Signatures of Primordial Black Hole and Neutron Star Interactions

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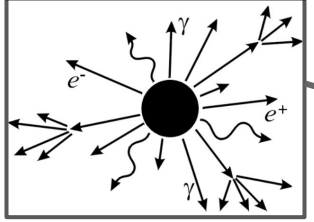
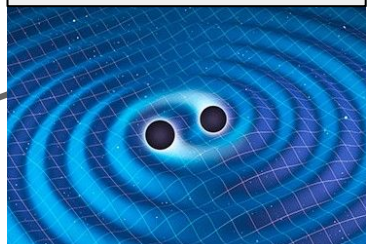
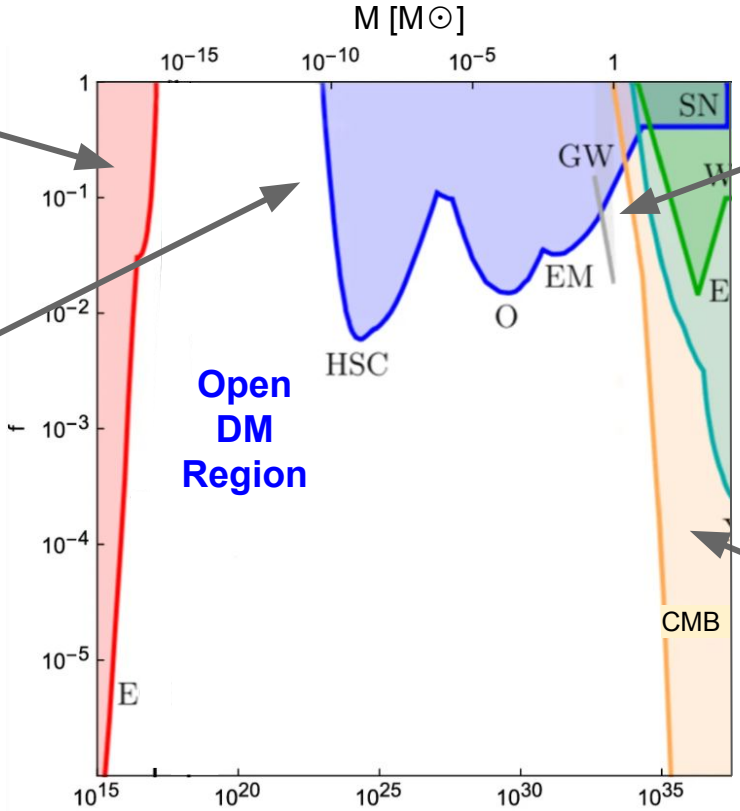
Status

