BH Astrophys. Ch3.6

Outline

1. Some basic knowledge about GRBs

2. Long Gamma Ray Bursts (LGRBs)

- Why so luminous?
- What's the geometry?
- The life stages
- The supernova connection
- The collapsar model

3. Short Gamma Ray Bursts (SGRBs)

4. Other types of GRBs

- Ghosts
- X-ray flashes
- Low Energy GRBs

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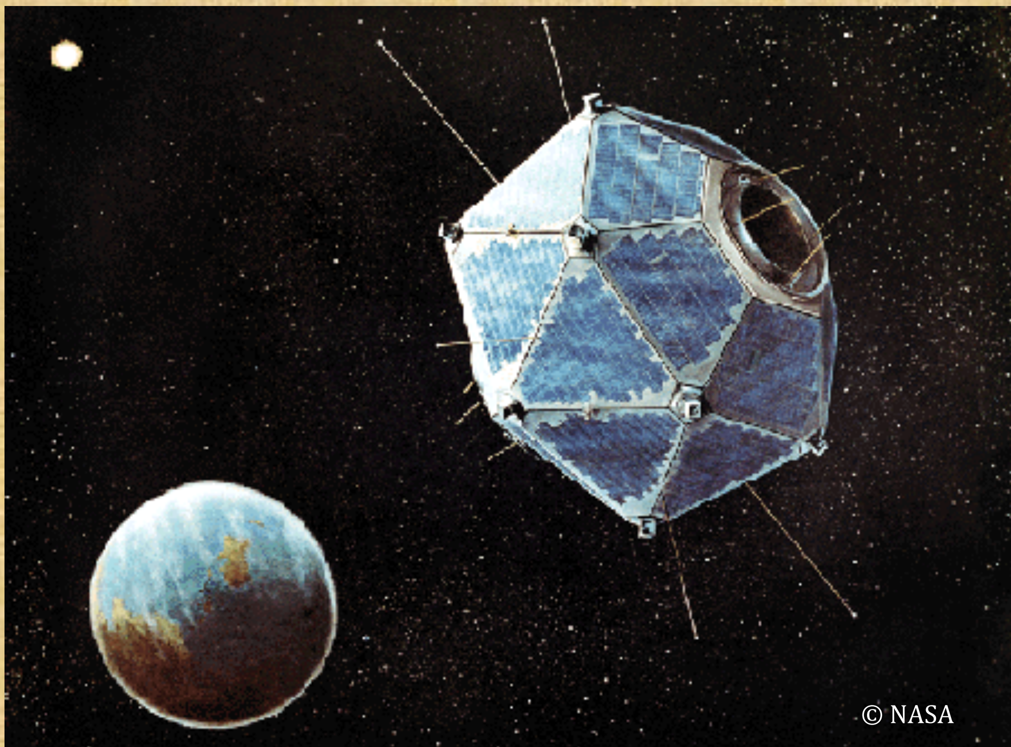
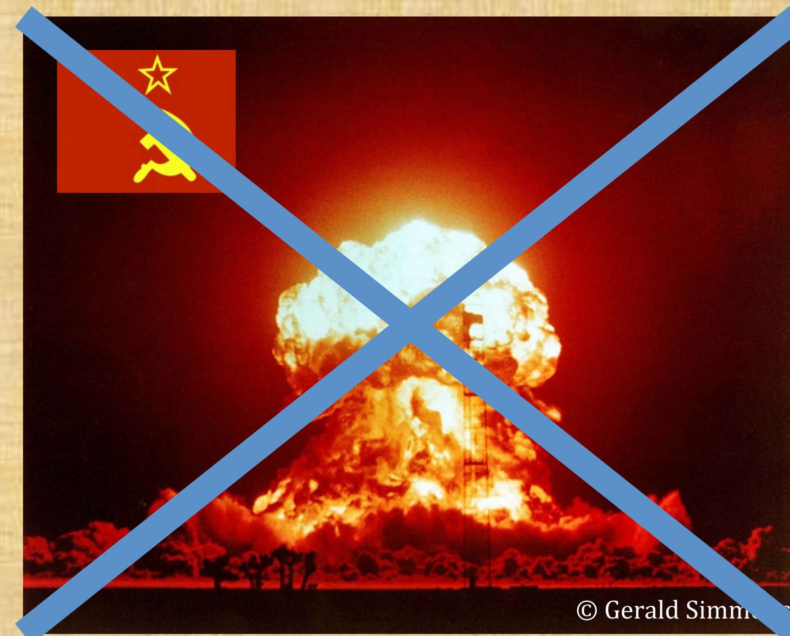
- Low luminosity GRBs

Pre Compton Era – The Vela satellites (1967~1990)



