Title: Forging Heavy Elements with Primordial Black Holes

Date: Aug 24, 2017 04:00 PM

URL: http://pirsa.org/17080071

Abstract: <p>Primordial black holes (PBHs) can appear from early Universe dynamics. We show that some or all of heavy element abundance from r-process nucleosynthesis can be produced in interactions of tiny primordial black holes with neutron stars (NSs), if PBHs make up a few percent or more of the dark matter. A PBH captured by a NS will eventually consume it. For a rapidly rotating pulsar, the resulting star spin-up will eject significant amount of cold neutron rich material. The ejection, decompression and decay of nuclear matter can produce electromagnetic transients, like kilonovae and fast radio bursts. Beta decay of ejected material yields positron emission consistent with the observed 511 keV-line from the Galactic Center. Lack of accompanying gravity wave (GW) signal and neutrino emission allows to distinguish these events from supernovae and compact object mergers. Finally, if the consumed star was part of a binary system, long after the event a distinct detectable GW signal from the binary merger with an atypically small solar mass BH will carry information about star's destruction.</p>

Forging Heavy Elements with Primordial Black Holes

Volodymyr Takhistov (UCLA)

Seminar, Perimeter Institute

(6.20.2017)

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

... *since nowadays important news are spread by Twitter,*

from Department of Energy Office of Science:

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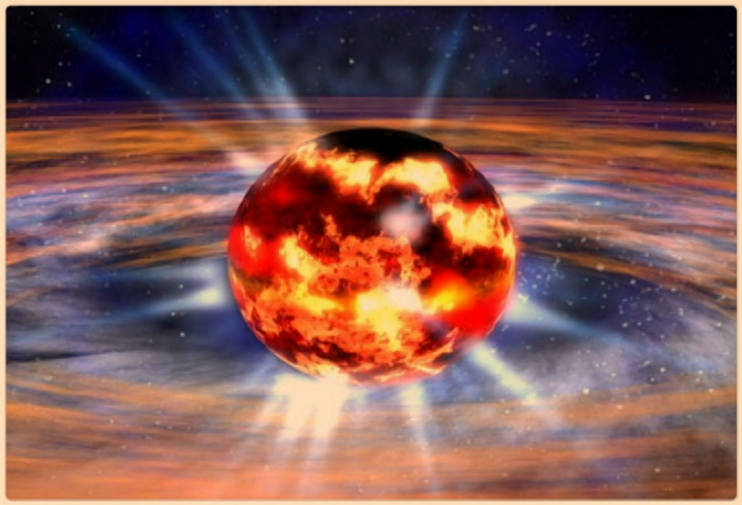
DOE Science @doescience · Aug 9

Researchers @UCSanDiego have reported that tiny black holes could have produced elements heavier than iron bit.ly/2wIOw8V @UCLA



Prelude

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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 → collapse to BH

  ... *improbable without new physics*

see reviews
[Carr,Kuhnel,Sandstad,17; Khlopov,10]

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

$$10^{15}\ {\rm g} \lesssim M_{\rm BH} \lesssim 10^{55}\ {\rm g}$$

Hawking evaporation ← → curvature restriction

General Setup

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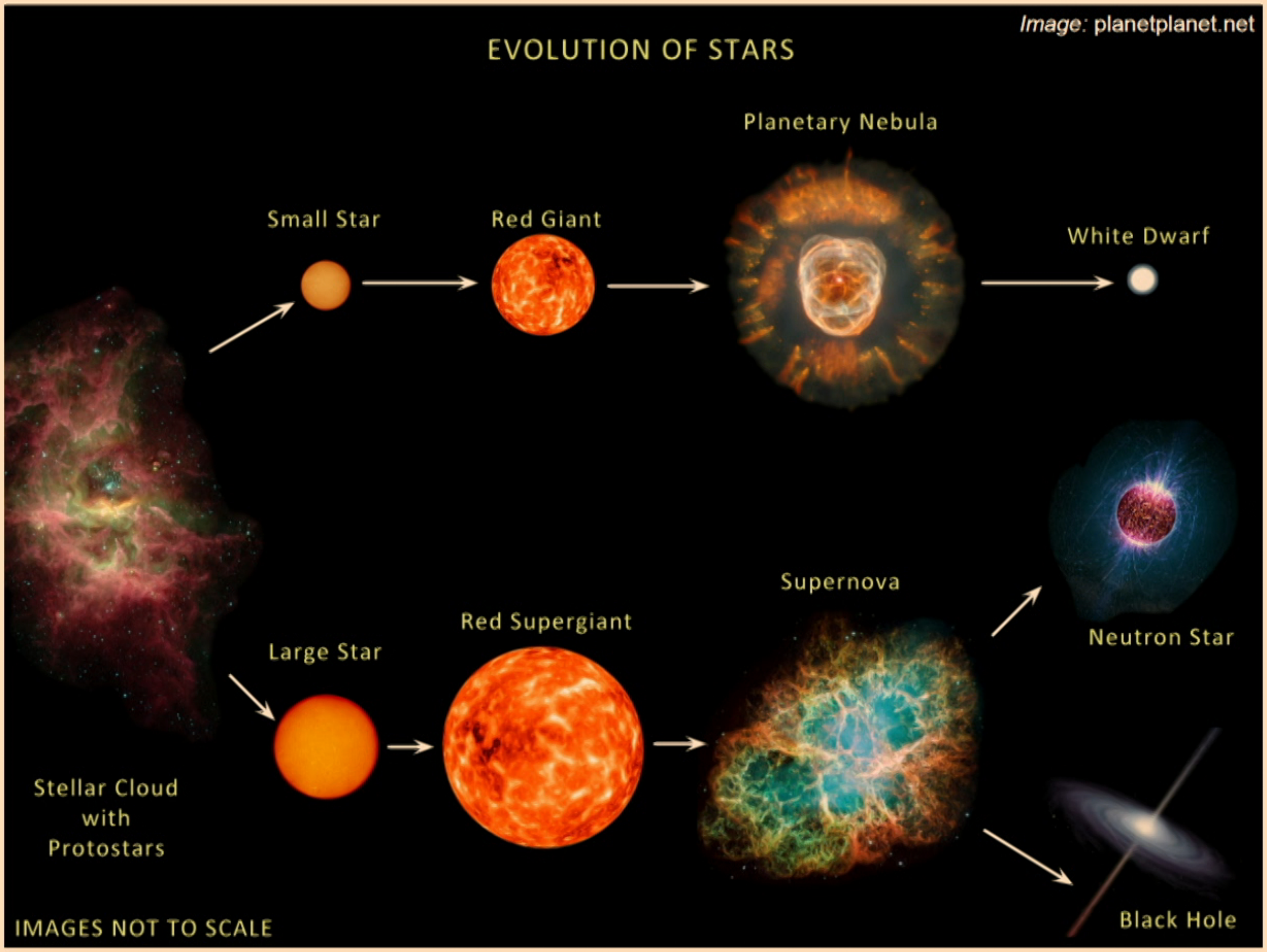
... what are the astrophysical consequences?

Neutron Star Formation



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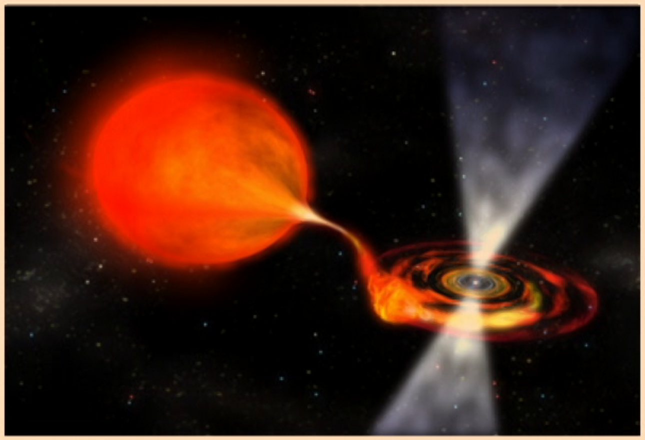
  → binary pulsar accretes matter from companion, spun-up and "recycled" → MSP

