GRBs : the hard X-ray window

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Outline…

- Why observing GRBs?
- Some requirements of a GRB mission
- GRB follow-up in hard X-rays

Warning: These slides do not provide an overview of the field, they are simply aimed to foster discussions…

Why observing GRBs?

- GRBs are luminous high-energy transients likely associated with catastrophic accretion of matter by a newly born black hole or with the fast slowing down of a newborn magnetar.

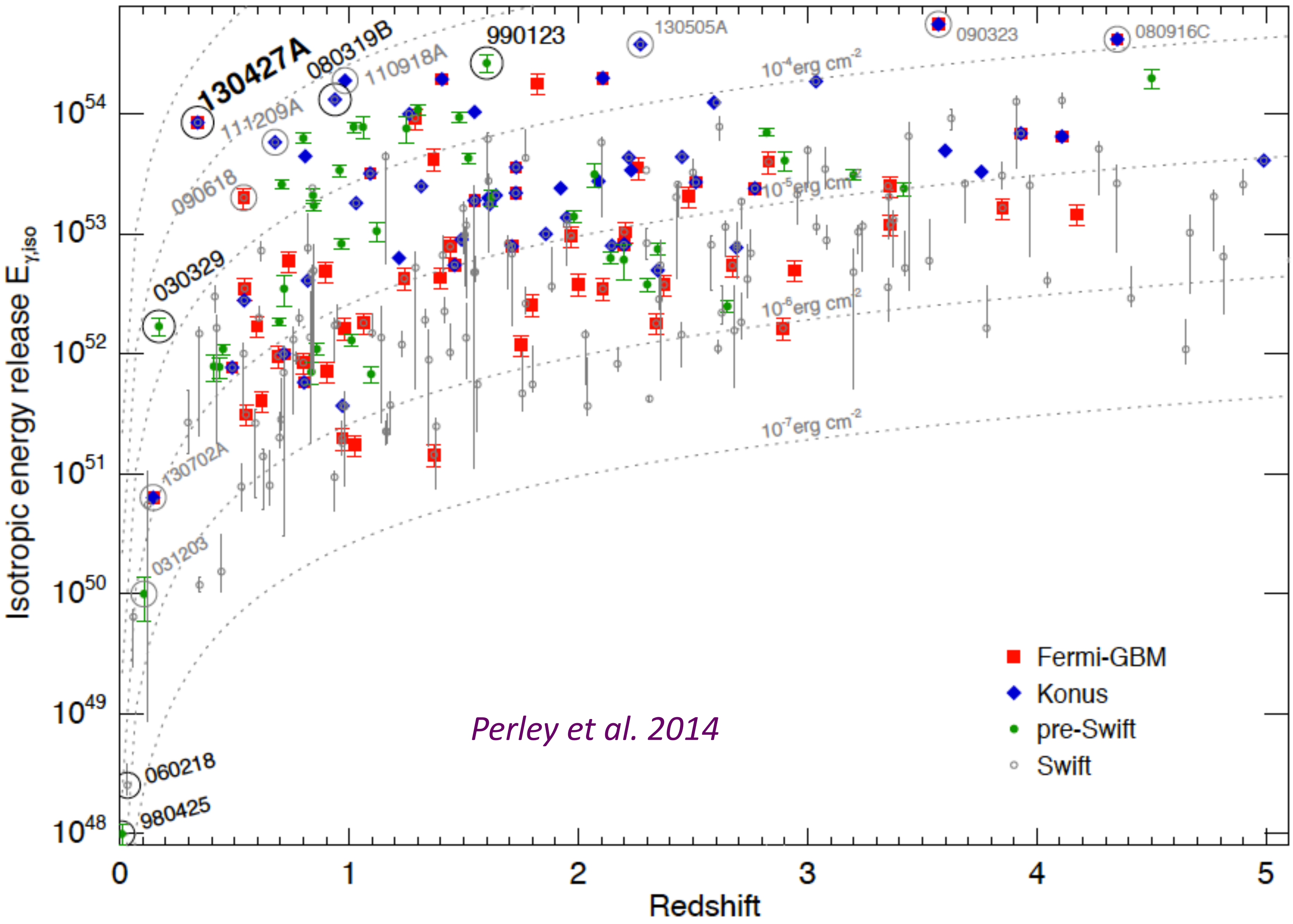
- The physics of GRBs in interesting and complex, it involves newly born black holes and magnetars, catastrophic accretion, and ultra-relativistic jets

- GRBs open a new window on cosmic explosions and on the progenitors of stellar mass black holes

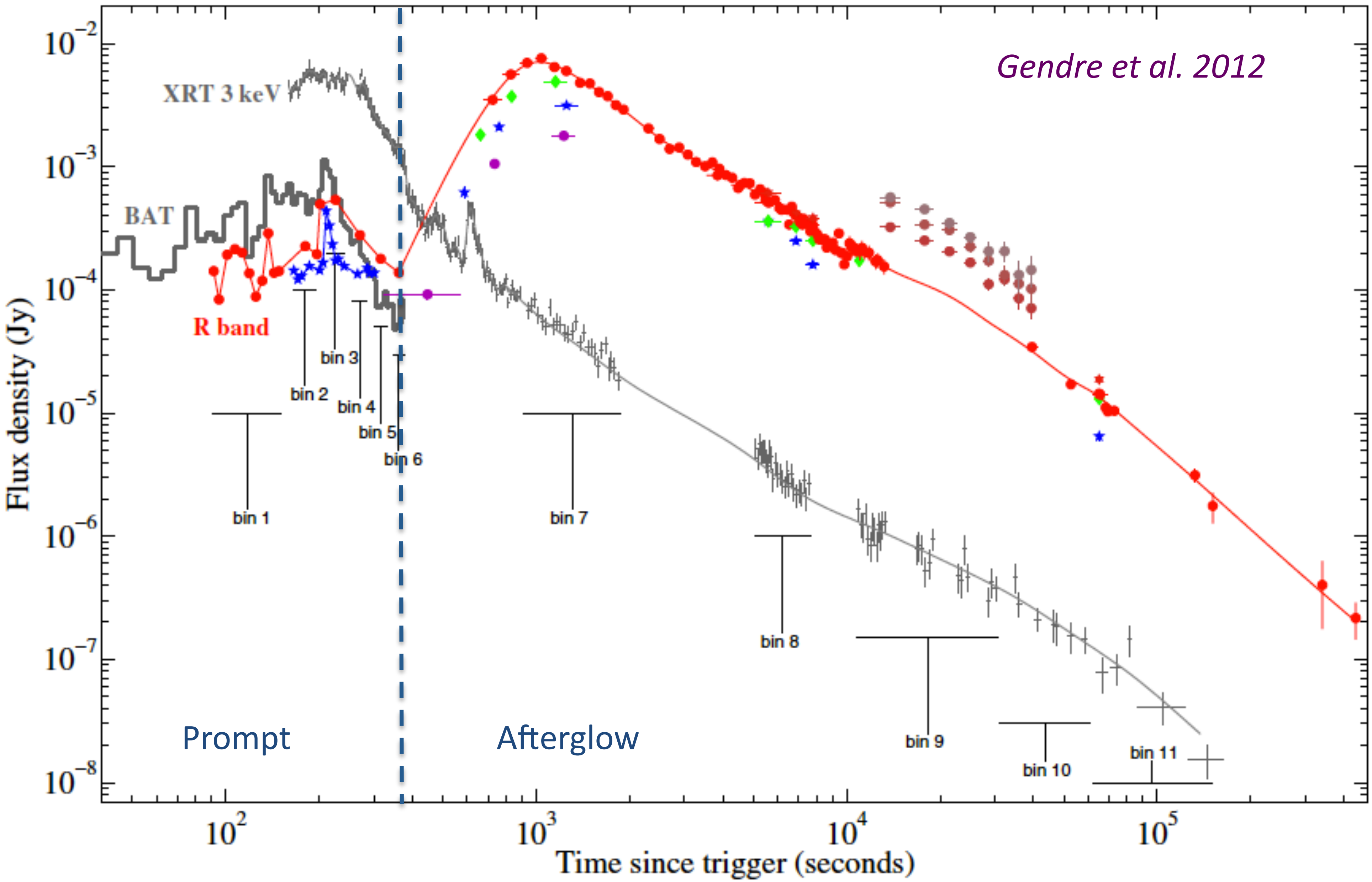
- GRBs are primary candidate sources for multi-messenger astrophysics, GW, neutrinos, CR

