A MODEL FOR MASER LINE PROFILES OF LATE-TYPE STARS

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ABSTRACT. The profiles of maser lines from spherically symmetric expanding shells are computed with the help of a simple model.It is shown that a beaming effect must be taken into account in order to correctly account for the OH profiles of type II OH stars.

1.INTRODUCTION

According to the models of Elitzur et.al.(1976) and of Reid et.al.(1977), the two OH emission features of type II OH stars originate in the near and far side of an expanding circumstellar shell. We present here a more complete derivation of the profiles of maser lines which takes into account the whole contribution of a spherical shell. The profiles depend only on the expansion velocity law V(r) and on the population difference across the maser transition n(r) . We remark that since the equation for radiation transfer takes similar forms in the cases of optically thin thermal emission and of saturated maser emission (in both cases the intensity of radiation increases linearly with column density),the same "thermal" profiles are obtained in both cases. The typical profiles with two peaks can only be obtained if the maser intensity depends on a power $m>1$ of the amplification path length; this occurs in the case of unsaturated masers, or in the case of saturated maser emission with a beaming effect.

2.BASIC ASSUMPTIONS

The first step in the calculation of the line profile is to obtain the profile I(p,v) observed in a line-of-sight that passes at a distance p from the center.The length of the amplification path contributing to the intensity at a velocity v in the spectrum, limited by the Doppler shift due to the velocity gradient along the path,is $\Delta l(z) = \Delta v/(dv/dz)$,where z is the distance along the line-of-sight, v the projection of V(r) , and Δv the thermal width of the line.

We assume that the observed intensity in a given line-of-sight and at a given velocity is proportional to some power of the length $\Delta l(z)$ and

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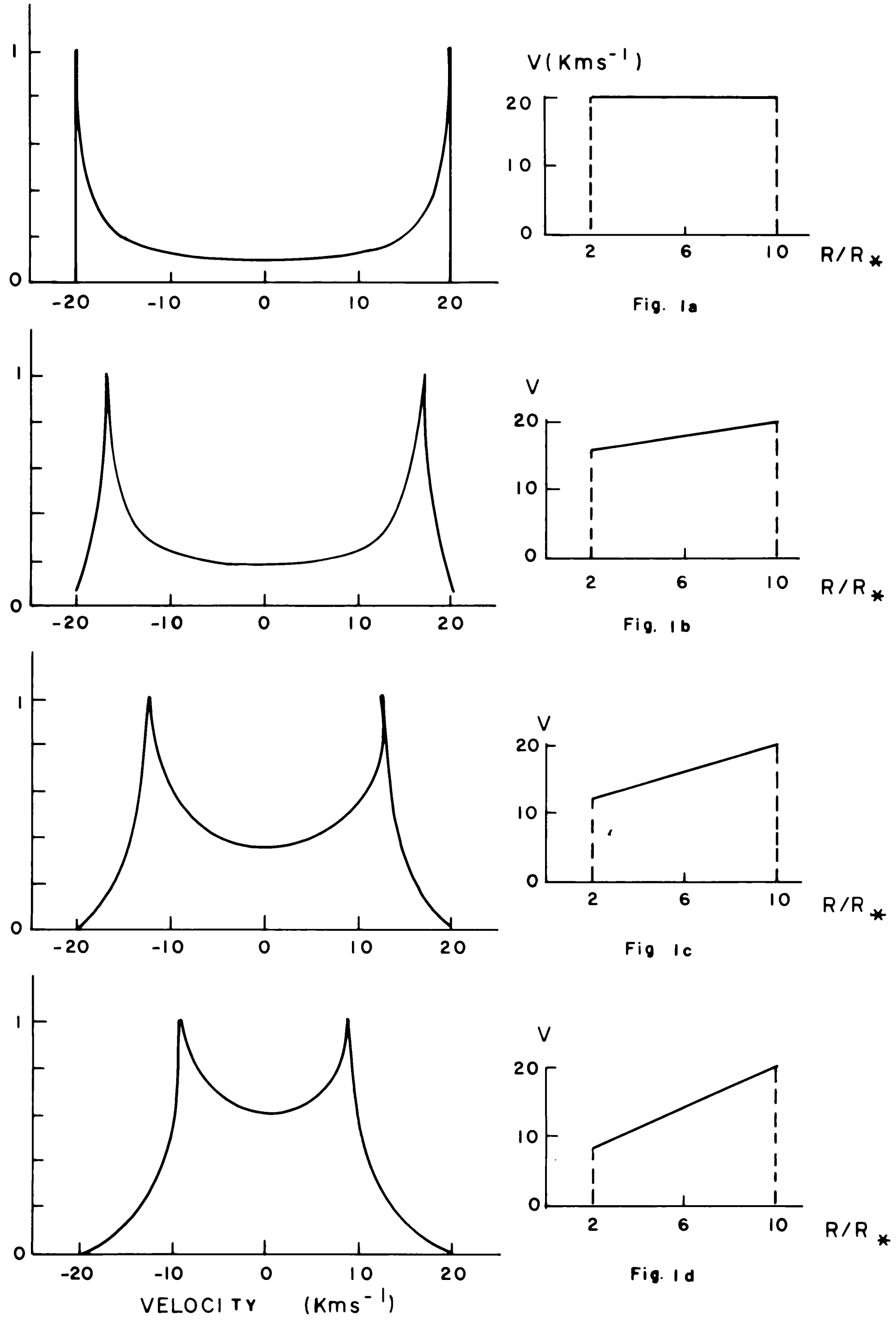

