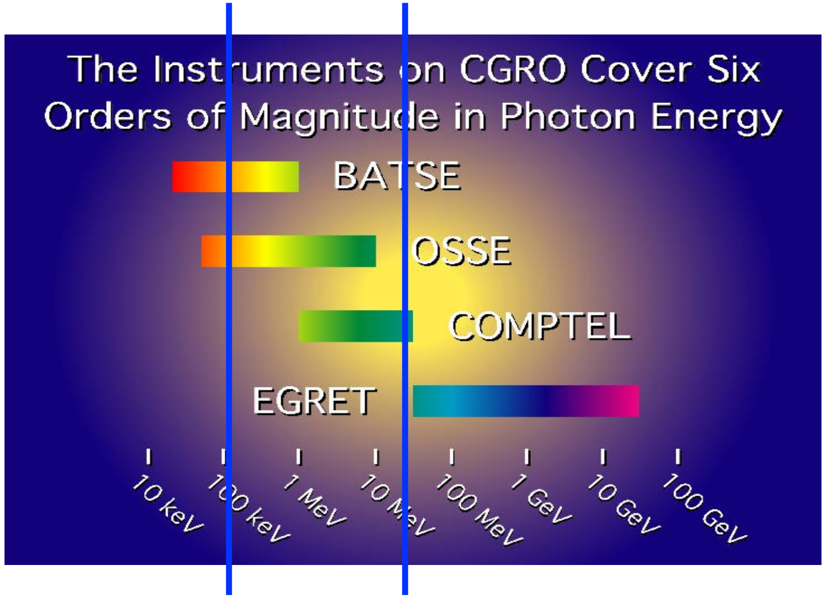
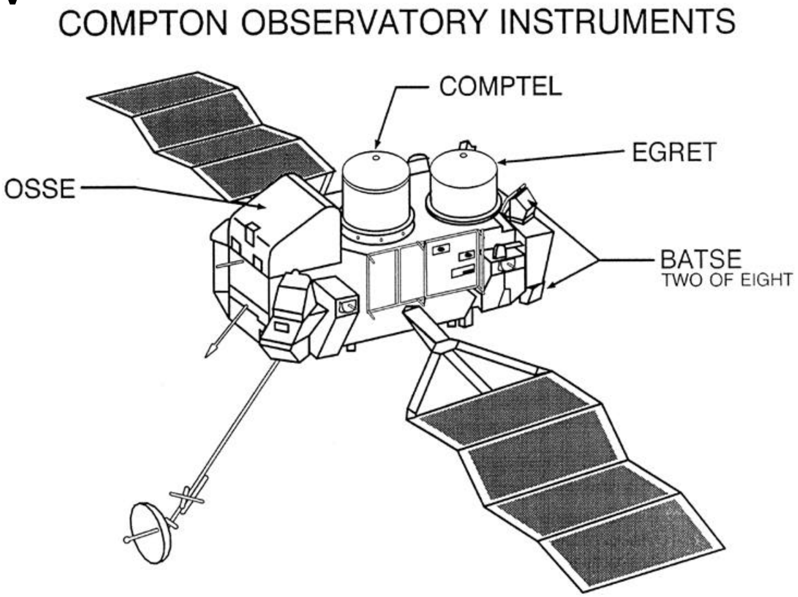
Astrofisica Nucleare e Subnucleare

Gamma ray Bursts – II

The Compton Gamma Ray Observatory

http://cossc.gsfc.nasa.gov

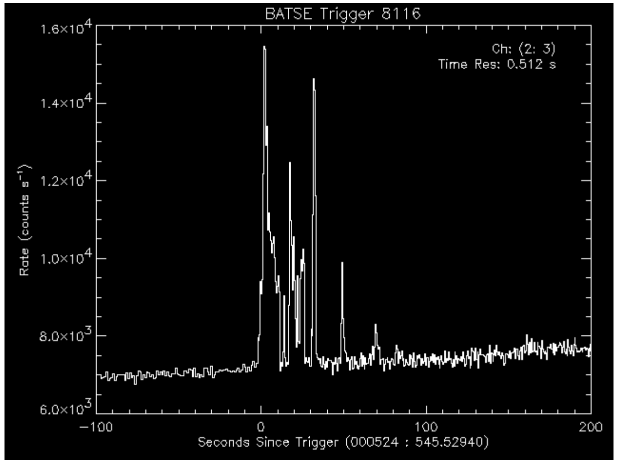




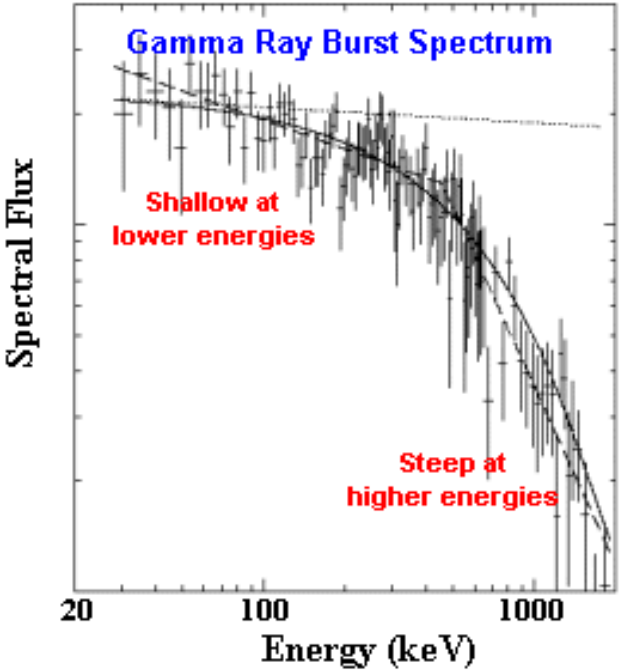
The Compton Gamma Ray Observatory (CGRO) is a sophisticated satellite observatory dedicated to observing the high-energy Universe. It is the second in NASA's program of orbiting "Great Observatories", following the Hubble Space Telescope.
While Hubble's instruments operate at visible and ultraviolet wavelengths, Compton carries a collection of four instruments which together can detect an unprecedented broad range of high-energy radiation called gamma rays. These instruments are the Burst And Transient Source Experiment (BATSE), the Oriented Scintillation Spectrometer Experiment (OSSE), the Imaging Compton Telescope (COMPTEL), and the Energetic Gamma Ray Experiment Telescope (EGRET).

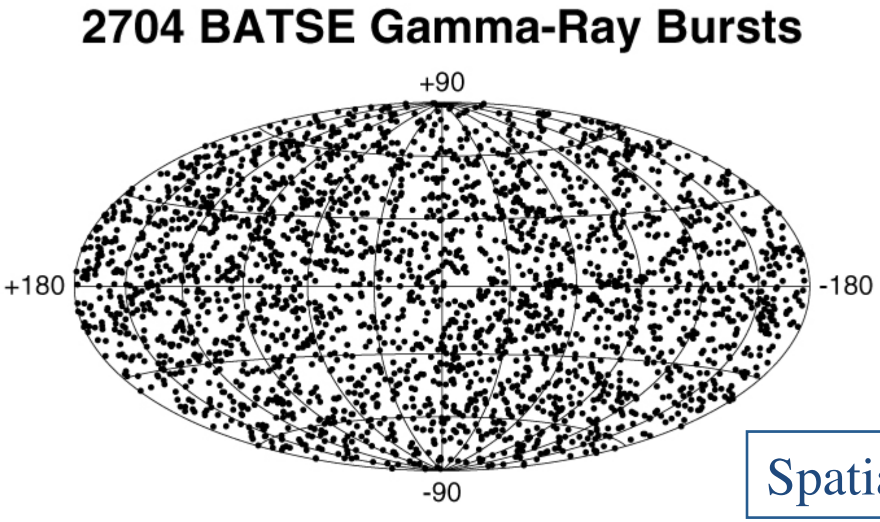
Gamma-Ray Bursts

Temporal behaviour



Spectral shape





Spatial distribution

GRB: where are they?

The great debate (1995)

Flux: 10^{-7} erg cm^{-2} s^{-1}

Distance: 1 Gpc

Energy: 10^{51} erg

Distance: 100 kpc

Energy: 10^{43} erg

Cosmological - Galactic?

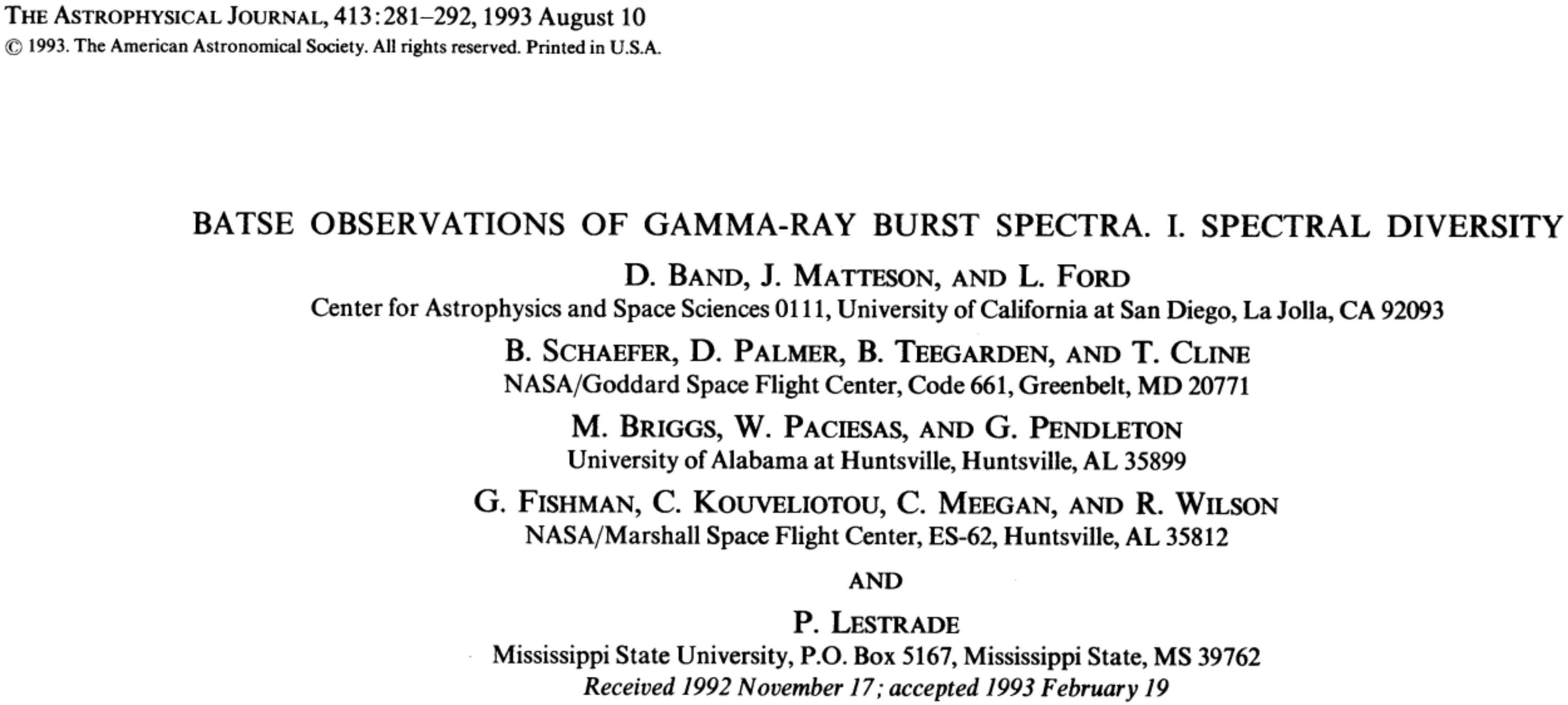
Need a new type of observation!

Exercise #2

- Find the GRB function by David Band (1993)
- Find the review paper by Piran 1999 on GRB afterglow
- Find the paper by L.Amati on Ep-Eiso correlation (2002)
- Find the papers of the “Great Debate (1995)”

Exercise #2

- Find the GRB function by David Band (1993)



THE ASTROPHYSICAL JOURNAL, 413:281–292, 1993 August 10

BATSE OBSERVATIONS OF GAMMA-RAY BURST SPECTRA. I. SPECTRAL DIVERSITY

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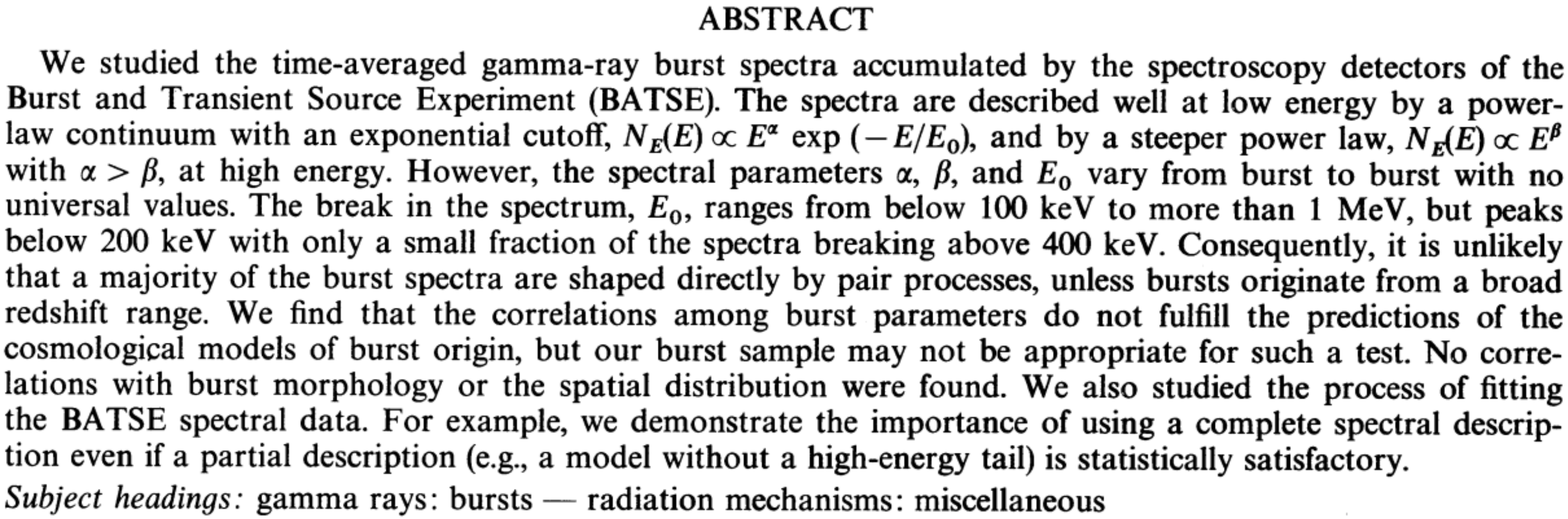
Received 1992 November 17; accepted 1993 February 19

Exercise #2

- Find the GRB function by David Band (1993)



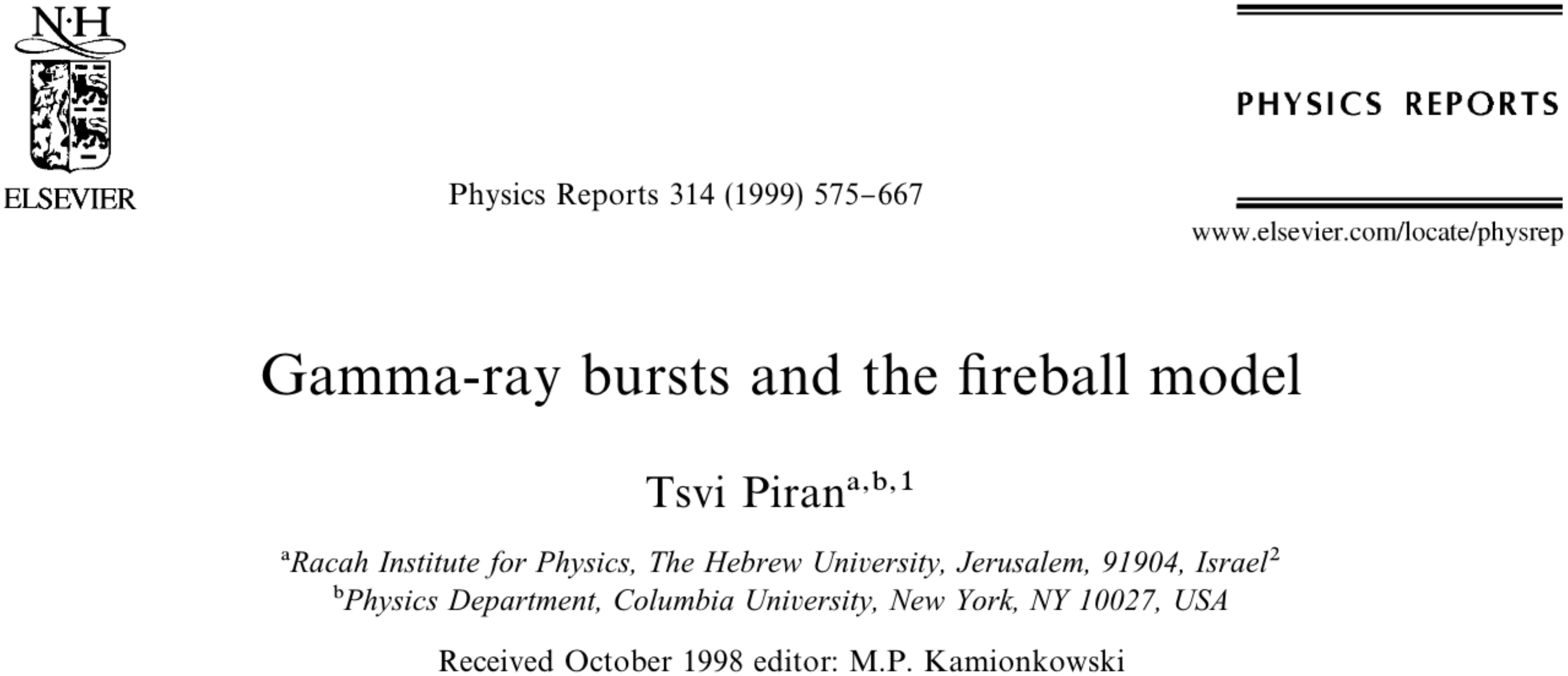
ABSTRACT

We studied the time-averaged gamma-ray burst spectra accumulated by the spectroscopy detectors of the Burst and Transient Source Experiment (BATSE). The spectra are described well at low energy by a power-law continuum with an exponential cutoff, $N_E(E) \propto E^{\alpha} \exp(-E/E_0)$, and by a steeper power law, $N_E(E) \propto E^{\beta}$ with $\alpha > \beta$, at high energy. However, the spectral parameters α, β, and E_0 vary from burst to burst with no universal values. The break in the spectrum, E_0, ranges from below 100 keV to more than 1 MeV, but peaks below 200 keV with only a small fraction of the spectra breaking above 400 keV. Consequently, it is unlikely that a majority of the burst spectra are shaped directly by pair processes, unless bursts originate from a broad redshift range. We find that the correlations among burst parameters do not fulfill the predictions of the cosmological models of burst origin, but our burst sample may not be appropriate for such a test. No correlations with burst morphology or the spatial distribution were found. We also studied the process of fitting the BATSE spectral data. For example, we demonstrate the importance of using a complete spectral description even if a partial description (e.g., a model without a high-energy tail) is statistically satisfactory.

Subject headings: gamma rays: bursts — radiation mechanisms: miscellaneous

Exercise #2

- Find the review paper by Piran 1999 on GRB afterglow



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Physics Reports 314 (1999) 575–667

PHYSICS REPORTS

www.elsevier.com/locate/physrep

Gamma-ray bursts and the fireball model

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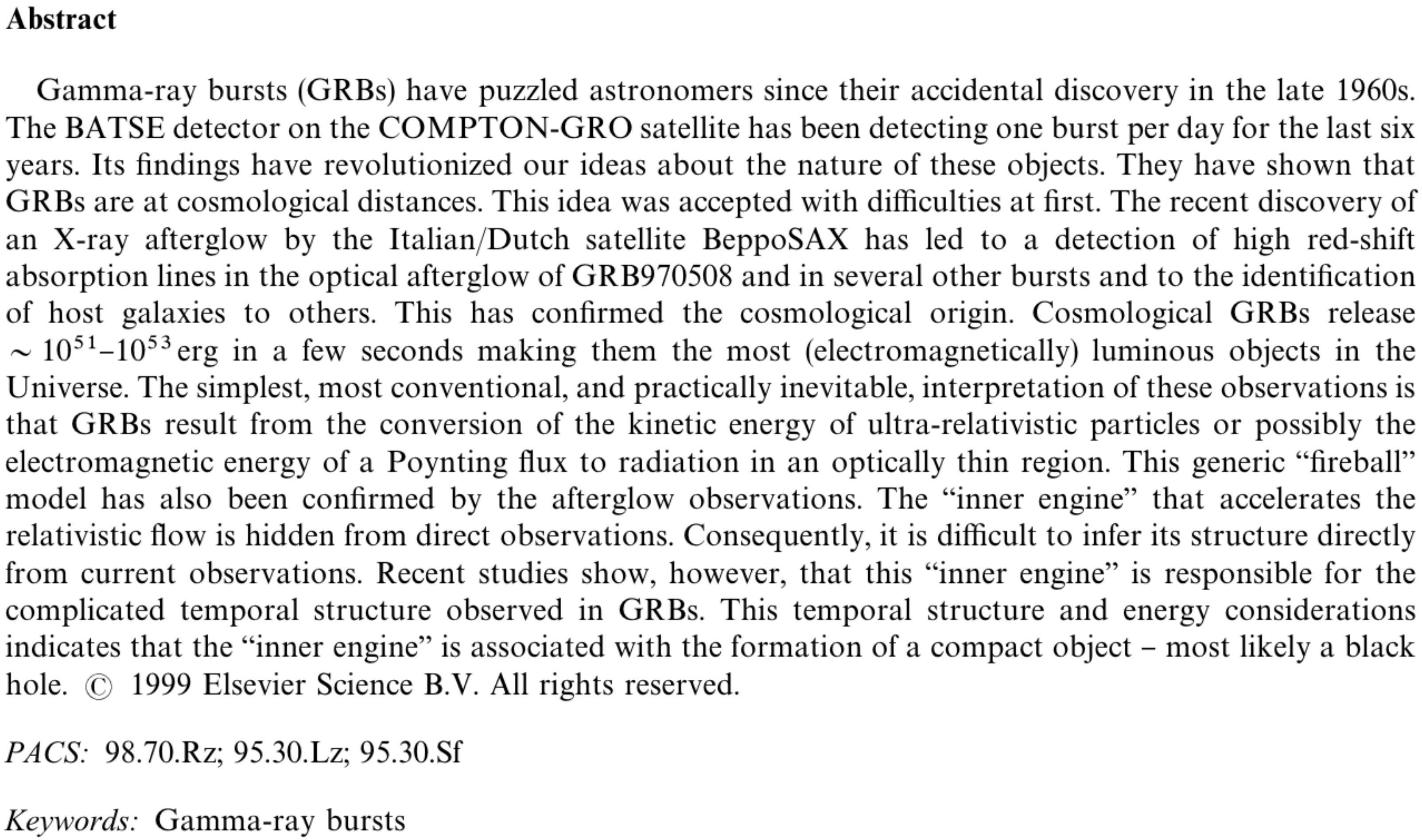
Received October 1998 editor: M.P. Kamionkowski

Exercise #2

- Find the review paper by Piran 1999 on GRB afterglow



Abstract

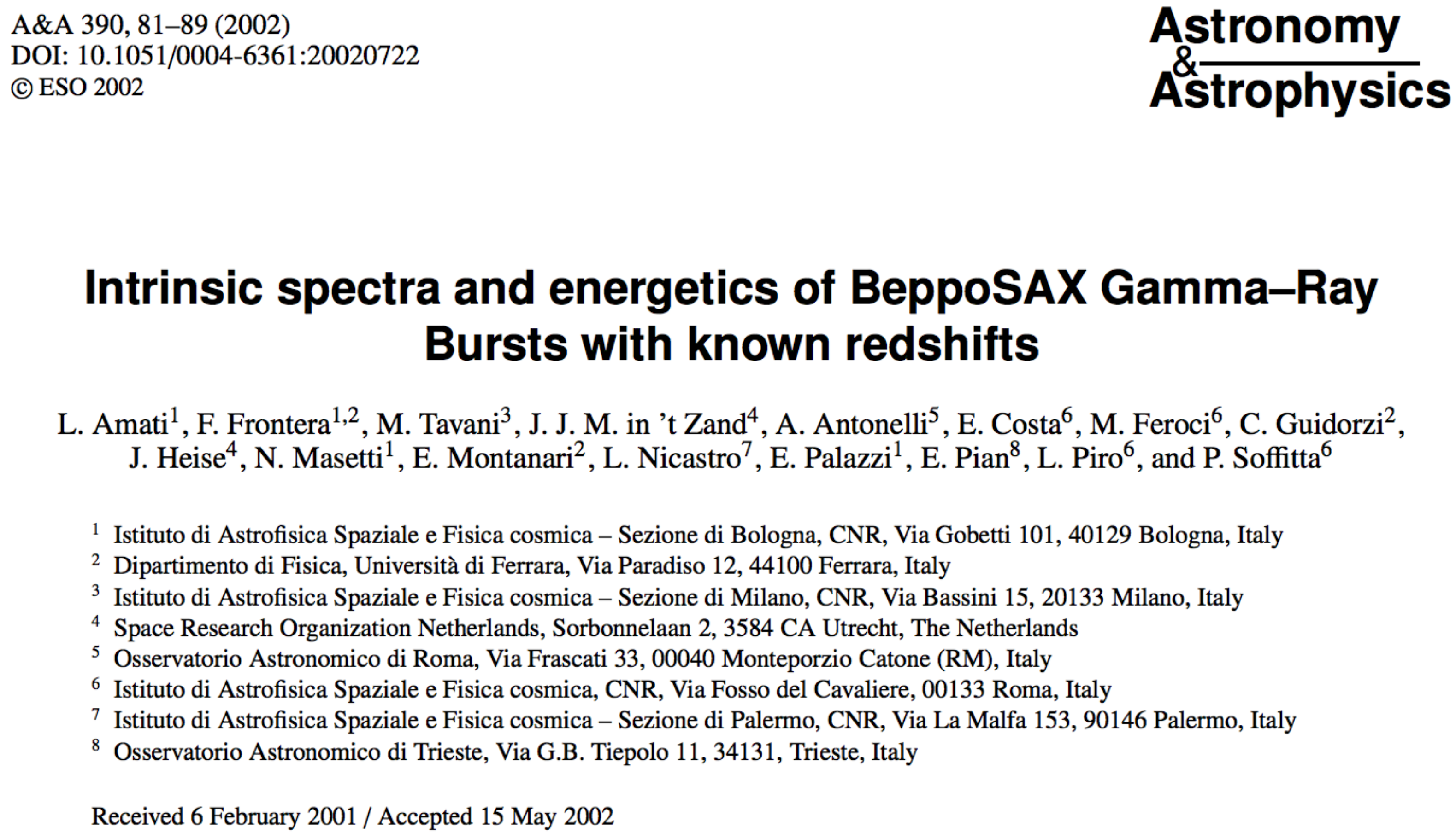
Gamma-ray bursts (GRBs) have puzzled astronomers since their accidental discovery in the late 1960s. The BATSE detector on the COMPTON-GRO satellite has been detecting one burst per day for the last six years. Its findings have revolutionized our ideas about the nature of these objects. They have shown that GRBs are at cosmological distances. This idea was accepted with difficulties at first. The recent discovery of an X-ray afterglow by the Italian/Dutch satellite BeppoSAX has led to a detection of high red-shift absorption lines in the optical afterglow of GRB970508 and in several other bursts and to the identification of host galaxies to others. This has confirmed the cosmological origin. Cosmological GRBs release $\sim 10^{51}$–10^{53} erg in a few seconds making them the most (electromagnetically) luminous objects in the Universe. The simplest, most conventional, and practically inevitable, interpretation of these observations is that GRBs result from the conversion of the kinetic energy of ultra-relativistic particles or possibly the electromagnetic energy of a Poynting flux to radiation in an optically thin region. This generic "fireball" model has also been confirmed by the afterglow observations. The "inner engine" that accelerates the relativistic flow is hidden from direct observations. Consequently, it is difficult to infer its structure directly from current observations. Recent studies show, however, that this "inner engine" is responsible for the complicated temporal structure observed in GRBs. This temporal structure and energy considerations indicates that the "inner engine" is associated with the formation of a compact object – most likely a black hole. © 1999 Elsevier Science B.V. All rights reserved.

PACS: 98.70.Rz; 95.30.Lz; 95.30.Sf

Keywords: Gamma-ray bursts

Exercise #2

- Find the paper by L.Amati on Ep-Eiso correlation (2002)



A&A 390, 81–89 (2002)
DOI: 10.1051/0004-6361:20020722

Astronomy & Astrophysics

Intrinsic spectra and energetics of BeppoSAX Gamma–Ray Bursts with known redshifts

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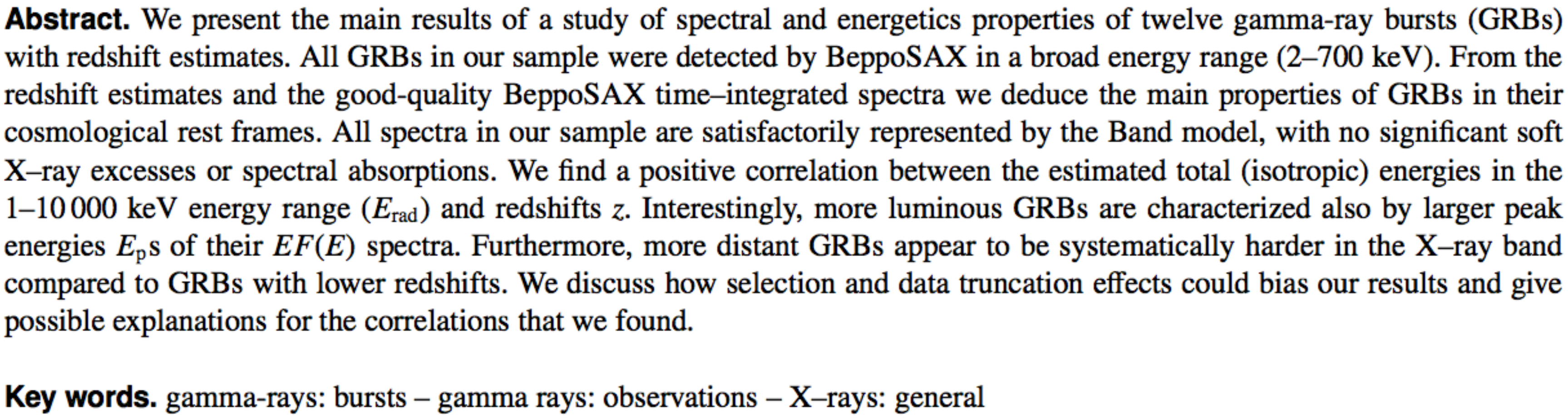
Received 6 February 2001 / Accepted 15 May 2002

Exercise #2

- Find the paper by L.Amati on Ep-Eiso correlation (2002)



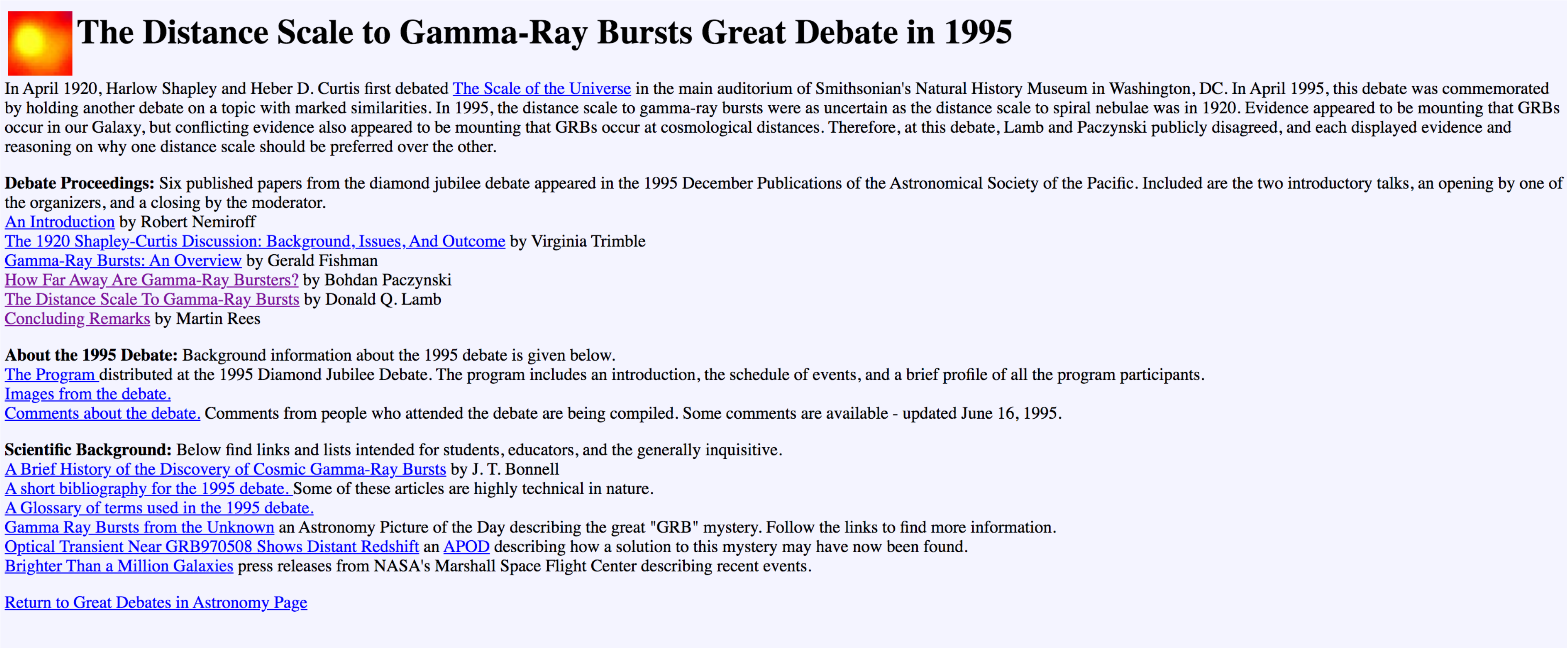
Abstract. We present the main results of a study of spectral and energetics properties of twelve gamma-ray bursts (GRBs) with redshift estimates. All GRBs in our sample were detected by BeppoSAX in a broad energy range (2–700 keV). From the redshift estimates and the good-quality BeppoSAX time–integrated spectra we deduce the main properties of GRBs in their cosmological rest frames. All spectra in our sample are satisfactorily represented by the Band model, with no significant soft X–ray excesses or spectral absorptions. We find a positive correlation between the estimated total (isotropic) energies in the 1–10 000 keV energy range ($E_{\rm rad}$) and redshifts z. Interestingly, more luminous GRBs are characterized also by larger peak energies $E_{\rm p}$s of their $EF(E)$ spectra. Furthermore, more distant GRBs appear to be systematically harder in the X–ray band compared to GRBs with lower redshifts. We discuss how selection and data truncation effects could bias our results and give possible explanations for the correlations that we found.

Key words. gamma-rays: bursts – gamma rays: observations – X–rays: general

Exercise #2

https://apod.nasa.gov/debate/debate95.html

- Find the papers of the “Great Debate (1995)”



The Distance Scale to Gamma-Ray Bursts Great Debate in 1995

In April 1920, Harlow Shapley and Heber D. Curtis first debated The Scale of the Universe in the main auditorium of Smithsonian's Natural History Museum in Washington, DC. In April 1995, this debate was commemorated by holding another debate on a topic with marked similarities. In 1995, the distance scale to gamma-ray bursts were as uncertain as the distance scale to spiral nebulae was in 1920. Evidence appeared to be mounting that GRBs occur in our Galaxy, but conflicting evidence also appeared to be mounting that GRBs occur at cosmological distances. Therefore, at this debate, Lamb and Paczynski publicly disagreed, and each displayed evidence and reasoning on why one distance scale should be preferred over the other.

Debate Proceedings: Six published papers from the diamond jubilee debate appeared in the 1995 December Publications of the Astronomical Society of the Pacific. Included are the two introductory talks, an opening by one of the organizers, and a closing by the moderator.
An Introduction by Robert Nemiroff
The 1920 Shapley-Curtis Discussion: Background, Issues, And Outcome by Virginia Trimble
Gamma-Ray Bursts: An Overview by Gerald Fishman
How Far Away Are Gamma-Ray Bursters? by Bohdan Paczynski
The Distance Scale To Gamma-Ray Bursts by Donald Q. Lamb
Concluding Remarks by Martin Rees

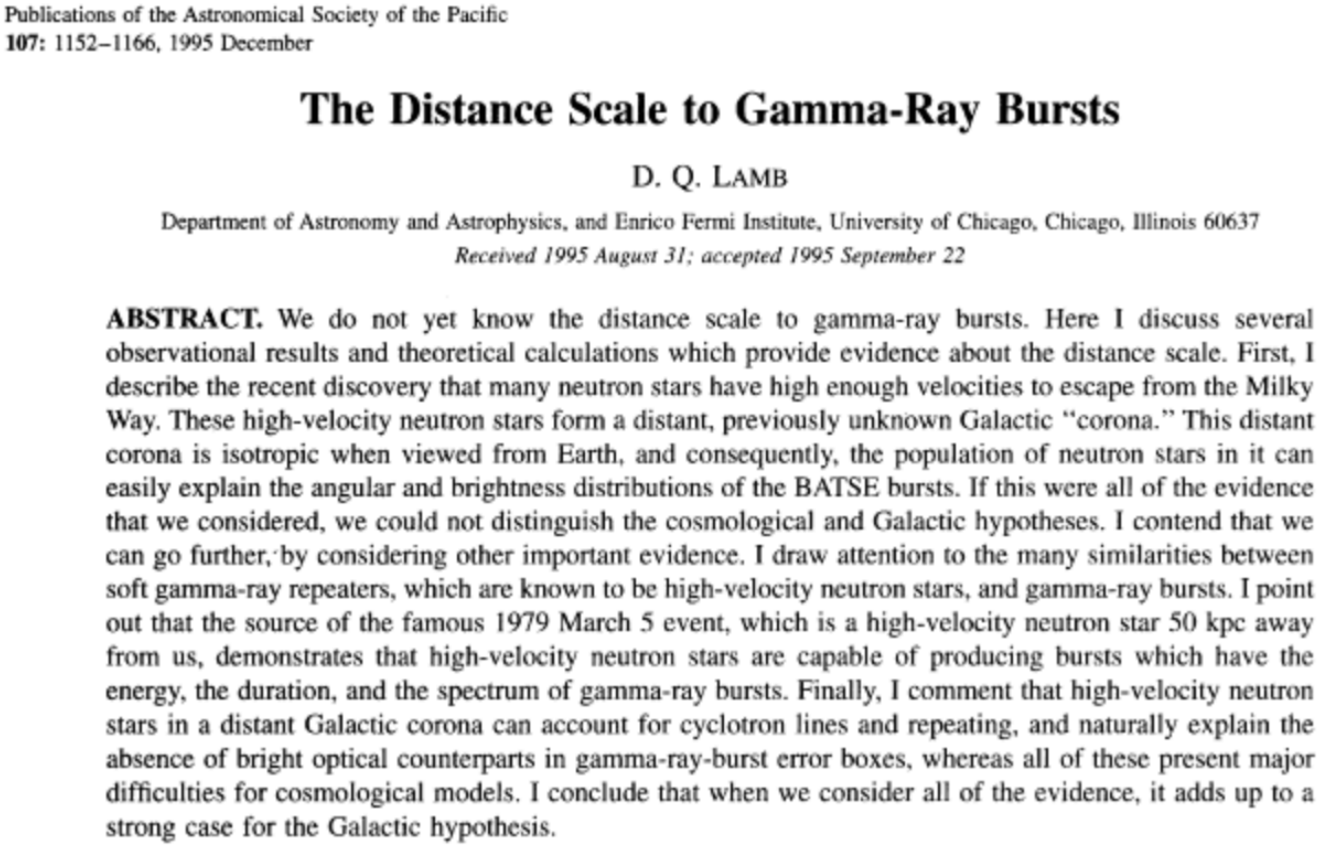
About the 1995 Debate: Background information about the 1995 debate is given below.
The Program distributed at the 1995 Diamond Jubilee Debate. The program includes an introduction, the schedule of events, and a brief profile of all the program participants.
Images from the debate.
Comments about the debate. Comments from people who attended the debate are being compiled. Some comments are available - updated June 16, 1995.

Scientific Background: Below find links and lists intended for students, educators, and the generally inquisitive.
A Brief History of the Discovery of Cosmic Gamma-Ray Bursts by J. T. Bonnell
A short bibliography for the 1995 debate. Some of these articles are highly technical in nature.
A Glossary of terms used in the 1995 debate.
Gamma Ray Bursts from the Unknown an Astronomy Picture of the Day describing the great "GRB" mystery. Follow the links to find more information.
Optical Transient Near GRB970508 Shows Distant Redshift an APOD describing how a solution to this mystery may have now been found.
Brighter Than a Million Galaxies press releases from NASA's Marshall Space Flight Center describing recent events.