Image: NASA/Dana Berry



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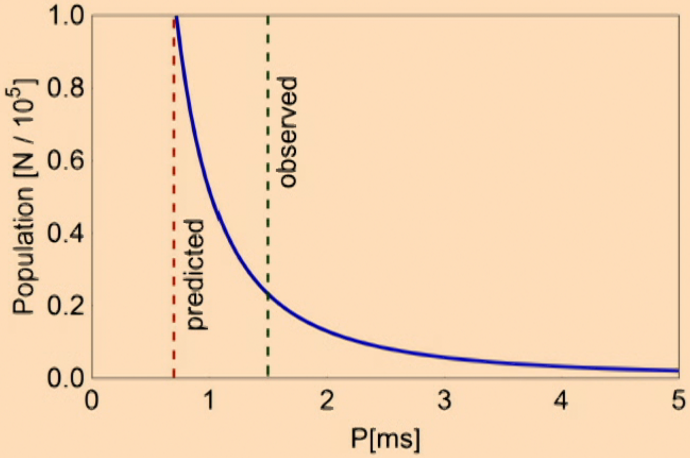
- Population vs. rotation period: [Cordes,Chernoff,97; Lorimer,13]



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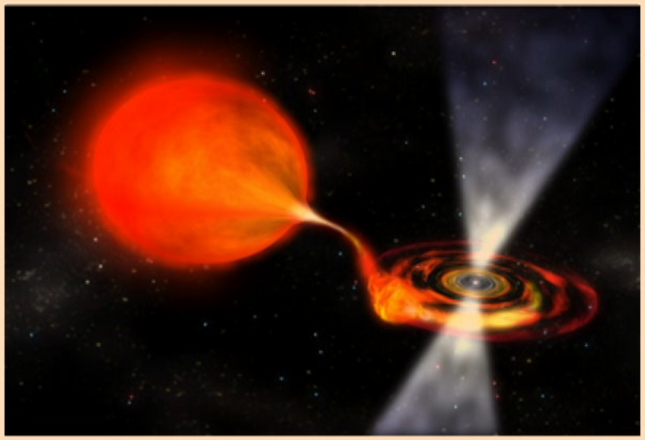

NS-PBH Capture

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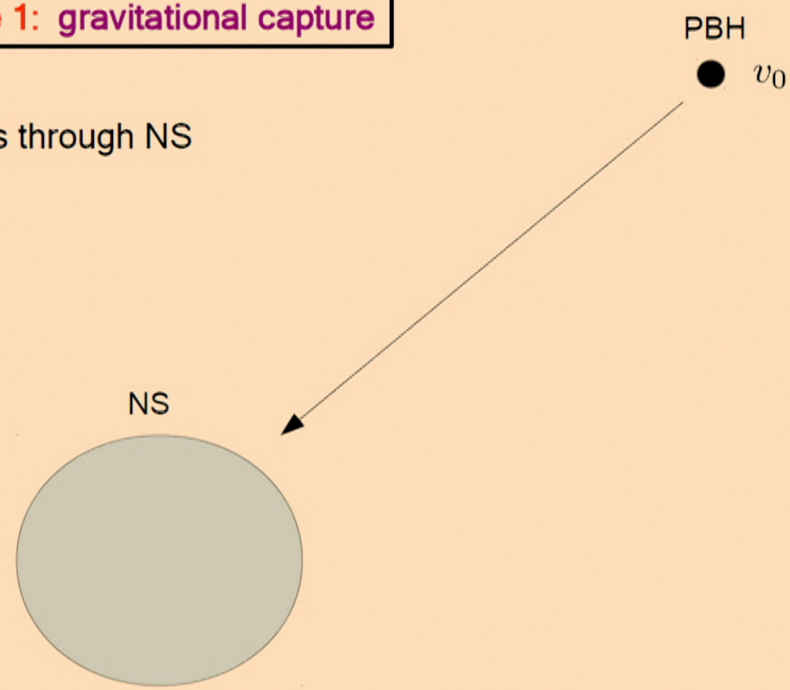

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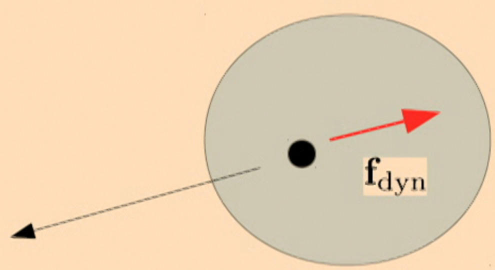

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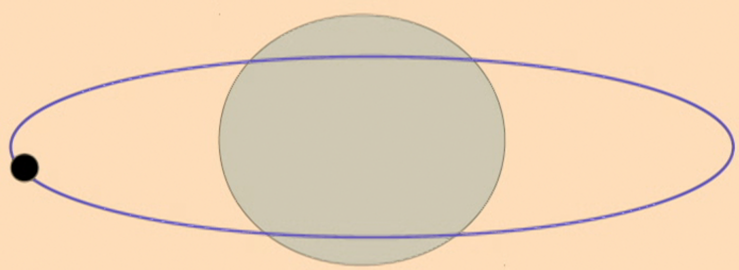
→ if $E_{\mathrm{loss}} > \mathrm{KE}_{\mathrm{PBH}}$ → **captured !**



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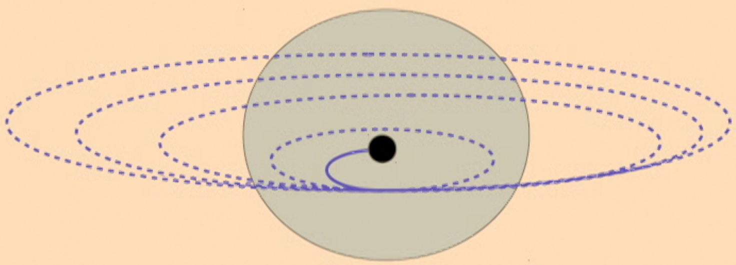
Stage 2: PBH in NS

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



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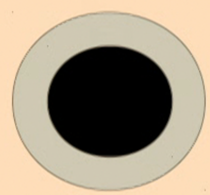
Stage 3: BH grows inside

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



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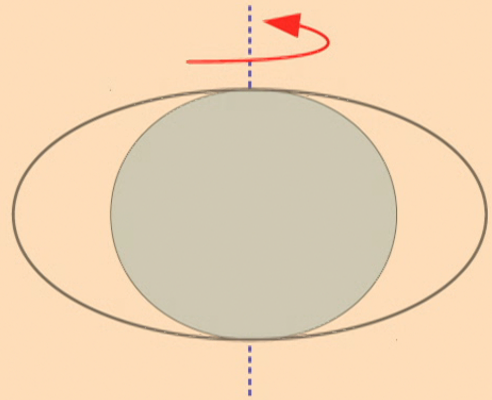
Bonus: consistent with recently discovered young GC magnetar [Mori+,13; Kennea+,13]

→ 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)

[Shapiro,Teukolsky,83]



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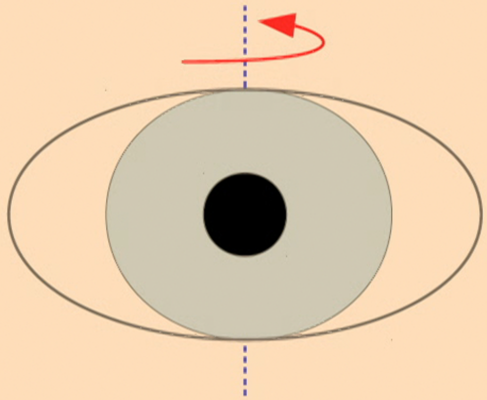

Add BH → can analytically show (see paper) surface matter exceeds escape speed
→ **ejected mass !!**

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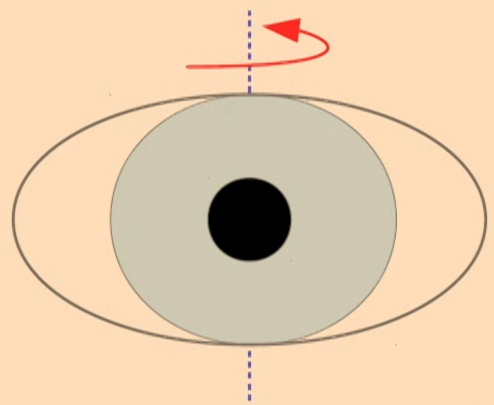

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* Differential rotation can occur → calculated that viscosity and magnetic stresses eliminate

