GRBs @ SOXS

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on behalf of SWG 11
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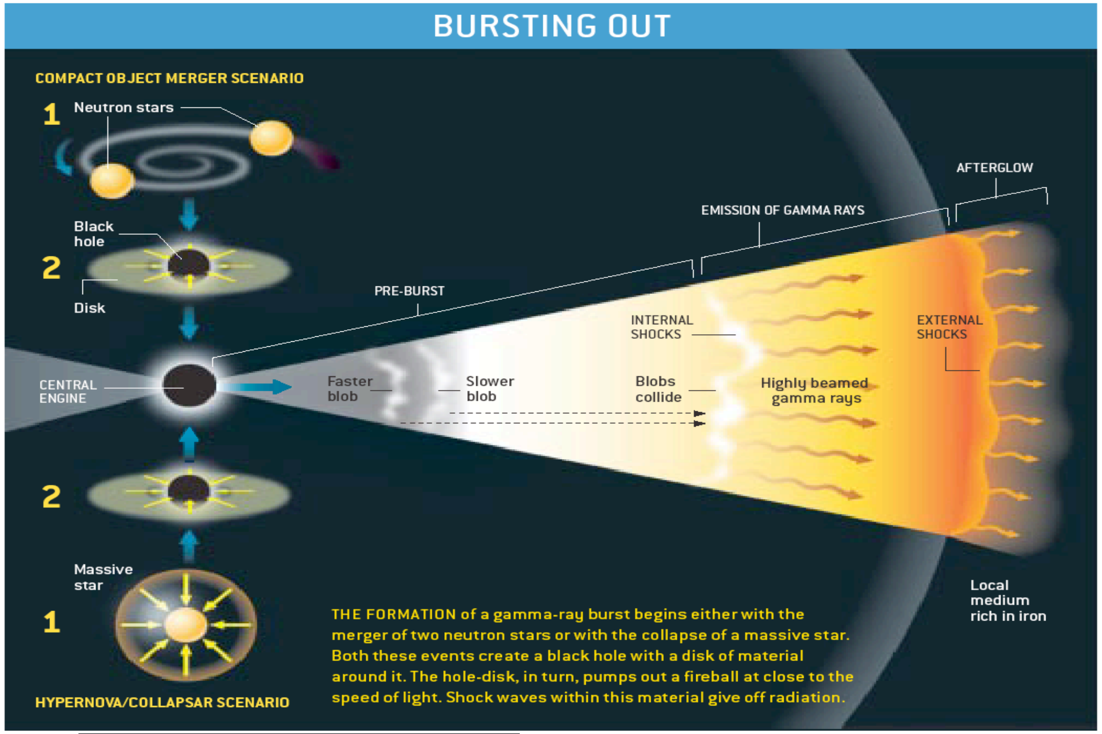
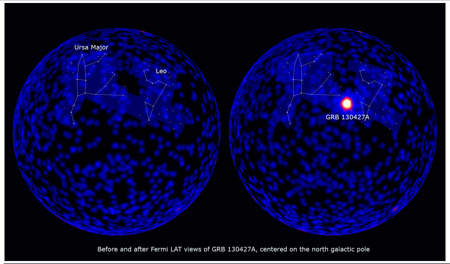
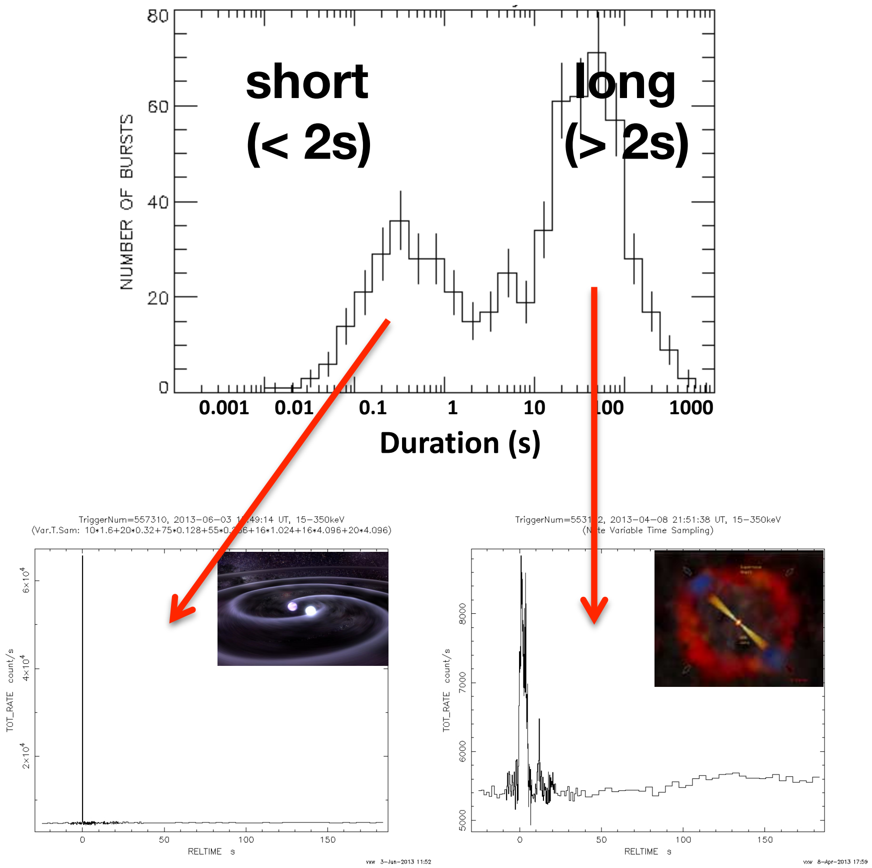


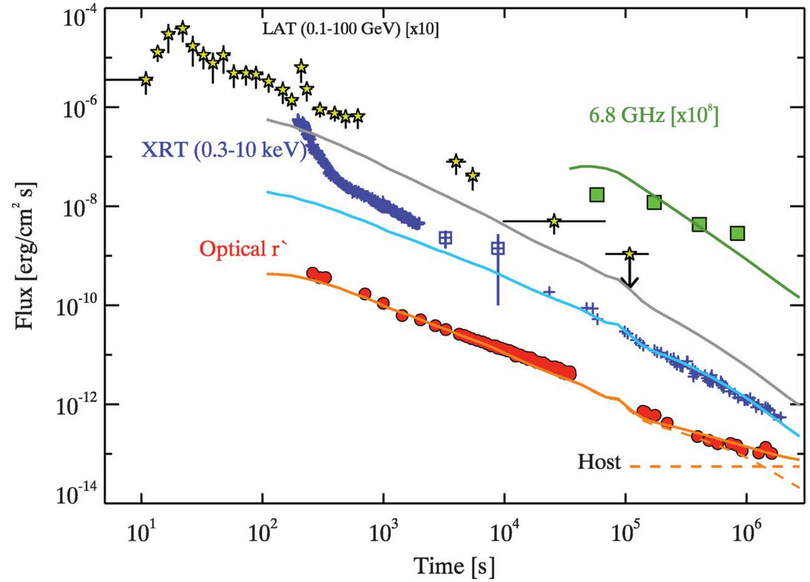


GRB: a brief, sudden, intense flash of gamma-ray radiation

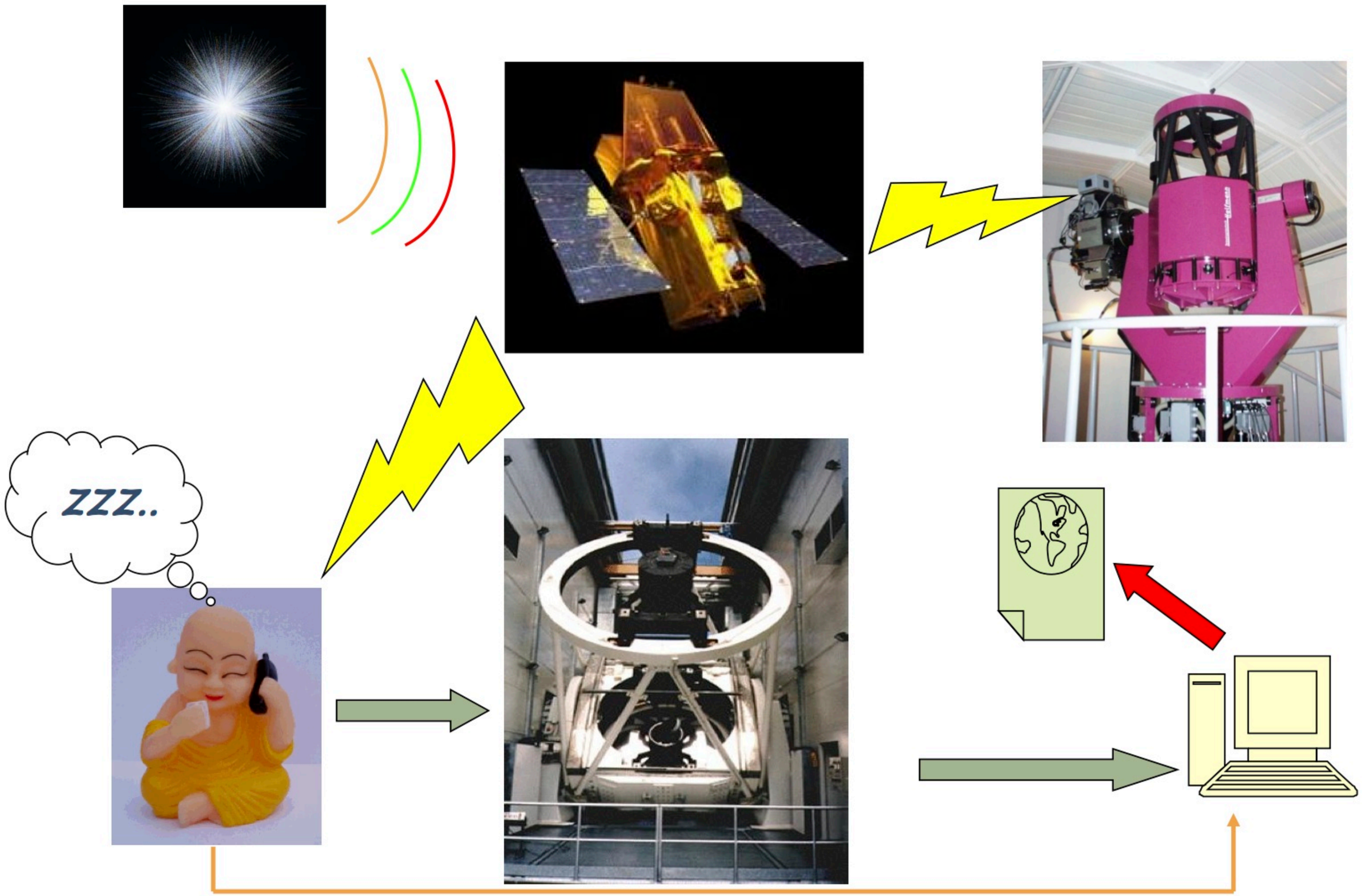


Duration: **from few ms to hundreds of s**
Frequency: **10 keV – 1 MeV**
Fluence: **10^{-7} - 10^{-3} erg cm^{-2}**
Flux: **10^{-8} - 10^{-4} erg cm^{-2} s^{-1}**
Distance: **<z>=2.1 ~ 10^{28} cm**

