

Lecture XXII.

Gamma-ray bursts

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A PATH TO MARS

BUILDING BLOCKS

<p>Production</p> <p>1</p>	<p>Space Launch System (SLS)</p> <p>Heavy lift launch system that transports crew and all elements from Earth to space enabling the path to Mars.</p>
<p>Production</p> <p>2</p>	<p>Orion</p> <p>Crew transportation vehicle that carries humans from Earth to in-space habitats and back.</p>
<p>Early Development</p> <p>3</p>	<p>Transit Habitat</p> <p>The primary crew living quarters, the habitat has all the systems necessary to keep the crew healthy.</p>
<p>Early Development</p> <p>4</p>	<p>Deep Space Tug</p> <p>The tug moves in-space elements to other locations, utilizing solar electric and chemical propulsion.</p>
<p>Concept</p> <p>5</p>	<p>Mars Lander/Heat Shield</p> <p>The heat shield is needed to enter the Martian atmosphere so the lander can perform a propulsive landing.</p>
<p>Concept</p> <p>6</p>	<p>Mars Ascent Vehicle</p> <p>A small crew vehicle that carries crew to the surface of Mars (with the lander) and back to space and is also a small habitat for short stays.</p>



1 + 2

SLS and Orion
Primary transportation capabilities established

Today
Low Earth Orbit Missions
ISS is a testbed for deep space hardware and operations

2 + 3 + 4

Exploration Habitat
Key systems demonstrated

5 + 6

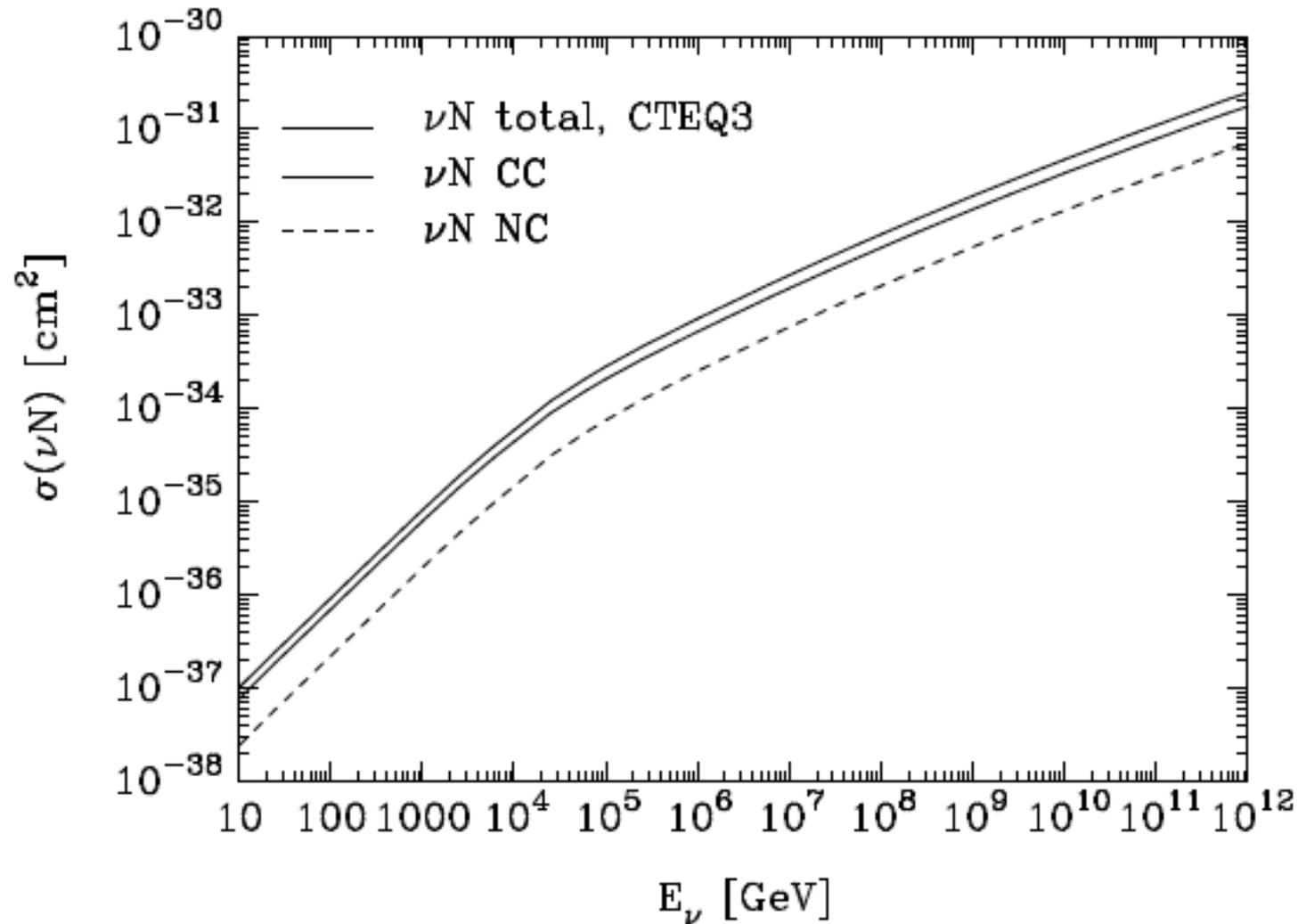
Mars Surface Capability
Descent and ascent on Mars

2 + 3 + 4

Mars Transit Vehicle
Interplanetary crew transport

HW: Should we be afraid of cosmic rays or neutrinos when traveling to Mars? (calculate energy deposited in a human by neutrinos and cosmic rays over the duration of the trip and compare to deposition from dangerous levels of radiation)

Neutrino cross section



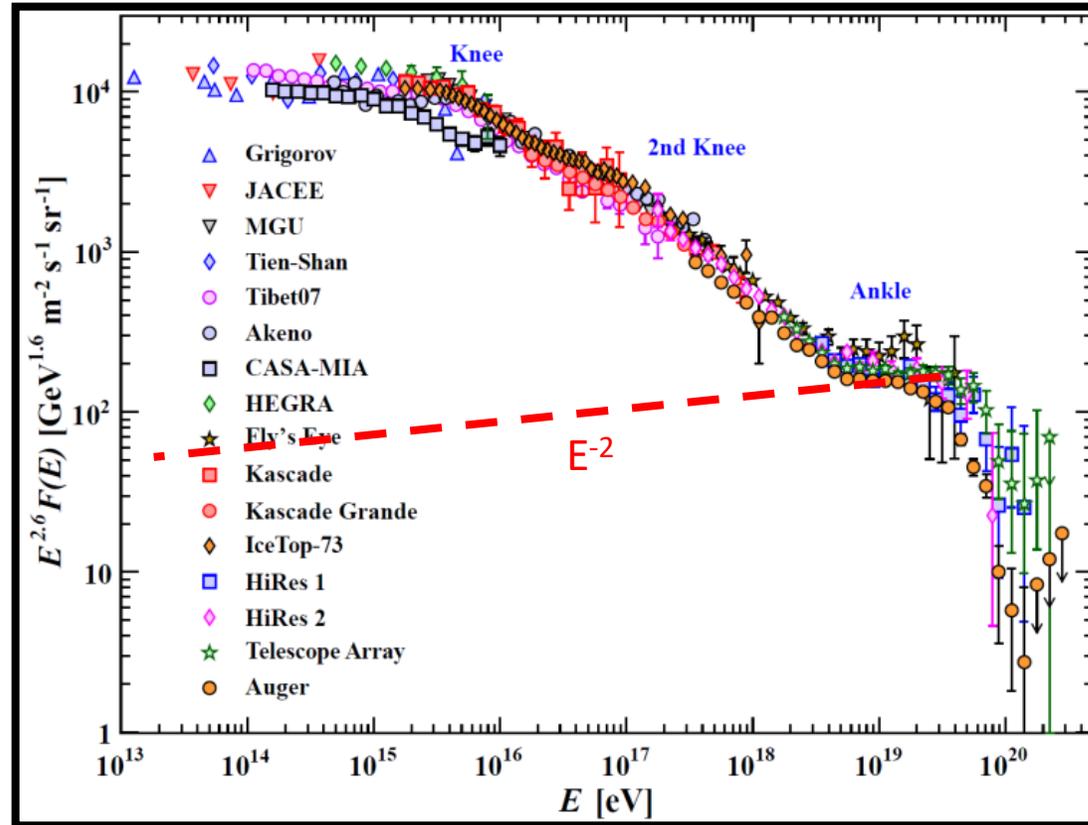
What fraction will cross the Earth at 10 TeV energy? (the energy of the LHC)

$$\frac{d\Phi}{dz} = -n\sigma\Phi$$

$$\Phi = \Phi_0 e^{-n\sigma z}$$

(pp cross section at 10 TeV --- $\sim 10^{-25}$ cm²)