Growing BH in NS: ejected mass

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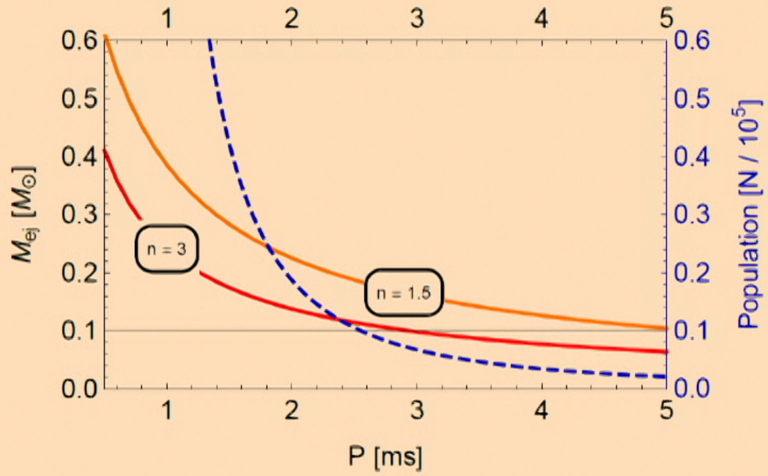
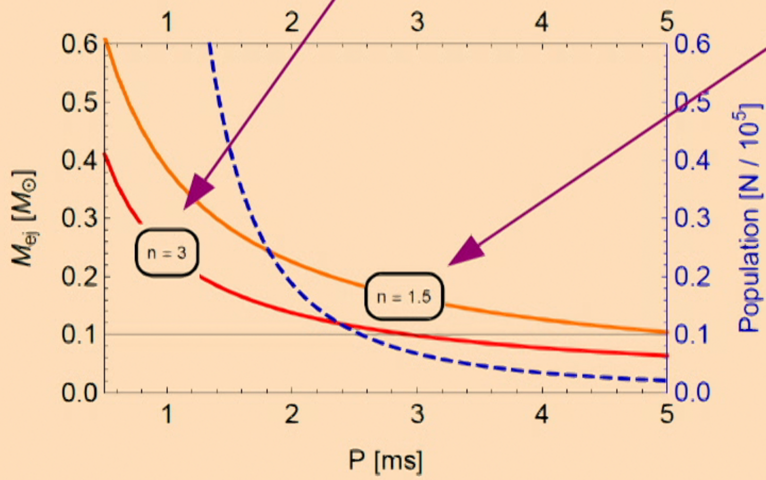


Growing BH in NS: ejected mass

- Ejected mass:

cored NS profile (n = 3 polytrope)

less cored NS profile (n = 1.5 polytrope)



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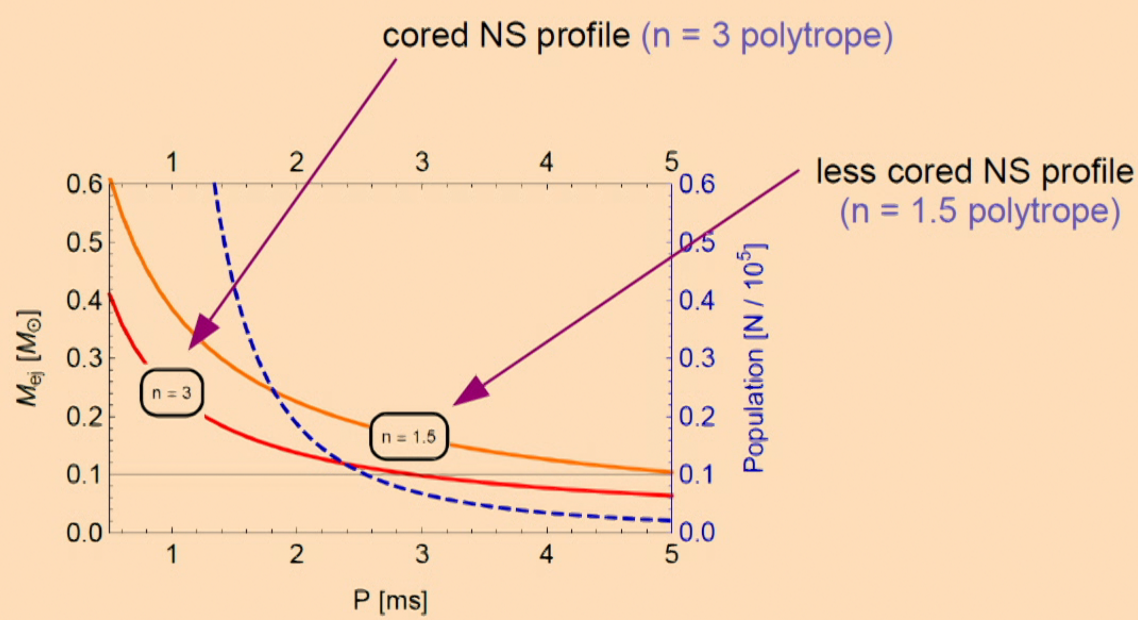

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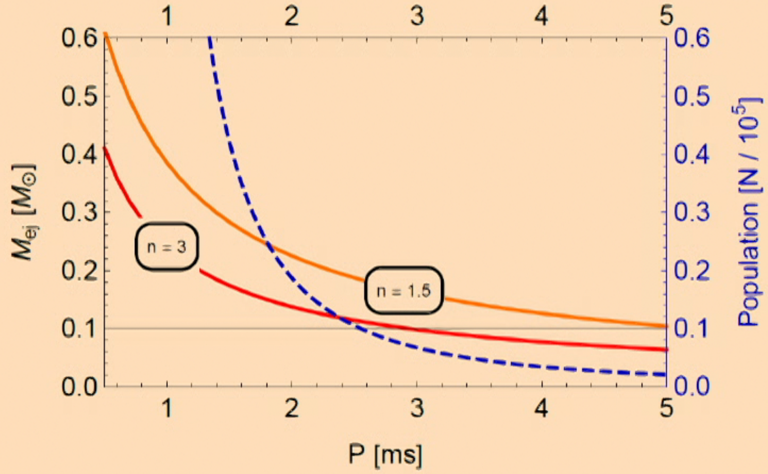

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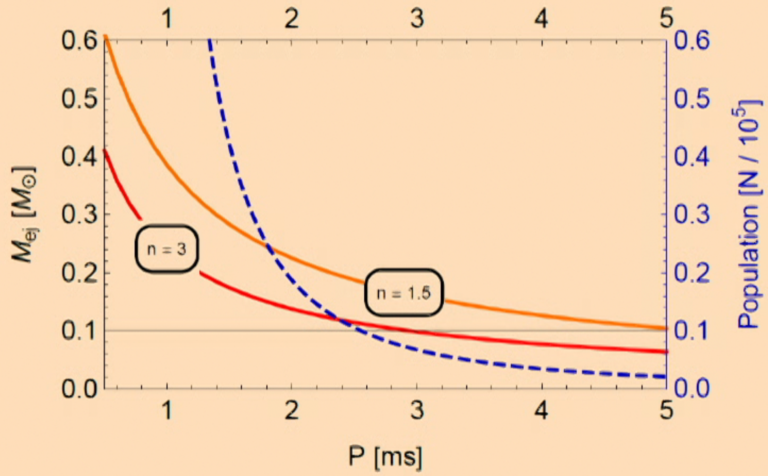

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- Ejecta neutron rich → **a site of r-process nuclesynthesis?**

R-process

- (R)apid-process nucleosynthesis: [long list (Meyer,Schramm, *others*)]

  - dominant mechanism for heavy element production

  - neutrons capture on seed nuclei faster than β-decay → build up heavy elements

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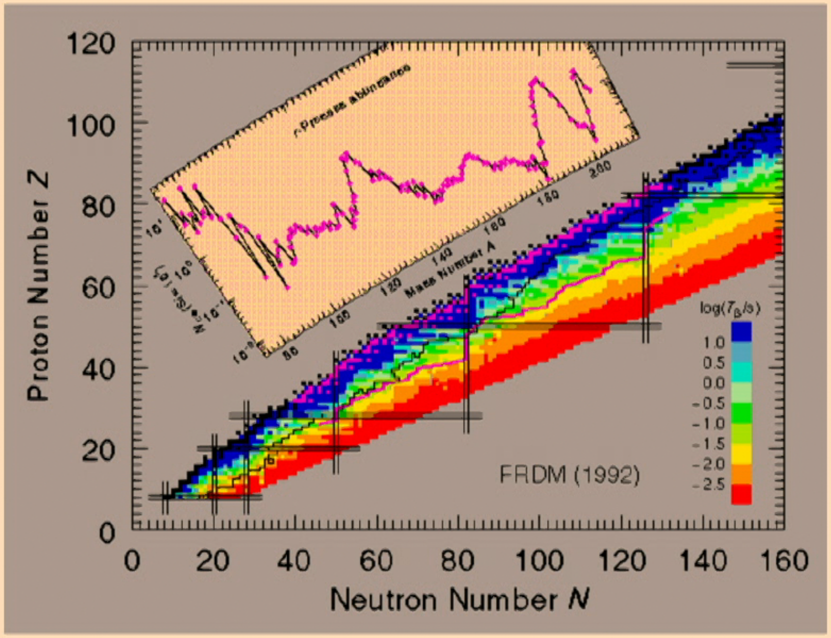

