A Large Amplitude Flaring dMe Star in the 1978 October 6B γ-ray Burst Error Box[*]

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1 Introduction

During a search for flaring optical counterparts to γ-ray burst sources (GRBs) on archival patrol plates, an optical outburst image was found in the 3200 arcmin^2 error box of the GRB which occurred on 1978 October 6 (GB 781006B = GBS 0008+13; Greiner et al. 1991) and was named S 10933 according to the convention of new Sonneberg variables. This outburst image appears on three simultaneously exposed plates taken on 1966 August 14/15 from 23.33 to 0.13 UT. The brightness estimates yielded $m_{\rm pg} = 13\overset{\rm m}{.}3 \pm 0\overset{\rm m}{.}1$ and $m_v = 13\overset{\rm m}{.}8 \pm 0\overset{\rm m}{.}2$ with a high negative colour index of $C = -0\overset{\rm m}{.}5 \pm 0\overset{\rm m}{.}3$.

The coordinates of these images (measured on the Tessar plate Te$_3$ 5154) are (equinox 1950.0) $\alpha = 0^{\rm h}\ 10^{\rm m}\ 07\overset{\rm s}{.}6$, $\delta = +12° 51'24''$ (1σ error of $\pm 2''$). Within the 3σ error circle of the position of the object a star of $m_B = 18$ is visible on the Palomar Observatory Sky Survey prints. Here, we report spectroscopic observations of this faint object.

2 Observations and Results

CCD B and R images of the field of the optical transient were obtained from 1991 November 10 to 12 with the 1.2 m telescope at Observatoire de Haute-Provence (OHP). Low and medium resolution spectra of the brightest optical object A were obtained on 1992 February 4, 7 and 8 with the CARELEC spectrograph attached at the OHP 1.93 m telescope. Further spectroscopic observation were obtained using the 3.5 m telescope at Calar Alto, equipped with the Cassegrain spectrograph, on 1992 Sep 28 – Oct 1. The slit was put parallel to the row of faint objects apparently aligned with the bright candidate. On 1992 Sep 30, three spectra with a grating of 60 Å/mm were acquired.

Table 1. Other large amplitude flares

Star	Δm_B (mag)	References
CZ Cnc	≈ 9.5	Lovas 1977, Schaefer 1990, Greiner & Motch 1994
AF Psc	≈ 7.5	Bond 1976, Greenstein 1977
UV Cet	≈ 6.5	Jarrett & Gibson 1975
EV Lac	≈ 6.0	Roizman & Shevchenko 1982
AM Her (comp)	≈ 5.9	Shakhovskoy et al. 1993
S 10933	≥ 5.2	this work, Greiner & Motch 1995
AD Leo	≈ 4.1	Hawley & Pettersen 1991
G102–21	≈ 3.9	Pagano et al. 1995

The spectral type of the central object was estimated by comparing our flux calibrated spectra with spectra in electronic atlases (Jacoby et al. (1984) and Turnshek *et al.* (1985)). We conclude that the central star is a M3–M5e late type dwarf. The lack of Li absorption tells us that the star is older than $\approx 10^7$ yr (Rebolo 1991). Comparison with photometric standards in NGC 7790 (Christian *et al.* 1985) yielded $B = 18.50 \pm 0.20$.

Two additional objects lie within or slightly outside the 3σ error circle of the archival flare event. These are at least 2^m fainter than the dMe star. They are aligned southeastwards from the central dMe star together with a third one which is already outside the 3σ position. Our long slit spectra of the three aligned objects show that the brightest notch (object D) located at the end of the apparent alignment is an M star, however without noticeable Balmer emission. No usable spectra could be obtained from notches B and C located in between the dMe star and object D. These objects exhibit flat continua without recognizable emission or absorption features.

3 Discussion

3.1 The flare star

Our observations leave no doubt that the bright dMe star is responsible for the large optical flare of 1966. The spectral type indicates an absolute magnitude M_V in the range of 10 to 14 and a distance of 40 to 250 pc. The apparent magnitudes during the flare and in quiescence translate into visual luminosities (blue band) of 4×10^{31} $(d/100 \text{ pc})^2$ erg/s and 3.5×10^{29} $(d/100 \text{ pc})^2$ erg/s, respectively.

Assuming that the flare lasted as long as (or longer than) the exposure time of the discovery plates (40 min), implies a peak amplitude of about $\Delta m_B \approx 5^m.2$. Alternatively, if the event belongs to the class of fast flares with typical duration shorter than ≈ 10 minutes, the peak amplitude could have been as high as $7-9^m$. For comparison, other large amplitude flaring stars are listed in Table 1. Even a peak amplitude of $5^m.2$ (corresponding to a flare energy release of 10^{35} $(d/100$ pc$)^2$ erg in the optical bandpass) are rare for a flare star and we can conclude that the event witnessed in 1966 was certainly unusual.

3.2 The relation to GBS 0008+13

At the time of the discovery (Greiner *et al.* 1991) it was assumed that the recorded optical flash was a likely counterpart candidate for a GRB. Indeed, this optical flash is well positioned within a 3200 arcmin^2 error box of a GRB which occured on October 6, 1978 (GB 781006B = GBS 0008+13, Atteia *et al.* 1987). The rather extreme value for the flare amplitude might favour speculations whether or not this flare is indeed related to a GRB. In fact, the possible relation with stellar flares was among the first models proposed to explain GRBs. Nearby flare stars are isotropic in the sky and have a $-3/2$ slope in their $\log N - \log S$ distribution (for a sampling distance smaller than ≈ 300 pc) and thus meet one of the statistical GRB criteria. Recently, Liang and Li (1993) have shown that flare stars could account for as many as half of the BATSE triggers without violating the observed $\log N - \log S$ distribution of GRBs.

