“We always find something, eh Didi, to give us the impression we exist?”

Raffaella Margutti
(Extragalactic) Gamma-Ray Transients

**TRADITIONAL**

- ✔ Gamma-Ray Bursts: SHORT (+GWs)
- ✔ Gamma-Ray Bursts: LONG
- ✔ Jetted TDEs

**LESS EXPLORED**

- ✔ FBOTs (manifestation of compact objects) New class of relativistic transients
- ✔ Strong SN shock interaction
- ✔ FRBs
Physical properties of Shocks from Transients

![Graph showing kinetic energy vs. velocity of the fastest ejecta. The x-axis is the velocity of the fastest ejecta (Γβ) labeled as Shock, and the y-axis is the kinetic energy in ergs. The graph has a logarithmic scale for both axes.](image)
Physical properties of Shocks from Transients

![Graph showing the relationship between kinetic energy (erg) and velocity of the fastest ejecta (Γβ = Shock). The graph distinguishes between non-relativistic and relativistic shocks.](chart.png)
Physical properties of Shocks from Transients

Relativistic SNe

RM+14, Alexander+2014

Physical properties of Shocks from Transients

Ordinary SNe

TDEs

ASASSN-14li

XMMSL1 J0740-85

Short-GRB jets

GW170817 (NS-NS)

Long-GRB jets

Sw J2058+05

Sw J1644+57

TDEs

09bb

12ap

Relativistic SNe

Sub-E GRBs

FBOTs

NON RELATIVISTIC

RELATIVISTIC

Kinetic Energy (erg)

Velocity of the fastest ejecta (Γβ) = Shock

0.01 0.10 1.00 10.00
First multi-messenger observations of the NS merger event GW170817

Ultra-relativistic (\(\Gamma >> 1\))
core of successful jet
\(E_{\text{jet}} = 10^{51}\) erg

Mildly-relativistic
wings (or cocoon)
\(\Gamma = \) a few

Red kilonova
(equatorial)
heavy r-nuclei
\(M = 0.04M_\odot, v = 0.1c\)

Blue kilonova
(polar)
\(M = 0.02M_\odot, v = 0.3c\)

ISM density
\(n \leq 10^{-2}\) cm\(^{-3}\)

GW localization
\(\Theta_{\text{jet}} = 3^\circ\)
\(\Theta_{\text{obs}} = 14^\circ - 19^\circ\)

Margutti & Chornock, ARA&A 2021
The emergence of a new X-ray component of emission at 3.5 yrs since merger

Hajela, Margutti et al., 2021
The Gamma-Ray counterpart to GW170817

Fermi-GBM (Goldstein+2017) and Integral (Savchenko+ 2017) detection of GRB170817A

![Graph showing GRB170817A's time profile with count rates in keV and energy isotropic equivalent in ergs.](Image)
The Gamma-Ray counterpart to GW170817: GRB170817A

MULTI-MESSENGER parameter =

- Jet launching time (BH formation?) +
- Jet/cocoon breakout time +
- Travel time to transparency radius

STRUCTURE of jets launched by NS-NS mergers
Structure $E(\theta)$ and $\Gamma(\theta)$ of the jet launched by GW170817

Margutti & Chornock, ARA&A 2021 and references therein
The Gamma-Ray counterpart of GW170817 -SENSITIVITY-

Fermi-GBM (Goldstein+2017) and Integral (Savchencko+2017) detection of GRB170817A

\[ \Delta t_{GW-\gamma} \]

\[ E_{pk} \ (\text{keV}) \]

\[ d = 40.7 \text{ Mpc} \]

Detectable @ \( d < 55-80 \text{ Mpc} \) 

\( P \approx 10\% \) to be better aligned

\( GW \approx 1/d \)

\( EM \approx 1/d^2 \)

Inferred GRB170817A on-axis

Margutti & Chornock, ARA&A 2021
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09bb
12ap

NON RELATIVISTIC

RELATIVISTIC

Velocity of the fastest ejecta \((\Gamma \beta)\) = Shock

Kinetic Energy (erg)
LGRB prompt
≈ hundreds
≈ hundreds

Ordinary SNe Ibc
≈ hundreds

09bb
12ap
100316D

GRB-SNe

Sub-E GRBs

NON RELATIVISTIC

RELATIVISTIC

Kinetic Energy (erg)

10^44
10^46
10^48
10^50

Velocity of the fastest ejecta (\Gamma \beta)

0.01
0.1
1.00
10.00
Relativistic jets from TDEs

Alexander et al., 2020

\[ \text{Kinetic Energy (erg)} \]

\[ \text{Velocity} \]

TDEs

Ordinary SNe

XMMSL1 J0740-85

ASASSN-14li

Sw J1644+57

Sw J2058+05

Long-GRB jets

NON RELATIVISTIC
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[Shocks]
FBOTS: A new type of relativistic transient

Ordinary SNe
XMMSL1 J0740-85
ASASSN-14li
TDEs

TDEs
Sw J1644+57
GW170817 (NS-NS)

Long-GRB jets

ASASSN-14li
XMMSL1 J0740-85
Sw J2058+05

Short-GRB jets

FBOTs
09bb
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Relativistic SNe
Sub-E GRBs

NON RELATIVISTIC

RELATIVISTIC

Velocity of the fastest ejecta \((\Gamma \beta) = \text{Shock}\)
Fast Blue Optical Transients

Sample studies: Drout+14 (PanSTARSS), Tanaka+16 (Subaru), Arcavi+16 (SNLS+PTF), Pursiainen+18 (DECam)

- **FBOTs**
- Type Ia
- SLSNe
- Type IIP/Ibc
FBOTS: A new type of relativistic transient

As radio-luminous as long GRB jets, yet clearly different from long GRB progenitors because of the presence of hydrogen.

Margutti+2019; Coppejans, Margutti et al., 2020; Ho+2019, 2020
Strongly interacting SN shocks

Margutti+2014

SN2009ip

Absoulte R band Magnitude vs Time since peak (days)

Obs Mag vs Time (days)
Strongly interacting SN shocks

Murase+2013; Katz+2011; 2012
Transient iPTF14hls

Fermi-LAT detection:

Sollerman+2019

Yuan+2018
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Discovery Phase Space

- Never seen (e.g., shock breakouts from WDs, FBOT jets)
- Maybe seen one (e.g., shock interaction, FRBs)
- One (e.g., Gamma-ray counterparts to GWs)
- A few (e.g., jetted TDEs, low-luminosity GRBs)

Faint and/or observationally Rare