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Modelling GRB 021004 by multiple energy injections(*)

A. de Ugarte Postigo(1), J. Gorosabel(1), A. J. Castro-Tirado(1), G. Jóhannesson(2), G. Björnsson(2), E. H. Gudmundsson(2), M. Bremer(3), J. M. Castro Cerón(4), S. Guzyi(5)(1), M. Jelínek(1), D. Pérez-Ramírez(6)
on behalf of a larger collaboration

(1) *Instituto de Astrofísica de Andalucía (IAA-CSIC) - Apartado de Correos 3004 E-18080 Granada, Spain*
(2) *Science Institute, University of Iceland - Dunhaga 3,IS-107 Reykjavík, Iceland*
(3) *IRAM - Institute de Radio Astronomie Millimétrique - 300 rue de la Piscine F-38406 Saint-Martin d'Hères,France*
(4) *Niels Bohr Institute, University of Copenhagen - Juliane Maries Vej 30 DK-2100 Copenhagen Ø, Denmark*
(5) *Nikolaev State University - Nikolska 24, 54030, Nikolaev, Ukraine*
(6) *Dpto. de Física (EPS), Universidad de Jaén - E-23071, Jaén, Spain*

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Summary. — GRB 021004 is one of the best sampled gamma-ray bursts (GRB) to date, however the nature of its light curve is still being debated. A compilation of multiwavelength (from radio to X-rays) observations, including unpublished optical/near-infrared and millimetre observations, is used to fit a model based on 7 refreshed shocks that took place during the evolution of the afterglow. They imply a total energy release of $\sim 8 \times 10^{51}$ erg. Analysis of the late photometry reveals that the GRB 021004 host is a low extinction ($A_V \sim 0.1$) starburst galaxy with $M_B \simeq -22.0$.

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1. – Introduction

At 12:06:13.57 UT 4th October 2002 a long-duration GRB triggered the instruments aboard the HETE-2 satellite. The detection was immediately transmitted to observatories all around the globe that began observing a few minutes after the burst. A fast identification of the optical afterglow [1] allowed observations of the event from the first stages, providing one of the best multiwavelength coverages of a GRB obtained to date.

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TABLE I. – *Model parameters. E_i are the injection energies, being E_0, the initial energy. Other parameters: initial Lorentz factor Γ_0, ambient density n_0, half opening angle θ_0, line of sight angle θ_ν, electron energy index p, fraction of internal energy stored in electrons after acceleration ϵ_e and fraction of internal energy stored in the form of magnetic field ϵ_B.*

Parameter	Value
E_0	1.5 10^{50}erg
E_1 (0.046 days)	2.2 E_0
E_2 (0.347 days)	0.7 E_0
E_3 (0.694 days)	4.6 E_0
E_4 (1.736 days)	10.0 E_0
E_5 (3.877 days)	8.6 E_0
E_6 (13.89 days)	10.0 E_0
E_7 (48.61 days)	15.0 E_0
Γ_0	770
$n_0(\mathrm{cm}^{-3})$	60.0
θ_0	$1^\circ.8$
θ_ν	$0.8\theta_0$
p	2.2
ϵ_e	0.35
ϵ_B	1.7×10^{-4}

We revisit the light curve of GRB 021004 using new data together with observations from the literature. Our study covers almost the complete history of the event, from a few minutes after the trigger to more than a year after, when the afterglow light disappeared into the underlying galaxy. We pay special attention to the bumpy nature of the light curve and, using the best multiwavelength sampling to date, apply the multiple energy injection model described in [2].

Throughout, we assume a cosmology where $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$ and $H_0 = 72$ km s^{-1} Mpc^{-1}. Under these assumptions, the luminosity distance of GRB 021004, at a redshift of $z = 2.3293$ [3], is $d_l = 18.2$ Gpc and the look-back time is 10.4 Gyr.

2. – Observations

For the study of GRB 021004 we obtained a large amount of observations from 8 observatories world-wide [4] in the optical/near-infrared and millimetre ranges. These photometric information were combined with previously published multiwavelength observations, covering from radio to X-rays [5-15] to obtain the completest possible data set.

3. – Results

3˙1. *Host Galaxy.* – In order to be able to constrain the model of the afterglow, we need to isolate the flux produced by the afterglow from that of the underlying host galaxy. For the study of the host galaxy we use the $BVIJ$-band magnitudes measured when the contribution of the afterglow was negligible, between $\sim 62(B)$ and $\sim 454(J)$ days after the burst.

