

# Shining Light on Dark Matter with Black Holes

**Volodymyr Takhistov**

*Kavli Fellow*

Kavli IPMU, University of Tokyo



# PBH Dark Matter

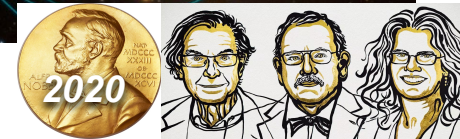
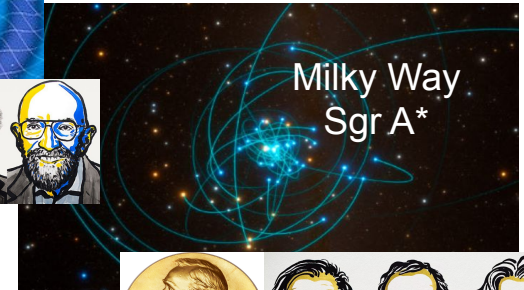
- Black holes

- astrophysical → old stars
- **primordial** → early Universe [Zeldovich, Novikov, 1967; Hawking, 1971; Carr, Hawking, 1974]

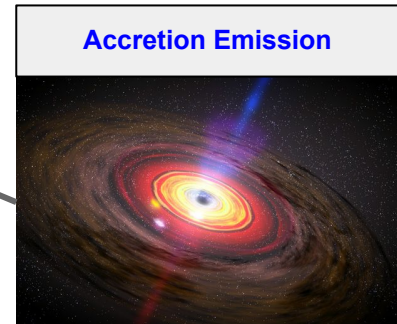
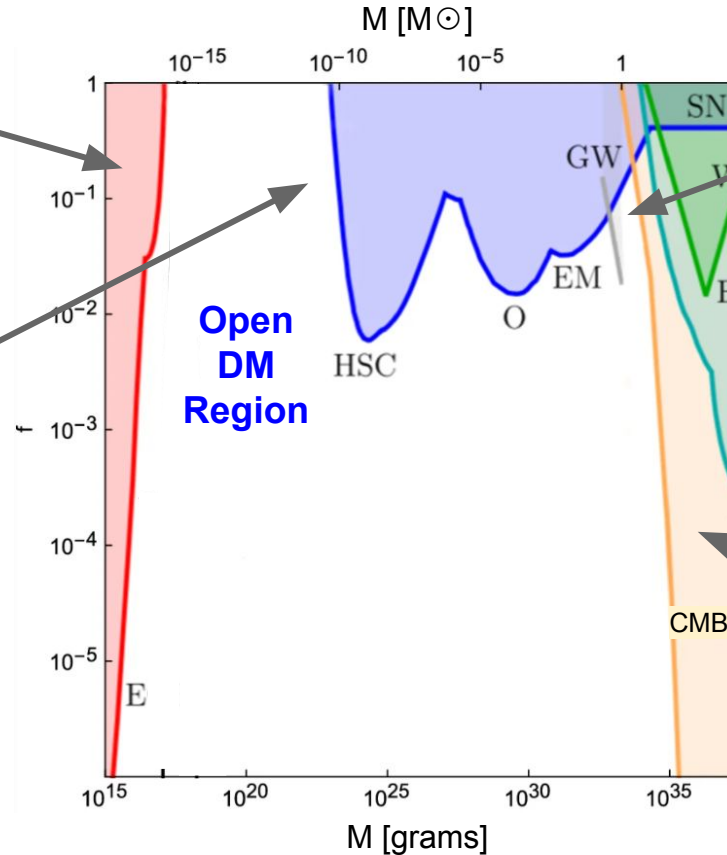
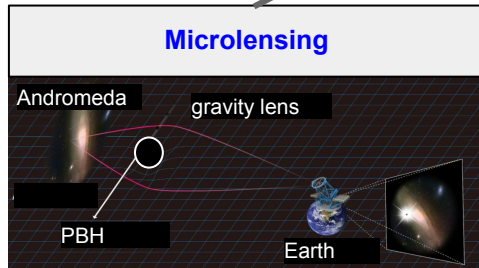
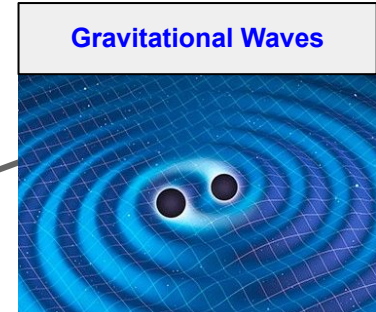
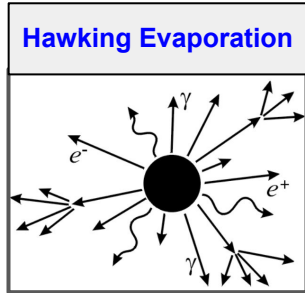


- Why PBH DM ?

