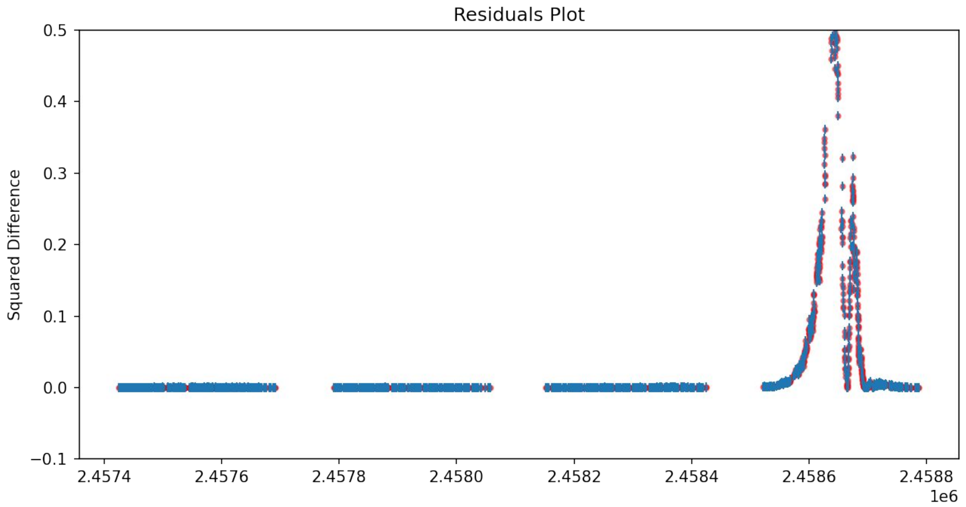
But why?

Residual Analysis

We know cleaner dataset gives us better outputs, but how to quantify that difference?

We use residual analysis. Basically :

- take the difference between the model y-values and the y values of the data points.
- Note that the y-values are the magnitudes, and the difference Δy is the error value
- Plot the Residuals
- Compare the residuals between clean versus messy data



