Deciphering the unusual stellar progenitor of GRB 210704A

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Abstract

GRB 210704A is a burst of intermediate duration (T90 ~ 1-4 s) followed by a fading afterglow and an optical excess that peaked about 7 days after the explosion. Its properties, and particular those of the excess, do not easily fit into the well established classification scheme of GRBs as being long or short, leaving the nature of its progenitor uncertain. We present multi-wavelength observations of this GRB and its counterpart, observed up to 115 days fater the burst. In order to decipher the nature of the progenitor system, we present a detailed analysis of the GRB high-energy properties (duration, spectral lag, and Amati Correlation), its environment, and late-time optical excess. We discuss three possible scenarios: a nearby short GRB, a distant long GRB, and an nearby exotic GRB, possibly in a cluster of galaxies. We find that traditional kilonova and suprernova model do not match well the properties of the optical excess, leaving us with the intriguing suggestion that this event was an exotic high-energy merger.

GRB 210704A: a long or a short GRB?

The duration of the prompt emission of GRB 210704A ranges from 1.0 to 4.7 s (Table 2). This discrepancy is due to the exsistence of the soft emission around T_0+5 s(Figure 1). The light curve alone is not clear whether the GRB is a long GRB (LGRB) or a short GRB (SGRB). GRB 210704A is consistent with being a SGRB at low redshift (z < 0.4) or with being a LGRB at high redshift (z > 0.4) in the Amati relation (top panel of Figure 2). The measured spectral lag of 80 ± 9 ms agrees with the lag-luminosity relation with the redshift range of 0.8 and 2.3 (bottom panel of Figure 2).

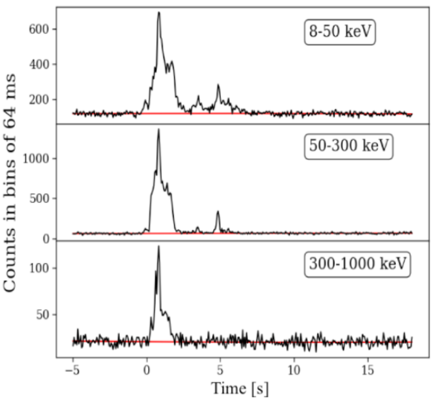

Figure 1 The Fermi-GBM light curve in three different energy bands. No emission around T0+5 s is evident in the high energy band (300-1000 keV).

Table 1 General information of GRB 210704A

Detection	Fermi/GBM, AGILE/MCAL, Fermi/LAT, AstroSat/CZTI, Konus-Wind, INTEGRAL/SPI-ACS, INTEGRAL/ISGRI
Trigger time	July 4, 2021 19:33:24.59 UTC (Fermi/GBM)
Position	RA, Dec (J2000) = 10:36:05.21, +57:12:59.1 with 90% error radius of 2.7" (Swift/XRT)

Table 2 T_{90} duration reported by different instruments for GRB 210704A

Instrument	T_{90} [s]	Energy [keV]	Reference
AGILE/MCAL	1.06	400-100000	Ursi et al. (2021)
AstroSat/CZTI	1.0	20-200	Prasad et al. (2021)
Fermi/GBM	4.7	50-300	Malacaria et al. (2021)
Konus-Wind	4.5	20-4000	Ridnaia et al. (2021)
INTEGRAL/SPI-ACS	3.5	80-1000	Minaev et al. (2021)

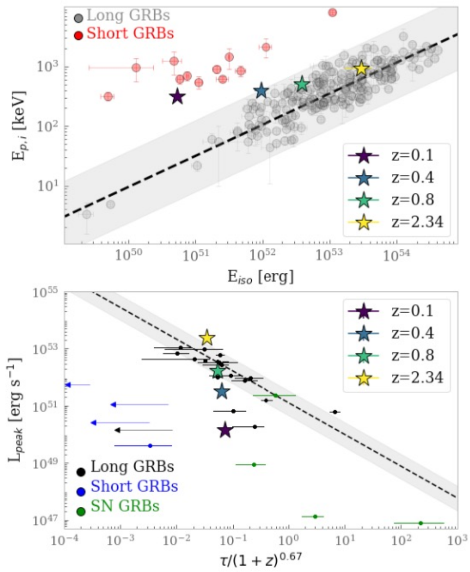

Figure 2 Top panel: The Epeak and Eiso Amati relation. Bottom panel: The lag τ and Lpeak relation. The stars are the estimated positions of GRB 210704A at z = 0.1, 0.2, 0.8, and 2.34.

