

# 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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**DOE Science** ✓ @doescience · Aug 9

Researchers @UCSanDiego have reported that tiny black holes could have produced elements heavier than iron [bit.ly/2wIOW8V](https://bit.ly/2wIOW8V) @UCLA



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# Motivation: PBH DM

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- 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):

$$\leftarrow 10^{15} \text{ g} \lesssim M_{\text{BH}} \lesssim 10^{55} \text{ g} \rightarrow$$

Hawking evaporation curvature restriction



# General Setup

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  - many in DM-rich environments (e.g. Galactic Center)
- GC contains highest SN/star-formation rate
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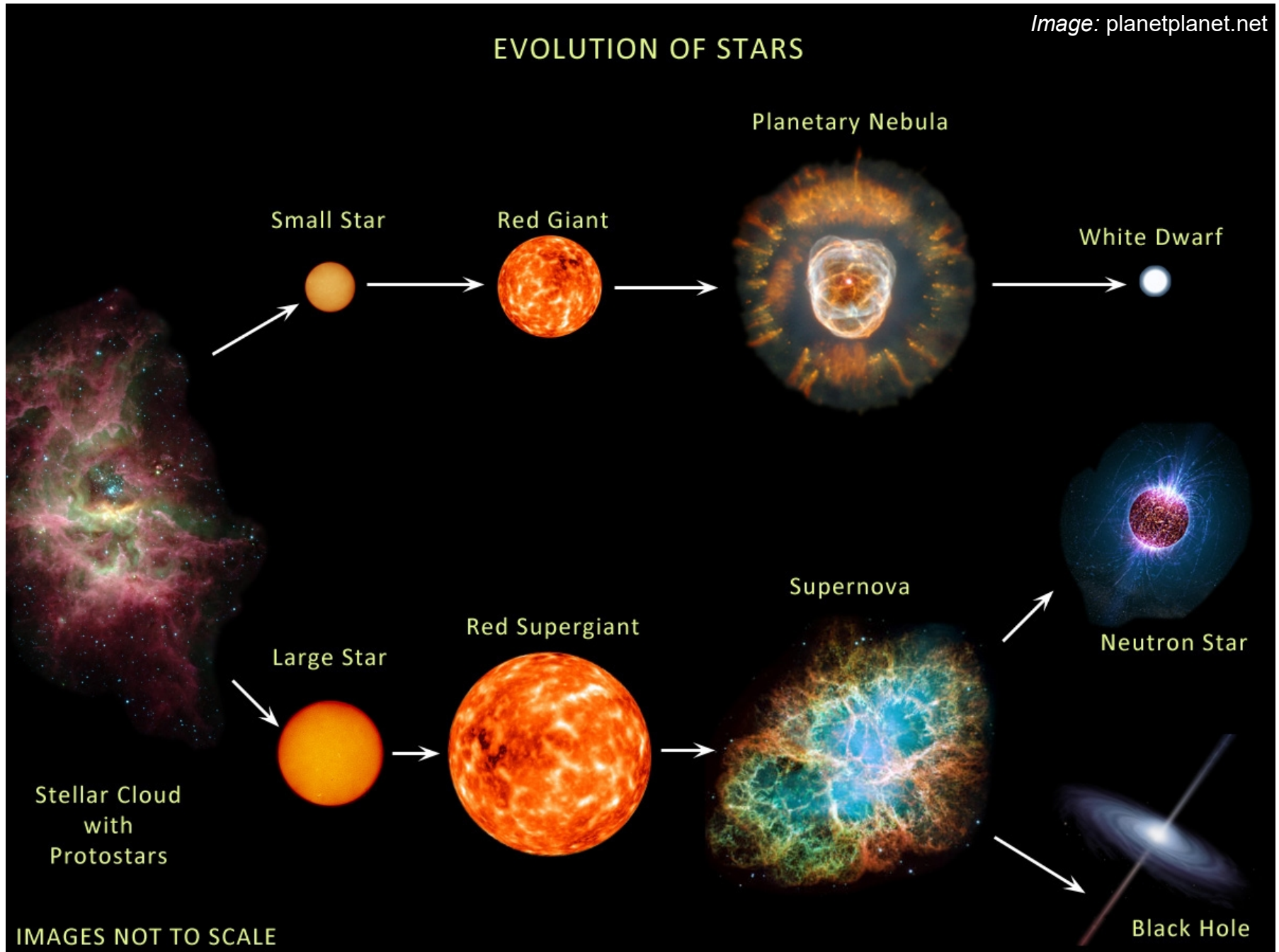
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**... what are the astrophysical consequences?**

# Neutron Star Formation



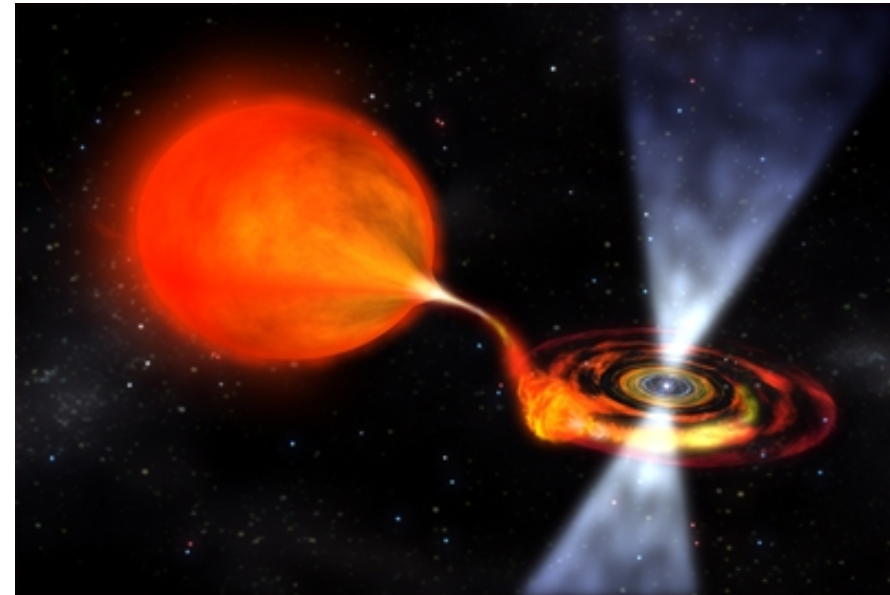
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Image: NASA/Dana Berry



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

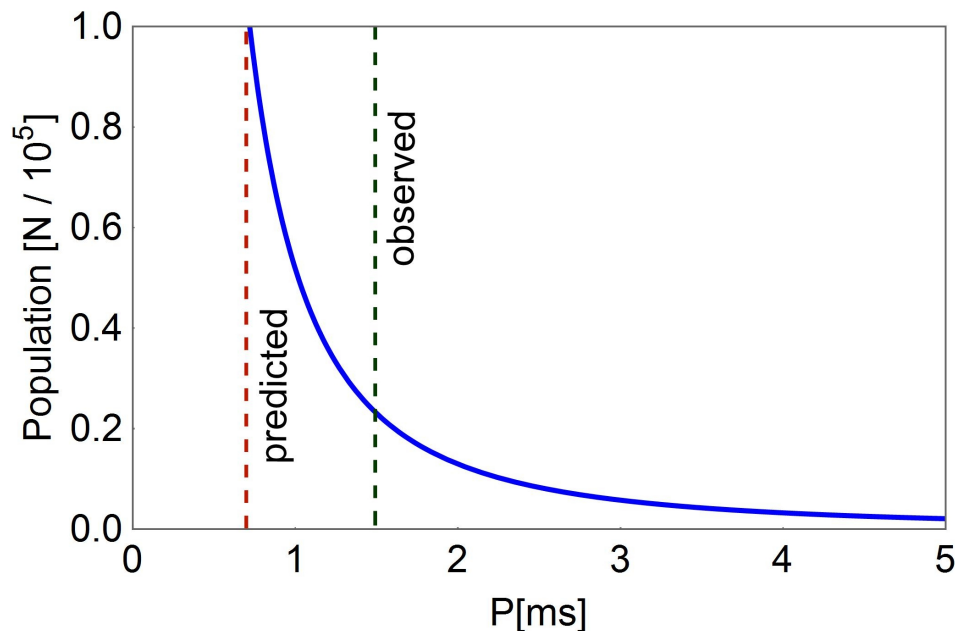
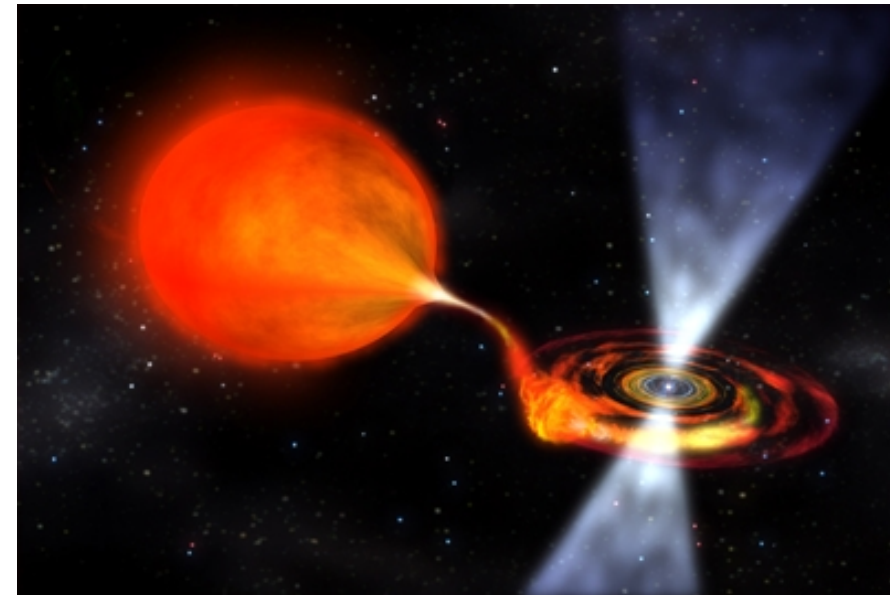


