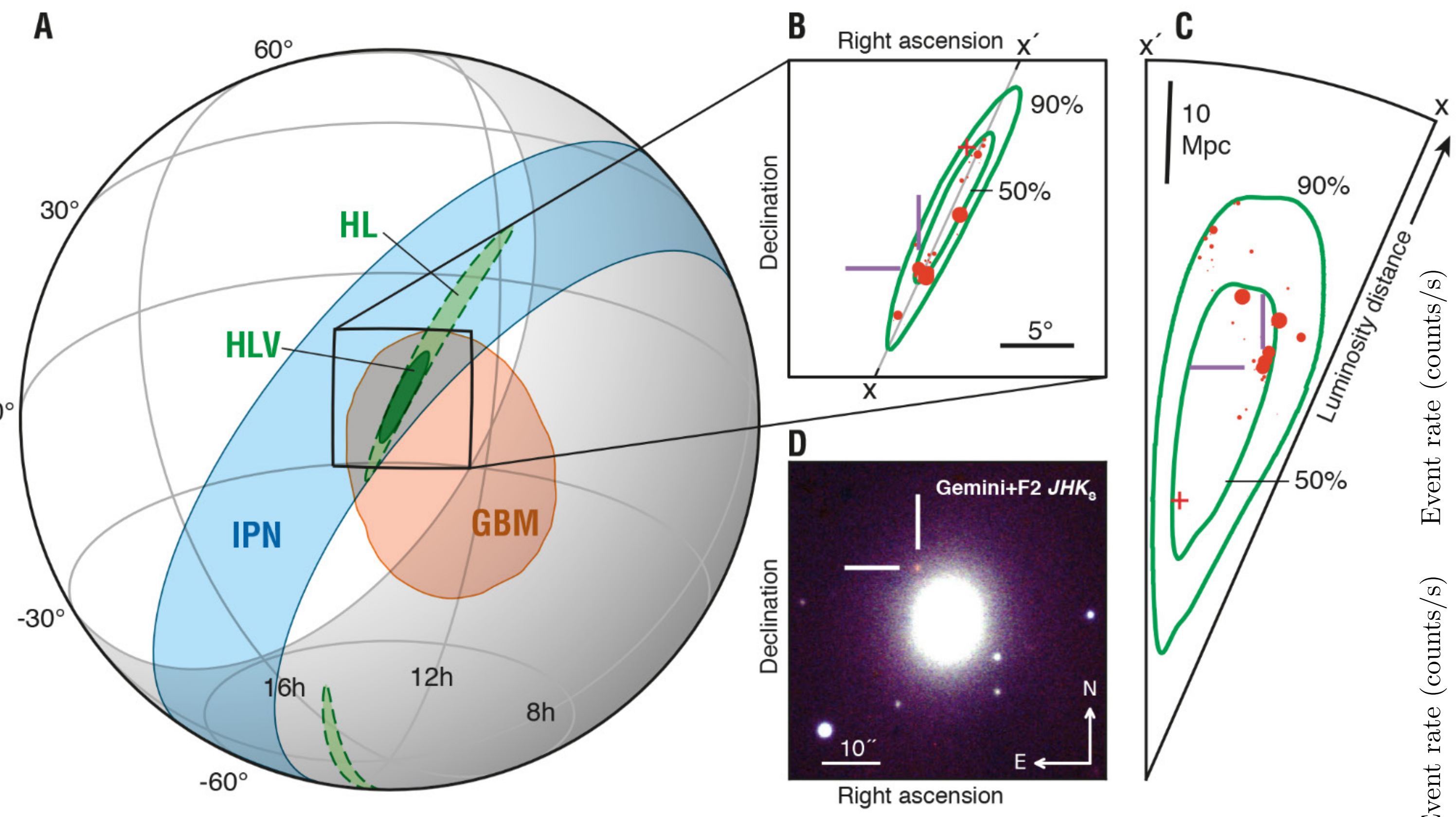
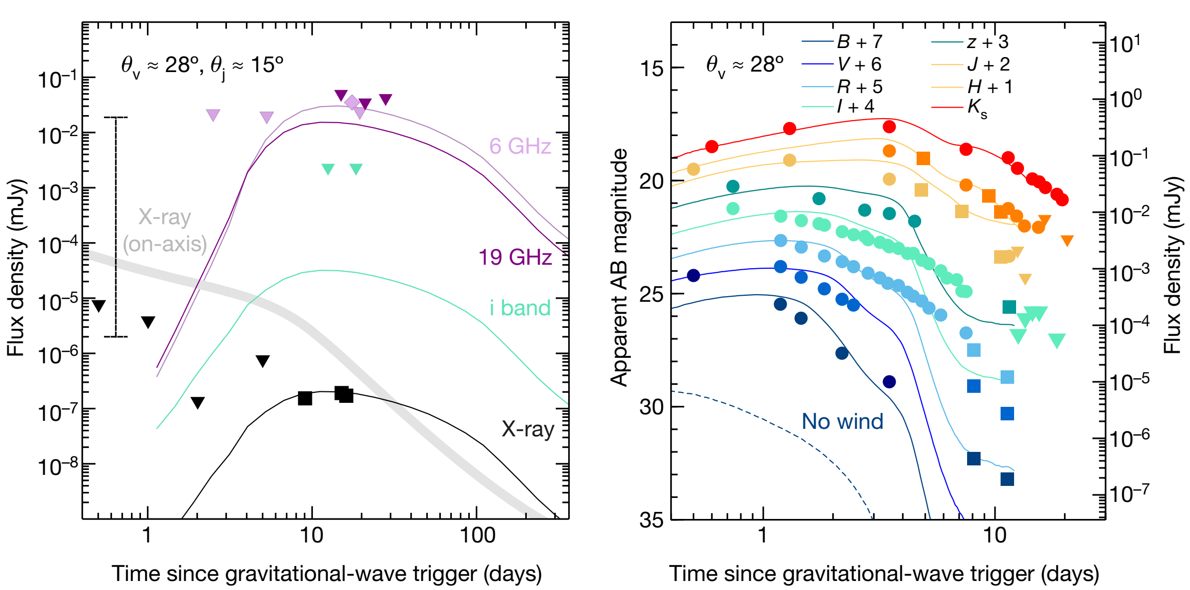
Resonant Shattering Flares:
Multimessenger Probes of Neutron Star Physics

David Tsang
(U. Southampton)

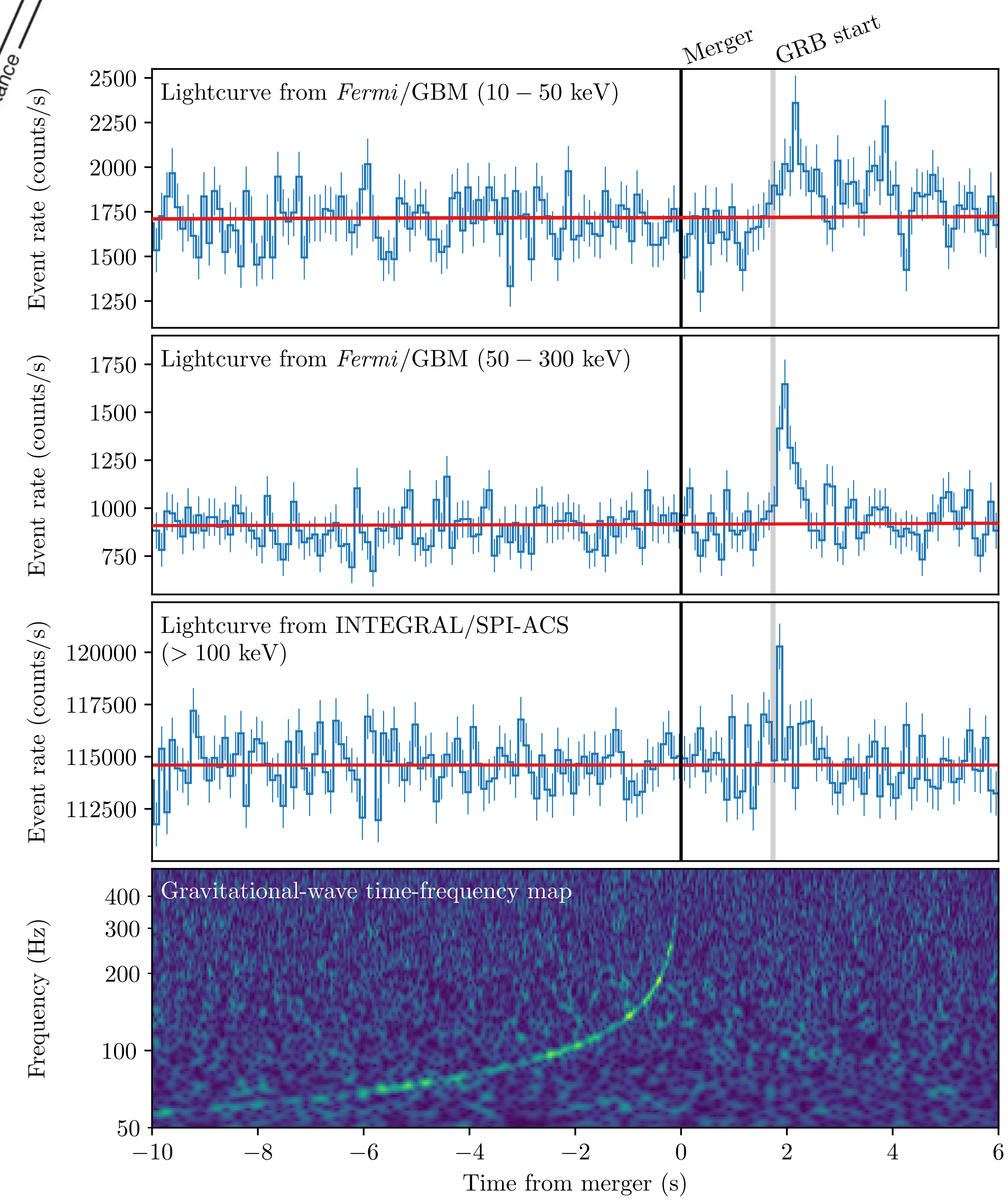
GW/EM170817 - A Golden Binary



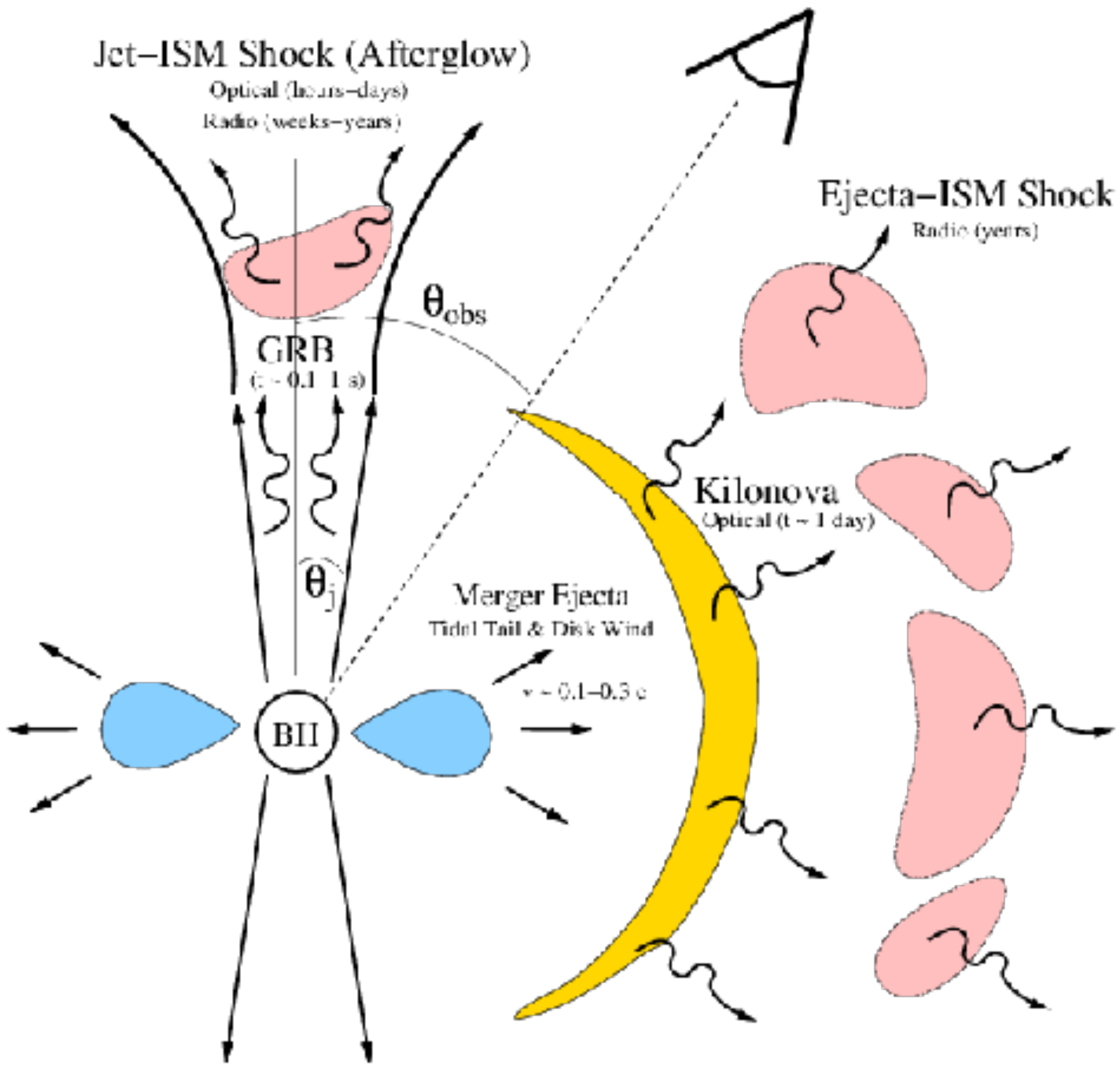
Kasliwal+ 2017



Troja+, 2017



LVC + Fermi, 2017



Metzger & Berger (2011)

