General outline of my 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.

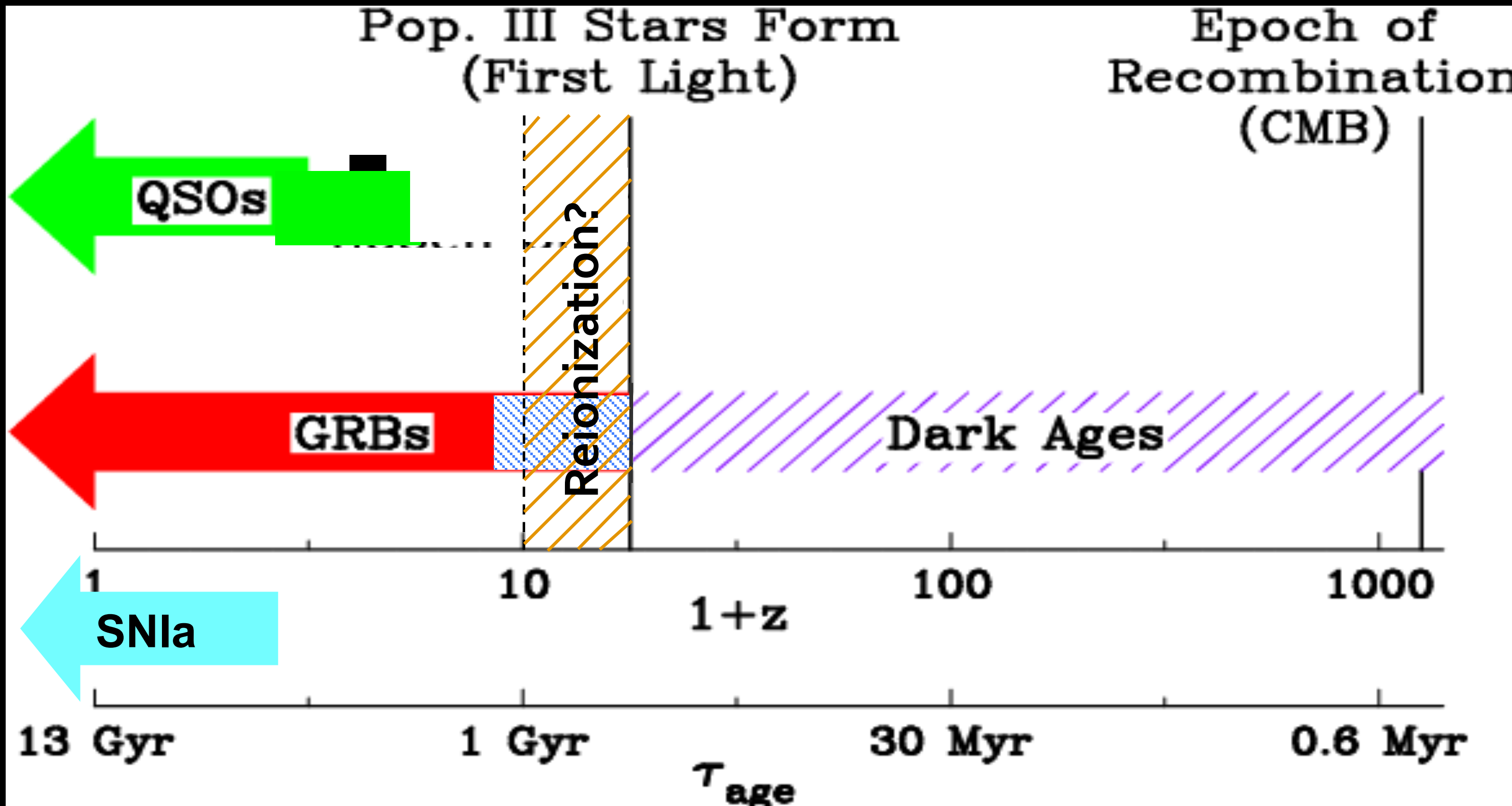
2) Theoretical picture: the standard model from its foundation to the latest debates

The standard model, progenitor, energy extraction mechanism, hydrodynamic of the fireball, radiative mechanism. Its developement and the present issues.

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

Observational approach to the possibility of standardizing GRB energetics and use them as (complementary) standard candles to constrain the cosmological parameters.

GRBs as a cosmological tool



1) ISM in hosts, IGM, epoch of reionization, CSFR, PopIII

2) Cosmological parameters

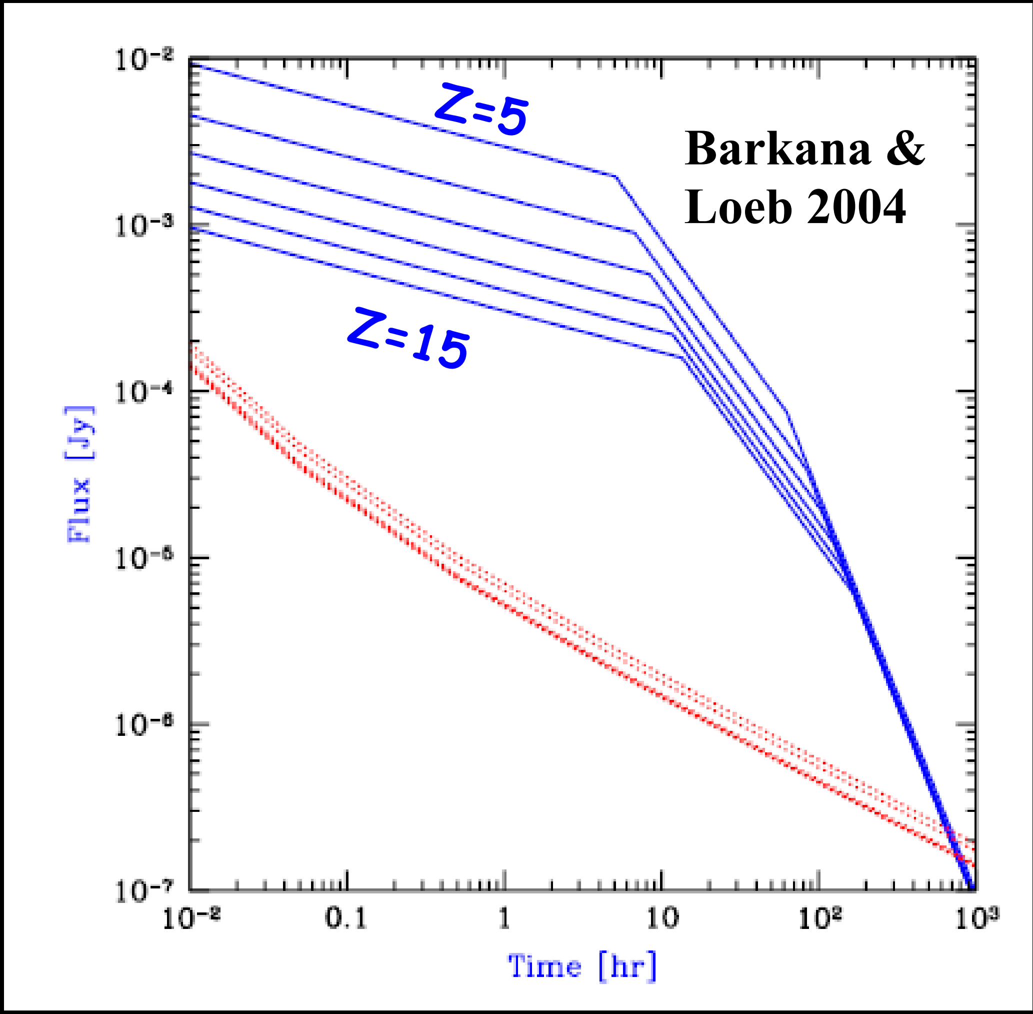
Advantages of GRBs…

1) Time stretching + afterglow powerlaw decay

2) No proximity effects

3) “clean spectrum”

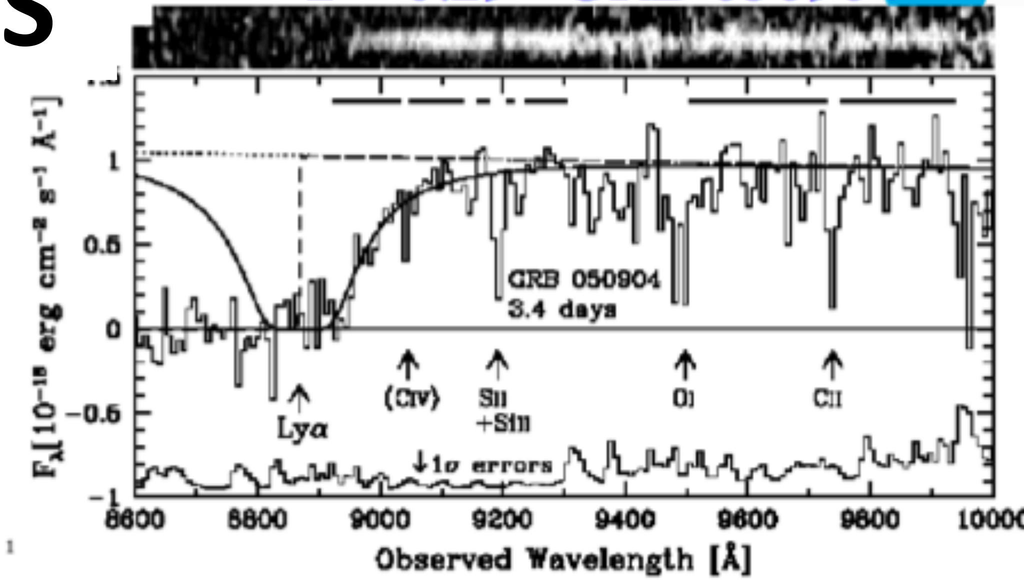
4) signposts the gal-beacons



High redshift GRBS

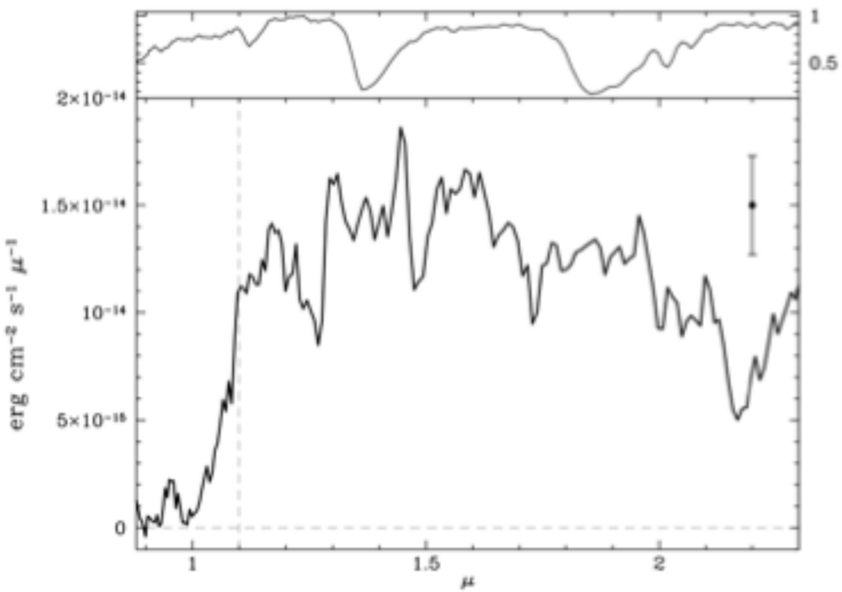
~ 7 are at
z>5

z = 6.29 GRB 050904



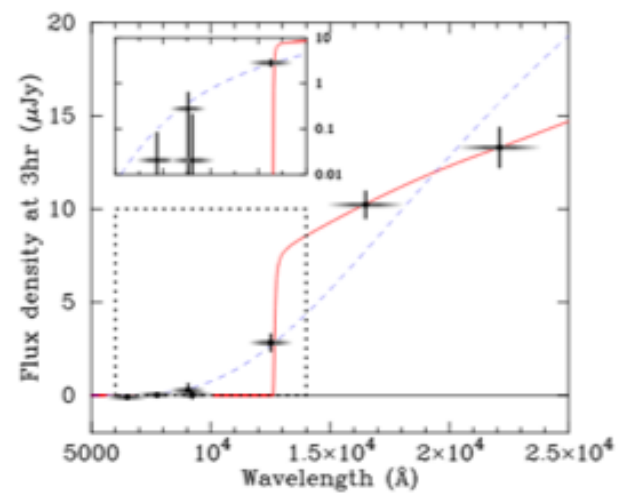
Tagliaferri et al. 2005, Kawai et al. 2006