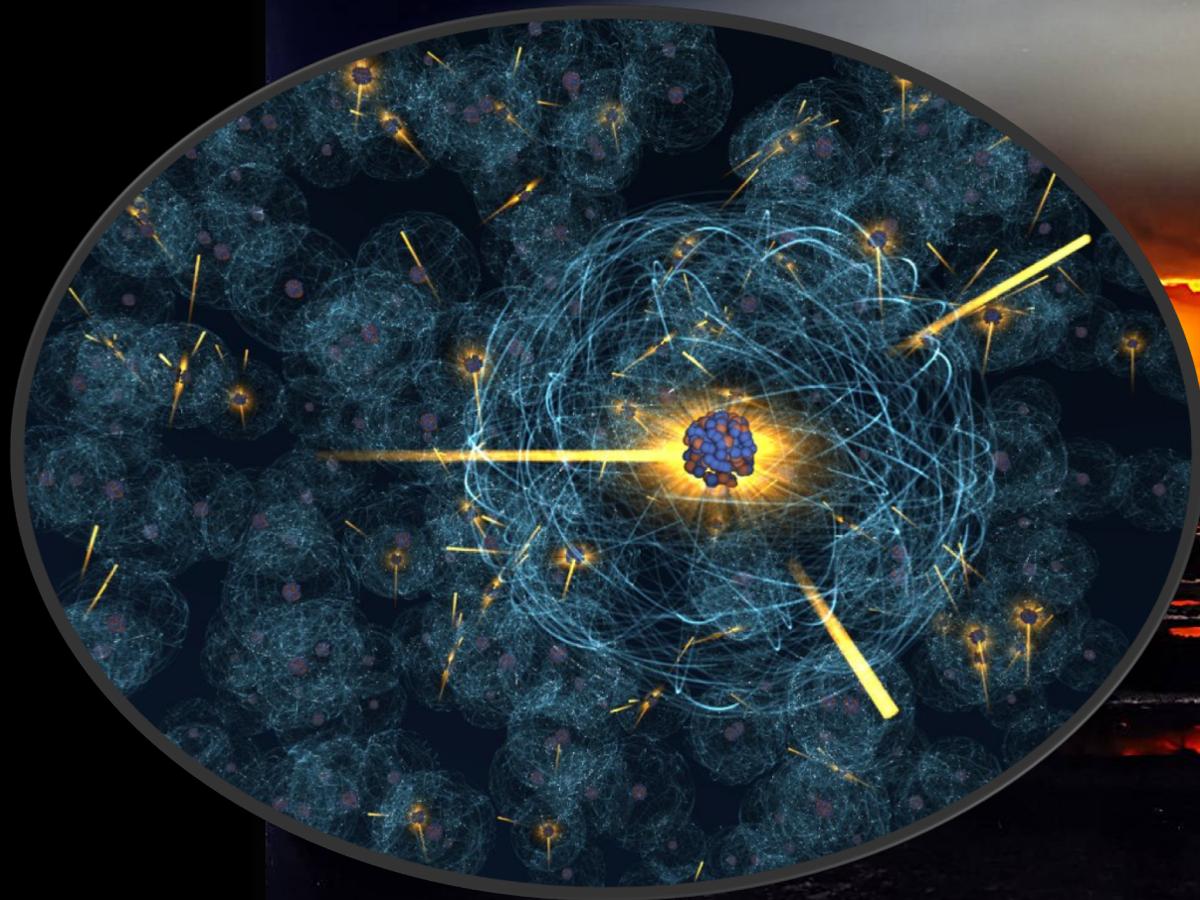
Neutrino flux upper bound



Extragalactic cosmic rays should eventually collide with gas and produce high energy neutrinos. What will be the neutrino flux if the extragalactic flux

- follows a Fermi spectrum and
- continues down to lower energies?

GAMMA-RAY BURSTS

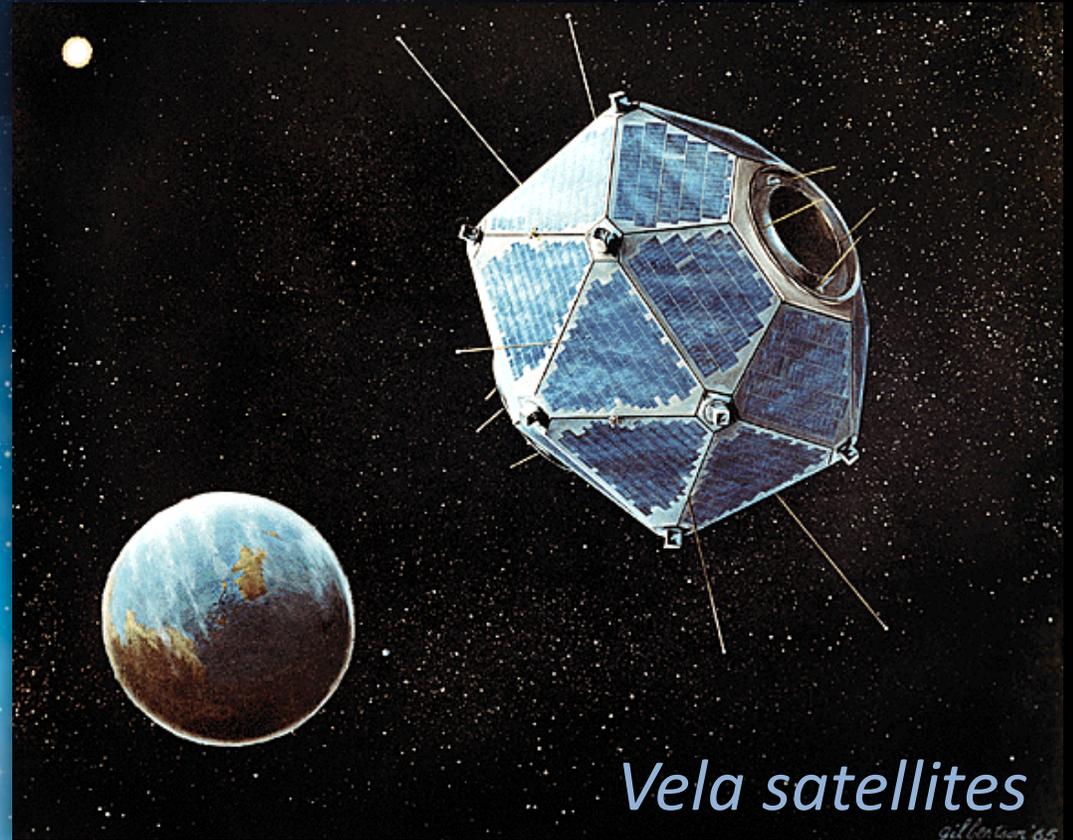


Vela satellites
gillerson '65

1960s

<http://www.youtube.com/watch?v=LLCF7vPanrY>

GAMMA-RAY BURSTS



Vela satellites

gillbertson '65

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

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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.

Subject headings: gamma rays — X-rays — variable stars

I. INTRODUCTION

On several occasions in the past we have searched the records of data from early *Vela* spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gamma-ray emission during the initial stages of the development of supernovae have since

1960s

GAMMA-RAY BURSTS



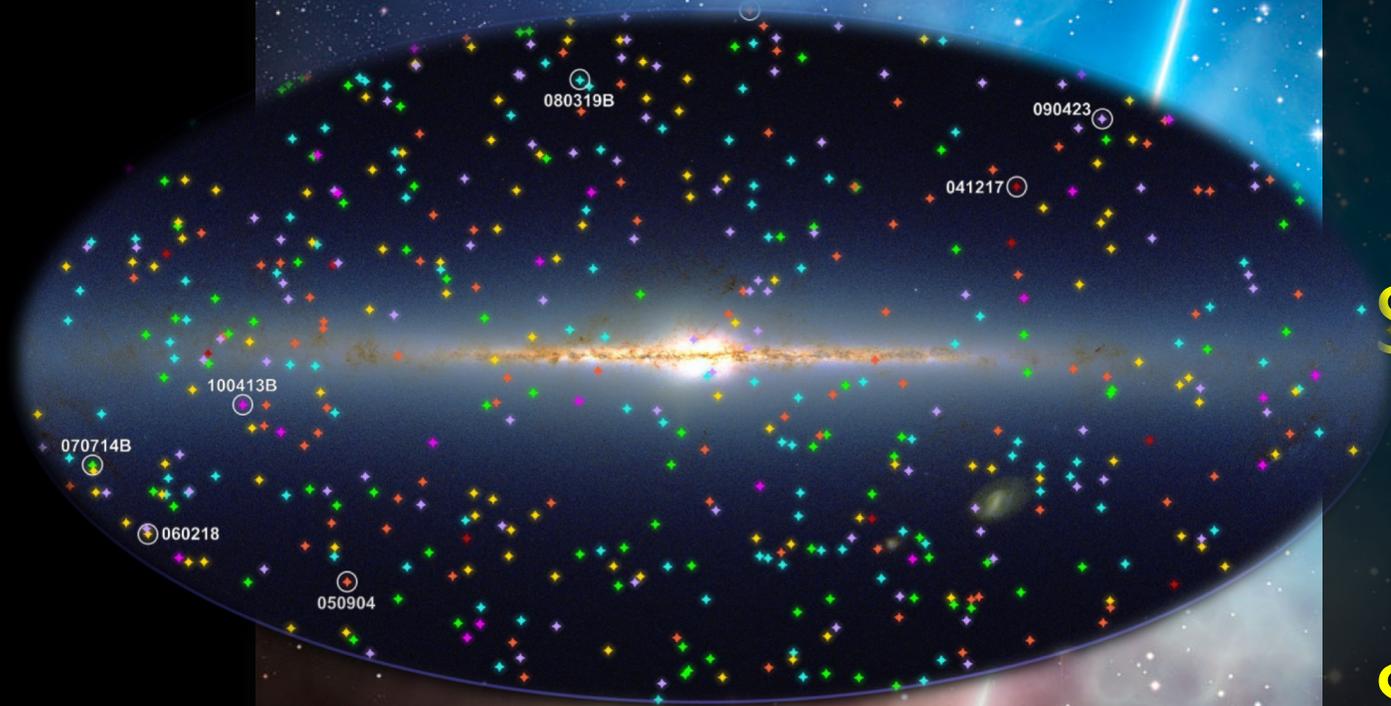
ORIGIN?

STRENGTH

SIZE

SOURCE

GAMMA-RAY BURSTS



ORIGIN?