- Distant GRBs probe the ISM and IGM in the young universe: metal enrichment, reionization, structure of matter along the LOS, gravitational lensing

- GRBs allow probing new physics: e.g. tests of Lorentz invariance



Isotropic energy release $E_{\gamma,iso}$
Redshift
130427A
080319B
110918A
990123
130505A
090323
080916C
111209A
090618
030329
130702A
031203
060218
980425
10^{-4} erg cm^{-2}
10^{-5} erg cm^{-2}
10^{-6} erg cm^{-2}
10^{-7} erg cm^{-2}
Fermi-GBM
Konus
pre-Swift
Swift
Perley et al. 2014



Gendre et al. 2012
XRT 3 keV
BAT
R band
Flux density (Jy)
Time since trigger (seconds)
bin 1
bin 2
bin 3
bin 4
bin 5
bin 6
bin 7
bin 8
bin 9
bin 10
bin 11
Prompt
Afterglow

Some facts about GRBs

- GRBs require excellent space-ground synergy

- GRBs are rare – *Interesting GRBs* are even more rare
  - Need to detect hundreds of GRBs to get a handful of remarkable events: high-z GRBs, ultra-long GRBs, nearby GRBs, sub-luminous GRBs…
  - A space mission dedicated to GRBs **must** detect hundreds of GRBs

- Physics: few bright and well-observed events have proved to be the key (e.g. GRB 130427)

Requirements of a GRB mission

Some GRB missions

Mission	Period	Energy range (keV)	Detection area (cm^2)	GRB loc./yr	Redshifts
BeppoSAX	1996–2002	**2-28** 40-700	**530***0.33 (x2)	10	9
HETE-2	2000–2006	**2-25** 7-400	**350***0.33 160	20 ---	19
INTEGRAL	2002–	**15-200**	**2600***0.5	10	5
SWIFT	2004–	**15-150**	**5200***0.5	90	250
Fermi	2008–	**>100000** 8-1000 200-40000	**~10000** 130 (x12) 130 (x2)	10 --- ---	10
SVOM	2020?	**4-100** 50-5000	**1000***0.4 250 (x3)	70-80 ---	

- Many future missions, like A-STAR, JANUS, Lobster, LOFT, propose detecting GRBs in the hard X-ray range, typically 1-20 keV, 2-50 keV,…

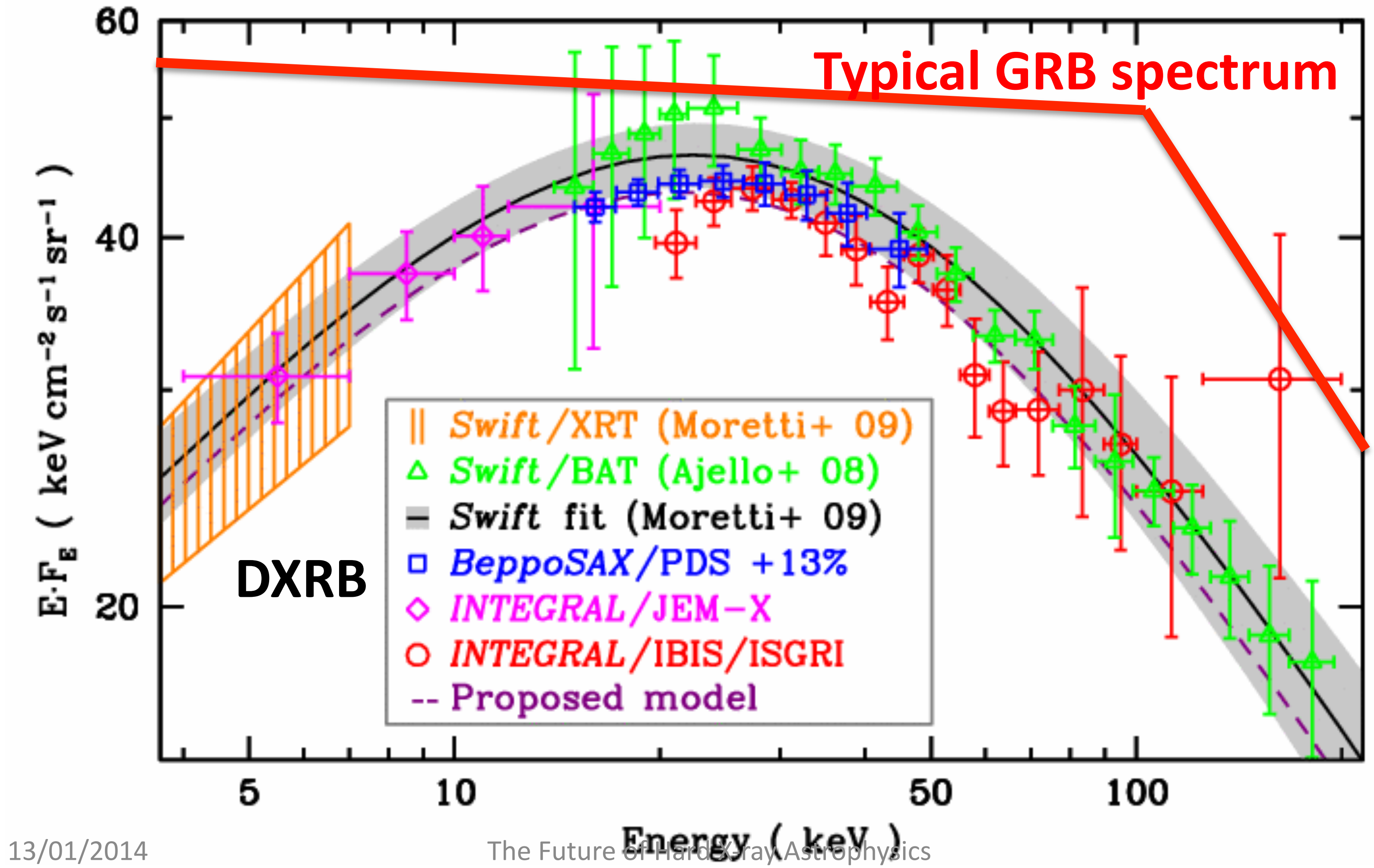
GRB detection

- The hard X-ray window (E>few keV) is a good window for GRB detection and localization
  - More photons
  - Permits the detection of the not-so-well-explored realm of X-Ray Flashes and high-z GRBs

- Detection and localization over a wide field of view – 2 options:
  - *Coded masks* (1D or 2D): intrinsic multiplexing, large background (DXRB), many photons, better for short transients – many flown
  - *Lobster eye optics*: no multiplexing, very low background, few photons, better for long soft transients – yet to be flown
  - **Both techniques require large detection area**

Coded masks: background for GRB detection

- Below ~100 keV the dominant background is the Diffuse X-Ray Background
- Going to lower energies improves the signal-to-noise ratio