Image: Los Alamos, Nuclear Data Group

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

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can explain both simultaneously with PBH-NS

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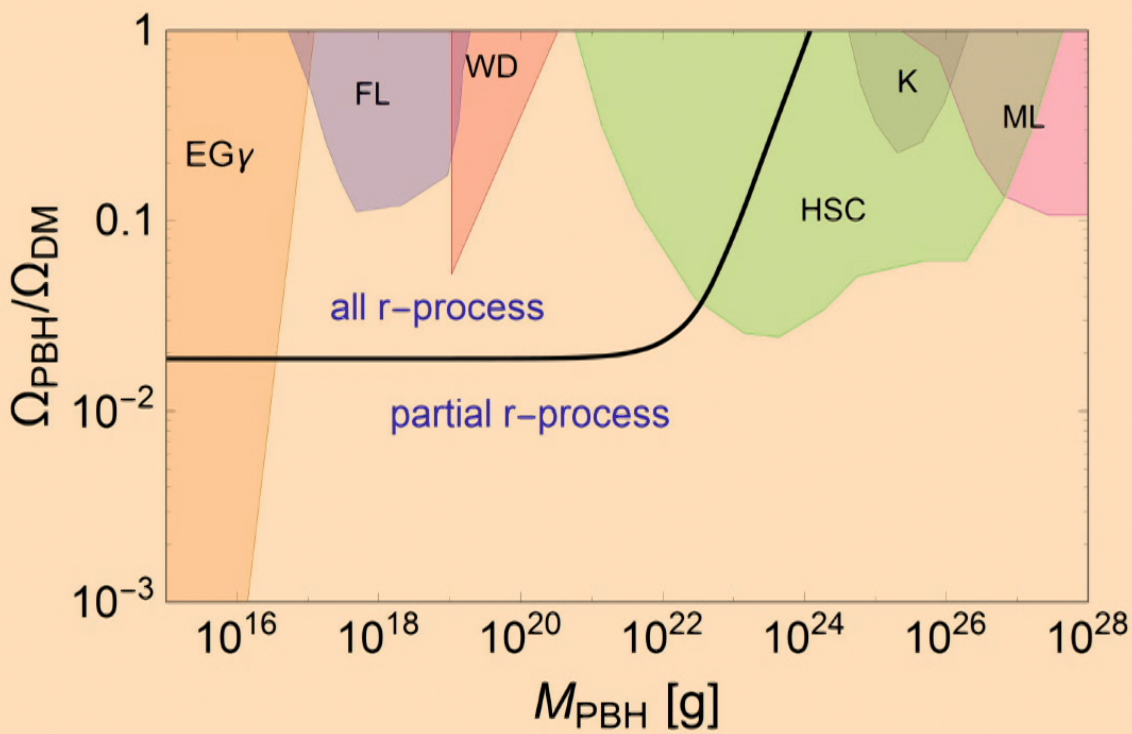

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Fast Radio Bursts (FRB)

- 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]

Solar-mass BHs: in astrophysics

- Smallest astrophysical black holes

observed: $\sim 5 - 10 M_{\odot}$ [Shaposhnikov,Titarchuk,09]

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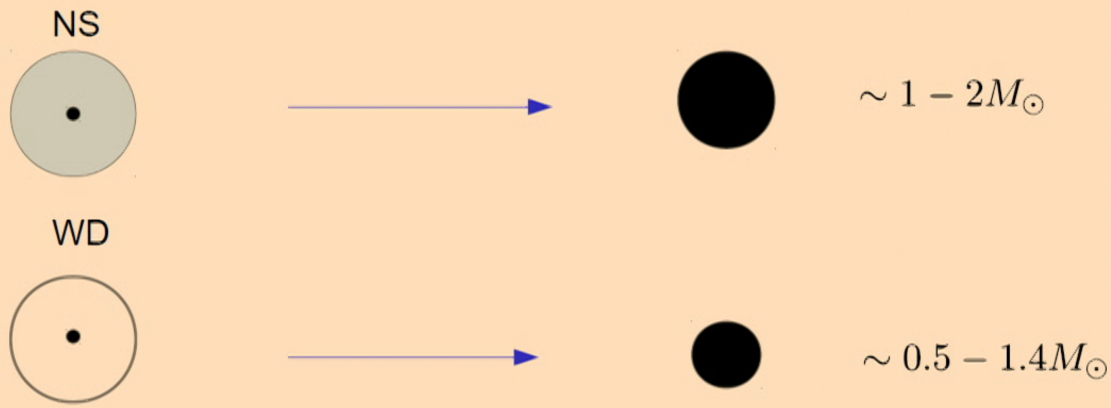

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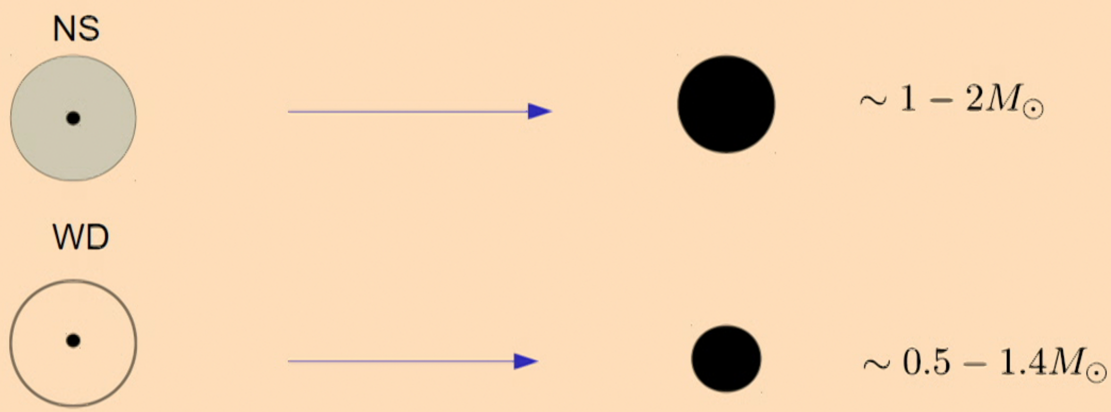

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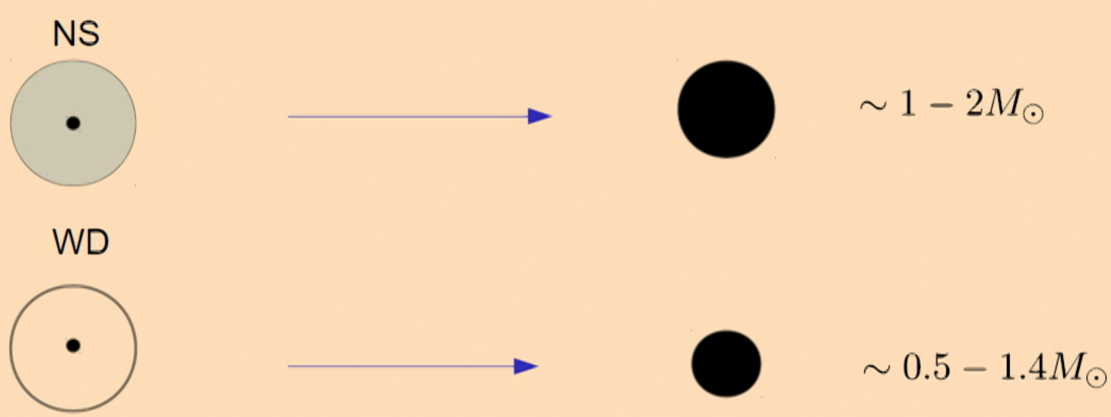

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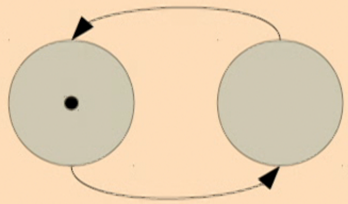
How to detect such BHs? $\rightarrow$ GW signal from binary mergers

Transmuted Binaries

NS-NS



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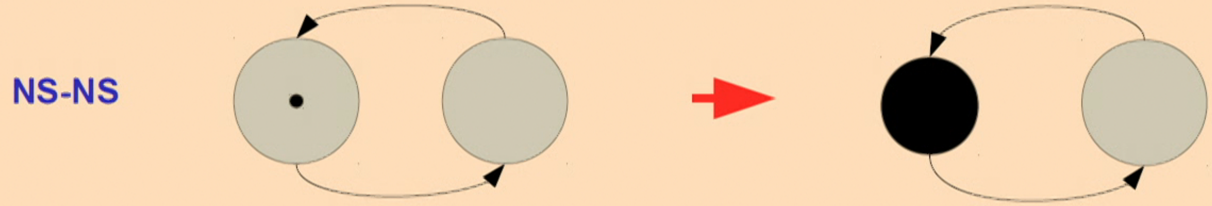

