genulens : A Tool for Gravitational Microlensing Events Simulation with a Galactic Model Based on Gaia and Microlensing Data

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ABSTRACT

This poster introduces genulens, a public tool to simulate microlensing events using Monte Carlo simulation based on the Galactic model developed by Koshimoto, Baba & Bennett (2021). The Galactic model includes the asymmetric drift of Galactic disk stars and the dependence of velocity dispersion on Galactic location in the kinematic model, which has not been considered in most previous models used for microlensing studies. The model was developed by fitting to spatial distributions of the Gaia DR2 disk velocity, VVV proper motion, BRAVA radial velocity, OGLE-III red clump star count, and OGLE-IV star count and microlens rate, optimized for use in microlensing studies. Using genulens, you can calculate the probability distribution of microlens parameters based on the new Galactic model. This enables you to do Bayesian analysis to derive the lens parameters for individual events, to distinguish degenerate models based on the Galactic prior, and to perform statistical analysis by comparing the distribution of microlens parameters between observations and models. This poster shows several examples of its use.

1.INTRODUCTION

Galactic model in microlensing studies

- Used to calculate the prior distribution of microlens parameters
  - in individual event analysis
    (e.g., Beaulieu et al. 2006, and most event analysis papers)
  - in statistical studies
    (e.g., Sumi et al. 2011, Mróz et al. 2017, Koshimoto et al. 2021)

→ *Crucial in microlensing studies* toward the Galactic Bulge

Models of unknown consistency with real data are used

- Each authors are using their own Galactic model, mostly **an arbitrary combination of** features taken from the Galactic models by Han & Gould (1995), Han & Gould (2003), and Robin et al. (2003), in addition to some authors' original modifications.

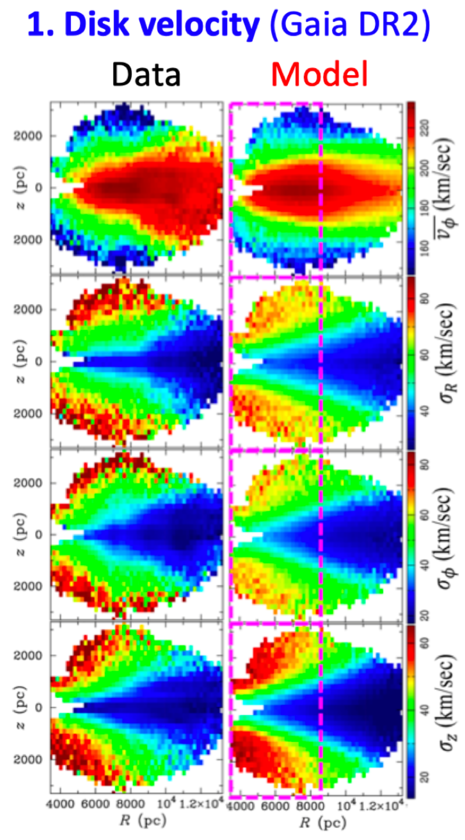
→ Although mixing of different features from different models could mess up its consistency with observations, *none of them were seriously tested with real data.*

