PUMPING OF STRONG H_2O COSMIC MASERS

V.S. Strelnitsky
Astronomical Council, USSR Academy of Sciences

ABSTRACT

All the existing models of H_2O masers fail to explain such a strong source as W49 N. Observed and theoretical quantities are related by: $n_{H_2O}W_p\ \ell^3 \gtrsim 10^{46}$ S, where S is the maser flux density (in Janskys), n_{H_2O} is the H_2O number density (cm^{-3}), W_p is pump rate (s^{-1}), and ℓ is the length of amplification region on the line of sight (cm). Models involving vibrational activation (or deactivation) of H_2O by H_2 (Goldreich and Kwan, 1974; Norman and Silk, 1979), with the usual cross-section $\sigma^{\nu} \lesssim 10^{-19} cm^2$, require $\ell > 10^{16}$ cm for the strongest H_2O features ($\sim 10^4$ Jy), which is unacceptable in view of the VLBI results. Besides, because σ^{ν} is so small, it is questionable if vibrational pumping could control rotational level populations at all. Depending on the energy source and sink there are four possible schemes of rotational pumping: CR, RC, RR, and CC (C - collisional, R - radiative). The first was modelled by de Jong (1973) and by Shmeld et al. (1976). Though difficulties with the sink (Goldreich and Kwan, 1974; 1979) are avoidable in the model by Shmeld et al. (Strelnitsky, 1979), $\ell \gtrsim 10^{15} - 10^{16}$ cm is still required for the strongest features. Therefore other possibilities of rotational pumping are being investigated. One CC-model is presented below.

CC-pumping is possible if two kinds of particles with different temperatures are present. These can be electrons and H_2 molecules which at $T \sim 1000$ K compete in rotational excitation of H_2O when $10^{-6} \lesssim n_e/n_H \lesssim 10^{-4}$ (cf. Itikawa, 1972). In principle, both $T_H > T_e$ and $T_H < T_e$ may suffice for the pump, but numerical investigation (Bolgova, 1979) favors $T_H > T_e$ for H_2O $6_{16} - 5_{23}$ inversion. CC-pumping may be realized as follows. A strong stellar wind (e.g. $M \sim 10^{-5} M_{\odot}/yr$, $v_w \sim 400$ km/s) from a pre-MS star is stopped by clumps either generated by the interaction of the wind with the circumstellar nebula (Norman and Silk, 1979) or present in the nebula before the wind is switched on. At $\sim 10^{15}$ cm from the star the clumps are compressed to $n_H \sim 10^{11} cm^{-3}$ by the ram pressure of the wind and heated by MHD-turbulence (Norman and Silk, 1979)

B. H. Andrew (ed.), Interstellar Molecules, 591–592.

or by shock waves alternating with expansion waves. In both cases the average energy input reaches $\sim 10\,\rho\, v^3/d$, v being velocity of the gas at greatest scale d. With $v \sim 10$ km/s at $d \sim 10^{14}$ cm (e.g. shock velocity at indicated density) the input is $\sim 10^{-8}$ ergs/cm^3·s and gas with $n_{H_2O} \sim 10^{-3}\, n_H$, $n_e \sim 10^{-6}\, n_H$ is maintained at 1000 - 1500 K, its cooling being due primarily to H_2O (and/or CO, CH_4) vibrational photons generated by electron impact and leaked from the clump or lost on the cold dust. In shocks and in Alfvenic turbulence heavy particles are heated first and electrons will remain 5 - 10% cooler than H_2 owing to greater energy losses. Then W_p is $\sim 3.10^{-2}$ s^{-1} and $\ell \sim 3.10^{14}$ cm is sufficient to explain the strongest H_2O features. The fast (5-10 MeV) protons accelerated by the plasma turbulence in the compressed stellar wind or less energetic particles generated in the turbulent clump itself should ensure the required ionization losses ($\gtrsim 10^{-5}$ of the total energy input). The temperature of the gas is controlled by the (variable) stellar radiation, so the observed correlated variations of maser features (Gammon, 1976; White, 1979) could be explained by synchronous variations of the maser sink efficiency. These can also be explained by changes in n_e/n_H due to a variable flux of ionizing particles from the star's flare-ups.

Maser clumps may have protoplanetary origins. The accreted envelope of a very massive ($\sim 0.01\ M_\odot$) protoplanet (Perri and Cameron, 1973) at $\sim 10^{15}$ cm from a star of solar mass would have a radius of $\sim 10^{14}$ cm and would be torn off almost completely by the assumed stellar wind. This process gives birth to the described strong CC-pumped masers and subsequently to high velocity clouds (Strelnitsky and Sunjaev, 1972; Norman and Silk, 1979) of weaker maser emission pumped by rotational CC, CR or RC. However, the stability of the envelopes around massive protoplanets is open to question (Perri and Cameron, 1974).

REFERENCES

Bolgova, G.T.: 1979, submitted to Nauchn. Inf. Astron. Council.
Goldreich, P., and Kwan, J.: 1974, Astrophys. J. 191, pp. 93-100.
Goldreich, P., and Kwan, J.: 1979, Astrophys. J. 227, pp. 150-151.
Gammon, R.H.: 1976, Astron. Astrophys. 50, pp. 297-313.
Itikawa, I.: 1972, J. Phys. Soc. Japan 32, pp. 217-226.
de Jong, T.: 1973, Astron. Astrophys. 26, pp. 297-313.
Norman, C., and Silk, J.: 1979, Astrophys. J. 228, pp. 197-205.
Perri, F., and Cameron, A.G.W.: 1974, Icarus 22, pp. 416-425.
Shmeld, I.K., Strelnitsky, V.S., and Muzylev, V.V.: 1976, Astron. Zh. 53, pp. 728-741.
Strelnitsky, V.S.: 1979, submitted to Astron. Zh.
Strelnitsky, V.S., and Sunjaev, R.A.: 1972, Astron. Zh. 49, p. 704.
White, C.J.: 1979, Mon. Not. Roy. Astron. Soc. 186, pp. 377-381.