The fit of the host galaxy spectral flux distribution (SFD) is based on HyperZ [16], which compares our photometry whith available galaxy templates. The fitting assumes Solar metallicity, a Miller & Scalo [17] initial mass function (IMF), a Small Magellanic

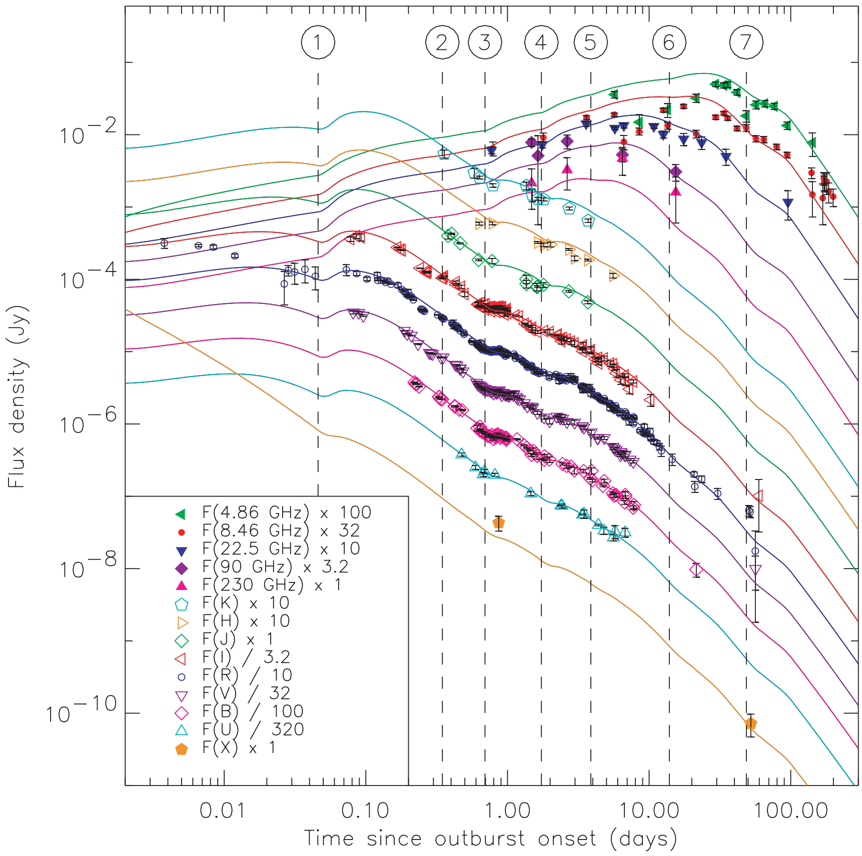

Fig. 1. – Multiband light curves from X-rays to radio. The dashed lines and numbers mark the time of the energy injections.

Cloud (SMC) extinction law [18] and a redshift of z=2.3293 [3]. The best fit (χ^2/d.o.f. = 0.1) is obtained with a $\sim$ 15 Myr starburst galaxy with an absolute magnitude of $M_B = -22.0 \pm 0.3$ and an intrinsic extinction of $A_V = 0.06 \pm 0.08$. This fit allows us to predict magnitudes for the photometric bands that where not observed so we may substract the host galaxy from the light curves and isolate the afterglow.

The best fit of the afterglow light curves is obtained when we correct the photometry with a Small Magellanic Cloud (SMC) extinction law and $A_V \sim 0.1$. The parameters that result from the modelling are displayed in table I.

3˙2. *Modelling(see fig.1).* – We adopt the standard fireball model [19] to interpret the data. To account for the observed light curve brightenings, we modify the model by adding multiple energy injection episodes (see [2] and [20] for a detailed discussion).

Due to the high redshift of this object the Lyman-α break is shifted to the range of the U-band. Thus, we must consider a correction for the Lyman-α blanketing that attenuates the flux in this band. We use the model described in [21] at this redshift and convolve it with the Johnson U-band. This yields a reduction of the measured flux to 82% of the original one. Due to the uncertainty of this approximation we do not use the corrected U-band for fitting the model, but only for the verification of it.

4. – Conclusions

Due to the early detection and rapid follow-up of GRB 021004 we had the opportunity of obtaining a very complete dataset concerning temporal range, wavelength coverage and sample density. This allowed us to introduce important constrains on the models capable to explain the bumps present in the afterglow light curve.

In our analysis we assume several energy injection episodes to explain the light curve. A reasonable scenario includes an initial burst followed by 7 refreshed shocks. These add up to a total burst energy of 7.8×10^{51} ergs, that were emitted through a collimated jet with an initial half-opening angle of $1^\circ.8$, pointing almost directly towards us.

A study of the photometric data of the host galaxy of GRB 021004 reveals a bright ($M_B = -22.0 \pm 0.3$) starburst galaxy with low extinction ($A_V = 0.06 \pm 0.08$).

Further tests of afterglow models with this multiwavelength dataset are encouraged. Future efforts should be aimed towards obtaining multiwavelength photometry and polarimetric observations in order to be able to discriminate between the different models. A more detailed discussion can be found in [4].

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