# Brennpunkte extragalaktischer Forschung

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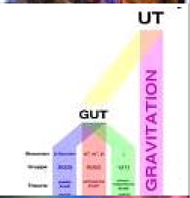
# Distanzrekord für Galaxienhaufen: 1.9

- Kombination der Daten von Chnadra, optischen und infrarot Teleskopen
- Entfernung von 10.2 Milliarden Lj
- Universum hatte 25% seines jetzigen Alters
- JKCS041
- Die größten gravitationell gebundenen Systeme im All
- Chandra: heißes Gas zw. den Galaxien
- „Tyrannosaurus Rex“, älter als alle bekannten Galaxienhaufen

# Dieses Semester: Programm

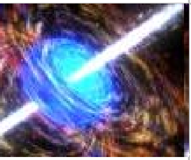



- **Heute: Die Themen des Semesters – Überblick**
- **30.10. Gamma-Ray Bursts**
- 13.11. GUT & TOE (Stringtheorie, etc.)
- 27.1l. LHC & HIGGS
- 11.12. Inflation

Winterferien: 23.12.-06.01.10

- 08.01.10 Vor dem Urknall
- 22.01.10 Zeit & Lichtgeschwindigkeit
- 05.02.10

# Das Programm für heute

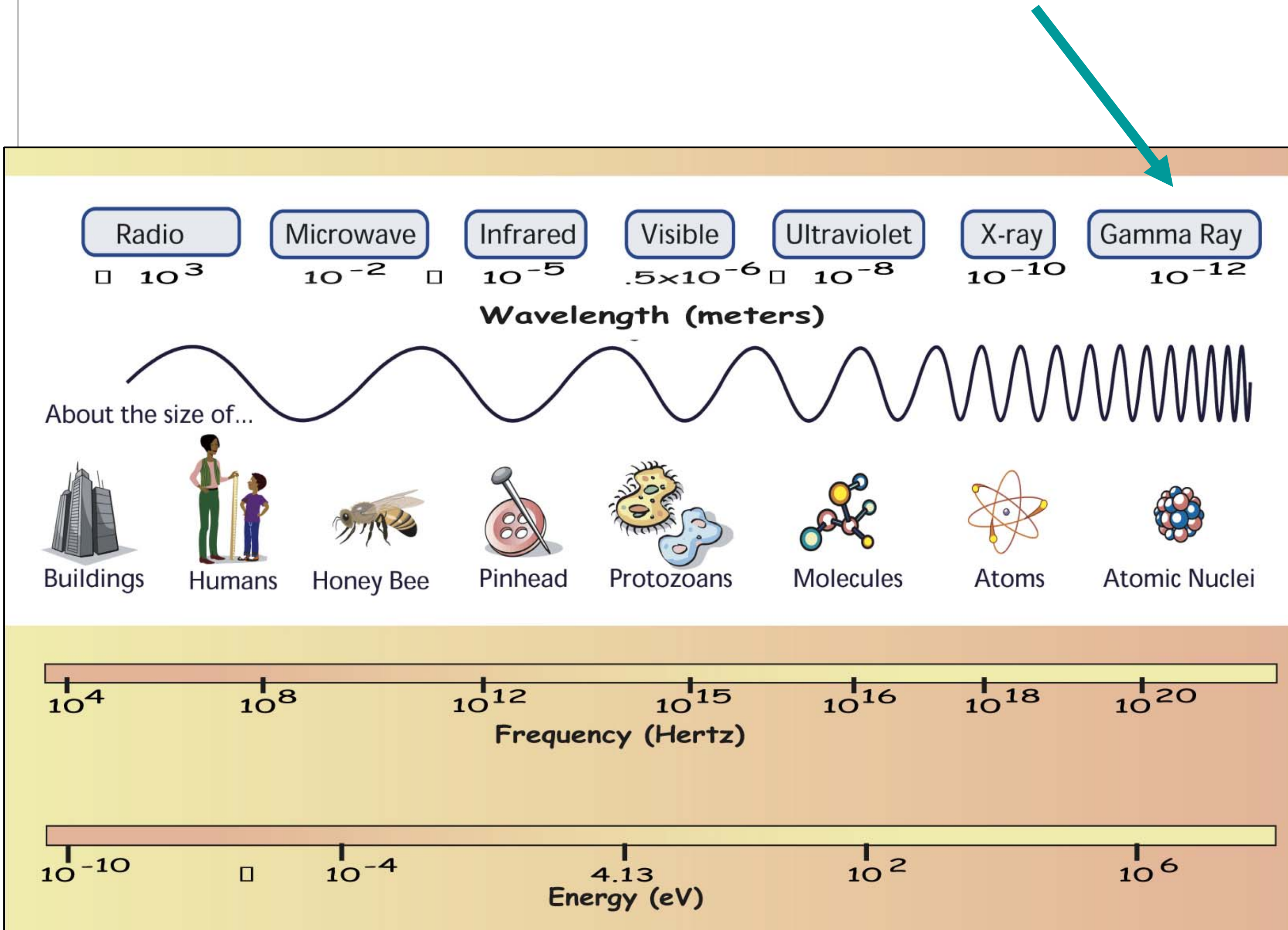


- **30.10. Gamma-Ray Bursts**

- Die Geschichte ihrer Entdeckung
- Die verschiedenen Arten
- Die Energiebilanz
- Was verursacht die verschiedenen Typen? Wie unterscheiden sie sich?
- Wie werden sie beobachtet? (Fermi, Swift, etc.)
- Sterne und Schwarze Löcher
- Kosmologische Implikationen:Gamma-ray bursts in den Frühphasen des Universums – wann gab es die ersten Schwarzen Löcher, die ersten Sterne?
  - Die Sensation – das am weitesten entfernte Objekt im Universum – ein GRB!!!
- etc.

# GRBs
# - eine kurze Einführung

# Gamma rays: E > $10^6$ eV



# Geschichte der Gamma-Astronomie

- 1950er: Vorhersagen über Gammastrahlenemission unserer Galaxis
- 1962: Mit Ranger-3 wird die diffuse Gamma-Hintergrundstrahlung entdeckt
- 1967: Die Satelliten Vela 4a und b beobachten den ersten Gamma-Ray Burst
- 70er-90er: Diverse Teleskop, Ballon oder Satelliten gestützte Experimente (COS-B, Whipple …)
- 1991: CGRO wird gestartet. An Bord:
  - BATSE – Burst And Transient Source Experiment
  - OSSE – Oriented Scintillation Spectrometer Experiment
  - COMPTEL – COMPton TELescope
  - EGRET – Energetic Gamma Ray Experiment Telescope

# GRBs: die Entdeckung

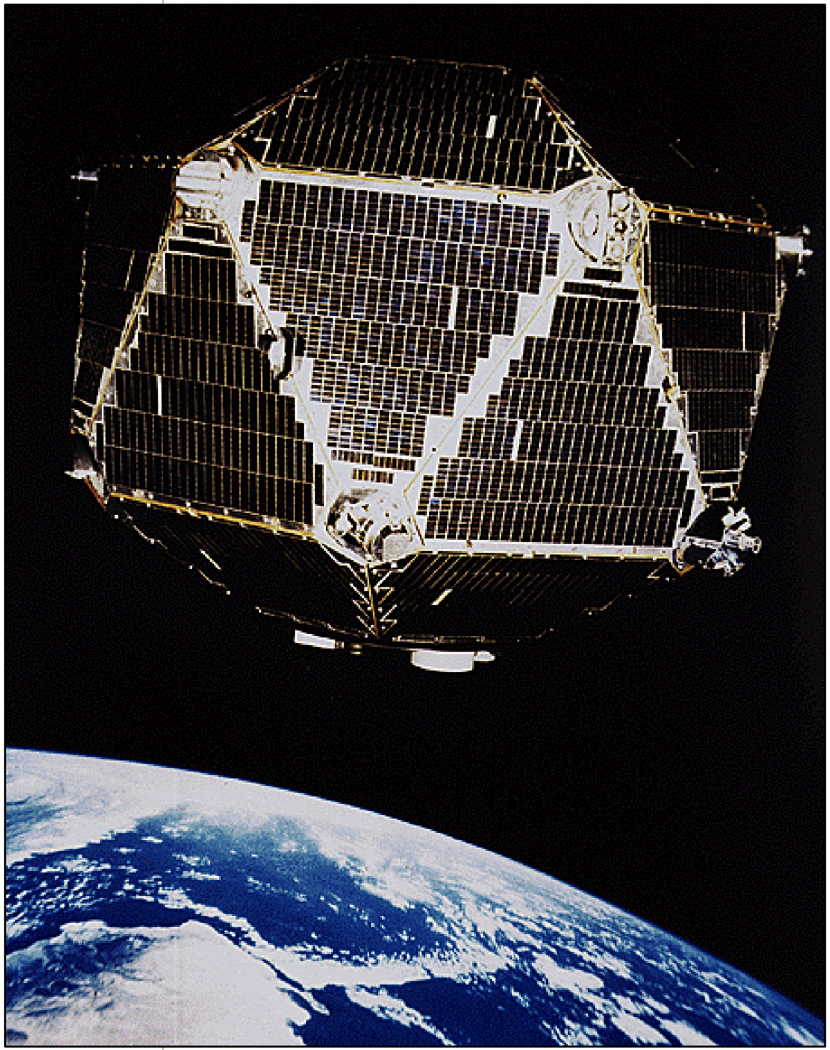
Kurioserweise begann das Gamma Ray Burst- Kapitel moderner Astrophysik mit einer Entdeckung des amerikanischen Militärs. In den 1960er-Jahren umkreisten Aufklärungssatelliten die Erde, um nach Gammastrahlung zu fahnden, die bei oberirdischen Atombombenversuchen frei wird. Einer dieser Späher registrierte 1969 tatsächlich einen Gammablitz. Allerdings war der nicht von der Erde gekommen, sondern aus dem Weltraum. Es folgten weitere Blitze dieser ...

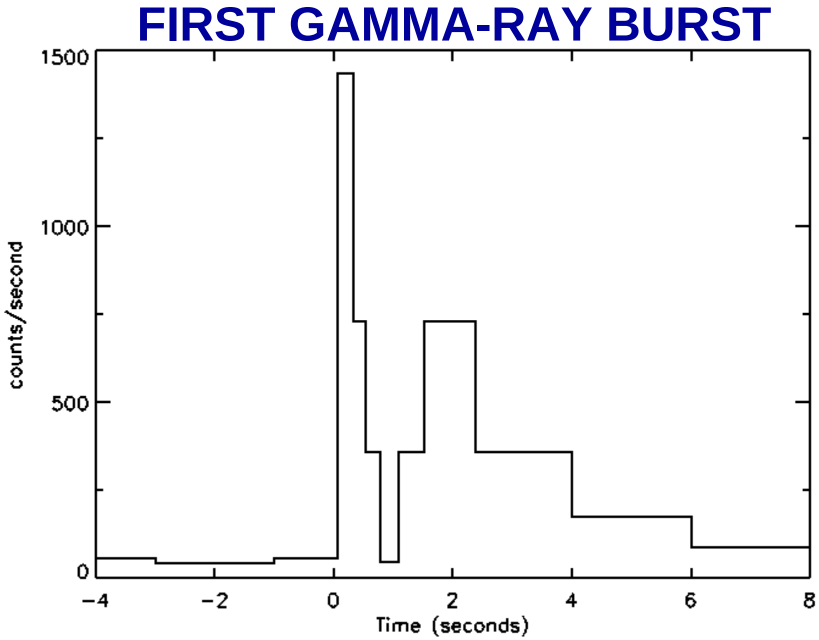
Because our atmosphere is virtually opaque to gamma-radiation from outer space it wasn't until the 1960s, when gamma-ray detecting satellites were flown, that the first gamma-ray bursts (GRBs) were detected. The year 1963 saw the landmark signing of the Partial Test Ban Treaty by the world superpowers. It was a promise that nuclear weapons would not be tested underwater, in the atmosphere, or outer space so as to protect the environment from radioactive fallout. As a result, that year the US Air Force sent into orbit the first of a series of satellites designed as a verification of international adherence to the ban. The satellites, called Vela, had X-ray, gamma-ray, and neutron detectors on-board. As all three such types of emission are expected from a nuclear blast, a coincident detection of all of them would have been a clear indication of a nuclear test.

# GRBs: die Entdeckung

- The satellite detectors were triggered many times over the lifetime of the Vela program but (luckily) none appeared to have the tell-tale signatures of a nuclear detonation. In 1972, a team at Los Alamos National Laboratory in New Mexico reanalysed the data from the previous decade and determined that a number of bursts of gamma-rays must have originated from somewhere other than the Earth or the Sun. This was accomplished by noting the small difference in the trigger times of the same event, as seen by different satellites. Since light has a finite travel speed, a timing difference translates directly into an angle of radiation incidence with respect to the satellite positions. Knowing where the satellites were at the time of the trigger allowed a crude position to be found. The spectacular discovery of GRBs (see Fig. 2) was announced in 1973 in the famous paper of Klebesadel, Strong, and Olson called 'Observations of Gamma-Ray Bursts of Cosmic Origin.' Dr. Ray Klebesadel, who still works at Los Alamos National Laboratory, often refers to the events as *gamma bursts* --- conspicuously leaving out his namesake --- perhaps out of modesty for having been the co-discover of what has become one of the most mysterious events known to humanity.

# Vela Program (1969-1979)






- Discovered in 1971 while looking for nuclear test ban violations (or July 2nd, 1967)

# Gamma-ray bursts

- **Gammablitze**, **Gammastrahlenblitze**, **Gammastrahlenausbrüche** oder auch **Gammastrahlenexplosionen** (engl. *Gamma Ray Burster* oder *Gamma Ray Bursts*, oft abgekürzt *GRB*) sind gewaltige hochenergetische Ausbrüche im Universum von kurzer Dauer, mit denen große Mengen an Gammastrahlen einhergehen.

- Ihre Dauer beträgt Milli-Sekunden bis maximal einige Minuten, die einzige bekannte Ausnahme (GRB 060218) dauerte 33 Minuten.

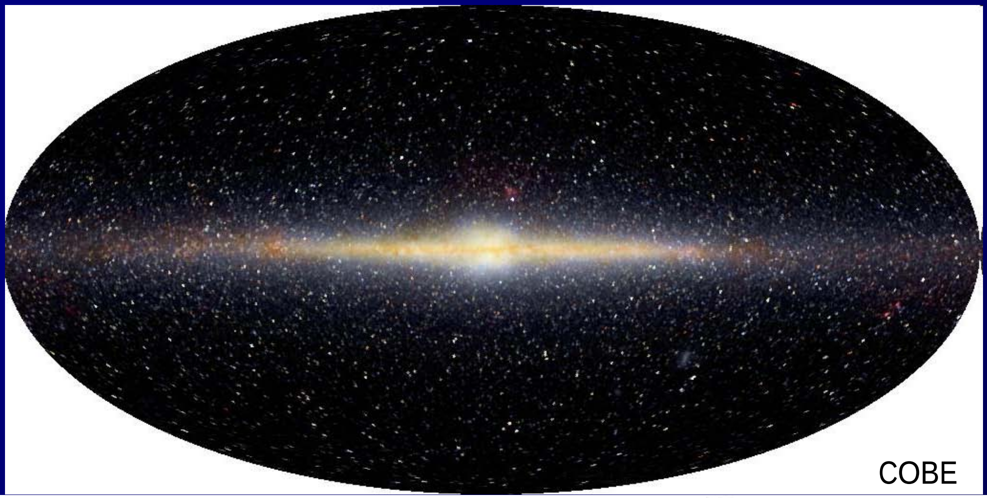
- Sie werden am ganzen Himmel beobachtet.

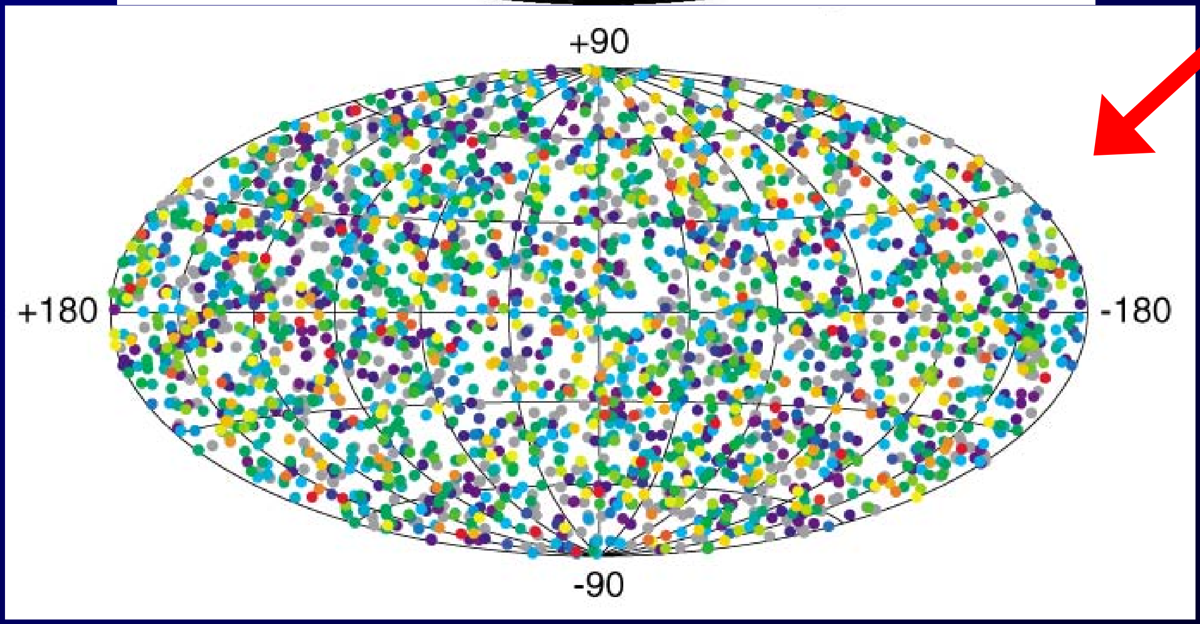
- Nomenklatur: Gammastrahlenausbruch am 5. 7. 1999 = GRB990705, gibt es mehrere an einem Tag, werden sie aufsteigend mit Buchstaben des Alphabets gekennzeichnet, z.Bsp. GRB950917A

- 1997 konnte erstmals ein GRB optisch nachgewiesen werden, durch sein optisches Nachleuchten (GRB afterglow)
- Wichtig: die zeitliche Entwicklung des Nachleuchtens, die Lichtkurve. Sie zeigt sehr unterschiedliche Charakteristika in Form von Minima und Maxima. Ist die Lichtkurve im Minimum, ist der GRB vorbei. Lichtkurven werden klassifiziert um die zugrundeliegende Physik zu verstehen. Nachleuchten im optischen und im Röntgenbereich, über Tagen und Wochen.

