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GRS 1915+105: A superluminal source in the Galaxy

(stars/x-ray bursts/γ-ray bursts)

LUIS F. RODRÍGUEZ* AND I. FELIX MIRABEL†

*Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 70-264, 04510 México, Distrito Federal, México; and †Service d'Astrophysique/Commisariat a la Energie Atomique, Direction des Sciences de la Matiere/Departement d'astrophysique, physique des particles, nucleaire, et Instrumentation Asocieé Centre d'Etudes de Saclay, F-91191 Gif-sur-Yvette, France

ABSTRACT We present the results of additional observations of the high energy source GRS 1915+105, which produces ejecta with apparent superluminal motions. The observations reported here were carried out with the Very Large Array at 3.5 cm and 20 cm. The 3.5-cm observations made during 1994 May allowed us to continue following the proper motions of the bright 1994 March 19 ejecta, as well as those of a subsequent, fainter ejection. The proper motions of the 1994 March 19 ejecta continued to be ballistic (i.e., constant) over the period of about 75 days where they remained detectable. From the observations in 1994 March–May we have identified three ejections of pairs of plasma clouds moving ballistically in approximately the same direction on the sky with similar proper motions. The 20-cm observations made during 1994 November and December were used to search, yet unsuccessfully, for extended jets or lobes associated with GRS 1915+105.

The hard x-ray transient GRS 1915+105 was discovered by the satellite GRANAT (1) on August 15, 1992. Since then, during repeated periods that lasted several months, it was observed as one of the brighter sources in the sky at energies ≥20 keV (2). Unlike typical x-ray novae, this transient exhibits a slow rise to maximum x-ray luminosity and frequent recurrent activity that lasts several months. The fairly hard spectrum observed by Systeme d'Imagerie Gamma a Masque Aleatoire (SIGMA; ref. 3) and Burst and Transient Source Experiment (BATSE; ref. 2), with emission up to 220 keV and changing photon index between −2.5 and −3.0, are consistent with its being a collapsed object in a binary system. GRS 1915+105 is close to the galactic plane (l = 45.37°, b = −0.22°), and no optical counterpart to a limiting magnitude of 21 in the R band has been found (1, 4). The observations in the H (1.65 μm) and K (2.2 μm) bands of the time variable infrared counterpart indicate that the source is beyond ≥20 magnitudes of optical absorption (4).

Mirabel and Rodríguez (5) found that GRS 1915+105 produces double-sided relativistic ejections of plasma clouds that appear to have superluminal transverse motions. Superluminal motions had been observed before only for radio-emitting components in a number of distant quasars and active galactic nuclei, and, to our knowledge, GRS 1915+105 is the first example of the superluminal phenomenon in our Galaxy. This source had drawn the attention of Mirabel and Rodríguez (5) because during their initial search for the radio counterpart with the Very Large Array (VLA) there were noted intriguing changes in position. From 1992 December to 1993 October the VLA data showed in the centimeter range a time variable [0.1 to 7 milli-Jansky (mJy)], unresolved (≤1″) radio source (4) that appeared to vary by as much as 1″ in position. However, at that time the flux densities were faint and the observations were too scattered in time and with modest angular resolution to understand the origin of these mysterious displacements. In 1993 November 29, during the course of a VLA monitoring program to study possible time variations in the spatial structure of the source, for the first time a remarkable high radio state was observed (6). Since then, a monitoring program was started with the Nançay radiotelescope, and a new radio outburst with fluxes ≥1 Jy was observed with the Nançay and VLA radiotelescopes on 1994 March 24 (7). On that date, the VLA had recently moved to the configuration that provides the higher angular resolution, and until 1994 April 30 Mirabel and Rodríguez (5) followed the evolution of a pair of bright radio condensations moving away from a compact core at relativistic velocities. This very bright ejection, estimated to have taken place on 1994 March 19, is the one best studied (5). However, both before and after this remarkable event, GRS 1915+105 ejected condensations of similar proper motions to those of the 1994 March 19 event but of flux densities one to two orders of magnitude weaker.