Estimating the a priori probability of discovering such a large amplitude flaring star in a rather large (3200 arcmin^2) γ-ray error box is difficult because of the various statistical biases in flare star catalogs and flare observational data bases. There are convincing evidences that flare activity preferentially occurs in rather young stars (e.g. Mirzoyan 1990). Most flaring M stars exhibit strong Balmer emission (Pettersen 1991) while kinematical studies of dMe stars show that they belong to the young disk population with a mean age of $\approx 2 \times 10^9$ yrs (Giampapa & Liebert 1986). However, old stars in close binaries may also exhibit strong flaring activity (Haisch et al. 1991).

Using the stellar population model of Robin & Crézé (1986) which explicitly handles the age parameter, we predict that ≈ 10 stars with $B \leq 18.5$ and younger than 10^9 yrs should be present inside the GRB error box, including two late M type dwarf stars. Therefore, in the absence of stronger constraints on the age of the Me dwarf and reliable statistics on flare amplitudes, we cannot prove that this particular flare star has caused the γ-ray burst GB 781006B, nor can we dismiss the flare star explanation for this particular GRB.

4 Summary

We have identified the 1966 optical flash to be caused by a B=$18^{\rm m}5$ mag dMe flare star. We think that the relation between this flare star and the γ-ray burst source GBS 0008+13 is possible but unlikely. Even in this case of an unique archival object observed on synchronously exposed plates inside a GRB error box we are still left with an explanation other than a γ-ray burst optical counterpart.

Our identification confirms the feasibility of searching archival plate collections for real optical flashes of astrophysical origin. Unfortunately, the existence of an unknown number of such large amplitude flaring stars as the one reported here poses serious problems for wide-field GRB optical flash searches. More details can be found in Greiner & Motch (1995).

References

Atteia J.-L., Barat C., Hurley K., Niel M., Vedrenne G., Evans W.D., Fenimore E.E.,
    Klebesadel R.W., Laros J.G., Cline T., Desai U., Teegarden B., Estulin I.V.,
    Zenchenko V.M., Kuznetsov A.V., Kurt V.G., 1987, ApJS 64, 305
Bond H.E., 1976, IBVS 1160
Christian C.A., Adams M., Barnes J.V., Butcher H., Hayes D.S., Mould J.R., Siegel
    M., 1985, PASP 97, 363
Giampapa M.S., Liebert J., 1986, ApJ 305, 784
Greenstein J.L., 1977, PASP 89, 304
Greiner J., Naumann Ch., Wenzel W., 1991, A&A 242, 425
Greiner J., Motch C., 1994, IBVS 4092
Greiner J., Motch C., 1995, A&A 294, 177
Haisch B., Strong K.T., Rodono M., 1991, ARA&A 29, 275
Hawley S.L., Pettersen B.R., 1991, ApJ 378, 725
Jacoby G.H., Hunter D.A., Christian C.A., 1984, ApJS 56, 257
Jarrett A.H., Gibson J.B., 1975, IBVS 979
Liang E.P., Li H., 1993, A&A 273, L53
Lovas M., 1977, IBVS 1345
Mirzoyan L.V., 1990, IAU Symp 137, L.V. Mirzoyan, B. Pettersen & M.K. Tsvetkov
    (eds.), Kluwer, Dordrecht, p. 1
Pettersen B.R., 1991, Mem. S.A. It. 62, 217
Pagano I., Ventura R., Rodonò M., Peres G., Micela G., 1995, this volume p. 95
Rebolo R., 1991, in IAU Symp 145, Evolution of Stars: The Photospheric Abundance
    Connection, G. Michaud & A. Tutukov (eds.), p. 85
Robin A., Crézé M., 1986, A&A 157, 71
Roizman G.Sh., Shevchenko V.S., 1982, Sov. Astron. Lett. 8, 85
Schaefer B.E., 1990, ApJ 353, L25
Shakhovskoy N.M., Alexeev I.Yu., Andronov I.L., Kolesnikov S.V., 1993, in Cata-
    clysmic variables and related physics, O. Regev & G. Shaviv (eds.), Inst. Phys.
    Publ., Bristol, p. 237
Turnshek D.E., Turnshek D.A., Craine E.R., Boeshaar P.C., 1985, An Atlas of Digital
    Spectra of Cool Stars, Western Research Company, Tucson

H. Zinnecker: Have any of the large amplitude flare stars that you have listed
been observed with ROSAT pointed observations, and if so, have any been de-
tected?

J. Greiner: The objects CZ Cnc, AF Psc, and S 10933 are not covered by
ROSAT pointed observations. The other flare stars of Tab. 1 are all observed by
ROSAT and to my knowledge are also detected (quiescent emission).

D. Dravins: What accuracy in γ-ray burst positions will be required in order
for flare stars not to contribute any significant background in searches for optical
counterparts?

J. Greiner: With the present number density of known flare stars (outside of
stellar clusters) one needs 1 arcmin^2 sized error boxes to push the flare star
contamination below 0.1%. However, discoveries of quite a substantial number
of new flare stars even in the galactic field (see e.g. Richter *et al.* 1995, these
proceedings, p. 69), make this estimate an upper limit.