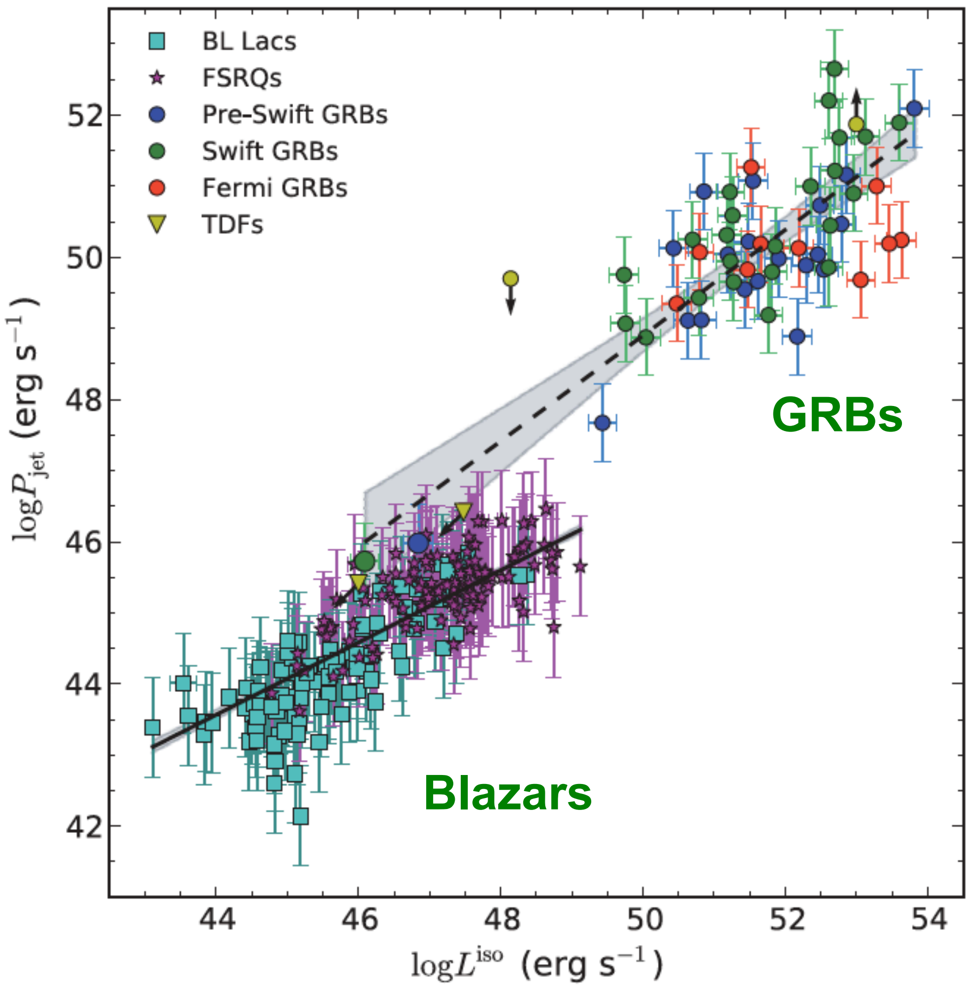
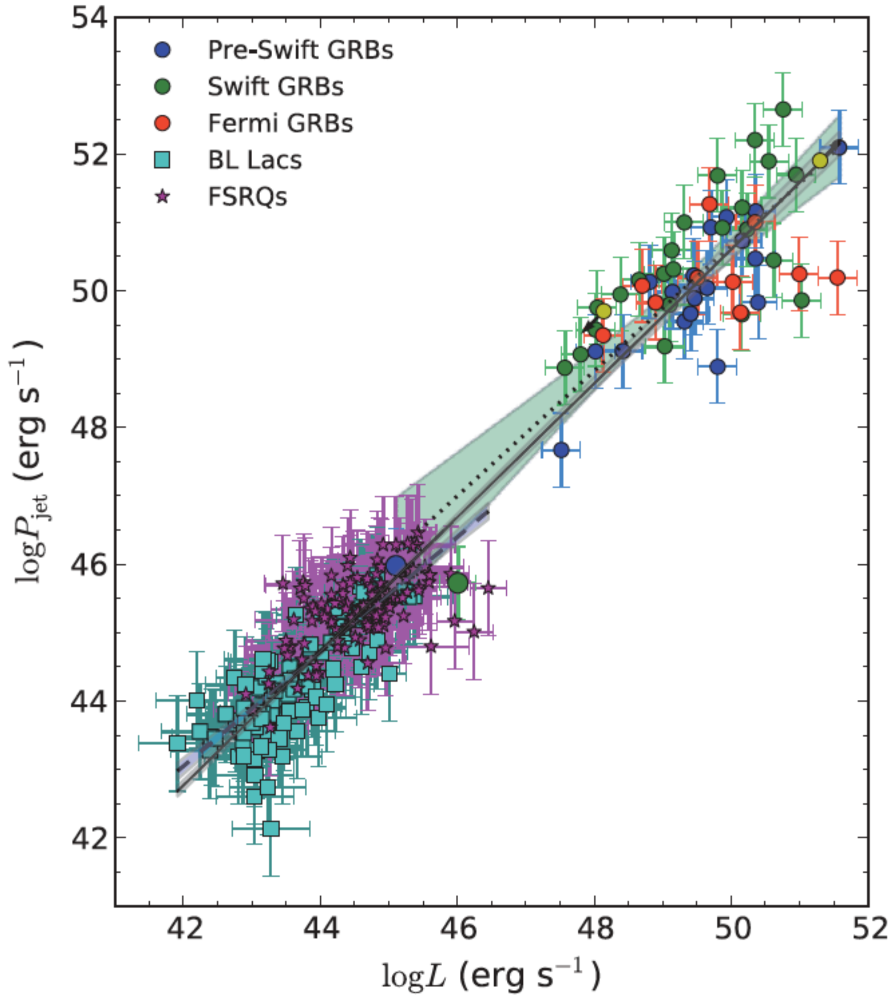
6 October 2015

Relativistic Jets: an Overview of Recent Progress

Elena Pian
INAF, IASF Bologna
& Scuola Normale Superiore di Pisa

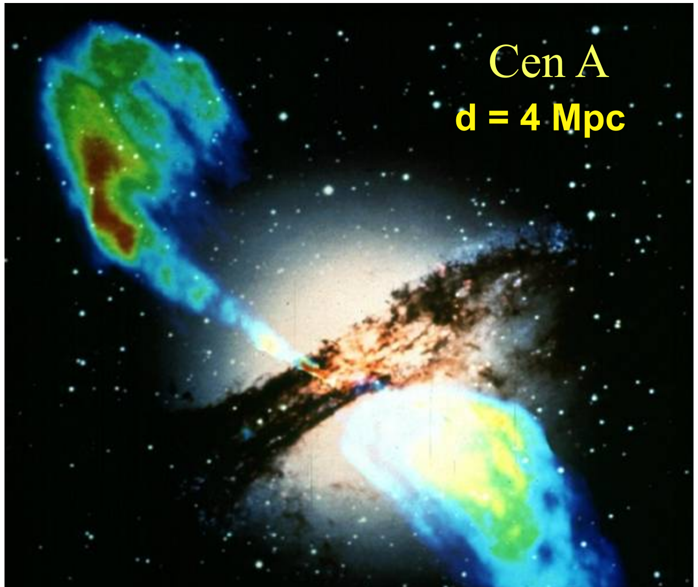
A universal scaling for the energetics of relativistic jets From black hole systems

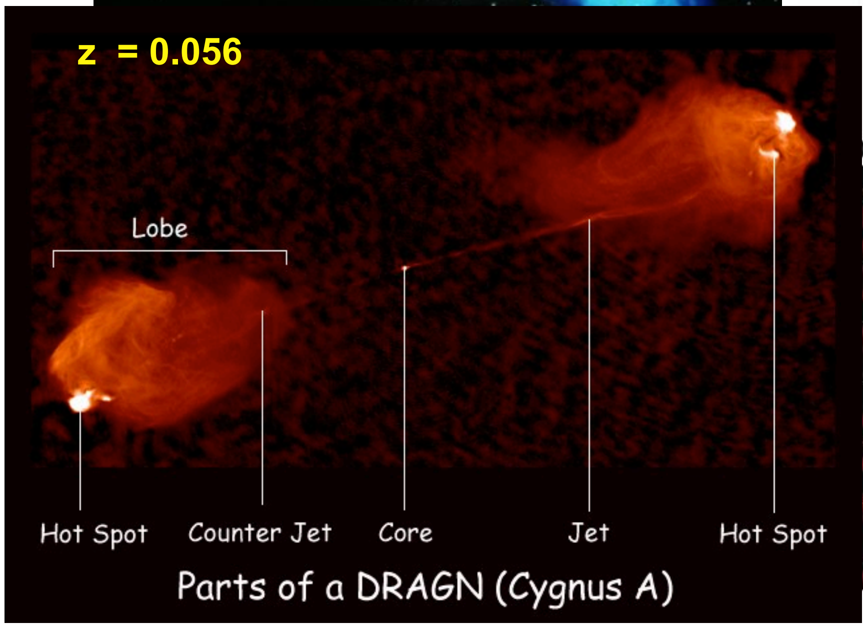


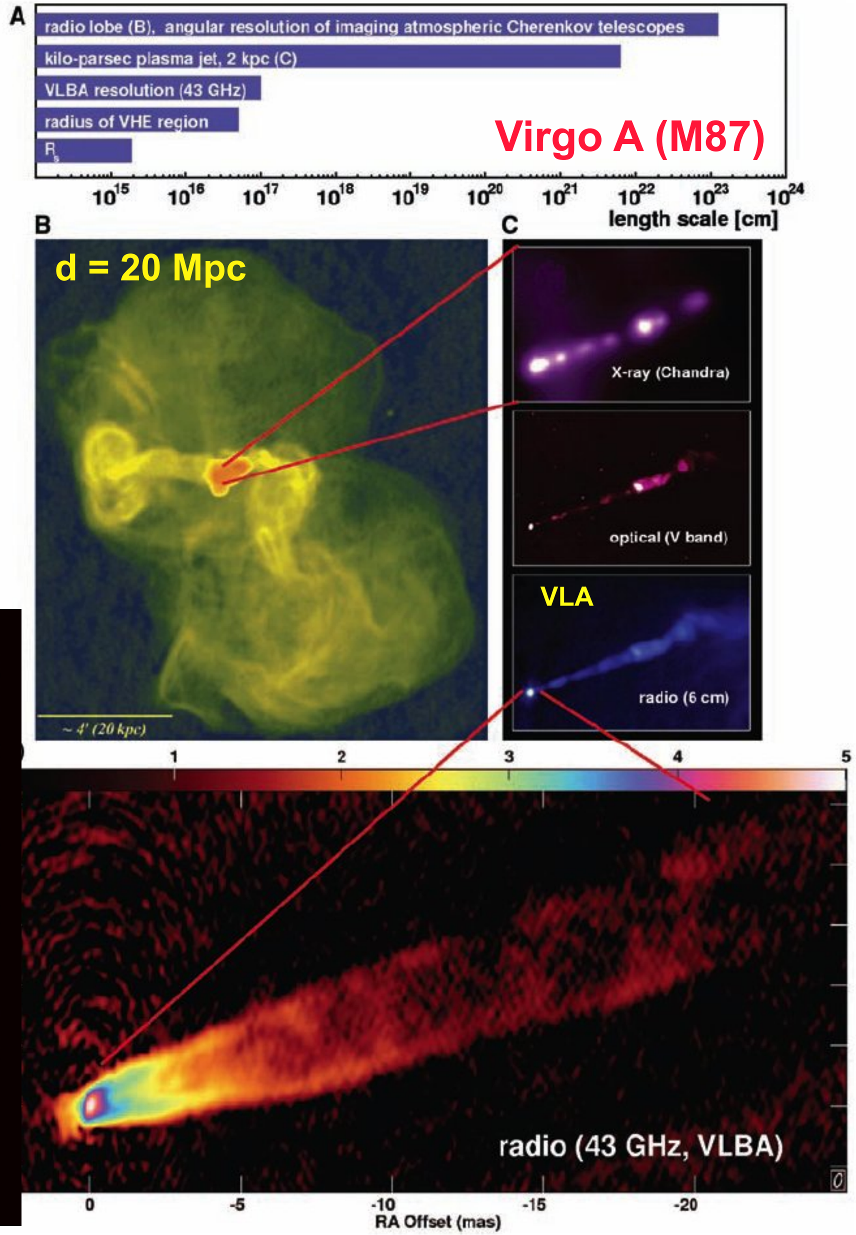


Nemmen et al. 2012

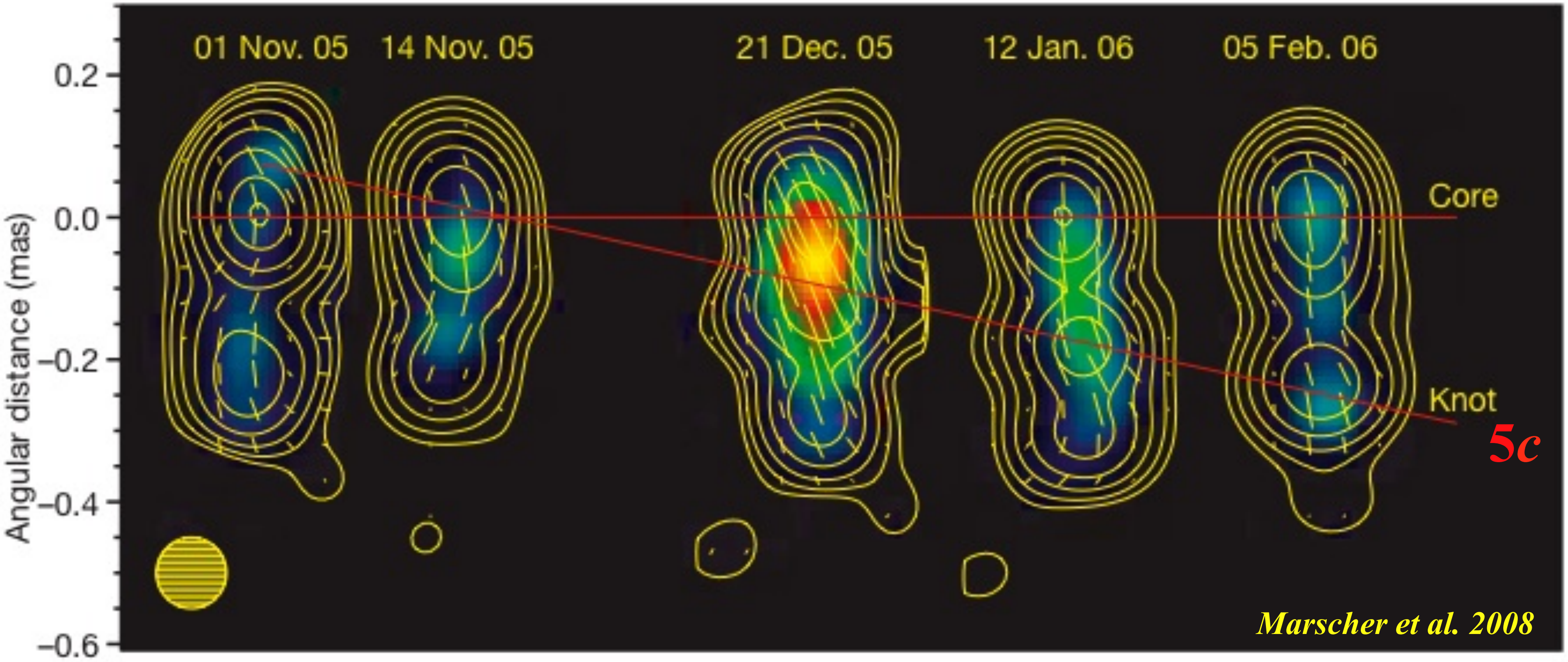
Extragalactic Jets: **radiogalaxies and blazars**
Lorentz factors Γ~ 10-20







