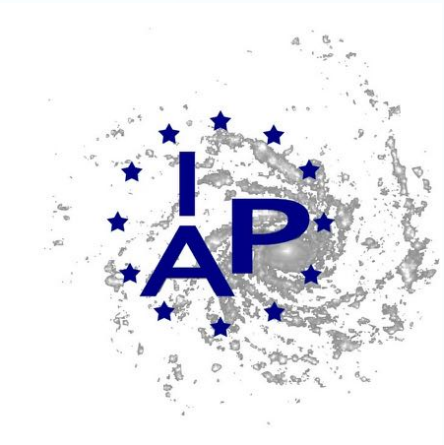


Recent Developments in Relativistic Jets from Gamma-ray Burst Science

R. Duque, F. Daigne & R. Mochkovitch

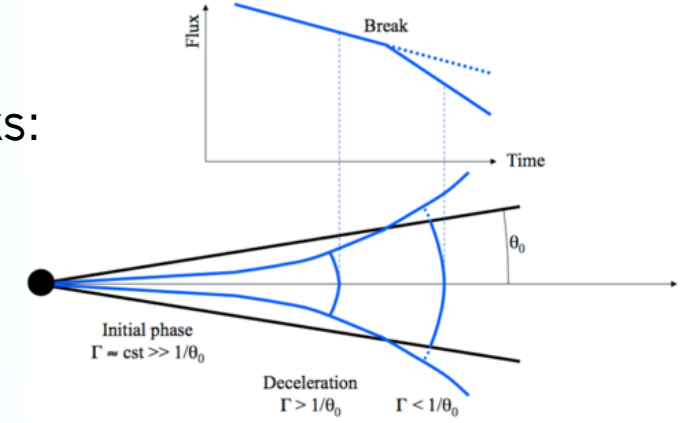
Simulating relativistic outflows (Meudon) – Nov. 29th 2019

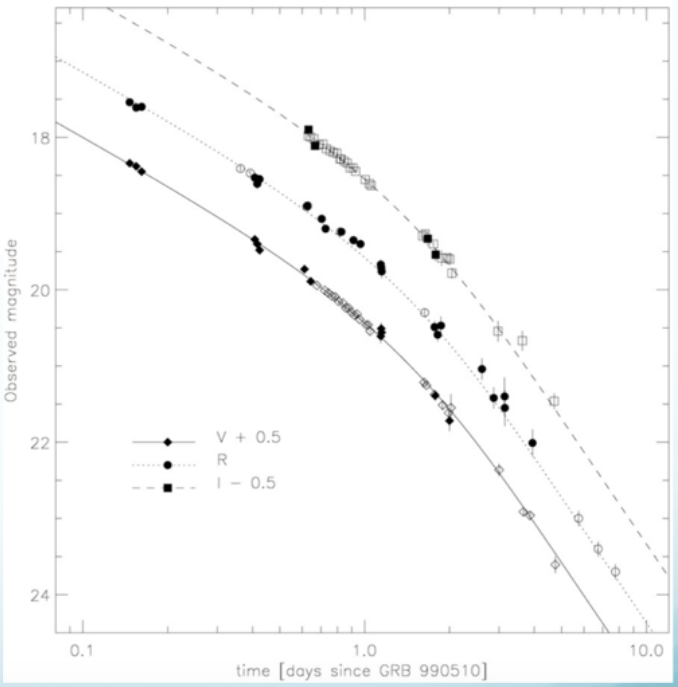
Introduction to jets in GRBs

- Jet solve the **compacity puzzle** in GRBs, posed by > 1 MeV photons escaping < 1 light-second region

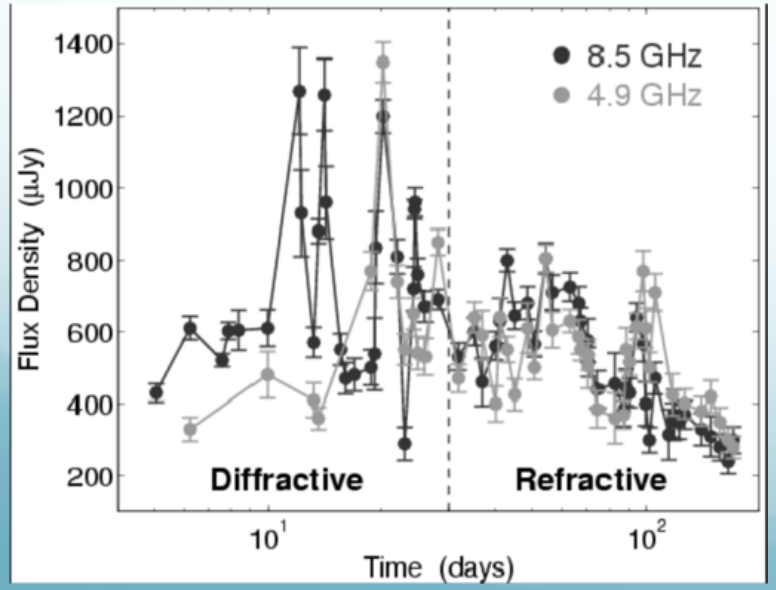
Annihilation of HE light

- Achromatic jet-breaks:





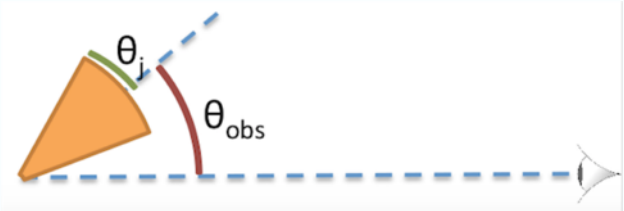
- Radio scintillation:

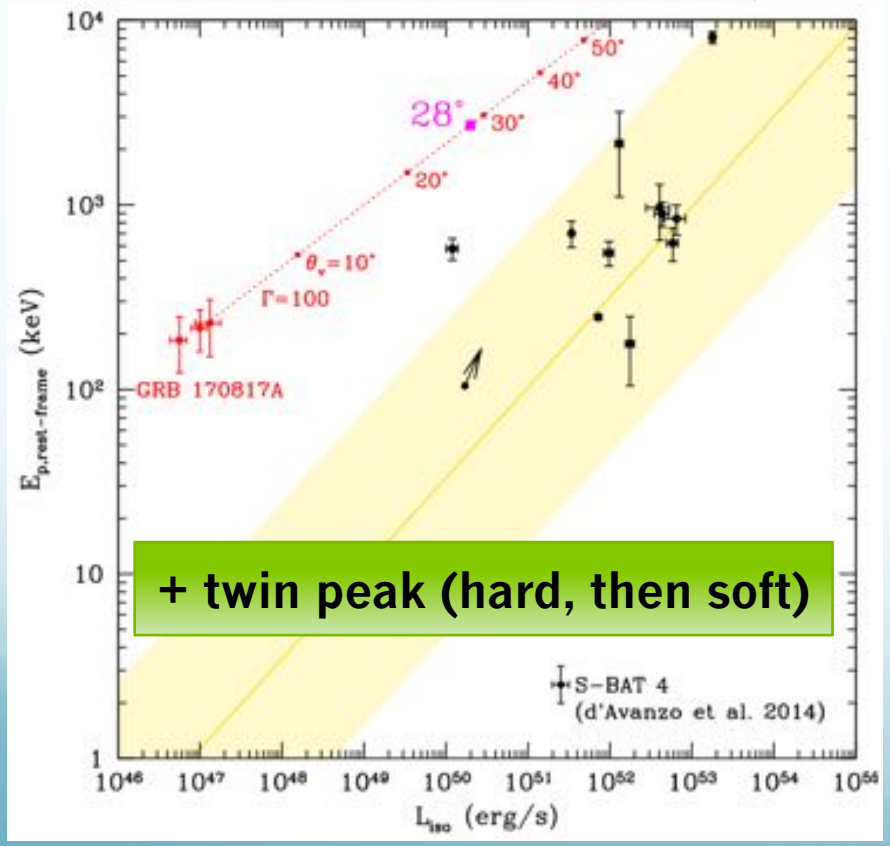


+ UR jets natural in "fireball" model

GRB170817A

Not a regular short GRB!





Alternative model:
Shock break-out (Nakar 2012)

