The Raymond and
Beverly Sackler Faculty
of Exact Sciences
Tel Aviv University

Some open questions in BNS and BH-NS mergers

Ehud Nakar

Tel Aviv university

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Some open questions

- Where are the magnetars?
- Where does the fast and massive KN blue component come from?
- On the energy budget of the jet
- What are the properties of the ejecta fast tail?
- How a merger produces a 100s long central engine ?
- How the gamma-ray emission shut-off abruptly ?

Where are the magnetars?

Or

What would the merger of the double pulsar look like?

Galactic BNS systems that dominate the merger rate have a total mass of $2.5 - 2.6 M_{\odot}$

↓

A mergere remnant with $M_{rem} < 2.35 M_{\odot} \lesssim 1.2 M_{TOV} \approx 2.4 - 2.7 M_{\odot}$

↓

A super-massive NS with high B (a stable magnetar)

↓

An ejecta with $>10^{52}$erg

Why do we not see such mergers?

On the energy budget of the sub-relativistic ejecta

Or

Where does the fast and massive blue component come from?

GW 170817:

$\sim 0.02 M_\odot$ Lanthenides poor ejecta at 0.2-0.3c ($E_{kin} \approx 10^{51} erg$)

Dynamical ejecta – typically, not enough mass (and energy)

Secular ejecta – not fast enough (and not enough energy)

What drives this ejecta?

On the energy budget of the jet
and
Analogy to long GRBs

The accreted mass in GW 170817: $M_{acc} \sim 0.05 M_{\odot}$

$$M_{acc} c^2 \sim 10^{53} \text{ erg}$$

The relativistic jet energy $10^{49} - 10^{50}$ erg $\approx 10^{-4} - 10^{-3} \mathrm{M_{acc} c^2}$

The jet engine cannot be too efficient or too inefficient

LGRB outflow energy budget:

- Accretion energy $\sim 10^{54}\ erg$
- Relativistic narrowly collimated outflow with ~10^{51} erg
- Newtonian wide outflow (supernova) with $1 - 5 \cdot 10^{52}$ erg

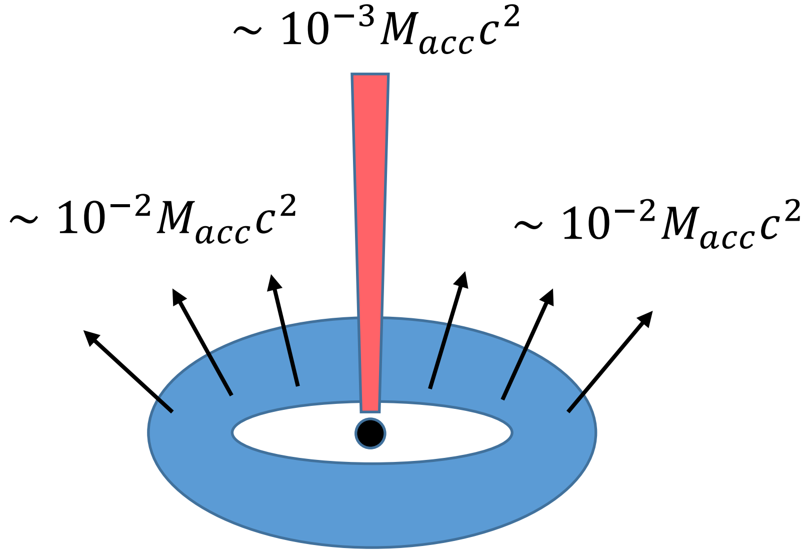
Gamma-ray bursts energy budget

Long GRBs:

- $M_{acc} \sim 1\, M_{\odot}$
- Newtonian wide outflow
  $\sim 10^{-2} M_{acc} c^2\ (\sim 10^{52} erg)$
- Relativistic collimated outflow
  $\sim 10^{-3} M_{acc} c^2\ (\sim 10^{51} erg)$

Short GRBs (GW 170817):

