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Understanding the Prompt Emission of GRB 170817A

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Outline

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1. Event Rates
2. Ejecta Topology
3. Radiation Mechanism
4. 1.7 s Time Delay

1 **Event Rates**

2 **Ejecta Topology**

3 **Radiation Mechanism**

4 **1.7 s Time Delay**

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1 Event Rates

2 1.7 s Time Delay

0 Prompt Emission of GRB 170817 in a Nutshell

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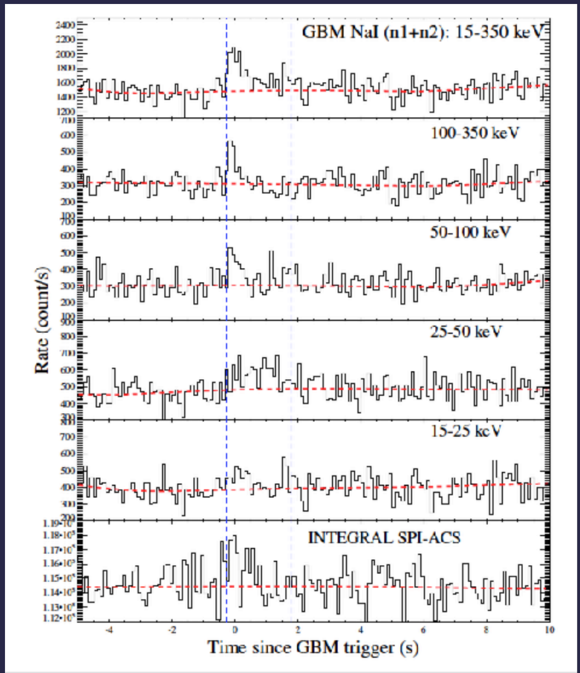

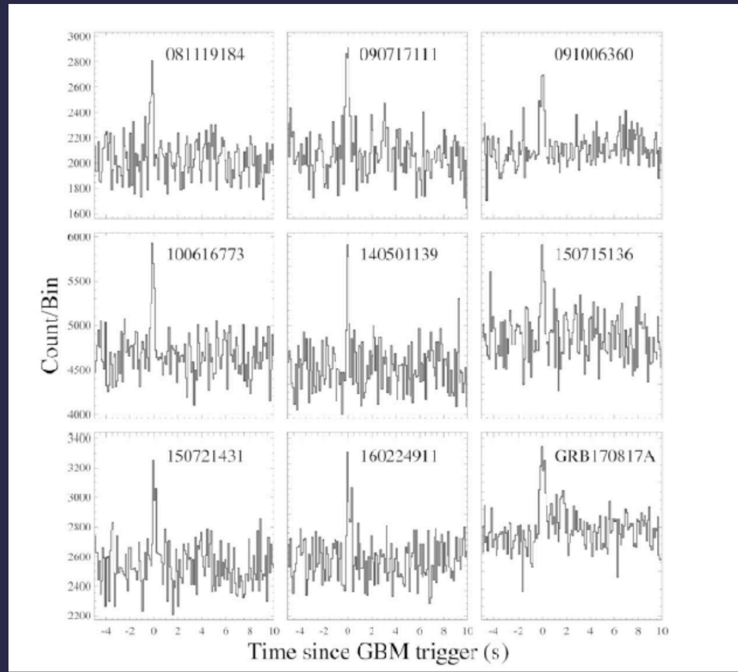

Short: 2s;
Slightly weak

light curve :
unnoticeable, perfectly normal

Zhang, B.-B. et al 2018, Goldstein et al 2017

see also Eric's talk , Burn et al 2018

Prompt Emission of GRB 170817 in a Nutshell

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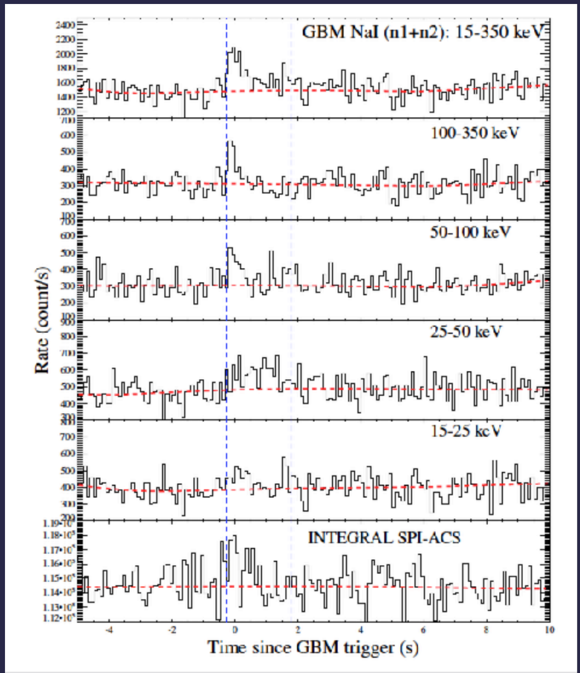

