

Forging Heavy Elements with Primordial Black Holes

Volodymyr Takhistov (UCLA)



Seminar, COSMO-VIA

(10.20.2017)

Based on: George Fuller, Alex Kusenko, VT [PRL (2017), arXiv:1704.01129]

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- Renewed interest: GW detection (PBH?), novel production mechanisms/signatures, no hints of popular DM particle candidates (e.g. WIMPs)
 - PBH appear in many BSM scenarios and strictly, don't require non-SM physics
 - **plausible that regardless of DM origin, some in PBH !**

Motivation: PBH formation

- PBH formation: density contrast $\frac{\delta\rho}{\rho} \sim \mathcal{O}(1)$ within horizon \rightarrow collapse to BH
... *improbable without new physics*

see reviews
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- Thus, PBHs can span vast mass range (with mass spectrum):



General Setup

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 - many in DM-rich environments (e.g. Galactic Center)
- GC contains highest SN/star-formation rate
 - many neutron stars (NS), typically spinning (pulsars)

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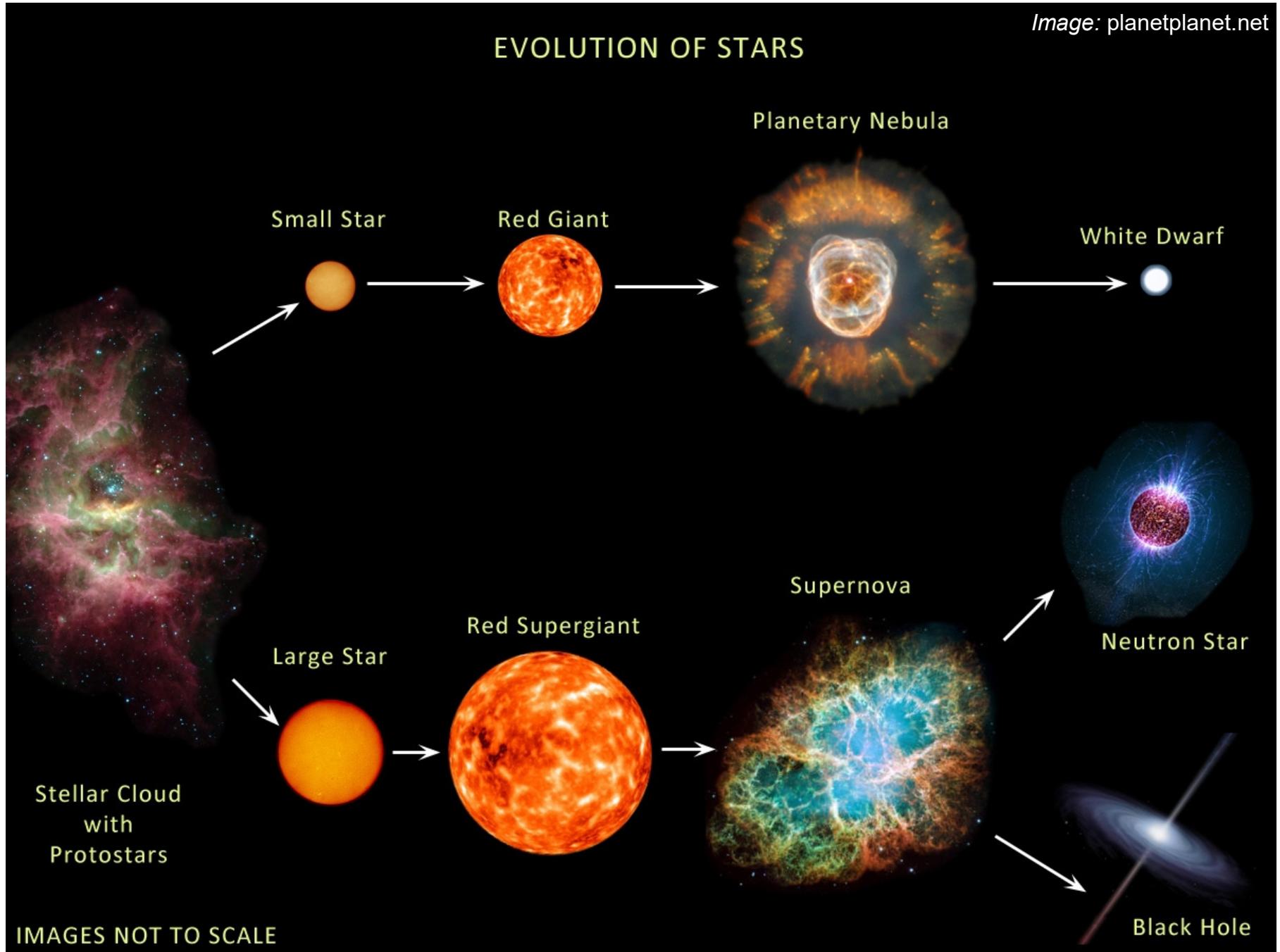
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... what are the astrophysical consequences?

Neutron Star Formation



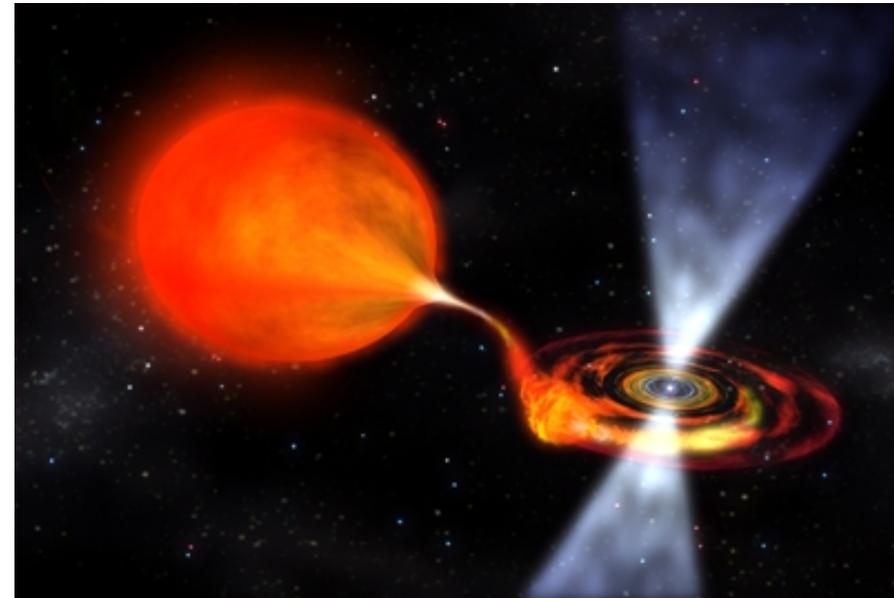
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- Population vs. rotation period: [Cordes,Chernoff,97; Lorimer,13]

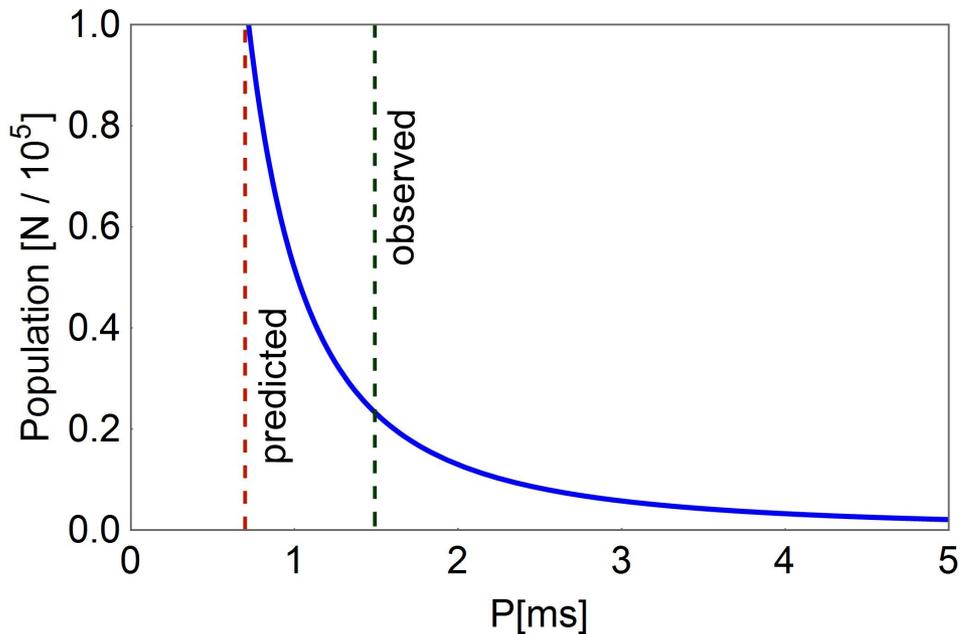
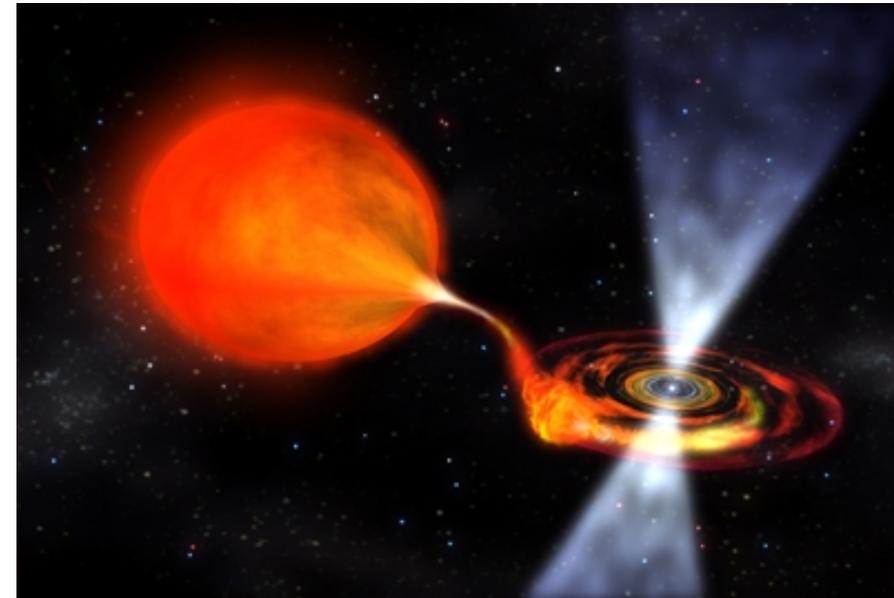


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NS-PBH Capture

- [Case A](#): PBH captured during star formation → unlikely [Capela,Pshirkov,Tinyakov,13-14]