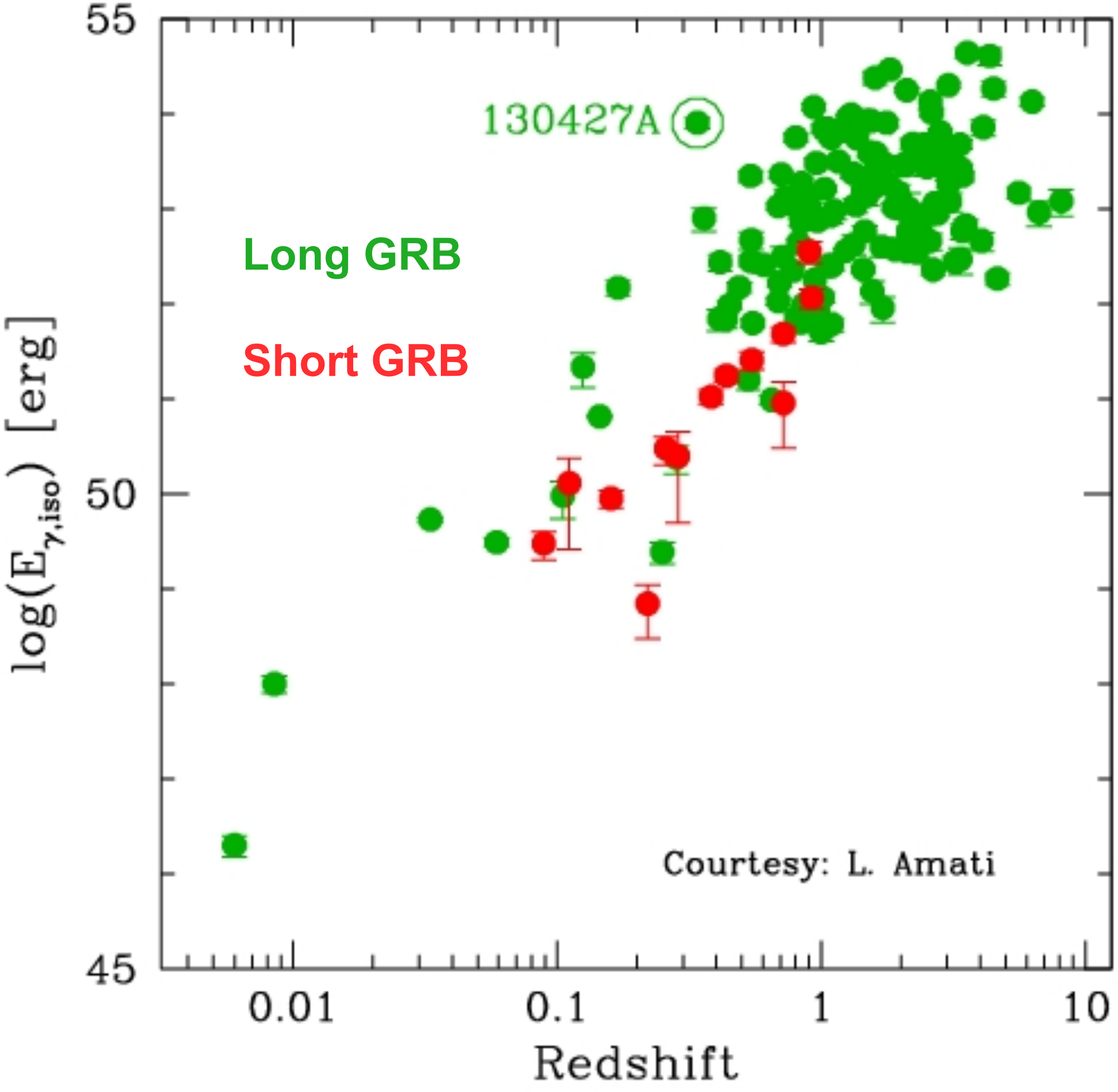
Superluminal motions in extragalactic VLBA jets



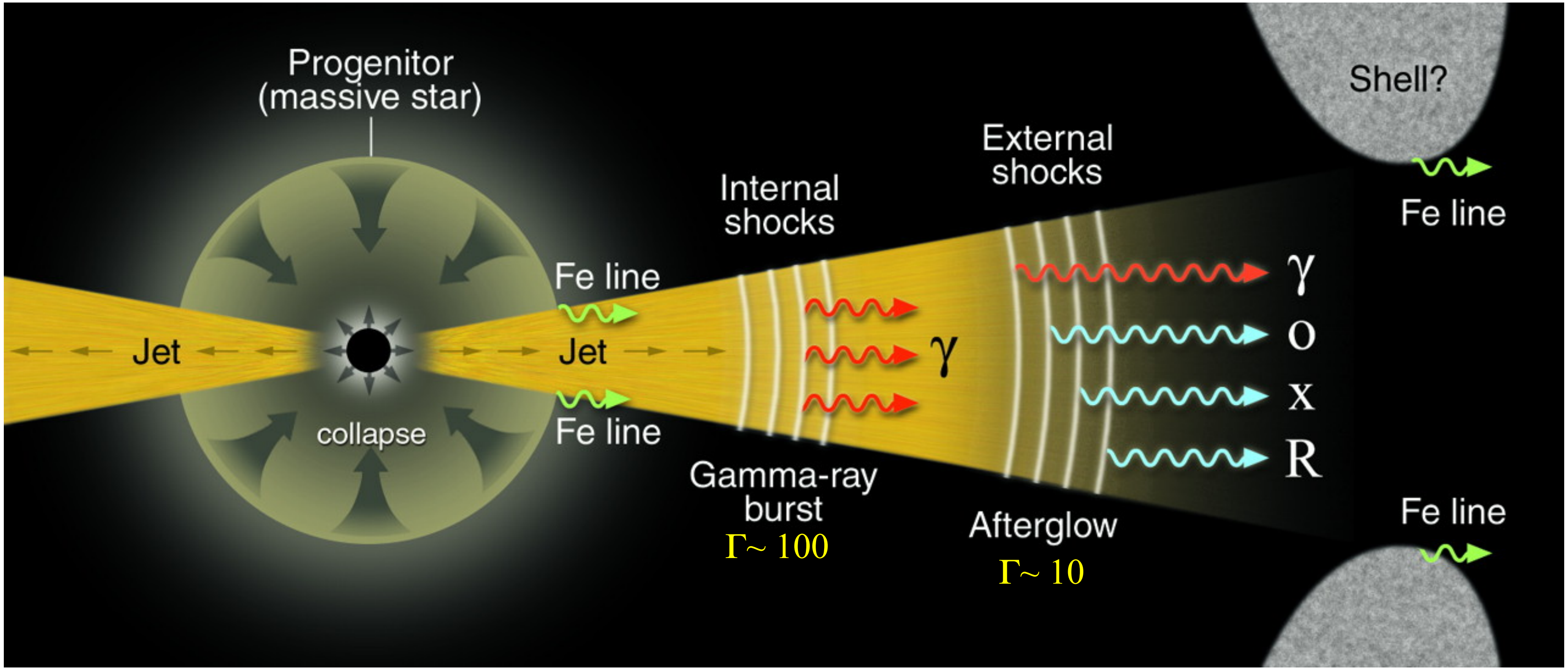
Lorentz factor: $\Gamma = \frac{1}{\sqrt{1-\beta^2}}$ Doppler factor: $\delta = \frac{1}{\Gamma(1-\beta\cos\theta)}$

If we assume that θ = 5 deg: β_{app} = 5 ➜ β = 0.9866 ➜ Γ = 6 ➜ δ = 9.5
β_{app} = 20 ➜ β = 0.9994 ➜ Γ = 30 ➜ δ = 7.6

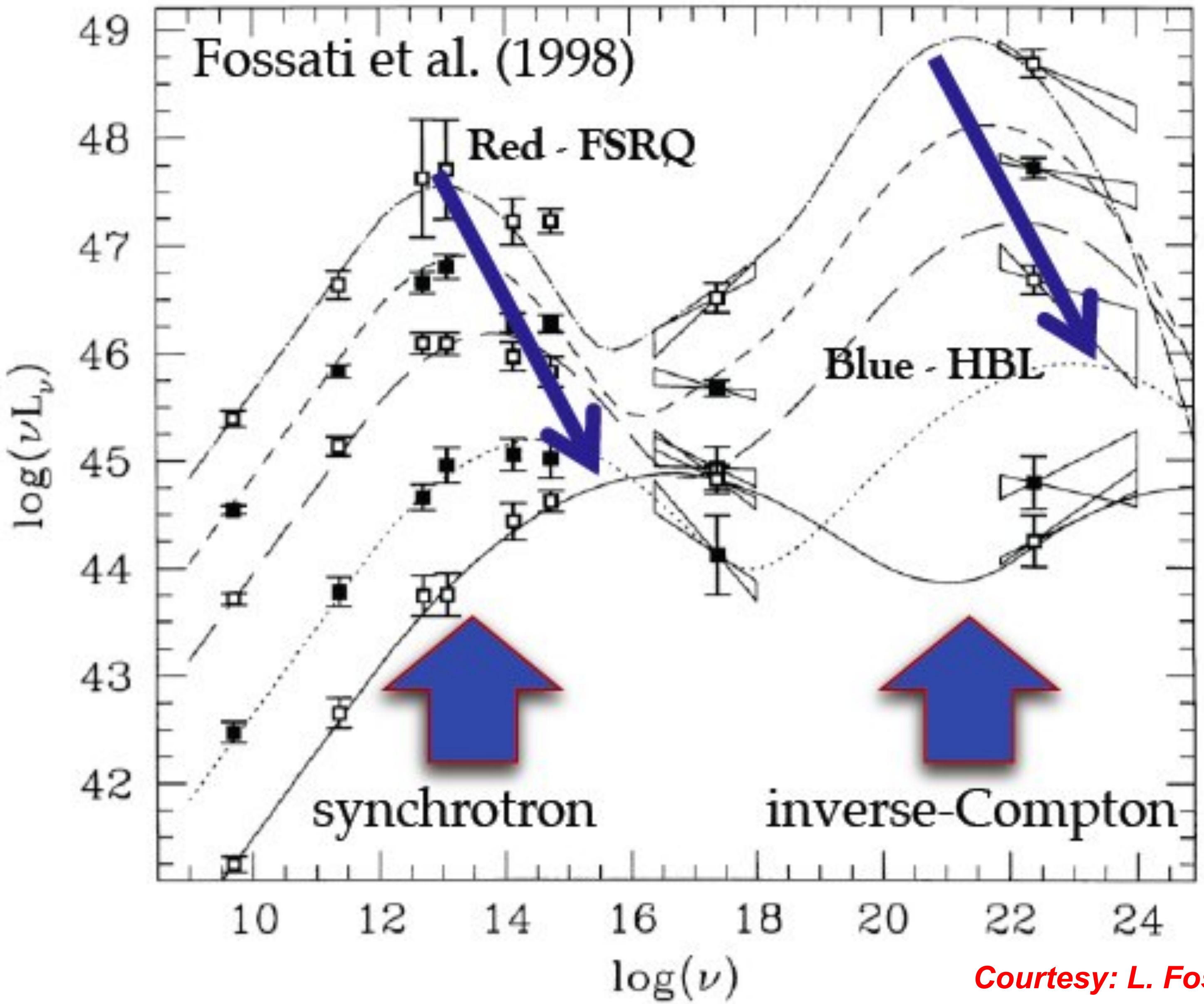
Isotropic irradiated γ–ray energy vs redshift (~400 GRB redshifts known)



GRB jet "artist concept"

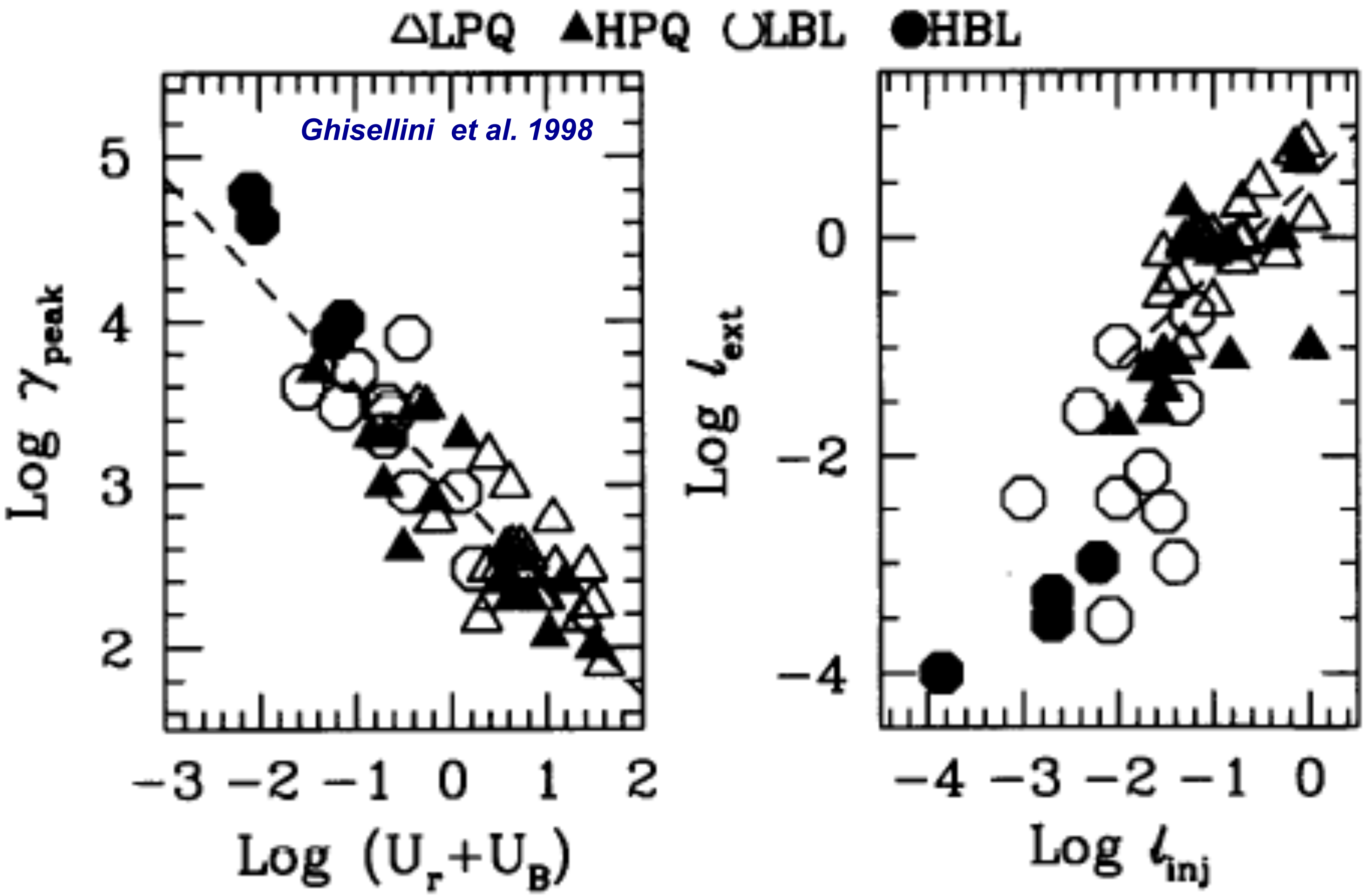


Blazars "spectral sequence"



Courtesy: L. Foschini

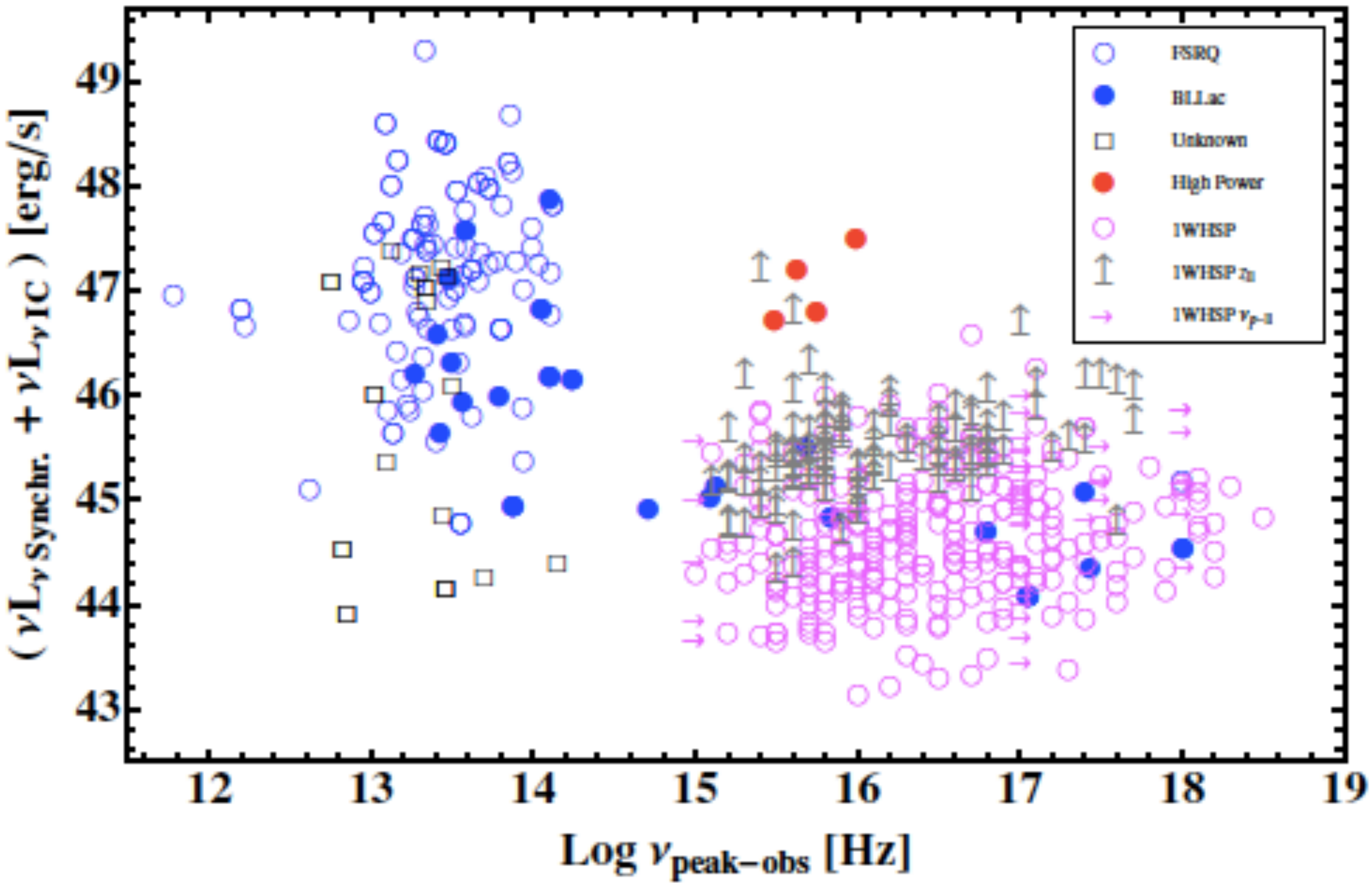
Blazars sequence: internal vs external photon fields



