V WORKSHOP CHALLANGES OF NEW PHYSICS IN

SPACE

Rio de Janeiro – April 28 to May 3 2013
CENTRO BRASILERO DE PEQUISAS FISICAS – CBPF -TEO

GAMMA RAY BURSTS

Giancarlo Ghirlanda
giancarlo.ghirlanda@brera.inaf.it
Istituto Nazionale di Astrofisica (INAF)
Osservatorio Astronomico di Brera

General outline of 3 talks

1) Gamma Ray Bursts: the observational pillars after two decades of observations

Global observational properties of GRBs in the frequency/time domain (prompt and afterglow – long and short), their typical energetics, distance scale, spectral properties etc.

2) Theoretical picture: the standard model from its foundation to the latest debates

3) Gamma Ray Bursts in the cosmological context: present status, issues and perspectives

Definition

Short (< 10^{3} sec) intense emission episodes of high energy γ-ray photons...

1973-1997

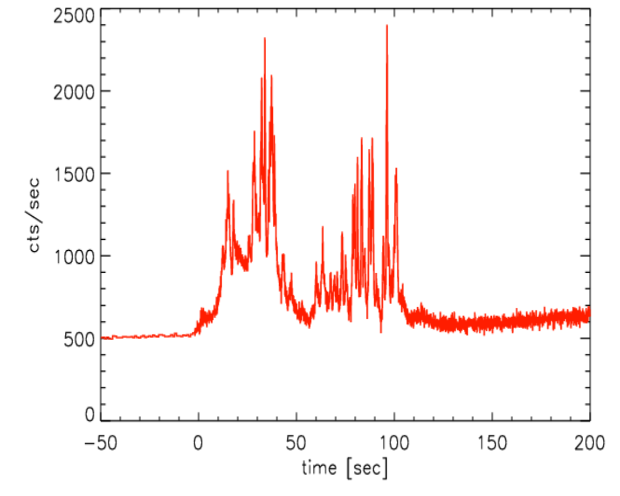
PROMPT

... accompained by a considerable long lasting emission at lower energies (X-ray, Optical, IR and Radio)

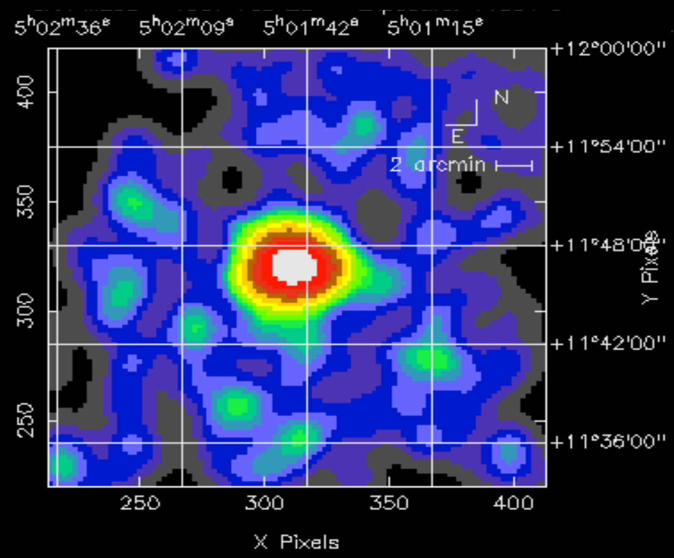
> 1997

AFTERGLOW

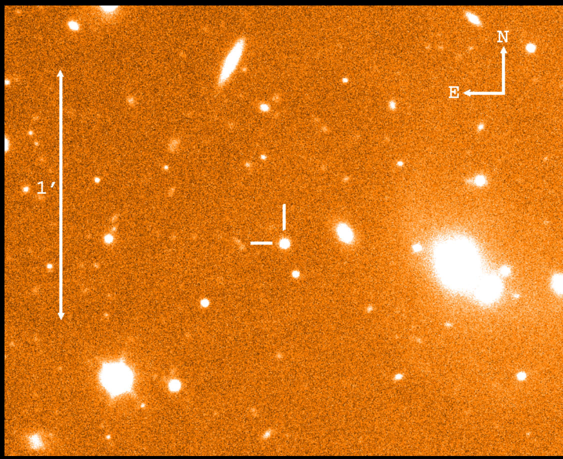
γ-ray



X-ray

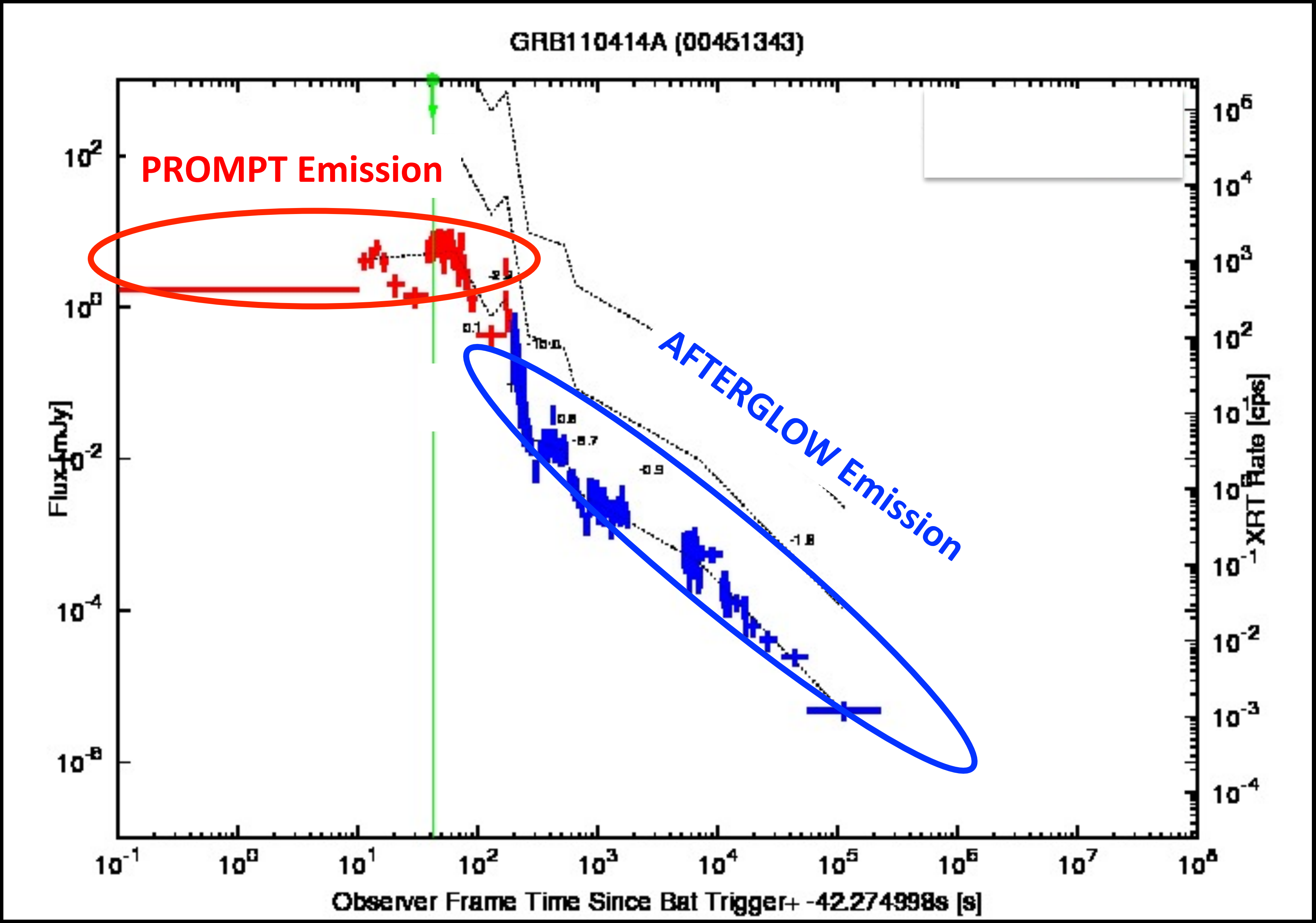


Optical



... ...

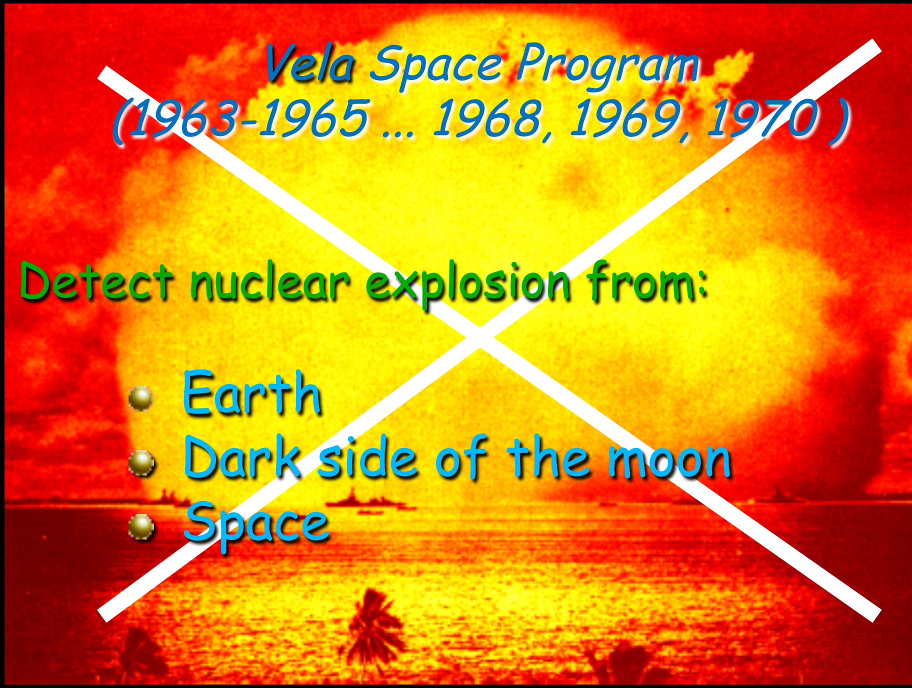
Nomenclature

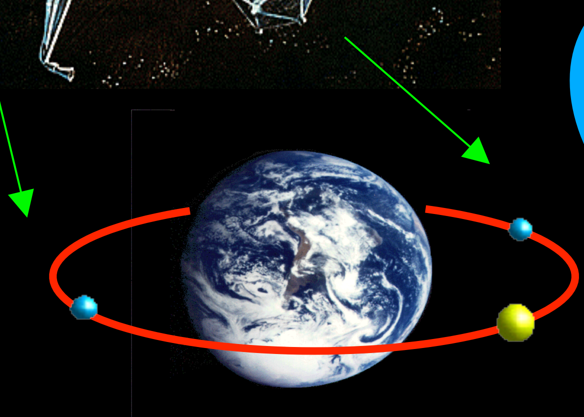


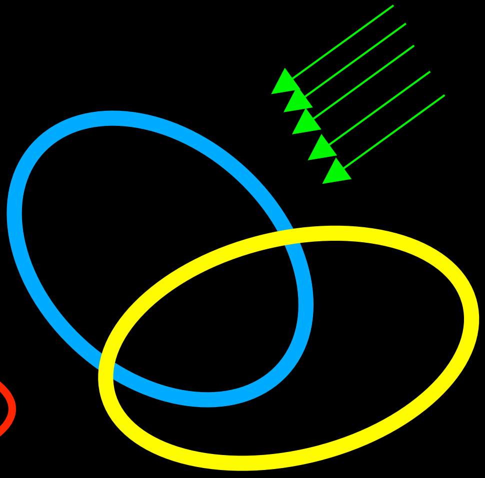
HYSTORICAL DEVELOPMENT

History

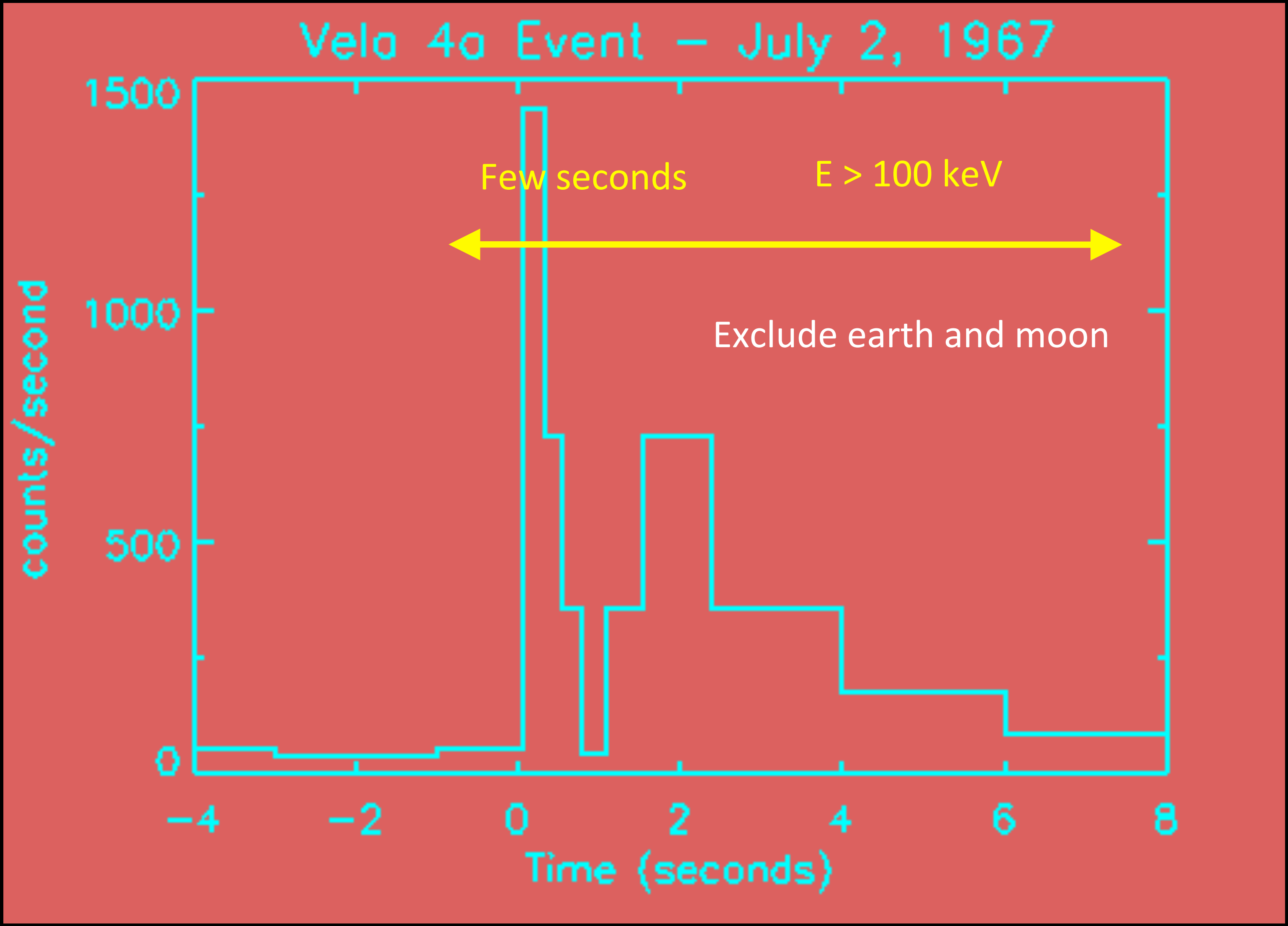
5 August 1963 US + UK + USSR sign the LTBT=Limited Test Ban Treaty, banning nuclear weapon tests in the atmosphere, in outer space, and under water.





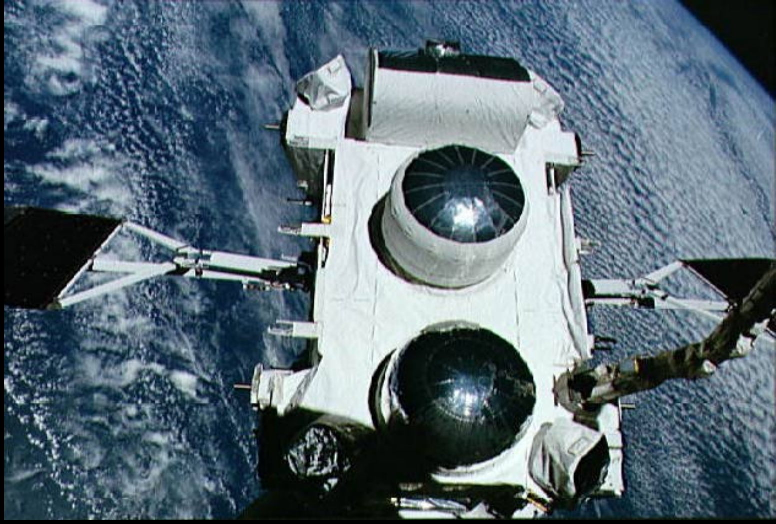


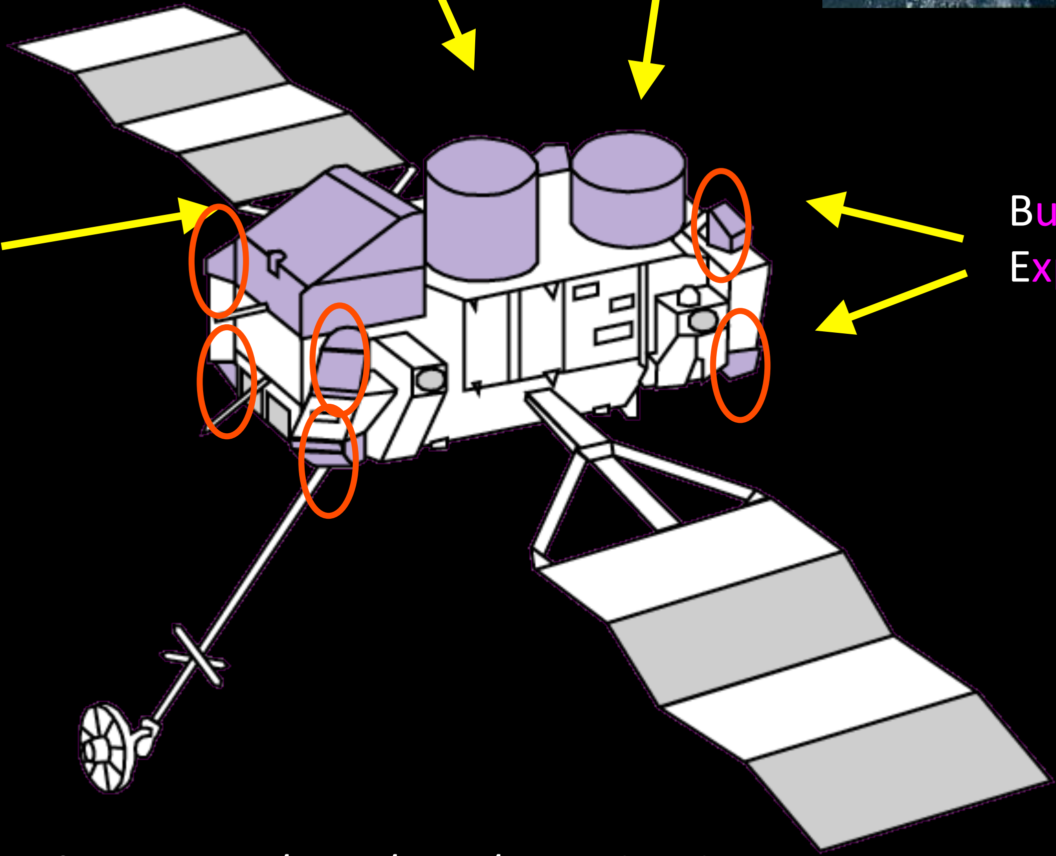
(probably) one of the First Gamma Ray Burst



Klebesadel, Strong, Olson, 1973, ApJ, 182, L85

Compton Gamma Ray Observatory (CGRO) 1992-2000





Burst And Transient Source Experiment (BATSE)

0.03 – 2 MeV

~ 1-5 keV e_res.

