

**Max Planck Institut für extraterrestrische Physik
Advisorseminar Astrophysik**

GAMMA-RAY BURSTS

Isotropy, time profiles and spectral characteristics

by Maria Fürmetz

Abstract



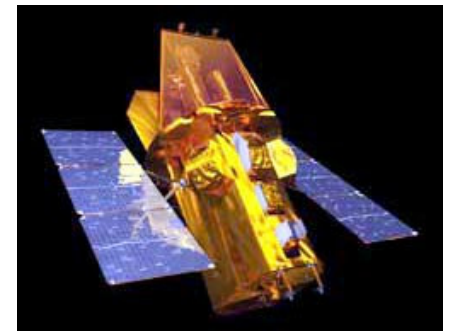
- What are Gamma Ray Bursts (GRBs)?
- History of GRB-detecting
- Collecting and editing of data
- Observations and their consequences
- (Possible) models of emerging
- Conclusion and open questions

What are Gamma-Ray Bursts?

- Short-living bursts of gamma-ray photons, most of the power radiated in 100-500 keV range
- Lasting anywhere from a few milliseconds to several minutes
- Brightest source of cosmic gamma-ray photons in the observable universe

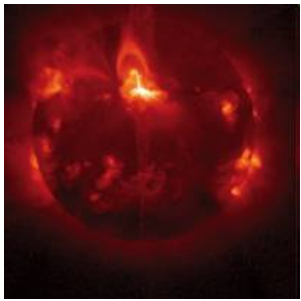
History of GRB-detecting

- 1960s: First discovered by U.S. military satellites, looking out for violation of the nuclear test ban treaty
- 1991-2000: CGRO-mission (with BATSE)
- 1996-2002: Beppo-SAX
- 2002: INTEGRAL (with IBIS, SPI, JEM-X, OMC)
- 22.11.2004: SWIFT (with BAT, XRT, UVOT)



Collecting and editing of data – sorting & background subtraction

- Distinction between GRBs and other events (with solar or particle origin) occurring in the data stream:



(Yohkoh satellite)

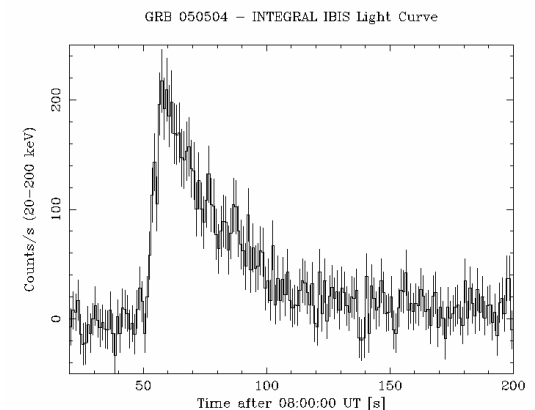
- localization in celestial coordinates → rejection of e.g. bursts from the sun and the atmosphere
- using detections of other missions to compare
- applying of a significance threshold

- Subtracting the background (consists of cosmic radiation, solar flashes and trapped particles in the magnetic field of the earth) :

(Mainly) linear fit to the background

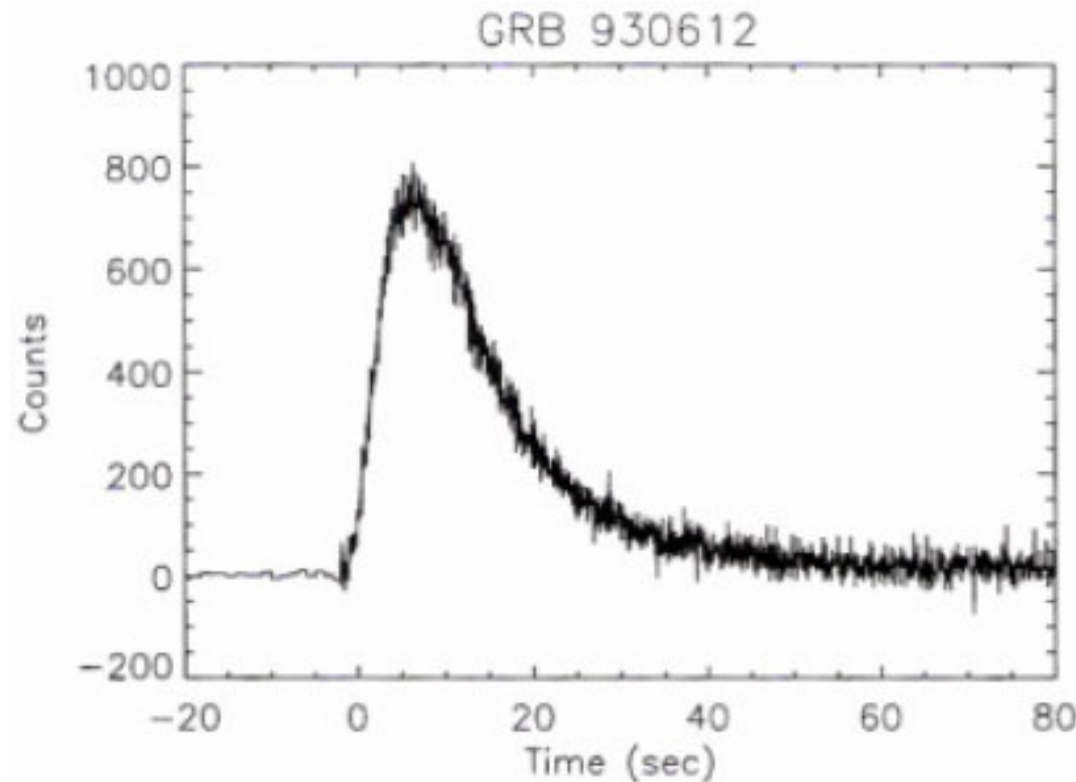
before and after the event

→ subtracting of resulting background counts



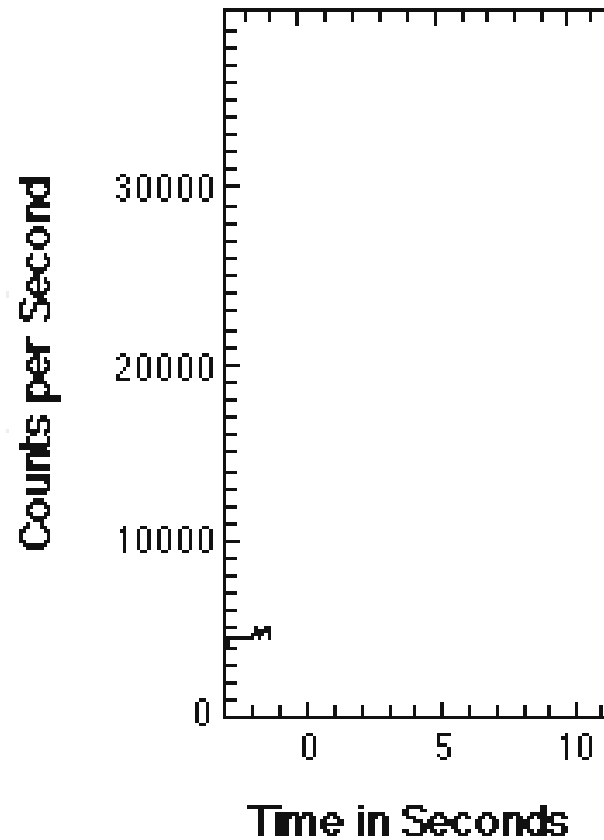
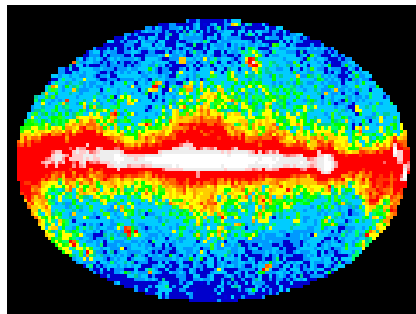
Collecting and editing of data – creating time profiles

- Time profile (light curve): detector counts number of photons in a certain energy range (SPI-ACS: 20 keV – 8 MeV, SWIFT: 15-150 keV) with a typical time resolution of 50 ms



(Kocevski et al. 2003)

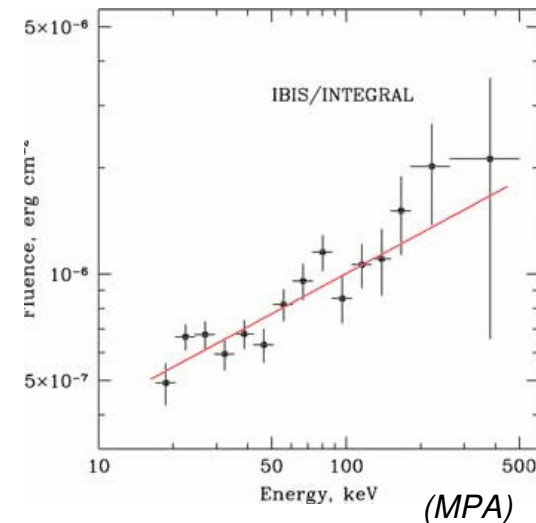
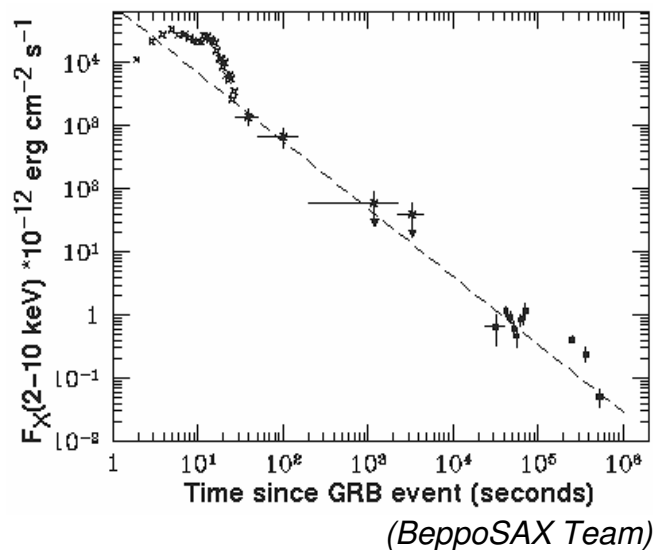
Collecting and editing of data – creating time profiles II



