The global EVN view of the radio counterpart of GW170817

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(Re)solving the jet/cocoon riddle of the first gravitational wave electromagnetic counterpart

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If GW/GRB 170817 had a standard jet ($\theta_{\text{jet}} \sim 10 \text{ deg}$)

$$P(< \theta_{\text{jet}} = 10^\circ) = 1.5\%$$

Alternatives

- Ultrarelativistic ($\Gamma \sim 100$) jet OFF-AXIS
- Mildly relativistic ($\Gamma \sim 7$) isotropic outflow
- Isotropic blast wave

Solve the probability issue
Account for the low luminosity
Debeaming

Peak position:
- Dynamics,
- Geometry
- Orientation

If GW/GRB 170817 had a standard jet ($\theta_{\text{jet}} \sim 10 \text{ deg}$)
Alternatives + Modifications

- Isotropic blast wave
- Off-axis jet
- Solve the probability issue
- Account for the low luminosity
- Shallow rise phase as $t^{0.8}$

$\Gamma_1 < \Gamma_2 < \Gamma_3$
$E_1 > E_2 > E_3$

$G_1 > G_2 > G_3$
$E_1 > E_2 > E_3$

Mooley+2018; Nakar+2018; Troja+2018; Margutti+2018; Xie+2018; D’Avanzo+2018; …

The first 20 days

One year of (mostly radio) observations
Origin of structure

Isotropic blast wave

Off-axis jet

Solve the probability issue

Account for the low luminosity

Shallow rise phase as $t^{0.8}$

$G_1 < G_2 < G_3$

$E_1 > E_2 > E_3$

Choked jet (not successful)

Structured Jet (successful)

$E_{\text{jet}} < E_{\text{ejecta}}$

In both cases the radial or angular structure may be due to the interaction of the jet head with the merger ejecta

Perego+2017

Bromberg+2011

Kilonova ejecta

Jet’s head & contact discontinuity

Contact discontinuity

remnant disk

Jet

Outer Cocoon

Inner Cocoon

Kilonova ejecta
$E(\Gamma \beta) = E_0 (\Gamma \beta)^{-\alpha}$

$E_0 = 1.5 \times 10^{52} \text{ erg}$

$\alpha = 6$

$\Gamma_{\text{max}} = 6$

$\Theta = 30, 45, 60 \text{ deg}$

$p = 2.15; \varepsilon_e = 0.1; \varepsilon_B = 10^{-4}$

$E_{\text{core}} = 2.5 \times 10^{52} \text{ erg}; s_1 = 5.5$

$\Gamma_c = 250; s_2 = 3.5; \vartheta_{\text{core}} = 3.4 \text{ deg}$

$n_{\text{ism}} = 4 \times 10^{-4} \text{ cm}^{-3}; \vartheta_{\text{view}} = 15 \text{ deg}$

$E_{K, \text{iso}}(\theta) = \frac{E_{\text{core}}}{1 - (\theta/\theta_{\text{core}})^{s_1}}$

$\Gamma(\theta) = 1 + \frac{\Gamma_{\text{core}} - 1}{1 + (\theta/\theta_{\text{core}})^{s_2}}$
Contribute:
1) Magnetic field configuration
   (randomness & compression)
2) $\Gamma$
3) Geometry ($\theta_{\text{jet}}$; $\theta_{\text{view}}$
4) Emission mechanism

$\Pi < 12\% \ (90\%)$

Still compatible with a structured jet with B component perp. shock
Structured jet has larger displacement and smaller size than cocoon
Imaging


Global-VLBI EVN project (GG084) + eMERLIN (CY6213) {EVN (RG009)}

12-13 March 2018 = 204.7 days @ 5 GHz (32 ant. but VLA)

8 μJy/beam rms

Peak brightness 42 ± 8 μJy/beam [cnst. interpolating closest JVLA F=47±9 μJy]

8-22 March (12 runs) eMERLIN

F_p < 60 μJy/beam

beam = 3.5x1.5 mas; PA=-6 deg

S = 2.9 mas (1DGaussian fit but F=93 μJy)

S = 1.3±0.6 mas (2DGaussian fit with F=47 μJy)
Imaging


Structured jet model

Cocoon (30 deg)

Cocoon (45 deg)
Bayesian approach (MonteCarlo implementation)

\[
P(\sigma_x, \sigma_y, F|F_p) = \frac{P(F_p|\sigma_x, \sigma_y, F)P(F)P(\sigma_x, \sigma_y)}{P(F_p)} = \int \frac{P(F_p|\sigma_x, \sigma_y, F)P(F)P(\sigma_x, \sigma_y)}{P(F_p)} dF
\]

Probability of excluding a size \((\sigma_x, \sigma_y)\) given that we measure a peak brightness of \(42\pm8\ \mu\text{Jy/beam}\)

Size (Bayesian) test → Structured Jet P=70%
Imaging

(II) apparent motion [Mooley+2018]

VLBA + VLA + GBT: 2/4 epochs (Sept 2017 – Apr. 2018, L,S,C,C) @ <75d> and <230d> (4.5 GHz)

230 days

75 days

HSA

EVN

2.7 ± 0.3 mas
At least 10% of BNS launch a jet that successfully breaks out of the merger ejecta.
Conclusions

GW/GRB170817: did a relativistic narrow jet or a cocoon produce the (non-thermal) long lived afterglow emission?

Multi-wavelength modeling of $L(t)$ (10-240 days) cannot tell apart the two scenarios.

High resolution radio observations:

- Imaging:
  1. Size < 3 mas (95%) @ 204.7 days (EVN global VLBI)
  2. Proper motion 2.7 mas @ 75-230 days (HSA)

At least 10% of BNS might produce a jet that breaks out of the polar ejecta. Jet structure due to interaction with merger ejecta.

Thank you EVN!

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