Jets in GRBs (and other relativistic explosions)

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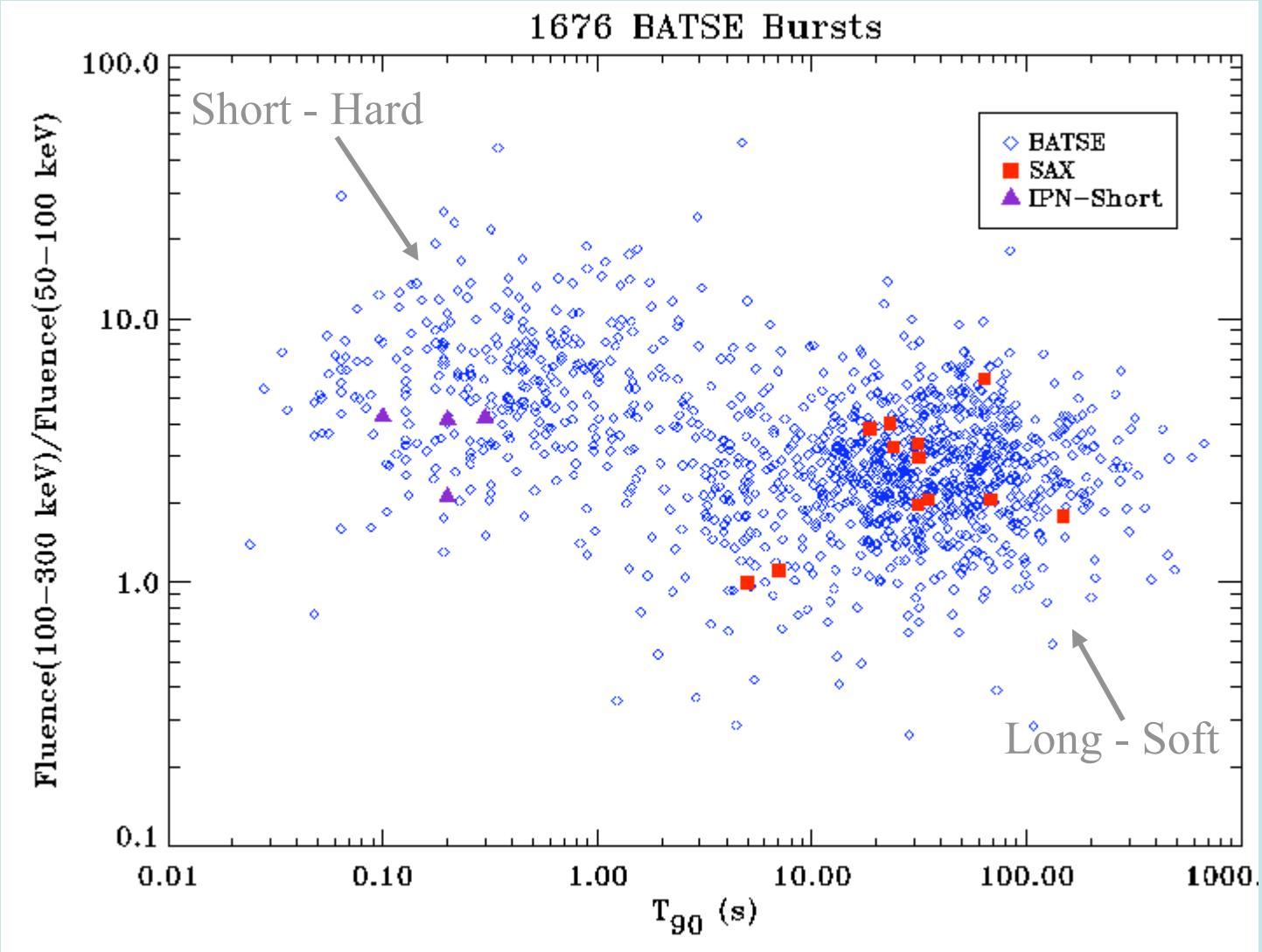
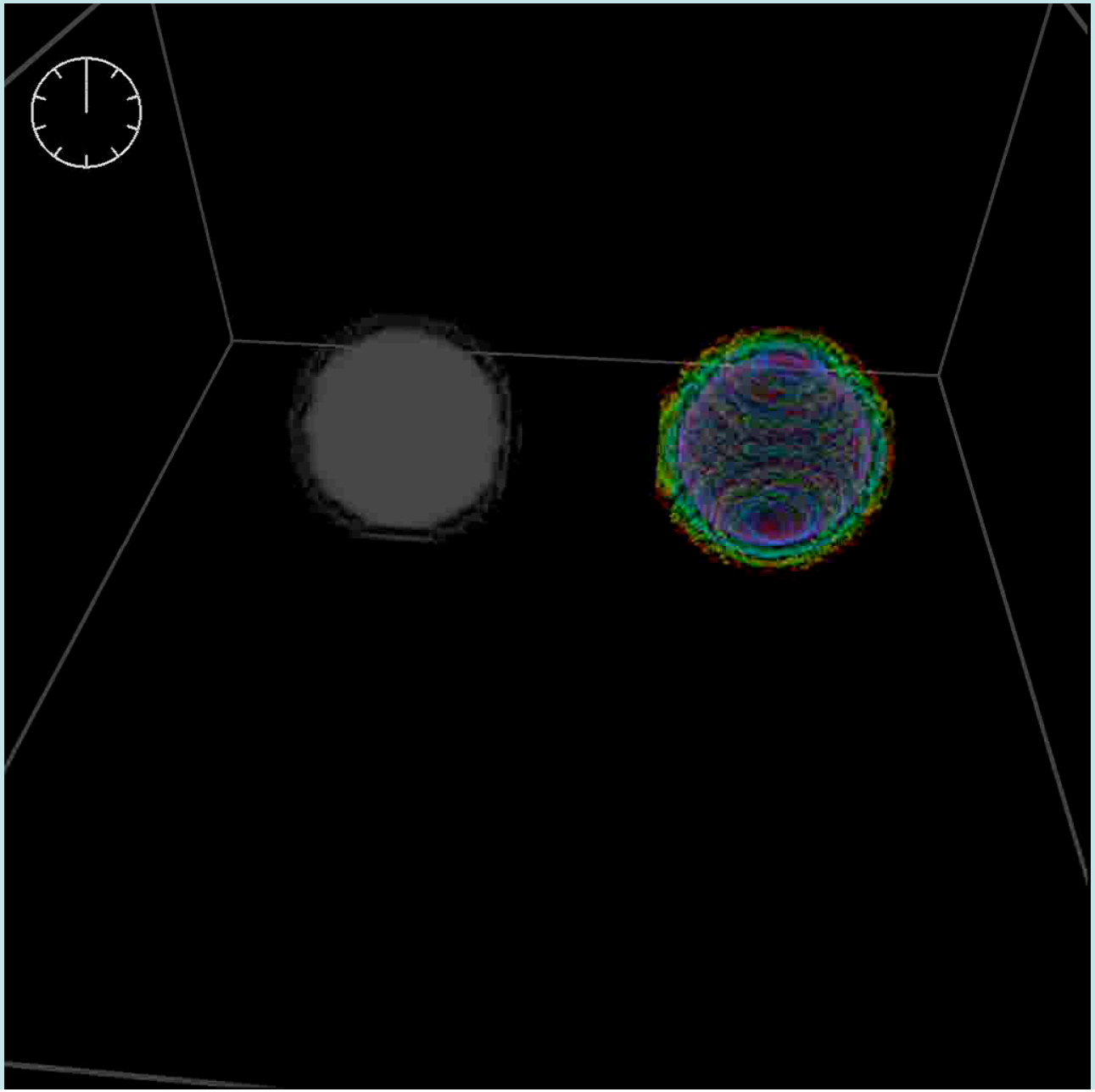
Two classes of GRBs