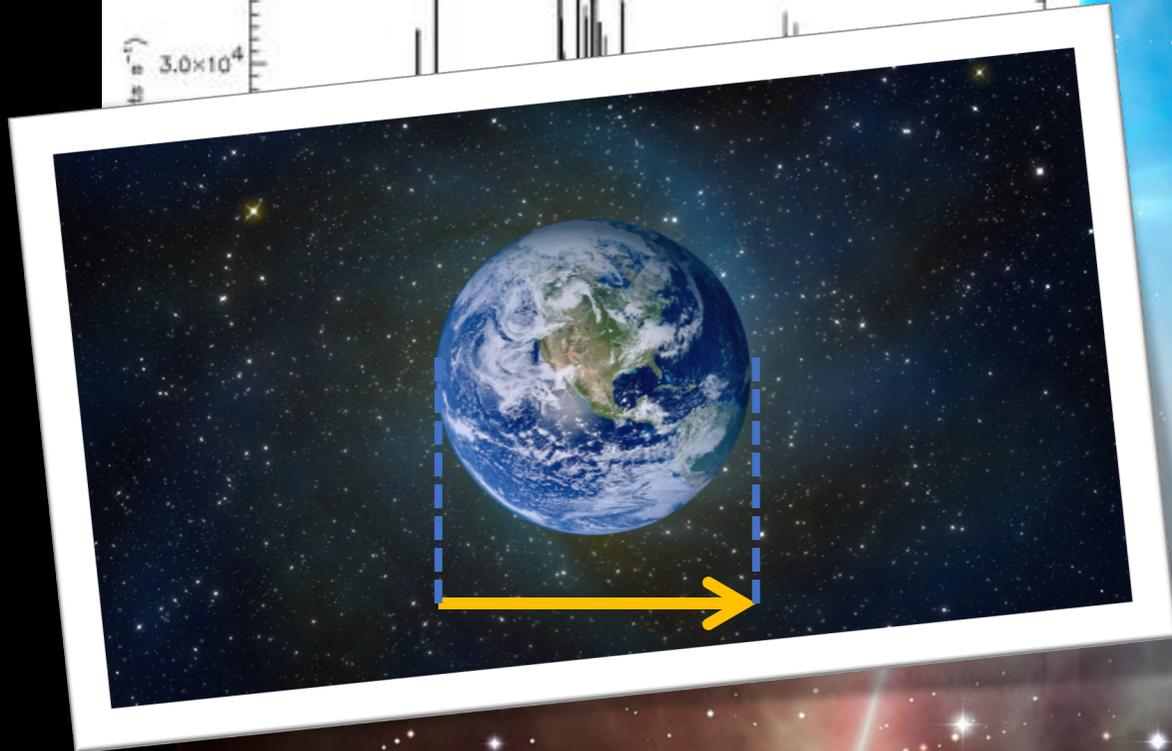
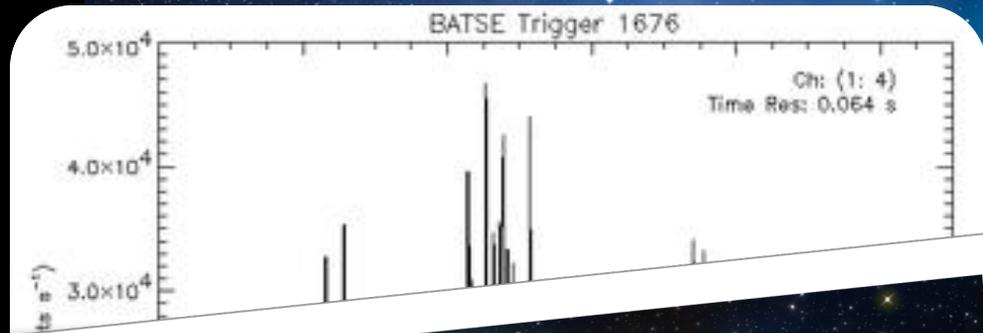
STRENGTH

EXTRAGALACTIC
→
ENERGETIC

SIZE

SOURCE

GAMMA-RAY BURSTS



ORIGIN?

STRENGTH

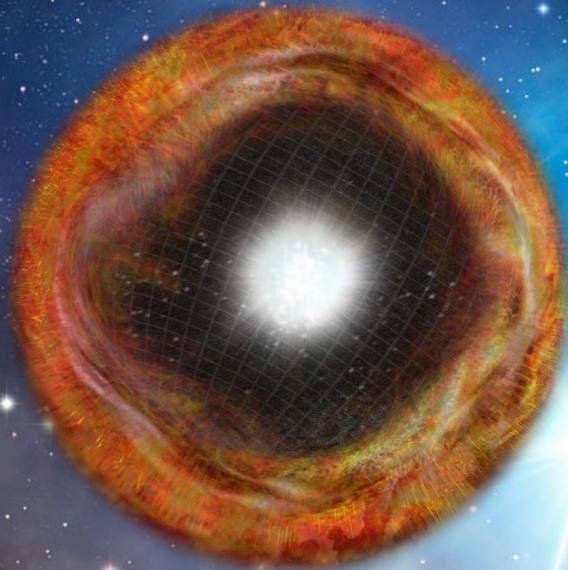
EXTRAGALACTIC
→ **ENERGETIC**

SIZE

SMALL!
(*< EARTH*)

SOURCE

GAMMA-RAY BURSTS



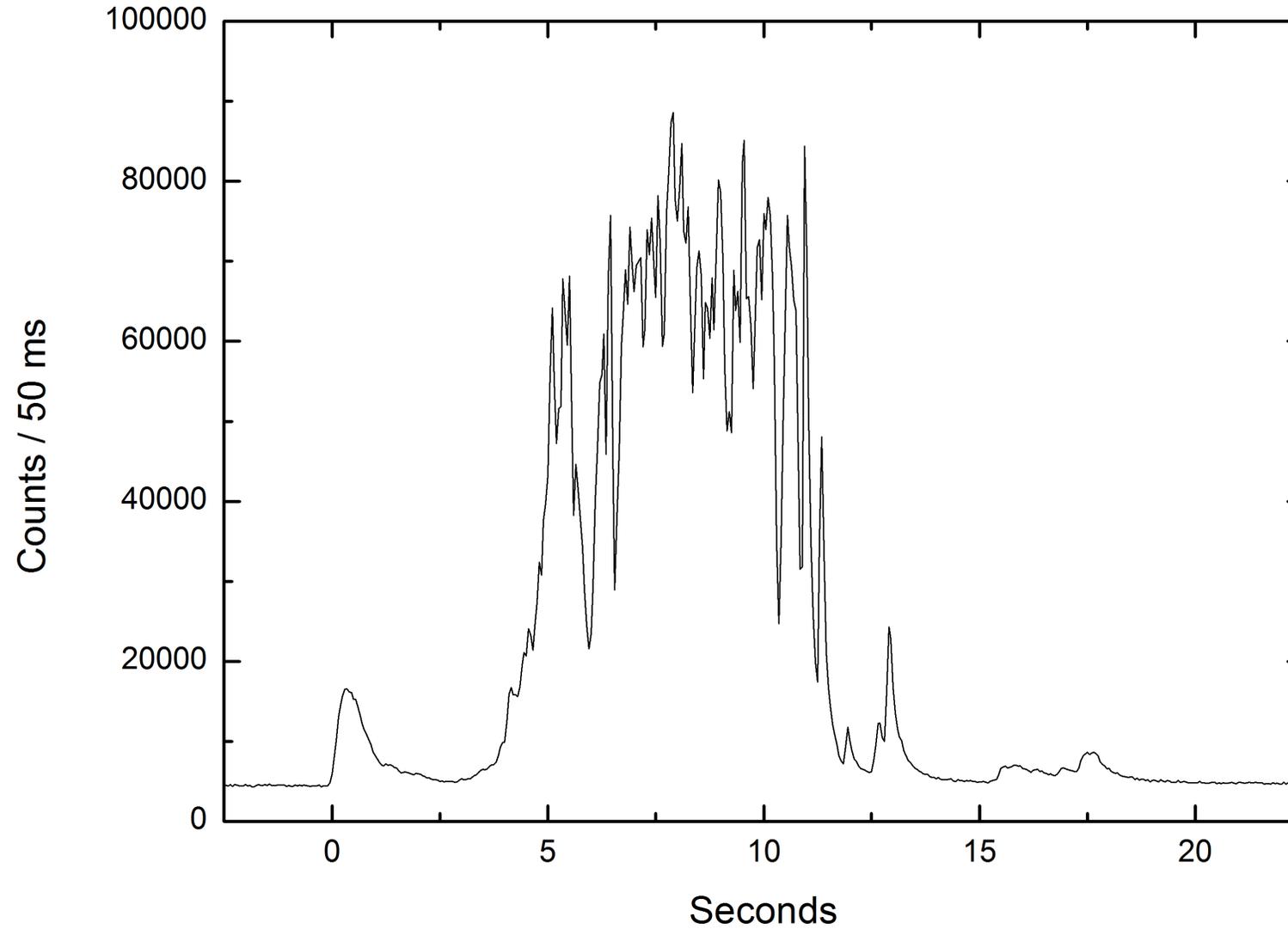
ORIGIN?

STRENGTH EXTRAGALACTIC
→ ENERGETIC

SIZE **SMALL!**
(*< EARTH*)

