GRBs @ TNG

Paolo D'Avanzo
INAF-OAB
on behalf of the CIBO collaboration

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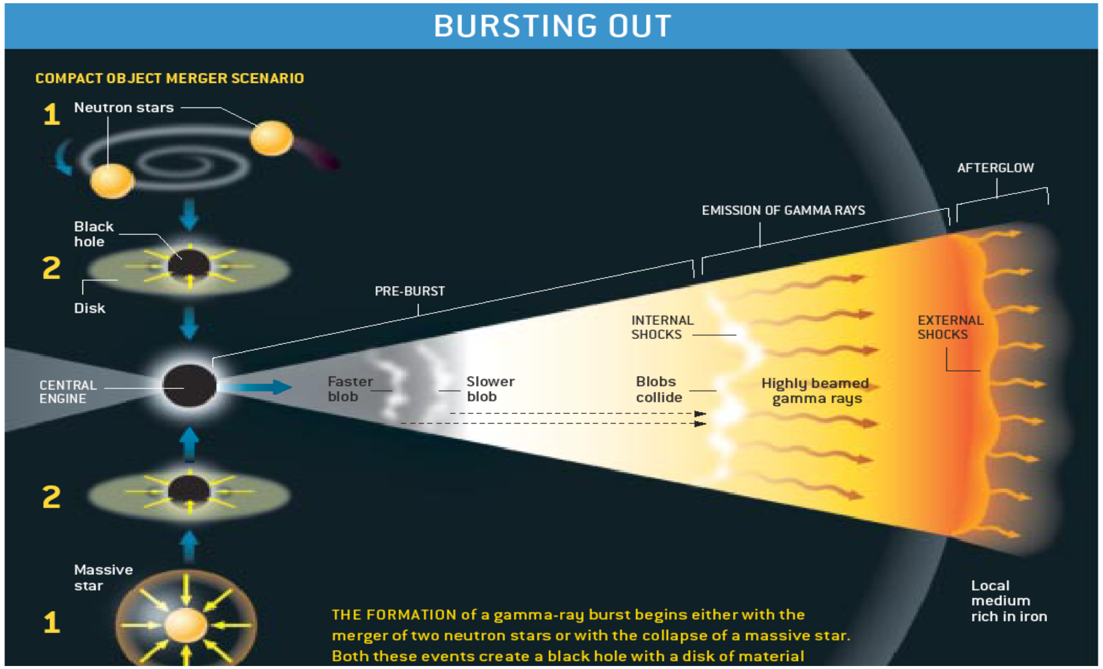
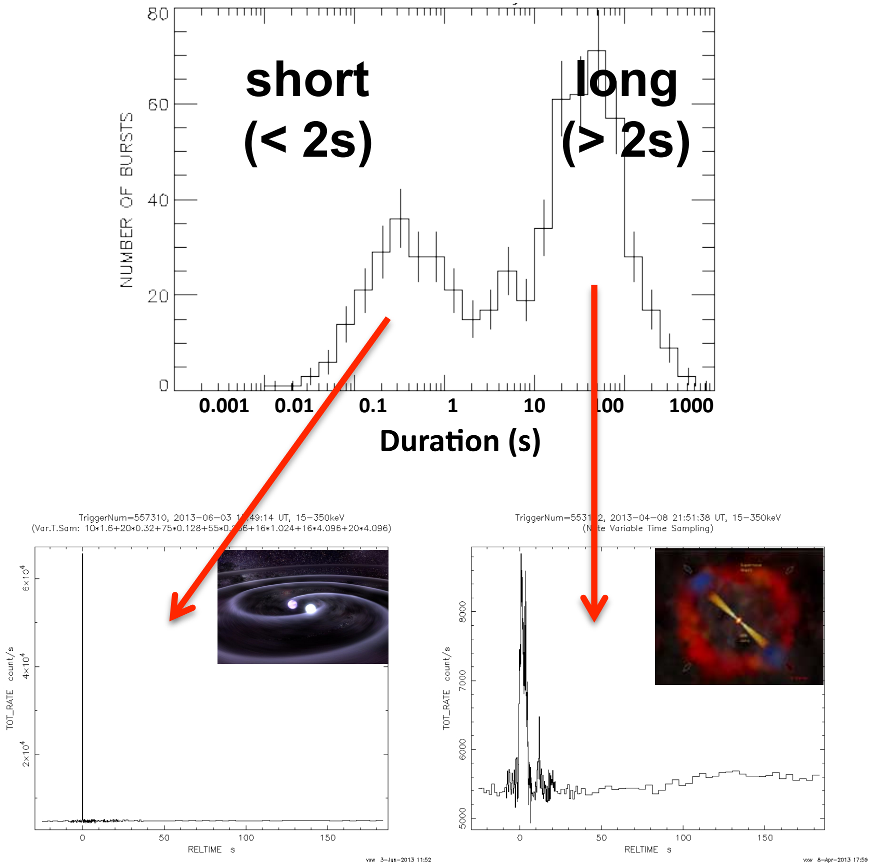
Coordinamento Italiano Burst Ottici

The C.I.B.O. collaboration, formed in 2000, involves most of the Italian astronomers interested in optical and infrared observations of the GRB afterglows and their host galaxies (HGs). Many members of the collaboration are also part of the Italian *Swift* team.

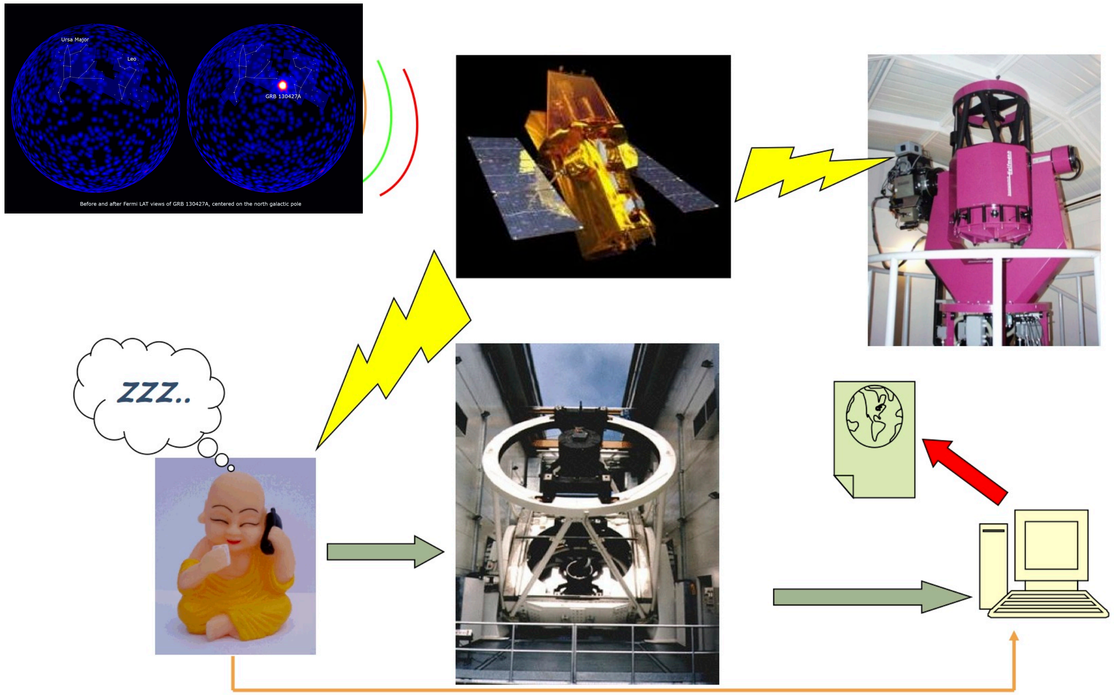
C.I.B.O. Activities:

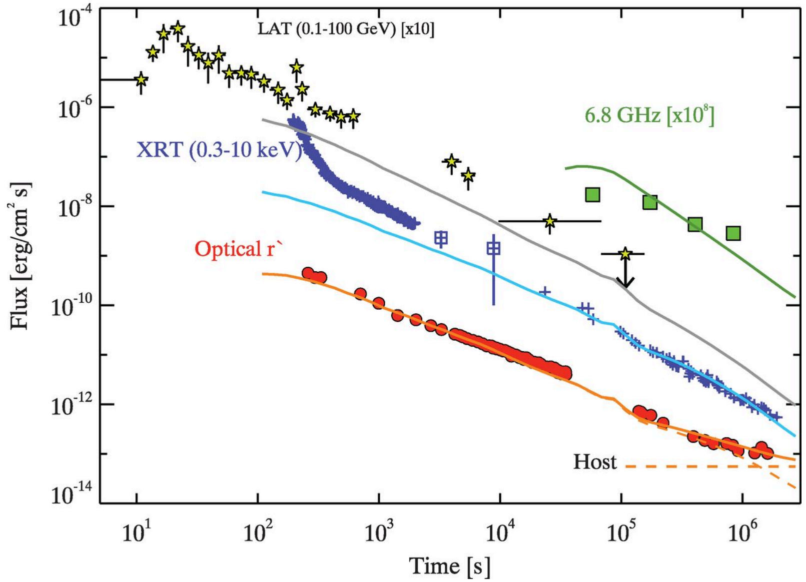
- Follow up observations of GRBs & HGs with TNG since 2000
- Follow up observations of GRBs with small Italian Telescopes since 2000
- Follow up observations of GRBs with REM since 2005
- Follow up observations of GRBs & HGs with LBT since 2008

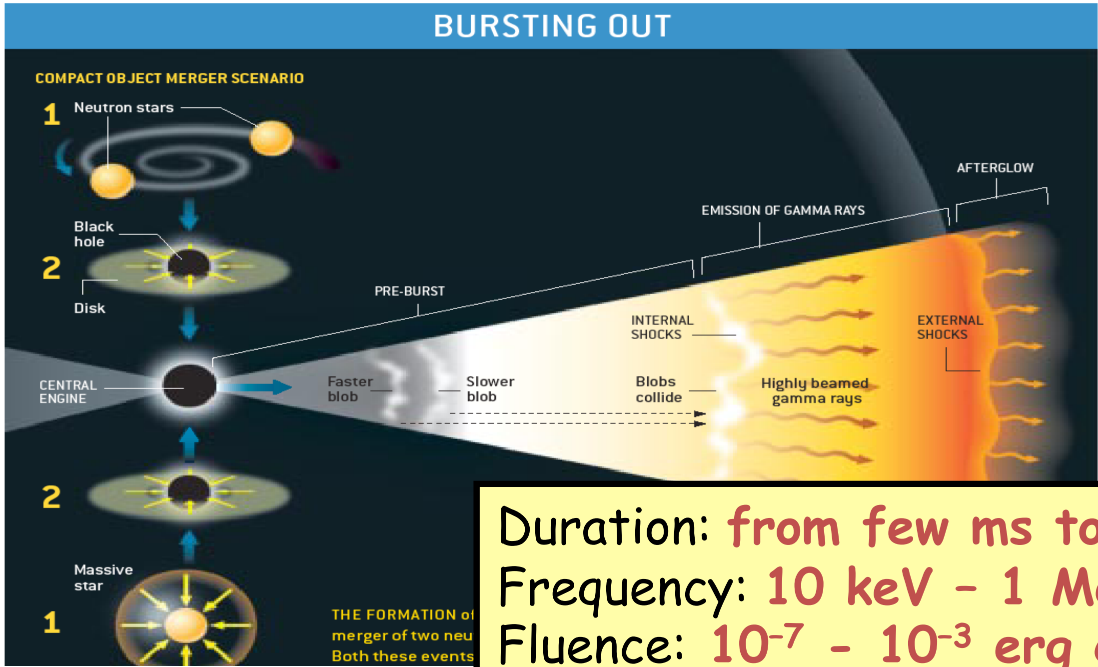


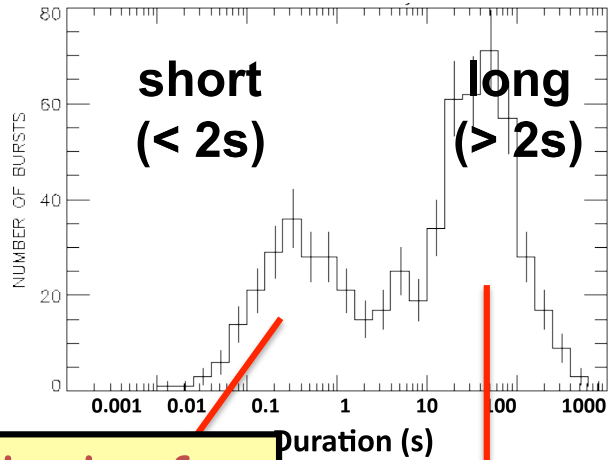


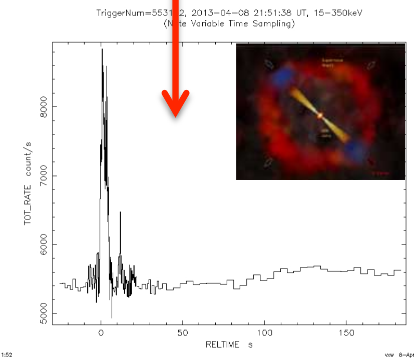
How to catch a GRB

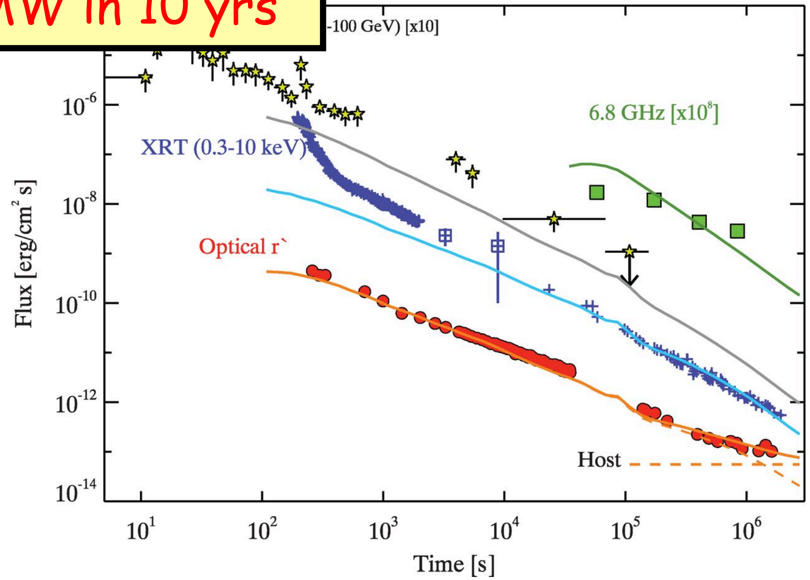


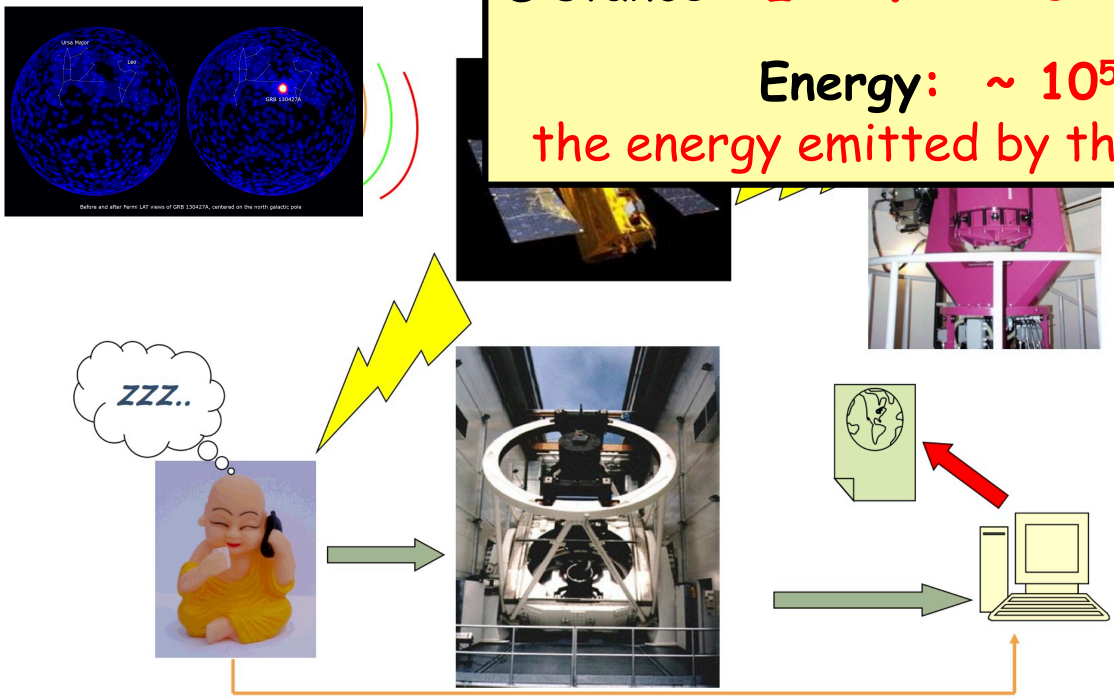












Duration: from few ms to hundreds of s

Frequency: 10 keV – 1 MeV

Fluence: 10^{-7} - 10^{-3} erg cm^{-2}

Flux: 10^{-8} - 10^{-4} erg cm^{-2} s^{-1}

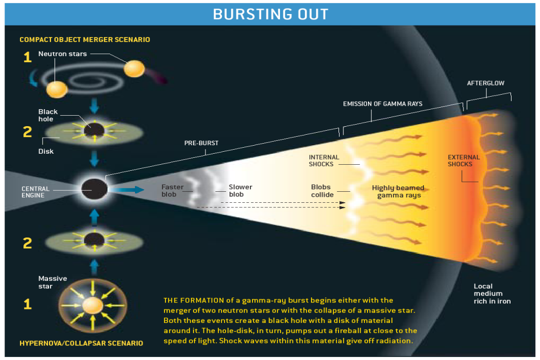
Distance: $<z>=2.1 \sim 10^{28}$ cm

Energy: ~ 10^{53} erg

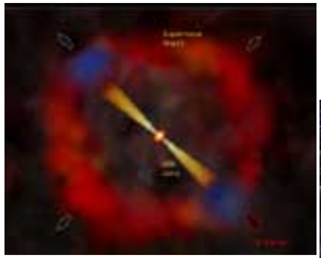
the energy emitted by the MW in 10 yrs

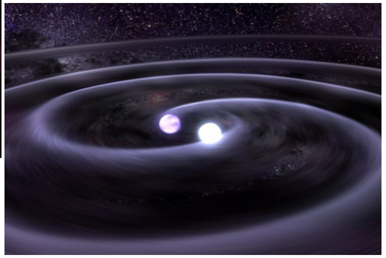
Science with GRBs

- <u>GRB physics</u>
  - Shocks
  - Role of magnetic fields
  - Jets
  - Accretion/ejection: extreme regimes

