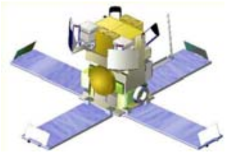
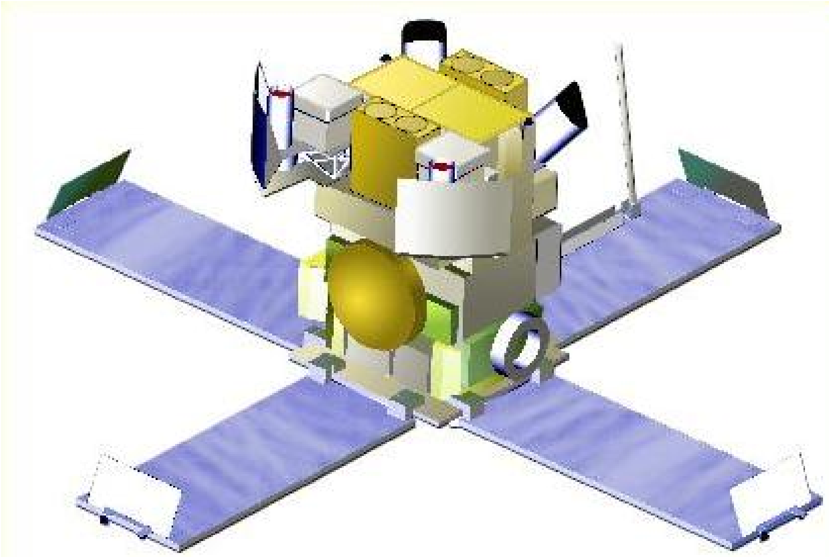
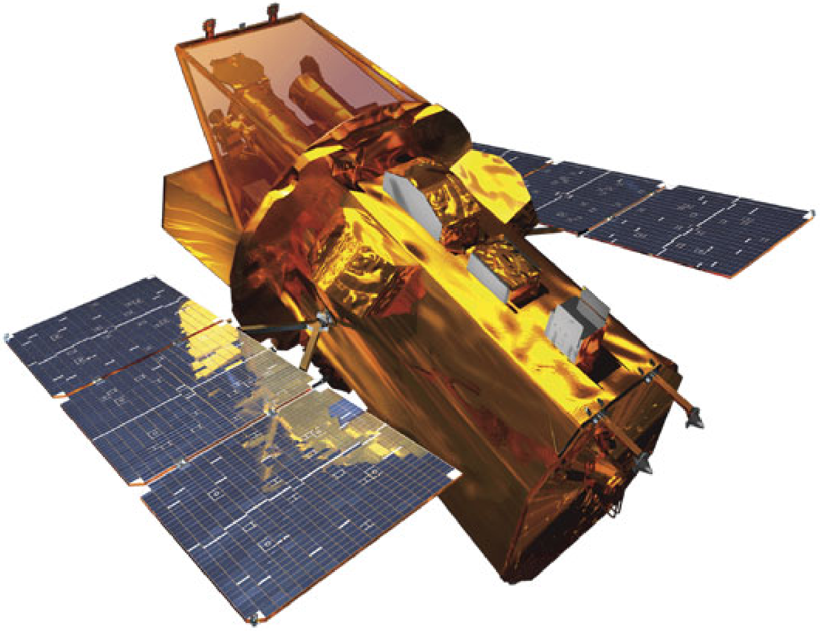


X-Ray Flashes

D. Q. Lamb (U. Chicago)

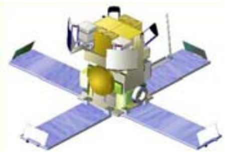


HETE-2

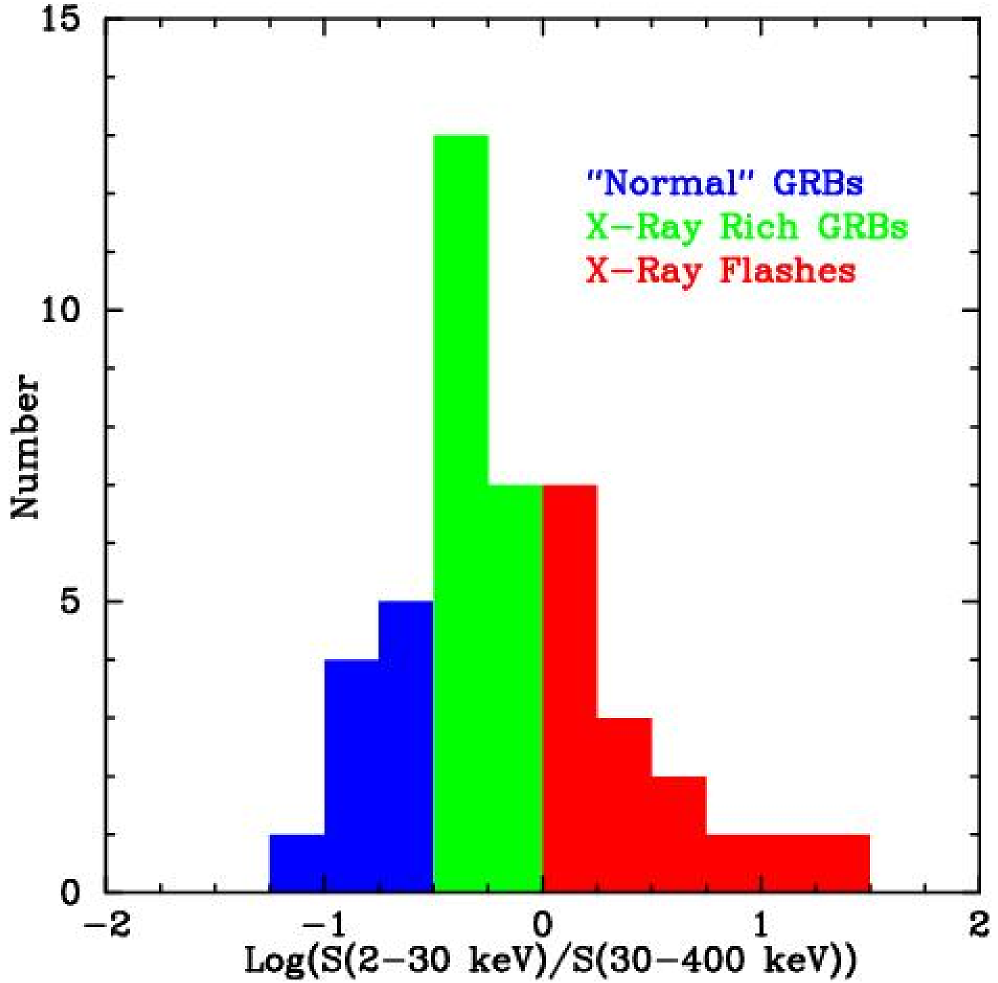


Swift

“Astrophysical Sources of High-Energy Particles and Radiation”
Torun, Poland, 21 June 2005



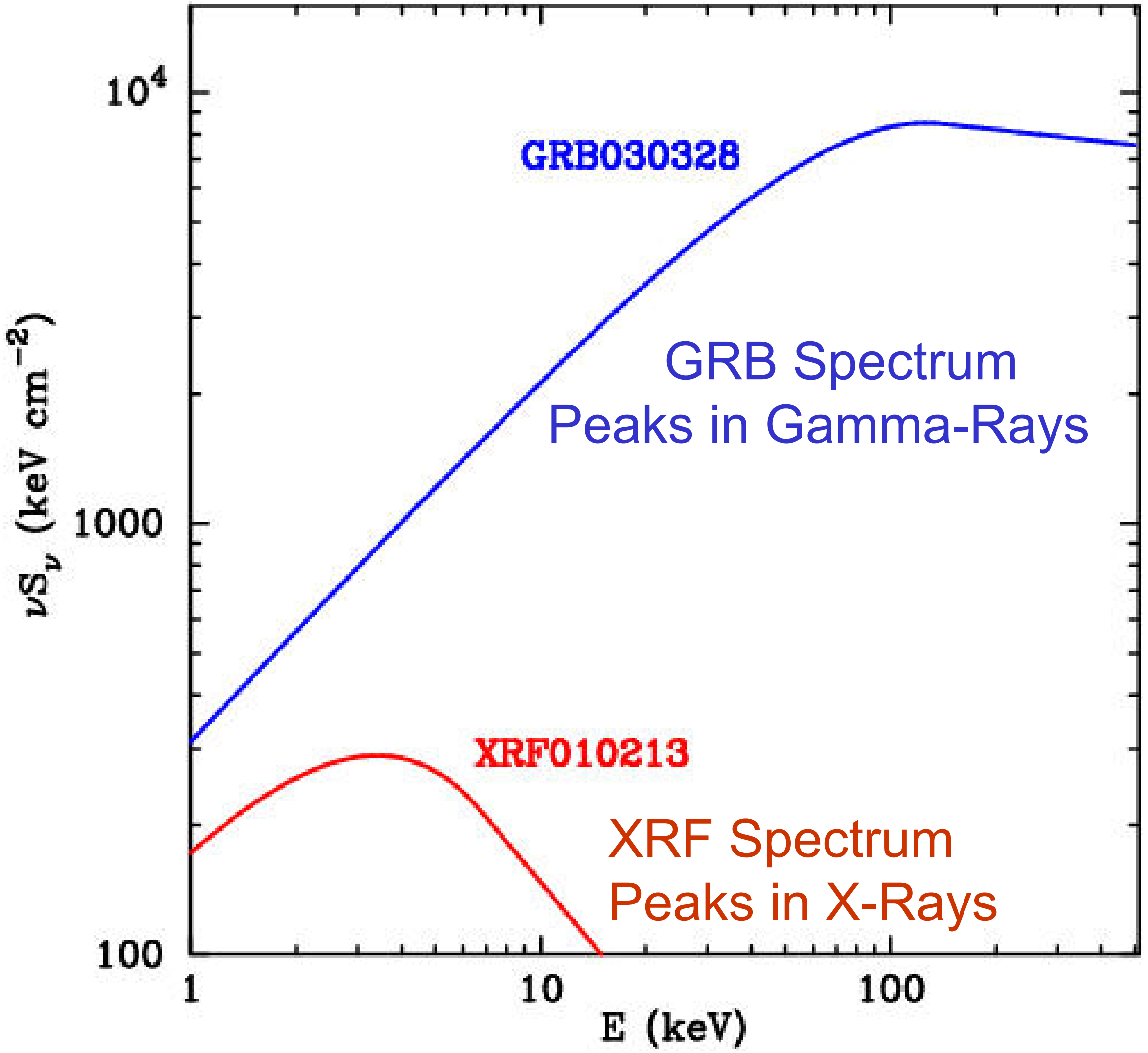
X-Ray Flashes



- X-Ray Flashes discovered by *Heise et al. (2000)* using WFC on *Beppo*SAX
- Defining X-ray flashes as bursts for which log (S_x/S_γ) > 0 (i.e., > 30 times that for "normal" GRBs)
  - ~ **1/3** of bursts localized by HETE-2 are XRFs
  - ~ **1/3** are "X-ray-rich" GRBs ("XRRs")
- Nature of XRFs is still largely unknown

