Mergers as a Probe of Particle Dark Matter

arXiv: 2009.01825 [astro-ph.HE]

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Summary

- Recent discoveries of low mass black holes (BHs) pose fundamental questions about their origin.

(Stellar or Primordial?)

GW190814: Gravitational Waves from the Coalescence of a 23 $M_\odot$ Black Hole with a 2.6 $M_\odot$ Compact Object

LIGO Scientific Collaboration and Virgo Co[...]

(Dated: June 24, 2020)

ABSTRACT

We report the observation of a compact binary coalescence involving [...] a compact object with a mass of 2.50 – 2.67 $M_\odot$ (all measurements q[...] The gravitational-wave signal, GW190814, was observed during LIG[...] run on August 14, 2019 at 21:10:39 UTC and has a signal-to-noise ratio of 25 in the three-detector network. The source was localized to 18.5 deg^2 at a distance of 241^{+41}_{-45} Mpc; no electromagnetic counterpart has been confirmed to date. The source has the most unequal mass ratio yet measured with gravitational waves, $0.112^{+0.008}_{-0.009}$, and its secondary component is either the lightest black hole or the heaviest neutron star ever discovered in a double compact-object system. The dimensionless

REPORT

A noninteracting low-mass black hole–giant star binary system

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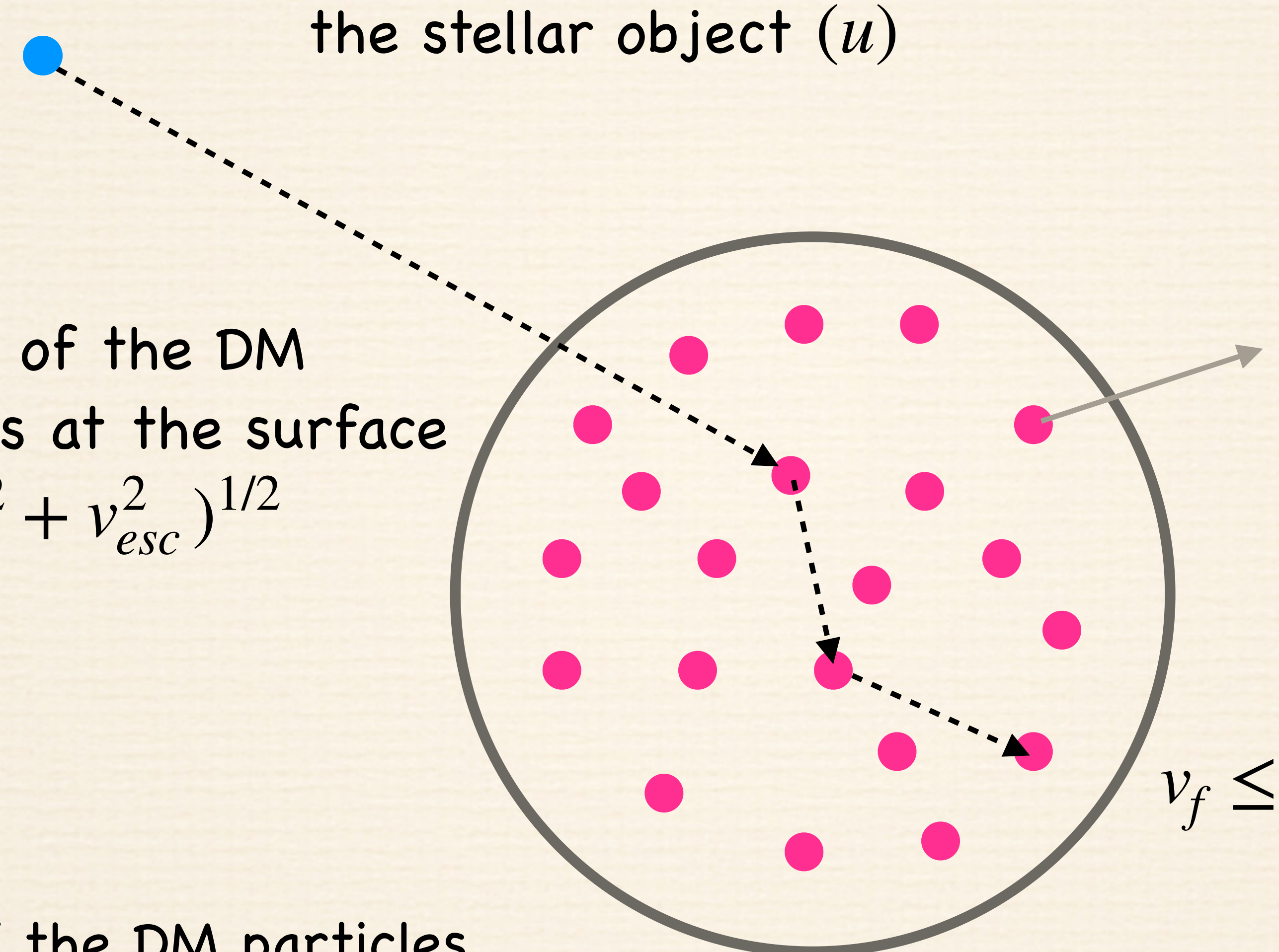
GW190425: Observation of a Compact Binary Coalescence with Total Mass $\sim 3.4 M_\odot$