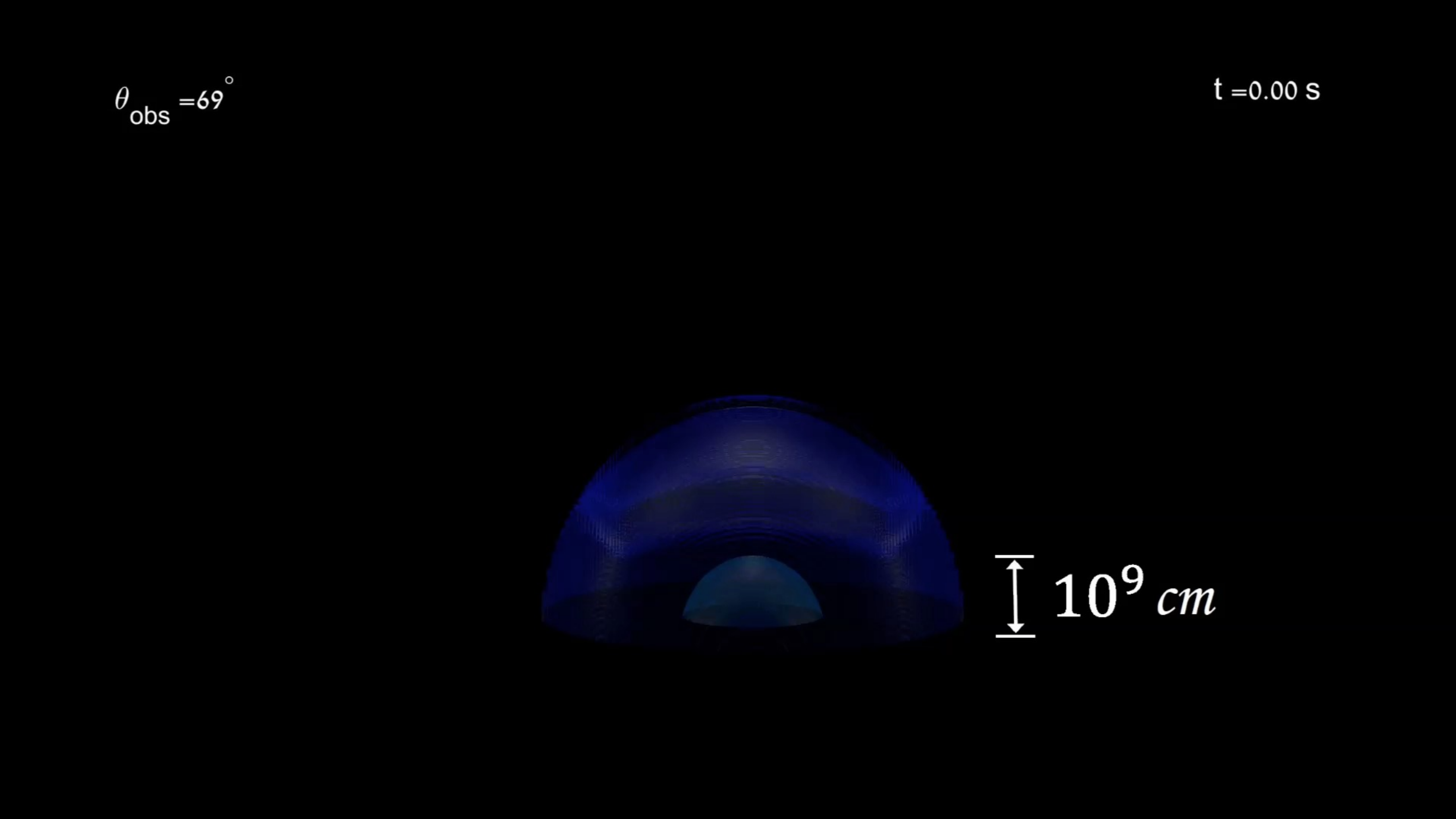
- $M_{acc} \sim 0.1\, M_{\odot}$
- Newtonian wide outflow
  $\sim 10^{-2} M_{acc} c^2\ (\sim 10^{51} erg)$
- Relativistic collimated outflow
  $\sim 10^{-4} - 10^{-3} M_{acc} c^2\ (10^{49} - 10^{50} erg)$



What are the properties of the ejecta fast tail ($\gtrsim 0.6c$)?

