Active Galactic Nuclei: from Central Engine to Host Galaxy
ASP Conference Series, Vol. 290, 2003
S. Collin, F. Combes, and I. Shlosman

Water Masers in Molecular Disks in Active Galaxies

Natalia Babkovskaia and Juri Poutanen

Astronomy Division, P.O.Box 3000, FIN-90014 University of Oulu, Finland

Abstract. Following Deguchi (1981) we concentrate on the hot-gas–cold-dust pumping mechanism for water maser at $\lambda = 1.35$ cm based on the difference between gas and dust temperatures and special features of the ice spectrum. However, in contrast to the Deguchi model, we suggest the way to obtain the temperature difference in the stationary case. We consider the case of the unsaturated maser when the fraction of the solid angle in which the maser amplification takes place is extremely small. This allows us to uncouple the population balance and the radiative transfer equations and investigate the dependence of the inversion of maser level populations on the gas and dust temperatures and their concentrations. We apply results of our calculations to the molecular maser disk in the Seyfert galaxy NGC 4258.

1. Introduction

Sources of strong water maser emission at $\lambda = 1.35$ cm have been found in many astrophysical objects such as active galactic nuclei, carbon rich stars, comets, and protostellar regions. Maser emission is a powerful tool for investigation of the physical conditions in the emitting regions because of its high sensitivity to the parameters of the medium in which the maser amplification takes place.

There are two main mechanisms for the maser pumping. The first one was suggested by de Jong (1973). In this model, the heat sink is provided by the loss of far infrared photons from the surface of a maser cloud. The second one is the cold-dust–hot-gas model proposed by Deguchi (1981). Collison and Watson (1995) have shown that the latter mechanism is more efficient comparing with the former one. Following the Deguchi (1981) model we consider the cold-dust–hot-gas maser pumping mechanism. This mechanism is based on the differences between gas and dust temperatures and the special features of the absorption coefficient of ice. The upper maser level is populated due to the absorption of 100 μm and 85 μm infrared photons corresponding to the $4_{14} \rightarrow 5_{05}$ and $5_{05} \rightarrow 6_{16}$ transitions in ortho-H_2O molecule. The heat sink is realized due to the cold dust absorption of 45 μm photons corresponding to the $5_{23} \rightarrow 4_{14}$ transition.

2. Unsaturated Maser in Geometrically Thin Optically Thick Disk

Maser pumping mechanism suggested by Deguchi is realized only in the unstationary case because the origin of the temperature difference is the burst of the infrared luminosity during the protostar formation. We suggest a way to achieve the necessary difference of gas and dust temperatures in the stationary case if there is a mixture of gas and different types of dust which have different temperatures depending on their spectral properties. Since some grains heat the gas while other cool it, the gas temperature takes an intermediate value. These conditions are achieved when there is no thermodynamical equilibrium between the radiation and the matter. Such a layer exists near the surface of the optically thick disk while the inner layers could be fully thermalized.

We consider the case of the unsaturated maser in the geometrically thin optically thick disk when the fraction of the solid angle in which the maser amplification takes place is extremely small. In that case the inverse effect of the maser emission on the signal level populations can be neglected. This allows us to uncouple the population-balance and the radiative transfer equations and calculate the inversion of maser level populations. In the case of hot-gas–cold-dust pumping mechanism the inversion of maser levels depends on four quantities: hydrogen concentration N_{H_2}, the difference between gas and dust temperatures $T_{gas} - T_{ice}$, the gas temperature and the ratio between water and dust concentrations N_w/N_{ice}.

It was suggested (Collison and Watson, 1995) that the water maser in the Seyfert galaxy NGC 4258 is saturated. According to our estimations the maser seems to be unsaturated. Therefore, the results of our calculations of the inversion can be applied to this source. We first calculate the inversion of the population of maser levels locally and then integrate the radiative transfer equation to obtain the radiation flux in the central and high velocity components of the maser line at $\lambda = 1.35$ cm. Comparing theoretical and observational maser spectrum we obtain the key parameters of the molecular masing disk in the galaxy NGC 4258: $T_{gas} = 400\,\mathrm{K}$, $T_{ice} = 130\,\mathrm{K}$, $N_w = 8 \cdot 10^2\,\mathrm{cm}^{-3}$, $N_{ice} = 4 \cdot 10^{-2}\,\mathrm{cm}^{-3}$, and $N_{H_2} = 10^9\,\mathrm{cm}^{-3}$. We interpret the main features of the maser spectrum such as a regular, discrete structure of high velocity components (Miyoshi et al., 1995) by including spiral shear waves.

Acknowledgments. This work was supported by the Centre for International Mobility, the Magnus Ehrnrooth Foundation, and the Finnish Graduate School for Astronomy and Space Physics.

References

Collison, A., Watson, W. 1995, ApJ, 452, L103

Deguchi, S. 1981, ApJ, 249, 145

de Jong, T. 1973, A&A, 26, 297

Miyoshi, M., Moran, J., Herrnstein, J. R., Greenhill, L. J., Nakai, N., Diamond, P. J., Makoto, I. 1995, Nature, 373, 127