

New Manifestations **of Primordial Black Hole Dark Matter**

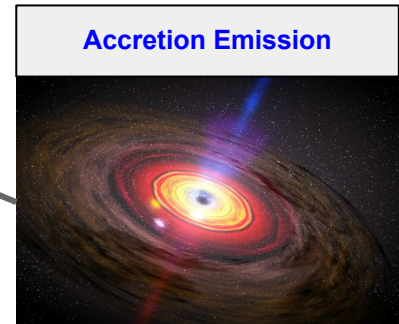
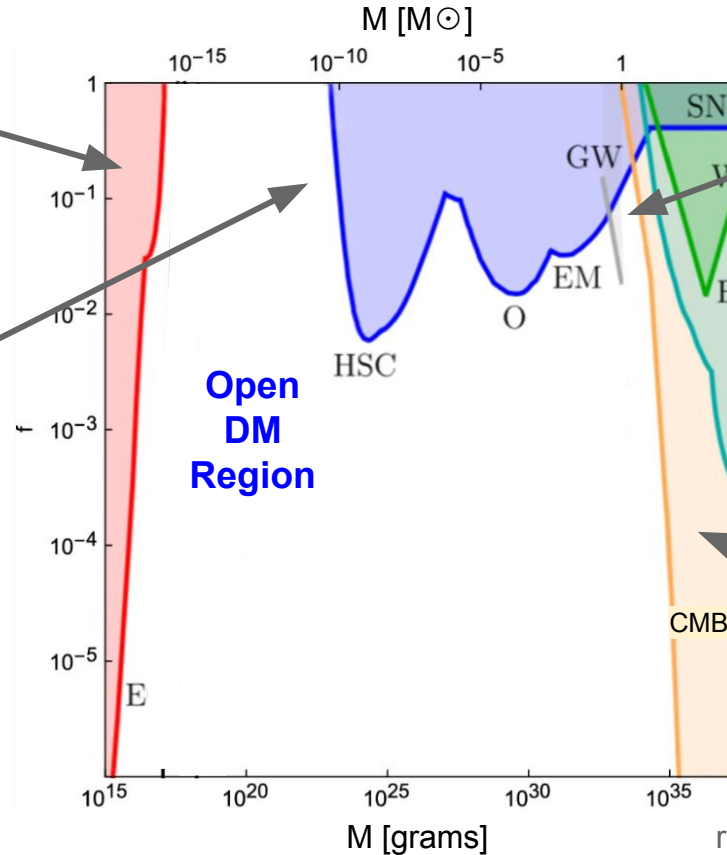
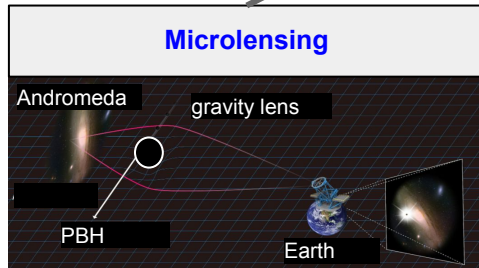
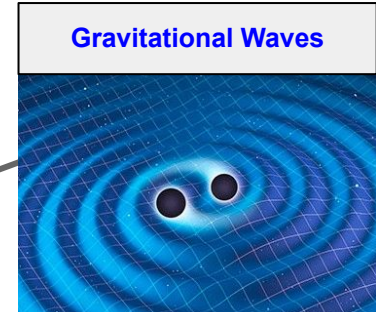
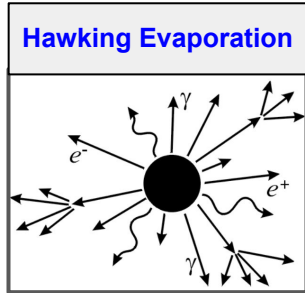
Volodymyr Takhistov

