Astron. Astrophys. 325, L29–L31 (1997)

ASTRONOMY
AND
ASTROPHYSICS

LETTER

Letter to the Editor

Optical polarization properties of GRO J1655–40

F. Scaltriti[1,⋆], G. Bodo[1], G. Ghisellini[2], M. Gliozzi[3], and E. Trussoni[1]

[1] Osservatorio Astronomico di Torino, Strada dell'Osservatorio 20, I-10025 Pino Torinese (TO), Italy
[2] Osservatorio Astronomico di Milano, Sezione di Merate, Via Bianchi 46, I-22055 Merate (MI), Italy
[3] Dipartimento di Fisica Generale dell'Università, Via P. Giuria 1, I-10125 Torino, Italy

Received 12 June 1997 / Accepted 1 July 1997

Abstract. The superluminal source GRO J1655-40 (Nova Scorpii) has been observed in July 1996, when in active phase at X-ray energies, with the multichannel photopolarimeter (UBVRI) of the Torino Observatory, using the 2.15-m telescope of Complejo Astronomico El Leoncito (Argentina). A significant amount of intrinsic linear polarization ($\gtrsim$3 %) has been detected in the VRI bands, with the polarization direction parallel to the accretion disk plane. The possible origin of the polarized light and its implications on the structure of the system are shortly discussed.

Key words Polarization – stars: individual: GRO J1655–40 – stars: novae, cataclismic variables

1. Introduction

The discovery of superluminal motions in the two galactic sources GRS 1915+105 (Mirabel & Rodriguez 1994) and GRO J1655–40 (Nova Scorpii, Hjellming & Rupen 1995) has motivated a large interest in these last years. In fact the data collected over a large range of wavelengths show for these objects a phenomenology akin to that of AGNs: thermal and non thermal emission from radio frequencies to hard X-ray energies, large amplitude variability on short and long time scales, outflow of collimated plasma at relativistic velocities. The much greater detail in which they can be observed has raised the hope that these 'microquasars' and other objects which, like SS433, show similar behaviour, might provide a test for the models developed for their larger galactic counterparts.

The microquasars are associated with binary systems, with the secondary star providing the accreting material onto the primary, which is very likely to be a black hole. Besides the superluminal motion, peculiar properties of these objects are the strong outbursts at radio and X-ray frequencies. At X-ray energies, the rise time of bursts in GRS 1915+105 can range from few months to few days (Greiner et al. 1996), while GRO J1655–40 appears as a typical X-ray nova. In both sources a radio flare can follow the X-ray burst, and sometimes outflowing superluminal blobs appear few days after the radio peak (for a general survey on the properties of the two microquasars, see Mirabel & Rodriguez 1996).

In contrast with GRS 1915+105, strongly absorbed because it lies on the galactic plane at 12.5 kpc, we can observe the optical counterpart of GRO J1655–40, so that for this last object we know that it is associated to an eclipsing binary star (distance 3.2 kpc) with period of $2^{\rm d}.62$ and mass fuction = $3.24 M_\odot$ (the mass of the central black hole should lie in the interval $\approx 6.4 - 7.6\, M_\odot$). The optical magnitude is highly variable: in the quiescent phase it is $V \approx 17.3$ while in outburst it can rise up to $V \approx 14.4$ (Baylin et al. 1995). It is likely that in the former case the optical flux is mainly coming from the companion (an F-type star), while in the active phase the luminosity is dominated by the accretion disk and jet, with strong broad hydrogen emission lines (for a detailed discussion of the optical properties of GRO J1655–40 see Orosz & Bailyn 1996).

At radio frequencies, the source usually flares at intervals of few months, and some of these bursts are followed by the ejection of the radio emitting clouds at a velocity 0.92c and with an angle $\approx 85°$ with respect to the line of sight (the position angle is $\approx 47°$). At X-ray energies a soft component is always present, while during the bursts a hard tail up to 600 keV also appears. At intermediate luminosity, the flux shows very little absorption at soft energies, while absorption lines and edges are observed at energies $\approx 6 - 8$ keV. These data imply quite strict constraints on the geometry of the emitting region (Tanaka 1996, Zhang et al. 1997).

