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FEBRUARY 1998

FEBRUARY'S SOLAR ECLIPSE:
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FROM A CITY

Gamma Rays of Doom

Why You Should Worry About Merging Neutron Stars

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Pairs of Neutron Stars in Our Galaxy

Name	Distance	Period	Decay Time
PSR B1534+12	0.5 kpc	10.1 hr	2.73 Gyr
PSR B1913+16 [1]	7.3 kpc	7.75 hr	0.30 Gyr
PSR B2127+11C [2]	10.6 kpc	8.05 hr	0.22 Gyr
PSR B2303+46 [3]	2.3 kpc	296 hr	4000 Gyr
PSR J1518+4904 [3]	0.7 kpc	207 hr	2400 Gyr

Notes: 1. Hulse-Taylor pulsar (1st direct evidence for gravitational rad.)
2. In Globular Cluster M13
3. Suspected binary neutron stars, masses not firmly established

Supernova NS "kicks": ~ 10^3 km/s $\times$ 1 Gyr → ~ 1 Mpc ☹☹☹

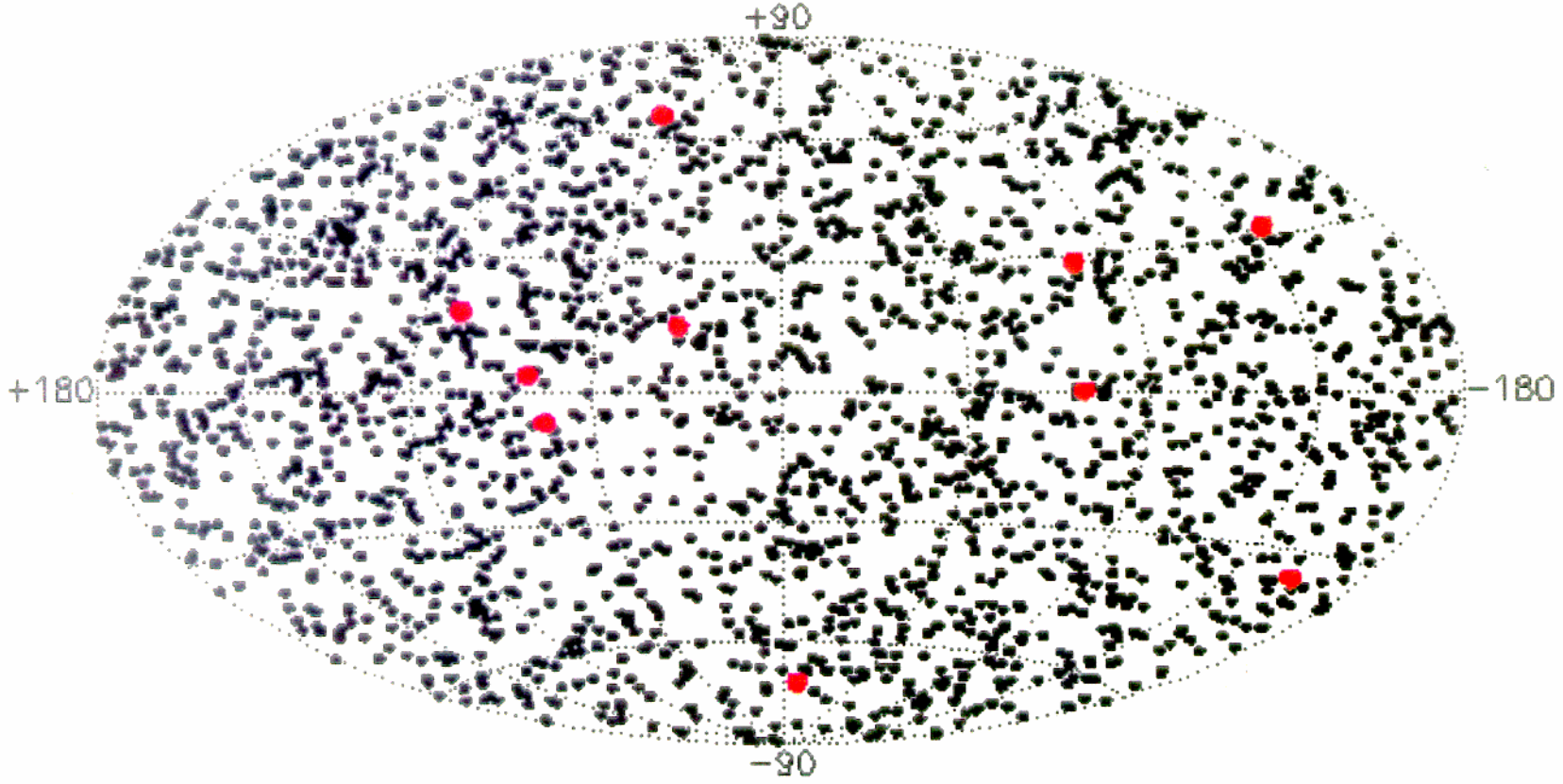
Selected Length Scales (Adapted from © Niel Brandt niel@ast.cam.ac.uk)

1.4×10^{-15}	meters			Rough nuclear radius
5.3×10^{-11}	meters			Hydrogen atom radius
1.8	meters			Humans
6.3×10^{6}	meters			Earth's radius
7×10^{8}	meters	2×10^{-8}	pc	Sun's radius
1.5×10^{11}	meters	5×10^{-6}	pc	Earth-to-Sun mean distance (1 Astronomical Unit = 1 AU)
2×10^{15}	meters	0.065	pc	♣ Oort Cloud size (Sun's "Sphere of Influence")
3.08×10^{16} meters = 1 parsec (pc) = 3.26 light-years = 206,265 AU				
4×10^{16}	meters	1.3	pc	Sun to nearest star (Proxima Centauri)
3×10^{17}	meters	10	pc	Supernova biological extinction radius
5×10^{18}	meters	170	pc	Distance to supergiant Betelgeuse (supernova in 10^4 yrs)
1.5×10^{19}	meters	500	pc	♣ Milky Way semi-thickness (~ 95% of stars contained)
3×10^{19}	meters	1	Kilo pc	Gamma-Ray Burst biological extinction radius ?
4×10^{20}	meters	13	Kilo pc	♣ Milky Way disk radius
2×10^{21}	meters	65	Kilo pc	♣ Rough Milky Way dark matter halo radius
2×10^{22}	meters	600	Kilo pc	♣ Distance to M31 (Andromeda Nebula)
7×10^{23}	meters	22	Mega pc	Distance to center of Virgo cluster of galaxies
3×10^{25}	meters	1	Giga pc	♣ Luminosity distance to z=0.158 quasar 3C273
1.5×10^{27}	meters	5	Giga pc	♣ Most distant known quasars, Gamma-Ray Bursters

Selected Power Scales (Adapted from © Niel Brandt niel@ast.cam.ac.uk)

150	watts			Human being under normal conditions
2×10^4	watts			Car
1×10^5	watts			Running Tyrannosaurus Rex
3×10^8	watts			Nuclear power reactor
3×10^8	watts			Rough thunderstorm electrical power generation rate
3×10^{11}	watts			USA average electricity usage rate in 1986
8×10^{13}	watts			Powerful nanosecond pulse laser
4×10^{26}	watts	=	1 L_o =	Solar luminosity
4×10^{30}	watts		1×10^4 L_o	Cygnus X-1 X-ray luminosity (few solar-mass black hole)
1×10^{31}	watts		3×10^4 L_o	Crab Nebula energy output
1×10^{35}	watts		3×10^8 L_o	Rough luminosity of Galactic-halo gamma-ray burst
5×10^{35}	watts		1×10^9 L_o	Type II supernova peak photon luminosity
3×10^{36}	watts		8×10^9 L_o	Milky Way power output
1×10^{39}	watts		3×10^{12} L_o	10^8 solar mass accreting black hole (~ quasar luminosity)
2×10^{41}	watts		5×10^{14} L_o	Luminosity of z=2.286 ultraluminous galaxy F10214+4724
2×10^{45}	watts		5×10^{18} L_o	Isotropic luminosity of GRB 971214 (T_{50} dur ~ 20 s; z = 3.412)

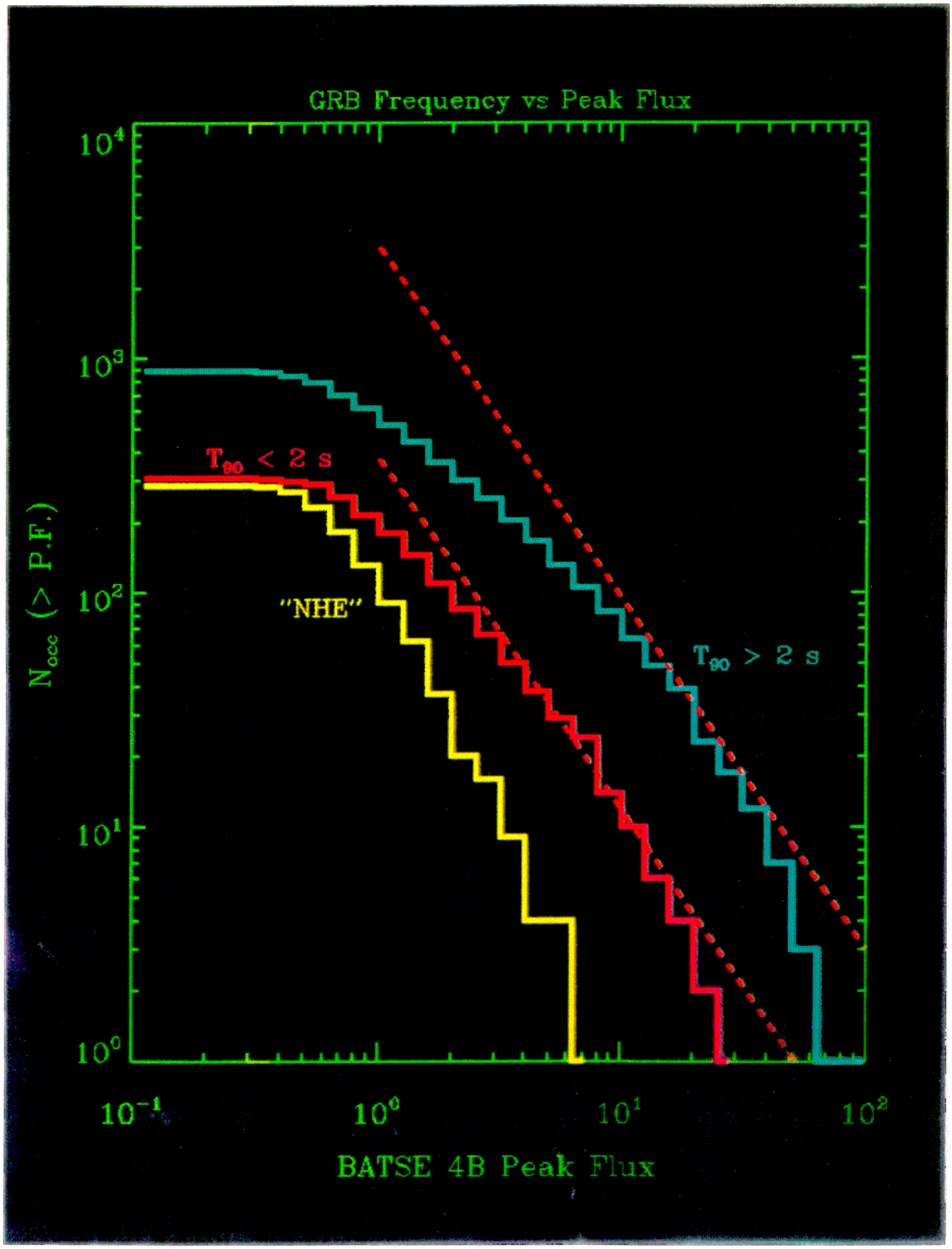
GRB Sky Distribution in Galactic Coodinates:
Seven Years of BATSE Observations



2109 Events

Map by Robert Mallozzi

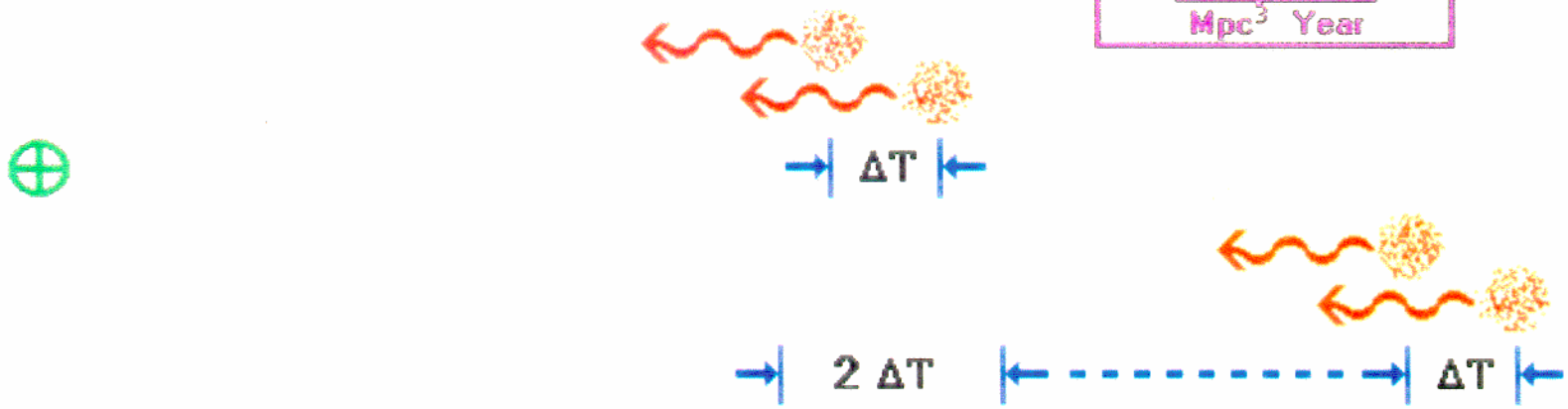
J. Norris, SSI 1998



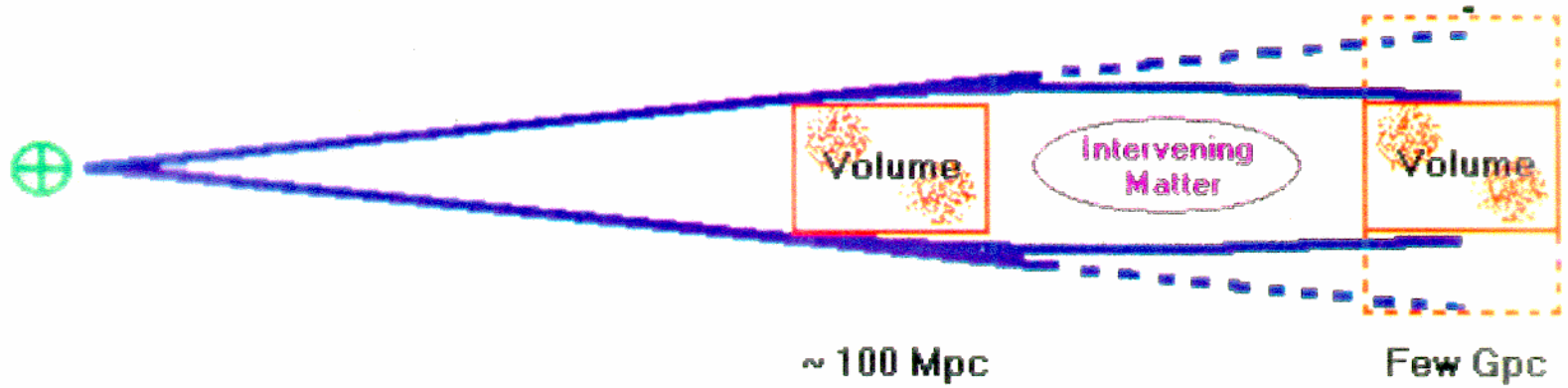
Time Dilation

Constant "Universal" GRB Rate Density:

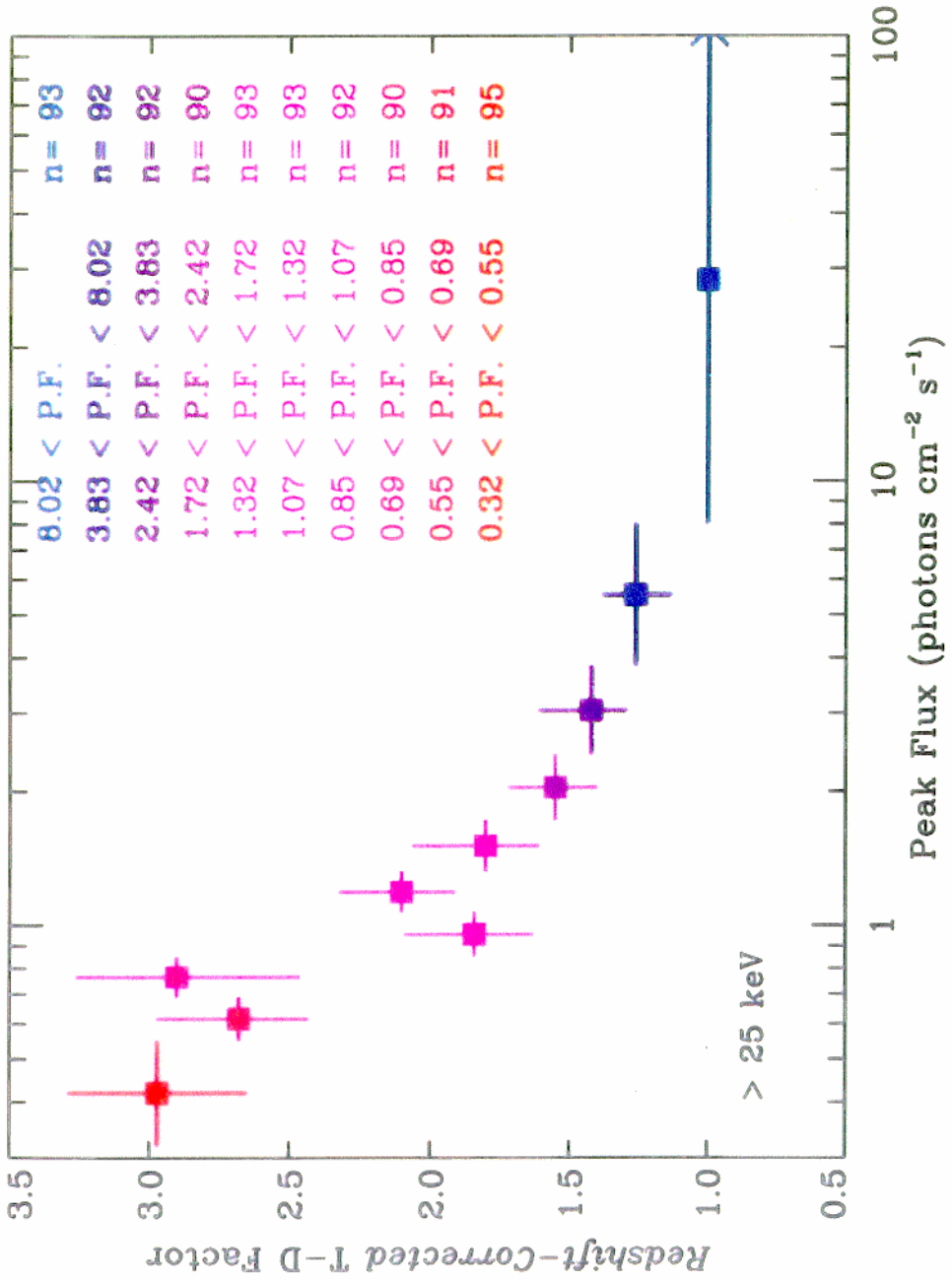
$$\frac{\text{Bursts}}{\text{Mpc}^3\ \text{Year}}$$

