Highlights of BATSE Non-GRB Observations (1991-2000)

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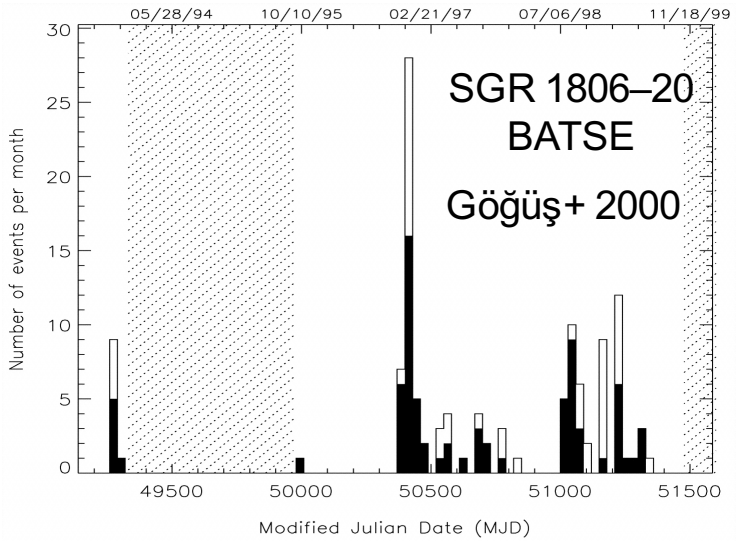
Monitoring the Low-Energy Gamma-ray Sky

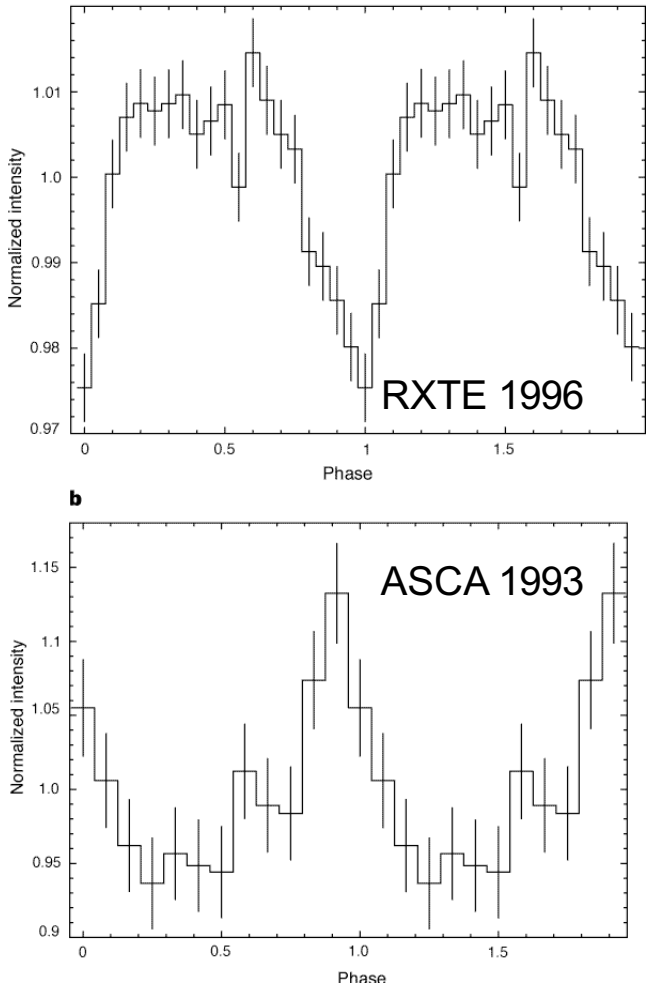
- CGRO/BATSE in orbit for >9 years
- GRBs were BATSE's main science objective but there were others:
  - Monitoring transient & variable persistent sources
  - SGRs
  - Solar flares
  - Surprises?
- BATSE techniques for non-triggered source monitoring
  - Earth occultation (all sources)
  - Epoch folding (pulsed sources)
  - Power spectra (noisy sources)

Soft Gamma-ray Repeaters

- Pre-BATSE: 3 SGR sources
  - SGR 0525–66, SGR 1806–20, SGR 1900+14
- BATSE not optimized for SGRs but detected many bursts from 1806–20 and 1900+14
- BATSE also discovered one new SGR source (SGR 1627–41)
- Outburst episode of SGR 1806–20 in late 1996 led to *RXTE*/PCA ToO
  - Discovery of 7.47 s pulsations
  - Combined with ASCA archive data ⇒ $\dot{P} \approx 2.6 \times 10^{-3}$ s/yr
  - Implied $B \approx 8 \times 10^{14}$ gauss ⇒ magnetar!