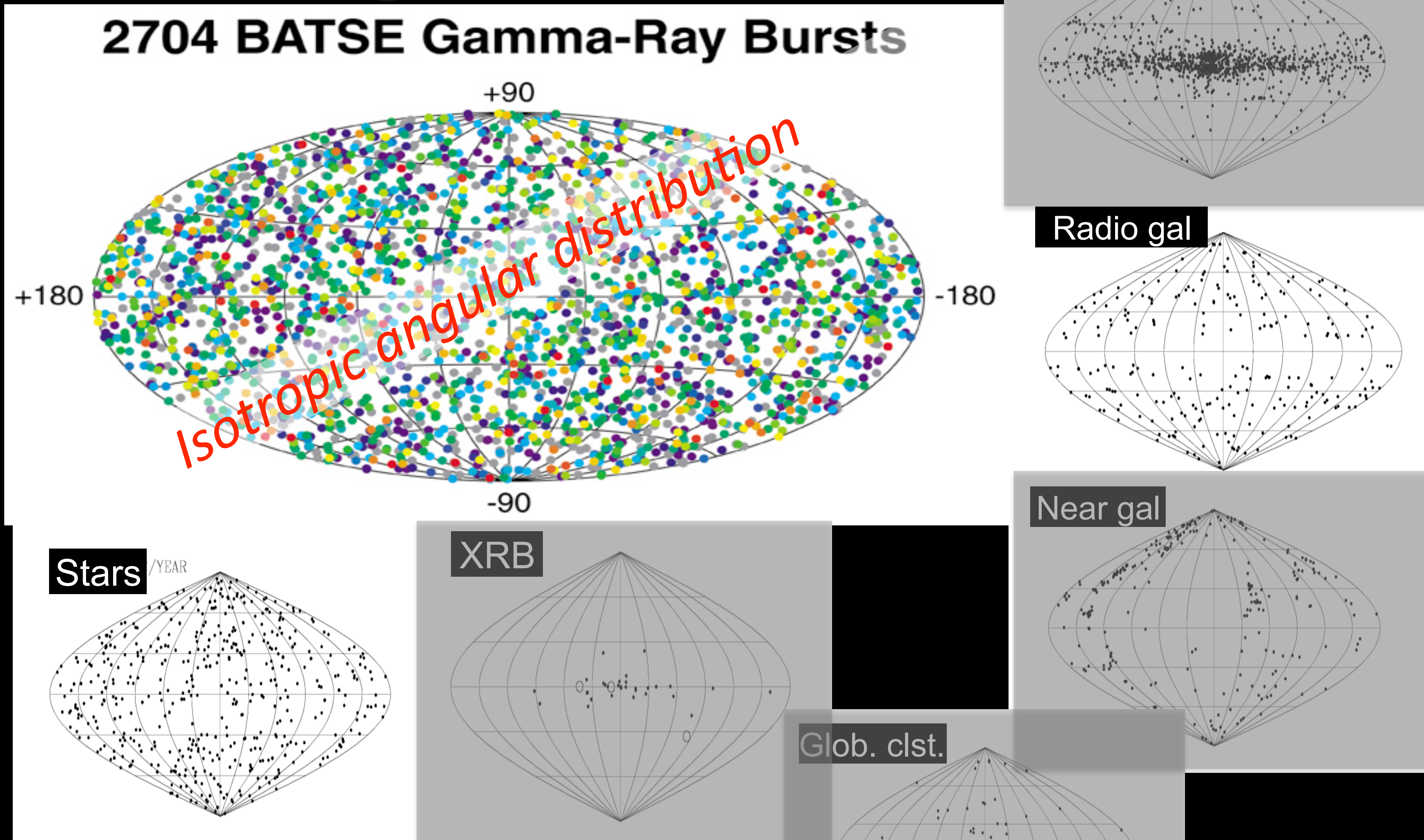
~ 10 ms t_res

F ~10^{-7} erg/cm^2

~ 4π fov

http://heasarc.gsfc.nasa.gov/docs/cgro/index.html

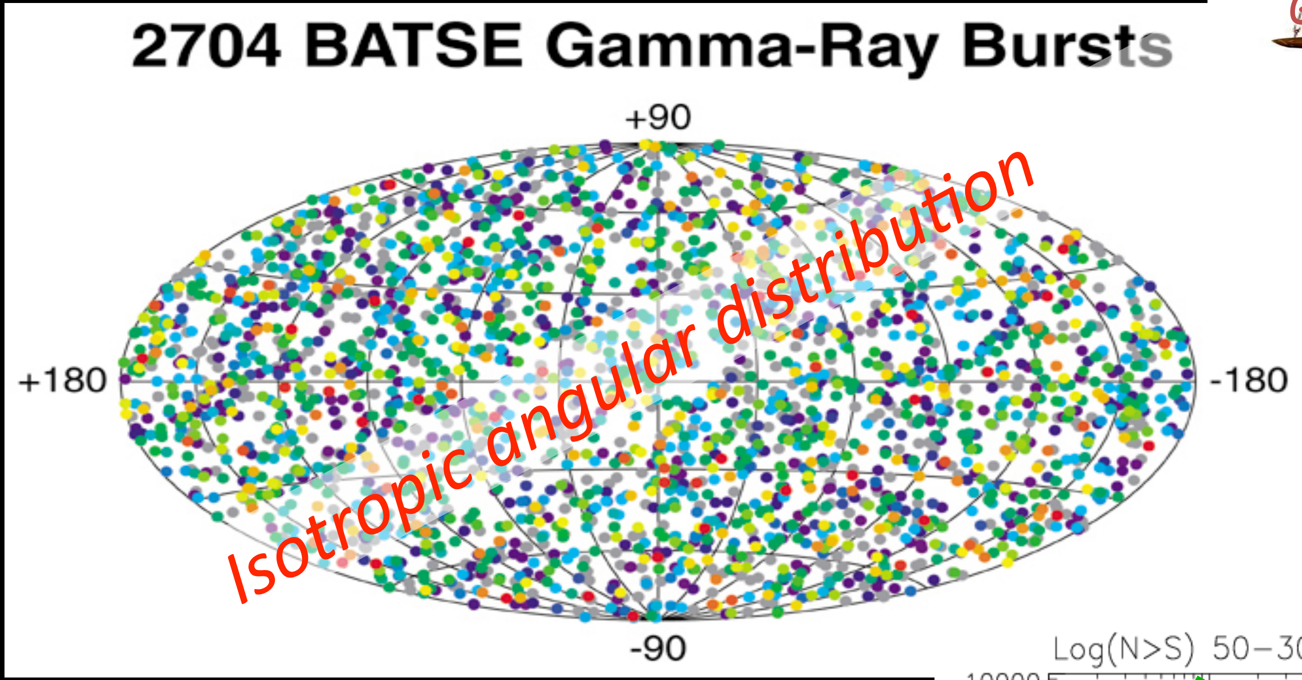
The “great debate”

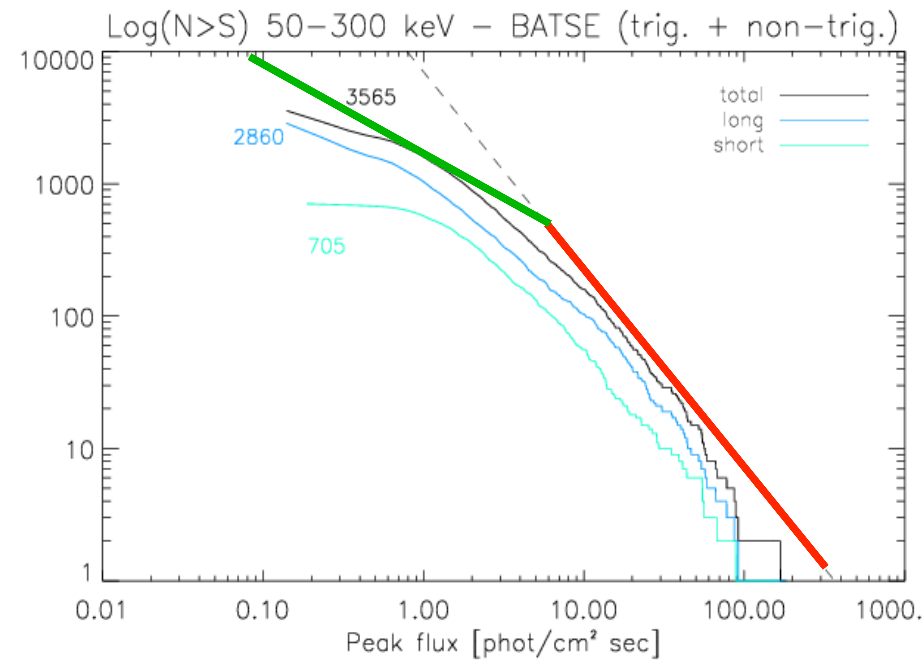


Galactic or Cosmological ?

Paczynsky B., PASP, 107, 1167

The "great debate"

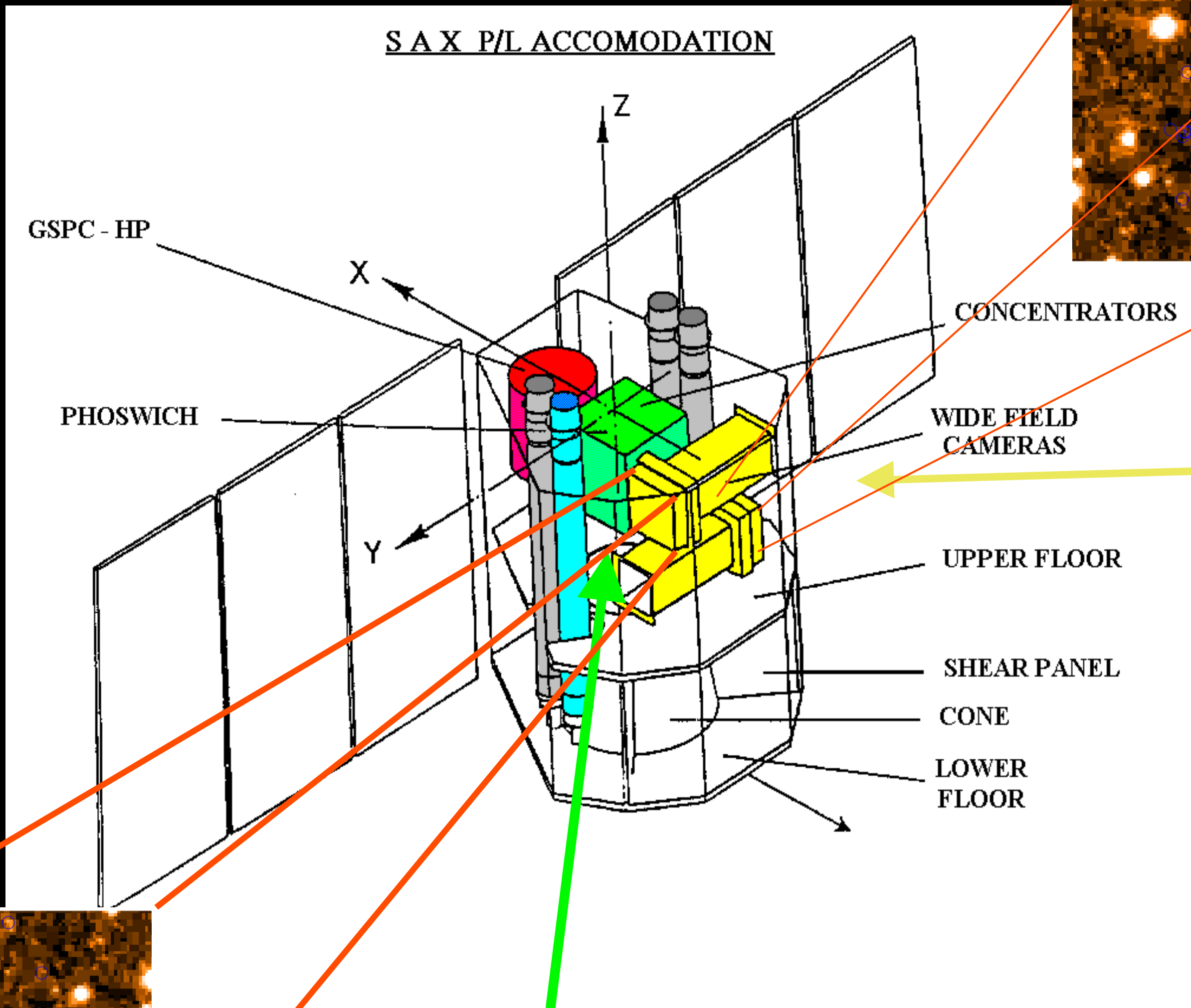


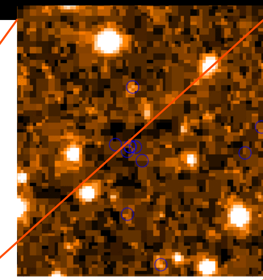


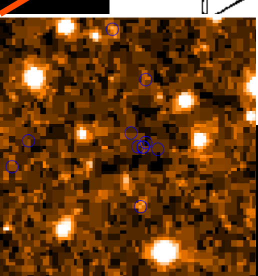
BeppoSax (1996-2002)

http://www.asdc.asi.it/beppsax/

(Italian-Dutch satellite for X-ray astronomy)





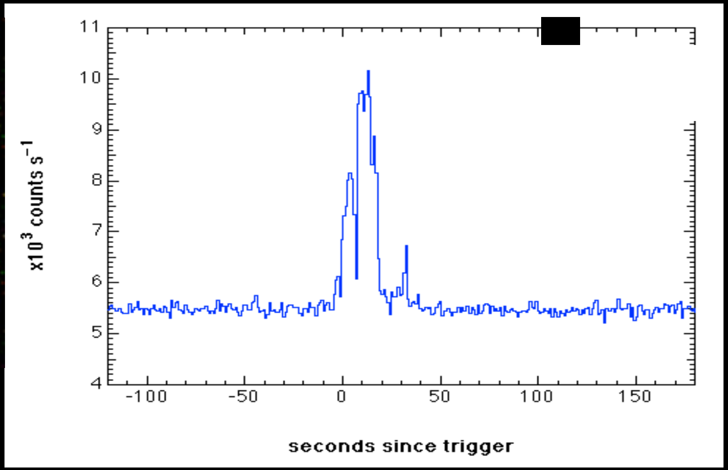


Wide Field Camera (WFC)
(2-30 keV; 20x20 degree FOV
angular resolution 5 arc min)

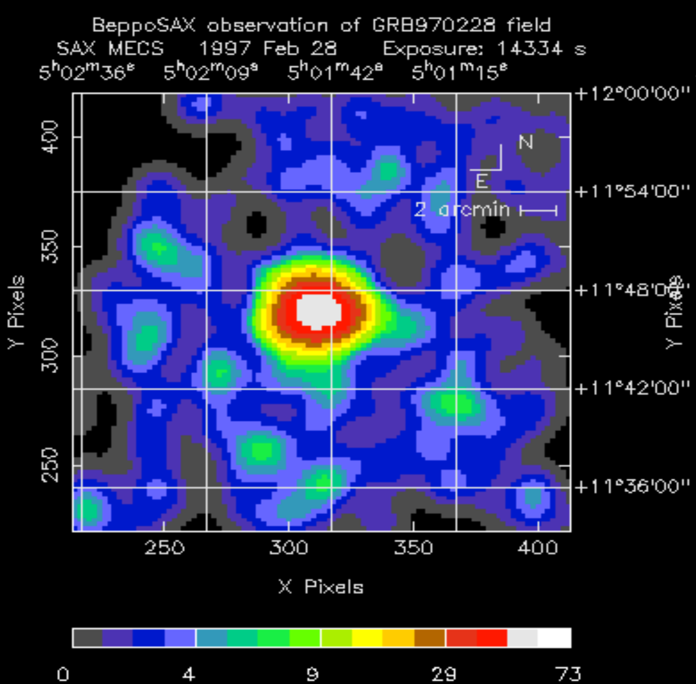
The scintillator (anti-coincidence shields of the Phoswich detector) are able to detect gamma-rays 60-600 keV and get crude angular information

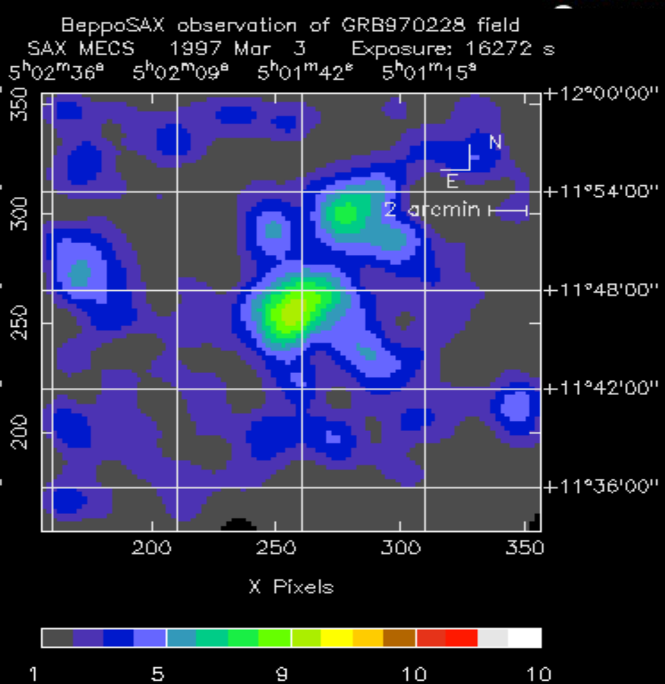
The answer to the "great debate"

28 Feb 1997



GRB 970228 is in the FOV of the WFC



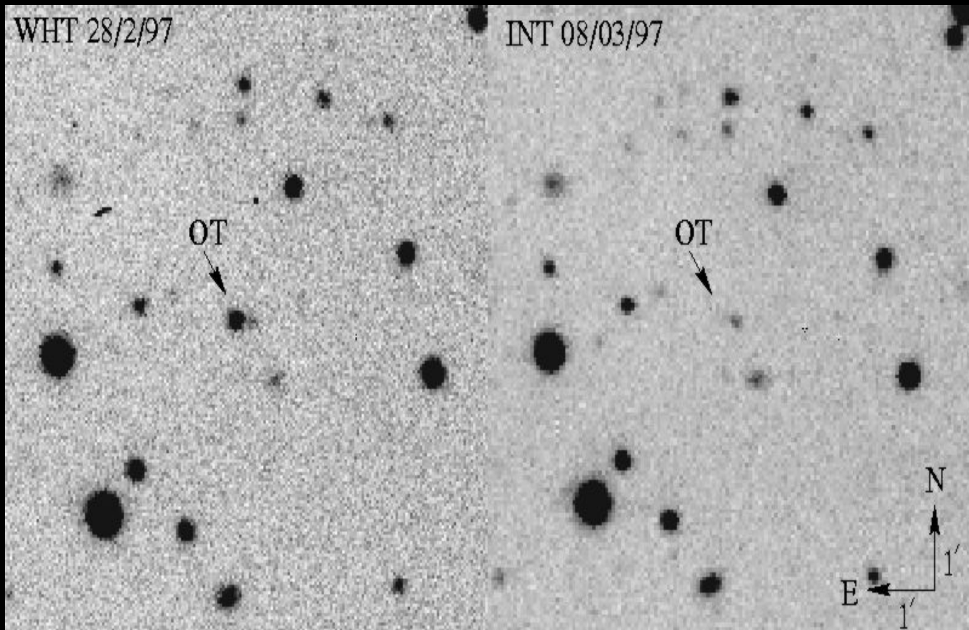


Afterglow discovery: emission from the burst in the X ray

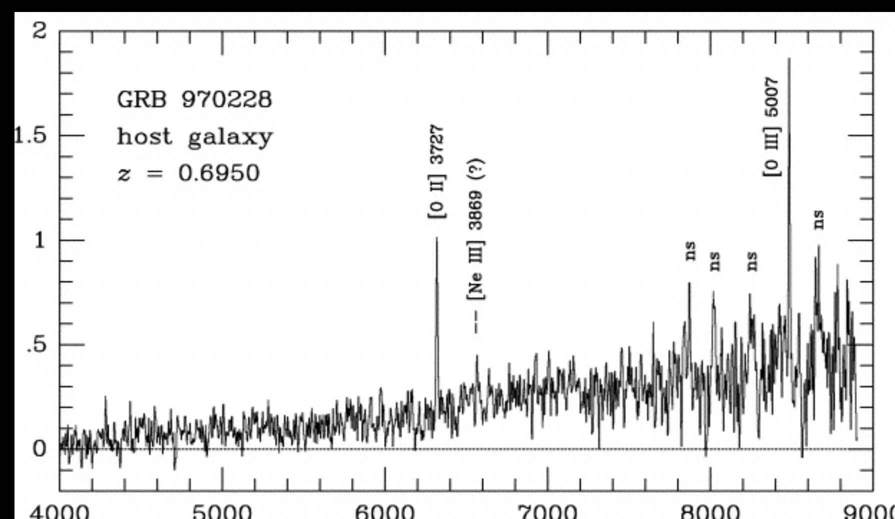
1. Fading
2. Well localized

Groot, Galama, van Paradijs, et al IAUC 6584, March 12, 1997

Redshift !!