- GWs can provide tidal constraints
- But, kNe & SGRBs don’t tell us much about NS structure
- Only (messy) post merger physics
  - r-process
  - M_{ejecta}

Mad Max: Fury Road (2015)

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RSFs are bright, isotropic EM counterparts that can provide detailed asteroseismic constraints on NS physics

Tidal Resonance

- Tidal Resonance can transfer huge amounts of energy from orbit to modes
- Need a mode that:
  - strains the crust
  - couples to the tidal field ($l=2$, spheroidal)
  - hits a resonance well before merger ($f < 1$ kHz)

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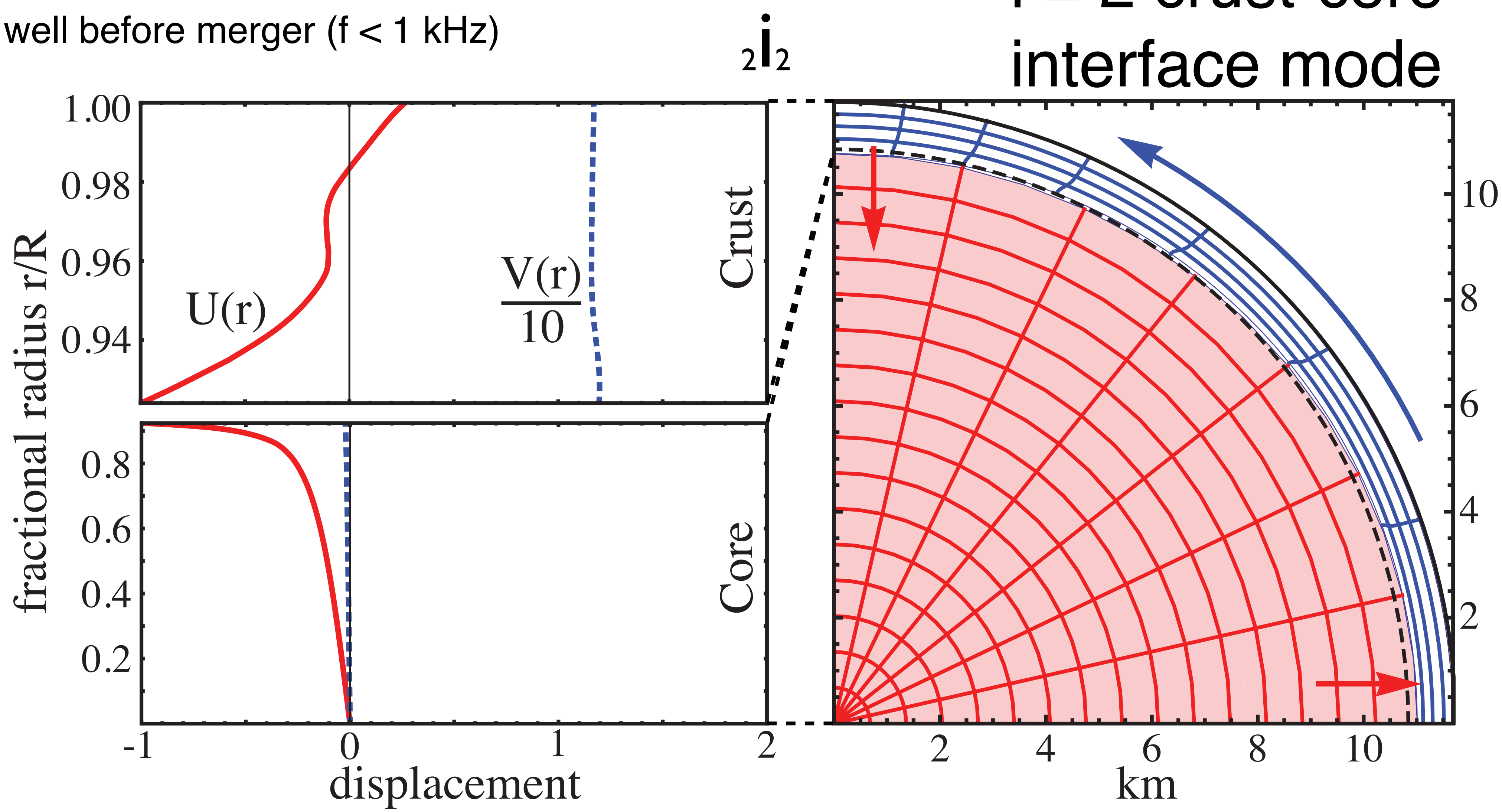
l = 2 crust-core interface mode



DT+, PRL, 108, 011102 (2012)

T-Mobile 11:21 am 83%

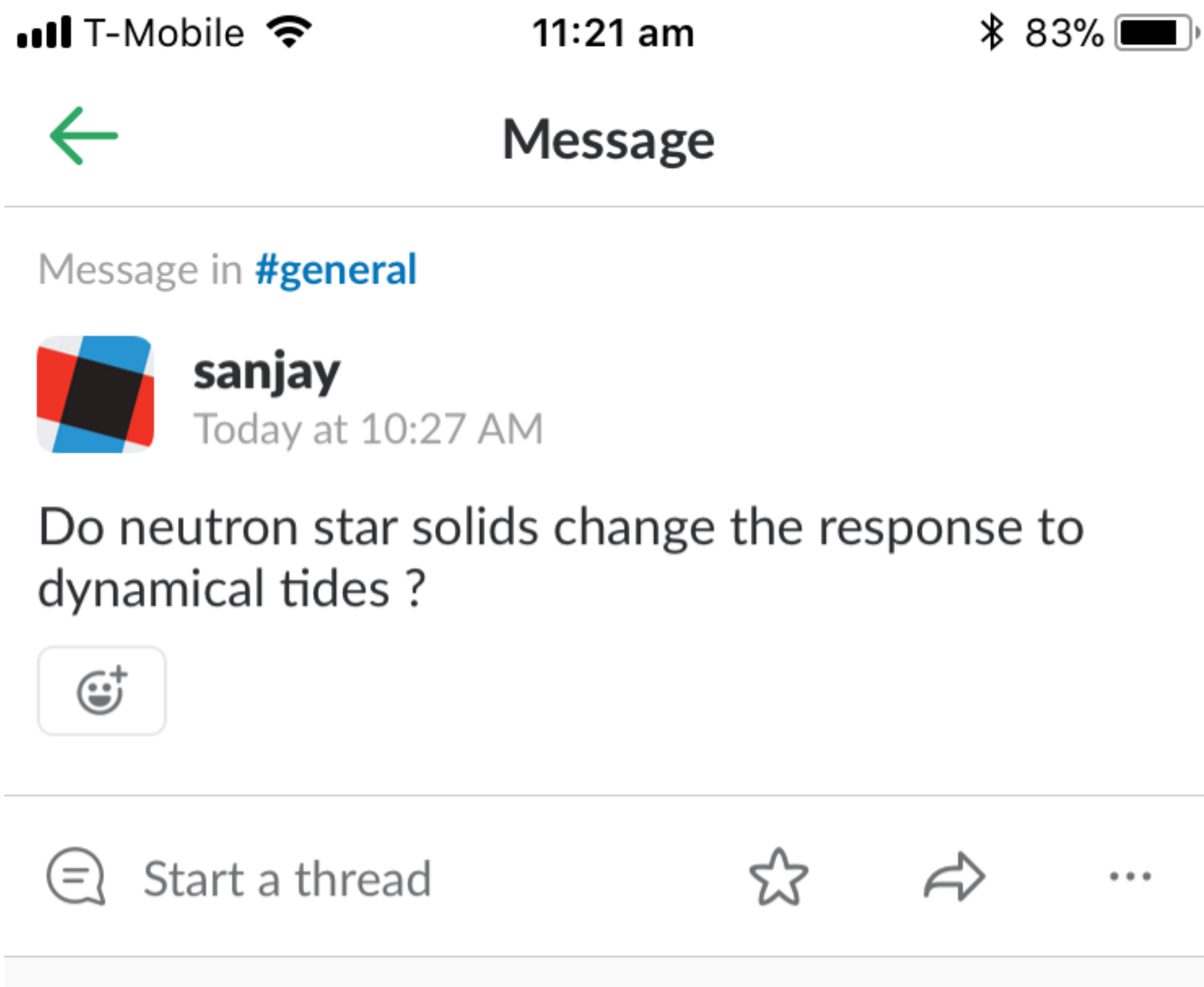
Message

Message in #general

sanjay
Today at 10:27 AM

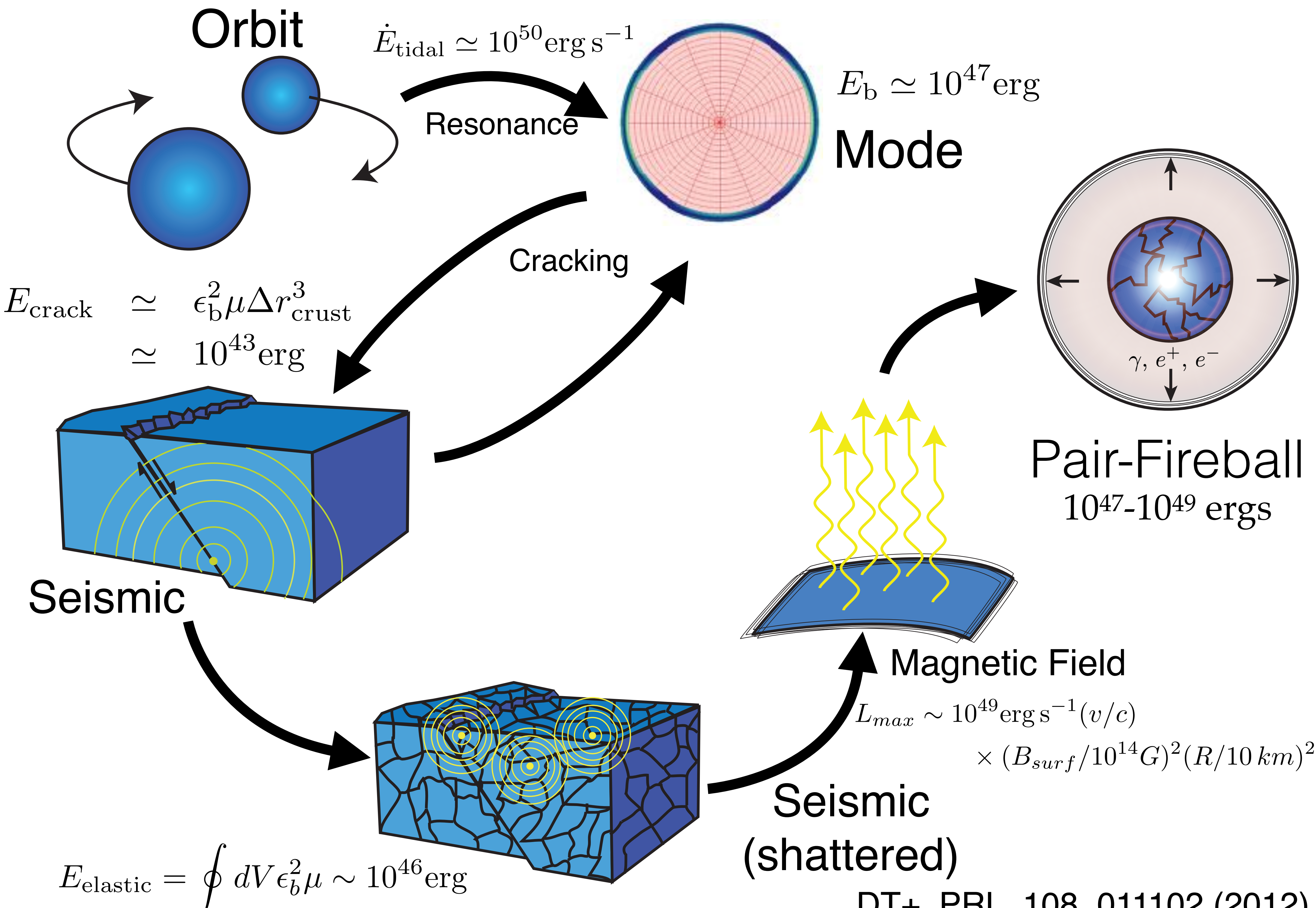
Do neutron star solids change the response to dynamical tides ?