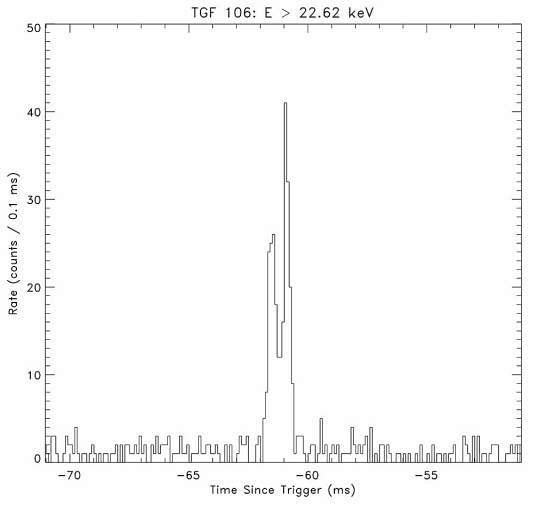
SGR 1806–20



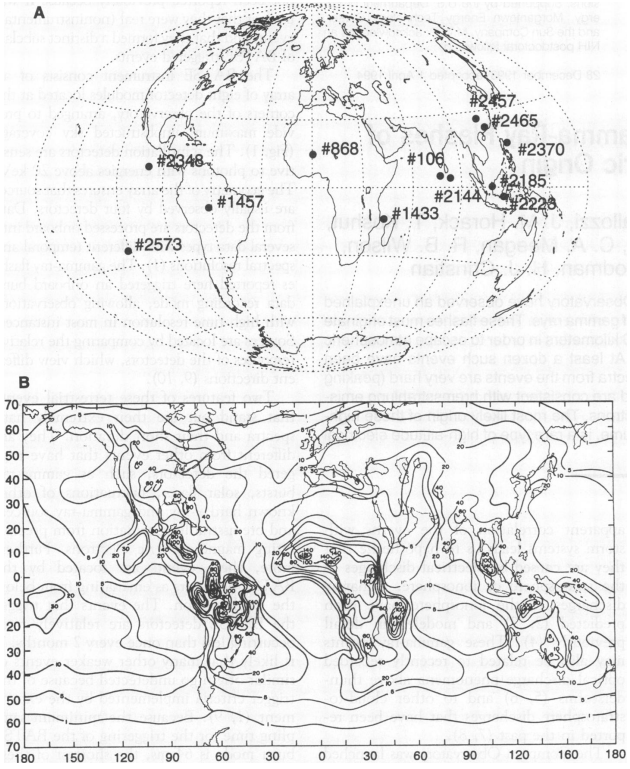
Kouveliotou+ 1998

Terrestrial Gamma-ray Flashes

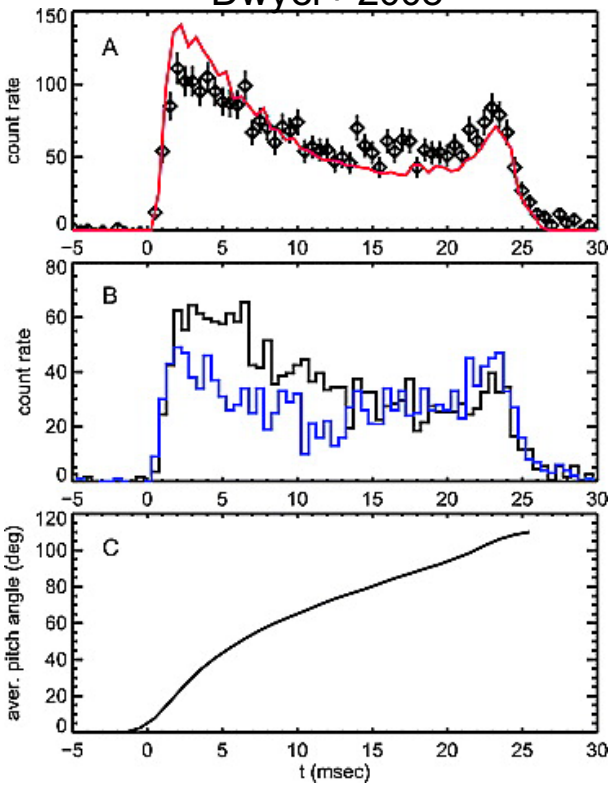
- Subset of BATSE triggers with unusual characteristics
  - Very short duration ≲ few ms
  - Very hard spectrum
  - Localized to Earth
- Associated with regions of thunderstorm and lightning activity
- Most TGFs are bremsstrahlung gamma-rays from accelerated electrons/positrons
- Longer duration events (> few ms) are actually escaped particles



