ICRA – ICRANet Press release
Discovering Early Gamma-Ray Burst Emissions with Cosmological Time Dilation

Gamma-ray bursts (GRBs), in a few seconds, release luminosities (in gamma-rays) comparable to the luminosity of all stars in the observable Universe, which makes them detectable to the dawn of galaxy and stellar formation. The repointing time of the XRT instrument onboard the Neil Gehrels Swift Observatory satellite has posed challenges in observing and studying GRB early X-ray emissions within ≈ 40 *s after a GRB trigger by gamma-ray detectors. To address this issue, a team of scientists from ICRA and ICRANet adopted a novel approach that capitalizes on the cosmological time dilation in GRBs at the furthest boundaries of the observable Universe (with a cosmological redshift z ranging up to* ~ 9*, i.e., only* ~ 500 *million years after the big bang) and analyzed all the* 368 *GRBs with a measured distance in the Swift GRB catalog from the year 2005 until December* 31^{st}*, 2023. This allowed to unveil the early X-ray emission in more than* 220 *GRBs and to validate the observation of the collapse of the carbon-oxygen (CO) core and the coeval newborn neutron star (*ν*NS) formation triggering the GRB event in the binary-driven hypernova (BdHN) scenario. For three prototypical BdHNe I, it is shown the* ν*NS spin-up due to supernova ejecta fallback and its subsequent slowing down due to the X-optical-radio synchrotron afterglow emission: a brief gravitational wave signal may separate the two stages due to a fast-spinning* ν*NS triaxial-to-axisymmetric transition. By analyzing the long GRB redshift distribution for the different BdHN types, it is inferred that BdHNe II and BdHNe III may originate the NS binary progenitors of short GRBs. The paper has been published by The Astrophysical Journal on May* 9^{th}*, 2024.*

Important astronomical breakthroughs are often marked by the possibility of studying events occurring in the nearby Universe. On the contrary, in this work, it is presented how the observation of GRBs at a very high cosmological distance, by exploiting the cosmological time dilatation factor $(1+z)$ as a novel observational tool, can allow to enter the *terra incognita* of the very early GRB X-ray emission. This emission is currently inaccessible to the Swift/XRT detector in nearby events, which paradoxically would be more suitable to be studied: the significant instrumental delay of repointing the Swift/XRT detector following the GRB trigger, always bigger than ~ 40 s expressed in the observer's rest frame, prevents their early X-ray emission observations. However, due to the cosmological time dilation, a time interval Δt measured on Earth corresponds to a time interval $\Delta t/(1+z)$ in the cosmological source rest-frame, where z is its cosmological redshift. In other words, a phenomenon appearing to our instruments on the Earth to last 50 s may last 10 s if the source is at $z = 4$, like if we were observing the phenomenon in slow motion. Therefore, the time needed by Swift/XRT to start its observations after the GRB trigger may correspond to a much shorter actual time for sources with a large redshift z, exactly by a factor $(1+z)$. If, e.g., Swift/XRT starts to observe a GRB 60 s after the trigger in the observer frame, it is observing the X-ray signals emitted $60/(1+z)$ s after the trigger in the cosmological rest-frame of the source. This corresponds to the possibility of observing 10 s after the trigger for a GRB with $z = 5$: the higher the GRB redshift, the shorter the time Swift/XRT can observe the source after the GRB trigger. This is clearly shown in Fig. 1 where it is presented the observational XRT time delays for all the 368 GRBs analyzed in the observer frame (upper panel) and the cosmological rest frame of each source (lower panel) as a function of their cosmological redshifts z. The green dotted line marks the 43.88 s minimum time delay in both panels, and the red dashed line in the bottom panel corresponds to this minimum delay rescaled as a function of the redshift of the source: $43.88/(1+z)$ s. More than 220 sources, which were observed by Swift/XRT with a delay greater than 43.88 s, would not have been deemed interesting from the early X-ray emission point of view. However, thanks to their large cosmological redshift, when looking at their cosmological rest frames, it is clear that they have been observed less than 40 s after the trigger.