Polarimetry of the prompt hard X-ray emission

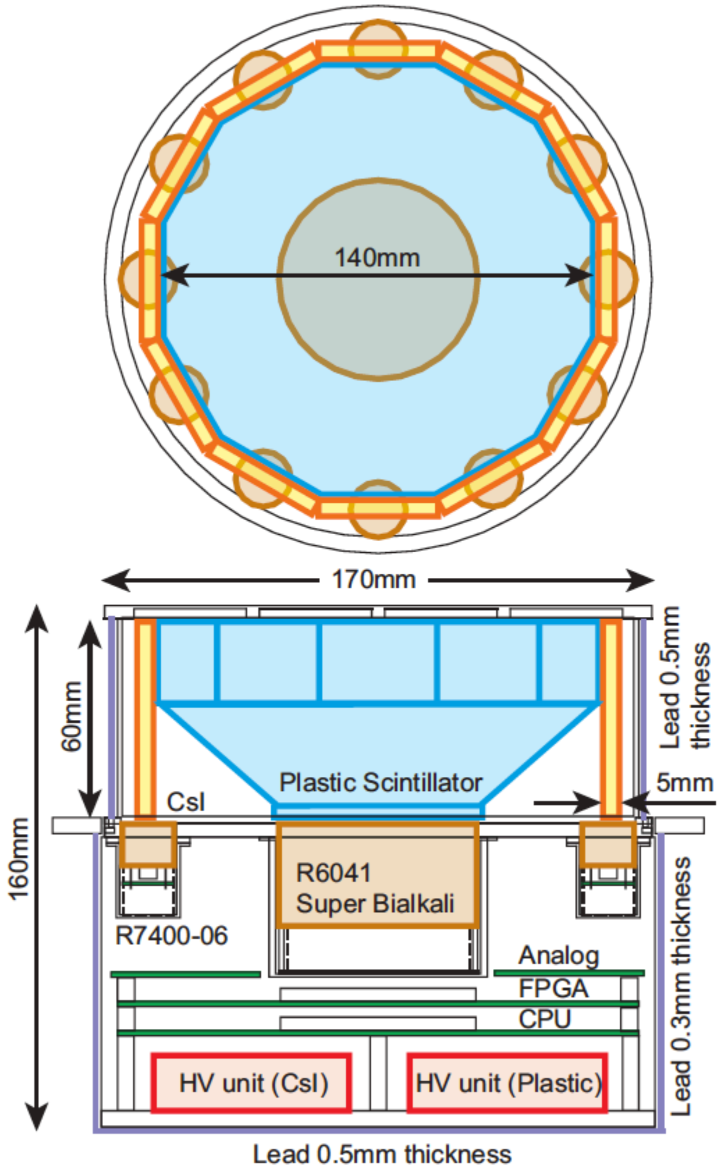
- The detection of the prompt GRB emission in hard X-rays allows the localization of the source, and the measure of the prompt emission (spectrum, light curve, polarization) close to the maximum of the SED (spectral energy distribution)

- The spectro-temporal evolution of GRBs is well studied, but the polarization of the prompt emission remains to be explored :
  - The polarimetry of the prompt high-energy emission provides a unique diagnostic of the physics at work during the prompt phase, when most of the energy is radiated
  - The hard X-ray window (≈100 keV) is well suited to measure the polarization of the prompt emission, using the sensitivity to polarization of the Compton interaction

  - The next 3 slides show recent results from the GAP polarimeter suggesting (after RHESSI? and INTEGRAL) that some GRBs are highly polarized
  - There is a true need for sensitive polarimetry of the prompt GRB emission

GAP

Yonetoku et al. 2011
PASJ, 63, 625



Results of Polarization Analyses

Yonetoku et al. 2013

GRB	Polarization Degree (%)	Duration T90 (sec)	Incident Angle (deg)	E_p (keV)	fluence (erg cm^{-2})	flux (photon cm^{-2} s^{-1})
100826	27 ± 11	100	20	606^{+134}_{-109}	2.94×10^{-4}	9.03
110721	84^{+16}_{-28}	11	30	$375.5^{+26.5}_{-23.6}$	3.43×10^{-5}	6.71
110301	70 ± 22	7	48	$106.80^{+1.85}_{-1.75}$	3.35×10^{-5}	75.59
110825	< 47	12	29	$233.6^{+21.9}_{-19.9}$	5.06×10^{-5}	6.16
110625	< 56	27	41	190^{+17}_{-14}	6.09×10^{-5}	8.21
100715	< 83	30	19	-	-	-
101014	< 71	30	54	$181.40^{+5.66}_{-5.44}$	1.88×10^{-4}	3.74

90% upper-limit

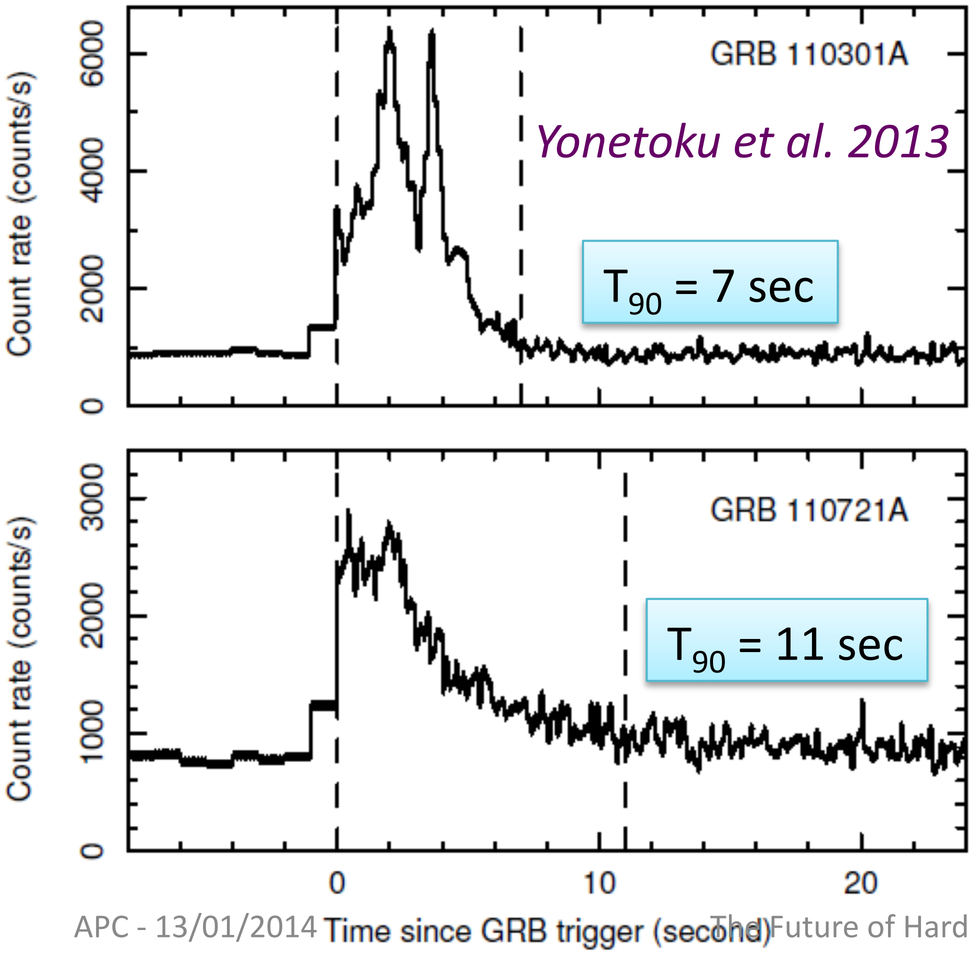
- Significant Polarization was detected from bright 3 GRBs.
- GRB100826A : Polarization angle changed (3.5σ confidence level.)
- GRB110721A & GRB110301A : Polarization angle was stable.

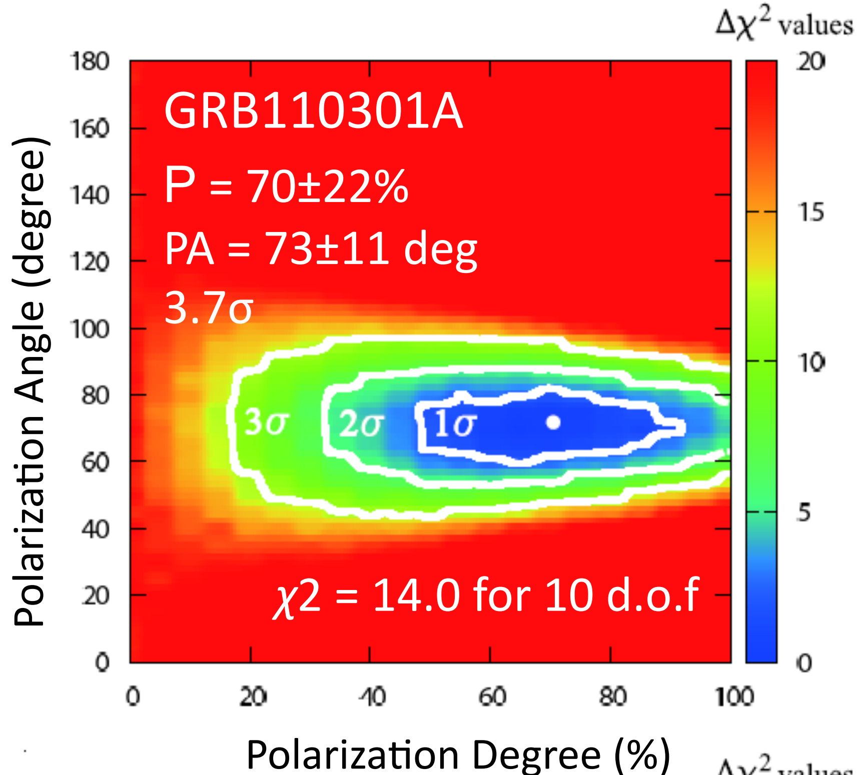
We need the emission model to explain both cases of change and no-change of polarization angle.