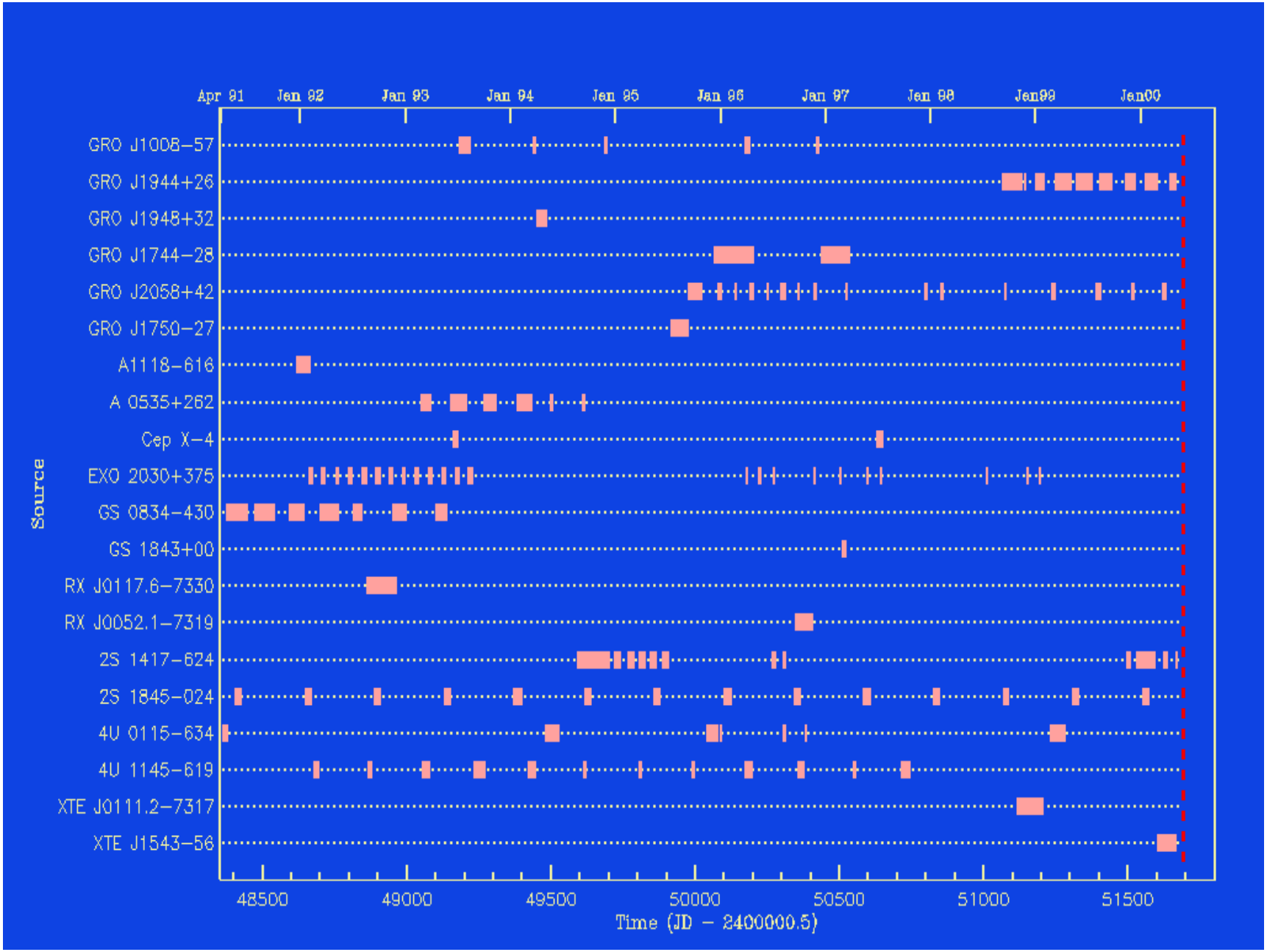
Fishman+ 1994

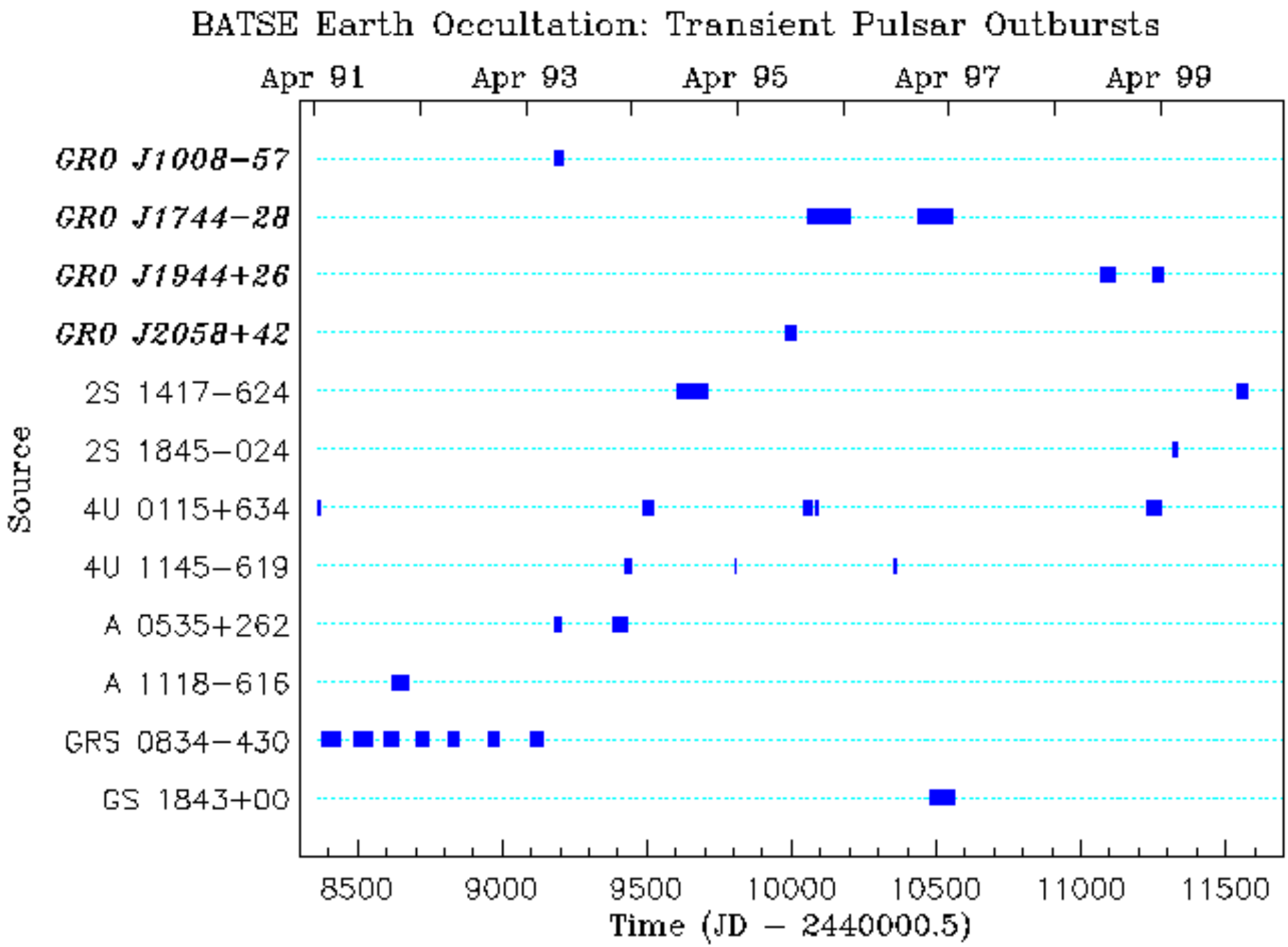


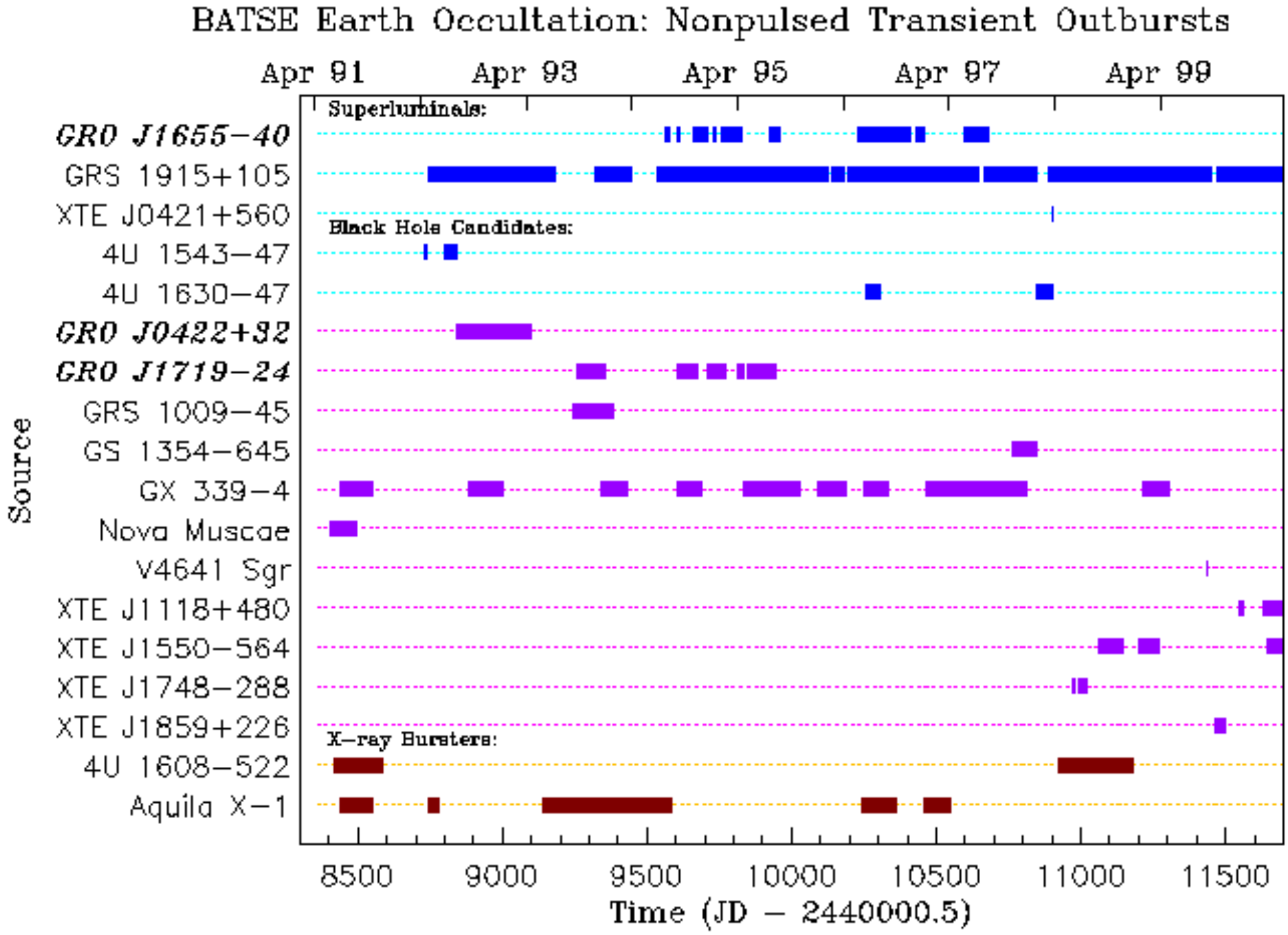
Dwyer+ 2008



Transient Pulsed Sources Detected with BATSE

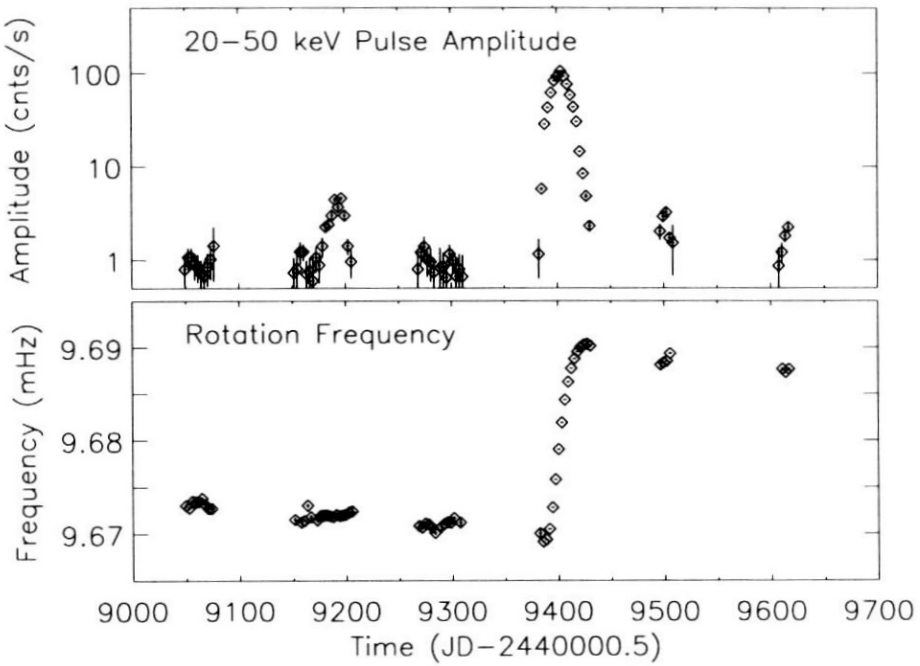



BATSE Earth Occultation: Transient Pulsar Outbursts
Apr 91
Apr 93
Apr 95
Apr 97
Apr 99
GRO J1008−57
GRO J1744−28
GRO J1944+26
GRO J2058+42
2S 1417−624
2S 1845−024
4U 0115+634
4U 1145−619
A 0535+262
A 1118−616
GRS 0834−430
GS 1843+00
Source
8500
9000
9500
10000
10500