HETE-2 X-Ray Flashes vs. GRBs

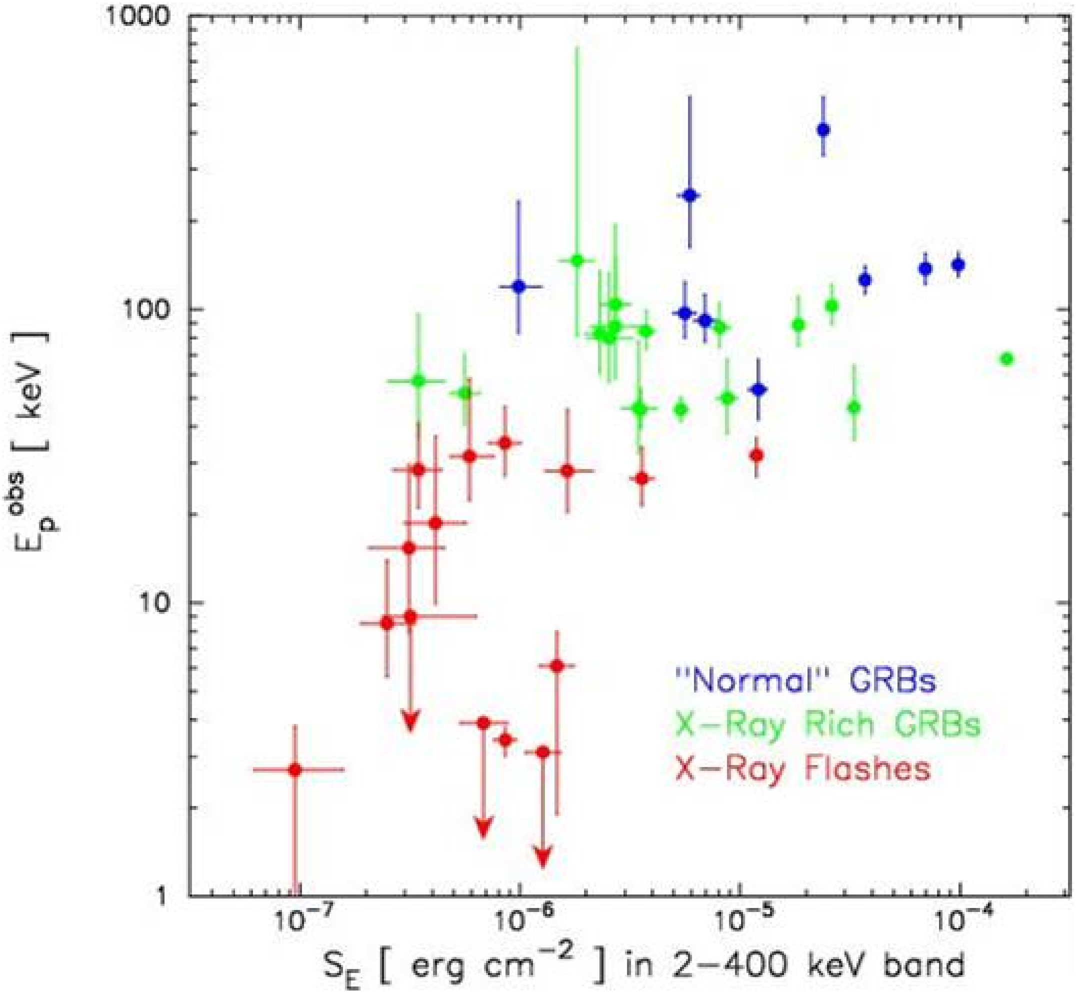
Sakamoto et al. (2004)



GRB Spectrum
Peaks in Gamma-Rays

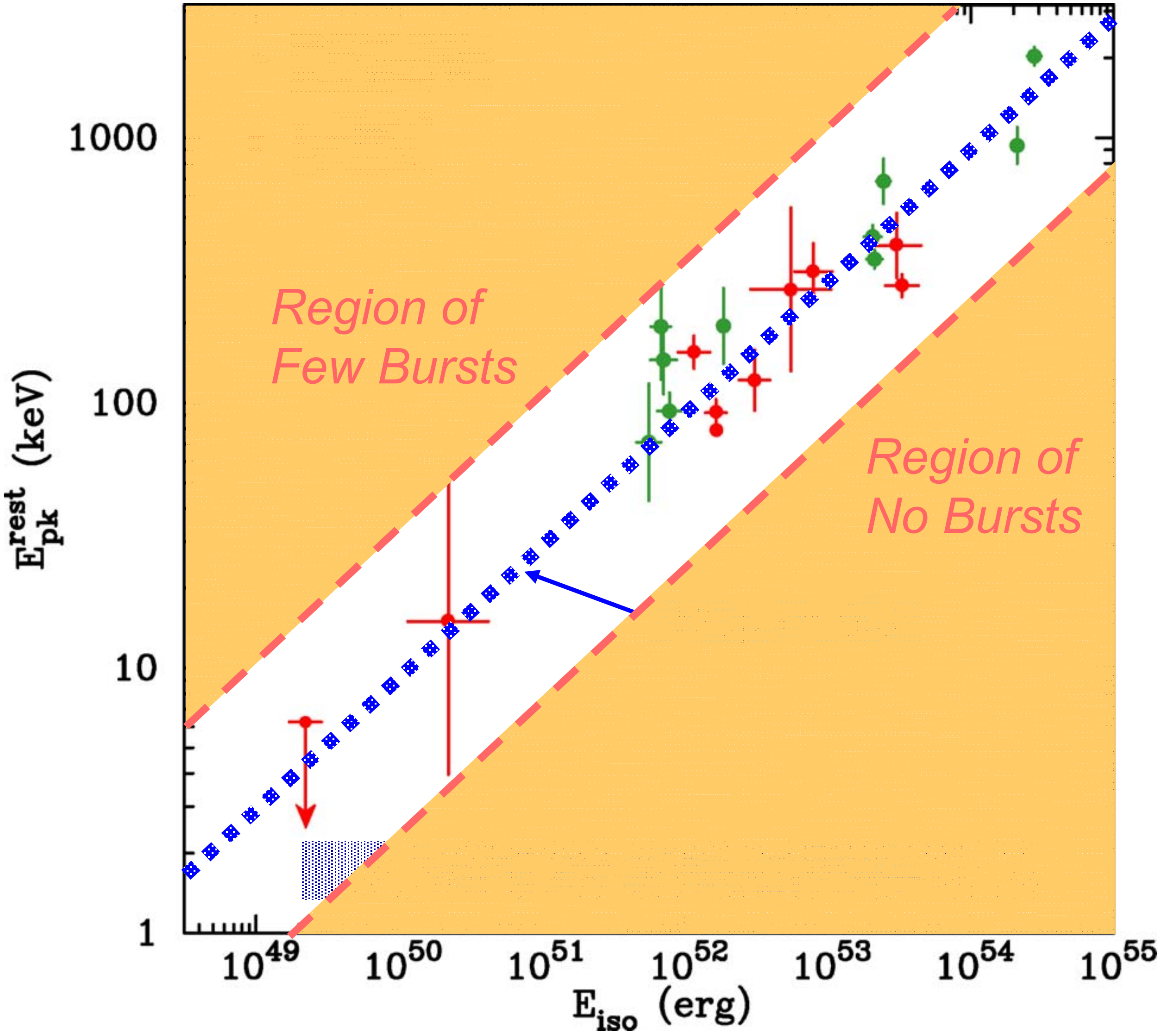
XRF Spectrum
Peaks in X-Rays

Density of HETE-2 Bursts in (S, E_{peak})-Plane



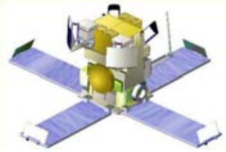
Sakamoto et al. (2005)

Dependence of Burst Spectral Peak Energy (E_{peak}) on Isotropic-Equivalent Energy (E_{iso})



HETE-2 results confirm & extend the *Amati et al. (2002)* relation:

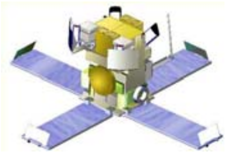
$$E_{peak} \sim \{E_{iso}\}^{0.5}$$



Implications of HETE-2 Observations of XRFs and X-Ray-Rich GRBs

HETE-2 results, when combined with earlier *Beppo*Sax and optical follow-up results:

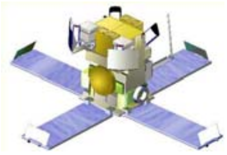
- Provide strong evidence that properties of XRFs, X-ray-rich GRBs (“XRRs”), and GRBs form a continuum
- Suggest that these three kinds of bursts are closely related phenomena
- Key result: ***approximately equal numbers of bursts per logrithmic interval*** in most observed properties (S_E, E^{obs}_{peak}, E_{iso},E_{peak}, etc.)