(Laura Whitlock, GSFC und NASA)

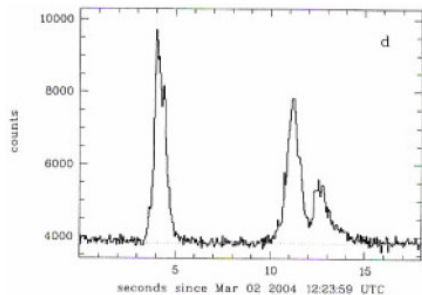
Collecting and editing of data – energy spectra, fluxes and fluences

- Energy spectrum: energy distribution of incoming photons; some detectors have several energy channels (e.g. BATSE has 4 different channels)
- Flux: energy per cm^2 and s
- Fluence: time-integrated flux, energy per cm^2



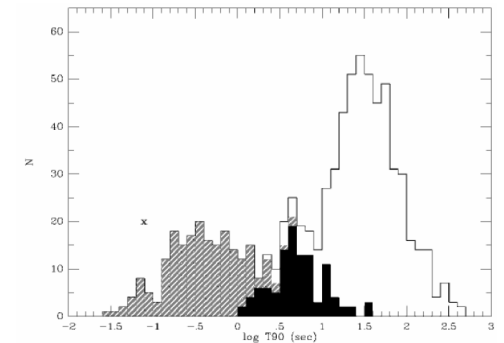
Collecting and editing of data – important timescales

- FWHM: full width at half maximum
- T_{90} : observer frame duration, time interval over which a burst emits from 5% to 95% of its total measured counts
- T_{50}^{em} : summed time for which the burst has emission stronger than 50% of peak flux level (for cases with long periods of quietness)

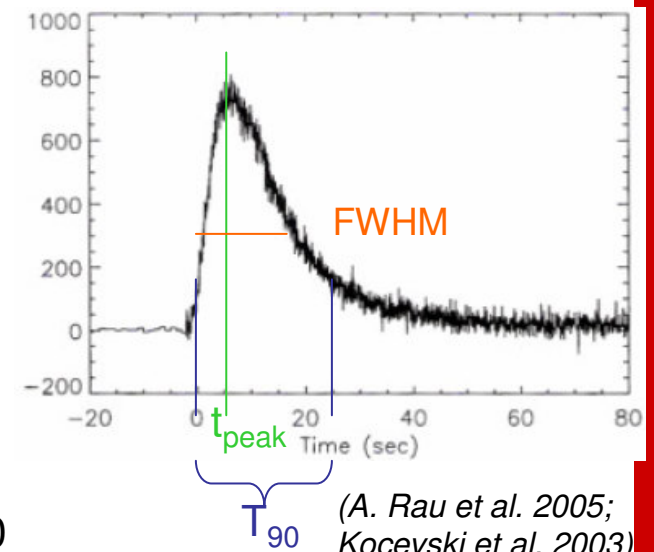


has emission stronger than 50% of peak flux level (for cases with long periods of quietness)

- rise time: from left end of T_{90} to t_{peak}
- decay time: from t_{peak} to right end of T_{90}

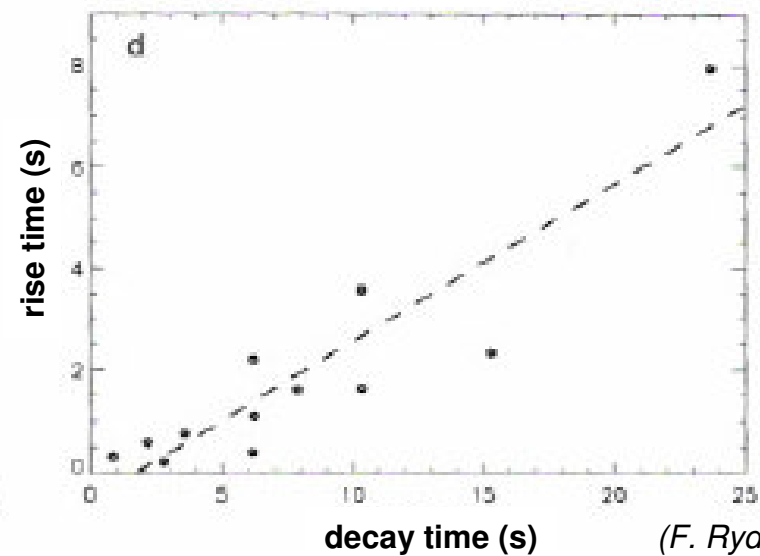
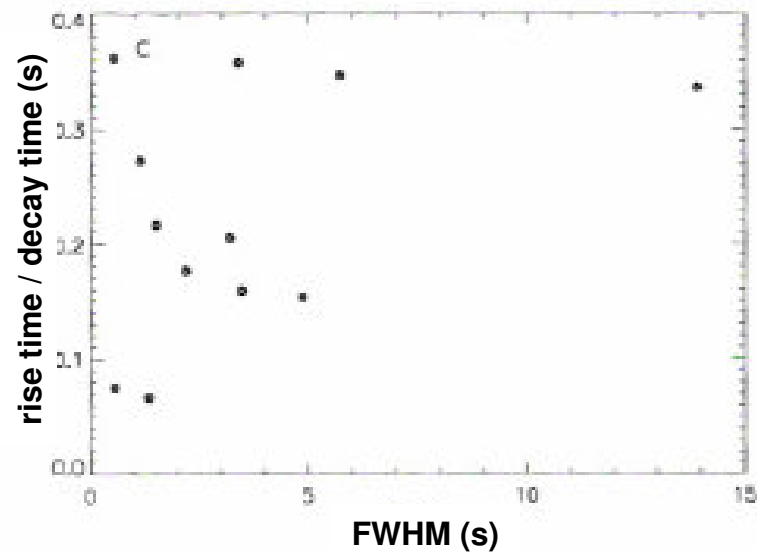
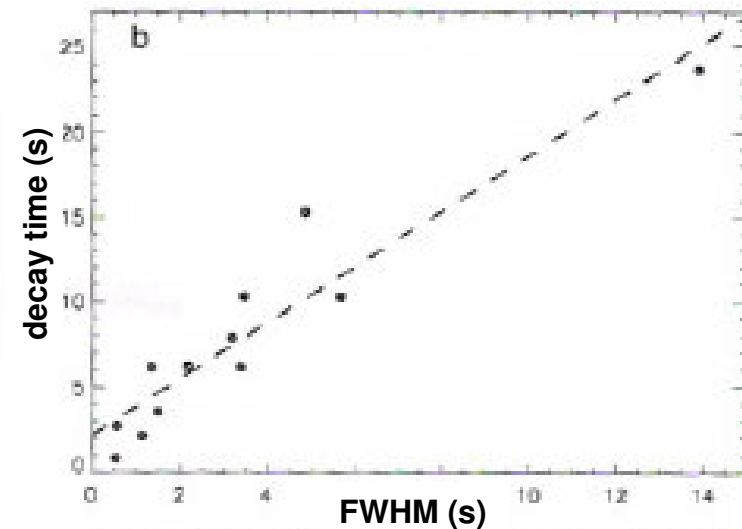
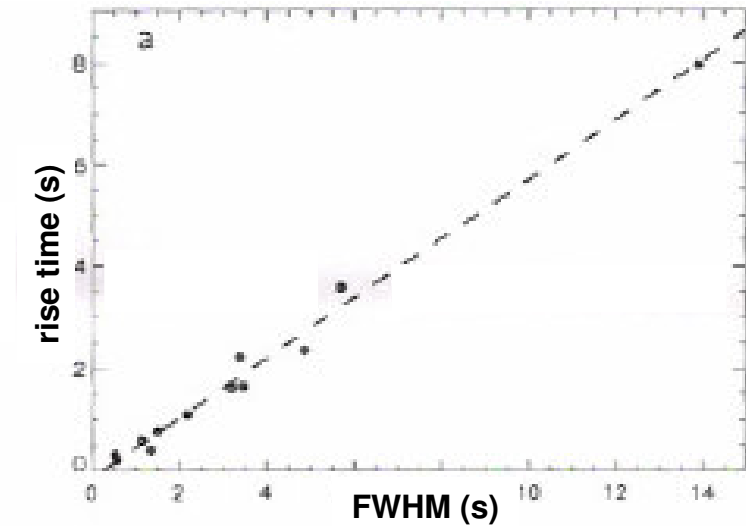


