From Supernovae to Gamma-Ray Bursts

The SNe zoo

age < 100 Myr

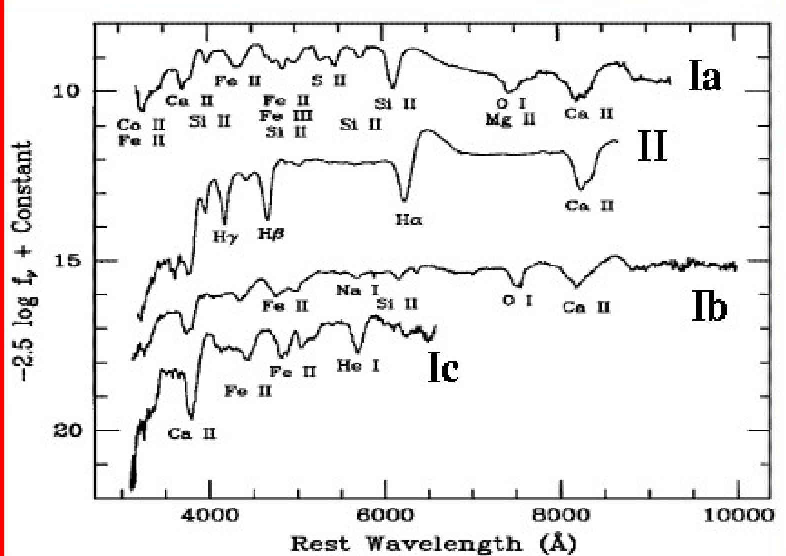
progenitor mass

$8\ M_\odot$

SN Ia

detonation of an accreting white dwarf

no Hydrogen
(Si^+ absorption)



SN II

IIn IIL IIP IIb

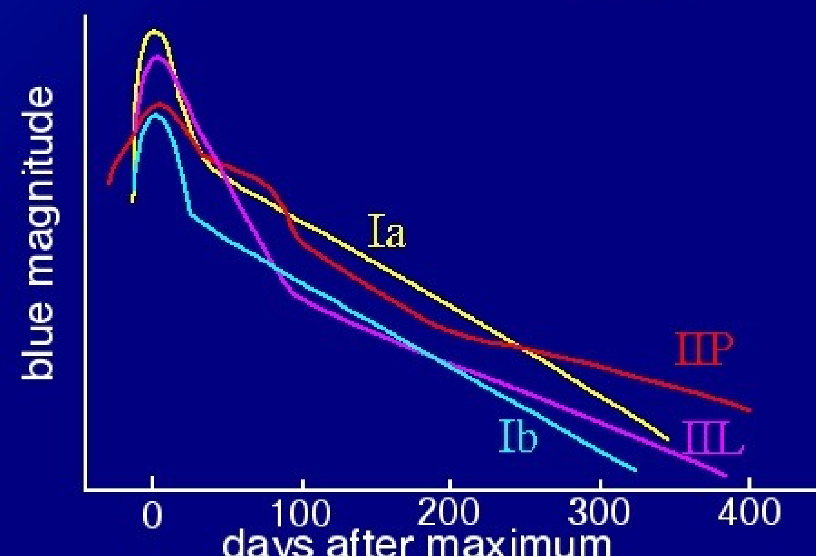
core collapse of a massive star

Hydrogen lines

SN Ib/c

core collapse
(outer layers stripped by winds)

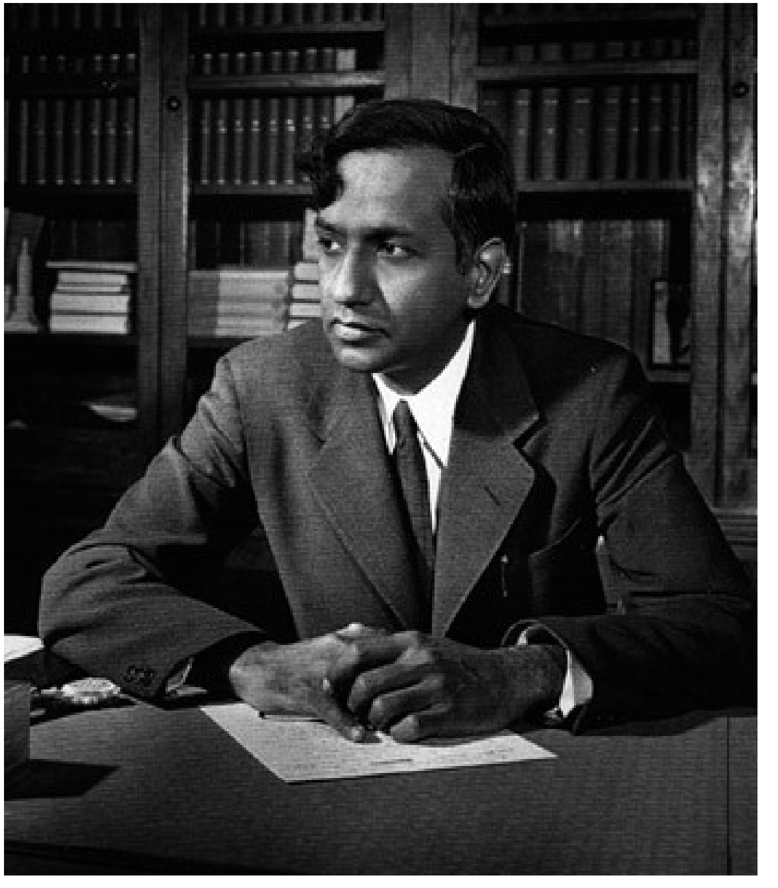
no Hydrogen
(no Si^+)



Chandrasekhar limit

- Predicted gravity will overcome electron degeneracy pressure if **white dwarf mass** greater than 1.4 $M_{\odot}$

- A WD in a **binary** system can reach this limit either though accretion or merging

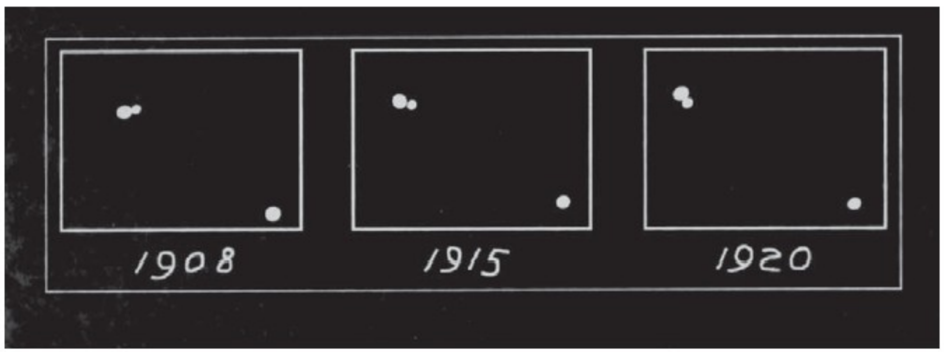


Subrahmanyan Chandrasekhar (1910-1995)