Black Hole-Neutron Star (Rupert, Janka)



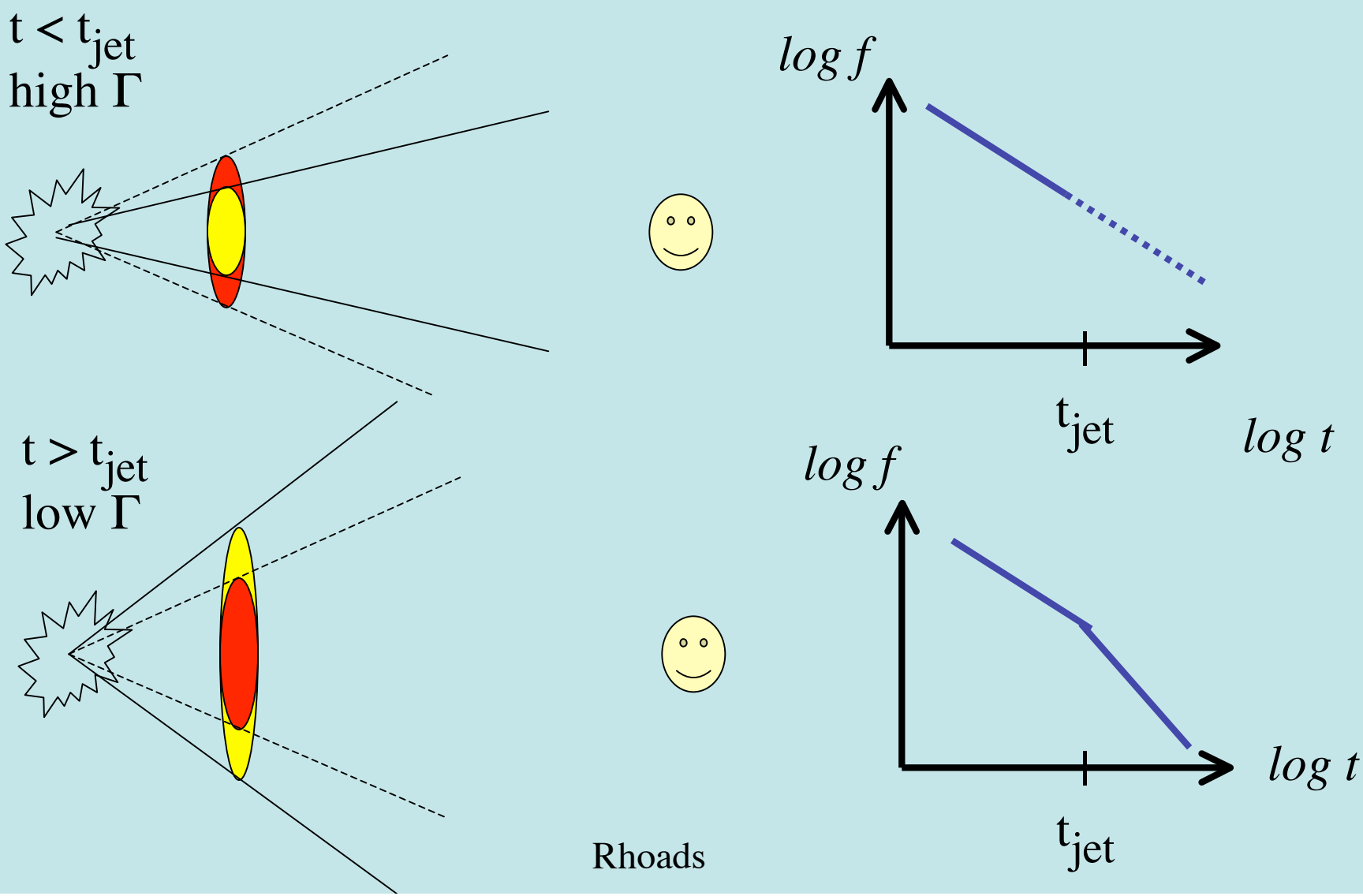
Why are jets interesting?

- Collimation ("jets") sets the true scale for the energetics:

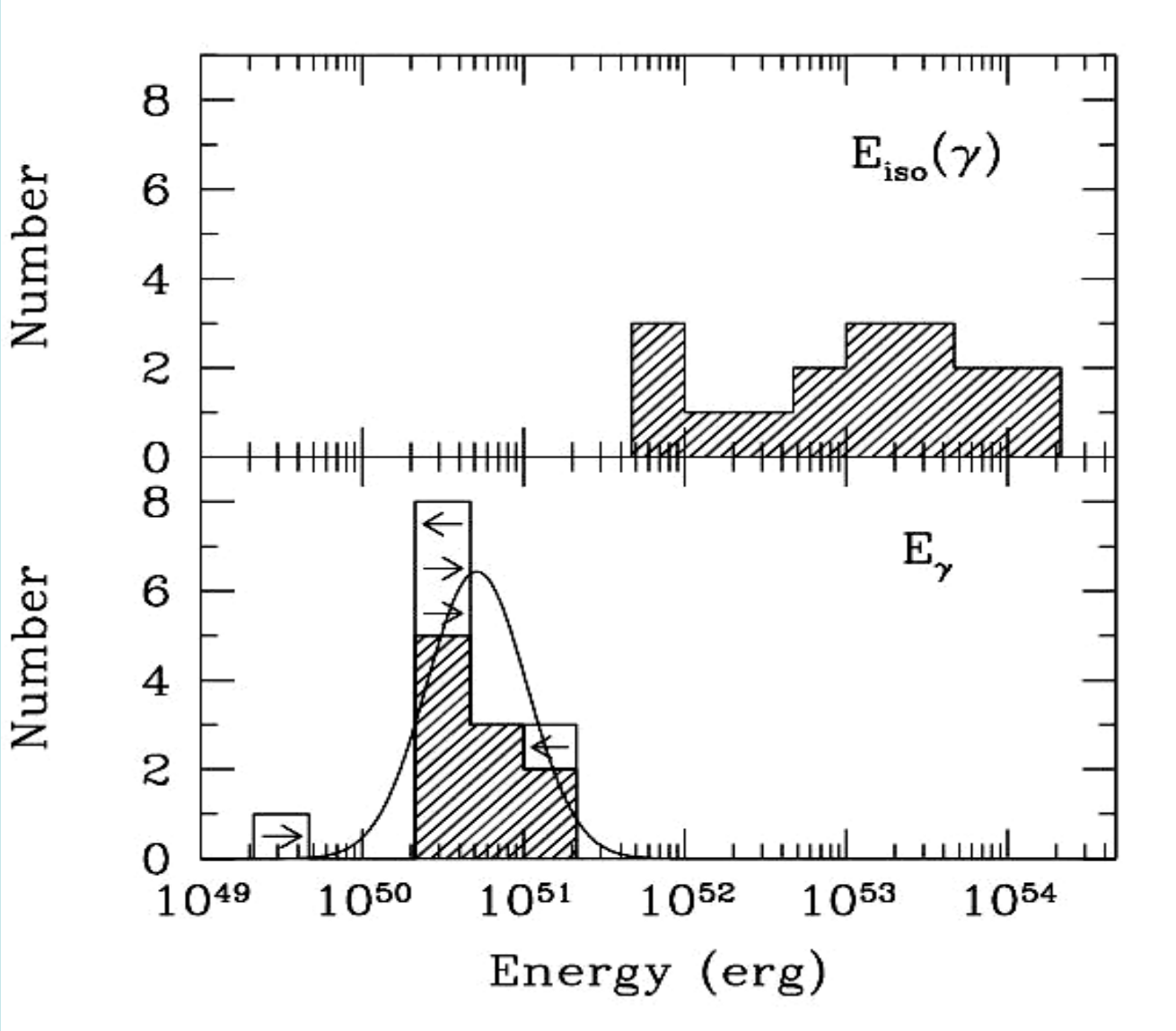
  True Energy = Isotropic Energy x f_B
- Collimation sets the true event rate