Start a thread



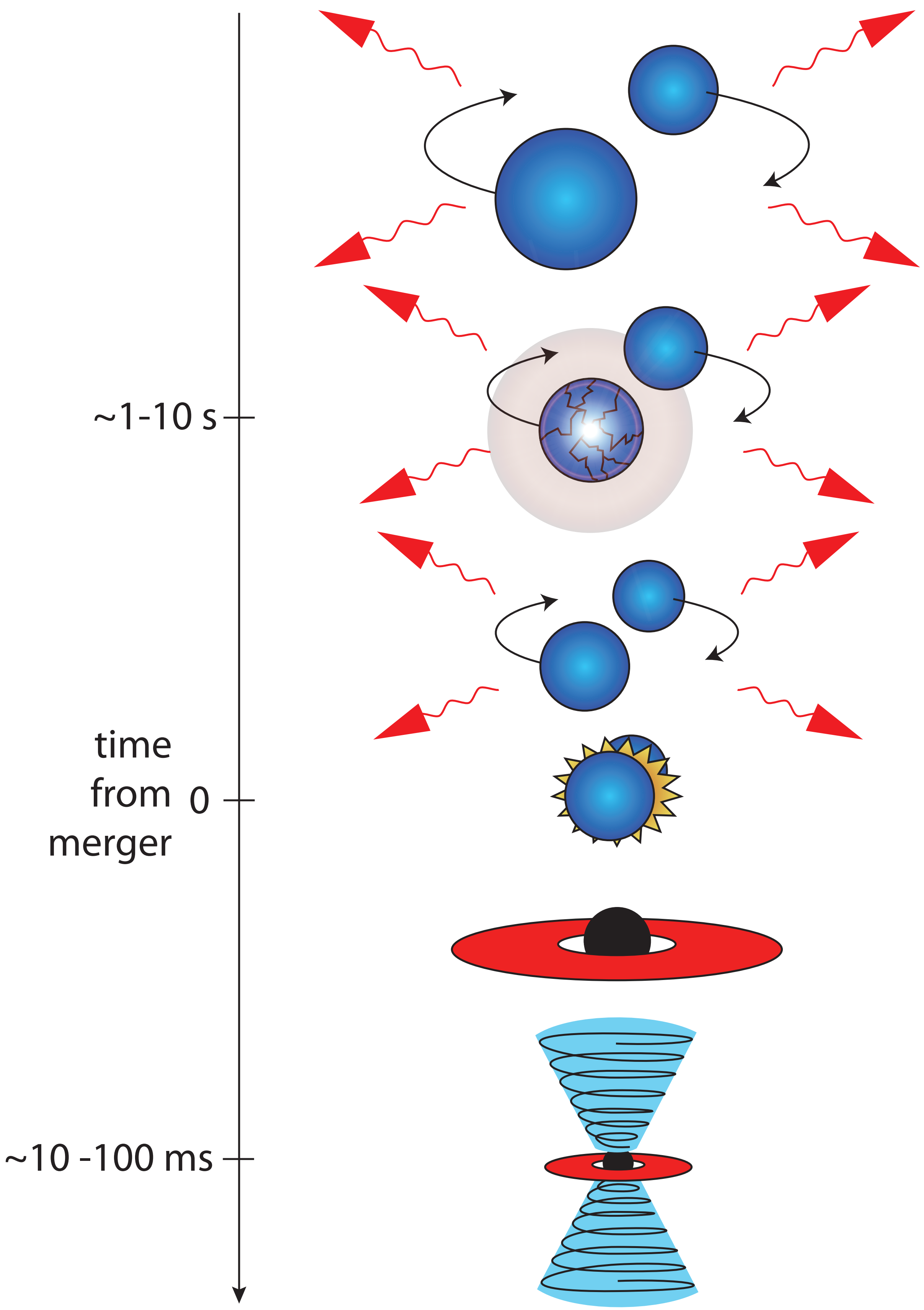
The i-mode exists because of the solid-fluid transition.
The frequency depends on the core-crust transition radius and shear speed…

Resonant Shattering Flares



DT+, PRL, 108, 011102 (2012)
DT, ApJ, 777, 103 (2013)

Resonant Shattering Flares



- $E_{RSF} \sim 10^{47} - 10^{49}$ erg, $\Delta t_{RSF} \sim 0.1$s
- RSF model can be easily **tested with EM/GW coincident timing**
    - Predicts weak GRB-like emission **seconds <u>before</u>** the chirp coalescence

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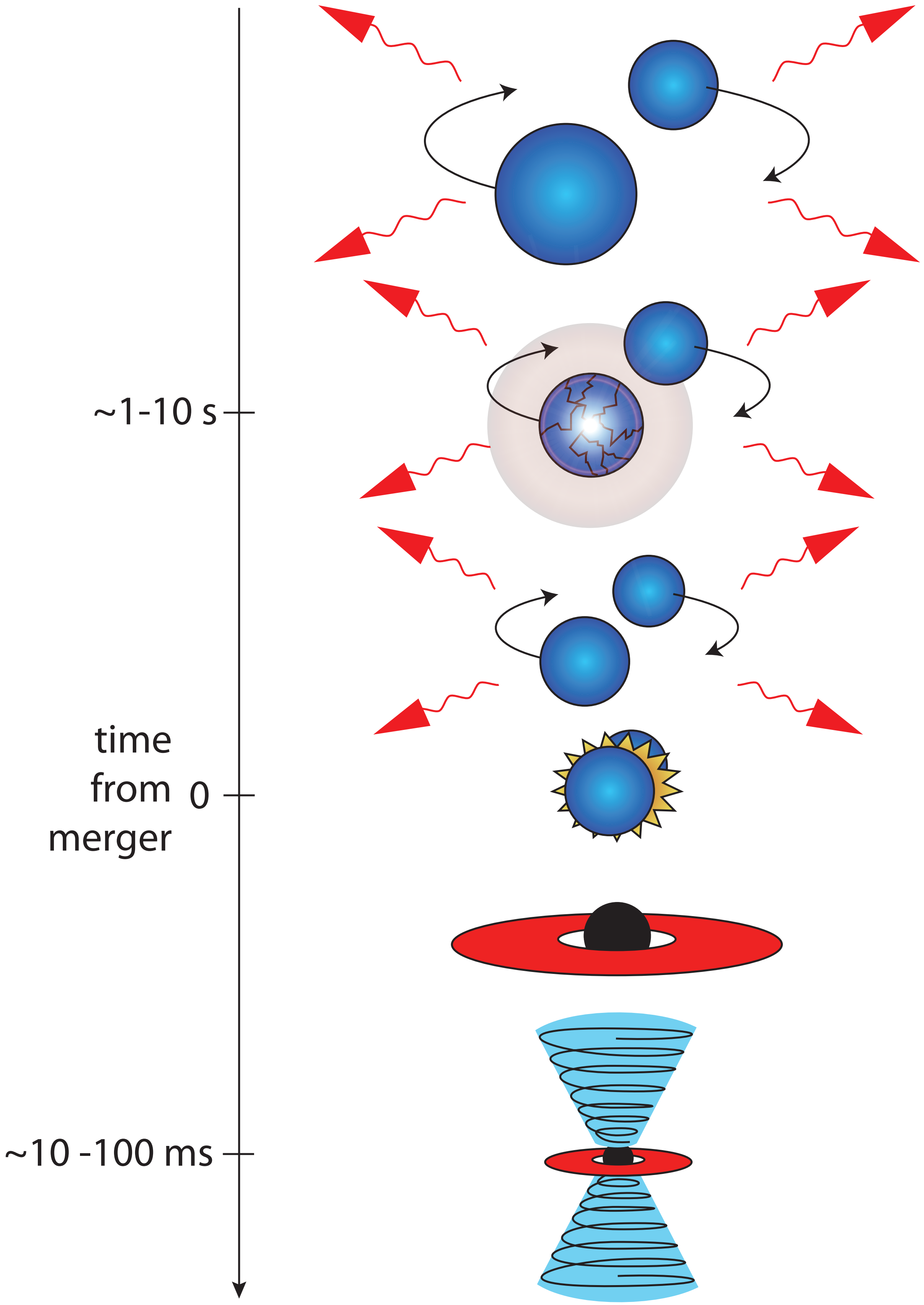

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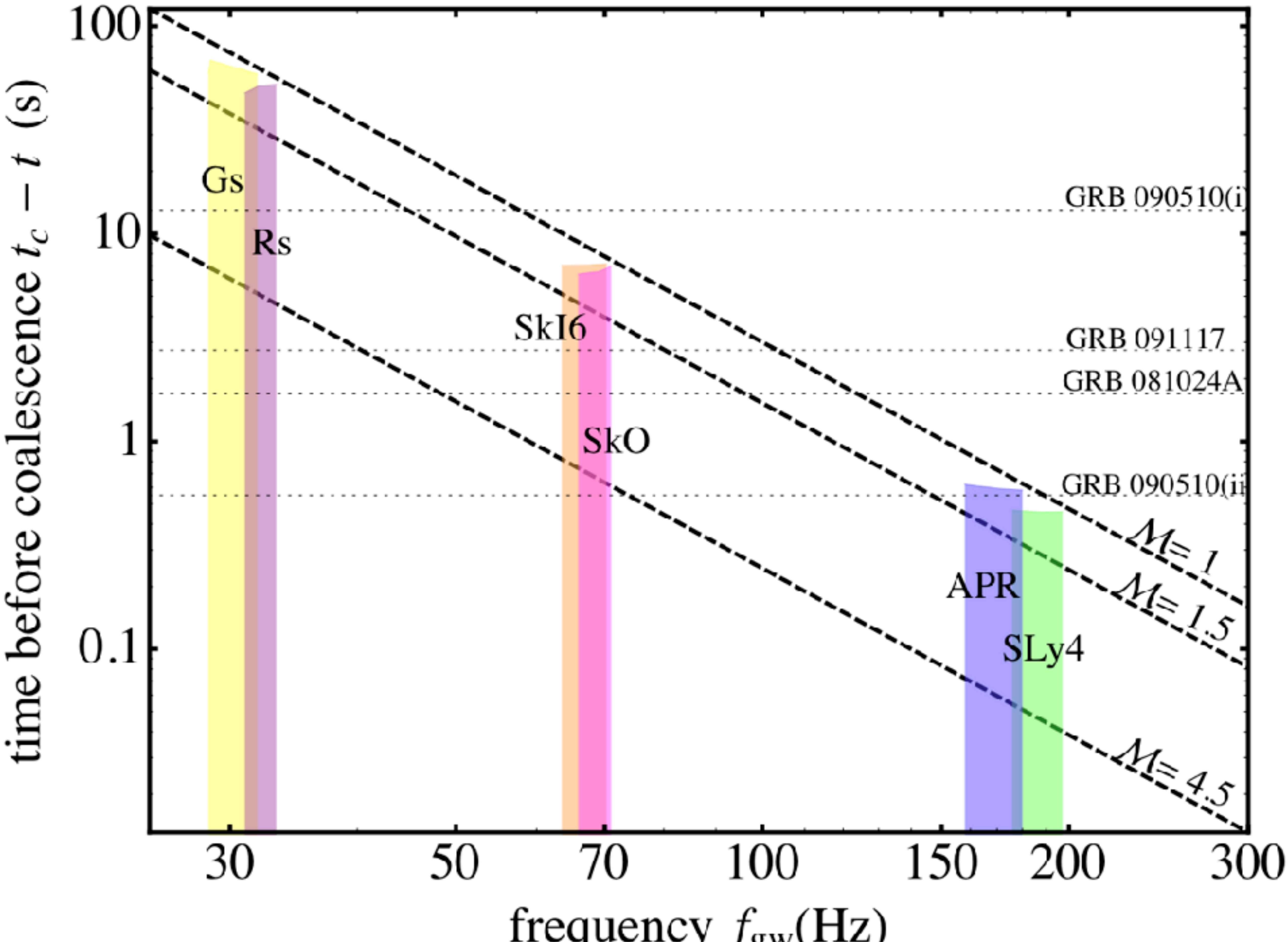
    - The **timing** of the RSF provides **precision asteroseismology** of the NS i-mode