- alternative to particle DM
- gravitational wave era
- can appear in many new-physics models
- help solve astronomy puzzles
- *black holes exist*



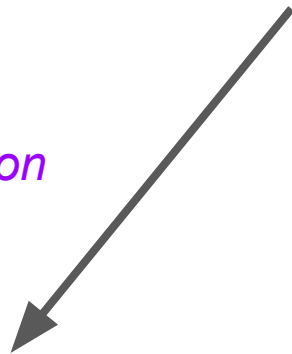
# Status



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

# Interesting PBH Formation Scenarios from Scalar Fields

*scalar  
fragmentation*



PBHs peaked in mass  
+ high spin possible

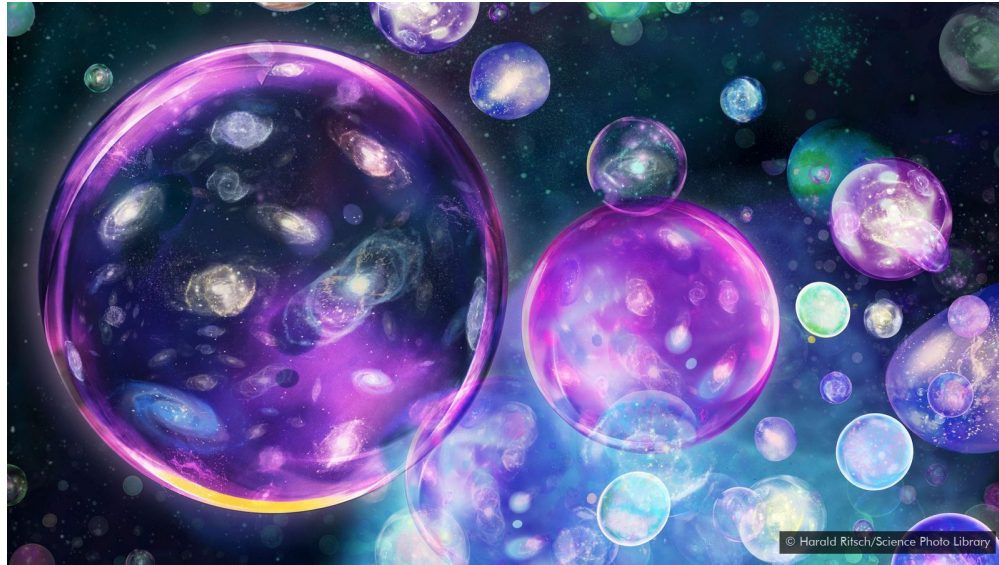
*vacuum bubble  
multiverse*



PBHs broadly  
distributed in mass

e.g. oscillons [Cotner, Kusenko, **VT**, 2018;  
Cotner, Kusenko, Sasaki, **VT**, 2019]

