PHY 7097 | Modern Astrophysics

Lecture XXII.

Gamma-ray Bursts

UF UNIVERSITY of FLORIDA

Imre Bartos | Spring 2018

University of Florida (UF)

United States of America (USA)

Research | Collaboration | Relationships

1 January 2017 - 31 December 2017

Region: Global
Subject/journal group: All

The table to the right includes counts of all research outputs for University of Florida (UF) published between 1 January 2017 - 31 December 2017 which are tracked by the Nature Index.

Hover over the donut graph to view the WFC output for each subject. Below, the same research outputs are grouped by subject. Click on the subject to drill-down into a list of articles organized by journal, and then by title.

Note: Articles may be assigned to more than one subject area.

AC	FC	WFC
558	109.41	97.48

Outputs by subject (WFC)

Subject	AC	FC	WFC
Chemistry	107	34.34	34.34
Physical Sciences	346	37.45	25.52
Earth & Environmental Sciences	38	12.41	12.41
Life Sciences	104	36.56	36.56

Top articles by Altmetric score in current window

GW170104: Observation of a 50-Solar-Mass Binary Black Hole Coalescence at Redshift 0.2.
Physical Review Letters
2017-06-02

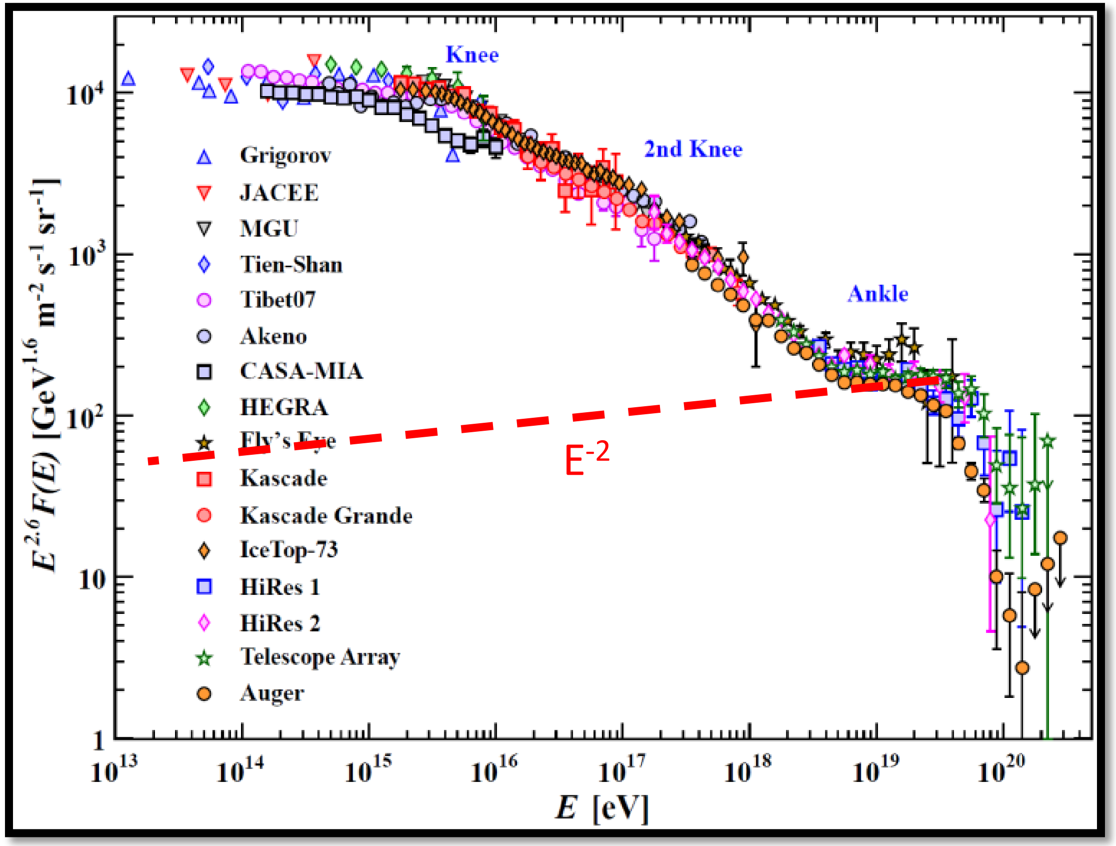
Multi-messenger Observations of a Binary Neutron Star Merger
The Astrophysical Journal Letters
2017-10-16

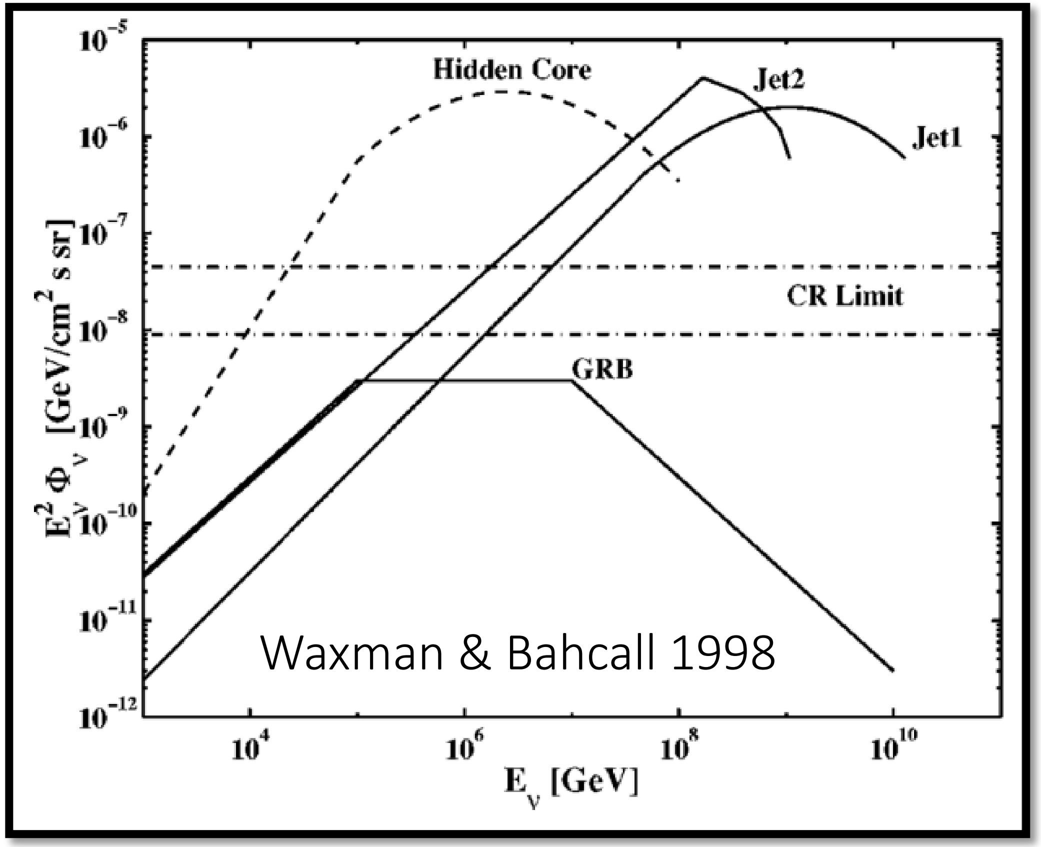
GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral
Physical Review Letters
2017-10-20

A chemical genetic roadmap to improved tomato flavor
Science
2017-01-27

A randomized synbiotic trial to prevent sepsis among infants in rural India
Nature
2017-08-16

Waxman-Bahcall upper bound

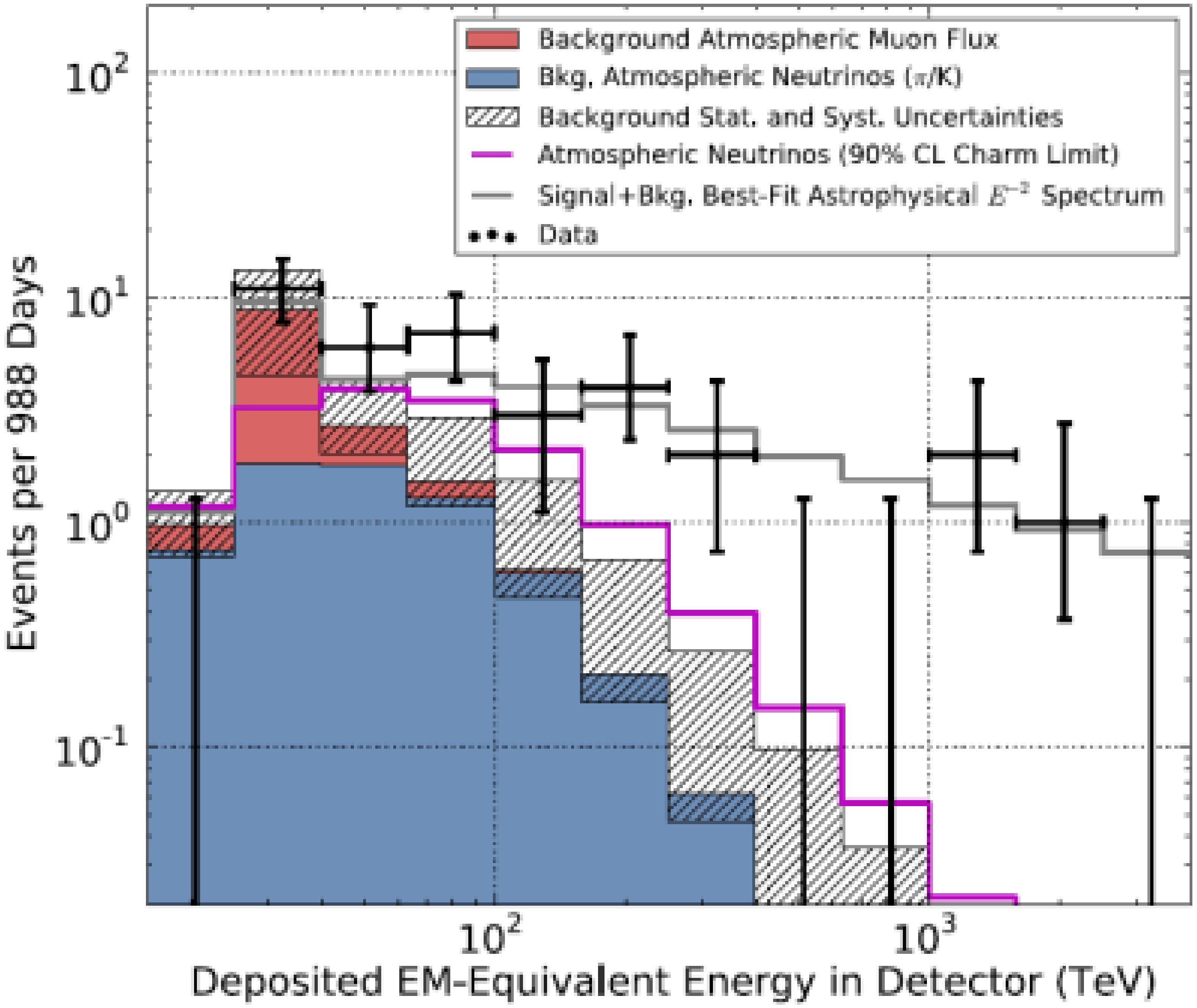




Extragalactic cosmic rays should eventually collide with gas and produce high energy neutrinos. What will be the neutrino flux if the extragalactic flux