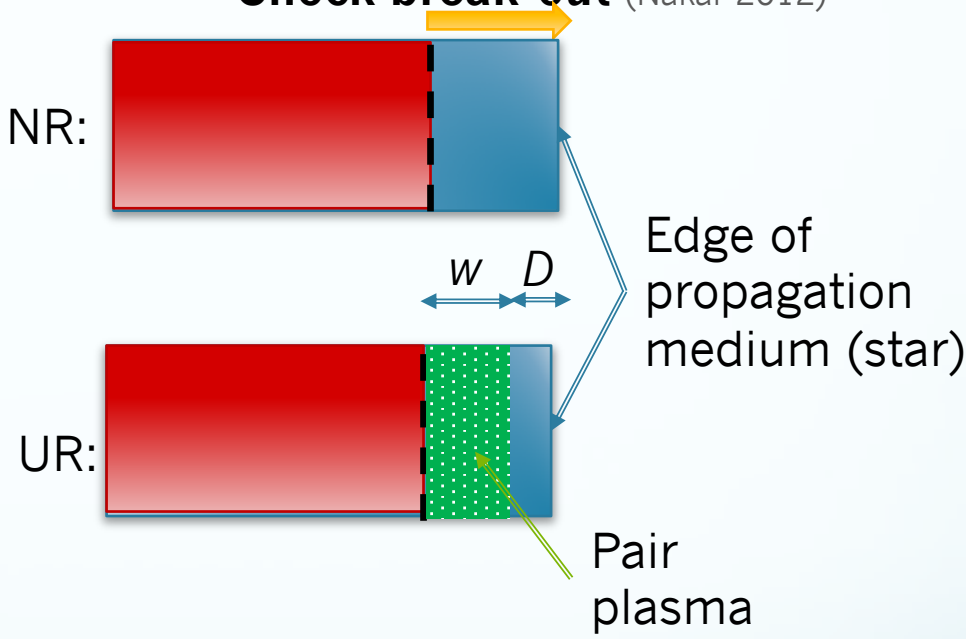


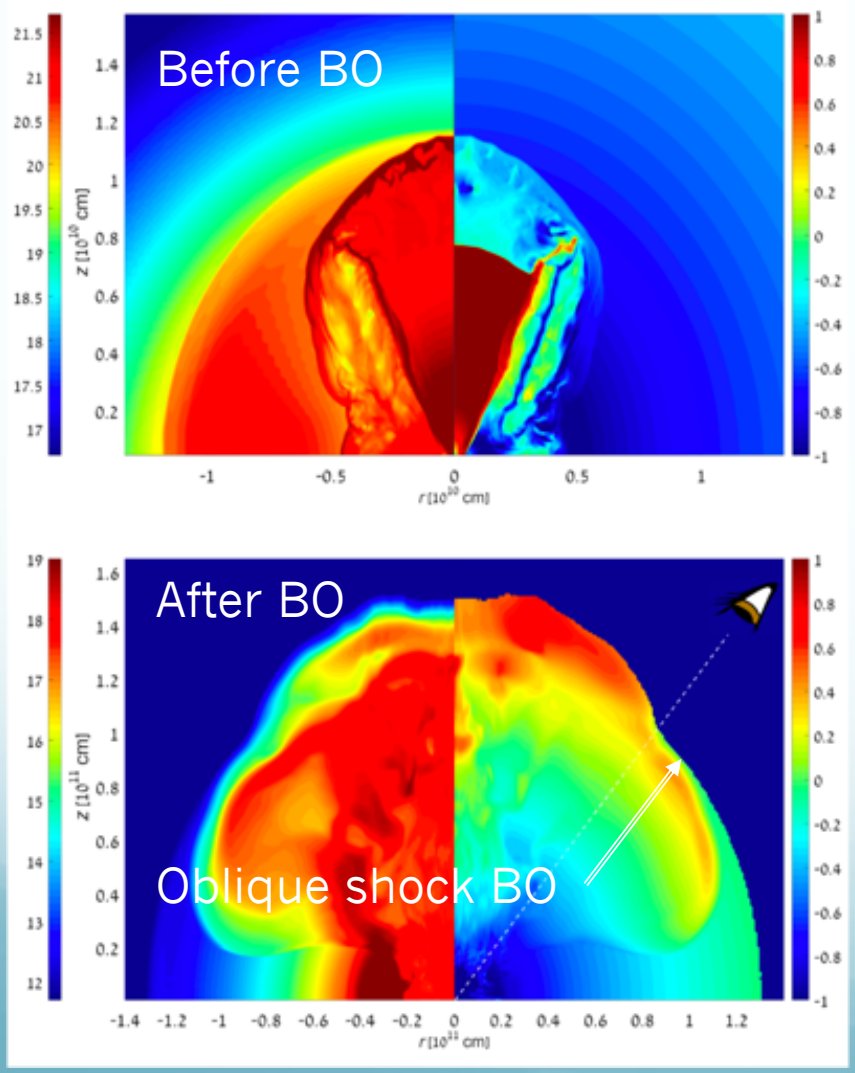
Figure courtesy F. Daigne

Photon leak: $\tau = 1/\beta_{sh}$
UR shock: pairs increase τ
➔ $w \sim D$ at breakout
➔ Hard → Soft spectral evolution

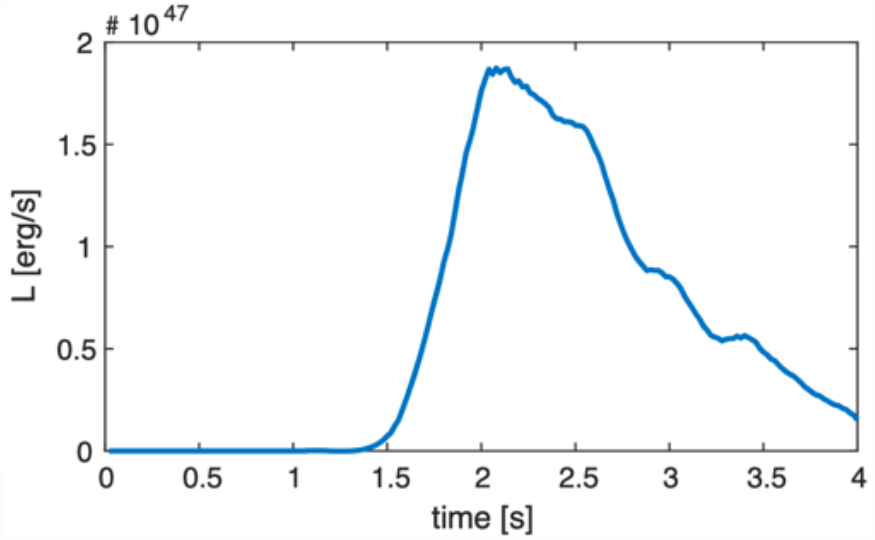
also works in SN, planet formation, etc.

Shock breakout from jet in merger ejecta

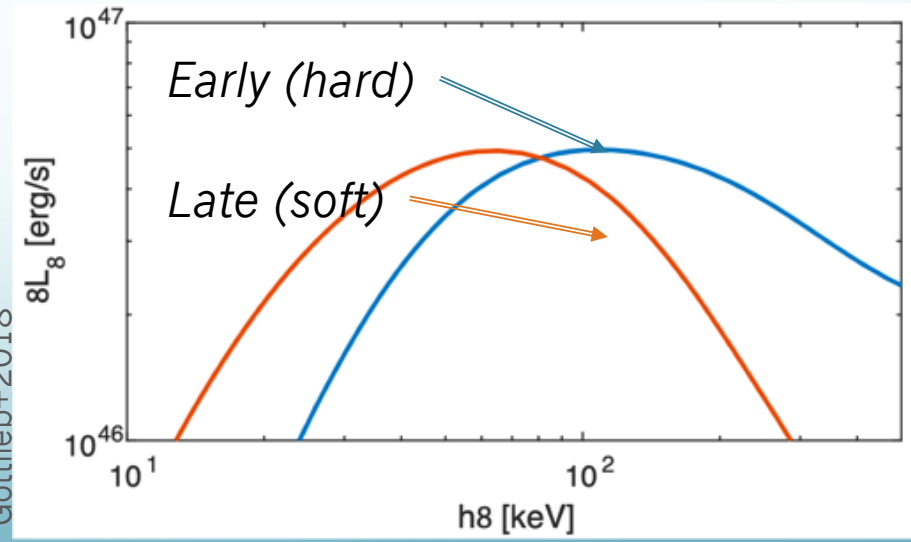
Initial jet **propagates within merger ejecta**, and **breaks out**



Light-curve:



Spectrum:



Gottlieb+2018

Emergence of jet structure post-breakout

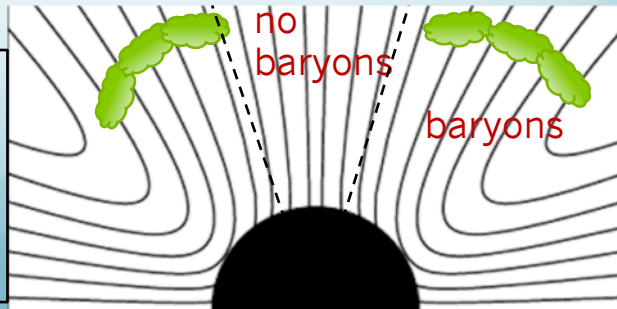
Jet/ejecta interaction **may or may not give rise to collimated jet**!
➔ Depends on jet energy, opening angle, ejecta velocity profile

- Chocked jet
- Cocoon
- **Shallow structured outflow**

➔ Structured jet!