  True Event Rate = Obs Event Rate x f_B^{-1}
- Collimation angle is a key diagnostic of how energy is transported outwards
- Collimation angle may provide insight into the nature of the central engine

Light Curves provide Evidence for Collimation



GRB Energetics: Tiger becomes Lamb

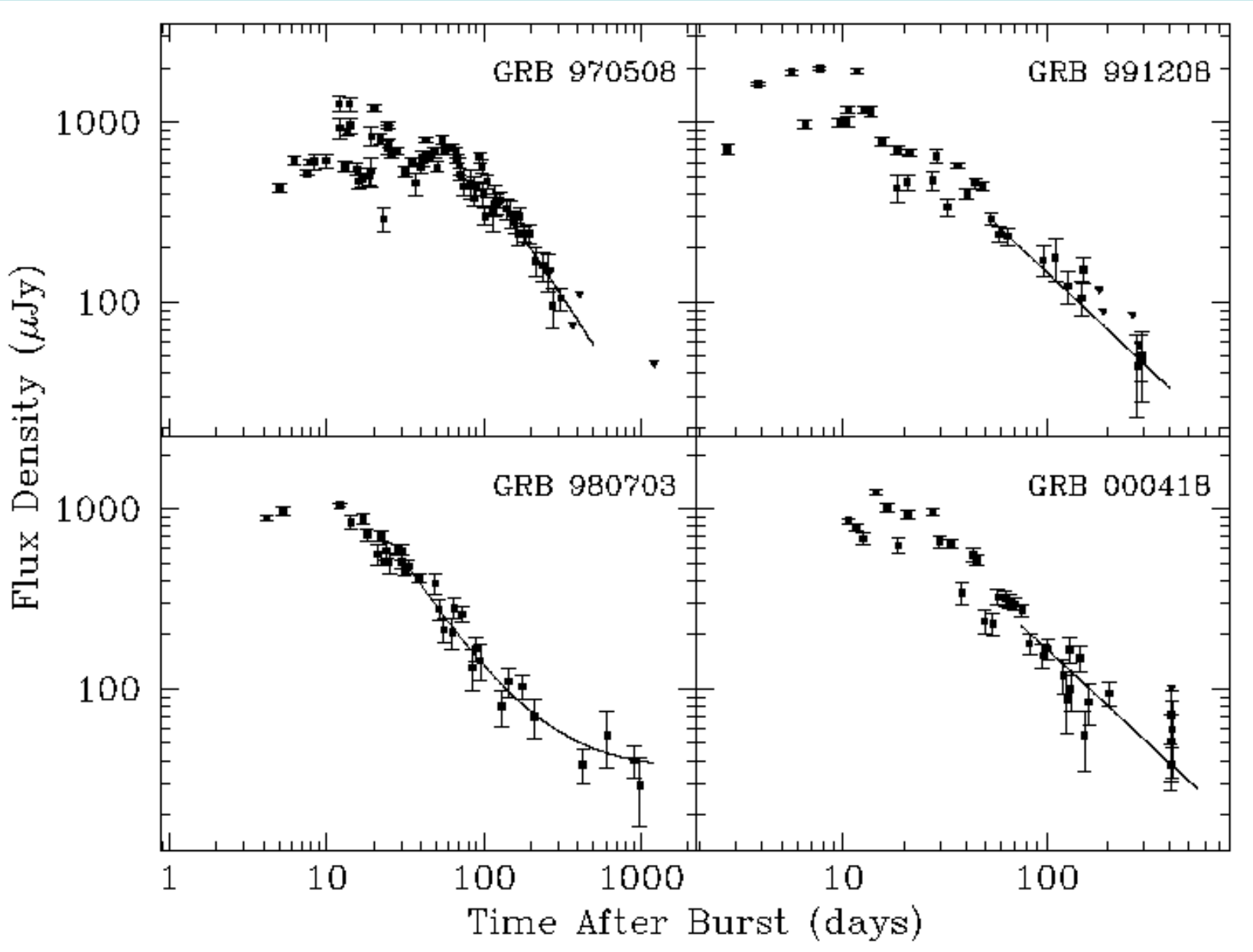


Before the beaming correction (isotropic)

After the beaming correction

(Frail et al.)

