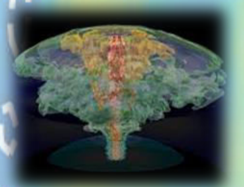
The global EVN view of the radio counterpart of GW170817



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University Milano Bicocca

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

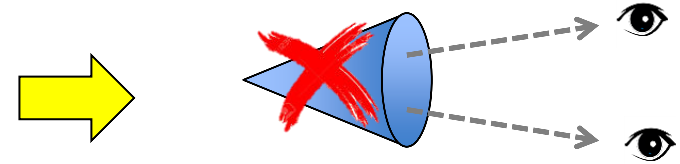
arXiv:18081.00469

Ghirlanda, Salafia, Paragi, Giroletti, Yang, Marcote, Blanchard, Agudo, An, Bernardini, Beswick, Branchesi, Campana, Casadio, Chassande–Mottin, Colpi, Covino, D'Avanzo, D'Elia, Frey, Gawronski, Ghisellini, Gurvits, Jonker, van Langevelde, Melandri, Moldon, Nava, Perego, Perez-Torres, Reynolds, Salvaterra, Tagliaferri, Venturi, Vergani, Zhang

14th European VLBI Network Symposium and Users Meeting _ 8-11/10/2018 _ Granada/ES

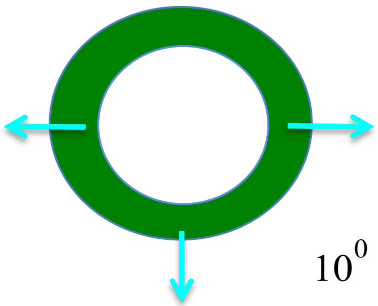
If GW/GRB 170817 had a standard jet ($\vartheta_{jet} \sim 10$ deg)

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

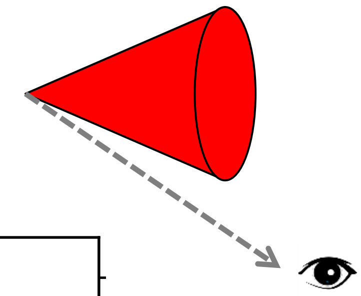


Alternatives

Isotropic blast wave

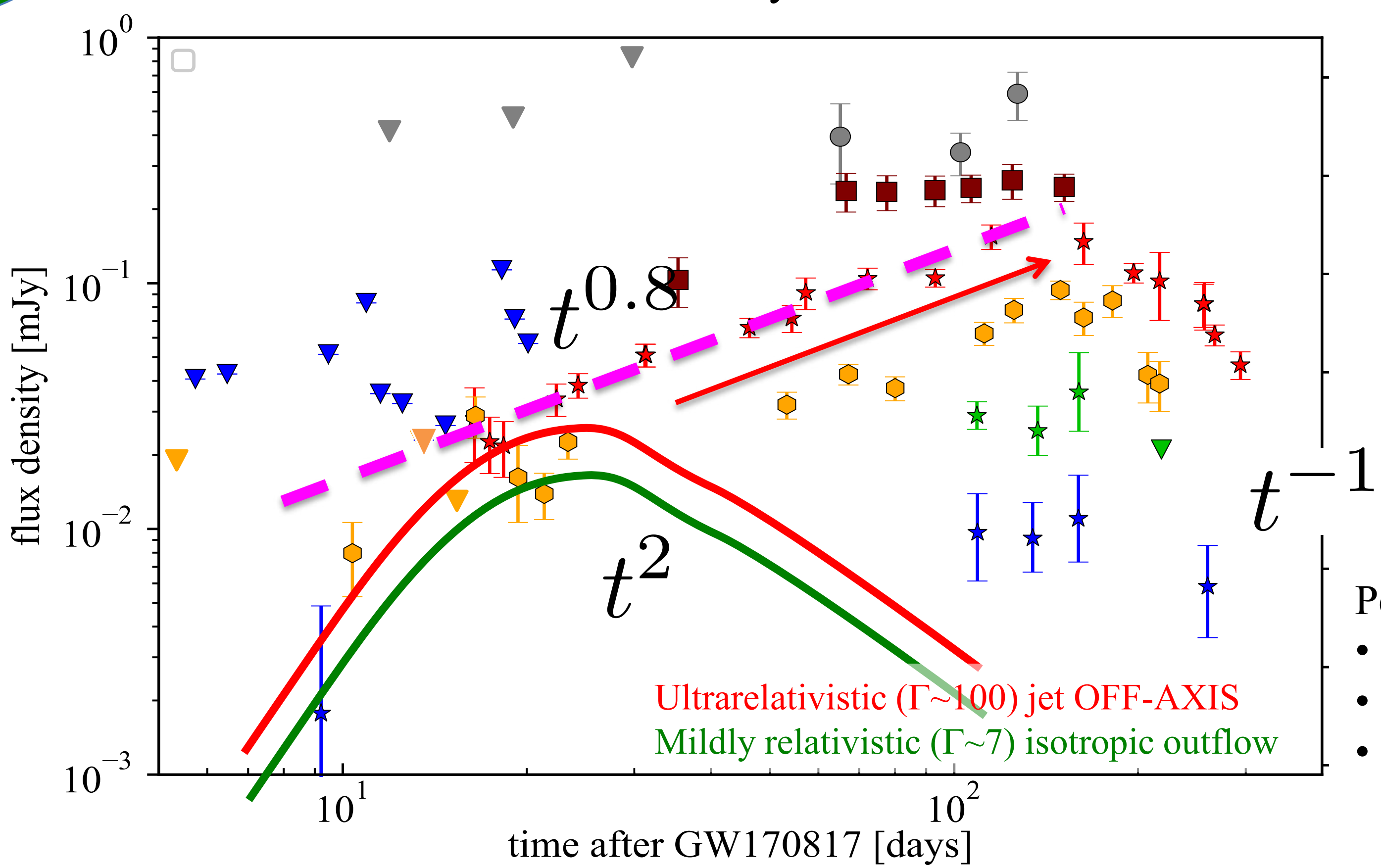


Off-axis jet



Solve the probability issue

$\Gamma \leq 10$ → Account for the low luminosity ← Debeaming

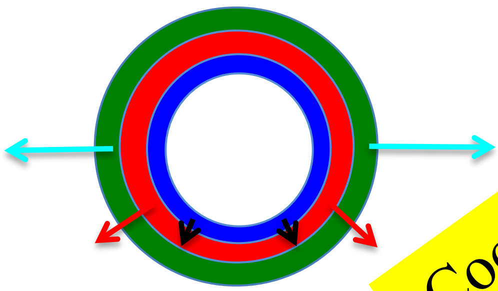


Peak position:

- Dynamics,
- Geometry
- Orientation

Alternatives + Modifications

Isotropic blast wave



+ radial structure

$\Gamma_1 < \Gamma_2 < \Gamma_3$

$E_1 > E_2 > E_3$

Cocoon

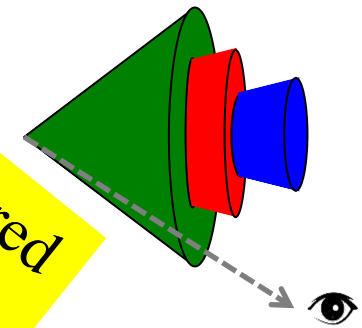
Solve the probability issue

Account for the low luminosity

Shallow rise phase as $t^{0.8}$

Structured jet

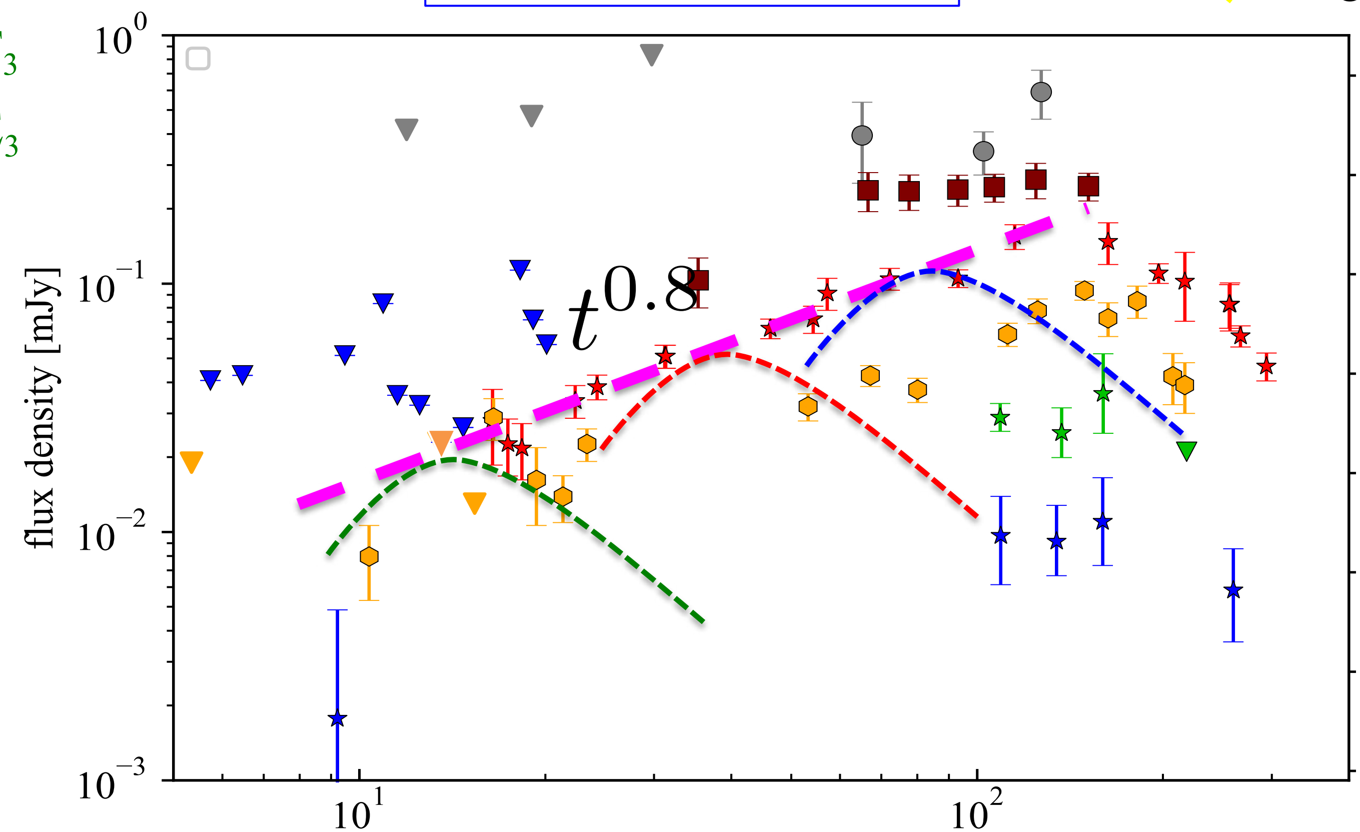
Off-axis jet



+ angular structure

$\Gamma_1 > \Gamma_2 > \Gamma_3$

$E_1 > E_2 > E_3$



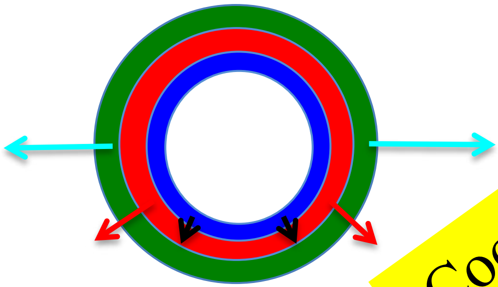
Mooley+2018;
Nakar+2018; Troja+2018;
Margutti+2018; Xie+2018;
D'Avanzo+2018 …

The first 20 days

One year of (mostly radio) observations

Origin of structure

Isotropic blast wave



Cocoon

+ radial structure

$\Gamma_1 < \Gamma_2 < \Gamma_3$

$E_1 > E_2 > E_3$

$E_{jet} < E_{ejecta}$

Choked jet
(not sucessful)

