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The enigmatic radio emission from θ^1 Orionis A

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Abstract. The bright star θ^1 Orionis A, the third most luminous OB star in the Orion Trapezium Cluster, is known as a strongly variable non-thermal radio source. The physical nature of the emission mechanism has been a matter of debate since almost two decades. In this contribution we re-analyse available radio data in combination with near-infrared observations to investigate the radio-emission mechanism and the nature of the underlying stellar source. The constraints on the size of the non-thermal radio emission imply the presence of very large magnetic structures, while the infrared data suggest the stellar source is a pre-main sequence intermediate mass star. We therefore suggest that the flaring radio emission of θ^1 Orionis A emerges from strong magnetic shearing and reconnection between the magnetic (possibly chemically peculiar) intermediate-mass star θ^1 Orionis A2 and its circumstellar disk.

Key words. Stars: radio stars – Stars:

1. Introduction

The object θ^1 Orionis A is a luminous OB star in the center of the Orion Nebula Cluster. High spatial resolution imaging and photometric monitoring actually revealed its stellar multiplicity (Lohsen 1975; Baldwin & Mattei 1976; Petr et al. 1998). The primary component, θ^1 Ori A1, is a B0.5V high-mass star that is eclipsed by a T Tauri type star with an orbital period of P=65.4d. The tertiary component, named θ^1 Ori A2, is separated from θ^1 Ori A1 by $\sim 0.2''$ and its stellar properties are mostly unknown.

What makes θ^1 Ori A special is the detection of strong, nonthermal radio emission that had first been found by Garay et al. (1987) and Churchwell et al. (1987) in VLA observations. During repeatedly observed flaring events at $\lambda = 2$cm and 6cm, the source had been the brightest radio source in the whole Orion Nebula cluster. The radio emission is variable with a ratio of 40 between the strongest flare and the quiescent level (Felli et al. 1993). During an extensive monitoring, lasting 250 days, Felli and co-authors noticed that the time scale of the variability must be smaller than the sampling interval of 10–20 days. Furthermore, Churchwell et al. (1987) found the source to be unpolarized at 2 cm (either circular or linear) to a level of less than 5% and resolved at a resolution of 0.1”. The nature of the radio emission, variable but associated to a large structure, as well as the identification of the unique source (which component of the triple system) has been a puzzling issue since then.

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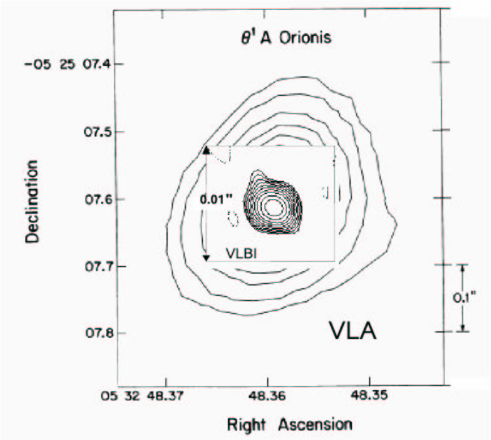

Fig. 1. Radio morphology of θ^1Ori A at large-scale (VLA, beam 0".14 × 0".13, λ = 2cm, Churchwell et al. 1987) and small-scale (VLBI, 2 mas circular beam, λ = 6 cm, Garrington et al. 2002).

2. New results from radio observations – radio structure

Recent radio observations carried out with MERLIN and global VLBI providing sub-mas astrometry have finally solved the positional uncertainty of the θ^1Ori A radio source: Garrington et al. (2002) indisputable associated the radio emission with the visual component θ^1Ori A2.

In Figure 1 we show the radio image of θ^1Ori A by Churchwell et al. (1987), partially resolved at the VLA resolution of 0.1", together with the VLBI image of Garrington et al. (2002), also just resolved at 2 mas. We postulate here, that the radio emission indeed is a combination of thermal emission coming from a large (VLA-resolution) source, and non-thermal emission coming from a much smaller (VLBI-resolution) source being responsible for the strong variability. Still, the nonthermal emission region is rather large, 1 mas corresponding to ~0.45AU, or to 20 R_*, for $1R_* = 4.5R_\odot$. The size of the magnetosphere (Alfvén radius R_A, André et al. 1988) for mass loss rate 10^{-8}M$_\odot$yr^{-1} and terminal wind velocity $v_\infty \simeq 300$ km s^{-1} (Montmerle this volume) may reach 20 R_* only for a magnetic field strength of 10 kG.