Return to Great Debates in Astronomy Page

Exercise #2

- Find the papers of the “Great Debate (1995)”



Publications of the Astronomical Society of the Pacific
107: 1152–1166, 1995 December

The Distance Scale to Gamma-Ray Bursts

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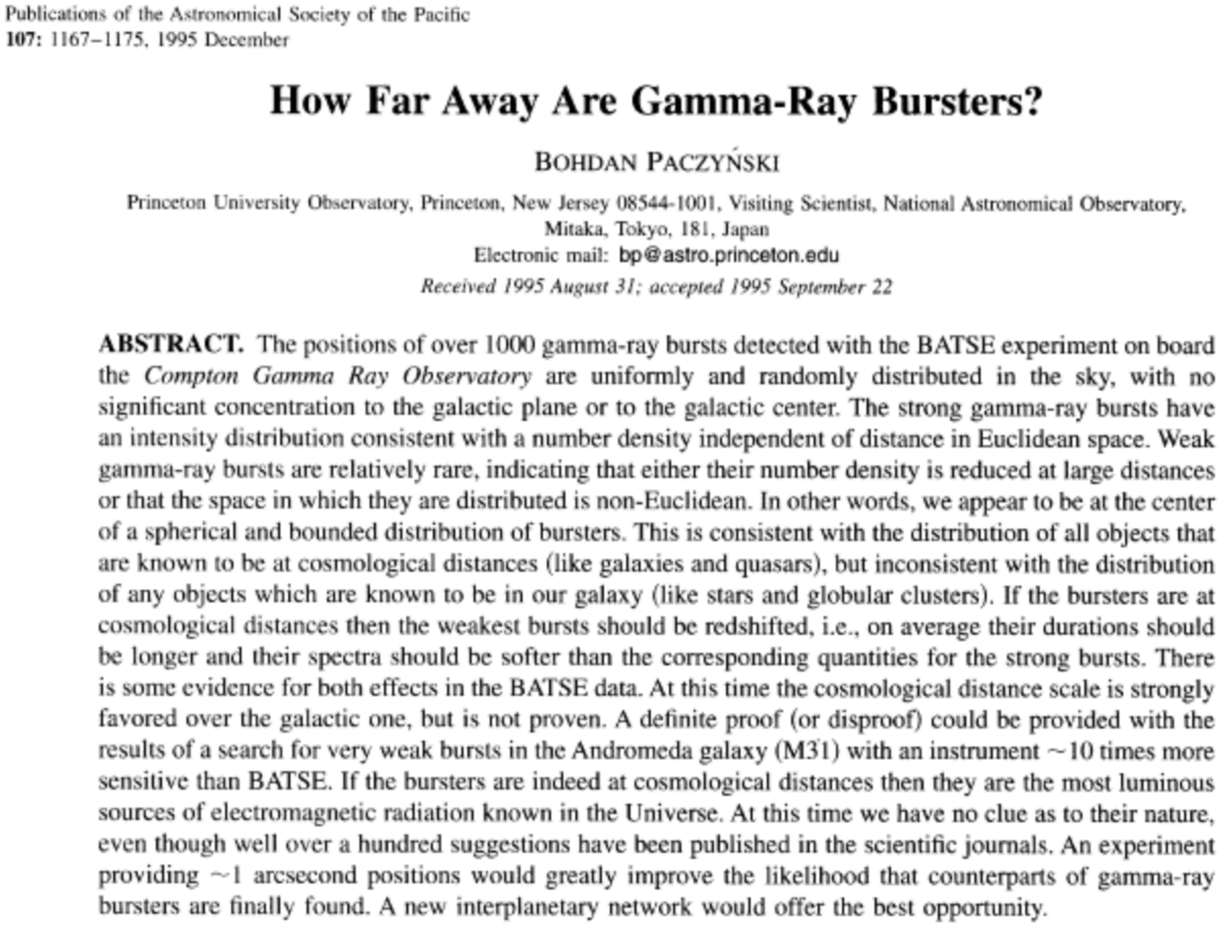
Received 1995 August 31; accepted 1995 September 22

ABSTRACT. We do not yet know the distance scale to gamma-ray bursts. Here I discuss several observational results and theoretical calculations which provide evidence about the distance scale. First, I describe the recent discovery that many neutron stars have high enough velocities to escape from the Milky Way. These high-velocity neutron stars form a distant, previously unknown Galactic “corona.” This distant corona is isotropic when viewed from Earth, and consequently, the population of neutron stars in it can easily explain the angular and brightness distributions of the BATSE bursts. If this were all of the evidence that we considered, we could not distinguish the cosmological and Galactic hypotheses. I contend that we can go further, by considering other important evidence. I draw attention to the many similarities between soft gamma-ray repeaters, which are known to be high-velocity neutron stars, and gamma-ray bursts. I point out that the source of the famous 1979 March 5 event, which is a high-velocity neutron star 50 kpc away from us, demonstrates that high-velocity neutron stars are capable of producing bursts which have the energy, the duration, and the spectrum of gamma-ray bursts. Finally, I comment that high-velocity neutron stars in a distant Galactic corona can account for cyclotron lines and repeating, and naturally explain the absence of bright optical counterparts in gamma-ray-burst error boxes, whereas all of these present major difficulties for cosmological models. I conclude that when we consider all of the evidence, it adds up to a strong case for the Galactic hypothesis.

Exercise #2

- Find the papers of the “Great Debate (1995)”



Publications of the Astronomical Society of the Pacific
107: 1167–1175, 1995 December

How Far Away Are Gamma-Ray Bursters?

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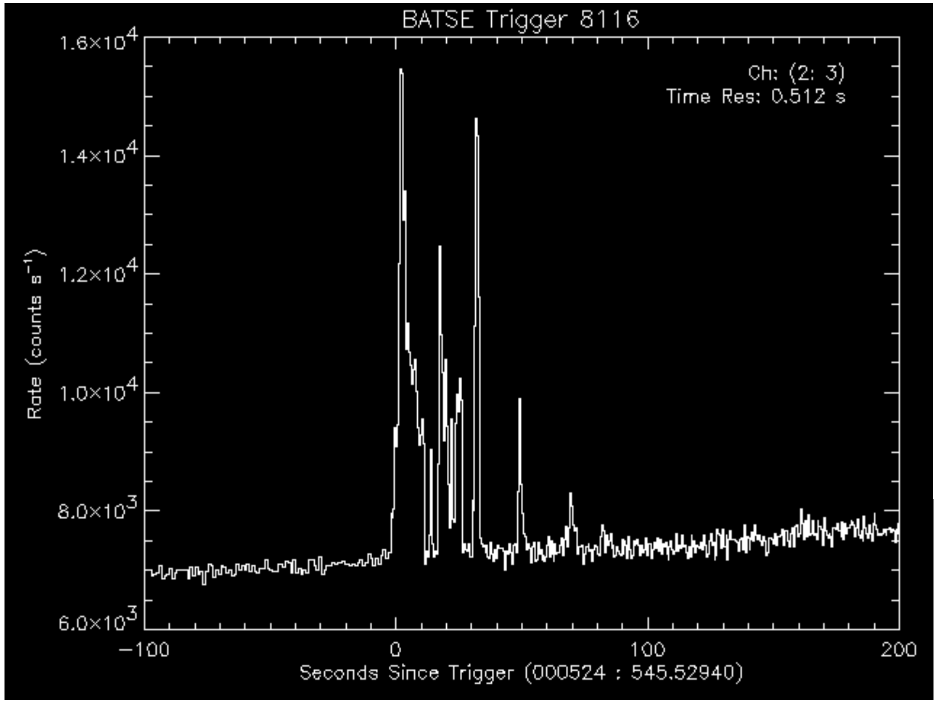
Received 1995 August 31; accepted 1995 September 22

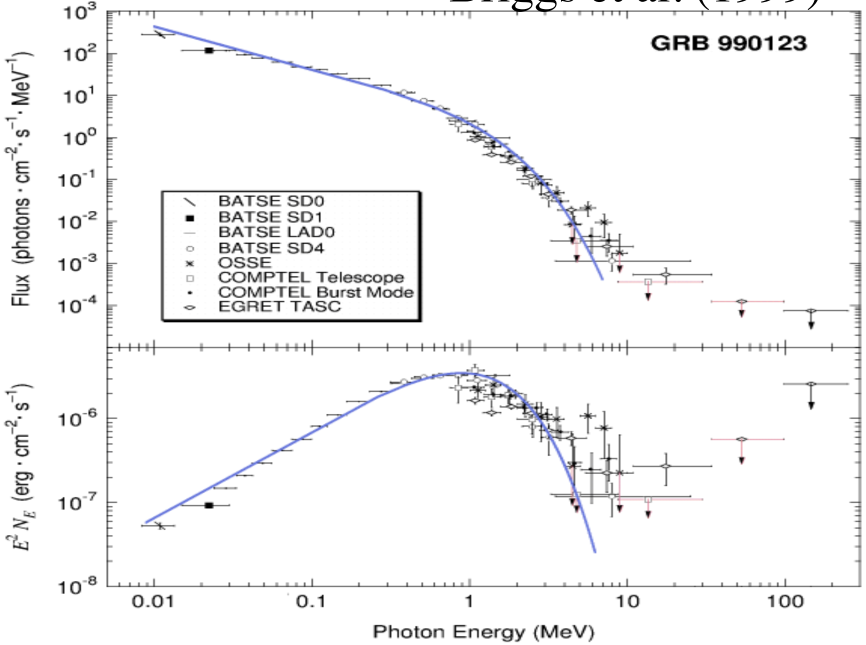
ABSTRACT. The positions of over 1000 gamma-ray bursts detected with the BATSE experiment on board the *Compton Gamma Ray Observatory* are uniformly and randomly distributed in the sky, with no significant concentration to the galactic plane or to the galactic center. The strong gamma-ray bursts have an intensity distribution consistent with a number density independent of distance in Euclidean space. Weak gamma-ray bursts are relatively rare, indicating that either their number density is reduced at large distances or that the space in which they are distributed is non-Euclidean. In other words, we appear to be at the center of a spherical and bounded distribution of bursters. This is consistent with the distribution of all objects that are known to be at cosmological distances (like galaxies and quasars), but inconsistent with the distribution of any objects which are known to be in our galaxy (like stars and globular clusters). If the bursters are at cosmological distances then the weakest bursts should be redshifted, i.e., on average their durations should be longer and their spectra should be softer than the corresponding quantities for the strong bursts. There is some evidence for both effects in the BATSE data. At this time the cosmological distance scale is strongly favored over the galactic one, but is not proven. A definite proof (or disproof) could be provided with the results of a search for very weak bursts in the Andromeda galaxy (M31) with an instrument ~10 times more sensitive than BATSE. If the bursters are indeed at cosmological distances then they are the most luminous sources of electromagnetic radiation known in the Universe. At this time we have no clue as to their nature, even though well over a hundred suggestions have been published in the scientific journals. An experiment providing ~1 arcsecond positions would greatly improve the likelihood that counterparts of gamma-ray bursters are finally found. A new interplanetary network would offer the best opportunity.

The compactness problem

Light curve variability ~ 1 ms



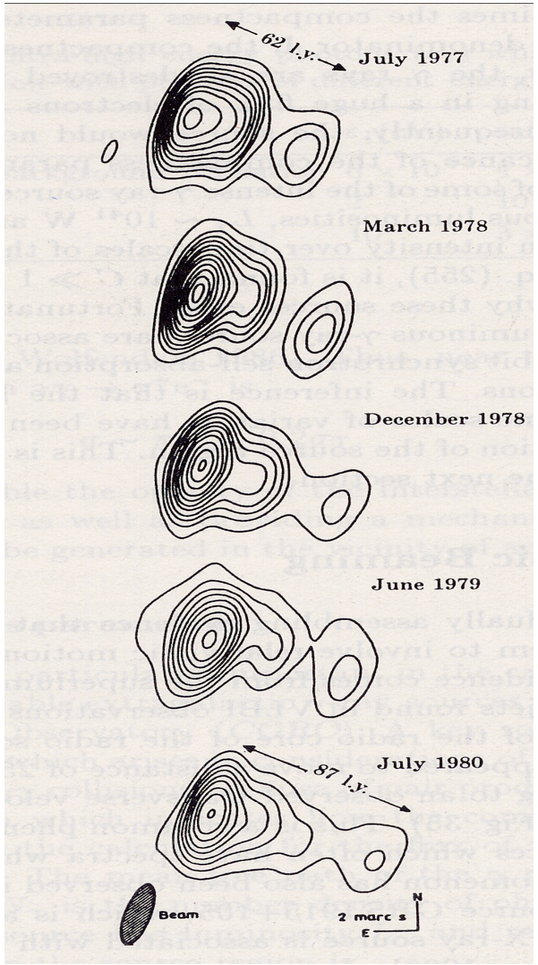
Briggs et al. (1999)

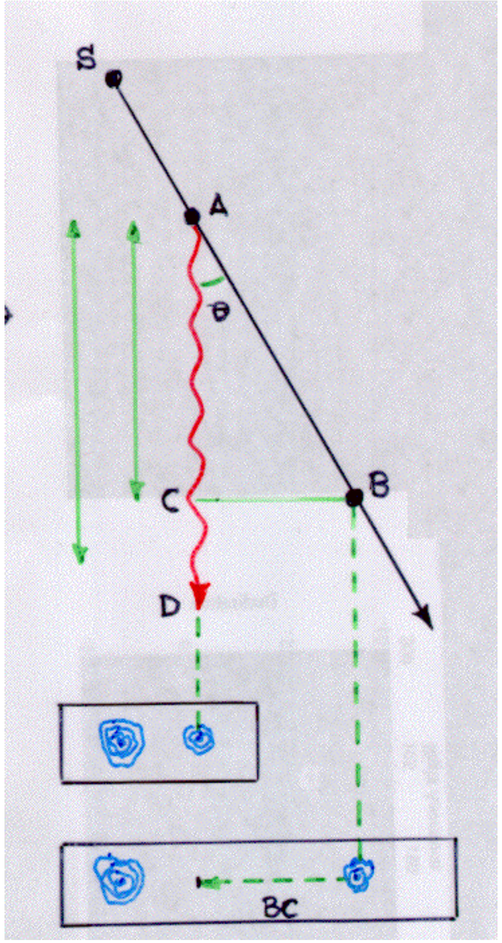


Non thermal spectra

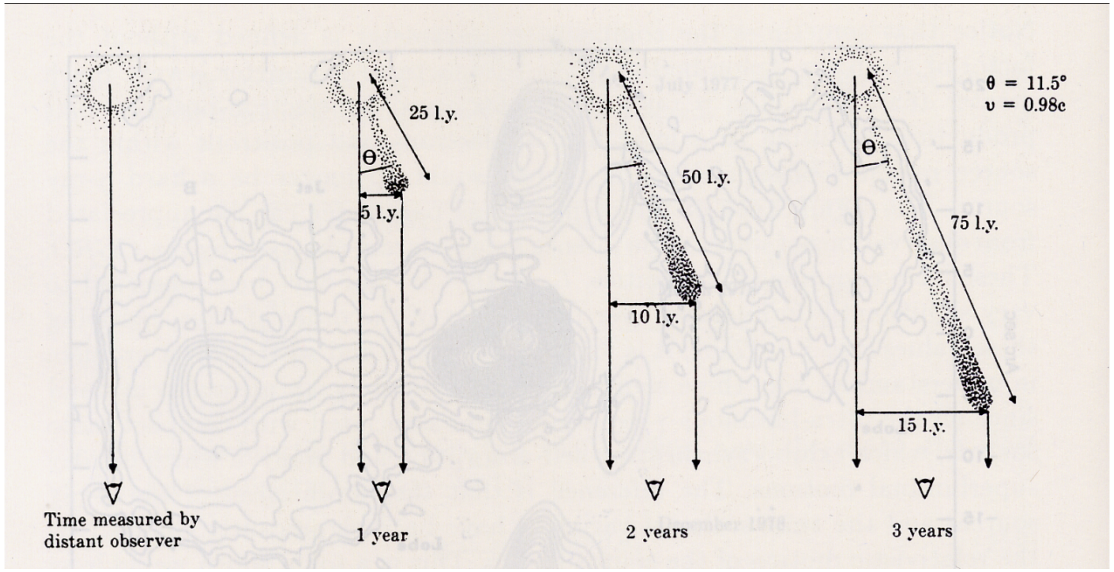
- Fluence (γ): $(0.1\text{-}10) \times 10^{-6}$ erg/cm^2 $(\Omega/4\pi)$
- Total Energy: $E \sim 10^{51} \div 10^{52}$ erg

Superluminal motion





Superluminal motion



Arrival time of “bullets” emission

$$t'_A = t_A + \frac{D + v\delta t\cos\theta}{c}$$

$$t'_B = t_B + \frac{D}{c}$$

$$\delta t' = \delta t(1-\beta\cos\theta)$$

$$v_\perp = \frac{v\sin\theta}{1-\beta\cos\theta}$$

$$\cos\theta = \frac{v}{c}$$

$$\sin\theta = \sqrt{1-\beta^2}$$

$$v_\perp = \gamma v$$

The compactness problem

$$R_i < c\delta t \qquad \gamma\gamma \rightarrow e^+e^-$$

$$\boxed{\tau_{\gamma\gamma} = \frac{f_p \sigma_T F D_L^2}{R_i^2 m_e c^2} \approx 10^{17} f_p \left(\frac{F}{10^{-6} erg/cm^2}\right)\left(\frac{D_L}{3Gpc}\right)^2\left(\frac{\delta t}{1ms}\right)}$$

$$\tau_{\gamma\gamma} >> 1$$

Very High Optical Depth to pair production

Size

Pair fraction

$$\Gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad R_i < \Gamma^2 c\delta t \quad f_p \rightarrow f_p \Gamma^{-2\alpha}$$

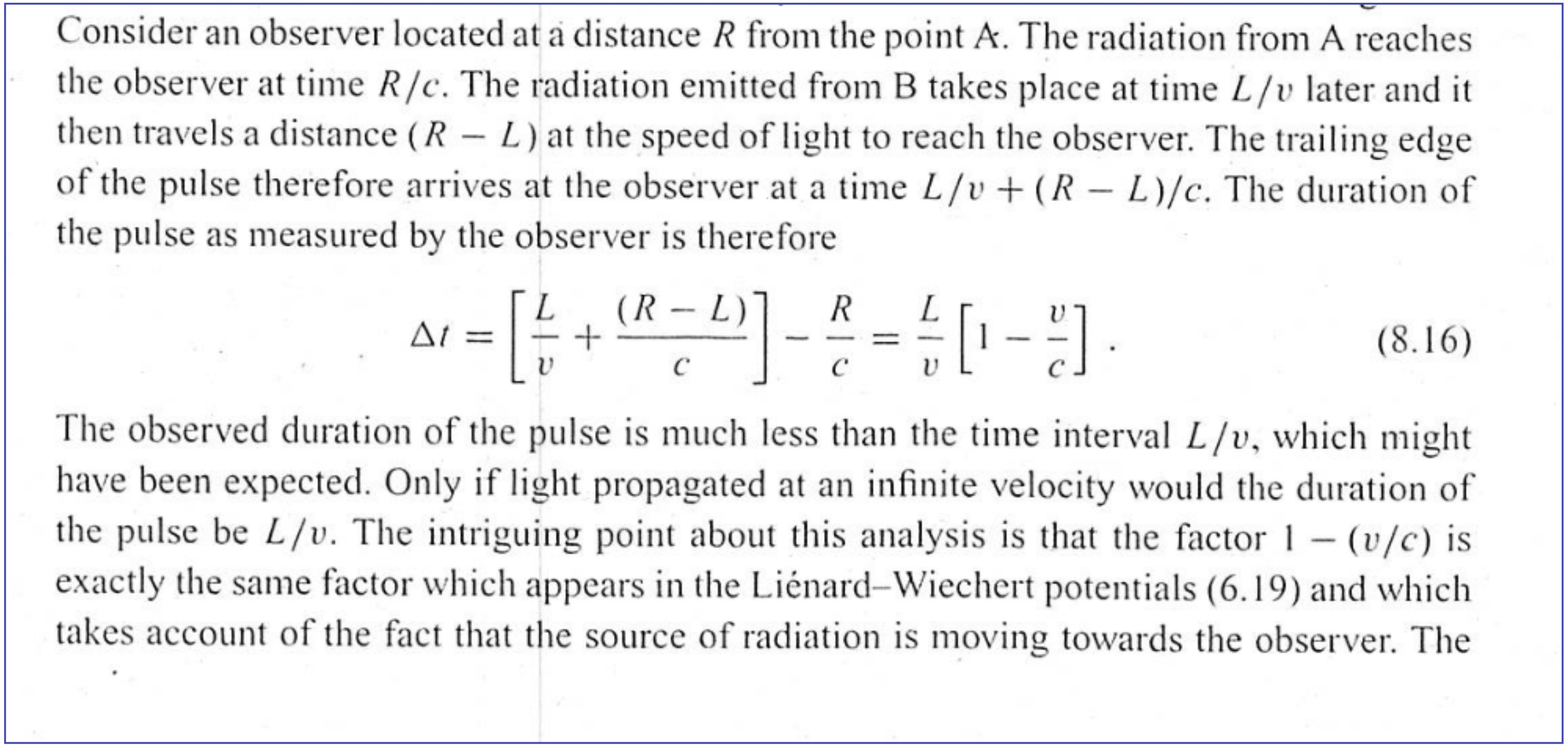
$$\boxed{\tau_{\gamma\gamma} = \frac{f_p \sigma_T F D_L^2}{R_i^2 m_e c^2} \approx \frac{10^{17}}{\Gamma^{4+2\alpha}} f_p \left(\frac{F}{10^{-6} erg/cm^2}\right)\left(\frac{D_L}{3Gpc}\right)^2\left(\frac{\delta t}{1ms}\right)}$$

$$\Gamma \approx 10^2 \div 10^3$$

Piran (1999)

Relativistic motion of the emitting region

Radial transformations

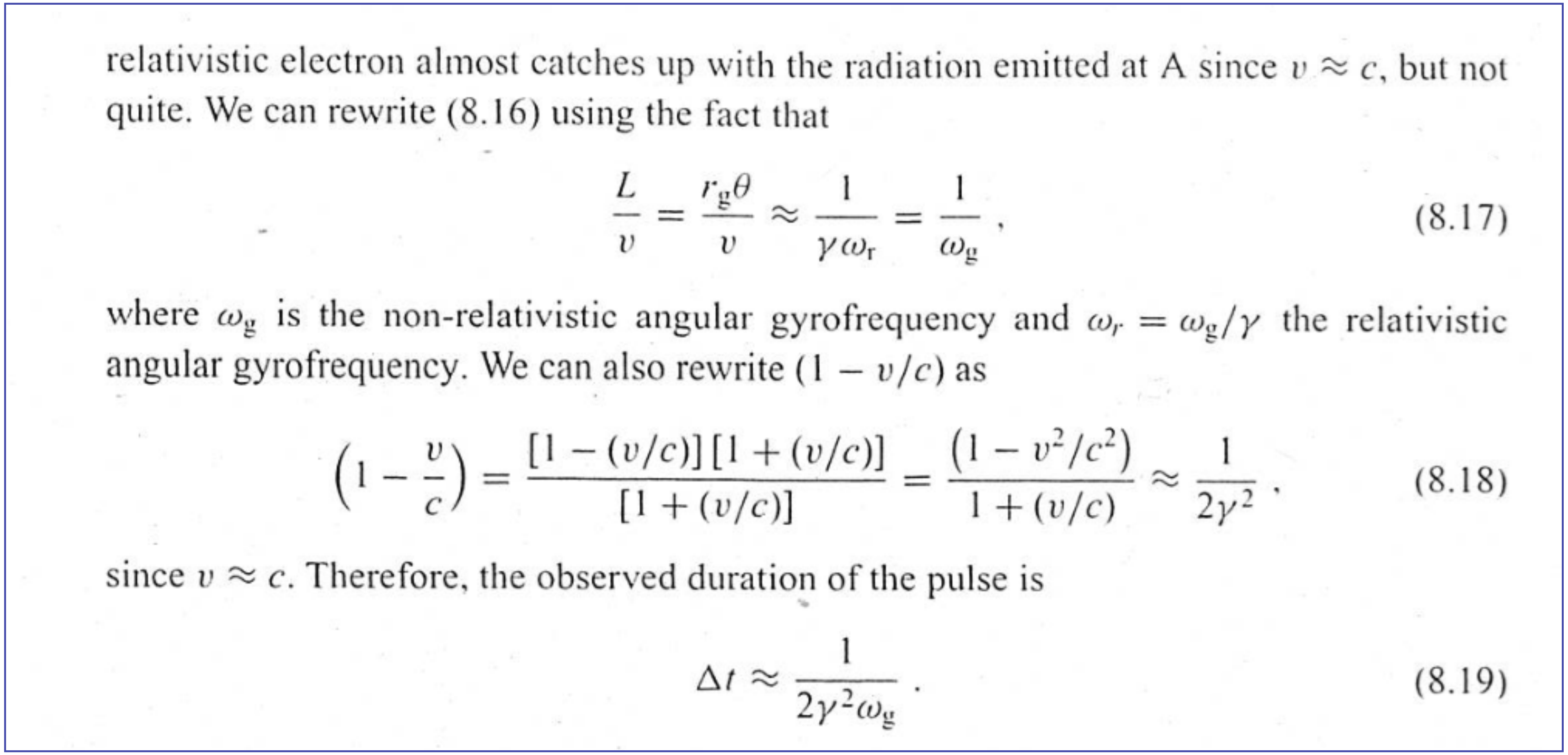


Consider an observer located at a distance R from the point A. The radiation from A reaches the observer at time R/c. The radiation emitted from B takes place at time L/v later and it then travels a distance $(R - L)$ at the speed of light to reach the observer. The trailing edge of the pulse therefore arrives at the observer at a time $L/v + (R - L)/c$. The duration of the pulse as measured by the observer is therefore

$$\Delta t = \left[\frac{L}{v} + \frac{(R-L)}{c}\right] - \frac{R}{c} = \frac{L}{v}\left[1 - \frac{v}{c}\right] . \tag{8.16}$$

The observed duration of the pulse is much less than the time interval L/v, which might have been expected. Only if light propagated at an infinite velocity would the duration of the pulse be L/v. The intriguing point about this analysis is that the factor $1 - (v/c)$ is exactly the same factor which appears in the Liénard–Wiechert potentials (6.19) and which takes account of the fact that the source of radiation is moving towards the observer. The

Radial transformations



relativistic electron almost catches up with the radiation emitted at A since $v \approx c$, but not quite. We can rewrite (8.16) using the fact that

$$\frac{L}{v} = \frac{r_g \theta}{v} \approx \frac{1}{\gamma \omega_r} = \frac{1}{\omega_g}\,, \tag{8.17}$$

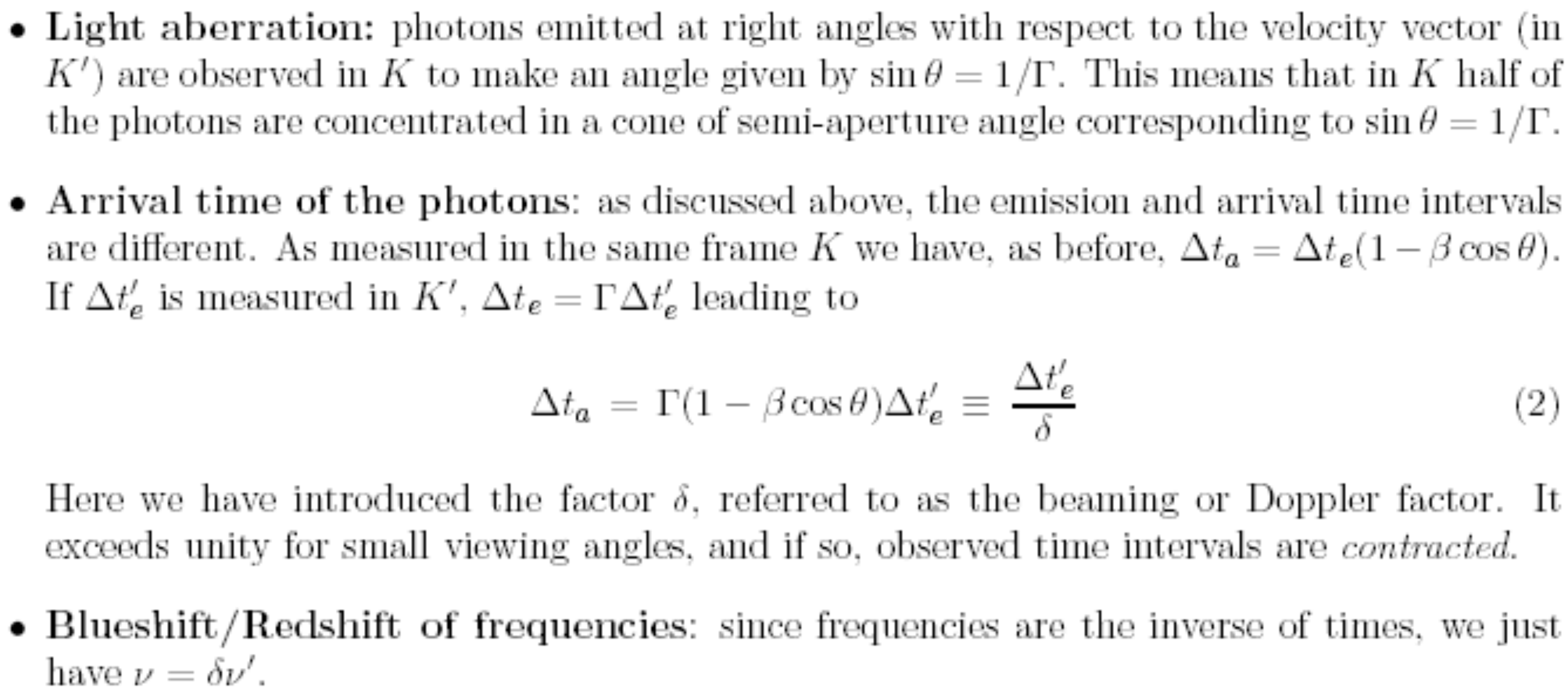
where ω_g is the non-relativistic angular gyrofrequency and $\omega_r = \omega_g/\gamma$ the relativistic angular gyrofrequency. We can also rewrite $(1 - v/c)$ as

$$\left(1 - \frac{v}{c}\right) = \frac{[1-(v/c)]\,[1+(v/c)]}{[1+(v/c)]} = \frac{\left(1 - v^2/c^2\right)}{1+(v/c)} \approx \frac{1}{2\gamma^2}\,. \tag{8.18}$$

since $v \approx c$. Therefore, the observed duration of the pulse is

$$\Delta t \approx \frac{1}{2\gamma^2 \omega_g}\,. \tag{8.19}$$

Relativistic effects



- **Light aberration:** photons emitted at right angles with respect to the velocity vector (in K') are observed in K to make an angle given by $\sin\theta = 1/\Gamma$. This means that in K half of the photons are concentrated in a cone of semi-aperture angle corresponding to $\sin\theta = 1/\Gamma$.

- **Arrival time of the photons**: as discussed above, the emission and arrival time intervals are different. As measured in the same frame K we have, as before, $\Delta t_a = \Delta t_e(1-\beta\cos\theta)$. If $\Delta t'_e$ is measured in K', $\Delta t_e = \Gamma\Delta t'_e$ leading to

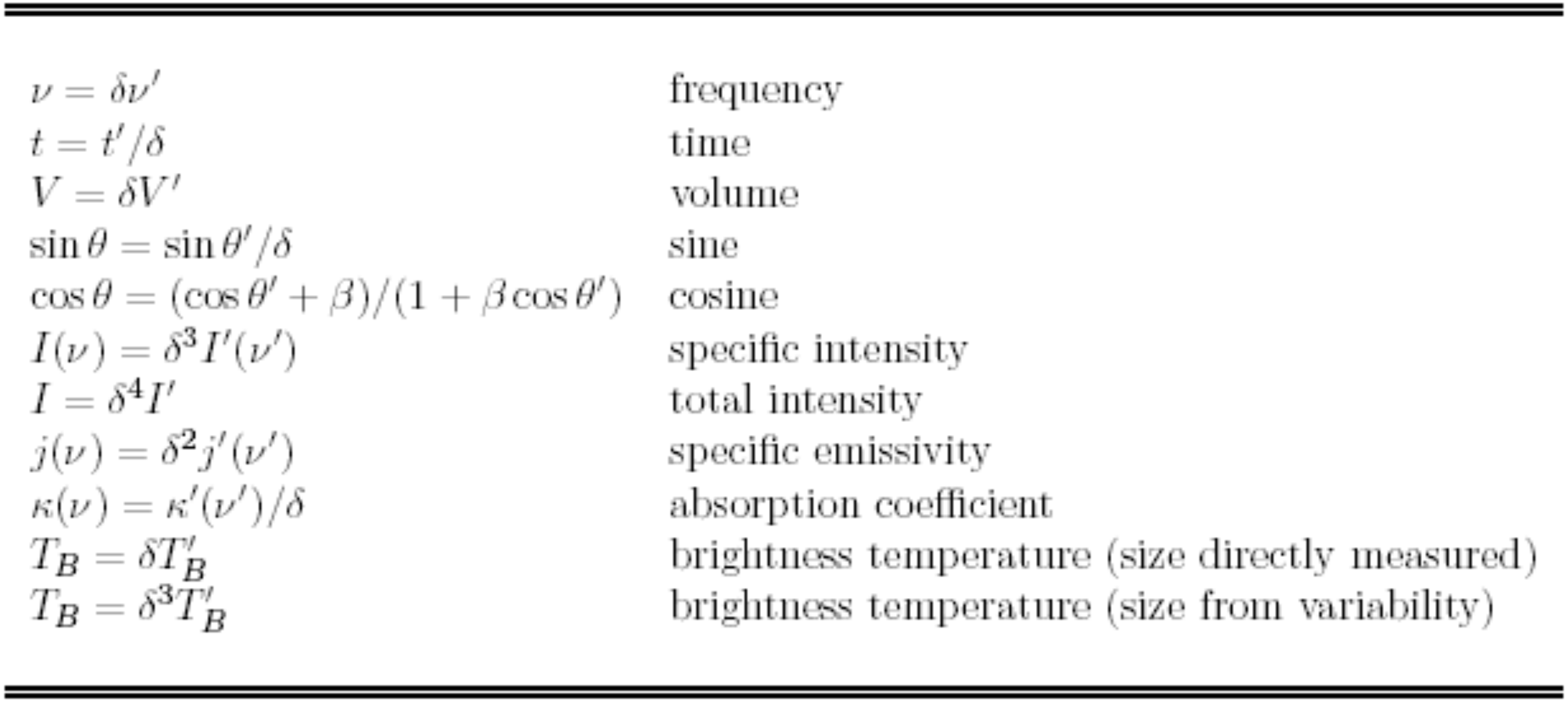
$$\Delta t_a \; = \; \Gamma(1-\beta\cos\theta)\Delta t'_e \; \equiv \; \frac{\Delta t'_e}{\delta} \qquad (2)$$

  Here we have introduced the factor δ, referred to as the beaming or Doppler factor. It exceeds unity for small viewing angles, and if so, observed time intervals are *contracted*.

- **Blueshift/Redshift of frequencies**: since frequencies are the inverse of times, we just have $\nu = \delta\nu'$.

Ghisellini astro-ph/9905181

Relativistic effects



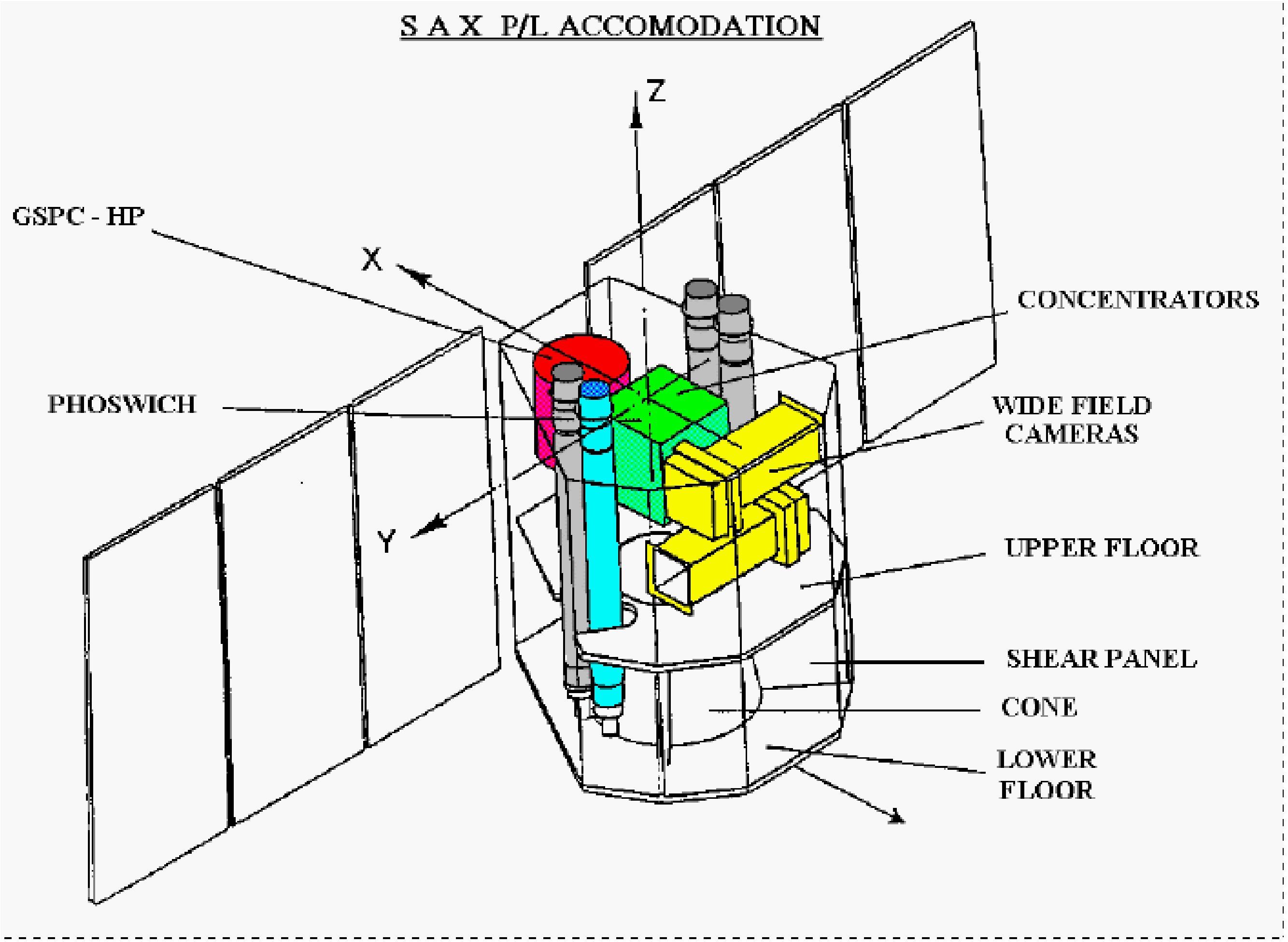
$\nu = \delta\nu'$	frequency
$t = t'/\delta$	time
$V = \delta V'$	volume
$\sin\theta = \sin\theta'/\delta$	sine
$\cos\theta = (\cos\theta' + \beta)/(1 + \beta\cos\theta')$	cosine
$I(\nu) = \delta^3 I'(\nu')$	specific intensity
$I = \delta^4 I'$	total intensity
$j(\nu) = \delta^2 j'(\nu')$	specific emissivity
$\kappa(\nu) = \kappa'(\nu')/\delta$	absorption coefficient
$T_B = \delta T'_B$	brightness temperature (size directly measured)
$T_B = \delta^3 T'_B$	brightness temperature (size from variability)

$\delta = \gamma(1-(V/c)\cos\theta)$

Ghisellini astro-ph/9905181

Astrofisica Nucleare e Subnucleare
Gamma ray Bursts – Detectors II

BeppoSAX (1995 - 2002)



Spatial Aperture Modulation

- **Alternative to temporal modulation**
- **Requires two-dimensional position-sensitive detectors**
- **The spatial modulation is achieved by a pattern of holes in an otherwise absorbing plate, providing a unique spatial code**

Coded-aperture (or coded-mask) Telescopes

Principle: the mask pattern (in the form of the shadow produced by the parallel beam of an X-ray source) is recognized by the two-dimensional position-sensitive detector. Any shift in the pattern is related to a shift of the source position.

