In Gamma-Ray Burts, Timing (vs. Energy) Is Literally Everything*

J.P. Norris

GLAST SWG, September 2002

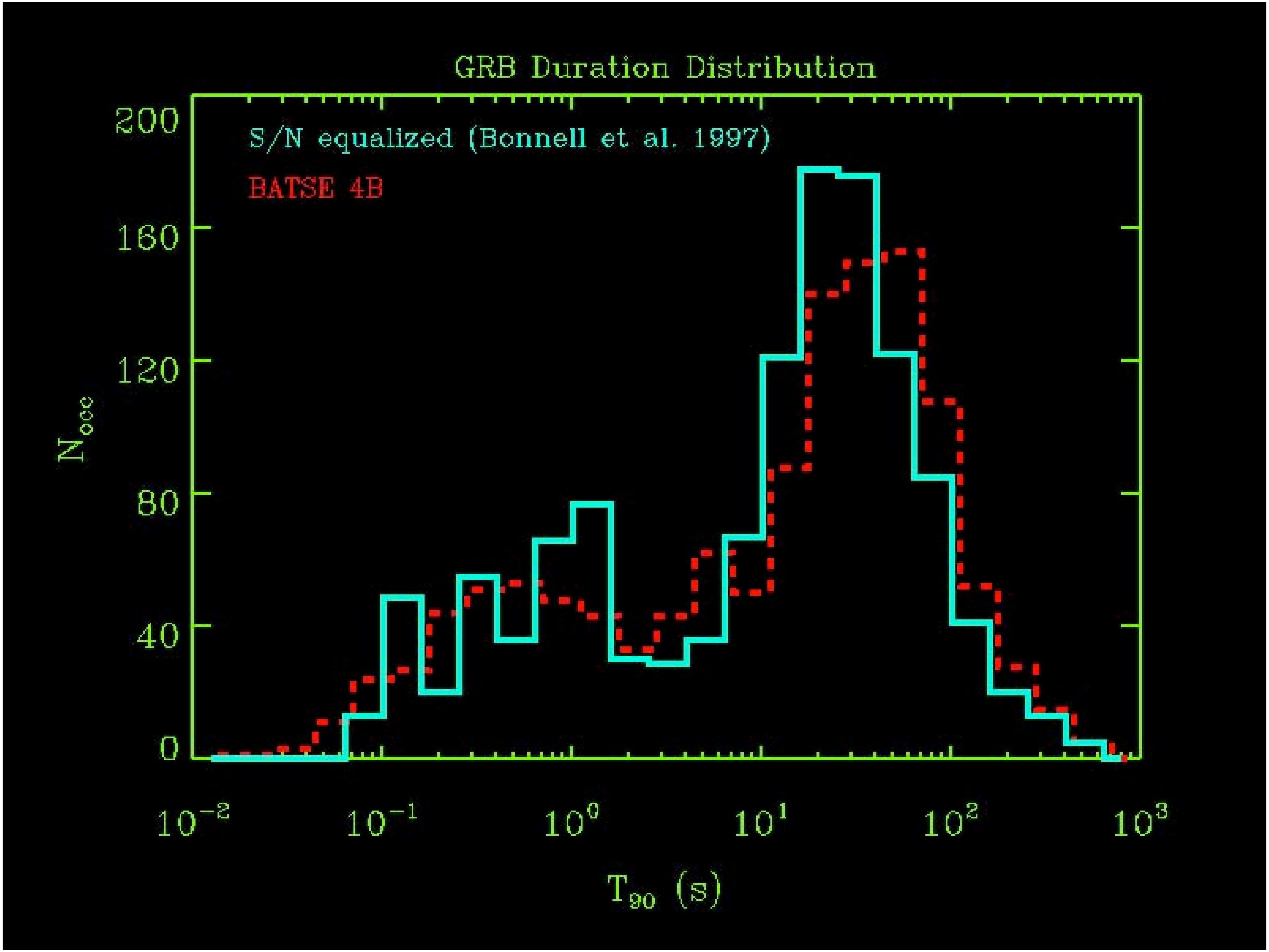
Timescales in GRBs:

(1) Bimodal Duration Distribution

(2) "Contiguous Emission Episodes" — Pulse Conglomerates

(3) Individual Pulses, organized in time and energy

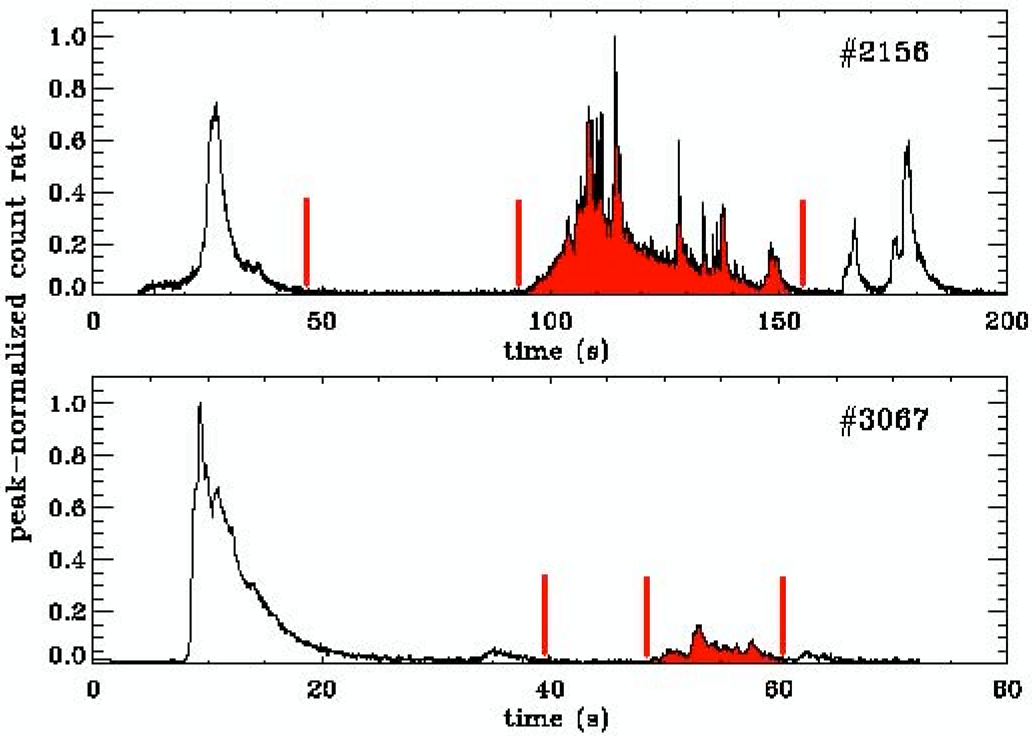
* (almost: there's also polarization)


GRB Duration Distribution
S/N equalized (Bonnell et al. 1997)
BATSE 4B
N_{occ}
0
40
80
120
160
200
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
T_{90} (s)

Quiescent times in gamma-ray bursts – I. An observed correlation between the durations of subsequent emission episodes

Enrico Ramirez-Ruiz★ and Andrea Merloni

Institute of Astronomy, Madingley Road, Cambridge CB3 0HA



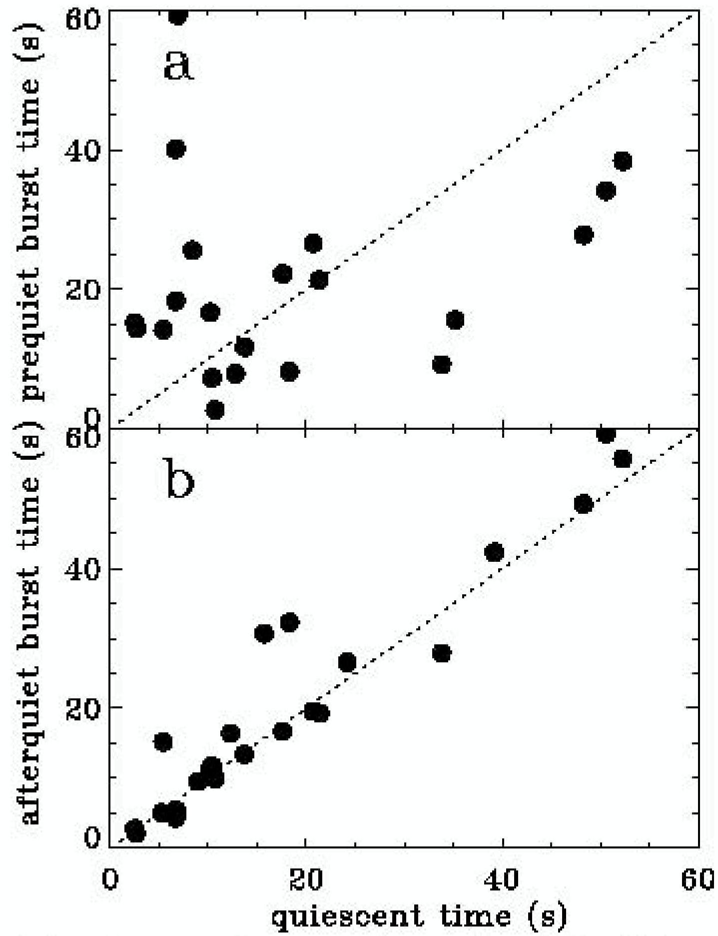
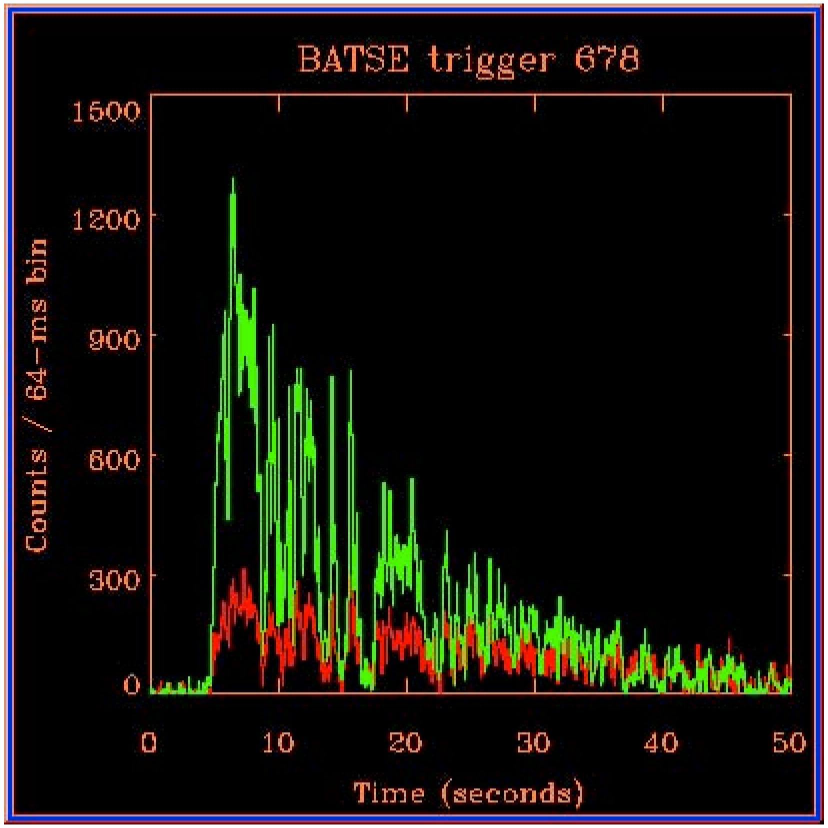
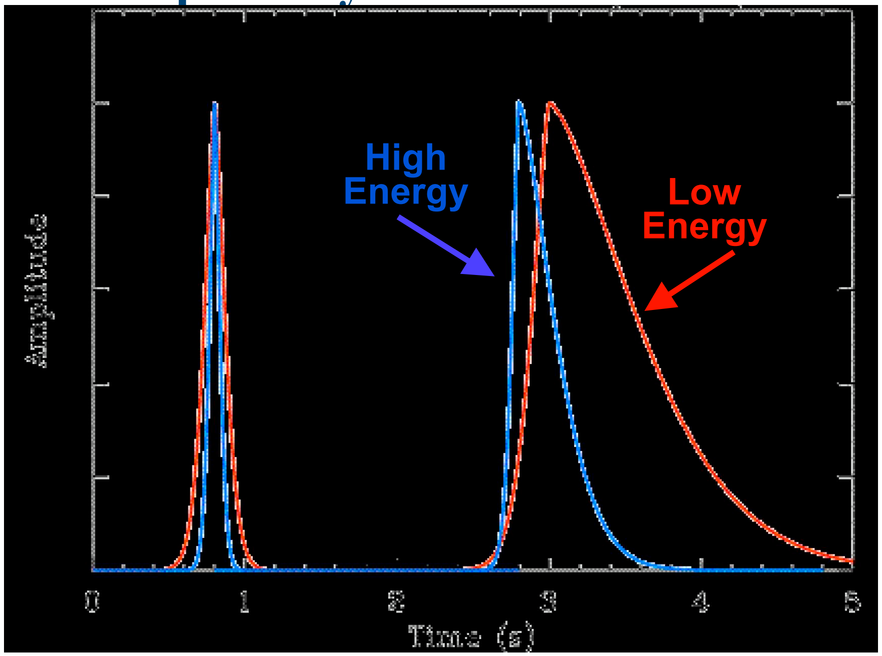


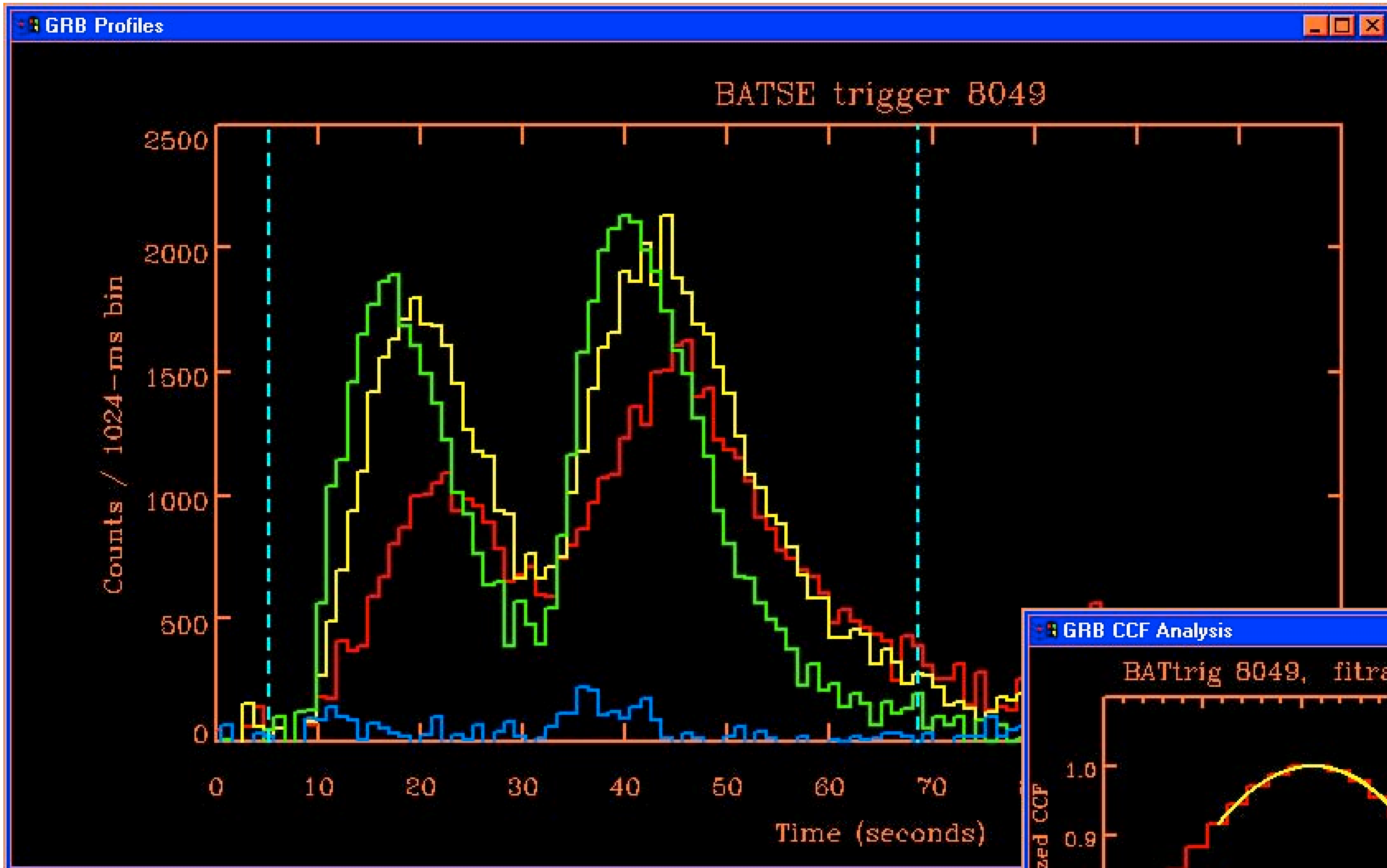
Figure 3. Correlations between the temporal properties of the different emission periods. In panel (a) we plot the duration of an emission episode (pre-quiet burst time) against the duration of the following quiescent time. No clear correlation is found in this case. In panel (b) we plot the duration of an emission episode (after-quiet burst time) against the duration of the previous quiescent time. There is a clear trend: the longer the quiescent time, the longer the duration of the following emission period.

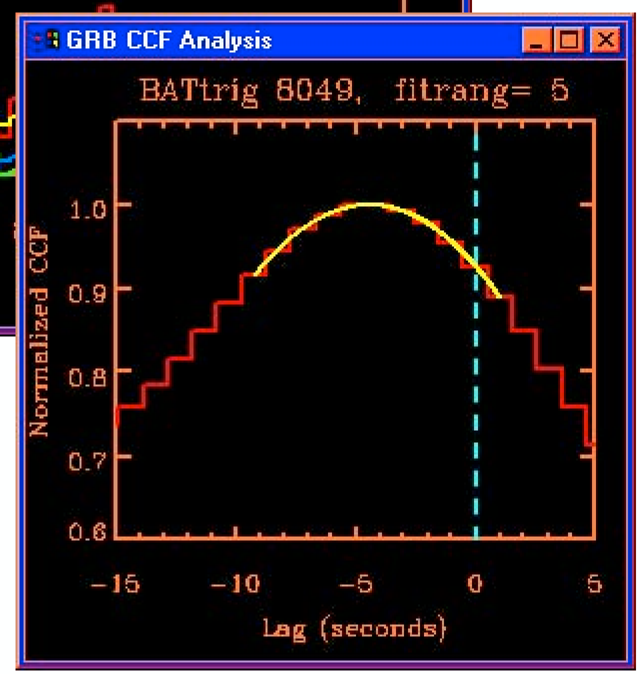
Overview. GRB time profiles are notoriously heterogeneous – chaotic and unpredictable in appearance – challenging to physical modeling attempts. The first quantitative indication of a global tendency was the "" asymmetry parameter (Nemiroff et al. 1994): Bursts are asymmetric on all timescales. Even for bursts at one extreme (example at right), where the spike-like pulses are nearly symmetric at BATSE energies, the envelope is asymmetric.





The "Pulse Paradigm" (Norris et al. 1996) further elucidates burst behavior: Pulses range from narrow and nearly symmetric, to wide and asymmetric, with low energy lagging high energy (schematic at left).



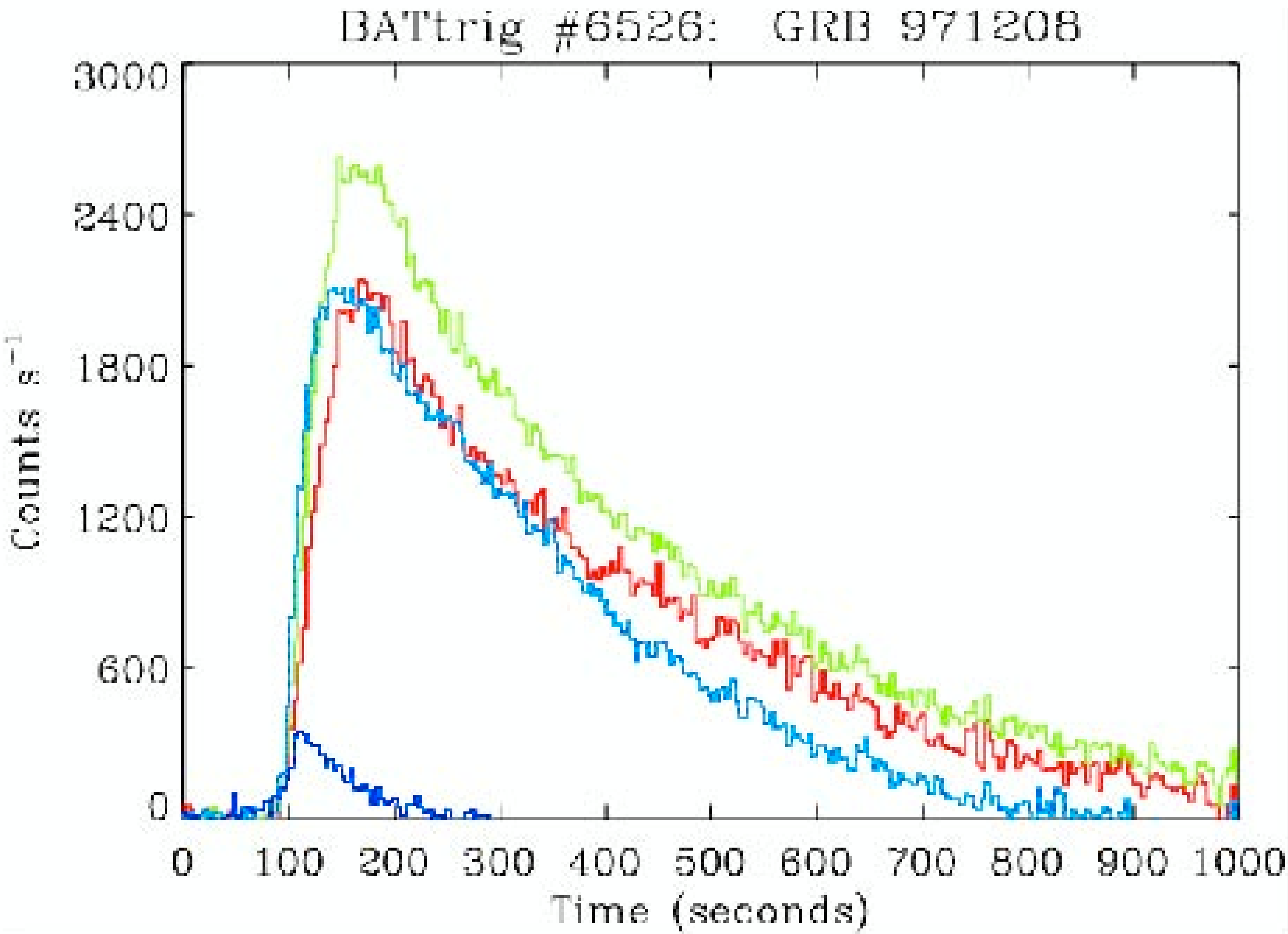


> 300 keV : blue

100-300 keV : green

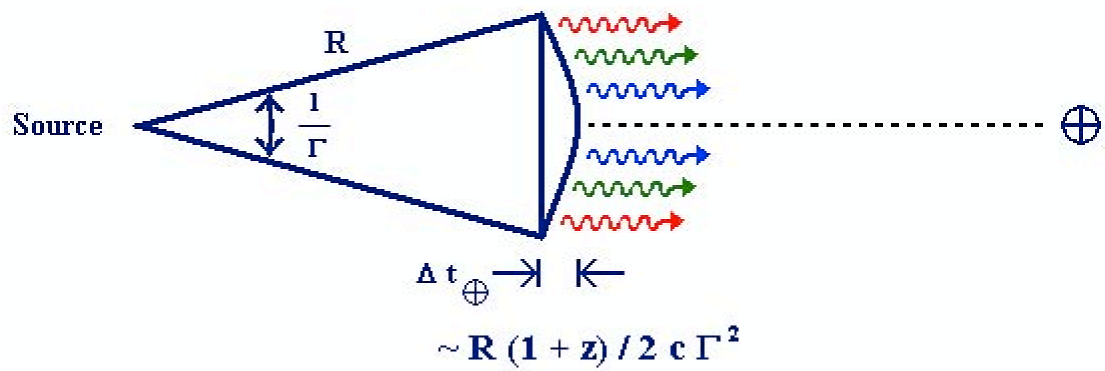
50- 100 keV : yellow

25- 50 keV : red



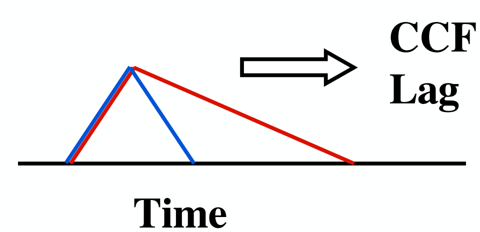
BATtrig #6526: GRB 971208
3000
2400
1800
1200
600
0
Counts s^{-1}
0
100
200
300
400
500
600
700
800
900
1000
Time (seconds)

Simplistic geometrical explanation of connection between temporal lag as function of energy:

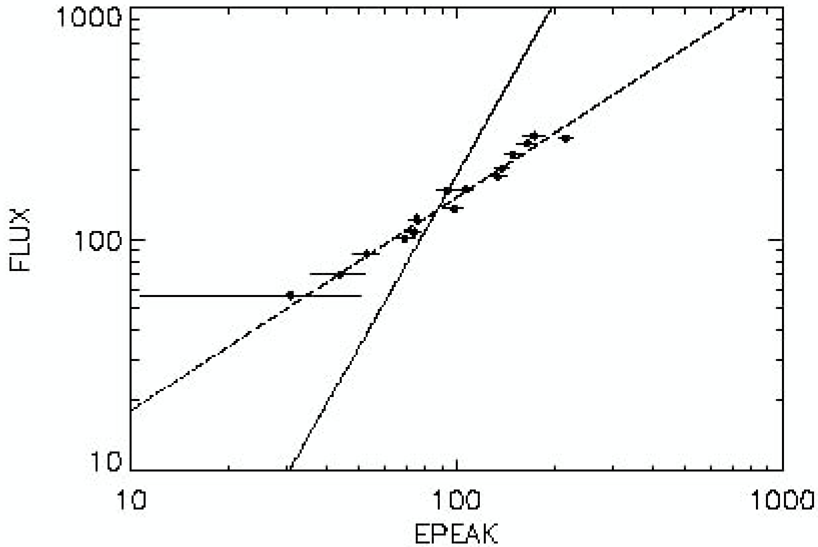


$$\nu_{\text{line-of-sight}} = 2\,\Gamma\,\nu_{\text{source}}$$

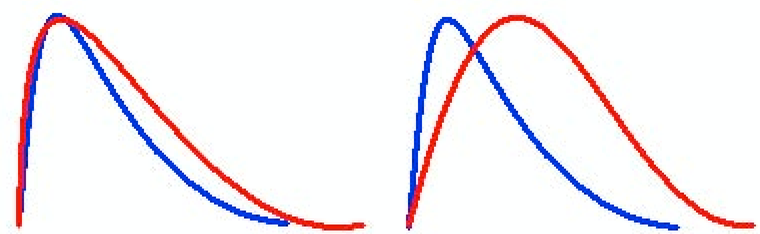
$$\nu_{\text{emission edge}} = \Gamma\,\nu_{\text{source}}$$



From Soderberg & Fenimore (GRBs Rome 2000):
(astro-ph/0103277)



Red: lower energy; Blue: higher energy



GRB 970201: Locus of Flux(t) vs. $E_{peak}(t)$ in decay phase of pulse evolves faster than pure relativistic kinematics of colliding shells.

Measures such as off-axis shells, varying shell thicknesses could not reproduce the observed pulse decay profiles.

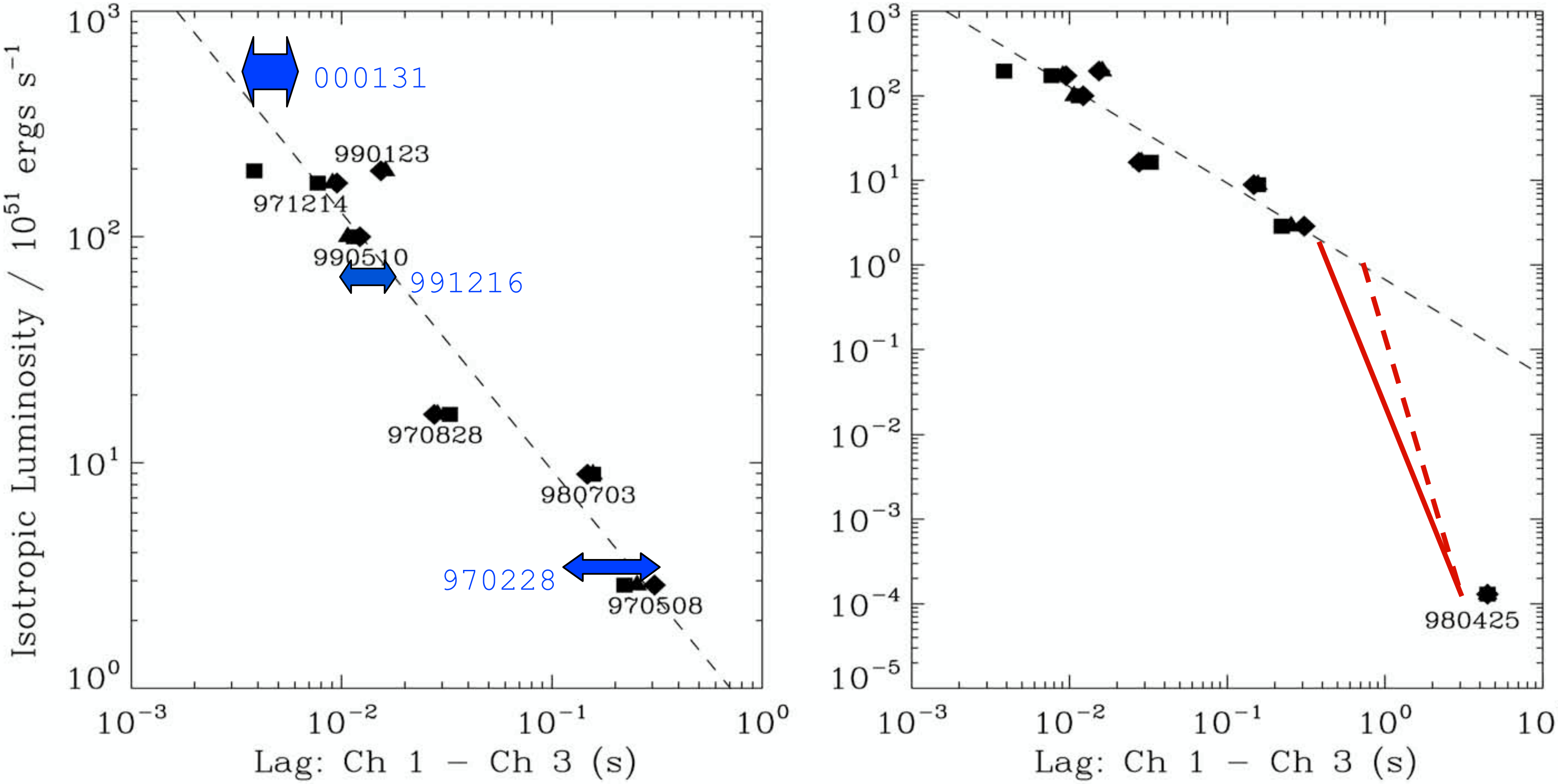
Only slow cooling timescales superposed on the kinematics effected sufficient pulse evolution to match pulse spectral behavior.

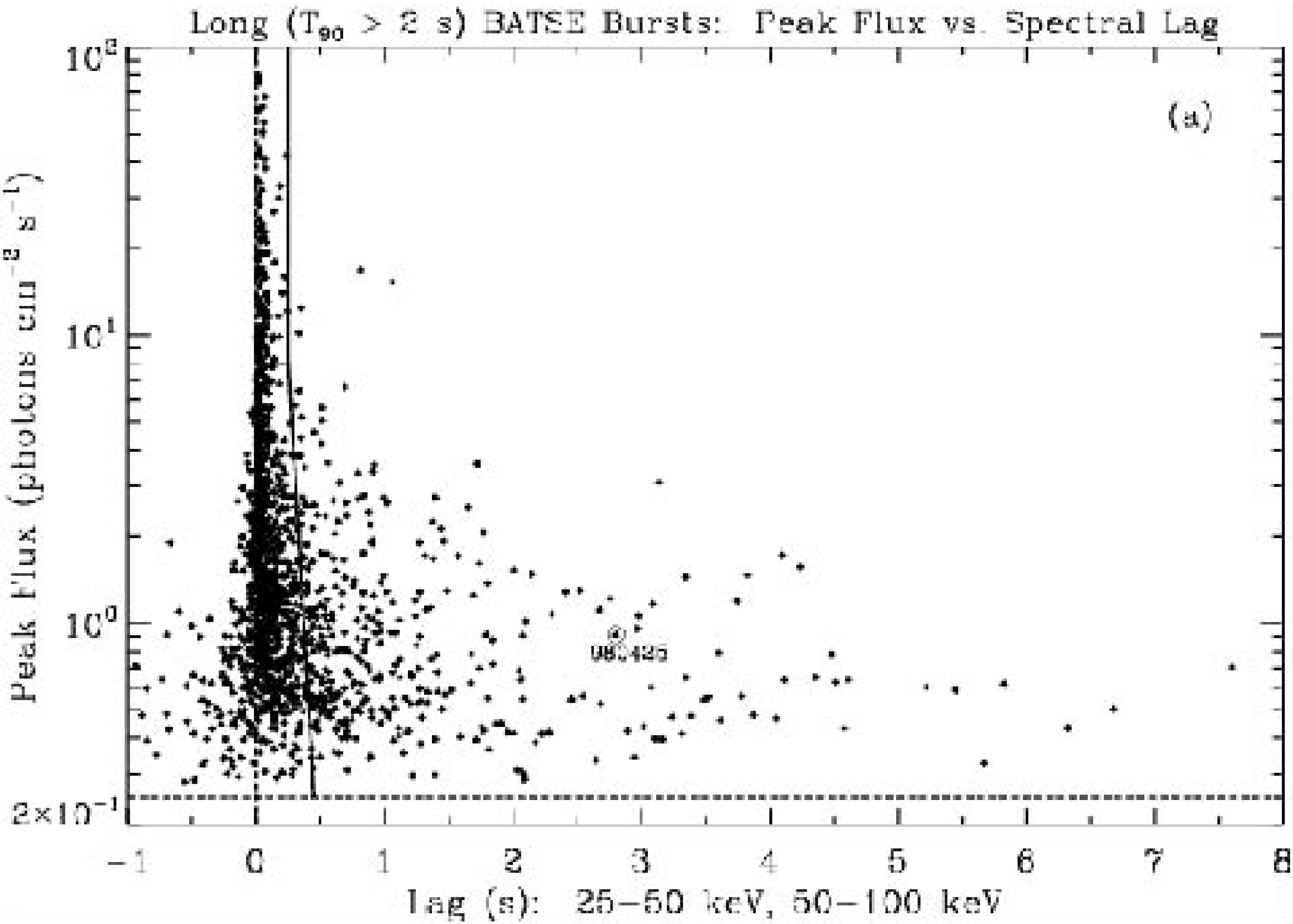
Left. Not observed: pulse peak is energy-independent, and pulse centroid only slightly later in time at low energy.

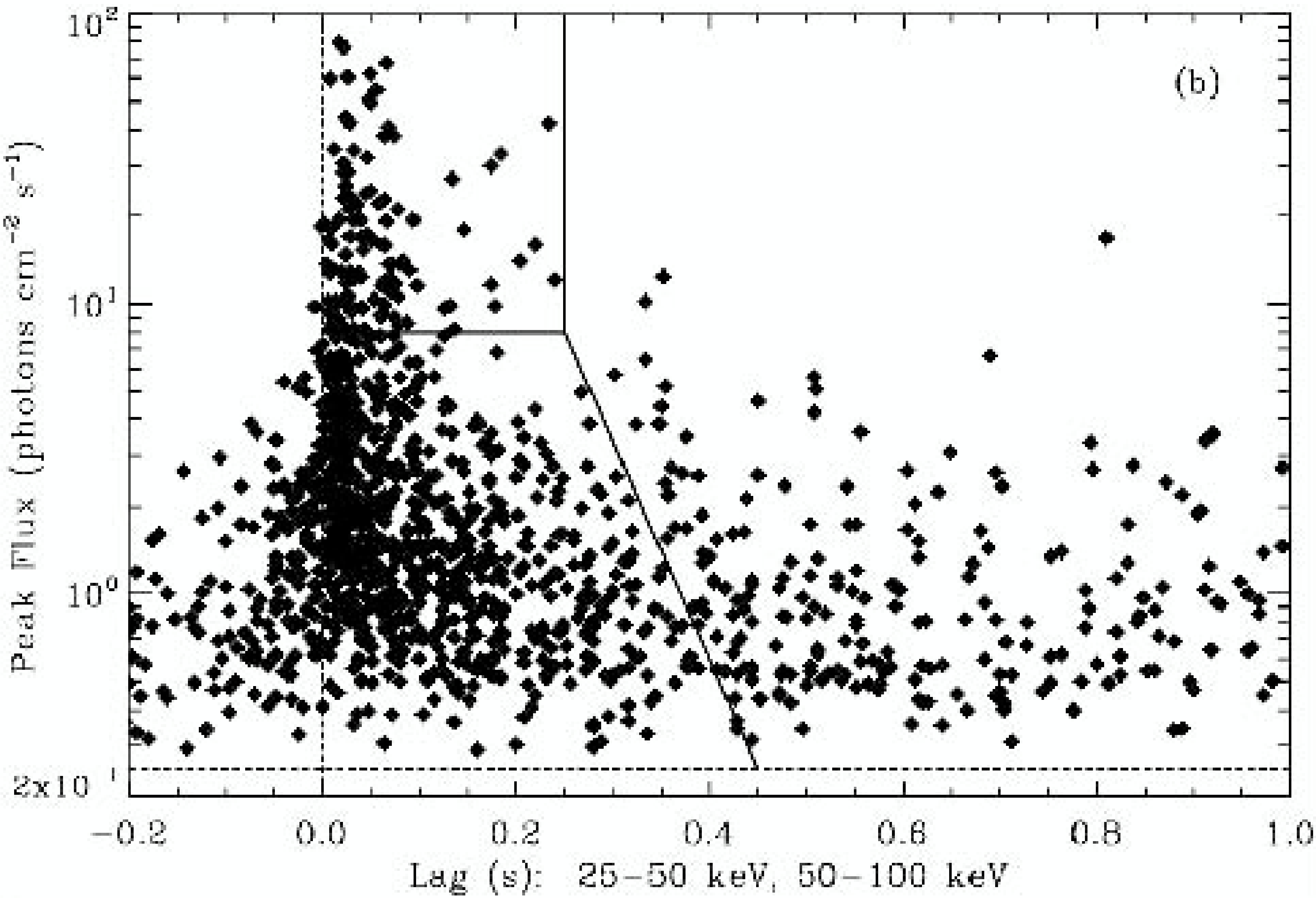
Right. Observed: pulse peak shifts to later times at lower energies, centroid shifts significant fraction of pulse width. (Slow cooling required to reproduce the Observed behavior.)

A Main Sequence “HR Diagram for Gamma-Ray Bursts”

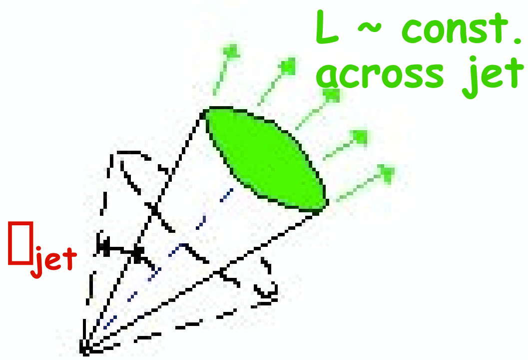
$$L_{53} \approx 1.1 \times (\tau_{lag}/0.01\ \mathrm{s})^{-1.15}$$

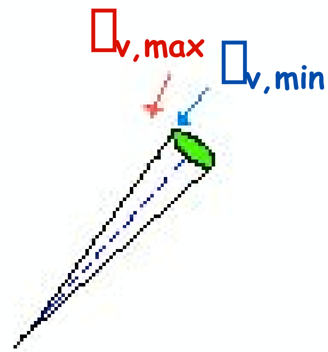


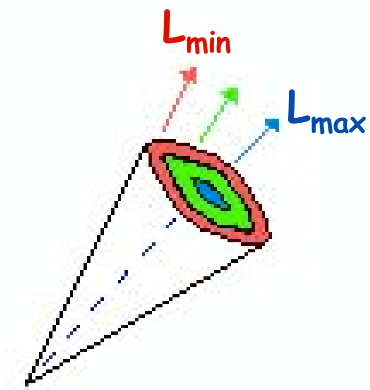

Long (T_{90} > 2 s) BATSE Bursts: Peak Flux vs. Spectral Lag
(a)
Peak Flux (photons cm^{-2} s^{-1})
10^2
10^1
10^0
2×10^{-1}
980425
Lag (s): 25–50 keV, 50–100 keV
−1
0
1
2
3
4
5
6
7
8



(b)
Peak Flux (photons cm^{-2} s^{-1})
10^2
10^1
10^0
2×10^{-1}
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
Lag (s): 25–50 keV, 50–100 keV







θ_{jet} varies,
~ 2°–20°.

θ_{view} varies,
outside jet cone.

θ_{view} varies,
inside profiled jet.

Beaming Fraction

$\int_{4\pi} L d\Omega$ ~ constant,

→ $\Omega \propto L^{-1}$.

Viewing angle

Special Relativity:

Lorentz contraction

& Doppler boost

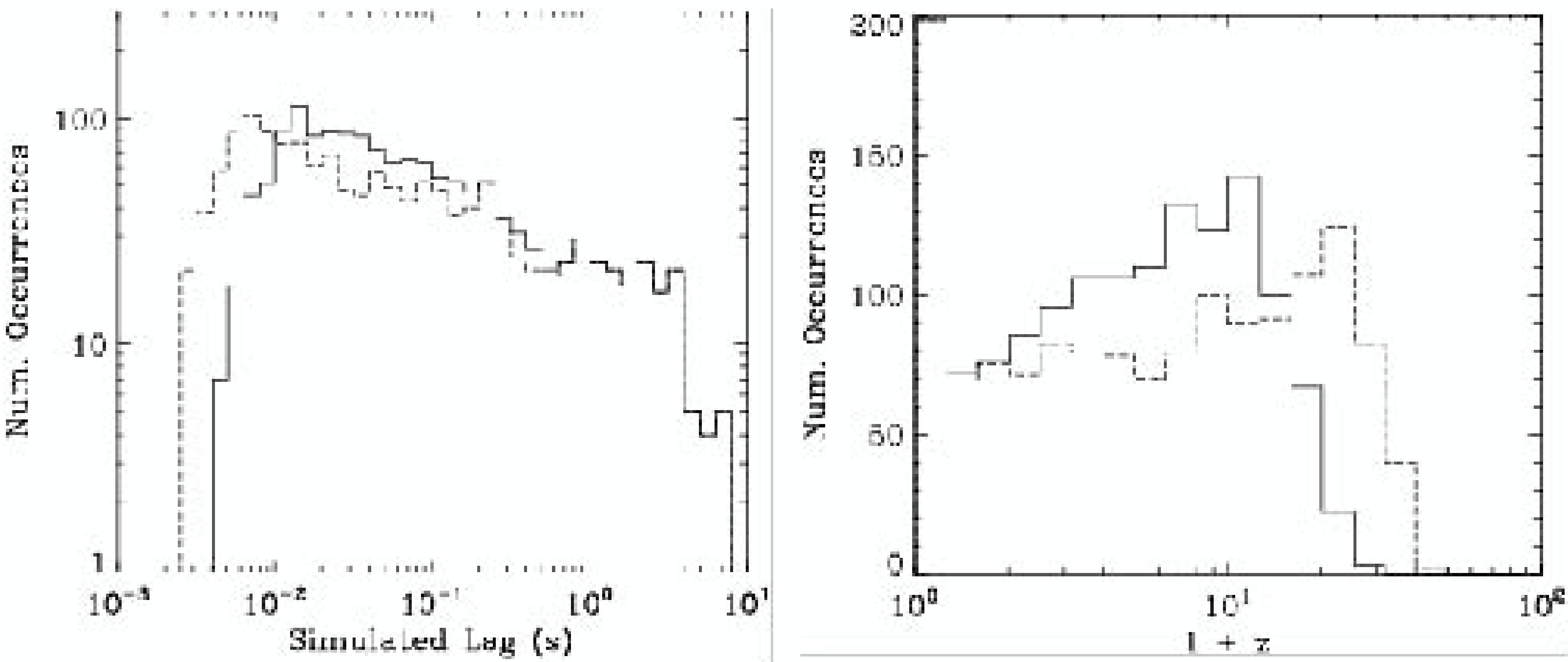
Profiled jet

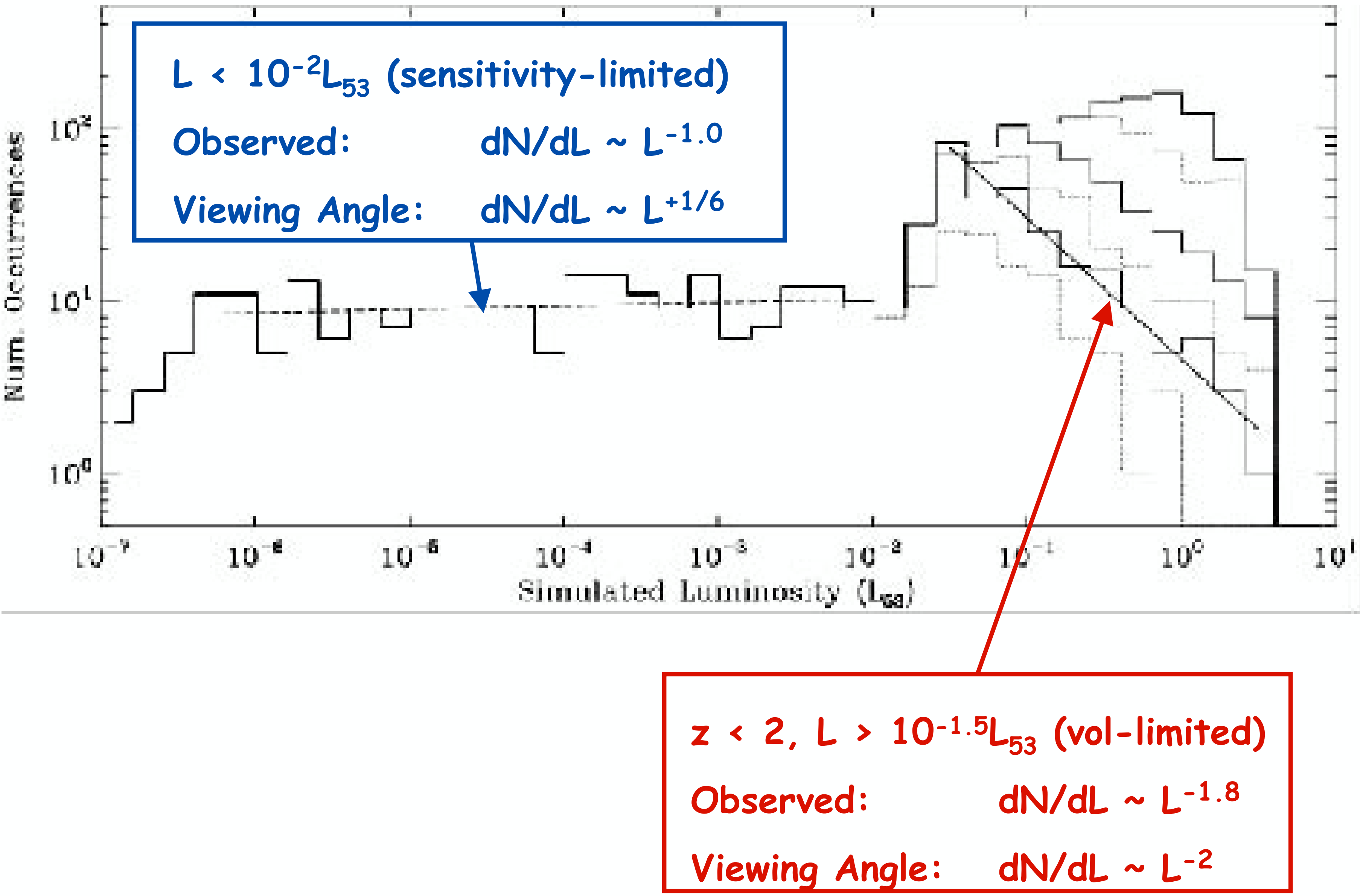
L(θ) reflects $\Gamma(\theta)$:

30 < $\Gamma(\theta)$ < 1000

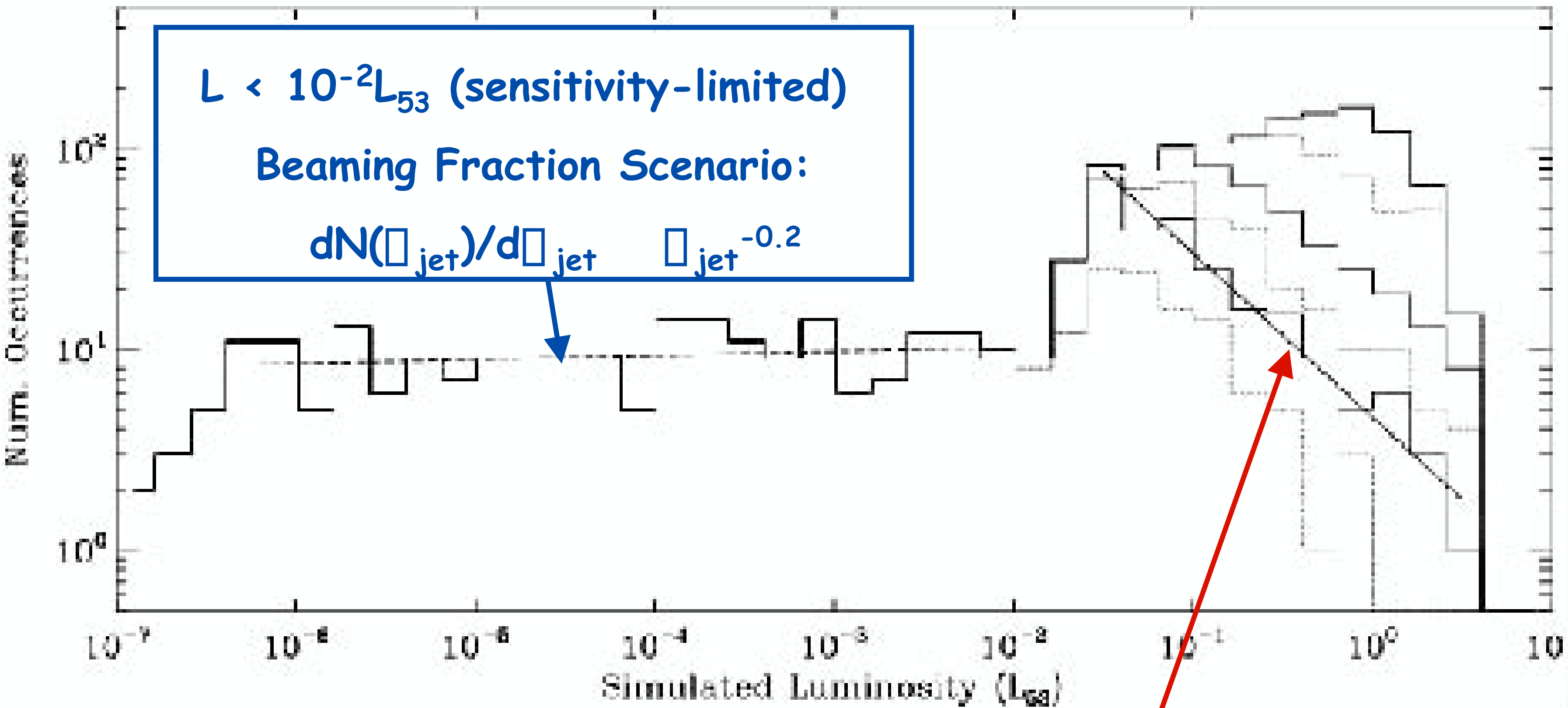
(jet fastest on axis)

All three models realize *broad observed*, but
narrow actual Luminosity and Energy distributions.


Num. Occurrences
100
10
1
Simulated Lag (s)
Num. Occurrences
200
150
100
50
0
1 + z



L < 10^-2 L_53 (sensitivity-limited)
Observed: dN/dL ~ L^-1.0
Viewing Angle: dN/dL ~ L^+1/6
z < 2, L > 10^-1.5 L_53 (vol-limited)
Observed: dN/dL ~ L^-1.8
Viewing Angle: dN/dL ~ L^-2
Num. Occurrences
Simulated Luminosity (L_53)



$L < 10^{-2}L_{53}$ (sensitivity-limited)

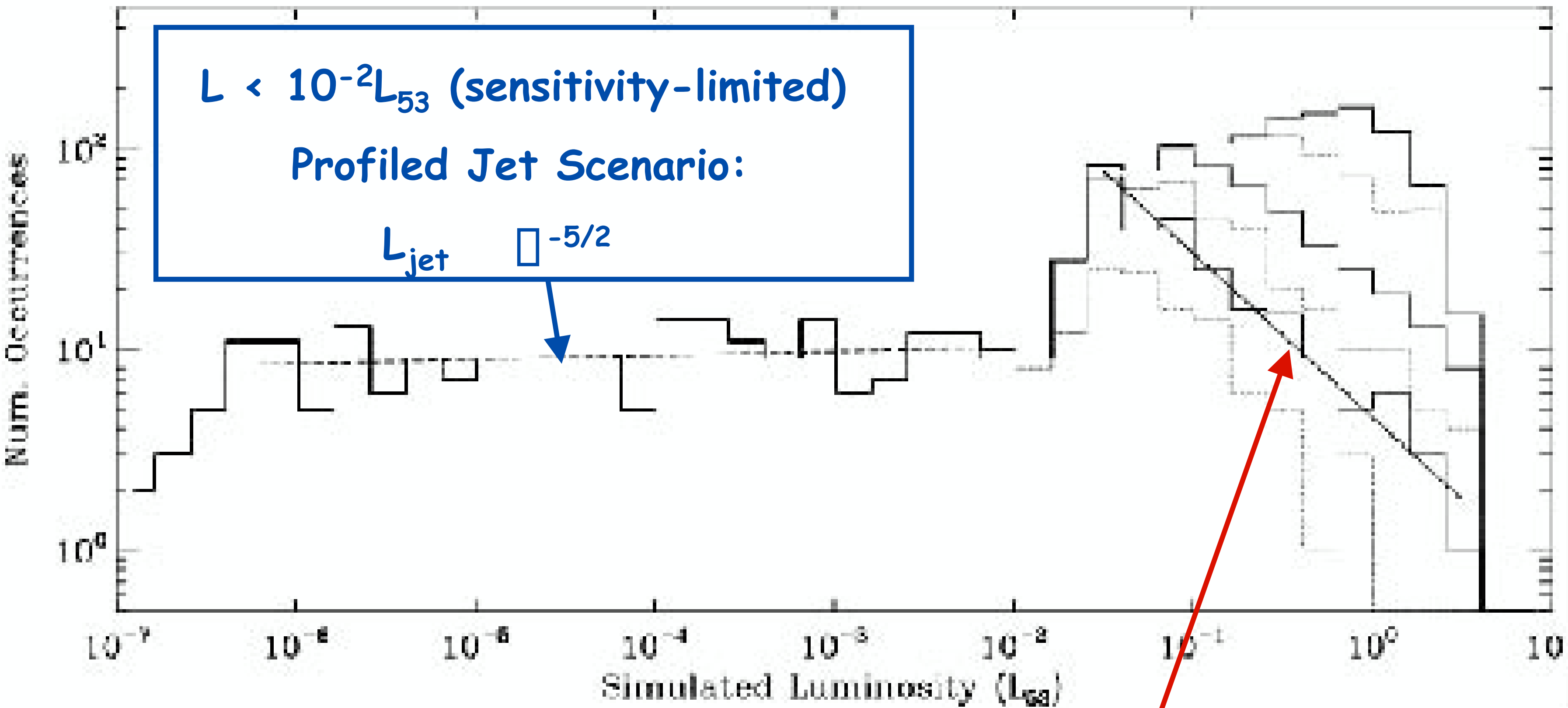
Beaming Fraction Scenario:

$dN(\square_{jet})/d\square_{jet}\quad \square\ \square_{jet}^{-0.2}$

$z < 2$, $L > 10^{-1.5}L_{53}$ (vol-limited)

Beaming Fraction Scenario:

$dN(\square_{jet})/d\square_{jet}\quad \square\ \square_{jet}^{+0.5}$



$z < 2$, $L > 10^{-1.5} L_{53}$ (vol-limited)

Profiled Jet Scenario:

L_{jet} □$^{-5/2}$

Conclusions/Predictions

- **High-luminosity GRBs:**

  - GRB Distribution in redshift continues to rise to $z \sim 10$. But, this result has large uncertainty, arising from extrapolated correction for redshift of the energy-dependent time profiles.

  - In a volume-limited regime ($z < 2$), $dN_{vol}/dL \sim L^{-1.8}$. This dependence is easily producible in the profiled jet scenario.

    Whereas, in the pure viewing angle scenario no wiggle room is left for range of beaming fractions or viewing angle (dN_{vol}/dL would be too steep). The variable beaming fraction scenario requires $dN(\theta_{jet})/d\theta_{jet} \propto \theta_{jet}^{+0.5}$, a rising dependence.

  - For highly luminous GRBs ($L_{51} > 3$–20), the required fraction of participating SNe is: $R_{GRB} \sim 0.003$–$0.015 \times R_{SNIb/c}$.

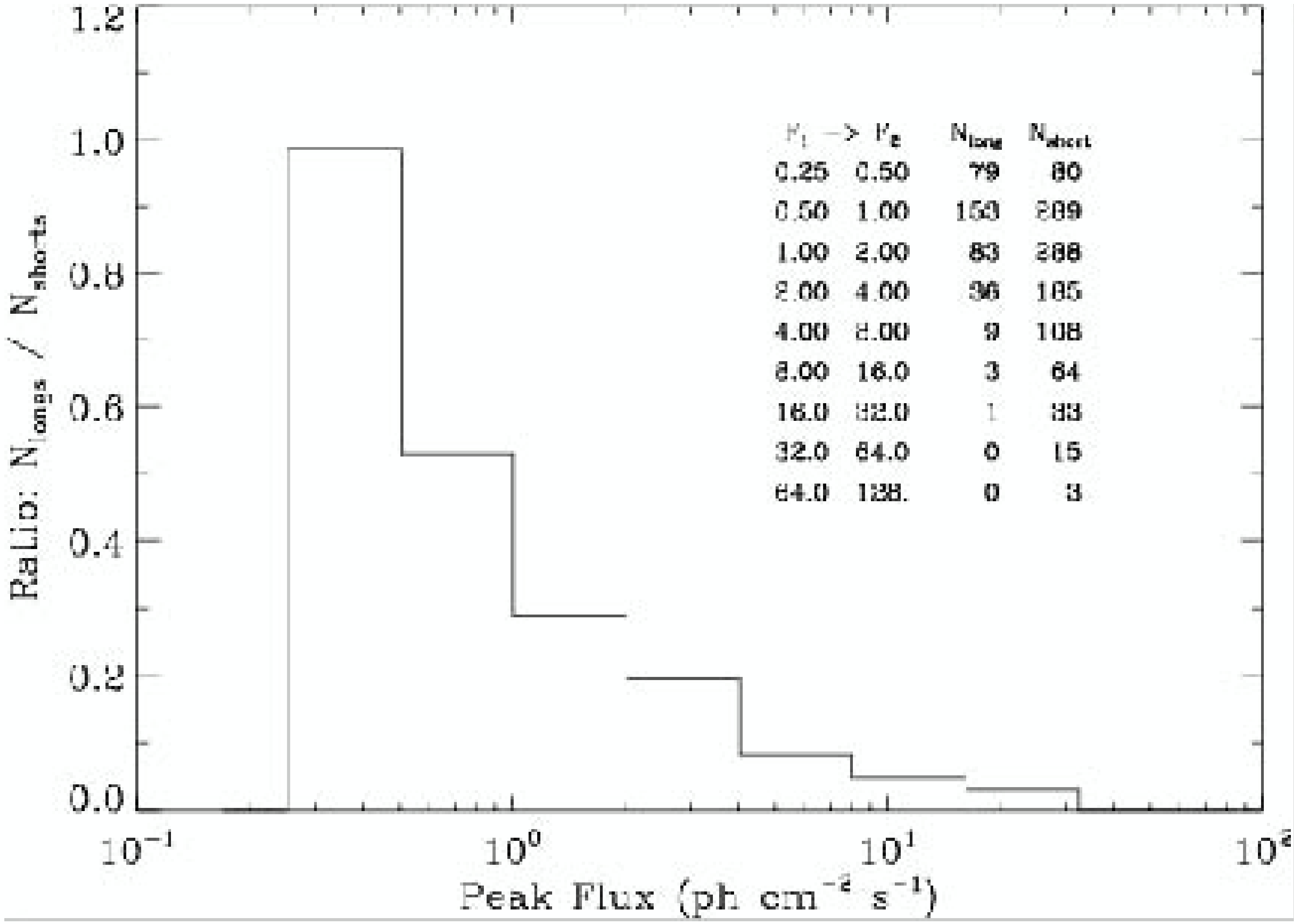
A Population of Long Spectral Lag Gamma-Ray Bursts (in: astro-ph/0201503)

J.P. Norris

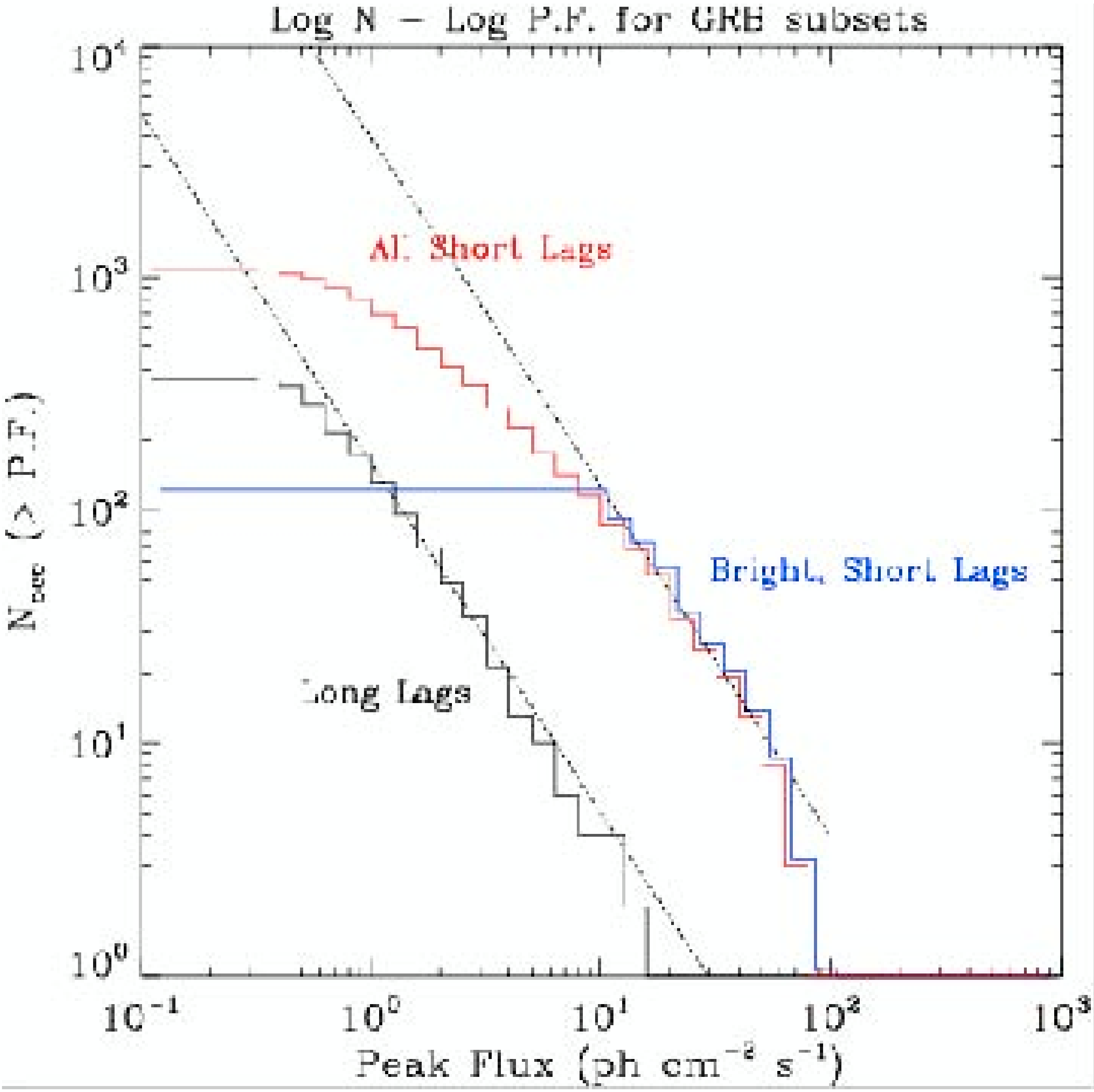
Subsample (~ 7%) of soft-spectrum BATSE GRBs:

- Very long pulses and spectral lags (>~ 1 s)
- Tendency towards Supergalactic Plane
- $d < 100$ Mpc
- Ultra-low luminosity (<~ 10^{48} ergs s^{-1})
- R_{GRB} ~ _ $R_{SN\ Ib/c}$

Could be LIGO II sources (but probably not UHECR sources).



Ratio: N_{longs} / N_{shorts}
Peak Flux (ph cm^{-2} s^{-1})
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10^{-1}
10^{0}
10^{1}
10^{2}
P_1 -> P_2 N_{long} N_{short}
0.25 0.50 79 80
0.50 1.00 153 289
1.00 2.00 83 288
2.00 4.00 36 185
4.00 8.00 9 108
8.00 16.0 3 64
16.0 32.0 1 33
32.0 64.0 0 15
64.0 128. 0 3



Log N – Log P.F. for GRB subsets
All Short Lags
Bright, Short Lags
Long Lags
$N_{\rm sec}$ (> P.F.)
Peak Flux (ph cm^{-2} s^{-1})
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

M. J. Hudson (1993)

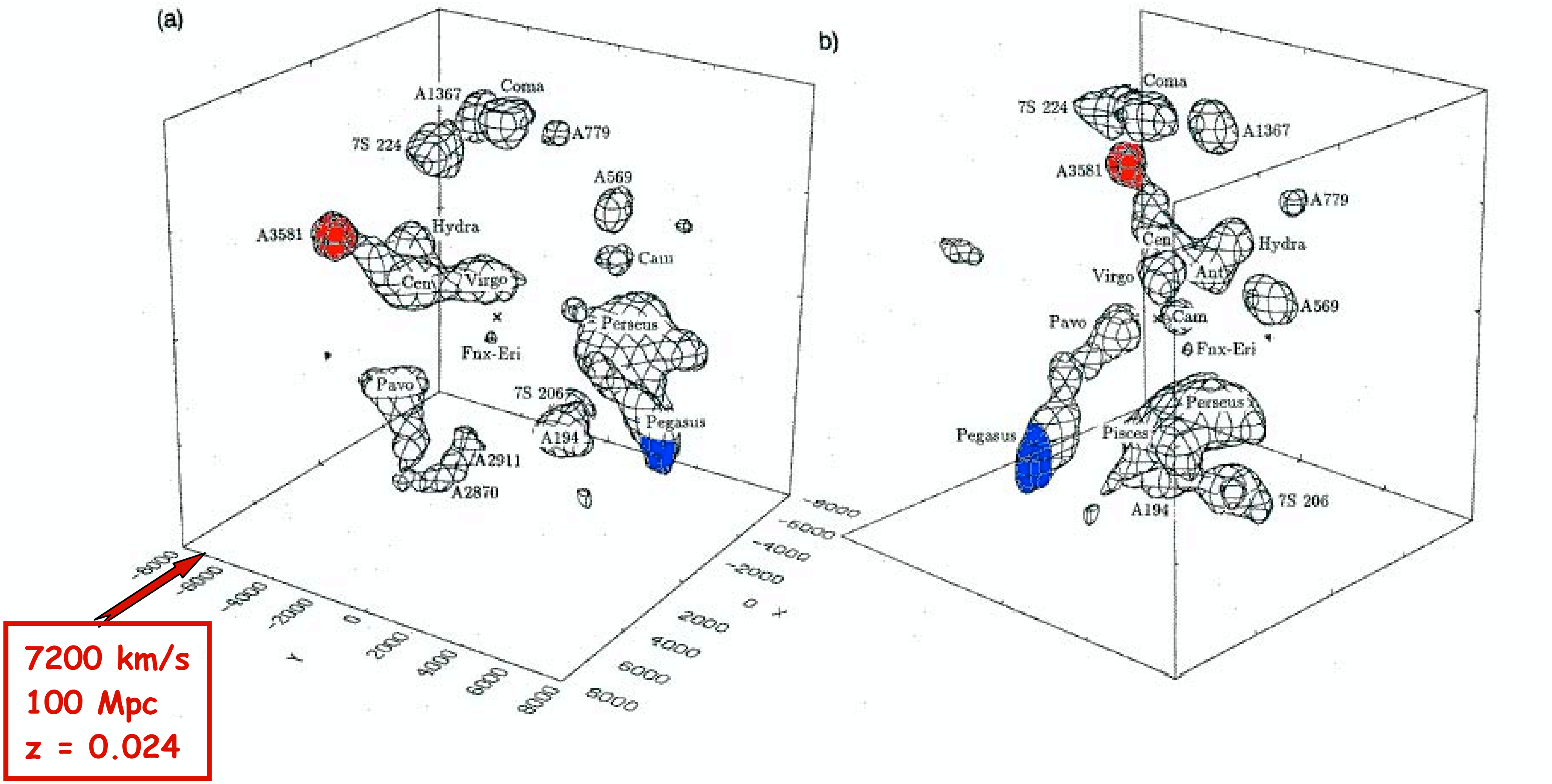
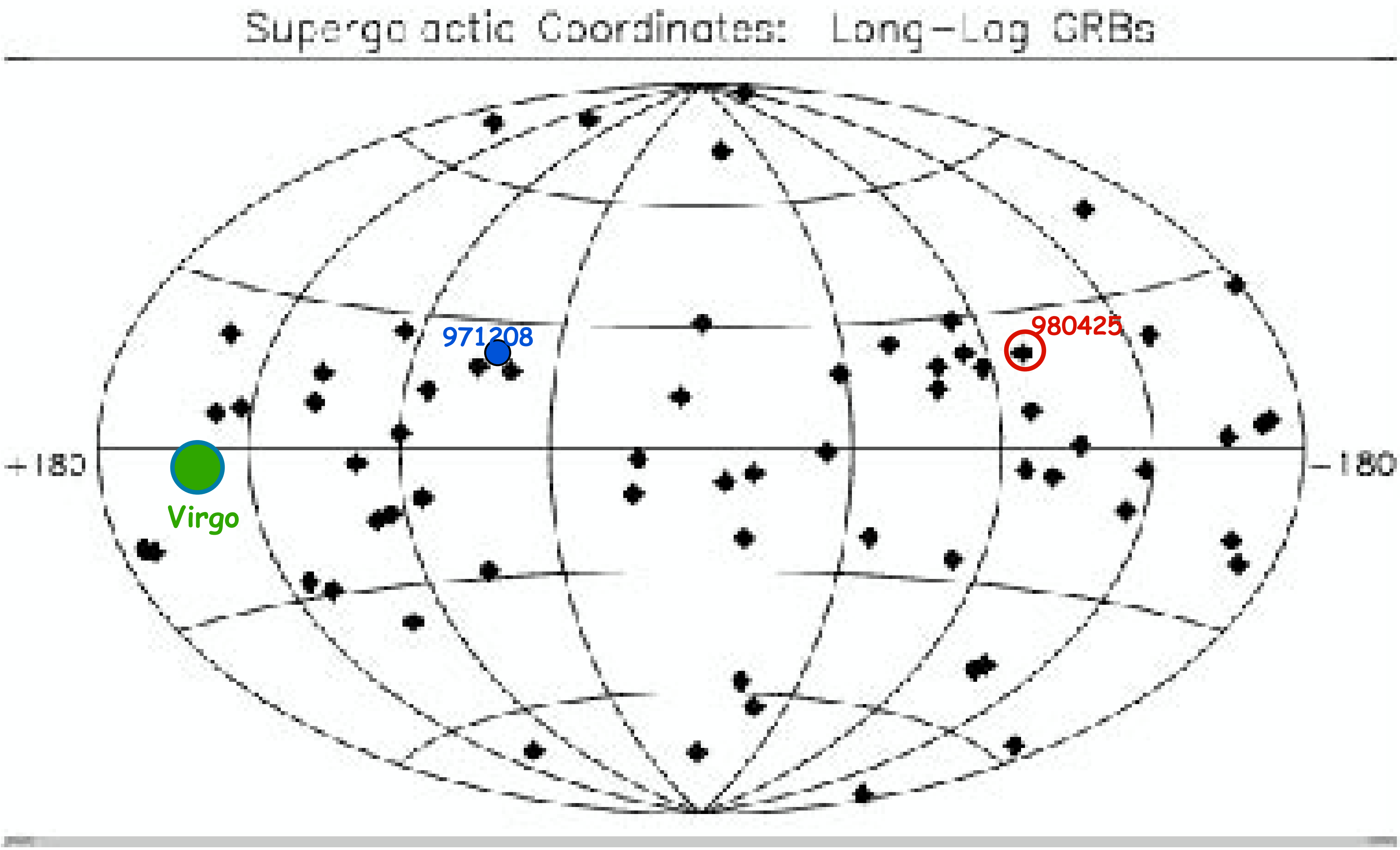
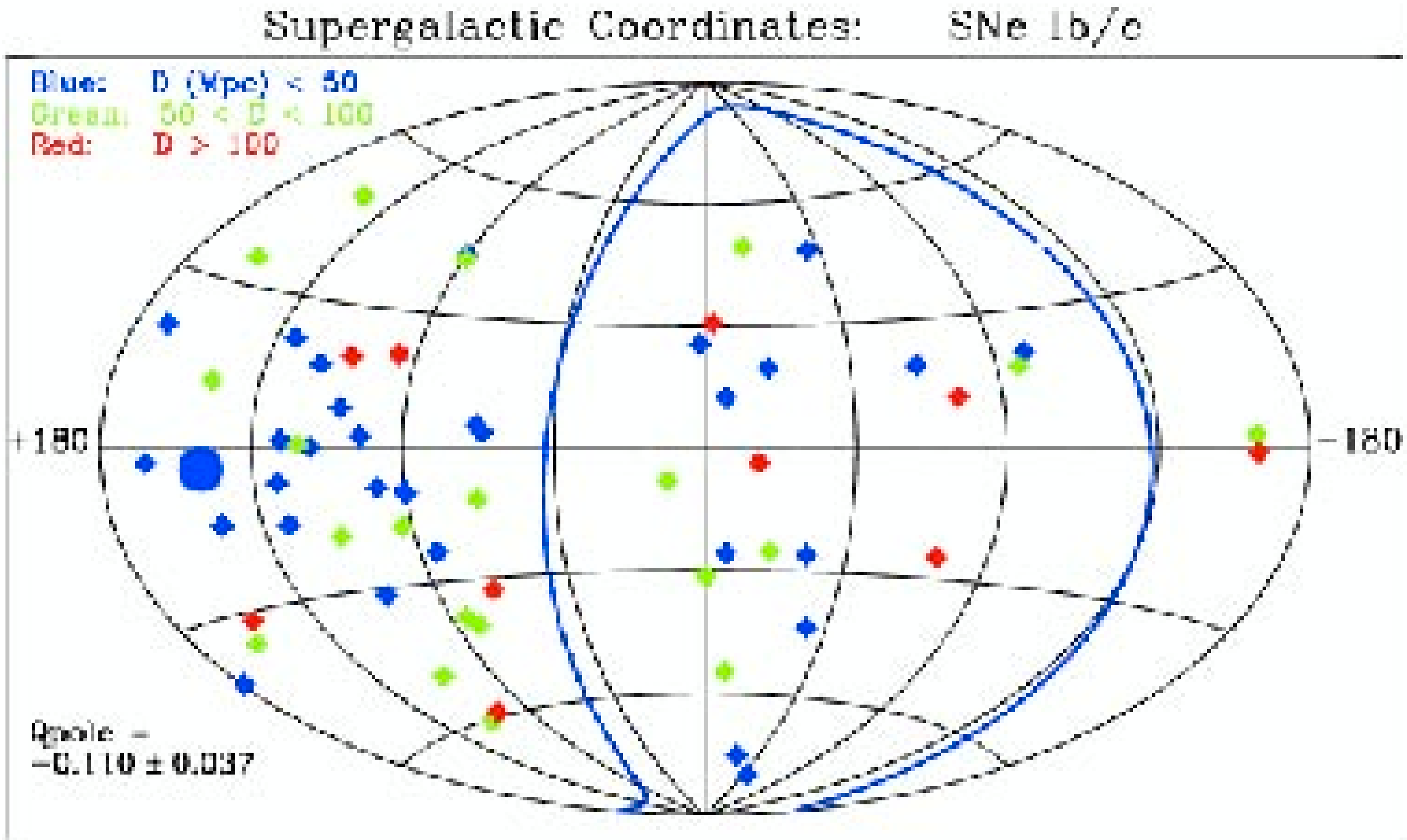


Figure 10. Three-dimensional isodensity contour plots of the local Universe. The density field (average mask model) has been smoothed with a 500 km s^{-1} Gaussian filter. Only features within 8000 km s^{-1} are shown. The Local Group lies at the centre of the plot (indicated by an 'x'), with the North Galactic Pole towards the top of the box (the Z-axis). The X-axis is towards the Galactic Centre and the Y-axis is in the direction of galactic rotation. Superclusters are labelled with the name of the nearest cluster or group. The isodensity contour is at $\delta_L = 1.5$. (a) The viewpoint is from $l = 35°$, $b = 25°$, nearly perpendicular to the Supergalactic Plane. (b) The viewpoint has been rotated by 90° in longitude so that it is almost aligned with the Supergalactic Plane; it is now from $l = 125°$, $b = 25°$. Note the concentration of superclusters towards the Supergalactic Plane.



Supergalactic Coordinates: Long-Log GRBs
+180
-180
971208
980425
Virgo

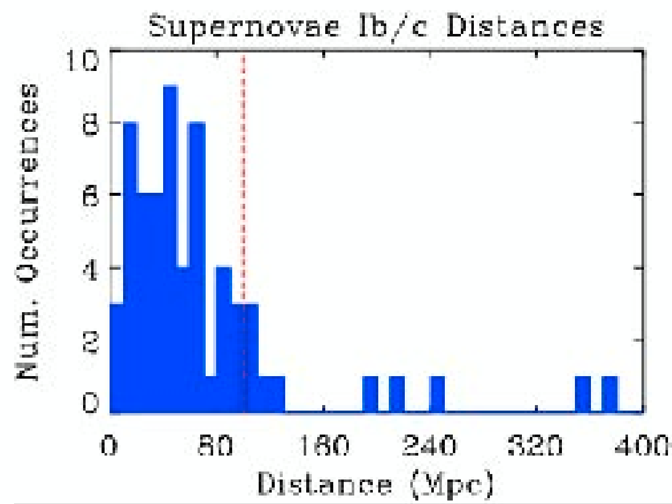


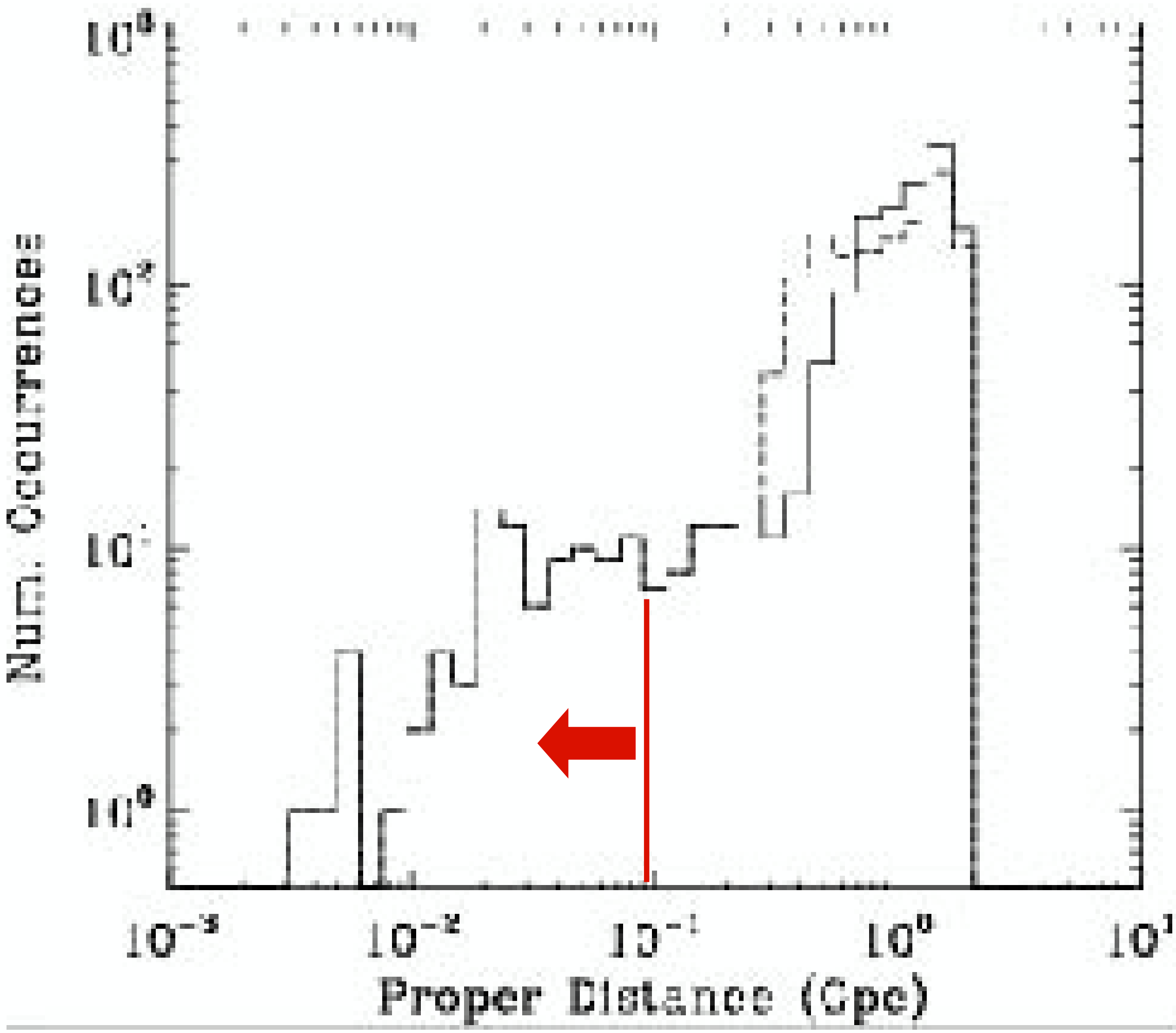
SNe Ib/Ic : 62 detected 1954-2001.75,

(> 2/3 since 1998.0)

With 85% at distances < 100 Mpc.

Only ~10% of "nearby" SNe are detected.





See ~ 90 GRB Sources w/in 100 Mpc: R_{GRB} ~ 100/yr ~ _ $R_{SNIb/c}$

Grav. Wave Strain h > 10^{-24} ➜ Possible LIGO II sources

Possible Confirmation Approaches

(1) Untriggered BATSE bursts: For F_p < 0.25 ph cm^{-2} s^{-1} long-lag bursts predominate. But, larger localization errors; ID'ing as bona fide GRBs is problematic.

(2) ~ 400-500 additional triggered BATSE bursts.

(3) Cross-correlation of nearby matter distribution (d < 100 Mpc) and GRB positions (M. Hudson).

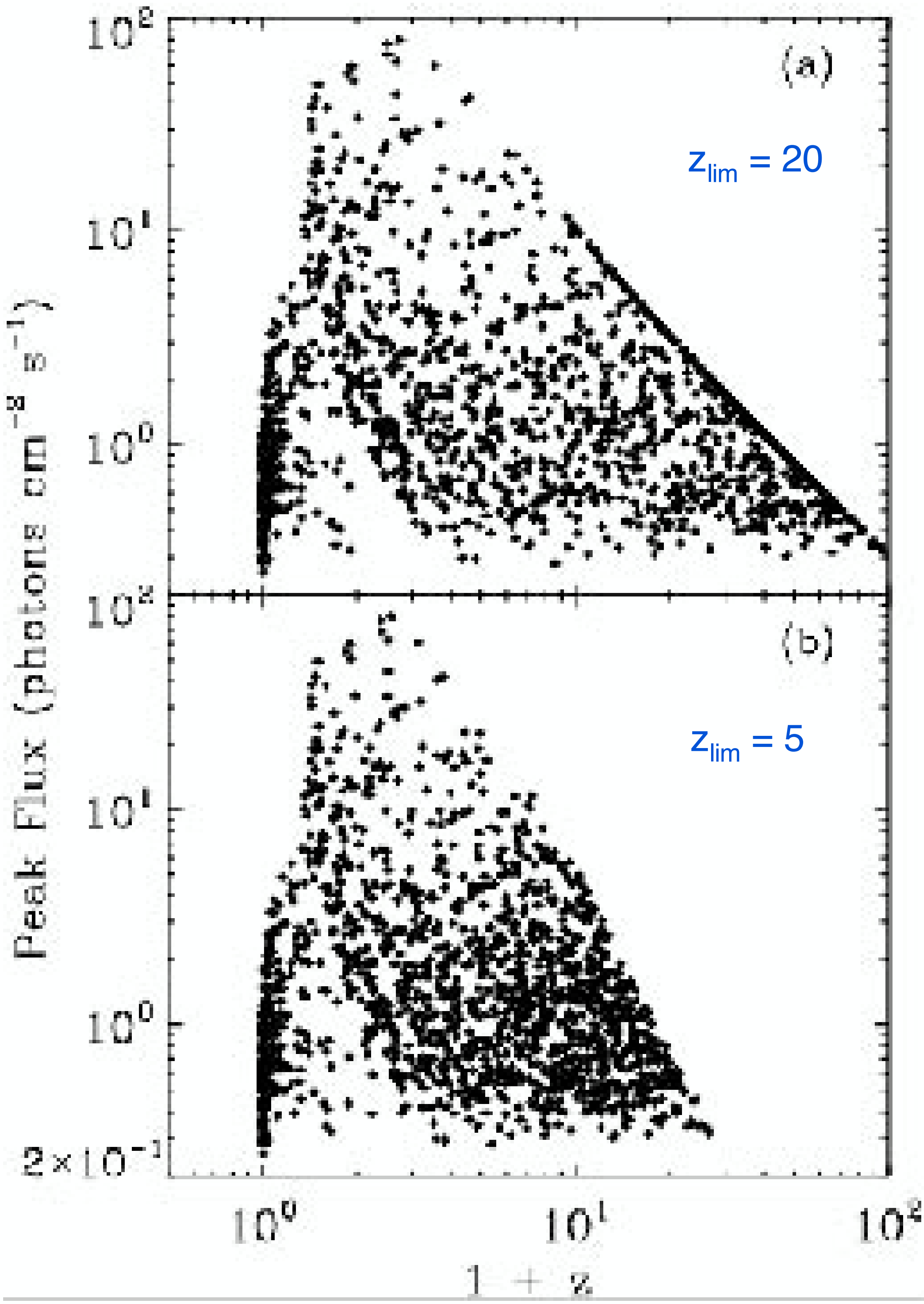
(4) Extrapolation of SNe light curves to T_0, comparison with GRB times and positions (J. Bonnell).

(5) Swift

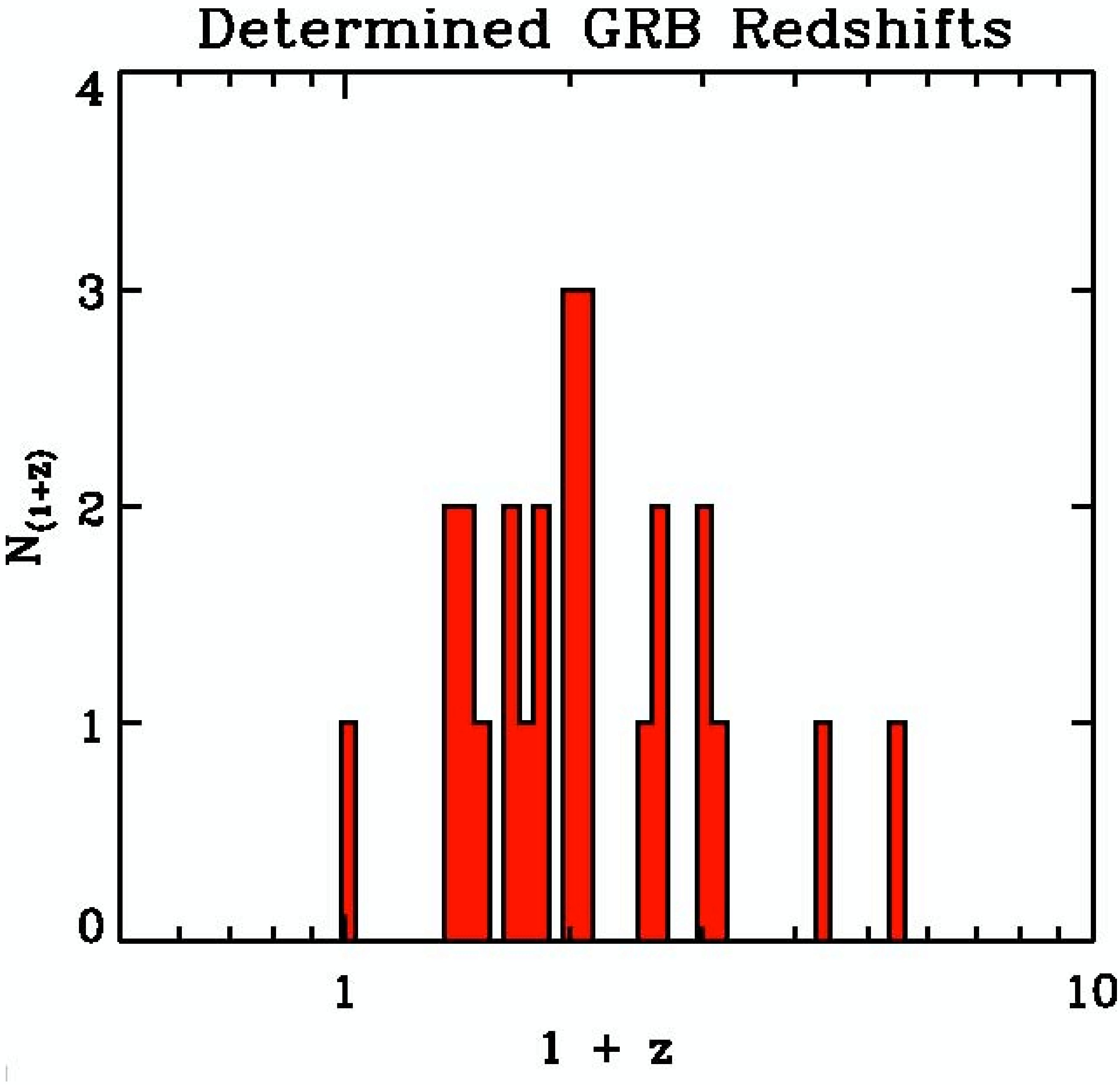
Conclusions/Predictions:

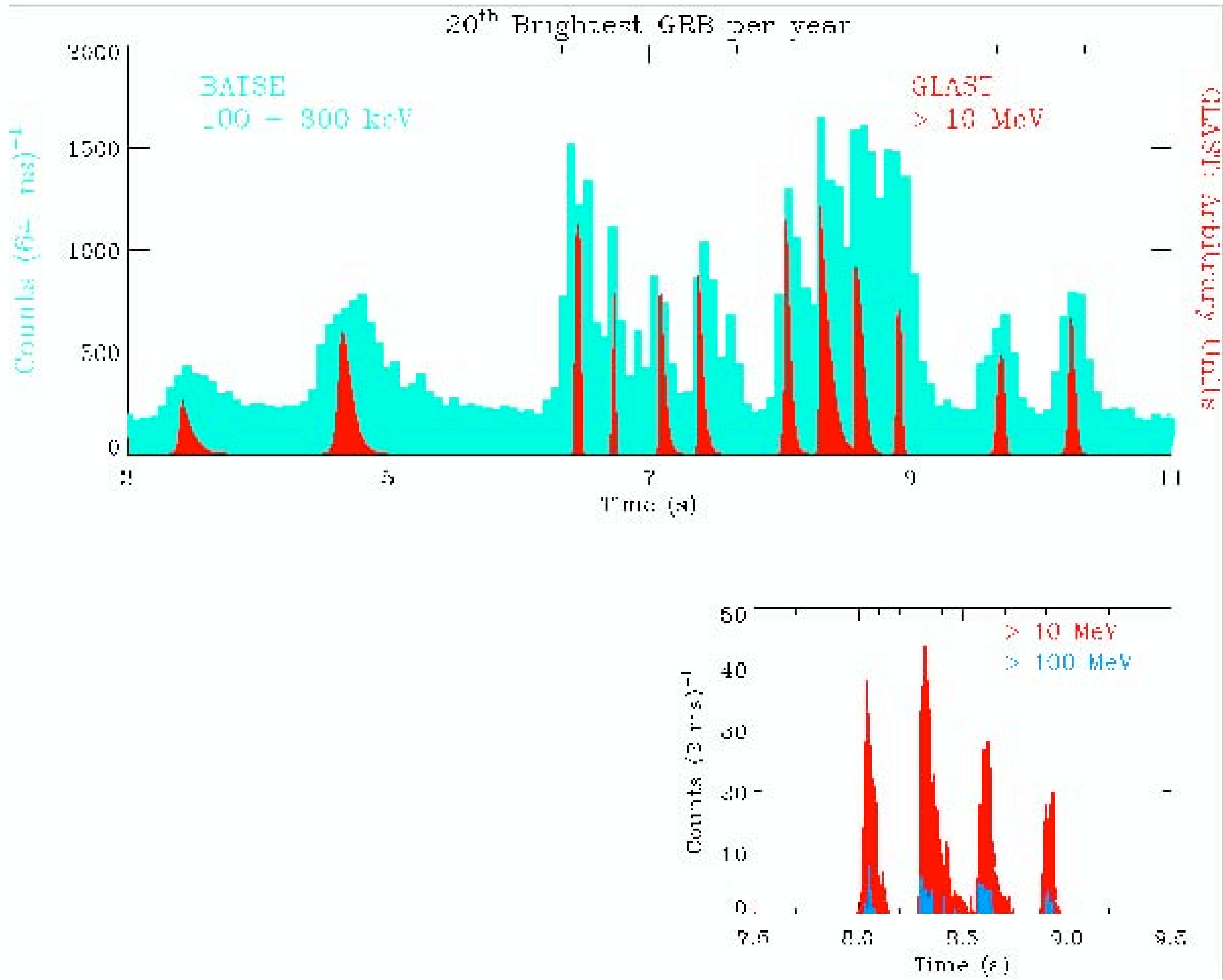
➢ **Near BATSE trigger threshold: Long-lag (ultra low-Luminosity) GRBs become numerous (~ 50% of BATSE sample):**

- For Long-lag GRBs (□$_{ag}$ > 0.35 s), $N(>F_p)$ $F_p^{-3/2}$
- Long-lag GRBs have very soft spectra.
- For □$_{ag}$ > 1.5 s ➔ >2 □ Quadrupole w.r.t. Super-G plane.
- R_{GRB} ~ 100/yr ~ _ $R_{SNIb/c}$.
- LIGO II sources?
- Swift should see a larger fraction of "really long-lag" GRBs. ➔ Many chances to find the associated SNe. Untriggered BATSE bursts should be dominated by "really long-lag" GRBs.



(a)
z_{lim} = 20
(b)
z_{lim} = 5
Peak Flux (photons cm^{-2} s^{-1})
1 + z


Determined GRB Redshifts
4
3
2
1
0
$N_{(1+z)}$
1
10
1 + z



20th Brightest GRB per year
BATSE
100 – 300 keV
GLAST
> 10 MeV
Counts (64 ms)$^{-1}$
GLAST: Arbitrary Units
Time (s)
> 10 MeV
> 100 MeV
Counts (2 ms)$^{-1}$
Time (s)

Rock of Ages

Wit's Edn by Dave Barry

By Dave Barry
Sunday, February 17, 2002; Page W44

You can skip this column. I'm sure you have more important things to do. You don't need to waste your valuable time reading about how MILLIONS OF PEOPLE, POSSIBLY INCLUDING YOU, RECENTLY WERE ALMOST KILLED BY A GIANT SPACE ROCK. And there are more coming and nobody is doing anything about it. Excuse me for going into CAPS LOCK mode, but I am a little upset here. In case you didn't hear about it, which you probably didn't: On January 7, an asteroid 1,000 feet across -- nearly three times the current diameter of Marlon Brando -- barely missed Earth, which is most likely your planet of residence.

What do I mean by "barely"? I mean that this asteroid, traveling at 68,000 mph, came within 400,000 miles. In astronomical terms, that is nothing. To get an idea how close this thing came, imagine that your head is Earth. Now hold your right hand, representing the sun, at arm's length. Now take your left forefinger, representing the asteroid, and move it toward Earth at 68,000 mph until your pinkie is up to the knuckle in your left nostril. Now try to type a sentence. That is what I mean by "barely."

... As it happens, the American Astronomical Society was holding a conference in Washington at the very same time as the asteroid nearly hit Earth. I know this because the New York Times covered the heck out of the conference. Here's the scary part: The Times did not print one word about the asteroid. Instead, as this thing whizzed past, the Times printed the following exciting astronomy news:

JANUARY 8 -- Astronomers have discovered that certain gamma rays, which they used to think came from billions of light-years away, in fact came from only a few hundred million light-years away!

JANUARY 9 -- Having studied the far edges of the universe with the Hubble telescope, astronomers now believe that roughly 14 billion years ago, stars formed more quickly than was previously thought!

JANUARY 10 -- Astronomers "peering deep into the heart of the Milky Way" have discovered more than 1,000 sources of "powerful X-rays," far more than were previously known!