Kavli Fellow

Kavli IPMU, University of Tokyo



Status



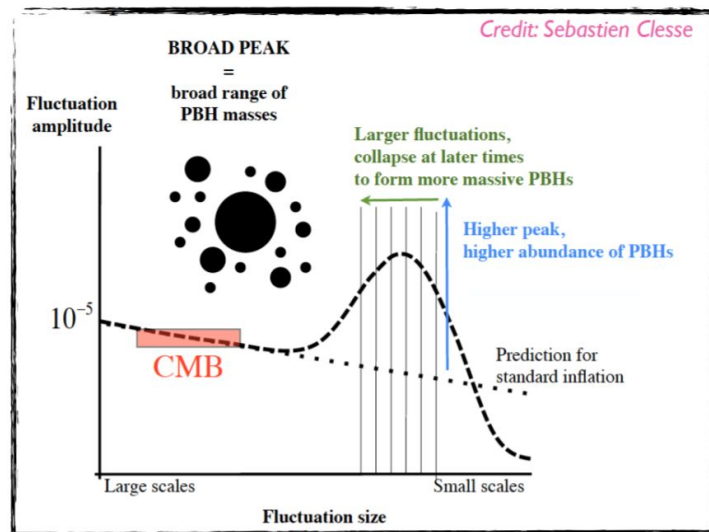
review [Sasaki+, 2017; Carr, Kohri+, 2020...]

“Standard” PBH Formation

- Big perturbations ($\delta \sim 1$) enter horizon \rightarrow collapse [Sasaki, Kawasaki, Yanagida, Carr...]

$$M_H \approx \frac{c^3 t}{G} = 10^{15} \text{ g} \left(\frac{t}{10^{-23} \text{ s}} \right)$$

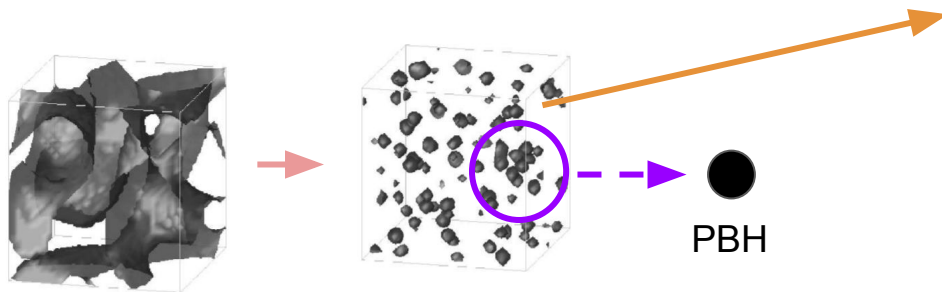
- Need to fine tune inflaton potential
 \rightarrow sensitive to restrictions on field behavior
- Example: “string swampland conjectures”
[Kawasaki, V.T., *PRD*, 1810.02547]



Distinct PBH Features Possible

scalar fragmentation

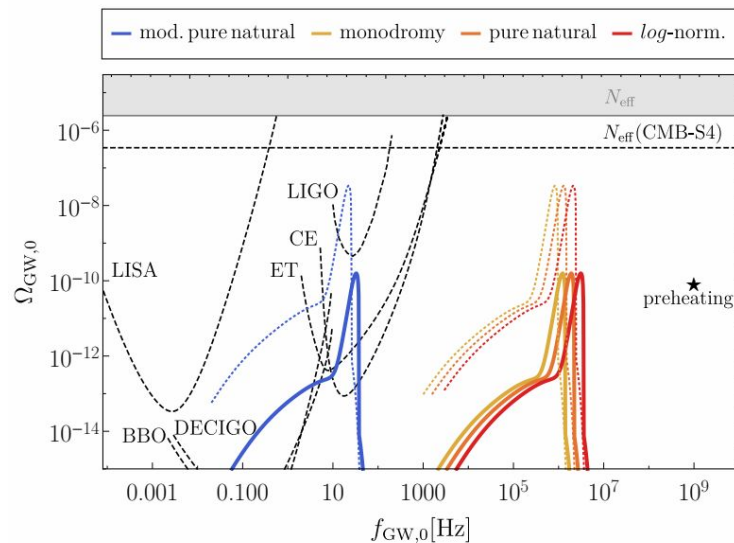
enhanced GWs from inflation oscillon decays
→ novel probe of inflationary physics



