Shining Light on Dark Matter with Black Holes

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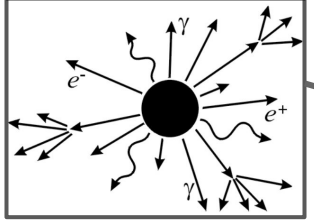
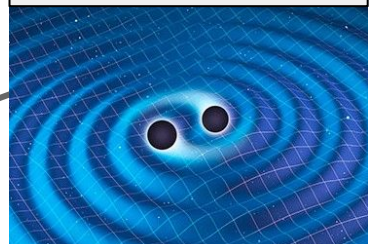
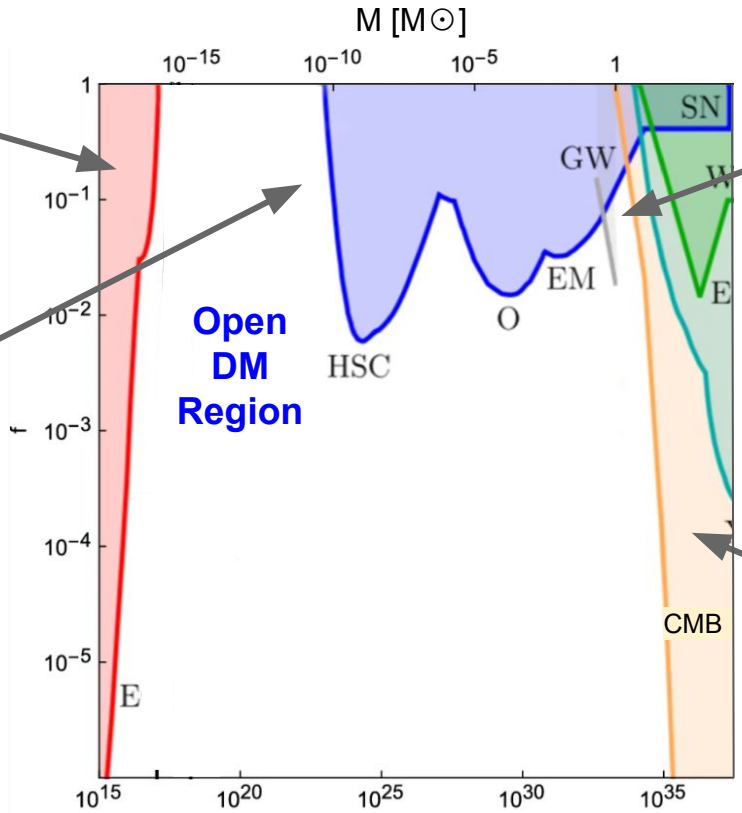
PBH Status

