Primordial Black Holes in Extrasolar Systems

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- Astrophysical black holes
  - Formed by stellar collapse
  - Mass of the black hole at least 2.3 times the mass of the solar sun
- Primordial black holes
  - Formed in points where there are large fluctuations of energy
  - Mass can be really small

What are extrasolar systems?

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James Webb Telescope took the first direct image of a planet outside our solar system!

Primordial black holes

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We aim to further constrain the properties of primordial black holes by examining their encounters with star systems

Method

- Three-body gravitational problem
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Question

Given a close encounter between a flyby primordial black hole with a star-planetary system, how do different dynamical parameters impact the orbital parameters of the planet?

Orbital Parameters

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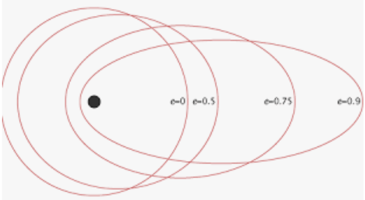
Change in eccentricity (angular momentum)



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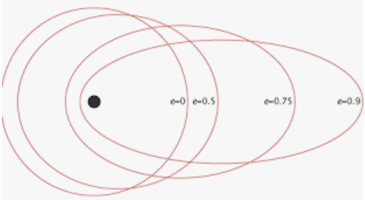
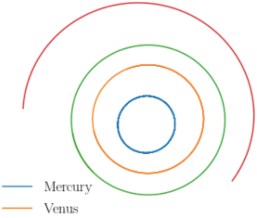
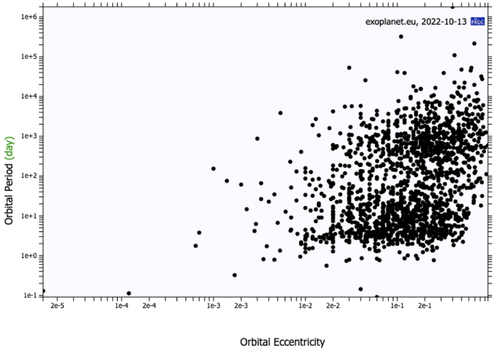


Change in semi-major axis (binding energy)



Exoplanet Database

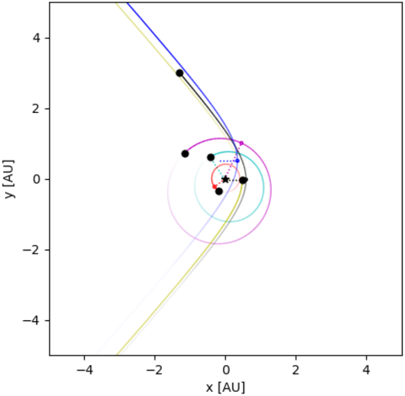


Idea

We want to use exoplanet measurements to constrain the possibilities of close encounters with primordial black holes

Simulations

- Open software REBOUND (RL12)



Dynamical Parameters Considered

For each class of simulations, we vary a dynamical parameter of the flyby and compute the average change in eccentricity and semi-major axis due to the flyby

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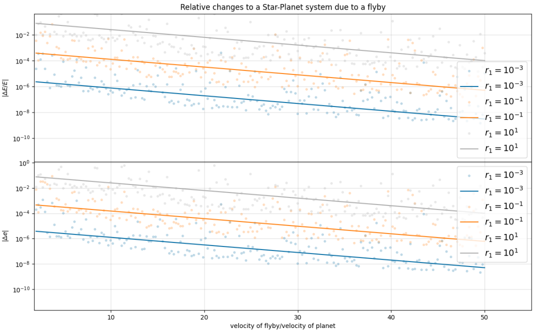
Variables

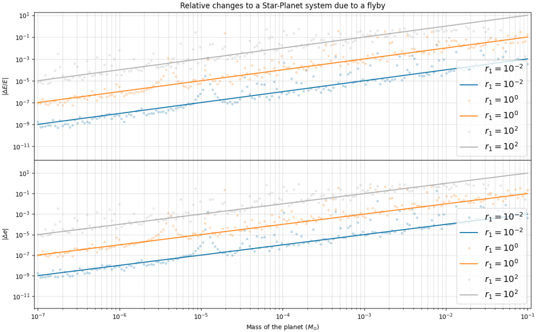
- Velocity of the flyby v_∞
- Mass of the flyby M_*
- Impact parameter the flyby b_*
- Mass of the planet M_1
- Initial eccentricity of planet e_0
- Initial semi-major axis of planet a_0

Primordial black holes in extrasolar systems



The x-axis shows increasing velocity v_∞ of the flyby. Each point represent the average of 10 simulations. The line of best fit is of the form $y = C \cdot 10^{\alpha \cdot x}$ where C is a constant depending on the mass, and $\alpha \approx -0.06$ is a good fit.