z = 8.2 GRB 090423



Salvaterra et al. 2009
Tanvir et al. 2009

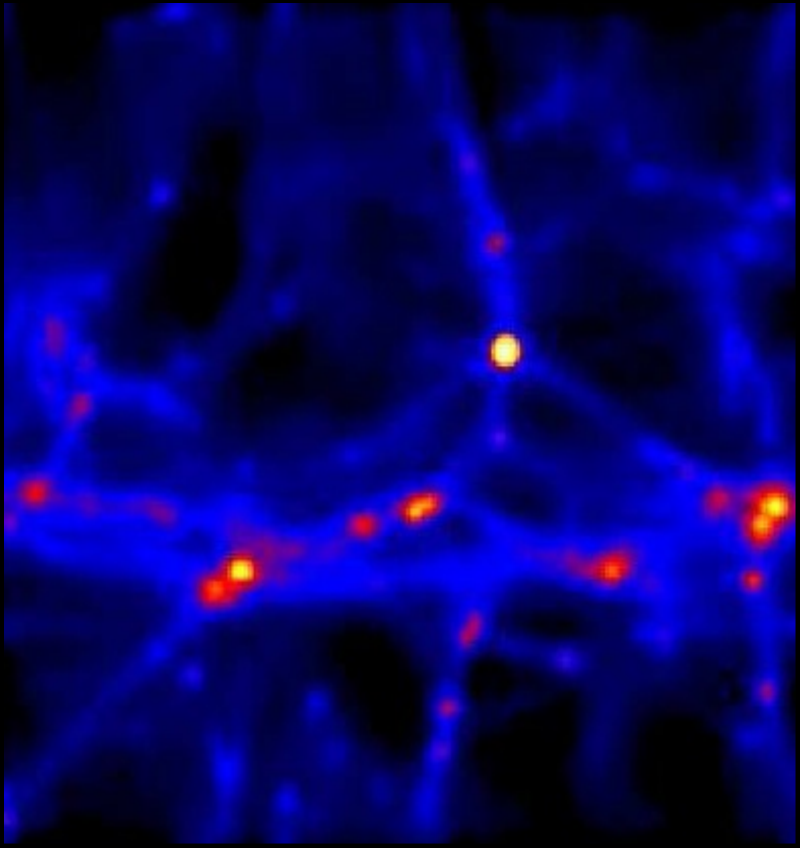
z = 9.4 GRB 090429B



Cucchiara et al. 2011

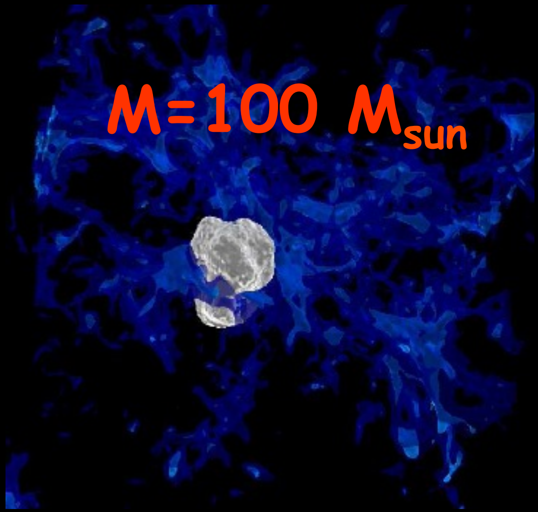
Population III stars

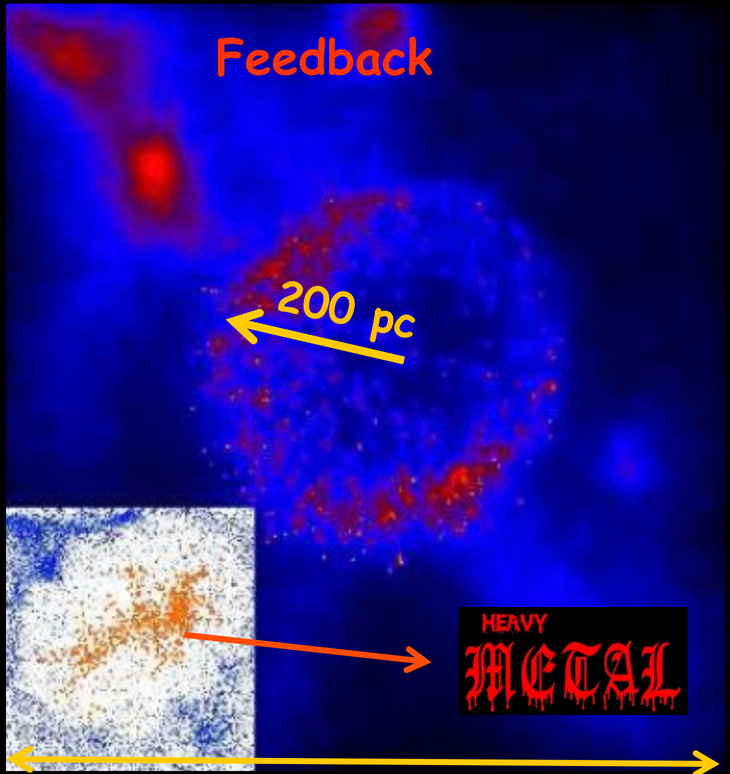
Z=20



10 Kpc

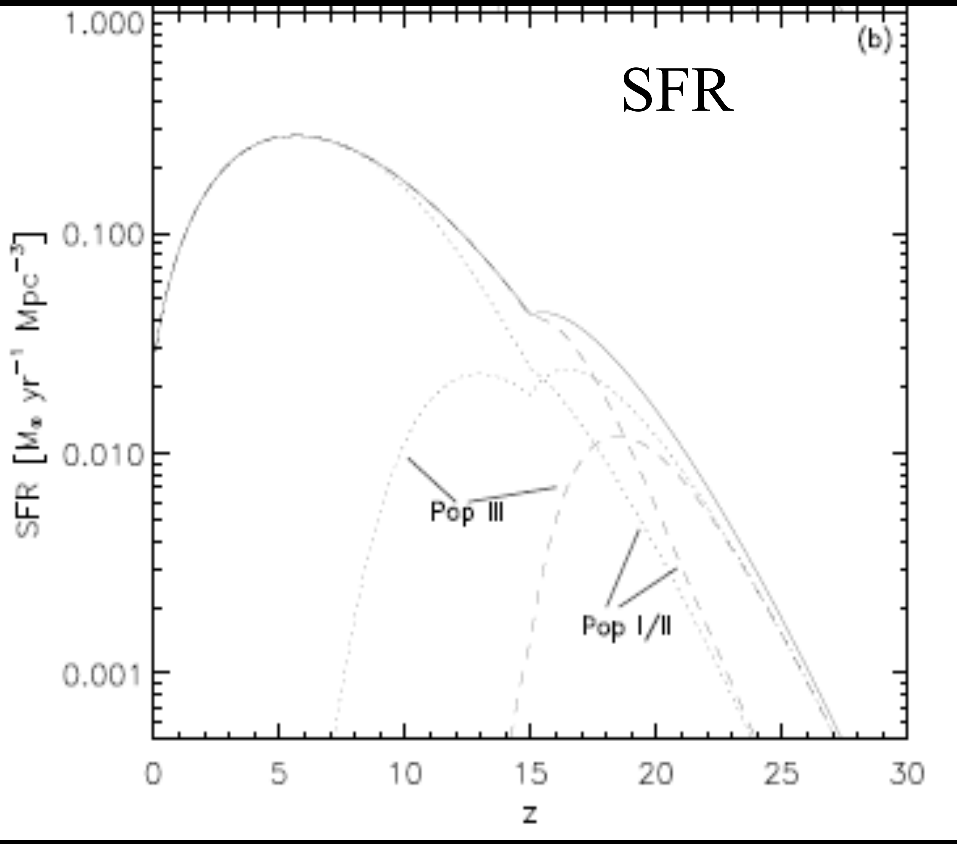
Broom & Loeb 2003; Loeb & Broom 2004

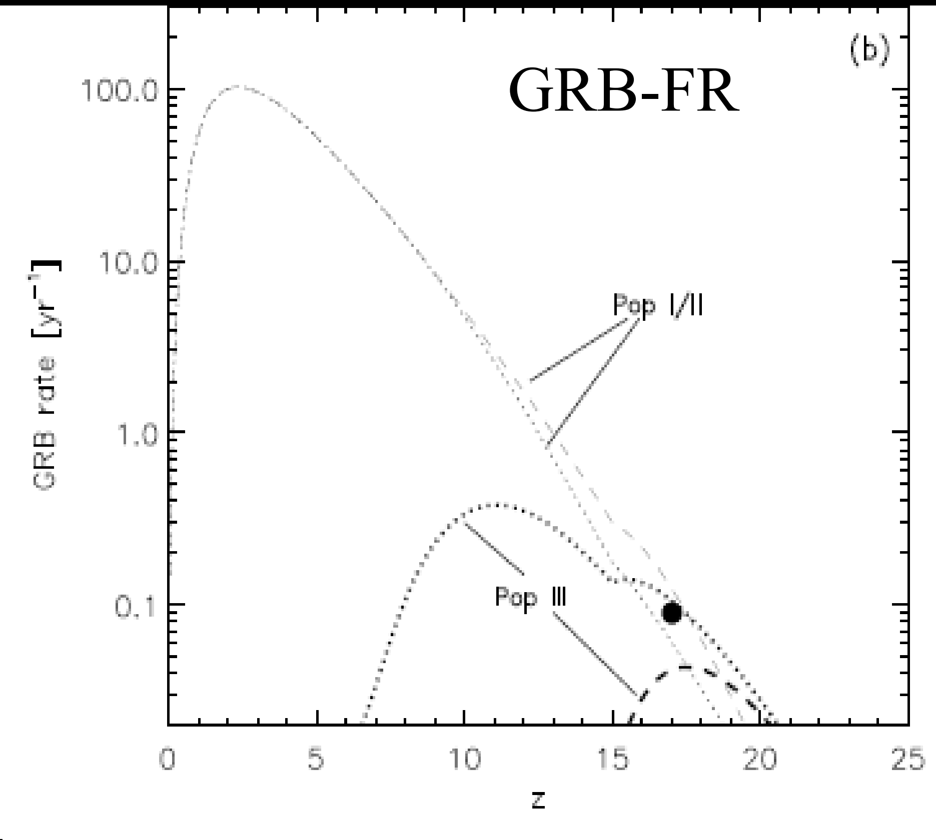




1 Kpc

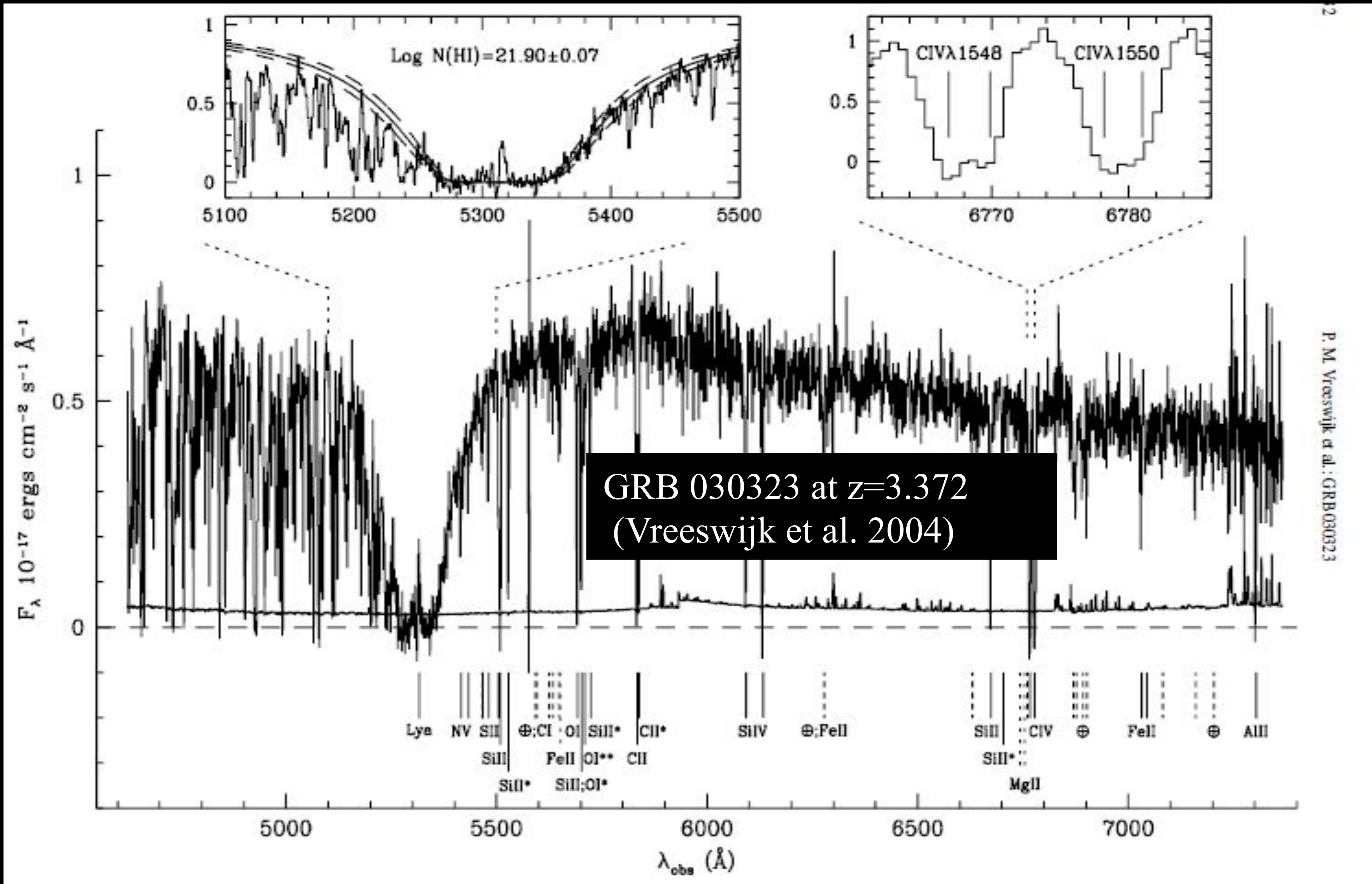
GRB from Pop-III



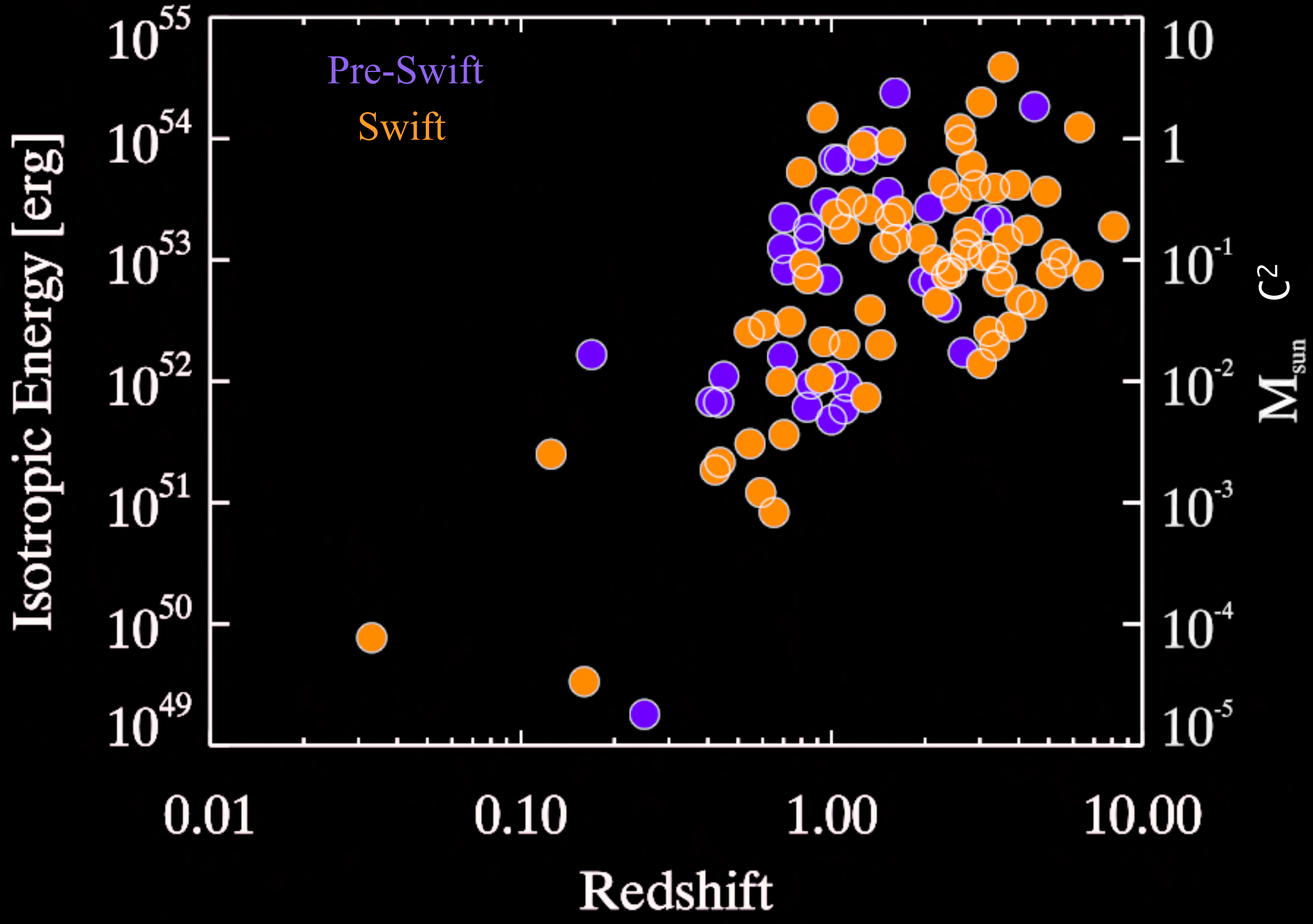


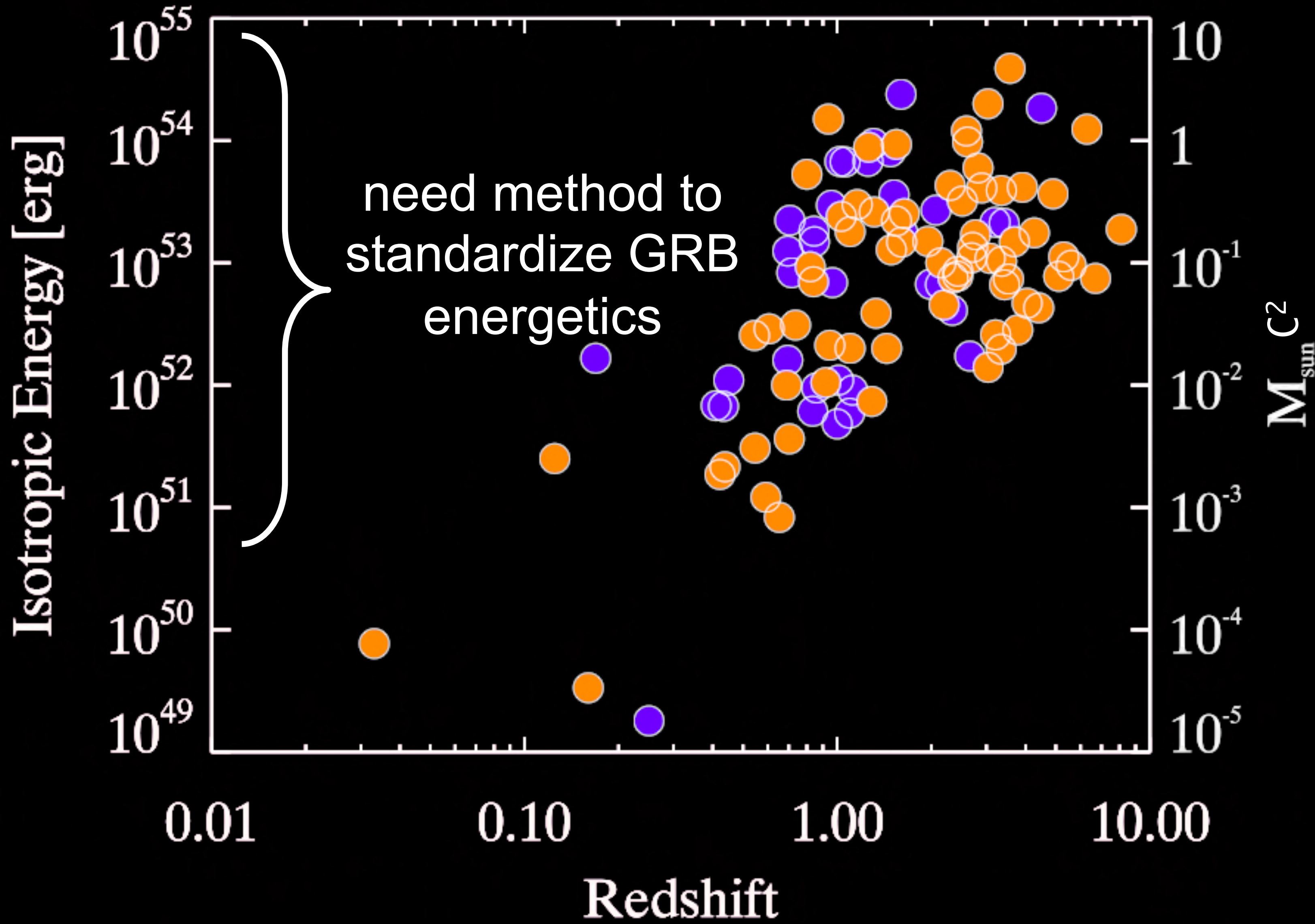
Very high z GRBs ⟷ **Pop III**

Analysis of the Red Damping Wing to Constrain the Reionization

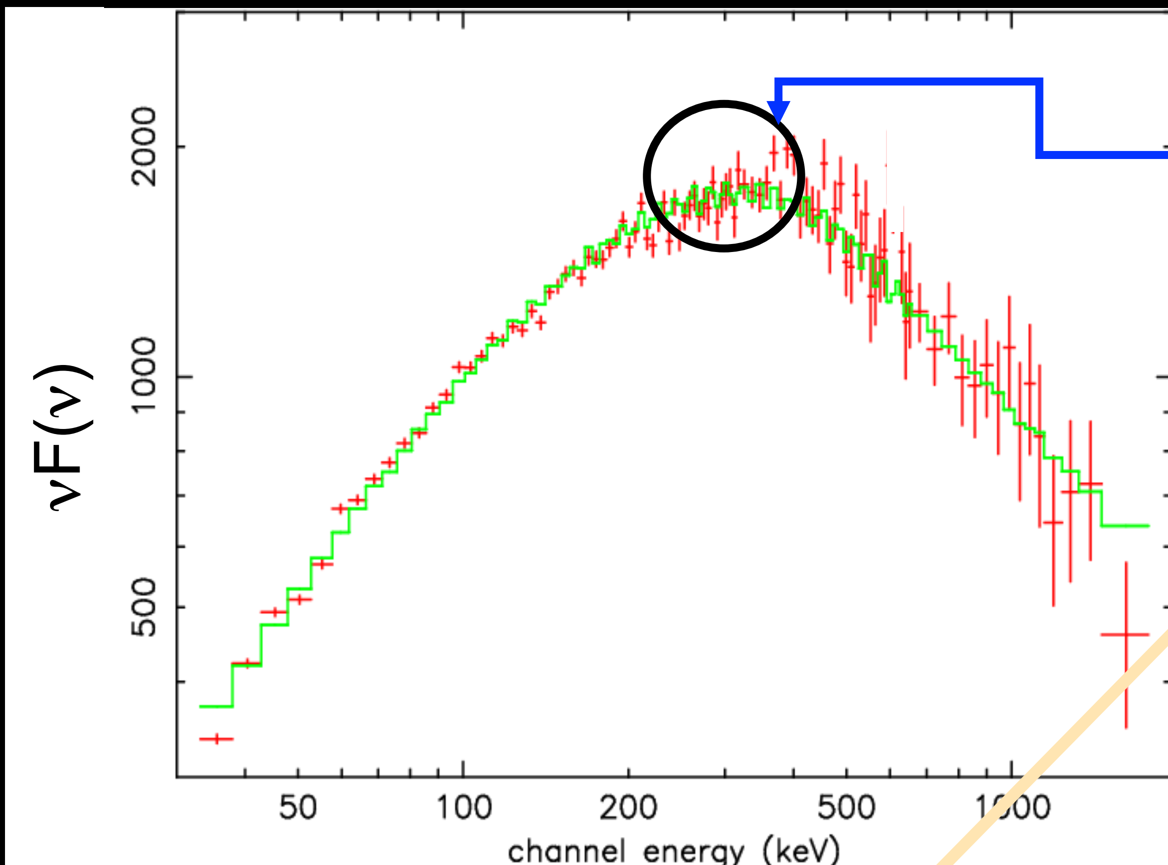


GRBs as standard candles




need method to standardize GRB energetics
Isotropic Energy [erg]
10^{55}
10^{54}
10^{53}
10^{52}
10^{51}
10^{50}
10^{49}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$M_{sun} c^2$
0.01
0.10
1.00
10.00
Redshift

Prompt emission spectrum



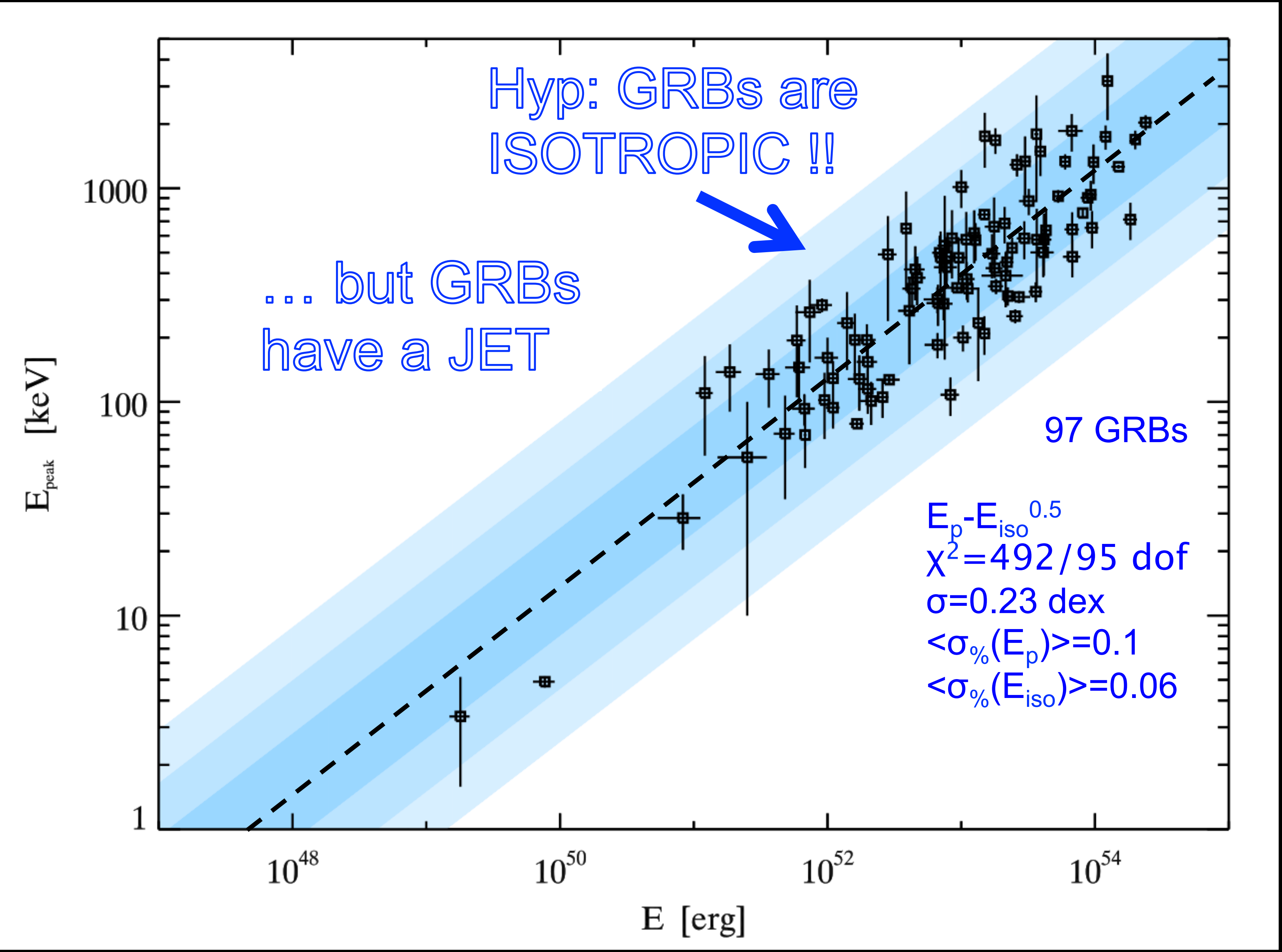
GRB Peak Energy

E_{peak}

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

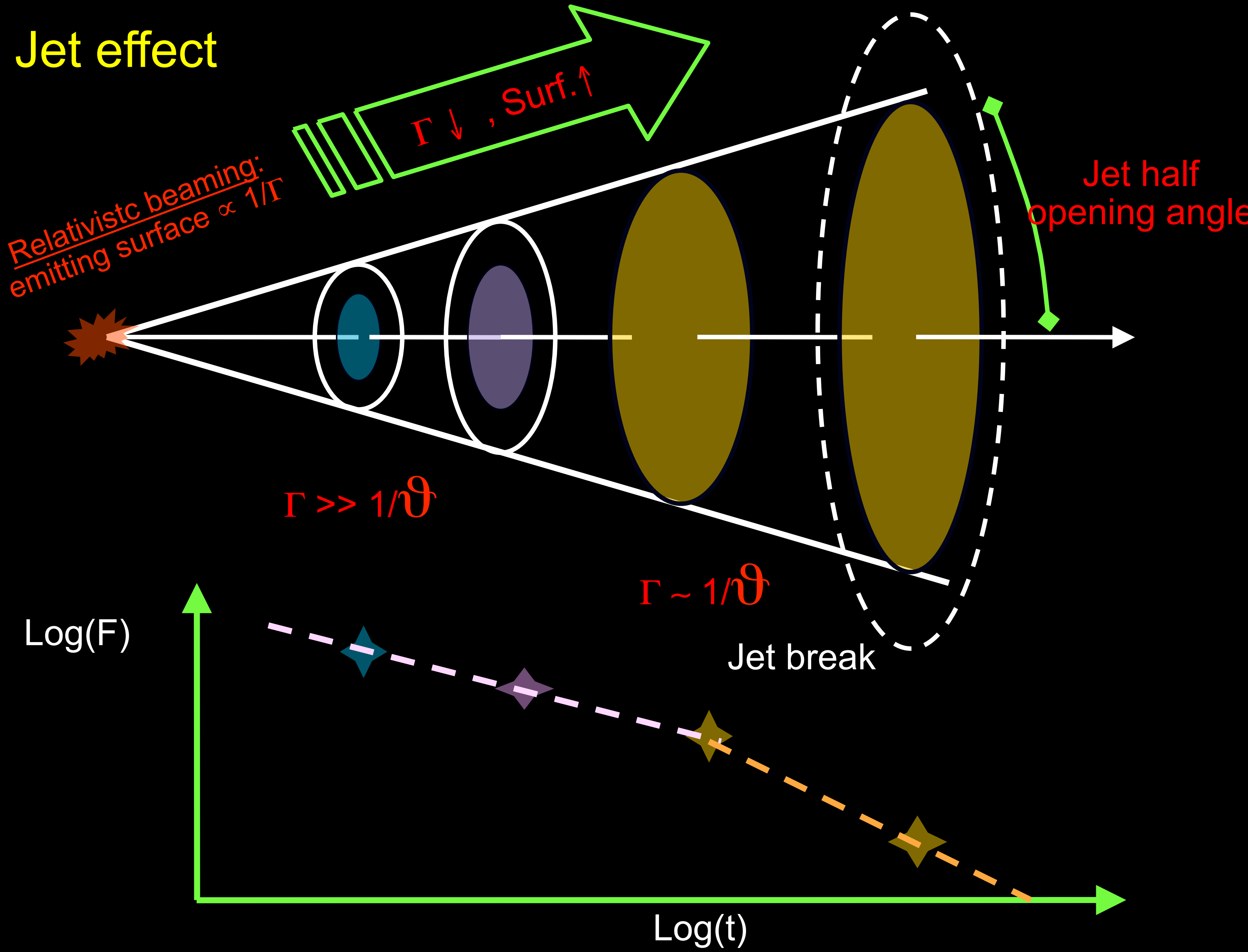
$$E_{iso} = \frac{4\,\pi\, d_L(z)^2}{1+z} \int_{\Delta E} F(E,z,\ldots)\, dE$$

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

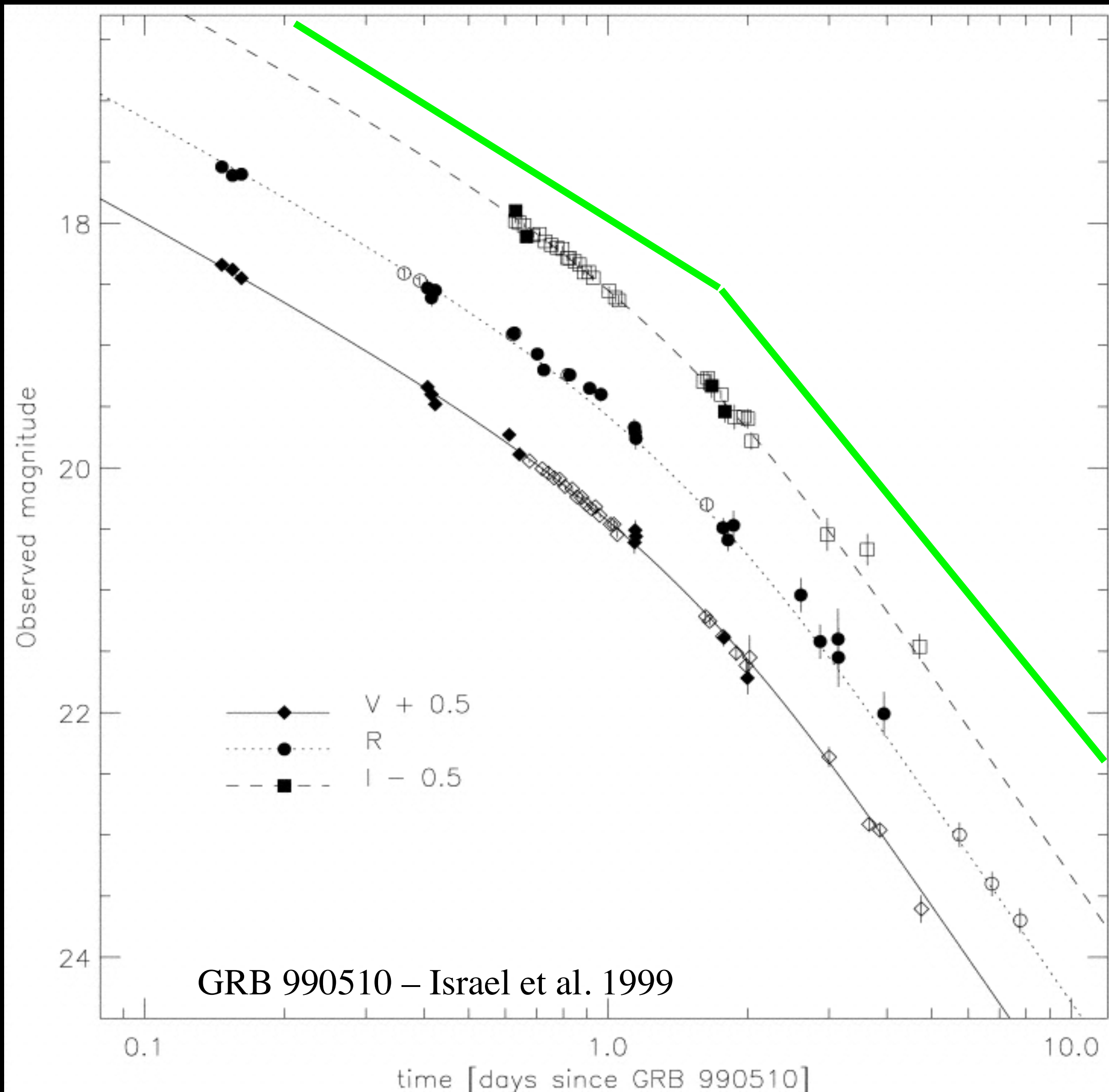


Amati et al. 2002; Lamb et al. 2003; Yonetoku et al. 2004; Ghirlanda et al. 2004,2005; Amati et al. 2008; Nava et al. 2008; Ghirlanda et al. 2009