Hawking Evaporation

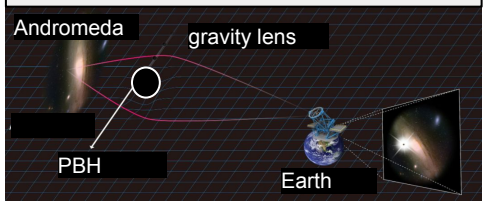


Gravitational Waves

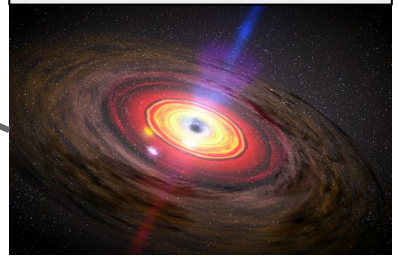




Microlensing



Accretion Emission



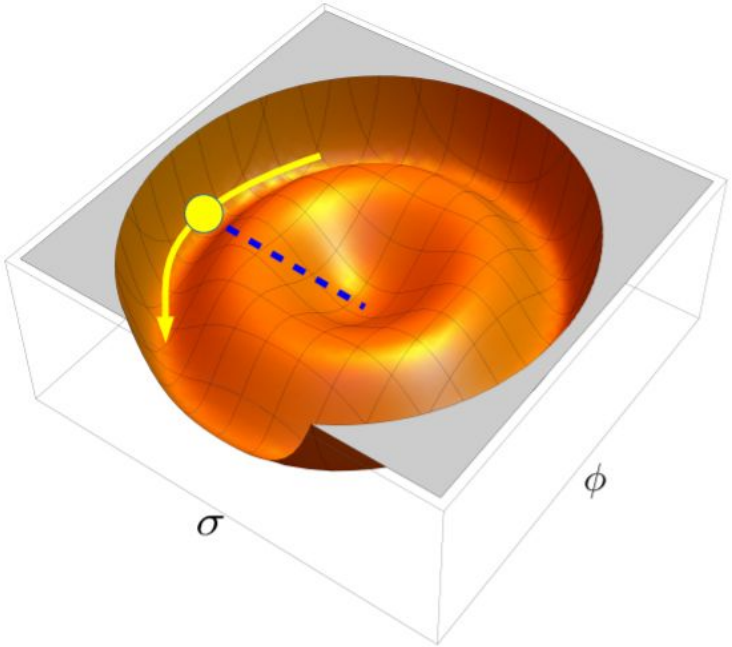
review [Sasaki+, 2017; Carr+, 2020...]

PBHs from Bubble Multiverse

- Generic mechanism for making PBHs broadly distributed in mass

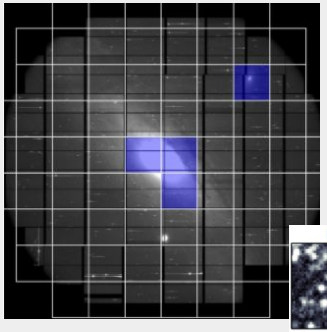
[Deng, Vilenkin, Sasaki...]

Black Holes from Bubble Multiverse *Revisited*

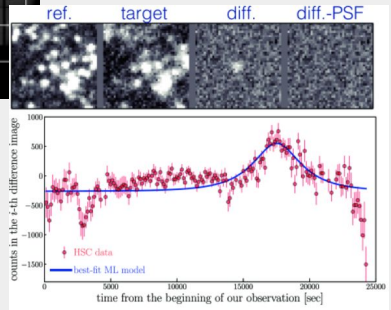


[Kusenko, Sasaki, Sugiyama, Takada, **VT**, Vitagliano, *Phys.Rev.Lett.*, 2001.09160]

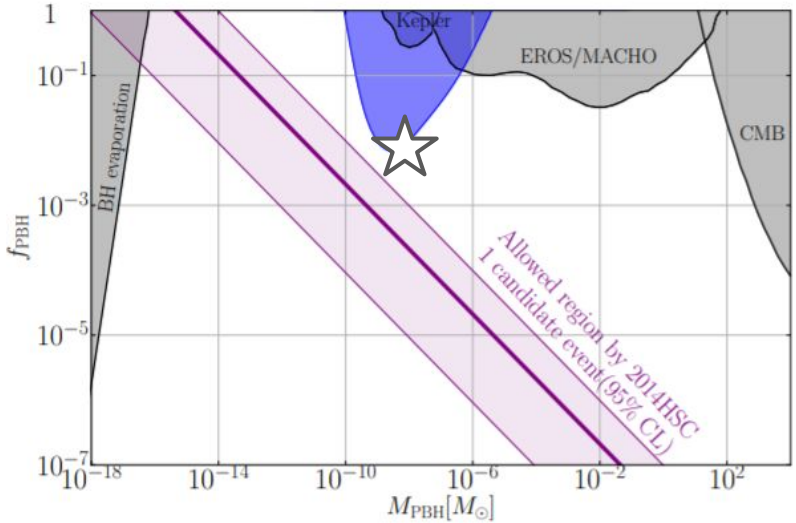
PBH DM from Bubble Multiverse: Detected by HSC ?!