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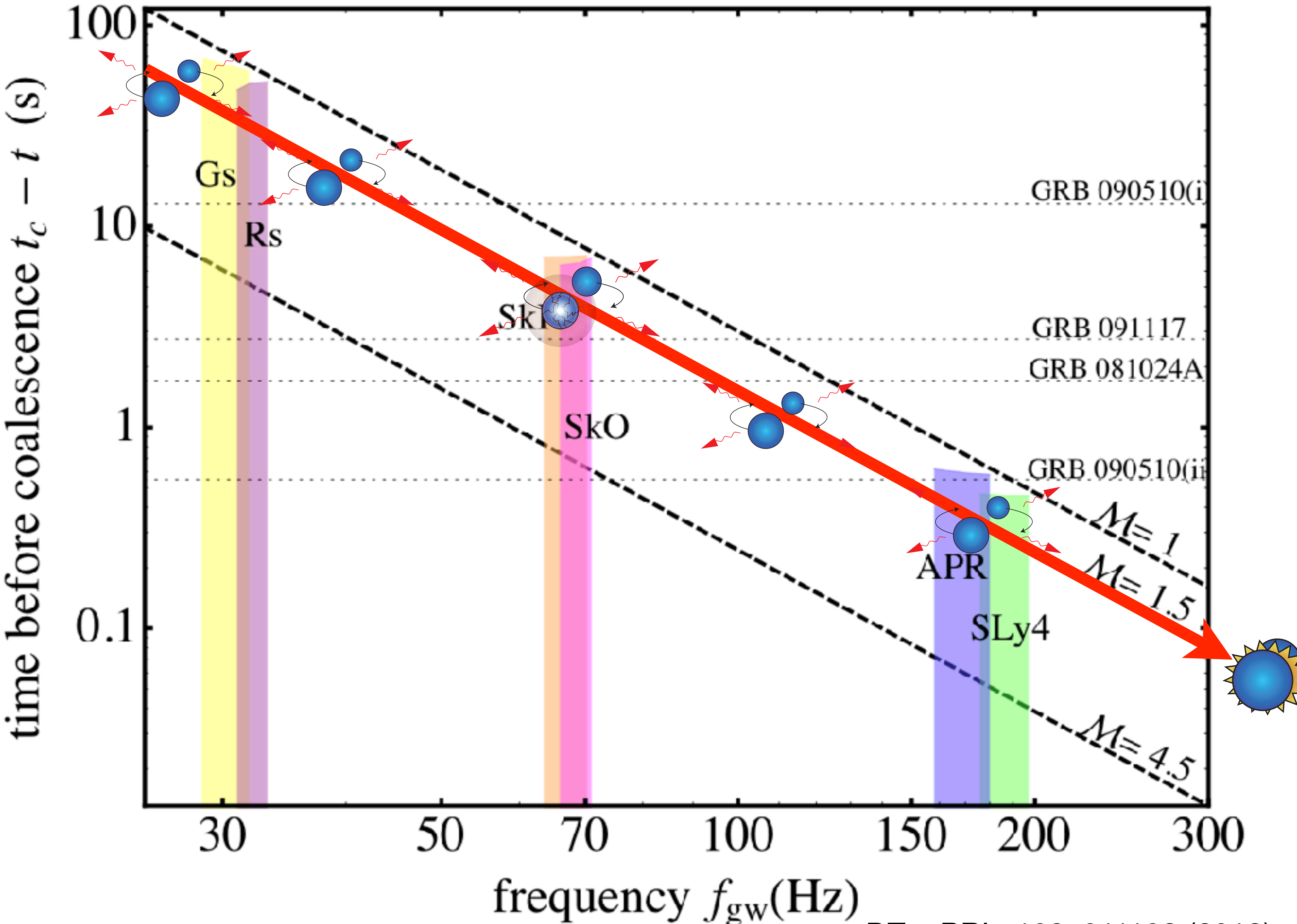

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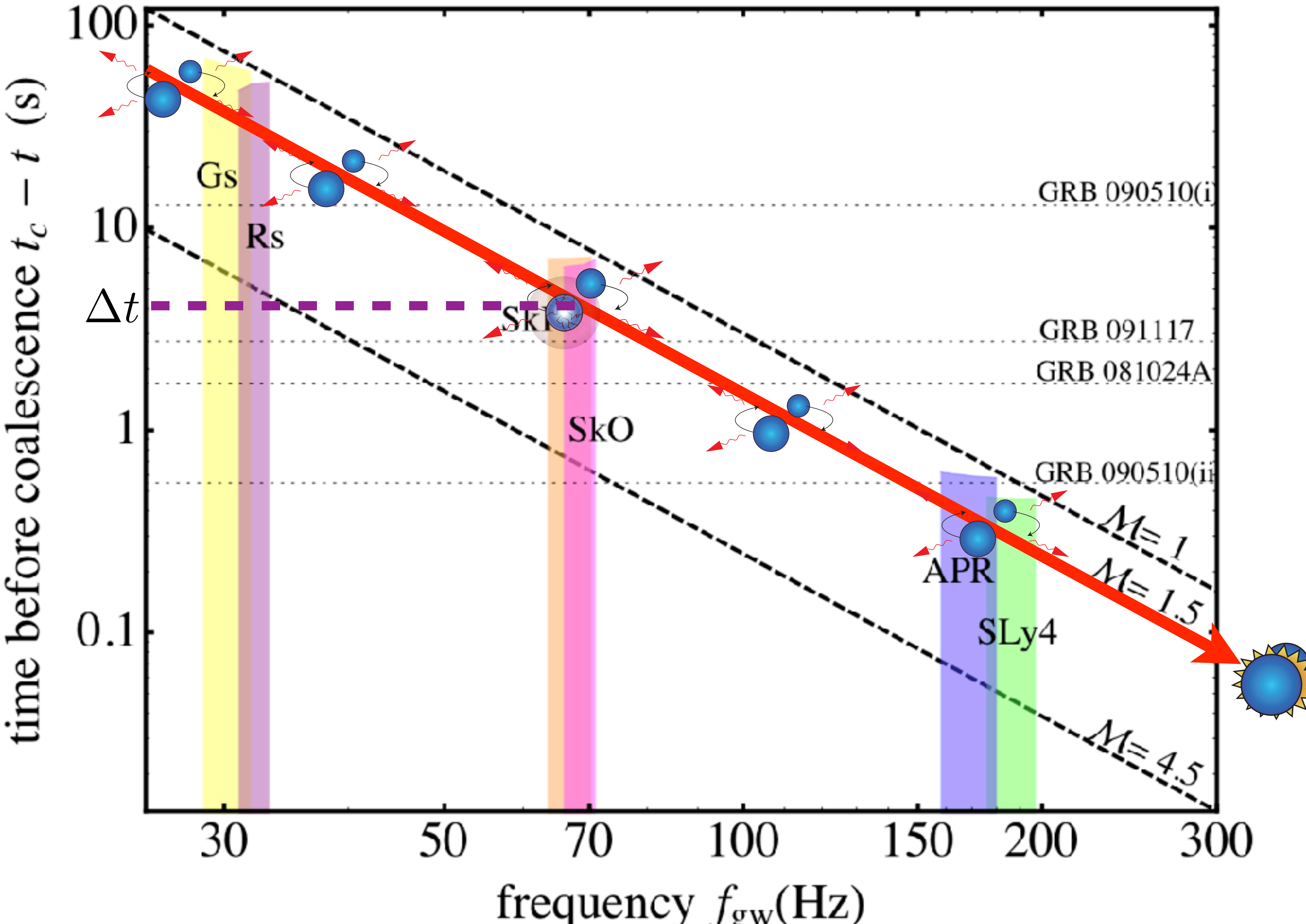

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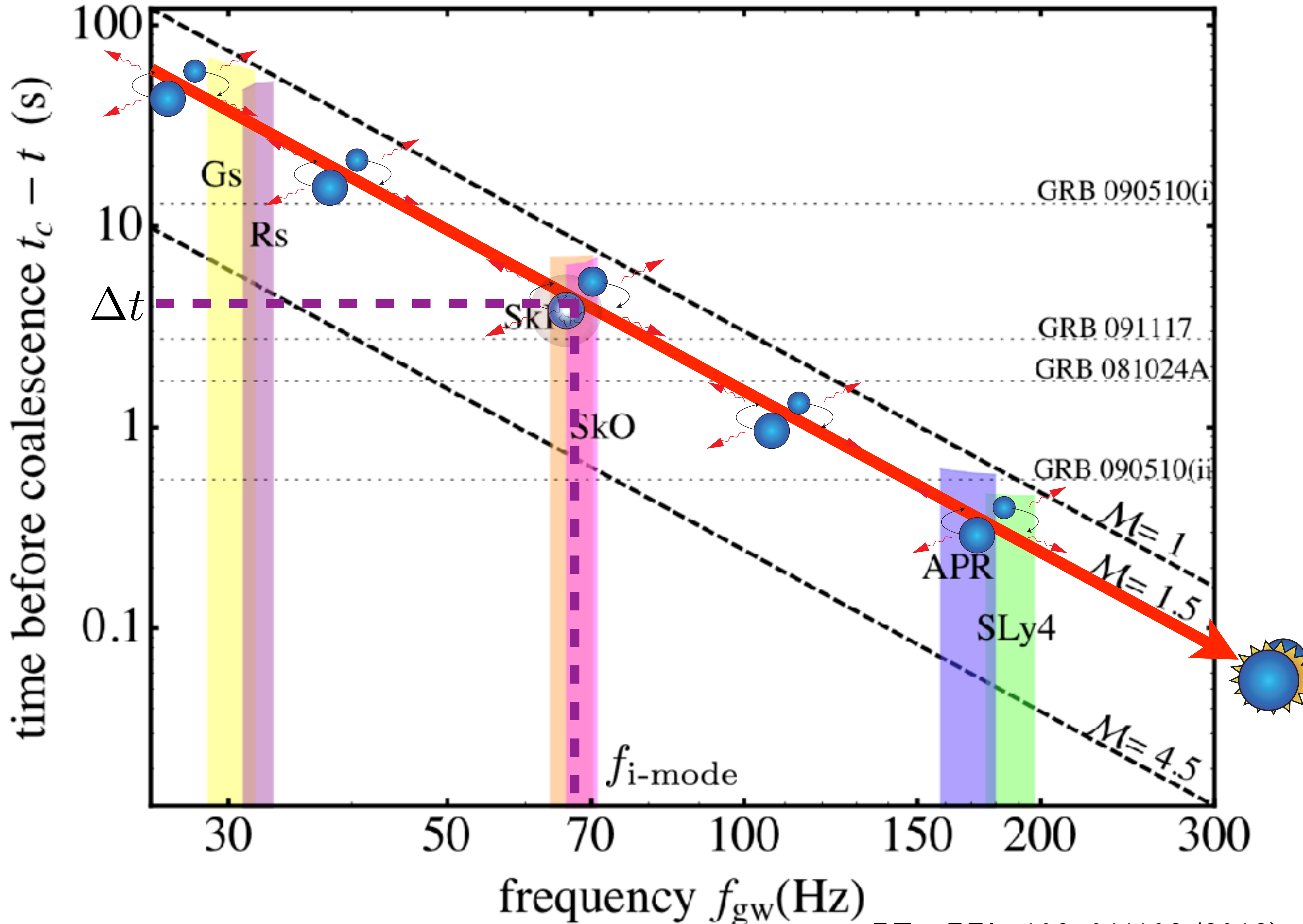