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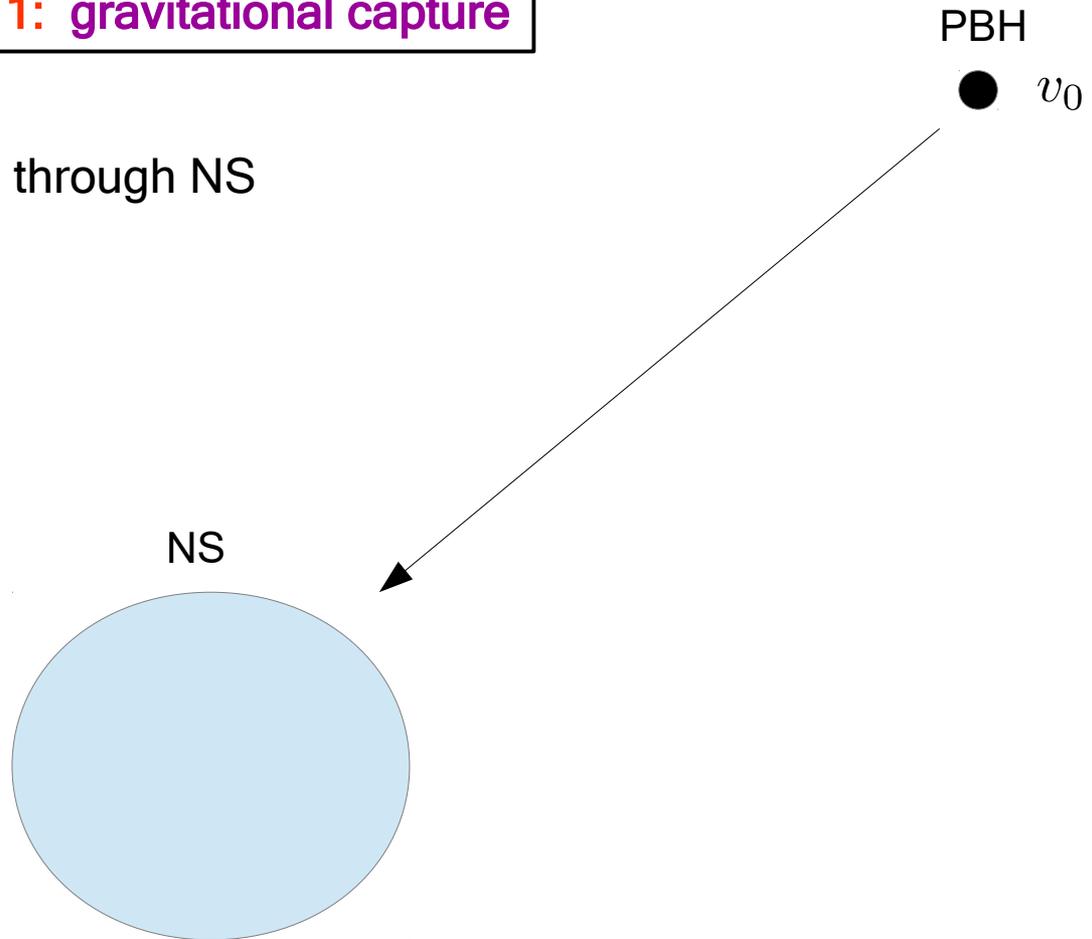
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Stage 1: gravitational capture

→ PBH approaches and passes through NS



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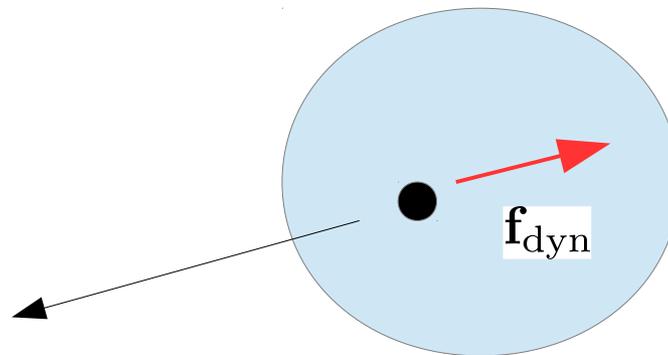
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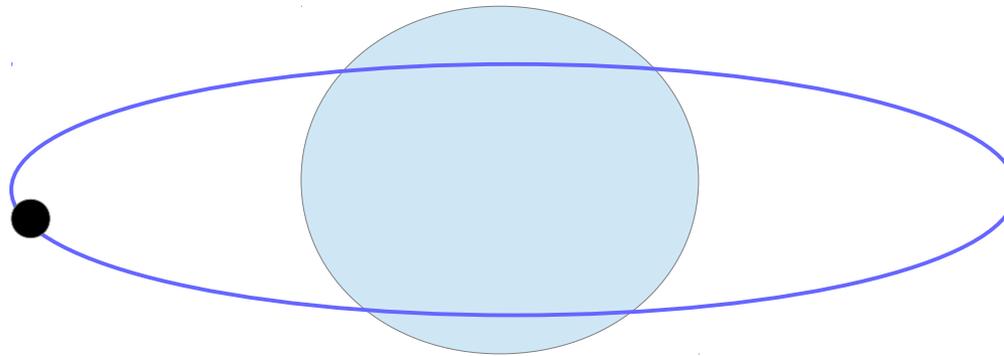


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- if $E_{\text{loss}} > \text{KE}_{\text{PBH}} \rightarrow \text{captured !}$

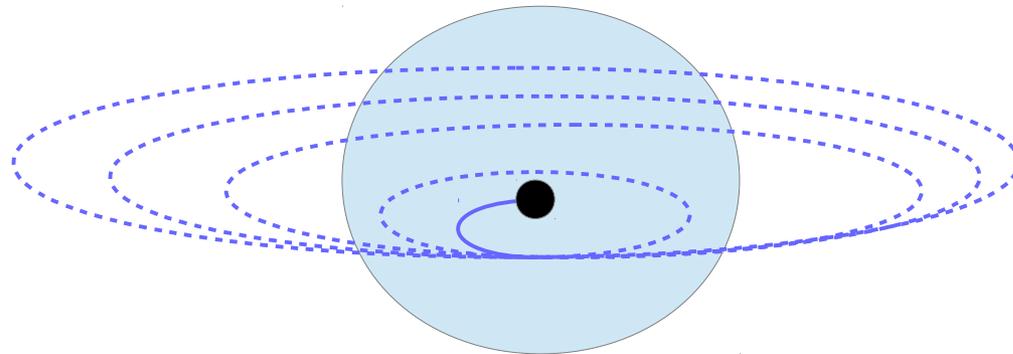


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Stage 2: PBH in NS

→ captured PBH continues passing through NS, until it settles inside

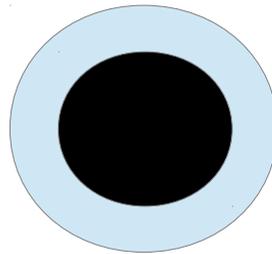


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Stage 3: BH grows inside

→ PBH inside NS grows via Bondi spherical accretion, consuming the host star



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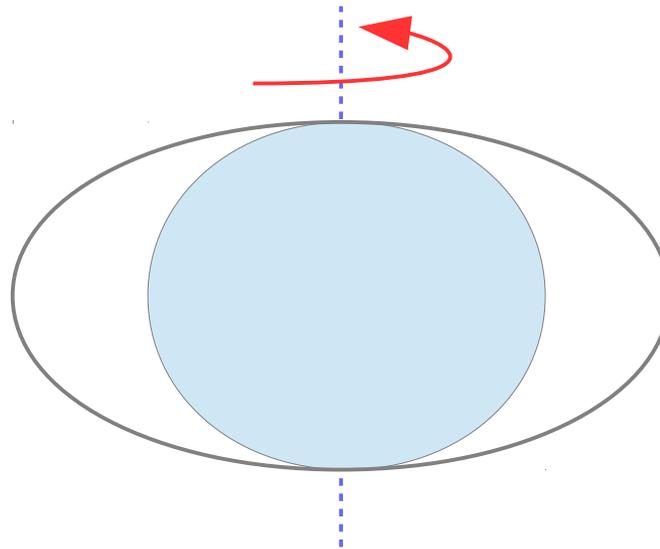
Bonus: consistent with recently discovered young GC magnetar [Mori+,13; Kennea+,13]

→ shows unusual activity ... a hint of PBH consumption ??

Growing BH in NS: angular momentum transfer

- MSP spinning near mass shedding limit → elongated spheroid (Roche lobe model)