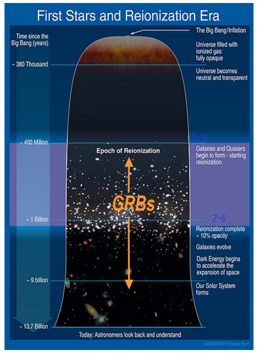


- <u>Progenitors</u>
  - Long GRBs: GRB-SN connection
  - Short GRBs: compact objects merging (GW)





- <u>GRB as cosmic probes</u>
  - From the local Universe to the re-ionization era
  - Circumburst environment / IGM
  - Chemical history of the Universe



Since 2004 Swift observed > 1000 GRBs: legacy/statistical approach to tackle the above science cases

GRB complete samples

Since 2004, Swift observed more than 100 GRBs (> 100 short GRB). It is now possible to follow a statistical approach (beyond single event studies). To this end, we selected complete (flux-limited) samples of events, with favorable observing conditions for ground-based observations (redshift determination)

BAT6 sample

Salvaterra+12

- 124 **long** GRB
- peak flux > 2.6 photons/s/cm^2
- ~85% with redshift (wrt 40% whole Swift sample)

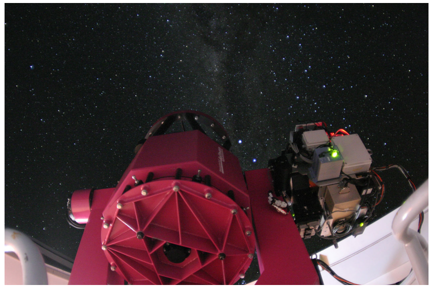
SBAT4 sample

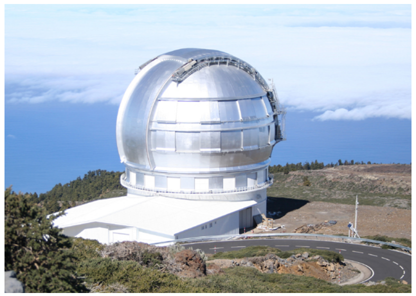
D'Avanzo+14

- 27 **short** GRB
- peak flux > 3.5 photons/s/cm^2
- ~60% with redshift (wrt 25% whole Swift sample)

- ✓ luminosity function and redshift distribution
- ✓ prompt/afterglow emission rest-frame properties, comparison, correlations
- ✓ GRB environments
- ✓ host galaxy properties
- ✓ simulations and predictions for high-z and GW (rates)

Synergy with other facilities





GRBs @ TNG: Long Term Programs

(a legacy approach)

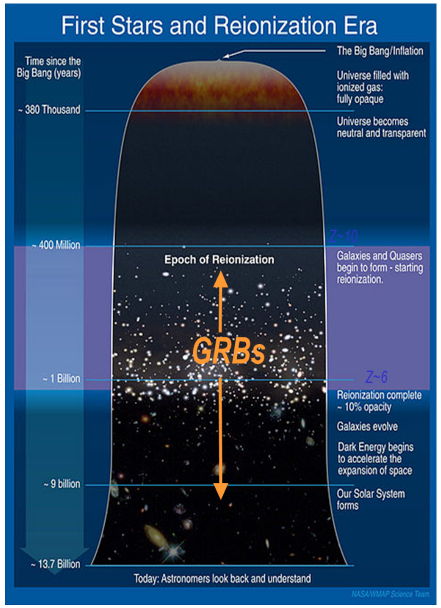
Since **AOT22** (**2010**; now AOT35) we started a series of Long Term Programs focused on well defined scientific projects:

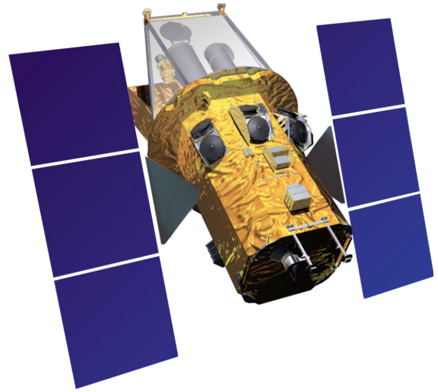
- candidate high redshift GRBs
- GRB-SN
- short GRBs
- events belonging to the BAT6 / SBAT4 complete (flux-limited) samples

GRBs as cosmic probes

Thanks to their brightness, long GRBs are detectable from the local Universe to very high redshift. A unique tool to study:

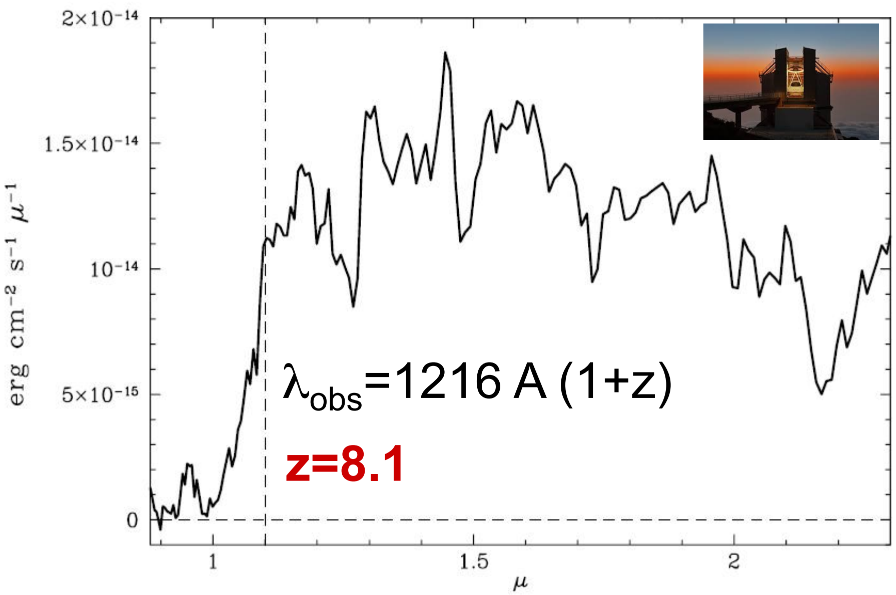
- cosmic star formation history
- metallicity & dust evolution
- the properties of faint galaxies that would be missed by 'traditional' surveys





8 GRB @ z > 6

TNG Amici prism spectrum



nature Vol 461|29 October 2009|doi:10.1038/nature08445

LETTERS

Salvaterra et al., 2009, Nature

GRB 090423 at a redshift of $z \approx 8.1$

R. Salvaterra[1], M. Della Valle[2,3,4], S. Campana[1], G. Chincarini[1,5], S. Covino[1], P. D'Avanzo[1,5], A. Fernández-Soto[6], C. Guidorzi[7], F. Mannucci[8], R. Margutti[1,5], C. C. Thöne[1], L. A. Antonelli[9], S. D. Barthelmy[10], M. De Pasquale[11], V. D'Elia[9], F. Fiore[9], D. Fugazza[1], L. K. Hunt[8], E. Maiorano[12], S. Marinoni[13,14], F. E. Marshall[10], E. Molinari[1,13], J. Nousek[15], E. Pian[16,17], J. L. Racusin[15], L. Stella[9], L. Amati[12], G. Andreuzzi[13], G. Cusumano[18], E. E. Fenimore[19], P. Ferrero[20], P. Giommi[21], D. Guetta[9], S. T. Holland[10,22,23], K. Hurley[24], G. L. Israel[9], J. Mao[1], C. B. Markwardt[10,23,25], N. Masetti[12], C. Pagani[15], E. Palazzi[12], D. M. Palmer[18], S. Piranomonte[9], G. Tagliaferri[1] & V. Testa[9]

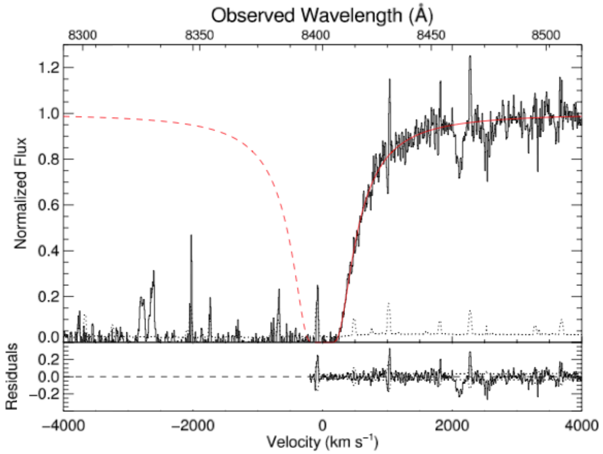
LumDist = 84.7 Gpc,

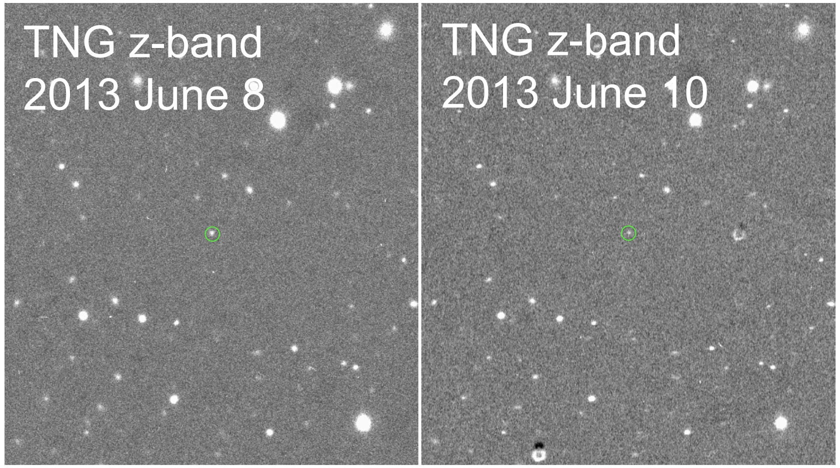
AgeUniv = 0.6329 Gyr

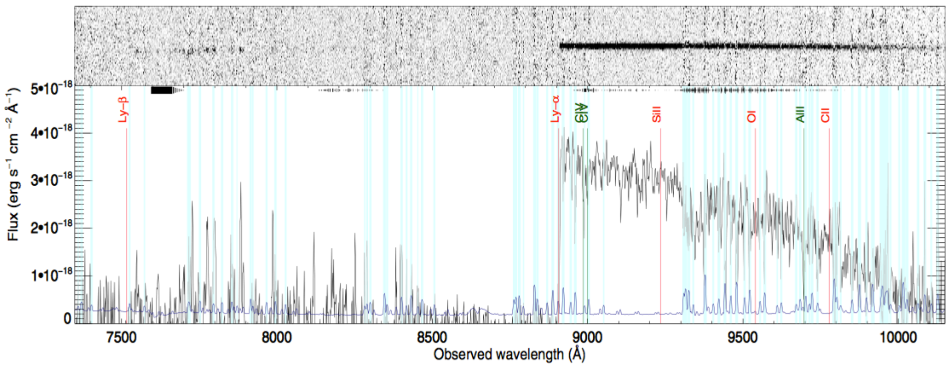
GRBs as cosmic probes

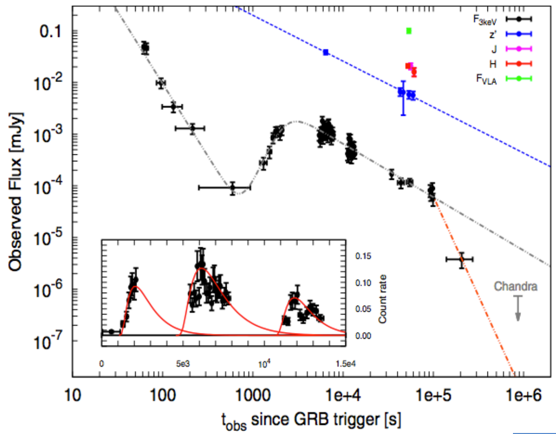
GRB 130606A
z = 5.91
Hartoog et al. 2015



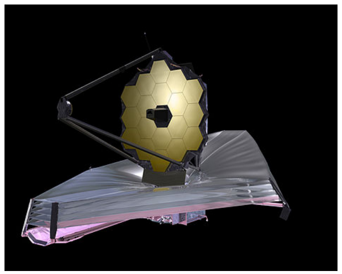




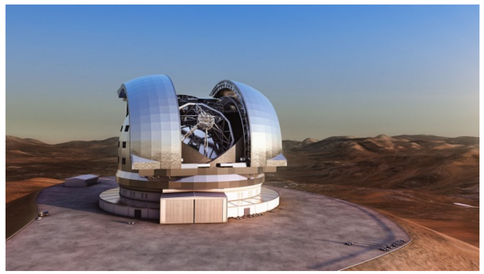




GRB 140515A
z = 6.33
Melandri et al. 2015

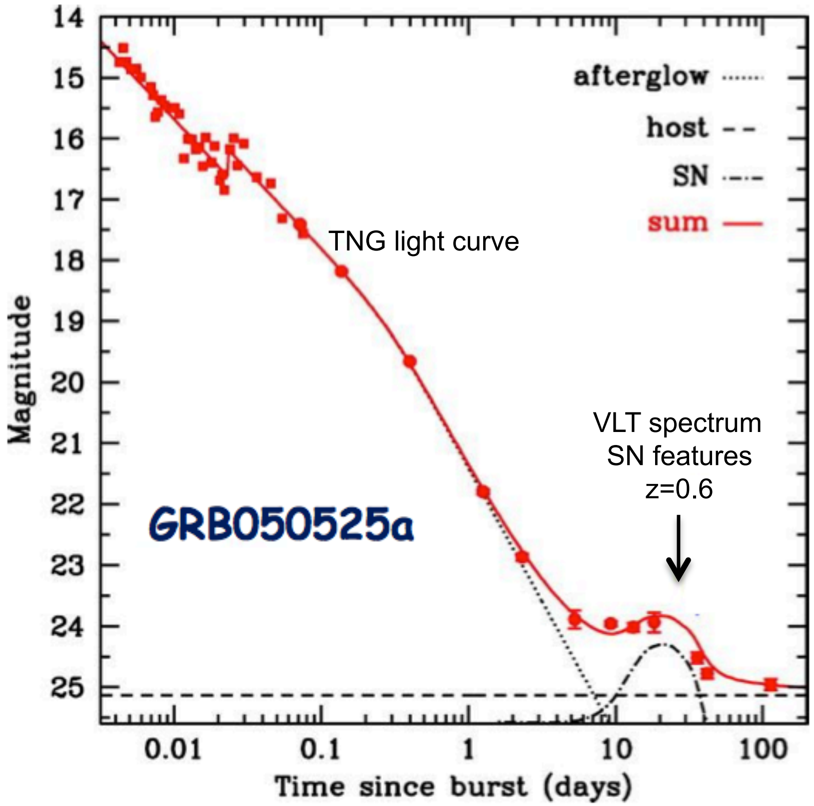



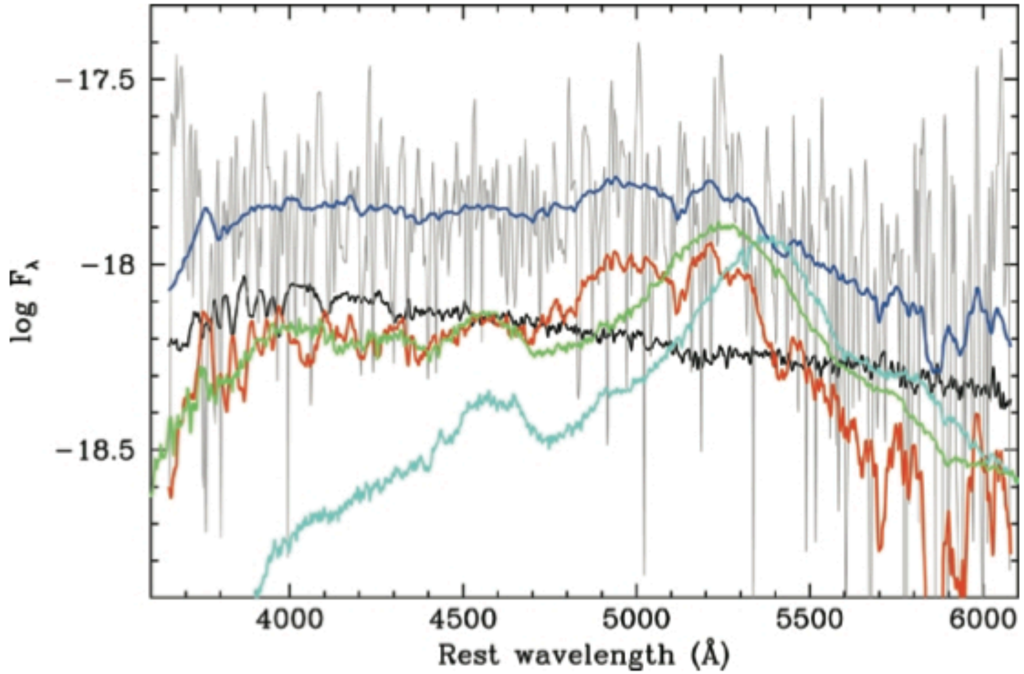
High-z GRBs:
ideal targets for JWST / E-ELT