(Soma Mukherjee et al., 1998)



(A. Rau et al. 2005;
Kocevski et al. 2003)

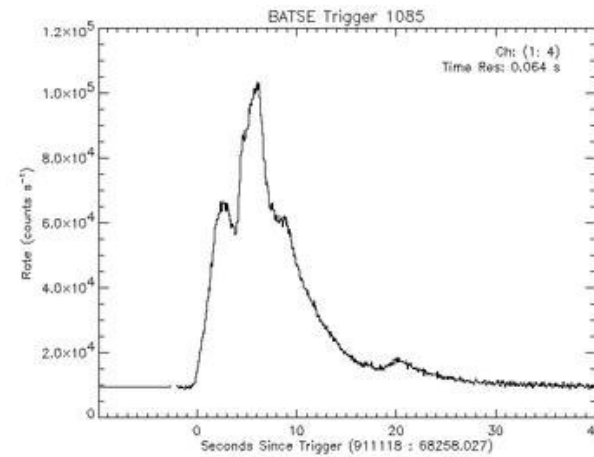
Collecting and editing of data – a few time correlations



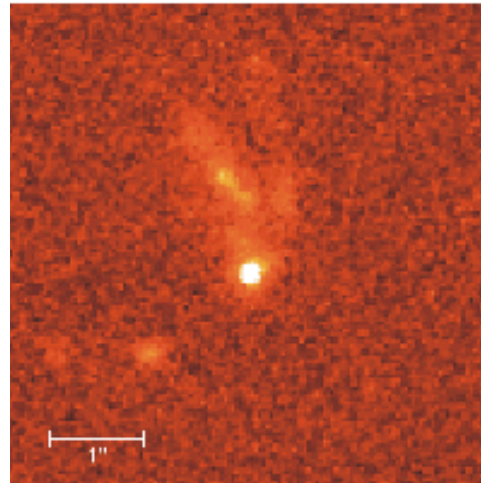
(F. Ryde et al. 2003)

Observations and their consequences

- **Distribution of GRBs**
- Time profiles
- Afterglows
- Spectra



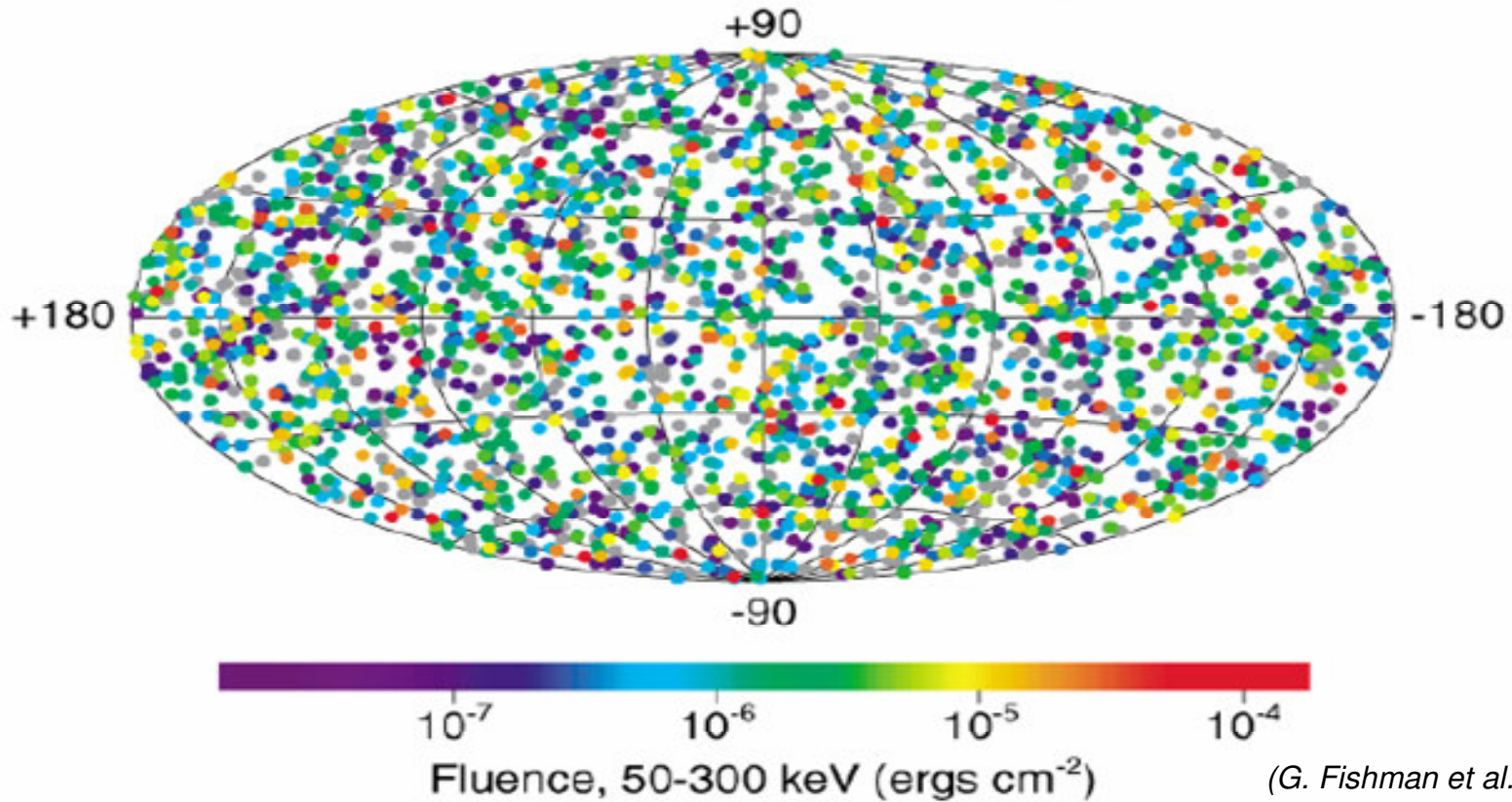
Typical time profile



First optical afterglow

(Andrew Fruchter)