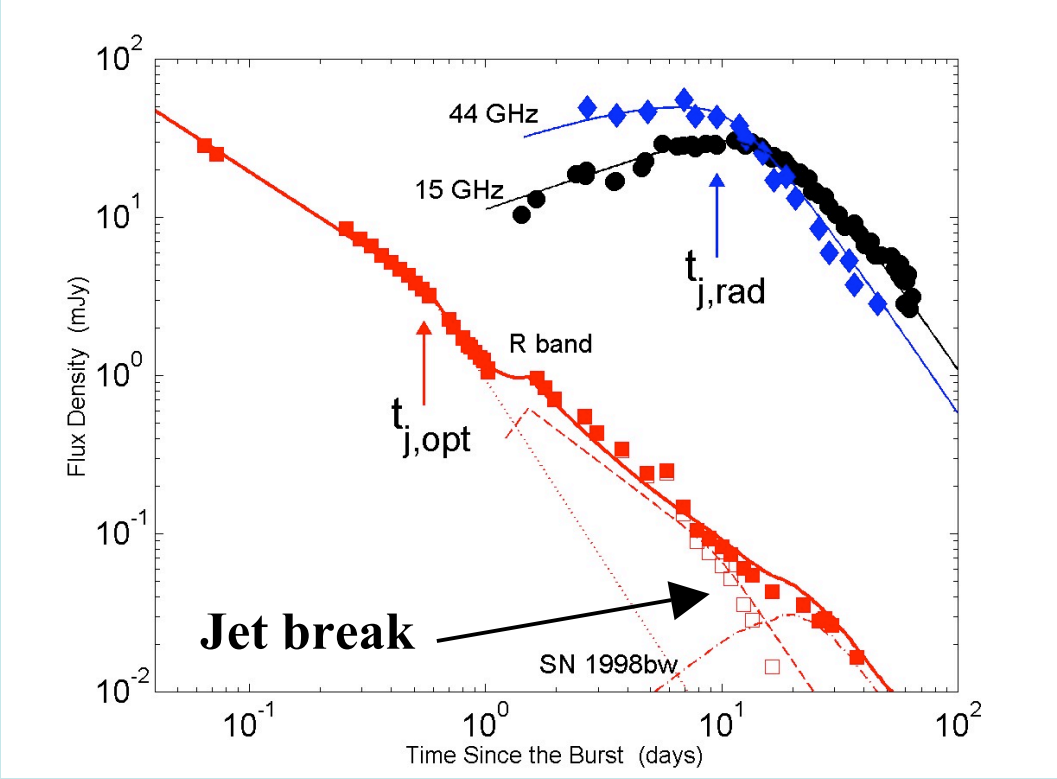
Radio Afterglows: Angular Size and Calorimetry



Z

Gray Cloud: The second nearest GRB 030329 is peculiar

Puzzle: A single fireball does not account for radio & X-ray emission



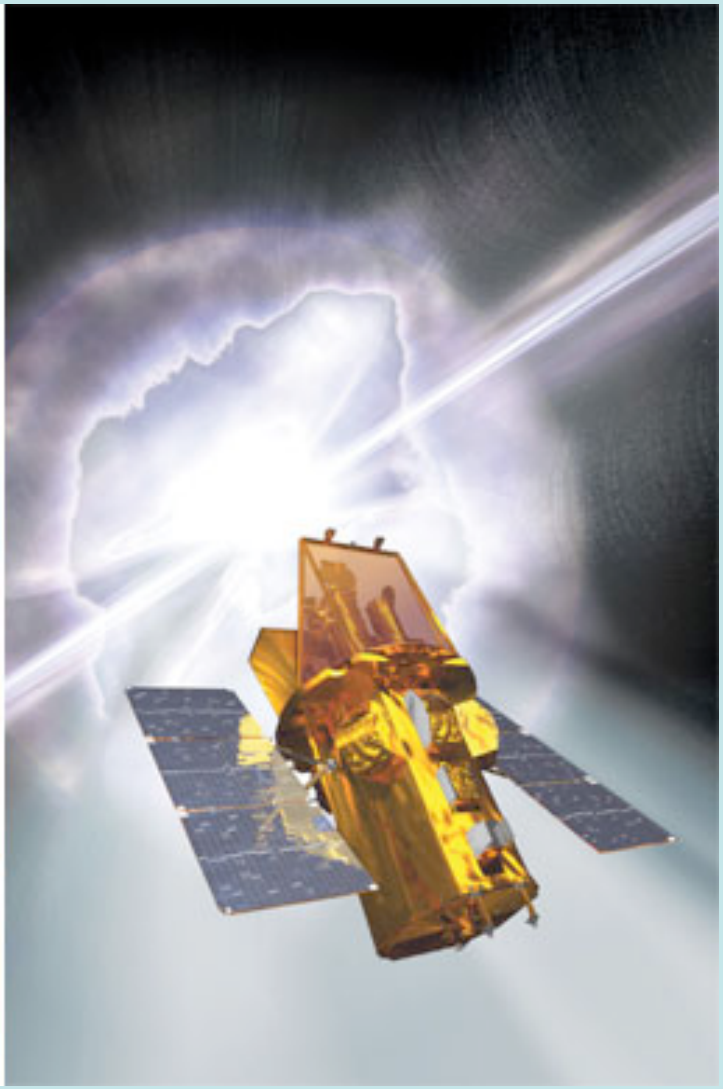
A possible solution:

(1) a narrow, ultra-relativistic jet with low energy which produces X-ray & optical

(2) a wide, mildly relativistic jet carrying the bulk of the energy and powering the radio