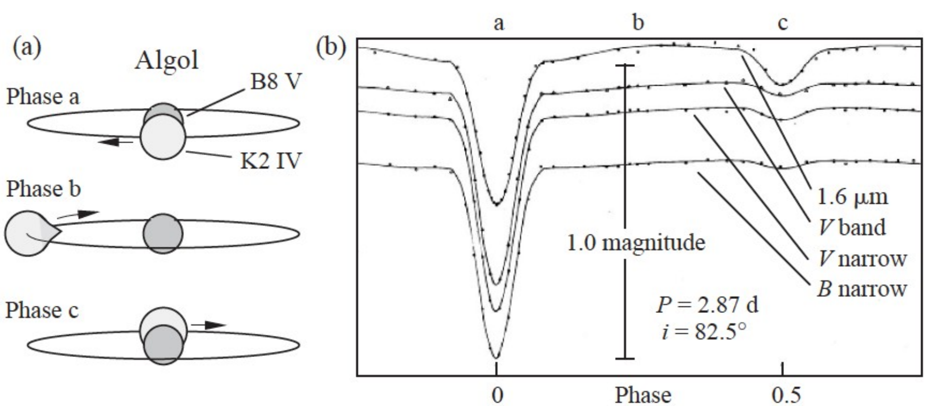
Binary stars

Fraction of stars in binary (multiple) systems: ≈50%

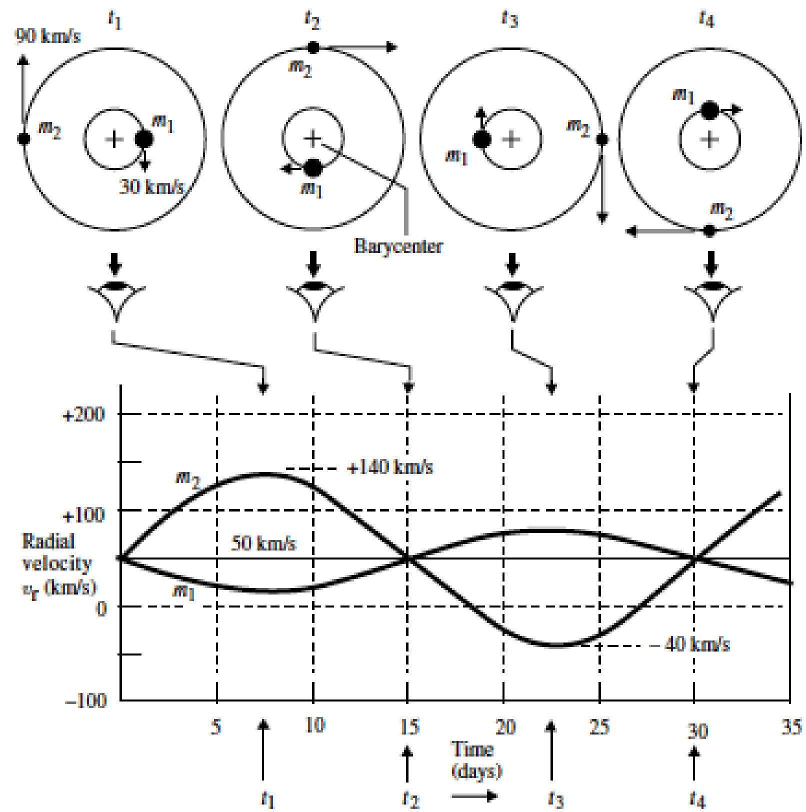
Visual binary



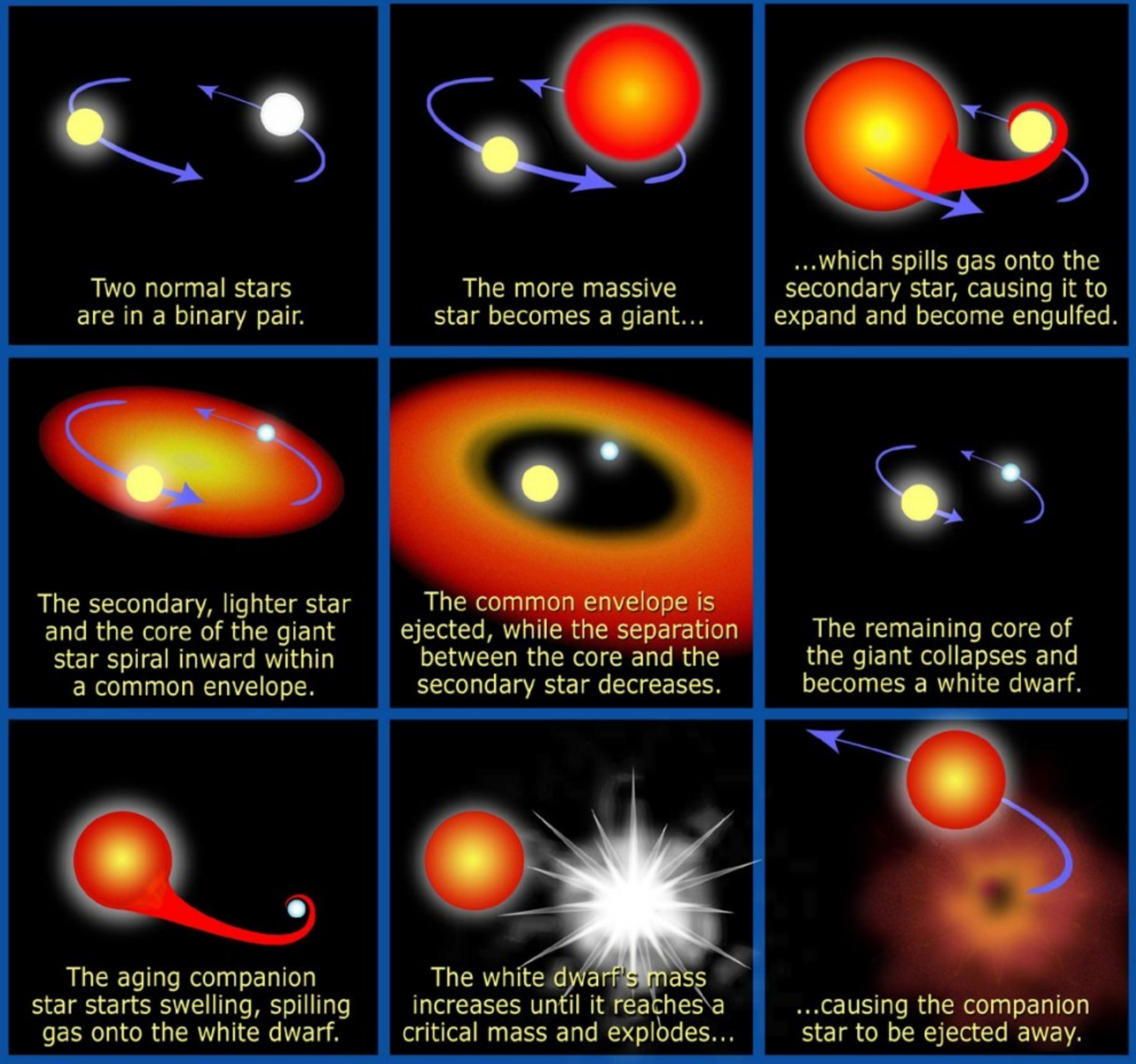
Eclipsing binary



Spectroscopic binary



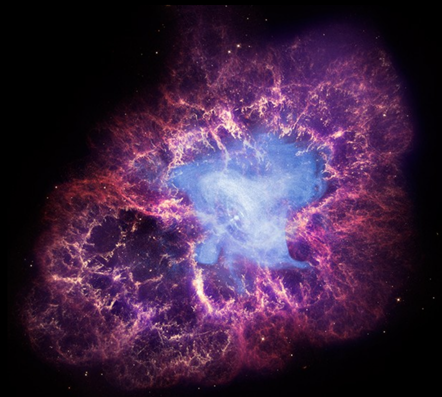
The progenitor of a Type Ia supernova



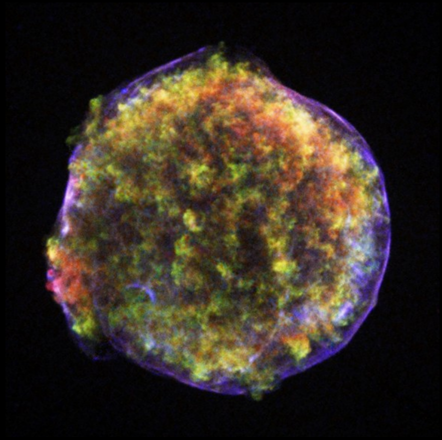
Galactic Supernovae

In a galaxy such as the Milky Way, a supernova should occur once every 50 to 100 years. The last few were:

SN 1006
(1006 A.D.)

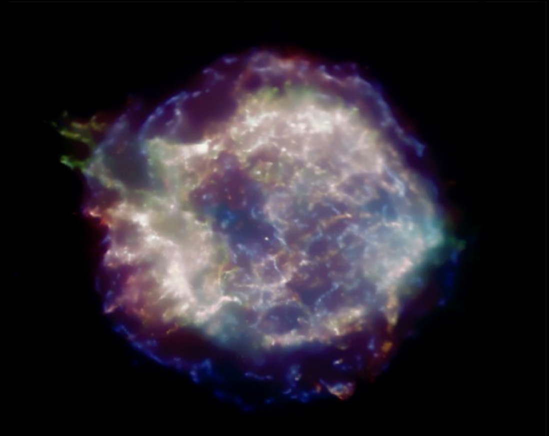


Crab Supernova
(1054 A.D.)



Tycho's Supernova
(1572 A.D.)

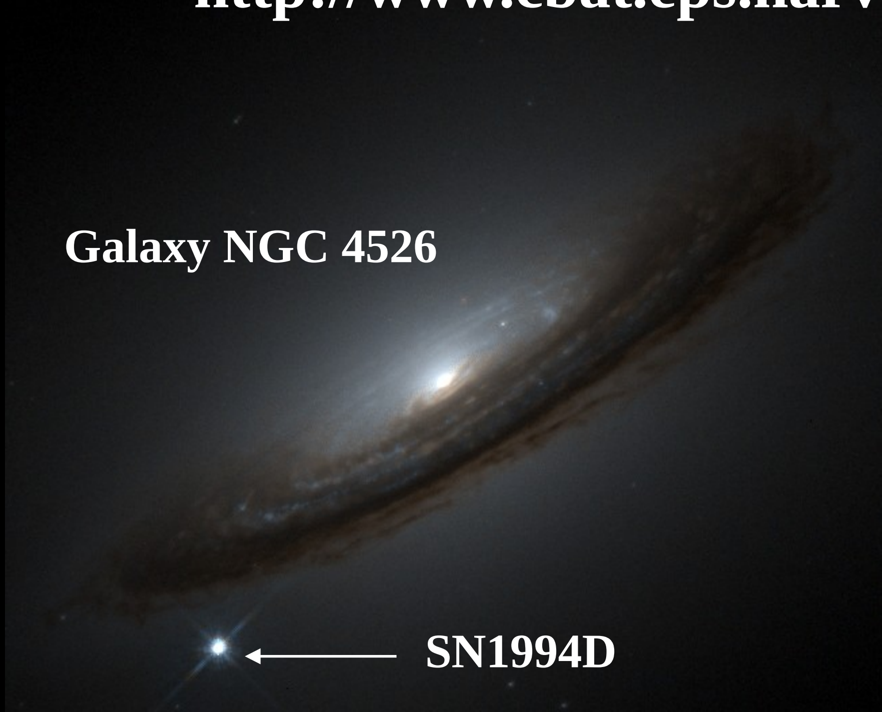
Kepler's
Supernova
(1604 A.D.)

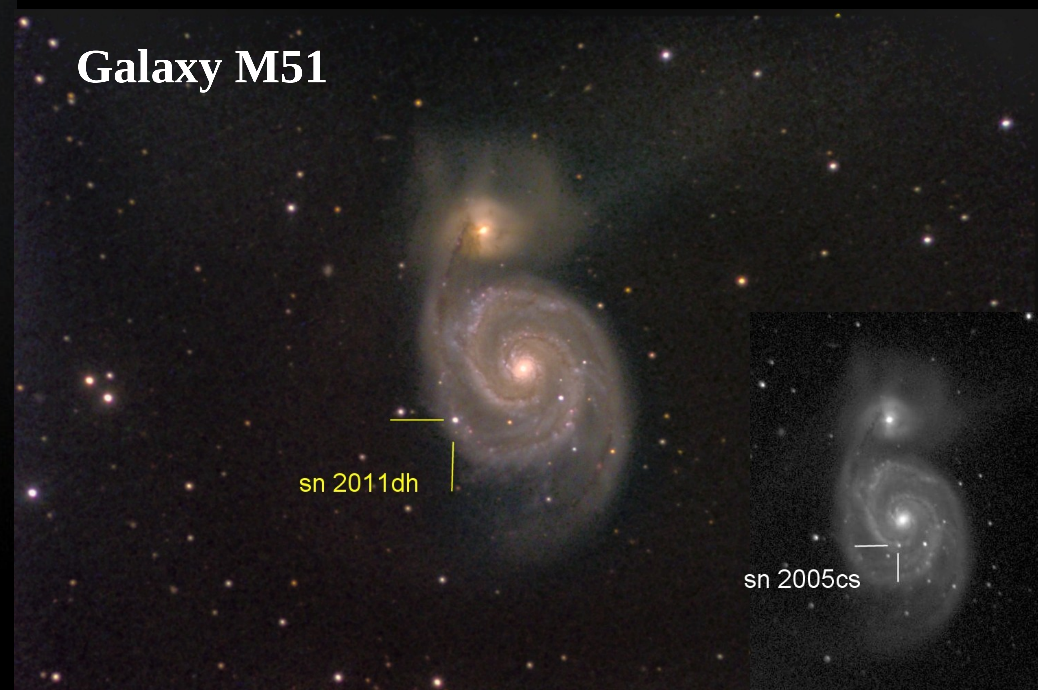


Casseopia A
(1680 A.D.?)