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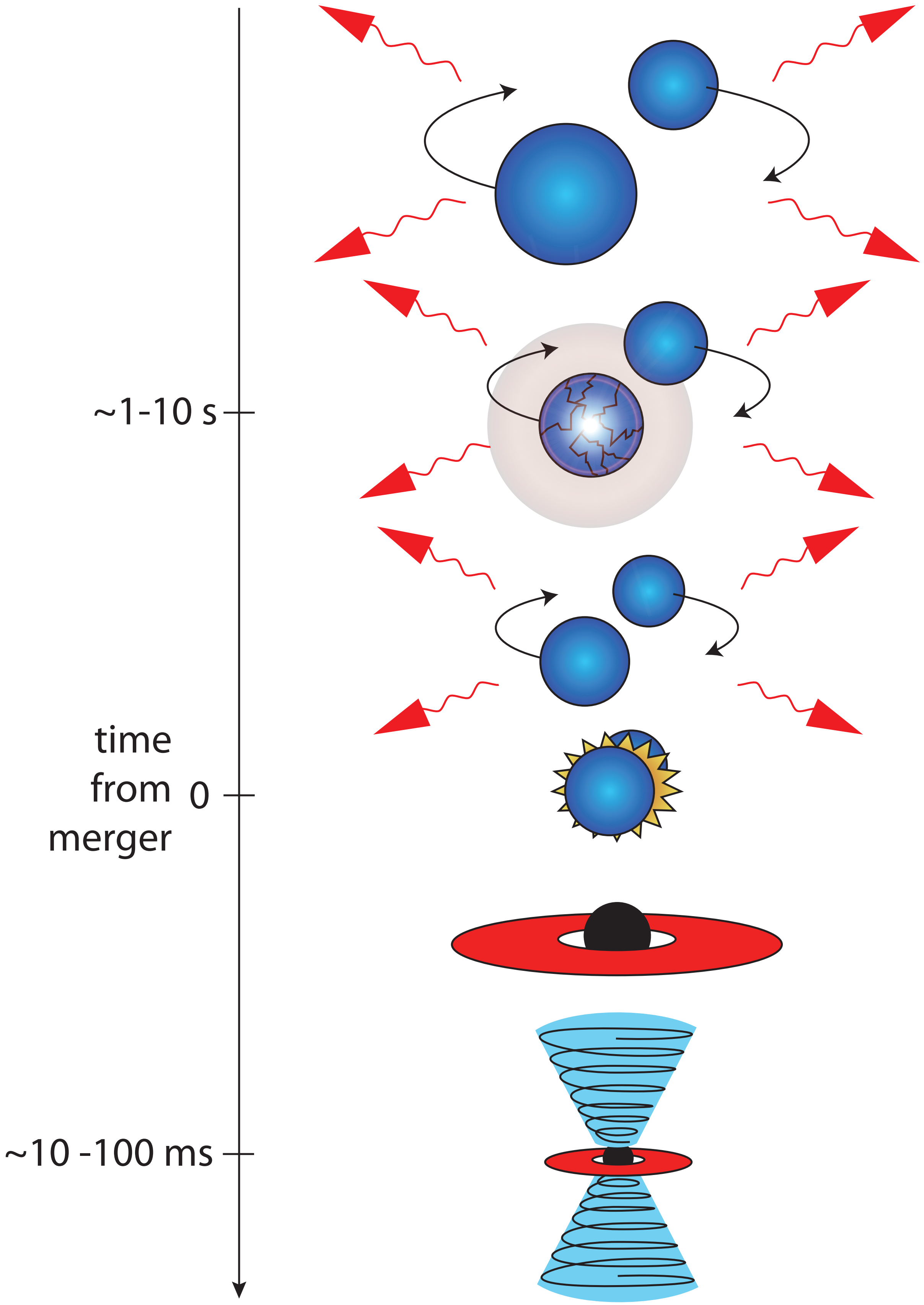

- $E_{RSF} \sim 10^{47} - 10^{49}$ erg, $\Delta t_{RSF} \sim 0.1$s
- RSF model can be easily **tested with EM/GW coincident timing**
  - Predicts weak GRB-like emission **seconds <u>before</u>** the chirp coalescence
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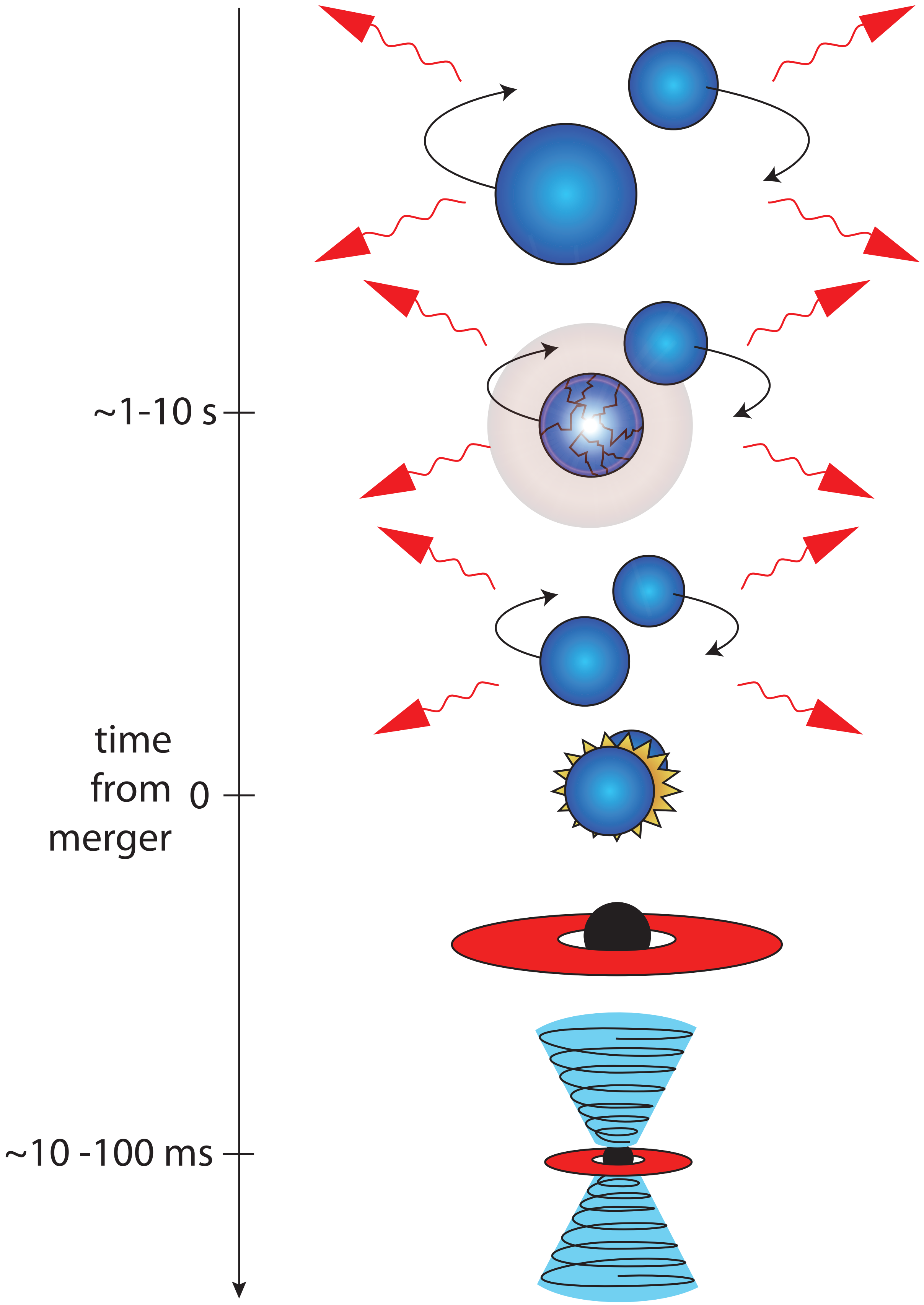
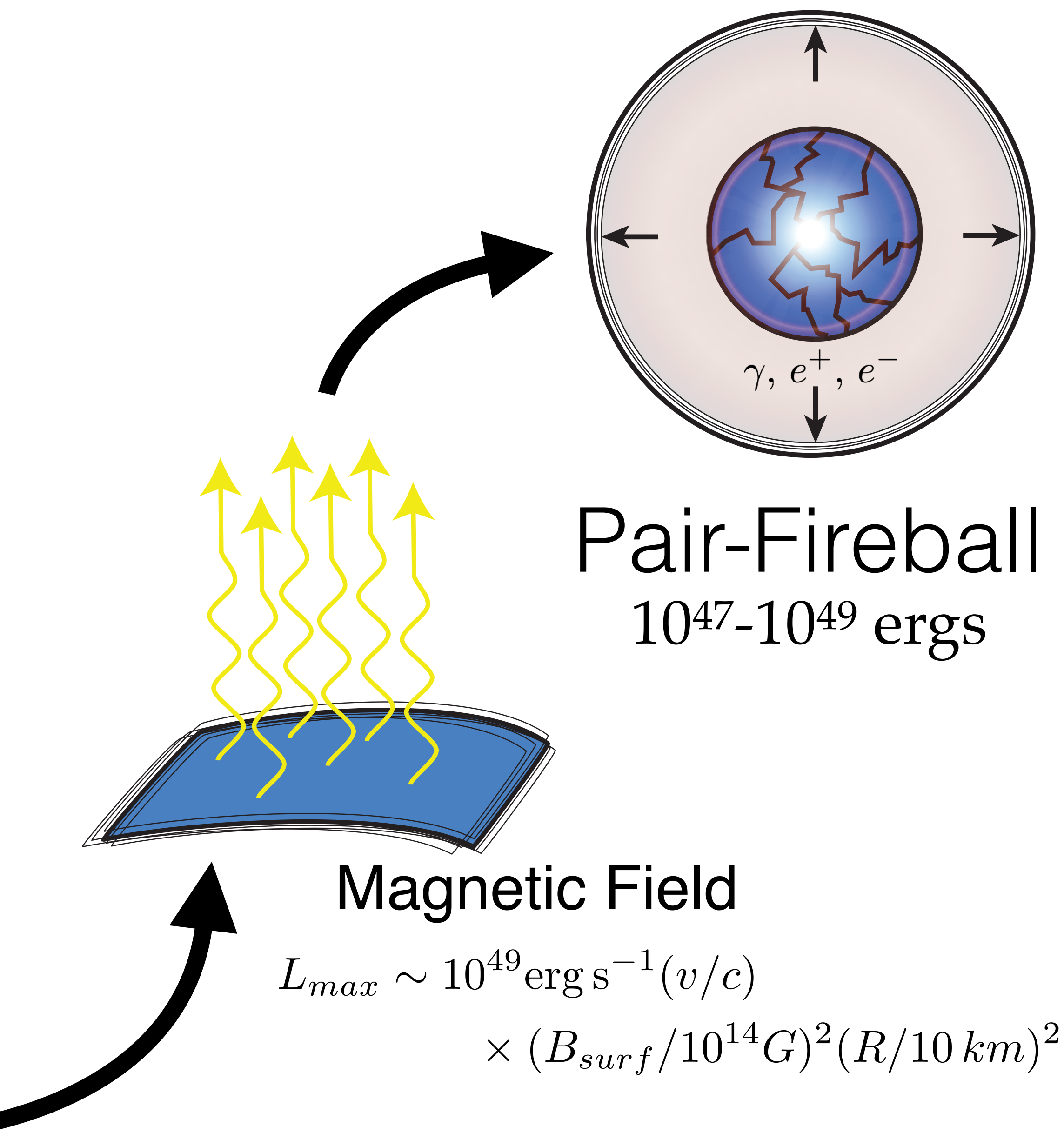
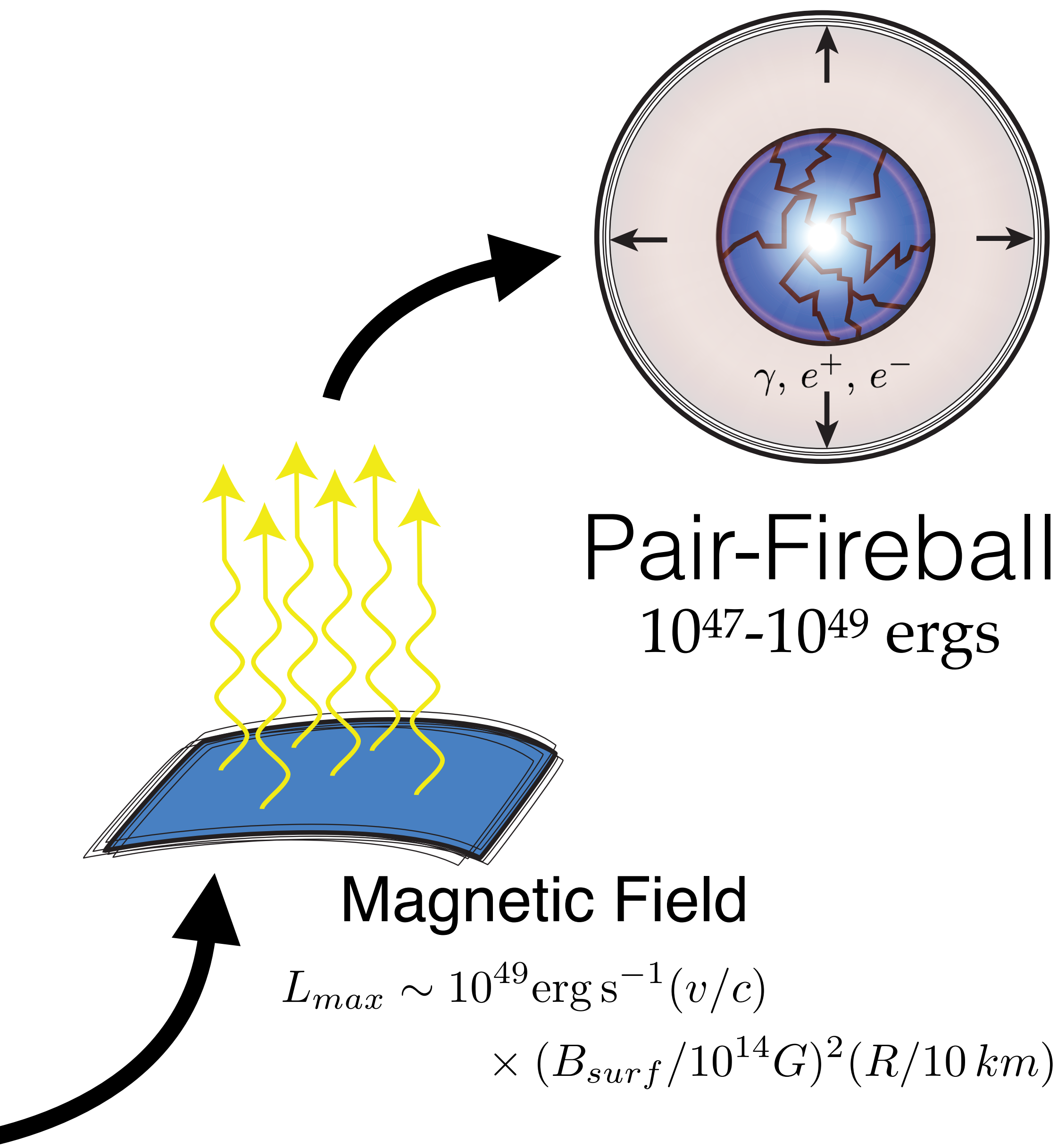


