

Primordial Black Holes

New Opportunities

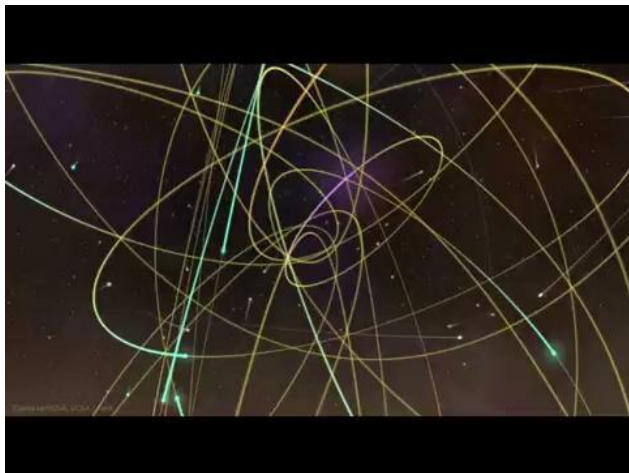


Volodymyr Takhistov

QUP, KEK

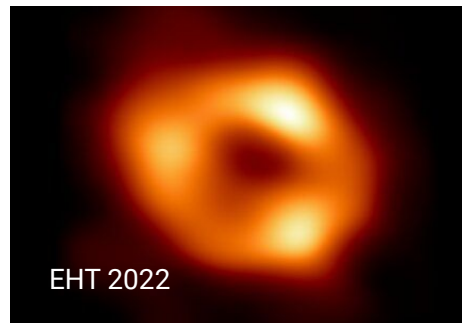
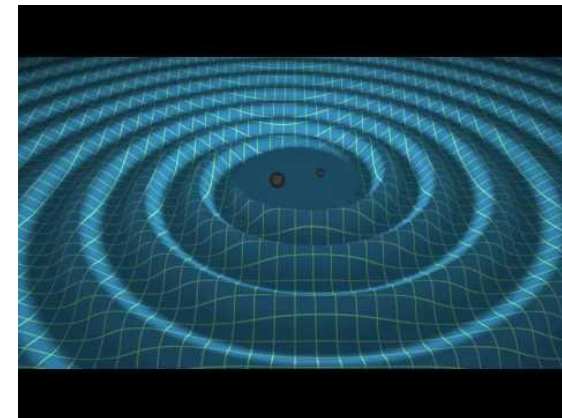


Black Holes **Definitively Exist, Central in Astronomy**



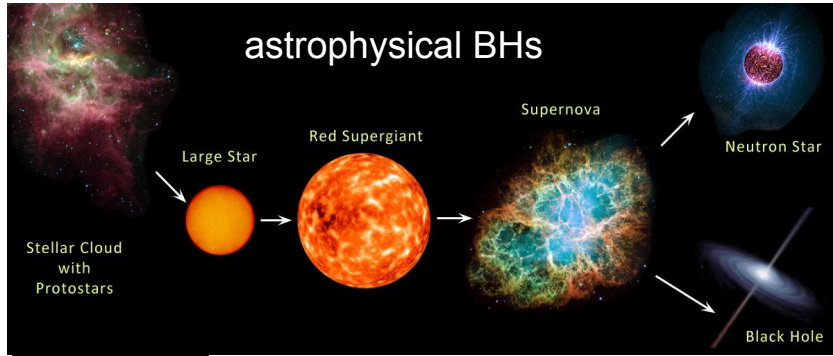
Sgr A*
Milky Way

BH binary merger

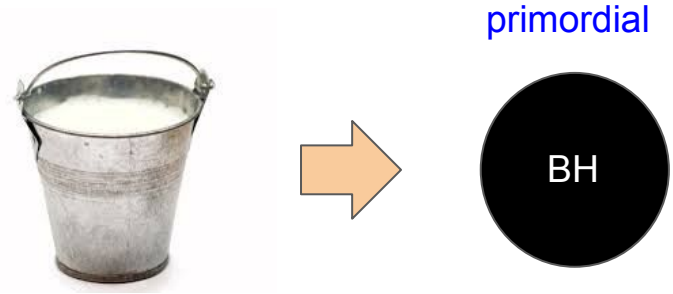


EHT 2022

Primordial Black Holes (PBHs)