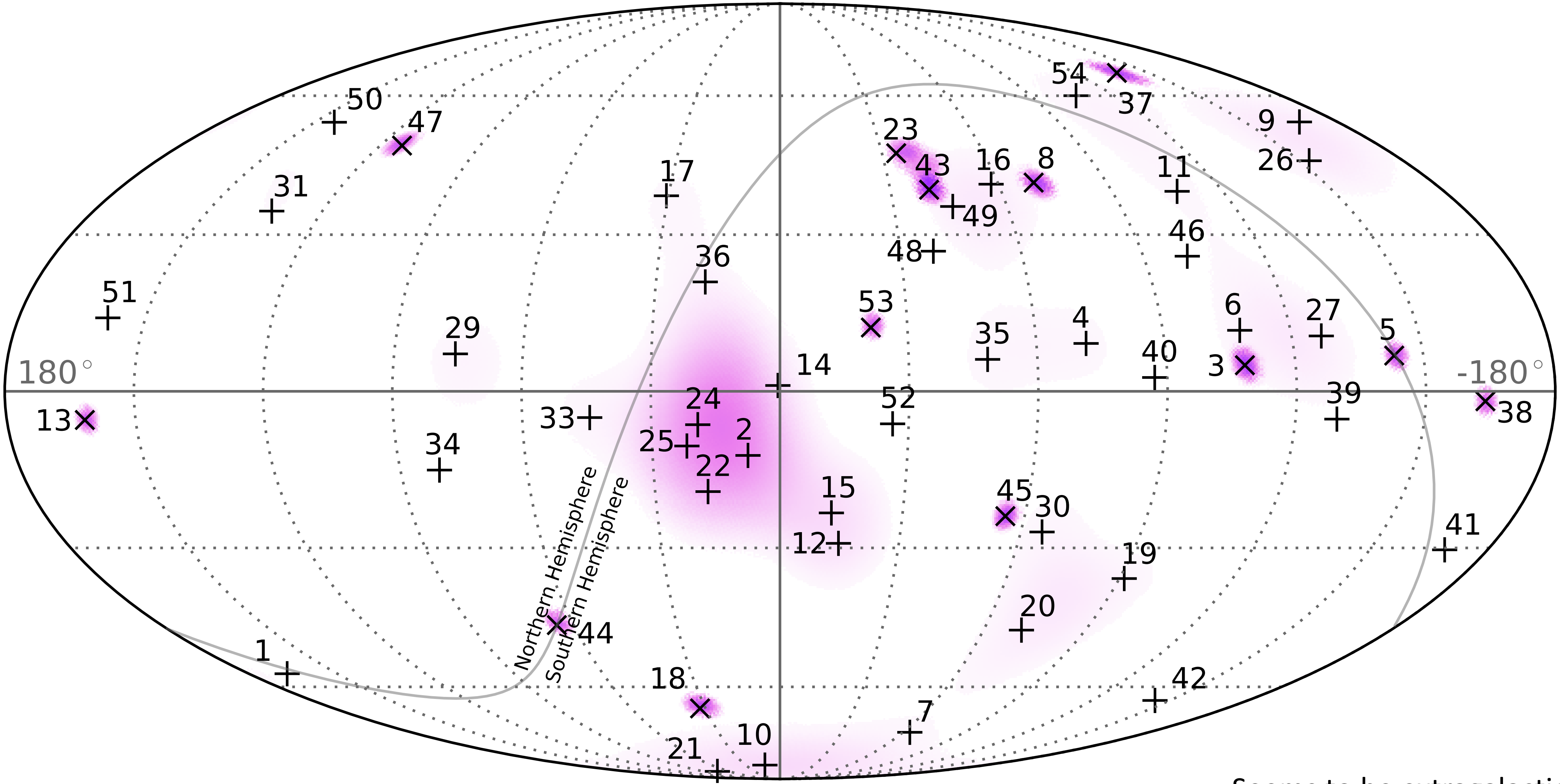
- follows a Fermi spectrum and
- continues down to lower energies?

Discovery of "diffuse" astrophysical neutrino flux



- Excess neutrino flux over expected background at >100 TeV
- No identified source
- Spectrum consistent with Fermi process

Detected high-energy neutrinos (>100 TeV)



Seems to be extragalactic

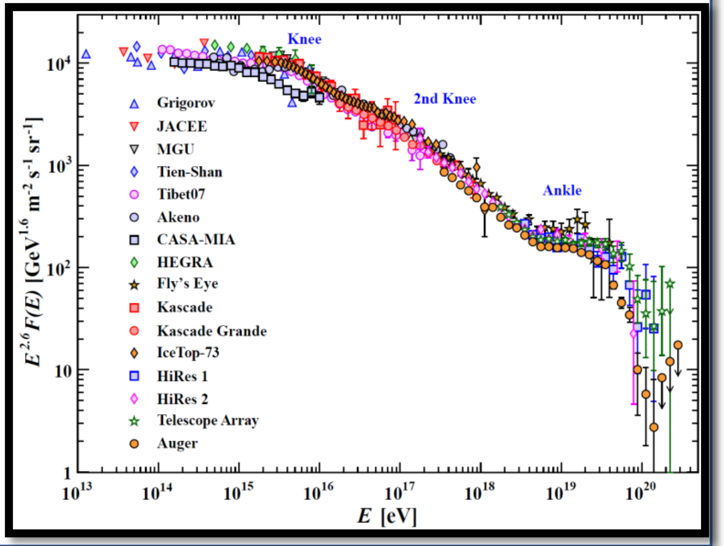
Neutrino spectrum from starburst galaxies

Distribution of galaxy luminosities (Schechter function):

$$\Phi(L)dL = (\frac{\Phi^*}{L^*})(\frac{L}{L^*})^\alpha \exp(-\frac{L}{L^*})dL$$

$L_{MW} \sim 1\ \mathrm{M_\odot yr^{-1}}$

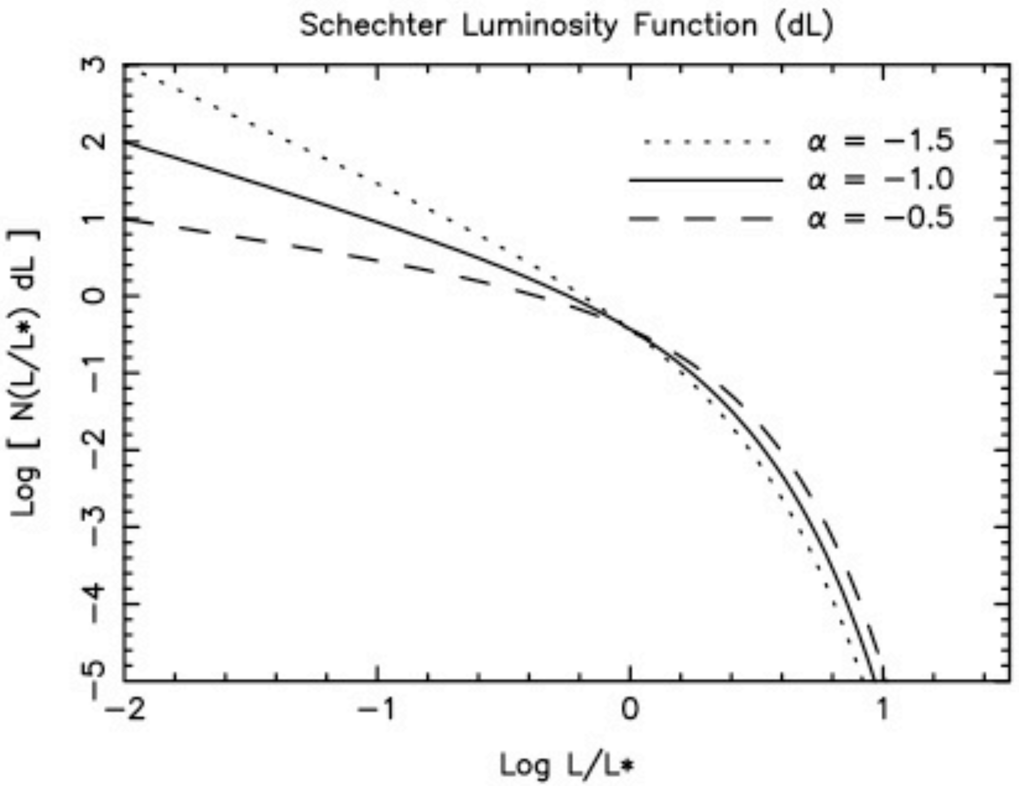
Cosmic rays above 10^{15} eV escape from the Milky Way.



$\alpha = 1.4$

$L^* = 625\,\mathrm{M_\odot yr^{-1}}$

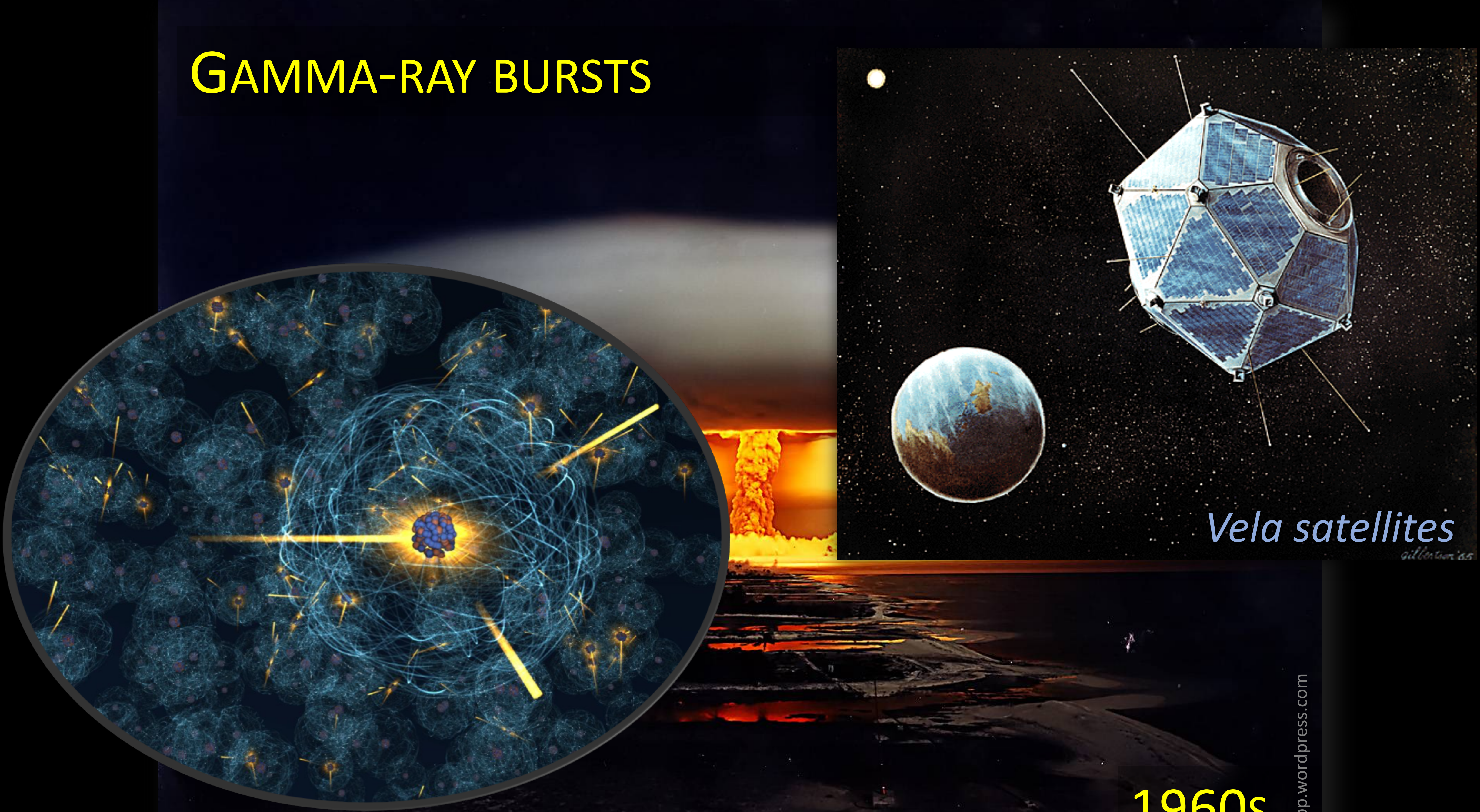
$\Phi^* = 2.2 \times 10^5\ \mathrm{Mpc^{-3}}$



- Cosmic rays are emitted by sources (e.g. GRB/supernovae) within galaxies with dN/dE~E-2 spectrum.
- Neutrinos are produced with energy ~5% of the interacting cosmic ray's energy.