Energy: ~ 10^{53} erg
the energy emitted by the MW in 10 yrs



How to catch a GRB



Fast (min/hours) reaction – telescope with flexible schedule (ToO)

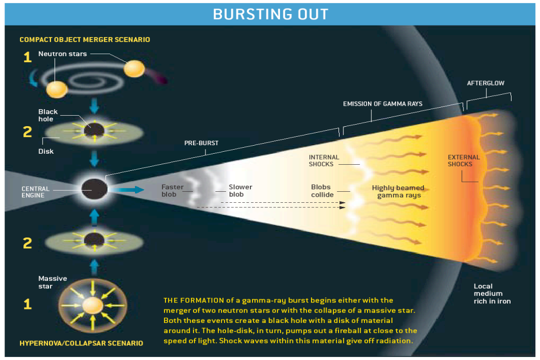
GRBs @ SOXS

By taking the t0 and RA, Dec coordinates of all the ~1400 GRBs *Swift* detected in the 2004-2020 period (16 years of operations), it results that ~730 events (52% of the total) were observable for at least one hour within 24h from the t0 from La Silla and that, among these, ~130 events (9% of the total) were promptly observable, i.e. they exploded during the La Silla nighttime.
So, keeping just *Swift* as a reference (~10% of the Swift GRBs are short), **every year** we have about:

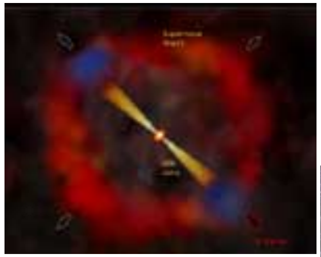
- **40 long GRBs** visible for at least one hour within 24h from the t0 from La Silla (among those: 7 events promptly visible)
- **4 short GRBs** visible for at least one hour within 24h from the t0 from La Silla (among those: 1 event promptly visible)

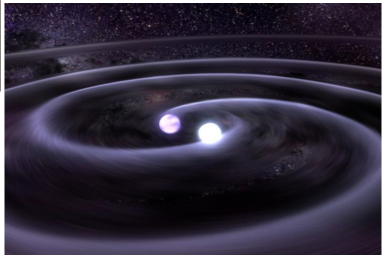
Science with GRBs

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

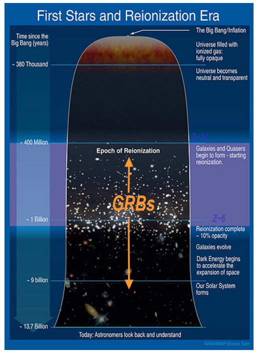


- <u>Progenitors</u>
  - Long GRBs: GRB-SN connection
  - Short GRBs: compact objects merging -> multi-messenger (GW) & KNe (heavy elements)





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

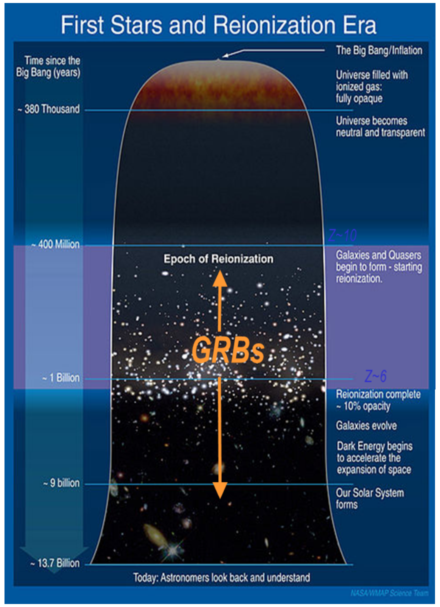


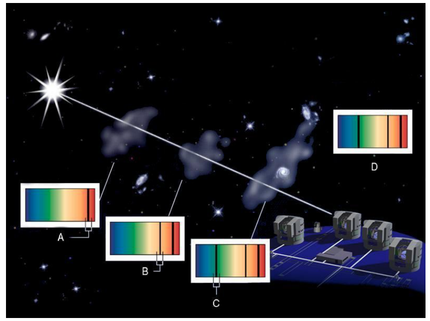
Since 2004 *Swift* observed > 1600 GRBs: legacy/statistical approach to tackle the above science cases

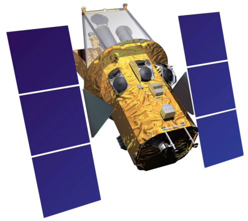
GRBs as cosmic probes

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

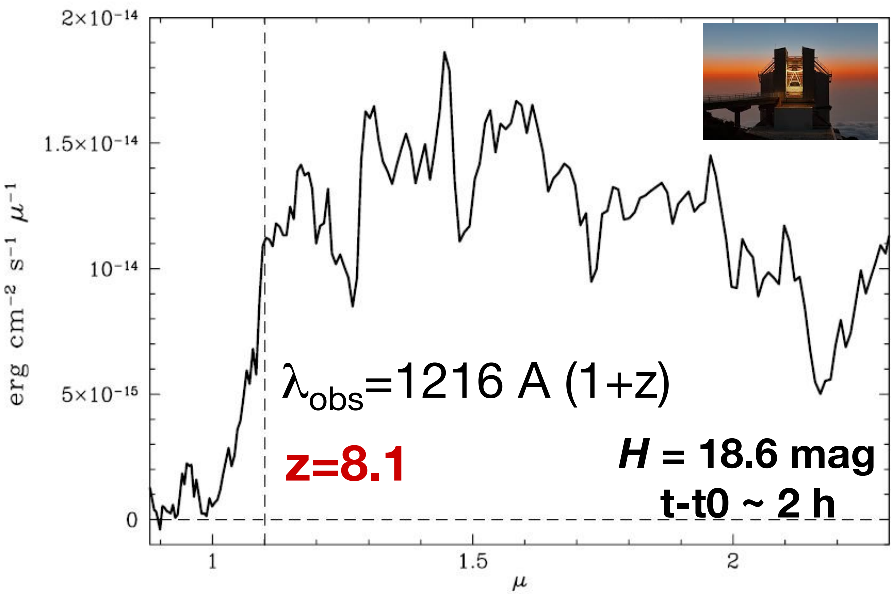


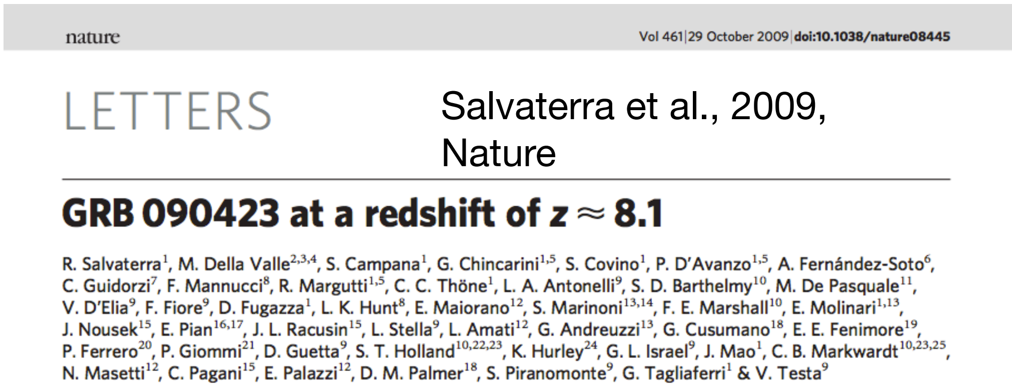




8 GRB @ z > 6

TNG Amici prism spectrum





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

LETTERS

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]

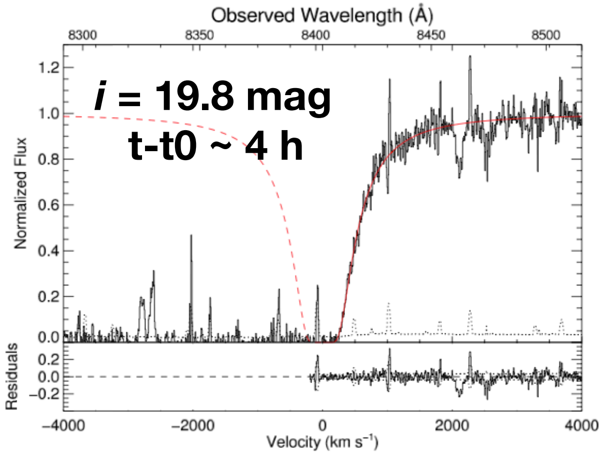
Salvaterra et al., 2009, Nature

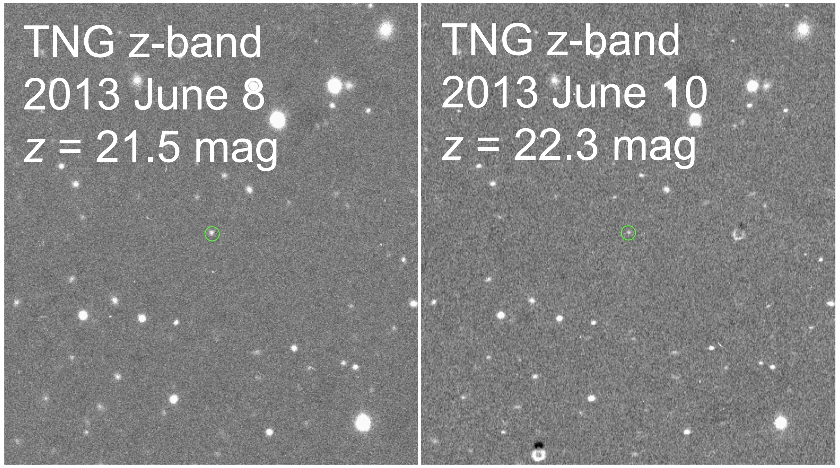
LumDist = 84.7 Gpc,
AgeUniv = 0.6329 Gyr

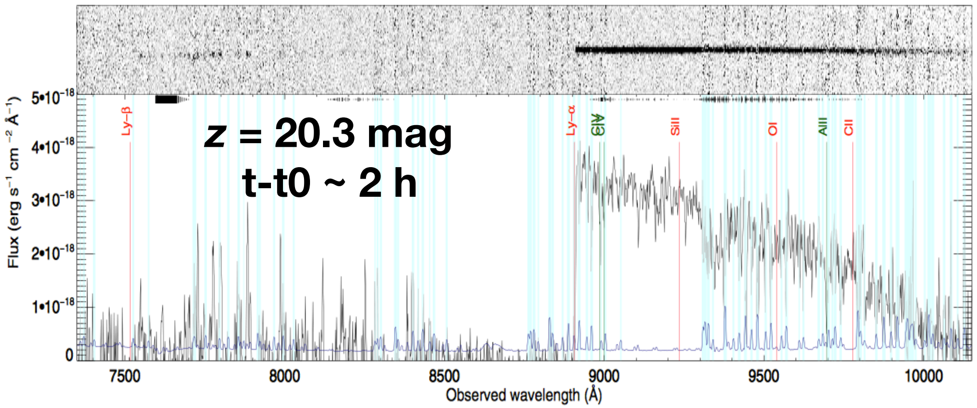
see also Tanvir et al. 2009, Nature (VLT spectrum)