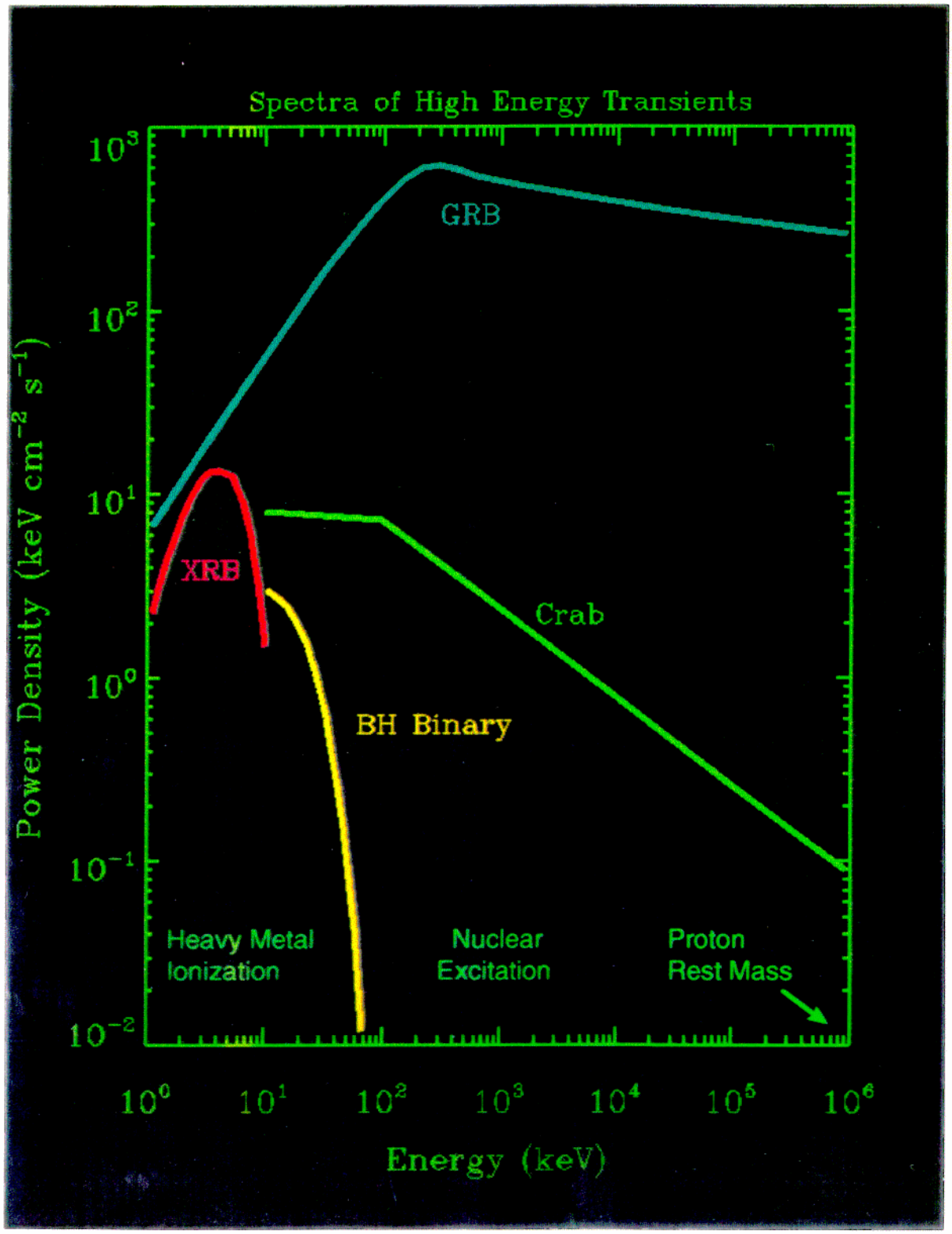


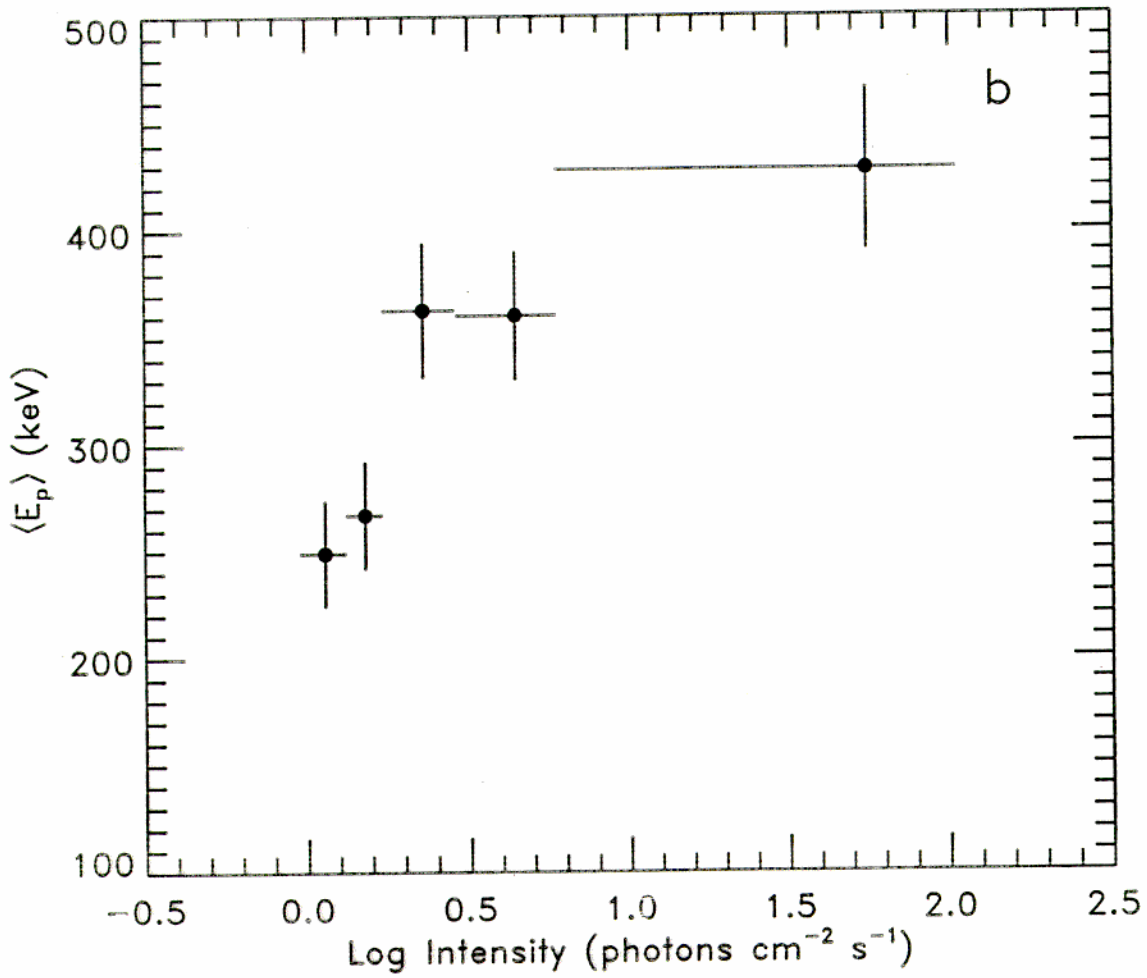
Gravitational Lensing



J. Norris, SSI 1998



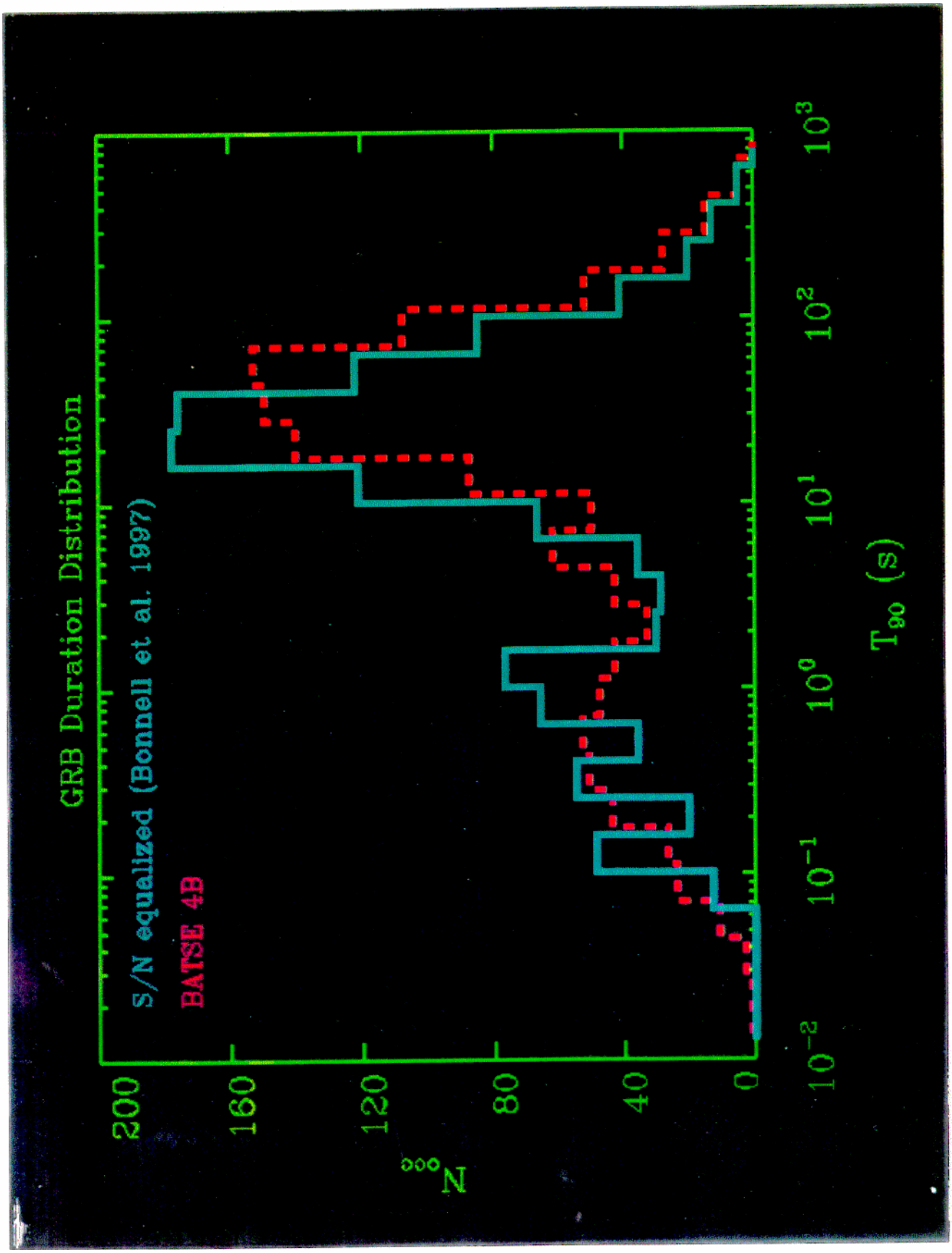




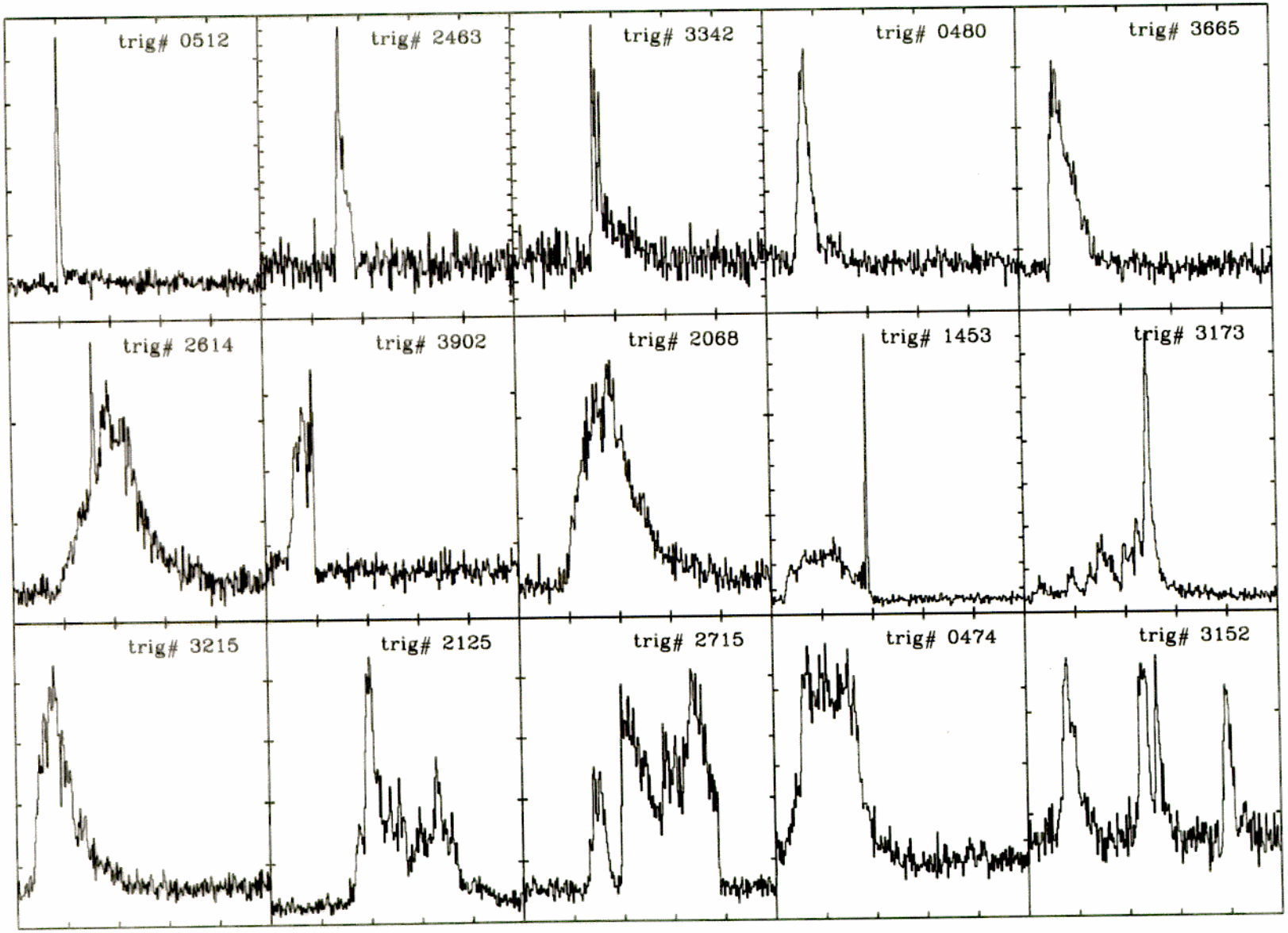
The $\nu\mathcal{F}_\nu$ Peak Energy Distributions of Gamma-Ray Bursts Observed by BATSE

Robert S. Mallozzi[1,2], William S. Paciesas[1,2], Geoffrey N. Pendleton[1,2]
Michael S. Briggs[1,2], Robert D. Preece[1,2]
Charles A. Meegan[2], Gerald J. Fishman[2]

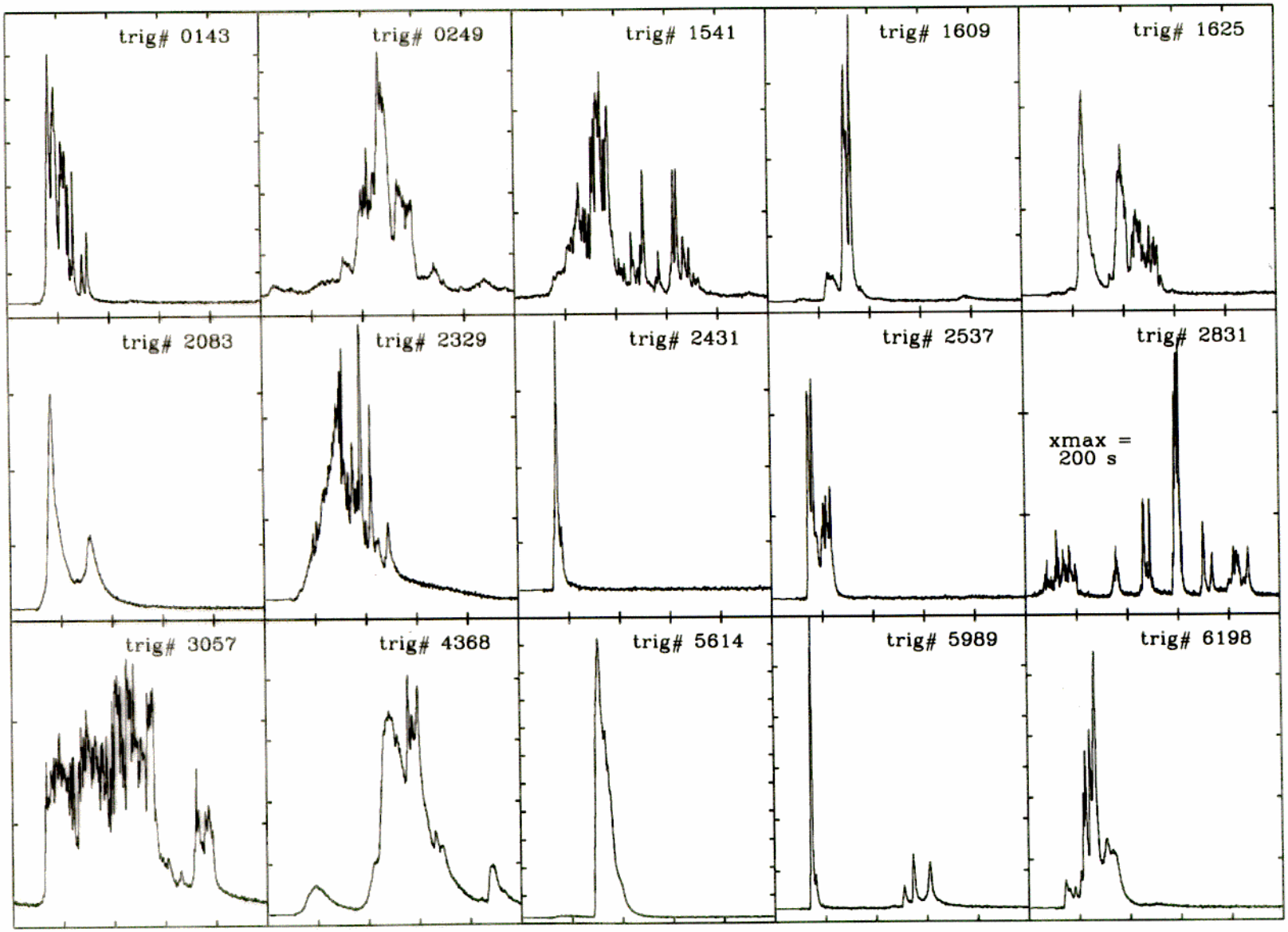
J. Norris, SSI 1998



Bright, Short Bursts: $T_{90} < 2$ s resolution = 2 ms xmax = 500 ms



Bright, Long Bursts: $T_{90} > 2$ s resolution = 64 ms xmax = 50 s



Summary, Pre-Afterglow Era: GRB Extrinsic, Intrinsic Statistics

Four Pieces of Evidence favored Cosmological Distance Scale
(And were consistent with redshifts z ~ 1–3 for dimmer bursts)

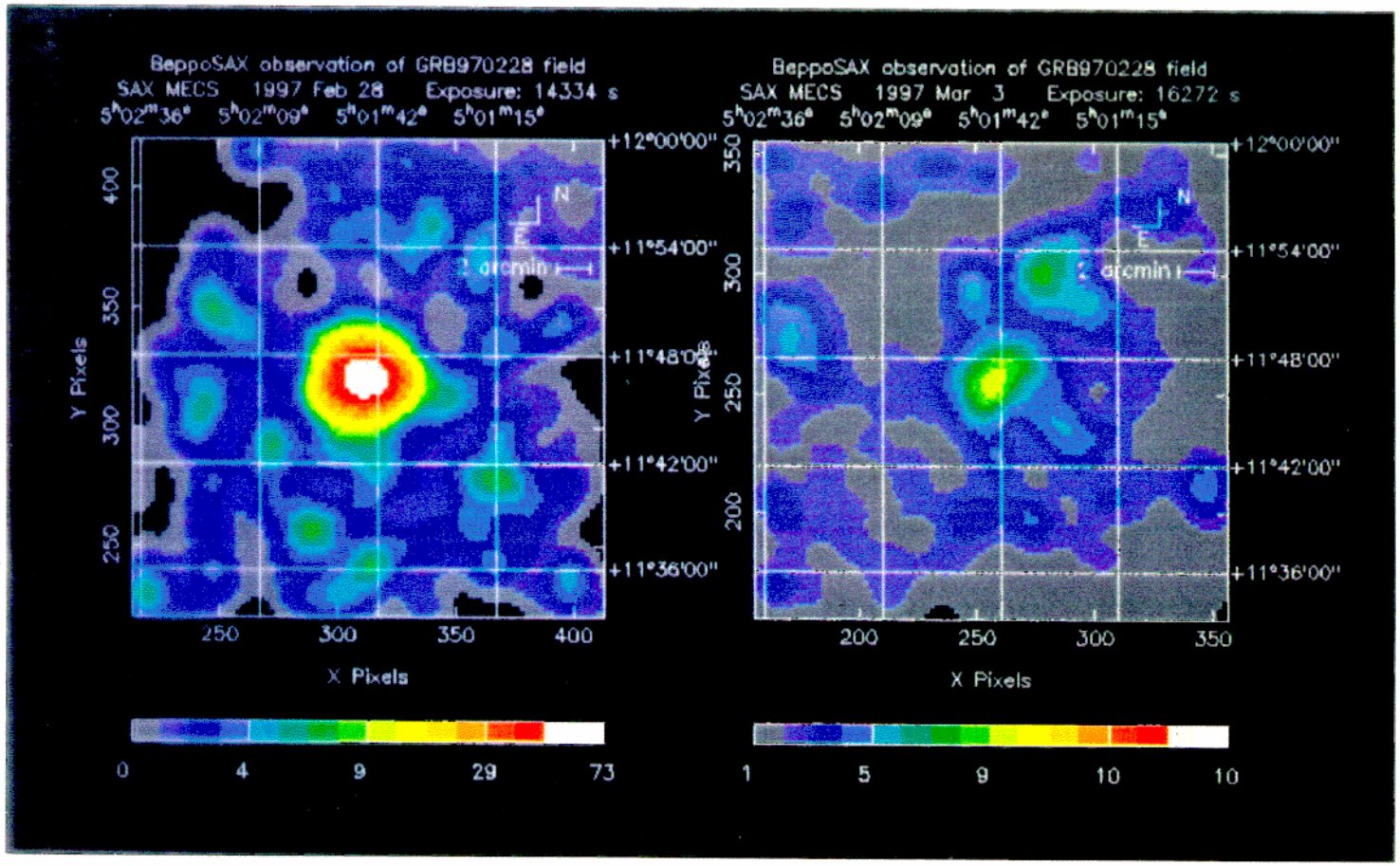
- **Isotropy of Burst Positions – No indication of Dipole, or Quadrupole**
- **Dimmest Bursts Undernumerous – As if Edge of Distribution Sampled**
- **Time Dilation of Temporal Structure, Dimmest Bursts Relative to Brightest**
- **Apparent Redshift of Spectra, Dimmest Bursts Relative to Brightest**

GRBs have a Bimodal Duration Distribution.

