Cosmic Matrix in the Jubilee of Relativistic Astrophysics

Remo Ruffini

and collaborators

ICRANet Pescara – Nice – Rio – Rome – Yerevan

Università "La Sapienza" - Rome

14th Marcel Grossmann Meeting – MGXIV

July 12th-18th, 2015, Rome

The four pillars of relativistic astrophysics

- Supernovae
- Neutron stars
- Black holes
- GRBs

Pulsars and Neutron stars rotational energy

$$\left(\frac{dE}{dt}\right)_{obs} \simeq 4\pi^2 \frac{I_{NS}}{P^3}\frac{dP}{dt}$$

Chinese, Japanese, Korean astronomers (1054 A.D.)

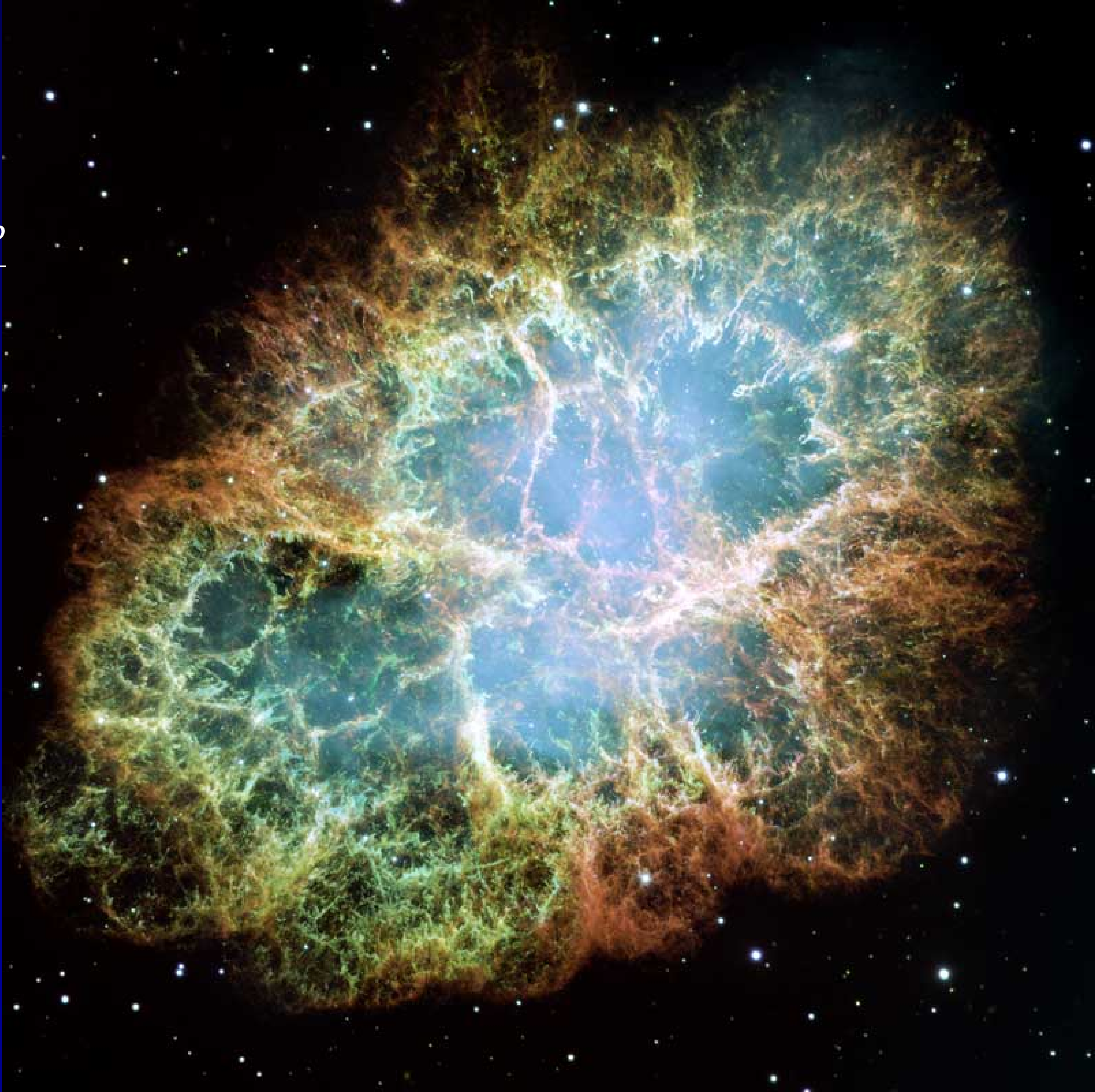
R. Oppenheimer & R. Volkoff (1939)

J. Bell & T. Hewish (1967)

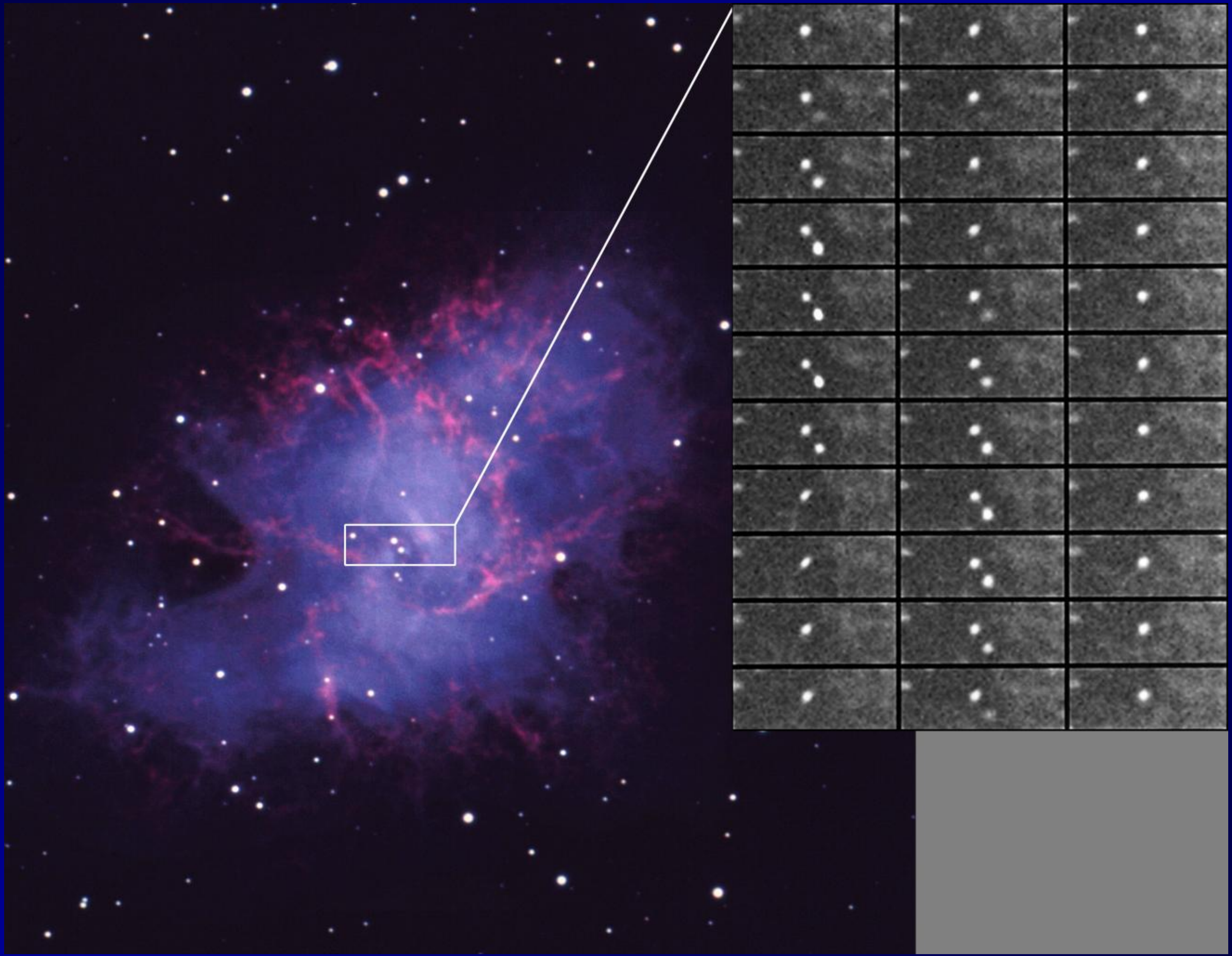
UHECRs (2000-2011)

AGILE Flare (2011)

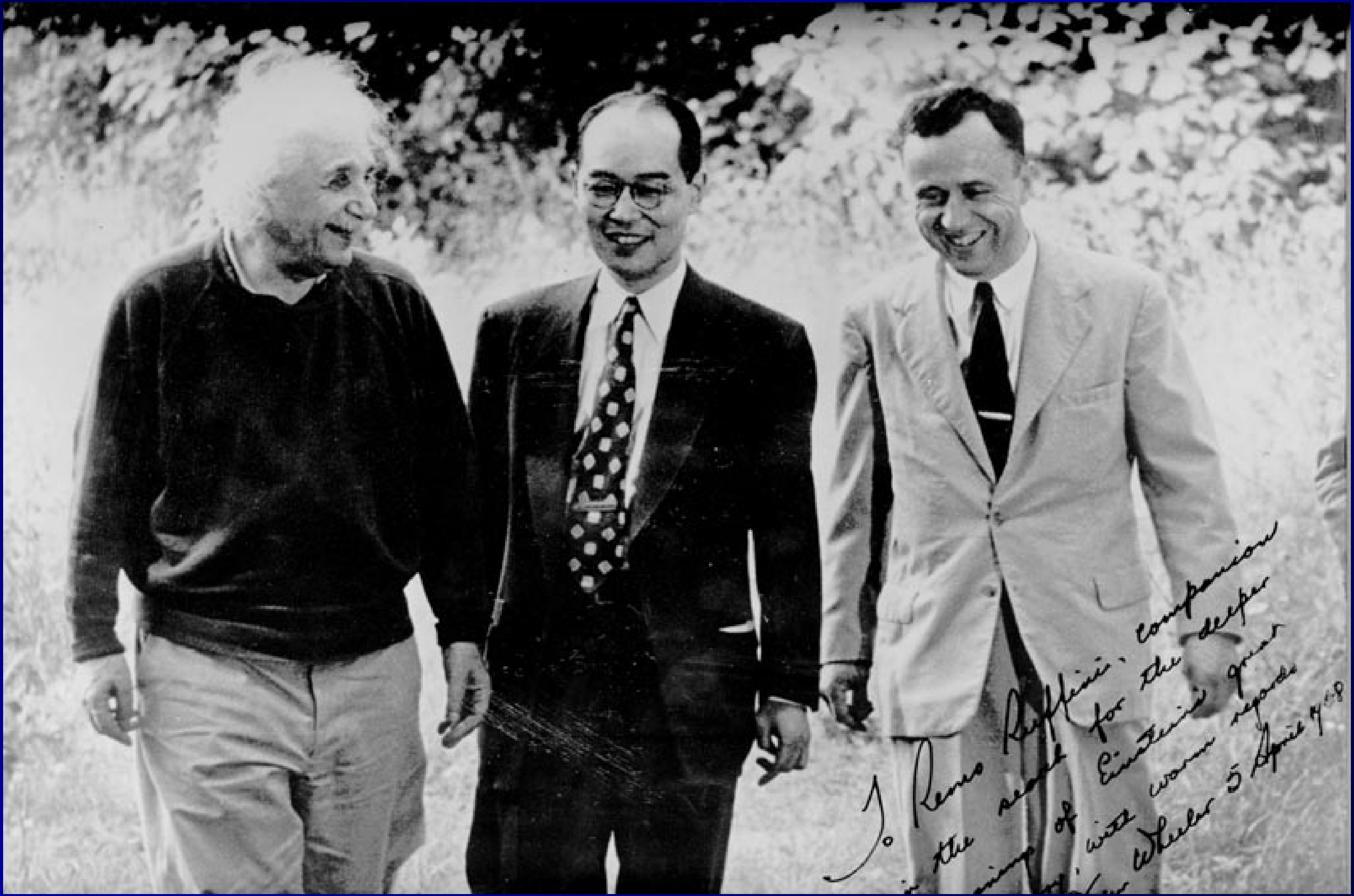
Open issue: the emission of the remnant.



Crab Nebula Pulsar



Einstein, Yukawa and Wheeler: the birth of Relativistic Astrophysics



Princeton, 1971

Joseph Henry Laboratories, Princeton University

Introducing the black hole

According to present cosmology, certain stars end their careers in a total gravitational collapse that transcends the ordinary laws of physics.

Remo Ruffini and John A. Wheeler

The quasistellar object, the pulsar, the neutron star have all come onto the scene of physics within the space of a few years. Is the next entrant destined to be the black hole? If so, it is difficult to think of any development that could be of greater significance. A black hole, whether of "ordinary size" (approximately one solar mass, 1 $M_\odot$), or much larger (around 10^6 $M_\odot$ to 10^{10} $M_\odot$, as proposed in the nuclei of some galaxies) provides our "laboratory model" for the gravitational collapse, predicted by Einstein's theory, of the universe itself.

A black hole is what is left behind after an object has undergone complete gravitational collapse. Spacetime is so strongly curved that no light can come out, no matter can be ejected and no measuring rod can ever survive being put in. Any kind of object that falls into the black hole loses its separate identity, preserving only its mass, charge, angular momentum and linear momentum (see figure 1). No one has yet found a way to distinguish between two black holes constructed out of the most different kinds of matter if they have the same mass, charge and angular momentum. Measurement of these three determinants is permitted by their effect on the Kepler orbits of test objects, charged and uncharged, in revolution about the black hole.

How the physics of a black hole looks depends more upon an act of choice by the observer himself than an anything else. Suppose he decides to follow the collapsing matter through its collapse down into the black hole. Then he will see it crushed to indefinitely high density, and he himself will be torn apart eventually by indefinitely increasing tidal forces. No restraining force whatsoever has the power to hold him away from this catastrophe, once he crossed a certain critical surface known as the "horizon." The final collapse occurs a finite time after the passage of this surface, but it is inevitable. Time and space are interchanged inside a black hole in an unusual way; the direction of increasing proper time for the observer is the direction of decreasing values of the coordinate r. The observer has no more power to return to a larger r value than he has power to turn back the hands on the clock of life itself. He can not even stay where he is, and for a simple reason: no one has the power to stop the advance of time.

Suppose the observer decides instead to observe the collapse from far away. Then, as price for his own safety, he is deprived of any chance to see more than the first steps on the way to collapse. All signals and all information from the later phases of collapse never escape; they are caught up in the collapse of the geometry itself.

That a sufficient mass of cold matter will necessarily collapse to a black hole (J. R. Oppenheimer and H. Snyder,[1]) is one of the most spectacular of all the predictions of Einstein's standard 1915 general relativity. The geometry around a collapsed object of spherical symmetry (nonrotating!) was worked out by Karl Schwarzschild of Göttingen, father of the American astrophysicist Martin Schwarzschild, as early as 1916. In 1963 Roy Kerr[2] found the geometry associated with a rotating collapsed object. James Bardeen has recently emphasized that all stars have angular momentum and that most stars—or star cores—will have so much angular momentum that the black hole formed upon collapse will be rotating at the

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Remo Ruffini and John Wheeler are both at Princeton University; Wheeler, currently on leave from Princeton, is spending a year at Cal Tech and Moscow State University.

The Black Hole Mass-Energy formula

$$m^2 = \left(m_{ir} + \frac{e^2}{4m_{ir}}\right)^2 + \frac{L^2}{4m_{ir}^2},$$

$$S = 16\pi m_{ir}^2,$$

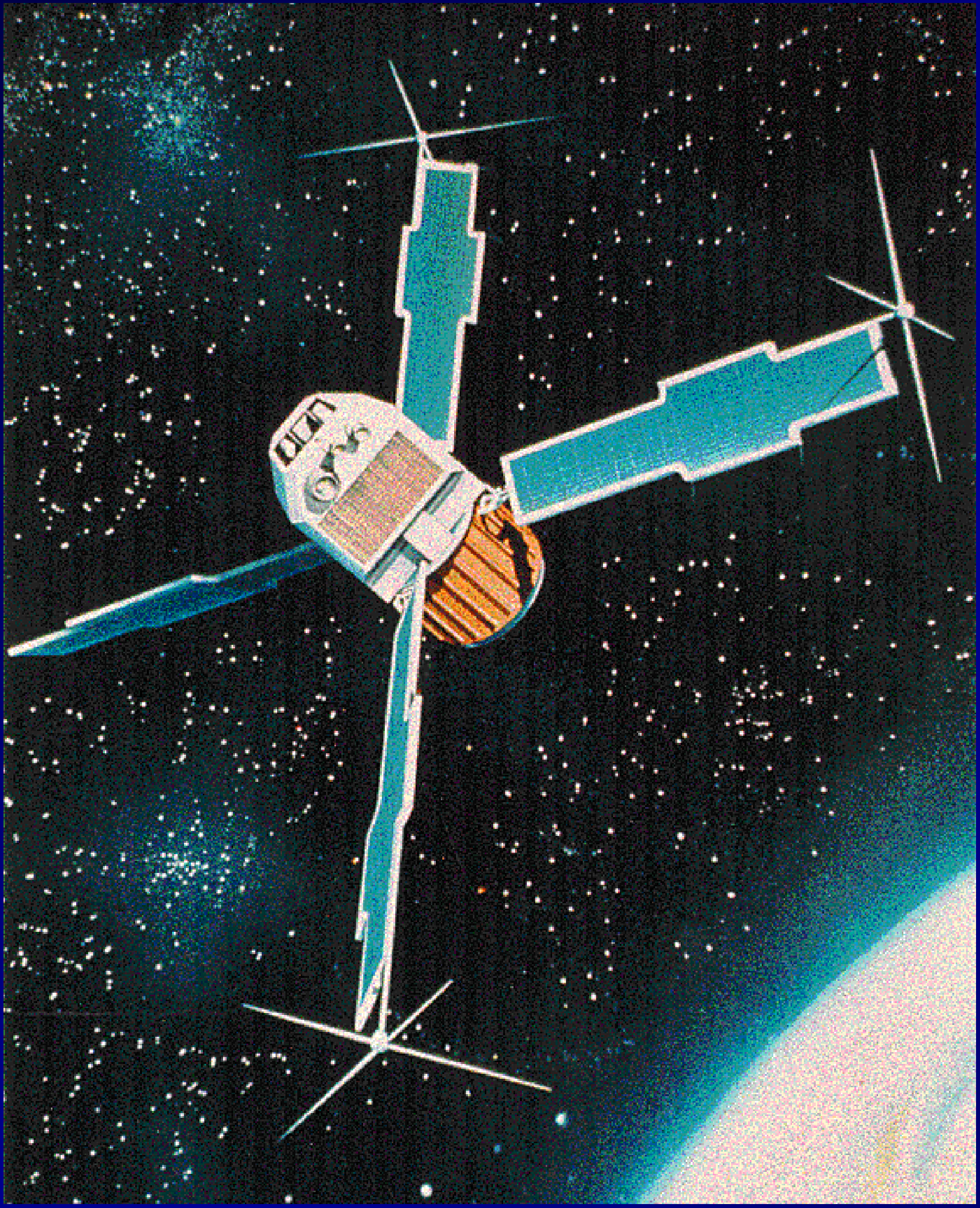
$$\frac{L^2}{4m_{ir}^4} + \frac{e^4}{16m_{ir}^4} \leq 1,$$

$$\delta S = 32\pi m_{ir}\delta m_{ir} \geq 0$$

5th Texas Symposium, 1970

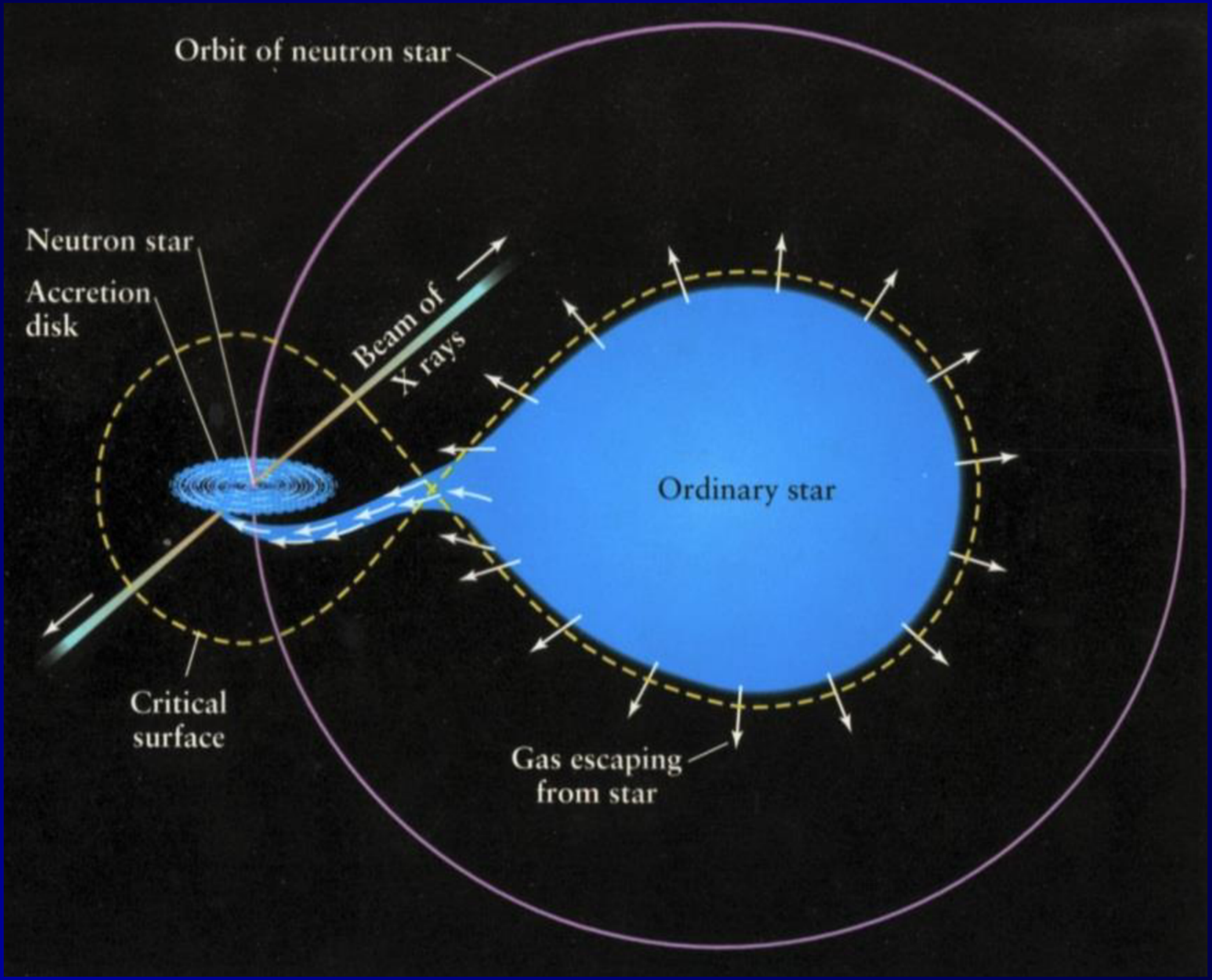
Christodoulou, Ruffini, 1971

Uhuru satellite (1970-1973)



X-Ray: 2-20 keV

Cen-X3


Orbit of neutron star
Neutron star
Accretion disk
Beam of X rays
Ordinary star
Critical surface
Gas escaping from star