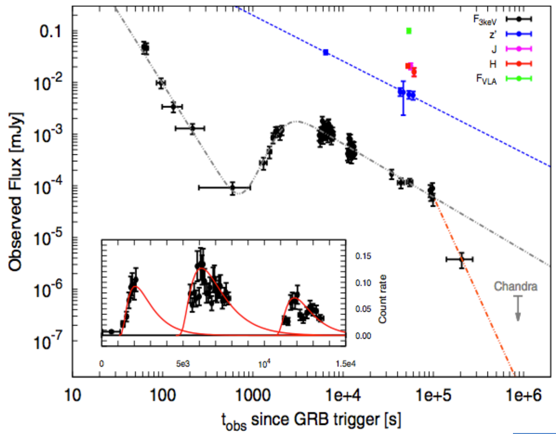
GRBs as cosmic probes

GRB 130606A
z = 5.91
Hartoog et al. 2015

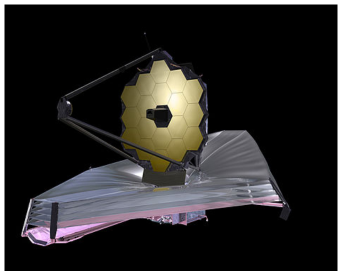




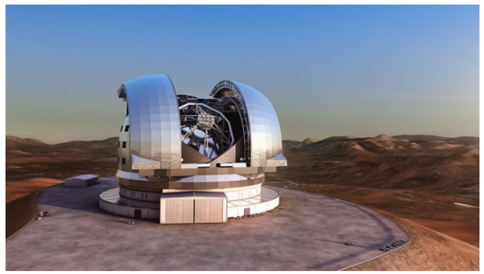




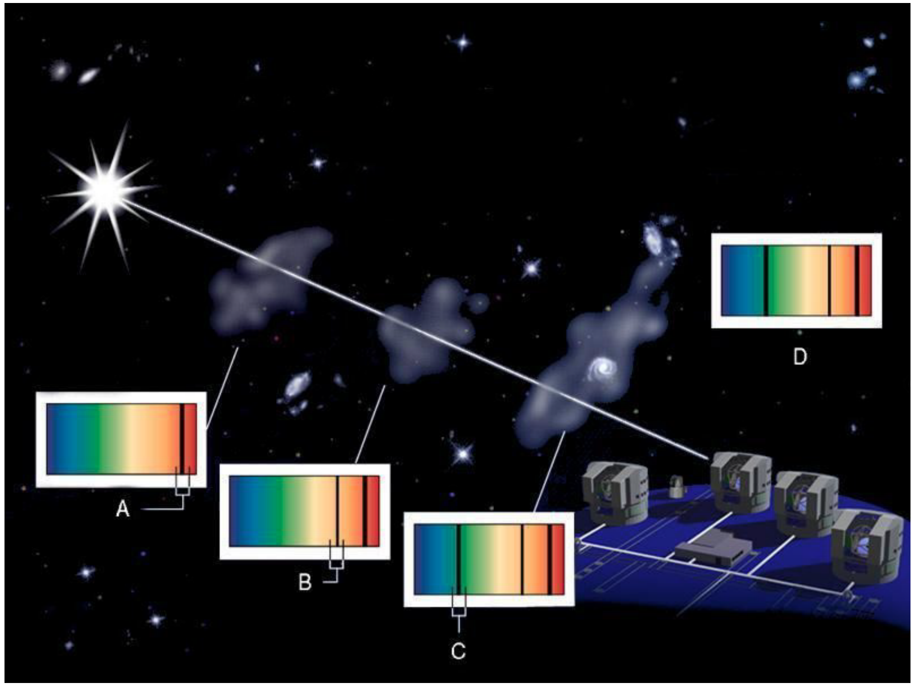
GRB 140515A
z = 6.33
Melandri et al. 2015



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



GRBs as cosmic probes



Concerning long GRBs, the Swift statistics tells us that in about 50% of the cases there is an optical/NIR detection and in 30% of the cases there is a prompt UVOT detection (bright afterglow).

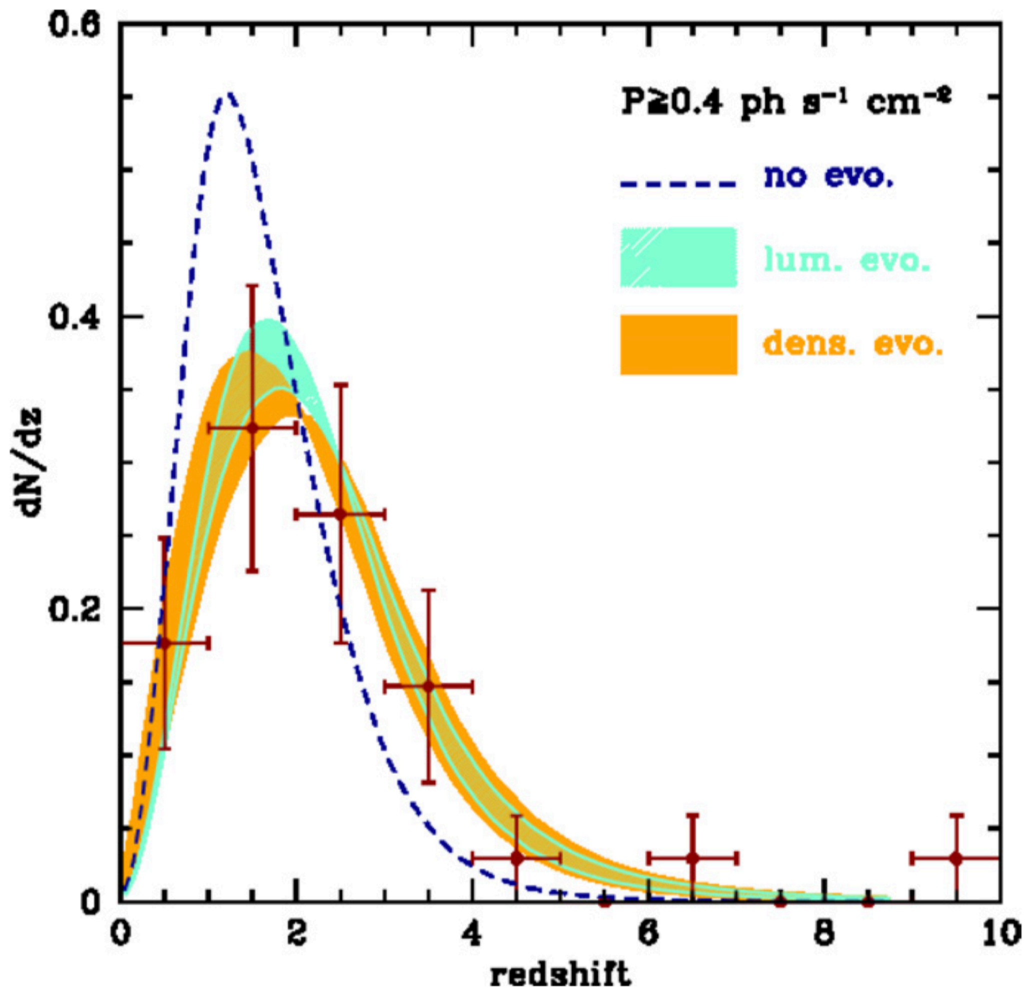
40 long GRB/year visible from La Silla. 12 (30%) with a UVOT detection (average V ~ 18 mag, according to UVOT statistics). For those 12 events, 1800s of SOXS exptime would provide a SNR ~ 20-30 spectrum. Well enough for redshift determination and the detailed study of the spectral lines. We may want to repeat the following night, to check for some variability, for the **brightest events** (~1/3 of the cases) with a longer exposure (1h). So:
[(12 UVOT detected LGRBs)x1800s] + [(0.33) x (12 UVOT detected LGRBs) x 3600s] = **10 hours/year**.

Then we have ~8 more long GRBs with a **faint** (V > 19 mag) optical/NIR detection (not detected by UVOT, so possibly high-z/dark/dusty). For those we may need an imaging shot first and then a spectrum (40 minutes). Let's assume 1 h overall.
So: (8 LGRBs) x 3600s = **8 hours/year**.

Then we have ~50% of the long GRBs **without a clear optical/NIR afterglow** (~ 20 events/year; also those possibly high-z/dark/dusty). For those we will carry out imaging to search for a counterpart (two bands: r and z/y). 0.5 hours per event. Overall **10 hours/year.**

10 + 8 + 10 = 28 hours/year

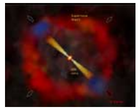
GRBs as cosmic probes (high-z)



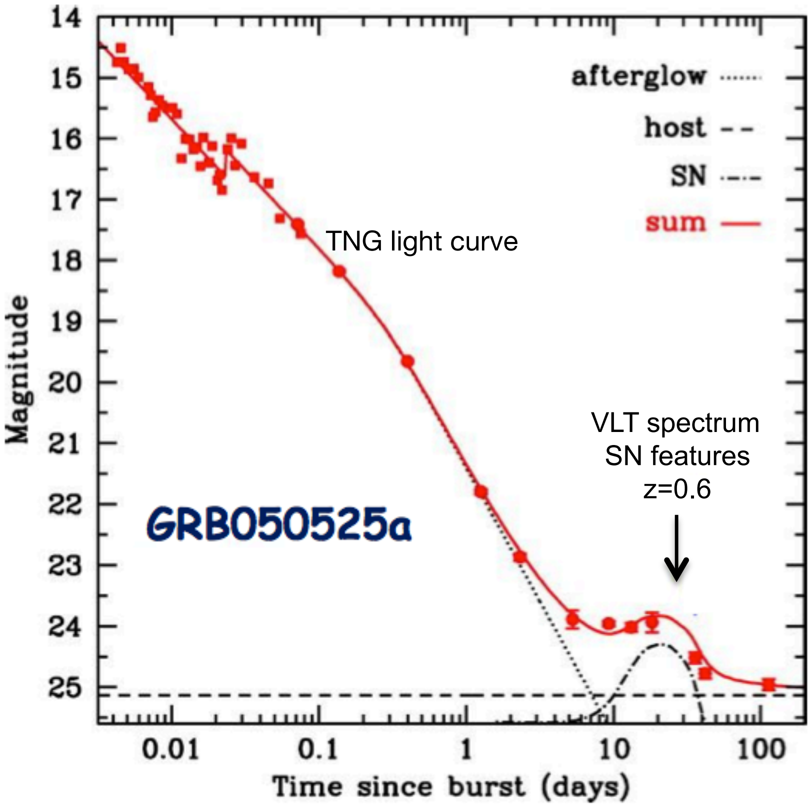
Assuming the redshift distribution of Salvaterra+2012, we expect ~5% of the *Swift* long GRBs to lie at $z > 5$ (high redshift). This means 2 events/year for us. For those, we may need imaging (rizy) + deep spectroscopy: 3 hours per event.

