New opportunities for primordial black hole detection

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PBH Dark Matter

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

- Why PBH DM ?
  - no clear signs of particle DM
  - GW astronomy [Kovetz, Ali-Haïmoud, Sasaki, Garcia-Bellido, Riotto, Profumo, Byrnes...]
  - can appear in many BSM models
  - help solve astro puzzles [Carr, Dolgov, Tkachev…]
  - already possible in standard cosmology (unlikely)

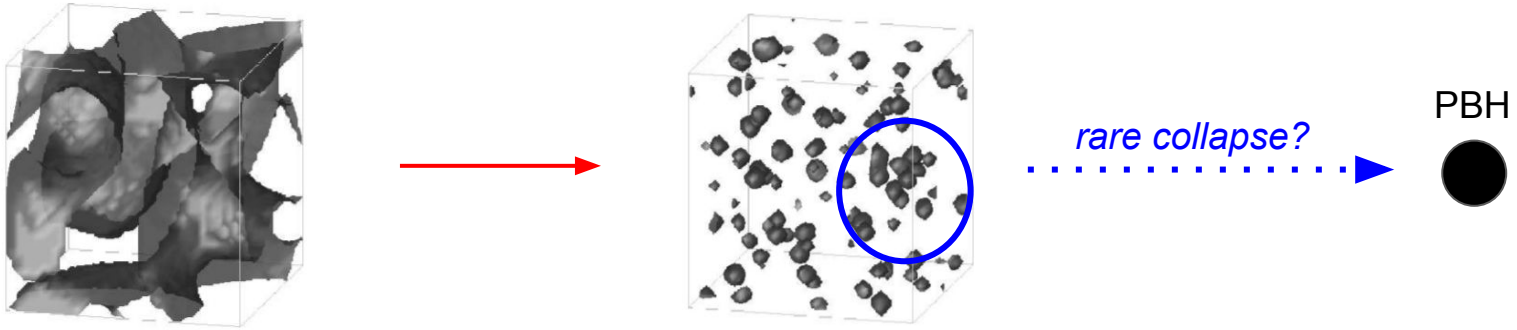
→ typical formation from inflationary perturbations requires tuning...
→ need exciting observables to test vast parameter space

Black Holes from Scalar Fragments

- Scalars very generic in BSM theories (SUSY)
- Post-inflation self-interacting scalars could fragment from instabilities (Q-balls/oscillons)

  **** if gravity is weakest force, fragmentation possibly very generic* [Kusenko, **VT**, Yamada, Yamazaki, 2019]

simulations [Multamaki, Vilja, 2002]



- PBHs from overdense region collapse (unrelated to inflation perturbations)

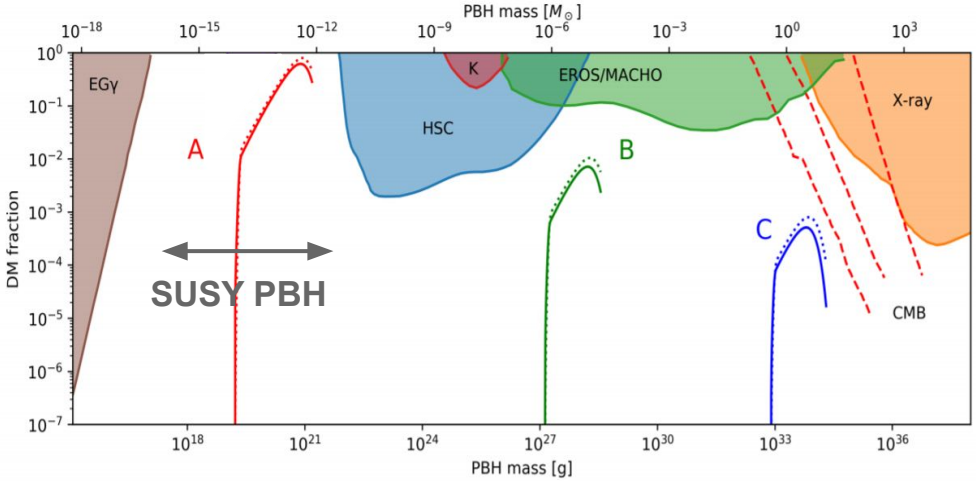
  [Zel'dovich (early ideas); Cotner, Kusenko, Sasaki, **VT**]

Black Holes from Scalar Fragments

PBHs from low-scale SUSY

$$\rho_\phi \sim M_{\rm SUSY}^4$$

$$M_{\rm PBH} \sim 10^{20}\,{\rm g}\left(\frac{100\ {\rm TeV}}{M_{\rm SUSY}}\right)^2$$