Subaru (HSC)
Hyper-Suprime Cam
Andromeda
microlensing
event



[Niikura+, *Nature Astron.*, 2019]



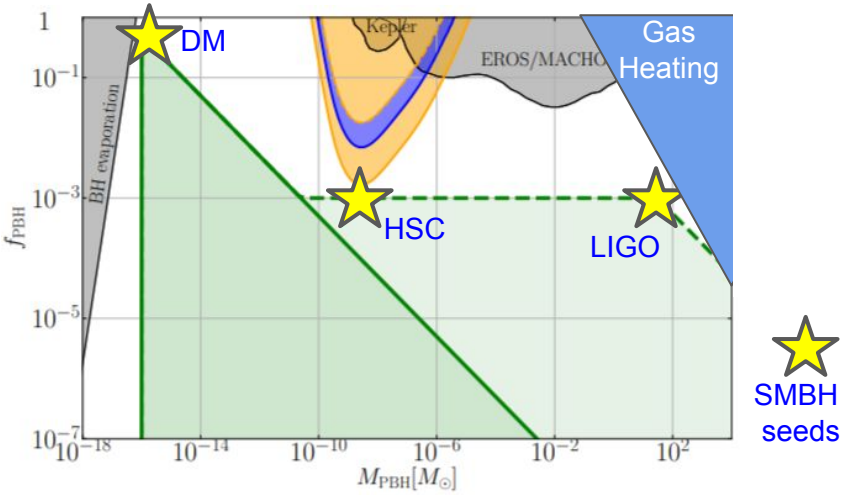
- **PBH DM from bubble multiverse consistent with detected HSC event !**

  → *tail of broad PBH distribution allows for indirect test of open DM window*

[Kusenko, Sasaki, Sugiyama, Takada, **VT**, Vitagliano, *Phys.Rev.Lett.*, 2001.09160]

PBH DM from Bubble Multiverse: Detected by HSC ?!

- Generalized model explains many observables simultaneously (DM, LIGO, SMBH seeds…)



**** indirectly test NANOGrav GWs with HSC via PBHs*

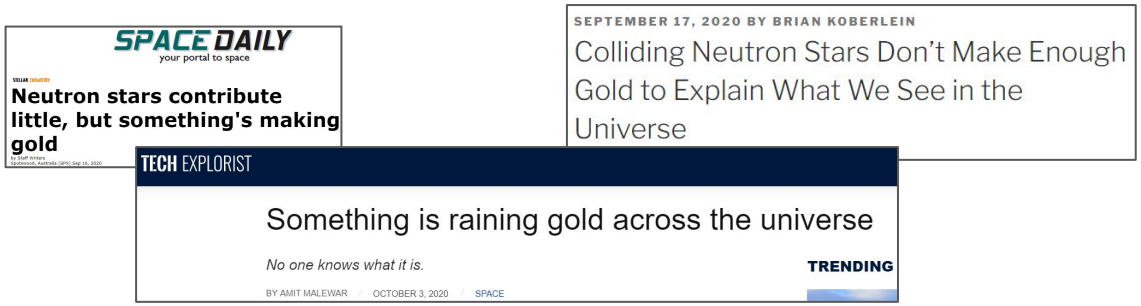
[Sugiyama, **VT+**, *Phys.Lett.B*, 2010.02189]

- **Will be definitively tested with new HSC data !**

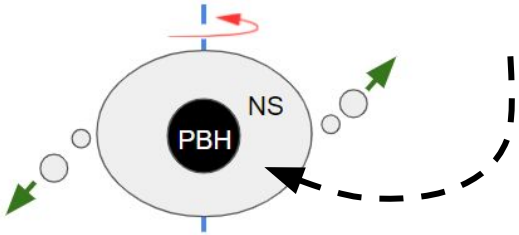
[Kusenko, Sasaki, Sugiyama, Takada, **VT**, Vitagliano, *Phys.Rev.Lett.*, 2001.09160]

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*]

