

# Orientation Effects in Bipolar Nebulae: Can disks do it?

Hektor Monteiro<sup>1</sup>, Hugo E. Schwarz<sup>1</sup> & Ryan Peterson

<sup>1</sup> – Cerro Tololo Interamerican Observatory – Chile

## Abstract

In this work we investigate how a disk affects the radiation emitted by an embedded star. We show correlations obtained from broad-band observations of bipolar nebulae indicating that an orientation effect is at play on these systems. The IR radiations relative to total radiation increases with inclination while the NIR and BVR radiation relative to total decreases. This is an expected effect if we consider the system as being made up of a dense dusty disk being irradiated by a hot star. We calculate 2D models to try and reproduce the observed behavior with different disk and star configurations. We show preliminary results for some disk geometries.

## Observations

We collected a sample of bipolar planetary nebula and symbiotic nebula from the literature that contained sufficient data to produce a reasonable spectral energy distribution (SED). After constructing the SEDs we compared the luminosity emitted in each band relative to the total luminosity with the inclination angles. The inclination angles were determined by the three authors independently, being in agreement within 15 degrees in most cases. Some discrepant cases differed as much as 30 degrees, but these were few. Table 1 shows the objects studied and the luminosities for each band as well as the final inclinations. In figure 1 we show the graph with the relative luminosities for each band as a function of the inclination. One can clearly see the increase of relative IR as well as the decrease of JHK and BVR with inclination.

## Models

To try to explain this observed behavior, we propose that the systems are composed of a dusty disk being irradiated by a star (or stars!). This radiation heats up the dust that is responsible by the radiation emitted in the IR. The combined effect of this re-radiation with the extinction produced by the disk is what would create the observed effect. In figure 2 we show schematically how the disk is expected to affect the relative radiation from each band. The model used here is a simple 2D radiative transfer that calculates the temperature of the grains of a disk structure defined by a square grid. By requiring conservation of luminosity and iterating we determine the temperature of the dust in each cell. Secondary radiation is as of yet not accounted for. We have studied four basic disk shapes with different densities and combinations of stars irradiating them.

For the dust characteristics we adopt typical interstellar grains with  $R_v=3.1$  with properties calculated by Li & Draine (2001) and a dust to gas ratio 0.008. For all different disk shapes adopted we obtained temperature maps. With the temperature maps and disk structures we calculated a random sample of star-disk systems with random inclination angles. This simple method assumes a general temperature, taken here as the average temperature obtained from the 2D code. We also obtain attenuation functions from the 2D code that will be used to calculate the extinction of the star light when intercepted by the disk. Also from the code we obtain the amount of starlight absorbed by the disk. With this we assume that this energy is re-radiated in the IR as a blackbody with the average temperature mentioned before. Figure 3 shows the plots obtained for a few runs for different temperature and star systems.

We also present here the correlation for the three bands with inclination obtained fully with the 2D code and a more realistic disk structure. The grid dimension (disk outer radius) is  $1.7e16$  cm and the star system used was a  $1.0e5K$  star with 1000 solar luminosities and a  $3.5e3K$  star with  $3.0e3$  solar luminosities. The density structure is show in figure 4. In figure 5 and 6 we show the correlation obtained and the SED for different inclination angles.

## Conclusions

The results show that a disk with sufficient density and size is able to produce the general observed behavior. It is interesting to notice that the simple model did not do well when we considered a double system with a luminous cold star as well as the hot ionizing one. In the other hand, the more precise 2D code copes well with that star and in fact needs it to reproduce the observed results. These results are only preliminary and much more detail should be accounted for to be able to pin-point the actual disk structure needed. Even so, we can safely say that, yes, disks can do it!

