Primordial Black Holes in Extrasolar Systems

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What is a black hole?

Region of space with a lot of energy that nothing can escape the gravity

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
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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
- We treat the primordial black hole as a passing flyby, encountering with a star-planetary system
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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 eccentricity (angular momentum)

Change in semi-major axis (binding energy)
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 $v_\infty$
- 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 $v_\infty$ 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.
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.
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

[Graph showing the number of close encounters vs. distance from the center of the galaxy (kpc).]
Results-so-far

Unit of velocity: (kpc/Myr)

![Graph showing averaged relative velocity at the time of close encounter vs. distance from the center of the galaxy (kpc)]
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.
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References
