Short Gamma Ray Bursts: what we have learnt from GRB/GW170817

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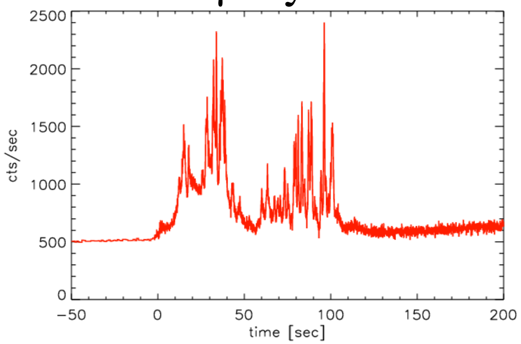
1) What is a Gamma Ray Burst
2) What 170817 tells us about short GRB jets
3) Extend to the population of short GRBs

Gronignen– 2019/03/26

Gamma Ray Bursts

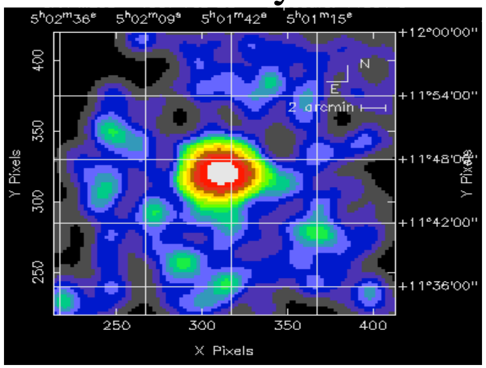
>1973
Short flashes of keV photons
PROMPT

γ-ray

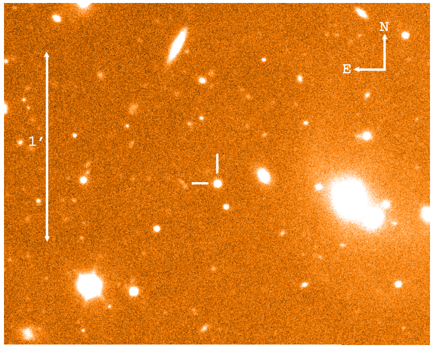


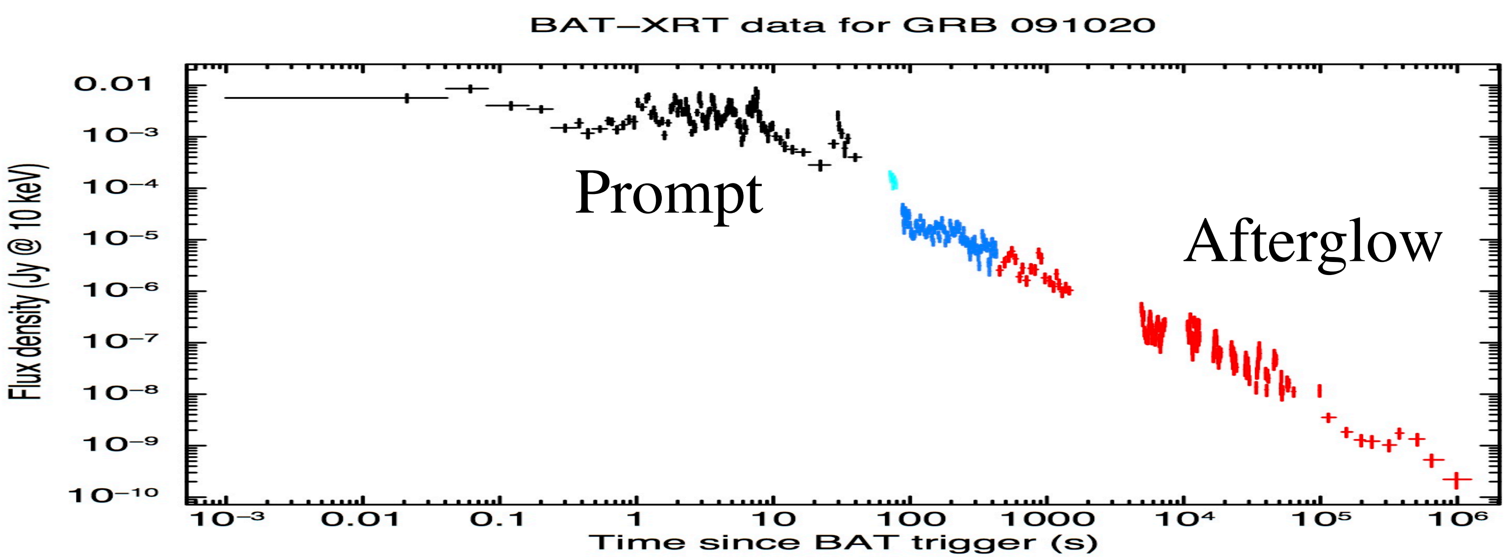
>1997
Accompained by emission at lower frequencies
AFTERGLOW

X-ray



Optical

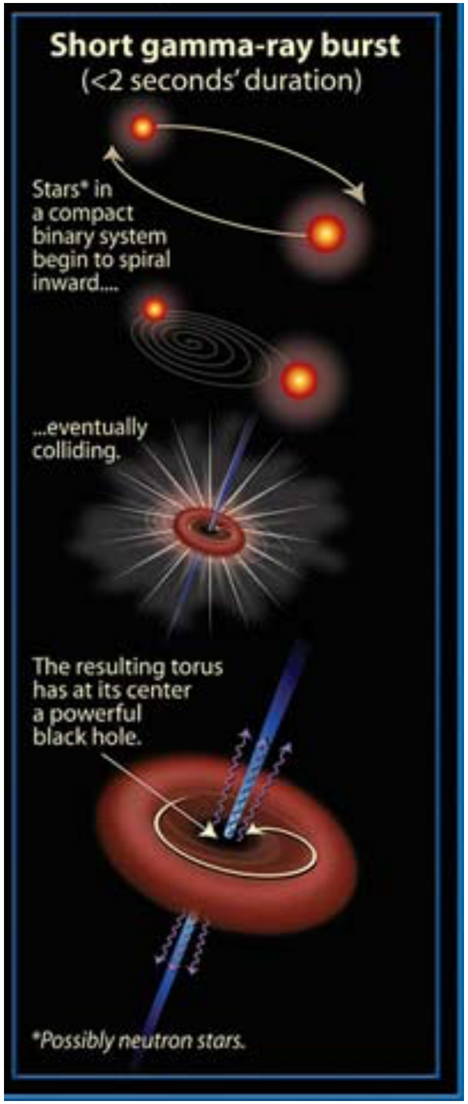


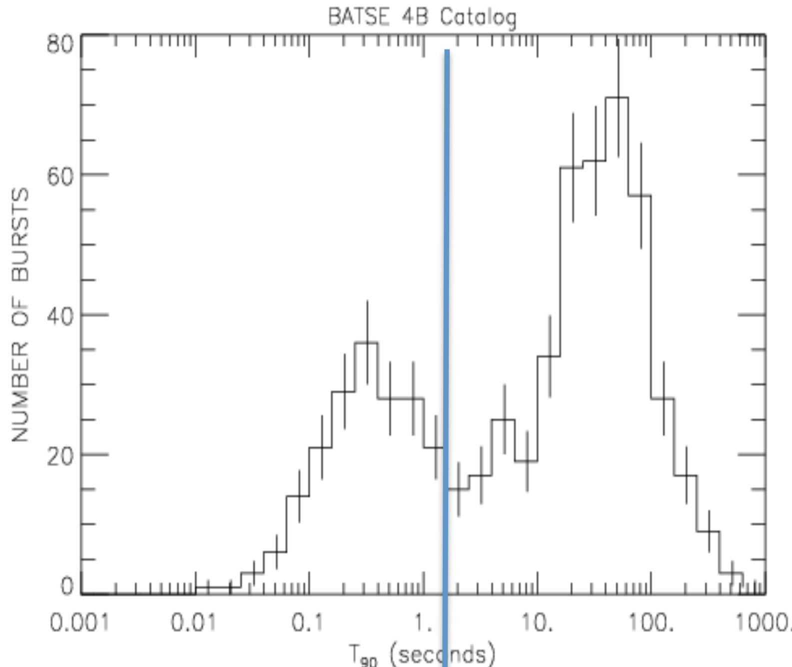


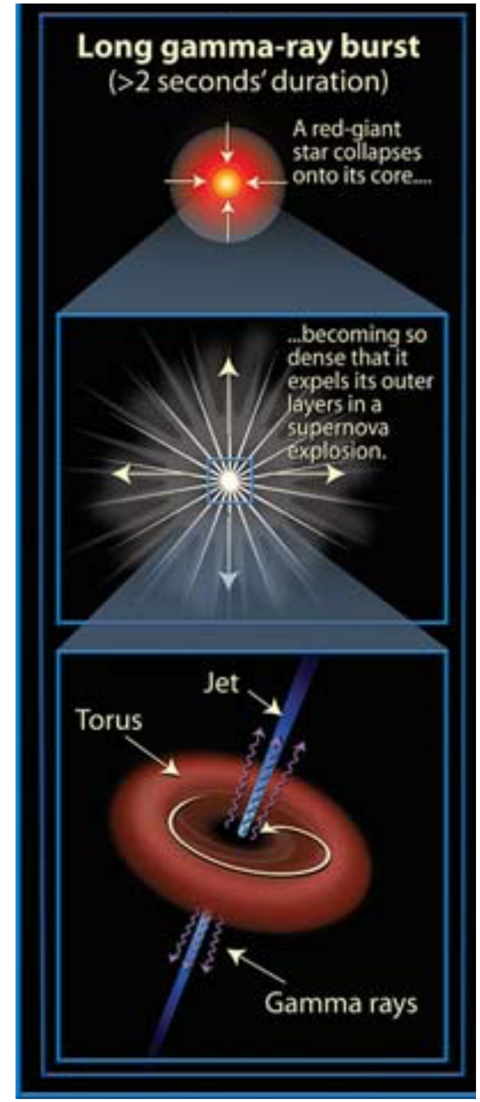
http://www.swift.ac.uk/burst_analyser/

(e.g. Piran 2004, RMP)