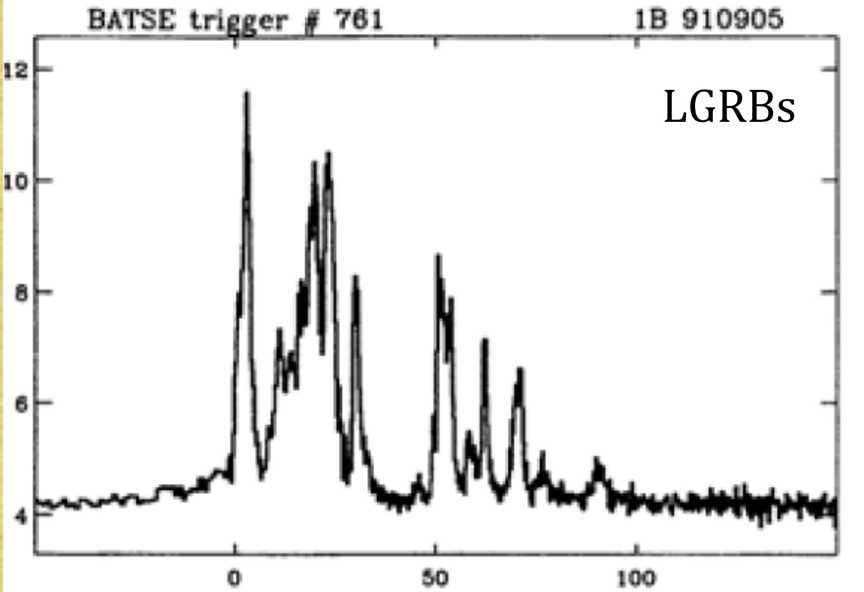


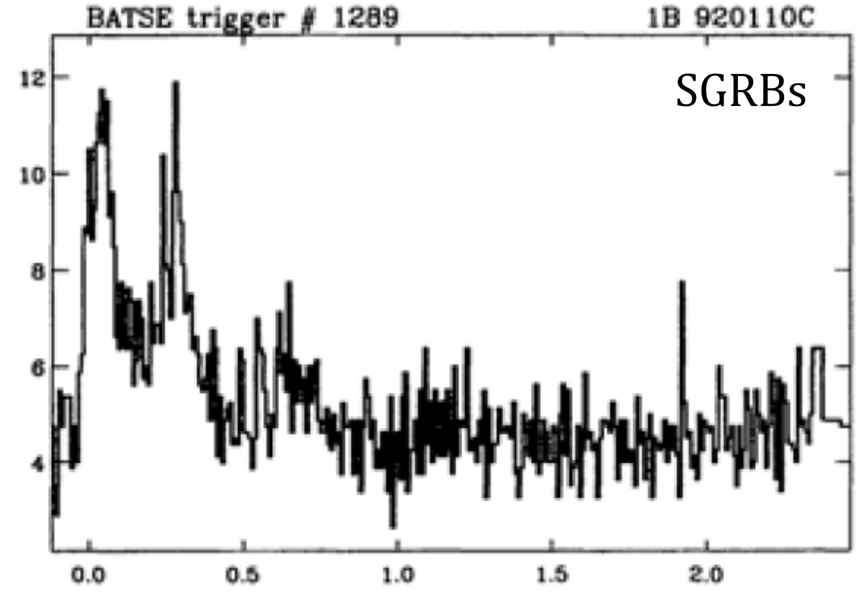
Questions of the era:

What are these flashes?

Where do they come from? Extragalactic? Galactic?

