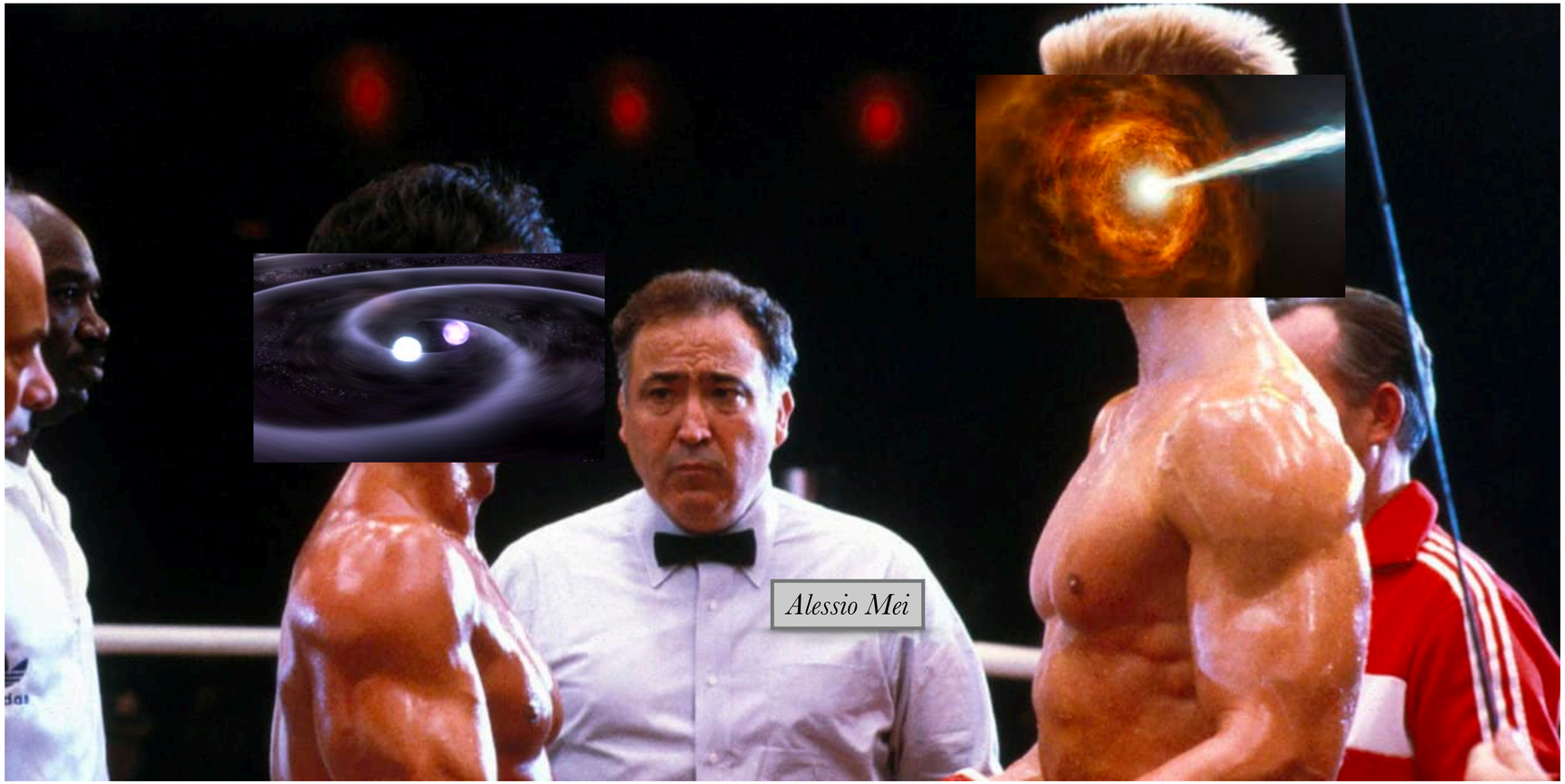
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

