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

-- light curves, luminosity function and event rate density

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Gravitational Wave detections

Binary Black Hole mergers

Binary Neutron star mergers

Abbott et al. 2016c, LRR, 19,1
Gravitational Wave detections

Binary Black Hole mergers

Binary Neutron star mergers

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

<table>
<thead>
<tr>
<th>Event Type</th>
<th>BH (Metzger &amp; Berger 2012)</th>
<th>Magnetar (Gao et al. 2013)</th>
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<tbody>
<tr>
<td>Gamma-ray</td>
<td>sGRB</td>
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<tr>
<td>X-ray</td>
<td>--------------------------</td>
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**EM counterparts following NS-NS mergers**

**BH as post-merger product**

- **BH (Metzger & Berger 2012)**
  - Jet–ISM Shock (Afterglow)
  - Ejecta–ISM Shock
  - Merger Ejecta
  - Tidal Tail & Disk Wind

**Magnetar as post-merger product**

- **Magnetar (Gao et al. 2013)**
  - Jet–ISM shock (Afterglow)
  - Poynting Flux
  - X-ray emission

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<th>Optical</th>
<th>Radio</th>
<th>X-ray</th>
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</table>
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:

\[
\dot{E} = I\dot{\Omega} = \frac{B_p^2 R^6 \Omega^4}{6c^3} - \frac{32G I^2 \epsilon^2 \Omega^6}{5c^5}
\]

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

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

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

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

Trapped zone emission:

\[ L_{X,\text{trapped}}(t) = e^{-\tau} \frac{\eta B_p^2 R^6 \Omega^4(t)}{6c^3} + (\nu_L L_{\nu,X})_{\text{bb}} \]

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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
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What do we have from observations?

X-ray plateaus in SGRBs

\[ B \left( \mu_B = 10^{15} \text{G}, \sigma_B = 0.2 \right); \quad P_i = 1 \text{ms} \]

Ejecta mass \( \left( \mu_{\text{Mej}} = 10^{-2} \text{M}_\odot, \sigma_{\text{Mej}} = 0.5 \right) \)

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

Fraction of supra-massive NS

Collapse time from SMNS \( \rightarrow \) BH

Gao et al. 2016
A gallery of possible LCs

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

\[ \Omega_{\text{jet}} + \Omega_{\text{free}} + \Omega_{\text{trapped}} = 4\pi \]

\[ k_\Omega = \frac{\langle \Omega_{\text{free}} \rangle}{\langle \Omega_{\text{jet}} \rangle} \]

- Trapped zone contribution
  - \( k_\Omega = 10 \)
- Free zone contribution
  - \( k_\Omega = 3 \)
- \( k_\Omega = 1 \)

With no confirmed obs., \( k_\Omega \) is constraint to be the order of unity.

Sun et al. 2017
Global distribution of event rate density

In comparison with other observed extra-galactic high-energy transients:
- Long & Short GRBs
- SN shock breakouts
- Tidal disruption events

Sun et al. 2017

The X-ray Universe June/6-9/2017
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 Gpc$^{-3}$ 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!