On 2019 April 25, the LIGO Livingston detector observed a compact binary coalescence with signal-to-noise ratio 12.9. The Virgo detector was also taking data that did not contribute to detection due to a low signal-to-noise ratio, but were used for subsequent parameter estimation. The 90% credible intervals for the component masses range from 1.12 to 2.52 $M_\odot$ (1.46–1.87 $M_\odot$ if we restrict the dimensionless component spin magnitudes to be smaller than 0.05). These mass parameters are consistent with the individual binary components being neutron stars. However, both the source-frame chirp mass $1.44^{+0.02}_{-0.02}\,M_\odot$ and the total mass $3.4^{+0.3}_{-0.1} M_\odot$ of this system are significantly larger than those of any other known binary neutron star (BNS) system. The possibility that one or both binary components of the system are black holes cannot be ruled out from gravitational-wave data. We discuss possible

- Detection of a sub-Chandrasekhar mass (< 1.4 $M_\odot$) BH is usually thought as a smoking gun signature of its primordial origin.
- We study a simple and elegant formation mechanism of low mass BHs which can be a viable alternative of fine-tuned primordial black holes (PBHs).
- Non-annihilating Dark matter (DM) owing to their non-zero interaction strength with stellar nuclei can gradually accumulate inside compact objects, and eventually transmute them to low mass BHs.
- Origin of a low mass BH (transmuted or primordial) can easily be tested via several simple yet powerful probes.
- Cosmic evolution of the binary merger rates, especially, measurement of binary merger rates at higher redshifts can conclusively test the origin of low mass BHs.

Formation of low mass transmuted BHs: Dark core collapse



v_f : final velocity of the DM particles

$v_{\rm esc}$: escape velocity of the stellar object

Press & Spergel (1985), Gould (1987),...

Schematic diagram for DM accretion in a stellar object.

Gould (1987),...

- Baryonic capture rate of incoming DM particles:

$$\sigma_{\chi n}^{\rm sat} = \frac{\pi R^2}{N_n}$$

Scattering cross section

$$C = \frac{\rho_\chi}{m_\chi} \int \frac{f(u)du}{u} (u^2 + v_{\rm esc}^2)\, N_n \,{\rm Min}\left[\sigma_{\chi n}, \sigma_{\chi n}^{\rm sat}\right] {\rm g_1(u)}$$

Capture rate (assumes single scattering)

Incoming DM flux

Number of targets

geometrical cross section

Capture Probability $P\,(v_f \leq v_{\rm esc})$

*For a detailed treatment of multiple scattering, see Dasgupta, Gupta, and **Ray** 1906.04204 (JCAP)