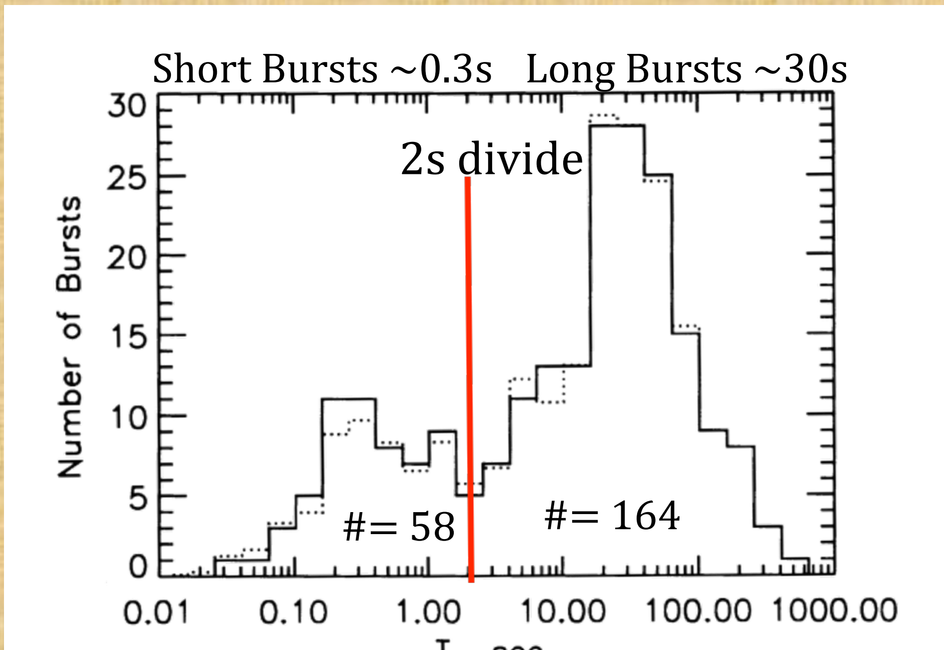
The long and short GRBs





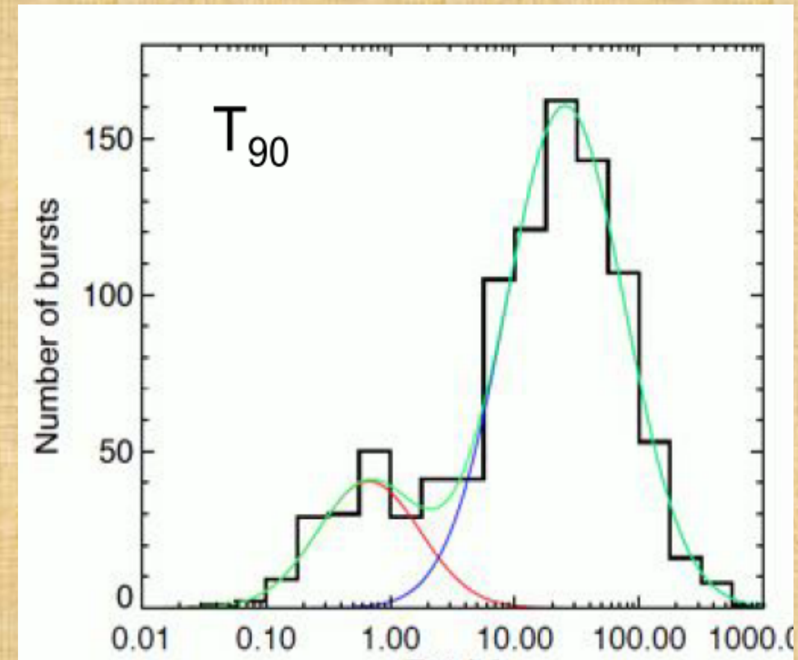
The (common) classification

Situation in 1993



C. Kouveliotou ApJ, 413, L101 (1993)

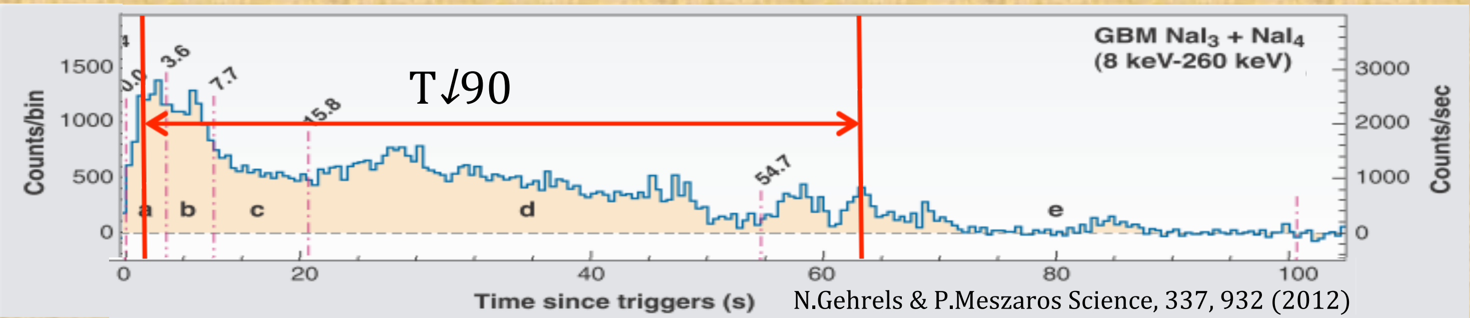
Situation in 2012



Fermi+ 2012

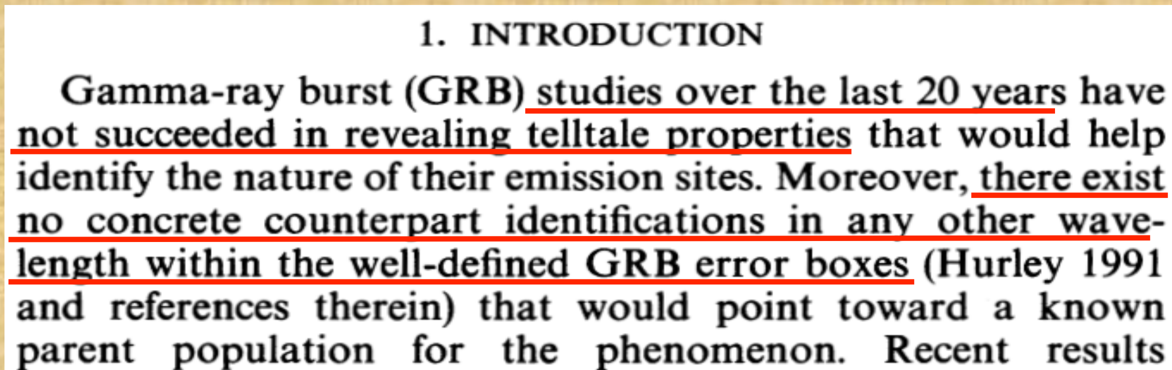
Bimodal distribution with a divide at 2 sec！

Possibly two different classes of objects causing the bursts.



N.Gehrels & P.Meszaros Science, 337, 932 (2012)