Peak random Lorentz factor anticorrelates with total jet power (see exceptions in Padovani et al. 2012, Arsioli et al. 2015)

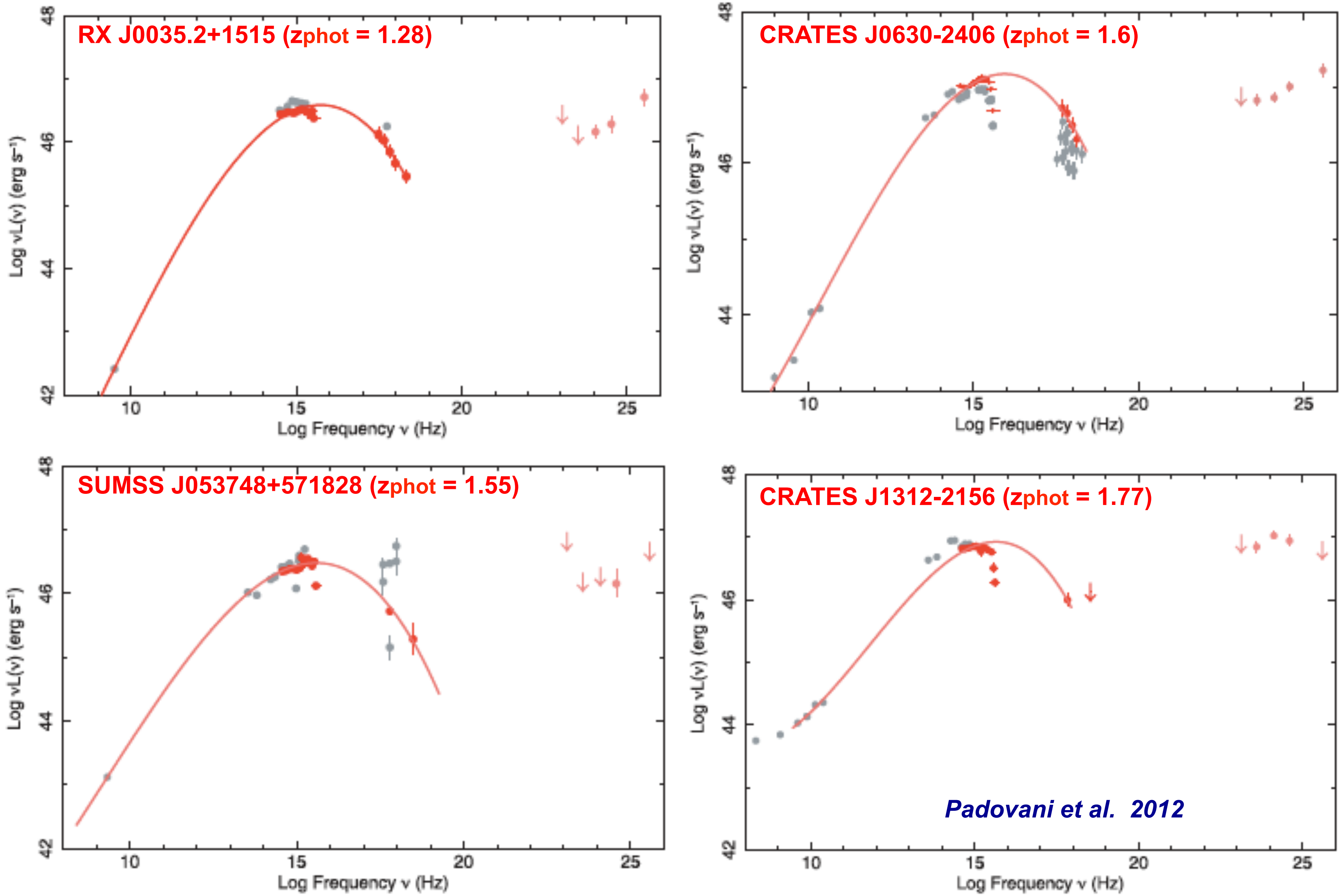
External photon compactness correlates with injected power, see also Sbarrato et al. 2012

A counterexample: High power, high synchrotron peak blazars

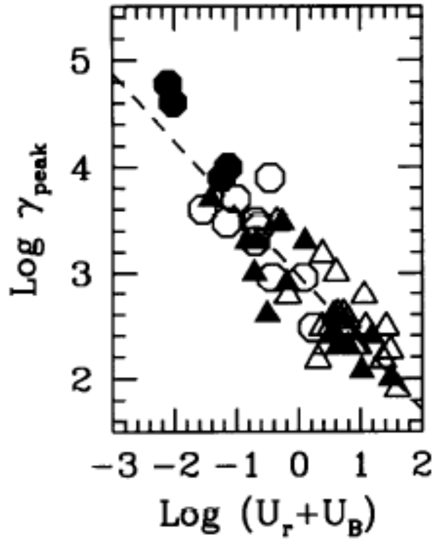


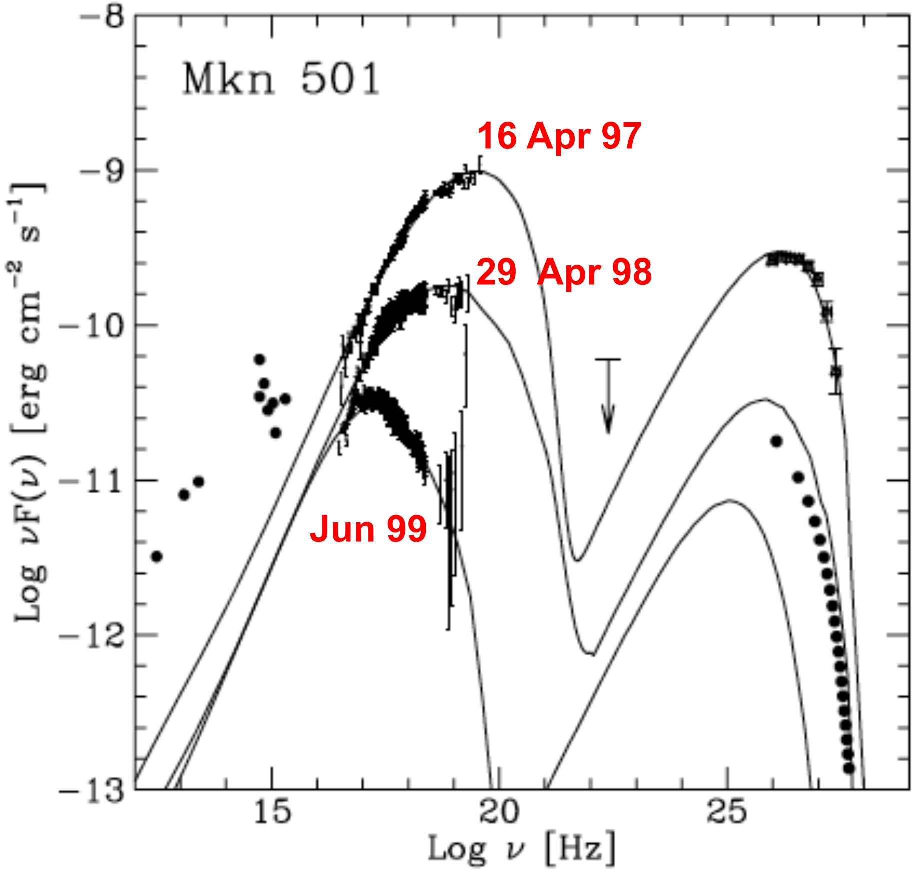
Padovani, Giommi, Rau 2012; Arsioli et al. 2015

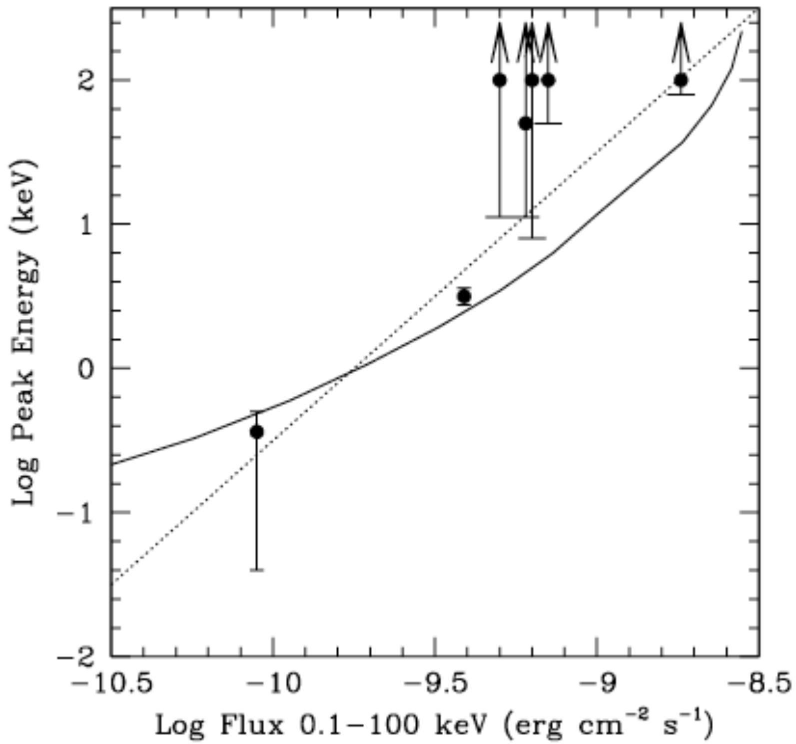
High power, high synchrotron peak blazars



Synchrotron peak frequency vs power anticorrelation <u>does not hold</u> in individual sources

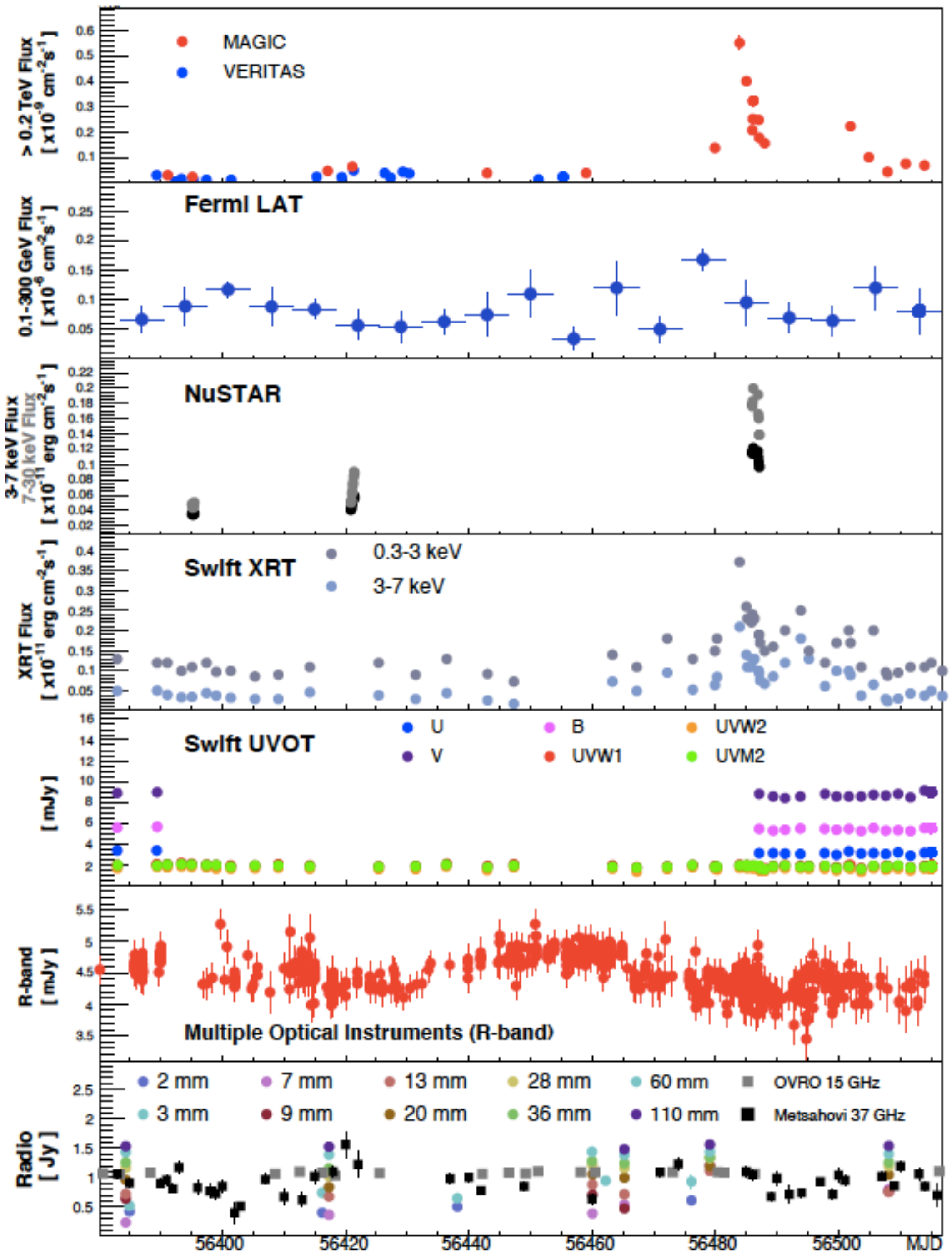


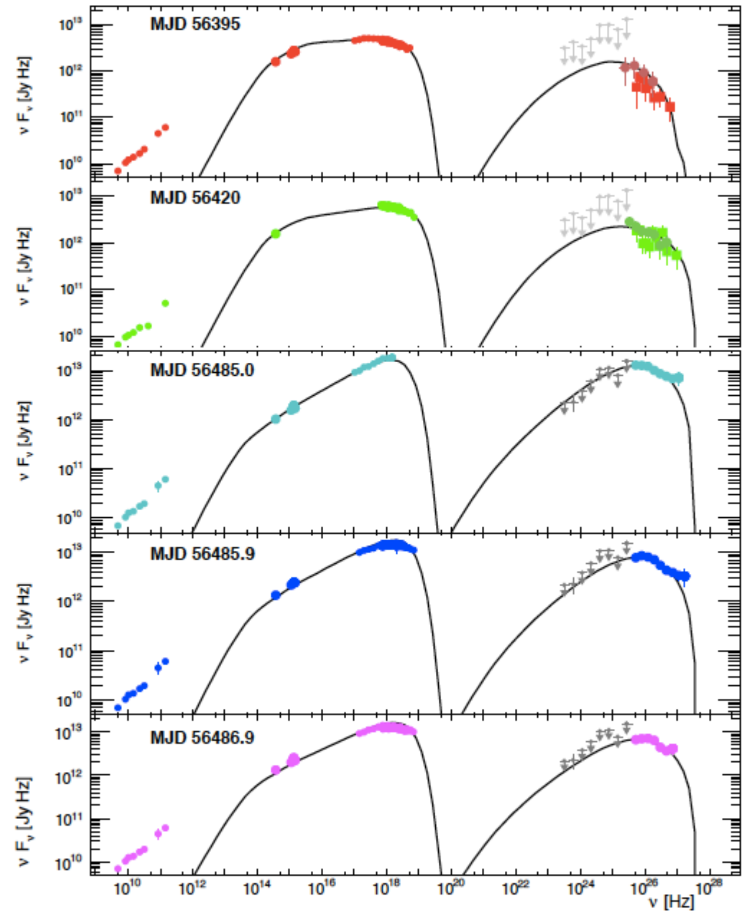




Ghisellini 1999; Tavecchio et al. 2001

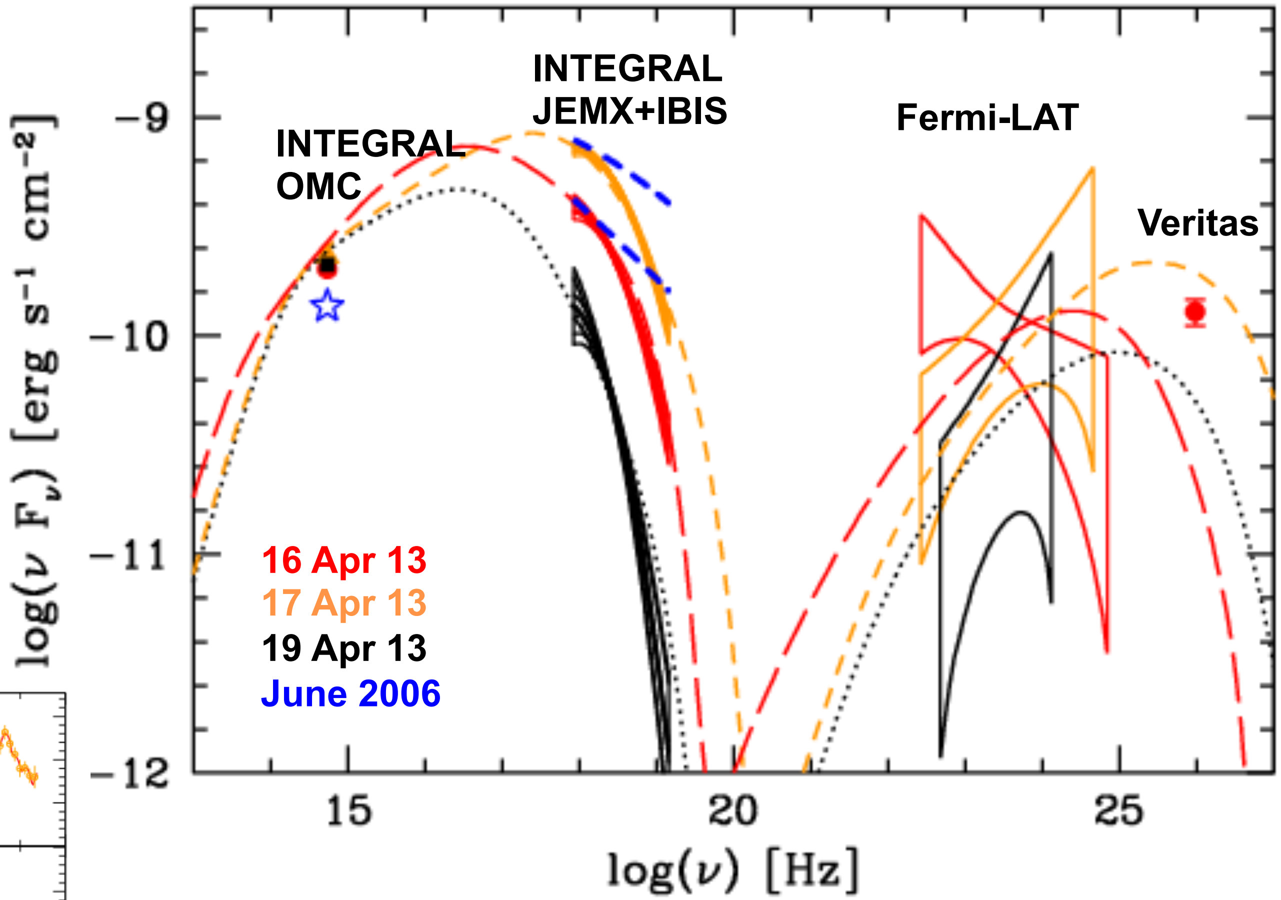
Nustar observations of Mkn501 in August 2013