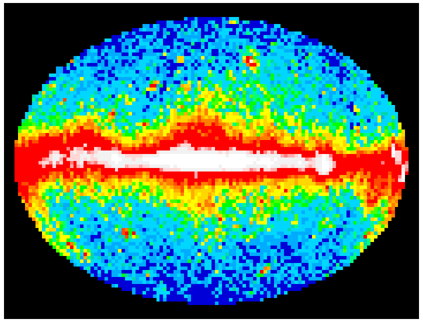
More distant supernovae

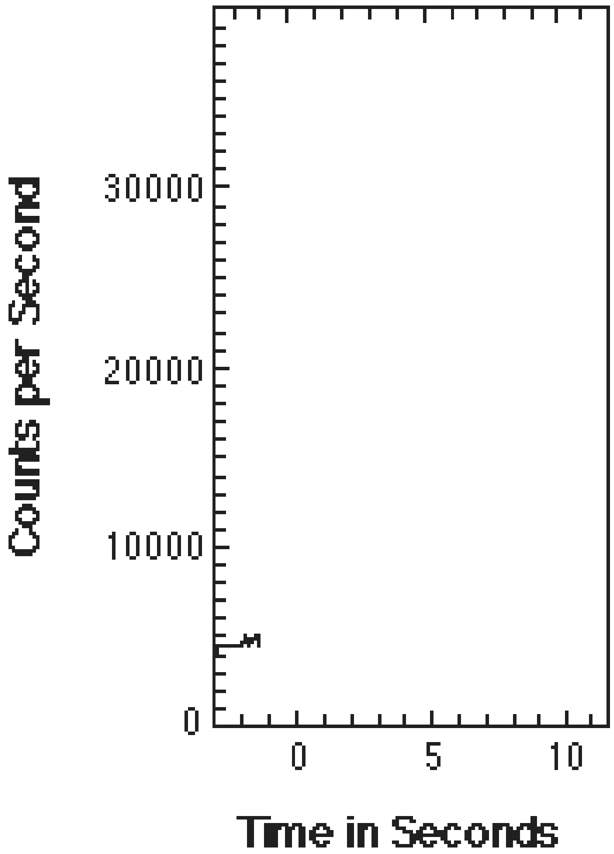
Real-time list of all Supernovae:
http://www.cbat.eps.harvard.edu/lists/Supernovae.html





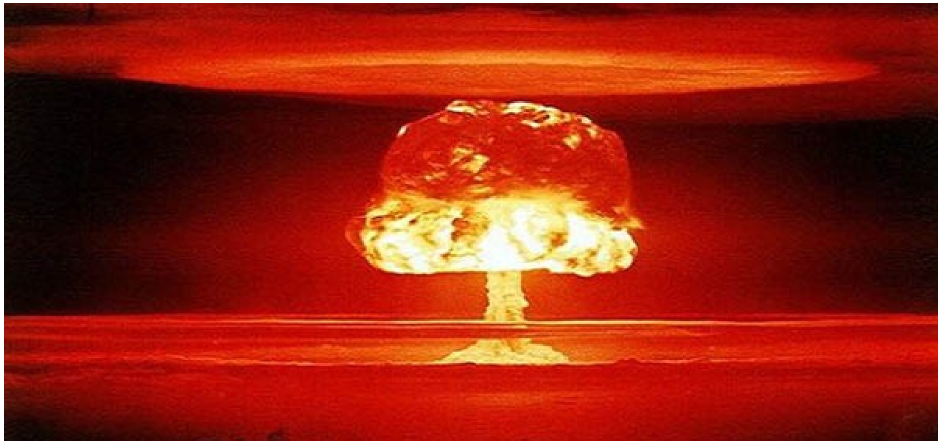
Gamma-Ray Bursts (GRBs)

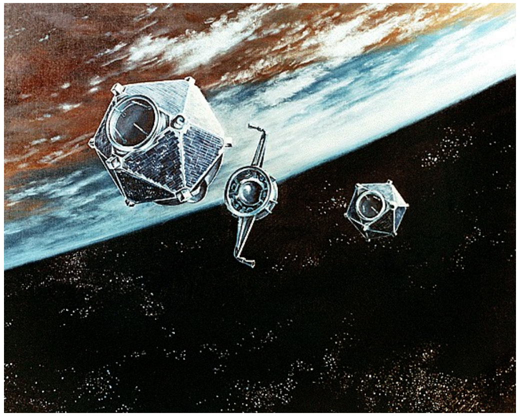




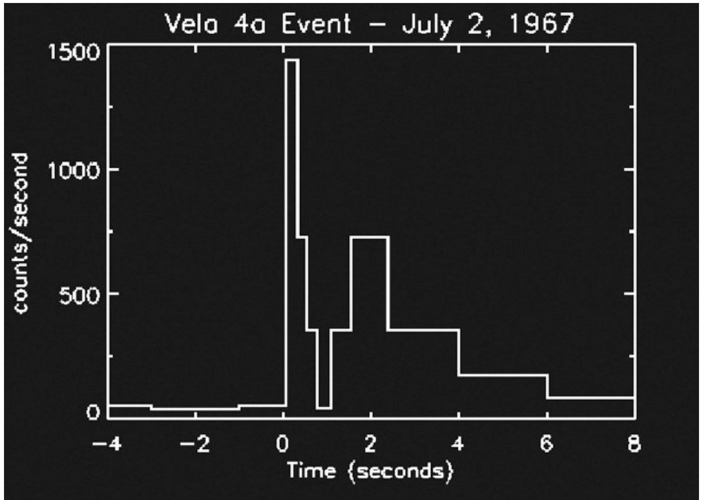
Short (~1-100 s) and **bright** (even brighter than the whole sky!) bursts of **gamma-rays** (E~10-1000 keV; non-thermal spectra)

The discovery of GRBs

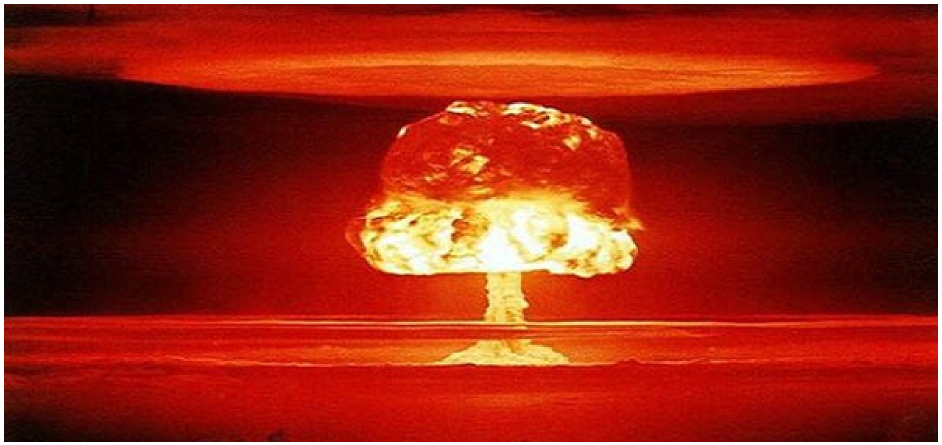


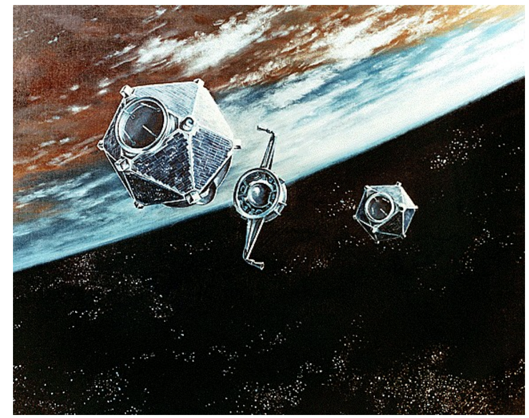


Discovered by Vela satellites, launched by US Air Force to monitor the ban of **nuclear tests** in atmosphere and space



The discovery of GRBs





Discovered by Vela satellites, launched by US Air Force to monitor the ban of **nuclear tests** in atmosphere and space

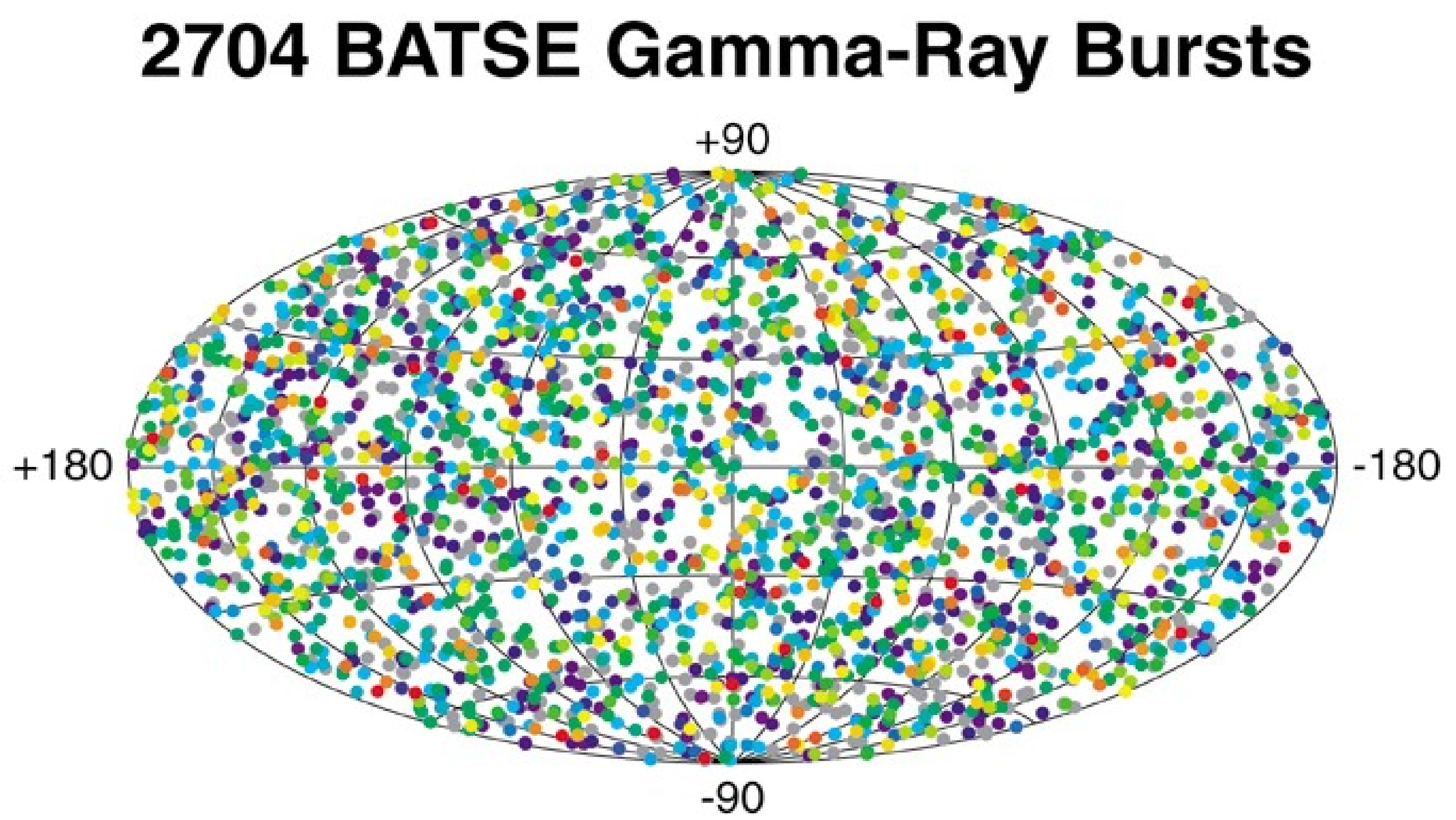
OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.