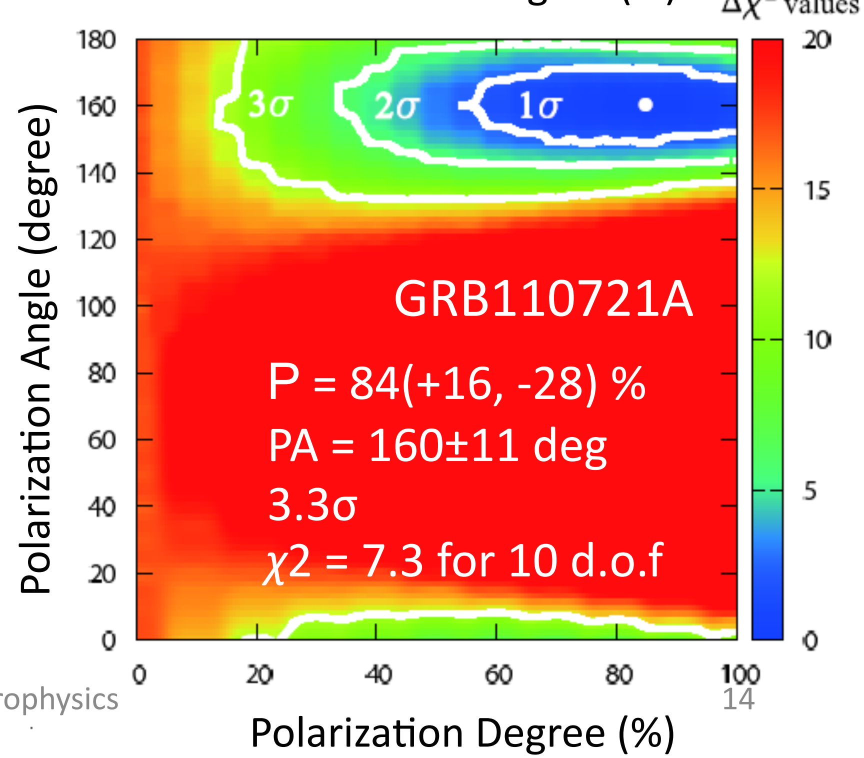
GRB110301A & GRB110721A

We detected the polarization from two bright GRBs with high significance.

The polarization angles did not change during the prompt GRBs.





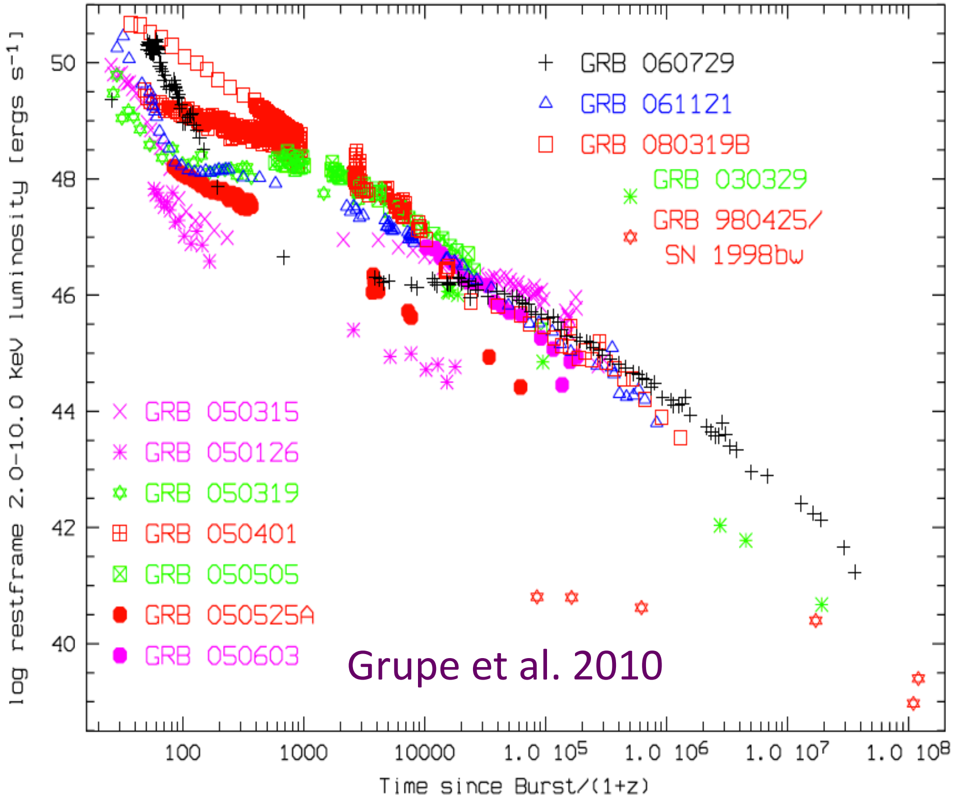


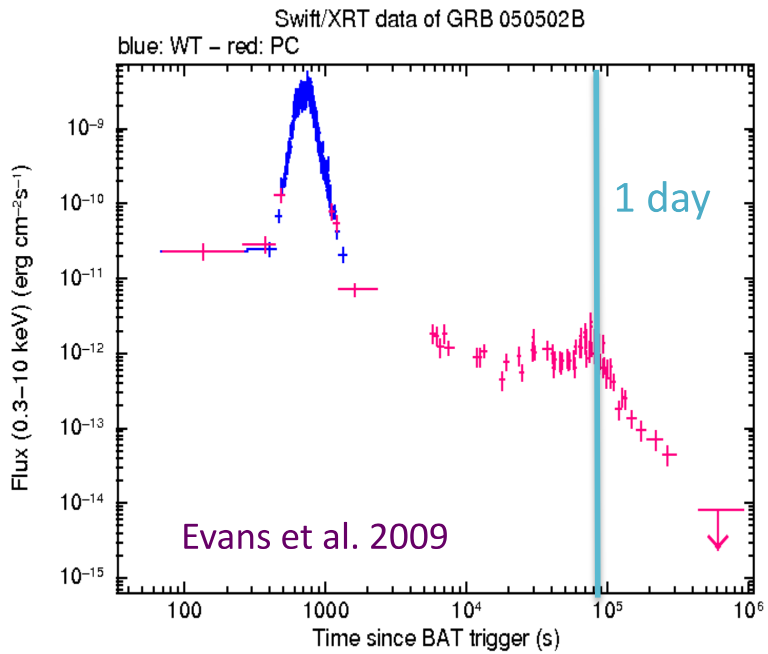
GRB follow-up in hard X-rays

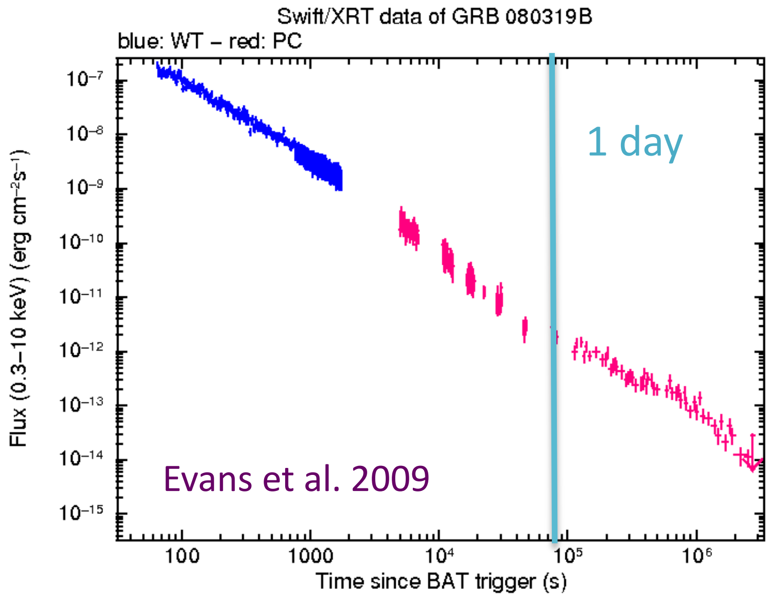
X-ray follow-up (general)