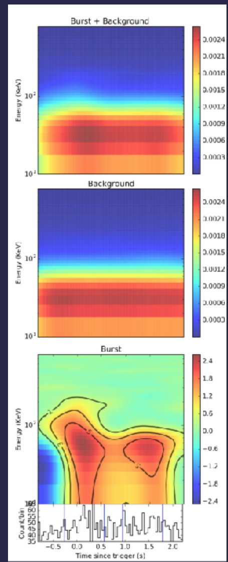

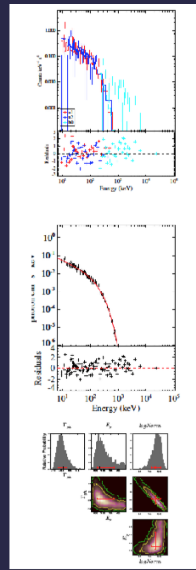

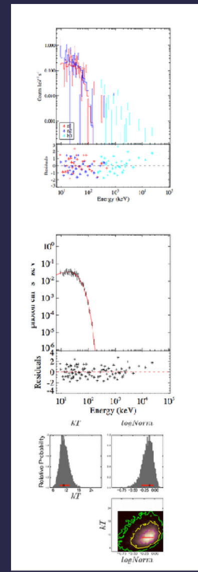

Precise Measurement in Time-Energy Domain

Ep=149 keV
alpha = -0.66

kT= 10.8 keV

Short: 2s;
Slightly weak

Two Episodes :
Seemingly different spectra

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

Prompt Emission of GRB 170817 in a Nutshell

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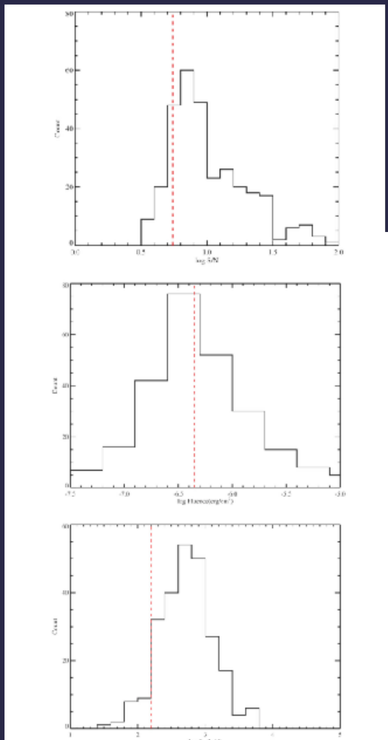
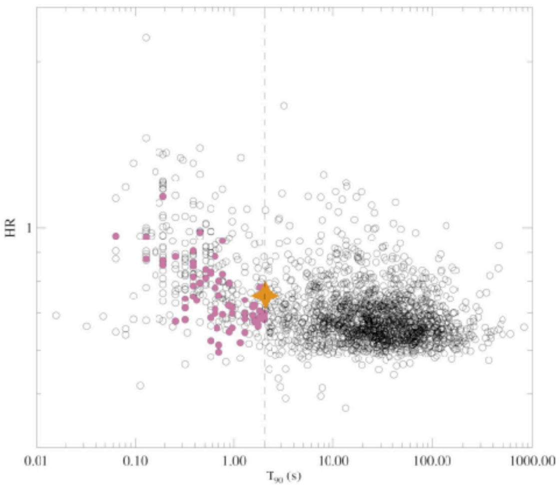
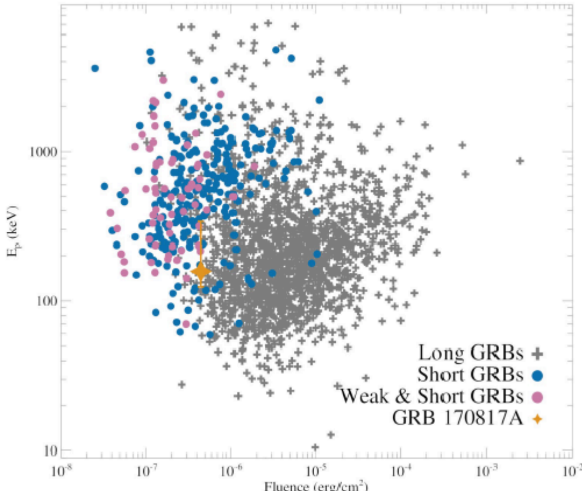
total spanning duration (s)	~ 2.05
spectral peak energy (first peak) E_p (keV)	$149.1^{+229.4}_{-24.2}$
total fluence (erg cm^{-2})	$2.24^{+3.51}_{-0.53} \times 10^{-7}$
spectral lag (25-50 keV vs 50-100 keV)	0.03 ± 0.05 s

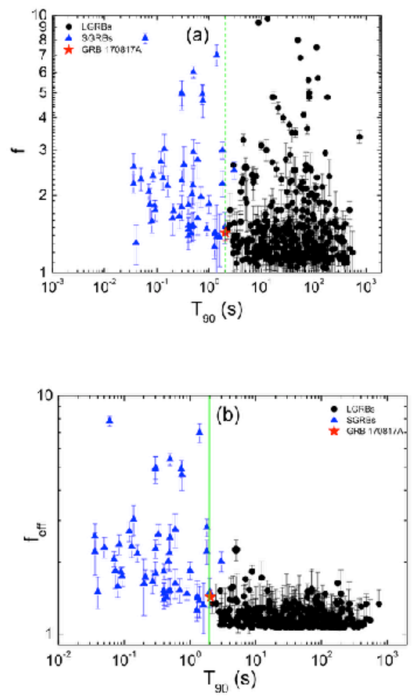


“Perfectly Normal”

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

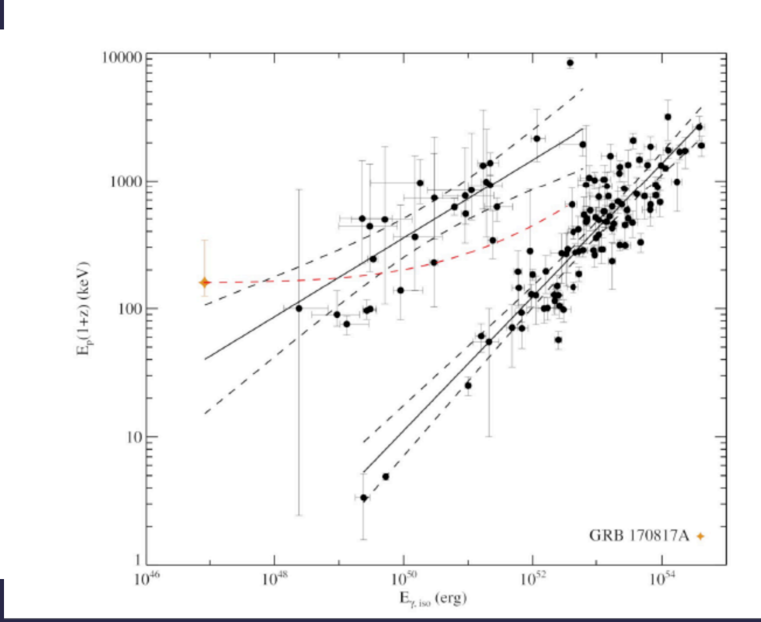






Prompt Emission of GRB 170817 in a Nutshell

total spanning duration (s)	$\sim$2.05
spectral peak energy (first peak) E_p (keV)	$149.1^{+229.4}_{-24.2}$
total fluence (erg cm^{-2})	$2.24^{+3.51}_{-0.53} \times 10^{-7}$
spectral lag (25-50 keV vs 50-100 keV)	0.03 ± 0.05 s
redshift z	~ 0.009
luminosity distance $D_{\rm L}$ (Mpc)	39.472
total isotropic energy $E_{\rm iso}$ (erg)	$4.17^{+6.54}_{-0.99} \times 10^{46}$
peak luminosity $L_{\rm iso}$ (erg s^{-1})	$1.6^{+2.5}_{-0.4} \times 10^{47}$



Physically Special
Observationally Rare (only one case)
Statistically Indicative (e.g, Event Rate)

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

1 Event Rate — GRB Rate from Fermi/GBM

$$N_{\rm sGRB} = \frac{\Omega_{\rm GBM} T_{\rm GBM}}{4\pi} \rho_{0,\rm sGRB} V_{\rm max} \geq 1$$

$T_{\rm GBM}$ ~ 4.5 year , $\Omega_{\rm GBM}$ ~ 4π ,

$V_{\rm max} = 4\pi D^3_{\rm L,max}/3.$ $D_{\rm L,max}$ ~ 65 Mpc ,

$$\rho_{0,\rm sGRB}(L_{\rm iso} > 1.7 \times 10^{47} \, {\rm erg \, s^{-1}}) \geq 190^{+440}_{-160} \, {\rm Gpc^{-3} \, yr^{-1}}$$