PBHs peaked in mass
+ big spin possible

oscillons from inflaton

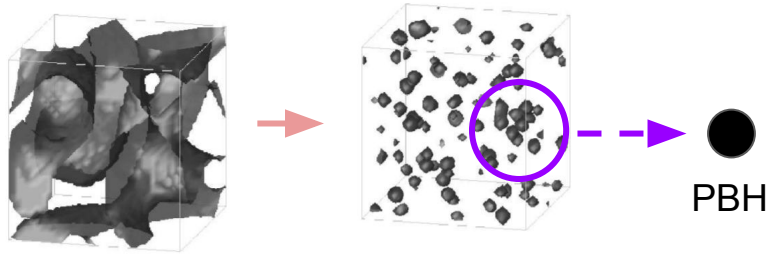
[Cotner, Kusenko, V.T., *PRD*, 1801.03321;
Cotner, Kusenko, Sasaki, V.T., *JCAP*, 1907.10613]



[Lozanov, V.T., 2204.07152]

Distinct PBH Features Possible

scalar fragmentation

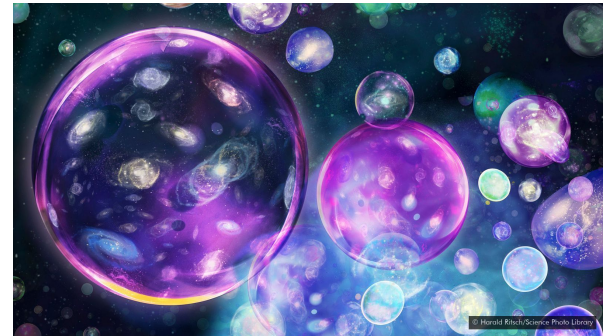


**PBHs peaked in mass
+ big spin possible**

oscillons from inflaton

[Cotner, Kusenko, **V.T.**, *PRD*, 1801.03321;
Cotner, Kusenko, Sasaki, **V.T.**, *JCAP*, 1907.10613]

vacuum bubble “multiverse”



**PBHs broadly
distributed in mass**

[Deng, Vilenkin, Sasaki...;

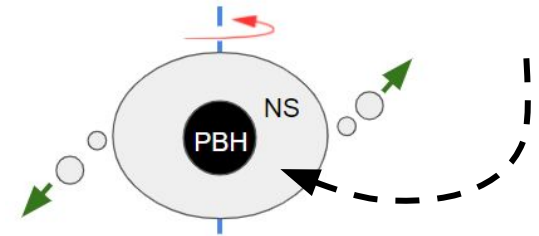
[Kusenko, Sasaki, Sugiyama, Takada, **V.T.**,
Vitagliano, *PRL*, 2001.09160]

Making Gold with Tiny PBHs

- **Origin of heavy elements (gold) major long-standing problem**
→ *neutron star mergers great, but might not be enough* e.g. [Kobayashi+, 2020]



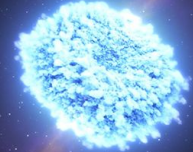
- **Elegant solution: asteroid-mass PBHs making DM**
captured by neutron stars, small PBHs eat & explode them
→ “r-process nucleosynthesis” factories



[Fuller, Kusenko, V.T., PRL, 1704.01129] + Viewpoint Highlight by H.-T. Janka

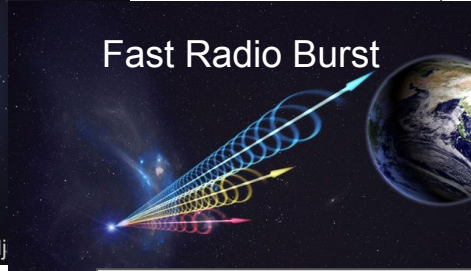
Neutron Stars (+ White Dwarfs) as PBH Laboratories