Berger et al. 2003

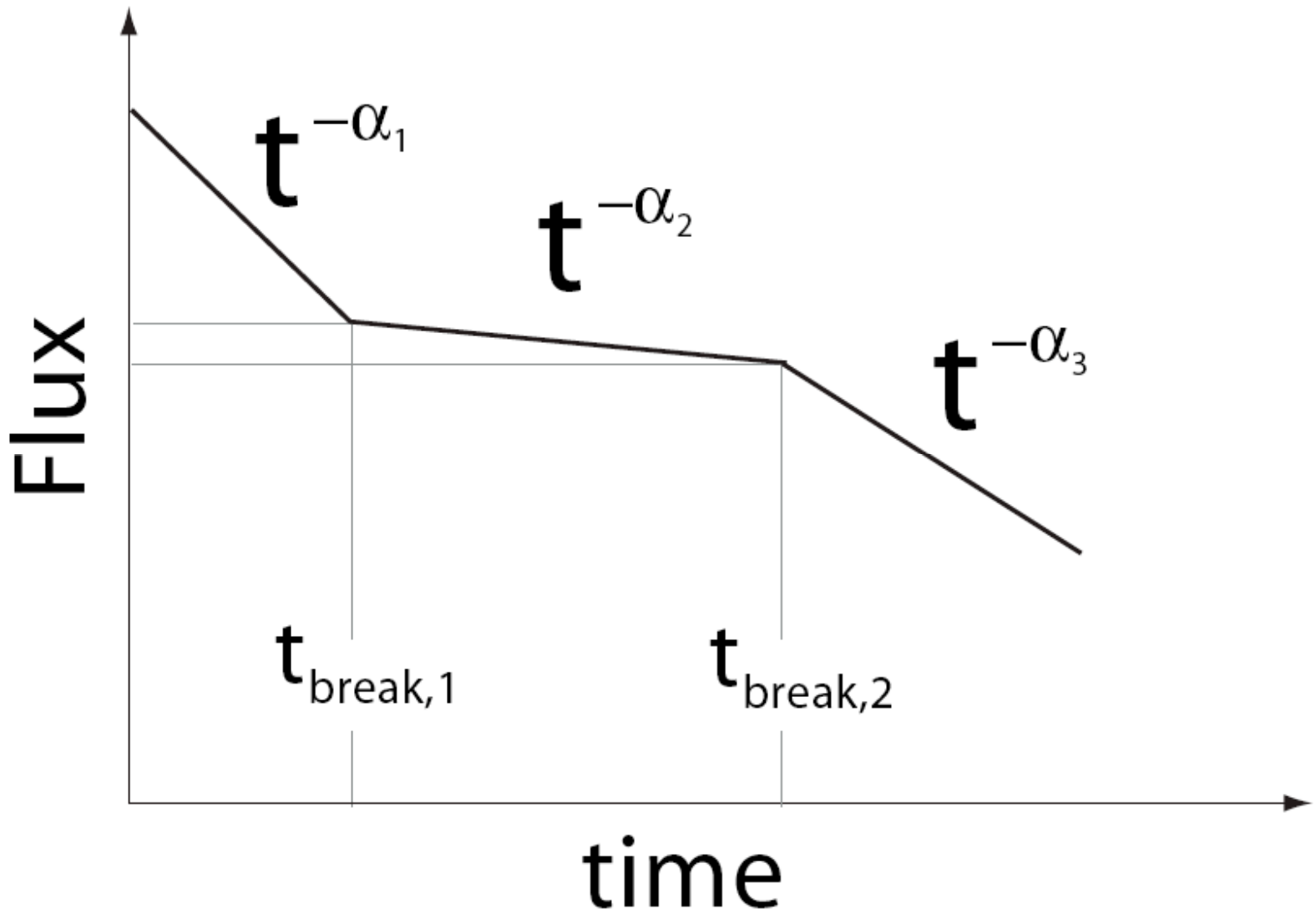
Launch of Swift



20 November 2004

Jets disappeared

Complicated X-ray Light Curves



Nousek et al

X-ray Flares

- Flares are seen in almost all GRBs.
- In some cases, flares appear to dominate the energetics
- In some cases continued activity is seen days after the event
  - Engine
  - Refreshed shocks?
- Finally leading to the question

  ARE JET BREAKS FUNDAMENTAL?

Falcone et al.

Chromatic Breaks

- Very few Swift events exhibited achromatic breaks (X-ray, optical)
  - Olympic grading led to only one Gold medal

Liang et al.

- Chromatic breaks arise from
  - Evolution of microphysical parameters
  - Different regions of emission

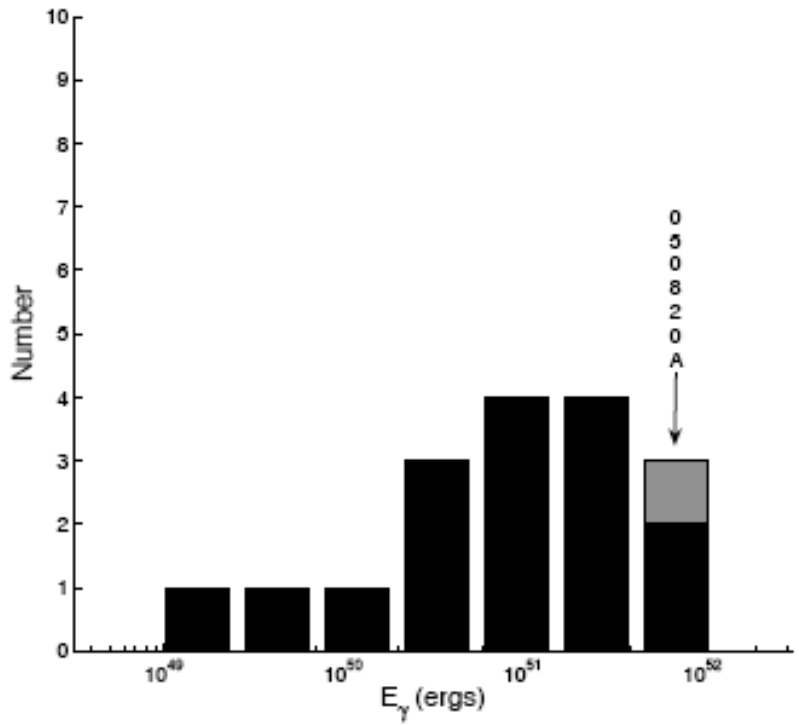
Panaitescu et al

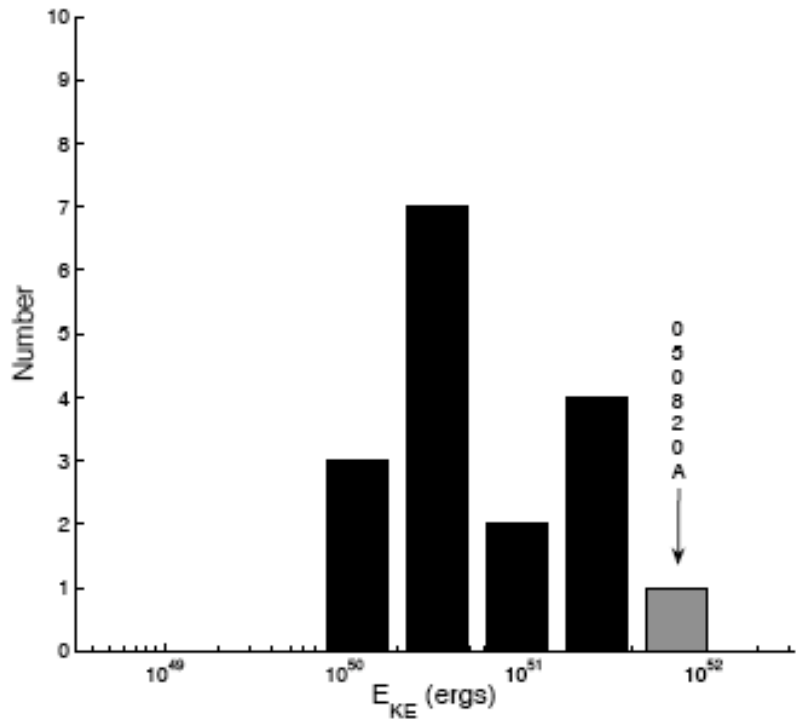
Summary & Conclusion

- Multiple sources of energy
  - Explosion
  - Energy injection
- Structured Jets
- Viewing Geometry matters Panaitescu & Vestrand
- Jets do exist but need measurements capable of calorimetry or size