- Nur mittels Nachleuchten kann über die Beobachtung von Emissionslinien die Rotverschiebung bestimmt werden

# Gamma ray burst locations




Gamma ray bursts observed by the BATSE instrument on the Compton Gamma Ray Observatory

(about one gamma ray burst per day was observed)

2704

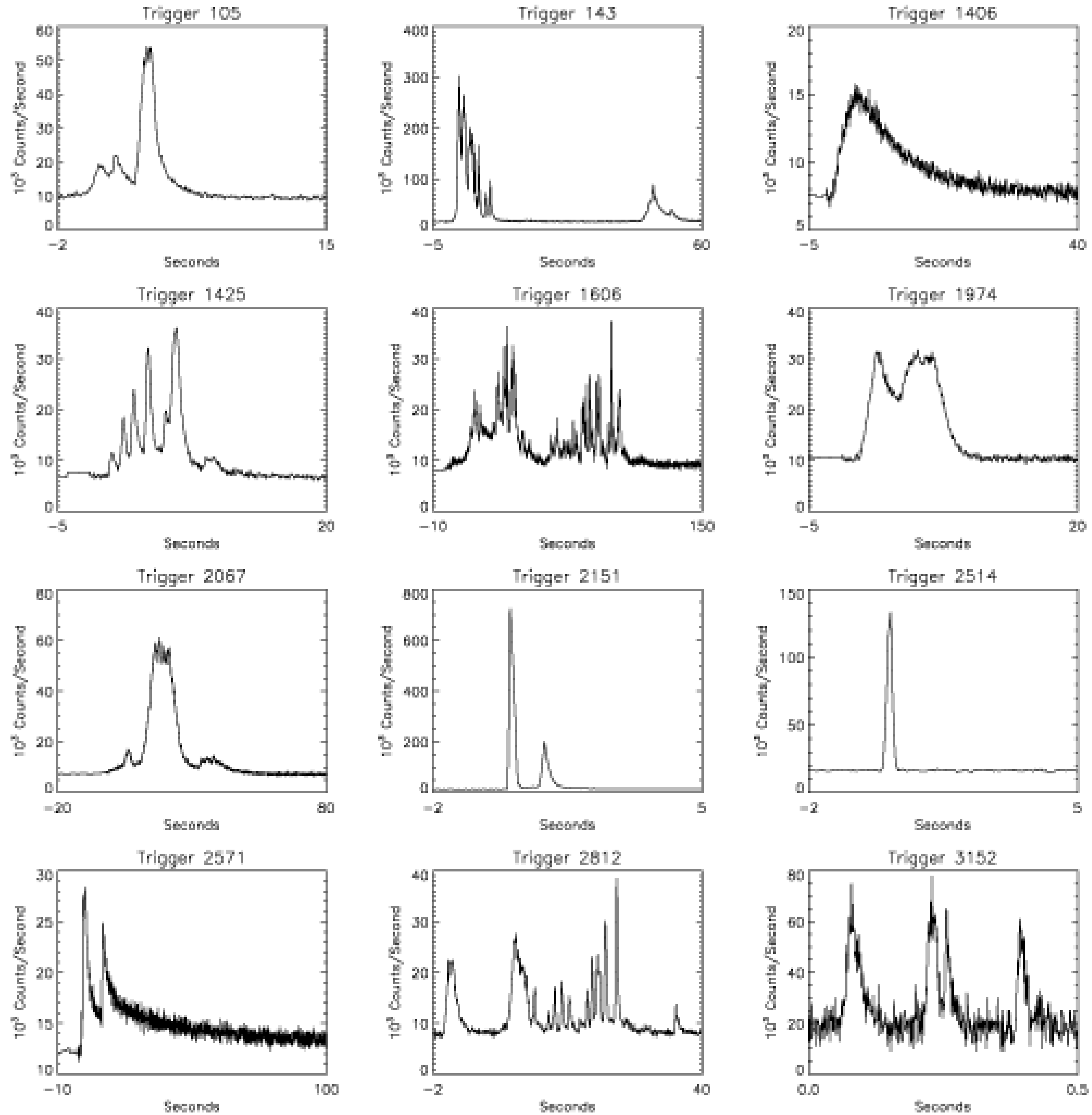
# Gamma-ray bursts

- Es gibt 2 Typen von GRBs:
  - Die **langen GRBs**: 2-1000 sek, junge, sehr massereiche Sterne (O-Sterne, oder Wolf-Rayet-Sterne) kollabieren und enden in einer Hypernova. Hypernovae sind noch heftigere Sternexplosionen als Supernovae, aber von der Physik her verwandt. Das Nachleuchten in anderen Wellenlängenbereichen wurde bisher nur bei den langen GRBs beobachtet!! Voläufersterne sind junge, massereiche Sterne

  - Die **kurzen GRBs**: 0.01-2 sek, Verschmelzungsprozesse von kompakten Objekten: Doppelsternsysteme aus Neutronensternen NS-NS merging, oder NS-BH merging; alte Neutronensterne sind Vorläufersterne; Kein Nachleuchten jemals beobachtet

- **Sie setzen in zehn Sekunden mehr Energie frei als die Sonne in Milliarden von Jahren. Für die Dauer seines Leuchtens ist ein Gammablitz heller als alle übrigen Gammastrahlenquellen am Himmel. Die gigantischsten Explosionen, die im Universum bekannt sind.**
  - **Freiwerdende Energie bei kurzen GRBs: $10^{48}$-$10^{50}$ erg**
  - **Lange GRBs: $10^{51}$-$10^{53}$ erg; 1 erg= $10^{-7}$ Joule**

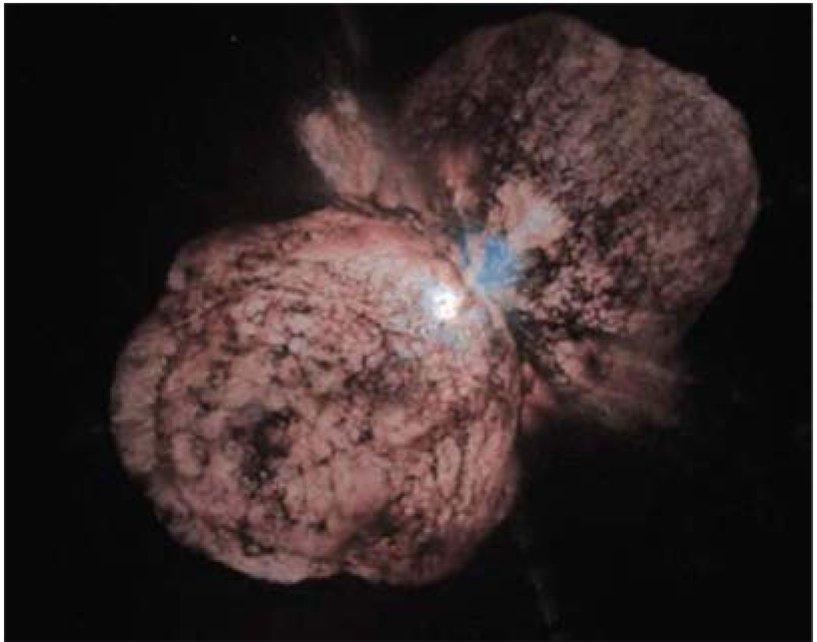
# Wie sehen GRBs aus?




J.T. Bonnell (NASA/GSFC)

# Gamma-ray bursts

- **Naher GRB wäre für die Erdbewohner fatal – (Kandidat Eta Carinae mit 100 Sonnenmassen mit 7500 Lj recht weit entfernt)**
- In der Milchstraße sind die langen GRBs mit dem größten Energieoutput sehr selten! Grund: zu viele Metalle
- Gefährlichkeit der GRBs hängt ganz wesentlich von der Ausrichtung des GRBs zur Erde ab.



# Gamma-ray bursts

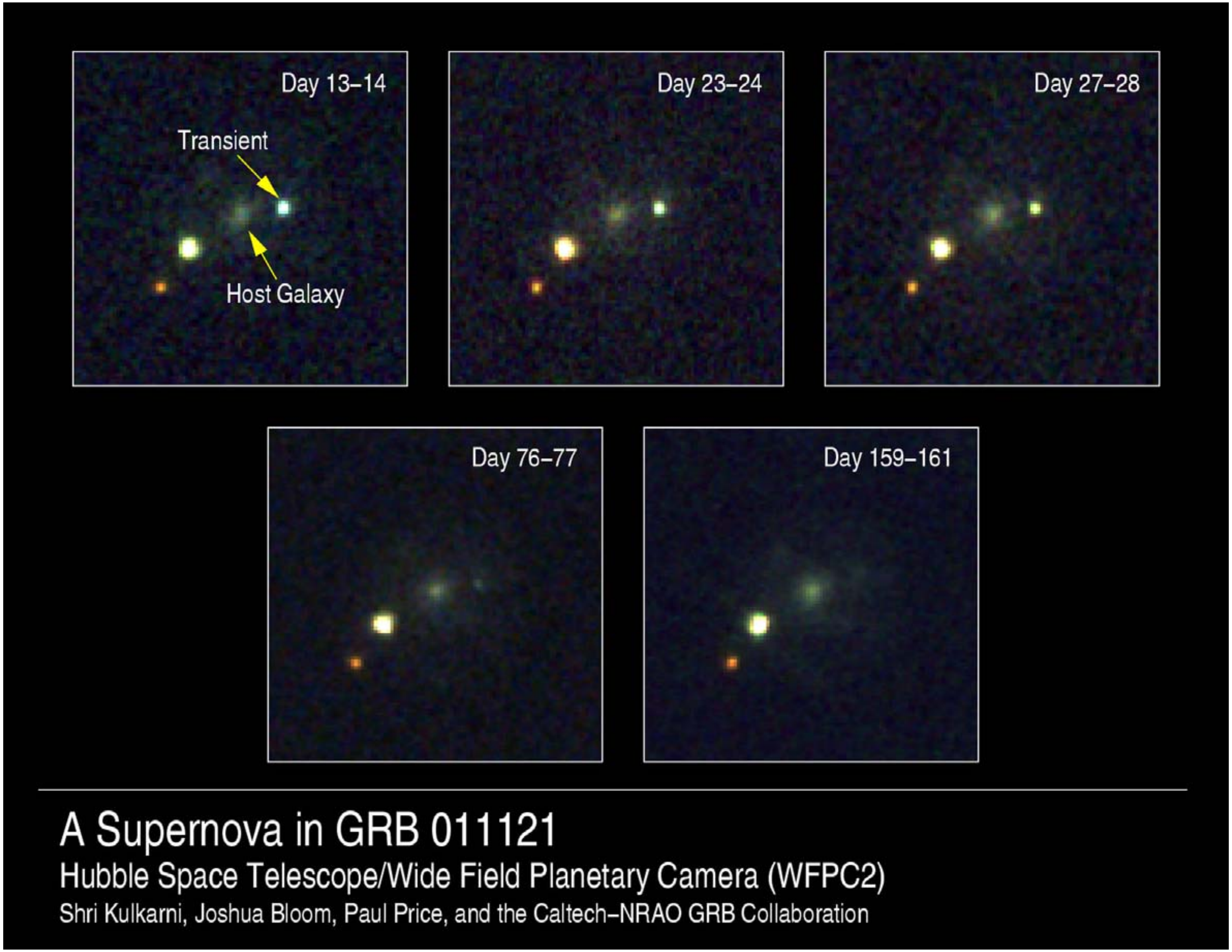
- *670702:* Der erste GRB, der jemals entdeckt wurde.
- *970228:* Der erste GRB, bei dem erfolgreich ein Nachleuchten festgestellt werden konnte.
- *970508:* Der erste GRB mit einer exakt bestimmten Rotverschiebung
- *980425:* Der erste GRB, der in Verbindung mit einer Supernova (SN 1998bw) beobachtet wurde; zeigte eine enge Beziehung zwischen SN und GRBs auf.
- *990123:* Der erste GRB, bei dem eine Emission im sichtbaren Bereich festgestellt wurde.
- *041227:* Die Erde wird von einem gewaltigen Gammastrahlenausbruch getroffen, dessen Wellenfront von einem Stern in nur 50.000 Lj Entfernung ausging.
- *050509B:* Der erste kurze GRB, bei dem der Ursprungskörper festgestellt werden konnte (unterstützte die Theorie, dass kurze GRB nicht mit Supernovae in Verbindung stehen).

# Gamma-ray bursts

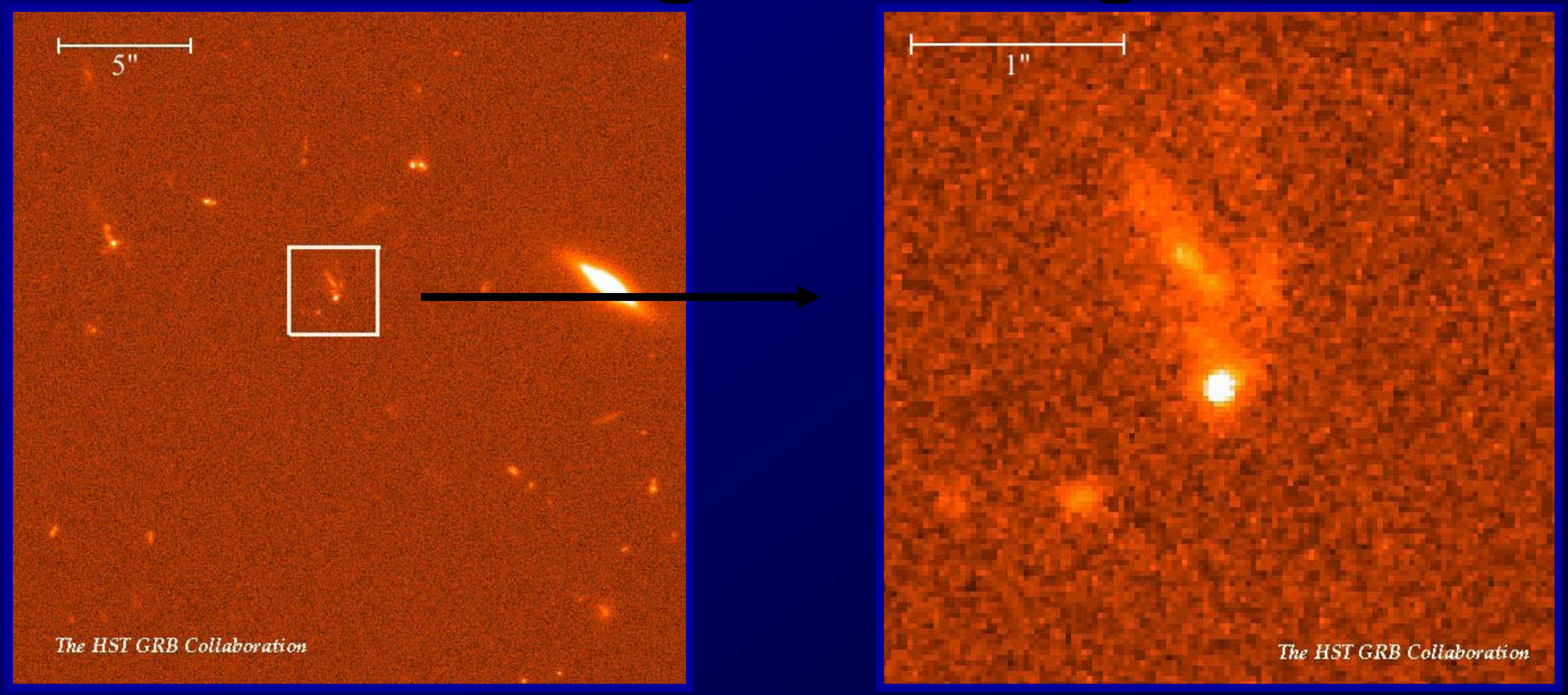
- *050724:* Ein kurzer GRB, als dessen Ursprung ein um ein Schwarzes Loch kreisender Neutronenstern festgestellt wurde.
- *050904:* Mit 12,7 Mrd. Lj der alte Entfernungsrekord für einen GRB mit einer Rotverschiebung von 6,29.
- *080319B:* Hellster GRB und hellste Supernova, die jemals entdeckt wurden (absolute Helligkeit: -36 mag); außerdem erster GRB, der mit bloßem Auge beobachtet werden konnte (scheinbare Helligkeit: 5,76 mag); zugleich das am weitesten entfernte Objekt, das jemals mit bloßem Auge zu beobachten war.
- *080913:* Der am weitesten von der Erde entfernte GRB mit einer Rotverschiebung von 6,7 (entspricht 12,8 Mrd. Lj); damit das zweitälteste dokumentierte Ereignis im Universum.


Der Schlüssel zum
Verständnis:
Das Nachglühen!!

# What do gamma ray bursts actually look like?

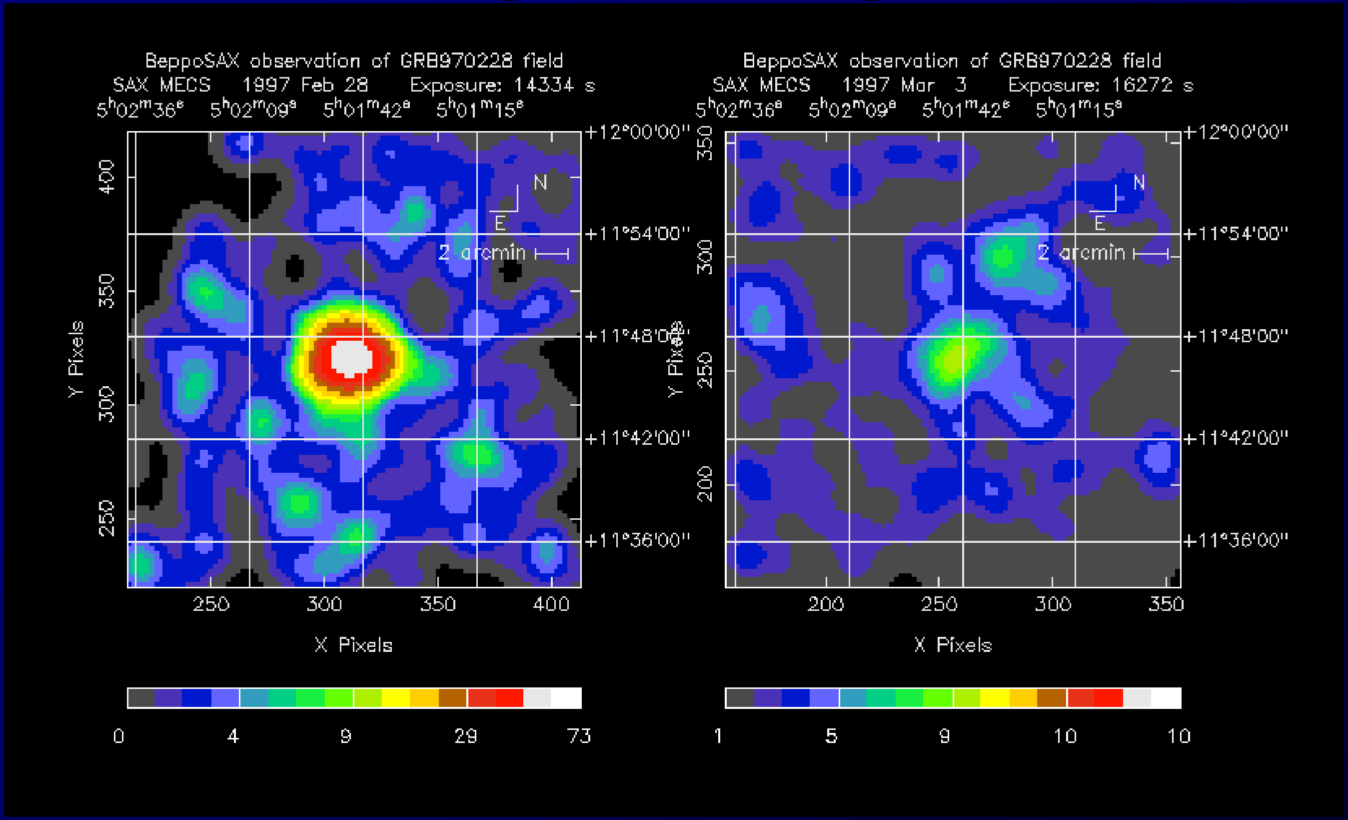


# Visible Light Afterglows




- Fading visible light persists for months
- Redshifts from host galaxies → distances
- Record: z = 4.5 → 12 billion light years

# X-ray Afterglows



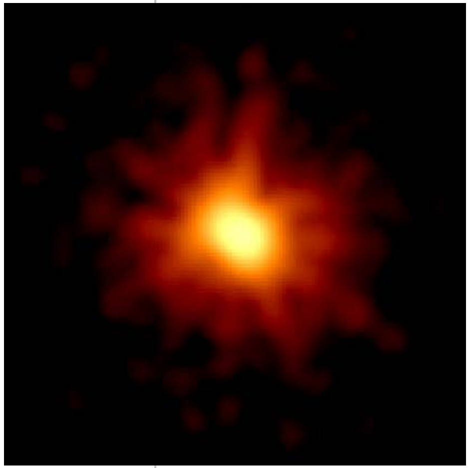

8.5 hours after GRB

5 days later

- Discovered in 1997 by BeppoSAX satellite

Lynn Cominsky

# Gamma-ray bursts



**080319B GRB mit dem Swift Röntgenteleskop**

**080319B GRB mit dem Swift Optik-/Ultraviolett-Teleskop**

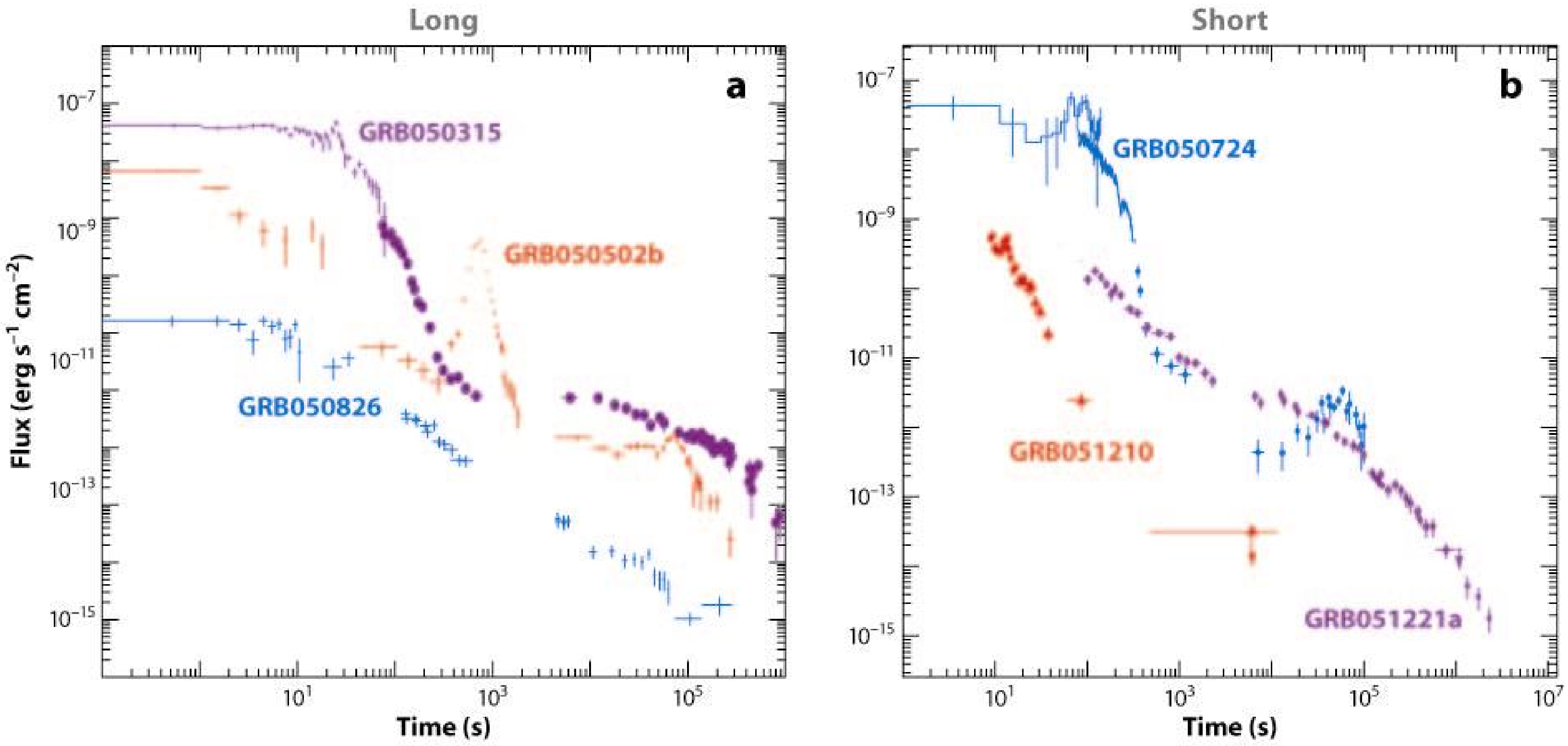



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**Figure 6** Representative examples of X-ray afterglows of (*a*) long and (*b*) short *Swift* events with steep-to-shallow transitions (GRB050315, 050724), large X-ray flares (GRB050502B, 050724), and rapidly declining (GRB051210) and gradually declining (GRB051221a, 050826; flux scale divided by 100 for clarity) afterglows.