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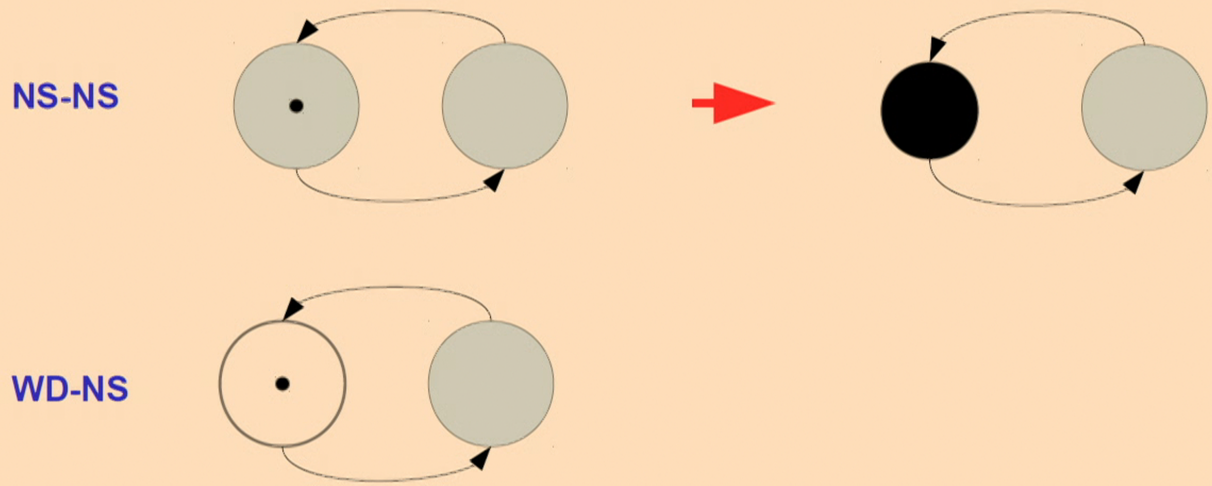

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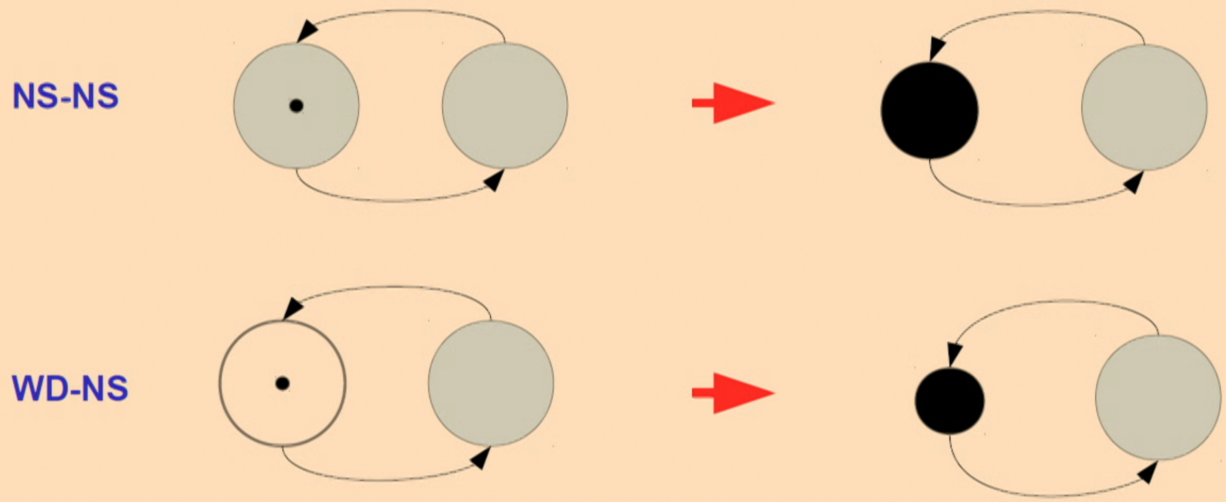