11000
11500
Time (JD − 2440000.5)

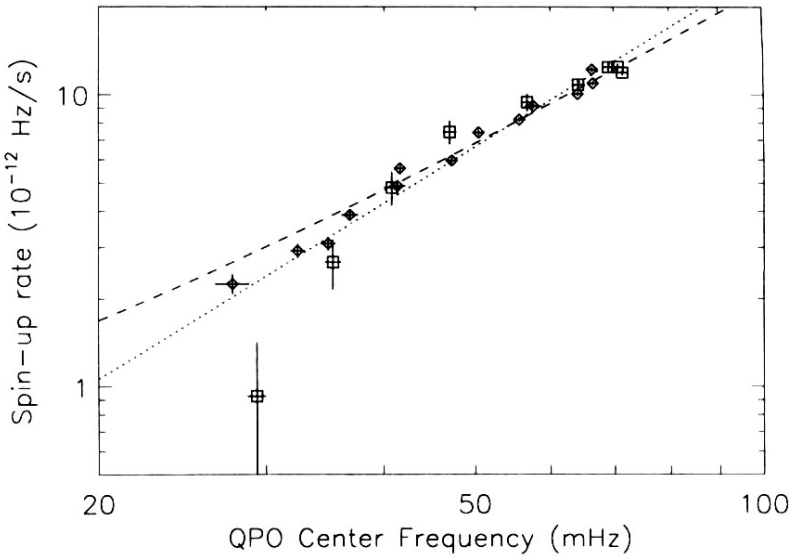

BATSE Earth Occultation: Nonpulsed Transient Outbursts
Apr 91
Apr 93
Apr 95
Apr 97
Apr 99
Superluminals:
GRO J1655−40
GRS 1915+105
XTE J0421+560
Black Hole Candidates:
4U 1543−47
4U 1630−47
GRO J0422+32
GRO J1719−24
GRS 1009−45
GS 1354−645
GX 339−4
Nova Muscae
V4641 Sgr
XTE J1118+480
XTE J1550−564
XTE J1748−288
XTE J1859+226
X−ray Bursters:
4U 1608−522
Aquila X−1
Source
8500
9000
9500
10000
10500
11000
11500
Time (JD − 2440000.5)