In early Universe, just roughly take scoop of $\sim 50\%$ overdensity to make BH

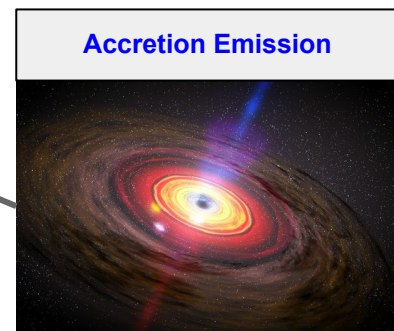
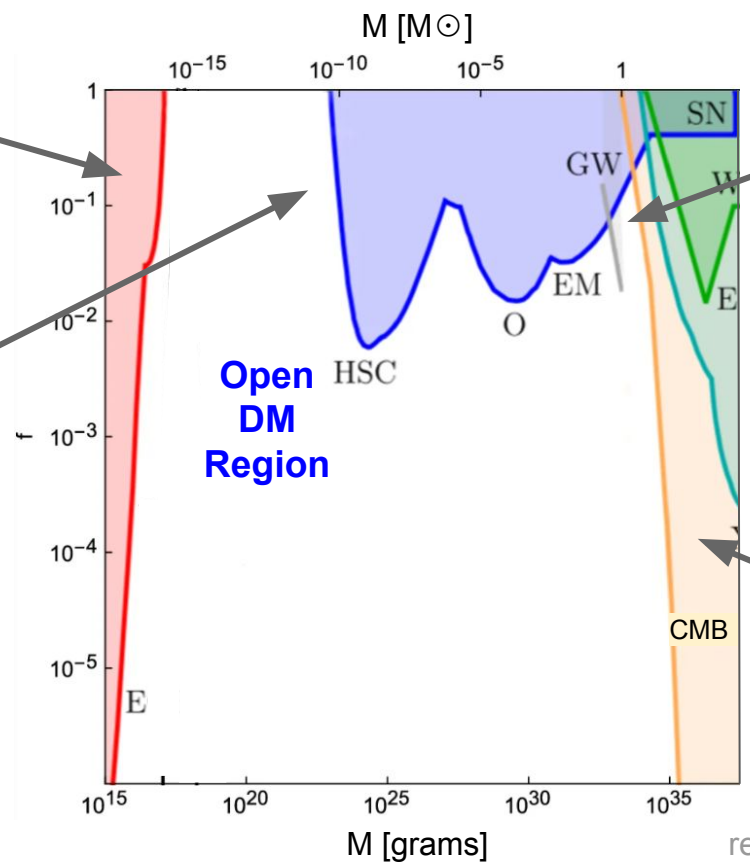
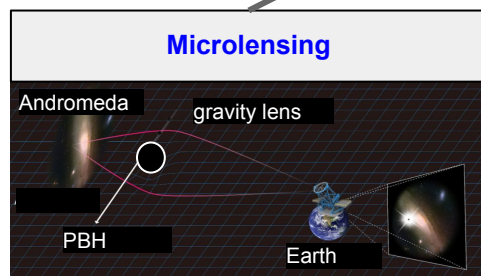
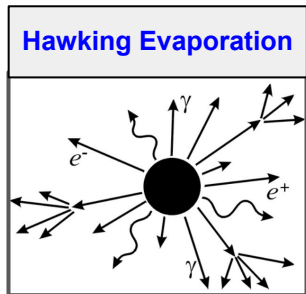