Coded Mask Imaging

The Coded Mask Technique

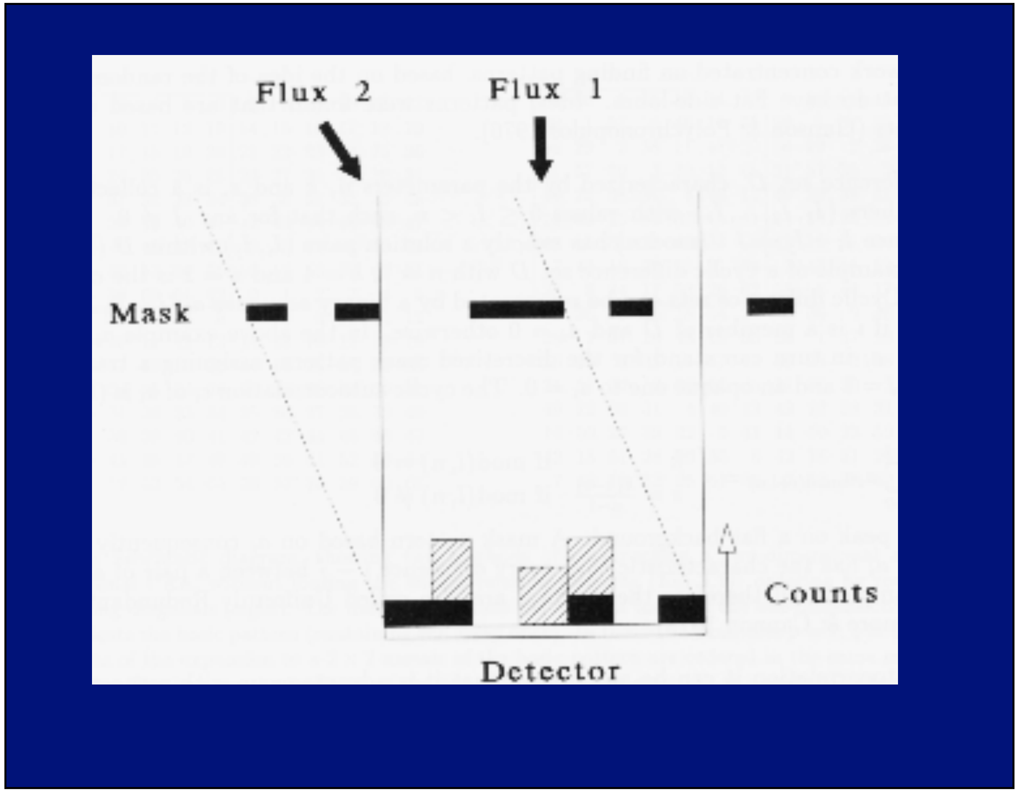
is the worst possible way of making a telescope

Except when you can 't do anything better !

- Wide fields of view
- Energies too high for focussing, or too low for Compton/Tracking detector techniques
- Very good angular resolution
- The best energy resolution

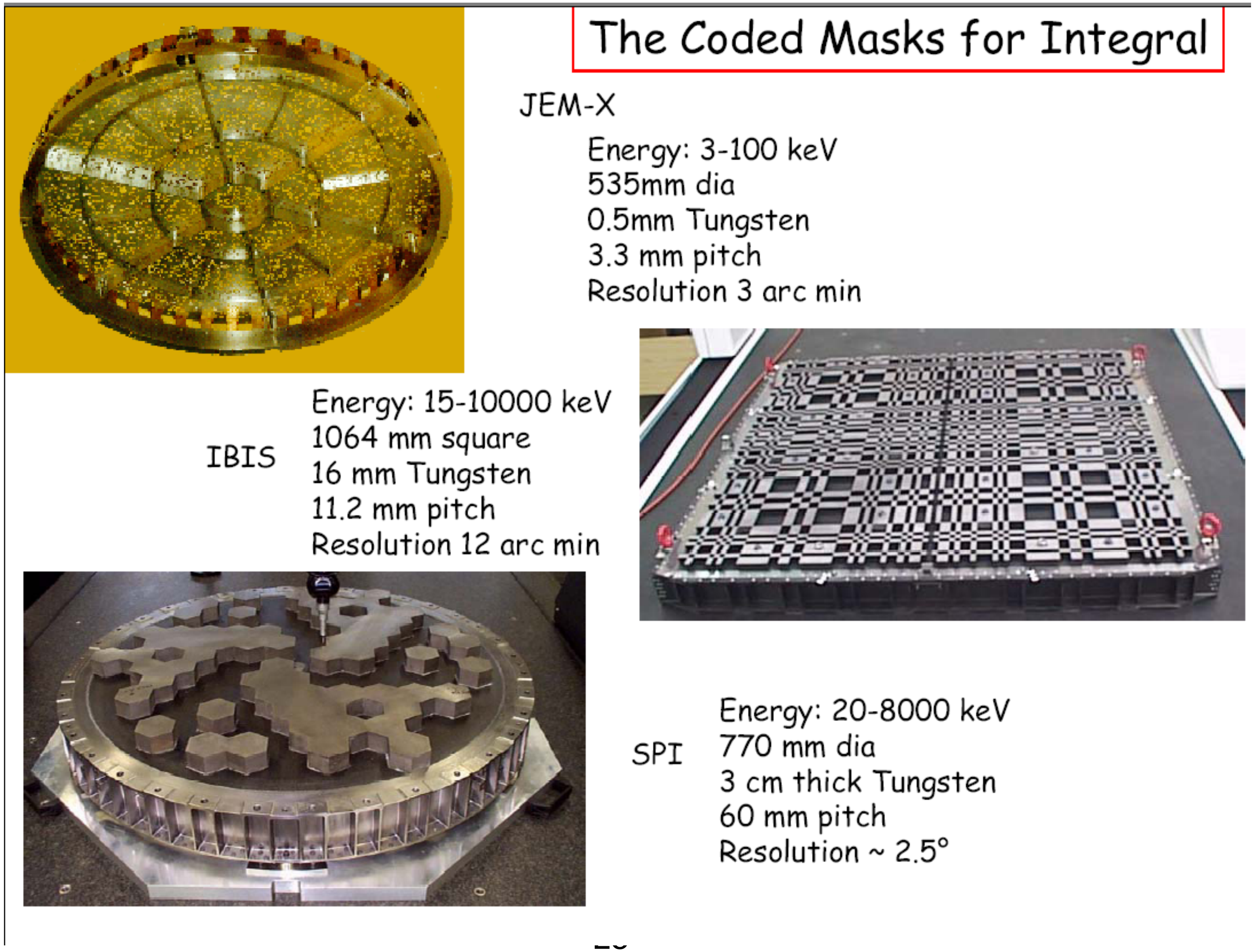
Coded Mask Imaging

The principle of the camera is straightforward: photons from a certain direction in the sky project the mask on the detector; this projection has the same coding as the mask pattern, but is shifted relative to the central position over a distance uniquely correspondent to the direction of the photons. The detector accumulates the sum of a number of shifted mask patterns.
Each shift encodes the position and its strength encodes the intensity of the sky at that position.



http://asd.gsfc.nasa.gov/archive/cai/coded_intr.html

Coded Mask Imaging



The Coded Masks for Integral

JEM-X

Energy: 3-100 keV
535mm dia
0.5mm Tungsten
3.3 mm pitch
Resolution 3 arc min

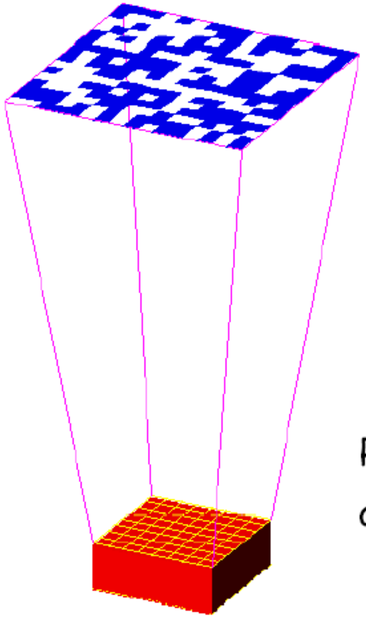
IBIS

Energy: 15-10000 keV
1064 mm square
16 mm Tungsten
11.2 mm pitch
Resolution 12 arc min

SPI

Energy: 20-8000 keV
770 mm dia
3 cm thick Tungsten
60 mm pitch
Resolution ~ 2.5°

Coded Mask Imaging



How to recover an image

Basic method :
' Correlation with the Mask Pattern '

Recorded pattern is Convolution of source distribution and the mask pattern, plus some background B

$$D = S \otimes M + B$$

Suppose we form an image as [†]

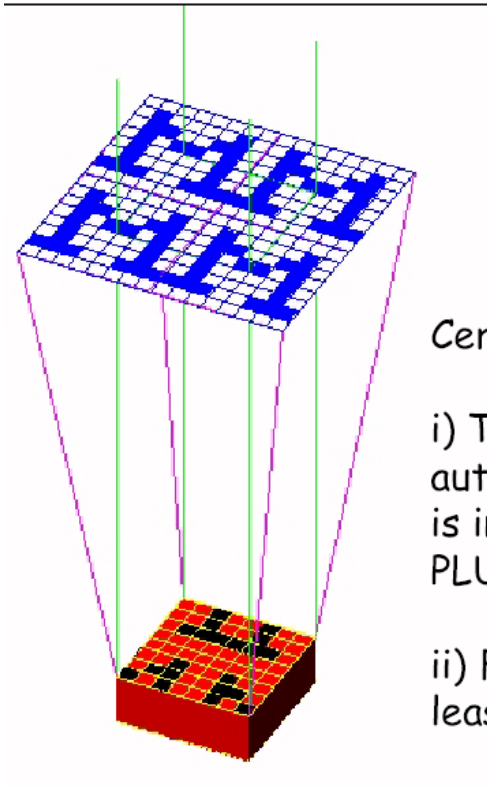
$$I = M \otimes D = M \otimes S \otimes M + M \otimes B$$
$$= M \otimes M \otimes S + M \otimes B$$
$$= ACF(M) \otimes S + M \otimes B$$

where ACF indicated the Autocorrellation function.

If ACF(M) were a Delta function and if $M \otimes B$ were zero we would have recovered S.

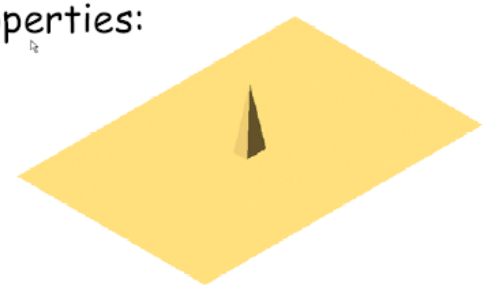
[†] coordinate reversals are ignored here

Coded Mask Imaging



'Optimum coded ' designs or 'URAs' (Uniformly Redundant Arrays)

Certain patterns have the properties:



i) Their DISCRETE, CYCLIC autocorrelation function is indeed a Delta function, PLUS A FLAT LEVEL.

ii) For uniform background, $M \otimes B$ is not zero, but it is at least FLAT.

If you can:

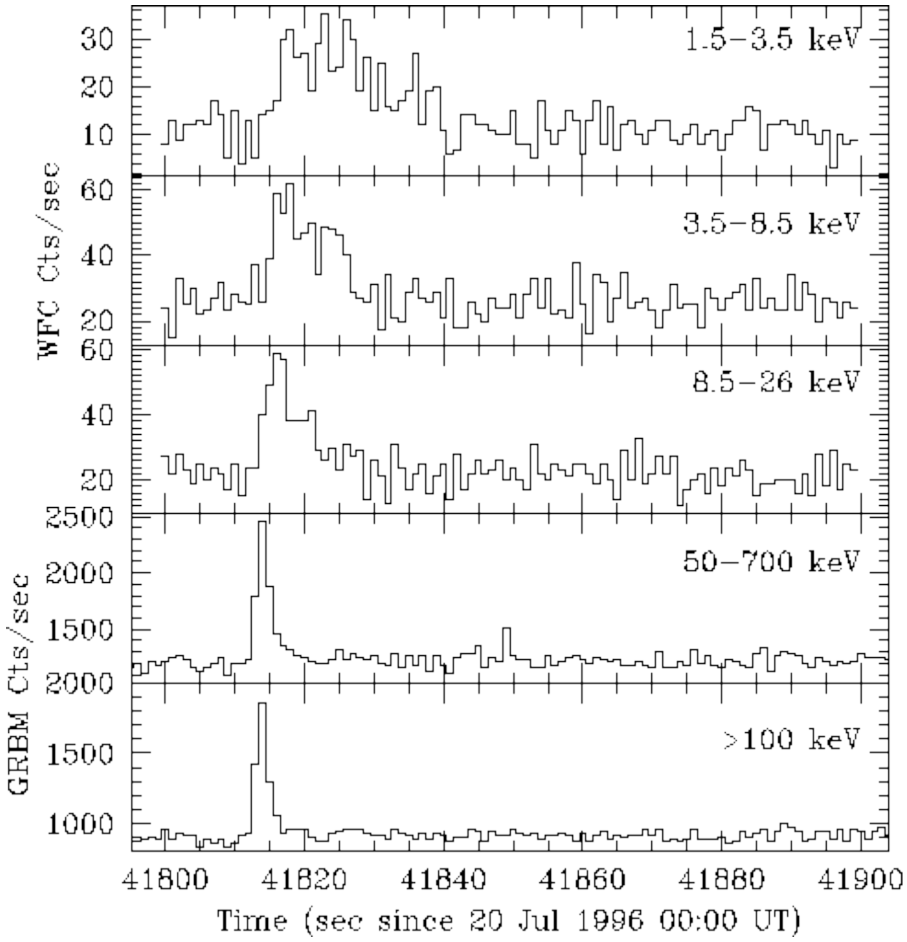
Arrange that coding is cyclic
Use Binned (discrete) arrays
Be prepared to subtract a DC level

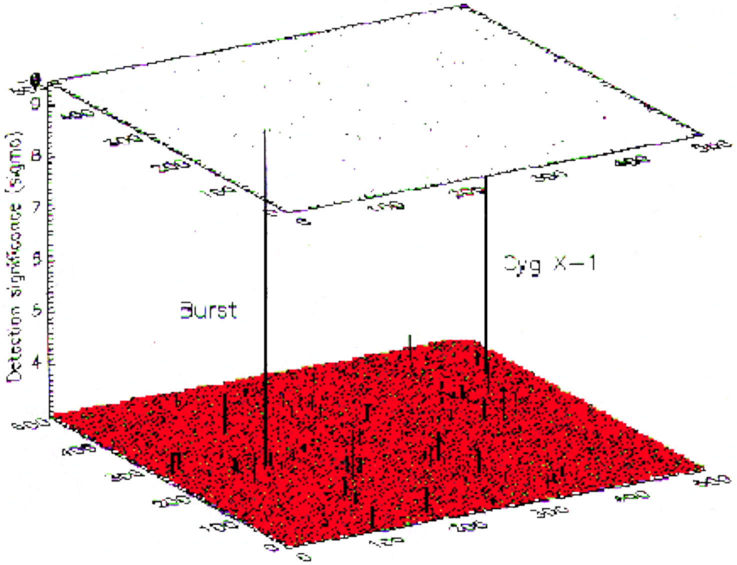
Then this is just what is needed

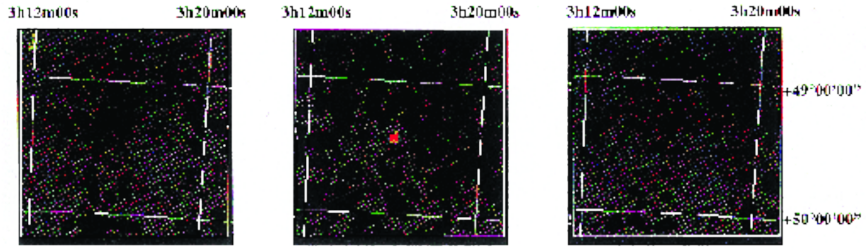
The GRB phenomenon

- simultaneous detection of GRBs by GRBM and WFC

→ very accurate localization (few arcmin)







52 ksec before GRB

30 sec during GRB

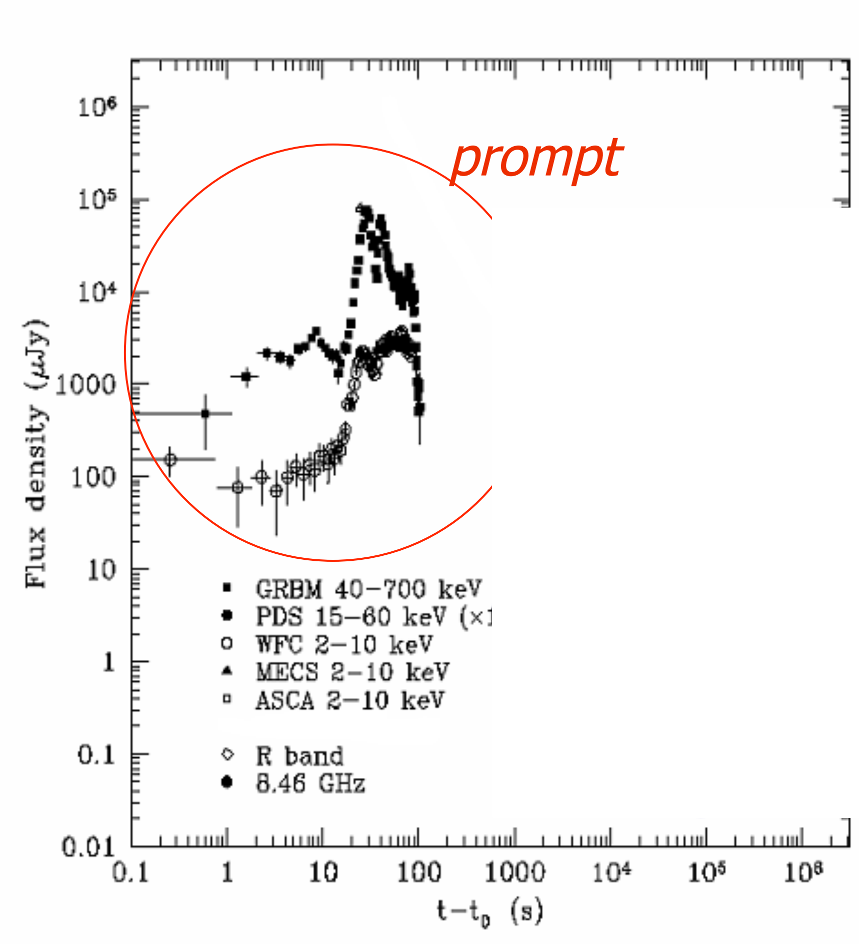
48 ksec after GRB

GRB960720, Piro et al., A&A, 1998

The GRB phenomenon

- in 1997, thanks to BeppoSAX observations, discovery of fading X-ray, optical, radio emission following the GRB

- photons received during the classical GRB phenomenon are then called “prompt emission” and the subsequent fading emission is called “afterglow emission”



Adapted from Maiorano et al., A&A, 2005

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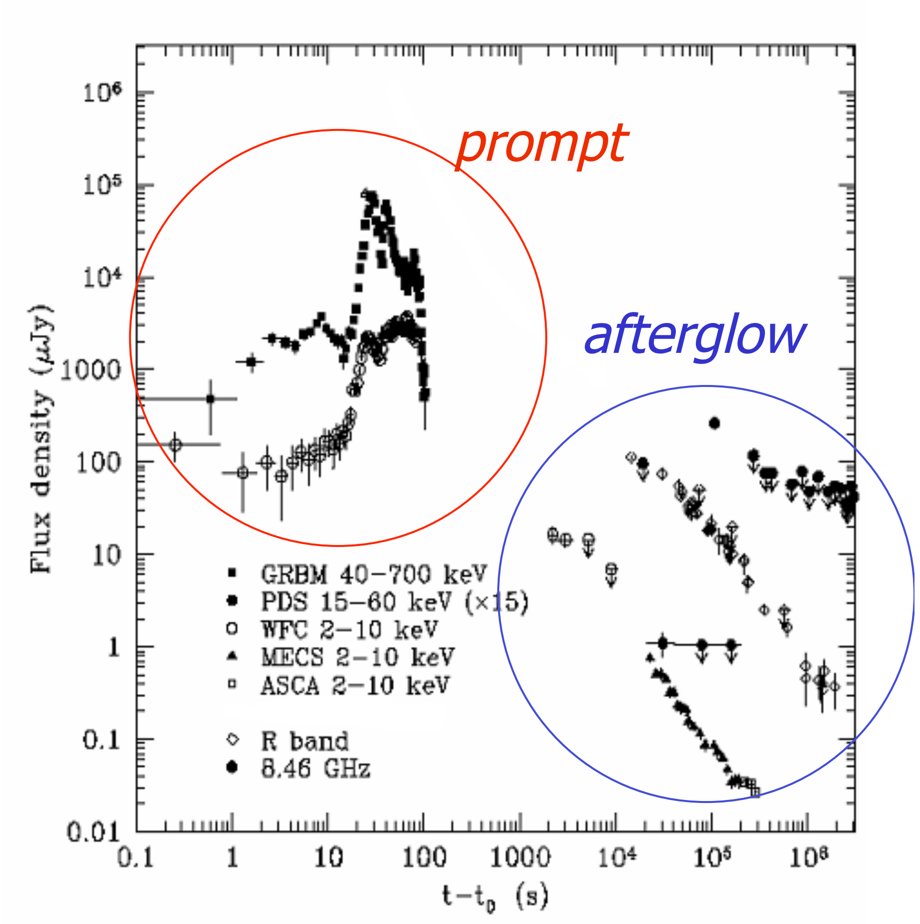
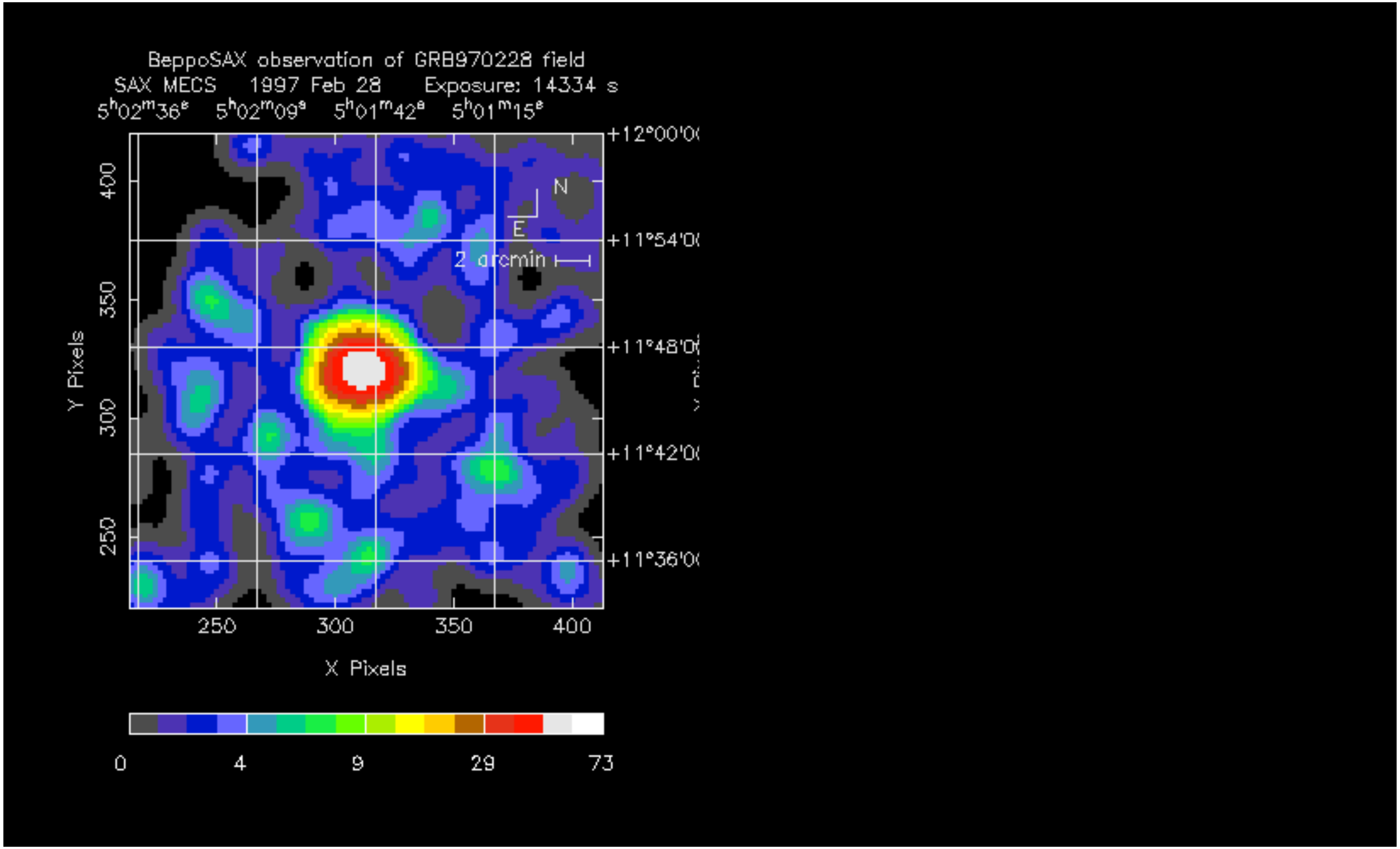


Adapted from Maiorano et al., A&A, 2005

GRB970228 – first good localization



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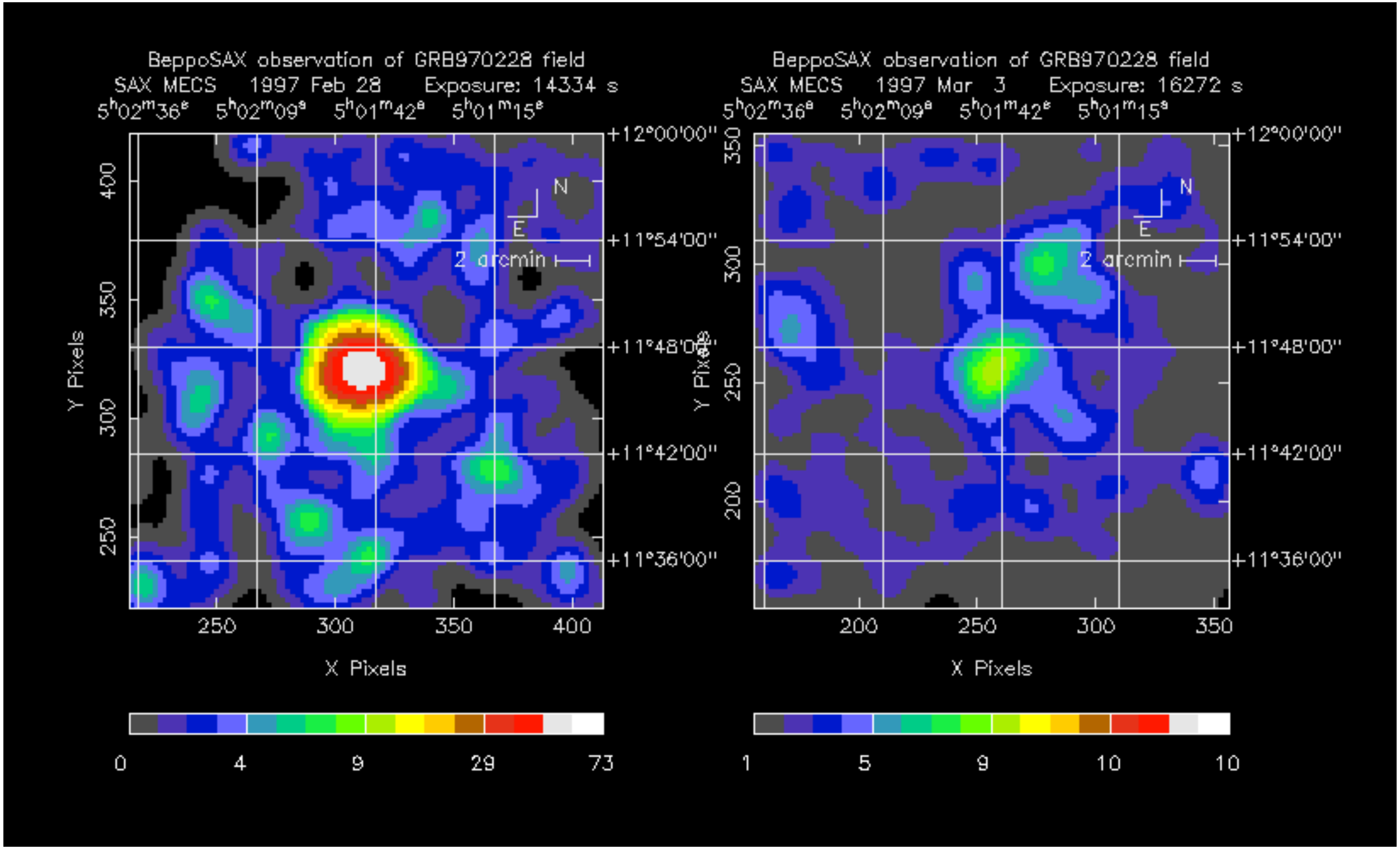
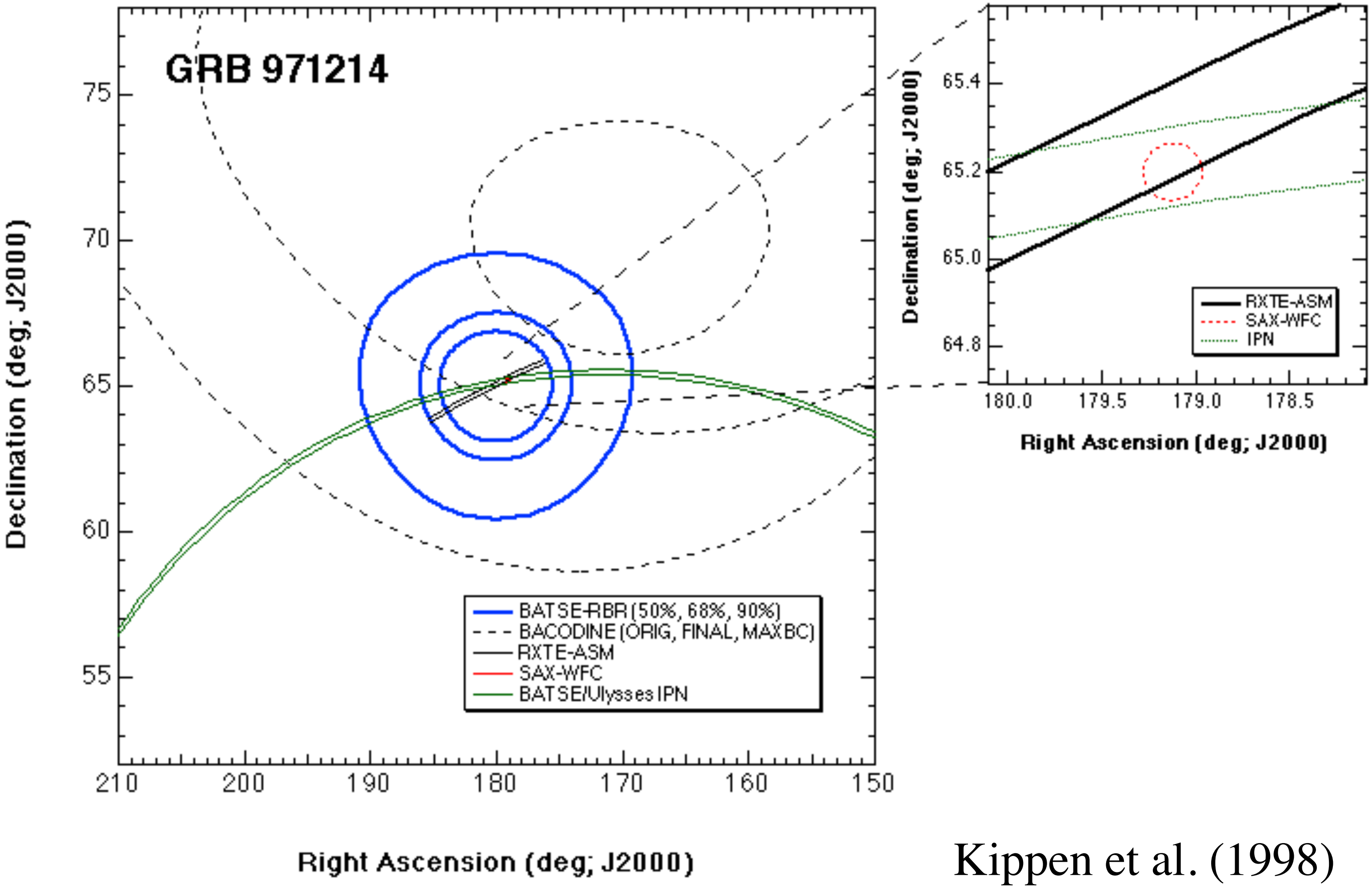
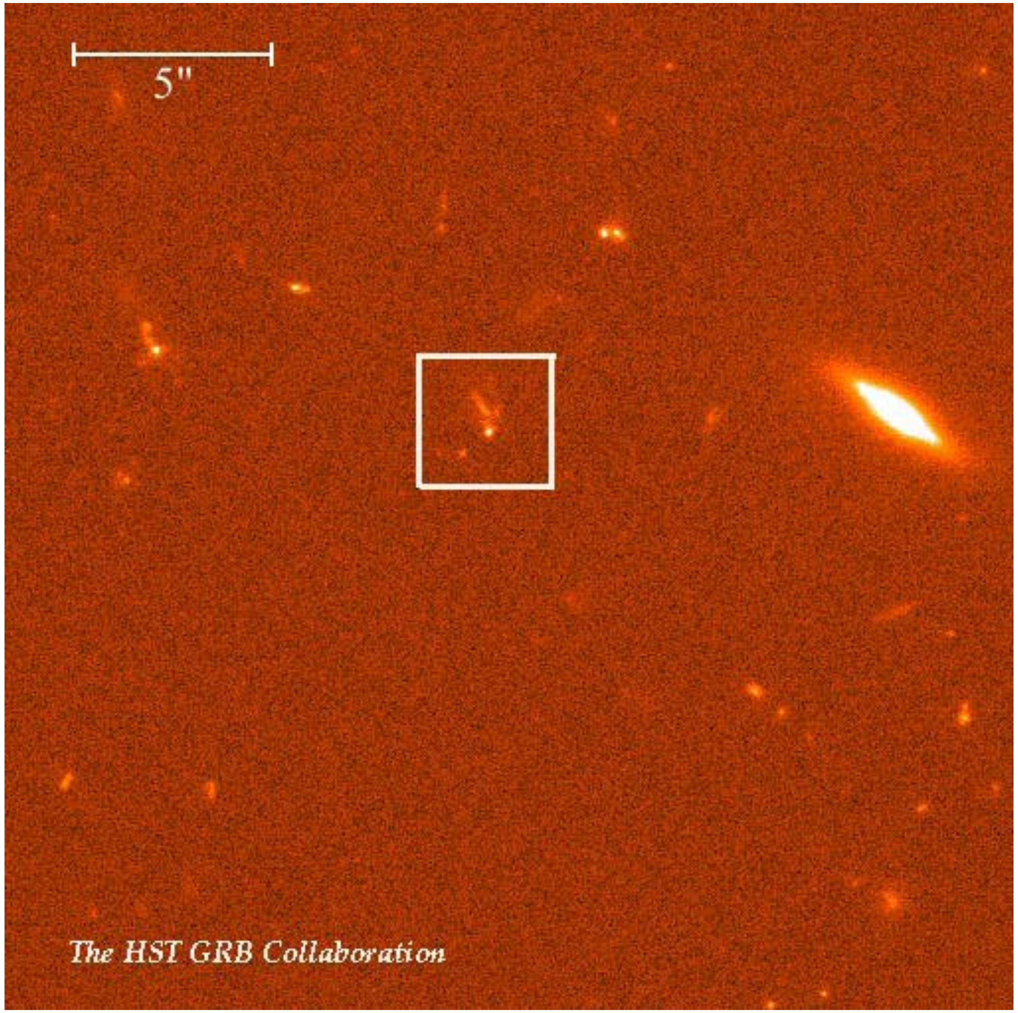


BeppoSAX



Kippen et al. (1998)

Afterglow Observations

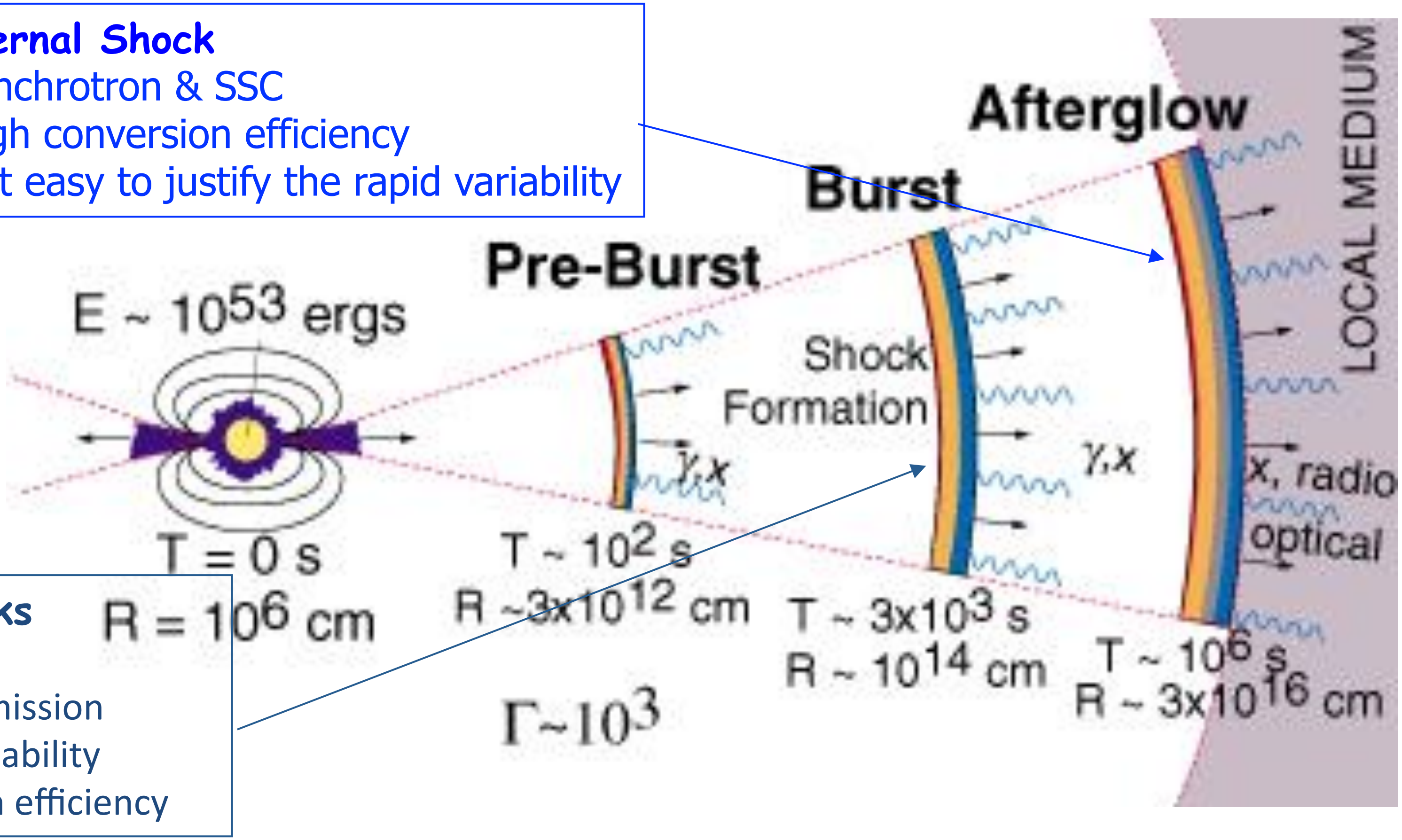


Identificazione delle Host Galaxies

Fruchter et al (1999)

The Fireball model

- Relativistic motion of the emitting region
- Shock mechanism converts the kinetic energy of the shells into radiation.
- Baryon Loading problem

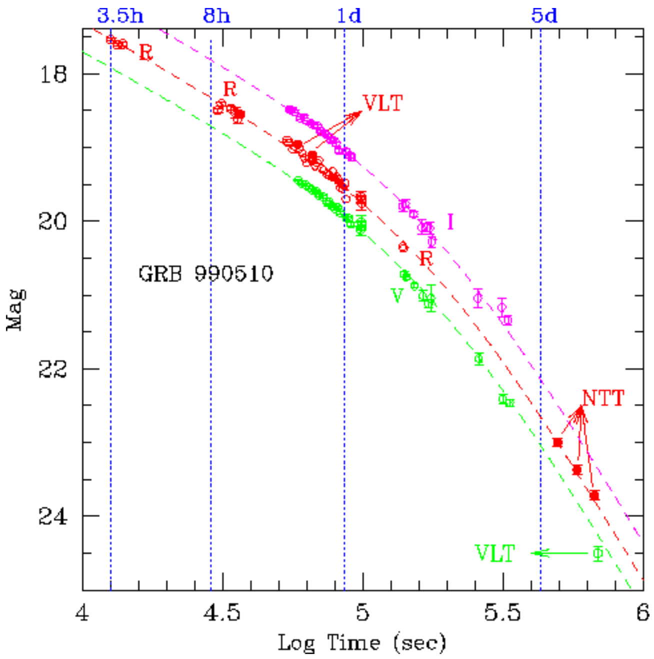


External Shock
- Synchrotron & SSC
- High conversion efficiency
- Not easy to justify the rapid variability

