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Accretion disc and bipolar outflow in Orion KL

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Abstract.
We studied the structure of a star formation region in Orion KL, with angular resolution 0.1 mas or 0.05 AU. The structure consists of a 27 AU accretion disk, a bipolar outflow, comet-like bullets and an envelope. The accretion disk is divided into proto-planetary rings with $V_{rot} \sim \Omega R$ and period T=180 yrs. The kinetic energy of the rotating disk is transformed into bipolar outflow and bullets, the velocity of which are ∼ 10 km/s. The outflow has a helical structure, determined by injector precession. The high directivity of H_2O maser emission of the rings together with precession affect its visibility. The shell amplifies emission by more than two orders at V=7.65 km/s.

Key words. young star, masers, accretion disk, bipolar outflow, shell

1. Introduction

Gravitational instabilities in gas-dust complexes lead to the formation of active zones containing protostars and are accompanied by powerful H_2O maser emission at $\lambda = 1.35$ cm. The maser emission could be associated with ambient gas and dust, where planets and comets also form. H_2O maser radiation is a good indicator of these processes and offers the possibility of detecting and investigating spatial structure and dynamics with VLBI methods. In Orion KL star formation is accompanied by outbursts of H_2O maser emission. We measured the fine structure of the outburst region with the global VLBI network and the VLBA. The angular resolution was ∼ 0.1 mas or 0.05 AU and velocity resolution 0.05 km/s (Matveyenko L.I. 1981).

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2. Structure of star formation region

2.1. Accretion disk

The H_2O super maser emission was observed in Orion KL from 1979-1988 with flux densities ($F \leq 8$ MJy) and 1998-1999 ($F \leq 4$ MJy). The emission was linearly polarized $m \leq 75\%$. The profile width was $\Delta V \sim 0.5$ km/s and velocity V_{LSR}=7.65 km/s. The structure of the flare region is a chain of four groups of compact ≤ 0.1 AU components during 1979-1987 (Fig. 1). The diameters of the circles are $\sim logT_b$. The brightness temperatures of the sources are $T_b = 10^{15} - 10^{16}$ K. The components are distributed along a thin S-shaped structure 27 × 0.3 AU, $T_{peak} = 10^{13-14}$ K (Fig. 1). Velocities of the components increase along the chain from $V_W = 6.45$ km/s to $V_E = 8.75$ km/s (Fig. 1., bottom right). The velocity gradient is $\Delta V/\Delta L \approx 0.16$ km/s/AU. The velocities of the brightest components $T_b \sim 10^{17} K$

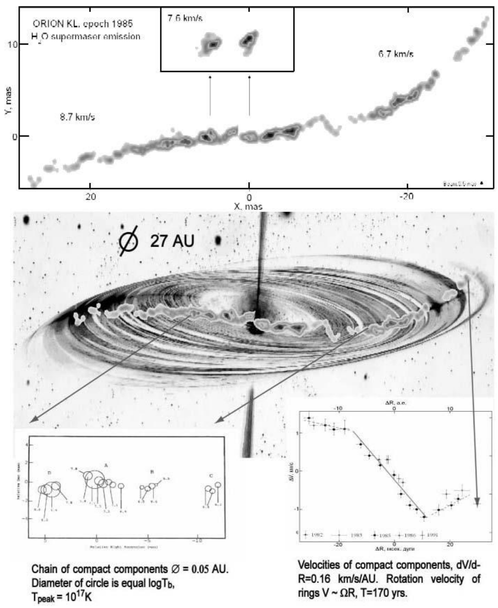

Fig. 1. Compact components distributed along S-shaped structure (top) corresponding to an accretion disk visible edge-on (center). Compact components (left) are distributed along the structure. Velocity distribution of compact components (right).

are $V \sim 7.65$ km/s (Matveyenko et.al. 1998; Demichev et al. 2004).

2.2. Bipolar outflow

During the quiescent period in 1995 a bipolar outflow and comet-like bullets were seen (Matveyenko et.al. 1998). The outflow size was $4.5 \times 0.07 AU$, $PA = -33^{\circ}$, and brightness temperature $T_b = 10^{12}$ K. In the central part of the structure is located a bright $T_b = 10^{13}$ K compact 0.05×0.15 AU, $PA = -44^{\circ}$ source - injector. The bullets are observed at a distance of 27 AU NW, and 22 AU SE with radial velocities $\Delta V_{NW} \sim -0.18$ km/s and $\Delta V_{SE} \sim 0.32$ km/s. During 1998-1999 the brightness temperatures of the structure increased by more than 3 orders (Fig. 2). The outflow was highly collimated, orientation was $PA = -45°$ at first, later $PA = -38°$. The helical form of the outflow suggests precession of the injector axis, with a period $T \sim 10$ yrs