If you've seen one GRB, you've seen one GRB – Each one is different.

There was no good evidence for repetition – Catastrophic Explosions?

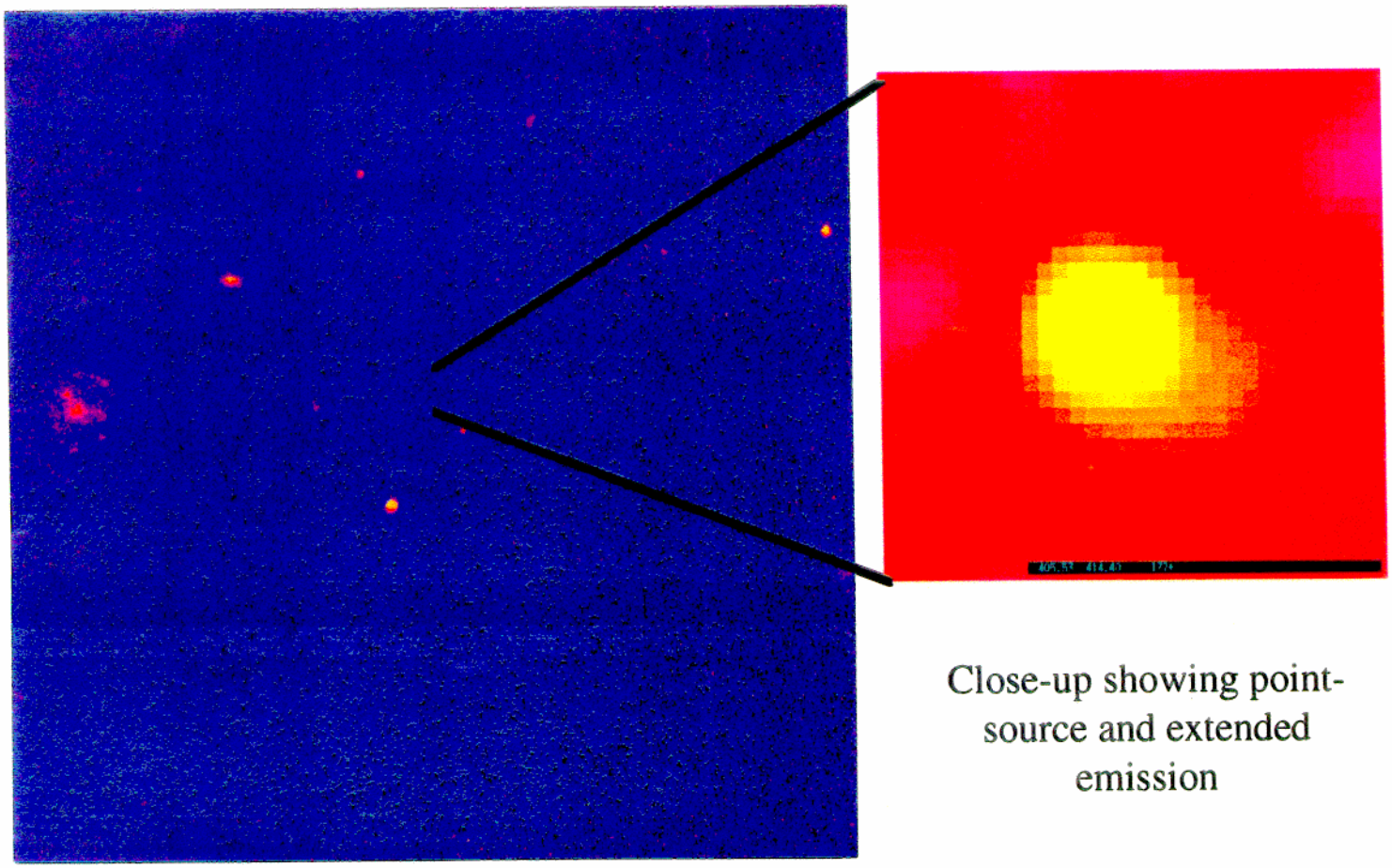
GRB 970228 Field: BeppoSAX Observation



February 28

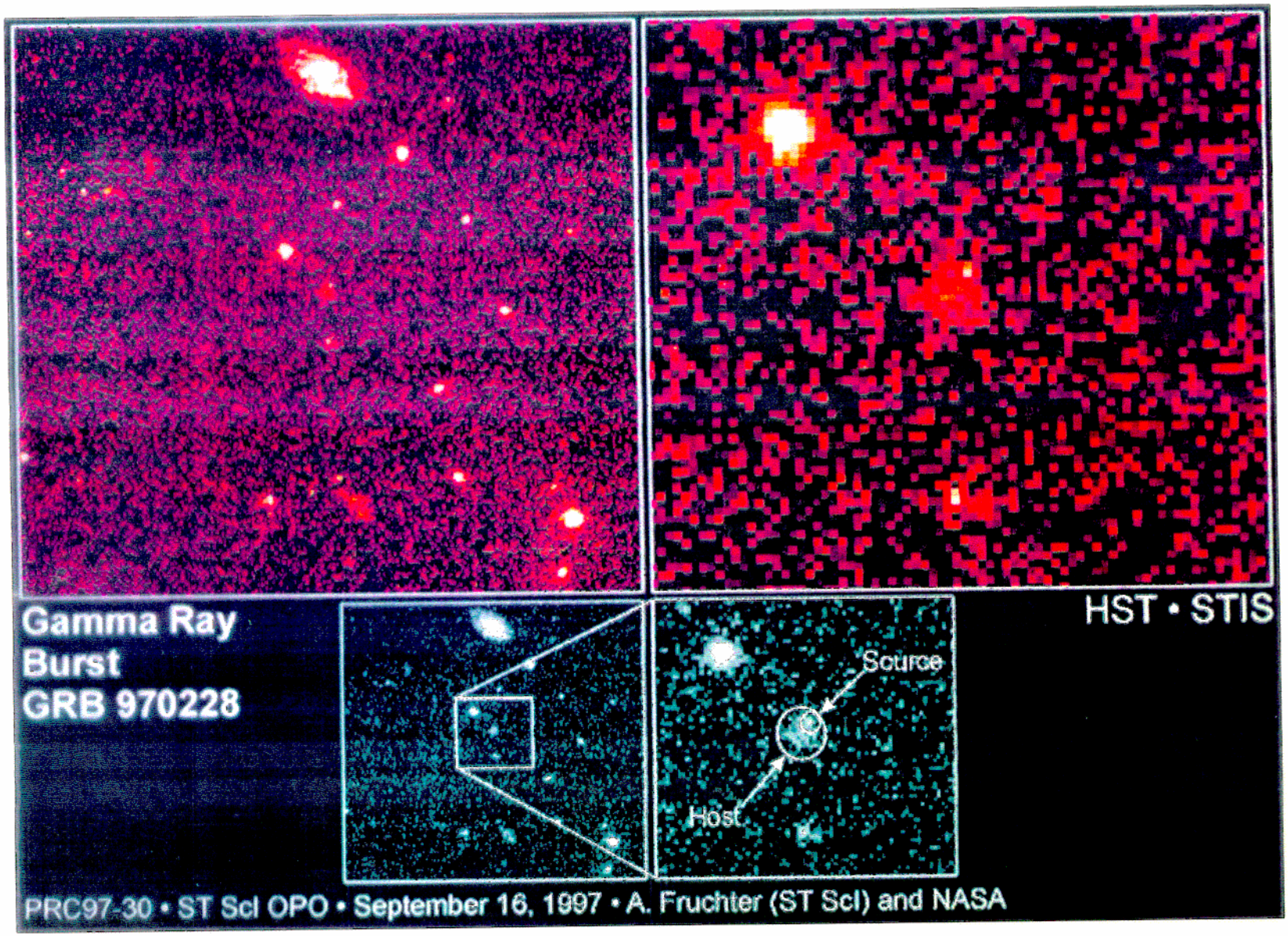
March 3

March 26: HST Observation of Optical Transient



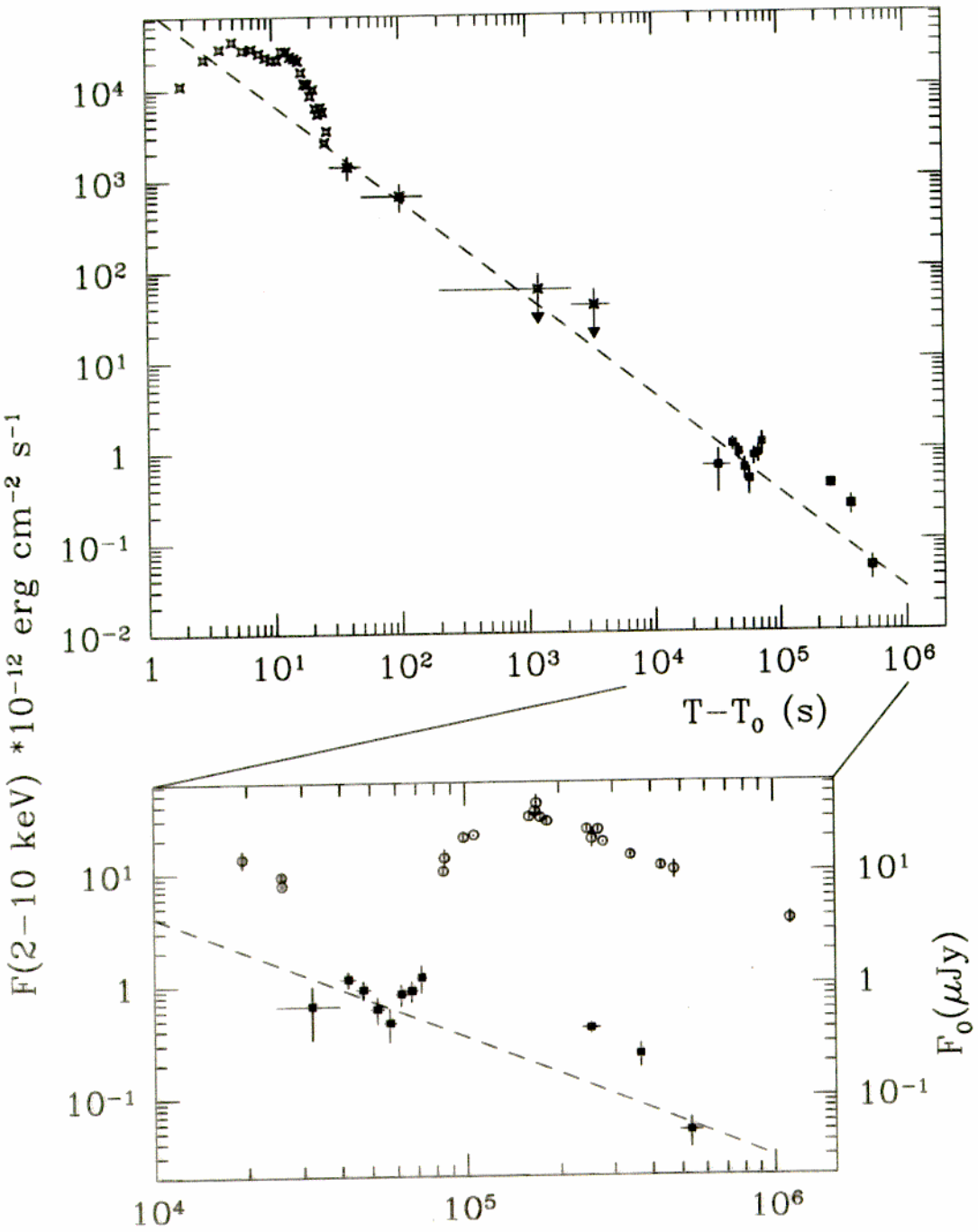
Close-up showing point-source and extended emission