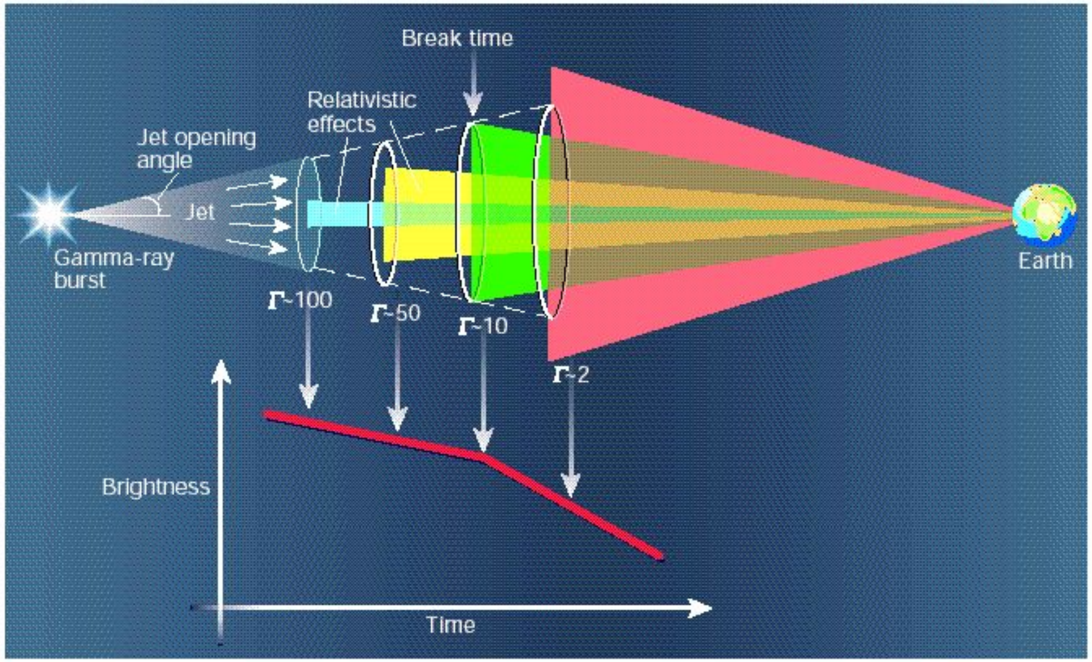
Internal Shocks
- Source activity
- Synchrotron Emission
- Rapid time Variability
- Low conversion efficiency

Afterglow Observations

Harrison et al (1999)

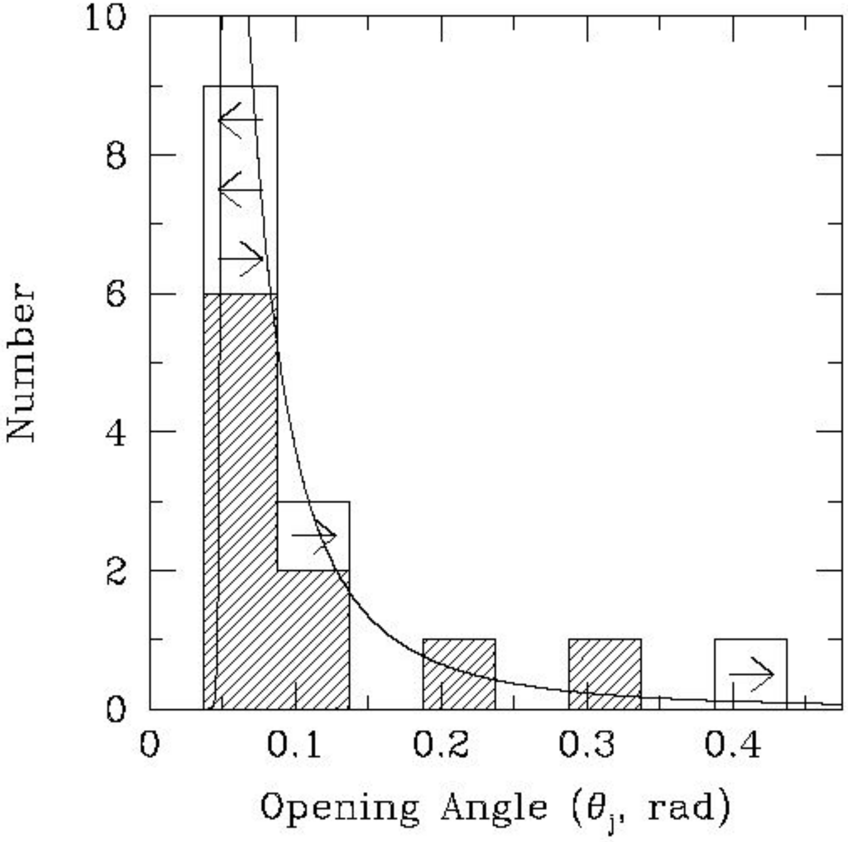


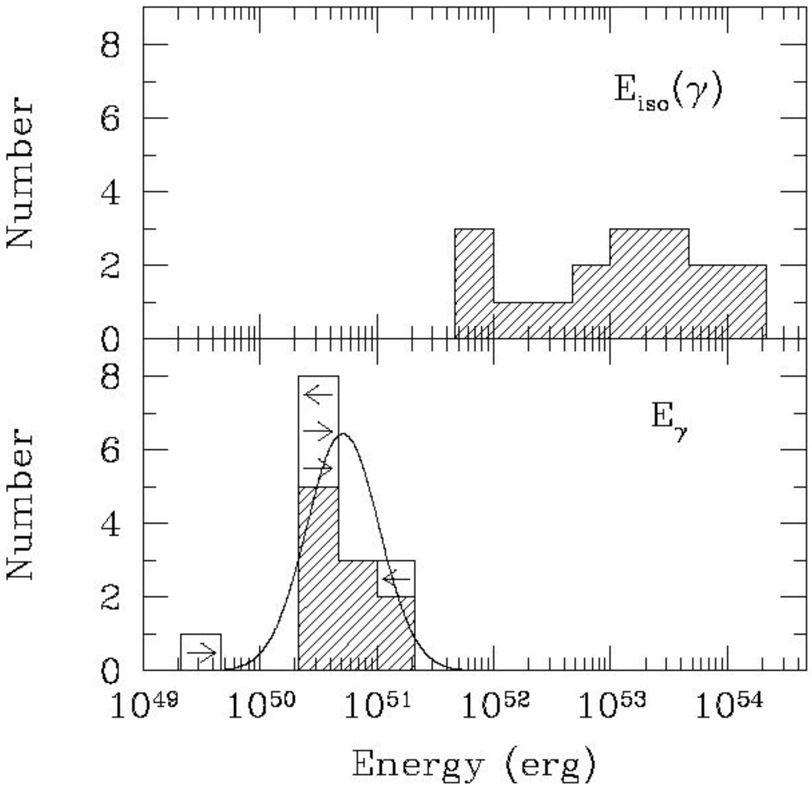
Achromatic Break



Woosley (2001)

Jet and Energy Requirements

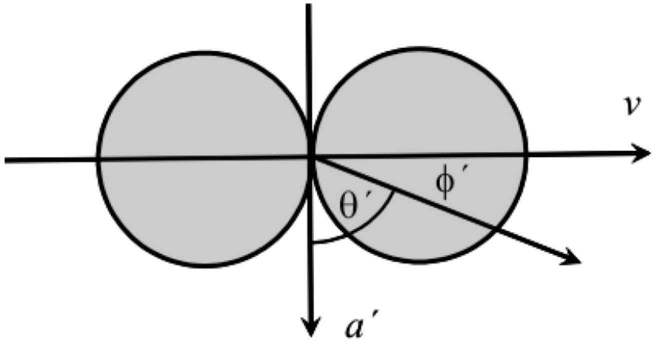




Frail et al. (2001)

Relativistic beaming

Beaming of the Emitted Radiation



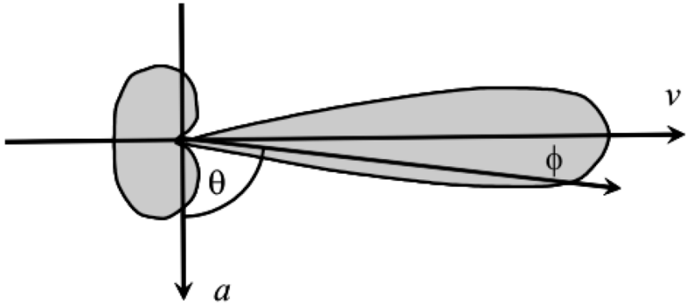
To centre of particle's orbit

We can therefore work out the radiation pattern in the laboratory frame of reference by applying the aberration formulae with the results illustrated schematically in the diagrams. The angular distribution of radiation with respect to the velocity vector in the frame S′ is $I_\nu \propto \sin^2\theta' = \cos^2\phi'$. We may think of this as being the probability distribution with which photons are emitted by the electron in its rest frame. The appropriate aberration formulae between the two frames are:

$$\sin\phi = \frac{1}{\gamma}\frac{\sin\phi'}{1 + (v/c)\cos\phi'} \qquad ; \qquad \cos\phi = \frac{\cos\phi' + v/c}{1 + (v/c)\cos\phi'} \qquad (20)$$

Relativistic beaming

Beaming of the Emitted Radiation



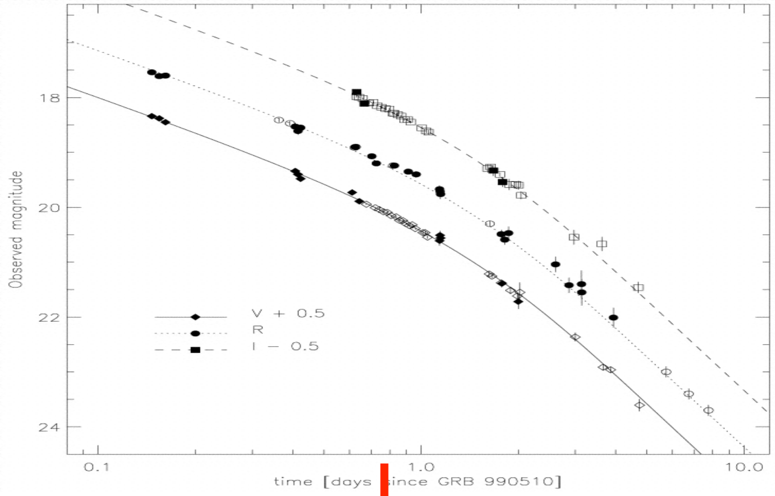
To centre of particle's orbit

Consider the angles $\phi' = \pm\pi/4$ in S', the angles at which the intensity of radiation falls to half its maximum value in the instantaneous rest frame. The corresponding angles ϕ in the laboratory frame of reference are

$$\sin\phi \approx \phi \approx 1/\gamma \qquad (21)$$

The radiation emitted within $-\pi/4 < \phi' < \pi/4$ is beamed in the direction of motion of the electron within $-1/\gamma < \phi < 1/\gamma$. A large 'spike' of radiation is observed every time the electron's velocity vector lies within an angle of about $1/\gamma$ to the line of sight to the observer. The spectrum of the radiation is the Fourier transform of this pulse once the effects of time retardation and aberration are taken into account.

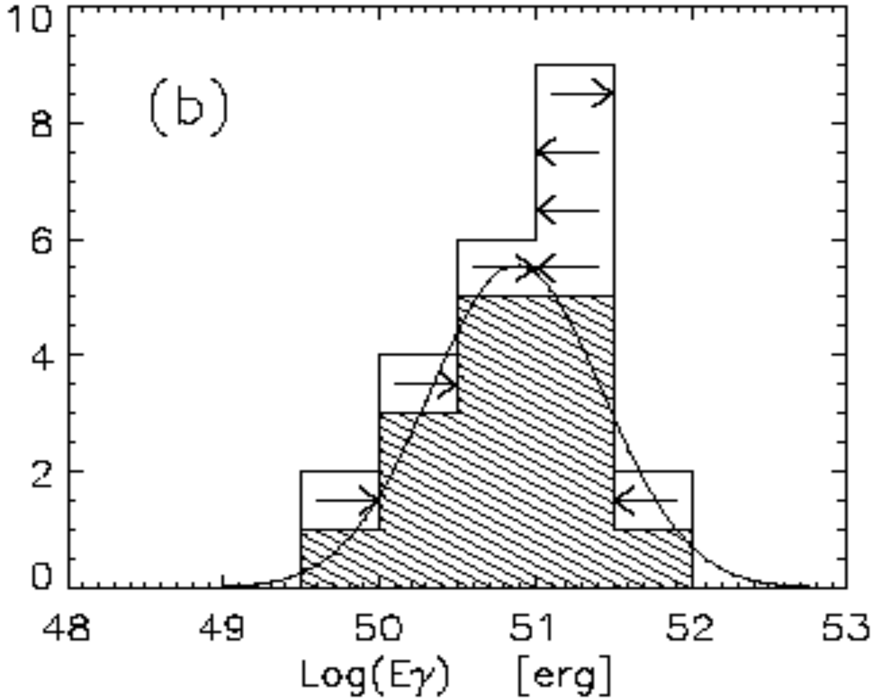
Jet breaks



- breaks in the afterglow decay light curves -> collimation ?

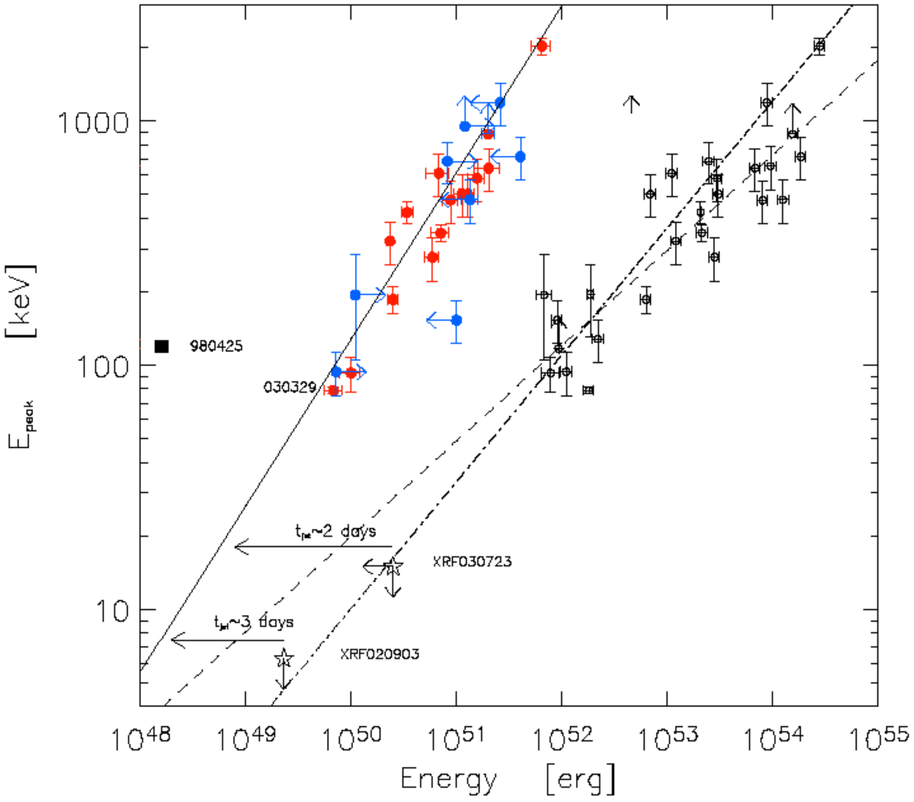
$$\theta = 0.09 \left(\frac{t_{jet,d}}{1+z}\right)^{3/8} \left(\frac{n\,\eta_\gamma}{E_{\gamma,iso,52}}\right)^{1/8}$$

$$E_\gamma = (1-\cos\theta)E_{\gamma,iso}.$$

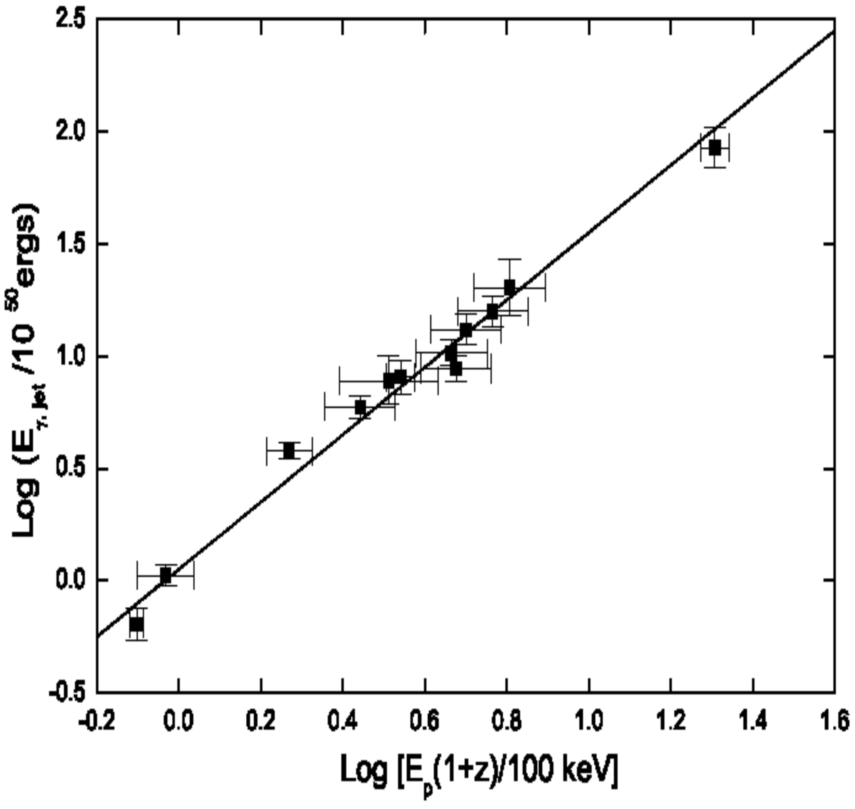


❑ by substituting Eiso with the collimation corrected energy Eγ the correlation still holds, with a lower dispersion and a steeper slope (Ghirlanda et al. 2004, Dai et al. 2004)

❑ this correlation uses 3 parameters (Ep,i, Eiso and tb)

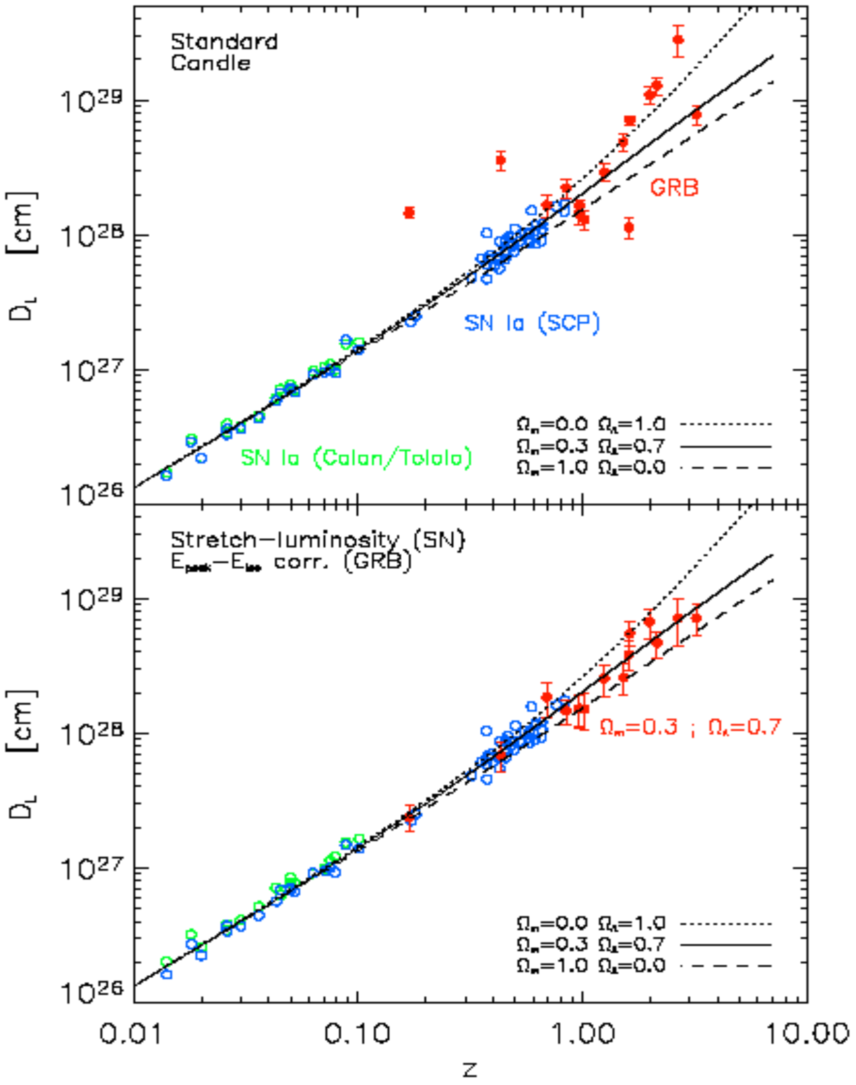


Ghirlanda, Ghisellini & Lazzati, ApJ, 2004

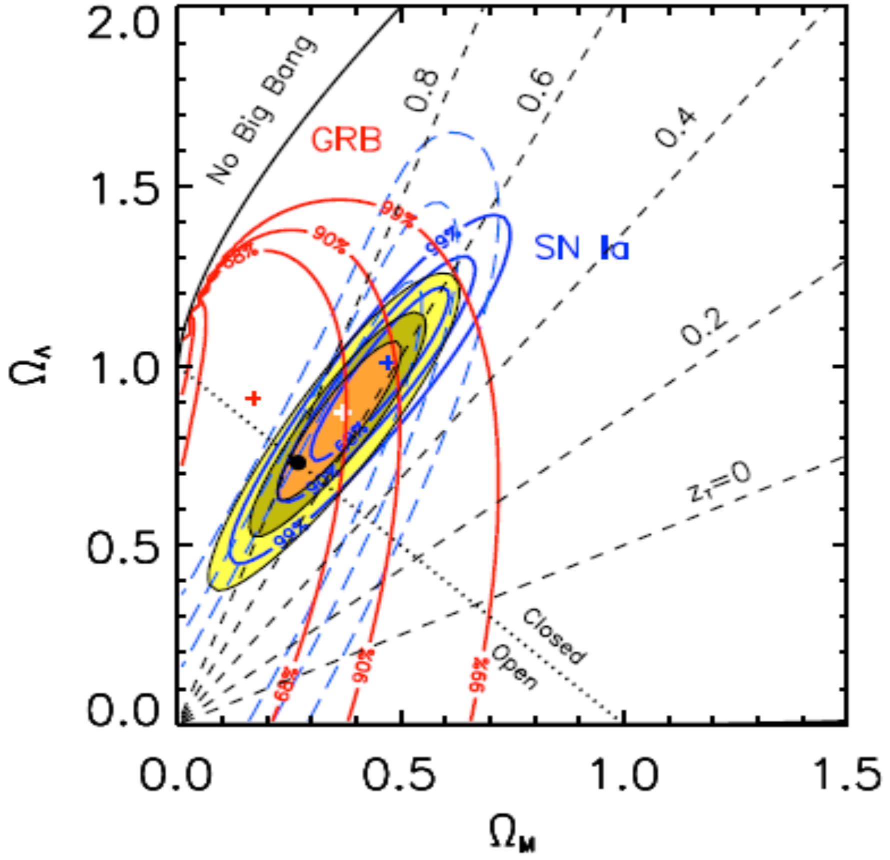


Dai et al., ApJ, 2004

❑ use of the Ep,i-Eγ , Ep,i-Eiso-tb and $E_{p,i}$-L_{iso}-$T_{0.45}$correlations for the estimate of cosmological parameters in a way similar to SN Ia



Ghirlanda et al.,ApJ, 2004

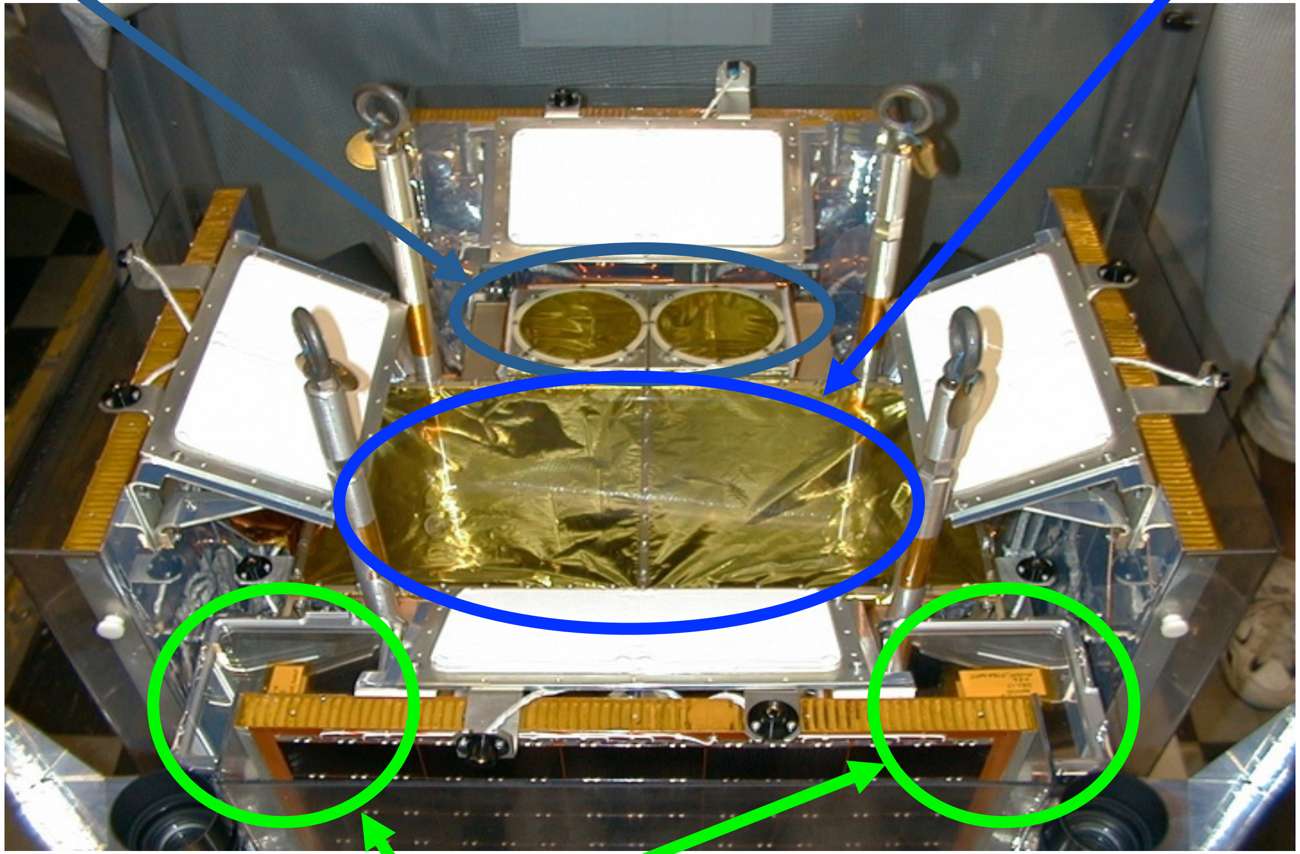


Ghisellini et al. 2005

HETE-2 Science Instrument Package

French Gamma-ray Telescope
(FREGATE): 5-500 keV; ~π FOV

Wide-Field X-ray Monitor **(WXM):**
2-25 keV; ~5’-10’ localizations



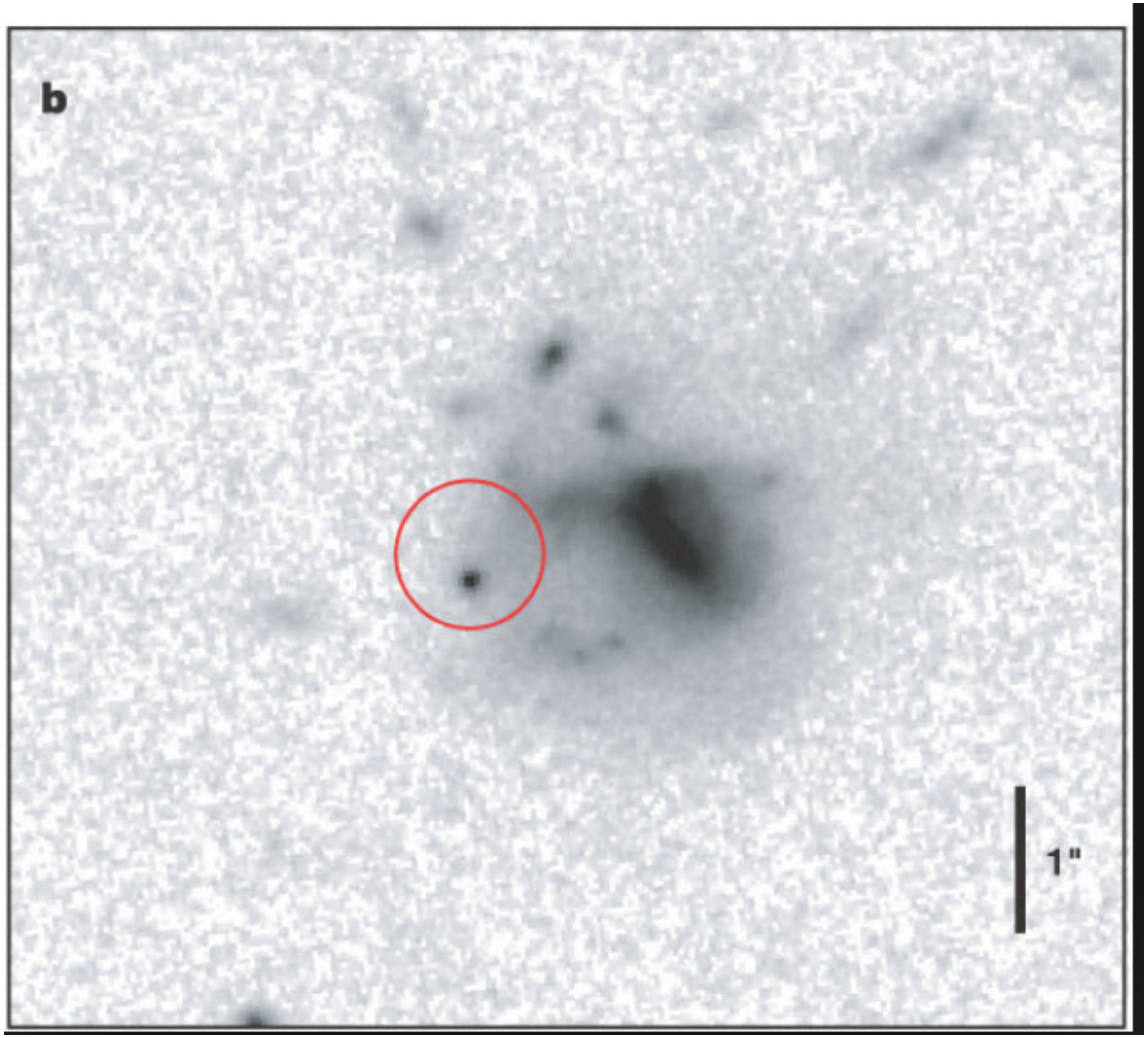
Soft X-ray Cameras **(SXC):**

1-10 keV; ~30” localizations

Hete-II results

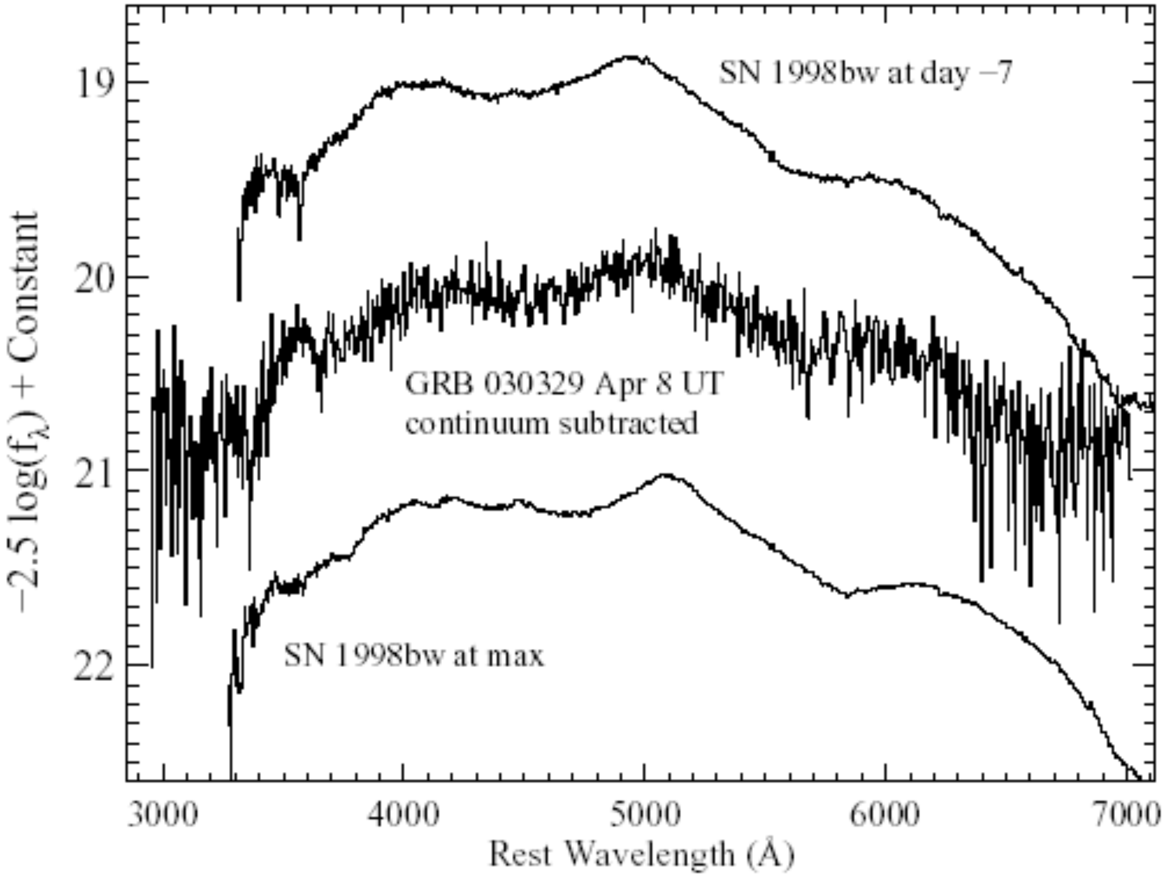
- The discovery of GRB 030329 -- connecting GRBs with supernovas.
- The discovery of GRB 050709 -- the first short/hard GRB with optical afterglow -- the cosmological origin of this subclass of GRBs.
- Dark bursts…. Some of these dark GRBs fade in the optical very rapidly, others are dimmer but detectable with large (meter class) telescopes.
- The establishment of another subclass of GRBs, the less energetic X-Ray Flashes (XRF), and its first optical counterpart.
- The first to send out arcminute positions of GRBs to the observation community within tens of seconds of the onset of GRB (and in a few instances, while the burst was ongoing).

GRB050709



(Fox et al. 2005)

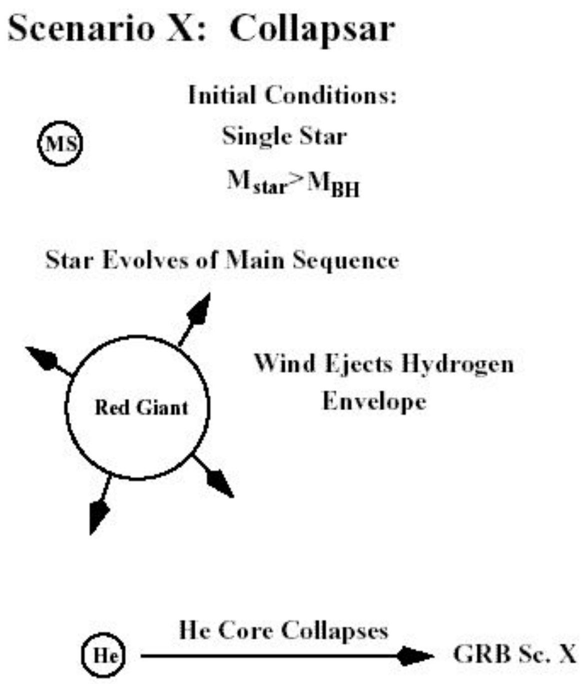
GRB 030329: the “smoking gun”?

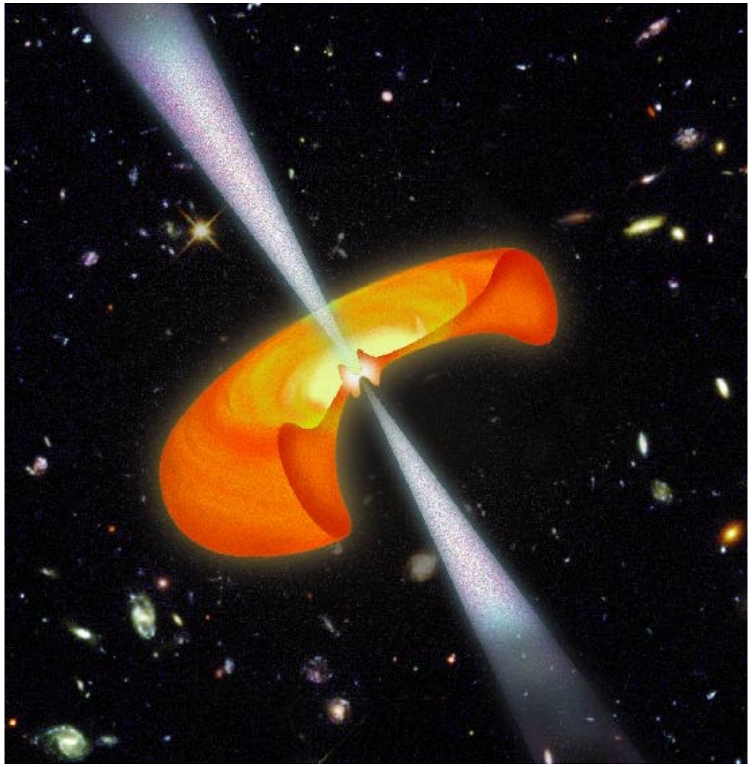


(Matheson et al. 2003)

Collapsar model

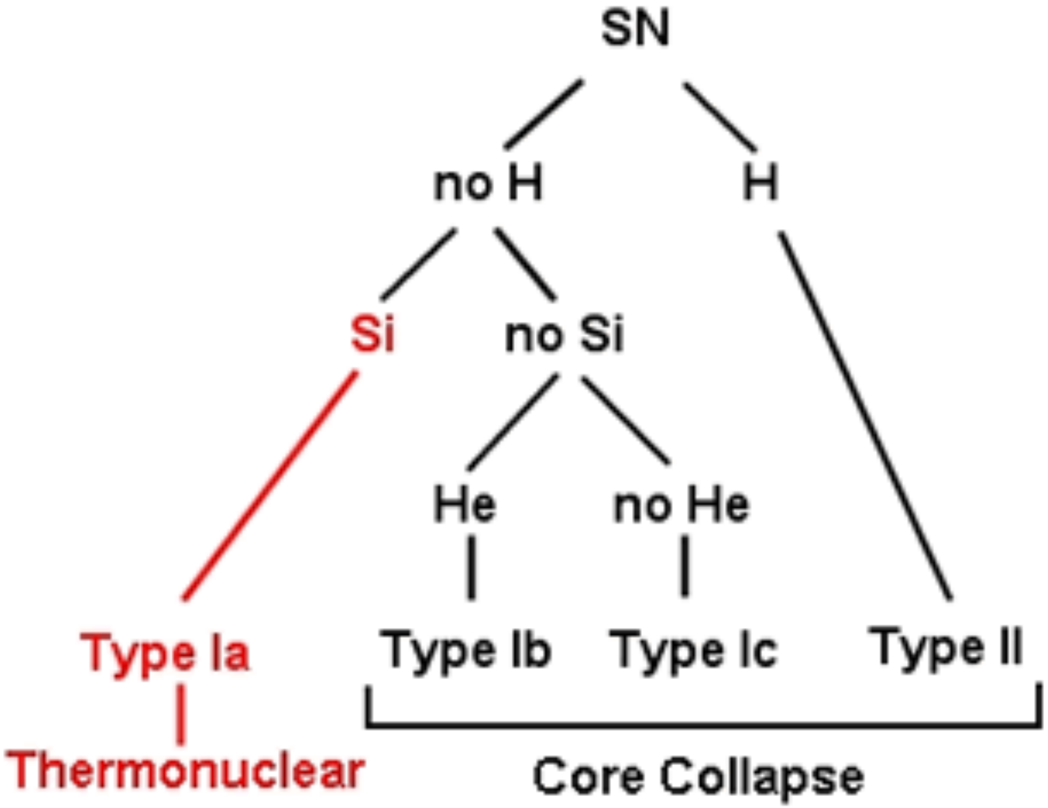
Woosley (1993)



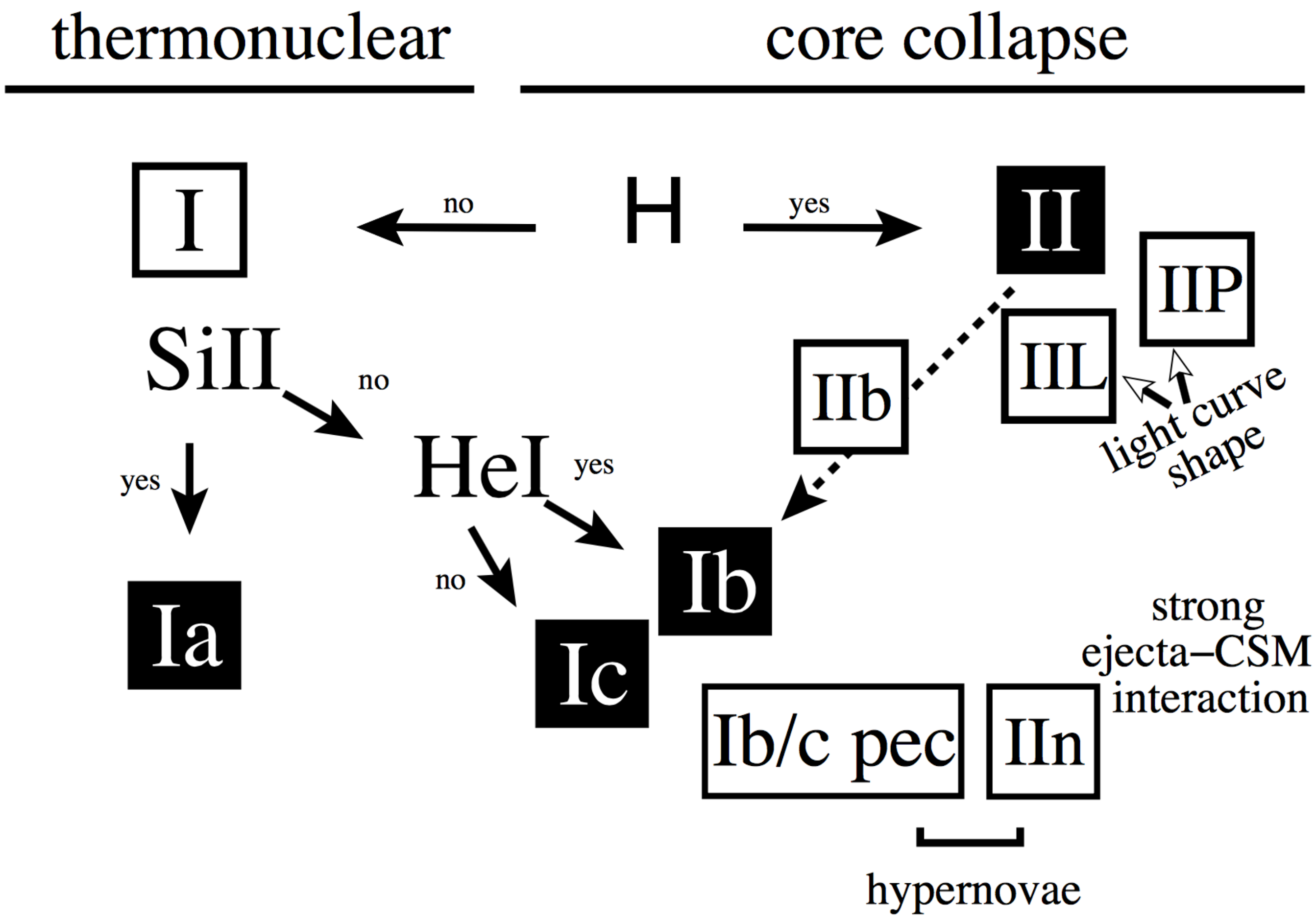


- Very massive star that collapses in a rapidly spinning BH.
- Identification with SN explosion.