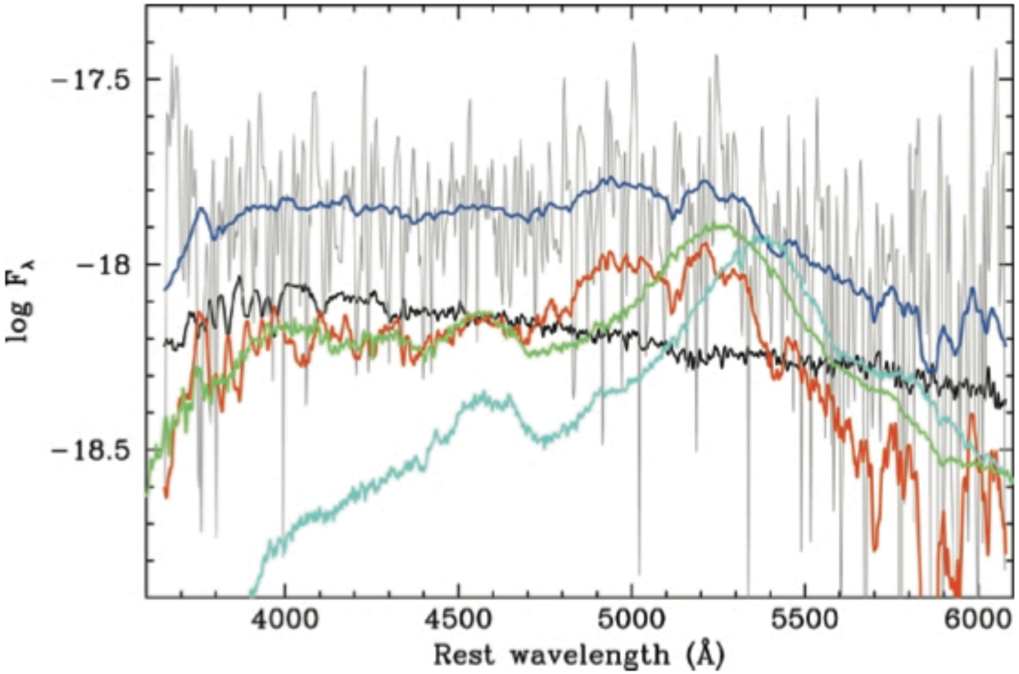
6 hours/year in total.