Hawking Evaporation

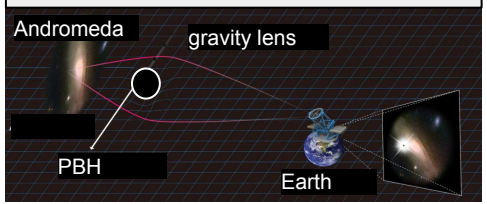


Gravitational Waves

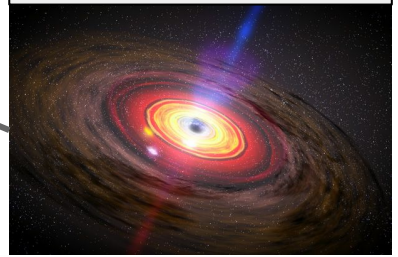




Microlensing

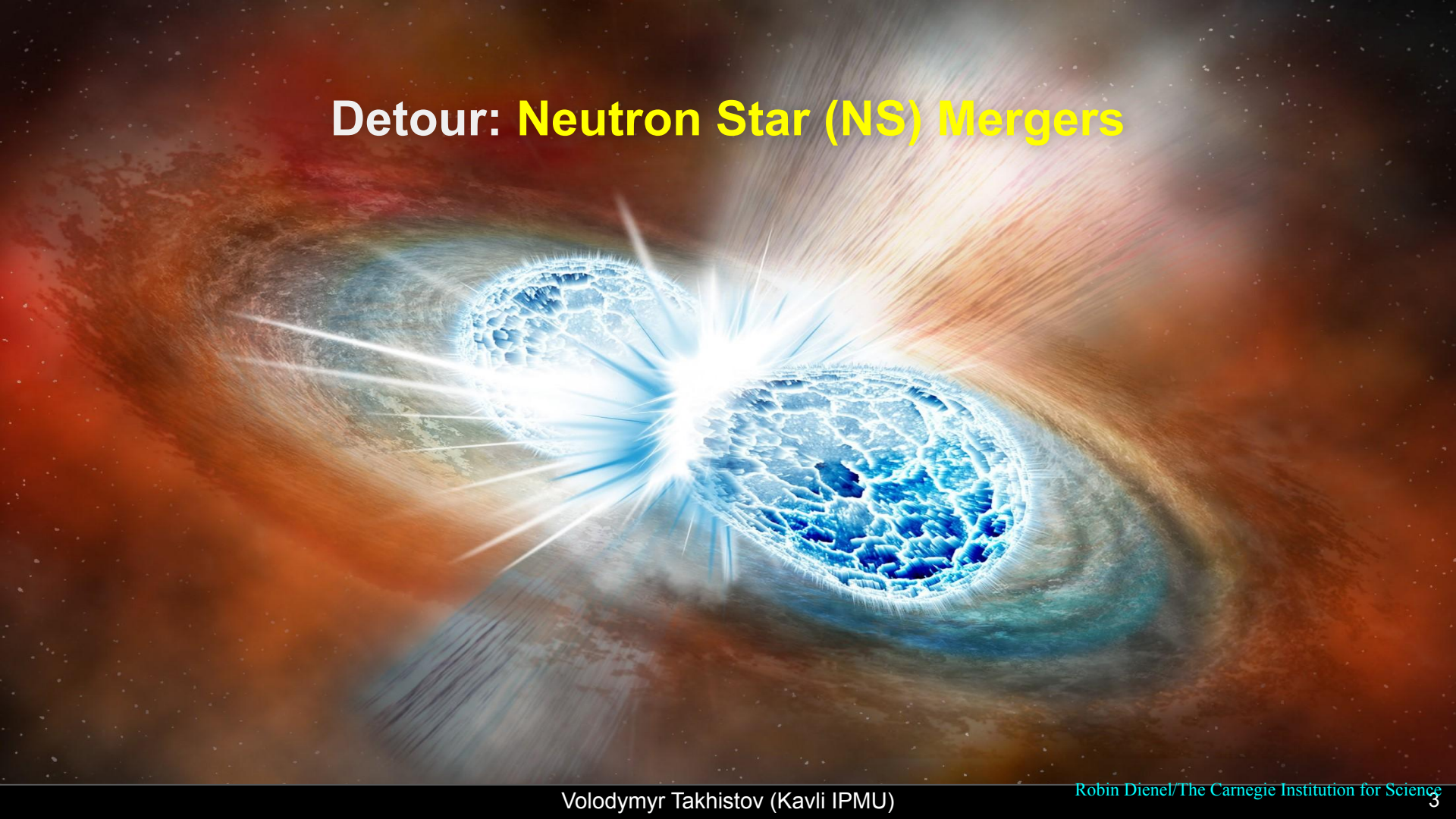


Accretion Emission

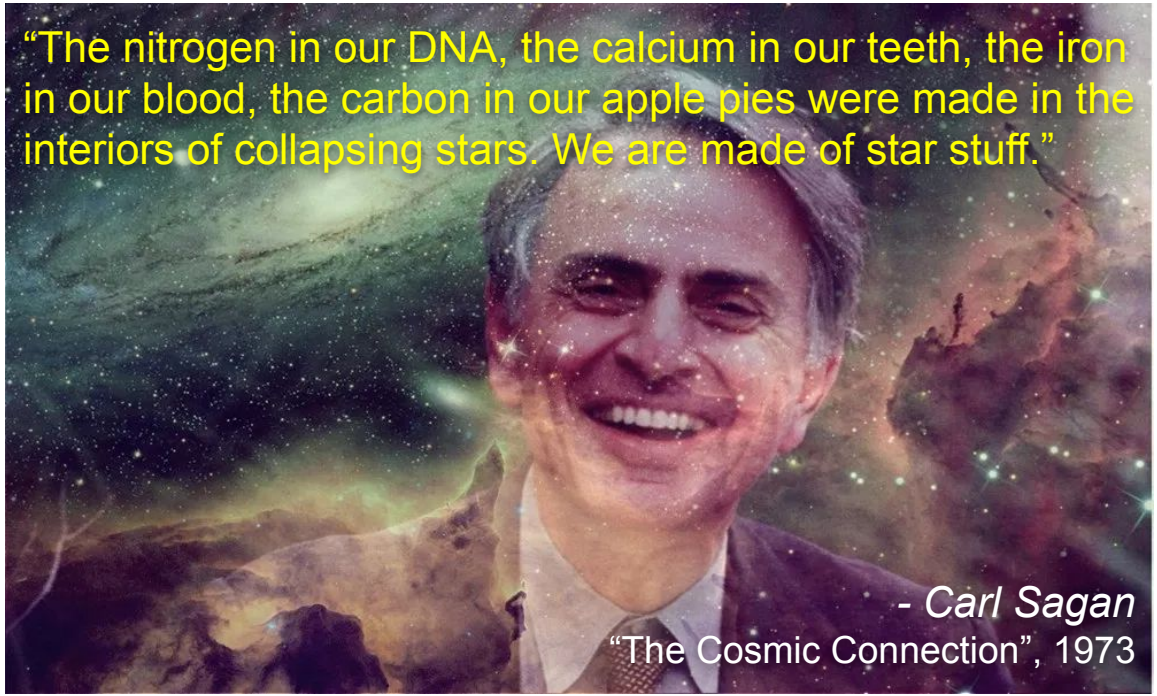


review [Sasaki+, 2017; Carr, Kohri+, 2020...]

Detour: Neutron Star (NS) Mergers



Robin Dienel/The Carnegie Institution for Science