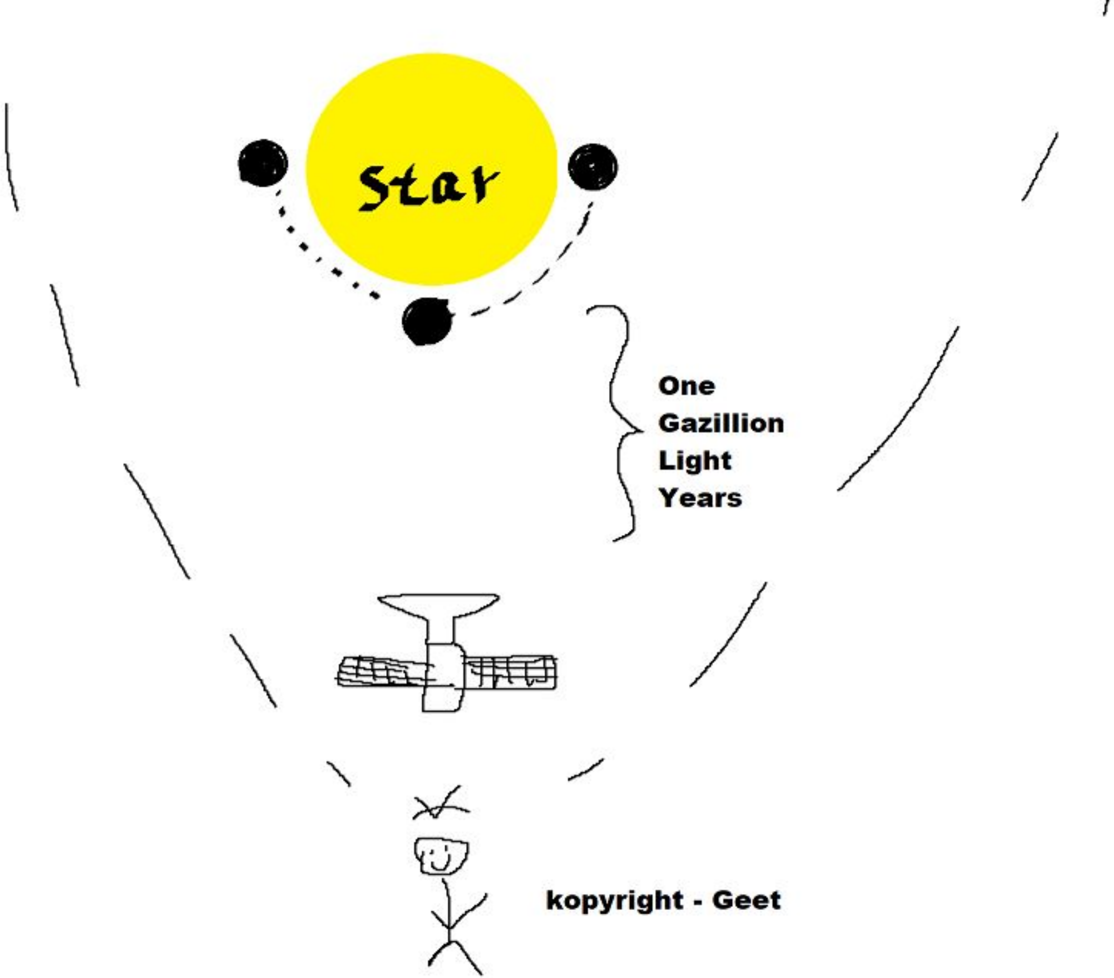
(a) BLG-0148

(b) BLG-0164

Figure 8: Residual variability between clean distribution and messy distribution

BIAS

- Measurement of observed values from any microlensing event is non-trivial unless certain assumptions are put in place. (the asterisk from the second slide)
- One of these fundamental assumptions is assuming that both the lensing and source objects act as points
- Another limitation that needs to be addressed is blend, which is the contribution to the brightness by other objects


Star
One
Gazillion
Light
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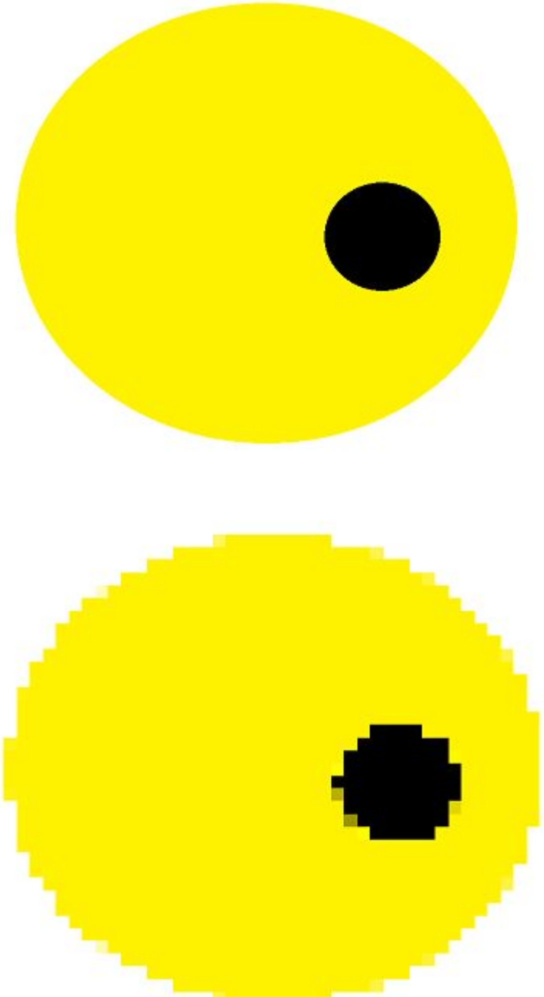