This new methodology allows the analysis of the very early transient X-ray regimes in GRB afterglows, which pose a stringent test for all GRB theoretical models. Within the context of the binary-driven hypernova (BdHN) model, it is applied to three BdHNe I at high redshift: GRB 090423 at $z = 8.233$, GRB 090429B at $z \approx 9.4$, and GRB 220101A at $z = 4.61$. The cosmological time dilation enables observing the very early X-ray afterglow emission in these three GRBs (see, e.g., Fig. 2 and Fig. 3). It is thus validated the observation of the collapse of the carbon-oxygen (CO) core and the coeval newborn neutron star (νNS) formation triggering the GRB event in the BdHN scenario. It is also evidenced by the νNS spin-up due to supernova ejecta fallback and its subsequent slowing down due to the X-optical-radio synchrotron afterglow emission. A brief gravitational wave signal may separate the two stages due to a fast-spinning νNS triaxial-to-axisymmetric transition.

Equally important is the byproduct of analyzing the redshift distribution of all the 368 GRBs of the sample within the BdHN model. The similarity between the redshift distribution of BdHNe II and BdHNe III and that of short GRBs supports the hypothesis that the BdHNe II and BdHNe III remnants, after evolving into binary NS systems, could later become progenitors of short GRBs. This unique prediction of the BdHN scenario deserves further attention from an observational and a theoretical point of view.

Indeed, new missions with wide field-of-view soft X-ray instruments designed to simultaneously observe the GRB X-ray and gamma-ray emissions from the moment of the GRB trigger without any time delay, such as the THESEUS and HERMES missions, present a great opportunity.

For more information:

Contact:
Prof. Remo Ruffini
Director, ICRANet
Phone: (+39) 085 2305 4201, mobile: (+39) 339 475 2566
E-mail: ruffini@icra.it

Reference article:
"Probing electromagnetic-gravitational wave emission coincidence in a type I binary-driven hypernova family of long GRBs at very-high redshift";
C.L. Bianco, M.T. Mirtorabi, R. Moradi, F. Rastegarnia, J.A. Rueda, R. Ruffini, Y. Wang, M. Della Valle, L. Li, S.R. Zhang;
ApJ, 966 (2024) 219;
DOI: 10.3847/1538-4357/ad2fa9