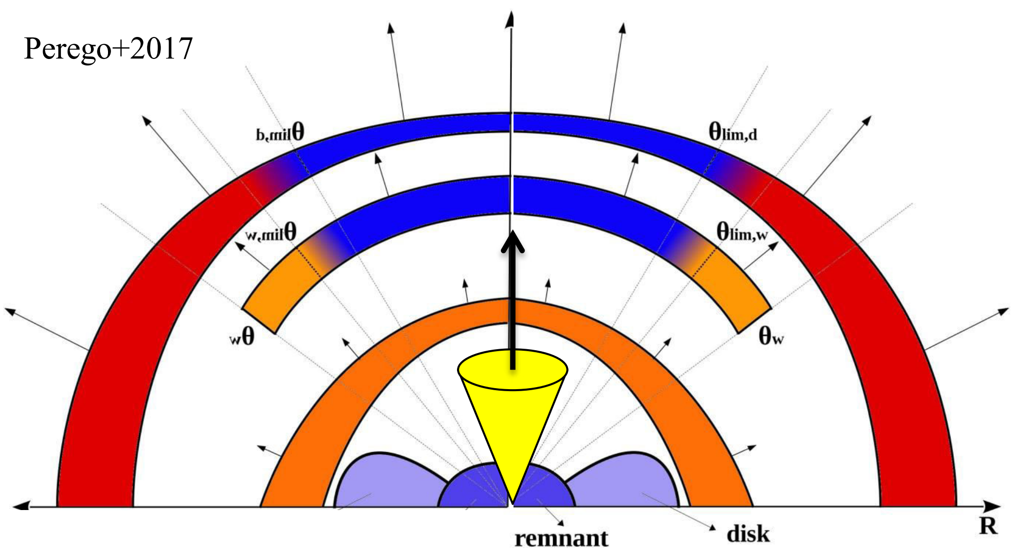
with some
degree of
anisotropy

Solve the probability issue

Account for the low luminosity

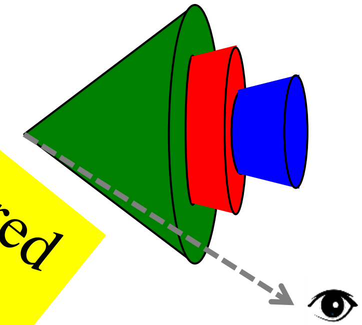
Shallow rise phase as $t^{0.8}$

Perego+2017



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

Off-axis jet



Structured jet

+ angular structure

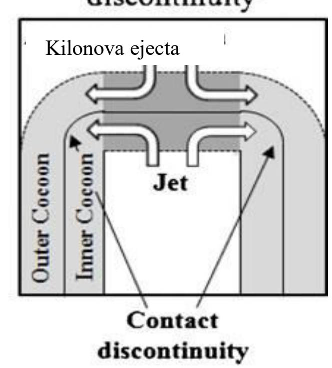
$\Gamma_1 > \Gamma_2 > \Gamma_3$

$E_1 > E_2 > E_3$

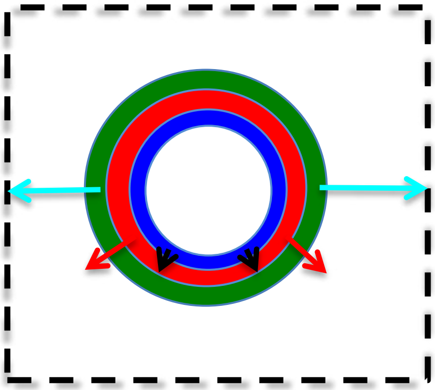
$E_{jet} < E_{ejecta}$

Structured Jet
(sucessful)

Jet's head & contact discontinuity

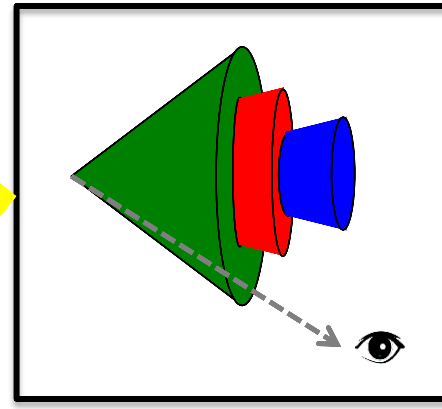


Bromberg+2011



Cocoon

Structured jet



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

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

$\alpha = 6$

$\Gamma_{max} = 6$

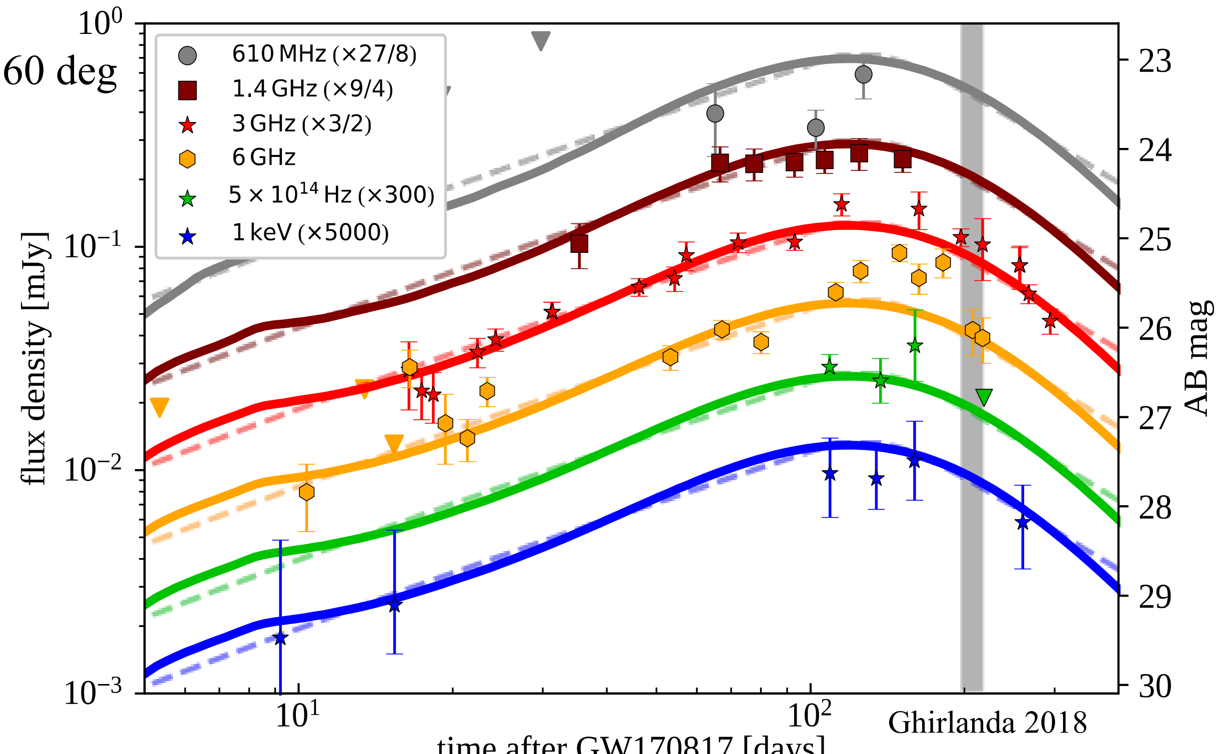
$\Theta = 30, 45, 60$ deg

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

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

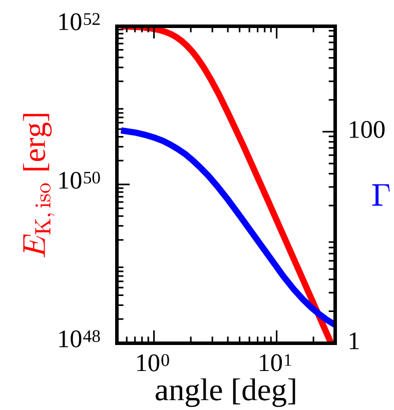
$\Gamma_c = 250$; $s_2=3.5$; $\vartheta_{core}=3.4$ deg