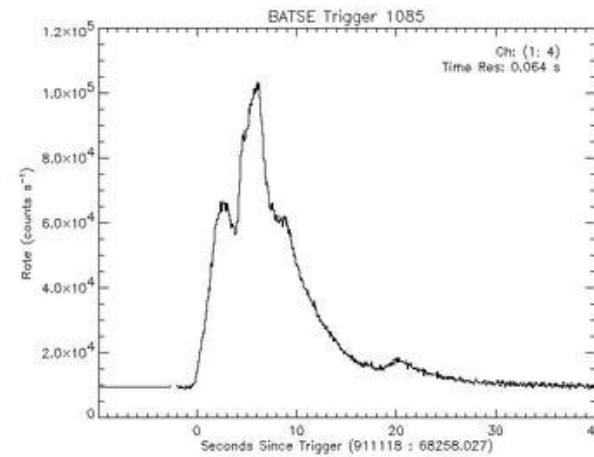
Celestial distribution



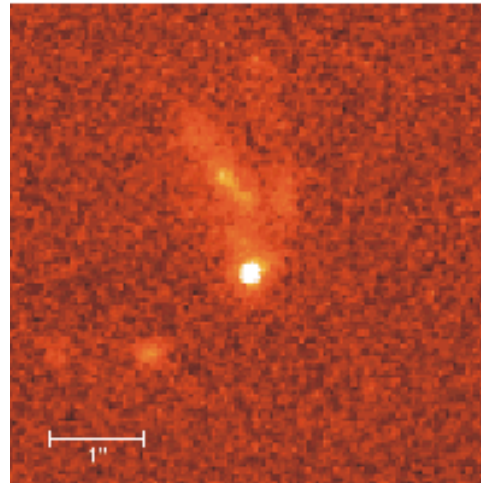
Homogenous distribution ↪ cosmic origin

Observations and their consequences

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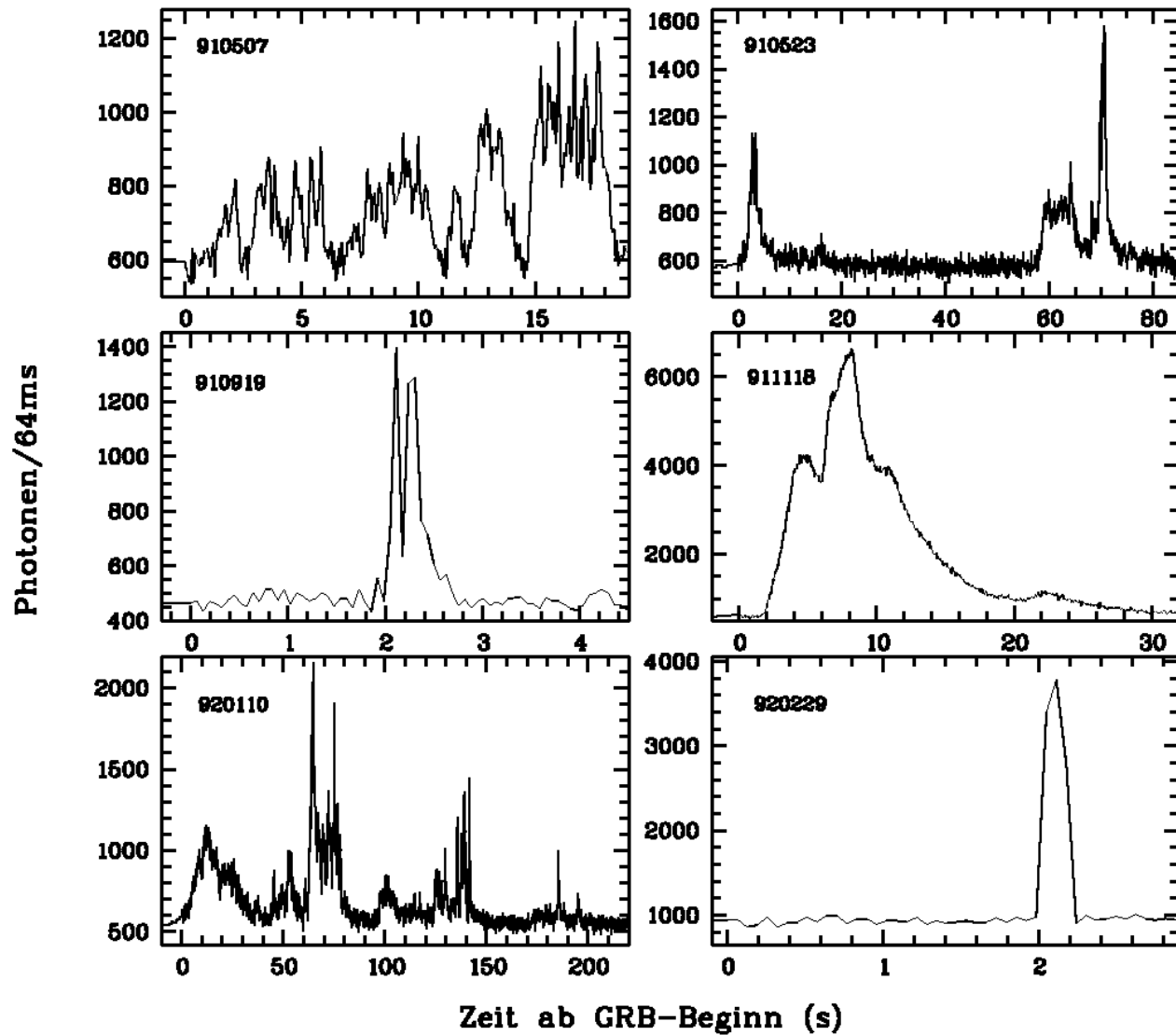
Typical time profile



First optical afterglow

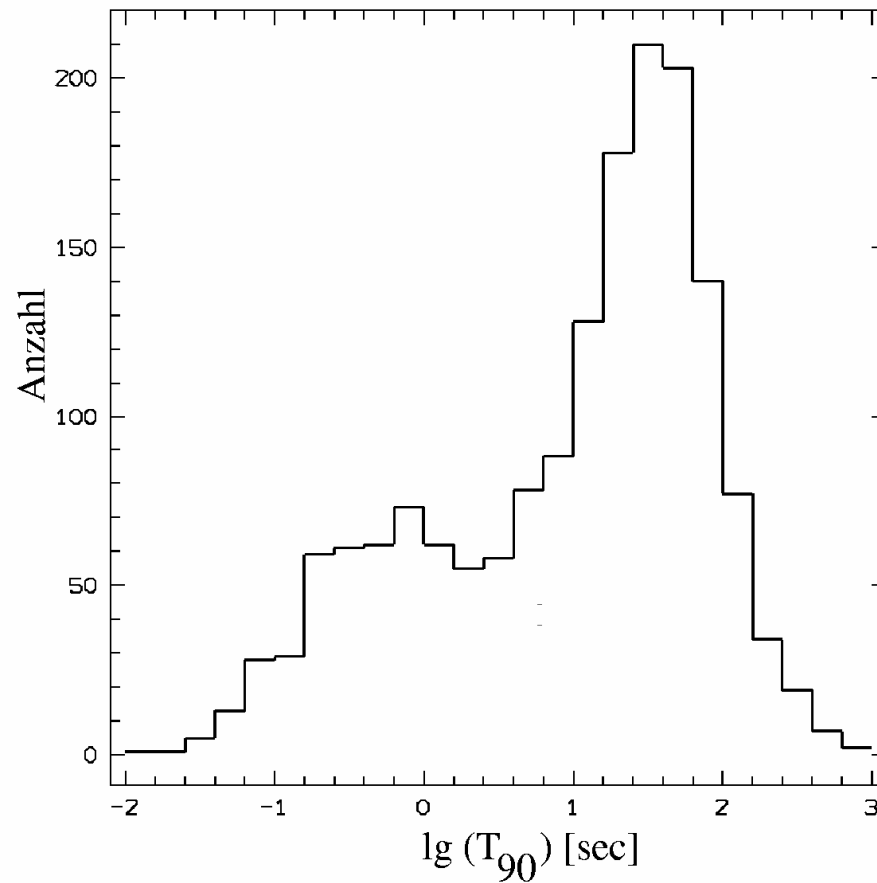
(Andrew Fruchter)

Time profiles – different examples



(S. Klose)

Time profiles – distribution of T_{90} -durations of GRBs

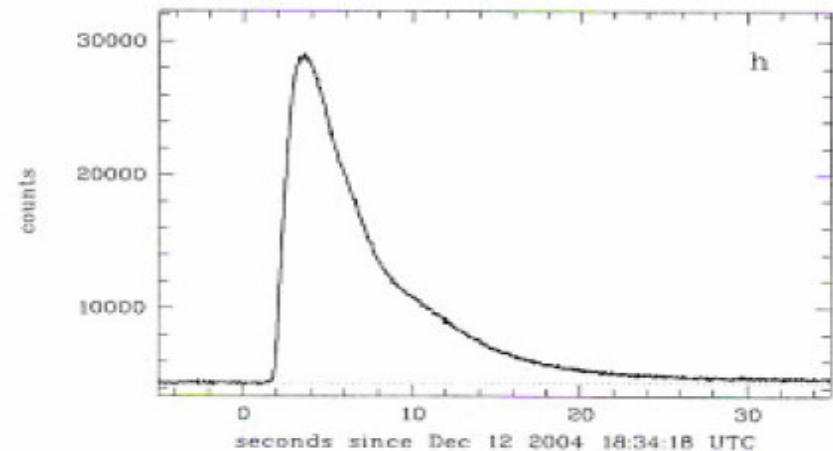
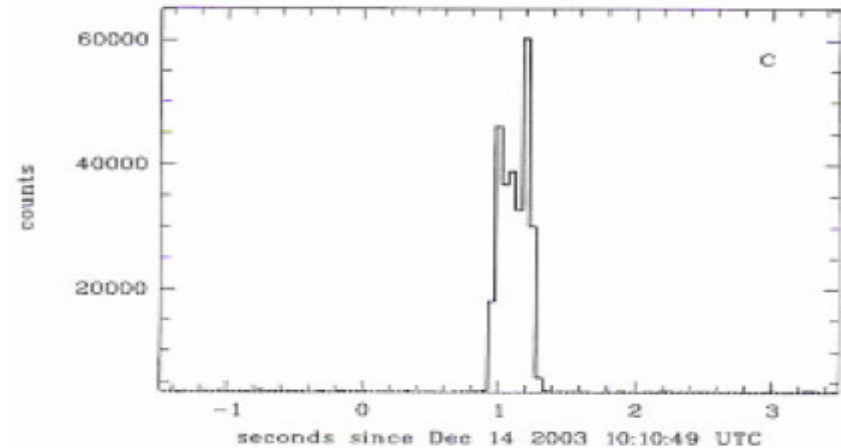


(BATSE-team, 1999)

Time profiles – short and long GRBs

Two different classes of time profiles:

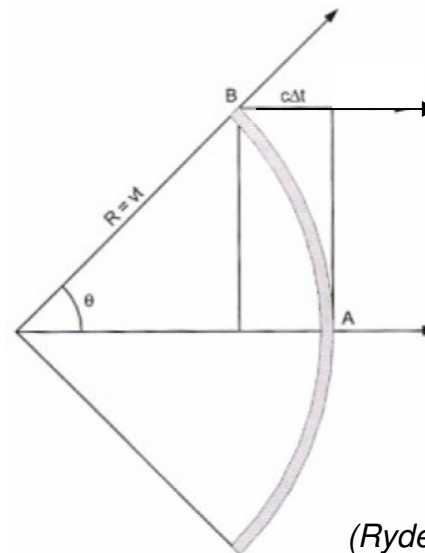
- Short GRBs: duration from 0,01s-2s
- Long GRBs: duration from 2s-1000s



(A. Rau et al. 2005)

Time profiles – what can we learn from?