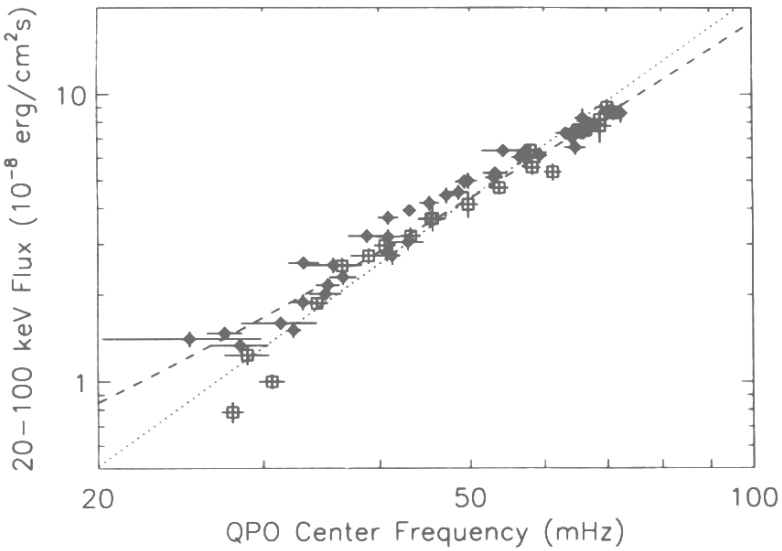
A 0535+262

- Transient X-ray binary pulsar
  - P_{pulse} ~ 103 s
  - P_{orb} ~ 111 d
  - B*e* star companion
- "Giant" outburst in Feb/Mar 1994
  - spin-up (~10^{-11} Hz s^{-1})
  - QPO with $\nu_{QPO} > \nu_{pulse}$
  - ν_{QPO} strongly correlated with spin-up torque & luminosity



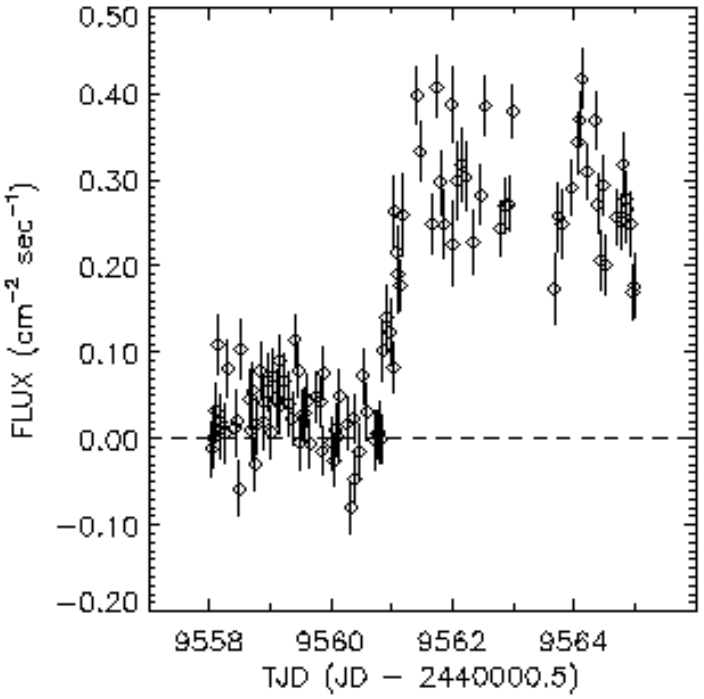
Finger+ 1996



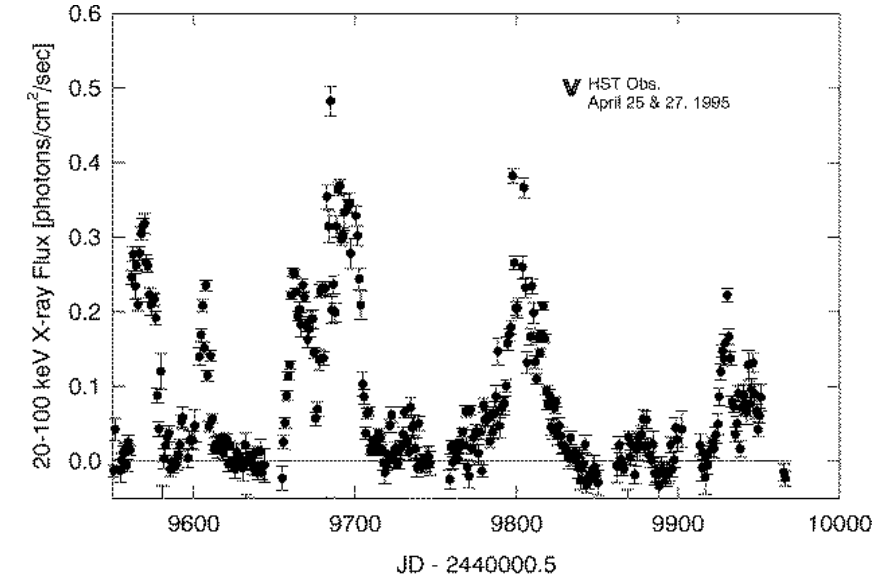


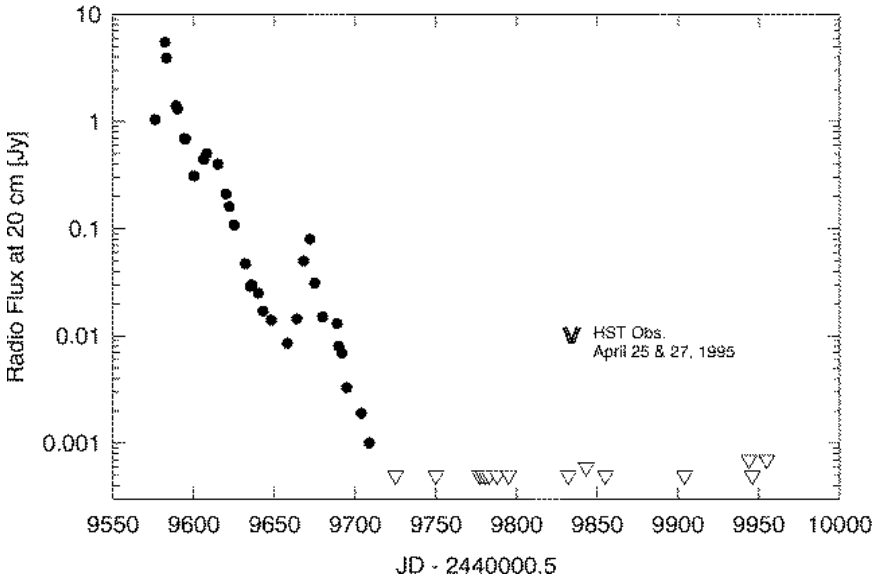
GRO J1655–40

- Transient black hole candidate
- Series of strong outbursts beginning in July 1994
- Remarkably fast rise (< 8 hr)