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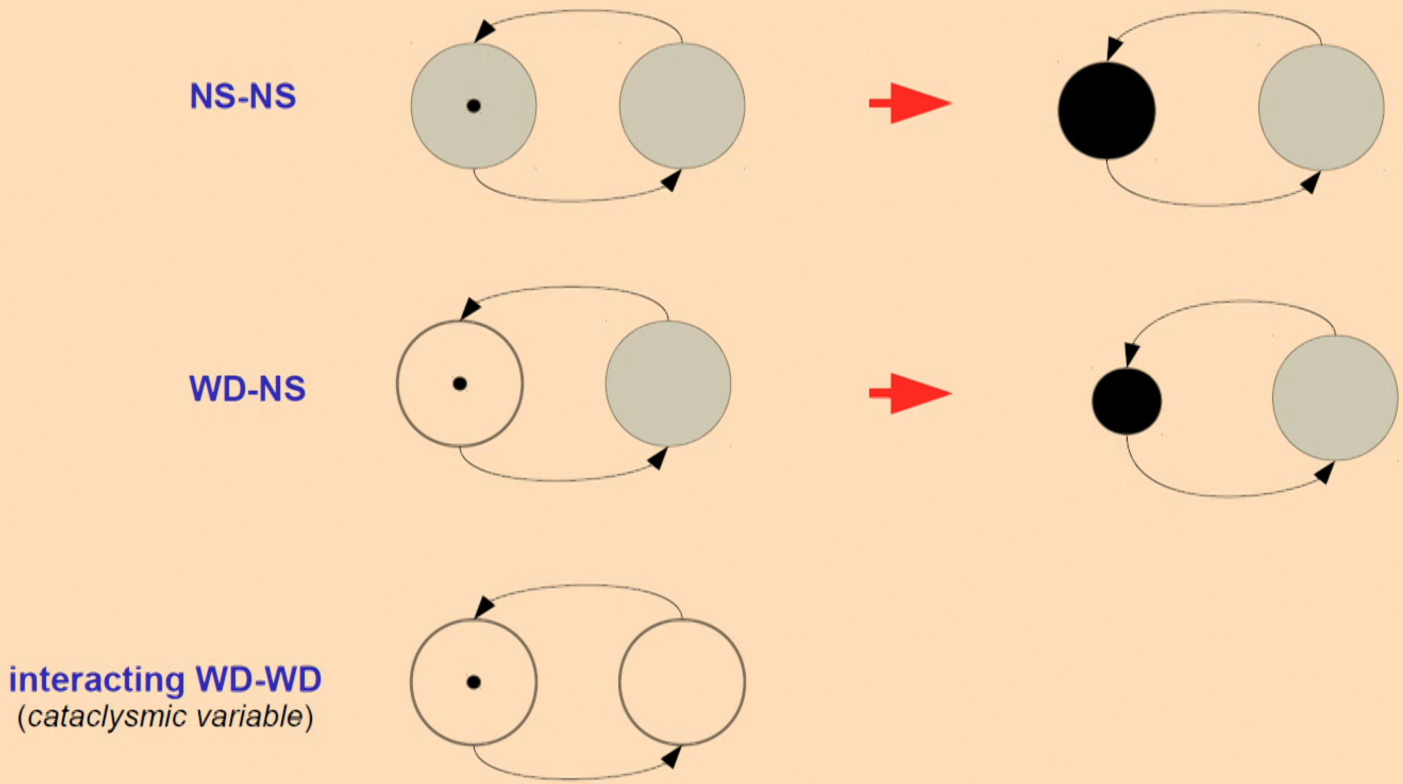
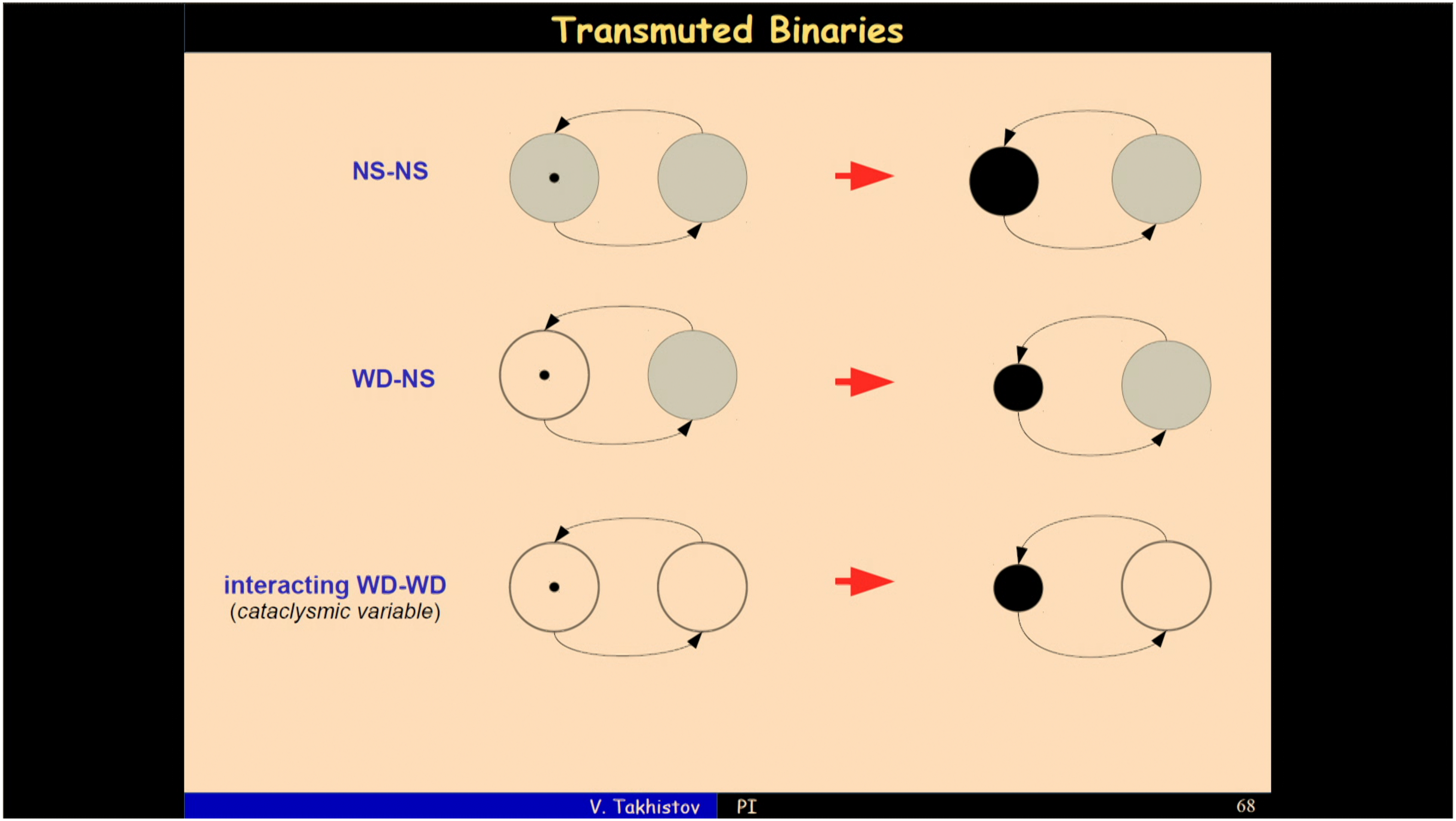
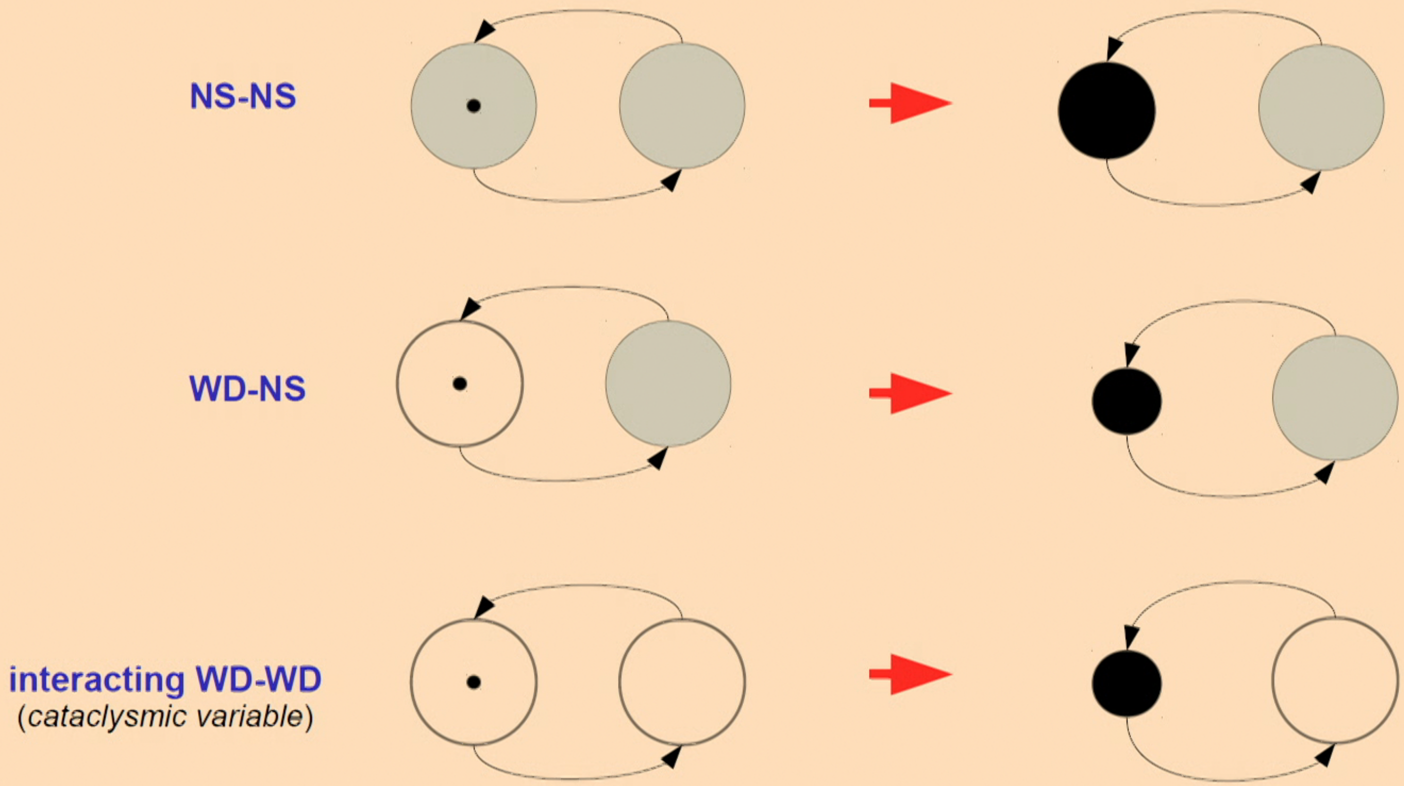
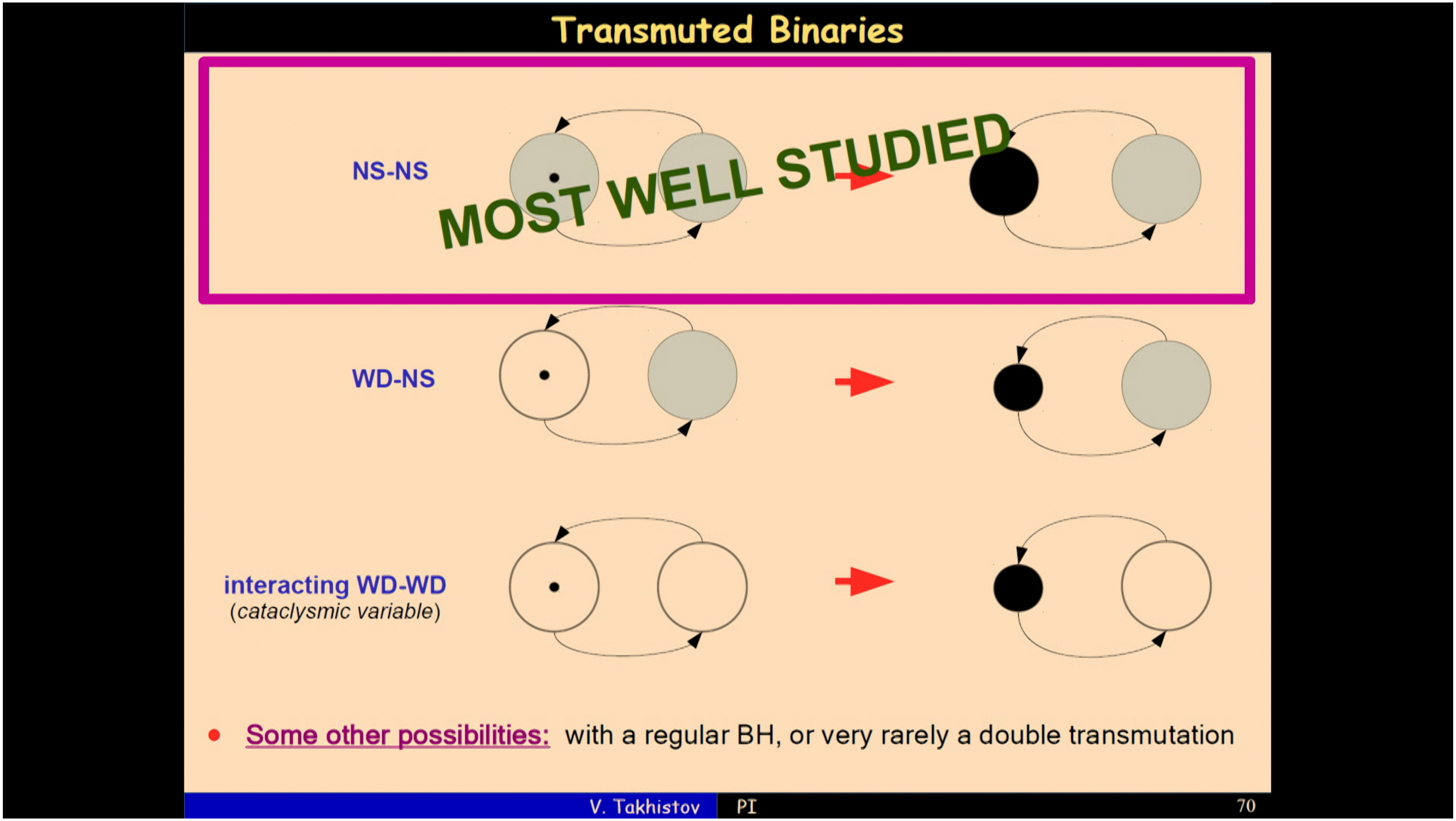