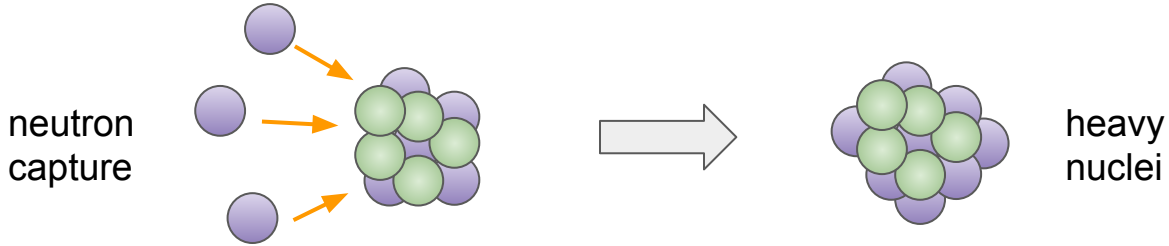
Where do heavy elements (gold) come from?

→ **major problem**

Heavy Element Production in Merger Material

- Ejected material is neutron rich → great site for r-process

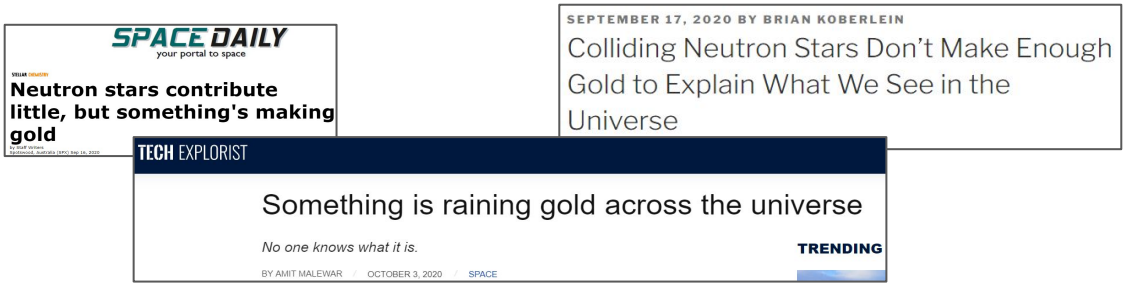
- **R-process nucleosynthesis**
  → main furnace of heavy elements in astronomy