PBHs as dark matter

... a ***“Standard Model”*** candidate, but benefits from beyond SM physics



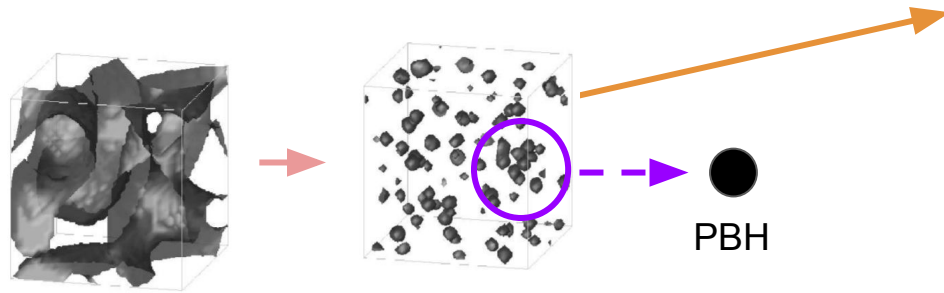
PBH DM Status



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

Distinct PBH Features Possible

scalar fragmentation

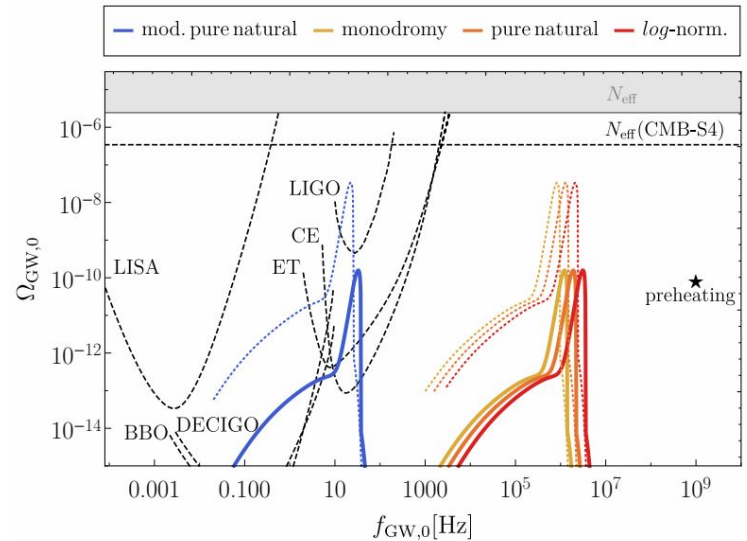


**PBHs peaked in mass
+ big spin possible**

inflaton oscillons

[Cotner, Kusenko, **VT**, *PRD*, 1801.03321;
Cotner, Kusenko, Sasaki, **VT**, *JCAP*, 1907.10613]

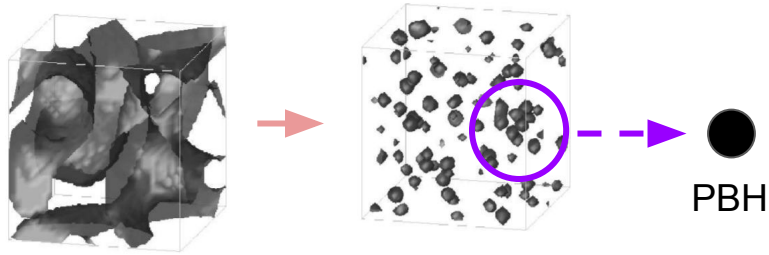
decays of oscillons can lead to BIG GWs
→ novel probe of early Universe physics



[Lozanov, **VT**, 2204.07152]

Distinct PBH Features Possible

scalar fragmentation



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

inflaton oscillons

[Cotner, Kusenko, **VT**, *PRD*, 1801.03321;
Cotner, Kusenko, Sasaki, **VT**, *JCAP*, 1907.10613]

vacuum bubble “multiverse”



**PBHs broadly
distributed in mass**

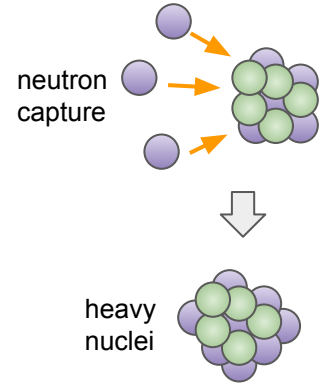
[Deng, Vilenkin, Sasaki...;