GRB-SNe

GRB 050525A/SN 2013cq
z = 0.61
Della Valle et al. 2006

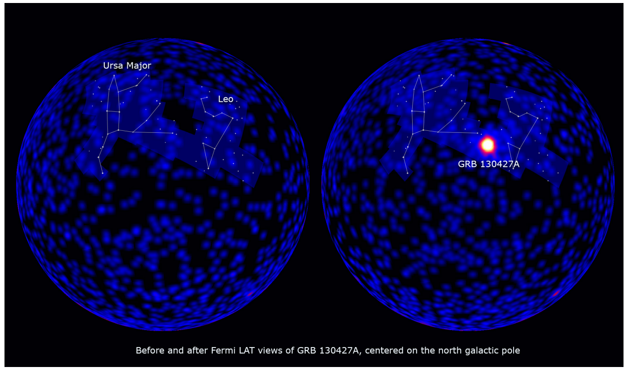


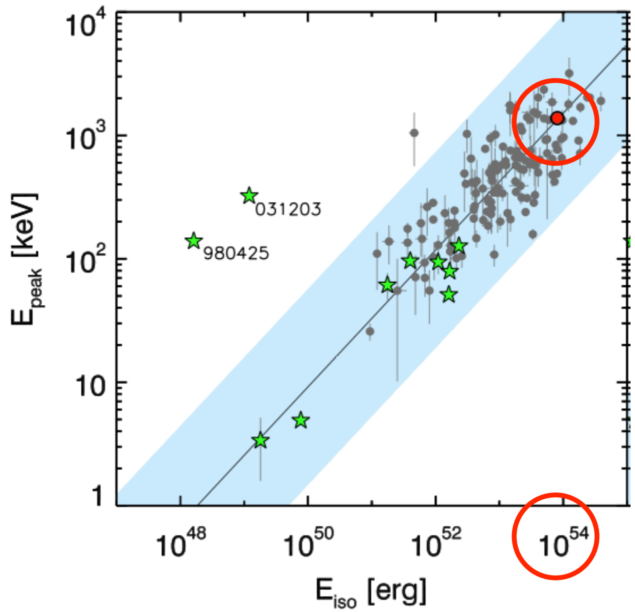


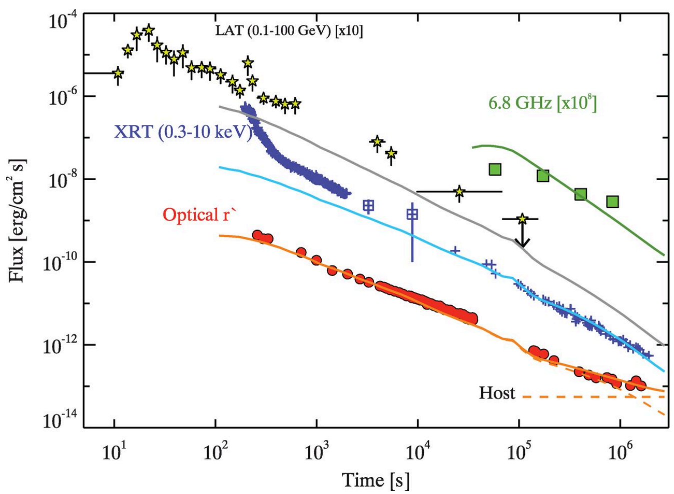
GRB-SNe

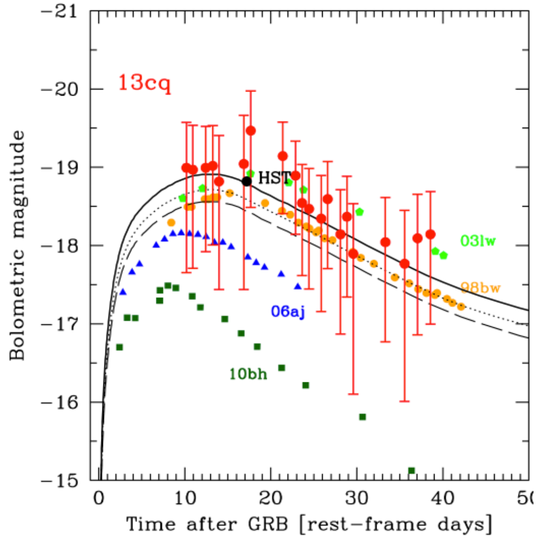
GRB 130427A/SN 2013cq
("a nearby, ordinary monster")
z = 0.34

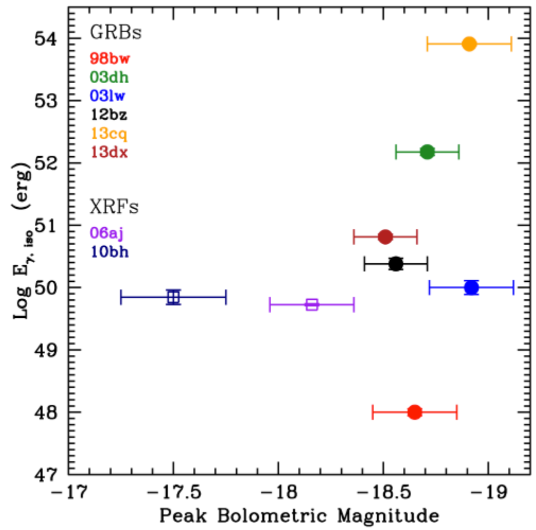
Maselli et al. 2014 Science
Melandri et al. 2014



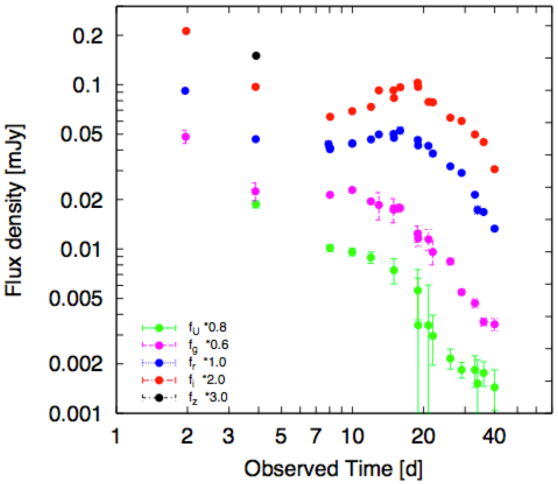


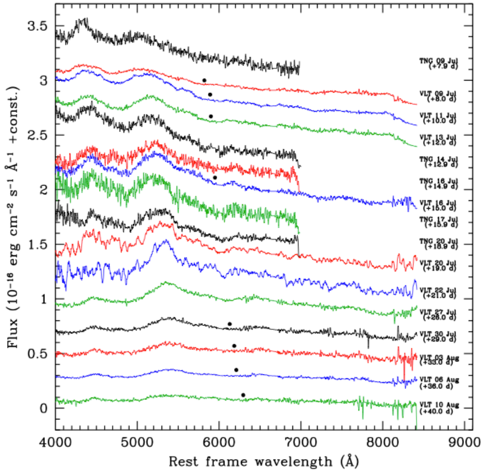


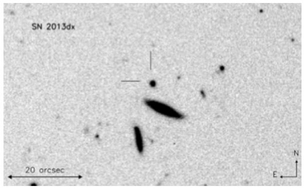




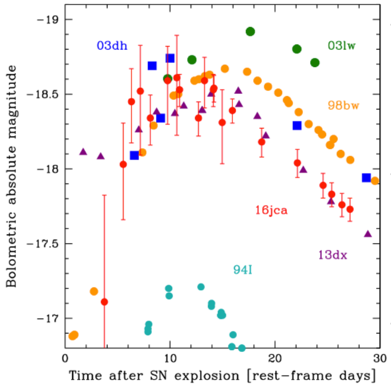
GRB-SNe

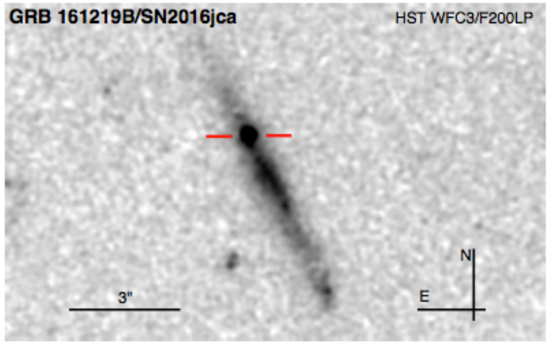






GRB 130702A/SN 2013dx
z = 0.145
D'Elia et al. 2015

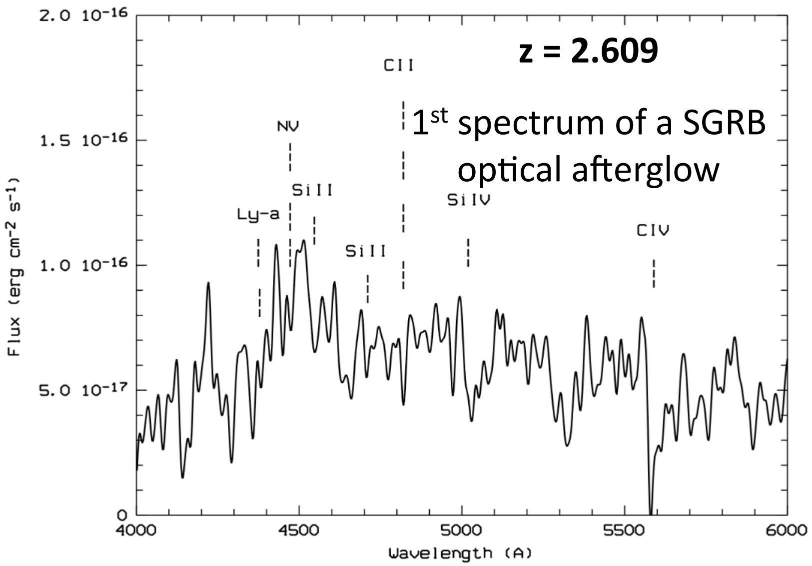


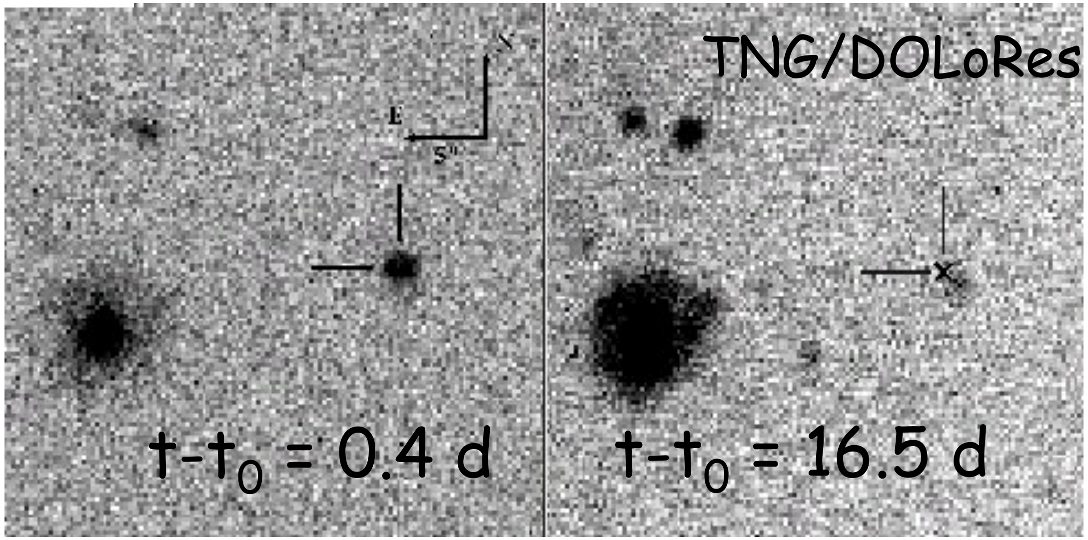


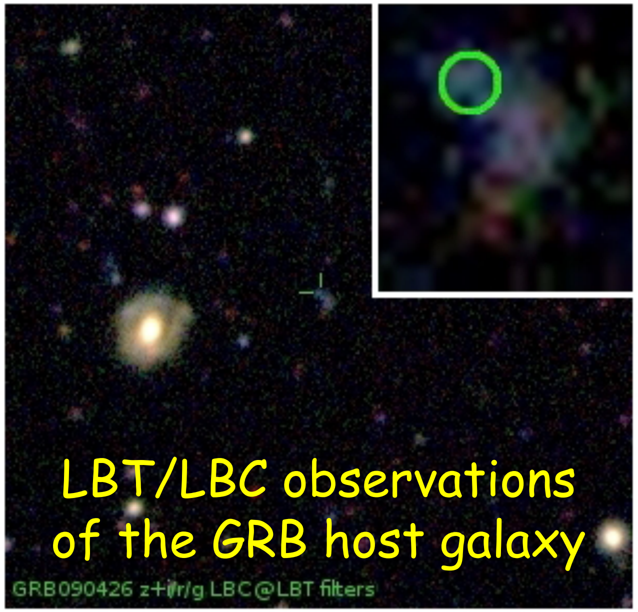
GRB 161219B/SN 2016jca
z = 0.148
Ashall et al. Nature Astr. (submitted)

The farthest short-duration GRB

GRB 090426: T_{90} = 1.25 s -> SGRB



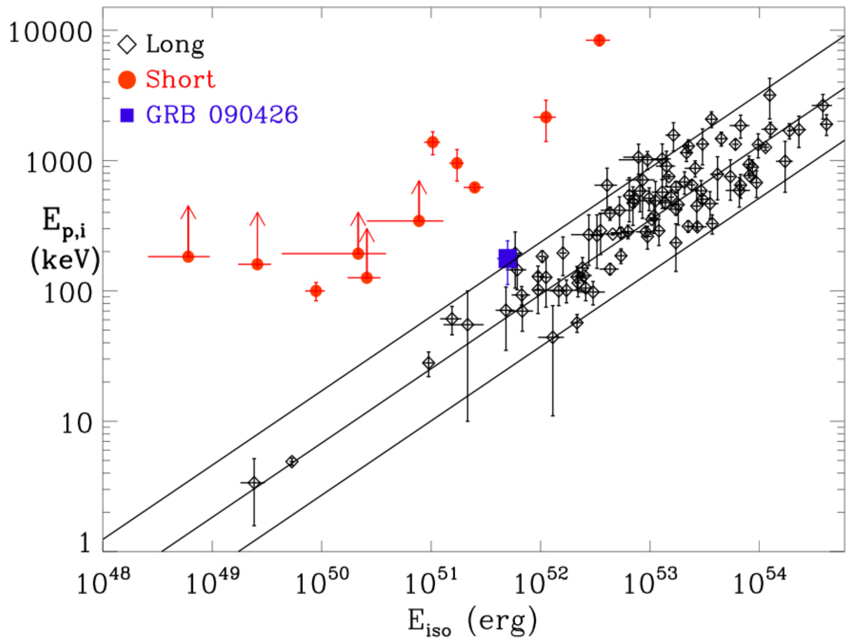




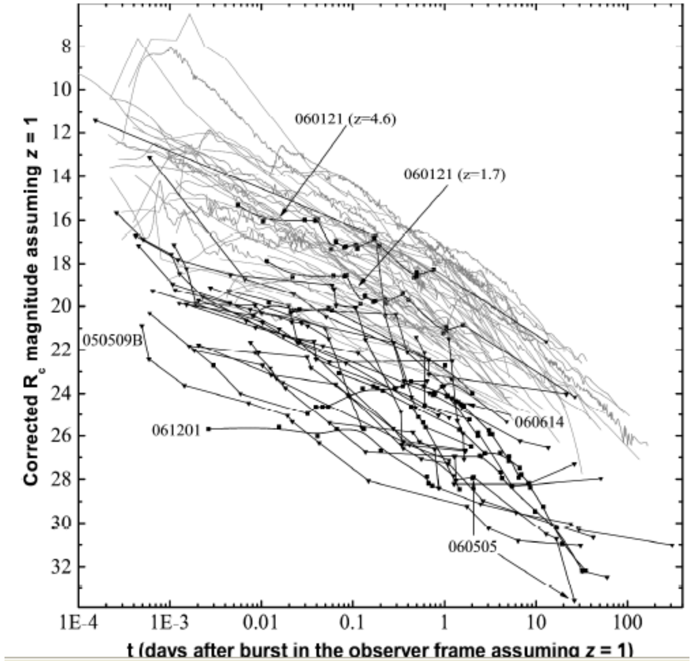
host galaxy, prompt spectral and energy properties are consistent with the LGRB class

Long-short classification is tricky

Antonelli et al. 2009



Short GRBs



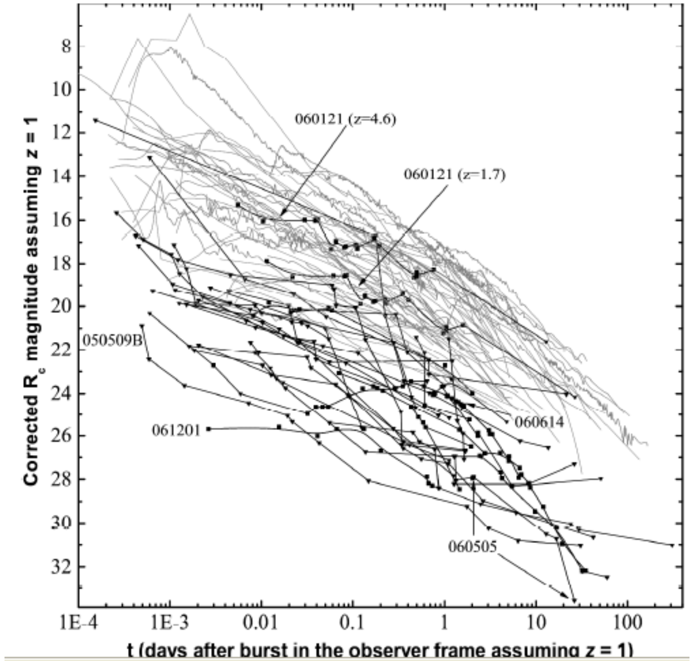
Short GRBs afterglows are fainter wrt long GRBs:

- less dense environment?