- Successful jet
- Structured jet
- Core+wings/sheath
- Mildly-relativistic outflow
- **Steep structured outflow**

Levinson & Eichler, 1993: Structured outflow as solution to **baryon loading puzzle**

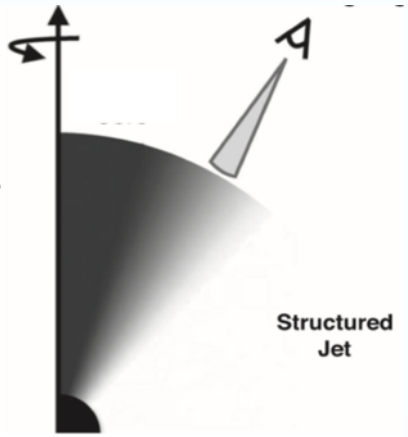


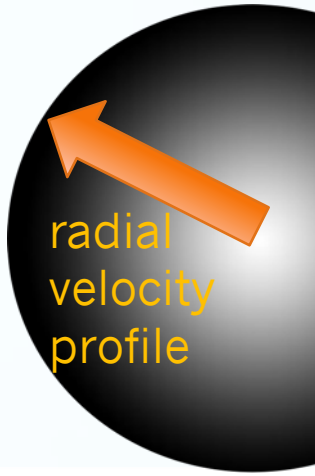
Was there a jet in GRB170817A?

Early expectations:

- ✓ Jet hydro and analytic estimates (Duffel+18)
  - ➔ Yes, most jets are successful!
  - + if jet can break-out, then jet successful
  - + negligible thermal energy deposited by jet ir ejecta
- ✓ short GRB statistics (Beniamini+18)
  - ➔ Yes, most mergers result in collimated jets

angular *vs.* radial



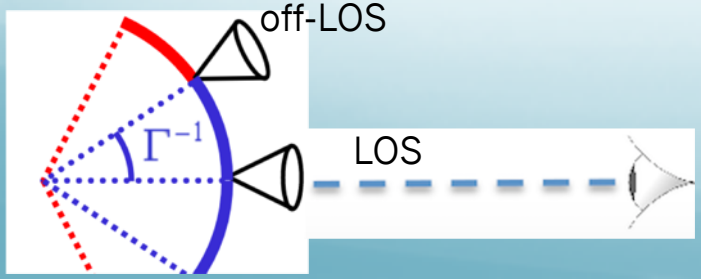


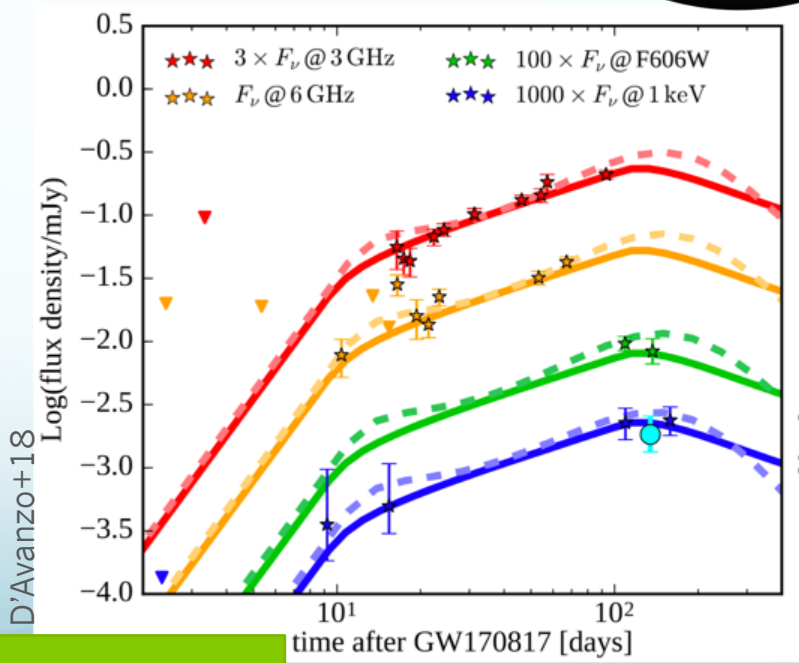
- **Information from afterglow**:

Either 1) Dominated by **LOS material** and there is **energy injection** (*radial structure*)

or

2) Off-LOS energetic material **progressively seen** (*angular structure*)



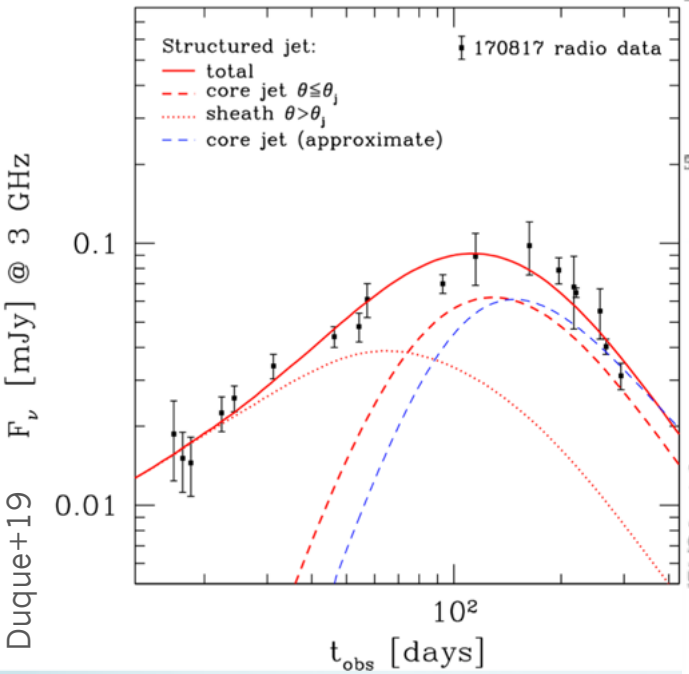


Both work well!