Gamma Ray Bursts





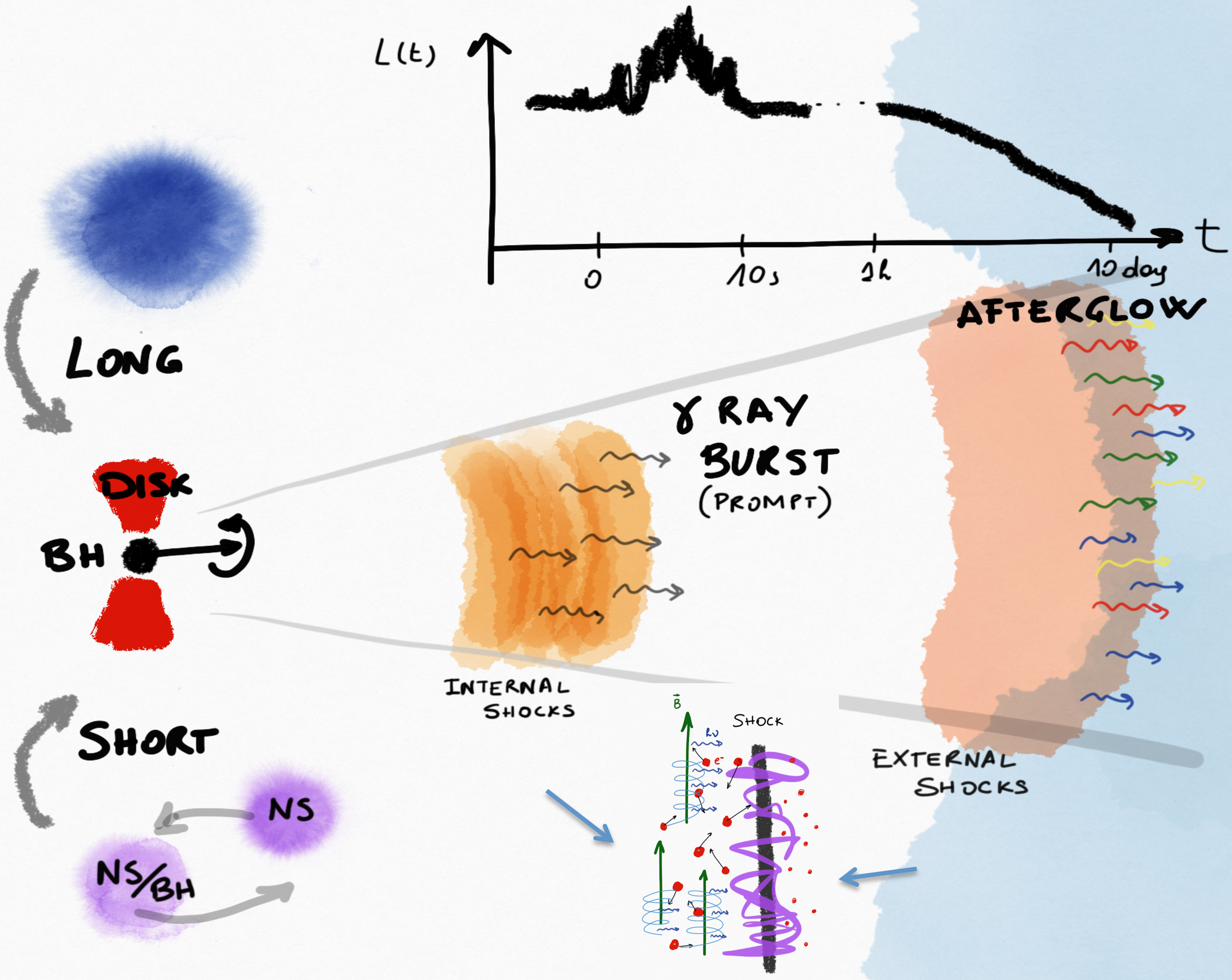


Progenitor	NS-NS(BH) (1)	Single M>> (some)
Energy	10^{49-53} erg	10^{48-54} erg
Spectra	Harder	Softer
Afterglow	Fainter	

duration ←→ central engine activity

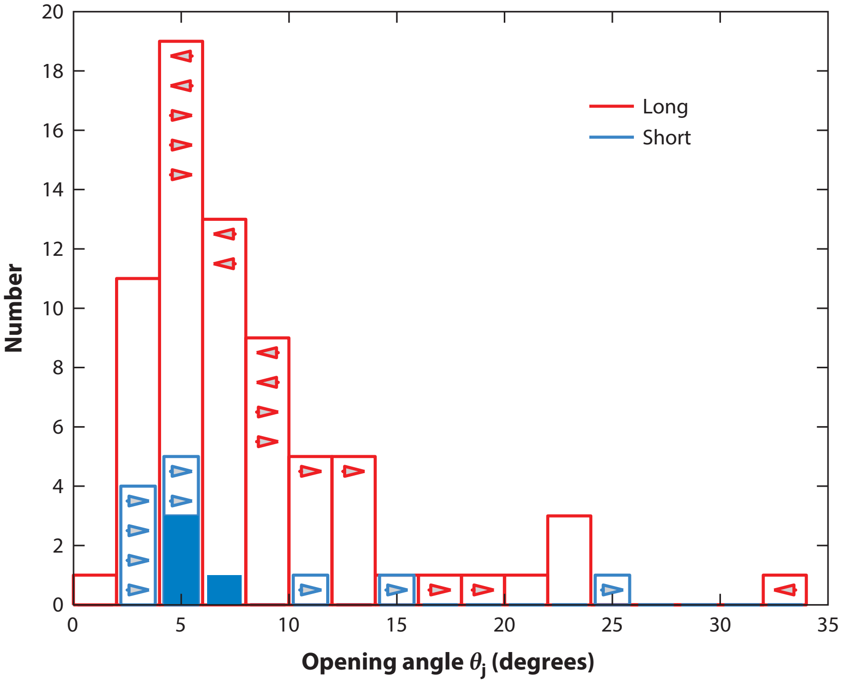
Relativistic jets

Gamma Ray Bursts

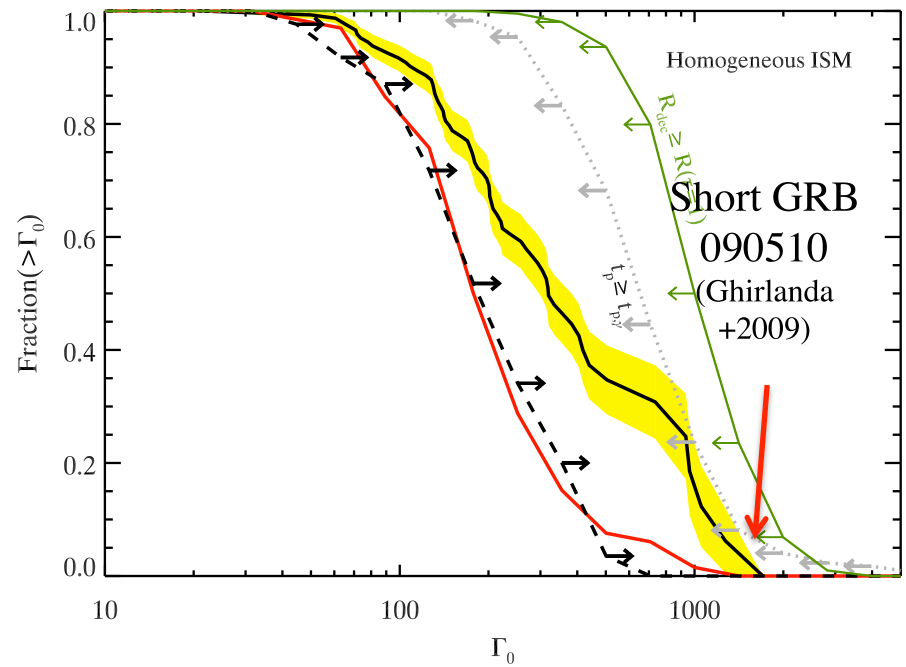


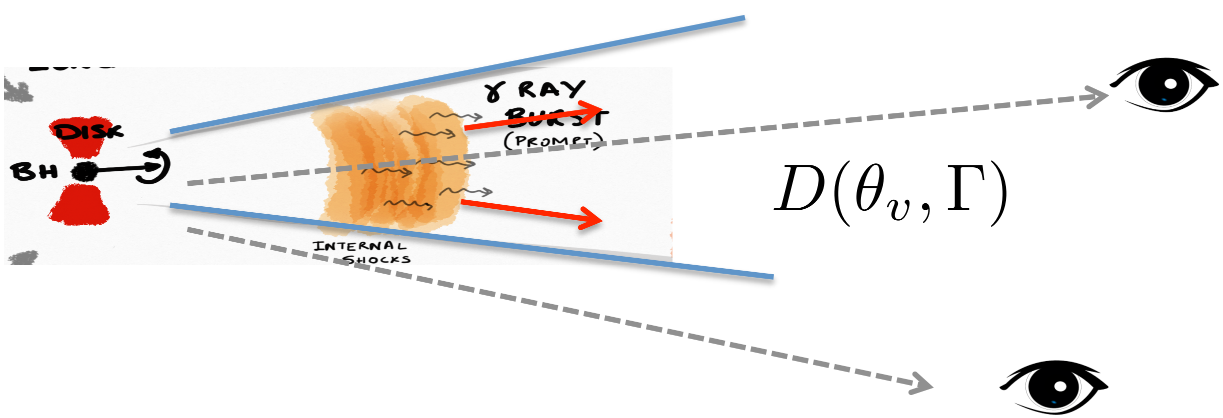
1 GRBs: collimation and relativistic beaming