GRB-SNe

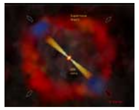


GRB 050525A/SN 2013cq
z = 0.61
Della Valle et al. 2006





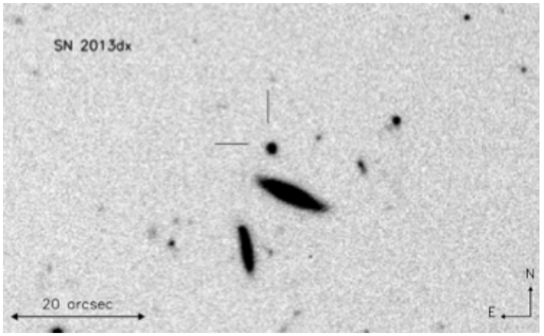
GRB-SNe

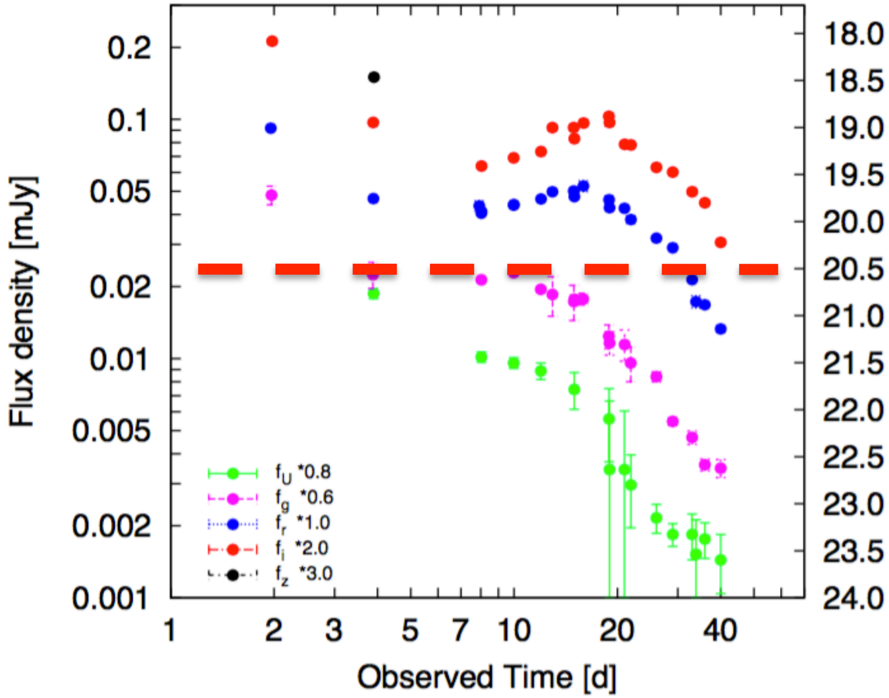


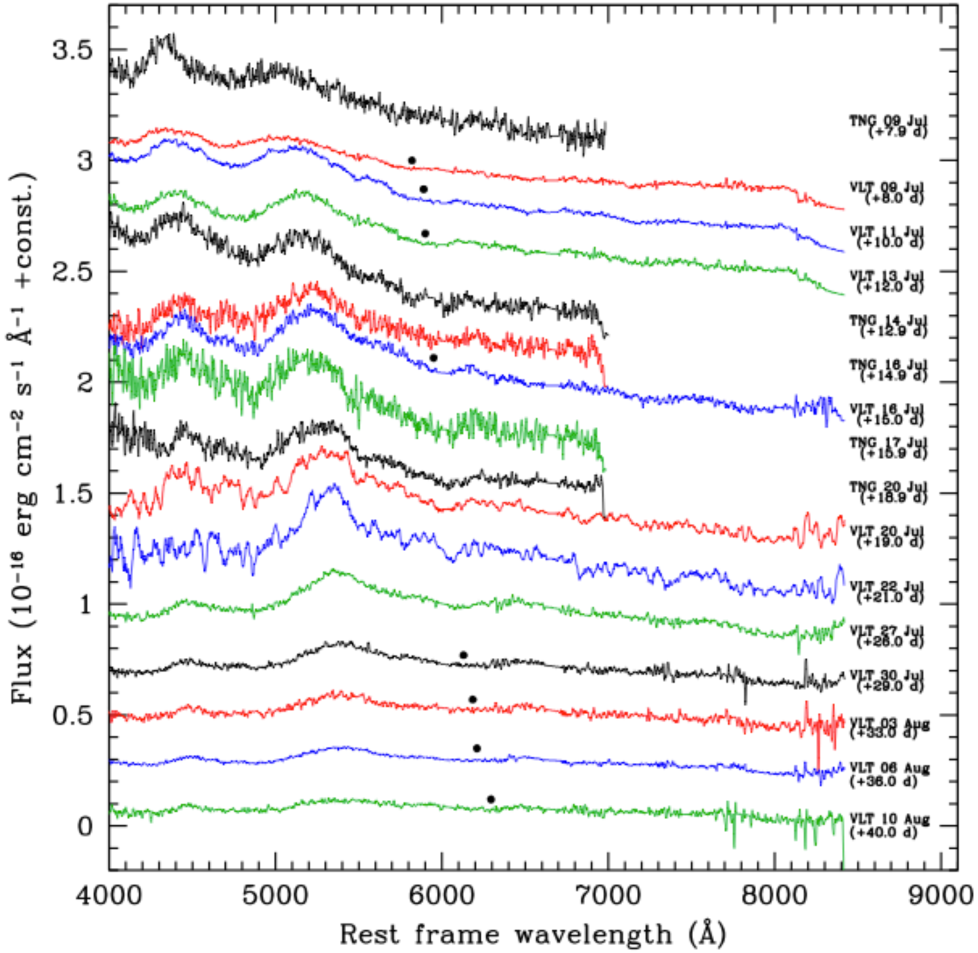
GRB 130702A/SN 2013dx

z = 0.145

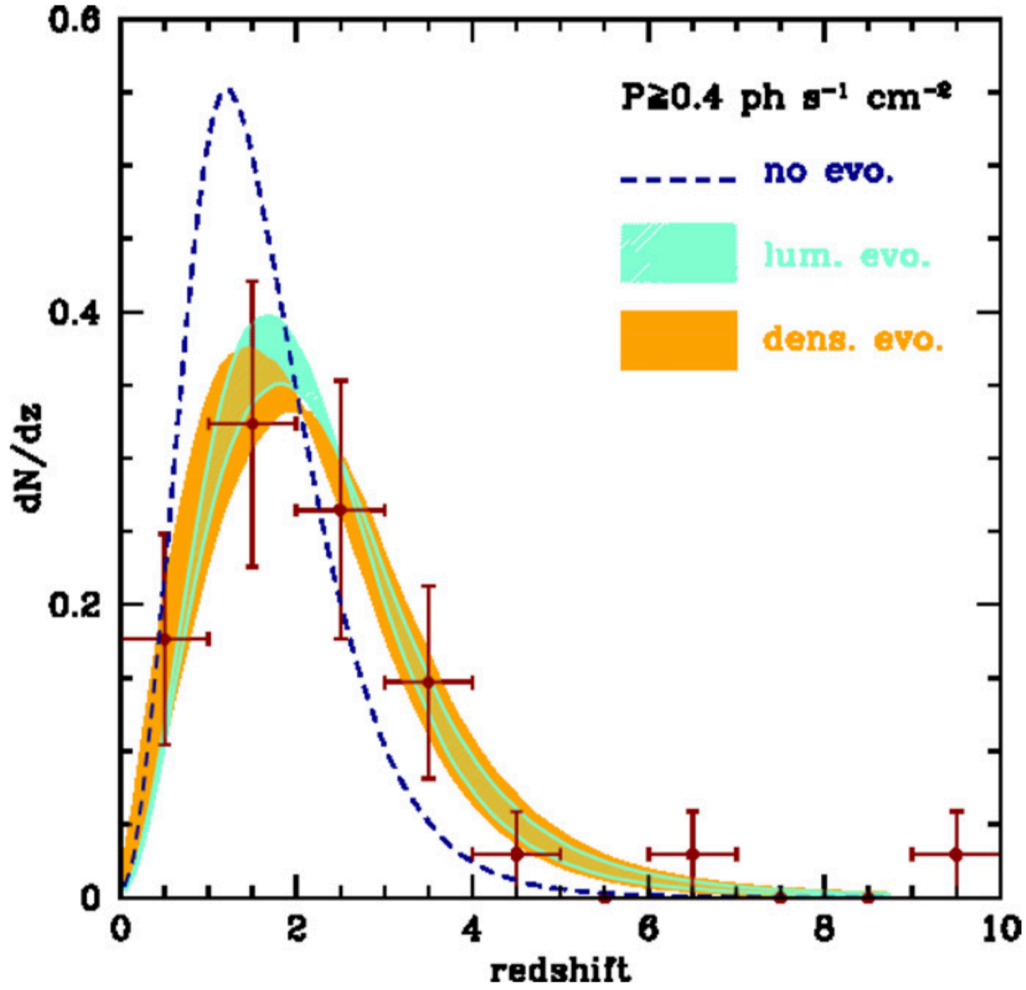
D'Elia et al. 2015







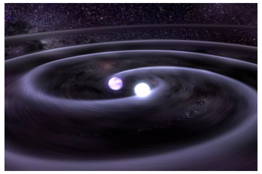
GRB-SNe

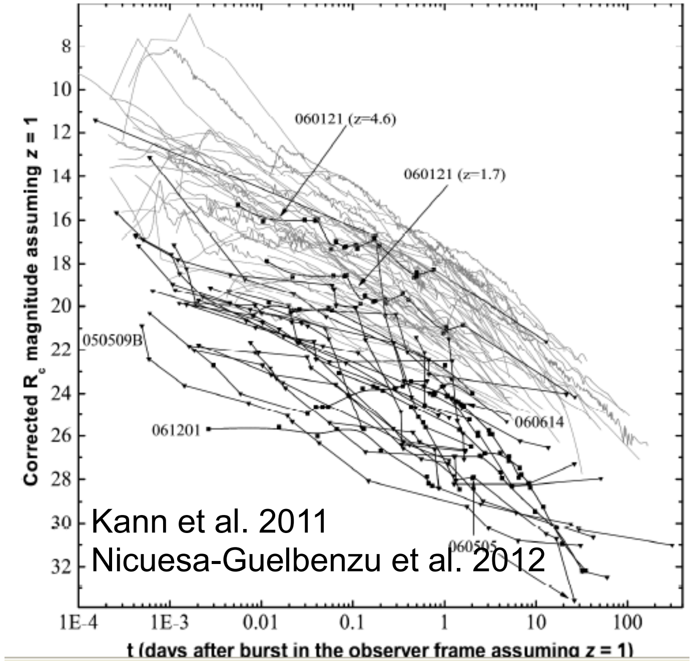


Assuming the redshift distribution of Salvaterra+2012, we expect ~2-5% of the *Swift* long GRBs to lie at $z <$ 0.2-0.3. This means 1-2 events/year for us. We can assume a monitoring of 5-10 spectra over 15-30 days (to monitor the SN evolution). Assuming 1.3 hours per epoch (1 hour spectrum + 0.3 hour photometry) over 7 epochs we end up with

9 hours/year.

Short GRBs





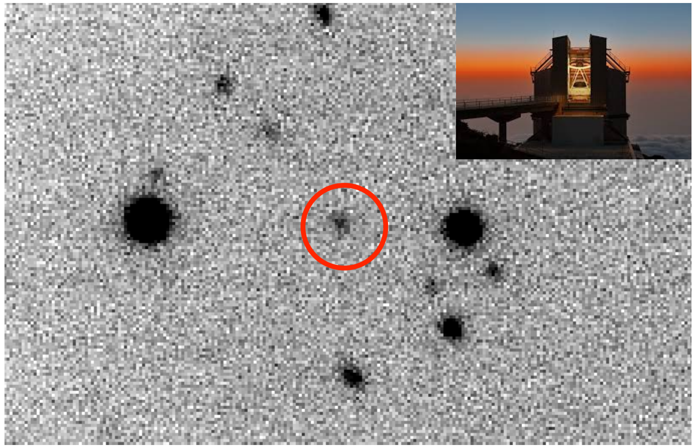
Kann et al. 2011
Nicuesa-Guelbenzu et al. 2012

Short GRBs afterglows are fainter wrt long GRBs:

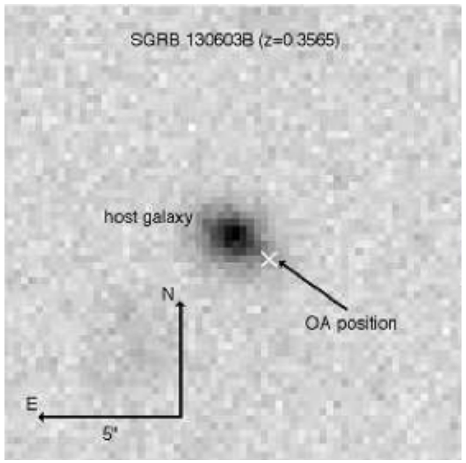
- less dense environment?

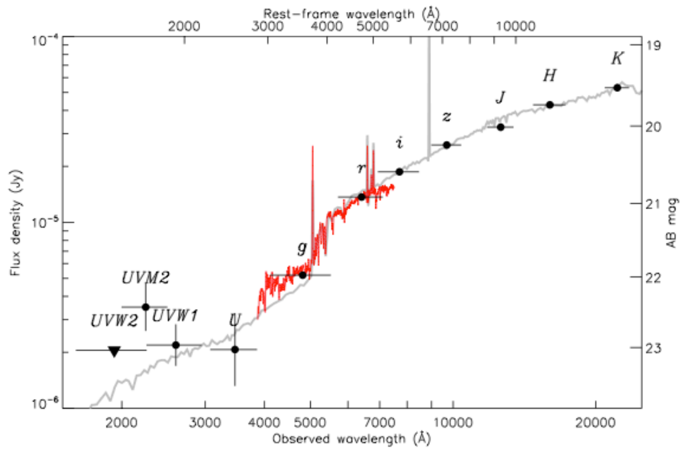
- less energetic?

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

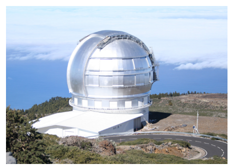


GRB 160927A
AG detection (r ~ 22.6 mag)
T-T0 = 2.1 h

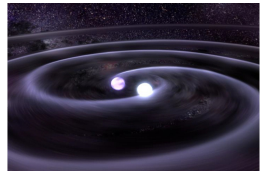


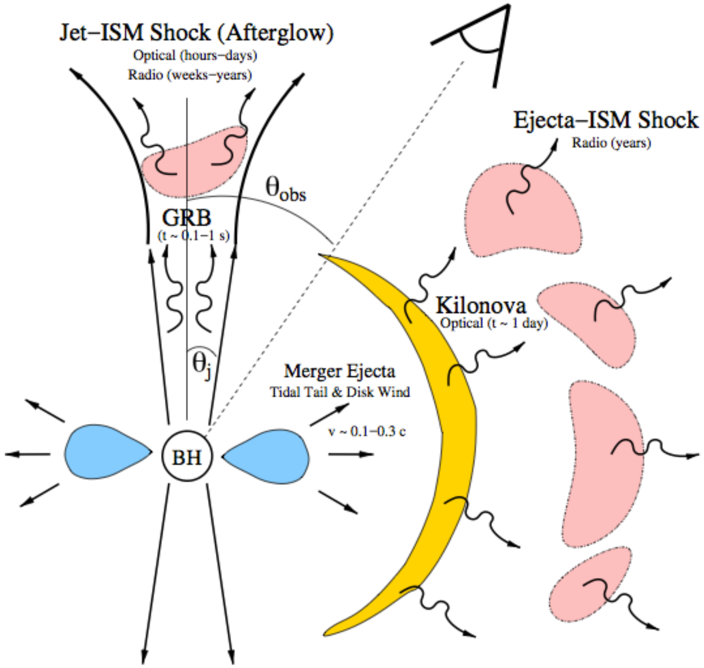


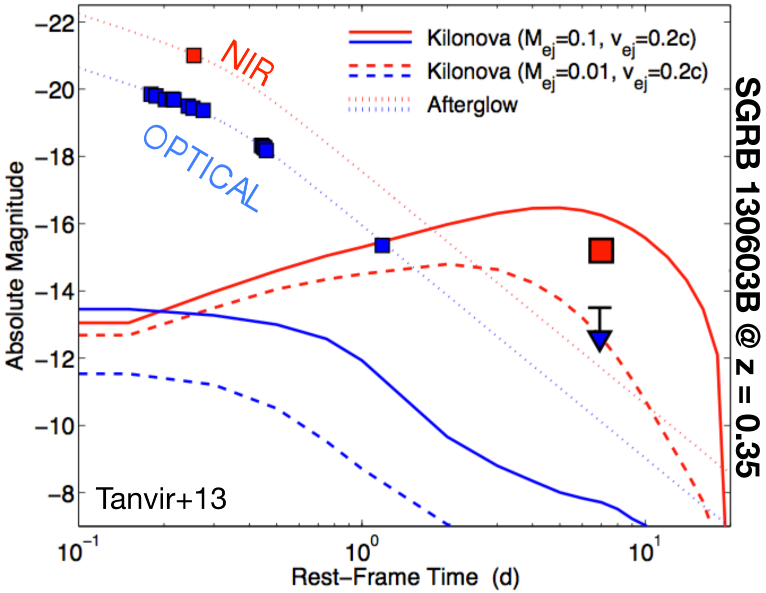
GRB 130603B
De Ugarte Postigo et al. 2014

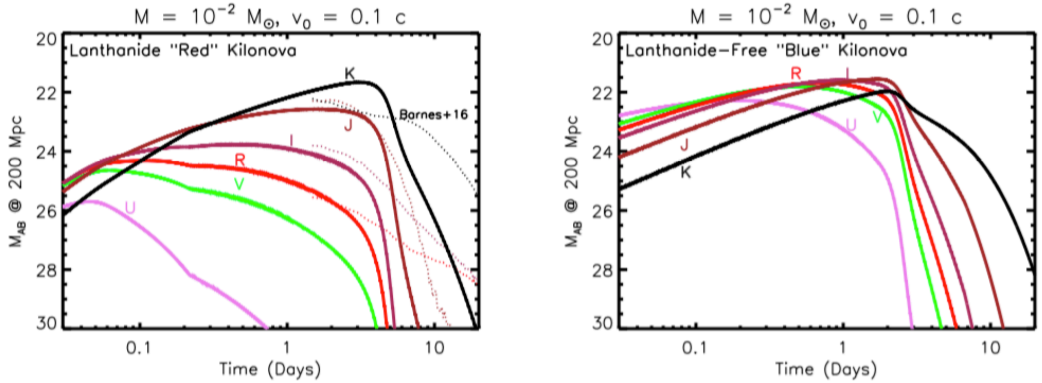


Short GRBs & kilonovae



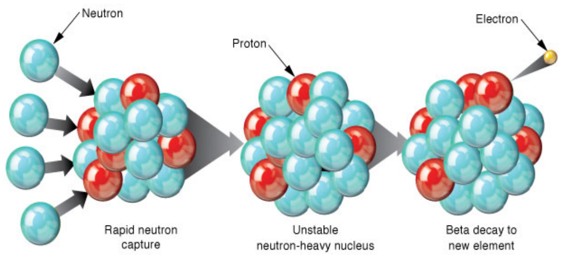


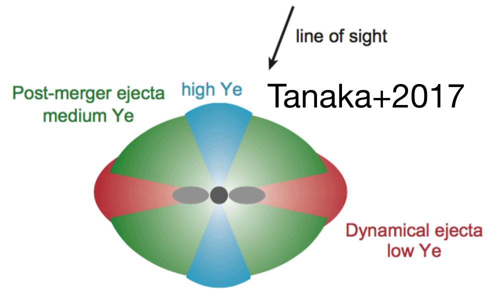




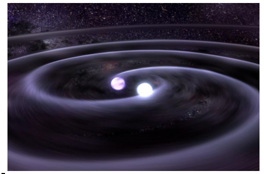
A key signature of an NS–NS/NS–BH binary merger is the production of a so-called "**kilonova**" (KN) due to the decay of **heavy radioactive species** produced by the r-process and ejected during the merger that is expected to provide a source of heating and radiation (Li and Paczynski 1998; Rosswog, 2005; Metzger et al., 2010).