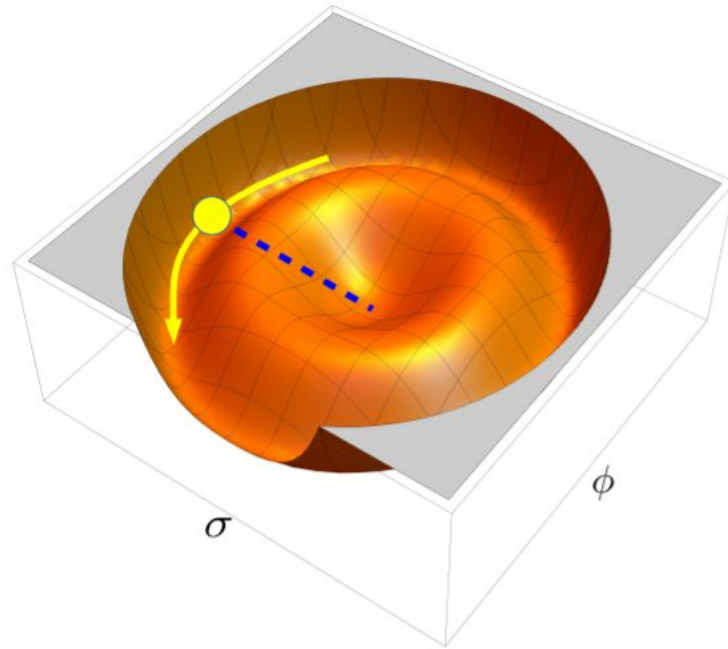
# PBHs from Bubble Multiverse



- Generic mechanism for making PBHs broadly distributed in mass

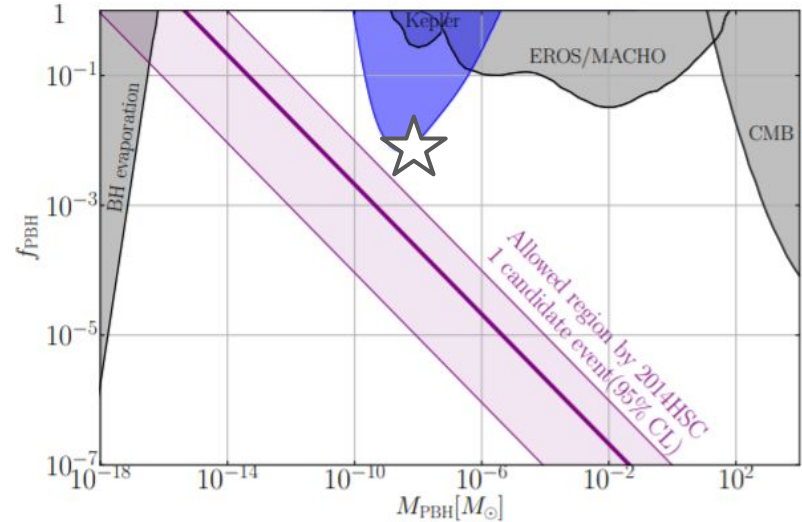
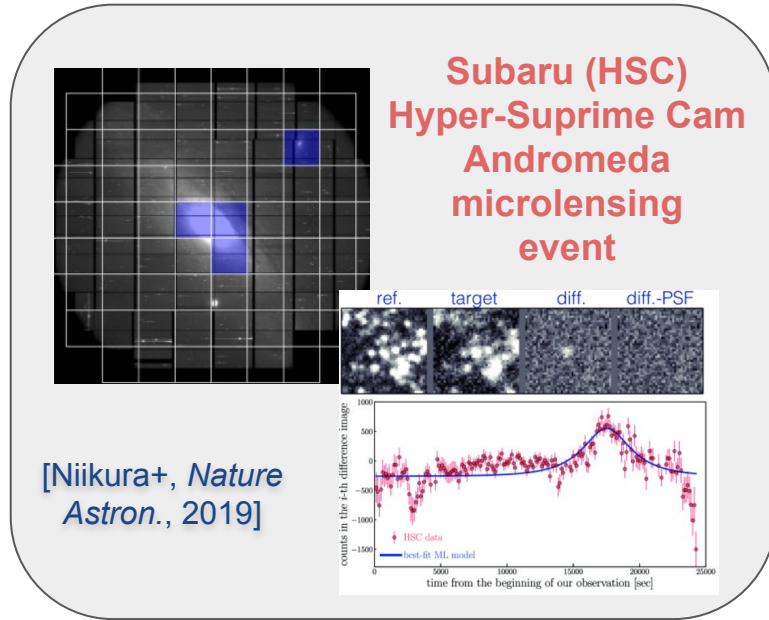
[Deng, Vilenkin, Sasaki...]

# Black Holes from Bubble Multiverse *Revisited*



[Kusenko, Sasaki, Sugiyama, Takada, VT, Vitagliano, *Phys.Rev.Lett.*, 2020]

# PBH DM from Bubble Multiverse: Detected by HSC ?!

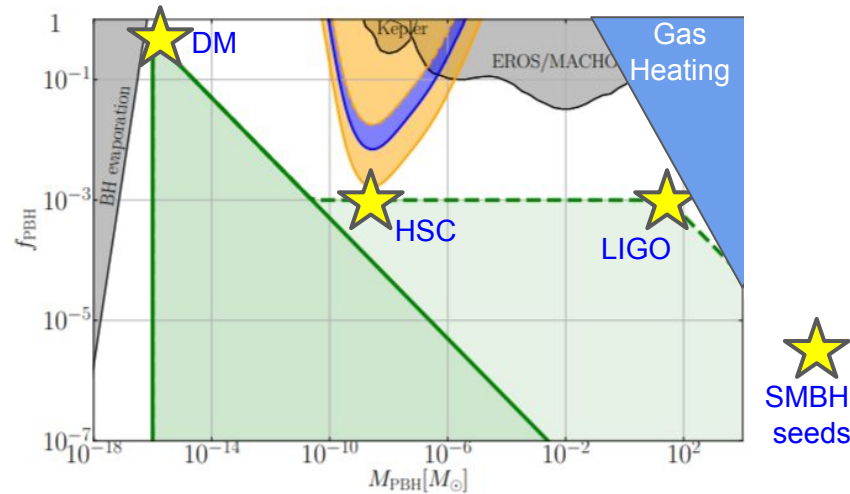


- **PBH DM from bubble multiverse consistent with detected HSC event !**  
→ *tail of broad PBH distribution allows for indirect test of open DM window*