SOURCE 1. MASSIVE STARS
2. BINARY MERGERS

Light curves

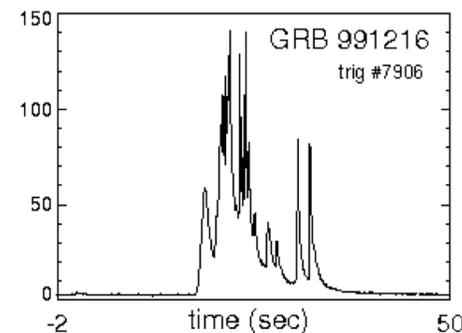
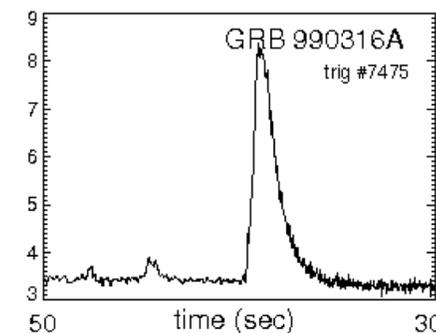
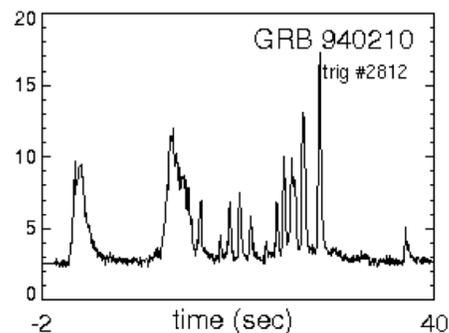
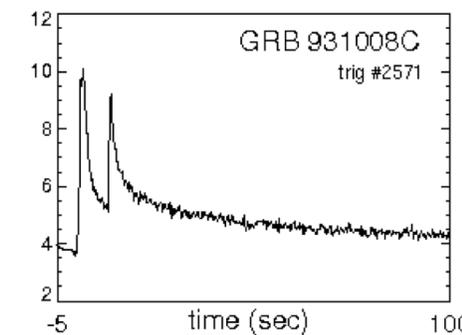
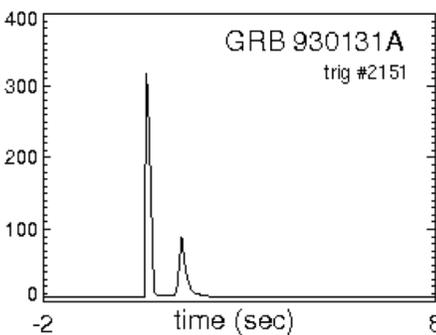
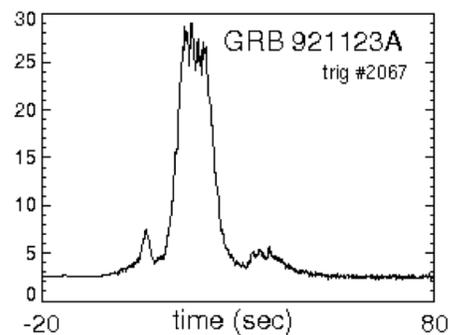
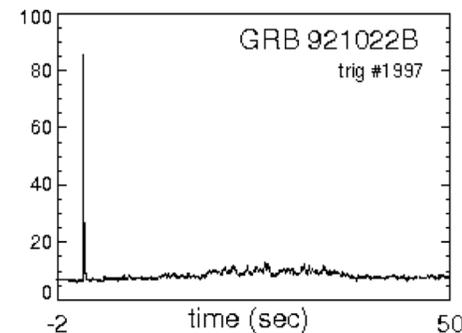
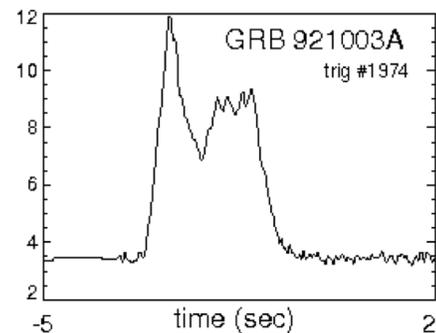
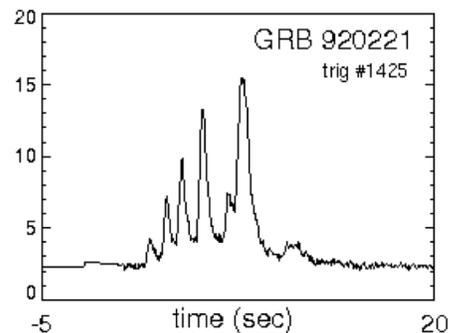
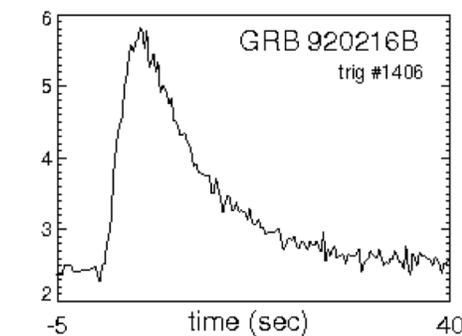
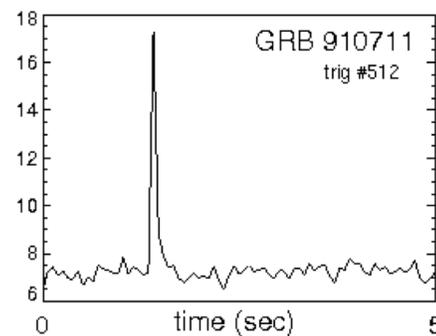
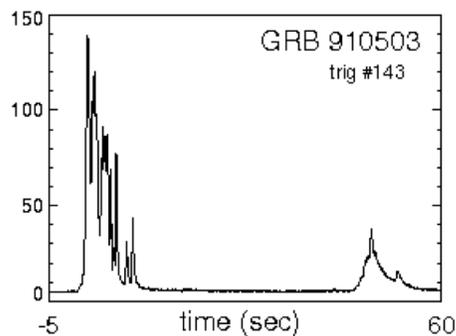


Light curves

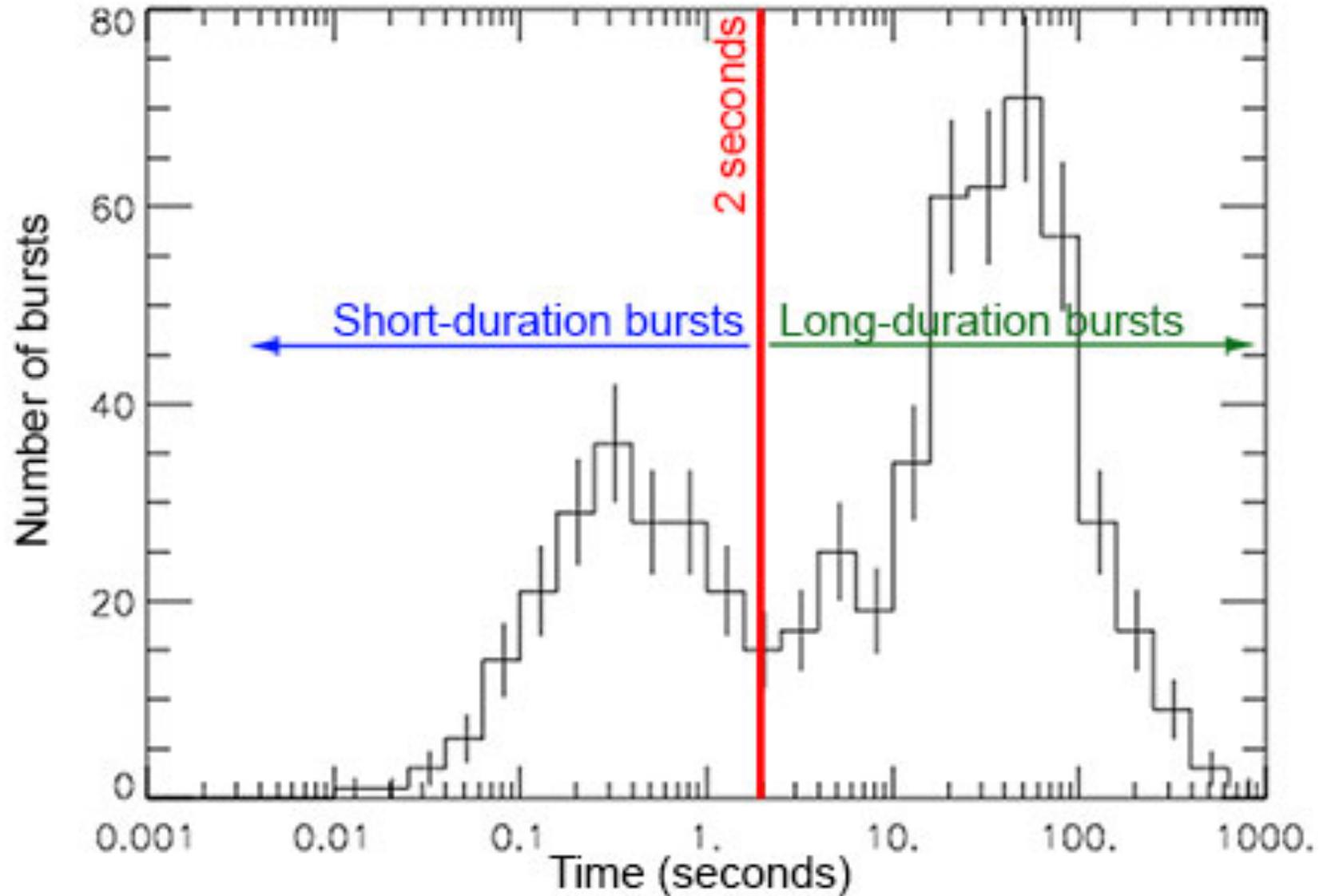
No two GRB light curves are identical.

Duration: milliseconds - minutes

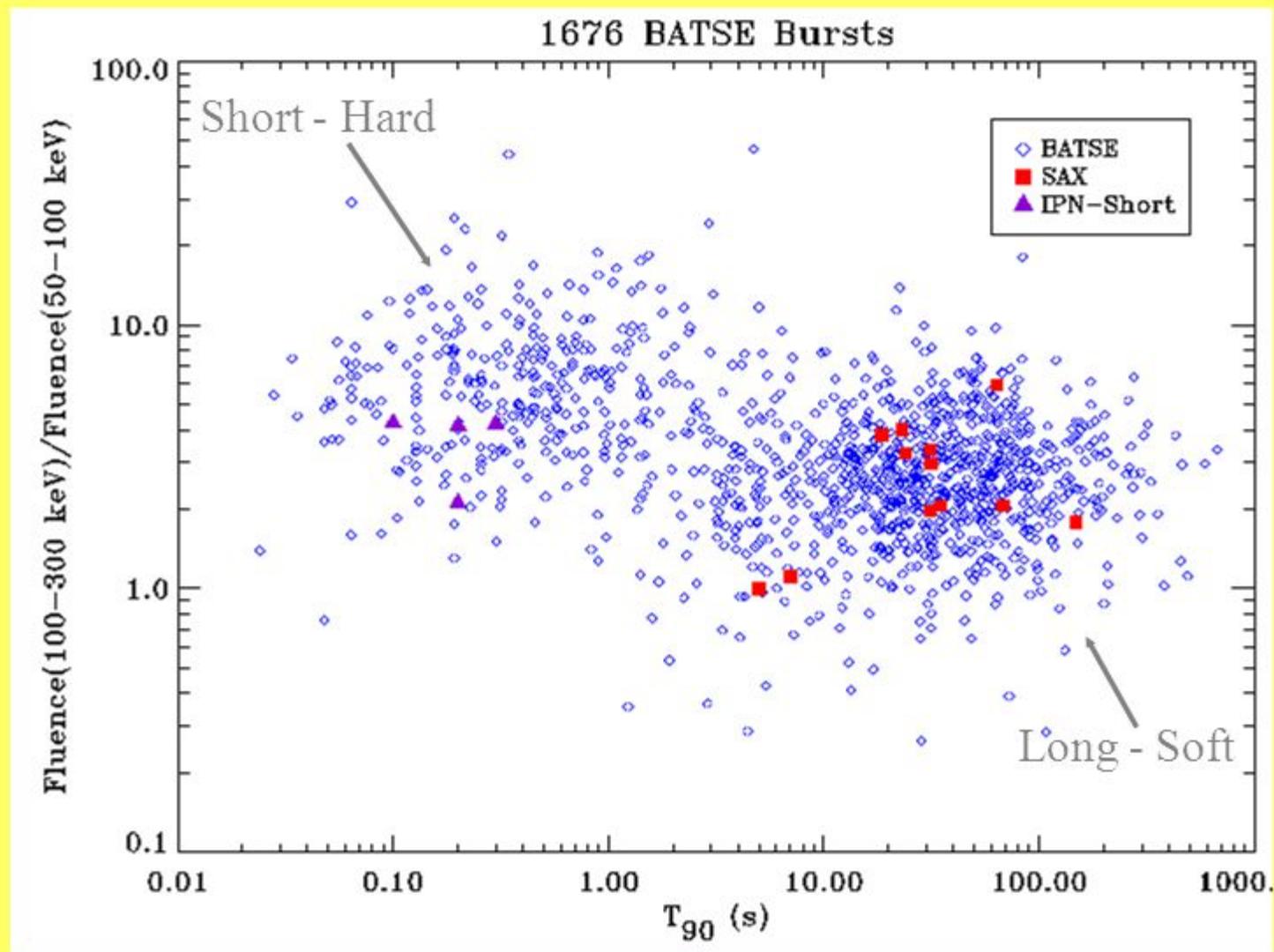
Some are not continuous (precursors).