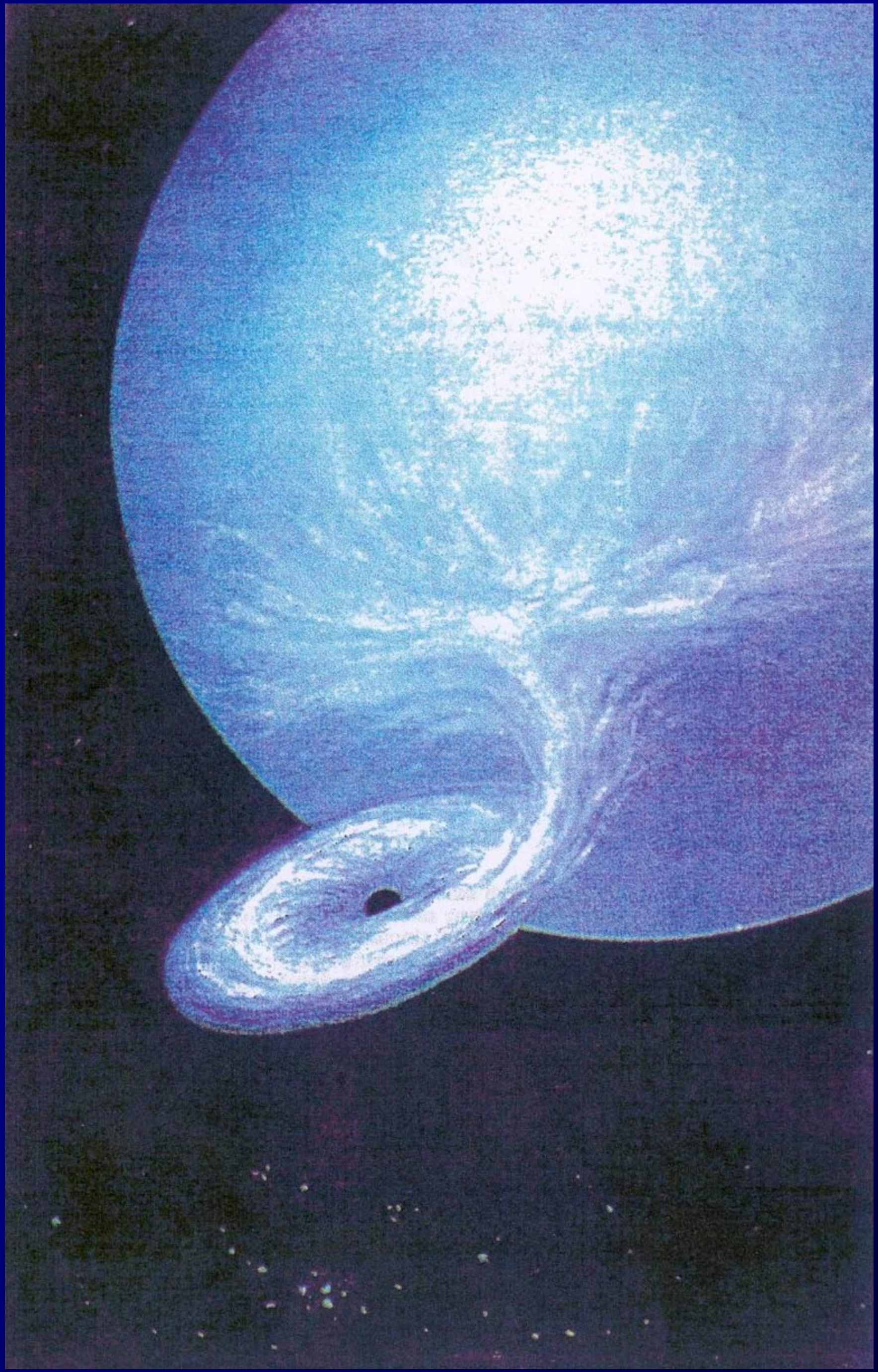
The identification of the first black hole in our galaxy: Cygnus X-1

$\Phi = 10^{37}$ **erg/s** $= 10^4 L_\odot$
$= 0.01(dm/dt)_{acc}c^2$

Absence of pulsation due to uniqueness of Kerr-Newmann black holes

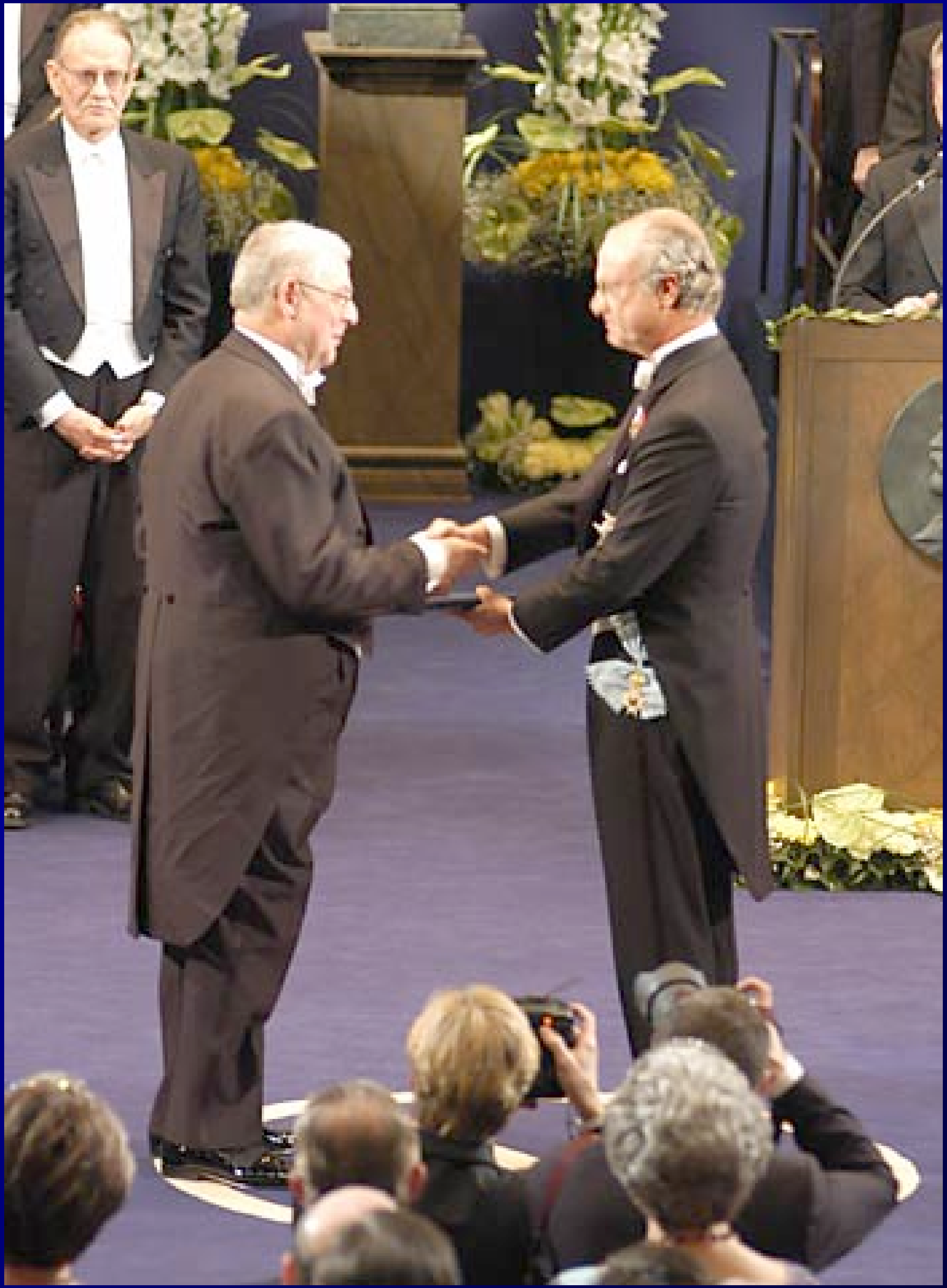
$M > 3.2\, M_\odot$

Leach & Ruffini, 1973

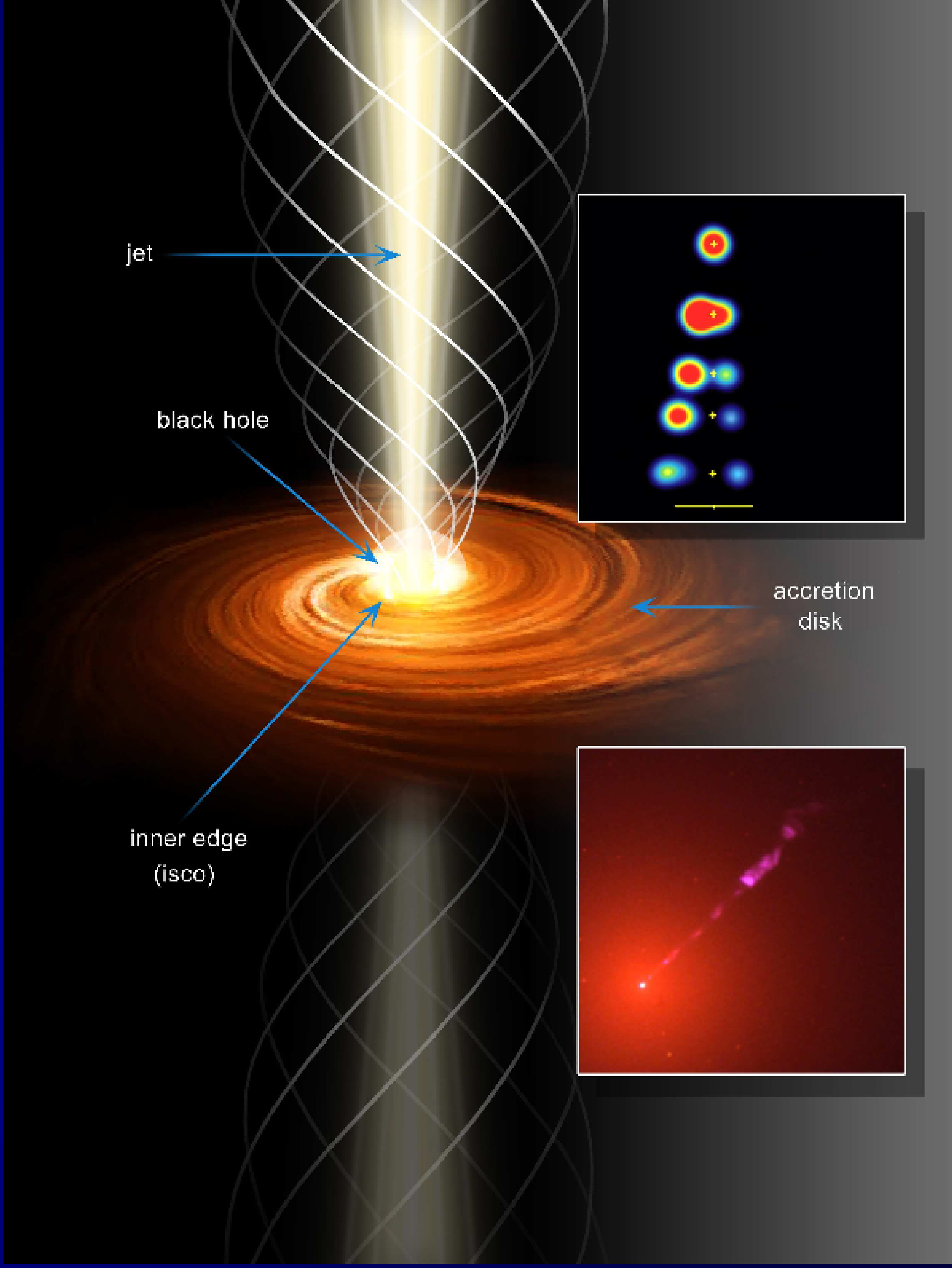


Cressy – Morrison award (NY, 1973)

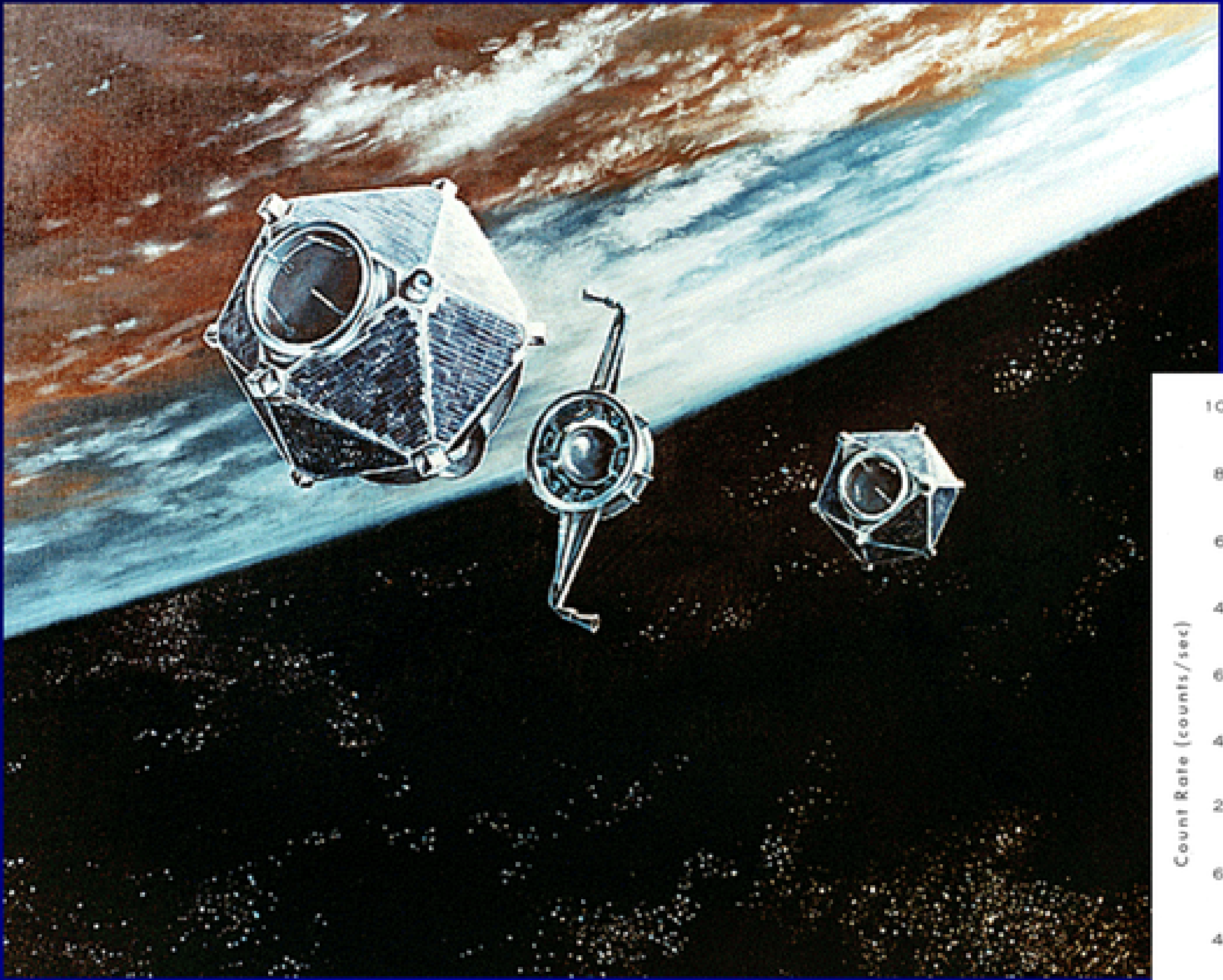
Giacconi, Sweden (2002)



Mirabel & Rodriguez (1992, 1994)



Vela satellites and GRBs(60s-70s)



X-Ray: 3-12 keV
Gamma: 150-750 keV

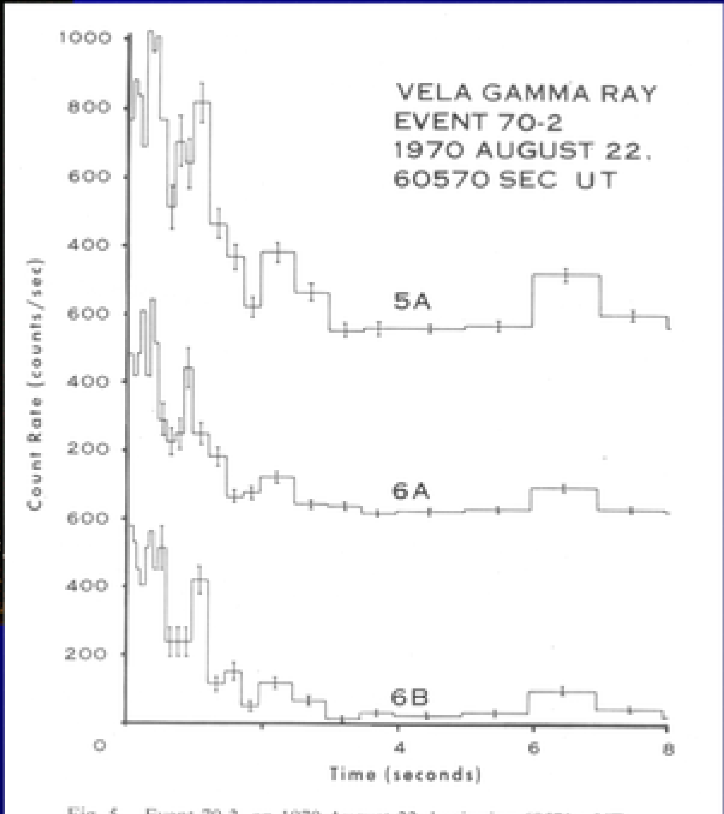


Fig. 5. Event 70-2, on 1970 August 22, beginning 60571 s UT.

R.W. Klebesadel, I.B. Strong, & R.A. Olson, ApJ Lett., 182, 1973

H. Gursky & R. Ruffini, AAAS, S. Francisco, 1974

Quantum Electrodynamical Effects in Kerr-Newmann Geometries

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Joseph Henry Physical Laboratories, Princeton University, Princeton, New Jersey 08540

and

Remo Ruffini†
Institute for Advanced Study, Princeton, New Jersey 08540
(Received 13 January 1975)

Following the classical approach of Sauter, of Heisenberg and Euler and of Schwinger the process of vacuum polarization in the field of a "bare" Kerr-Newman geometry is studied. The value of the critical strength of the electromagnetic fields is given together with an analysis of the feedback of the discharge on the geometry. The relevance of this analysis for current astrophysical observations is mentioned.

and possibly of galactic nuclei. In particular this work naturally leads to a most simple model for the explanation of the recently discovered γ-rays bursts.[19] It is desirable that possible coin-

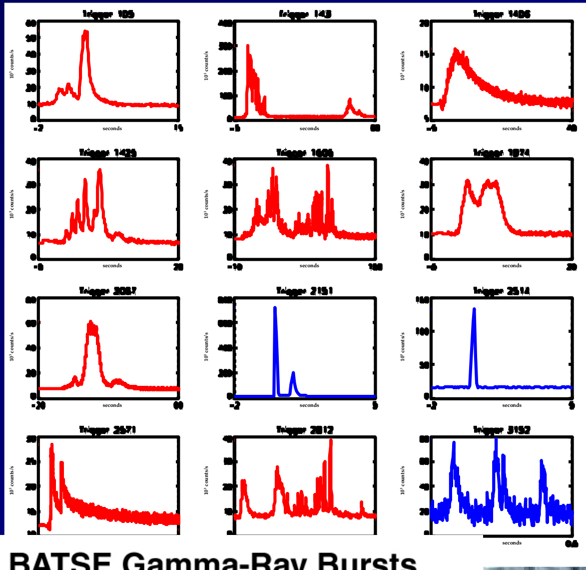
Expected energy: ~ 10^{54} (M_{BH}/M_{Sun}) erg

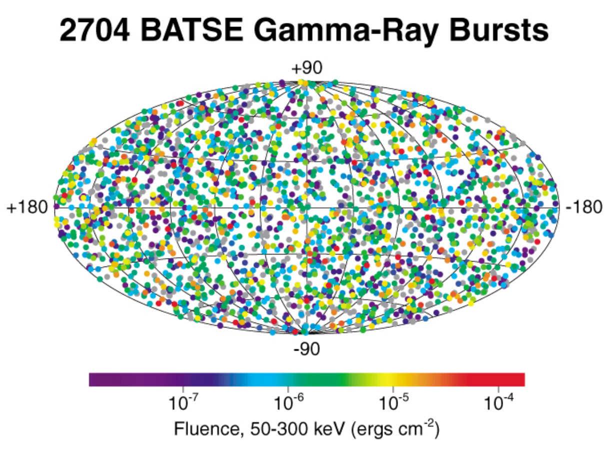
Vallée des Merveilles, 1975

Wilson – Everitt – Ruffini – Damour

CGRO – BATSE (1991-2000)

Gamma: 20-2000 keV





THE ASTROPHYSICAL JOURNAL, 395:L83–L86, 1992 August 20

GAMMA-RAY BURSTS AS THE DEATH THROES OF MASSIVE BINARY STARS

RAMESH NARAYAN,[1] BOHDAN PACZYŃSKI,[2] AND TSVI PIRAN[3]
Received 1992 March 24; accepted 1992 June 5

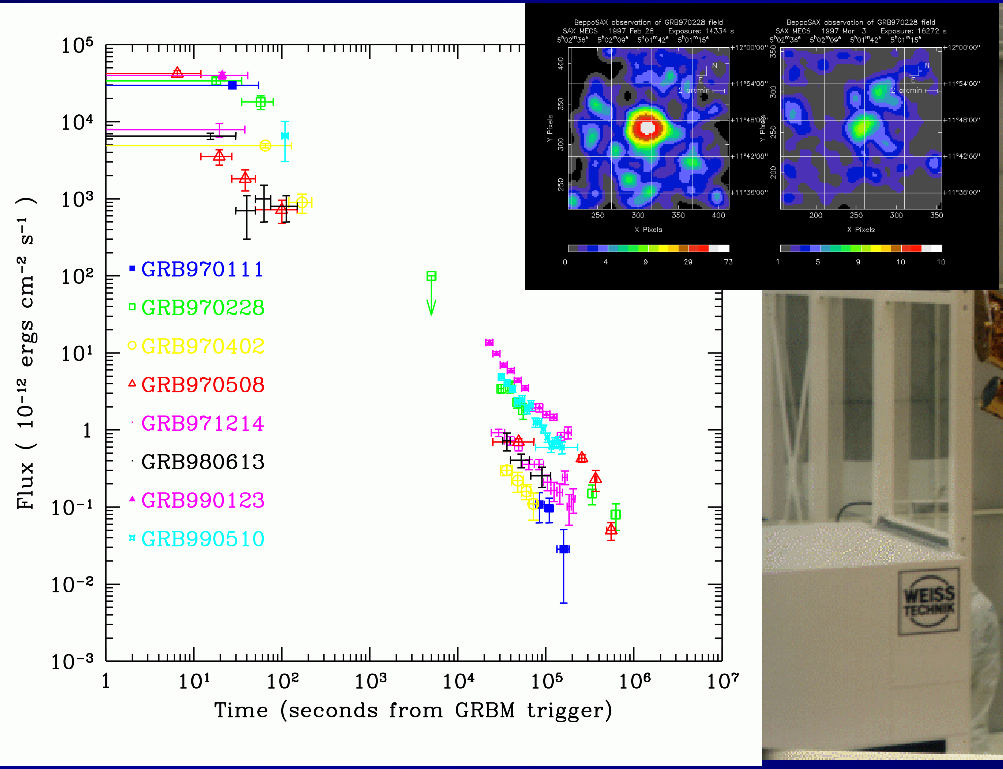
ABSTRACT

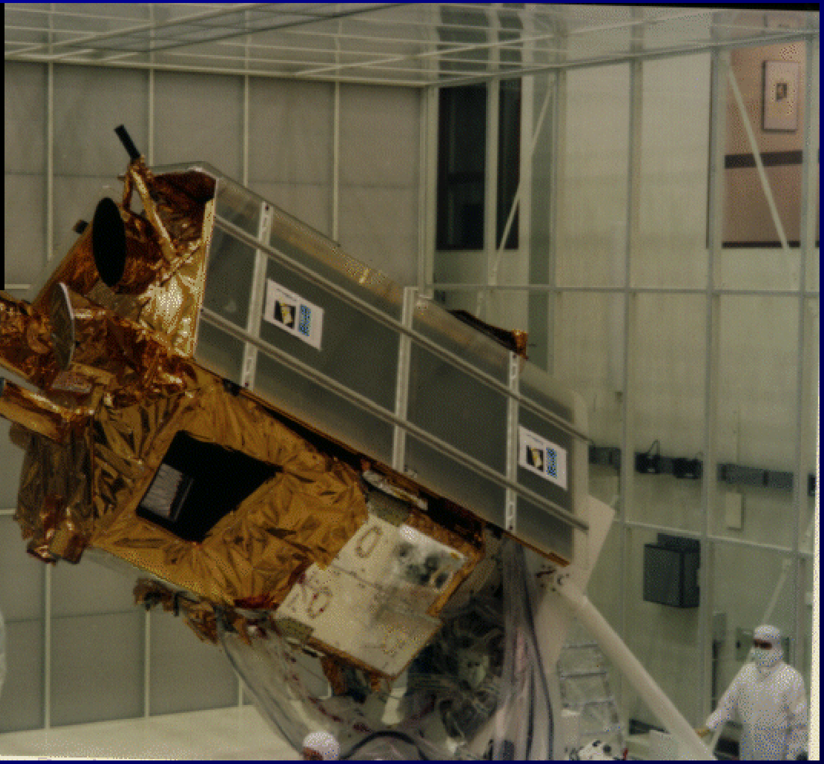
We propose that gamma-ray bursts are created in the mergers of double neutron star binaries and black hole neutron star binaries at cosmological distances. Two different processes provide the electromagnetic energy for the bursts: neutrino-antineutrino annihilation into electron-positron pairs during the merger, and magnetic flares generated by the Parker instability in a postmerger differentially rotating disk. In both cases, an optically thick fireball of size $\lesssim$ 100 km is initially created, which expands ultrarelativistically to large radii before radiating. The scenario is only qualitative at this time, but it eliminates many previous objections to the cosmological merger model. The strongest bursts should be found close to, but not at the centers of, galaxies at redshifts of order 0.1, and should be accompanied by bursts of gravitational radiation from the spiraling-in binary which could be detected by LIGO.