Scientific Importance of XRFs

As *most extreme* burst population, XRFs provide severe constraints on burst models and unique insights into

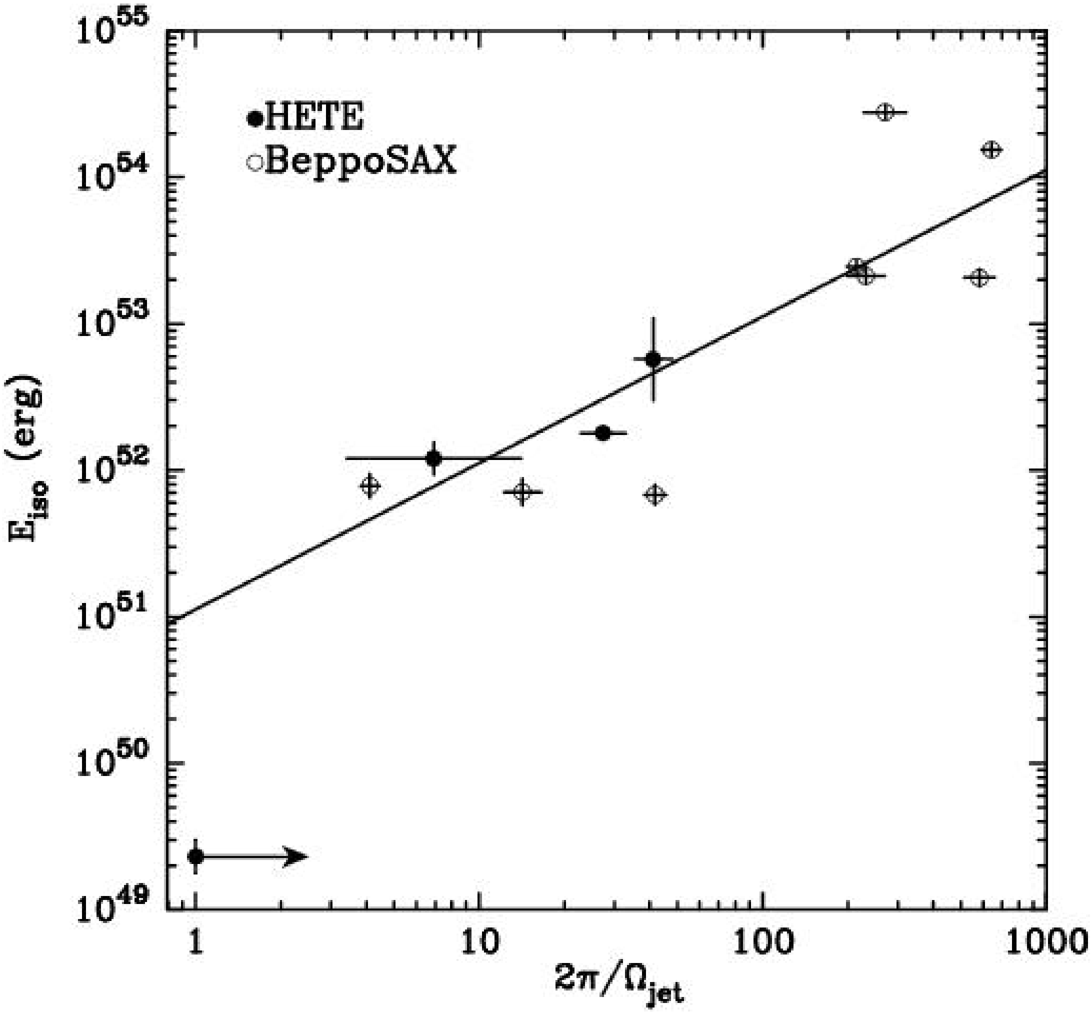
- **Structure of GRB jets**
- GRB rate
- Nature of Type Ic supernovae



Physical Models of XRFs

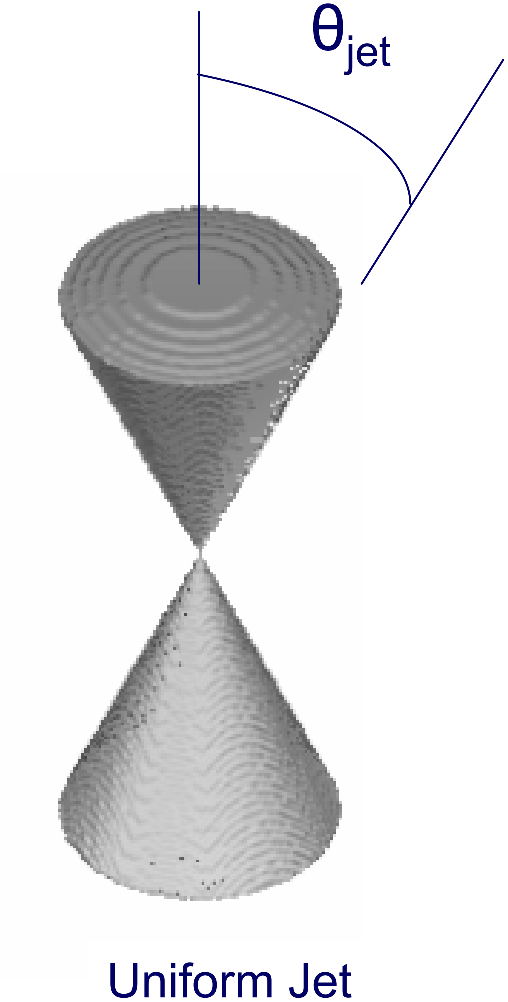
- X-ray photons may be produced by the hot cocoon surrounding the GRB jet as it breaks out and could produce XRF-like events if viewed well off axis of jet (*Meszaros et al. 2002, Woosley et al. 2003*).
- "Dirty fireball" model of XRFs posits that baryonic material is entrained in the GRB jet, resulting in a bulk Lorentz factor $\Gamma \ll 300$ (*Dermer et al. 1999, Huang et al. 2002, Dermer and Mitman 2003*).
- At the opposite extreme, GRB jets in which the bulk Lorentz factor $\Gamma \gg 300$ and the contrast between the bulk Lorentz factors of the colliding relativistic shells are small can also produce XRF-like events (*Mochkovitch et al. 2003*).
- A highly collimated GRB jet viewed well off the axis of the jet will have low values of E_{iso} and E_{peak} because of the effects of relativistic beaming (*Yamazaki et al. 2002, 2003, 2004*).

Observed E_{iso} Versus Ω_{jet}



Lamb, Donaghy, and Graziani (2005)

Relation Between E_{iso} and E^{inf}_{γ}



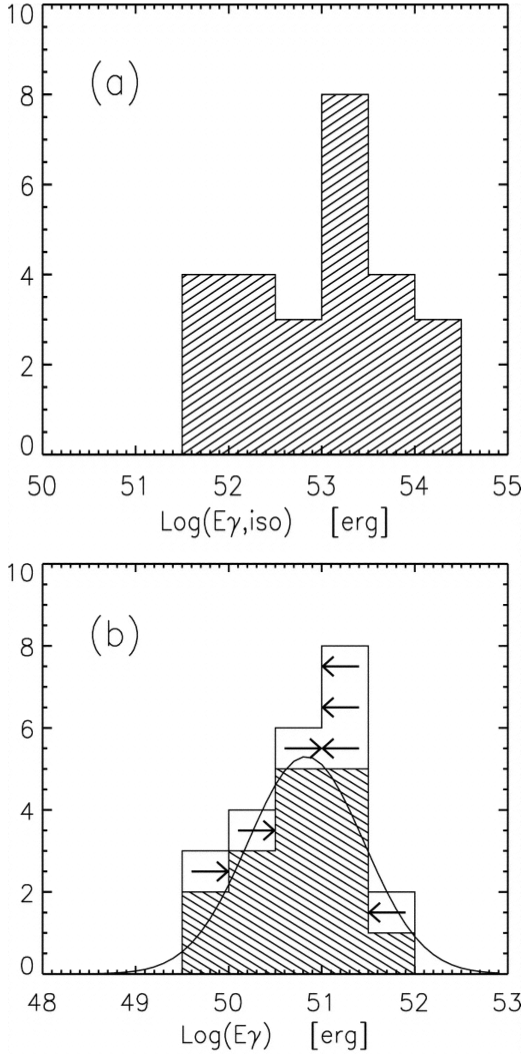
Uniform Jet

$$E^{inf}_{\gamma} = (1-\cos\theta_{jet})\,E_{iso}$$
$$= \Omega_{jet}\,E_{iso}$$

E_{iso} = isotropic-equivalent radiated energy

E^{inf}_{γ} = inferred radiated energy

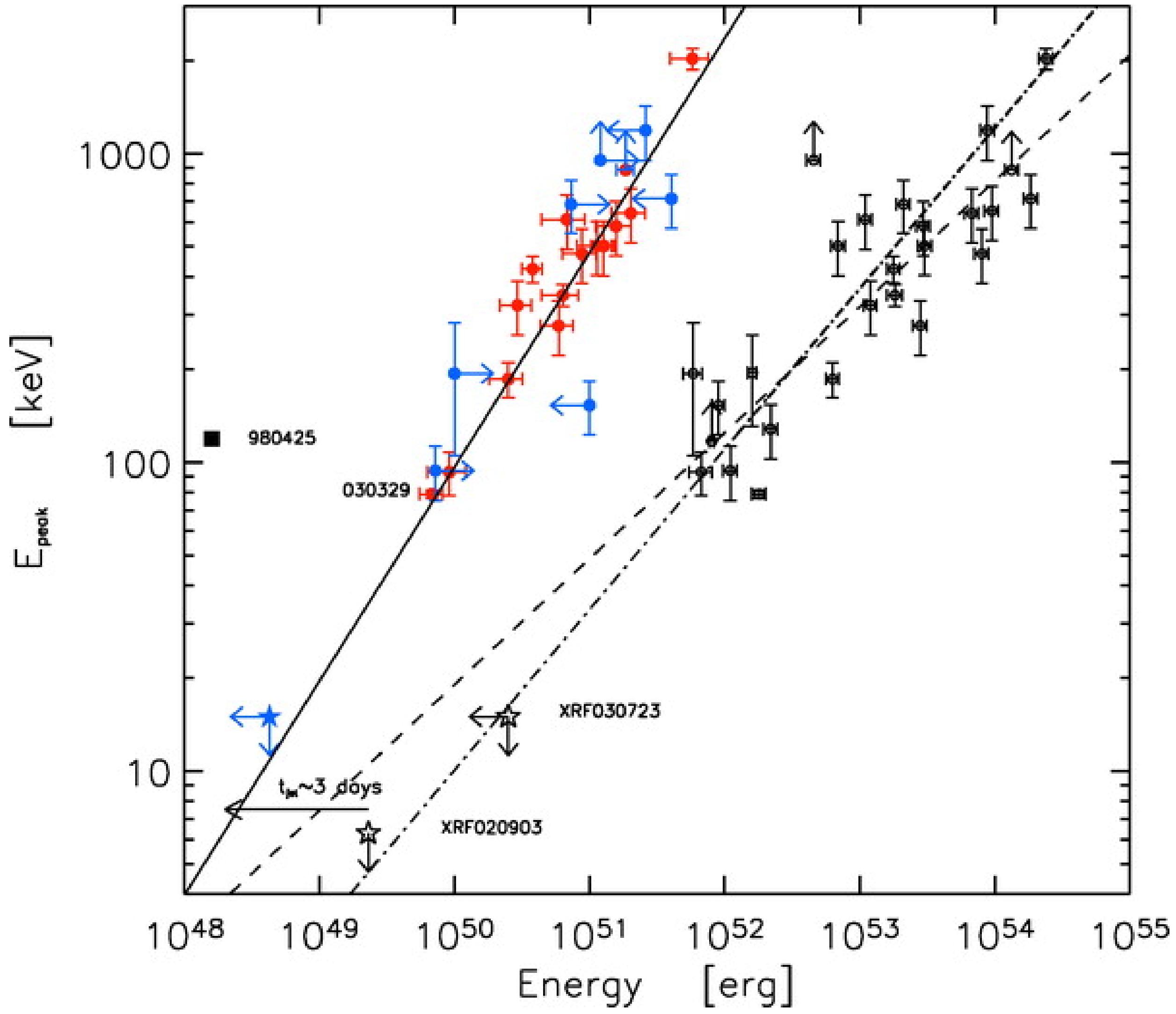
Distributions of E_{iso} and E_{γ}



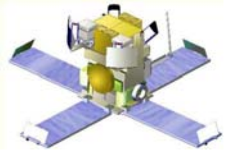
- E_{iso} distribution is broad
- E^{inf}_{γ} distribution is considerably narrower

