FRB 171019: An event of binary neutron star merger?

Jinchen Jiang, Weiyang Wang, Rui Luo, Shuang Du, Xuelei Chen, Kejia Lee&Renxin Xu

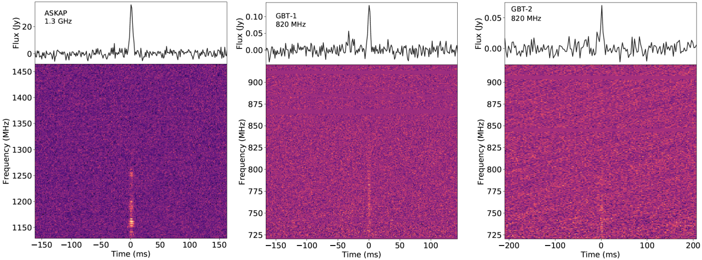
Peking University & National Astronomical Observatories of China

jiangjinchen@pku.edu.cn

October 12, 2019

Overview

Observation

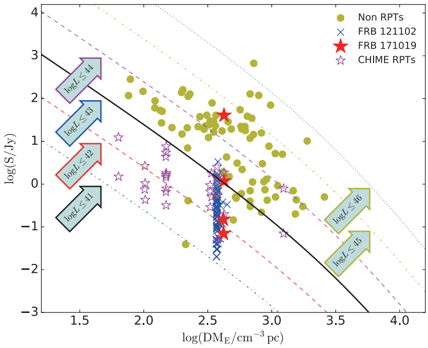


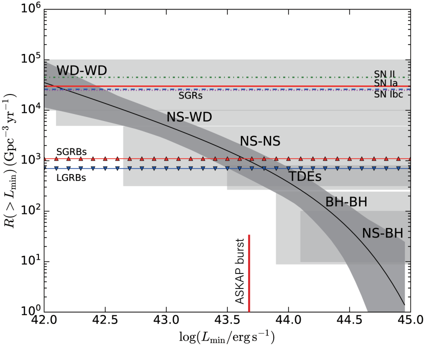
Kumar P., et al., 2019 (arXiv:1908.10026)

No	Telescope	Obs Freq (MHz)	Obs Time (h)	TOA[d] (MJD)	DM (pc/cm^3)	Fluence (Jy · ms)	Burst Width (ms)
1[ab]	ASKAP	1129.5-1465.5	986.6	58045.56061371	461 ± 1	219 ± 5	5.4 ± 0.3
2[b]	GBT	720-920	10.6	58319.356770492	456.1 ± 0.4	0.60 ± 0.04	4.0 ± 0.3
3[b]				58643.321088777	457 ± 1	0.37 ± 0.05	5.2 ± 0.8
4[c]	CHIME	400-800	17 ± 3	58700.38968	460.4 ± 0.2	$\gtrsim$ 7	6 ± 2

[a] Shannon, R. M., Macquart, J.-P., Bannister, K. W., et al. 2018, Nature, 562, 386
[b] Kumar P., et al., 2019 (arXiv:1908.10026)
[c] CHIME/FRB Collaboration 2019, The Astronomer's Telegram, 13013, 1
[d] Burst time of arrivals are referenced at different frequencies: 1464 MHz for ASKAP, 920 MHz for GBT, and 400 MHz for CHIME.

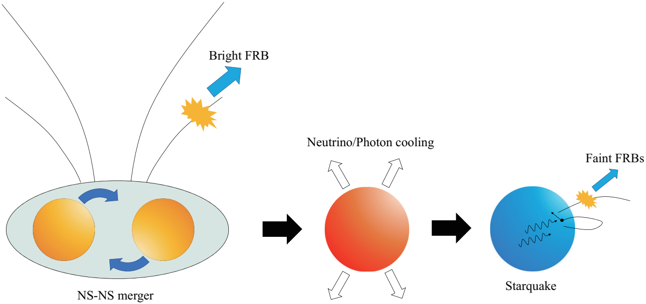
Luminosity





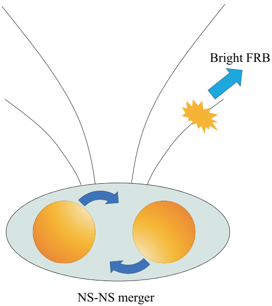
Provided by Rui Luo

A complex model



- One-off burst: unipolar induction at the end of inspiral.
- Repeating bursts: Starquake and magnetic reconnection on the remnant compact star.