- less energetic?

Need to pinpoint them, study the host galaxy, measure z

Short GRBs



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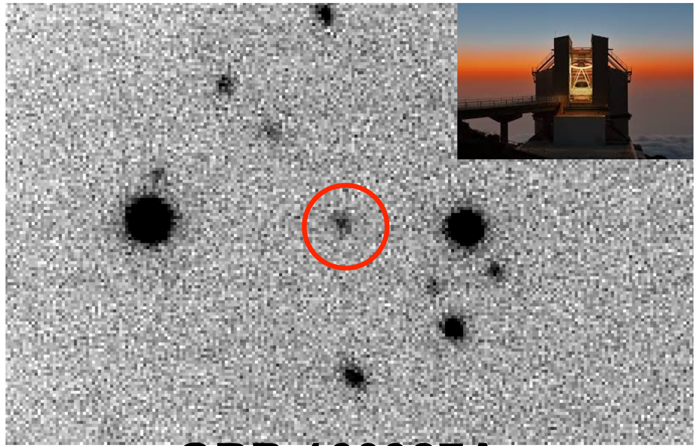
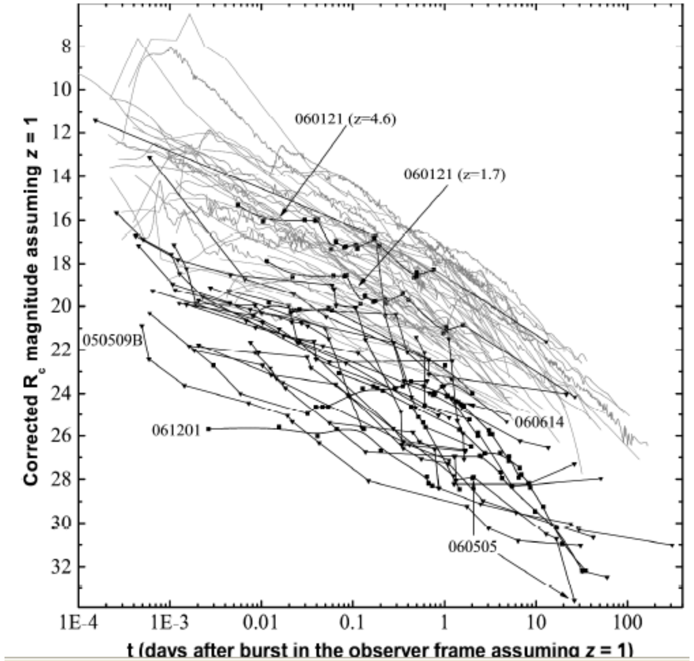


GRB 160927A

AG detection (r ~ 22.6 mag)

T-T0 = 2.1 h

Short GRBs



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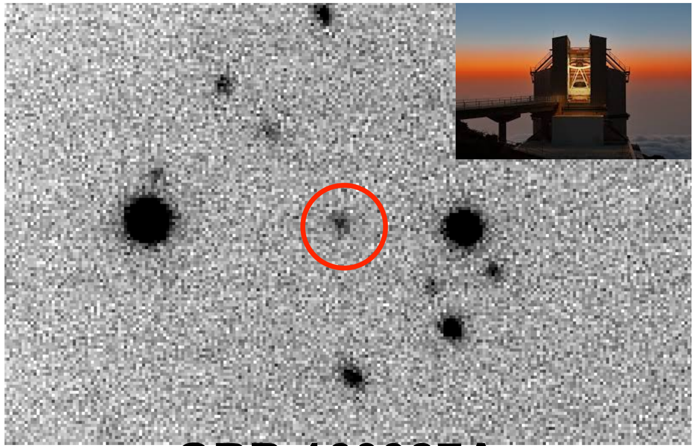

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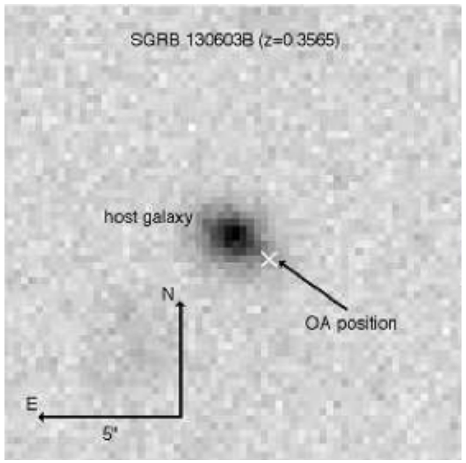
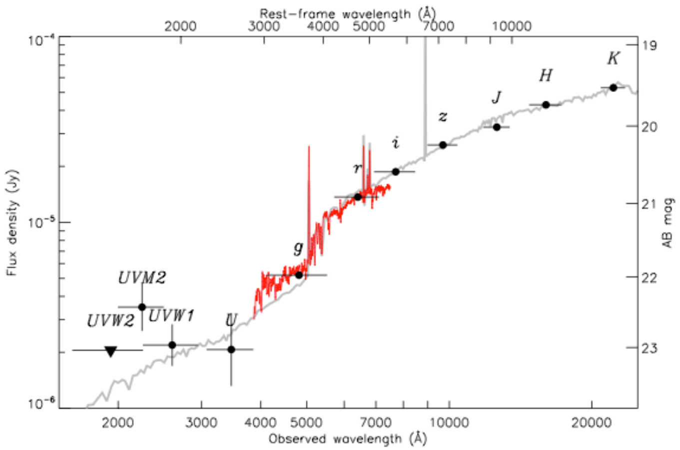
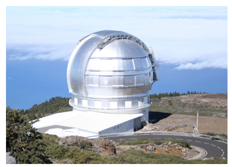




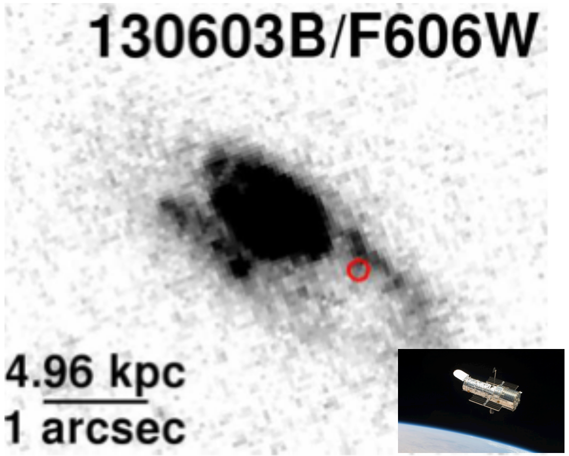
GRB 130603B (macronova!)

De Ugarte Postigo et al. 2014

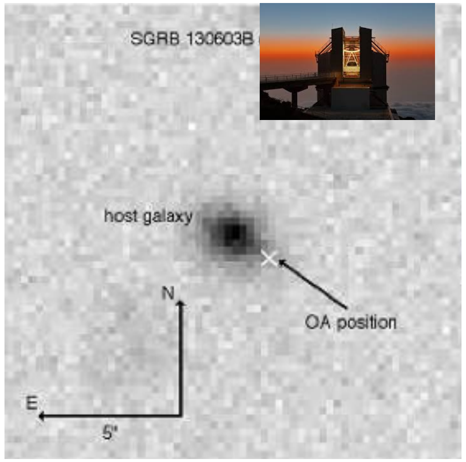




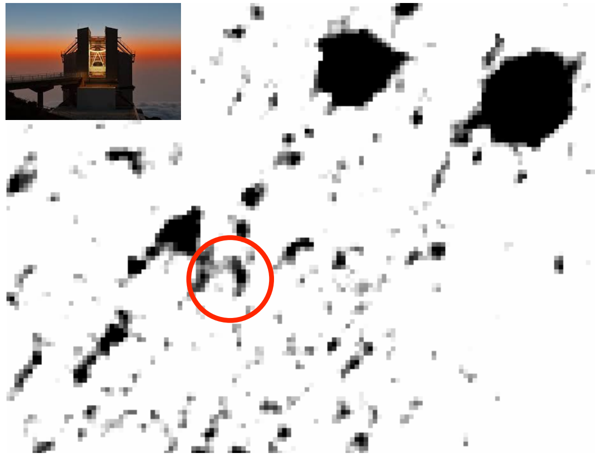
Short GRBs



GRB 130603B
Fong & Berger 2013



GRB 130603B
De Ugarte Postigo +2014



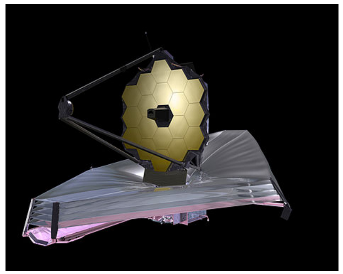
GRB 151229A
HG detection (r ~ 25 mag)

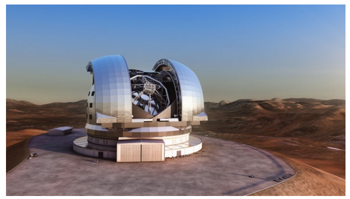
Short GRB HGs with large aperture / future telescopes

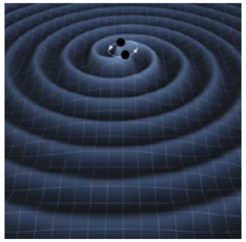
- Redshift determination also for fainter targets (LBT, VLT, JWST, E-ELT)

- High spatial resolution (JWST, E-ELT): detailed study of the environment, constraints on the progenitors

→ Implication for GW progenitor models and rates

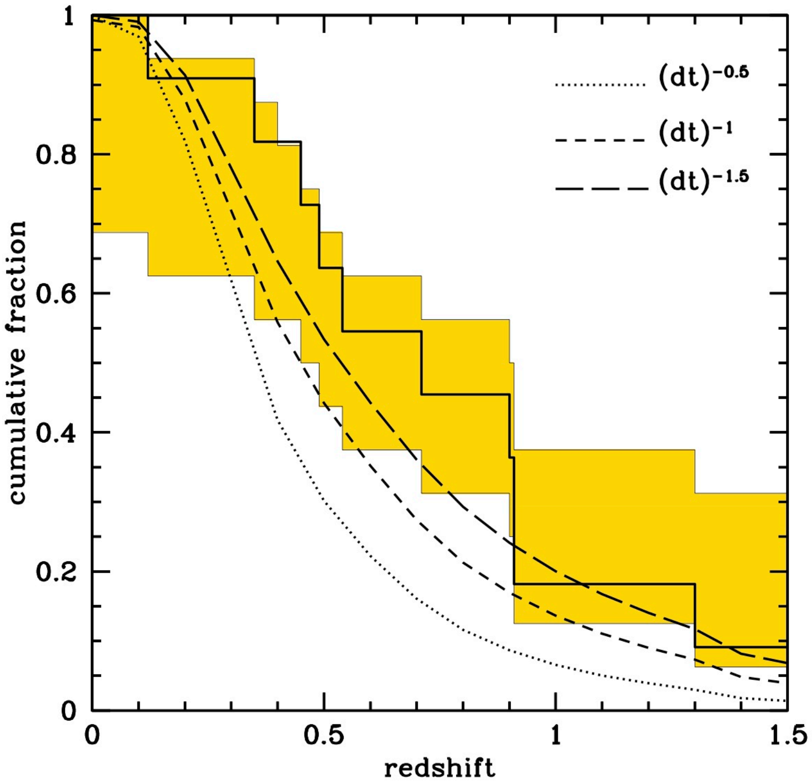




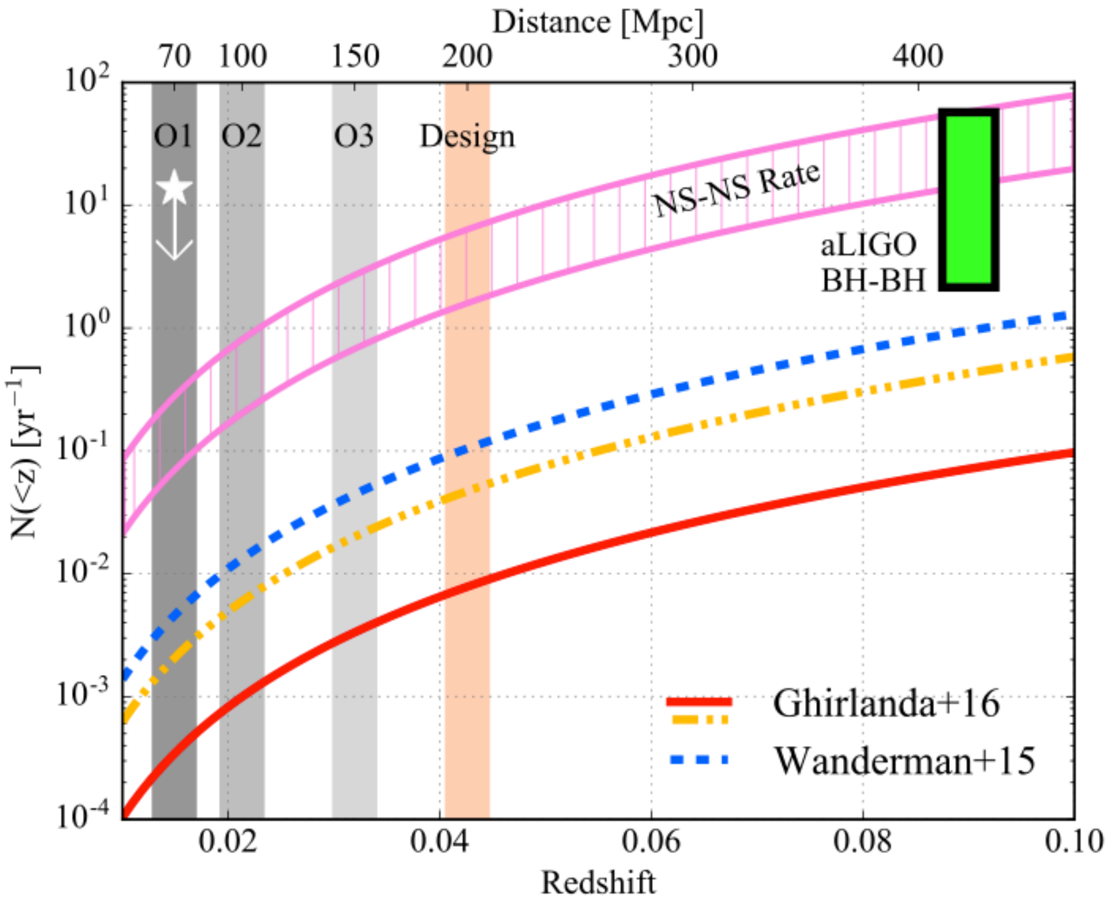


Short GRBs & GW

Complete sample of short GRB (SBAT4) to derive short GRB redshift distribution and rate in the LIGO/Virgo horizon



D'Avanzo et al. 2014



Ghirlanda et al. 2016

GRBs @ TNG: Long Term Programs

(a legacy approach)

Since **AOT22** (**2010**; now AOT35) we started a series of Long Term Programs focused on well defined scientific projects:

- candidate high redshift GRBs
- GRB-SN
- short GRBs
- events belonging to the BAT6 / SBAT4 complete (flux-limited) sample

NUMBERS (since 2010, LTP):

- observed ~ 5 GRB/semester falling in the above categories (~ 60 GRB overall)

- an average request of ~30 hr/semester (now 10)

- 55 GCN circulars

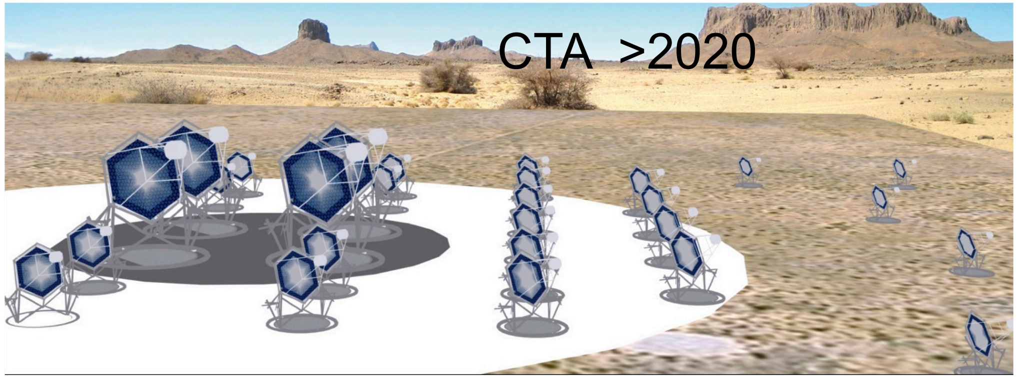
- 26 paper published (1 Sci, 1 Nat), 1 paper submitted (Nat Astr.)