In this paper we present the results of additional VLA observations made during 1994 with the purpose of (*i*) following the proper motions of the ejecta, and (*ii*) searching for extended jets and lobes that could be associated with GRS 1915.

Observations of Proper Motions

The 3.5-cm VLA observations were made in the A/B configuration during 1994 May 10 and 31. The approaching and receding condensations of the 1994 March 19 ejection were still detectable in these data, and in Fig. 1 we plot their angular displacements from the stationary core, in addition to the displacements already reported by Mirabel and Rodríguez (5). As shown in the Fig. 1, the angular displacements are consistent with ballistic (that is, unaccelerated) proper motions. The fit to the data is that given in ref. 5. After 1994 May 31, the VLA moved to configuration B, and the lack of angular resolution plus the decrease in flux density with time of the condensations and the appearance of new ejecta made identification of the 1994 March 19 condensations very difficult.

These data and those of 1994 April 30 of Mirabel and Rodríguez (5) have been used to follow the proper motions of an approaching condensation that was ejected in an event following that of 1994 March 19. This approaching condensation is evident in the 1994 April 30 map shown in figure 1 of

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Abbreviation: VLA, Very Large Array.

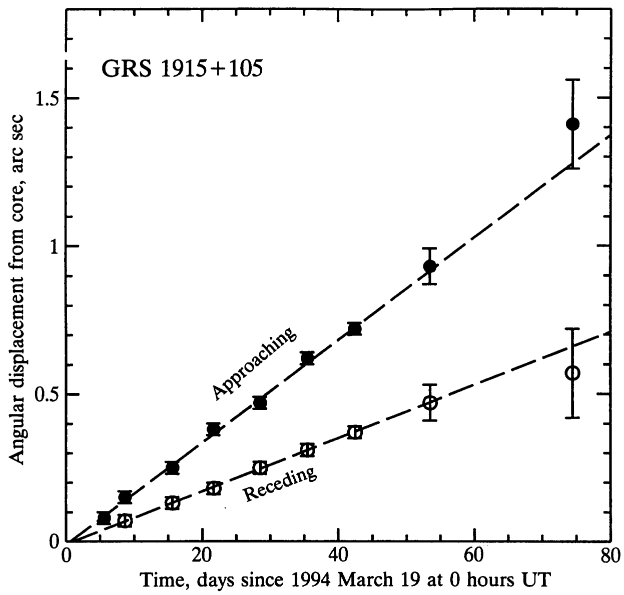

FIG. 1. Angular displacements of the bright radio-emitting components of the 1994 March 19 event as they move from the stationary compact core as a function of time. The two last data points are reported here. The previous data points as well as the fits (dashed lines) are from ref. 5. We find that the proper motions are consistent with ballistic motion for the time interval of ≈75 days over which we could follow the condensations.

ref. 5 and reproduced here as Fig. 2. From the available data we estimate a proper motion of μ_a = 15 ± 2 milliarc sec/day, consistent with the more accurate value of μ_a = 17.6 ± 0.4 milliarc sec/day found in ref. 5 for the approaching condensation of the 1994 March 19 ejection. From extrapolation of the proper motions, we estimate that the new ejection took place around 1994 April 10.

Also before the bright 1994 March 19 ejection, we had observed ejecta from GRS 1915. The approaching and receding condensations of an ejection that we estimate took place in 1994 February 16 can be seen in the 1994 March 27 and April 3, 9, and 16 maps shown in Fig. 2. The proper motions for these ejecta are consistent within observational error with those of the 1994 March 19 event. The time separation between ejections suggests a quasiperiodicity with intervals in the range of 20–30 days.

