Part Ic. CH_3OH MASERs

Cosmic MASERs: From Protostars to Blackholes
IAU Symposium, Vol. 206, 2002
V. Migenes and M. J. Reid, eds

Interstellar methanol masers

Karl M. Menten
Max-Planck-Institut für Radioastronomie
Auf dem Hügel 69, D-53121 Bonn, Germany

The asymmetric rotor molecule methanol (CH_3OH) has hundreds of transitions at centimeter-, millimeter-, and submillimeter wavelengths. Many of these are excited in the hot ($T \gtrsim 150$ K), dense ($n \gtrsim 10^6$ cm^{-3}) molecular cloud cores surrounding newly formed massive stars or protostars. The high temperatures in these cores cause evaporation of icy grain mantles, releasing copious amounts of complex molecules, such as methanol, in the gas phase, which in hot cores has abundances (up to 10^{-6} relative to H_2) that are two or more orders of magnitude higher than in cold dark clouds.

Most notably, strong, in some cases very strong, interstellar maser emission has been discovered, to date, in more than three dozen methanol transitions at cm- and mm-wavelengths. All of these are detected in regions of high-mass star formation and belong to either one of two classes: class I or class II. Class I methanol masers, first detected by Barrett et al. (1971) in the $J_{k=2} \rightarrow J_{k=1}E$ ($J = 2, 3, 4 \ldots$) transitions near 25 GHz toward the Orion BN/KL region, are frequently, if not generally, associated with outflows driven by young massive stellar objects and possibly trace the working surface of these flows with ambient molecular cloud material. Dozens of class I masers have been discovered mostly in the $7_0 \rightarrow 6_1A^+$ transition near 44 GHz, a number of which have been mapped with the Very Large Array.

Class II CH_3OH masers, the most prominent of which are the $5_1 \rightarrow 6_0A^+$ and $2_0 \rightarrow 3_{-1}E$ lines near 6.7 and 12.2 GHz, respectively, are generally found close (within a few thousand AU) to the embedded massive star that dominates the energy output of a region and has, in many cases, already ionized an ultracompact HII region. As reported by others in these proceedings, to date several hundreds of 6.7 GHz masers have been detected, mostly with telescopes in the southern hemisphere. Arcsecond accuracy positions have been determined for many of these with the Australia Telescope Compact Array. An ever increasing number has been mapped with milliarcsecond accuracy using the European VLBI Network. In several sources the maser spots seem to be aligned in string-like structures, which have been interpreted to trace circumstellar disks, although so far no conclusive evidence for (Keplerian) rotation has been presented.

The pumping of class I methanol masers is almost certainly collisional. The observed pattern of maser action in some transitions and enhanced absorption (over-cooling) in others can be explained from the energy level structure and the fact that $\Delta k = 0$[1] collisions are preferred relative to $\Delta k = \pm 1$ collisions, leading

[1] k is the quantum number of the projection of the angular momentum J on the symmetry axis. $-J \leq k \leq J$ for the E symmetry species.

to overpopulation of whole k ladders relative to others and giving rise, e.g., to the masers in the $4_{-1} \rightarrow 3_0 E$ and $5_{-1} \rightarrow 4_0 E$ transitions near 36 and 84 GHz, respectively, and enhanced absorption in the 12 GHz $2_0 \rightarrow 3_{-1} E$ line, which is, as mentioned above, one of the two dominant class II *maser* lines. If, in contrast, a strong far infrared field is present, infrared excitation becomes important and class II CH_3OH masers arise, while class I transitions do not show maser action. The pumping most likely involves excitation to the first torsionally excited state, which is above $\gtrsim 300$ K, and subsequent de-excitation to the ground state. Because torsional excitation has a $\Delta k = \pm 1$, but not 0, selection rule, netting an effective $\Delta k \pm 2$ selection rule for de-excitation following excitation, one again ends up with a situation in which whole, or large parts of, neighboring ladders are overpopulated relative to each other. This situation is supported by observations.

Although statistical equilibrium calculations have been performed that seem to explain the observed masers, reliable quantitative estimates of the physical conditions in the masing regions have to await the calculation of collisional excitation rate coefficients. Such calculations are possible with modern computer technology and are actually being performed as of this writing.

Since in the past there has been some confusion about the relationship of class I and class II CH_3OH masers based on low spatial resolution single dish data, it is worth pointing out that interferometry shows that, while on parsec scales class I and class II CH_3OH masers might be found in the same general star forming region (e.g. Sgr B2), they are usually well separated from each other. Also, in some sources, like Sgr B2, the class I masers might pinpoint the interaction region of a cloud-cloud collision and, near the Galactic center, the interface of the Sgr A supernova remnant with dense molecular cloud material.

References

Barrett, A. H., Schwartz, P. R., & Waters, J. W., 1971, ApJ, 168, 101