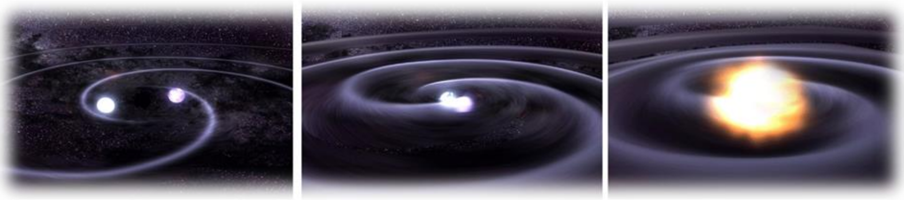


NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

X-ray counterpart of GWs due to binary neutron star mergers

-- light curves, luminosity function and event rate density

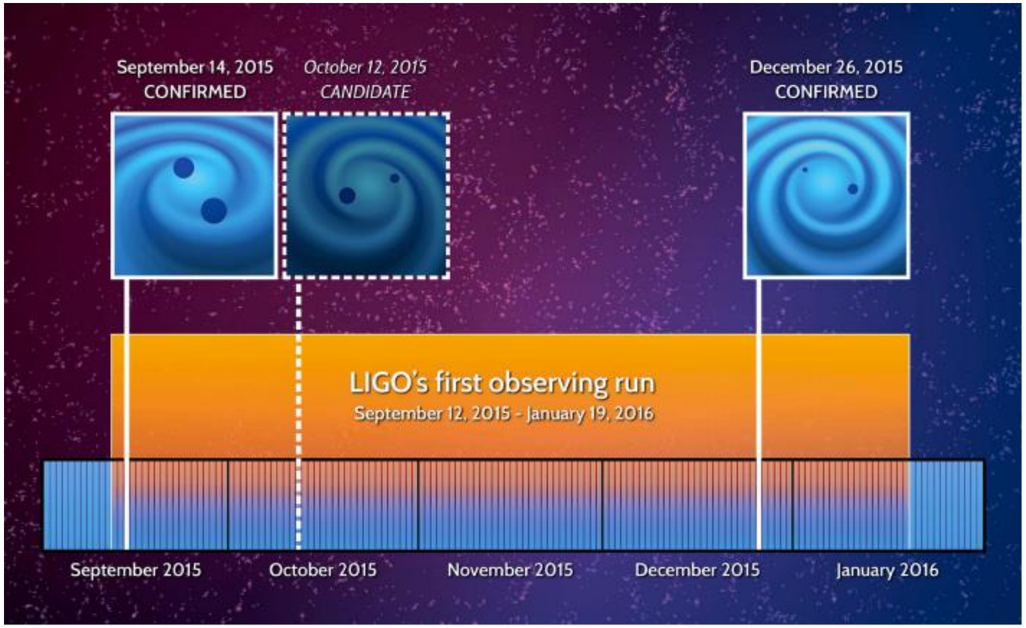
Hui Sun (Peking University, NAOC)

Collaborators: Bing Zhang (University of Nevada, Las Vegas),
He Gao (Beijing Normal University)

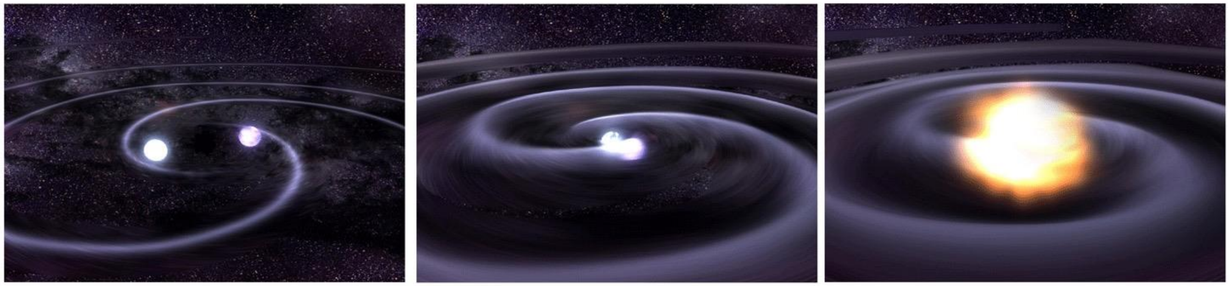
The X-ray Universe 2017 Italy_Rome June 6-9