Fong et al. 2016

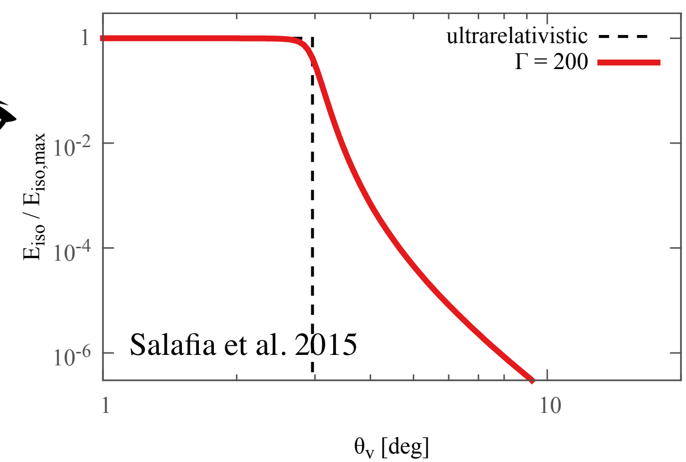


GG et al. 2018

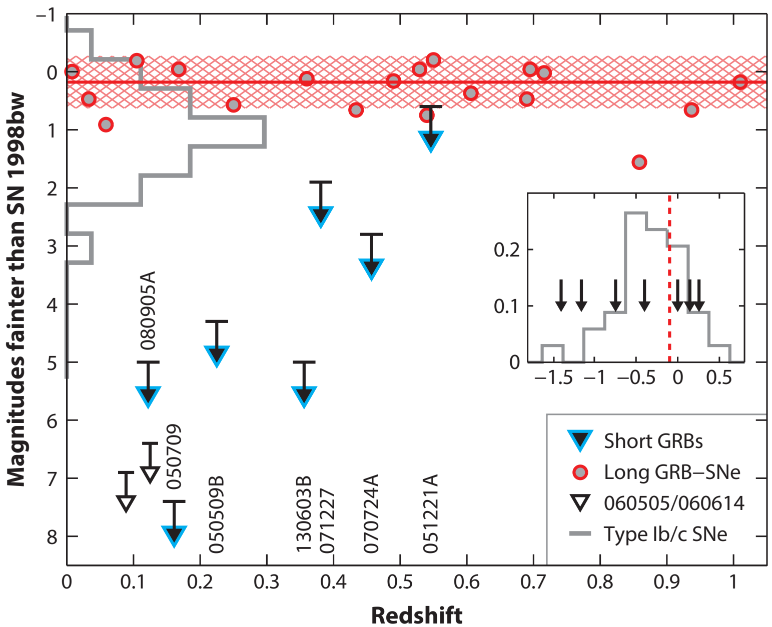


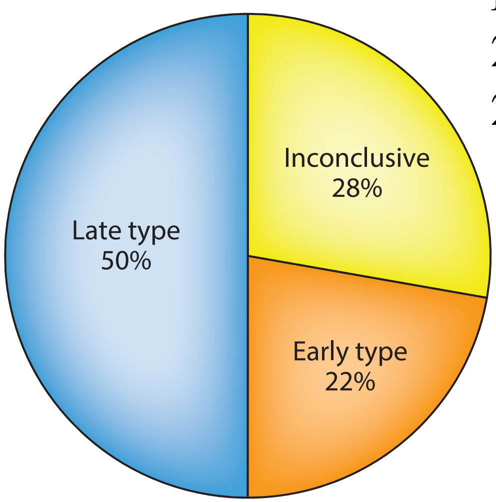


$$D(\theta_v, \Gamma)$$

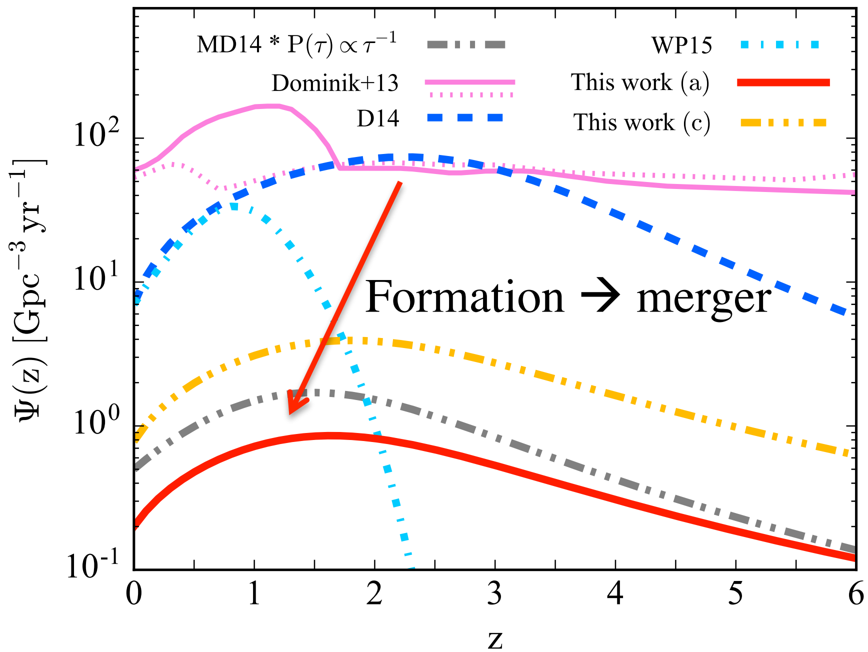


1 Clues on short GRB progenitors





Berger et al. 2010, 2013; Fong et al. 2013



Ghirlanda et al. 2016

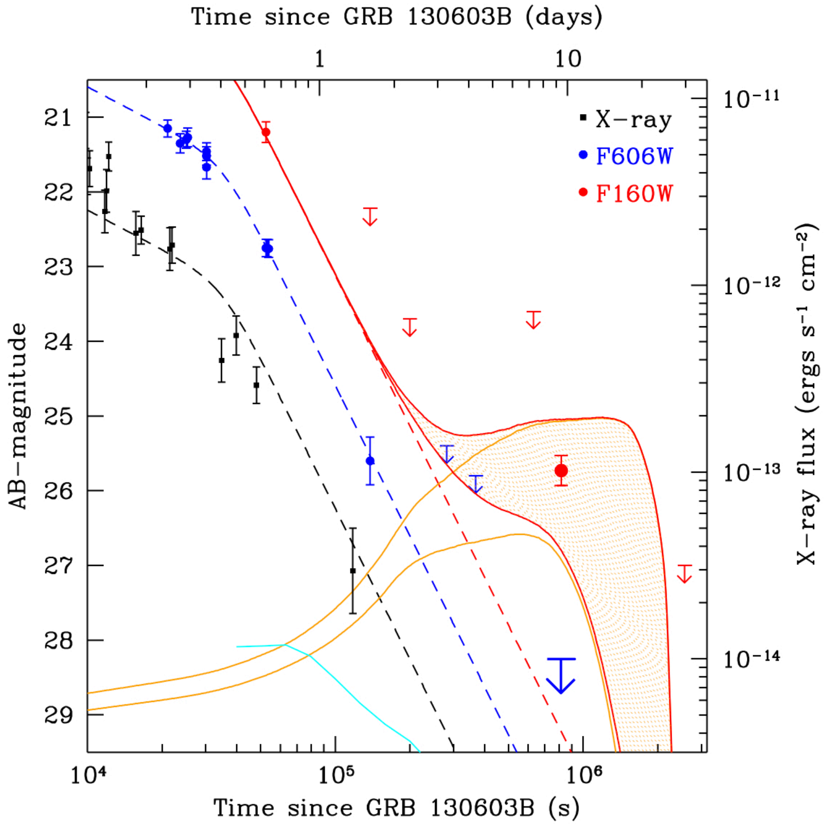
Kilonova ?

Li & Paczyński 1998; Kulkarni 2005; Rosswog 2005; Metzger et al. 2010 …

Kilonova

Before 2017

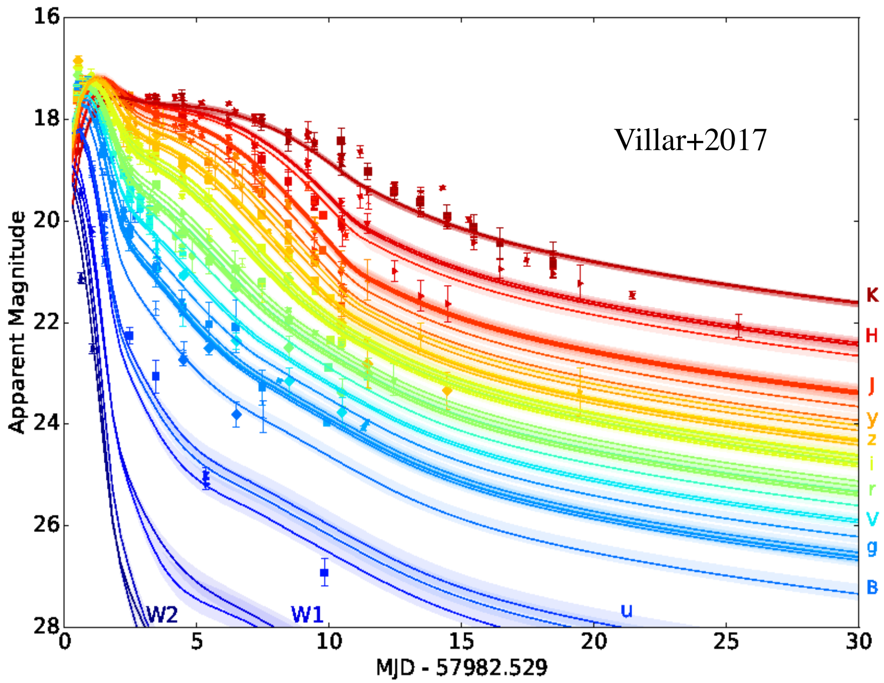
Tanvir et al. 2013; Berger et al. 2013



Few other: Jin et al. 2016 …

170817

Coulter et al. 2017 Nat; Andreoni+2017; Cowperthwaite+2017; Diaz+2017; Drout+2017; Pian+2017; Kasliwal+2017; Smartt +2017; Tanvir+2017; Valenti+2017; Covino+2017 … …

