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Formation of protoplanetary with radiation of SiO maser from Orion-IRC2

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Abstract. Here we report a study of formation of protoplanetary with radiation of SiO maser from Orion-IRC2 using a new model, i.e. the distinct multiple rotating and expanding disc-rings of Orion-IRC2 SiO (ν =1, J-2-1) maser for explanation of the fact that the several small peaks superposed the double-peaked spectral profile and the relative position map.

1. 1. Cross-correlation spectrum

The observation of SiO (ν =1, J=2-1) maser were made by Plambeck et al. (1990) in 1989 March with the Hat Creek millimeter array. The cross-correlation spectrum of the SiO (ν =1, J=2-1) maser was obtained at a 220m antennae spacing on 1989 March 20[see Fig. 1 in Plambeck et al. (1990)]. From the spectral profile it is found that there are five peaks in the spectrum. After fitting and computation we have found the following function for the spectral profile of SiO (ν =1, J=2-1) maser.

$$S(Jy) = \tag{1}$$

$$\frac{1}{\frac{1}{1250}(V_{lsr}-14.5)^2+\frac{1}{1830}}, when 9.9kms^{-1} \leq V_{lsr} \leq 20kms^{-1};$$

$$\frac{1}{\frac{1}{200}(V_{lsr}-8.0)^2+\frac{1}{350}}, when 3.1kms^{-1} \leq V_{lsr} \leq 9.9kms^{-1};$$

$$\frac{1}{\frac{1}{250}(V_{lsr}+2.3)^2+\frac{1}{600}}, when -3.2kms^{-1} \leq V_{lsr} \leq 3.1kms^{-1};$$

$$\frac{1}{\frac{1}{500}(V_{lsr}+4.5)^2+\frac{1}{1050}}, when -5.65kms^{-1} \leq V_{lsr} \leq -3.2kms^{-1};$$

$$\frac{1}{\frac{1}{450}(V_{lsr}+6.7)^2+\frac{1}{740}}, when -10kms^{-1} \leq V_{lsr} \leq -5.65kms^{-1}$$

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Assume the disc-rings of SiO (ν =1, J=2-1) maser are rotating and expanding along radial direction. The velocity laws has been taken for simplicity to be of the form $V_r = V_{r0}(\rho)^\epsilon$ and $V_t = V_{t0}(\rho)^\beta$, where V_r and V_t are the radial and tangential velocities at radius r from the central star, V_{r0} and V_{t0} are the initial velocities at $r = r_0$ and $\rho = r/r_0$. The gas density d has been assumed to fall off as 1/r. In general, the disc will be inclined at some angle θ to the line of sight. The disc geometry and coordinate systems adopted are shown in Fig. 2 of Barvainis (1984)'s paper. After a series of computation the flux density of SiO maser radiation from a point at y in a disc-ring of r and θ is as follows:

$$S = \frac{1}{a(V_{lsr} - Vp)^2 + b} \tag{2}$$

where

$$a = \frac{\epsilon}{(Q\Delta V_{therm})cos(\theta)V_{r0}(r/r_0)^\epsilon},$$

$$V_p = -(1 + \frac{1-\beta}{2\epsilon})(y/r)cos(\theta)V_{t0}(r/r_0)^\beta,$$

$$b = a[V_p/(1 + \frac{1-\beta}{2\epsilon})]^2[\frac{1}{\epsilon}(V_{r0}/V_{t0})^2(r/r_0)^{\epsilon-\beta} - (\frac{1-\beta}{2\epsilon})^2].$$

where Q is parameter which is determined by model and fitting for observational results. ϵ, β,r_0, V_{r0}, V_{t0}, and $Q\Delta V_{therm}$ in (2) are parameters determined preparatory with our fitting results ,i.e. formula (1), and the knowledge for Orion-IRC2 SiO maser. According to the previous analysis and the fitting results, θ and r of the disc-ring, and y of radiation point in every disc-ring will be determined from (1) and (2). The parameters are selected as follows (Barvainis 1984): $\epsilon = 0.5, \beta = 0.5, r_0 = 41AU, V_{r0} = 10kms^{-1}, V_{t0} = -11kms^{-1}, (Q\Delta V_{therm}) = 82$. The computational results are shown in Table 1.

Table 1. Our results with the spectrum

peak	θ	r(AU)	y(AU)
1	53°06'	56.6	-25.1
2	84°12'	57.4	-15.2
3	83°48'	78.0	+0.75
4	76°42'	59.0	+10.4
5	78°30'	58.2	+2.74

2. 2. Relative position map

From the observations of SiO (ν =1, J=2-1) maser made by Plambeck et al. (1990) in 1989 March with the Hat Creek millimeter array, the relative position map (Fig. 1 in Plambeck et al. 1990) has been generated. Assuming that a component, for example i-th component, is in the rotating and expanding disc-ring, we have obtained the following relationship (Yu 1994):

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$$\rho_i^2 = \rho^2 - \frac{\rho^2}{V_e^2}\psi$$

where

$$\psi = [(V_i - V_0)/(cos\theta) - \rho_i D\omega]^2,$$

ρ_i is projected distance of link-line between i-th component and o-point, ρ is one of the radius r of disc-ring. V_e is expanding velocity of disc-ring, V_i is the radial velocity of i-th spot, V_0 is the system velocity of disc-ring, ω is angular velocity of the rotation of disc-ring, D is distance of Orion-IRC2. We may find from the formula, for the same definite rotating and expanding disc-ring, ρ, V_e, and ω are definite, of course, so are V_0, D, and θ. We take a new idea, i.e. distinct multiple rotating and expanding disc-ring: We can find that the distribution of points with coordinate values ρ_i^2 and ψ is divided in a few regions as orientation of linear monotonous decrease by degree. Thus we consider that SiO (ν=1, J=2-1) maser components distributed as disc-rings in the disc according to a few regions, then do analysis, fitting, respectively, make corresponding to straight line using least square method, which dispersion of statistics is least. The intersections of the straight line with axes in the figure are values of ρ^2 and V_e^2, respectively. The parameters of Orion-IRC2 are selected from Plambeck et al. (1990) and Genzel et al. (1981): V_0=+5kms^{-1}, D=480pc. $\omega = V_t/r = \frac{V_{t0}(r/r_0)^\beta}{r}$, where r_0=41AU, V_{t0}=10kms^{-1}, β=0.5. Finally the center position of Orion-IRC2 selected is $\Delta RA = 0.022arcsec, \Delta DEC = -0.068arcsec$ in the relative position map. Our computational results are shown in Table 2.

Table 2. Our results with relative position map

disc-ring	V_{lsr} of components (km^{-1})	angle of tilt	radius (AU)	rotating angular velocity ($10^{-10}s^{-1}$)	expanding velocity (kms^{-1})
1	16.7, 15.6, 14.5, 13.5, 12.4, 6.9	53° 06'	35.5	9.9	37
2	11.3, 10.2, 8.0, -1.2	84° 12'	36.0	9.5	100
3	20.0, -2.3	83° 48'	51.8	6.1	136
4	18.9, 17.8, -4.5, -7.7, -8.8,- 9.9	76° 42'	40.3	9.2	110
5	9.1, -3.4, -5.6, -6.7	78° 30'	39.4	9.3	103

From the results obtained with the spectrum and relative position map it is found that there are five disc-rings with different angle of tilt around protostar. Maybe, the multi-peaks in the spectrum and the distribution of SiO ($\nu = 1, J = 2 - 1$) maser components in the relative position map just suggest that the disc-rings with different angle of tilt can evolve and become the planets in orbits with different obliquity moving around the main sequence star.

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