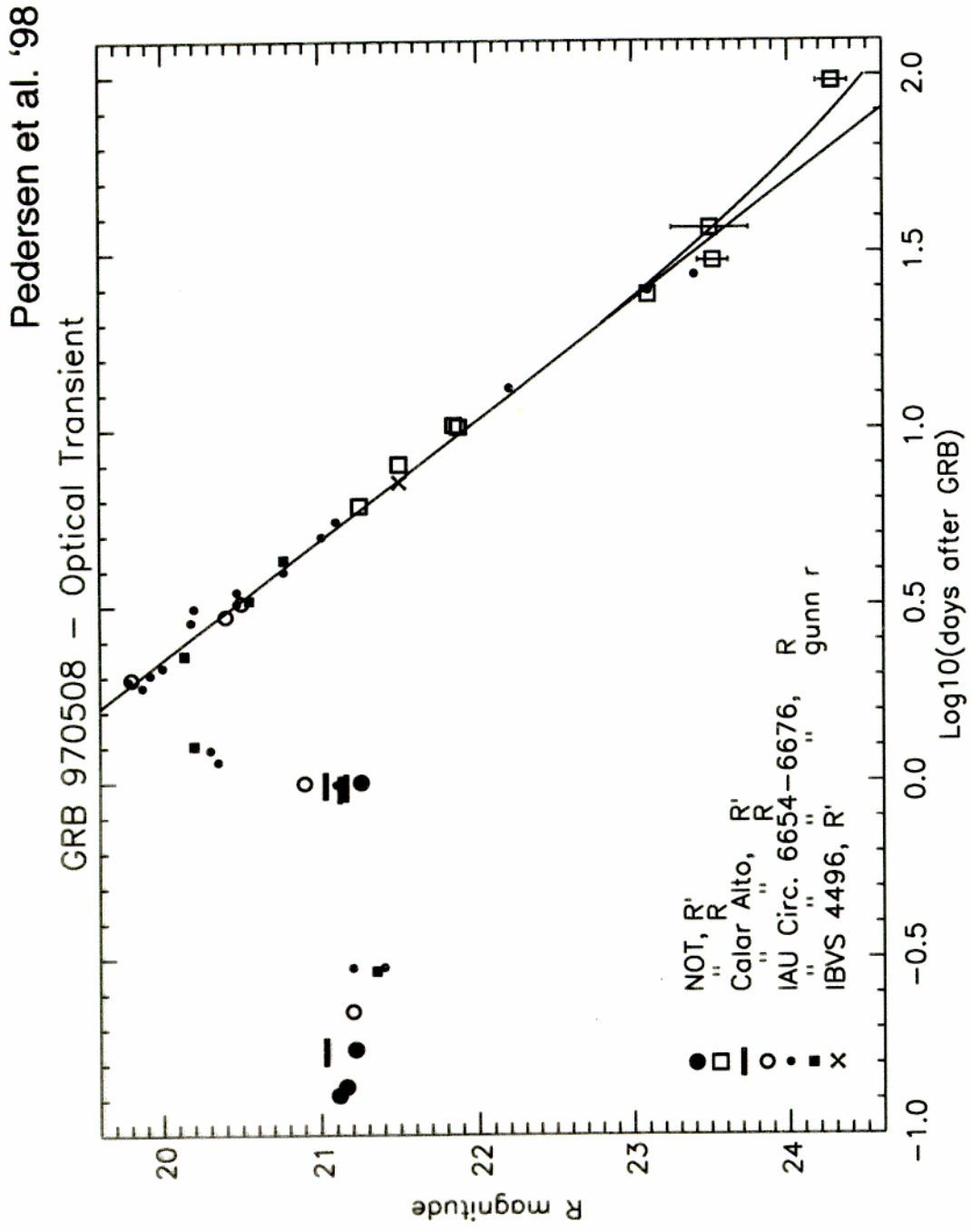
WFPC2 Visual Band image



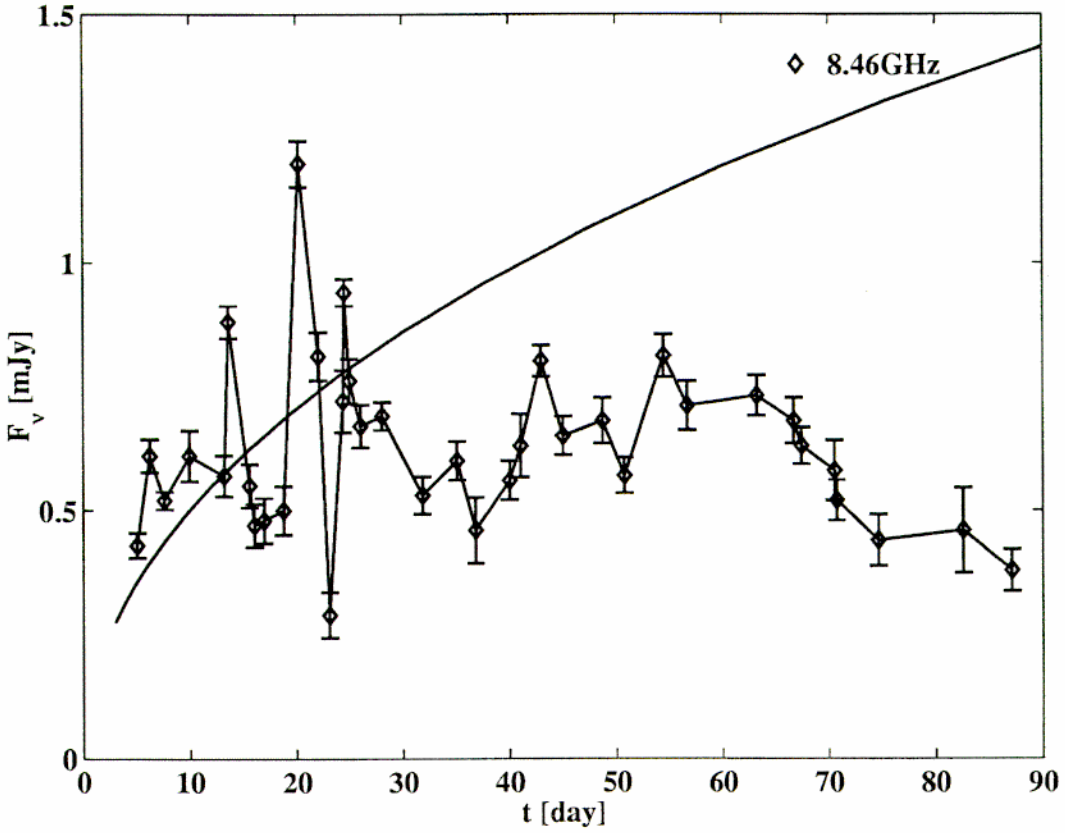
GRB970508: X-ray light curve

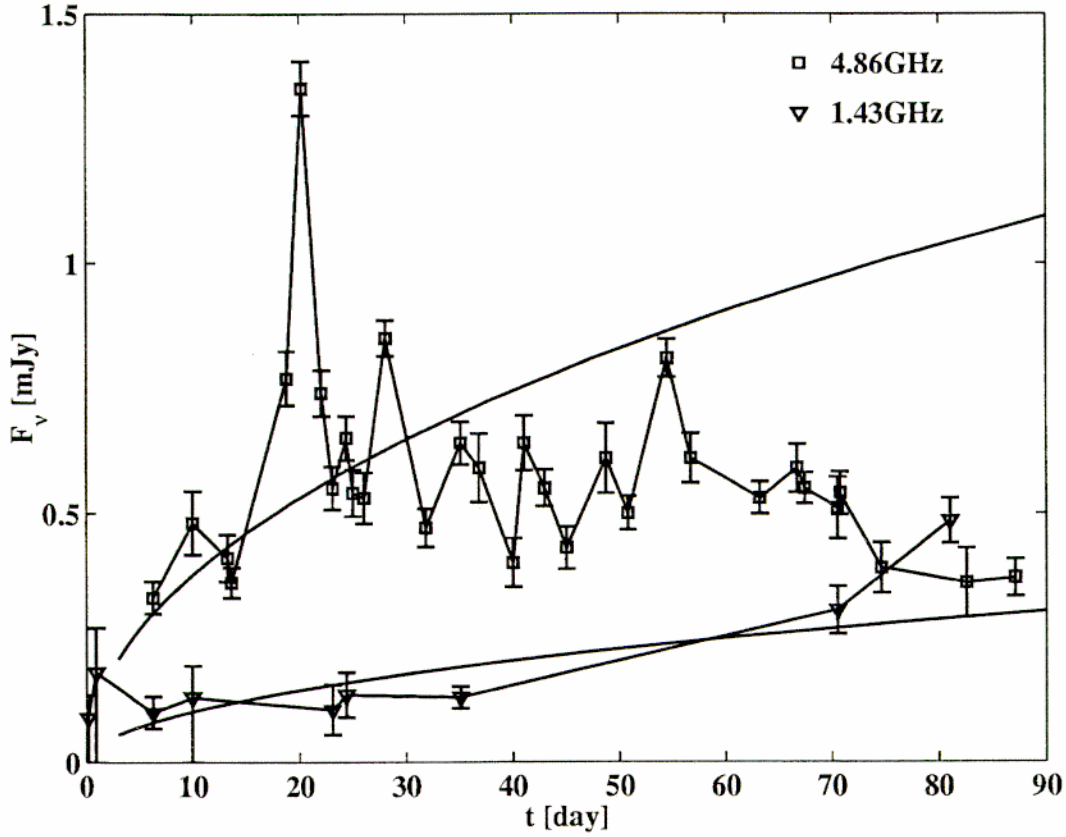
Piro et al. '98





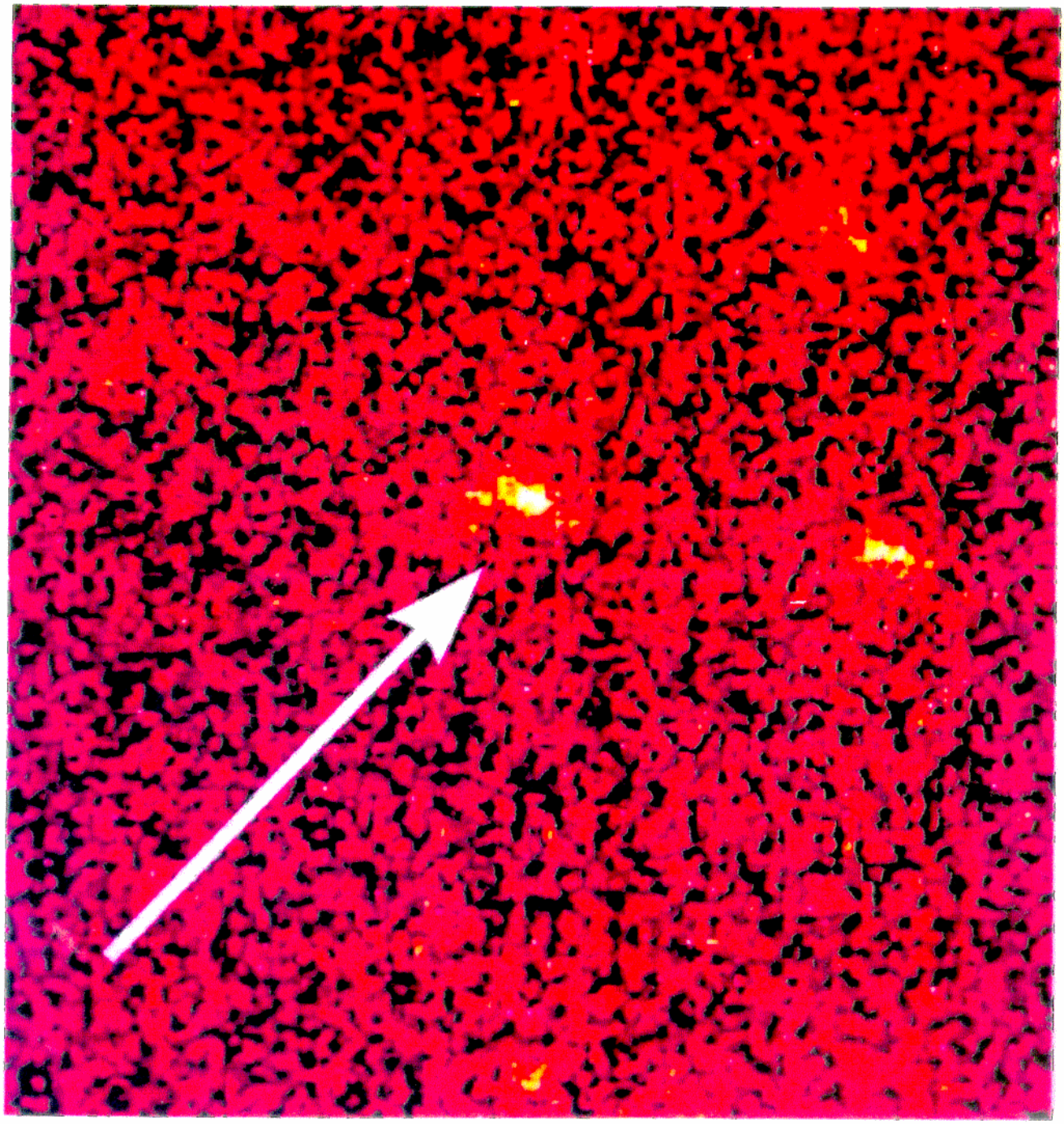
GRB970508: Radio light curves Waxman et al. '98