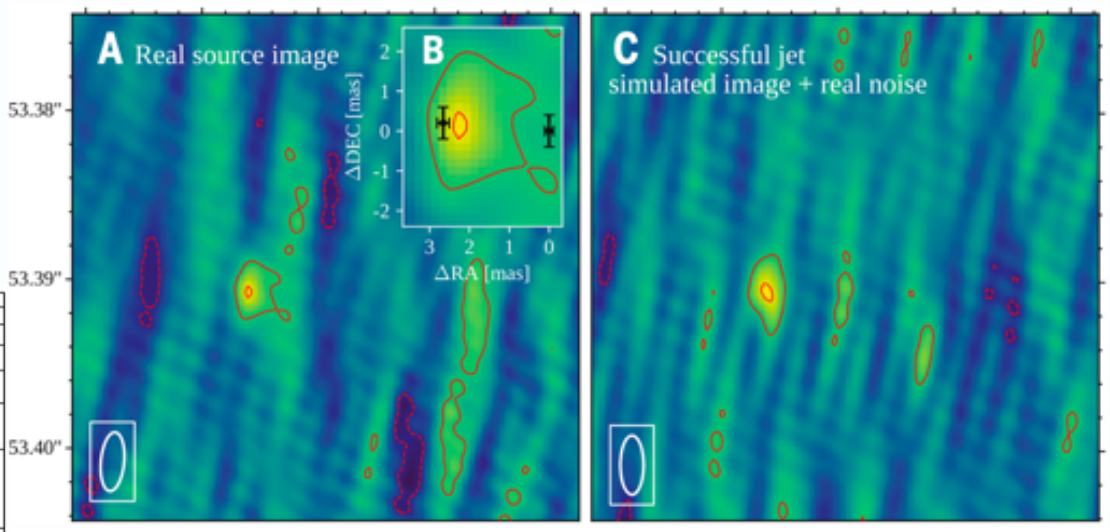
see also Lazzati+17, Margutti+18, Lamb+17,...

VLBI imagery confirms jet emergence

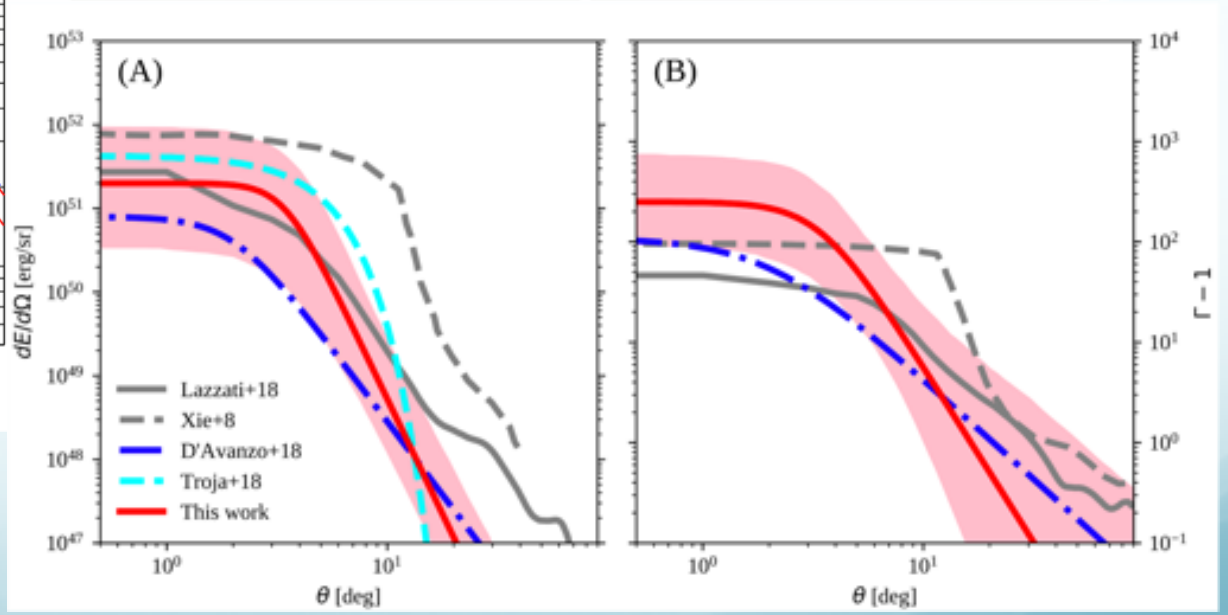
VLBI imagery:
➔ **Superluminal motion**
of remnant



Duque+19



Ghirlanda+19



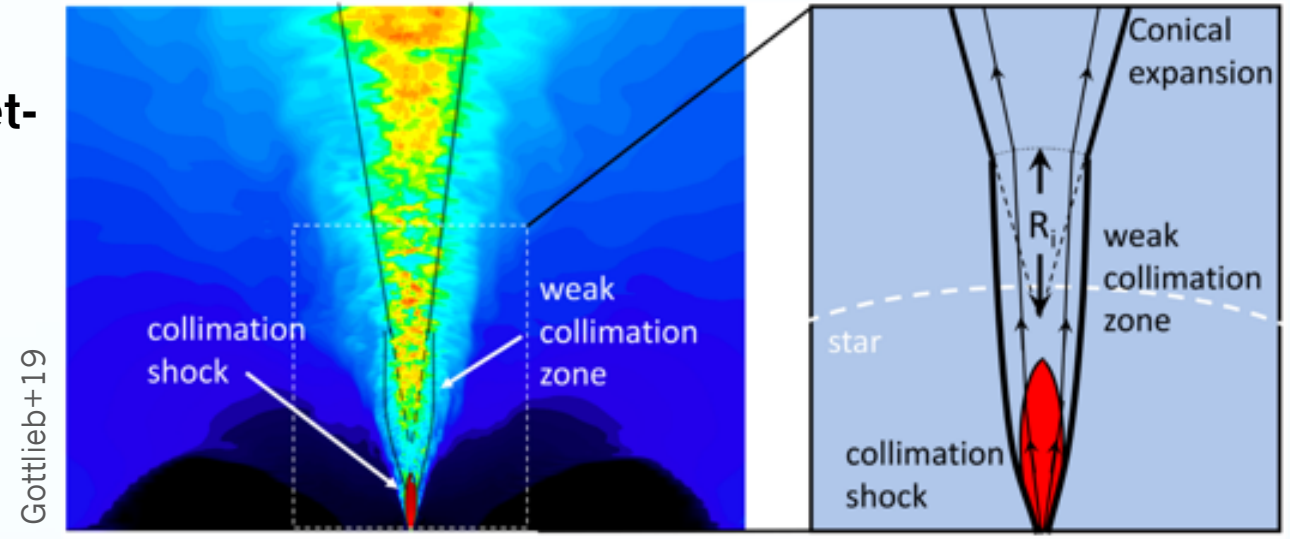
- shallow jet structure
- jet opening angle ~ 4°
- viewing angle ~ 15°