Search for Extended Jets and Lobes

To search for extended jets and lobes associated with GRS 1915+105, we did sensitive 20-cm continuum observations of the region with the VLA in the C configuration during 1994 November 16 and 25 and December 2 and 18. A map made with these data is shown in Fig. 3. No evidence for extended jets was found in this map. Our interest was aroused by the existence of two radio sources located symmetrically about 17′ from GRS 1915+105 and at a position angle of 157° ± 1°, consistent with the position angle of ejection determined by Mirabel and Rodríguez (5). However, these two radio objects are bright sources in the IRAS catalog (IRAS 19124+1106 and IRAS 19132+1035, respectively), and their 20-cm radio continuum flux densities (80 and 40 mJy, respectively) and 100-μm infrared flux densities (580 and 490 Jy, respectively) are consistent with their being H II regions located at ≈10 kiloparsec and powered by late O-type stars. Nevertheless, given the remarkable symmetry with respect to GRS 1915+105 and the coincidence in position angle with the compact ejecta, further research could be interesting.

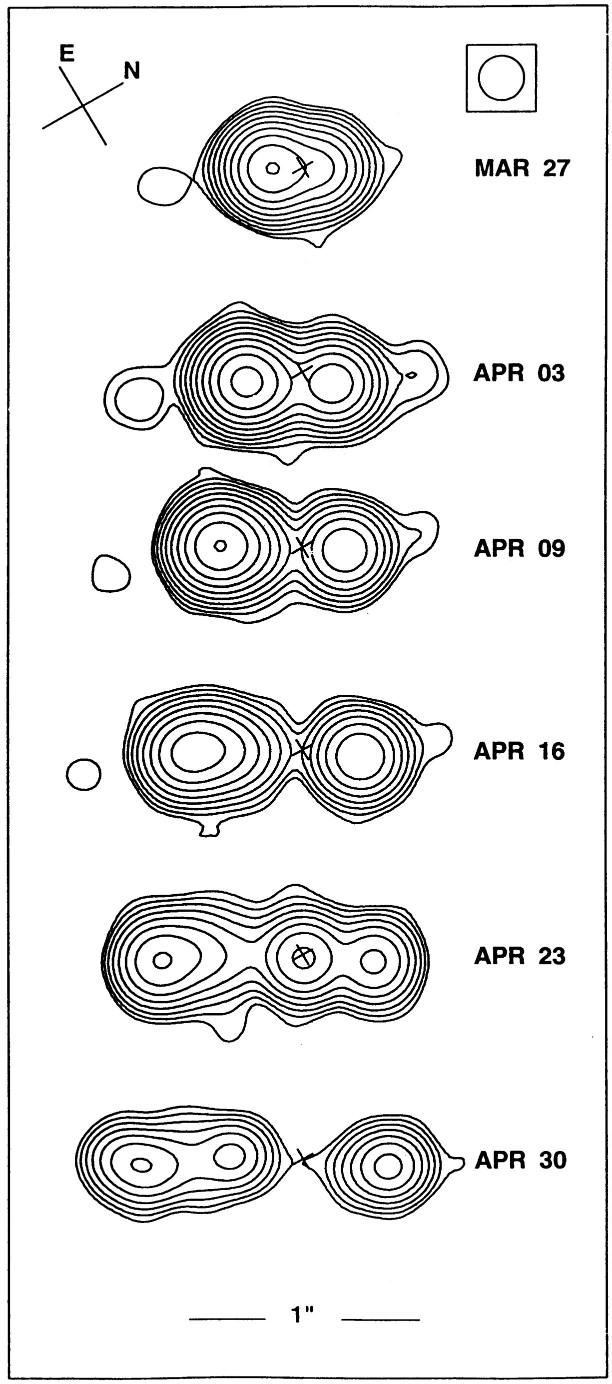

FIG. 2. Pair of radio condensations moving away from the hard x-ray source GRS 1915+105. These uniform-weight VLA maps were made at λ3.5 cm for the 1994 epochs shown on the right side of the figure. Contours are 1, 2, 4, 8, 16, 32, 64, 128, 256, and 512 times 0.2 mJy per beam for all epochs except for March 27, where the contour levels are in steps of 0.6 mJy per beam. The half power beam width of the observations, 0.2 arc sec, is shown in the top right corner. The position of the stationary core is indicated with a small cross. The maps have been rotated 60° clockwise for easier display, and the actual orientations of the north and east are also shown in the top left. The scale of 1 arc sec is also indicated at the bottom of the figure. Note in the first four epochs the presence of a fainter pair of condensations ahead of the bright ones and in the last epoch the presence of a new southern component. [Modified with permission from ref. 5 (copyright Macmillan).]