[Kusenko, Sasaki, Sugiyama, Takada, VT, Vitagliano, *Phys.Rev.Lett.*, 2020]

# PBH DM from Bubble Multiverse: Detected by HSC ?!

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



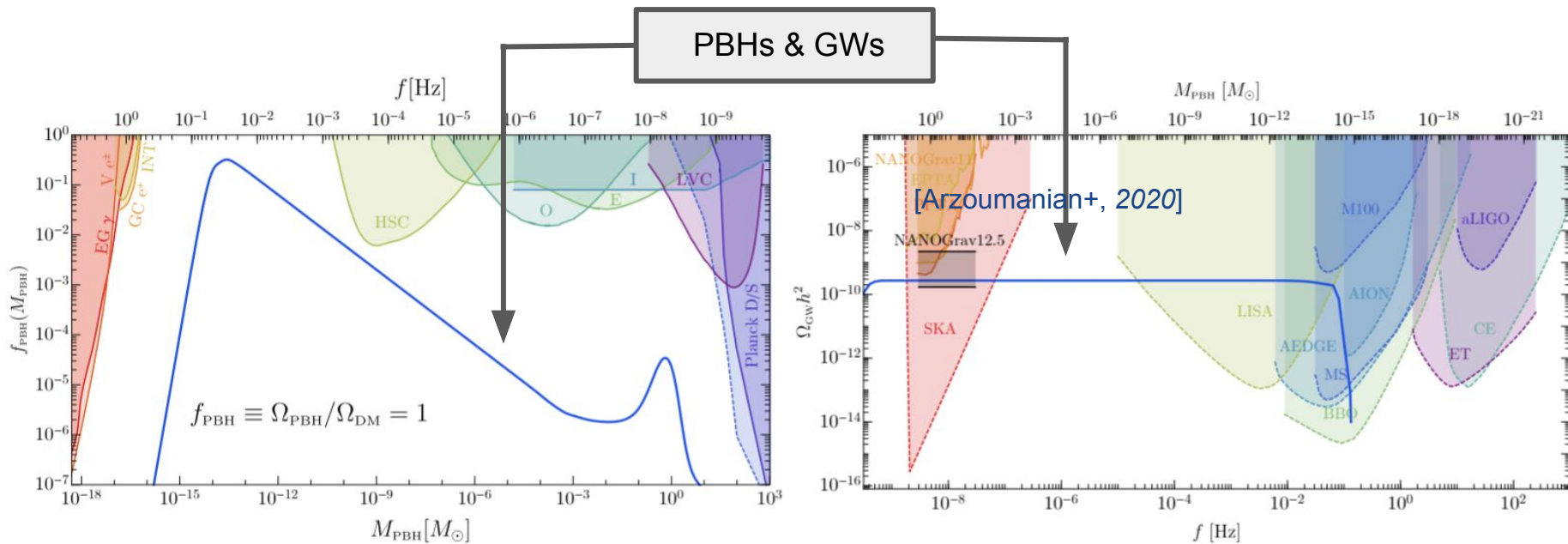
- Will be definitively tested with new HSC data !

[Kusenko, Sasaki, Sugiyama, Takada, VT, Vitagliano, *Phys.Rev.Lett.*, 2020]



