Cosmic Masers - from OH to H_0
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Massive star-formation toward G28.87+0.07

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Abstract. We investigated the high-mass star-forming region G28.87+0.07 by means of maser kinematics, including H_2O, CH_3OH, and OH, and radio to infrared, continuum observations. All observational evidence suggests that these masers are associated with the same young star of 20-30 $M_\odot$, still in the main accretion phase and surrounded by a rich stellar cluster.

Keywords. ISM: individual objects (G28.87+0.07) – ISM: kinematics and dynamics – masers – techniques: interferometric

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Understanding the process of high-mass star formation represents a challenge from both theoretical and observational points of view. A few years ago, we started an observational project to study the high-mass star-forming process by comparing interferometric images of thermal lines of molecular tracers with multi-epoch VLBI studies in three well known maser species (OH, CH_3OH and H_2O). At present, three sources (IRAS 20126+4104, G16.59−0.05 and G23.01−0.41) have been already analyzed (Moscadelli *et al.* 2011, Sanna *et al.* 2010a, Sanna *et al.* 2010b). The results demonstrate that **the synergy between VLBI, multi-species maser observations and (sub)mm interferometric observations of thermal molecular lines is crucial to achieve a multi-scale picture of the environment of newly formed massive (proto)stars**. Here we represent our study of the high-mass star-forming region (HMSFR) G28.87+0.07.

We observed the HMSFR G28.87+0.07 with the VLBI phase-referencing technique in three powerful maser transitions: 22.2 GHz H_2O (VLBA, four epochs), 6.7 GHz CH_3OH (EVN, four epochs), and 1.665 GHz OH (VLBA, one epoch). In addition, we also performed VLA observations of the radio continuum emission at 1.3 and 3.6 cm with both the A- and C-arrays, and Subaru observations of the mid-infrared continuum emission. We also made use of data from the Hi-GAL/Herschel, ATLASGAL/APEX, as well as other surveys of the Galactic plane. More details on the observations are described by Li *et al.* 2012. From all these observations, we draw the following conclusions:

(*a*) The bipolar distribution of line-of-sight velocities and the general pattern of observed relative proper motions indicate that the water masers are tracing a (proto)stellar jet along the northeast-southwest direction (Fig. 1), which is also powering the large-scale outflow (Furuya *et al.* 2008).

(*b*) The positions of the CH_3OH maser features roughly along the jet axis (Fig. 1), and the similarities in the spectral shape of the water and methanol maser emissions, suggest that also the CH_3OH masers could originate in the same jet, albeit associated with more quiescent gas than that traced by the water masers.

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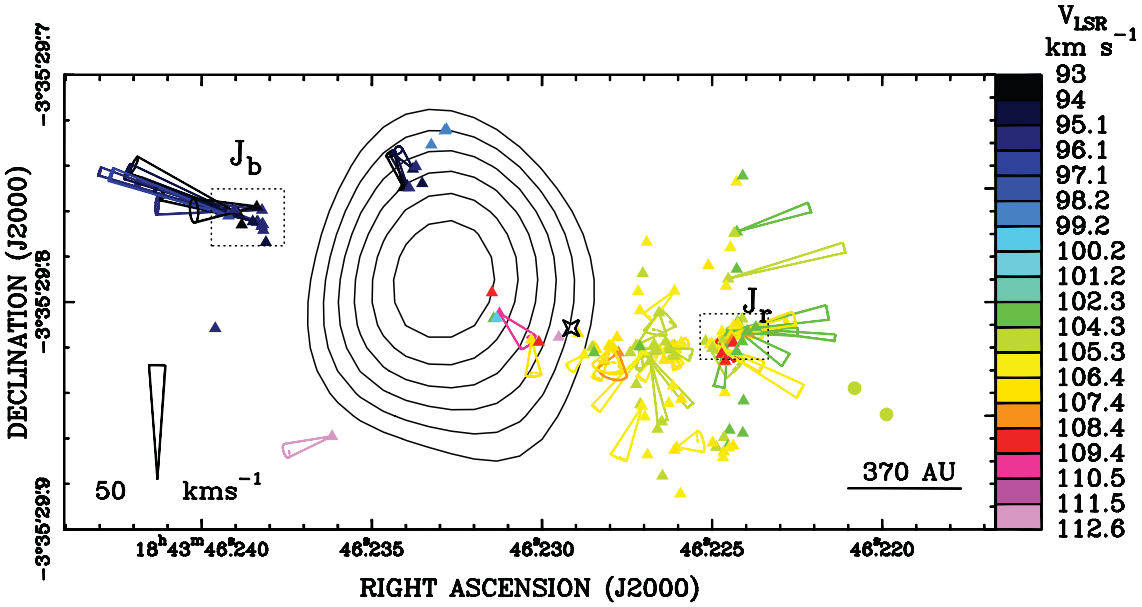

Figure 1. Proper motions of 22 GHz H_2O masers (triangles) relative to their "center of motion" (marked with a cross), and spatial distribution of 6.7 GHz CH_3OH masers (dots) in G28.87+0.07. Different colors are used to indicate the maser LSR velocities, according to the color scale on the righthand side of the plot. The cones indicate the 3-D velocities of the water maser features relative to the "center of motion" . Points without an associated cone have been detected only over one or two epochs and the associated proper motion cannot be computed or is considered unreliable. The cone opening angle gives the 1σ uncertainty on the proper motion direction. The length of the cone is proportional to the velocity, with the amplitude scale indicated in the lower left corner of the figure. Open dotted rectangles mark two clusters of water masers located at the northeast and southwest edge of the distribution (labeled "J_b" and "J_r", respectively), moving fast and close to the northeast-southwest direction. The VLA 1.3 cm continuum emission is plotted with solid contours. Contour levels range from 40% to 90% of the peak emission (0.62 mJy beam^{-1}) at multiples of 10%.

(*c*) The continuum sources "HMC" is spatially associated with the observed H_2O, CH_3OH and OH masers. Whether the free-free emission arising from this source is due to an HII region or a thermal ionized jet cannot be unambiguously established with the present data. However, we believe that the jet hypothesis is more consistent with the direction of the water maser motions, which outline expansion in a bipolar flow.

(*d*) The combined information obtained from IR observations, permits to estimate with good accuracy the luminosity (2×10^5 $L_\odot$) and gas mass (3×10^3 $M_\odot$) of the star forming region of G28.87+0.07, and establish that ∼90% of the luminosity is coming from the radio source "HMC". We conclude that this source must contain multiple stars, with the most massive being at least as luminous as 3×10^4 $L_\odot$. The lack of an associated HII region indicates that the 20–30 $M_\odot$ star must be still undergoing heavy accretion from the surrounding envelope.

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References

Furuya, R. S., Cesaroni, R., Takahashi, S., *et al.* 2008, *ApJ*, 673, 363
Li, J. J., Moscadelli, L., Cesaroni, R., *et al.* 2012, *ApJ*, accepted
Moscadelli, L., Cesaroni, R., Rioja, M. J., *et al.* 2011, *A&A*, 526, 66
Sanna, A., Moscadelli, L., Cesaroni, R., *et al.* 2010a, *A&A*, 517, 71
Sanna, A., Moscadelli, L., Cesaroni, R., *et al.* 2010b, *A&A*, 517, 78

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