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# Morphology of the Red Rectangle Proto-Planetary Nebula

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The morphology of the Red Rectangle (RR) proto-planetary nebula (PPN) exhibits several singular attributes. Most prominent are a series of linear features perpendicular to the symmetry axis which appear as “ladder rungs” across the nebula. At the edge of each “rung” gas seemingly flows in a parabolic shape towards the center of the nebula.

We present a new model of the RR which explains these features as a projection effect of the more-common spherically-symmetric outflows seen in other PPN (*e.g.* Egg Nebula). Using the 3D morpho-kinematic modeling software *shape*, we have created a model of the RR that consists of spherical shells evacuated by a biconal outflow. When the symmetry axis is oriented perpendicular to the line of sight, the spherical shells become linear thereby reproducing the “rungs” seen in the RR. When oriented at different inclinations, the linear features become spherical as observed in the Egg Nebula.

# Morphology of the Red Rectangle Proto-Planetary Nebula

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## Introduction

The red rectangle (RR) (figure 1) is an unusual post-AGB object which was first identified by Cohen et al 1975. The RR exhibits many singular features (figure 2) which have attracted much attention in recent years. Among these include its distinctive "X" shape, the peculiar "ladder rungs" perpendicular to the axis of symmetry and the bright knots (vortices) that seem to connect the ladder rungs to the "X". We present here a simple morphological model of the red rectangle that attempts to explain all three of these features.

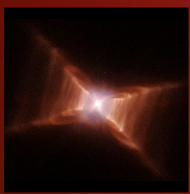

**Figure 1:** Red Rectangle (H. Van Winckel (KU Leuven), M. Cohen (UC Berkeley), H. Bond (STScI), T. Gull (GSFC), ESA, NASA).

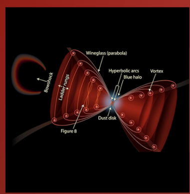


**Figure 2:** Schematic of the RR (*A. Feild / STScI / NASA - Schematic*)

## Model

A morphological model of the RR was developed using the SHAPE (Steffen et al 2010) software which can model radiative transfer, including scattering, through gaseous nebulae. The visible image, in particular the red colour, is the result of photoluminescence from an organic solid and is not the result of simple dust scattering (Wada et al 2009, Cohen et al 2004). Nevertheles, we applied a scattering model as the two processes are similar. The model consists of 4 parts (figure 3):

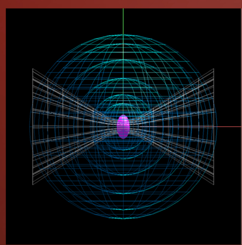

**Figure 3:** Mesh SHAPE model of the RR. The model consists of spherical shells evacutated by a bi-cone. The elliptical cocoon of dust in the middle enshrouds the star.

1) A central source supplying the photons which are scattered by the nebula.

2) A thick elliptical cocoon of dust enveloping the source.

3) Spherical shells of dust with the source as the common center. Each shell is spaced at near regular intervals representing periodic mass loss from central source. The shells only scatter light and do not emit.

4) A pair of evacuated bi-cones. The bi-cones originate from the central source and remove all material within their volume. This provides a path for the photons from the central source to reach the spherical shells. The walls of the bi-cone are dense and represent material that has been swept up by the evacuating process. The walls also scatter light.

## Results

Figure 4 shows the rendering of the above model. Clearly noticeable is the overall "X" shape to the nebula, the ladder rungs and the bright knots. The "X" shape is a result of the increase density along the walls of the bi-cone. The emergence of the ladder rungs and knots are a consequence of the scattering nature of the nebula. The bi-cones cut off the "tips" of the spherical shells and thus produce a sequence of evacuated cones. Photons emitted from the source no longer hit the spherical shells, but a small percentage leak through the walls and illuminate the ring around the cone base. When the nebula is perpendicular to the line of sight, the base of the cones appear as straight lines, giving rise to the apparent ladder rungs. The knots are produced in a similar manner. The optical depth through the circular base of the cone is greatest at the point where the tangent is parallel to the line of sight. Thus there is more scattering material at the edge of the ladder rungs which subsequently appear as bright knots.

When the model is rotated by only 20 degrees (figure 5, left panel), the linear ladder rungs disappear and concentric arcs emerge. This is a consequence of rotating the circular base of the cones. The further the cone is tilted, the more circular the arcs appear. Interestingly we observe such concentric arcs in several other PPN, such as the Egg nebula (figure 5, right panel).

## Conclusion

We have presented a simple morphological model to explain some features of the RR nebula. The model, if correct, has consequences for the evolution of the RR. What causes the bi-cones to be evacuated? A possible cause is that of high speed collimated outflows from the source. Because the linear appearance of the ladder rungs is created when the spherical shells are destroyed, the high speed outflows must occur AFTER the mass loss episodes. It should therefore be possible to put constraints on when the outflow was launched by determining the age of the most recent ladder rungs.

Our model results show that the intrinsic structure of the Red Rectangle is similar to that of the Egg Nebula, and the "spider web" structure of the RR is nothing more than the concentric arcs commonly seen in PPNs and PNs (Kwok et al. 1998).

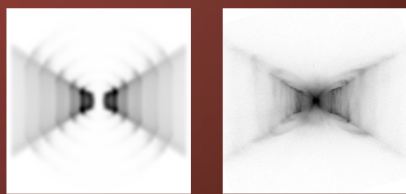

**Figure 4:** Rendering of the SHAPE model (left) and inverted image of the RR (right) (H. Van Winckel (KU Leuven), M. Cohen (UC Berkeley), H. Bond (STScI), T. Gull (GSFC), ESA, NASA).

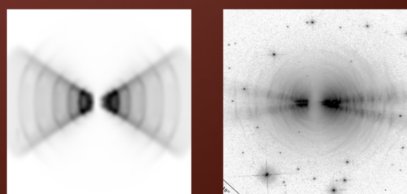

**Figure 5:** Model rotated by 20 deg (left). The right panel is an image of the Egg Nebula (Sahai et al 1998). The concentric arcs in the model mimic those seen in the Egg nebula.

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