THE FORMATION OF PLANETARY NEBULAE WITH CLOSE BINARY NUCLEI

J. Saltzman
Dept. of Physics and Astronomy, Tel-Aviv University,
Ramat-Aviv, ISRAEL

M. Livio
Dept. of Physics and Astronomy, University of Florida,
Gainesville, FL 32611

G. Shaviv*
Joint Institute for Laboratory Astrophysics, University of
Colorado and National Bureau of Standards, Boulder, CO 80309

Recent observations of nuclei of planetary nebula have shown that some of the central stars are binaries and even close binaries with periods of hours to few days.

Theories of PN formation discuss only the formation of a nebula from a single star. Recently Livio et al. (1979) (LSS) have discussed the possible formation of a PN with a close binary central system. The basic idea is that the system started as a widely separated binary. The process of mass transfer from the red giant to the companion main sequence star, the ejection of gaseous nebula and the decrease in separation occur simultaneously. The sequence of events is as follows: the red giant starts to lose mass to the secondary when they are widely separated. The secondary expands and overflows the outer critical surface passing through the second Lagrange point L_2. An instability arises in which matter flows out of the system through L_2. A steady state is established in which matter flows through L_1, the secondary tries to expand and matter flows out via L_2. A crucial point is that the timescale for the whole process described above is the same as the timescale for the disappearance of the ejected nebula.

Here we report on some further calculations on the form of mass loss. LSS assume particle trajectory for which the angular momentum loss per unit mass $d\ \ell n\ J / d\ \ell n\ m = 1.7(1+q)^2/q$ where q is the mass ratio. This expression was derived by Kuiper (1941) and verified

*On leave of absence from Dept. of Physics and Astronomy, Tel-Aviv University, Tel-Aviv, ISRAEL.

M. J. Plavec, D. M. Popper and R. K. Ulrich (eds.), Close Binary Stars: Observations and Interpretation, 571–573.

later by Nariai (1975) and Lin (1977). The treatment was, however, criticized by Prendergast (1960). Prendergast claims that since the mean free path of the particles is very much smaller than the orbital separation the single particle approximation is not justified.

We have therefore reformulated the Lubow and Shu (1975) hydrodynamic equations and series expansion and adopted them to the case of outflow from L_2. The basic assumptions are: (1) the expansion parameter is $\varepsilon = v_{sound\ isothermal}/v_{orbital} \ll 1$, (2) the zero order equation is the single particle equation. (3) Assume the following nondimensional units: length=separation, velocity~orbital velocity so that $v_{sound} \cong \varepsilon$. Then streamlines originate from an ε neighborhood of L_2 with $|\vec{v}| = \varepsilon$. The ejection angle is given by the asymptotic solution of the linearized three-body problem. (4) The system of coordinates is distance from L_2 (along the streamline), the normal to the flow in the plane, and the normal to the plane of motion. (5) Hydrostatic equilibrium perpendicular to the orbital plane was assumed.

Our preliminary results are that for low <u>initial ε</u> the alignment and subsequent motion are practically independent of $\vec{v}_{initial}$. <u>No disk is formed</u>, the streamlines do not intersect for some range of parameters used in the model. There are few percent corrections to ν.

Finally we would like to draw attention to a few possible candidates. Basically we should expect a nonspherical PN. Livio (1979) has compiled a list of possible candidates; let me bring three examples of such objects:

<u>NGC 1360 (220-53°1)</u>

CPD-26 389 is a single line spectroscopic binary with a period of 8 days and mass function of 0.19 M_o. The nebula is non-spherical.

<u>UU Sagittae, Abel 63</u>

This is an eclipsing binary with $P = 0.465^d$, $M_1 = 0.9\ M_o$, $M_2 = 0.7\ M_o$. The nebula is very non-spherical.

<u>NGC 2346</u>

This is an A0 plus an O subdwarf with variable radial velocity. Non-spherical nebula.

Why do we see few PN with CBS? There exists a compromise between the reduction in separation and the ejected mass. When the ejected mass is large a very close contact binary is formed. The less massive star may dissipate completely and the hot central star may cool before the nebula becomes transparent. On the other hand, if the ejected mass is small the nebula becomes transparent very quickly and the stars remain widely separated.

https://doi.org/10.1017/S0074180900065529 Published online by Cambridge University Press

RERERENCES

Kuiper, G.P.: 1941, Ap. J. 93, p. 133.
Lin, D.N.C.: 1977, M.N.R.A.S. 179, p. 265.
Livio, M.: 1979, preprint.
Livio, N., Saltzman, J. and Shaviv, G.: 1979, M.N.R.A.S. 188, p. 1.
Lubow, S.H. and Shu, F.H.: 1975, Ap. J. 198, p. 383.
Nariai, K.: 1975, Astron. Astrophys. 43, p. 309.
Prendergast, K.H.: 1960, Ap. J. 132, p. 162.

DISCUSSION FOLLOWING SALTZMAN, LIVIO AND SHAVIV

Shu: In our paper (Shu, Lubow, and Anderson, Ap. J., 229, 223, 1979) on mass and energy flows in contact binaries, we presented our 1975 unpublished results on the same problem. You may be interested in comparing your results with those tabulated in our paper. In particular, we found that mass could be ejected all the way to infinity only for a range of mass ratios between 0.064-0.78.

Tutukov: L_2 was determined only for solid body rotation systems But to have solid body rotation at least several thermal time scales must pass. The envelope of the primary (at least in the case B systems) expands in the same or shorter time scale The original big common envelope seems rather possible in this case. Did you consider this case?

Nariai: υ Sgr and HD 30353 that are hydrogen-deficient binaries eject mass through the Lagrangian point. When I was studying these stars twelve years ago, I thought that a similar mechanism could be applied to the formation of planetary nebulae. But I could not follow the problem further because of the difficulty in observing the planetary nuclei at that time. I am very happy today to hear that Dr. Shaviv is trying to apply the mechanism to the formation of planetary nebulae with the recent results of observations.