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# NS-PBH Capture

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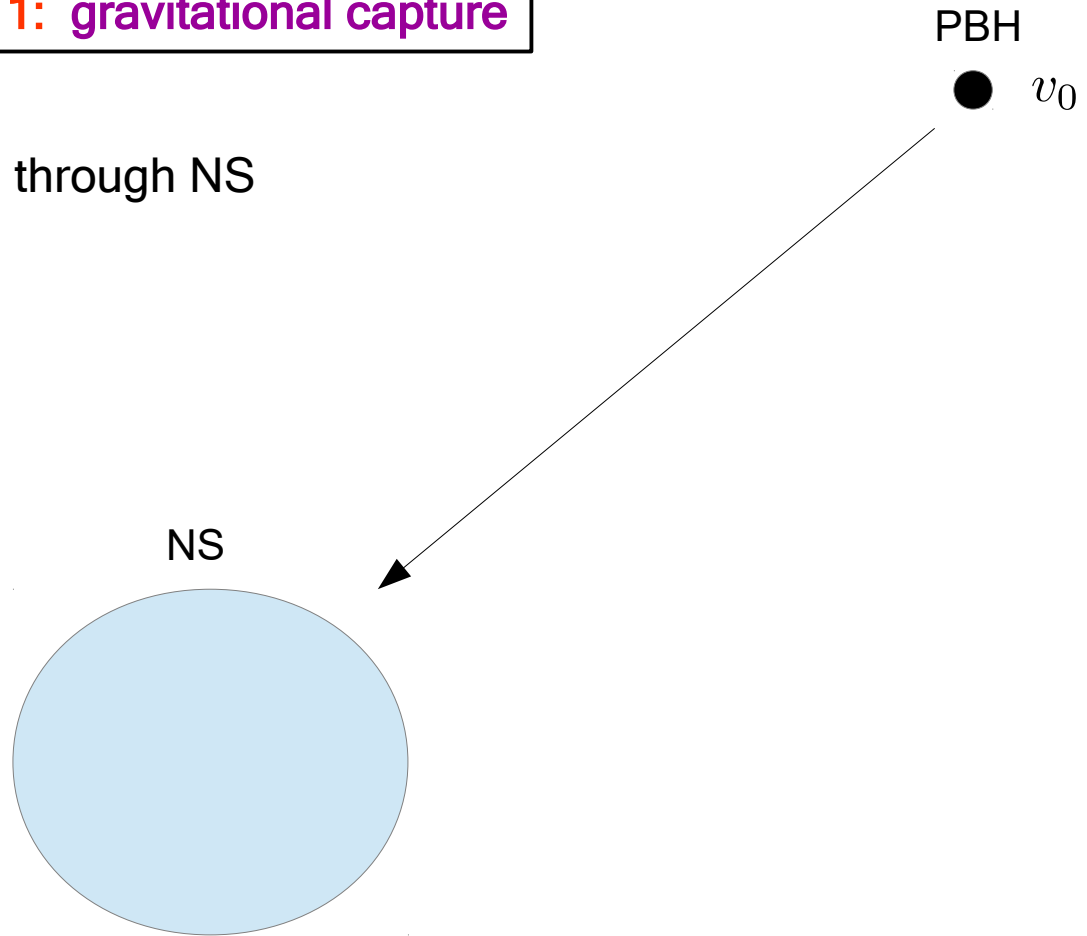
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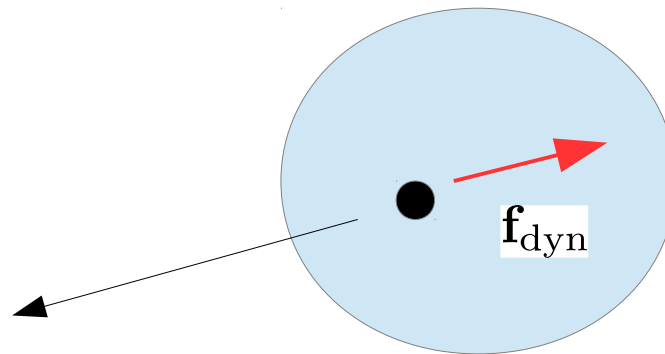
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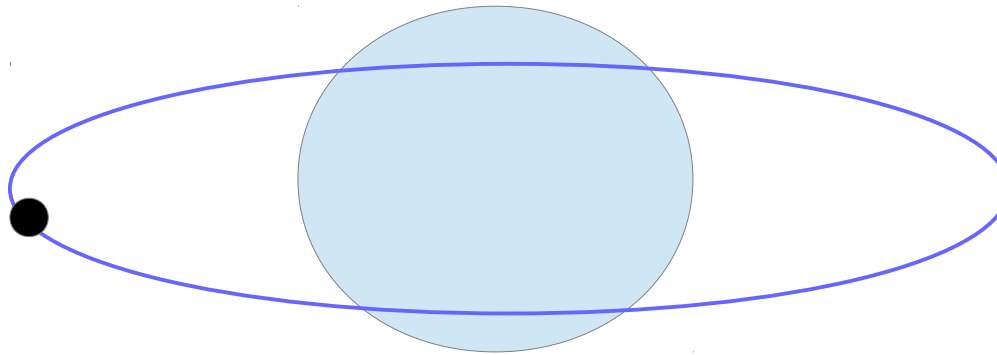
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- if  $E_{\text{loss}} > KE_{\text{PBH}} \rightarrow \text{captured !}$

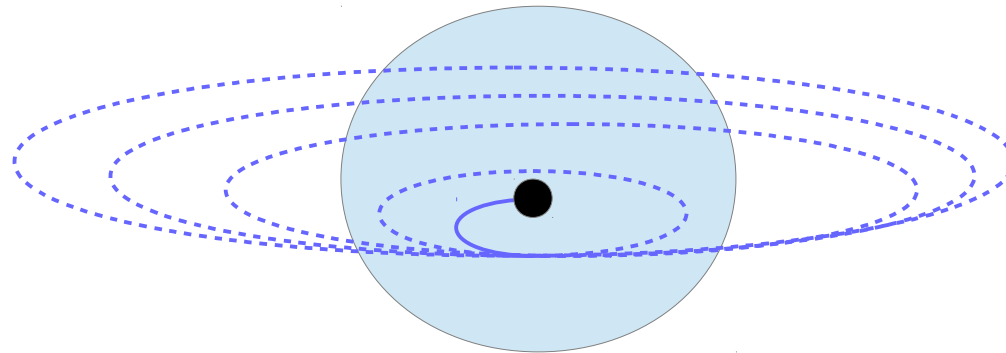


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## Stage 2: PBH in NS

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

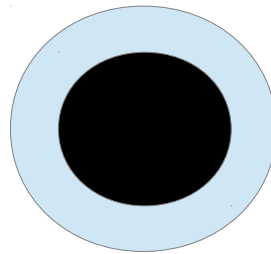


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**Stage 3: BH grows inside**

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





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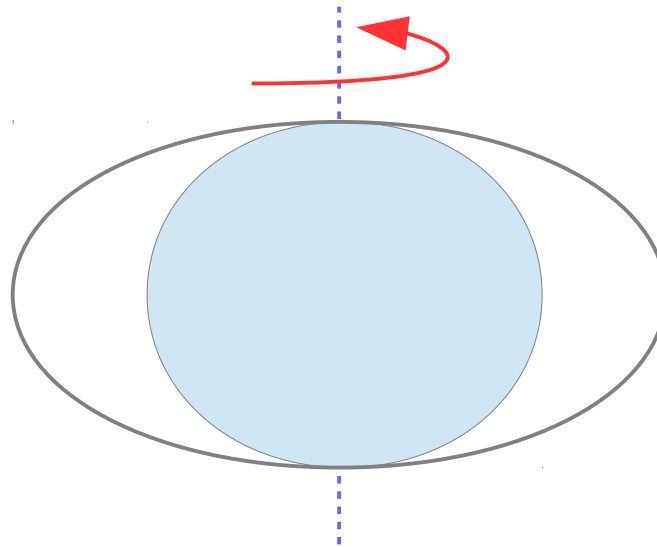
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**Bonus:** consistent with recently discovered young GC magnetar [Mori+,13; Kennea+,13]  
→ shows unusual activity ... a hint of PBH consumption ??