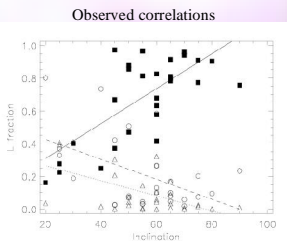


Figure 1

Objeto	$L_{IRAS}$	$L_{JHK}$	$L_{BVR}$	$L_{total}$	Inclination**
19032	$1.91 \times 10^{-4}$	$1.08 \times 10^{-3}$	$9.49 \times 10^{-2}$	$9.61 \times 10^{-1}$	50
H47	$7.43 \times 10^{-4}$	$1.79 \times 10^{-3}$	$1.70 \times 10^{-1}$	$7.59 \times 10^{-1}$	60
H49-25	$5.20 \times 10^{-4}$	$9.35 \times 10^{-3}$	$2.51 \times 10^0$	$7.57 \times 10^{-1}$	90
H49-36	$1.14 \times 10^{-4}$	$1.89 \times 10^{-3}$	$1.88 \times 10^{-1}$	$4.01 \times 10^{-1}$	45
H49-111	$5.61 \times 10^{-4}$	$1.22 \times 10^{-3}$	$5.63 \times 10^{-2}$	$9.40 \times 10^{-1}$	70
H49-114	$2.40 \times 10^{-4}$	$1.75 \times 10^{-3}$	$2.53 \times 10^{-1}$	$9.73 \times 10^{-1}$	45
H49-143	$1.14 \times 10^{-4}$	$4.83 \times 10^{-3}$	$3.24 \times 10^{-1}$	$9.67 \times 10^{-1}$	55
IC4406	$5.12 \times 10^{-4}$	$9.05 \times 10^{-3}$	$9.98 \times 10^{-2}$	$9.18 \times 10^{-1}$	65
IT131-147	$3.83 \times 10^{-4}$	$1.07 \times 10^{-3}$	$3.64 \times 10^{-1}$	$6.78 \times 10^{-1}$	65
K2-46	$8.12 \times 10^{-4}$	$6.44 \times 10^{-3}$	$7.91 \times 10^{-1}$	$9.14 \times 10^{-1}$	65
M1-8	$4.18 \times 10^{-4}$	$3.95 \times 10^{-3}$	$3.30 \times 10^{-1}$	$2.77 \times 10^{-1}$	35
M1-15	$9.57 \times 10^{-4}$	$1.07 \times 10^{-3}$	$3.68 \times 10^{-1}$	$2.23 \times 10^{-1}$	20
M1-16	$6.21 \times 10^{-4}$	$2.22 \times 10^{-3}$	$1.61 \times 10^{-1}$	$5.77 \times 10^{-1}$	67.5
M1-28	$2.11 \times 10^{-4}$	$2.91 \times 10^{-3}$	$3.11 \times 10^{-1}$	$9.68 \times 10^{-1}$	55
M1-91	$8.78 \times 10^{-4}$	$1.69 \times 10^{-3}$	$7.41 \times 10^{-2}$	$9.10 \times 10^{-1}$	30
M2-48	$3.92 \times 10^{-4}$	$3.04 \times 10^{-3}$	$2.98 \times 10^{-1}$	$6.69 \times 10^{-1}$	20
M3-26	$1.97 \times 10^{-4}$	$4.48 \times 10^{-3}$	$1.90 \times 10^{-1}$	$8.28 \times 10^{-1}$	40
MyCn18	$1.58 \times 10^{-4}$	$1.42 \times 10^{-3}$	$4.42 \times 10^{-1}$	$8.12 \times 10^{-1}$	50
Mr1	$3.12 \times 10^{-4}$	$7.30 \times 10^{-3}$	$7.18 \times 10^{-1}$	$8.53 \times 10^{-1}$	50
Mr3	$2.80 \times 10^{-4}$	$3.29 \times 10^{-3}$	$1.65 \times 10^{-1}$	$7.99 \times 10^{-1}$	55
NGC51	$1.92 \times 10^{-4}$	$2.11 \times 10^{-3}$	$5.91 \times 10^{-1}$	$4.16 \times 10^{-1}$	60
N246	$6.03 \times 10^{-4}$	$2.07 \times 10^{-3}$	$4.22 \times 10^{-1}$	$3.71 \times 10^{-1}$	60
N249	$2.28 \times 10^{-4}$	$4.24 \times 10^{-3}$	$7.88 \times 10^{-1}$	$8.78 \times 10^{-1}$	35
H49-194	$2.85 \times 10^{-4}$	$2.33 \times 10^{-3}$	$5.07 \times 10^{-1}$	$4.70 \times 10^{-1}$	65
DI Cms	$8.51 \times 10^{-4}$	$1.61 \times 10^{-3}$	$7.95 \times 10^{-1}$	$2.49 \times 10^{-1}$	70
S43-237	$7.80 \times 10^{-4}$	$1.80 \times 10^{-3}$	$9.80 \times 10^{-1}$	$9.80 \times 10^{-1}$	70
CR1,2658	$3.23 \times 10^{-4}$	$1.04 \times 10^{-3}$	$2.65 \times 10^{-1}$	$6.22 \times 10^{-1}$	60
MS-9	$1.28 \times 10^{-4}$	$2.15 \times 10^{-3}$	$2.02 \times 10^{-1}$	$7.74 \times 10^{-1}$	50
R Aps	$7.10 \times 10^{-4}$	$3.67 \times 10^{-3}$	$5.01 \times 10^{-1}$	$1.82 \times 10^{-1}$	32.5

## Expected behavior of star-disk system

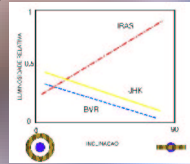


Figure 2

## Model Correlations

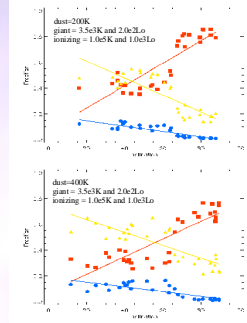


Figure 3

## Correlation obtained with 2D model

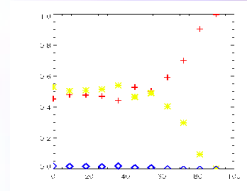


Figure 4

## Density distribution used in 2D calculation

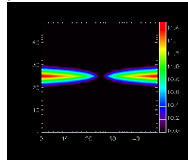


Figure 5

## SED's for different inclinations from 2D model

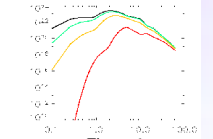


Figure 6