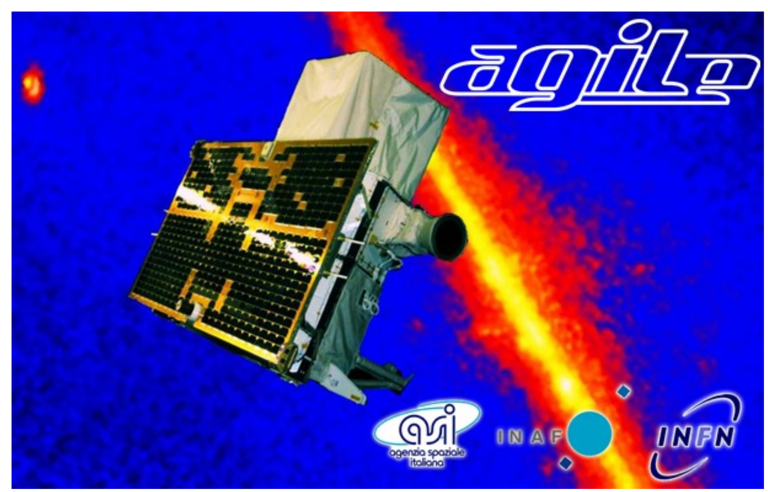
Isotropic distribution, in contrast with most (Galactic) models

⇒ at cosmological distances or very nearby

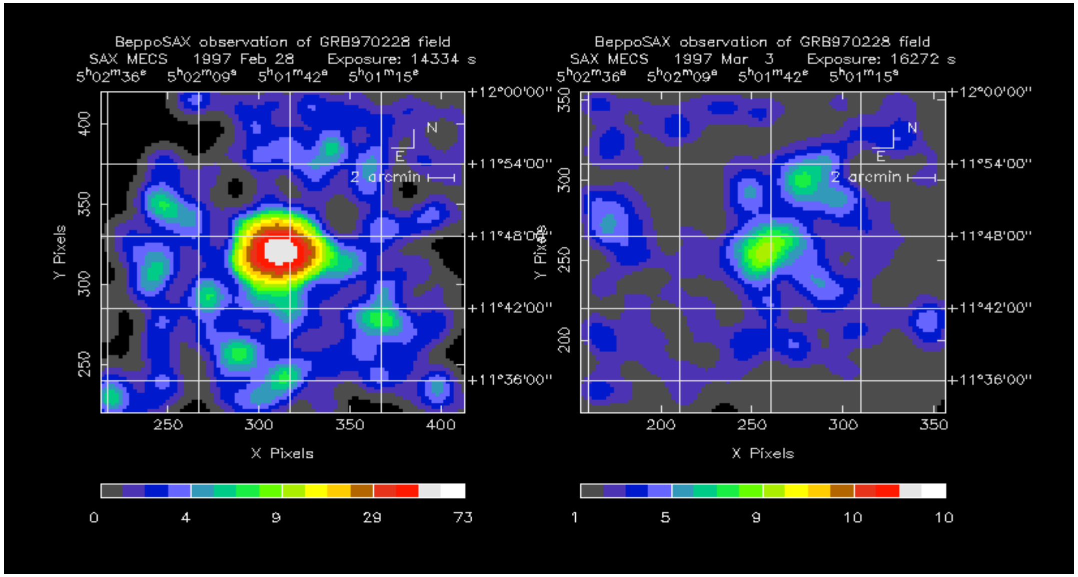
GRB origin has remained a mystery for ~30 years

Italy in space

- ✓ X-ray astronomy pioneers (rocket in 1962 and *Uhuru* satellite in 1972): **Bruno Rossi** (1905-1993) and **Riccardo Giacconi** (1931-, Nobel in 2002)
- ✓ 3rd country launching a **satellite** (San Marco 1, 1964)
- ✓ One of the few countries with 2 national astronomy space missions: ***BeppoSAX*** (X-rays; 1996-2002) and ***AGILE*** (gamma-rays; 2007-)

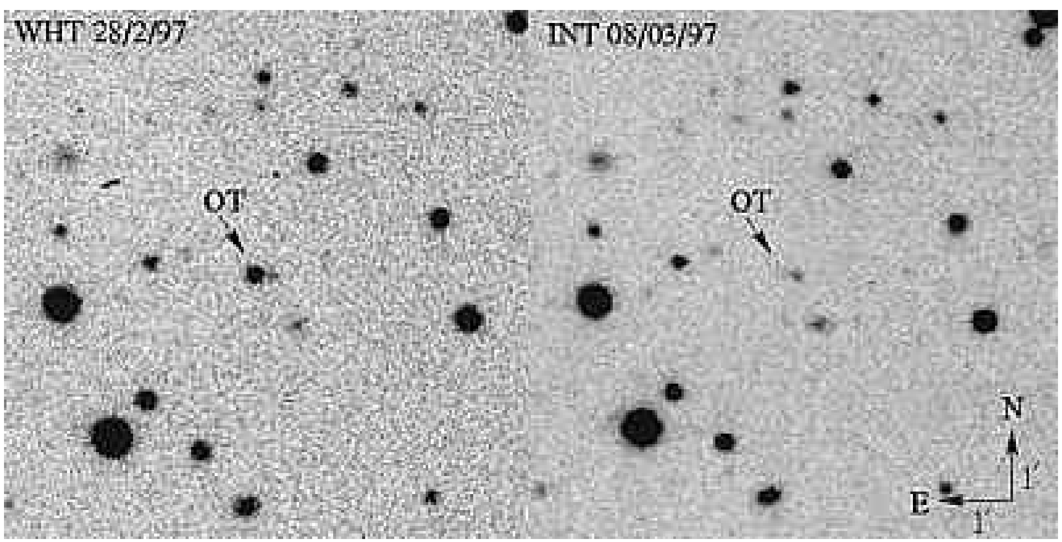


GRB afterglows: the mystery is solved!



BeppoSAX discovers **X-ray afterglows** *(Costa et al. 1997)*

⇒ GRB position ~arcmin



Optical afterglow

(van Paradijs et al. 1997)

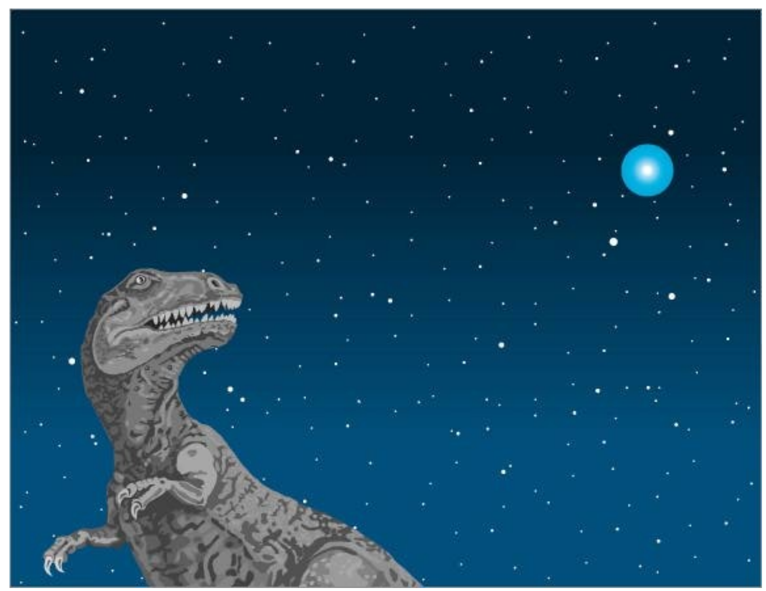
⇒ position ~1"

⇒ host galaxy and redshift (z ~ 0.0085 - 9.4)

⇒ **E_{iso}~10^{51}-10^{54} erg**

The brightest cosmic explosions (after the Big Bang)

- In less than **few minutes** a GRB emits more energy than our Galaxy in 100 years!
- GRBs are hundreds of times brighter (but less frequent) than **supernovae**!
- A GRB in our Galaxy might have caused **mass extintions**!



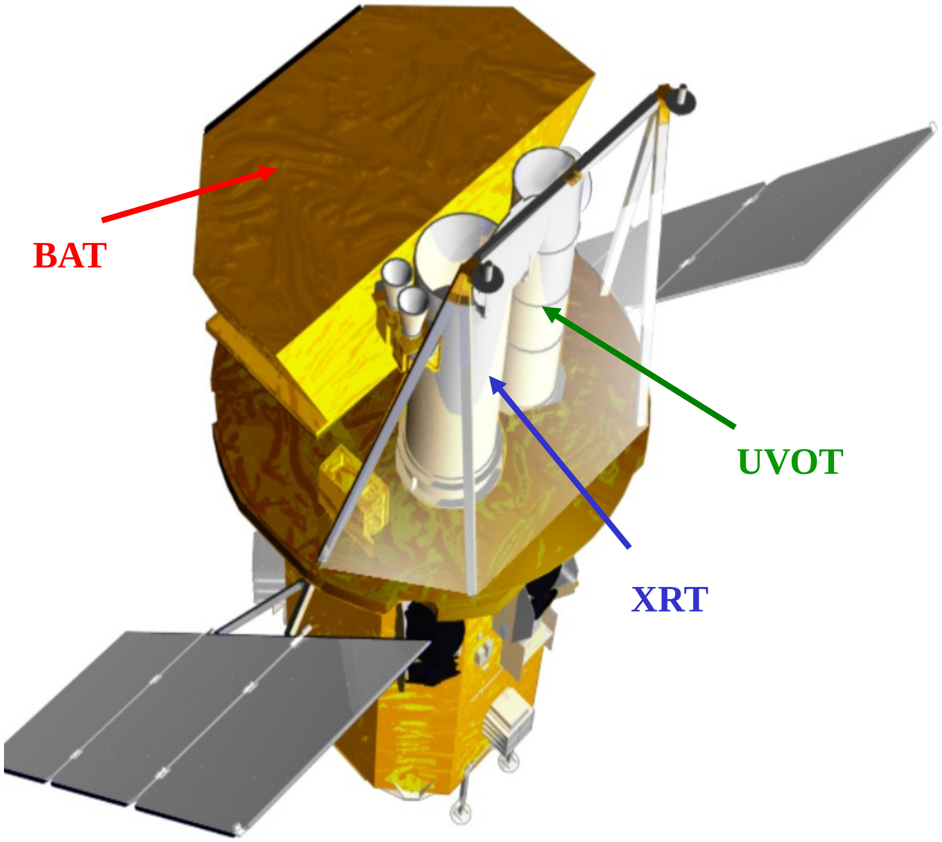
The *Swift* Satellite

Launch: 2004 November 20

Burst Alert Telescope (BAT)
- Coded mask + CdZnTe detectors
- 2 sr field of view

X-Ray Telescope (XRT)
- Mirror + CCD detector
- Arcsec GRB positions

UV-Optical Telescope (UVOT)
- Sub-arcsec position
- 22 mag sensitivity



Spacecraft slews to GRB in <100 s

TITLE: GCN CIRCULAR
NUMBER: 13182
SUBJECT: **GRB 120401A**: Swift detection of a burst
DATE: **12/04/01 05:33:59 GMT**
FROM: David Palmer at LANL <palmer@lanl.gov>

A. P. Beardmore (U Leicester), W. H. Baumgartner (GSFC/UMBC),V. D'Elia (ASDC), A. Maselli (INAF-IASFPA),C. J. Mountford (U Leicester), C. Pagani (U Leicester),K. L. Page (U Leicester), D. M. Palmer (LANL),T. Sakamoto (NASA/UMBC), M. H. Siegel (PSU),R. L. C. Starling (U Leicester) and B.-B. Zhang (PSU) report on behalf of the Swift Team:

At **05:24:15 UT**, the Swift Burst Alert Telescope (**BAT**) triggered and located GRB 120401A (trigger=519043). Swift slewed immediately to the burst. The BAT on-board calculated location is RA, Dec 58.068, -17.671 which is

RA(J2000) = 03h 52m 16s
Dec(J2000) = -17d 40' 15"

with an **uncertainty of 3 arcmin** (radius, 90% containment, including systematic uncertainty). As is typical for an image trigger, no activity is apparent in the immediately available light curve.