- two complete different classes of bursts → at least two different models of emerging (see later)
- rise time much shorter than decay time → hint on relativistic expanding (curvature effect)



B: photons delayed by

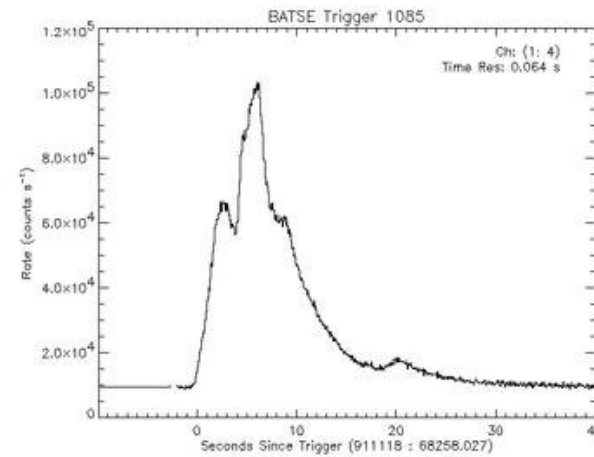
$$\Delta t = \frac{\Gamma}{1 - \beta \cos \theta}$$

(Ryde&Petrosian, 2002)

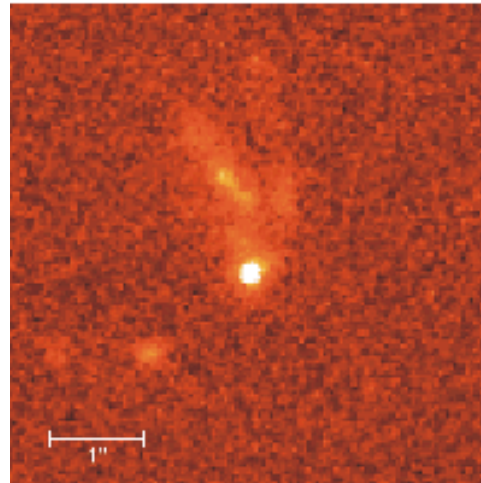
- decay time gives information about radius of emission (generally very small, a few ten kilometers)

Observations and their consequences

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- **Afterglows**
- Spectra



Typical time profile



First optical afterglow

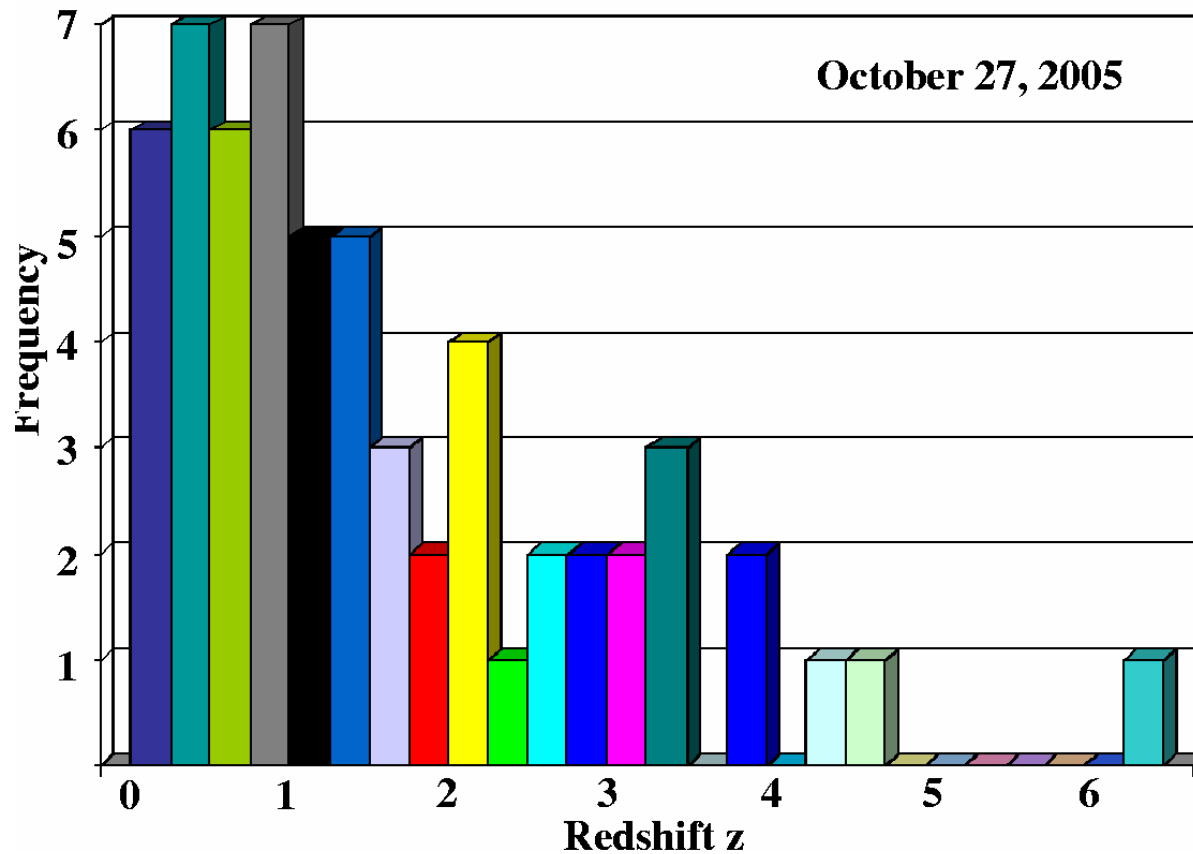
(Andrew Fruchter)

Afterglows - properties

- Dominated by wideband synchrotron radiation from X- to radio range
- For practically all of the GRBs for that an X-ray observation is made an X-ray afterglow is detected, only for ~50% an optical one (unknown reason) and only for ~30% one in the radio range (probably insufficient sensitivity)
- First afterglow of a long GRB observed 1997, of a short GRB 2005
- Durations up to several weeks

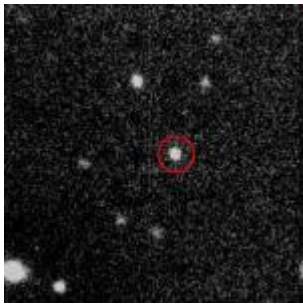
Afterglows – redshift distribution

High redshift is confirmed  most GRBs far away

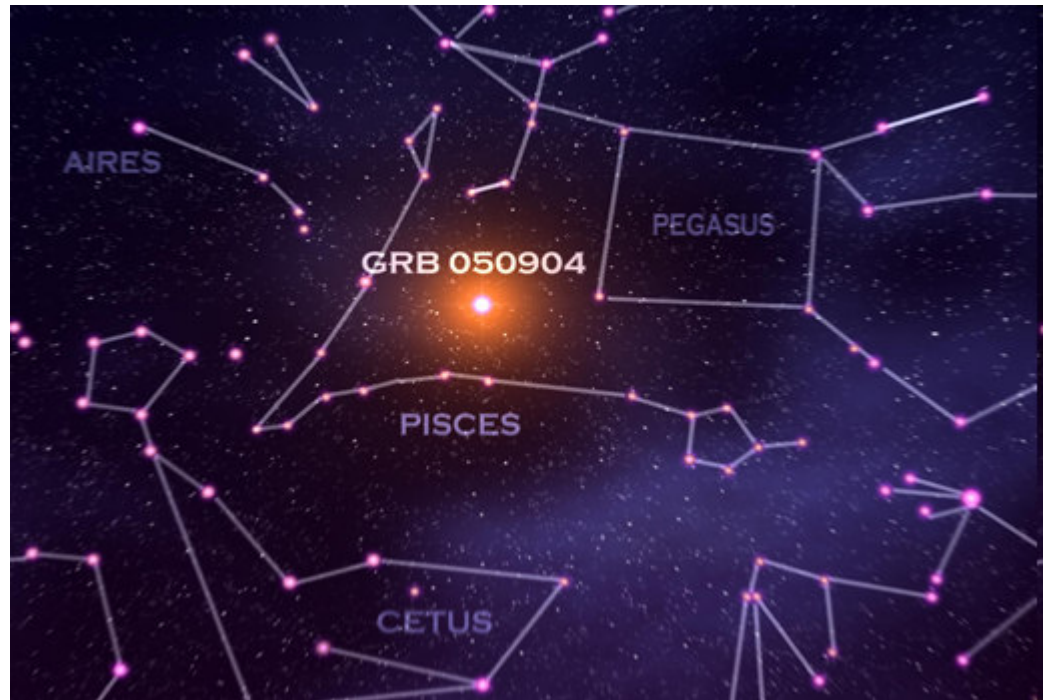


(Sylvio Klose, 2005)

Afterglows – redshift distribution II



(Dr. Daniel Reichart)



(NASA)

Burst with the highest redshift ever measured:
detected by SWIFT on September 4, 2005
nearly 13 billion years away with a redshift of 6,29