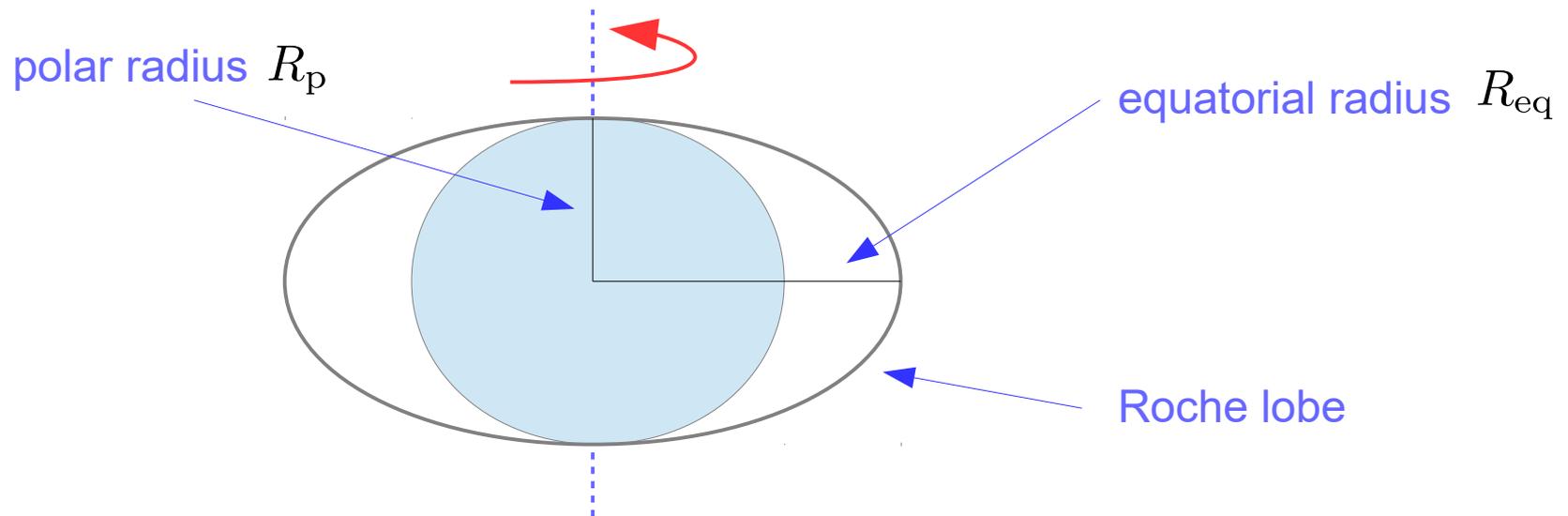
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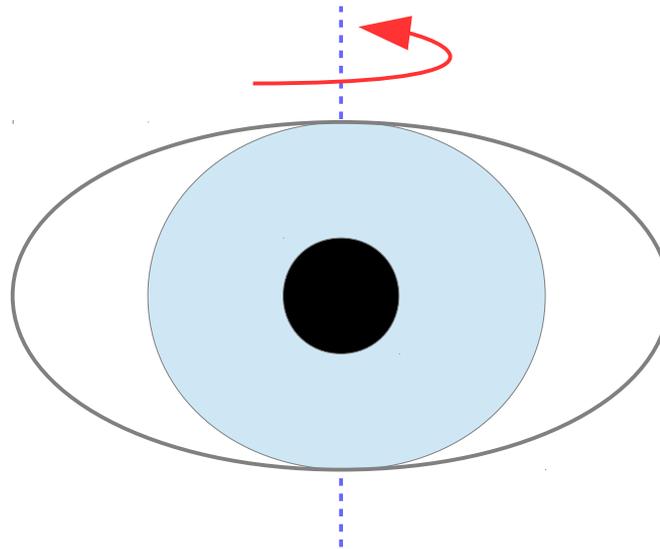
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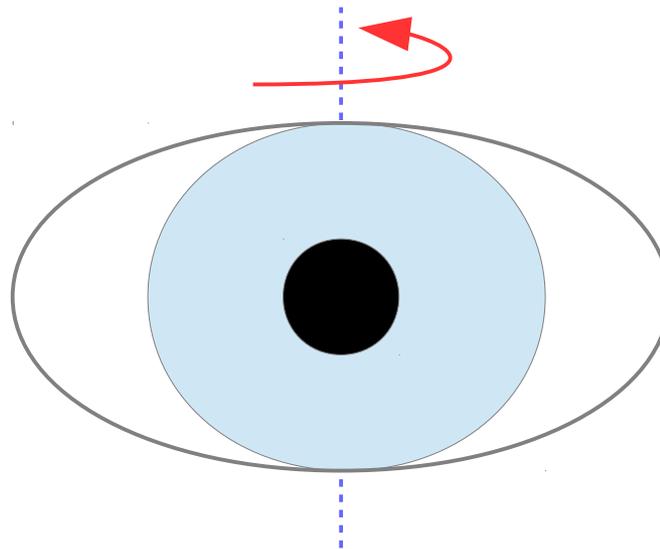


Add BH → can analytically show (see paper) surface matter exceeds escape speed
→ **ejected mass !!**

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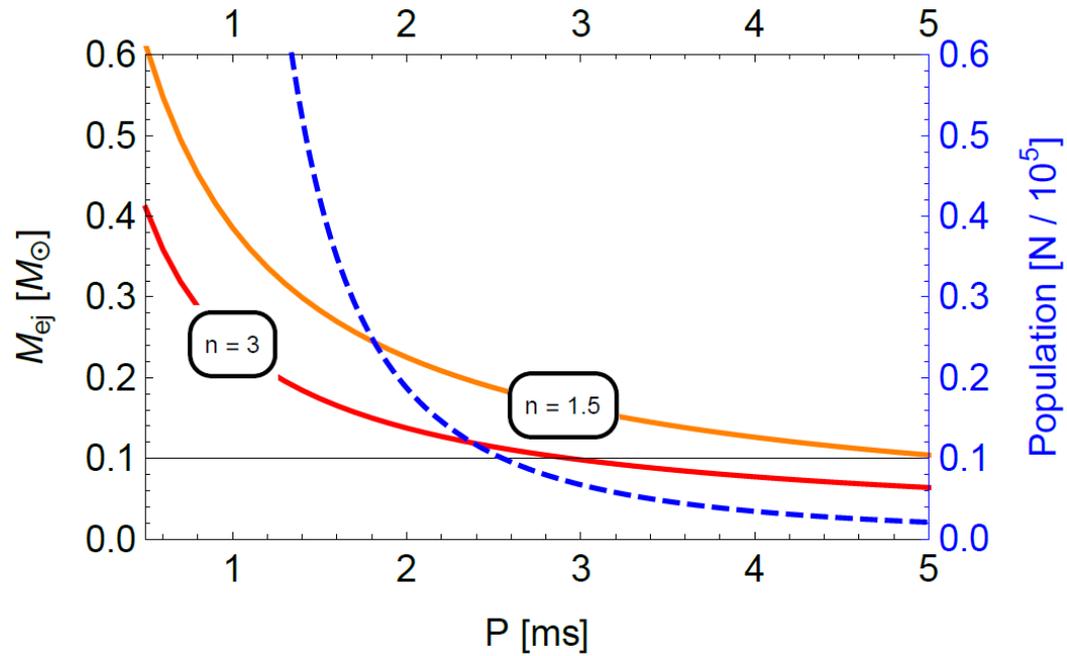


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* Differential rotation can occur → calculated that viscosity and magnetic stresses eliminate

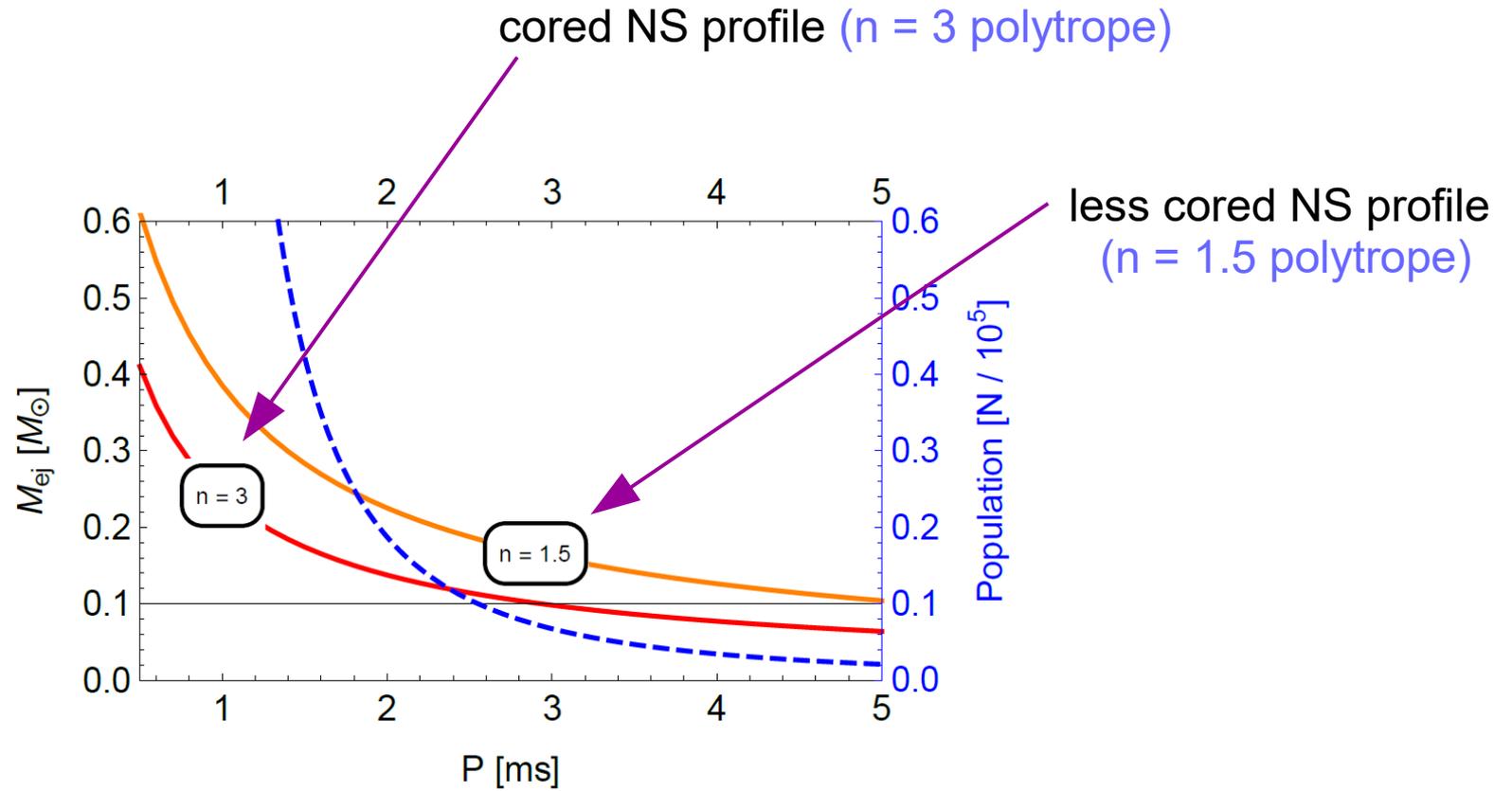
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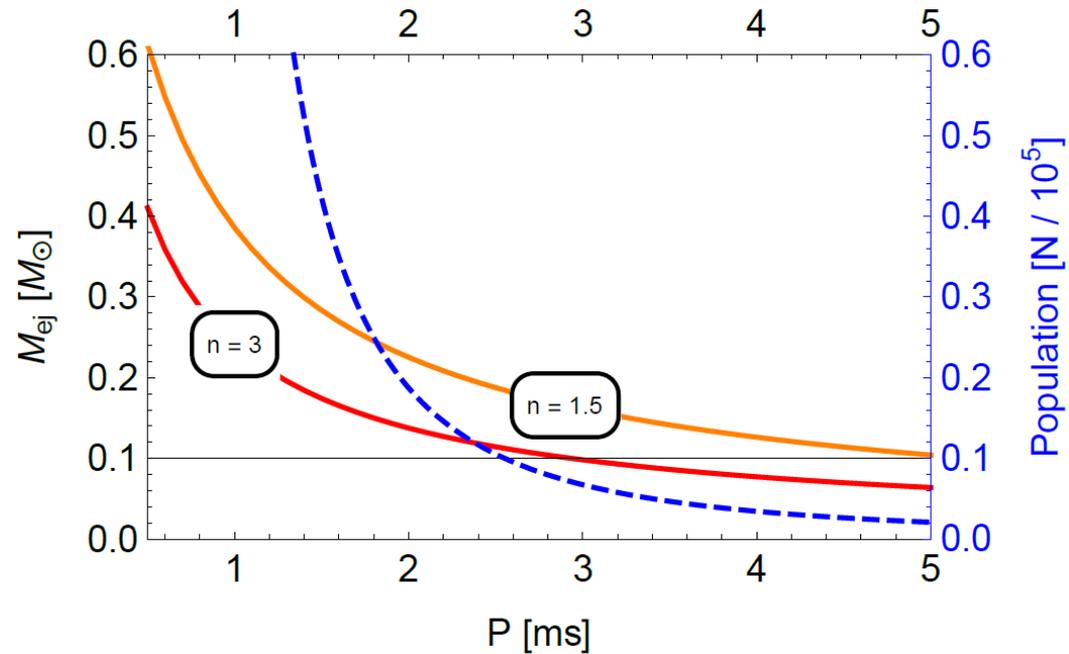
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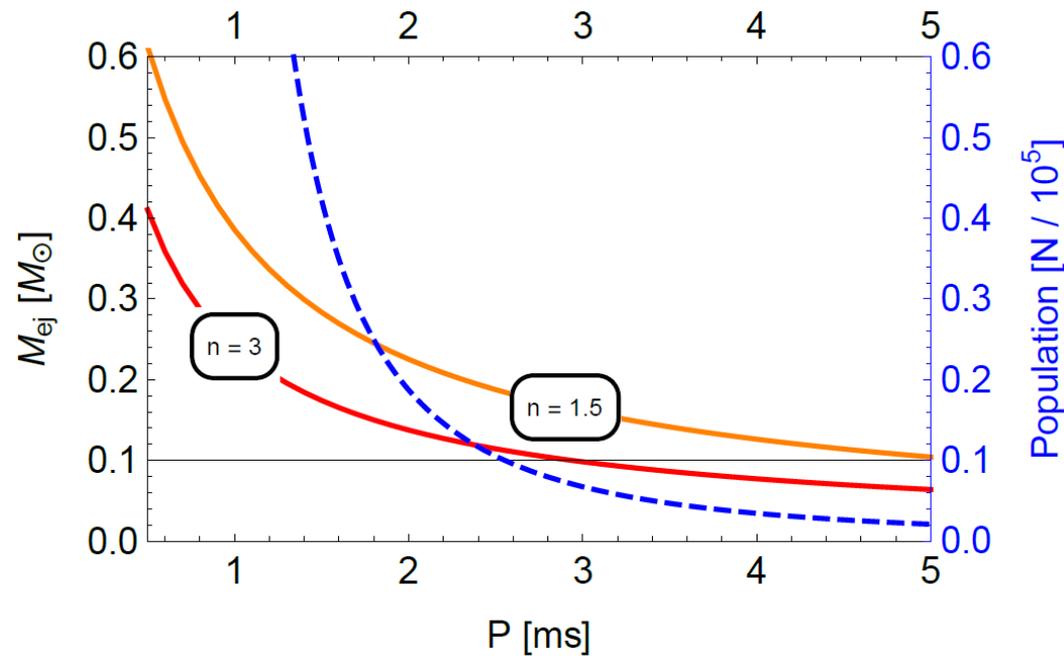
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- Ejecta neutron rich → **a site of r-process nucleosynthesis?**