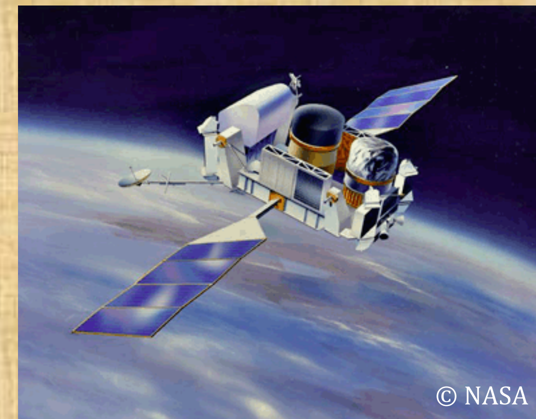
The situation as of 1993

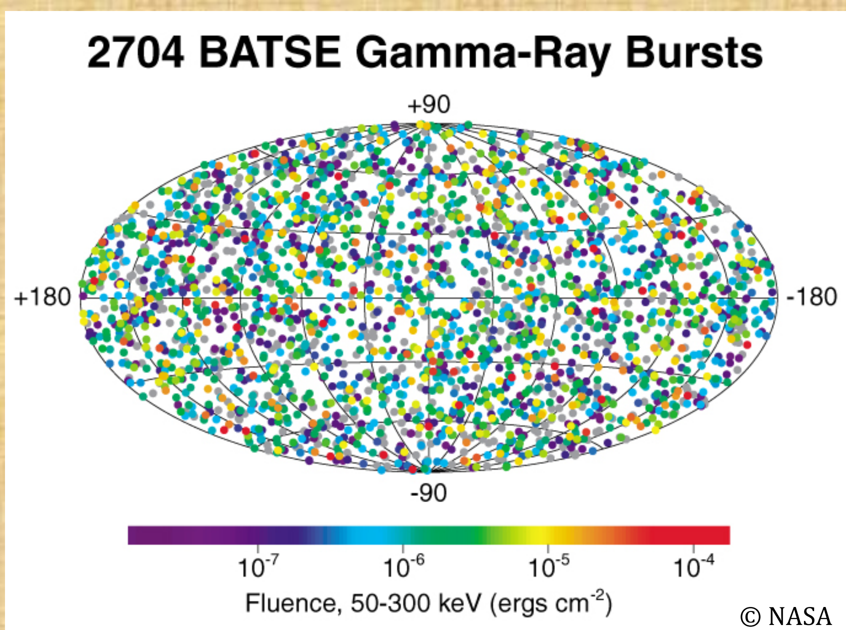


1. INTRODUCTION

Gamma-ray burst (GRB) studies over the last 20 years have not succeeded in revealing telltale properties that would help identify the nature of their emission sites. Moreover, there exist no concrete counterpart identifications in any other wavelength within the well-defined GRB error boxes (Hurley 1991 and references therein) that would point toward a known parent population for the phenomenon. Recent results

C. Kouveliotou ApJ, 413, L101 (1993)





http://gcn.gsfc.nasa.gov/

More likely to be extra-galactic！

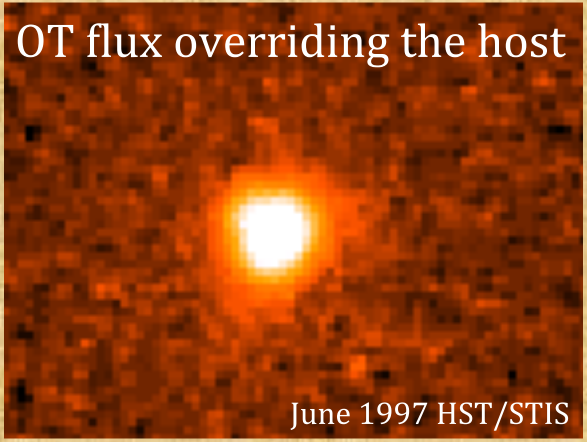
The counterpart in other wavelengths?

GRB 970508
First direct evidence of extragalactic origin

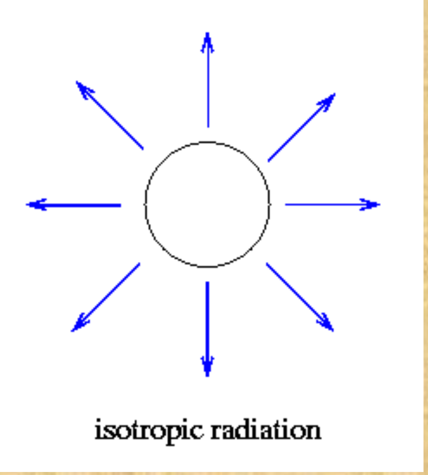
Table 1 OT J065349+79163 absorption lines Metzger, M., et al., 1997, Nature, 387, 878

λ_{vac} (Å)	Unc.	W_λ (Å)	Unc.	λ_{rest} Å	z	Assignment
4,302.5	1.8	1.3	0.3	2,344.2	0.8354(8)	Fe II
4,359.7	1.4	1.3	0.3	2,374.5	0.8360(6)	Fe II
4,372.2	1.5	1.4	0.3	2,382.8	0.8349(6)	Fe II
4,746.7	1.7	1.0	0.4	2,586.7	0.8350(7)	Fe II
4,769.7	1.3	2.3	0.2	2,600.2	0.8344(5)	Fe II
4,941.1	1.5	1.3	0.3	2,796.4	0.7670(5)	Mg II
4,953.9	1.5	1.0	0.4	2,803.5	0.7670(5)	Mg II
5,130.4	1.1	2.7	0.2	2,796.4	0.8346(4)	Mg II
5,144.0	1.1	3.0	0.2	2,803.5	0.8348(4)	Mg II
5,232.6	1.3	1.8	0.2	2,853.0	0.8341(5)	Mg I

Measured optical counterpart to be at z ~ 0.835



At such distances, the isotropic luminosity would be huge! ~ 10↑52 ergs/s! Way brighter than any Supernova!



For quick reference : http://www.mpe.mpg.de/~jcg/grb970508.html

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- Spectral lag GRBs
- Low luminosity GRBs

LGRBs—Why so luminous?

The puzzle

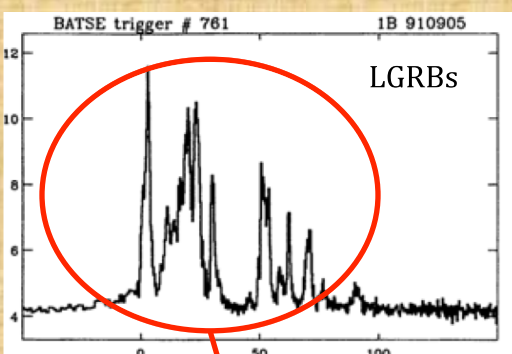
Observed: Small size + high γ-ray flux + optically thin synchrotron emission

Photon-photon interaction should produce e^-, e^+ pairs that thermalize the plasma

Optically thick thermal spectrum

What happened ?