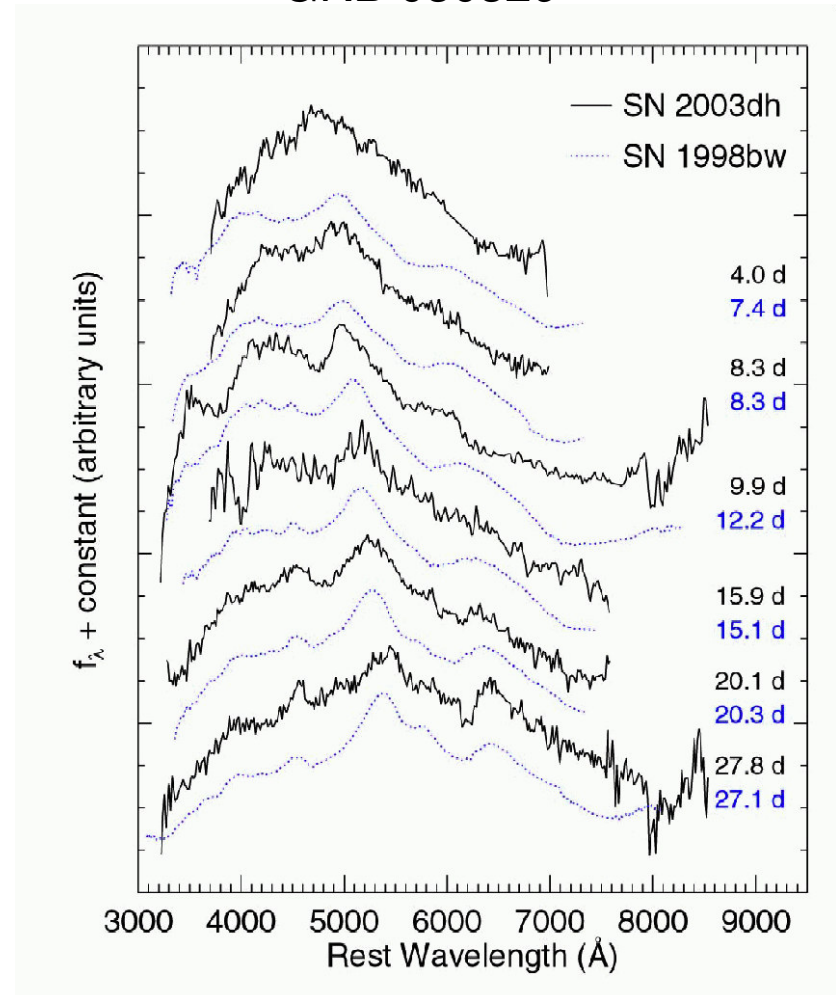
Afterglows – supernova features

Characteristic supernova-features found in some spectral exposures



GRB-Supernova-connection

GRB 030329



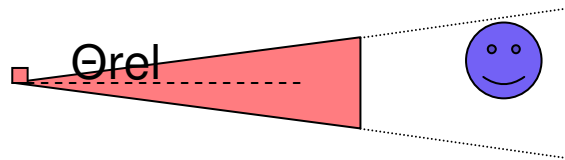
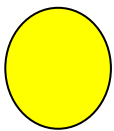
(Hjorth et al. 2003).

Afterglows – hint on jets

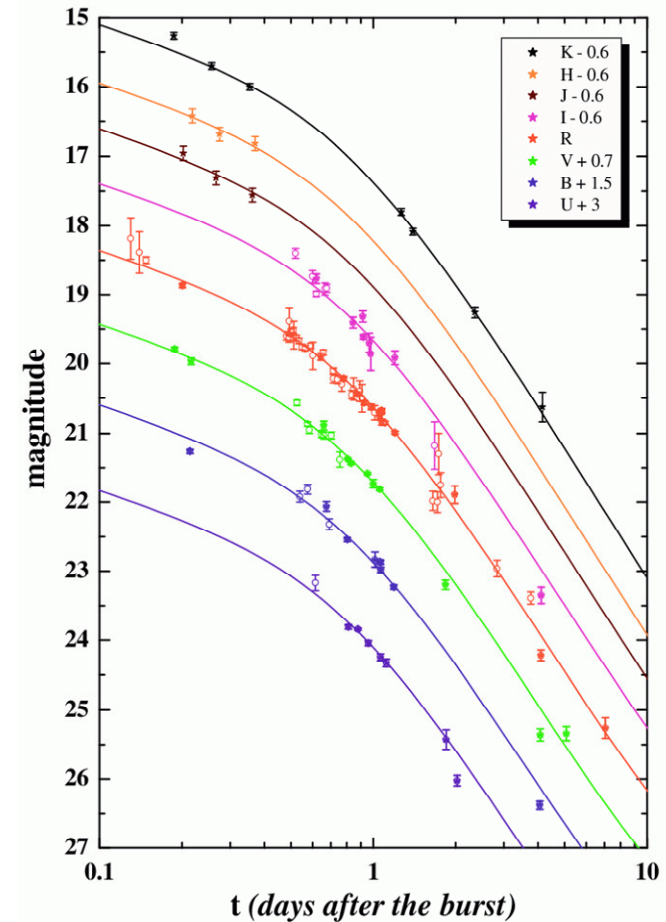
breaks in the light curves in many GRBs

↪ hint on collimated energy
mission (jets)

- relativistic effect
- break when $\Theta_{\text{rel}} = \Theta_{\text{jet}}$



$\Theta_{\text{rel}} = 1/\Gamma$ (increases with time)



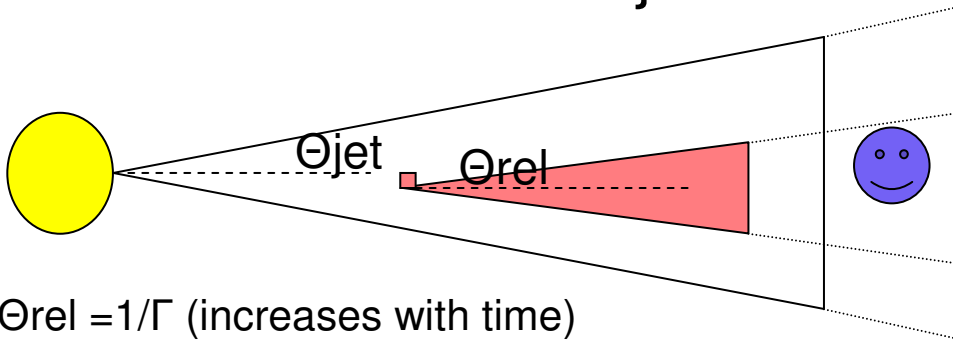
(Sylvio Klose et al., ESO)

Afterglows – hint on jets

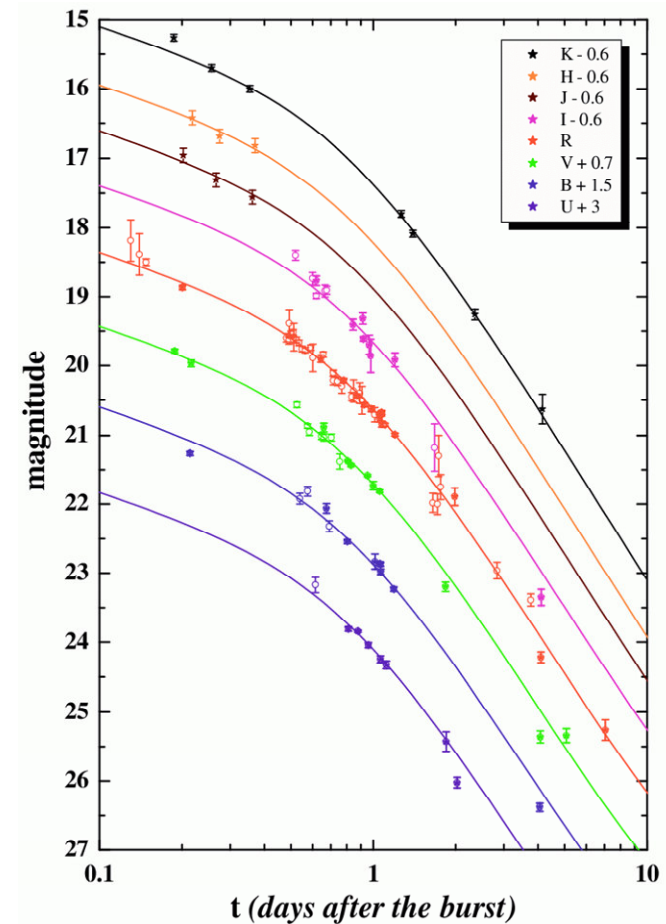
breaks in the light curves in many GRBs

↪ hint on collimated energy
mission (jets)

- relativistic effect
- break when $\Theta_{\text{rel}} = \Theta_{\text{jet}}$



$\Theta_{\text{rel}} = 1/\Gamma$ (increases with time)
 $\Theta_{\text{jet}} = \text{collimation angle } (\sim 8 - 10^\circ)$



(Sylvio Klose et al., ESO)

Afterglows – hint on jets I

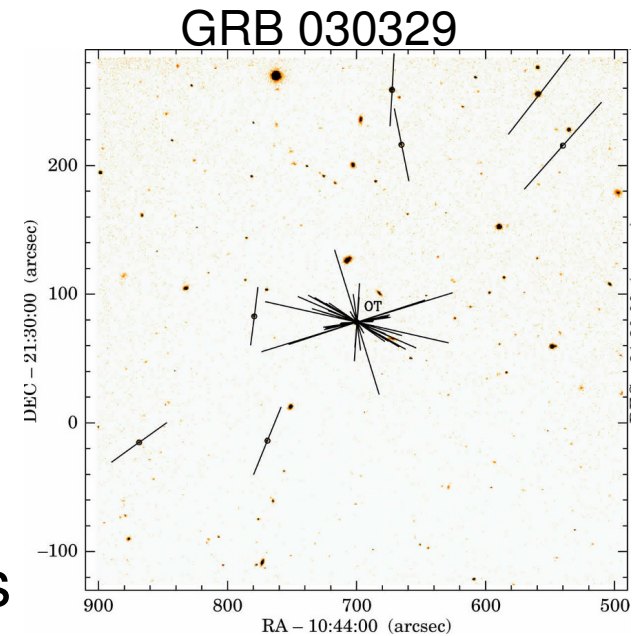
change of polarization ($\sim 1-3\%$)
around jet-break time