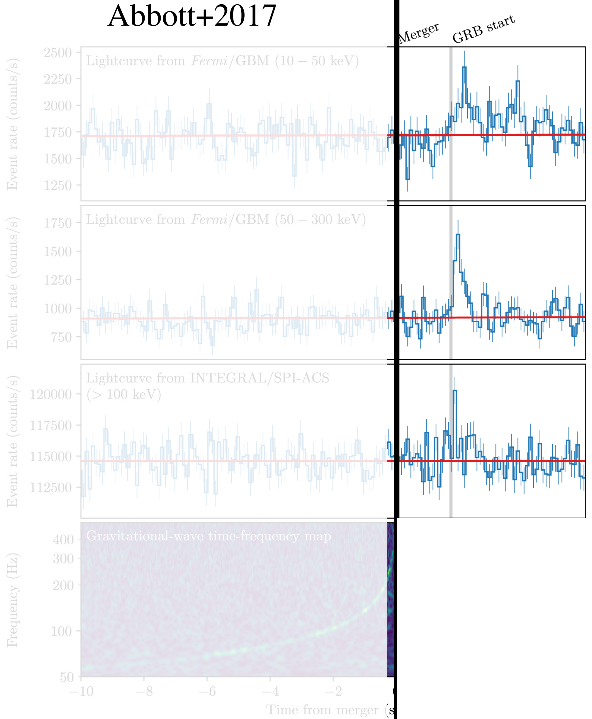


poster Mochkovitch R. for KN forth. detection

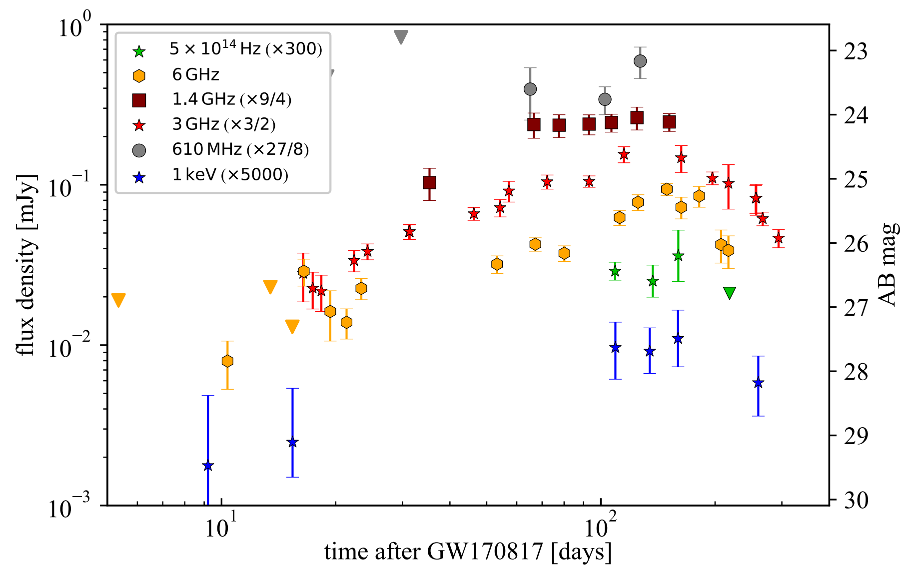
The short Gamma Ray Burst

2

Abbott+2017



Kilonova



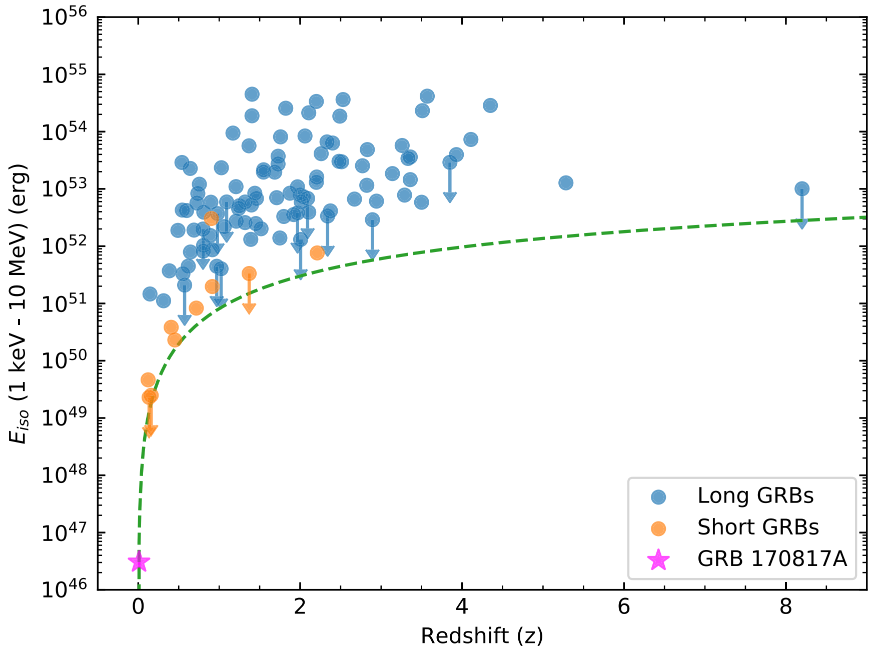
Short
Gamma
Ray
Burst

Gravitational
Waves

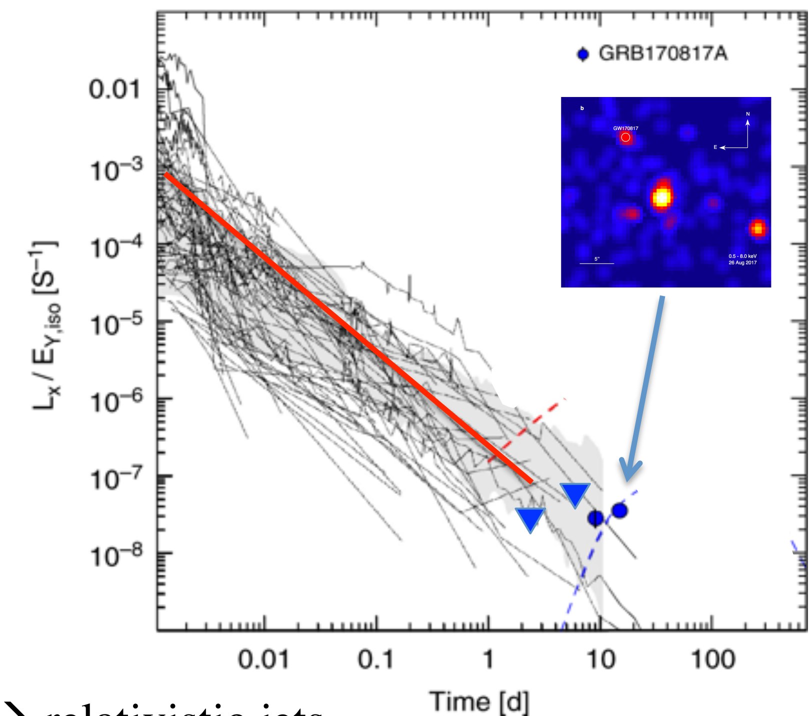
Afterglow

Short GRBs and 170817

Abbott+2017; Goldstein+2017; Zhang+2018



Troja+2017; Fong+2017



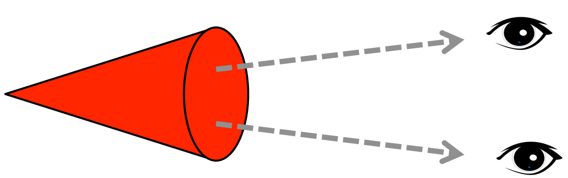
Gamma Ray Bursts → relativistic jets

If 170817 were a standard (Γ>>100; ϑ_{jet}~10°) GRB

$L \sim 10^{51}$ erg/s ✗

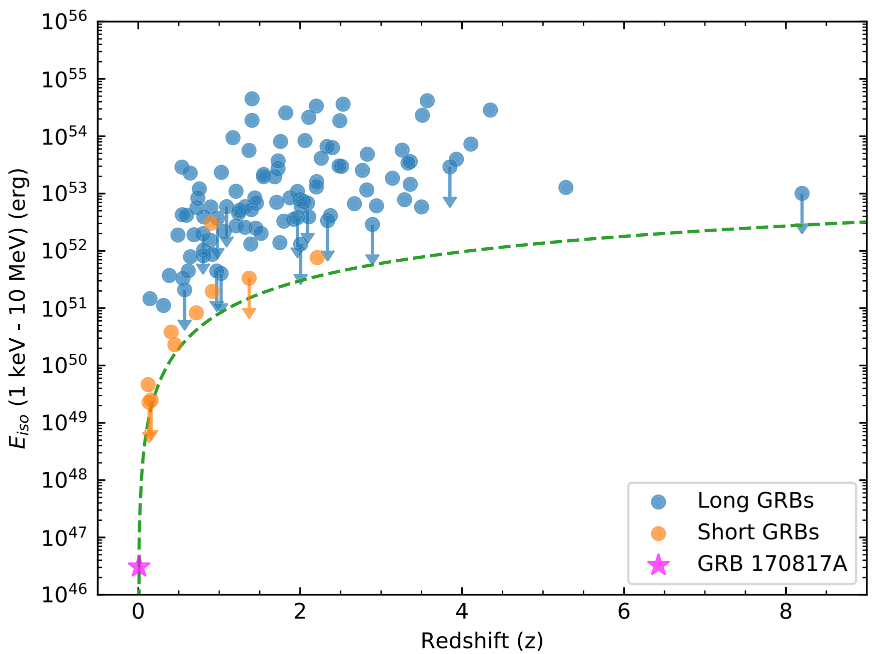
Afterglow t^{-1} ✗

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

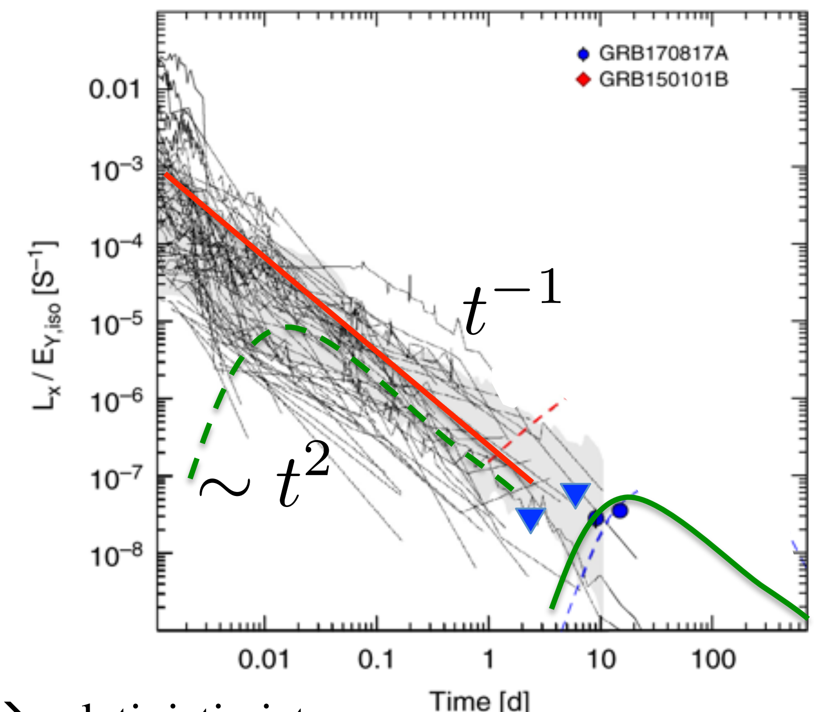


GRB 170817 – Off axis jet

Abbott+2017; Goldstein+2017; Zhang+2018



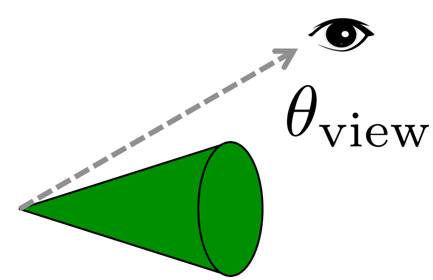
Troja+2017; Fong+2017



Gamma Ray Bursts → relativistic jets

If 170817 were a standard (Γ~100; ϑ_{jet}~10°) GRB **off-axis**

- ✓ L~10^{47} erg/s (debeaming)
- ✓ Afterglow appears when $\frac{1}{\Gamma(t)} \sim \theta_{\rm view}$
- ✓ Consistent with GW inclination

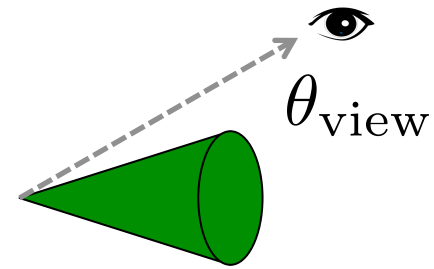


Pian et al. 2017; Margutti et al. 2017; Nakar et al. 2017; Granot et al. 2017 …

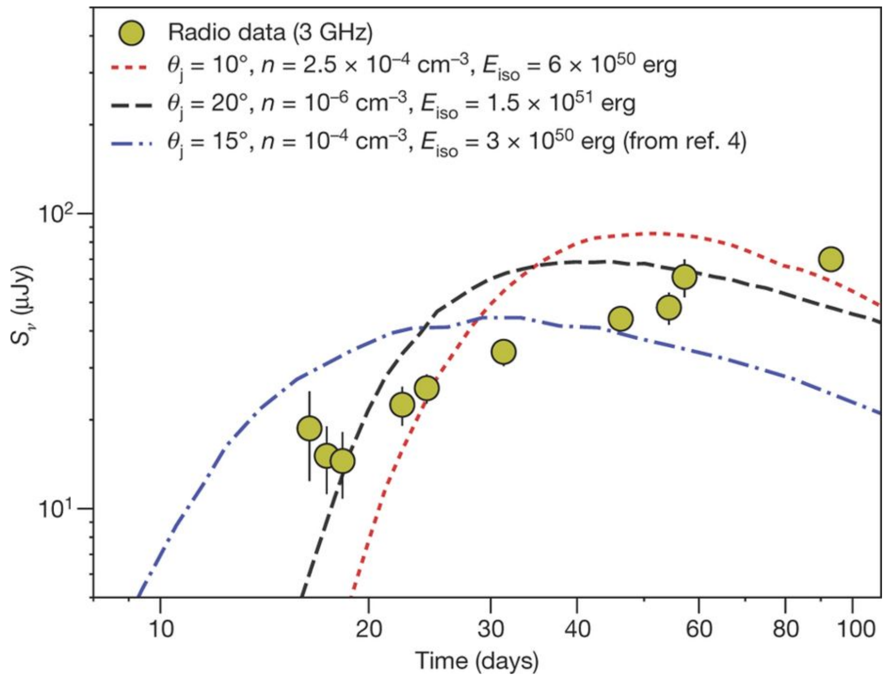
GRB 170817 – Unexpected afterglow

Gamma Ray Bursts → relativistic jets

If 170817 were a standard ($\Gamma \sim 100$; $\vartheta_{jet} \sim 10°$) GRB **off-axis**



- ✓ $L \sim 10^{47}$ erg/s (δ^{-3})
- ✓ Afterglow appears when $$\frac{1}{\Gamma(t)} \sim \theta_{\text{view}}$$
- ✓ Delay GW-EM
- ✗ Soon after peak the afterglow should decay normally (t^{-1}), instead shallow rise



Mooley et al. 2018; Nat.

Non standard jet seen off-axis

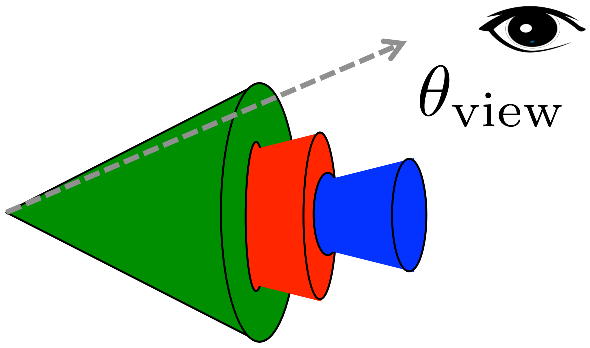
GRB 170817 – Structured jet model

Gamma Ray Bursts → relativistic structured jets

If 170817 were a structured jet

- ✓ L~10^{47} erg/s (δ^{-3})
- ✓ Afterglow appears when
- ✓ Delay GW-EM
- ✓ Shallow rise of the radio light curve

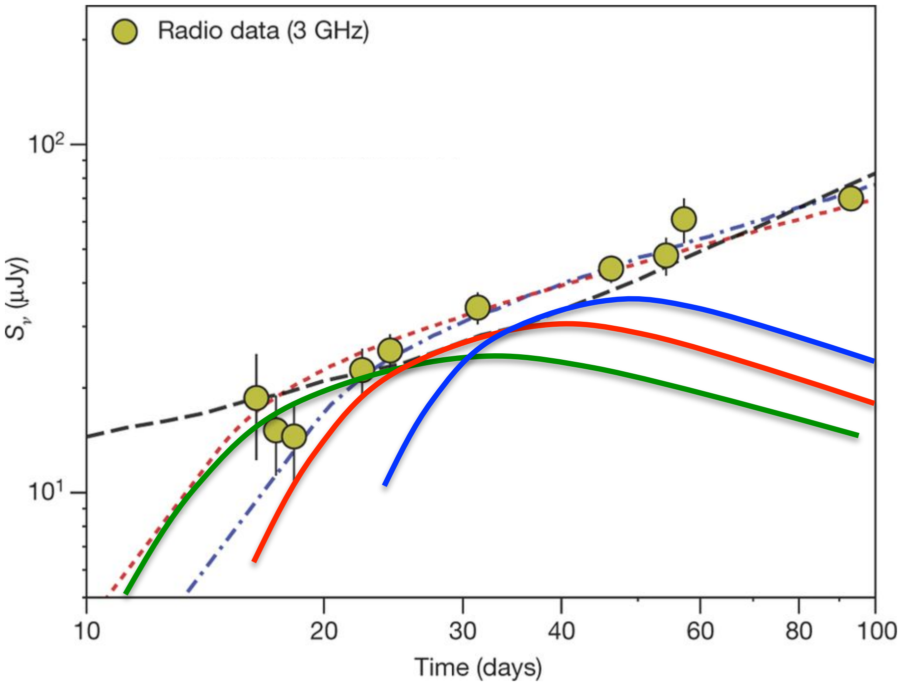
$$\frac{1}{\Gamma(t)} \sim \theta_{\rm view}$$