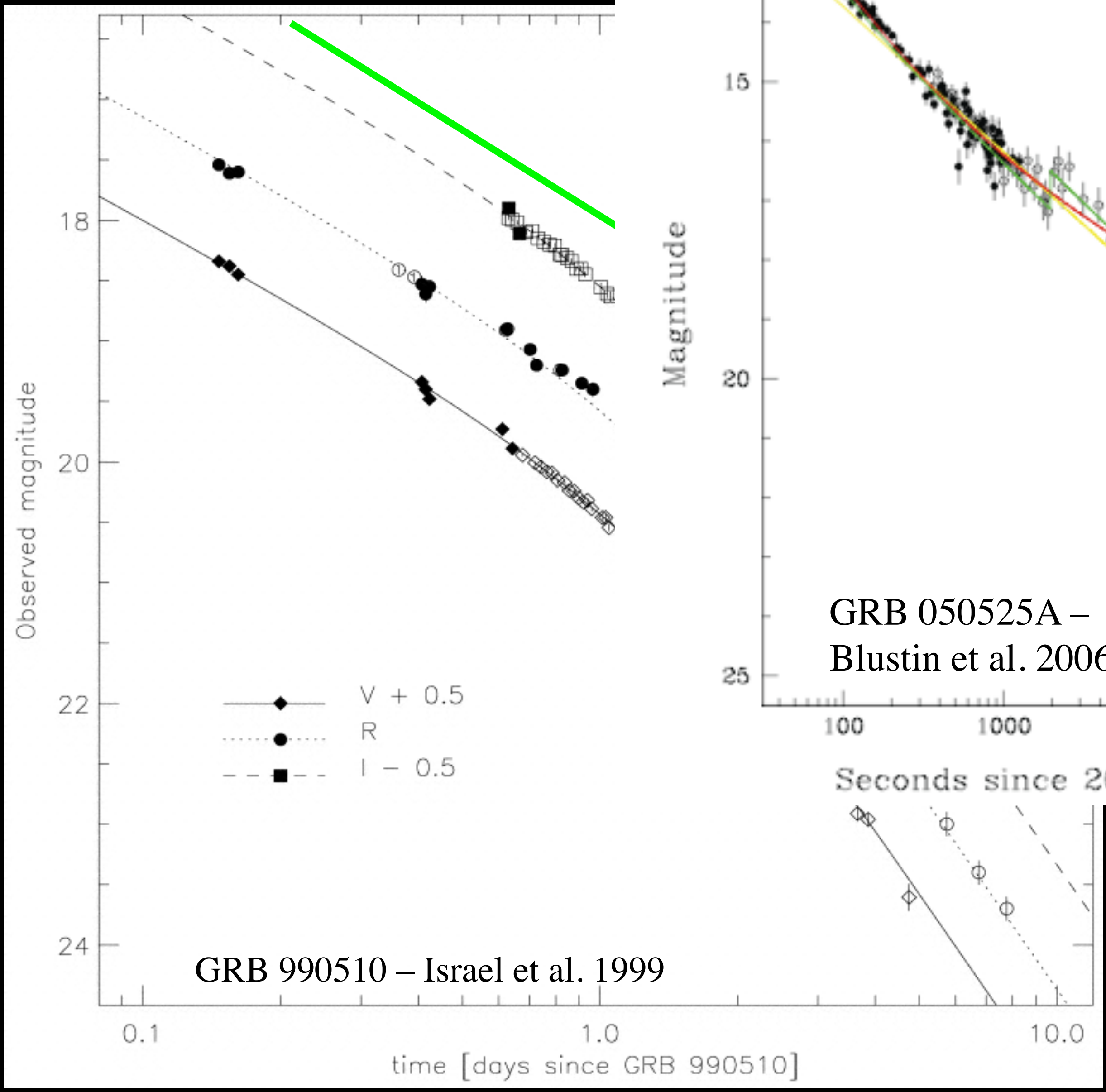
Jet effect

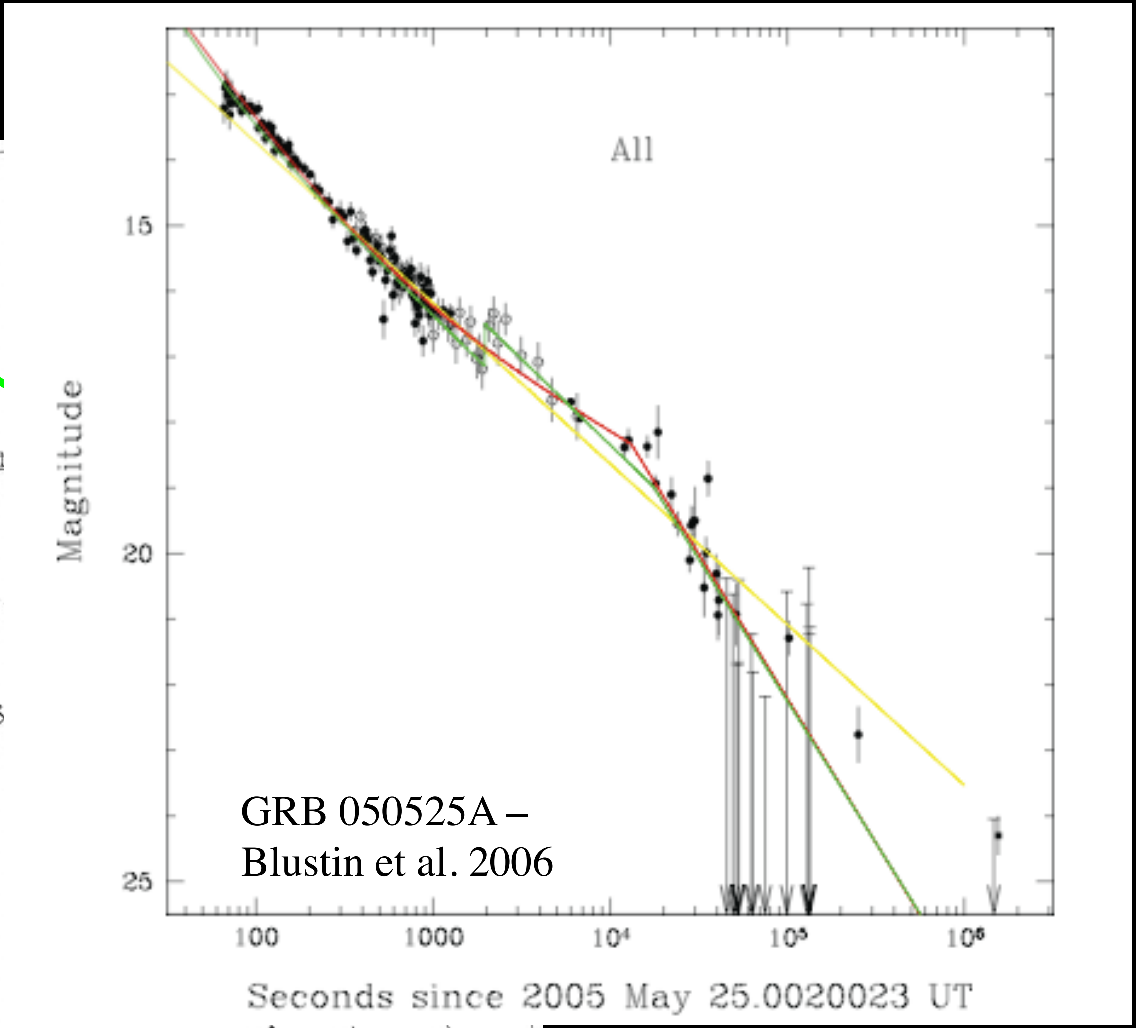

Relativistc beaming:
emitting surface ∝ 1/Γ
Γ ↓ , Surf.↑
Jet half
opening angle
Γ >> 1/ϑ
Γ ~ 1/ϑ
Jet break
Log(F)
Log(t)

Obs. evidences of Jet breaks

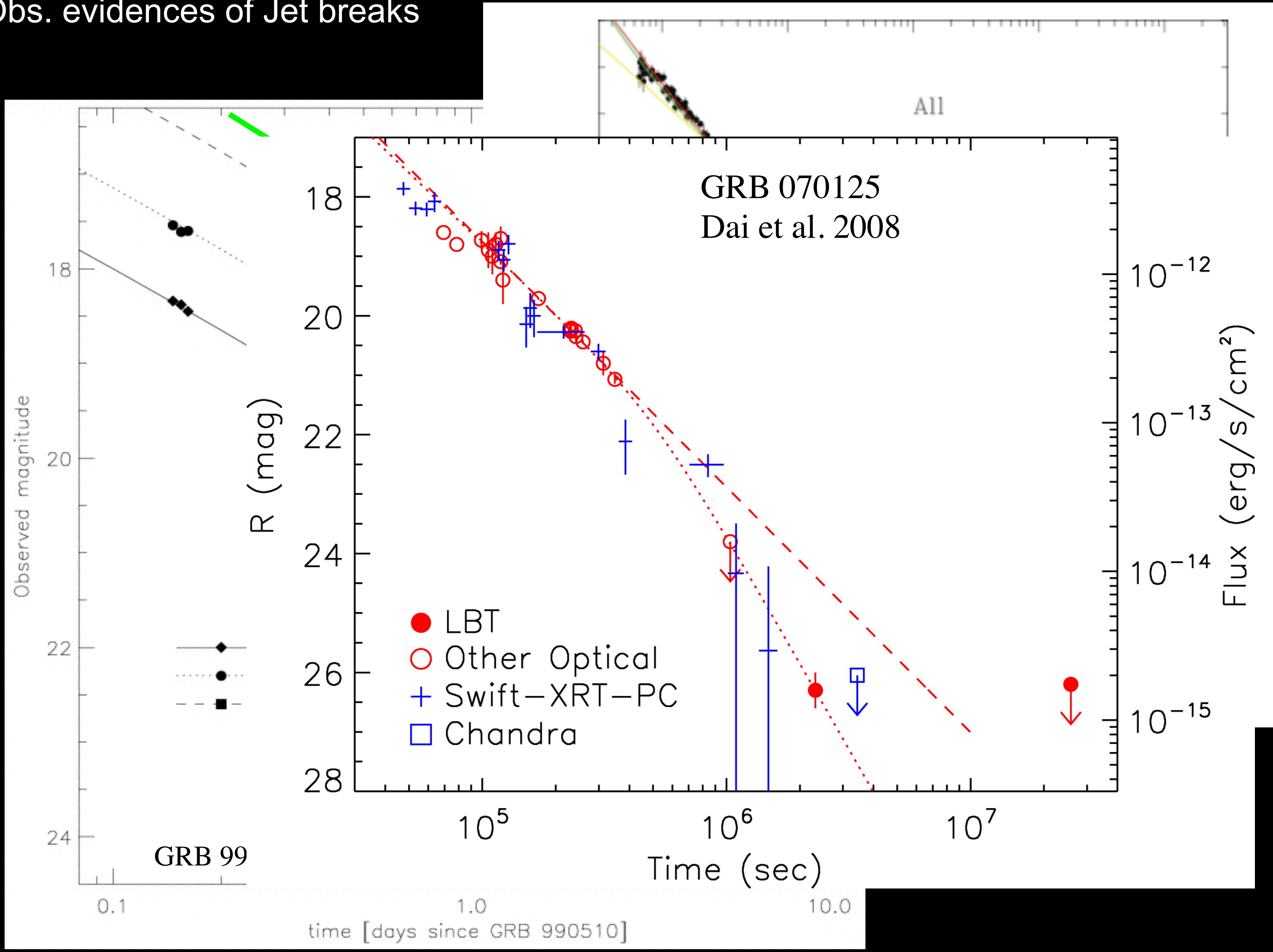


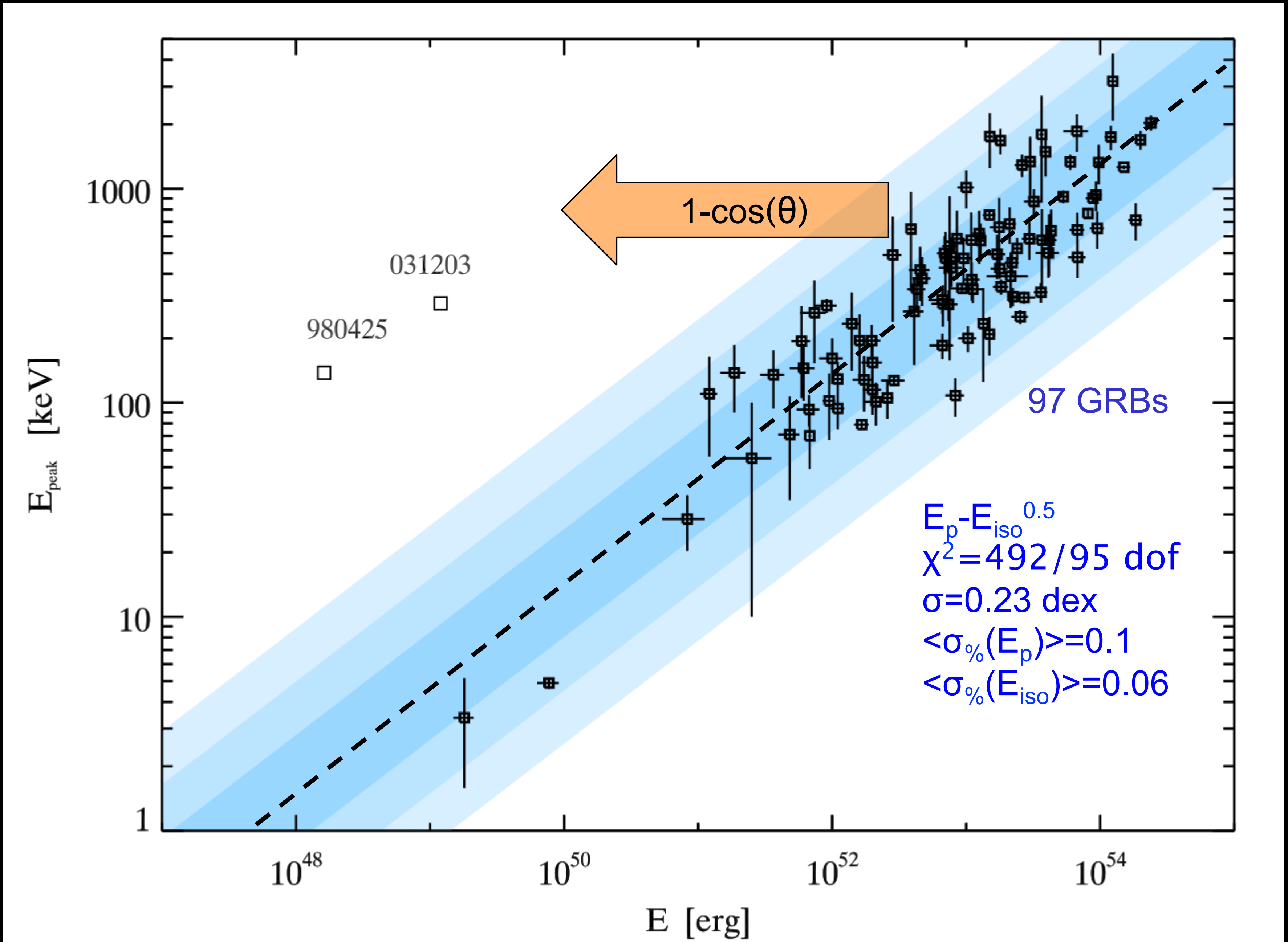
Obs. evidences of Jet breaks



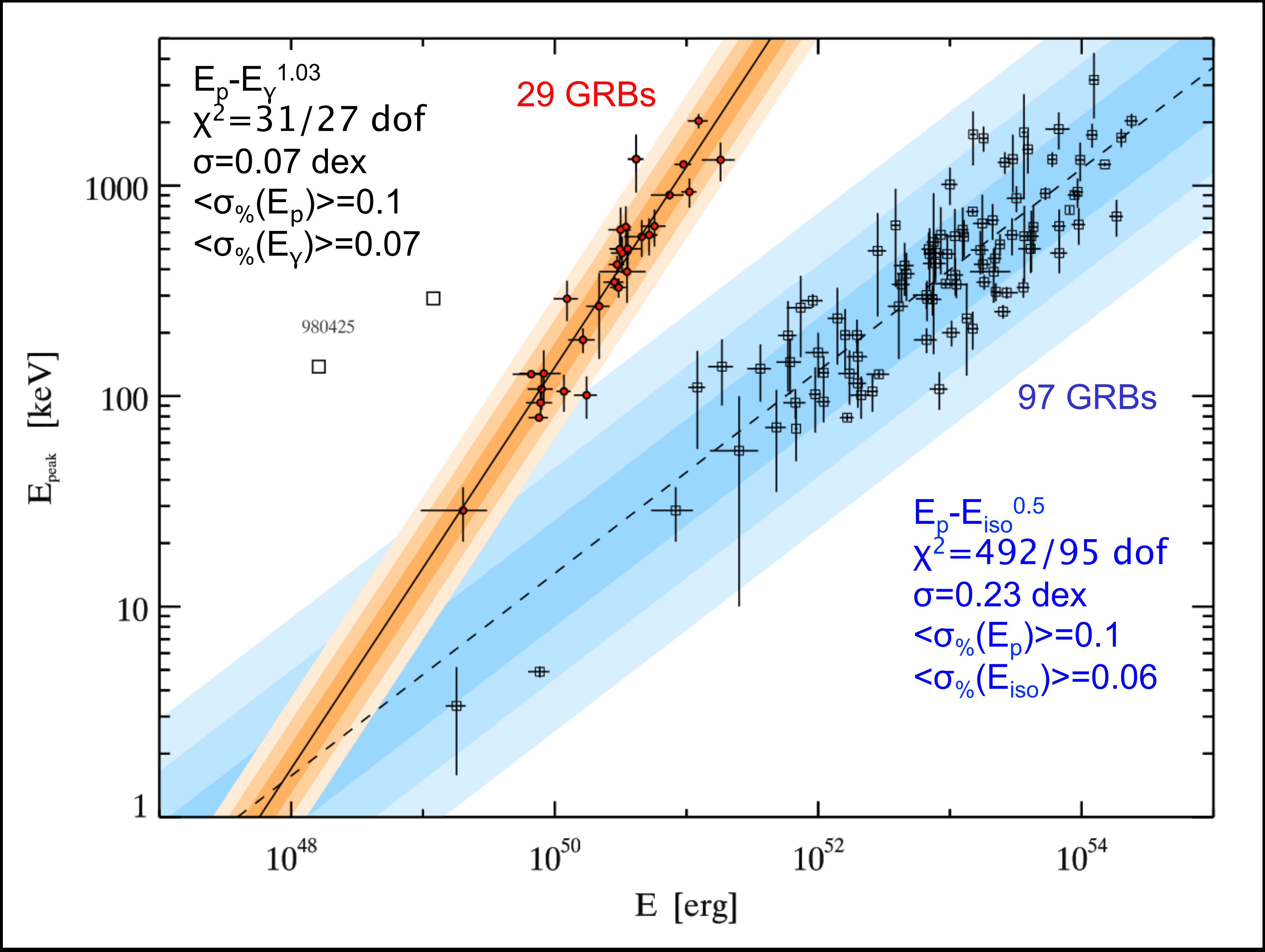


Obs. evidences of Jet breaks



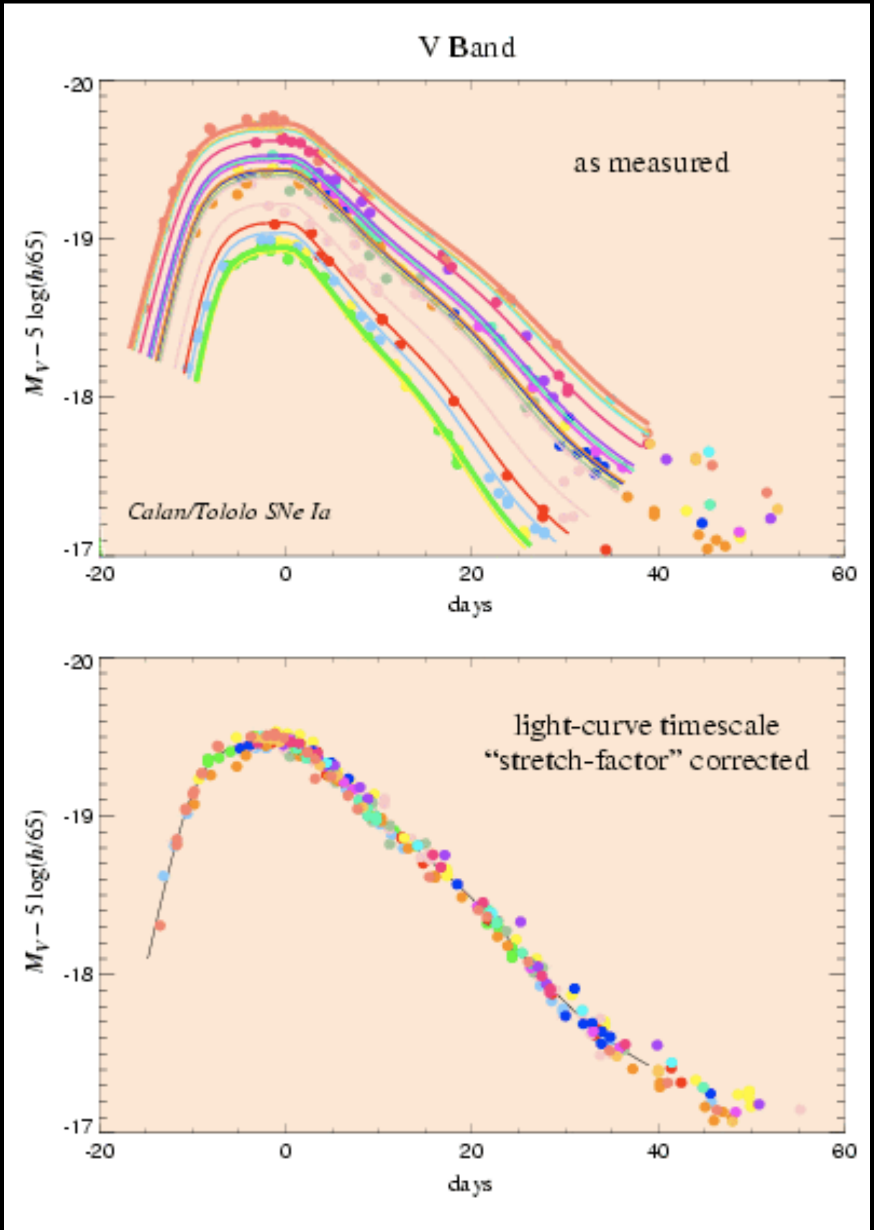


1-cos(θ)
031203
980425
97 GRBs
Ep-Eiso0.5
χ2=492/95 dof
σ=0.23 dex
<σ%(Ep)>=0.1
<σ%(Eiso)>=0.06
Epeak [keV]
E [erg]
1000
100
10
1
1048
1050
1052
1054



E_p-$E_\gamma^{1.03}$
χ^2=31/27 dof
σ=0.07 dex
<σ%(Ep)>=0.1
<σ%(Eγ)>=0.07
29 GRBs
980425
97 GRBs
E_p-$E_{iso}^{0.5}$
χ^2=492/95 dof
σ=0.23 dex
<σ%(Ep)>=0.1
<σ%(Eiso)>=0.06
1000
100
10
1
10^{48}
10^{50}
10^{52}
10^{54}
E_{peak} [keV]
E [erg]