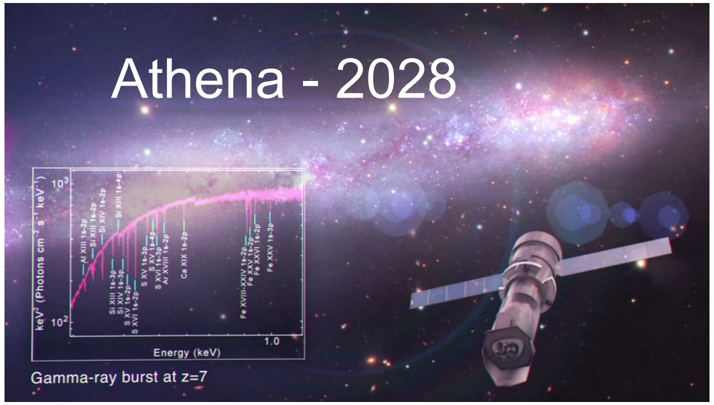
Conclusions & desiderata

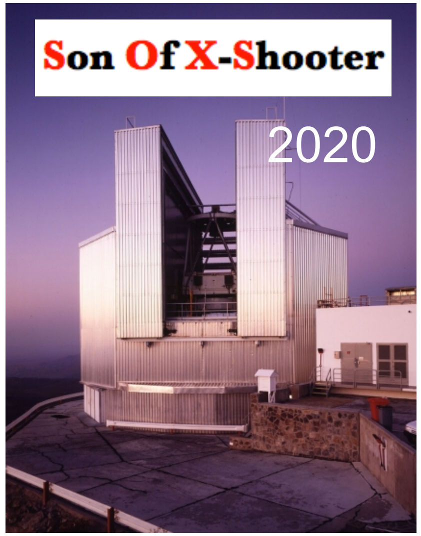
- **GRBs have an high science impact in many astrophysical fields**
- *Swift* is providing (and will provide) to the world GRB community a wealth of data (90 GRB/yr)
- The use of TNG in GRB studies played (and is playing) a crucial role in keeping the Italian community in a leading role in this highly competitive research field
- Such role has been (and will be) enhanced by the LTP approach and by the synergy with other facilities (e.g. REM, NOT, LBT, VLT, HST, XMM)
- **High visibility and scientific return with relatively little amount of consumed time**

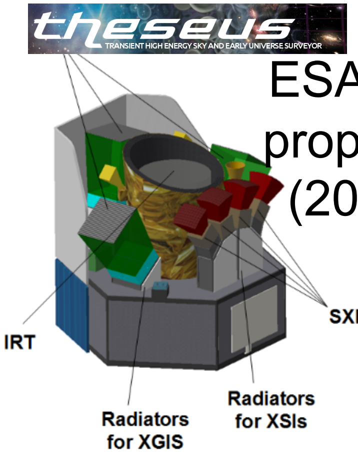
- Northern emisphere telescope with flexible schedule (ToO)
- OPT/NIR imaging + low/medium-res spectroscopy (SOXS North?)

2020 and beyond: Time-Domain Astronomy Era

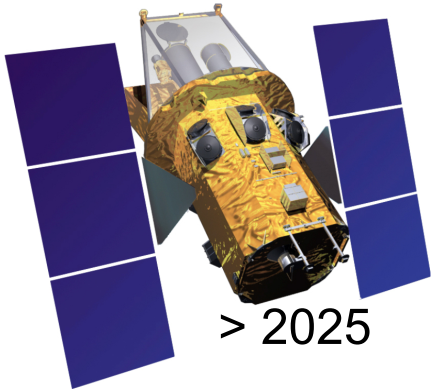






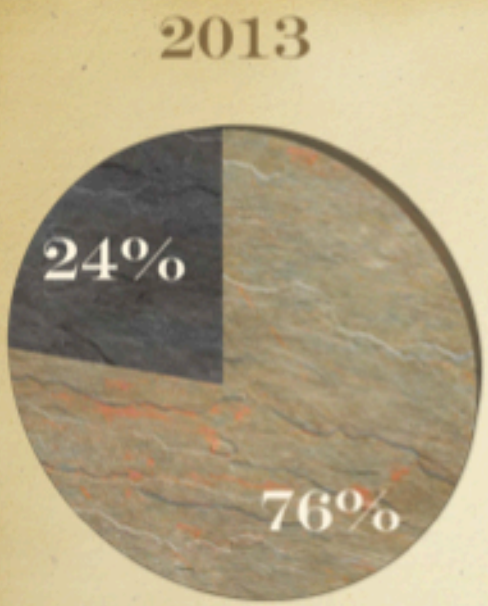


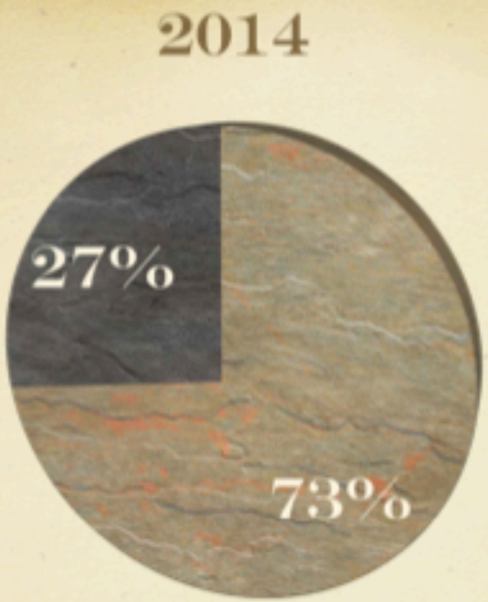
ESA M5
proposal
(2028)

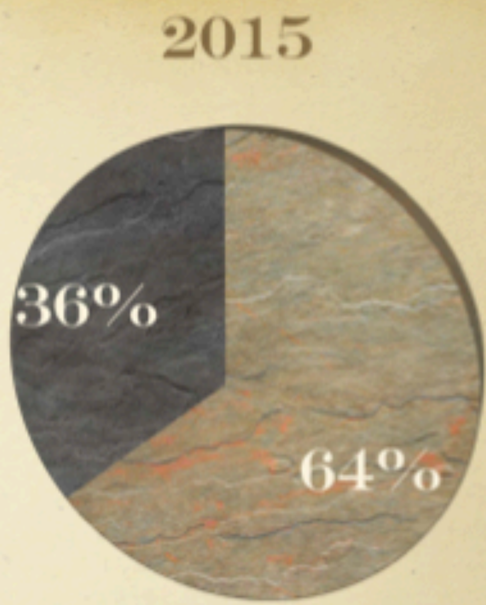


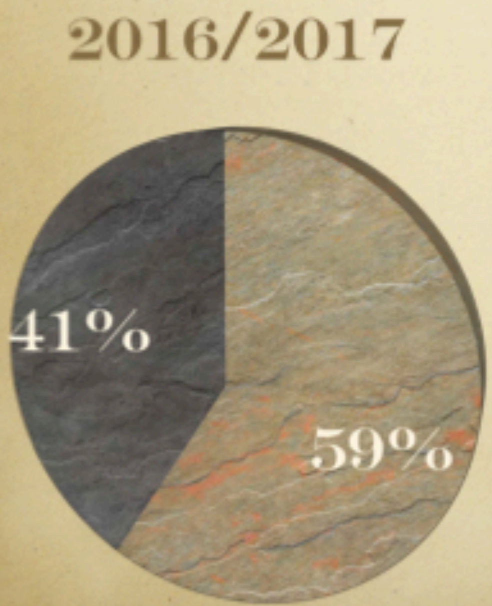
2020 and beyond: Time-Domain Astronomy Era

Publications per year



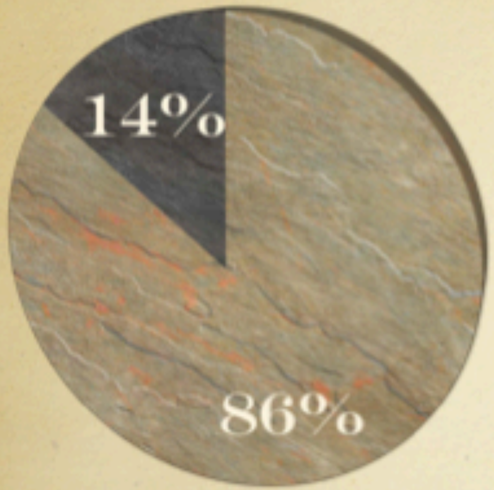




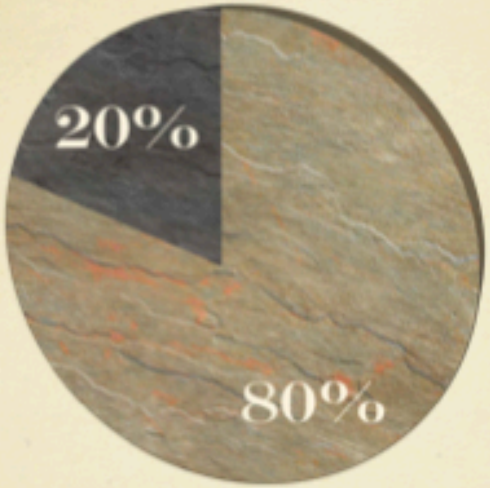


- LRS/NICS
- HARPS/GIANO

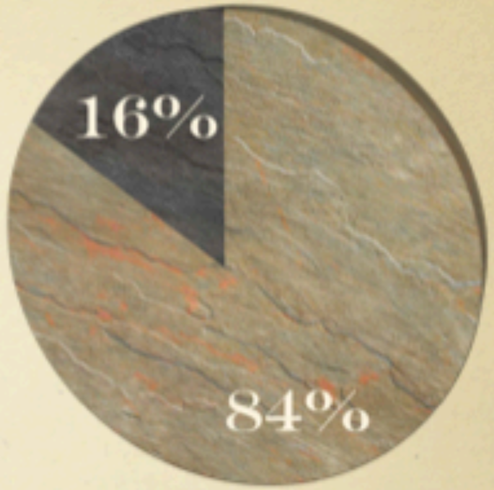
2013



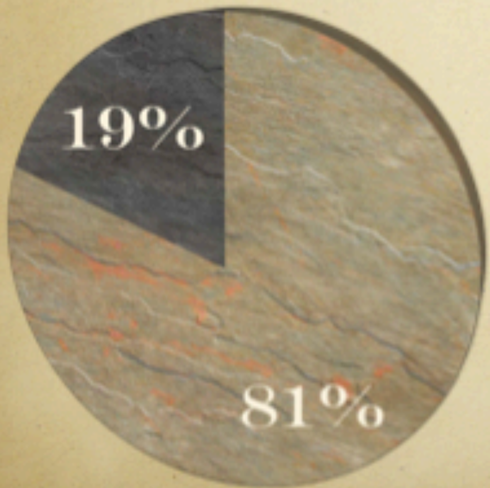
2014



2015



2016/2017

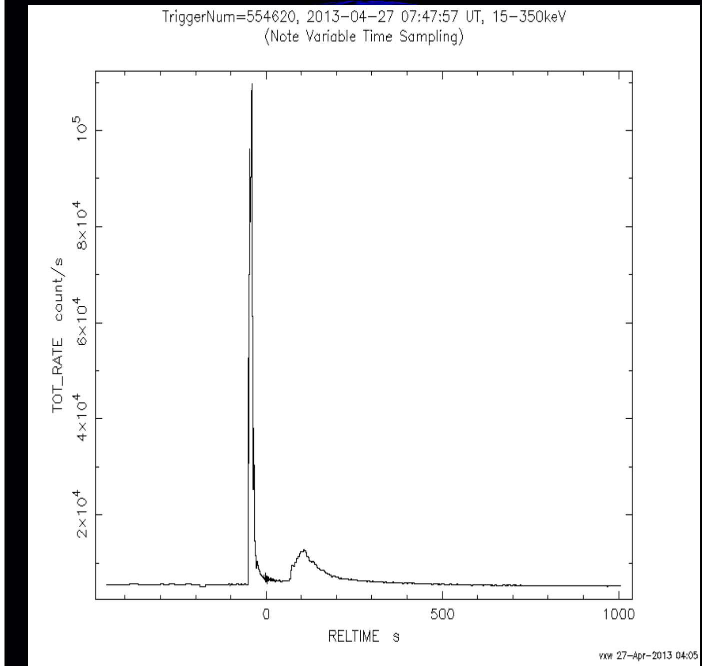


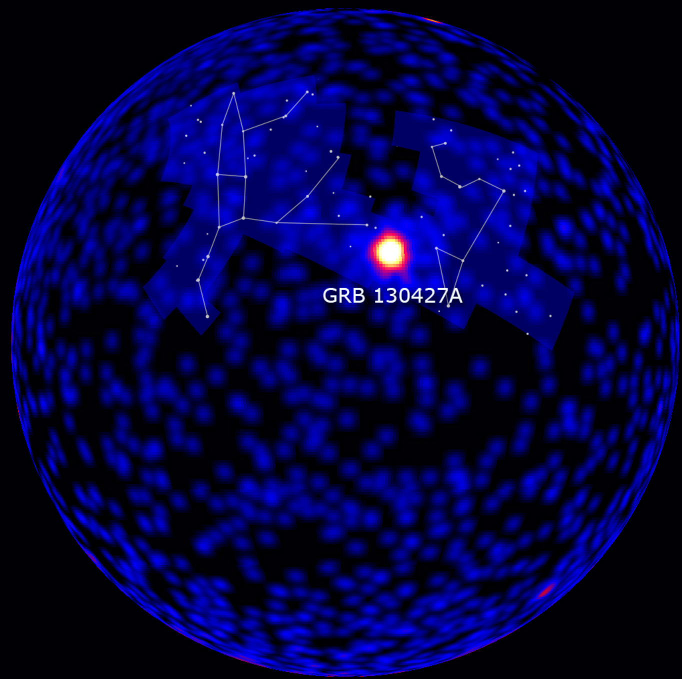
Publications per year normalised by awarded hrs

- LRS/NICS
- HARPS/GIANO

What is a Gamma-Ray Burst?

Brief, sudden, intense flash of gamma-ray radiation





Duration: from few ms to hundreds of s

Frequency: 10 keV – 1 MeV

Fluence: 10^{-7} - 10^{-3} erg cm^{-2}

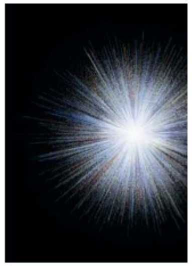
Flux: 10^{-8} - 10^{-4} erg cm^{-2} s^{-1}

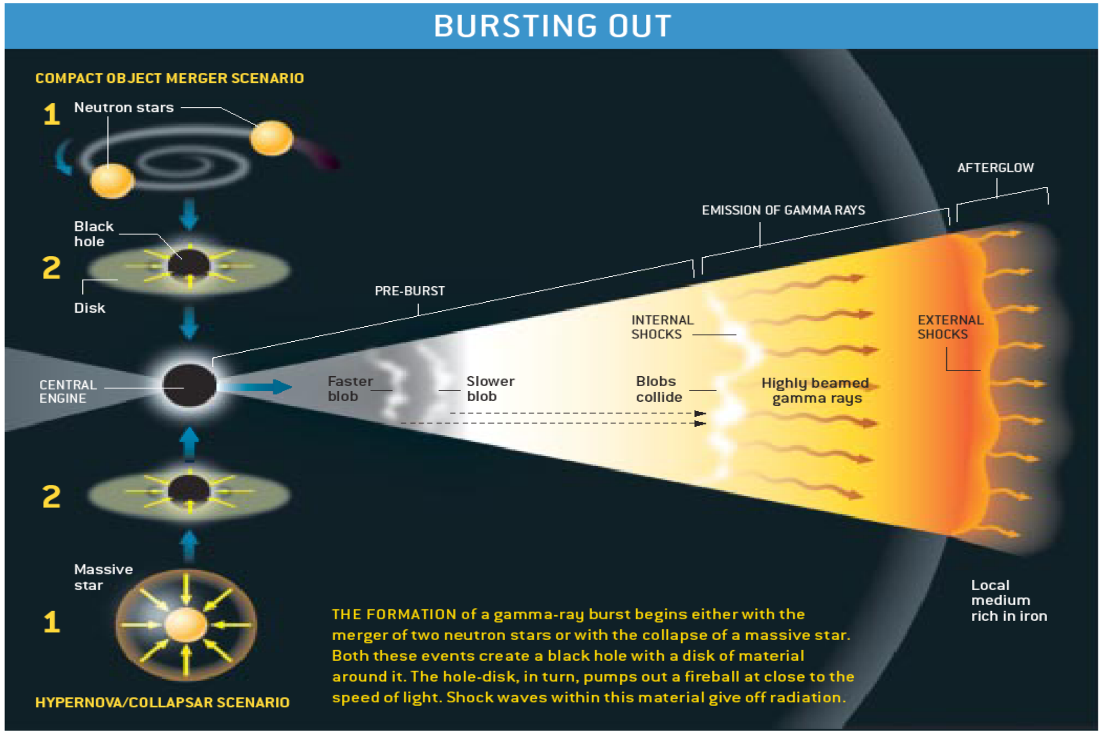
Distance: $\langle z \rangle = 2.1 \sim 10^{28}$ cm