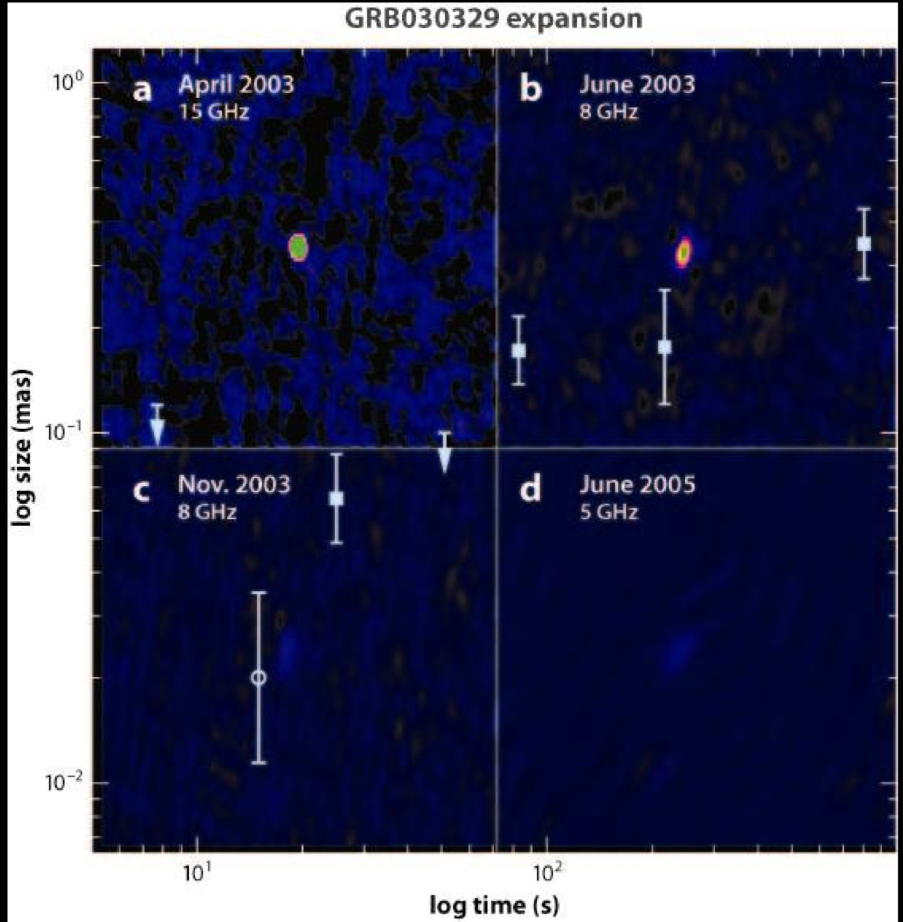


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**Figure 8** The growth of GRB030329 with time as measured using VLBI (Pihlström et al. 2007 and references therein). In the background are the images from (*a*) April 2003 (15 GHz), (*b*) June 2003 (8 GHz), (*c*) November 2003 (8 GHz), and (*d*) June 2005 (5 GHz) with the same intensity scale. The resolution for the four images is not constant in time, but this is accounted for in the analysis of the source size.

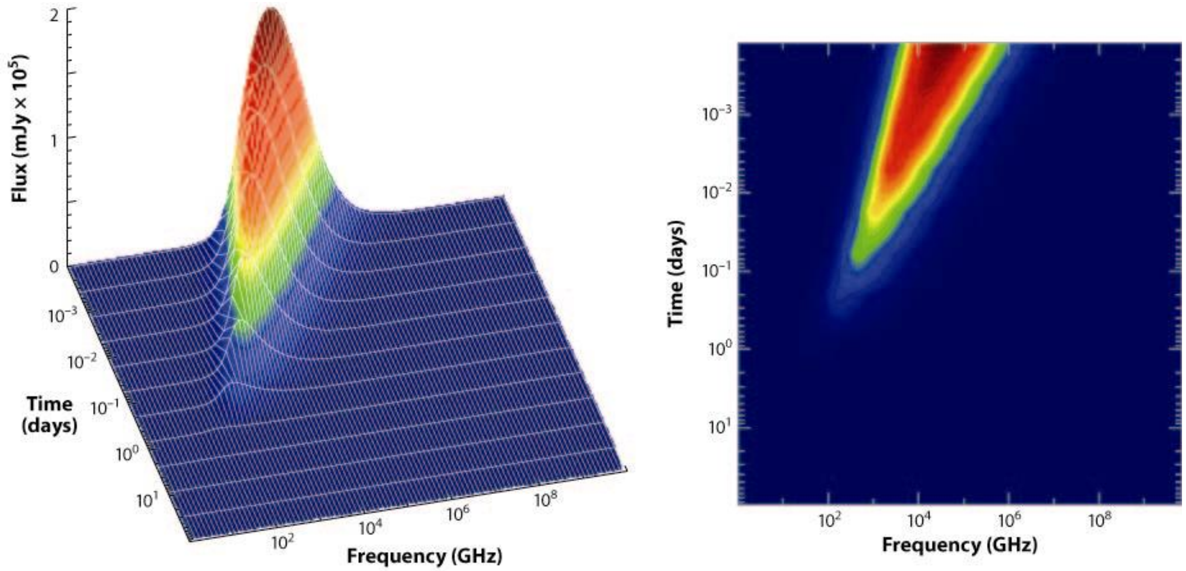


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**Figure 3** The evolving synchrotron afterglow of a γ-ray burst. Shown is a theoretical model (Gou, Fox & Mészáros 2007) for the afterglow of the *Swift* GRB050904. The model is presented without extinction and as it would have been observed at redshift $z$ = 2; the burst itself occurred at $z$ = 6.29. The evolution of the synchrotron peak to lower frequencies is clearly visible. More subtle effects, including evolution of the synchrotron cooling and self-absorption frequencies, and the associated synchrotron self-Compton emission of the blastwave at higher frequencies are not readily visible in this model.

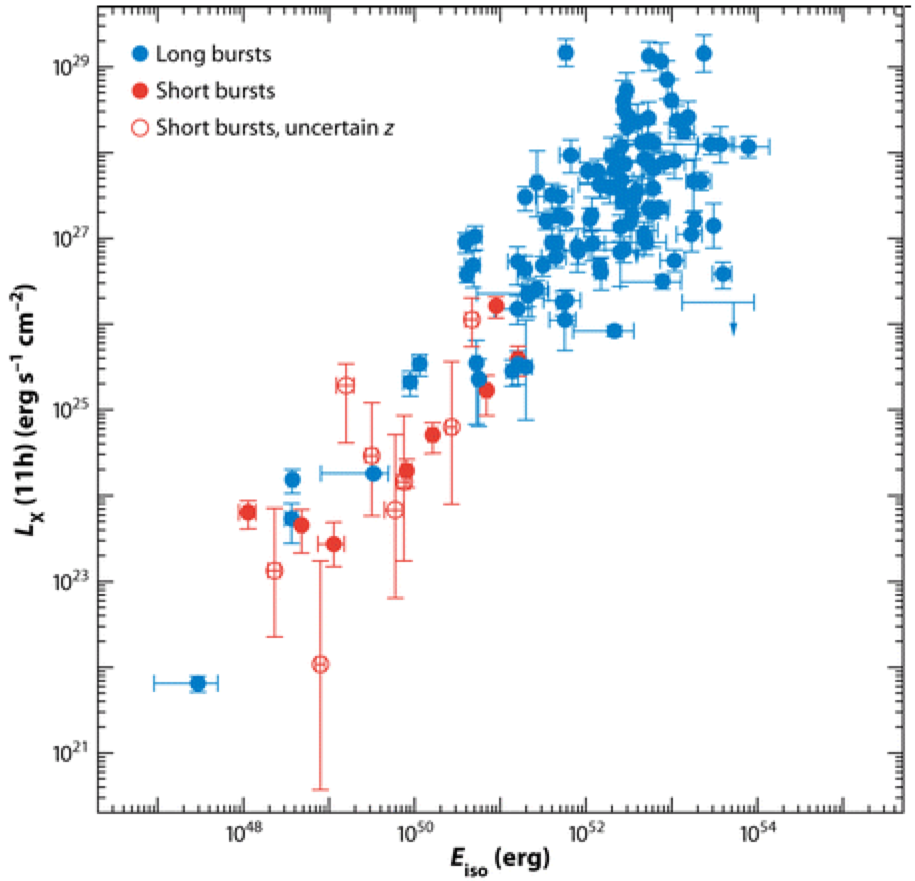


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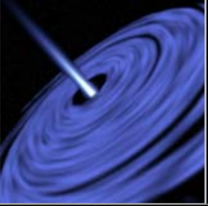
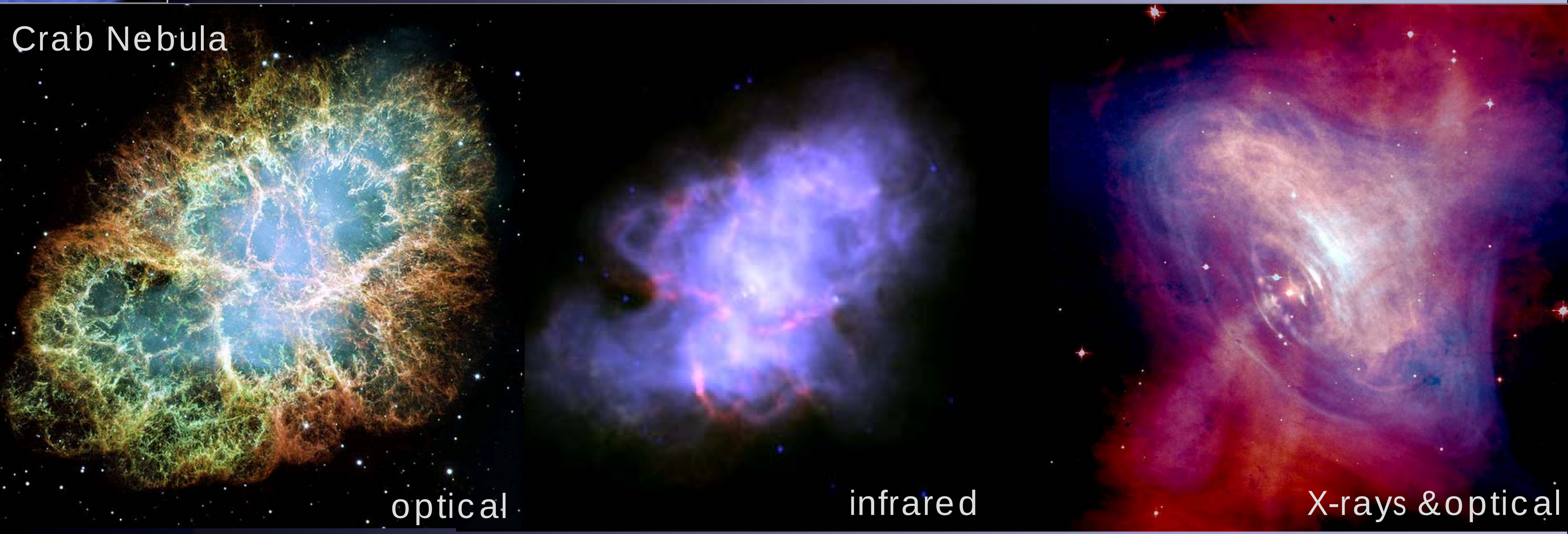
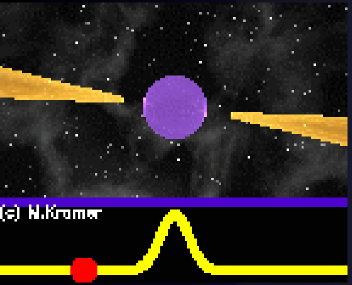
**Figure 9** Isotropic-equivalent luminosity of GRB X-ray afterglows scaled to *t* = 11 h (5-keV source frame) after the burst trigger as a function of their isotropic γ-ray energy release (adapted from Nysewander, Fruchter & Pe'er 2009).

# GRBs
# - die Energiebilanz



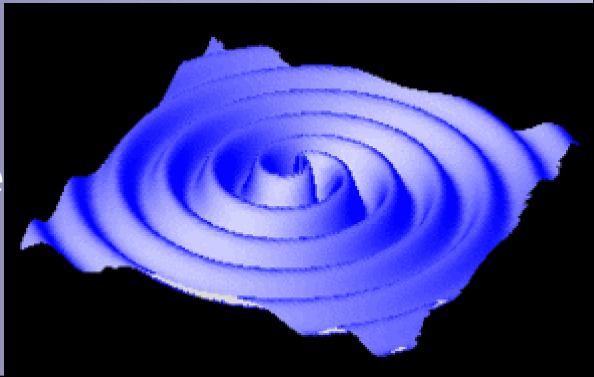
# Stellar Black Holes / Pulsars ($1\ M_\odot < M_{BH} < 100\ M_\odot$)



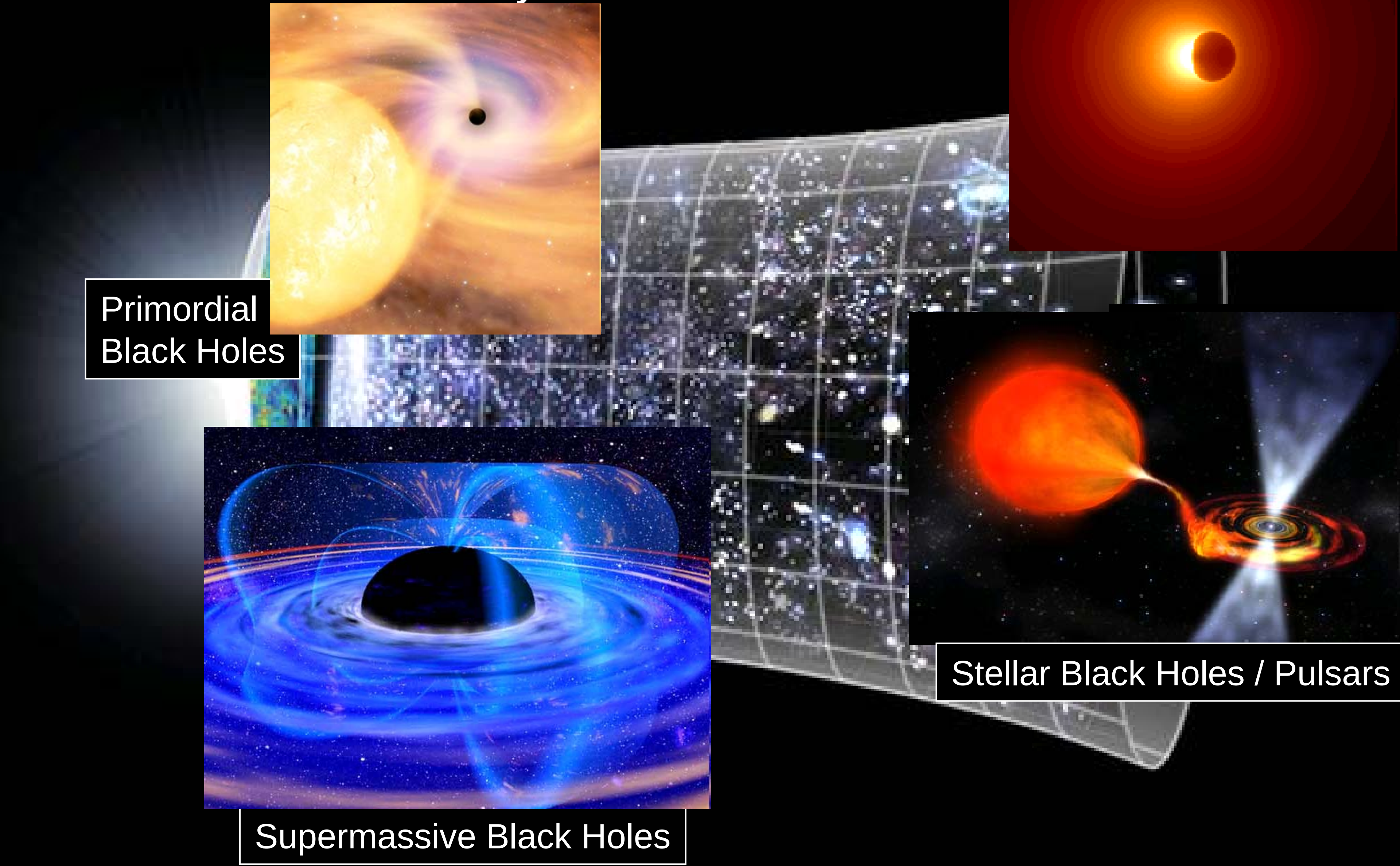




- Pulsars as precise cosmical clocks
- probes for strong gravity : space-time in violent conditions

- Direct Detection & study of gravitational wave background by pulsar- timing arrays



# Black Holes are the engines of our Universe's history



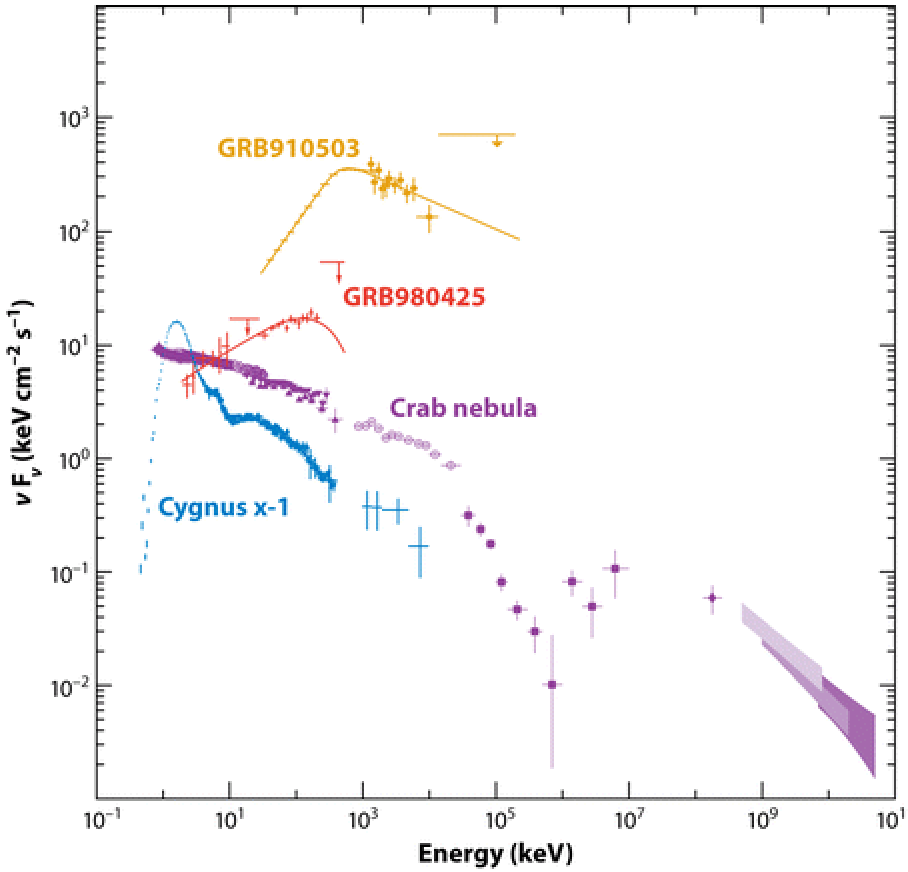



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**Figure 1** Gamma-rays are excellent probes of the most energetic phenomena in nature, which typically involve dynamical nonthermal processes and include interactions of high-energy electrons with matter, photons, and magnetic fields; high-energy nuclear interactions; matter–antimatter annihilation; and possibly other fundamental particle interactions. Shown here are representative spectra $\nu F_{\nu}$ $\nu^2 N(\nu)$ of γ-ray bursts (GRBs) (Kaneko et al. 2007, 2008) along with the Crab pulsar nebula (Kuiper et al. 2001) and the galactic black hole candidate Cygnus X-1 (McConnell et al. 2002).