Similar to Supernovae Ia

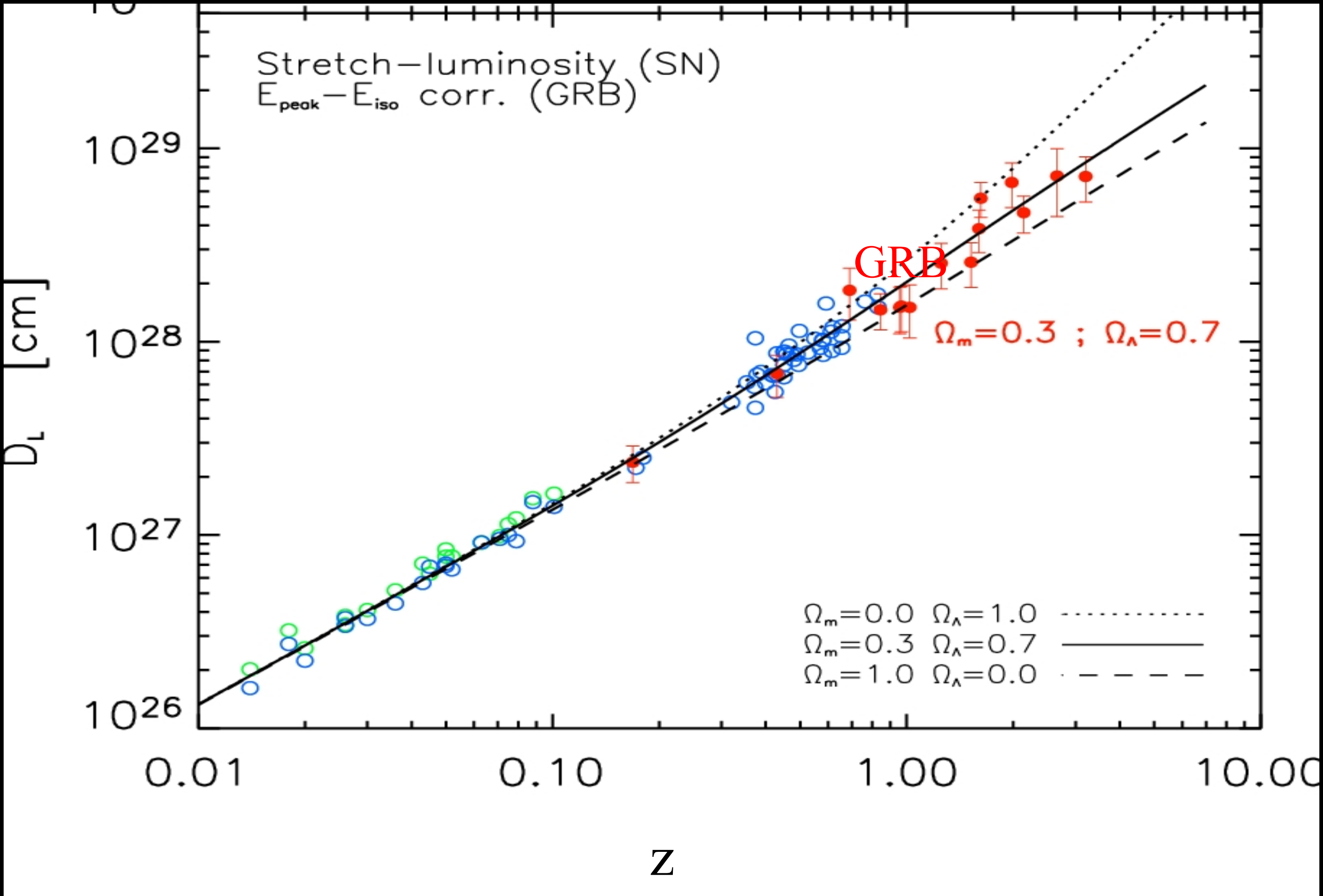


Perlmutter 1998

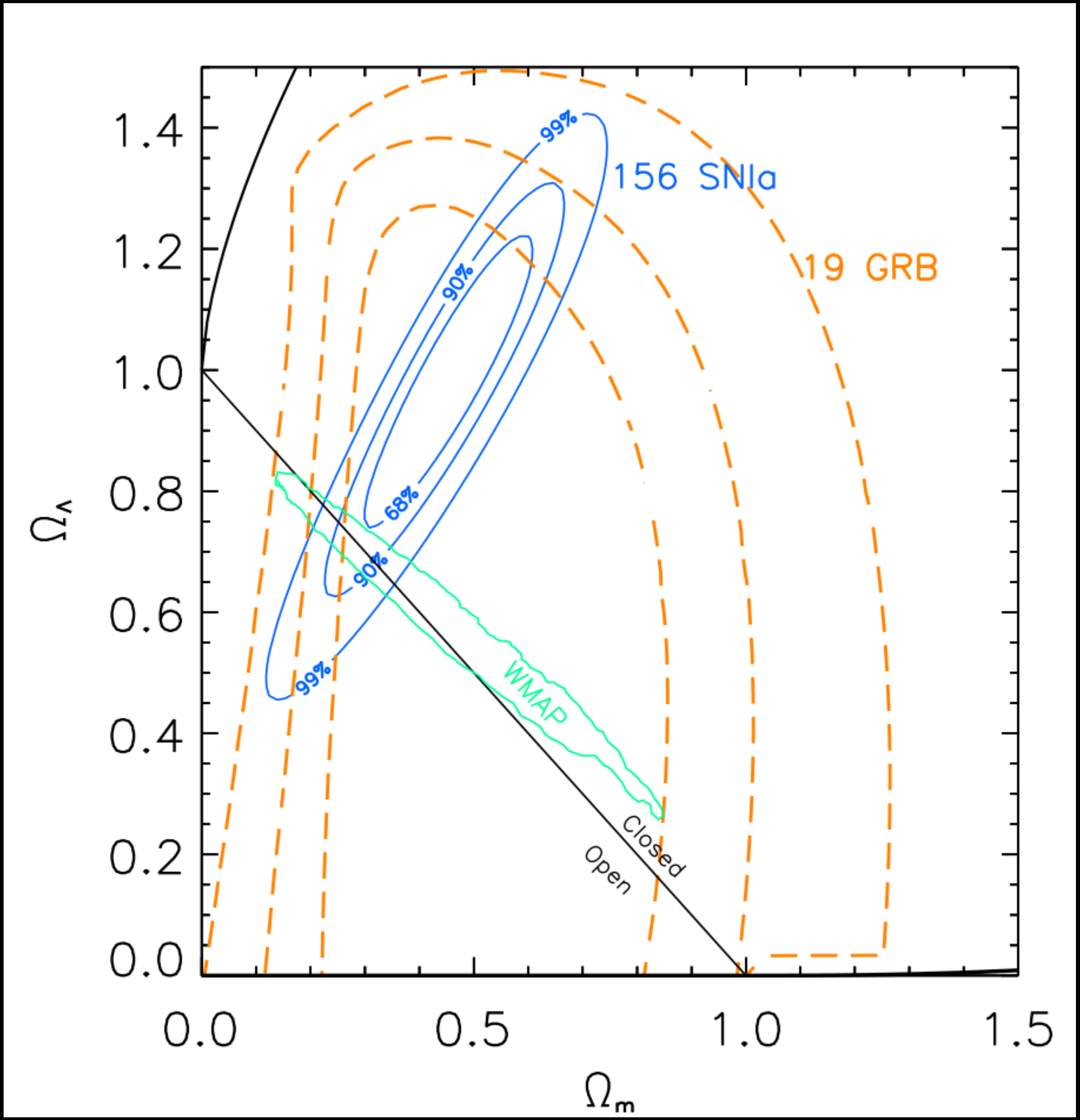
"Stretching Luminosity"

- ✓ Tight correlation
- ✓ Calibration by low redshift events

The Hubble diagram



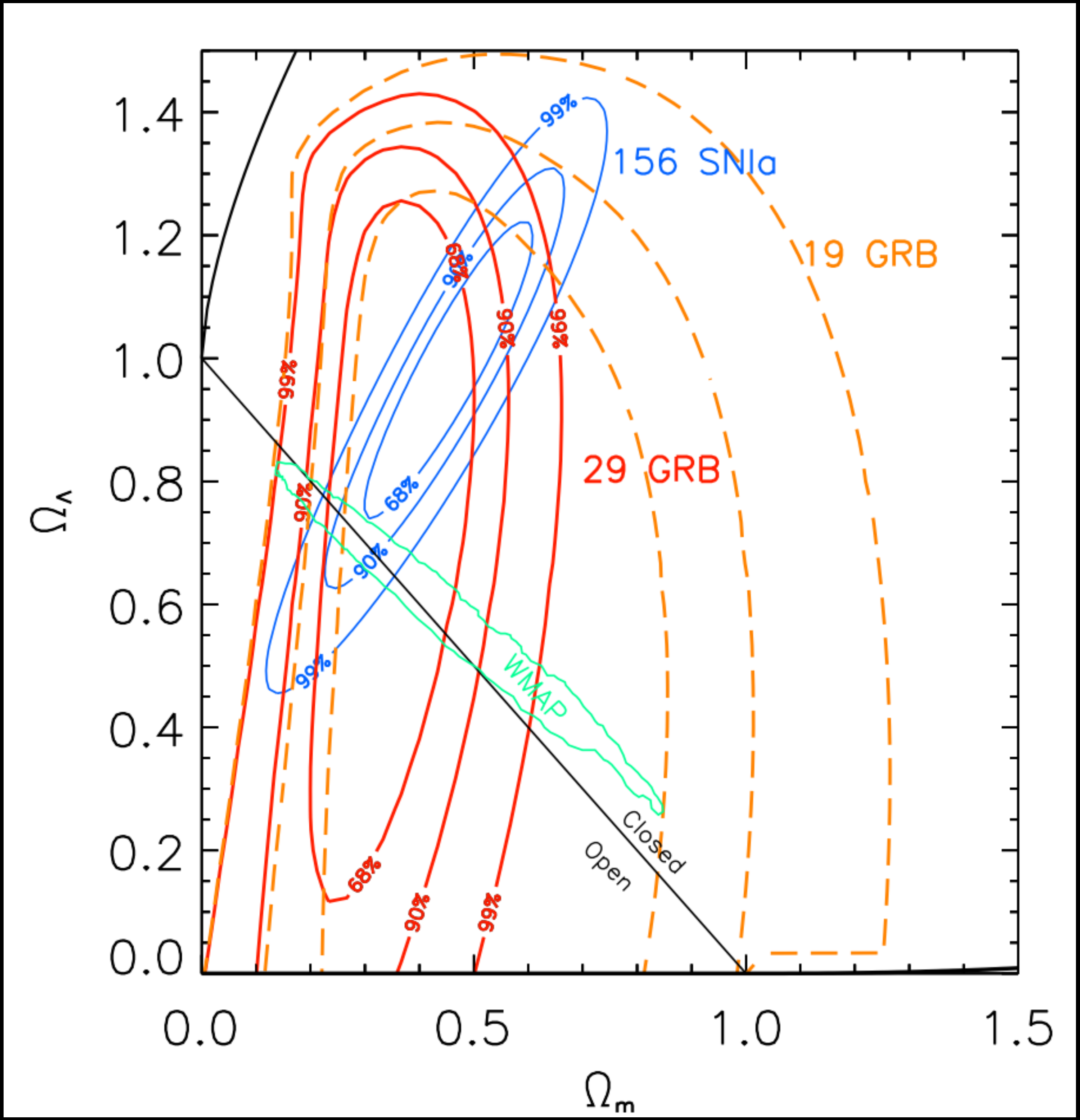
Constraints on $\Omega_M - \Omega_\Lambda$ with the Ep-Eγ correlation



19 GRBs

Ghirlanda, Ghisellini, Firmani, Lazzati 2004,2005

Constraints on Ω_M–Ω_Λ with the Ep-Eγ correlation



19 GRBs

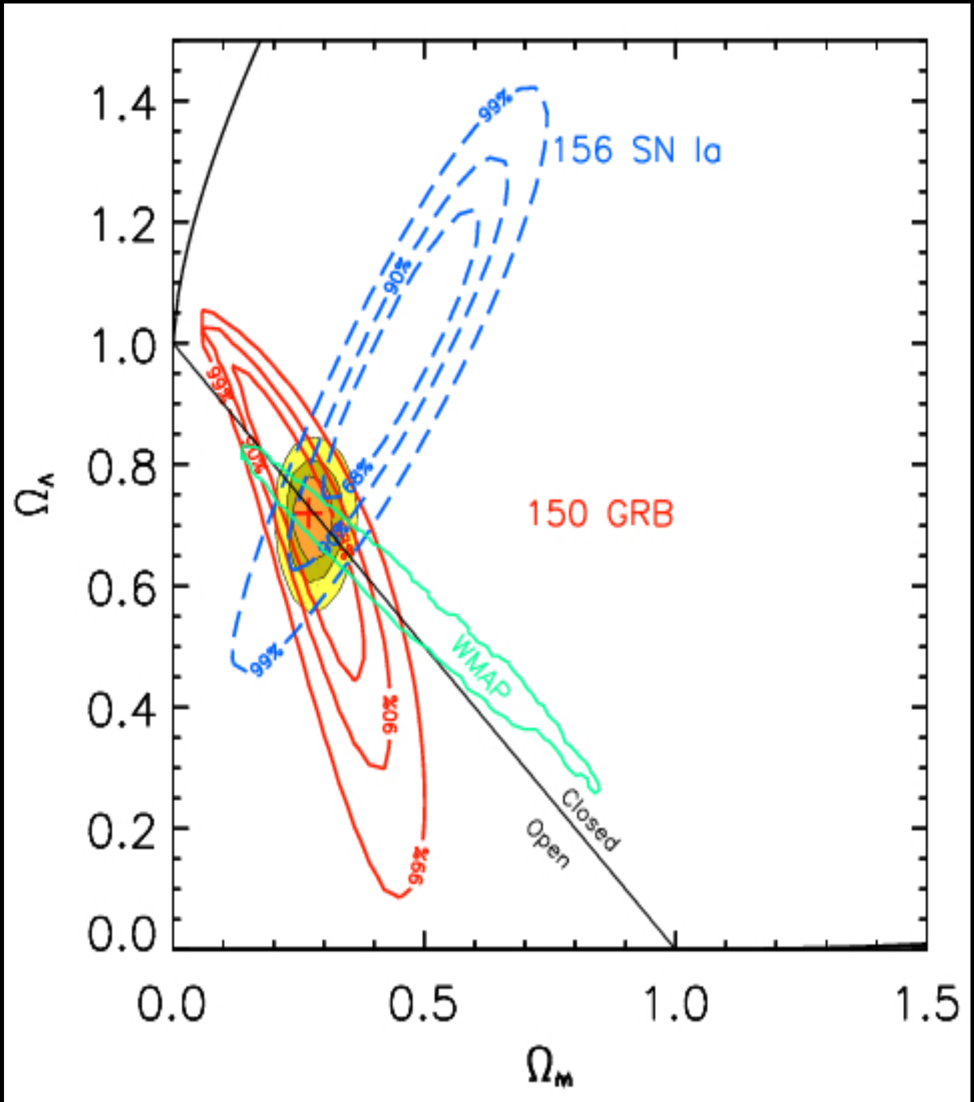
29 GRBs

Ghirlanda, Ghisellini, Firmani, Lazzati 2004,2005; Ghirlanda et al. 2007

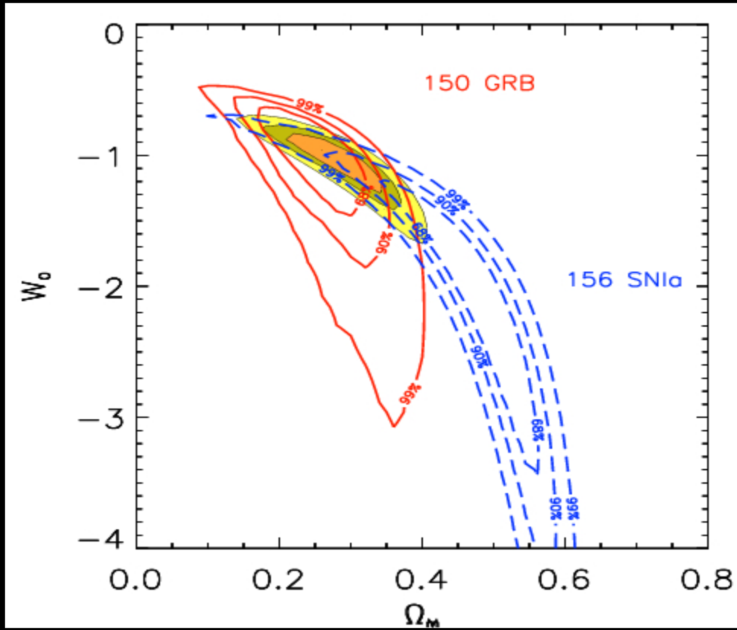
Ghirlanda, Ghisellini, Firmani, Nava et al., 2006

Simulation of 150 GRBs

- GRBs follow the SFR
- $E_{peak} - E_{iso}$ relation
- $E_{peak} - E_{\gamma}$ relation



$\Omega_m - \Omega_\Lambda$ plane



Dark Energy EOS ($p=w_o\rho c^2$)

Issues & critics raised about the Ep-Eg correlation and its cosmological use

1) Few Jet opening angles measured

2) The Ep-Eg correlation is model dependent

3) The correlation is not calibrated (no low z bursts)

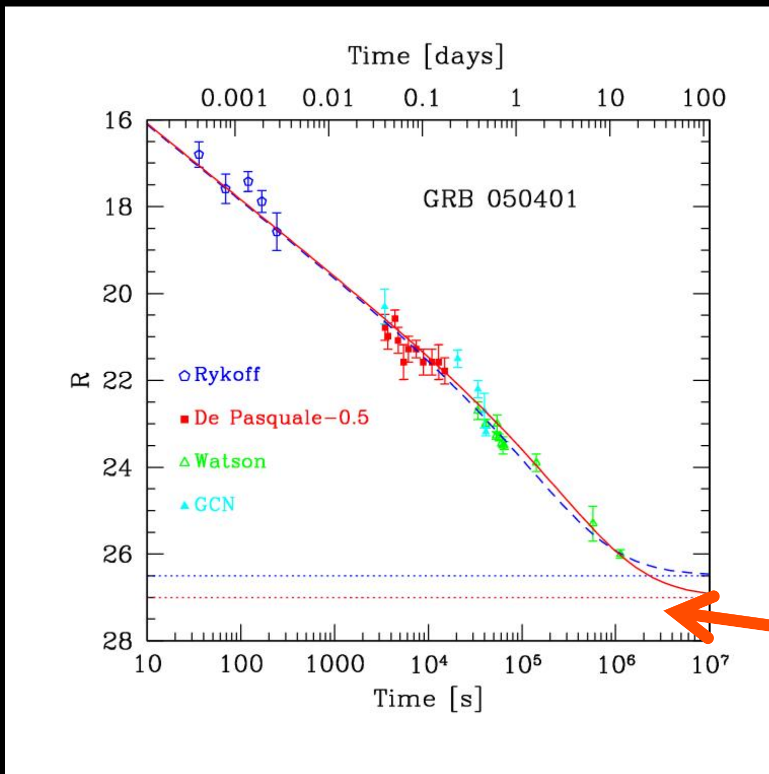
4) Evolution with z

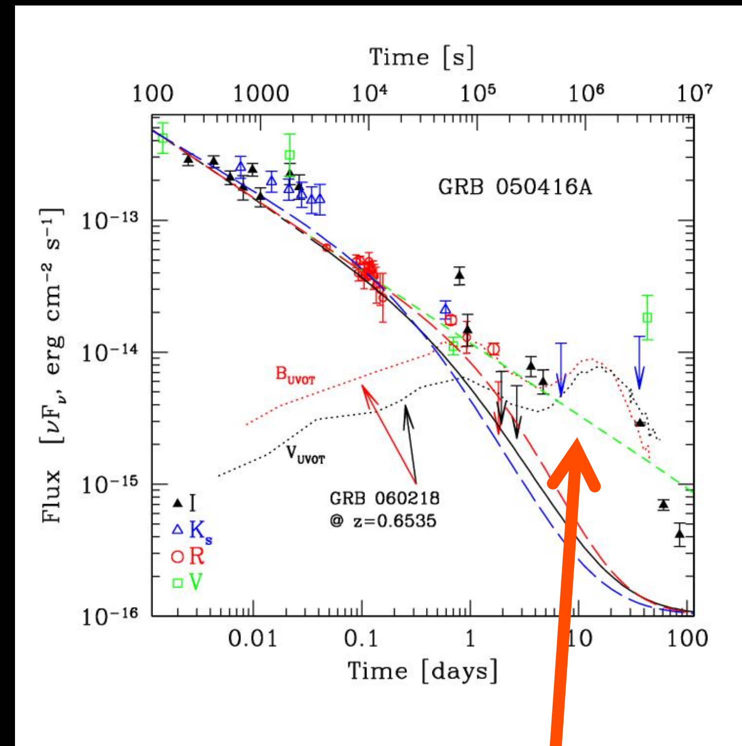
5) Outliers & selection effects

Few Jet opening angles → ~40 GRBs (Ghirlanda et al. 2013)

Delicate measure

[Ghirlanda et al. 2007]