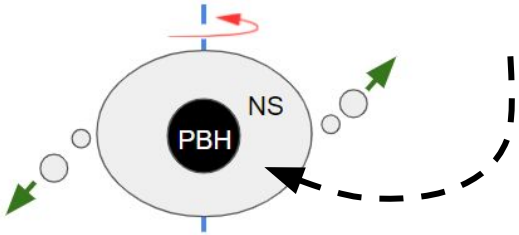
- Nuclear reactions in expanding ejecta produce heat + afterglow (kilonova)

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

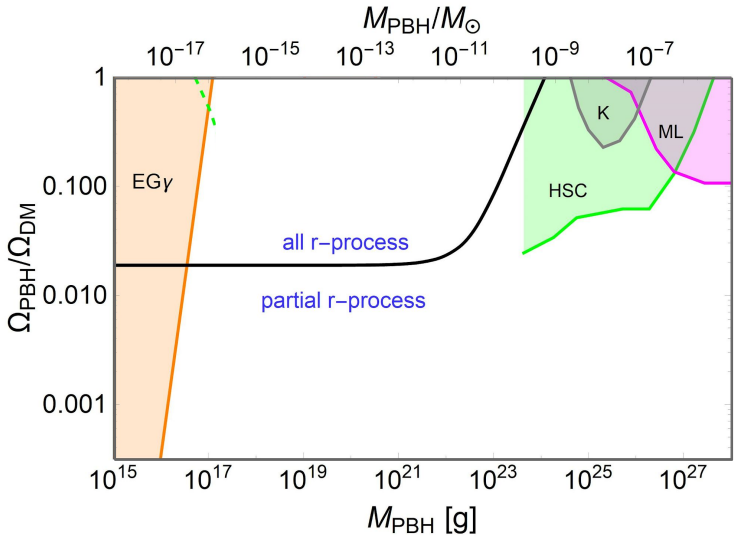


…need more simulations, interesting ideas by D. Radice

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

PBH-NS: Nucleosynthesis

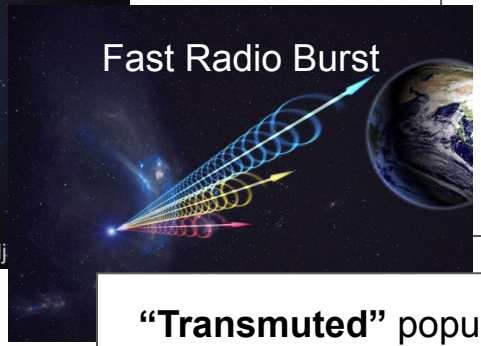
- Neutron-rich ejecta
  → heavy element production



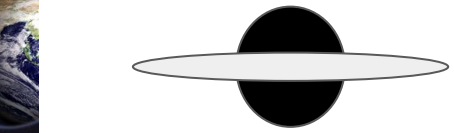
- PBH-NS emission consistent with Milky Way & Ultra-faint Dwarf abundance

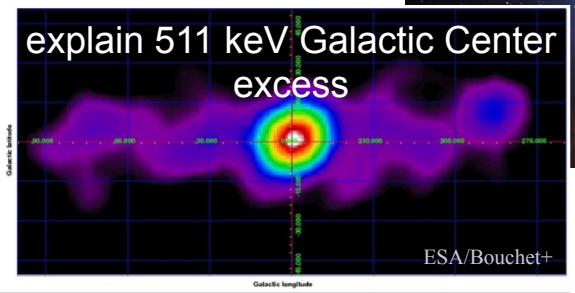
[Fuller, Kusenko, **V.T.**, *PRL*, 1704.01129]

