PROCEEDINGS OF SCIENCE

"Pi of the Sky" limits on the optical precursor to the naked-eye burst GRB080319B

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I present results of the search for an optical precursor to the naked-eye burst – GRB080319B, which reached 5.87^{m} optical peak magnitude in the "Pi of the Sky" data. A burst of such a high brightness could have been preceded by an optical precursor luminous enough to be in detection range of our experiment. We set a continuous limit of 12^{m} (V-band equivalent) based on the "Pi of the Sky" data, 20 minutes prior to the explosion. This is the most robust limit for a GRB optical precursor measured up to date.

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Figure 1: Comparison of the real (left) and simulated (right) GRB080319B images (in peak brightness), which were close to the frame corner, where the PSF is most deformed. The simulated PSF, used for the precursor search described in this contribution, reproduces the real PSF in great detail.

1. Optical precursors to GRBs

The predictions of optical precursor models are limited in scope, most likely owing to the very few observations providing any limits on this type of emission [1]. The main motivation for the search for the precursor is the knowledge acquired from studies of the naked-eye burst that the optical emission can be simultaneous with the γ-ray emission [2]. There is a possibility, that the observed γ-ray precursors are also accompanied by optical precursors. In most cases, the observed optical emission was less luminous than the γ-ray emission, and the optical precursor, if accompanying γ-ray, would be too weak to be detected. However, the extreme brightness of GRB080319B in the optical band, relative to the moderate intensity in γ band hints that it could be possible to have an optical precursor bright enough to be seen, even if the γ-ray precursor was not visible to experiments[3].

2. The "Pi of the Sky" experiment

The "Pi of the Sky" experiment is designed for the monitoring of a large fraction of the sky with high time resolution (10 s) and self-triggering capabilities [4]. This approach resulted in the autonomous detection of the naked-eye burst GRB080319B at its very beginning [5]. The strategy also allows the search for optical precursors to GRBs.

To meet the requirement for monitoring a large fraction of the sky, the "Pi of the Sky" apparatus makes use of cameras with a very wide field of view – $20^\circ \times 20^\circ$ each. For stars positioned far from the optical axis, this causes significant image deformations, much larger than in other astronomical experiments. This was also the case for GRB080319B. To improve measurements and signal seeking capabilities a model of the PSF of the "Pi of the Sky" system, based on modified Zernike polynomials, was created [6].

Simulated PSFs obtained from the model are very close to real images even for the most deformed stars, as can be seen in Fig. 1.

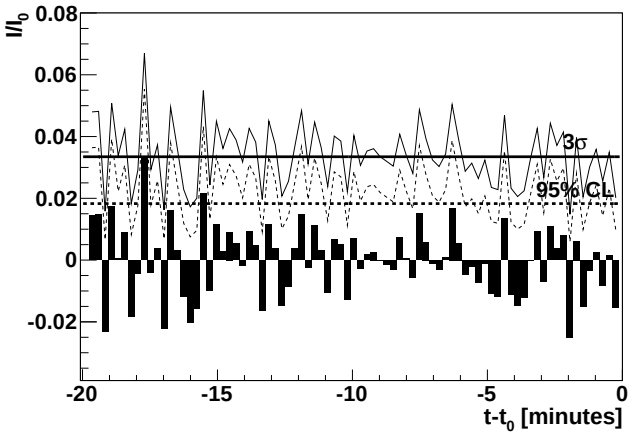

Figure 2: Signal value at the GRB080319B position relative to the nearby reference star, $\frac{I}{I_0}$, obtained from the PSF profile fit to the data from the k2a camera of the "Pi of the Sky" prototype as a function of time before the burst $t - t_0$ (vertical bars). We also indicate the limits on the precursor luminosity calculated assuming no signal (thick lines) and taking the actual signal measured for each frame (thin lines). Limits are calculated at both the 3σ level (solid lines) and 95% confidence level (dashed lines).

3. Search for the optical precursor

The search was performed by fitting the model PSF at GRB coordinates to all the 10 s frames covering 19 minutes prior to the explosion obtained with two cameras (with the internal names k2a and k2d) of the "Pi of the Sky" prototype. Figure 2 shows the fitted signal value of $\frac{I}{I_0}$ for the k2a camera, for all considered frames. No signal exceeding the 3σ has been found for this camera. In this approach, where we assume "no signal" in the place of the GRB on the frame, the resulting 3σ limiting magnitude for the k2a camera in the polynomial photometry is 11.67^{m}.

The method that we used also allowed us to set limits on particular frames based on the fitted signal level in the GRB coordinates. The 3σ limits calculated on single frames of the k2a camera fluctuate in most cases between 11.5^{m} and 12.25^{m}.

The combined scale for a precursor was also computed as the weighted average of scales fitted for both cameras. No signal above 3σ level was found in the combined signal distribution. The standard 3σ limit calculated assuming a zero signal is 12^{m} (fig. 3). The 3σ limit based on the measured signals for single frames is between 11.5^{m} and 12.6^{m} for most frames.

4. Conclusions

The combined 3σ limit, assuming no signal is a 12^{m} apparent magnitude, being just 0.35% of the peak flux measured with "Pi of the Sky".The limit is significantly deeper compared to the limit set by RAPTOR-Q (2.5%) in a similar time period [7]. The rough estimation gives the limit on the absolute magnitude of the precursor of -31.9^{m}.

If we assume that the optical precursor luminosity is proportional to the main peak luminosity, and the proportion is similar to that observed for γ-ray emission, i. e. 10-100 times dimmer than the

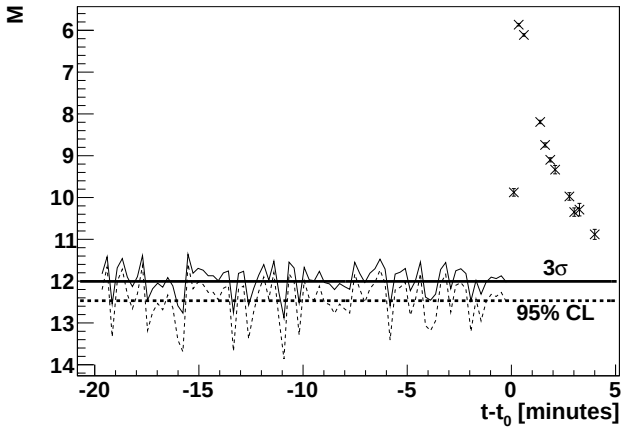

Figure 3: Limiting magnitude M (V-band equivalent) for the optical precursor emission from GRB080319B as a function of time before the burst $t - t_0$. Limits to the precursor luminosity were calculated assuming no signal (thick lines) and taking the actual signal measured for each frame (thin lines). Limits were calculated at the 3σ level (solid lines) and 95% confidence level (dashed lines) and are based on combined data from two cameras of the "Pi of the Sky" prototype. The points with error bars represent the GRB080319B "Pi of the Sky" flux.

peak luminosity [8], we can rule out the possibility of GRB080319B having an optical precursor. According to our presented calculations, the precursor would have to be at least 300 times dimmer than the peak luminosity.

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