Ghirlanda, Ghisselini, and Lazzati (2004);
see also Frail et al. (2001), Bloom et al. (2003)

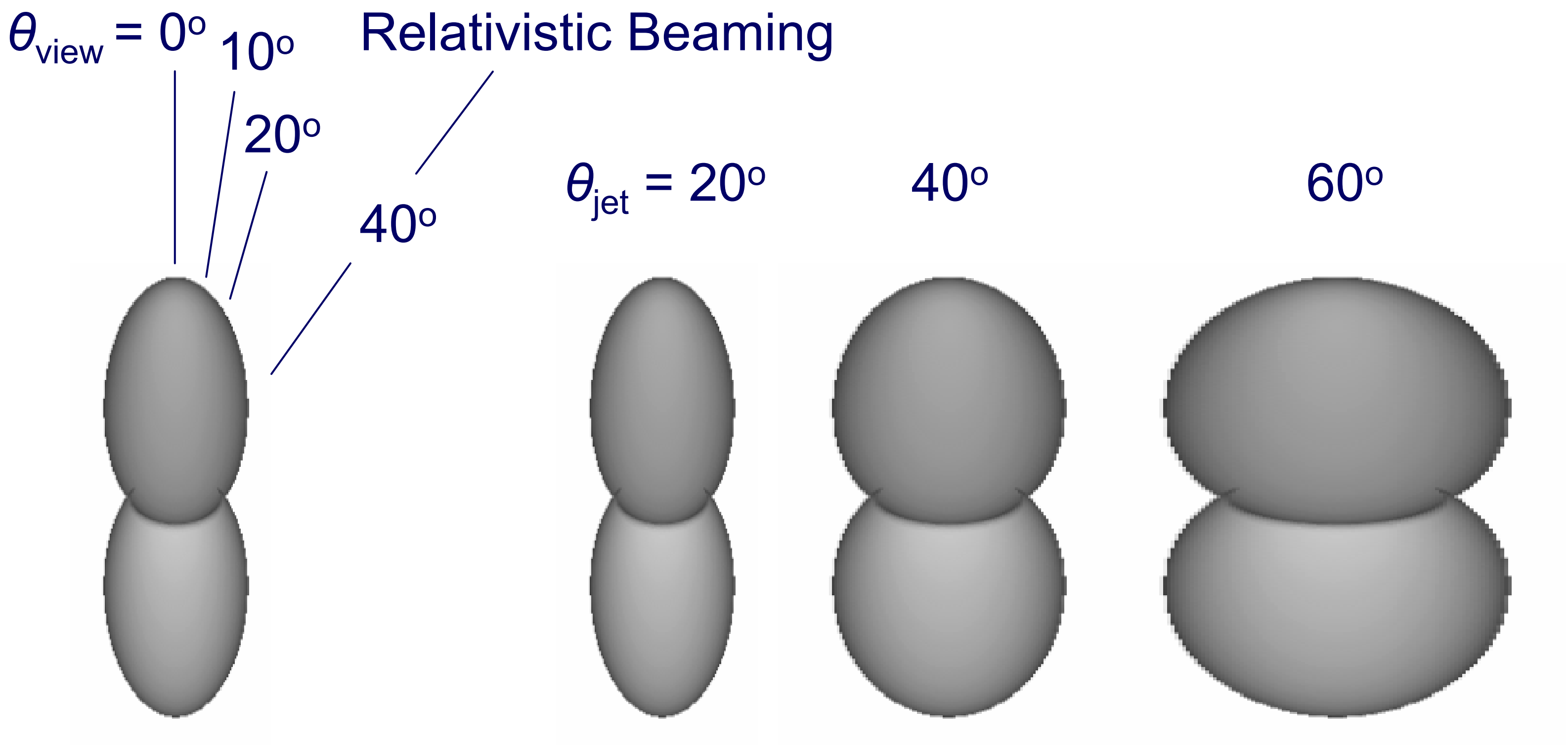
Dependence of E_{peak} on E_{iso} and E^{inf}_{γ}



Ghirlanda, Ghisselini, and Lazzati (2004)



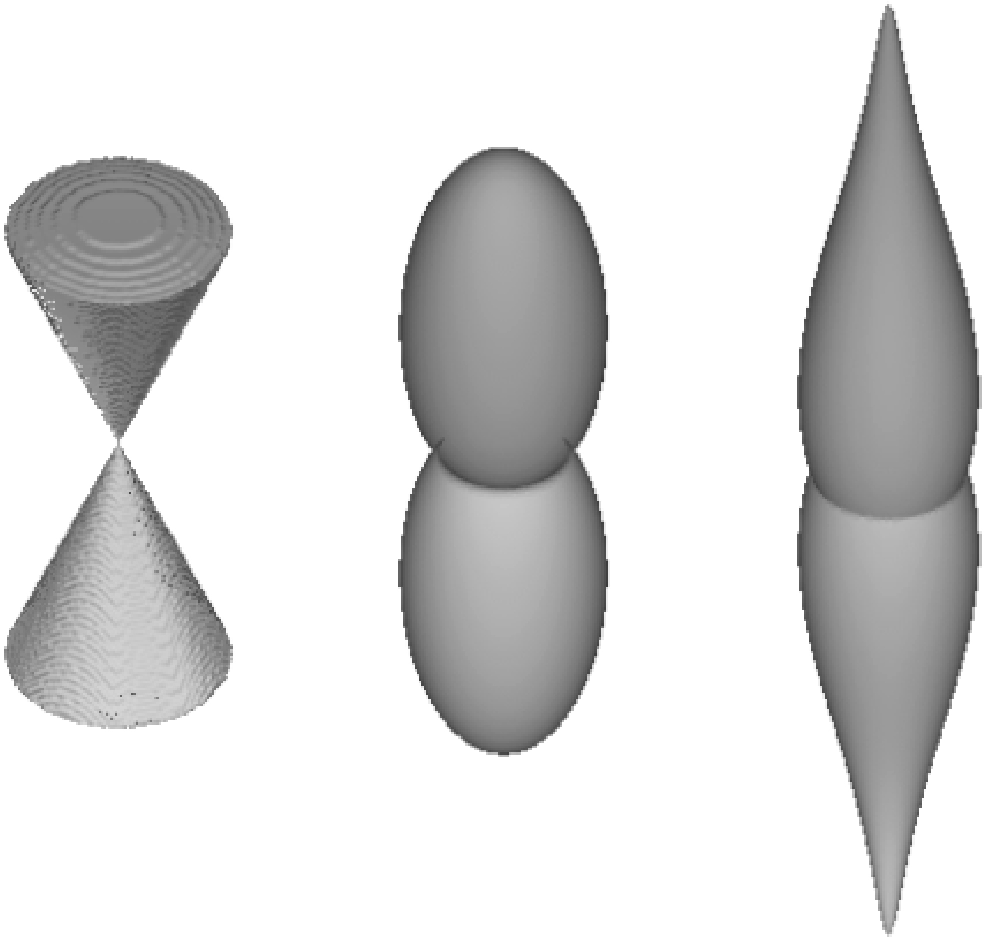
Universal vs Variable Opening Angle Jets



Universal Jet:
Differences due to *different viewing angles θ_{view}*

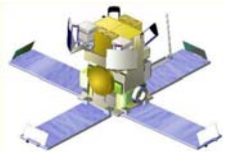
Variable Opening Angle (VOA) Jet:
Differences due to *different jet opening angles θ_{jet}*

Jet Profiles



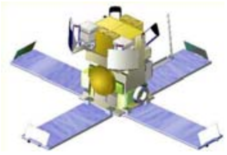
Uniform Jet Gaussian/Fisher Jet Power-Law Jet

Rossi, Lazzati, Salmonson, and Ghisellini (2004)



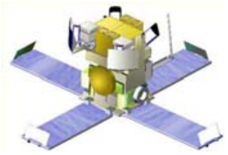
Phenomenological Burst Jets

Jet Profile	Jet Opening Angle
Uniform	Variable
Gaussian/Fisher	Variable
Power-Law	Universal
Uniform	Universal
Gaussian/Fisher	Universal
Uniform	Variable + Relativistic Beaming
Gaussian/Fisher	Variable + Relativistic Beaming
Power-Law	Universal + Relativistic Beaming
Uniform	Universal + Relativistic Beaming
Gaussian/Fisher	Universal + Relativistic Beaming