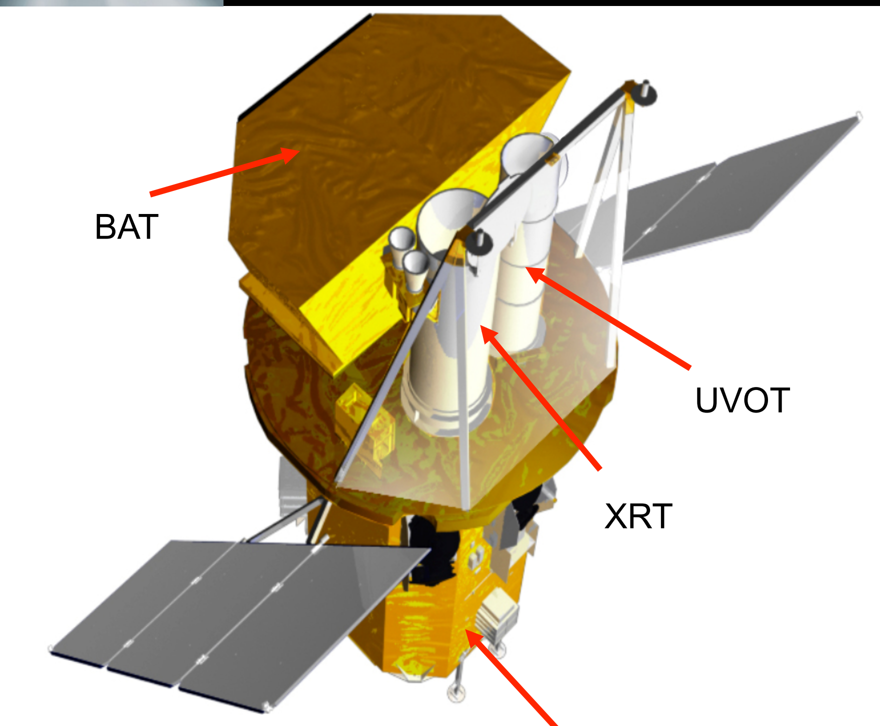
WHT 28/2/97
INT 08/03/97
OT
OT
N
E
1′
1′



GRB 970228
host galaxy
z = 0.6950
[O II] 3727
[Ne III] 3869 (?)
[O III] 5007
ns
ns
ns
ns
2
1.5
1
.5
0
4000
5000
6000
7000
8000
9000

Since Nov. 2004

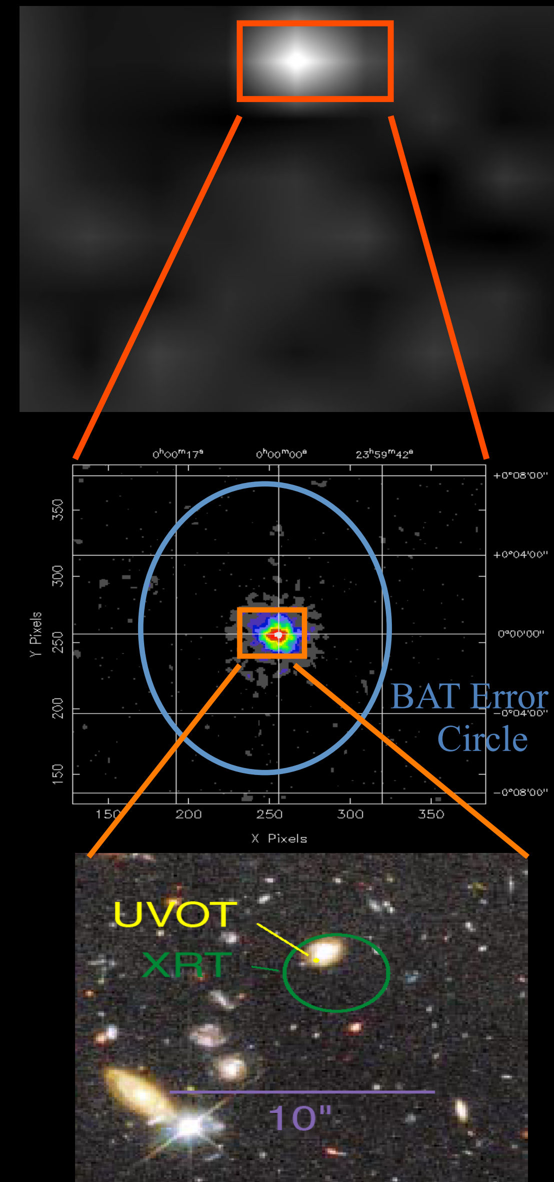
Swift: “everything in space”



T<10 sec
θ< 4′
E>15 keV

T<100 sec
θ < 5″
E<10 keV

T<300 sec
Optical/NIR



Satellite slews (1 min) and repoints its X ray (XRT) and UV telescopes to observe the error region of the GRB.

http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html

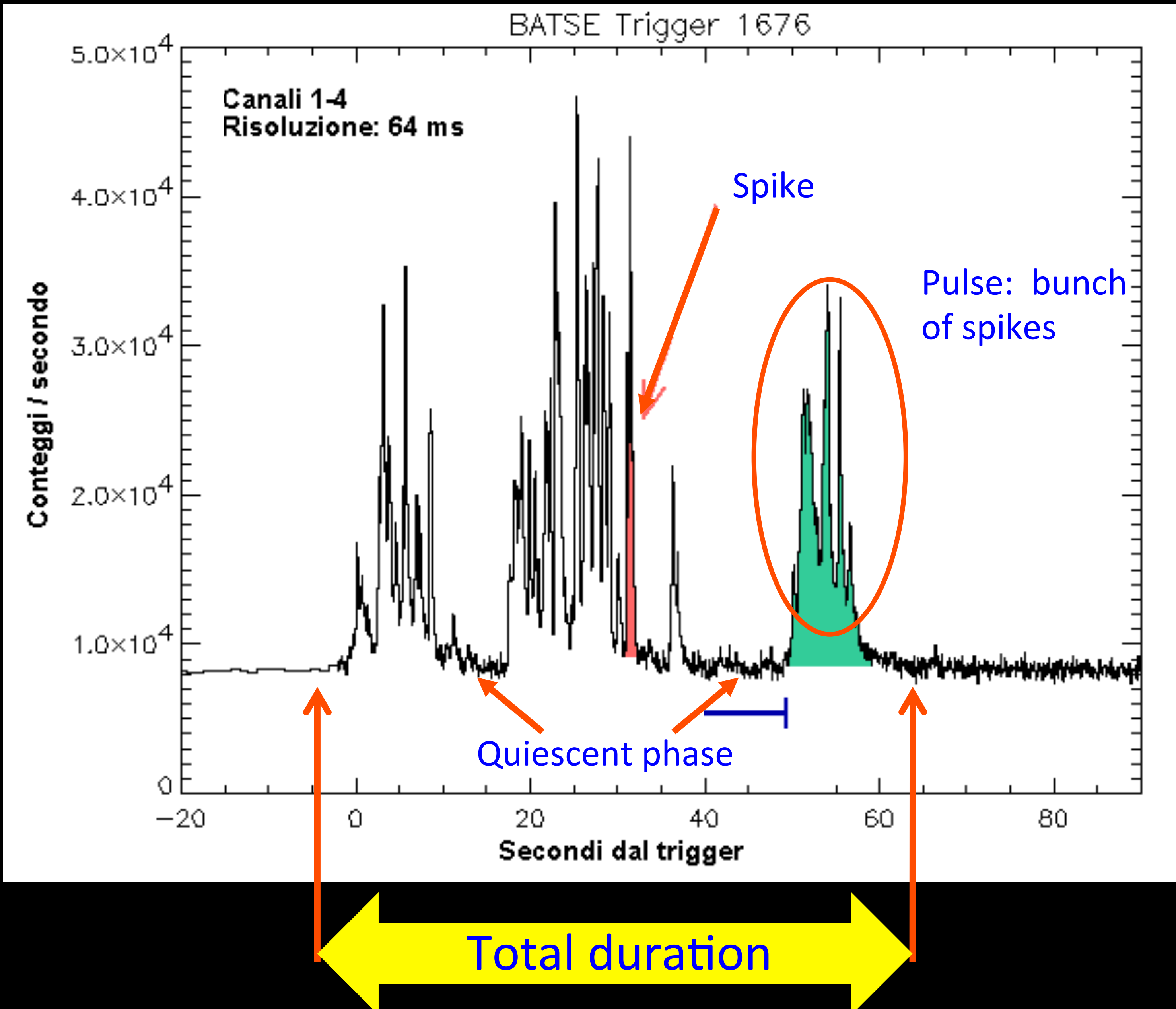
Lessons from the past (instrumental):

1. γ-ray detector in space (wide FOV, Large energy range …)
2. Fast slew (X-ray repoiting in <1 min)
3. Optical/NIR facilities (long term or dedicated)
4. Everything else … …

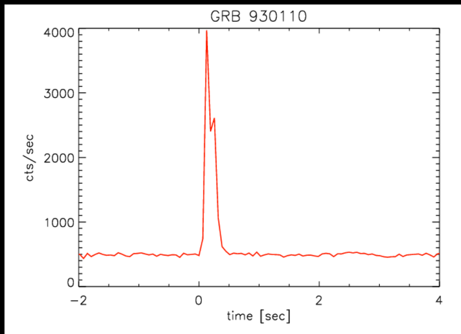
PROMPT EMISSION

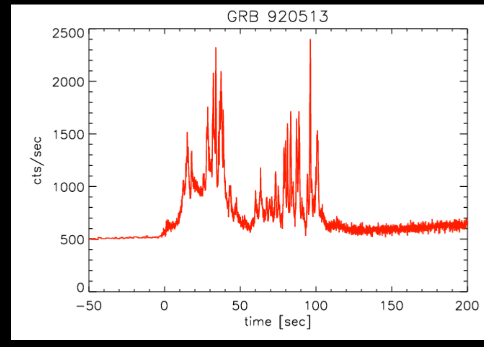
What is detected by in orbit dedicated GRB detectors
Emission of photons with typical energies > 10-100 keV

Prompt: how many timescales ?

