Seminar Talk

GRB Afterglows:
X, Opt/IR, Radio

by

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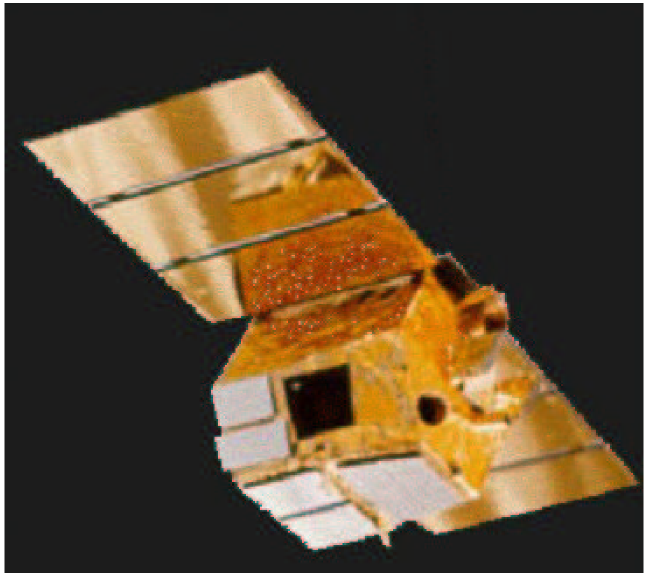
Overview

- History of Discovery and First Afterglow
- Reminder: Classification, Fireball Shock Scenario
- Afterglow Theory: Power Law
- Global Properties of Afterglows
- Afterglow Observations
- Special Effects
- Future Observational Problems

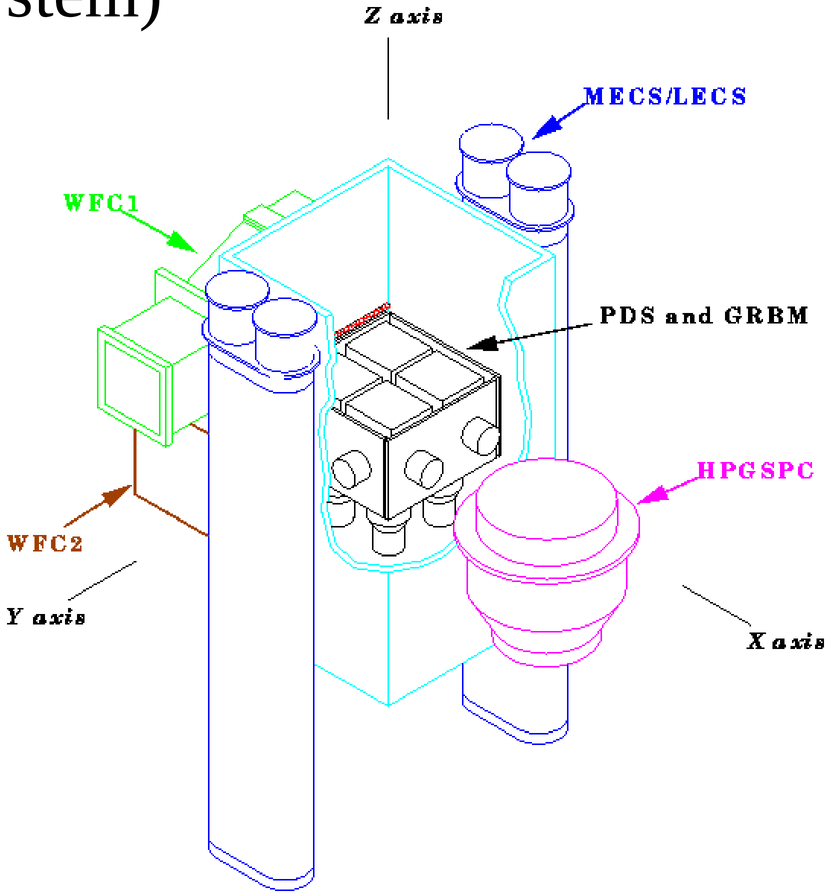
History of Discovery

- first detection of a GRB in 1967 by US military satellites
- first observation of an afterglow in 1997 by satellite BeppoSAX
- BeppoSAX was able to locate the GRB with sufficient accuracy
- so observation with an optical telescope was possible and the redshift could be derived



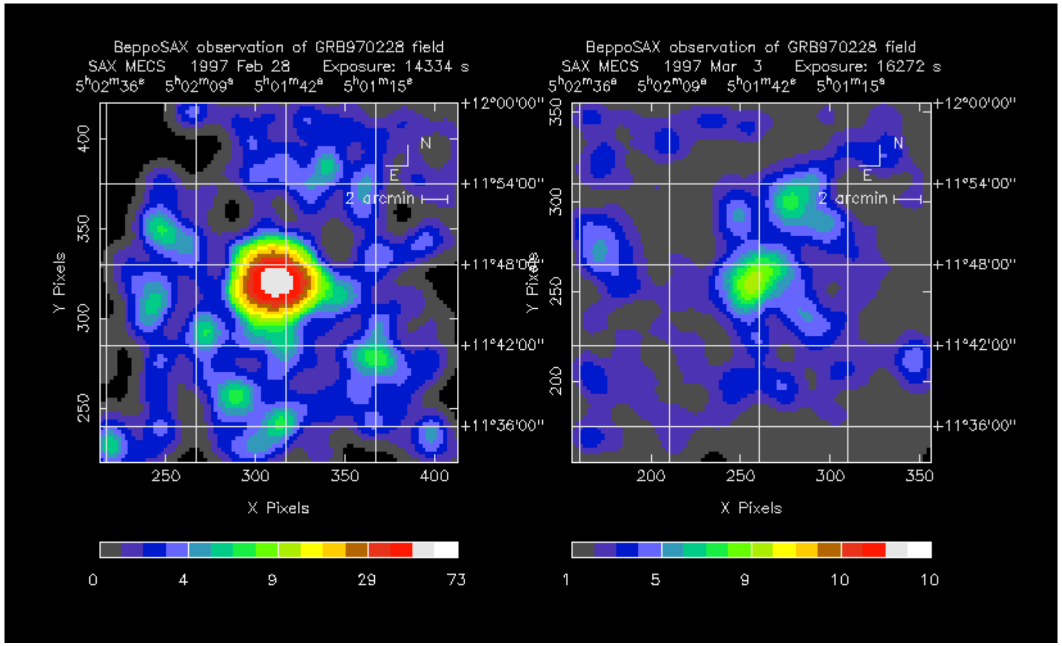
Instruments of BeppoSAX

- PDS (Phoswich Detector System)
  - used to trigger on GRB
- 2 WFI (Wide Field Imager)
  - field of view 40° x 40°,
  - 2-30 keV, resolution 3'
- NFI (Narrow Field Imager)
  - field of view 1° x 1°,
  - 0.5-10 keV, resolution 1'