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

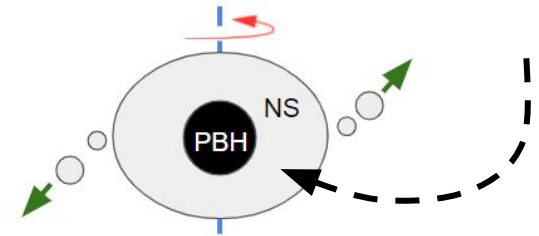
Making Gold with Tiny PBHs

- 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



...need more simulations

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

Neutron Stars (+ White Dwarfs) as PBH Laboratories

“orphan kilonova” without gravitational waves

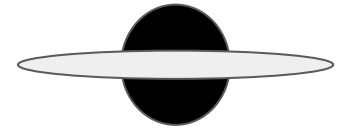


UC Berkeley; Makasdjian/

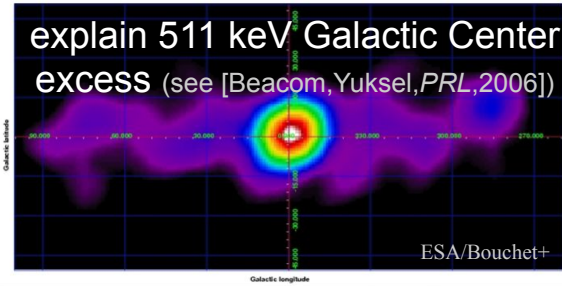
Fast Radio Burst



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



explain 511 keV Galactic Center
excess (see [Beacom, Yuksel, PRL, 2006])

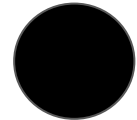
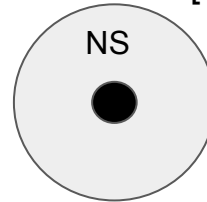


ESA/Bouchet+

*** can explain with regular NS-NS

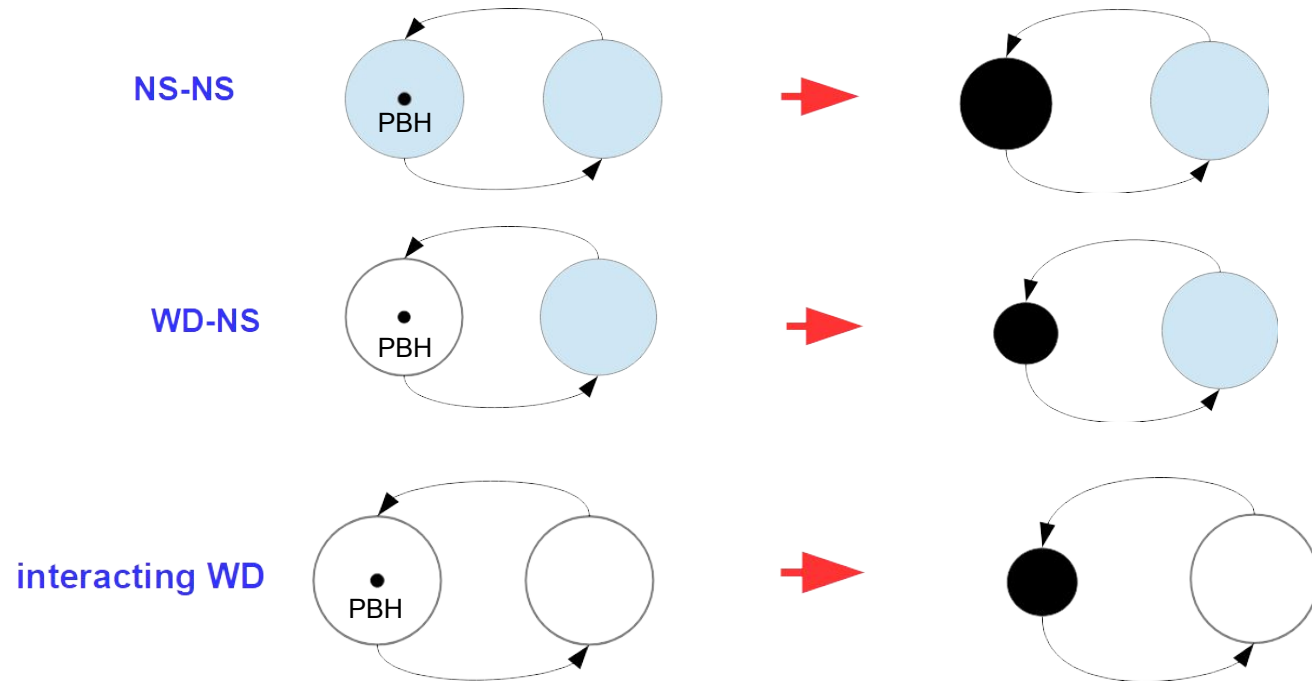
[Fuller, Kusenko, Radice, VT,
Phys.Rev.Lett., 1811.00133]

