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Probing Primordial Black Holes as Dark Matter Candidates via X-ray Microlensing

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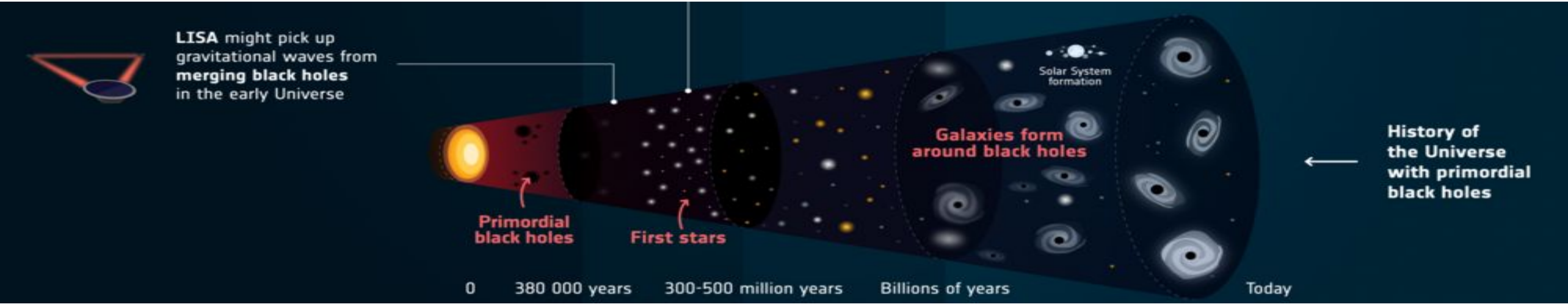


Wikipedia: https://en.wikipedia.org/wiki/Primordial_black_hole

Motivation and Background:

- Current model of dark matter (DM) suggests that it is non-baryonic
  - Non-baryonic matter is matter that is not made of baryons (particles composed of odd # of quarks)
  - Does not have electromagnetic or nuclear interactions
  - Observational and Theoretical evidence from Big Bang Nucleosynthesis constraints, Cosmic Microwave Background Measurements, structure formation. etc.
- Examples of non-baryonic dark matter candidates:
  - Weakly Interacting Massive Particles
  - Axions
  - Sterile Neutrinos
  - Primordial Black Holes (PBHs)
- What are PBHs?
  - BH that are created in the very early universe
  - Created from density fluctuations
  - Density fluctuations collapse into PBHs during the radiation domination period prior to baryogenesis

Method:

- Current Constraints have been placed using Hawking evaporation, gravitational microlensing, relic radiation, gravitational waves, and stellar system dynamics
- This has left the mass window of $[10^{-16}, 10^{-11}]\ M_{\odot}$ unbounded
- Mass scale corresponds to a length scale based on the Schwarzschild radius, determining size of PBH
  - $R_{Schw} \in [2.9\text{x}10^{-13}, 2.9\text{x}10^{-8}]$ m
- PBH of this size is much smaller than wavelength of optical light, cannot microlens using optical stars
  - Instead use objects that emit smaller wavelengths, i.e. x-ray pulsars

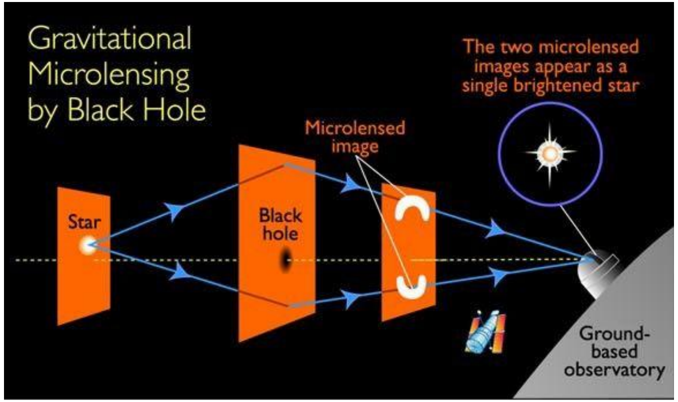


Image from: nasa.gov

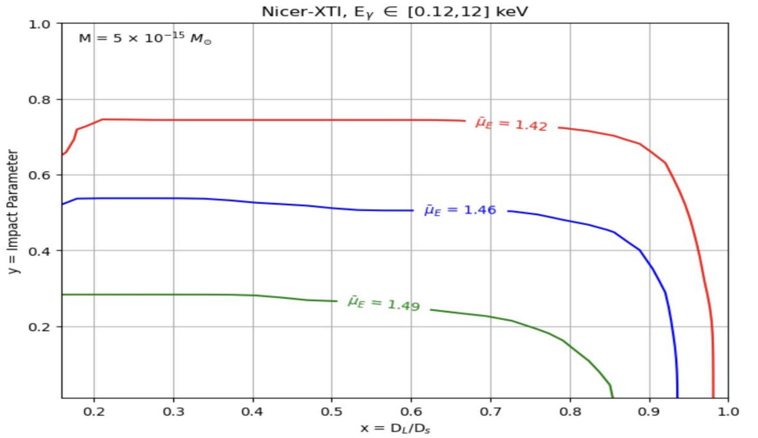
Method:

- Microlensing event is classified as a temporary brightening (magnification) of a background star
- By modeling the expected event rate assuming what fraction of PBHs make up DM we can place constraints
- Microlensing magnification falls into two regimes defined by the parameter w and the impact parameter (y)
  - If $w > y^{-1}$ the lensing falls into the regime of geometric optics
  - If $w < y^{-1}$ the lensing falls into the regime of wave optics
    - Magnification suppressed for $w \ll y^{-1}$

$$w \equiv \frac{4GME_\gamma}{\hbar c^3} = \frac{2R_{\mathrm{Schw}}E_\gamma}{\hbar c}$$

- The magnification is given by the equation below
- Based on the expected count rate of microlensing event estimate a <u>minimum</u> threshold for the energy averaged magnification to detect microlensing events
  - Working backwards this allows us to obtain a y_{thresh} vs x

$$\mu(w, y, a_{\mathrm{S}}(x)) = a_{\mathrm{S}}^{-2} e^{-y^2/(2a_{\mathrm{S}}^2)} \frac{\pi w}{1 - e^{-\pi w}} \times \int_0^\infty dz z e^{-z^2/(2a_{\mathrm{S}}^2)} I_0(yz/a_{\mathrm{S}}^2) \left| {}_1F_1\left(\frac{iw}{2}, 1; \frac{iwz^2}{2}\right)\right|^2$$

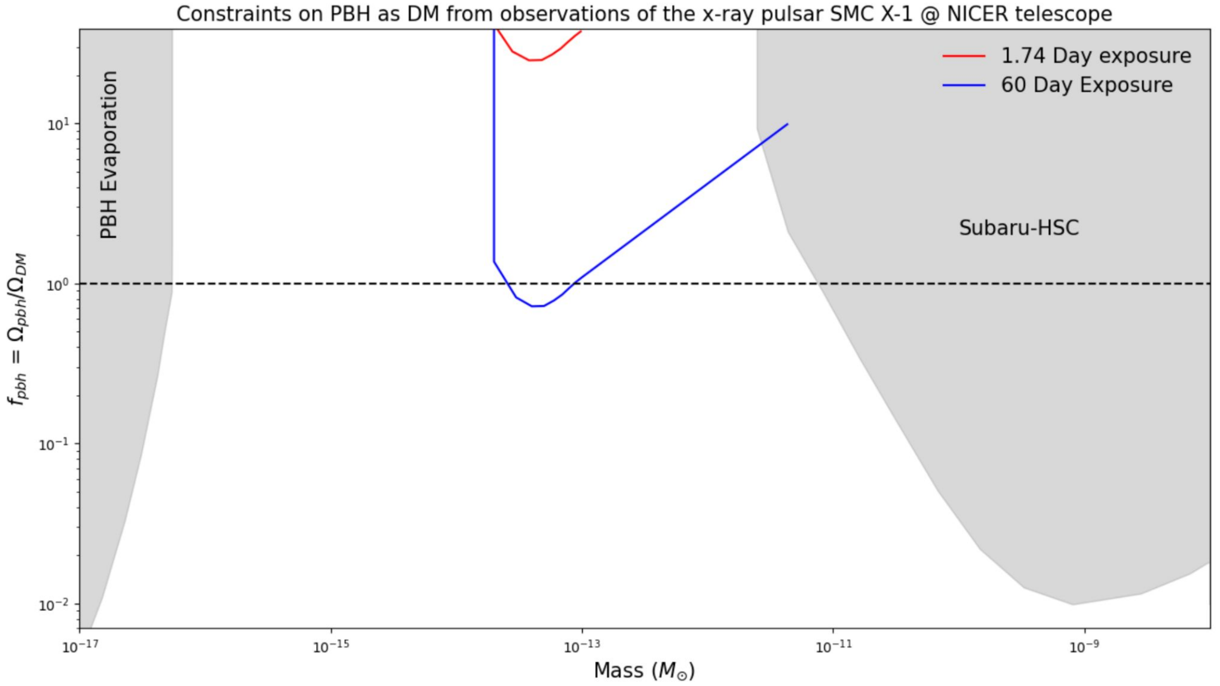


Conclusion(Preliminary):

- After obtaining y_{thresh} vs. x the following equation can be used to determine f_{PBH} for masses in the range $M \in [10^{-16}, 10^{-11}]\ M_{\odot}$

$$\frac{d\Gamma}{dt_{\mathrm{E}}} = f_{\mathrm{PBH}} \frac{2D_{\mathrm{S}}}{Mv_0^2} \int_0^1 dx \rho_{\mathrm{DM}}(x) v_{\mathrm{E}}^4(x) e^{-v_{\mathrm{E}}^2/v_0^2} \times \int_0^{y_{\mathrm{T}}(x)} \frac{dy}{\sqrt{y_{\mathrm{T}}^2 - y^2}} \times \mathbb{P}(n_\sigma) \ ,$$

Assuming NFW DM density profile



References:
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