Bohdan Paczy´nski , Peter M´esz´aros, Martin Rees showed that observations were consistent with an optically thin fireball of e^-, e^+, B field expanding at $\Gamma \sim 300$ (0.999995c) !



Fast variations?

Irregularities in the outflow

Turbulence from interaction with external medium

Engine sputtering

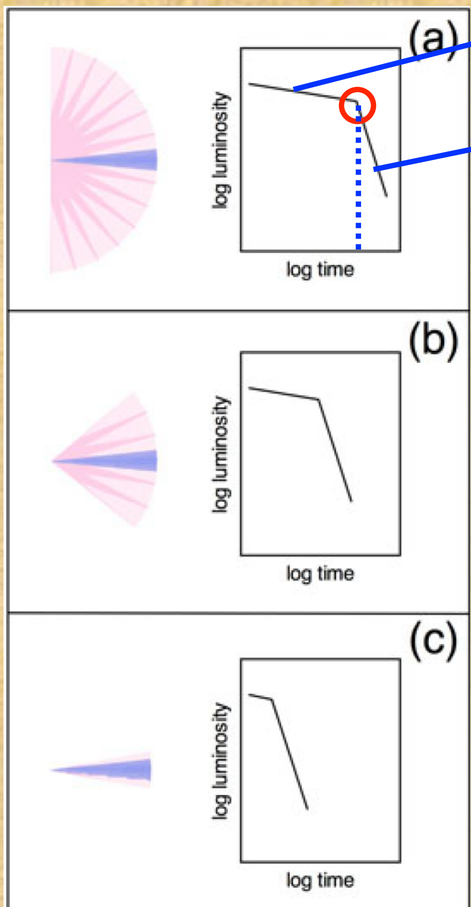
These internal shocks slow the flow as they convert kinetic energy into accelerated particles and γ-rays

LGRBs—What's the geometry?

High Γ factor → Confined view of emission →

- Spherical ?
- Cone shaped?
- Hemispherical ?
- Jet?

Beaming breaks



$F \propto t^{-1.1}$

$F \propto t^{-2}$

The case of GRB 990123 showed a beaming break at around 2 days, indicating the original flow angle is $\sim 6^{\circ}$

This reduces the required luminosity in γ-rays to 10^{51} erg/s similar to strong SNs (this holds true for almost all LGRBs)

This also implies that there are a lot of GRBs hidden from us due to beaming effects!

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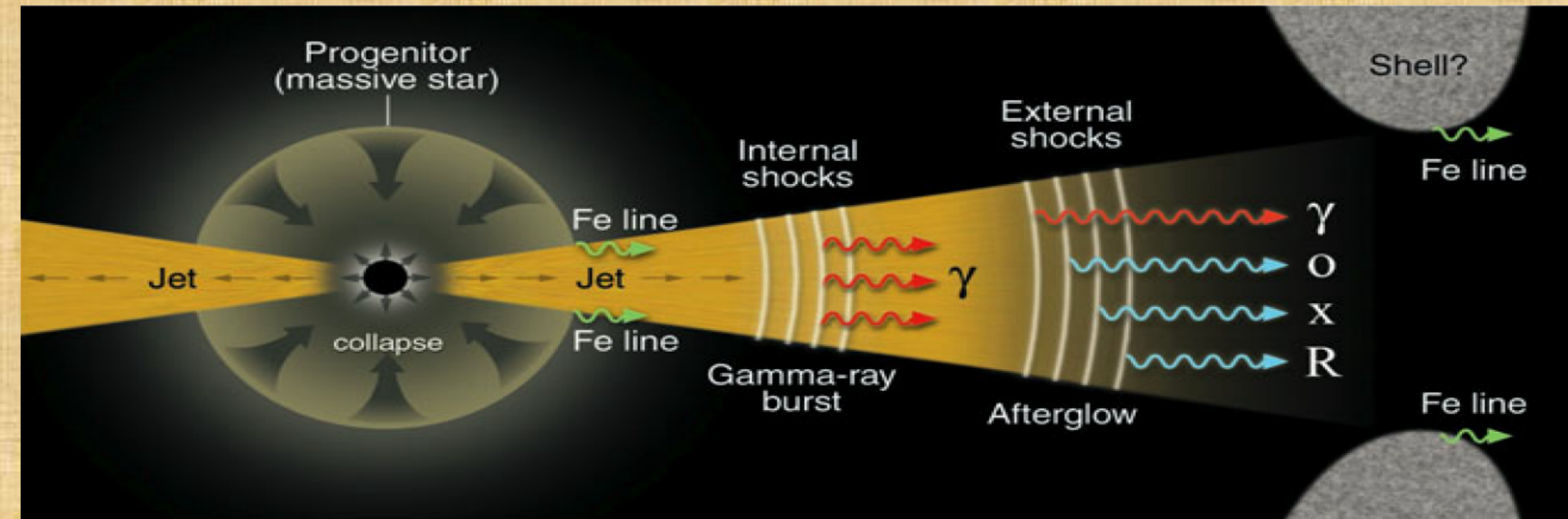
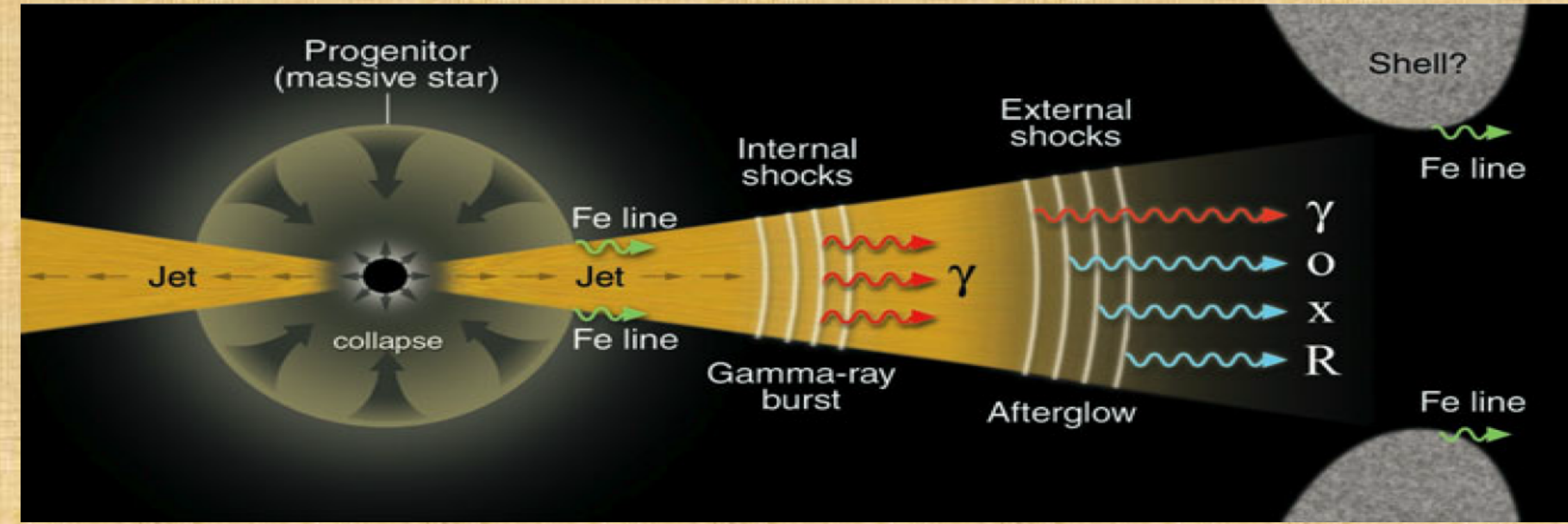
LGRBs—Life stages