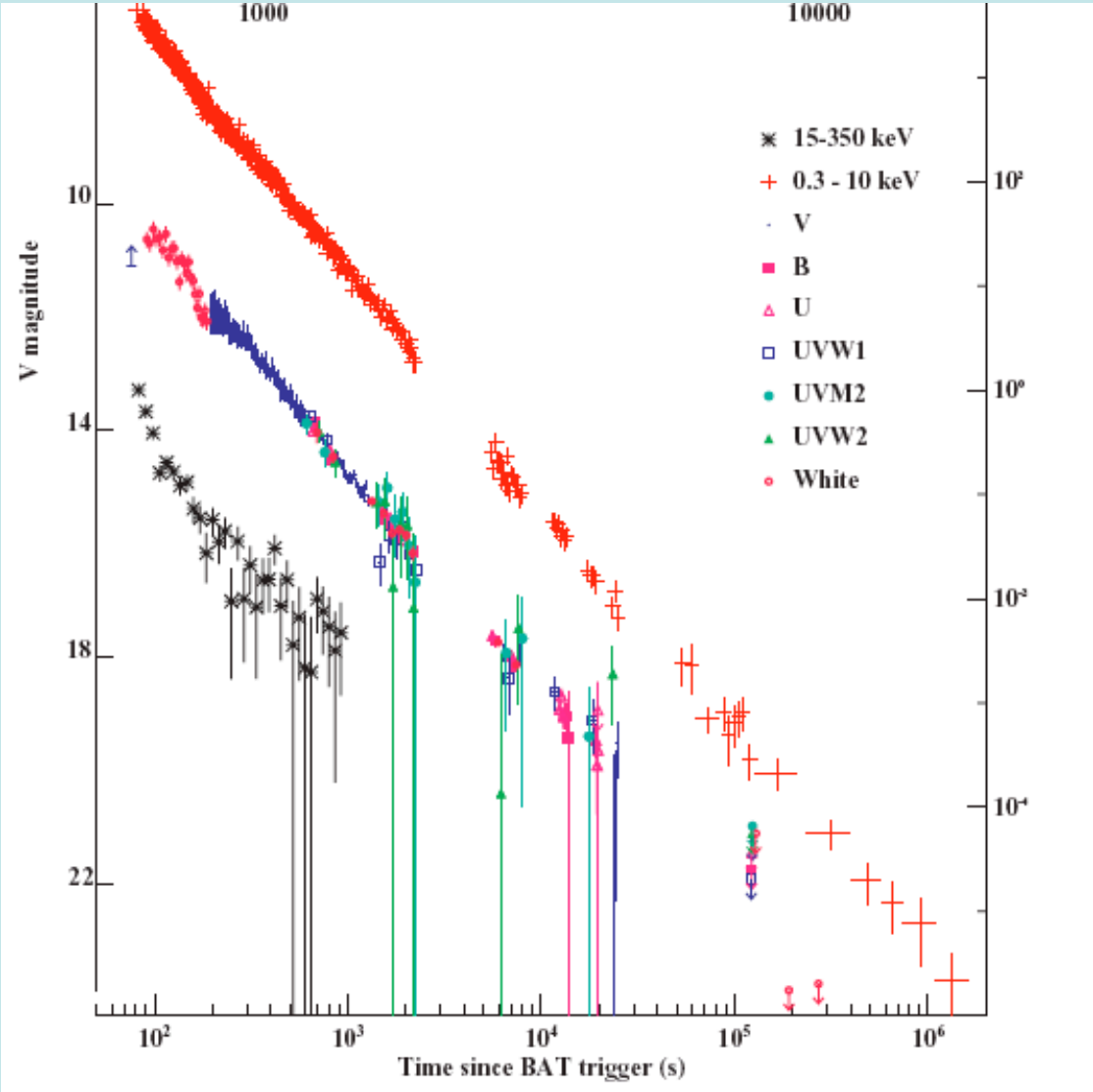
Hyper-Energetic Events

- Jets are clearly inferred in the brightest Swift (and IPN) bursts
  - GRB 050820A — Cenko et al
  - GRB 050904 — Frail et al
  - GRB 070125 — Chandra et al
- The energy budget of GRBs may be as high as 10^{52} erg


Number
0
1
2
3
4
5
6
7
8
9
10
10^{49}
10^{50}
10^{51}
10^{52}
E_γ (ergs)
050820A


Number
0
1
2
3
4
5
6
7
8
9
10
10^{49}
10^{50}
10^{51}
10^{52}
E_{KE} (ergs)
050820A

GRB 061007: A break-less event

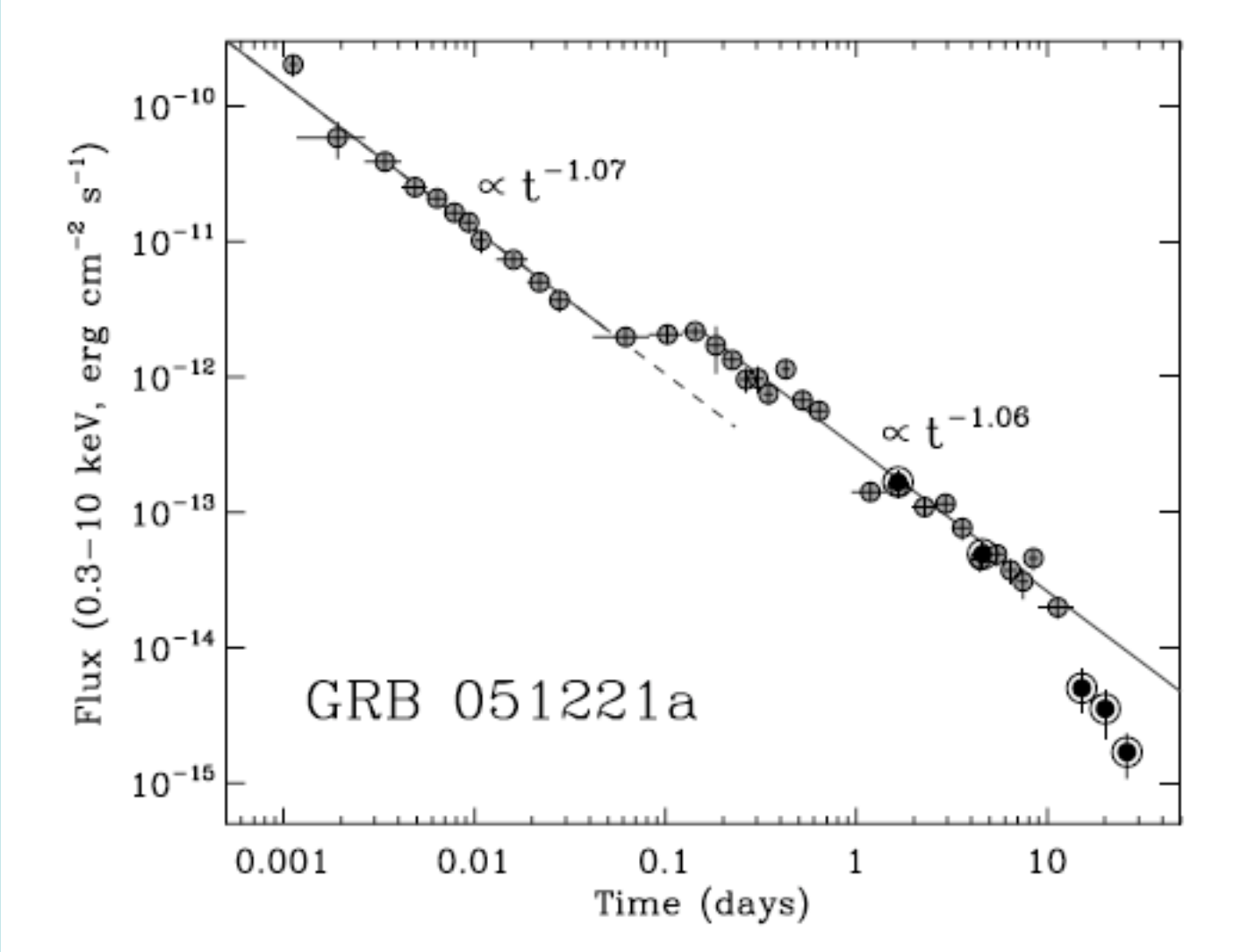


Ultra-narrow jets: GRB 061007 (also 080319B)