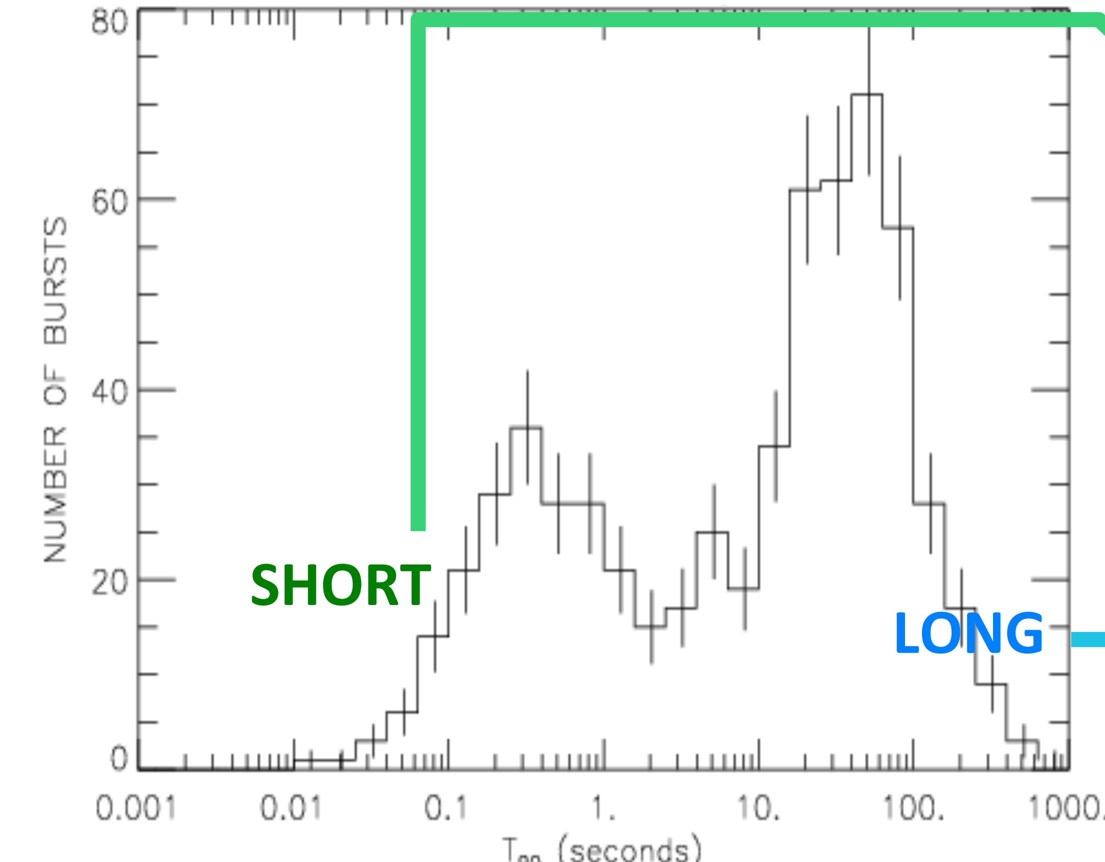


Duration: 2 classes
Hardness: 2 classes

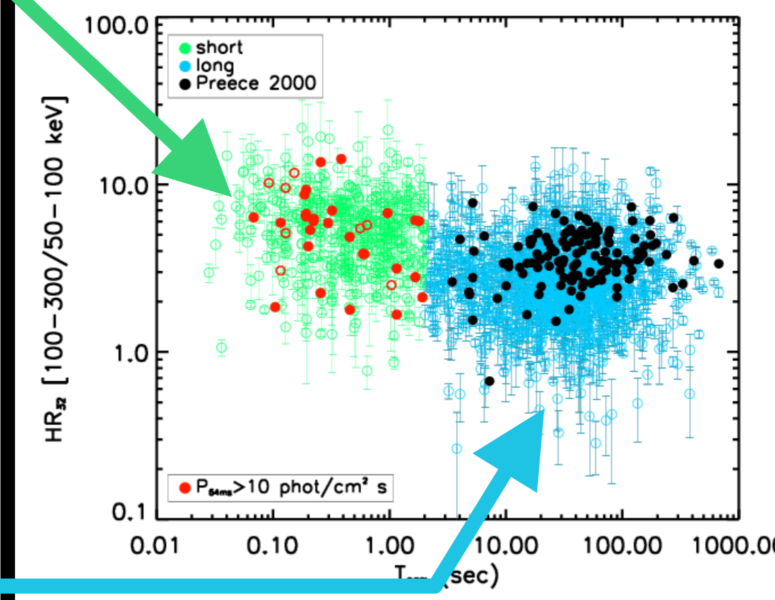




GRB duration distribution is bimodal



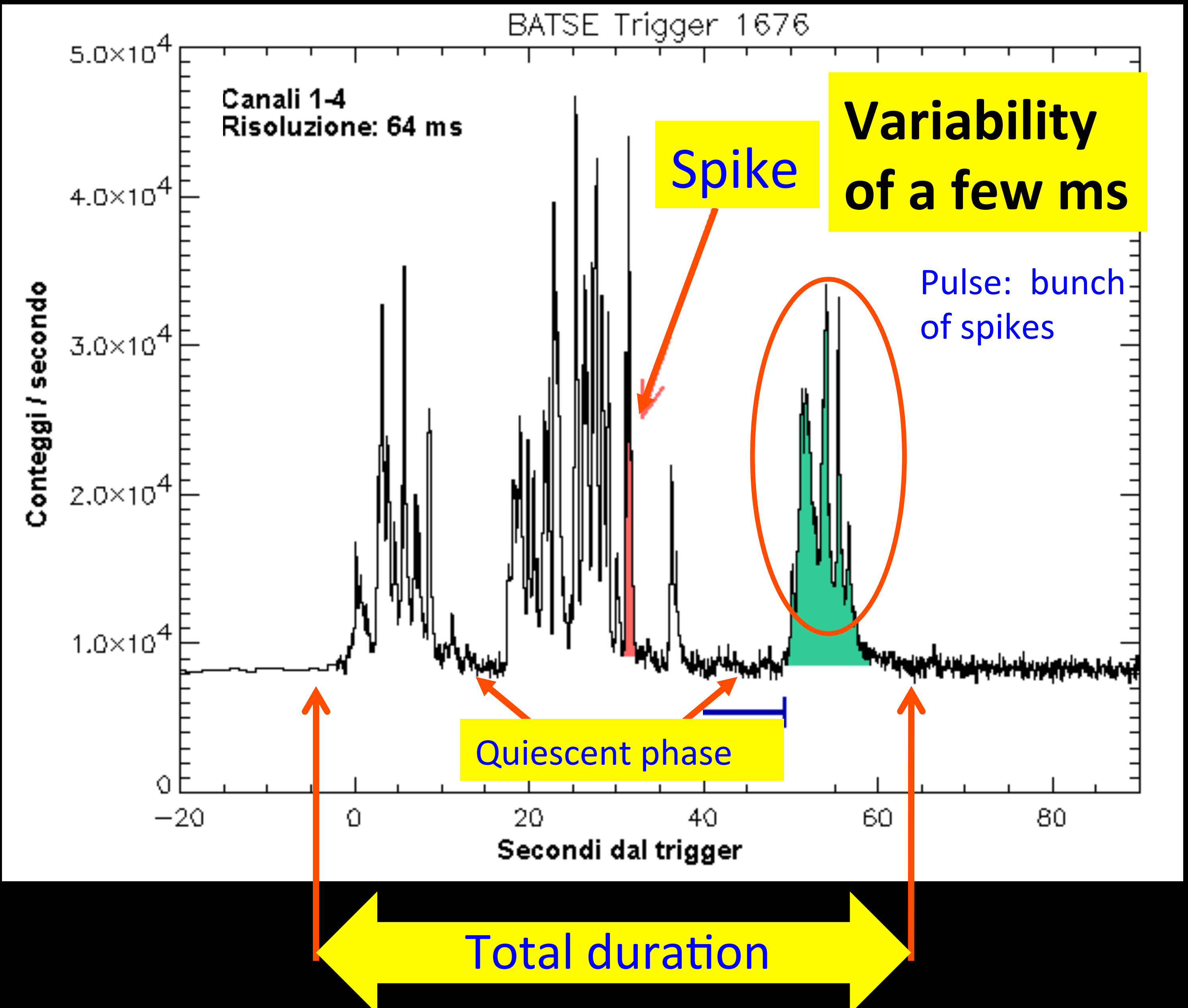
Hardness – Duration



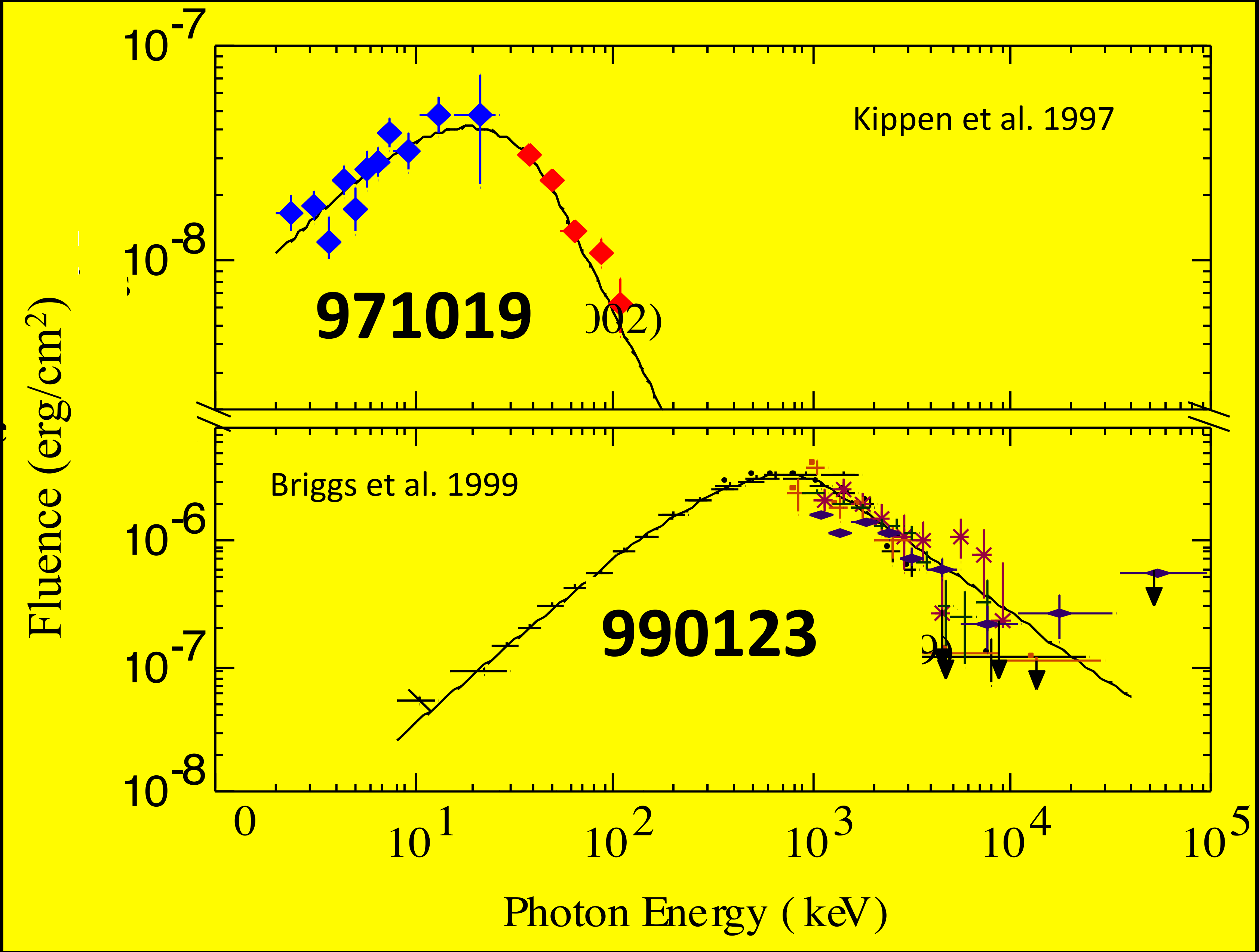
Paciesas et al. 2002, Kouveliotou et al. 1994

Short/long classification is based on observed properties … not so easy now !

Prompt: how many timescales ?

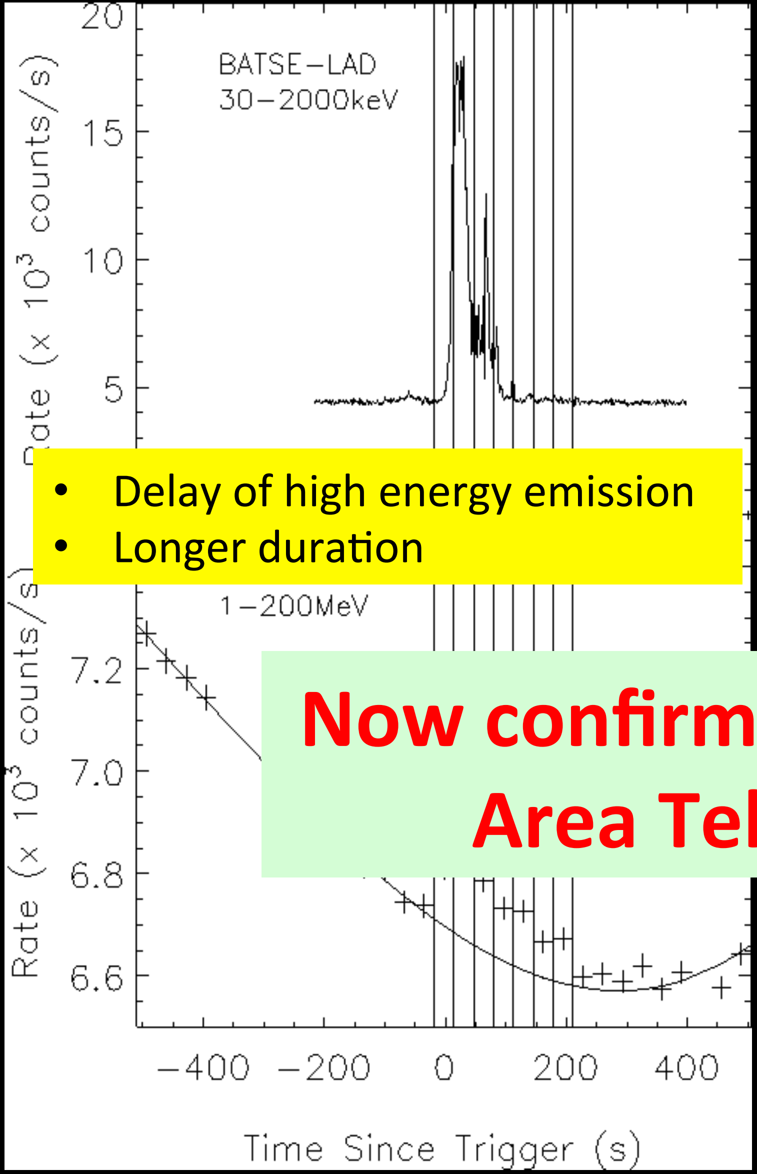


Prompt: The spectrum

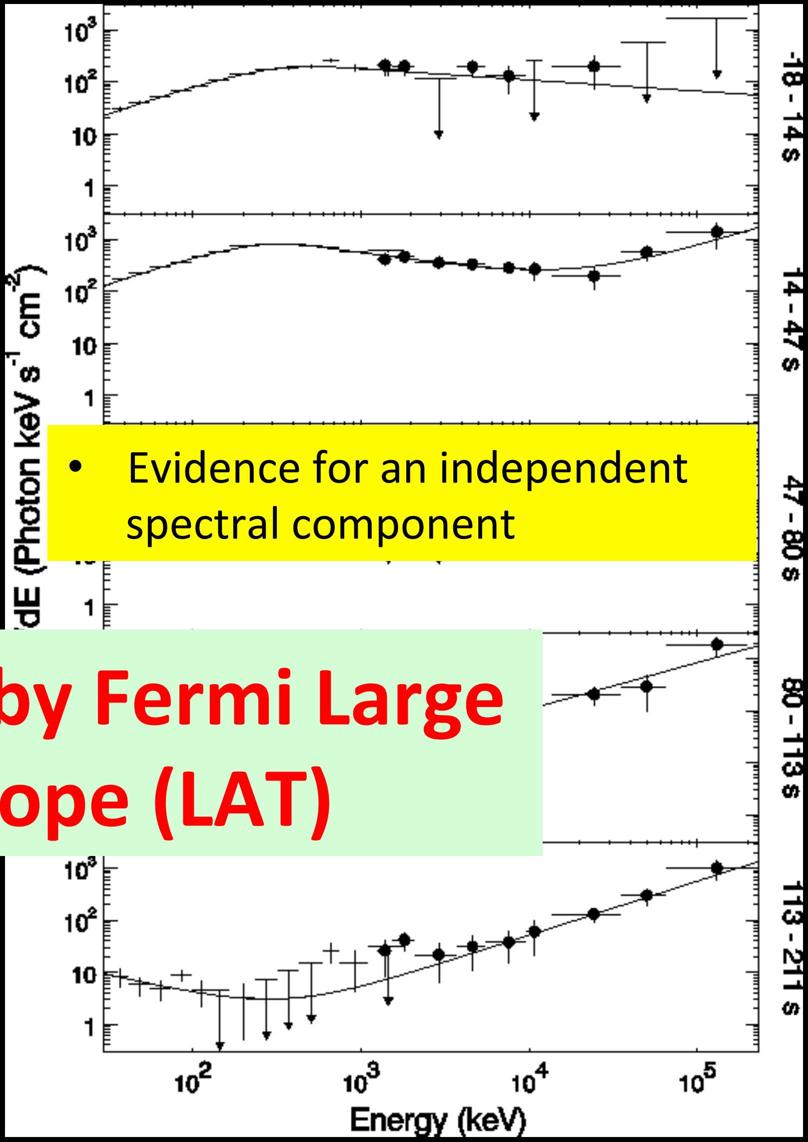


Prompt: GeV emission

GRB 941017 (Gonzales et al. 2004)



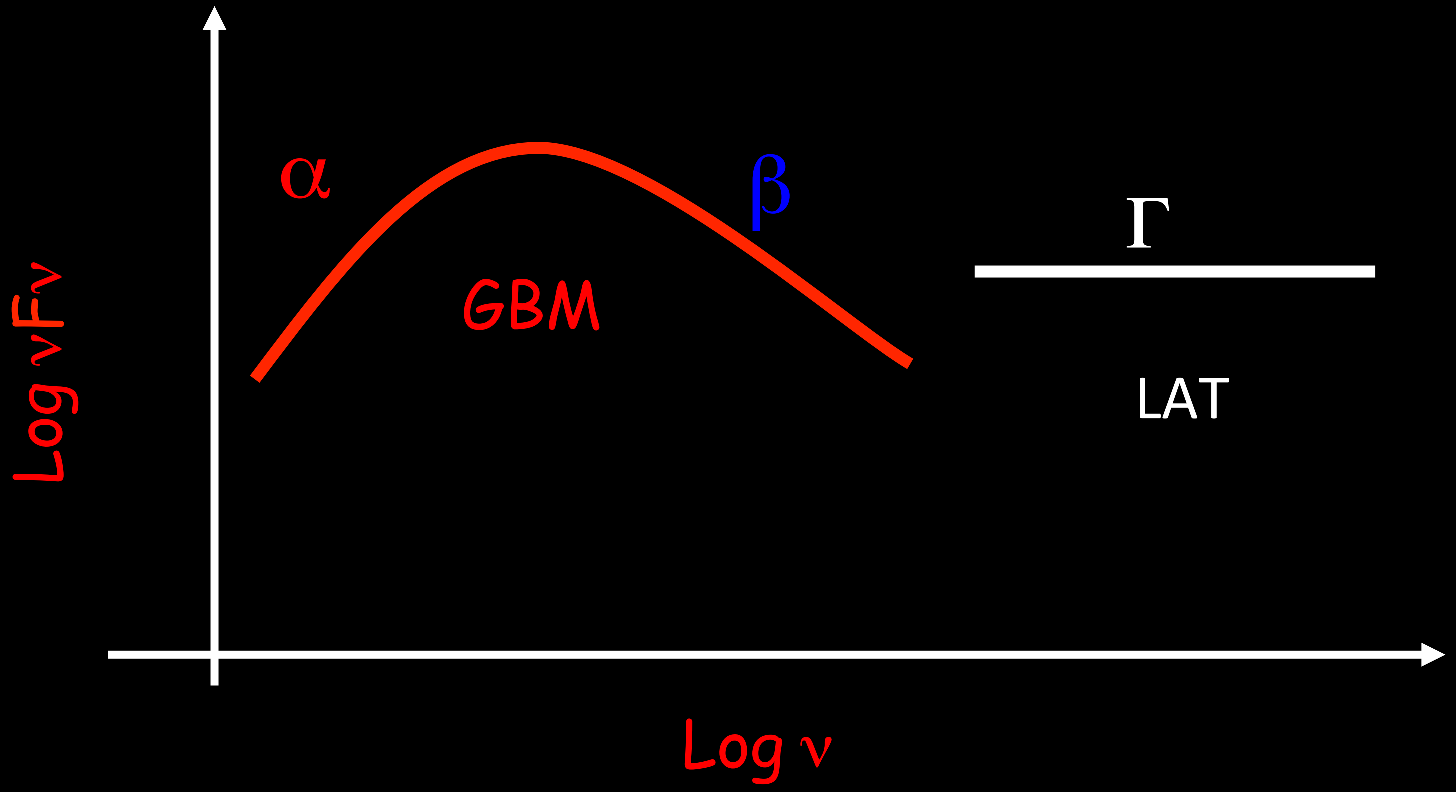
- Delay of high energy emission
- Longer duration



- Evidence for an independent spectral component

Now confirmed by Fermi Large Area Telescope (LAT)

High energy spectrum of a GRB



On going take home list

Prompt emission:

Temporal

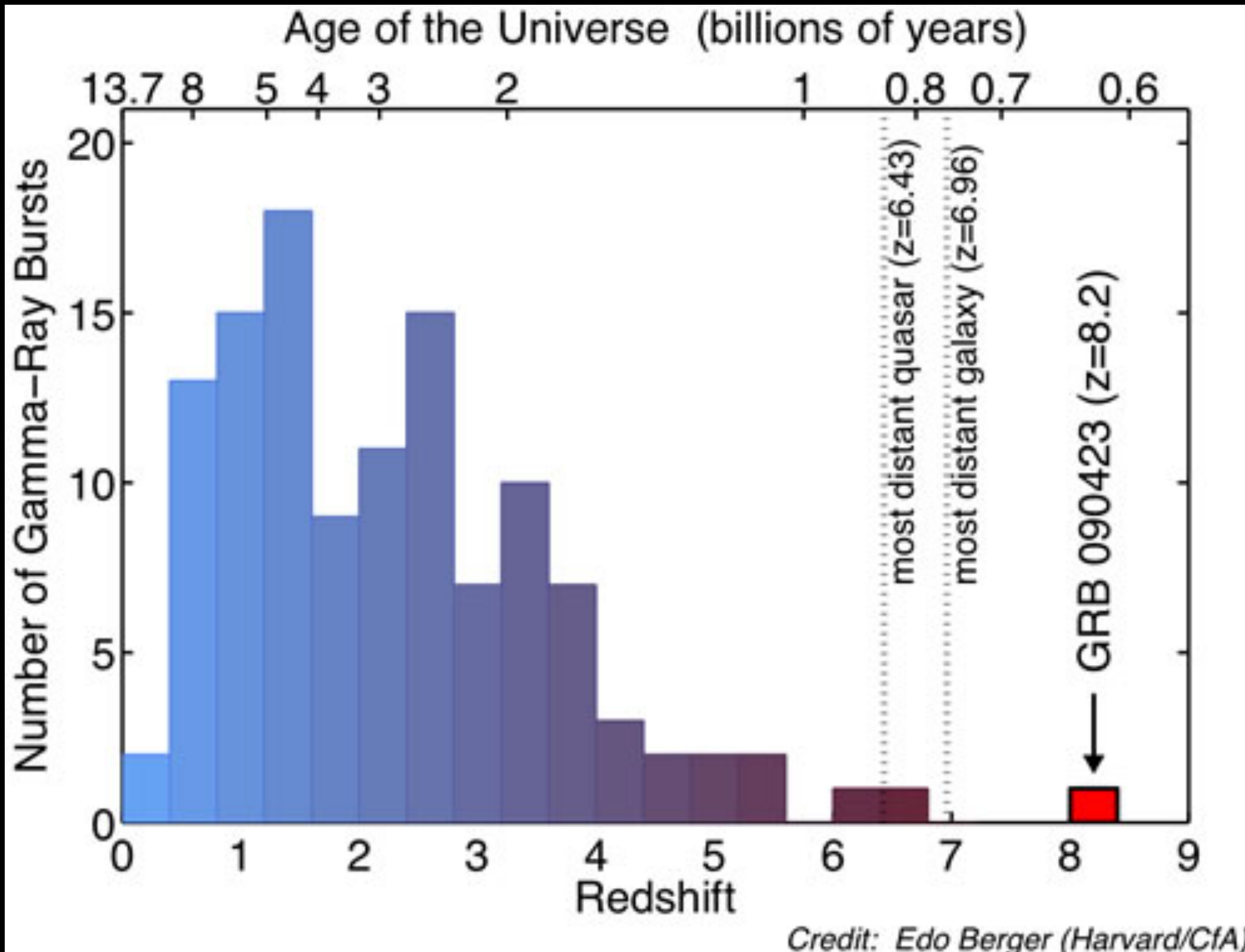
1. 2 populations: short/long
2. Highly variable (few ms)
3. Quiescent phases (shut down)

Spectral

4. Featureless, non-thermal spectra (but 5% pure planck)
5. Most photons 300 keV (peak energy)
6. Extended/delayed emission @ GeV