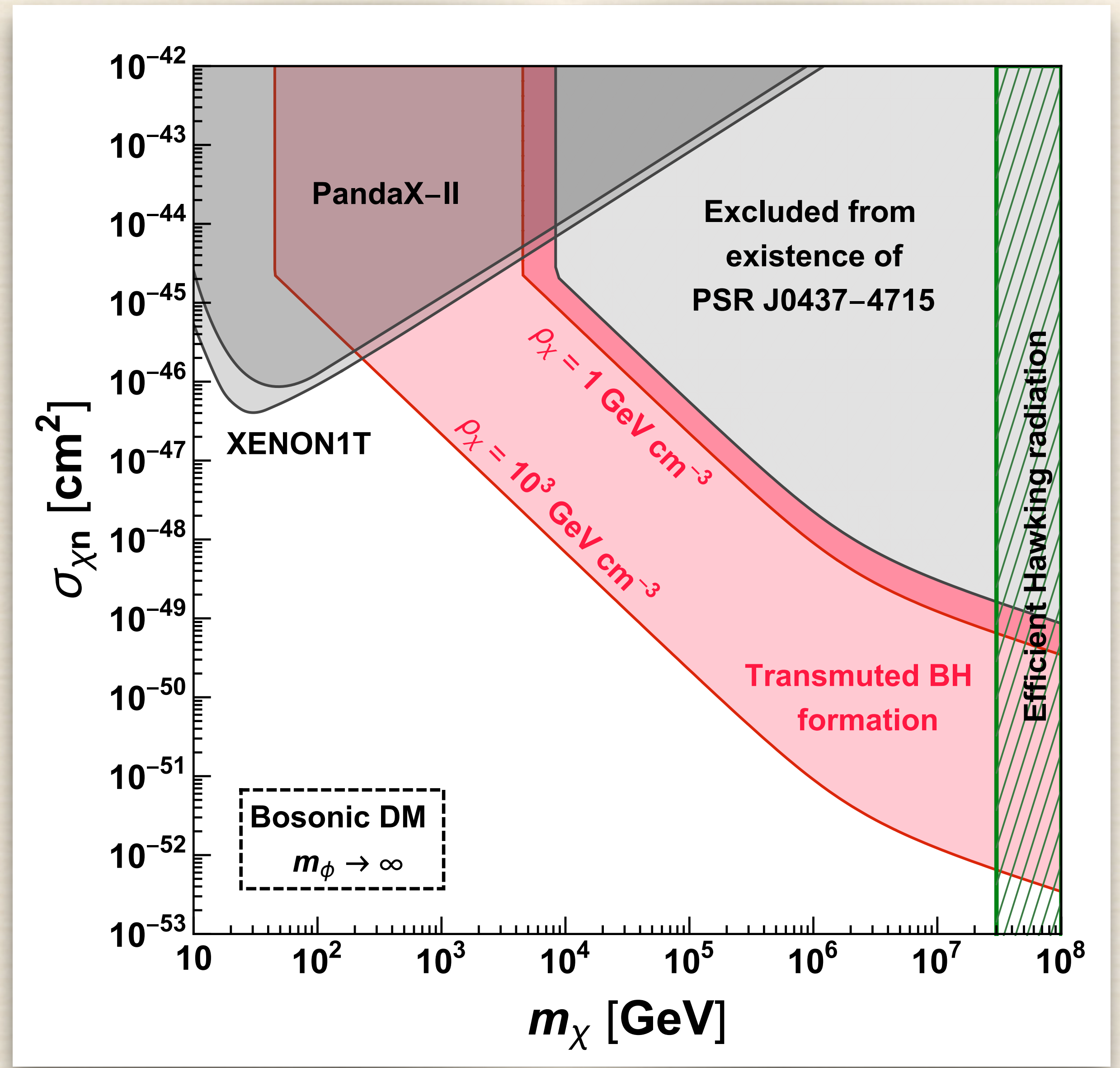
*See Dasgupta, Gupta, and **Ray** 2006.10773 (JCAP) for estimation of the capture probability for interactions mediated via arbitrary mass mediators