# Growing BH in NS: angular momentum transfer

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

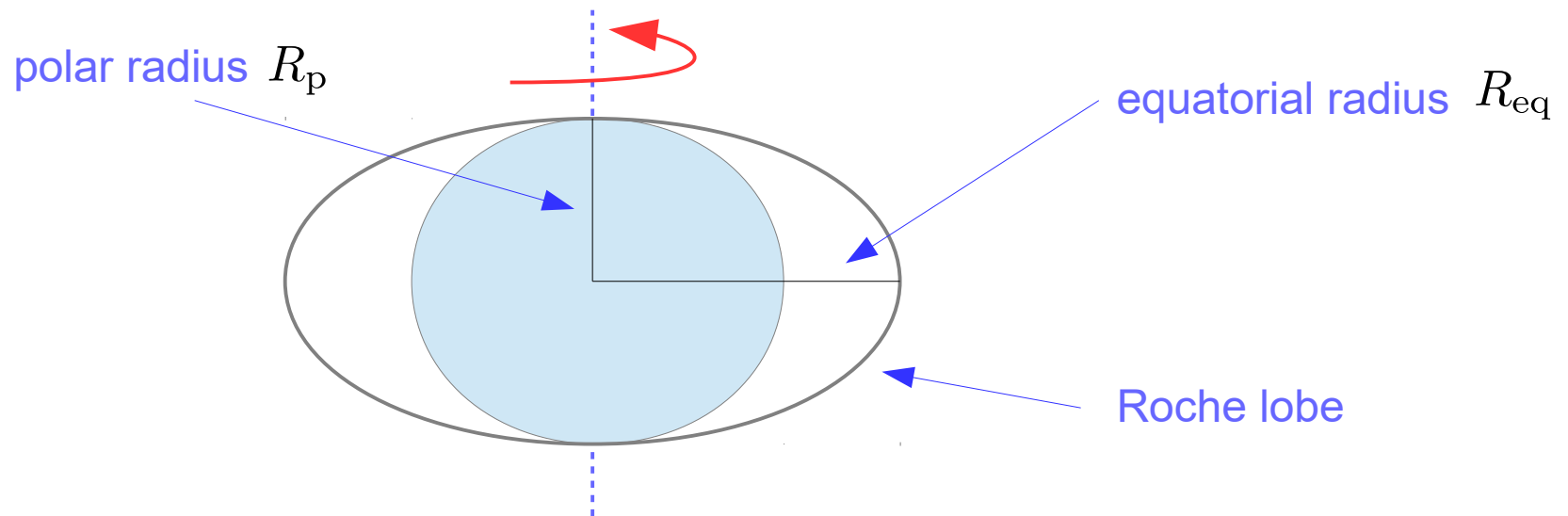
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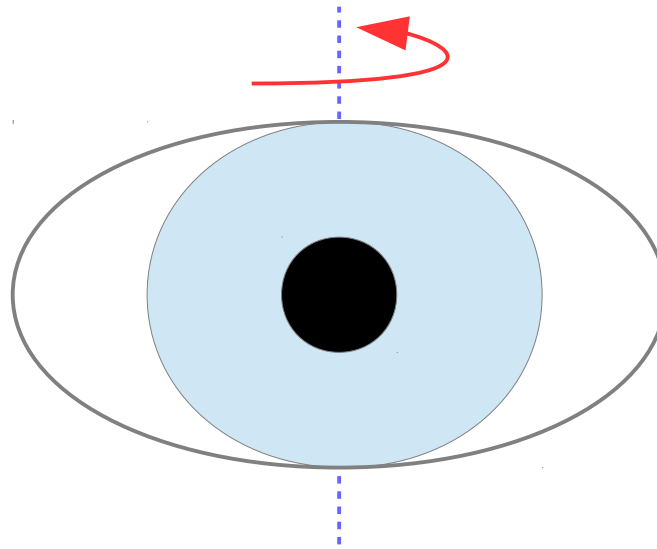
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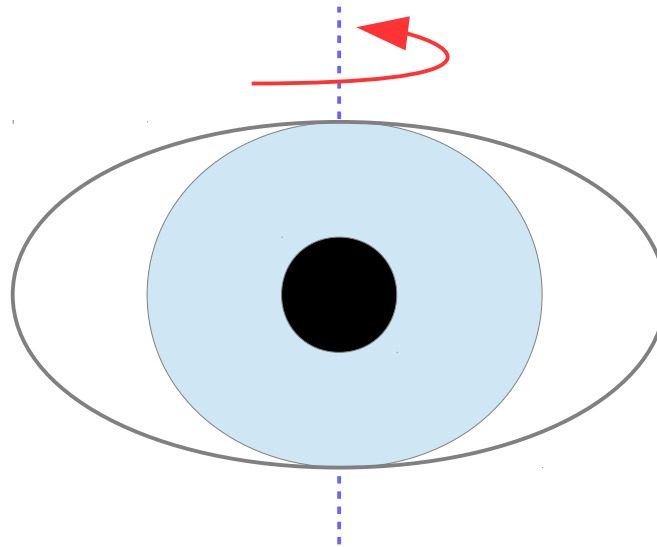


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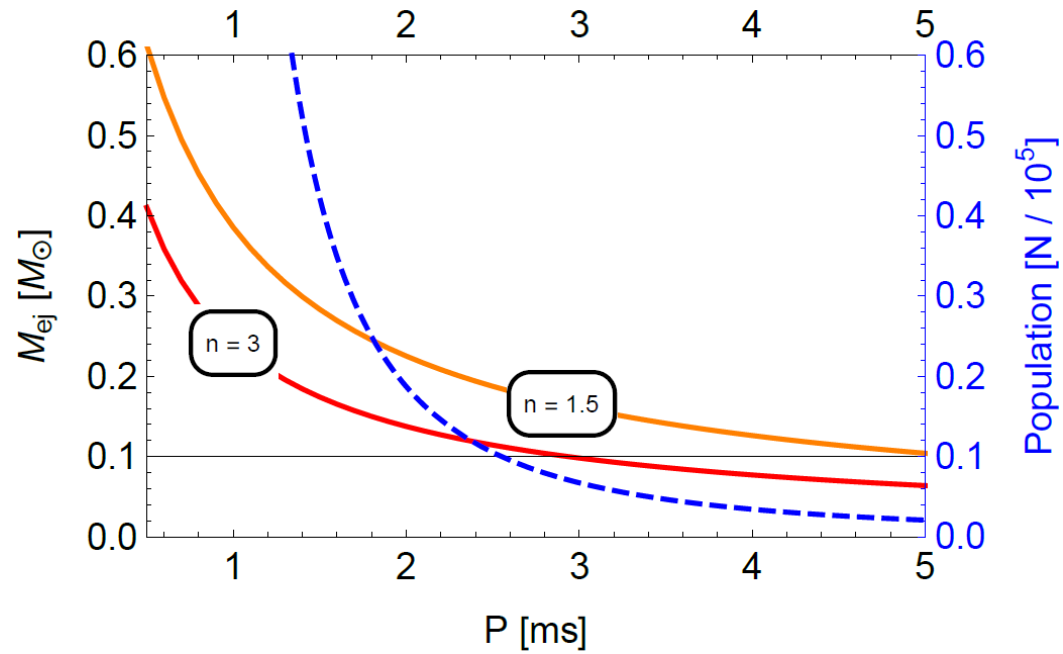


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\* Differential rotation can occur → calculated that viscosity and magnetic stresses eliminate