$\Gamma_1 > \Gamma_2 > \Gamma_3$

$E_1 > E_2 > E_3$

Discrete→continous structure

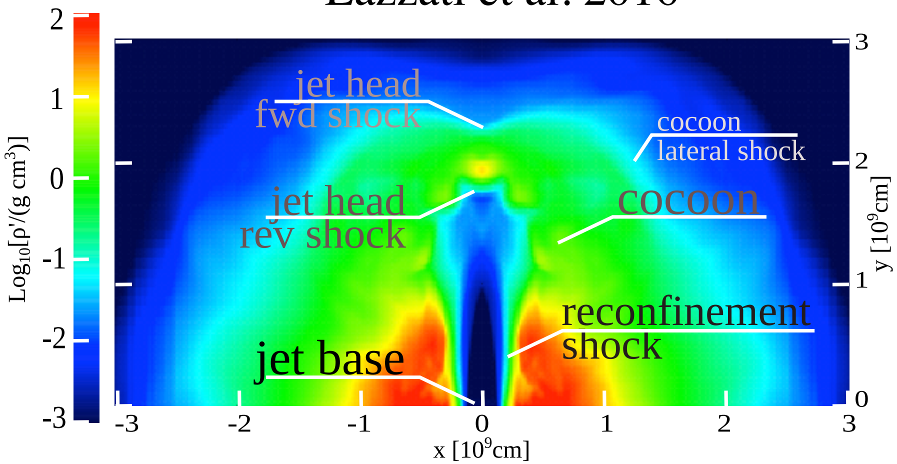


Peak is a combined effect of beming and orientation

Structured jet in GRBs
Rossi et al. 2002; Zhang et al. 2002; Granot et al. 2009
… …
Salafia et al. 2015, 2015b, Pescalli et al. 2015

Structured jet: a natural expectation

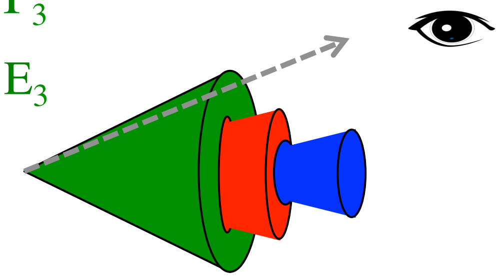
Lazzati et al. 2016



Succesfull jet
Angular structure

$\Gamma_1 > \Gamma_2 > \Gamma_3$

$E_1 > E_2 > E_3$

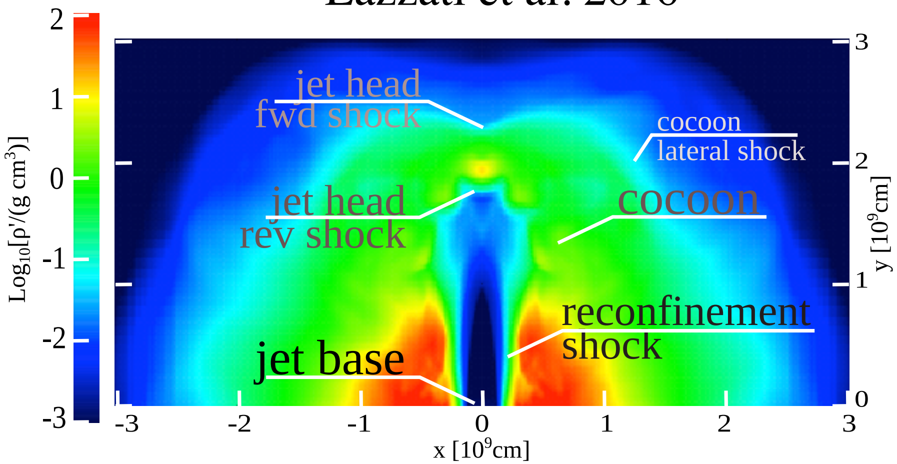


Gottlieb, Nakar et al. 2018

Succesfull jet
or
Structured jet

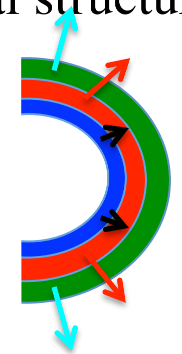
2 Structured jet: a natural expectation … but

Lazzati et al. 2016



Choked jet

Radial structure



$\Gamma_1 < \Gamma_2 < \Gamma_3$

$E_1 > E_2 > E_3$

Kasliwal+2018; Mooley+2018; Nakar et al. 2018

Choked jet

or

Failed jet

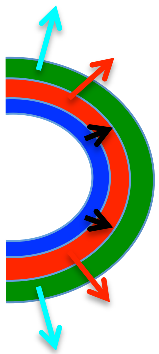
or

Cocoon

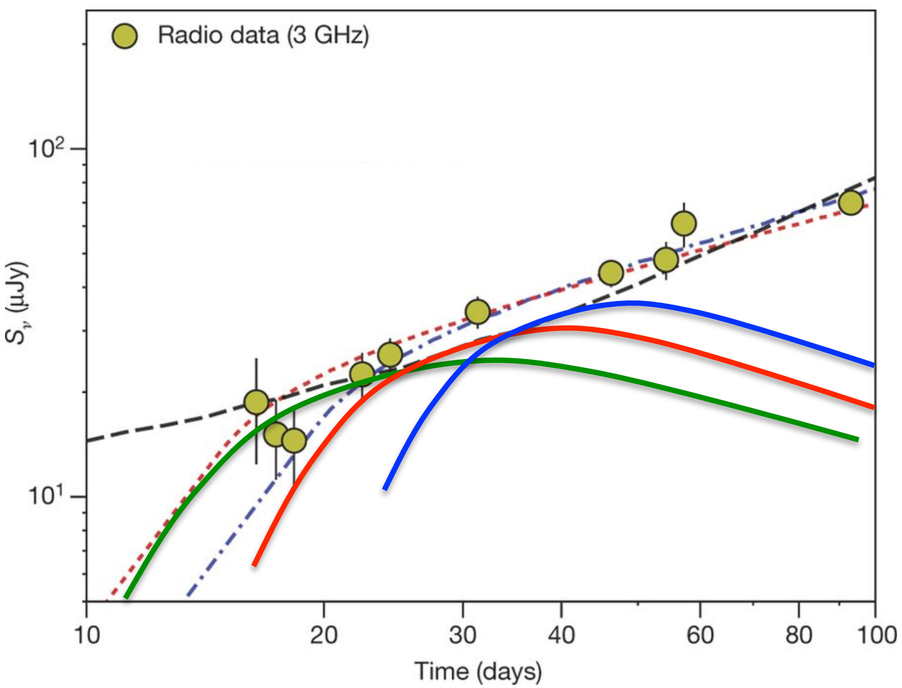
GRB 170817 – choked jet model

Gamma Ray Bursts → relativistic structured jets

If 170817 were a structured jet



- ✓ L~10^{47} erg/s (intrinsically)
- ✓ Afterglow appears → deceleration
- ✓ Delay GW-EM → transparency or dissipation
- ✓ Shallow rise of the radio light curve → energy injection



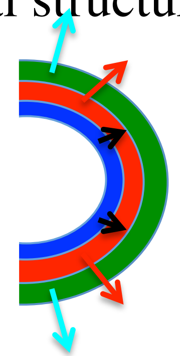
Discrete→continous structure

Peak is a dynamic effect

Which structure?