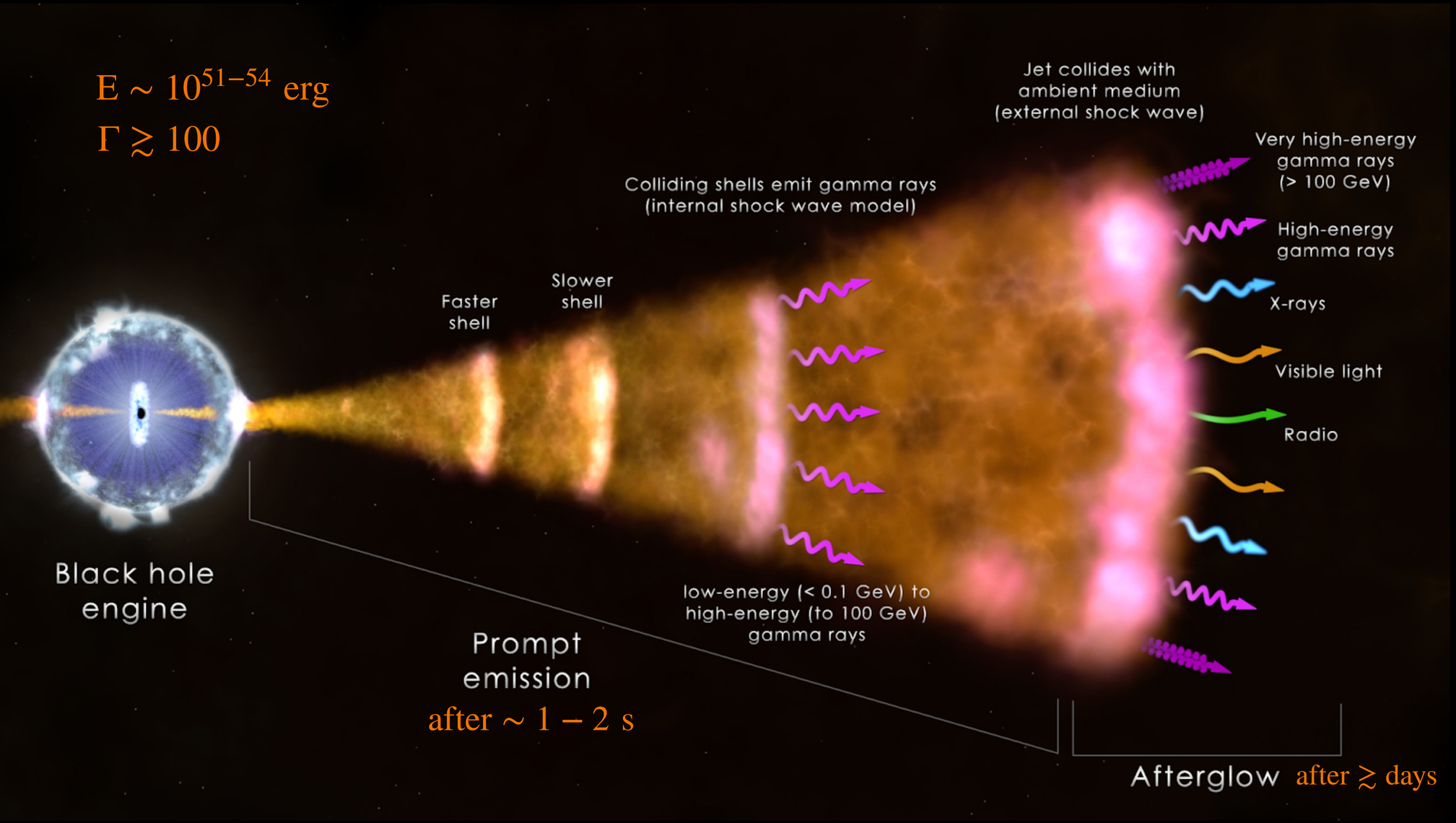
AP Science Fair

The dawn of a new astronomy

THE MYSTERY OF GAMMA-RAY BURST PROGENITORS

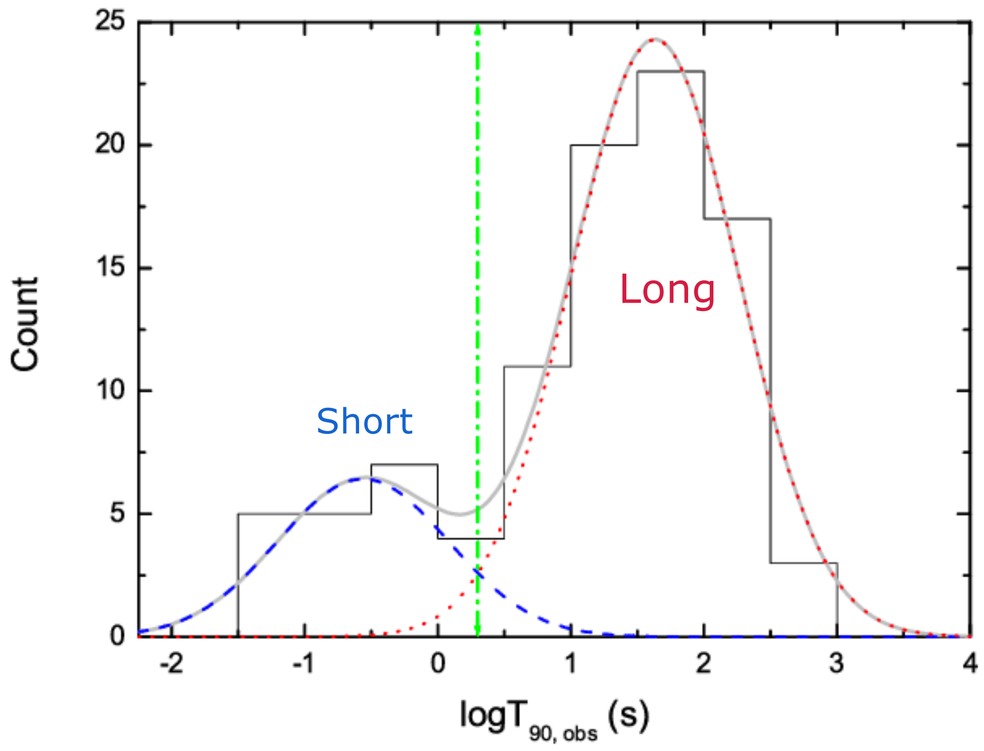


