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DETECTION OF A COLLIMATED JET TOWARDS A HIGH-MASS PROTOSTAR

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RESUMEN

Presentamos el descubrimiento de una fuente triple de radiocontinuo asociada al objeto IRAS 16547−4247. Los índices espectrales de los tres componentes son consistentes con un chorro impulsado por una estrella masiva tipo 'O' en proceso de formación, en donde los componentes de radiocontinuo exteriores corresponden al gas chocado en las superficies de trabajo del chorro. La emisión en radiocontinuo detectada del objeto central se piensa que proviene del chorro mismo, antes de la formación de una región H II detectable. Los tres componentes de radiocontinuo se ubican dentro de un núcleo molecular de masa $10^3\,M_\odot$. Nuestro descubrimiento hace de IRAS 16547−4247 el objeto estelar joven más luminoso ($\sim 6.2\times10^4\,L_\odot$) del cual emana un chorro térmico, sugiriendo que el mecanismo que produce los chorros en la formación de estrellas de baja masa también opera en la formación de estrellas de alta masa.

ABSTRACT

Here we present the discovery of a triple radio continuum source associated with IRAS 16547−4247. The spectral indices of the three components are consistent with a jet powered by a massive O-type star in the process of formation, with the outer radio components being the shocked gas at the working surfaces of the jet. The detected radio continuum emission from the central object is thought to arise from the jet itself, prior to the formation of a detectable H II region. All three radio continuum components are located within a molecular core of mass $10^3\,M_\odot$. Our discovery makes IRAS 16547−4247 the most luminous ($\sim 6.2\times10^4\,L_\odot$) young stellar object from which a thermal jet emanates, suggesting that the mechanism that produces jets in low-mass star formation also operates in high-mass star formation.

Key Words: **ISM: INDIVIDUAL (IRAS 16547−4247) — ISM: JETS AND OUTFLOWS — STARS: FORMATION**

1. INTRODUCTION

The earliest phases of massive star birth are not well defined. The emerging consensus is that massive star formation begins in cold ($<$ 30 K) dense ($> 10^5\,\mathrm{cm}^{-3}$) cores of giant molecular clouds (GMCs). Once the stars become hot enough they ionize the surrounding gas, forming ultra-compact H II (UCH II) regions, which then start to expand. It is not clear if the stars themselves are formed by an accretion process similar to that for low-mass stars or instead by collisions with lower-mass stars—perhaps it is a combination of both (see review by Garay & Lizano 1999). The high detection of bipolar molecular outflows in massive stars (e.g., Beuther et al. 2002) indicates that flows are a ubiquitous phenomena in the formation of stars across the mass spectrum. Frequently observed towards young low-mass stars are highly collimated radio jets as well as Herbig-Haro (HH) objects and it is now widely accepted that jets are intimately linked to the formation of both molecular outflows and HH objects (see review by Reipurth & Bally 2001). The interplay between collimated jets and molecular outflows in massive stars (B and O-type stars) is less clear. In this higher mass regime observations of jets are difficult, particularly because the evolutionary timescales of jets are expected to be much shorter. Of all the known sources to have collimated jets, the four with the brightest luminosity are: Cepheus A-HW2 at 725 pc (Gómez et al. 1999); HH 80/81 at 1.7 kpc (Marti, Rodríguez, & Reipurth 1998); IRAS 20126+4104 at 1.7 kpc (Shepherd et al. 2000) and G 192.16−3.82 at 1.8 kpc (Shepherd, Claussen, & Kurtz 2001). All of these objects have luminosities less than $2\times10^4\,L_\odot$. Up until now no such jets have been detected towards any O-type stars.