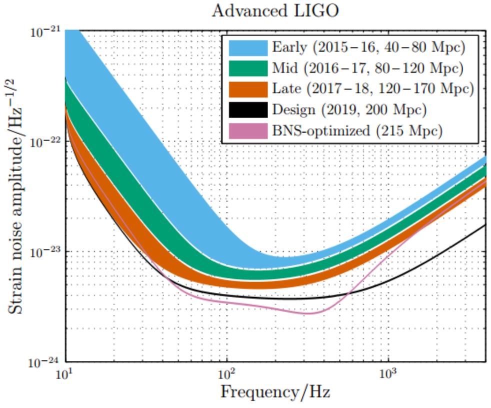
Gravitational Wave detections

Binary Black Hole mergers



Binary Neutron star mergers





Abbott et al. 2016c, LRR, 19,1

Gravitational Wave detections

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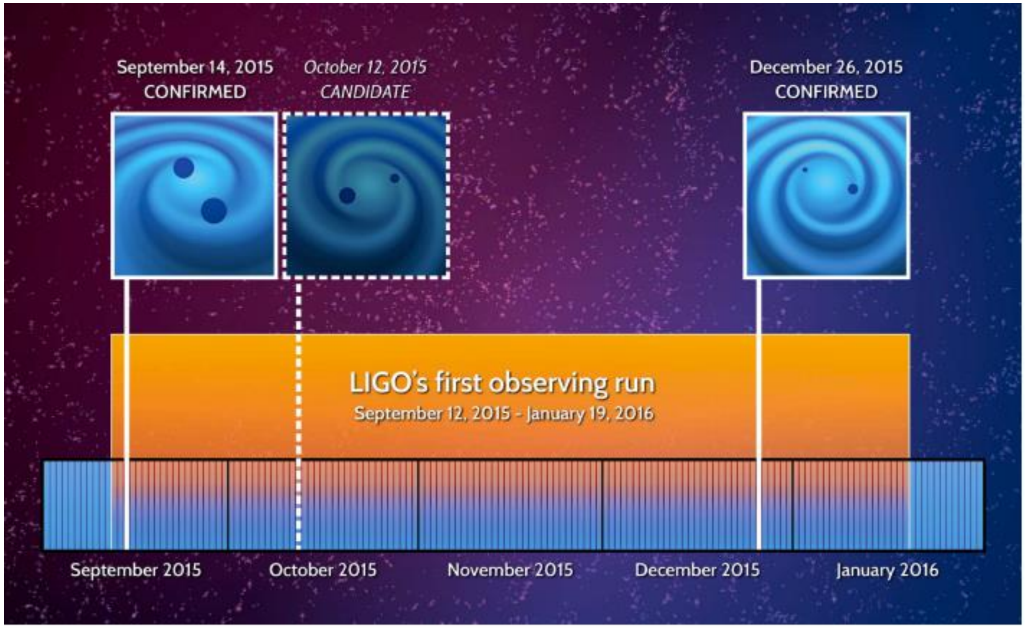
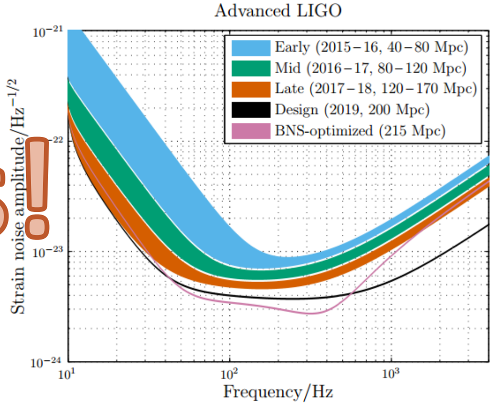


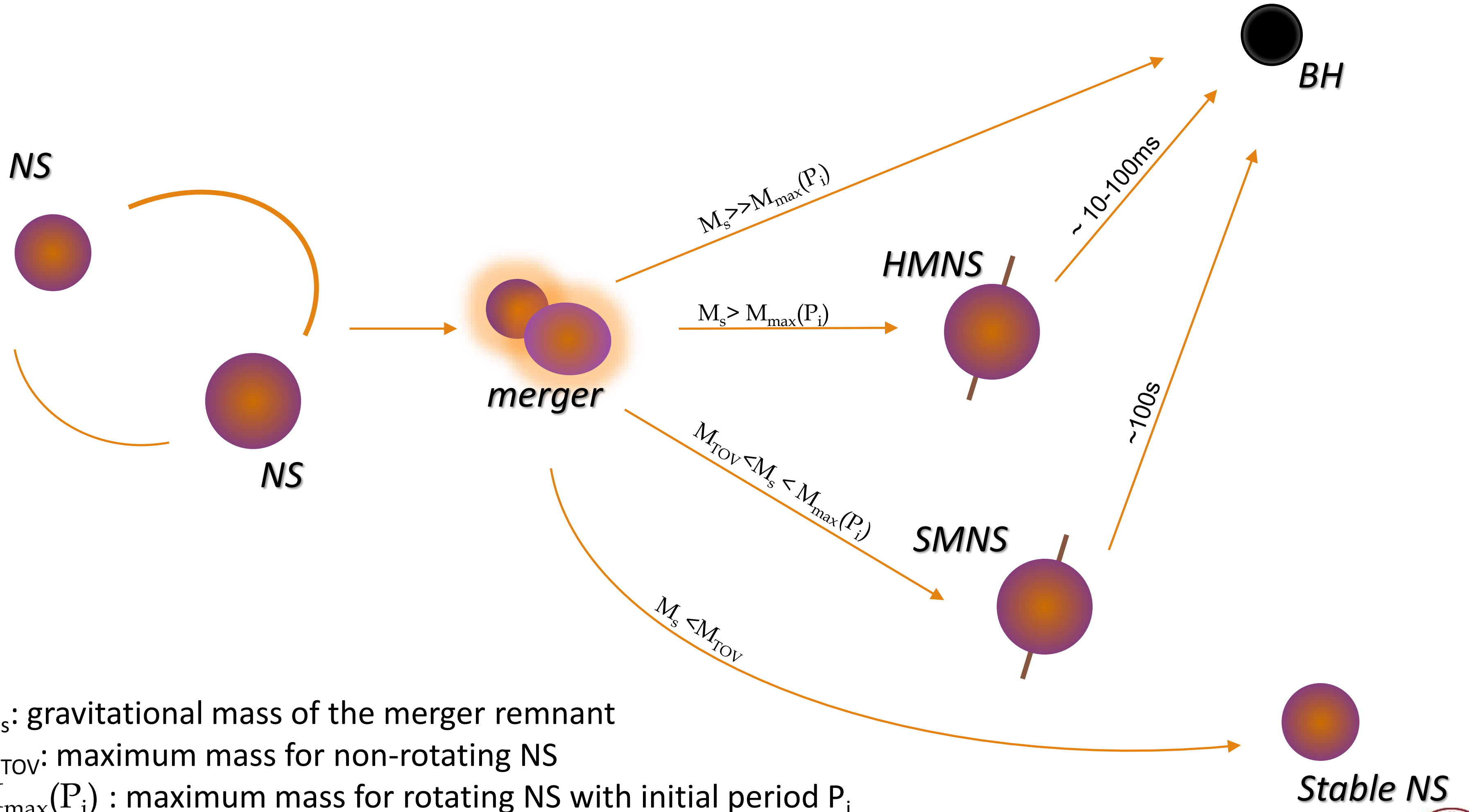
Binary Neutron star mergers

EM detections!

