The structure of jets in Gamma Ray Bursts

G. Ghirlanda

Outline:

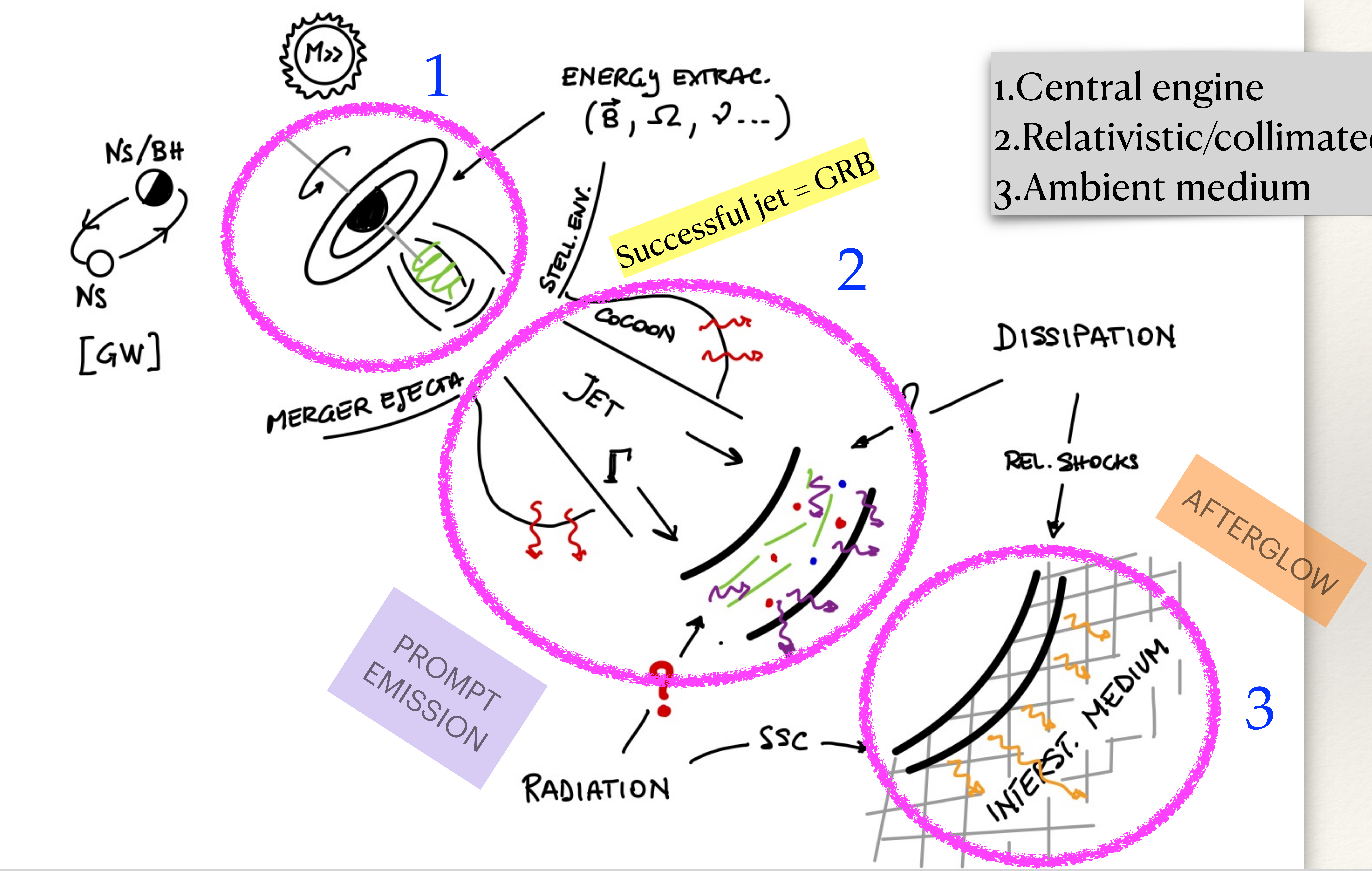
1) Collimation in GRBs

2) Structure of GRB jets

3) Hunting for structure signatures

4) Perspectives

GRB recipe



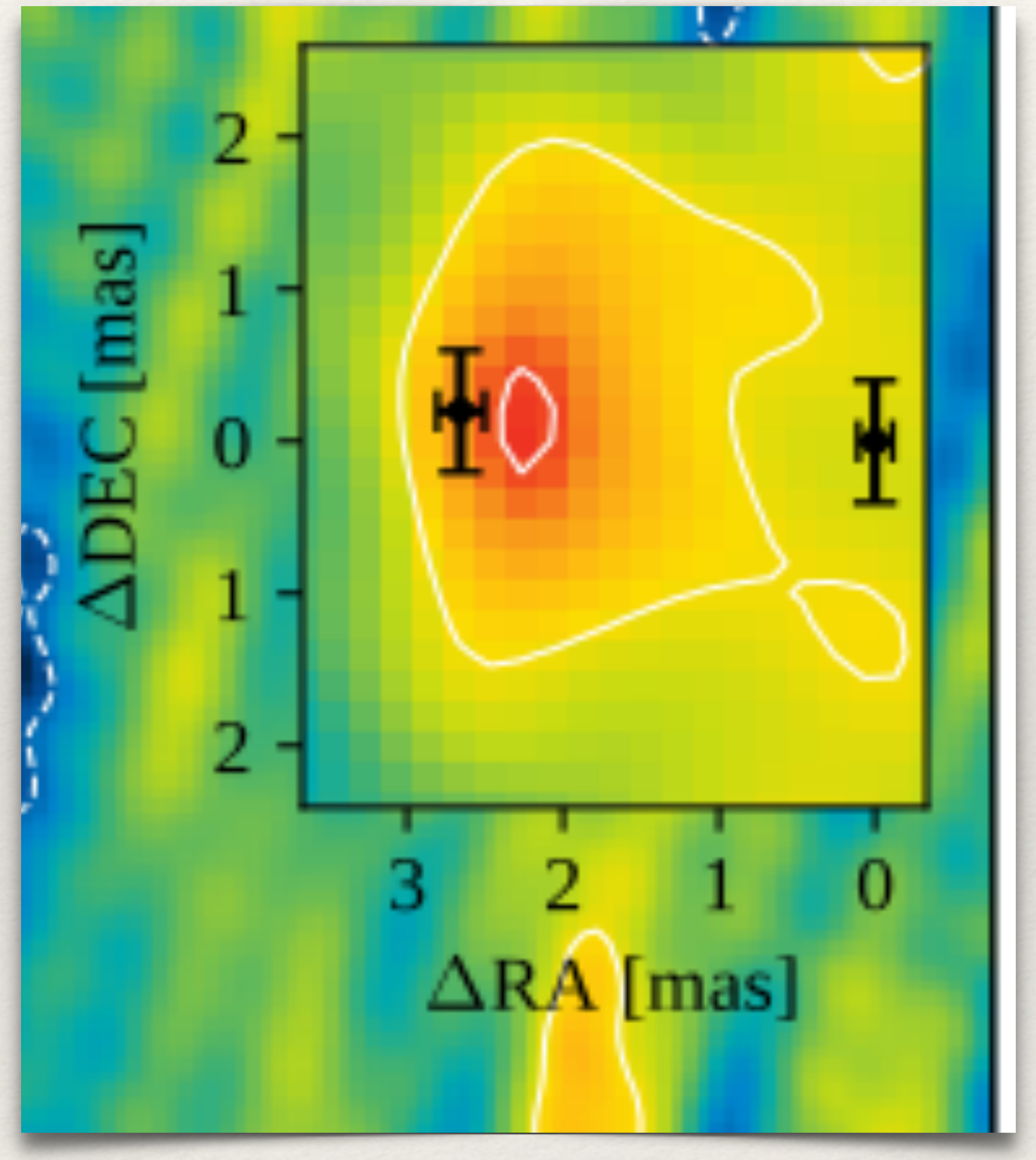
1. Central engine
2. Relativistic/collimated/powerful outflow
3. Ambient medium

Ingredient #2: relativistic & collimated

Relativistic:

1) Compactness $\tau_{\gamma\gamma,R} \sim \Gamma^{2\beta-2}\tau_{\gamma\gamma,NR}$

2) Proper motion and/or size expansion

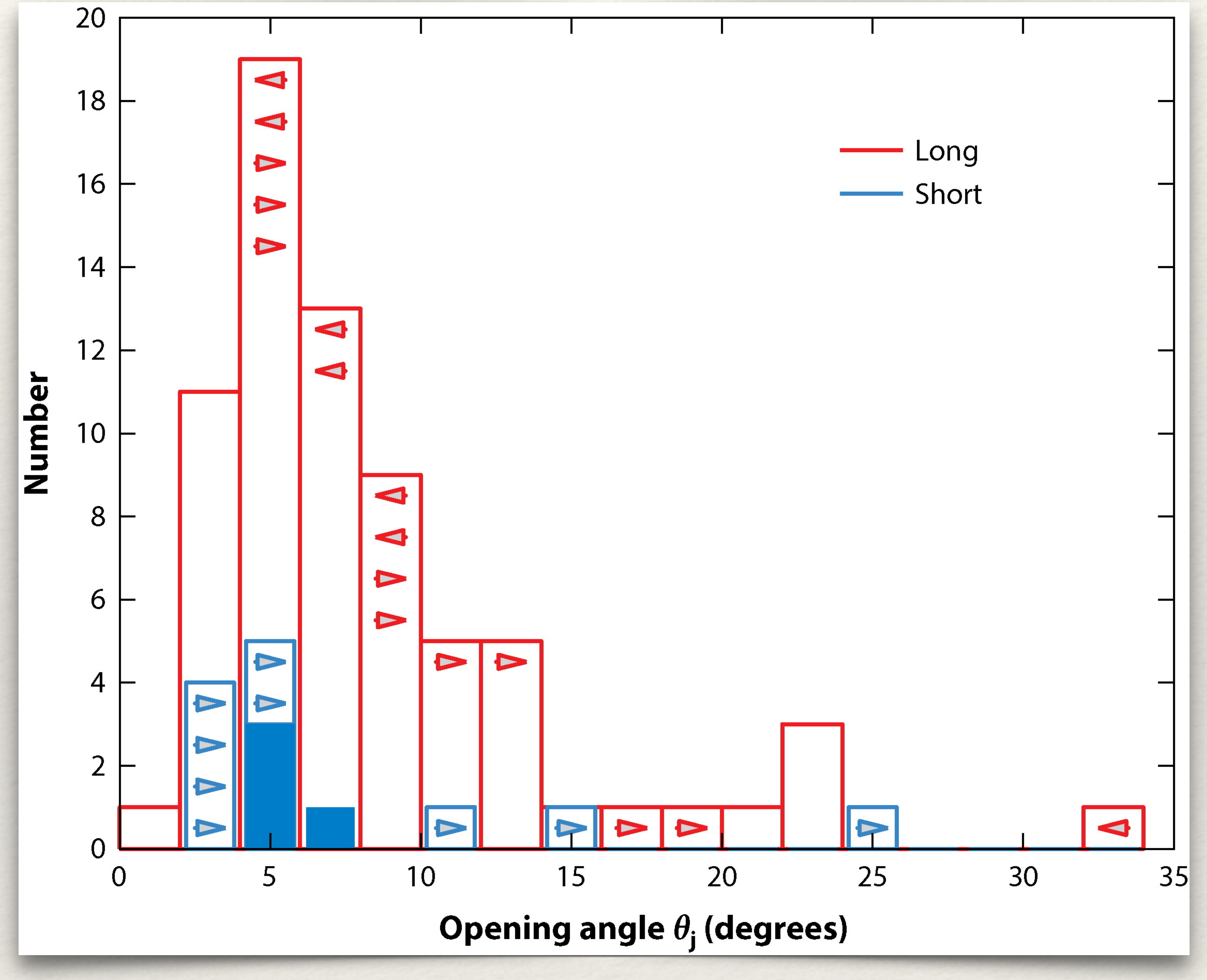


Mooley+2018; GG+2019

Collimated:

1) Energy budget $E_{jet} \sim \frac{E_{\gamma,\mathrm{iso}}\theta^2}{\eta}$

2) Afterglow jet break



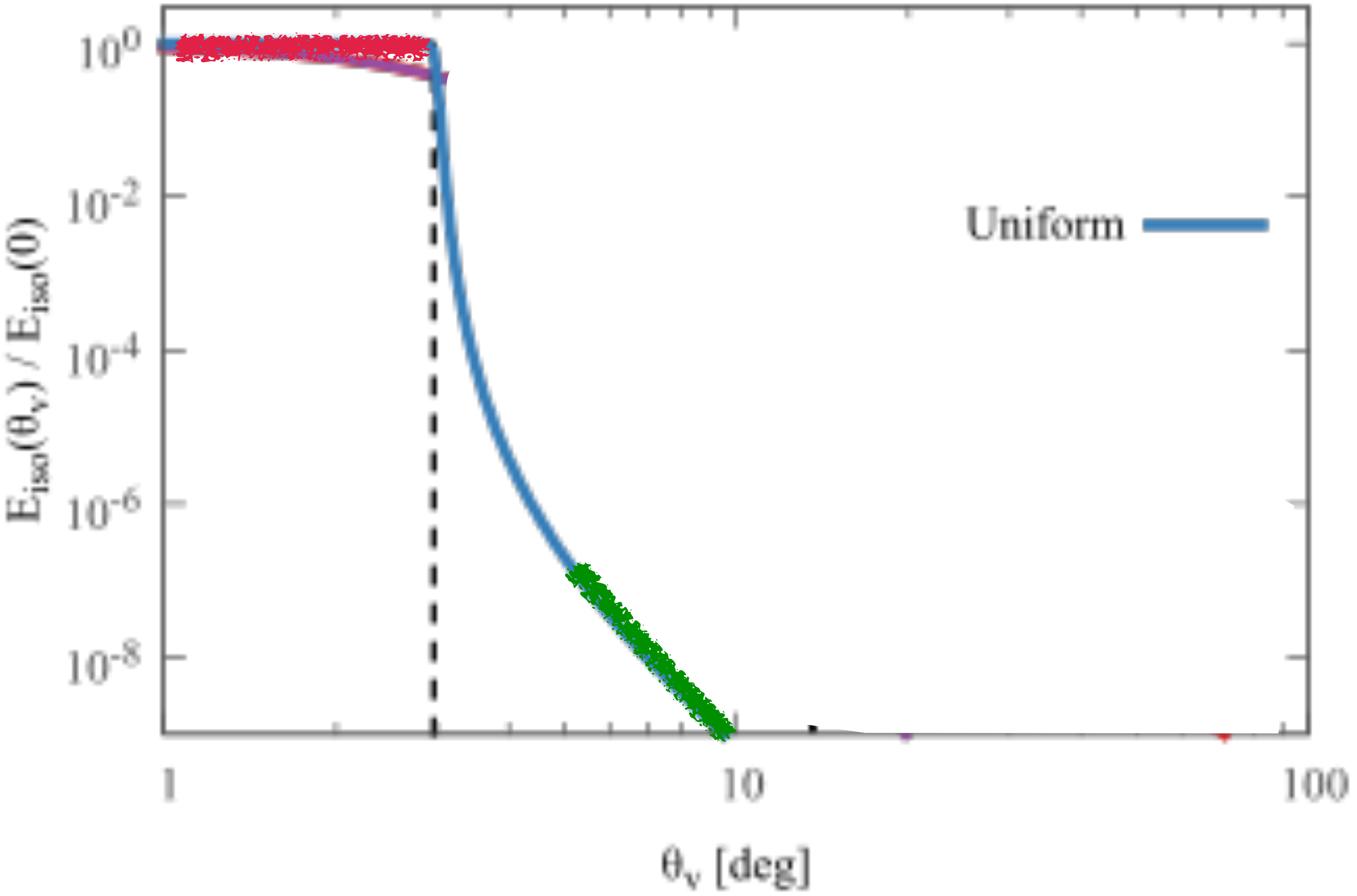
Berger 2014

How they look like depends on **Intrinsic properties** and **orientation**

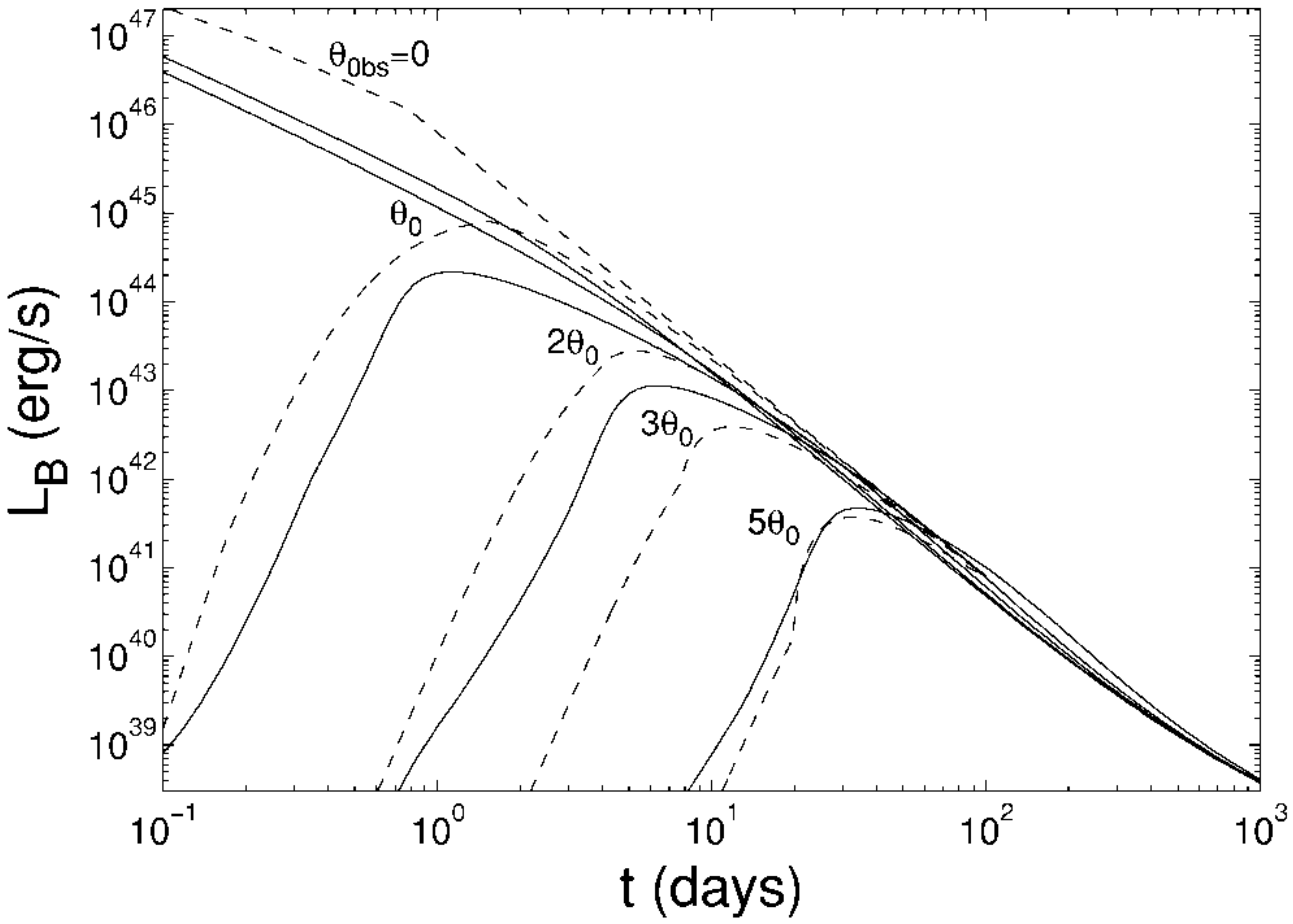
Viweing angle effects

Top hat or Uniform jet: $E,\ \Gamma\ |\ \theta_{jet}$

PROMPT EMISSION



AFTERGLOW EMISSION



Granot 2002

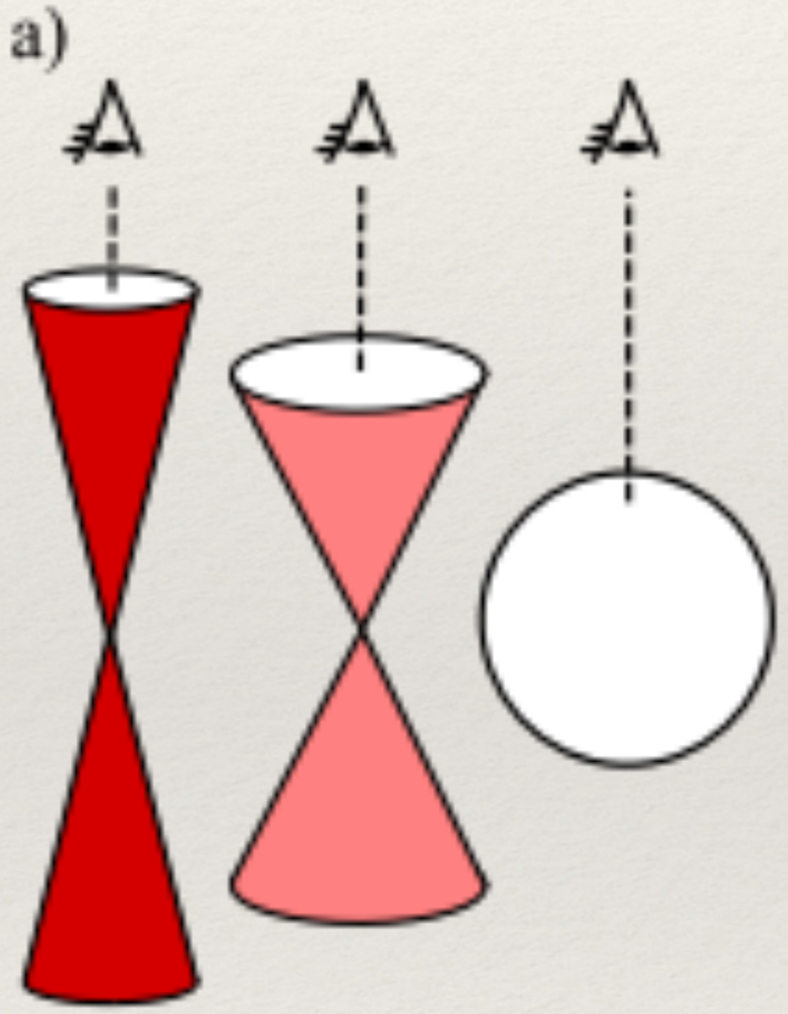
Strong depression of the observed luminosity (more prompt than afterglow) for slightly off axis observers