The fireball model

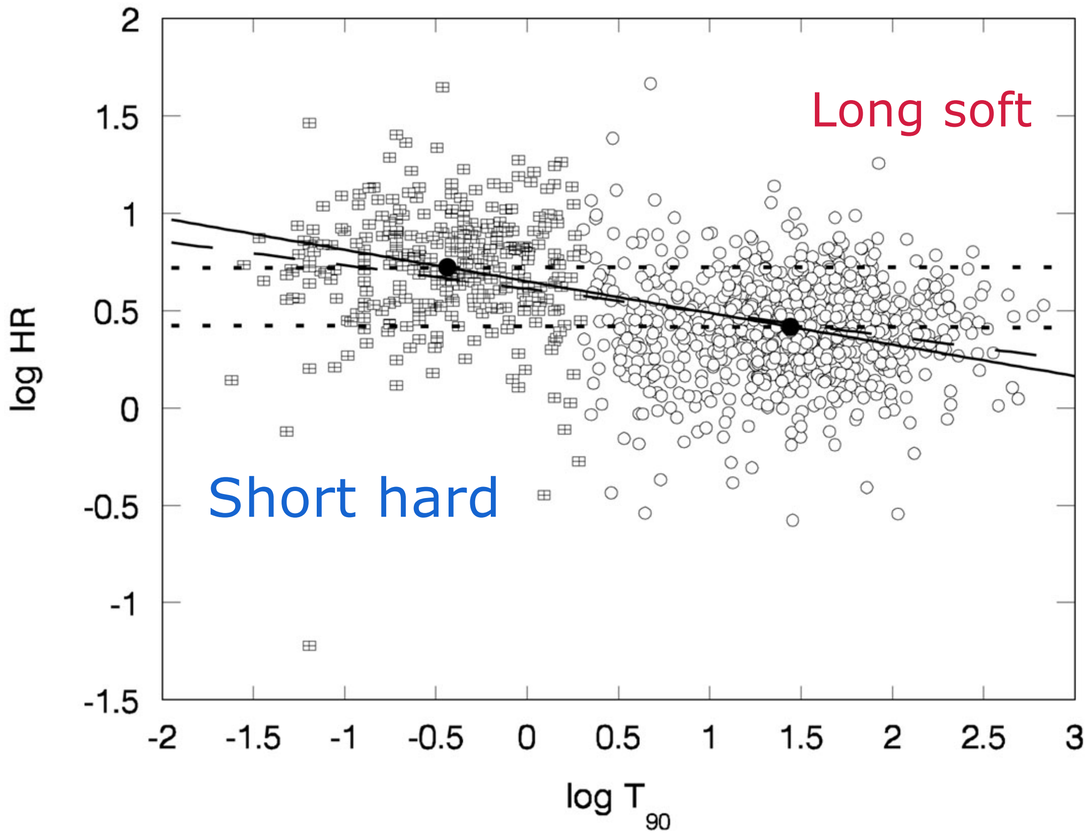


The duration-hardness bimodality

Kouvelitou et al. 1993



Qin et al. 2000