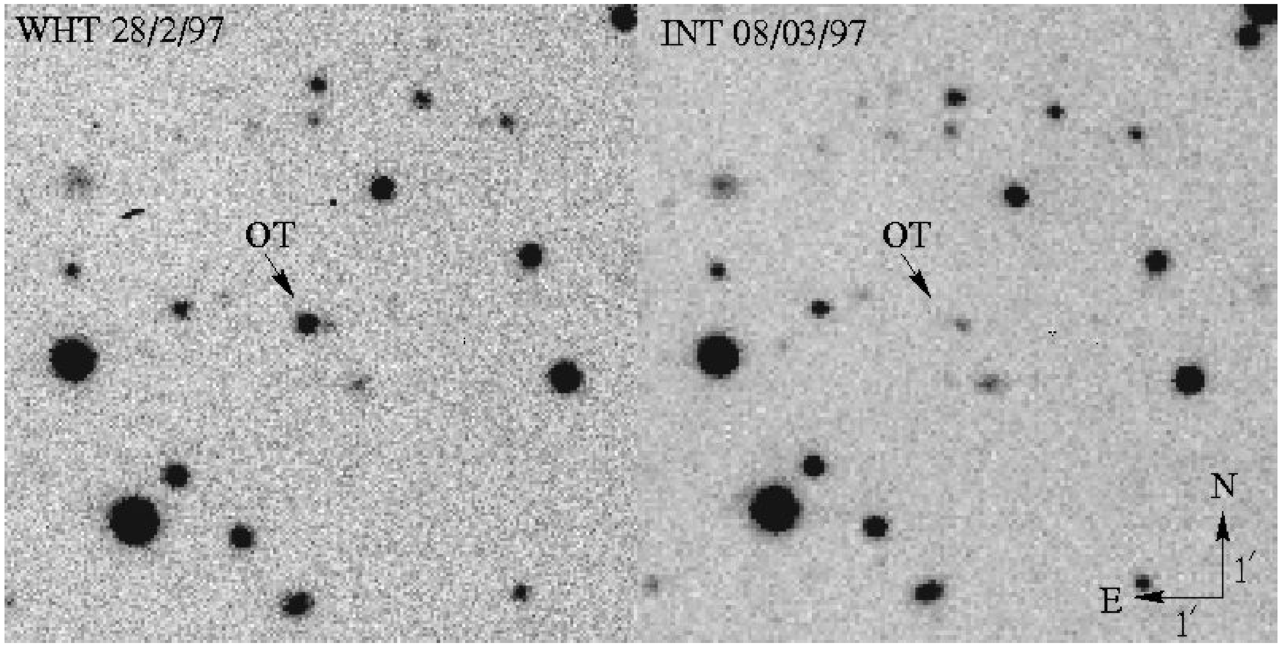
First Afterglow
GRB 970228

- exposures taken by BeppoSAX in X-rays (1-10 keV)
- conditions: same field of view, same exposure time, four days apart, different scaling => fading X-ray source



First Afterglow GRB 970228

- optical transient fades within a week
- exposures taken with Wilhelm-Herschel-Telescope and Isaac-Newton-Telescope on La Palma



First Afterglow
Deriving Distances of GRBs

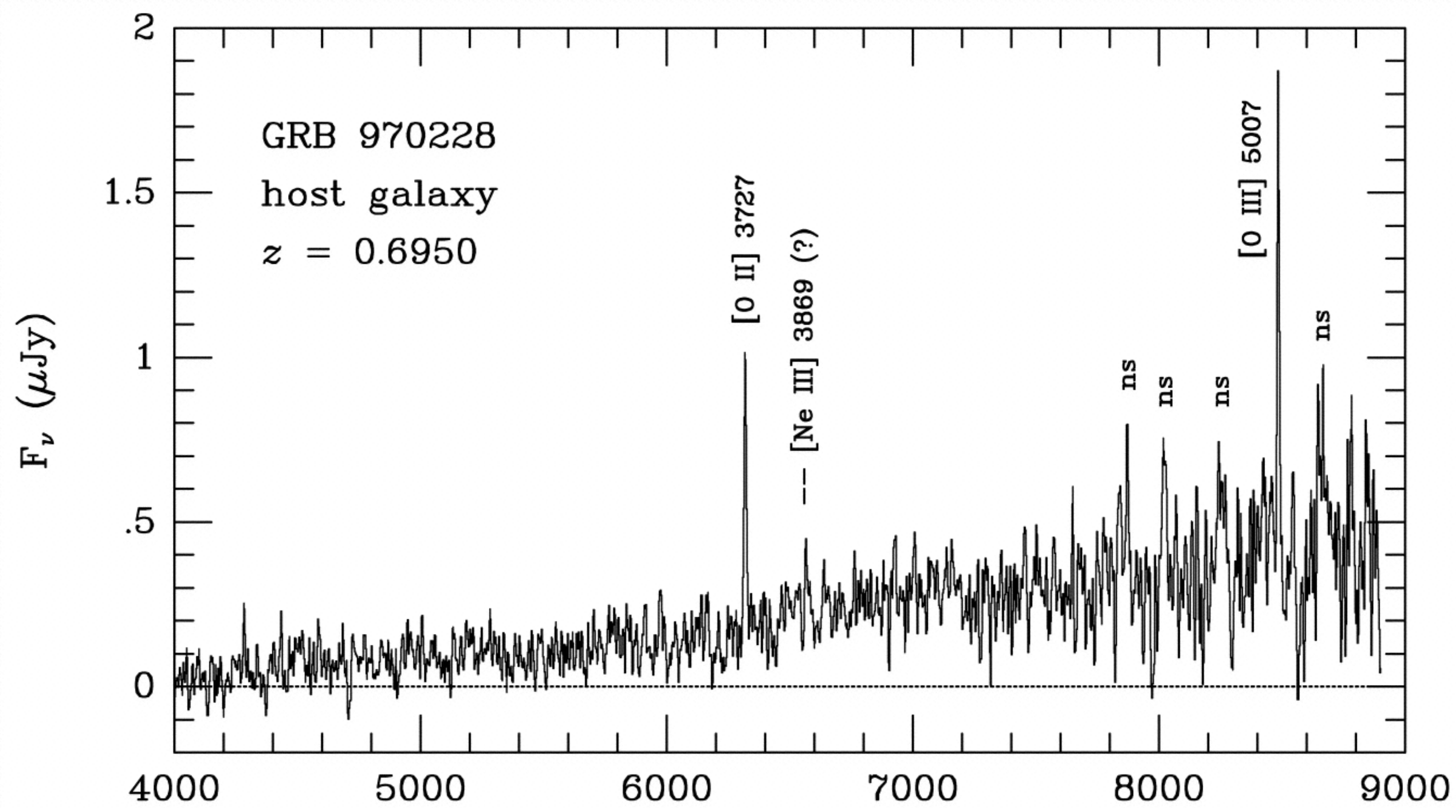
- three theories until 1997: GRBs are events in
  - galactic disc: 10^{38} erg
  - galactic halo: 10^{42} erg
  - distant galaxy: 10^{52} erg