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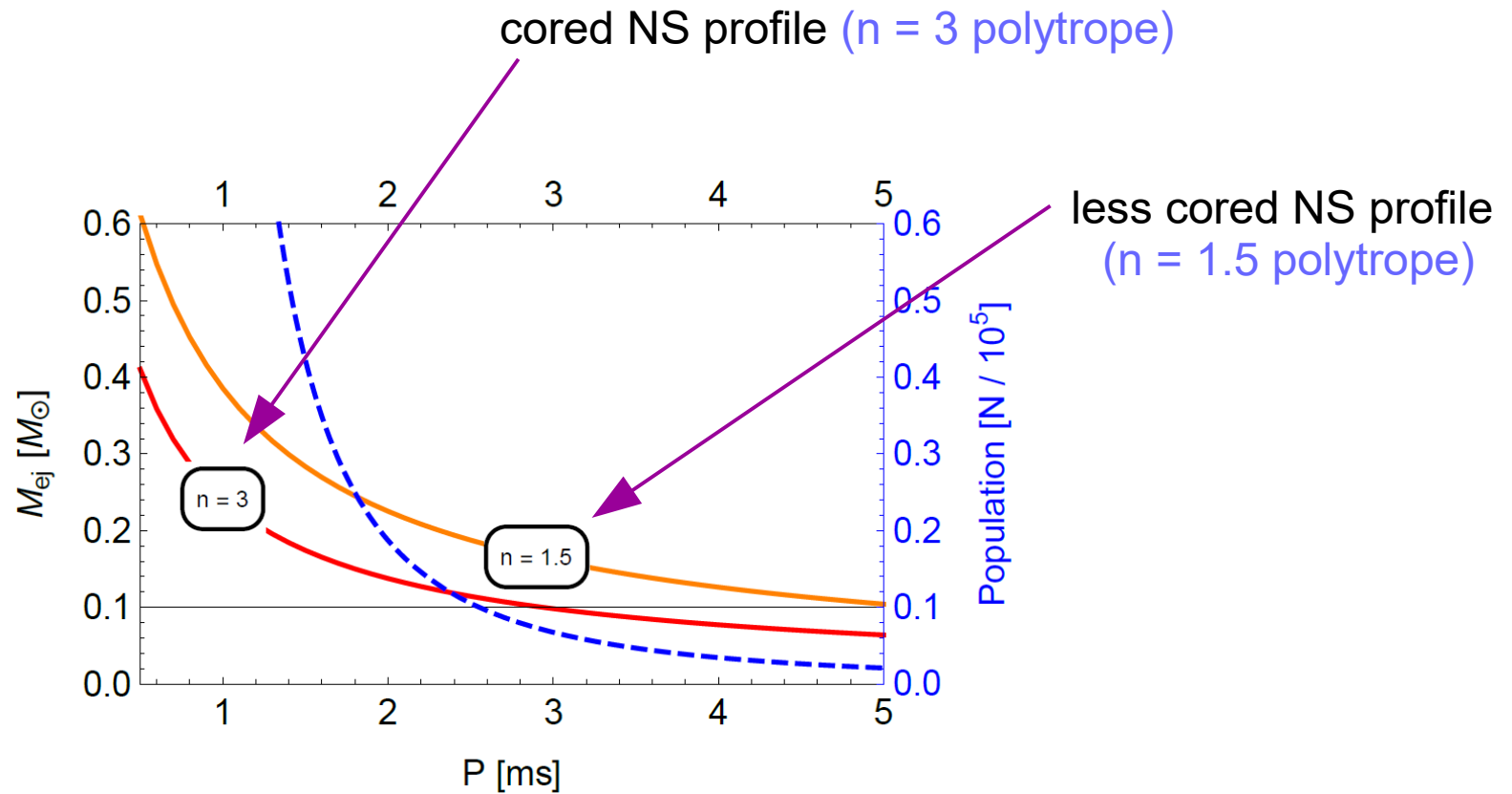
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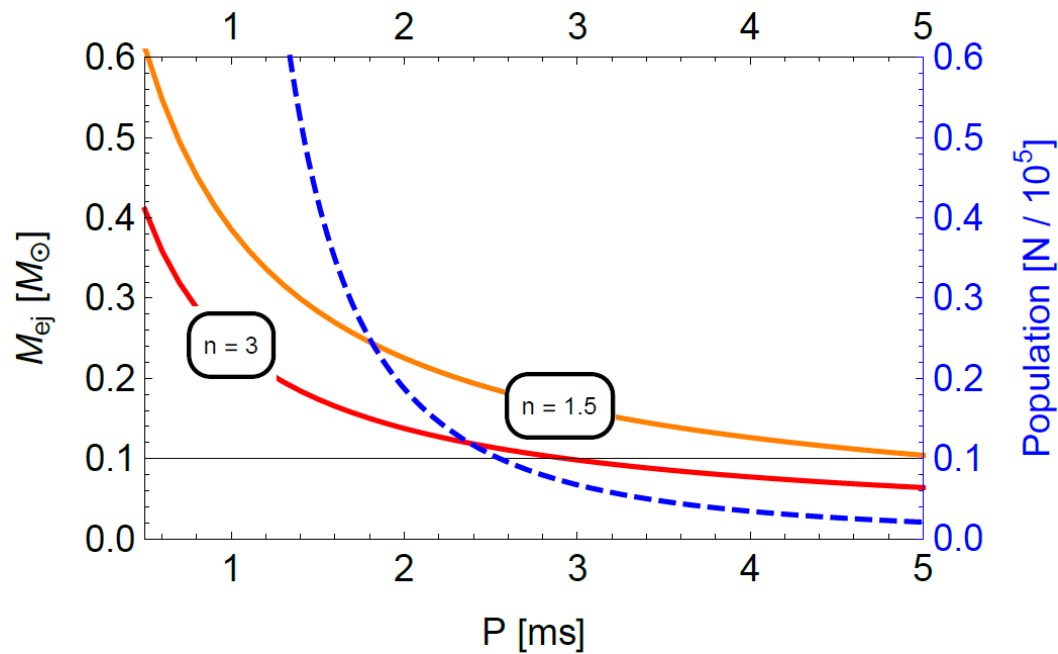
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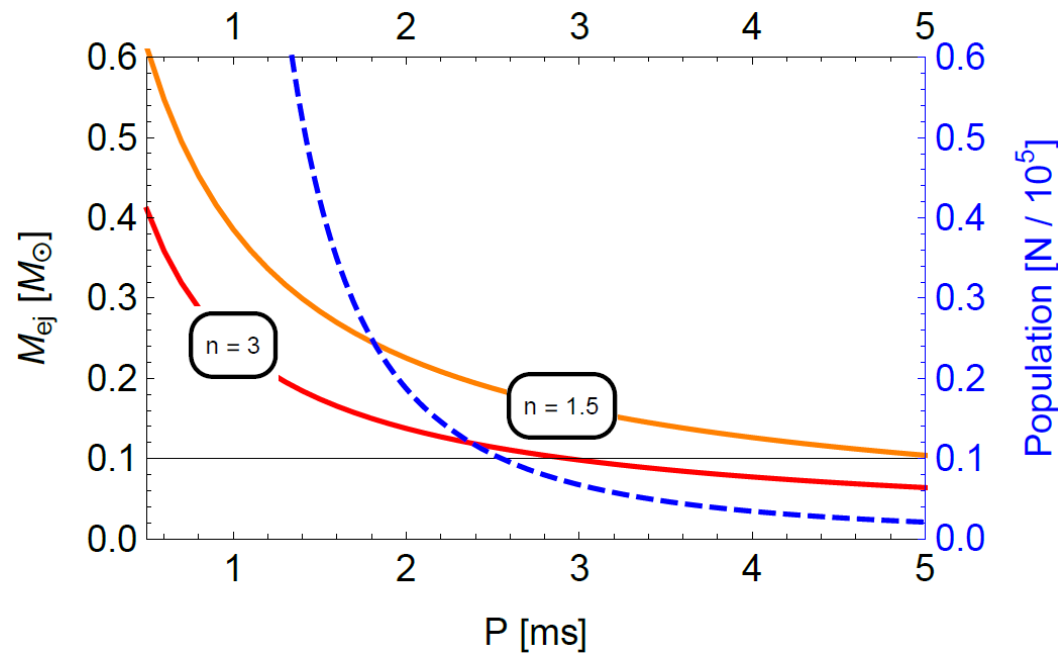
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- Ejecta neutron rich  $\rightarrow$  **a site of r-process nucleosynthesis?**

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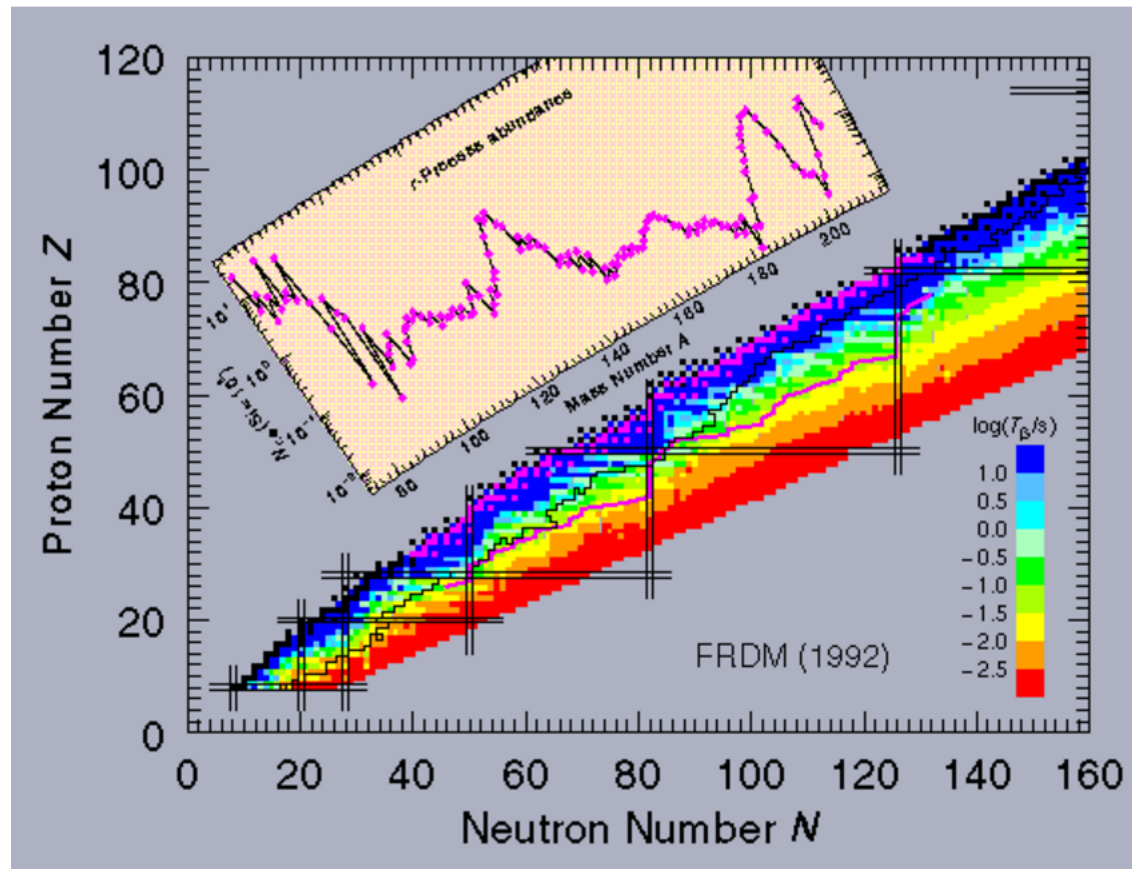
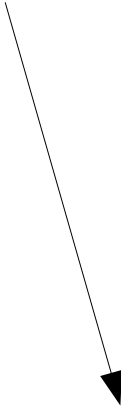