Very detailed study of jet structure!

see also Mooley+18, Hotokezaka+19

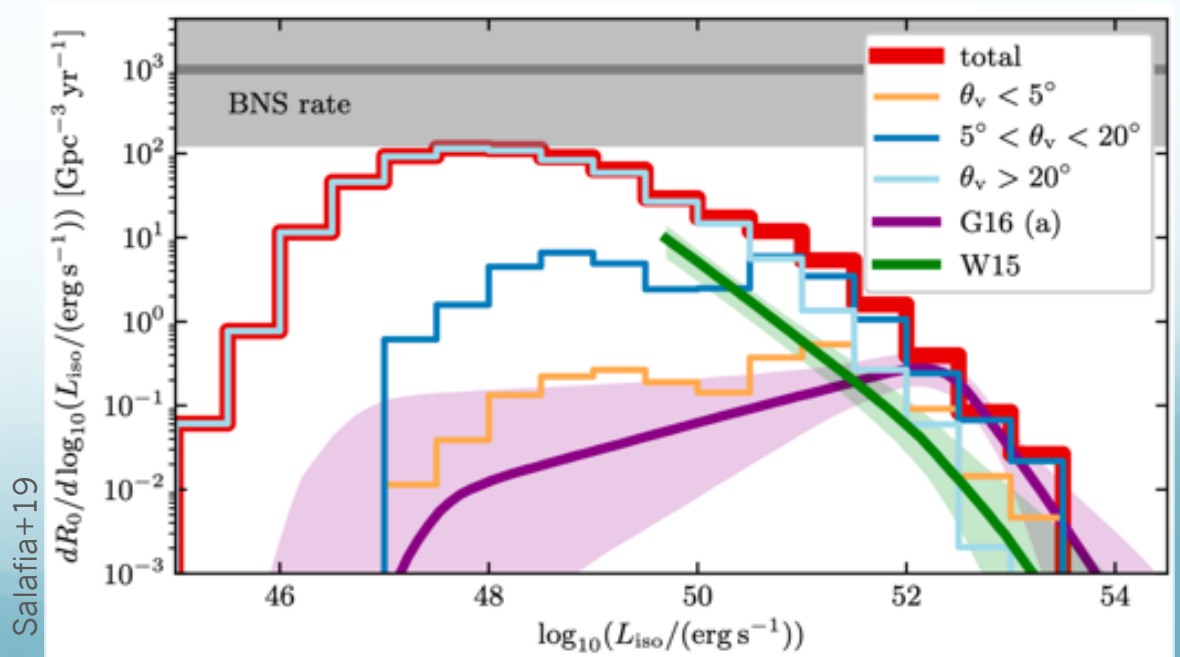
Jet formation & in-jet physics

Gottlieb+2018: Link of **jet-cocoon interaction with photospheric emission**



Gottlieb+19

Salafia+2019: Link of **universal jet structure with short GRB luminosity function**



Salafia+19

see also Kathirgamaraju+19, Gill+19

What now?

Should we expect more events with detailed jet studies?

➔ **Population study!**

N/N_{GW} (%)

Duque+19

Pop. model	G16	WP15
GW+KN	100	100
GW+KN+JAG(p)	38	11
GW+KN+JAG(e)	15	2.6
GW+KN+JAG(e)+KNAG	3.0	1.5
GW+KN+JAG(e)+VLBI	14	1.9
GW+KN+JAG(e)+KNAG+VLBI	2.9	1.3
GW+GRB	1.7	1.7

afterglow photometry + VLBI

1540^{+3200}_{-1220} BNS/Gpc^3/yr (Abbott+2018)