$$S = \frac{F}{4\pi r^2}$$

- for the first time redshift measured for GRB 970228 using host galaxy emission lines
- so distance derived and thus energy scale established

First Afterglow
Deriving Distances of GRBs

- example of calculating redshift $z = \frac{\lambda - \lambda_0}{\lambda_0} \approx \frac{8482 - 5007}{5007} \approx 0{,}694...$



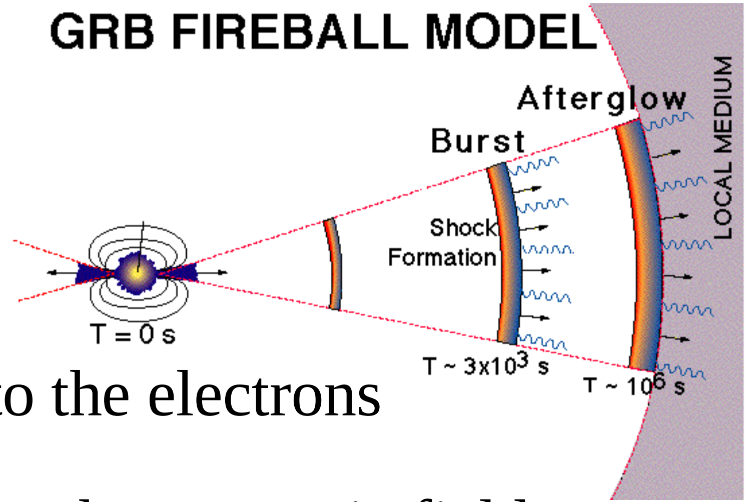
Djorgovski 1997

Reminder
Classification of GRBs

- long bursts: gravitational collaps of one massive star
  - duration longer than 2 sec, mean 30 sec
  - mass accretion rate of 0.1 solar mass per second by the recently built black hole
  - **all current afterglow data is for long bursts only**
- short bursts: merging of two compact objects
  - duration less than 2 sec, mean 0.3 sec
  - too small mass for a long burst

Reminder
Fireball Shock Scenario

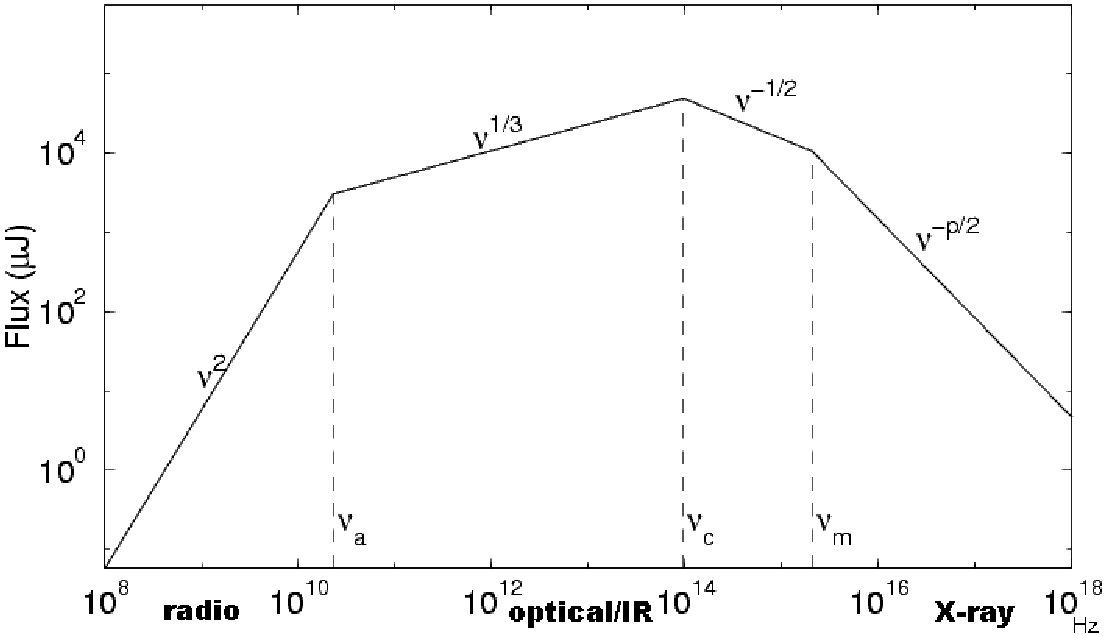
- ejection of a high relativistic jet by a central engine and formation of internal and external shocks
- external shockfront emits broad-band synchrotron spectrum ranging from X-ray over optical to radio
- four basic parameters
  - n: local medium density
  - E_0: total energy of burst
  - ε_e: energy portion distributed to the electrons
  - ε_B: energy portion distributed to the magnetic fields



