RevMexAA (Serie de Conferencias), **42**, 34–35 (2013)

GRB 101225A: AN UNUSUAL STELLAR DEATH ON CHRISTMAS DAY

C. C. Thöne,[1] A. de Ugarte Postigo,[1,2] C. L. Fryer,[3] K. L. Page,[4] J. Gorosabel,[1] M. Aloy,[5] D. Perley,[6] and the Christmas Burst Collaboration

RESUMEN

Los brotes de rayos Gamma (GRB) se acompañan de luminiscencia producida por radiación sincrotrón que permite detectarles hasta grandes distancias en el Universo. Presentamos el inusual objeto GRB 101225A, también llamado el "Brote de Navidad", brote de rayos gamma muy largo en el tiempo, seguido de luminiscencia brillante en rayos X y de una peculiar contrapartida óptica. Con el GTC/OSIRIS hemos detectado una galaxia anfitriona extremadamente débil, seis meses después del brote inicial.

ABSTRACT

Gamma-ray bursts are usually followed by afterglows produced by synchrotron radiation which makes them detectable out to the far Universe. Here we present the unusual GRB 101225A, also named the "Christmas burst", an extremely long γ-ray burst followed by a bright X-ray afterglow and a peculiar optical counterpart. The X-ray spectrum shows an additional thermal component while the UV-optical-IR SED evolves as a cooling, expanding black-body until 10 days, after which a faint supernova emerges. With GTC/OSIRIS, we detect an extremely faint host galaxy 6 months after the burst.

Key Words: gamma-ray burst: individual (101225A)

1. INTRODUCTION

GRBs have so far been divided into two classes, short and long GRBs, according to their γ-ray duration, and connected to two different progenitors (Kouveliotou et al. 1993). In both cases, a black hole is accreting the remaining material and ejecting part of it in the form of two ultra-relativistic jets. In the so-called fireball model, internal and external shocks create synchrotron emission reaching from γ to radio wavelenghts. The spectral-energy distribution and the lightcurve therefore follow broken powerlaws (Zhang & Meszaros 2004). This model has been confirmed by numerous observations.

Long GRBs have been securely connected to broad-line Type Ic supernovae and hence to massive stars (Woosley & Bloom 2006). They are usually found in dwarf, star-forming galaxies with low metallicities. For some GRB-SNe, an additional thermal component in the X-ray afterglow had been found and attributed to the shock breakout of the star or the circumstellar wind (Campana et al. 2006; Starling et al. 2011; Page et al. 2011).

2. OBSERVATIONS

GRB 101225A was detected by *Swift* on Dec. 25, 2010, 18:37:45 UT in an image trigger (Racusin et al. 2010). It had a $T_{90} > 2000$ s and a very soft spectrum putting it at the extreme end of the hardness-duration distribution of *Swift* GRBs (Sakamoto et al. 2011). XRT detected a bright counterpart in X-rays showing a very shallow decay for the first $\sim$0.2 days before decaying rapidly with $t^{-5/3}$, inconsistent with a synchrotron nature. An optical counterpart was discovered by AlFOSC/NOT 1.54 h after the burst (Xu et al. 2010). We started an extensive, worldwide UV-optical-IR (UVOIR) follow-up, including OSIRIS/GTC, until 2 months after the event. Spectroscopy of the event at 2 and 41 days post burst with OSIRIS/GTC and LRIS/Keck did not reveal any absorption or emission lines.

The bright X-ray afterglow showed an additional component to the power-law fit, best modeled with a blackbody (BB) of T$\sim$1 keV and a radius of $\sim$1 $R_\odot$ (assuming a redshift of $z = 0.33$). The BB component can be detected until 8 ks, contributing around 20% to the total flux and shows no temporal evolution. At later times, the S/N becomes too low to determine different components in the X-ray SED.

With the UVOIR observations we derive an SED at 7 epochs from 0.07 to 40 days after the burst

[1]IAA-CSIC, Glorieta de la Astronomía s/n, 18008 Granada, Spain (cthoene@iaa.es).
[2]DARK, NBI, Univ. of Copenhagen, Juliane Maries Vej 30, 2100 Copenhagen, Denmark.
[3]LANL, MS D409, CCS-2, Los Alamos, NM 87545, USA.
[4]Dept. of Physics & Astronomy, Univ. of Leicester, Univ. Road, Leicester LE1 7RH, UK.
[6]Dept. de Astronomía y Astrofísica, Univ. de Valencia, 46100 Burjassot, Spain.
[6]UC Berkeley, Astronomy Dep., 601 Campbell Hall, Berkeley CA 94720, USA.