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

1

Event Rate — GRB Rate from Fermi/GBM

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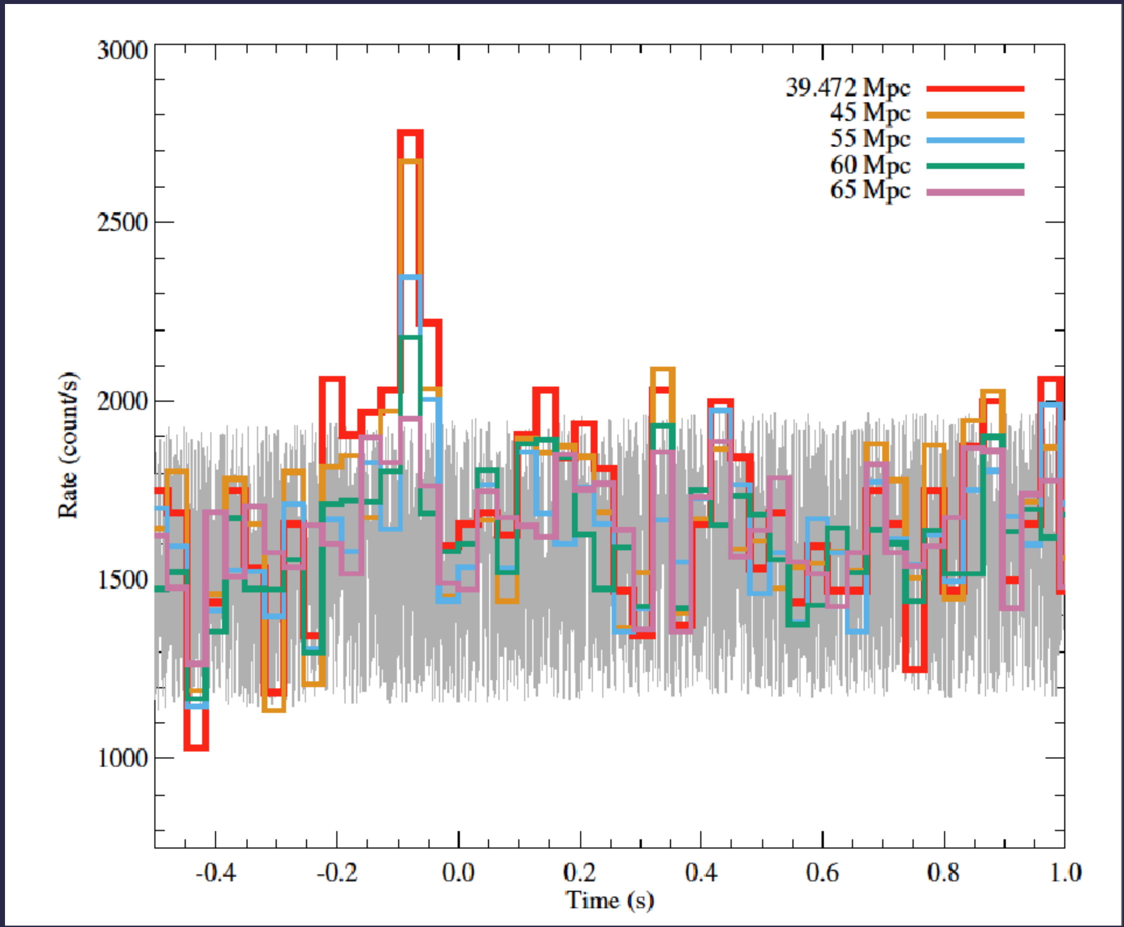

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

1 Event Rate — GRB Rate from Fermi/GBM

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$$N_{\mathrm{sGRB}} = \frac{\Omega_{\mathrm{GBM}} T_{\mathrm{GBM}}}{4\pi} \rho_{0,\mathrm{sGRB}} V_{\mathrm{max}} \geq 1$$

T_{GBM} ~ 4.5 year , Ω_{GBM} ~ 4π ,

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Zhang, B.-B. et al 2018, Nature Communications, 9, 447

2 Event Rate — NS-NS Merge Rate from LIGO

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$$N_{\mathrm{NS-NS}} = \frac{\Omega_{\mathrm{LVC}}}{4\pi}\rho_{0,\mathrm{NS-NS}}(V_{\mathrm{max,O1}}T_{\mathrm{O1}} + V_{\mathrm{max,O2}}T_{\mathrm{O2}}) = 1.$$

Noticing $\Omega = 4\pi$ for GW detectors, taking NS-NS merger horizon $\sim$ 60 Mpc and $\sim$ 80 Mpc for O1 and O2, respectively, and adopting a duty cycle of $\sim$ 40% for both O1 and O2, we estimate

$$\rho_{0,\mathrm{NS-NS}} = 1100^{+2500}_{-910}\ \mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}.$$

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

2 Event Rate — Much More Promising than Previous Thought

$$\rho_{0,\mathrm{sGRB}}(L_{\mathrm{iso}} > 1.7 \times 10^{47}\,\mathrm{erg\,s^{-1}}) \geq 190^{+440}_{-160}\ \mathrm{Gpc^{-3}\,yr^{-1}}.$$

$$\rho_{0,\mathrm{NS-NS}} = 1100^{+2500}_{-910}\ \mathrm{Gpc^{-3}\,yr^{-1}}.$$

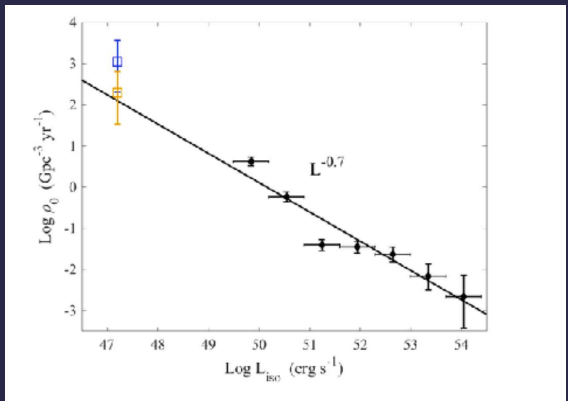

Table 2. Short GRB rates in yr^{-1} (68% errors) within the volume corresponding to different distances.

Ghirlanda et al 2016

	R	D	H
NS–NS	≤200 Mpc	≤300 Mpc	≤450 Mpc
Model (a)	$0.007^{+0.001}_{-0.003}$	$0.024^{+0.004}_{-0.007}$	$0.077^{+0.014}_{-0.028}$
Model (c)	$0.028^{+0.005}_{-0.010}$	$0.095^{+0.017}_{-0.034}$	$0.299^{+0.054}_{-0.108}$

Pre-LIGO: a few Gpc $^{-3}$ yr $^{-1}$

There might be even less luminous sGRB

or :

A few similar NS-NS sGRBs hidden in theGBM archives

Zhang, B.-B. et al 2018; see a good case in Burn et al 2018

3

What makes such a low-luminosity GRB?