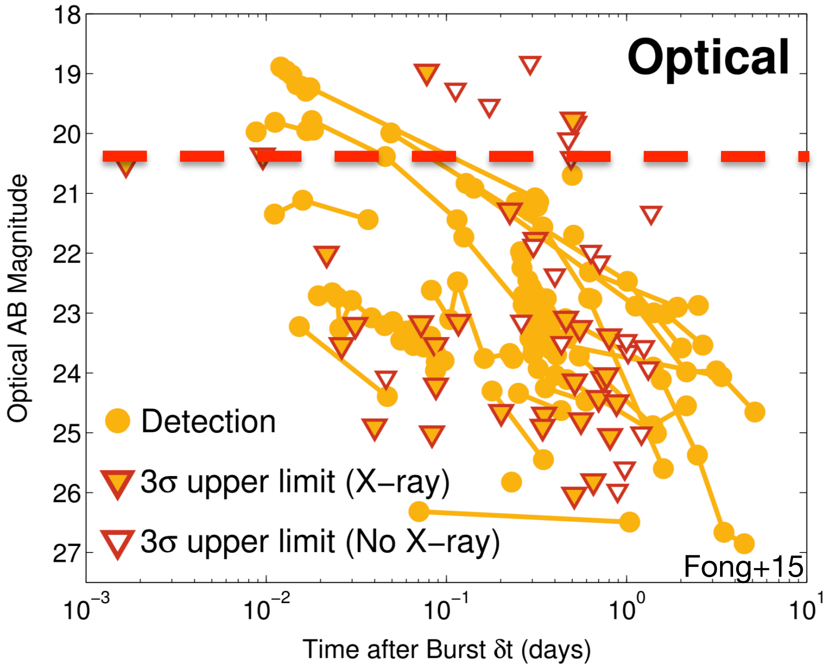
First compelling observational evidence: the KN AT2017gfo associated to GW 170817 / GRB 170817A (Pian+2017, Smartt+2017) @ 41 Mpc.

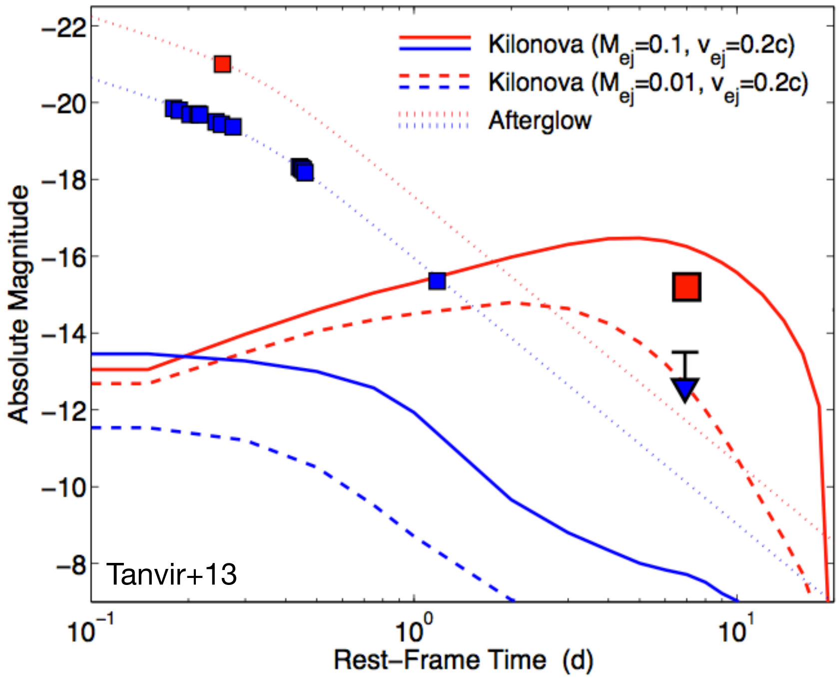




Short GRBs







It will be really hard obtain an afterglow spectrum (the very few got so far were obtained with 8m telescopes). In light of this, our goal there is to monitor the light curve (in more than one band) in order to constrain the afterglow decay to:

1) try a spectrum with a larger telescope (e.g. VLT/Xshoooter);

2) search for a KN component at late time with 8m and/or HST/JWST (easier to spot if you already have the afterglow decay and color).

This would translate into 2-3 epochs of multifilter photometry. Let's say:

Epoch 1 (t-t0 = 1d) -> 300s per filter (griz) -> 1200s overall -> R(AB) ~ 23.9 mag, SNR = 5

Epoch 2 (t-t0 = 2d) -> 600s per filter (griz) -> 2400s overall -> R(AB) ~ 24.3 mag, SNR = 5

Epoch 3 (t-t0 = 3d) -> 900s per filter (griz) -> 3600s overall -> R(AB) ~ 24.5 mag, SNR = 5

and one further epoch to search for the host galaxy (if not already reached in Epoch 3):

Epoch 4 (t-t0 > 20d) -> 3600s with the r filter -> R(AB) ~ 25.2 mag, SNR = 5.

Finding a host galaxy can be useful for future follow-up studies with VLT/HST/JWST.

So, 3 hours of imaging per SGRB, overall **12 hours (assuming 4 SGRBs) per year.**

Sources of GRB triggers in the SOXS era

Total

-40 long GRBs/year visible from La Silla.

Among those:

- 12 UVOT detected / bright -> 10 hours
  - 1 @ $z < 0.3$ for GRB/SN studies -> 9 hours
- 8 with an optical/NIR afterglow -> 8 hours
  - 2 @ $z > 5$ -> 6 hours
- 20 without a clear optical/NIR afterglow -> 10 hours

- 4 short GRBs/year from La Silla -> multiepoch photometry -> 12 hours

-> 12 + 10 + 9 + 8 + 6 + 10 = 55 hours/year

We may want to add ~ 5 hours for imaging for the search of host galaxies of interesting long GRBs, limits to SN-less long GRBs, deep searches of afterglows (dark/dusty), spectra to classify orphan afterglows candidates (up to 1 orphan afterglow candidate per year bright enough for SOXS spectroscopy). This takes us up to 60 hours/year.

Taking into account 20% of overheads, we go to 72 hours.

Then we have to take into account SVOM and Einstein Probe.
SVOM is expected to detect about 60-70 GRB/year. Although it's not easy to make simple predictions (one has to take into account the orbit, attitude…) we can assume that some GRBs will be detected both by Swift and SVOM. Einstein Probe is lacking a gamma-ray detector. The current experience reveals that it is not easy to understand if an EP detected X-ray transient is a GRB. So far we have sparse EP triggers, just a few revealed to be GRBs. Then there are many (they can be up to 100/yr) other (interesting) fast X-ray transients. However, these cannot be counted/followed by the SOXS GRB WG (it is another matter to be discussed: classifications??).
So, we increase our estimate above by 50%. This translates into ~ 108 hours/year.

We will not follow events lacking a sub-arcmin position. If this were the case, our total time request can be reduced by 20% (from the Swift experience), becoming therefore

~ 86 hours/year

(10 nights/year; 5.5% of the whole SOXS GTO time).

Time share (first guess): 80% (IT), 10% (UK), 10% (DK/FI)

GRB samples

Since 2004, Swift observed more than 1400 GRBs (> 140 short GRB). It is now possible to follow a statistical approach (beyond single event studies). To this end samples of events, with favorable observing conditions for ground-based observations (redshift determination), have been selected.

> 70% of Swift GRBs are missing a redshift measure.

X-shooter sample

Jakobsson+04; Fynbo+09
Hjorth+12, Selsing+in prep.

- 157 **long** GRB
- ~55% with redshift (wrt 40% whole Swift sample)