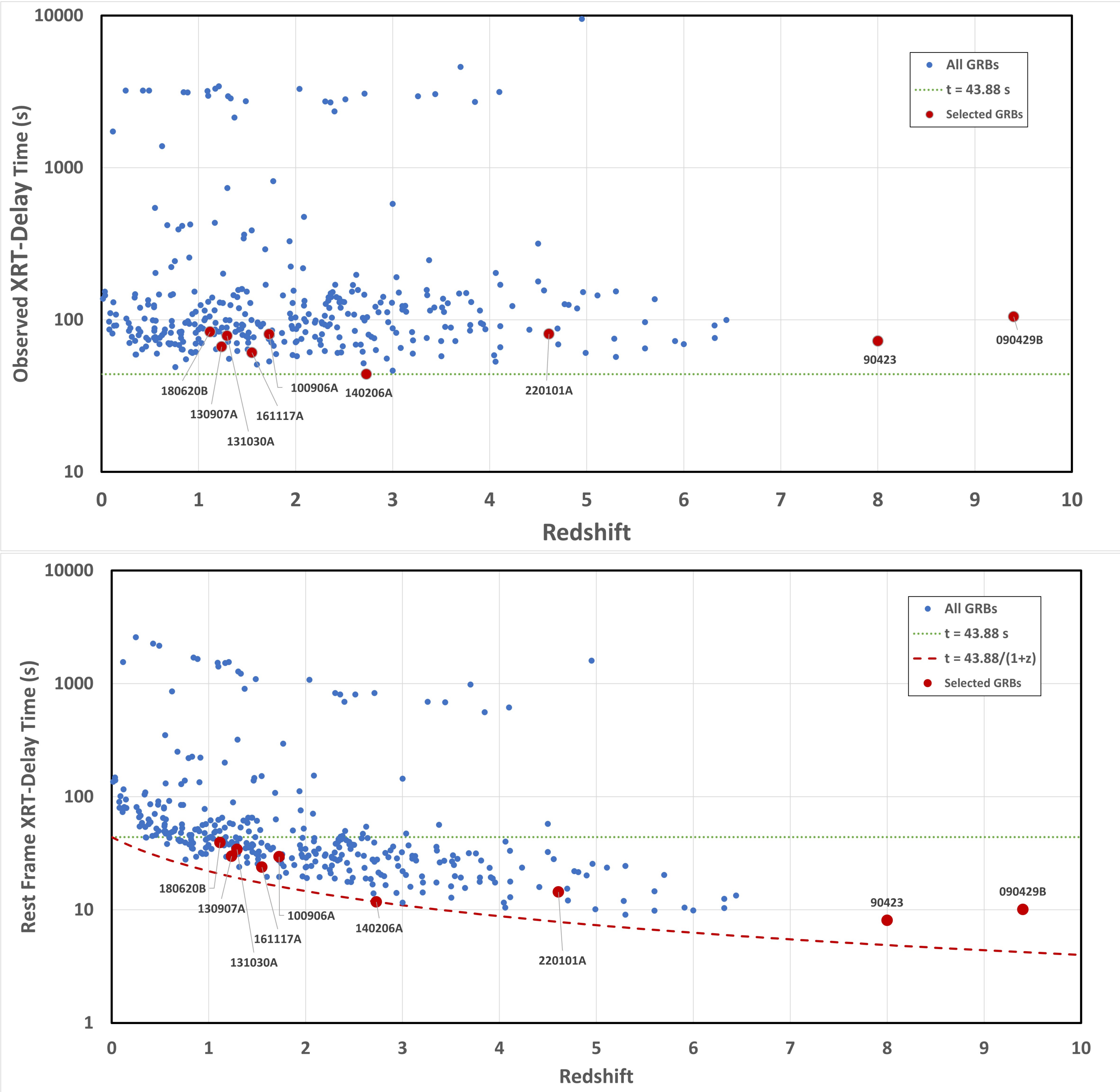

FIG. 1. The Swift/XRT time delay in the observer's frame (upper panel) and the cosmological rest-frame of the source (lower panel) as a function of their cosmological redshifts. The red points mark selected GRB sources. Details in Bianco et al., ApJ, 966 (2024) 219.