R-process

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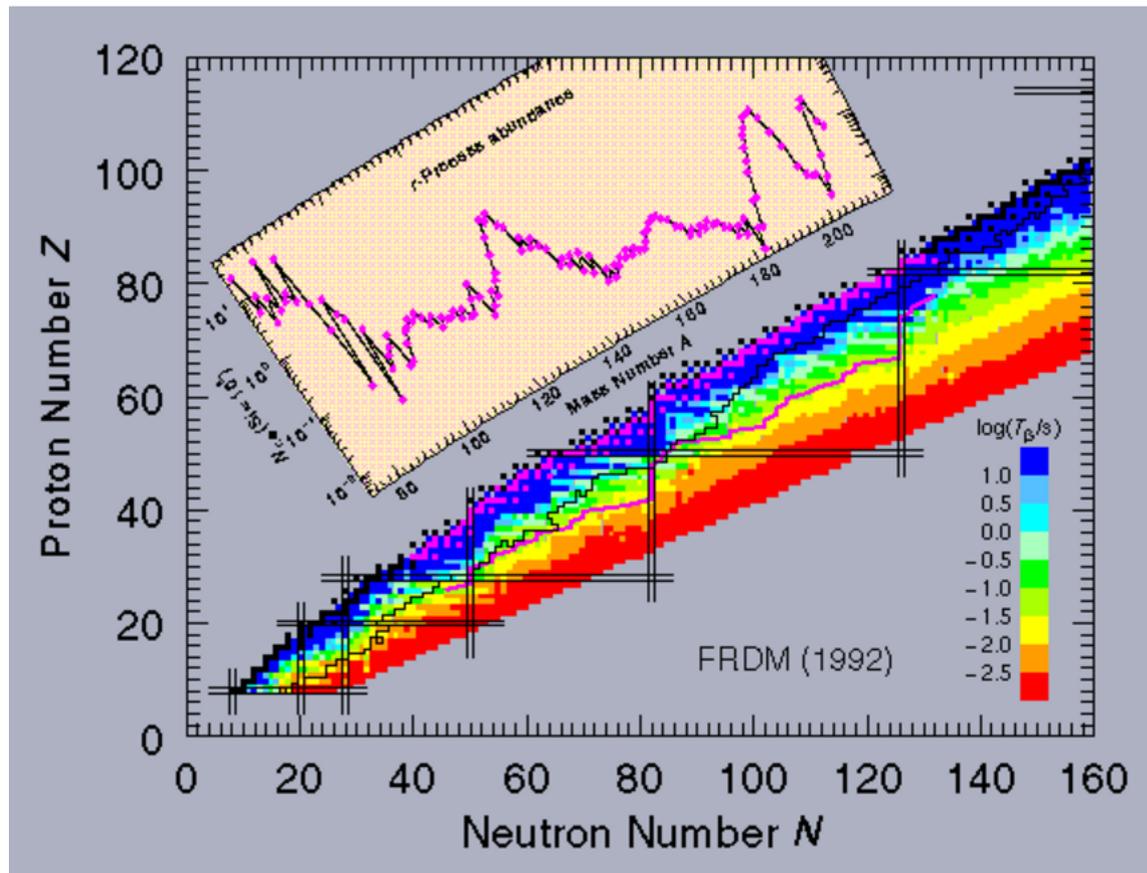


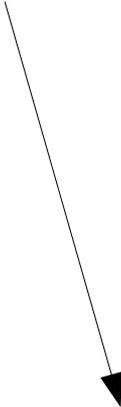
Image: Los Alamos,
Nuclear Data Group

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recent GW detection w/ a short GRB ...

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PBH-NS r-process material O(10) larger than COM, several orders vs. SN !!

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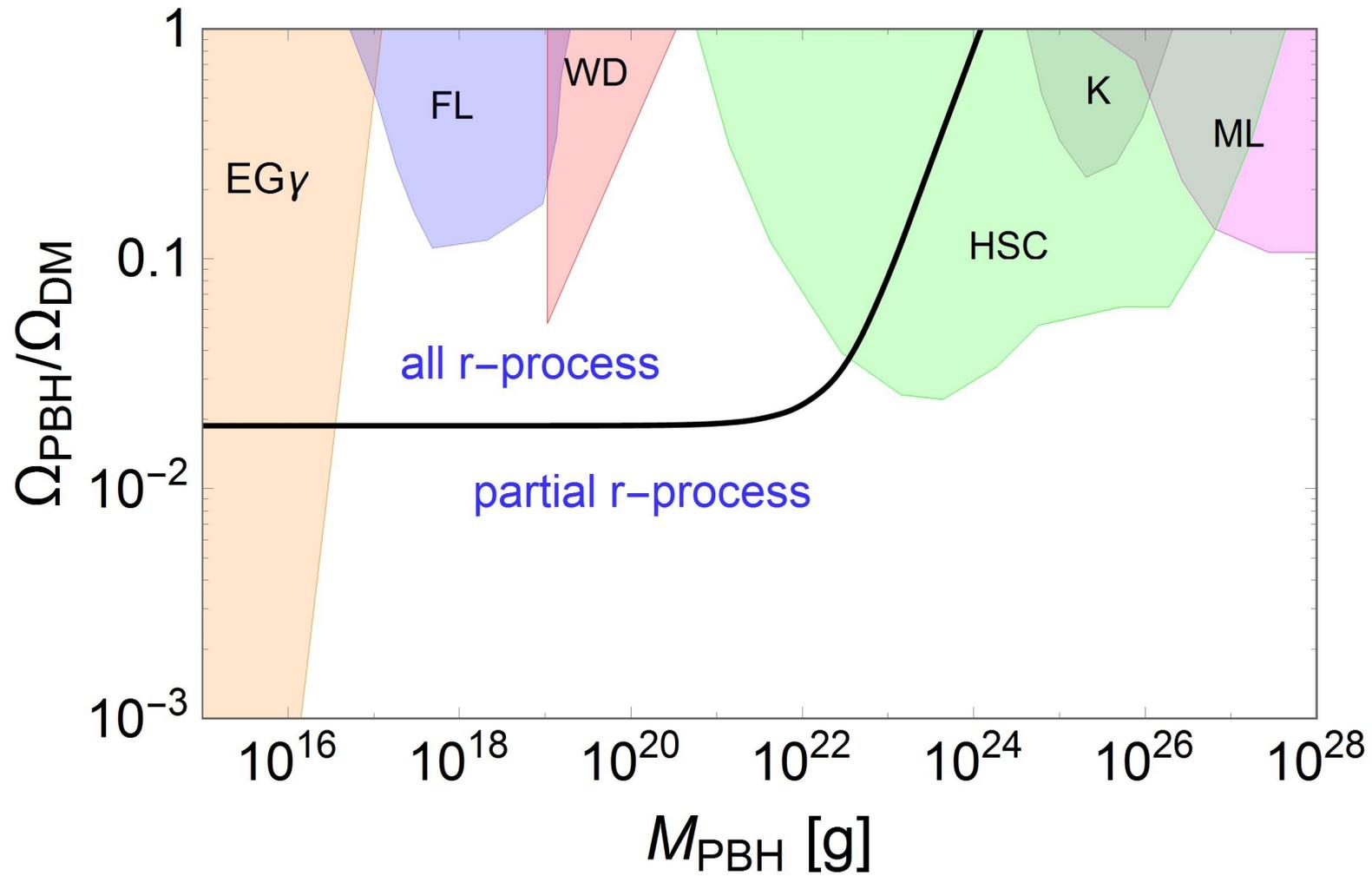
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can explain both simultaneously with PBH-NS

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Fast Radio Bursts (FRB)

- Large energy release stored in magnetic flux tubes, if only (1-10)% of energy converted to radio waves → non-repeating FRB !