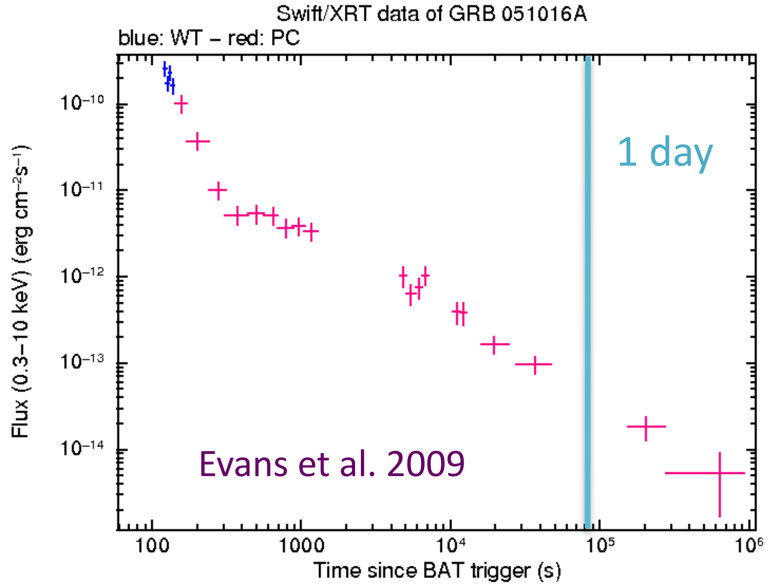
- Most GRBs have bright X-ray afterglows, lasting hours to days. A *sensitive* X-ray telescope may:
  - Permit the detection of late afterglow breaks, providing measures of beaming angles for broad jets (θ_j> few degrees)
  - Identify the faint afterglows of short GRBs (potential GW sources).
  - Identify the afterglows of dark and highly redshifted GRBs, pinpointing galaxies at z ~ 6-10.

X-ray afterglows









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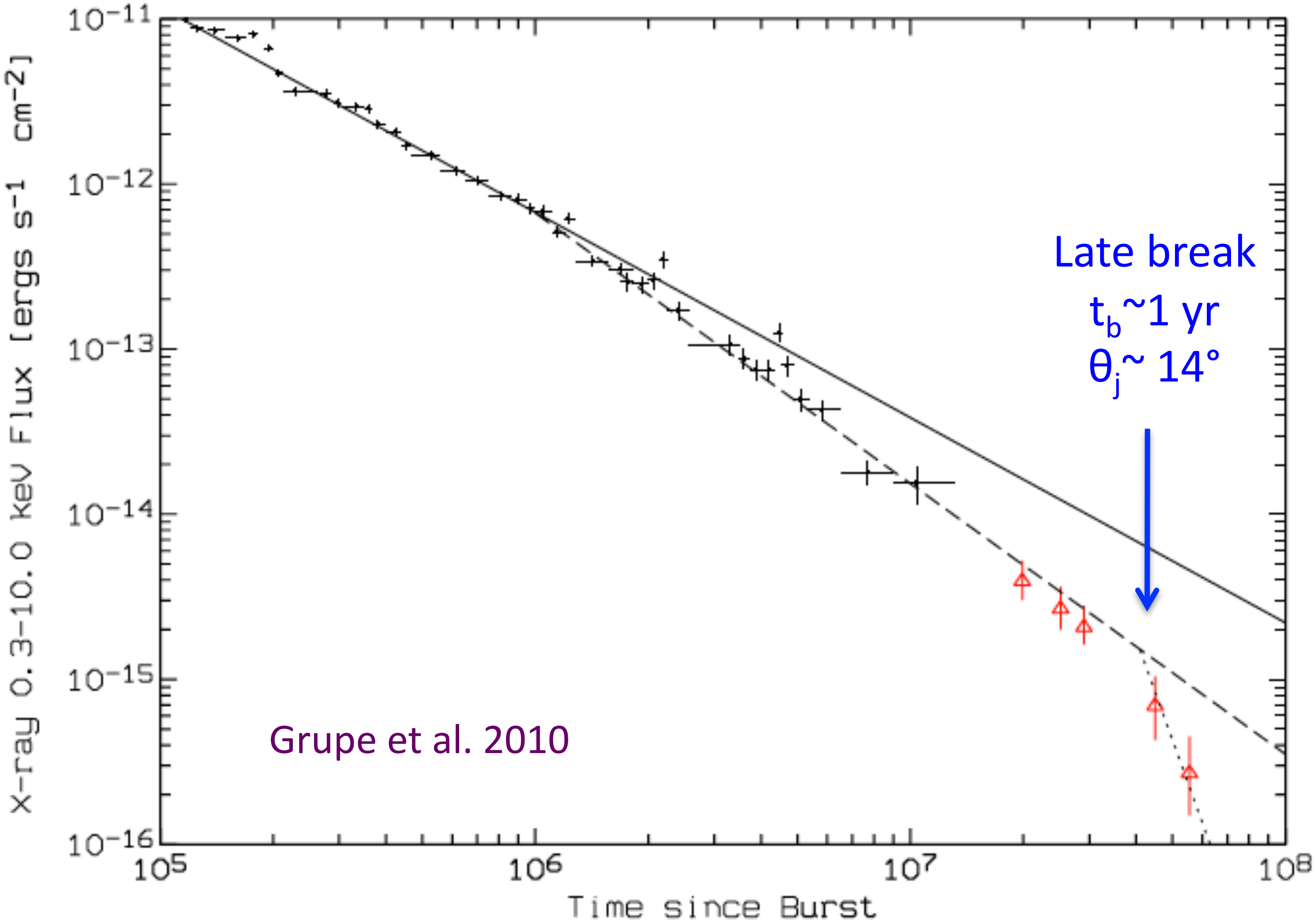
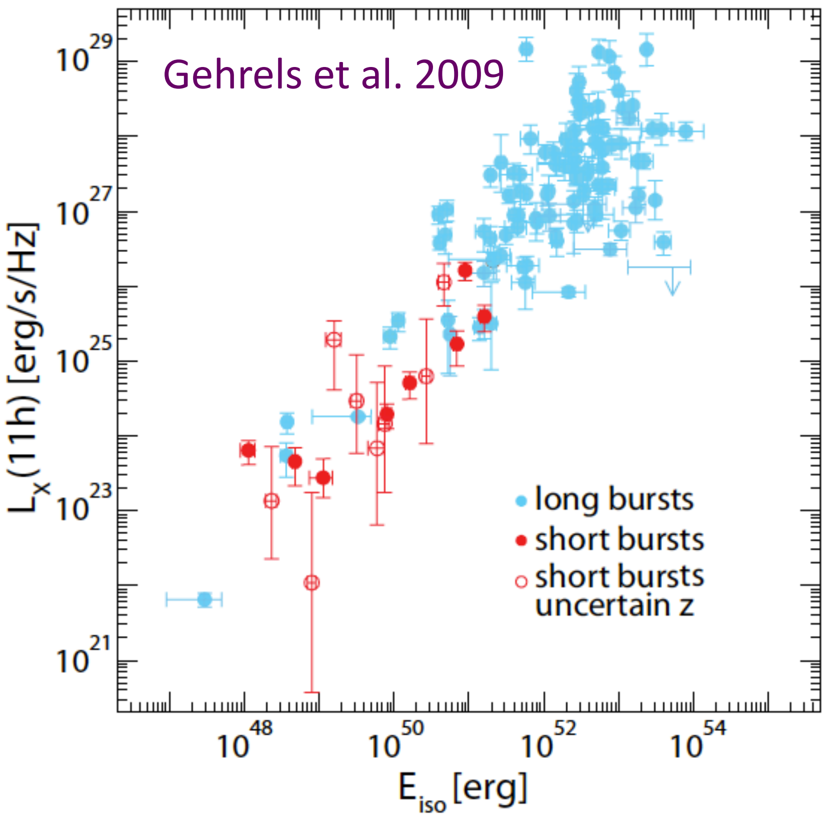
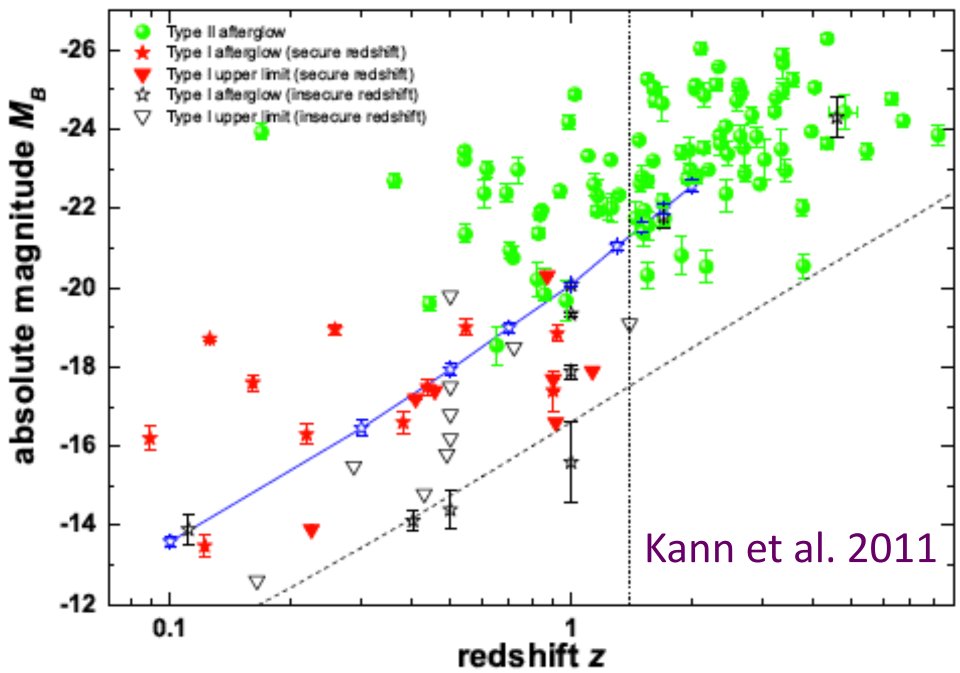
Late X-ray breaks