Subject headings: accretion, accretion disks — black hole physics — gamma rays: bursts — gravitation — magnetic fields — stars: neutron

BeppoSAX (1996-2002)

GRBM: 40-700 keV
WFC: 2-26 keV
NFI: 2-10 keV





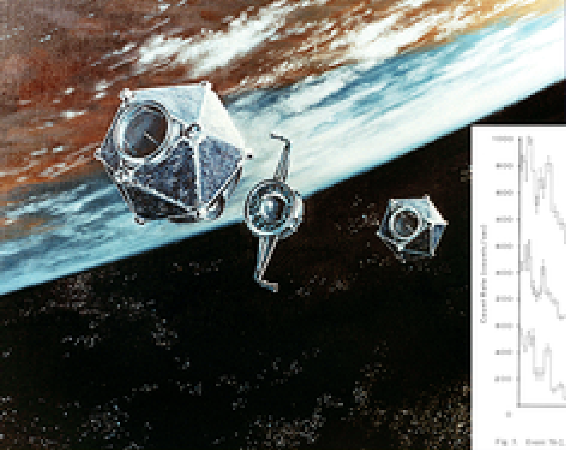
Swift (2004-)

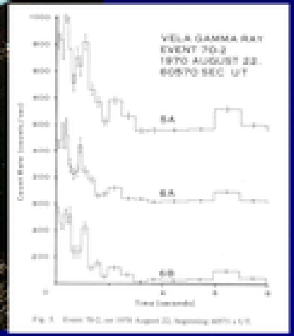
BAT: 15-150 keV
XRT: 0.3-10 keV

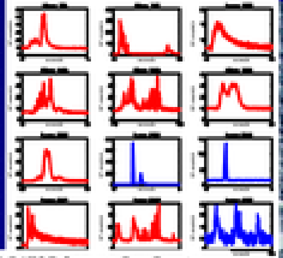
Fermi (2008-)

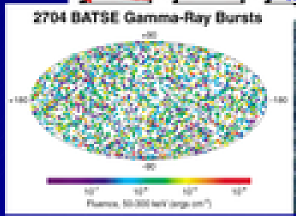
GBM: 8 keV-40 MeV
LAT: 20 MeV-300 GeV

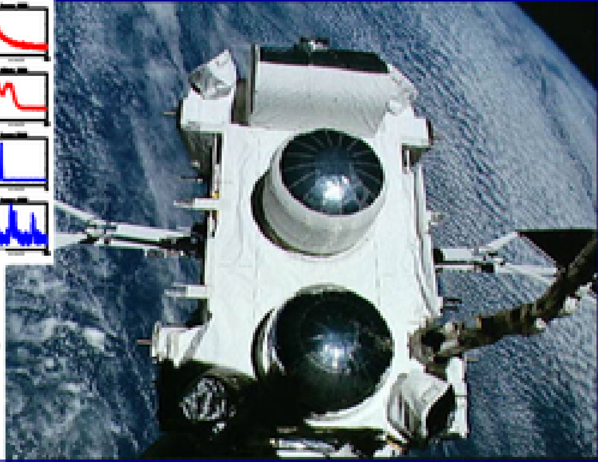
E=10^{54} erg

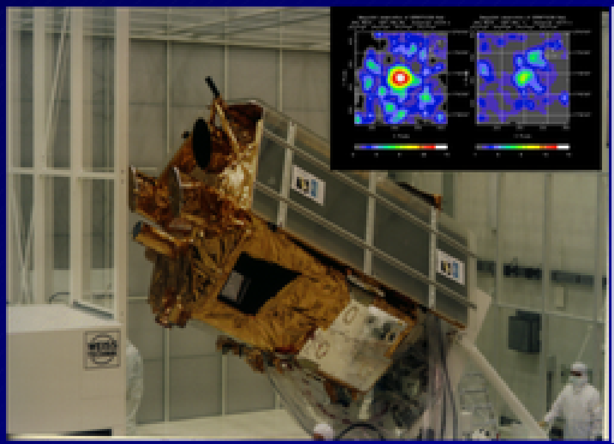


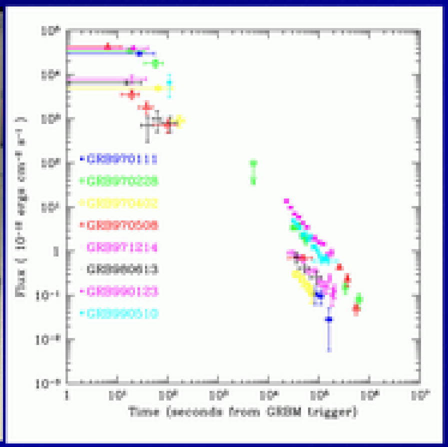

VELA GAMMA RAY
EVENT 70-2
1970 AUGUST 22
60570 SEC UT
5A
6A
6B
Time (seconds)

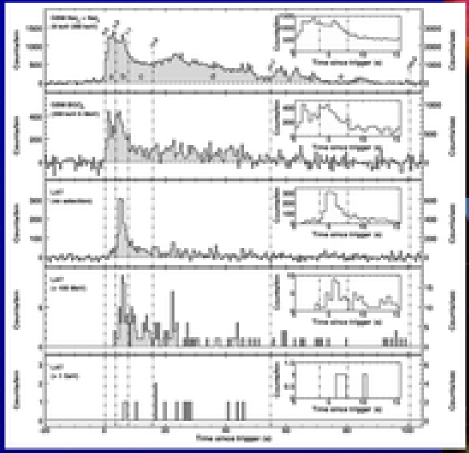


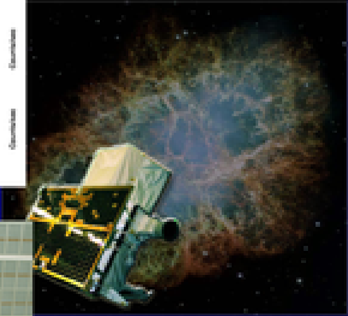

2704 BATSE Gamma-Ray Bursts

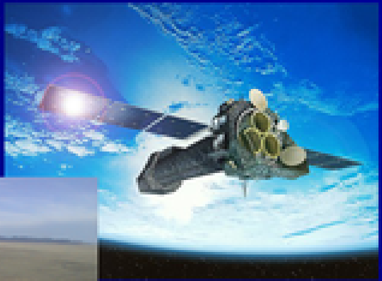


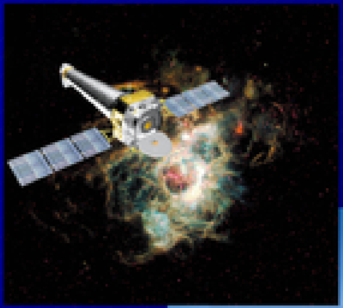


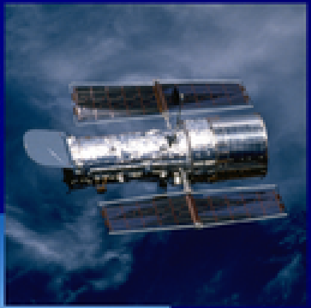

GRB970111
GRB970228
GRB970402
GRB970508
GRB971214
GRB980613
GRB990123
GRB990510
Time (seconds from GRBM trigger)









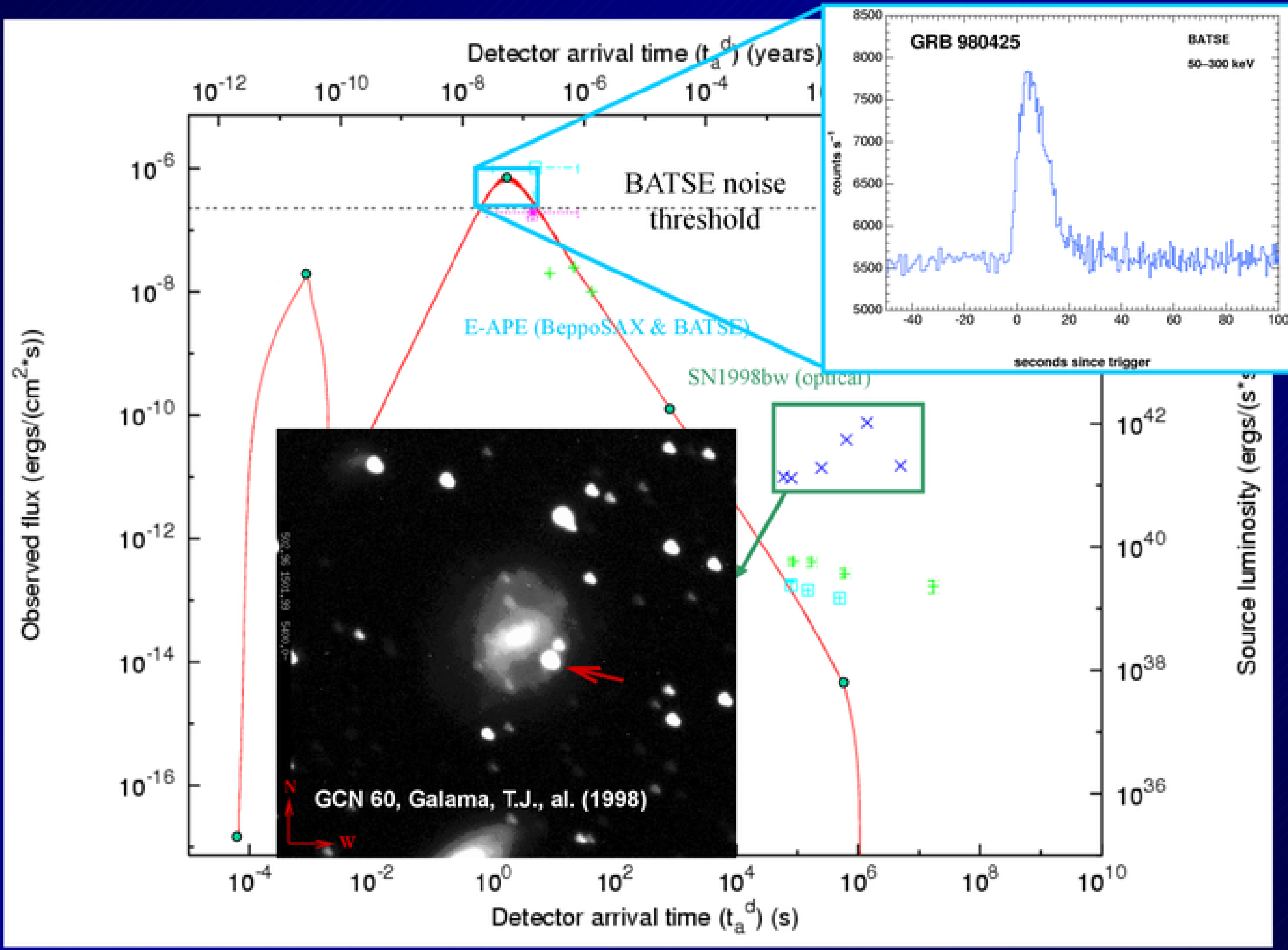


The four pillars of relativistic astrophysics and the “Cosmic Matrix”

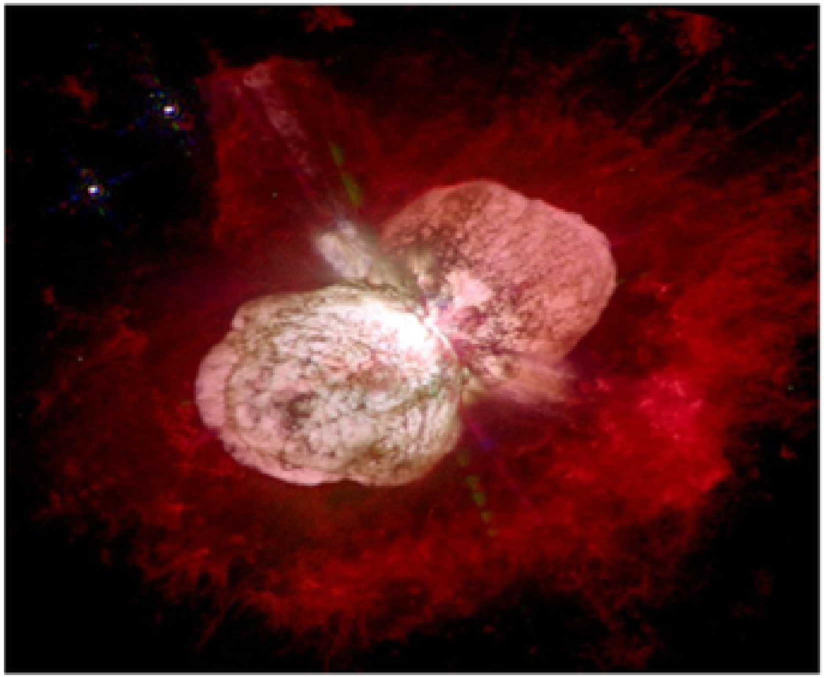
- Supernovae
- Neutron stars
- Black holes
- GRBs

In the
“Cosmic Matrix”

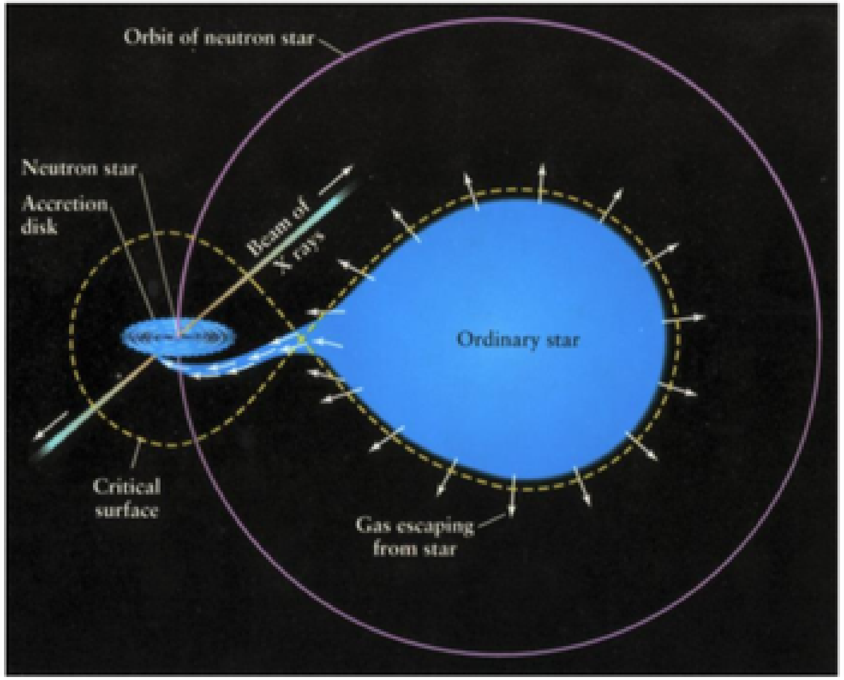
GRB 980425 - SN1998bw



From the progenitor to the IGC sequence: the case of long GRBs related to SNe



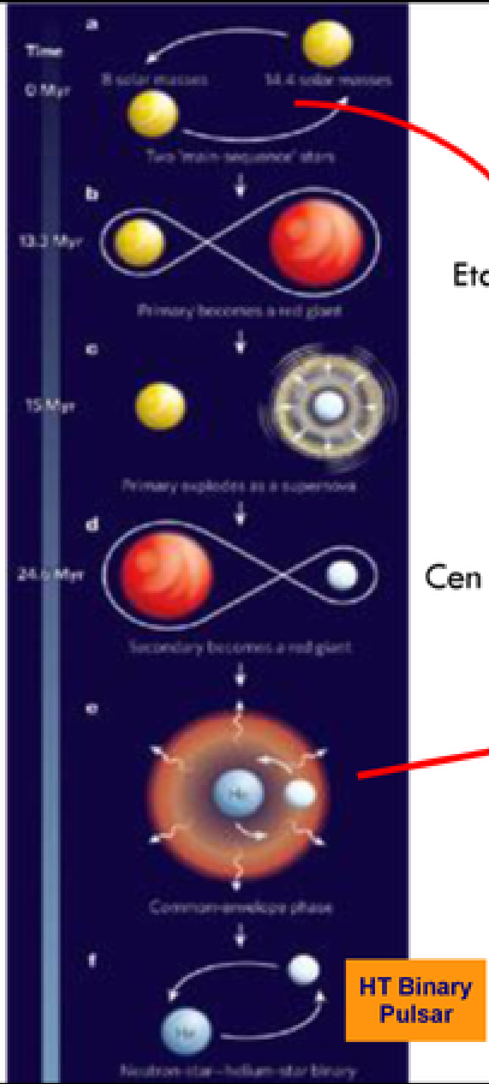
Massive Binary
(Eta Carinae, Porb=5.5 yr)



Massive Star-Neutron Star X Ray Binary
(Centaurus X-3, Porb=2.1 days)

The IGC Binary Progenitor

Binary sequence

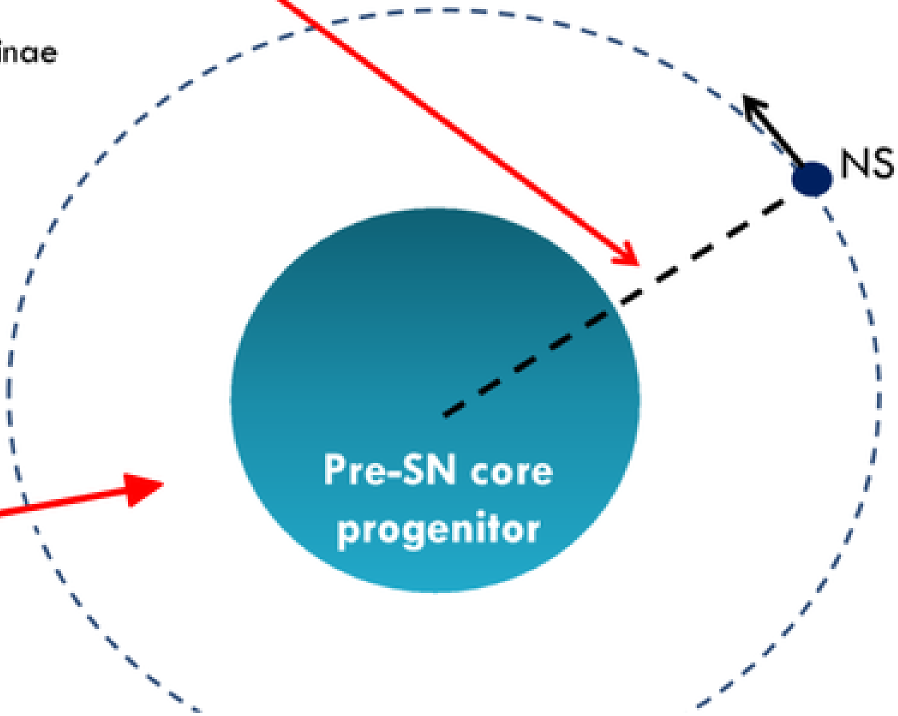


Eta Carinae

Cen X-3

Nomoto & Hashimoto (1988)
Nomoto et al. (1994)
Iwamoto et al. (1994)
and others…

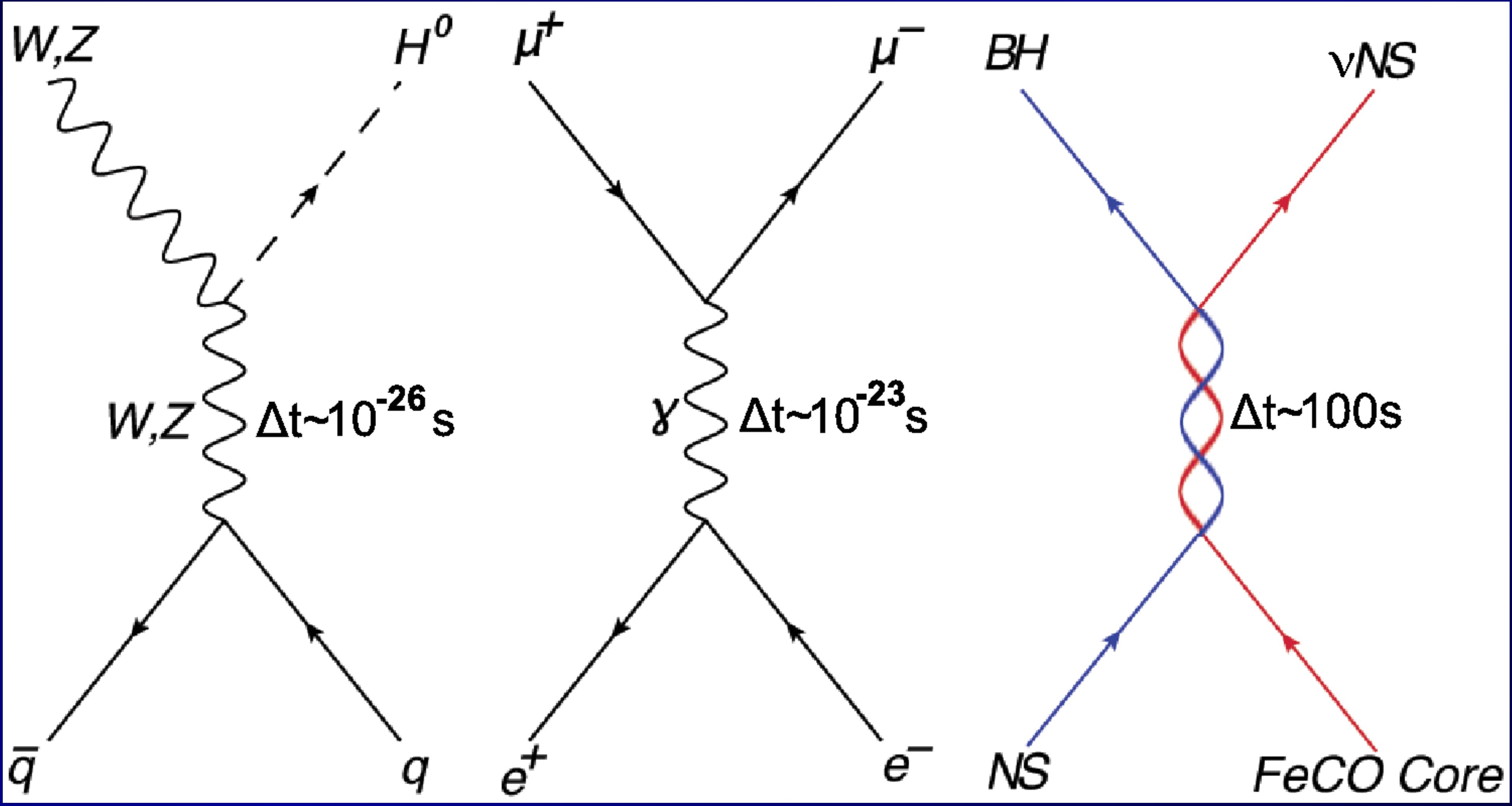
$$v_{\rm orb} = \sqrt{\frac{G(M_{\rm SN\text{-}prog} + M_{\rm NS})}{a}} = 1.15 \times 10^8 \left(\frac{M_{\rm SN\text{-}prog} + M_{\rm NS}}{M_\odot}\right)^{1/2} \ {\rm cm\,s^{-1}}$$