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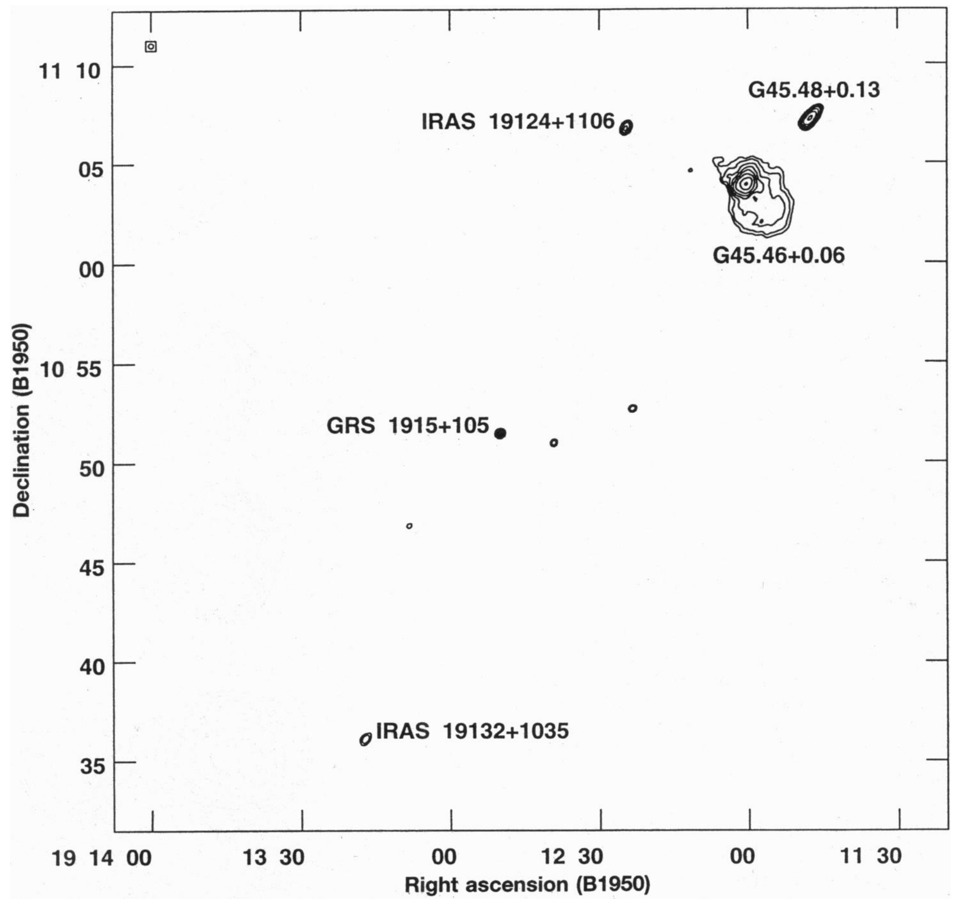

FIG. 3. VLA map at 20 cm of the GRS 1915+105 region made in the C configuration. Contours are −4, 4, 8, 16, 32, 64, 128, 256, and 512 times 0.5 mJy per beam, the rms noise of the map. The half power contour of the beam is shown in the top left corner. The sources G45.48+0.13 and G45.46+0.06 are well-known H II regions. We detected radio continuum emission associated with the bright IRAS sources IRAS 19124+1106 and IRAS 19132+1035, which appear symmetrically located with respect to GRS 1915+105. Most probably, these IRAS sources are H II regions powered by late O-type stars. The map is not corrected for primary beam response, and sources away from the phase center appear weaker than they are. The sources away from the phase center also show bandwidth (radial) smearing.

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