GRB diversity

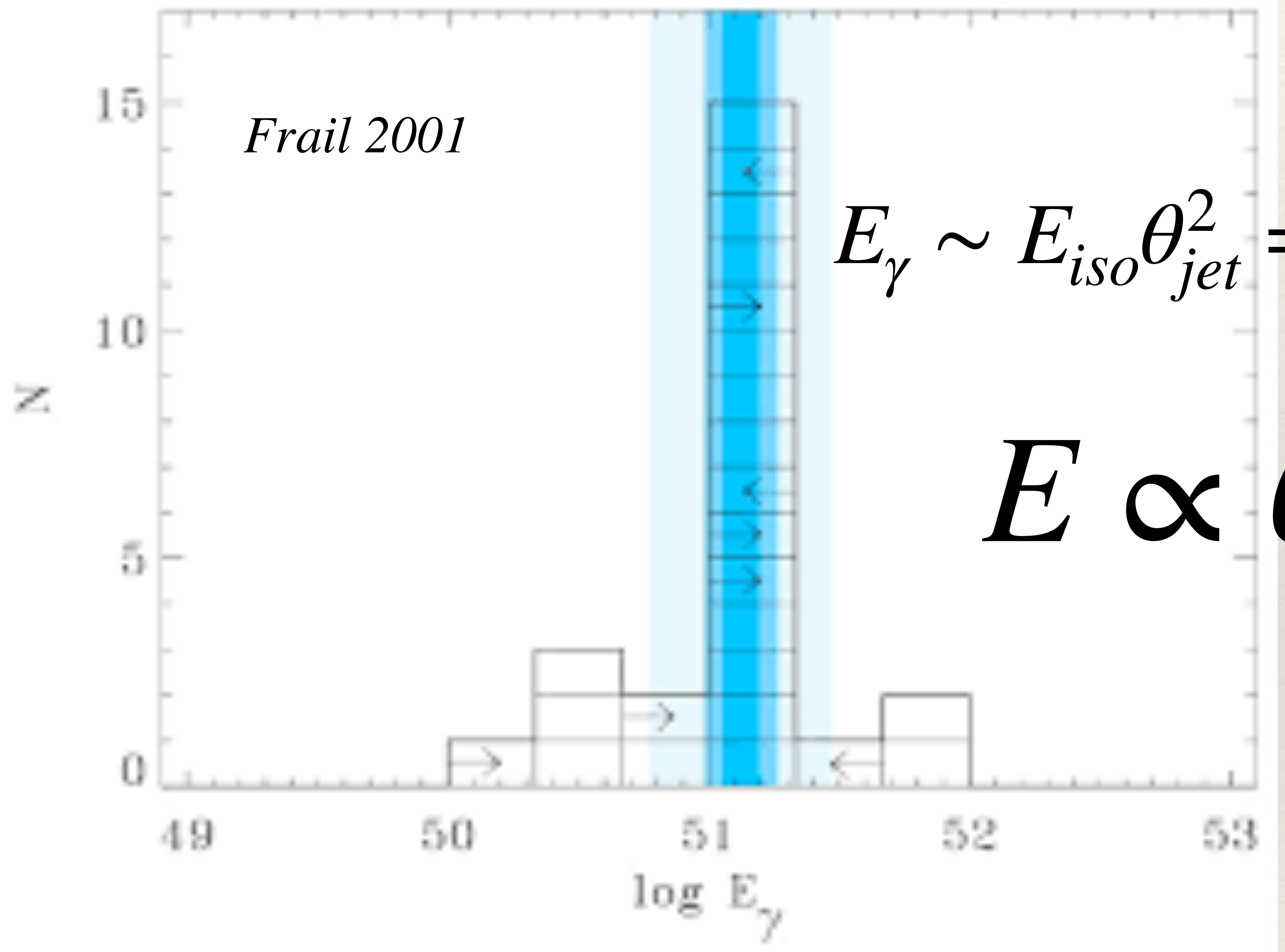
Uniform jet
Top hat jet

Structured jet
<u>Universal</u> jet

GRB diversity —> Intrinsic



GRB diversity —> θ_v



$E_\gamma \sim E_{iso}\theta^2_{jet} = \text{const}$

$E \propto \theta^{-2}$

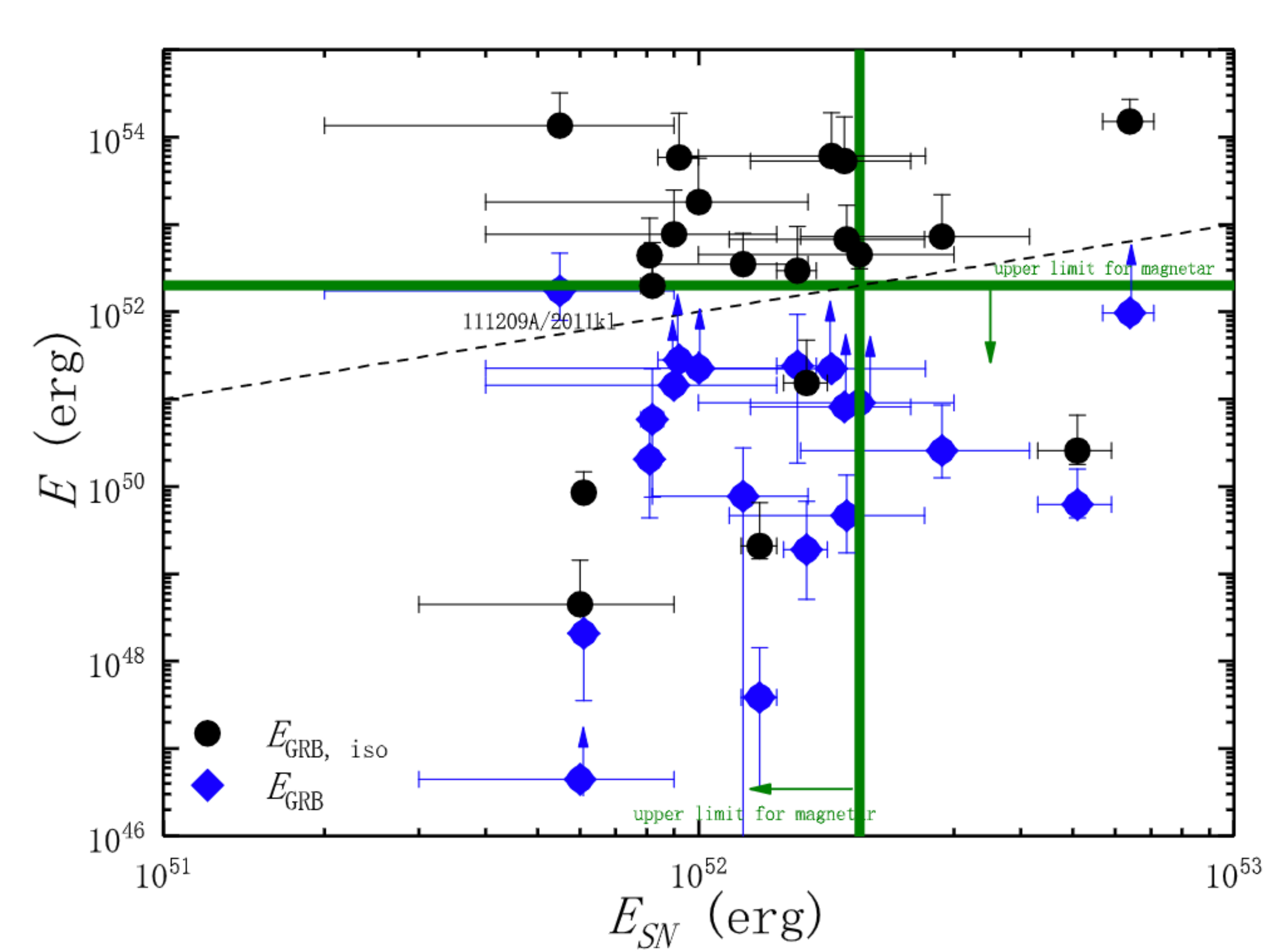
(Lipunov et al. 2001) Rossi + 2002; Zhang+ 2002

Strctured jet + cocoon
Uniform jet + cocoon
Structured cocoon
…

2017 Aug → Many …

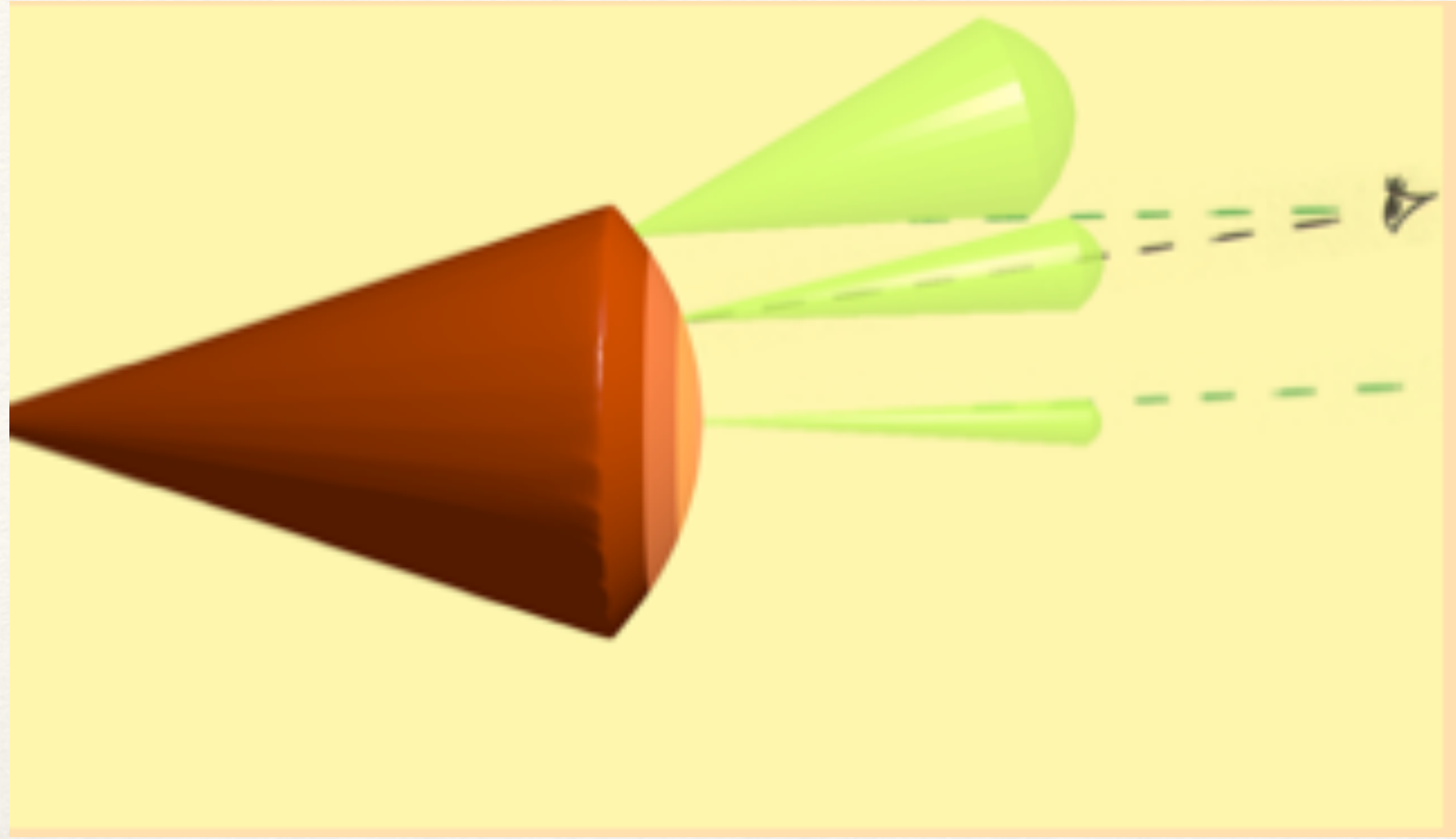
Structured jet = Universality (only orientation matters)