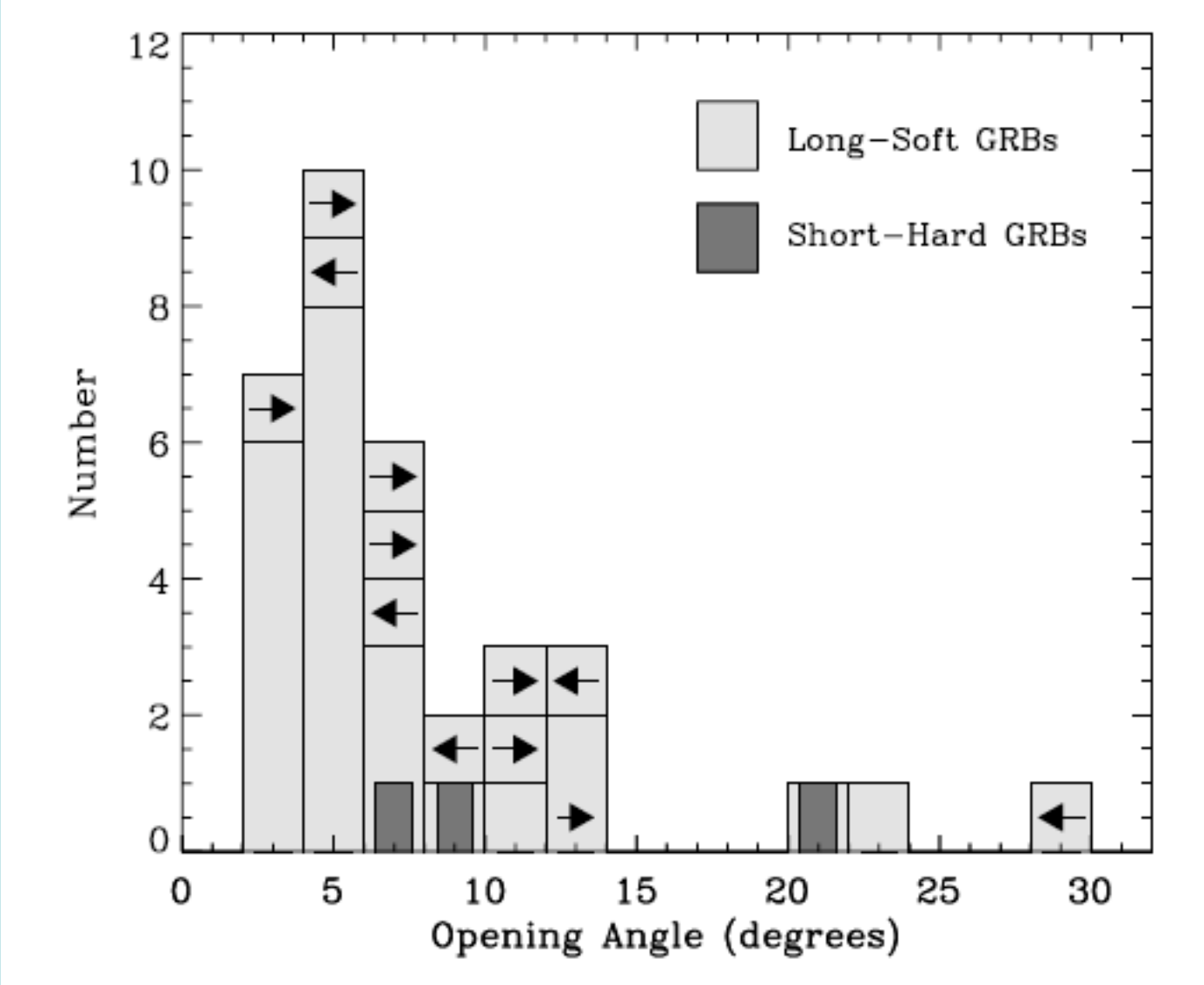
- GRB 061007: one of the brightest Swift bursts
  - $z = 1.26$
  - E_{iso} 1×10^{54} erg
- No “jet break” from to 80s
- Simplest explanation
  - Jet break too place < 80 s
  - Opening angle = 0.8 degree
  - $E_{true} = 1 \times 10^{50}$ erg