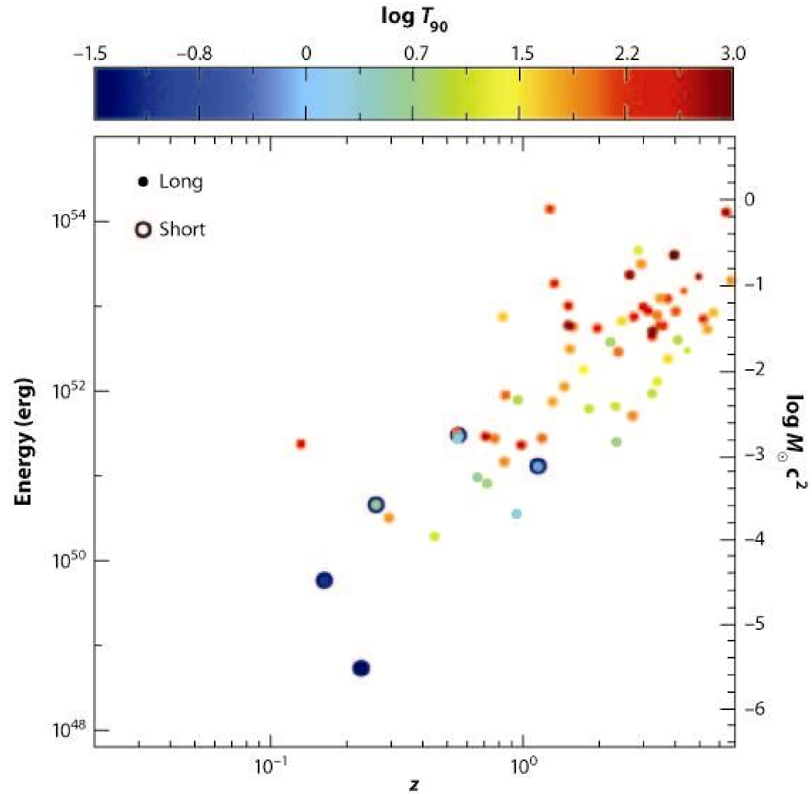


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**Figure 2** Apparent isotropic γ-ray energy as a function of redshift and observed duration. The energy is calculated assuming isotropic emission in a common comoving bandpass for a sample of short and long GRBs with measured redshifts. This spread in the inferred luminosities obtained under the assumption of isotropic emission may be reduced if most GRB outflows are jet-like. A beamed jet would alleviate the energy requirements, and some observational evidence does suggest the presence of a jet.

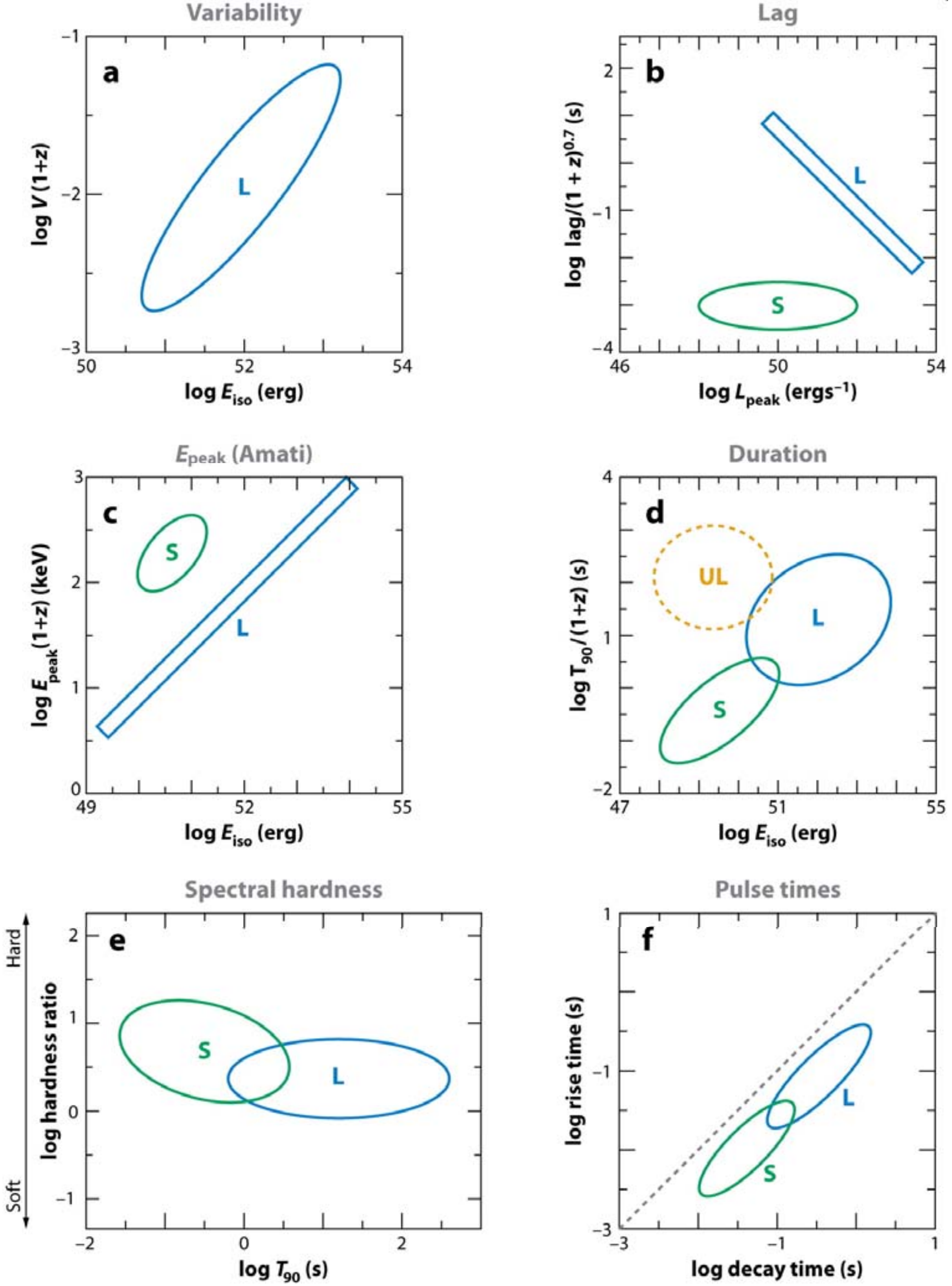


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**Figure 5** Schematic diagrams illustrating the most widely discussed correlations between various prompt emission properties for long (L), short (S), and underluminous (UL) GRBs. (*a*) Variability scaled to the burst frame versus $E_{iso}$ (Fenimore & Ramirez-Ruiz 2000, Reichart et al. 2001, Schaefer 2006). The variability is a measure of the spikiness of the light curve and is defined as the mean square of the time signal after removing low frequencies by smoothing. (*b*) Spectral lag scaled to the burst frame versus peak luminosity (Norris & Bonnell 2006, Gehrels et al. 2006). (*c*) $E_{peak}$ scaled to the burst frame versus $E_{iso}$ (Amati et al. 2002 for *BeppoSAX* GRBs; Amati 2006 for *Swift* GRBs; Lloyd-Ronning & Ramirez-Ruiz 2002 for BATSE events). (*d*) Duration scaled to the burst frame versus $E_{iso}$. (*e*) Spectral hardness versus observed duration (Kouveliotou et al. 1993). (*f*) Pulse rise time versus its decay time (Norris et al. 1996).

# What if the light from a gamma ray burst is beamed (like a flashlight?)

- How does that affect how much energy we think they have?
- How does that affect how many of them we see?

NASA / SkyWorks Digital

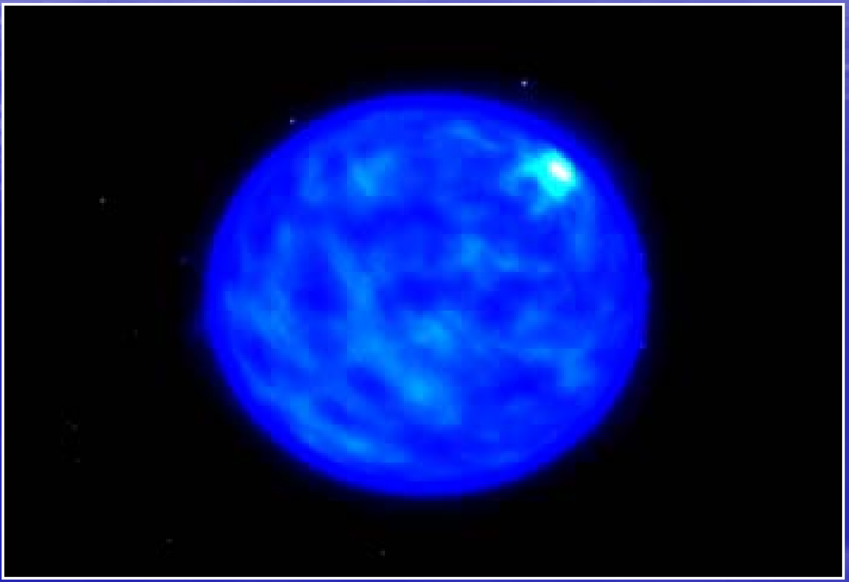
# GRBs: energetics

- **Energetics of GRBs**
- Gamma-rays can be produced in nuclear explosions
- when relativistic particles collide with low energy photons
- If the explosion is uniform, energy release is:$10^{47}$ J
- This is not possible!

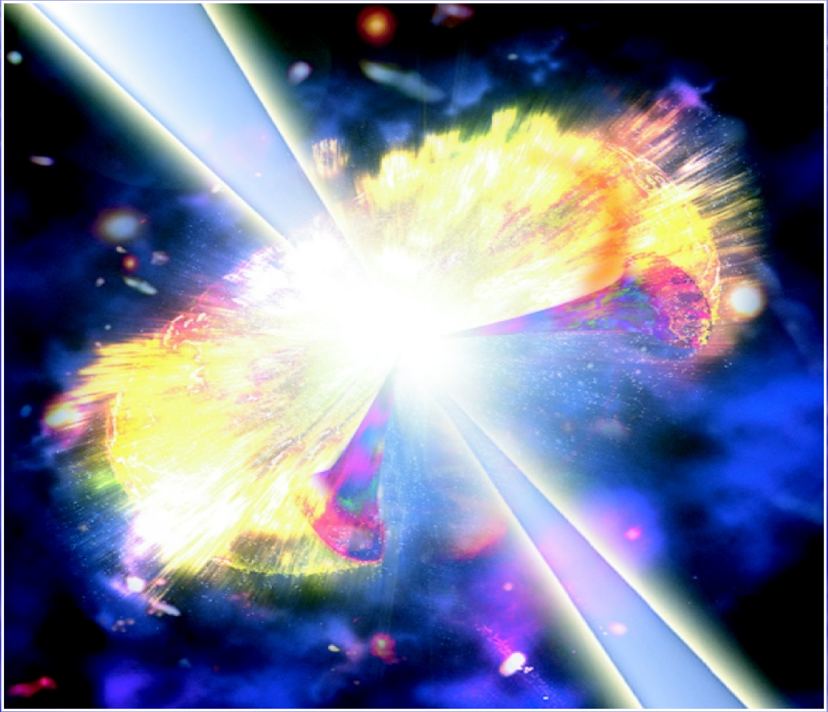
- **Energetics of GRBs**
- Energy release is along a narrow jet
- Opening angle varies greatly
- True energy release is constant at $10^{44}$ J
- comparable to a supernova
- Consequence: we can't see all the GRBs
- 500 occur a day

# Zwei verschiedene GRB-Typen

# Hypernova



Credit: Dana Berry

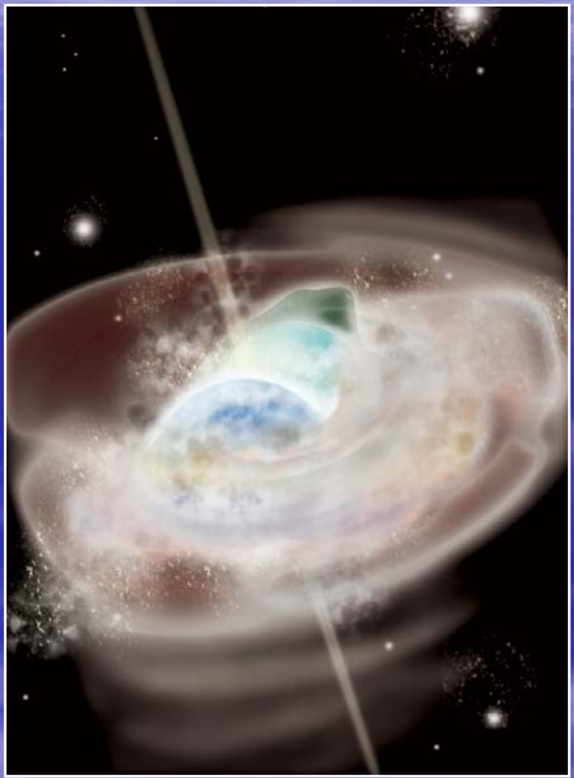


Credit: D. Armbrecht

- Super-supernova – death of star ~ 100 $M_o$
- Material remaining after burst → afterglow

# Catastrophic Mergers

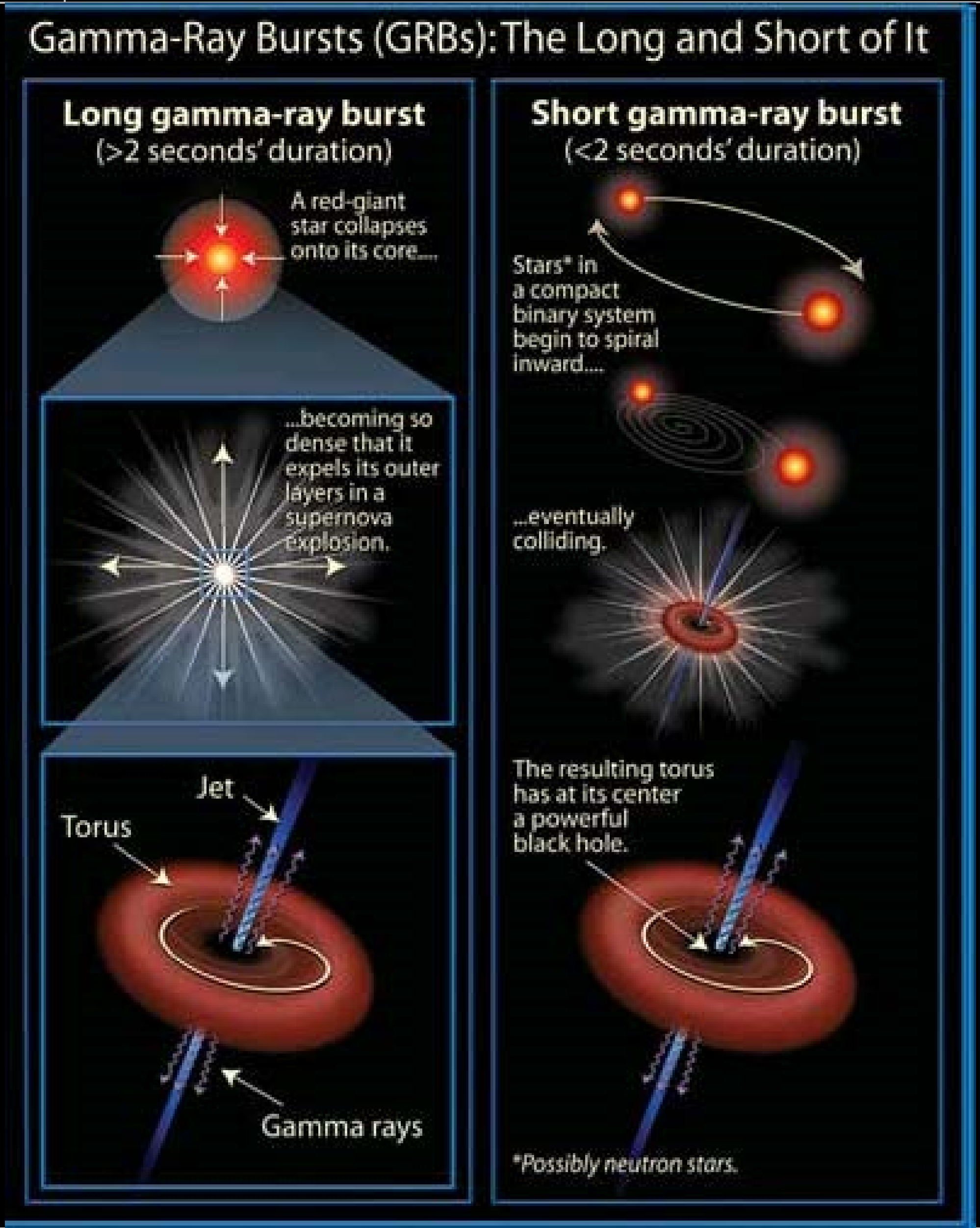
Credit: Dana Berry

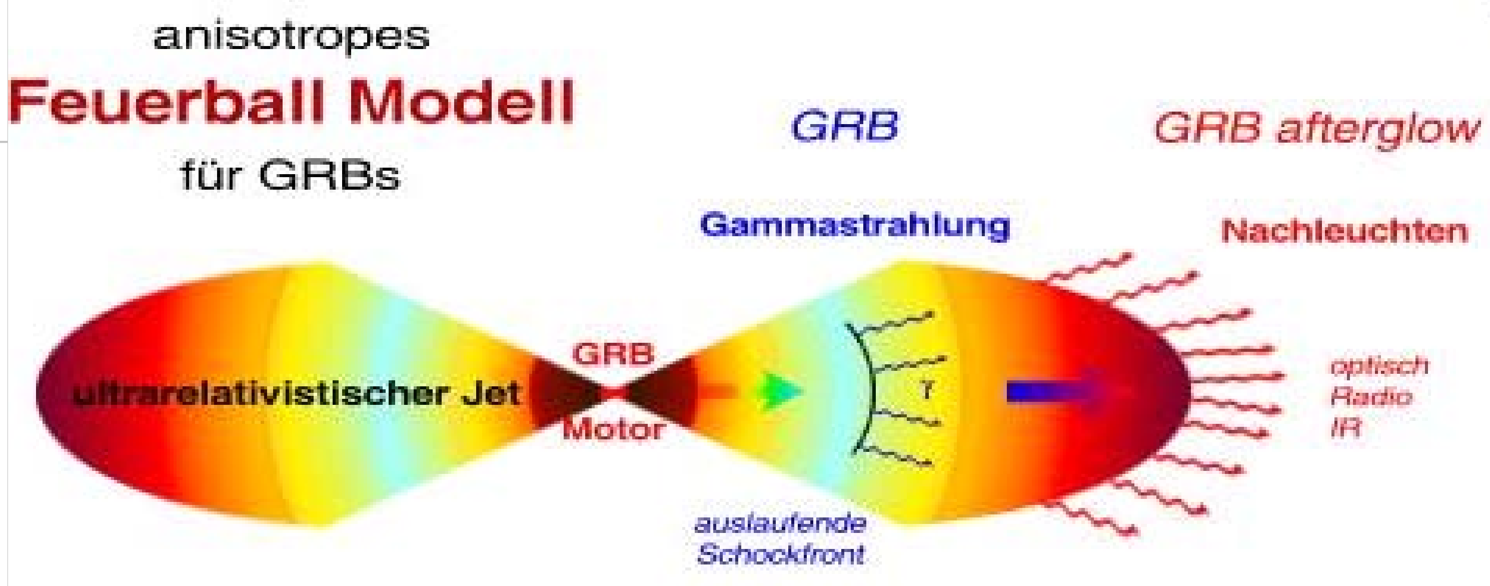


Credit: Aurore Simonnet

- Death spiral of 2 neutron stars or black holes
- Possible origin of short bursts