“Transmuted” population of solar-mass BHs
[VT, PLB, 1707.05849]



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

Transmuted Solar-Mass BH Mergers

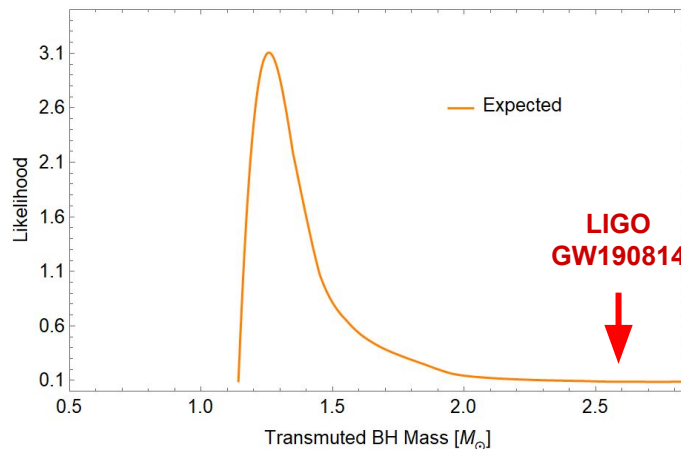
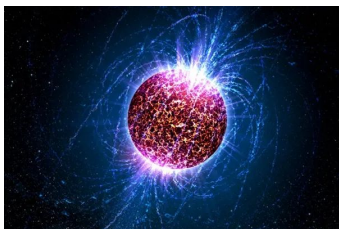


*Look for
sub-solar mass
mergers !*

[VT, PLB, 1707.05849]

Origin of Solar-mass Black Holes

- Solar-mass ($\sim 1\text{-}2.5 M_{\odot}$) BHs unexpected in astrophysics \rightarrow PBHs ? particle DM accumulation?
[Reddy, Baryakhtar, Tsai, Capela, Tinyakov, Yu, Kouvaris...]
- **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

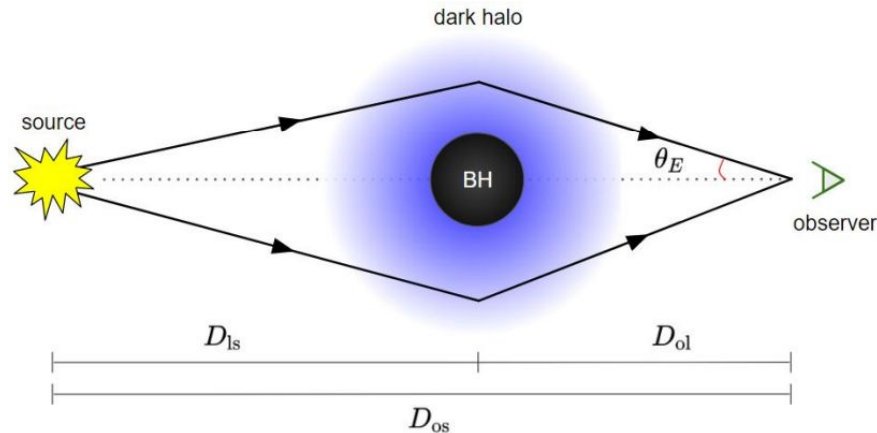


Large ($> 1.5 M_{\odot}$) candidates unlikely to be from DM-NS interactions!