Abbott et al. 2016c, LRR, 19,1



NS-NS merger



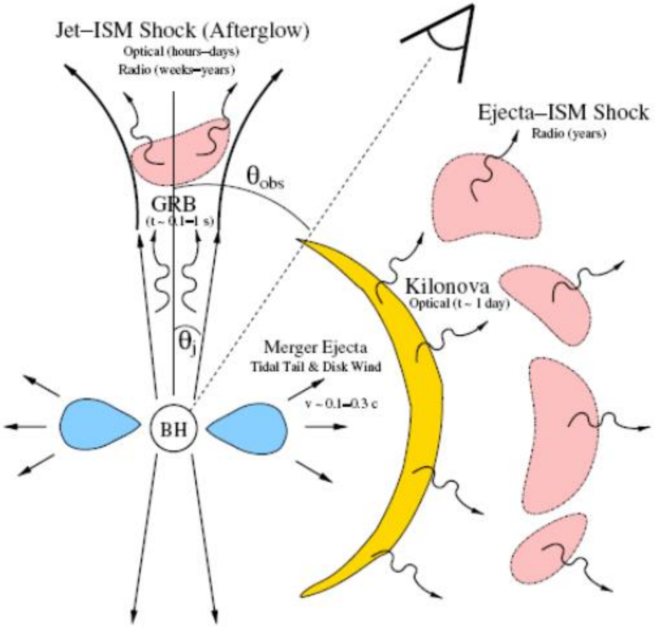
M_s: gravitational mass of the merger remnant

M_{TOV}: maximum mass for non-rotating NS

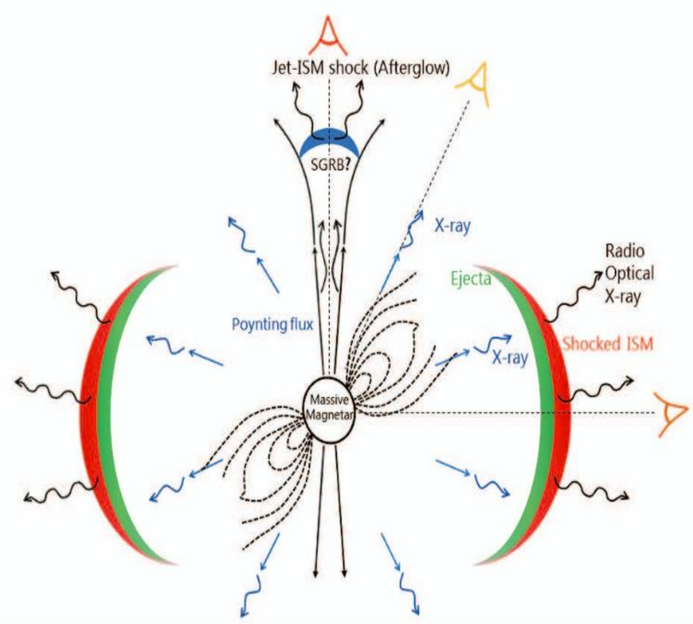
$M_{max}(P_i)$: maximum mass for rotating NS with initial period P_i

EM counterparts following NS-NS mergers

BH as post-merger product



Magnetar as post-merger product



	BH (Metzger & Berger 2012)	Magnetar (Gao et al. 2013)
Gamma-ray	sGRB	sGRB
Optical	Kilo-nova (Li & Paczyński 1998, Tanvir+2013)	Merger-nova (Yu et al. 2013)
Radio	Radio Afterglow (Nakar & Piran 2011)	Radio Afterglow (Gao et al. 2013)
X-ray	------------	