2

Choked jet
Radial structure



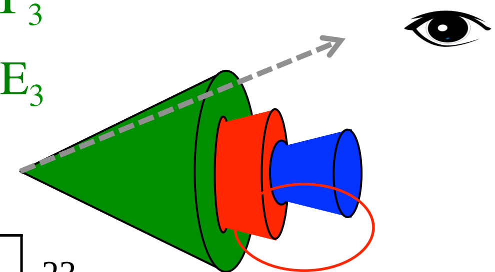
$\Gamma_1 < \Gamma_2 < \Gamma_3$

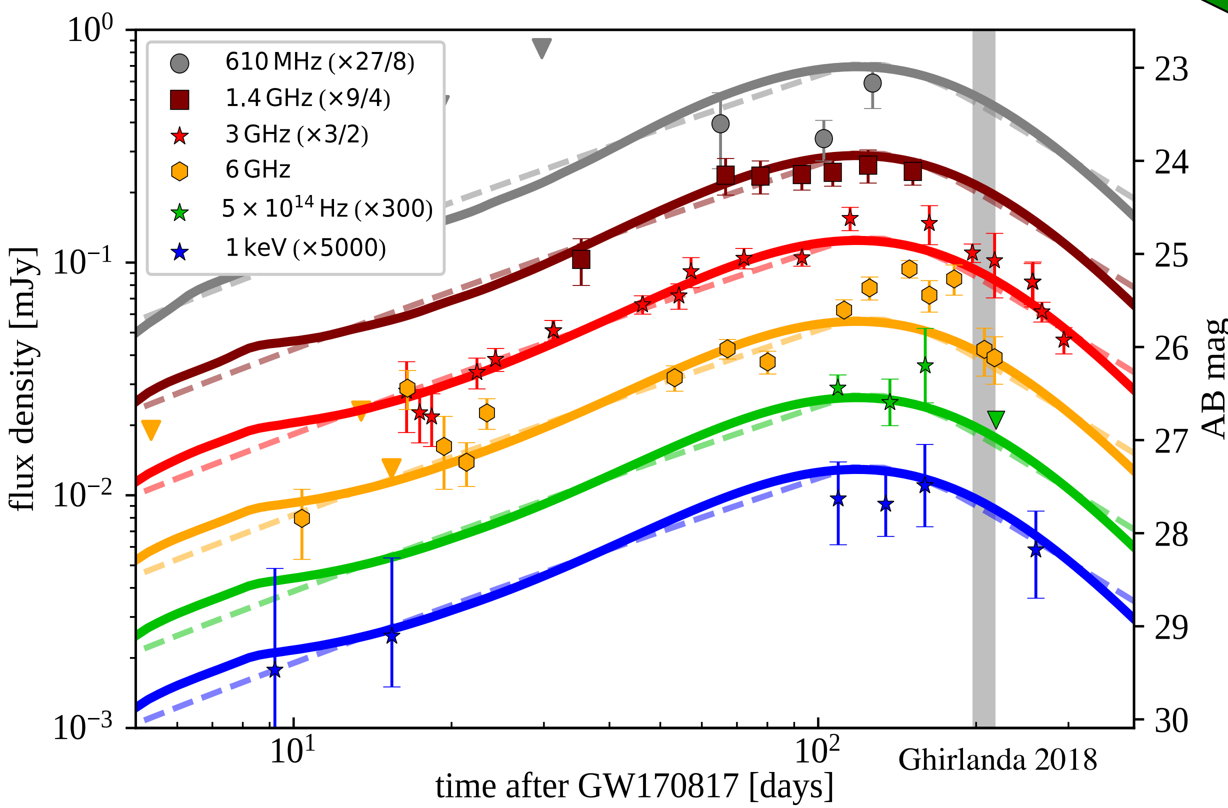
$E_1 > E_2 > E_3$

Succesfull jet
Angular structure

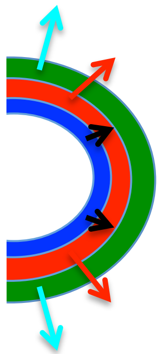
$\Gamma_1 > \Gamma_2 > \Gamma_3$

$E_1 > E_2 > E_3$



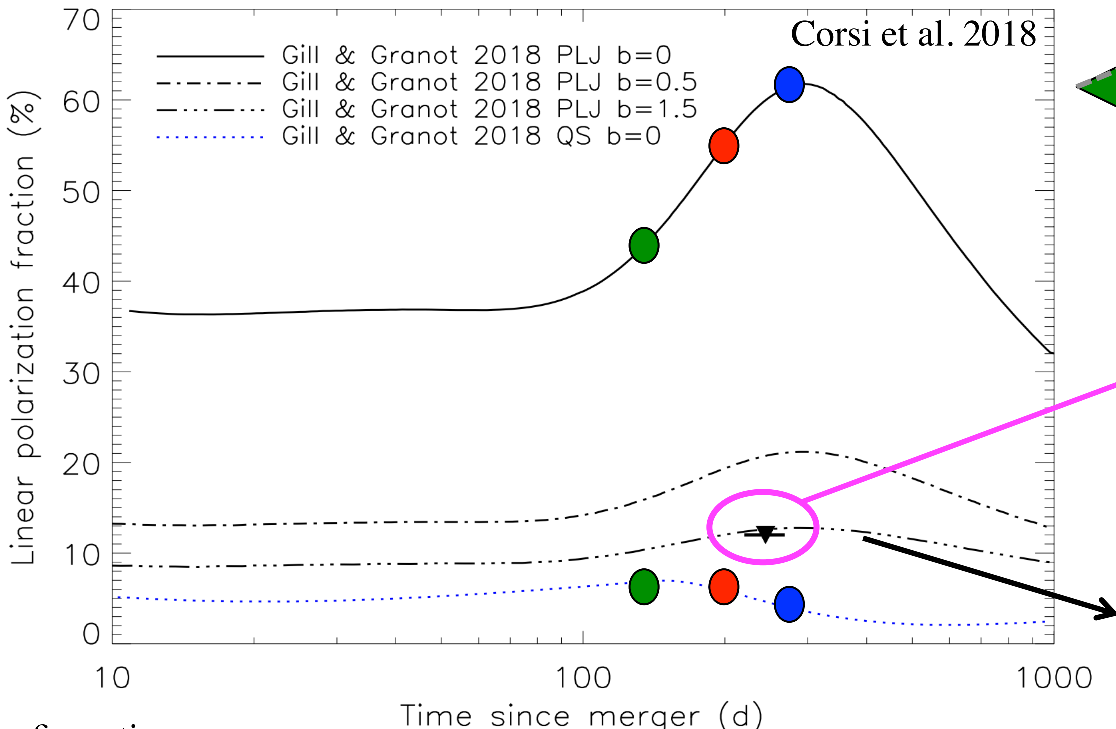


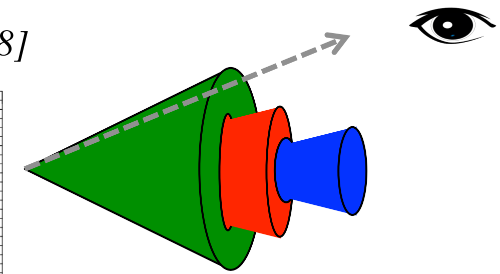
Polarization



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

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





JVLA @ 244d, 2.8 GHz

Π<12% (90%)

Corsi et al. 2018

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

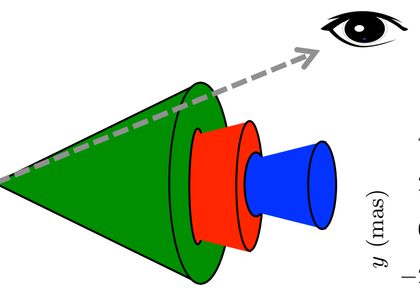
Contribute:

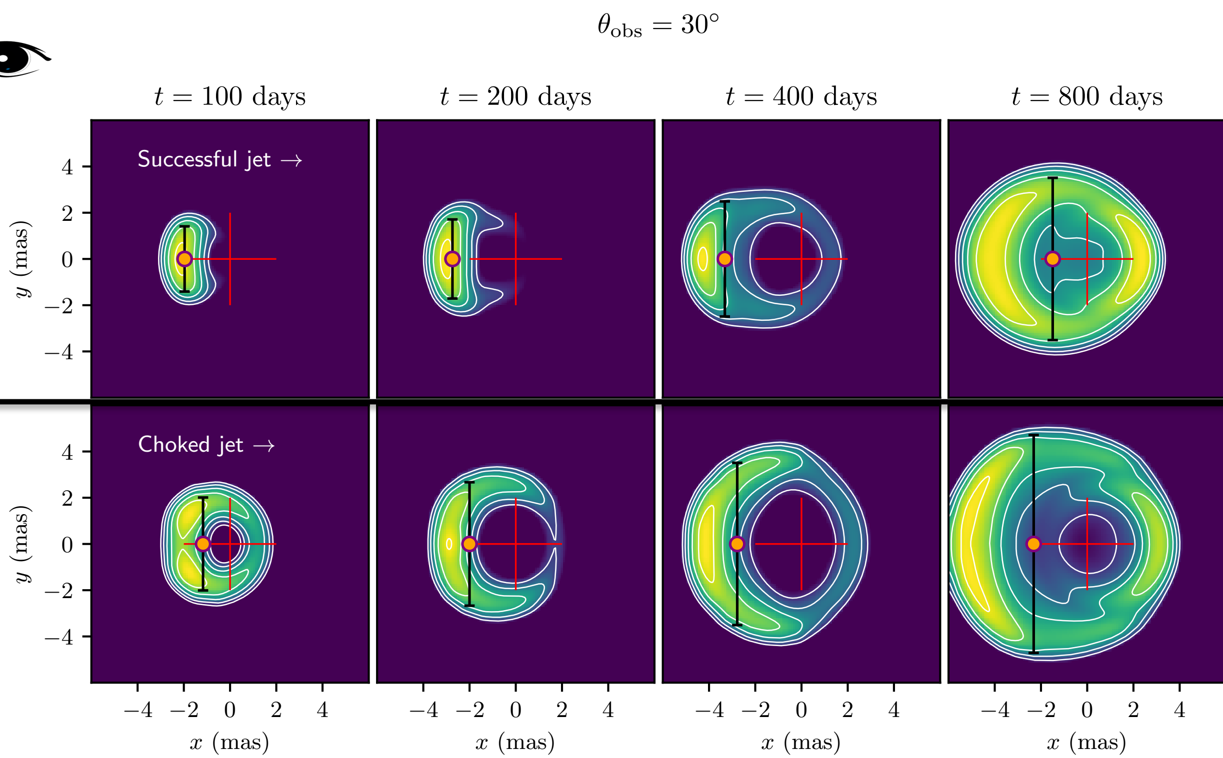
1) Magnetic field configuration (randomness & compression)
2) Γ
3) Geometry (ϑ_{jet} ; ϑ_{view})
4) Emission mechanism

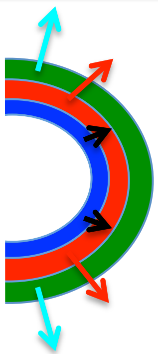
Imaging

1) apperent motion
2) source size

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







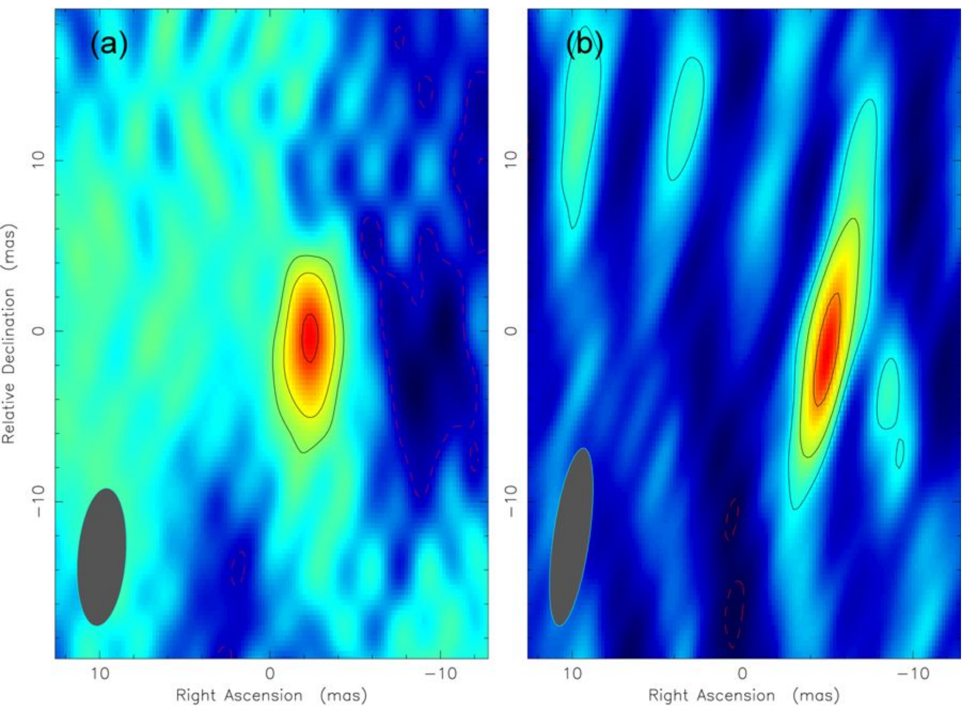
Structured jet has larger displacement and smaller size than choked jet

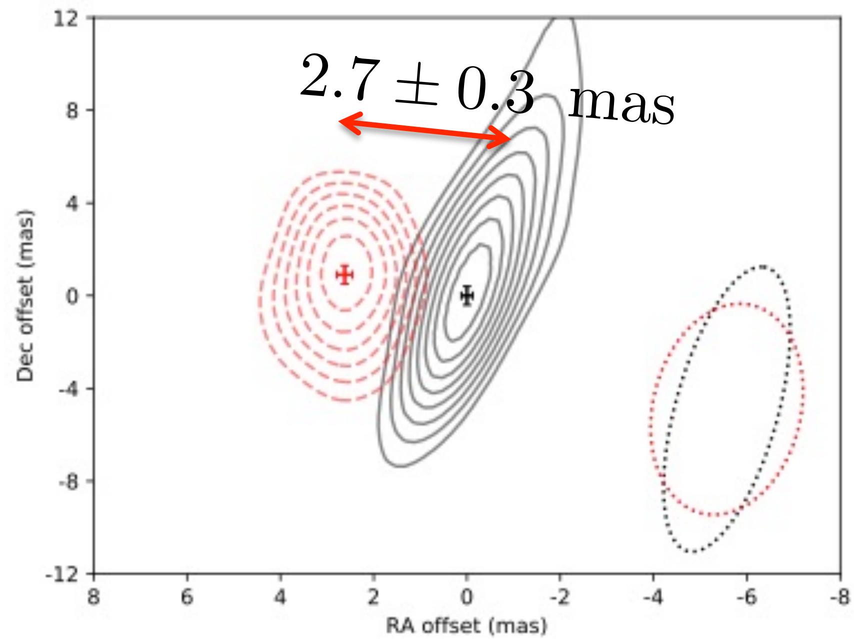
Imaging

Apparent motion *[Mooley+2018, Nat.]*

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

230 days 75 days





Imaging

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

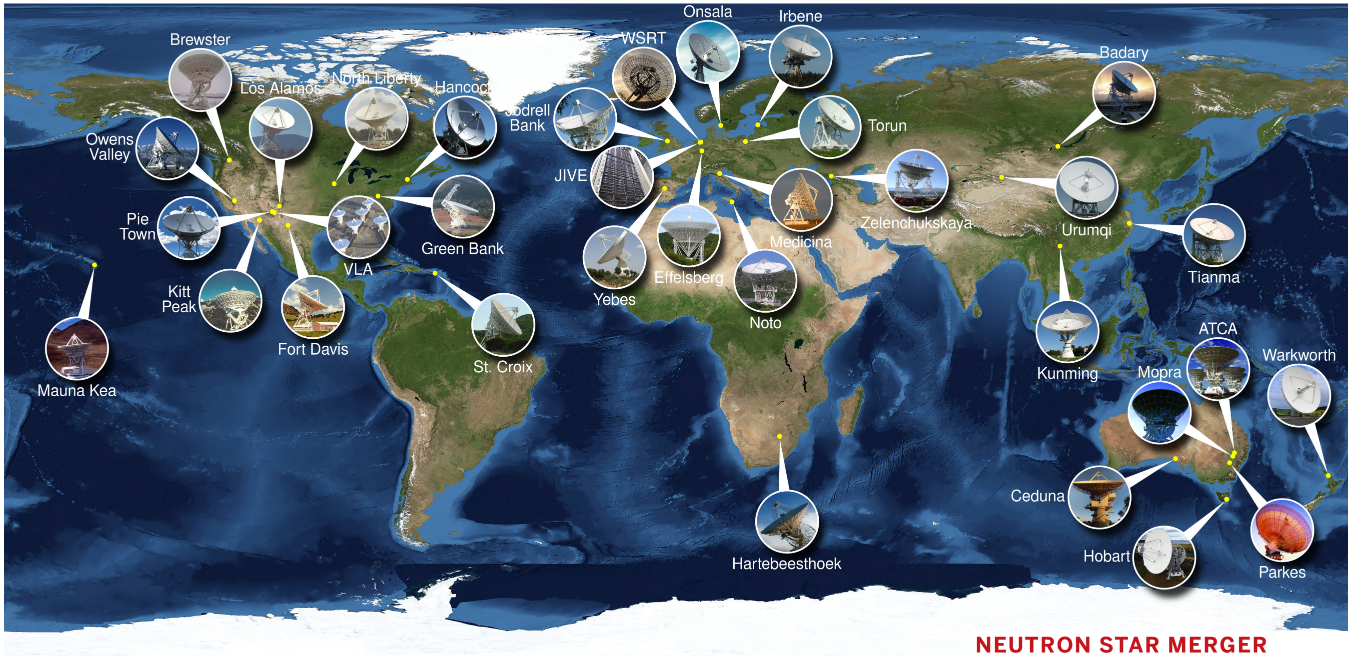


Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

33 telescopes
5 continents
11 Research Institutes

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

NEUTRON STAR MERGER

Science

Compact radio emission indicates a structured jet was produced by a binary neutron star merger