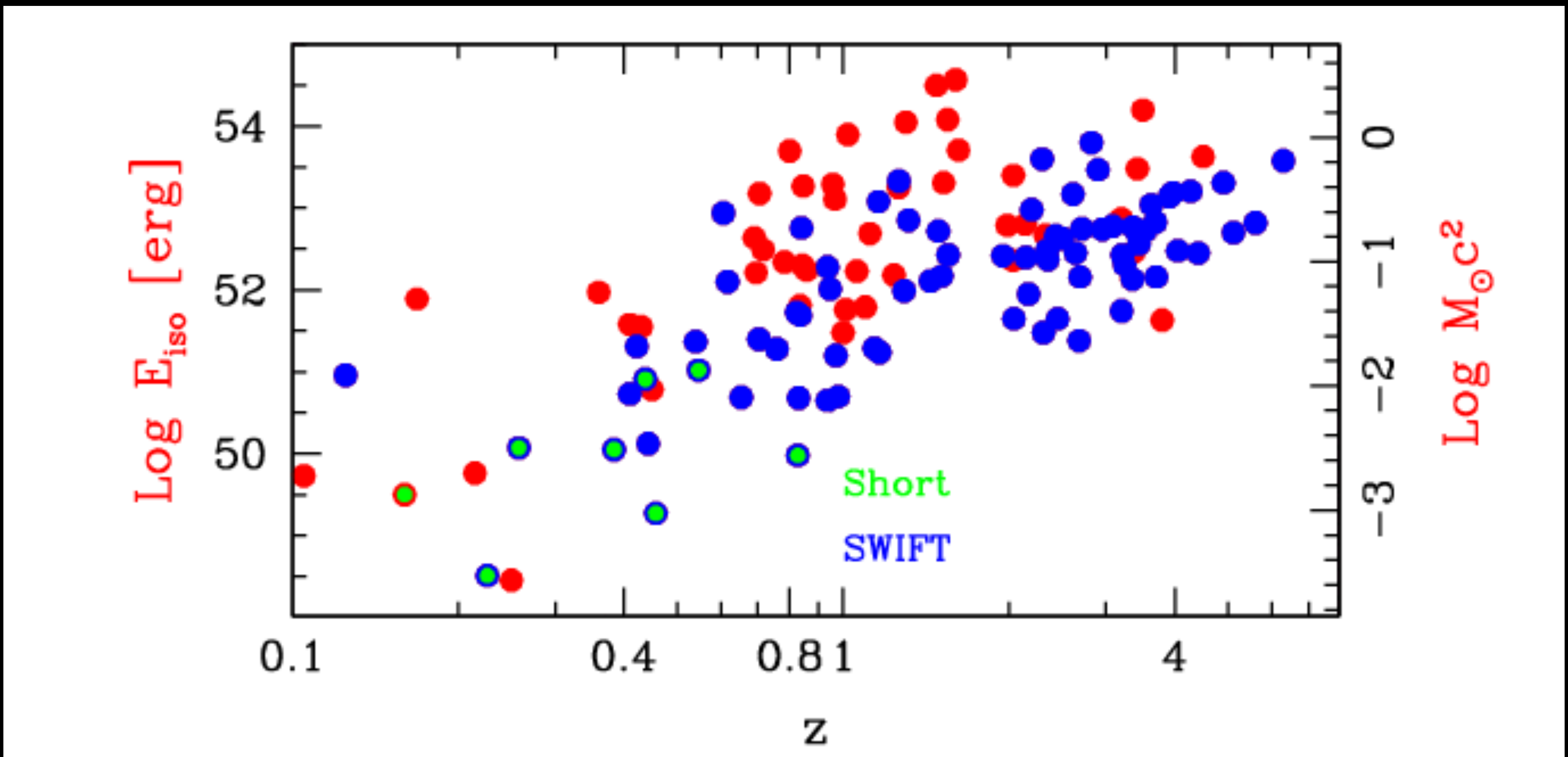
DISTANCE SCALE

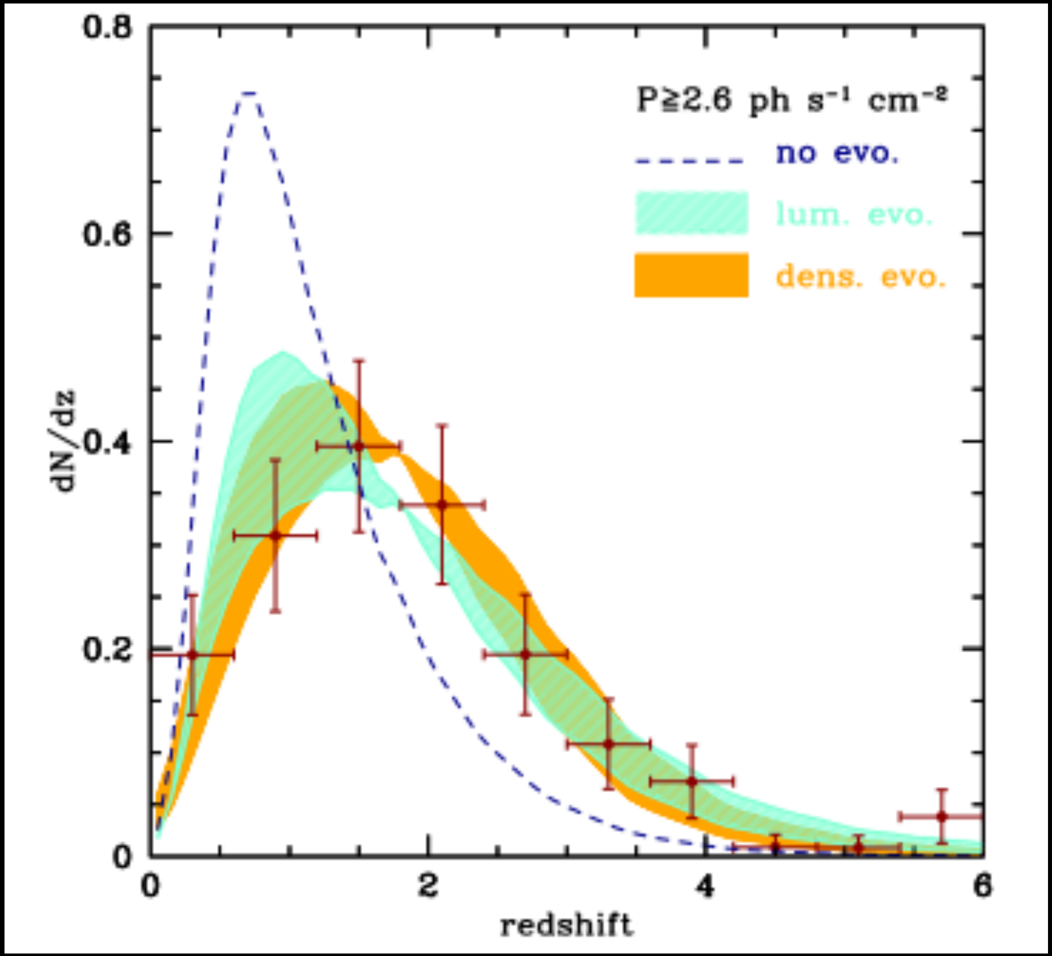
Observed redshift distribution



Energetics

ASSUMING ISOTROPY !!!!





Complete sample (with bright flux cut) of Swift GRBs → 95% with measured redshift.

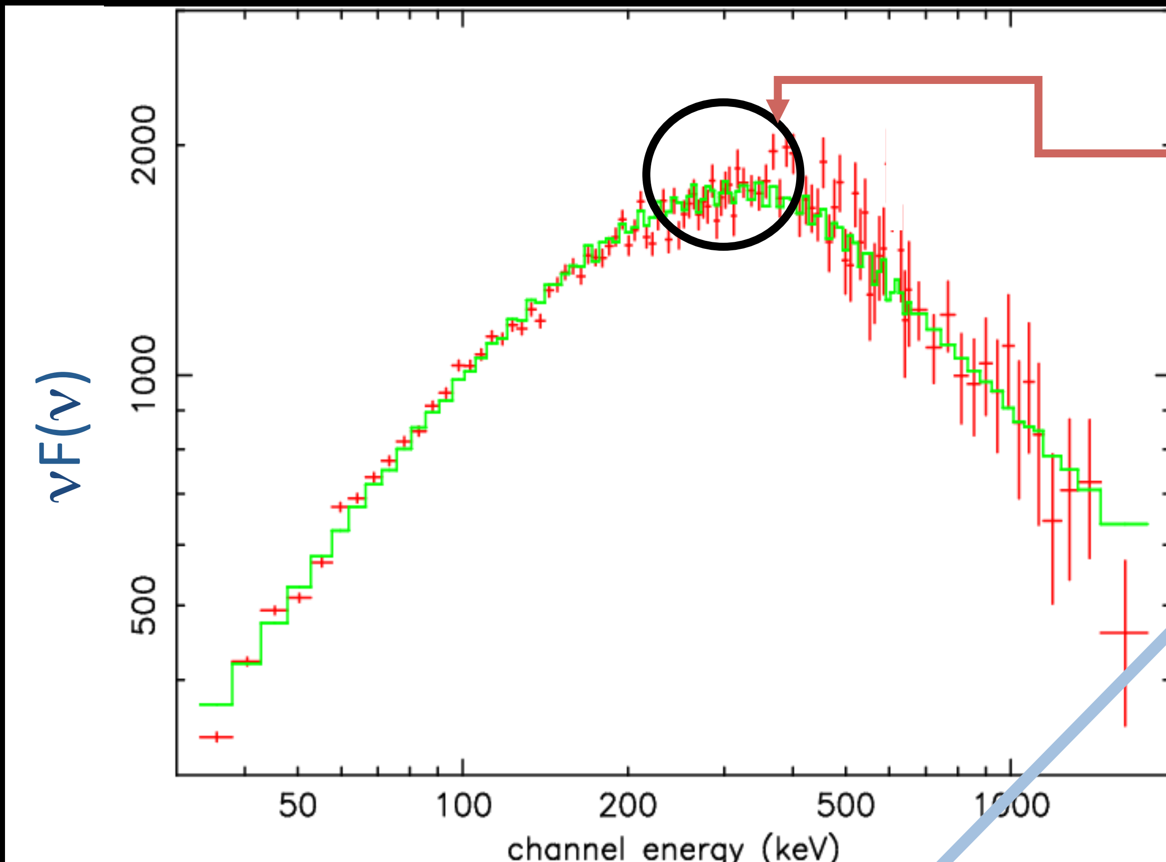
Allows statistical studies of GRBs almost free from instrumental selection effects

Deriving the luminosity function by jointly fitting the redshift distribution and the Peak flux distribution:

Strong luminosity, Lcut $\propto (1 + z)^{2.3}$, or density, GRBFR/SFR$\propto (1 + z)^{1.7}$, evolution

Salvaterra et al. 2012

Prompt emission spectrum



GRB Peak Energy

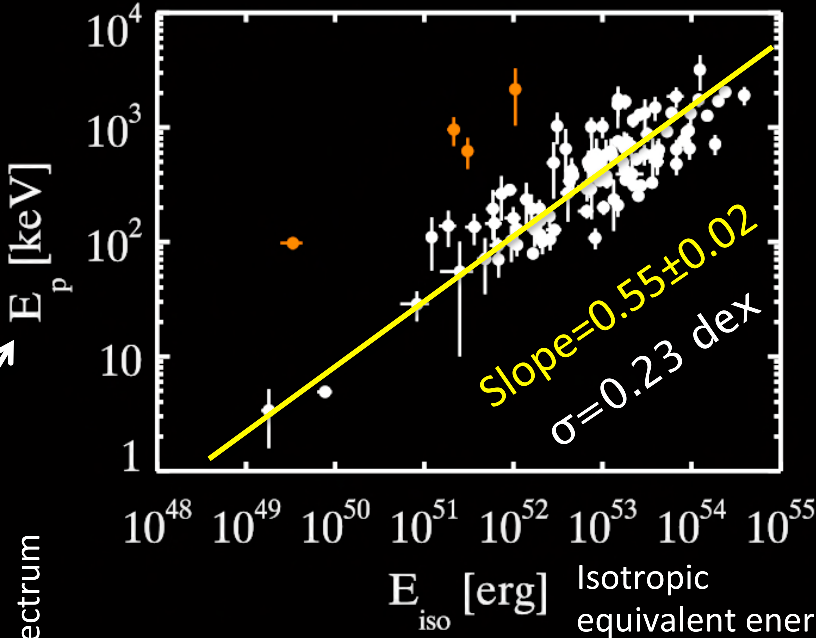
E_{peak}

(i.e. where most of power comes out)

$$E_{iso} = \frac{4 \pi d_L(z)^2}{1+z} \int_{\Delta E} F(E,z,...)\, dE$$

e.g. Band et al. 1993; Preece et al. 2000; Ryde 2000, 2002; Ghirlanda et al. 2002; Kaneko et al. 2006

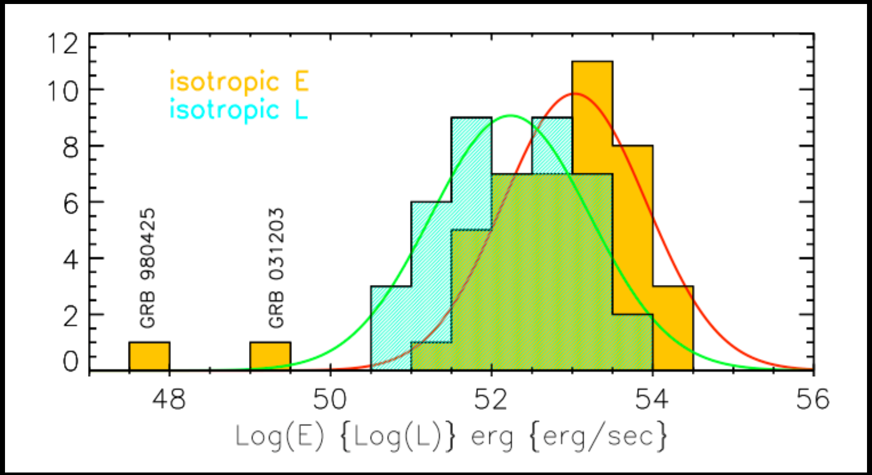
Energy(luminosity) – Spectrum correlations



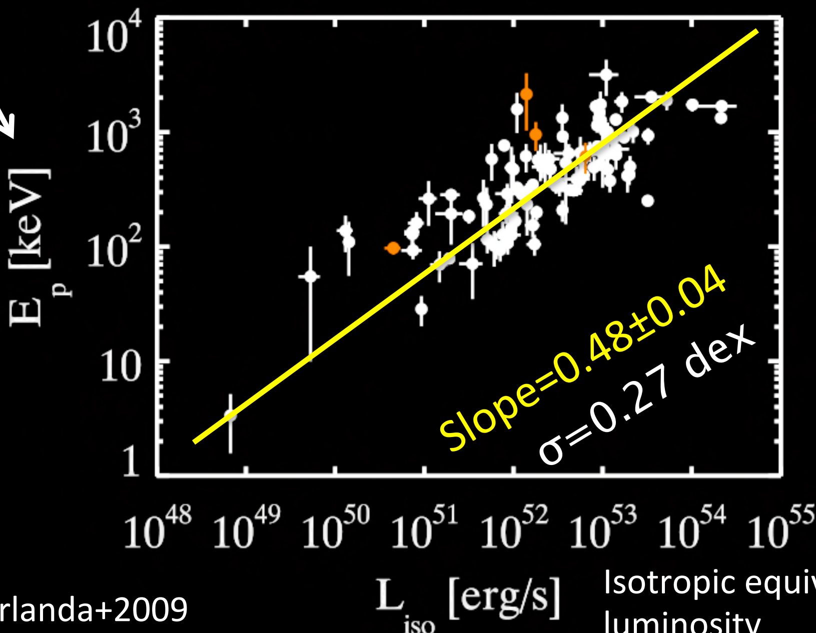
Isotropic equivalent energy

Eiso-Ep (Amati et al. 2002)
{Ghirlanda et al. 2005, 2009, Nava et al. 2010 …}

Peak energy of the vFv prompt emission spectrum



- Are they due to selection effects?
- Better energetics or luminosities?



Isotropic equivalent luminosity

Liso-Ep (Yonetoku et al. 2004)
{Ghirlanda et al. 2005, 2009, Nava et al. 2010 …}

Ghirlanda+2009

On going take home list

Prompt emission:

Temporal

1. 2 populations: short/long
2. Highly variable (few ms)
3. Quiescent phases (shut down)

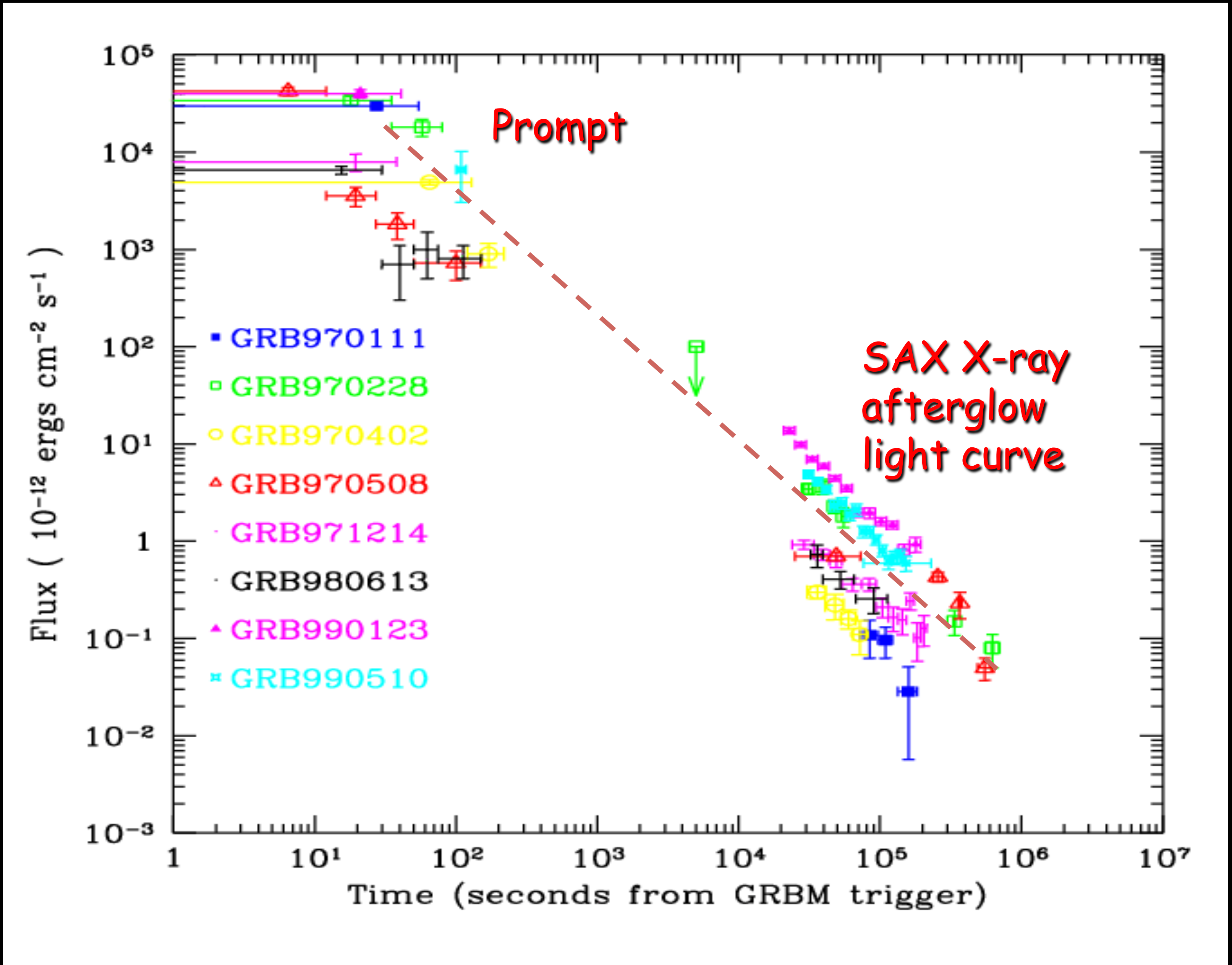
Spectral

4. Featureless, non-thermal spectra (but 5% pure planck)
5. Most photons 300 keV (peak energy)
6. Extended/delayed emission @ GeV
7. $\mathbf{E}_{\mathrm{peak}} \propto \mathbf{E}_{\mathrm{iso}}^{\mathbf{0.5}}$ (long NOT short)
8. $\mathbf{E}_{\mathrm{peak}} \propto \mathbf{L}_{\mathrm{iso}}^{\mathbf{0.5}}$ (long AND short)

