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SURVIVAL TIME OF PREPLANETARY NEBULAE DEBRIS

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RESUMEN

En un trabajo anterior (Fierro, 1993) propusimos que podrían existir planetas y cuerpos menores alrededor de las estrellas progenitoras de nebulosas planetarias. En el momento de la formación de la nebulosa estos objetos se podrían evaporar e interactuar con la envolvente, alterando su morfología y su composición química. En este trabajo se calcula el tiempo de vida de un planeta de hielo, similar a Neptuno, que estuviera en la vecindad de una estrella central. Se piensa que la tasa de material evaporado en forma de OH sería suficiente para explicar los máseres observados en algunas progenitoras.

ABSTRACT

In a previous paper (Fierro, 1993) we suggested the possibility and the consequences of having planets, rings and ring arcs around planetary nebulae and the interactions they might have with the nebulae, concerning their morphology and chemical composition. In the present paper we calculate the survival time of an ice planet around a newly formed preplanetary nebula and the conditions that would have to exist in order for its evaporation to account for the OH molecules that produce OH maser emission observed in some possible progenitors.

Key words: **PLANETARY NEBULAE: GENERAL — PLANETARY SYSTEMS**

1. INTRODUCTION

Lately it has been suggested that planet forming is a rather frequent event (see for instance the Proceedings of the conference dedicated to Planetary Systems edited by Nickle, 1993) specially in solar type stars (Strom et al., 1992; O'Dell, 1993). The planets and ring material surrounding the stars could have a great variety, and be quite massive, as the disk surrounding Beta Pictoris.

Several authors have suggested that planetary disintegration is responsible for observed features around planetary nebula central stars. For instance Dopita & Liebert (1989) have been able to explain the nebula around EGB 6/PG 0950+139 by the ablation of a Jupiter like planet. Sahai *et al.* (1991) have interpreted the CO torus around the planetary nebulae IC 4406 as a product of planet evaporation.

When a solar type star turns into a planetary nebulae (PN) the nucleus (PNN) becomes very hot and could evaporate nearby planets and be responsible for some of the features observed in envelopes (PNE). Such features are density inhomogeneities, chemical composition peculiarities or large scale structures (Fierro, 1993).

In this paper we propose that the PNN could evaporate an ice planet when it is in its Mira phase and produce the observed OH feature. We first describe the way in which the planet would be destroyed, then how its debris would form a disk, and finally compare these results with the available observations of OH/IR stars.

2. ICE PLANET EVAPORATION RATE

A planet can evaporate if enough energy is produced by the star it orbits. For instance, for water ice production the surface temperature must reach at least 300° K. The evaporation rate is given by:

$$Q = R^2/r^2 \pi F(1-A)N/L, \qquad (1)$$

where Q is the molecule production rate in moles/sec; R is the planet's radius; r is the distance to the PNN in a.u.; F is the star's radiation rate at the planet's location in joule/cm^2; A is the planet's albedo; N is Avogradro's number; and L is the latent heat in kJ/mol (6 KJ/mol for CO and 50 KJ/mol for H_2O).

In order for this expression to be valid we have made the supposition that the planet is a rapid rotator, in order for the whole surface to be illuminated, and that internal heat conduction is not important (Delsemme & Rud, 1973). In any case, if the planet is a slow rotator the results would have to be approximately reduced by a factor 4.

Livio & Soker (1984) have suggested that planets surrounding mass losing stars could accrete material if they are massive enough. They have calculated the critical mass and distance of the companion in order to produce this effect. In the present paper we suggest that the planet has a small surface gravity, smaller than the critical value suggested by Livio & Soker, and consequently does no accrete material and is almost completely ablated.

In Figure 1 we have plotted the particle production rate of two ice planets as a function of distance to the Mira star, one Neptune's size, one half, and the other twice its size. As expected the production rate is larger if the planet has a great radius and is near the exciting star.

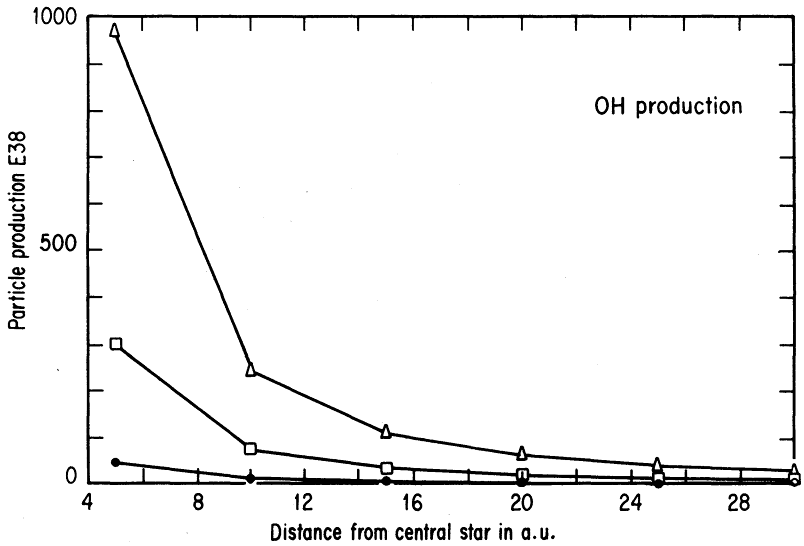

Fig. 1. Particle production rate.