2. OBSERVATIONS

IRAS 16547−4247 is one object from a sample of 20 luminous *IRAS* sources that we are studying in

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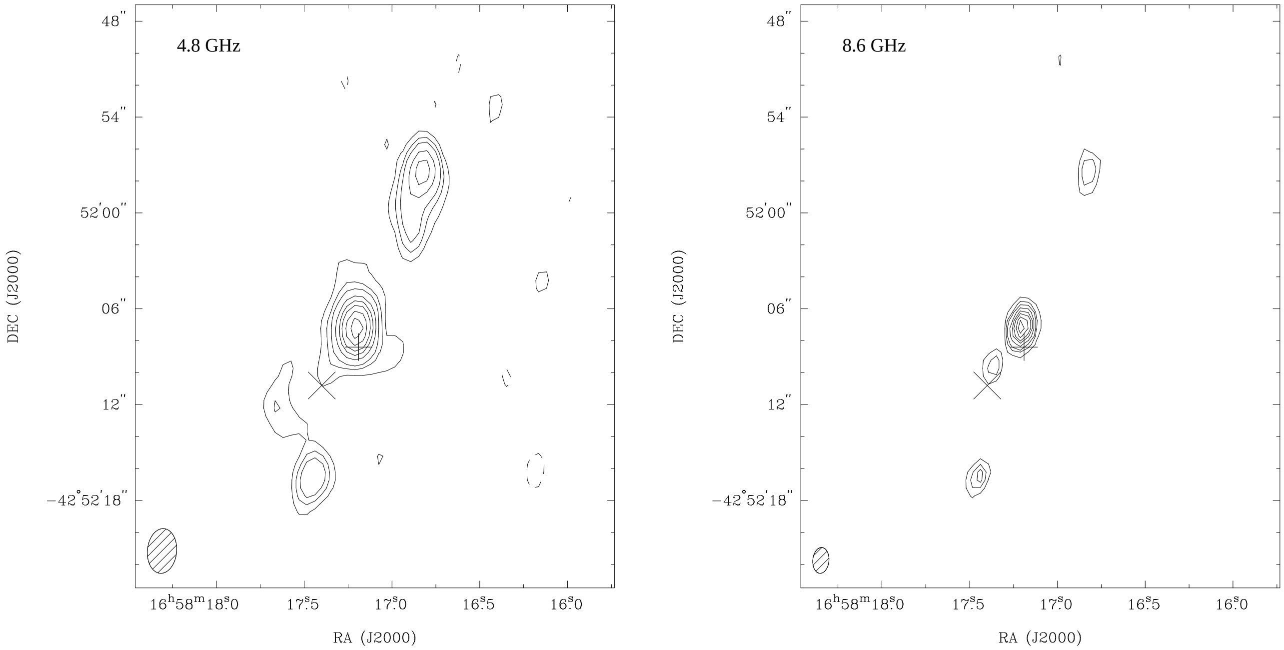

Fig. 1. ATCA maps of the radio continuum emission from IRAS 16547−4247. Beams are shown in the lower left corner of each panel. Contour levels are -1, 1, 2, 3, 5, 7, 9, 12, and 15 times 0.30 mJy beam^{-1} ($1\sigma = 0.096$ mJy beam^{-1} at 4.8 GHz, and 0.070 mJy beam^{-1} at 8.6 GHz). Also shown are the OH maser position (+) from Caswell (1998) and the H_2O position (×) from Forster & Caswell (1989).

detail. These sources are thought to be representative of young massive star-forming regions. Our goal is to understand the physical and chemical differences between different stages of early evolution. The sources in our sample were chosen from the Galaxy-wide survey of CS(2–1) emission towards 843 *IRAS* sources with infrared colours typical of compact H II regions (Bronfman, Nyman, & May 1996). Each source selected for our sample showed line profiles indicative of either inward or outward motions and in some cases broad wings. Their *IRAS* luminosities were in the range 2×10^4 to $4 \times 10^5\,L_\odot$, implying that they all contain at least one embedded massive star ($> 8\,M_\odot$). Our study involves radio continuum observations at four frequencies (1.4, 2.5, 4.8, and 8.6 GHz) using the Australia Telescope Compact Array (ATCA), 1.2 mm continuum observations using the SIMBA 37-channel bolometer array installed at the SEST, as well as a series of SEST molecular-line observations between 85 and 250 GHz.