Afterglow Theory
Afterglow Synchrotron Spectrum

- envelope of many single-electron-synchrotron-spectra in disordered magnetic fields
- peaks are shifting by time to lower frequencies (ν_m in optical within one hour)
- simple power law

$$F_\nu \propto \nu^{-\beta}$$

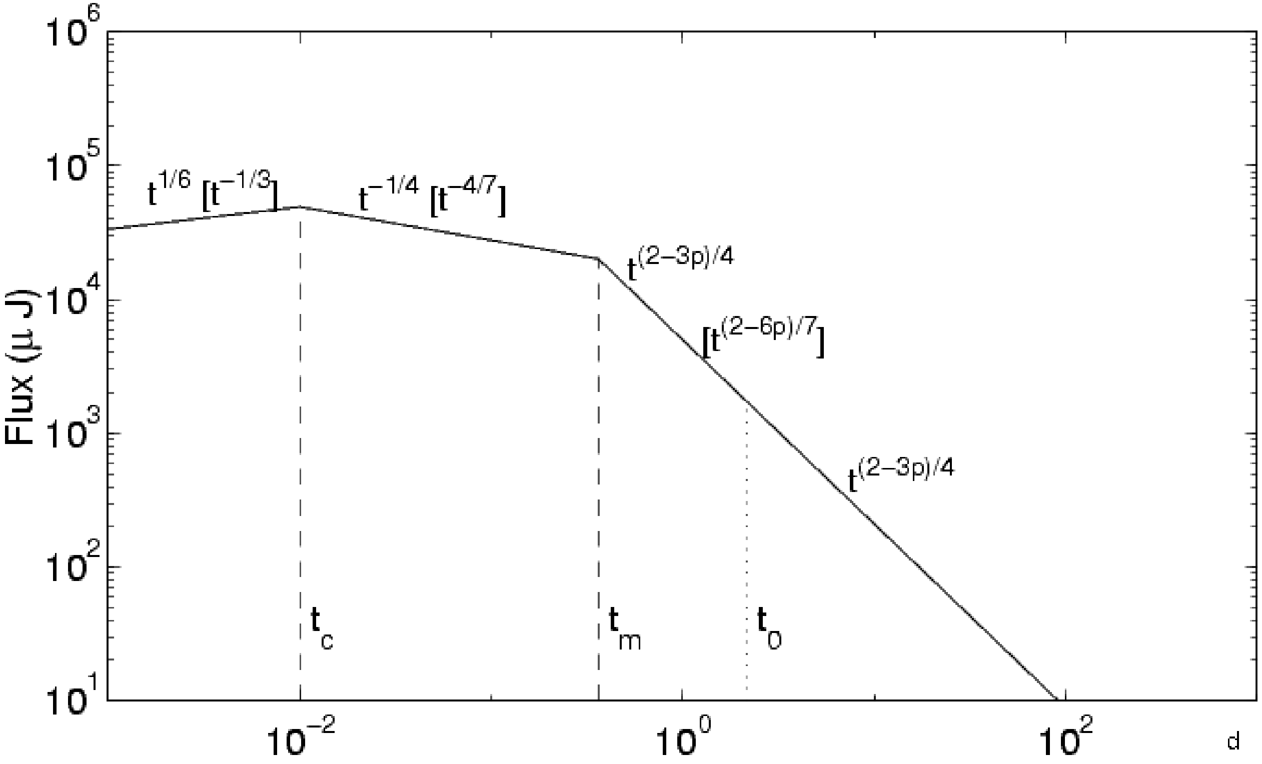


Piran 1997

Afterglow Theory
Afterglow Light Curve

- light curves describe temporal evolution of energy flux integrated over a certain energy range (e.g. R band or soft X-ray)
- power law

$$F_t \propto t^{-\alpha}$$



Piran 1997

Afterglow Theory
GRB Power Law

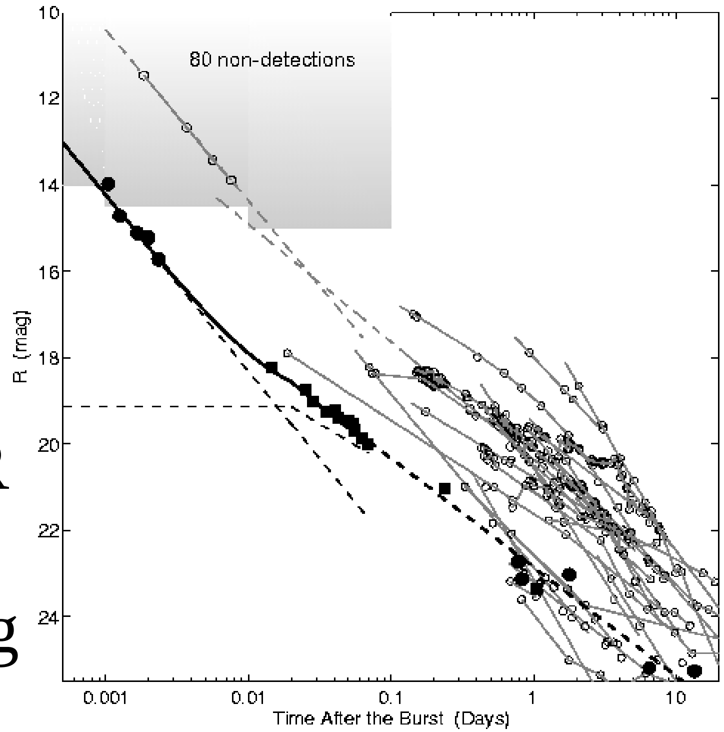
- combination of spectrum and light curve
- only valid for frequencies above ν_m $$F \propto t^{-\alpha} \nu^{-\beta}$$
- simple: only two parameters describe many observations
- with detection of ν_c, ν_m and/or z and estimation of α, β all basic fireball parameters can be derived (n, E_0, ε_B, ε_e)