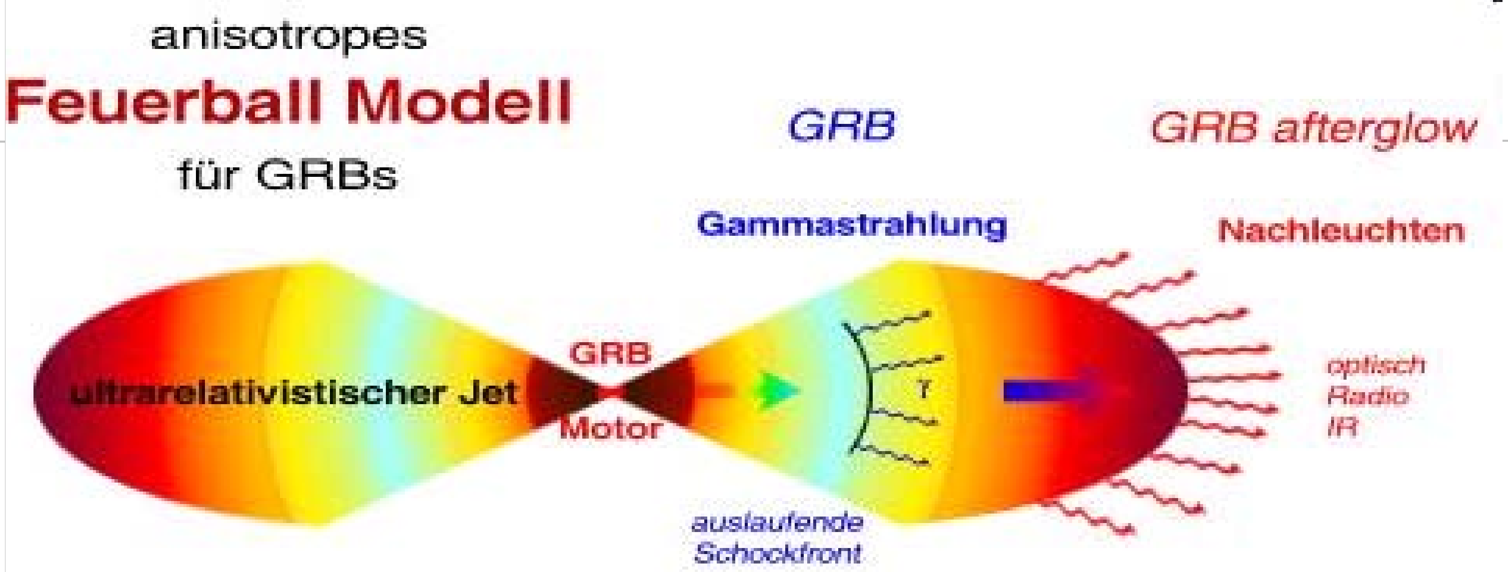
# Gamma-ray bursts





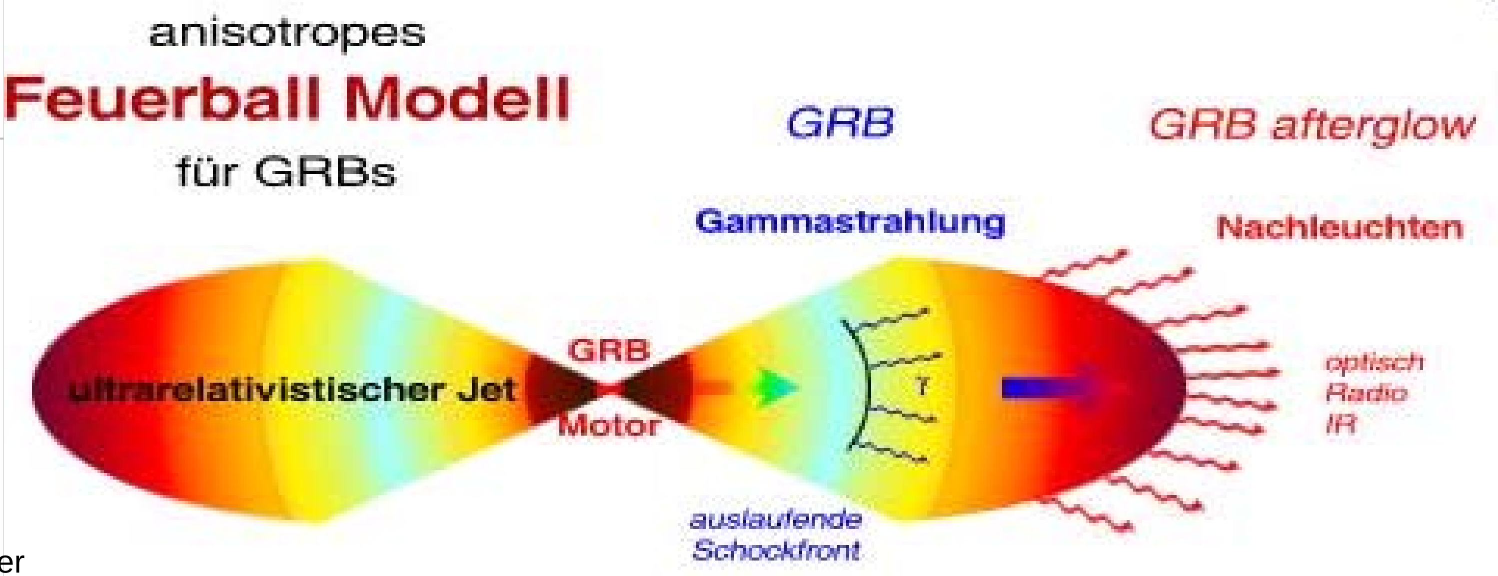

A. Müller

- Anisotropes Feuerball-Modell (anisotropic fire ball) is aktuell favorisiertes physikalisches Modell, um GRBs zu verstehen
- GRB-Motor: Hypernova oder Kollaps von mindestens 2 kompakten Objekten treibt Schockfront nach außen
- Schockfront trifft auf interstellares Medium
- 99.99995% der Vakuumlichtgeschwindigkeit, ultra-relativistische Geschwindigkeiten
- Am Bugschock wird die kinetische Energie des Feuerballs auf die Elektronen und Photonen des CBM (Circum Burst Medium) übertragen
- In der innersten Schale entstehen die Gammaquanten des GRBs: prompte Emission, dahinter entsteht das Nachleuchten der anderen Wellenlängenbereiche – Nachleuchten im UV, Optischen, Infraroten und Radiobereich

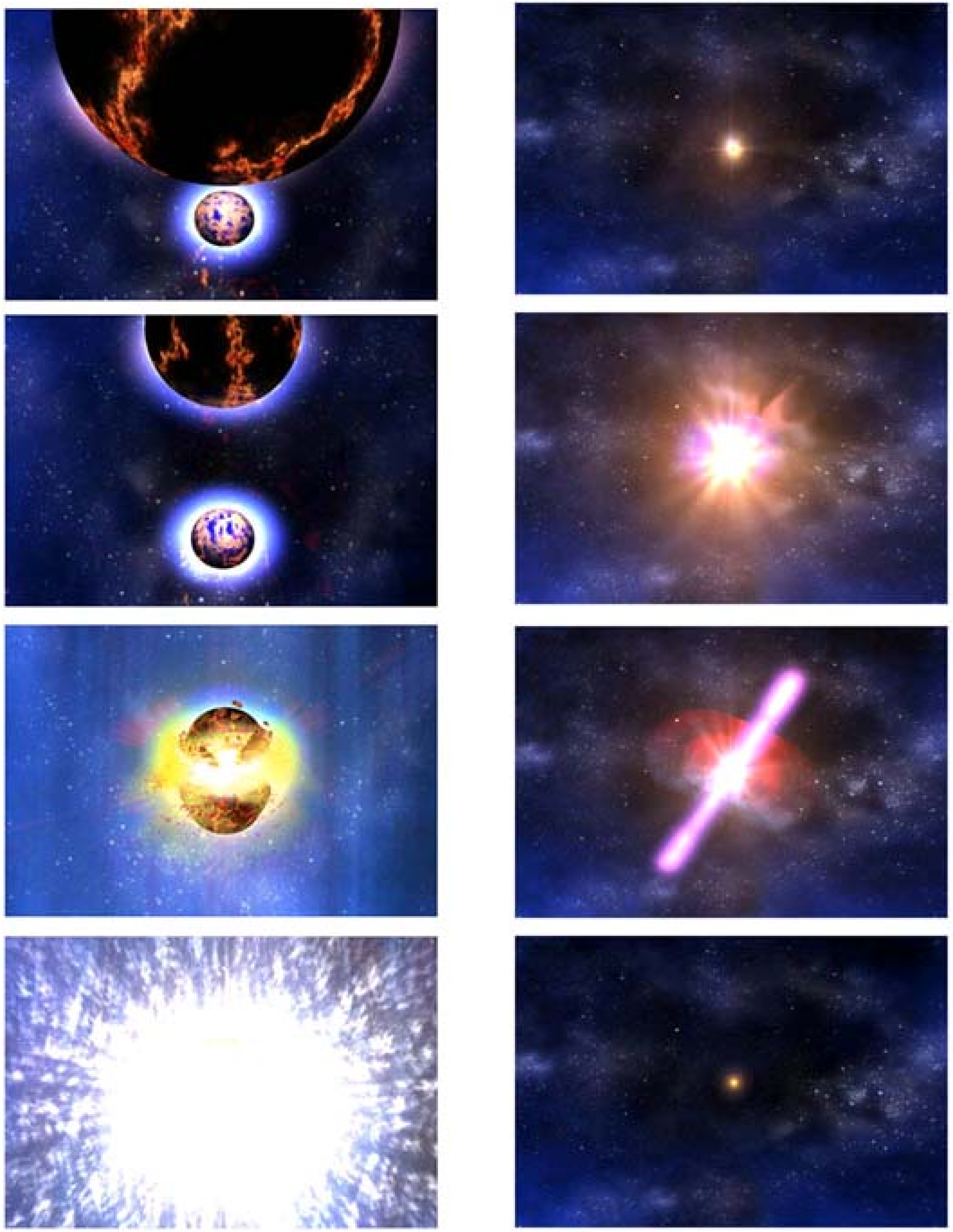



A. Müller

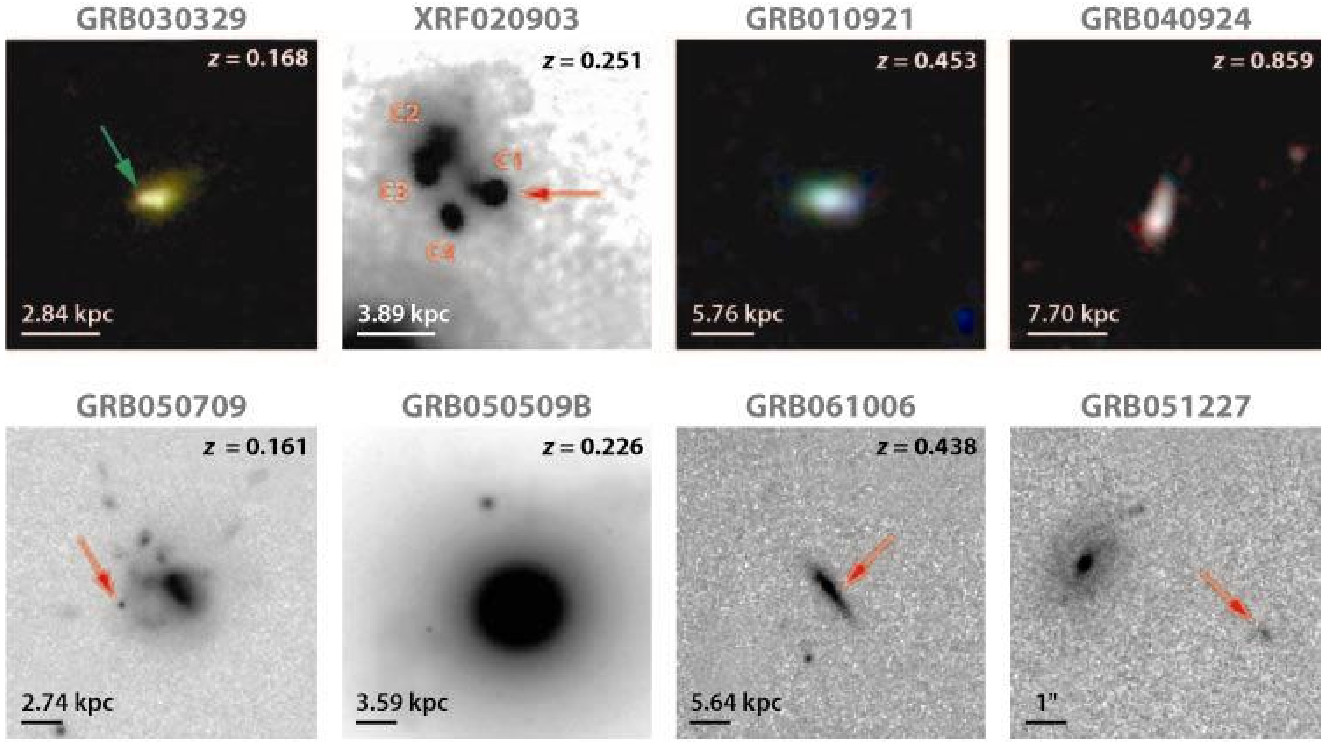
- Schlüsselelement: stellare, ultra-relativistische Jets, entstehen im Kollaps des Vorläufersterns oder des Vorläufersystems
- Beamingfaktor: relativistischer Doppler-Faktor, ein Maß dafür, wie sehr die elektromagnetischen Wellen, die vom GRB-Jet ausgehen, verschoben werden; Blauverschiebungseffekt, GRB-Strahlung wirkt energiestärker als sie ist; Gebeamte Strahlung ist energetischer und heller!!
- Hier entsteht ein stellares Schwarzes Loch – rotierende SL spielen vermutlich die entscheidende Rolle (Kerr-Lösung)


anisotropes
Feuerball Modell
für GRBs
GRB
GRB afterglow
Gammastrahlung
Nachleuchten
ultrarelativistischer Jet
GRB
Motor
γ
optisch
Radio
IR
auslaufende
Schockfront

A. Müller

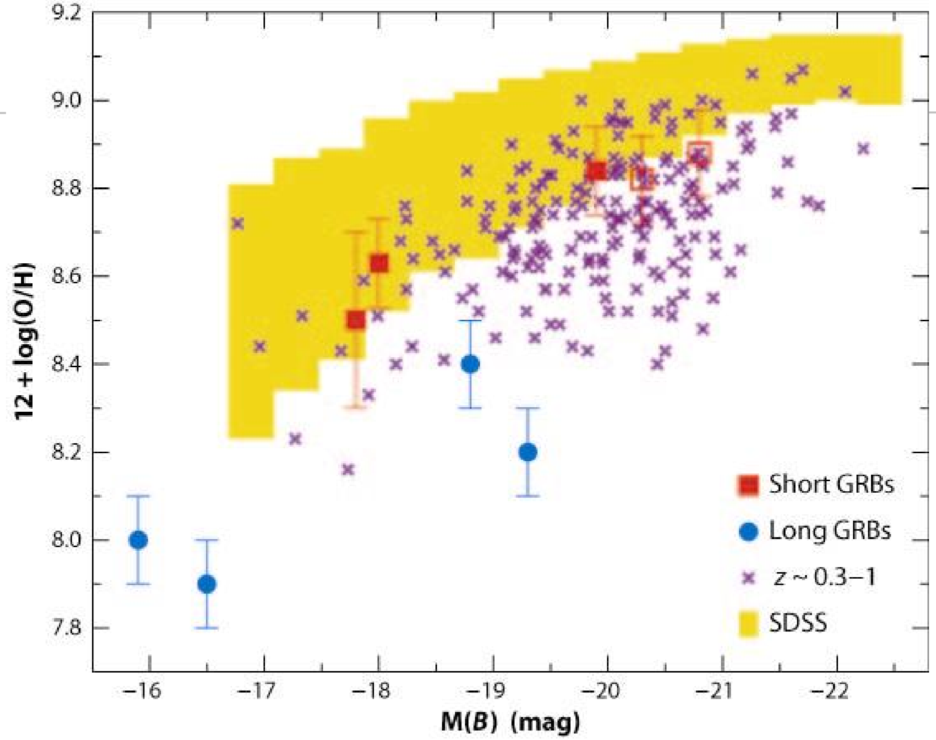


- http://www.nasa.gov/vision/universe/watchtheskies/short_burst.html




Gehrels N, et al. 2009.
Annu. Rev. Astron. Astrophys. 47:567–617

**Figure 11** A selection of the host galaxies of long-duration (*top row*) and short-duration (*bottom row*) γ-ray bursts, as imaged by the *Hubble Space Telescope*. An attempt has been made to choose pairs of long- and short-burst host galaxies with comparable redshifts; lower-redshift hosts are emphasized because these reveal their structure more readily in short exposures. Images are oriented with north up and east to the left, and the physical length scale for a one-arcsecond angular distance is indicated in each panel (except for GRB051227); arrows point to the location of the burst where this is known to approximately pixel precision. Individual burst notes: GRB030329 was the first classical long GRB to be associated with a well-observed spectroscopic supernova (Hjorth et al. 2003, Stanek et al. 2003); XRF020903 was the first X-ray flash event to yield a redshift measurement (Soderberg et al. 2004); GRB050709 was the first short burst with optical afterglow—indicated by the arrow—detected (Fox et al. 2005, Hjorth et al. 2005b); GRB050509B was the first short burst with detected afterglow (Gehrels et al. 2005, Bloom et al. 2006); GRB051227 has a faint candidate host, of unknown redshift probably >1, visible at the optical afterglow location; the spiral galaxy to the east has redshift $z$ = 0.714 (Foley et al. 2005). Long-burst host images from Wainwright, Berger & Penprase (2007); short-burst host images from Fox et al. (2005) and this review.




Gehrels N, et al. 2009.
Annu. Rev. Astron. Astrophys. 47:567–617

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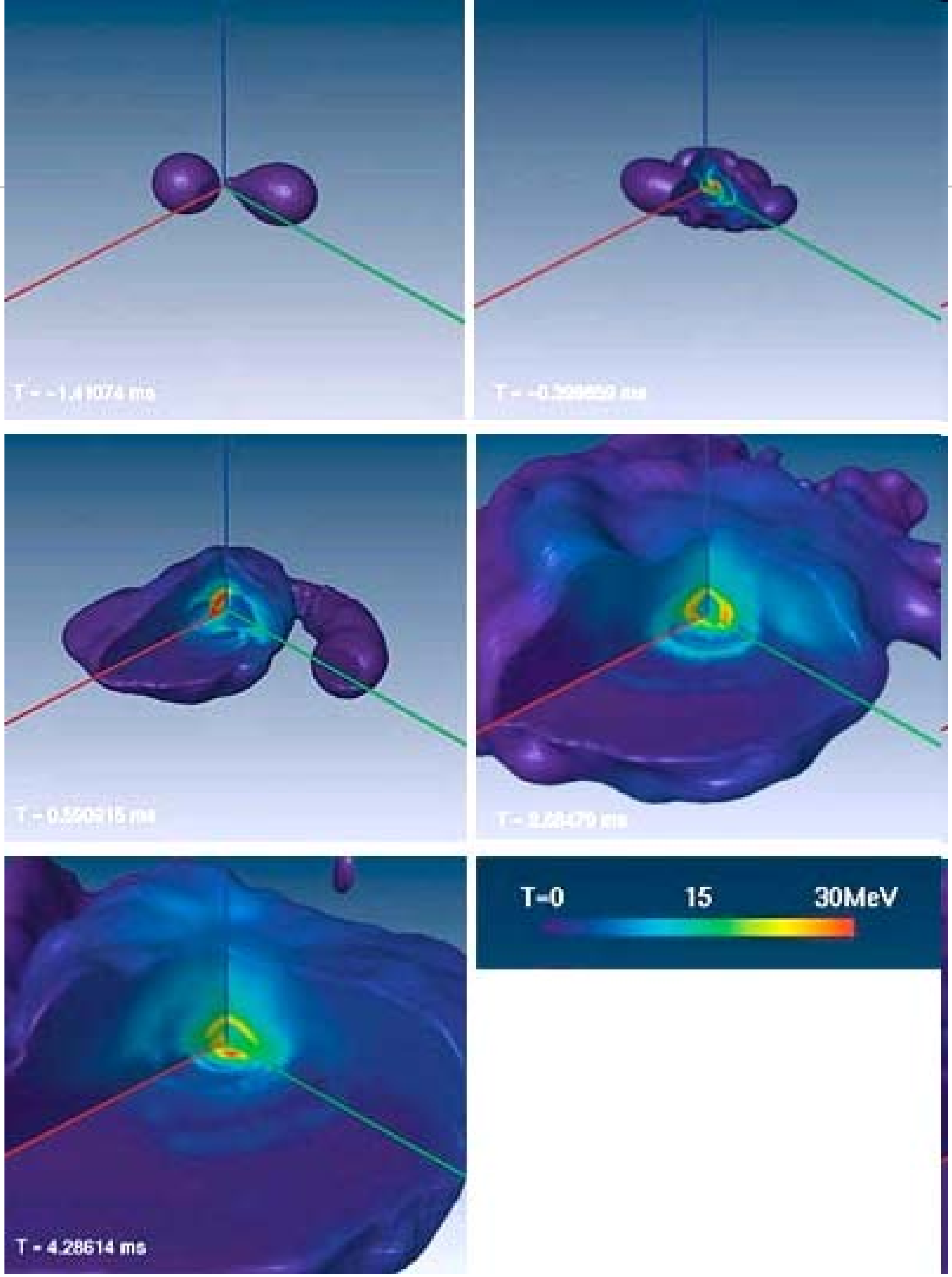
**Figure 12** Metallicity as a function of *B*-band absolute magnitude for the host galaxies of short (*red*) and long (*blue*) GRBs. The yellow bars mark the 14–86 percentile range for galaxies at *z* 0.1 from the Sloan Digital Sky Survey (Tremonti et al. 2004), whereas crosses designate field galaxies at *z* 0.3–1 (Kobulnicky & Kewley 2004). Both field samples exhibit a clear luminosity-metallicity relation. The long GRB hosts tend to exhibit lower-than-expected metallicities (Stanek et al. 2006), whereas the hosts of short GRBs have higher metallicities by 0.6 dex and are moreover in excellent agreement with the luminosity-metallicity relation. From Berger (2009).




Miguel Aloy, Ewald Müller, Hans-Thomas Janka
MPI für Astrophysik

# DREI verschiedene GRB-Typen ?

# 2006: 2 ungewöhnliche GRBs

- Langer GRB060614 mit einer Dauer von 102 s (z=0.125)

- Langer GRB060505 mit einer Dauer von 4s

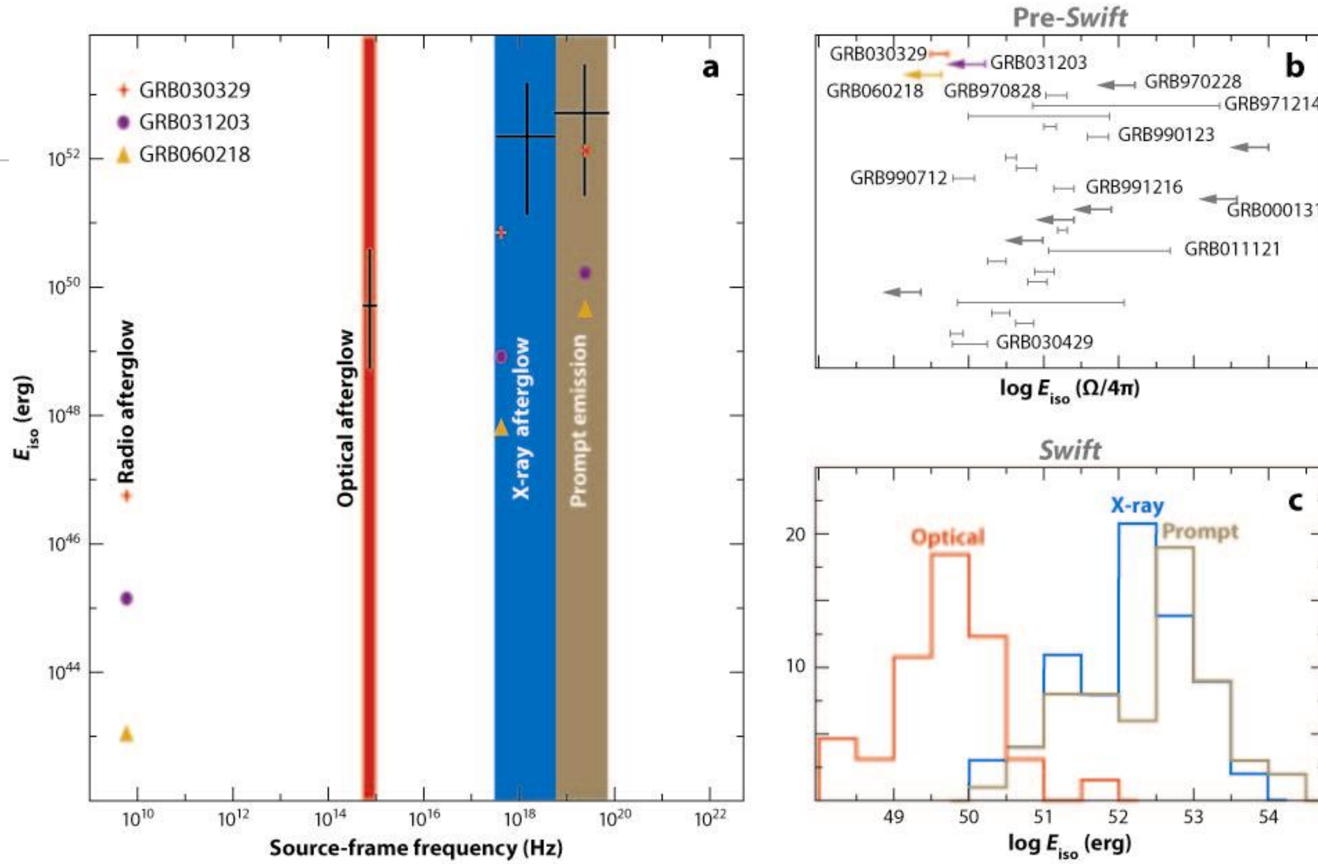
- Mit einem langen GRB sollte eine Supernova auftreten – keine entdeckt

- Außergewöhnlich lichtschwache GRBs?
- Lichtkurve passt eher zu kurzen GRBs
- Eine neue Klasse?