“orphan kilonova” without gravitational waves

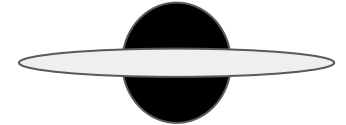


UC Berkeley: Makasdj

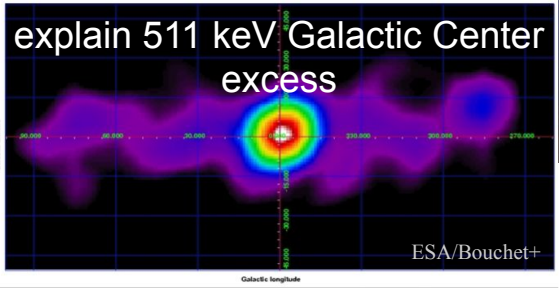
Fast Radio Burst



If **disk + BH** remains →
“orphan Gamma-ray Burst”
without gravitational waves
[V.T., *PLB*, 1710.09458]



explain 511 keV Galactic Center excess

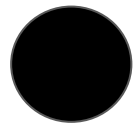
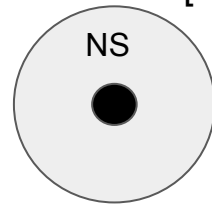


ESA/Bouchet+

*** can explain with regular NS-NS

[Fuller, Kusenko, Radice, V.T.,
PRL, 1811.00133]

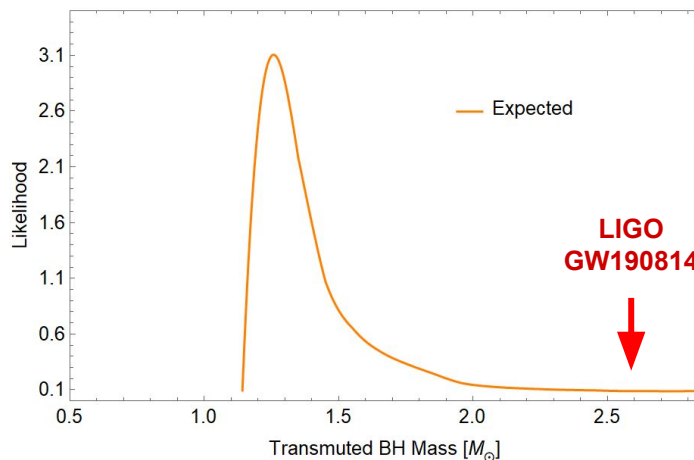
“Transmuted” population of solar-mass BHs
[V.T., *PLB*, 1707.05849]



[Fuller, Kusenko, V.T., *PRL*, 1704.01129; V.T., *PLB*, 1707.05849; V.T., *PLB*, 1710.09458]

Origin of Solar-mass Black Holes

- Solar-mass ($\sim 1\text{-}2.5 M_{\odot}$) BHs unexpected in astrophysics \rightarrow PBHs ?
- **LIGO detected candidate event** [Abbott+, *ApJL*, 2020...] ...**how to tell BH origin ?**
- **Solution:** *transmuted* BHs from PBHs (or particle) DM eating NSs follow NS mass distribution

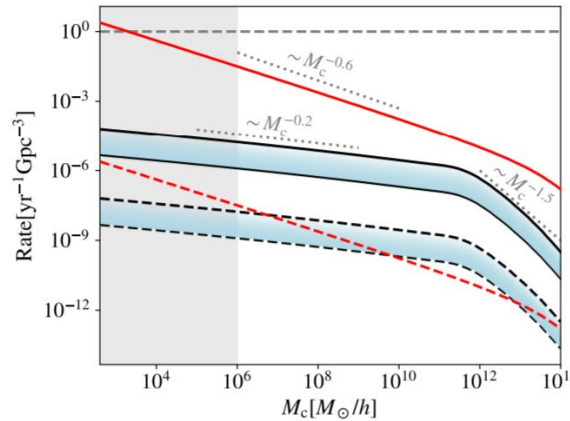
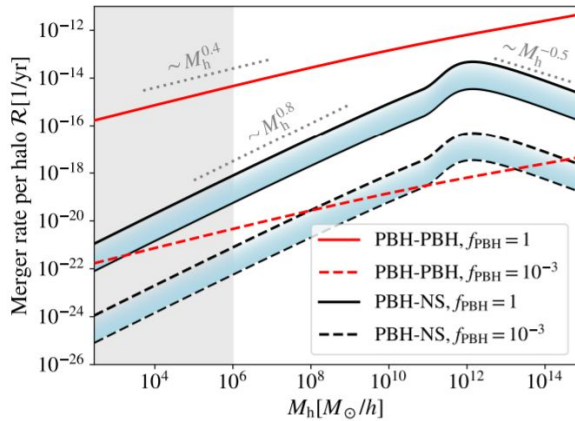


Large ($> 1.5 M_{\odot}$) candidates unlikely to be transmuted BHs!