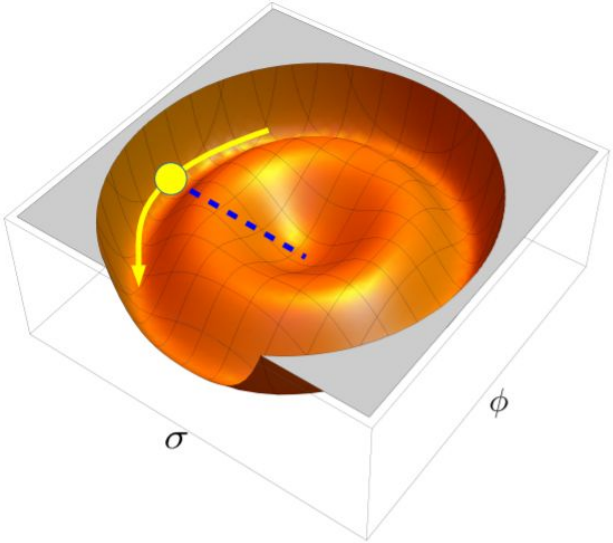


- **Big (a ~ 1) BH spin possible** (hard to make in usual mechanisms)

[Cotner, Kusenko, Sasaki, **VT**]

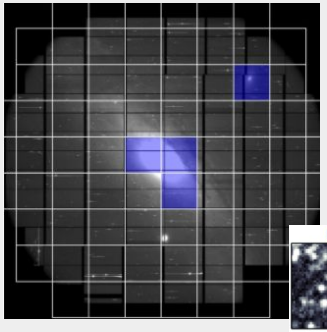
Black Holes from Bubble Multiverse

- Multi(scalar)-field inflation well motivated → vacuum bubble “multiverse” generic prediction
- Collapsing bubbles form PBHs with extended mass-spectrum

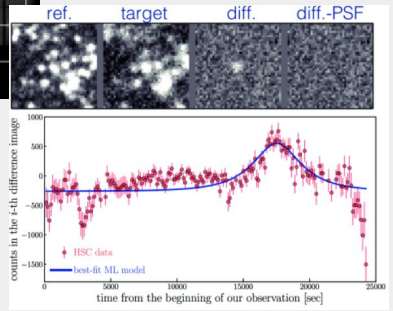


[Vilenkin *et. al.*; Kusenko, Sasaki, Sugiyama, Takada, **VT**, Vitagliano, *Phys. Rev. Lett.*, 2020]

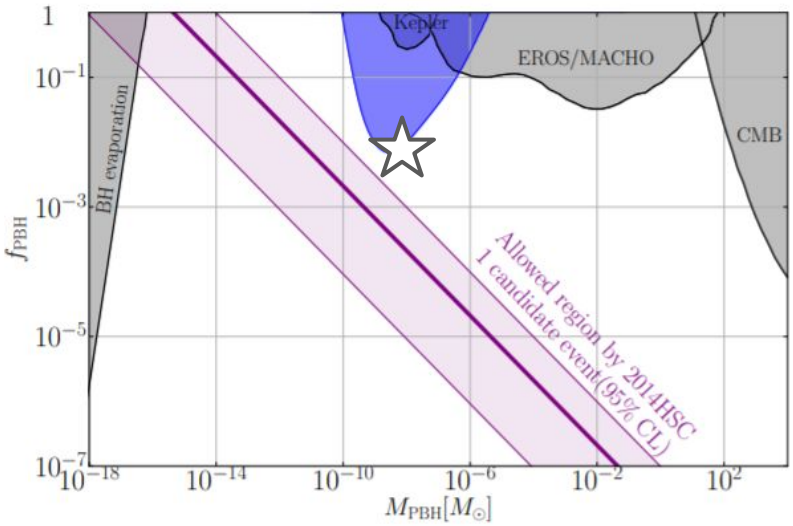
PBH DM from Bubble Multiverse: Detected by HSC ?!



Subaru HSC Andromeda microlensing event



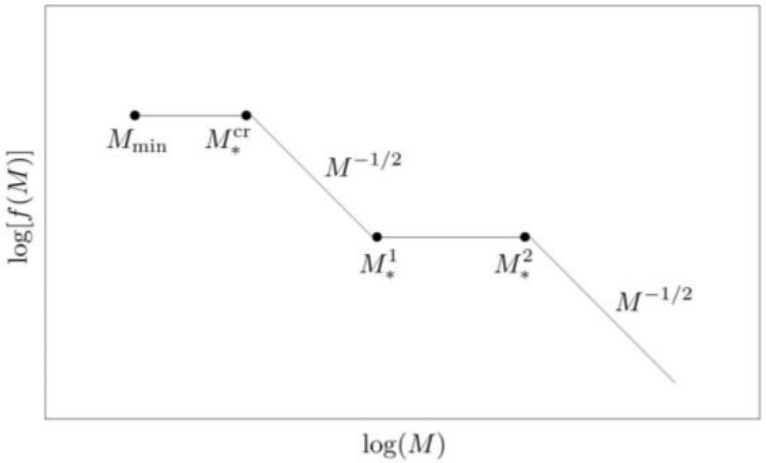
[Niikura, Takada, More+, *Nature Astron.*, 2019]