Classificazione delle SNe

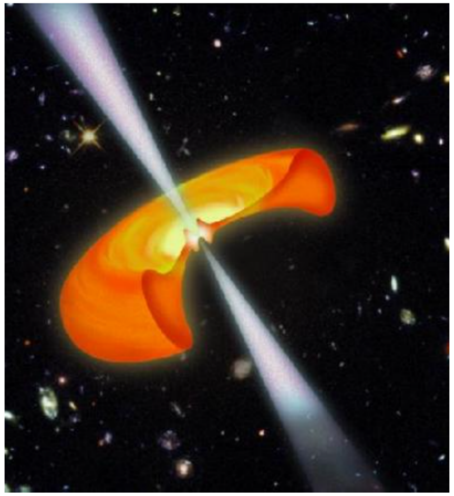


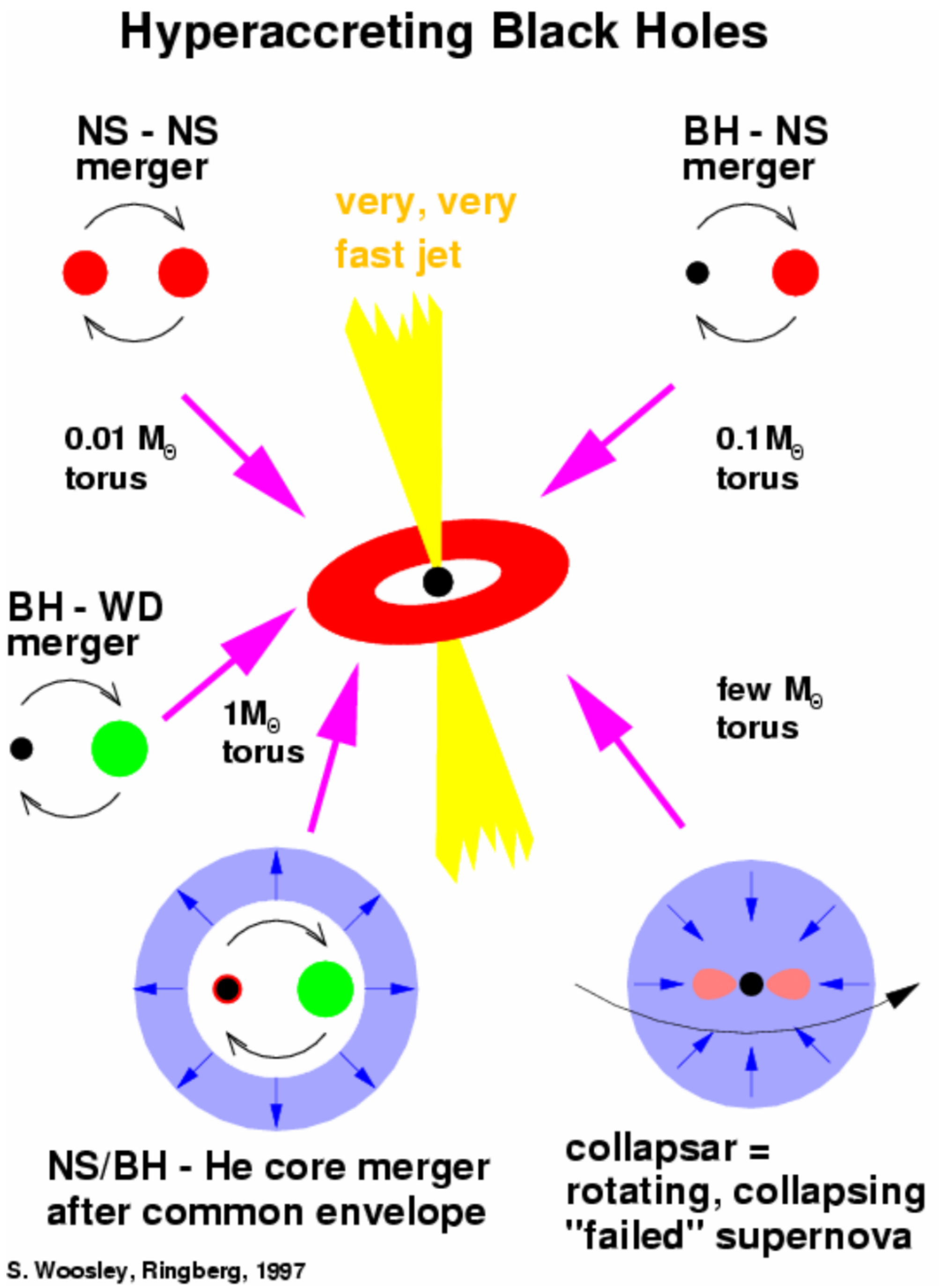
Classificazione delle SNe



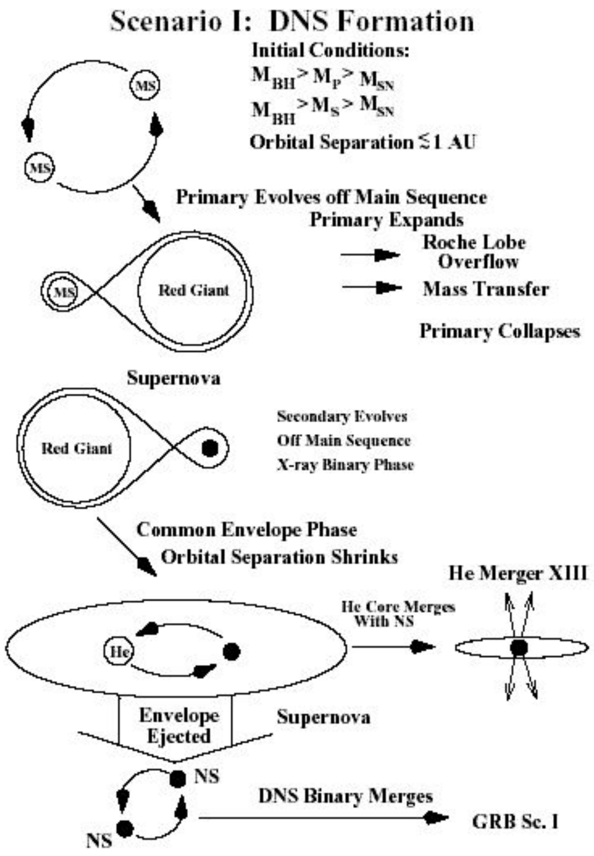
Black-Hole Accretion Disk (BHAD) Models

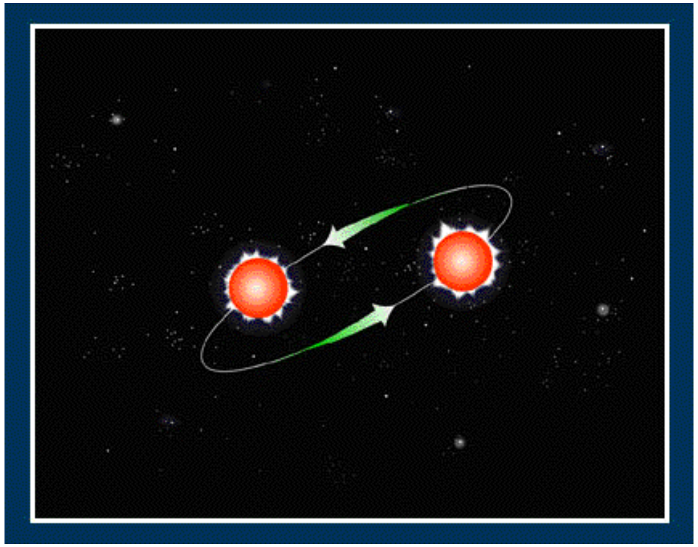
Binary merger or Collapse of rotating Star produces Rapidly accreting Disk (>0.1 solar Mass per second!) Around black hole.

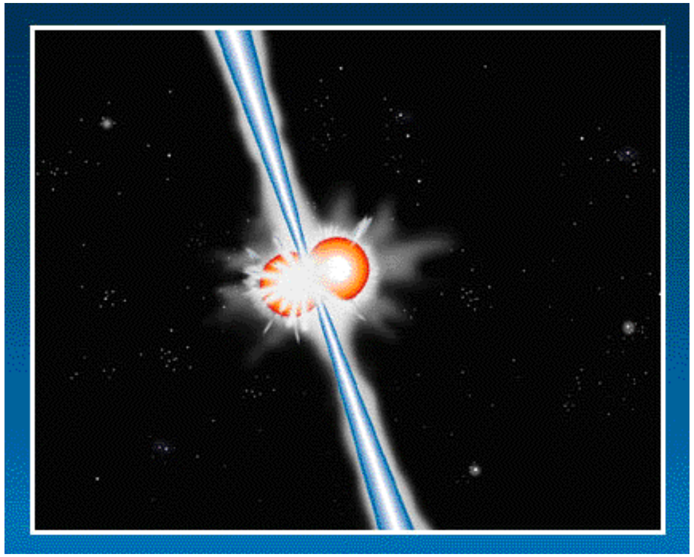




NS/BH Binary Mergers



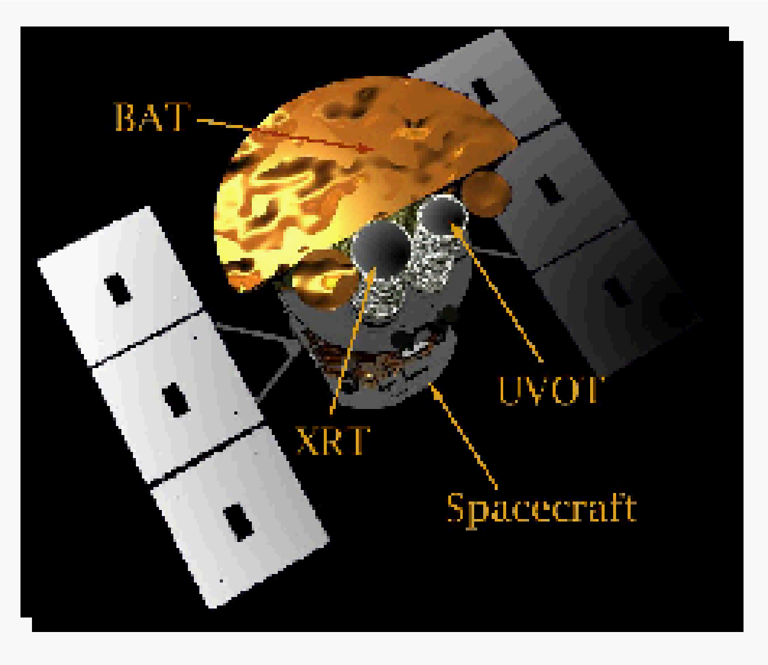




Merging of compact objects (NS-NS, NS-BH, BH-BH).
These objects are observed in our Galaxy.
The merging time is about 10^8 yr, via GW emission.

Eichler et. al. (1989)

SWIFT



In orbita dal 2004

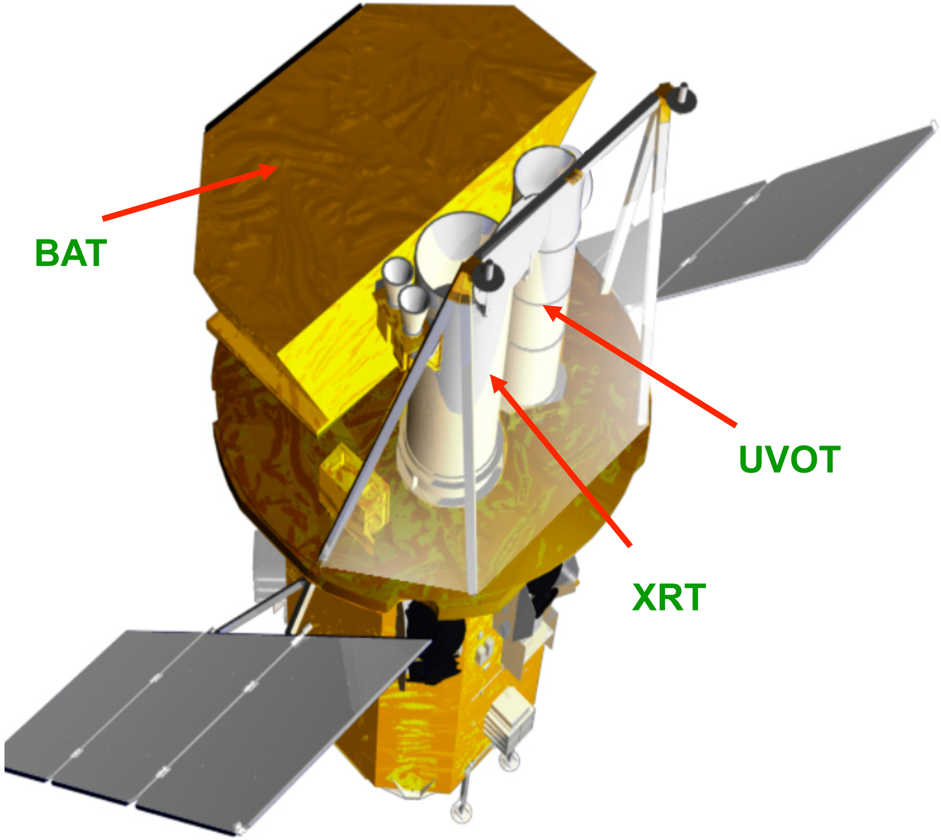
Swift Instruments

Instruments

- Burst Alert Telescope (BAT)
  - New CdZnTe detectors
  - Most sensitive gamma-ray imager ever
- X-Ray Telescope (XRT)
  - Arcsecond GRB positions
  - CCD spectroscopy
- UV/Optical Telescope (UVOT)
  - Sub-arcsec positions
  - Grism spectroscopy
  - 24th mag sensitivity (1000 sec)
  - Finding chart for other observers

Spacecraft

- Autonomous re-pointing, 20 - 75 s
- Onboard and ground triggers



Swift

Details

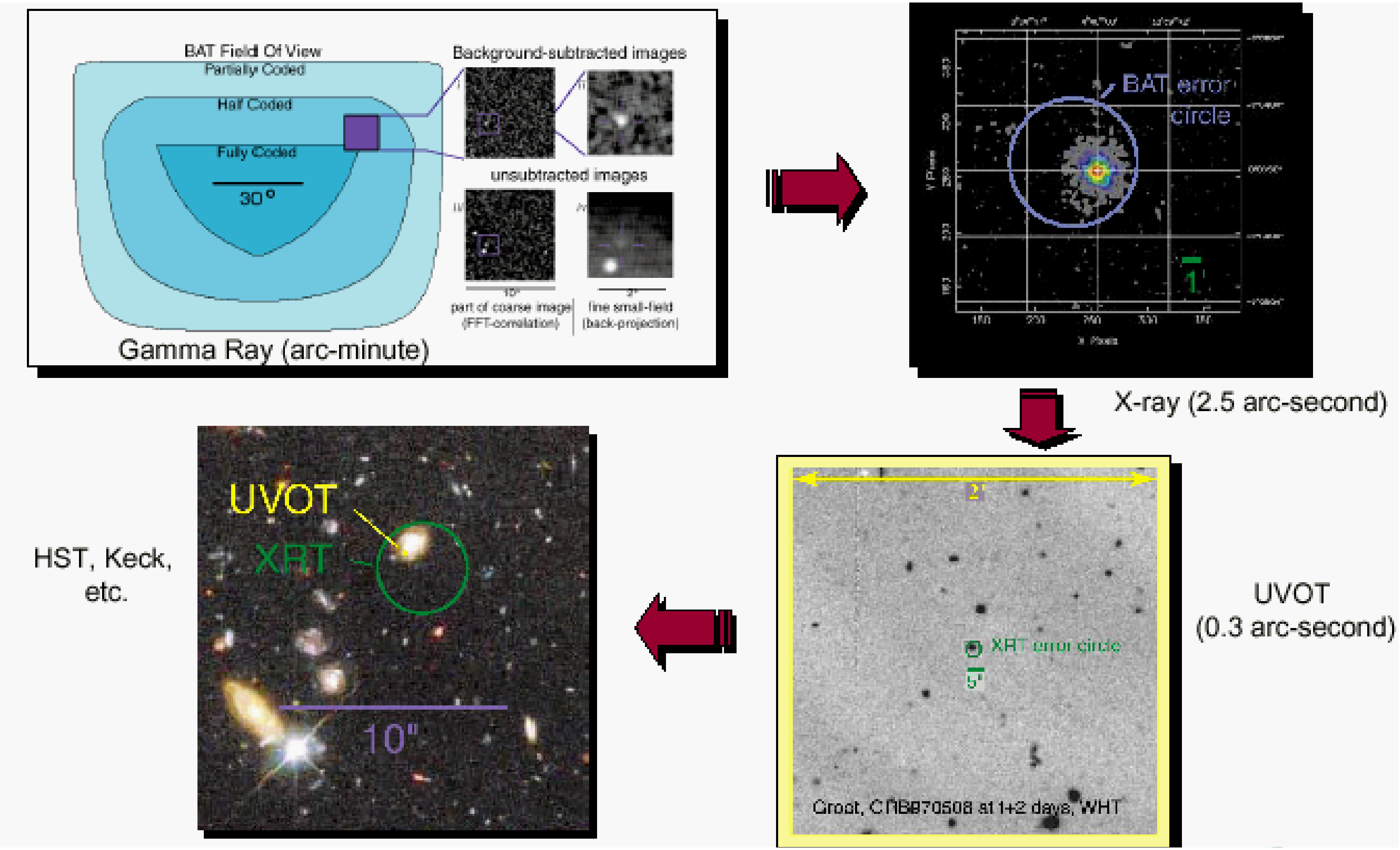
- **BAT** (15-350 keV). Large (2 sr) field of view – detects bursts with arc min accuracy. And tells observers immediately.

- *Swift* automatically determines if it can view the GRB, and if so, slews to it.

- **XRT** (0.3-10 keV) and **UVOT** (~1000-6000 Å) begin observing typically within 100 s of the trigger.

- XRT can automatically detect afterglows, and downlinks limited data immediately. ~90% of BAT GRBs have promptly detected XRT afterglows.

SWIFT


BAT Field Of View
Partially Coded
Half Coded
Fully Coded
30°
Background-subtracted images
unsubtracted images
part of coarse image (FFT-correlation)
fine small-field (back-projection)
Gamma Ray (arc-minute)
BAT error circle
1'
X Pixels
Y Pixels
X-ray (2.5 arc-second)
2'
XRT error circle
5"
Groot, GRB970508 at 1+2 days, WHT
UVOT (0.3 arc-second)
UVOT
XRT
10"
HST, Keck, etc.

Mission Capabilities

Multiwavelength observations on all time scales

>100 GRBs per year of all types

BAT sensitivity 2 - 5 time better than BATSE

Arcsec positions & counterparts for 100’s GRBs

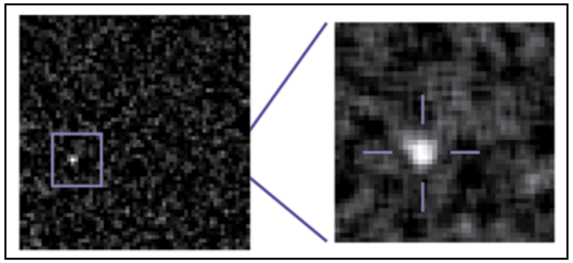
Rapid GRB notifications via GCN

Identification of host galaxies offsets

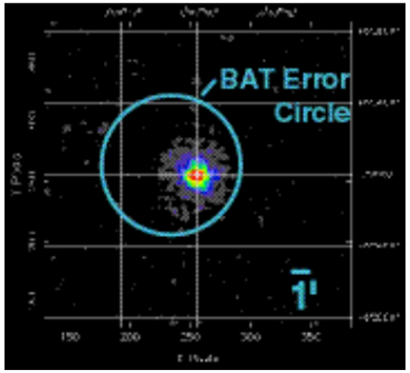
X-ray and UV/optical spectroscopy

Upload capability to slew to GRB and transients detected by other observatories

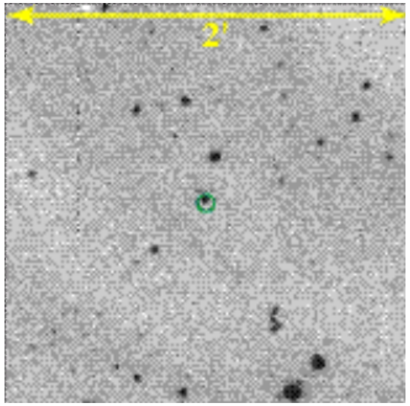
BAT



XRT



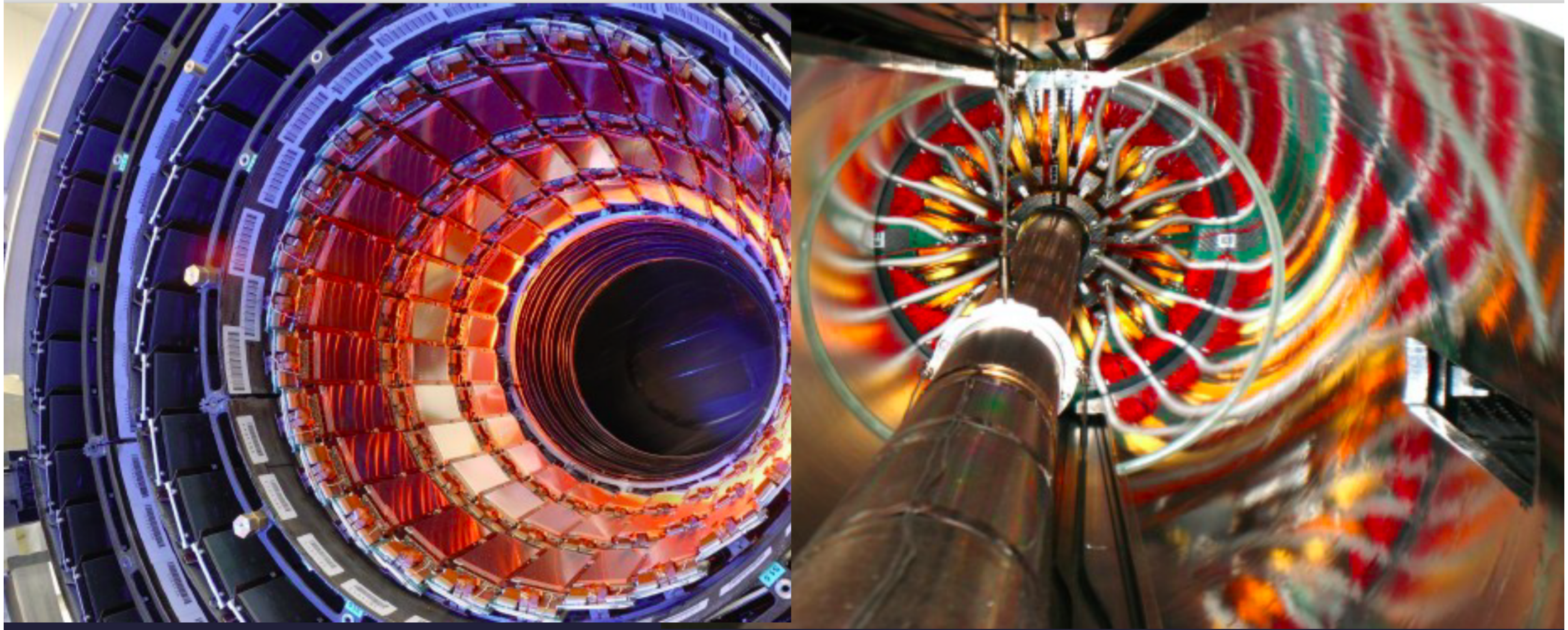
UVOT



Swift Observatory in Goddard Clean Room

Astrofisica Nucleare e Subnucleare

Solid State Detectors



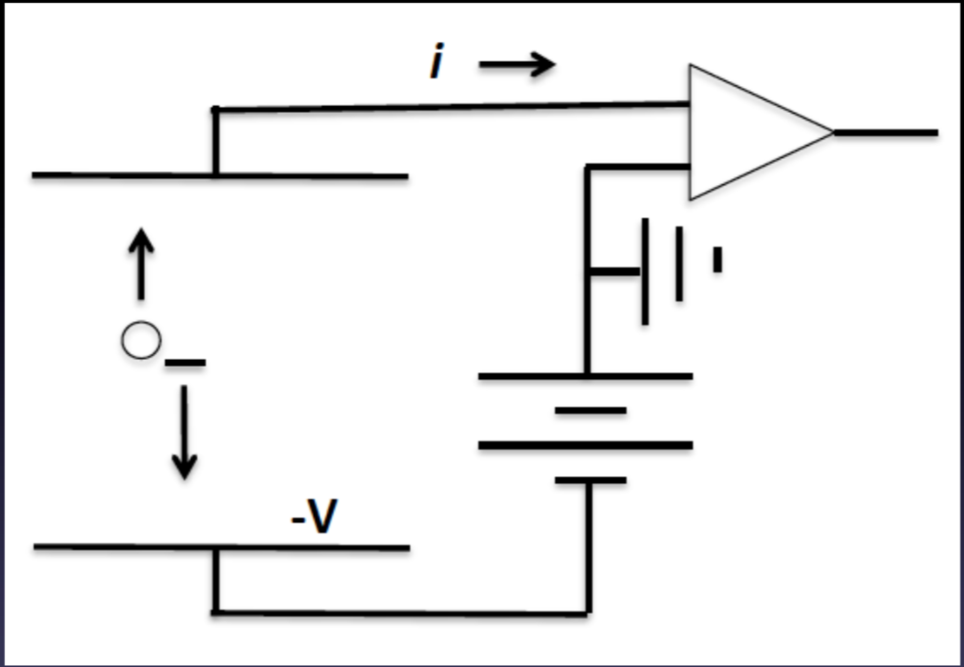
Detectors for Particle Physics

Semiconductor Detectors

D. Bortoletto

Solid State Detector

- A solid state detector is an ionization chamber
  - Ionizing radiation creates electron/hole pairs
  - Charge carriers move in applied E field
  - Motion induces a current in an external circuit, which can be amplified and sensed.

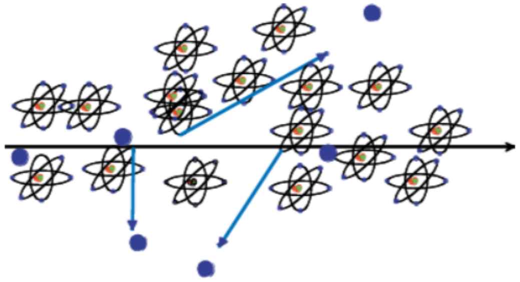


	Gas	Solid
Density	**Low**	**High**
Atomic number (Z)	**Low**	**Moderate (Z=14)**
Ionization Energy (ε_I)	**Moderate (≈ 30 eV)**	**Low (≈3.6 eV)**
Signal Speed	**Moderate (10ns-10μs)**	**Fast (<20 ns)**

Solid State Detectors

Gas Detectors

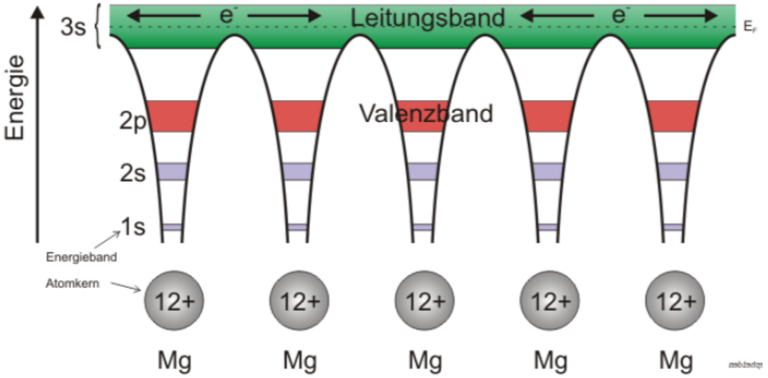
In gaseous detectors, a charged particle is liberating electrons from the atoms, which are freely bouncing between the gas atoms.



An applied electric field makes the electrons and ions move, which induces signals on the metal readout electrodes.

For individual gas atoms, the electron energy levels are discrete.

Solid State Detectors

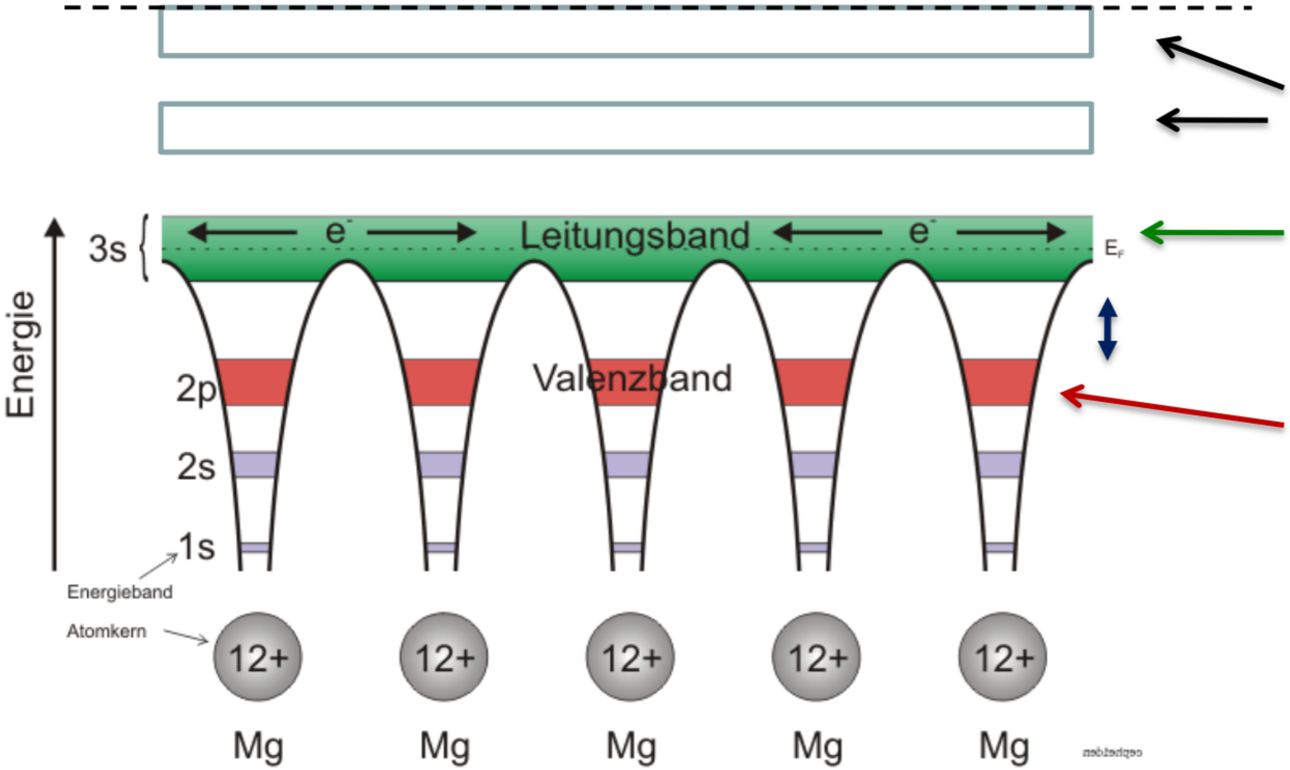


In solids (crystals), the electron energy levels are in ‘bands’.

Inner shell electrons, in the lower energy bands, are closely bound to the individual atoms and always stay with ‘their’ atoms.

In a crystal there are however energy bands that are still bound states of the crystal, but they belong to the entire crystal. Electrons in these bands and the holes in the lower band can freely move around the crystal, if an electric field is applied.

Solid State Detectors



Free Electron Energy

Unfilled Bands

Conduction Band

Band Gap

Valance Band

Conductor, Insulator, Semiconductor

In case the conduction band is filled the crystal is a conductor.

In case the conduction band is empty and ‘far away’ from the valence band, the crystal is an insulator.

In case the conduction band is empty but the distance to the valence band is small, the crystal is a semiconductor.

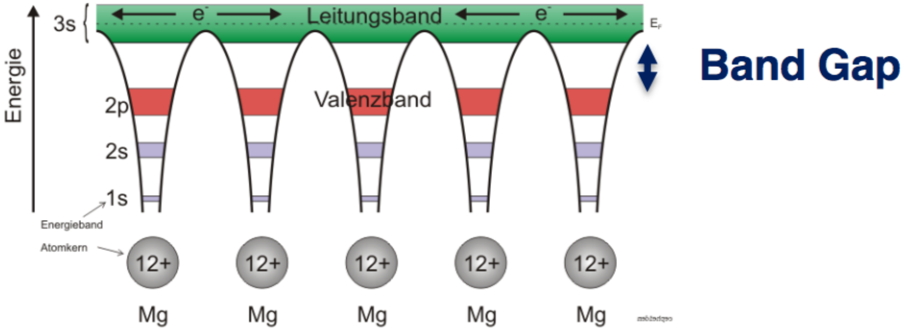
Solid State Detectors

Band Gap, e-h pair Energy

The energy gap between the last filled band – the valence band – and the conduction band is called band gap E_g.

The band gap of Diamond/Silicon/Germanium is 5.5, 1.12, 0.66 eV.

The average energy to produce an electron/hole pair for Diamond/Silicon/Germanium is 13, 3.6, 2.9eV.



Temperature, Charged Particle Detection

In case an electron in the valence band gains energy by some process, it can be excited into the conduction band and a hole in the valence band is left behind.

Such a process can be the passage of a charged particle, but also thermal excitation → probability is proportional Exp($-E_g/kT$).

The number of electrons in the conduction band is therefore increasing with temperature i.e. the conductivity of a semiconductor increases with temperature.

Solid State Detectors

Primary 'ionization':

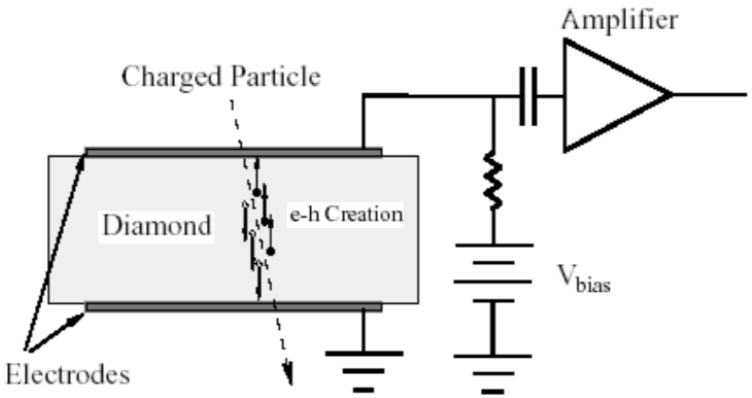
The average energy to produce an electron/hole pair is: Diamond (13eV), Silicon (3.6eV), Germanium (2.9eV)

Comparing to gas detectors, the density of a solid is about a factor 1000 larger than that of a gas and the energy to produce and electron/hole pair e.g. for Si is a factor 7 smaller than the energy to produce an electron-ion pair in Argon.

Solid State vs. Gas Detector:

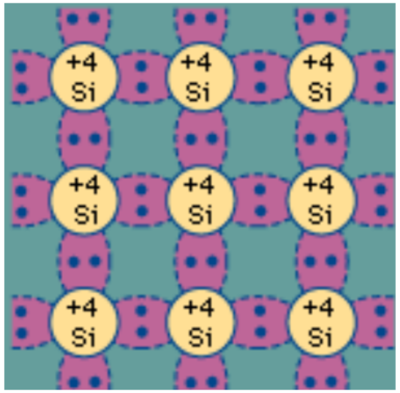
The number of primary charges in a Si detector is therefore about 10^4 times larger than the one in gas → while gas detectors need internal charge amplification, solid state detectors don't need internal amplification.

While in gaseous detectors, the velocity of electrons and ions differs by a factor 1000, the velocity of electrons and holes in many semiconductor detectors is quite similar → very short signals.

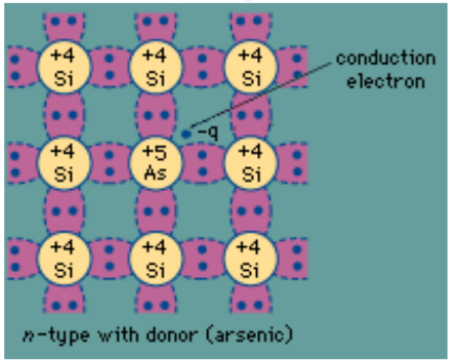


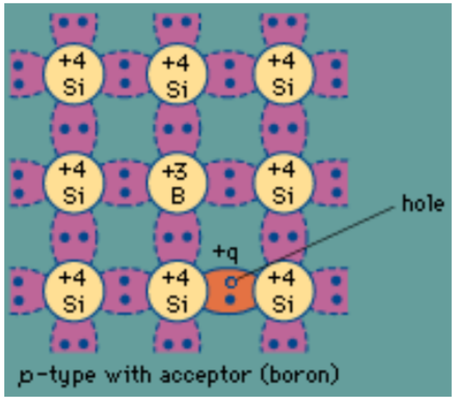
Diamond → A solid state ionization chamber

Doping of Silicon



doping



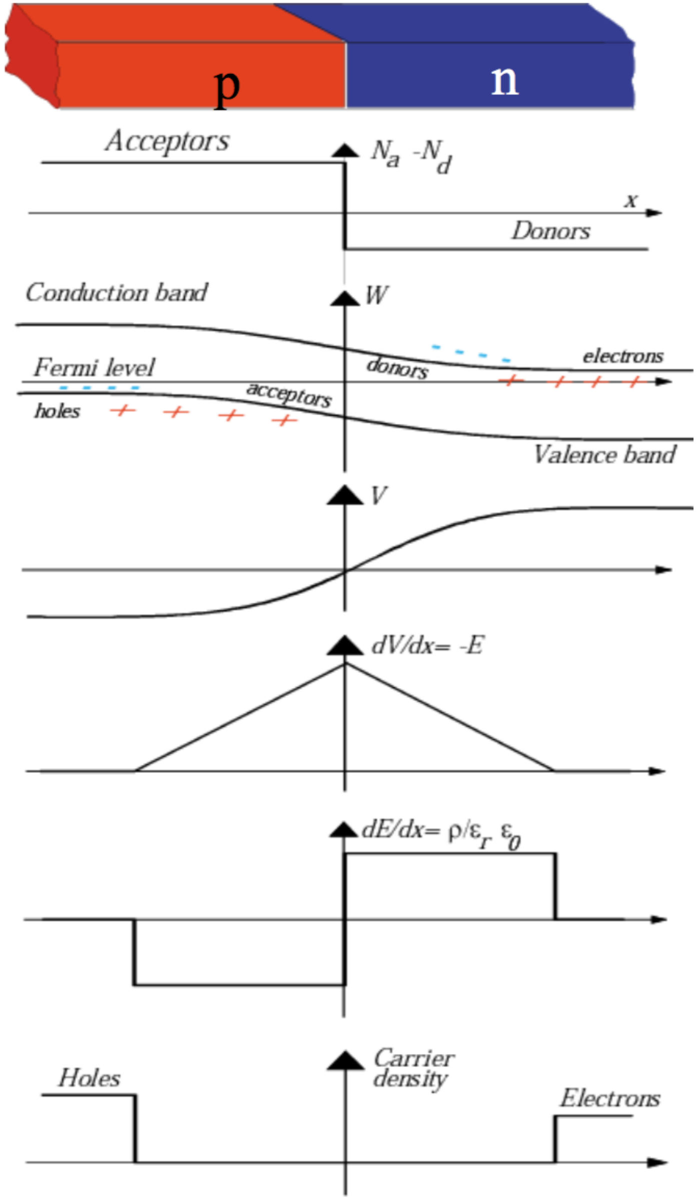


In a silicon crystal at a given temperature the number of electrons in the conduction band is equal to the number of holes in the valence band.