In this Letter we report the first optical polarimetric observations of GRO J1655–40, that we performed in July 1996, in a

Send offprint requests to: F. Scaltriti

⋆ Visiting Astronomer, Complejo Astronomico El Leoncito operated under agreement between the Consejo Nacional de Investigaciones Cientificas y Tecnicas de la Republica Argentina and the National Universities of La Plata, Cordoba and San Juan.

Table 1.

Filter	$P_{obs}(\%)$	θ_{obs}	Julian Date
V	2.4 ± 0.8	$124° \pm 9°$	2450277.5644
R	3.4 ± 0.5	$121° \pm 4°$	-
I	3.4 ± 1.3	$122° \pm 11°$	-
V	3.1 ± 0.7	$123° \pm 6°$.	2450280.6040
R	4.1 ± 0.6	$131° \pm 4°$	-
I	2.5 ± 2.0	$138° \pm 20°$	-

(the errors are at 1σ level)

period of high activity of the source at X-ray frequencies. In fact a strong flare was detected at the end of April by RXTE/ASM (energy range 2 - 12 keV, Remillard et al. 1996), with the flux increasing up to ≈ 1. Crab in roughly one week. In that period, at optical wavelengths the source magnitude was $V \approx 15.4$ (Horne et al. 1996). At the end of May an increase of the hard component of the X-ray flux was detected by BATSE (energy range 20 - 100 keV), attaining a value of $\approx 0.6 - 0.9$ Crab at the beginning of July (Harmon et al. 1996a). This phase of high X-ray luminosity (and high variability) was still present at the end of October (Harmon et al. 1996b). At radio frequencies, after a quiescent period of nearly 1.5 year, the source flared in the last decade of May up to a flux $\approx 0.02 - 0.05$ Jy, at the same time of the beginning of the hard X-ray burst (Hunstead & Campbell-Wilson 1996, Hjiellming & Rupen 1996).

In the following Sections 2 and 3 we describe the observations and present our results, while in Section 4 we discuss the possible origins of polarization and their implications on the models of the system.

2. The observations

The observations were performed on July 12 and 15 1996, at the 2.15-m telescope of Complejo Astronomico El Leoncito (Argentina) with the five channel photopolarimeter of Torino Observatory. This instrument allows to get the magnitude and the polarimetric parameters simultaneously in the bands $UBVRI$ by means of a set of dichroic filters that reflect the incoming beam towards five different photomultipliers. The selection is such that the resulting passbands are very close to the standard system $UBVRI$. The ordinary and extraordinary rays, obtained by a calcite block, are observed alternatively by means of a rotating chopper. The observing procedure allows to eliminate automatically the sky polarization, as required for faint objects or when the moonlight is present (for a detailed description of the instrument, see Scaltriti et al. 1989). The data have been processed with an algorithm which provides the observed degree of polarization P_{obs} and position angle.

3. Results

The following average magnitudes were found in the five bands: U = 18.24 ± 0.13, B = 17.91 ± 0.05, V = 16.24 ± 0.08, R = 15.34 ± 0.03 and I = 14.62 ± 0.07. The flux in U and B bands was too weak to provide useful reliable polarimetric data; therefore in Table I we list only the VRI detections, with the statistical uncertainties. Real detection of polarization is accepted only at 3σ level. We see that in VRI bands no significant variation of the parameters has been detected; through the weighted average over the three bands we get finally the following values for the polarization parameters: P_{obs} = 3.1% ± 0.7% and θ_{obs} = 126° ± 6°.