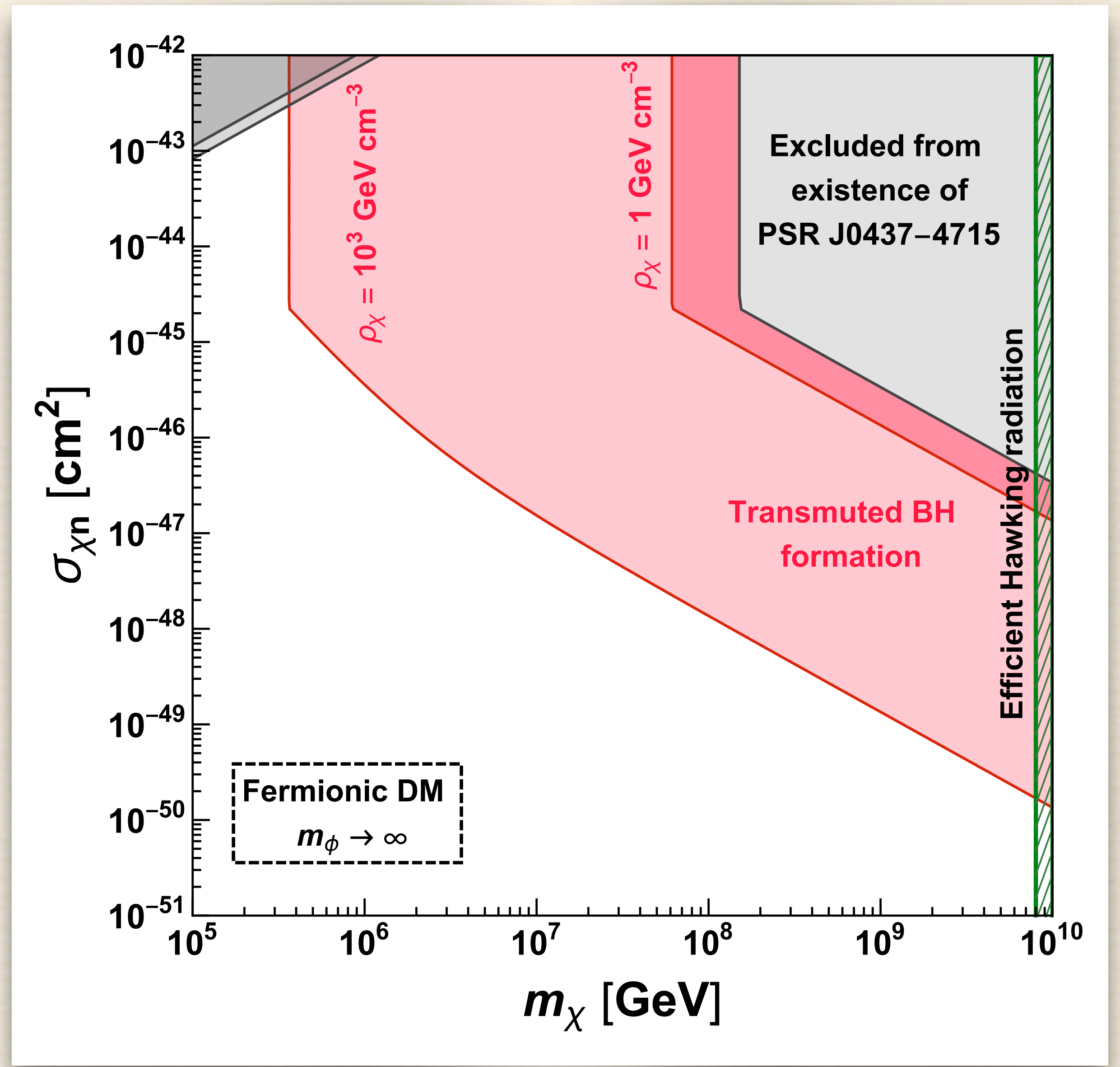
- Dark core collapse:

Goldman (1989), McDermott (1103.5472), Kouvaris (1104.0382),..., Dasgupta (2006.10773),...