BAT6 sample

Salvaterra+12

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

and more…

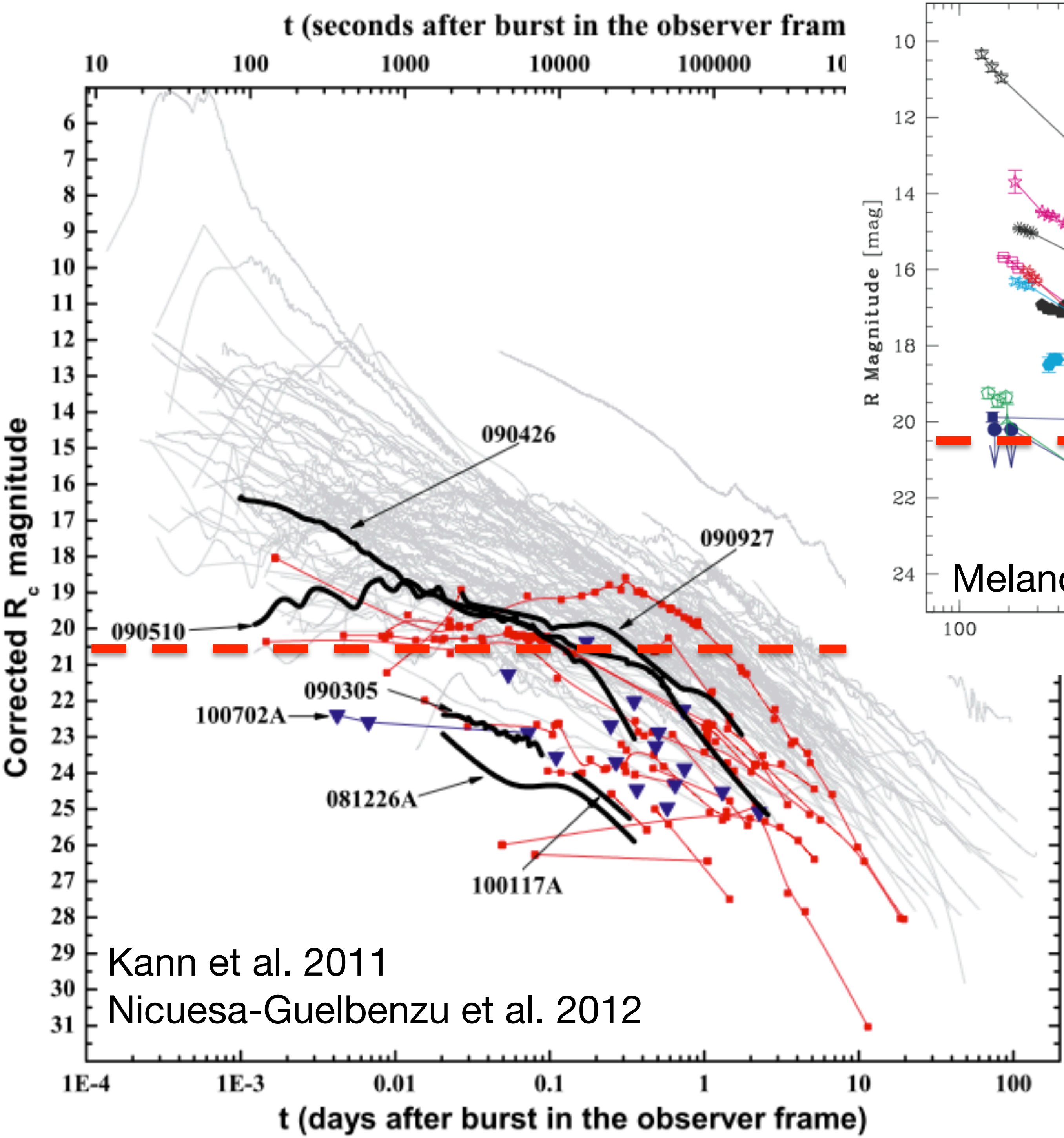
SBAT4 sample

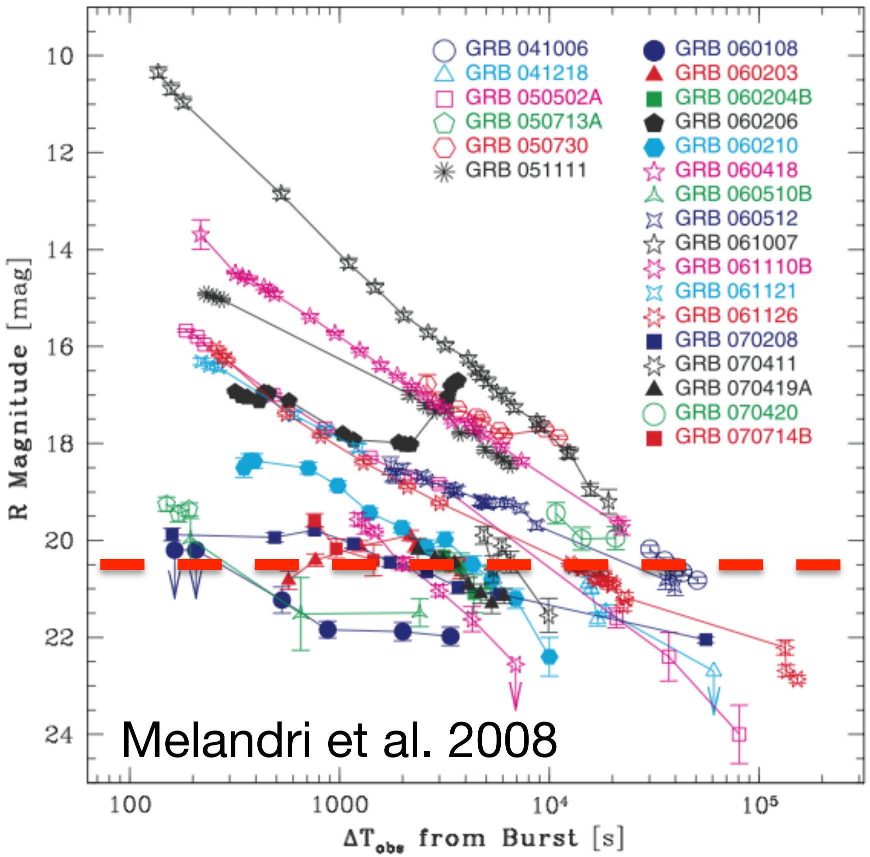
D'Avanzo+14

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

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

GRBs from an (optical) observational point of view: some numbers



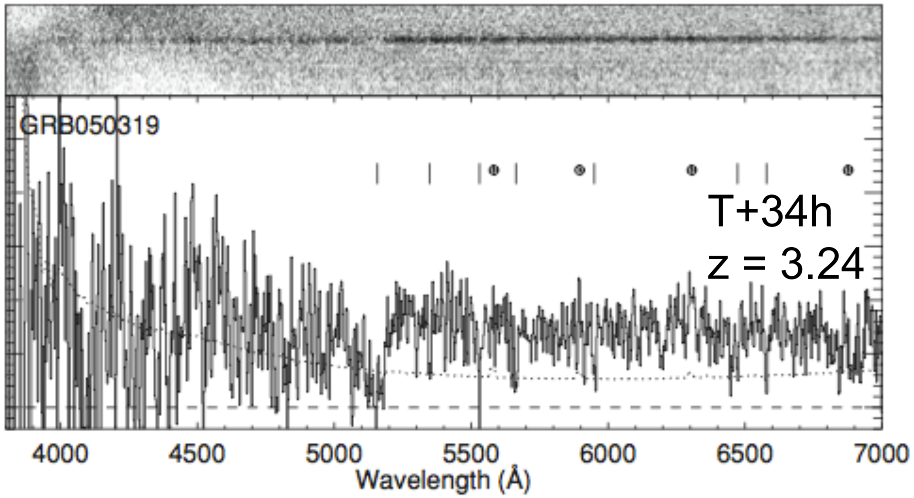


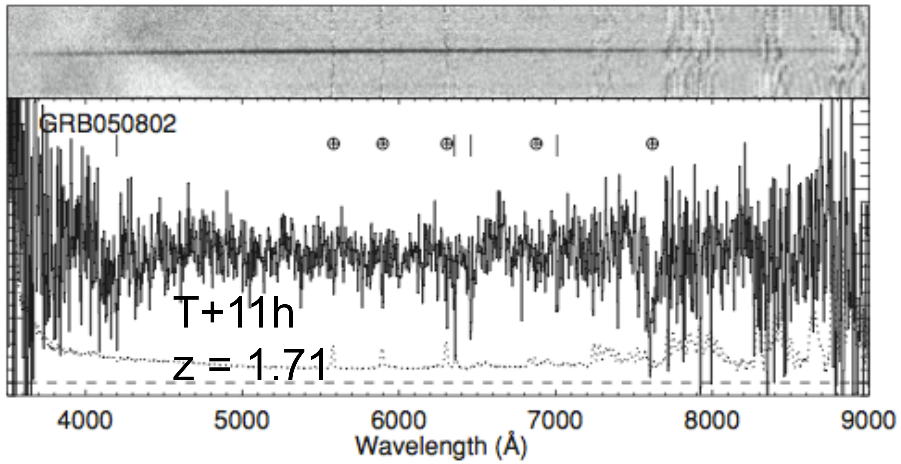
Observed GRB afterglow optical light curves

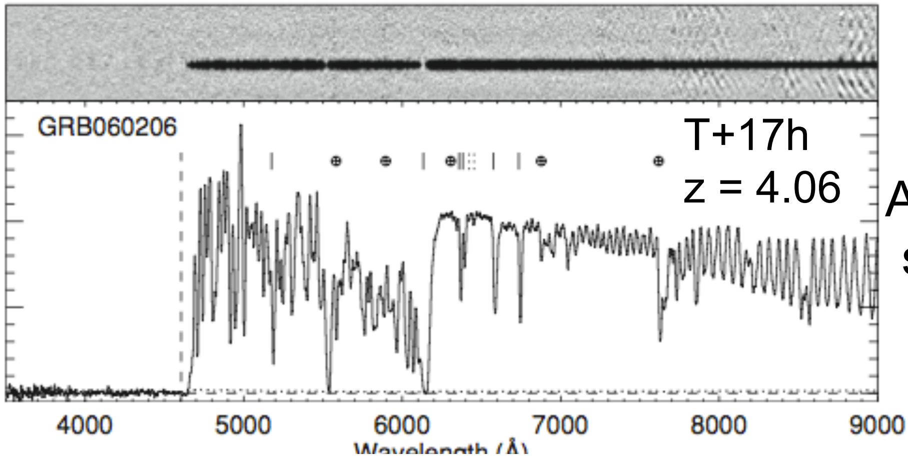
Fynbo et al. 2009

Low-res spectroscopy of 77 GRB optical afterglows (mainly NOT and VLT)