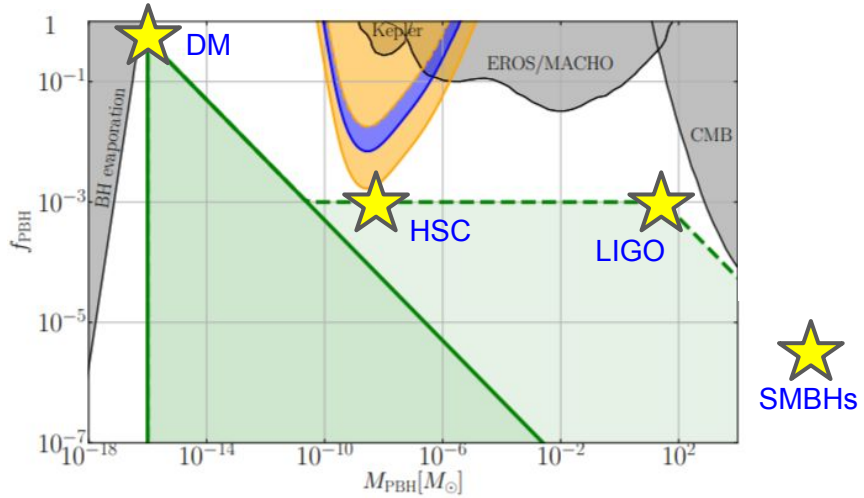


- **PBH DM from bubble multiverse consistent with detected HSC event !**

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

PBH DM from Bubble Multiverse: One Model for All





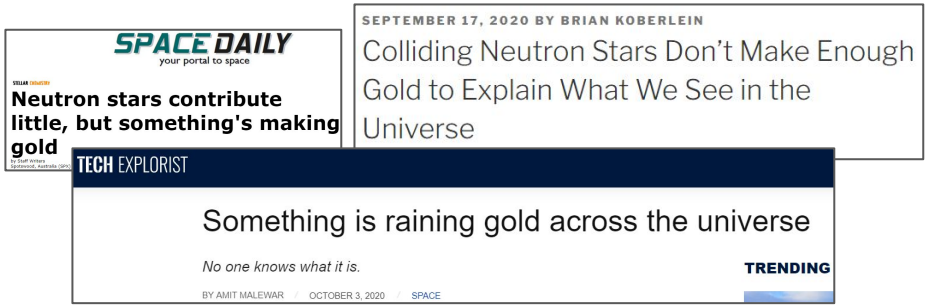
- **Generalized model for everything:** DM, HSC & LIGO events, seeds of supermassive BHs

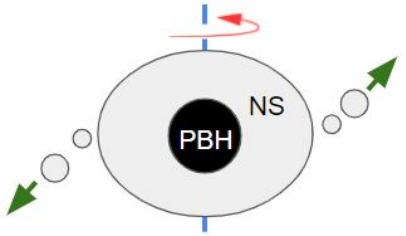
Upcoming HSC observations will definitively test bubble multiverse PBH DM !

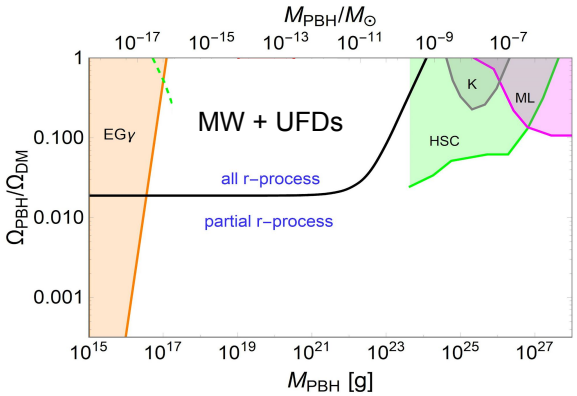
[Kusenko, Sasaki, Sugiyama, Takada, **VT**, Vitagliano, *Phys. Rev. Lett.*, 2020]