Total number of captured DM particles $\geq$ Number of particles required for black hole formation

Dasgupta, Laha, and **Ray** 2009.01825 (PRL)

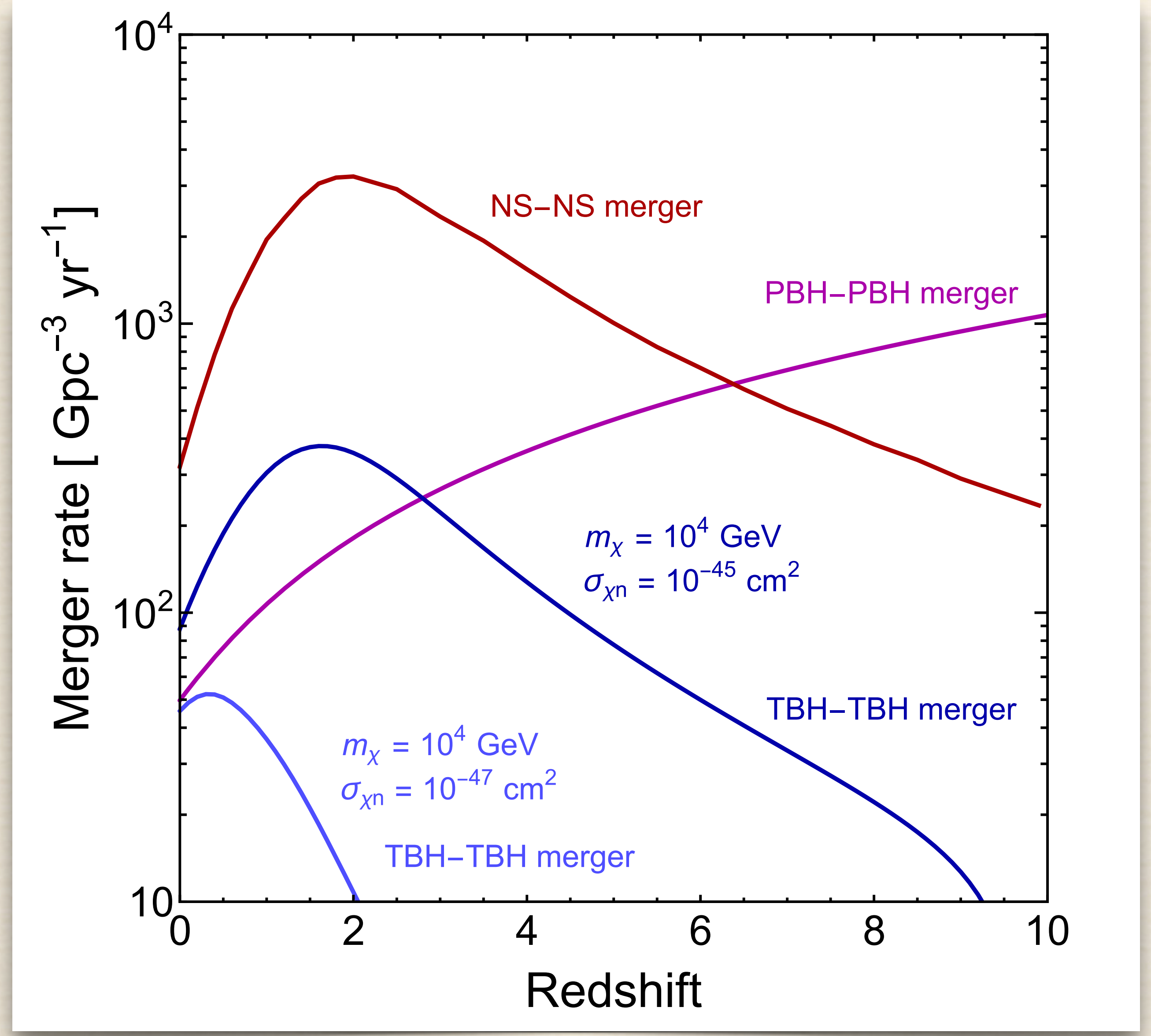




Parameter space for transmuting a 1.3 $M_\odot$ neutron star to a comparable mass ($\leq$ 1.3 $M_\odot$) BH for non-annihilating bosonic (left)/fermionic (right) DM. Contact interaction between DM and stellar nuclei is assumed in these plots.