[V.T., *PRL*, 2008.12780]

Identifying Black Hole - Neutron Star (BH-NS) Mergers

- PBH-PBH been linked with LIGO BH-BH GW events [Sasaki, Byrnes, Riotto, Kamionkowski...]
- **First reported BH-NS candidates by LIGO** [Abbott+, *ApJL*, 2021...] *....from PBHs?*
- Unlike PBH-PBH, PBH-NS can only form after star formation



PBH-NS rates subdominant

→ **NS-BH are astrophysical**

*** even if PBH-PBH significant**

[Sasaki, V.T., Vardanyan, Zhang, *ApJ*, 2110.09509]

Are Intermediate-mass BHs Primordial ?

- GW190521 event $\sim 150 M_{\odot}$ merger mass [Abbott+, *PRL*, 2020], first definitive IMBH detection
- **New general cosmology-independent observable:** interactions and **heating** of gas
- **Gas heating mechanisms:**
 - gravitational drag (dynamical friction)
 - accretion disk photons
 - accretion outflows / winds
- Great testing site: dwarf galaxies (Leo T)

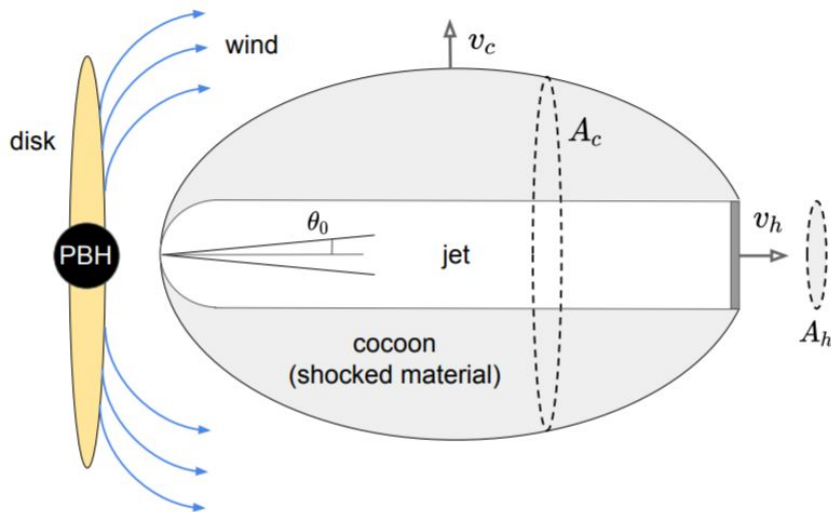
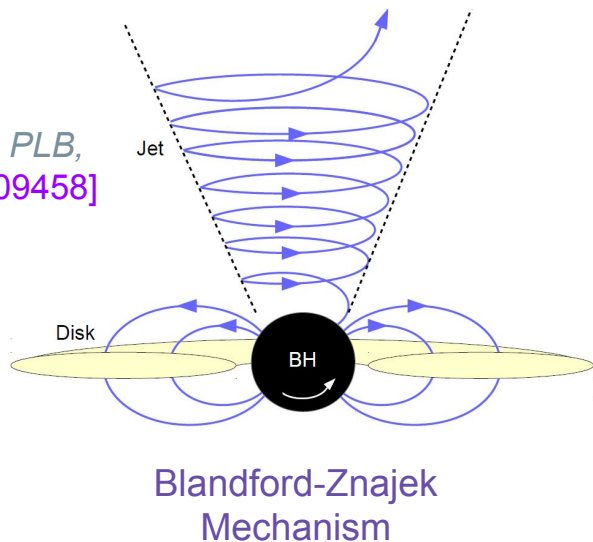