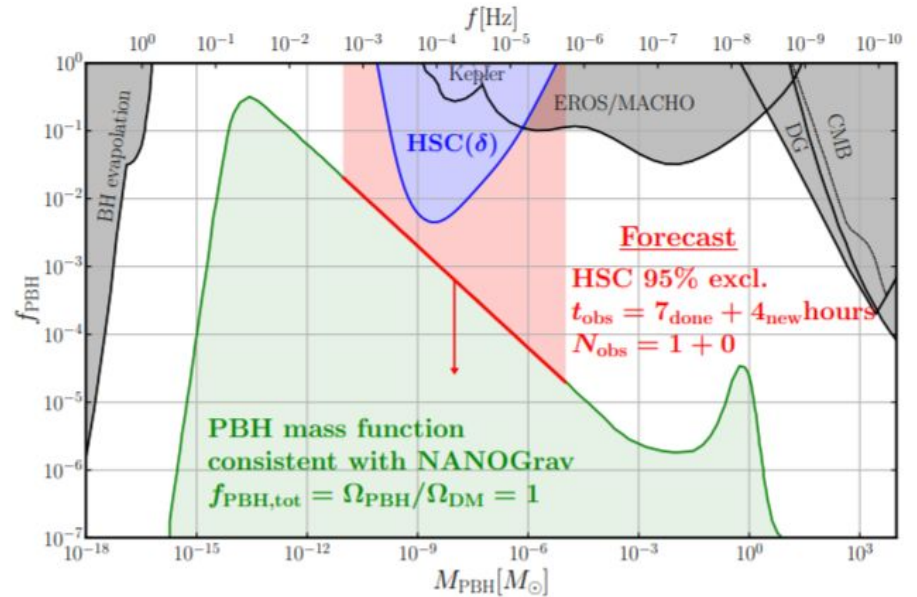
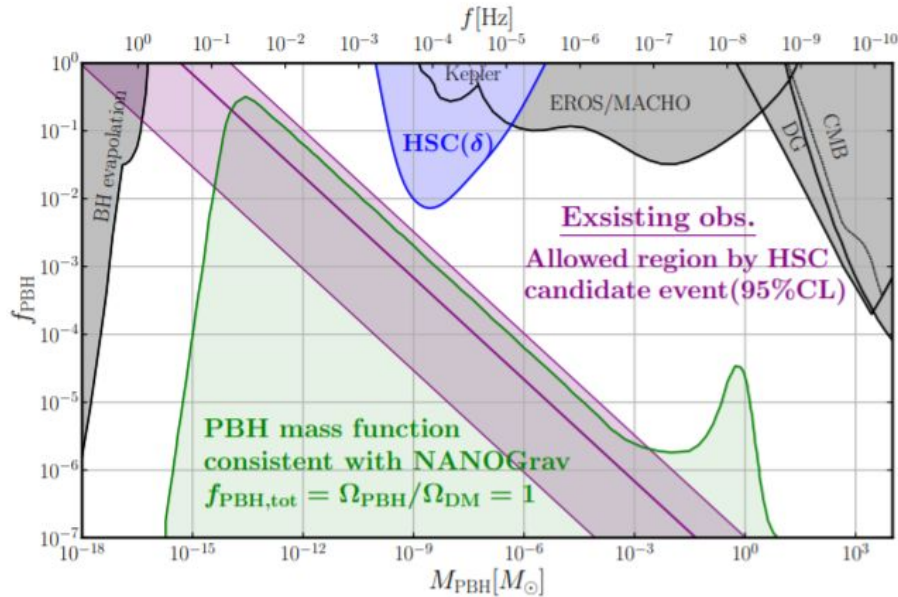
# PBHs and NANOGrav GWs

Power spectrum:  $\mathcal{P}_\zeta(k) \approx A_\zeta \Theta(k_s - k)\Theta(k - k_l)$



[De Luca, Franciolini, Riotto, *PRL*, 2020]

# Probing GWs with Optical Telescopes



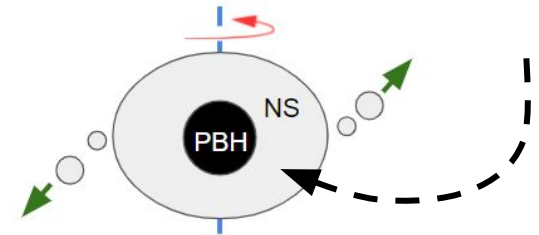
[Sugiyama, VT, Vitagliano, Kusenko, Sasaki, Takada, 2020]

# 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.*, 2017] + Viewpoint Highlight by H.-T. Janka

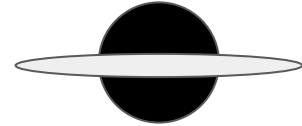
# Neutron Stars (+ White Dwarfs) as PBH Laboratories

“orphan kilonova” without gravity waves

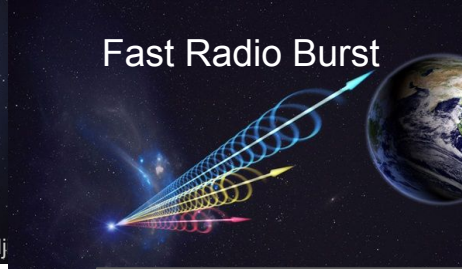


UC Berkeley: Makasdj

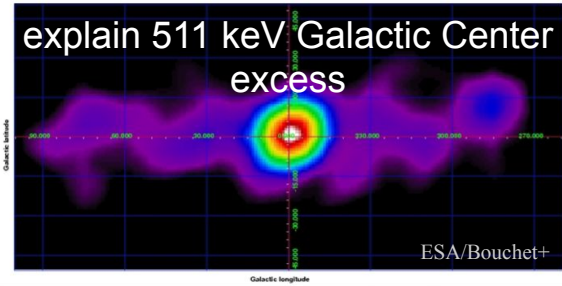
If disk + BH remains →  
“orphan Gamma-ray Burst”  
without gravity waves