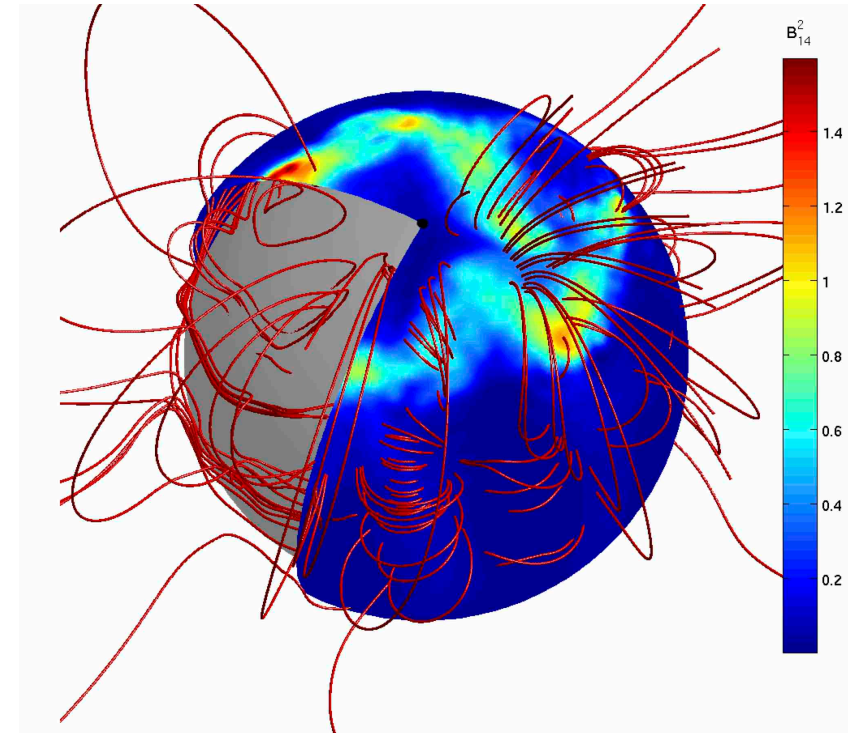
- E_{RSF} ~ 10^{47} - 10^{49} erg, Δt_{RSF} ~ 0.1s
- RSF model can be easily **tested with EM/GW coincident timing**
    - Predicts weak GRB-like emission **seconds <u>before</u>** the chirp coalescence
    - The **timing** of the RSF provides **precision asteroseismology** of the NS i-mode
    - i-mode frequency dependent on EOS, NS bulk properties and shear velocity at base of the crust
    - Constrains nuclear physics? (Symmetry energy, EOS…)



γ, e^+, e^-
Pair-Fireball
10^{47}-10^{49} ergs
Magnetic Field
$L_{max} \sim 10^{49} \mathrm{erg\,s^{-1}} (v/c) \times (B_{surf}/10^{14} G)^2 (R/10\,km)^2$



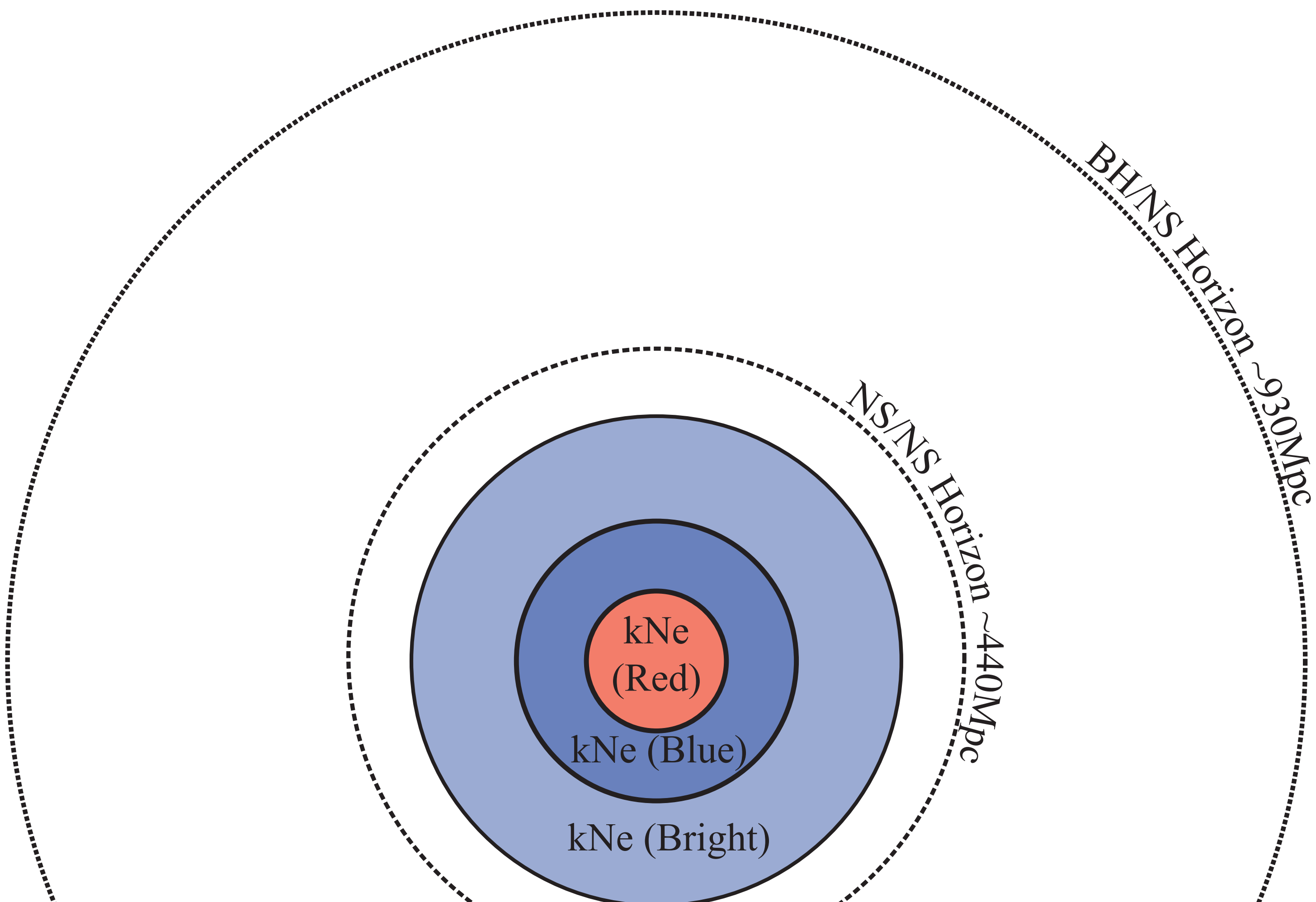
$$L_{max} \sim 10^{49}\,\mathrm{erg\,s^{-1}}(v/c) \times (B_{surf}/10^{14}G)^2(R/10\,km)^2$$



Gourgouliatos & Hollerbach (2018)

- NS Surface B-field determines max luminosity
- Surface B-field depends on initial conditions, age, toroidal field, accretion history, core flux vs crust only (see e.g. Ho, Andersson, & Graber [2017])
- Do not expect bright RSFs for all NS
  - e.g. RSF not seen in GW170817

How detectable are EM counterparts?



(kNe detectability from Kalsiwal & Nissanke, 2014)

(DT et al. in prep)

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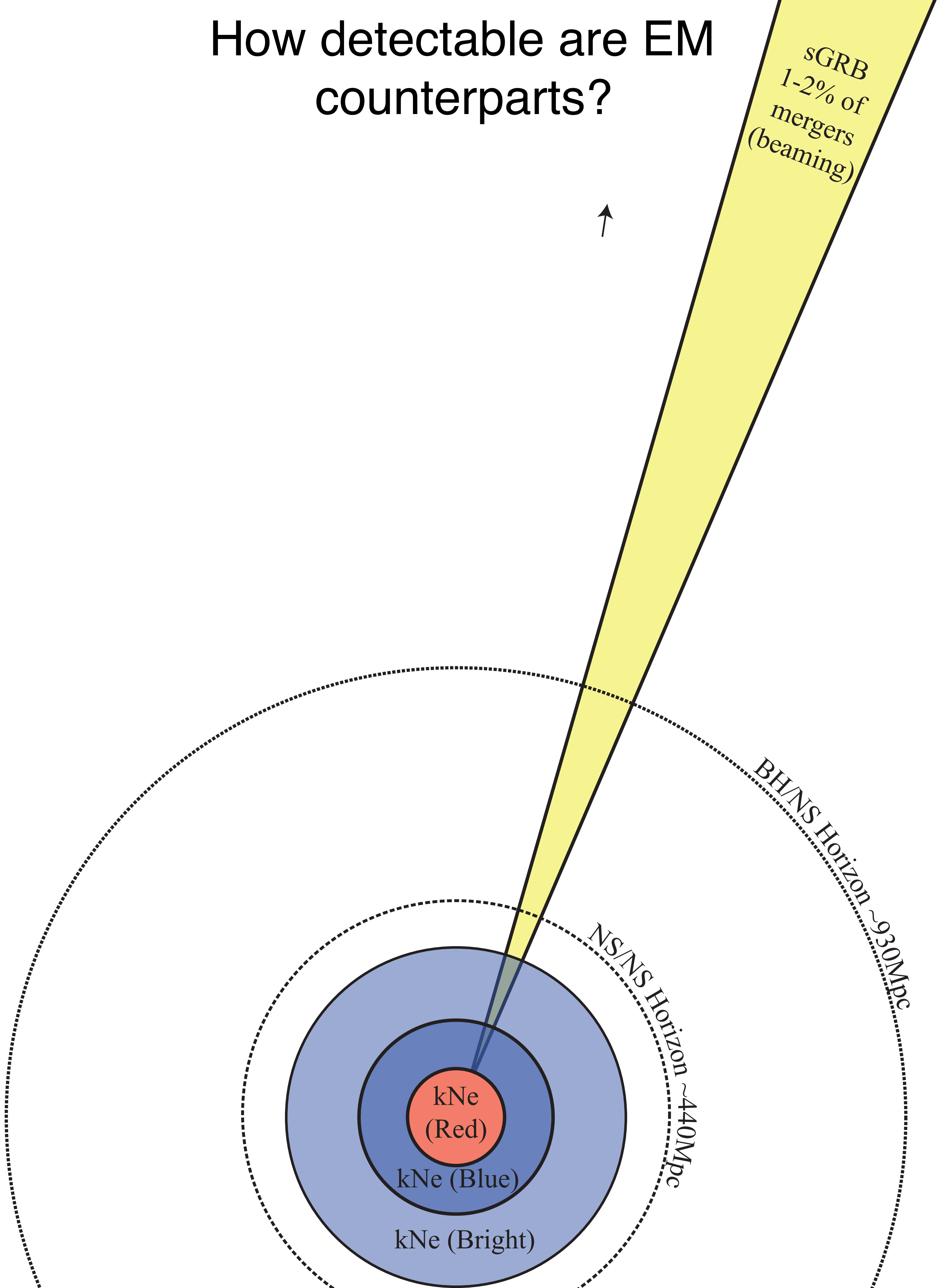