EM counterparts following NS-NS mergers

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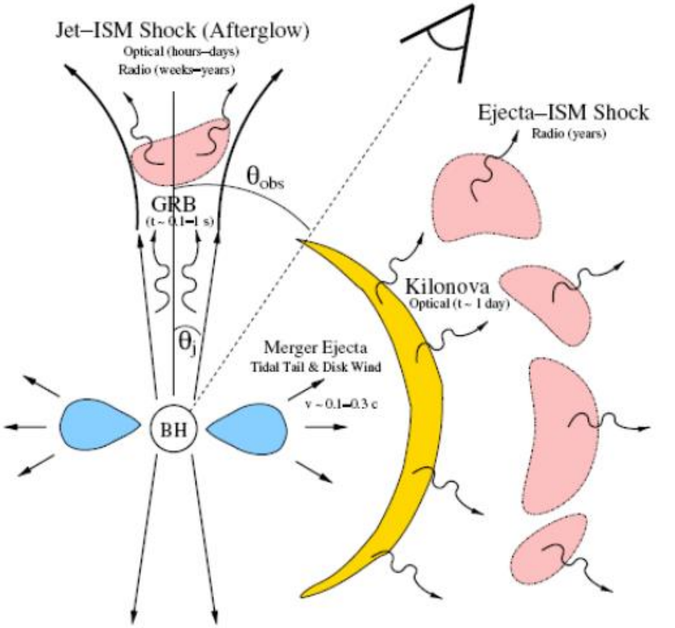
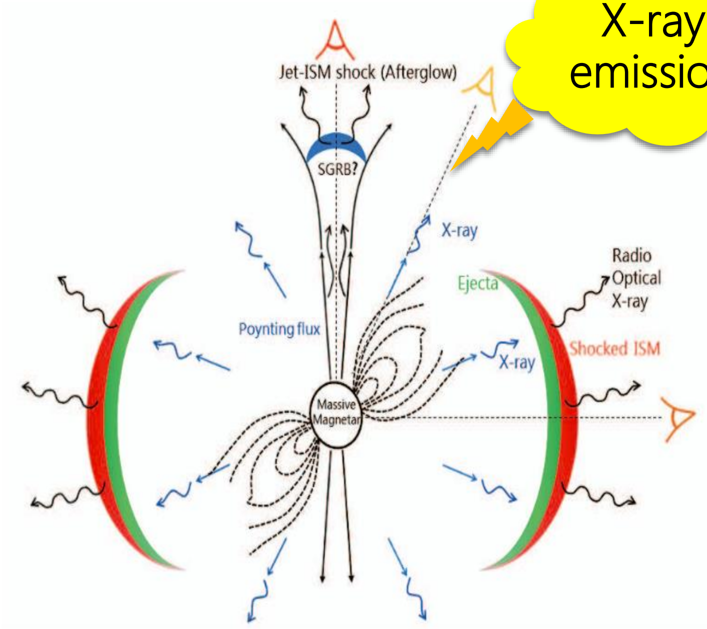


Magnetar as post-merger product

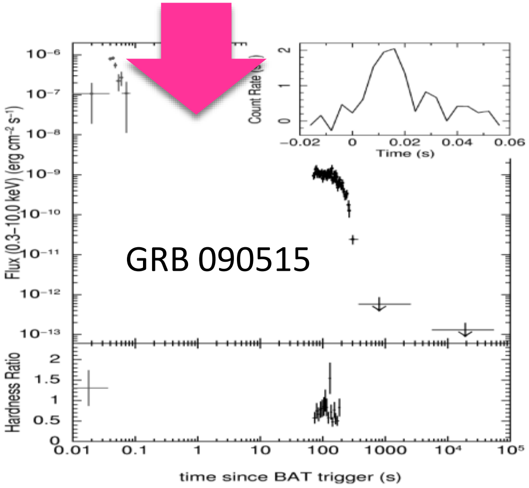


X-ray emission

	BH (Metzger & Berger 2012)	Magnetar (Gao et al. 2013)
Gamma-ray	sGRB	sGRB
Optical	Kilo-nova (Li & Paczyński 1998, Tanvir+2013)	Merger-nova (Yu et al. 2013)
Radio	Radio Afterglow (Nakar & Piran 2011)	Radio Afterglow (Gao et al. 2013)
X-ray	------------	X-ray emission (Zhang 2013)

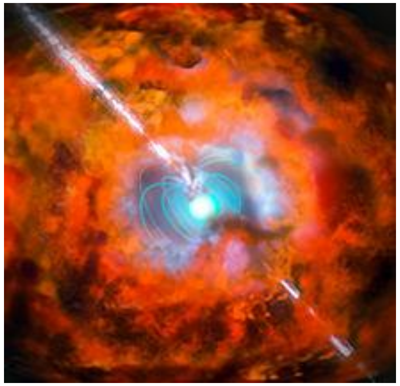
Magnetar

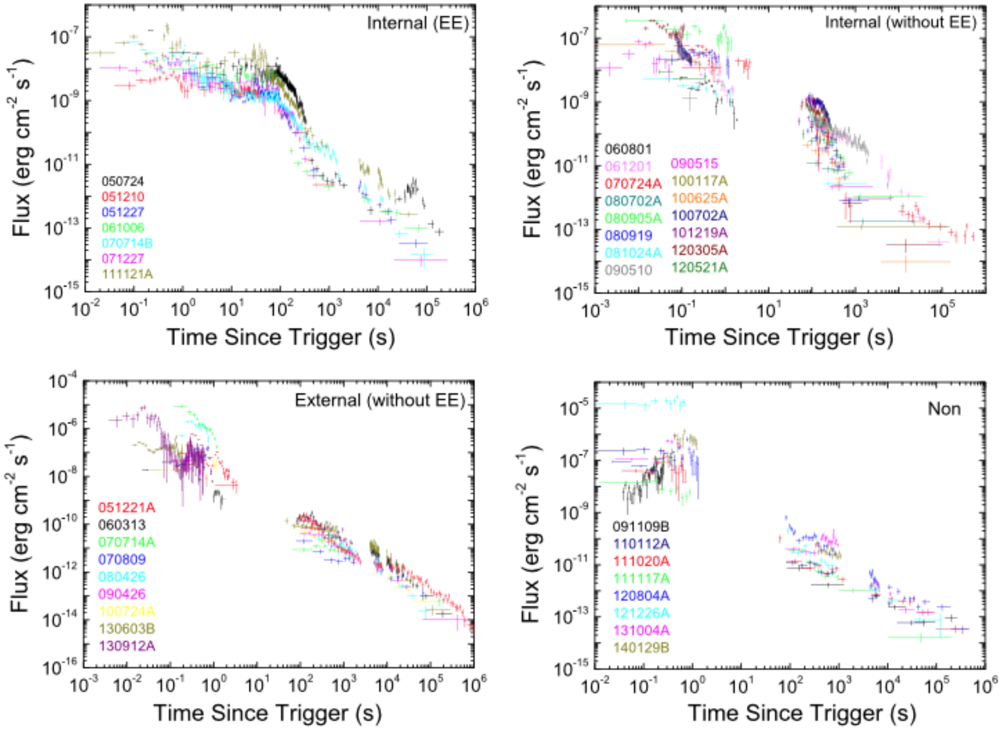
'Smoking gun'