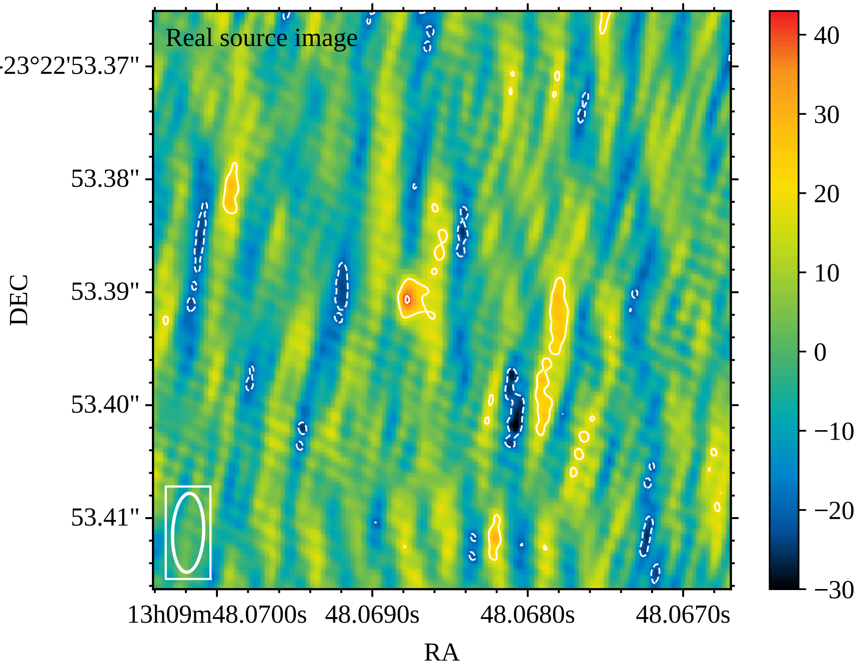
G. Ghirlanda[1,2,3*], O. S. Salafia[1,2,3*], Z. Paragi[4], M. Giroletti[5], J. Yang[6,7], B. Marcote[4], J. Blanchard[4], I. Agudo[8], T. An[9], M. G. Bernardini[10†], R. Beswick[11], M. Branchesi[12,13], S. Campana[1], C. Casadio[14], E. Chassande-Mottin[15], M. Colpi[2,3], S. Covino[1], P. D'Avanzo[1], V. D'Elia[16], S. Frey[17], M. Gawronski[18], G. Ghisellini[1], L. I. Gurvits[4,19], P. G. Jonker[20,21], H. J. van Langevelde[4,22], A. Melandri[1], J. Moldon[11], L. Nava[1], A. Perego[3‡], M. A. Perez-Torres[8,23], C. Reynolds[24], R. Salvaterra[25], G. Tagliaferri[1], T. Venturi[5], S. D. Vergani[26], M. Zhang[27,28]

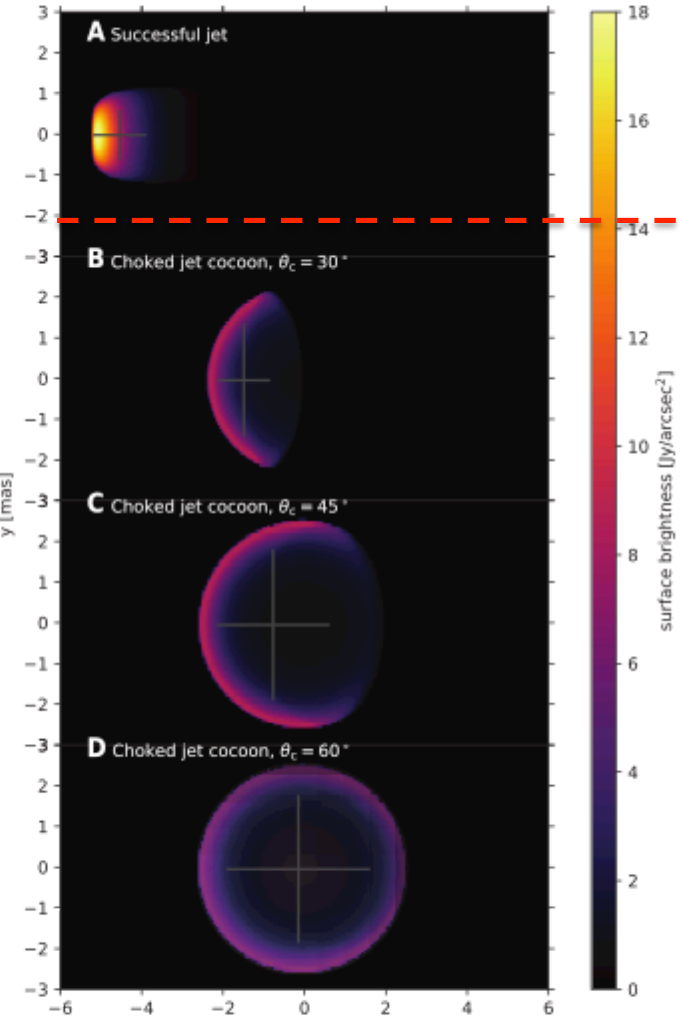
Imaging

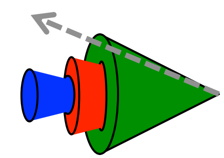
Size constraints

[GG et al. 2019]

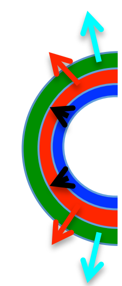
Global VLBI observation 12-13 March (204.7 days) @ 5 GHz







< 2 mas



> 3 mas

8 µJy/beam rms

Peak brightness 42 ± 8 µJy/beam

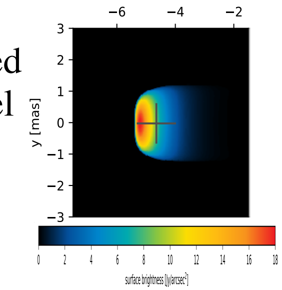
Imaging

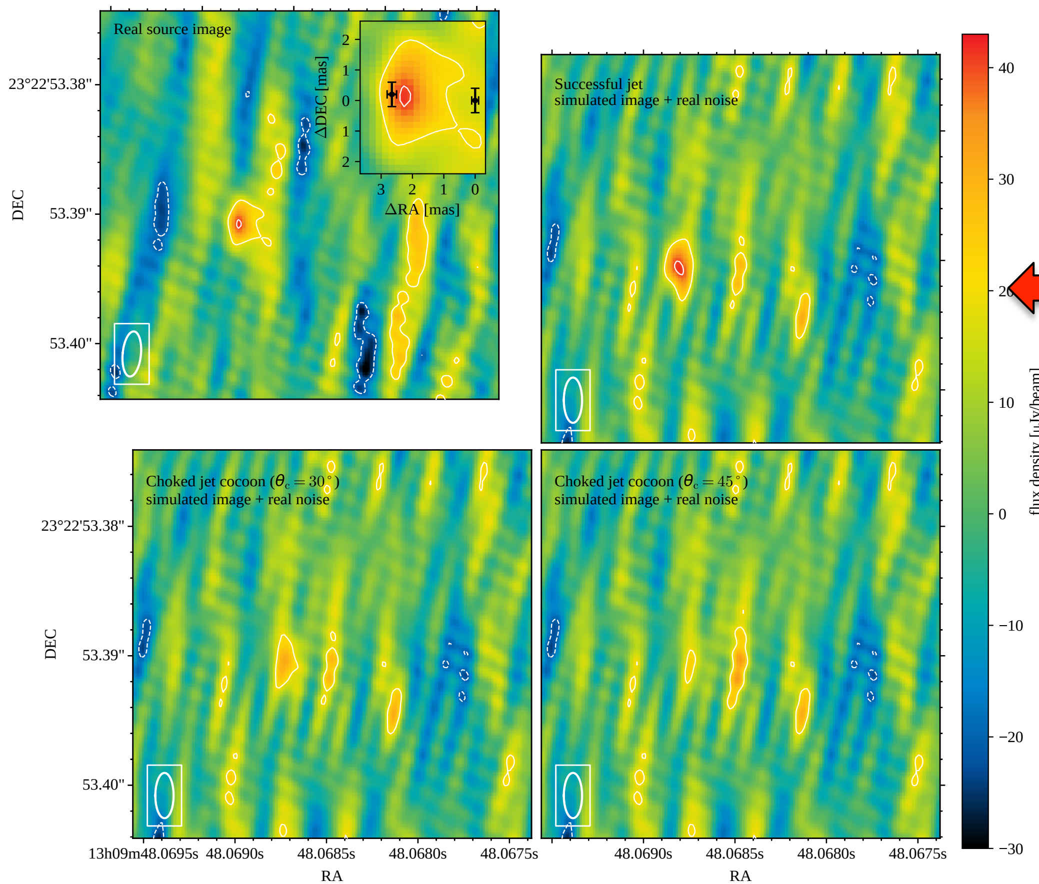
Size constraints

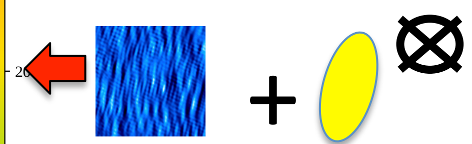
[GG et al. 2019]

Global VLBI observation 12-13 March (204.7 days) @ 5 GHz

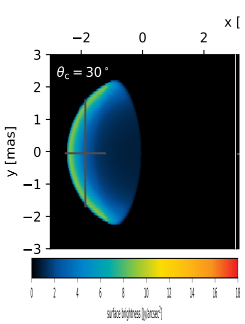
Structured jet model



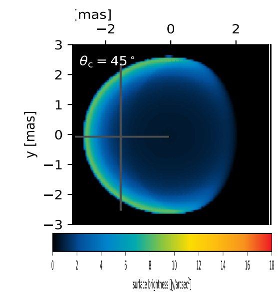




Choked jet
(30 deg)