Fast Radio Burst



explain 511 keV Galactic Center  
excess

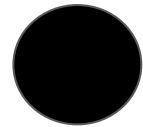
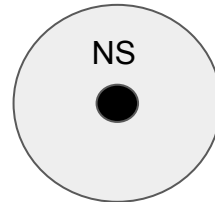


ESA/Bouchet+

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

[Fuller, Kusenko, Radice, VT,  
*Phys. Rev. Lett.*, 2019]

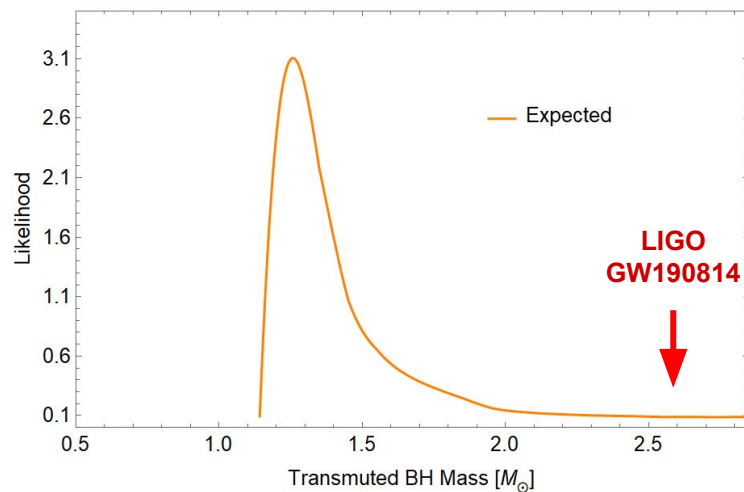
“transmuted” population of solar-mass BHs



[Fuller, Kusenko, VT, *Phys.Rev.Lett.*, 2017; VT, 2018; VT, 2019]

# 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:** BHs from tiny PBH (or particle) DM eating NSs follow NS mass distribution

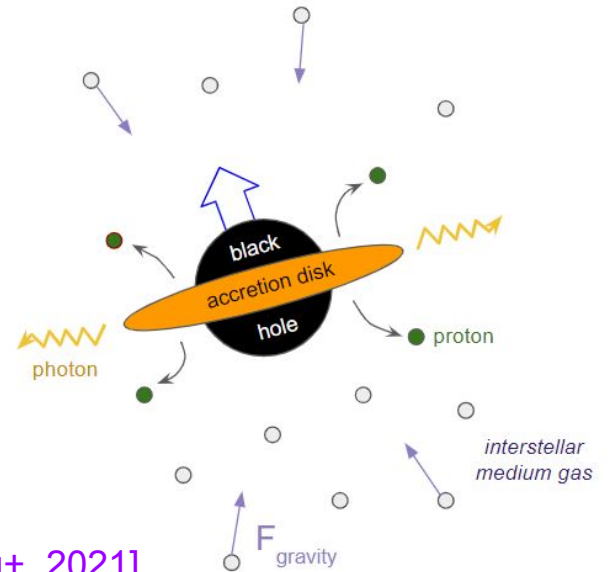


Large ( $> 1.5 M_{\odot}$ ) candidates unlikely to be transmuted BHs!

[VT+, *Phys.Rev.Lett.*, 2021]