- SN zu schwach, so daß das ausgeworfene Material wieder zurückfiel auf das Schwarze Loch und somit nicht als hell leuchtender Ausbruch in Erscheinung trat

- Bislang 4000 GRBs, die gut in 2 Klassen passen – 2 Ausreißer noch nicht genug, um das Modell zu überdenken


Kosmologische
Relevanz der  GRBs?




Gehrels N, et al. 2009.
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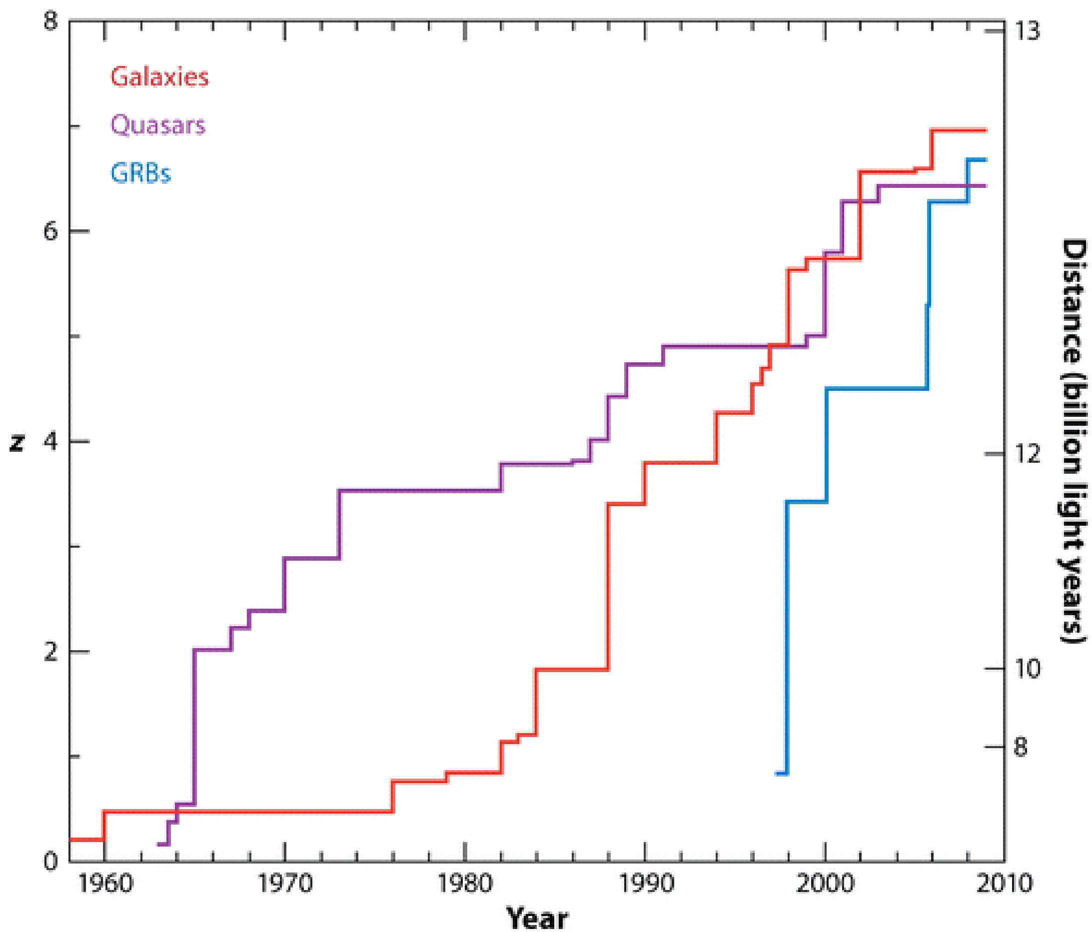
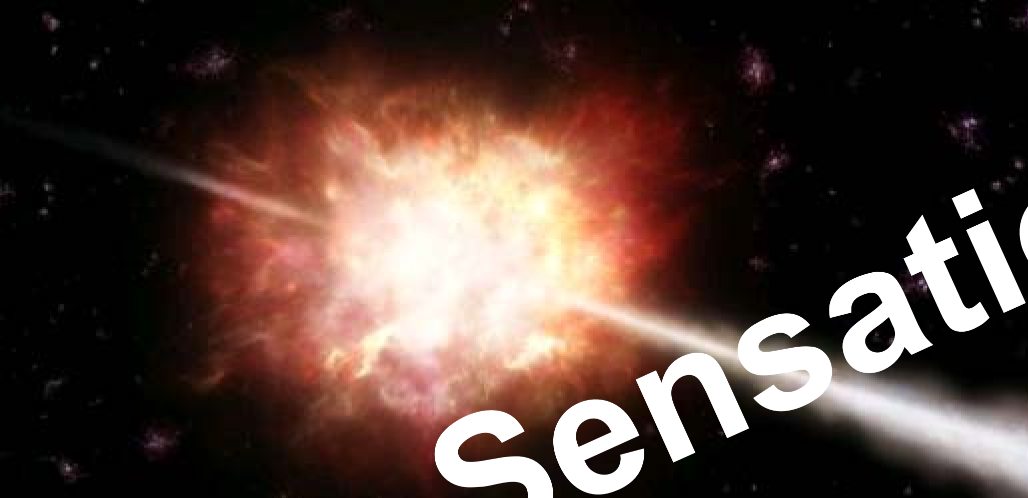
**Figure 10** The radiated-energy inventory of *Swift* GRBs. (*a*) Summary of the isotropic-equivalent total emitted energy of the prompt and afterglow emission for *Swift* GRBs in the source frame (adapted from Kaneko et al. 2007). (*b*) Comparisons of collimation-corrected total emitted γ-ray energy, $E_{iso}(\Omega/4\pi)$, of pre-*Swift* GRBs, where $E_{iso}$ is used as an upper limit for GRBs with no jet angle constraints. (*c*) Distributions of cumulative isotropic-equivalent total emitted energy for *Swift* GRBs.

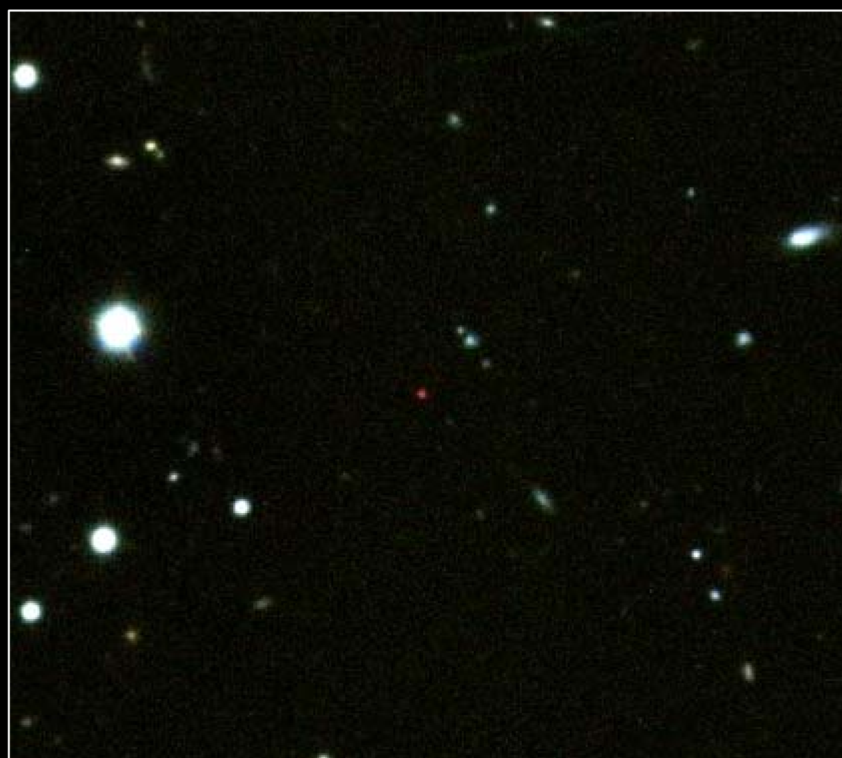



Gehrels N, et al. 2009.
Annu. Rev. Astron. Astrophys. 47:567–617

**Figure 16** High-z record holders. The history of most distant objects detected in categories of galaxies, quasars, and GRBs. (R. McMahon & N. Tanvir, private communication)

# Die Sensation!!





# Rekordausbruch

Für dieses Bild von GRB 090423 wurden Daten des UV/optischen-Teleskops (blau, grün) und des Röntgenteleskops (orange, rot) von Swift kombiniert.

**Bild**: NASA / Swift / Stefan Immler

- GRB090423, Sternbild Löwe, 10 sec
- 630Mio Jahre nach dem Urknall
- Tod eines Sterns und Geburt eines Schwarzen Lochs
- Kein optisches Nachglühen:UV-Licht würde Richtung sichtbares Licht rotverschoben, UV-Licht wird durch dort vermehrt vorhandenes Wasserstoffgas absorbiert
- 3h nach GRB: Infrarotquelle entdeckt (Mauna Kea); Entfernung mit Gemini North-Teleskop: 13 Milliarden Lichtjahre Entfernung
- Rotverschiebung: **8.2 !!**

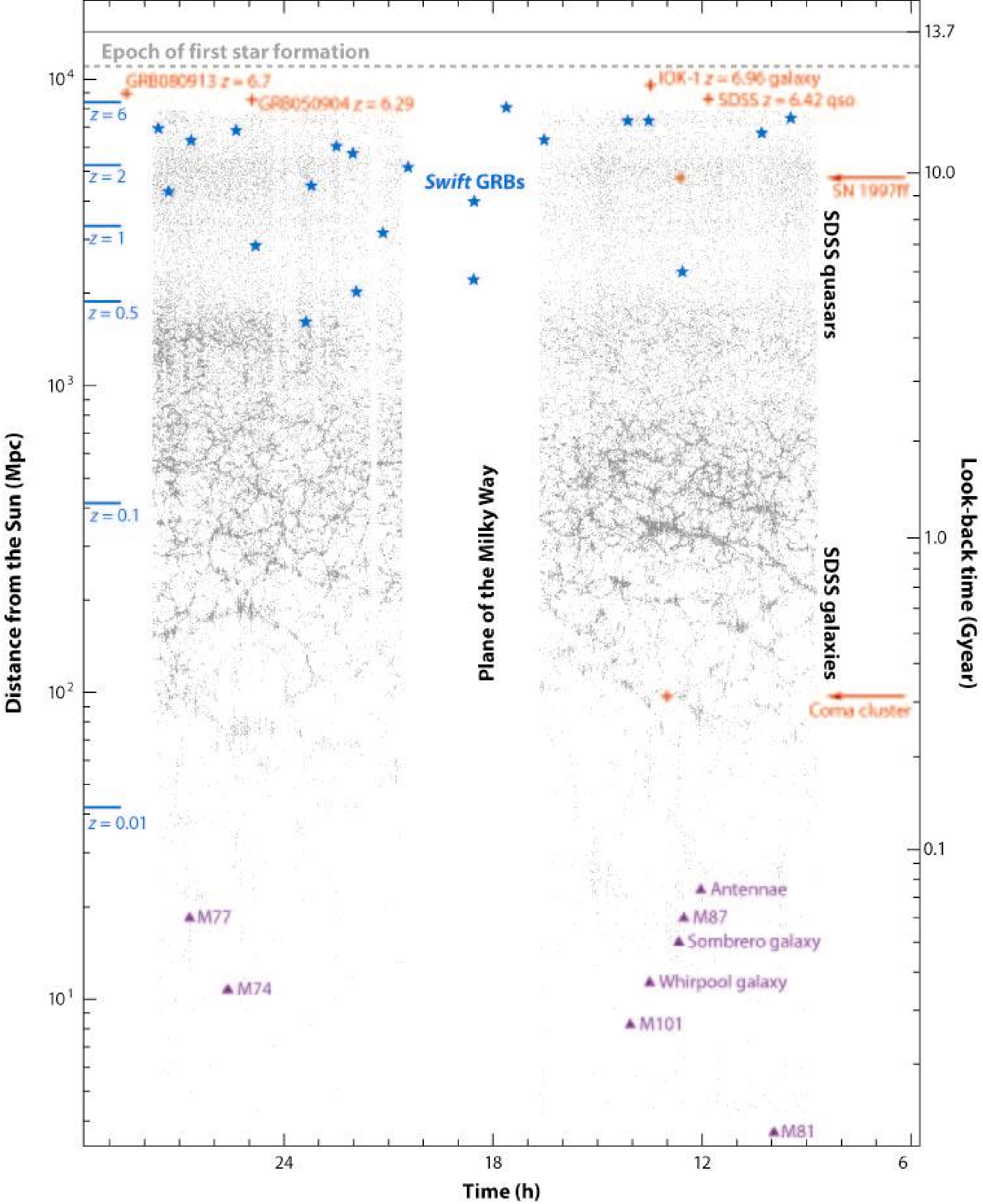



**Figure 15** A 360° vista showing the entire sky, with visible structures stretching back in distance, time, and redshift. The most distant light we observe comes from the radiation leftover from the Big Bang: the CMB. As we descend the chart, we find the most distant objects known, followed by a web of Sloan Digital Sky Survey (SDSS) quasars and galaxies. Closer to home, we start to see a collection of familiar "near" galaxies (*purple triangles*). Also marked are all Swift GRBs with known distances (*blue stars*); SN 1997ff, the most distant type Ia supernova at $z = 1.7$; and the archetypal large galaxy cluster, the Coma cluster. The redshift distances of most distant GRBs are comparable to the most distant galaxies and quasars [adapted from Ramirez-Ruiz (2006a)].

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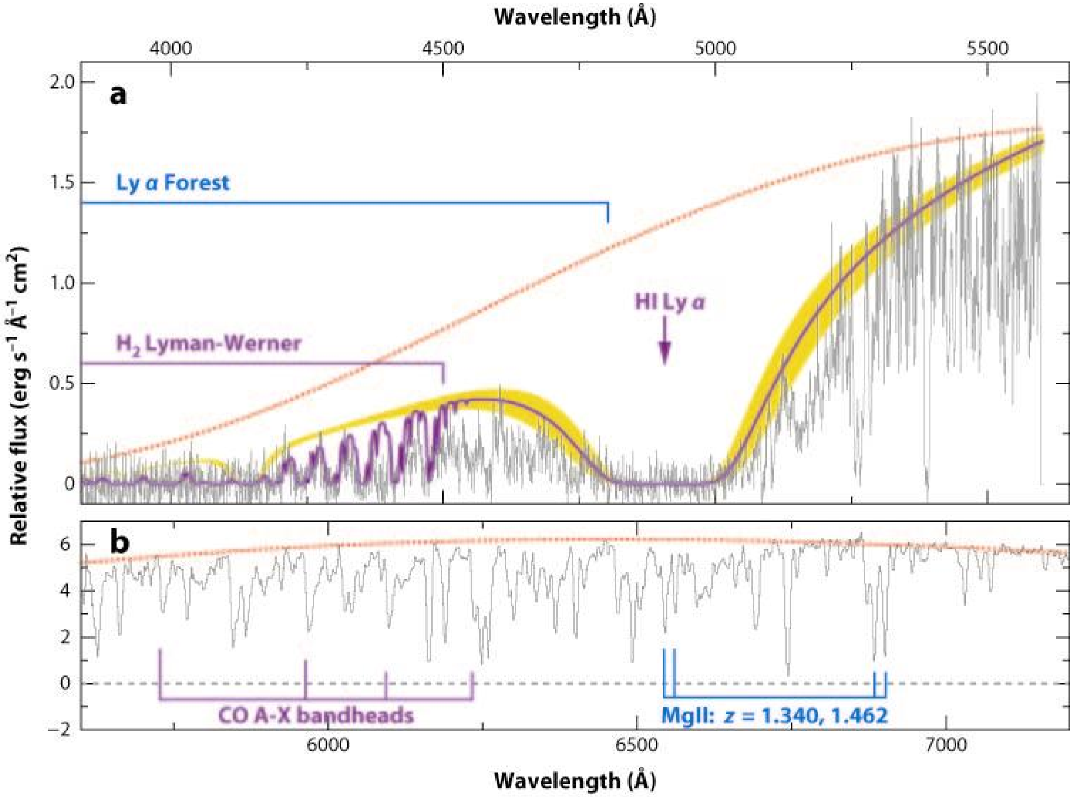
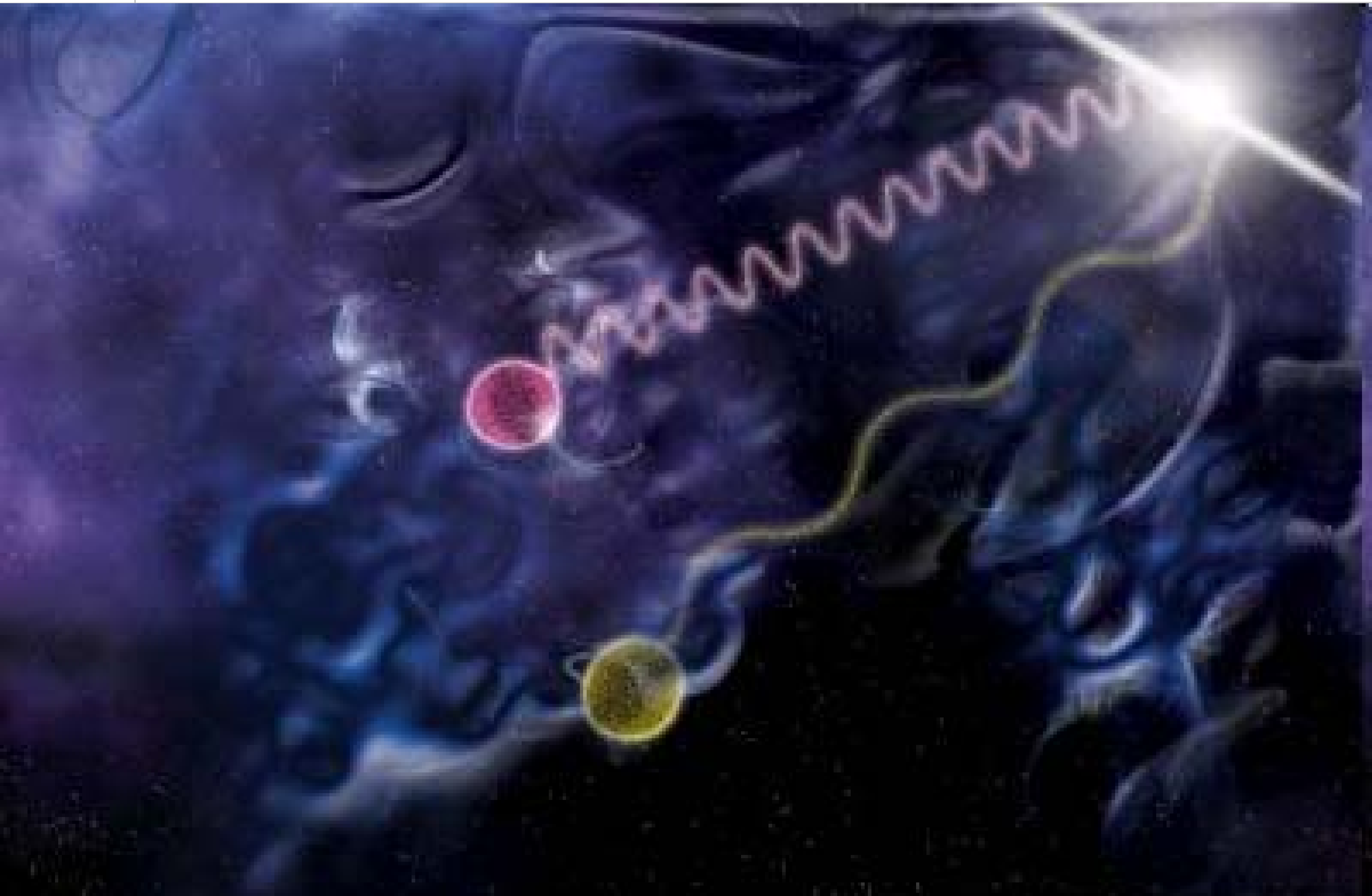



Gehrels N, et al. 2009.
Annu. Rev. Astron. Astrophys. 47:567–617

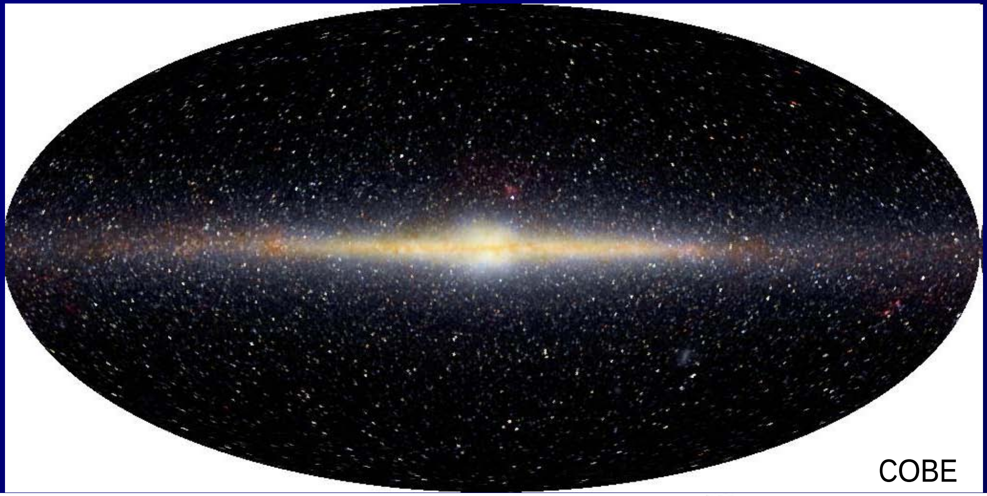
**Figure 13** (*a*) Keck/LRIS spectrum of the afterglow for GRB080607 (Prochaska et al. 2009). The red dashed lines indicate a model of the intrinsic afterglow spectrum reddened heavily by dust in the host galaxy (rest-frame $A_V \approx 3.2$). At λ ≈ 4900 Å, one identifies a damped Lyman-alpha (Ly α) profile associated with HI gas near the GRB. The yellow shaded region overplotted on the gray data corresponds to an HI column density $N_H = 10^{22.7\pm0.15}$ cm$^{-2}$. The model (*purple solid line*) includes absorption from $H_2$ Lyman-Werner transitions. The line opacity at λ > 5500 Å is dominated by metal-line transitions from gas in the host galaxy and includes bandheads of the CO molecule. Surprisingly, this is the only sightline to date to show strong molecular absorption (Tumlinson et al. 2007). It also exhibits a roughly solar metallicity. (*b*) The spectral region or features corresponding to intergalactic Ly α and Mgii absorption. The redshift for GRB080607 is $z$ = 3.036.