Paciesas+ 1996

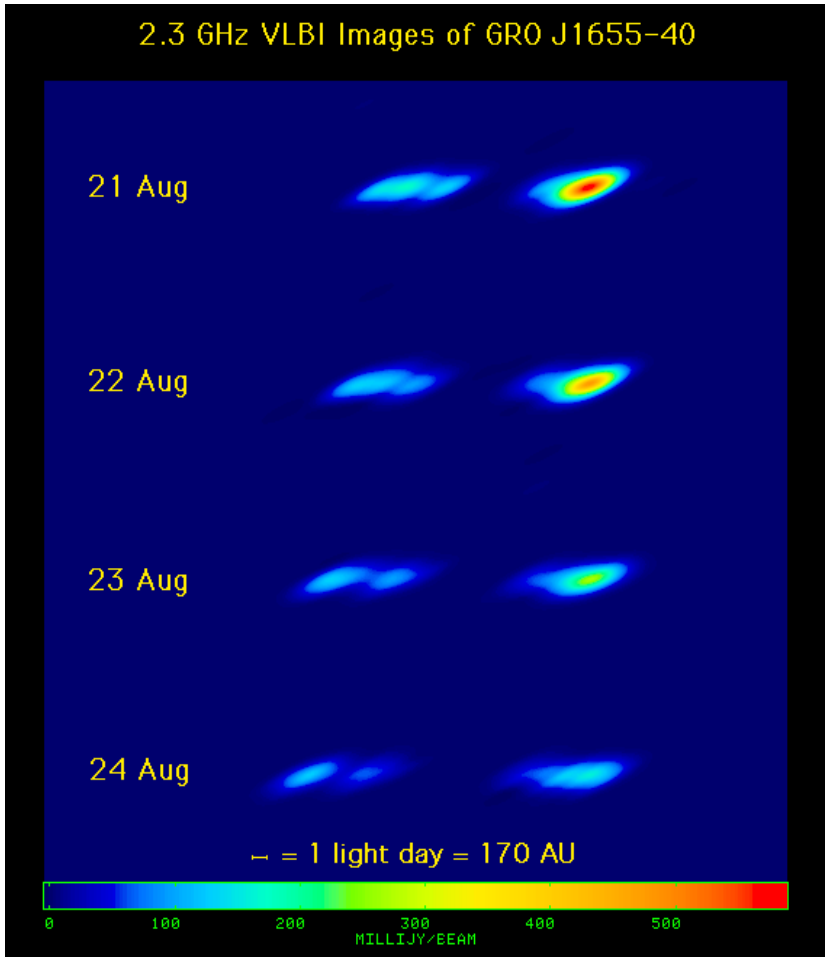




Tavani+ 1996

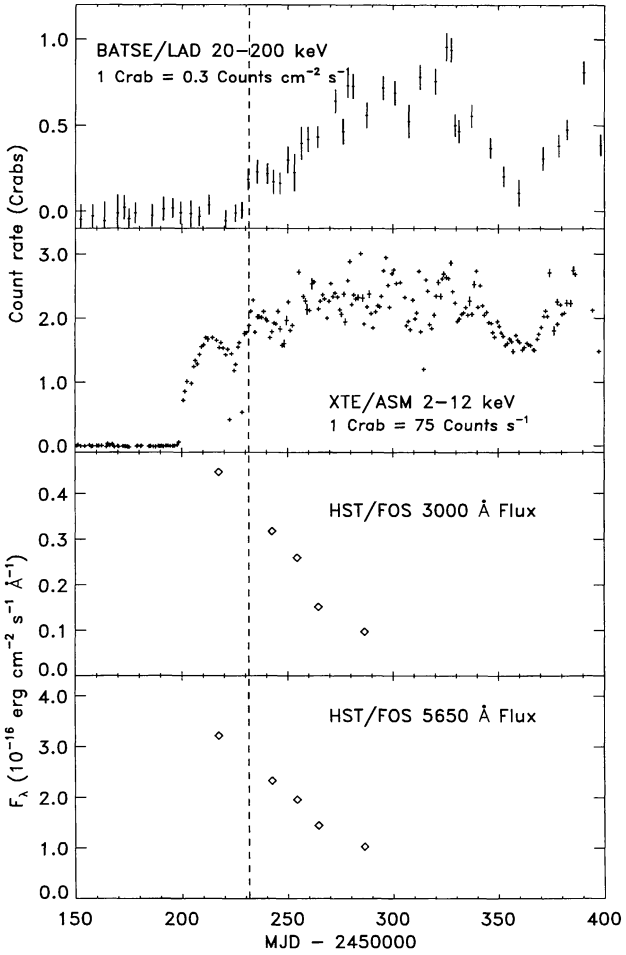
GRO J1655–40

- Superluminal expansion seen in radio
  - Two-week delay relative to hard X-rays



Tingay+ 1995

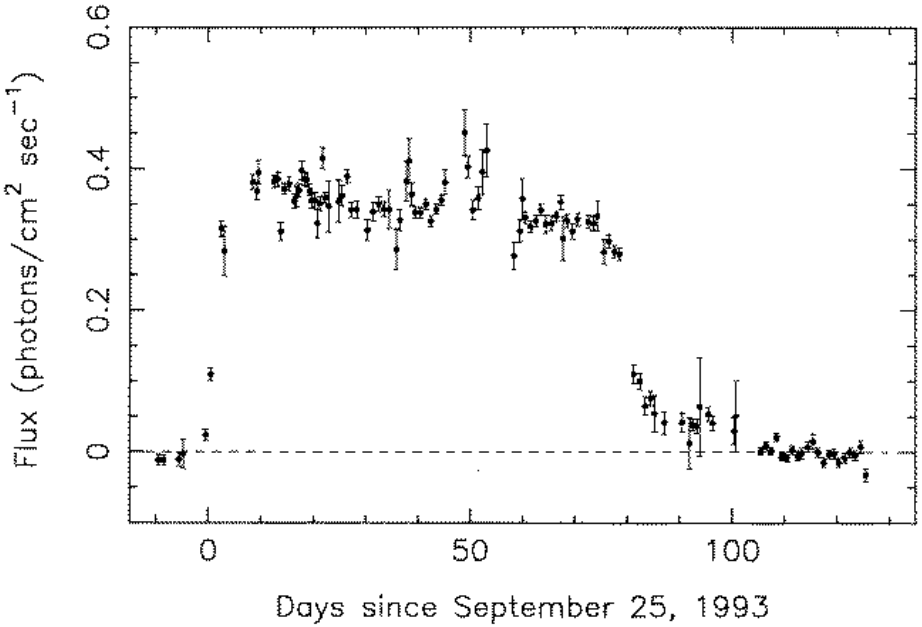
- Later outburst (1996) started first in optical & soft x-ray
  - Heating wave started in outer disc & moved inward