To deduce the intrinsic polarization of the source, P_* and θ_*, it is necessary to know the contribution of the interstellar polarization, i.e. the values of P_{is} and θ_{is}. Taking into account the uncertainties (at the 3σ level) in the VRI measurements, we believe that a detailed analysis, based on the Serkowski law for the interstellar polarization (Serkowski 1971), does not provide reliable informations. Therefore we assumed the interstellar polarization angle as given by the survey catalogues: in the region of the sky containing the object we estimate $\theta_{is} \approx 36°\pm16°$ (Hall 1958). With these values of θ_{obs} and θ_{is}, reminding the '2θ' dependence of the Stokes parameters (Serkowski 1962), we deduce that the observed and interstellar polarization vectors have approximately the same direction. If we further assume, as a working hypothesis, $P_{is} = 1\%$, we derive the values of the intrinsic polarization parameters for GRO J1655–40: $P_* = 4.1\% \pm 0.7\%$ and $\theta_* = 126° \pm 5°$. This implies also that the lower limit of the fraction of polarized emission is $P_{*,\,\min} \approx 3.1\%$.

4. Discussion

The first important result of our observation is the quite low luminosity of the source at optical wavelengths, when it is highly active at X-ray energies. In fact, data from XTE archive (http://space.mit.edu/XTE/asmlc/scrs/-nsco94.html, pag. 3) show that in the days of our observations the flux in the 2–10 keV band was $\approx 2.4 - 3$ Crab. On the other hand, the detection of a non null fraction of polarized optical emission from GRO J1655–40 can be expected during the phase of high activity of the object. In fact the polarization is expected to be related to the accretion disk/black hole system and not to the companion, which is an ordinary star. By comparing θ_* with the position angle of the jet ($\approx 47°$), we see that the polarization direction is approximately parallel to the accretion disk plane, then the magnetic field will be nearly parallel to the jet direction.

Referring to the problem of the origin of the polarized optical continuum, from the available data we cannot say whether it is due to a nonthermal emission process or electron scattering. We outline the main implications and constraints of these two mechanisms.

Non thermal process. In analogy with AGNs, we expect the observed polarized flux continuum to be related to synchrotron emission from the relativistic plasma inside the jet (see e.g. Ghisellini et al. 1985). We remark in particular that BL Lac and HPQ objects, like GRO J1655–40 and GRS 1915+105, show polarized, highly variable optical emission. The relatively low level of the observed polarization (with respect to the maximum expected from synchrotron radiation) can be due to some intrinsic inhomogeneity of the magnetic field or to the presence of thermal gas in the jet. A possible support to this picture could come from the detection of very high energy radiation, in the hard γ–ray band: the optical synchrotron radiation, in fact, ensures the presence of high energy electrons that can emit, by the inverse Compton process, up to hard γ–ray energies. If γ–rays are actually detected, they will have to originate quite far from the center in order to avoid the absorption, then also the polarized optical radiation (with B nearly parallel to the jet) will be emitted far from the central object. We can argue that the electrons synchrotron emitting at optical wavelengths belong to the same population emitting at radio frequencies. The detection of such optical emission from the radio blobs should be within the capabilities of the Hubble Space Telescope, however the 1995 observation of Tavani et al. (1995) with HST was negative.

Thomson Scattering. The value of θ_* implies the presence of scattering plasma above the accretion disk. We remark that a similar structure is also required by the X-ray properties deduced from the ASCA observations (Tanaka 1996). The detection of absorption lines and edges implies the presence of a thick cool torus around the outer edge of the disk, with column density $N_H > 10^{23}$ cm^{-2}. On the other hand, the above column density would imply an absorption, at soft energies, higher respect to the observed one; this suggests the presence of extended plasma above the accretion disk. We can roughly verify that the picture deduced from X-ray observations is consistent with our polarization data, using the relationship between the degree of polarization and some general properties of the scattering material. For sake of simplicity we assume that the plasma fills a prolated ellipsoid with constant density (n_o) and with the source of optical photons in its center. In this case the amount of polarization expected is given by (Brown & McLean 1977):

$$P \simeq \frac{3}{16}\,\tau_{scatt} R\, f(a) \sin^2 i$$

where τ_{scatt} is the optical depth, i is the inclination angle of the equatorial plane and $f(a)$ is a function of the ratio a of the equatorial to polar radius. Taking into account that by soft X-ray poperties must be $\tau_{scatt} = \sigma_T n_o R \simeq 1$, from the above fomula we see that $2\% \lesssim P \lesssim 7\%$ for $0.3 \lesssim a \lesssim 0.7$.