Selected Results: Mass of planet



The x-axis shows the increasing initial mass of the planet. The line of best fit is of the form $y = C \cdot x$ where C is a constant depending on the mass.

Question

So far, we have looked at how a single encounter affects the orbital parameters of the planet.

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Next step

- Frequency for which the passing primordial black hole comes within a planetary-star system over the entire galaxy
- Relative velocity with which the passing primordial black hole passes the planetary-star system

Numerical Simulations

- We implement galactic numerical simulations
- Software: GALA (PW17)

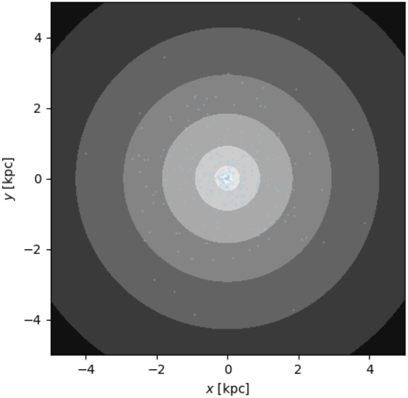
Method

- MilkyWay Potential
- Initialize a population of primordial black holes over the entire galaxy
- Random sampling of the velocity vectors of the primordial black holes
- Fix the distance of a population of stars from the center of the galaxy
- Random sampling of the velocity vectors of the stars

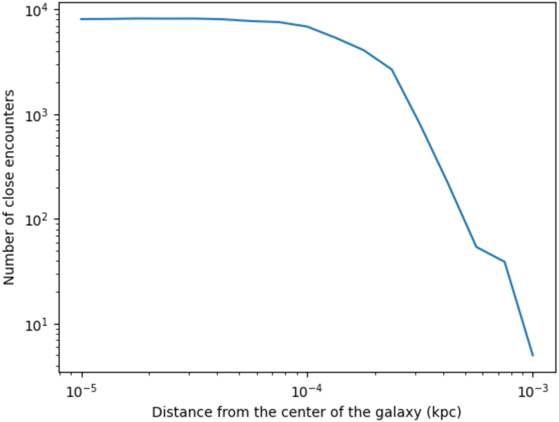
Simulations

Starting Configuration

300 primordial black holes, 50 stars.

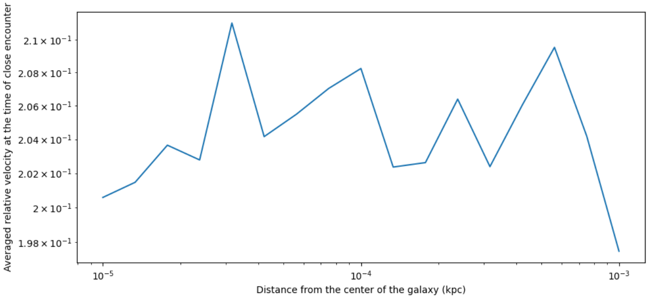


Results-so-far



Results-so-far

Unit of velocity: (kpc/Myr)



Summary

- We can estimate the number of close encounters over the galaxy
- We can estimate the impact of close encounters on the orbital parameters of the planet

Future direction

- For primordial black holes of mass M, how would the existence of a number of such primordial black holes affect the orbital parameters of planets across the galaxy?
- Use the exoplanet measurements to constrain the mass of primordial black holes

Acknowledgement

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- Thank you for listening!

References

[PW17] Adrian M. Price-Whelan, *Gala: A python package for galactic dynamics*, The Journal of Open Source Software **2** (2017), no. 18.

[RL12] H. Rein and S.-F. Liu, *REBOUND: an open-source multi-purposein/i-body code for collisional dynamics*, Astronomy &amp Astrophysics **537** (2012), A128.