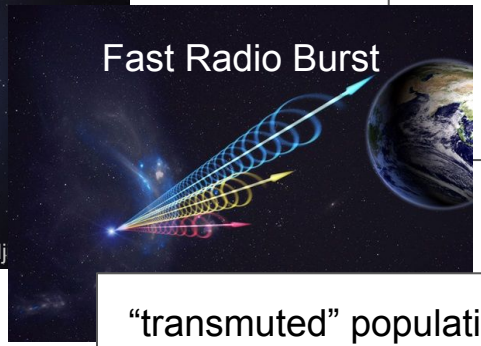


- **Elegant solution: asteroid-mass PBHs making DM**
  captured by neutron stars, small PBHs eat & explode them
  → "r-process nucleosynthesis" factories

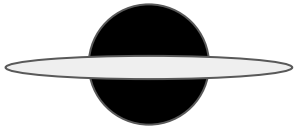


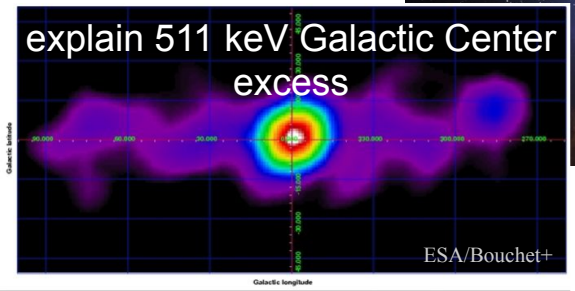
[Fuller, Kusenko, **VT**, *Phys.Rev.Lett.*, 1704.01129] + Viewpoint Highlight by H.-T. Janka

Neutron Stars (+ White Dwarfs) as PBH Laboratories



If **disk + BH** remains →
“orphan Gamma-ray Burst” without gravity waves

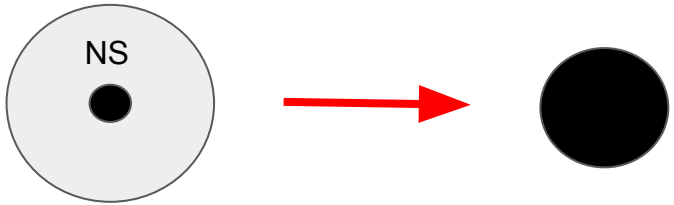




*** *can explain with regular NS-NS*

[Fuller, Kusenko, Radice, **VT**, *Phys. Rev. Lett.*, 1811.00133]

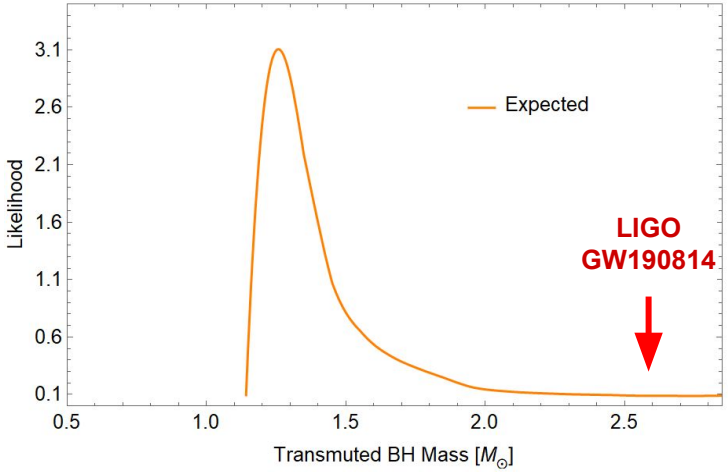
“transmuted” population of solar-mass BHs



[Fuller, Kusenko, **VT**, *Phys.Rev.Lett.*, 1704.01129; **VT**, *Phys.Lett.B*, 1707.05849; **VT**, *Phys.Lett.B*, 1710.09458]

Origin of Solar-mass Black Holes

- Solar-mass (~1-2.5 M⊙) BHs unexpected in astrophysics → PBHs ?
- **LIGO detected candidate event** [Abbott+, *ApJL*, 2020...] **...how to tell BH origin ?**
- **Solution:** BHs from tiny PBH (or particle) DM eating NSs follow NS mass distribution