Or

What is the gamma-ray origin in GW170817



$\theta_{obs} = 69^\circ$
$t = 0.00$ s
$10^9\ cm$

$$m_{\rm bo} \approx 4 \times 10^{-8} \beta_{\rm s,bo'}^{-1} \left(\frac{R_{\rm bo}}{10^{12}\ \rm cm} \right)^{2} \left(\frac{\kappa}{0.16\ \rm cm^2\ g^{-1}} \right)^{-1}\ \rm M_{\odot}$$

$$E_{\rm bo} \sim 7 \times 10^{46}\ {\rm erg}\ \frac{\gamma_{\rm s,bo}(\gamma'_{\rm s,bo} - 1)}{\beta'_{\rm s,bo}} \left(\frac{R_{\rm bo}}{10^{12}\ \rm cm} \right)^{2}$$

$$T_{\rm bo} \sim 50 \gamma_{\rm s,bo} \gamma'_{\rm s,bo}\ \rm keV$$

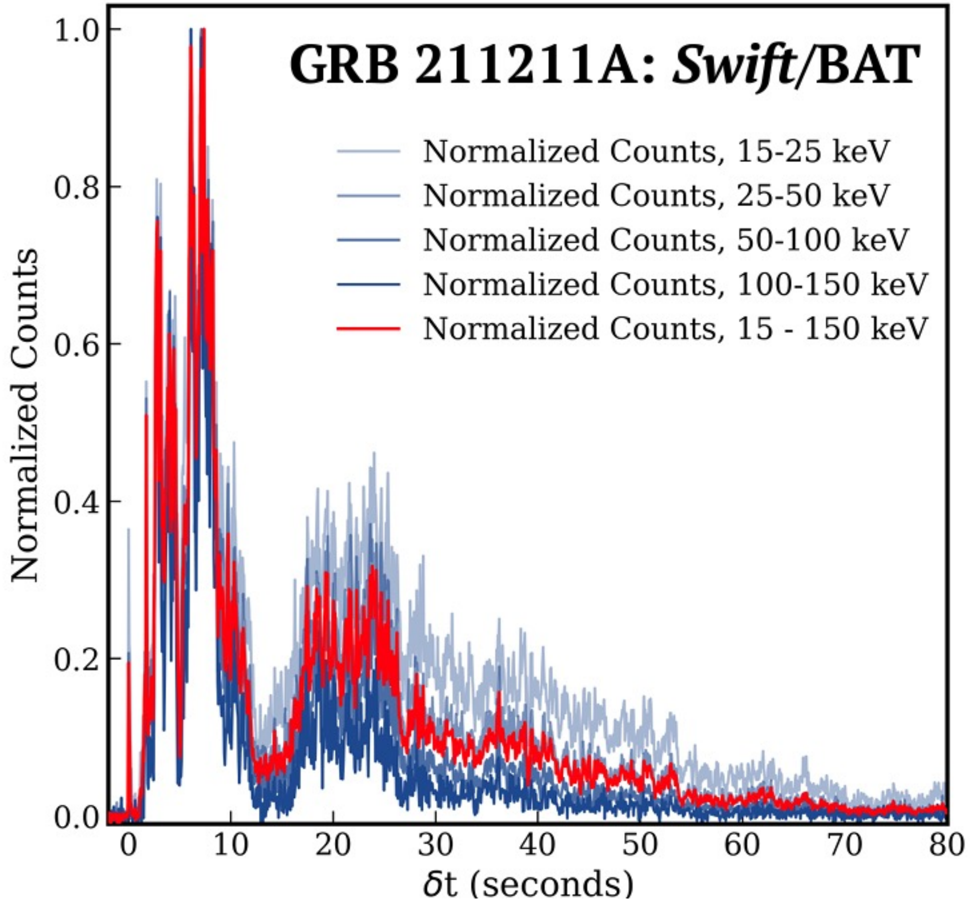
$$t_{\rm bo} \sim 1 \left(\frac{E_{\rm bo}}{10^{46}\ \rm erg} \right)^{1/2} \left(\frac{T_{\rm bo}}{100\ \rm keV} \right)^{-2.5}\ \rm s$$