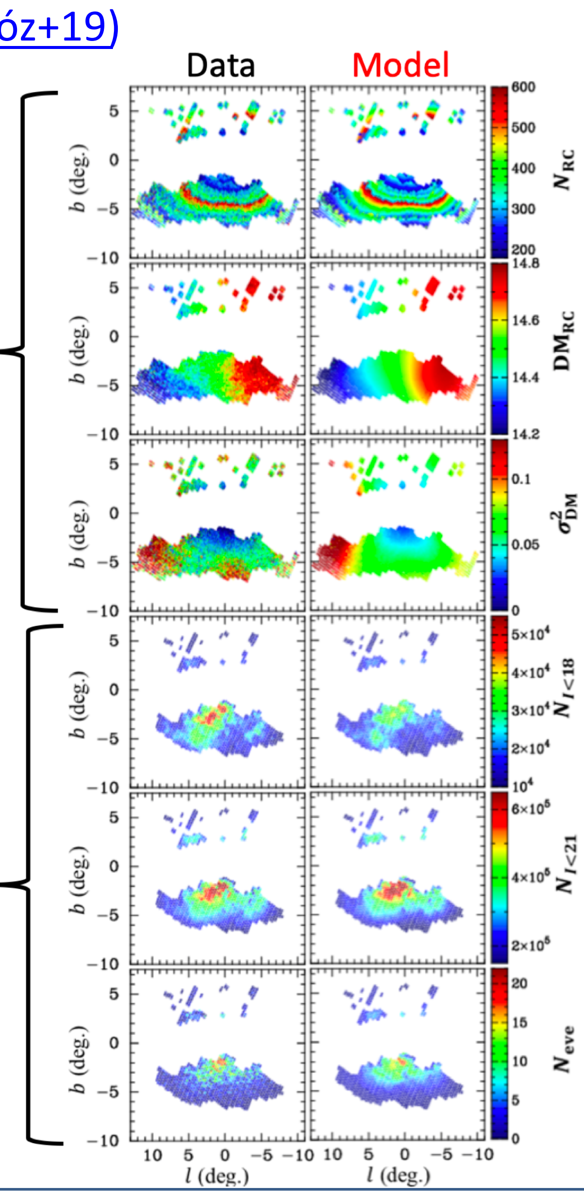
2. THE NEW GALACTIC MODEL

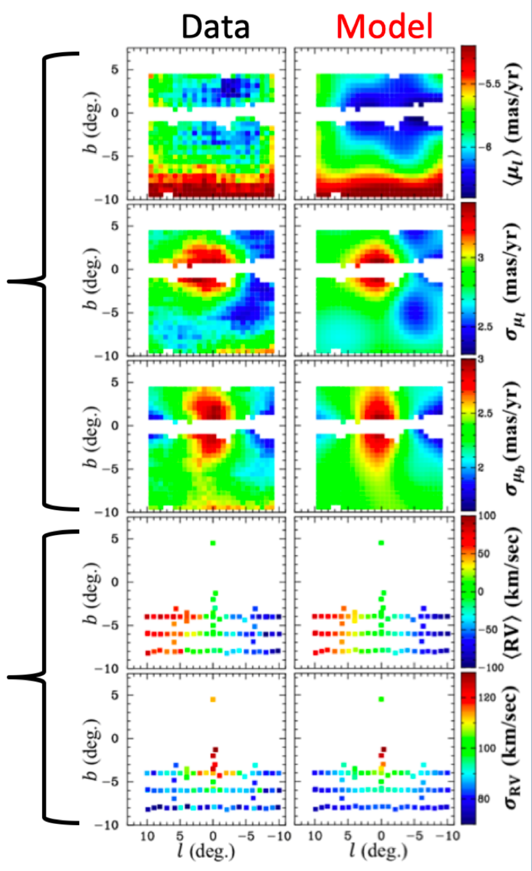
Fitted to recent bulge data!

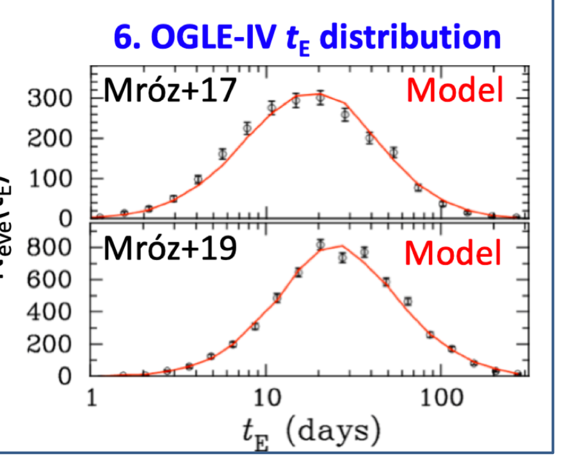
- Koshimoto, Baba & Bennett (2021) develops a new Galactic model based on recent data (see right figure) toward the Galactic bulge.
- Confirmed that the MOA 9-yr t_E distribution can be perfectly reproduced with no extra fit (Sumi+, in prep.)

- Fitted to distributions of
  1. Disk velocity (Gaia DR2, Katz+18)
  2. Bulge RCG count (OGLE-III, Nataf+13)
  3. Star & μlens count (OGLE-IV, Mróz+19)
  4. Proper motion (VVV, Clarke+19)
  5. RV (BRAVA, Rich+07)
  6. t_E (OGLE-IV, Mróz+17, 19)



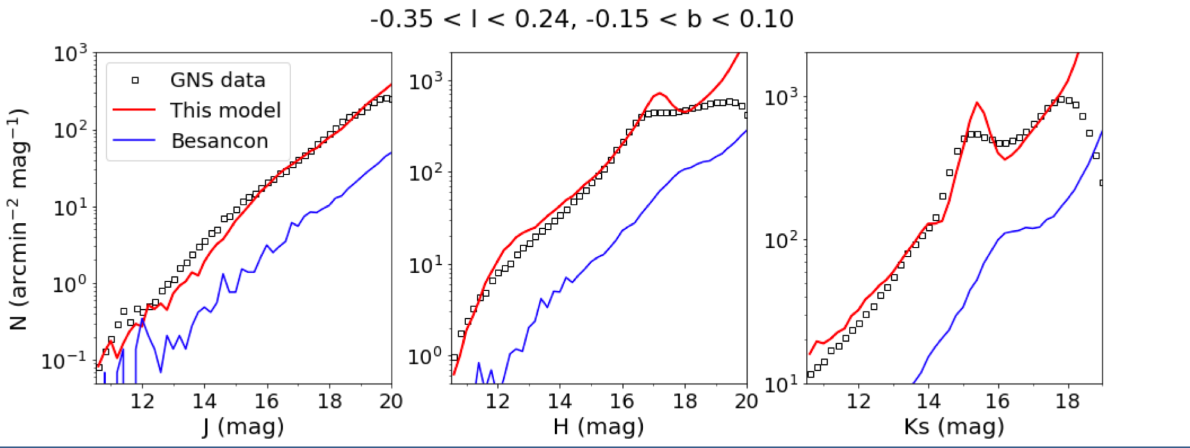






Can be used also in the GC region

- Although the fit region is $|b| \gtrsim 2°$ (see right figure), the nuclear stellar disk (NSD) component was later added, and a moderate agreement with the GALACTICNUCLEUS data (Nogueras-Lara+19) in the GC region is confirmed (figure below, Koshimoto+ in prep.).