AFTERGLOW EMISSION

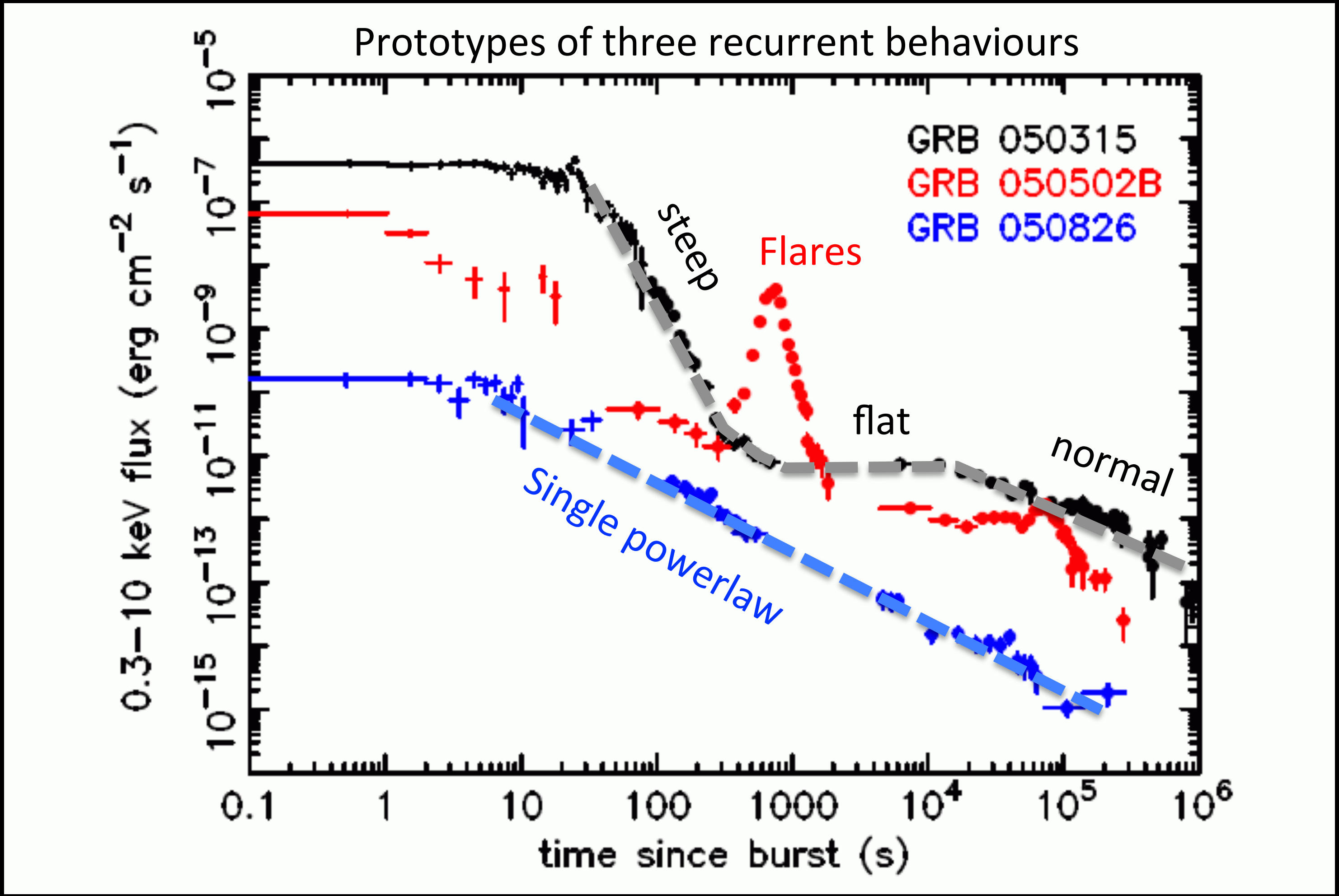
What is detected by in orbit dedicated instruments (X-ray)
or by ground based telescopes (Optical/NIR – Radio)
Emission of photons with typical energies < (<<) 10-100 keV

X ray Afterglow – Before Swift



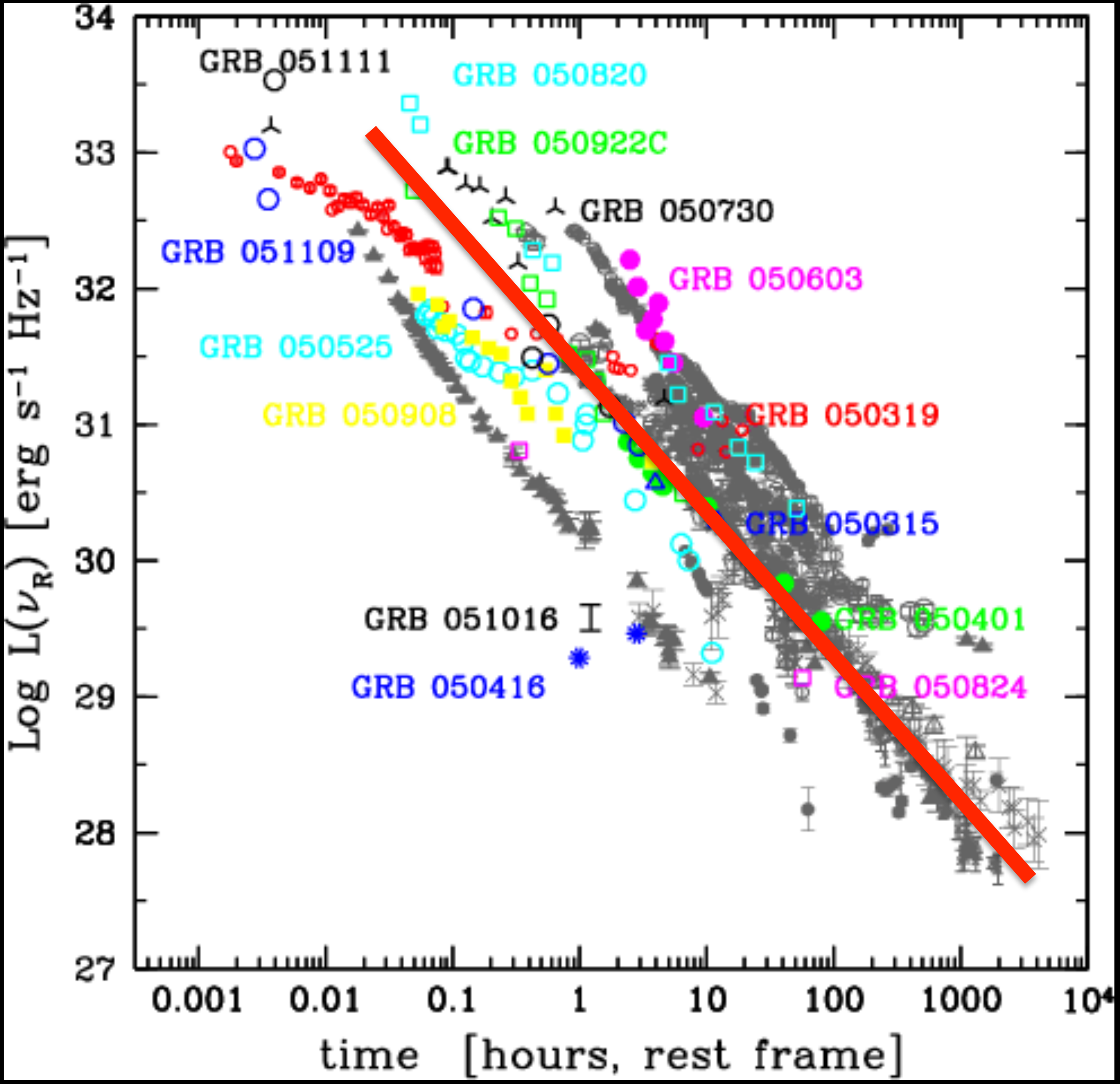
Piro astro-ph/0001436

X ray Afterglow: Now



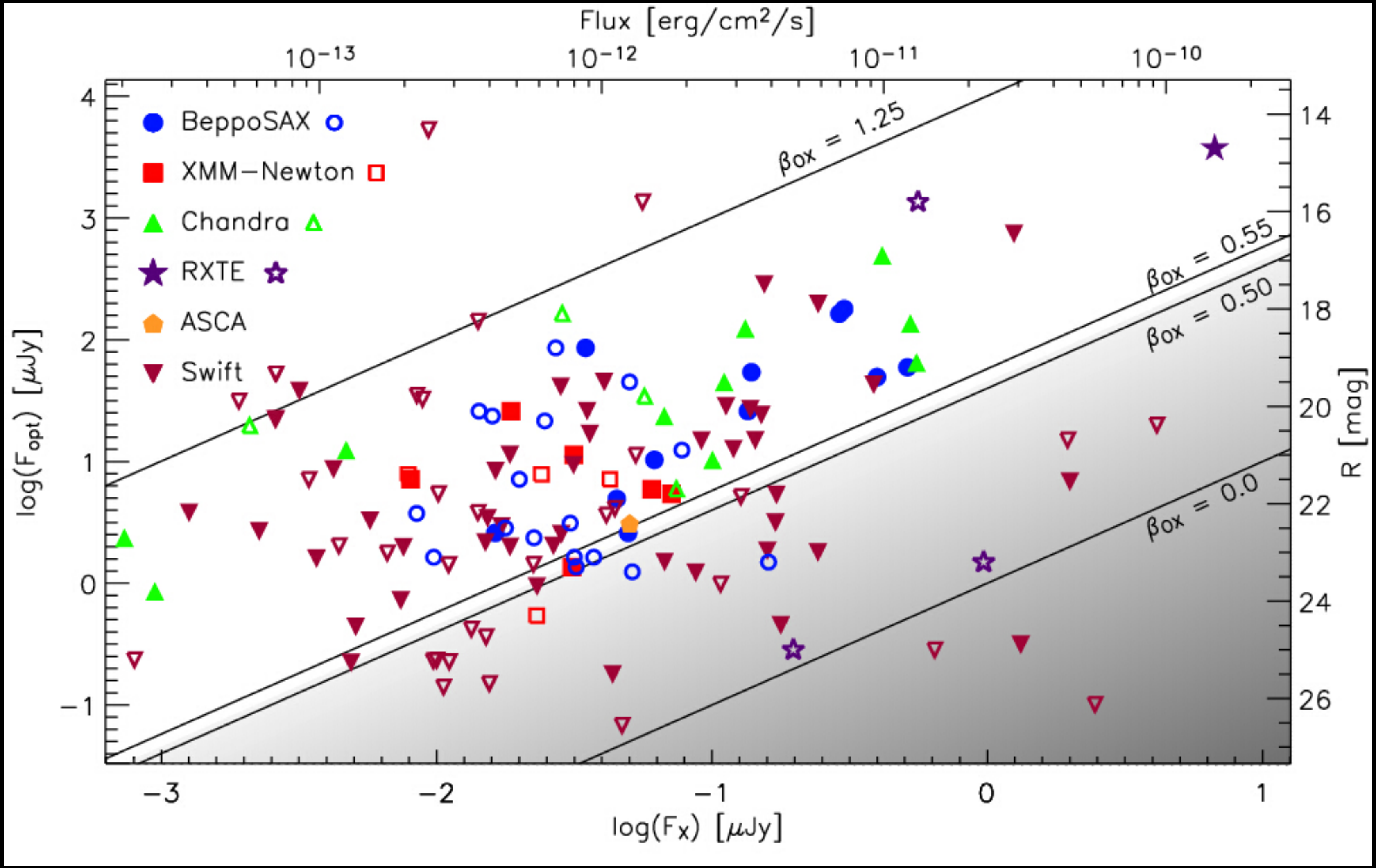
99% detected by Swift X-ray telescpe
within 1 min and followed up to few days.

Optical Afterglow

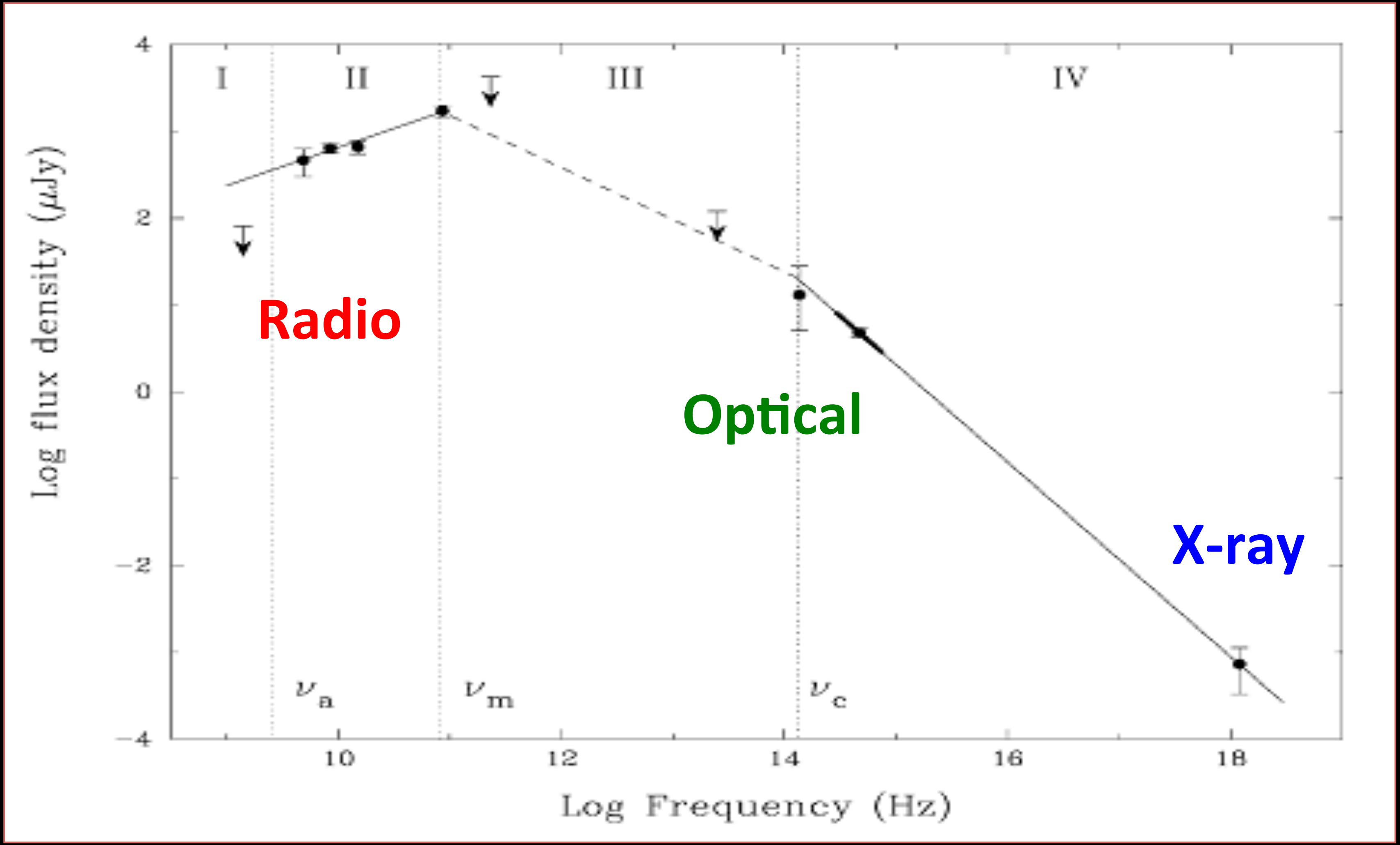


The Dark side of GRBs

~40-50% of GRBs are optically DARK

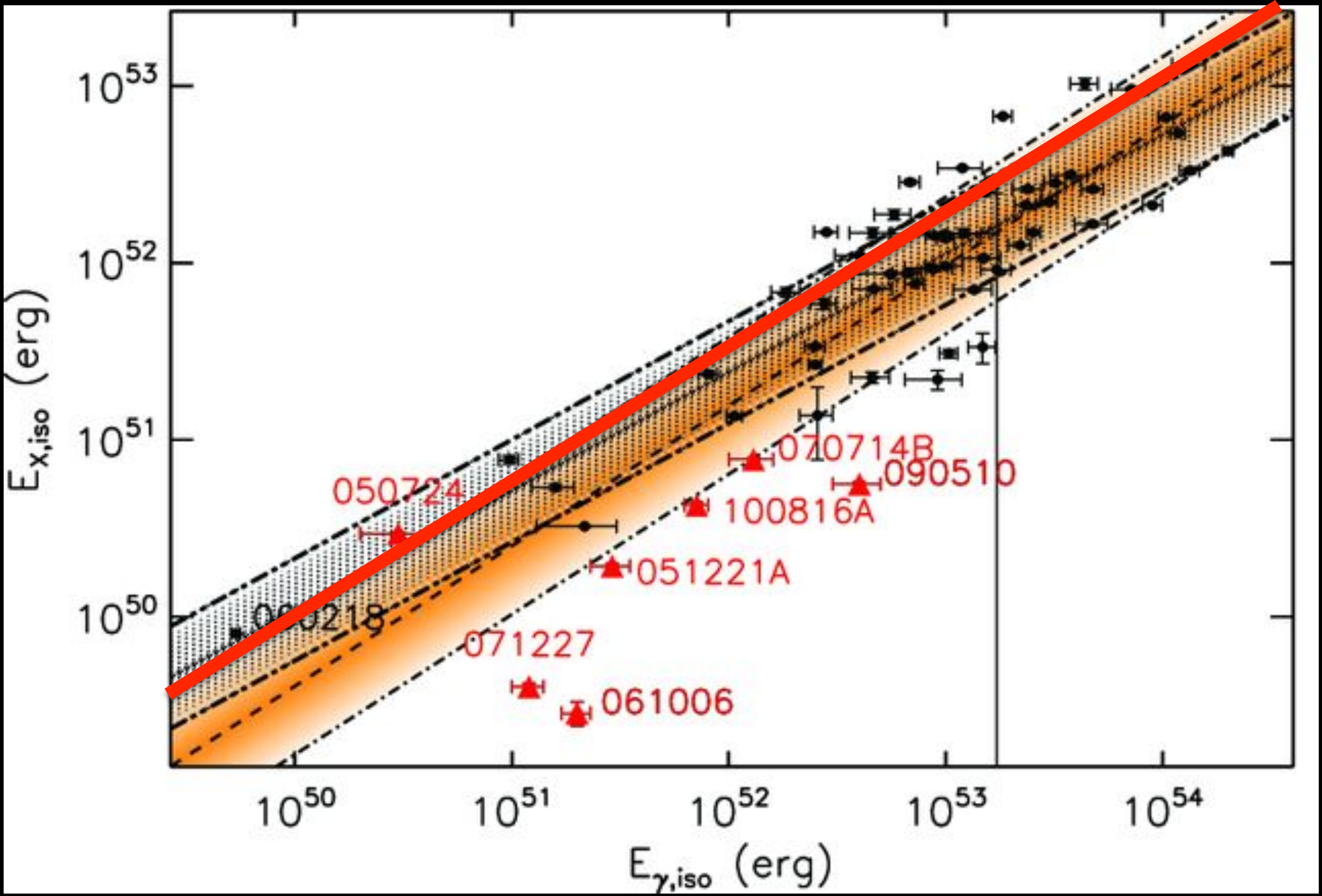


The Afterglow spectrum



Frail et al. 1997

Afterglow/Prompt energetic



Margutti R et al. MNRAS 2013;428:729-742

On going take home list

Prompt emission:

Temporal

1. 2 populations: short/long
2. Highly variable (few ms)
3. Quiescent phases (shut down)

Spectral

4. Featureless, non-thermal spectra (but 5% pure planck)
5. Most photons 300 keV (peak energy)
6. Extended/delayed emission @ GeV
7. $\mathbf{E}_{\mathrm{peak}} \propto \mathbf{E}_{\mathrm{iso}}^{\mathbf{0.5}}$ (long NOT short)
8. $\mathbf{E}_{\mathrm{peak}} \propto \mathbf{L}_{\mathrm{iso}}^{\mathbf{0.5}}$ (long AND short)

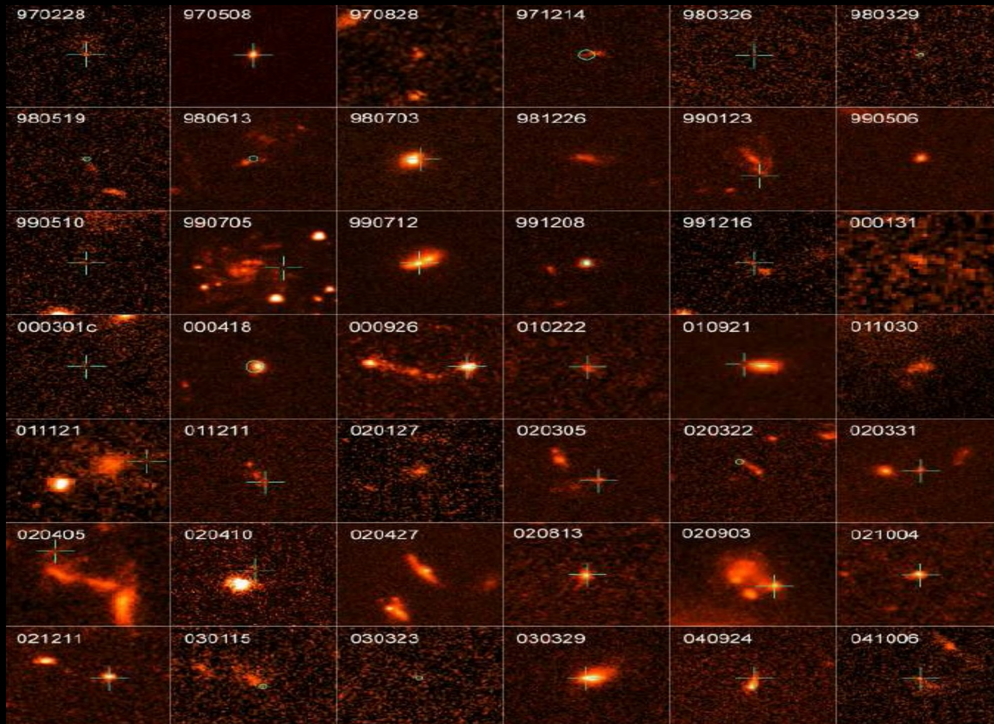
Afterglow emission:

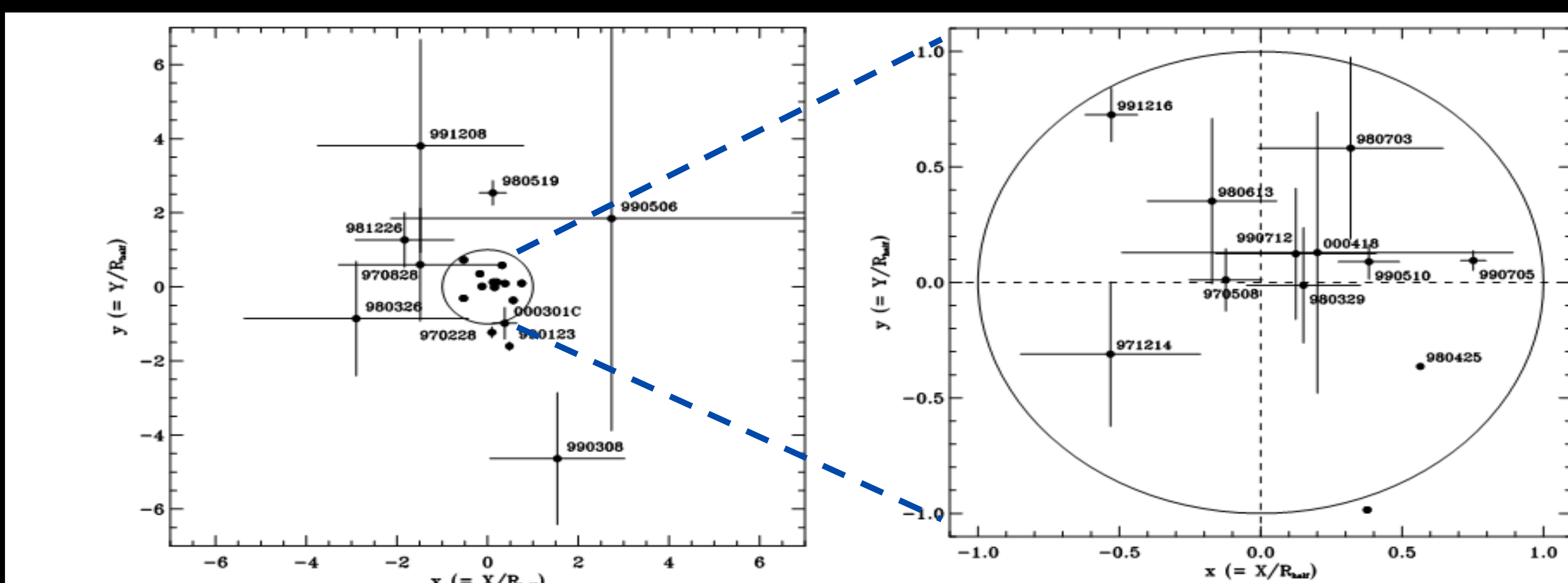
1. Different slopes (mostly in X-ray)
2. Optical/NIR more canonical
3. 40-50% Dark in Optical
4. Late time flares
5. Featureless, with breaks at characteristic frequencies
6. Self absorbed in Radio (few)
7. Eafterglow < Eprompt

HOSTS
&
PROGENITORS

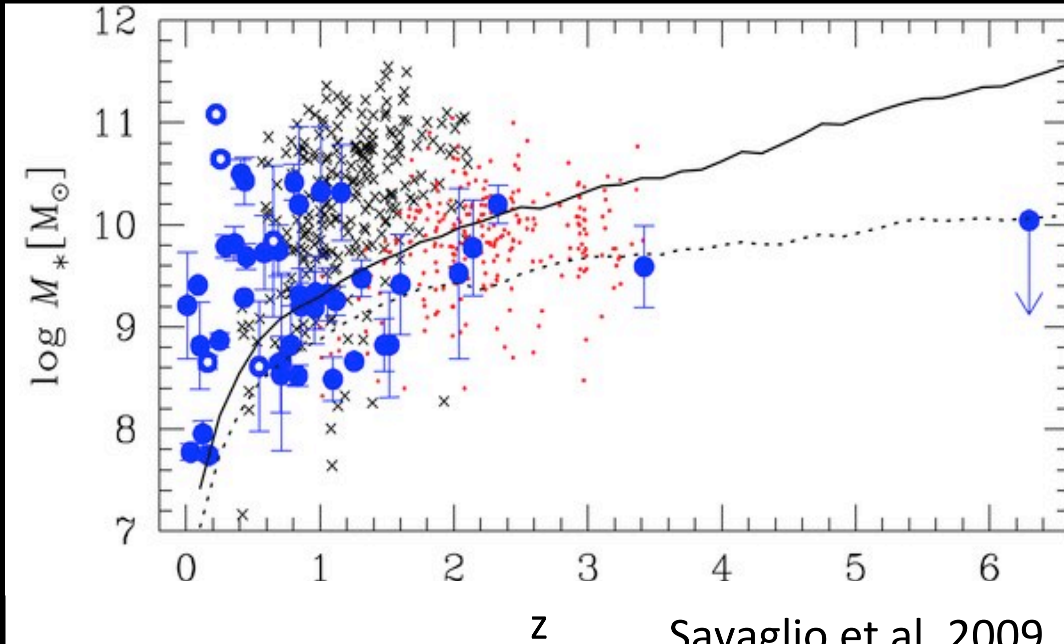
LONG GRB HOSTS

Fruchter et al. 2005





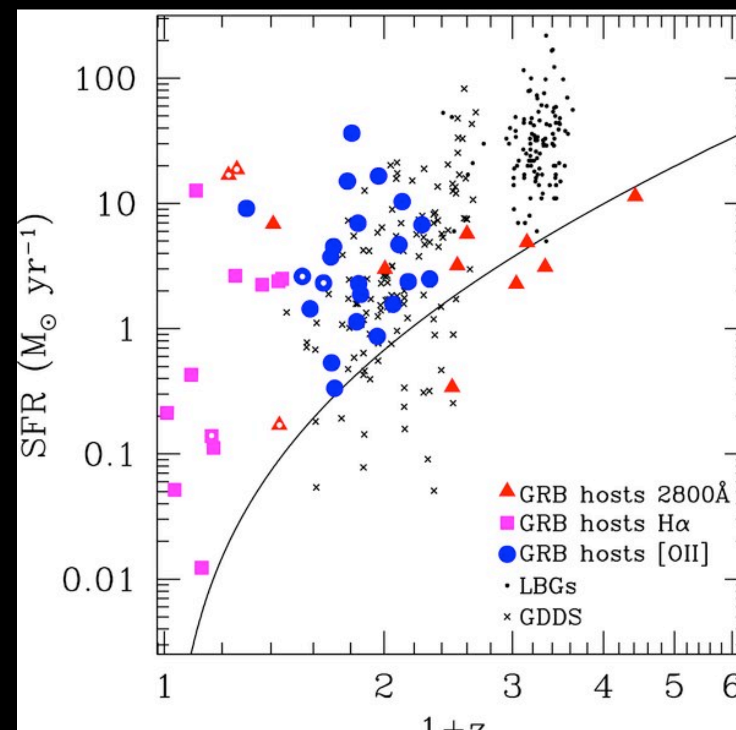
Berger et al. 2005



Savaglio et al. 2009

GRB Hosts smaller and bluer than hosts of core collapse SN

GRB Hosts have smaller SFR and typical specific SFR of normal galaxies

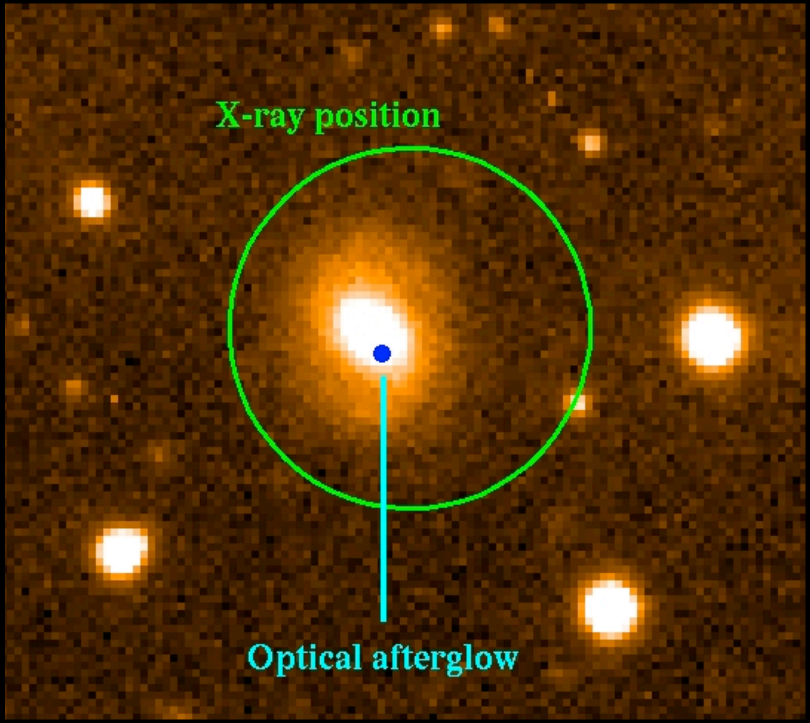


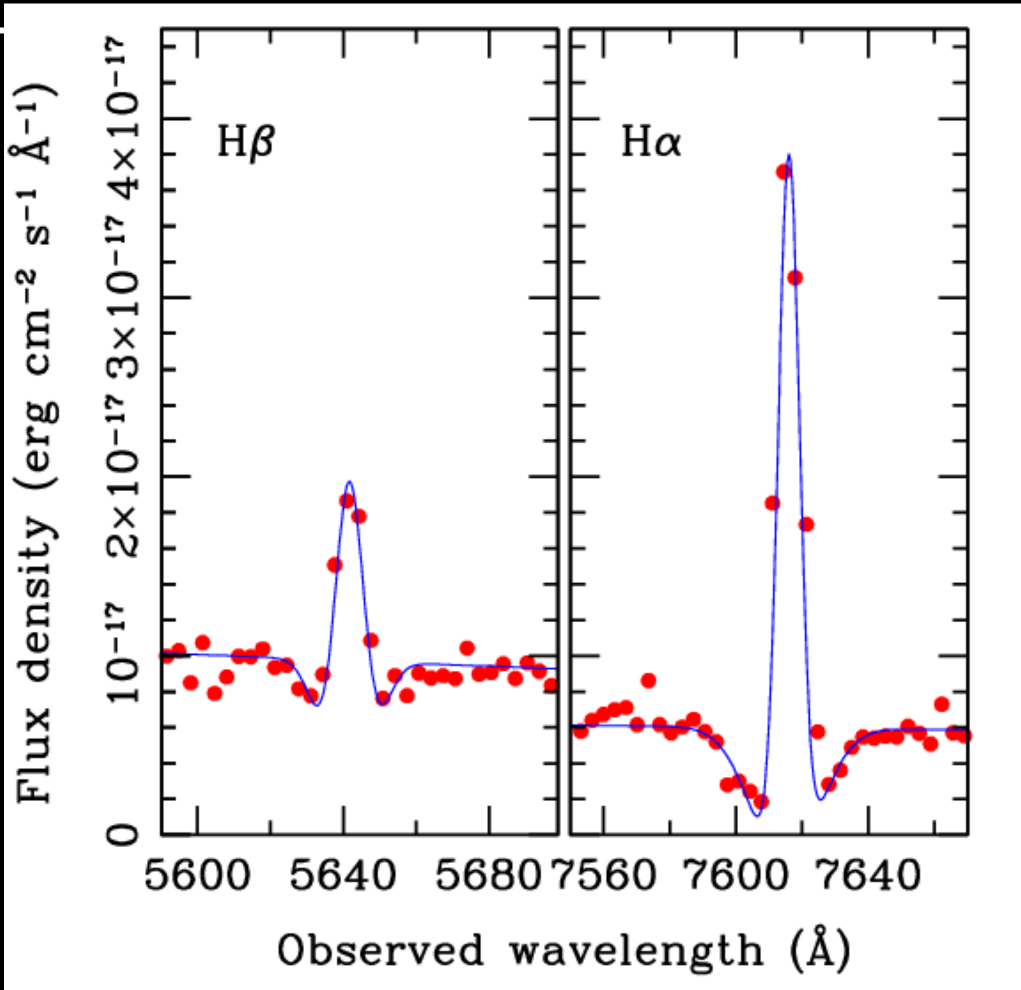
Short GRB host galaxies

Early AND late-type systems

GRB 050709: star forming host

GRB 050724: early-type



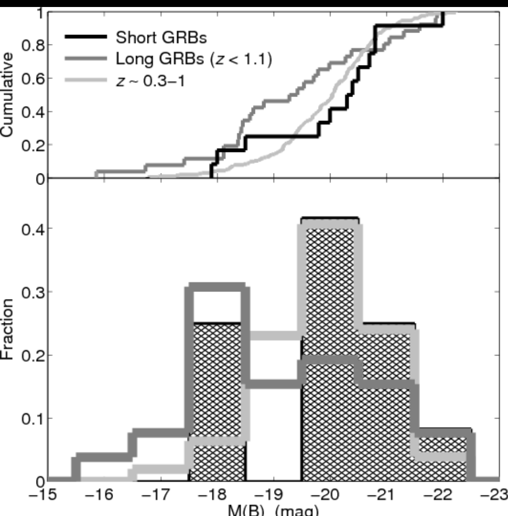


Berger et al. 2005, Malesani et al. 2007

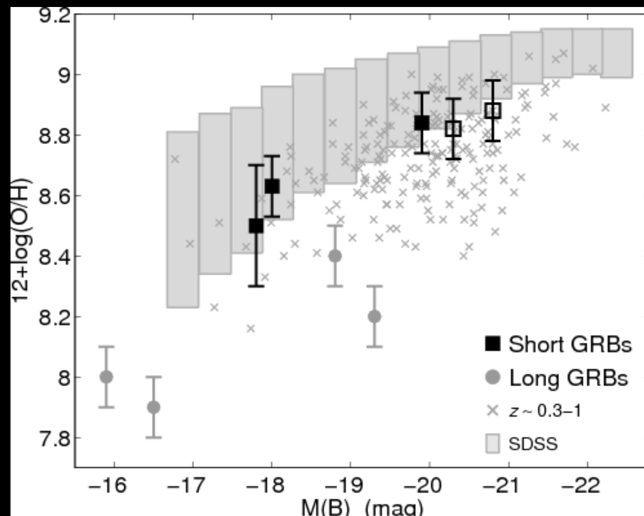
Covino et al. 2006

Short *vs.* long GRB host galaxies

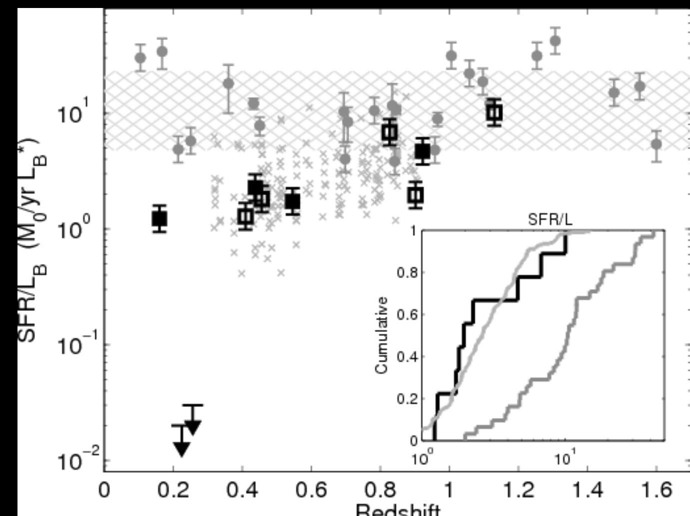
M(B)