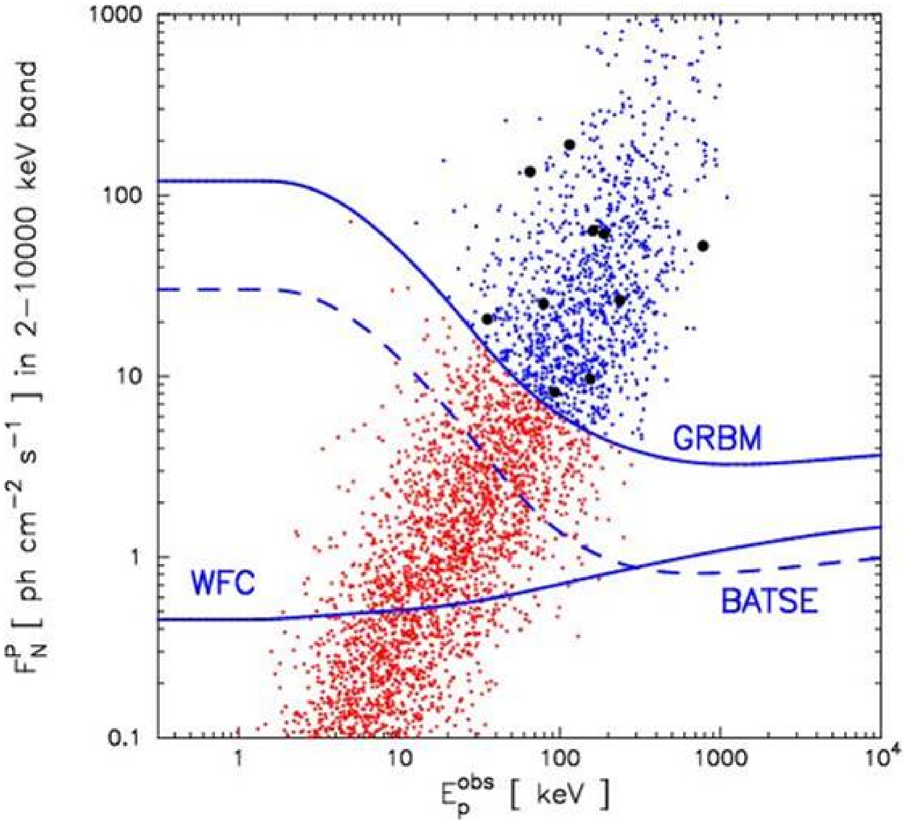
Graziani's Universal Jet Theorem

- Universal jet model that produces *narrow distribution* in one physical quantity (e.g., $E^{\mathrm{inf}}_{\gamma}$) produces *narrow distributions* in all other physical quantities (e.g., E_{peak}, E_{iso}, etc.)
- And *vice versa*: Universal jet model that produces *broad distribution* in one physical quantity (e.g., E_{iso}) produces *broad distributions* in all other physical quantities (e.g., E_{peak}, $E^{\mathrm{inf}}_{\gamma}$, etc.)
- But this is not what we observe – what we observe is are *broad distributions* in E_{peak} and E_{iso}, but a relatively *narrow distribution* in $\mathrm{E}^{\mathrm{inf}}_{\gamma}$
- Variable opening angle (VOA) jets can do this because they have an additional degree of freedom: the distribution of jet opening angles θ_{jet}

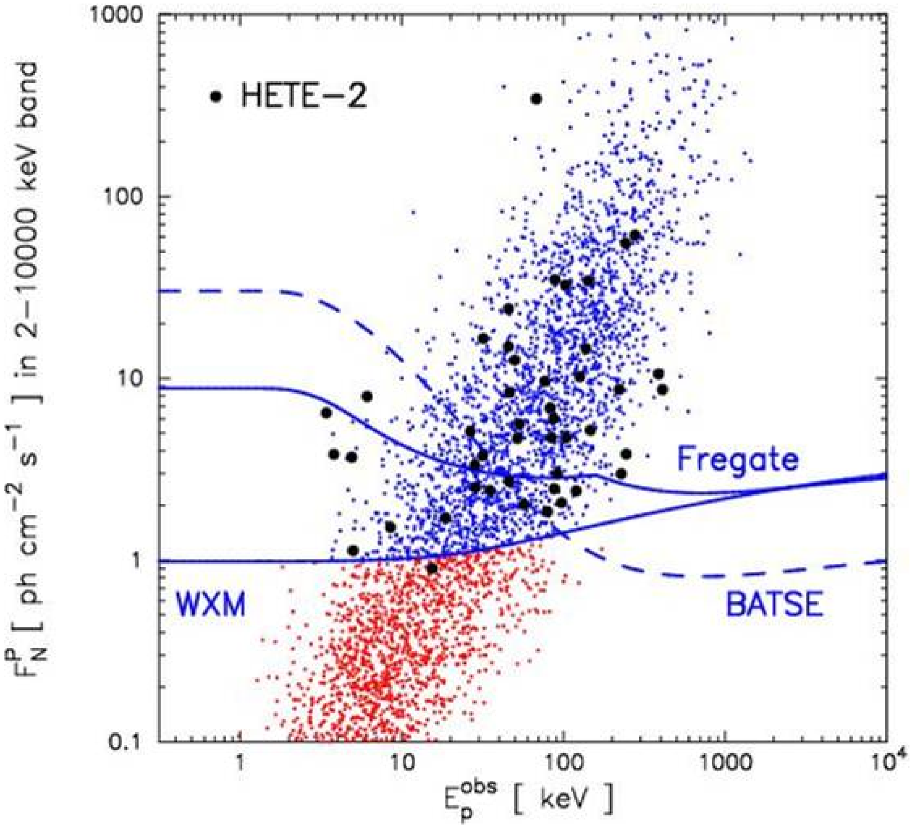


Determining If Bursts are Detected

DQL, Donaghy, and Graziani (2004)



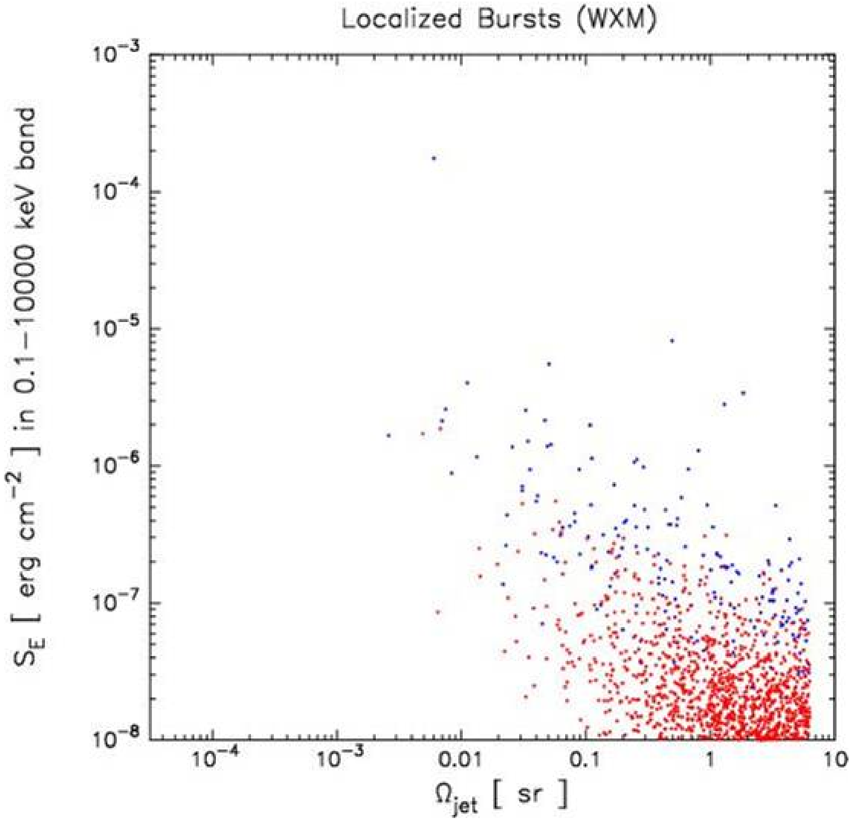
*Beppo*SAX bursts



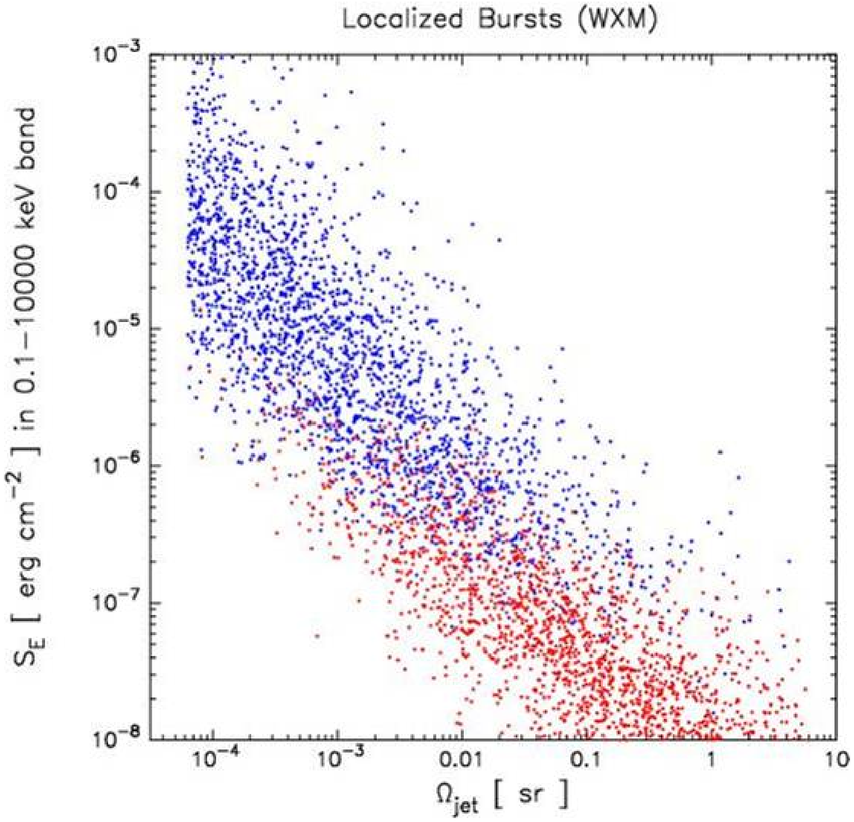
HETE-2 bursts

Uniform Variable Opening-Angle Jet vs. Power-Law Universal Jet

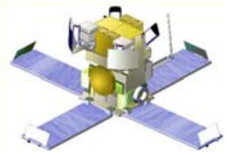
DQL, Donaghy, and Graziani (2005)