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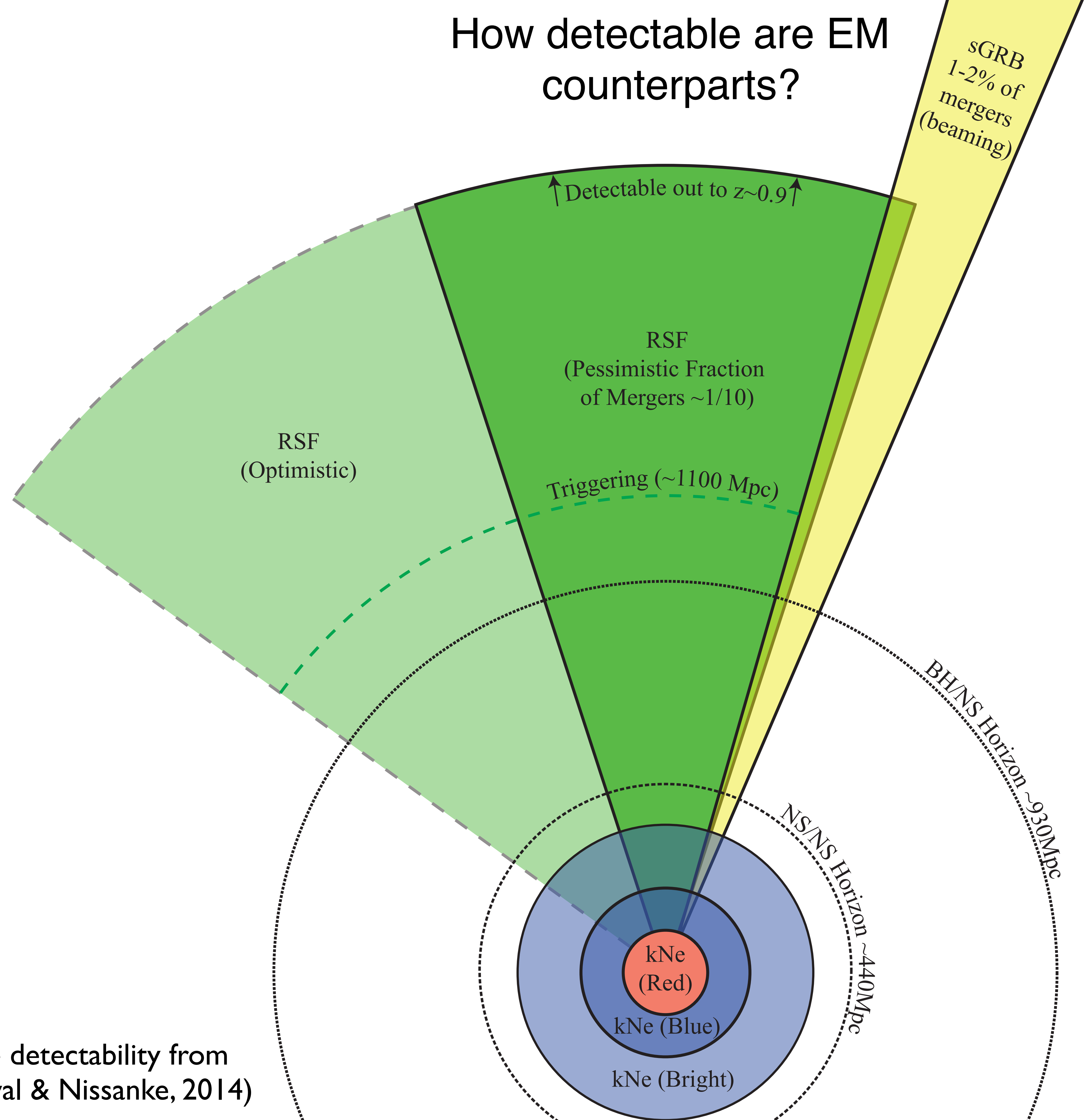

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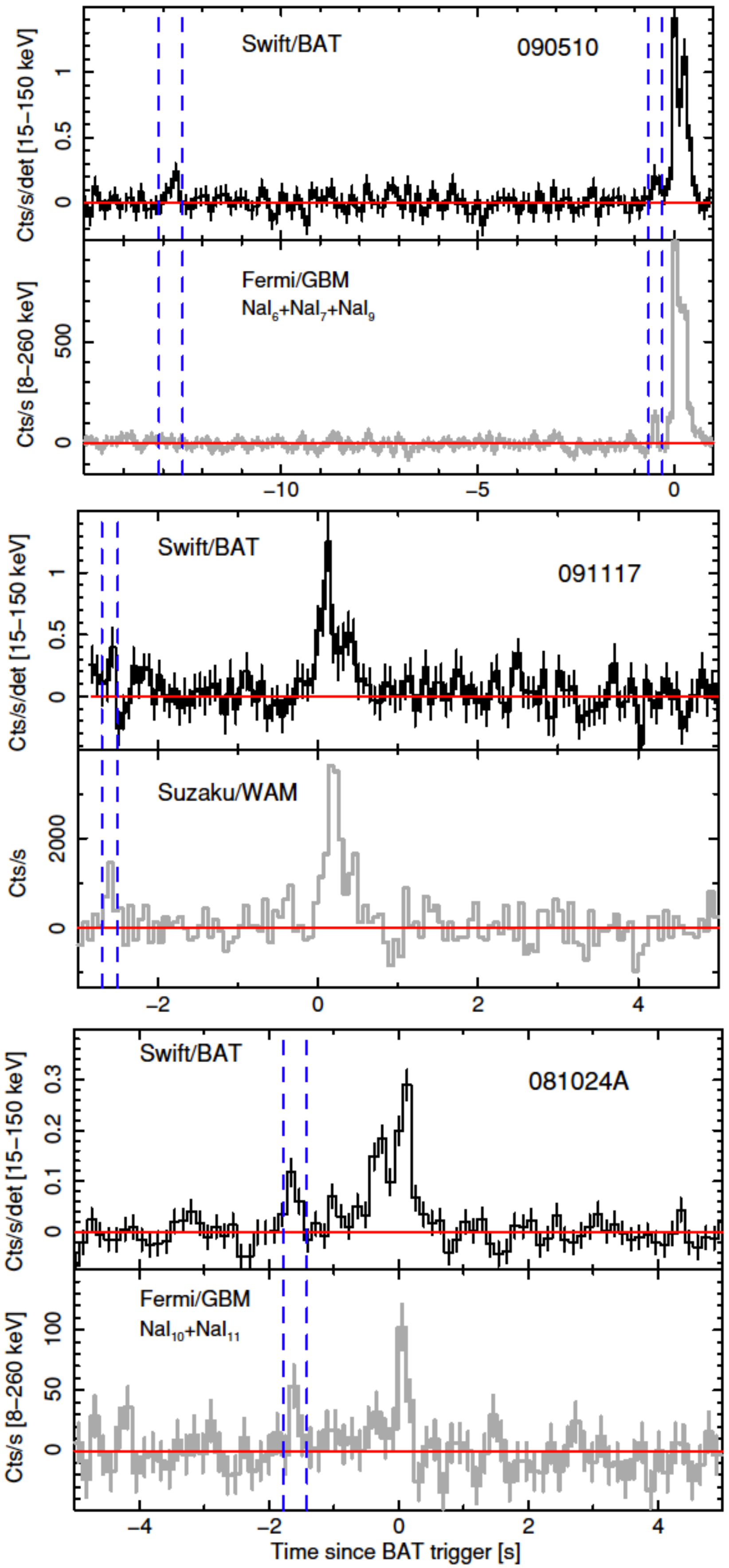
SGRB Precursors



Troja et al. ApJ, 723, 1711 (2010)

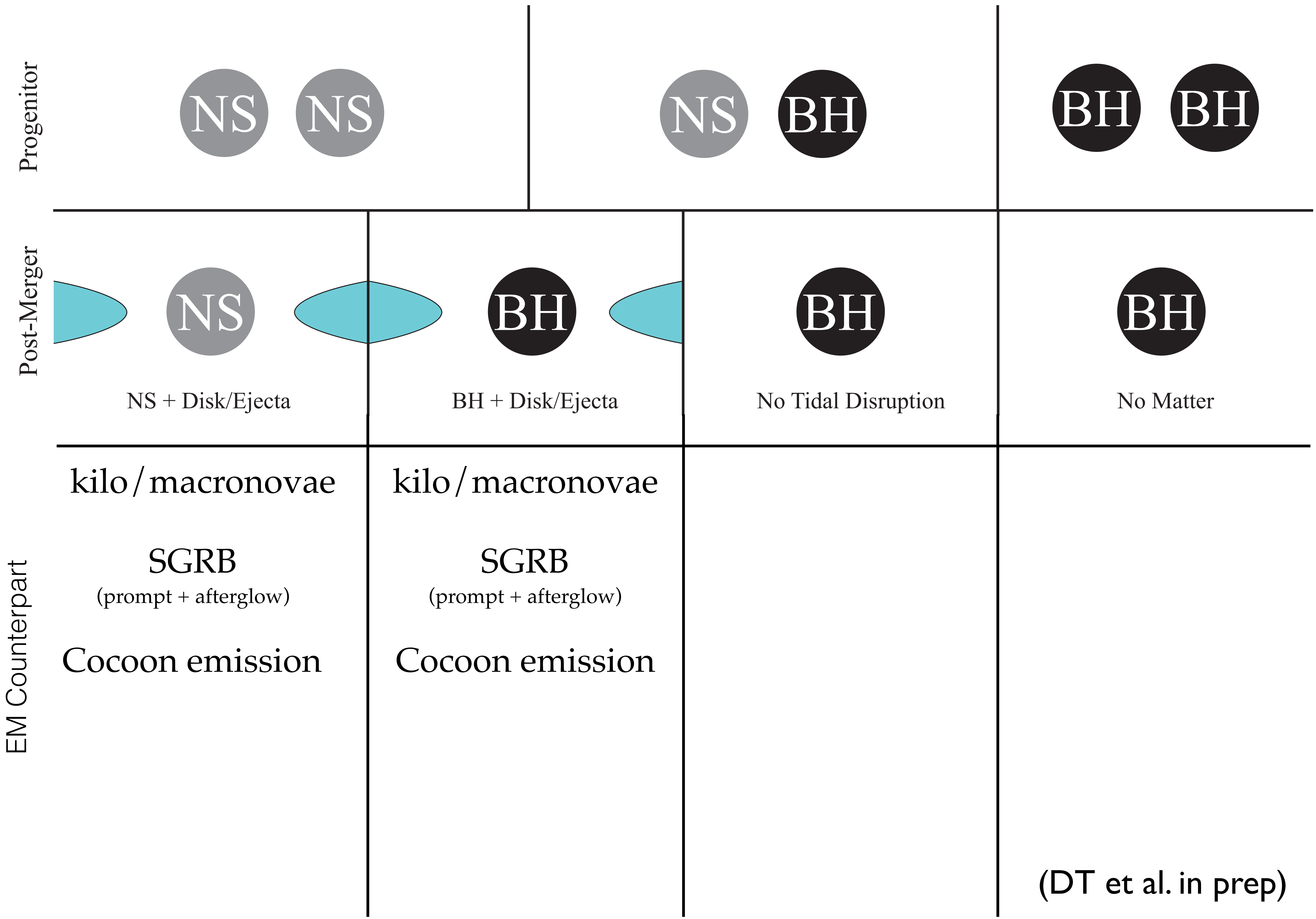
Potential Orphan RSFs?