- Short duration GRBs ($T_{90} < 2$, $\bar{T}_{90} = 0.2$ s)

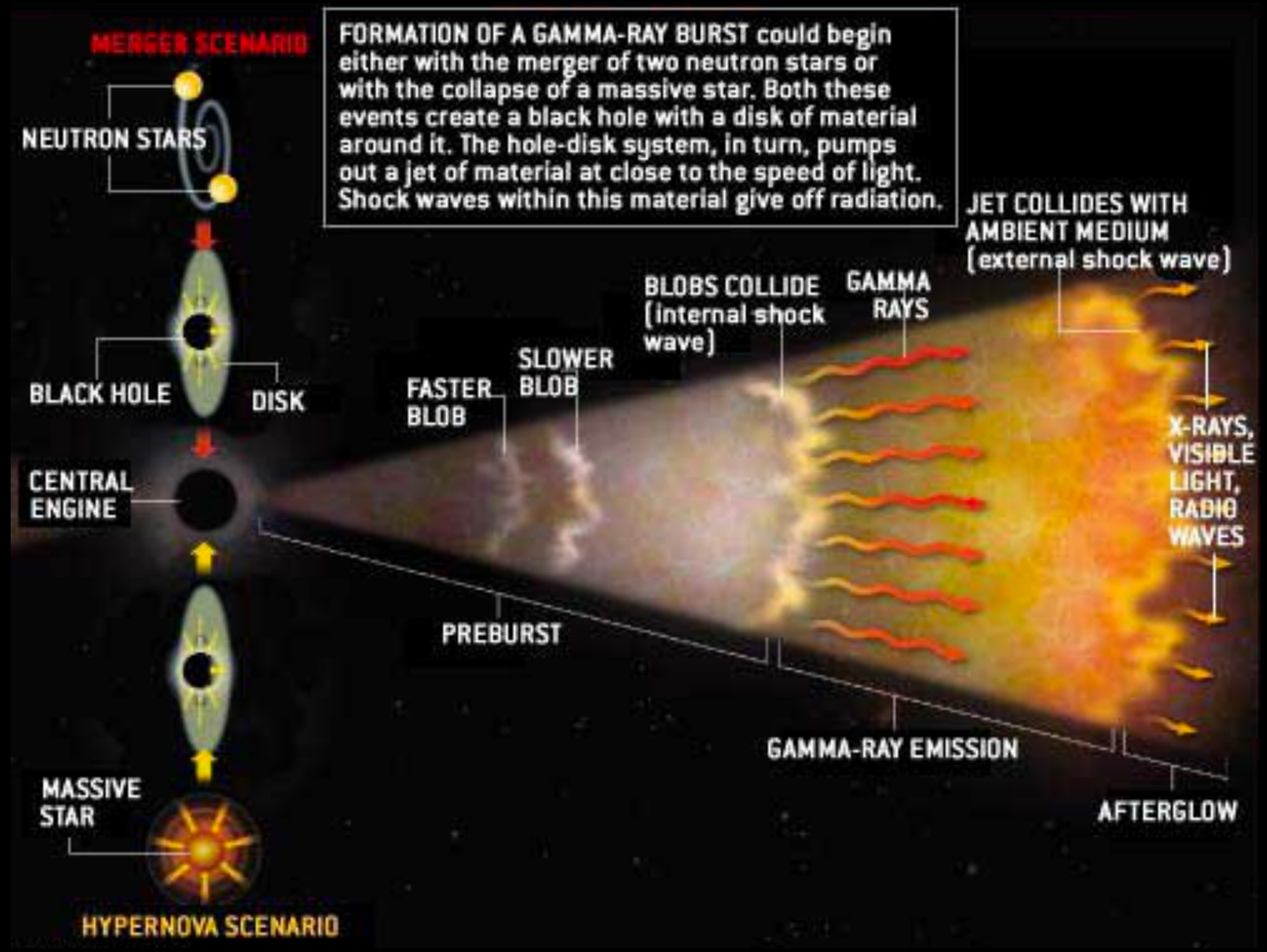
- Long duration GRBs ($T_{90} > 2$, $\bar{T}_{90} = 30$ s)