↪ 2nd hint on collimated energy
emission

Consequences:

An opening angle of a jet of 10° results
in a beaming factor $\left(\frac{4\pi}{d\Omega_{\text{jet}}}\right)$ of ~ 130

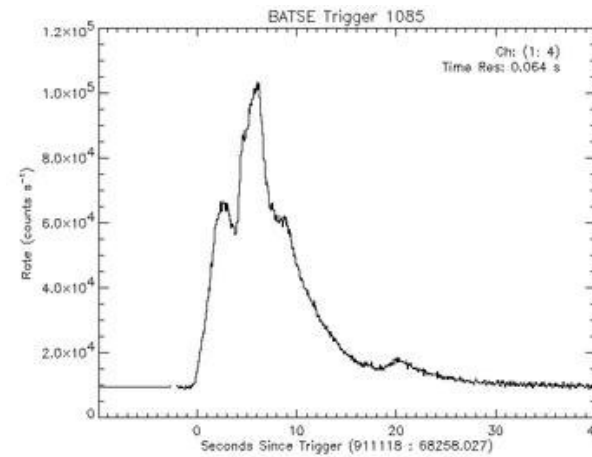
- event rate is increased:
lots of bursts not seen
- total energy is overestimated
(most GRBs at $\sim 10^{51}$ erg instead of $\sim 10^{54}$ erg)



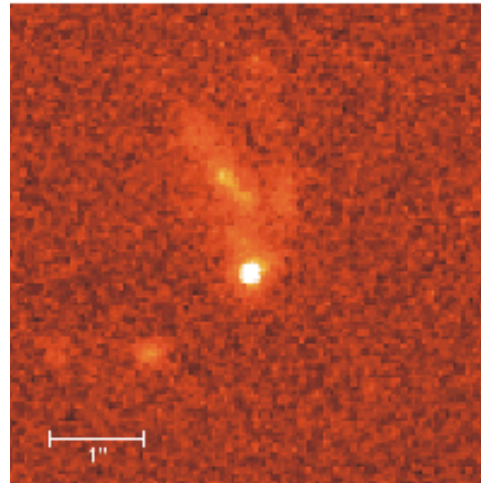
(J. Greiner et al. 2003)

Observations and their consequences

- Distribution of GRBs
- Time profiles
- Afterglows
- **Spectra**



Typical time profile



First optical afterglow

(Andrew Fruchter)

Spectra - modeling

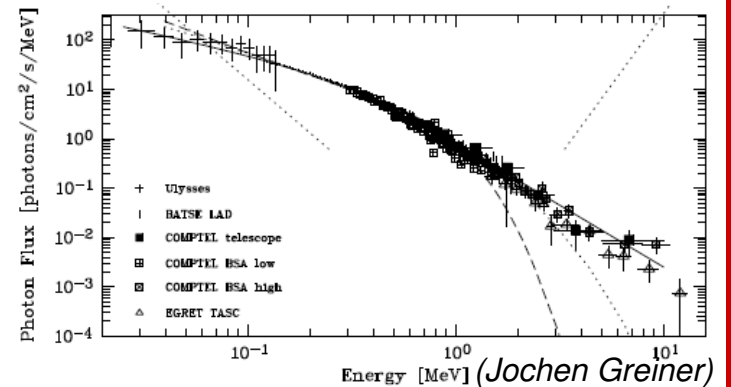
Energy spectra of GRBs can be modeled by the so called „GRB-function“:

$$f(E) = \begin{cases} A(E/100)^\alpha e^{-E(2+\alpha)/E_{\text{peak}}} & \text{if } E < \frac{(\alpha - \beta)E_{\text{peak}}}{(2 + \alpha)} \equiv E_{\text{break}} , \\ A \left[\frac{(\alpha - \beta)E_{\text{peak}}}{100(2 + \alpha)} \right]^{(\alpha - \beta)} \exp(\beta - \alpha)(E/100)^\beta & \text{if } E \geq \frac{(\alpha - \beta)E_{\text{peak}}}{(2 + \alpha)} . \end{cases}$$

α : power-law index for rise phase (~ -1)

β : power-law index for decay phase ($\sim -2,4$)

E_{break} : break energy



Spectra - modeling

Energy spectra of GRBs can be modeled by the so called „GRB-function“:

$$N_E(E) = \begin{cases} C \cdot E^\alpha \cdot e^{-\frac{E}{E_{\text{peak}}}} & E_{\text{break}} \geq E \\ C \cdot E^\beta \cdot e^{+\frac{E}{E_{\text{peak}}}} & E_{\text{break}} < E \end{cases}$$

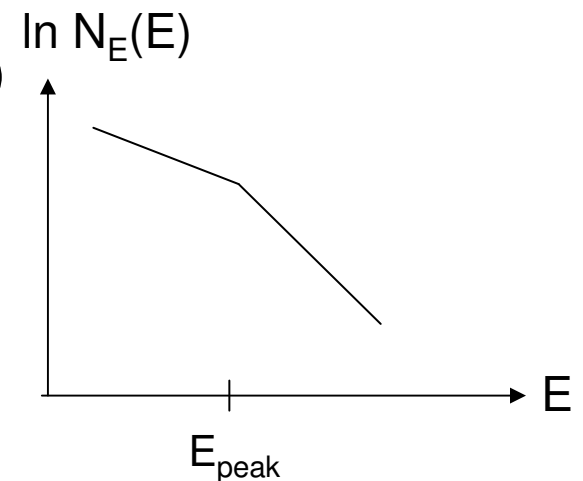
α : power-law index for rise phase (~ -1)

β : power-law index for decay phase ($\sim -2,4$)

E_{break} : break energy

→ no indication of a blackbody spectrum

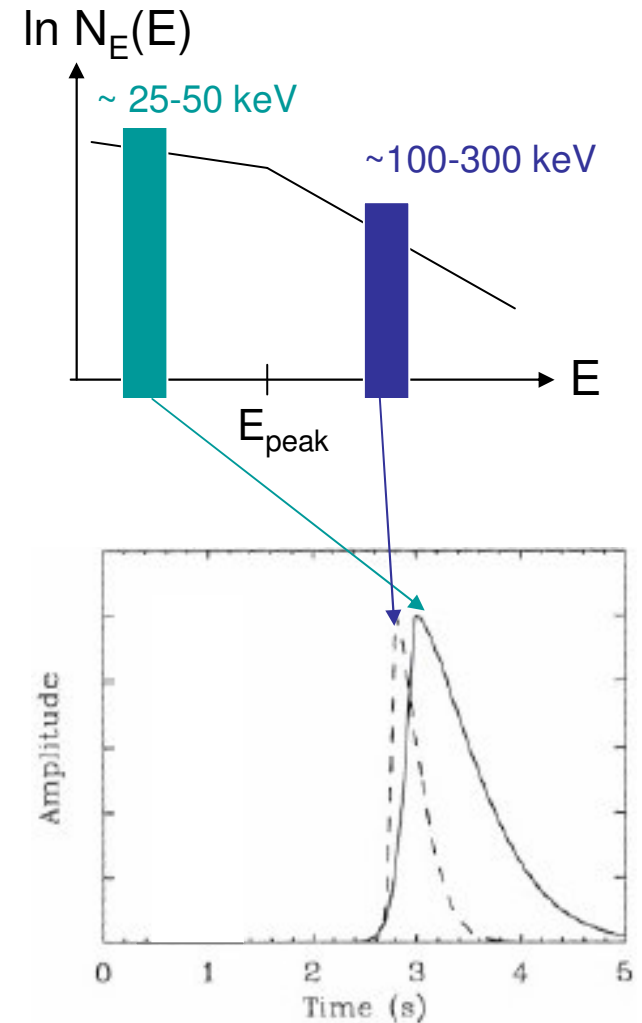
→ only non-thermal radiation



Spectra – anticorrelation between spectral lag and peak luminosity

For a small sample of BATSE data:
time profiles are made out of two
different energy ranges

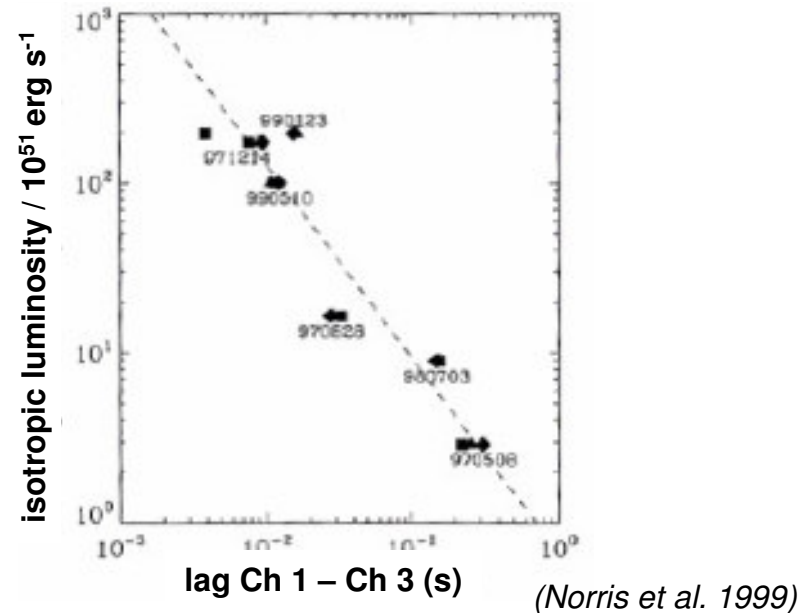
→ peaks are time-shifted, this time is
represented by the spectral lag