Search Identification

- **Easy to identify:**

- no neutrino emission → distinguish vs. SN

- no gravity waves → distinguish vs. COM

Tiny PBHs from the Past

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gravity waves from unusual solar-mass BHs

Based on: [VT](#) [arXiv:1707.05849]

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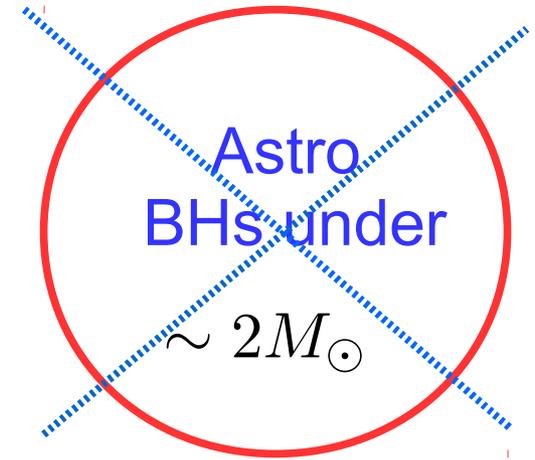
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Solar-mass BHs: in astrophysics

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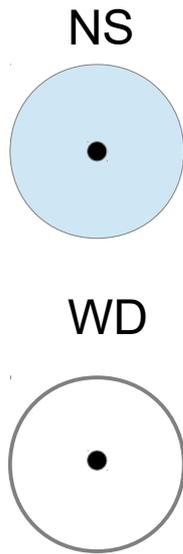
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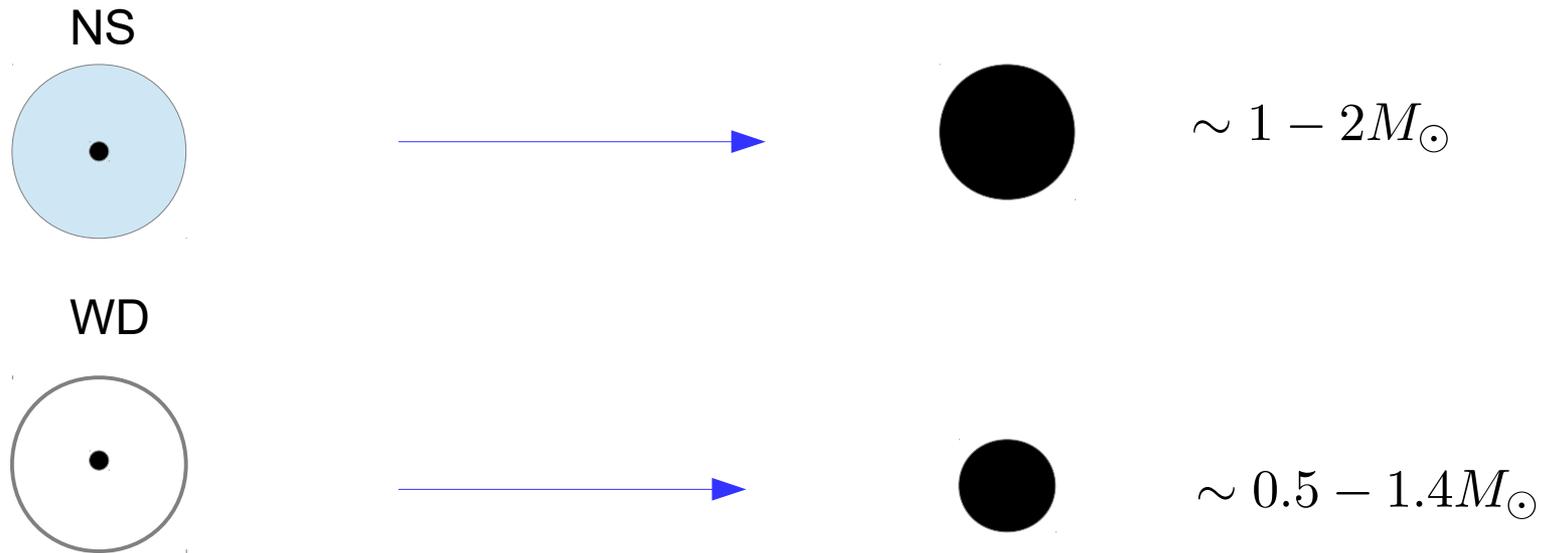
Solar-mass BHs: from tiny PBH capture

- [PBH-star systems](#): factories of atypical solar mass BHs



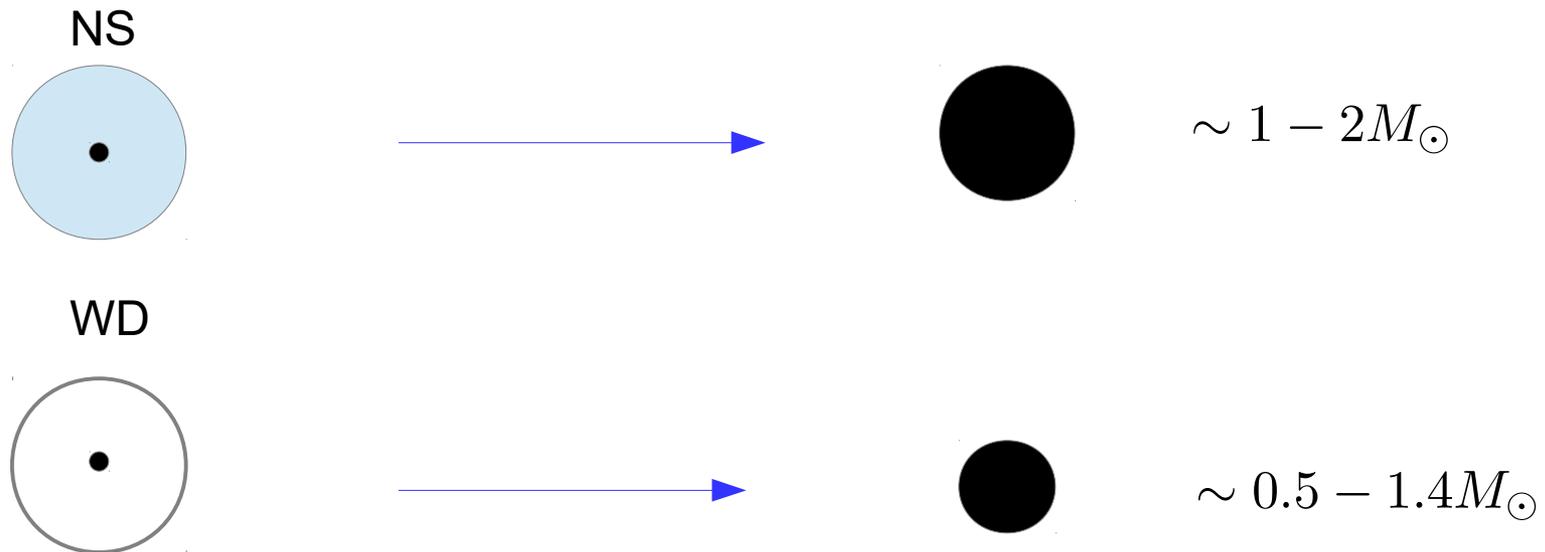
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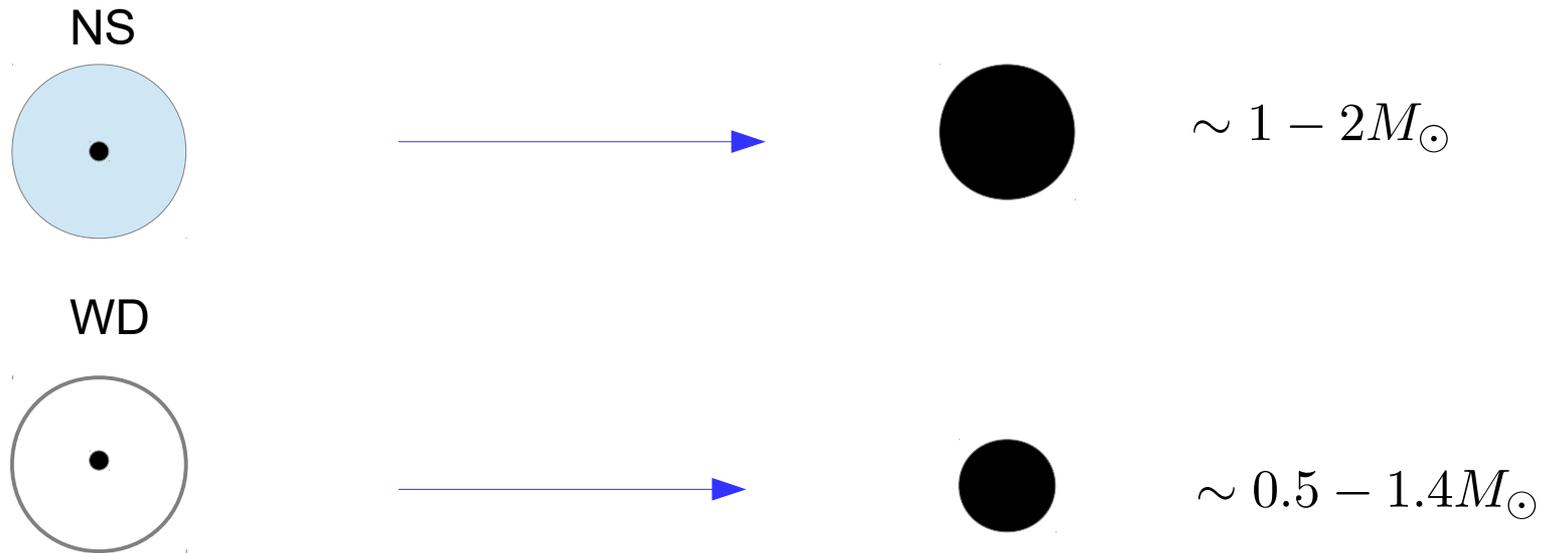


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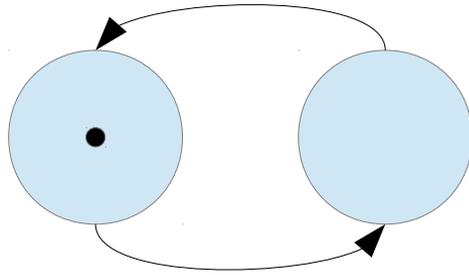
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How to detect such BHs? → GW signal from binary mergers