Alternate Models Analysis

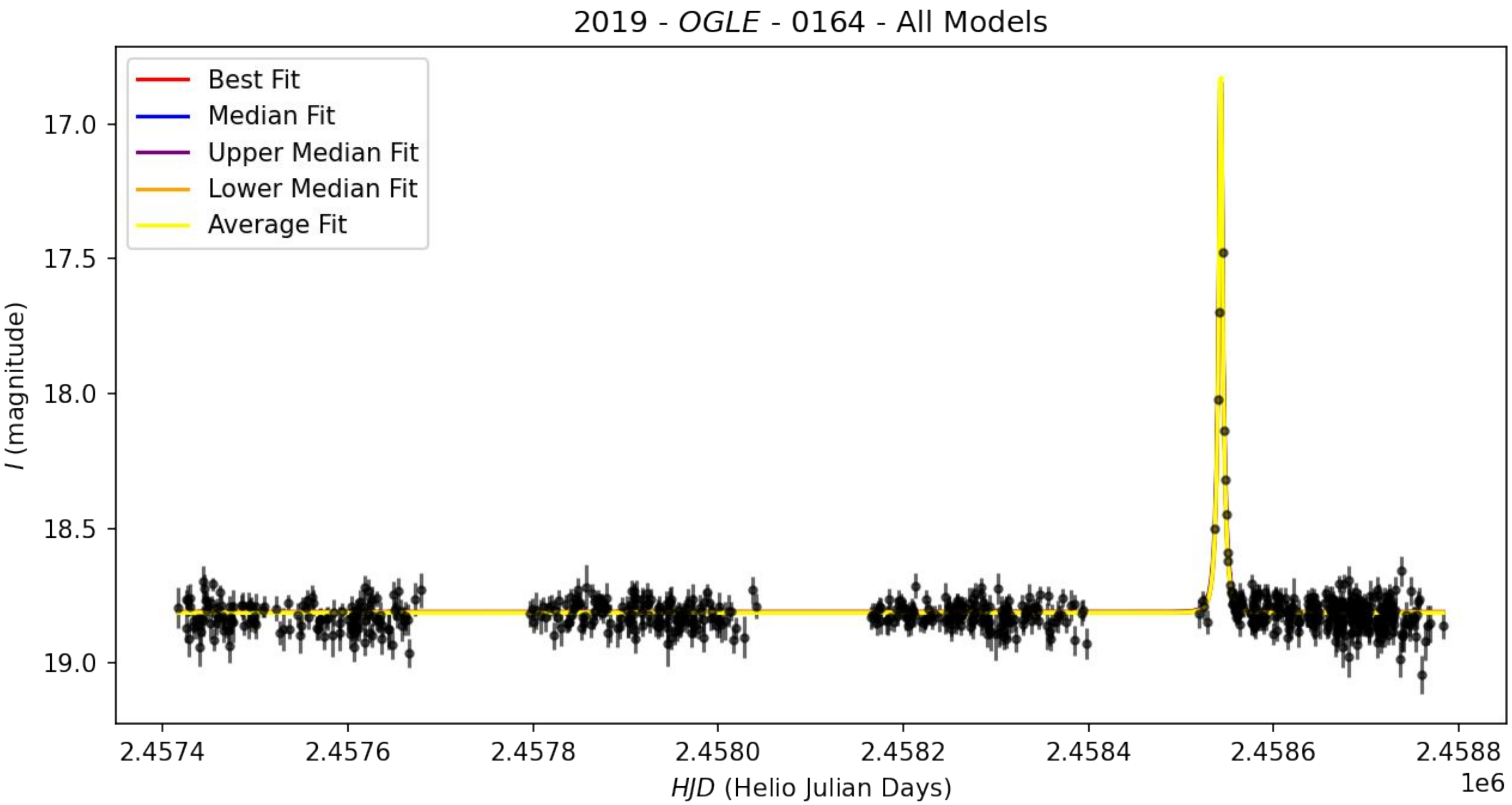
It is worth mentioning that there are several different ways to obtain reasonable parameters:

- Optimization gives the best fit model to the data since it relies on minimizing a χ^2 function

- There are also the median values taken from the MCMC analysis (both upper and lower when errors are taken into account)

- Finally there is the average of all MCMC values for each parameter

- To check the variability of these different parameter values, all five models were plotted together on the same plot for the BLG-0164 data set



2019 - OGLE - 0164 - All Models
Best Fit
Median Fit
Upper Median Fit
Lower Median Fit
Average Fit
17.0
17.5
18.0
18.5
19.0
I (magnitude)
2.4574
2.4576
2.4578
2.4580
2.4582
2.4584
2.4586
2.4588
1e6
HJD (Helio Julian Days)

Alternate Models Conclusion

- Despite its variability, the models deviate from each other negligibly.
- So even though there might be many ways of extracting parameters, they are close enough to each other that it is reasonable to ignore them.
- So we only consider the optimized model when talking about the best fit.

Conclusions and Key Takeaways

The model fitting of the data sets have revealed critical information about the Paczynski Light Curve:

- MCMC analysis shed some light on our inherent assumptions made and how those affect the data
- Data Quantification Analysis shows that there is a direct correlation between the amount of noise and the variability in the parameter
- It is noteworthy to mention that the conclusions derived from the experiments and the probability distribution for the parameters is based on the initial assumption that all events include point like sources and lense
- This means that the Paczynski Curve will **<u>not necessarily</u>** be an effective model to predict lensing trajectories for events that aren't single source and lens events, as we cannot make the point-like assumption in those cases

BIBLIOGRAPHICAL REFERENCES

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