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The first winged microquasar.

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Abstract

Microquasars are stellar binary systems that share strong physical and morphological analogies with extragalactic sources of relativistic jets. In this work, we report very deep radio images of the microquasar GRS 1758−258 . At sensitivities down to the few μJy level, GRS 1758−258 broadens these already known analogies by including the same 'wing' phenomenon observed in some radio galaxies. The so called winged radio galaxies display secondary radio lobes, with Z or X-shaped morphologies, whose physical interpretation often invokes the merger of super-massive black holes with spin-flip. GRS 1758−258 remarkably displays Z-type wings too, extending on parsec linear scales as long as the main jet flow. Owing to its stellar nature, the most physically conceivable explanation is based on hydrodynamic backflow when the relativistic ejecta interacts with a nearby cloud. Moreover, emission line surveys of the region do confirm the existence of such a cloud at a kinematic distance consistent with that of GRS 1758−258. By extrapolating these findings to the extragalactic case, we conclude that not all winged radio galaxies are secure sites of previous black hole coalescence since the alternative backflow scenario could also be at work in many cases.

1 Introduction

The realm of extragalactic radio sources hosts objects with a rich variety of morphologies in their large-scale collimated outflows. In particular, the so-called radio galaxies are often sorted into one of the two Fanaroff-Riley types (FRI or FRII) according to their radio lobe brightness aspect [1]. Yet, there is a significant fraction of distorted cases that challenge the simplicity of this historical classification scheme. Among them, the growing group of winged radio galaxies (WRGs) stands out as a remarkable sub-class whose radio lobe morphology, with X or Z-type appearances, is not apparently consistent with a single ejection axis [2, 3]. It is worth to mention here that a high fraction of X-type sources could actually be Z-types too distant to be recognized as such [4]. Different physical explanations have been proposed to account for the WRG existence with no consensus being reached within the astrophysical community. The strongest debate is between, but not limited to, the supporters of the hydrodynamic [5, 6, 7] versus the super-massive blackhole merger scenarios with spin-flip [8, 9, 10]. Solving this issue is nowadays relevant in the context of the new-born gravitational wave astronomy since WRGs could have implications for the gravitational wave background if a blackhole coalescence is indeed behind their origin [3].

In this contribution, we report about the remarkable winged features found in the microquasar known as GRS 1758−258 located in the close vicinity of the Galactic Center. This object was originally discovered in hard X-rays by the coded mask telescope *SIGMA* on board the satellite *GRANAT* back in the 90s of the past century [11]. Bipolar radio jets were detected soon after [12] and they have been intensively studied over the years [13, 14]. The similarity of the newly found wings with those seen in some WRGs reinforces the parallelism between stellar sources of relativistic jets and their extragalactic relatives, such as radio galaxies and quasars. Moreover, the maturity of nowadays stellar evolution knowledge also enables a new perspective when trying to discriminate among possible physical scenarios where wings can form. A fully detailed account of all our results can be found elsewhere [15].

2 Radio observations

To obtain a radio image of GRS 1758−258 as deep as possible, we carried out dedicated observations with the *Jansky* Very Large Array (VLA) at the 6 cm wavelength. In addition, historical VLA runs of the same source were retrieved from the NRAO Science Data Archive with the idea of trying to merge them with the modern data. To achieve good sensitivity at the arc-minute angular scales, typical of our target radio jets, the C configuration of the array was preferred. The log of observations used and their instrumental setup are listed in Table 1.

Table 1: Radio observations of GRS 1758−258

Run Id.	Date	Array Configuration	Bandwidth (MHz)
AM385	1992 Sep 10-11	D	50
AM345	1992 Sep 26-27	D	50
AM428	1993 Oct 03-04	CD	50
AM560	1997 Aug 03-24	C	50
AS930	2008 Apr 01-12	C	50
16A-005	2016 Mar 04-22	C	2048

The reader is referred to the Methods section in [15] for a comprenhensive account of how calibration was carried out using both the CASA and AIPS software packages. This was a painful process because combining modern and historical VLA data sets is by no means straightforward. The final result is presented in the map shown in Fig. 1 whose noise level is a low as 4.3 μJy beam^{-1} and noticeably improved over our previous works[14].

3 Discussion

In addition to the already known extended radio jets, the most interesting fact in Fig. 1 is that GRS 1758−258 exhibits the same characteristics of a Z-type WRG. Notably, the observed secondary lobes have an angular scale comparable to that of the main jet flow. This is the first time that such a morphology in observed in a microquasar system. Two consequences immediately follow from this discovery: i) The analogy between galactic and extragalactic sources of relativistic outflows is reinforced to include the terminal jet lobes; ii) The spin-flip scenario is ruled out in a downsized winged jet flow. This is because our current understanding of stellar evolution in binary systems precludes the merger of black holes during the past existence of this microquasar. Indeed, a non-degenerate star, acting as mass donor onto a single compact object, is presumed to exist in GRS 1758−258 [16].