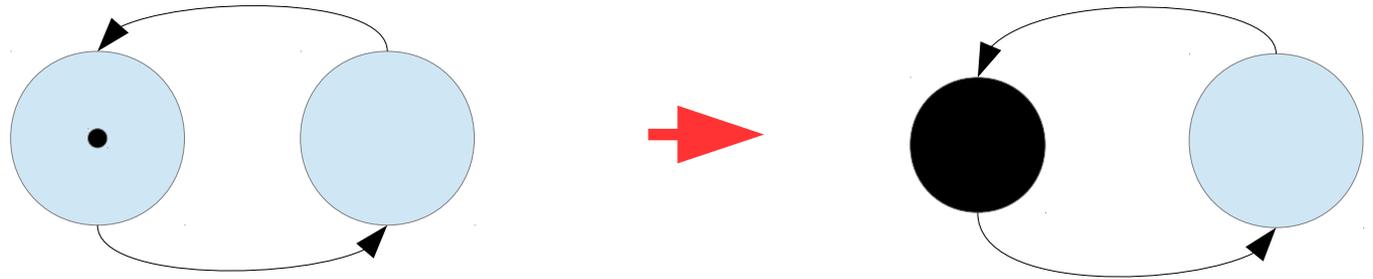
Transmuted Binaries

NS-NS



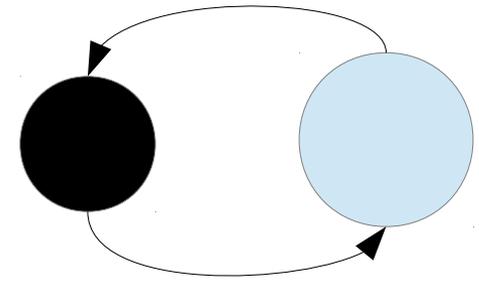
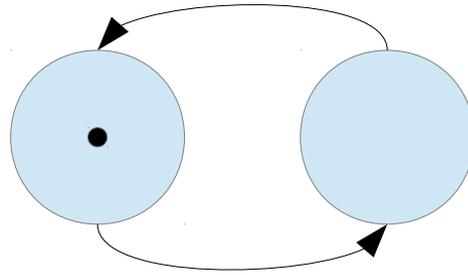
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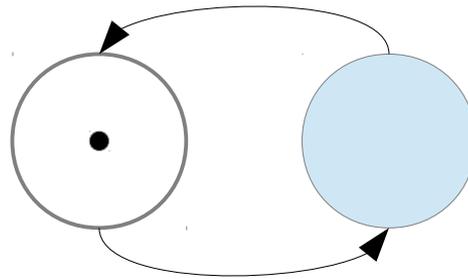


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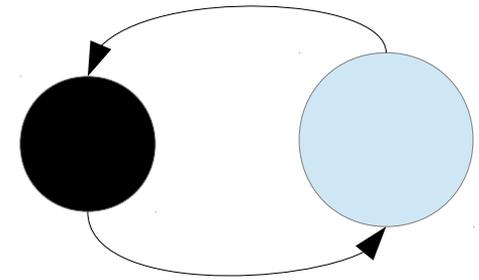
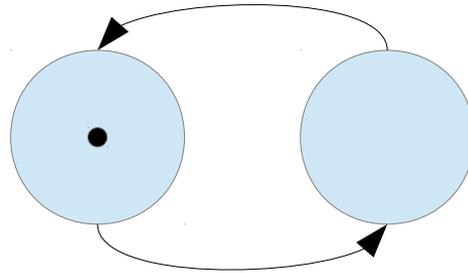


WD-NS

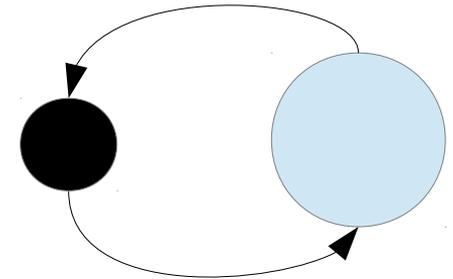
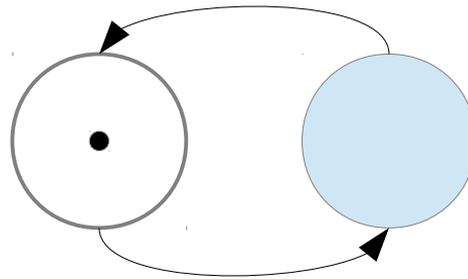


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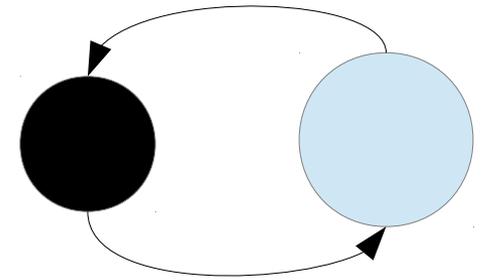
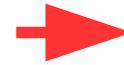
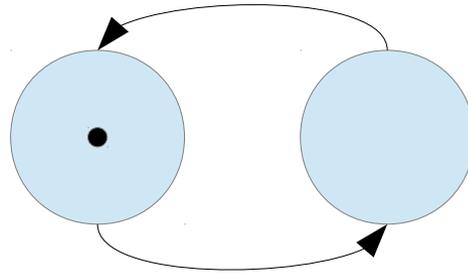


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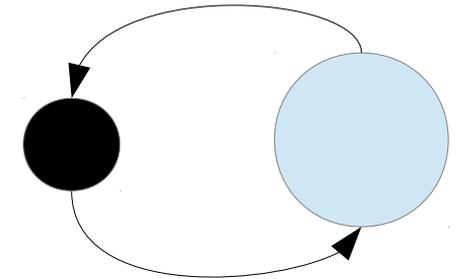
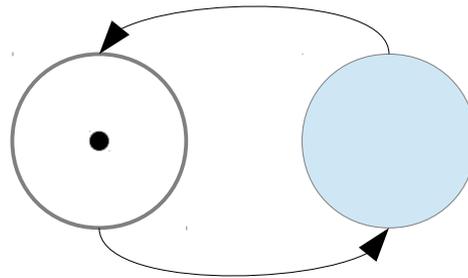


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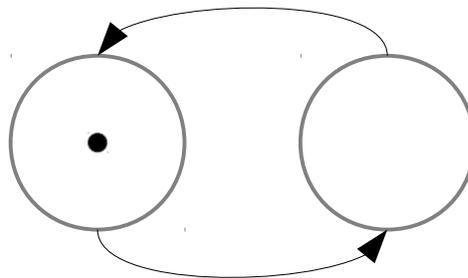
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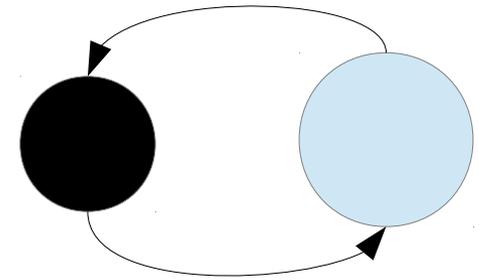
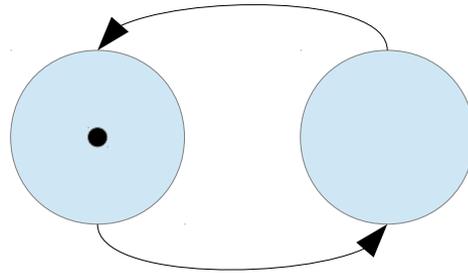


interacting WD-WD
(cataclysmic variable)

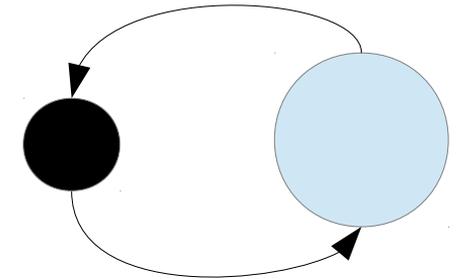
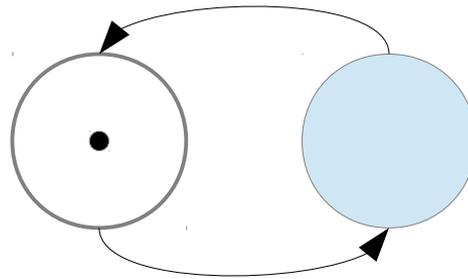


Transmuted Binaries

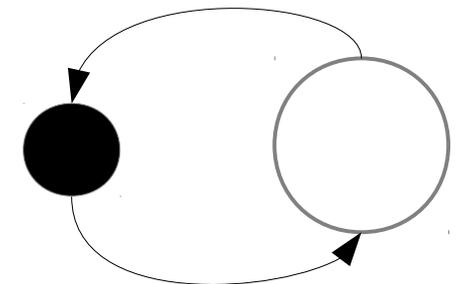
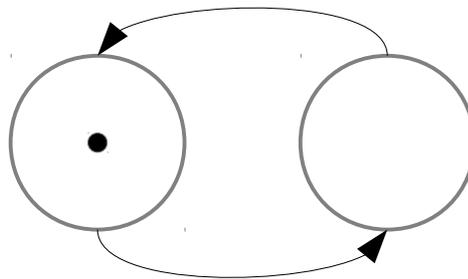
NS-NS



WD-NS

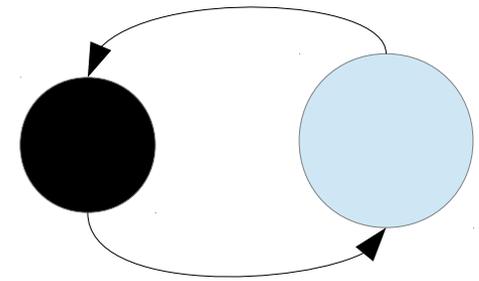
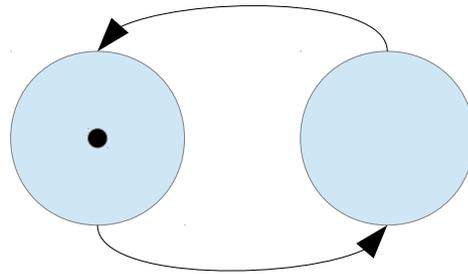


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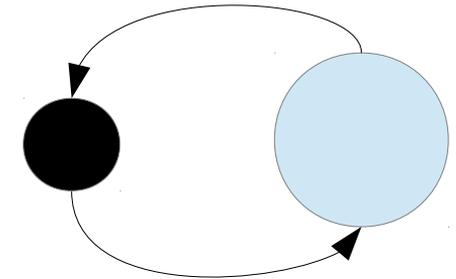
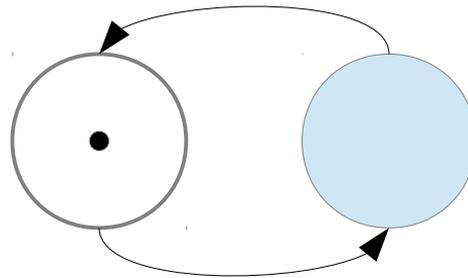