The **XRT** began observing the field at **05:26:14.1 UT**, 118.3 seconds after the BAT trigger. XRT found a bright, uncatalogued X-ray source located at RA, Dec 58.0835, -17.6349 which is equivalent to:

RA(J2000) = +03h 52m 20.04s
Dec(J2000) = -17d 38' 05.6"

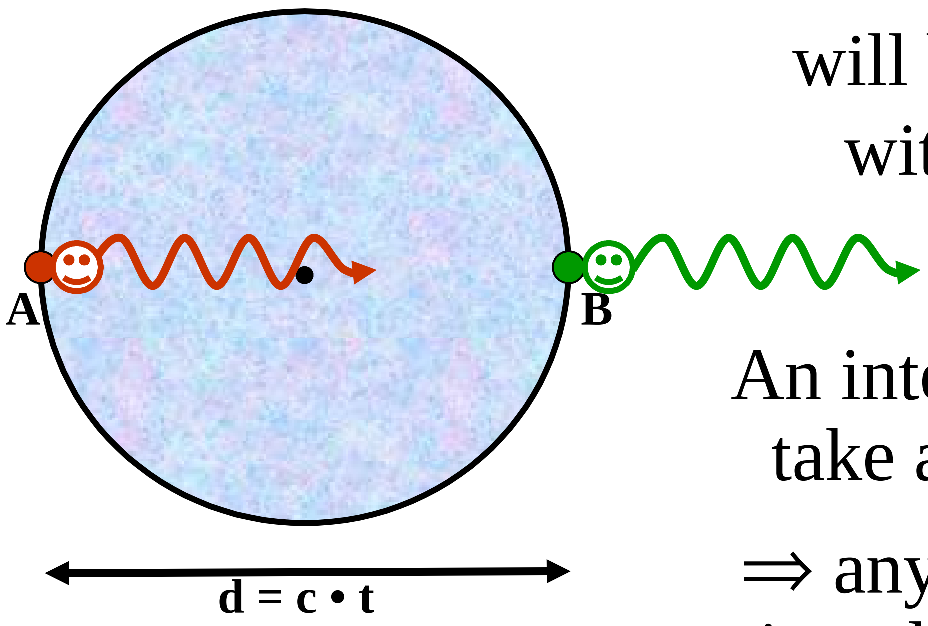
with an **uncertainty of 5.4 arcseconds** (radius, 90% containment). This location is 140 arcseconds from the BAT onboard position, within the BAT error circle. No event data are yet available to determine the column density using X-ray spectroscopy.

The initial flux in the 2.5 s image was 1.35e-09 erg cm^-2 s^-1 (0.2-10keV).

UVOT took a finding chart exposure of 150 seconds with the White filter starting 127 seconds after the BAT trigger. **No credible afterglow candidate** has been found in the initial data products. The 2.7'x2.7' sub-image covers 100% of the XRT error circle. The typical 3-sigma upper limit has been about 19.6 mag. The 8'x8' region for the list of sources generated on-board covers 100% of the XRT error circle. The list of sources is typically complete to about 18 mag. No correction has been made for the expected extinction corresponding to E(B-V) of0.05.

Burst Advocate for this burst is A. P. Beardmore (apb AT star.le.ac.uk). Please contact the BA by email if you require additional information regarding Swift follow-up of this burst. In extremely urgent cases, after trying the Burst Advocate, you can contact the Swift PI by phone (see Swift TOO web site for information: http://www.swift.psu.edu/too.html.)

The size of a variable object



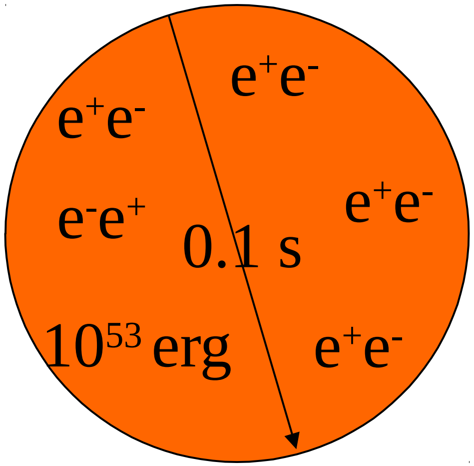
If photons **A** and **B** are emitted simultaneously, **A** will be detected later than **B**, with a time delay: $t = d/c$

An intensity change from **A** will take a time $t = d/c$ to reach **B**

⇒ any intensity variation with time dutation ***t*** must have been emitted from a region of size:

$$d < c \bullet t$$

GRB Explosions are Highly Relativistic



A large amount of energy, ~10^{53} erg, packed in a small space of ~ c × 0.1 s.

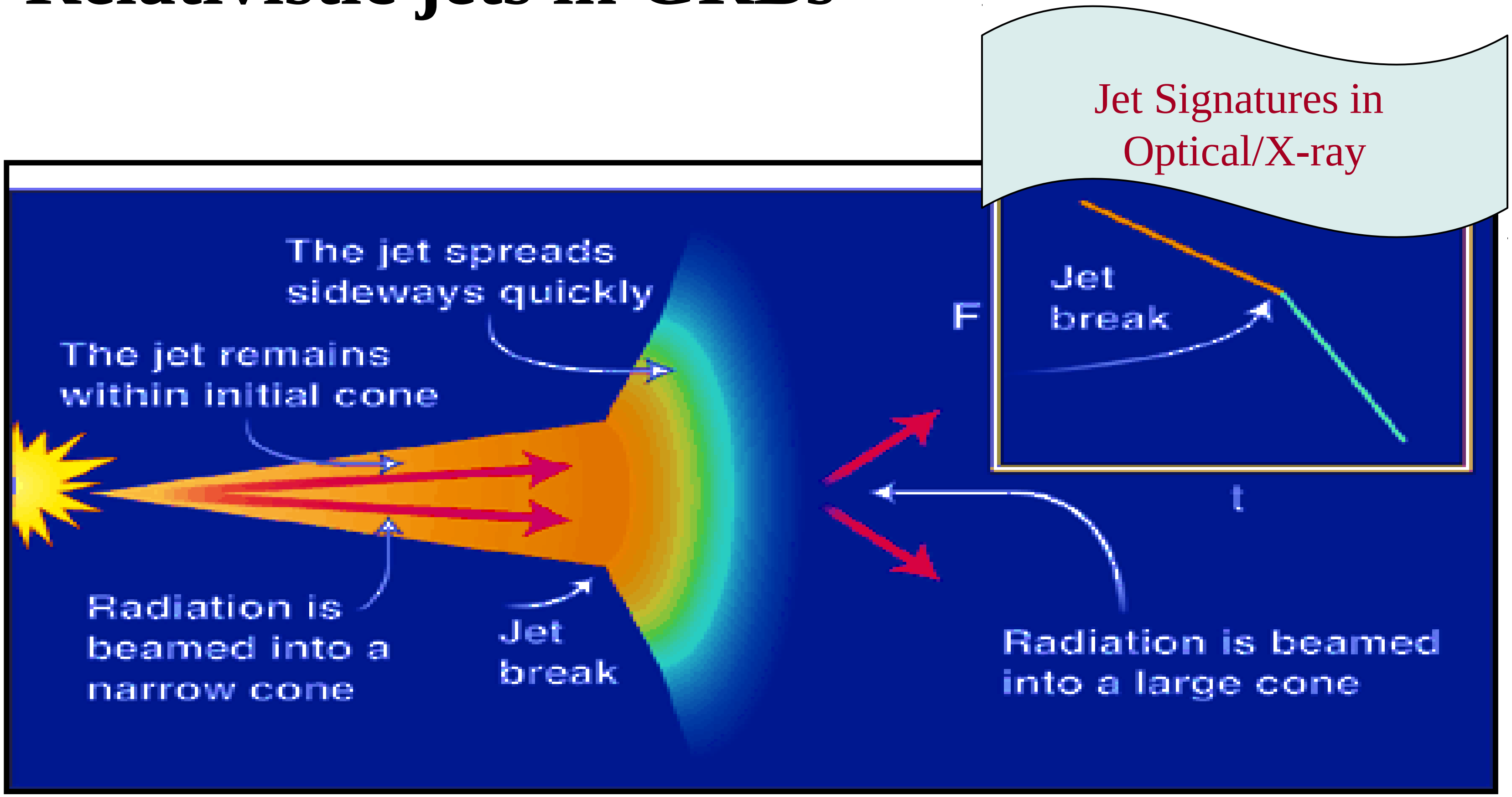
Is highly optically thick to e^+e^- pair production: τ ~ 10^{15}

In this case we should not see any γ's above ~ MeV and see thermal emission

Relativistic outflow ($\Gamma \approx$100-1000) **solves this compactness problem**

High energy density in any case leads to relativistic flow
(Paczynski 1986, ApJ 308, L43 ; Goodman 1986, ApJ 308, L47)