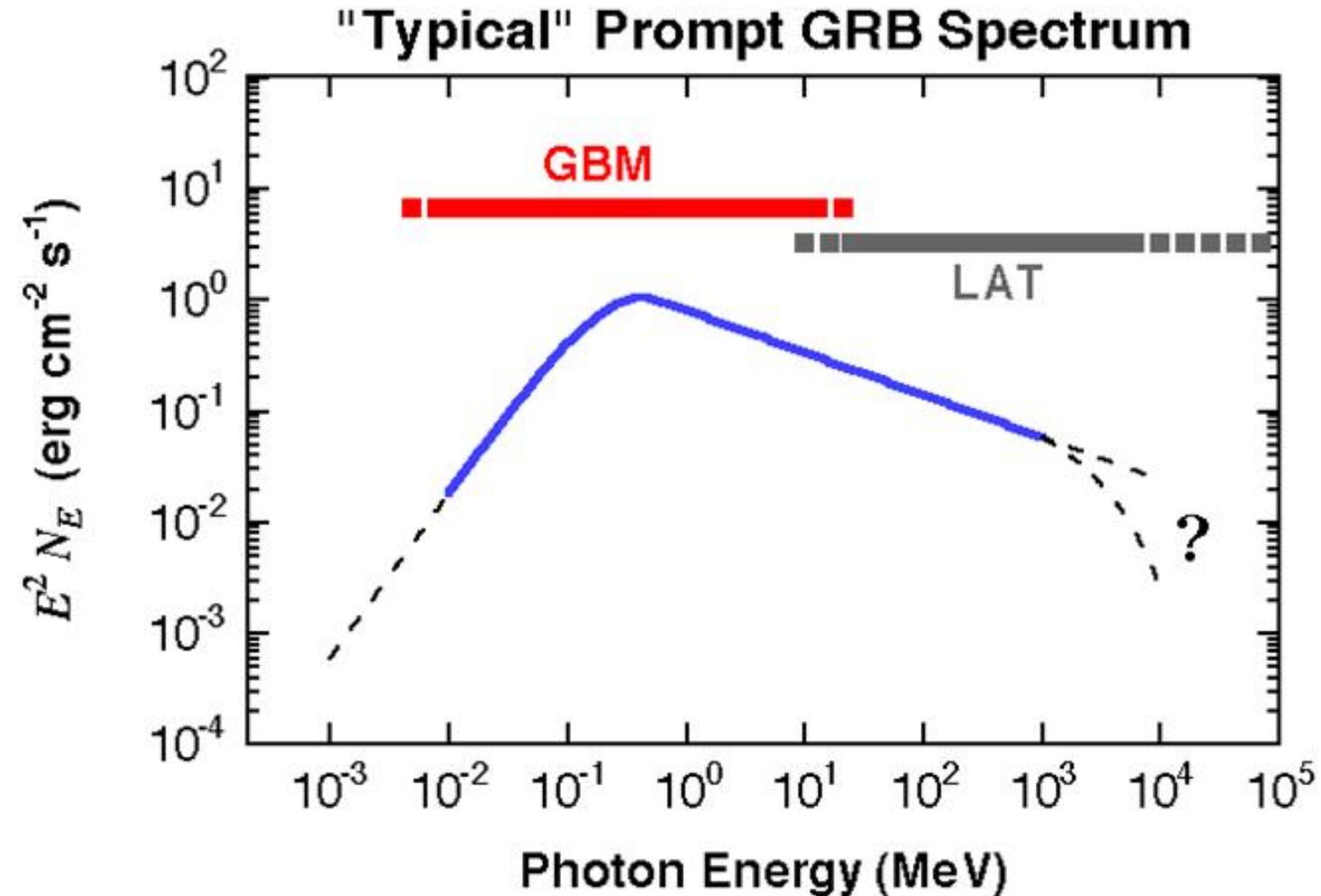
Long vs short GRBs



Two classes of GRBs



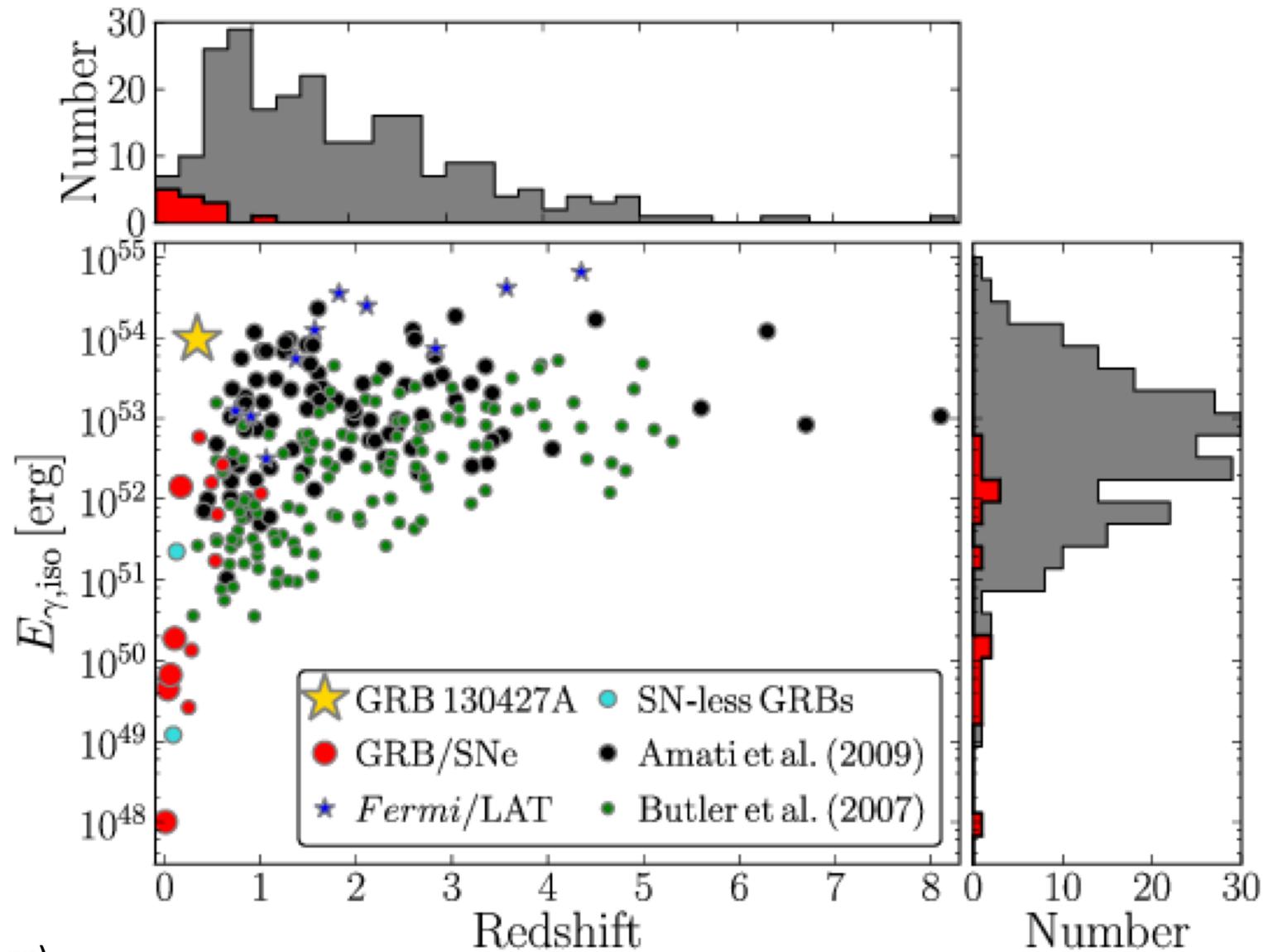
GRB spectrum



Band spectrum
(broken power-law)

$$N(E) = \begin{cases} N_0 \left(\frac{E}{100 \text{ keV}} \right)^\alpha \exp \left[-\frac{E}{E_0} \right], & E \leq E_b \\ N_0 \left(\frac{E_b}{100 \text{ keV}} \right)^{\alpha-\beta} \exp[\beta - \alpha] \left(\frac{E}{100 \text{ keV}} \right)^\beta, & E > E_b \end{cases} \quad (1)$$

Energetics



(solar mass = 1.8×10^{54} erg)

Fireball model

Luminosity is many orders of magnitude beyond the Eddington luminosity:

$$L_E = 4\pi GMm_p c / \sigma_T = 1.25 \times 10^{38} (M/M_\odot) \text{ erg s}^{-1}$$

So the high-temperature plasma expands → outflow.