Why structured jet is appealing



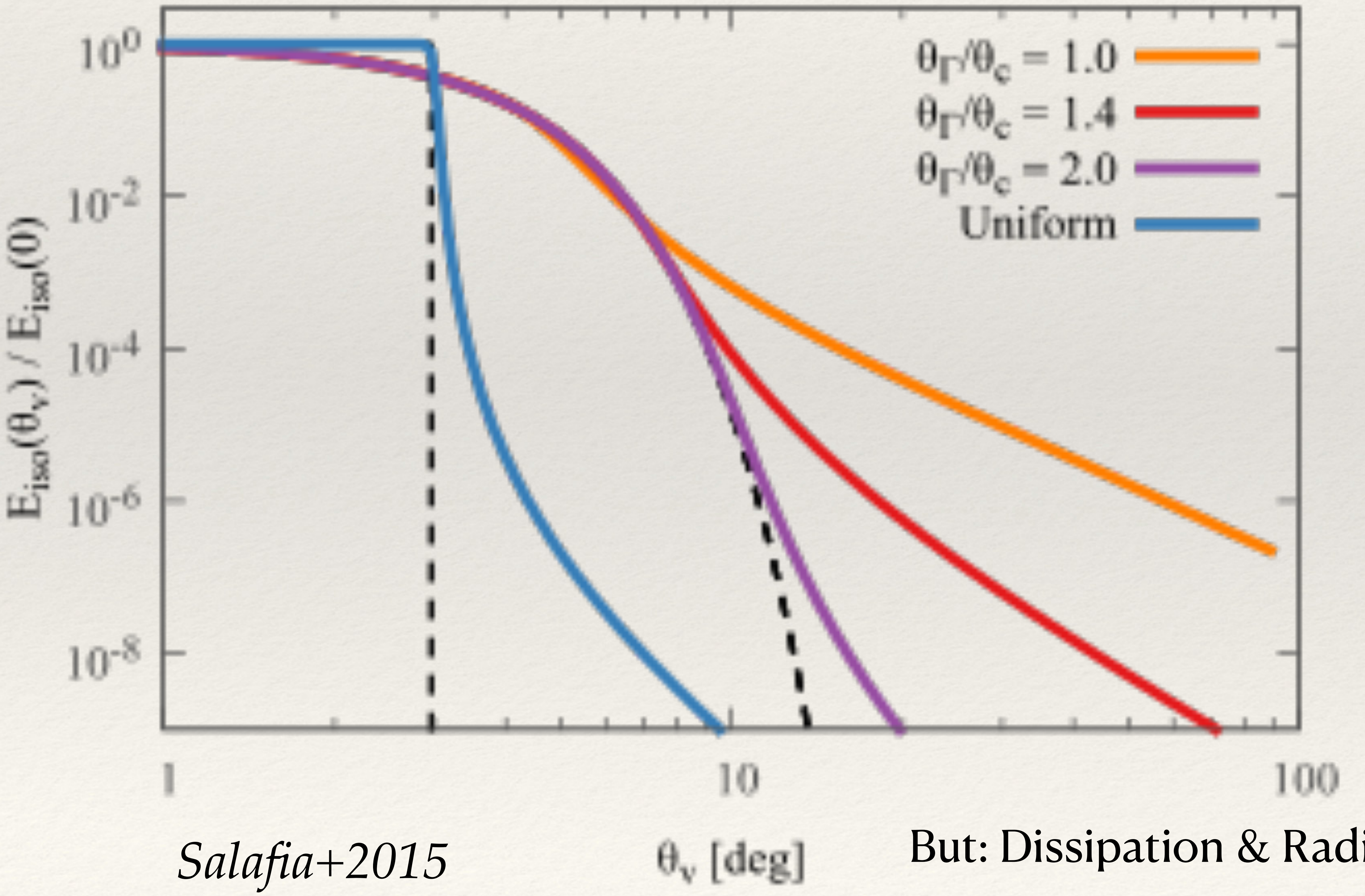
Lu et al. 2018

Viewing angle effects: structured jet



PROMPT EMISSION

$E(\theta)$ $\Gamma(\theta)$

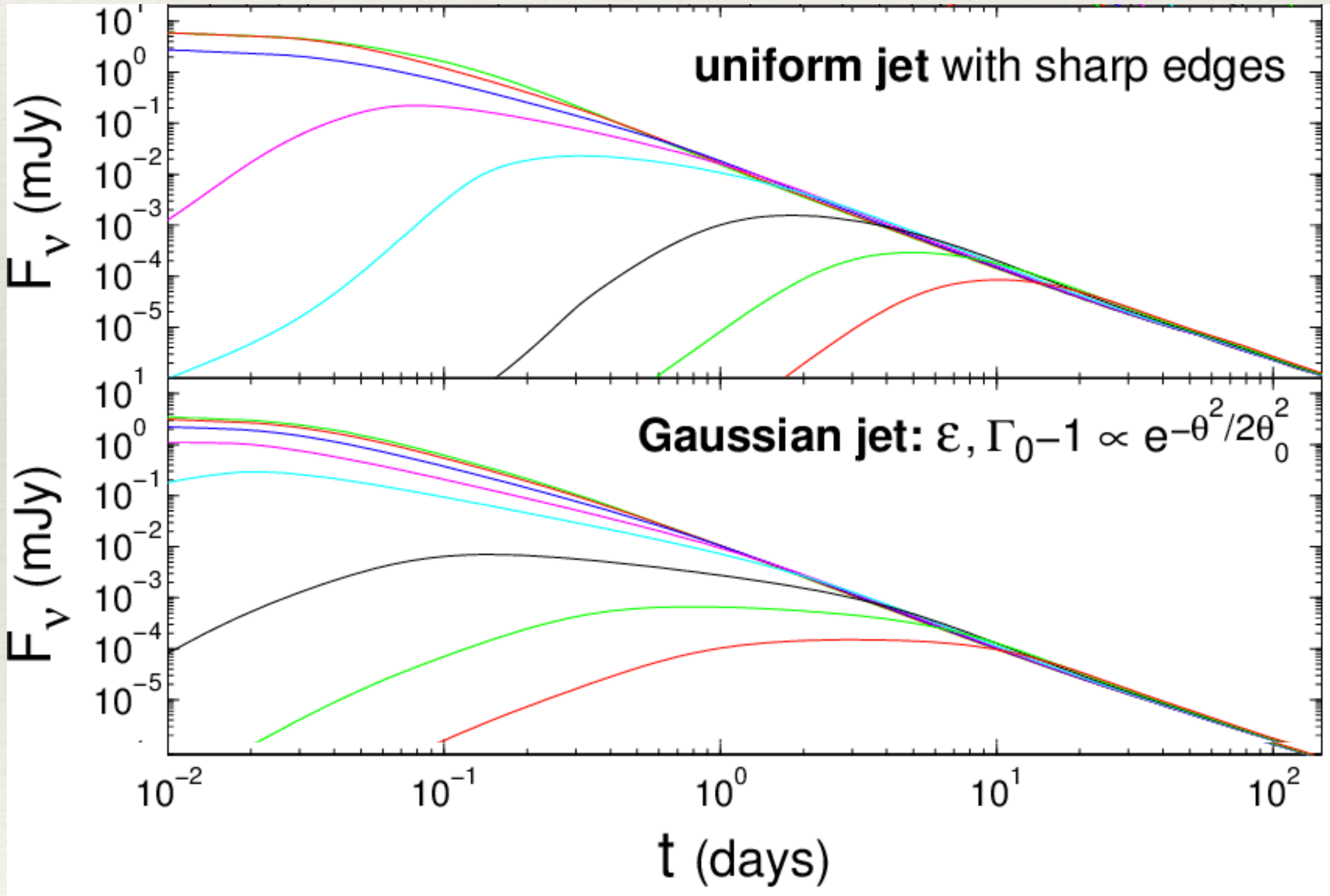


Salafia+2015

But: Dissipation & Radiation

AFTERGLOW EMISSION

$E(\theta, t)$ $\Gamma(\theta, t)$



Eichler & Granot 2006

Why do we care about jet structure?