Late X-ray afterglow of GRB 060729 detected with Chandra

Short GRBs



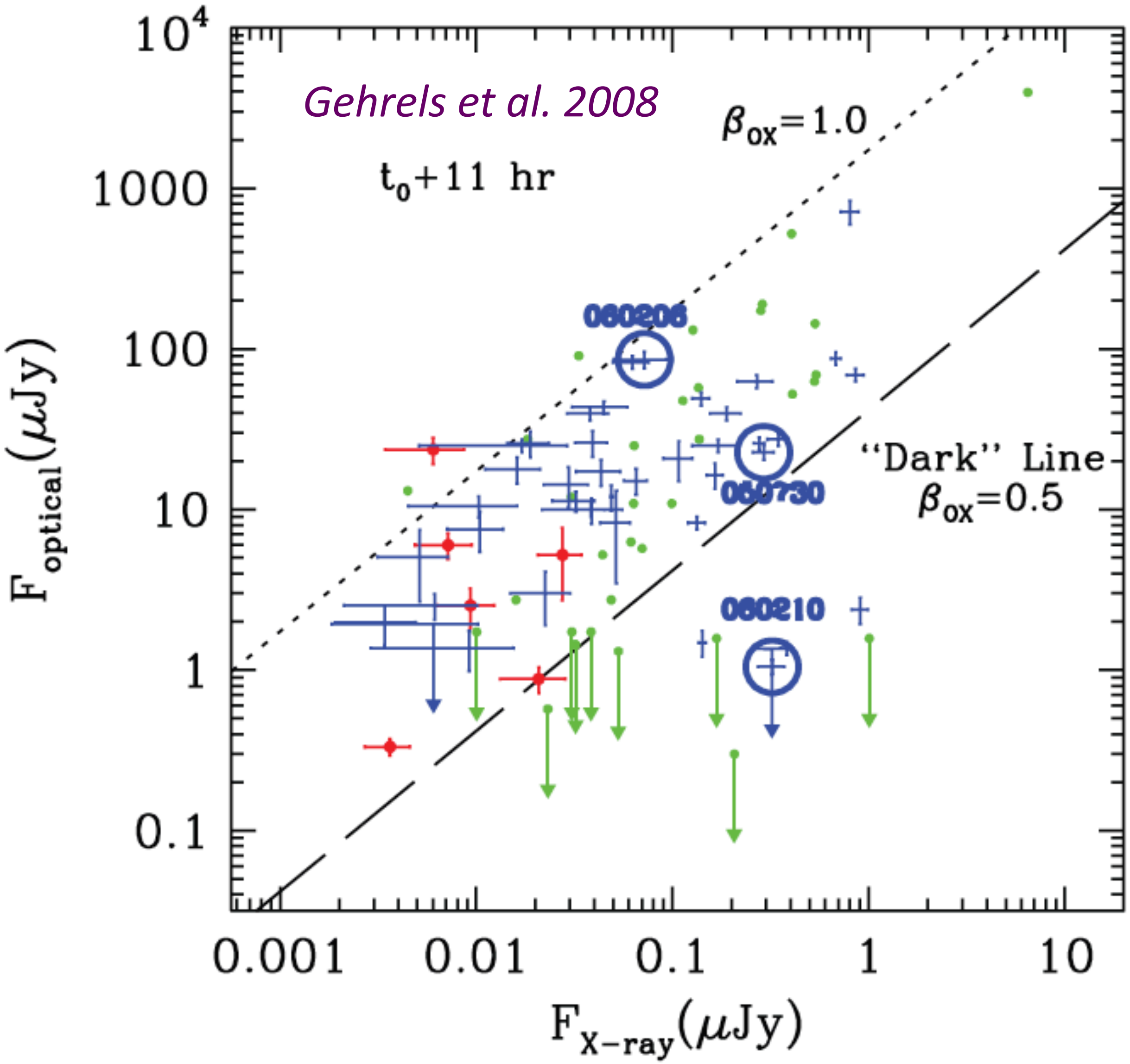


X-ray (left) and optical (right) luminosity of short (red) and long (cyan/green) GRBs.

X-ray afterglows of short GRBs are fainter and decay faster, remaining visible for shorter times.

Dark GRBs

- Swift GRB afterglows: F_{opt} vs F_X
- Dark GRBs have faint visible afterglows, but normal X-ray afterglows



GRB follow-up in *hard X-rays*

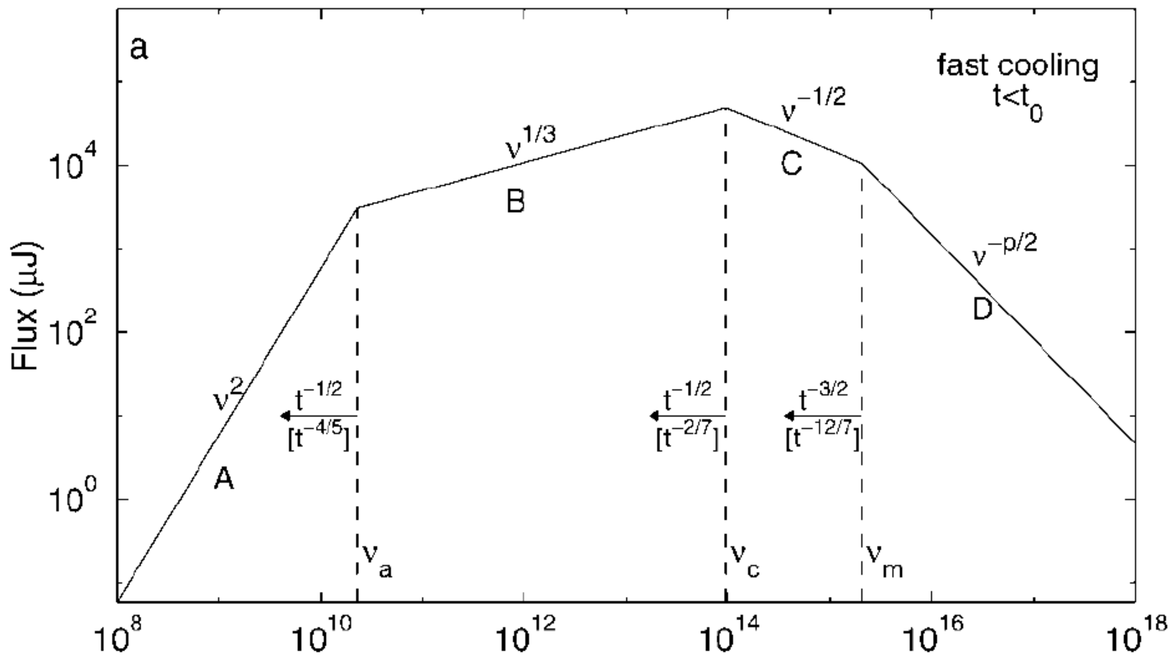
- A broad spectral coverage is fundamental to understand the physics of the afterglow