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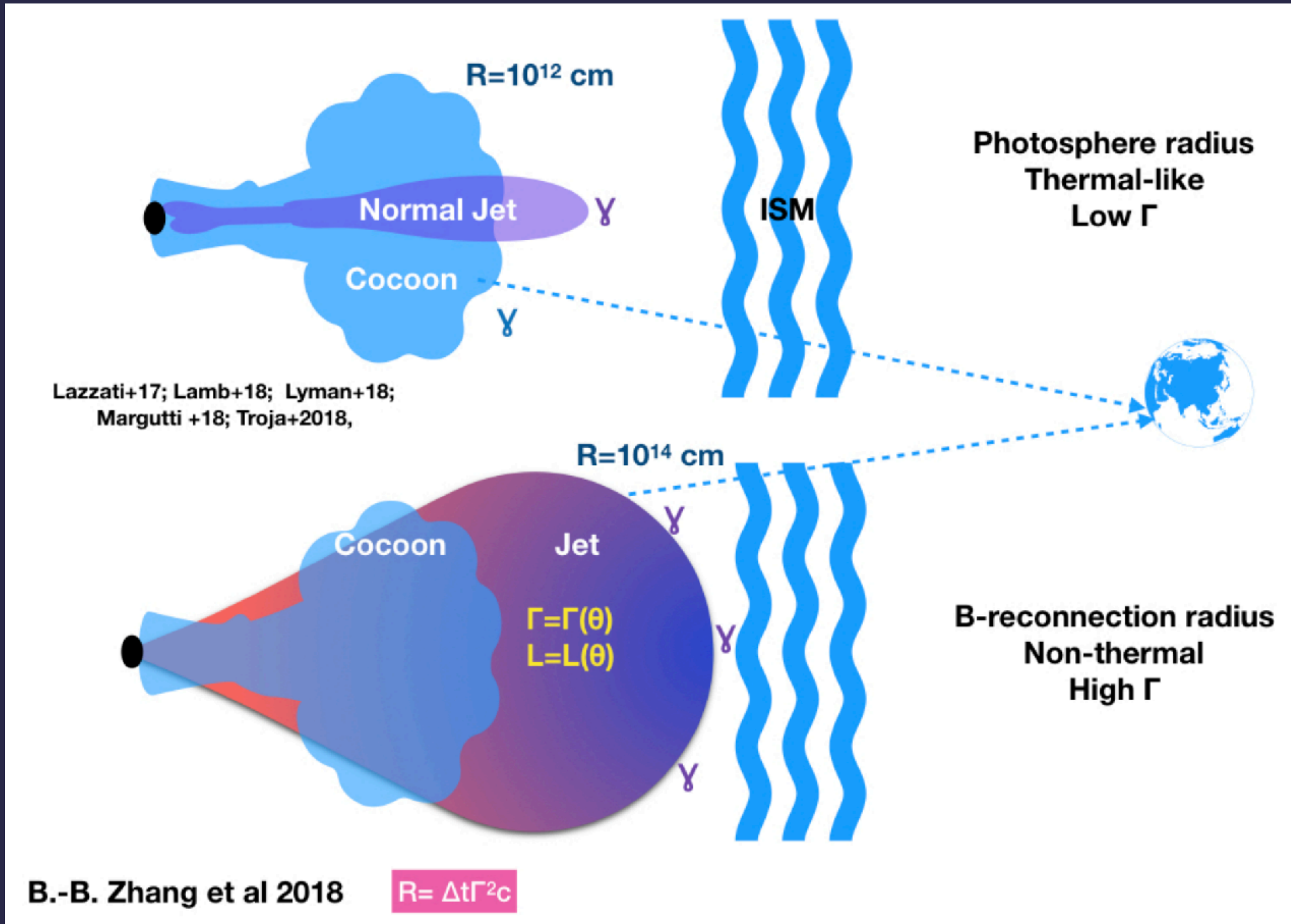
Option 1: Cocoon

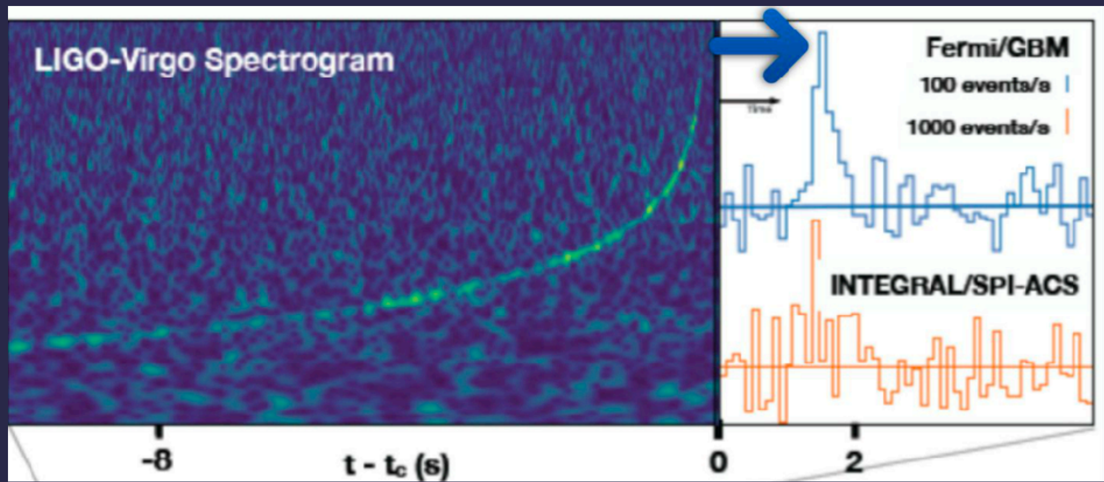
Option 2: Jet



See talk by
Paz Beniamini

What makes such a low-luminosity GRB?

The 1.7 s time delay seems a clue!



What makes the 1.7 s time delay?

1) Delayed launch of the jet?

What did the system do in 1.7 s ? (very long time after the merger)

Accretion time ? too short!

2) **Delay formation of a BH?**

But BH for GRB 170817A is not even needed.

3) **Delayed dissipation (magnetic field amplification)?**

Allowed but not needed.

4) **Central engine delay (propagation)?**

Jet needs travel to a distance (R) to emit gamma-rays!

3

What makes the 1.7 s time delay?

1) Delayed launch of the jet? **(mysterious)**

What did the system do in 1.7 s ? (very long time after the merger)

Accretion time ? too short! Δt_{acc}

2) **Delay formation of a BH?** **(maybe mysterious)**

But BH for GRB 170817A is not even needed.

Δt_{jet}

3) **Delayed dissipation (magnetic field amplification)?** **(mysterious)**

Allowed but not needed.

4) **Central engine delay (propagation)?** Δt_{prop}

Jet needs travel to a distance (R) to emit gamma-rays!

3

What makes the 1.7 s time delay?