Power-law universal jet



Uniform variable opening-angle (VOA) jet



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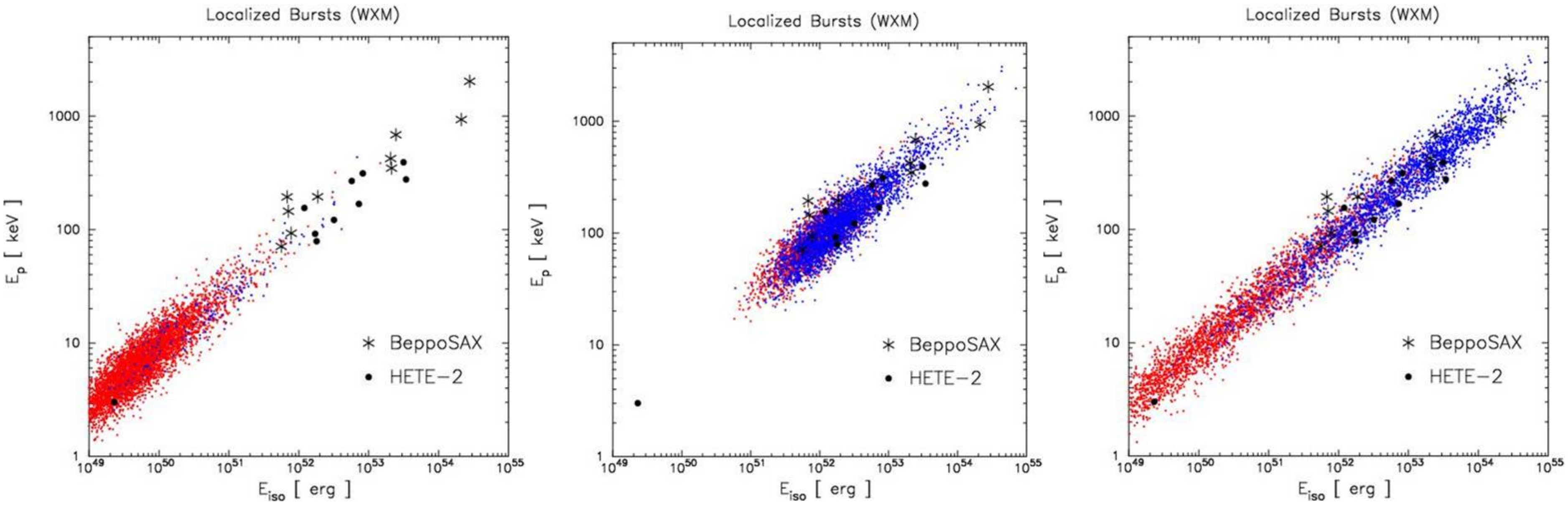
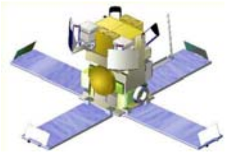
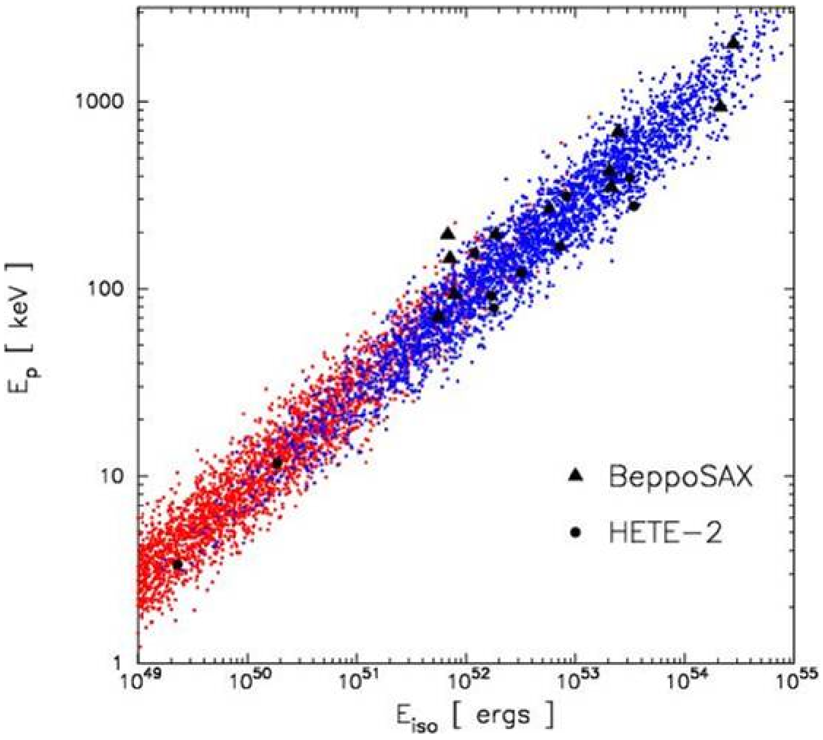


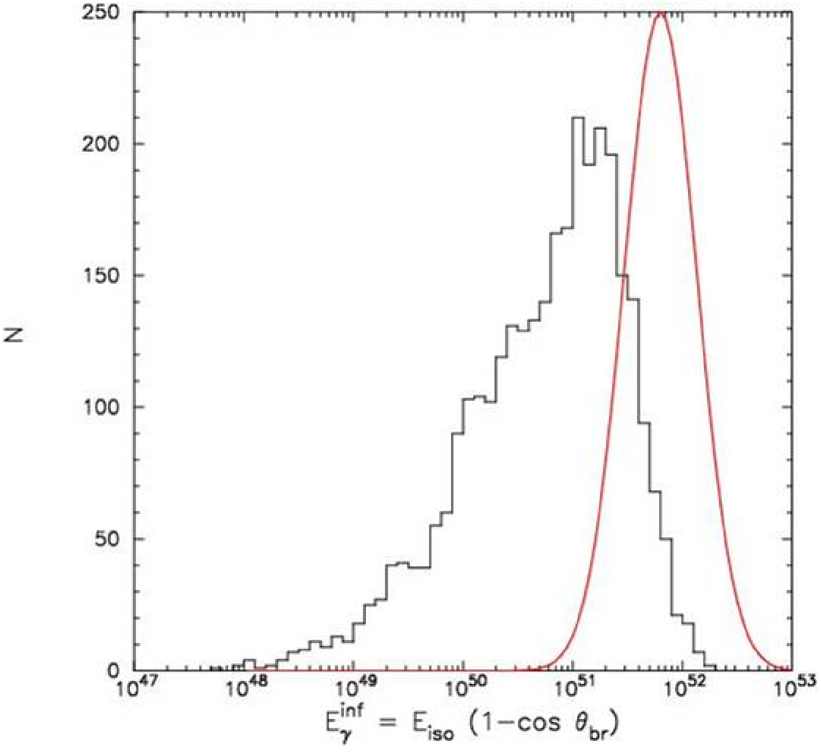
- VOA uniform jet can account for *both* XRFs and GRBs
- Universal power-law jet can account for GRBs, but not *both* XRFs and GRBs – because distributions in $E_{\rm iso}$ and $E^{\rm obs}_{\rm peak}$ are too narrow



Gaussian/Fisher Universal Jet

DQL, Donaghy, and Graziani (2005)





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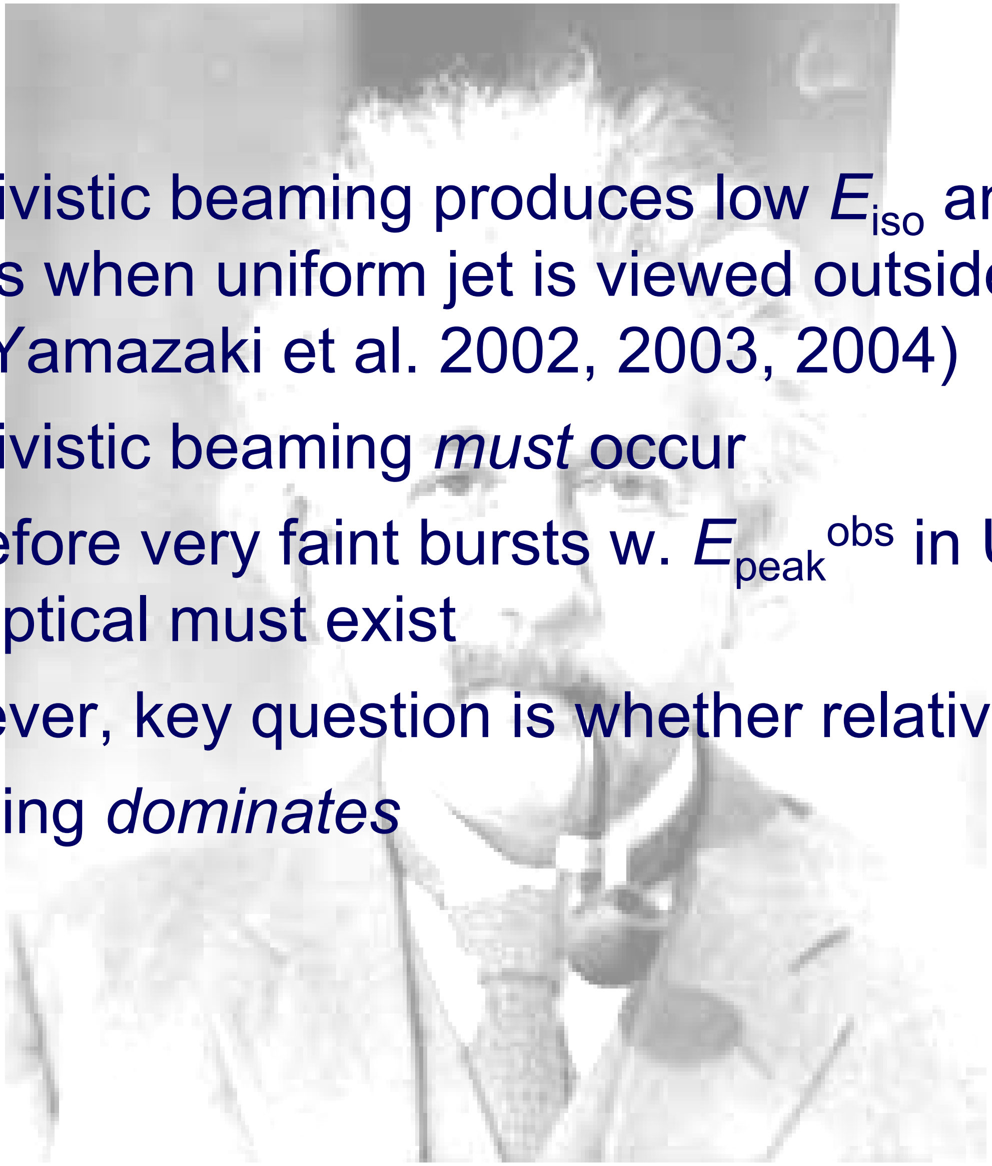
Gaussian/Fisher	Variable
Power-Law	U l
Uniform	sal
Gaussian/Fisher	Universal
Uniform	Variable + Relativistic Beaming
Gaussian/Fisher	Variable + Relativistic Beaming
Power-Law	Universal + Relativistic Beaming
Uniform	Universal + Relativistic Beaming
Gaussian/Fisher	Universal + Relativistic Beaming

