Constraints on Primordial Black Holes with Microlensing :Wave & Finite Source Effects / PBH from Multiverse

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Collaborators 1 : Toshiki Kurita, Masahiro Takada

Collaborators 2 : Alexander Kusenko, Misao Sasaki, Volodymyr Takhistov, Masahiro Takada, Edoardo Vitagliano

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Contents of talk

Wave & Finite source Effects for PBH microlensing.

Collaborators 1 : Toshiki Kurita, Masahiro Takada

Forecast of constraint & detection of PBH from Multiverse universe.

Collaborators 2 : Alexander Kusenko, Misao Sasaki, Volodymyr Takhistov, Masahiro Takada, Edoardo Vitagliano

Gravitational Microlensing

Gravitational lens bend the path of light.

 \rightarrow lens object magnifies the brightness of background star.



PBH as a candidate of DM

PBH is one type of black hole that is formed soon after the Big Bang.

- A candidate of Dark Matter (DM).
- If exists, PBH can be detected by gravitational microlensing.
 - Microlensing time scale is determined by PBH mass, velocity & distance from observer
 - . $v_{\rm PBH} \sim 200 \rm km/sec$

$$t_{\rm E} = \frac{R_{\rm E}}{v_{\rm PBH}} = 9.8 \min\left(\frac{M_{\rm PBH}}{10^{-10}M_{\odot}}\right)^{1/2} \\ \times \left(\frac{v_{\rm PBH}}{200 \rm km/sec}\right)^{-1} \left(\frac{d_{\rm L}}{d_{\rm S}}\frac{d_{\rm S} - d_{\rm L}}{d_{\rm S}}\right)^{1/2}$$

tensing PBH MW DM halo

M31 DM halo



PBH constraint

Assume PBH is DM, and compute expectation number of PBH microlensing events.



Carry out microlensing observation, and count the number of microlensing events, N_{obs} .

Compare them.

$$f_{\rm PBH} \equiv \frac{\Omega_{\rm PBH}}{\Omega_{\rm DM}} < \frac{N_{\rm obs}}{N_{\rm exp}}$$



SS, T. Kurita, M. Takada (2019)

Wave & Finite Source Effects

Wave Effect

Light PBH makes too weak gravitational potential to bent light path

$$\lambda \sim 2R_{\rm Sch} = \frac{4GM_{\rm PBH}}{c^2}$$

Finite Source Effect

Larger size of source star leads less magnification.



These effects leads to small detectability, i.e. small eventrate Γ

Light goes through potential w/o interference





SS, T. Kurita, M. Takada (2019)

Wave & Finite Source Effects



1 Night Observation with Subaru HSC



We found 1 candidate microlensing event, among ~ 15,000 variable stars.

 $N_{\rm obs} = 1$

Result : PBH constraint from 1 night observation



We made a new constraint with 1 candidate event from HSC.
Wave effect set a cutoff for PBH constraint.

Updated constraint & Forecast



PBHs from vacuum bubble

Lent's start with multi fields inflation



Fields go to false vacuum by quantum tunneling

- Vacuum bubbles are formed in background inflating universe.
- Bubble initially expands and eventually collapses to form PBH.

Fate of Vacuum bubbles



Heavy bubble=supercritical



 $M < M_{\rm cr}$

 Bubble collapses into PBH
 Power spectrum of subcritical bubbles is flat;

 $f_{\rm PBH}(M < M_{\rm cr}) = {\rm const}$

- Bubble inflates and forms a baby universe in our universe.
- However, supercritical bubble seen from the outside of the baby universe is PBH.
- Spectrum depend on the dominating type of energy.

$$f_{\rm PBH}(M > M_{\rm cr}) \propto \begin{cases} M^{-1/2} & (RD) \\ const & (MD) \end{cases}$$

Fate of Vacuum bubbles

Light bubble=subcritical

Heavy bubble=supercritical



Forecast: PBH spectrum from Multiverse model

We focus on the PBH spectrum from Multiverse model.



A. Kusenko, M. Sasaki, SS, M. Takada, V. Takhistov, E. Vitagliano (in prep)

Can explain LIGO, HSC, OGLE events and DM as PBH at the same time.
 2014 HSC observation (Niikura et al., (2019)) started to probe this scenario.
 19 hours of total observation time can test this scenario at a 3-*σ* level (assuming null detection for future survey).

Forecast: Minimum case of Multiverse model

The most pessimistic case of multiverse model for PBH DM.



A. Kusenko, M. Sasaki, SS, M. Takada, V. Takhistov, E. Vitagliano (in prep)

The most pessimistic case, but still explain all DM by PBH.

= Peaks at open window. No flat spectrum.

***29 hours of total** observation time for HSC can test this model for PBH DM at a $3-\sigma$ level (assuming null detection for future survey).

Summary of my talk

PBH constraint with microlensing by HSC

We made the **new constraint** on PBH abundance.

Wave & Finite source Effect are significant for light PBH constraints.

PBH from Multiverse model

Multiverse model can explain a variety of PBH candidates; <u>DM+LIGO+HSC+OGLE</u>.

***29 hours** of total observation time for HSC can test this model for PBH DM at a $3-\sigma$ level.