GRB 090515

Rowlinson et al. 2010



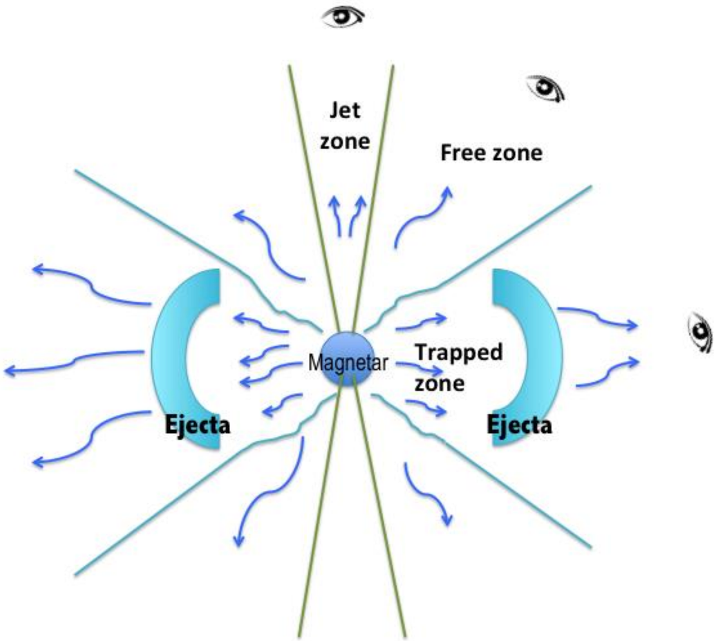


With the joint BAT-XRT light curve analysis, a minimum 22% of supra-massive NSs as the central engine of sGRBs.

Lv et al. 2015, Gao et al. 2016, PRD

Model

- Magnetar as central engine.
- Isotropic wind emission.
- Different viewing angles.



Spin down law :

$$\dot{E} = I\Omega\dot{\Omega} = -\underbrace{\boxed{\frac{B_p^2 R^6 \Omega^4}{6c^3}}}_{\text{EM}} - \underbrace{\boxed{\frac{32 G I^2 \epsilon^2 \Omega^6}{5c^5}}}_{\text{GW}}$$

Yu et al. 2013, Zhang 2013, Sun et al. 2017

Model

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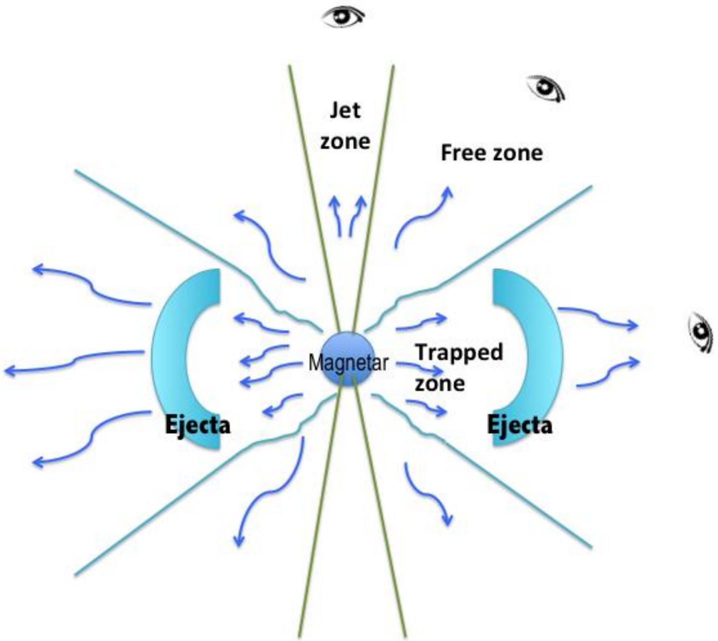

- Jet/Free zone emission (spin down wind dissipation:)

$$L_{\rm X,free}(t) = \eta L_{\rm sd} = \frac{\eta B_p^2 R^6 \Omega^4(t)}{6c^3}$$

- Trapped zone emission:

$$L_{\rm X,trapped}(t) = \underbrace{\boxed{e^{-\tau}}}_{\text{Ejecta}} \frac{\eta B_p^2 R^6 \Omega^4(t)}{6c^3} + (\nu_{\rm X} L_{\nu,\rm X})_{\rm bb}$$

Yu et al. 2013, Sun et al. 2017

Model

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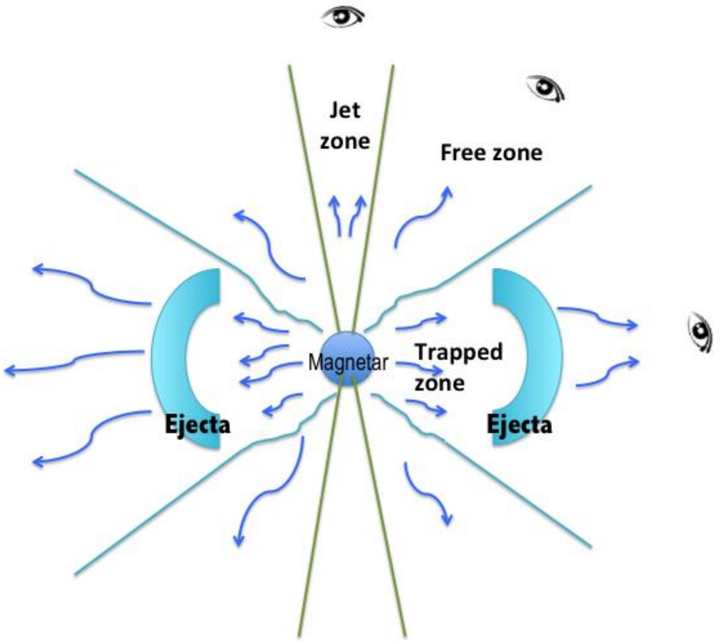

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Luminosity function & Event rate density

Yu et al. 2013, Sun et al. 2017

Simulations

Why do we do simulations?