(Norris et al, 1999)

Spectra – anticorrelation between spectral lag and peak luminosity II

- The larger the spectral lag the lower the luminosity



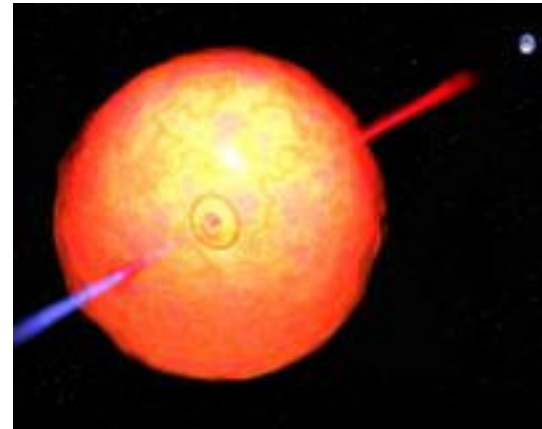
- Expectation for future: spectral lags for the general population of GRBs translate into luminosities
problem: small energy range of SWIFT → waiting for GLAST

Models of emerging

Origin of GRBs not completely understood yet, especially that of short GRBs.

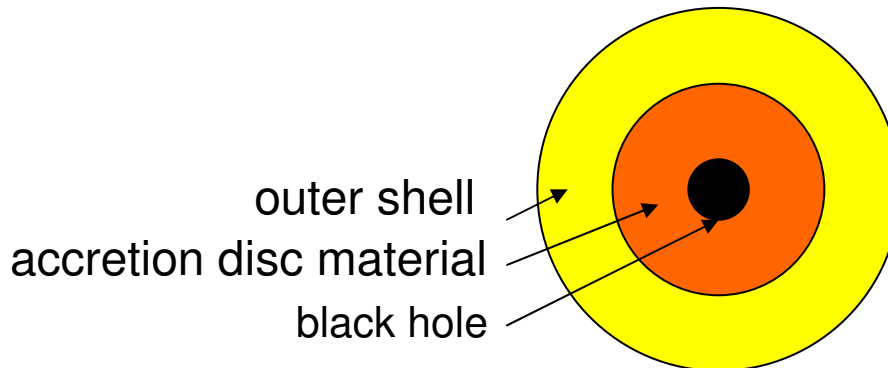
Favored models:

- long GRBs: collapsar model
- short GRBs: colliding neutron stars



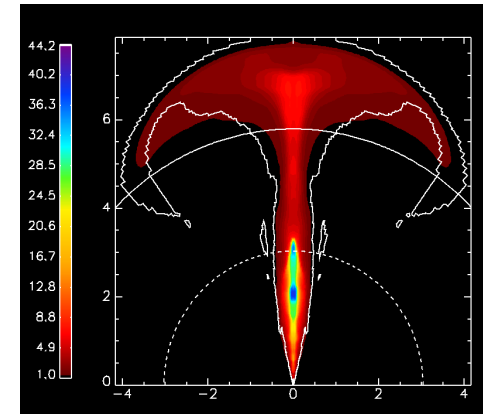
Collapsar model

- theoretical basic principle: **fireball model**
 - much energy deposition in a small volume
 - relativistic expanding shock wave
- collapse of a massive star → formation of a black hole in the centre, an accretion disc and a repulsion of the outer shell

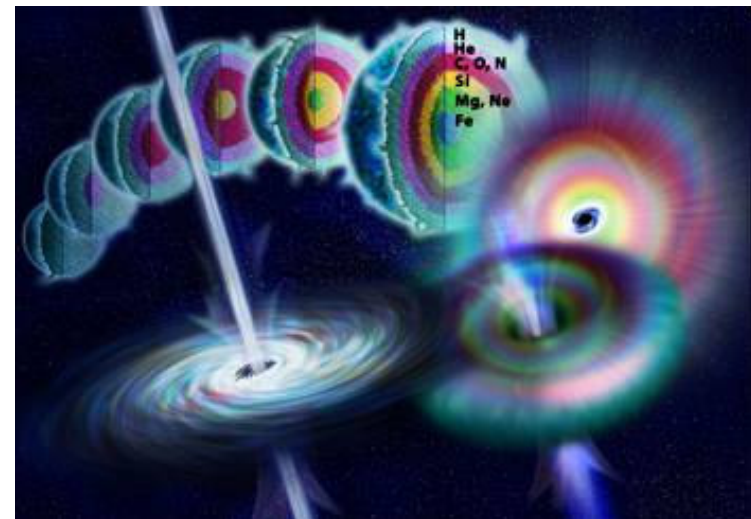


Collapsar model II

- material from the accretion disc is accelerated and rotates around the black hole, in the end it is absorbed
- gravitational binding energy is collimated near the axis of rotation
 - jet(s) is/are emitted with relativistic speed



(Miguel Angel Aloy, Ewald Müller)



(NASA)

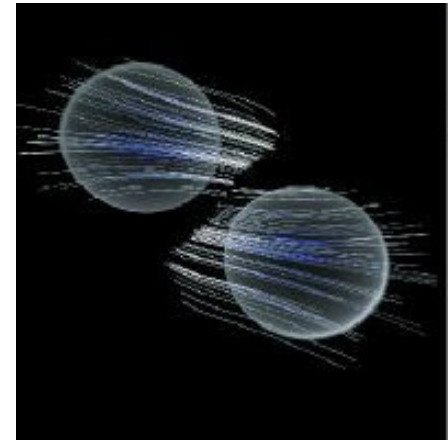
Collapsar model III

- γ -radiation arises when kinetic energy of the ultra-relativistic bulk outflow is transformed by synchrotron and/or inverse Compton emission
- as soon as shock wave reaches the interstellar medium it is decelerated \rightarrow afterglow



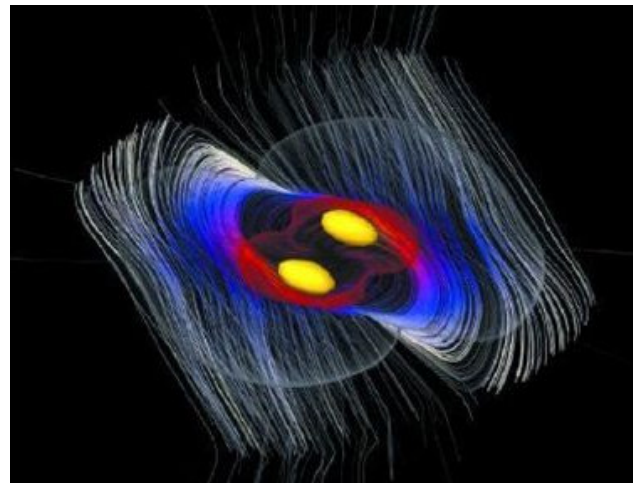
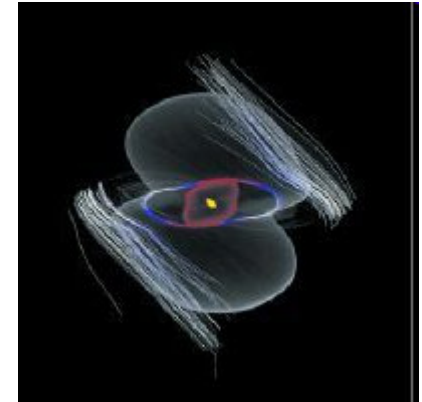
Colliding neutron stars

- both partners of a binary star system explode as a supernova → two neutron stars can be born
- can orbit each other for billions of years
- limited lifetime because of radiation of gravitational waves
 - ↳ reduction of distance
 - ↳ collision and destruction of both stars
 - ↳ formation of a black hole, small amount of matter forms a rotating cloud of gas



Colliding neutron stars II

- ↪ cloud of gas stabilized by centripetal force but internal friction slows it down, finally it is absorbed
- ↪ gas is heated by friction
- ↪ energy emission: probably jets (quickly high velocities, don't have to make their way through dense stellar layers)



(Werner Bengert from NPACI, ZIB & NCSA)

Conclusion and open questions

- GRBs are the brightest and energetic events known in our universe
- A lot of details are established due to highly modern detectors – but their real origin(s) still remain(s) open (including the emerging of the gamma ray photons)
- Do GRBs influence the abundance in the interstellar medium?
- Have there any GRBs been in our neighborhood in the last billion years? And what would happen if one occurs there these days?

References

- Jochen Greiner: Gamma Ray Bursts
- Papers:
 - F. Ryde et al.: Gamma-ray bursts observed by the INTEGRAL-SPI anticoincidence shield: A study of individual pulses and temporal variability, A&A 2003
 - J.P. Norris et al.: Connection between energy-dependent lags and peak luminosity in gamma-ray bursts, AJ 2000
 - A. Rau et al.: The 1st INTEGRAL SPI-ACS gamma-ray burst catalogue, A&A 2005
 - Dan Kocevski et al.: Search for relativistic curvature effects in gamma-ray burst pulses, AJ 2003
 - Felix Ryde: The cooling behavior of thermal pulses in gamma-ray bursts, AJ 2004
- Web