Model: One-off burst

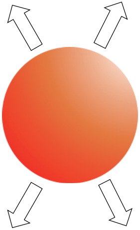


$$
\begin{aligned}
\Omega &= (GM(1+q)/a^3)^{0.5} \\
r_{\rm cap} &\simeq a(\frac{a\Omega}{c})^{0.5} \\
\Phi &\simeq \frac{B\Omega r_{\rm cap}^2}{2c} \\
n_e &= \mathcal{M} n_{\rm GJ} \\
\dot{E} &\simeq \Phi\pi r_{\rm cap}^2 n_e e c \\
L &\sim 10^{-3}\dot{E} \sim 1\times10^{45}{\rm erg/s}
\end{aligned}
$$

(Here L is the luminosity in $10^7 - 10^{11}$Hz.)

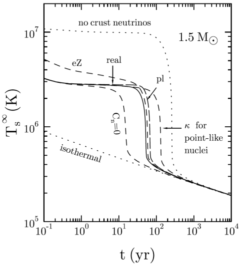
Cooling of the proto-compact star

Neutrino/Photon cooling



Neutron Star

$\sim 10^1 - 10^2$ years

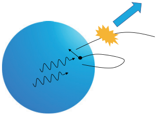


Chamel N., Haensel P., 2008, LRR, 11, 10

Strangeon Star

$$t_{\rm solid} = \frac{E_{\rm in}}{4\pi R^2 \sigma T_p^4} = 7.8 \times 10^6 E_{\rm in,52} R_6^{-4}\ {\rm s} \sim 90{\rm d}$$

Model: Repeating bursts



Electric field generated by magnetic connection

$$E_{\parallel} \simeq \frac{2\pi\sigma_s v_{\rm A} B}{c} = 2.1\times10^{9}\sigma_{s,-3}v_{{\rm A},8}B_{14}\,{\rm esu}$$

Electric field generates plasma

$$n_e \simeq \frac{E_{\parallel}}{4\pi e\lambda} = 3.5\times10^{12}\sigma_{s,-3}\Omega_{{\rm osc},3}B_{14}\,{\rm cm}^{-3}$$

Coherent radiation

$$N_e = \mu n_e(\frac{\gamma_e c}{\nu})^3 = 9.4\times10^{22}\mu_{-1}\eta_1\sigma_{s,-3}\Omega_{{\rm osc},3}B_{14}\gamma_{e,2}^{3}\nu_9^{-3}$$

$$L_{\rm iso} = 8.3\times10^{40}N_{\rm pat}\mu_{-1}\eta_1\sigma_{s,-3}^{2}\Omega_{{\rm osc},3}^{2}B_{14}^{2}\gamma_{e,2}^{8}\nu_9^{-4}\,{\rm erg\,s}^{-1}$$

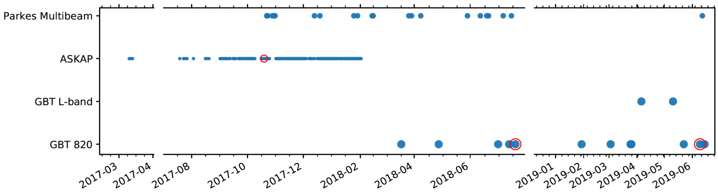
Discussion

Luminosity

	Observation $L_{\rm iso}$	Model $L_{\rm iso}$
ASKAP (merger) burst	6×10^{43}erg/s	$\sim 10^{43}$erg/s
GBT (starquake) bursts	6×10^{40}erg/s	$10^{41} - 10^{42}$erg/s
CHIME (starquake) burst	$> 2 \times 10^{42}$erg/s	

- The luminosity difference between the ASKAP burst and the GBT bursts is consistent with the difference between the merger burst and starquake bursts in our model.
- The luminosity of the CHIME burst is larger than the GBT bursts. This can be explained by an increase of the patch number N_{pat} in the starquake model.
- A repeating burst as luminous as the ASKAP burst would rule out our model.

Discussion: Detection time interval



Kumar P., et al., 2019 (arXiv:1908.10026)

Telescope	Obs Time (h)	TOA (MJD)
ASKAP	986.6	58045.56061371
Parkes	12.4	–
GBT	10.6	58319.356770492 58643.321088777
CHIME	17 ± 3	58700.38968

Time interval limitation

- The 1st GBT burst is ~ 9 months after ASKAP burst.
- There could be undetected bursts in the 9 months.