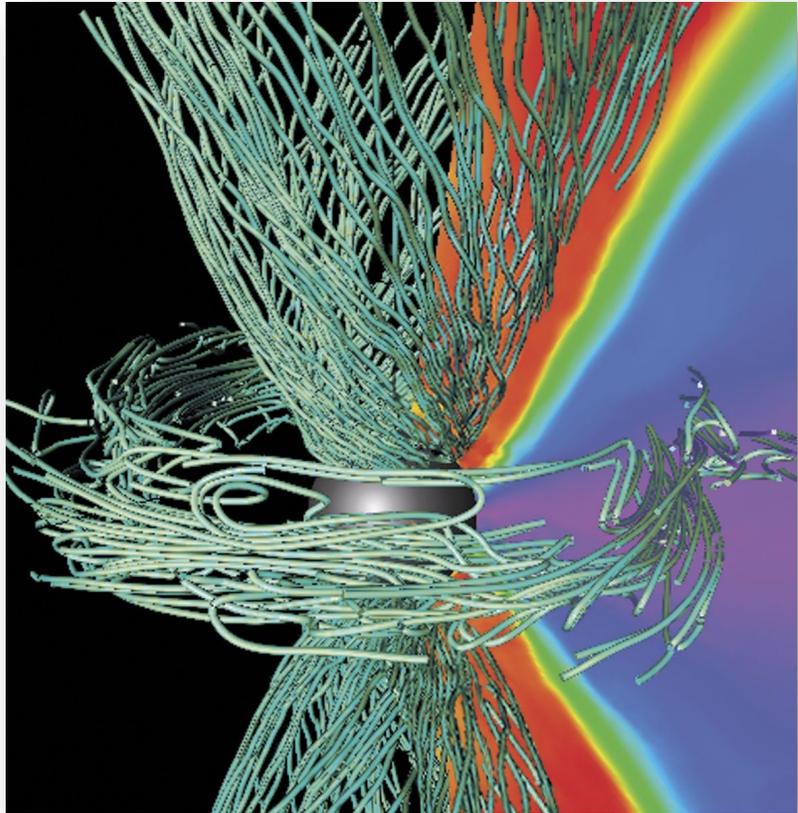
For very high luminosities, the large density of gamma photons could make the fireball opaque to photons for energies above 0.5 MeV.

$$\gamma\gamma \rightarrow e^\pm \quad m_e c^2 = 0.511 \text{ MeV}$$

But many GRB photons are $\gg 0.5 \text{ MeV}$ → outflow needs to be relativistic (so it is less dense)

Total energy, as seen, is much more than what stellar core collapse and other events are thought to be able to produce → beaming (all the radiation is focused into some jet, so the total luminosity is not that high.)

Relativistic outflow

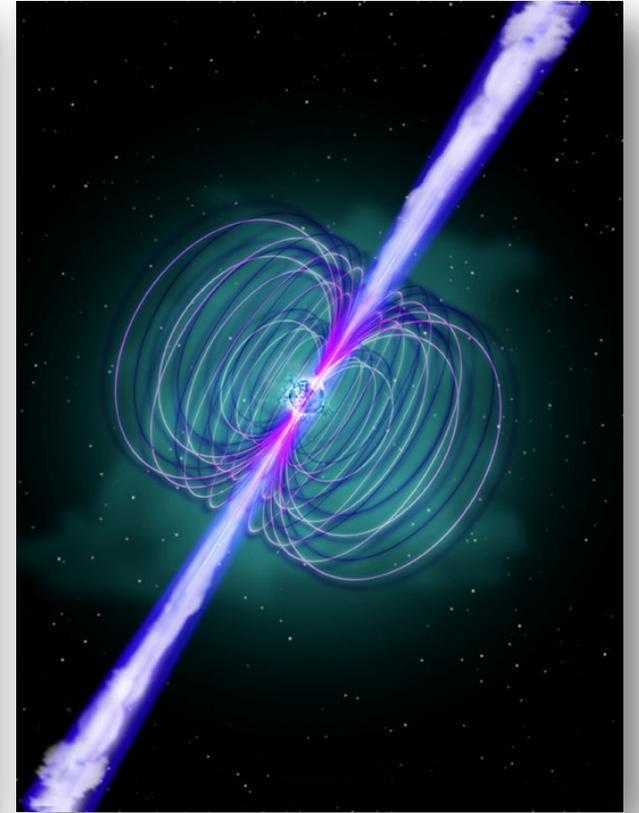


Magnetic field lines should be important (but we don't really know)

<http://sites.krieger.jhu.edu/astronomy/numerical-simulations/>

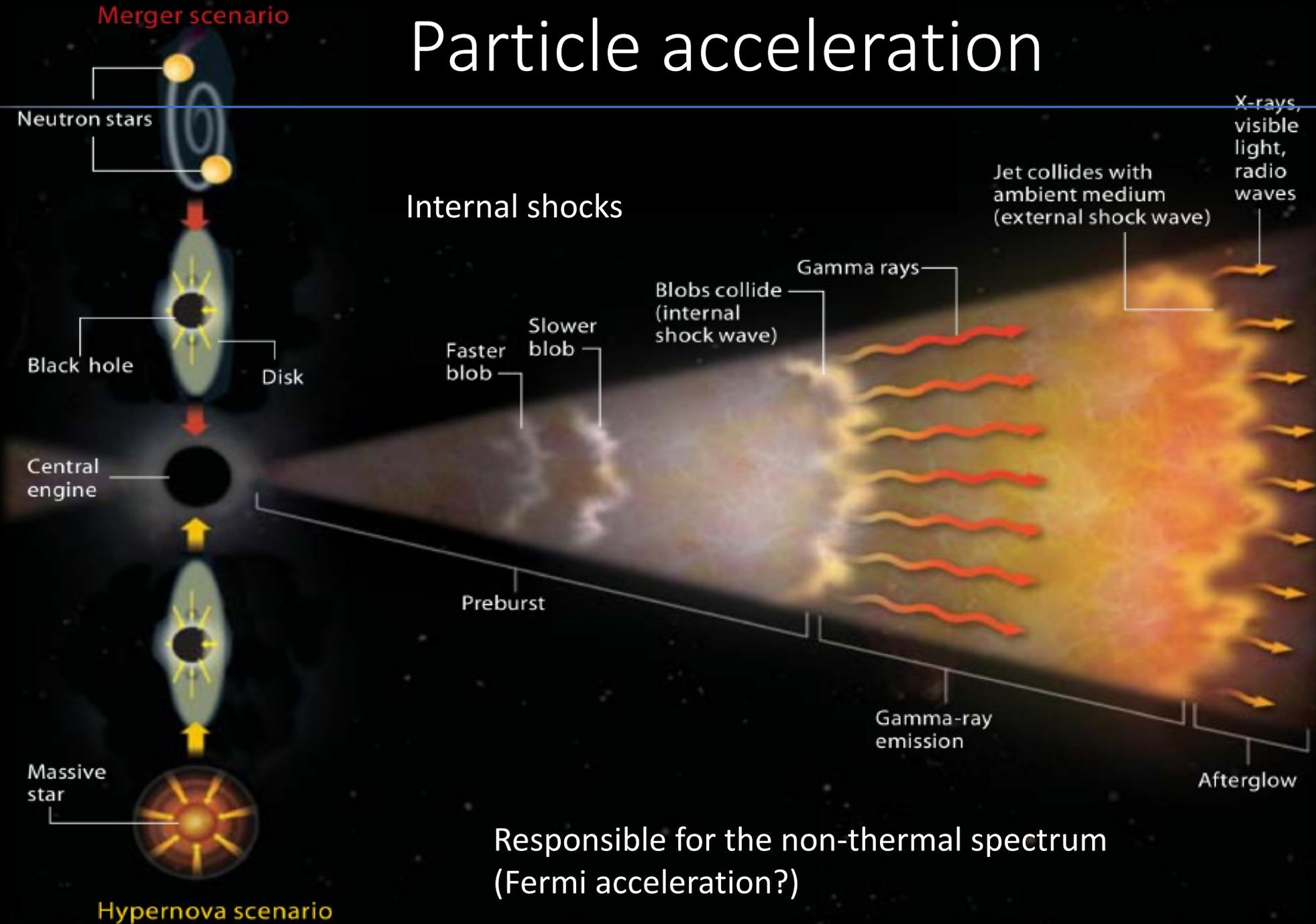


Accreting black hole



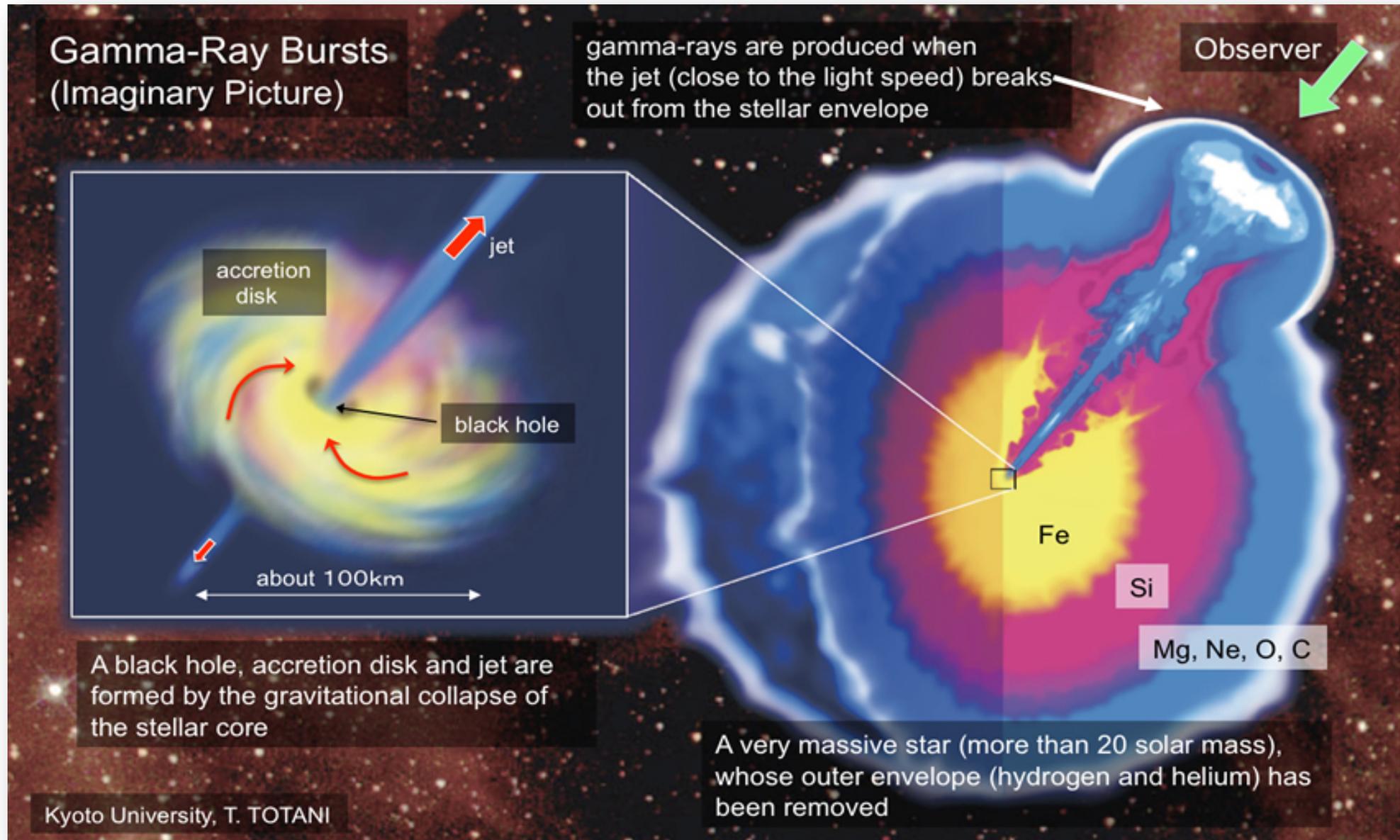
Magnetar
(neutron star with strong magnetic fields)