Global Properties of Afterglows

- X-ray afterglows are detected in nearly every GRB
- 60% of all localized bursts show an optical afterglow
  - resolution about ±0.5” with ground-based telescopes
- (probably) due to insufficent sensitivity of radio telescopes only 50% of all bursts show radio afterglows
  - radio positions accurate to 0.01”
  - thus good for location in host galaxy (galaxy size 1-3”)
  - then optical image made by HST with 0.01” after fading of burst to decide between merger / collapsar scenario

Afterglow Observations
Afterglows in Optical/NIR

- in general overlying components
  - afterglow itself
  - host galaxy
  - supernova
  - jet break
- light curves are closely equal
- only a few early detections at R band brighter than 15mag suggest flatter slope of α during first hours

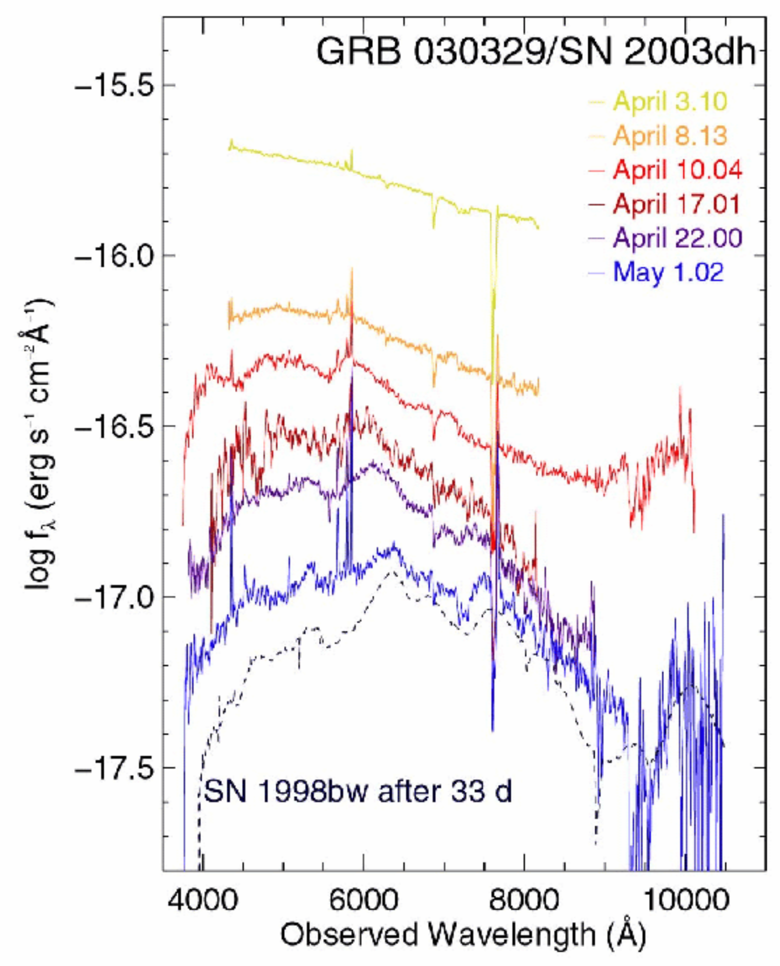


Bloom 2002

Afterglow Observations
Optical Afterglows and Extra Light

- bright supernova was discovered at the same position and distance as GRB 030329
- calculations show that the supernova explosion took place simultaneous with the GRB
- spectrum is developing from GRB to SN between day 4 to 20