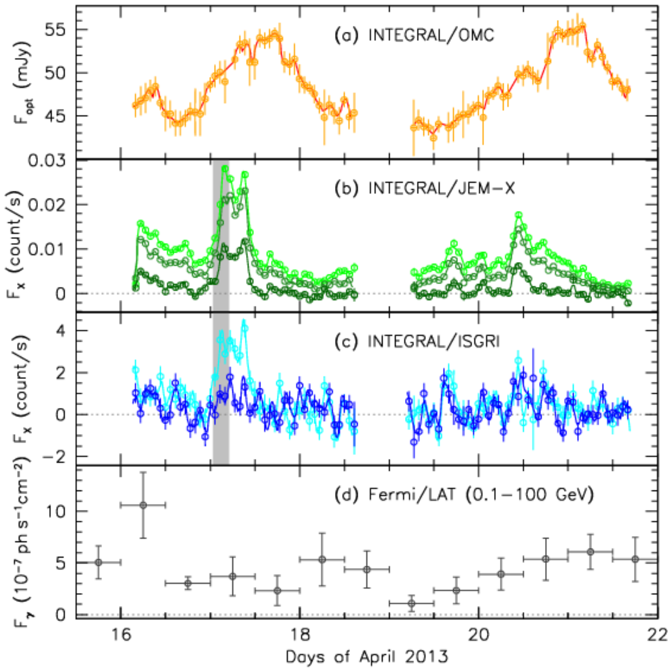


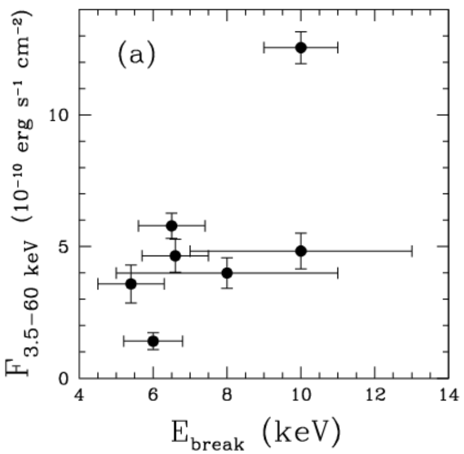
Furniss et al. 2015

High synchrotron peak BL Lac Mkn421 (z = 0.031)



April 2013



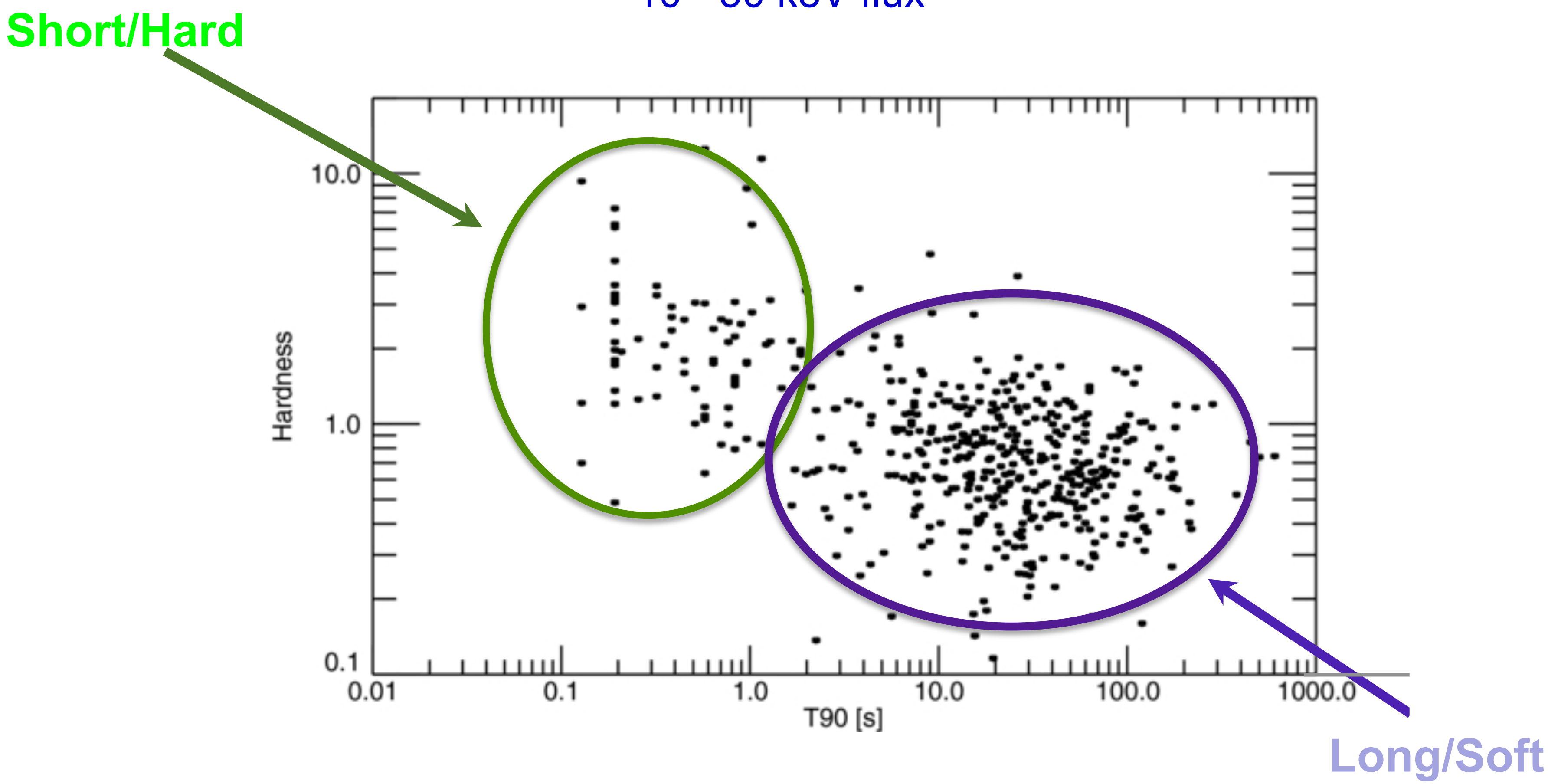


The peak energy correlates with the flux but has an upper limit of ~10 keV

Pian et al. 2014

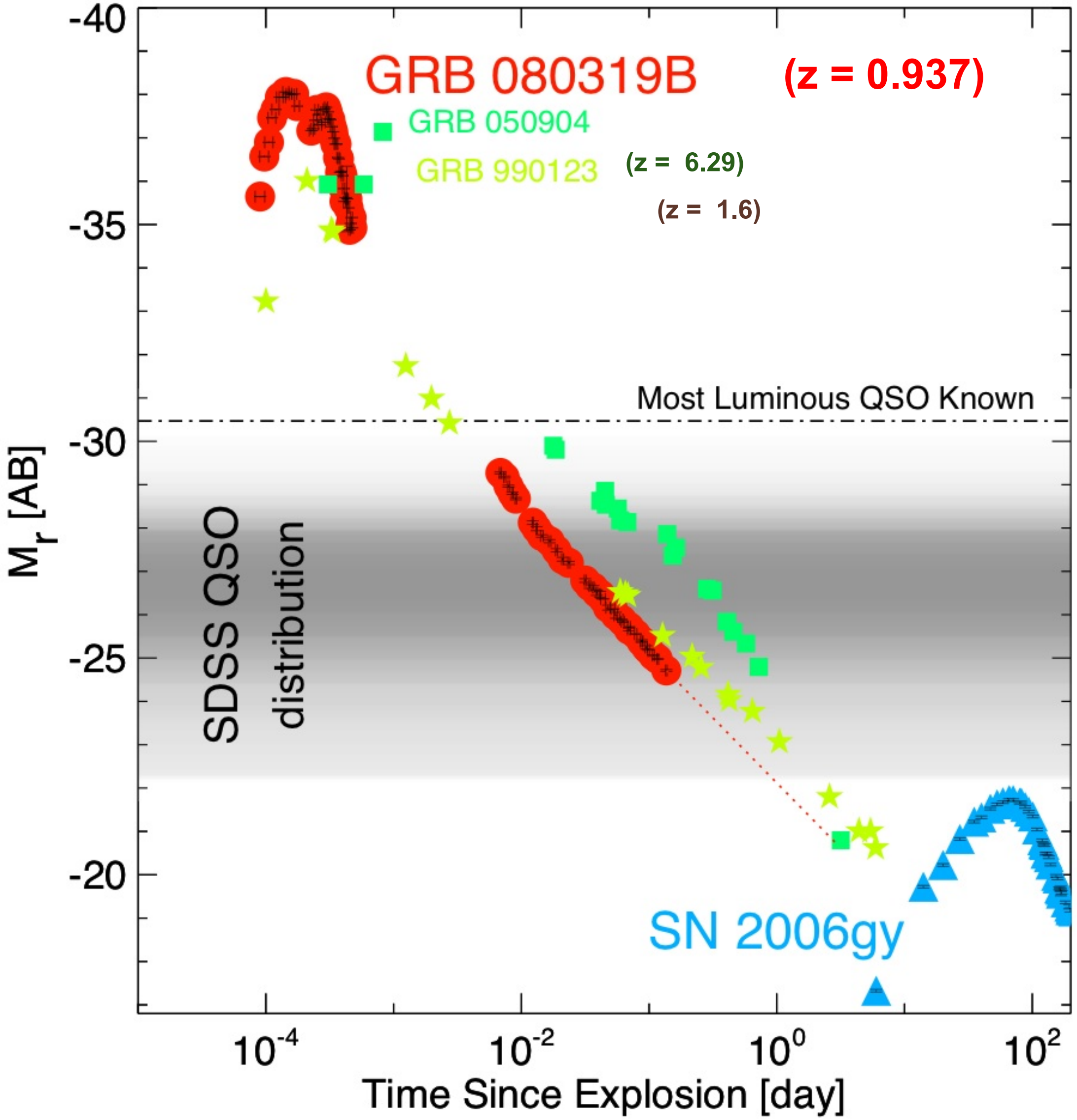
Hardness-Duration Classification of GRBs