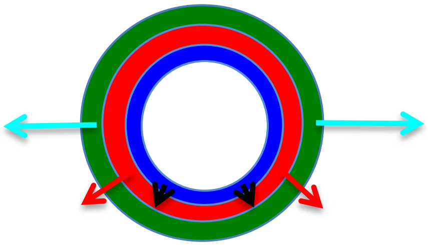
$n_{ism}=4\text{x}10^{-4}$ cm^{-3} ; $\vartheta_{view}=15$ deg



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

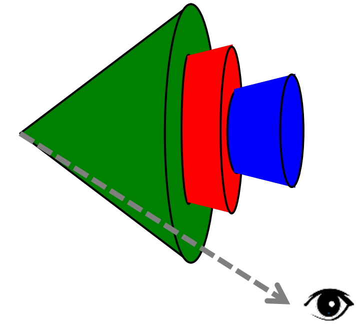
$$\Gamma(\theta) = 1 + \frac{\Gamma_{\rm core}-1}{1+(\theta/\theta_{\rm core})^{s_2}}$$





Cocoon

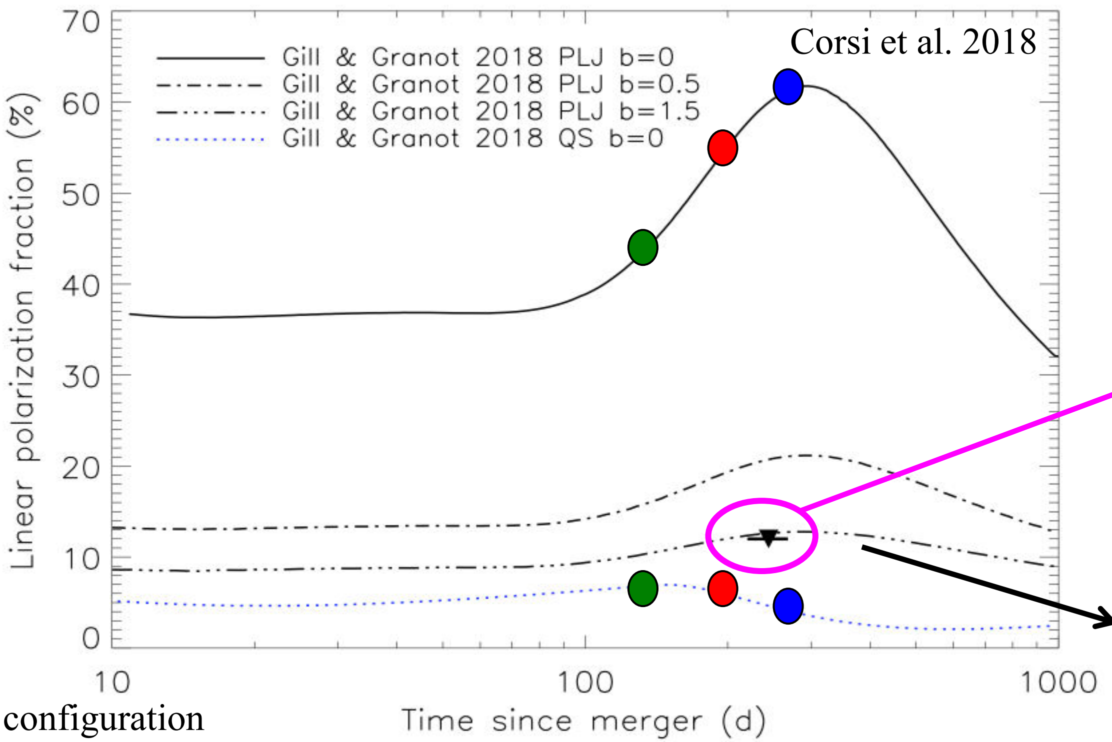
Structured jet



Polarization

[Rossi+2004 … Gill & Granot 2018; Nakar+2018; Lazzati+2018]

$$b = 2\frac{< B_{\perp} >}{< B_{\parallel} >}$$



JVLA @ 244d, 2.8 GHz

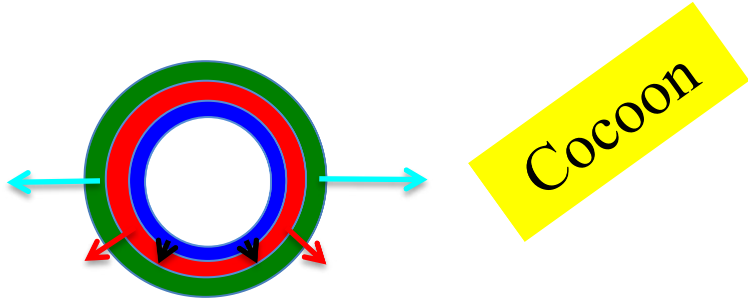
Π<12% (90%)

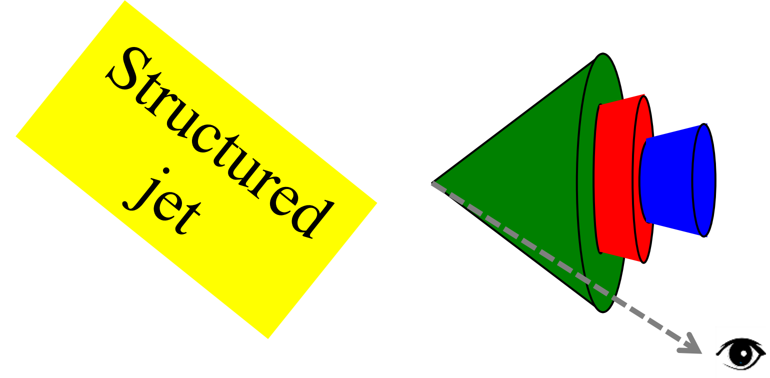
Corsi et al. 2018

Still compatible with a structured jet with B component perp. shock

Contribute:

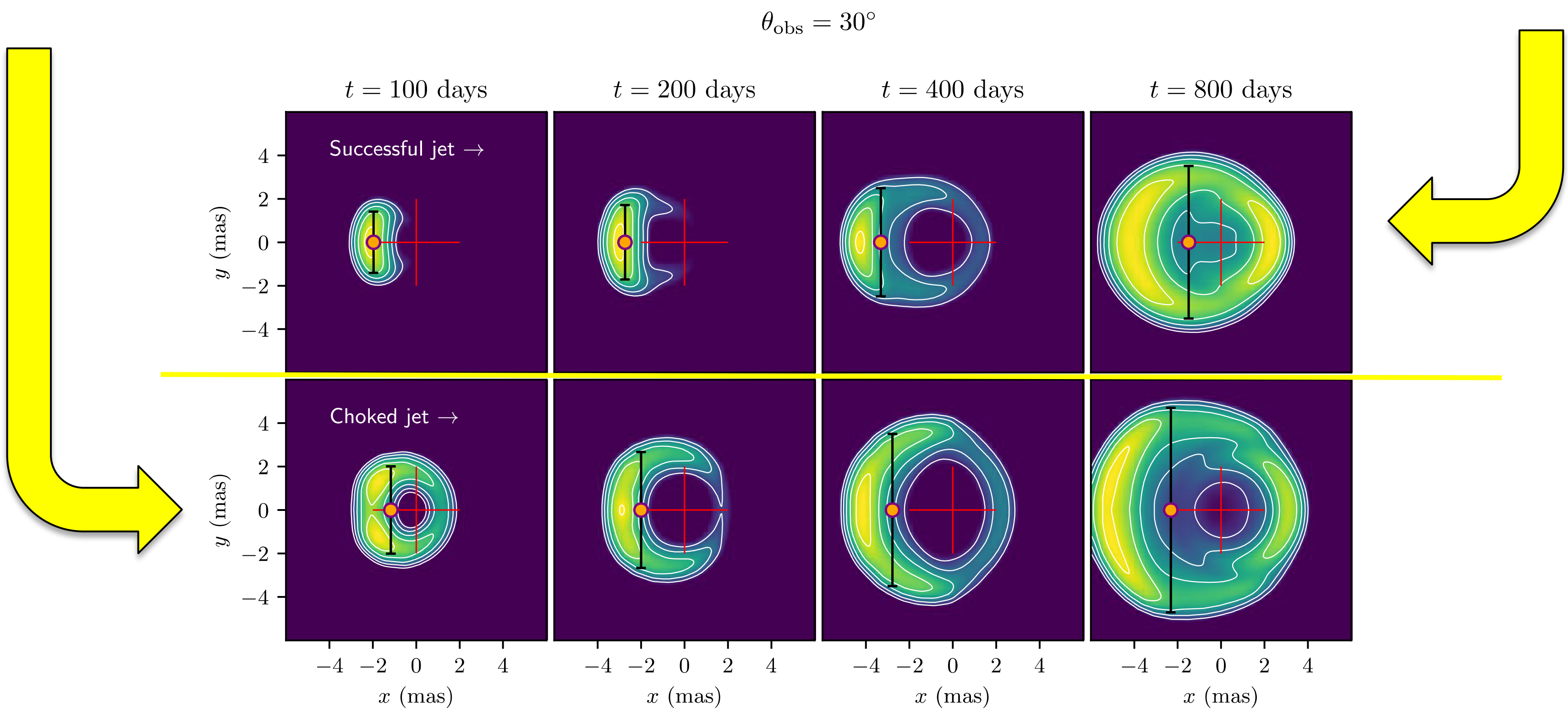
1) Magnetic field configuration (randomness & compression)
2) Γ
3) Geometry (ϑ_{jet} ; ϑ_{view}
4) Emission mechanism



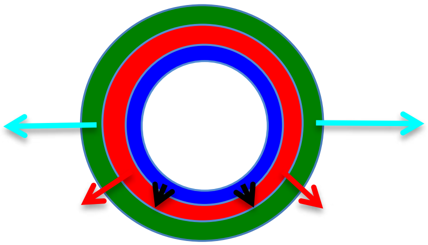


Imaging

[Gill & Granot 2018; Nakar+2018; Zrake+2018; Mooley+2018; Ghirlanda+2018]



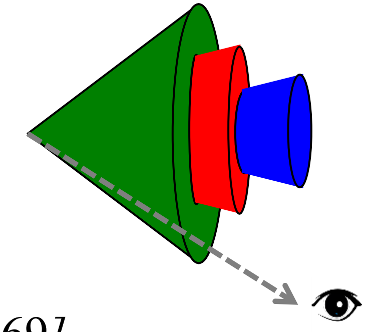
Structured jet has larger displacement and smaller size than cocoon