Making Gold with Black Holes

- GW170817 NS-NS merger detection settled the origin of heavy elements... ***but did it ?***
  → merger contributions overestimated [Kobayashi+, *2020*]



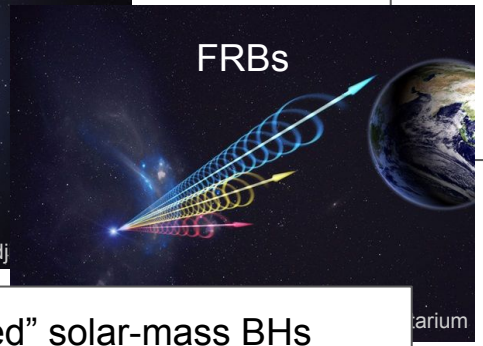




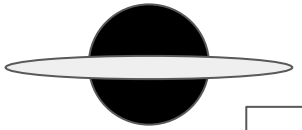
- **Asteroid-mass DM PBHs to the rescue**
  captured by NSs, PBHs consume and explode them
  → r-process nucleosynthesis gold factories

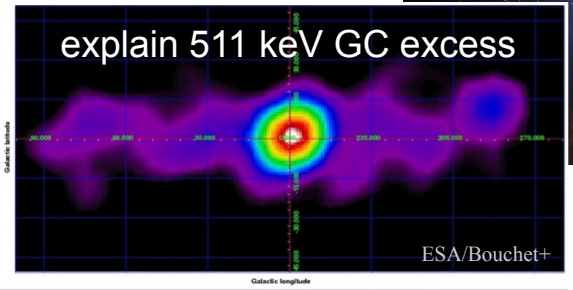
[Fuller, Kusenko, **VT**, *Phys. Rev. Lett.*, 2017]

Compact Stars as PBH Laboratories



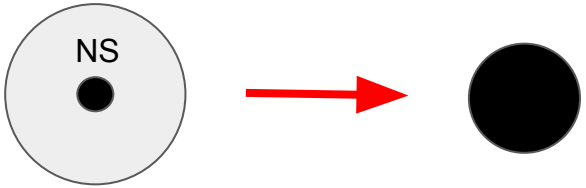
If **disk + BH** remains →
“orphan GRB” without GWs



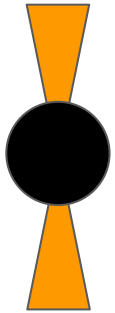


*** *can also explain with regular NS-NS*
[Fuller, Kusenko, **VT**, *Phys. Rev. Lett.*, 2019]

“transmuted” solar-mass BHs



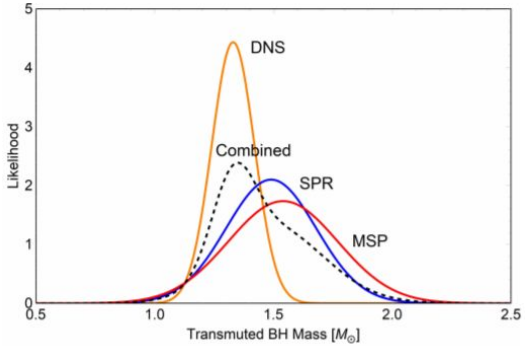
solar-mass microquasars



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

Origin of Solar Mass BHs

- Solar-mass BHs unexpected in astrophysics → signature of PBHs (or particle DM [Tinyakov...])
- LIGO events consistent with ~1.5-2.6 M⊙ BHs [Abbott+, *ApJL*, 2020...]
  ...**how to distinguish BH origin ?**
- Simple but powerful test: solar BH mass-function
  → *transmuted solar-mass BHs from small PBH or particle DM capture will follow NS masses*



Trial Fit	Candidate GW Events	Total Events	BH Mass ($M_\odot$)	K-S Test (p-value)
1	GW190814 GW190425	2	2.6 1.8	7.2×10^{-3}
2	GW190814 GW190425 GW170817	3	2.6 1.8 1.5	9.5×10^{-2}
3	test event 1 test event 2 test event 3 test event 4 test event 5 test event 6 test event 7	7	1.3 1.5 1.8 2.0 2.1 2.2 2.3	1.8×10^{-3}