HW: What will be the power spectral density of neutrinos observed from the Universe?

Gamma-ray bursts

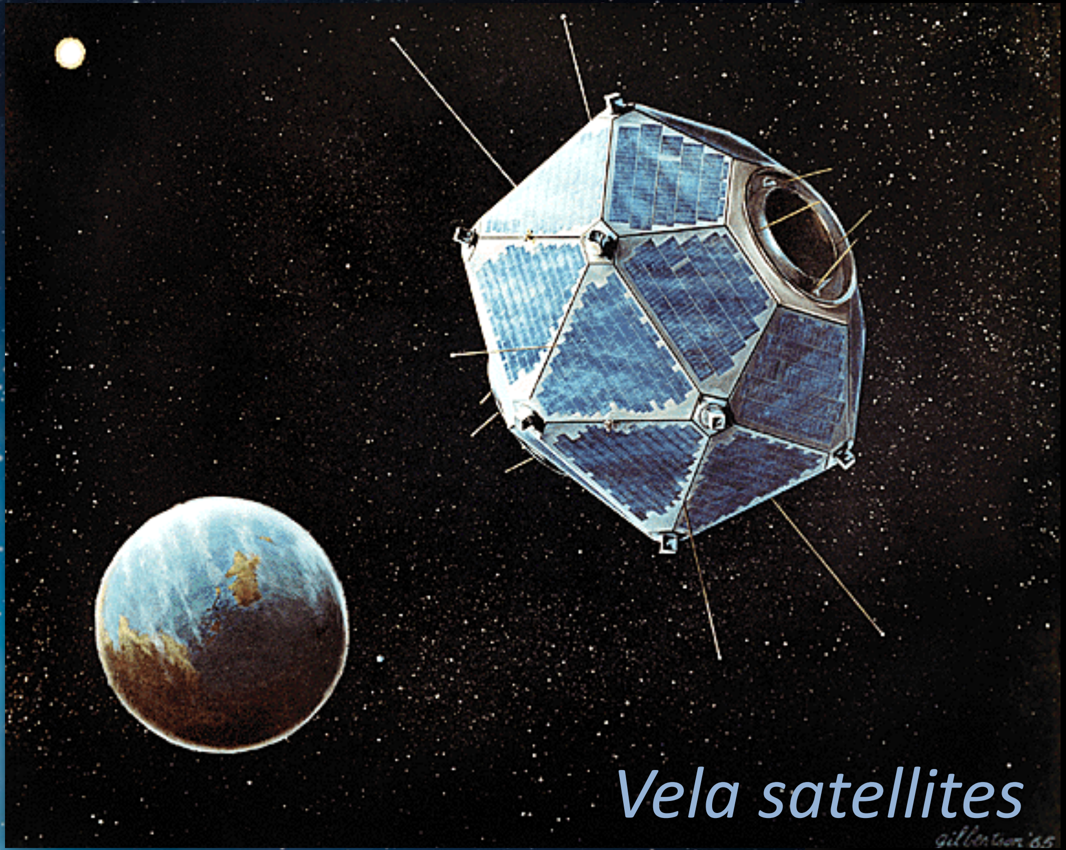


1960s

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

Gamma-ray bursts

?



OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

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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 $\sim$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-

1960s

Gamma-ray bursts

Origin?

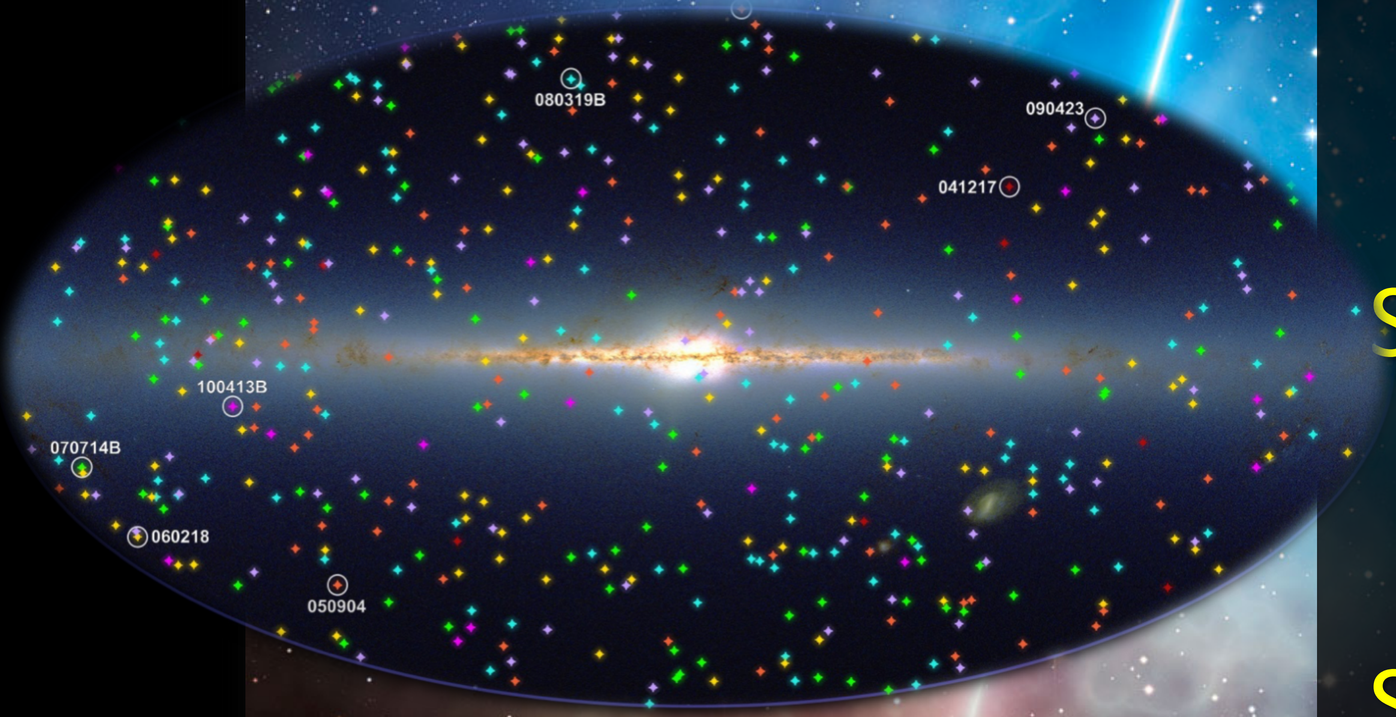
Strength

Size

Source

Gamma-ray bursts

Origin?



Strength

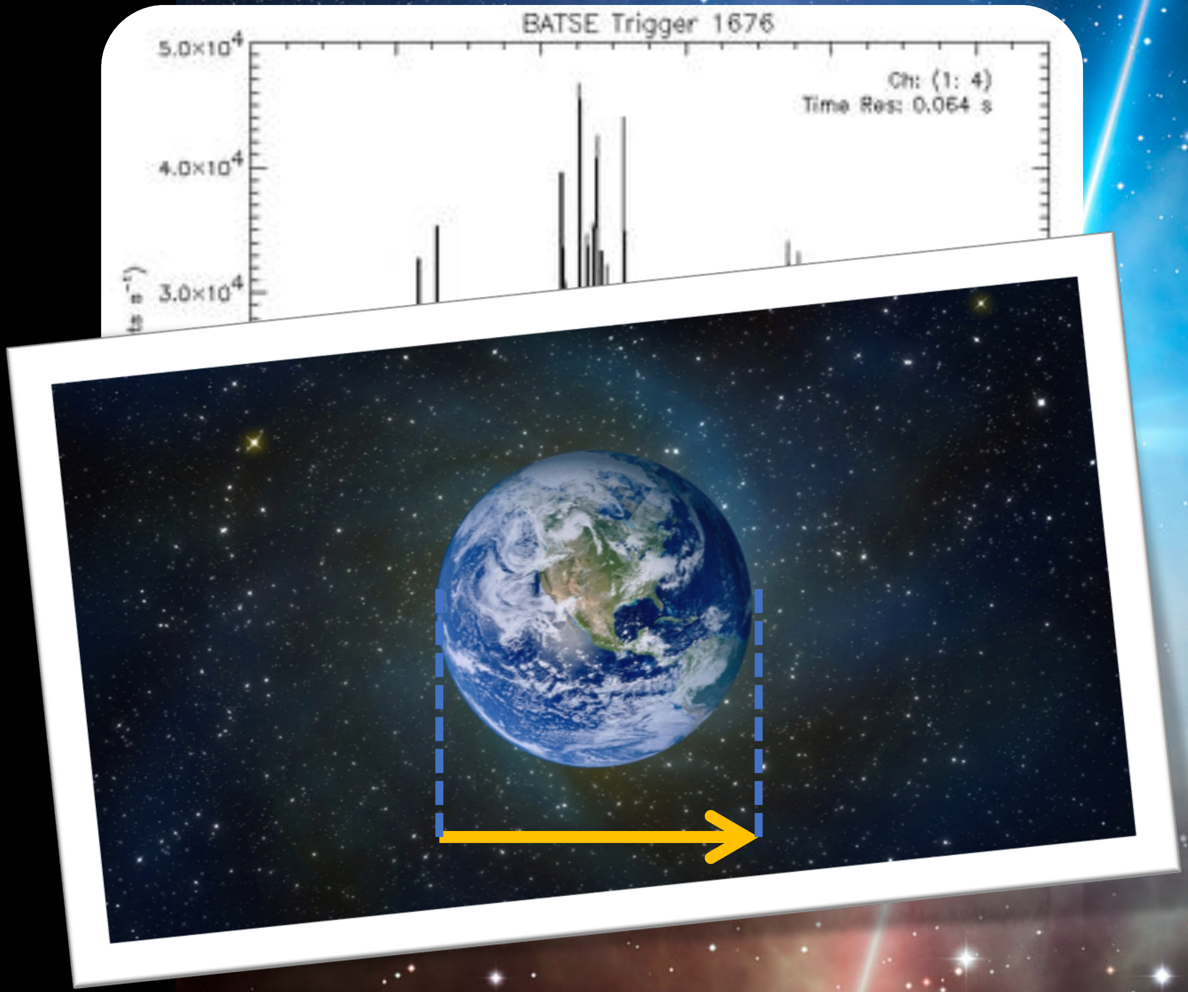
Extragalactic

Energetic

Size

Source

GAMMA-RAY BURSTS



ORIGIN?