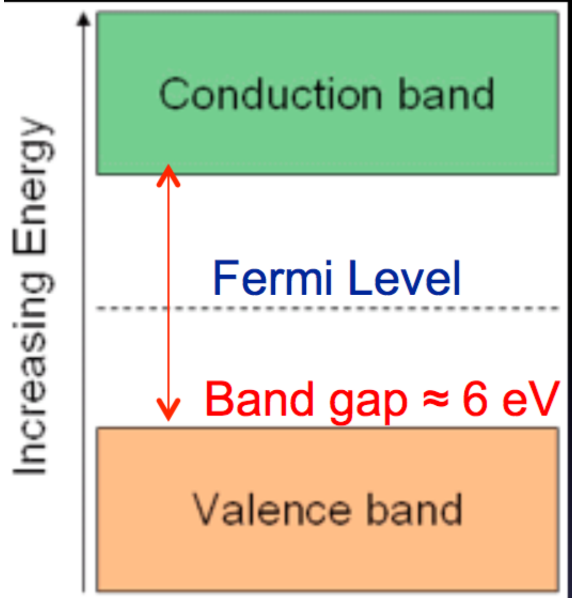
Doping Silicon with Arsen (+5) it becomes and n-type conductor (more electrons than holes).

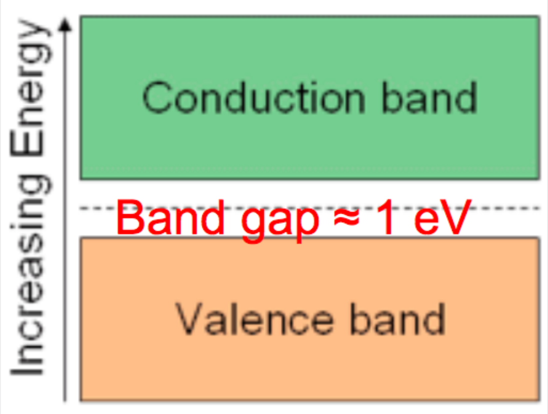
Doping Silicon with Boron (+3) it becomes a p-type conductor (more holes than electrons).

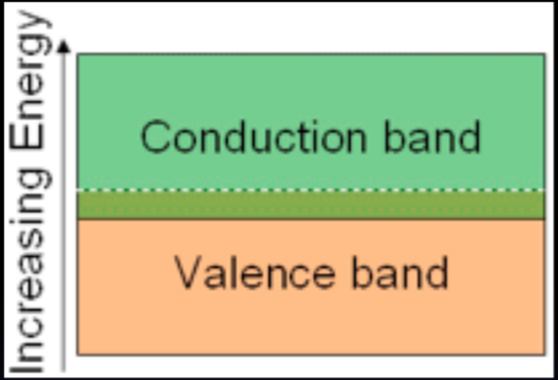
Bringing p and n in contact makes a diode.



Semiconductor

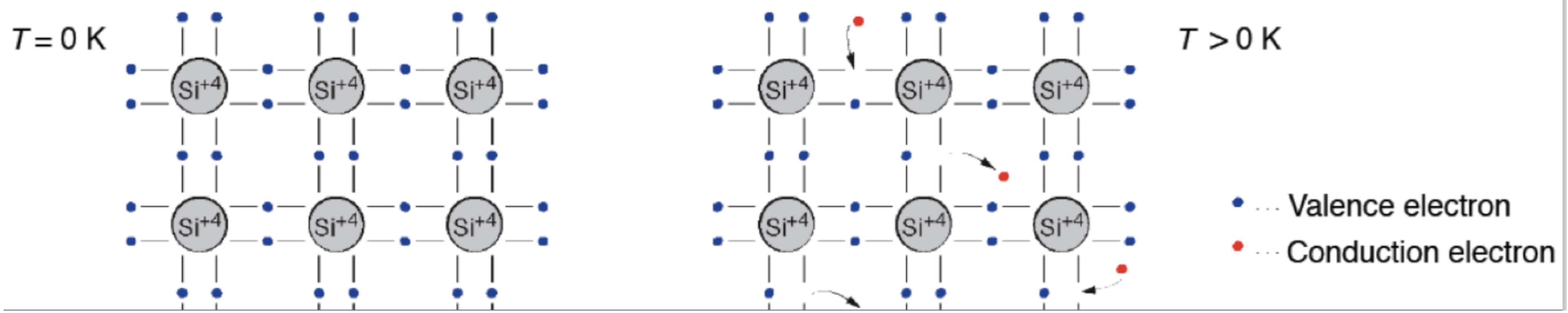






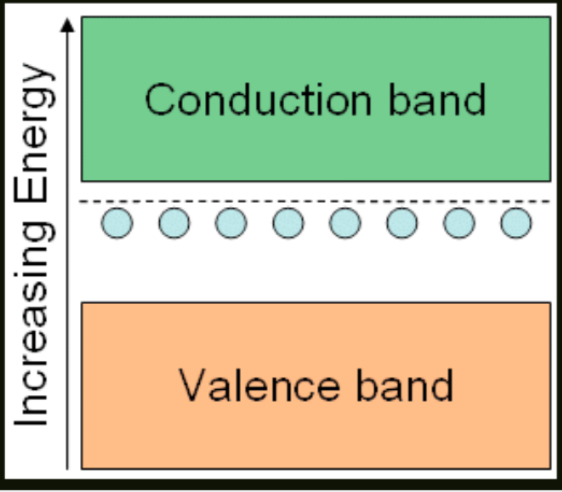
- Fermi level
  - Maximum electron energy at T = 0 K

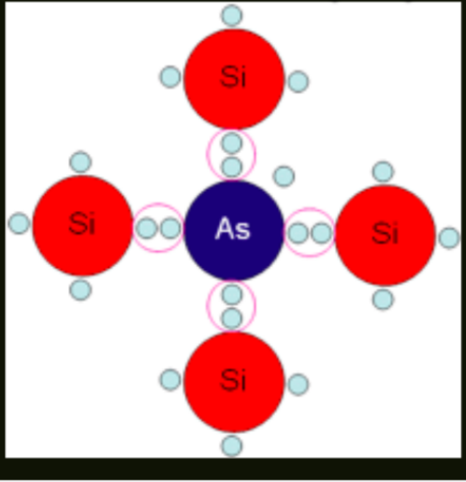
- Semiconductor: at room temperature electrons can already occupy the conduction band and may recombine with holes.
- Thermal equilibrium is reached between excitation and recombination when the charge carrier concentration $n_e = n_h = n_i$= intrinsic carrier concentration≈1.5×10^{10} cm^{-3}

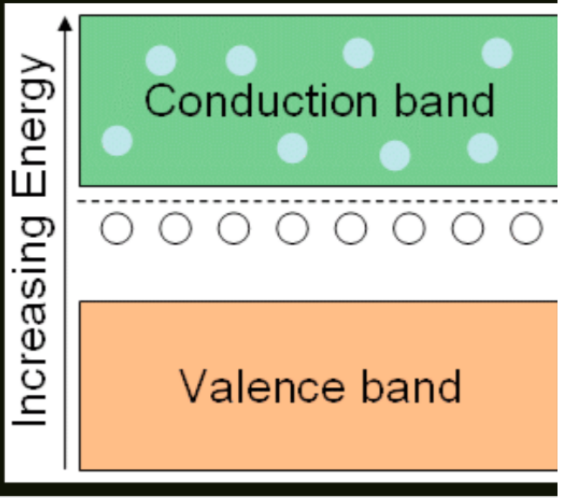


Doped semiconductors

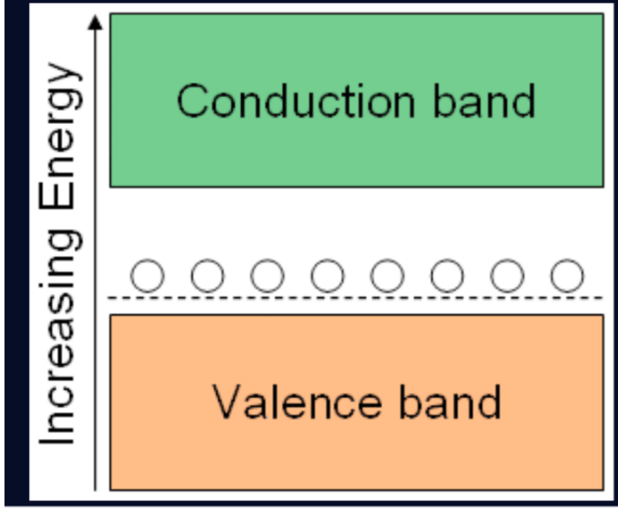
DONOR (N)

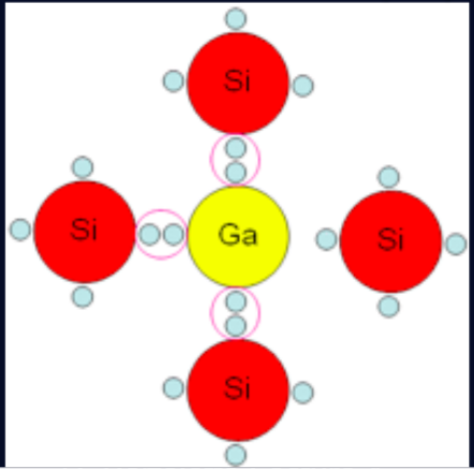


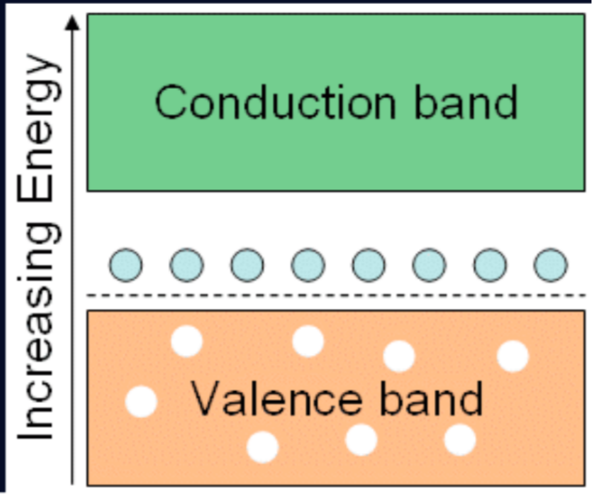




ACCEPTOR (P)

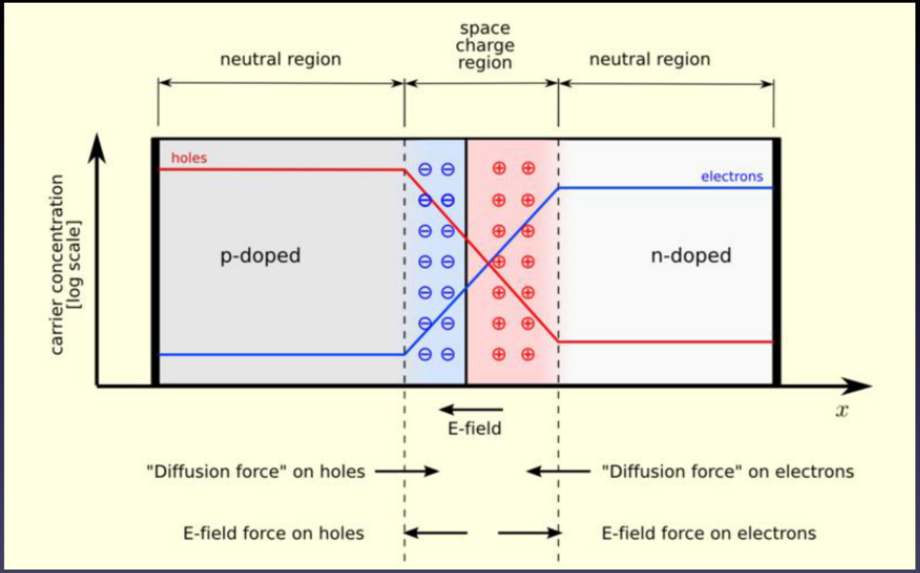


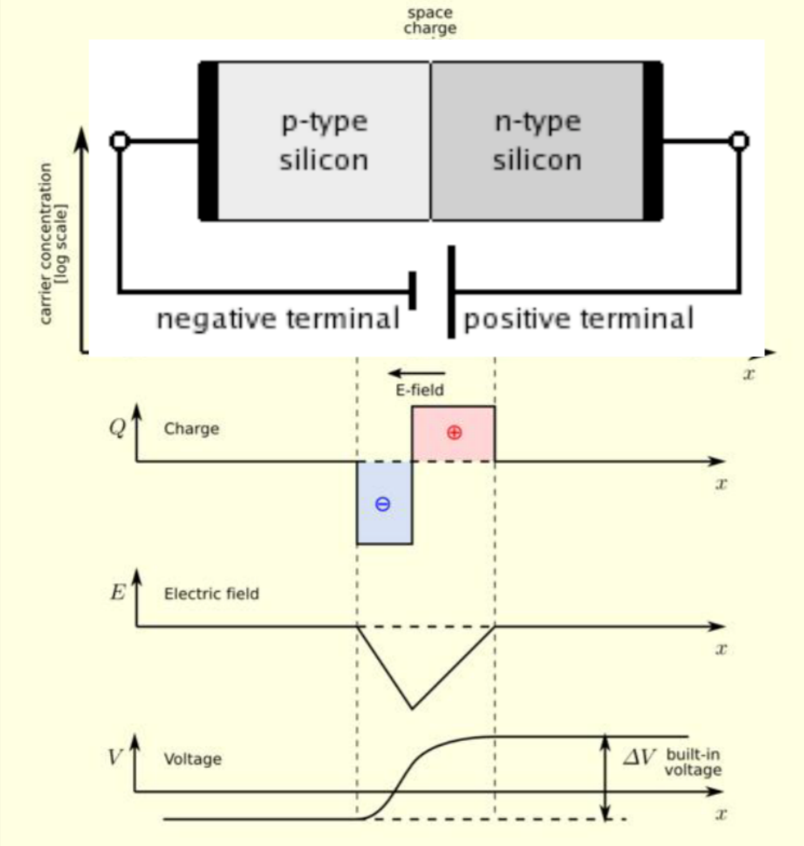




PN Junction

- PN junction without external voltage
  - Free charges move until the chemical potential is balanced by an electrical potential called the built-in potential





- The space charge (depletion) region can be made bigger by applying a reverse bias voltage

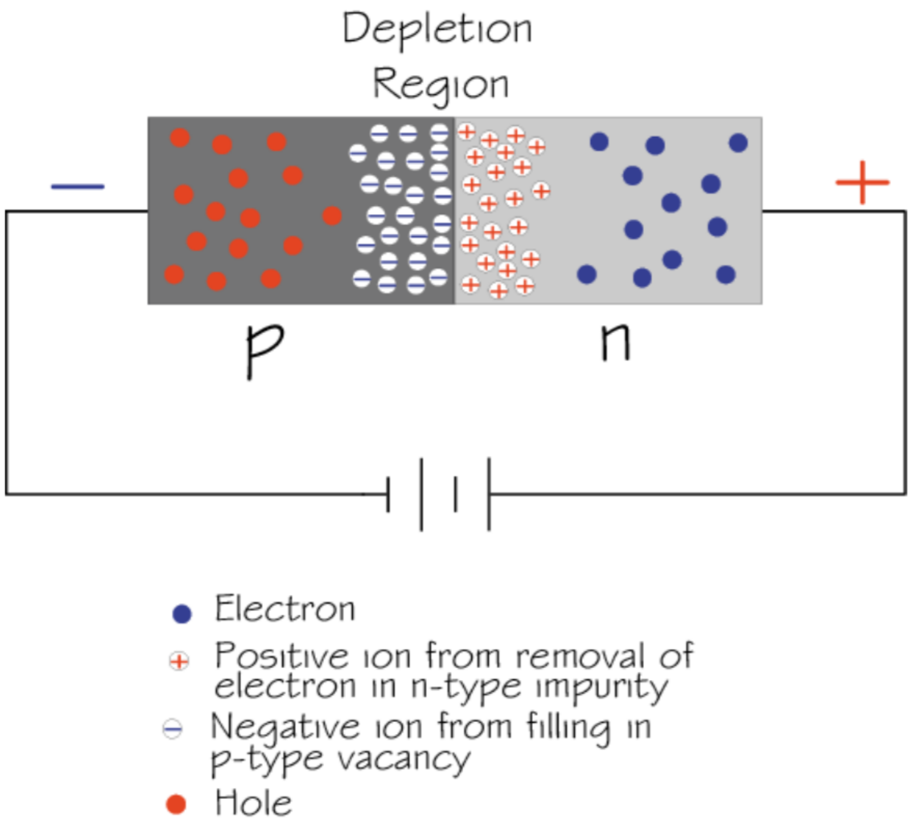
Si-Diode used as a Particle Detector !

At the p-n junction the charges are depleted and a zone free of charge carriers is established.

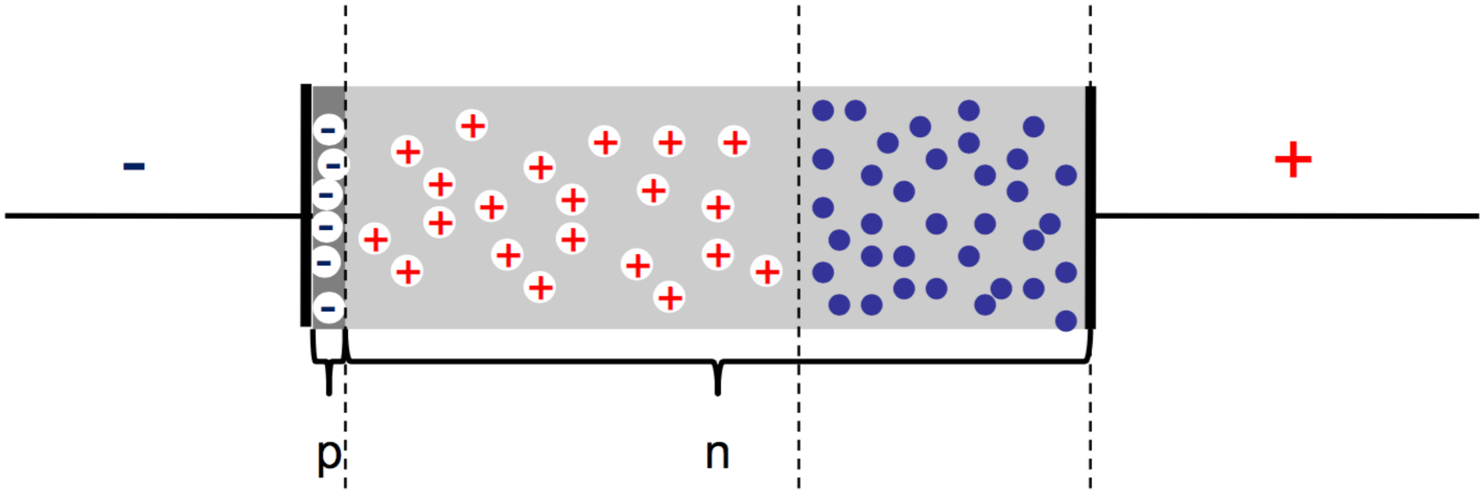
By applying a voltage, the depletion zone can be extended to the entire diode → highly insulating layer.

An ionizing particle produces free charge carriers in the diode, which drift in the electric field and induce an electrical signal on the metal electrodes.

As silicon is the most commonly used material in the electronics industry, it has one big advantage with respect to other materials, namely highly developed technology.



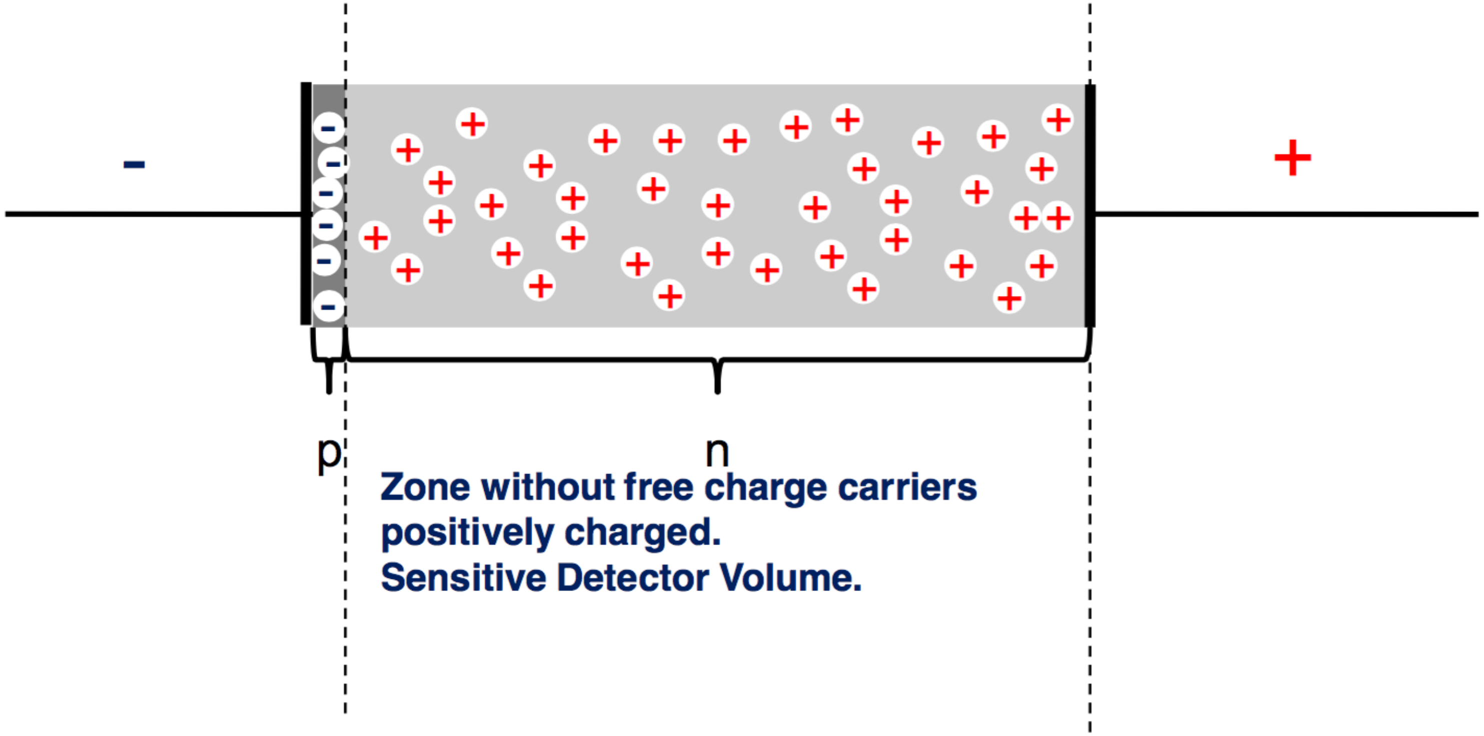
Under-Depleted Silicon Detector



Zone without free charge carriers positively charged. Sensitive Detector Volume.

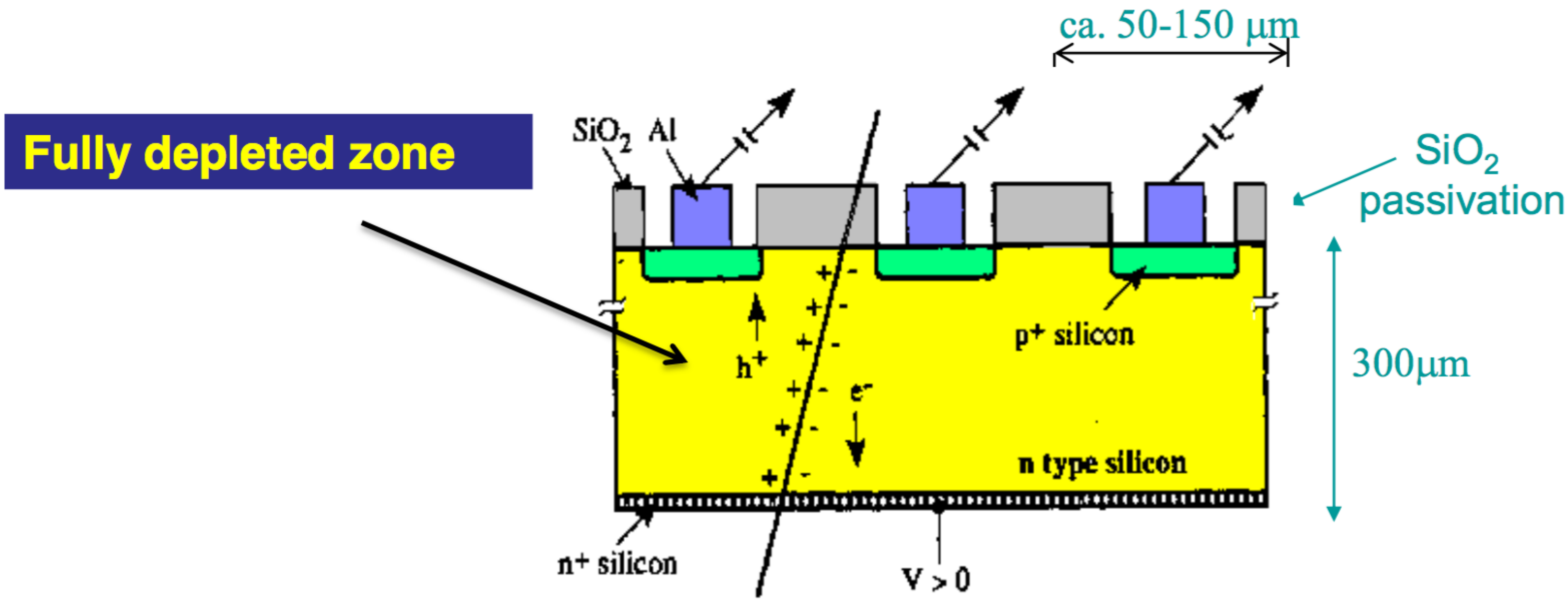
Zone with free electrons. Conductive. Insensitive to particles.

Fully-Depleted Silicon Detector



Zone without free charge carriers positively charged.
Sensitive Detector Volume.

Silicon Detector

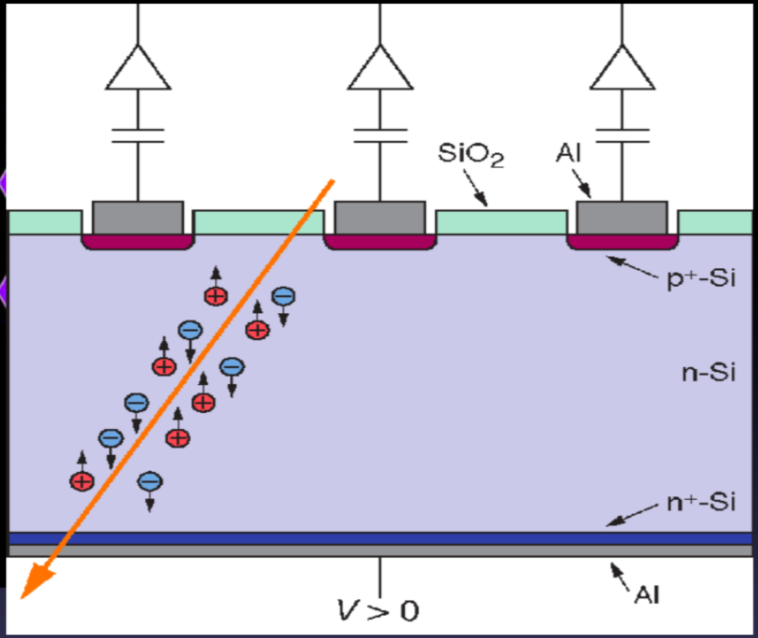

Fully depleted zone

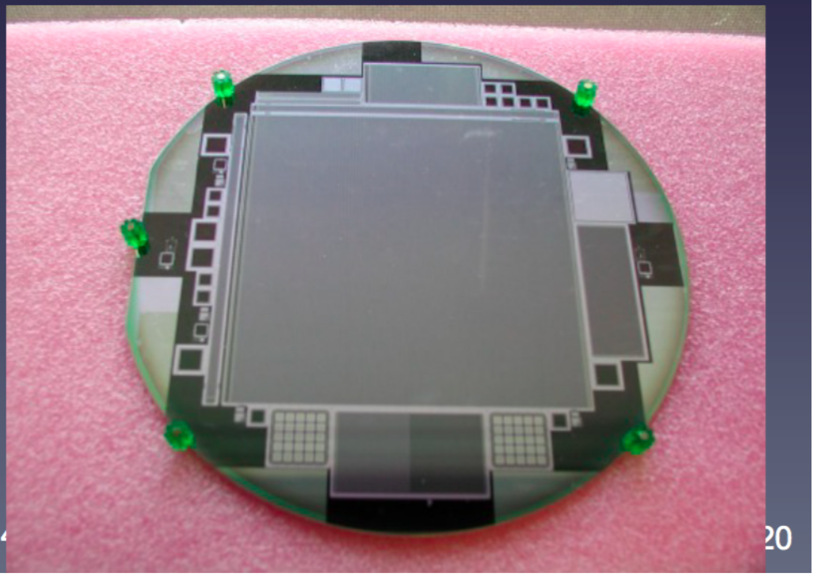
N (e-h) = 11 000/100µm

Position Resolution down to ~ 5µm !

Silicon Strip Detectors (SSD)

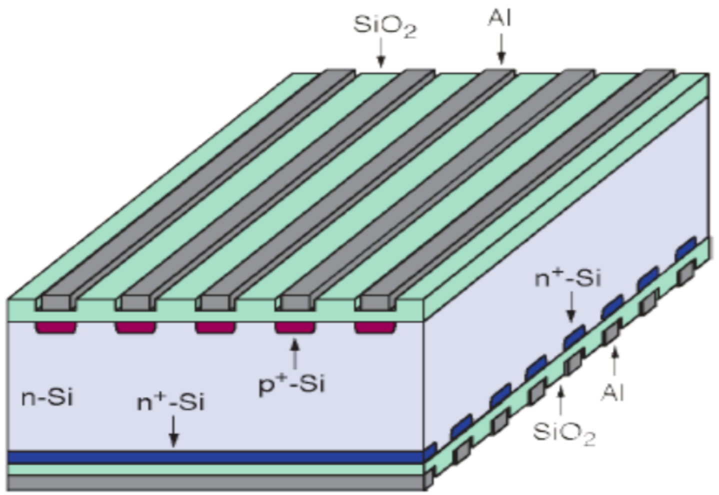
- By segmenting the implant we can reconstruct the position of the traversing particle in one dimension
- DC-coupled strip detector – simplest position sensitive Silicon detector
- Standard configuration:
  - Strips p implants
  - Substrate n doped (~2-10 kΩcm) and ~300μm thick
  - $V_{dep} < 200$ V
  - Backside Phosphorous implant to establish ohmic contact and to prevent early breakdown
- Highest field close to the collecting electrodes (junction side) where most of the signal is induced



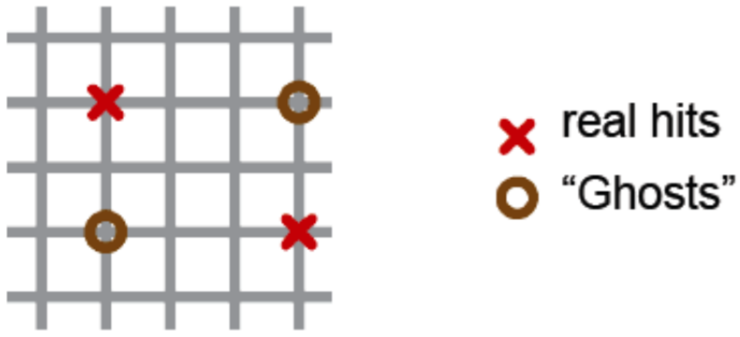


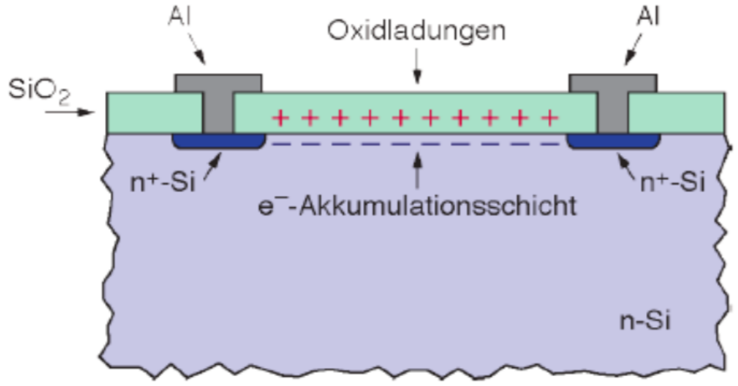
Double Sided Silicon Detectors

- **Advantages:**
  - More elegant for measuring 2 coordinates than using stereo modules
  - Saves material
- **Disadvantages:**
  - Needs special strip insulation of n-side (p-stop, p-spray techniques)
  - Complicated manufacturing and handling procedures
- Expensive
- Ghost hits possible



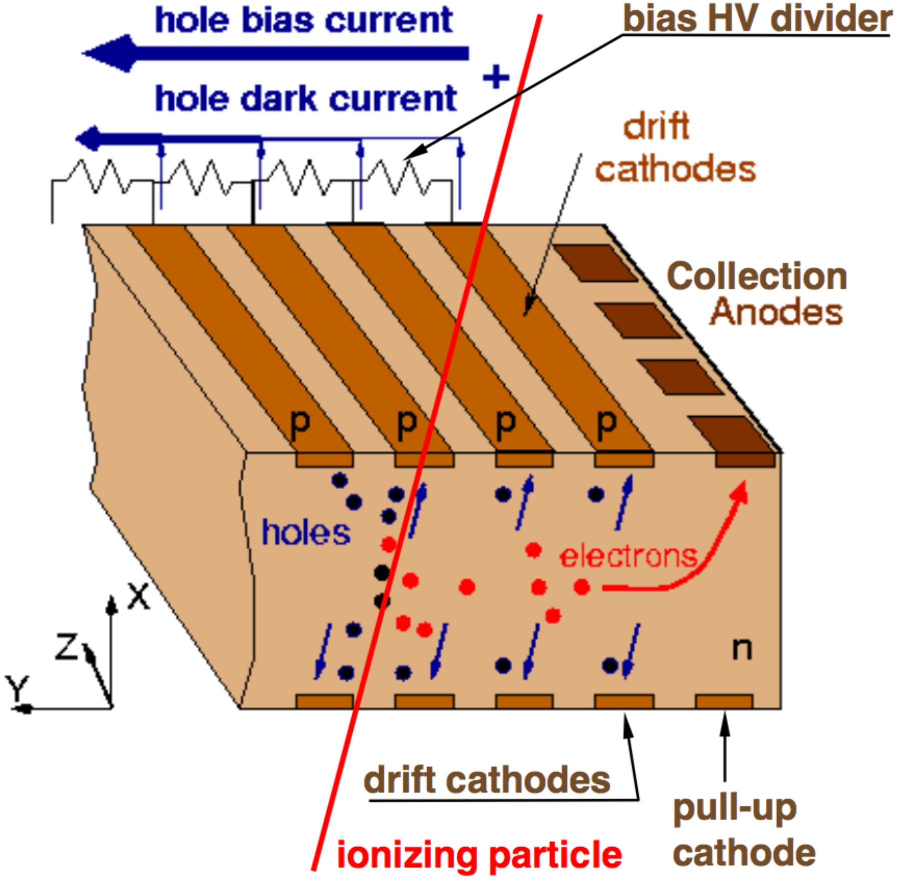
Scheme of a double sided strip detector (biasing structures not shown)

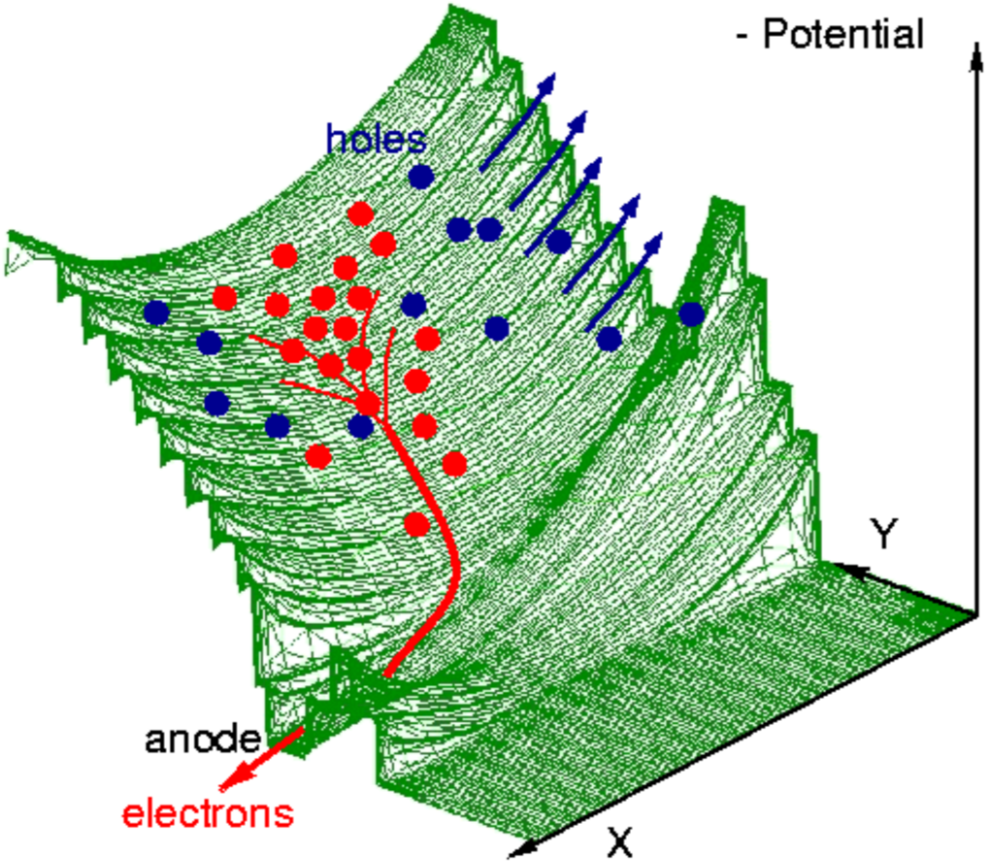




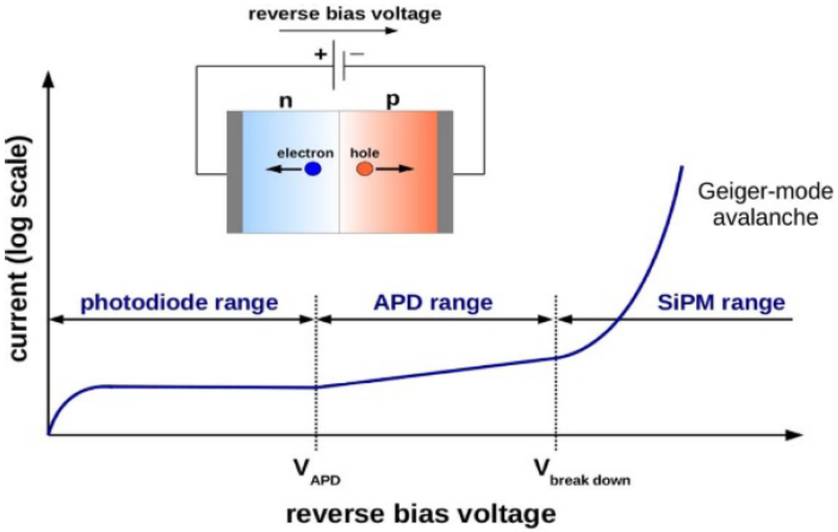
Positive oxide charges cause electron accumulation layer.

Silicon Drift Detector (like gas TPC !)