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

Cosmological Lensing, A Novel Test of Dressed PBHs

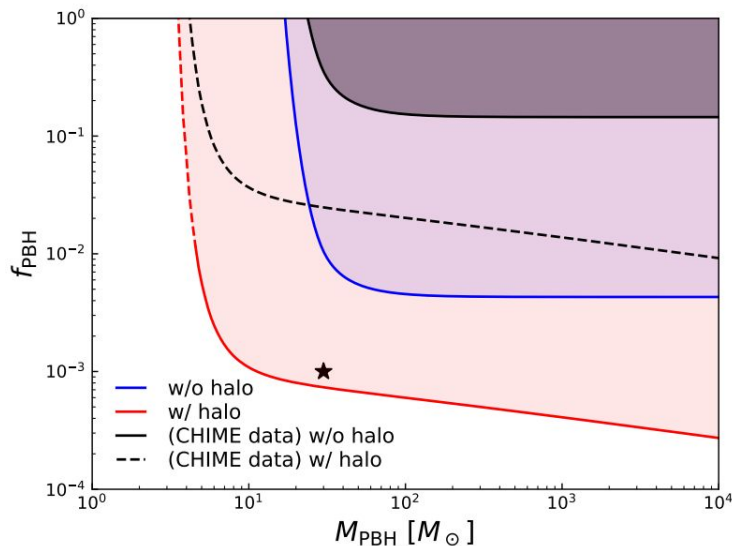
- Stellar-mass PBHs relevant for LIGO can only comprise subdominant DM
→ engulfed in massive halo dress of primary DM (e.g. axions) [Mack+, 2007; Ricotti+, 2008]
* *PBHs incompatible with annihilating WIMPs* [Lacki, Beacom, *ApJL*, 2010; ...]
- While local lensing is inefficient, strong cosmological lensing (e.g. FRBs) **can directly test !**



[Oguri, VT, Kohri, 2208.05957]

Cosmological Lensing, A Novel Test of Dressed PBHs

- Already start exploring with CHIME FRB data, with $\sim 10^5$ FRBs will probe LIGO region



- Method covers broad model range, need to study other lensing: supernovae, caustics

[Oguri, VT, Kohri, 2208.05957]

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)

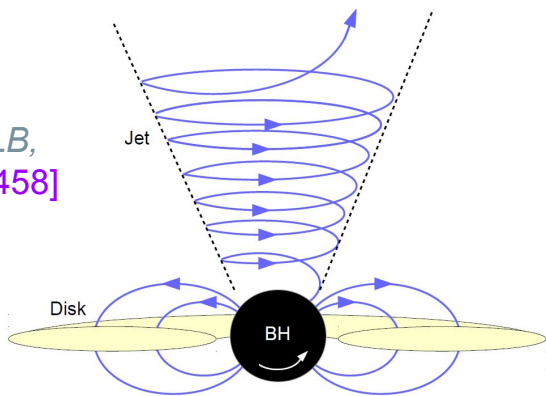


[Lu, VT+, *ApJ Lett.*, 2007.02213; VT+, *JCAP*, 2105.06099]