Image: Los Alamos,  
Nuclear Data Group

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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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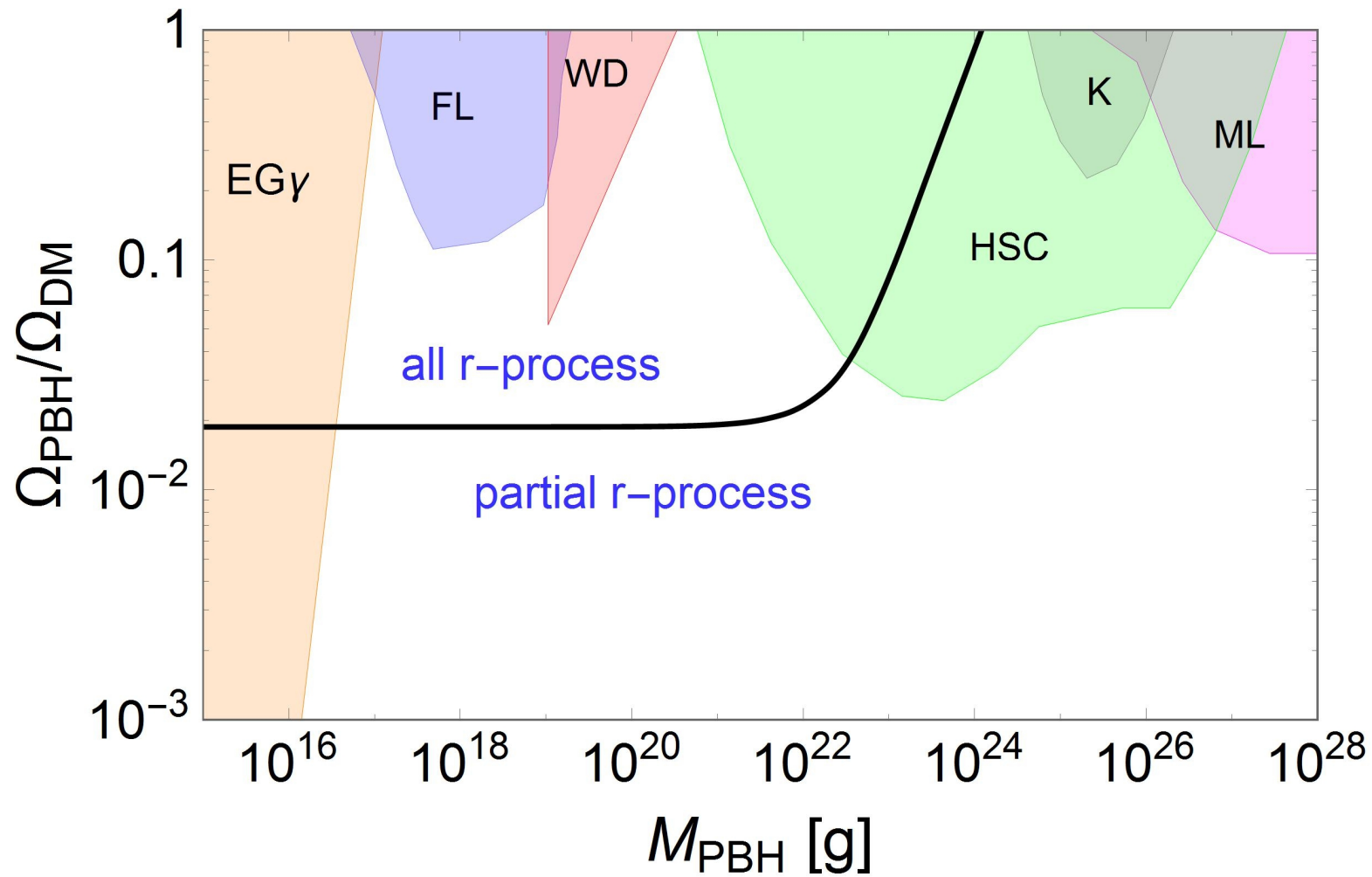
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can explain both simultaneously with PBH-NS

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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 !

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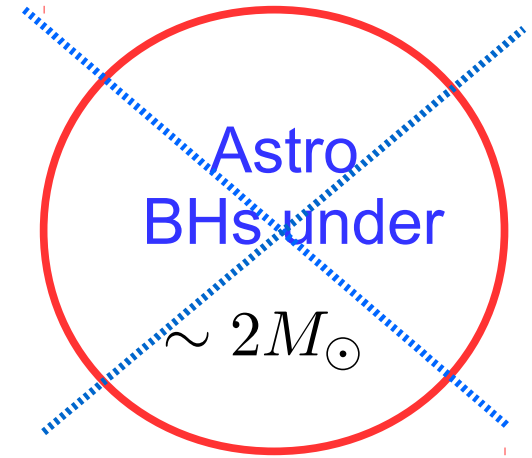
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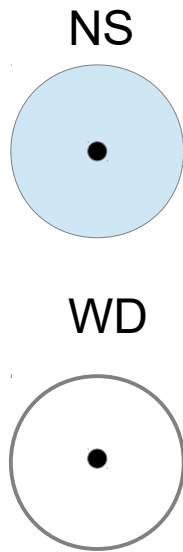
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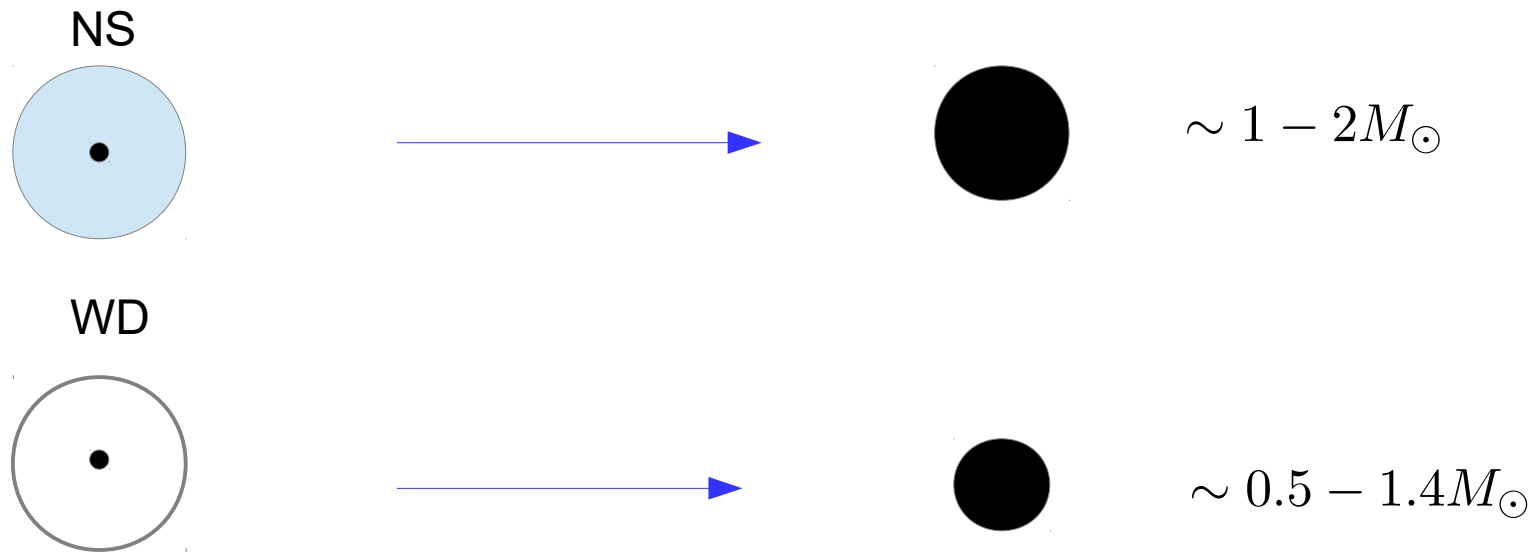
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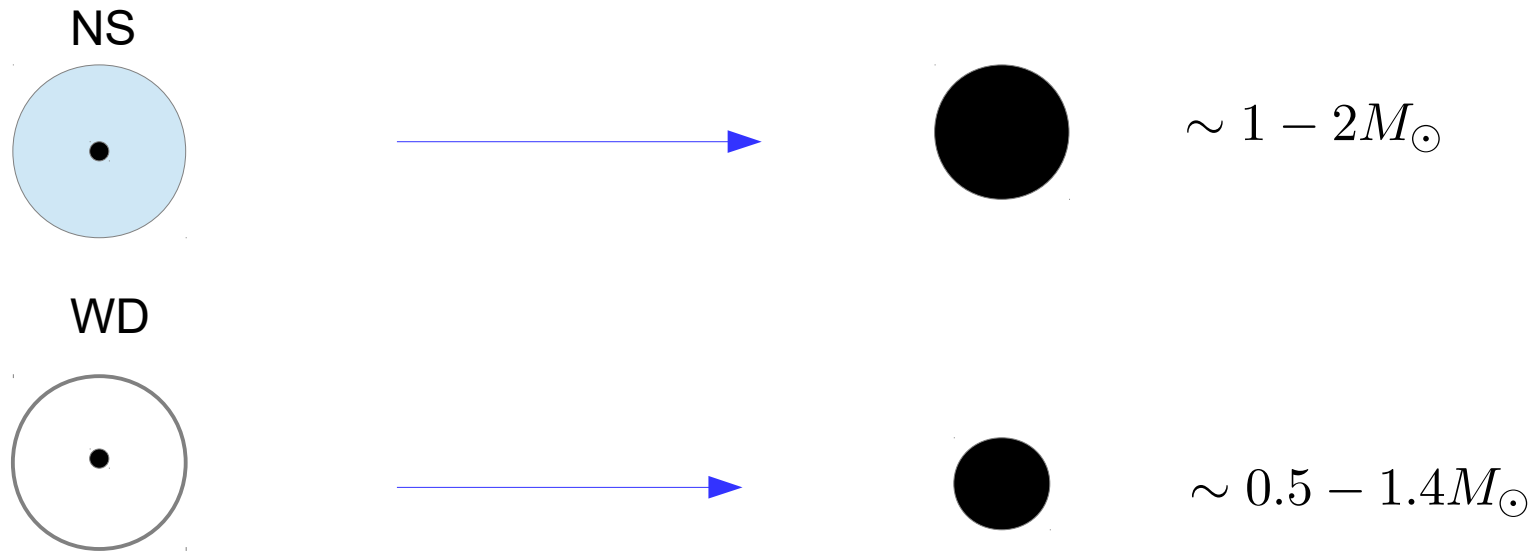
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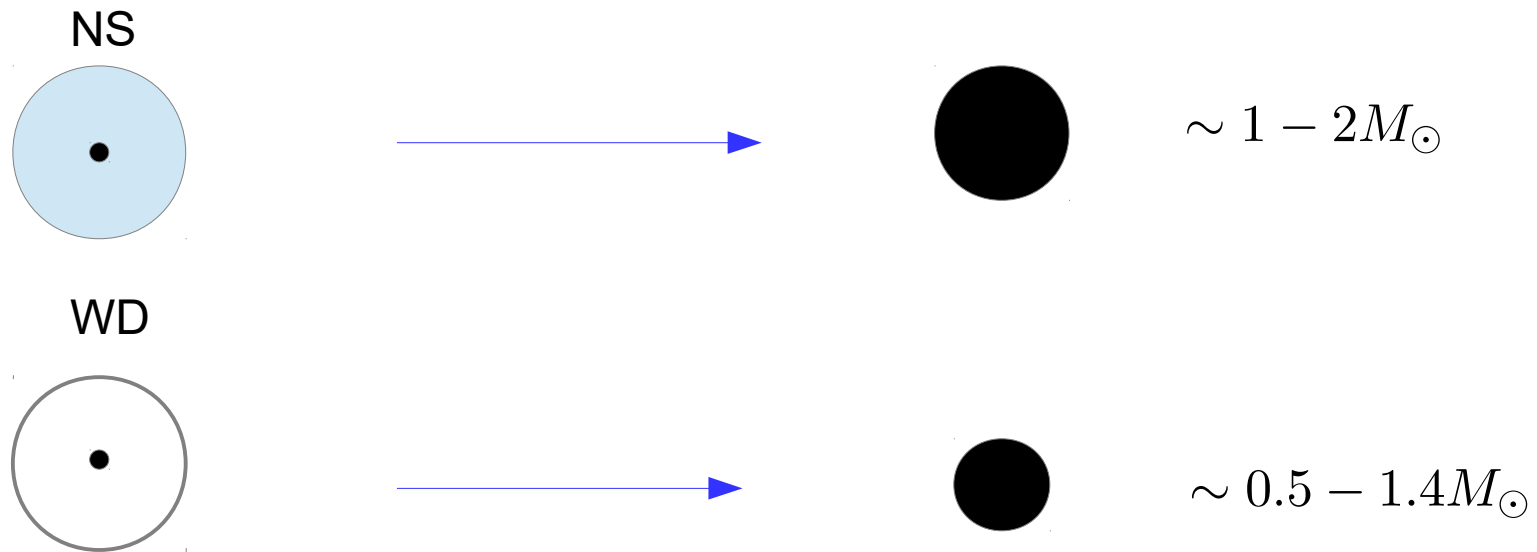
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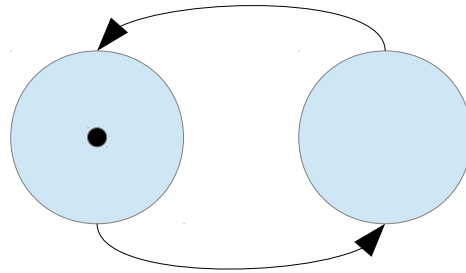
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**How to detect such BHs? → GW signal from binary mergers**