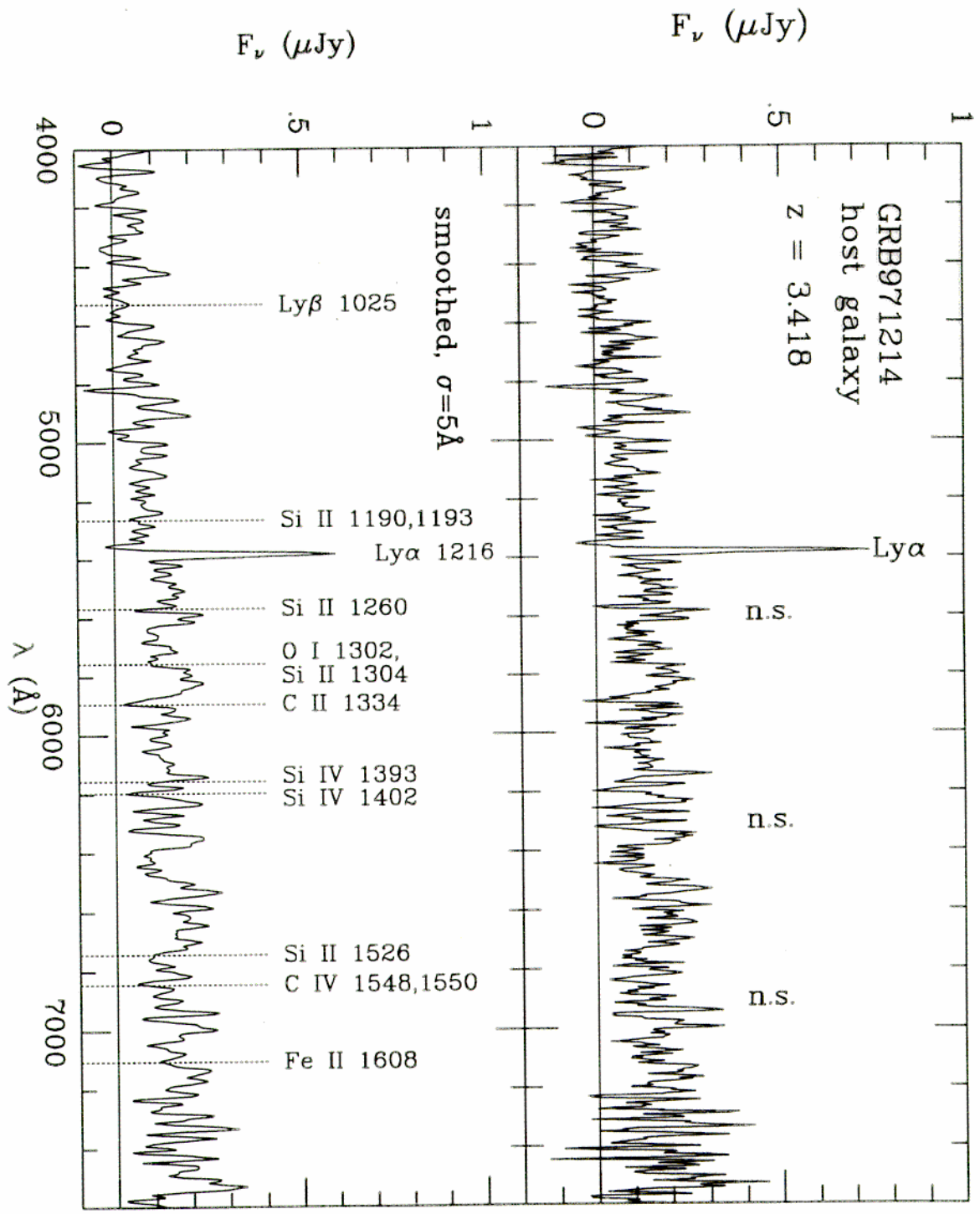




Gamma Ray Burst 971214
Hubble Space Telescope • STIS

PRC98-17 • ST ScI OPO • May 7, 1998 • S. R. Kulkarni and S. G. Djorgovski (Caltech), the Caltech GRB Team and NASA





Gamma-Ray Bursts with Optical Counterparts

GRB Date yymmdd	γ-ray Pk Flux† photon cm^{-2} s^{-1} (50–300 keV)	X-ray Pk Flux erg cm^{-2} s^{-1} (2–10 keV)	γ/x PF Ratio	Optical Pk Flux (R or V mag)	Comments Radio/Galaxy/etc.
970228	10.0	5.8×10^{-9}	1060	20.7	Galaxy, R = 24 mag
970508	1.2	2.3×10^{-8}	32	19.8	z = 0.835; Galaxy; Radio
971214	2.3	2.5×10^{-8}	56	21.7	Galaxy's z = 3.412
980326	1.3	*5.0×10^{-8}	16	21.0	Galaxy, R ≈ 25.5 mag
980329	13.3	2.4×10^{-8}	340	23.5	Galaxy, R ≈ 25.7 mag; Radio
980425	1.1	*3.8×10^{-8}	18	~ 13	SN1998bw, z = 0.0085
980519	6.9	*3.1×10^{-8}	140	20.4	Galaxy R ≈ 26 mag; Radio
980613	0.6	1.5×10^{-8}	25	22.9	Galaxy, R ≈ 24 mag
980703	2.4	4.2×10^{-8}	35	20.1	z = 0.966; Galaxy; Radio

* Converted from 2–28 keV band

† Conversion factor, photons to ergs, ≈ 6.15×10^{-7}

See the GRB Coordinates Network (maintained by Scott Barthelmy): http://gcn.gsfc.nasa.gov/gcn/

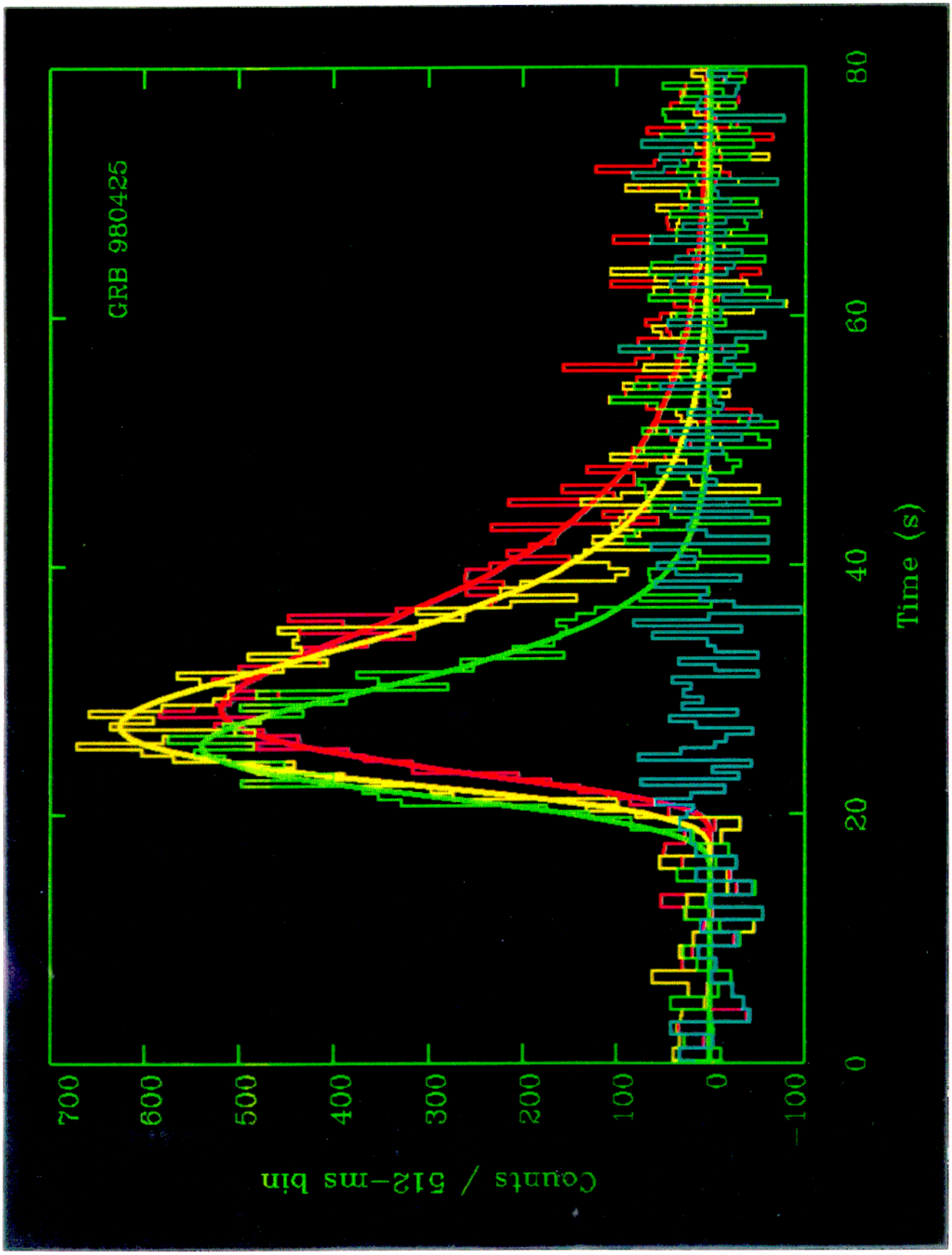
Summary, Afterglow Era

"Long" GRBs at Cosmological Distances;
Momentarily, Brightest Transients in the Universe

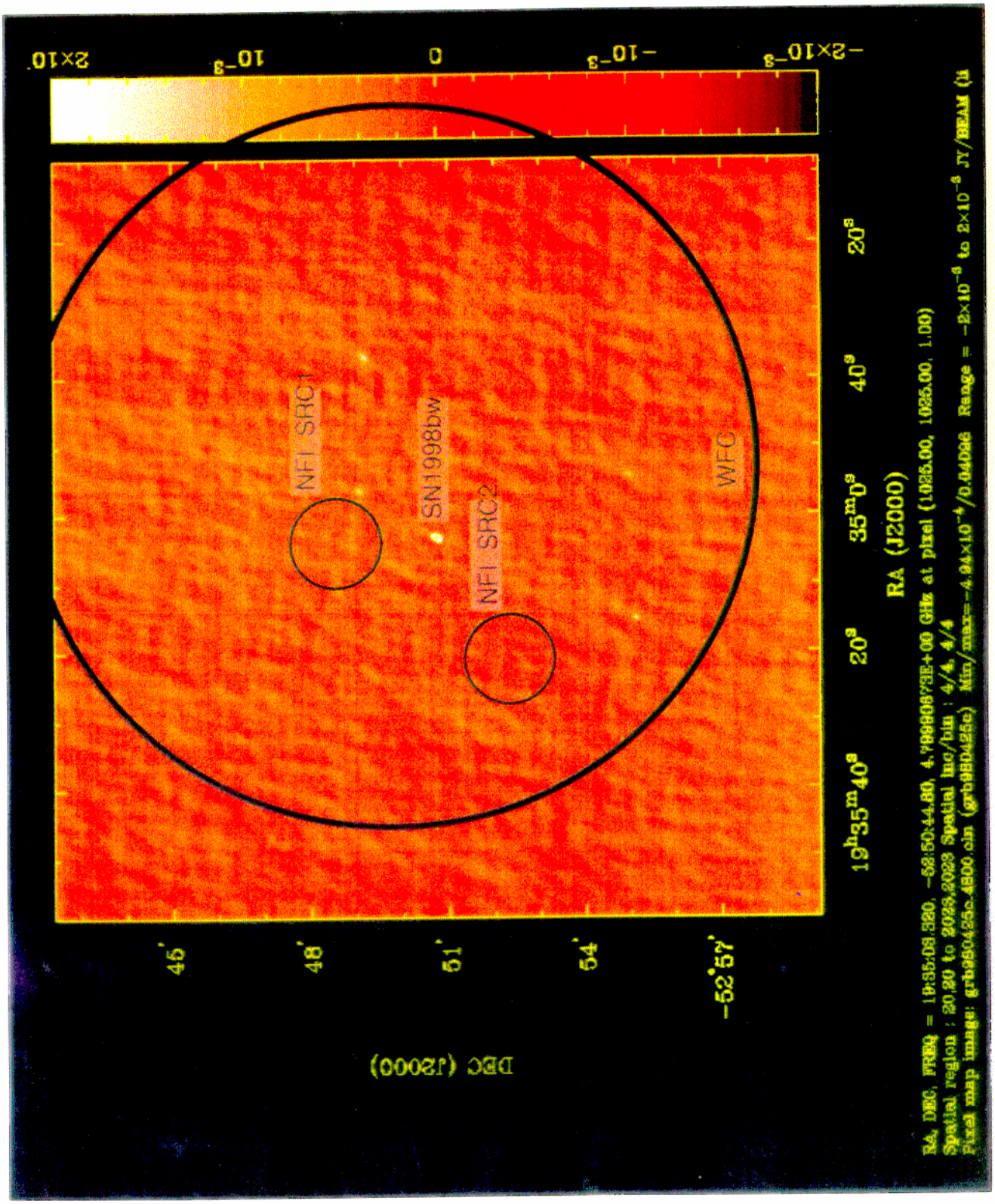
- GRBs with Optical Afterglows are Located in Distant, Early Galaxies.
- Spectroscopic Evidence for Reddening
- Excellent Evidence for Catastrophic Explosions
- NS–NS Mergers Contraindicated

? Short GRBs Yet to be Detected at Longer Wavelengths ?