Energy: $\sim 10^{53}$ erg

the energy emitted by the MW in 10 yrs

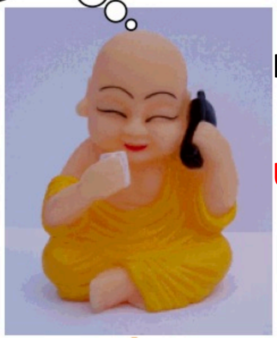
How to catch a GRB

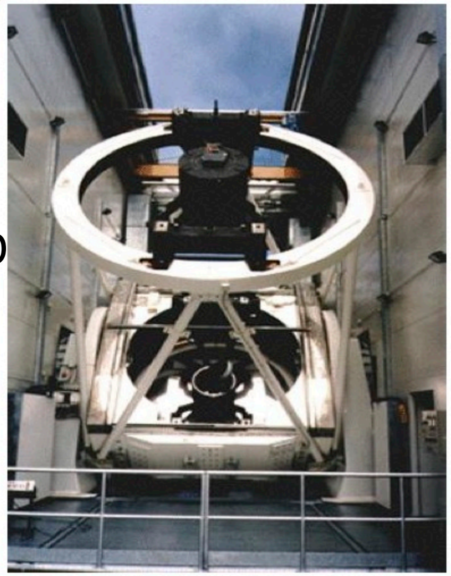


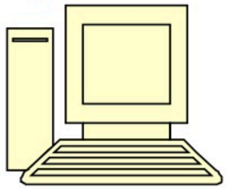


normal ToO

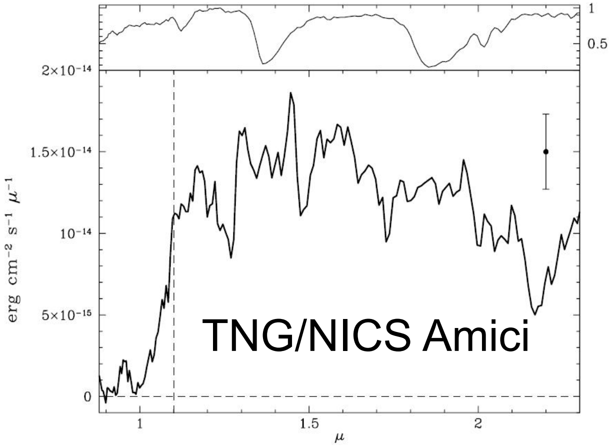
urgent ToO







GRBs as cosmic probes



GRB 090423

z = 8.1

LumDist = 84.7 Gpc,

AgeUniv = 0.6329 Gyr

nature Vol 461|29 October 2009|doi:10.1038/nature08445

LETTERS

Salvaterra et al., 2009, Nature

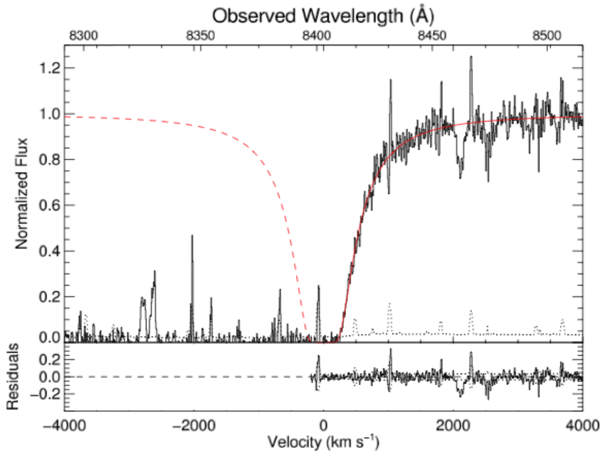
GRB 090423 at a redshift of $z \approx 8.1$

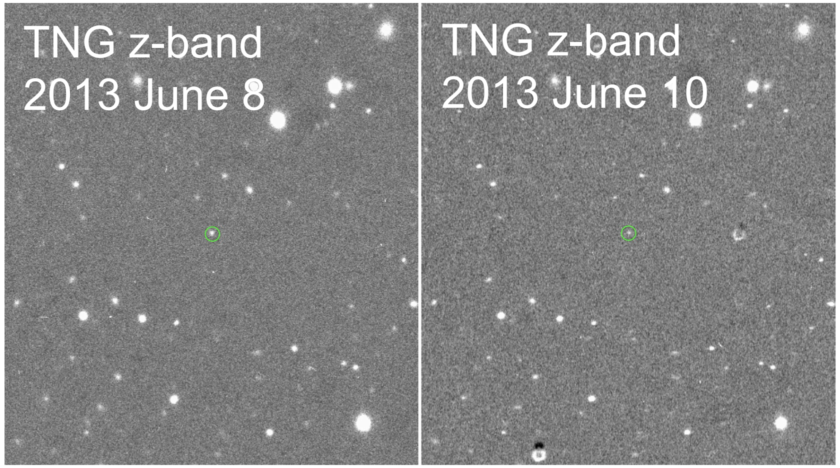
R. Salvaterra[1], M. Della Valle[2,3,4], S. Campana[1], G. Chincarini[1,5], S. Covino[1], P. D'Avanzo[1,5], A. Fernández-Soto[6], C. Guidorzi[7], F. Mannucci[8], R. Margutti[1,5], C. C. Thöne[1], L. A. Antonelli[9], S. D. Barthelmy[10], M. De Pasquale[11], V. D'Elia[9], F. Fiore[9], D. Fugazza[1], L. K. Hunt[8], E. Maiorano[12], S. Marinoni[13,14], F. E. Marshall[10], E. Molinari[1,13], J. Nousek[15], E. Pian[16,17], J. L. Racusin[15], L. Stella[9], L. Amati[12], G. Andreuzzi[13], G. Cusumano[18], E. E. Fenimore[19], P. Ferrero[20], P. Giommi[21], D. Guetta[9], S. T. Holland[10,22,23], K. Hurley[24], G. L. Israel[9], J. Mao[1], C. B. Markwardt[10,23,25], N. Masetti[12], C. Pagani[15], E. Palazzi[12], D. M. Palmer[18], S. Piranomonte[9], G. Tagliaferri[1] & V. Testa[9]

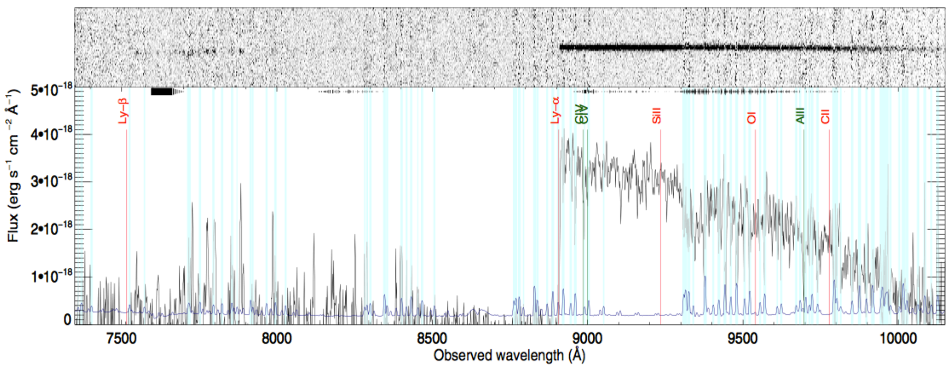
GRB 130606A

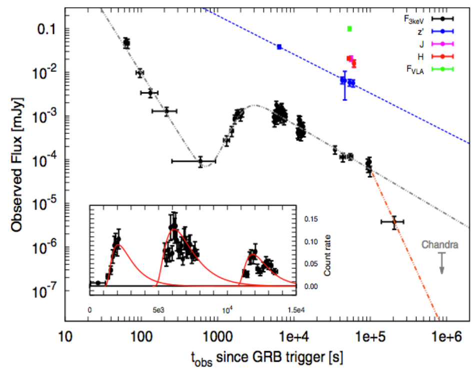
z = 5.91

Hartoog et al. 2015







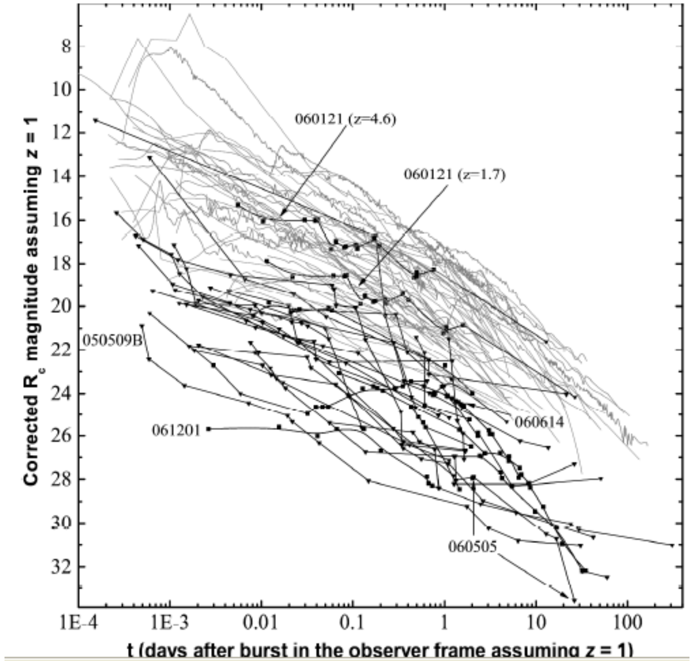


GRB 140515A

z = 6.33

Melandri et al. 2015

Short GRBs

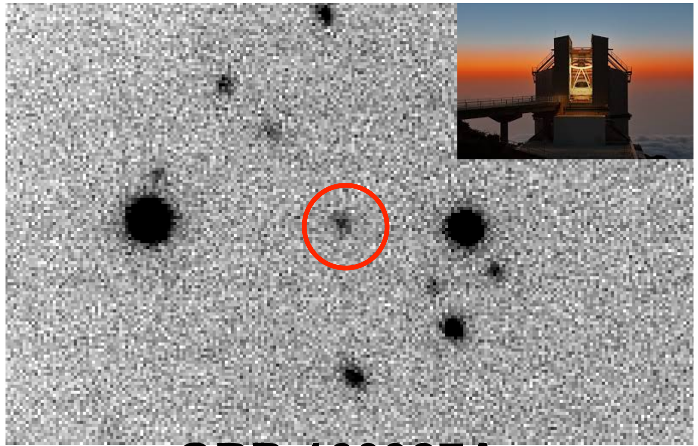


Short GRBs afterglows are fainter wrt long GRBs:

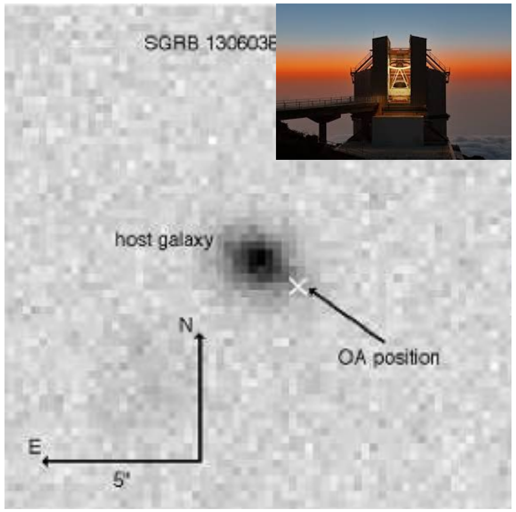
- less dense environment?

- less energetic?

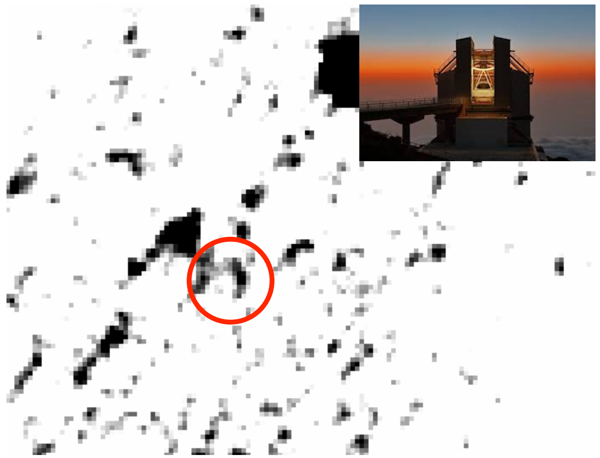
Need to pinpoint them, study the host galaxy, measure z



GRB 160927A
AG detection (r ~ 22.6 mag)
T-T0 = 2.1 h

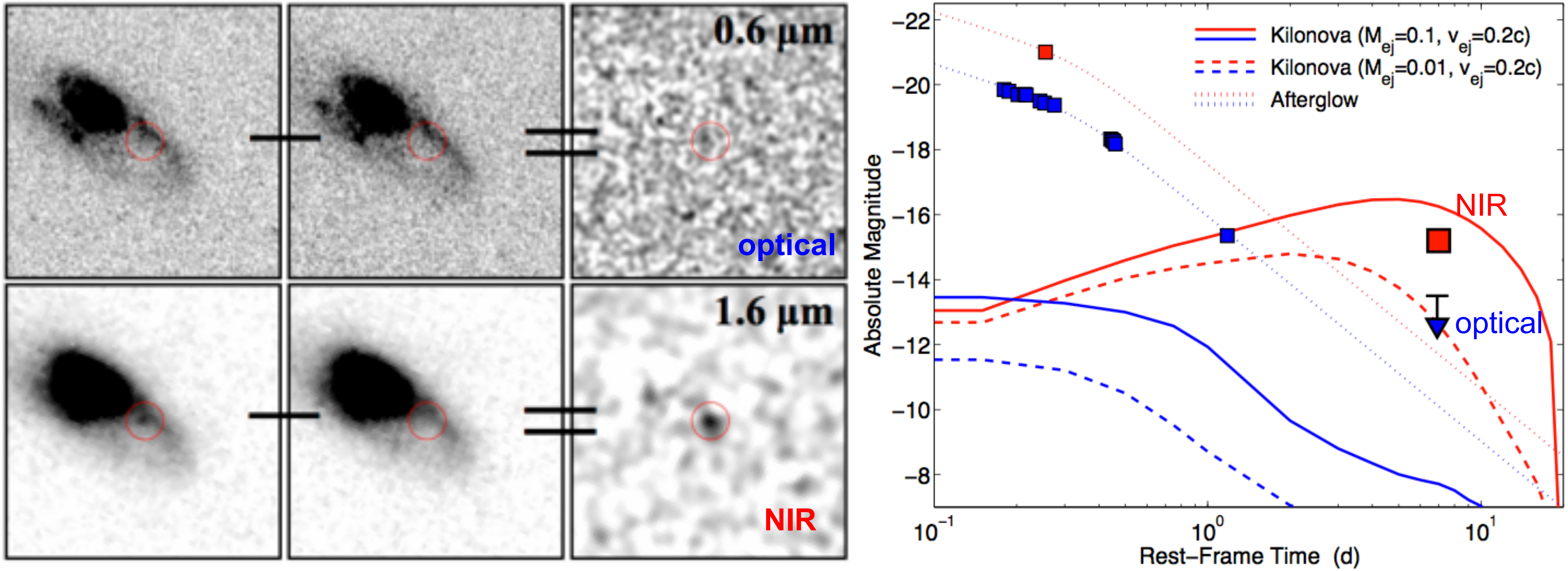


GRB 130603B
HG detection (R = 25 mag; K =)



GRB 151229A
HG detection (r ~ 25 mag)

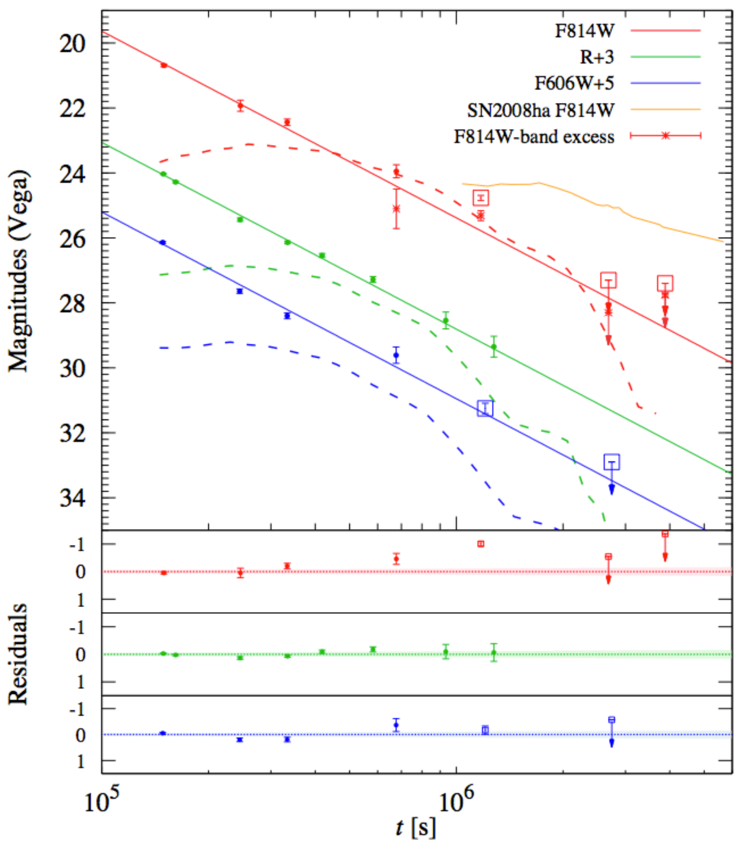
A Kilonova associated to GRB 130603B?