see also Gottlieb+19, Salem+18

Afterglow: OK
VLBI: rare…

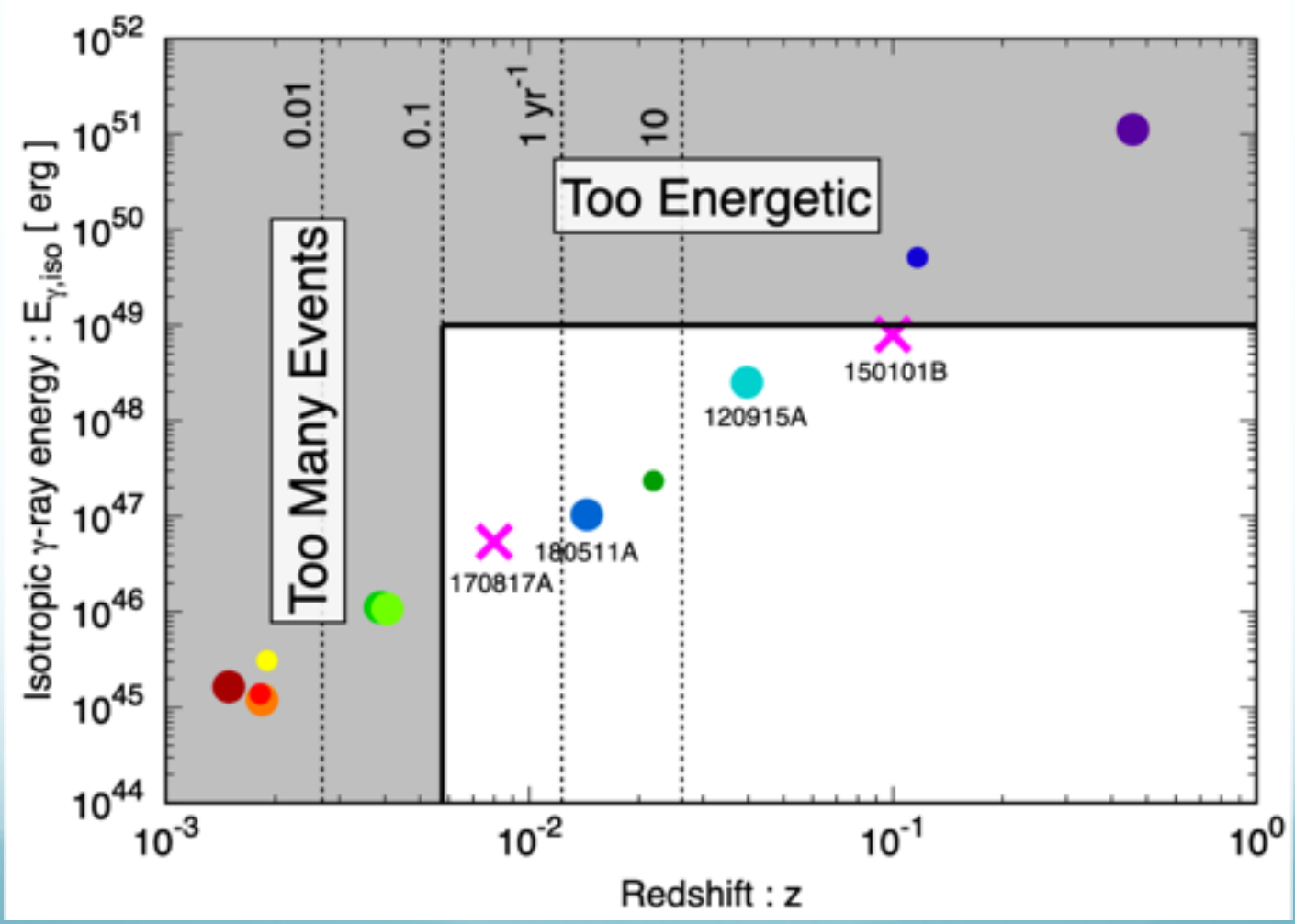
Depends on jet energy function

One spectacular event and then nothing?
No… now we have new IDEAS!

Cosmological GRBs

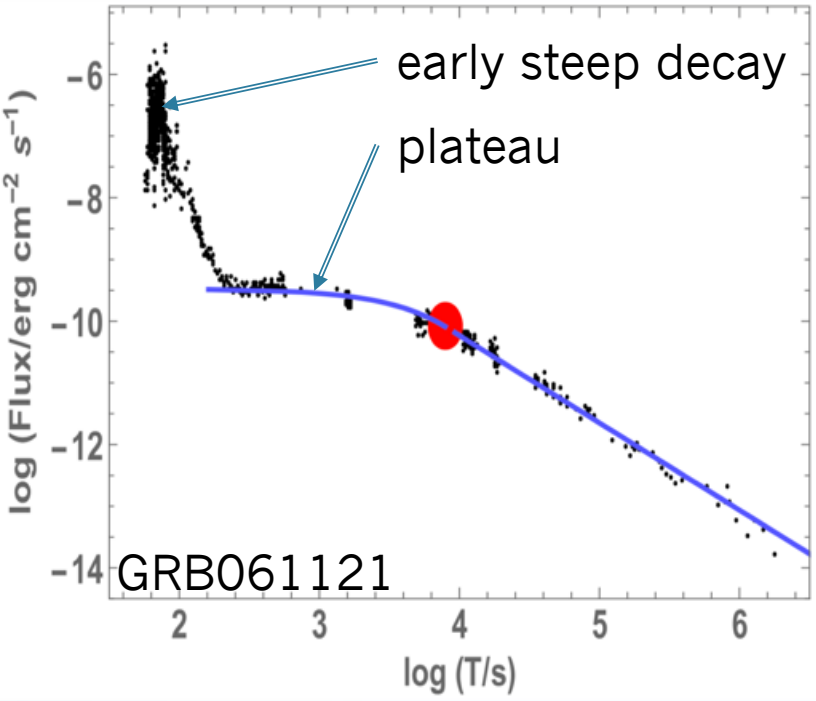
von Kinelin+2019: Fermi GBM short GRBs similar to GRB170817A (double peak: hard then soft)

➔ Consistent with shock break-out radiation?

