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Fine structures of star formation region in Orion KL epoch 2003

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Star formation is accompanied by powerful H_2O maser emission, which allows us to determine 3D structure. The structure of the active region in Orion KL consists of rigid-body rotating disk, diameter 27 AU, and highly collimated bipolar outflow. The surrounding matter is pulling to the disc, moves to the nozzle through helix arms, and ejects in the form of a bipolar outflow. The process is accompanied by powerful H_2O maser flares. In 1998 the flux was 4 MJy, $V = 7.65$ km/s, brightness temperatures of ejecting flows on exit of the nozzles reach $T_b > 10^{16}$ K. We conducted VLBI research of active region in quiescent epoch 2003 with 150 microarcsecond angular resolution. Velocity of the line profile is shifted to 8 km/s. The structure has highly collimated bipolar outflow with compact fragments, the brightness temperature of the nozzle is $T_b \leq 10^{14}$ K. The visible size of outflow increased from 2 to 9 AU. The outflow has gradient in line-of sight velocity ∼0.04 [km/s]/AU, which corresponds to its acceleration. Fragments are visible up to 46 AU. The outflow has very high collimation ∼250, which is determined by interactions with surrounding medium.

Keywords: Masers; Star formation; Bipolar outflows; Jets

1 Introduction

Gravitational instability in gas-dust complexes gives rise to active regions of protostar formation. The formation of protostars is accompanied by strong maser emission in water-vapor lines. The flux density reaches several tens of kJy. In extremely rare cases, intense H_2O maser flares are observed (Matveyenko et al. 1980). In the Orion Nebula, compact maser sources are concentrated in eight zones whose sizes reach 2000 AU (Downes et al. 1981). The line-of-sight velocities of the maser sources are within several tens of km/s. There were two high activity periods in one of the zones in Orion KL – 1979–1987 and 1998–1999. The flux densities of H_2O maser flares reached 8 MJy on velocity 7.65 km/s, and the linewidth of profile was 0.5 km/s. The coordinates of the active region are RA = 5h35m14s.121 and DEC = –05°22′36″.27 (2000.0).

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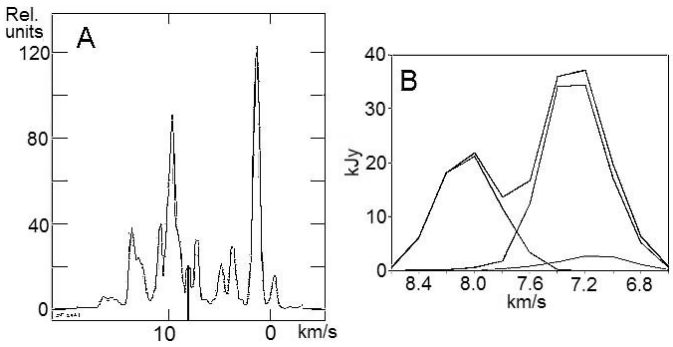


Figure 1 The spectral line of Orion KL. (A) – epoch 2003, KL spectra; (B) – epoch 2003.1, maser flare region.

Below, we analyze the fine structure of the active supermaser emission region over the quiescent epoch 2003, following the high activity of 1998–1999.

2 Superfine structure of active region – quiescent period

We studied the fine structure with the Very Long Baseline Array (VLBA) data from the NRAO archive. The line spectrum of Orion KL is shown in Fig. 1A. On the maser flare velocity 7–8 km/s – red line, flux does not exceed several KJy. Profile of the line spectrum in this range is shown in Fig. 1B.

The high signal to noise ratio allowed us to obtain radio maps with resolution 0.15 mas (0.07 AU) (Fig. 2 A–D). The fine structure of the active region is investigated. It is established that in the region corresponding to H_2O maser flare the structure remained the same as in the previous epochs – quiescence 1995 and high activity 1998 (Fig. 2E–F). It consists of bipolar outflow and compact fragments – bullets. The spectrum may be decomposed to three Gaussians with velocities 7.3, 7.1 and 8.1 km/s (Fig. 1B), each of which is a separate spatial feature. The 8.1 km/s line corresponds to a bipolar outflow (Fig. 2A); 7.3 and 7.1 km/s, to its remote fragments – bullets (Fig. 3) (Demichev & Matveyenko 2004).