3. MIRA STARS

Habing *et al.* (1989) have discussed the evidence for OH/IR stars being PN precursors, in particular the non-variable type. In their model, the AGB star has a $0.6M_{\odot}$ core and convective envelope measuring 10^{11} m and a $0.6M_{\odot}$ circumstellar shell with an OH layer whose radius is 3×10^{14}m. The central star luminosity is $6000L_{\odot}$. In Figure 2 we have plotted the survival time of three planets with radii 2, 5 and 8×10^{13} cm, if they were placed at several distances from the center of the OH/IR star. The complete evaporation would take several thousand years.

We believe that the OH maser could be accounted for completely by the disruption of one or several Neptune like planets in the vicinity of the central star. The scenario would be as follows:

1. The prePN would be a multiple system consisting of a solar type star surrounded by planets distributed in a similar fashion as in our system and whose total mass would be $0.1M_{\odot}$.

2. When the star turns into a red giant, and a Mira, the interior, metal rich planets would be engulfed by the star in a way similar to the scenario proposed by Goldstein (1987).

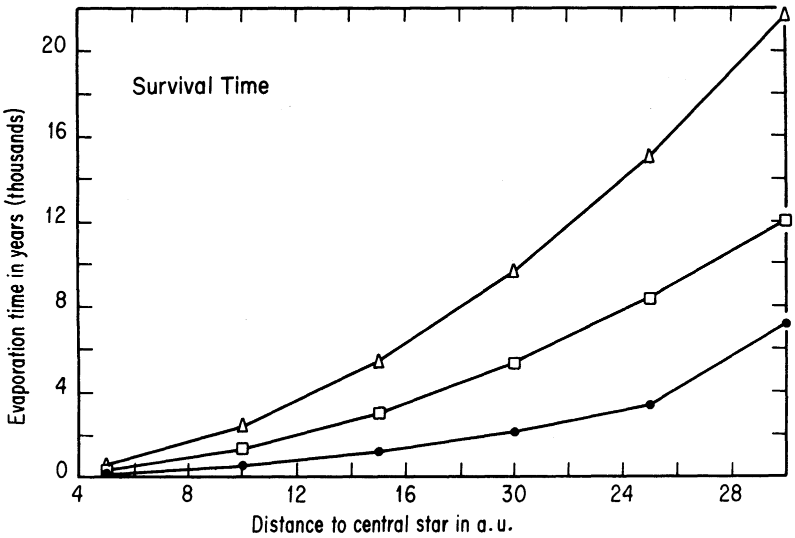

Fig. 2. Survival time.

3. Gaseous, massive and relatively nearby planets, like Jupiter's, would survive the Mira phase, accrete matter and subsequently produce material in a ring that could be swept out, due to heat generated by the white dwarf.

4. Icy, small planets, whose distances would be of the order or 10^{13} m, would evaporate, producing enough OH molecules to account for the maser emission and for the dust responsible for the IR excess; as would minor planets and moons. A Neptune size planet would have a metal rich nucleus that would survive ablation, that is to say it would outlive the PN stage and be a far companion of the white dwarf.

5. The evaporated planet's material would form a torus around the star due to the confinement of its evaporated material. The PNN's wind will interact with the evaporated material producing confinement according to the relation:

$$P = 3n_{OH}kT = \beta(\gamma L/c)(1/4\pi R^2). \tag{2}$$

Where P is the confining pressure and we have equated the gas pressure of the evaporating planet to the confining pressure due to the solar wind. β is the ratio of the stagnation pressure in the ionized gas to the ram pressure in the stellar wind. γ is the ratio of momentum in the stellar wind to that of the radiation field.

6. Since the PNN will be losing mass, the suggested planet would slowly drift out according to the relation proposed by Blaauw (1961) at a few m/seg. This velocity is small enough so that essentially the same amount of ablation is produced. This would enhance the torus length around the PNN and would allow for the maser effect of OH to take place.

If the particle production of a Neptune size planet is of the order of 10^{39} particles per second, they would disperse in a thin disk of 10^{21} cm^2 leading to densities of 10^8 cm^{-3} necessary for the OH maser effect.

If the planet's surface temperature is higher than 200°K, then dust fragments can be produced having diameters up to 1 cm. These dust particles would be dragged by the wind, and subsequently evaporate and contribute to the molecular formation.

In Dopita & Liebert's paper (1989) the Jovian planet slowly drifts into the star because of its proximity and due to the fact that it is submerged in the stars extended envelope. Our case is different since the suggested planet is much farther out.

7. van der Veen (1987) calculated the time duration of the OH maser which is of the order of 5000 years that is the same order as the ablation time for our suggested planet. See Figure 1.

4. CONCLUSION

Previous calculations complemented by ours have proven that some of the structures observed in prePN and PNN can be accounted for by planets that have been partially destroyed by the PNN.

In particular we have calculated the amount of OH necessary to produce the masers observed in some IR/OH stars and have found that an ice planet about the size and distance of Neptune could account for the amount of matter, supposing it is completely destroyed and forms a torus by drifting out and by interacting with the nucleus wind. We think temperature fluctuations observed in PNE, (Peimbert 1993) could be explained by clumps of material originated by planet disintegration.

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