Particle acceleration

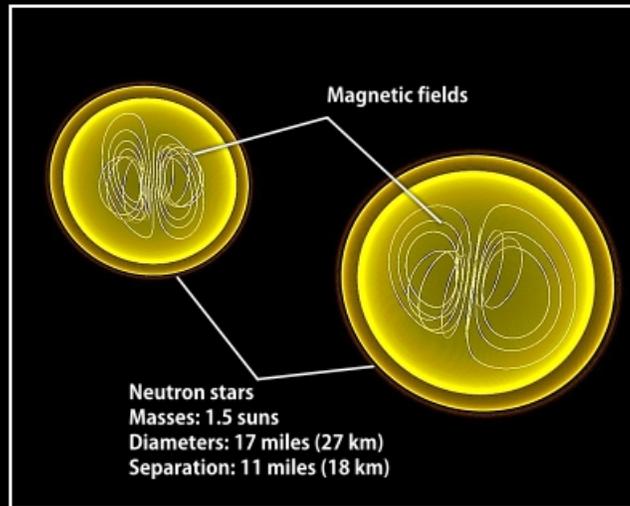


Responsible for the non-thermal spectrum (Fermi acceleration?)

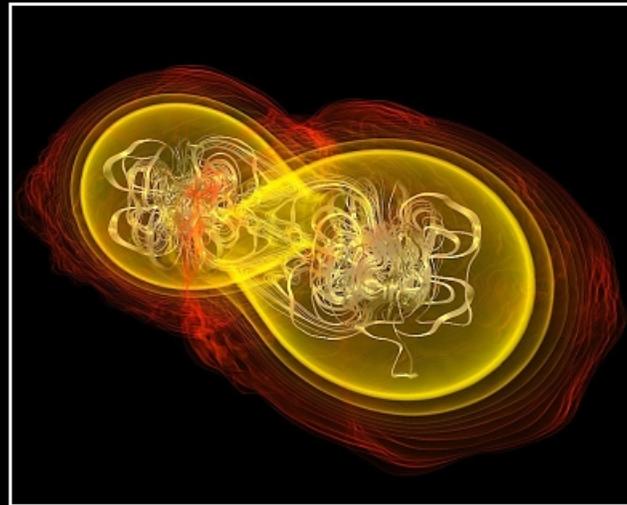
Long GRBs – stellar core collapse



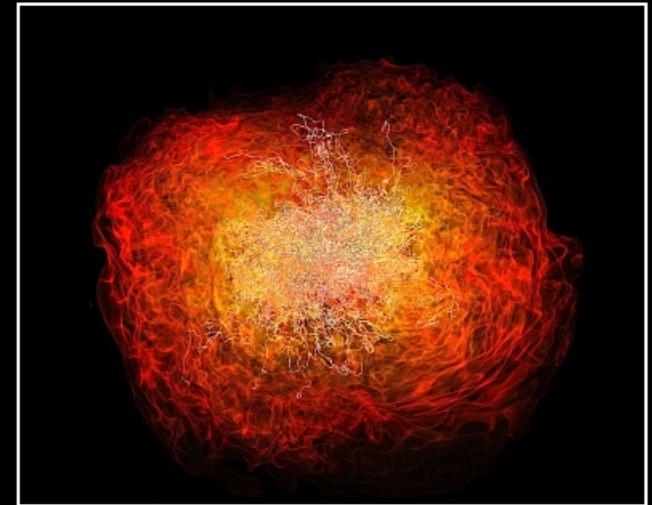
Short GRBs – binary mergers



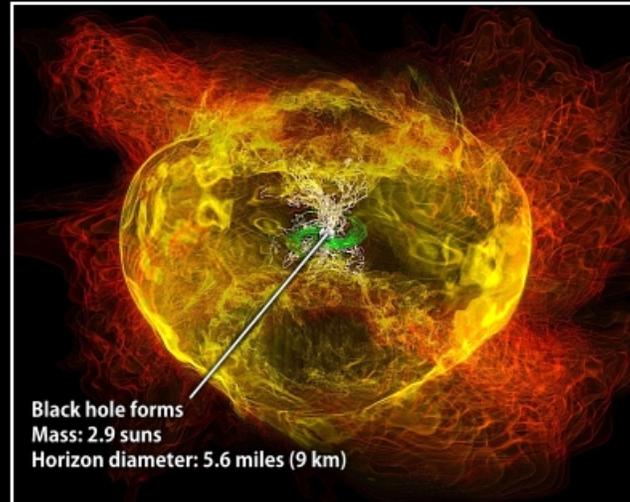
Simulation begins



7.4 milliseconds



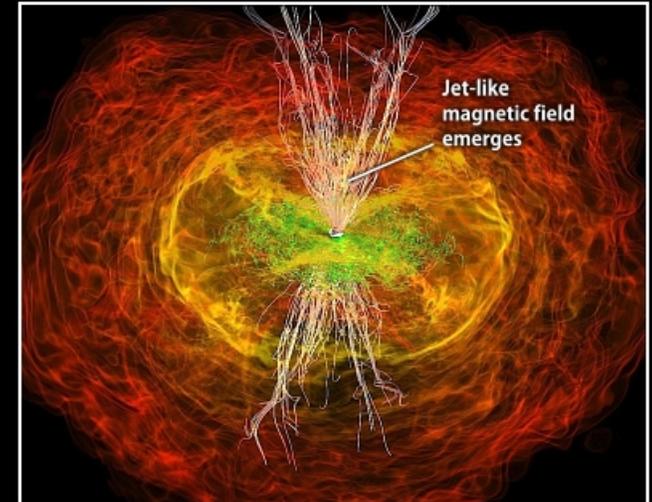
13.8 milliseconds



15.3 milliseconds



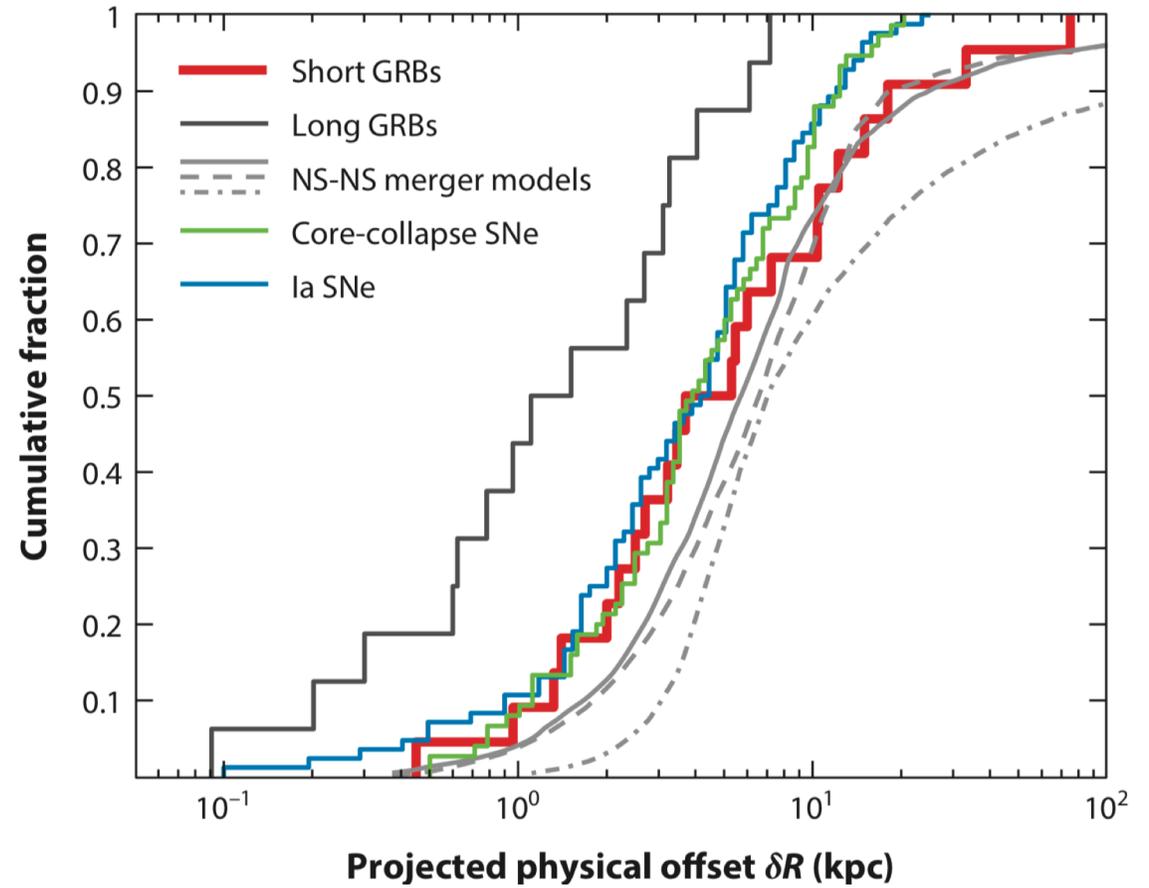
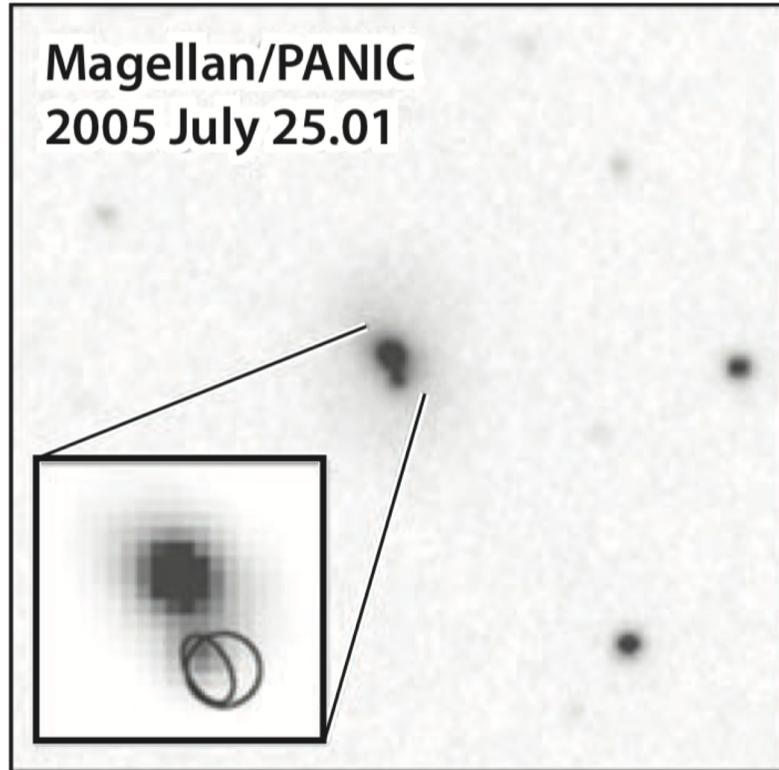
21.2 milliseconds