Tanvir et al. 2013; Berger et al. 2013
(but see also Jin et al. 2014)

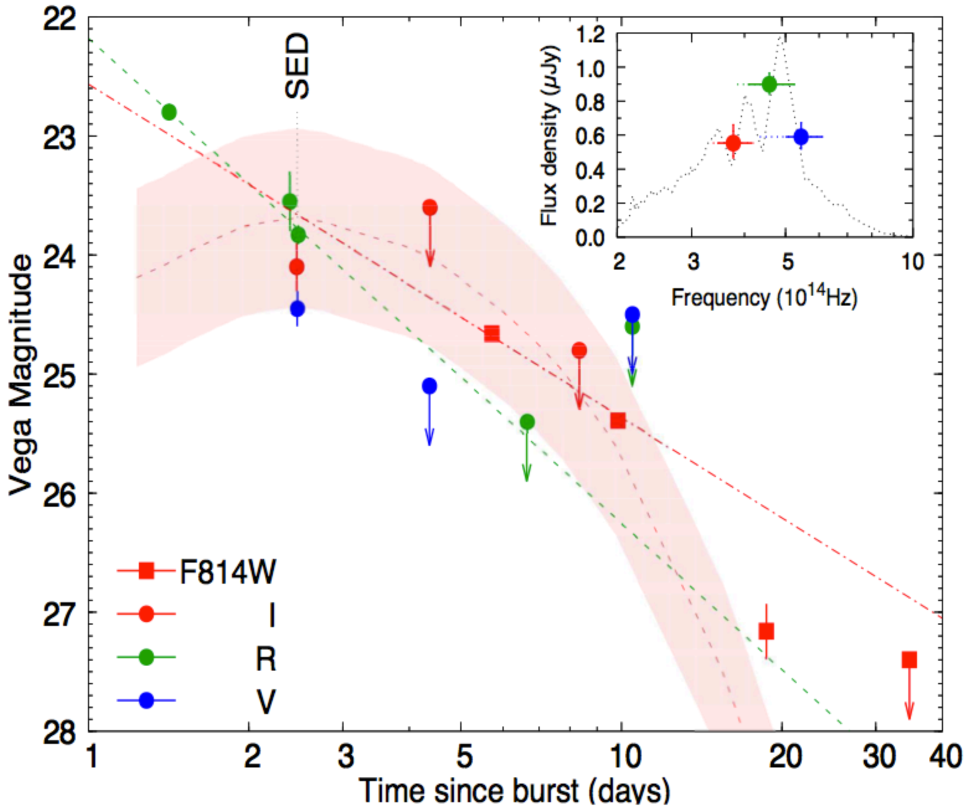
A Kilonova associated to GRB 060614 & GRB 050709?

GRB 060614



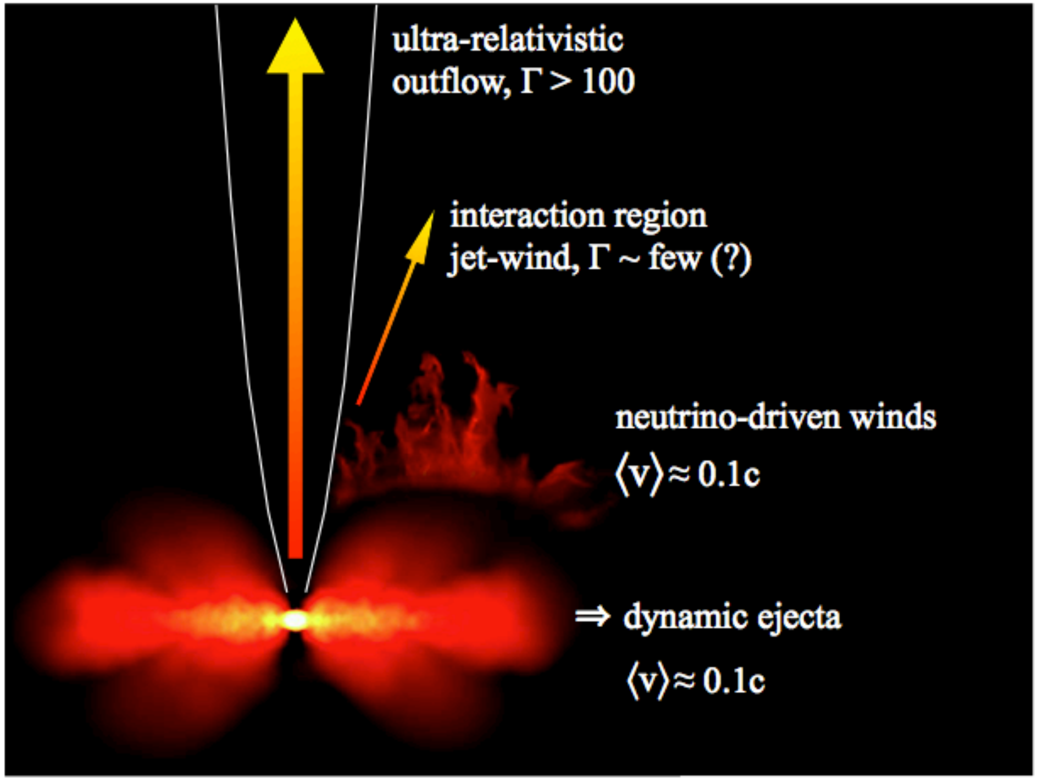
Yang et al. 2015

GRB 050709

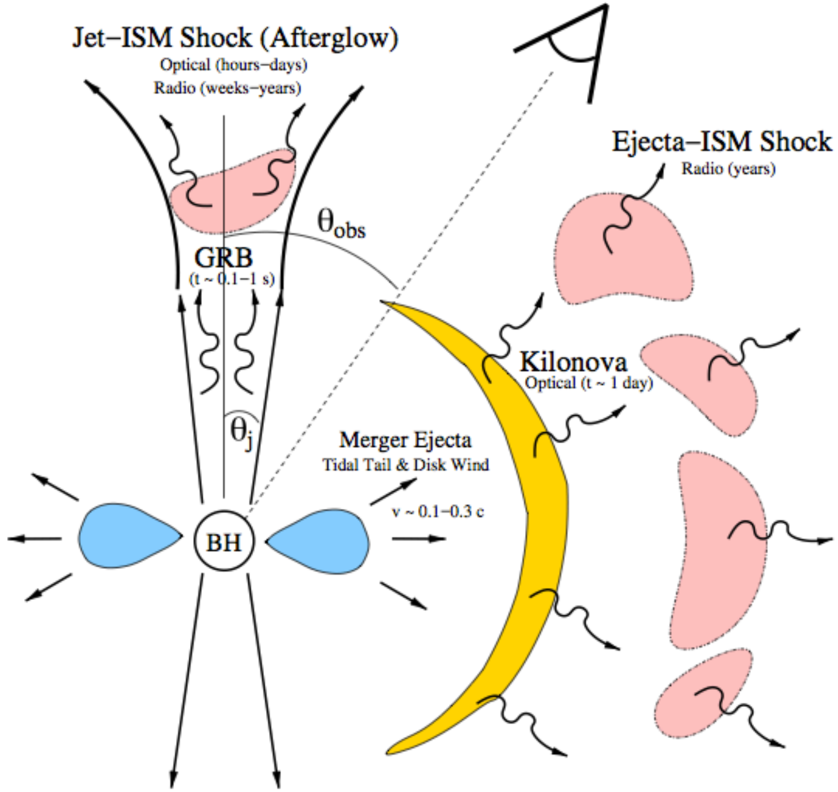


Jin et al., submitted, arXiv: 1603.07869

Jets in SGRBs



Rosswog 2012



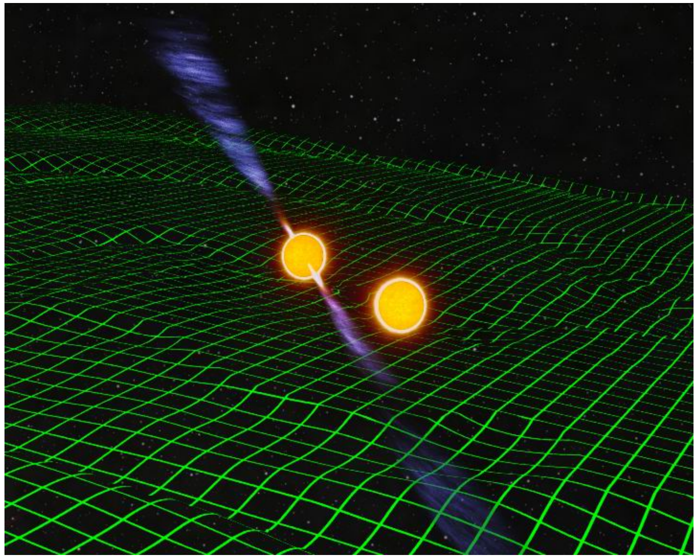
Metzger & Berger 2012

The progenitors of short GRBs

Most popular model:

Coalescence (merging) of a compact object binary system (NS-NS ; NS-BH)

While orbiting, the two objects emit gravitational waves losing energy: MERGING



- critical parameter: **merging time t_m**

Time between the formation of the system and its coalescence

$t_m \propto a^4$ (*a:* system separation) **->** **~10 Myr < t_m < ~10 Gyr**

- merging can occur in old and young stellar populations

"primordial binaries"

- **kick velocities**:

Compact objects are the remnants of core-collapse SNe, that can give a "kick"

The system can escape from the HG-> OFFSET! (**1÷100 kpc**)/low density CBM

(Belczynski & Kalogera 2001; Perna & Belczynski 2002; Belczynski et al. 2006)

Short GRB rate

Current estimates of local SGRB rates range from 0.1–0.6 Gpc^{-3} yr^{-1} (e.g. Guetta & Piran 2005; 2006) to 1–10 Gpc^{-3} yr^{-1} (Guetta & Piran 2006; Guetta & Stella 2009; Coward et al. 2012; Siellez et al. 2014, Wanderman & Piran 2015) to even larger values like 40-240 Gpc^{-3} yr^{-1} (Nakar et al. 2006; Guetta & Piran 2006).

Rates depend on the short GRB luminosity function $\phi(L)$ and redshift distribution $\psi(z)$.

Peak flux distribution

$$\frac{dN}{dt}(P_1 < P < P_2) = \int_0^{\infty} dz \frac{dV(z)}{dz} \frac{\Delta\Omega_s}{4\pi} \frac{\Psi_{\rm SGRB}(z)}{1+z} \times \int_{L(P_1,z)}^{L(P_2,z)} dL\phi(L),$$

$$\phi(L) \propto \begin{cases} (L/L_{\rm b})^{-\alpha_1} & L < L_{\rm b} \\ (L/L_{\rm b})^{-\alpha_2} & L \geq L_{\rm b} \end{cases}$$

SGRB redshift distribution is a delayed star formation rate

$$\Psi(z) \propto \int_z^{\infty} \Psi(z') P[t(z) - t(z')] \frac{dt}{dz'} dz'$$

$$P(\tau) \propto \tau^{n}$$

delay time (interval between binary formation and merging) distribution function

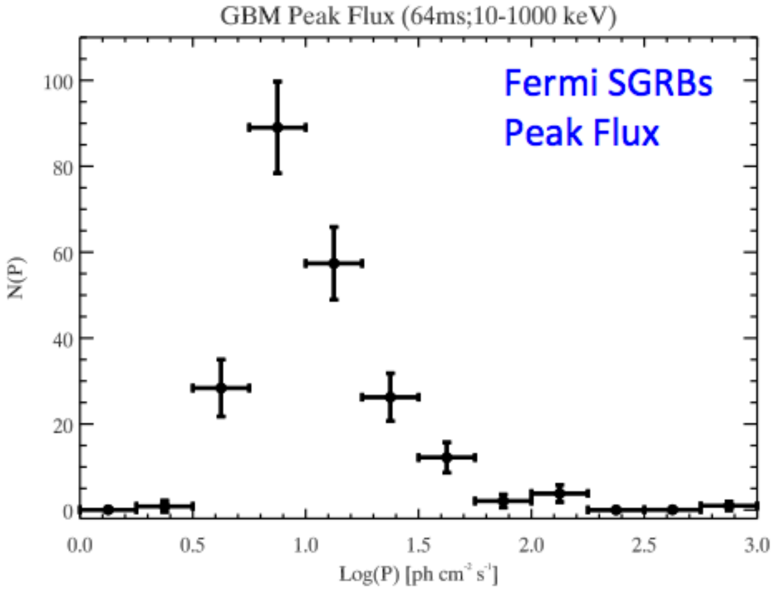
The parameters of such functions are usually constrained through:

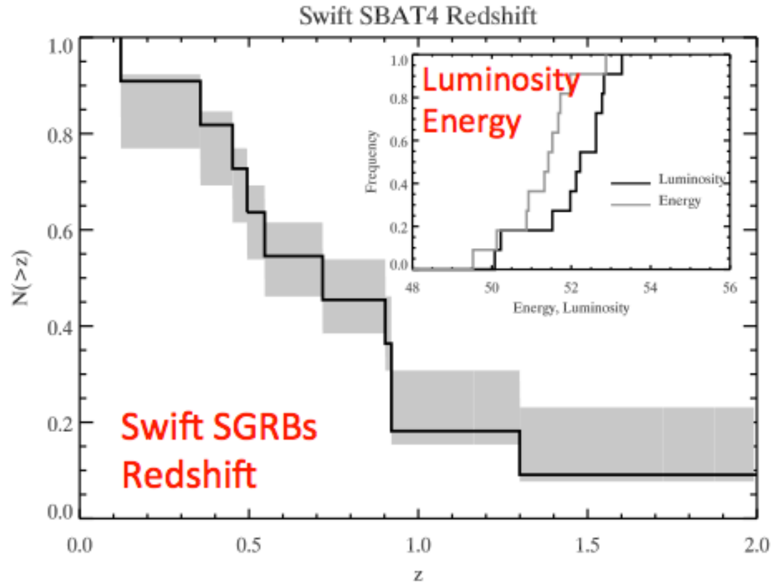
(1) by fitting the peak flux distribution of SGRBs detected by past and/or present GRB detectors (e.g BATSE, GBM)
(2) the observed SGRB redshift distribution

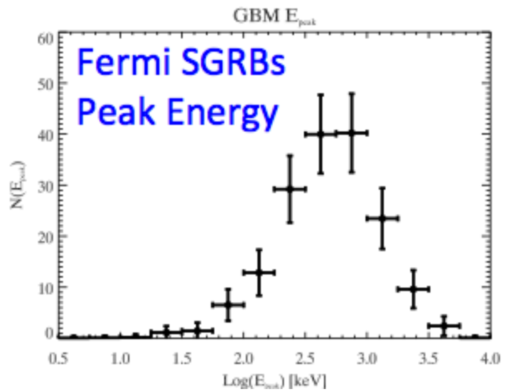
Short GRB rate: deriving luminosity function and redshift distribution

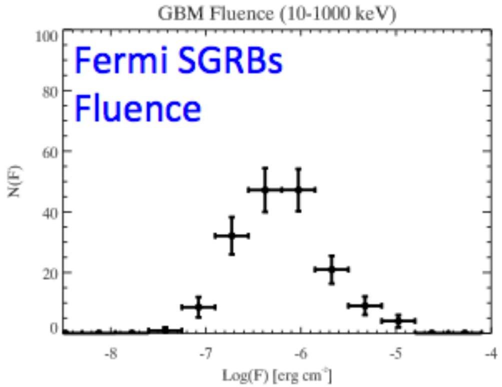
We derive the short GRB luminosity function and redshift distribution using:

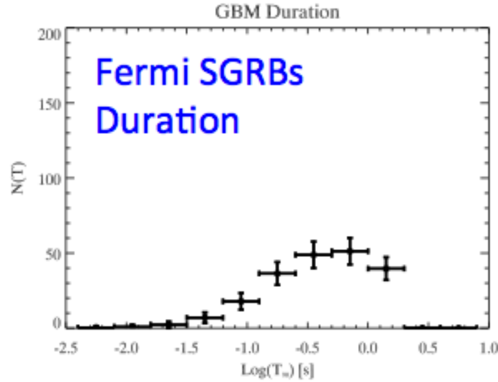
1) all the available observer-frame constraints of the large population of bursts detected by the *Fermi*/GBM
2) the rest–frame properties of the *Swift* SBAT4 complete sample