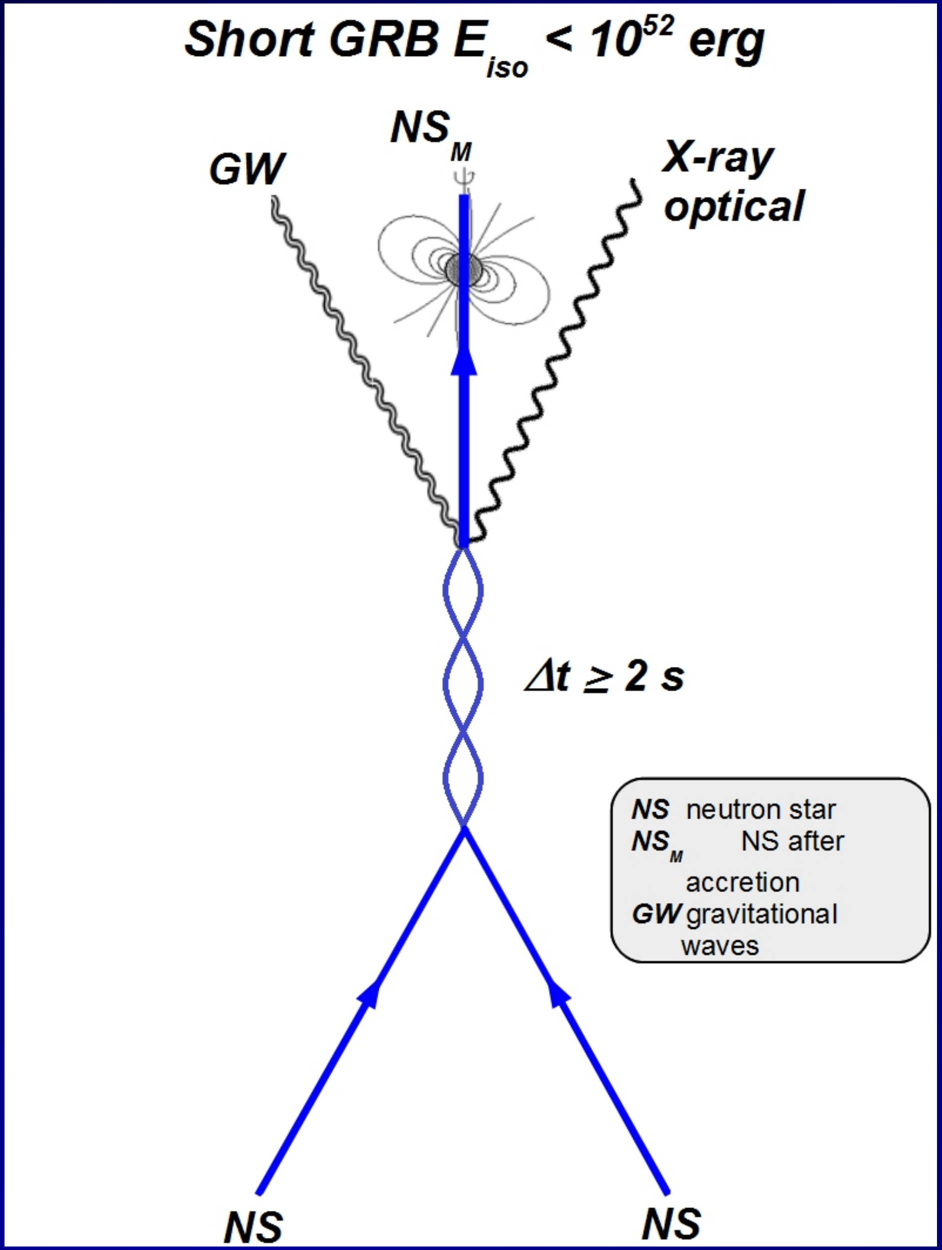
$$P = \sqrt{\frac{4\pi^2 a^3}{G(M_{\rm SN\text{-}prog} + M_{\rm NS})}} = 545 \left(\frac{M_{\rm SN\text{-}prog} + M_{\rm NS}}{M_\odot}\right)^{-1/2} \ {\rm s}$$

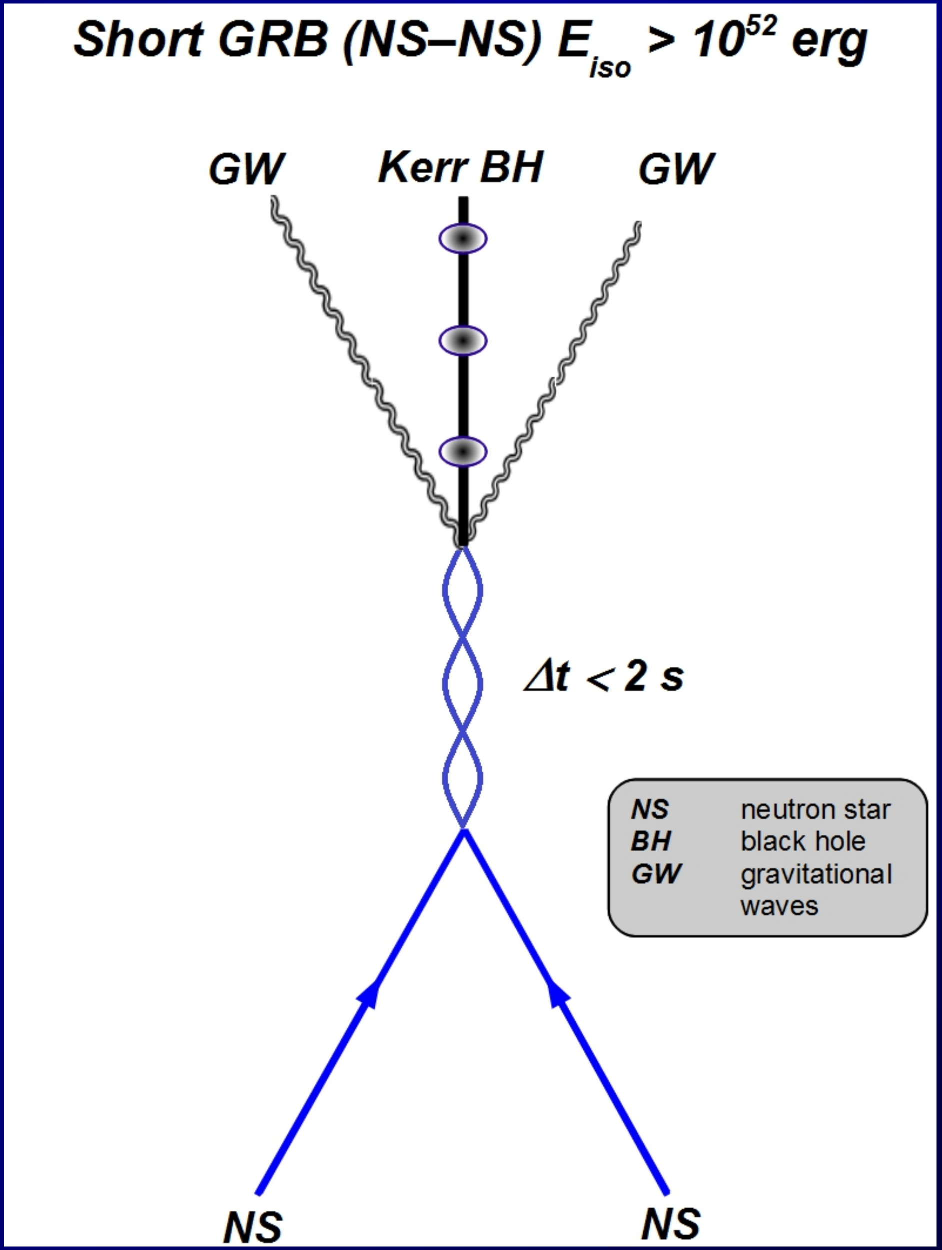
Rueda & Ruffini, ApJL (2012)
Izzo, Rueda, Ruffini, A&AL (2012)

S-Matrix vs. Cosmic Matrix

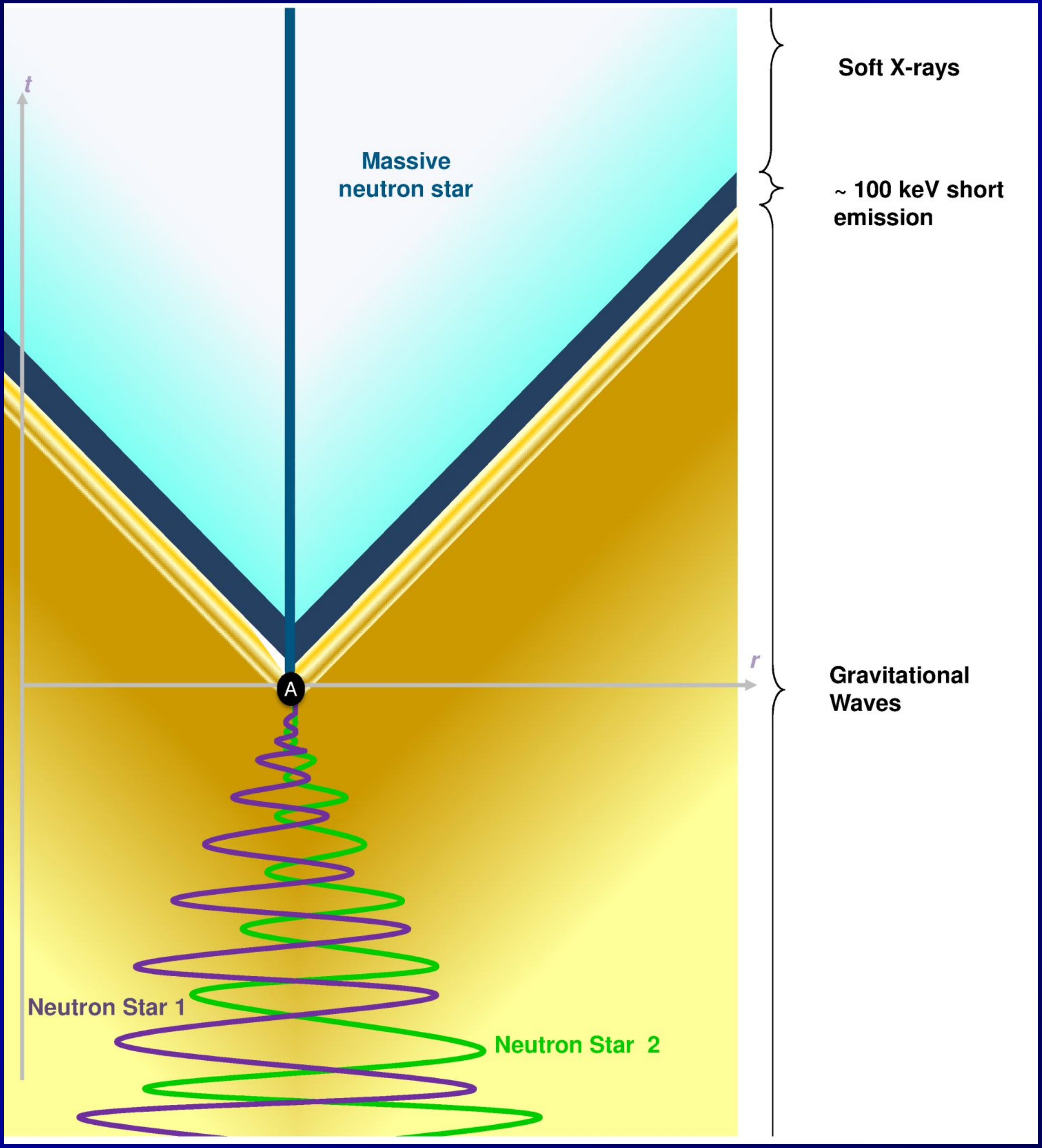


Cosmic Matrix for short GRBs



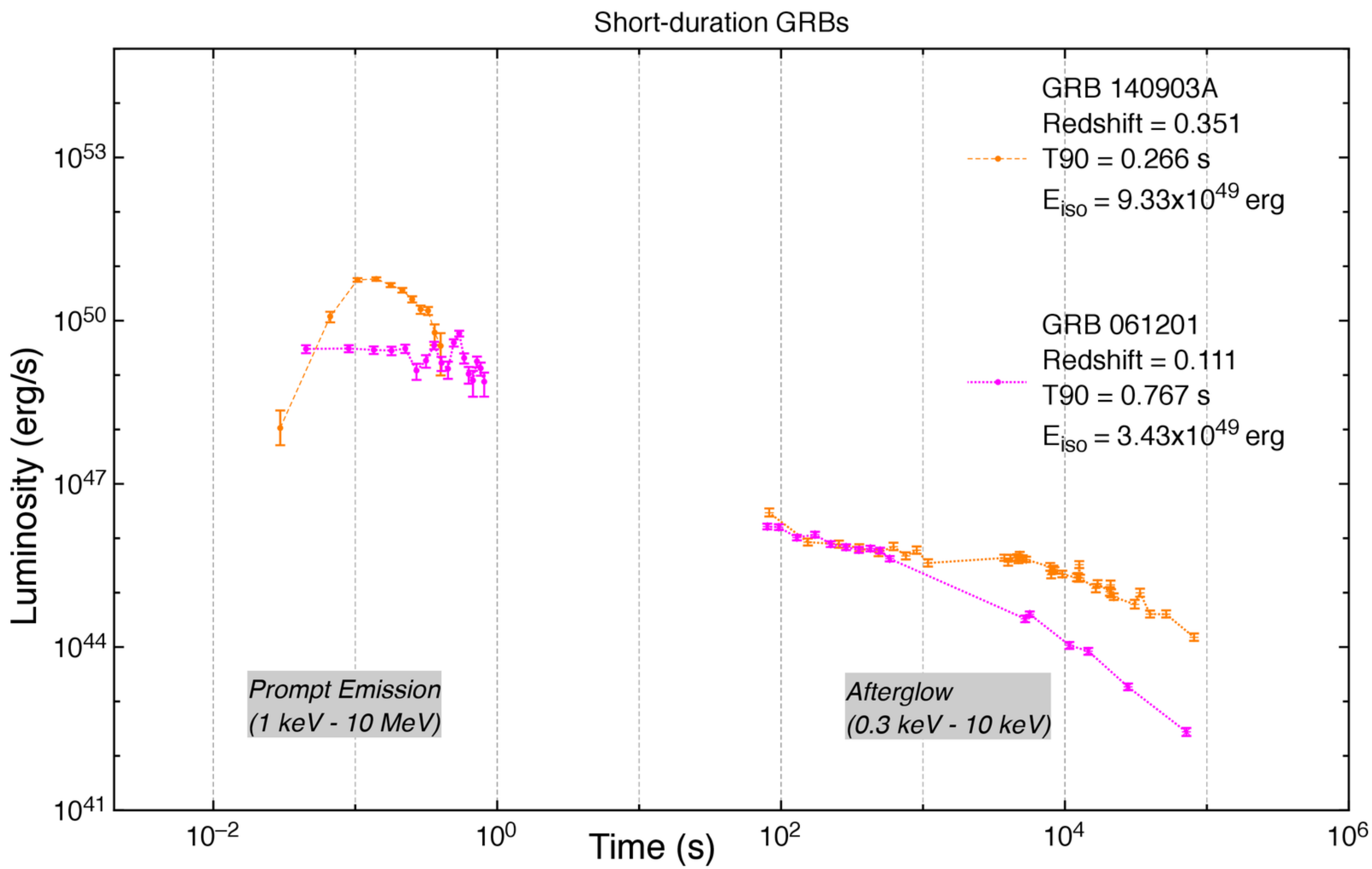


Short GRBs < 10^{52} erg



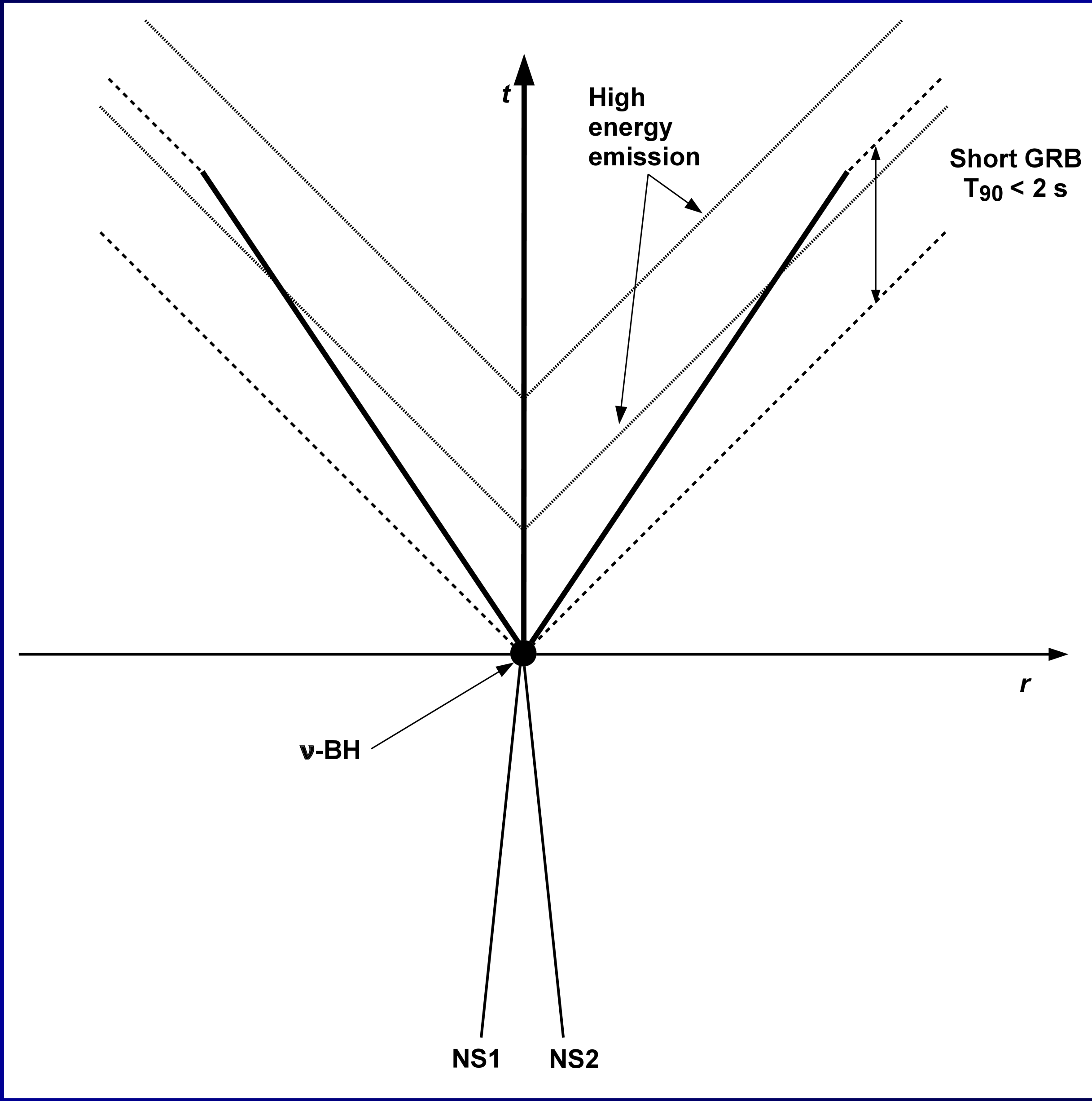
Light-curve

Short GRBs

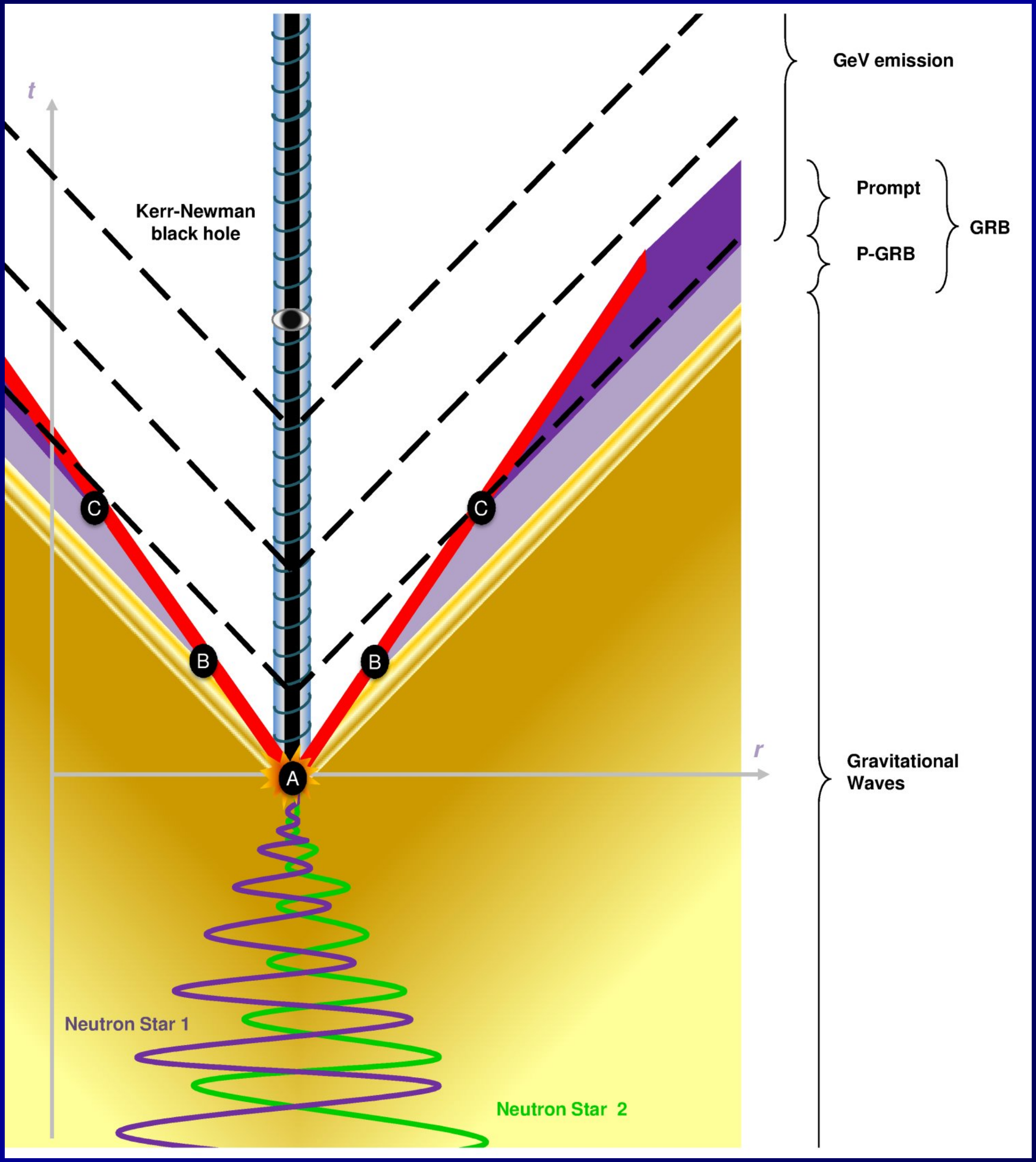


See M. Muccino's talk in session GB5-A on Thursday, July 16 and Y. Wang's talk in session GB5-B on Friday, July 17