Favored

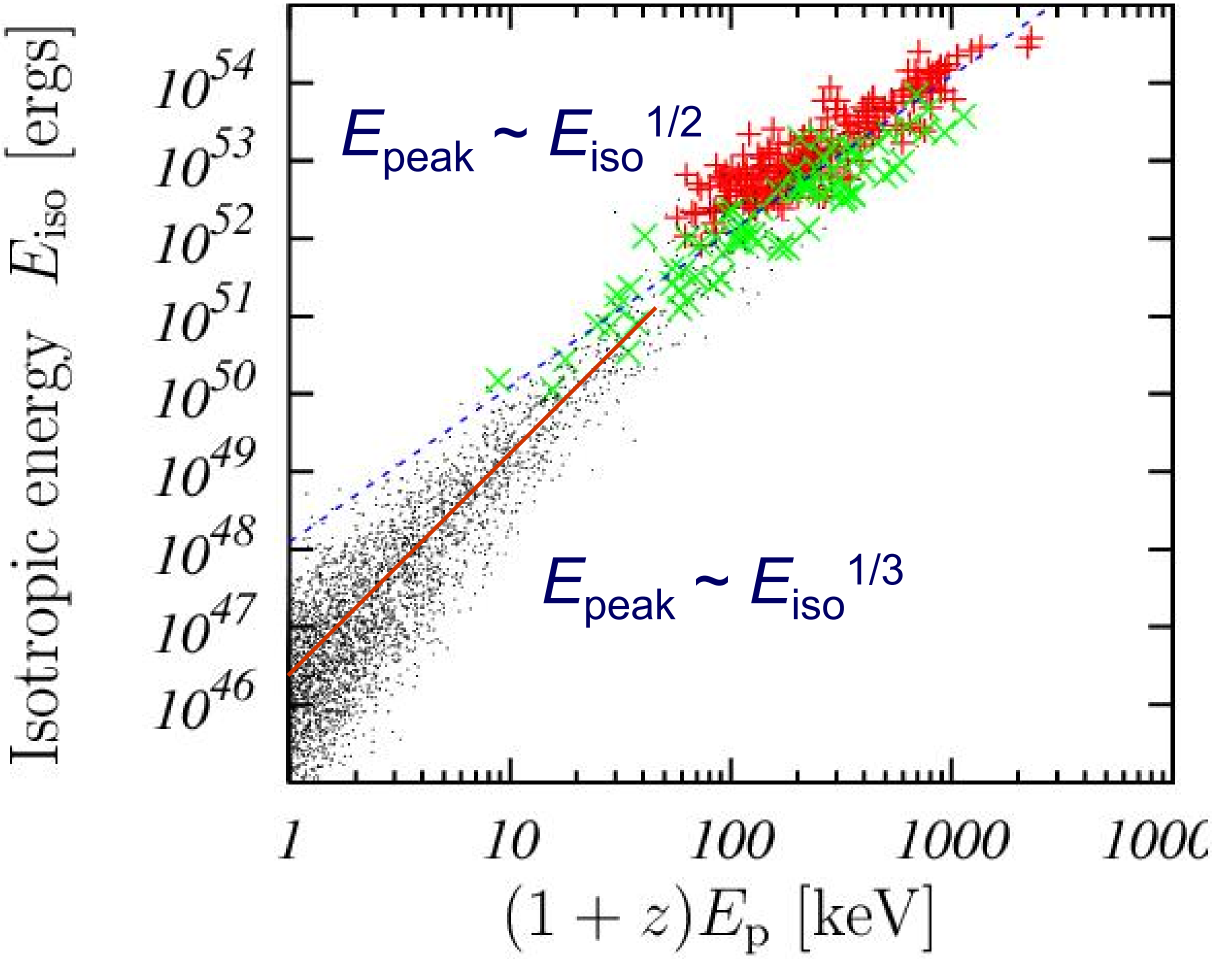
Disfavored

Special Relativistic Beaming



- Relativistic beaming produces low E_{iso} and E_{peak} values when uniform jet is viewed outside θ_{jet} (see Yamazaki et al. 2002, 2003, 2004)
- Relativistic beaming *must* occur
- Therefore very faint bursts w. $E_{\mathrm{peak}}^{\mathrm{obs}}$ in UV and optical must exist
- However, key question is whether relativistic beaming *dominates*

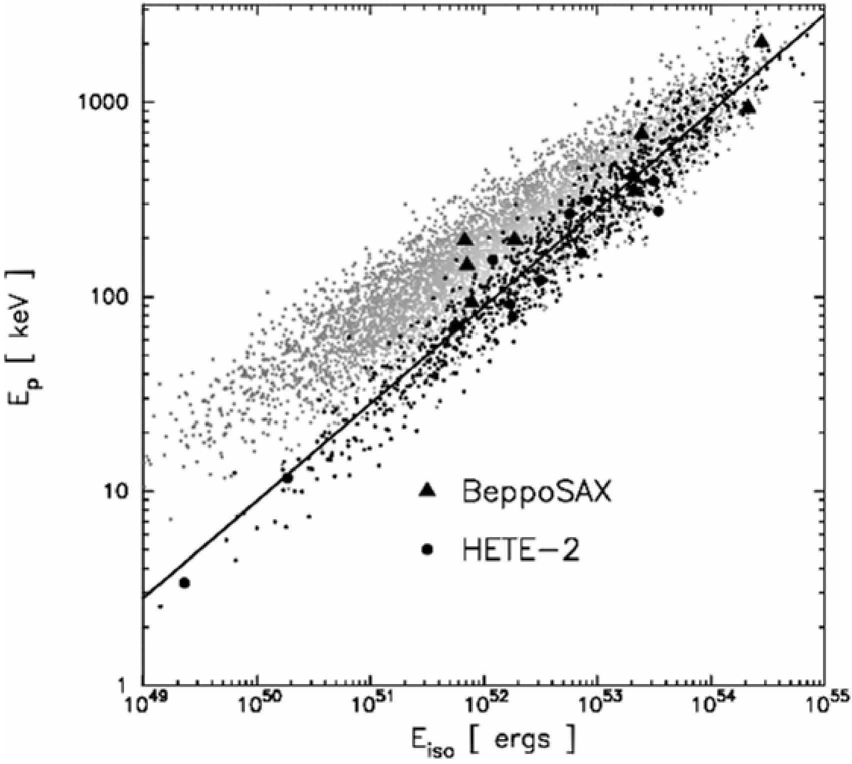
Uniform VOA Jet + Relativistic Beaming



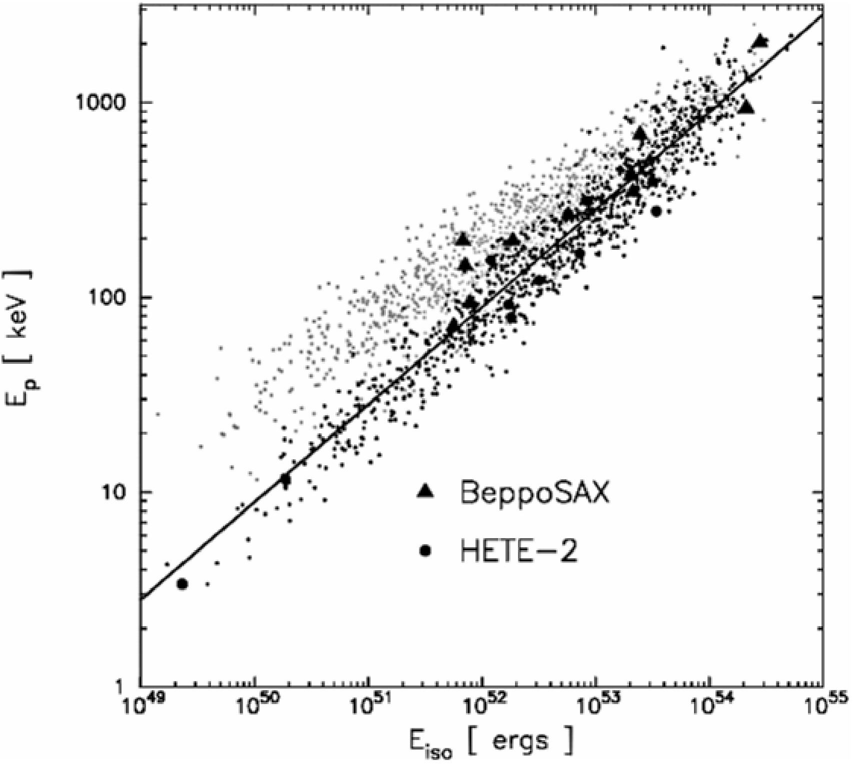
Yamazaki, Ioka, and Nakamura (2004)

Uniform VOA Jet
+ Relativistic Beaming

Donaghy (2005)