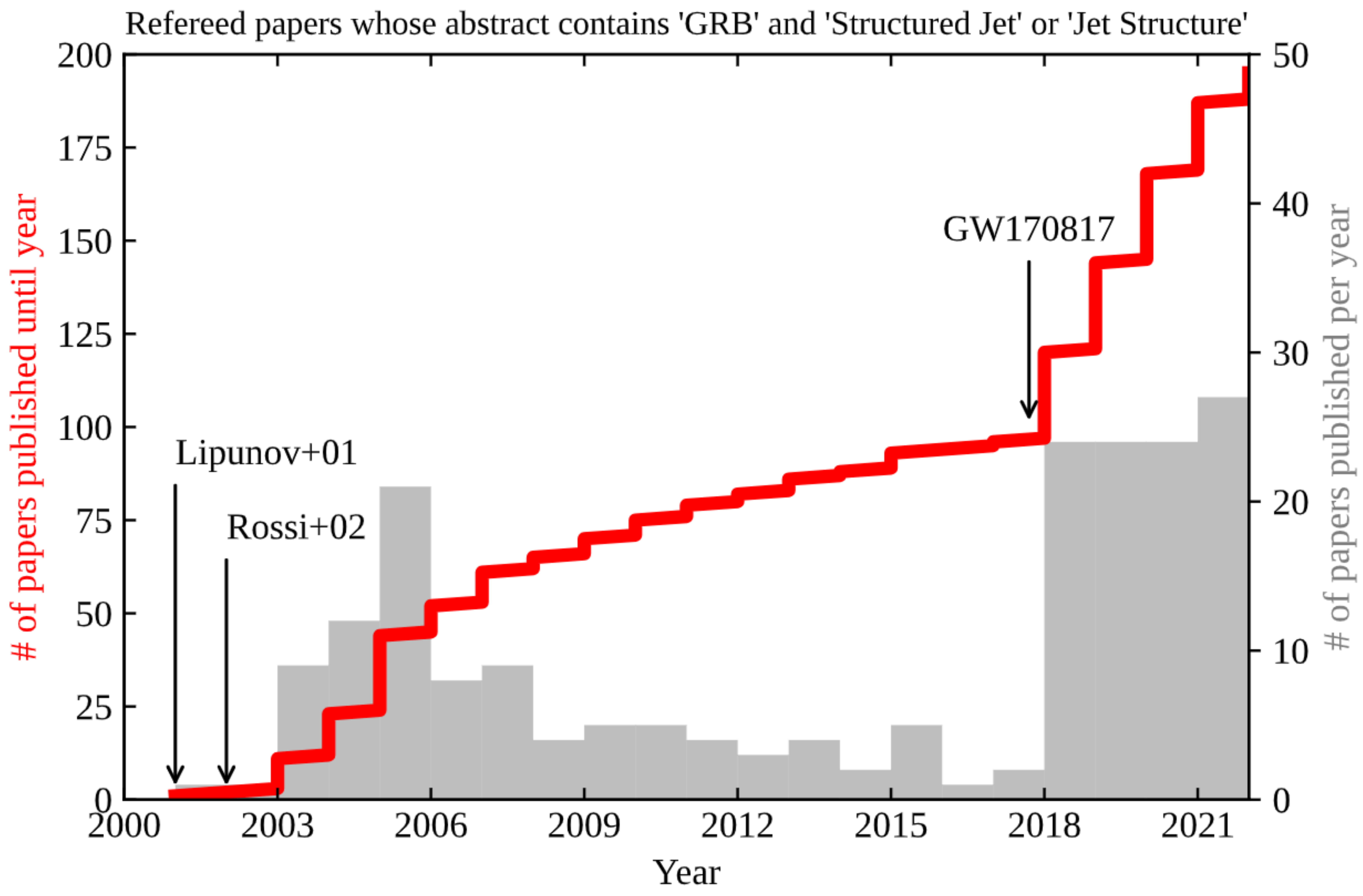
- Expected
- Determines observable properties
- It conveys information on otherwise unobservable phenomena (Jet-launching mechanism, jet-star material interaction, central engine ...)

Jet structure definition

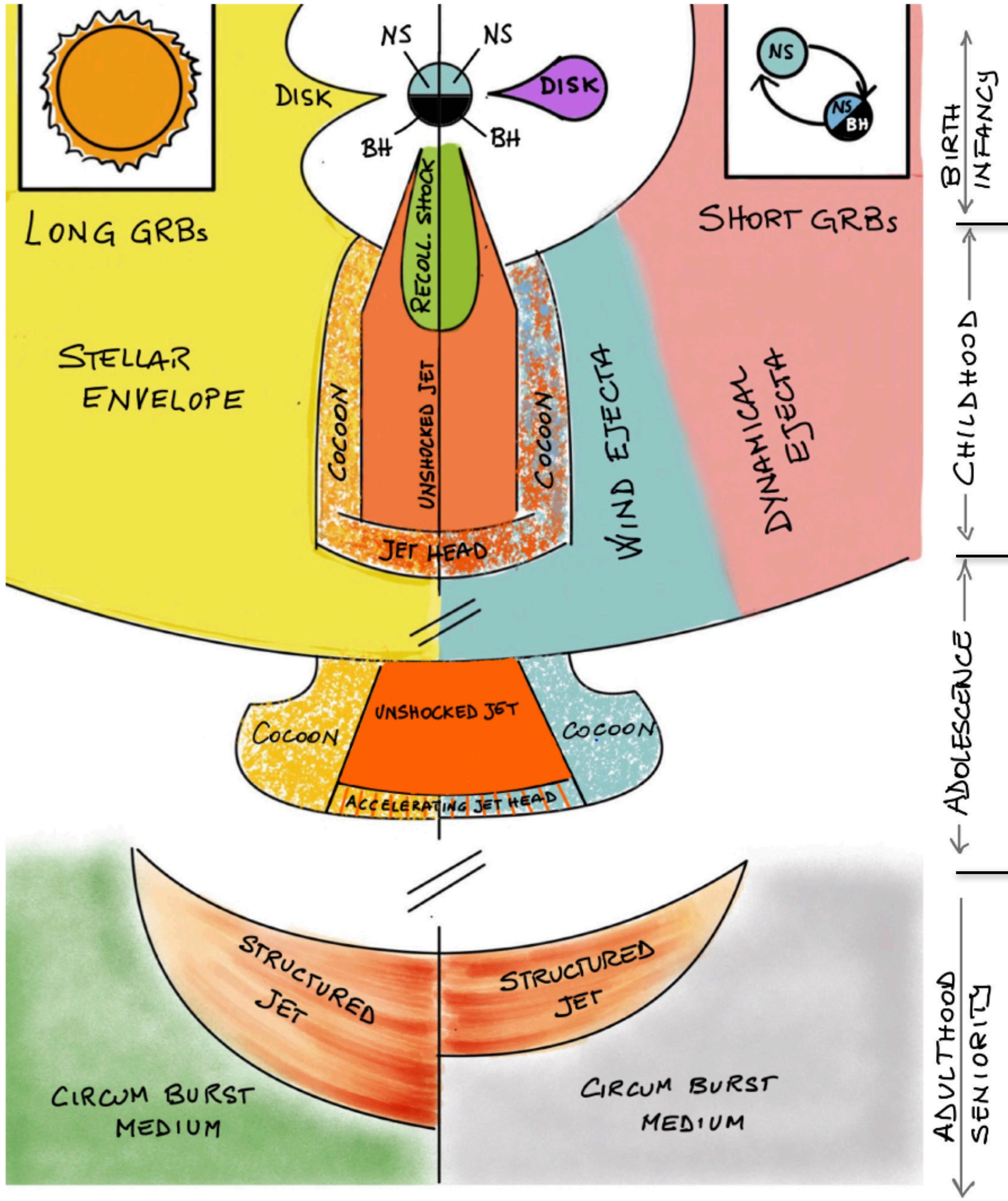
$$\frac{dE'}{d\Omega}(\theta, t)$$ (Jet internal energy)

$$\Gamma(\theta, t)$$

We care about jet structure!



A Picassian view of a GRB



Salafia & Ghirlanda 2022, Galaxy special issue

- Nature of the central engine
- Energy extraction mechanism

Initial conditions

- Jet Head formation
- Forward/reverse shock
- Cocoon - jet confinement effect

Angular structure

- Jet-cocoon breakout - free expansion
- First light (shock breakout emission)

Freezing of angular structure

- Prompt emission
- Afterglow emission

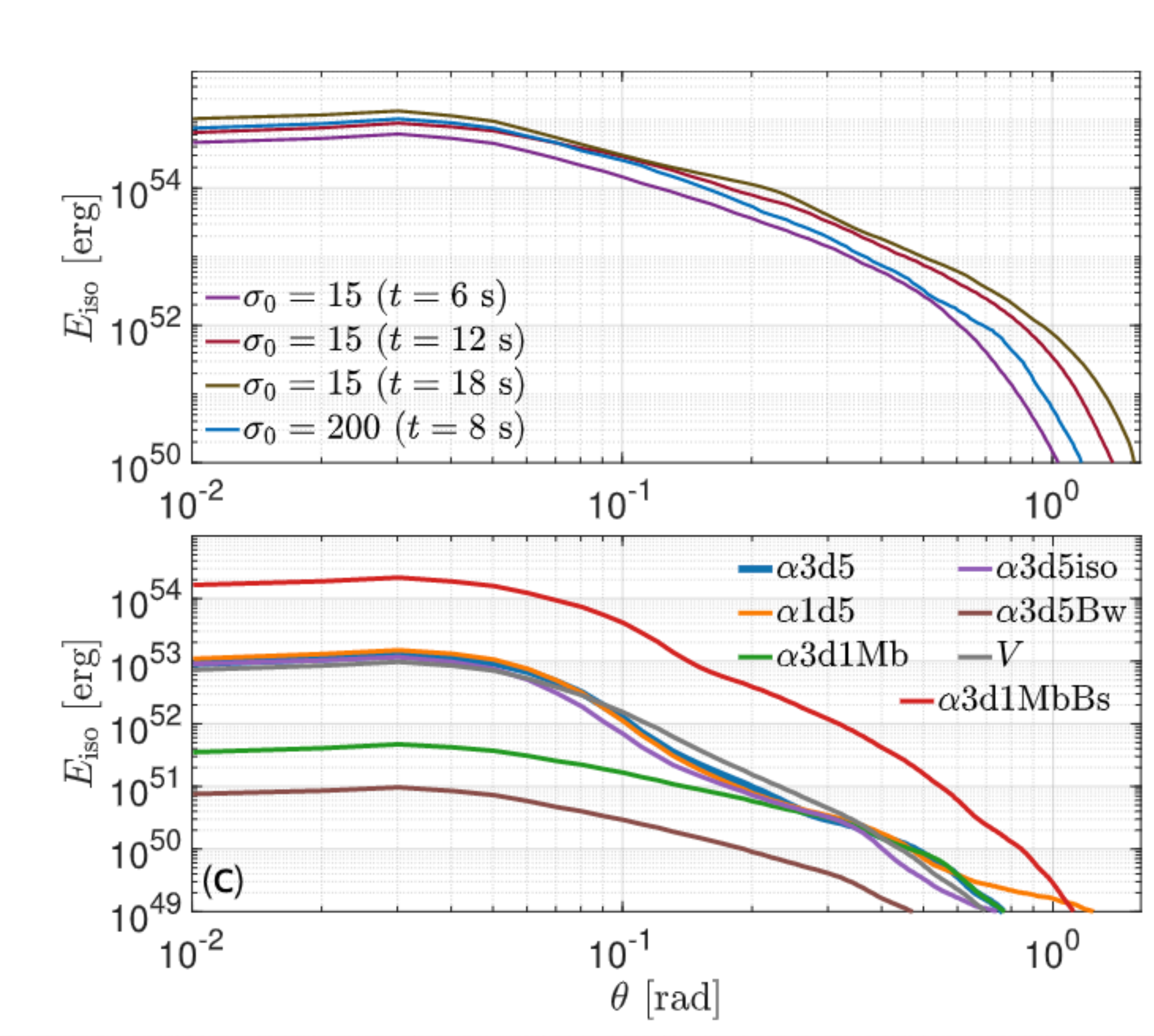
Non-relativistic transition —> Jet structure erase