- Using the same (broad) spectral range for detection and follow-up helps understanding the prompt-to-afterglow transition, and the emergence of the afterglow

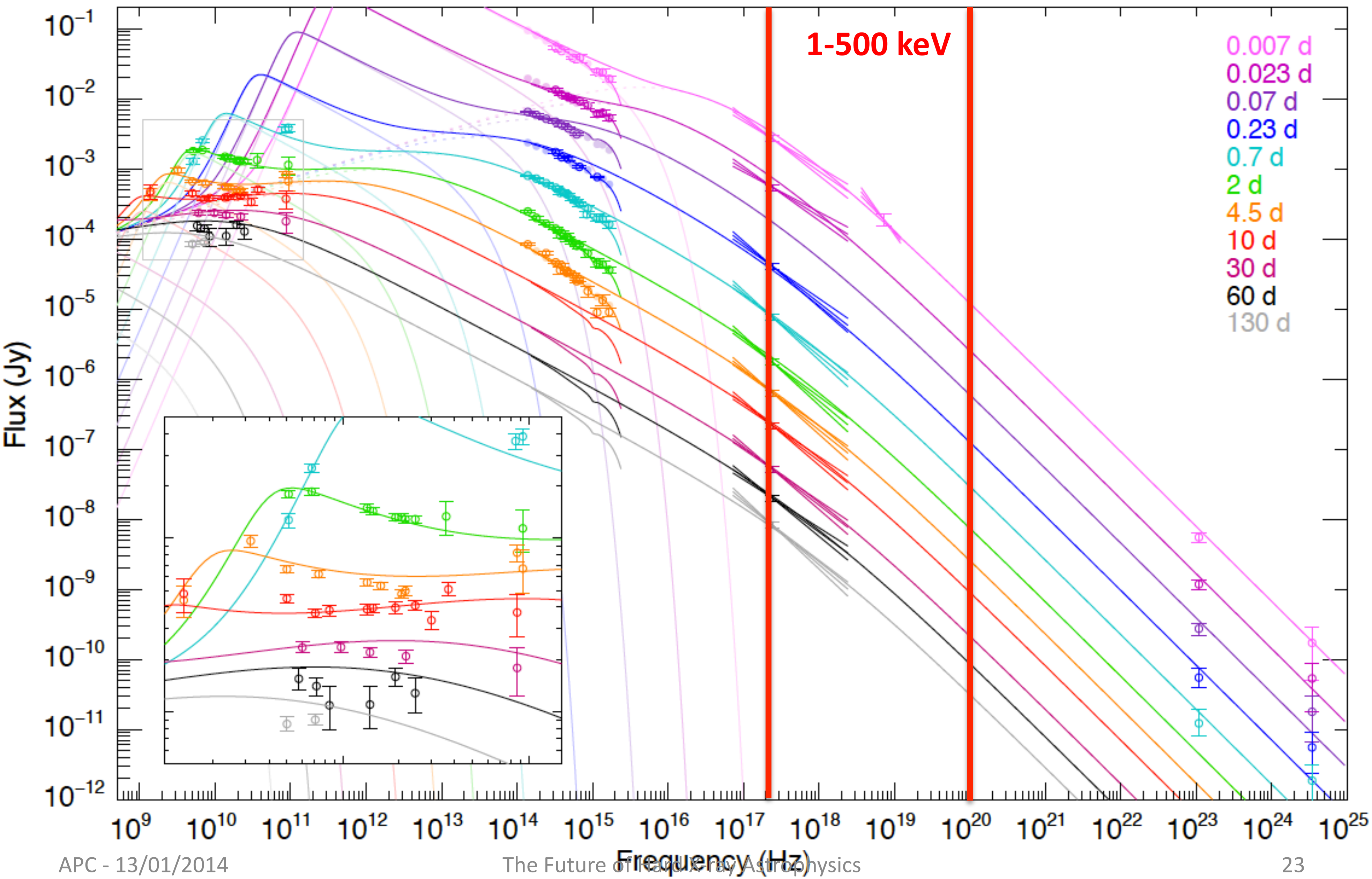
- Two recent observations with NuSTAR

Synchrotron spectrum of the afterglow

- The standard model attributes the afterglow to synchrotron emission of electrons accelerated at the external shock (when the relativistic jet impinges the external medium). This model predicts a spectrum made of connected power laws, evolving with time
- The validation of the standard model is very important (e.g. to interpret Fermi-LAT observation of GeV photons hours after trigger), but it relies on measuring the predicted power laws.

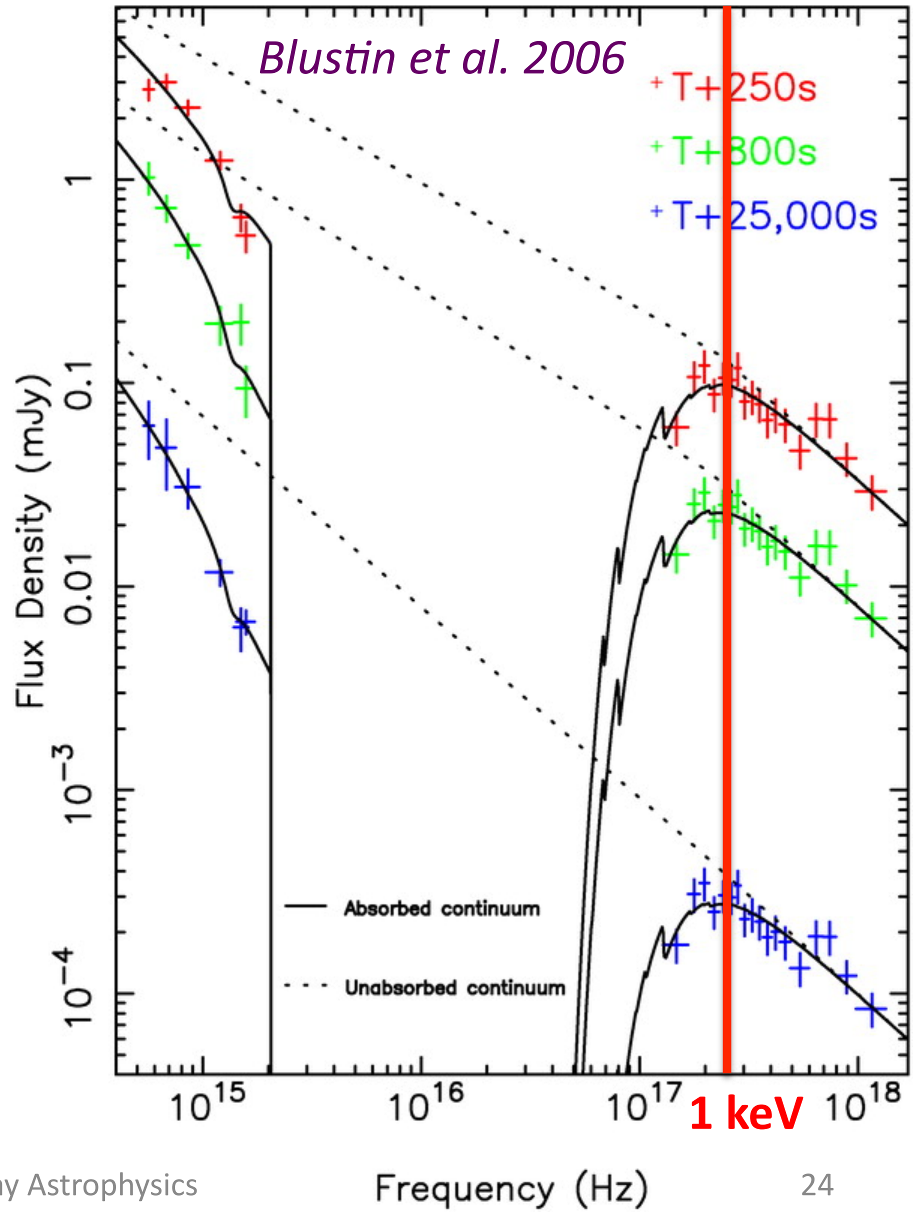


Perley et al. 2014



Hard X-ray follow-up

- A broad spectral range is required to measure the spectral slope of the afterglow in the X-ray range:
  - Accurate measure of the spectral slope
  - Identification of spectral breaks or curvature of the spectrum
  - Measure of N_H
  - Interpretation of optical emission