Cocoon

Imaging

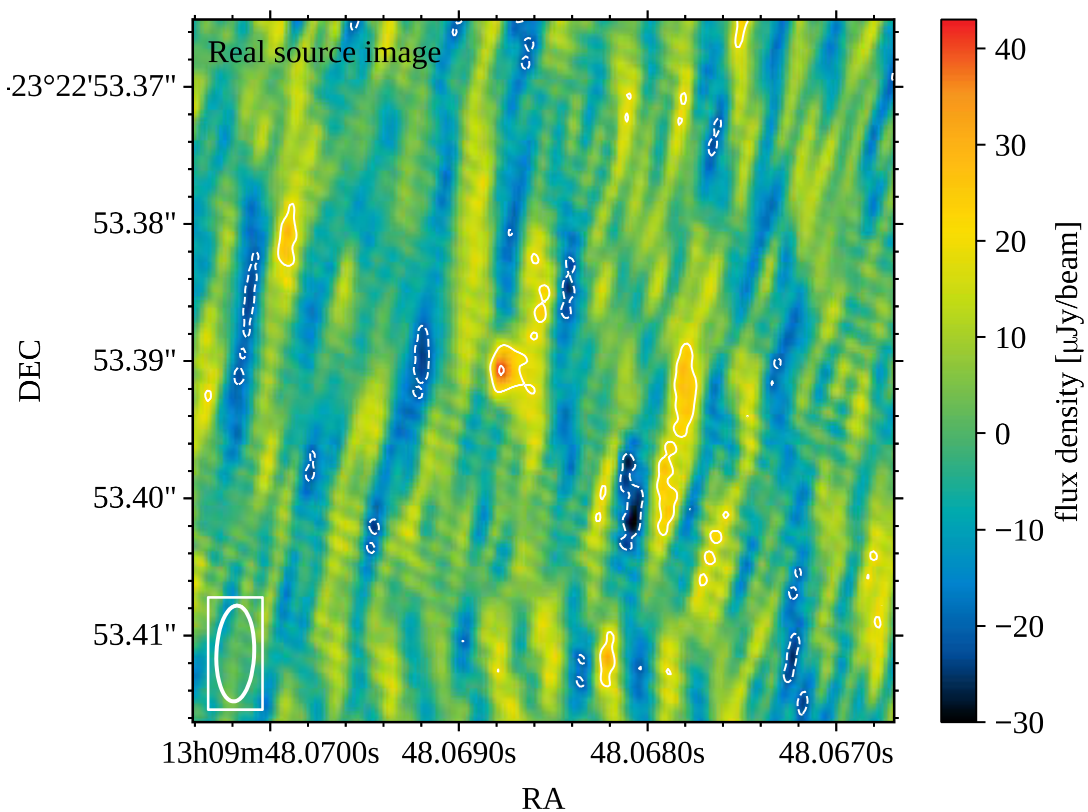
Structured jet



(I) Size constraint *[Ghirlanda+2018* arXiv:18081.00469*]*

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

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

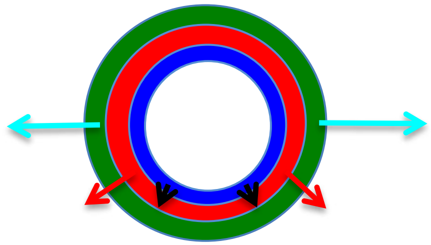


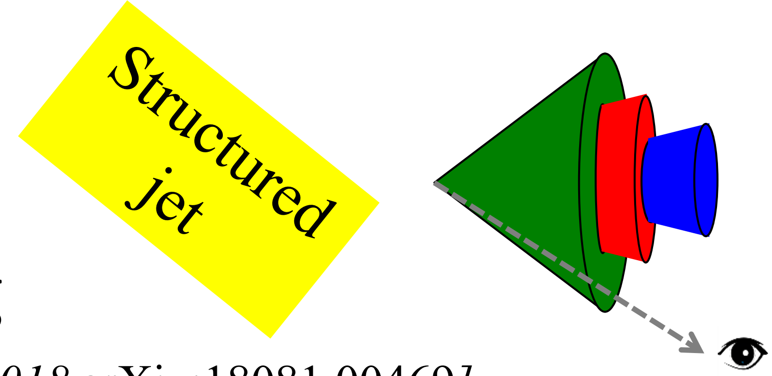
8 μJy/beam rms

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

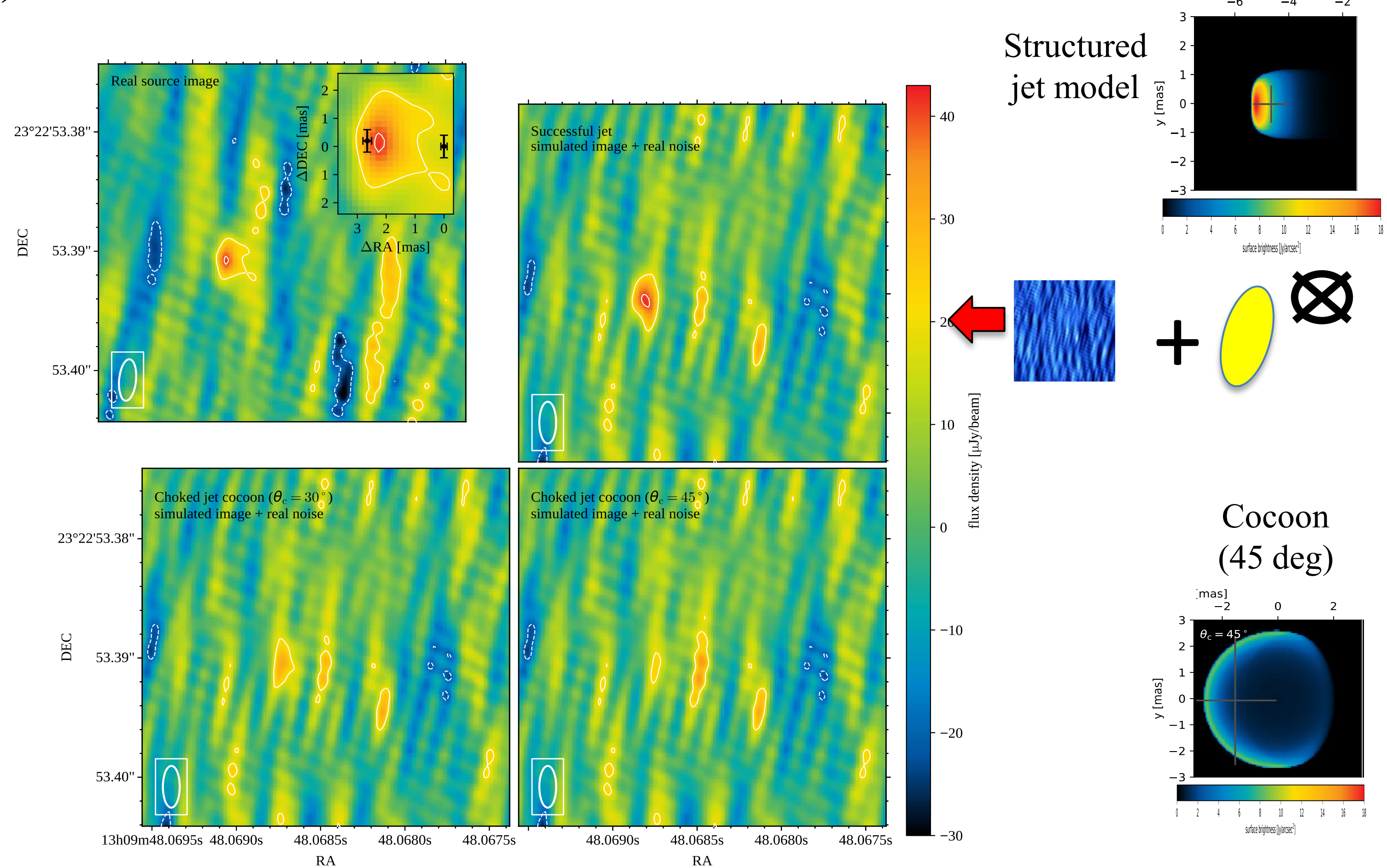
beam = 3.5x1.5 mas; PA=-6 deg
S =2.9 mas (1DGaussian fit but F=93 μJy)
S =1.3±0.6 mas (2DGaussian fit with F=47 μJy)