Tests for the origin of low mass BHs: Transmuted/ Primordial

- Cosmic evolution of the binary merger rates can be used as a probe to determine the origin of low mass BHs.



Distinct redshift dependence of the binary NS, PBH and transmuted BH (TBH) merger rates, especially at higher redshifts can be measured by the upcoming third generation GW experiments (Pre-DECIGO, Einstein Telescope).

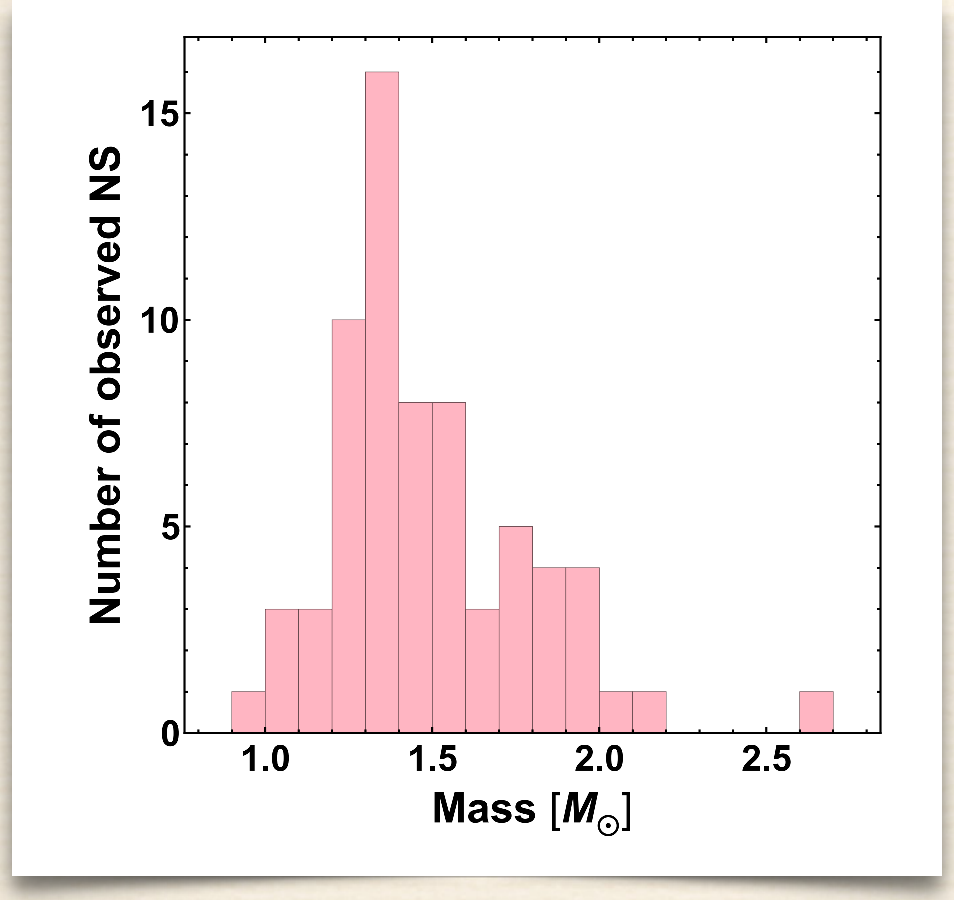
Dasgupta, Laha, and **Ray** 2009.01825 (PRL)