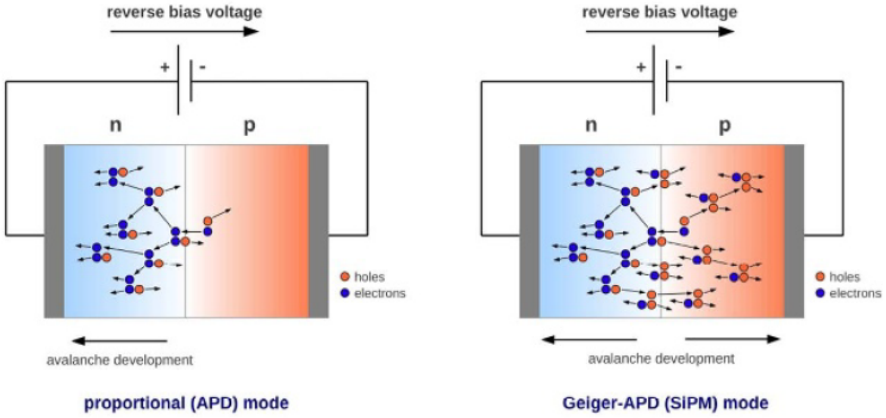




Silicon PMT

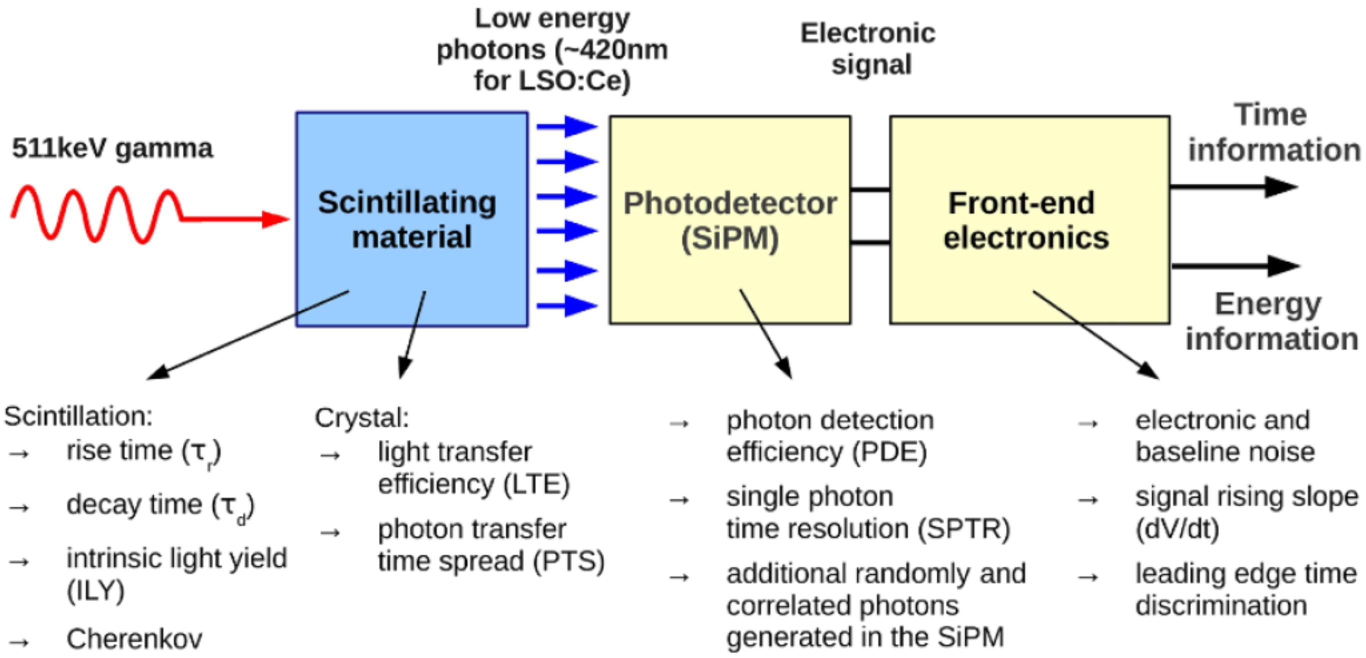


(a)



(b)

Silicon PMT



Low energy photons (~420nm for LSO:Ce)

Electronic signal

511keV gamma

Scintillating material

Photodetector (SiPM)

Front-end electronics

Time information

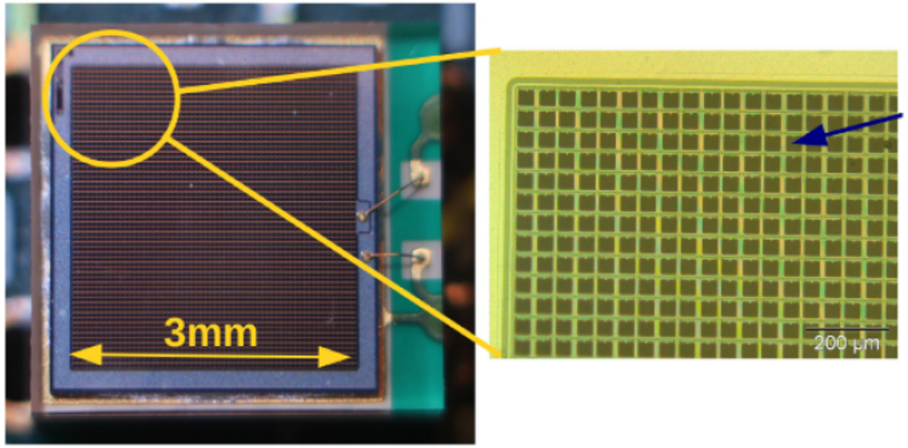
Energy information

Scintillation:
- → rise time (τ_r)
- → decay time (τ_d)
- → intrinsic light yield (ILY)
- → Cherenkov

Crystal:
- → light transfer efficiency (LTE)
- → photon transfer time spread (PTS)

- → photon detection efficiency (PDE)
- → single photon time resolution (SPTR)
- → additional randomly and correlated photons generated in the SiPM

- → electronic and baseline noise
- → signal rising slope (dV/dt)
- → leading edge time discrimination



Swift discoveries

Summary

- Currently >1300 GRBs with a few arc seconds positions from *Swift*/XRT.
- >400 *Swift* GRBs have redshifts (>70% of world total).
- Includes brightest GRB ever seen, and most distant one.

Questions for *Swift*

- Do short GRBs have afterglows, and hence can we locate them more precisely?
- Can we pin down the progenitors?
- Are there new subclasses of GRBs?
- Can we find high-redshift bursts and study the early universe?

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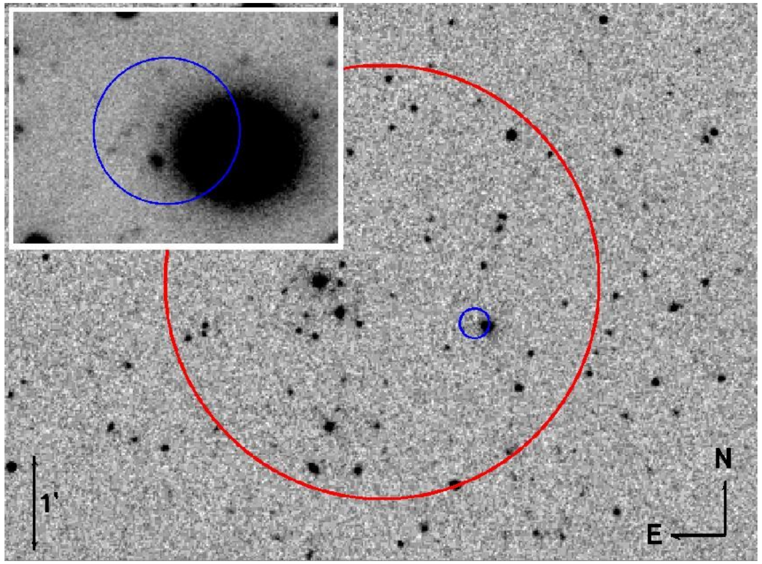
Swift discoveries

Short GRBs.

- GRB 050509B was a short GRB discovered by *Swift*, with an X-ray afterglow reported 2:29 after the trigger.

- Outskirts of an elliptical galaxy.
- Later sGRBs had optical afterglows too.
- Subsequently found in all galaxy types.

VLT image
Hjorth et al.



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Swift discoveries

Progenitors

- Short GRBs found in all types of galaxy – old population (compact merger/magnetar)
- Long GRBs always found in star forming galaxies and regions – deaths of massive stars.

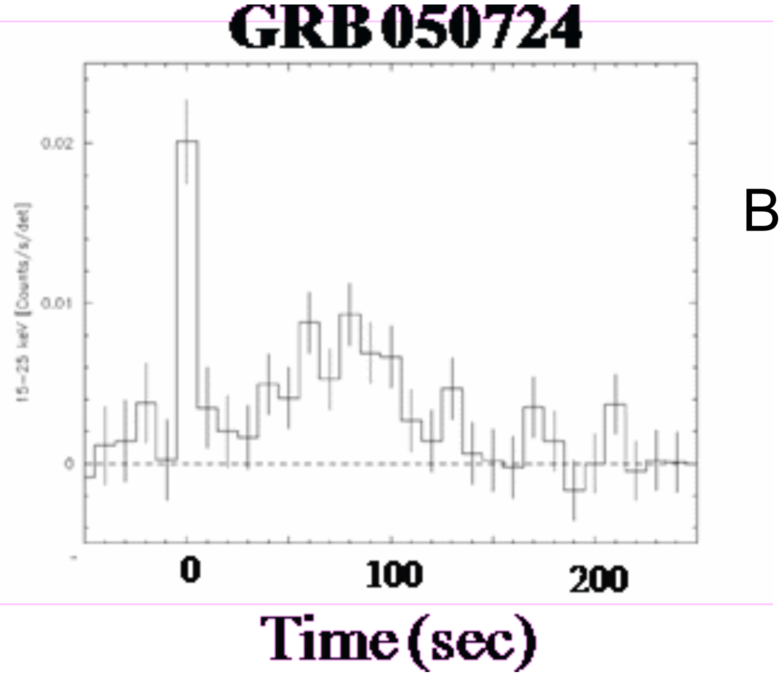
Questions for *Swift*

- Do short GRBs have afterglows, and hence can we locate them more precisely?
- Can we pin down the progenitors?
- Are there new subclasses of GRBs?
- Can we find high-redshift bursts and study the early universe?

Swift discoveries

Short GRB with extended emission

- Blurred the distinction between “short” and “long” bursts, and made it more detector-dependent.



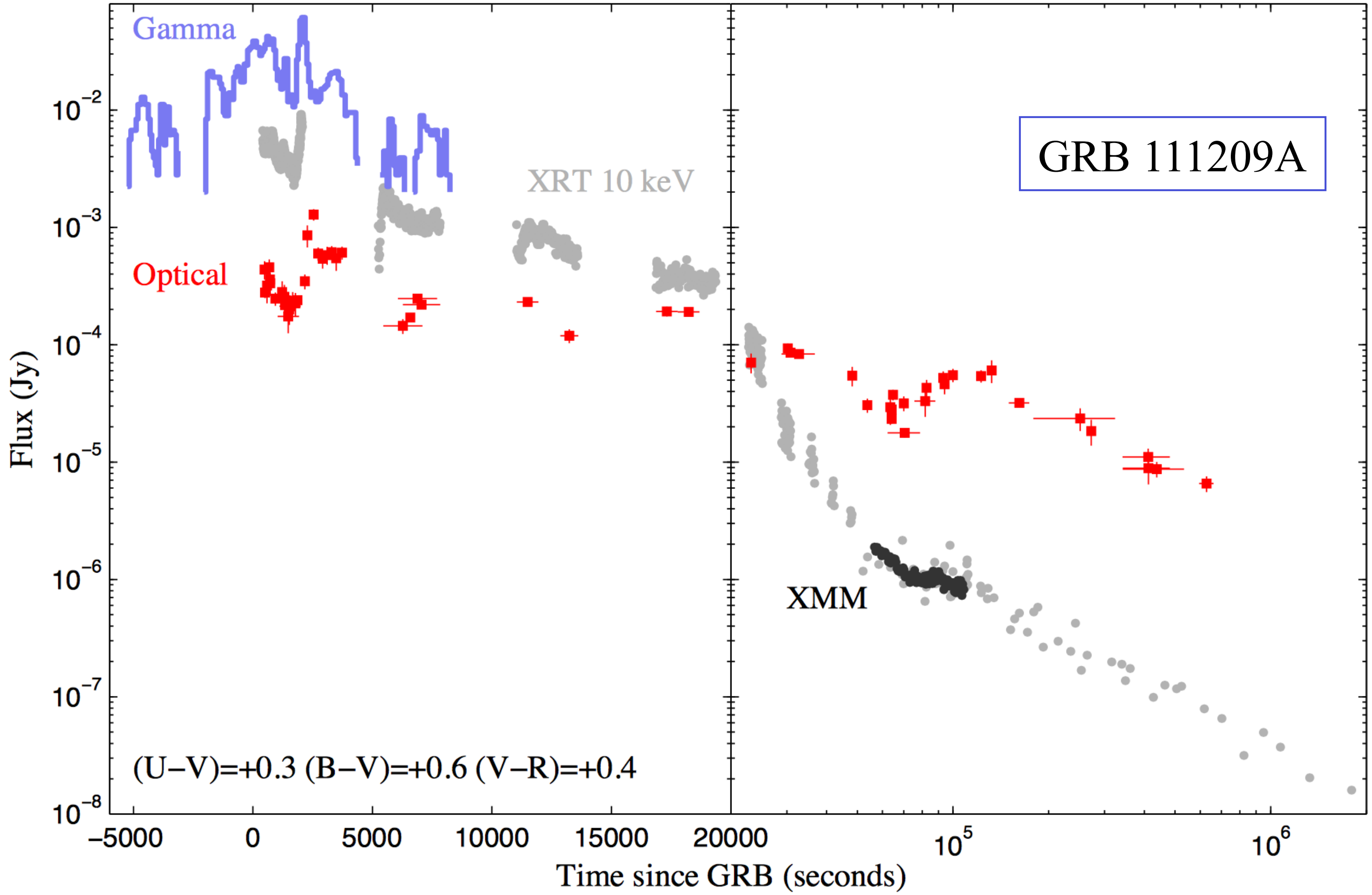
Barthelmy et al. 2005

Swift discoveries

Long GRBs with no SNe

- GRB 060614 and GRB 060505 were nearby, apparently long GRBs, with no related supernova, down to deep limits.
- The GRB taxonomy is clearly more complex than previously thought.
- Maybe a new, progenitor-based classification is needed?

Ultra Long GRBs



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- Do short GRBs have afterglows, and hence can we locate them more precisely?
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- Are there new subclasses of GRBs?
- Can we find high-redshift bursts and study the early universe?

Swift discoveries

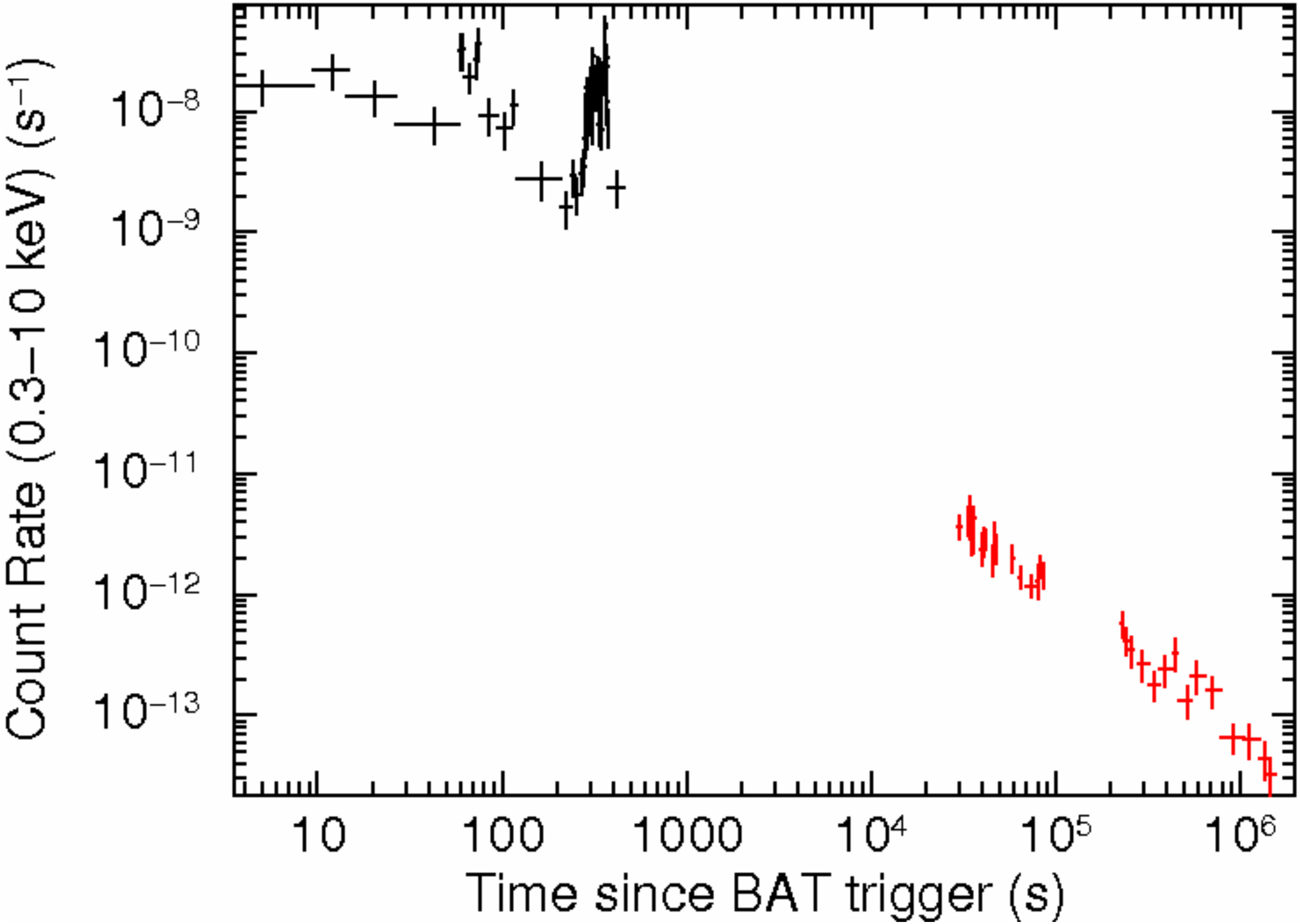
High redshift bursts

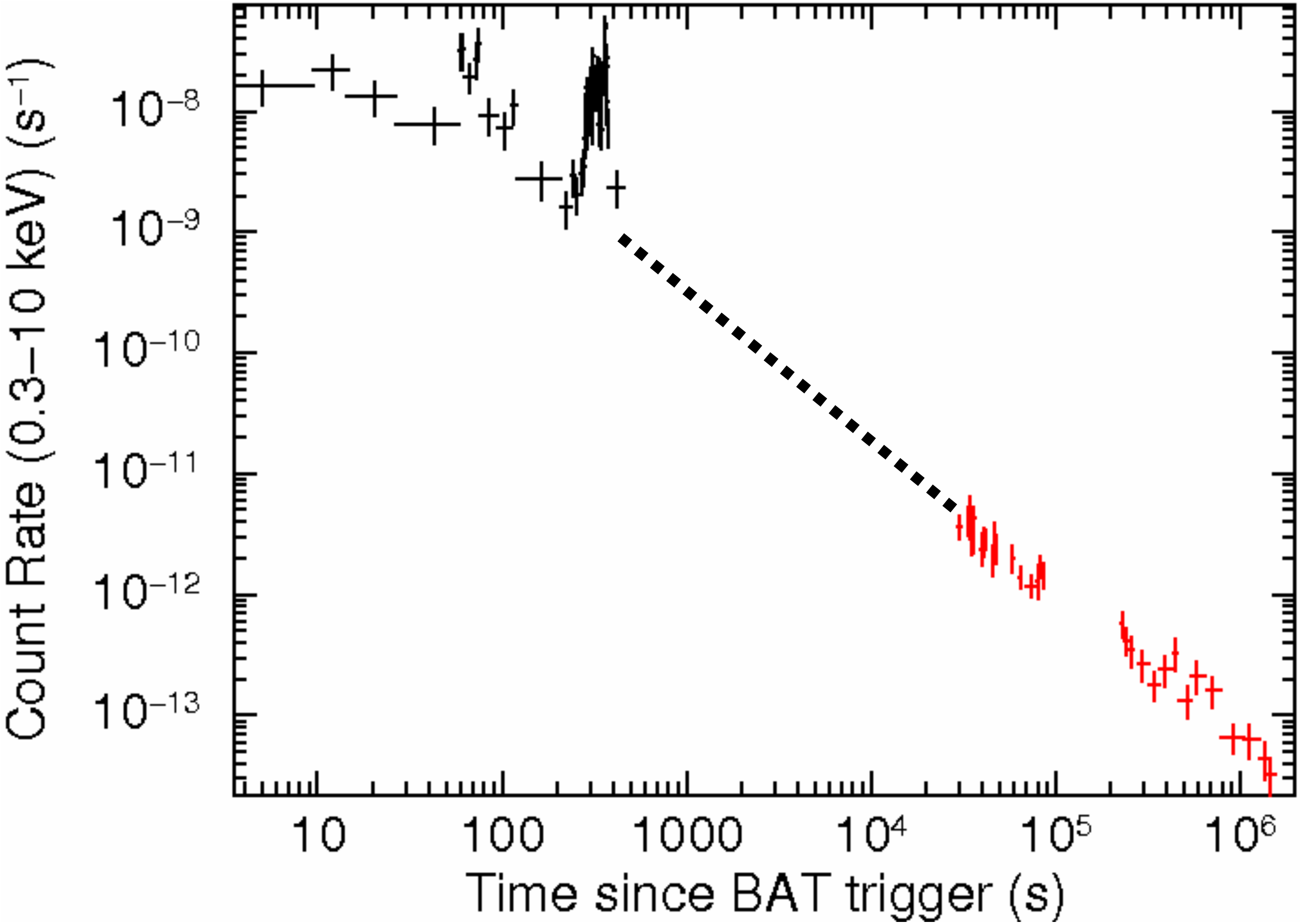
- 17 GRBs observed by *Swift* have $z>3.5$
- 10 have $z>4$, and 5 have $z > 5$ – a large, rapidly growing population of distant objects.
- GRB 050904 was at z=6.29 (Cusumano et al. 2007)
- GRB 080913 was at z=6.7, and was a fainter-than-normal burst! (Greiner et al. 2009)
- GRB 090423 was at z=8.26 !!!!
- GRB 090429B was at z=9.2 !!!!!!

Questions from *Swift*

New mysteries

- Complex X-ray afterglows.
- X-ray flares
- Jet breaks?
- Why do the different types of GRB have such similar afterglows?
- Why is the ambient medium (apparently) constant-density, not WR-wind type environment?
- What are the microphysics parameters?


Count Rate (0.3–10 keV) (s^{-1})
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10
100
1000
10^{4}
10^{5}
10^{6}
Time since BAT trigger (s)



Count Rate (0.3–10 keV) (s^{-1})
10^{-8}
10^{-9}
10^{-10}
10^{-11}
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100
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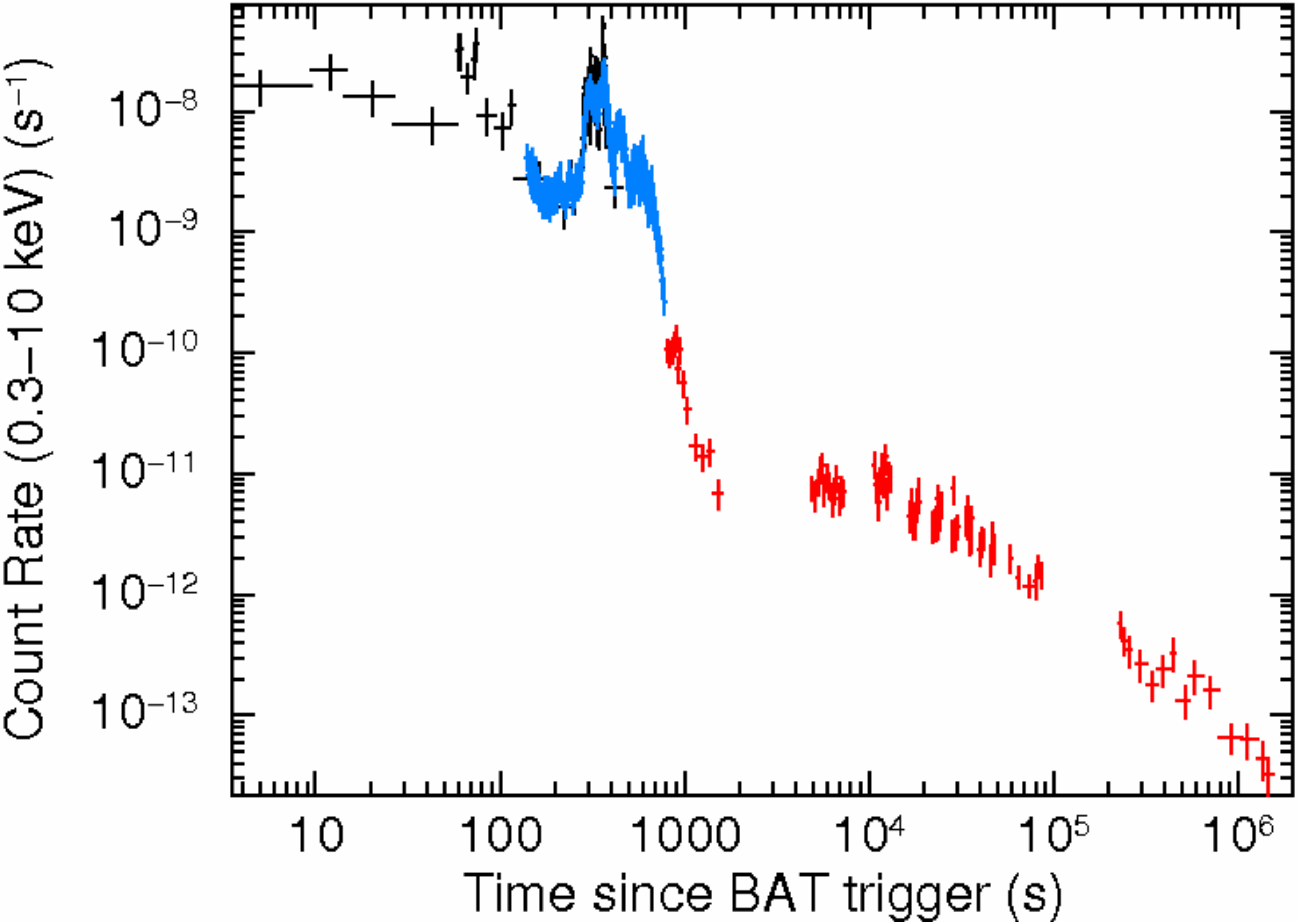
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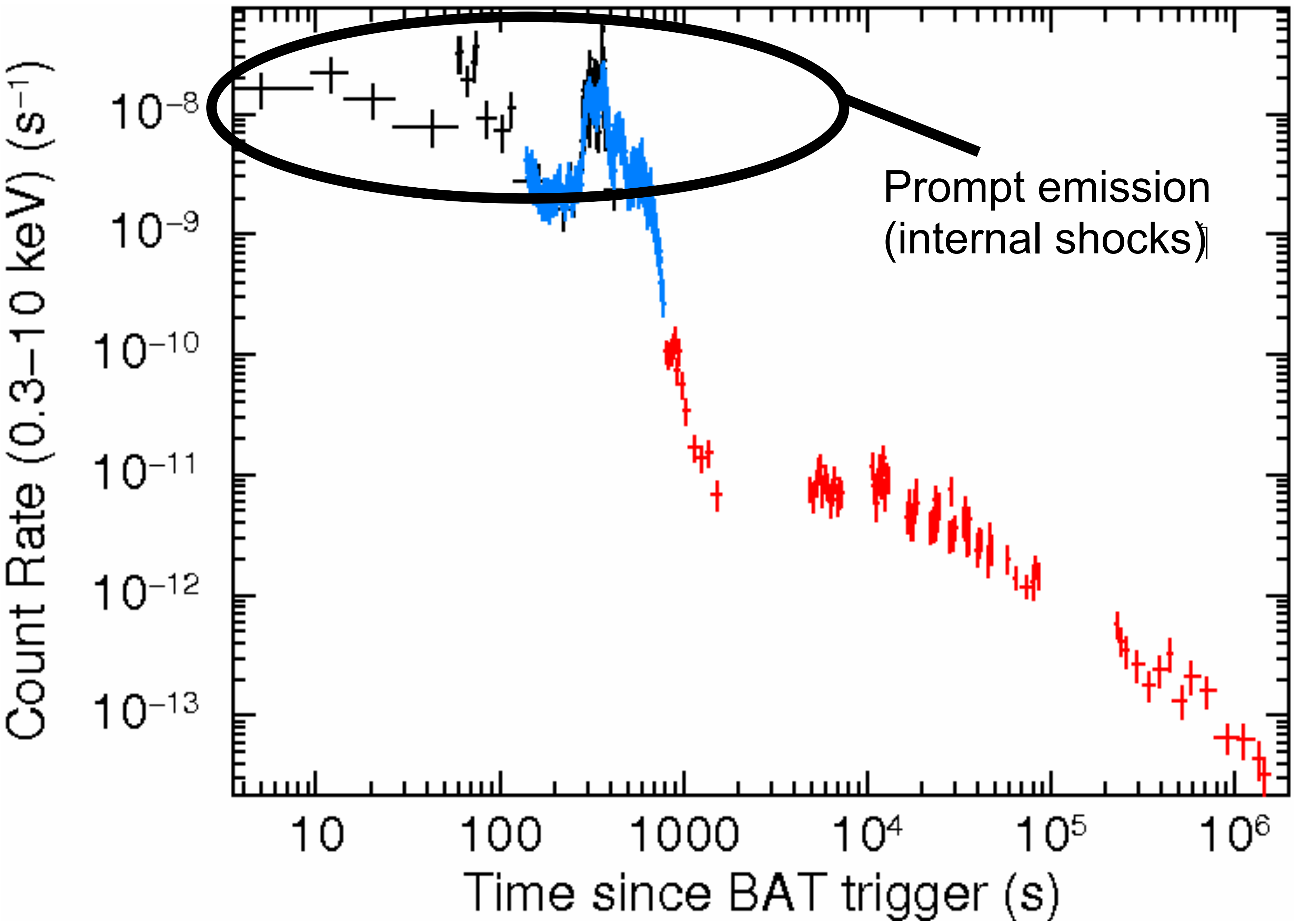
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10
100
1000
10^{4}
10^{5}
10^{6}
Time since BAT trigger (s)

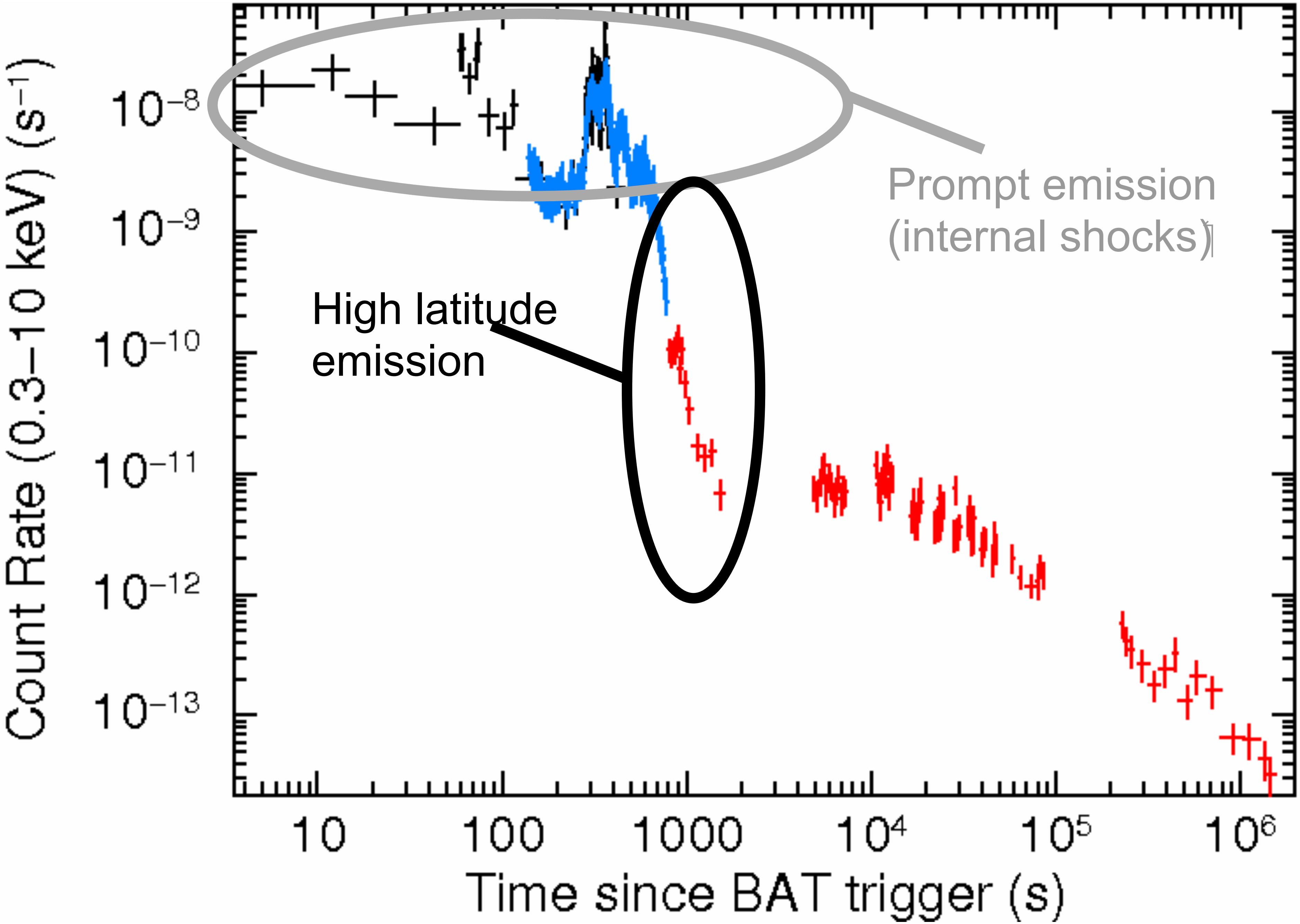
Swift discoveries

Complex X-ray light curves

- Most X-ray afterglows don't show the simple power-law decay seen at late times.
- The “canonical” light curves has 3 phases:

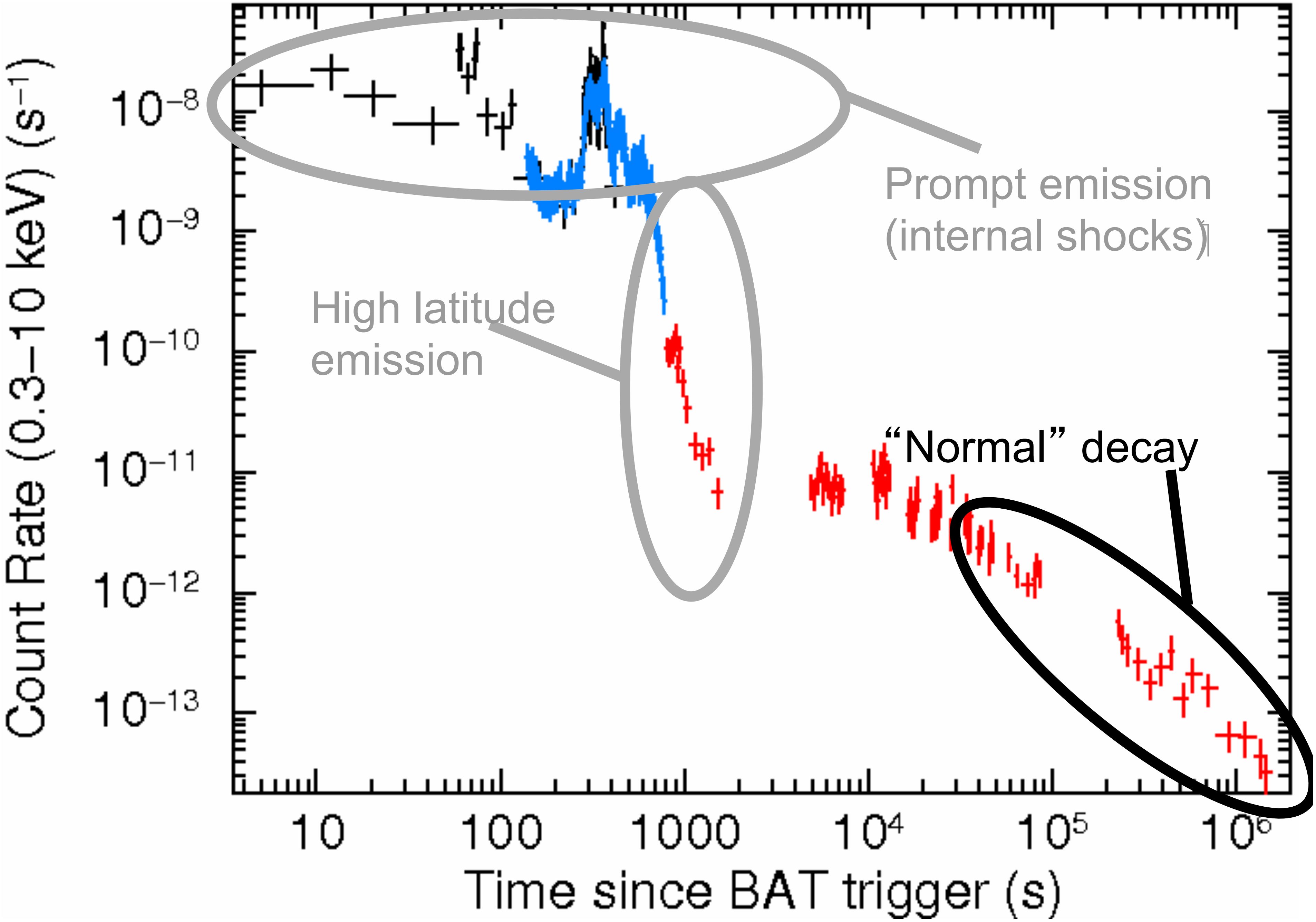


Prompt emission
(internal shocks)



Prompt emission (internal shocks)

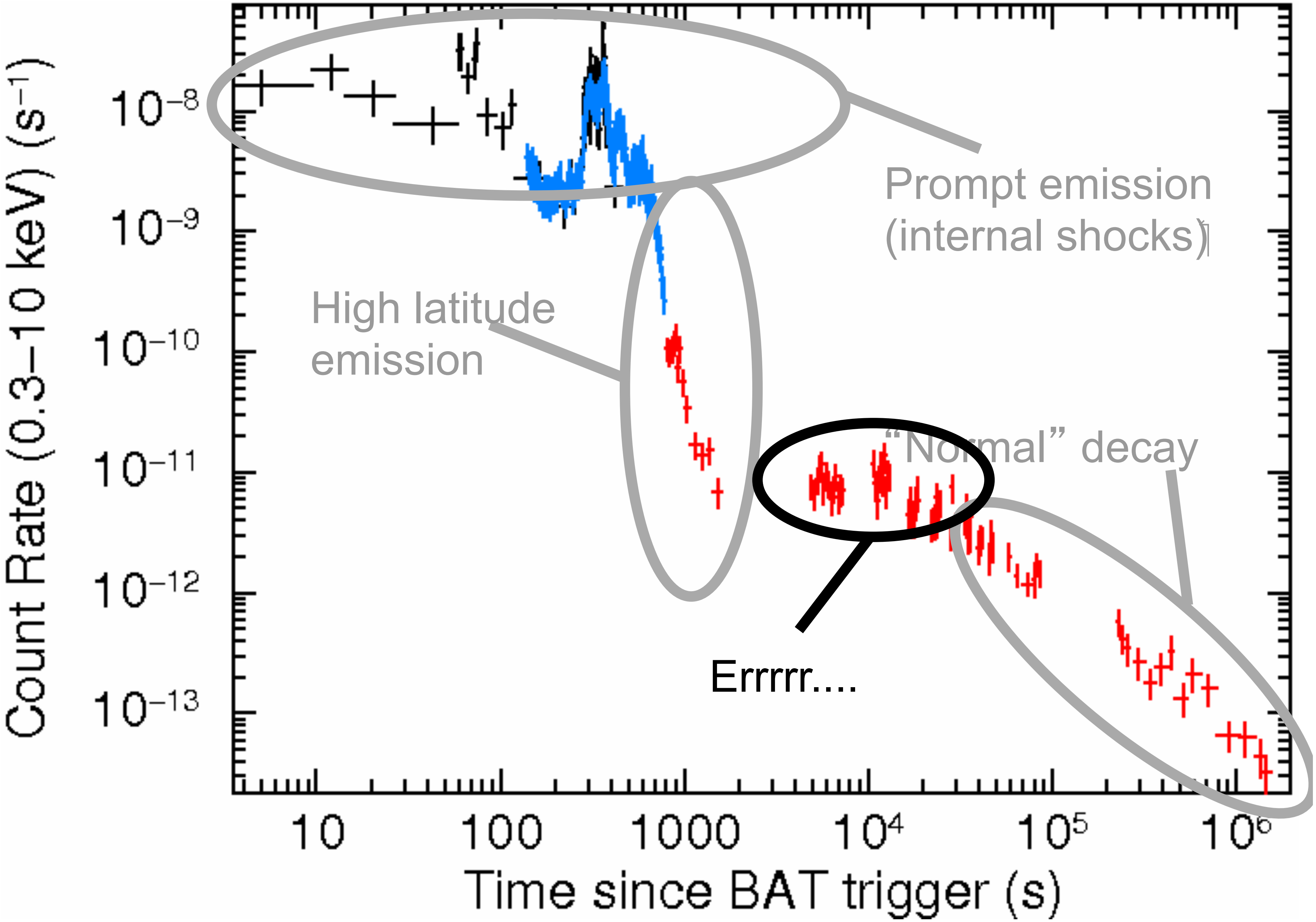
High latitude emission



Prompt emission (internal shocks)

High latitude emission

"Normal" decay



Prompt emission (internal shocks)

High latitude emission

"Normal" decay

Errrrr....