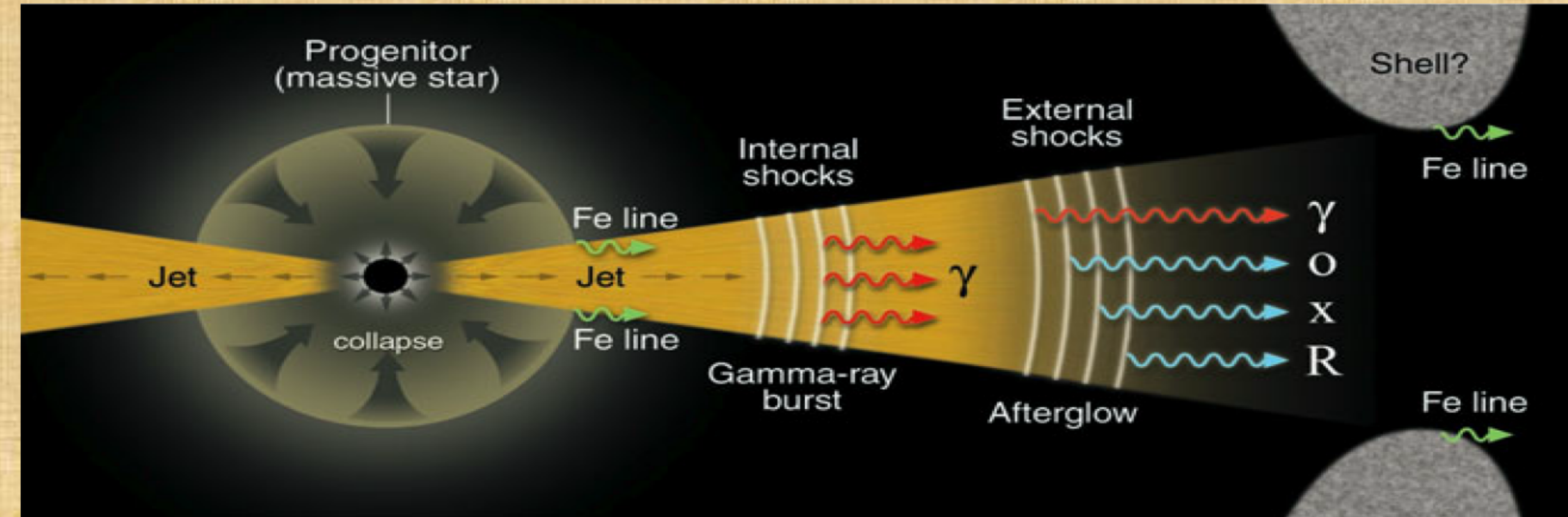
1. Inner Engine Activity. In the first few seconds of the initial explosion, a relativistic jet flow is generated by some means deep in the heart of the GRB central engine. The engine varies ("sputters") on a time scale δt of milliseconds or less, but stays turned on for the duration T of the GRB (up to several minutes). So, the size of the engine is less than 3×10^{7} cm, but the jet outflow itself can be much longer, $L = c\,T \approx 10^{13}$ cm or about 1 AU This large ratio of engine "on" time to dynamical time is typical of the other jet sources we have discussed in this and previous chapters. It indicates that the actual engine event is not explosive at all, but rather a relatively benign, quasi-stationary process.