Figure 1:Computed maser profiles for several expansion velocity laws.The velocity laws are indicated at the right of each profile.

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to some power of n(r). A convenient expression for n(r) is $n(r) = A\, r^{-q}$ in a shell ($R_1 < r < R_2$) and n(r)=0 outside this range. Therefore a convenient expression for the intensity due to a line-of-sight is:

$$I(p,v) = r^{-q} \left[dv(p,z)/dz \right]^{-m} \qquad (1)$$

where m , q are parameters which allow us to describe different situations. The profile from the whole envelope should be obtained by integrating I(p,v) over p. We substitute the integration over p by an integration over r using the relations:

$$p^2 = r^2 - z^2 \qquad (2) \; ; \qquad v(p,z)/V(r) = z/r \qquad (3)$$

$$\frac{dv(p,z)}{dz} = \frac{V(r)}{r} \left[1 - \frac{v^2}{V(r)^2} - \frac{v^2}{V(r)^2} \frac{d\ln v}{d\ln r} \right] \qquad (4)$$

The result is:

$$I(v) \propto \int_{R_1}^{R_2} v(r)^{-m} \left[1 - (v/V)^2 - (v/V)^2 (d \ln v / d \ln r) \right]^{1-m} r^{m+1-q} \, dr \qquad (5)$$

3. RESULTS AND DISCUSSION

When V(r)=V0 (constant), which occurs at large distances from the star, the expression (5) reduces to:

$$I(v) = \left[1 - (v/V0)^2 \right]^{1-m}$$

For m=1 we obtain I=constant, which corresponds to the rectangular profiles observed in the case of optically thin thermal emission.

For m=2 (intensity proportional to the square of the amplification path length) we obtain the same expression $I(v) = 1/(V0^2 - v^2)$ which was derived by Reid et.al.(1977) without stating the condition m=2 .

The integral (5) must be computed numerically for other velocity laws V(r). We show in figure 1 the normalized profiles that are obtained with linear increase of the expansion velocity (V(r)= A+ B*r) between 2 and 10 stellar radii, with m=2 and q=4. This choice of q corresponds to both density and pumping radiation flux decreasing like r(-2). We remark that the profiles obtained with moderate acceleration resemble the OH profiles of visible Miras.

The additional dependence of the intensity on the amplification path length (m=2) is a beaming effect. A large path length produces a large coherence area at the output, so that the radiation is concentrated in beam of smaller solid angle and the observer receives more radiation (the coherence area acts like a large emitting antena).

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