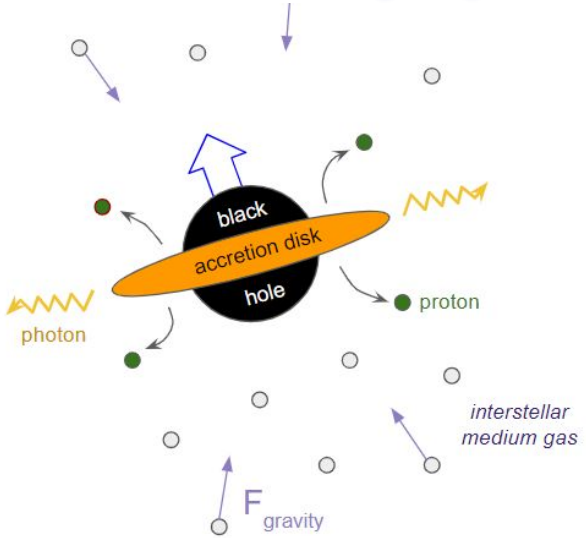


Large (> 1.5 M⊙) candidates unlikely to be transmuted BHs!

[**VT+**, *Phys.Rev.Lett.*, 2008.12780]

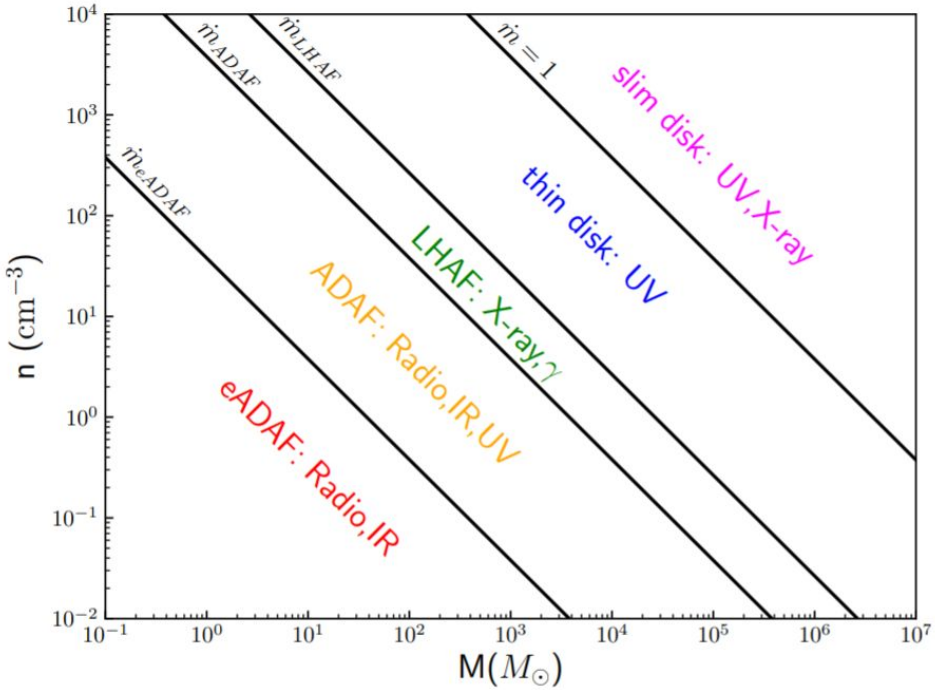
Are Intermediate-mass BHs Primordial ?

- GW190521 event ~ 150 M$_\odot$ merger mass [Abbott+, *PRL*, 2020], first definitive IMBH detection
- **New general cosmology-independent observable:** interactions and ***heating*** of gas
- Heating mechanisms:
  - gravity drag (dynamical friction)
  - accretion disk photons
  - accretion outflows / winds
- Great testing site: dwarf DM-rich galaxies (Leo T)



[Lu, **VT**+, *Astrophys.J.Lett.*, 2007.02213; **VT**, Lu+, 2105.06099]