In this context, what is the physical scenario that better fits the existence of a Z-type winged microquasar? In an attempt to answer this question, we inspected the environments of GRS 1758−258 using the Dame's carbon monoxide (CO) survey of the Galactic Plane[17]. As we report and discuss in [15], a conspicuous gas cloud appears to be hit by the microquasar jets and the backflow caused by this interaction with the interstellar medium (ISM) is very likely related to the formation of the wings. The CO cloud velocity with respect to the Local Standard of Rest (LSR) is centered at about 210 km s^{-1}, and the associated kinematic distance for this LSR velocity turns out to be ~ 8.5 kpc. This is in good agreement with the value usually adopted for this microquasar as required for this interpretation to be correct. The brightness difference between the northern and southern ejecta is attributed to a ISM with an asymmetric density distribution. Recent hydrodynamic backflow scenarios, such as [7], are thus favored to be also at work in the particular case of this microquasar.

4 Conclusions

Secondary radio lobes similar to those observed in WRGs have been detected for the first time in a microquasar. This observational discovery provides a step forward towards a unified knowledge of relativistic outflows in the universe, to be pursued in future works. By extrapolating our GRS 1758−258 findings to the extragalactic domain, another important conclusion is that WRGs are no longer secure tracers of past black hole mergers in the universe. Therefore, estimates of the gravitational wave background based on their observed population can be lower than predicted and in likely need of revision.

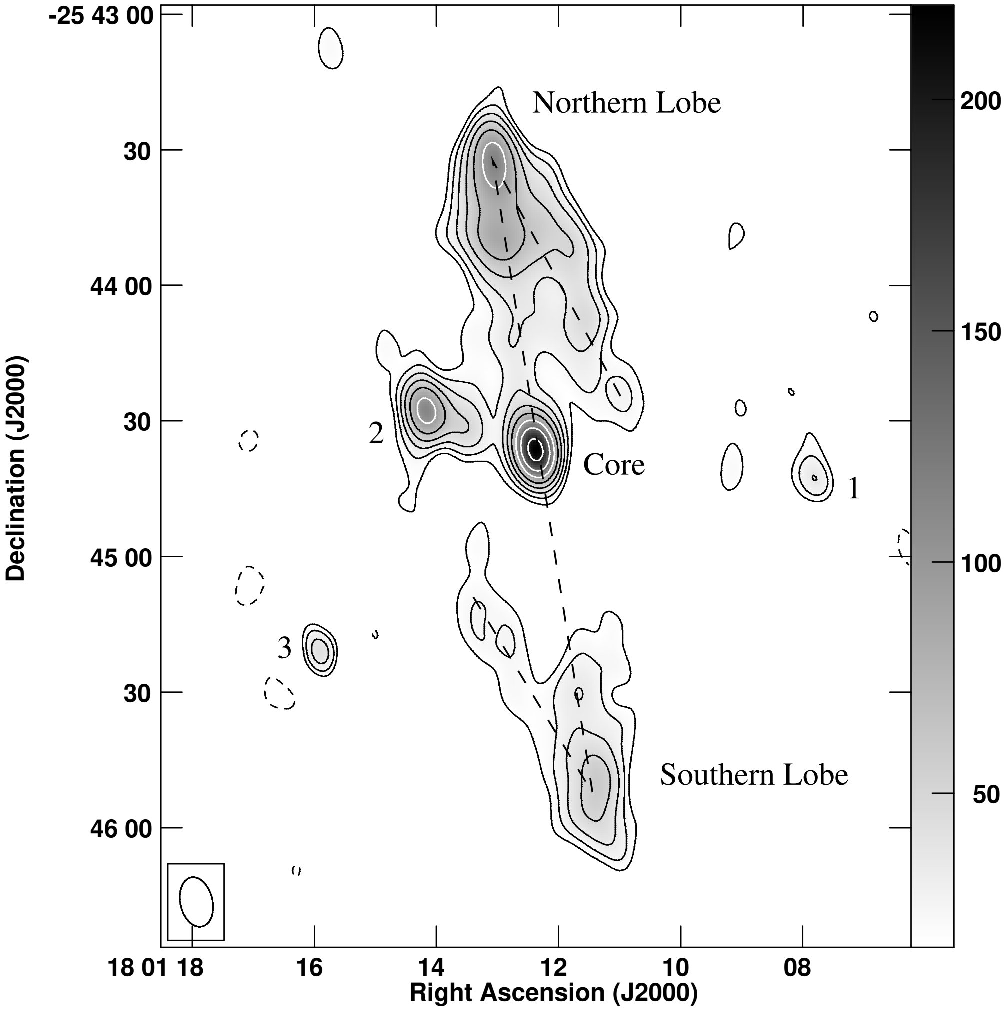

Figure 1: Deep radio image of the GRS 1758−258 radio jets and lobes at the 6 cm wavelength obtained as described in the text using the JVLA and the historical VLA data. The Z-shaped winged morphology is outlined by the dashed line. The bottom-left ellipse represent the half-power beam width of the restoring beam, measuring 11.13 × 7.12 arcsecond^2 with position angle of 12.7°. The positive contours shown start at the 4-σ level of 17.2 μJy beam^{-1}, and increase progressively by a factor of $\sqrt{2}$. The brightness scale is illustrated by the vertical bar in units of μJy beam^{-1}. Sources labelled 1, 2, and 3 are believed to be unrelated objects.

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