STRENGTH — EXTRAGALACTIC → ENERGETIC

SIZE — SMALL! *(< EARTH)*

SOURCE

Gamma-ray bursts

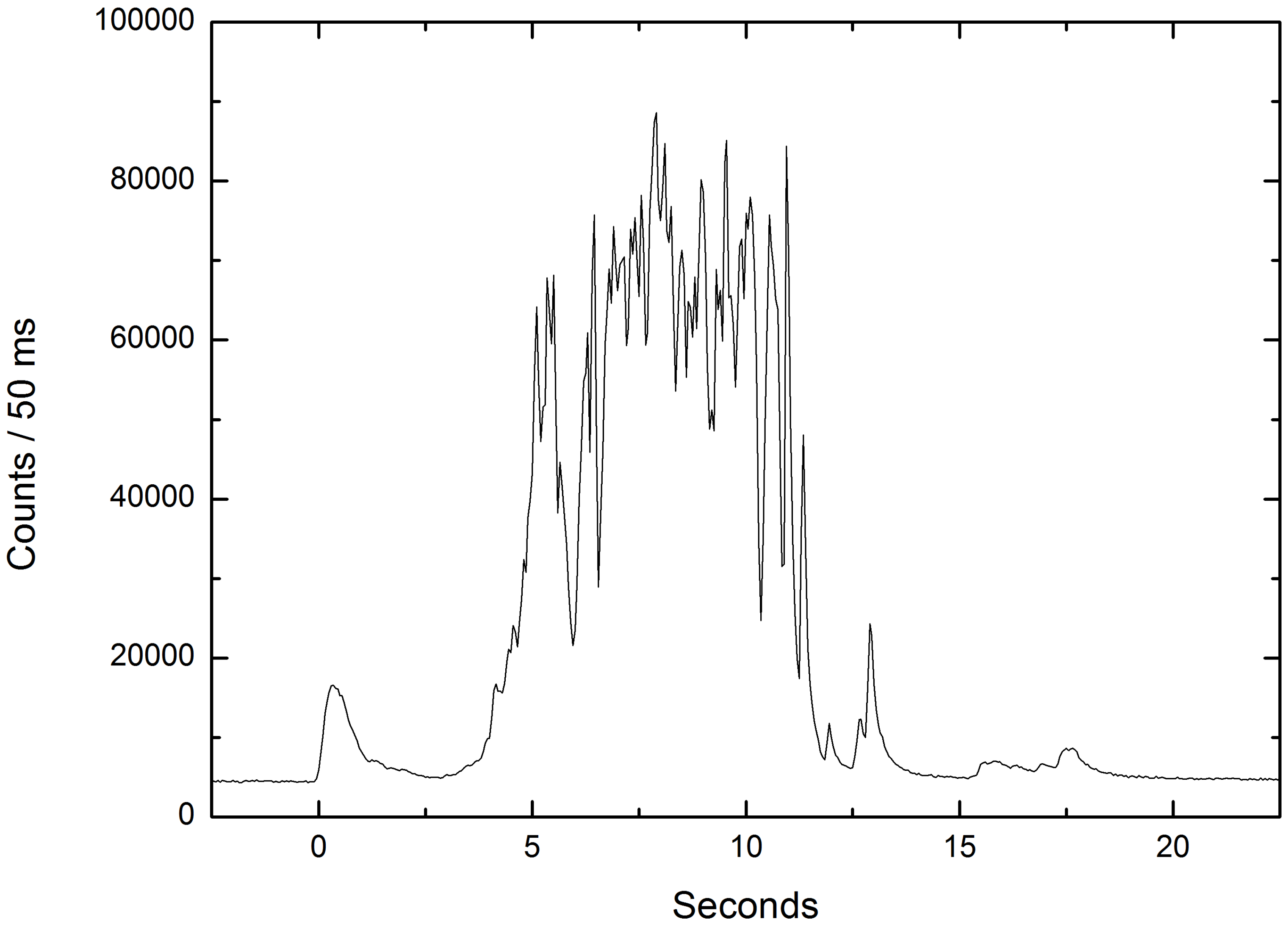
Origin?

Strength — Extragalactic → energetic

Size — Small!
(< Earth)

Source
1. Massive stars
2. Binary mergers

Light curves

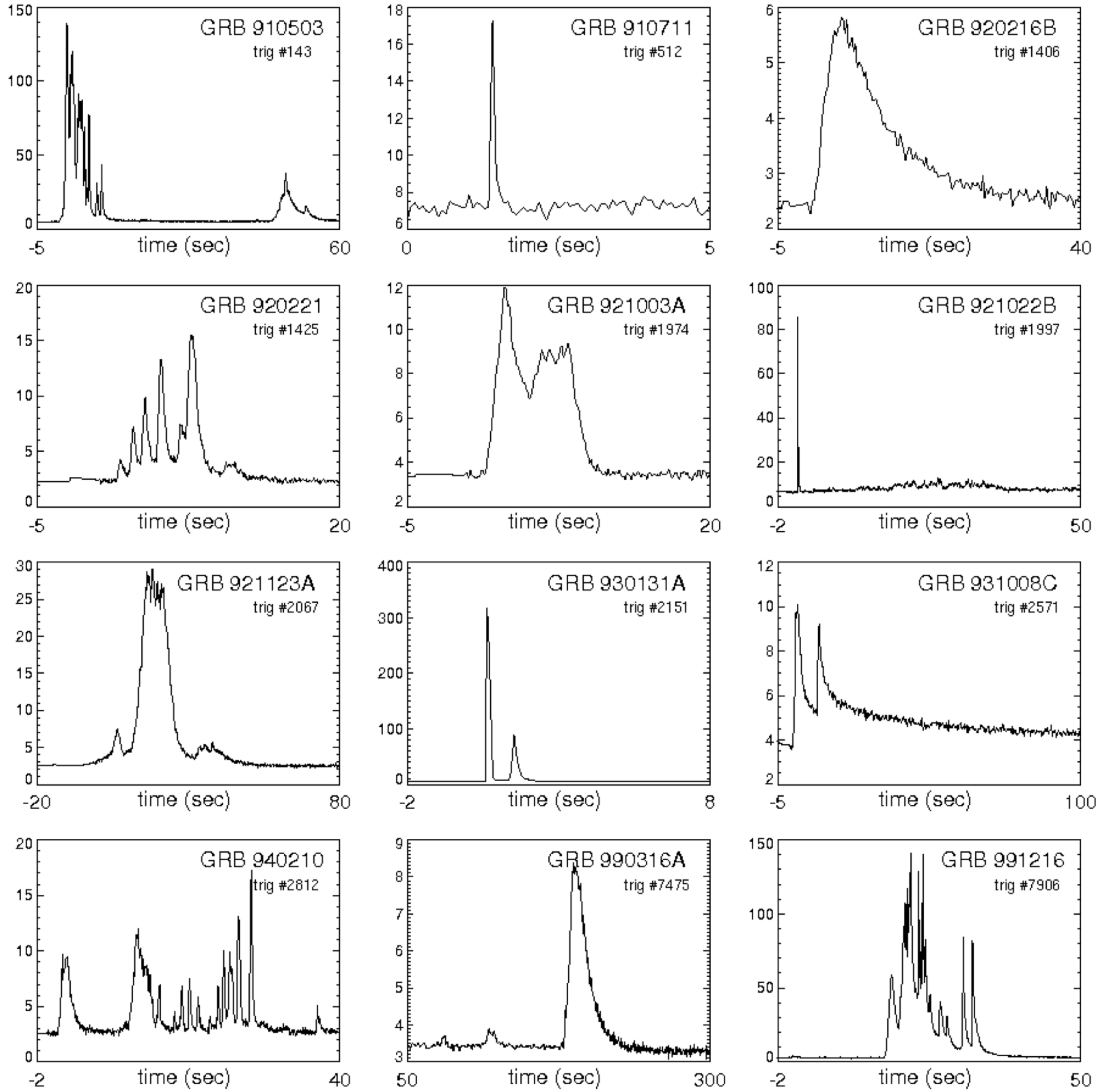


Light curves

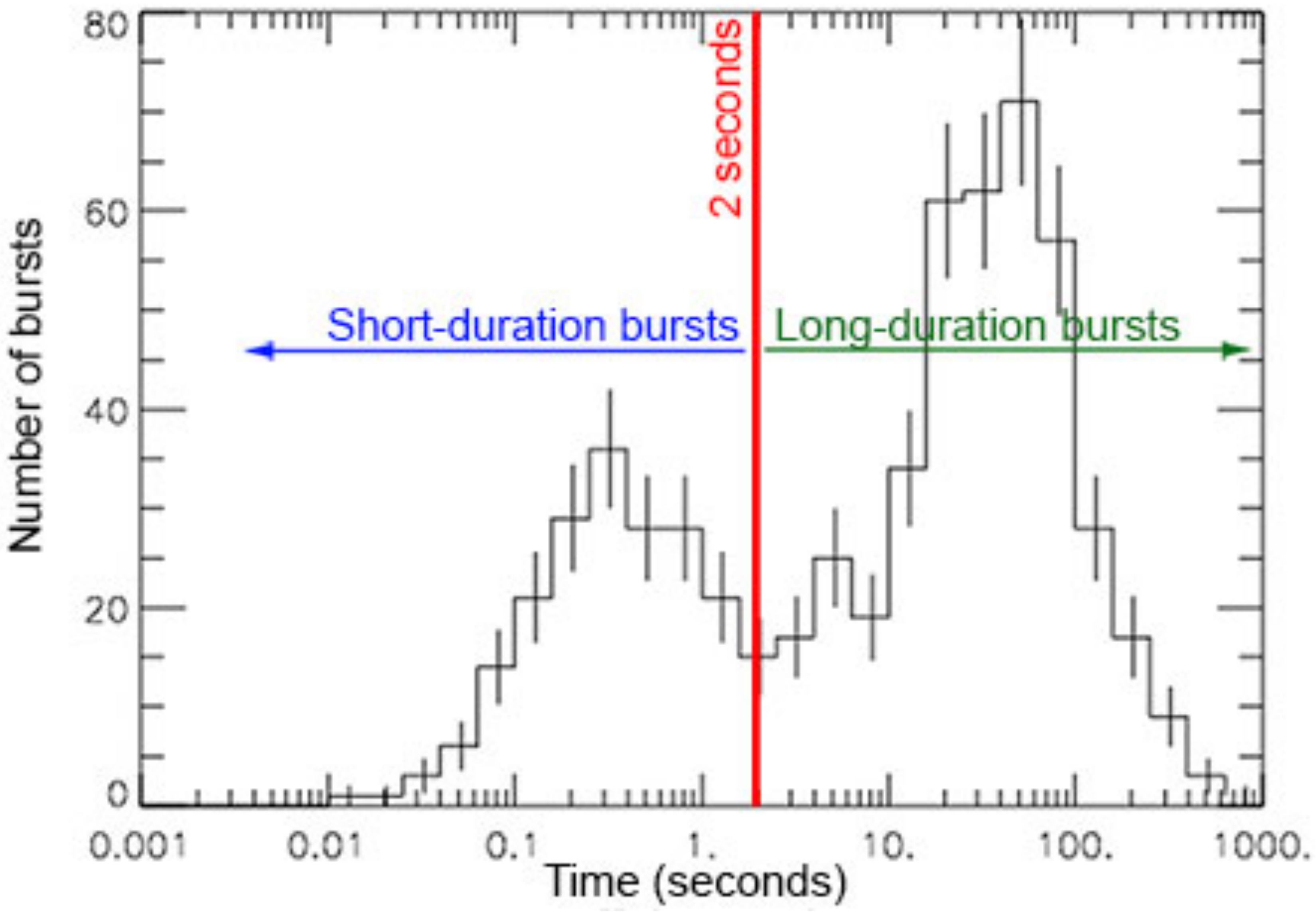
No two GRB light curves are identical.