Metallicity



SFR



Short GRB HGs share the same observational properties of field galaxies

Long GRB HGs are on average more star forming, fainter and with low metallicity

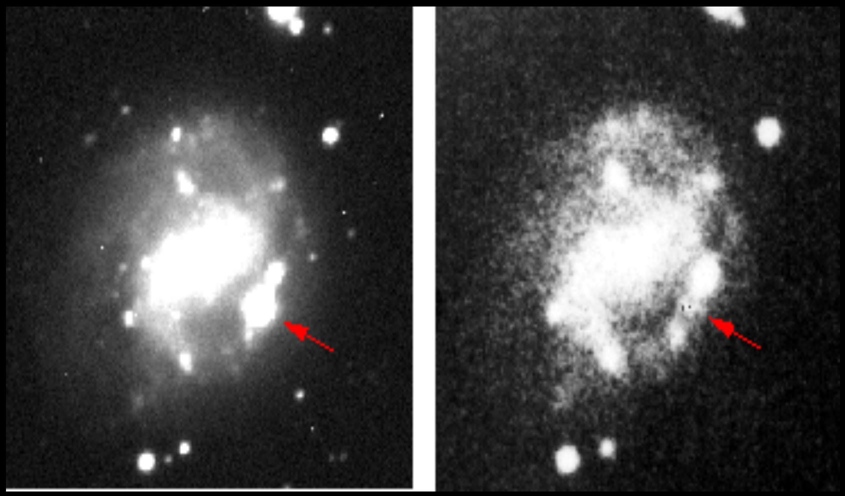
Evidence for two classes of progenitors

Berger 2009

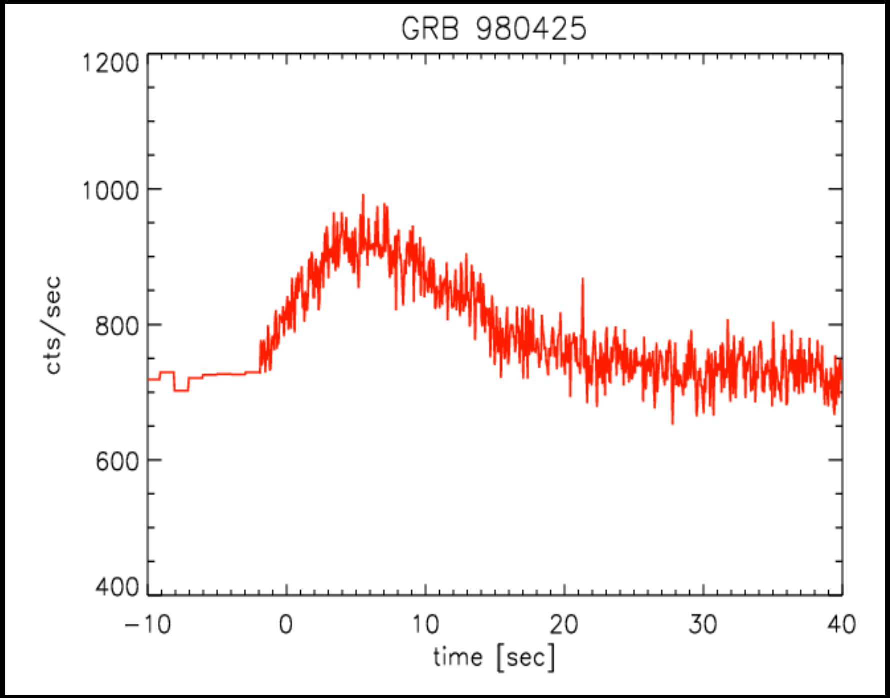
Possible biases, but see BAT6 and TOUGHT series of papers on complete samples studies

GRB SN connection – The first

SN 1998bw



GRB 980425

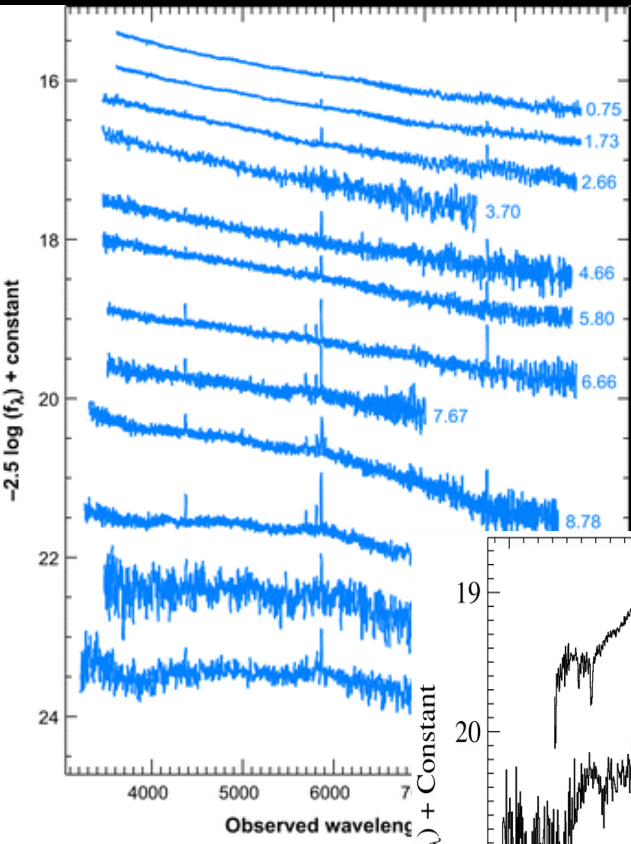


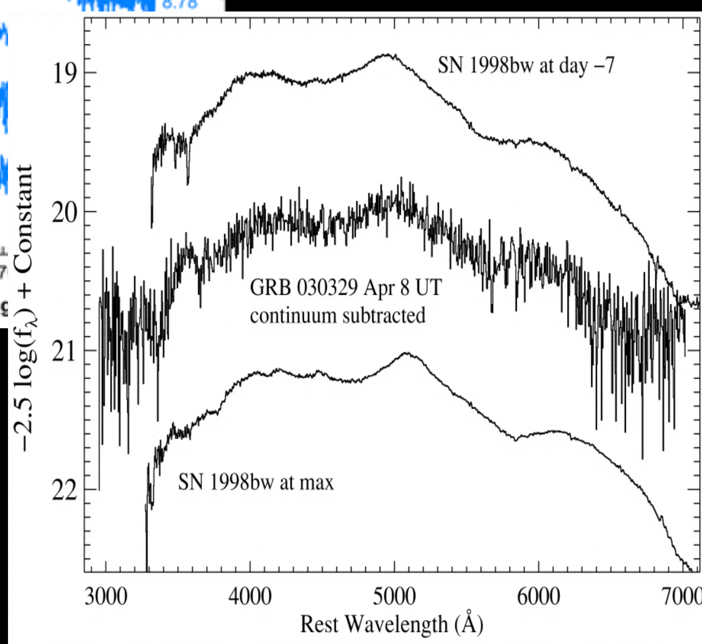
Type Ic supernova, d = 36 Mpc
Etot ~ 3 x 10^{52} erg
V=3x10^4 Km/s
of a massive CO star
(Iwamoto et al 1998; Woosley, Eastman, & Schmidt 1999)

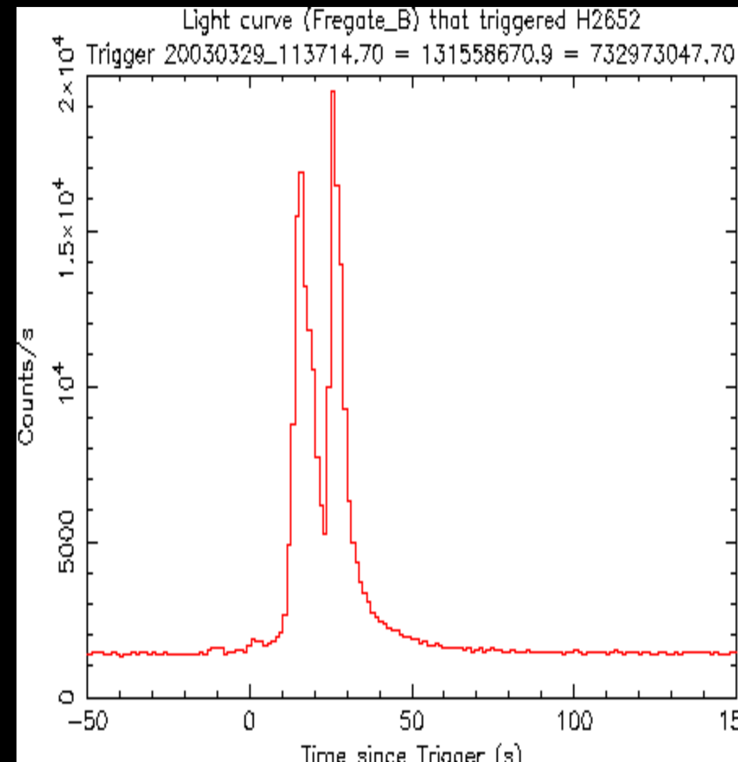
GRB E ~ 8 x 10^{47} erg;
T= 23 s

GRB SN connection – The second

SN 2003dh GRB 030329







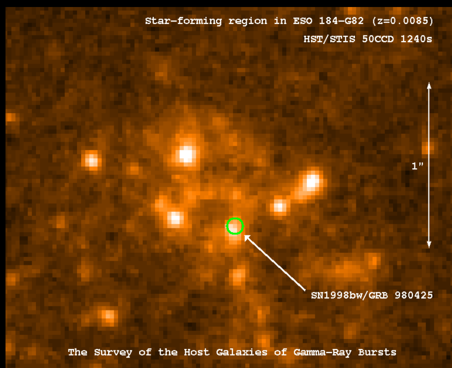
GRB E ~ 10^{52} erg

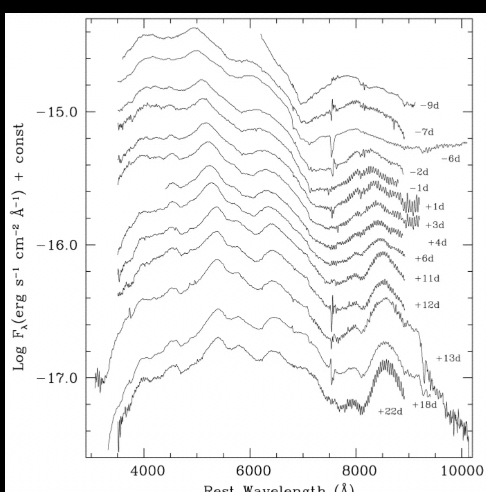
T ~ 60 sec

z=0.1685

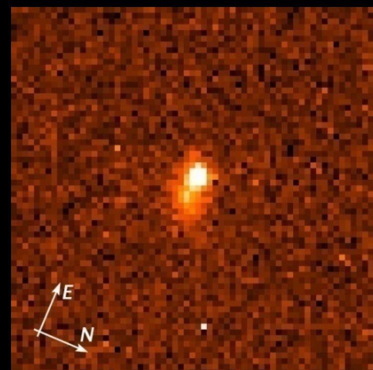
(long) GRB/SN Connection – a few

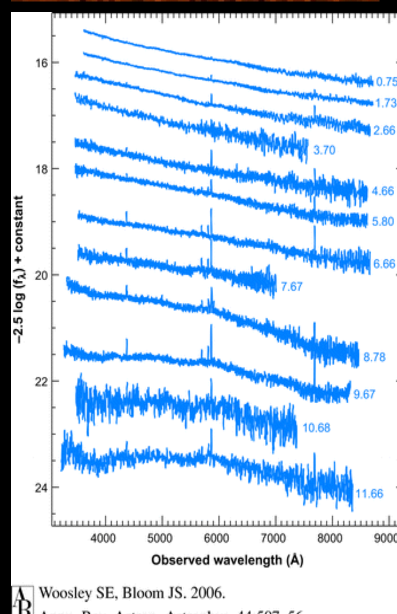
GRB 980425 (40 Mpc)



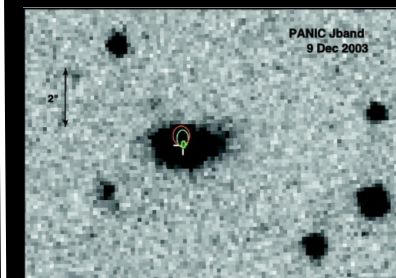


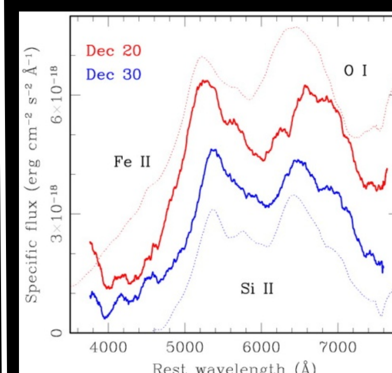
GRB 030329 (z=0.17)



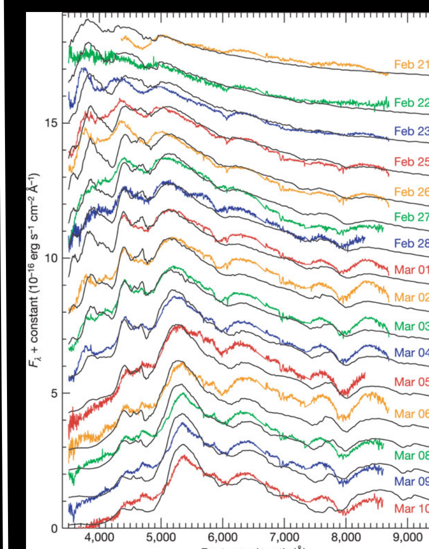


GRB 031203 (z=0.1)



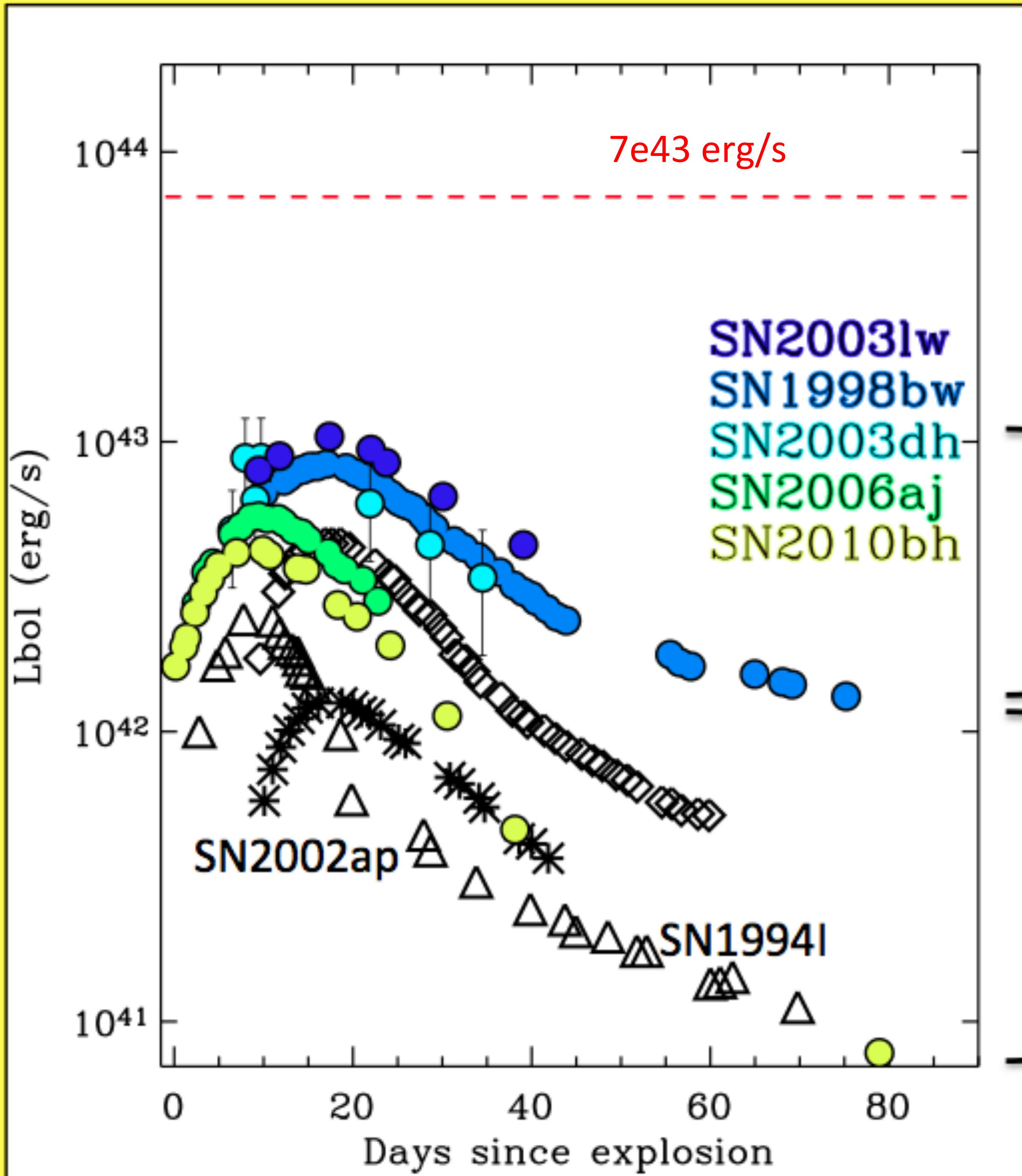


GRB 060218 (150 Mpc)



(Galama et al. 1998, Matheson et al. 2003, Malesani et al. 2004, Pian et al. 2006 … etc etc)

Hydrogen poor Super Luminous SN (Gal Yam 2012)



GRB/SNe

“Standard”, envelope stripped SN Ibc

GRB Part-I: take home list

Prompt emission:

Temporal

1. 2 populations: short/long
2. Highly variable (few ms)
3. Quiescent phases (shut down)

Spectral

4. Featureless, non-thermal spectra (but 5% pure planck)
5. Most photons 300 keV (peak energy)
6. Extended/delayed emission @ GeV
7. $\mathbf{E_{peak} \propto E_{iso}^{0.5}}$ (long NOT short)
8. $\mathbf{E_{peak} \propto L_{iso}^{0.5}}$ (long AND short)

Afterglow emission:

1. Different slopes (mostly in X-ray)
2. Optical/NIR more canonical
3. 40-50% Dark in Optical
4. Late time flares
5. Featureless, with breaks at characteristic frequencies
6. Self absorbed in Radio (few)
7. Eafterglow ~ 0.1 Eprompt

Hosts & Progenitors:

1. SF galaxies (irr for long all types for short)
2. Central regions or in ass with SF regions within the hosts
3. A dozen of long associated with broad lined SN Ibc
4. No SN associated with short

END PART-I