LGRBs—Life stages



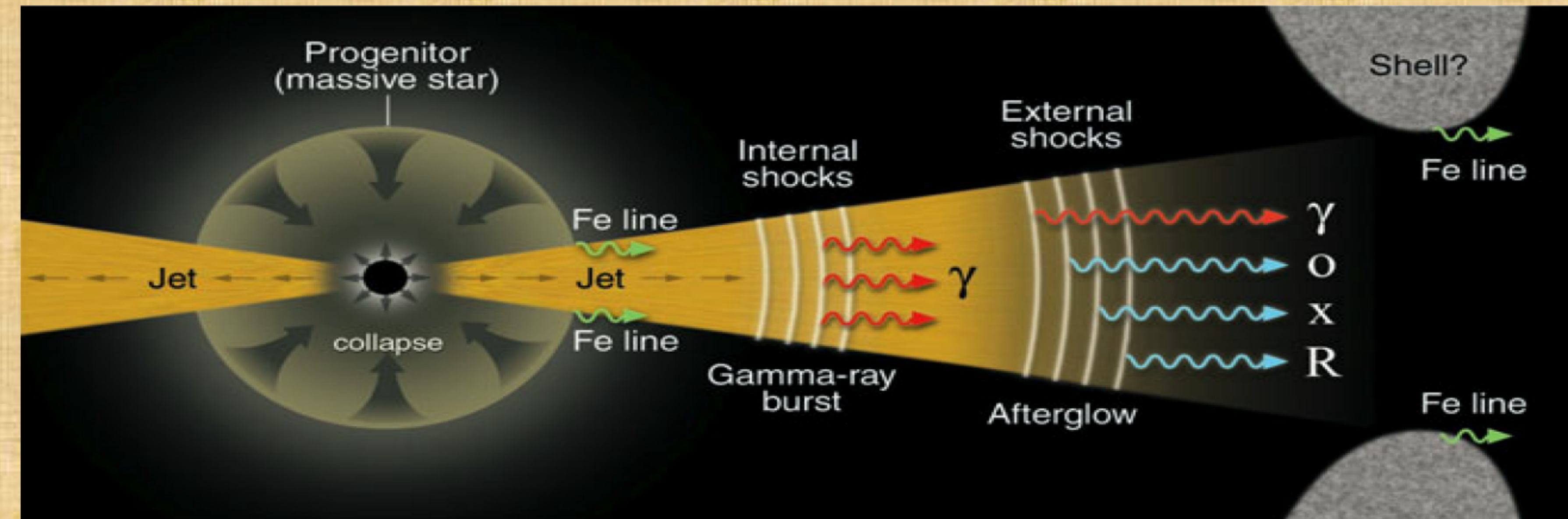
2. Energy Transfer Phase. When the jet flow starts out near the engine, it is not necessarily initially traveling at ultra-relativistic speeds. Instead, it probably is accelerated to the observed speeds ($\Gamma_{jet} \sim 300$) over distances considerably greater than 10^{7} cm. During its journey from 10^{7} to 10^{13} cm, the jet material is optically thick to γ-rays. These photons interact, produce $e^{+}e^{-}$ pairs, and come into thermal equilibrium with those pairs. Because thermal emission from the surface of the jet is not very bright, the GRB will not visible to observers in this stage. The opening angle of the jet will be $\theta \sim 0.1$ radians, so its width in the outer portion of the jet will be about 10^{12} cm.

LGRBs—Life stages



3. Gamma-Ray Burst Phase. Beyond 10^{13} cm, the jet becomes optically thin to pair production and releases its γ-rays in the direction of the relativistic flow. The irregular nature of the engine creates internal shocks in the jet that accelerate the electrons and positrons. Those particles, in turn, generate relativistic synchrotron emission that ultimately dissipates much of the kinetic energy in the flow. The jet therefore slows down to $\gamma_{jet} \sim 10$ at a distance of R ~ 10^{15} cm – one (light-) day after the initial engine began firing. Initially, when the jet has reached only 10^{13} cm, we see only a portion of the jet $\pi\gamma_{jet}^{-2} \sim 3 \times 10^{-5}$ steradians in solid angle. However, as it decelerates this increases to $\pi\theta^{2} \sim 3 \times 10^{-2}$ steradians by the time the jet reaches 10^{15} cm. At that point, it also is like a bullet in its rest frame, with a length of $\gamma_{jet} cT$ and a width Rθ that are about the same size, 10^{14} cm. In our rest frame, however, we see it as a flying pancake only 10^{13} cm thick. Also at this point, θ

LGRBs—Life stages



4. Afterglow Phase. The flow now enters an expansion phase, where it expands sideways at nearly c. The external (bow) shock created by the jet heats the interstellar medium as it sweeps it up, generating X-rays and optical emission that decay rapidly at a rate of $\sim t^{-2}$. In the late stages of this expansion phase, some GRBs show radio emission that initially scintillates, due to the scattering of the light from this point source by interstellar turbulence in our own Galaxy. After about 1 month, the scintillation ceases, indicating expansion to a size of about 10^{17} cm (one light-month). This is independent confirmation that the jet flow in GRBs is relativistic. During the expansion phase the flow decelerates to sub-relativistic speeds, expands to $\sim 10^{16}$ cm laterally, but only $cT \approx 10^{13}$ cm thick in its direction of motion. (Why?) This non-relativistic flying pancake now acts like a portion of an expanding supernova shell, sweeping up more material and becoming unstable and turbulent. Eventually it is halted altogether.