It is worth noticing that the polarization properties of our source are different from those found for SS 433 (Efimov et al. 1984), where the polarization direction, parallel to the directions of the radio jets, requires a scattering cloud concentrated on the equatorial plane. The origin of this difference between the two objects is likely to be related to the active phase of GRO J1655-40.

5. Summary

We have presented the first results on the optical multiwavelength polarization properties of the superluminal source GRO J1655–40 in active phase: in the VRI bands $\gtrsim 3\%$ of the light is polarized. The origin of the light polarization can be due either to a nonthermal process from the relativistic jet or to the electron scattering. Furthermore we have found that the source was not too bright in the V band, even though it is in outburst at X-ray energies.

For a better comprehension of the origin of the optical polarization further observations are necessary. First of all we expect that the amount of polarization decreases with the activity, and it should almost vanish in the quiescent phase, when the emission of the companion star prevails. Furthermore a monitoring of the variation of P_* with the orbital phase should allow to put constraints on the region where the polarized emission originates.

Acknowledgements. The authors wish to thank S. Massaglia, P. Rossi and M. Tavani for discussions and helpful suggestions

References

Aharonian F.A., Heinzelmann G., 1997, in "15th European Cosmic Ray Symposium 1996", Perpignan, France, 26-30 August 1996, in press
Bailyn C.D. et al., 1995, Nature, 374, 701
Brown J.C., McLean I.S., 1977, A&A, 141, 57
Efimov Y.S., Piirola V., Shakhovskoy N.M., 1984, A&A, 138, 62
Ghisellini G., Maraschi L., Treves A., 1985, A& A, 146, 204
Greiner J., Morgan E., Remillard R.A., 1996, ApJ, 473, L107
Hall J.S., 1958, Publ.of the U. S. Naval Obs., II Series, Vol. XVII, Part VI, 275
Harmon B.A., Wilson C.A., McCollough M., Zhang S.N., Paciesas W.S., Robinson C.R., 1996a, IAU circ. n. 6436
Harmon B.A., Robinson C.R., Fishman G.J., Zhang S.N., Paciesas W.S., 1996b, IAU circ. n. 6501
Hjellming R.M., Rupen M.P., 1995, Nature, 375, 464
Hjiellming R.M., Rupen M.P., 1996, IAU circ. n. 6411
Horne K., Harlaftis E.T., Baptista R., et al., 1996, IAU circ. n. 6406
Hunstead R., Campbell-Wilson D., 1996, IAU circ. n. 6411
Mirabel I.F., Rodriguez L.F., 1994, Nat, 371, 46
Mirabel I.F., Rodriguez L.F., 1996, in Solar and Astrophysical Magnetohydrodynamical flows, K.C. Tsinganos edt., Kluwer Acad. Publ., 683
Orosz J.A., Bailyn C.D., 1997, ApJ, 474, 876
Remillard R., Bradt H., Cui W., Levine A., Morgan E., Shirey B., Smith D., 1996, IAU circ. n. 6393
Scaltriti F., Piirola V., Cellino A., Anderlucci E., Corcione L., Massone G., Racioppi. F., and Porcu F., 1989, Mem. Soc. Astron. Ital., 60, 243
Serkowski K., 1962, Adv. Astron. Astrophys., 1, 289
Serkowski K., 1971, in *Proc. IAU Coll. 151*, Veröff. Remeis-Sternwarte, Bamberg 9, 11
Tanaka Y., 1996, in Röntgenstrahlung from the Universe, H.U. Zimmermann, J.E. Tümper, H. Yorke eds., MPE rep. 263, 85
Tavani M., Fruchter A., Zhang S.N., Harmon B.A., Hjellming R.N., Rupen M.P., Bailyn C., Livio M., 1996, ApJ, 473, L103
Zhang S.N. et al., 1997, ApJ, 479, in press

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.