Circumbinary disk and bipolar PNe formation theory

Zhuo Chen

June 2016

1 Introduction

Key words: bipolar planetary nebulae, circumbinary disk, pulsating AGB star, pulsation induced Roche-lobe overflow, common envelop, fall-back disk, luminous transient, L2 massloss, radiative transfer, dust formation, Virial theorem, radiative cooling

2 Boundary values

Outflow only outer boundary.
Pulsating AGB star with two states.

Model Name	$T_{eff}(K)$	$L(L_{\odot})$	r(AU)	$\rho(g/cm^3)$	$\Delta v(km/s)$	$\kappa_{ext}(cm^2/g)$
L_{low}	2800	2036	0.9	6×10^{-9}	4.0	10.0
L_{high}	3200	3473	0.9	6×10^{-9}	4.0	10.0

Low luminosity AGB star cannot push high mass loss rate wind. High luminosity can push $10^{-8} \sim 10^{-7}$ $M_{\odot}/yr$ wind out.

10 cm^2/g extinction opacity is a little high since many literatures suggest 5 cm^2/g opacity. The reason for my calculation is I only use partial luminosity. The long wavelength phonton will not be counted in L_{eff}. In the simulation, I use $L_{eff} = 0.9 * L$. Therefore the opacity become 9 cm^2/g. Actually, a detailed spectrum dependent analysis supports 5 $cm^2/g \sim 15$ cm^2/g extinction opacity.

Low luminosity state is kept for 60 yrs and then the AGB star is switched to high luminosity state.

3 Initial and physical condition

AGB mass: 1 $M_{\odot}$
Secondary mass: 0.5 $M_{\odot}$
Separation: 3 AU

Period: 1552 *days*

Cooling: 4000 K above use electron excitation cooling, 4000 K below use water-hydrogen molecular cooling.

Radiative transfer: Azimuthal symmetry is presumed around the z-axis of the AGB star. The opacity is summed and averaged around the azimuthal angle.

4 comments

1. A pre-existing gravitationally bound tori or structure (not necessarily has outflows in polar direction) is the key to achieve the later circumbinary disk with bipolar outflow. It is possible that all the bipolar planetary nebulae have had gravitationally bound tori or structure before the central AGB star's luminosity increase to the point that polar outflows can emerge. It is the very optically thick tori or structure that make such objects very hard to be discovered.

2. The tidal force can extract mass from the AGB star and the gas can leak out from L2 point because the secondary cannot adjust itself so fast to maintain its thermal equilibrium. Observations have found the eccentricity of many binary star with circumbinary disks to be high. So we can test the elliptic orbit in the next paper. The periastron theorem has been mentioned in many papers but no one validated it.

3. Resolution is an issue in the simulation. Since the cooling rate is proportional to the square of density. Poor resolution will underestimate the high density region by averaging it with low density region e.g. shock front, thus underestimate the cooling rate severely. The underestimated cooling rate will result in hotter gas, heating up the disk and eventually make the gas escape.

4. The expansion of the circumbinary disk can be explained with Virial theorem. Use $f_{rad} + f_{grav} + f_{centrifugal} = -\frac{dp}{dr}$. A more detailed discussion will be presented later. It can also be used to estimate the break-up luminosity.

5. Outflows from L2 point will carry more angular momentum.

6. Angular momentum can be gained after several fall-back. A gas parcel cannot gain enough angular momentum in one interaction with the secondary. If there is no pressure force from the surrounding gas, the gas parcel will do elliptic motion. When it goes inward, it may interact with the secondary again and may gain angular momentum. When there is a continuous of gas, the inner part will gain angular momentum continuously and transfer to the disk through mixing.

7. Why the disk can be stable (Keplerian)? The energy transfer route is: radiative force + gravitational force (L2 point) $\rightarrow$ kinetic energy $\rightarrow$ collide with the disk $\rightarrow$ thermal energy by shock $\rightarrow$ radiative cooling $\rightarrow$ low temperature and Keplerian motion. In this route, colliding with the disk means there is a pre-existing gravitationally bound tori or structure. Without collision, the cooling may not be strong enough and the high temperature gas will mostly escape.

8. Mass transfer and orbital decay could be the third paper of this series.