$$H = \frac{50 - 300 \text{ keV flux}}{10 - 50 \text{ keV flux}}$$



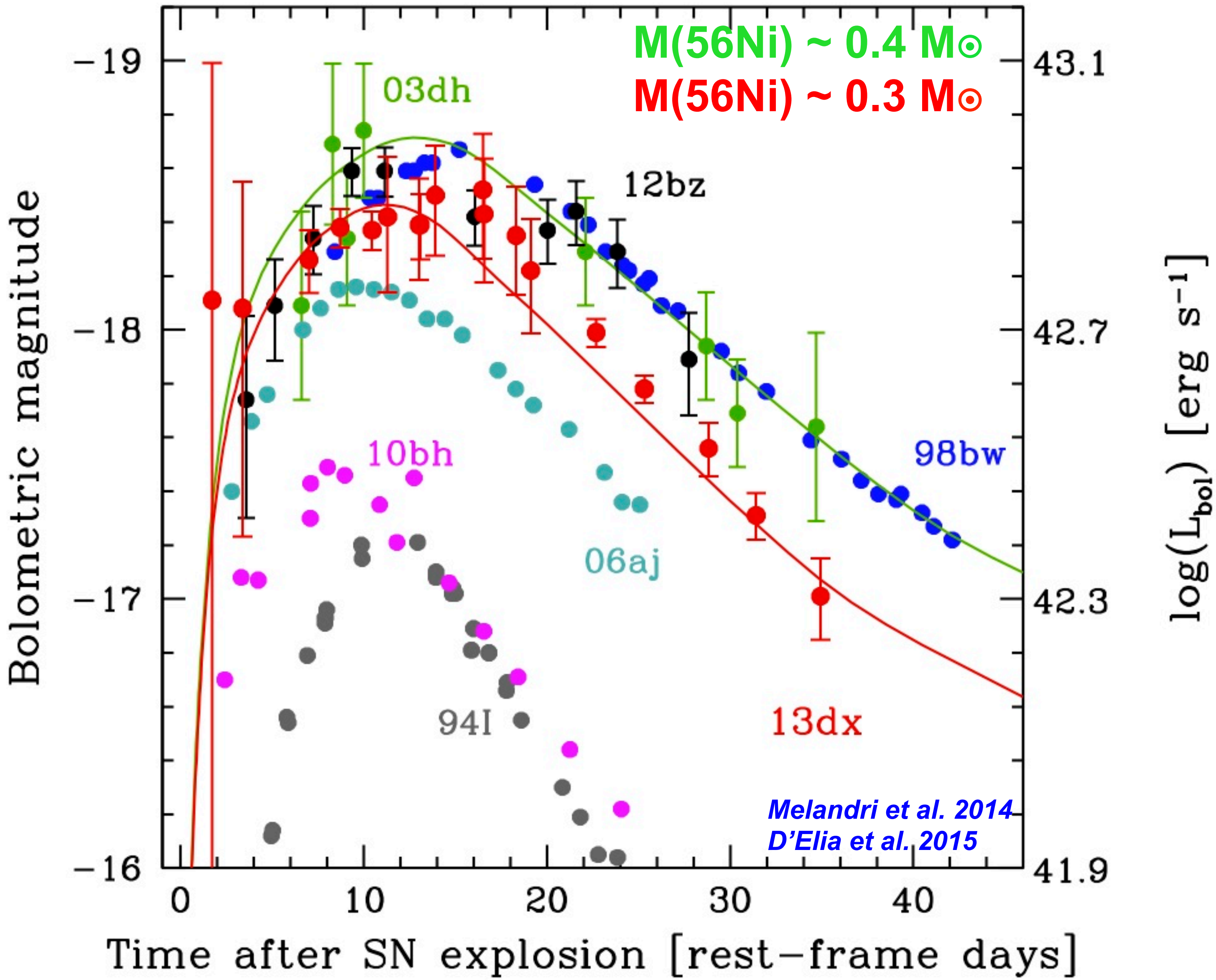
Kouveliotou+1993; von Kienlin+2014

Early Multiwavelength GRB Counterparts

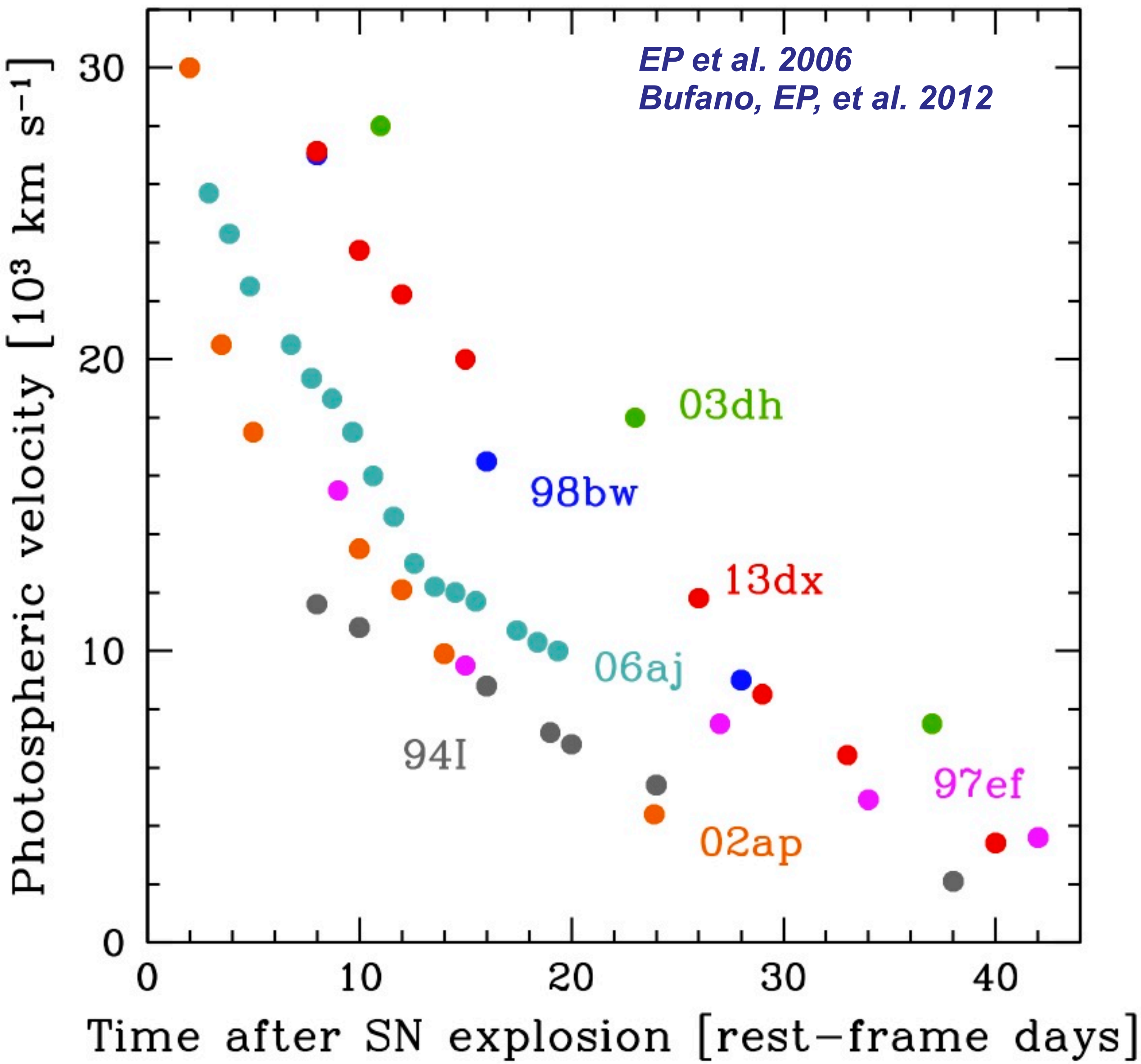


Bloom et al. 2008

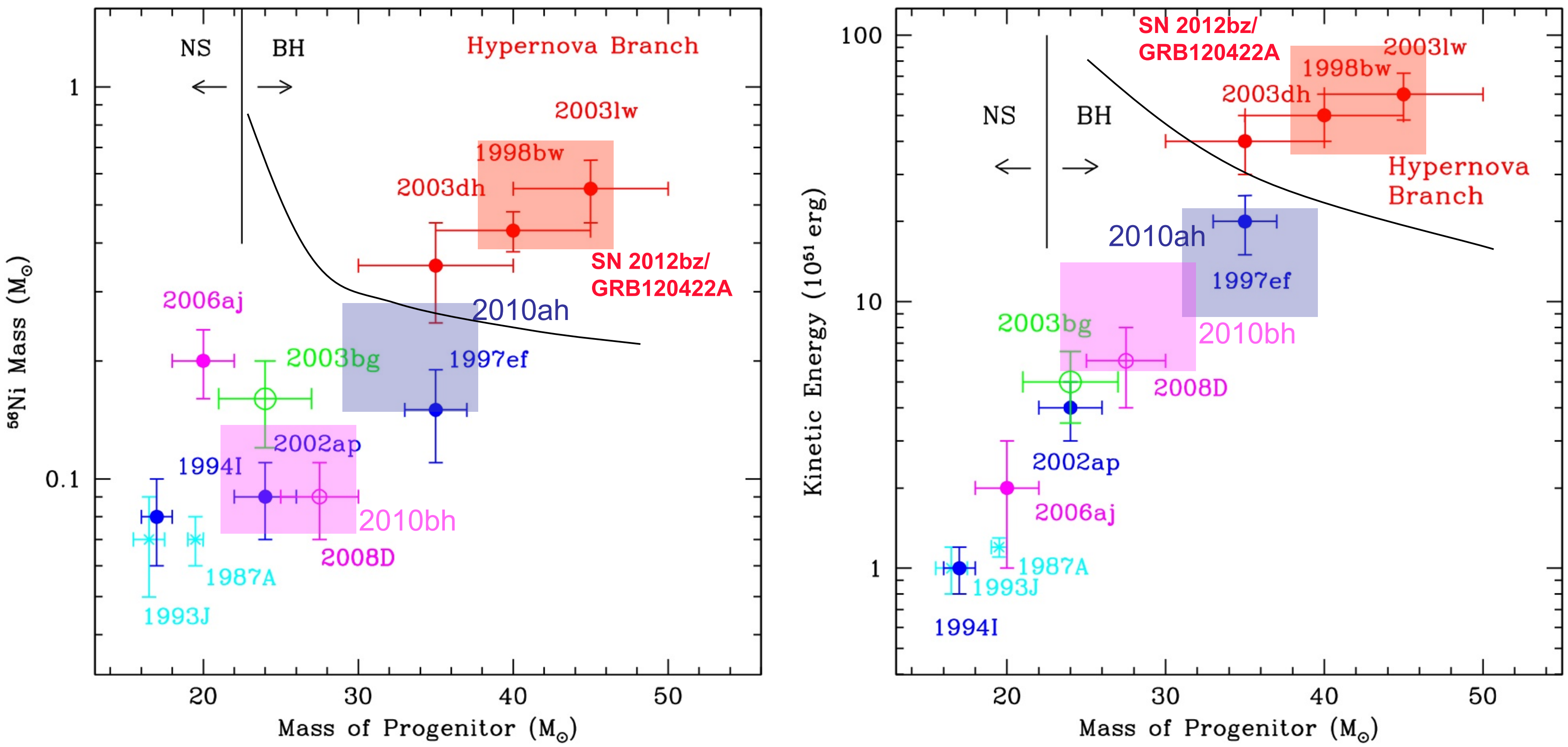
Light Curves of GRB Supernovae at z < 0.3



Photospheric velocities of Type Ic Sne: high kinetic energy

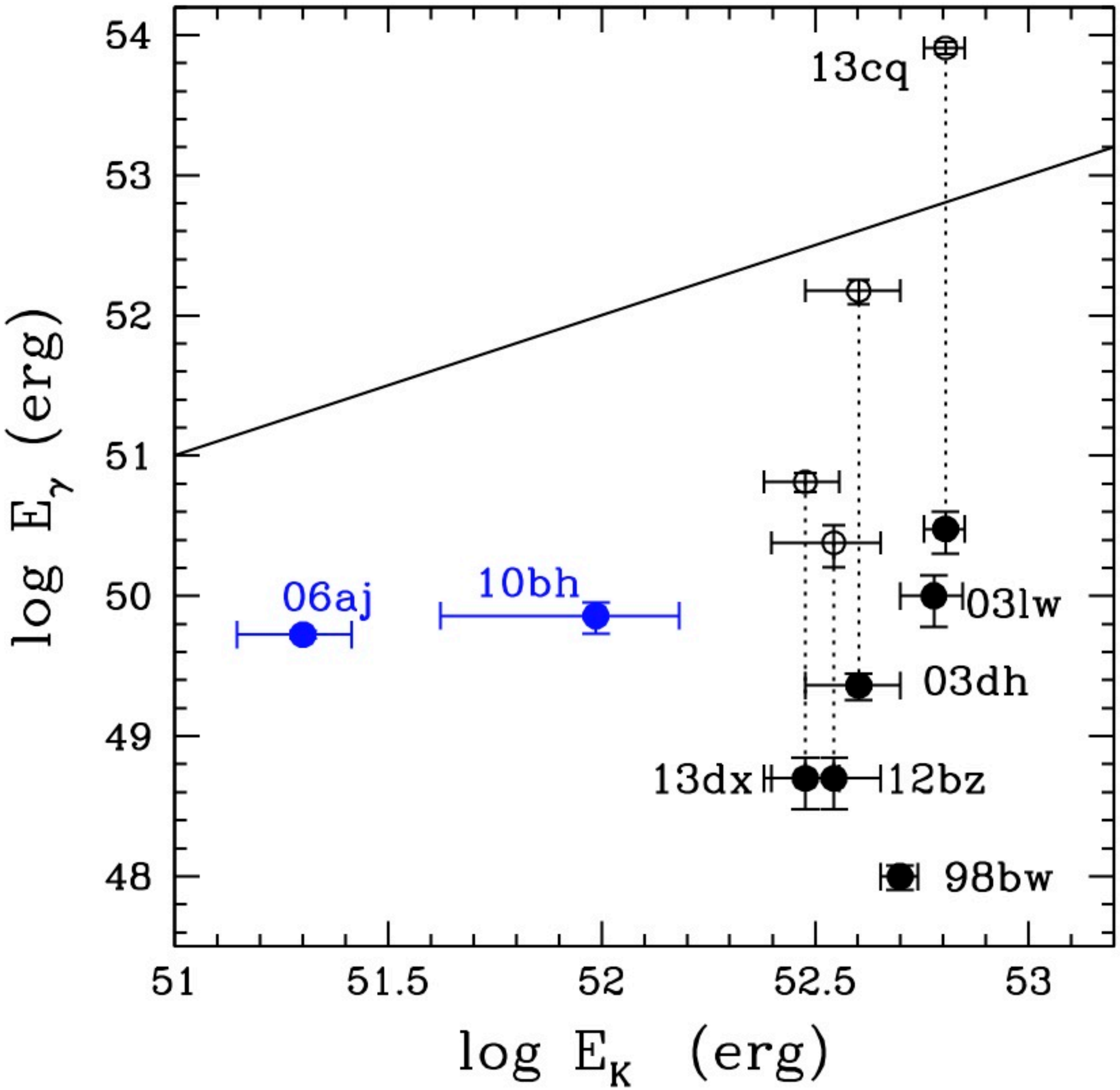


Properties of CC-Sne as f(M_{prog})



A minimum mass and energy seem to be required for GRBs:
(Mazzali et al. 2013)

GRB energy output versus SN kinetic energy



Supernova kinetic energy is very close to Rotational energy of millisecond NS

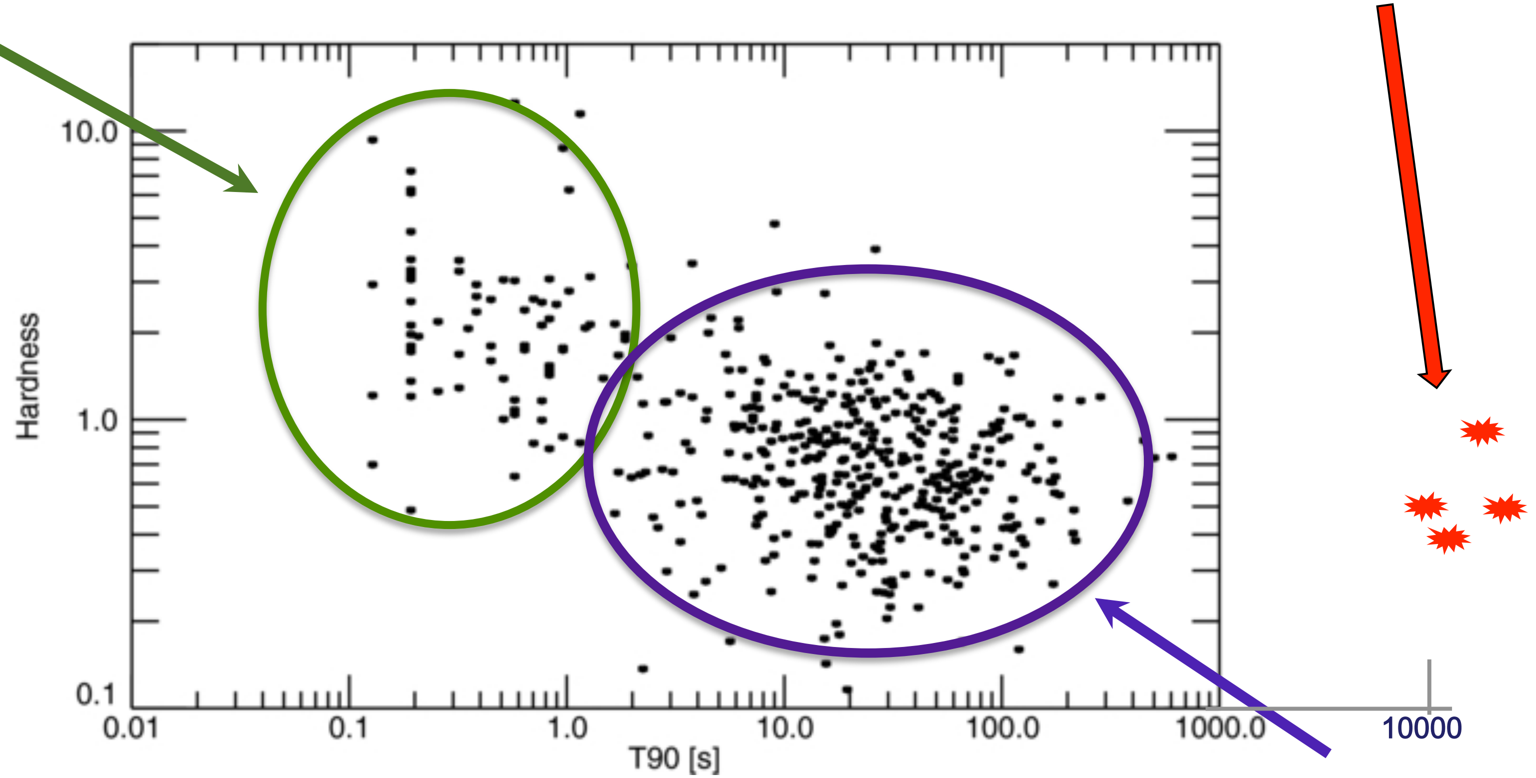
Mazzali, MacFadyen, Woosley, EP, Tanaka 2014