In 2003 the visible size of outflow increased from 5 AU on 3 January to 6 AU on 24 March, and up to 9 AU on 31 August (Figs. 1 and 2). Such an increase in visible size is determined by observation of fine structures, usually blended by bright ejector emission in the active epochs. The orientation of the outflow is PA $\sim -42°$, changing only slightly in 2003. The width of the outflow does not exceed 0.07 AU. The line of sight velocity of outflow decreases with time from $V = 8.07$ km/s in January–March to $V = 7.97$ km/s in August. The flux density of maser emission is 20 KJy in January, then increases to 32 KJy in March, after that slowly decreases to 27 KJy in the beginning of August and 30 KJy in the end. Emission line profiles have width in the range 0.51–0.61 km/s. Brightness temperature of the nozzle of the outflow reaches $T_\mathrm{b} \sim 10^{14}$ K (Table 1), and elongated structures have $T_\mathrm{b} \sim 10^{13}$ K. Its orientation PA $\simeq 42°$ changes only slightly, within 5 degrees to previous epochs (Table 1).

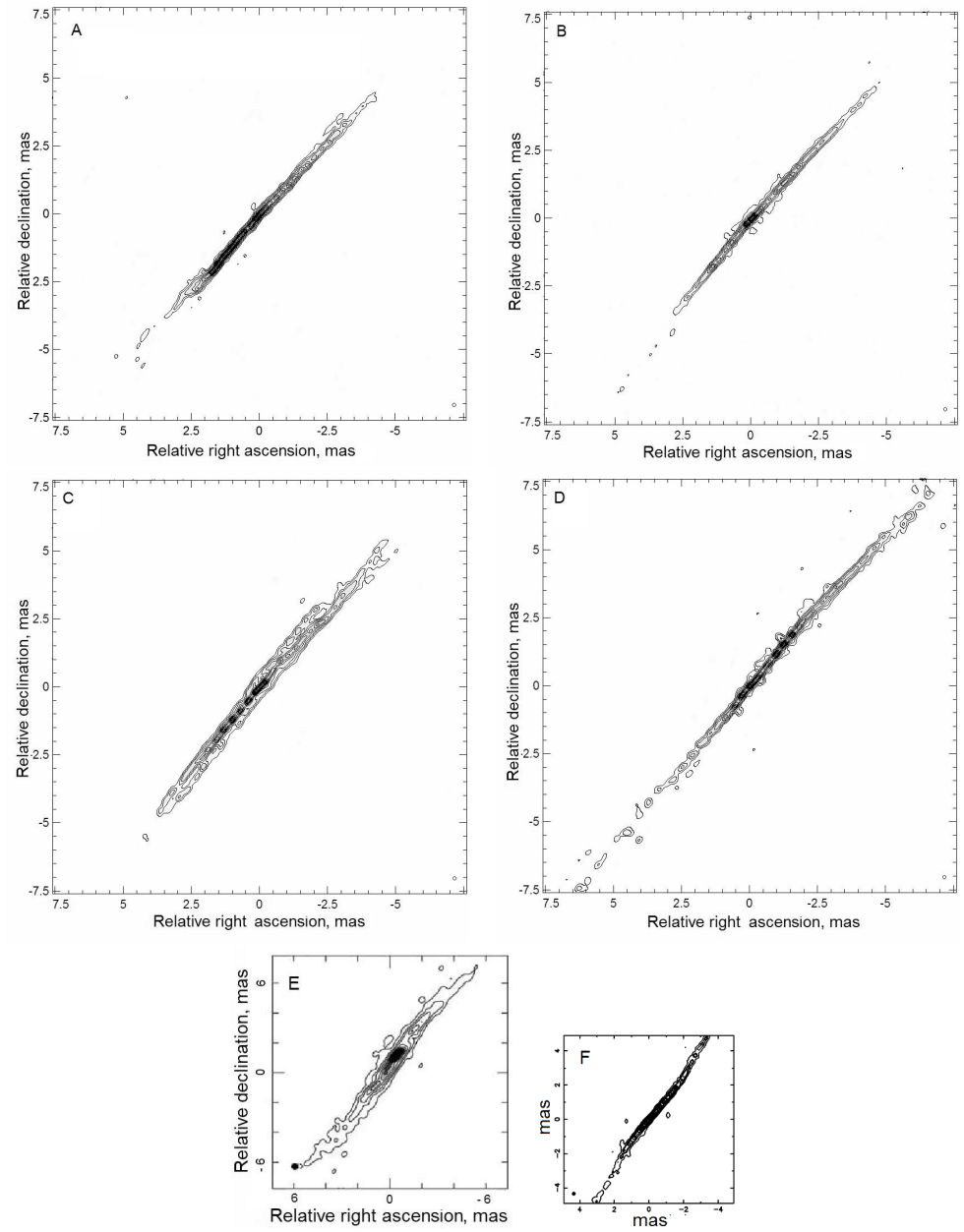


Figure 2 The superfine structure of bipolar outflow in different epochs: (A) – 03.01.2003; (B) – 24.03.2003 (C) – 03.08.2003; (D) – 31.08.2003 (E) – 26.05.1995; (F) – 14.10.1998.