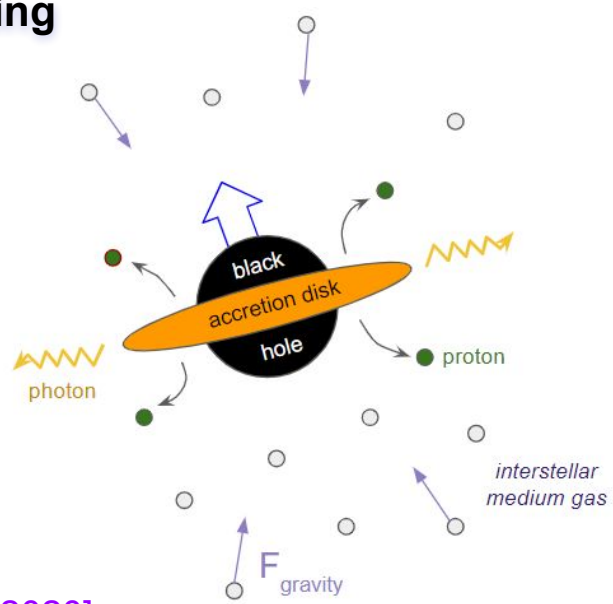
→ **Large (> 1.5 M⊙) candidates unlikely to be transmuted BHs!**

[**VT**, Fuller, Kusenko, 2020]

...related ideas [Dasgupta, Laha, Ray, 2020]

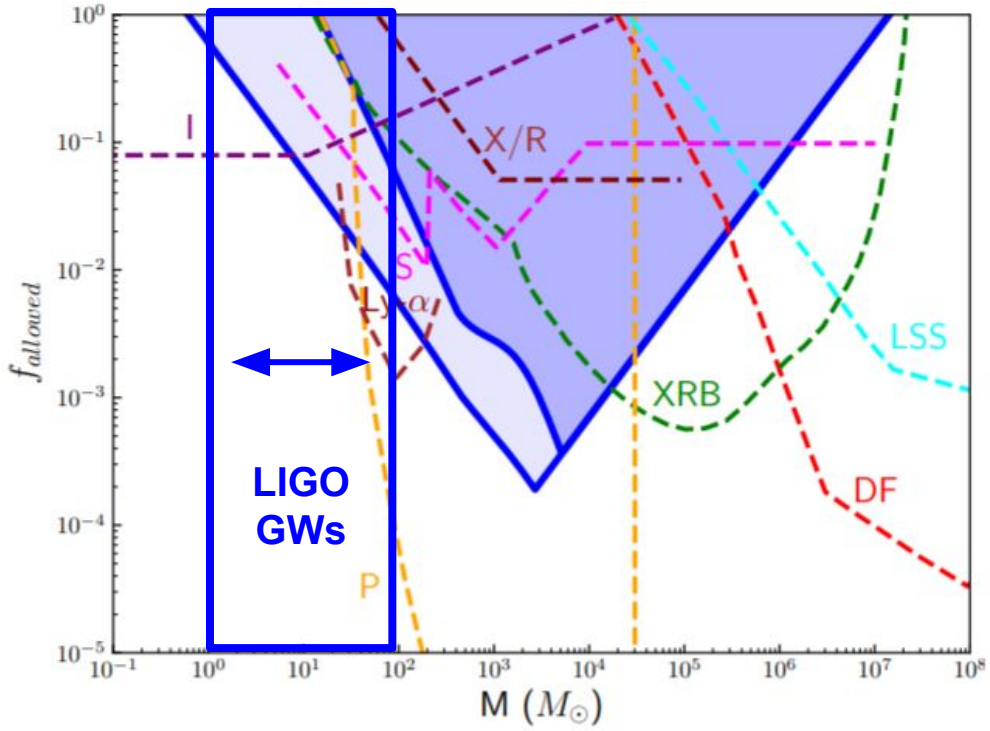
Are Intermediate-mass BHs Primordial ?

- GW190521 event ~ 150 M⊙ merger mass [Abbott+, *PRL*, 2020], first definitive IMBH detection
- New general cosmology-independent observable: **gas heating**
- Main PBH heating mechanisms of interstellar medium:
  - dynamical friction
  - accretion disk photon emission
  - accretion mass outflows / winds
- Great testing site: dwarf DM-rich galaxies (Leo T)



[Lu, **VT**, Gelmini, Hayashi, Inoue, Kusenko, 2020]

PBH Gas Heating



*** *can also use to constrain evaporating PBHs*

[Kim, 2020;
Laha, Lu, **VT**, 2020]

[Lu, **VT**, Gelmini, Hayashi, Inoue, Kusenko, 2020]

Summary

- Renaissance era in PBH research → intimate synergy with multi-messenger astronomy
- New general PBH formation scenarios with scalars: high spin, broad mass-spectrum…
  → upcoming definitive tests with optical telescopes
- Many interesting under-explored observables, especially from compact star interactions
- Simple powerful test to establish solar-mass BH origin: mass-function
- Novel general cosmology-independent probe of IMBHs: gas heating
- ***Marching towards definitive answers regarding the role of PBHs for DM and in physics !***