PBH Accretion Disks

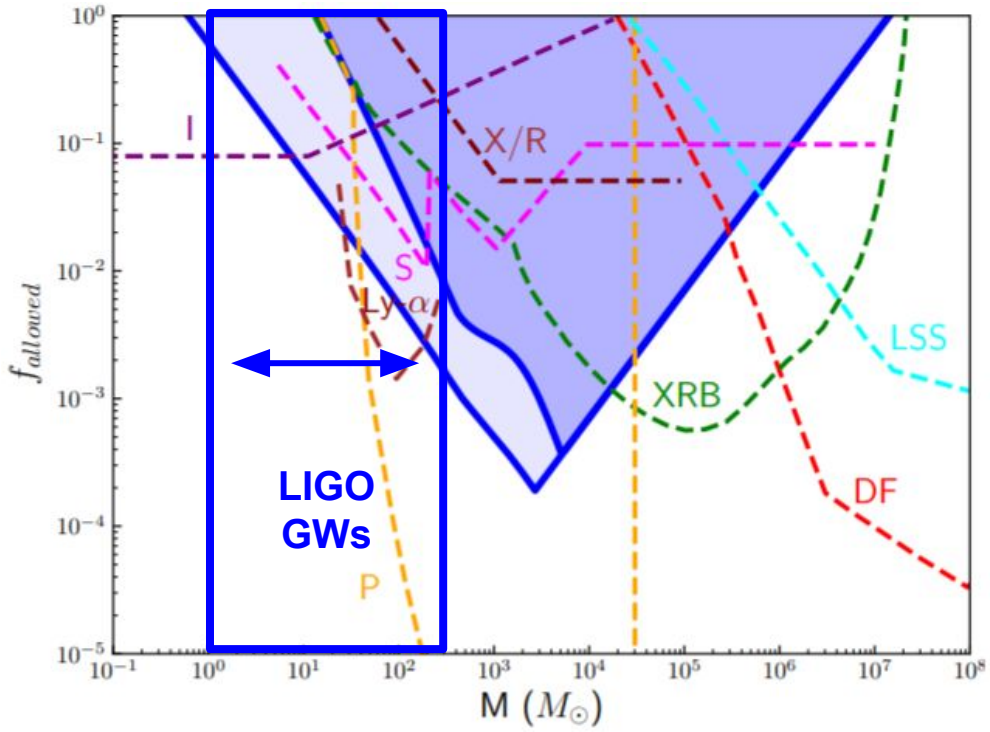


No accretion disk for small PBHs !

(need $M \gtrsim 10^{-13} M_\odot$)

[Lu, **VT**+, *Astrophys.J.Lett.*, 2007.02213; **VT**, Lu+, 2105.06099]

PBH Gas Heating

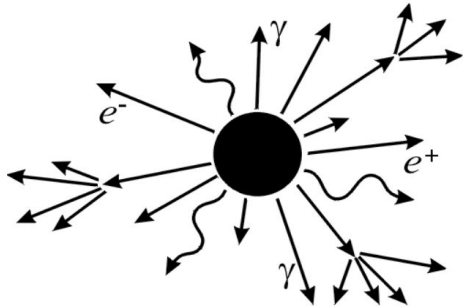


** gas heating from evaporating PBHs*
[Laha, Lu, **VT**, *Phys.Lett.B*, 2009.11837]
(also [Kim, 2020])

[Lu, **VT**+, *Astrophys.J.Lett.*, 2007.02213; **VT**, Lu+, 2105.06099]

Exploring Evaporating PBHs with GWs

- Evaporating PBHs with mass $\lesssim 10^9$ g unconstrained, ***how to explore scenarios ?***