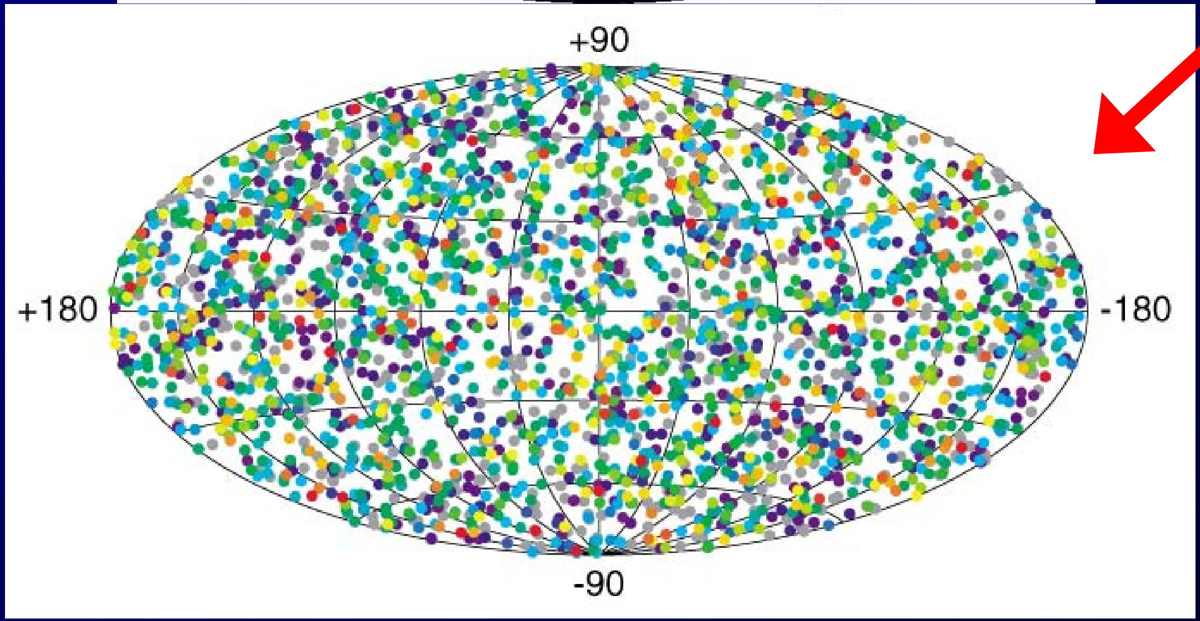
# Einstein hat recht



# Batse, SWIFT, Fermi

# Gamma ray burst locations



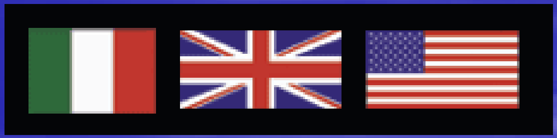




Gamma ray bursts observed by the BATSE instrument on the Compton Gamma Ray Observatory

(about one gamma ray burst per day was observed)

2704

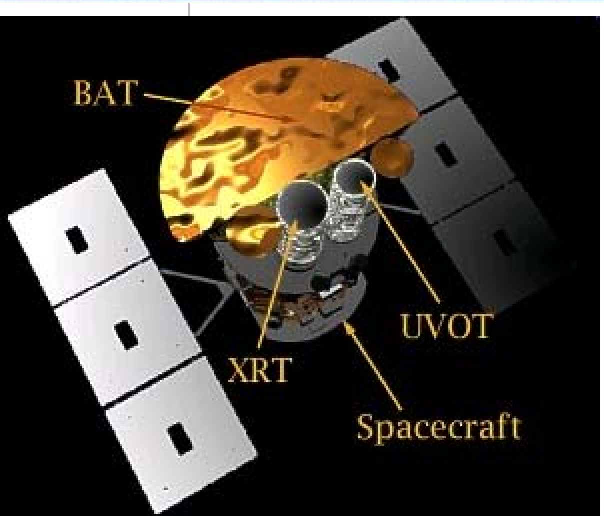
# Swift Gamma-ray Burst Mission

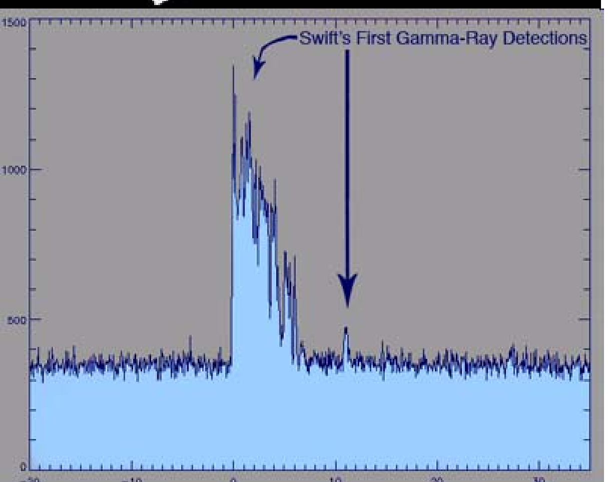


- Studies Gamma-Ray Bursts with a *swift* response
- Survey of “hard” X-ray sky
- Nominal 2-year lifetime

PENNSTATE

Mission Operations Center for Swift




- The first gamma-ray burst detected by Swift's Burst Alert Telescope was seen on December 11, 2004, beginning at 23:57 (UT). Time is measured on the X-axis; the number of gamma-ray photons is measured on the Y-axis. This chart captures the essence of the gamma-ray burst mystery -- a sudden rush of gamma rays lasting only about 7 seconds, coming seemingly from nowhere and disappearing forever.

Blitzt ein GRB auf, schwenkt Swift innerhalb von 20 bis 75 Sekunden vollautomatisch auf die Position des Blitzes, um Beobachtungen Aufzunehmen!!

Gamma-ray Burst Real-time Sky Map

http://grb.sonoma.edu/

# Swift Instruments

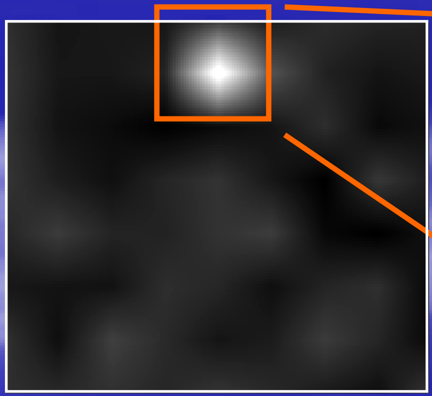
- Burst Alert Telescope (BAT)
- Ultraviolet/Optical Telescope (UVOT)
- X-ray Telescope (XRT)
- Autonomous re-pointing, 20 - 70 sec
- Onboard and ground triggers

Swift in GSFC clean room

# Observing Strategy

- BAT triggers on GRB, calculates position to < 4 arcmin
- Spacecraft autonomously slews to GRB position in 20-70 s
- XRT determines position to < 5 arcseconds
- UVOT images field, transmits finding chart to ground

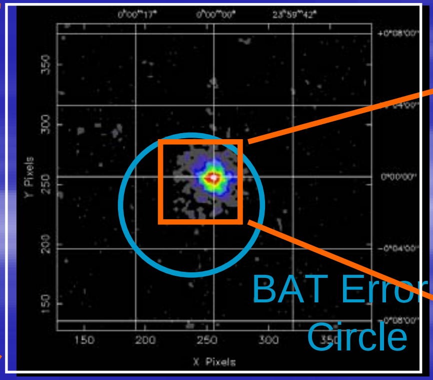
**BAT Burst Image**



**T<10 sec**

$\theta < 4'$

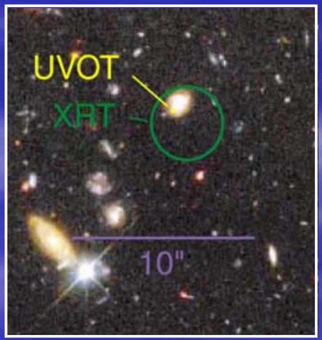
**XRT Image**




**T<100 sec**

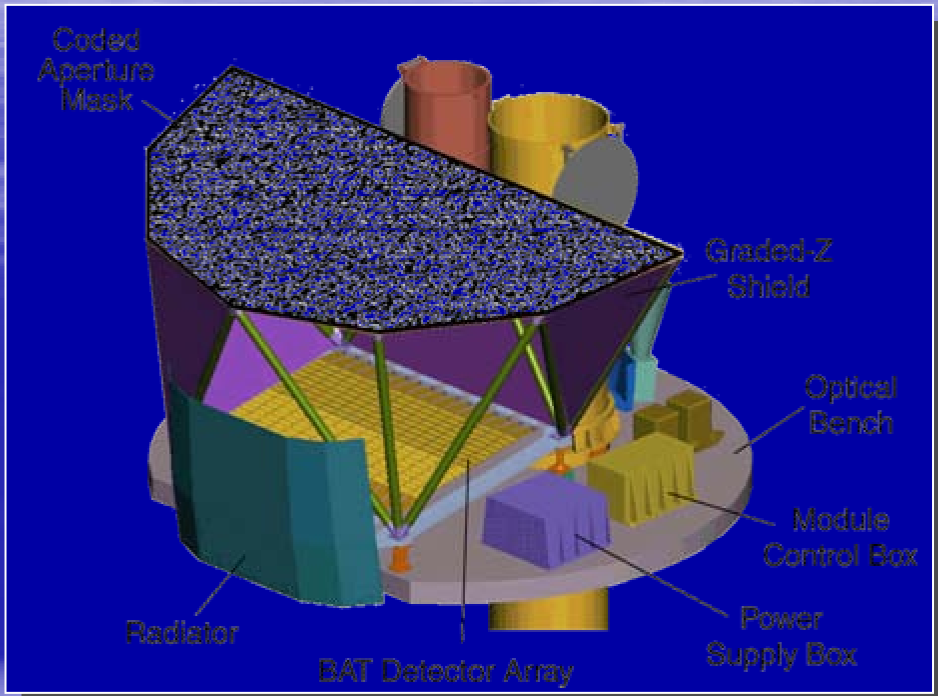
$\theta < 5''$

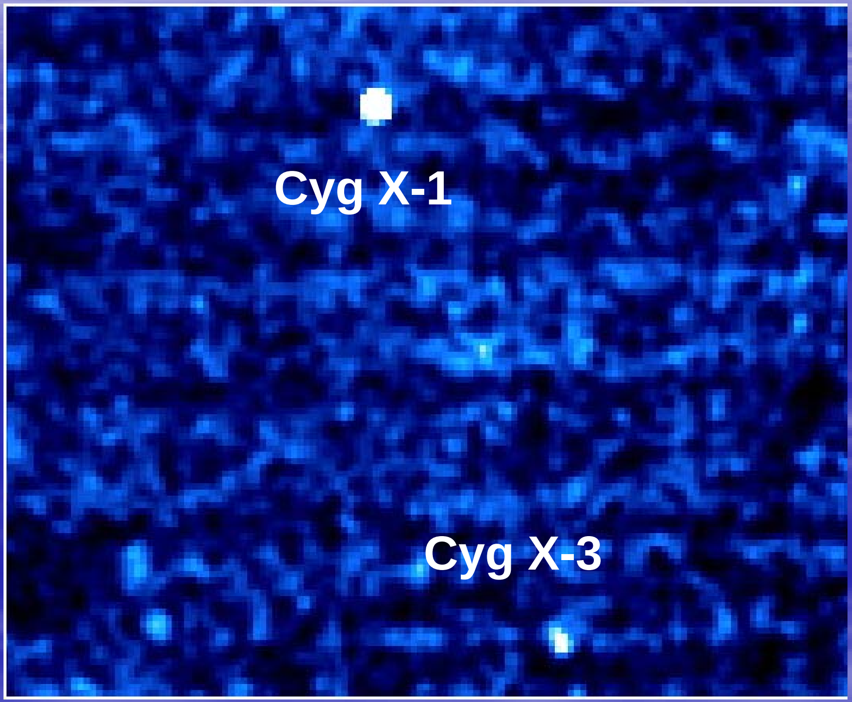
**UVOT Image**




**T<300 sec**

# Burst Alert Telescope



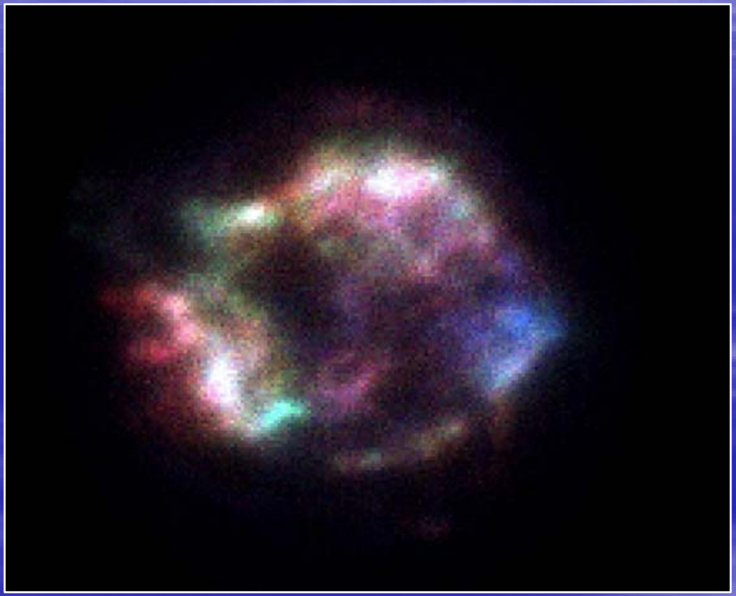

- Detect >100 GRBs per year
- Most sensitive gamma-ray imager ever
- CdZnTe detectors

**First light image 1/5/05**

# X-ray Telescope (XRT)

**XRT Characteristics**

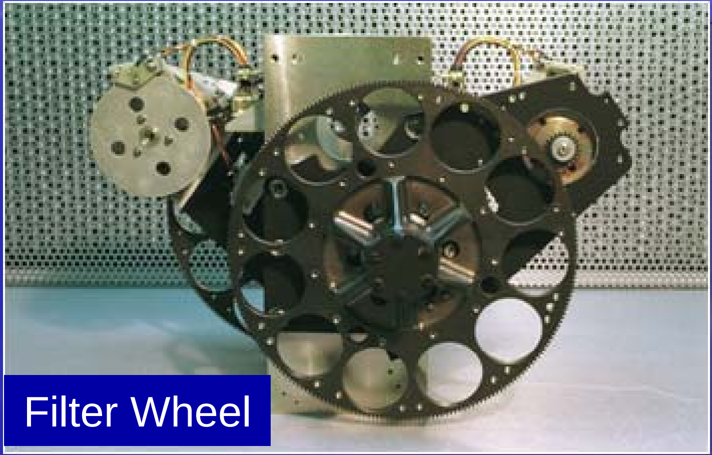
| | |
|---|---|
| Telescope | 3.5 m Wolter I, 12 shells |
| Telescope PSF | 15 arcsec HPD @ 1.5 keV |
| Position Accuracy | 2.5 arcseconds (2 sigma) |
| Detector | E2V CCD-22 |
| Detector Format | 600 x 600 pixels |
| Energy Resolution | 140 eV @ 5.9 keV |
| Timing Resolution | 0.14 / 1.1 milliseconds |
| Field of View | 23.6 x 23.6 arcminutes |
| Pixel Scale | 2.36 arcsec / pixel |
| Energy Range | 0.2 - 10 keV |
| Effective Area | 110 $cm^2$ @ 1.5 keV |
| Sensitivity | $2x10^{-14}$ erg $cm^{-2}s^{-1}$ in $2x10^4$ s |
| Max Flux | > 45 Crabs (45,000 cps) |
| Operation | Autonomous |



**Cas A**

**First light image 1/5/05**

# UV-Optical Telescope


- Arcsec imaging
- Grism spectroscopy
- 24th mag sensitivity (1000 sec)
- Finding chart for other observers

# UVOT

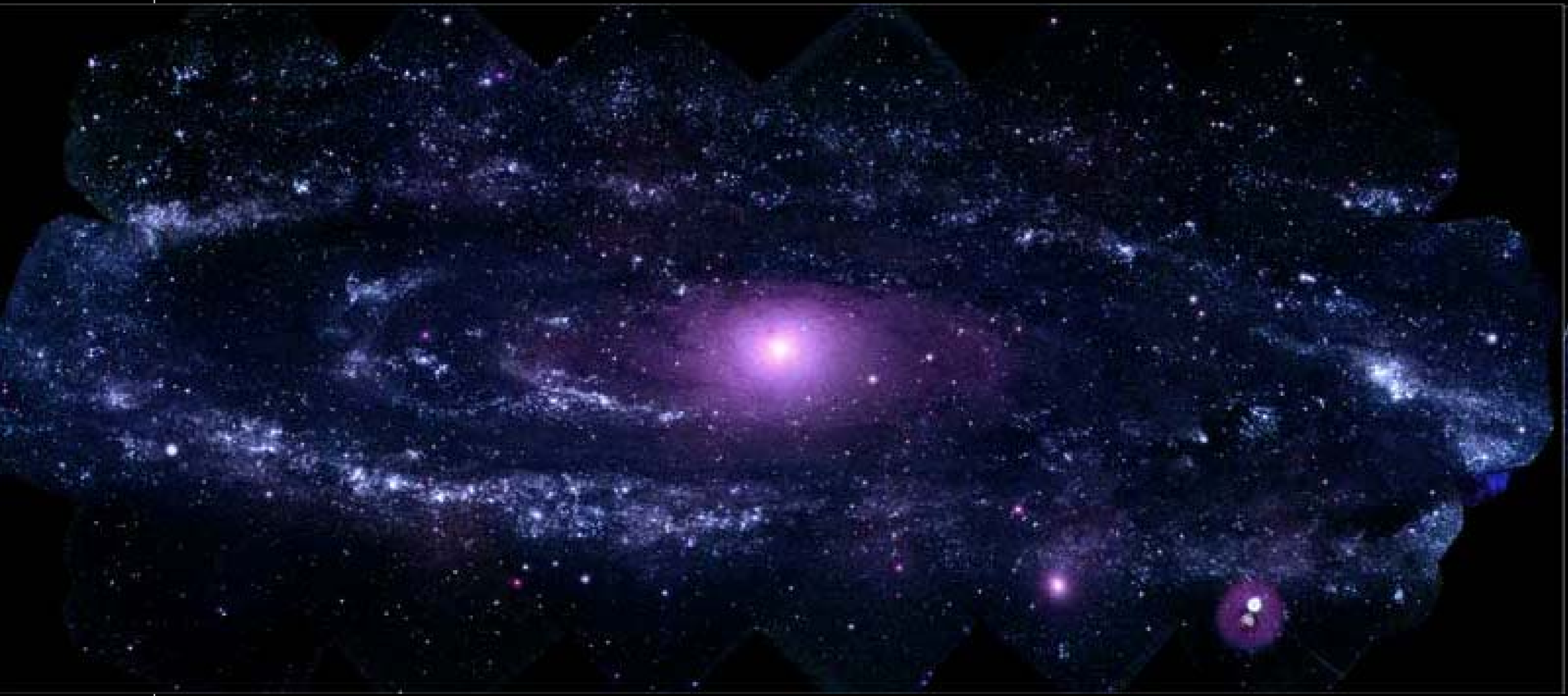
### UVOT Characteristics

| | |
|---|---|
| Telescope | 30 cm Ritchie-Cretien |
| Telescope PSF | 0.9 arcsec FWHM @ 350 nm |
| Position Accuracy | 0.3 arcseconds (2 sigma) |
| Detector | Microchannel-intensified CCD |
| Detector Format | 2048 x 2048 pixels |
| Spectral Resolutn | >300 @ 300 nm for $M_v < 17$ |
| Timing Resolution | 11 milliseconds |
| Field of View | 17 x 17 arcminutes |
| Pixel Scale | 0.5 arcsec / pixel |
| Spectral Range | 170 – 600 nm |
| Sensitivity | 24th magnitude in 1000 s |
| Max source | 8th magnitude |
| Operation | Autonomous |