GRB progenitors

What can emit

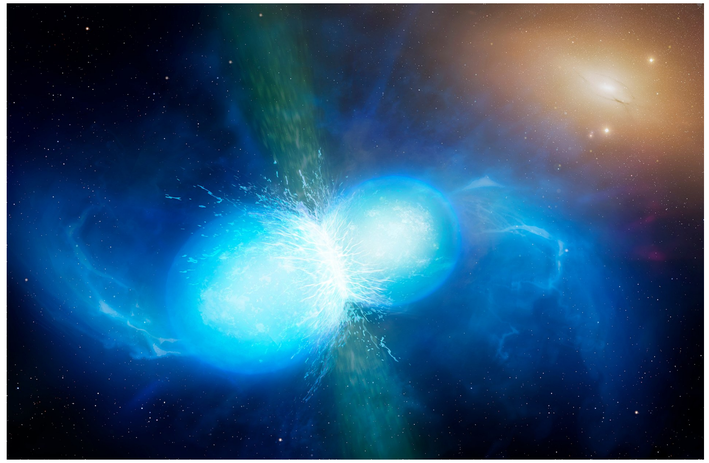
$E \sim 10^{51-54}$ erg

of gamma-rays in fractions of seconds/ hours?



Different progenitor, different duration

sGRBs



Binary neutron star mergers (BNS)

- sGRBs are observed far from the center of galaxies with low SFR and old stellar population.
- sGRB 130603B was observed in coincidence with the first kilonova.
- Multi-messenger observation of sGRB 170817A and at2017gfo with gravitational waves.

lGRBs

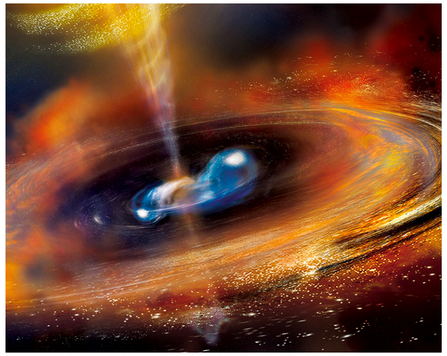
Collapse of massive stars (collapsars)

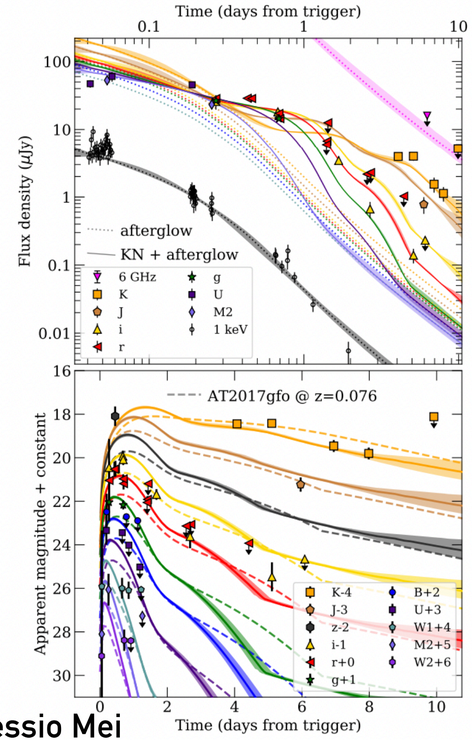
- lGRBs are observed close to the center of galaxies with high SFR and young stellar population.
- Many lGRBs observed in coincidence with supernovae (usually type Ic, e.g. lGRB 980425).