Short GRBs > 10^{52} erg



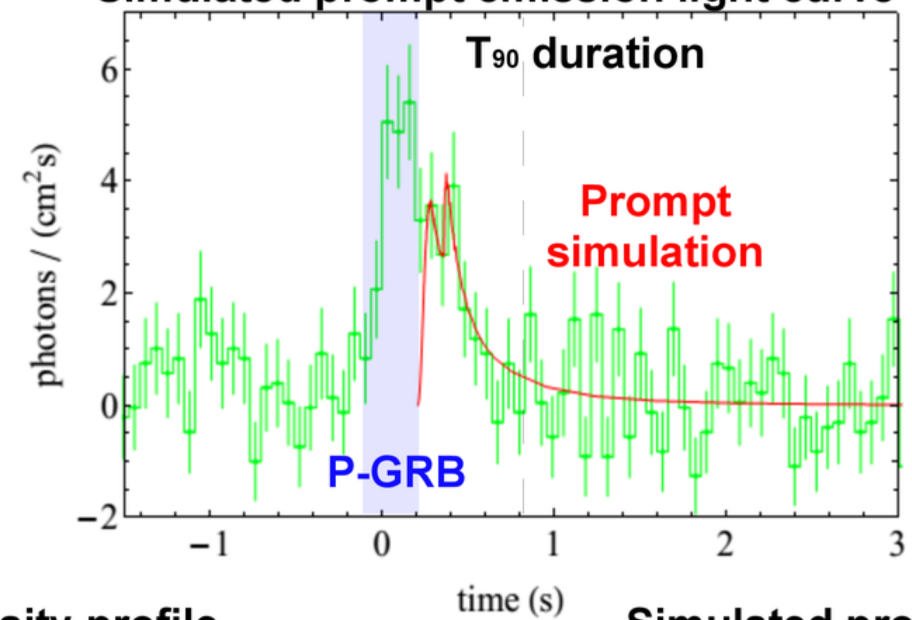
Short GRBs > 10^{52} erg



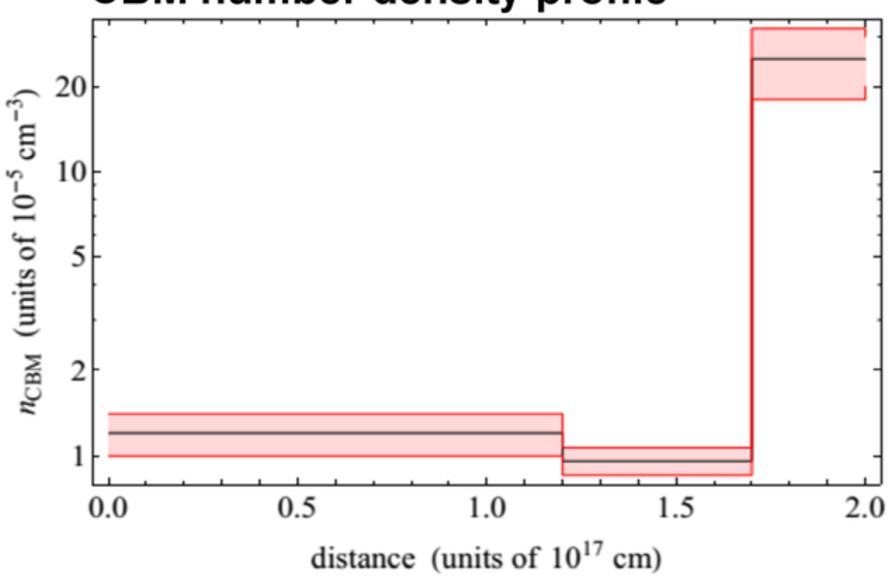
A family-2 short: the case of GRB 140619B

Ruffini, R., Muccino, M., Kovacevic, M. et al. 2015 ApJ (in press); arXiv:1412.1018

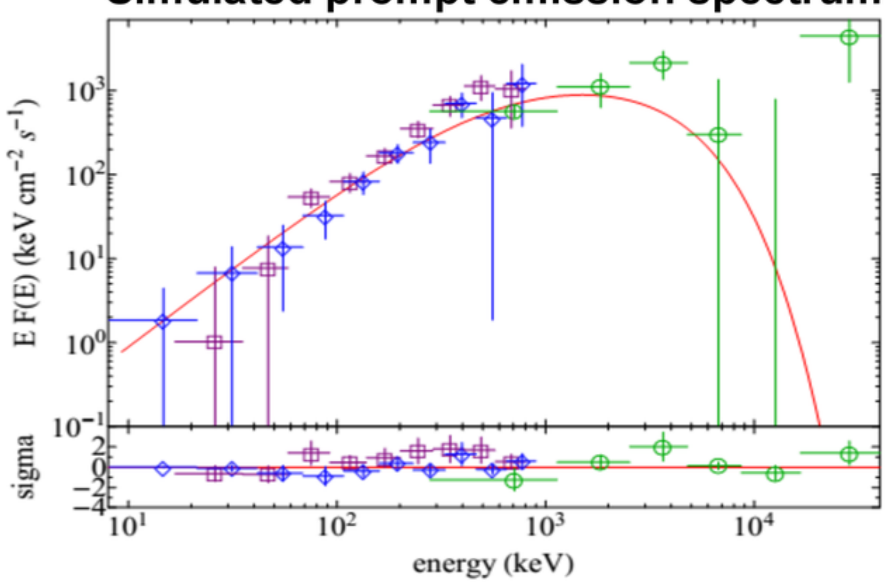
Simulated prompt emission light curve



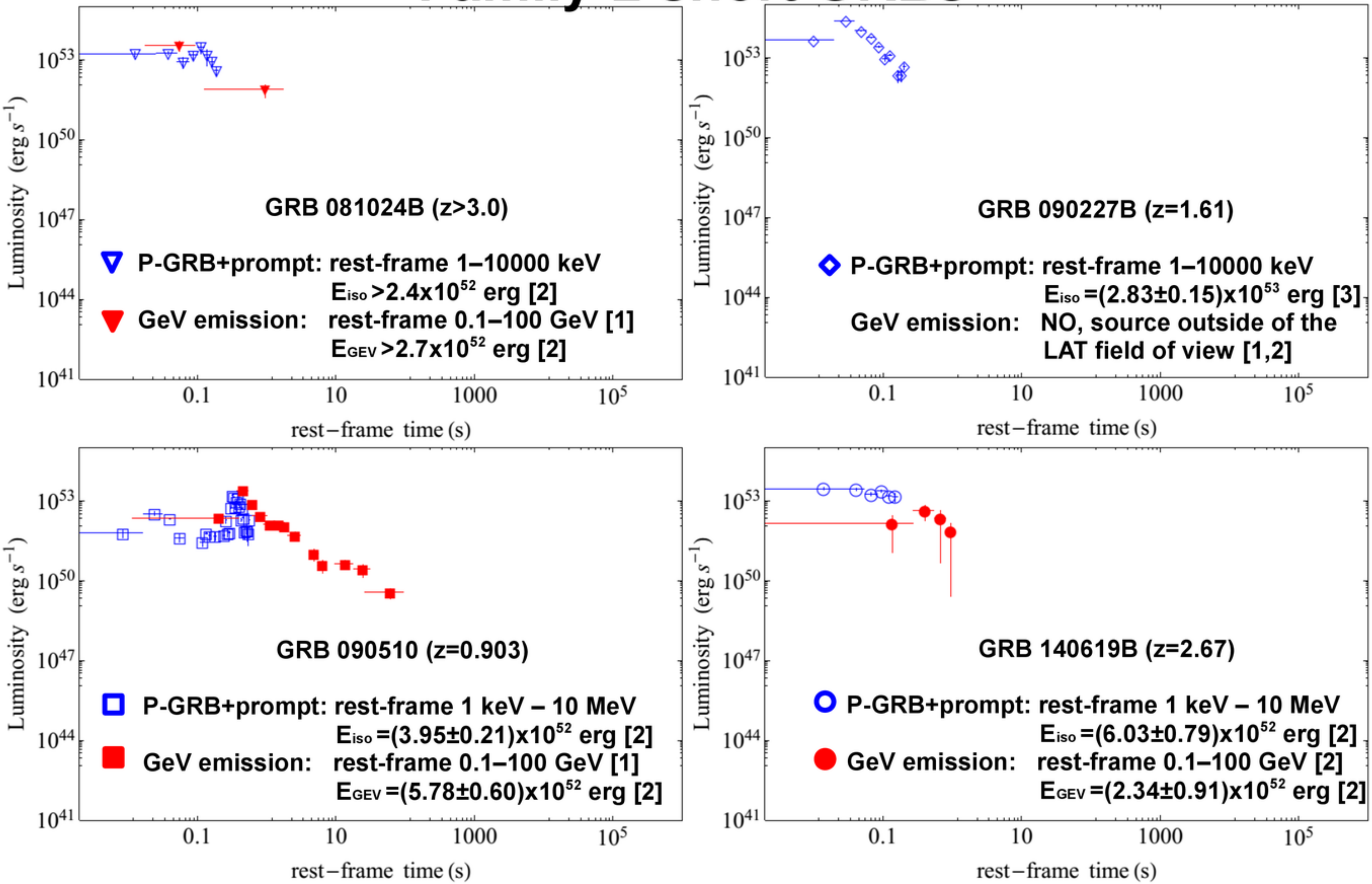
CBM number density profile



Simulated prompt emission spectrum

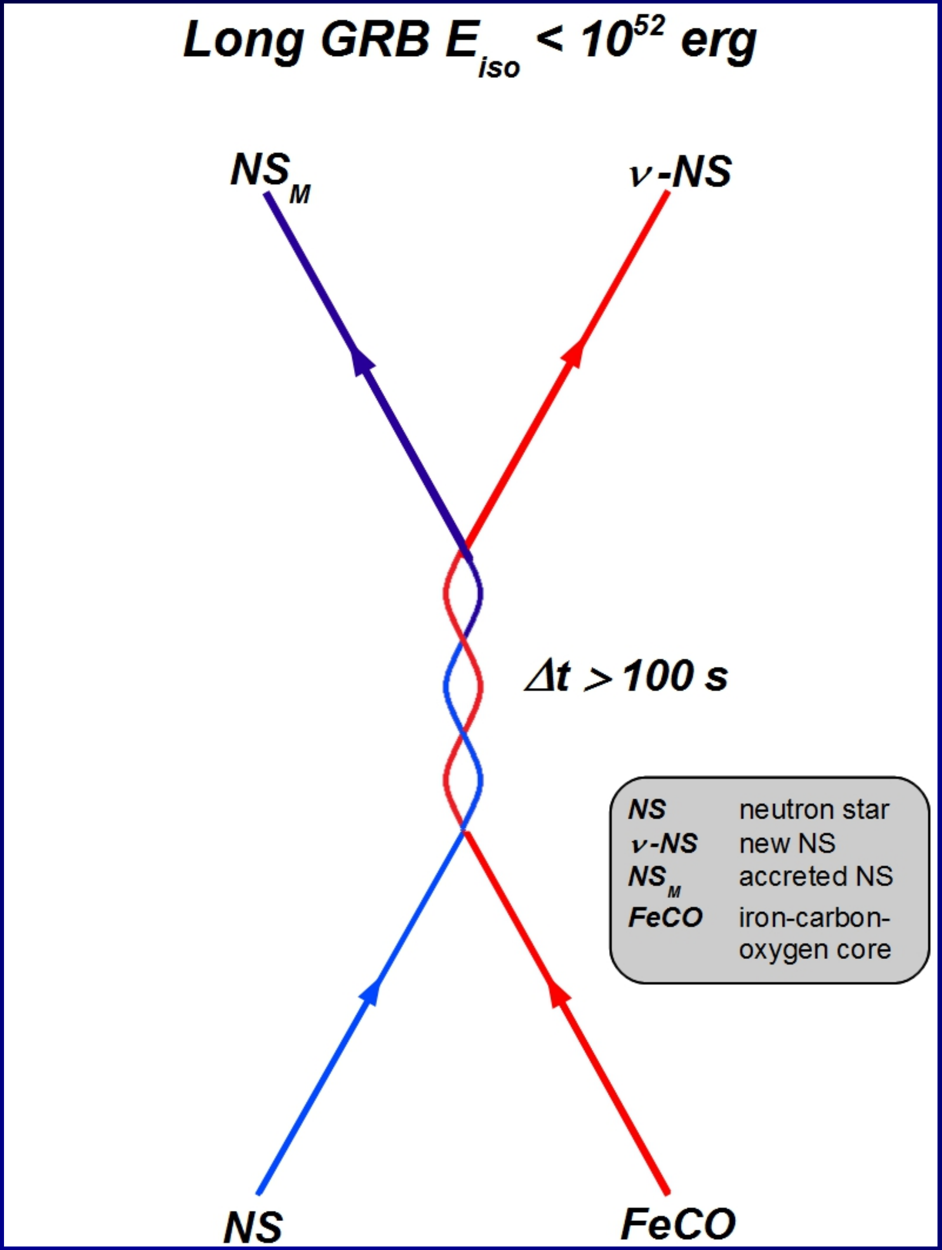


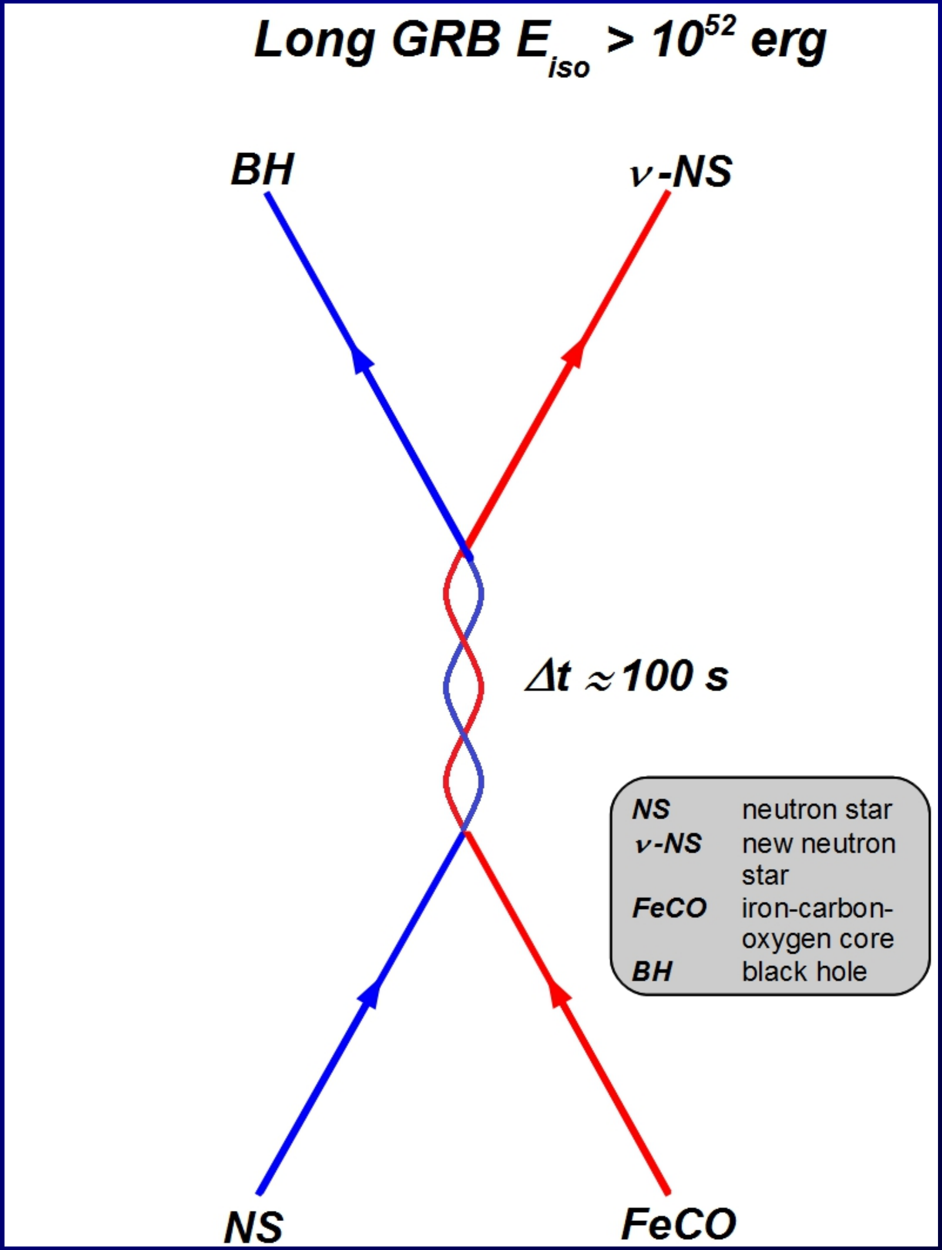
Family-2 short GRBs



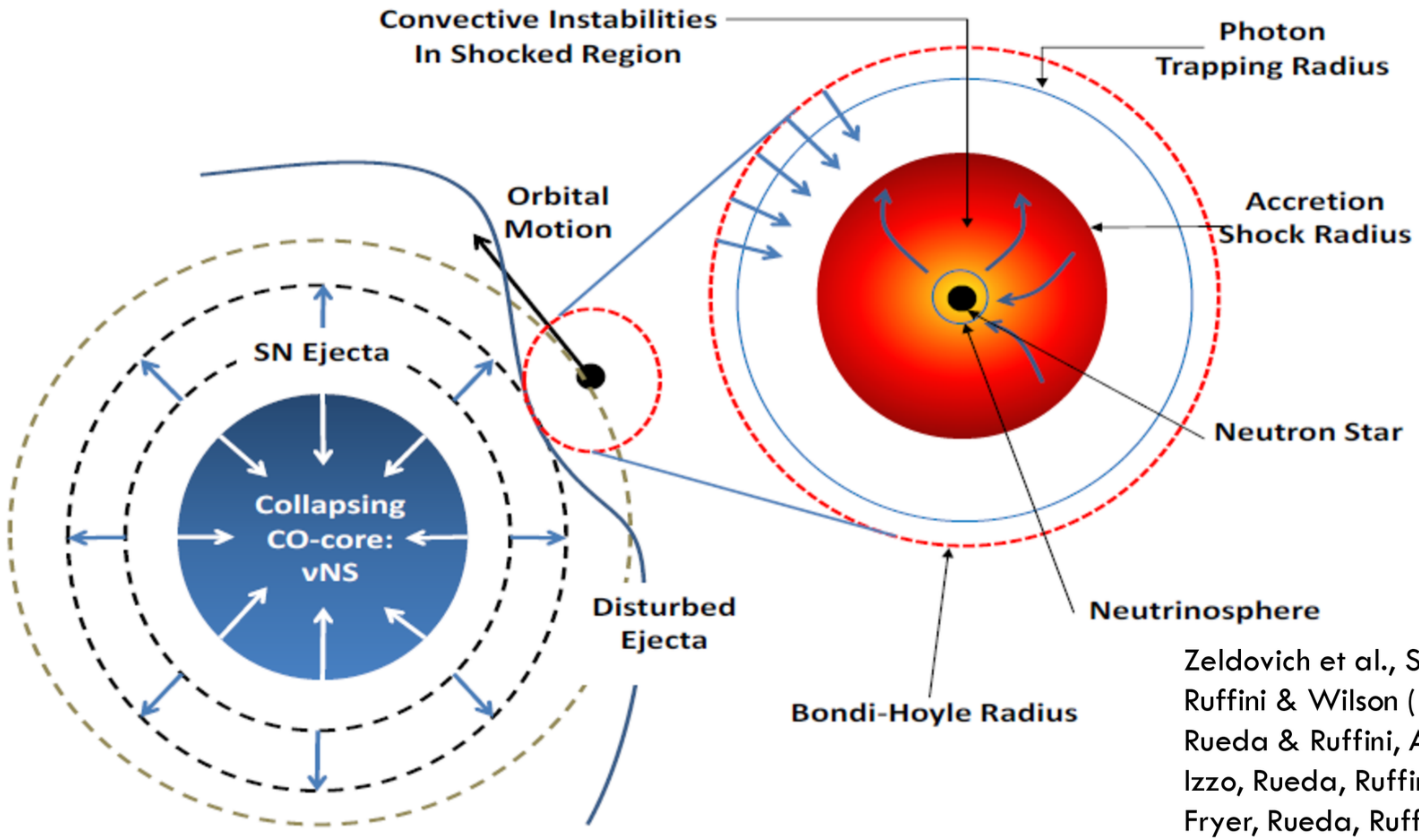
[1] Ackermann, M., Ajello, M., Asano, K., et al. 2013, ApJS, 209, 11
[2] Ruffini, R., Muccino, M., Kovacevic, M. et al. 2015 ApJ (in press); arXiv:1412.1018
[3] Muccino, M., Ruffini, R., Bianco, C. L., Izzo, L., & Penacchioni, A. V. 2013, ApJ, 763, 125.