$E_{RSF} \sim 10^{47}$ - 10^{49} erg, $t_{RSF} \sim 0.1$s

GRB	T_{90}(s)	z	BAT Fluence (10^{-7} erg cm^{-2})	$E_{BAT\ ISO}$ (erg)	Notes
150101B	0.018	0.13	0.23	2.6×10^{48}	High E_{kin}; Fong+ (2016)
050509B	0.073	0.225	0.09	1.1×10^{48}	Gehrels+ (2005)
060502B	0.131	0.287	0.4	7.9×10^{48}	Bloom+ (2006)
050906	0.128	0.031*	0.07	1.5×10^{46}	Levan & Tanvir (2008)

*no afterglow; host galaxy within BAT error box

Q: Is there a local orphan RSF component in SGRB population? (see e.g. Tanvir [2005])


Progenitor
NS NS
NS BH
BH BH
Post-Merger
NS
NS + Disk/Ejecta
BH
BH + Disk/Ejecta
BH
No Tidal Disruption
BH
No Matter
EM Counterpart
kilo / macronovae
SGRB
(prompt + afterglow)
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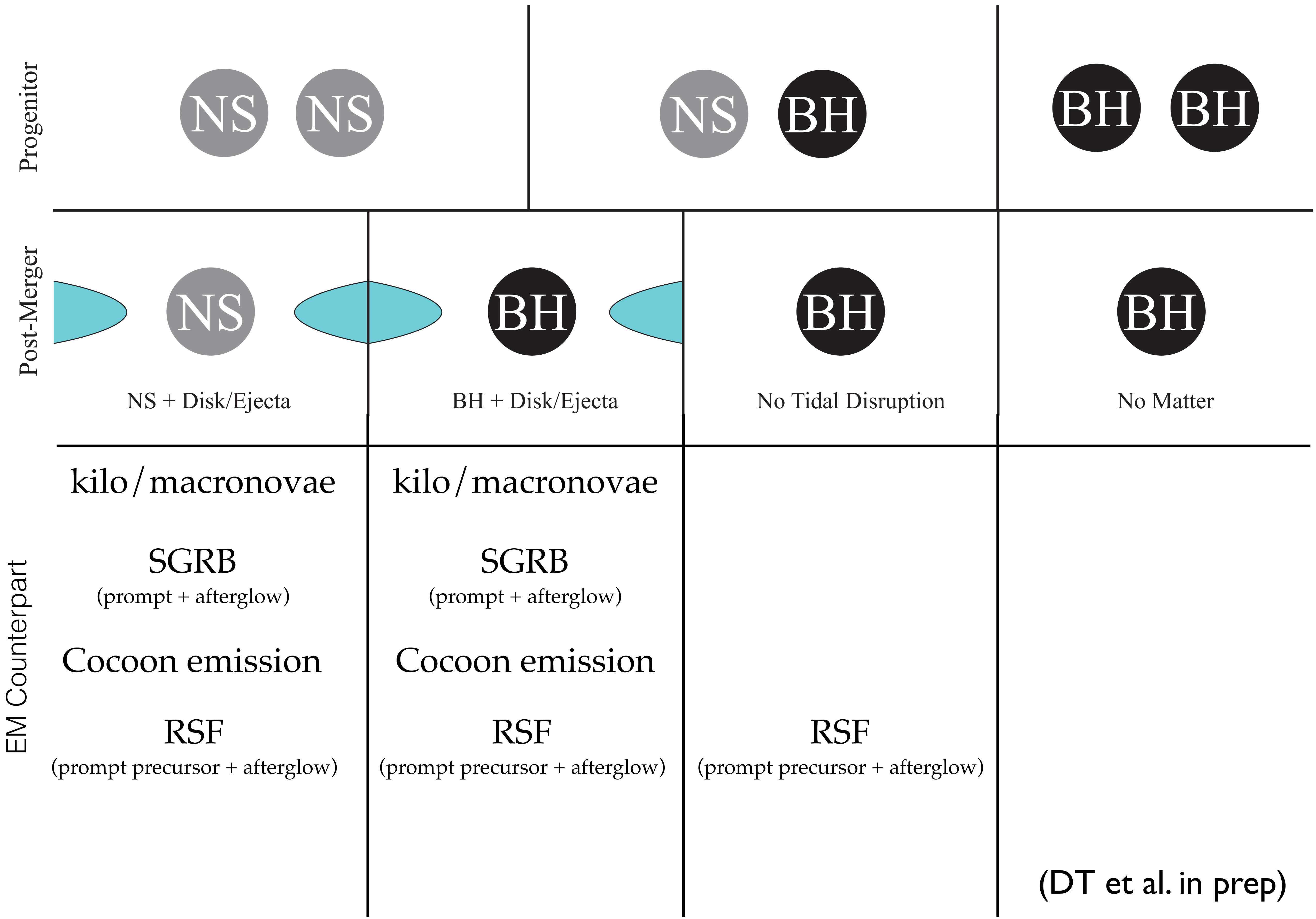
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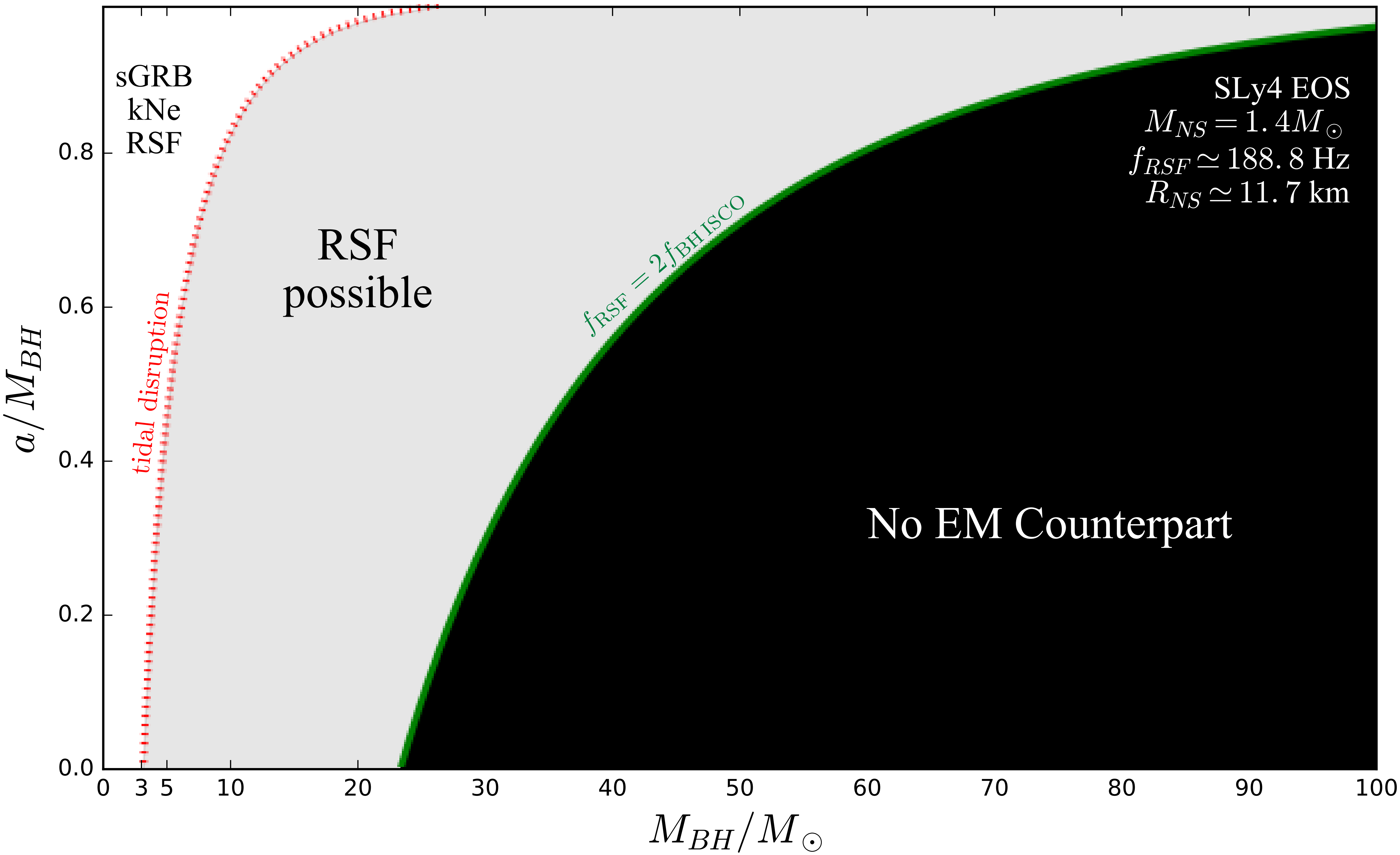
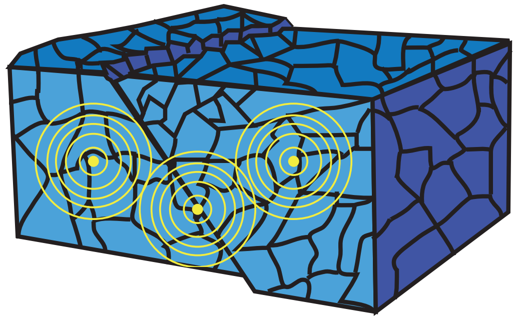
Black Hole - Neutron Star Mergers



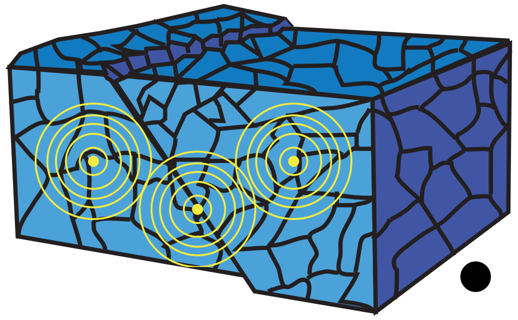
DT et al. (in prep)



Summary

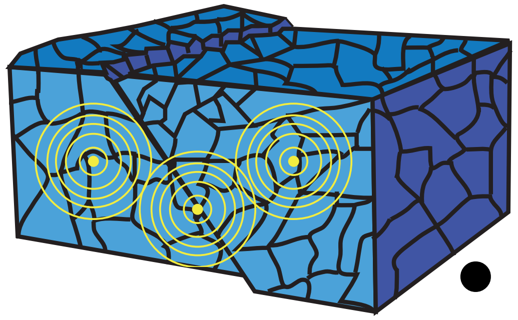
- RSFs caused by resonant tidal excitation of i-mode injecting energy into pair-fireball, seconds before merger
- RSFs are:
  - Isotropic
  - Bright: should be easily detectable within the LIGO horizon
  - $E_{RSF} \sim 10^{47} - 10^{49}$ ergs
  - $t_{RSF} \sim 0.1$s
- Can appear as SGRB precursors or orphan RSFs (underluminous, very short GRBs)

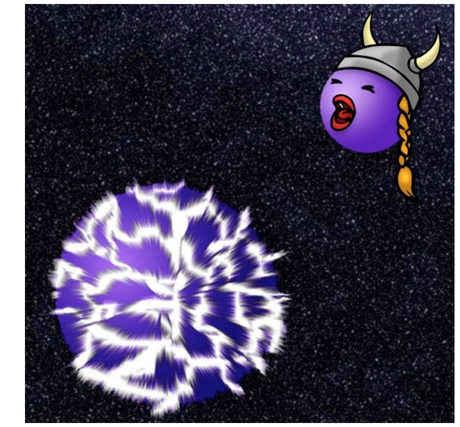
- Weak X-ray/Optical/Radio afterglow
- Coincident EM/GW timing will confirm RSF model and determine mode freq.
- Shear speed/nuclear physics constraints; Complementary to M, R, λ
- Does not need tidal disruption - larger fraction of NS-BH mergers



Questions

- Surface B-field - core vs crust evolution?
- N_{RSF}/N_{merger}?
- Excess of nearby orphan RSFs? Injection tests for burst pipelines?
- How do the core-crust transition density and (effective) shear modulus/speed depend on nuclear physics parameters? (model dependence?) Pasta layer thickness?
- What constraints on NS EOS and dense matter can we obtain with i-mode frequency from coincident timing?





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Steiner & Watts, (2009), PRL, 103, 181101