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(1) system holding time before launching the jet

$\Delta t_{\rm jet}$ (due to mysterious reasons)

(2) Accretion Time scale

$$\tau_{\rm acc} \simeq \frac{t_{\rm fb}}{\alpha} \simeq 5 \times 10^{-3} \left(\frac{\alpha}{0.1}\right) \mathrm{s},$$

$$t_{\rm fb} \simeq 2 \left(\frac{2}{G\rho_{\rm NS}}\right)^{1/2} \simeq 5 \times 10^{-4} s,$$

(3) jet propagation time before releasing gamma-rays

$$t_{\rm prop} \sim R/2\Gamma^2 c$$

3 What makes the 1.7 s time delay?

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$$\Delta t \sim (t_{\rm prop} + \tau_{\rm acc} + \Delta t_{\rm jet})(1+z) \simeq (t_{\rm prop} + \Delta t_{\rm jet})(1+z).$$

If it is at magnetic dissipation radius (synchrotron) :

$$t_{prop} = \frac{R}{\Gamma^2 c} = 1.7s(\frac{R}{5x10^{14}cm})(\frac{\Gamma}{100})^{-2} = 1.7s(\frac{R}{5x10^{12}cm})(\frac{\Gamma}{10})^{-2}$$

Δt_{jet} is not needed

Zhang, B.-B. et al 2018, Nature Communications, 9, 447

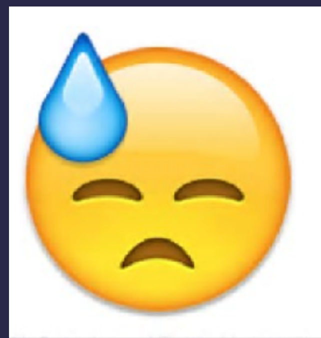
What makes the 1.7 s time delay?

$$\Delta t \sim (t_{\rm prop} + \tau_{\rm acc} + \Delta t_{\rm jet})(1+z) \simeq (t_{\rm prop} + \Delta t_{\rm jet})(1+z).$$

If it is at photosphere radius (thermal like) :

$$t_{prop} = \frac{R}{\Gamma^2 c} = 1.7s\left(\frac{R}{10^{11}cm}\right)\left(\frac{\Gamma}{<5}\right)^{-2} = 0.1s\left(\frac{R}{10^{11}cm}\right)\left(\frac{\Gamma}{10}\right)^{-2}$$

However with $\Gamma < 5$, the photosphere temperature is too low to explain Ep = 158 keV



For Γ = 10, an **artificial** Δt_{jet} **is needed.**

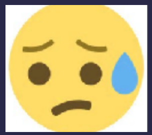
3 What makes the 1.7 s time delay?

If you really want a Δt_{jet} :

- Hyper-massive NS (HMNS) forms in between?

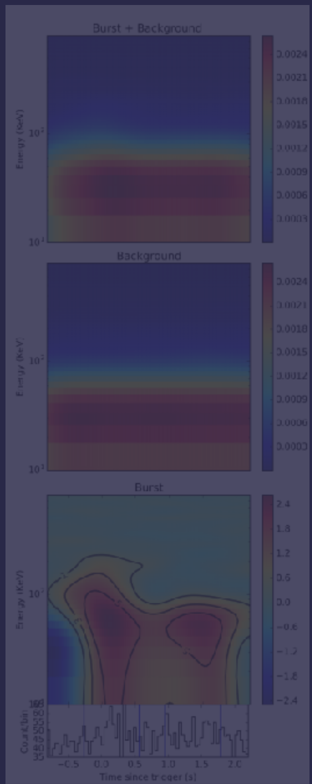
  ~ 100 ms (Rosswog et al 2013)

- Relativistic jet must break through the dynamical ejecta and/or neutrino driven wind.

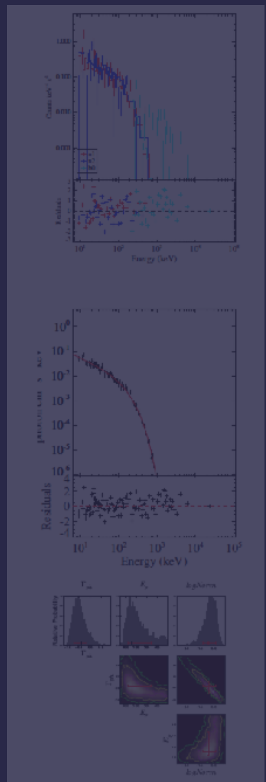
  at most <=1 s , no detailed calculation (Moharana & Piran 2017) 

What makes the 1.7 s time delay?

Any hints from the spectra?



Precise Measurement in Time-Energy Domain



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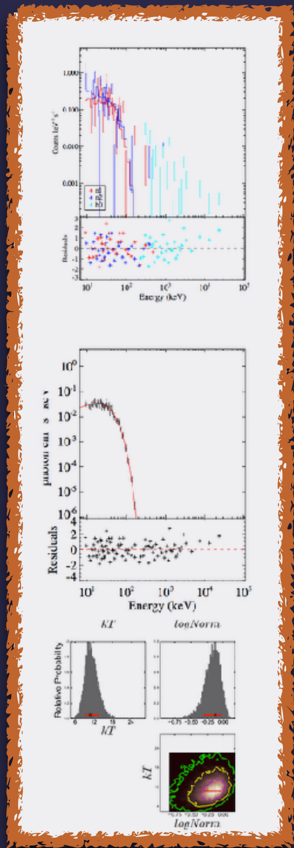
alpha = -0.66



kT= 10.8 keV

Supports photopshere model.

Yet not 100% conclusive.