3. RESULTS

Figure 1 shows the radio continuum maps at 4.8 and 8.6 GHz towards IRAS 16547−4247. The radio emission arises from three components aligned in a southeast-northwest direction. The outer components are symmetrically located in opposite directions from the central source, with peak positions separated by an angular distance of $\sim 20''$ (0.28 pc at the distance of 2.9 kpc: Bronfman, private communication). Using the radio data at all four frequencies, the spectral indices for each of the three components were measured. The spectral index for the central object is 0.49 ± 0.12 and is consistent with thermal emission produced by a biconical jet (Reynolds 1986). The spectral indices of the emission from the outer components are negative (-0.61 ± 0.26 and -0.33 ± 0.04) and are consistent with shock-induced synchrotron emission (Blandford & Eichler 1987). This arises at the working surface of the jets, where the collimated winds from the jet interact with the surrounding medium.

The 1.2 mm continuum emission detected towards IRAS 16547−4247 is just resolved with a diameter of 0.4 pc and has a flux density of 16.3 Jy. Assuming a dust opacity at 1.2 mm of 1 cm^2 g^{-1} (Ossenkopf & Henning 1994) we derive a mass of $1.3 \times 10^3\,M_\odot$. Results from the line observations indicate the presence of a molecular gas core with a molecular hydrogen column density $N(H_2) = 6 \times 10^{23}\,cm^{-2}$, density $n(H_2) = 5 \times 10^5\,cm^{-3}$, and mass of $9 \times 10^2\,M_\odot$. The triple radio source is located within the molecular core and centered on the 1.2 mm continuum emission peak.

The total luminosity of IRAS 16547−4247 is estimated to be $6 \times 10^4\,L_\odot$, equivalent to that of a single O8 ZAMS star. If an O8-type star were responsible for this high luminosity then we expect to measure a radio flux of 3 Jy at optically thin frequencies if embedded in a uniform density medium. However, the observed flux of the central source at 8.6 GHz is 6 mJy. One explanation for the high luminosity and weak radio emission could be that IRAS 16547−4247 is a dense, massive molecular core which hosts a young, massive protostar that is still undergoing an intense accretion phase, whereby dense material is still falling towards the protostar and quenching the development of an UCH II region (e.g., Yorke 1984). Under this premise the detected weak radio continuum emission from the central component is produced by internal shocks within the jet (e.g., Anglada et al. 1998). Adding support to this hypothesis are the characteristics of the observed molecular line profiles. For instance, the spectral appearance of the optically thick HCO^+(1–0) and optically thin $H^{13}CO^+$(1–0) lines are consistent with inward-moving motions with a characteristic infall speed of $0.75\,\mathrm{km\,s^{-1}}$, implying a mass infall rate of $\sim 1 \times 10^{-2}\,M_\odot\,\mathrm{yr}^{-1}$. This is ample for the suppression of an UCH II region around an O-type star ($\sim 1 \times 10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$ according to Walmsley 1995). Furthermore, in some species, particularly SiO and SO, the spectra show the presence of strong wing emission indicative of outflow activity.

IRAS 16547−4247 is associated with a *Midcourse Space Experiment* (*MSX*) unresolved emission source that is brightest at band E (18.2 to 25.1 μm). Interestingly, the source appears isolated from any bright star-forming regions. Perhaps this is why it is possible to detect a jet here.

4. CONCLUSIONS

The preponderance of the evidence suggests that we are seeing toward IRAS 16547−4247 a jet powered by a massive O-type star in the process of formation, with the outer radio lobes corresponding to the shocked gas at the working surfaces of the jet. Our discovery makes IRAS 16547−4247 the most luminous ($\sim 6.2 \times 10^4\,L_\odot$) young stellar object from which a thermal jet emanates, suggesting that the mechanism that produces jets in low-mass star formation also operates in high-mass star formation.

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