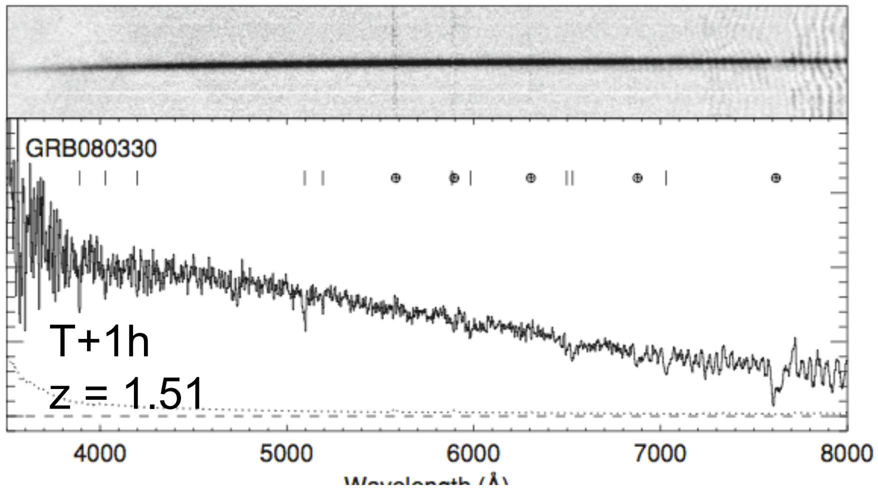
GRB	Instrument	Exptime (ks)	Airmass	Seeing (arcsec)	Δt (hr)	Mag_{acq}	Redshift	Ref.
050319	AlFOSC	2.4	1.1	1.3	34.5	21.0	3.2425	(1)
050401	FORS2	11.6	1.1–1.7	0.7	14.7	23.3	2.8983	(2)
050408	GMOS-N	3.6				21.0	1.2356	(3)
050730	FORS2	1.8	1.2	1.5	4.1	17.8	3.9693	(4)
050801	LRIS	1.8	1.9	...	5.7	20.7	1.38	(5)
050802	AlFOSC	4.8	1.2	0.7	11.4	20.5	1.7102	(6)
050820A	UVES	12.1	2.1	1.0	0.5	16.0	2.6147	(7)
050824	FORS2	3.0	1.8	0.7	9.5	20.6	0.8278	(8)
050908	FORS1	3.6	1.1	0.6	1.6	20.5	3.3467	(9)
050922C	AlFOSC	2.4	0.9	1.3	1.0	16.5	2.1995	(1)
060115	FORS1	3.6	1.3–1.6	0.7	8.9	22.0	3.5328	(10)
060124	LRIS	1.0	1.6	1.0	16.1	19.5	2.3000	(11)
060206	AlFOSC	2.4	1.0	1.2	0.3	17.5	4.0559	(12)
060210	GMOS-N	3.0	1.1	...	1.2	20.6	3.9133	(13)
060502A	GMOS-N	3.6	1.6	...	5.2	21.2	1.5026	(14)
060512	FORS1	3.6	2.5	1.6	3.0	19.9	2.1	(15)
060526	FORS1	9.9	1.1–1.4	1.3	8.8	19.5	3.2213	(1)
060604	AlFOSC	1.2	1.7	1.0	10.0	21.5	$\lesssim 3$	(16)
060607A	UVES	12.0	1.9–1.0	1.0	0.1	14.7	3.0749	(17)
060614	FORS2	1.8	1.2	0.7	21.1	19.8	0.1257	(18)
060707	FORS2	5.4	1.0	1.1	34.4	22.4	3.4240	(1)
060708	FORS2	3.6	1.2	0.6	43.0	22.9	1.92	(19)
060714	FORS1	5.4	1.1	0.7	8.5	20.4	2.7108	(1)
060719	FORS2	2.4	1.1	2.2	50.0	24.5	$\lesssim 4.6$	(5)
060729	FORS2	5.4	2.0–2.6	1.5	13.2	17.5	0.5428	(20)
060807	FORS1	7.2	1.8	0.8	9.5	22.9	$\lesssim 3.4$	(21)
060908	GMOS-N	1.8	1.2	1.6	2.0	19.8	1.8836	(22)
060927	FORS1	5.4	1.2	1.5	12.5	24.0	5.4636	(23)
061007	FORS1	5.4	1.2–1.3	0.9	17.4	21.5	1.2622	(24)
061021	FORS1	1.8	1.9	0.8	16.5	20.5	0.3463	(25)
061110A	FORS1	5.4	1.4–1.8	0.8	15.0	22.0	0.7578	(26)
061110B	FORS1	3.6	1.3–1.5	0.7	2.5	22.5	3.4344	(27)
061121	LRIS	1.2	1.2	...	0.2	17.8	1.3145	(28)
070110	FORS2	5.4	1.5–1.9	1.0	17.6	20.8	2.3521	(29)
070129	FORS2	1.8	2.2	1.0	2.2	21.3	$\lesssim 3.4$	(1)
070306	FORS2	5.4	1.2–1.3	1.0	34.0	23.1	1.4965	(30)
070318	FORS1	1.8	1.6	0.7	16.7	20.2	0.8397	(31)
070419A	GMOS-N	2.4	1.2–1.3	...	0.8	20.4	0.9705	(5)
070506	FORS1	2.7	1.6–1.8	1.1	4.0	21.0	2.3090	(32)
070611	FORS2	3.6	1.1–1.2	1.0	7.7	21.0	2.0394	(33)
070721B	FORS2	5.4	1.2–1.5	1.2	21.6	24.3	3.6298	(34)
070802	FORS2	5.4	1.2	0.5	1.9	21.9	2.4541	(35)
071020	FORS2	0.6	2.0	1.0	2.0	20.4	2.1462	(36)
071025	HIRES	1.8	1.35	...	...	...	5.2	(1)
071031	FORS2	1.8	1.2	1.0	1.2	18.9	2.6918	(37)

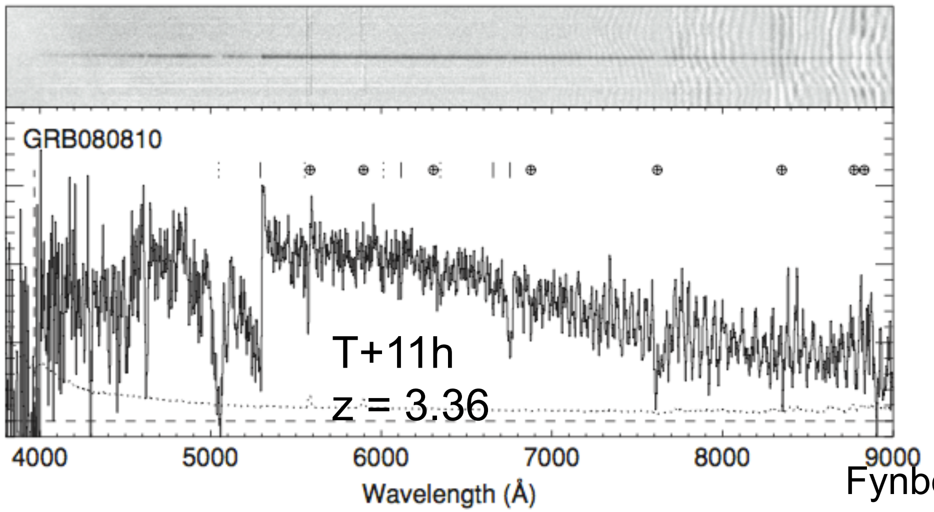


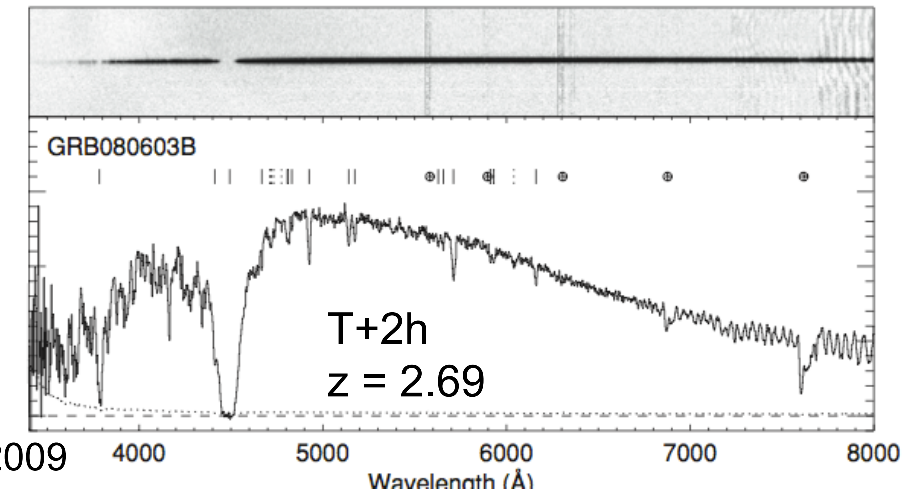




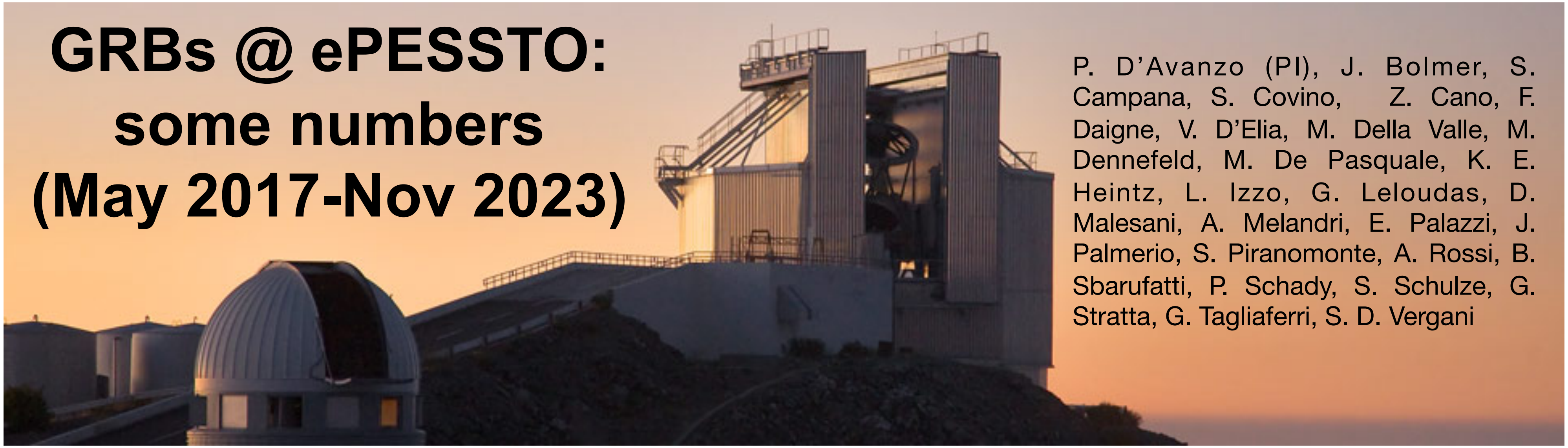
NOT
ALFOSC
spectra







Fynbo et al. 2009



GRBs @ ePESSTO: some numbers (May 2017-Nov 2023)

P. D'Avanzo (PI), J. Bolmer, S. Campana, S. Covino, Z. Cano, F. Daigne, V. D'Elia, M. Della Valle, M. Dennefeld, M. De Pasquale, K. E. Heintz, L. Izzo, G. Leloudas, D. Malesani, A. Melandri, E. Palazzi, J. Palmerio, S. Piranomonte, A. Rossi, B. Sbarufatti, P. Schady, S. Schulze, G. Stratta, G. Tagliaferri, S. D. Vergani

- Since May 2017 we have a GRB science proposal within the ePESSTO program @ NTT
--> main goal: **pinpoint the optical/NIR afterglow & measure redshift**

- the program is activated mainly for GRBs (nearly-) promptly visible from La Silla during ePESSTO nights (90 nights/year)

- one person of our team (at least) is always on call during the ePESSTO runs to update the Marshall, be in contact with the NTT observers, providing remote support in terms of finding chart, OB selection, target identification, data analysis and GCN/circular release within a few hours from the data acquisition.

- so far, we observed 12 GRBs (3 GRB/year, considering the COVID break; ~ in agreement with the estimates presented here of ~20 GRB/year promptly observable from La Silla and/or optically bright -> 25% of them during ePESSTO nights).

- 14 GCN Circulars and 3 papers: GRB 171010A/SN 2017htp (Melandri et al, 2019, MNRAS, 490, 5366); GRB 190114C (TeV detection, the MAGIC collaboration et al., 2019, Nature), GRB 190114C/SN 2019jrj (Melandri et al., 2022, A&A, 659, A39). Another paper is in preparation (short GRB 231117A).

Conclusions

- **GRBs have a high science impact in many astrophysical fields.**
- *Swift* is providing (and will provide) a wealth of data (90 GRB/yr, ~50% visible from La Silla). SVOM, EP and (hopefully) HERMES and THESEUS will provide triggers in the years of SOXS operations.
- In the past years, the majority of GRB redshifts were provided by the GRB X-shooter team (Stargate -> how to interact?).
- A southern hemisphere 4-m telescope with flexible schedule (ToO) equipped with OPT/NIR imaging + medium-res spectroscopy can do very well the job (→ SOXS!)
- Besides redshifts, a lot of science cases.
- **High visibility and scientific return with relatively little amount of consumed time (~40 GRB/yr, ~10 nights/yr)***

*** (can be reduced by ~20% by restricting to GRB sub-samples)**