Cosmic Matrix for long GRBs





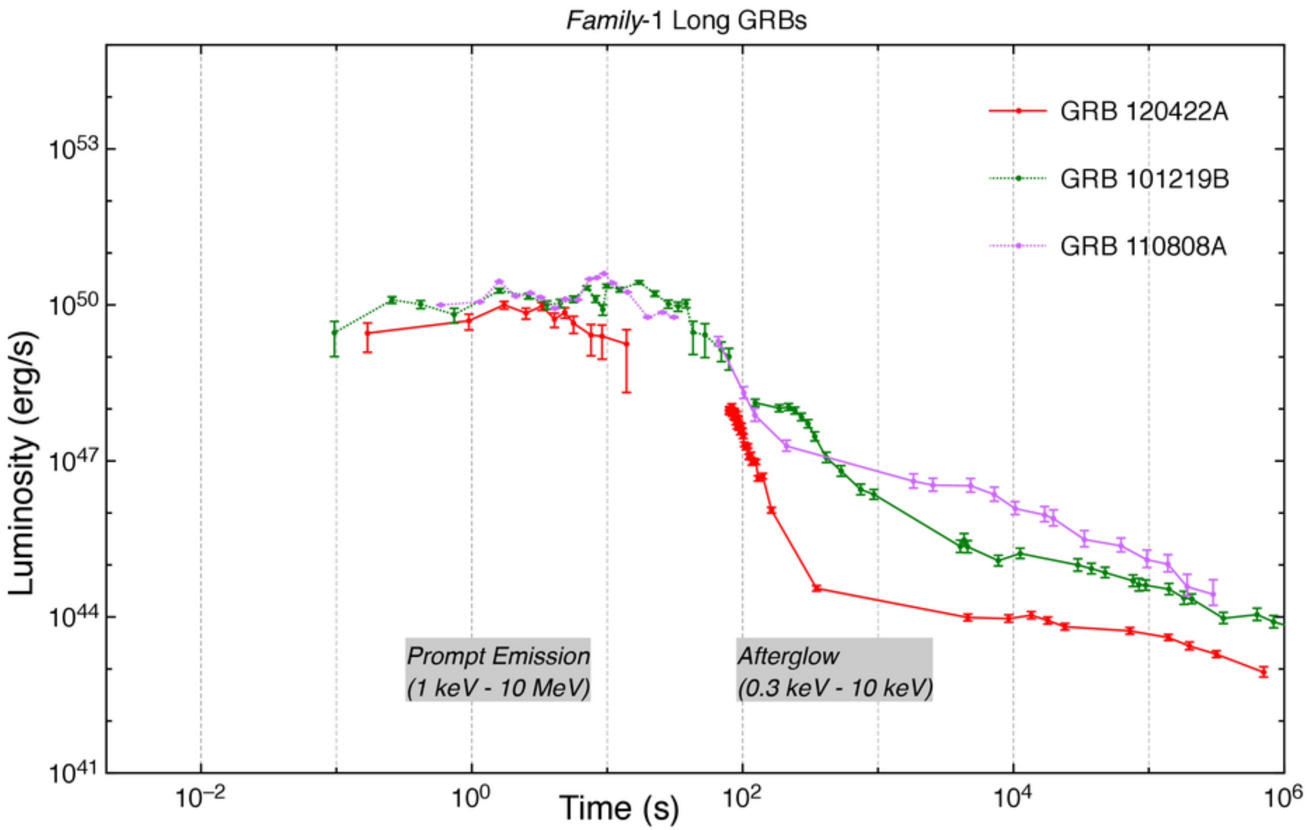
Hypercritical Accretion, Binary-Driven HNe, and IGC



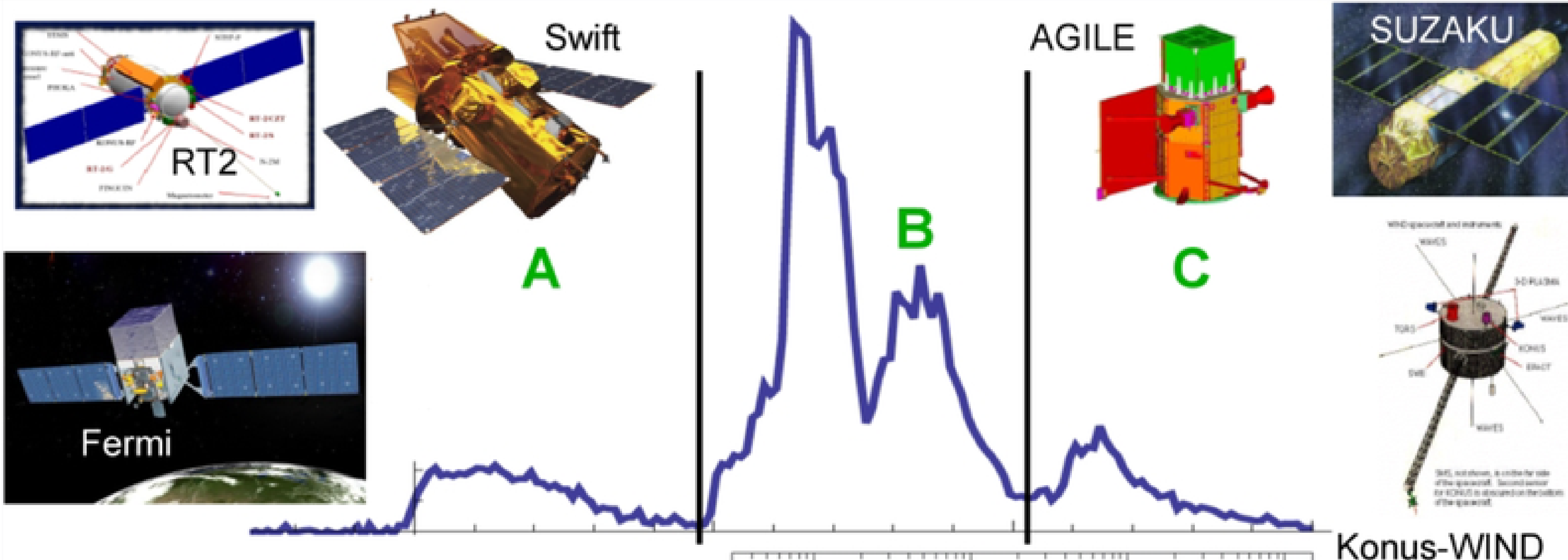
Zeldovich et al., Sov. Astron. (1972)
Ruffini & Wilson (1973)
Rueda & Ruffini, ApJL (2012)
Izzo, Rueda, Ruffini, A&AL (2012)
Fryer, Rueda, Ruffini, ApJL (2014)

Light-curve

Family-1 Long GRBs



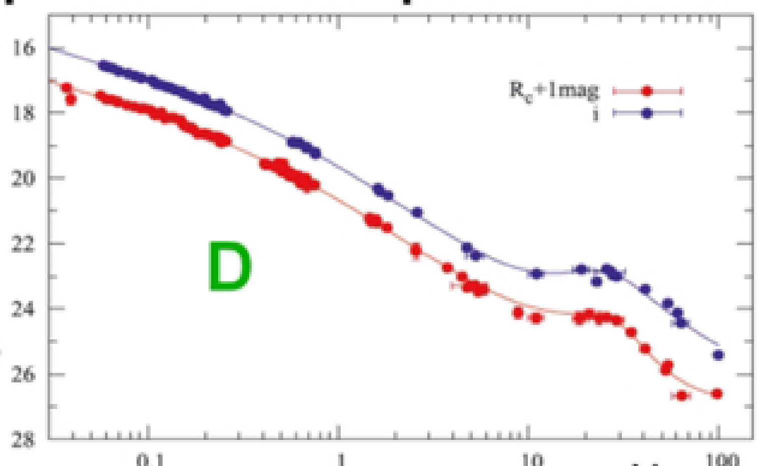
See Y. Wang's talk in session GB5-B on Friday, July 17



GRB 090618

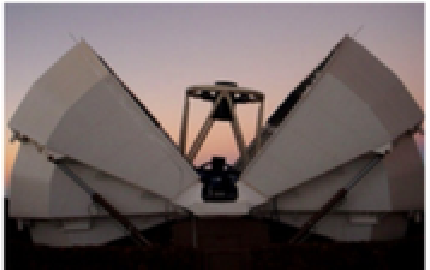
$E_{iso}=2.8\times10^{53}$ erg

Z=0.54



Ruffini et al. *PoS(Texas2010)*, 101 (2011)
Izzo et al., *A&A*, 543, A10 (2012)

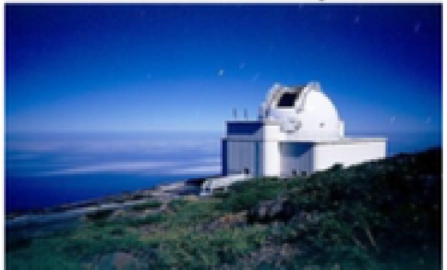
Faulkes North



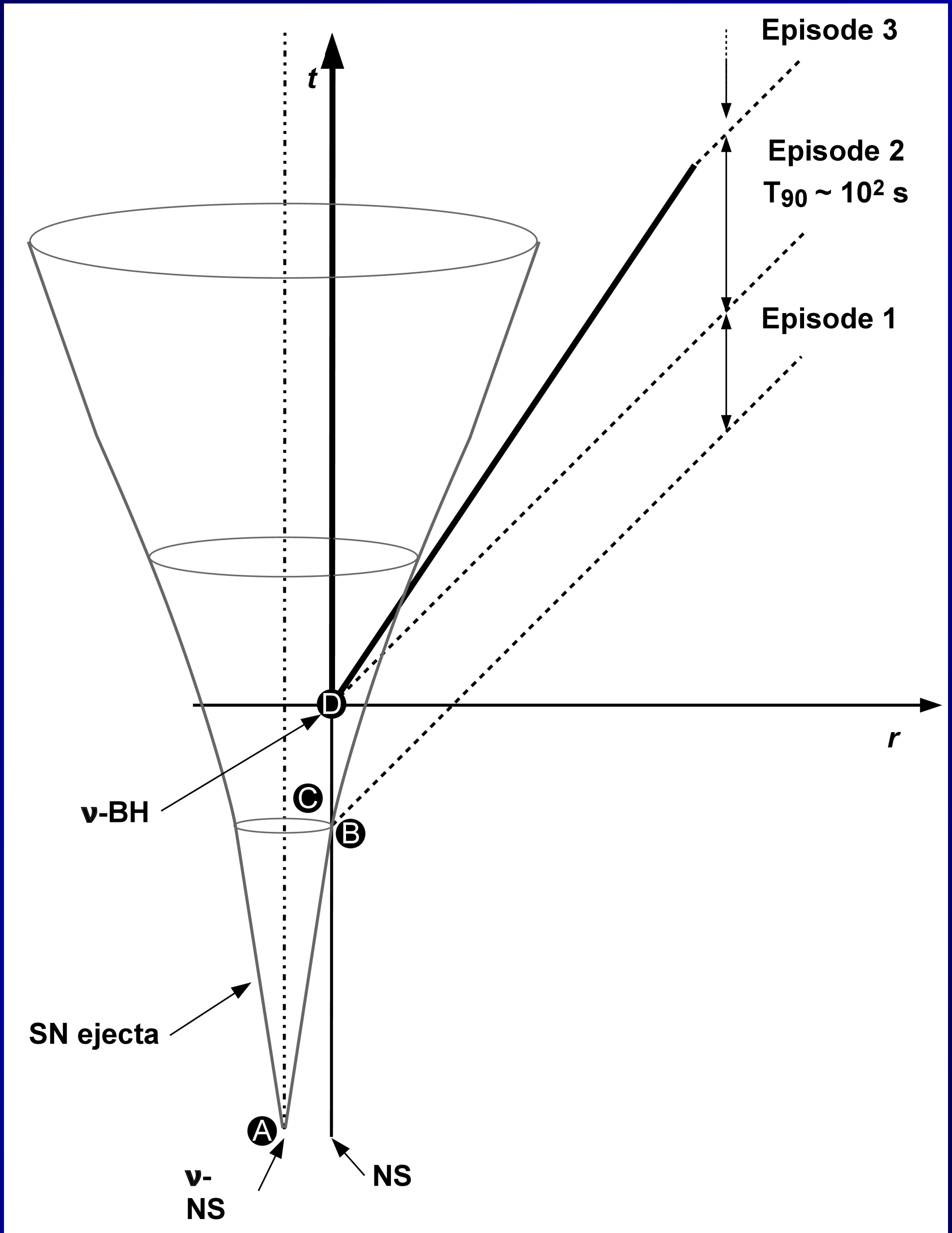
Gemini North

Herschel telescope

Newton telescope



Long GRBs > 10^{52} erg



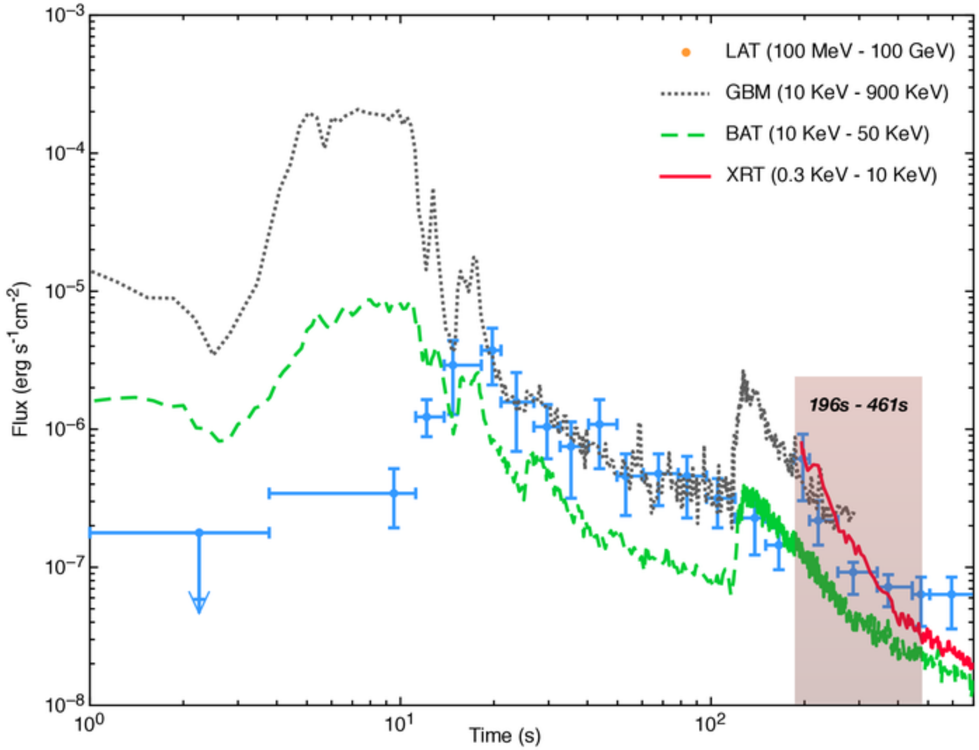
Episode-3
Thermal Emission

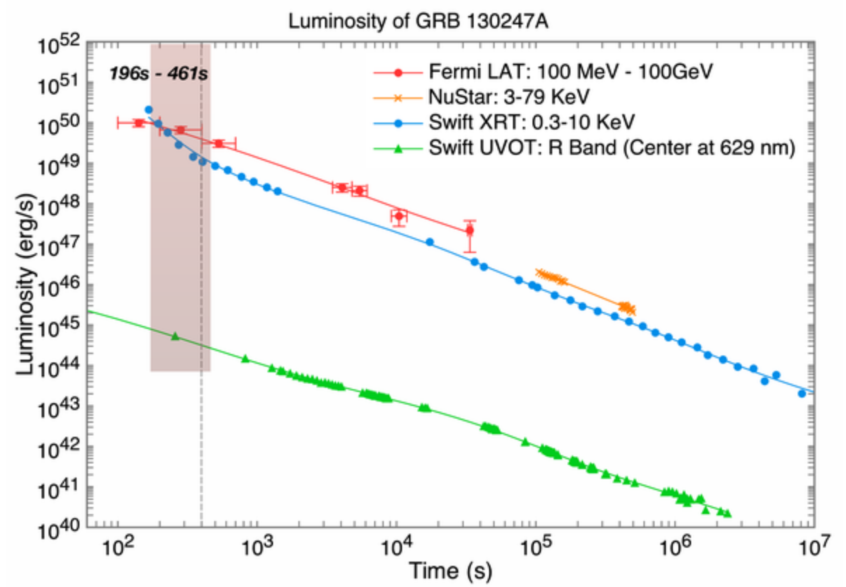
GRB 130427A

Light curve

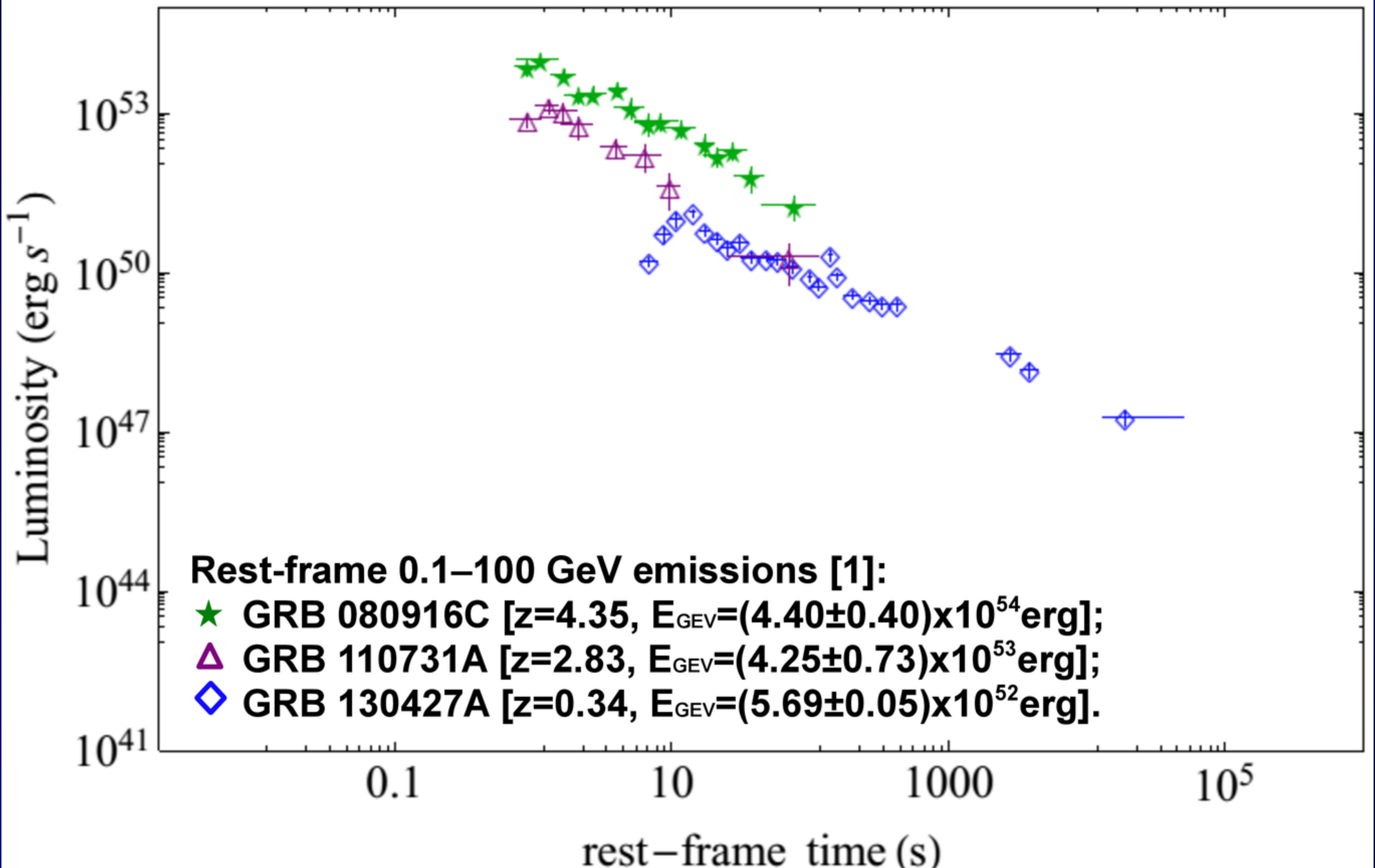
Isotropic Energy: 1e54 erg
Redshift: 0.34
Temperature: 0.3 keV
Radius: 1.7e13 cm

Ruffini, Wang, Enderli et al. 2015, ApJ, 798, 10



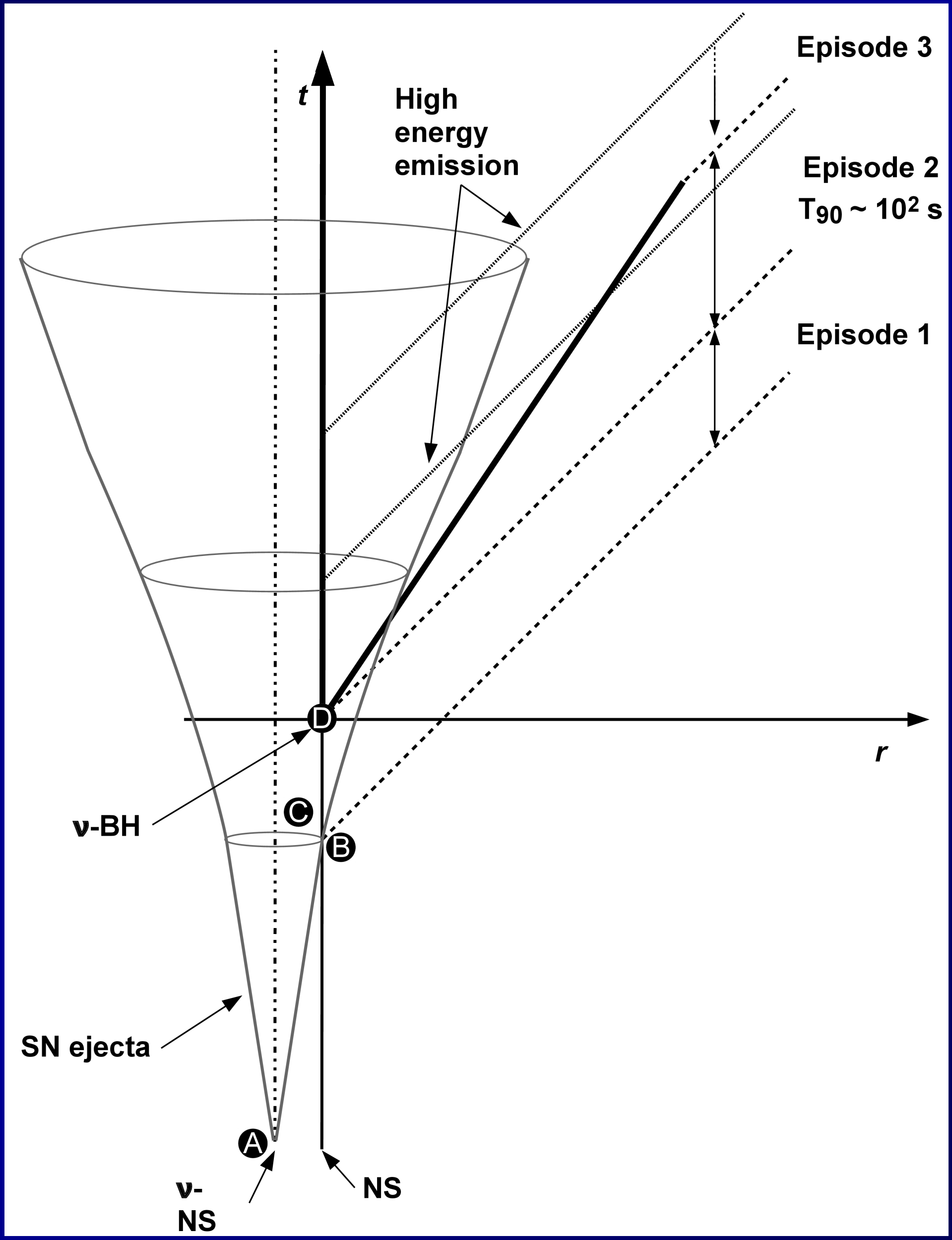


Family-2 long GRBs: GeV emission

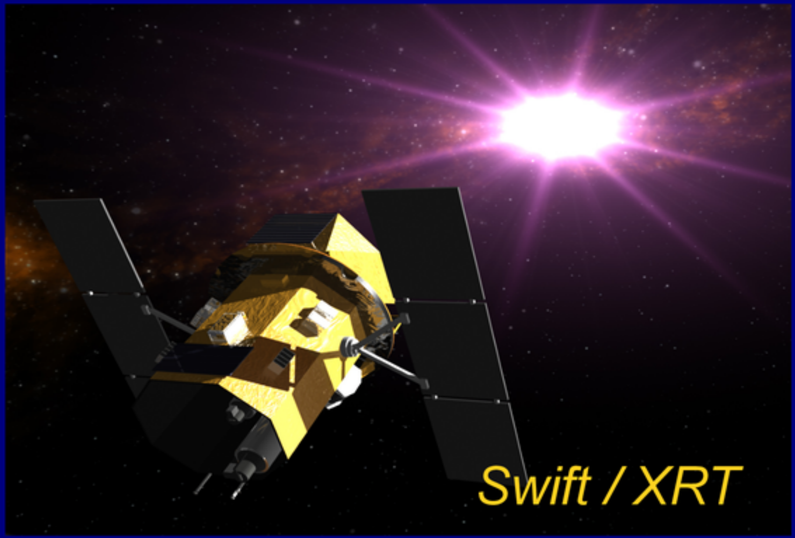


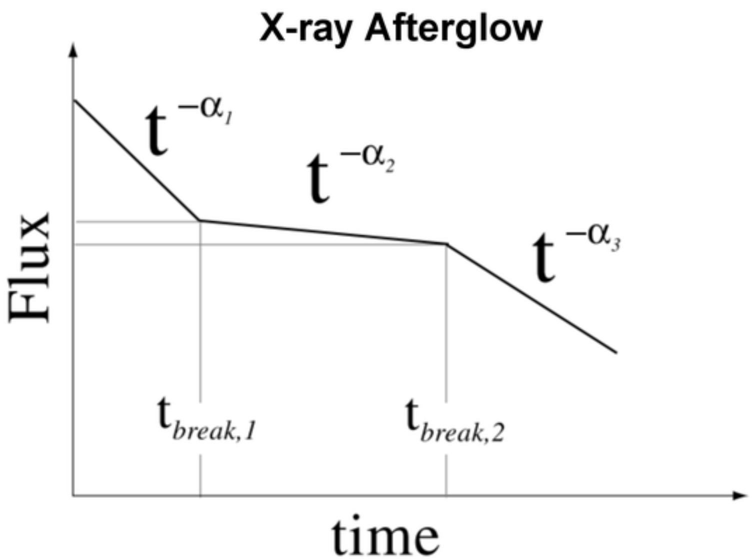
[1] Ackermann, M., Ajello, M., Asano, K., et al. 2013, ApJS, 209, 11