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LGRBs—the Supernova connection

1. Mostly found in star-forming galaxies.
2. The jets have energies comparable to SN

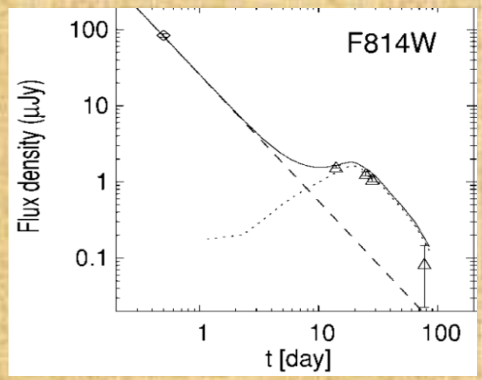
Are all LGRBs associated with SN?

Most likely Yes?

Examples:

GRB 980425 ⇔ SN 1998 bw
1. z~0.0086 (only 34 Mpc) would make the SN easily detectible.
2. SN is of type Ic-BL which is the SN with much greater energy than typical Type Ib/c.

GRB 011121 ⇔ SN 2001ke
Shows re-brightening of optical light curve ~1month after burst → The optical luminosity of the SN was still increasing while the GRB afterglow was already fading.



Do all SNs produce LGRBs ?

Most likely No!

GRB observed rate ~1/10↑6 yr

GRB actual rate ~1/10↑3 yr

SN rate ~1/50-100 yr

~1/10 of SNs!

*More likely associated with Type Ib/c-BL

*high Γ factor indicate accompanying formation of BH instead of NS.

LGRBs—the collapsar model

For some reason the SN fails to explode

↓

Mantle rains down on the proto-neutron star (PNS).

↓ After hours~days

PNS passes $1.5 M_\odot$ and collapses to a BH.

↓

Disk is formed from the mantle material.

↓

Neutrino emission and jets form.

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SGRBs—mergers?

Basic mechanism (same idea as LGRBs):
BH formation → rapid accretion → jet flow → brief fireball

Why are they short?

Less available material for accretion, 100~1000 times less

Maybe NS-NS, NS-BH mergers?

Only material available in this case is small amounts of stuff from SN outer layers.

Should be found in galactic halos, not SF regions.

GRB 050509 detected by Swift was able to be determined to be in a elliptical galaxy at z~0.225, exactly what was expected by merger scenario.

Good targets for gravity wave detectors.

GRB 050709 produced an optical afterglow, but it was located in a z=0.16 SF galaxy, which is still consistent with the merger model as binaries can exist in all types of galaxies.

Optical afterglow is consistent with this SF galaxy having more ISM for the jet to blast into.

A surprising pattern:
their energies are only 10^{48-49} erg (~300 less than LGRB)

Some SGRBs are highly beamed, relativistic jets.

Some SGRBs are just sprays of r-ray emitting material.

Consistent with formation of a “bare” black hole: no SN envelope around the engine to collimate the burst

A high z population (z=0.4~1.1) are seen as well (~1/3 of all SGRBs), which again is consistent with the NS-NS merger model (?)

The distant SGRBs are intrinsically more energetic than their low-redshift counterparts.

They produce typical 10^{48-49} erg bursts but we only see those that are highly beamed toward us.

The numbers of distant SGRBs must be considerably more than we see.

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Other Types of GRBs—Ghosts

LGRBs studied at other wavelengths

90% have X-ray detection

50% have Optical detection

40% have no Optical detection → called "Ghosts"

Possibilities:

1. The exploding massive star may be enshrouded in dense, dusty molecular clouds opaque to optical.

2. GRBs may occur in ULIRGs.

3. They may be low G sources and rapidly decay.

4. They might be at very high z (>10)

Other Types of GRBs—X-ray flashes

Emission mainly in X-rays with weaker accompanying γ-ray emission.

Possibilities:

Many are also ghosts.

1. The exploding massive star may be enshrouded in dense, dusty molecular clouds opaque to optical.
2. GRBs may occur in ULIRGs.
3. They may be low G sources and rapidly decay.
4. They might be at very high z (>10)

+

5. They are heavily loaded with protons and therefore are only mildly relativistic fireballs. (synchrotron emission ~100 lower in energy)

It is generally believed that there are a continuum of sources between strong γ-ray bursts and the X-ray flashes (which are weak in γ-rays).

Other Types of GRBs—Spectral lag GRBs

Long spectral lag → Low beaming factor

Example: GRB980425 ⇔ SN 1998bw

Suggestion: perhaps all spectral lag GRBs come from Type Ib/c SN.

Indeed, Spectral lag GRBs seem to be relatively nearby (<100Mpc)

and if their beaming factors~1 then the rate of these GRBs and the rate of SN Ib/c are comparable.

*These objects tend to be underluminous compared to other GRBs.

Other Types of GRBs—Low luminosity GRBs

GRBs with L < 10^{47} erg/s increases to ~100 times more events per cubic Gpc compared to normal GRBs.

At this stage little is known. It is much too early to tell whether or not they are produced by a different progenitor of mechanism from, say, the massive star/ collapsar one.

The relation among the X-ray flashes, low-luminosity GRBs, and SN Ib/c is not understood yet. However, it is important to remember that these SNs have little or no H/He in the outer envelope and that they are the most elongated explosions. The jet could easily break out of the star in some cases and be observed from a large range of viewing angles as a X-ray flash or low-γ_{jet}, long spectral lag GRB.

These peculiar GRBs may be the missing link between elongated SN which seem to produce NSs, and ultra-relativistic GRBs which produce BHs.