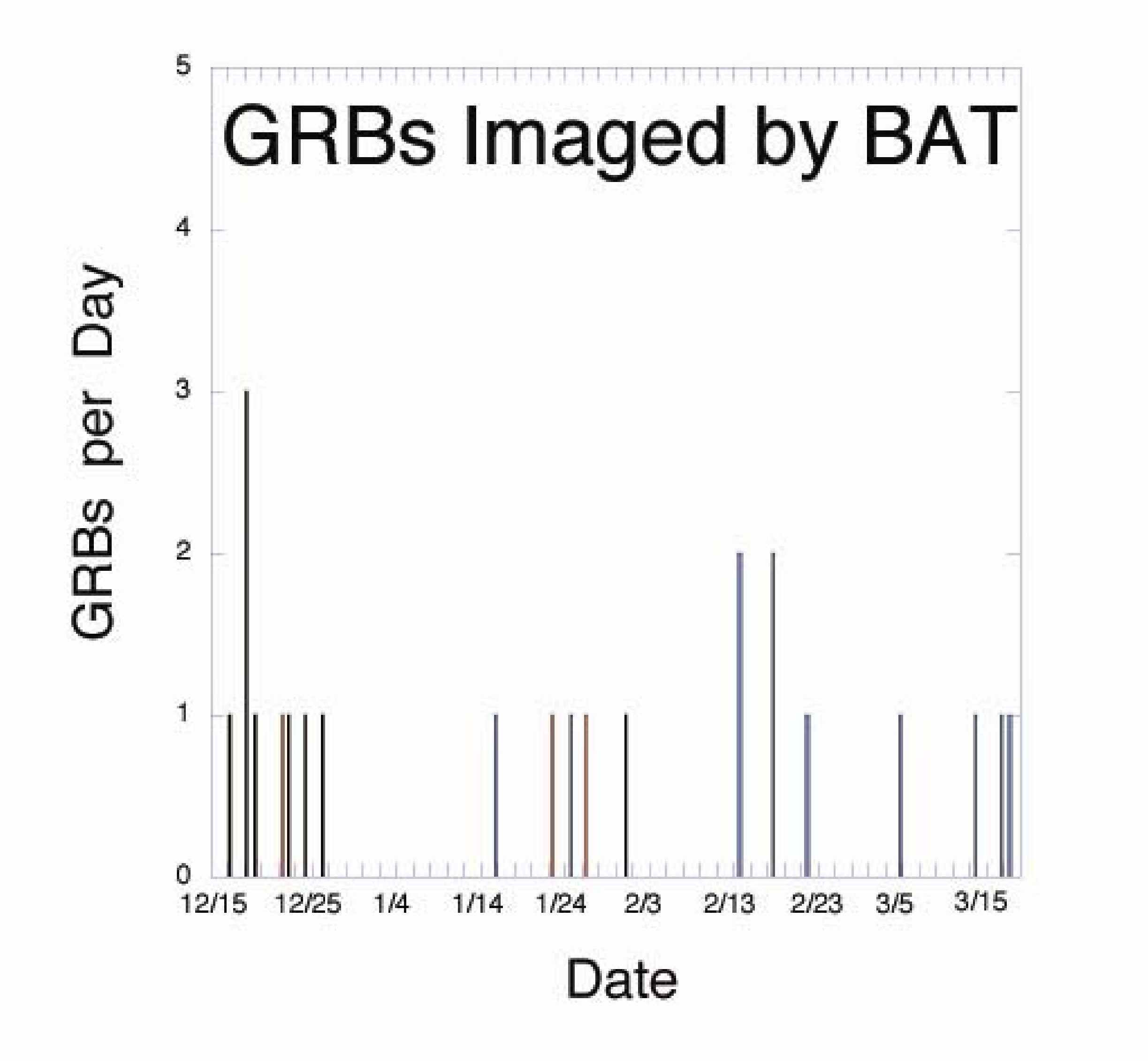
**M101**

**First light image 2/1/05**

# SWIFT: UV-Bild der Andromeda Galaxie



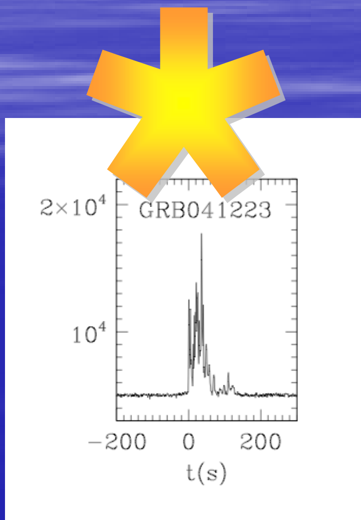
# Swift burst history



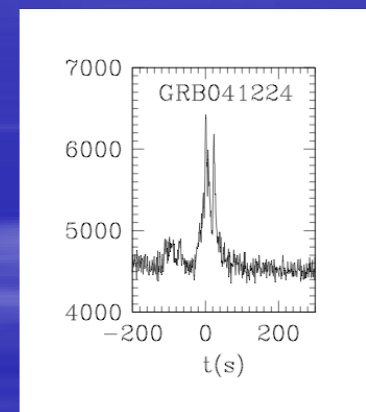

Lynn Cominsky

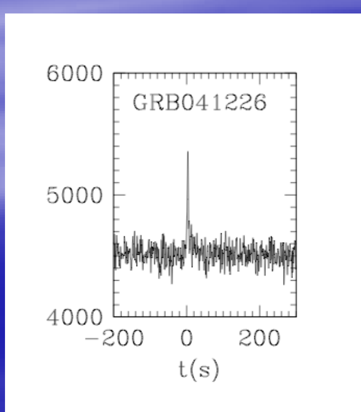
# Next 6 Swift bursts

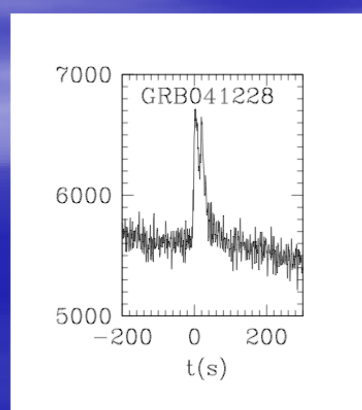
- GRB041223 – first x-ray afterglow

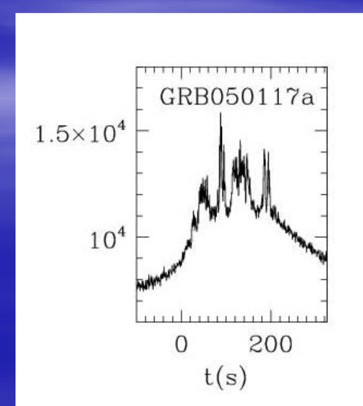


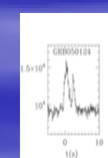


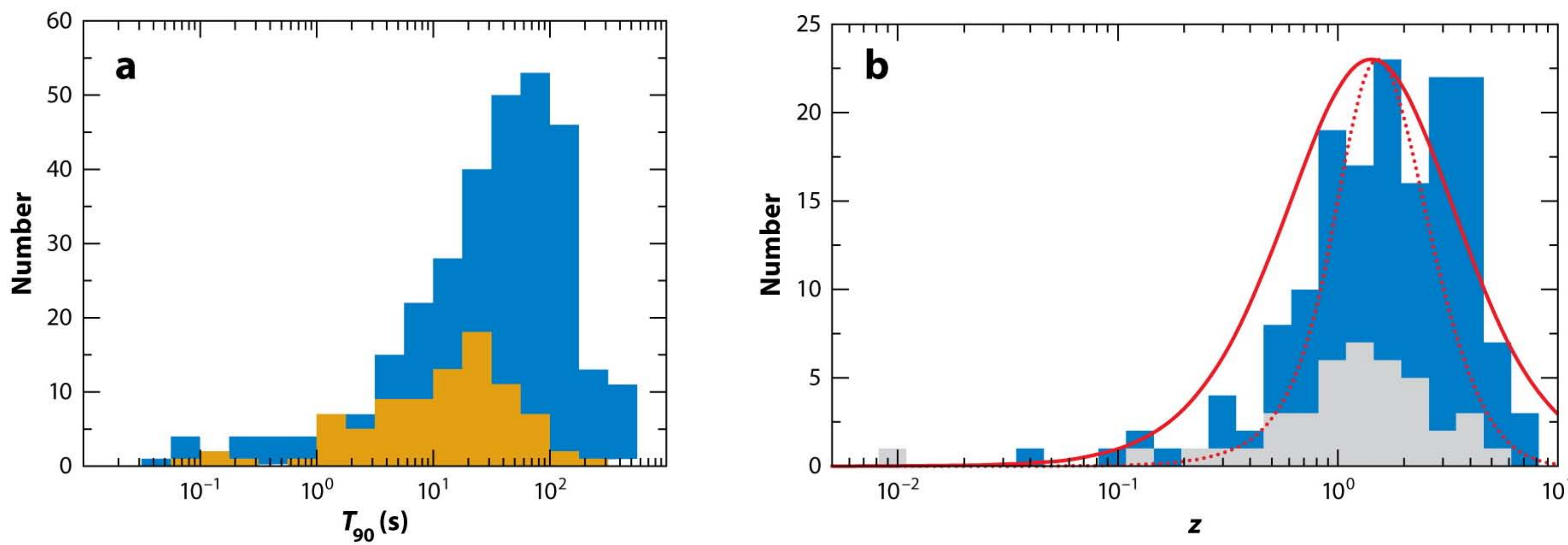


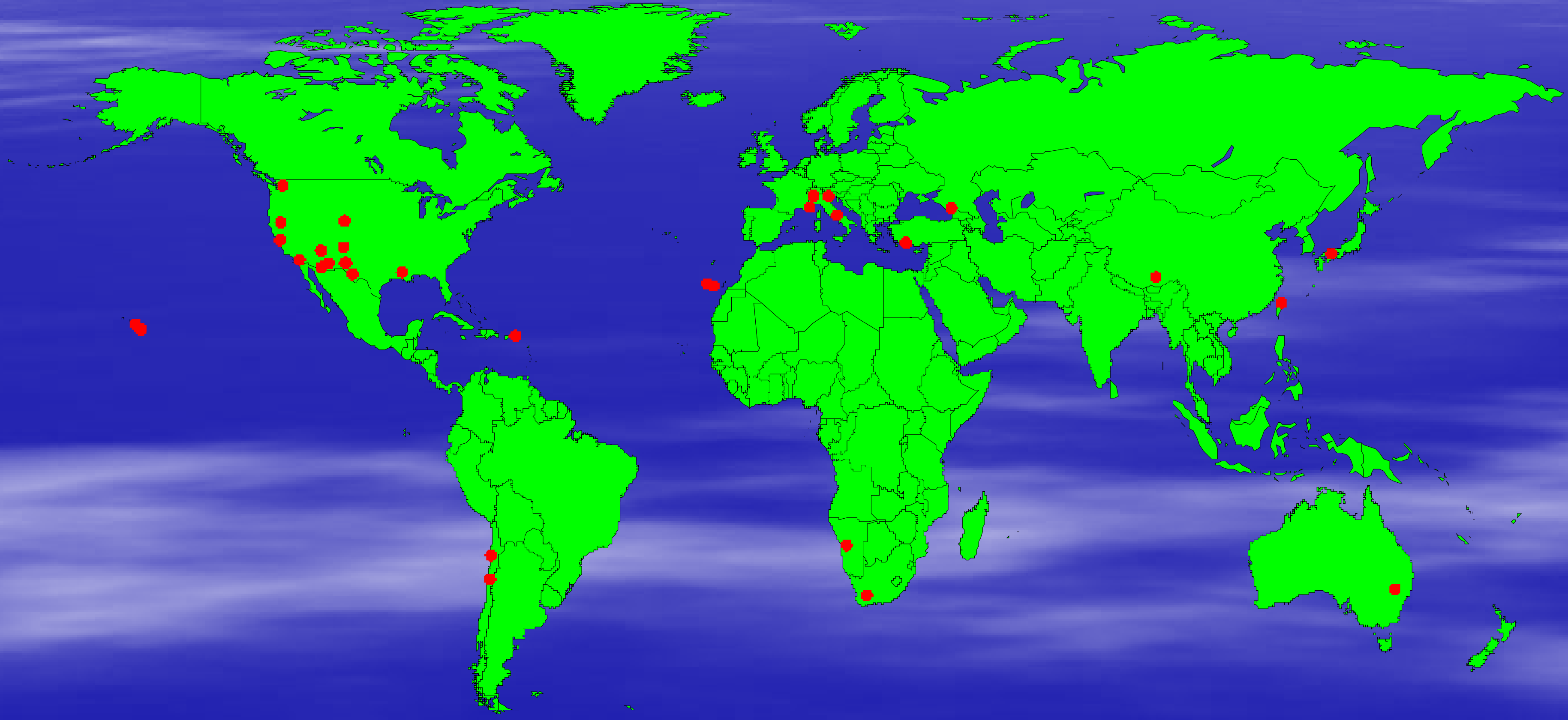






Gehrels N, et al. 2009.
Annu. Rev. Astron. Astrophys. 47:567–617

**Figure 4** Duration and redshift distribution for *Swift* GRBs. (*a*) The duration distribution. The blue histogram is the measured $T_{90}$ distribution; the orange one is corrected to the source frame: $T_{90}/(1 + z)$. (*b*) The redshift distribution for *Swift* GRBs in blue and pre-*Swift* GRBs in grey. *Swift* is detecting higher redshift bursts on average than pre-*Swift*. The thick solid red theory curve illustrates the evolution of a comoving volume element of the Universe; the thin dotted red curve is a convolution of the comoving volume with a model for the star-formation rate as calculated by Porciani & Madau (2001)

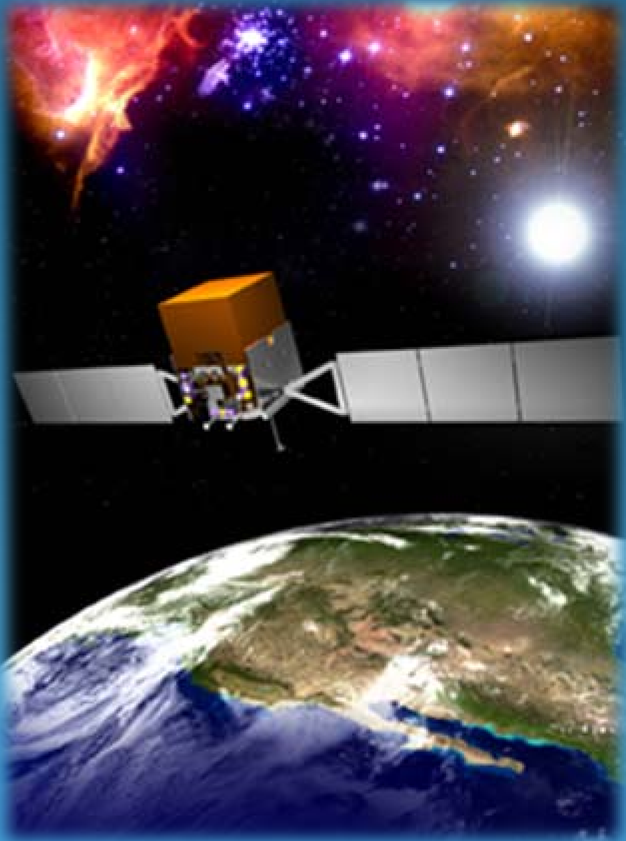
# Follow Up Network



**44 members using telescopes that span the globe**

Lynn Cominsky

# Gamma Ray Space Telescope



# Anforderungen an die Instrumente

**Large Area Telescope (LAT)**

- Großes „Blickfeld“, über 2 sr
- Messgenauigkeit von 1 arcmin
- Energiebereich von 30 MeV bis 300 GeV
- Kurze Messzeiten
- Lange Lebensdauer
- Fähigkeit die Signale der Kosmischen Strahlung zu verwerfen

**GLAST Burst Monitor (GBM)**

- Überwachung des gesamten Himmels zu jedem Zeitpunkt
- Großes Energiespektrum
- Gute Zeitauflösung

# Gamma-ray bursts: Fermi Ergebnisse

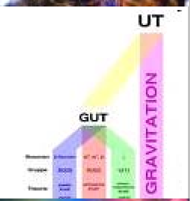
- The following is a GCN Circular circulated via the AAVSO network. For an archive and more information on circulars visit: http://lheawww.gsfc.nasa.gov/docs/gamcosray/legr/bacodine/gcn3_archive.html
- TITLE: GCN CIRCULAR NUMBER: 8822 SUBJECT: GRB 090117C - Fermi GRB Detection DATE: 09/01/18 06:15:23 GMT
- FROM: Valerie Connaughton at MSFC <valerie at nasa.gov> Valerie Connaughton (UAH) reports on behalf of the Fermi GBM Team:
- "At 15:10:40.18 UT on 17 Jan 2009, the Fermi Gamma-Ray Burst Monitor triggered and located GRB 090117C (trigger 253897842 / 090117632). The on-ground calculated location, using the GBM trigger data, is RA = 117.6, DEC = -40.3 (J2000 degrees, equivalent to 07h 50m, -40d 18'), with an uncertainty of 1.8 degrees (radius, 1-sigma containment, statistical only; there is additionally a systematic error which is currently estimated to be 2 to 3 degrees).
- The angle from the Fermi LAT boresight is 54 degrees.
- The GBM light curve consists of a precursor lasting tens of seconds until trigger time, followed by a single episode with substructure lasting a further 35 s. The total duration (T90) between 8 and 1000 keV is about 86 s. The time-averaged spectrum of the main emission from T0-2 s to T0+29 s is best fit by a Band function with Epeak = 247 +/- 41 keV, alpha = -1.0 +/- 0.1, and beta = -2.1 +/- 0.2, giving an 8-1000 keV fluence of (1.1 +/- 0.1) E-5 erg/cm^2.
- The precursor spectrum from T0-55 sec to T0-6 s is best fit using a power law function with an exponential high energy cutoff. The power law index is -1.3 +/- 0.1 and the cutoff energy, parameterized as Epeak, is 147 +/- 38 keV. The 8-1000 keV fluence of the precursor is (3.9 +/- 0.5) E-6 erg/cm^2. A 1-sec peak photon flux of 4.2 +/- 0.7 ph/s/cm^2 in the 8-1000 keV band is measured starting at T0+22.5 s. The spectral analysis results presented above are preliminary; final results will be published in the GBM GRB Catalog."

# GRB-Forschung in der Zukunft

# Vergangenheit, Gegenwart & Zukunft

| Mission | Trigger energy range | FOV | Detector area | Other wavelengths | GRB rate ($yr^{-1}$) |
|---|---|---|---|---|---|
| BATSE | 20 keV–1.9 MeV (LAD) | $4\pi$ sr | 2025 $cm^2$ per LAD | | 300 |
| | 10 keV–100 MeV (SD) | | 127 $cm^2$ per SD | | |
| *HETE-2* | 6–400 keV | 3 sr | 120 $cm^2$ | X-ray | |
| *Swift* | 15–150 keV | 1.4 sr | 5200 $cm^2$ | UV, Optical, X-ray | 100 (10% SGRBs) |
| *AGILE* | 30 MeV–50 GeV | 3 sr | | Hard X-ray | |
| *Fermi* | 20 MeV–300 GeV (LAT) | >2 sr (LAT) | >8000 $cm^2$ (LAT) | | 50 |
| | 8 keV to 1 MeV (GBM–LED) | 9.5 sr (GBM) | 126 $cm^2$ (GBM–LED) | | |
| | 150 keV to 30 MeV (GBM–HED) | | 126 $cm^2$ (GBM–HED) | | |
| *SVOM* | 4 keV–300 keV (CXG) | 2 sr (CXG) | | Optical, X-ray | 80 |
| | 50 keV–5 MeV (GRM) | 89° × 89° (GRM) | | | |
| *JANUS* | 1–20 keV | 4 sr | | Near-IR, X-ray | (high $z$) |
| *EXIST* | 5–600 keV (HET) | 3.6 sr (HET) | 5.96 $m^2$ (HET) | Optical, near-IR, X-ray | 300 |

# Nächste Vorlesung: in 2 Wochen




- Heute: Die Themen des Semesters – Überblick
- 30.10. Gamma-Ray Bursts
- **13.11. GUT & TOE (Stringtheorie, etc.)**
- 27.1l. LHC & HIGGS
- 11.12. Inflation
- Winterferien: 23.12.-06.01.10
- 08.01.10 Vor dem Urknall
- 22.01.10 Zeit & Lichtgeschwindigkeit
- 05.02.10