Adolescence

Gottlieb et al. 2022

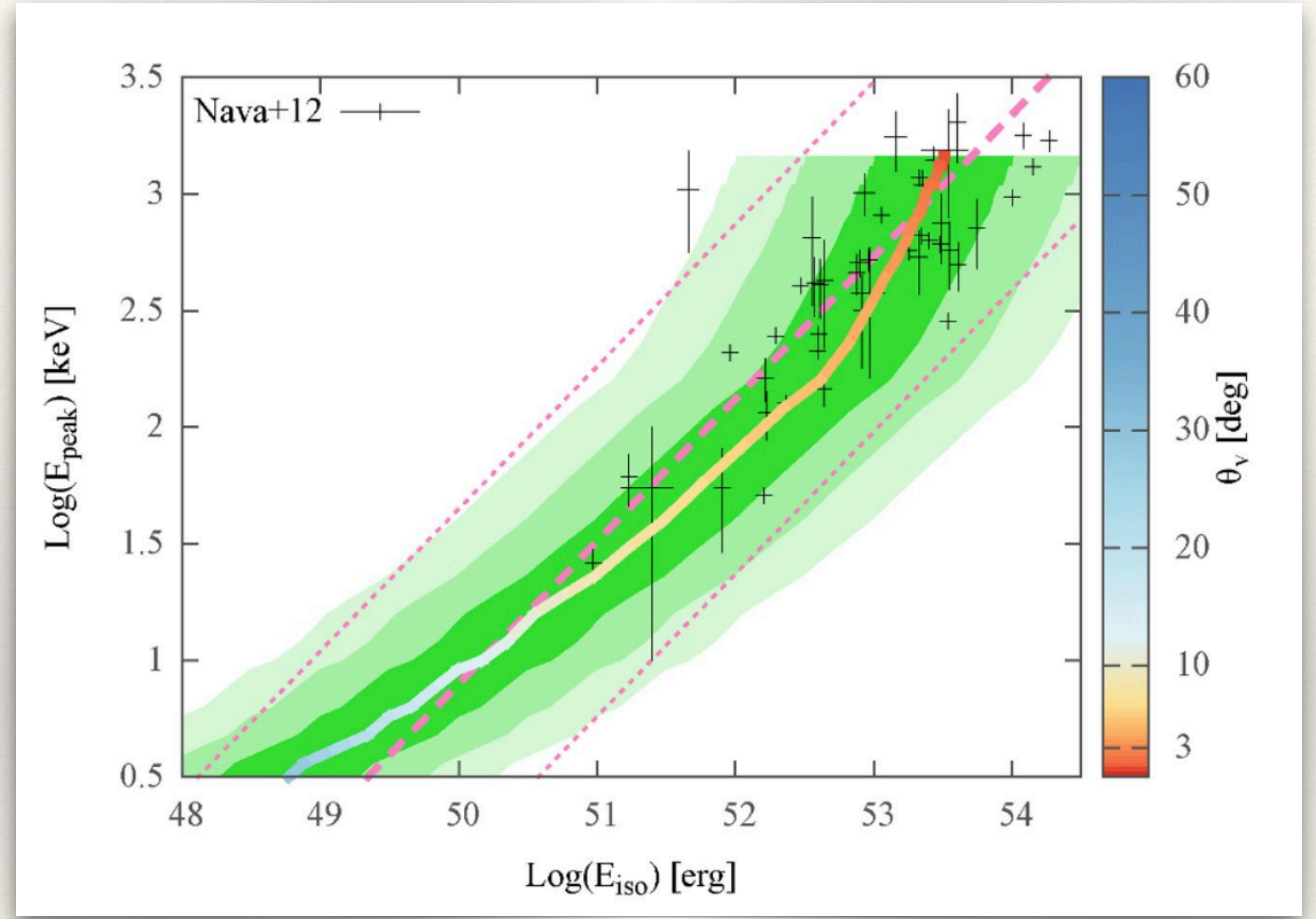
Collapsar

BNS merger



Hunting for structured jet signatures

PROMPT EMISSION

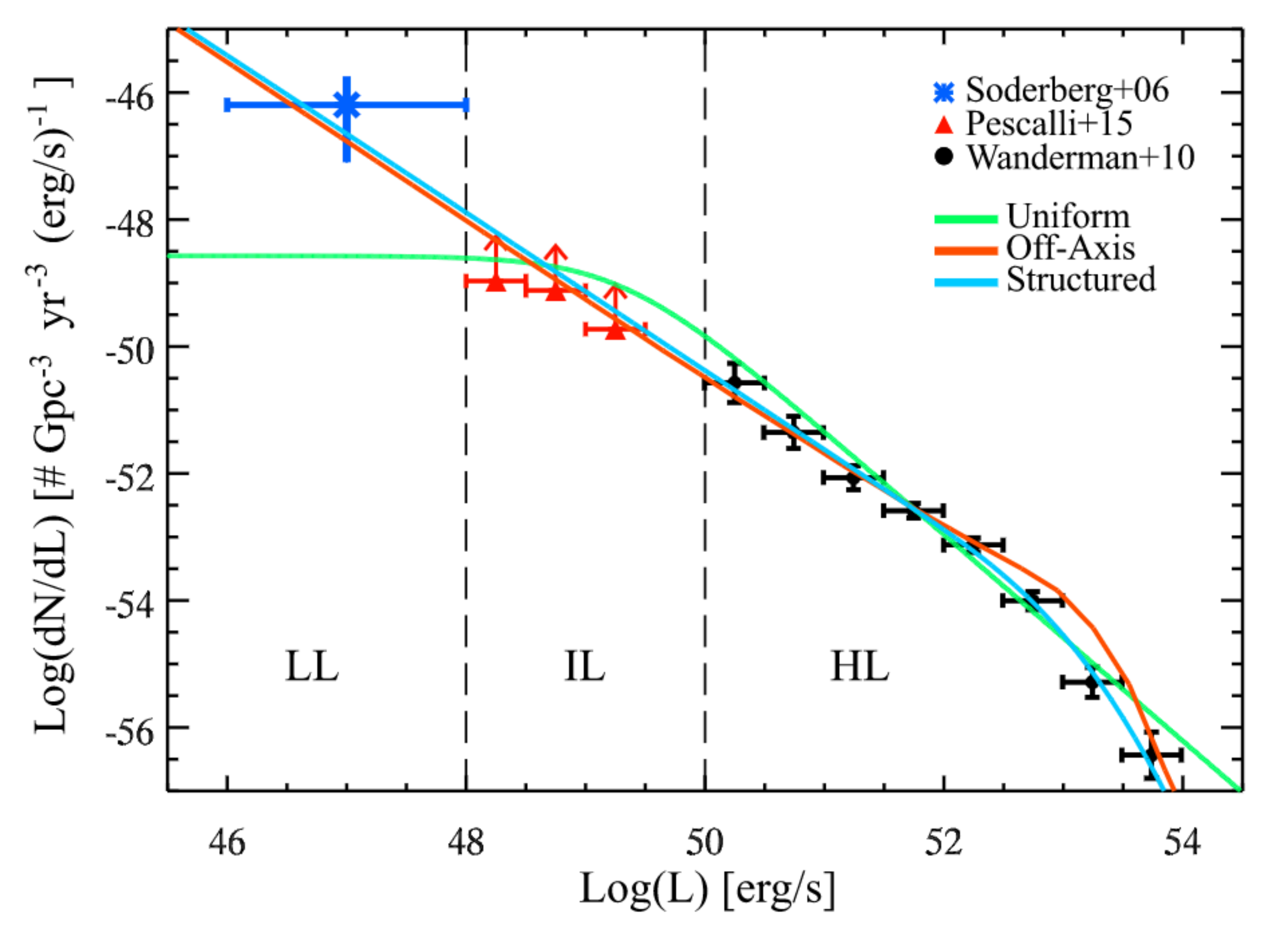


Salafia et al. 2015, Salafia & Ghirlanda 2022

consistent with rather than constraining jet structure

Hunting for structured jet signatures

LONG GRBs

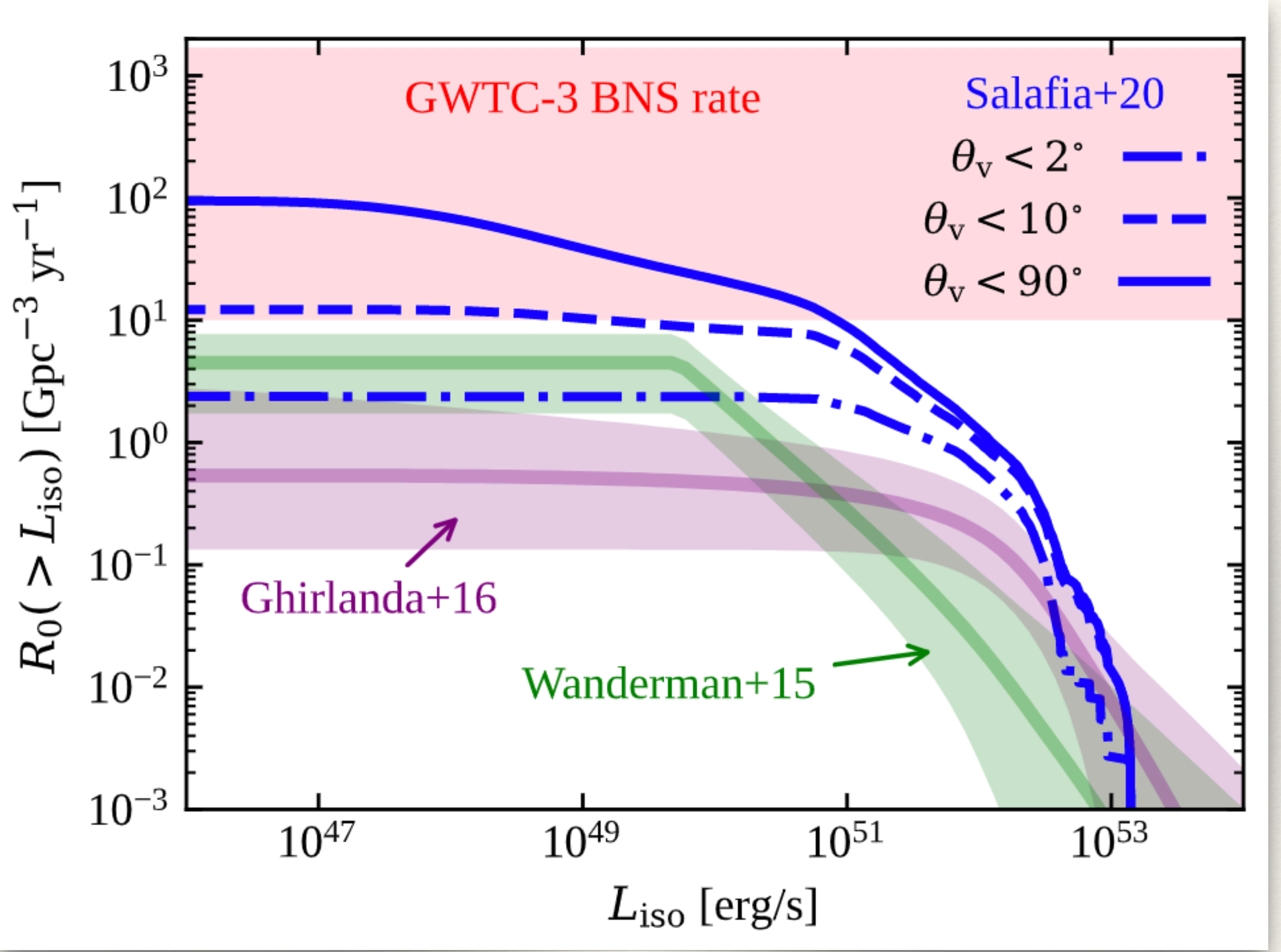