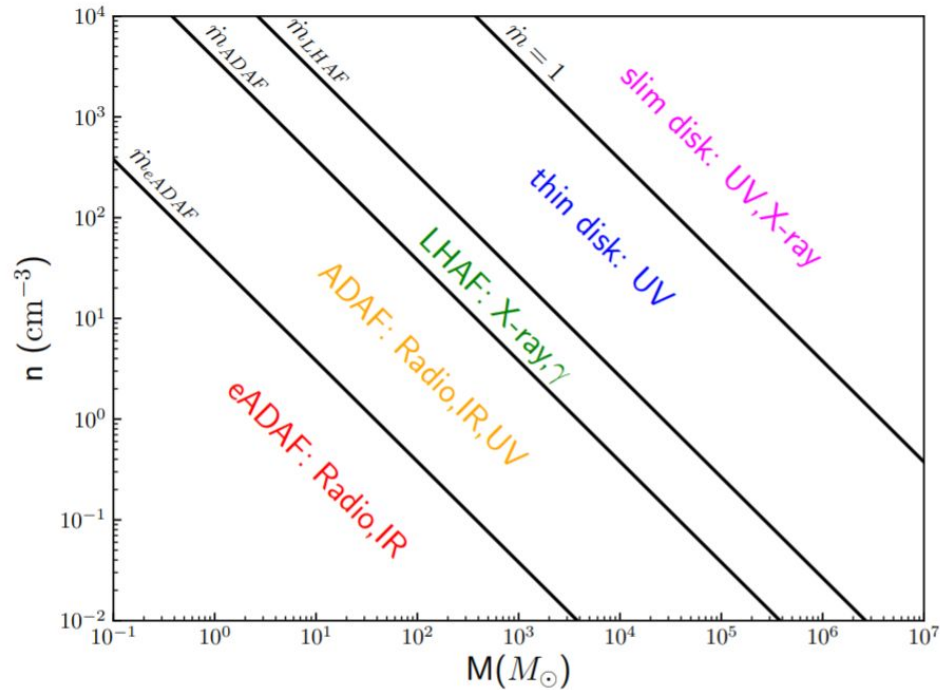
# Are Intermediate-mass BHs Primordial ?

- 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
- Heating mechanisms:
  - gravity drag (dynamical friction)
  - accretion disk photons
  - accretion mass outflows / winds
- Great testing site: dwarf DM-rich galaxies (Leo T)



[Lu, VT+, *Astrophys.J.Lett.*, 2021; VT, Lu+, 2021]

# PBH Accretion Disks

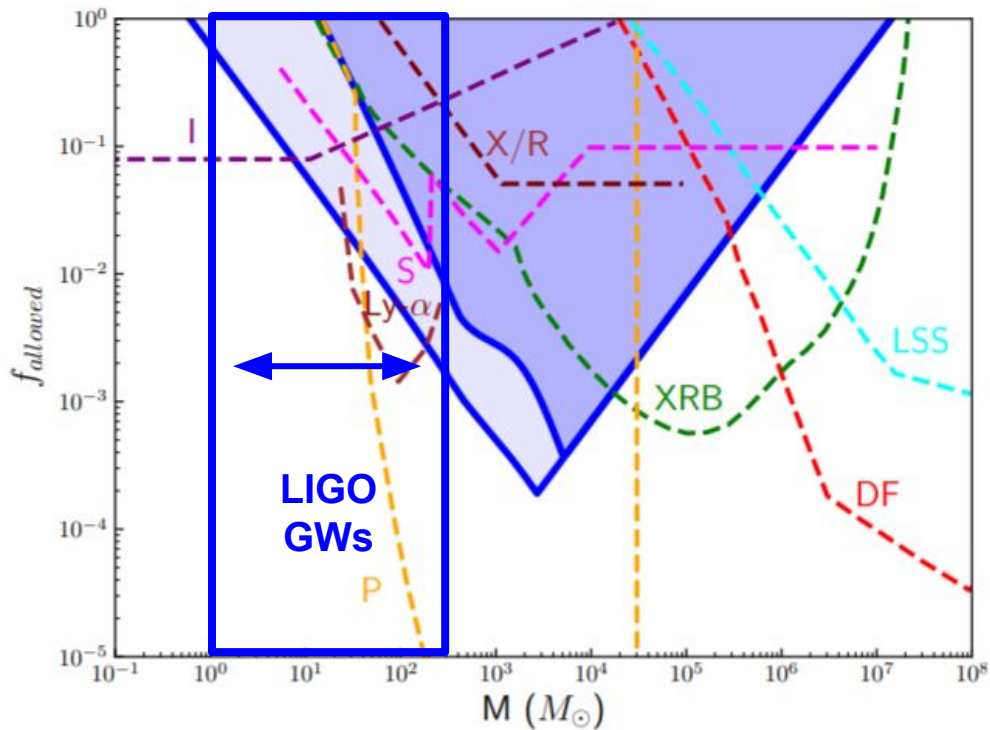


No accretion disk  
for small PBHs !