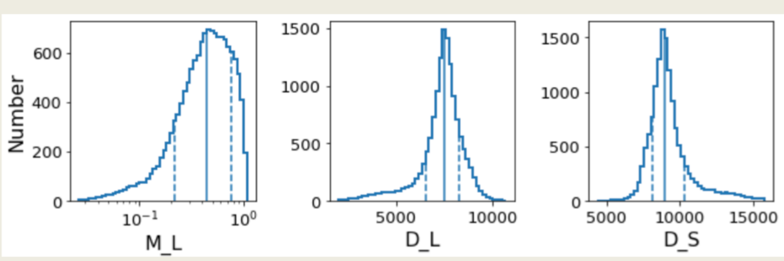
3. THE MODEL IS PUBLICLY AVAILABLE!!

genulens (Koshimoto & Ranc 2021)

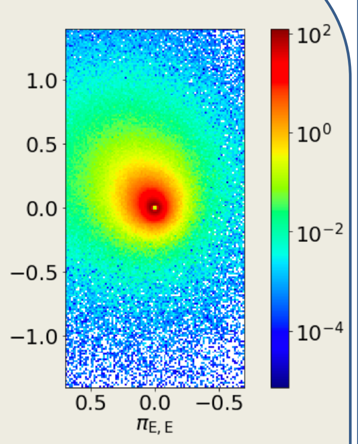
- A tool to simulate microlensing events.
  https://github.com/nkoshimoto/genulens

Part of sample calculations in this jupyter-notebook

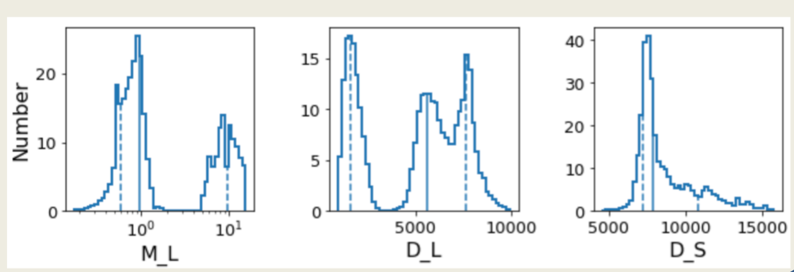
Posterior distribution of the lens mass and distance for a planetary event
(computational time: ~15 secs.)



Prior probability of $(\pi_{E,N}, \pi_{E,E})$ (= Fig.5 of Kondo+21.
computational time: ~14 secs.)



Posterior distribution of the lens mass and distance for a black hole candidate event
(computational time: ~4 mins.)



Applications of the Galactic model in papers

- **Koshimoto+21** used it to estimate the dependence of planet frequency on Galactocentric distance.
- **Kondo+21** used the Galactic $(\pi_{E,N}, \pi_{E,E})$ prior to strengthen the Spitzer's 1D parallax constraint.
- **Ranc+21** used the Galactic prior to calculate the posterior distribution of the lens property.
- **Terry+22** used the Galactic $(\mu_{rel,N}, \mu_{rel,E})$ prior to identify the likely lens object in the Keck image.
- **Johnson+22a,b in prep.** uses the Galactic model for their Roman survey simulation to predict its constraints on $\eta_\oplus$ (cf. Samson's talk in Session 3)
- **Kondo+22 in prep.** uses the Galactic model for their PRIME survey simulation (cf. Iona's talk in Session 1)

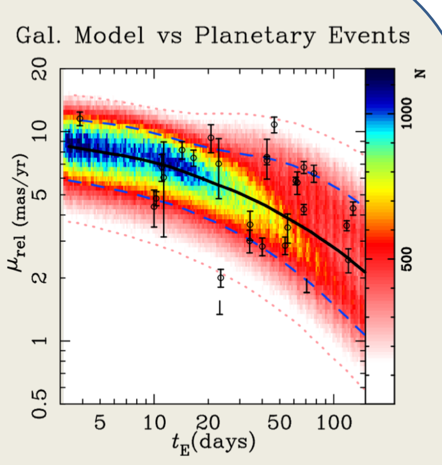


Fig. 1 of Koshimoto+21

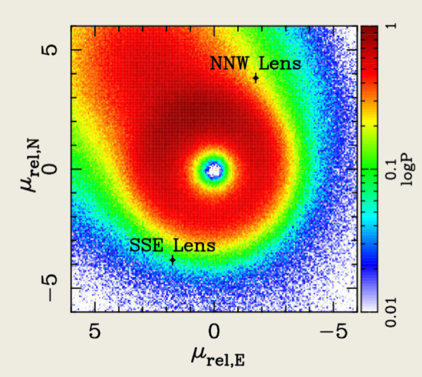


Fig. 5 of Terry+22.