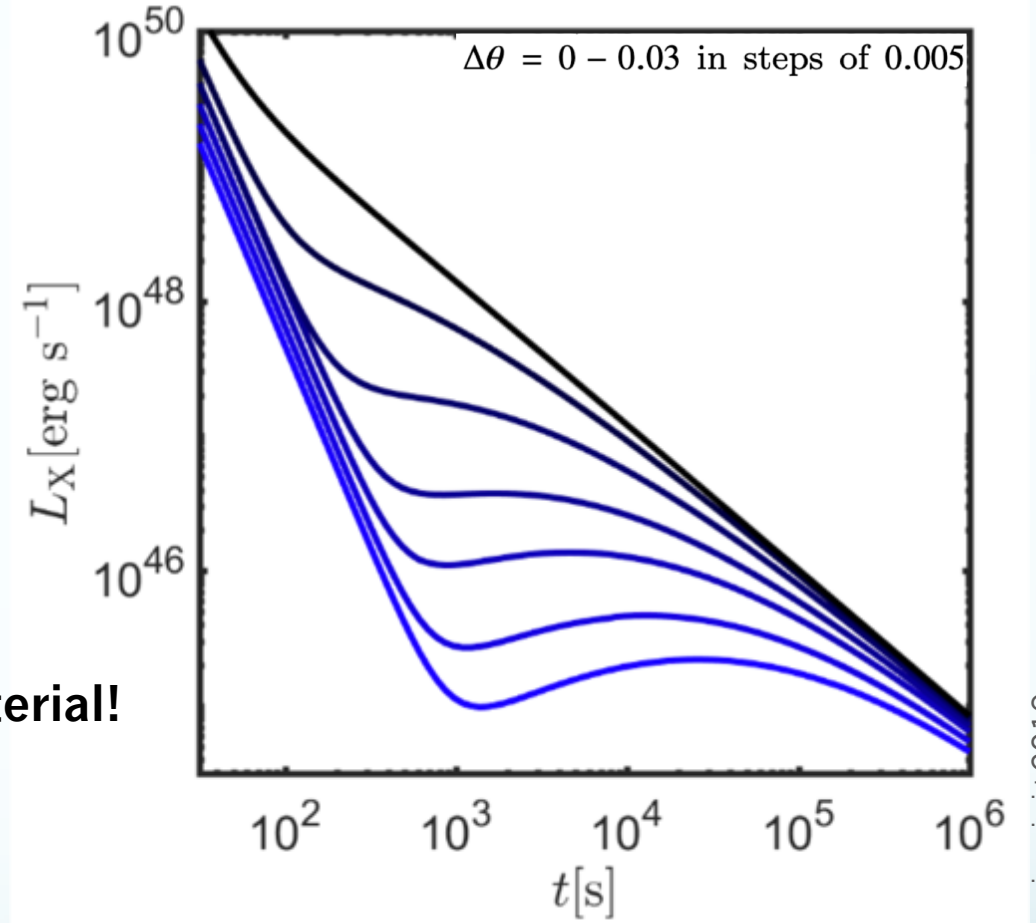


Matsumoto+19

X-ray afterglow plateaus

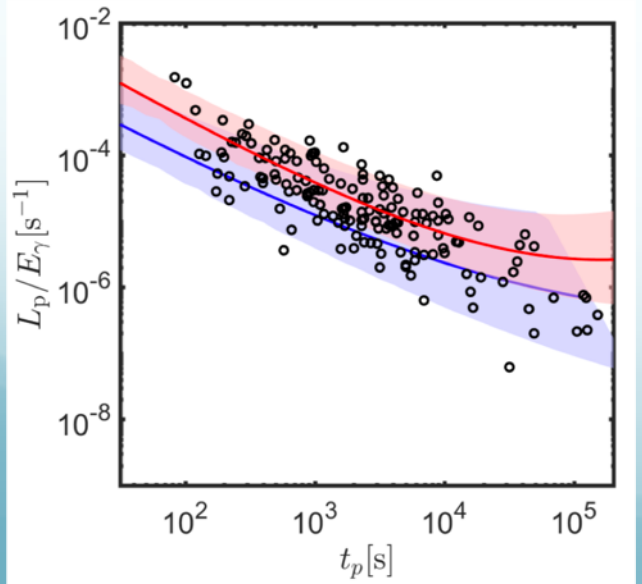


Dainotti+16



Beniamini+2019

= AG from de-boosted energetic material!



$E_{\rm kin,iso} = 10^{54}$ erg, $\theta_j = 0.1$, $\Gamma_j = 400$, $\eta_\gamma = 0.1$, $\epsilon_e = 0.1$, $\epsilon_B = 0.01$, $p = 2.2$ $\alpha = 8$, $\beta \gg 1$

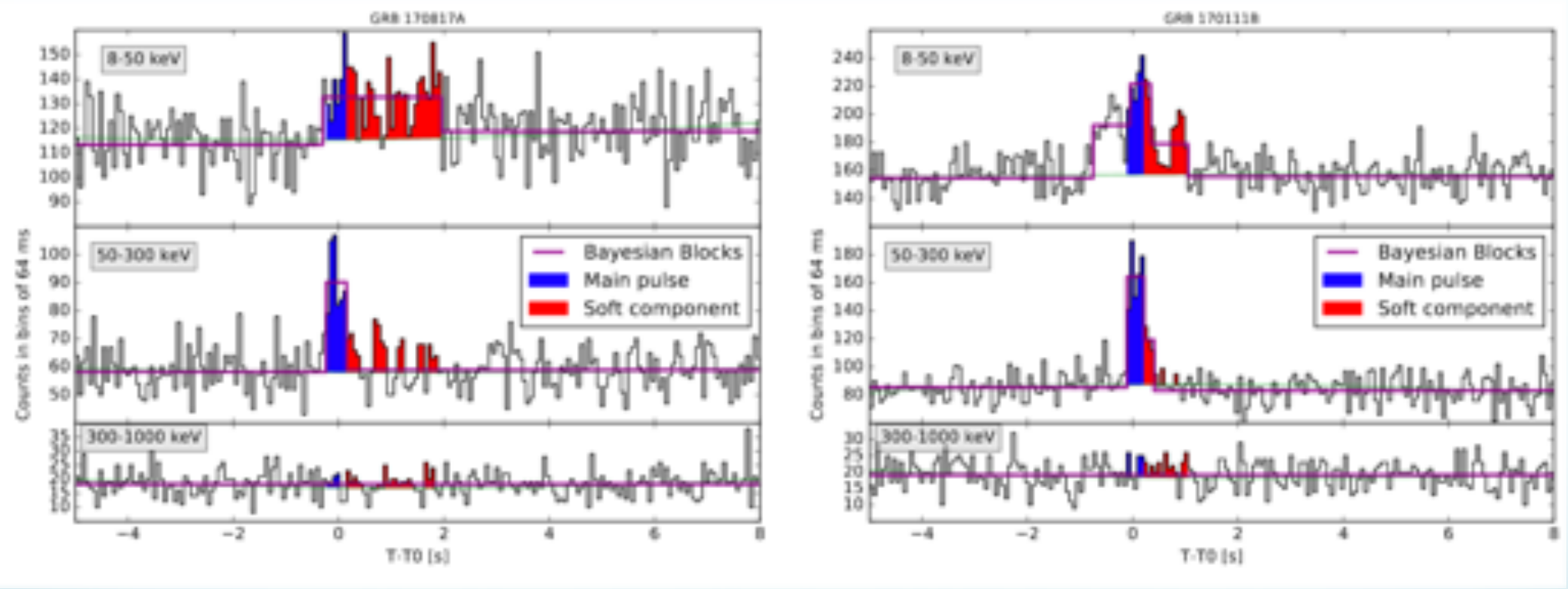
➔ Plateau MW light-curves and correlations naturally arise from structured jets!

see also Oganesyan+19

Conclusion

- From the point of view of GRB science, **progress has been made in the study of relativistic jets**
- Especially thanks to GRB170817A and counterparts
- **Prospects for similar events are not good,** not to mention **the difficulty to follow up GW events** and short GRBs in general (poorly localized, faint afterglow)
- Nonetheless, this event was a **big reveal, and brings much inspiration**
- Some classical/cosmological GRB observations are **naturally interpreted with structured jets or new emission** mechanisms such as shock break-out:
  - Afterglow plateaus and flares
  - Mildly-relativistic shocks and late-time behavior of GRB afterglows
  - Luminosity functions, GRB beaming factor and statistics
  - New approaches to the GRB progenitors: their populations and collapse mechanisms
  - Much (much) more!

Von Kienlin GRBs



Von Kienlin+2019