Hardness-Duration Classification of GRBs

$$H = \frac{\text{50 - 300 keV flux}}{\text{10 - 50 keV flux}}$$

Four GRBs with duration $>10^4$ s

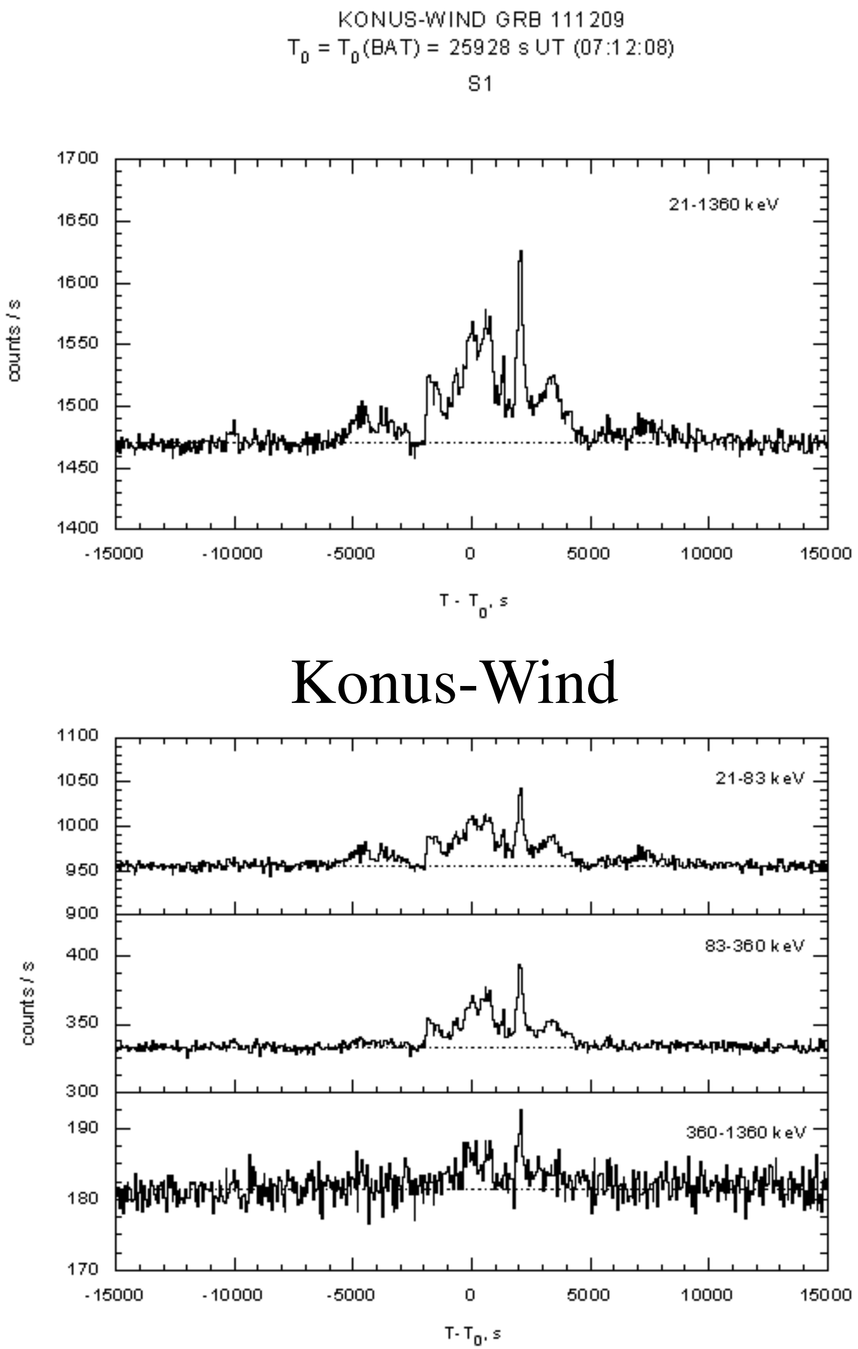
Short/Hard

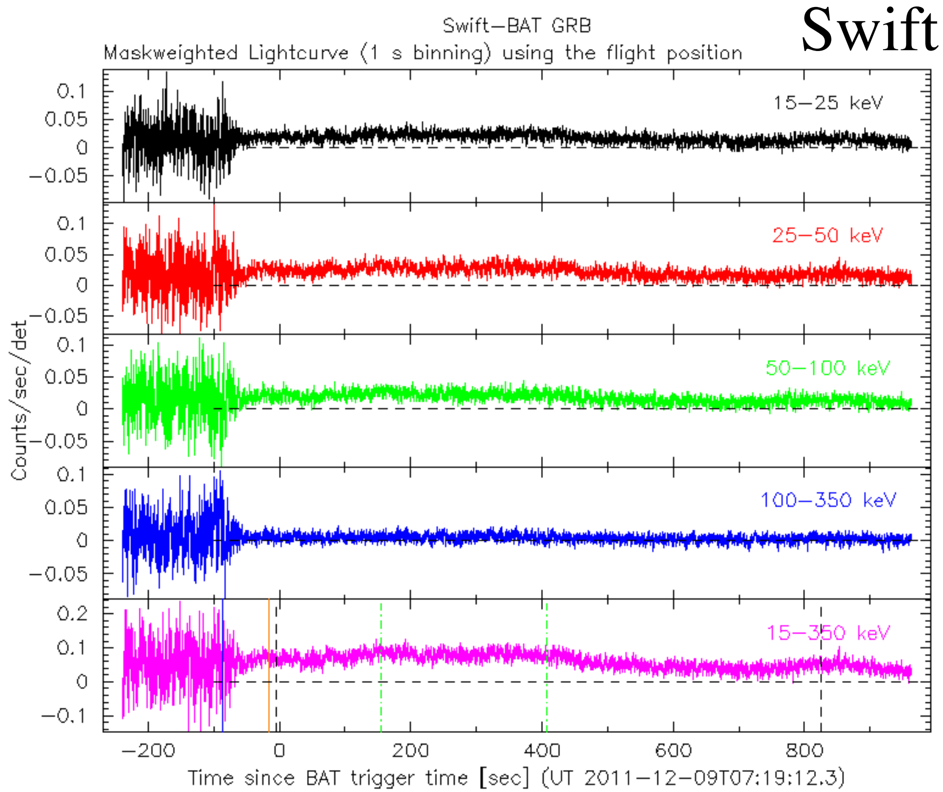


Long/Soft

Kouveliotou+1993; von Kienlin+2014

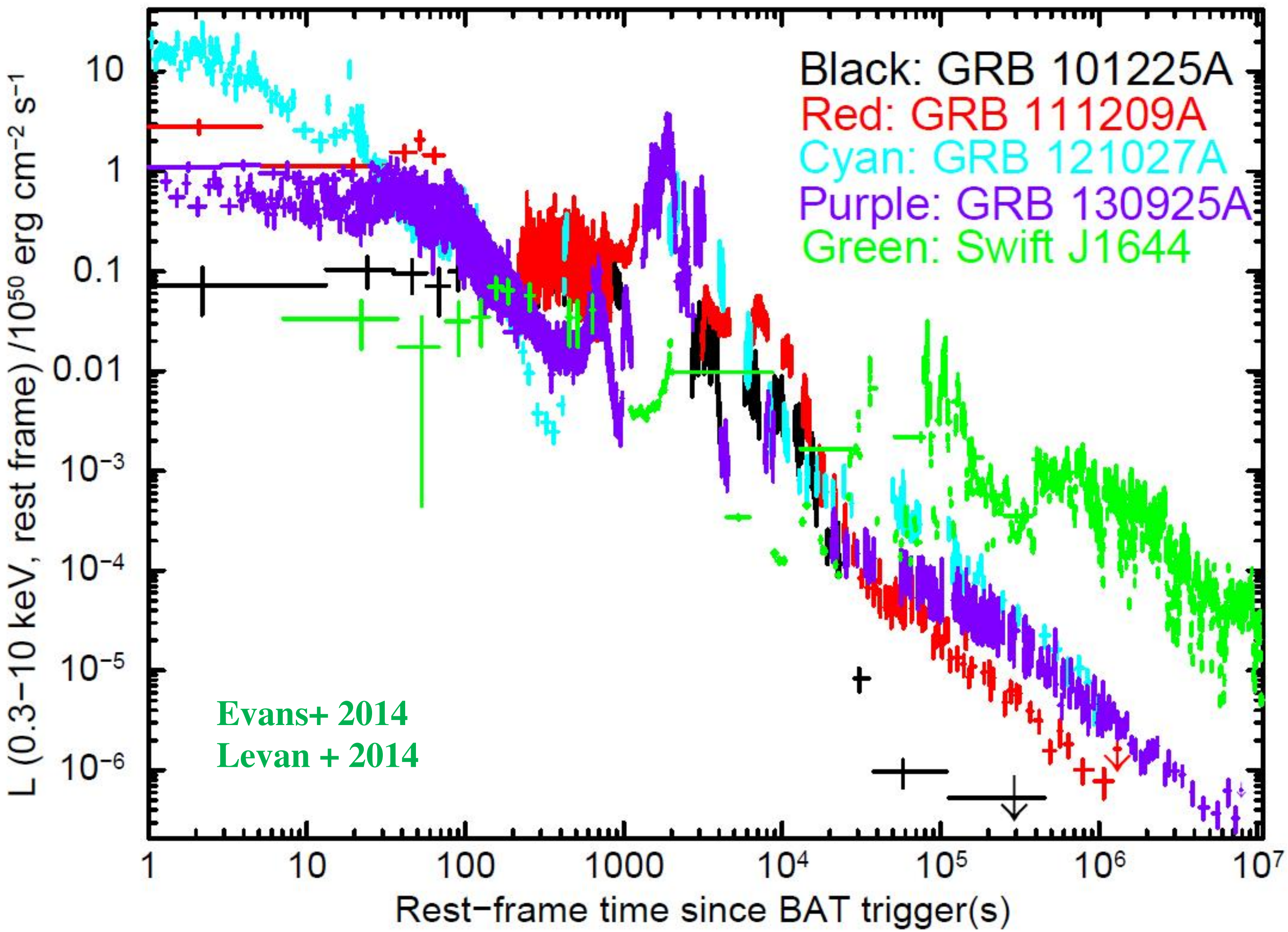
GRB 111209A (z = 0.677) prompt light curve





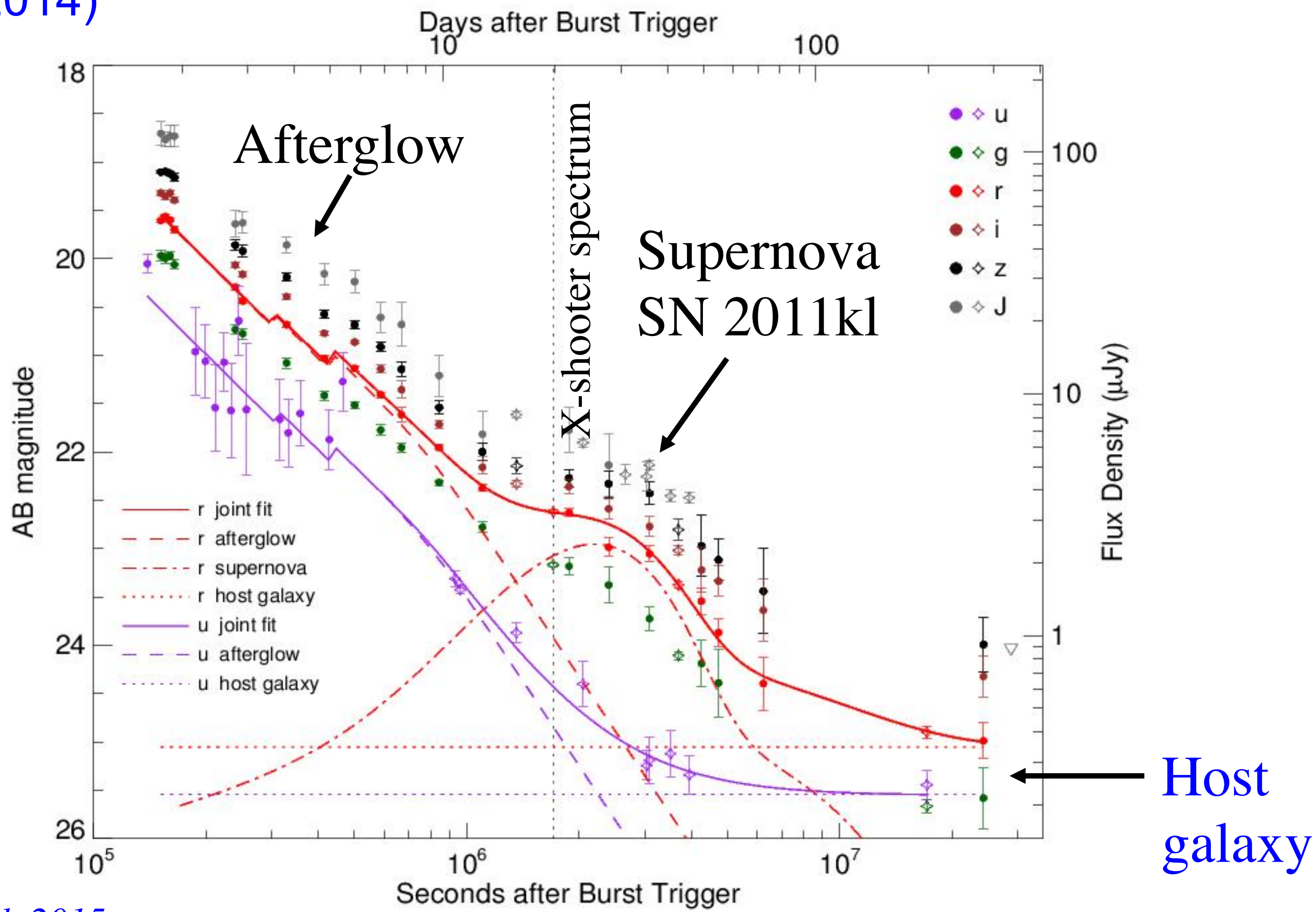
Ultra-long duration can be properly recognized only by interplanetary satellites

Ultra-long GRBs



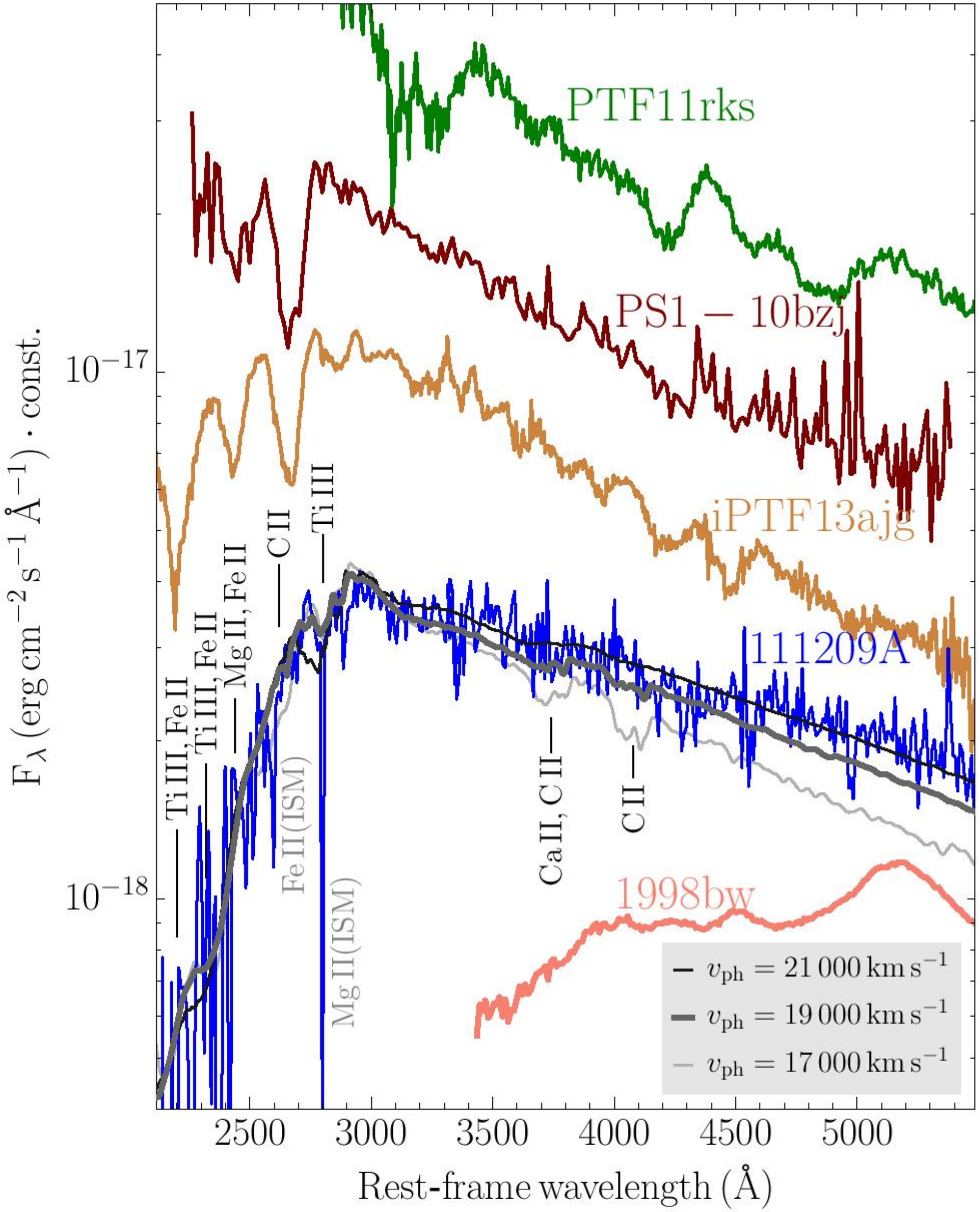
Ultra-long GRB 111209A (z = 0.677) & its SN

7-channel GROND@2.2m observations over 70 days
Added Swift/UVOT + publ. HST data (from Levan et al. 2014)



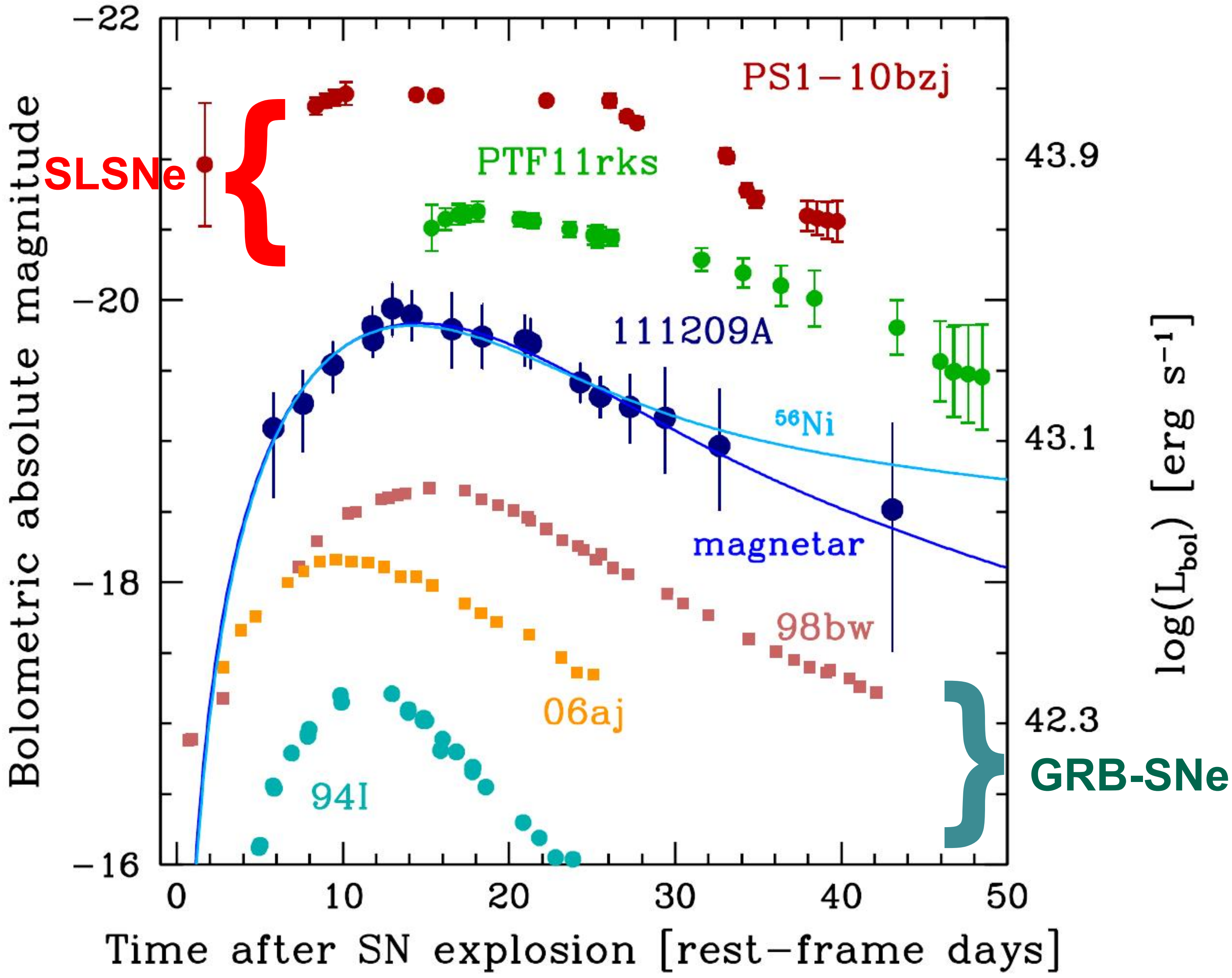
Greiner et al. 2015

SN 2011kl spectrum (z = 0.677)