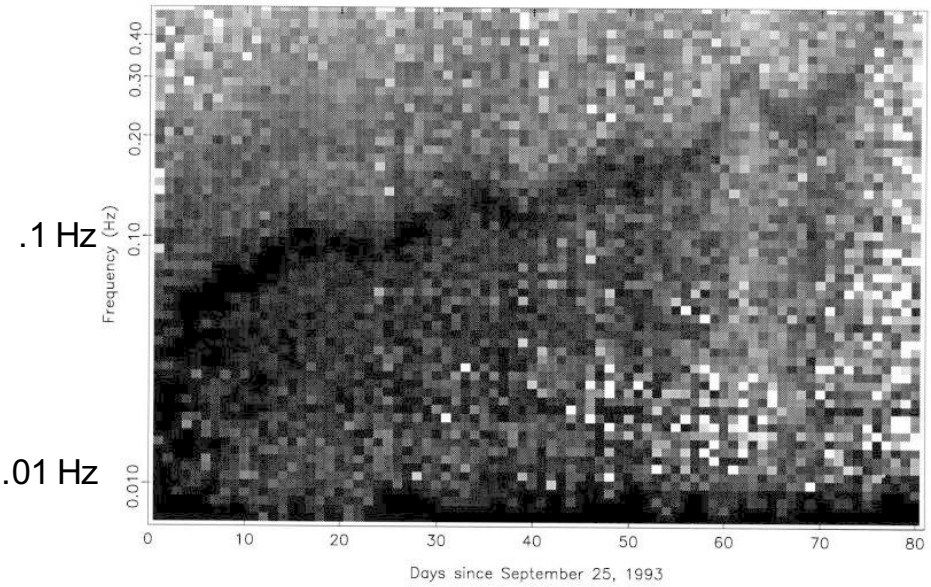


Hynes+ 1998

GRO J1719–24

- Transient black hole candidate discovered by BATSE & GRANAT/Sigma in late 1993
- Low-frequency QPO in time-series analysis
  - remarkable time evolution of ν_{QPO} from ~0.04 ÷ 0.3 Hz
  - ν_{QPO} doubled during initial rise
  - large variation not easily explained



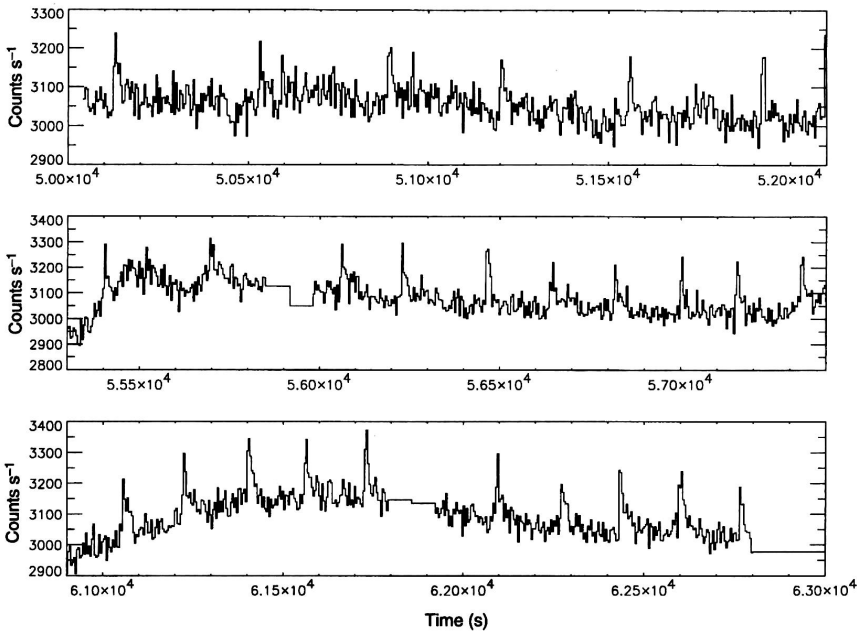


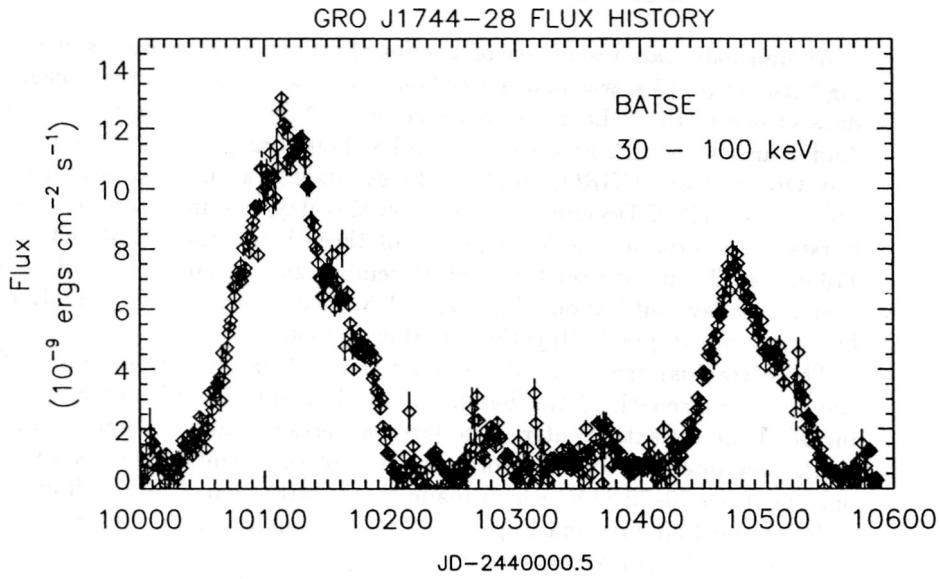
Van der Hooft+ 1996

Bursting Pulsar (GRO J1744–28)

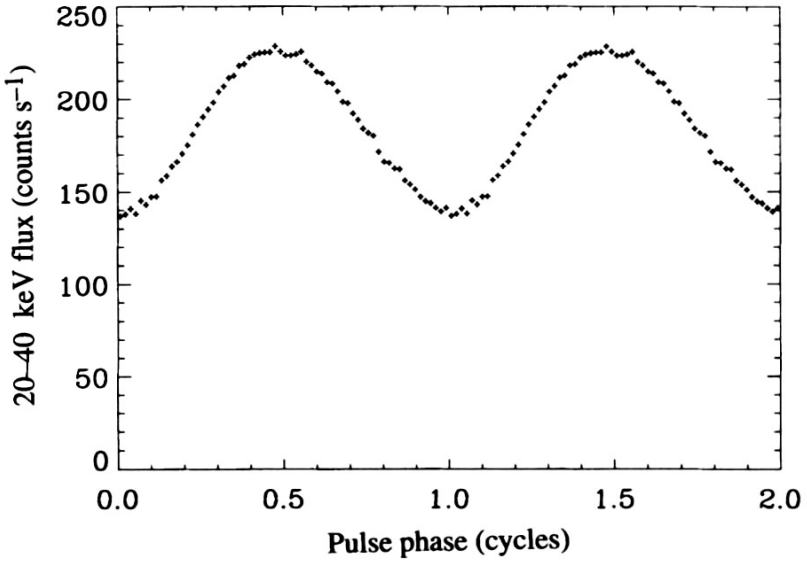
- Unique source
- Bursts first detected in raw BATSE data (Dec 1995)
- Later detected as a pulsar & via Earth occultation
- Binary P_{orb} ~ 11.8 d
- Two outburst episodes, spaced ~1 year apart