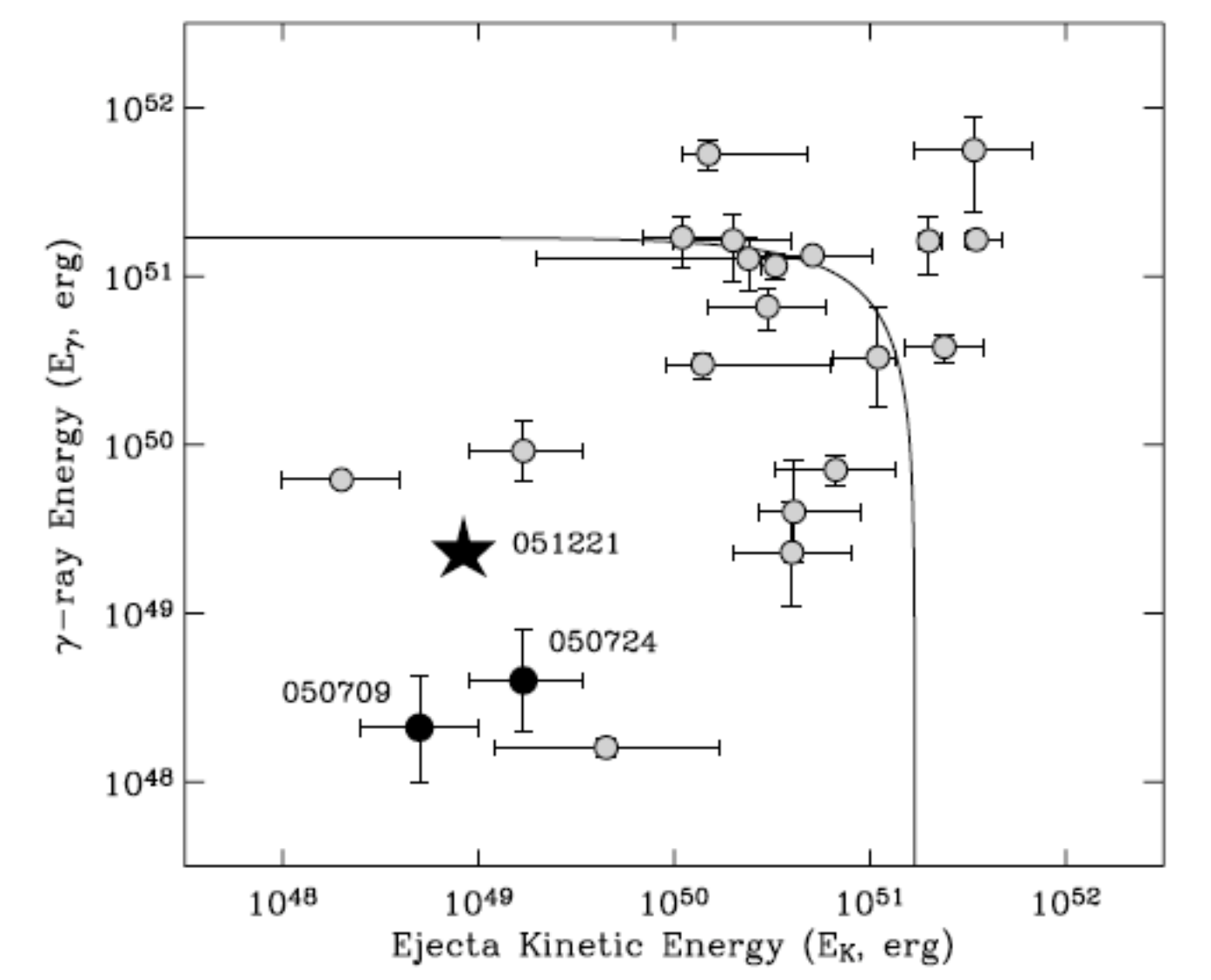
Schady et al. 2007
Bloom et al. 2008

Jets in Short Hard Bursts

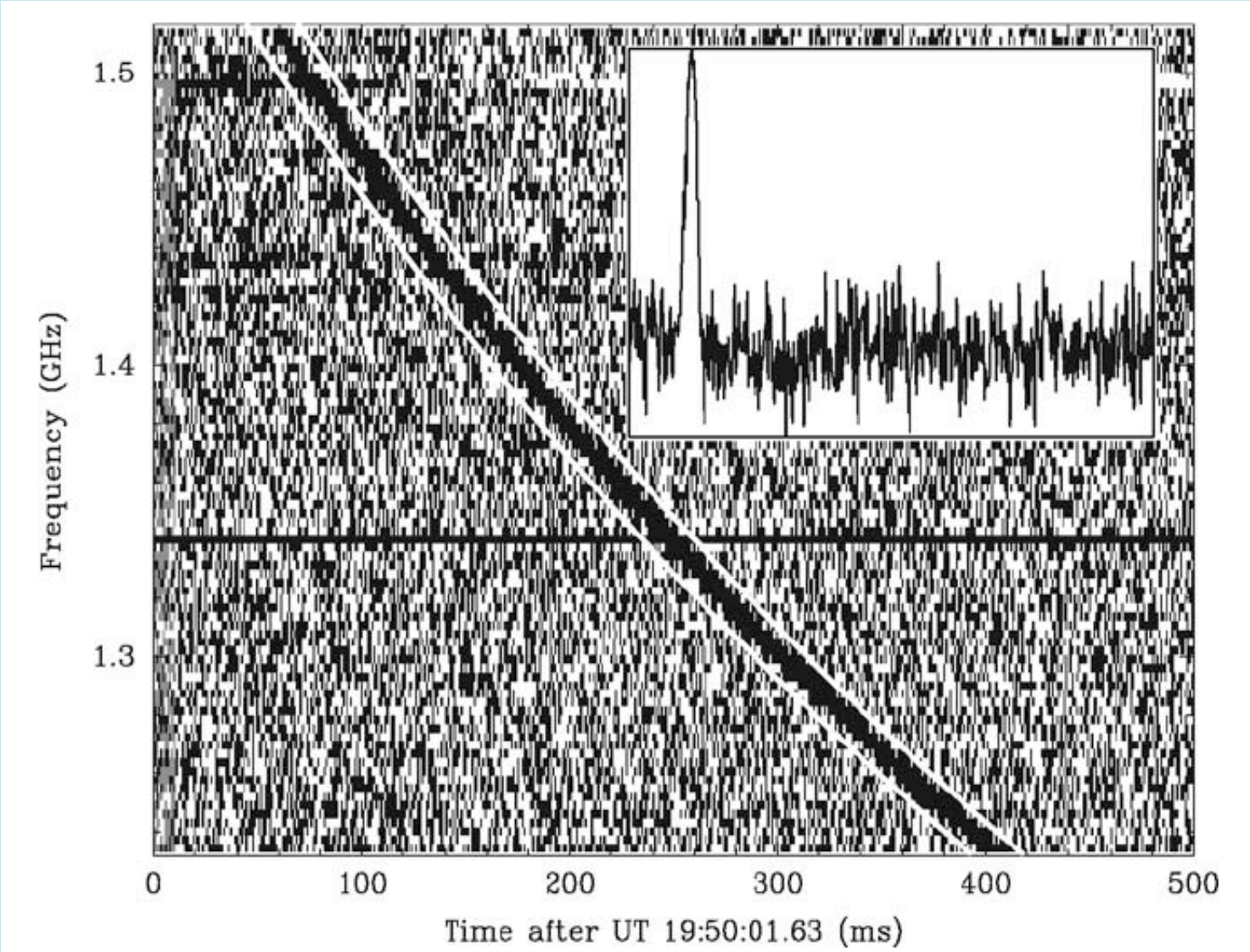


Soderberg et al.


Long−Soft GRBs
Short−Hard GRBs
Number
Opening Angle (degrees)
0
2
4
6
8
10
12
0
5
10
15
20
25
30


10^{52}
10^{51}
10^{50}
10^{49}
10^{48}
γ−ray Energy (E_γ, erg)
051221
050724
050709
10^{48}
10^{49}
10^{50}
10^{51}
10^{52}
Ejecta Kinetic Energy (E_K, erg)

Something very different (and potentially *transformational*)



Lorimer et al. 2007

Sparker is Extragalactic: Brightness Temperature

$$E_S \sim 7 \times 10^{43} D^2_{\rm Gpc}\,{\rm erg},$$

$$7.8 \times 10^{36} D^2_{\rm Gpc}\,{\rm K} \;\; {\rm at} \;\; \nu_0$$

$$6.4 \times 10^{41} D^2_{\rm kpc}\,{\rm K} \;\; {\rm at} \;\; \nu_c.$$

$\Rightarrow$ Coherent Radiation & Ultrarelativistic Flow

Conclusions

- In all well studied GRBs good to excellent evidence exists for highly collimated explosions
  - Radio observations are key
- The mystery of GRBs is now the narrowness and the wide diversity in the inferred opening angles
- Short hard bursts: in two cases a good case can be made for moderate angle jets
- Radio hyper-bursts (Sparkers) may well be the next frontier in ultra-relativistic explosive events