Duration: milliseconds - minutes

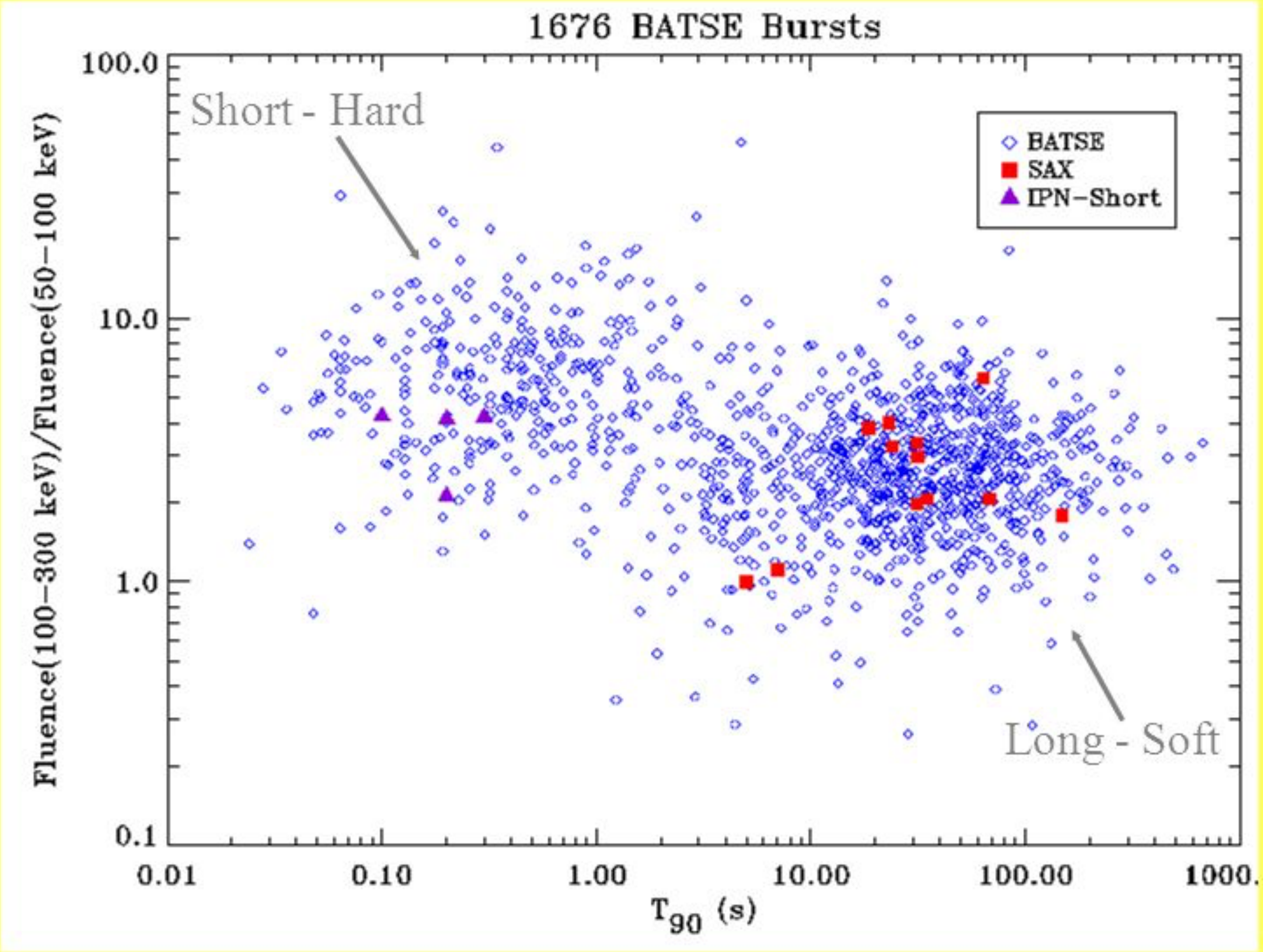
Some are not continuous (precursors).



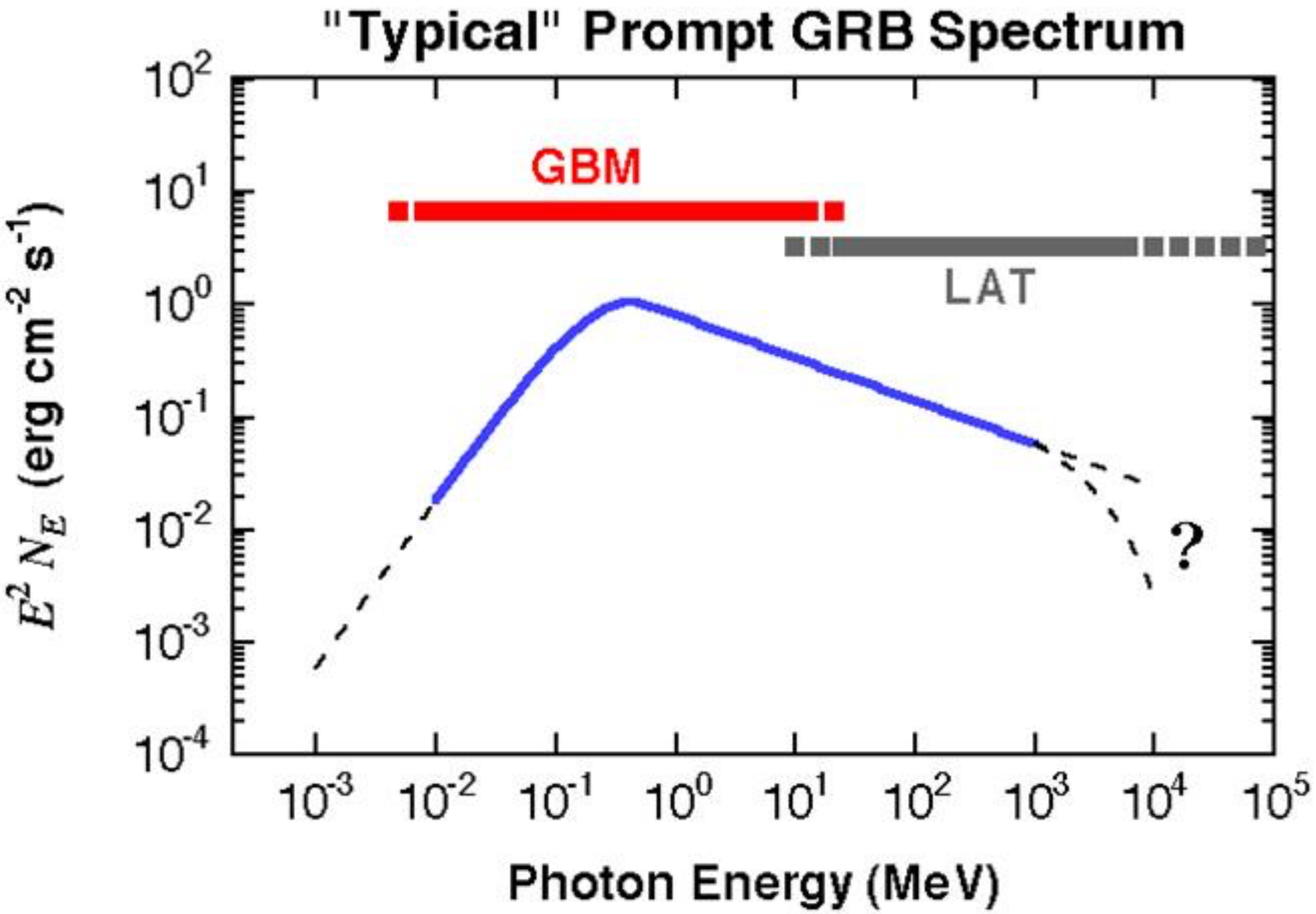
Long vs short GRBs



Two classes of GRBs



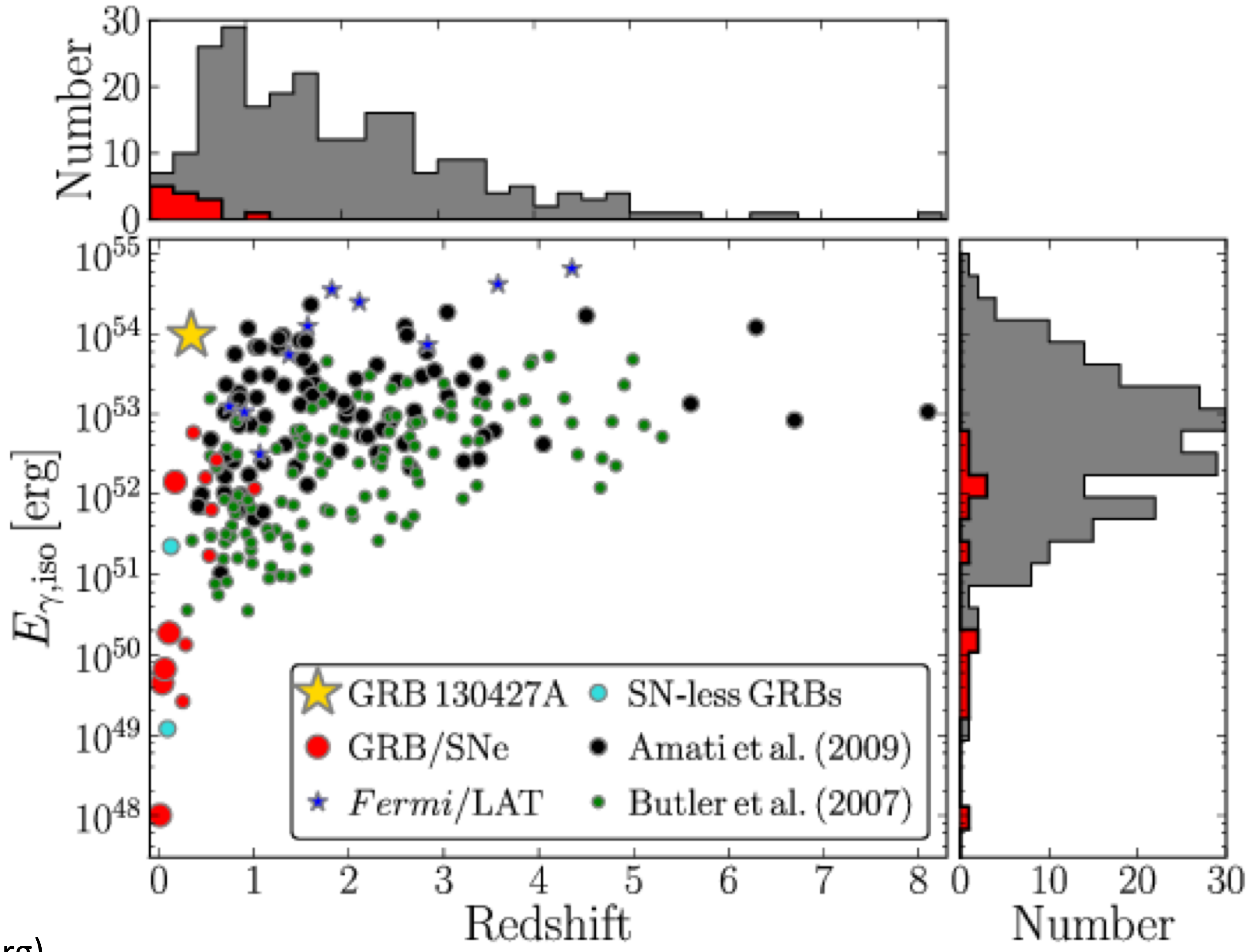
GRB spectrum



Band spectrum
(broken power-law)

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

Energetics



(solar mass = 1.8 x 10^{54} erg)

Fireball model

Luminosity is many orders of magnitude beyond the Eddington luminosity:

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

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.