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

[Lu, VT+, *Astrophys.J.Lett.*, 2021; VT, Lu+, 2021]

# PBH Gas Heating



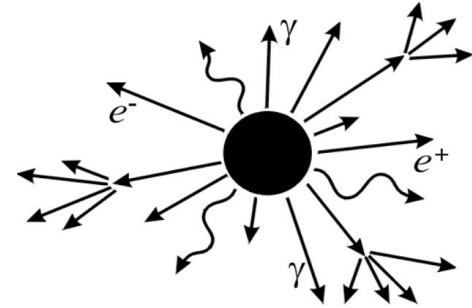
\* gas heating from evaporating PBHs [Laha, Lu, VT, 2020] (also [Kim, 2020])

[Lu, VT+, *Astrophys.J.Lett.*, 2021; VT, Lu+, 2021]



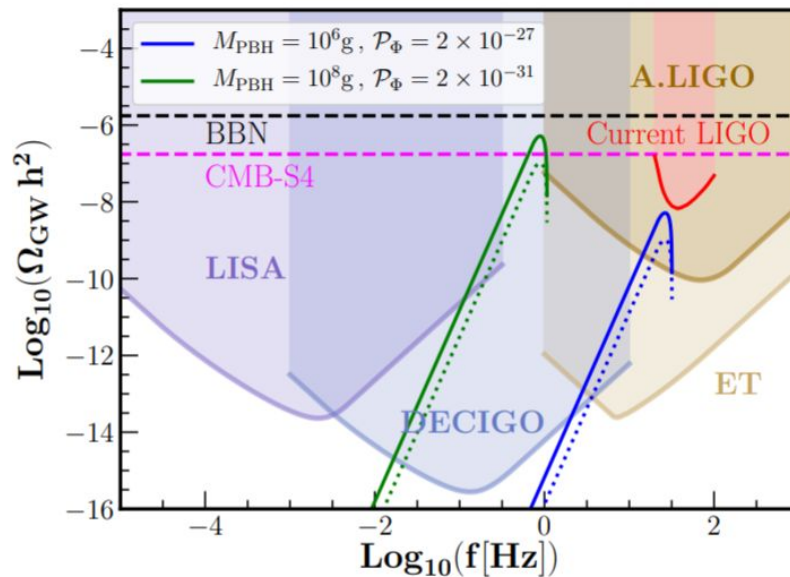
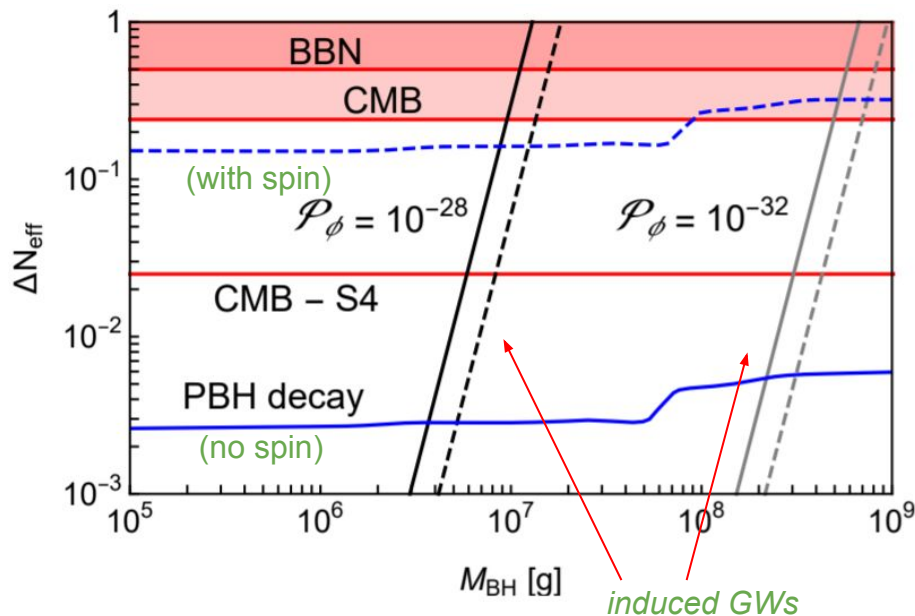
# Exploring Evaporating PBHs with GWs

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



- Evaporating PBH emission products  $\rightarrow$  “dark radiation”  $\rightarrow$  change  $\Delta N_{\text{eff}}$ 
  - PBH *spin* distribution can significantly modify [Hooper+ 2020; Arbey+, 2021; Masina, 2021]
- Rapid evaporation of PBHs dominating Universe  $\rightarrow$  induced GWs  $\rightarrow$  change  $\Delta N_{\text{eff}}$ 
  - 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, 2021]

# Summary

- Renaissance era in PBH research → intimate synergy with multi-messenger astronomy
- General formation scenarios based on scalar fields 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!