Afterglow Observations
Optical Afterglows and Extra Light



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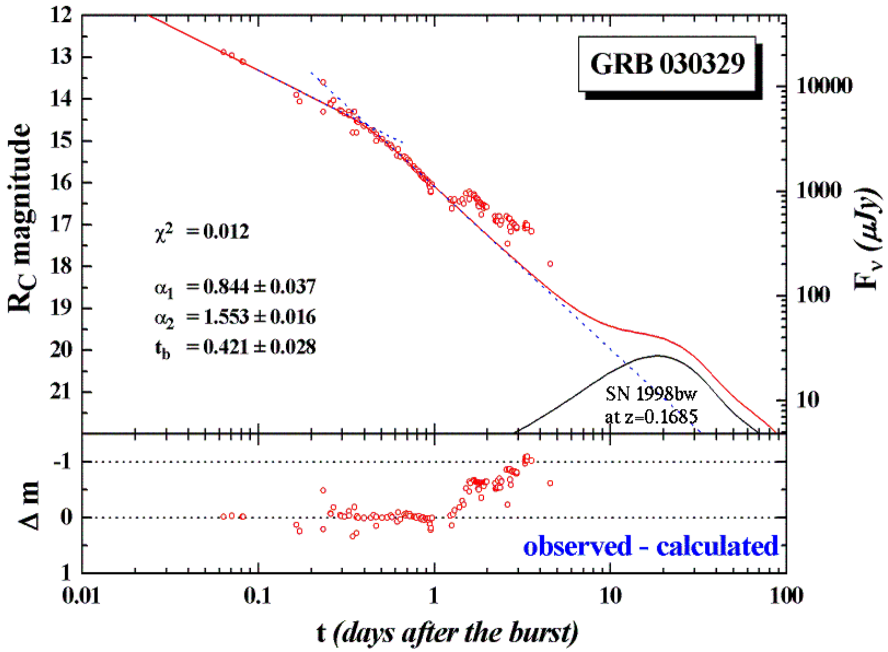
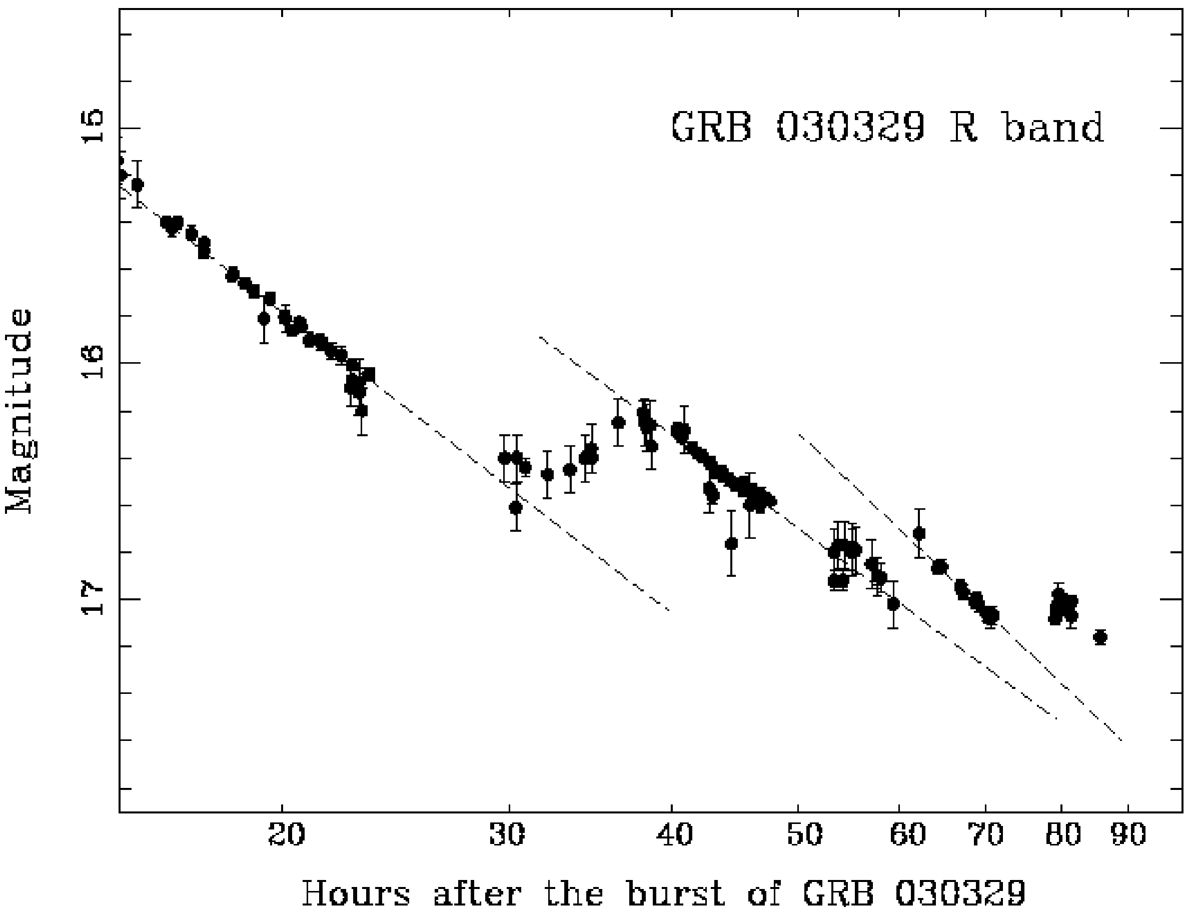


Klose 2003

Afterglow Observations
Rebrightening GRB 030329

- afterglow of GRB 030329 appears to decline with a power law after each re-brightening
- not yet completely understood

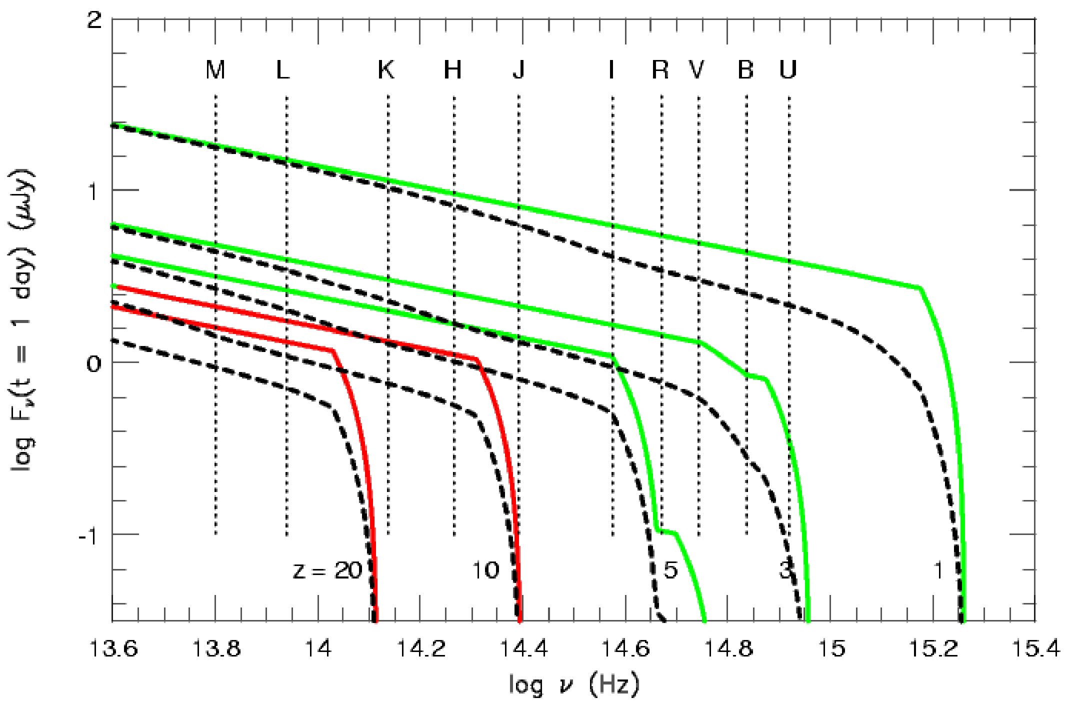


Afterglow Observations
Optically Dark Bursts

- no optical afterglow is observed in about 40% of all bursts
- some possible explanations
  - intrinsically dim bursts
  - GRBs explosion in very low-density environment, so no afterglow produced
  - bursts are absorbed by interstellar dust in its host galaxy
  - high redshift bursts (Lyα edge)

Afterglow Observations
Lyα Edge

- hydrogen atoms along the line of sight absorb photons with energies above Lyα = 121.6 nm, mostly UV light in rest frame
- with increasing redshift the edge is shifted towards lower frequencies
- there would be no spectrum in optical above z=7