The progenitor of non-collapssar long GRBs

or

How a merger produces a 100s long central engine

A minute long variable burst with what seems to be a kilonova



Rastinejad et al. 2022

Local rate lower by about an order of magnitude that sGRBs (rough estimate)

How the gamma-ray emission shut-off abruptly?

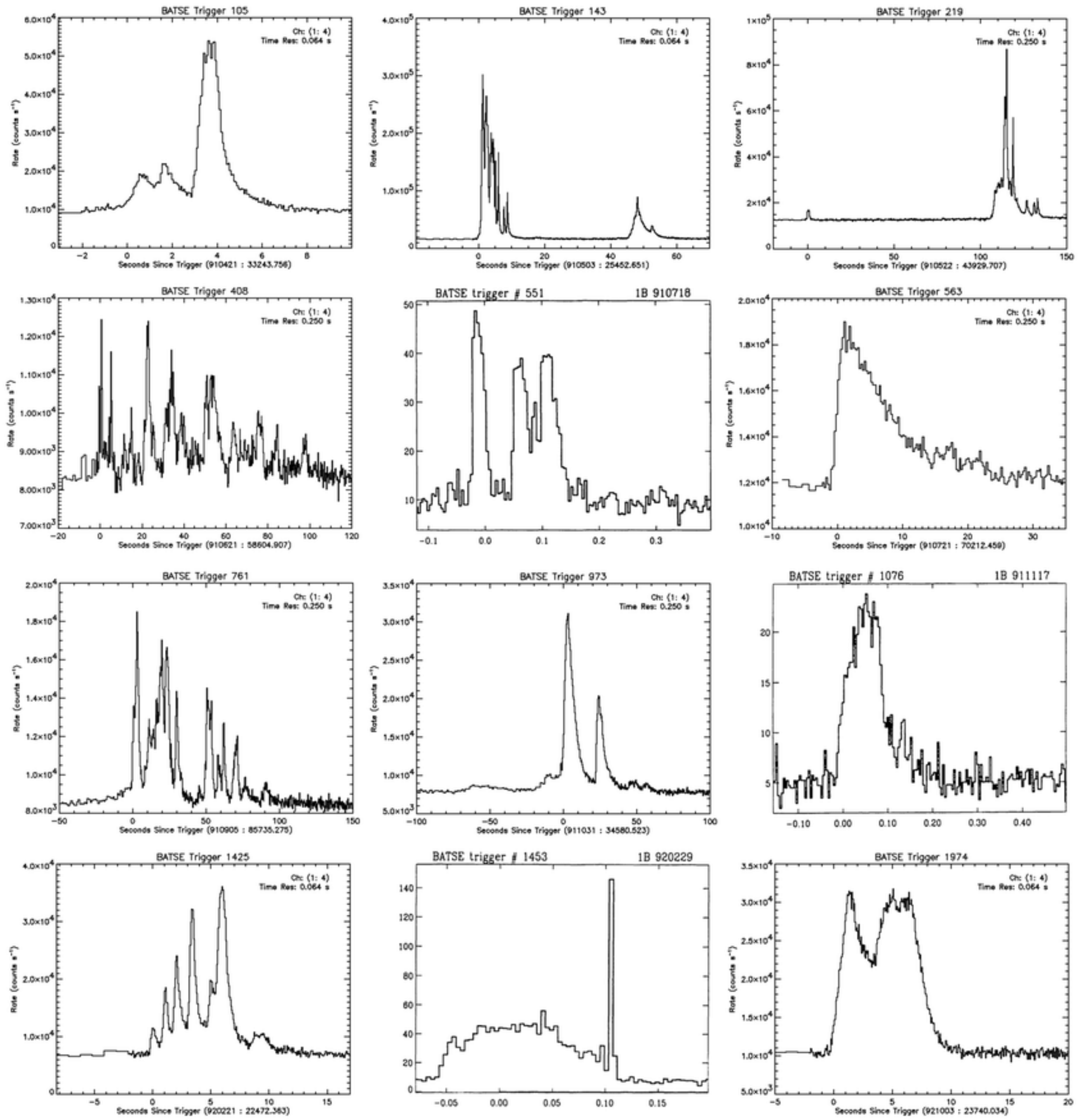
Prompt Gamma-ray emission shut-off time scale