[Lu, V.T., *ApJL*, 2007.02213; V.T., Lu+, *JCAP*, 2105.06099]

PBH Outflow Winds and Jets

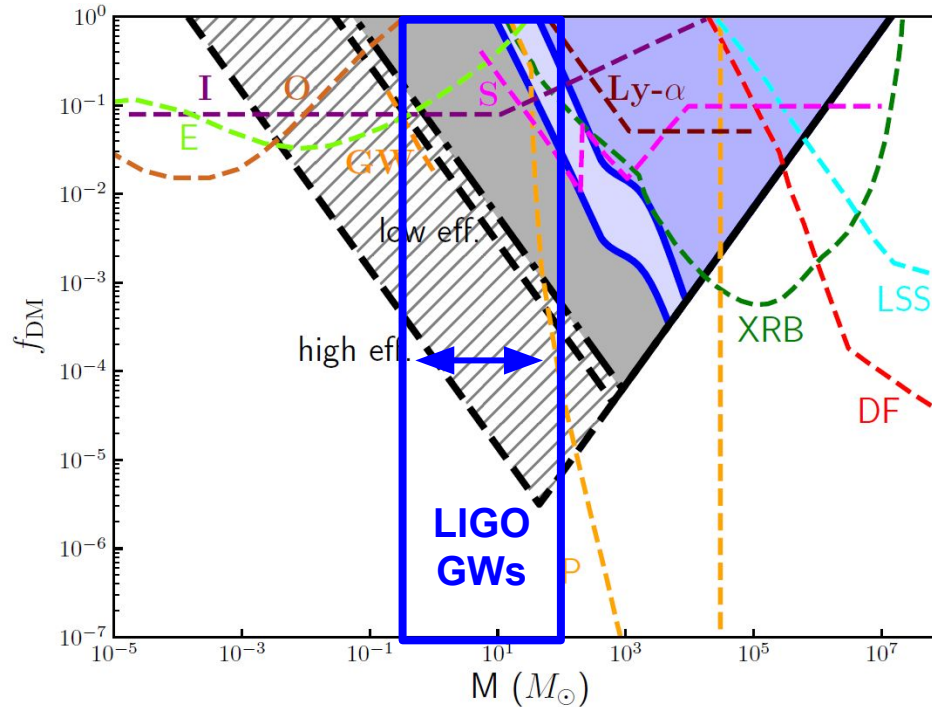
- Outflow winds and powerful jets (especially for spinning PBH) expected to deposit efficiently significant energy via shock heating $L \sim \epsilon \dot{M}$

[V.T., PLB,
1710.09458]



[V.T., Lu, Murase, Inoue, Gelmini, 2111.08699]

PBH Outflow Winds and Jets



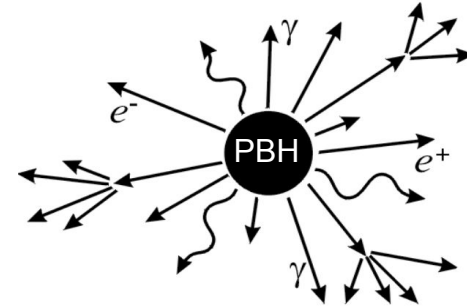
* gas heating from evaporating PBHs

[Laha, Lu, V.T., *PLB*, 2009.11837]
(also [Kim, 2020])

[V.T., Lu, Murase, Inoue, Gelmini, 2111.08699]