Long GRBs > 10^{52} erg

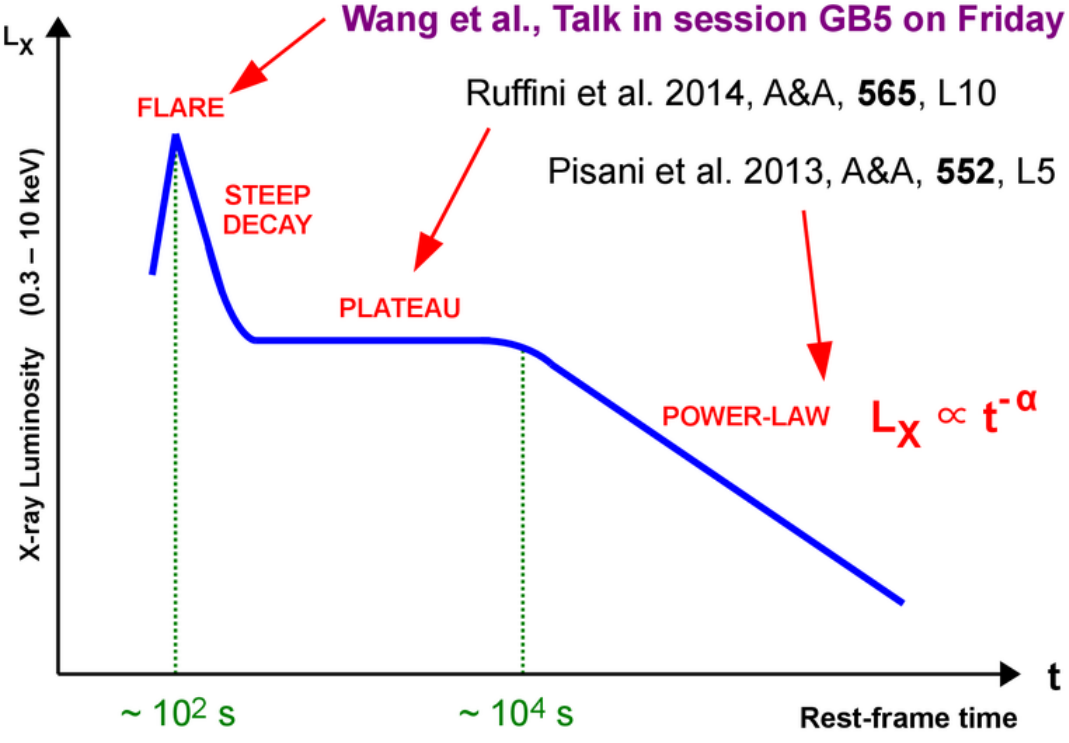


The Episode 3 of Binary-driven Hypernovae

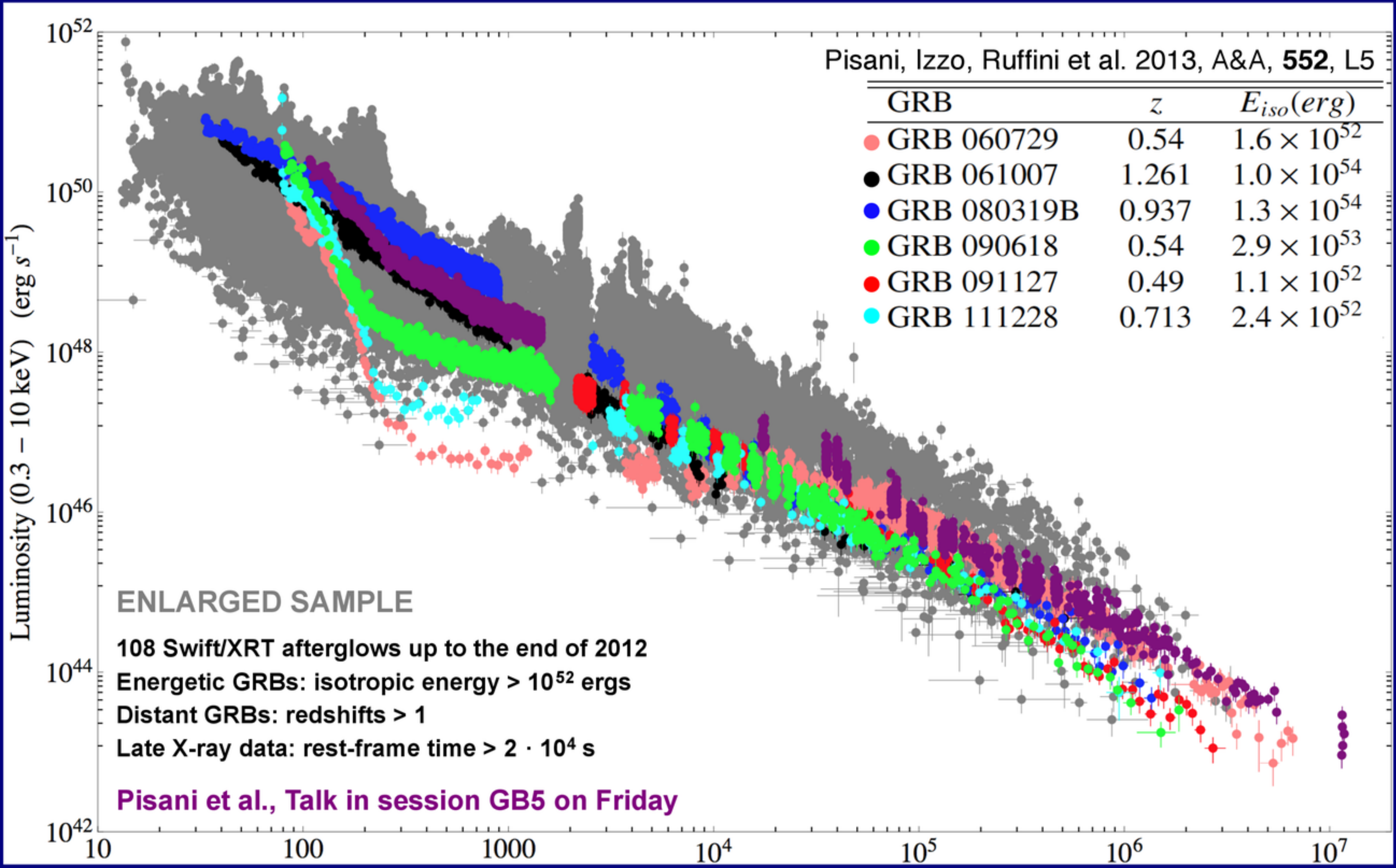




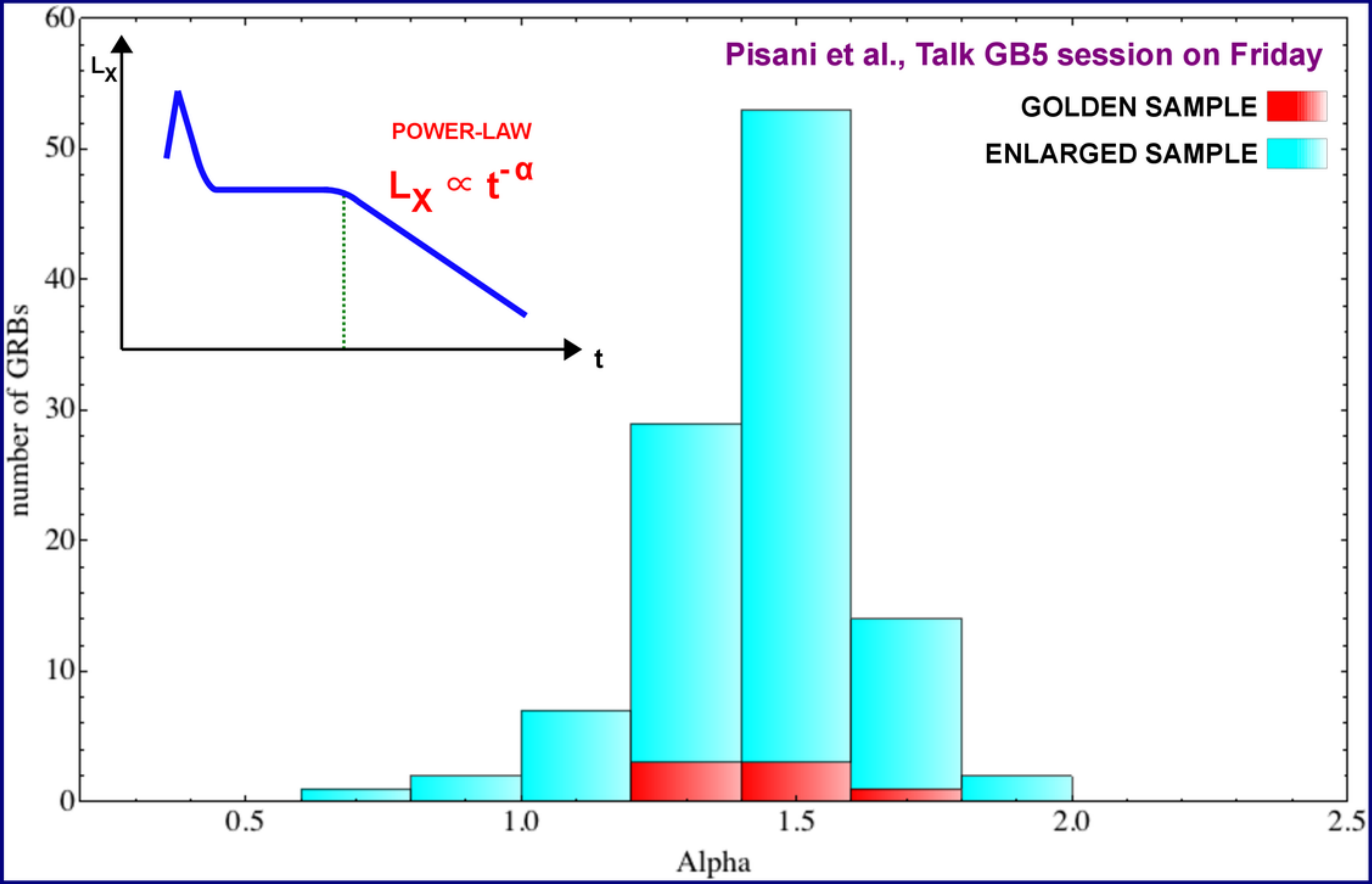
Nousek, Kouveliotou, Grupe et al. 2006, ApJ, **642**, 389



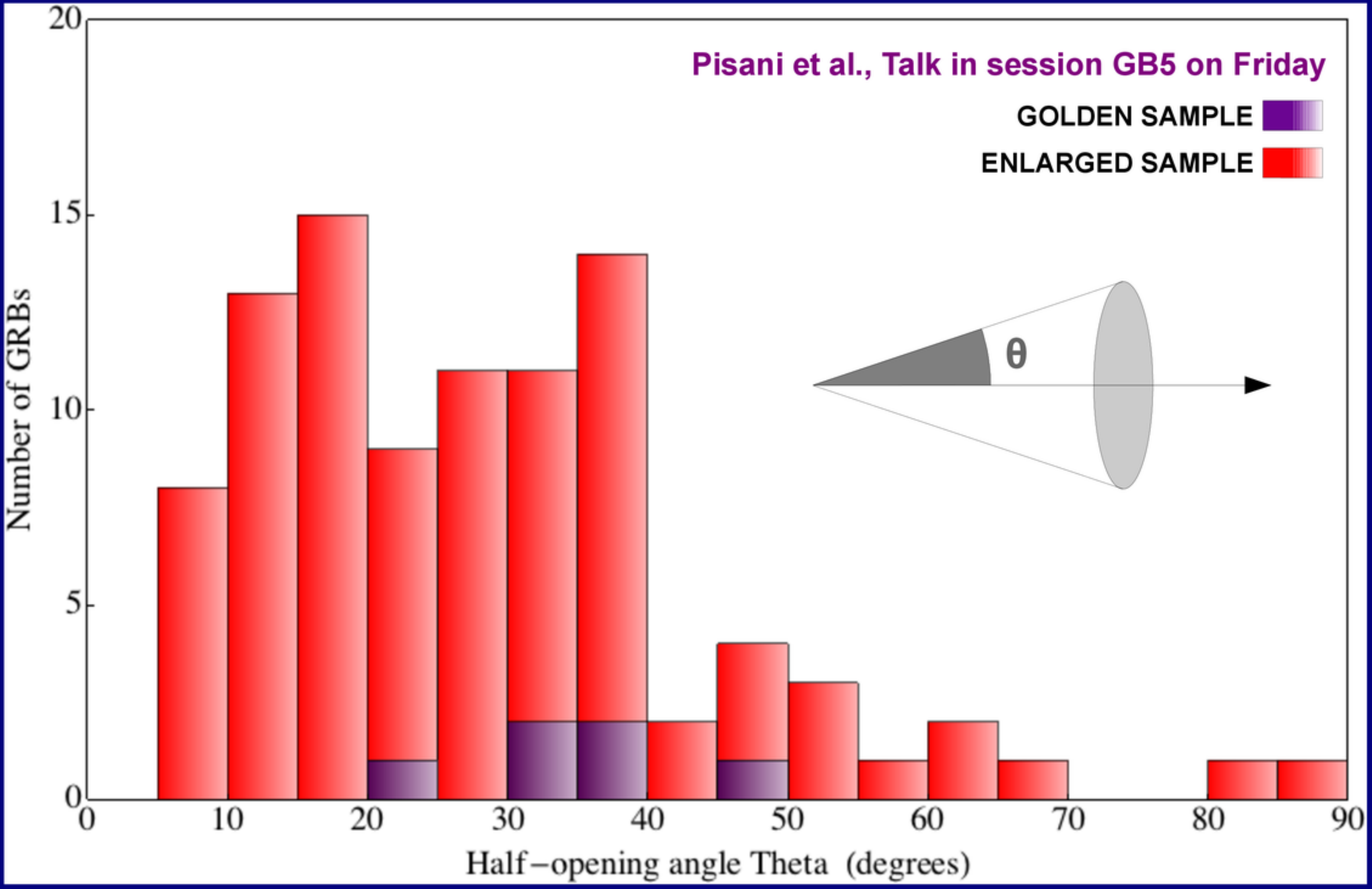
Episode 3 : High Redshifts



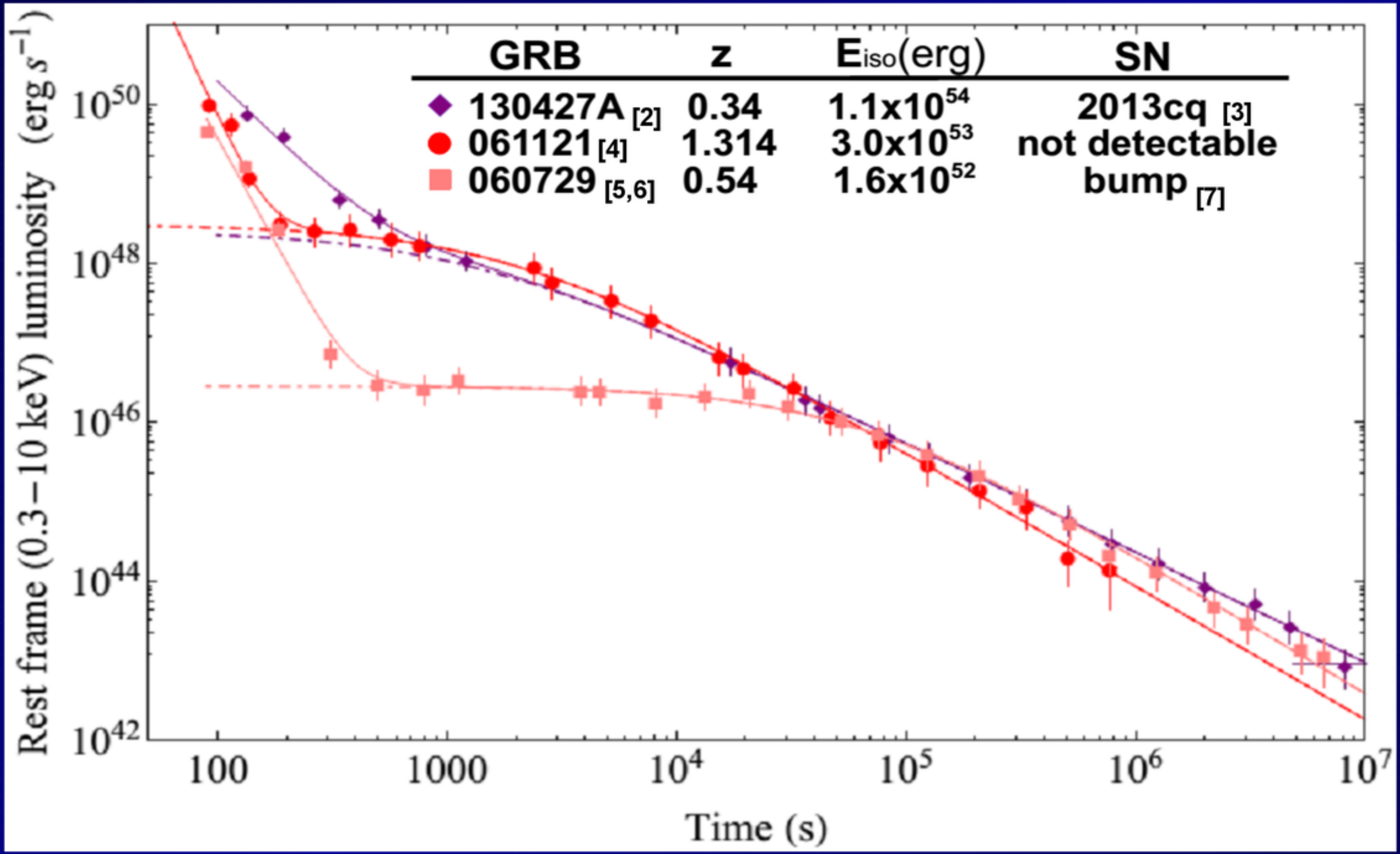
Episode 3 : Slopes of the late time Power-laws



Episode 3 : Beaming



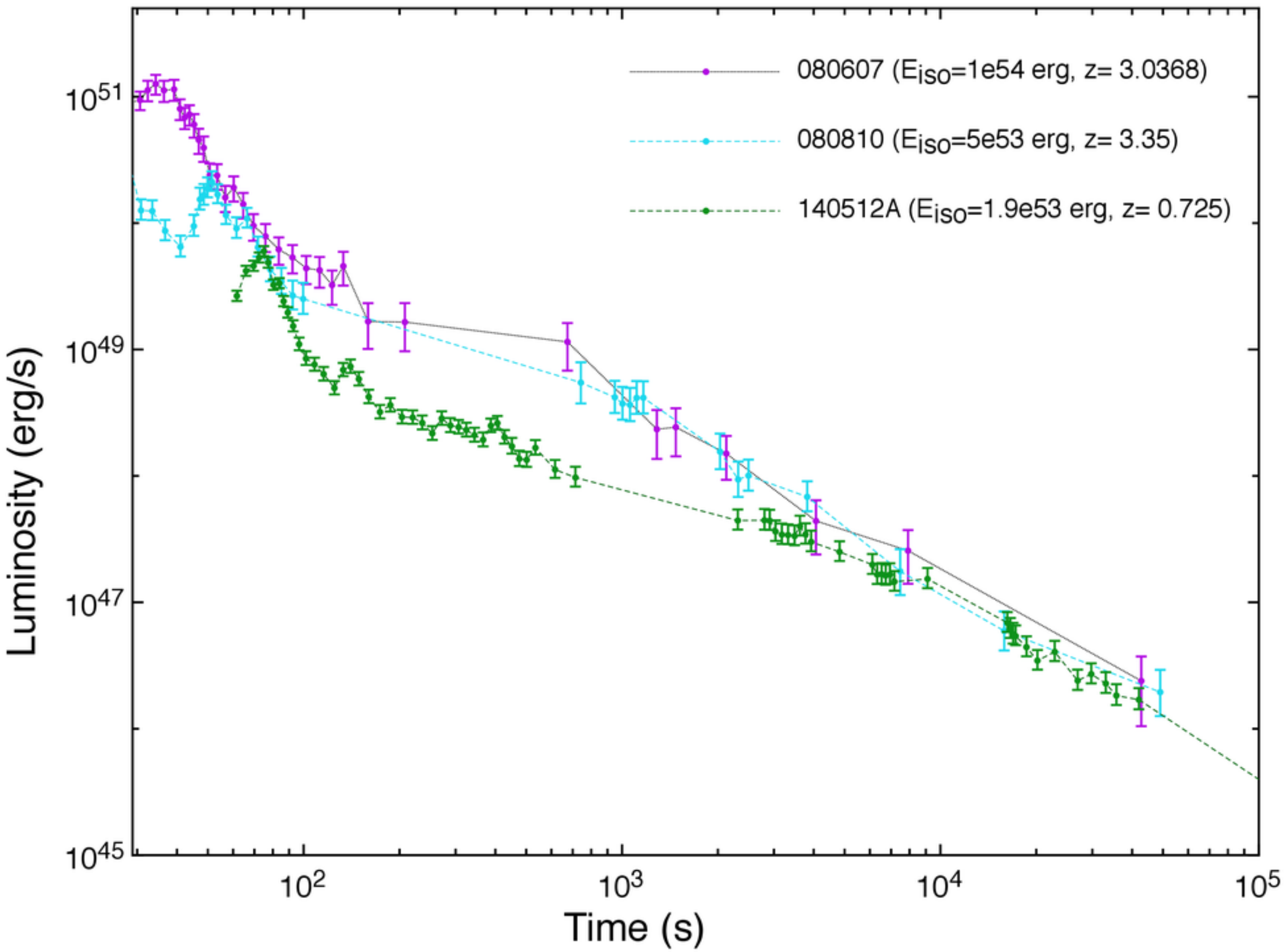
Episode 3 : Nested Structure



[1] Ruffini, R., Muccino, M., Bianco, C. L., et al. 2014, A&A, 565, L10
[2] Ruffini, R., Wang, Y., Kovacevic, M., et al. 2014, ArXiv e-prints
[3] Xu, D., de Ugarte Postigo, A., Leloudas, G., et al. 2013, ApJ, 776, 98
[4] Bloom, J. S., Perley, D. A., & Chen, H. W. 2006, 5826, 1
[5] Pisani, G. B., Izzo, L., Ruffini, R., et al. 2013, A&A, 552, L5
[6] Grupe, D., Gronwall, C., Wang, X.-Y., et al. 2007, ApJ, 662, 443
[7] Cano, Z., Bersier, D., Guidorzi, C., et al. 2011, MNRAS, 413, 669