$\rightarrow \quad t_{solid} \sim 3\,\text{months} \leq 9\,\text{months}$✓

Discussion: DM variation

Jet may change the DM?

$$N_{\rm e} \sim \frac{E_{\rm jet}}{\Gamma m_{\rm p} c^2} \sim \pi (r\theta)^2 l n_{\rm e} \qquad (r \sim c\Delta t)$$

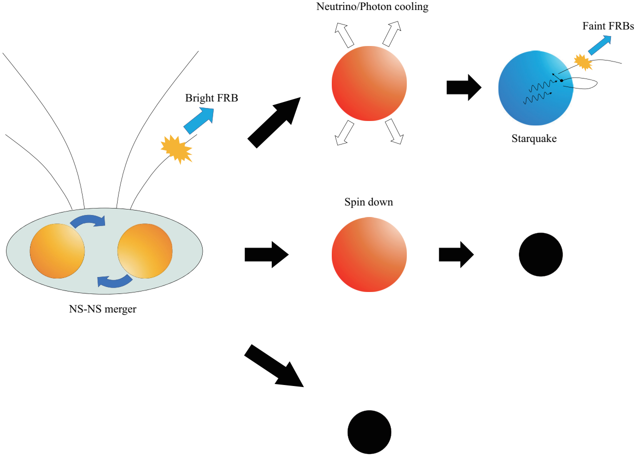
$$\begin{aligned} \mathrm{DM} &= \int_r^{r+l} n_e(r')dr' \sim \frac{E_{\rm jet}}{\pi \Gamma m_{\rm p} c^4 \Delta t^2 \theta^2} \\ &= 7.8 \times 10^{-3} E_{\rm jet,50} \Gamma_2^{-1} \theta_{-1}^{-2} \Delta t_7^{-2}\ \mathrm{pc} \cdot \mathrm{cm}^{-3}. \end{aligned}$$

No significant change of DM.

Telescope	MJD	DM ($\mathrm{pc/cm^3}$)
ASKAP	58045.6	461 ± 1
GBT	58319.4	456.1 ± 0.4
	58643.3	457 ± 1
CHIME	58700.4	460.4 ± 0.2

Discussion: Event rate

The event rate of repeating sources should be smaller than the event rate of NS-NS merger.



Summary

- Observations show the first brighter burst of FRB 171019 followed by three weaker repeaters about one year later.
- We propose a unified frame
  1. The first one-off FRB is generated at the moment before NS-NS or SS-SS merger through, e.g., unipolar inductor mechanism.
  2. The nascent remnant SS takes ~ 100 d to be solidified which accounts for the halcyon period between the one-off burst and the followed repeaters.
  3. After the solidification, starquakes induced by the spin-down of the SS generate the subsequent three weaker repeating FRBs.
- If another bright burst just like the first one of FRB 171019 were to be detected, it would mean that our model should be ruled out.

Thanks!

Appendix: One-off burst

$$\Omega = (GM(1+q)/a^3)^{0.5} \sim 3.7 \times 10^3 \,\mathrm{rad\,s^{-1}}$$

$$r_{\rm cap} \simeq a(\frac{a\Omega}{c})^{0.5} = 1.8 \times 10^6 \left(\frac{M}{1.4\mathrm{M_\odot}}\right)^{\frac{1}{4}} \left(\frac{1+q}{2}\right)^{\frac{1}{4}} a_{6.5}^{\frac{3}{4}} \,\mathrm{cm}$$

$$\Phi \simeq \frac{B\Omega r_{\rm cap}^2}{2c} = 6.2 \times 10^{19} B_{12} \left(\frac{M}{1.4\mathrm{M_\odot}}\right) \left(\frac{1+q}{2}\right) \mathrm{V}.$$

$$n_e = \mathcal{M} n_{\rm GJ} = 4.1 \times 10^{16} \mathcal{M}_3 \left(\frac{M}{1.4\mathrm{M_\odot}}\right)^{\frac{1}{2}} \left(\frac{1+q}{2}\right)^{\frac{1}{2}} a_{6.5}^{-\frac{3}{2}} B_{12} \,\mathrm{cm^{-3}}$$

$$\dot{E} \simeq \Phi \pi r_{\rm cap}^2 n_e e c = 1.3 \times 10^{48} \mathcal{M}_3 B_{12}^2 \left(\frac{M}{1.4\mathrm{M_\odot}}\right)^{\frac{3}{2}} \left(\frac{1+q}{2}\right)^{\frac{3}{2}} a_{6.5}^{-\frac{3}{2}} \,\mathrm{erg\,s^{-1}}$$

$$L \sim 10^{-3} \dot{E} \sim 1 \times 10^{45} \mathrm{erg/s}$$