Swift discoveries

Shallow decay phase

- Energy injection? (Zhang et al 2006). *But it has to go on for ~1 day.*

- Dust? [models light curves really well – Shao & Dai (2007). *But not the spectra (Shen et al. 2009)*.

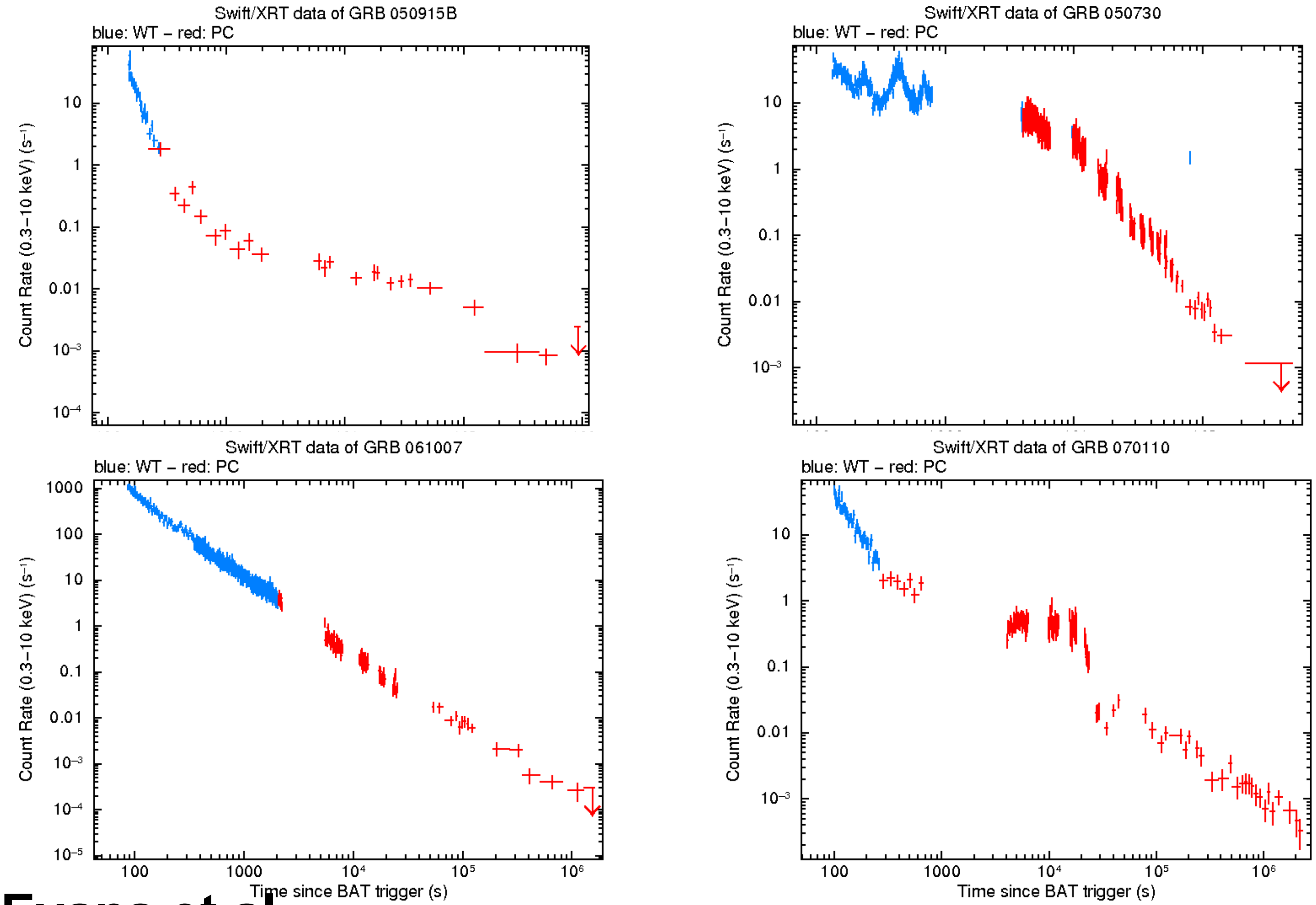
- Upscattered forward shock emission?

- Long-lived central engine (i.e. internal shock emission).

- And more....

Swift discoveries

Complex X-ray afterglows



Evans et al. 2009

Questions from *Swift*

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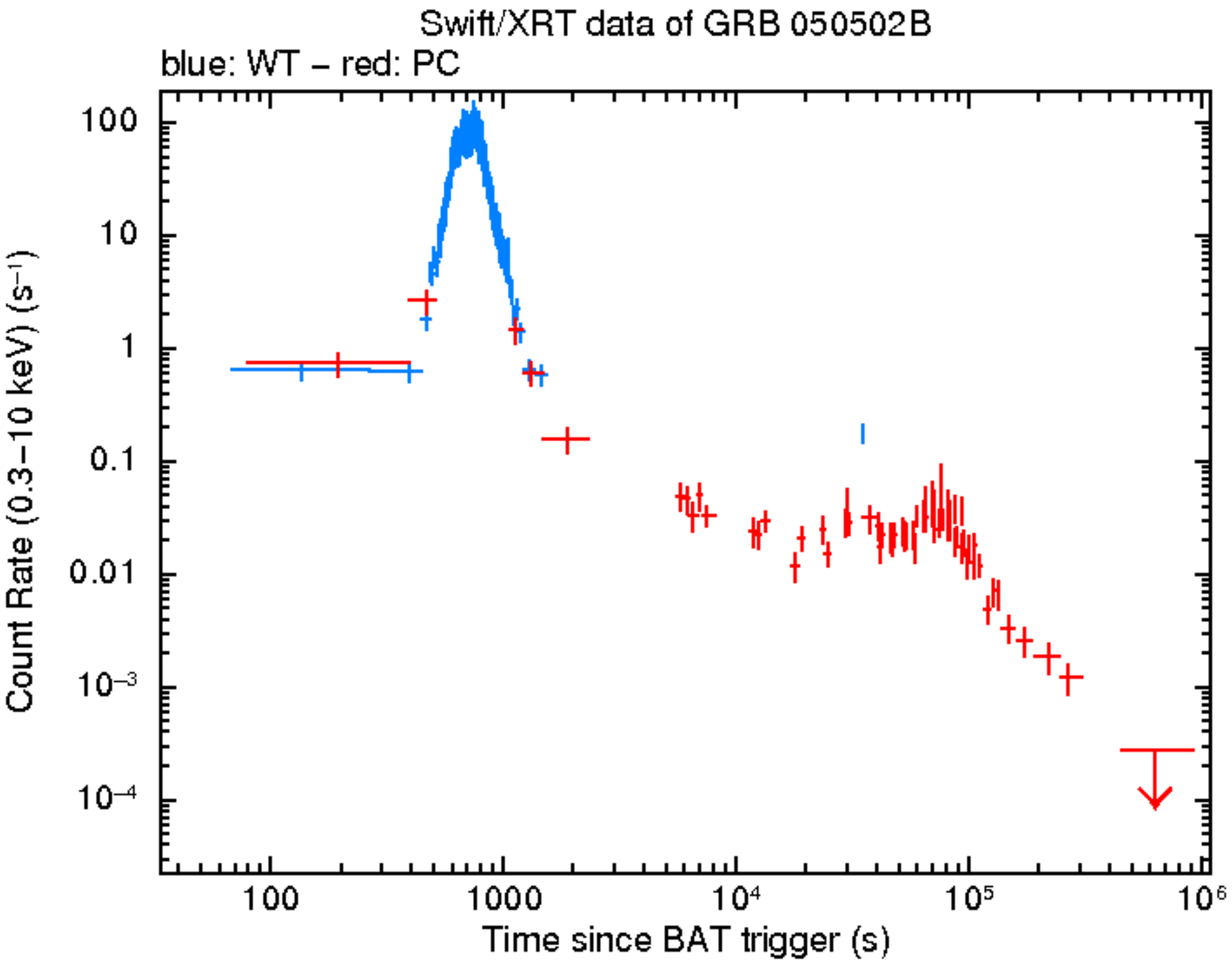
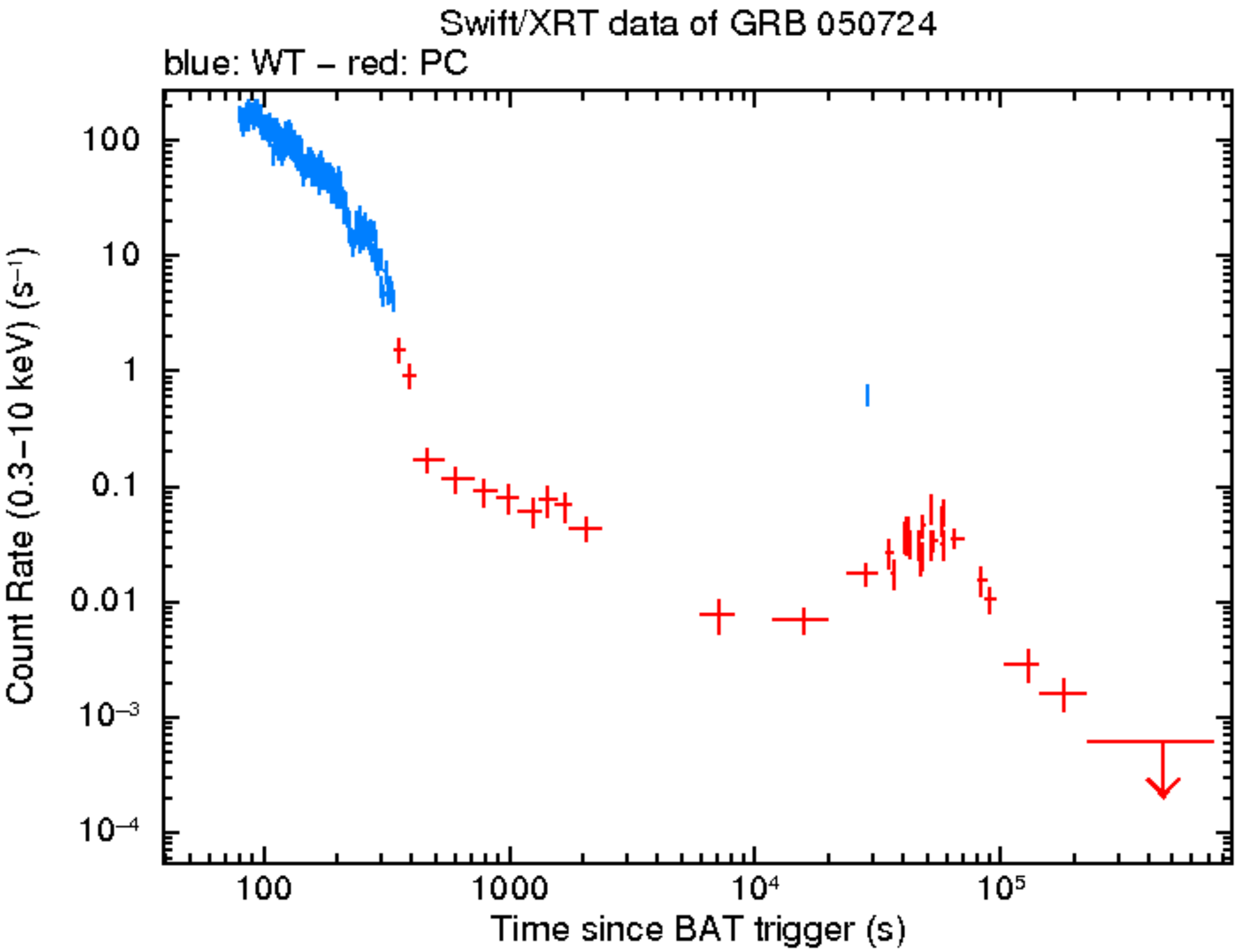
- What are the microphysics parameters?

Swift discoveries



Swift discoveries



Questions from *Swift*

New mysteries

- Complex X-ray afterglows.
- X-ray flares
- Jet breaks?
- Why do the different GRBs have such similar afterglows?
- Why is the ambient medium (apparently) constant-density?
- What are the microphysics parameters?

Swift discoveries

Where are the jet breaks?

- Strong, achromatic light curve steepening was expected in most/all GRBs – it's now exciting if we think we've got one!
- They could be hidden (Curran et al. 2008), or we're not considering enough possibilities (Racusin et al. 2009)
- Perhaps the jets are structured/complex, so breaks are not achromatic? (e.g. Oates et al. 2007, de Pasquale et al. 2008).

Swift discoveries

GRB 080319B

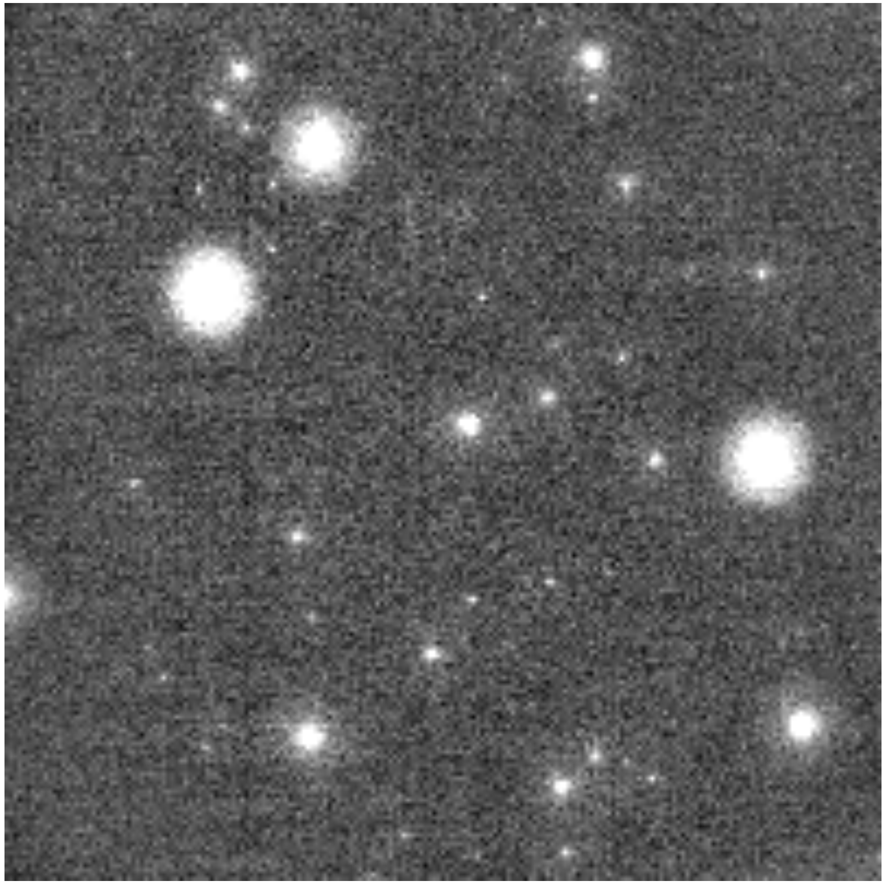
- Very bright – reached m_v=5.3.

Swift discoveries

GRB 080319B

- Very bright – reached m_v=5.3

Image from Pi of the sky.



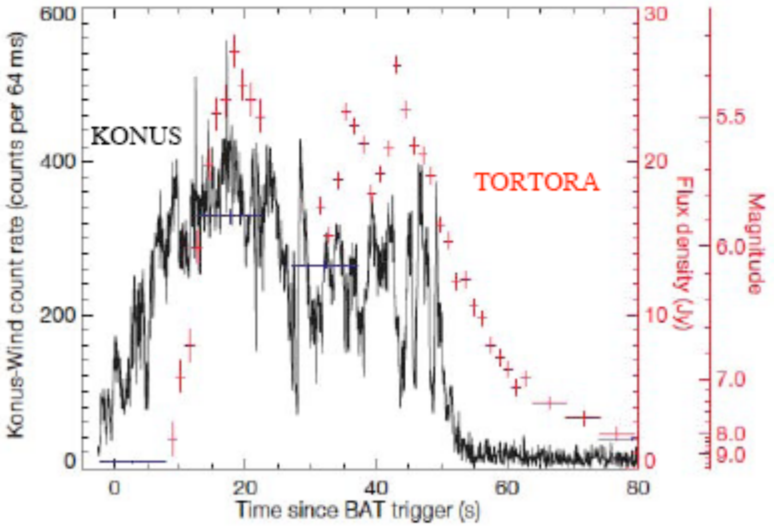
Swift discoveries

GRB 080319B

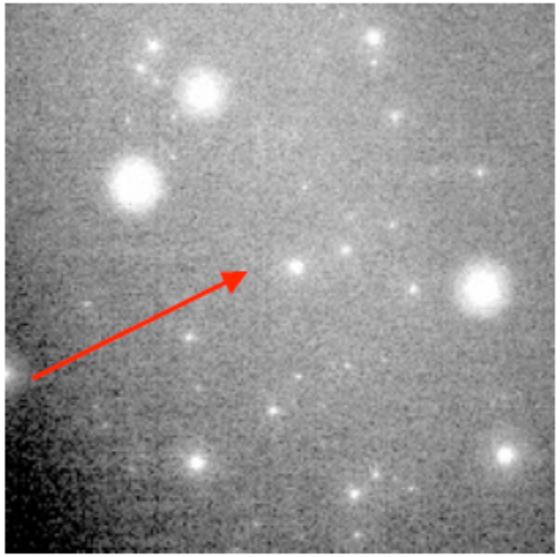
- Very bright – reached m_v=5.3
- z=0.9
- If it were at the Galactic centre, it would appear as bright as the Sun!
- Bright in X-rays and Gamma-rays, but nothing like as extraordinary as in the optical.
- Implies a complex jet structure (Racusin et al. 2008, Nature).

080319B

First "naked-eye" Burst GRB 080319B



Racusin et al.
2008



Pi-of-the-Sky

T90 = 50s   z = 0.94

Prompt optical observations:

Pi-of-the-Sky (Chile) pre-burst
RAPTOR (New Mexico)
REM/TORTORA (Chile)

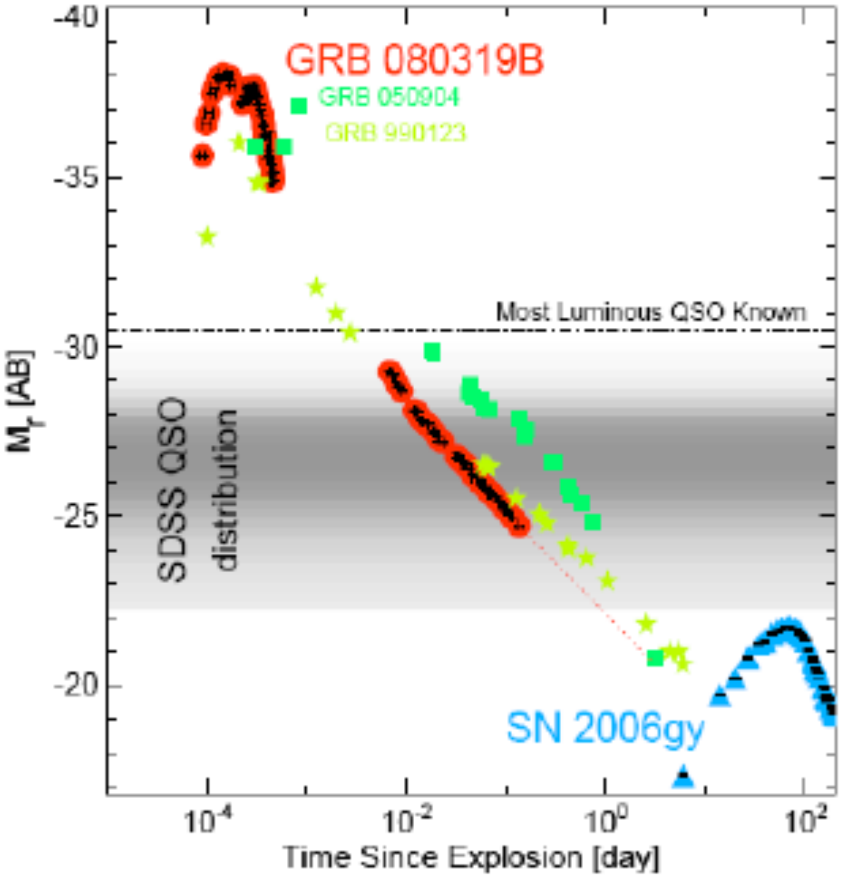
Peak brightness of 5.6 magnitudes!!

080319B

Even corrected for distance, brightest optical burst

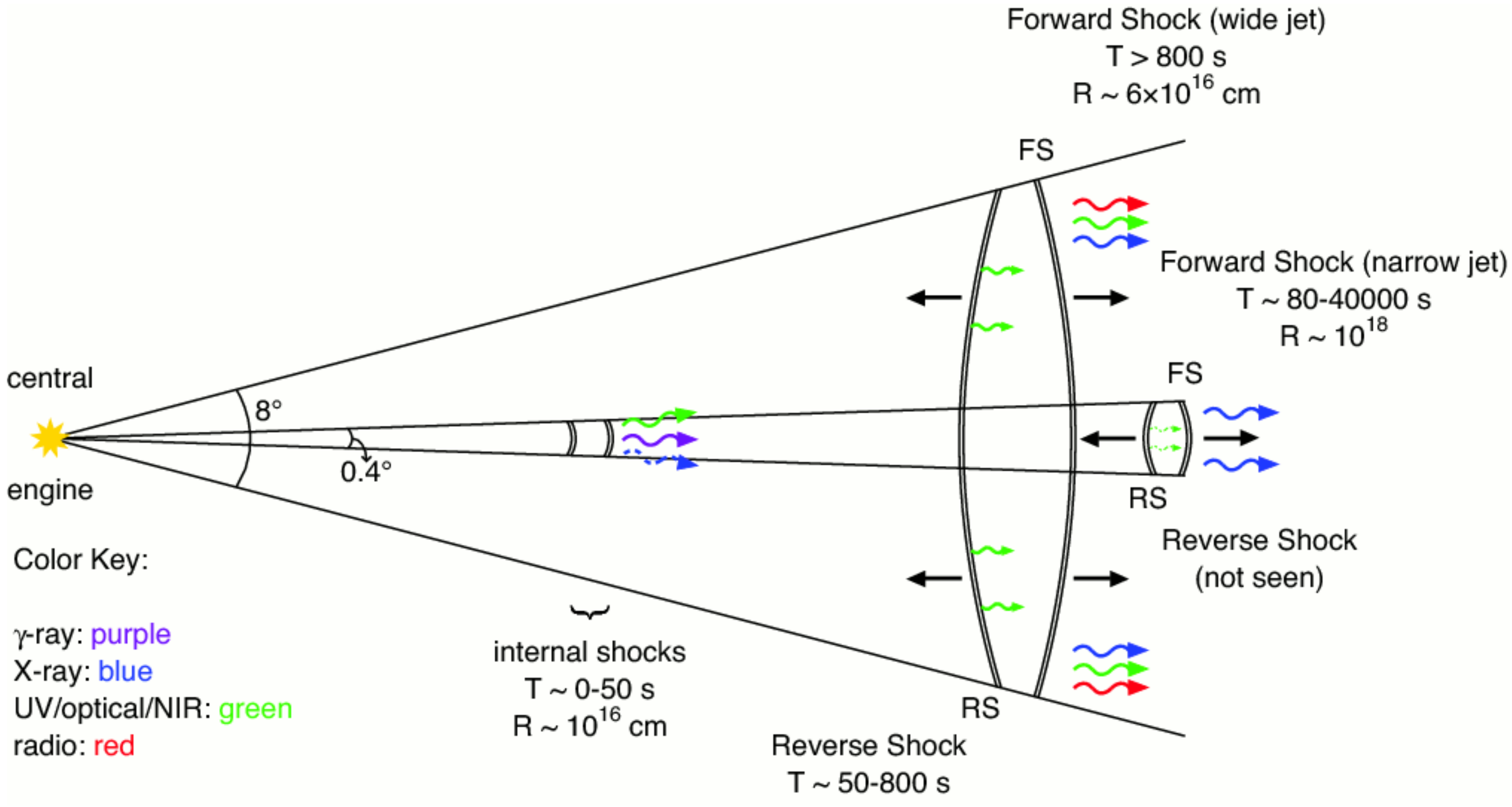
In our Galaxy, such a burst would be brighter than the sun!

GRBs much more luminous than most energetic quasars & SNe



Bloom et al. 2008

Swift discoveries



Forward Shock (wide jet)
T > 800 s
R ~ 6×10^{16} cm

FS

Forward Shock (narrow jet)
T ~ 80-40000 s
R ~ 10^{18}

FS

central
engine

8°

0.4°

RS

Reverse Shock
(not seen)

Color Key:

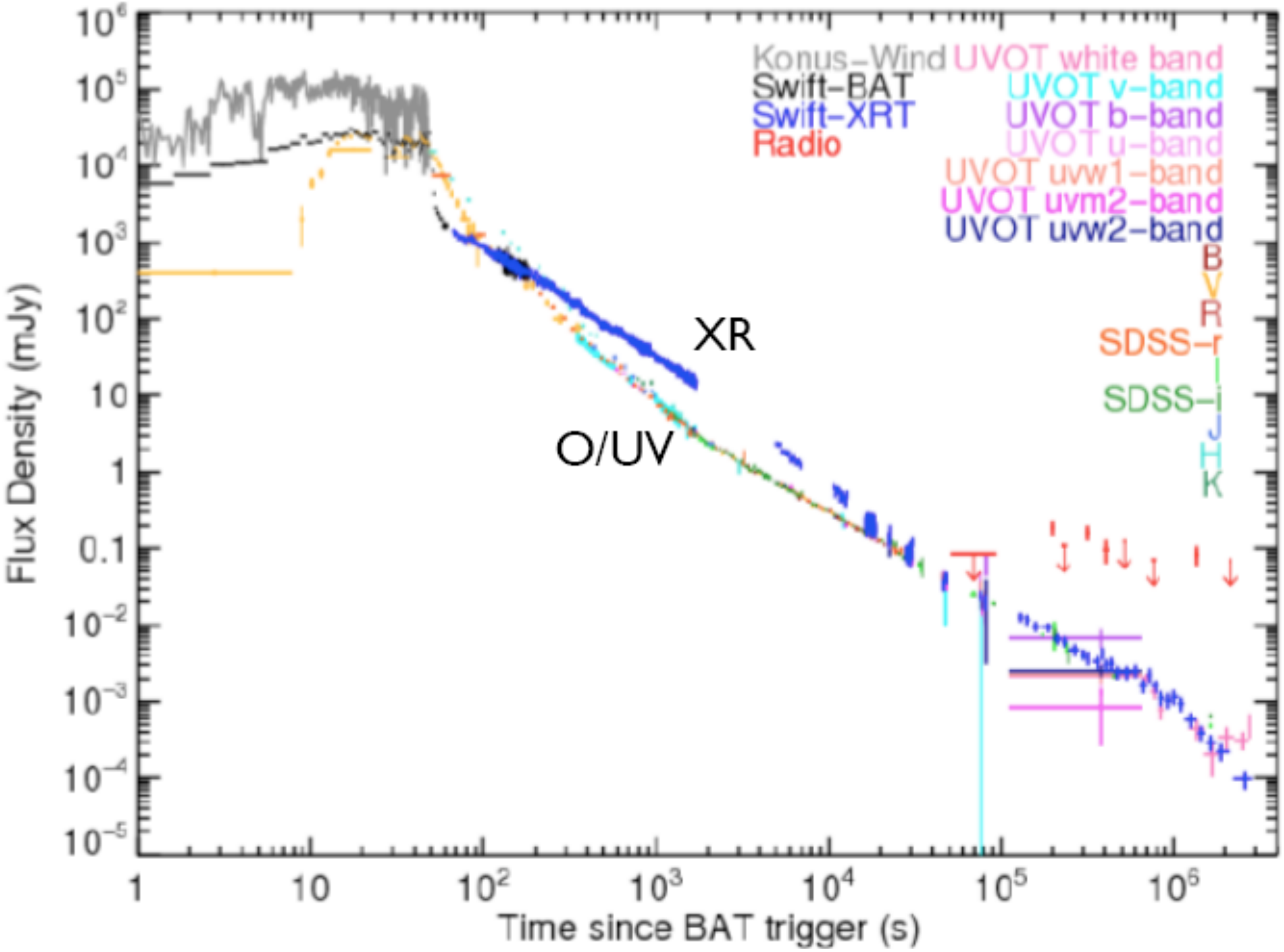
γ-ray: purple
X-ray: blue
UV/optical/NIR: green
radio: red

internal shocks
T ~ 0-50 s
R ~ 10^{16} cm

RS

Reverse Shock
T ~ 50-800 s

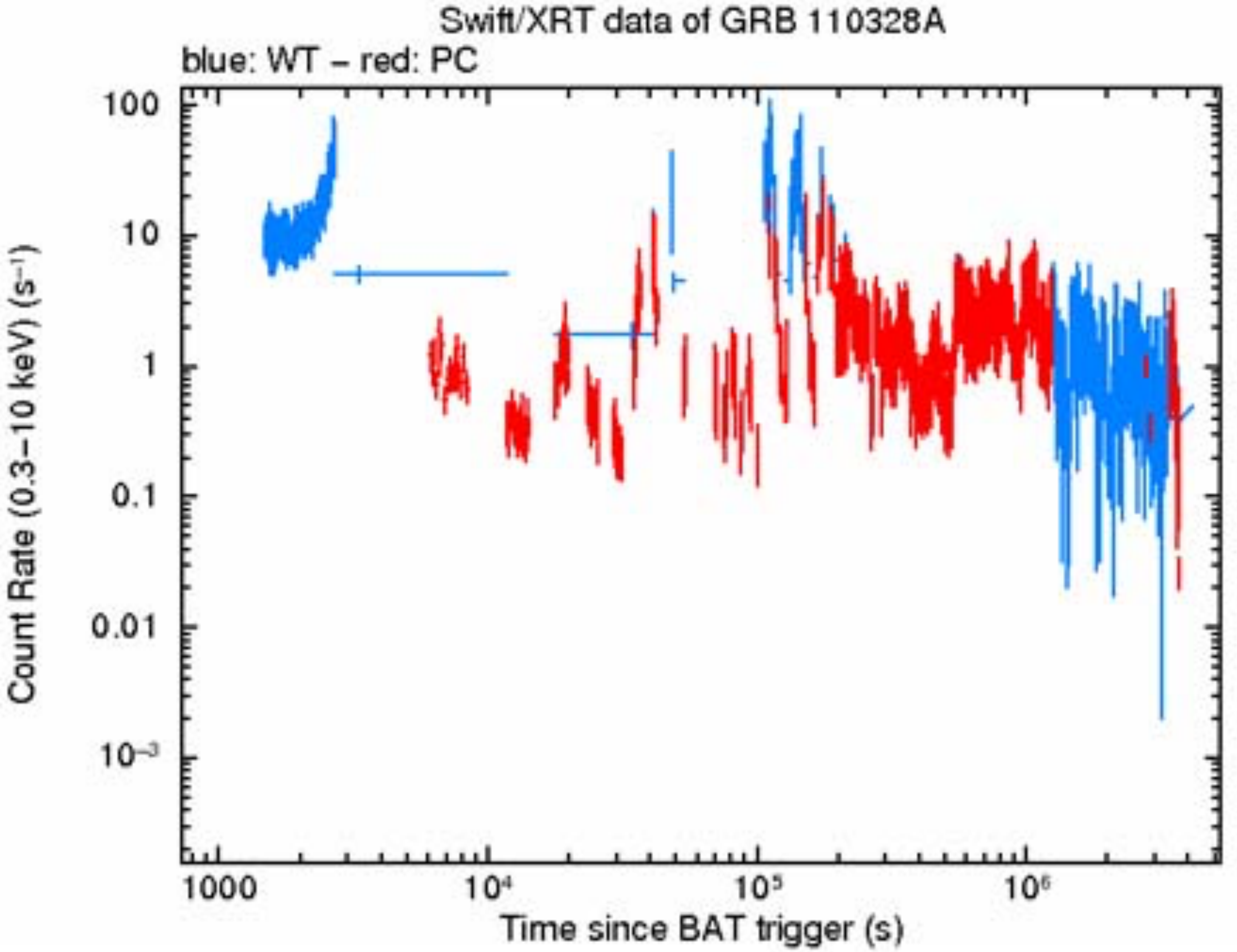
080319B


Konus-Wind
Swift-BAT
Swift-XRT
Radio
UVOT white band
UVOT v-band
UVOT b-band
UVOT u-band
UVOT uvw1-band
UVOT uvm2-band
UVOT uvw2-band
B
V
R
SDSS-r
I
SDSS-i
J
H
K
XR
O/UV
Flux Density (mJy)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Time since BAT trigger (s)
1
10
10^2
10^3
10^4
10^5
10^6

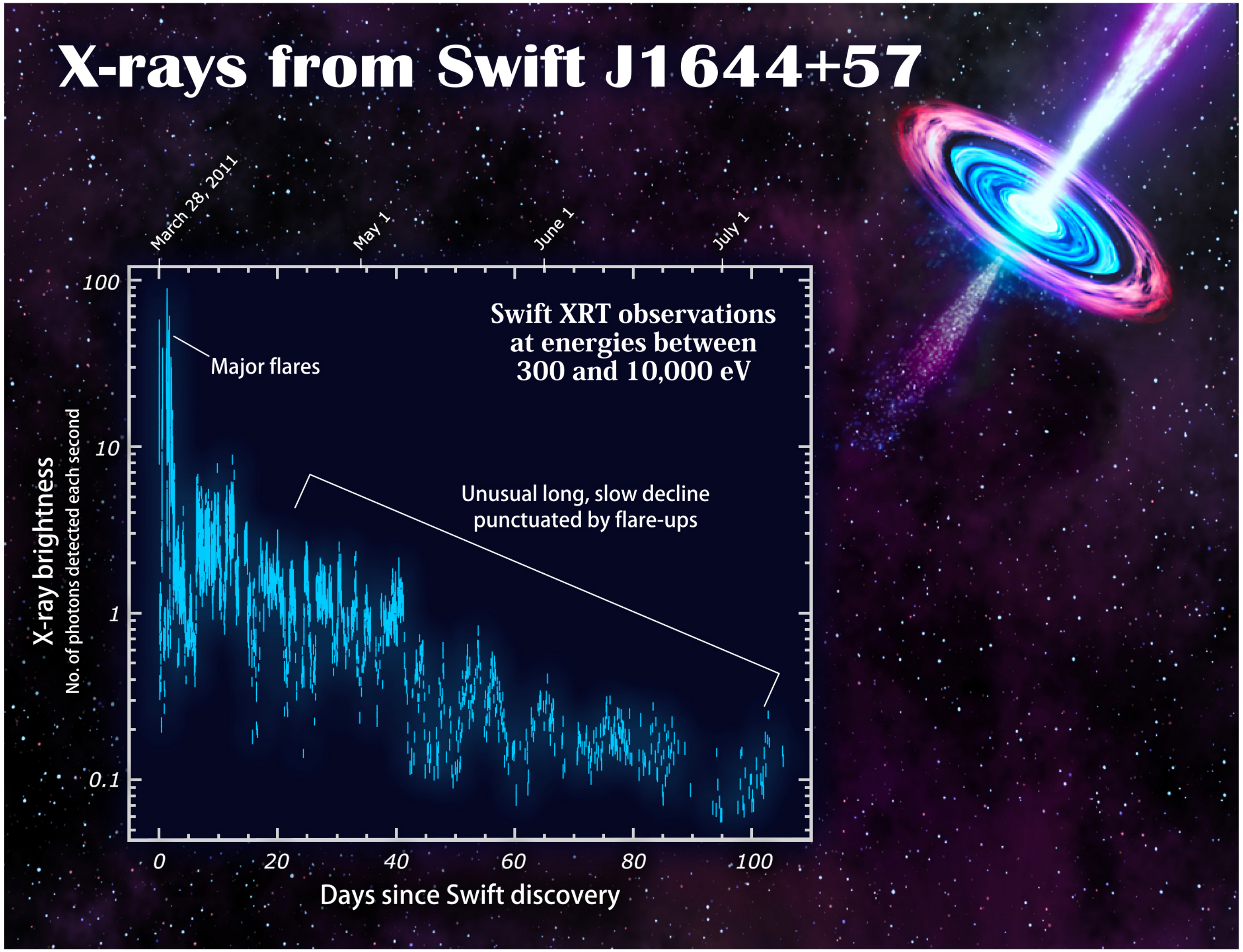
Summary

- *Swift* has helped to answer some questions:
  - Localised short GRBs
  - Supported collapsar and compact merger progenitor models.
- Asked a load of new questions!
  - What are the subtypes?
  - How do we get X-ray afterglows? And flares?
  - What is the jet structure?

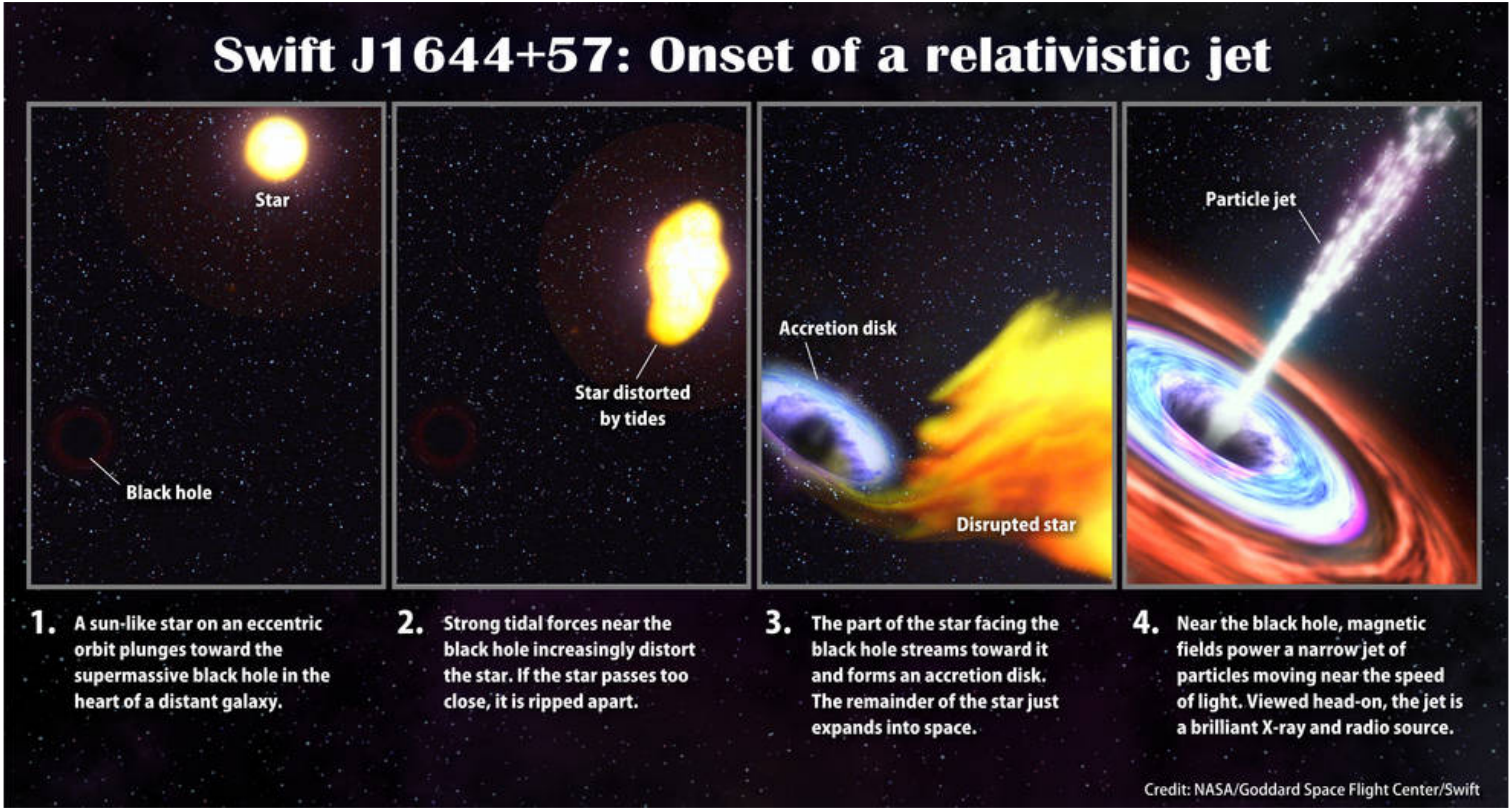
A peculiar GRB?



A peculiar GRB?



A peculiar GRB?



Exercise #3

- Check and navigate into Swift web sites
- Check the recently launched mission Einstein Probe
- Check what SVOM and Theseus missions will be …