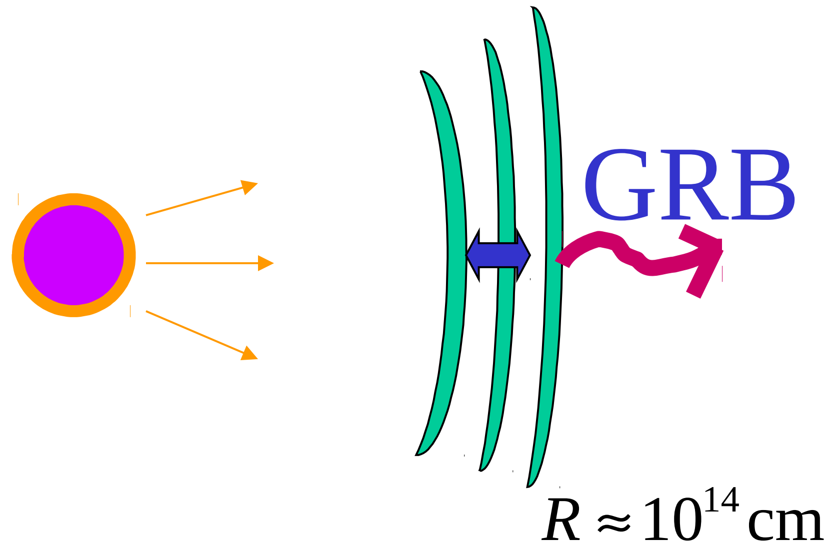
Relativistic jets in GRBs

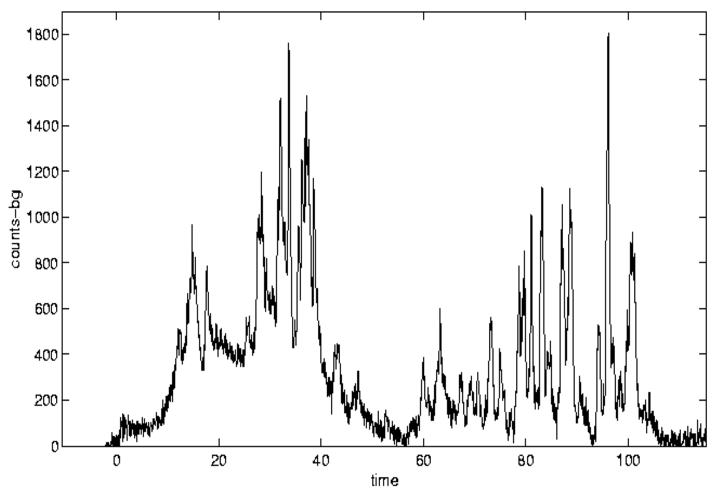


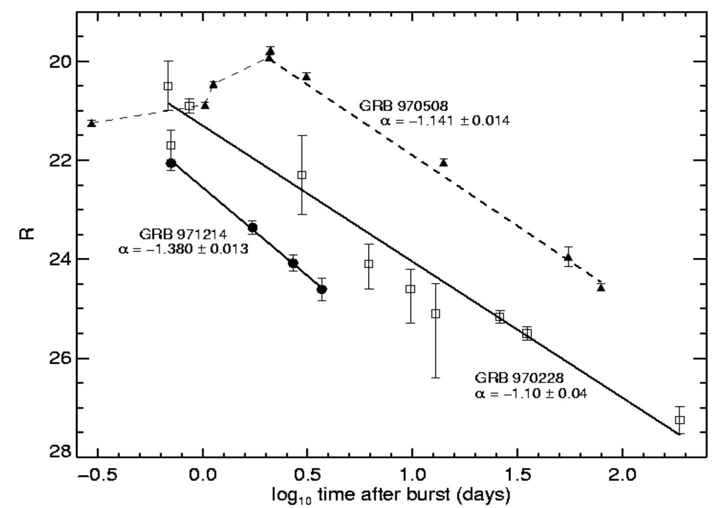
$$E_{\gamma} = (1 - \cos\theta_j)\, E_{iso,\gamma}$$

Prompt Emission: Internal Shocks

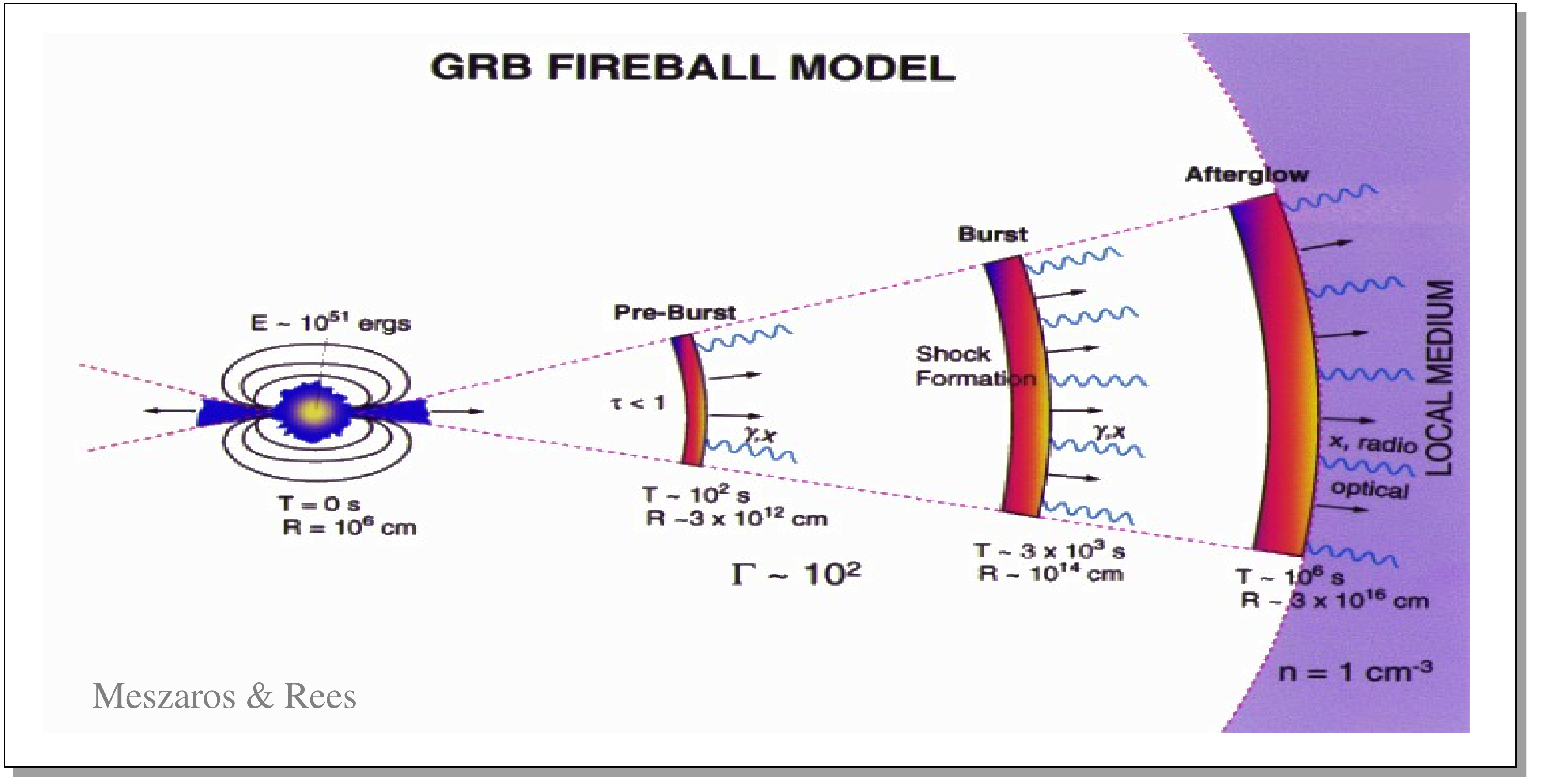
Afterglow emission: External Shocks







Fireball Model of GRBs



Most photons produced by relativistic electrons (**synchrotron**)

Shocks also accelerate protons ⇒ interactions with photons ⇒ pions, muons, **neutrinos** (10^{14} - 10^{19} eV)

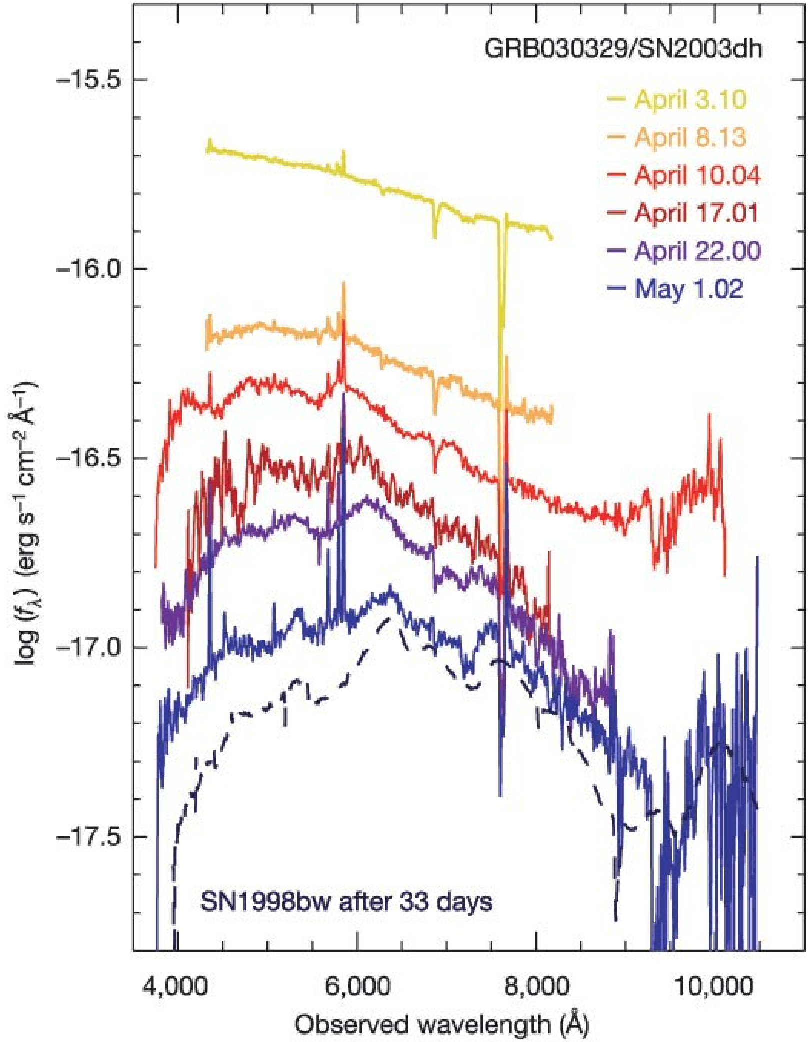
GRB/SN connection

GRB 980425/SN1998bw: z=0.0085

SN 1998bw in Spiral Galaxy ESO184-G82

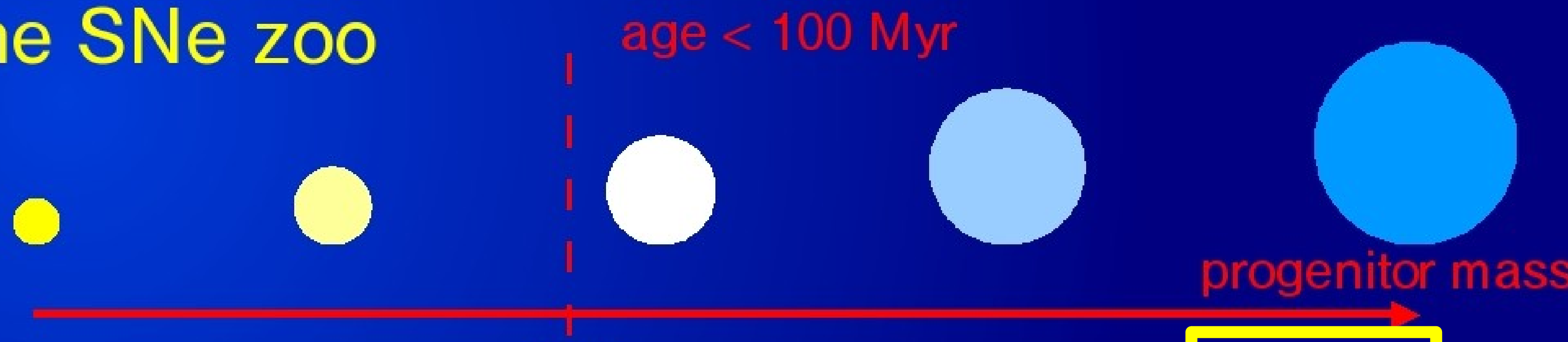
ESO PR Photo 39a/98 (15 October 1998)