T - central engine working time

Expectation: $L_j(t>T)$ decays over a timescale that is comparable to T

example, $L(t > T) \propto \left(\frac{t}{T}\right)^{-\alpha}$

Naive expectation: The decay of the engine should be seen in the prompt emission. e.g., late pulses should be on average fainter than early pulses



Fishman et al. 1994

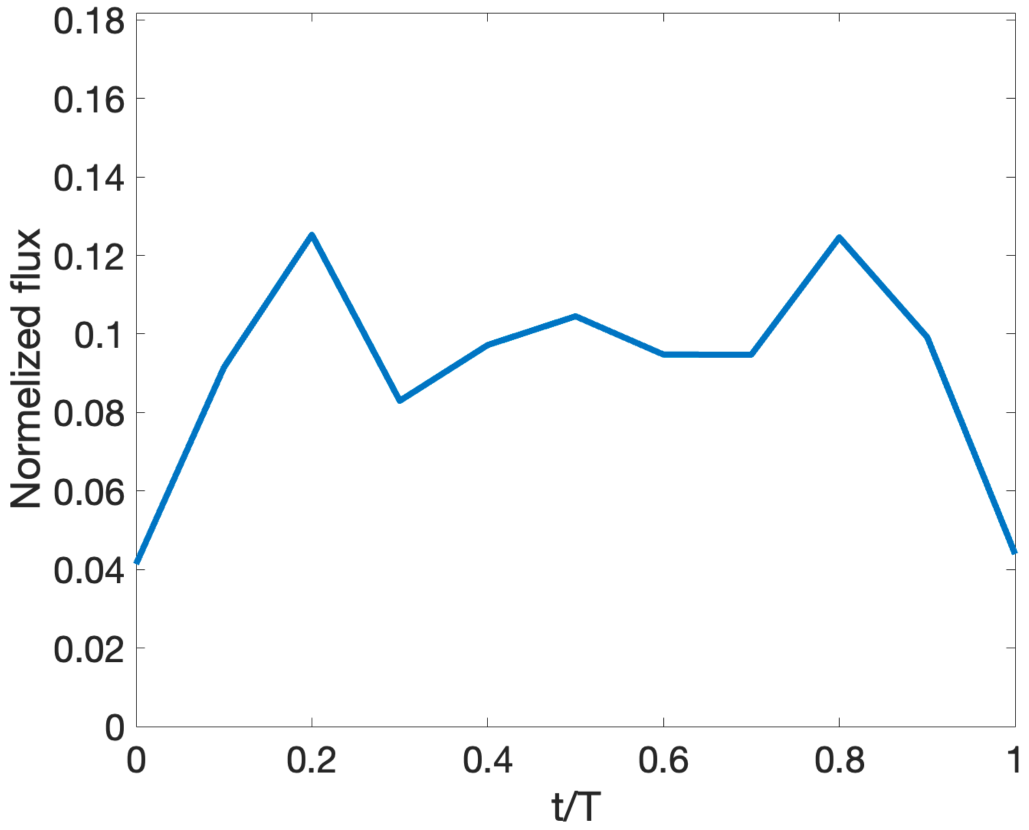
To identify the envelope temporal evolution:

- Normalized the time of each burst so t →t/T
- Normalized the flux so $\int F dt = 1$
- Sum all bursts

An average GRB light curve

Short GRBs

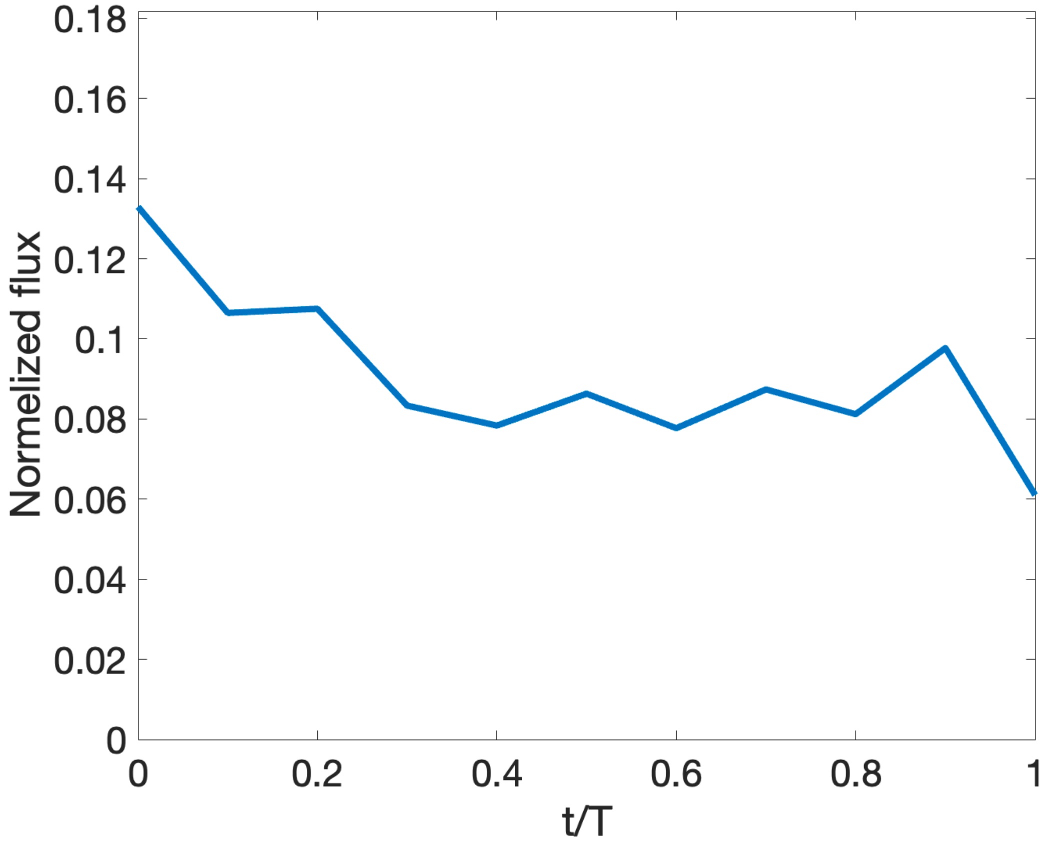
The average light curve of 36 brightest BATSE bursts with $0.5s<T_{90}<2s$



- Almost no evolution during the entire burst.
- The gamma-ray emission shuts over $\frac{\Delta t}{T} \ll 1$

Long GRBs

The average light curve of 49 brightest BATSE bursts with T_{90}>10s



- Almost no evolution during the entire burst.
- The gamma-ray emission shuts over $\frac{\Delta t}{T} \ll 1$

- In both short and long GRBs the engine ***average*** power is roughly constant in time.
- The prompt emission shuts off over $\frac{\Delta t}{T} \ll 1$. Either due to a sharp drop in the jet power or a drop in the radiative efficiency