Neutron Stars (+ White Dwarfs) **as PBH Laboratories**



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

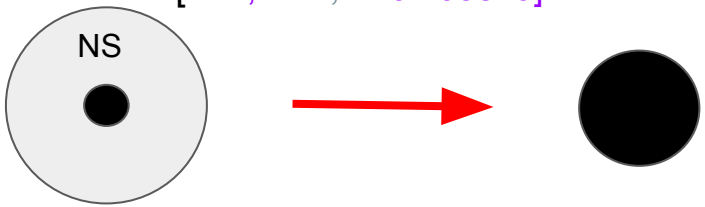




**** can explain with regular NS-NS*

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

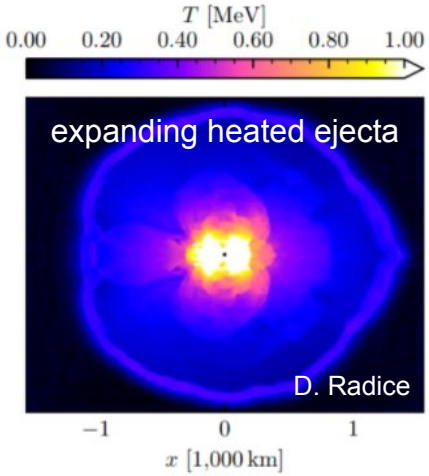
"Transmuted" population of solar-mass BHs
[**V.T.**, *PLB*, 1707.05849]

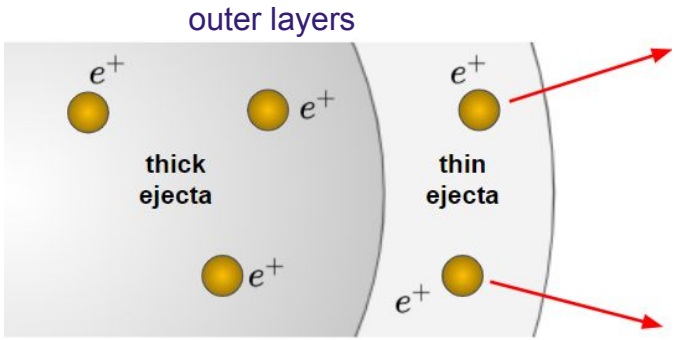


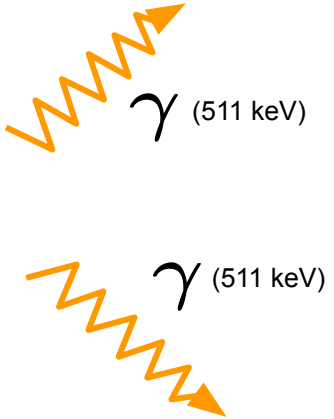
[Fuller, Kusenko, **V.T.**, *PRL*, 1704.01129; **V.T.**, *PLB*, 1707.05849; **V.T.**, *PLB*, 1710.09458]

Novel Generic Signal for NS Mergers

- Positrons produced in heated NS merger ejecta → some escape → annihilate to 511 keV