3 What makes the 1.7 s time delay?

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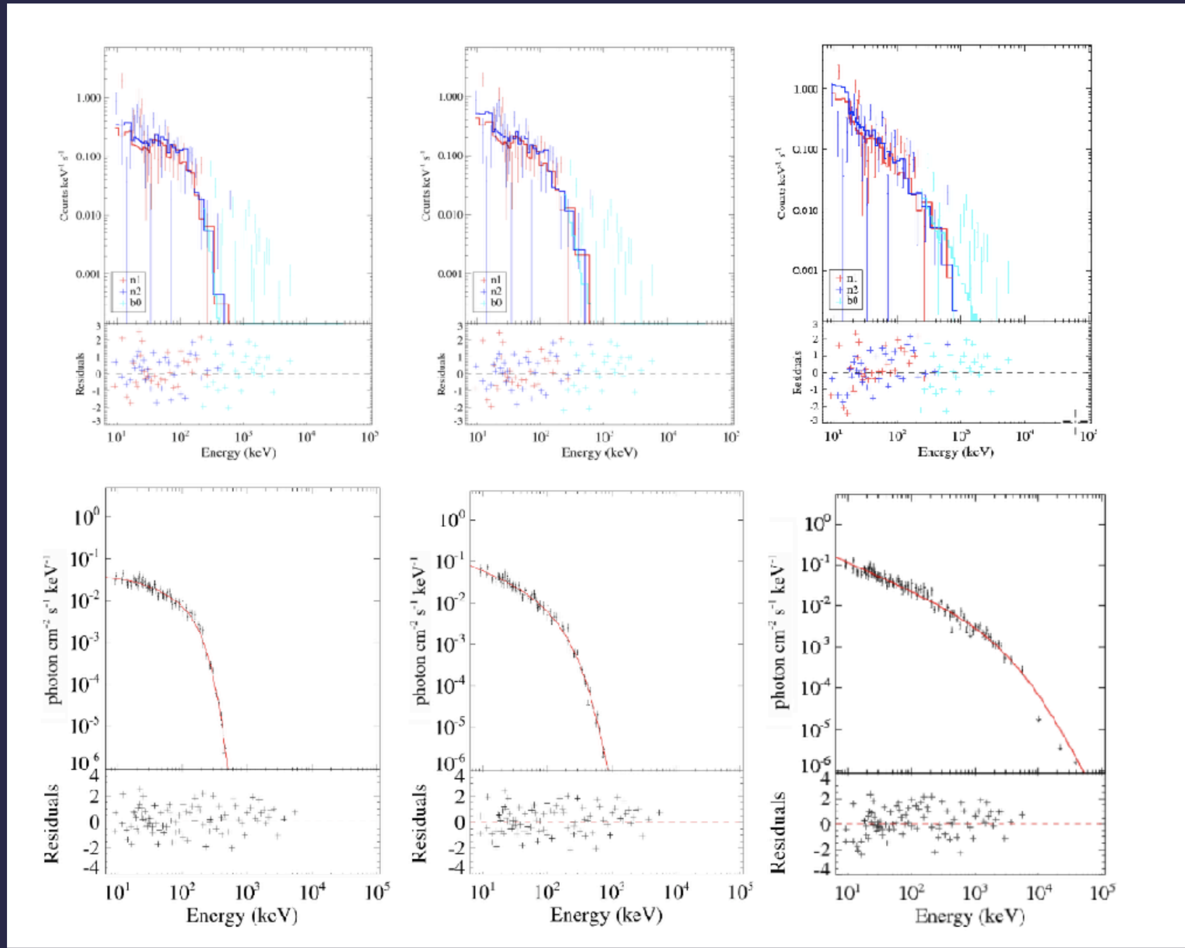
Physical Modeling

Meng, Geng, Zhang et al 2018



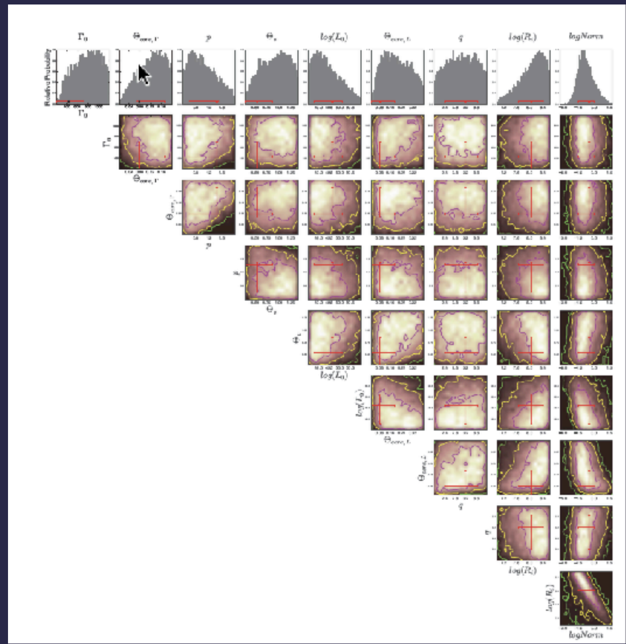
Structured Photosphere CPL Synchrotron

What makes the 1.7 s time delay?