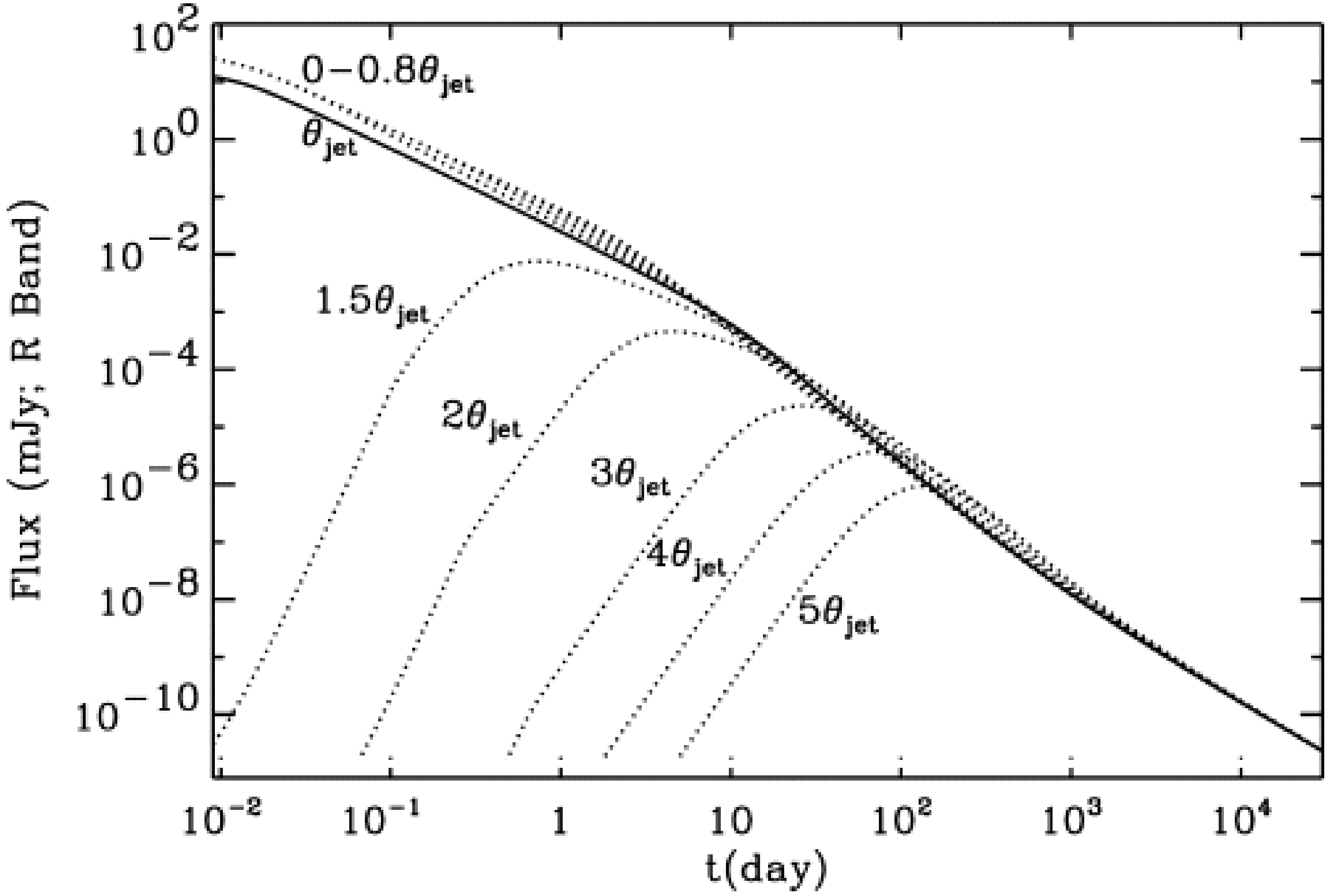


$\Gamma = 100$

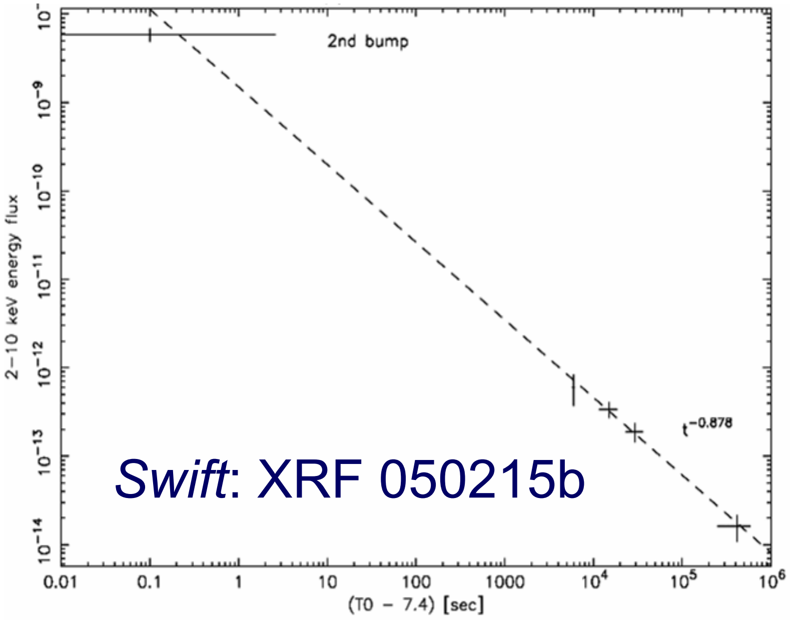


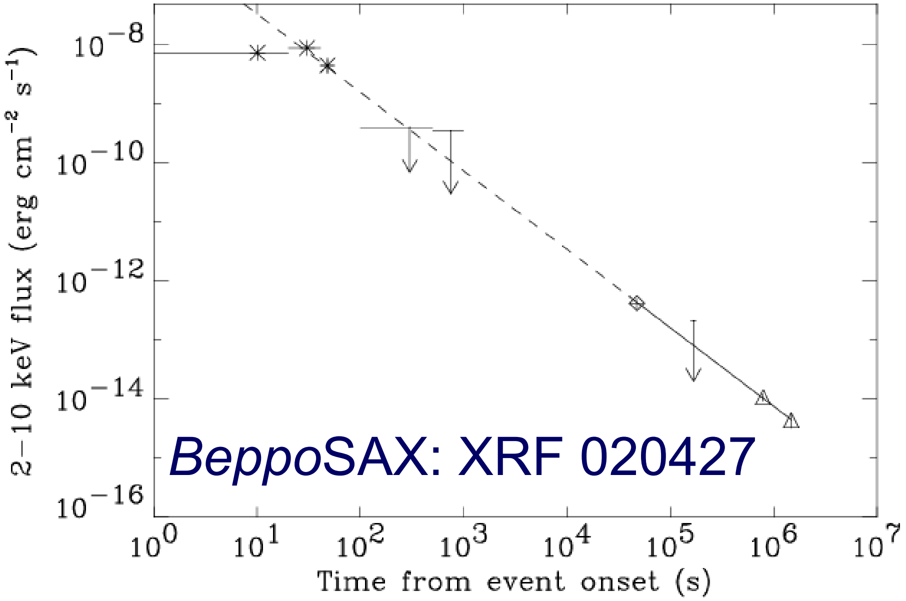
$\Gamma = 300$

Expected Behavior of Afterglow in Relativistic Beaming Model



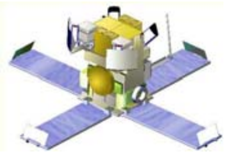
Observed Behavior of Afterglow





Swift/XRT observations of XRF 050215b show that the X-ray afterglow:

- Does *not* show increase followed by rapid decrease
- Rather, it *joins smoothly* onto end of burst
- It then fades *slowly*
- $S_{after}/S_{burst} \sim 1$
- Jet break time > 5^d (> 20^d) → $\theta_{jet} > 25^o$ (35^o) at $z = 0.5$



Phenomenological Burst Jets

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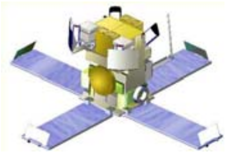
Uniform	riable
Gaussian/Fisher	Variable
Power-Law	U l
Uniform	sal
Gaussian/Fisher	Universal
Uniform	Variable + Relat istic Beaming
Gaussian/Fisher	Variabl tic Beaming
Power-Law	elativistic Beaming
Uniform	versal + Relativistic Beaming
Gaussian/Fishe	Universal + Relativistic Beaming

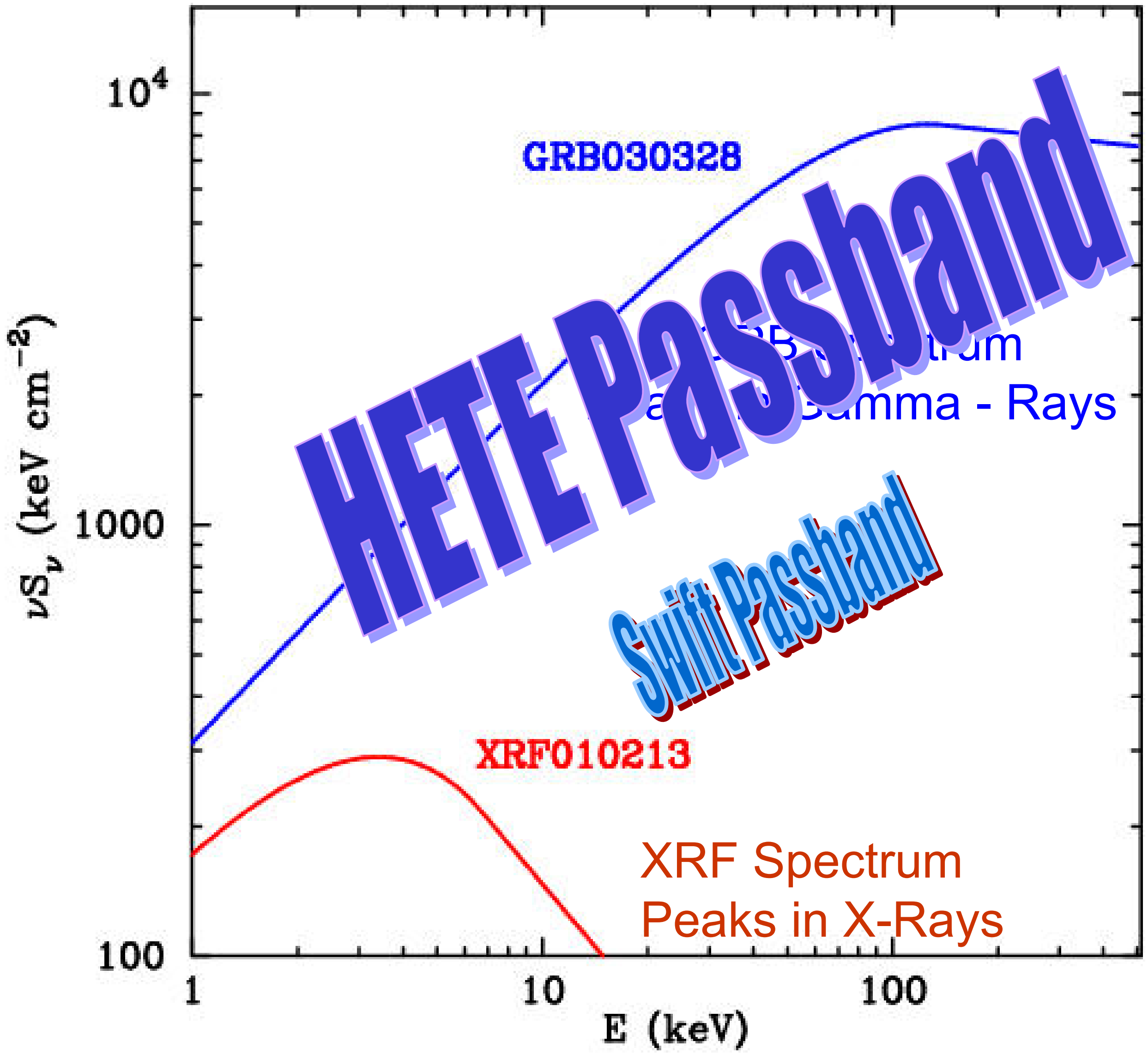
Favored

Disfavored

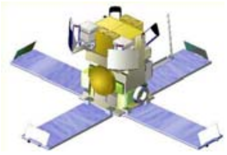
Strongly Disfavored



X-Ray Flashes vs. GRBs: HETE-2 and *Swift* (BAT)



Even with the BAT's huge effective area (~2600 cm^2), only HETE-2 can determine the spectral properties of the most XRFs.



Conclusions

- As *most extreme* burst population, XRFs provide unique information about structure of GRB jets
  - Variable opening angle jet models favored; universal jet models disfavored; relativistic beaming models strongly disfavored
  - Absence of relativistic beaming → $\Gamma > 300$
- Confirming these conclusions will require
  - prompt localization of many more XRFs
  - determination of E_{peak}
  - determination of t_{jet} from observations of X-ray afterglows
  - determination of redshifts z
- HETE-2 is ideally suited to do *the first two*, whereas *Swift* (with E_{min} ~ 15 keV and 15 keV < E < 150 keV) is not; *Swift* is ideally suited to do *the second two,* whereas HETE-2 cannot
- **Prompt *Swift* XRT and UVOT observations of HETE-2 XRFs can therefore greatly advance our understanding of XRFs – and therefore all bursts**