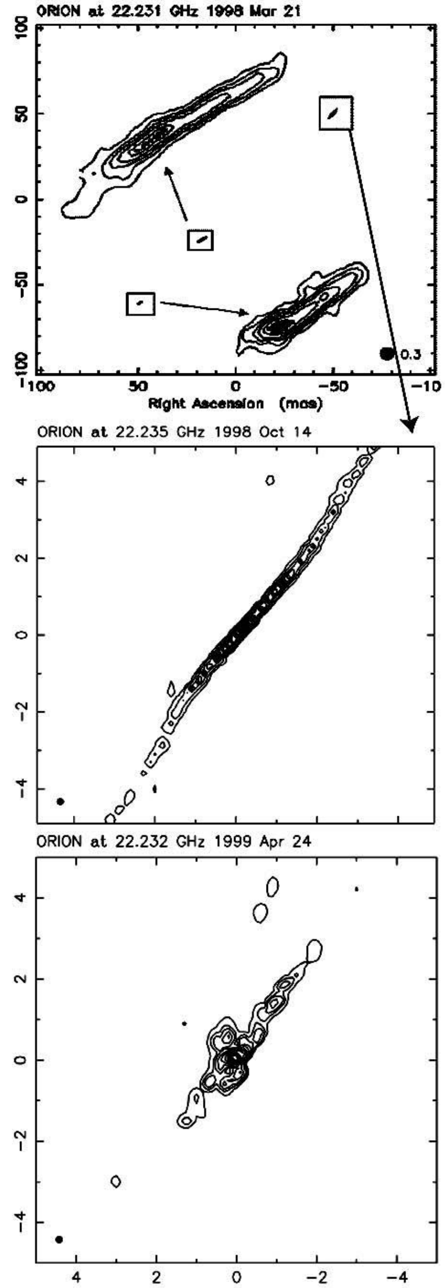

Fig. 2. Bipolar outflow on March 21 1998, comet-like head/tail components (top) Highly collimated bipolar outflow 1998 Oct 14 ,high activity period (center) Torus structure at the end of activity - Apr 24 1999 (bottom).

and angle 16°. Towards the end of the high activity period (April 1999) a toroidal structure was seen (Fig.2) (Matveyenko et.al. 2003, 2005). The relative radial velocities of outflows are $V_{NW} \sim 0.1$ km/s and $V_{SE} \sim -0.1$ km/s. Compact bright features are included in the outflow, the velocities of which are $V \sim 10$ km/s at the beginning, and $V \sim 3$ km/s in the end of the activity.

3. Interpretation

These studies of Orion KL show that H_2O super maser emission is determined by: accretion disk, torus, bipolar outflow, bullets, and shell. The disk is divided into proto-planetary rings viewed edge-on. The disk is in solid-body rotation with a rotation period ~170 yrs. The surrounding matter, including H_2O molecules, is accreted at the disk and ejected in the highly collimated bipolar stream. The kinetic energy of the rotating rings transforms to outflow $\sim V_{rot}^2$, where $V_{rot} \sim \Omega R$. The outflow direction is ~ 33° and differs from the orientation of the disk axis. The mass limit of a central object can be estimated from the outer disk region $R \leq 7AU$, $V_{rot} \sim 1$ km/s. In Keplerian approximation $M \sim 0.01 M_{\odot}$. Collisions, stellar wind and IR pump maser emission of the structures. The maser emission of the rings is concentrated in the azimuth plane $\leq 10^{-3}$. Visibility of the emission is determined by precession making the disk appear edge-on. Compact bright knots are located in the outflow with velocities $V \sim 10$ km/s at the beginning of activity 1998, and $V \sim 3$ km/s at the end 1999. The helix structure of outflow assumed connected with injector precession with period $T \sim 10$ yrs. A head/tail cometary structure is observed (Fig. 2). The tail can be in front of, or behind the head explaining relative velocities of stellar wind and the feature. The region of super maser radiation is located in the core of the dense molecular cloud - OMC-1, with velocity $V_{LSR} = 7.65$ km/s (Matveyenko et.al. 1998). This surrounding medium or envelope amplifies the emission of the structure by more than two orders of magnitude at velocities $V = 7.65$ km/s. The window of amplification is $\Delta V \sim 0.5$ km/s which limits visibility of structures.

4. Conclusion

Formation of the low mass star is accompanied by an accretion disk, bipolar outflow, and shell. An accretion disk $\oslash = 27$ AU is separated into proto-planetary rings and torus. Bipolar outflow has a helix form. Emission of rings has high directivity, visibility of the rings depends of precession. The limit of central body mass is $\sim 0.01\ M_{\odot}$. The surrounding matter, including H_2O molecules, is accreting at the disk, and ejected in the bipolar stream. Kinetic energy of the rings is transformed to the outflow, with velocity ~ 10 km/s.

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