3 Bipolar outflow velocity

We have determined that the line-of-sight velocity of the outflow profile is equal to 8 km/s in epoch 2003. This is 0.4 km/s more than in active epoch 1998 and quiescent

Table 1 Parameters of bipolar outflow in different epochs.

Date	F, KJy	Size, AU	$V_{\rm LSR}$, km/s	ΔV, km/s	PA°	$T_{\rm ej}, 10^{13}$ K
May 26 1995[a]	1	8×0.5	7.65	0.5	–37	0.1
Oct 14 1998[b]	2000	5×0.07	7.65	0.5	–39	1000
Jan 03 2003[c]	20	5×0.07	8.07	0.58	–43	5
Mar 24 2003	32	6×0.07	8.06	0.51	–42	10
Aug 03 2003	27	6×0.07	7.98	0.58	–41	5
Aug 31 2003	30	9×0.07	7.97	0.61	–42	6

[a]Matveyenko et al. 2000
[b]Matveyenko et al. 2004
[c]Ejector is not clearly visible

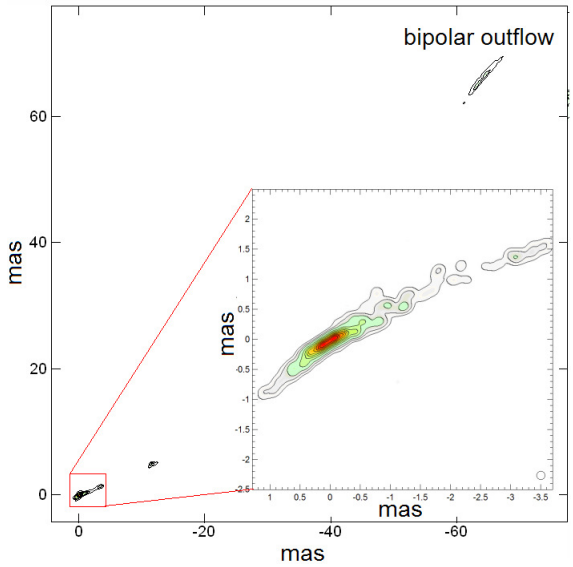


Figure 3 A fragment of the outflow (bullets) is located 46 AU away from the bipolar outflow (epoch 2003).

epoch 1995. The cause of this shift is unclear, but probably it is connected with decreasing of amplification in the surrounding envelope, which amplifies the maser emission by 2–3 orders of magnitude at a velocity of 7.6 km/s (Matveyenko et al. 2000). Changing of amplification may also result in a low maser flux with the same structure in 2003. The gradient of velocity along the outflow (the line side of view) is equal to 0.02 [km/s]/mas (0.04 [km/s]/AU), and is determined by acceleration. As is shown by Matveyenko et al. (2010) the outflows are accelerated to velocities of 40 km/s. The observed small relative velocities of 0.08 km/s in NW and 0.14 km/s in SE outflows are projections of outflow velocity determined by its orientation very close to the plane of view (Fig. 4). Collimated structures of the outflows were traced up to a distance of 5 AU; fragments, of 46 AU (Demichev & Matveyenko 2004). Very high

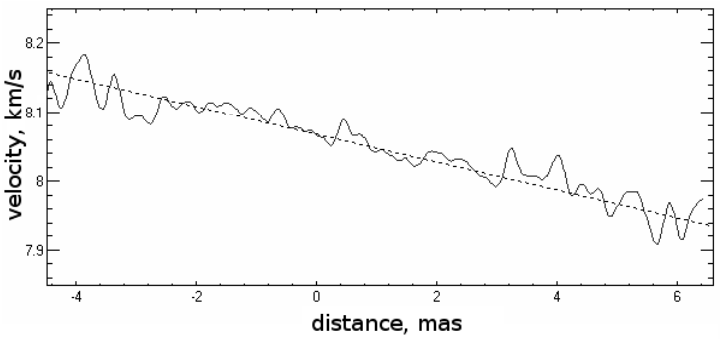


Figure 4 Velocity distribution along the outflow (Mar 24 2003).

collimation of the outflows reaches 250 and is the result of gas-dynamics interactions of rotating outflow with surrounding medium (Abrahamjan 2009). The outflow is collimated like a vortex or a tornado.

4 Conclusions

• The fine structure of the bipolar outflow is investigated in epoch 2003 in Orion KL active zone. The structure does not change.
• The visible size of the outflow increases to 9 AU and fragments – 46 AU, which determines very high collimation.
• The collimation is the result of gas dynamics: rotating outflow interacts with surrounding medium.
• The line-of-sight velocity of the outflow increases to 8.1 km/s, which is probably due to variations of surrounding medium amplification of maser emission.
• The outflow has a small gradient of the line-of-sight velocity, ∼0.04 [km/s]/AU along the structure that corresponds to its acceleration.

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