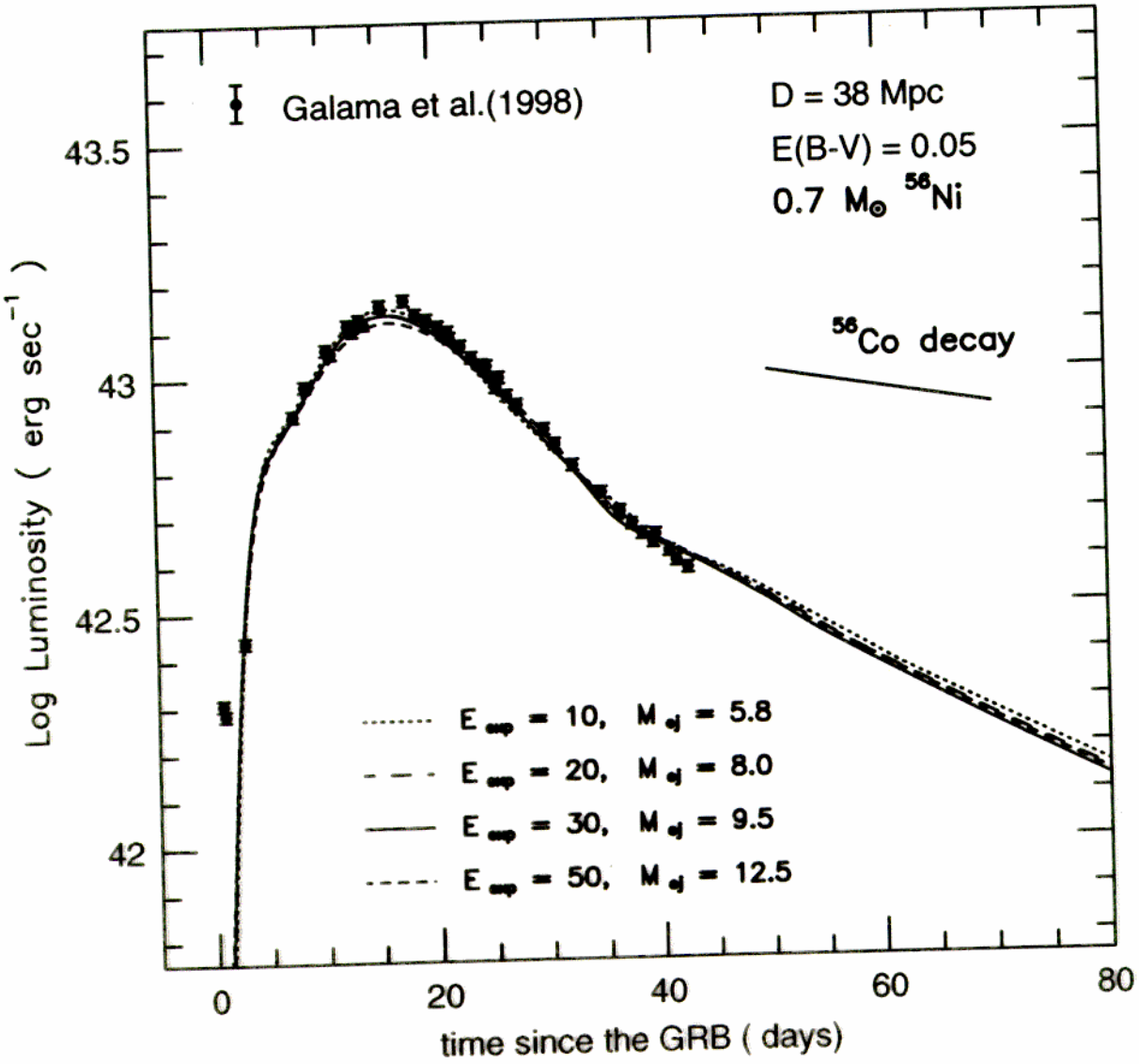
J. Norris, SSI 1998



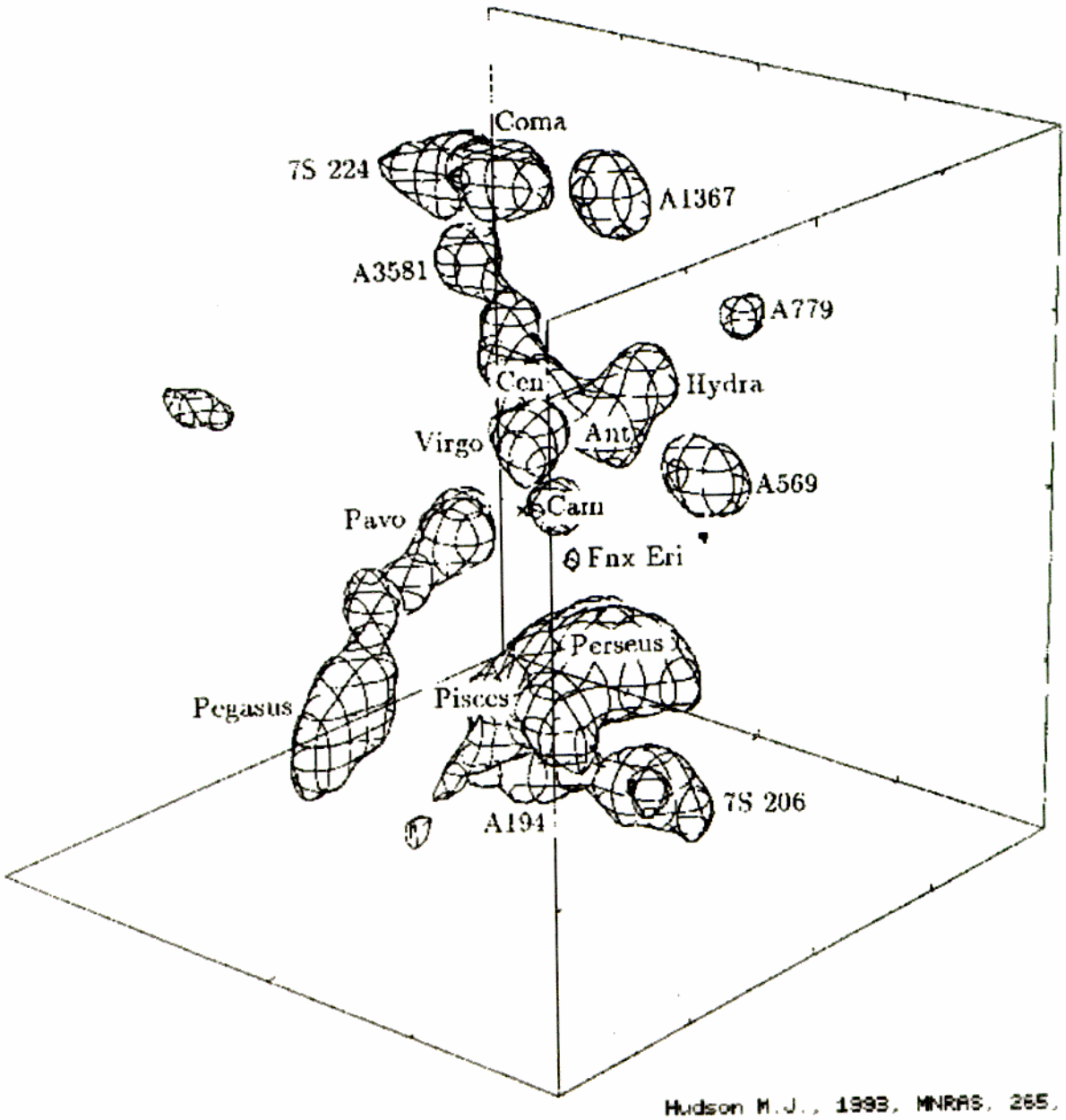
J. Norris, SSI 1998



J. Norris, SSI 1998



(b)



Hudson M.J., 1993, MNRAS, 265, 43

Supercluster distribution in nearby redshift space:
Radius ~ 80 Mpc — includes most of region where BATSE would be sensitive to "GRB / SNe type 1c"

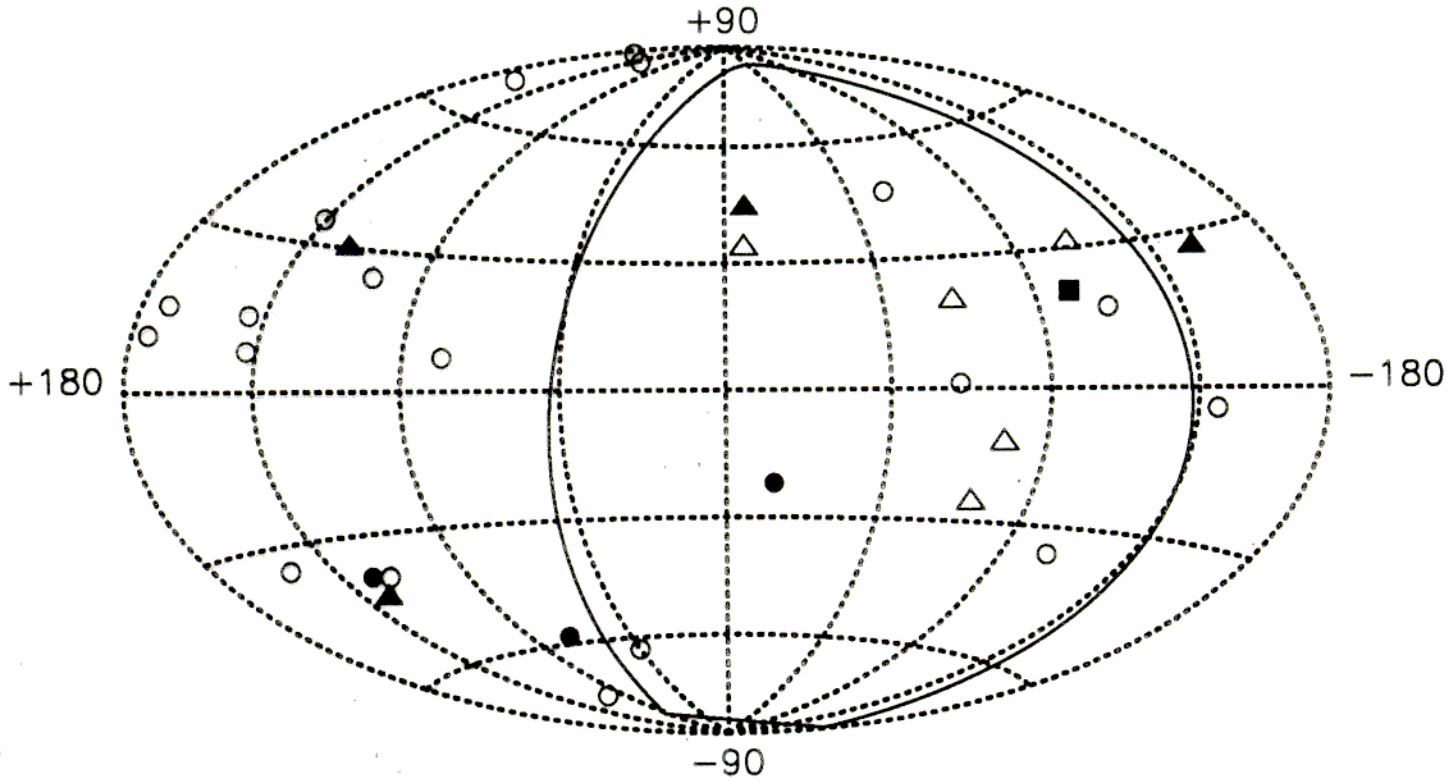


Fig. 5. – The 32 single-pulse GRBs plotted in the supergalactic coordinate system. Symbols have same meanings as in Figure 1, with square plotted for GRB 980425. No subset of single-pulse GRBs shows a tendency to cluster near the Supergalactic Plane. The quadrupole moment for the entire GRB single-pulse set is $-0.003^{+0.05}_{-0.05}$, not significantly different from zero.