GRB 030329/SN2003dh: z=0.1685

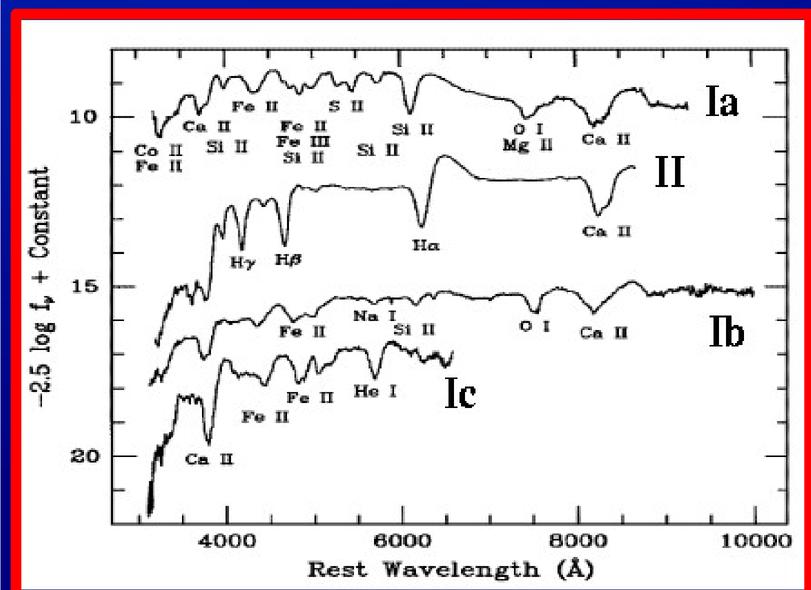


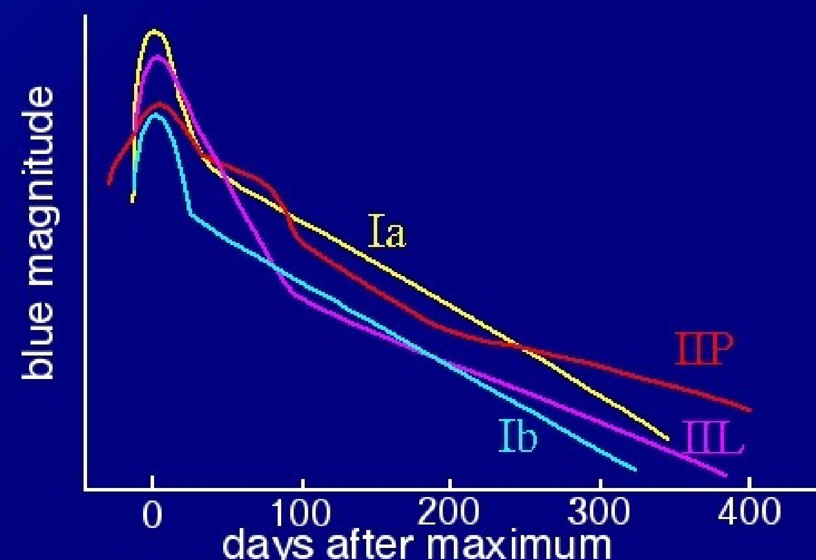
GRB progenitors: Collapsar

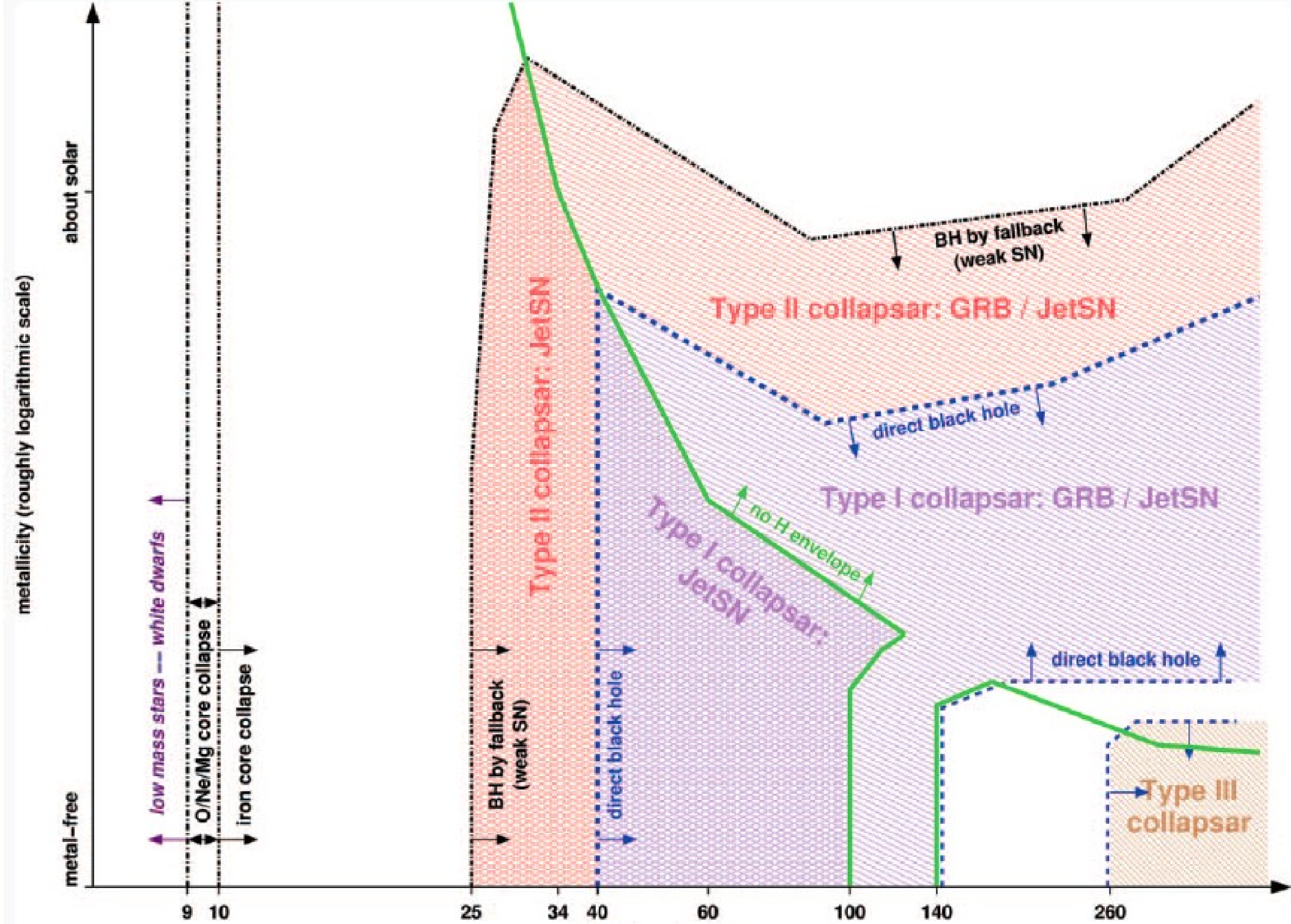
The SNe zoo



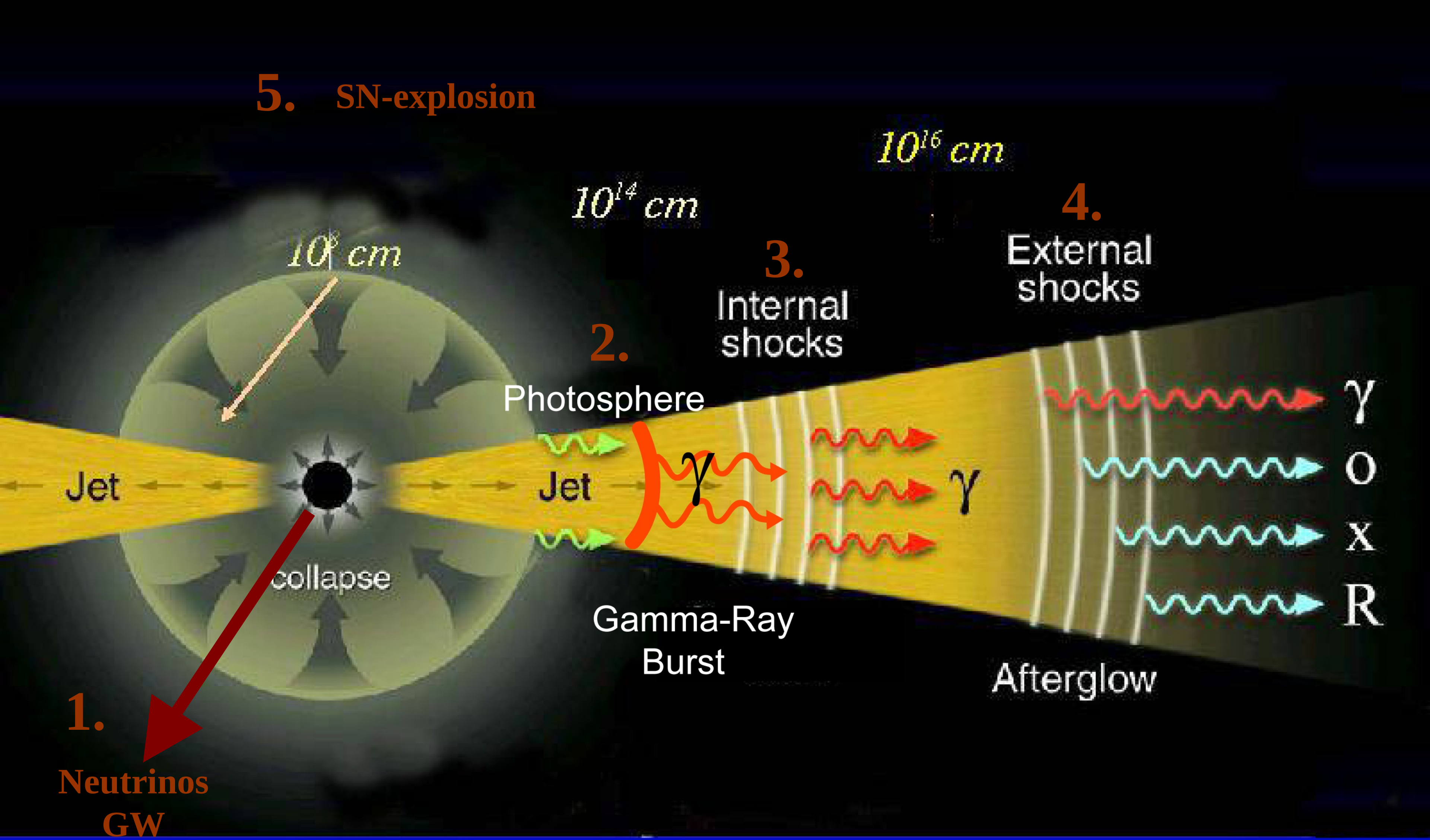
SN Ia	SN II	SN Ib/c
detonation of an accreting white dwarf	IIn IIL IIP IIb	core collapse (outer layers stripped by winds)
	core collapse of a massive star	
no Hydrogen (Si+ absorption)	Hydrogen lines	no Hydrogen (no Si+)