Transmuted Binaries

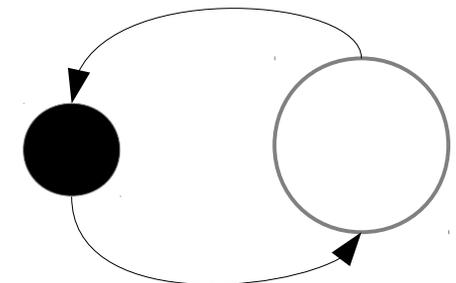
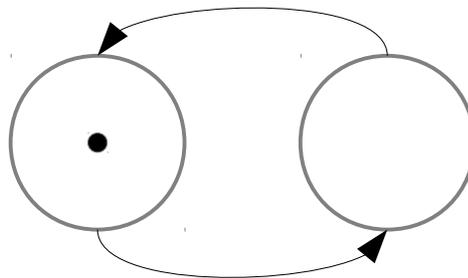
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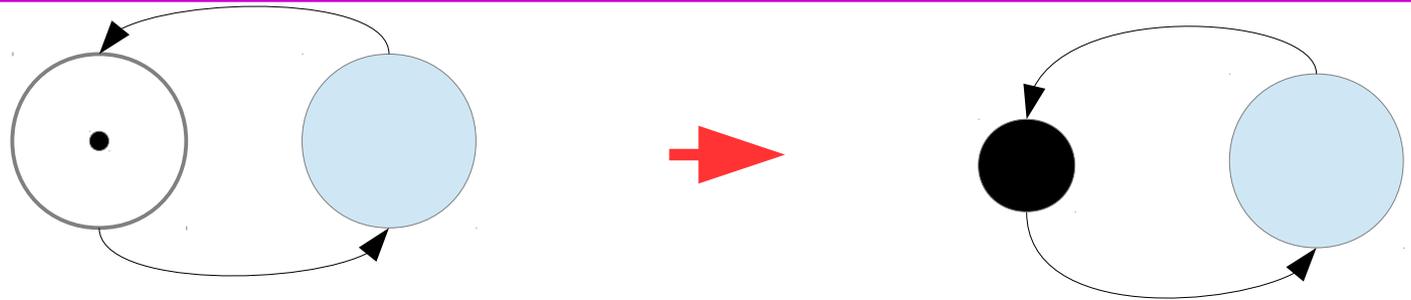
- Some other possibilities: with a regular BH, or very rarely a double transmutation

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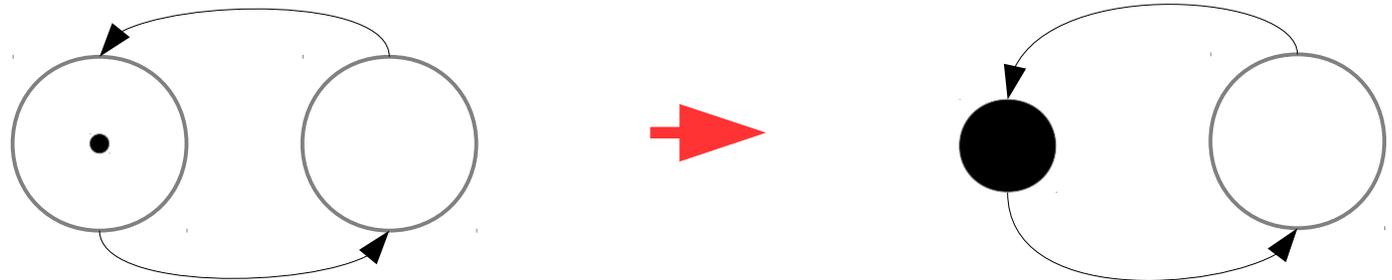
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Compact Object Mergers

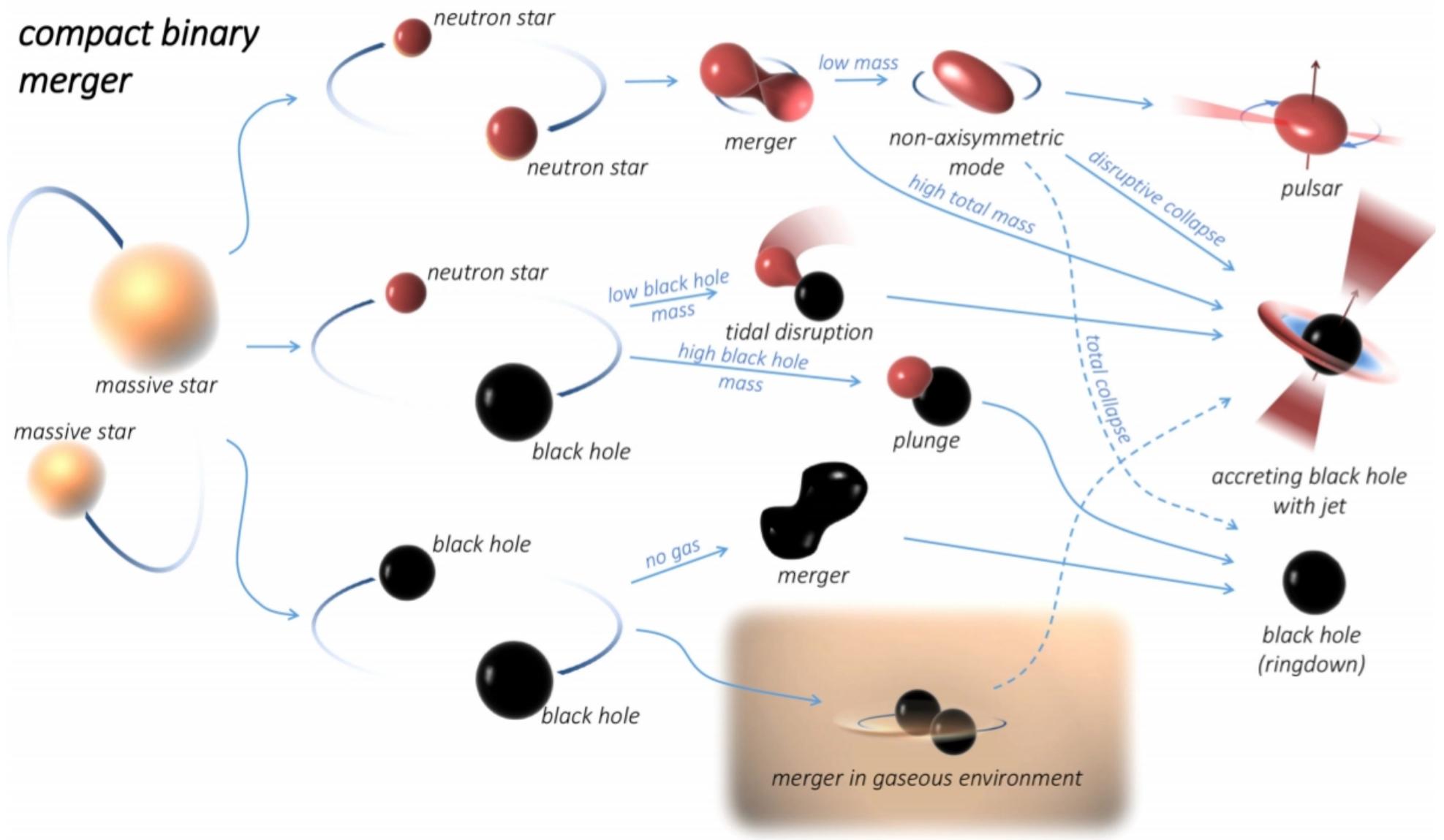


Image: Bartos, Kowalski, "Multimessenger Astronomy"

Binary GW Signals

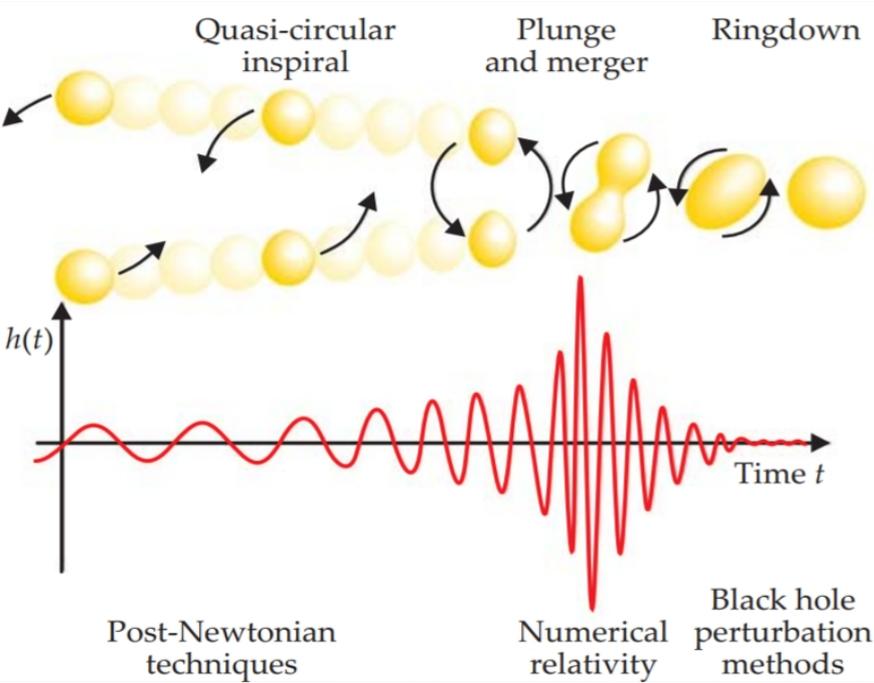


Image: Kurt, Caltech-JPL

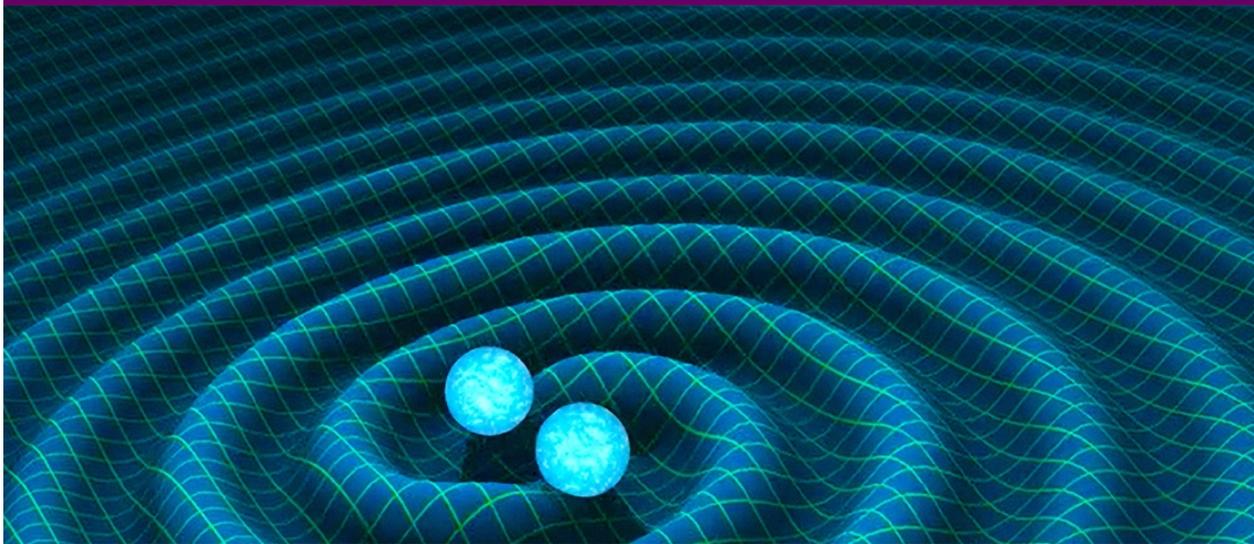


Image: [Baumgarte, Shapiro, 2011]