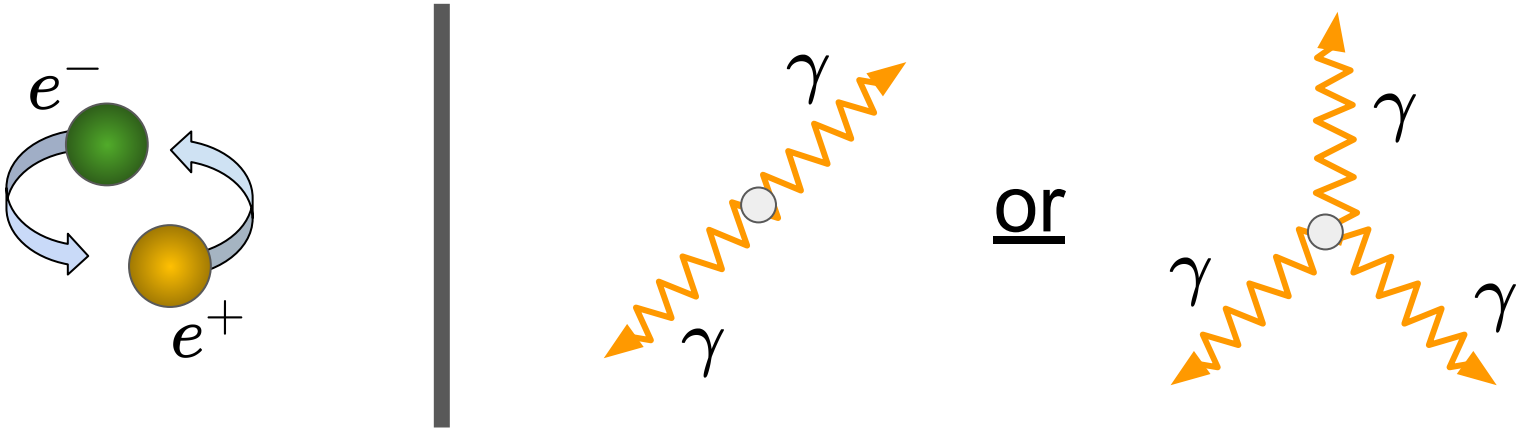


- **With LIGO observations can explain 511 keV signal in Galactic Center !**

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

511 keV radiation

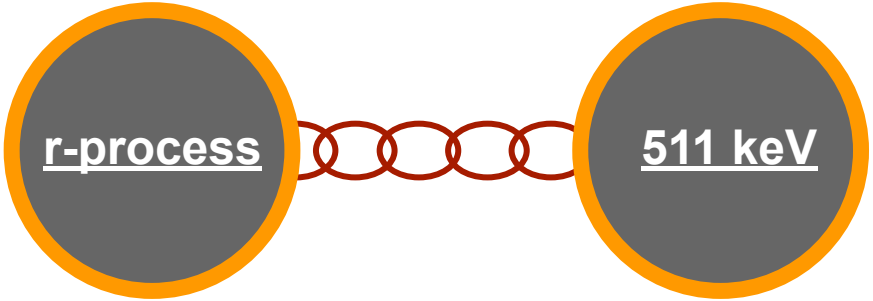
- Escaping ~MeV positrons annihilate via positronium bound state formation (as desired for Galactic Center excess) → **511 keV radiation** ✓



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

NS Signal Connection, Smoking Gun ?

- Proposal directly links r-process and 511 keV



- Observations of Reticulum II dwarf spheroidal hint at heavy elements + 511 keV ?

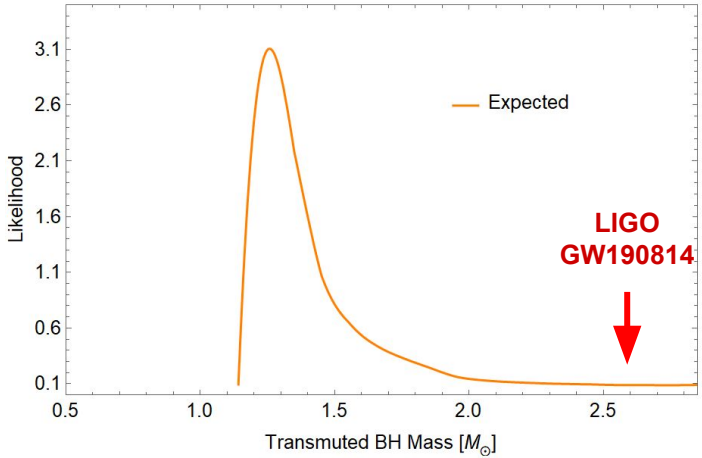
→ **smoking gun signal of mergers**

[Ji, Frebel+, *Nature*, 2016; Siegert+ 2016]
…Siegert+, 2021 → 511 keV might be reduced, but excess still possible

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

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:** *transmuted* BHs from PBHs (or particle) DM eating NSs follow NS mass distribution