Heger et al. 200



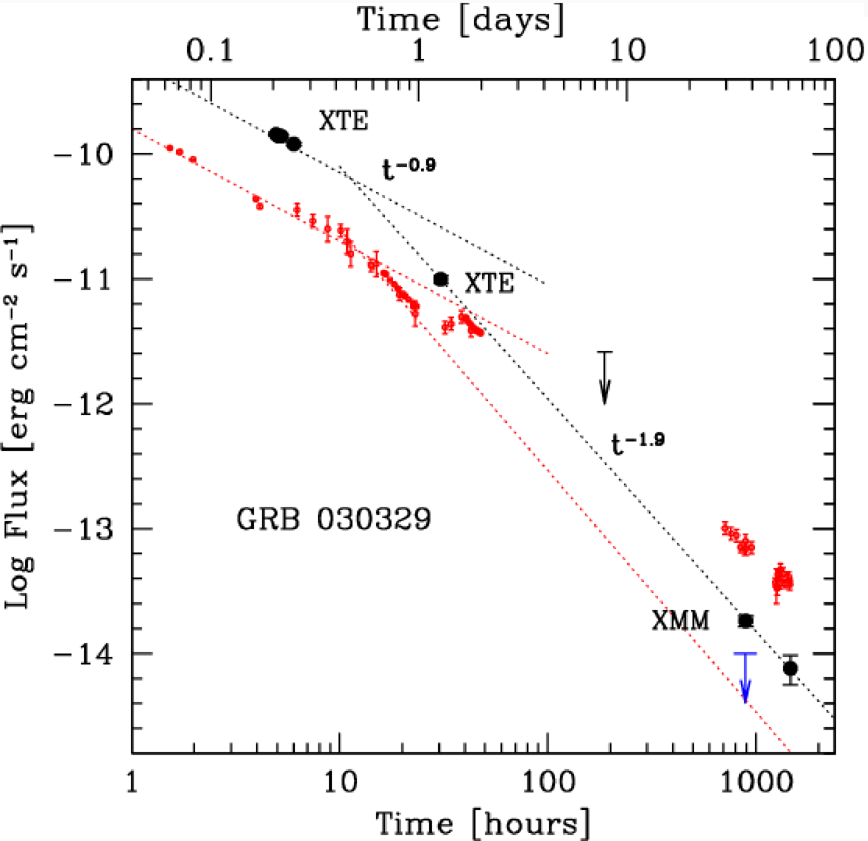
Collapsar Model

A&A 409, 983–987 (2003)
DOI: 10.1051/0004-6361:20031127

Astronomy & Astrophysics

The X-ray afterglow of GRB 030329

A. Tiengo[1,2], S. Mereghetti[1], G. Ghisellini[3], E. Rossi[4], G. Ghirlanda[1], and N. Schartel[5]



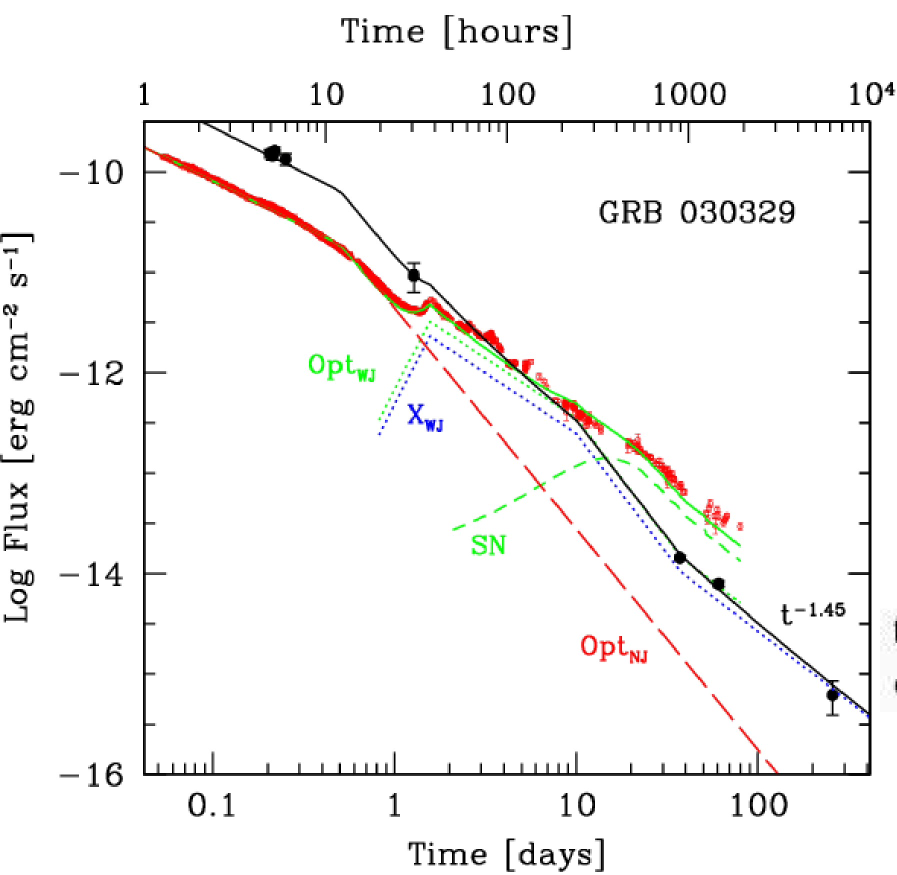
Comparison of X-ray data with many optical observations: at late time optical dominated by supernova, X-rays by afterglow.

A&A 423, 861–865 (2004)
DOI: 10.1051/0004-6361:20041027

Astronomy & Astrophysics

Late evolution of the X-ray afterglow of GRB 030329

A. Tiengo[1,2], S. Mereghetti[1], G. Ghisellini[3], F. Tavecchio[3], and G. Ghirlanda[3]



X-ray detection **258** days after GRB: it was the latest time detection of a GRB X-ray afterglow

The immediate prediction of this interpretation is that also the radio light curve should show a flattening from $\delta = 2$ to $\delta_{NR} \sim 1.5$ after $t \sim 40$ days.

Accurate Calorimetry of GRB 030329

D. A. Frail[1], A. M. Soderberg[2], S. R. Kulkarni[2], E. Berger[2], S. Yost[3], D. W. Fox[2] & F. A. Harrison[3]

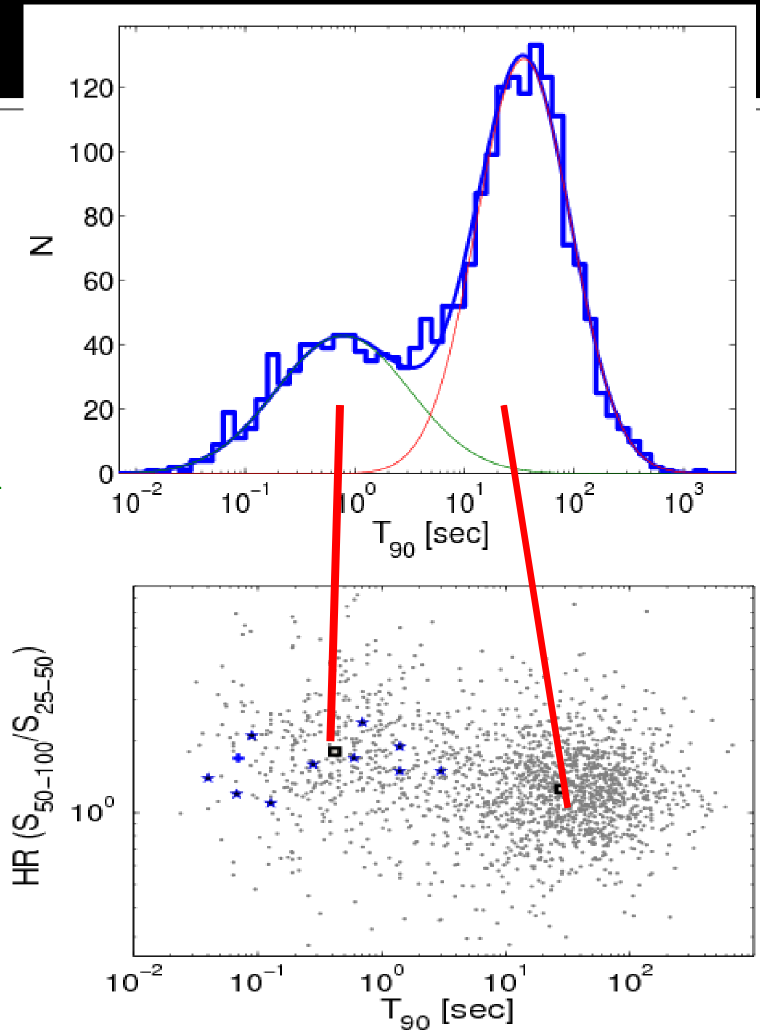
ABSTRACT

We report late-time observations of the radio afterglow of GRB 030329. The light curves show a clear achromatic flattening at 50 days after the explosion. We interpret this flattening as resulting from the blast wave becoming trans-relativistic. Modeling of this transition enables us to make estimates of the energy

As we predicted...

similar flattening of the X-ray emission is seen by *XMM-Newton* in which the decay index changed from $\alpha_X = -1.86 \pm 0.06$ to $\alpha_X = -1.40 \pm 0.15$ between 1.24 and 37 days and 37 and 258 days after the burst (Tiengo *et al.* 2003; Tiengo *et al.* 2004).

Short bursts with hard spectra



Long bursts with soft spectra

Different progenitors, as in Supernovae?

Short GRBs

Coalescence of two compact objects (NS-NS, NS-BH)