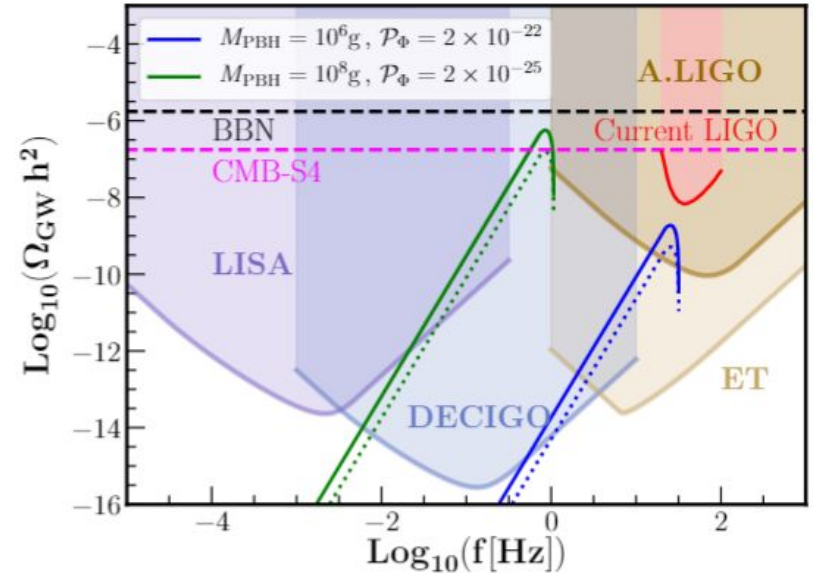
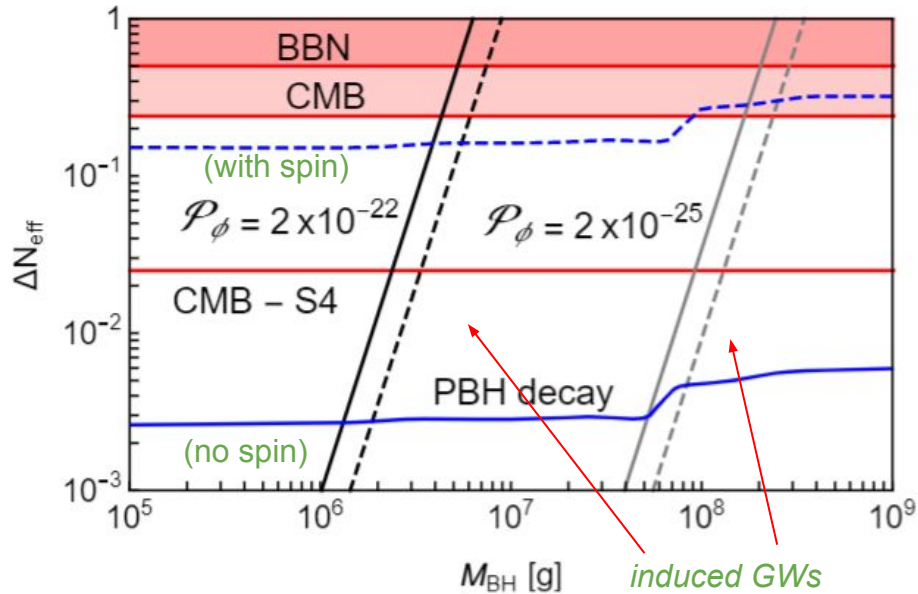
Exploring Evaporating PBHs with GWs

- Evaporating PBHs with mass $\lesssim 10^9$ g unconstrained, [how to explore scenarios ?](#)



- Evaporating PBH emission products → “dark radiation” → **change ΔN_{eff}**
 - **PBH *spin* distribution can significantly modify** [Hooper+ 2020; Arbey, Auffinger+, 2021; Masina, 2021]
- Rapid evaporation of PBHs dominating Universe → induced GWs → **change ΔN_{eff}**
 - **PBH *mass* distribution can significantly modify** [Inomata, Kohri+, 2019; Papanikolaou, Vennin+, 2020; Domenech, Lin, Sasaki, 2020...]

Exploring Evaporating PBHs with GWs

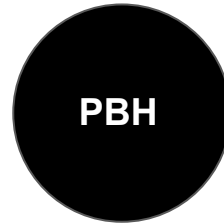


→ Coincidence signals allow probing many scenarios over broad mass-range !

[Domenech, V.T., Sasaki, *PLB*, 2105.06816]

Summary

- Renaissance era in PBH research
- Strong synergy with observational (especially multi-messenger) astrophysics
- Many new ideas emerging for PBH production, signals, solutions to old puzzles



... Dark Matter ?