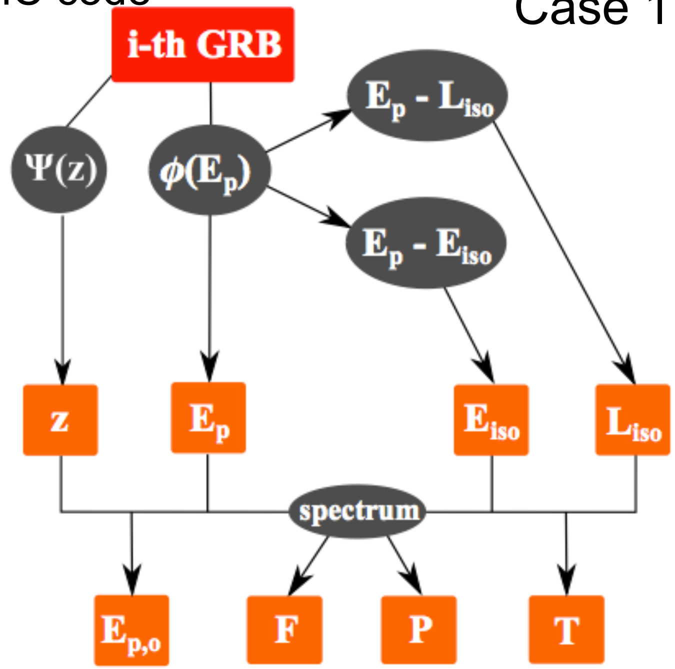




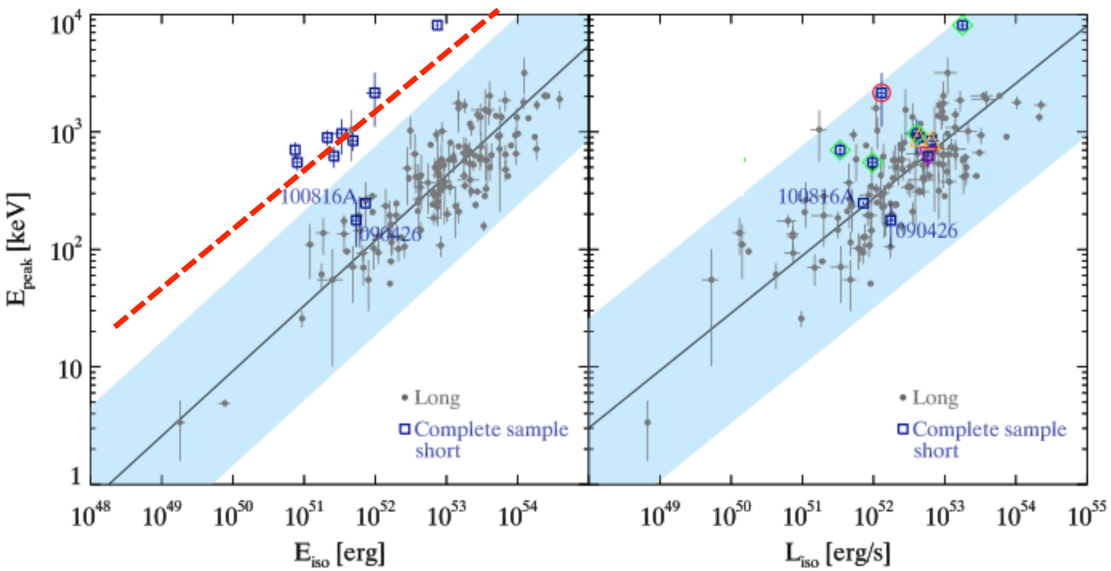
Short GRB rate: deriving luminosity function and redshift distribution

MC code

Case 1



“Amati relation” “Yonetoku relation”



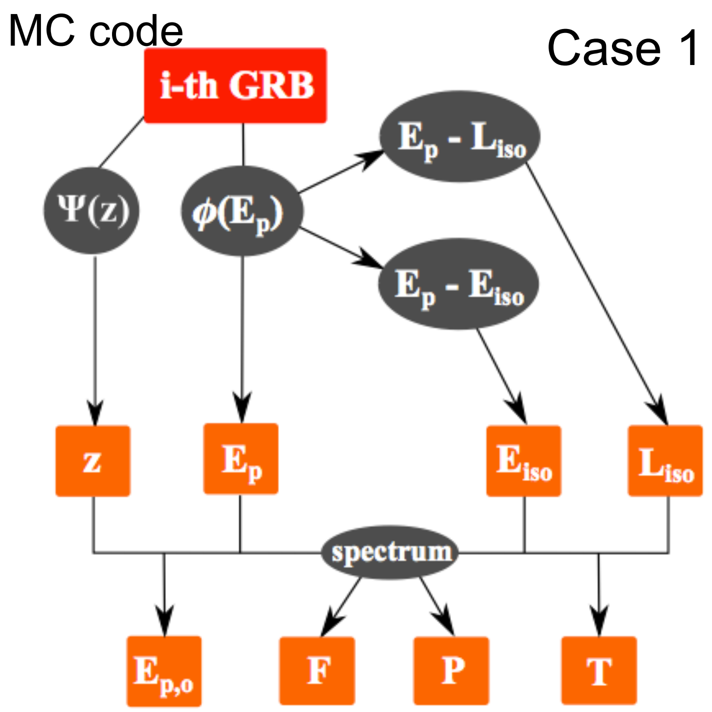
Amati et al. 2002; Younetoku et al. 2004

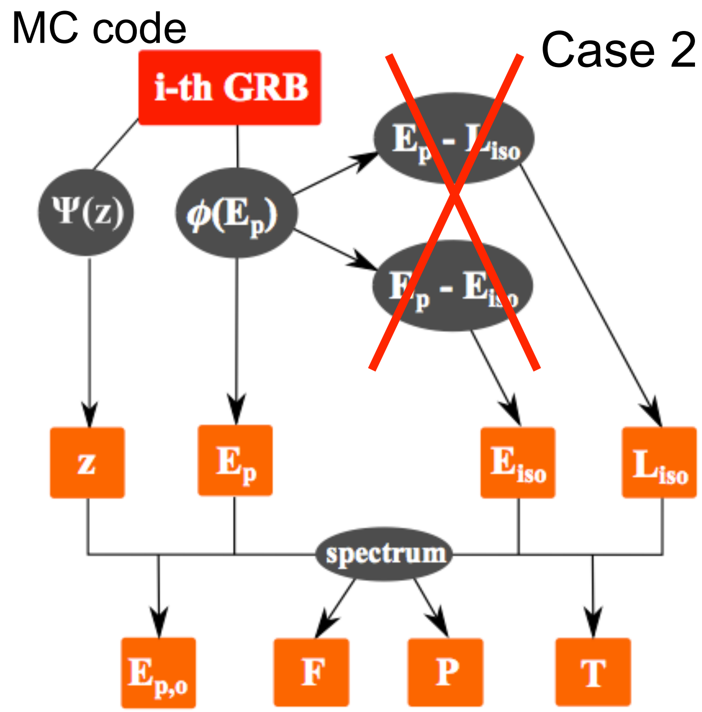
$$\Psi(z) = \frac{1 + p_1 z}{1 + \left(z/z_p\right)^{p_2}}$$

$$\phi(E_p) \propto \begin{cases} \left(E_p/E_{p,b}\right)^{-a_1} & E_p \le E_{p,b} \\ \left(E_p/E_{p,b}\right)^{-a_2} & E_p > E_{p,b} \end{cases}$$

T ~ 2(1+z)E/L

Short GRB rate: deriving luminosity function and redshift distribution





$$\Psi(z) = \frac{1 + p_1 z}{1 + \left(z/z_{\rm p}\right)^{p_2}}$$

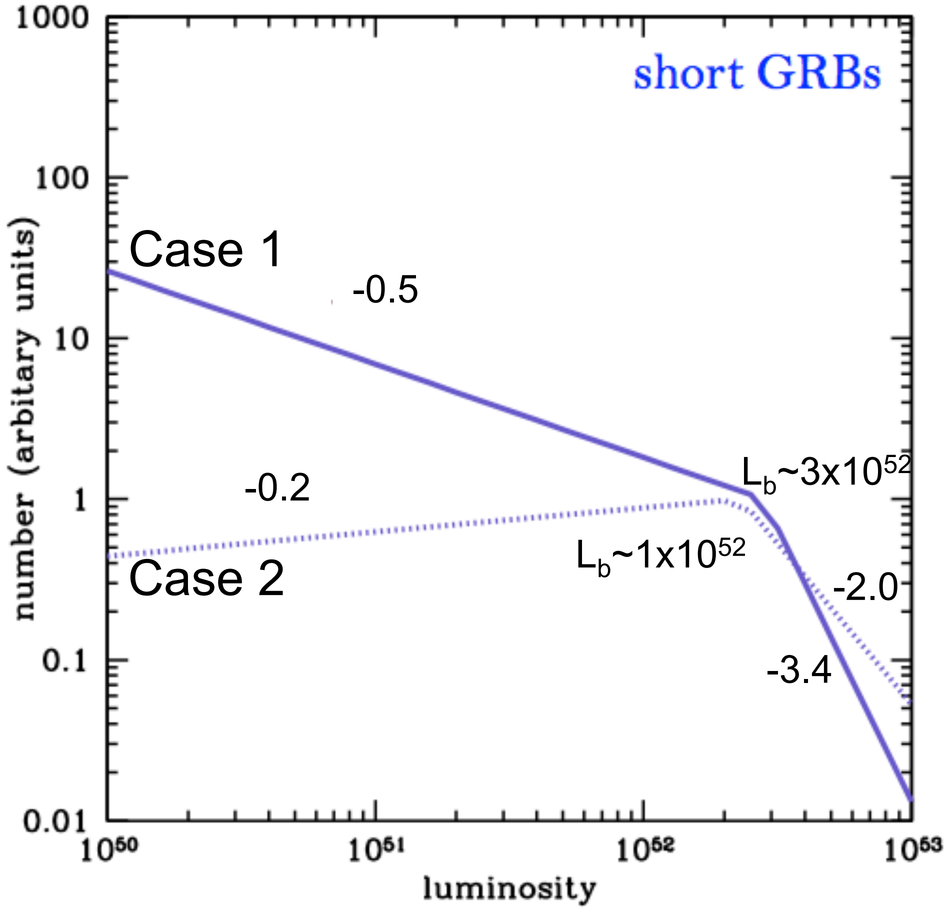
$$\phi(E_{\rm p}) \propto \begin{cases} \left(E_p/E_{\rm p,b}\right)^{-a_1} & E_p \le E_{\rm p,b} \\ \left(E_p/E_{\rm p,b}\right)^{-a_2} & E_p > E_{\rm p,b} \end{cases}$$

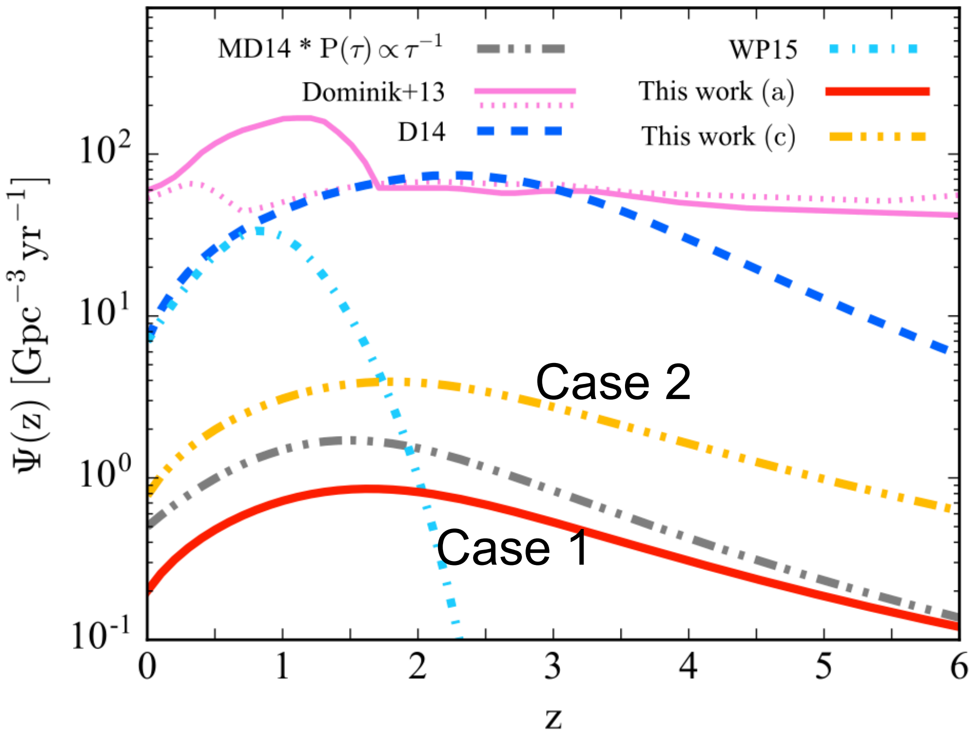
$T \sim 2(1+z)E/L$

$$P(L) \propto \begin{cases} (L/L_{\rm b})^{-\alpha_1} & L \le L_{\rm b} \\ (L/L_{\rm b})^{-\alpha_2} & L > L_{\rm b} \end{cases}$$

Lognormal distribution of durations

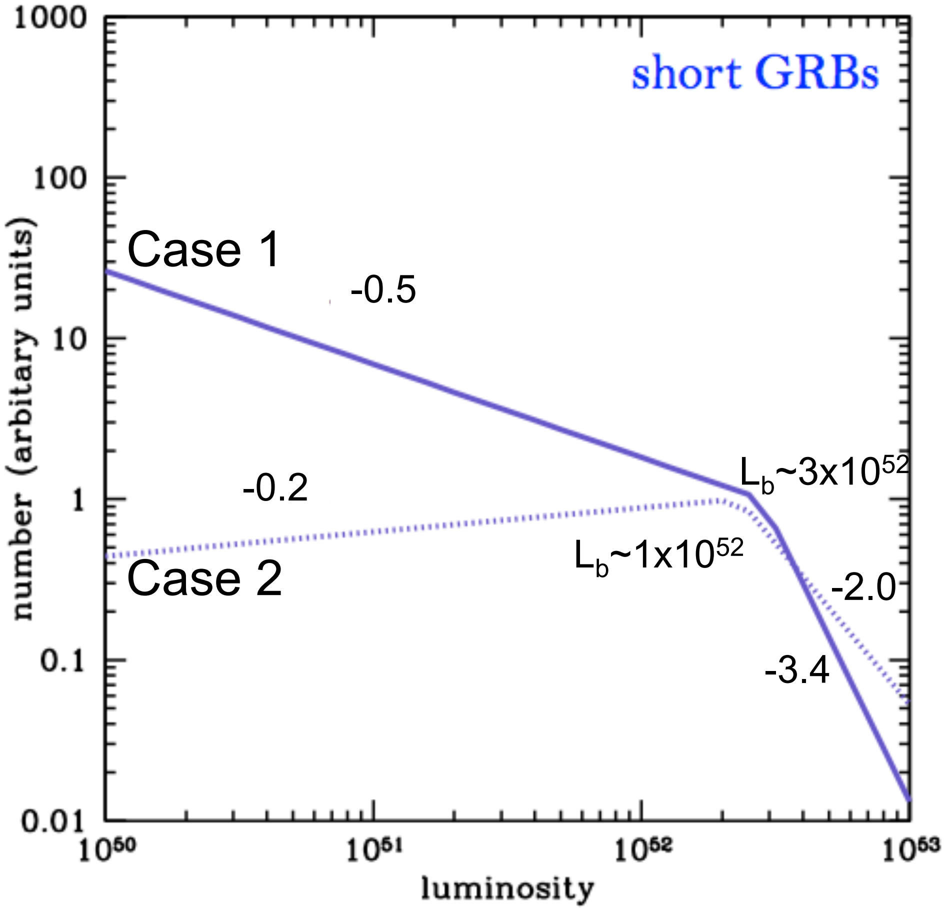
Short GRB luminosity function and redshift distribution

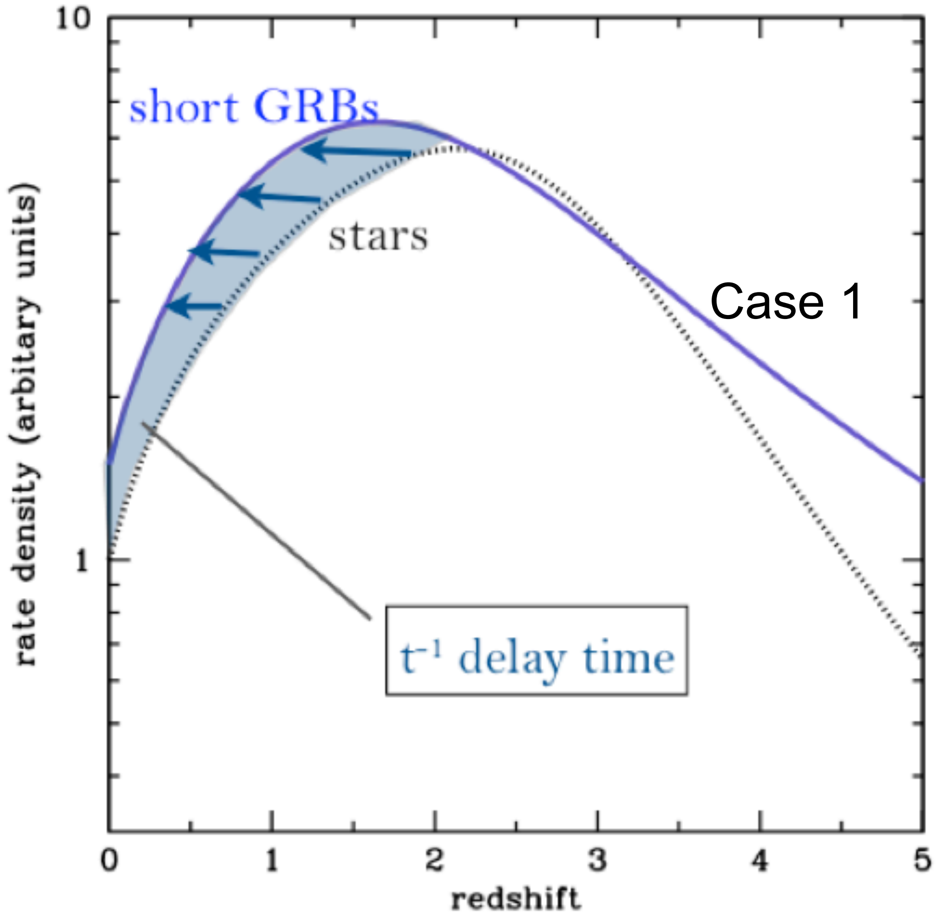




$$\phi(L) \propto \begin{cases} (L/L_b)^{-\alpha_1} & L < L_b \\ (L/L_b)^{-\alpha_2} & L \geq L_b \end{cases}$$

Short GRB luminosity function and redshift distribution





$$\phi(L) \propto \begin{cases} (L/L_b)^{-\alpha_1} & L < L_b \\ (L/L_b)^{-\alpha_2} & L \geq L_b \end{cases}$$

$$P(\tau) \propto \tau^{-1}$$

small delays favored; primordial binaries

Short GRB true rate