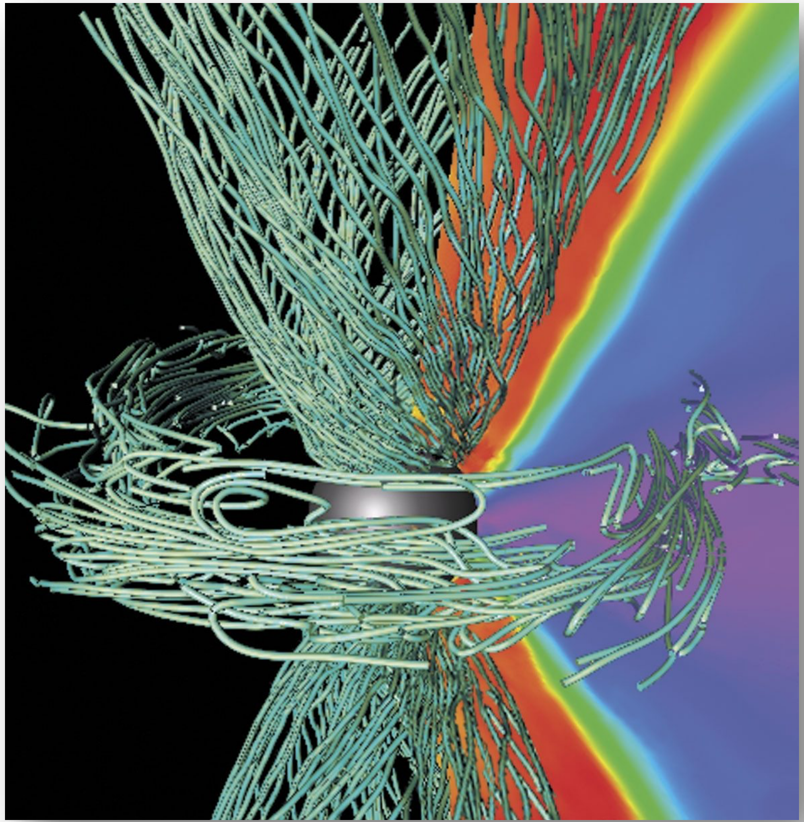
$$\gamma\gamma \rightarrow e^{\pm} \qquad m_e c^2 = 0.511\,\mathrm{MeV}$$

But many GRB photons are >> 0.5 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.)

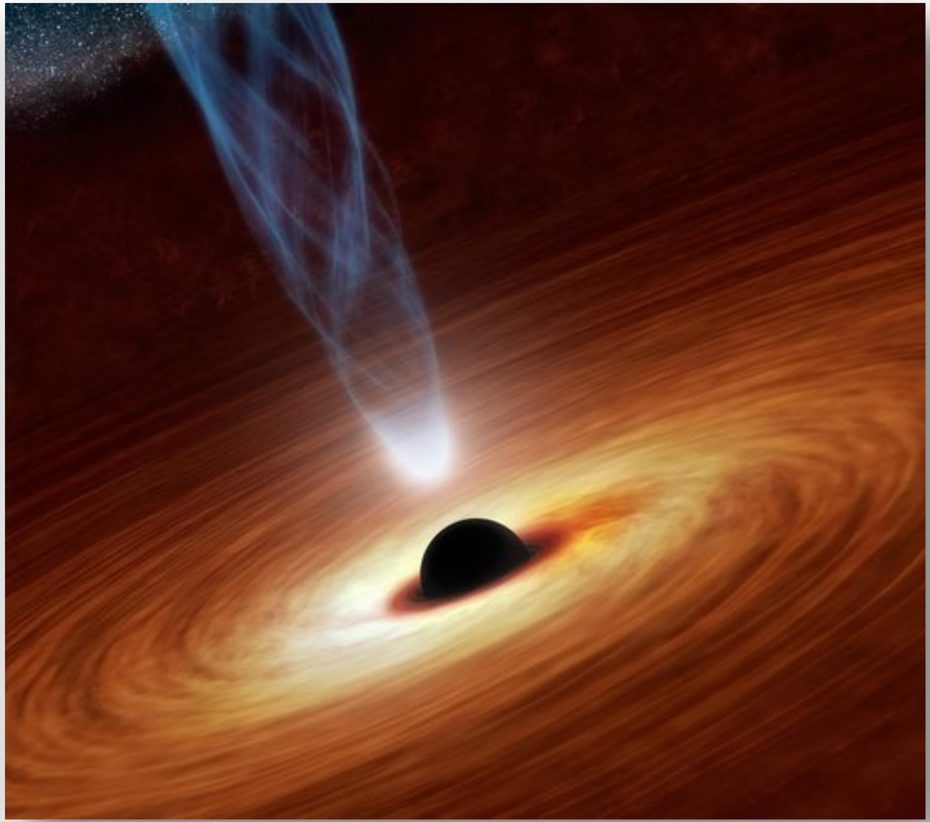
Meszaros RPP 2006

Relativistic outflow

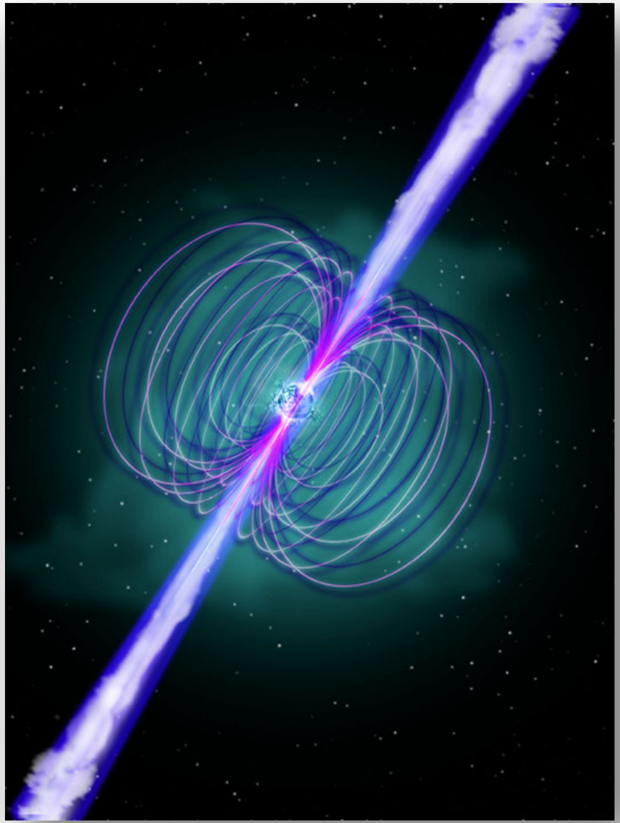


Magnetic field lines should be important (but we don't really know)

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

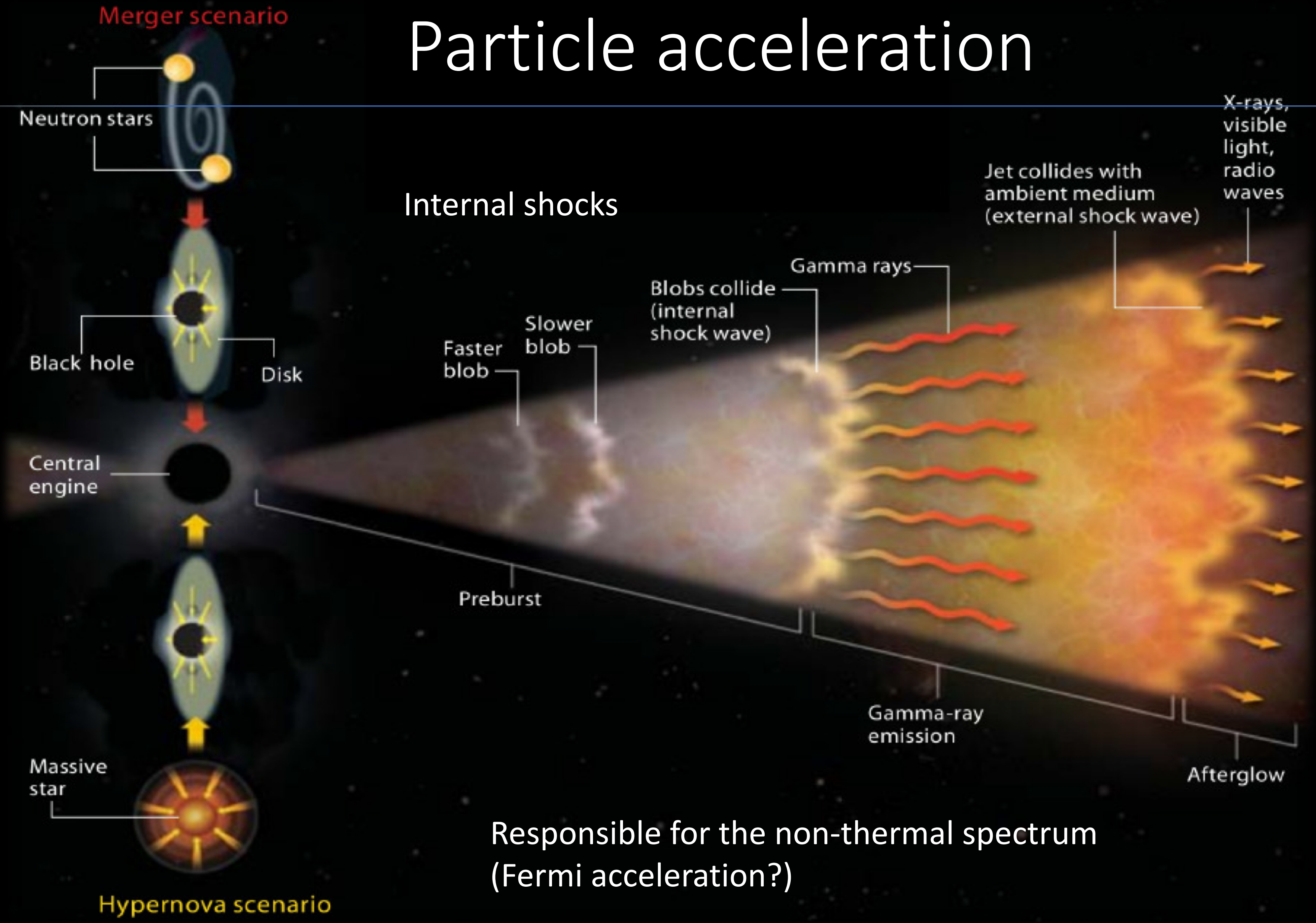


Accreting black hole



Magnetar
(neutron star with strong magnetic fields)