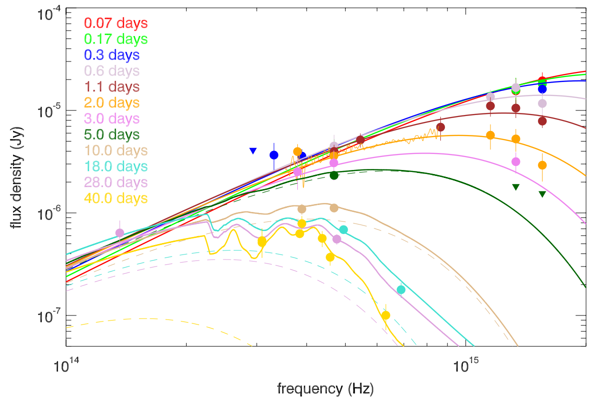

Fig. 1. UVOIR SED evolution from 0.07 to 40 days. Dashed lines show the continuation of the pure BB emission, the solid lines show the combination of SN and BB.

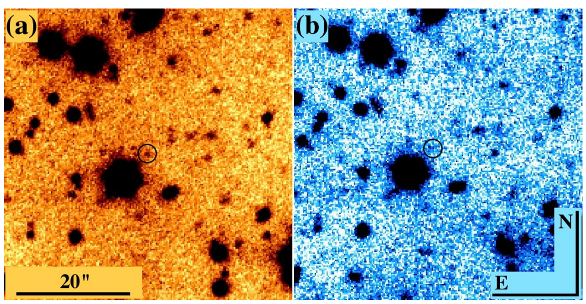

Fig. 2. Host galaxy from GTC in r' (left) and g' (right).

(see Figure 1). In contrast to other GRBs, the SED does not show a power law shape but instead is well modeled with an expanding, cooling blackbody for the first ∼10 days. The radius of the UVOIR BB increases from ∼13 to 45 AU while the temperature drops from 43,000 to 5,000 K from 0.07 to 18 days. Temperature and radius evolution of X-ray and UVOIR BB are inconsistent with each other and the two emissions much therefore come from different processes.

At ∼10 days, another component starts to appear, coincident with a flattening in the light curve. The light curve reaches a faint maximum at 30 days and a subsequent decay. This behaviour is well modeled with a supernova associated to GRB 101225A taking as template the "generic" GRB-SN GRB 980425/SN 1998bw (Galama et al. 1998), stretched by a factor of 1.25 in time and only 1/10th of its luminosity. For this we use the SED at 40 days which also allows us an accurate determination of the redshift taking advantage of two different r-bands that happen to fall on one of the broad SN emission lines and obtain $z = 0.33^{+0.07}_{-0.04}$.

Preimaging observations of the field of GRB 101225A from the PAnDAs survey (Richardson et al. 2011) did not reveal any host galaxy down to limits of $i' > 25.5$ and $g' > 26.9$. 6 month after the burst, we reobserved the field with OSIRIS/GTC during 4.1 h in g' and r' under good conditions. An unextended object is detected with $g' = 27.21 \pm 0.27$ and $r' = 26.90 \pm 0.14$ (see Figure 2). The object shows a blue color, consistent with a star-forming galaxy and lies well above the extrapolation of the light curve, we therefore propose this to be the host galaxy of GRB 101225A.

3. MODEL

Our preferred model to explain the observed features described above is a He-star – neutron-star binary merger which had been suggested as GRB progenitor in the past (Fryer & Woosley 1998). When the He-star leaves the main sequence, it expands and incorporates the NS, leading to a common envelope phase during which the He-star ejects most of its envelope in form of a thick shell. In our model, this shell forms a torus with a narrow opening (funnel) at the rotation axis.

When the two stars merge, an accretion disk and jet formation causes a GRB-like event, possibly with a magnetar as remnant explaining the prolonged emission. Only a small part of the jet escapes through the funnel while most of it interacts with the previously ejected material. Backwards scattered material from the inner boundary of the envelope leads to a hot spot causing the X-ray emission. Most of the jet gets thermalized when interacting with the material in the funnel wall, creating the observed UVOIR BB emission when it breaks out of the shell. In the end, the weak SN produced by this progenitor (the progenitor naturally implies a small Ni production) overtakes the other emission components. Campana et al. 2011 suggest an entirely different model for this event, assuming the tidal disruption of a minor body onto a Galactic neutron star.

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