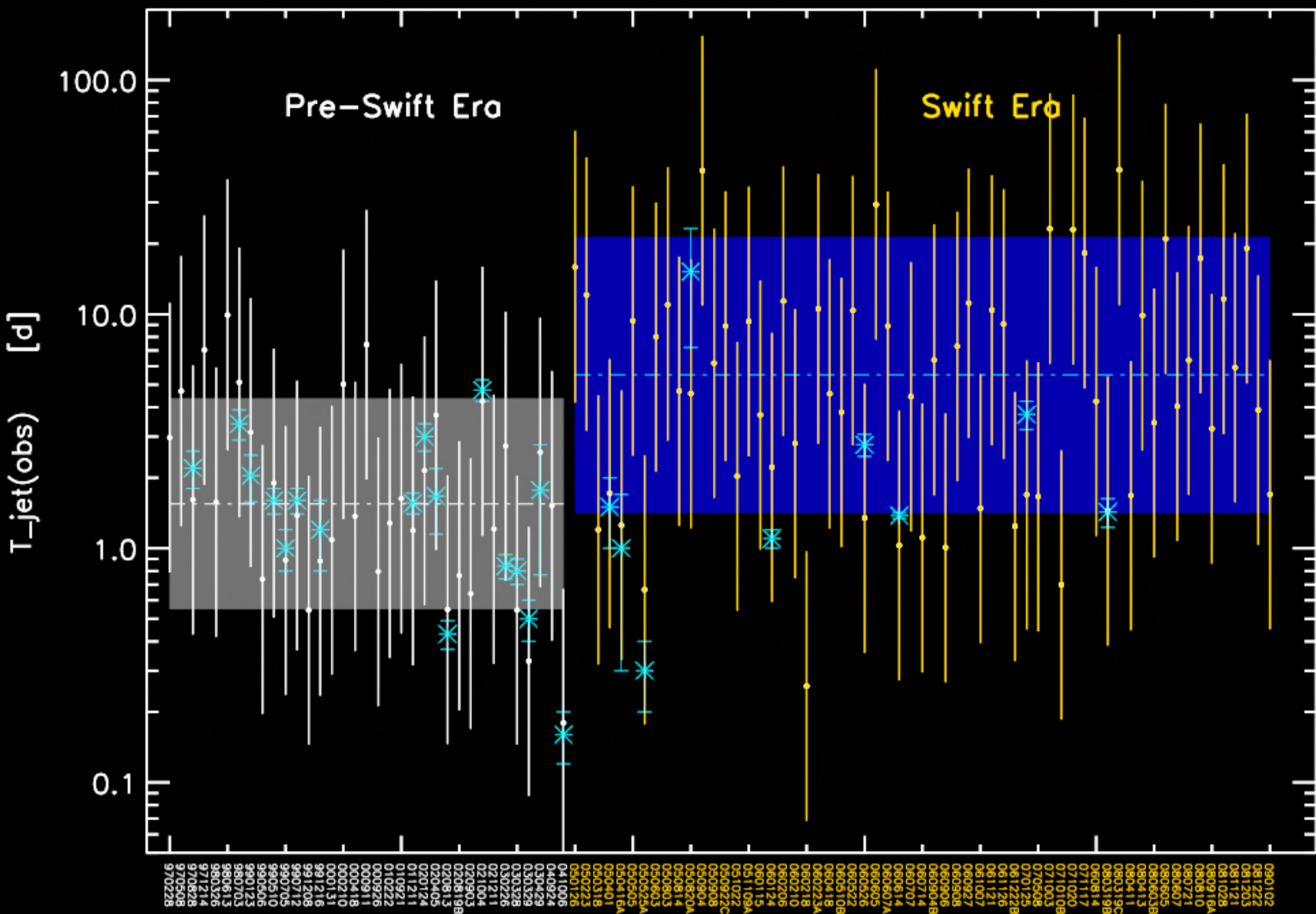




Account for Host and SN

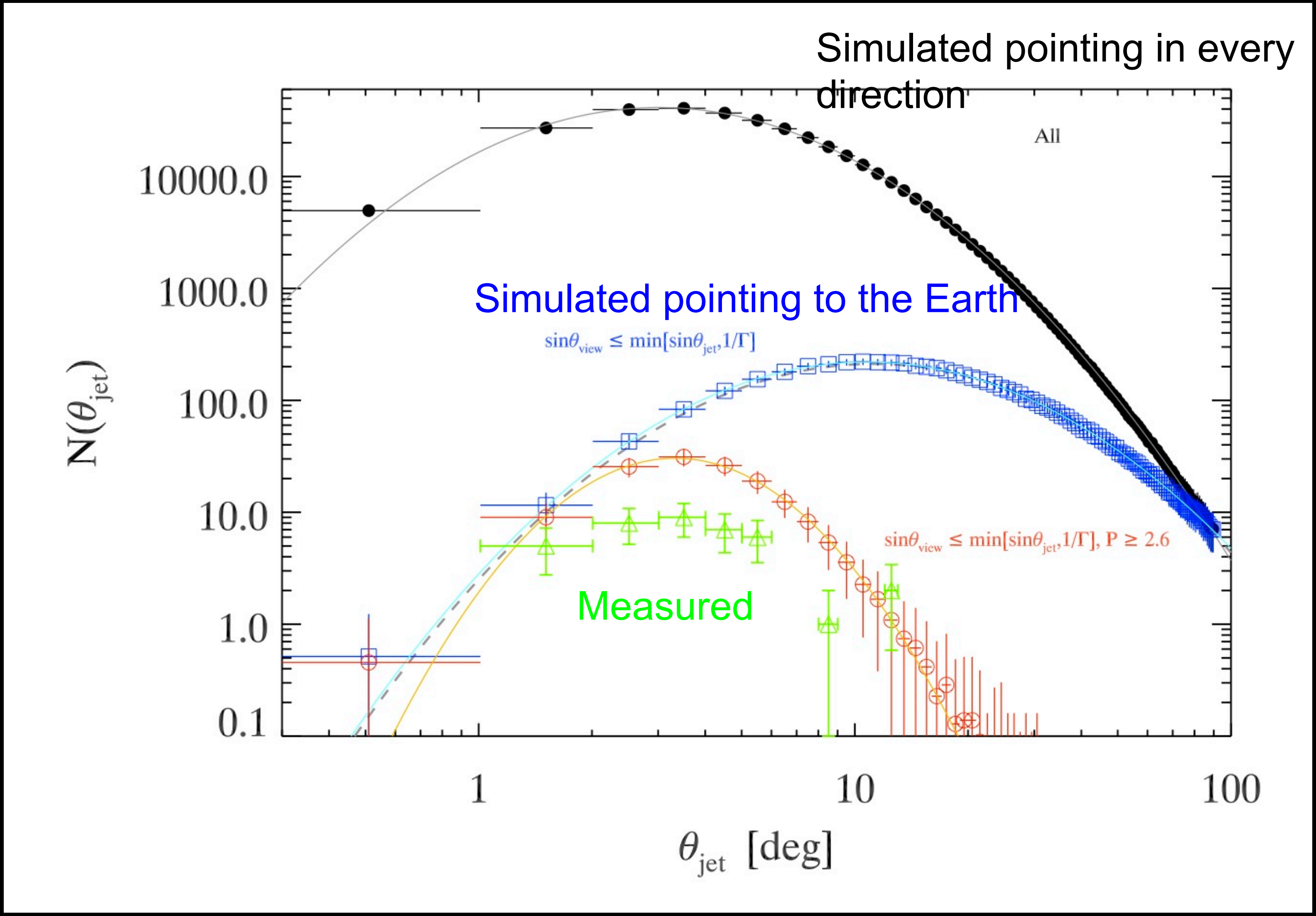
Need spend late time Telescope time

Optical better than X-ray



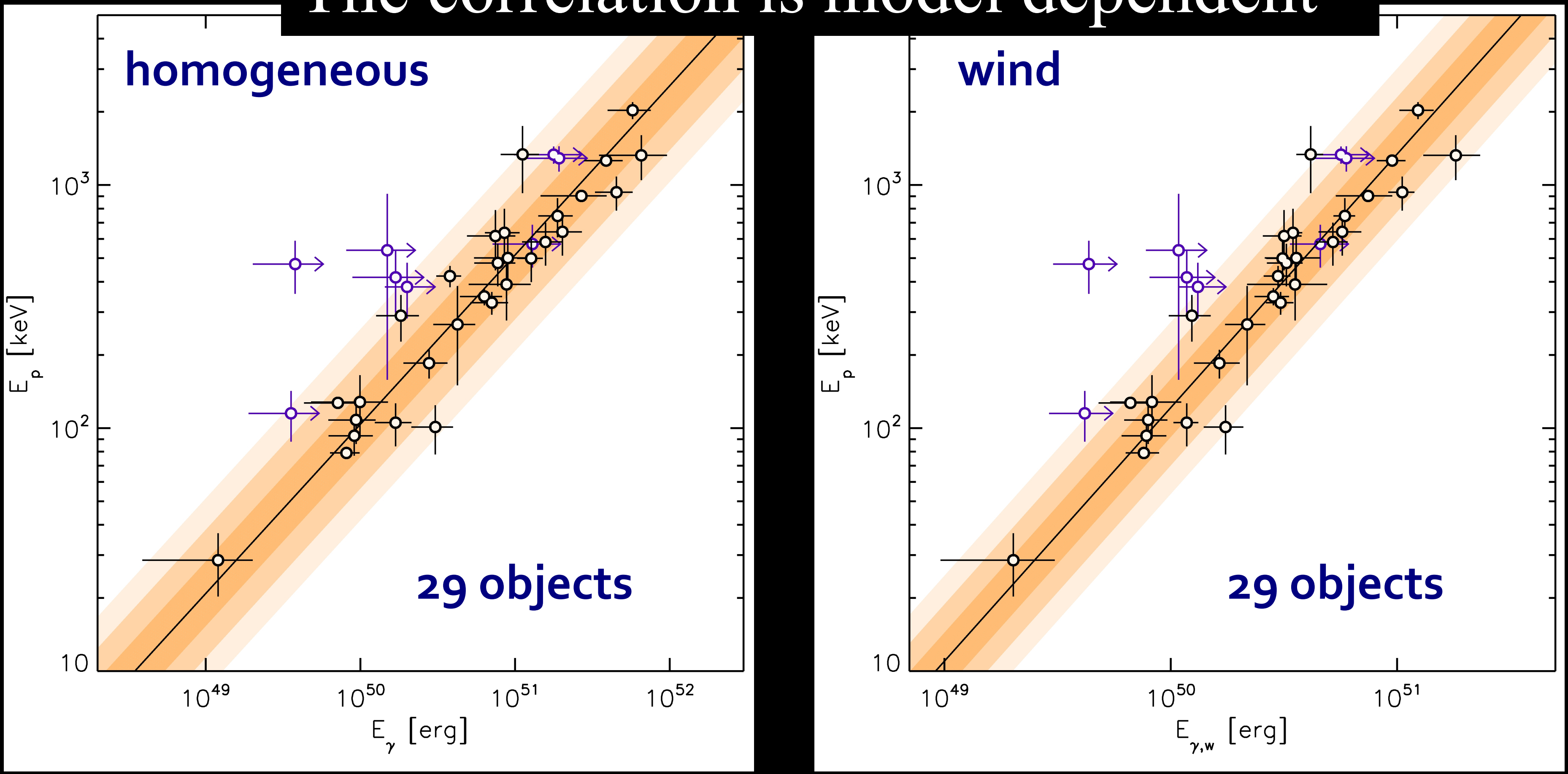
Pre-Swift Era
Swift Era
T_jet(obs) [d]
100.0
10.0
1.0
0.1

Distribution of jet opening angles



Ghirlanda et al. 2013

The correlation is model dependent

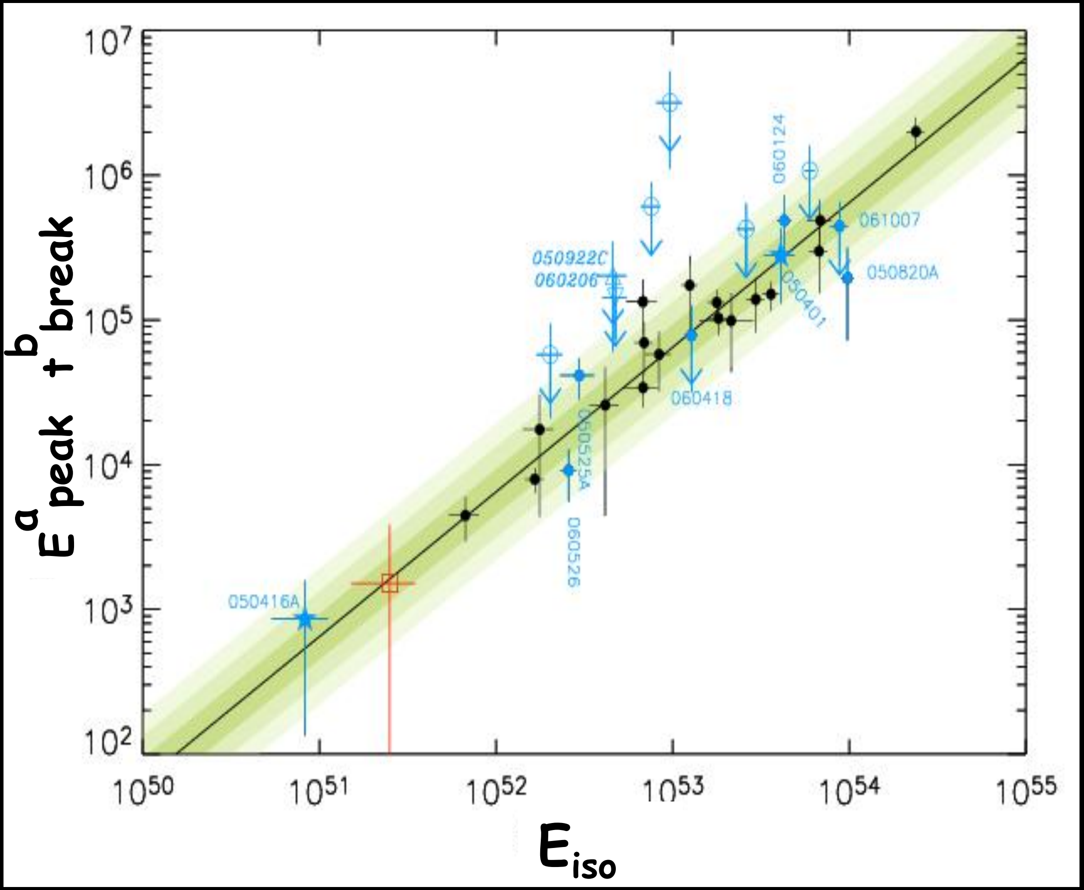


Ghirlanda et al. 2004, 2007, Nava et al., 2006

- slope = 0.70 ± 0.04
- scatter (1σ) = 0.11 dex
- $\chi^2_{red} \sim 1.5$ (27 dof)

- slope = 1.04 ± 0.05
- scatter (1σ) = 0.09 dex
- $\chi^2_{red} \sim 1.4$ (27 dof)

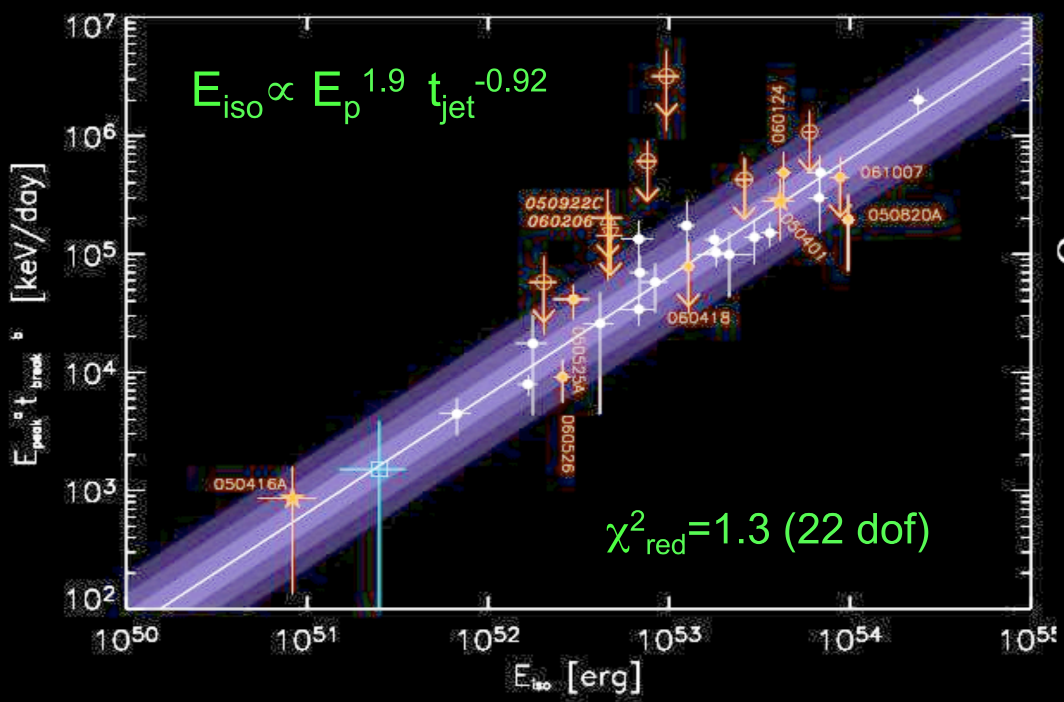
Liang & Zhang 2005
3-parameter correlation
$E_{peak} - E_{iso} - t_{break}$

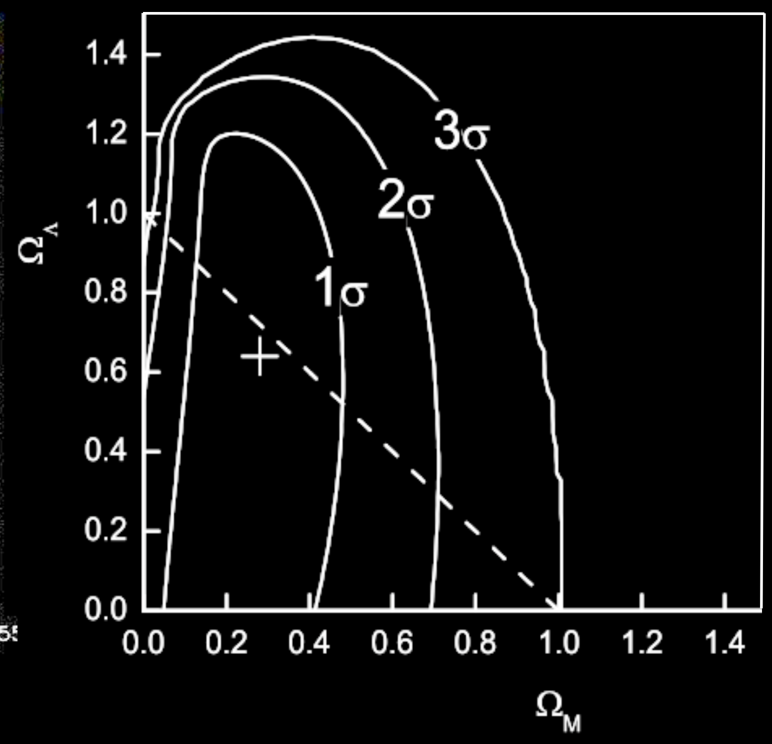


- Correlation (E_p-E_γ) is model dependent

- Correlation E_{iso}-E_p-t_{break} (Liang & Zhang 2005)

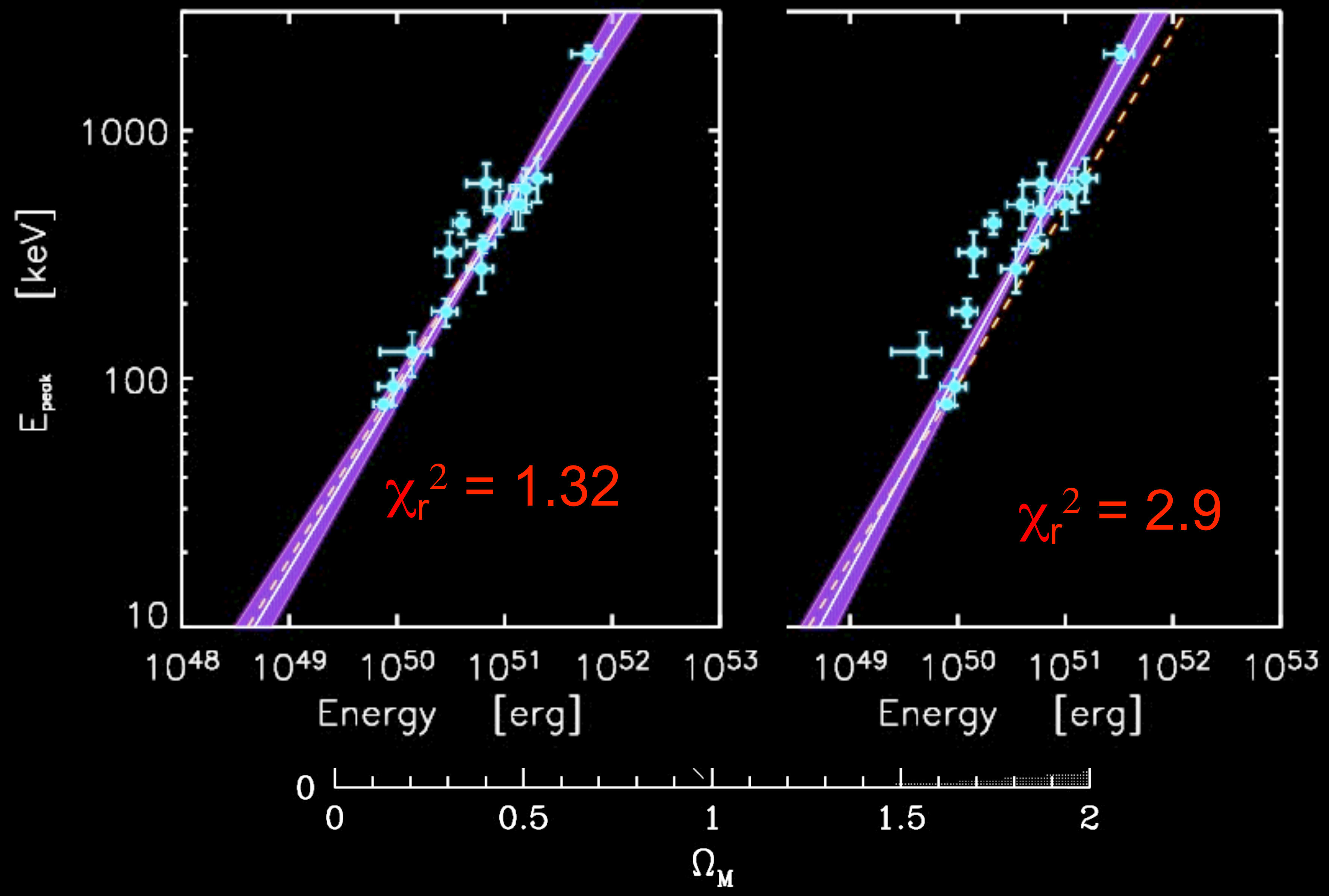
<u>Model independent</u>

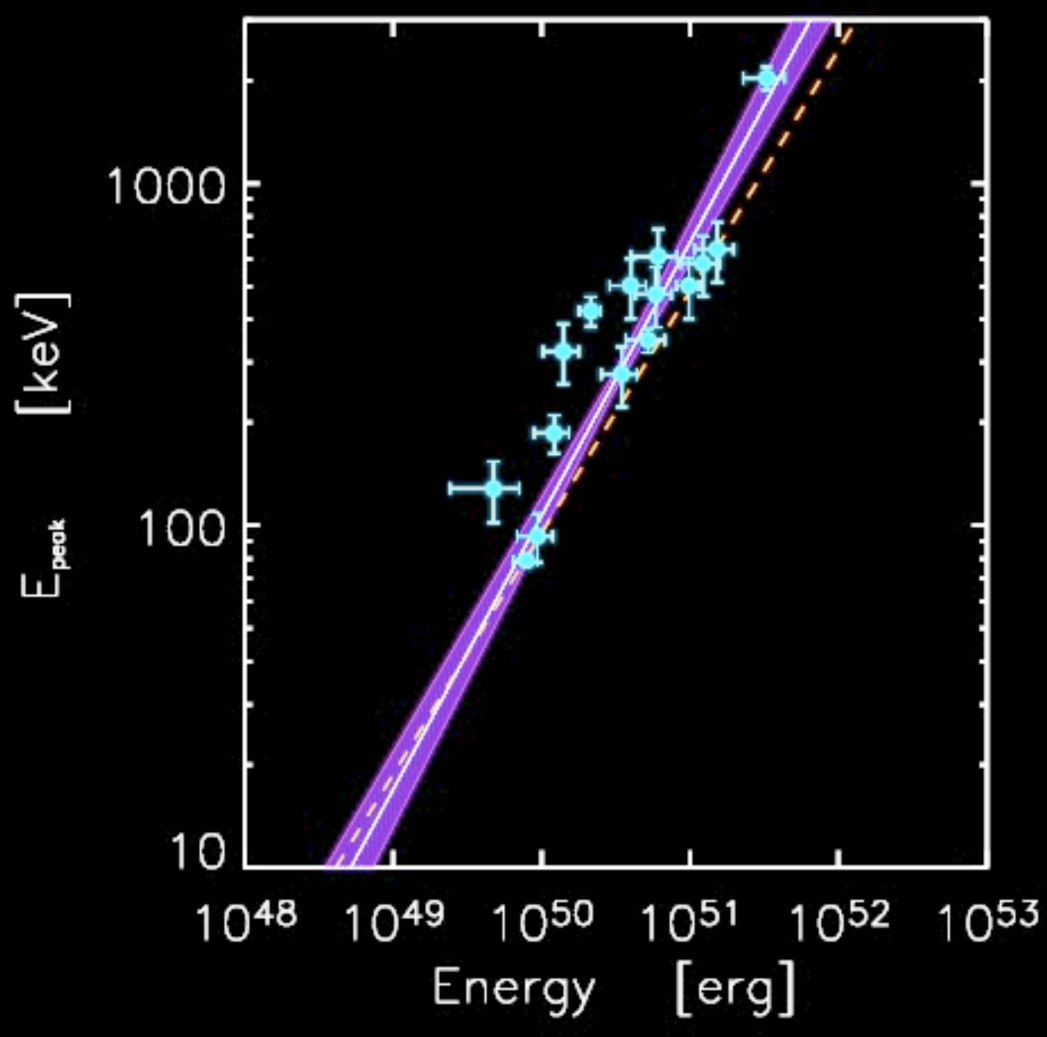




Ω_Λ–Ω_M plane

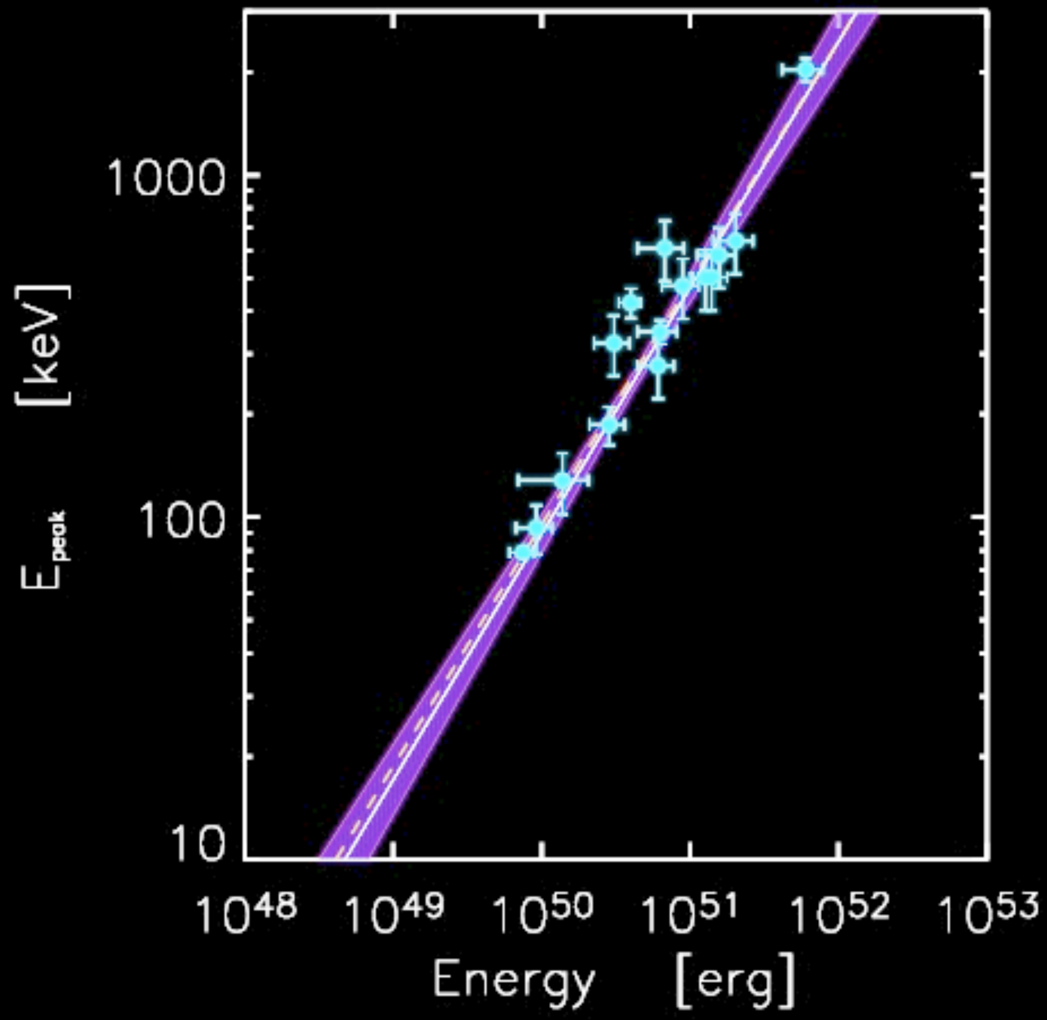
The correlation is not calibrated





1000
100
10
E_{peak} [keV]
10^{48} 10^{49} 10^{50} 10^{51} 10^{52} 10^{53}
Energy [erg]

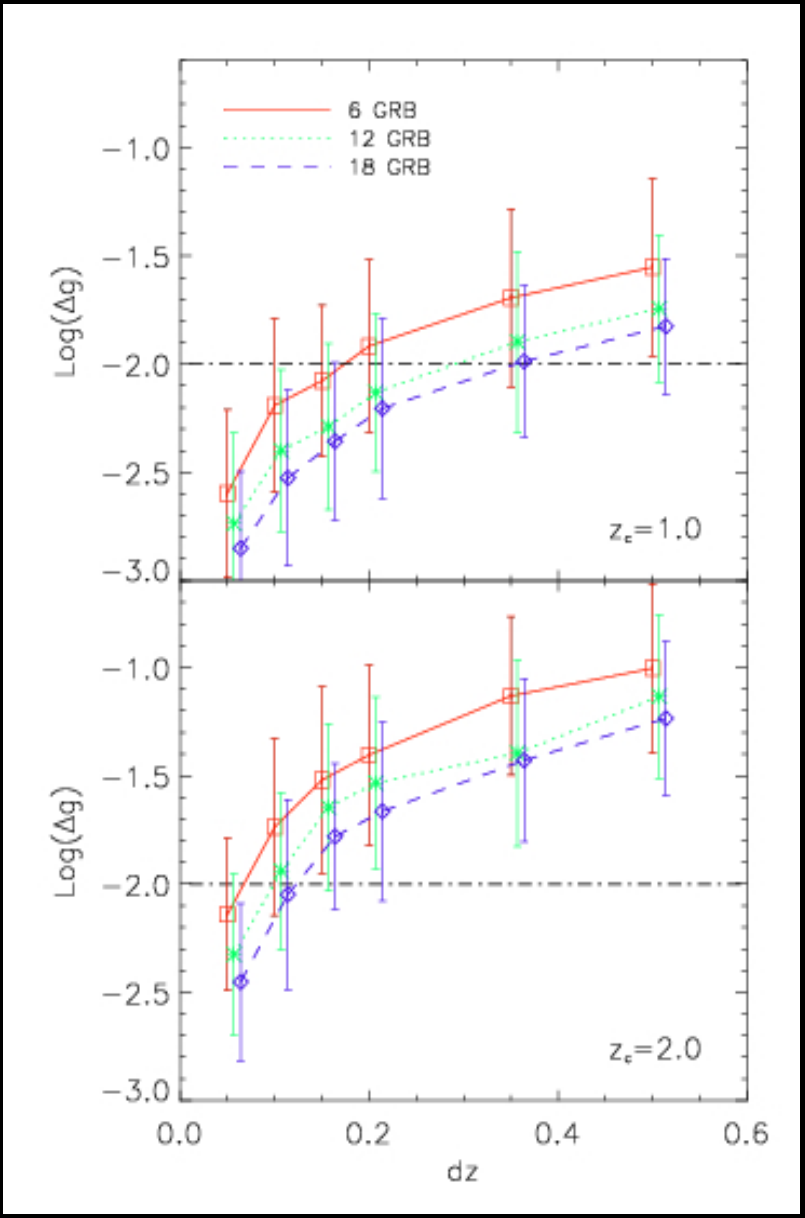
1.5 -1.5



E peak [keV]
1000
100
10
10^48 10^49 10^50 10^51 10^52 10^53
Energy [erg]

0.2 - 0.1

Calibration: very low redshift GRBs ?