Laub & Reichart 2001

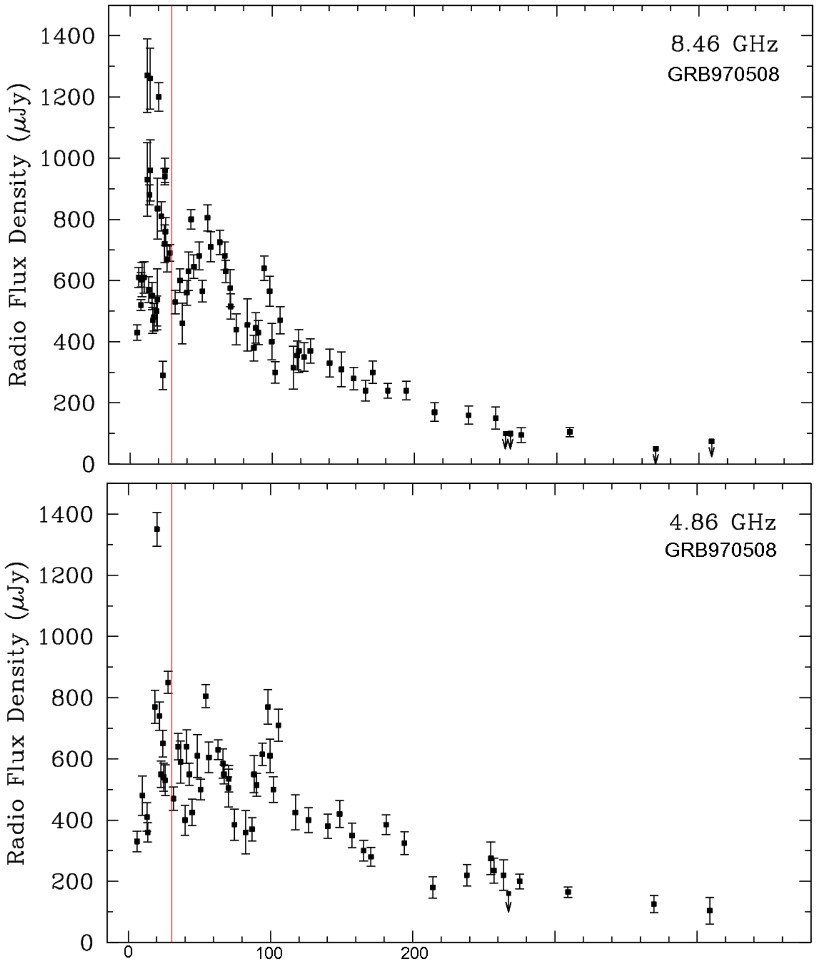
Afterglow Observations
Afterglows in Radio

- no simple power law decline
- it's possible to monitor the source for years with a latetime flattening often observed
- prompt, short-lived radio flares have been detected in several bursts (reactivation of the central engine)
- at their beginning radio afterglows show strong fluctuations (ISM scintillation effect)

ISM Scintillation effect Introduction

- due to atmospheric turbulences light from a point-like star is being randomly distorted, so the star is twinkling
- a comparable effect happens to radio waves penetrating interstellar matter
- separation in short lasting diffractive scintillation and long lasting refractive scintillation

ISM Scintillation Effect Observations



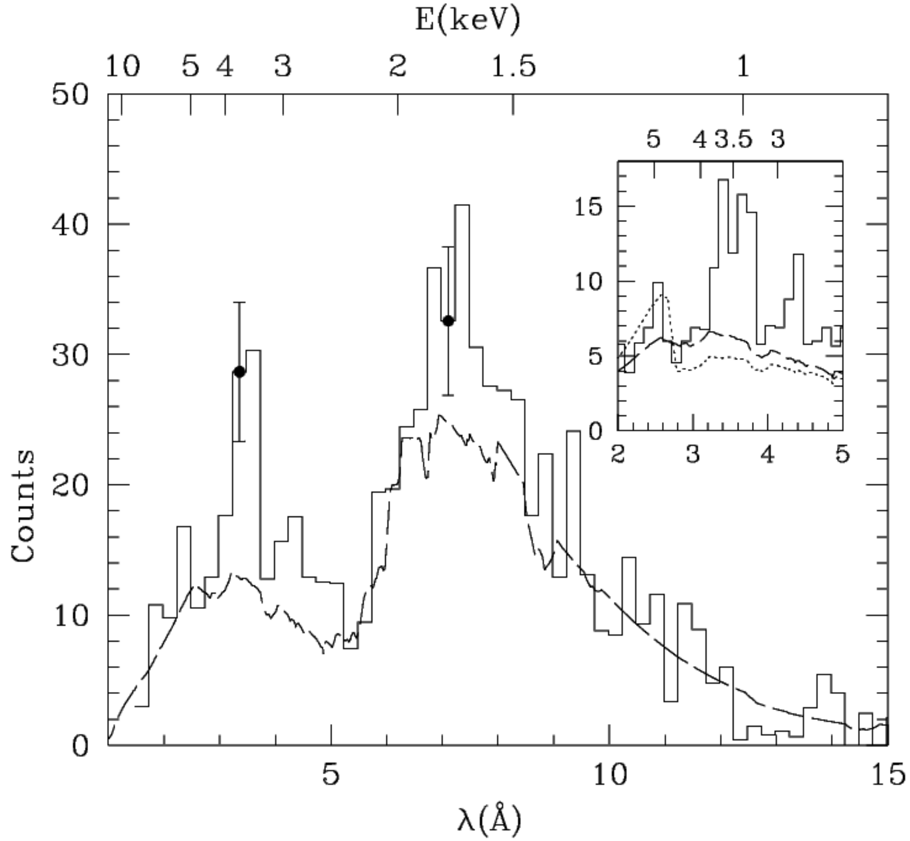
Frail, astro-ph/9910319

ISM Scintillation effect Separation

- diffractive scintillation
  - interference with small-scale irregularities in ISM
  - large amplitude, chromatic on 8.46 GHz (not correlated at different wavelength)
  - short time scale (up to 30 days)
- refractive scintillation
  - focusing and defocusing of the wave front by large-scale inhomogenities
  - small amplitude, achromatic (means broad-band)
  - long time scale (from 30 days)