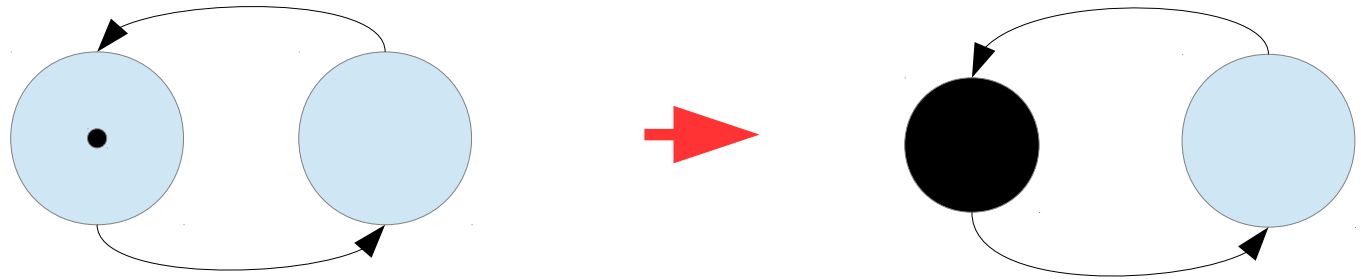
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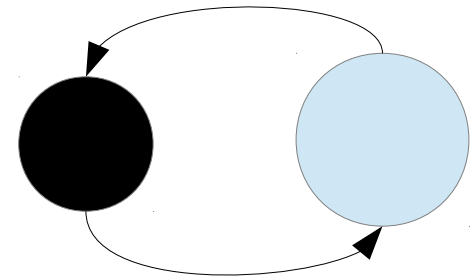
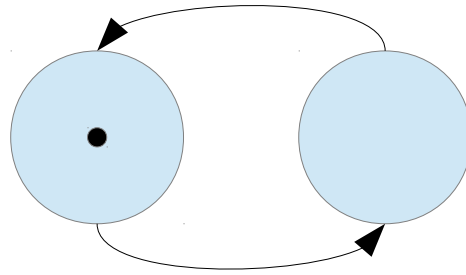
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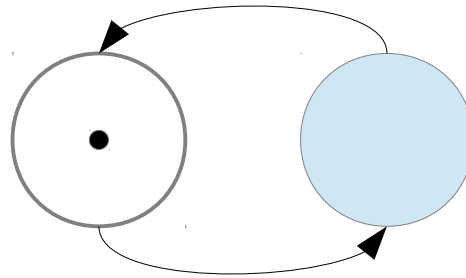


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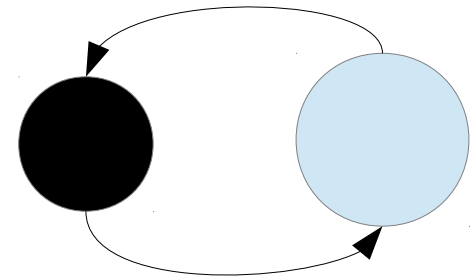
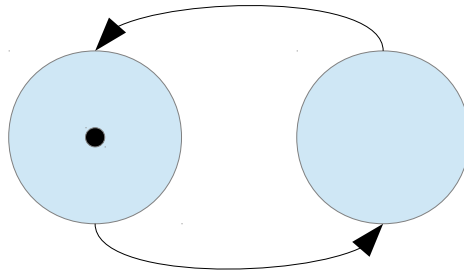


WD-NS

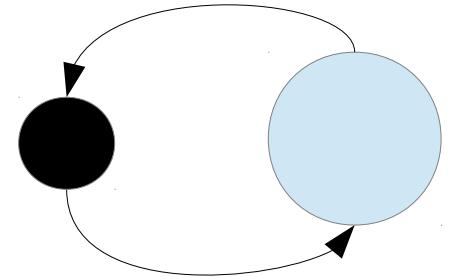
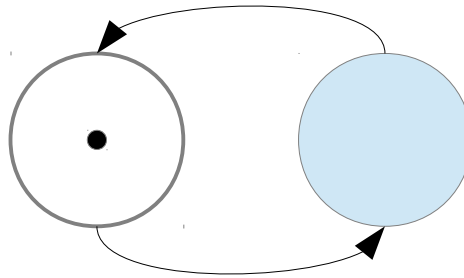


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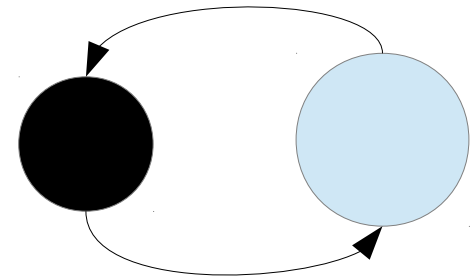
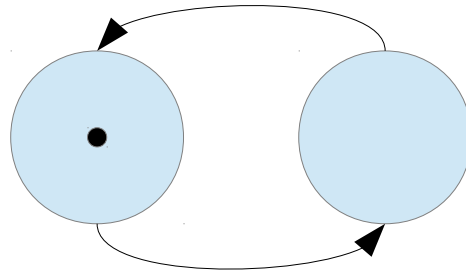


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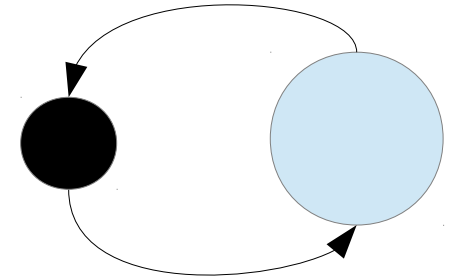
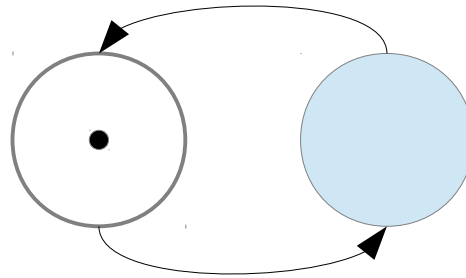


# Transmuted Binaries

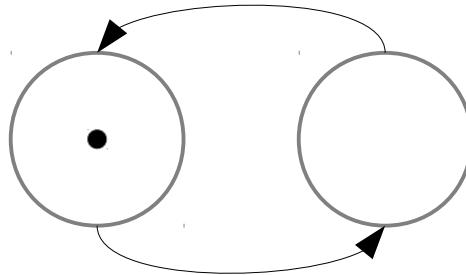
NS-NS



WD-NS

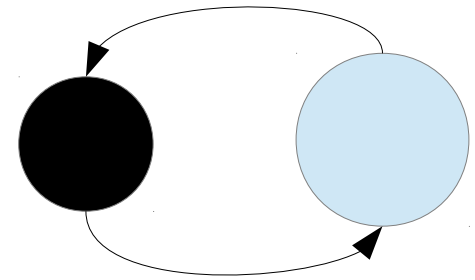
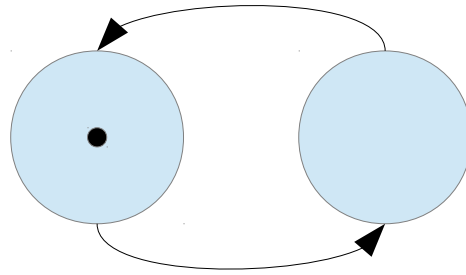


interacting WD-WD  
(cataclysmic variable)

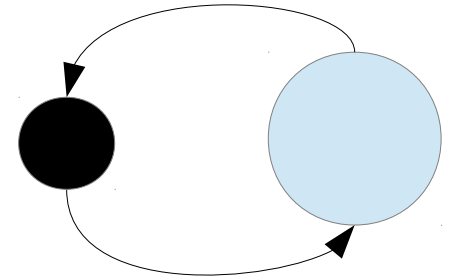
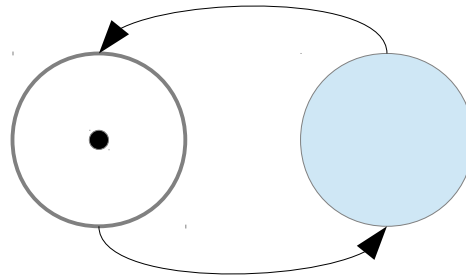