Duration is not a perfect indicator

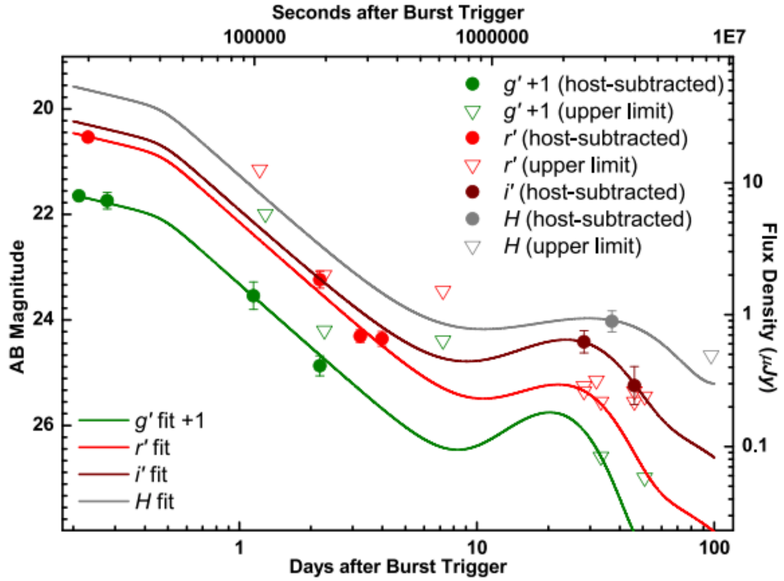
Rastinejad et al. 2022

lGRB 211211A



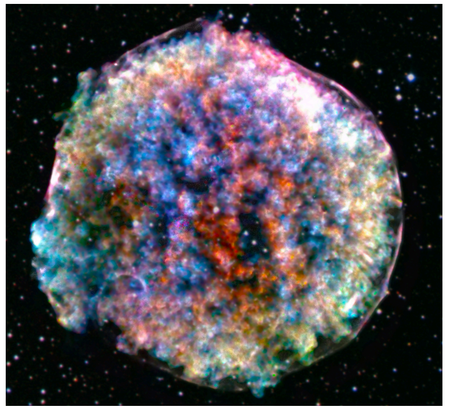


- lGRB 211211A had a duration of $T_{90} \simeq 30$ s and a softer extended emission up to ~60 s. It's spectral features were consistent with the ones of lGRBs, but in offset with the host galaxy.
- Associated with a kilonova, is the first merger-driven lGRB.



sGRB 200826A

- sGRB 200826A had a duration of $T_{90} \simeq 1$ s. Spectrally, it was consistent with sGRBs, but a SN type Ic was observed in coincidence with this emission.