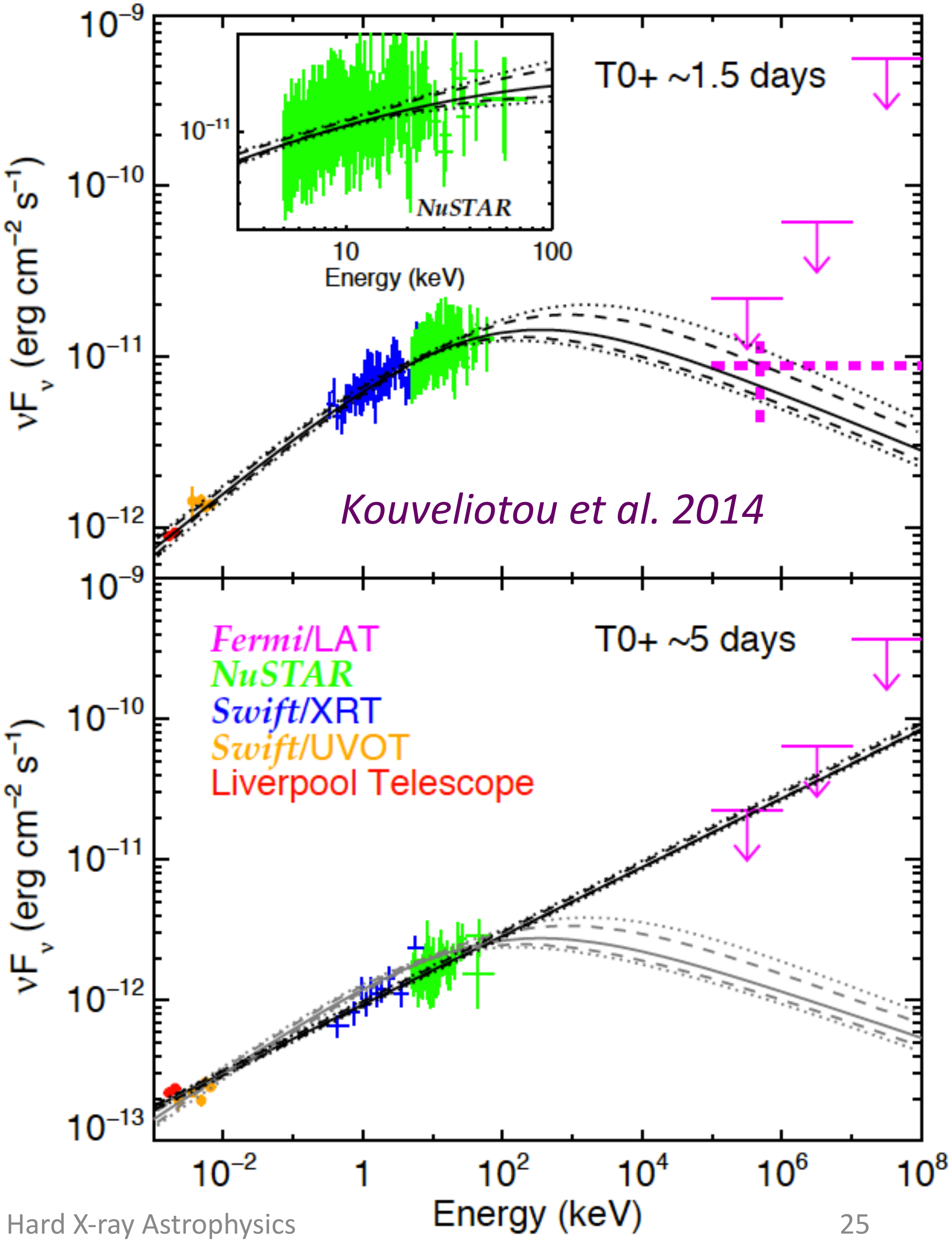
GRB 130427A with NuSTAR

- GRB 130427A

  Kouveliotou et al. (arXiv: 1311.5245):

  « The NuSTAR data are essential in constraining the shape of the broadband spectra. »

  « NuSTAR observations unambiguously establish a single afterglow spectral component from optical to multi-GeV energies a day after the event, which is almost certainly synchrotron radiation. »



GRB 130925A with NuSTAR

- GRB 130925A
  - Bellm et al. (Atel #5435): *«NuSTAR observes a broad absorption feature centered near 6 keV. Simultaneous Swift-XRT spectra support the existence of this feature at lower SNR. An F-test of a Gaussian absorption feature fit to the combined data sets yields a detection significance of 5.5 sigma. Preliminary searches for features in the early-time XRT data have not identified any clear signatures; additional tests are ongoing. »*

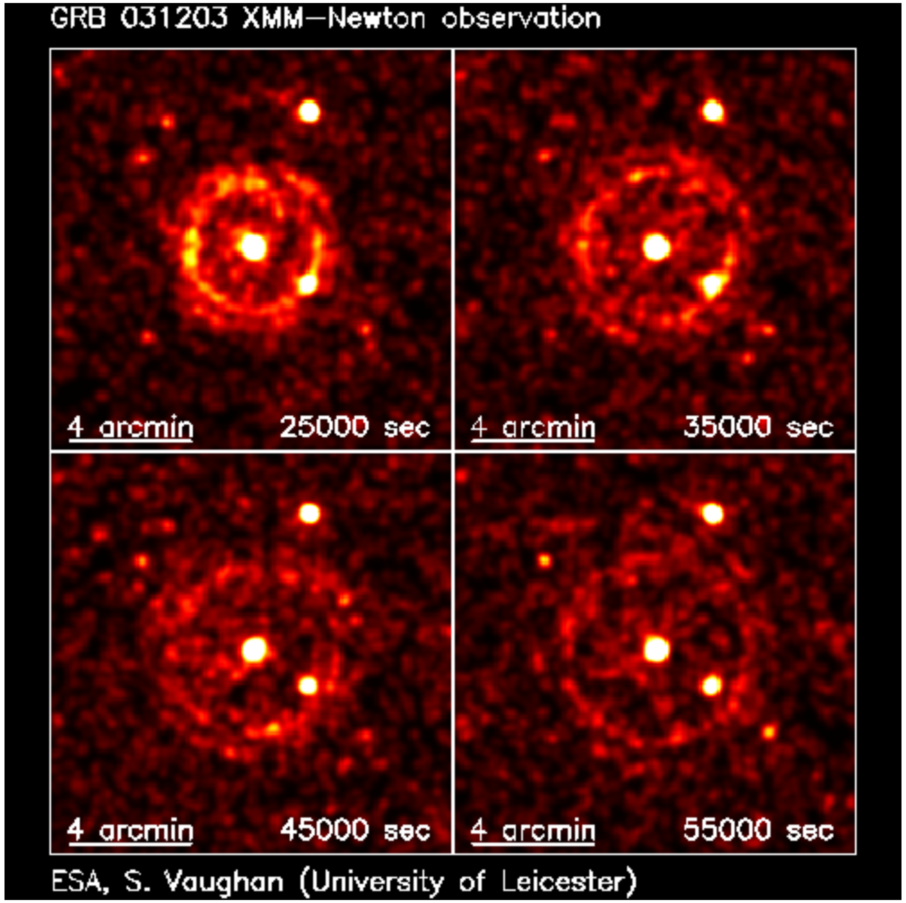
- *A suivre…*

Summary

- Prompt emission:
  - The hard X-ray window seems the best choice for GRB detection and initial location
  - Polarimetry is a high-priority scientific objective
  - Requires $\approx 10^3$ cm^2 of detection area to get enough photons

- Afterglow:
  - The extent of the spectral coverage is very important to understand the physics of the afterglow, with issues like the measure of the SED of the afterglow, the prompt-afterglow transition, and the interpretation of the optical emission

X-ray halos from GRBs (on galactic dust)



- Diffusion of GRB prompt X-rays by galactic dust
- Characteristic size of X-ray halos :

$$\frac{10'}{E * a}$$

  - E = energy (keV)
  - a = characteristic size of the grains
- The size of the halo depends on the size of the grains and their distribution along the line of sight
- For GRB 031203, for instance, there are two clouds at 880 pc and 1390 pc (Vaughan et al. 2004).