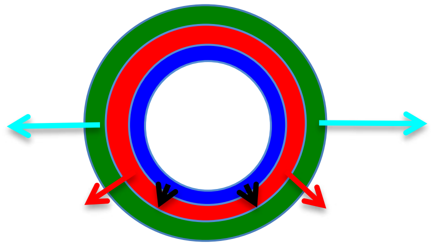




Imaging

(I) Size constraint *[Ghirlanda+2018* arXiv:18081.00469*]*

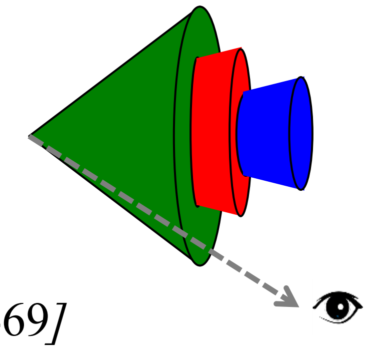




Cocoon

Imaging

Structured jet



(I) Size constraint *[Ghirlanda+2018* arXiv:18081.00469*]*

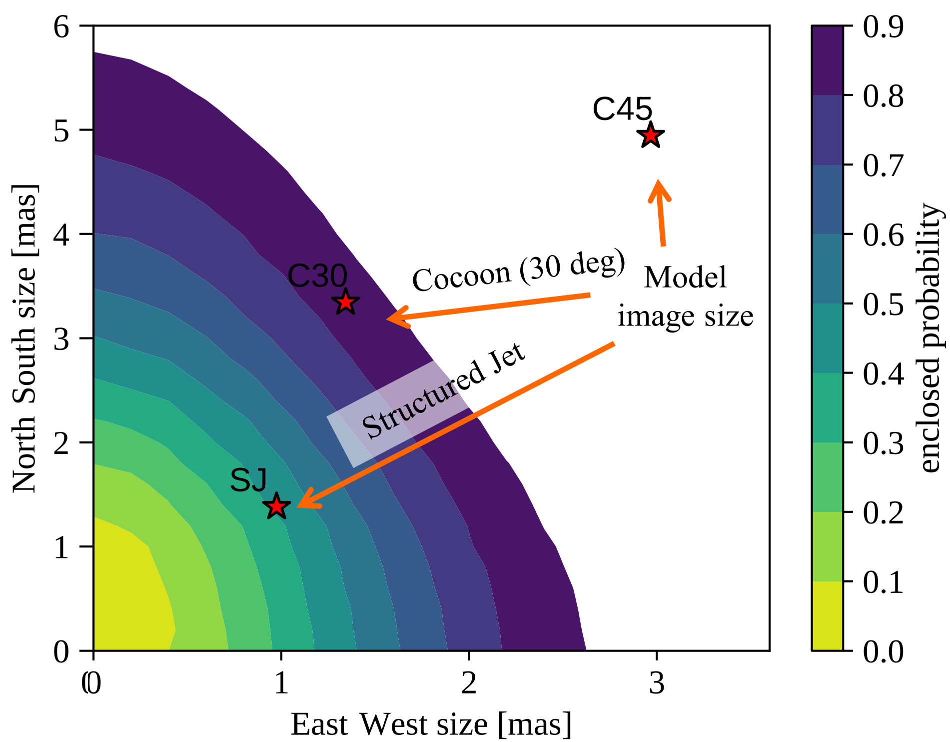
Bayesian approach (MonteCarlo implementation)

$$P(\sigma_x, \sigma_y, F|F_p) = \frac{P(F_p|\sigma_x, \sigma_y, F)P(F)P(\sigma_x, \sigma_y)}{P(F_p)}$$

$P(F)$: Gauss prior (47±9 μJy)

$P(\sigma_x, \sigma_y)$: Flat prior

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

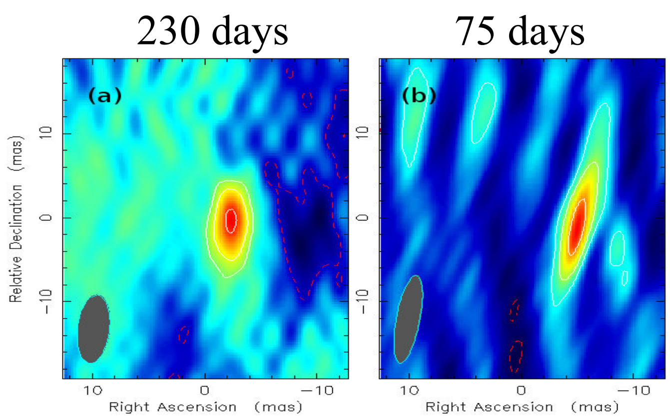


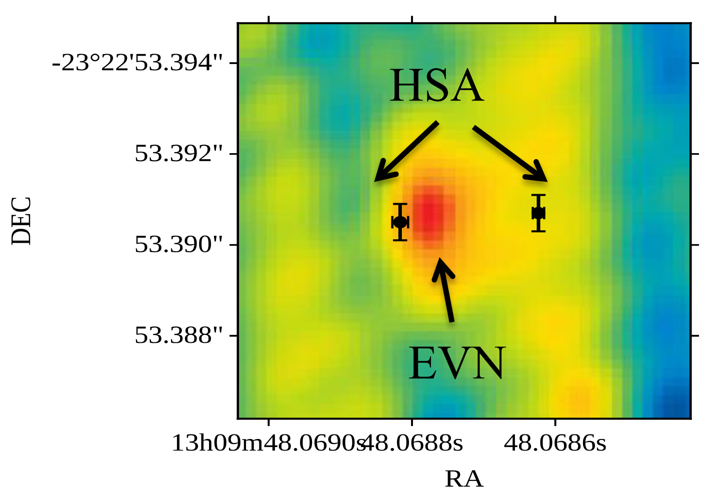
Probability of excluding a size (σ_x σ_y) given that we measure a peak brightness of 42±8 μJy/beam