Kouveliotou+ 1996





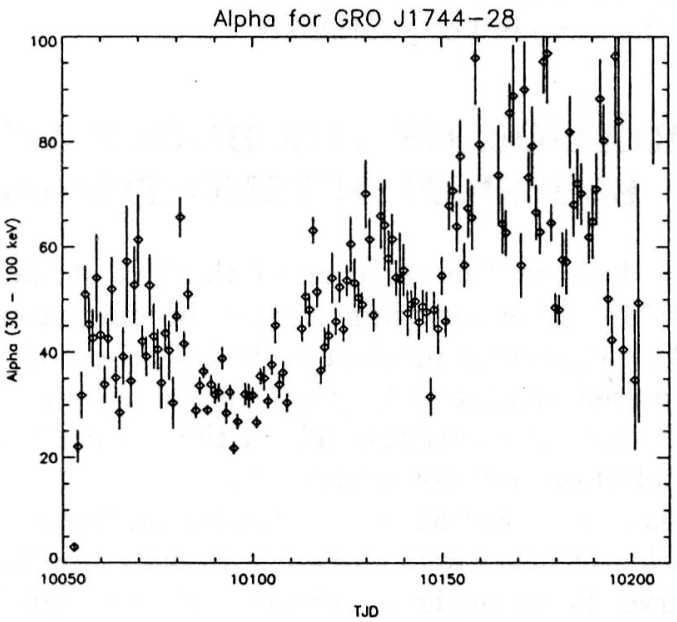
Kouveliotou & van Paradijs 1997



Finger+ 1996

Bursting Pulsar (GRO J1744–28)

- Type II bursts: accretion instability
  - Not BB spectrum
  - No spectral softening during burst
  - Persistent flux to burst flux ratio α < 20 (α < 4 on first day)
- Pulsations persist during bursts
  - Larger amplitude
  - Time lag
  - "Accretion curtain" model (Miller 1996)



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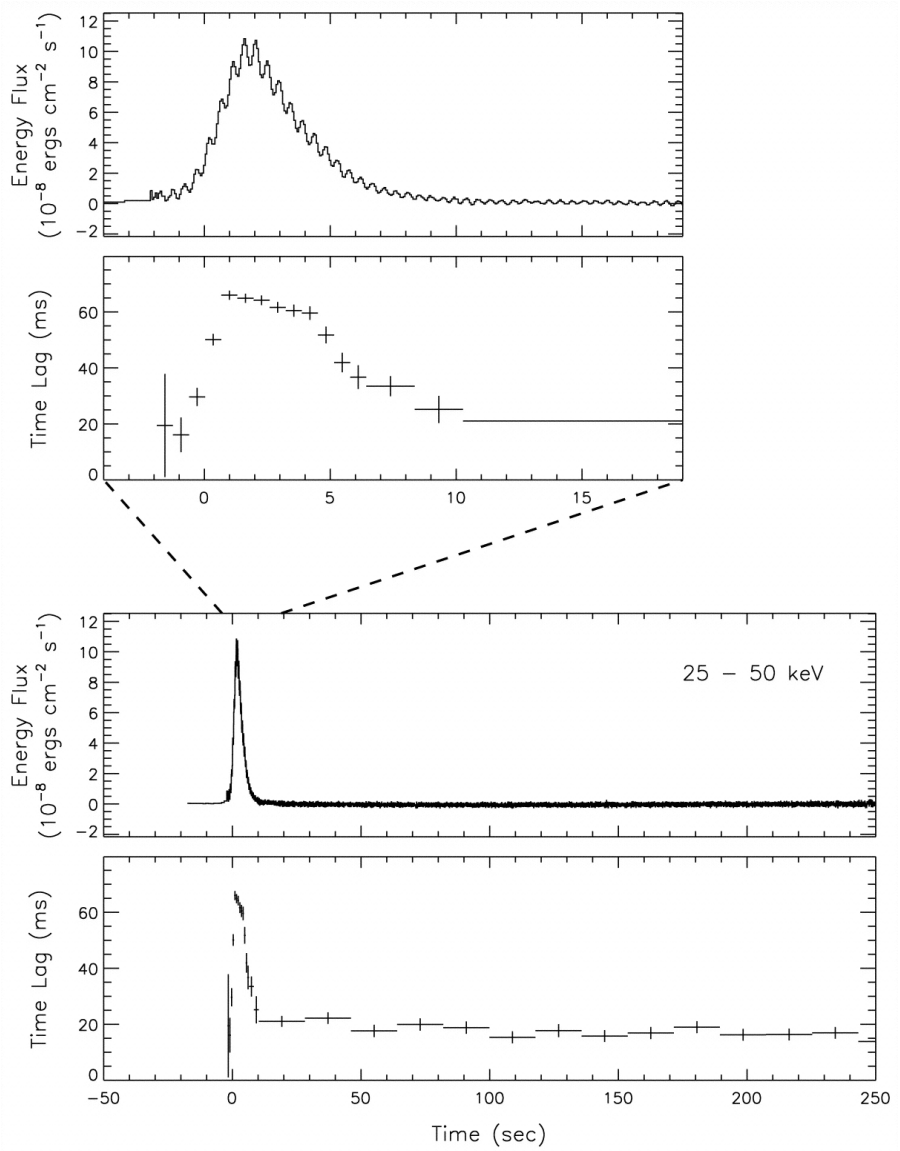

Woods+ 2000

Summary

- The hard X-ray/low-energy gamma-ray sky can be monitored with relatively simple detectors
- In addition to detecting known transient and highly variable sources, BATSE discovered:
  - Six new X-ray pulsars, incl the bursting pulsar GRO J1744–28
  - Three new BH candidates, incl the microquasar GRO J1655–40
  - One new SGR source
  - Terrestrial Gamma-ray Flashes from thunderstorms
- Determined or refined orbits of >14 X-ray binaries
- Monitored long-term variability of source fluxes, energy spectra, power spectra, pulsar period derivatives, etc.