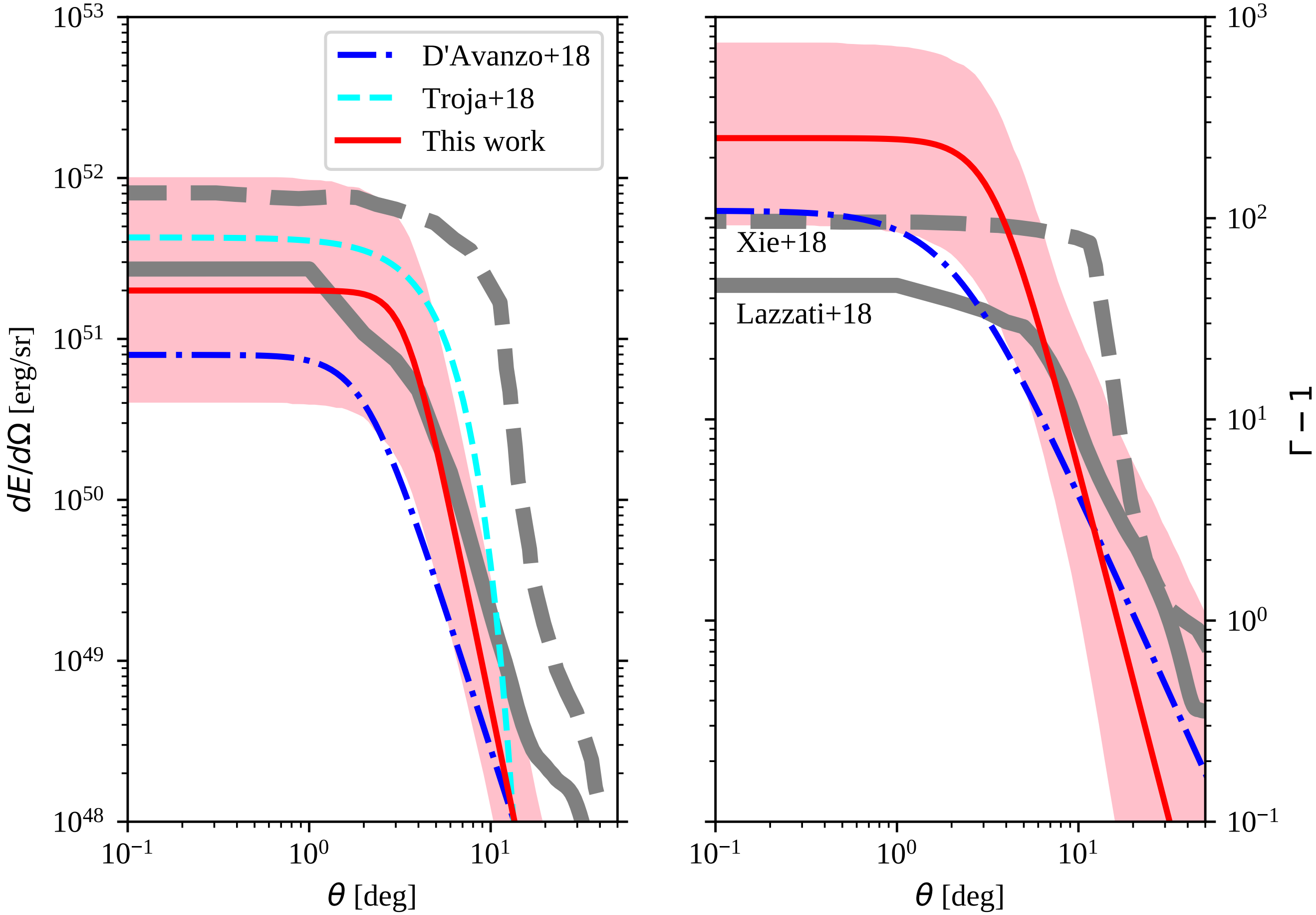
Choked jet
(45 deg)



Jet structure

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

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



[GG et al. 2019]

Structured jet and rates

3

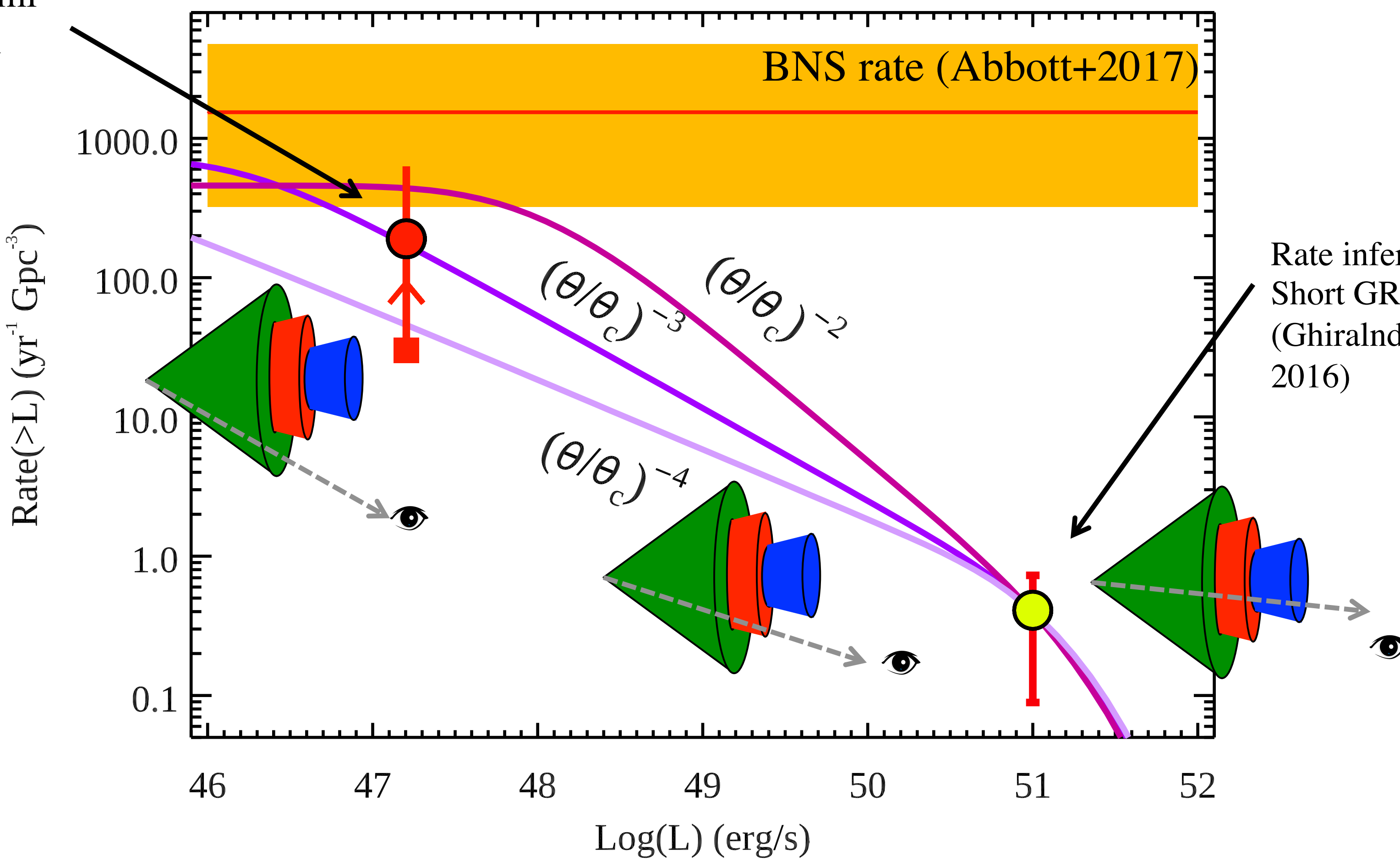
Structured jet model (universal structure) → Luminosity function (Pescalli et al. 2015; Salafia et al. 2015; Ghirlanda et al. 2016)

At least 10% of BNS launch a jet that succesfully breaks out of the merger ejecta

Rate infered from Fermi detection

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

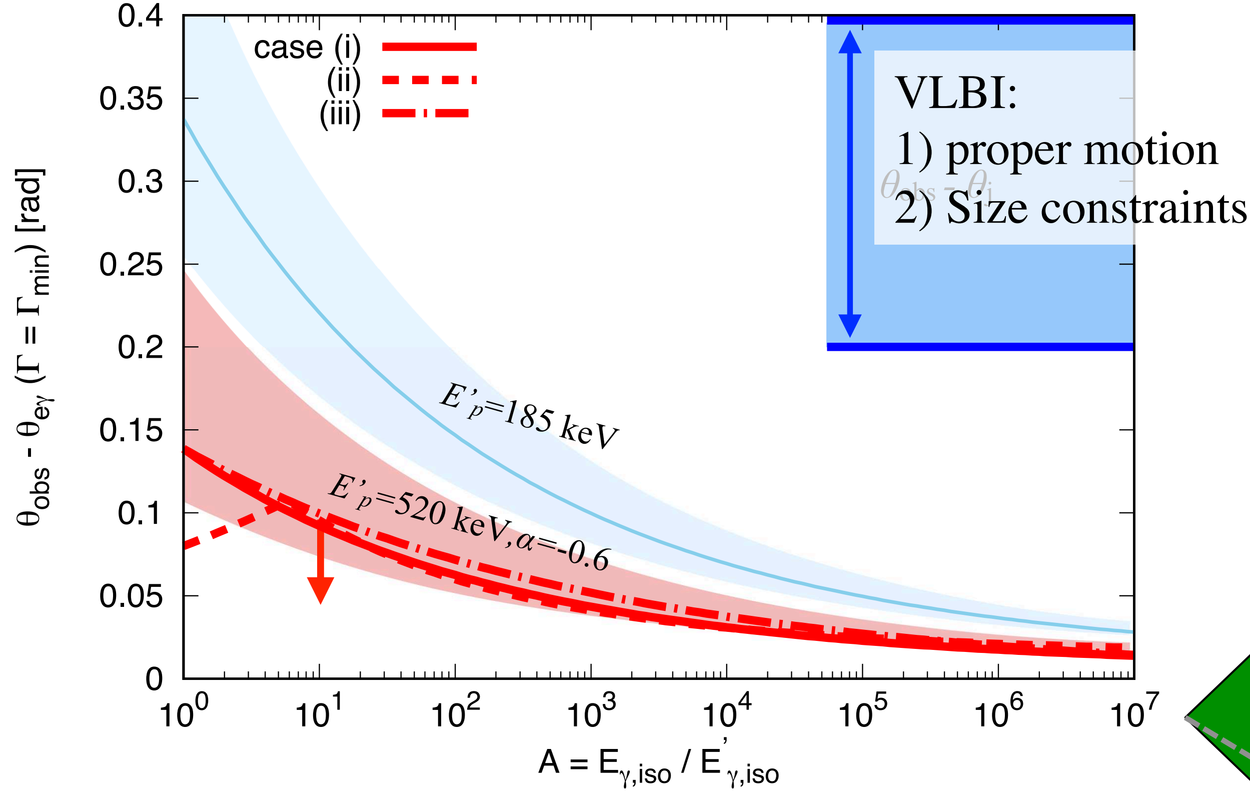
GG et al. 2019,



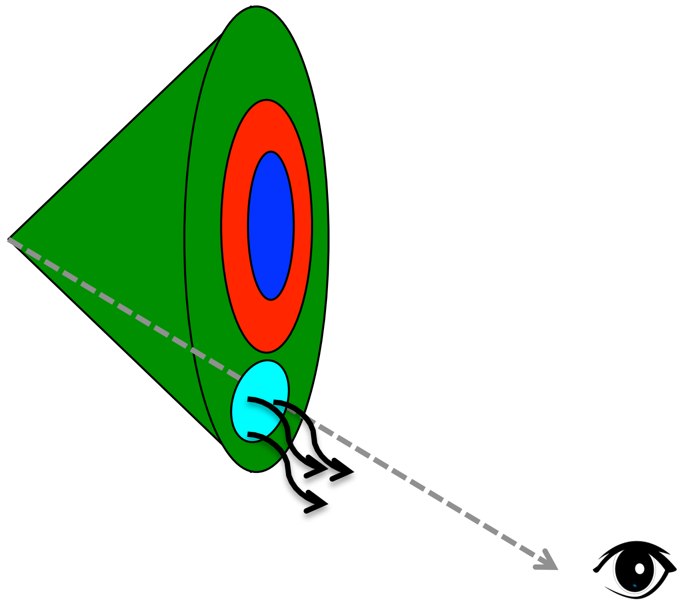
3

But what is the origin of the prompt emission?

Matsumoto et al. 2018



The core cannot produce the gamma rays of the prompt phase



The prompt emission is due to the patch of the structured jet which is moving close to the line of sight.

Conclusions

- L1: BNS merger are progenitors of short GRBs. (and BHNS? → Talk: O. S. Salafia)
- L2: close events, a lot of data … investigate the jet structure
- L3: GW/GRB170817: a relativistic jet with an angular distribution of energy/ velocity (structured jet) successfully broke out of the ejecta.
- L4: At least 10% of BNS might produce a jet that breaks out of the polar ejecta. Short GRB population (Talks: E. Howell, D. Paul, R. Duque)
- L4: Jet structure due to interaction with merger ejecta.
  Structured jets = universal properties (differences mostly due to viewing angle + relativistic dependent effects)
- L5: Prompt emission is produced by the patch of the jet near to the los (but spectrally hard)