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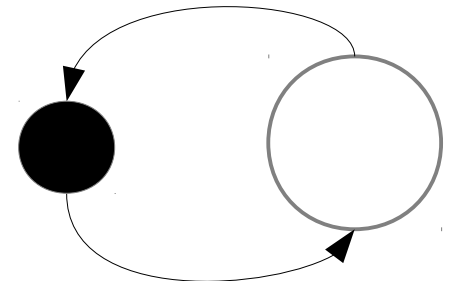
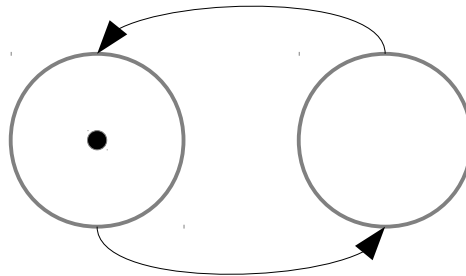
NS-NS



WD-NS

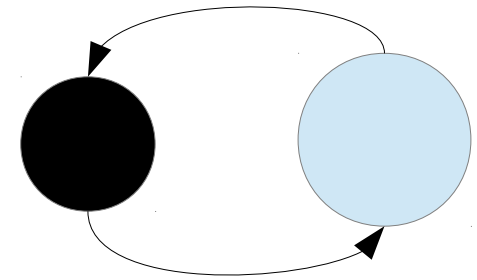
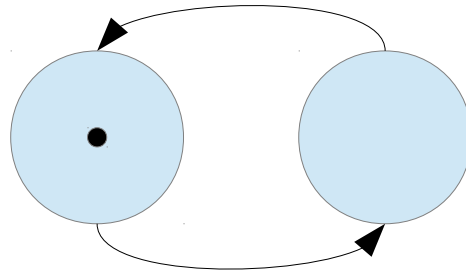


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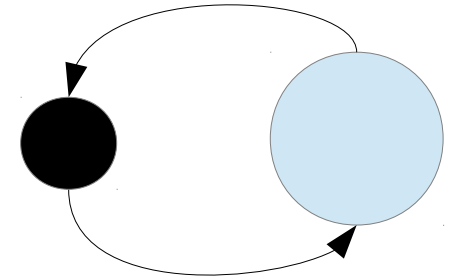
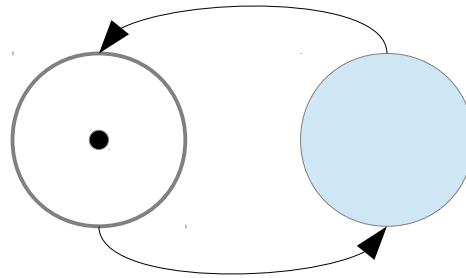


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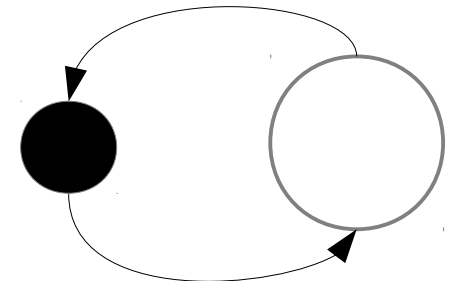
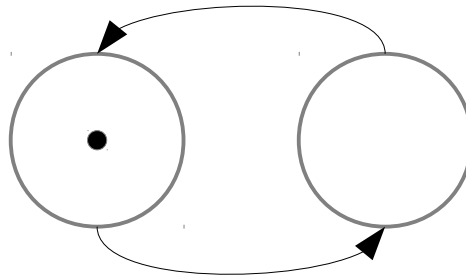
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- Some other possibilities: with a regular BH, or very rarely a double transmutation



# Transmuted Binaries

NS-NS

**MOST WELL STUDIED**

WD-NS

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(cataclysmic variable)

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# Compact Object Mergers

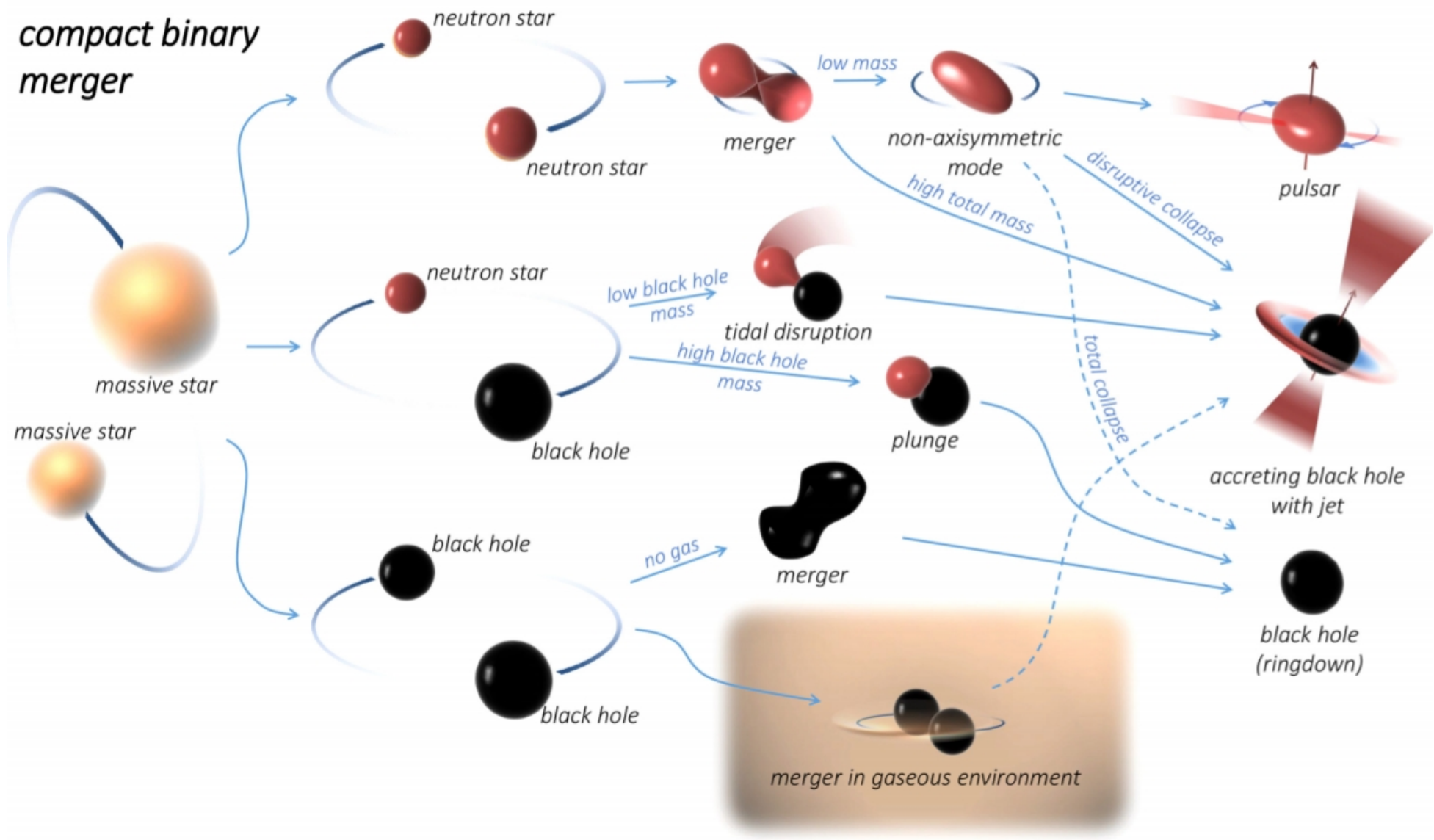


Image: Bartos, Kowalski, "Multimessenger Astronomy"

# Binary GW Signals

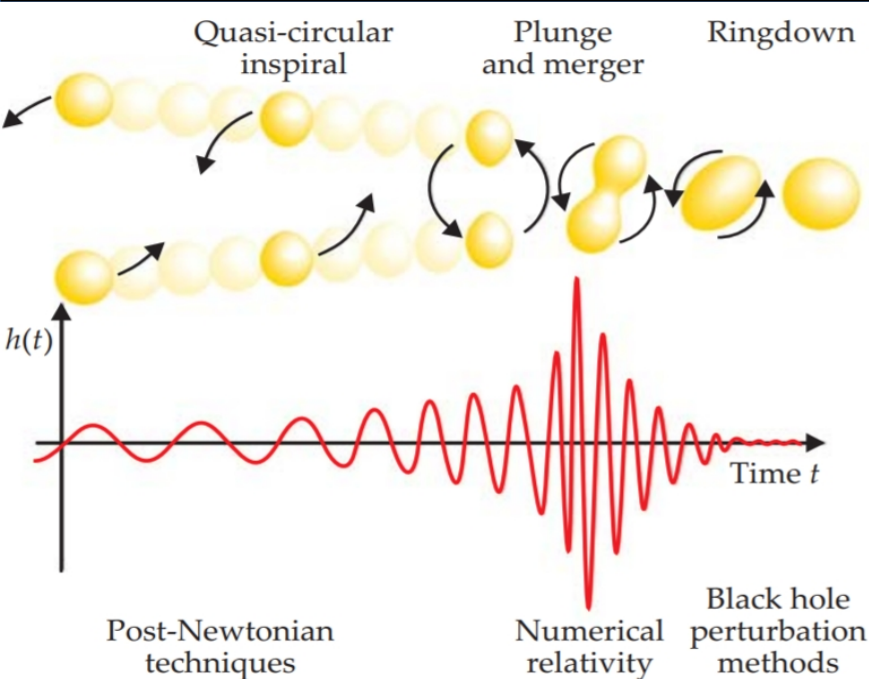


Image: [Baumgarte, Shapiro, 2011]