- SN 2011kl X-shooter spectrum reminiscent of SLSN
- Spectrum very blue and (nearly) no absorption lines:
  ➔ little ejecta
  ➔ high velocity
- Spectrum reproduced with radiation transport code (Mazzali+00) and a density profile $\rho \sim r^{-7}$
- featureless spectrum due to line blending ($v_{ph} \sim 20{,}000$ km/s)
- no evidence of freshly synthesized material mixed-in, unlike in GRB-SNe

SN 2011kl light curve

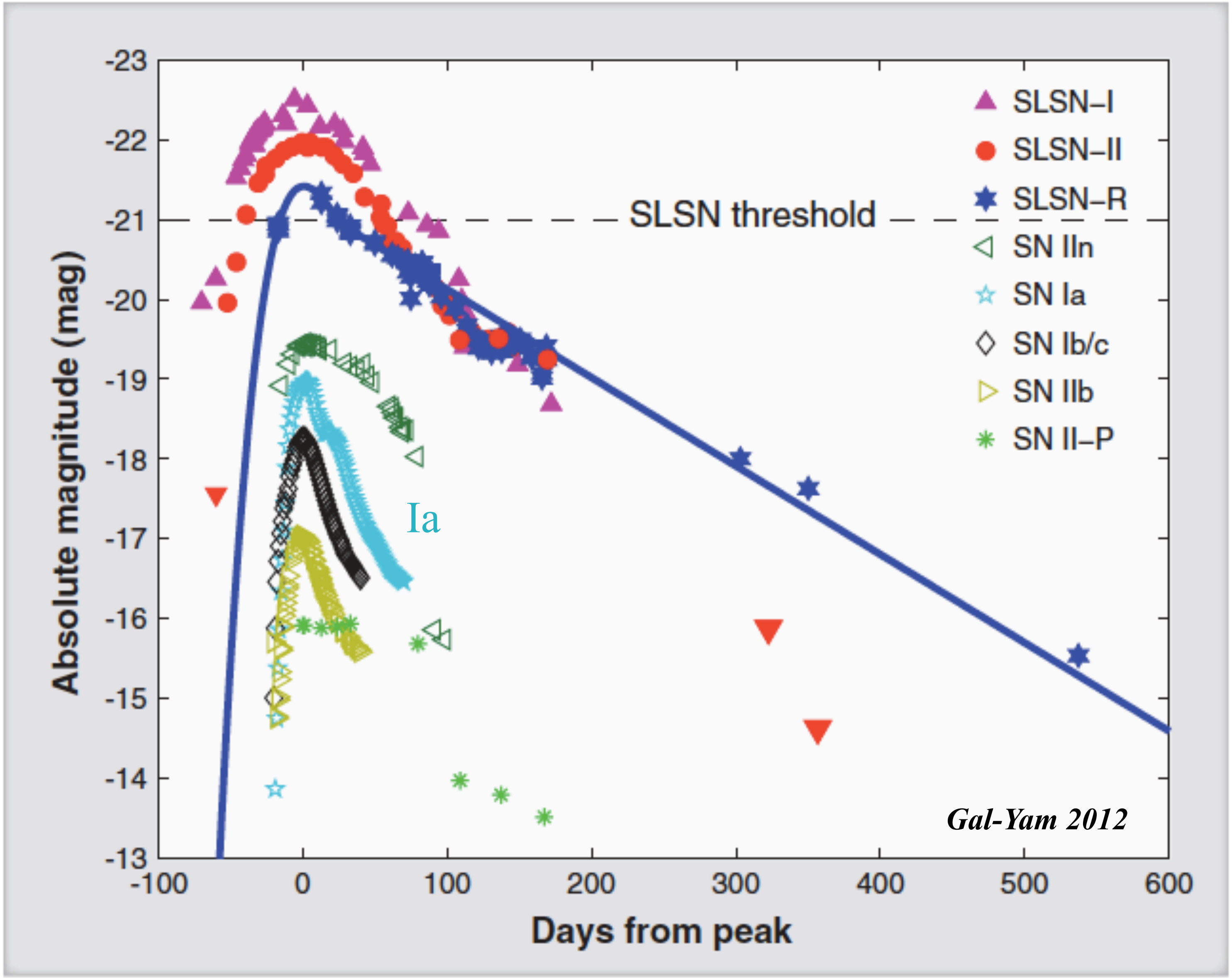


The missing link between GRBs
And SLSNe:

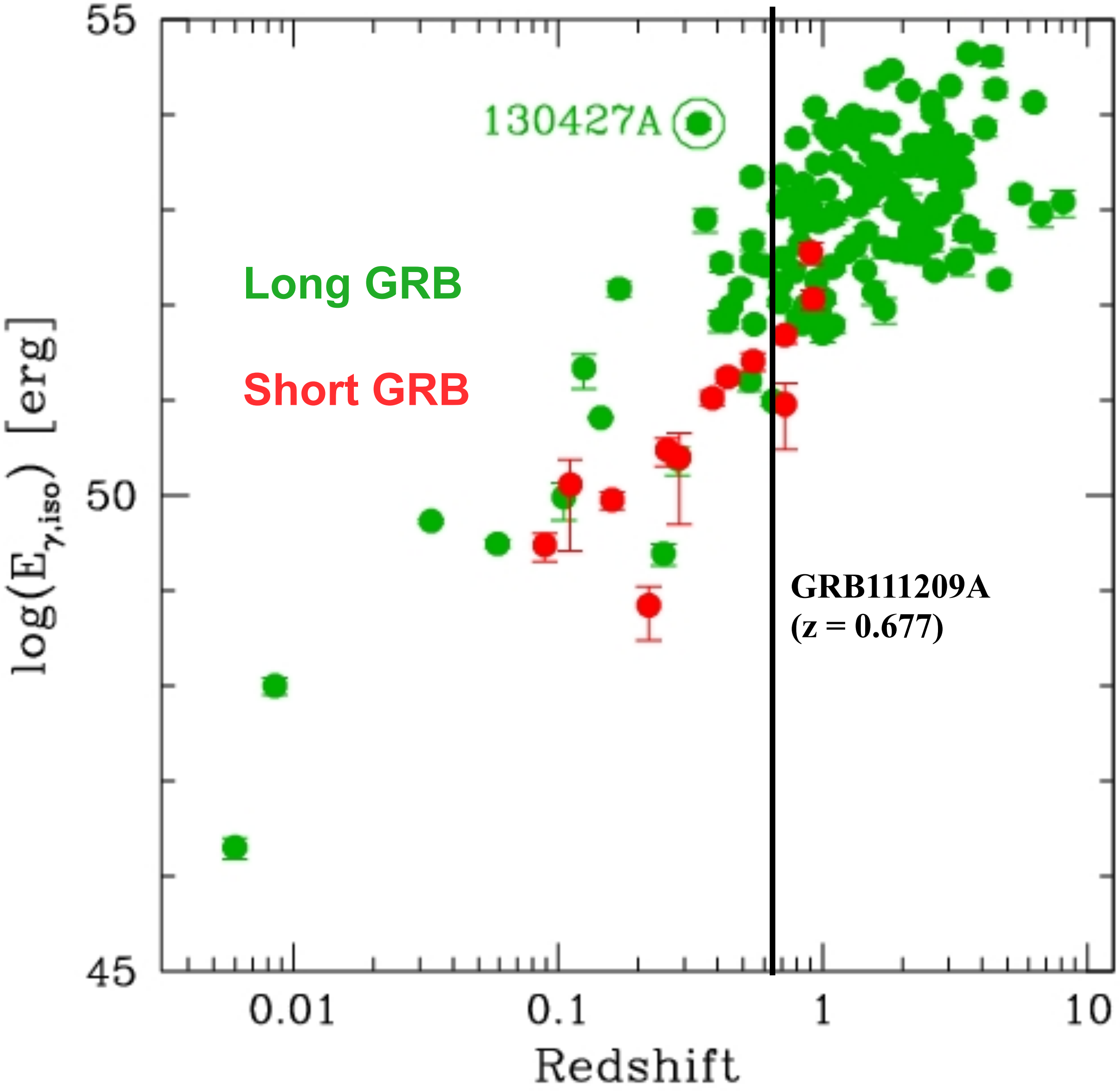
GRB111209A/SN2011kl: a very
luminous supernova associated with
an ultra-long GRB

A "compelling" case for magnetar?

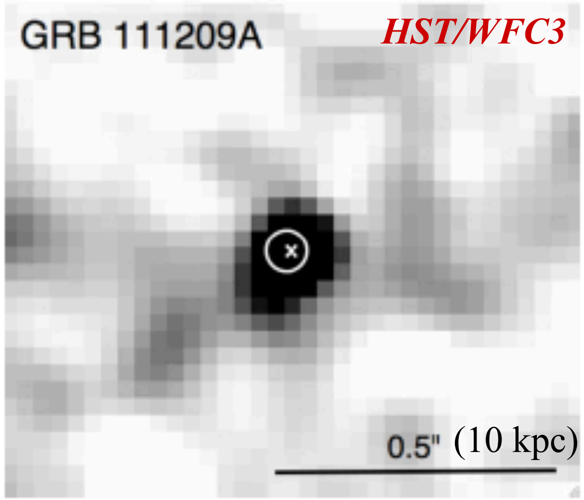
Supernova light curves

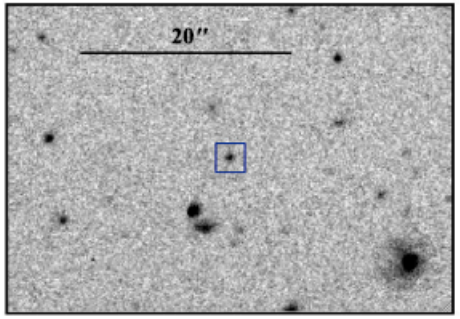


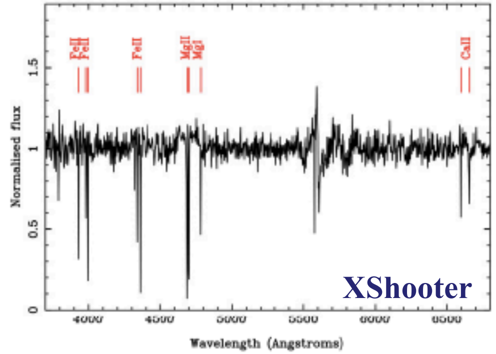
Isotropic irradiated γ–ray energy vs redshift

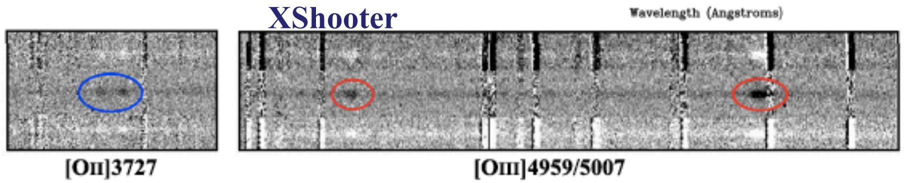


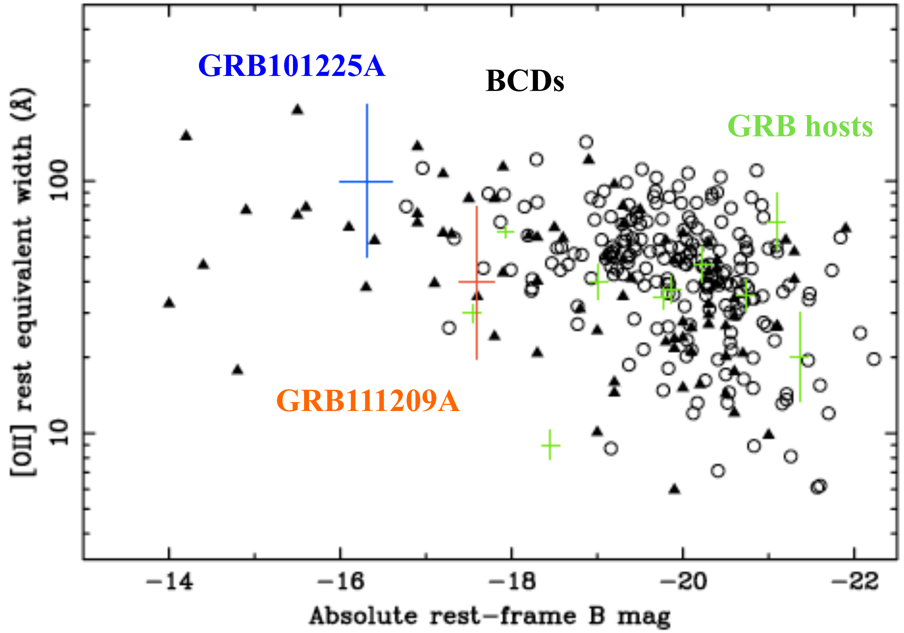
GRB111209A host: Low-extinction, highly star-forming, low Z