No detections of sGRB-less X-ray events yet!

Gao et al. 2016

Simulations

Why do we do simulations?

No detections of sGRB-less X-ray events yet!

What do we have from observations ?

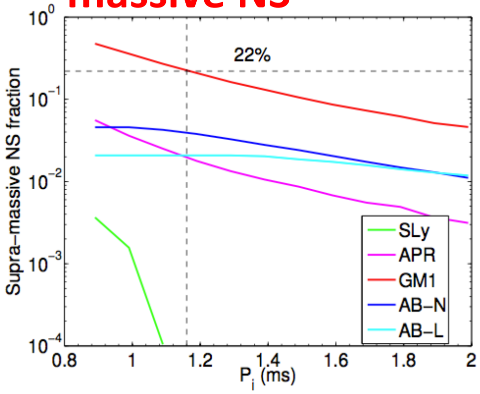
X-ray plateaus in SGRBs

B ($\mu_B = 10^{15}$G, $\sigma_B = 0.2$); P_i=1ms

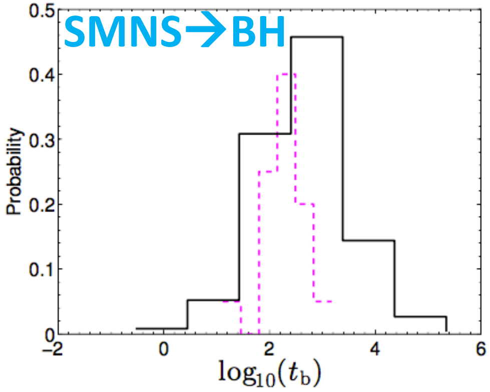
Ejecta mass ($\mu_{Mej} = 10^{-2} M_{sun}$, $\sigma_{Mej} = 0.5$)

Ellipticity $\varepsilon = 0.005$; Efficiency: $\xi = 0.5$, $\eta = 0.5$

Fraction of supra-massive NS

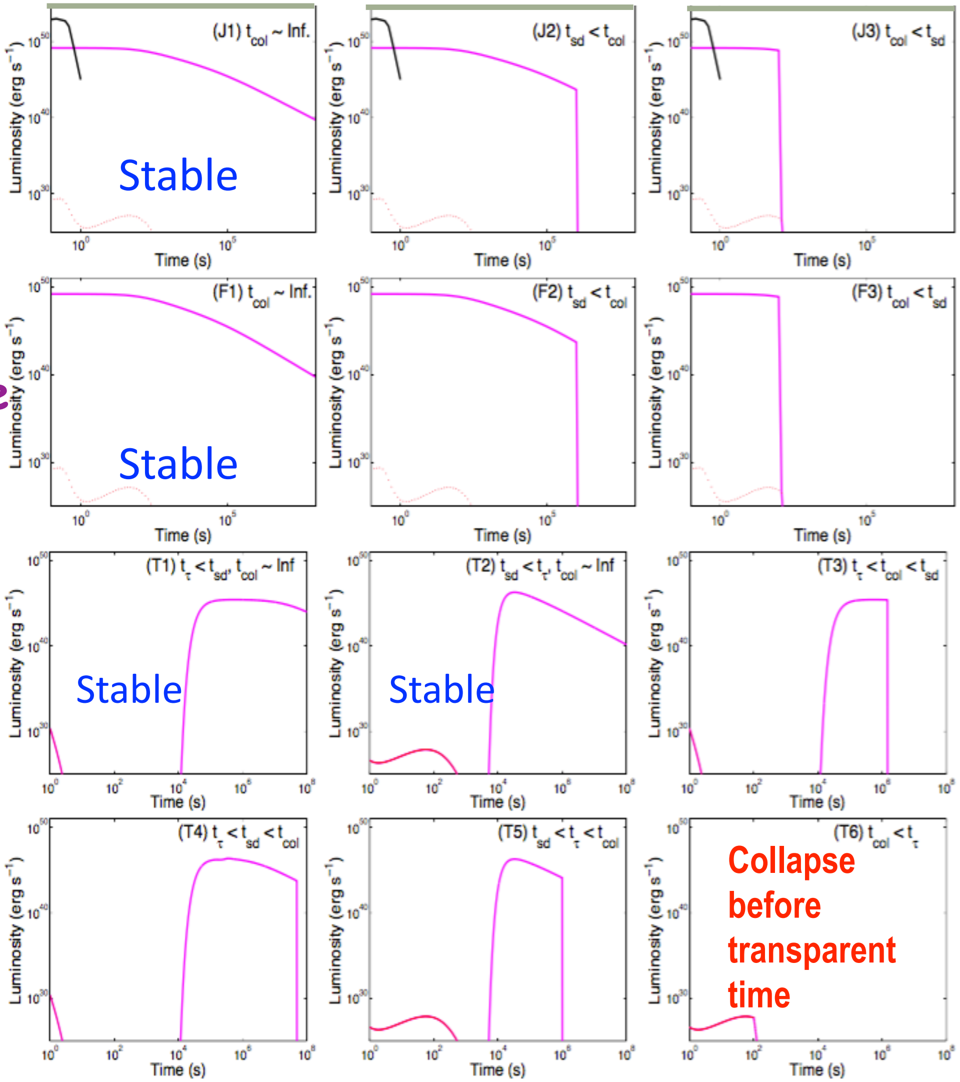


Collapse time from SMNS→BH



Gao et al. 2016

A gallery of possible LCs



Jet zone

Stable

Free zone

Stable

Trapped zone

Stable

Stable

Collapse before transparent time

X-ray emission can reach as bright as 10^{49} erg s^{-1} in free zone.