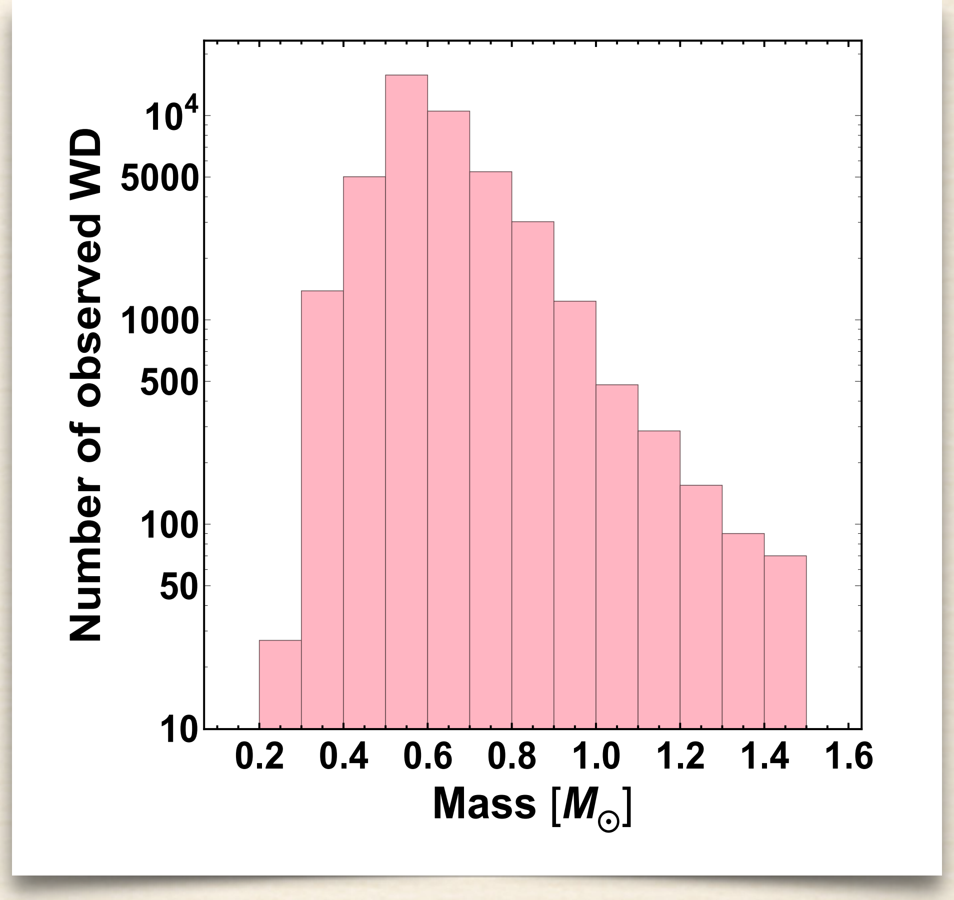
Dasgupta, Laha, and **Ray** 2009.01825 (PRL)

- Transmuted BHs track the mass distribution of their progenitors (Neutron Star/White Dwarf).

Mass distribution of the compact objects can be statistically compared against some well motivated PBH mass distribution to examine the origin of low mass BHs.

See also Takhistov et al. 2008.12780 (PRL)





Conclusions

- sub-Chandrasekhar mass BH is not a smoking gun signature of its primordial origin.
- Non-annihilating DM with non-zero interaction strength with nuclei is sufficient to produce a sub-Chandrasekhar mass BH of non-primordial origin.
- Mass distribution of the progenitors, cosmic evolution of the binary merger rates are some simple yet novel probes to test the transmuted/primordial origin of low mass BHs.
- With remarkable advances in GW astronomy, we have already started to observe unusually low mass BHs; measurements of the binary merger rates at high redshifts by the upcoming GW experiments will settle their origin. Stay tuned!

Thanks!

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