***Pescalli et al. 2015**, 2016; Salafia 2015; GG&Salvaterra 2022*

$\theta^{-\alpha}$ with $\alpha < -4$
Or Gaussian

Hunting for structured jet signatures

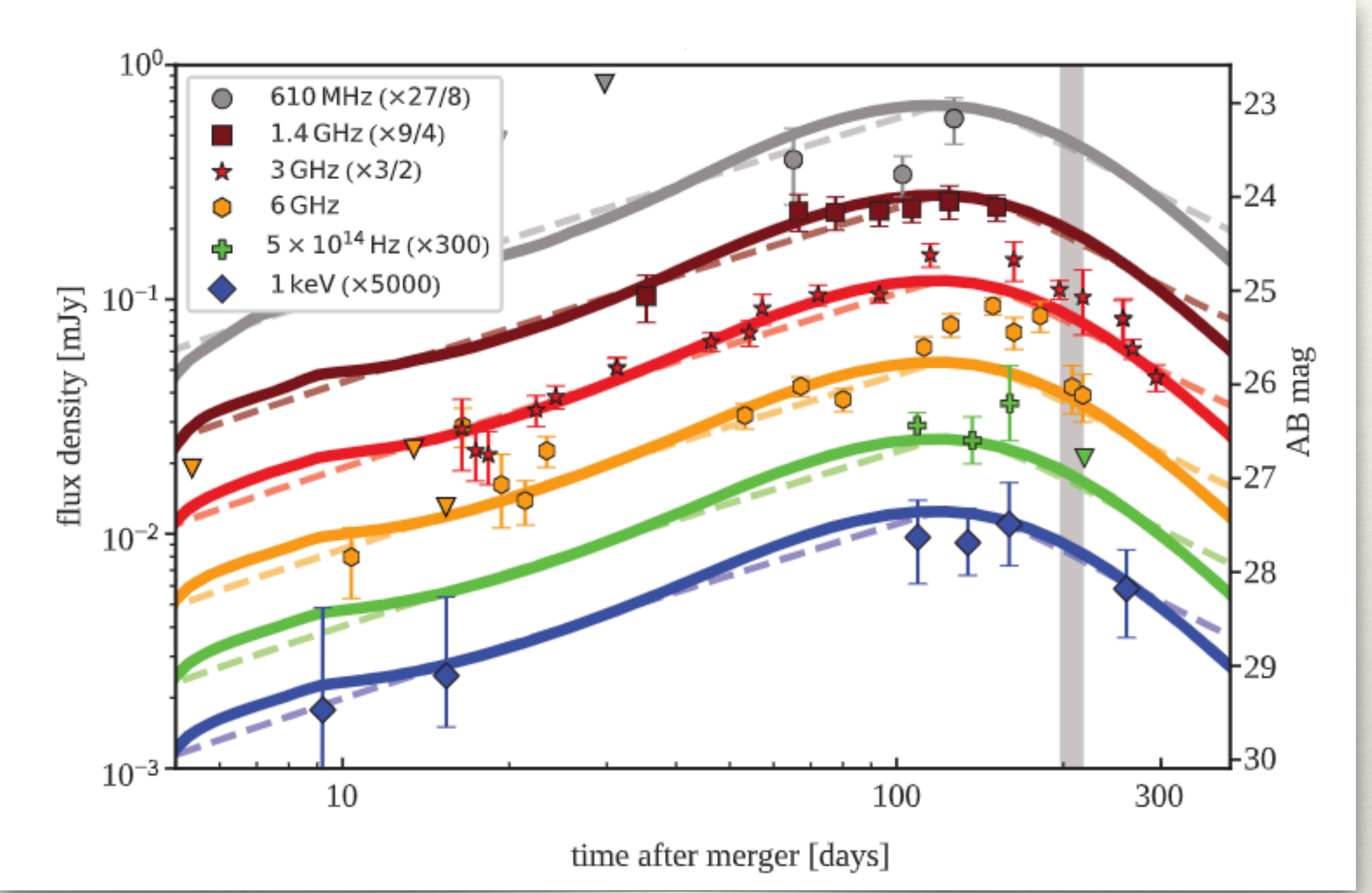
SHORT GRBs



$\theta^{-\alpha}$ with $\alpha < -3$

Salafia & Ghirlanda 2022

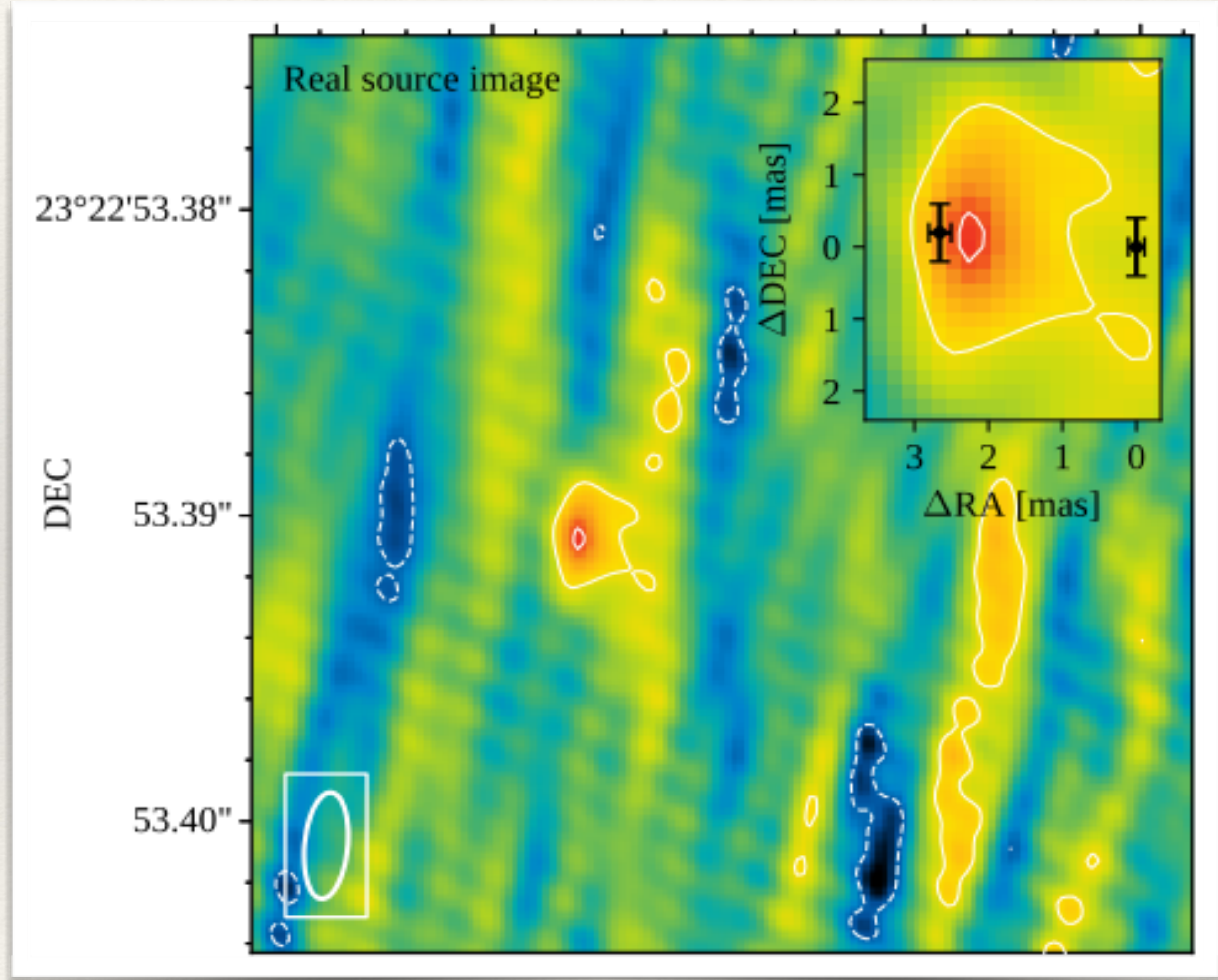
Hunting for structured jet signatures



GRB 170817:

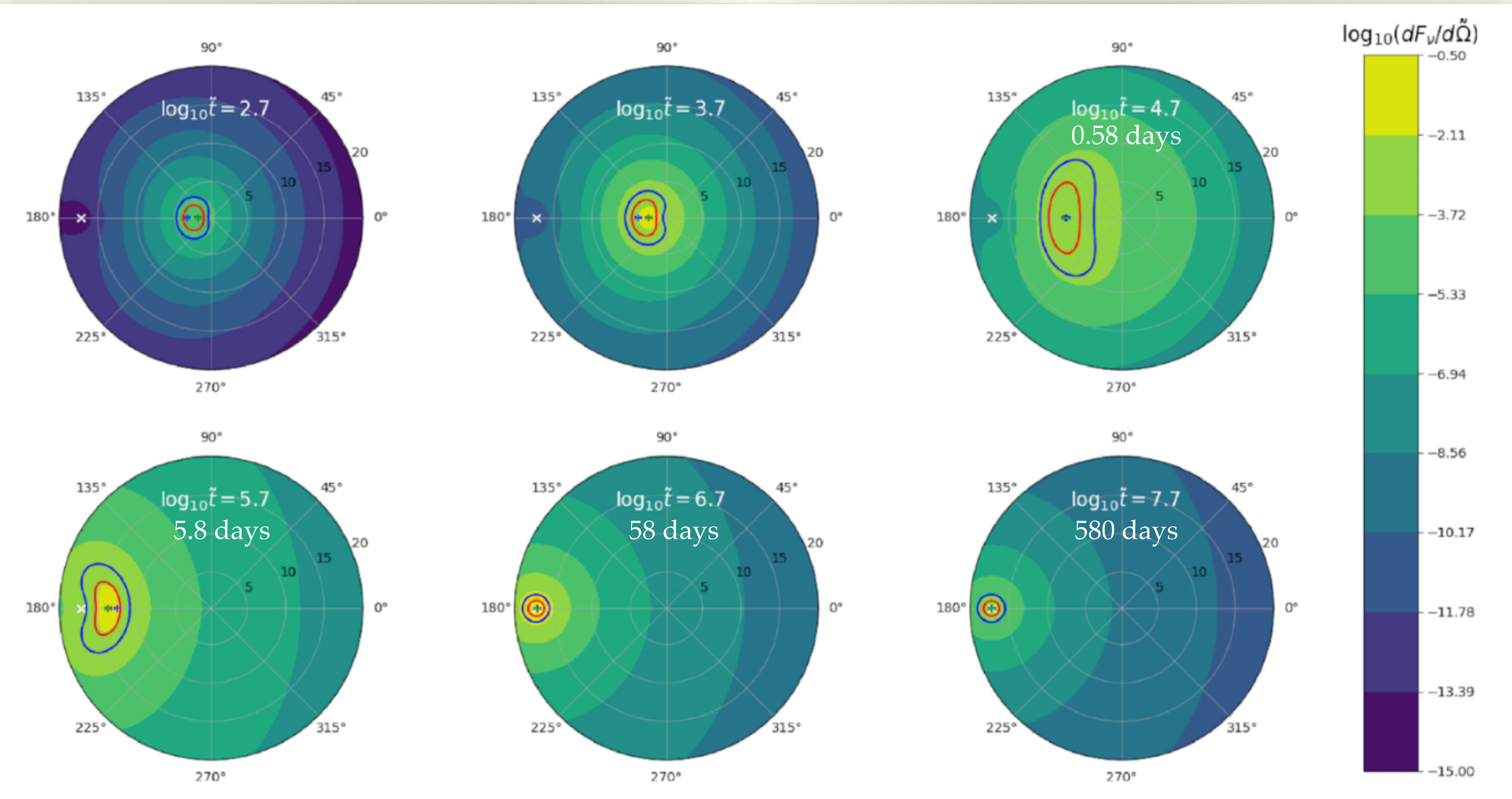
$$E \propto \theta^{-5.5}$$

$$\Gamma \propto \theta^{-3.5}$$



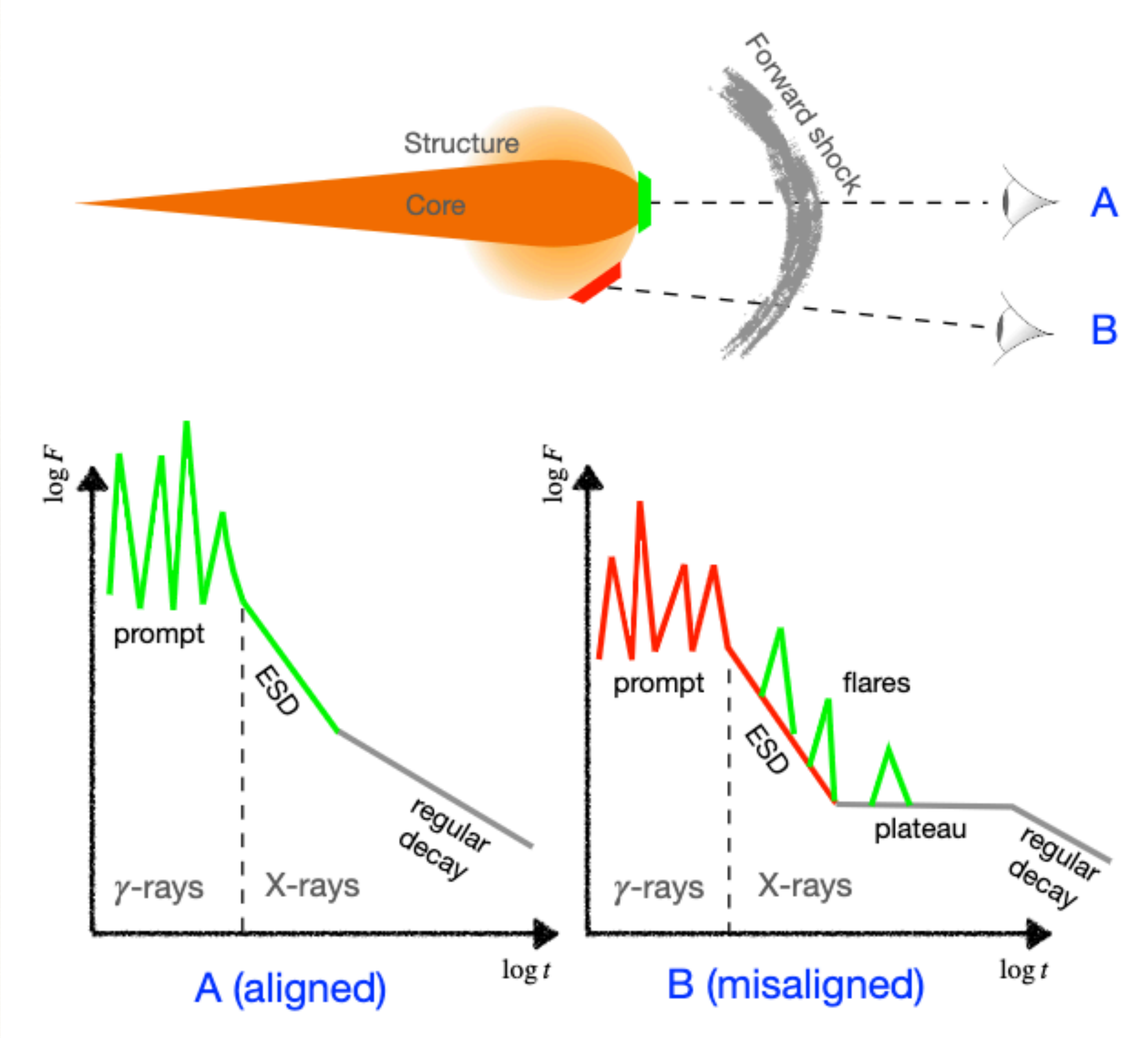
Mooley et al. 2018, D'Avanzo 2019, Ghirlanda et al. 2019

Hunting for structured jet signatures



Beniamini et al. 2022

Hunting for structured jet signatures



Steep decay / plateau: S. Ascenzi talk follows

Duque et al 2022

Conclusions

1.Relativistic Jets in GRBs

2.Jet ⇔ progenitor vestige interaction ➪ Jet structure

3.Structure ➪ Unobservable GRB prop.
- Initial conditions
- CE duration/enegy
- Vestige properties

4.$E(\theta); \Gamma(\theta) \propto \theta^{-\alpha}$:
- $\alpha > 3$ luminosity function (Pescalli et al. 2015)
- $\alpha > 3$ GW/GRB170817 (e.g. Ghirlanda et al. 2019)
- GRMHD simulations (Gottlieb et al. 2022)

HUNTING FOR JET STRUCTURE		
Observable	Constraining power	Difficulty
Prompt emission (spectrum, spectral energy correlations, etc)	Low	Easy
Early Afterglow (photometry)	High	Med
Late Afterglow imaging	High	High
Polarization (prompt/afterglow)	Low	High
Populations	Medium	Easy

COMBINATION OF SEVERAL OBSERVABLES IN FEW GRBS AND/OR POPULATION STUDIES

Salafia & Ghirlanda, 2022, Galaxies, 10(5), 93
https://www.mdpi.com/2075-4434/10/5/93

Thank you

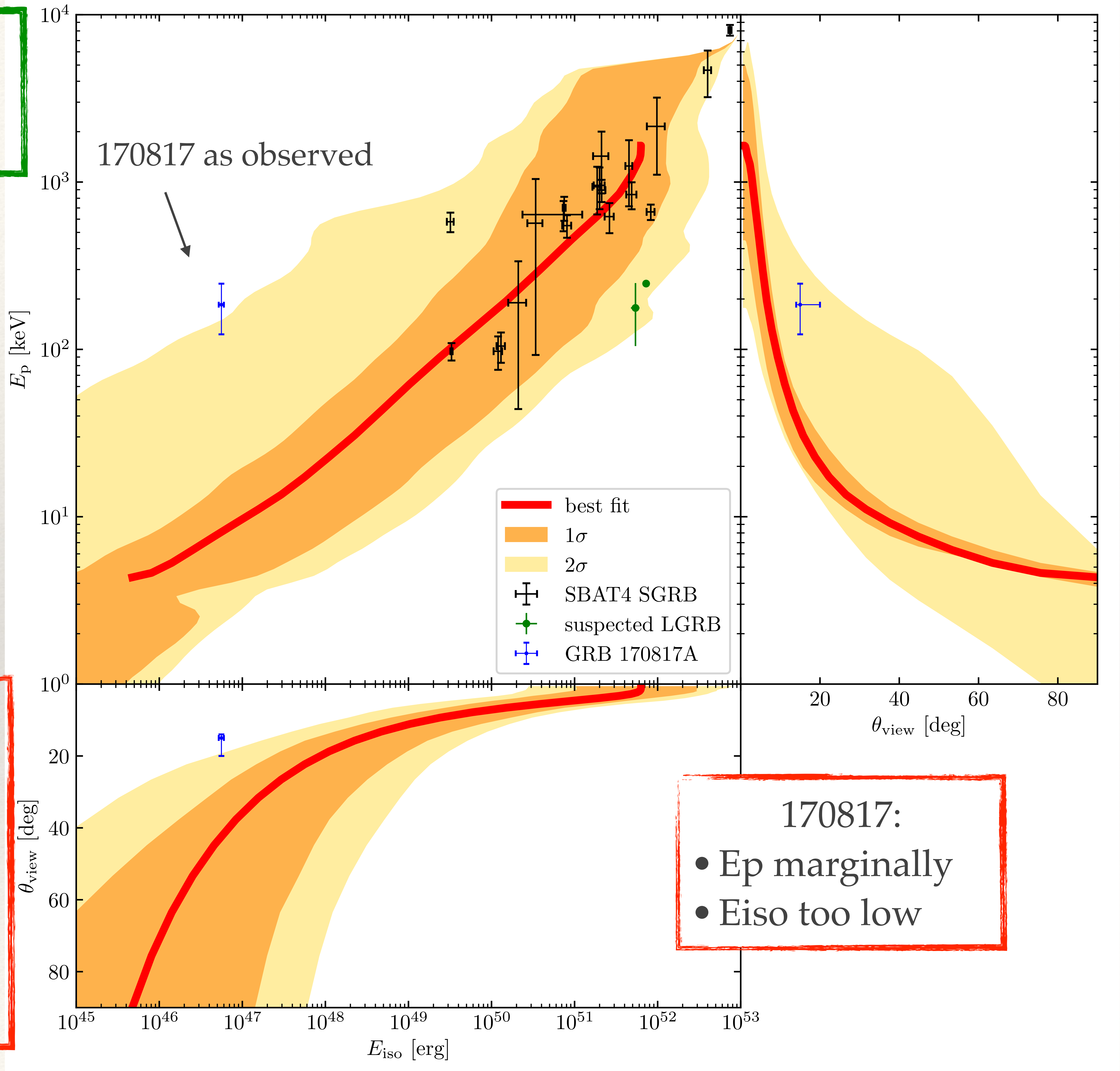
BACKUP SLIDES

Luminous short GRBs are fine with a structured jet (as predicted in Salafia+2015)

- Gaussian structure (e.g. Hotokezaka+2018)
- Other parm. structure (Salafia+2019; Ioka & Nakamura 2019)

✳ Another component (e.g. cocoon - Nakar+2019; Kasliwal+2019; Gottlieb+2019)

Salafia, Ghirlanda, Ascenzi, Ghisellini 2019



170817:
- Ep marginally
- Eiso too low