It takes around ten ks to get the ejecta transparent.

X-ray emission is around 10^{46-47} erg s^{-1} in trapped zone.

Merger-nova is too dim to observe in X-ray band.

Sun et al. 2017

Simulated luminosity function

$$\Omega_{\rm jet}+\Omega_{\rm free}+\Omega_{\rm trapped}=4\pi$$

$$k_{\Omega}=\frac{\langle\Omega_{\rm free}\rangle}{\langle\Omega_{\rm jet}\rangle}$$

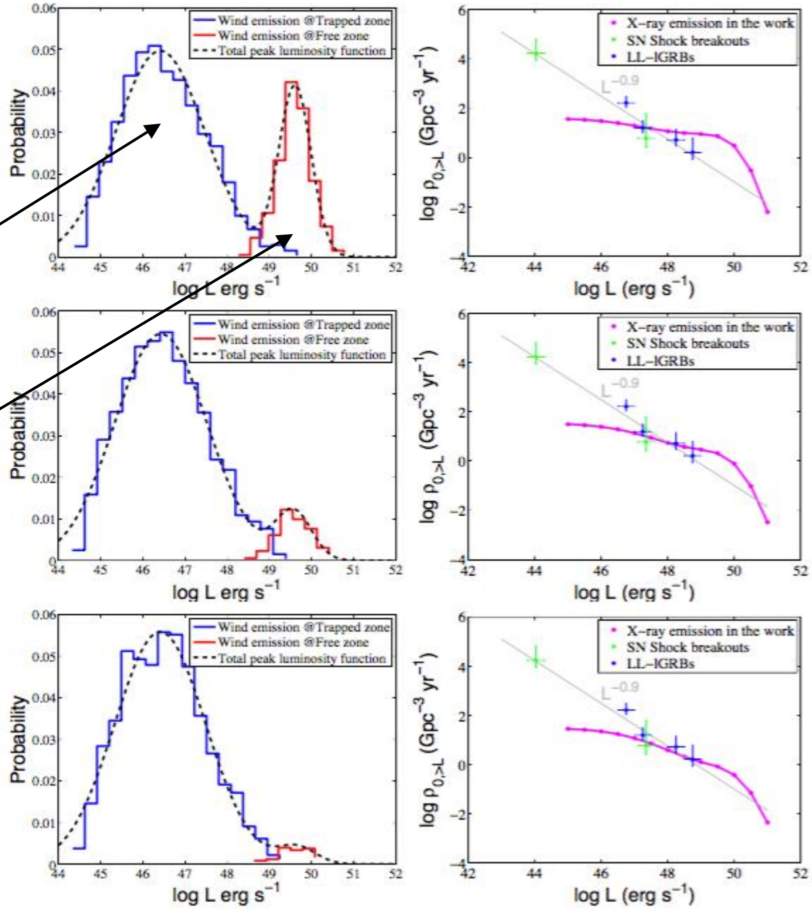
$k_{\Omega}=10$

Trapped zone contribution

$k_{\Omega}=3$

Free zone contribution

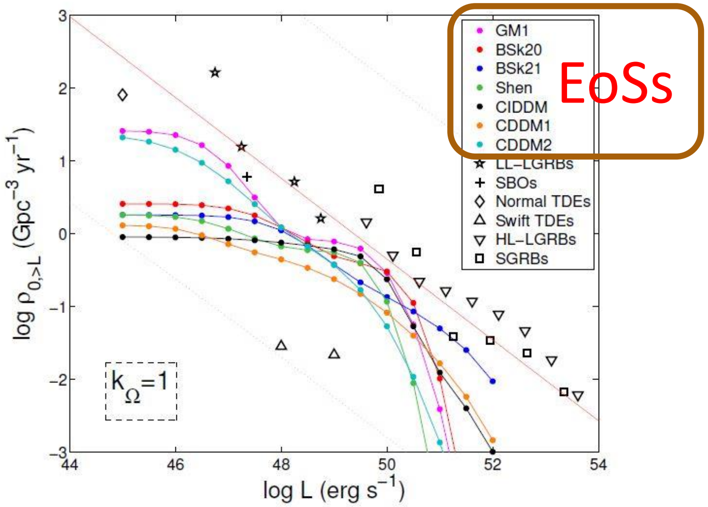
$k_{\Omega}=1$



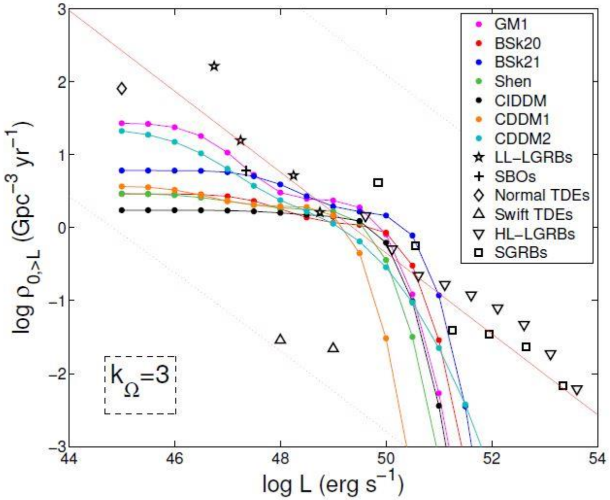
With no confirmed obs., k_{Ω} is constraint to be the order of unity.