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

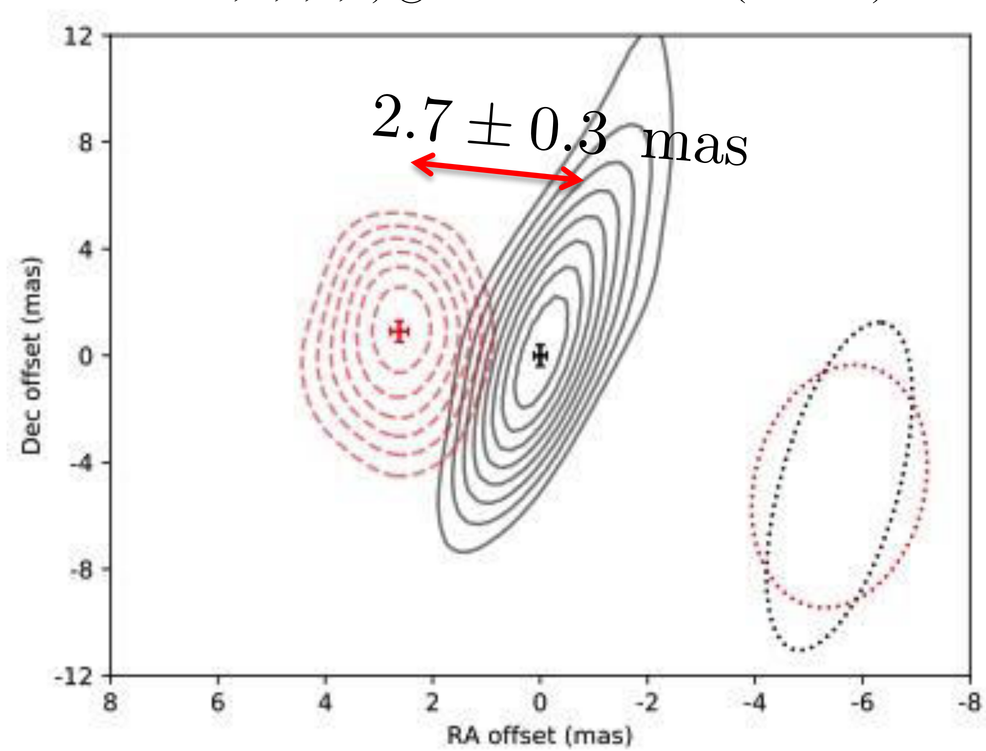
Imaging

(II) apparent motion *[Mooley+2018]*



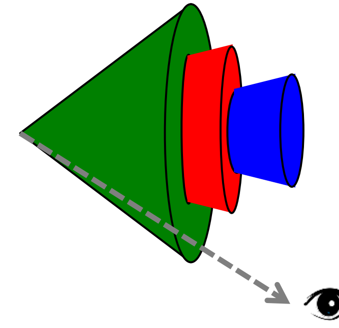


VLBA + VLA + GBT: 2/4 epochs (Sept 2017 – Apr. 2018, L,S,C,C) @ <75d> and <230d> (4.5 GHz)



Jets and rates

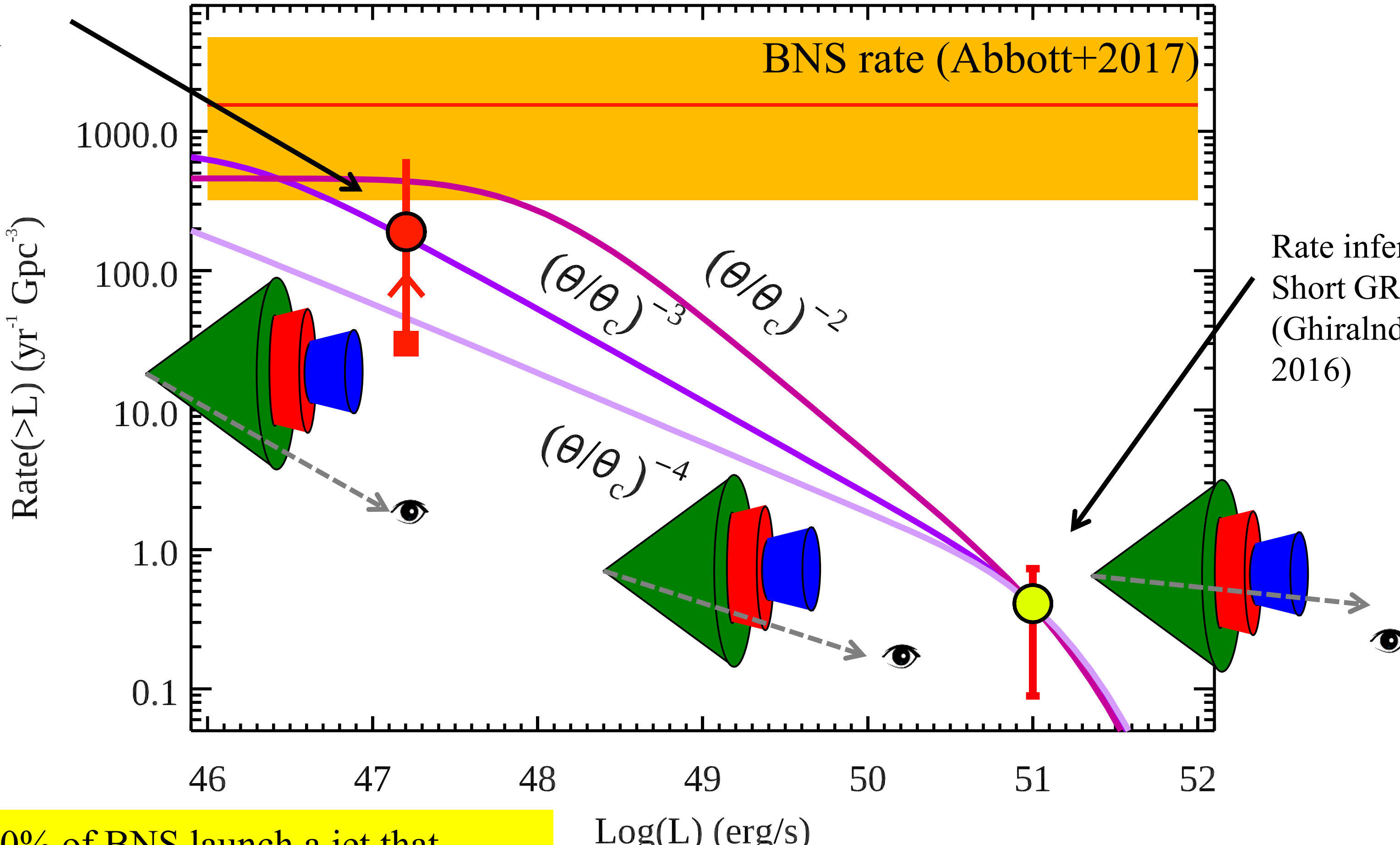
Structured jet



Structured jet model (universal structure) → Luminosity function (Pescalli et al. 2015; Salafia et al. 2015)

Rate infered from Fermi detection

Rate infered from Short GRBs (Ghiralnda et al. 2016)



At least 10% of BNS launch a jet that succesfully 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:
  [Polarization (<12% but geometry or B?)]
  - ✓ Imaging:
    1. Size < 3 mas (95%) @ 204.7 days (EVN global VLBI)
    2. Proper motion 2.7 mas @ 75-230 days (HSA)

  ⇒ Relativistic structured jet

- 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!

This presentation has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet].