# Quiescent state Nova Project

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## Introduction

Here we look for the equations of the system itself as binary stars, either for recurrent or classical novae, with the Roche potential, the equations of motion and fundamental concepts about the mechanism that drives the TNR, as we can work this observationally and theoretically, the observations will be left for the observational insight and here we will look just for equations and models.

## Types of binaries

First, if we want to see what a test particle feels while it is close to the binary system, we have to take care for the non inertial forces and the gravitational forces involved, and that lead us to the classical equations with the Roche potential:

$$\vec{a} = -\vec{\nabla}\Phi_R - 2\vec{\omega} \times \vec{v}$$

with:

$$\Phi_R(\vec{r}) = -\frac{GM_1}{|\vec{r} - \vec{r}_a|} - \frac{GM_2}{|\vec{r} - \vec{r}_b|} - \frac{1}{2}\omega^2 r_\perp^2$$

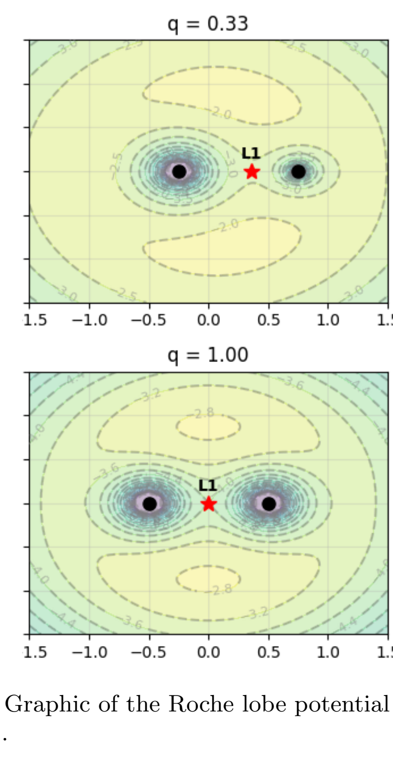


Figure 1: Graphic of the Roche lobe potential for $q = 0.33$ and $q = 1$.

Here, $\Phi_R$ have the two gravity forces and the centrifugal force, this potential is written considering the center of mass as the reference system. So with the potential around the stars the next step is to note that we can have three different configurations of the binaries, we have: **Detached**, they have no contact and there is no significant mass flow in the system. **Semi detached**, In this case we have one Roche lobe filling star, and that is precisely the kind of system we have in SyRNe. **Contact**, in this configuration, the two stars have filled their Roche lobe so the material is in contact.

As we can see in figure 1 the Roche lobe depends on the masses of our stars, this dependence can be well described with the dimensionless ratio $q = M_2/M_1$, where in figure 1 we have $q = 0.2$. In addition, the inner Lagrangian point L1 depends on $q$ also. Here we must take into account that the mass transfer can occur via different mechanisms, and for this work we will consider Roche Lobe Overflow (RLOF) or wind accretion, which is usually called Bondy-Hoyle Capture, and the final theory gives the names Bondy, Hoyle, and Littleton the equations related to this process. So, which process is taking place depends on the configuration of the system, that is:

- **Masses of the components** The mass ratio $q$ is the shape parameter of the Roche potential, so it is essential to understand the configuration of the system.
- **Separation a** This is the scale parameter, this parameter modify the size of lobes and gives important relations for the orbital period and the Roche lobe radius.
- **Kind of star** Perhaps the most important in order to determine the mechanism of mass transfer is the type of companion for the WD (thinking in the case of SyRNe) we can have MS stars for classical novae, and for SyRNe RG companions, however, for binary stars alone there are several configurations depending on the evolution of the system.

We will not focus our study in the accretion disk and the mass transfer process but it is important to note that we need to precise the configuration of the system and the mass transfer mechanism in order to understand what led us to the accumulation of mass that drives the TNR, but in this work, we will consider only the two mechanisms mentioned above: the RLOF and the BHL wind capture. We know that the wind from the secondary star may play an important role in mass transfer, and, also as we will see in the next section, this wind, which we will want to study in detail, is the key of our investigation: study the interaction of the wind with the nova ejecta.

## Mass transfer

For novae, either classical or recurrent we must have a flow of mass from the companion star to the WD in order to drive a TNR, it could be by different mechanisms depending of the evolutionary stage of the companion and the configuration of the system, but we are going to focus in the two cases mentioned above. In the BHL case, we expect that the wind from companion star is captured by the WD, and there is an efficiency factor $\eta$ that describes how the mass loss is compared to the actual accreted mass via some of these mechanisms. So in order to describe the mass accretion rate from BHL wind capture ($\dot{M}_{BHL}$) we must consider a stream of gas that is bounded gravitationally with the WD, so that implies:

$$\frac{1}{2}v_{\infty}^2 - \frac{GM}{r} < 0$$

Where $M$ is the mass of the WD $M_{WD}$, $v_{\infty}$ is the wind speed, and r is the distance from the star to the stream. So, if we study the mass transfer through this mechanism we can write $\dot{M}_{BHL} = \sigma v_{\infty} \rho_{\infty}$ with $\sigma$ a cross section that depends on an impact parameter b, which we can see in figure 2

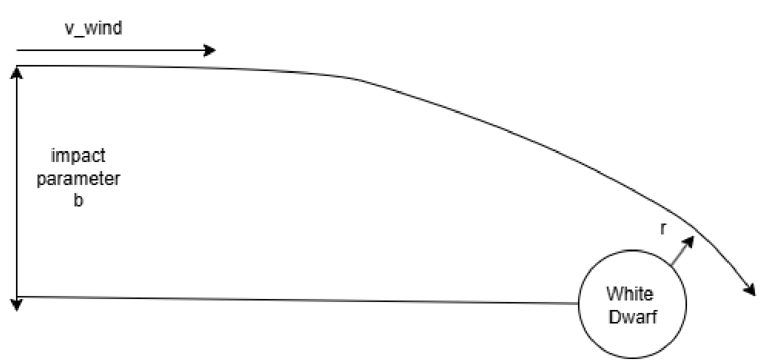


Figure 2: BHL wind capture sketch.