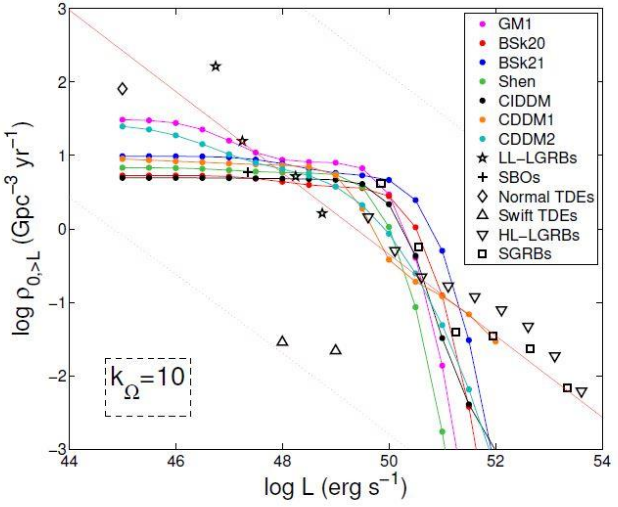
Sun et al. 2017

Global distribution of event rate density



EoSs



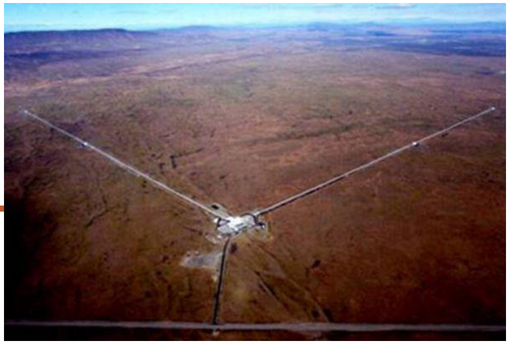


In comparison with other ***observed*** extra-galactic high-energy transients:

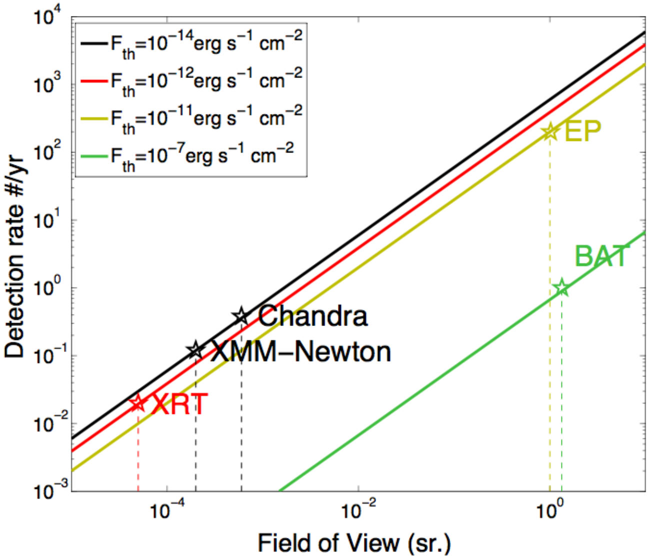
- Long & Short GRBs
- SN shock breakouts
- Tidal disruption events

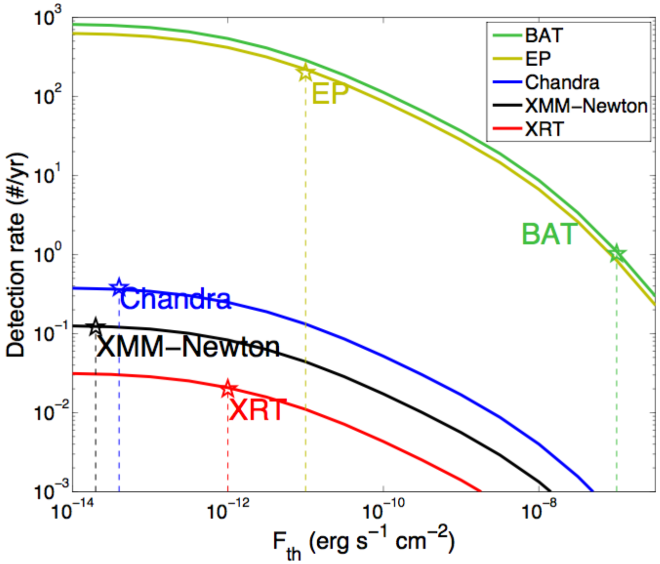
Sun et al. 2017

Detection rate



- BAT could detect 1-2 such transients every year.
- Einstein Probe will detect several tens such transients every year, while present X-ray telescopes are much less efficient.
- The joint aLIGO & high-energy detections of such events should be rare, roughly 1 per year all sky.





Sun et al. 2017

Conclusions

- The peak LF is bimodal, which can be fitted with two log-normal distribution components from free/trapped zone, respectively.
- We constraint the solid angle ratio of free zone to jet zone to unity.
- The event rate density of these transients above 10^{45} erg s^{-1} is around a few tens of $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$.
- The joint aLIGO-high-energy detections of such events should be rare, roughly 1 per year all sky. The detectability mostly depends on the field of view of the wide field X-ray/soft gamma-ray detectors.

Thank you!