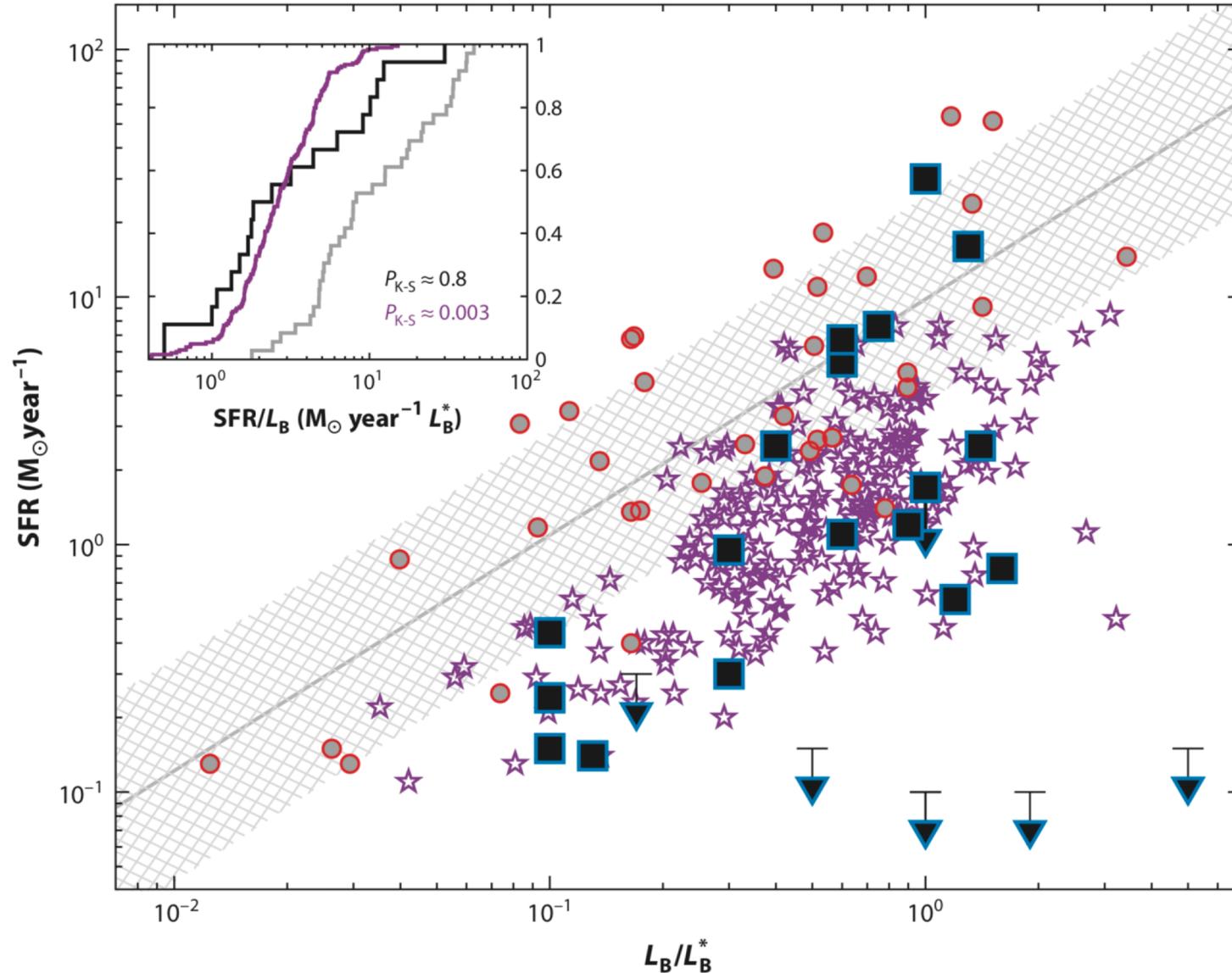
26.5 milliseconds

Fallback time

Kicks – short GRBs are often outside the host galaxy



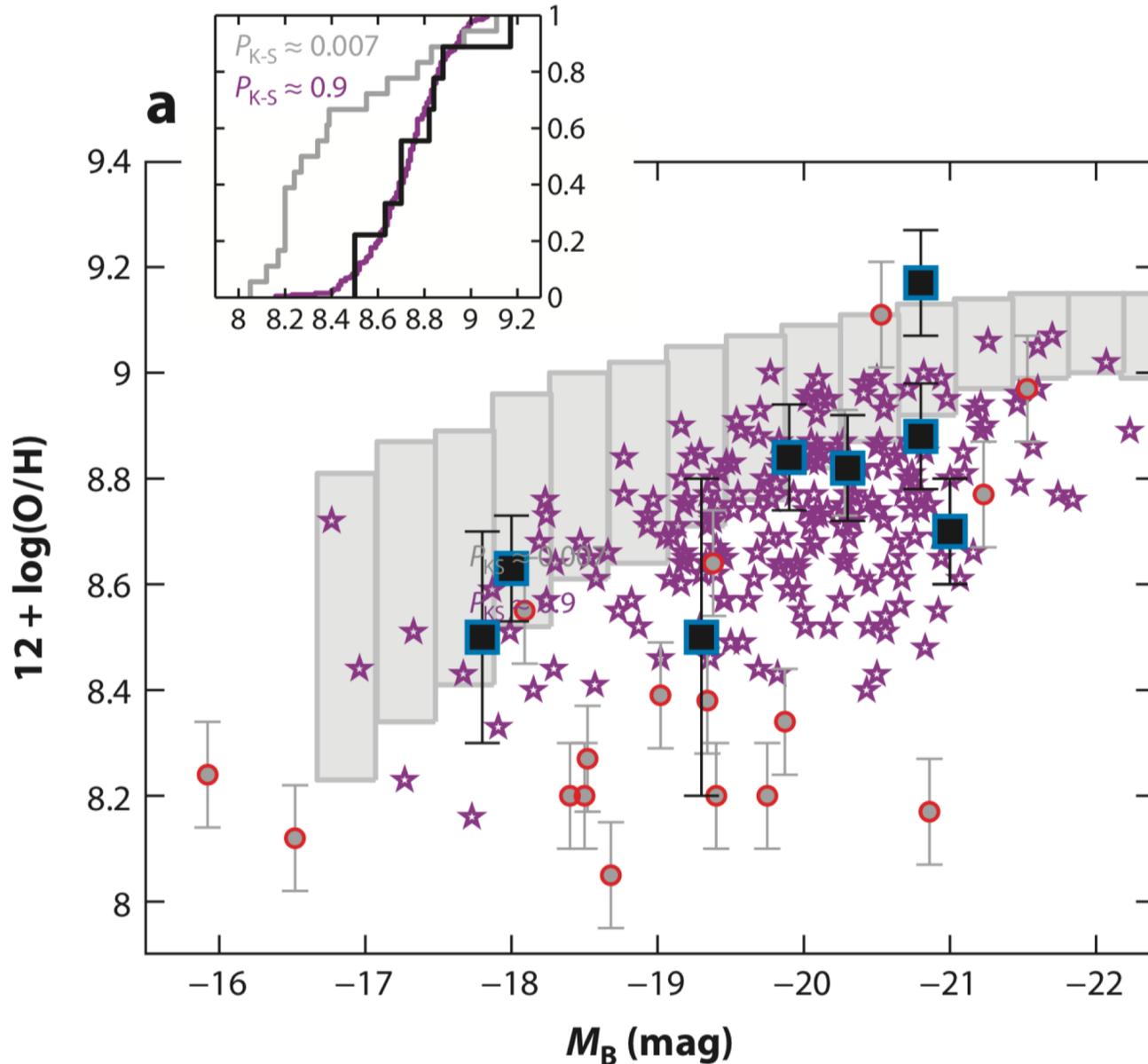
Star formation in host galaxies



Star-formation rate (SFR) as a function of rest-frame B-band luminosity for the host galaxies of short GRBs (*squares*), long GRBs (*circles*), and field star-forming galaxies at similar redshifts to short GRB hosts (*stars*; Kobulnicky & Kewley 2004).

Low star formation indicates that the binary formed a long time ago.

Metallicity of host galaxy



Metallicity as a function of host-galaxy rest-frame B-band luminosity for short GRBs (*squares*), long GRBs (*circles*), field galaxies at similar redshifts to short GRB hosts (*stars*; Kobulnicky & Kewley 2004), and the Sloan Digital Sky Survey luminosity-metallicity relation (Tremonti et al. 2004). Short GRB host galaxies have higher metallicities than long GRB hosts, but they closely track the luminosity-metallicity relation for the field galaxy population (*inset*).

Long GRBs prefer low-metallicity environments --- favorable for massive stellar explosions

Opening angles