Now, our cross section can be described as $\sigma = \pi b^2$ and if we set the condition mentioned above, the impact parameter, known as the Hoyle-Littleton radius, is:

$$b = \frac{2GM_{WD}}{v_\infty^2}$$

setting it up all together leaves us with:

$$\dot{M}_{BHL} = \sigma v_\infty \rho_\infty = \frac{4\pi G^2 M_{WD}^2 \rho_\infty}{v_\infty^3}$$

And, as we know, the mass loss from the red giant evaluated at the distance from the WD is $M = 4\pi a^2 \rho_\infty$ so we can rewrite the mass accretion from BHL as:

$$\dot{M}_{BHL} = \frac{1}{4}\left(\frac{GM_{WD}}{av_\infty^2}\right)^2 \dot{M}_{RG} \tag{1}$$

With equation 1 we can estimate the amount of mass that is currently accreted to the WD from the RG wind, but as we said, mass transfer in SyRNe can also occur via RLOF which has different approaches to estimate the value of mass accretion; here we work with two of them, one from Ritter [1988] and the other from Daigne [2014].

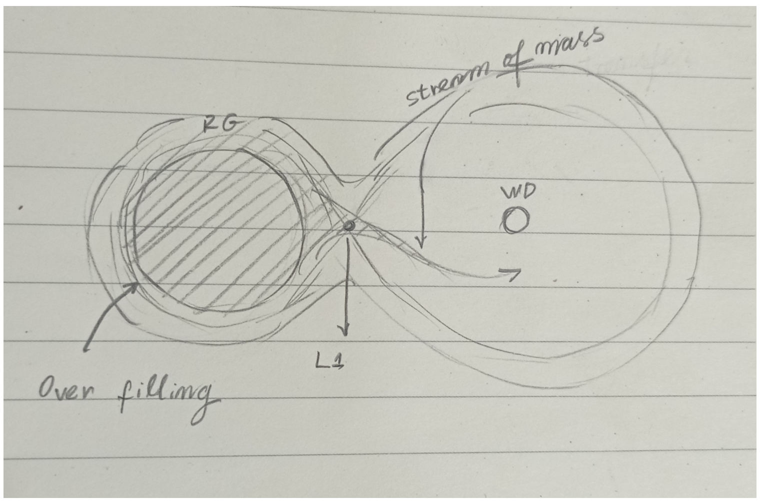


Figure 3: RLOF configuration sketch

This two approaches share the same scenario that is sketched in figure 3, where the RG overfills its roche lobe and the material starts 'falling' through the inner lagrangian point L1, Therefore, the estimation of mass transfer depends on if the energy of the stream can surpass or not the potential near L1. The consecutive step is to find quantities that can describe the mass flow through L1. For the Ritter approach, we have to find $\rho_{L1}$, the density in L1, to complete

$$\dot{M} = \rho_{L1} C_s Q \tag{2}$$

where $v_s$ is the sound speed and $Q$ the effective cross section of the flow. In order to find it, we can use the bernoulli's theorem:

$$\frac{1}{2}v_s^2 + \Phi + \int \frac{dP}{\rho} = cst \tag{3}$$

And by evaluating this constant at the photosphere, and at L1 it yields:

$$\frac{1}{2}v_s^2 + \Phi_{L_1} + \int^{L_1} \frac{dP}{\rho} = \Phi_{ph} + \int^{ph} \frac{dP}{\rho}$$

So, if we get the integrals together, on the other side the difference in the potential between this two points and use an equation state for isothermal gas we get to:

$$v_s^2 ln\rho_{L_1} - v_s^2 ln\rho_{ph} = -(\Phi_{ph} - \Phi_{L_1}) - \frac{1}{2}v_s^2$$

approximating $\Phi_{ph} - \Phi_{L_1} \approx g\Delta R$, with g the surface gravity, so we can use the scale height $H_p = v_s^2/g$, then $\Phi_{ph} - \Phi_{L_1} = (v_s^2/H_p)\Delta R$, and finally dividing by t $v_s^2$ makes us retrieve.

$$\ln\left(\frac{\rho_{L_1}}{\rho_{\rm ph}}\right) = -\frac{\Phi_{L_1} - \Phi_{\rm ph}}{c_s^2} - \frac{1}{2}\,\frac{v_s^2}{c_s^2}$$

so what making the exponentiation we get finally to:

$$\rho_{L1} = \frac{1}{\sqrt{e}}\rho_{ph} exp\left(-\frac{R_{rl} - R_*}{H_p}\right) \tag{4}$$

So our final mass accretion rate is:

$$\dot{M} = \dot{M}_0 exp\left(\frac{R_{rl} - R_*}{H_p}\right) \tag{5}$$

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ref: Carrol-Ostlie; Frank, King and Raine; Further work:

- have a brief description of the mass transfer and the accretion disk (also there are observational features for this)
- Indentify the mass transfer mechanism of T CrB and RS Oph
- Describe the wind equations

# References


Frédéric Daigne. *Objets Compacts & Phénomènes Associés*. EDP Sciences / CNRS Éditions, Paris, 2014. ISBN 978-2-7598-1193-8.

H. Ritter. Turning on and off mass transfer in cataclysmic binaries. , 202:93–100, August 1988.