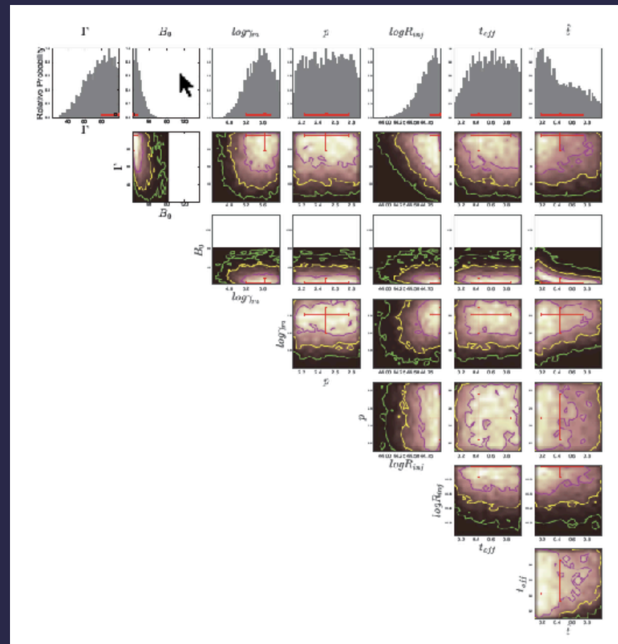
Physical Modeling

Meng, Geng, Zhang et al 2018

Both models are consistent
with observed data



Structured Photosphere



Synchrotron

3 What makes the 1.7 s time delay?

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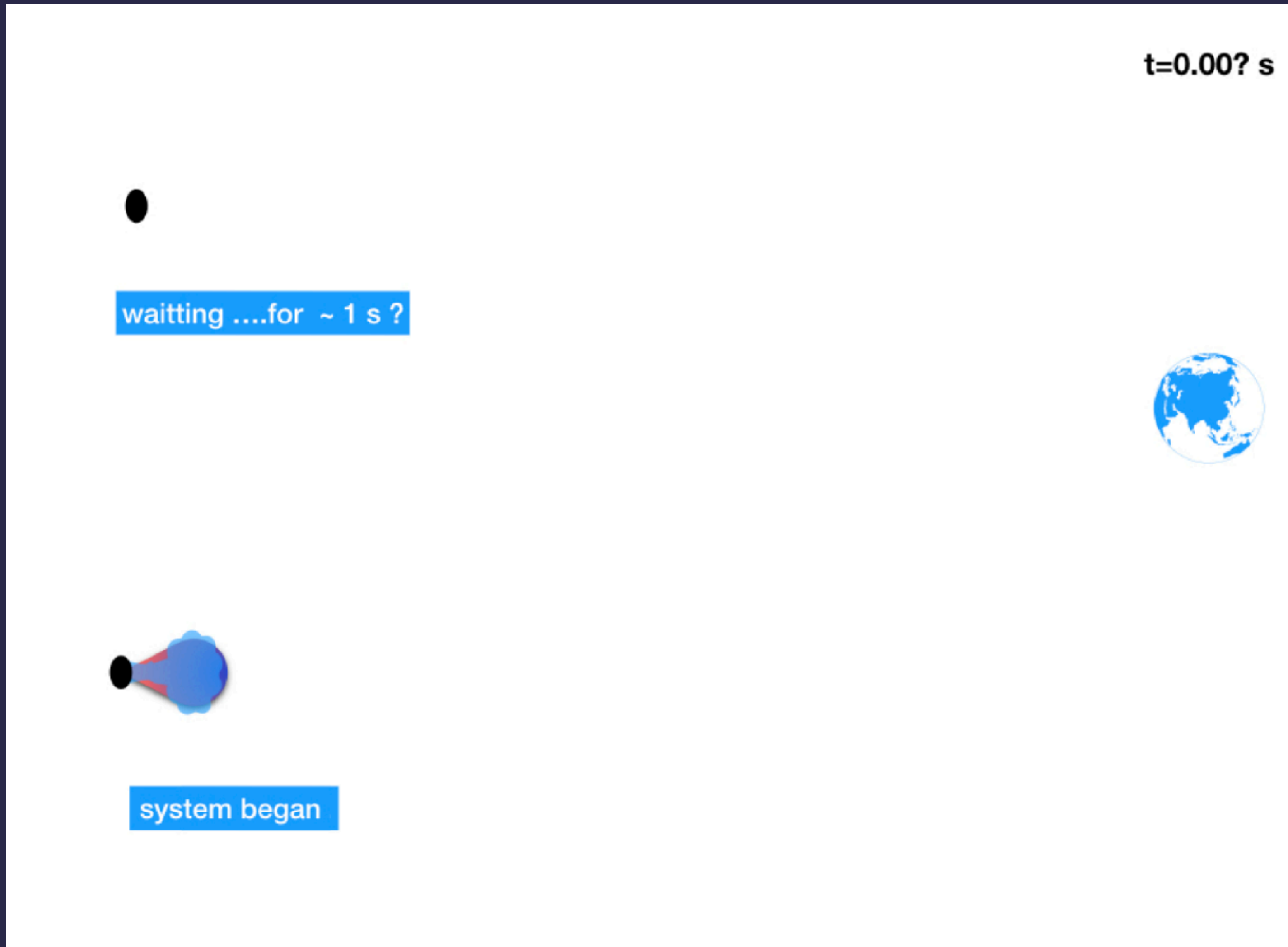
	Structure Photosphere	Magnetic Dissipation
Fits the Observed Spectrum	Yes	Yes
Thermal tail	Yes	
Radius	10^{11} cm	10^{13}cm
Γ	10	10-100
1.7s time delay	jet holding time needed	jet holding time not needed
T_{90}		$\Delta t \sim t_{\rm prop} \sim T_{90} \sim R_{\rm GRB}/\Gamma^2 c.$

3

What makes the 1.7 s time delay?

Option 1: Cocoon

Option 2: Jet



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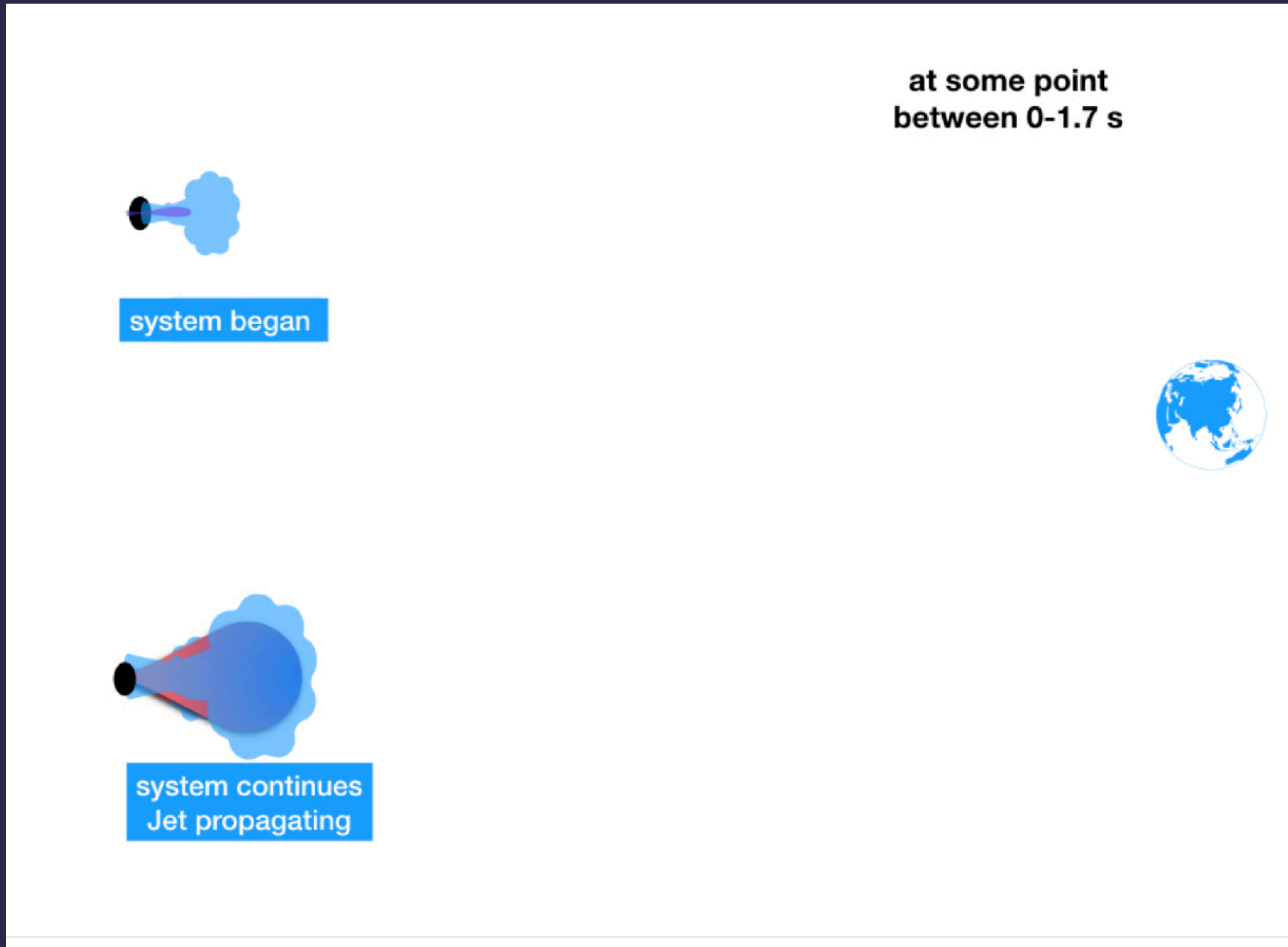