Problem: there are few events at low redshift

It is possible to use a given number of GRBs at the same (not necessarily low) redshift?

Simulation

Ghirlanda, Ghisellini, Firmani, Nava et al., 2006

Can we use other correlations?

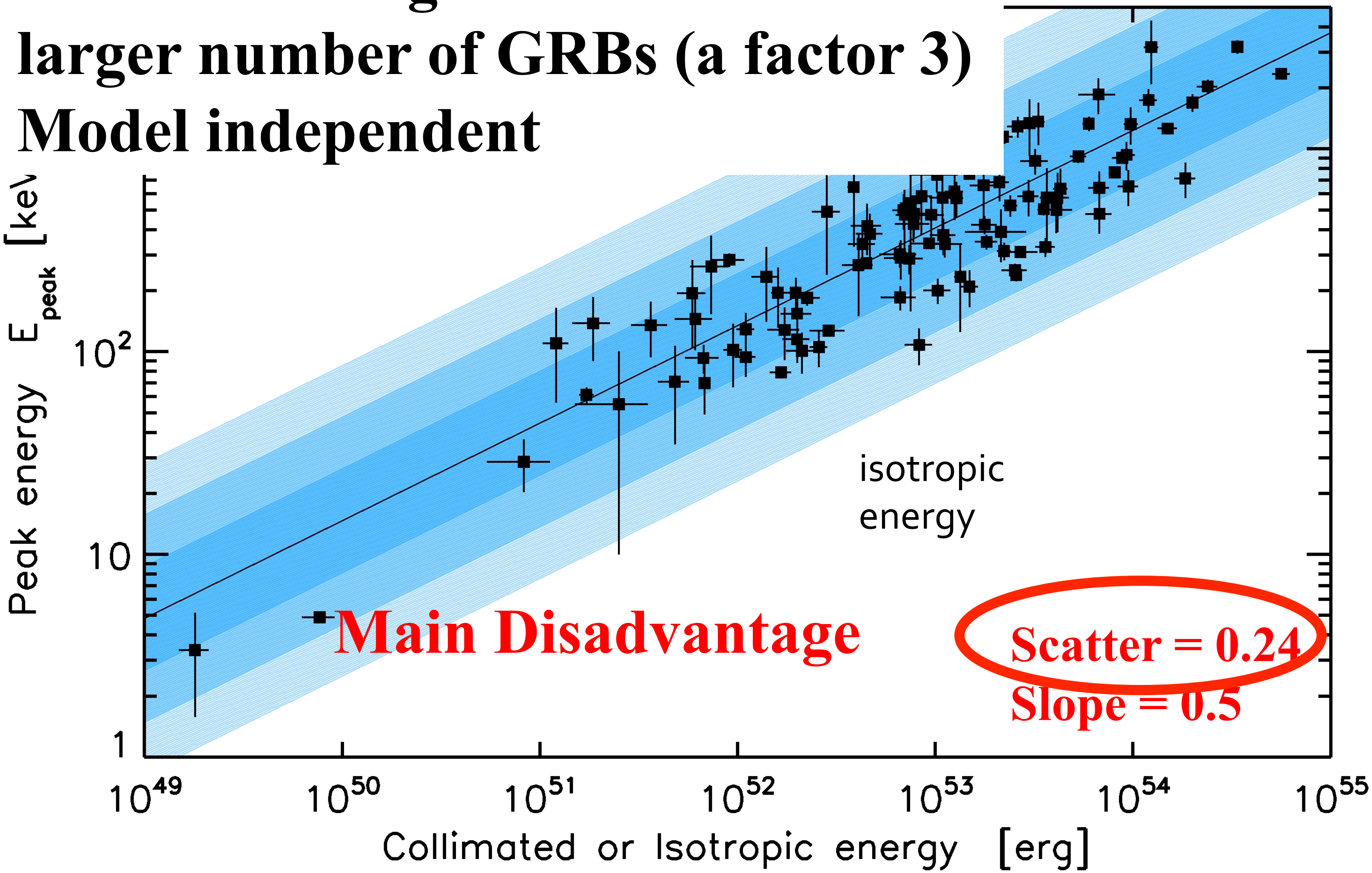
Amati et al. 2002 2008

E_{peak}- E_{iso}

Main Advantages:

larger number of GRBs (a factor 3)

Model independent



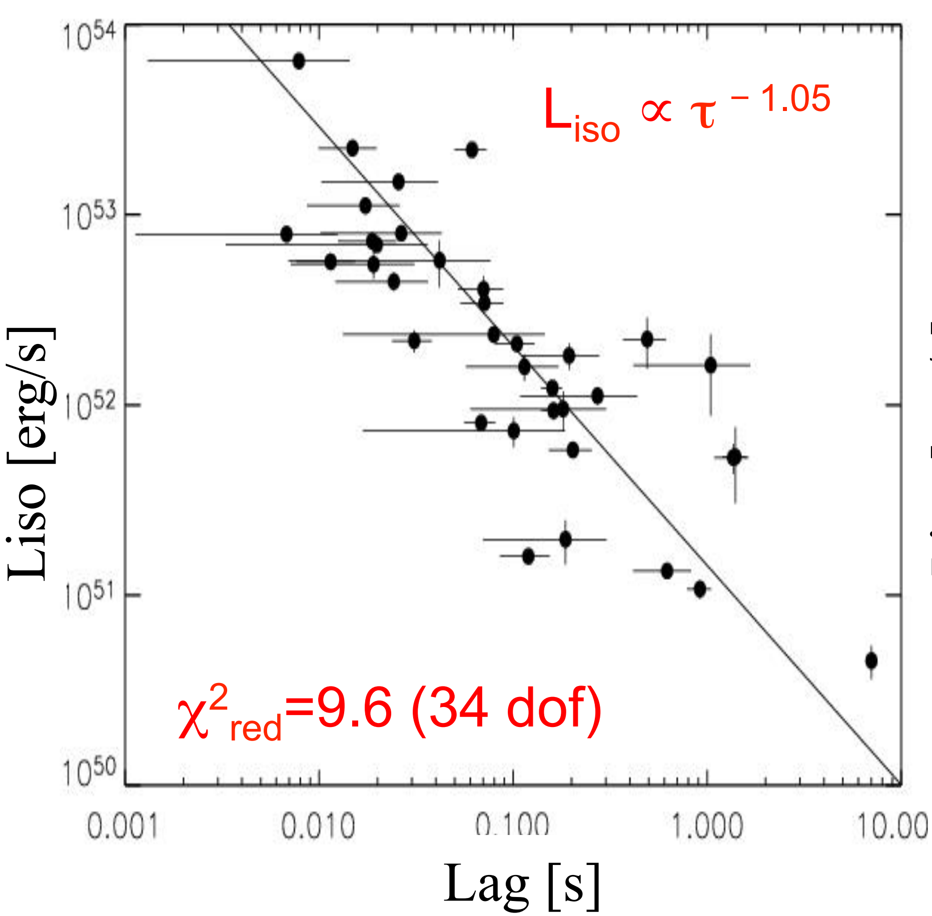
Main Disadvantage

Scatter = 0.24

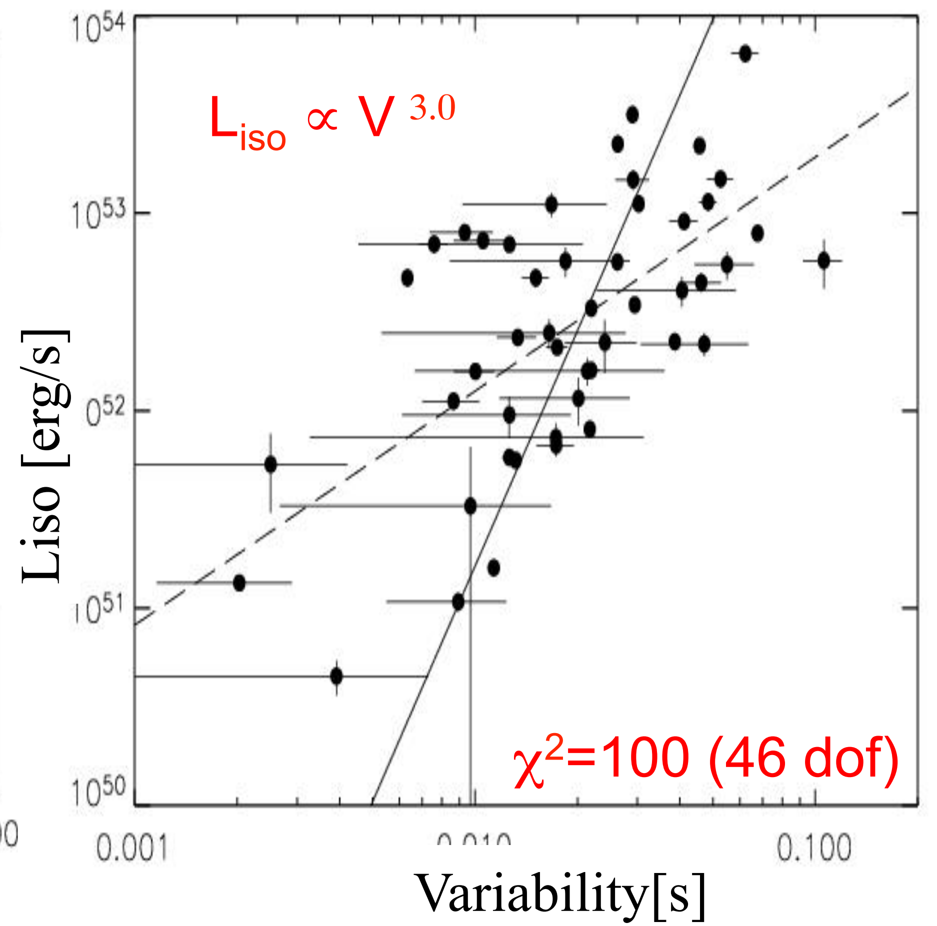
Slope = 0.5

…other correlations…

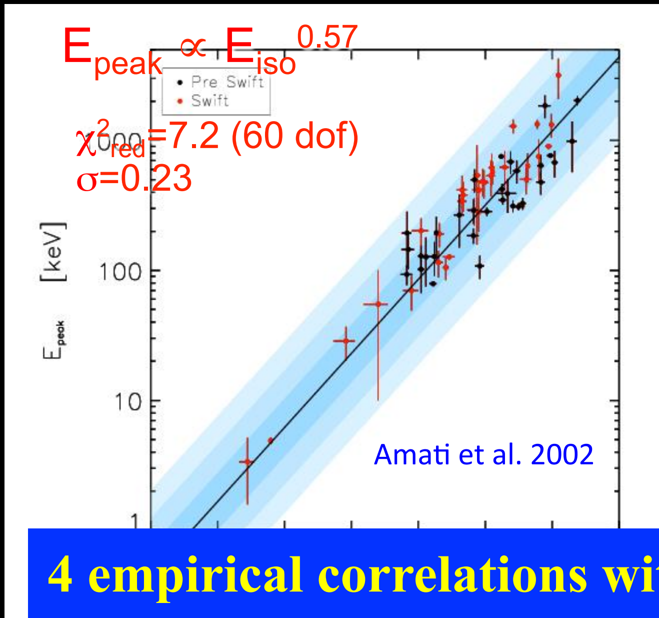
Lag – Luminosity

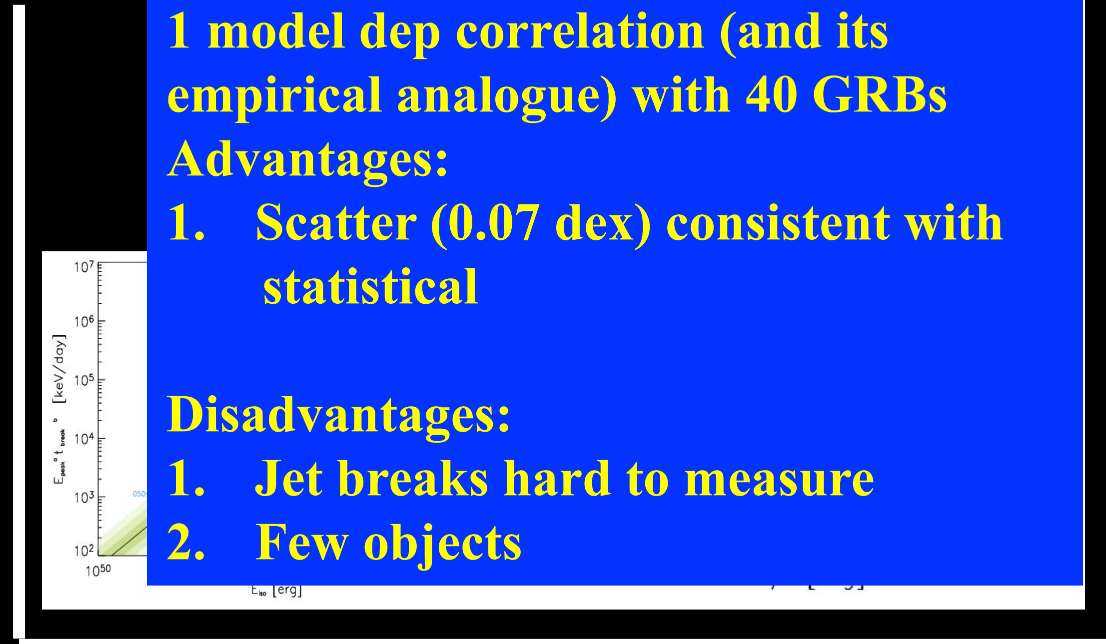


Lag – Variability



Which correlation(s) can we use?





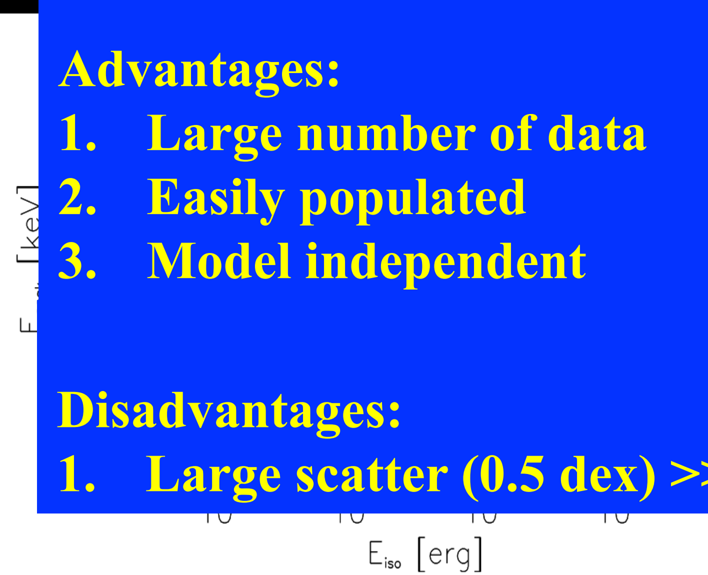
1 model dep correlation (and its empirical analogue) with 40 GRBs

Advantages:

1. **Scatter (0.07 dex) consistent with statistical**

Disadvantages:

1. **Jet breaks hard to measure**
2. **Few objects**



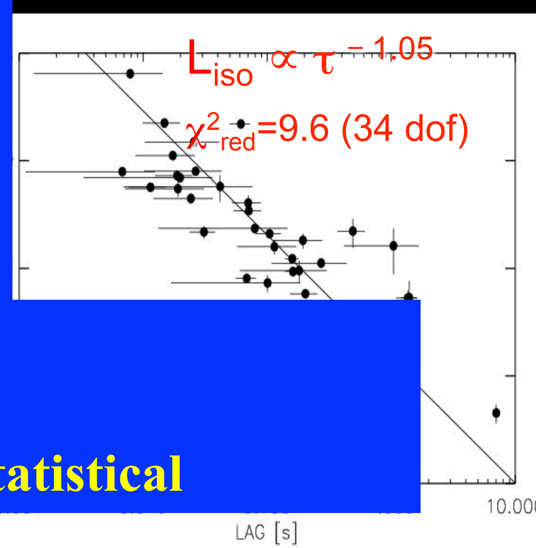
4 empirical correlations with ~ 100 GRBs

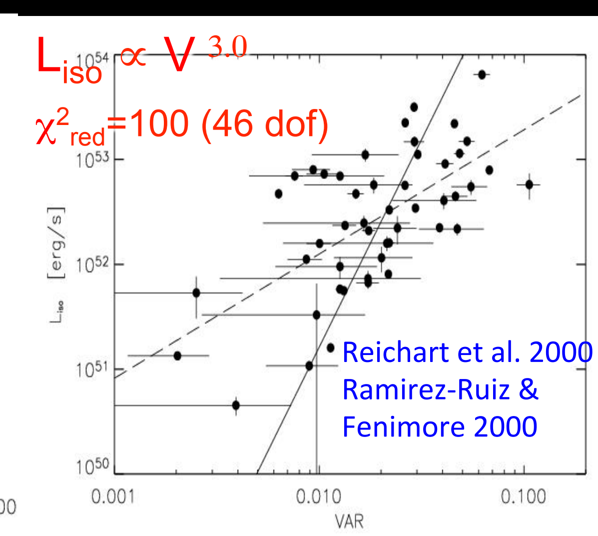
Advantages:

1. **Large number of data**
2. **Easily populated**
3. **Model independent**

Disadvantages:

1. **Large scatter (0.5 dex) >> statistical**



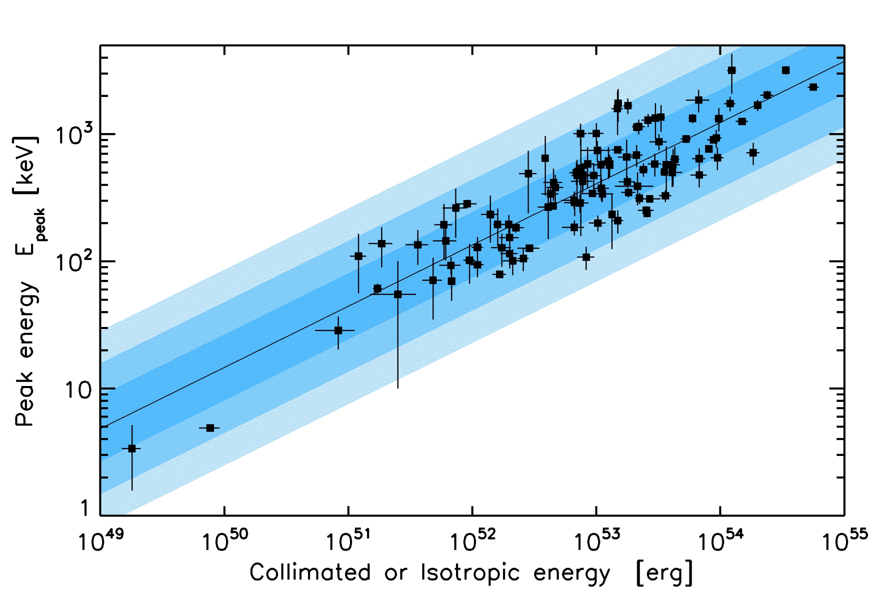


Three approaches:

1) Use a distance indicator with a scatter which is consistent with statistical errors (Ghirlanda et al. 2004,2005,2006, Firmani et al. 2005,2006, Liang&Zhang 2005, Xu et al. 2005,2006,2007; Izzo et al. 2009)

2) Use a distance indicator with a scatter much larger than statistical errors → introduce unknown systematic errors (Amati et al. 2008, 2009; Kodama et al. 2008; Capozziello&Izzo 2010)

3) Combine all the distance indicators and average out systematics and scatter (Schaefer et al. 2006, 2007)



Extrinsic variance σ^{ext}:

Kodama et al. 2008; Amati et al. 2008 introduce an extra scatter term

Assumptions on the extra scatter term:

1. equal for all bursts
2. gaussian
3. only on Ep

$$\log P[m,q,\sigma_x,\sigma_y|(x_i,y_i,\sigma_{x,i},\sigma_{y,i})] = \frac{1}{2}\sum_i \log[\frac{1}{2\pi(m^2\sigma_{x,i}^2+\sigma_{y,i}^2+m^2\sigma_x^2+\sigma_y^2)}] + -\frac{(y_i-mx_i-q)^2}{m^2\sigma_{x,i}^2+\sigma_{y,i}^2+m^2\sigma_x^2+\sigma_y^2}$$

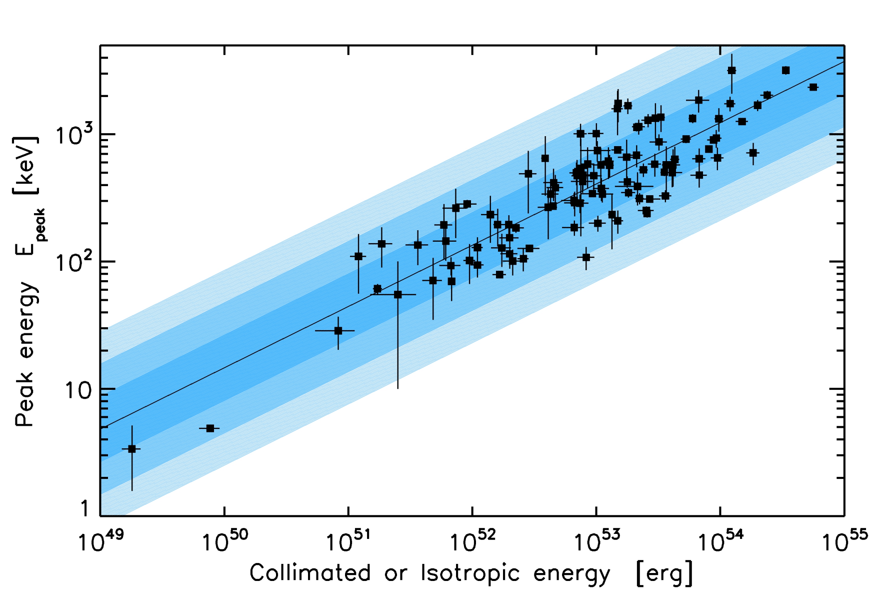
$$\mathbf{x_i = E_{iso,i} = 4\pi d_L(z_i)^2 F_i \ ; \ \sigma_{x_i} = \sigma_{E_{iso,i}}}$$

$$\mathbf{y_i = E_{peak,i} = E^{obs}_{peak,i}(1+z) \ ; \ \sigma_{y_i} = \sigma_{E_{peak,i}}}$$

$$\sigma_\mathbf{x} = \mathbf{0}$$

$$\sigma_\mathbf{y} \neq \mathbf{0}$$

Kodama et al. 2008;
Amati et al. 2008 … +

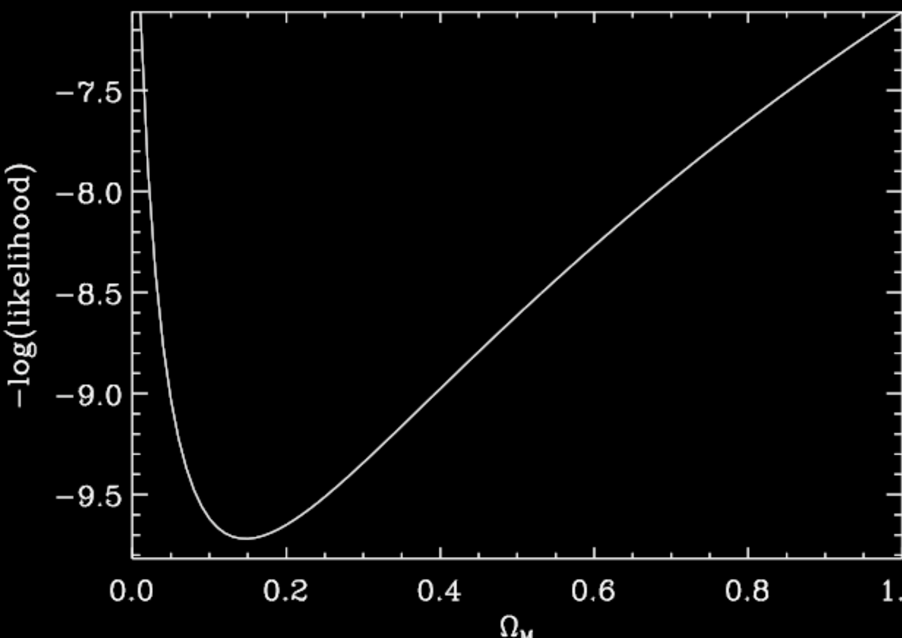


Extrinsic variance σ^{ext}:

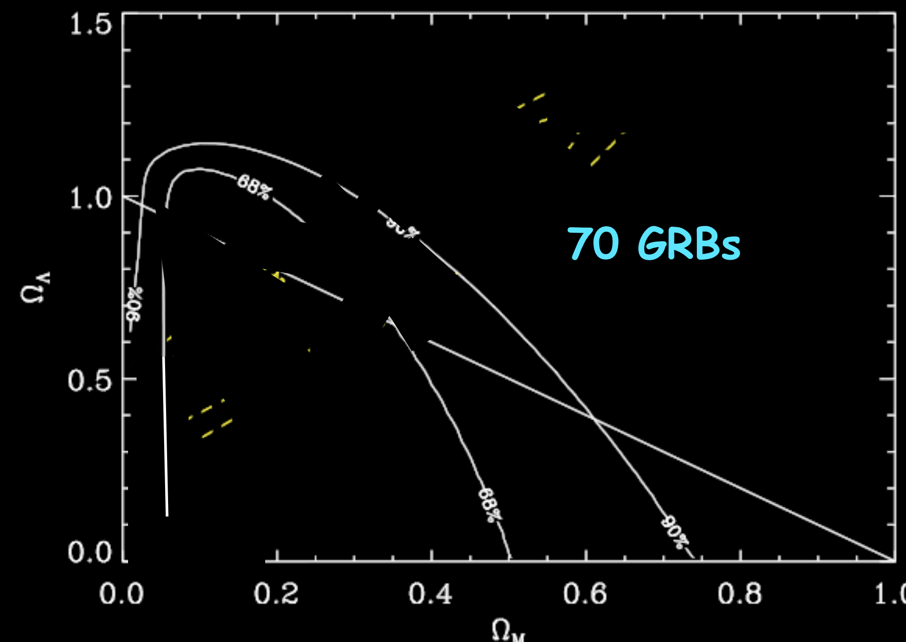
Kodama et al. 2008; Amati et al. 2008 introduce an extra scatter term

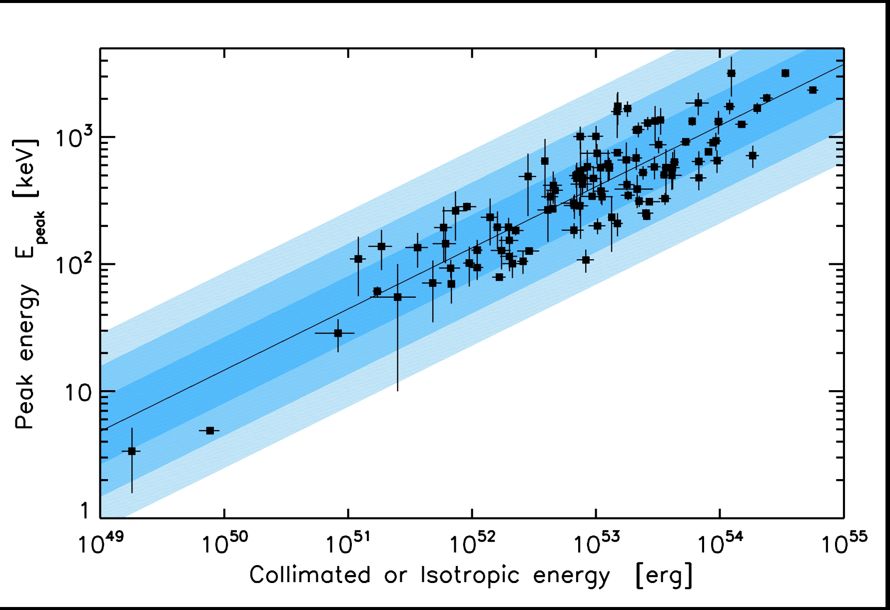
Assumptions on the extra scatter term:

1. equal for all bursts
2. gaussian
3. only on Ep



Flat Universe





Extrinsic variance σ^{ext}:

Kodama et al. 2008; Amati et al. 2008 introduce an extra scatter term

Assumptions on the extra scatter term:

1. equal for all bursts
2. gaussian
3. only on Ep

$$\log P[m,q,\sigma_x,\sigma_y|(x_i,y_i,\sigma_{x,i},\sigma_{y,i})] = \frac{1}{2}\sum_i \log\left[\frac{1}{2\pi(m^2\sigma_{x,i}^2+\sigma_{y,i}^2+m^2\sigma_x^2+\sigma_y^2)}\right] + - \frac{(y_i - mx_i - q)^2}{m^2\sigma_{x,i}^2+\sigma_{y,i}^2+m^2\sigma_x^2+\sigma_y^2}$$

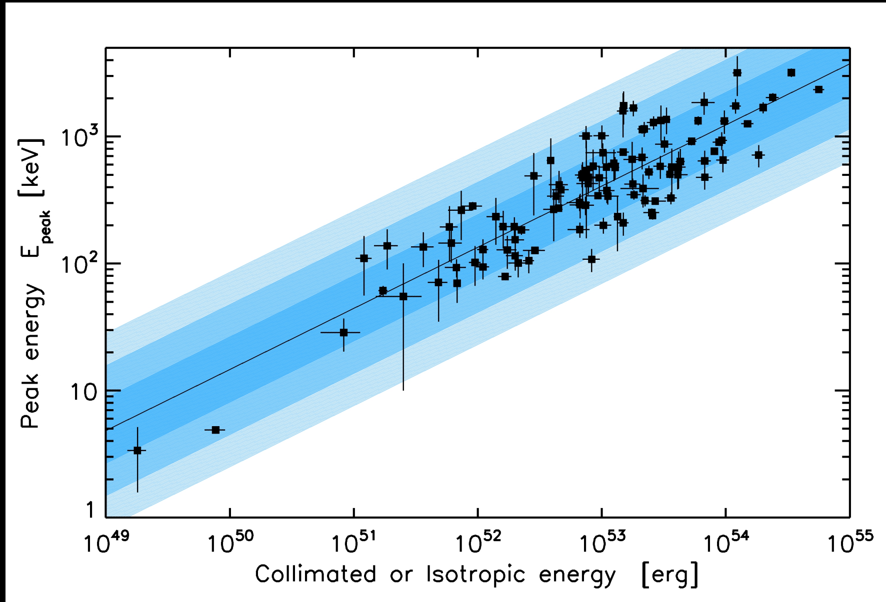
$$\mathbf{x_i = E_{iso,i} = 4\pi d_L(z_i)^2 F_i \;\; ; \;\; \sigma_{x_i} = \sigma_{E_{iso,i}}}$$

$$\mathbf{y_i = E_{peak,i} = E^{obs}_{peak,i}(1+z) \;\; ; \;\; \sigma_{y_i} = \sigma_{E_{peak,i}}}$$

$$\sigma_\mathbf{x} \neq 0$$

$$\sigma_\mathbf{y} = 0$$

… but cosmology acts on Eiso rather than on Epeak



Extrinsic variance σ^{ext}:

Kodama et al. 2008; Amati et al. 2008

Assumptions on the extra scatter term:

1. gaussian
2. equal for all bursts
3. only on Ep

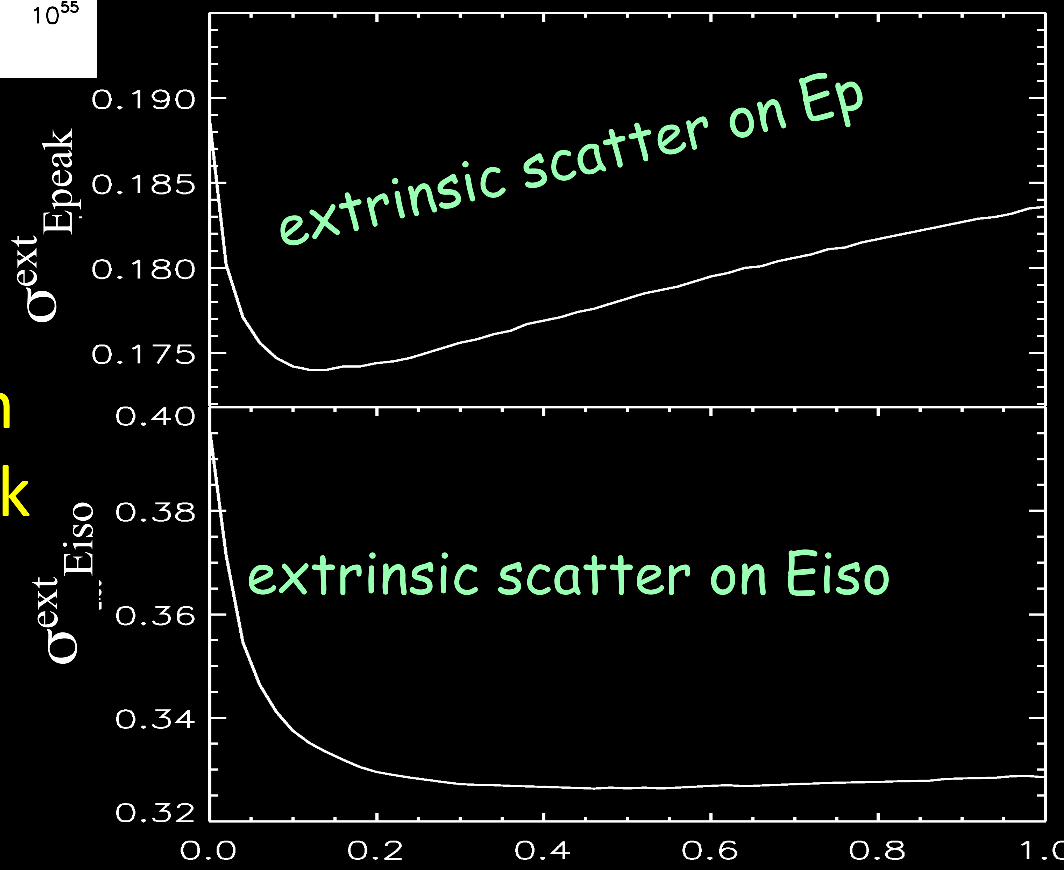
$$\sigma_{\mathbf{x}} = 0$$

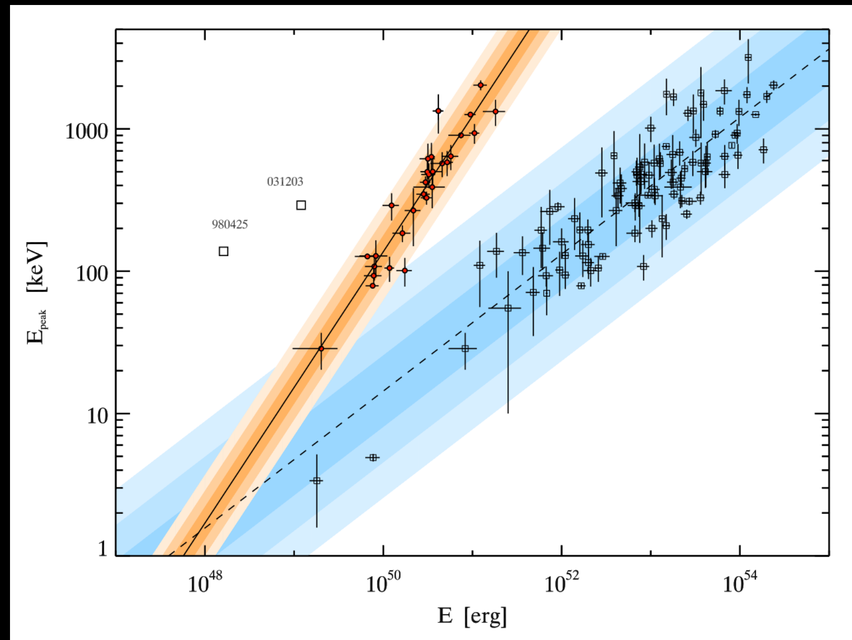
$$\sigma_{\mathbf{y}} \neq 0$$

... but cosmology acts on Eiso rather than on Epeak

$$\sigma_{\mathbf{x}} \neq 0$$

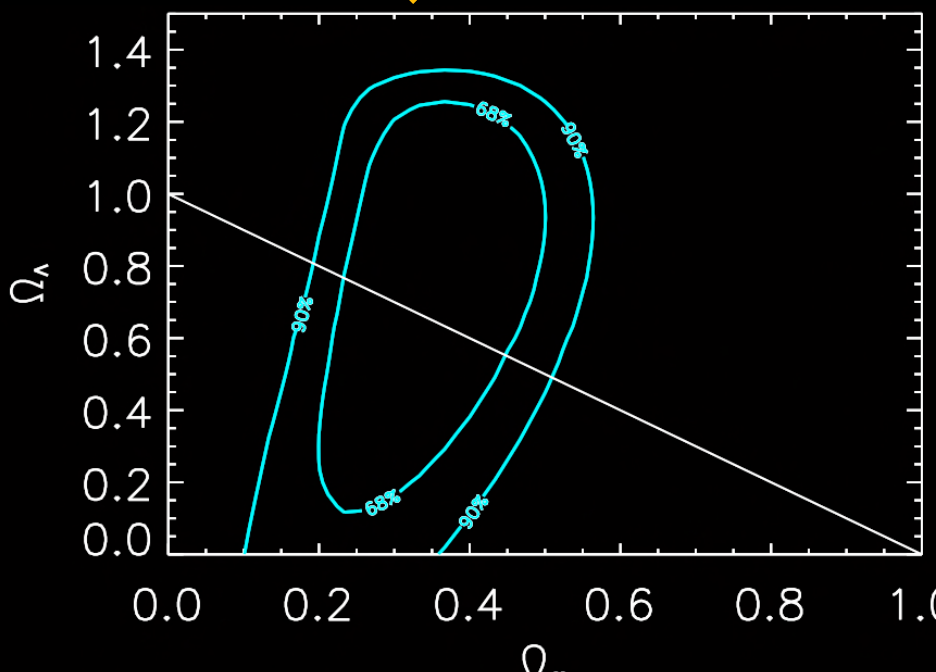
$$\sigma_{\mathbf{y}} = 0$$

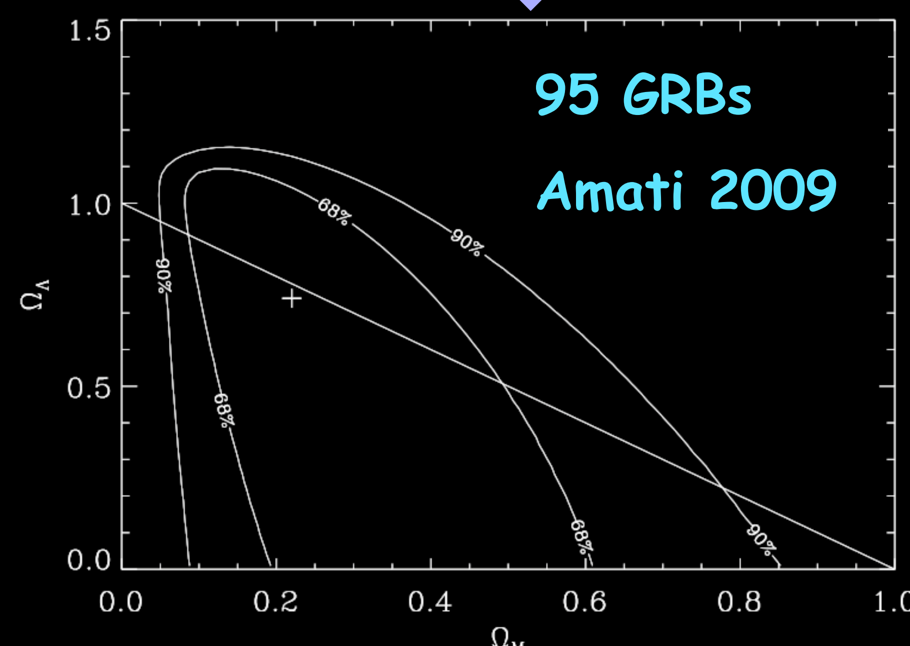




Ep-Eγ
29
GRBs

Ep-Eiso
95
GRBs

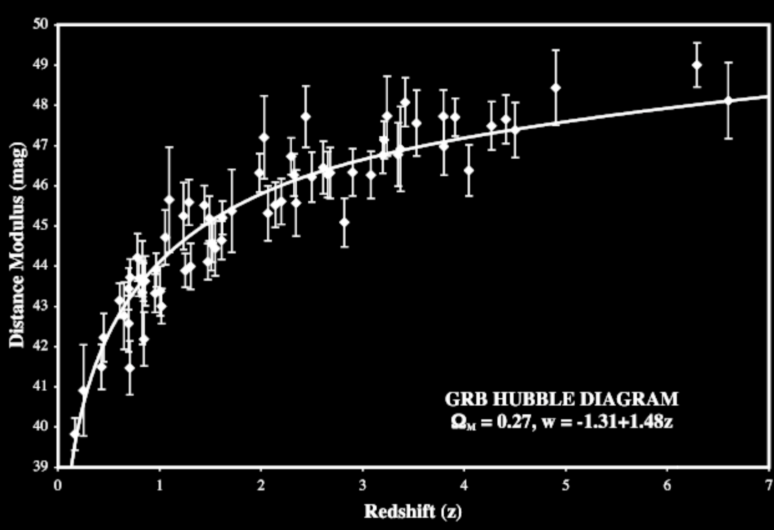


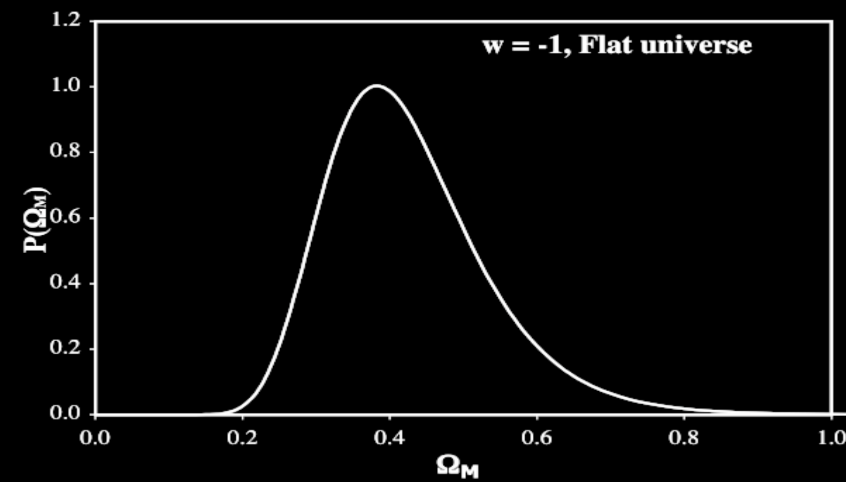


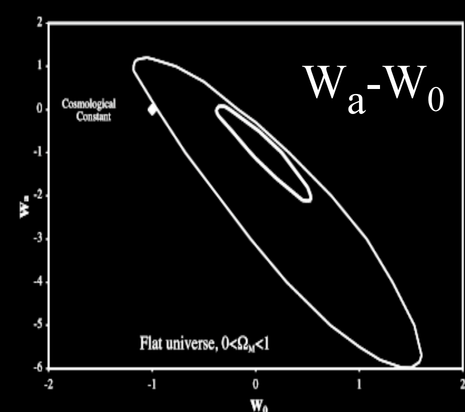
Schaefer et al. (2006, 2007) combine the following relations:

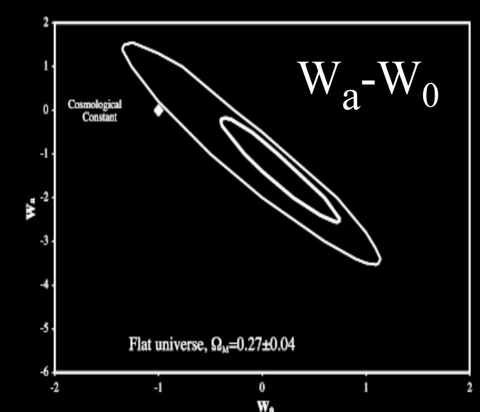
- ⋆ $L - \tau_{lag}$
- ⋆ $L - V$
- ⋆ $L - E_{peak}$
- ⋆ $E_{\gamma} - E_{peak}$
- ⋆ $L - \tau_{RT}$
- ⋆ $L - N_{peak}$

Method: each luminosity indicator gives an estimate of the distance modulus. Different distance moduli are combined weighting for their errors



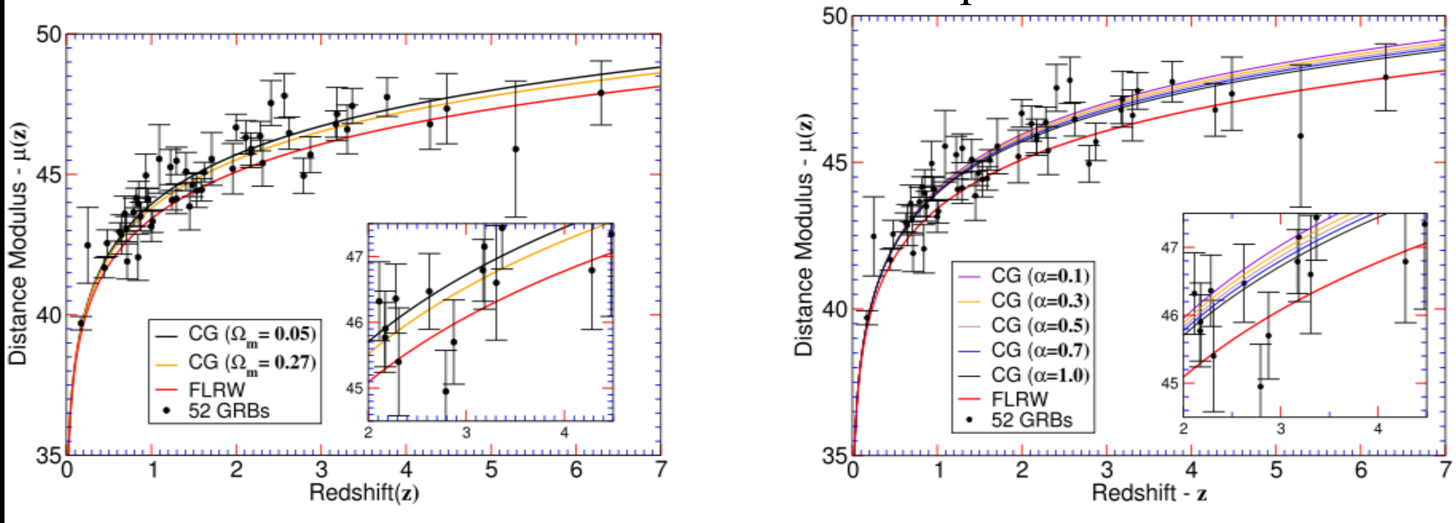




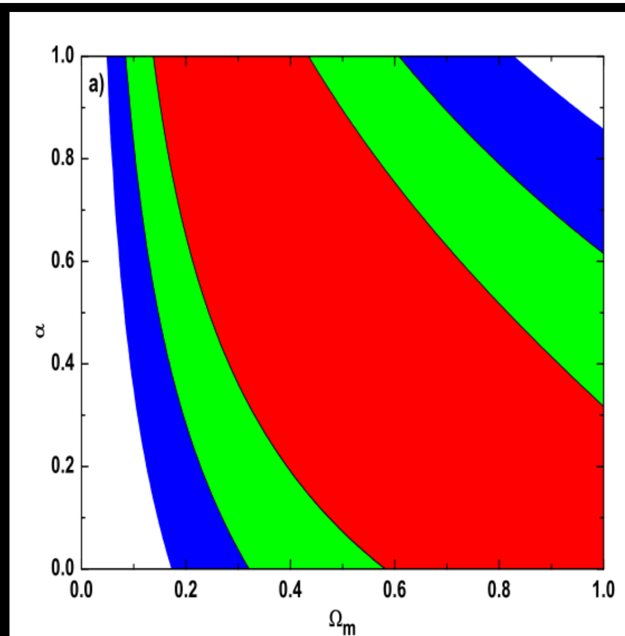


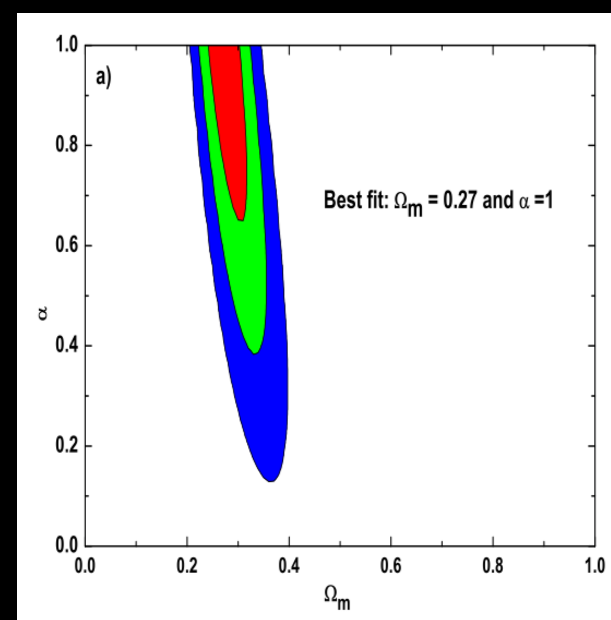
Other applications of the "Schaefer" method