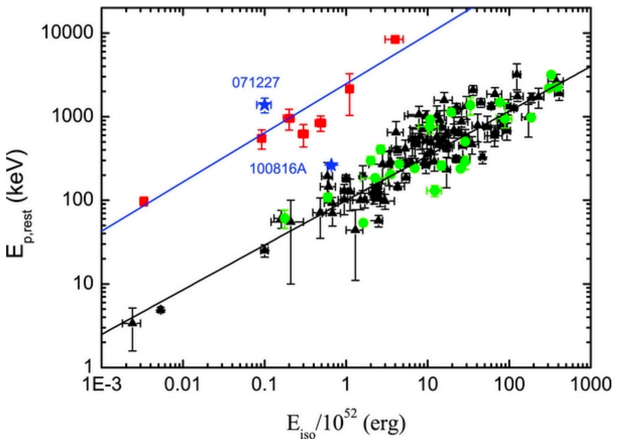


Rossi et al. 2021

Many indicators are good indicators

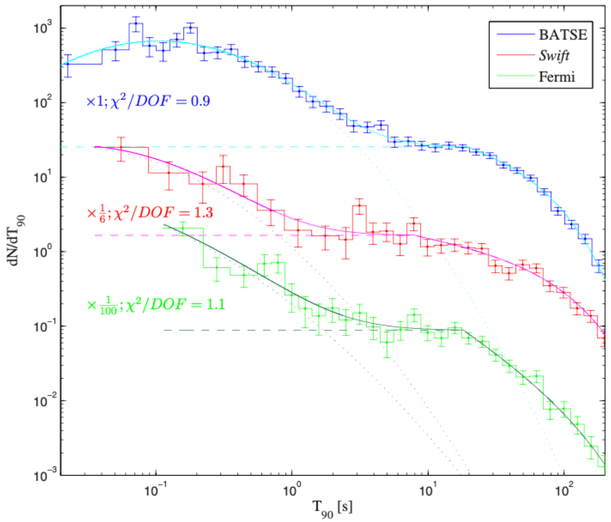
Amati relation

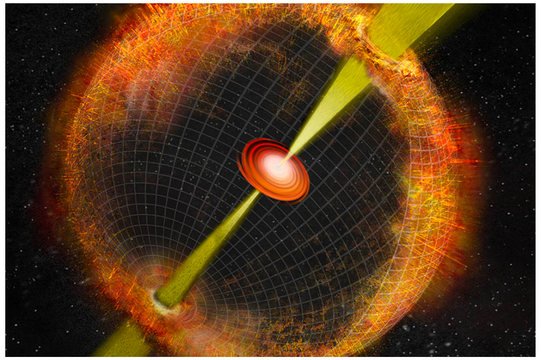
Amati et al. 2002, 2006



Non-collapsar probability

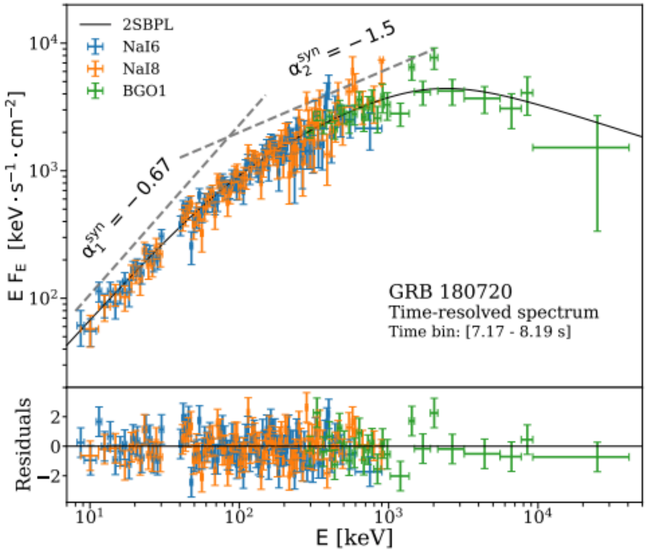
Bromberg et al. 2013





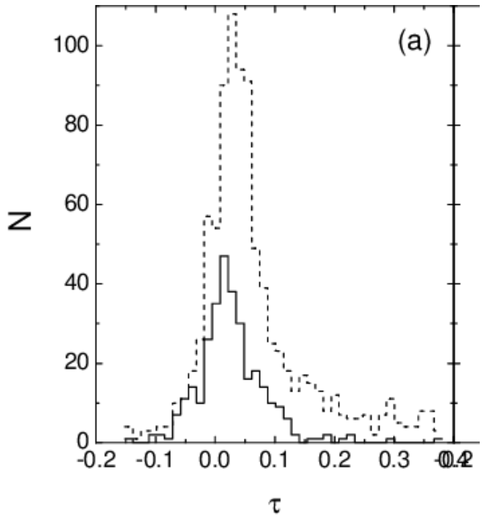
Low-energy spectral break

Oganesyan et al 2017, 2019, Ravasio et al. 2019



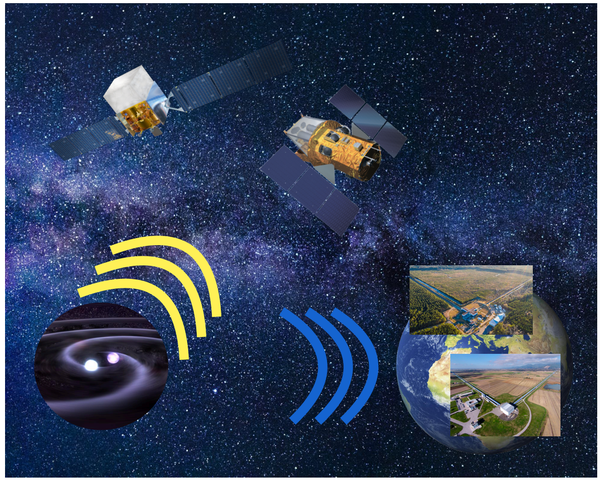
Spectral lag

Yi et al. 2006



GRB progenitors in O4

High FOV Gamma-ray instruments are triggered by GRB prompt emission



GW interferometers are triggered during the inspiral phase of the BNS.

Trigger and position

Good sky localisation up to ~10 s before the merger

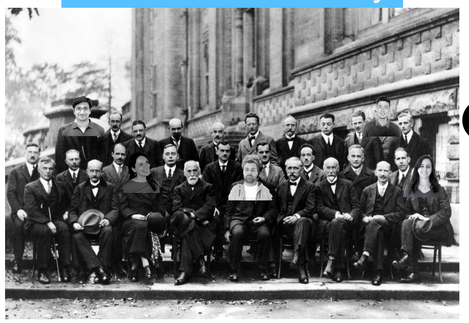
Gamma-Ray Coordinates Network

- Location of GRBs and other transients (Notices)
- Reports of follow-up observations (Circulars)

GCN