Image: Kurt, Caltech-JPL

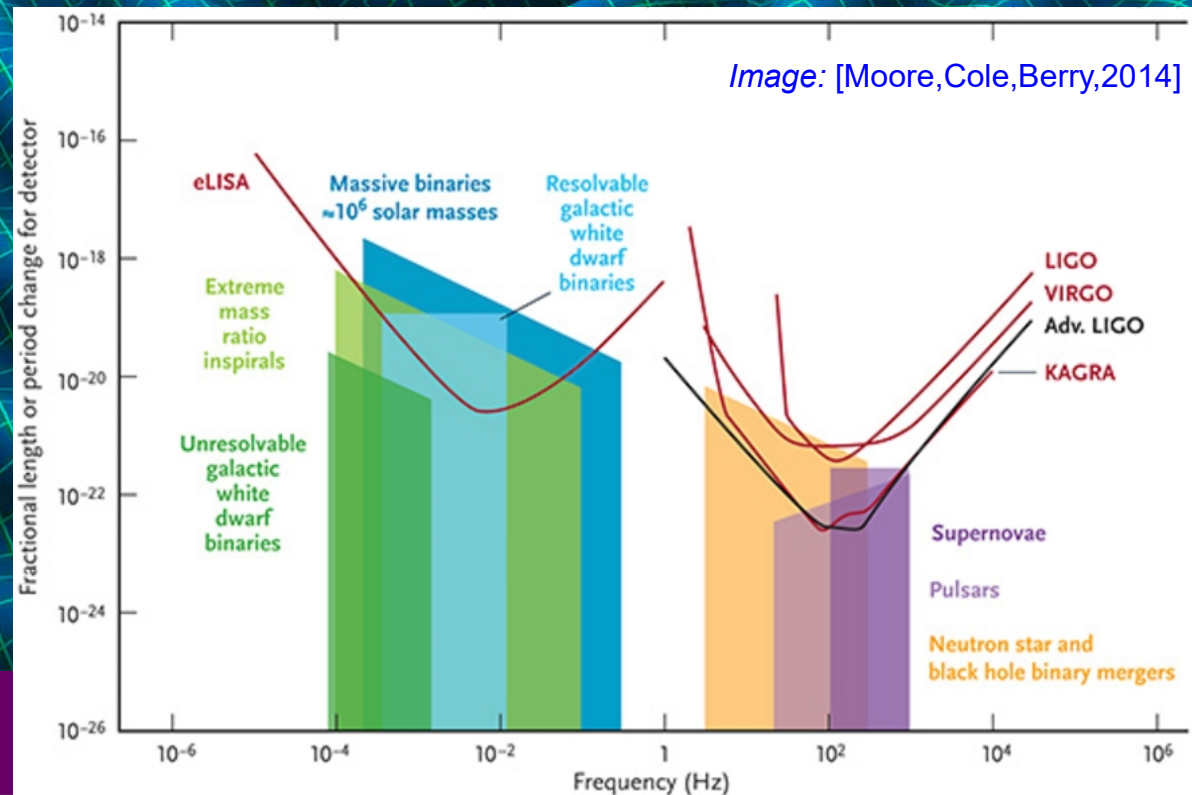
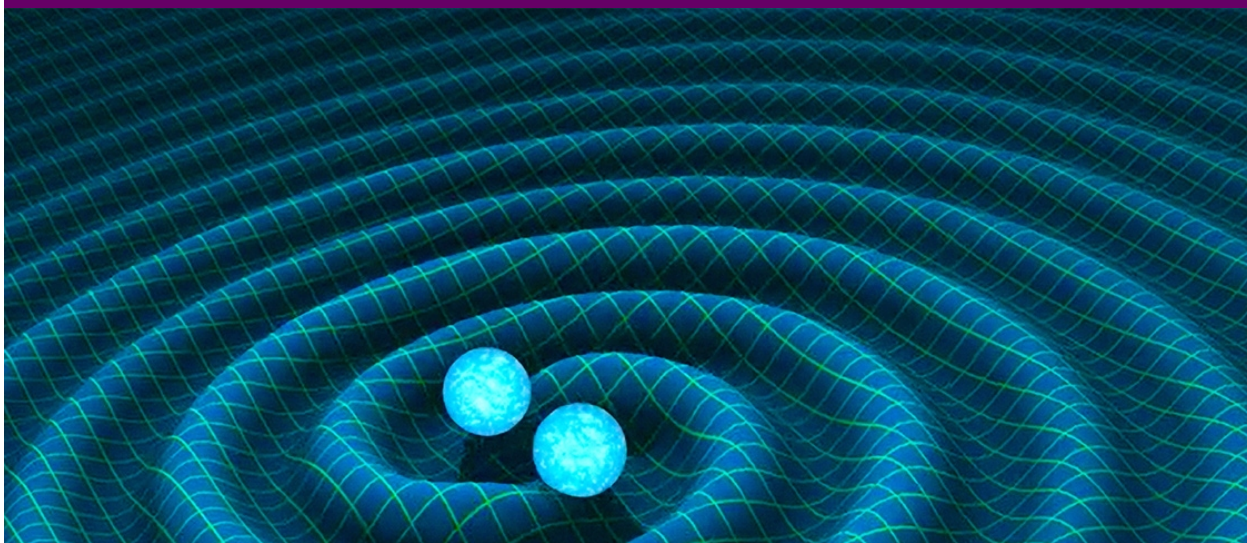


Image: [Moore, Cole, Berry, 2014]

# Transmuted GW Signals

- General features (merger time, GW luminosity, freq. t. variation, char. amplitude)
  - depend on chirp mass  $\mathcal{M}_c(M_1, M_2)$ , same if no mass change
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  - depend on chirp mass  $\mathcal{M}_c(M_1, M_2)$ , same if no mass change
  - ejected mass could be significant, will drastically alter
- Some other discriminating factors:
  - Merger phase (e.g. disk formation, intermediate NS, delayed sGRB)
  - ringdown phase

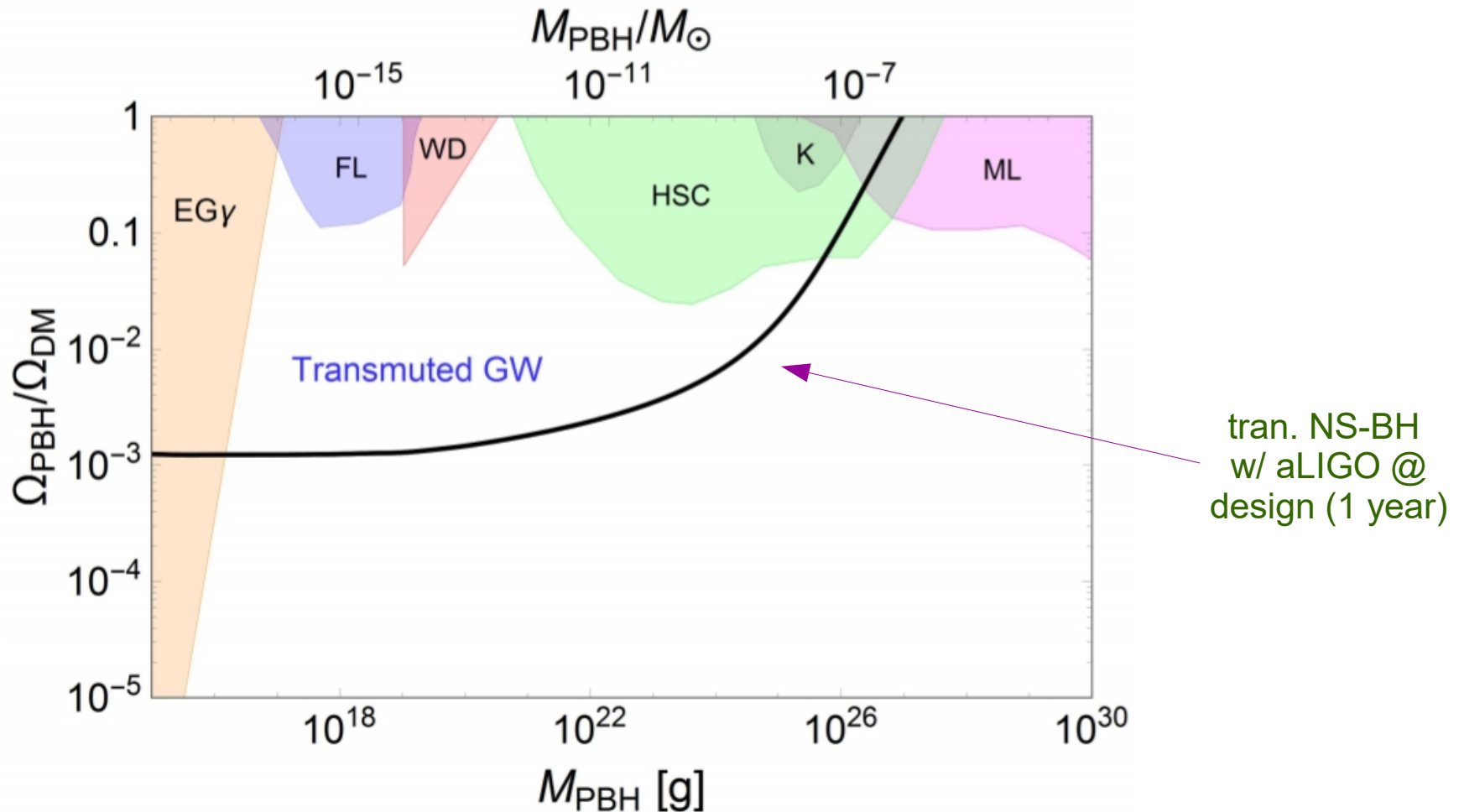


# GW Detection

- 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!**