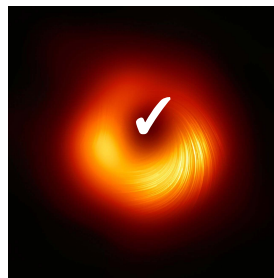
PBH Outflow Winds and Jets

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

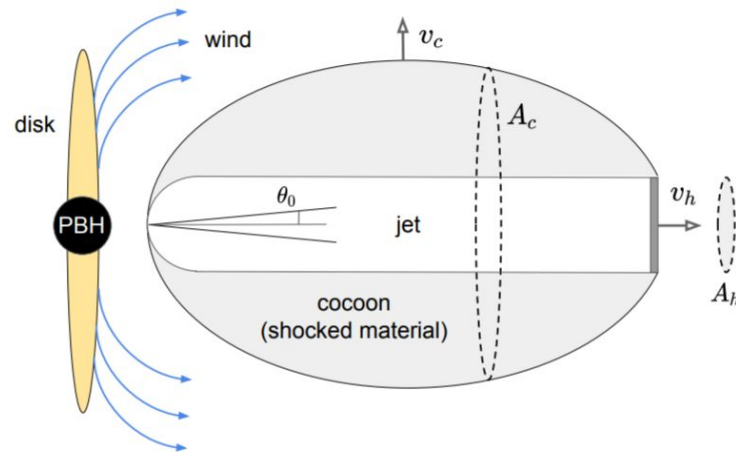
[VT, PLB,
1710.09458]



Blandford-Znajek
Mechanism

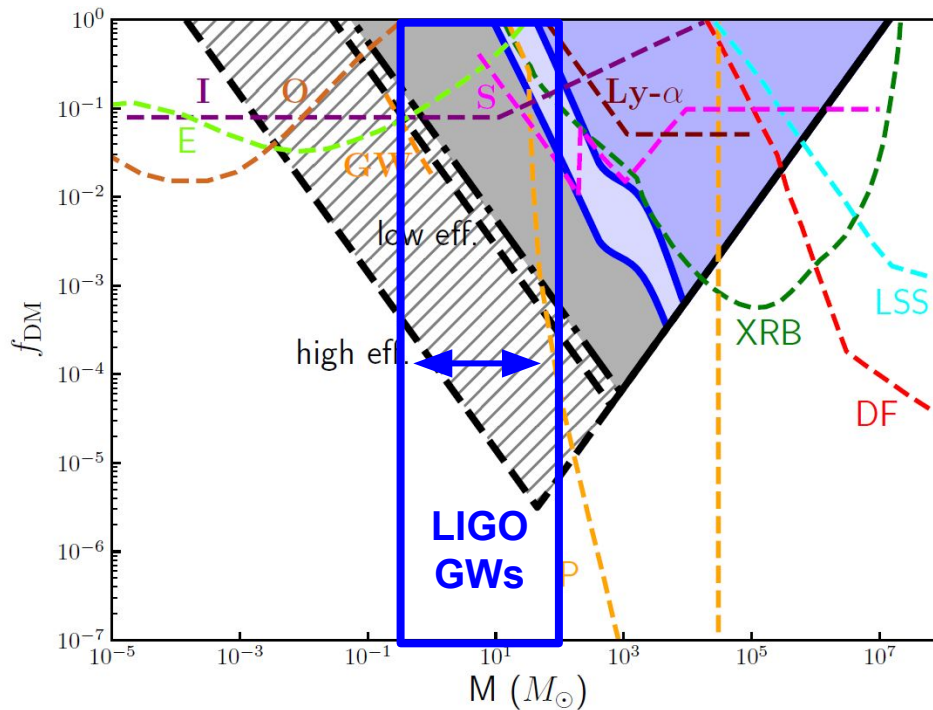


EHT M87
strong B-field + jet



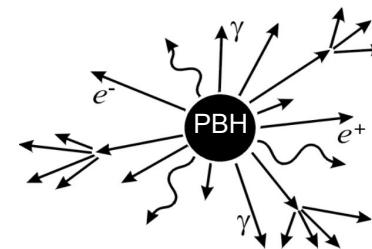
[VT+, MNRAS Lett., 2111.08699]

PBH Outflow Winds and Jets



* gas heating from evaporating PBHs

[Laha, Lu, VT, *PLB*, 2009.11837]
(also [Kim, 2020])

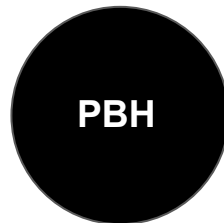


[VT+, *MNRAS Lett.*, 2111.08699]

Summary

- PBHs ~ “Standard Model” dark matter
- Renaissance in the field, synergy with multimessenger astronomy breakthroughs
- Distinct PBH features possible, can generically appear in many models
- Connections with long-standing astronomy puzzles and numerous signatures

Could be already lurking in the data ! → essential to confront new observations



... Dark Matter ?