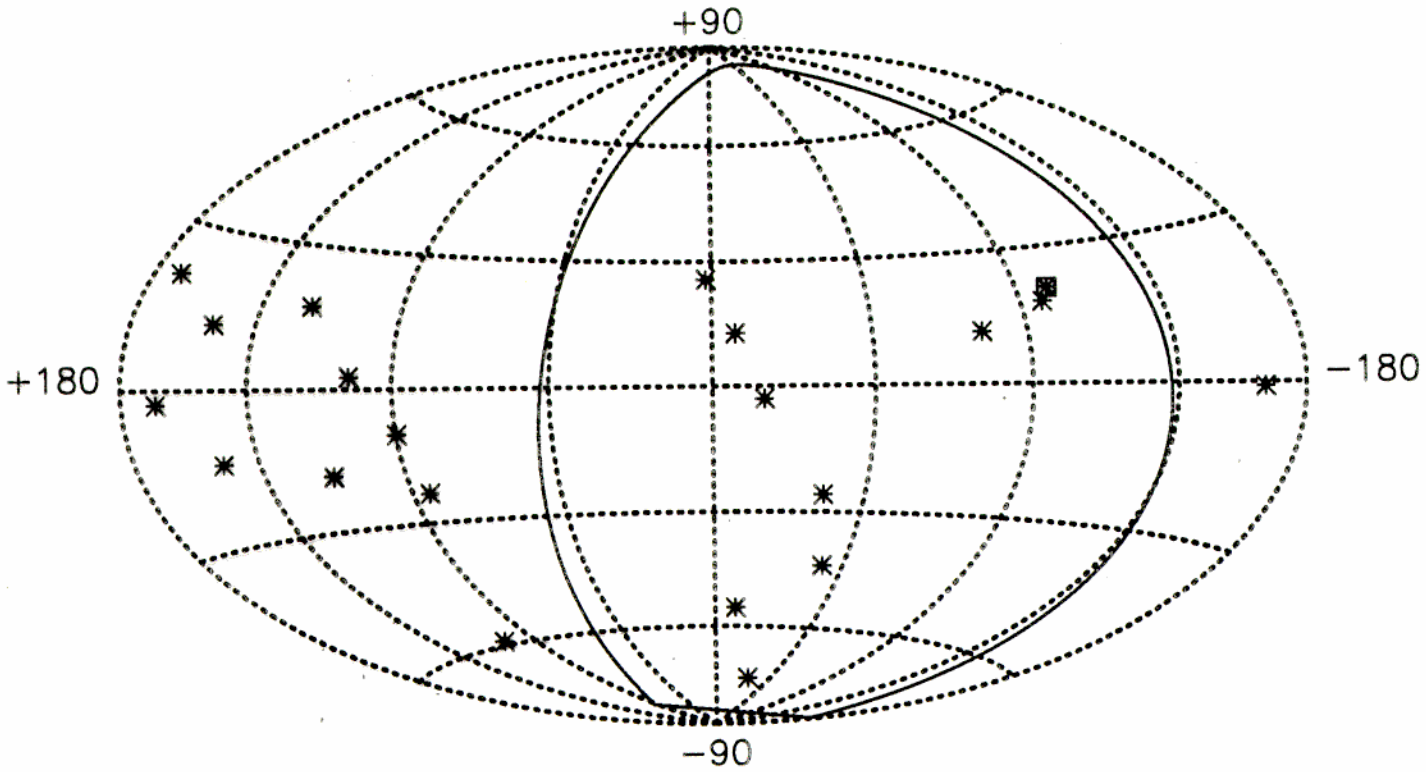
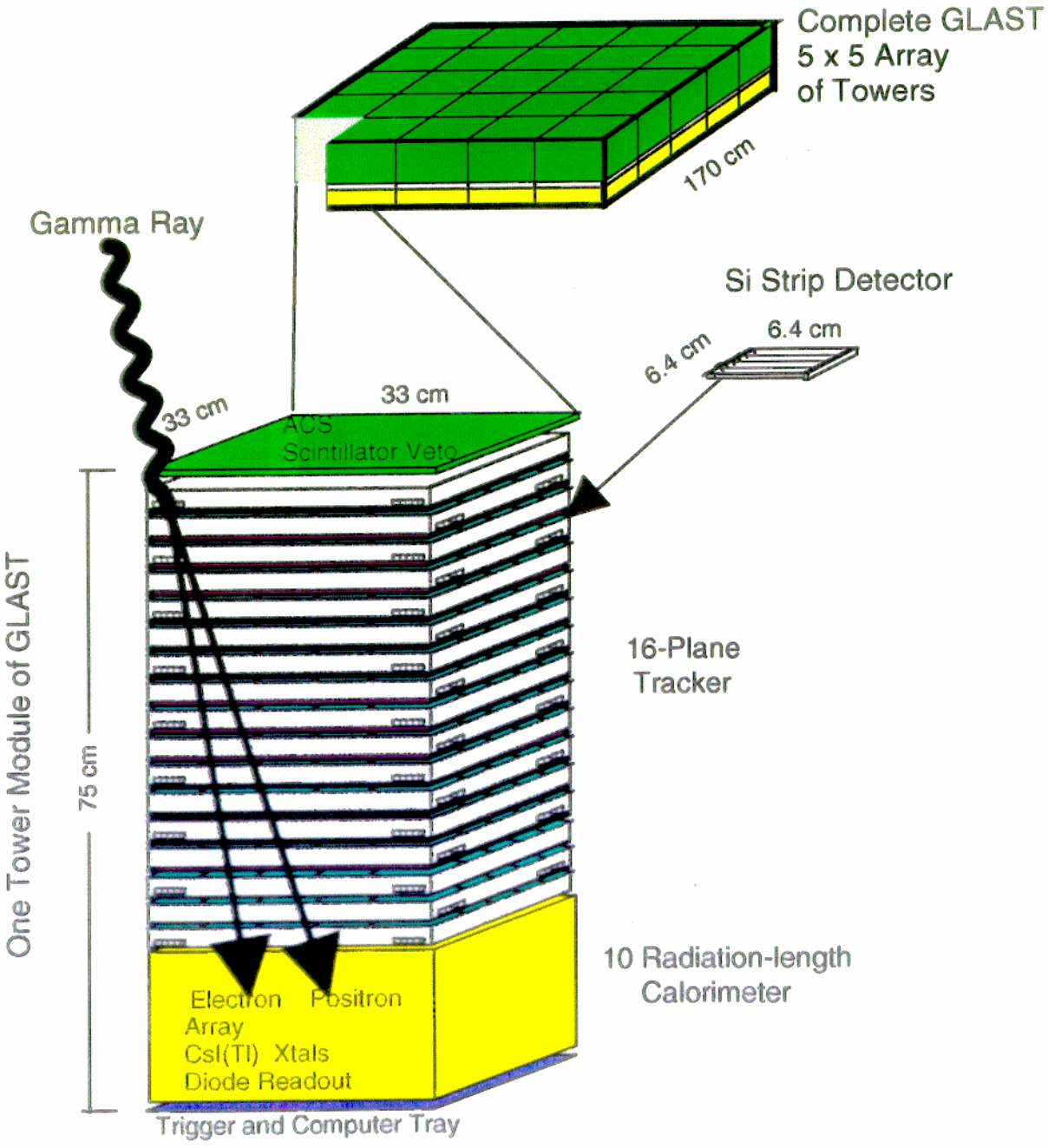
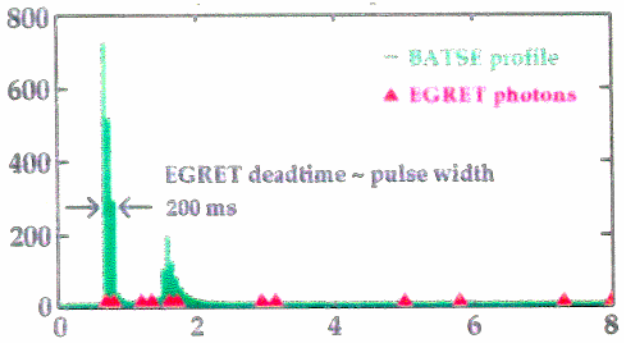


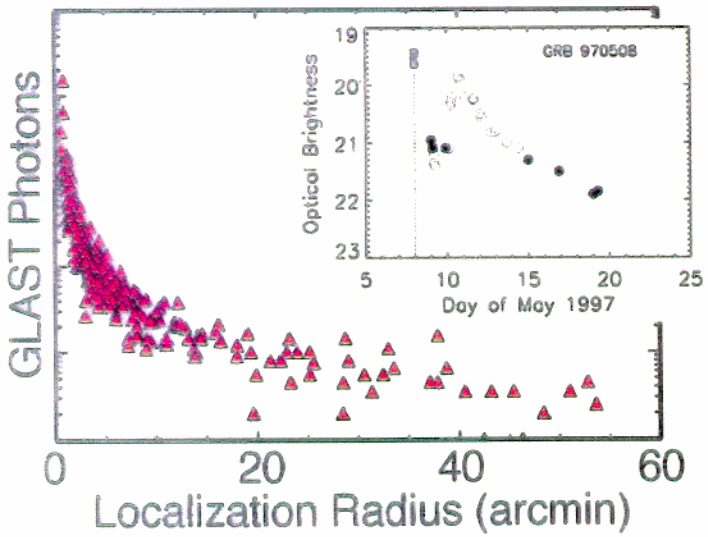
Fig. 4. – The 21 SN of type Ib or Ic found in the IAUC supernovae catalog, plotted in the supergalactic coordinate system. The continuous line is the Galactic Plane. Sixteen SNe fall within 30° of the Supergalactic Plane. Square plotted on top of SN 1998bw. The quadrupole moment, $\langle \sin^2 b - 1/3 \rangle$ for the SN distribution with respect to the Supergalactic is significantly oblate at the 2-σ level, $-0.138\ ^{+0.067}_{-0.043}$.

J. Norris, SSI 1998



GLAST: Gamma-Ray Bursts Explore Scale of Quantum Gravity *and* Epoch of Galaxy Formation

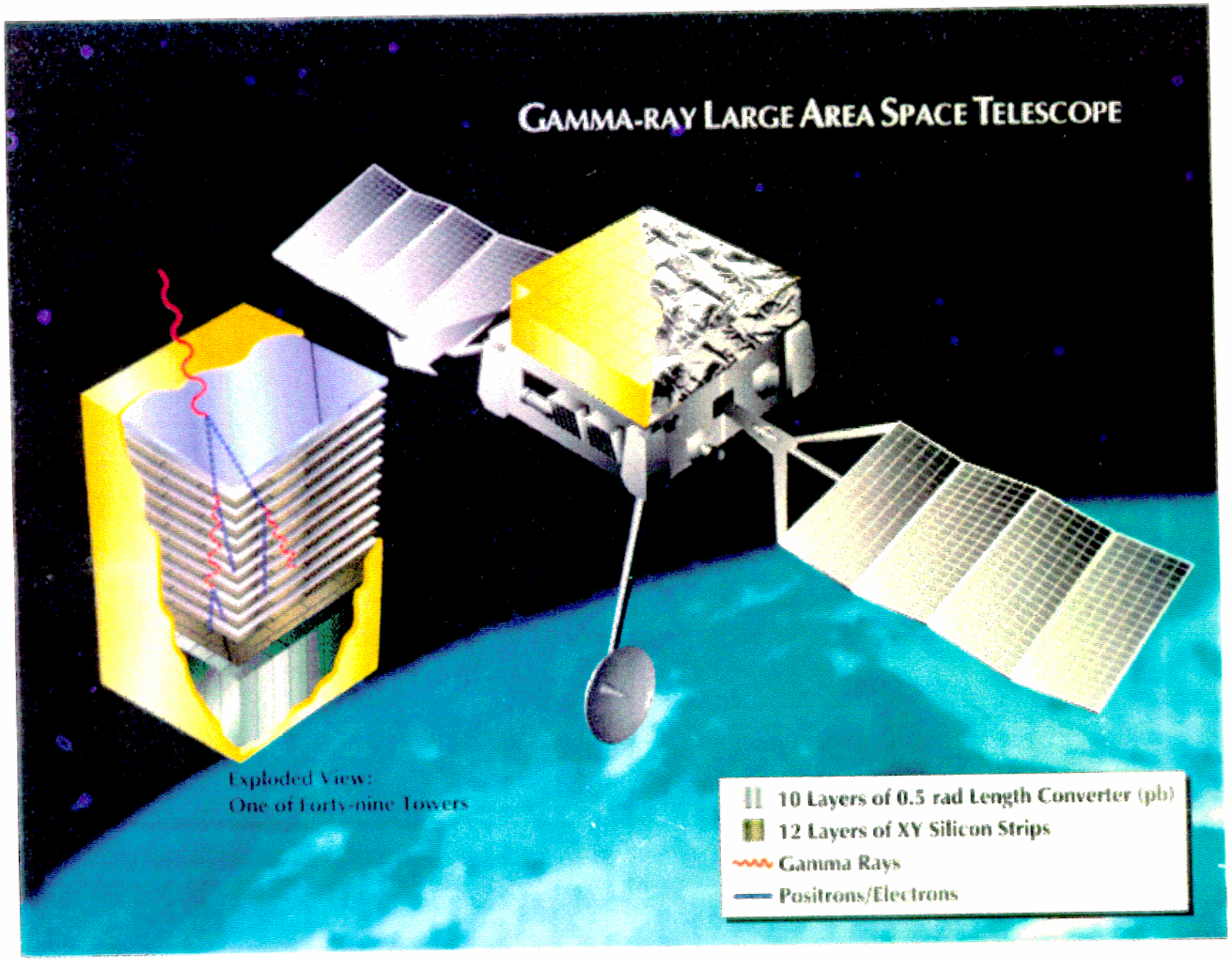


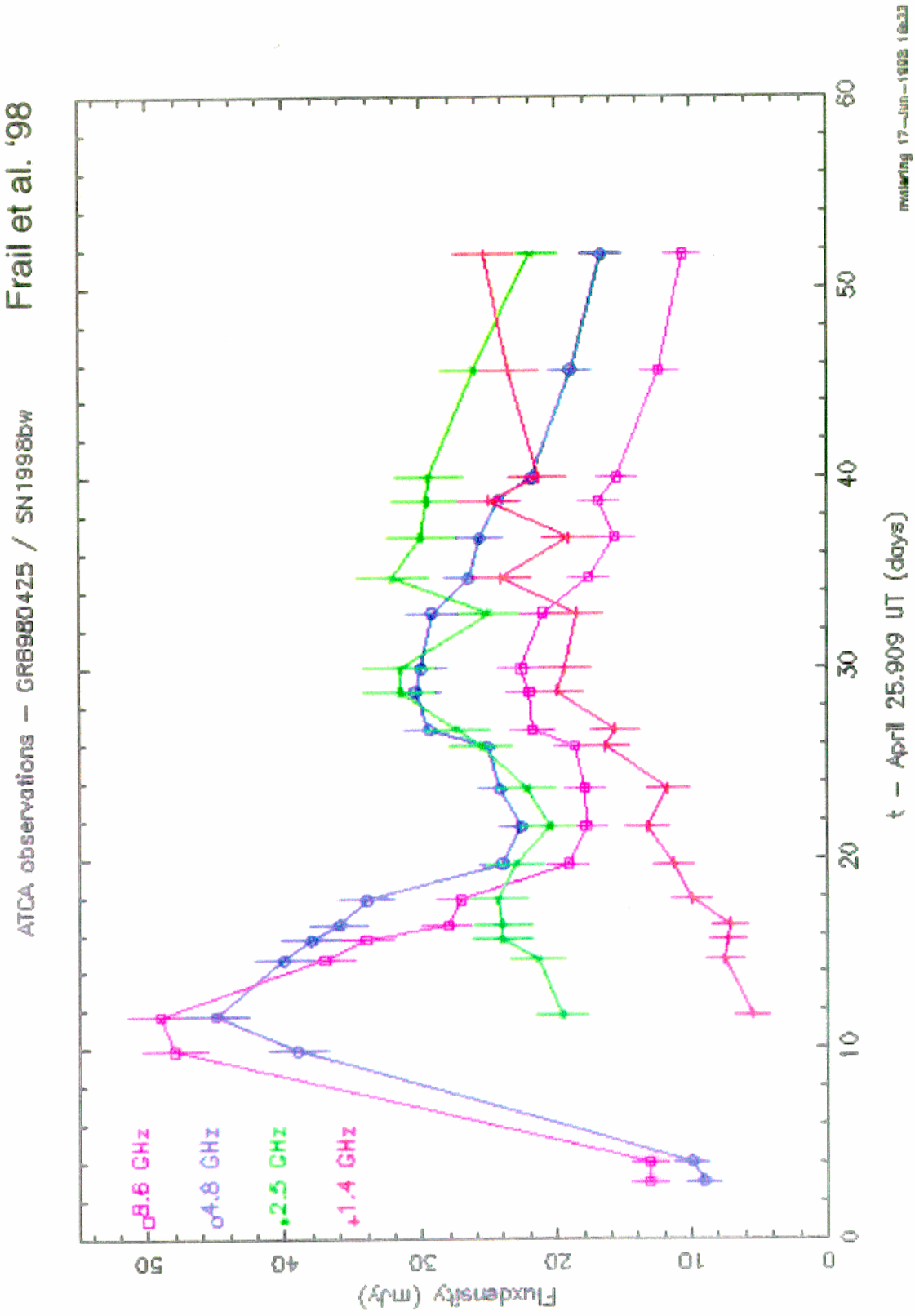


Millisecond structure at GeV energies + Gigaparsec distances probe explosion dynamics. And, may constrain E_{QG} (<~ 10^{19} GeV):

$$\Delta t = (E/E_{QG})(D_{GRB}/c) \sim 10 \text{ ms}$$

GLAST tracker imaging enables detection at longer wavelengths – measurement of redshifts and probe of early galaxy formation.





J. Norris, SSI 1998