Automatic pipelines

Scientific community



Follow-up

VHE

X-rays

Optical

Radio

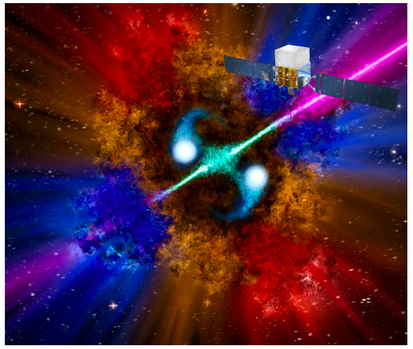
γ – rays

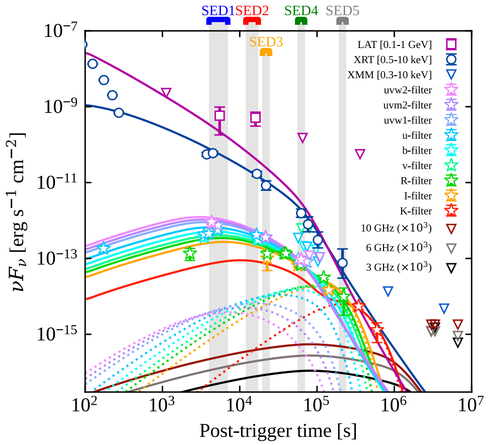
Fast-slewing instruments

~10^4 s

Mei et al. 2022

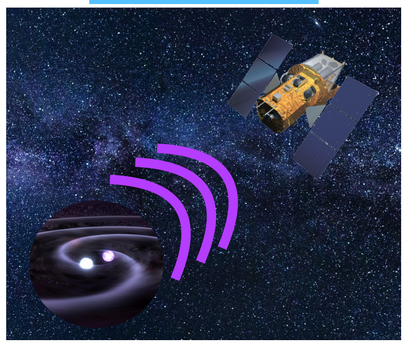
Late-time GeV emission





~100 s

Space-based



~20 s

Ground-based

Conclusions

- GRB duration bimodality suggests two classes: long and short, associated to different progenitors, collapsars and binary NS mergers, respectively.
- Duration only as indicator failed to classify GRBs associated to other transient emissions.
- The best way to classify a GRB is to mix different techniques involving different informations from the source.
- Having better diagnostic for GRB progenitors does not only provide precious informations on the central engine and acceleration mechanisms, but it is also crucial in the multi-messenger followup starting soon for O4!