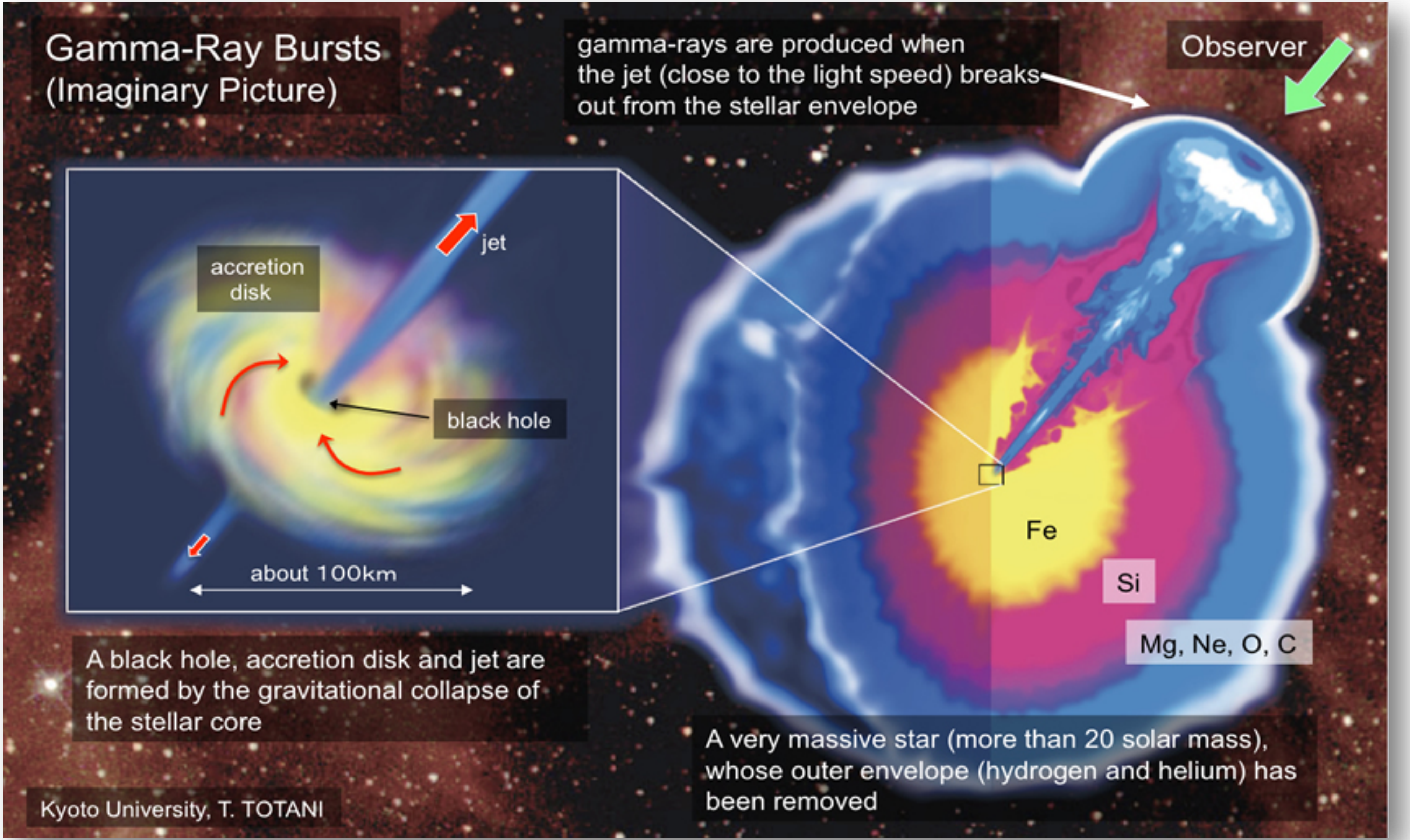
Particle acceleration



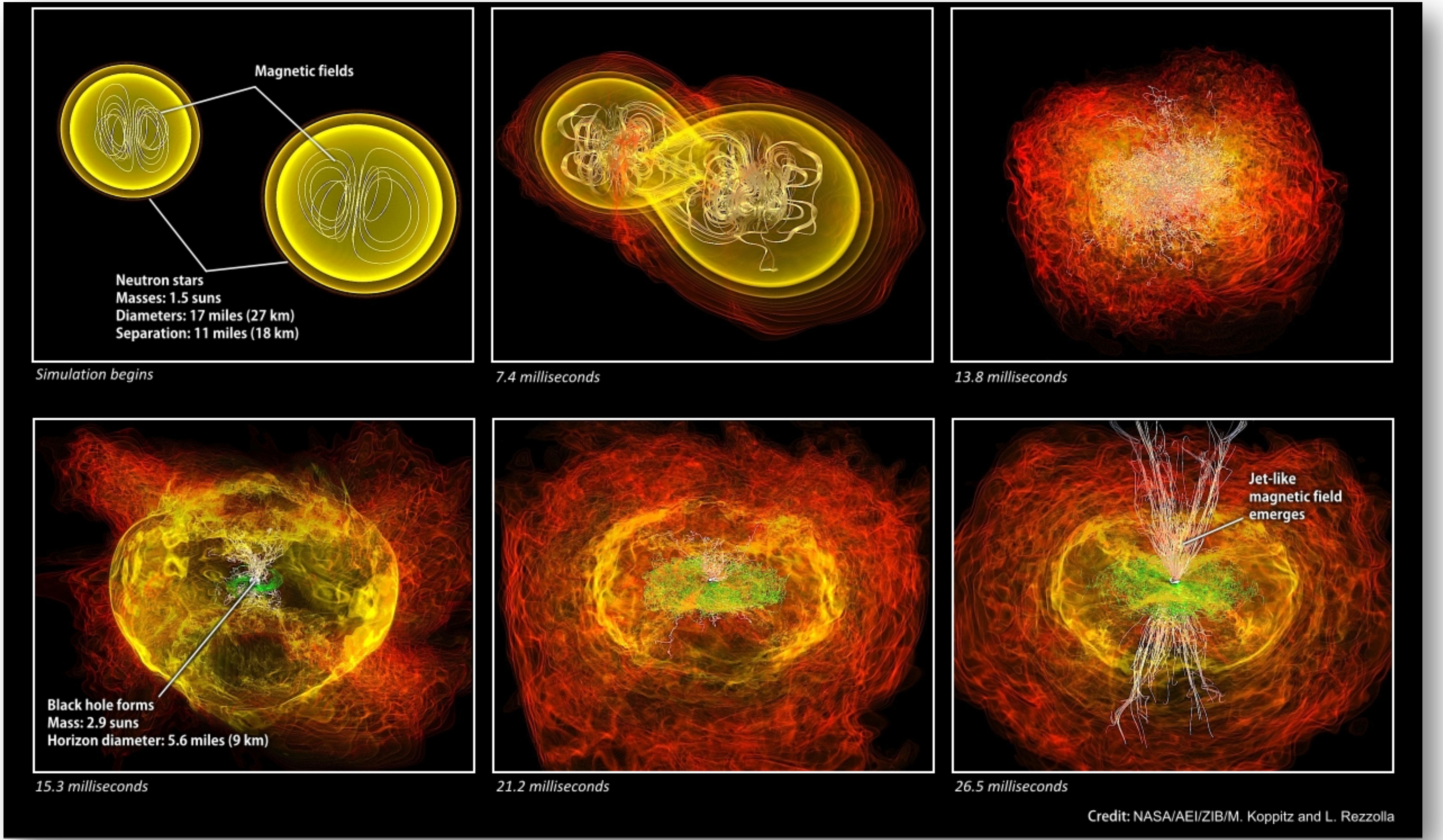
Internal shocks

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

Long GRBs – stellar core collapse

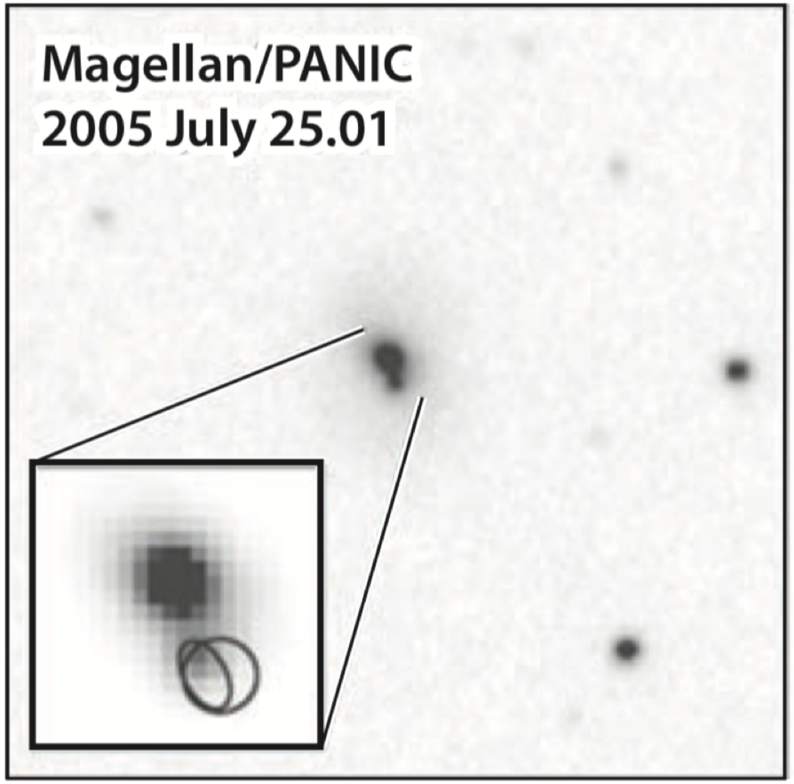


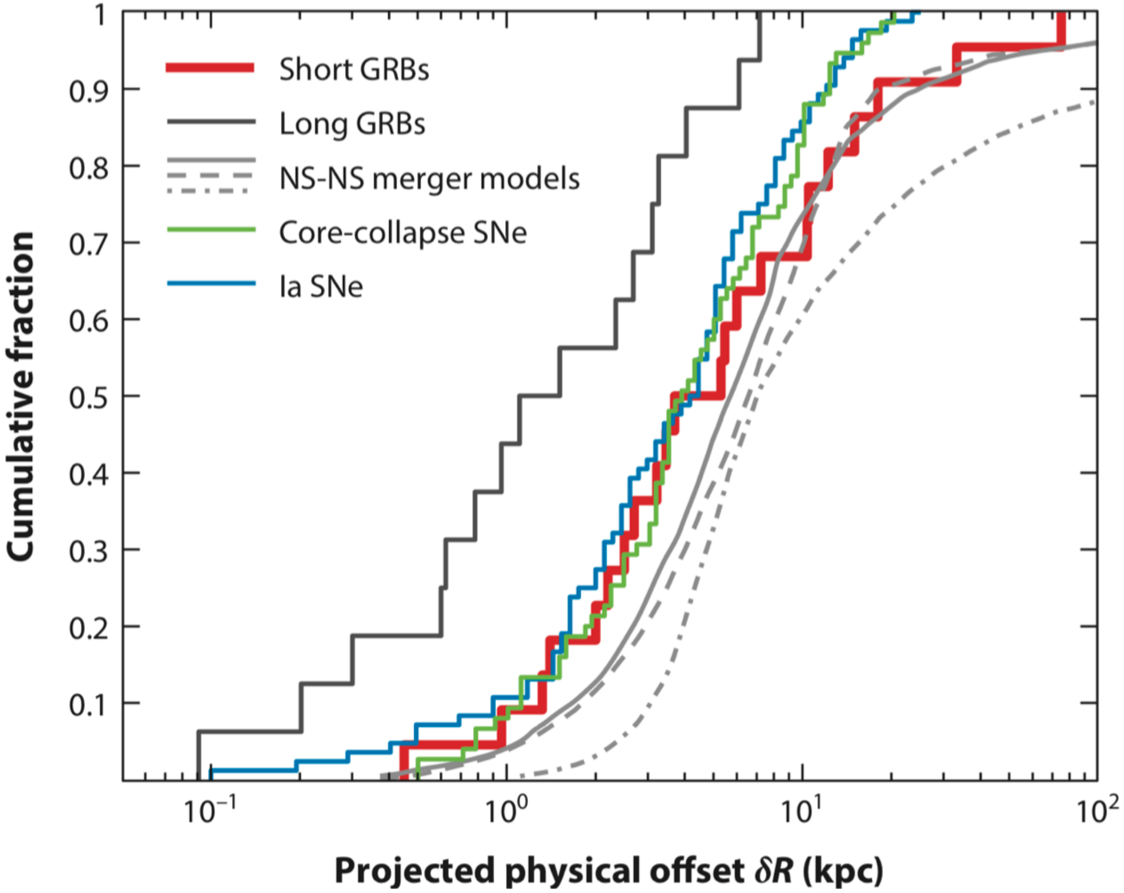
Short GRBs – binary mergers



Fallback time

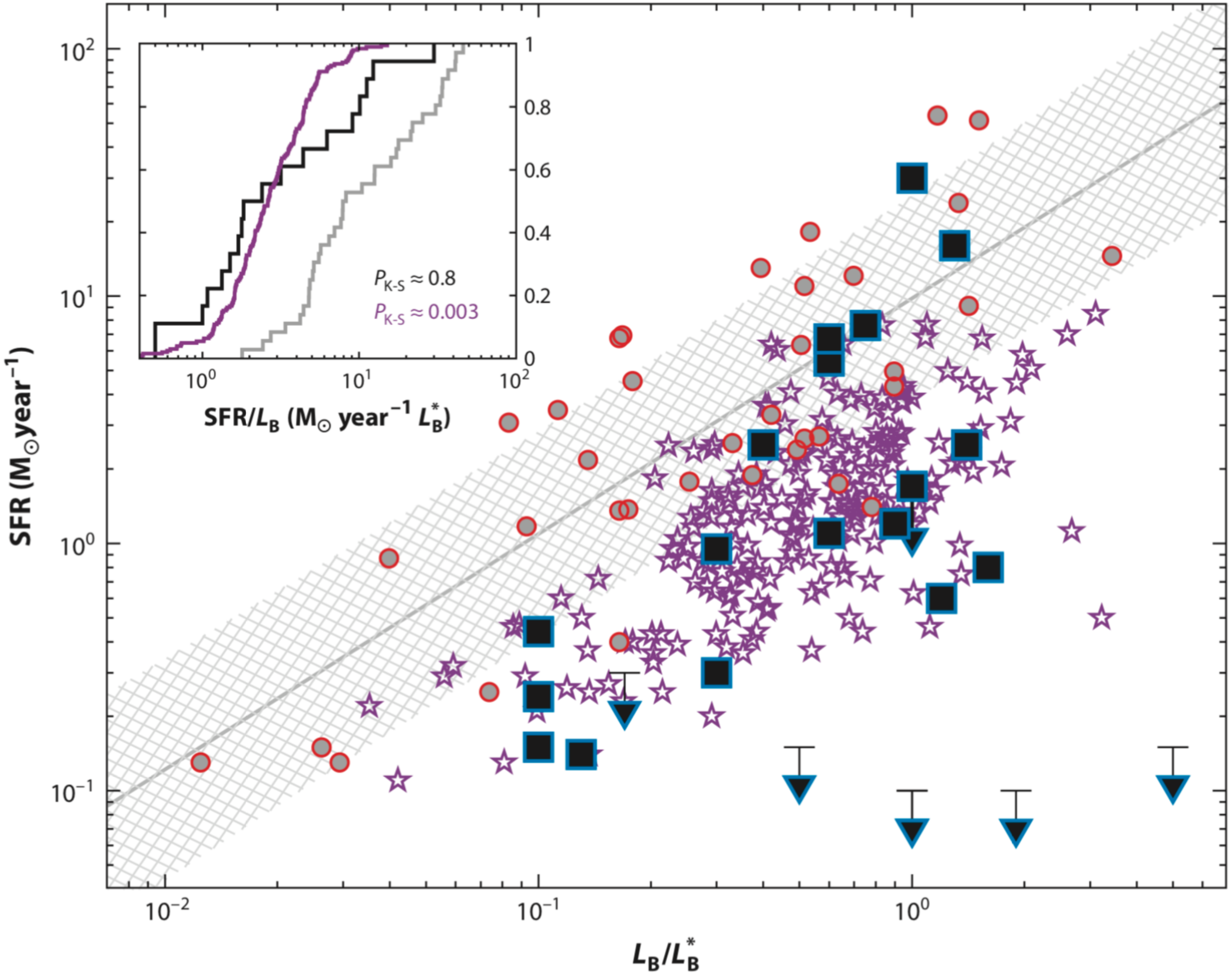
Kicks – short GRBs are often outside the host galaxy





Berger 2014

Star formation in host galaxies

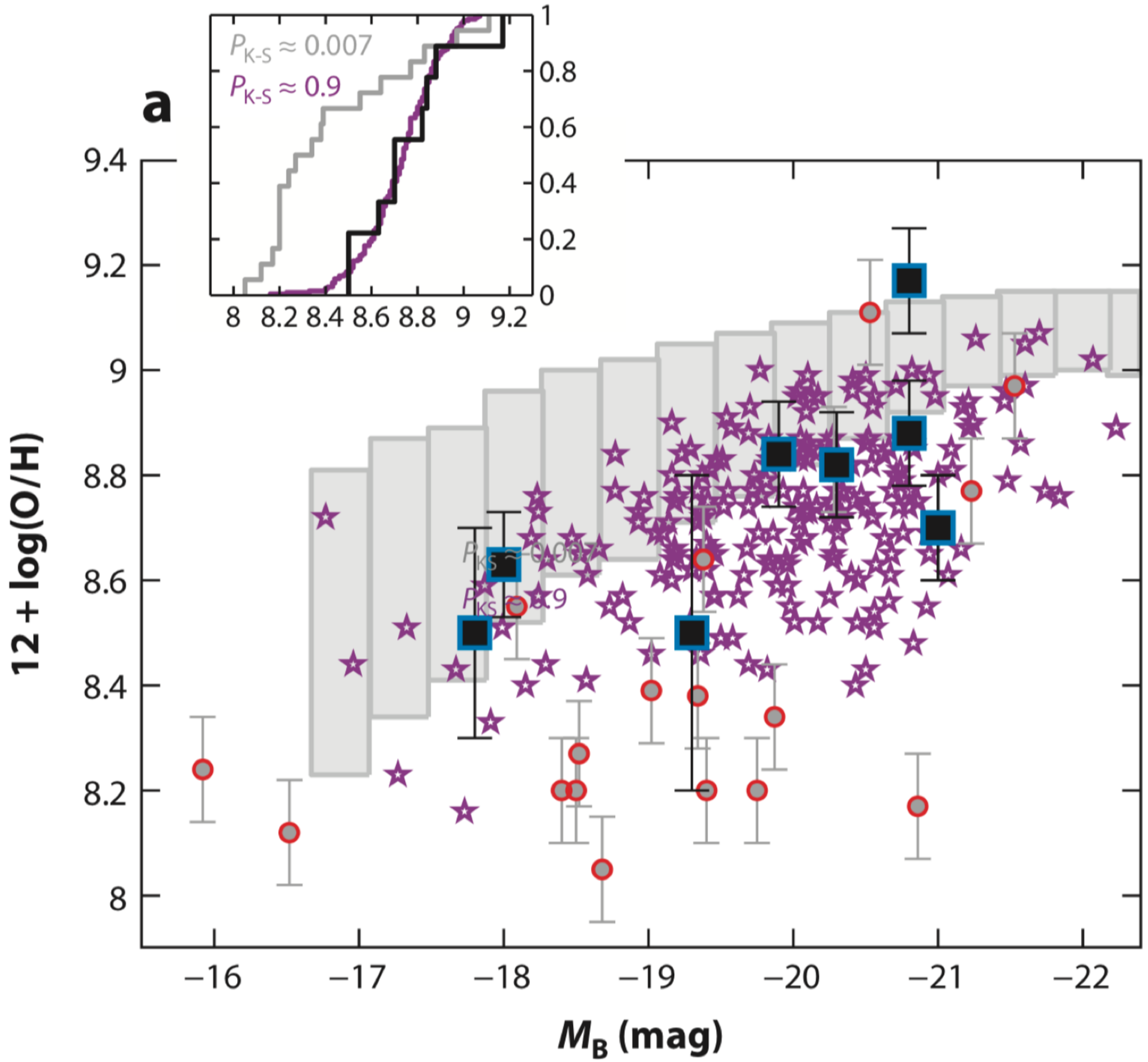


Star-formation rate (SFR) as a function of rest-frame B-band luminosity for the host galaxies of short GRBs (*squares*), long GRBs (*circles*), and field star-forming galaxies at similar redshifts to short GRB hosts (*stars*; Kobulnicky & Kewley 2004).

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

Berger 2014

Metallicity of host galaxy

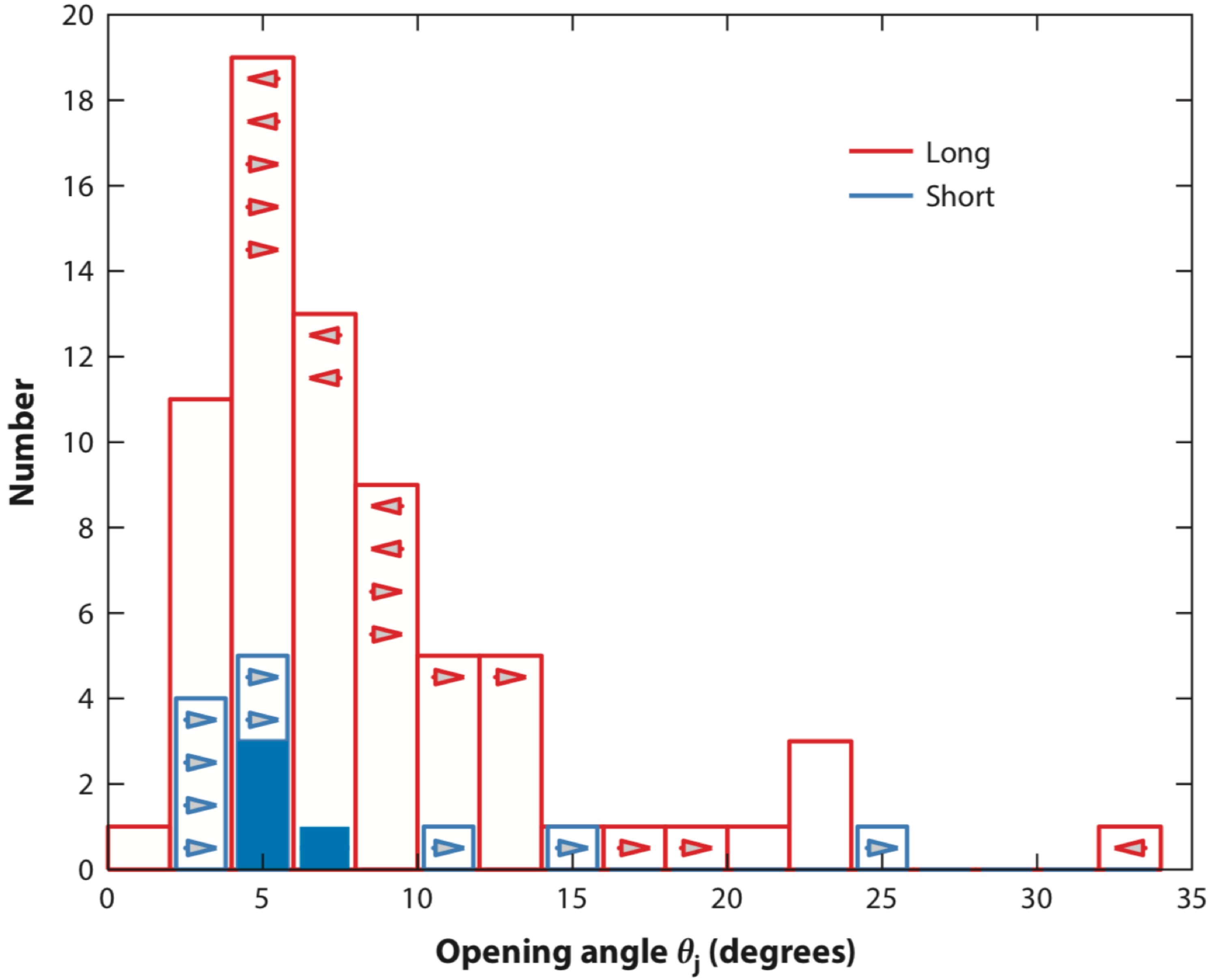


Metallicity as a function of host-galaxy rest-frame B-band luminosity for short GRBs (*squares*), long GRBs (*circles*), field galaxies at similar redshifts to short GRB hosts (*stars*; Kobulnicky & Kewley 2004), and the Sloan Digital Sky Survey luminosity-metallicity relation (Tremonti et al. 2004).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

Berger 2014

Opening angles



Berger 2014