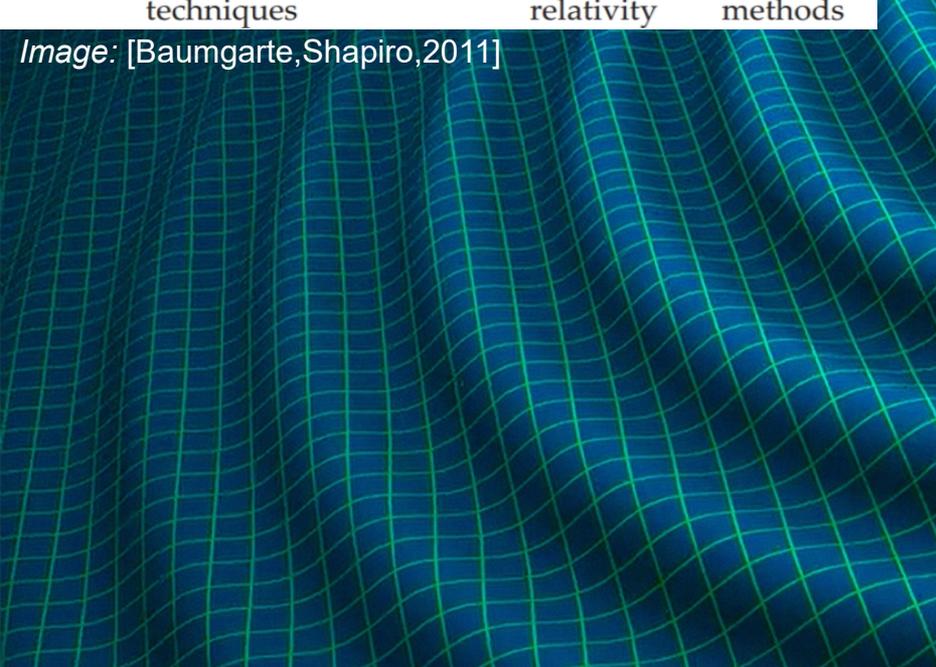
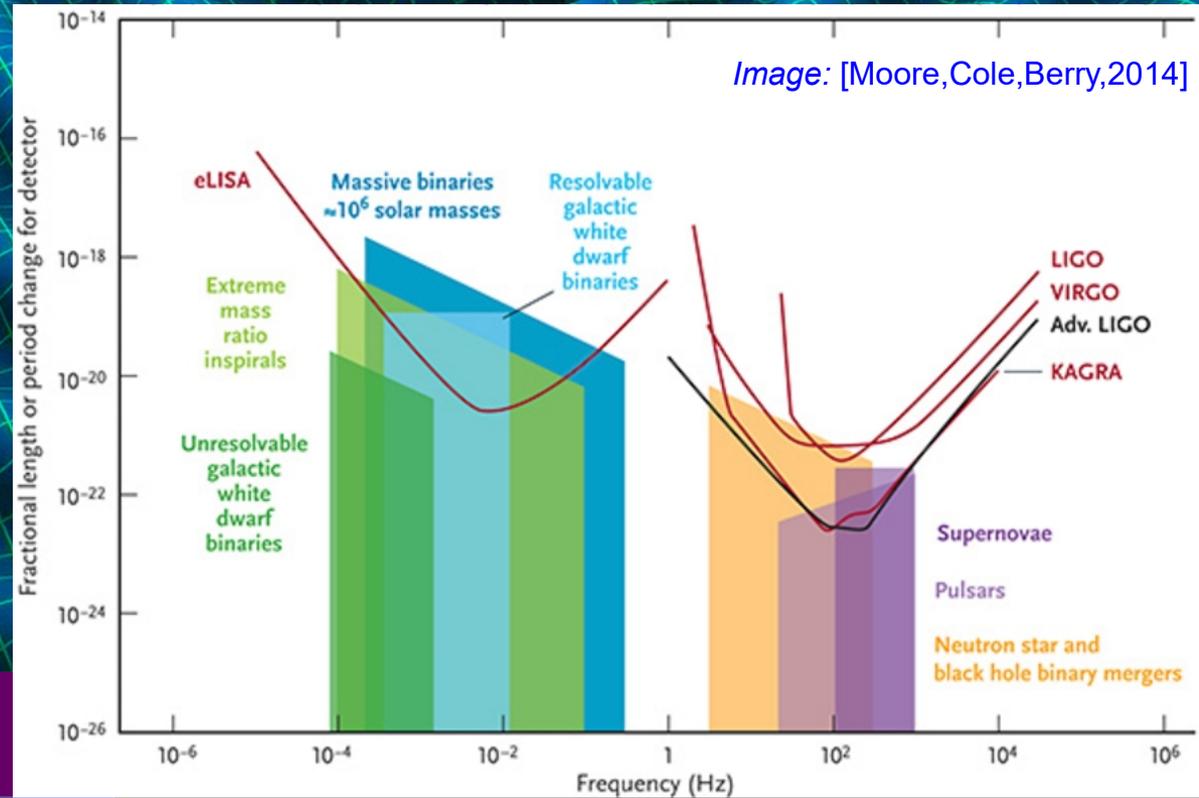


Image: [Moore, Cole, Berry, 2014]



Transmuted GW Signals

- General features (merger time, GW luminosity, freq. t. variation, char. amplitude)
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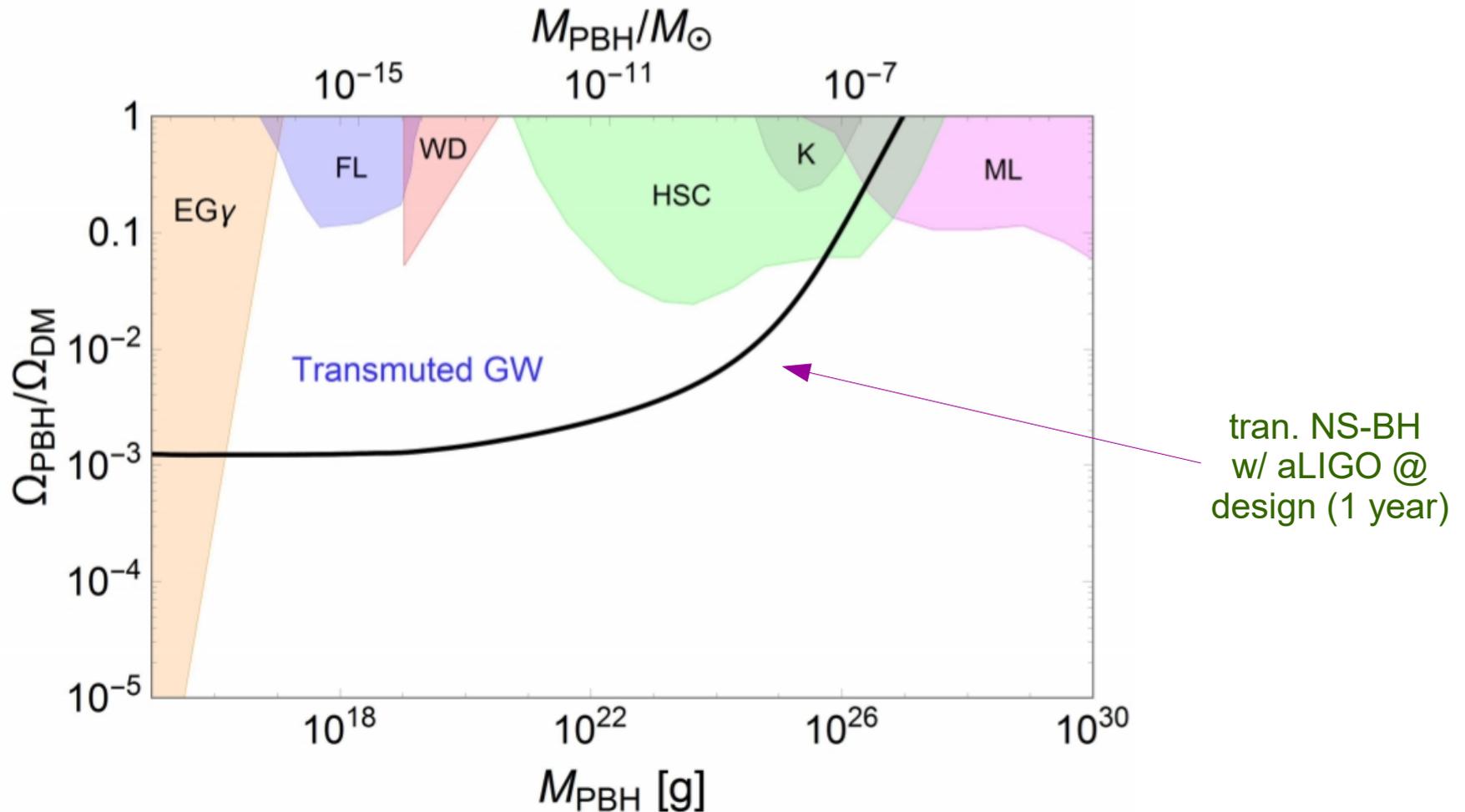
- Some other discriminating factors:
 - Merger phase (e.g. disk formation, intermediate NS, delayed sGRB)
 - ringdown phase

GW Detection

- Transmuted NS signals (e.g. NS-NS) → detectable by LIGO
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lower BH mass $M_{\text{BH}} \sim 1 - 5M_{\odot}$ thought to not be very relevant, but actually important to probe !

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→ **unique signals in experiments, new lamp-posts**

Thank You for Attention!