Transmuted Binaries
NS-NS
WD-NS
interacting WD-WD
(cataclysmic variable)
V. Takhistov
PI
68

Transmuted Binaries



- <u>Some other possibilities:</u> with a regular BH, or very rarely a double transmutation


Transmuted Binaries
NS-NS
MOST WELL STUDIED
WD-NS
interacting WD-WD
(cataclysmic variable)
Some other possibilities: with a regular BH, or very rarely a double transmutation
V. Takhistov
PI
70

Compact Object Mergers

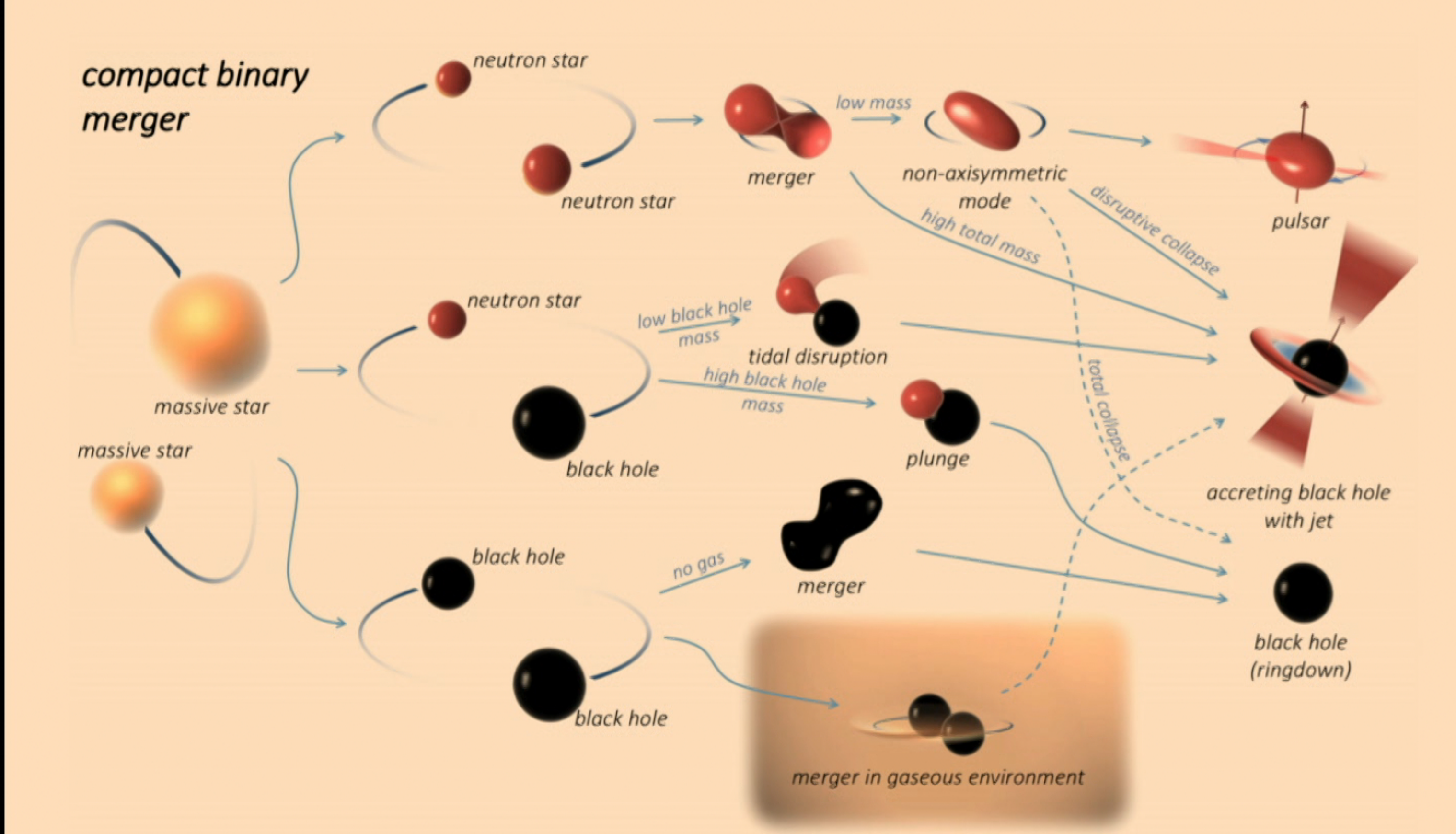


Image: Bartos, Kowalski, "Multimessenger Astronomy"

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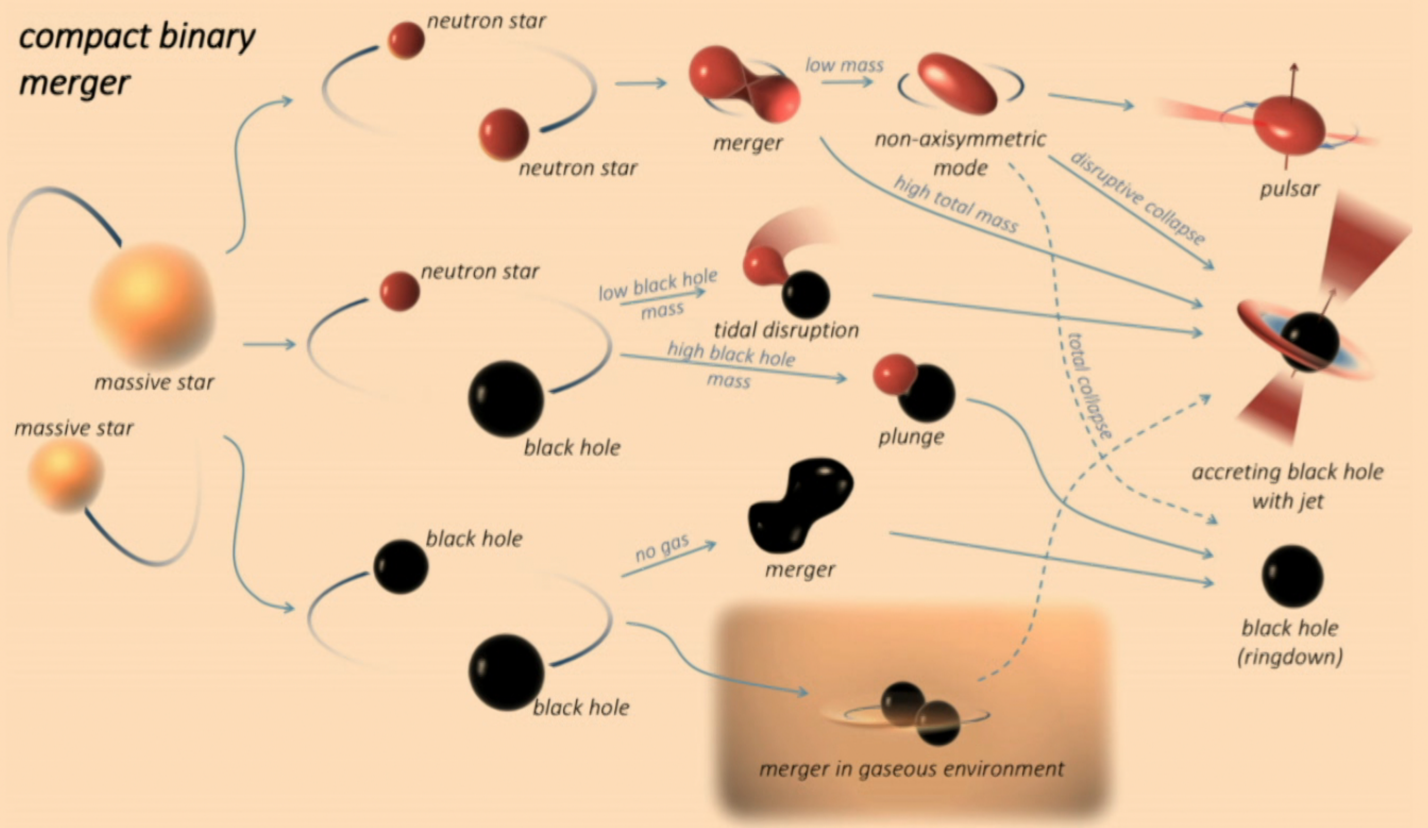