θ^1 OriA2 seems very similar to the young radio-emitting magnetic B star S1, in the ρ Oph cloud, also presenting a nonthermal source surrounded by a thermal extended halo (André et al. 1988).

3. Infrared observations

In order to investigate the stellar characteristics of the radio emitter θ^1 OriA2 we analyzed near-infrared data from the literature together with new measurements obtained with the ESO/ADONIS and ESO/NACO adaptive optics instruments (Petr-Gotzens & Massi, in prep.) Whenever speckle imaging or adaptive optics techniques were used, we could extract individual near-infrared photometry for both, θ^1 OriA2 and θ^1 OriA1. Surprisingly, we find that the system brightness at J, H, or K-band, as reported by the various authors, shows a large discrepancy (up to ~ $0.5^{\rm m}$ at J, ~ $0.6^{\rm m}$ at H, ~ $0.8^{\rm m}$ at K), which is larger than the typically quoted individual uncertainties. Either the photometry is complicated due to the large crowding in the Trapezium or the source is variable. On the other hand, the brightness ratio of θ^1Ori A1/θ^1Ori A2 is rather consistent across different authors. As there is no good reason why a specific measurement from a certain group of authors should be preferred, we translate the range of photometric results to an uncertainty in the near-infrared colours and magnitudes of θ^1Ori A2. Consequently, the possible space for the radio emitter θ^1Ori A2 in the colour-colour diagram (Fig. 2) and colour-magnitude diagram allows for a number of valid interpretations of its stellar nature.

From the colour-colour diagram we deduce that θ^1Ori A2 might either be a slightly extincted late-type dwarf or a highly extincted ($A_V > 3$mag) early type star (see also Schertl et al. 2003). However, the observed J-band luminosity of θ^1Ori A2 indicates that it is too luminous to be consistent with a young late-type, i.e. low-mass star. Comparing the possible positions of θ^1Ori A2 in the colour-magnitude diagram with pre-main sequence evolutionary tracks by Palla & Stahler (1999), we find that θ^1Ori A2 is at least a moderately massive, probably pre-main sequence star with

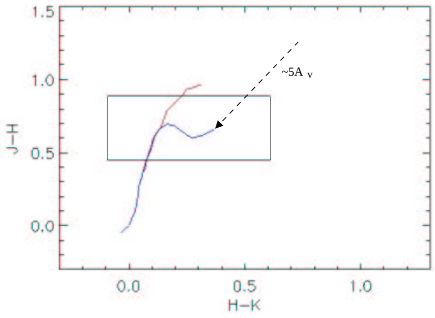

Fig. 2. Near-infrared colour-colour diagram for the star θ^1Ori A2. The box outlines the possible space for θ^1Ori A2 in this diagram. The box is large, because of the large differences in JHK-photometry reported by different authors. The solid lines indicate the location of dwarf and giant stars.

$M_\star > 3.5M_\odot$. On the other hand, from the photometric information alone, we cannot exclude that θ^1Ori A2 might even be a cool giant, as proposed by Vitrichenko et al. (2001), although we consider this option less likely (Petr-Gotzens & Massi 2007).

4. Conclusions

Given our constraints from the radio and the near-infrared data, the star could conceivably be a young magnetic star. The strong radio flares might imply the presence of a circumstellar disk, with interacting star-disk structures as described in Feigelson et al. (2002). In such a scenario radio flaring would be caused by shearing, disruption and subsequent reconnection of the magnetic fields between a young, chemically peculiar/magnetic, intermediate-mass star and its circumstellar disk (Feigelson & Montmerle 1999; Montmerle et al. 2000). The radio flaring rate, smaller than 10 days (Felli et al. 1993) could be related to the fast rotation period (of few days) of Herbig Be stars. In order to prove *i*) eventual periodicities in the non thermal emission and *ii*) the presence of a constant thermal emission, future simultaneous VLBI and VLA observations are scheduled.

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