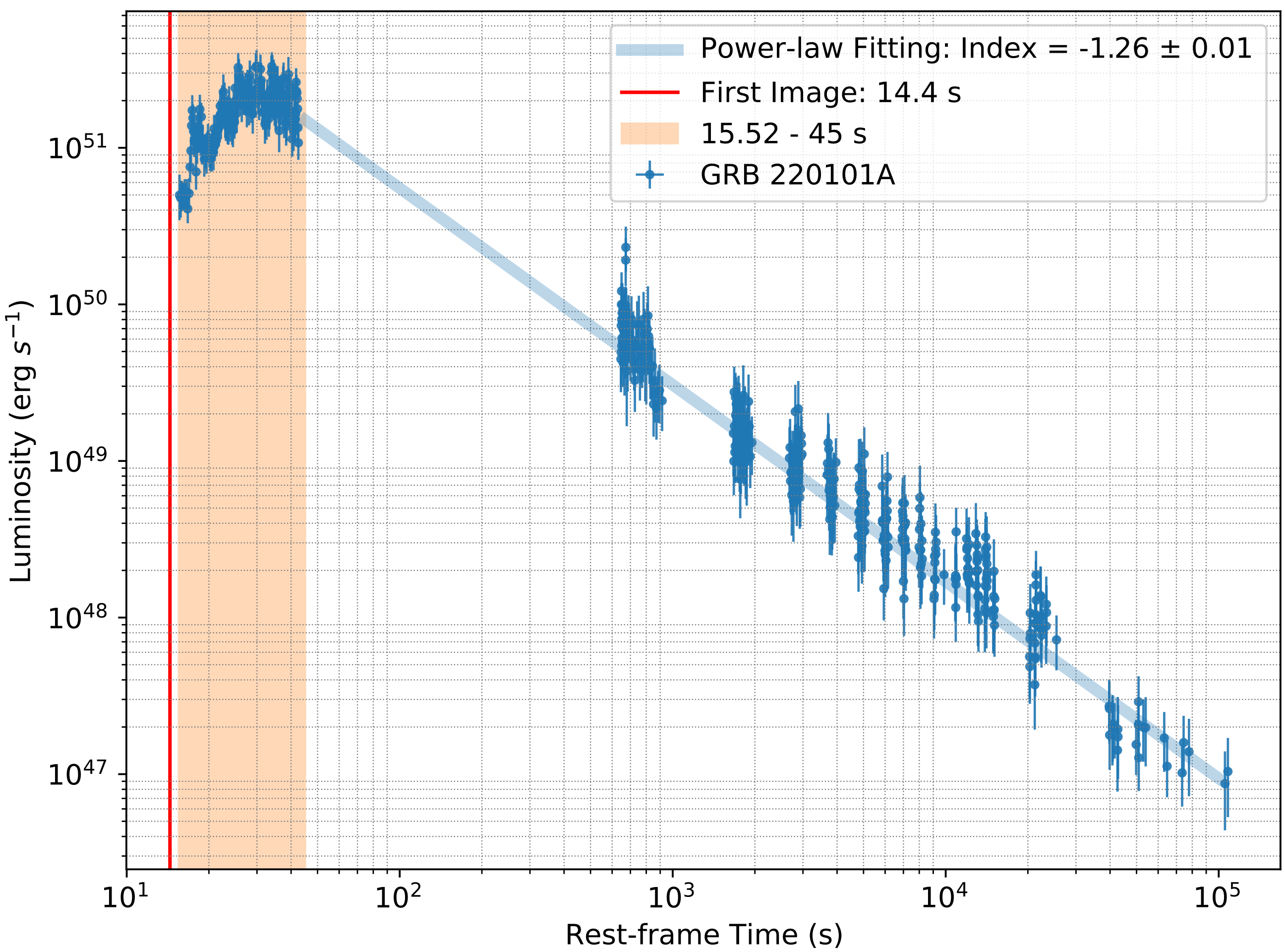

FIG. 2. The Swift-XRT 0.3–10 keV luminosity of GRB 220101A in the cosmological rest-frame. The red line at 14.4 s corresponds to the first observation by XRT. It follows the end of the SN-rise and indicates the spin-up phase of the νNS by the fallback accretion of matter initially ejected by the SN. It is followed by the slowing down phase starting at 45 s, corresponding to the decaying part of the X-ray afterglow. The orange strip, which extends from 15.52 s to 45 s, indicates the data observable thanks to the cosmological effect at $z = 4.61$ duly considered in this article. One of the key questions to be addressed is the possibility that, at the end of the spin-up phase, a short time ($\lesssim 1$ s) process of gravitational wave emission occurs due to a transition to a triaxial configuration of the fast spinning νNS, with characteristic strain $h_c \sim 10^{-23}$ at about kHz frequency. Details in Bianco et al., ApJ, 966 (2024) 219.

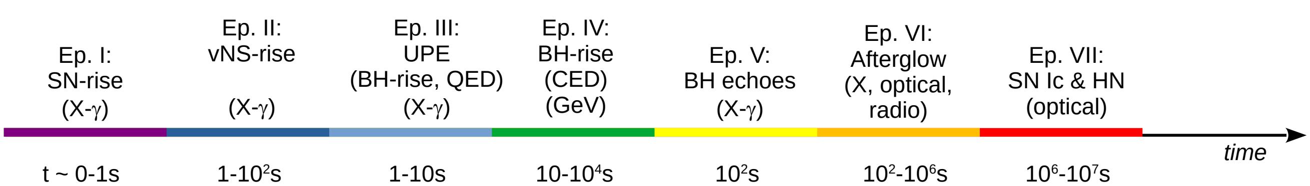

FIG. 3. Time sequence of the Episodes identified in BdHNe I. The times are orders of magnitude estimates. Details in Bianco et al., ApJ, 966 (2024) 219.