Signature of an excess component

We carried out an extensive campaign of the follow-up observations using the Deca-Degree Optical Transient Imager (DDOTI), the Large Monolithic Imager (LMI) on the 4.3-m Lowell Discovery Telescope (LDT), the Near Infrared Imager (NIRI) and the Gemini Numti-Object Spectrographs (GMOS) instrumets on the 8.1-m Gemini-North Telescope, the Hyper Suprime-Cam (HSC) on the Sumaru 8.2 m telescope, and the Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy (OSIRIS) instrument on the 10.4-m Gran Telescopio de Canarias (GTC).

As seen in Figure 3, the early optical (T0 < 2 days) and X-ray data are consistent with the standard external shock model in the segment of $\nu_m \leqq \nu_{opt} \leqq \nu_X \leqq \nu_c$ where ν_m is the synchrotron characteristics frequency and ν_c is the cooling frequency (Granot & Sari 2002). The combination of the power-law afterglow and the galaxy S1 (WISE J103604.24+571327.7 at z=0.0817, see Figure 4) underpredicts the optical and near-infrared photometry from T+5.1 to T+14.5 days (see Figure 3). The peak of the excess component around T+6.5 days is 3-5 times brighter than the afterglow and the host.

If we fit the grzJ data of the excess with the blackbody model, the obtained blackbody temperature range is from 2250 to 6150 K depending on radii.

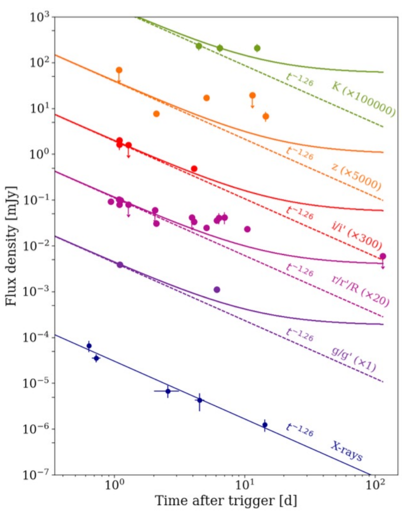

Figure 3 Optical and X-rau light curves of GRB 210704A. The dashed lines show the power-law fits to the afterglow and the solid lines show the combination of the power-law fit and the galaxy S1.

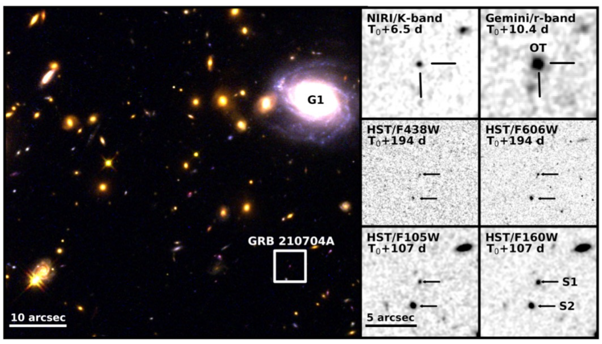

Figure 4 False-color image of the field of GRB 210704A as seen by HST (red: F160W, green: F105W, blue: F606W). The white box in the bottom right marks the position of GRB 210704A. The bright spiral galaxy G1 is marked in the top right. Side panels show a zoom of the field in different filters to compare the afterglow images obtained at 6.5 and 10.4 d with the late-time HST imaging obtained months after the explosions. The crosshair in the top panels marks the optical/infrared transient position, and the arrows mark the location of the sources S1 and S2, respectively.

Discussion

A nearby SGRB: An association to the galaxy S1 (the offset distance of 52 kpc) is possible as a SGRB's host. However, the observed peak luminosity and peak time of the excess emission do not match well with the properties of a kilonova (e.g., AT2017gfo).

A distance LGRB: Our photometric redshift estimate of the source S1 is z = 2.15 ± 0.10. If this source is the host, the prompt emission properties are consistent being a LGRB except for its duration. However, the excess component is significantly brighter than the known supernova.

	Association	Promp emission	Afterglow	Late-time excess
A nearby SGRB	z=0.08168 (galaxy G1)	✓	✓	✗
A distance LGRB	Z~2.15 (source S1)	✓	✓	✗