Special Effects
X-Ray Lines

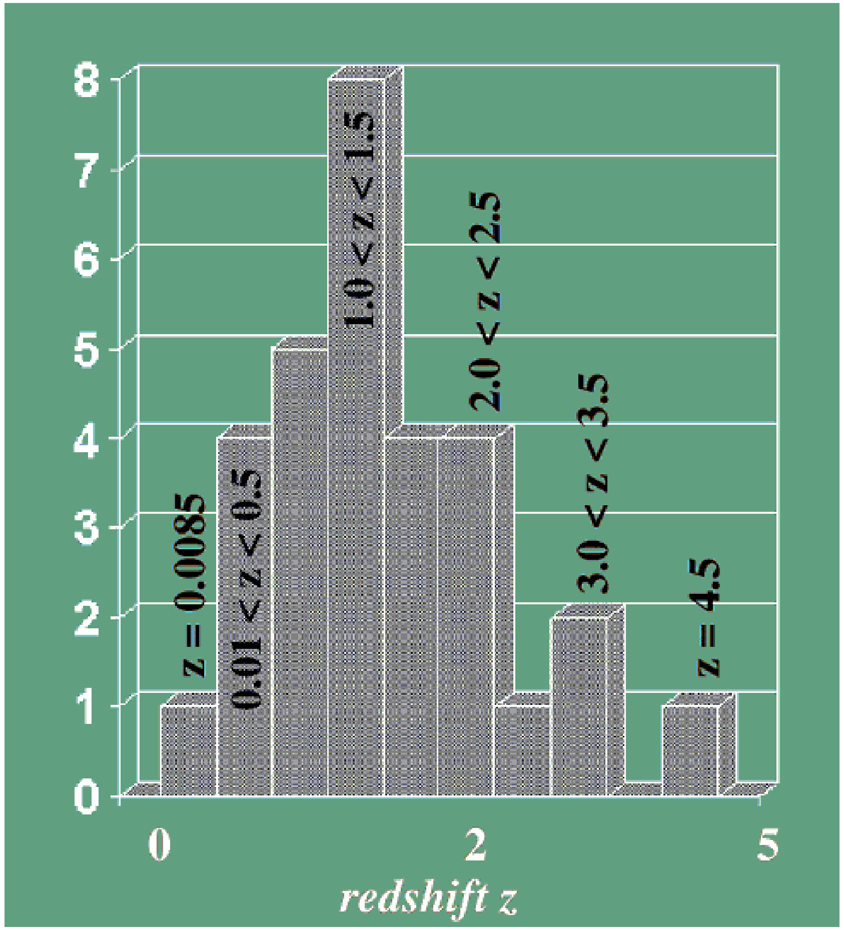
- (iron) emission lines (3.5 keV) overlying the power law continuum, detected with low significance (only 4.7σ)
- still under debate
- if correct, implies huge iron masses which requires SN explosion several month before GRB (this is unlikely)



Astro-ph/0011337

Special Effects
Cosmological Events

- GRBs show a wide range of redshifts from 0.0085 to 4.5
- thus studying cosmology is possible, e.g.
  - for collapsar model, GRB rate scales with star-formation rate
  - thus the SFR (z) could be derived for the early universe

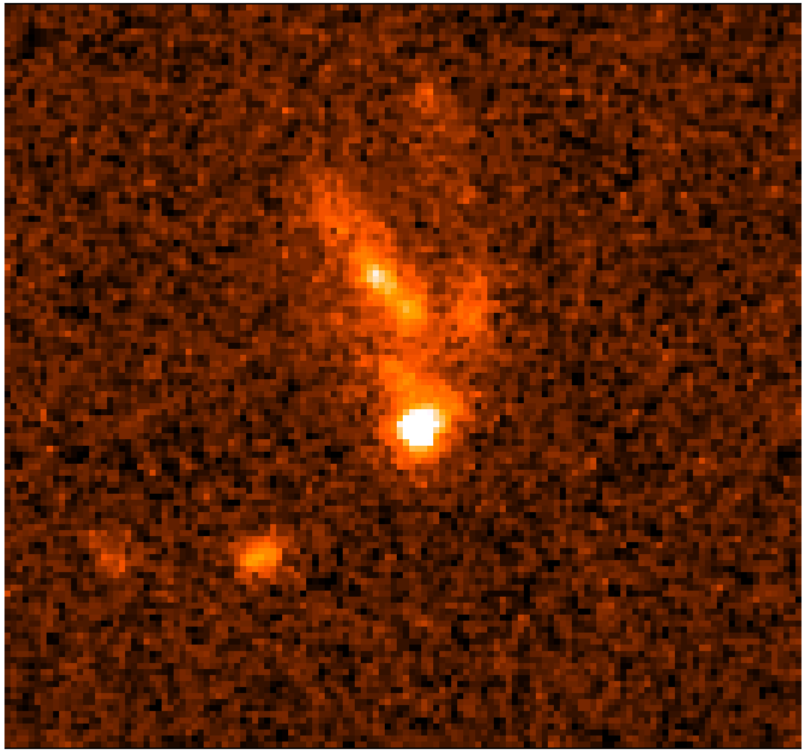


Special Effects
Afterglows and Host Galaxies

- every optical afterglow has an underlying host galaxy
- light curve converges to constant value corresponding to host galaxy
- imaging of host galaxy with HST and studying of GRB location in host
  - disc vs. Halo, collapsar vs. merger - model
  - location matches with star-forming regions, thus collapsar – model

Special Effects
Afterglows and Host Galaxies

- the fading optical afterglow of GRB 990123, as seen by HST on days 16, 59 and 380 after the burst



Special Effects
Jet Break

- while encountering external gas the jet is slowing down
- the beaming angle increases thus more and more of the jet can be observed which partly compensates the fading emission
- is the beaming angle as large as the jet itself a break in the light curve comes up

Future Observational Problems

- find afterglows from short bursts
- solve dark burst problem
- observe within minutes after GRB (GRB afterglow transition)
- search high-z-burst: “When did first stars form?”

GRB Afterglows: X, Opt/IR, Radio

Thank you for your attention!