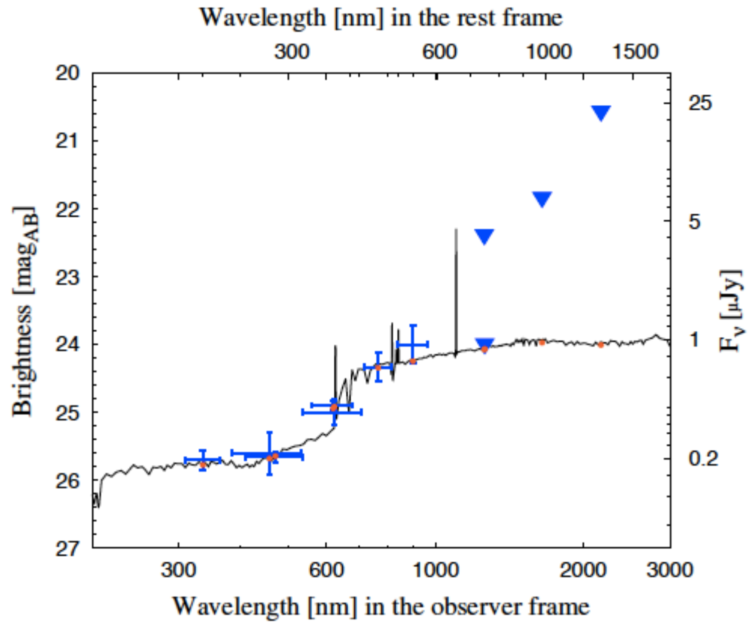








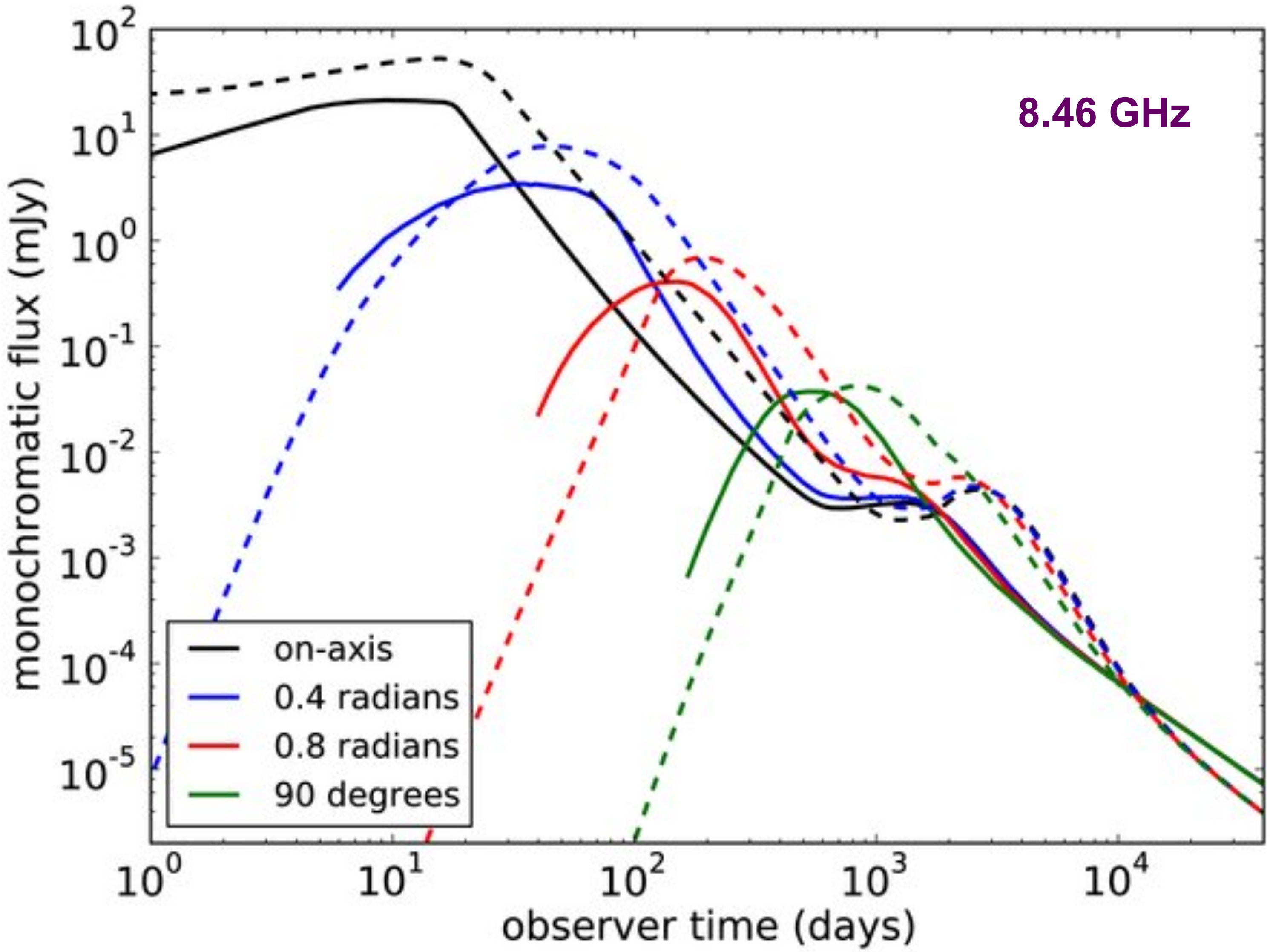




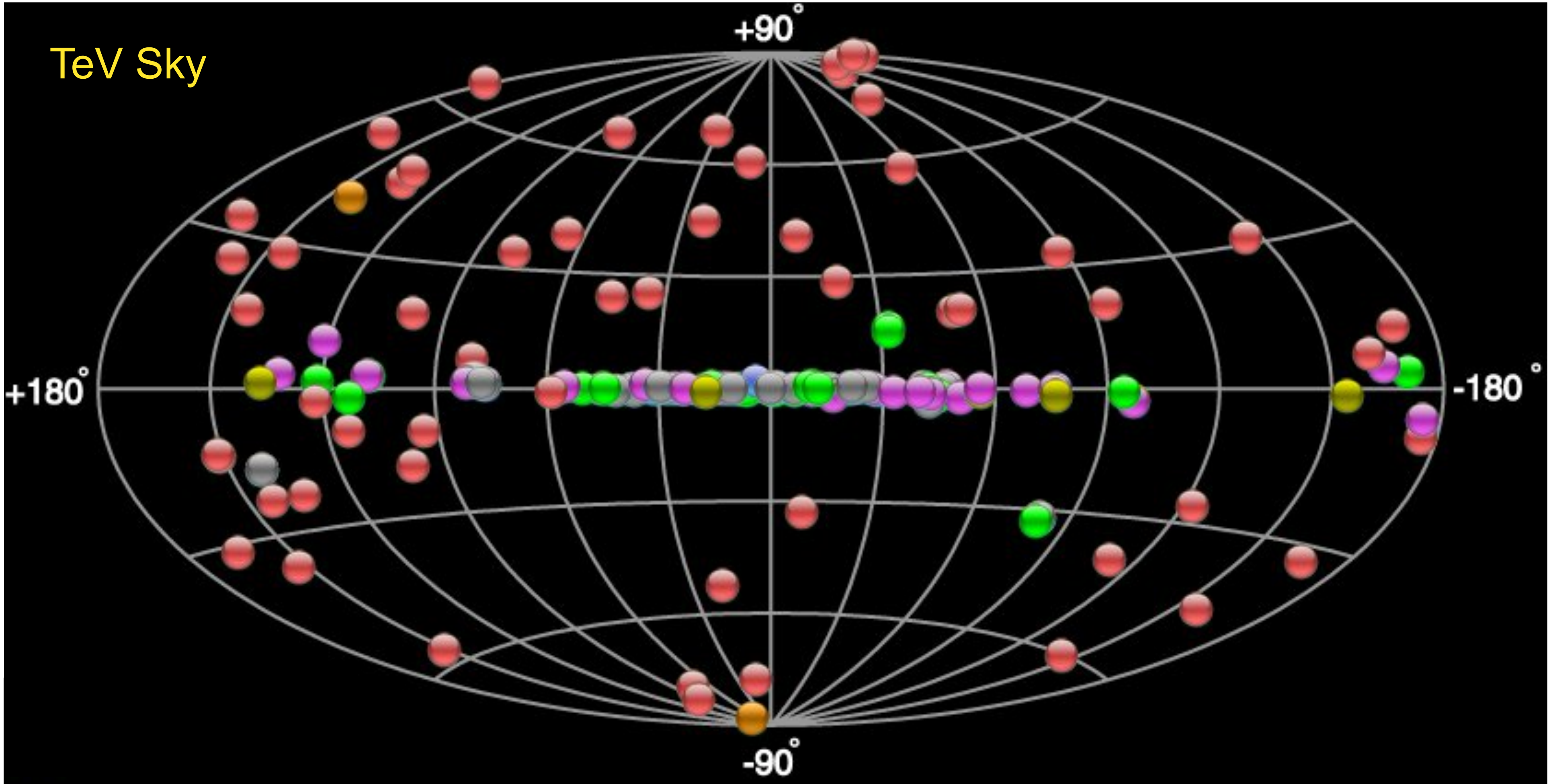
Levan et al. 2014

Kann et al. 2015

Simulated and analytical radio emission of GRBs



Van Eerten, Zhang, MacFadyen 2010



PWN

Starburst (M82, NGC253)

HBL, IBL, FRI, Blazar, FSRQ, LBL, AGN (unknown type)

Globular Cluster, Star Forming Region, uQuasar, Cat. Var., Massive Star Cluster, BIN, BL Lac (class unclear), WR

~150 sources

Shell, SNR/Molec. Cloud, Composite SNR, Superbubble

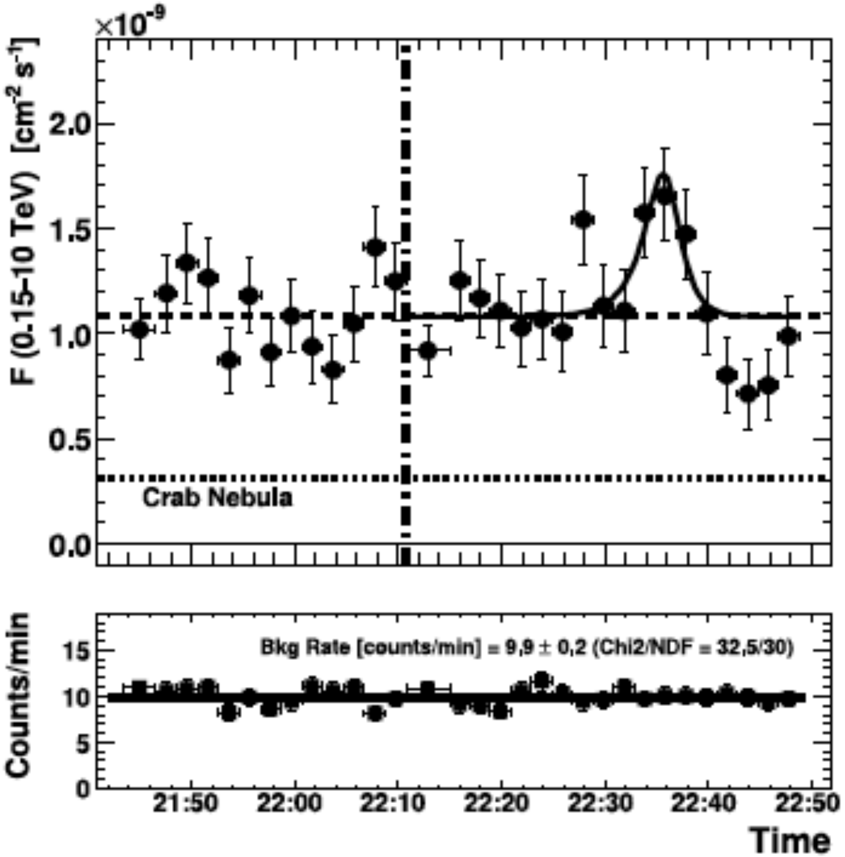
DARK, UNID, Other

Binary, XRB, PSR, Gamma BIN

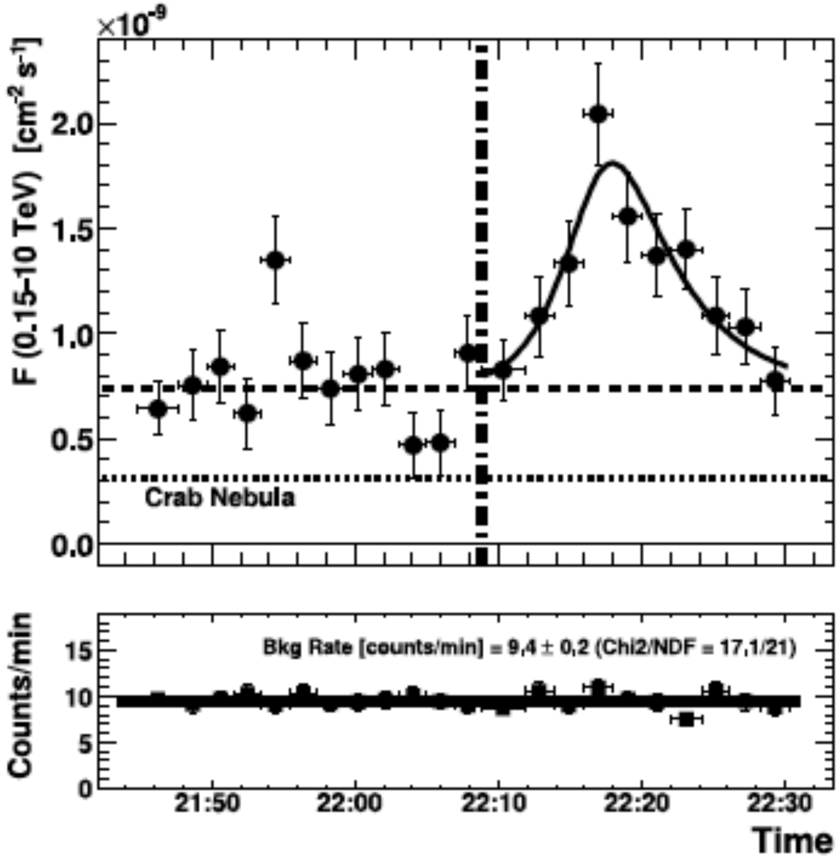
http://tevcat.uchicago.edu

TeV minute time-scale variability of Mkn501 (MAGIC)

30 June 2005

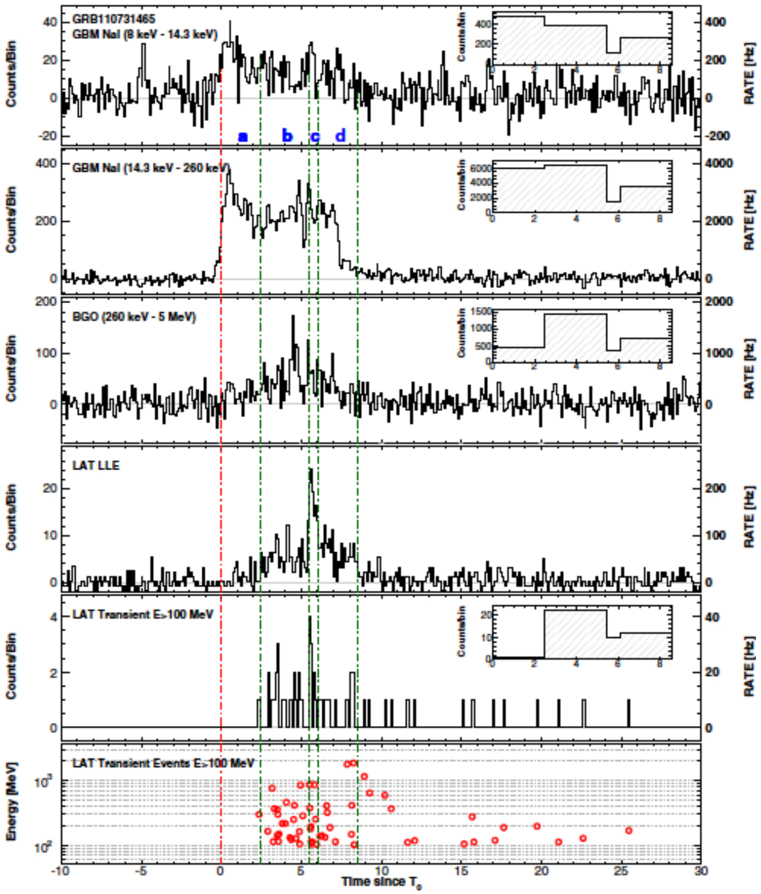


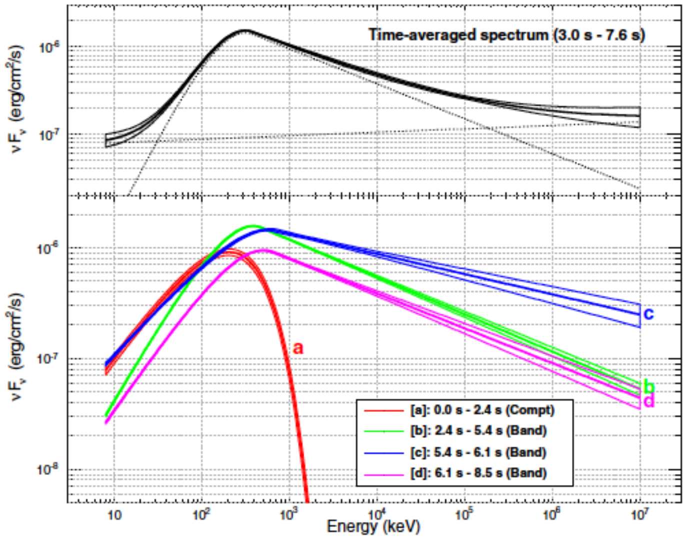
9 July 2005



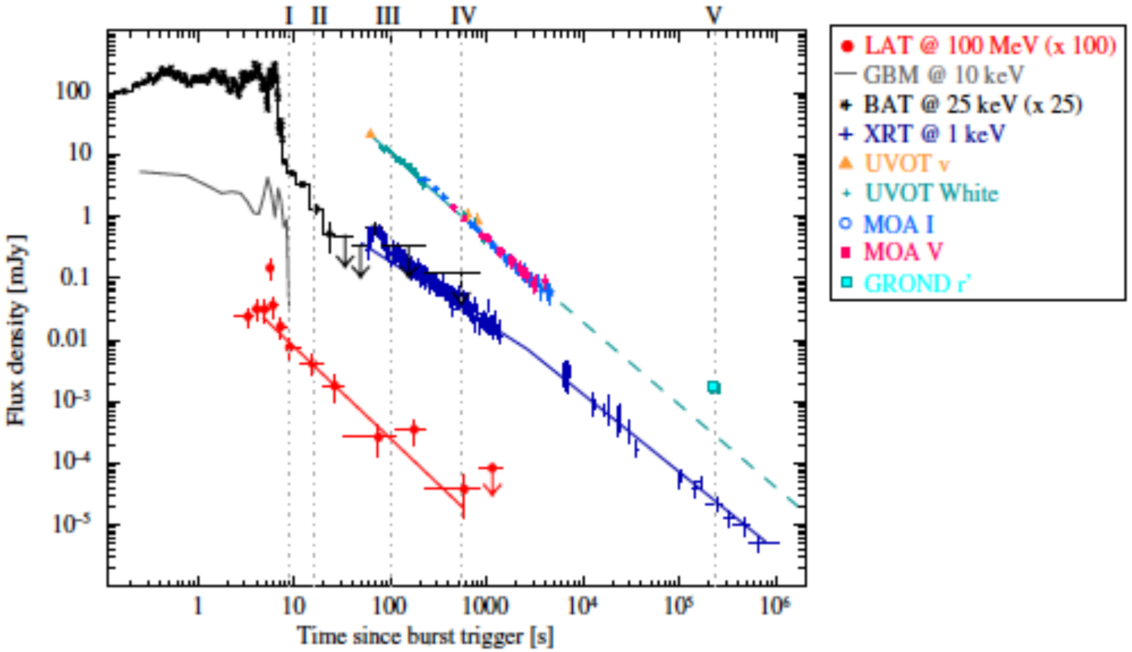
Albert et al. 2007

GRB110731A (z = 2.83) as a template to estimate TeV emission





Ackermann et al. 2013



scaling to z ~0.3 and extrapolating to 1 TeV, flux at 1000s is ~5 Crab

Conclusions and open problems

Analogies in relativistic jets on many scales, despite difference in origin

High synchrotron blazars may have intrinsic differences that allow only a subset of them to become really extreme. Correlated X-ray and TeV variability may be revealing in this sense

Are all GRB jets related to accretion on a promptly formed BH or is magnetar a viable scenario?

As it was done with AGNs, can we unify GRBs and supernovae based on their jet viewing angle?