3 Flares

Wang et al. Talk in session GB5 on Friday

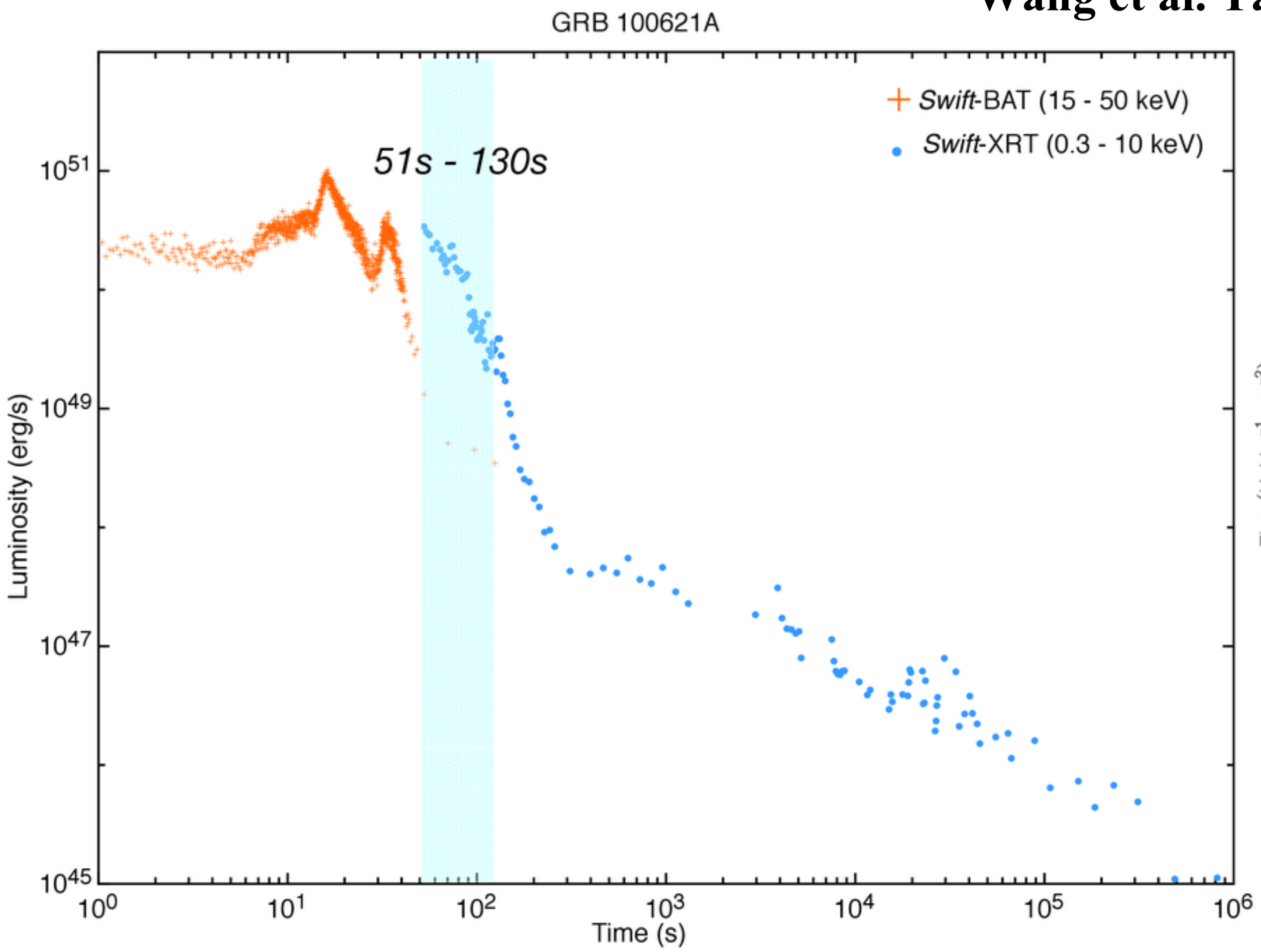


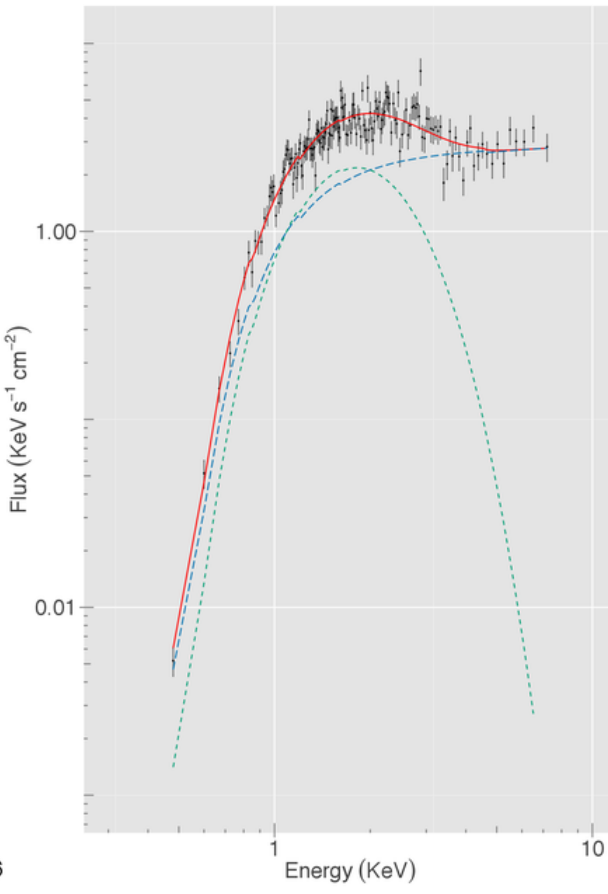
Episode-3
Thermal Emission

GRB 100621A

Isotropic Energy: 2.8e52 erg
Redshift: 0.542
Temperature: 0.39 keV
Radius: 5.13e12 cm

Wang et al. Talk in session GB5 on Friday

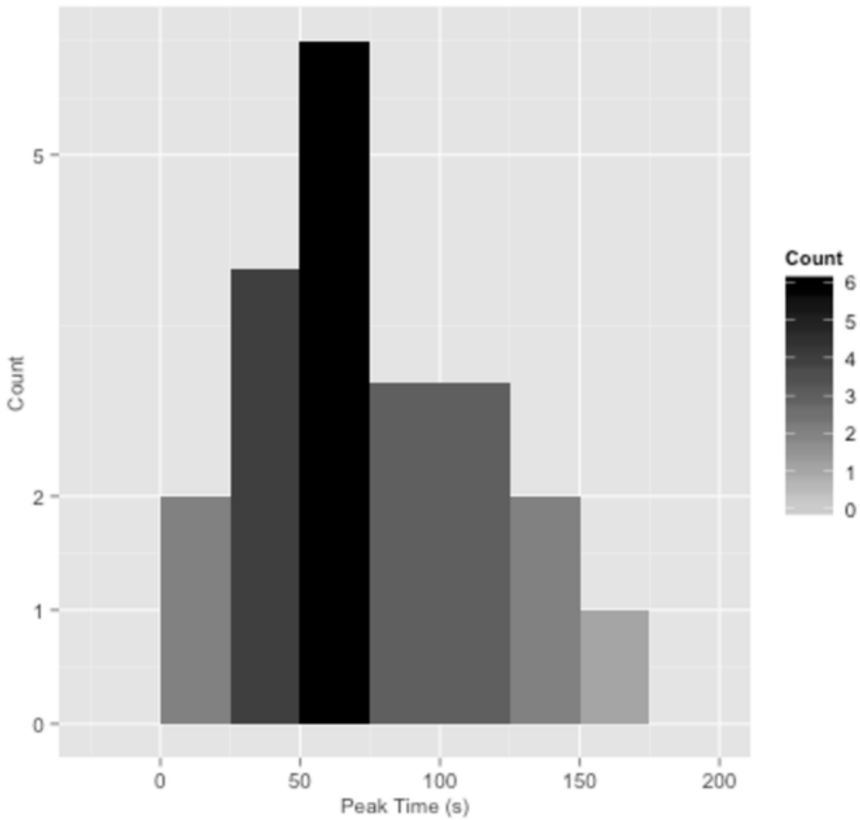


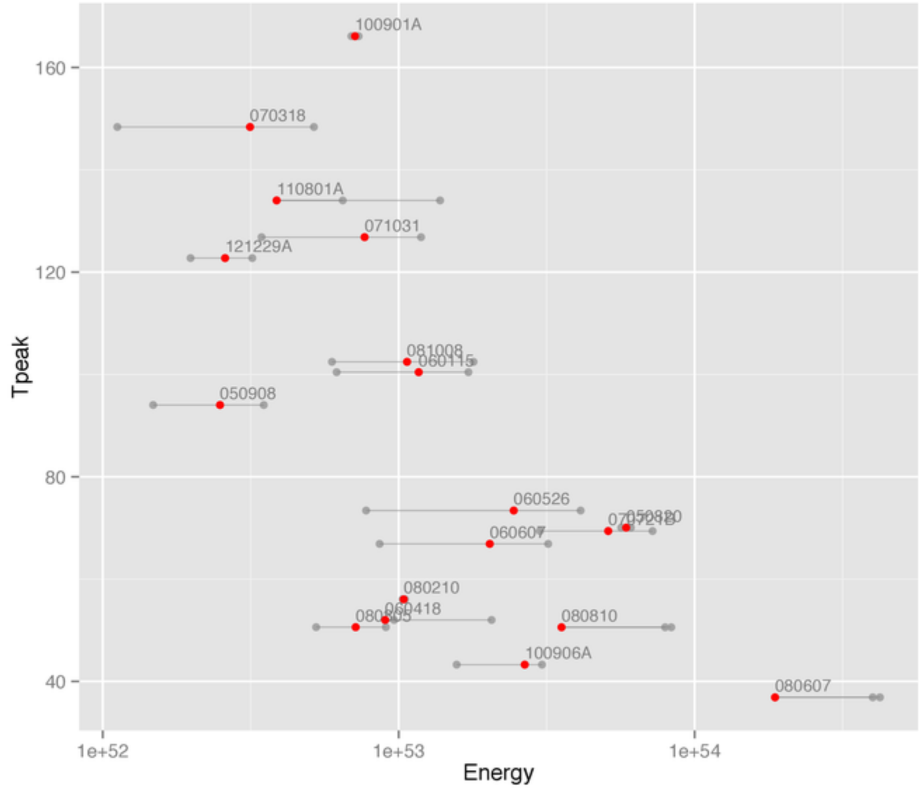


X-ray Flare

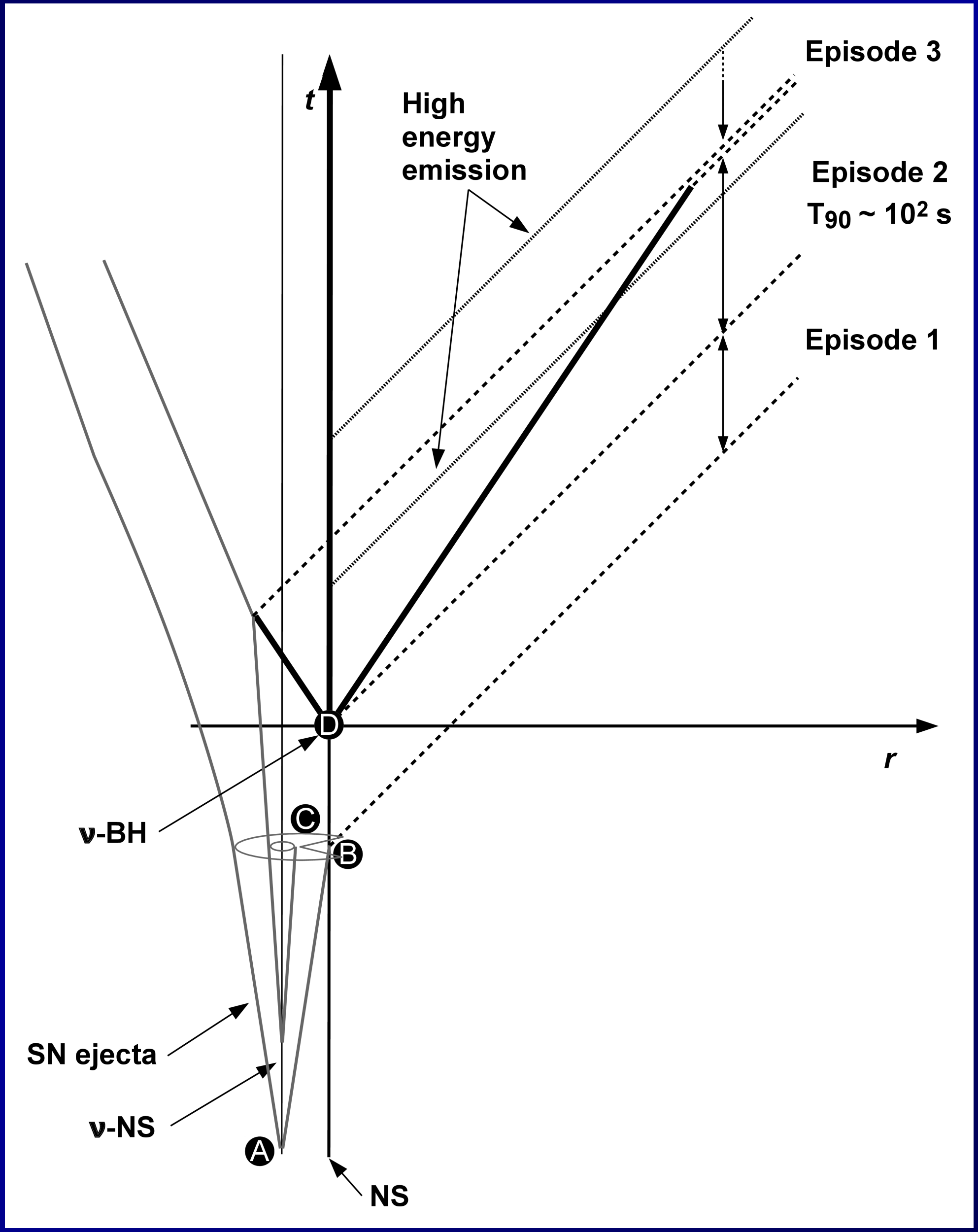
Peak Time

Wang et al. Talk in session GB5 on Friday

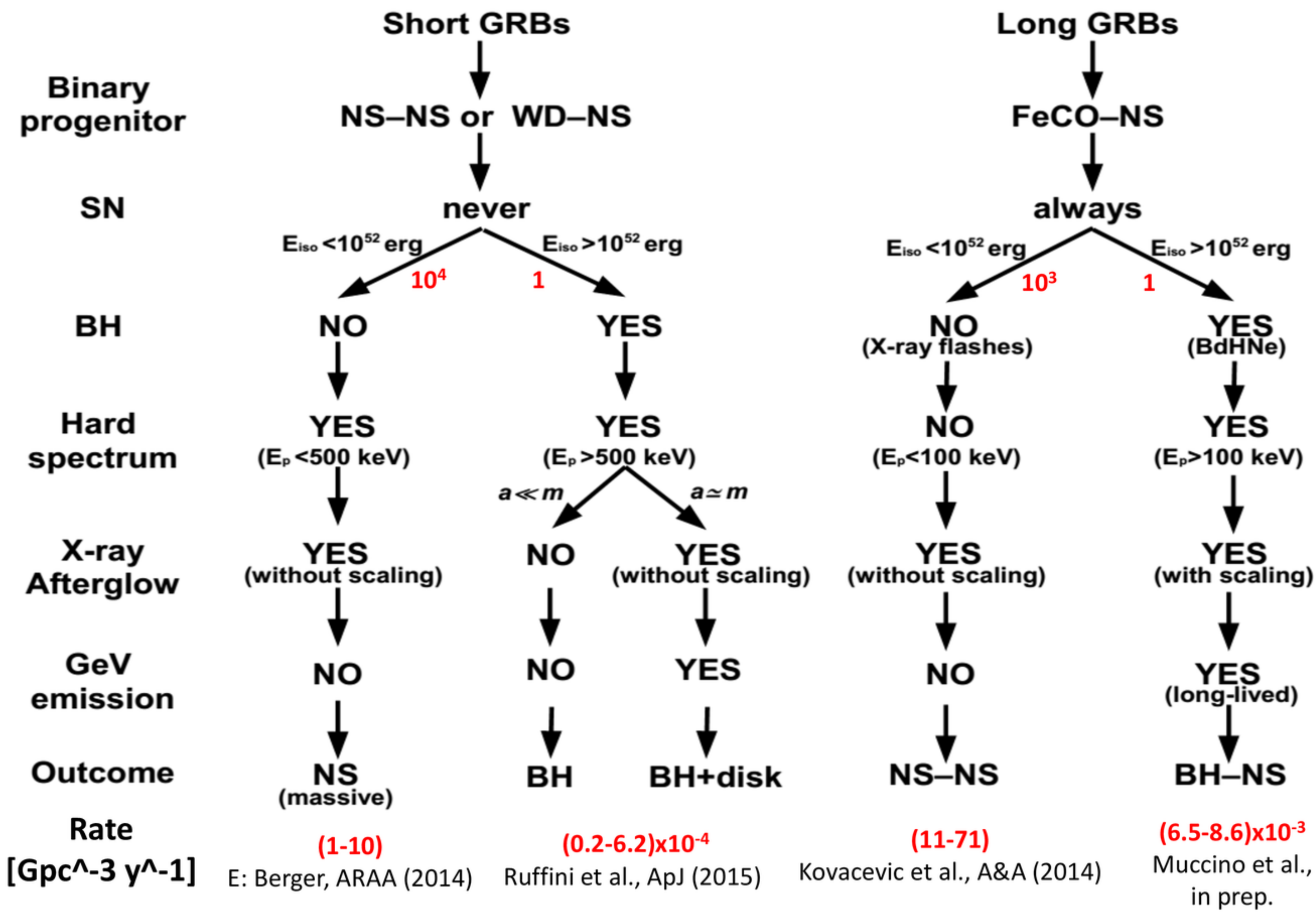




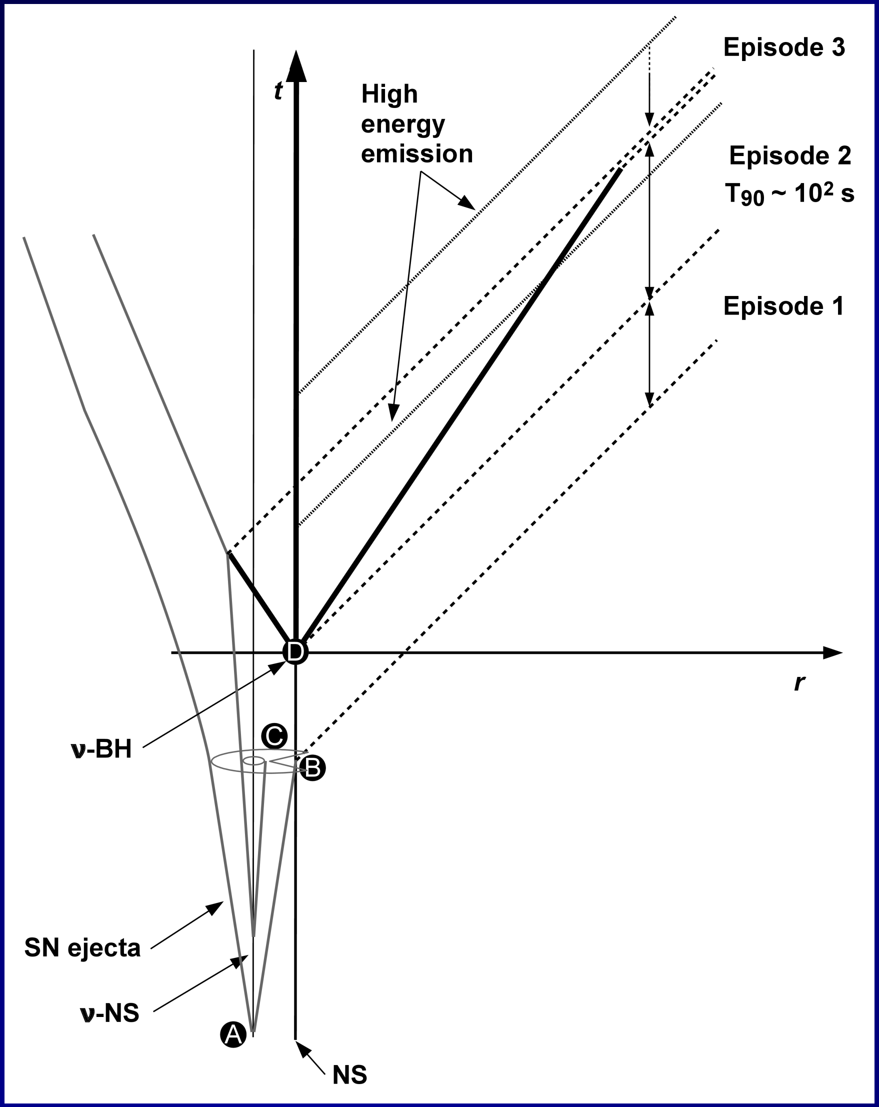
Long GRBs > 10^{52} erg

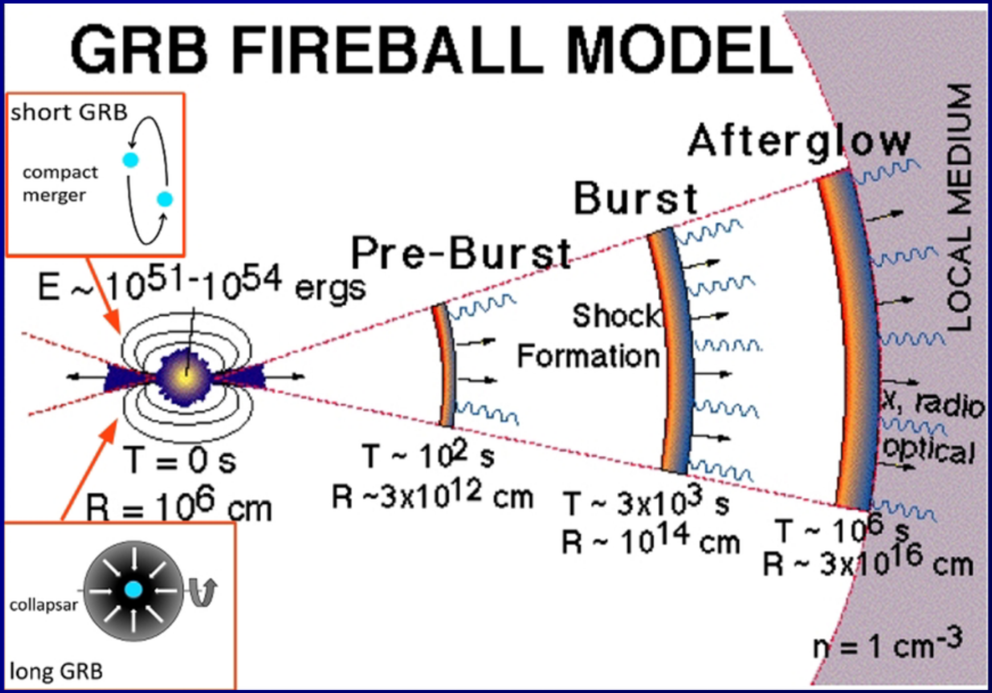


All GRBs are composite and originate from binary systems



Fireshell vs. Fireball





Conclusions on the GRBs

The traditional approach of considering a GRB as a single astrophysical process describable by a time integrated description was initially justified in view of its short duration estimated in a few seconds. With the increase of informations in the spectral distribution and time evolution obtained from the most powerful telescopes on earth (KECK, VLT, Gemini, Faulkes, Herschel, Newton, ...) and satellites (including Beppo-SAX, Swift, Fermi,Agile ...) the enormous energetics of GRB sources has been evidenced and the appropriateness of a time resolved analysis has surfaced and a much more composite picture of the GRB phenomena has emerged.

The essential process at the core of a GRB phenomenon is the formation of a Black Hole, which is generally preceded and followed by distinctly different astrophysical phenomena, each describable within a "Cosmic Matrix" related to the nature of the progenitors.

A variety of astrophysical scenarios are describable in each "Cosmic Matrix" involving: as "in" states, various binary systems composed of combination of neutron stars, white dwarfs, Supernovae at their onset; as "out" states, a newly born neutron star (ν-NS) a massive Neutron Star or a newly born Black Hole. Although the name of GRBs has been traditionally used for all these different matrices, only the ones involving the newly forming Black Hole should strictly be indicated as GRBs.

The necessary but not sufficient condition for the GeV emission is the formation of a newly born Black Hole

Conclusions on the Black Hole

The approach to a black hole takes place along a very long path, strictly marked by a precise sequence of events. They follow one another with increasingly pressing rhythms: each is marked by a different phase of gravitational collapse. As the path proceeds, the influence of general relativity becomes more and more pronounced. One finally reaches the birth of the “black hole”, completely and uniquely carved into the structure of space-time.

It is as if Nature chose to create a path that only people who can benefit from their knowledge of Einstein’s general relativity can recognize: the pauses, the succession of events, the final blackholic energy release and fully perceive the uniqueness of this cosmic event, second only to the birth of the Universe.

Thanks to...

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