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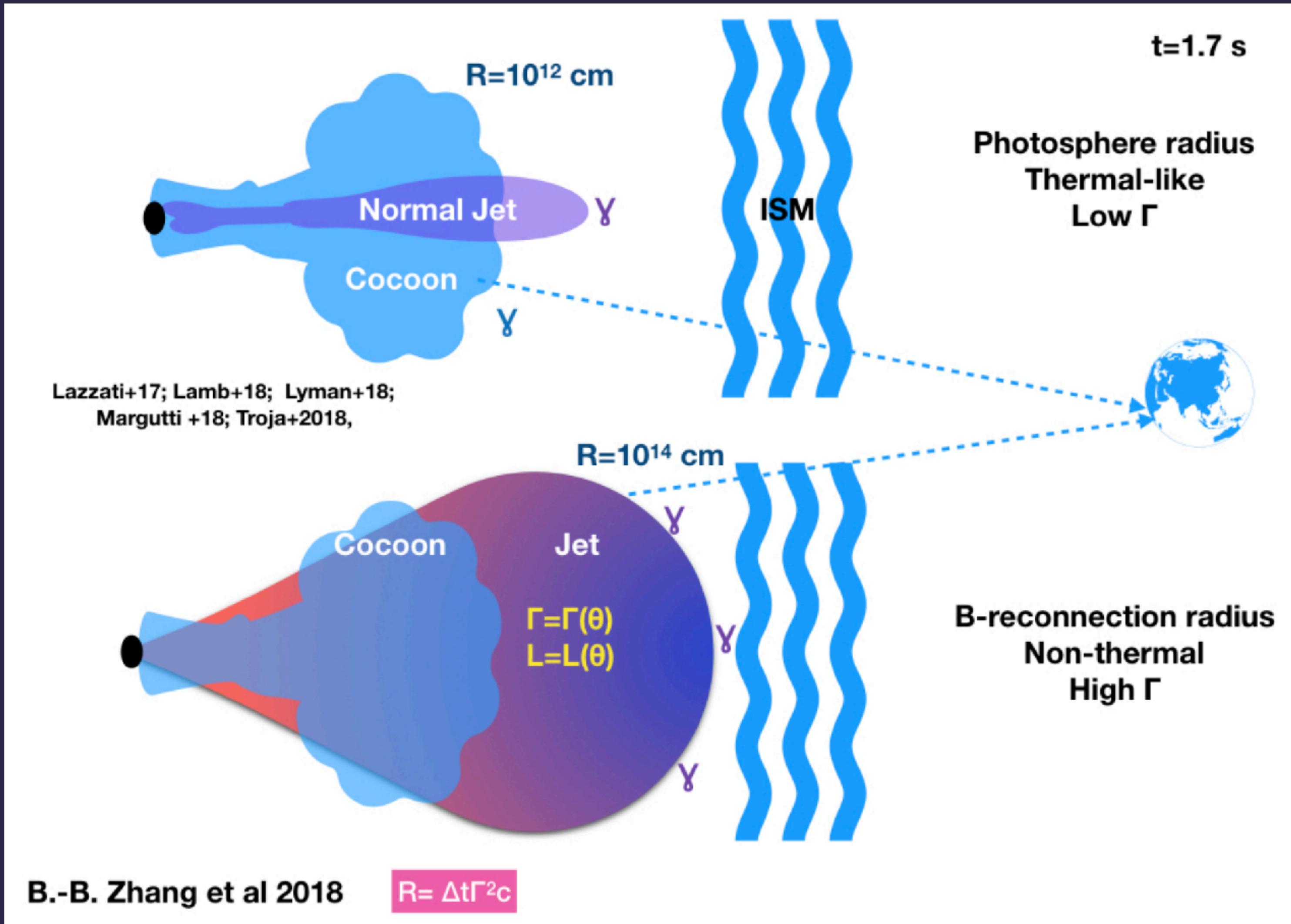
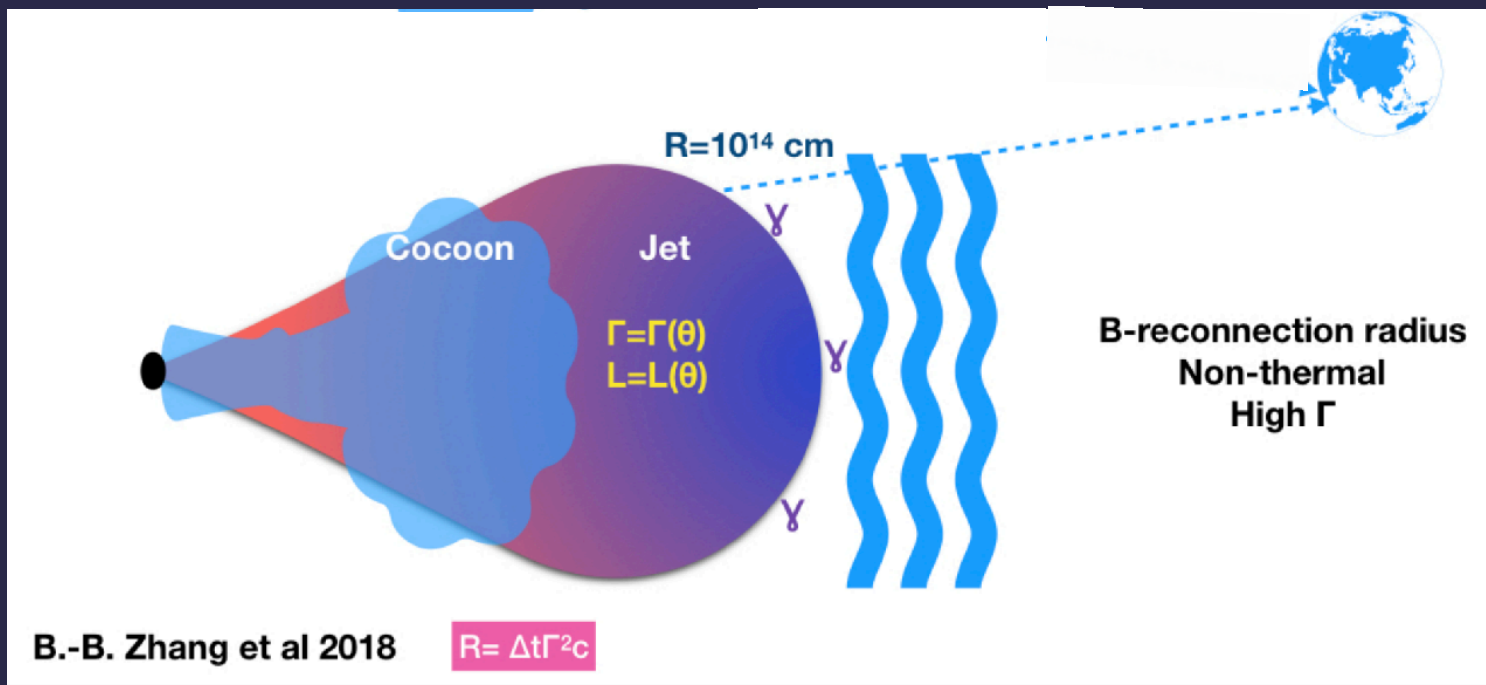


4 Conclusions:

- **Structure jet viewed at off-axis.**
- **Traditional GRB mechanism : large emission radius, Poynting-flux dissipation**
- **Central engine delay, no significant cocoon emission**
- **No BH formation needed**

Option 2: Jet

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Thanks!