Mosquera Cuesta et al. 2006

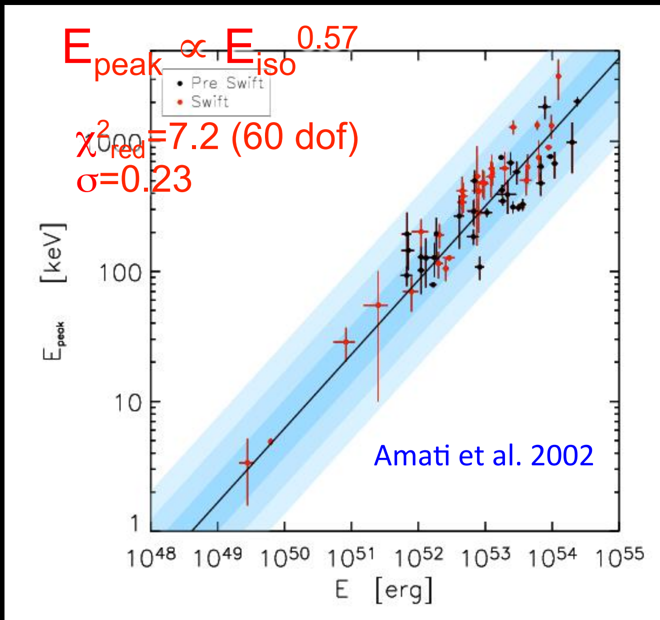


Busti et al. 2012

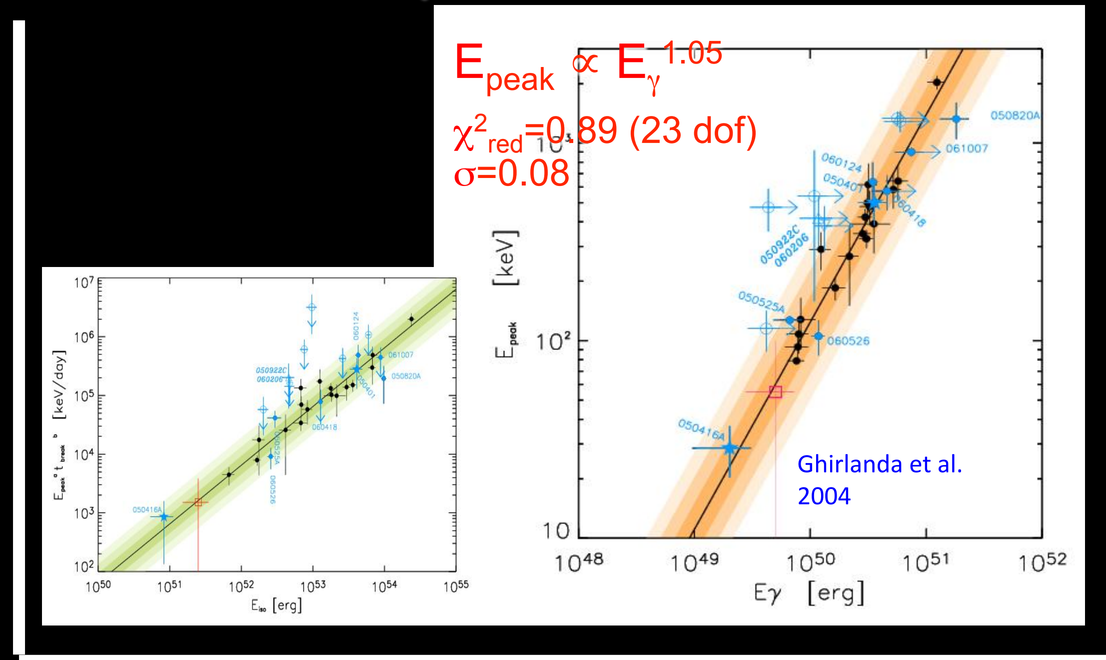




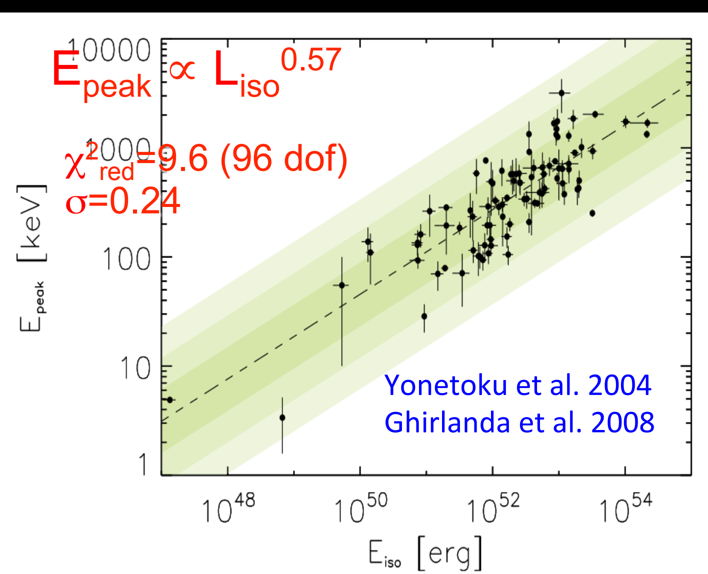
In summary



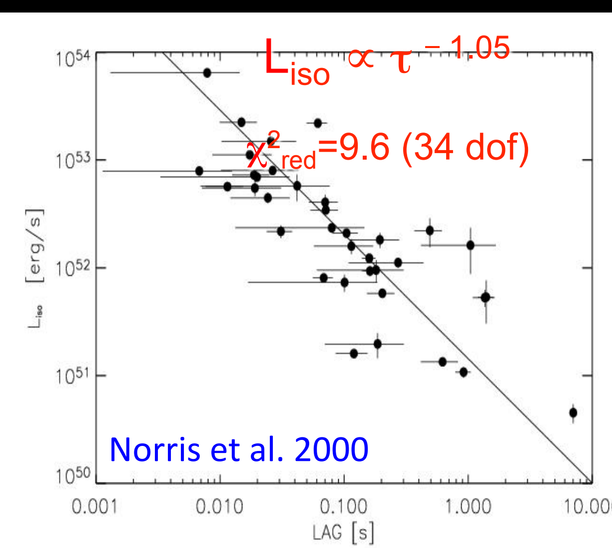
$E_{peak} \propto E_{iso}^{0.57}$
χ^2_{red}=7.2 (60 dof)
σ=0.23
Pre Swift
Swift
E_{peak} [keV]
E [erg]
Amati et al. 2002



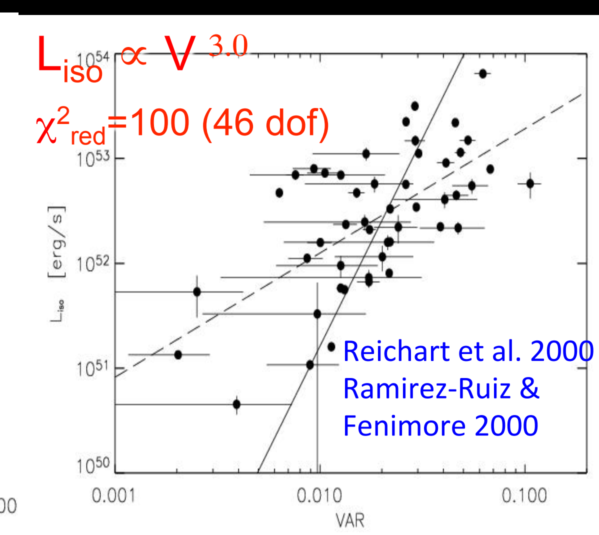
$E_{peak} \propto E_\gamma^{1.05}$
χ^2_{red}=0.89 (23 dof)
σ=0.08
E_{peak} [keV]
Eγ [erg]
E_{iso} [erg]
Ghirlanda et al. 2004



$E_{peak} \propto L_{iso}^{0.57}$
χ^2_{red}=9.6 (96 dof)
σ=0.24
E_{peak} [keV]
E_{iso} [erg]
Yonetoku et al. 2004
Ghirlanda et al. 2008

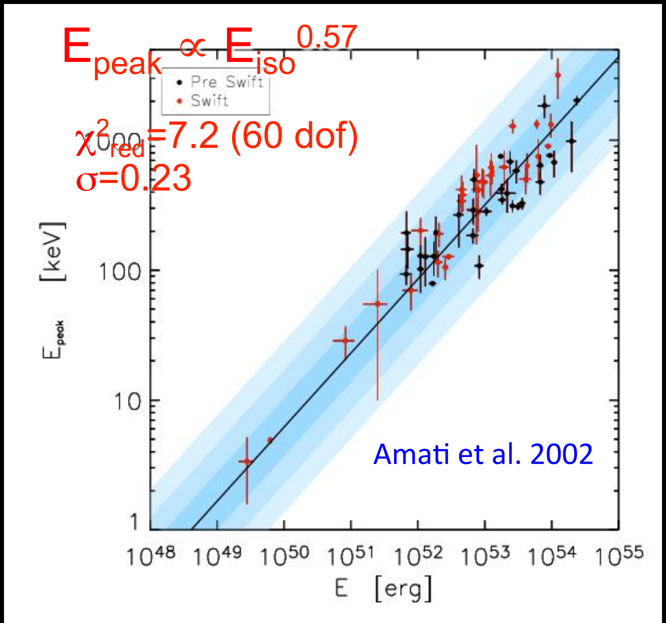


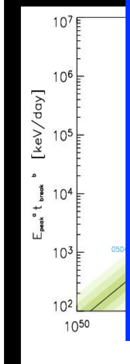
$L_{iso} \propto \tau^{-1.05}$
χ^2_{red}=9.6 (34 dof)
L_{iso} [erg/s]
LAG [s]
Norris et al. 2000



$L_{iso} \propto V^{3.0}$
χ^2_{red}=100 (46 dof)
L_{iso} [erg/s]
VAR
Reichart et al. 2000
Ramirez-Ruiz &
Fenimore 2000

In summary





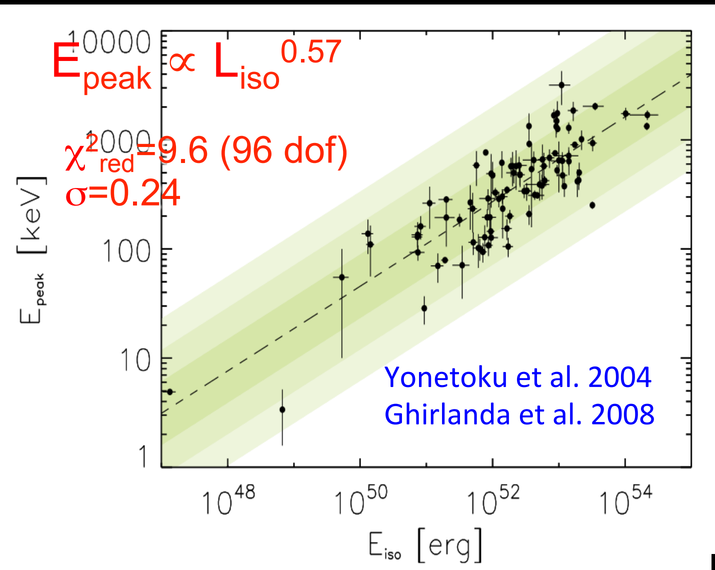
1 model dep correlation (and its empirical analogue) with 40 GRBs

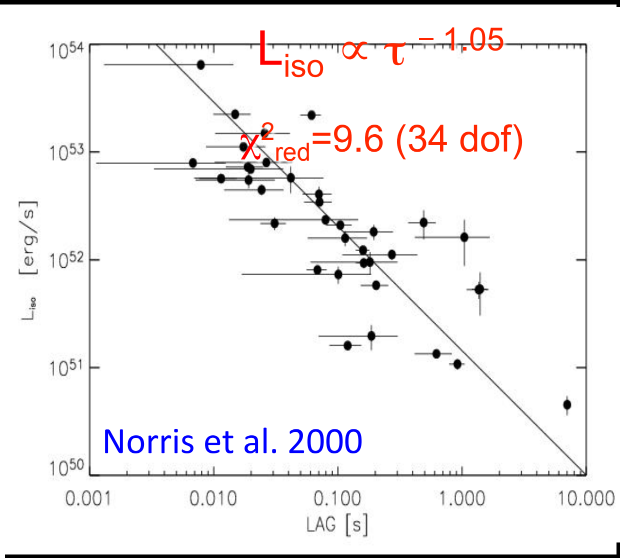
Advantages:

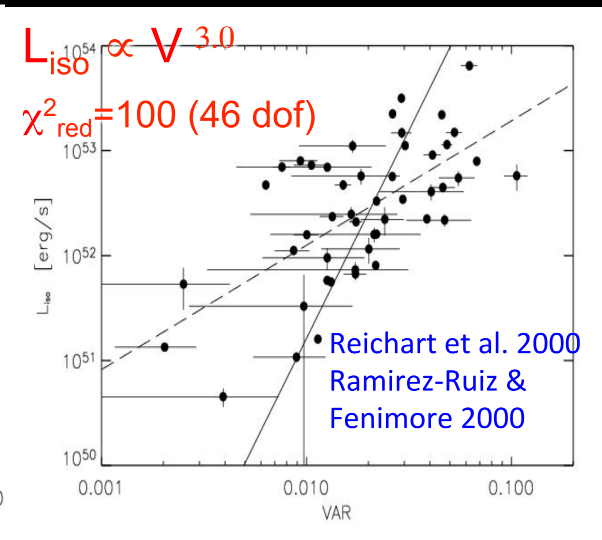
1. **Scatter (0.07 dex) consistent with statistical**

Disadvantages:

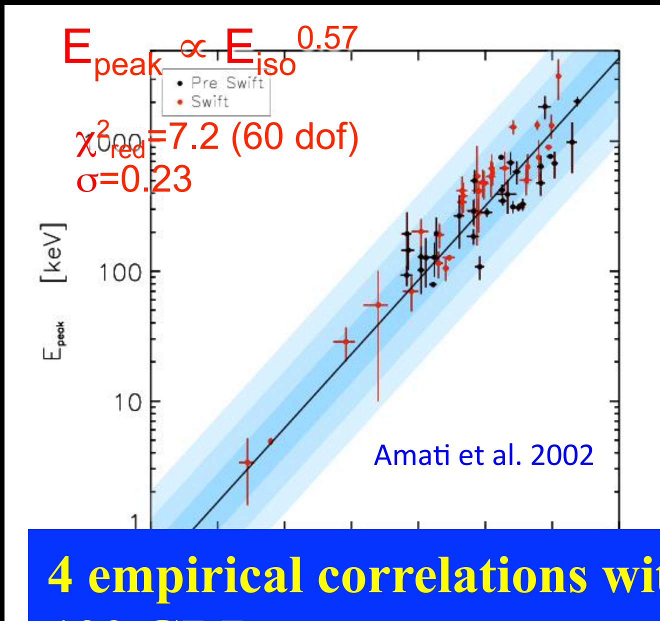
1. **Jet breaks hard to measure**
2. **Few objects**

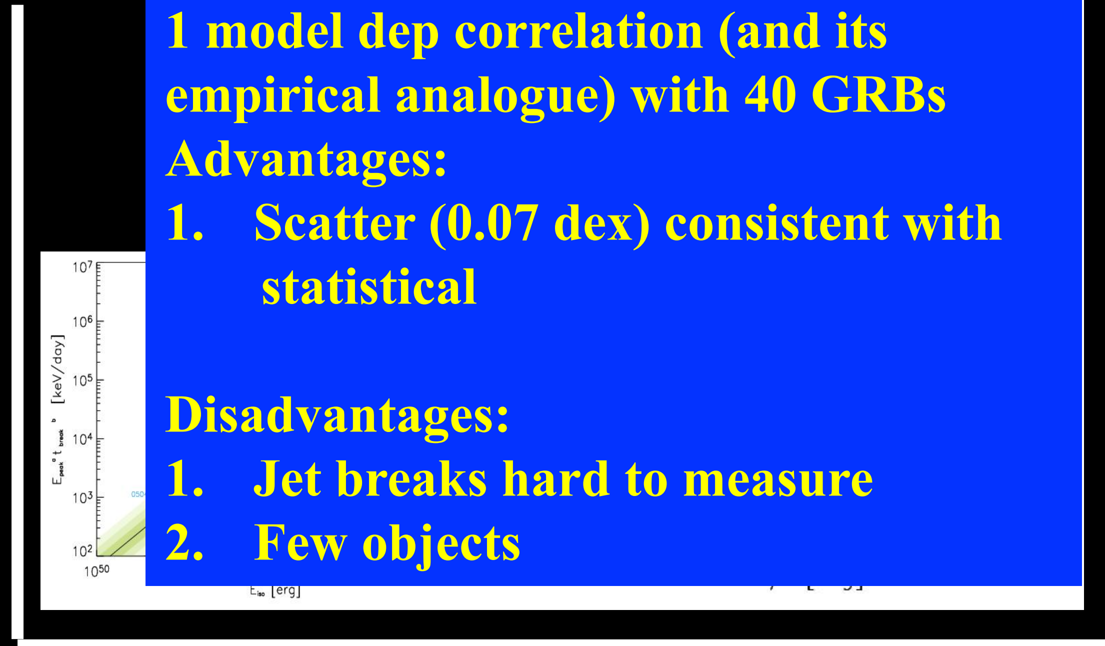






In summary





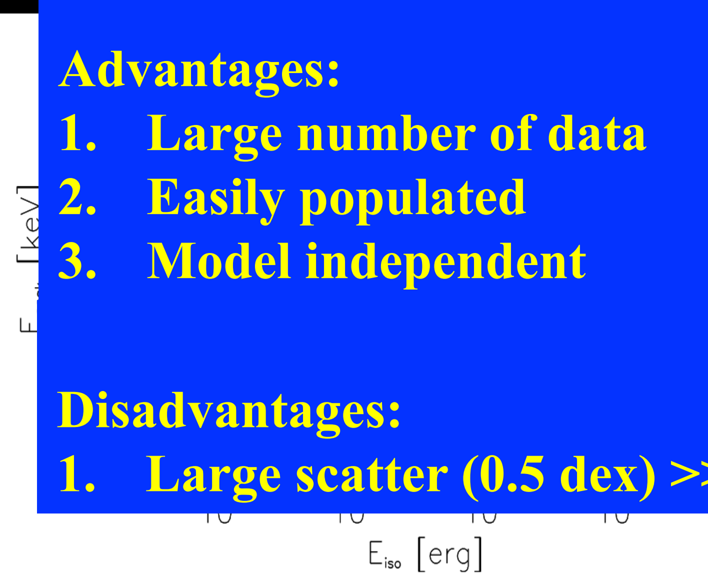
1 model dep correlation (and its empirical analogue) with 40 GRBs

Advantages:

1. **Scatter (0.07 dex) consistent with statistical**

Disadvantages:

1. **Jet breaks hard to measure**
2. **Few objects**



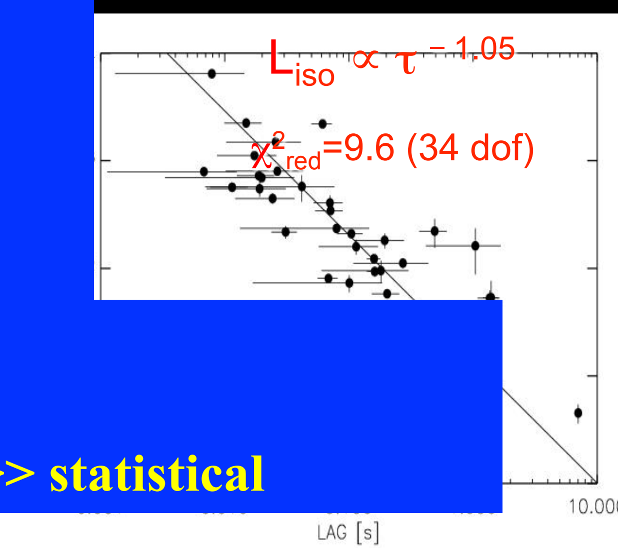
4 empirical correlations with ~ 100 GRBs

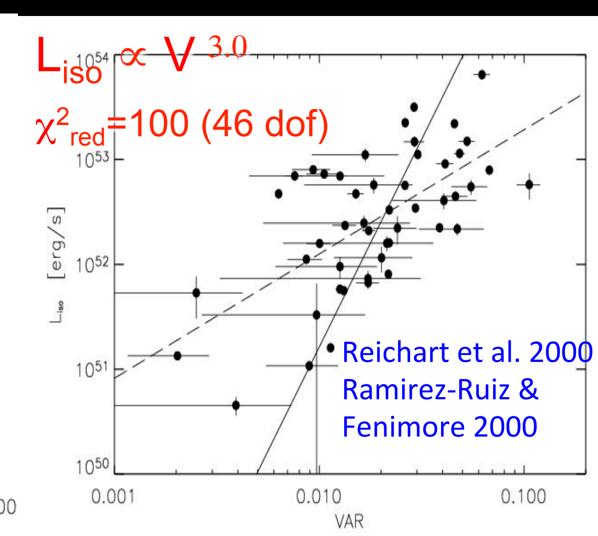
Advantages:

1. **Large number of data**
2. **Easily populated**
3. **Model independent**

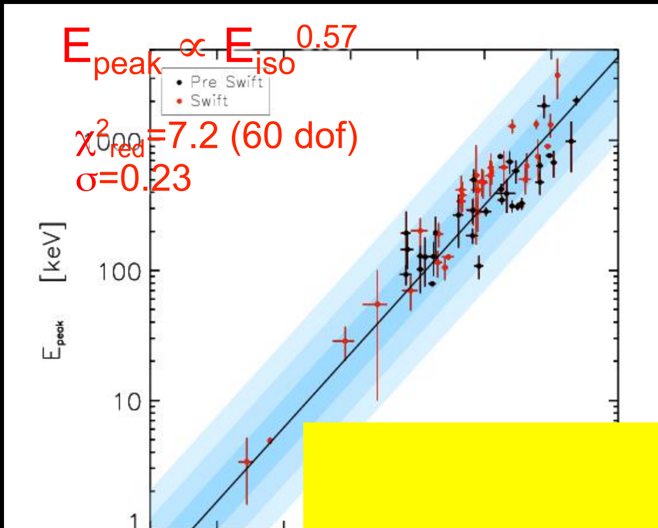
Disadvantages:

1. **Large scatter (0.5 dex) >> statistical**





In summary



1 model dep correlation (and its empirical analogue) with 40 GRBs

Advantages:

1. **Scatter (0.07 dex) consistent with statistical**

4 empirical
100 GRBs

Advantages

1. **Large n**
2. **Easily p**
3. **Model i**

Maybe … but
still a lot to understand

What could help is a physical interpretation

(e.g. see Ghirlanda et al. 2012 for a unifying interpret.)

Disadvantages:

1. **Large scatter (0.5 dex) >> statistical**

E_{iso} [erg]

LAG [s]

10.000