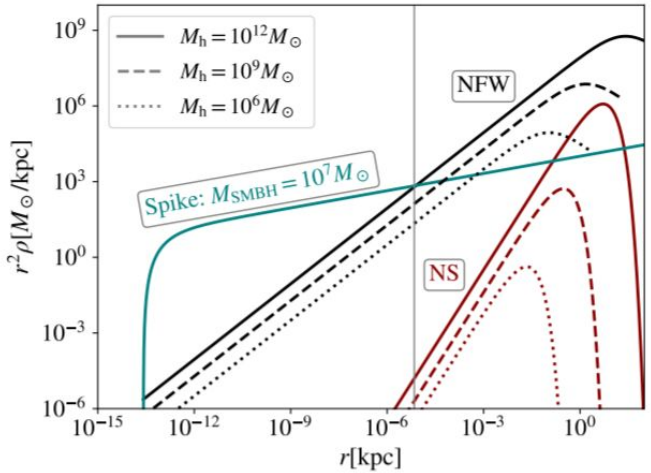


Large (> 1.5 M⊙) candidates unlikely to be from DM-NS interactions!

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

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

- PBH-PBH mergers have been associated with LIGO BH-BH GW observations
- **First BH-NS candidates observed by LIGO** [Abbott+, *ApJL*, 2021...] **....from PBHs?**
- Unlike PBH-PBH, PBH-NS can only form after star formation



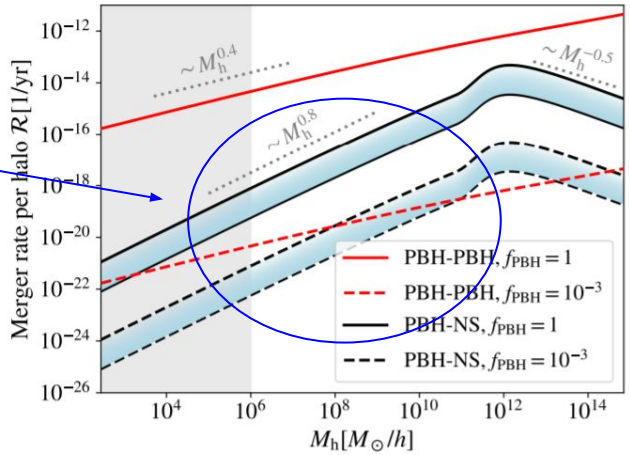
$$\mathcal{R}_{\rm PBH-NS} = 4\pi \int_0^{R_{\rm vir}} {\rm d}r r^2 \frac{\rho_{\rm NS}}{m_1} \frac{\rho_{\rm PBH}}{m_2} \langle \sigma v_{\rm rel} \rangle$$

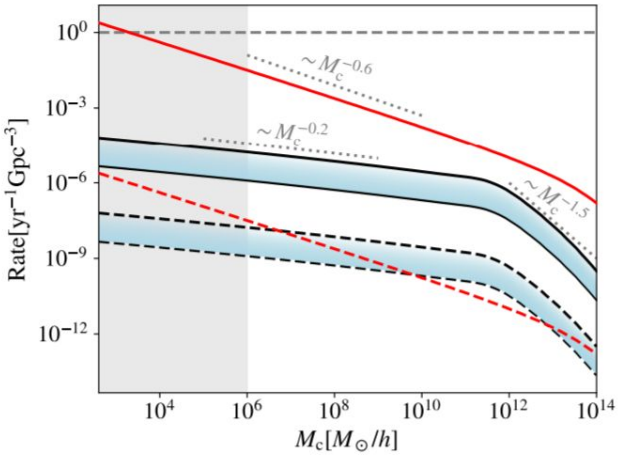
2-body scattering with GW emission

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

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

drop in stellar mass/halo





- **PBH-NS rates subdominant → observed NS-BH events are <u>astrophysical !</u>**
- *True, even if PBH-PBH are significant* → contributions from early Universe
- Do not expect significant multimessenger contributions / emissions from PBH-NS

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

Summary

- Renaissance era in PBH research synergistic with multimessenger astronomy
- New connection between 511 keV/r-process for NS mergers
- Novel signatures from NSs interacting with small PBHs, more to explore
- PBH-NS mergers do not significantly contribute to signatures, BH-NS astrophysical
  → *however, PBH-PBH mergers can play important role*

... Dark Matter ?