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Binary GW Signals

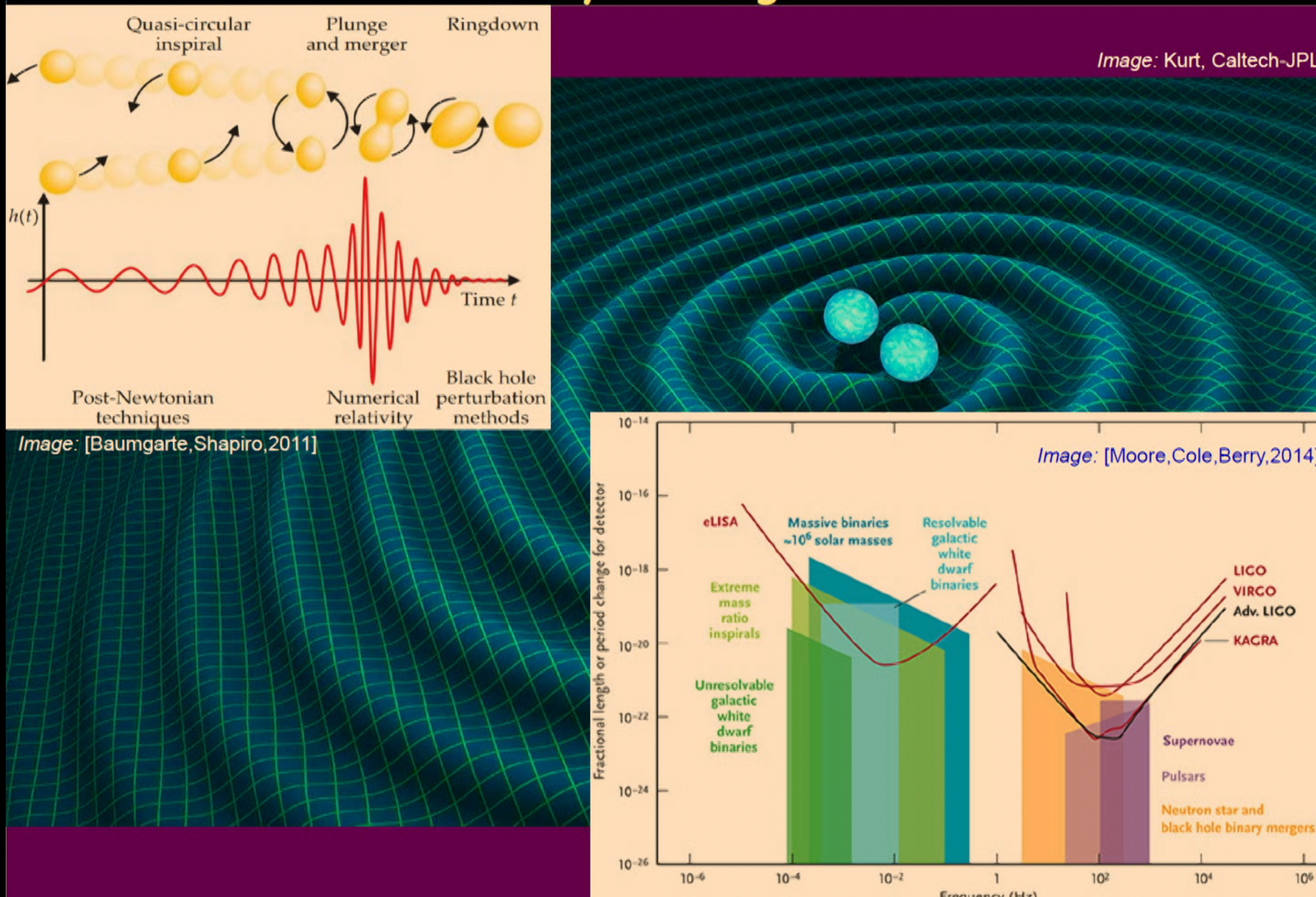

Image: [Baumgarte,Shapiro,2011]

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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- 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) $\rightarrow$ detectable by LIGO
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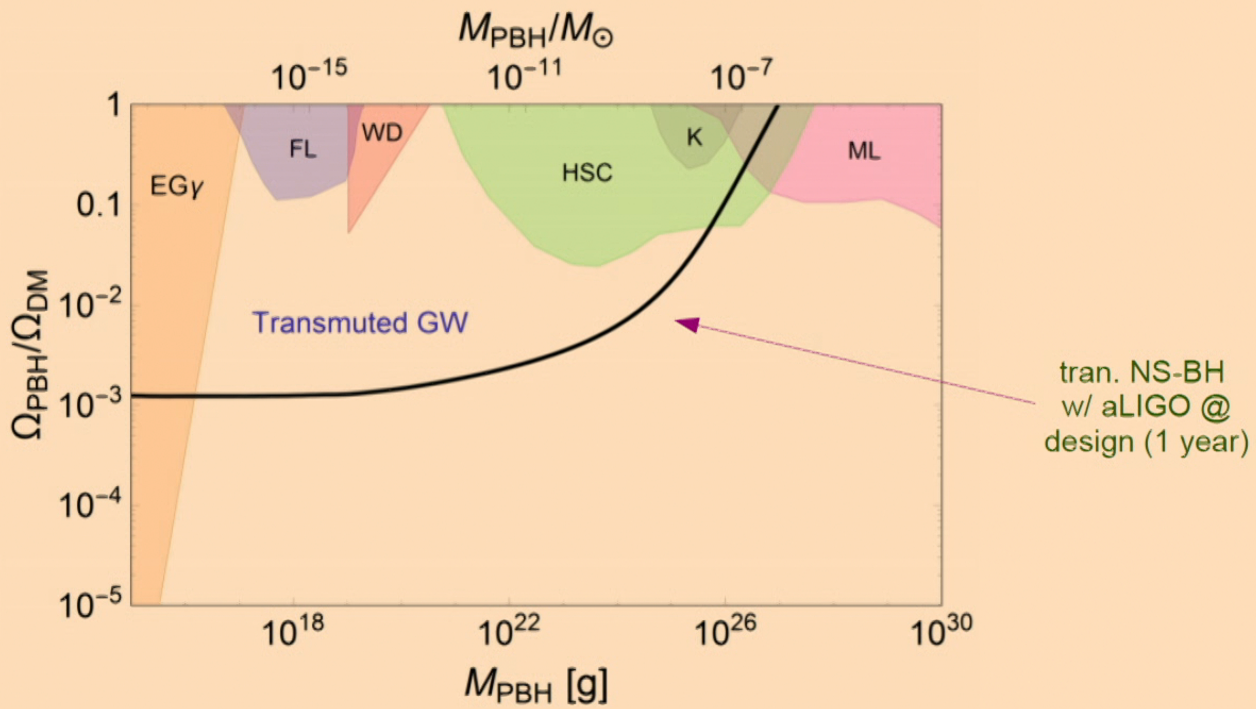

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lower BH mass $M_{\rm BH} \sim 1 - 5 M_{\odot}$ thought to not be very relevant, but actually important to probe !

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→ unique signals in experiments, new lamp-posts

Thank You for Attention!