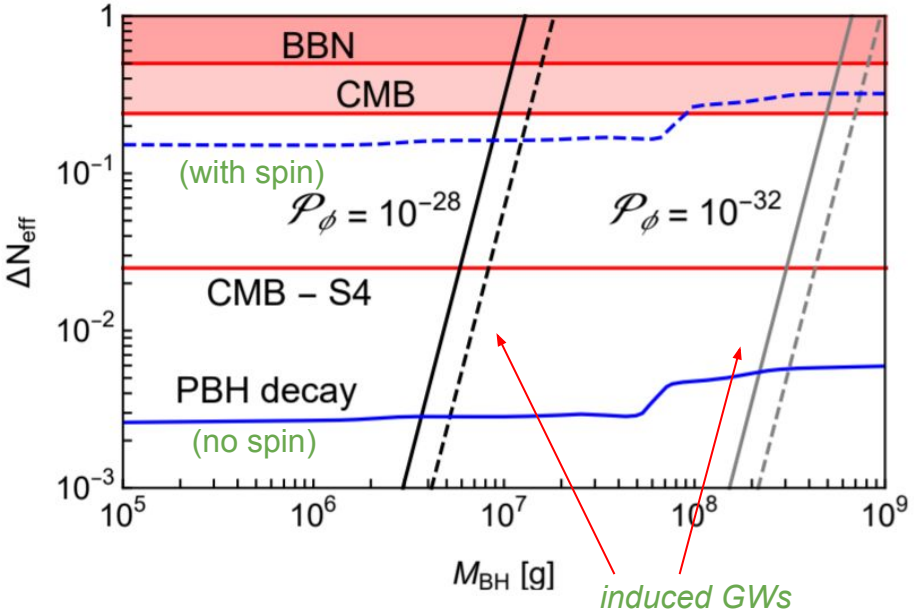
- Evaporating PBH emission products → "dark radiation" → change ΔN_{eff}
  - PBH *spin* distribution can significantly modify

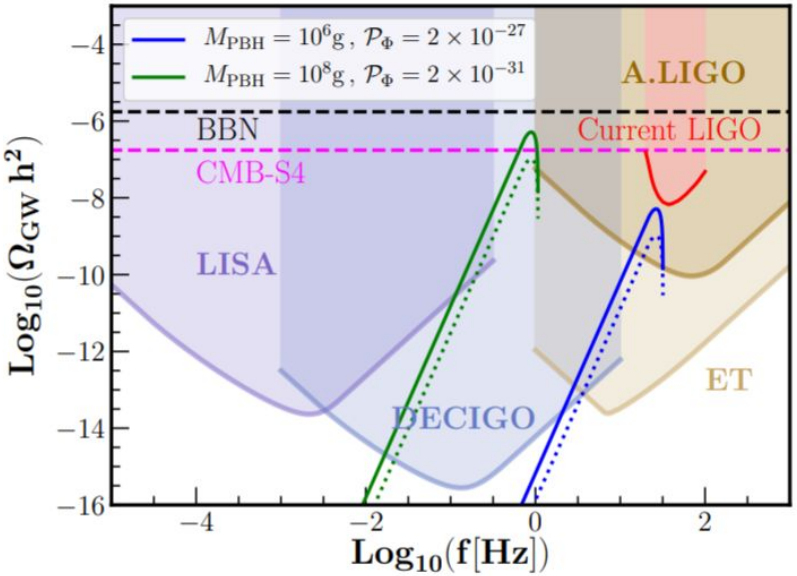
[Hooper+ 2020; Arbey, Auffinger+, 2021; Masina, 2021]

- Rapid evaporation of PBHs dominating Universe → induced GWs → change ΔN_{eff}
  - PBH *mass* distribution can significantly modify

[Inomata, Kohri+, 2019; Papanikolaou+, 2020; Domenech, Lin, Sasaki, 2020]

Exploring Evaporating PBHs with GWs





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

[Domenech, **VT**, Sasaki, 2105.06816]

Summary

- Renaissance era for PBHs, SM DM candidate → synergy with multi-messenger astronomy
- General formation scenarios based on scalars allow for PBHs with interesting features
- Many exciting astrophysical observables, especially from star interactions
- Simple powerful test based on mass-function can help establish solar-mass BH origin
- Gas heating provides novel general cosmology-independent probe of IMBHs
- Coincidence GW signals open exploration of uncharted territory of evaporating PBHs
- **Marching towards definitive answers regarding the role of PBHs for DM and in physics!**