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Can rotating stars shape the planetary nebulae?

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We explore the effect of asymetrical central star on the shape of ionized gas. The asymetry of the star can come from its rotation or from the presence of an absorbing equatorial disk. The models are performed using Cloudy_3D. We present some preliminary results.

Can stellar rotation shape the planetary nebulae?

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Introduction.

*There are many scenarios proposed for the formation and shaping of the bipolar planetary nebulae. Even though non of them is accepted as universally valid and it is most probable that different nebulae are formed by different mechanisms. In this poster we present another alternative scenario based on the effects of the stellar rotation on the stellar radiation field. The reaction of a **spherical** shell to an axi-symmetic radiation field is explored and we show that the shell is ionized in a bipolar pattern. This is **not** the observed bipolar nebula but a structure formed in the very early stages of the post-AGB evolution. We speculate that the nuclear region of an AGB is contracted at the end of the termo-nuclear reaction. This stellar remnant partially conserve its angular momentum and increase its rotational velocity about 2 orders of magnitude. Thus, the proto CSPN first has asi-symmetric radiation field due to the gravitational darkening, and then its wind is asi-symetric. The radiation field forms a bipolar structure which eventually evolve to a typical bipolar nebula.*

The proposed idea is based on the observed characteristics of the B[e]objects. Shortly, the B[e] stars are a heterogeneous group of objects which show strong Balmer lines in emission, emission lines of both permitted and forbidden lines of low ionized metals together with lines of high ionization species and strong IR excess. Among the B[e] stars are massive evolved supergiants, pre-main sequence Herbic B[e] star, symbiotic stars and several CSPN (Lamers et al., 1998).

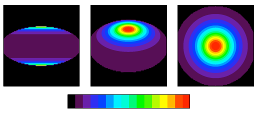

Figure 1. Flux emitted by a star rotation with 70% of its breakup velocity. The the values are in units of the polar flux. Left) Equatorial view. Center) Star seen from 30° above the equator. Right) Polar view.

Models:

The 3D photoionization models are performed using Cloudy_3D (Morisset, 2006). The CSPN luminosity seen by the nebula depends on the polar angle and is close to 3000 Lsol in the polar direction. The gas density is constant, set to 30000 H/cm3. The inner radius of the nebula is 10^16cm, the total size of the nebula being 3.6 10^16 in the polar direction (maximum extension).
We tested the idea using two models.
1) *We calculated the reaction of the spherical nebula to the radiation of a star without wind but with gravitational darkening. Fig. 1 shows the shape of a star rotating with 70% of its breakup velocity. von Zeipel's theorem (von Zeipel, 1924) states that the flux from the star at given latitude is proportional to the local effective gravity. Thus the flux at the equator is reduced and the temperature of the radiation is lower. The resulting axi-symmetric radiation ionizes the polar regions but keeps the equatorial regions cold and recombined (Figs. 2 and 4).*
2) *The second model considers a star similar to the B[e] stars. In certain combination of temperatures and densities, the stellar rotation can concentrate the stellar wind toward the equator (Lamers and Cassinelli, 1999, Curé et al. 2005). We used out code Astaroth (Georgiev et al. 2006, Zshargo et al., 2006). The presence of the disk alter the radiation field of the star even more than the gravitational darkening. Fig. 3 show the reaction of the spherical shel to the radiation field of the star with disk-like wind. As in the first model, the polar regions are ionized and the equator is kept neutral. (Figs. 3 and 5)*

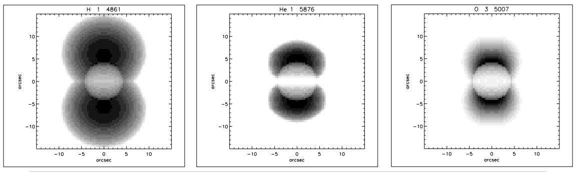

Figure 2. Model 1. Structure of the emission in Hbeta, HeI 5876 and [OIII] 5007 of a spherical nebula with central star rotating with 70% of its breakup velocity (as shown on Fig. 1)

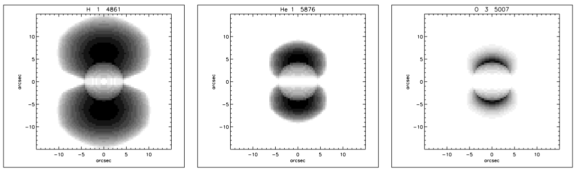

Figure 3. Model 2. Structure of the emission in Hbeta, HeI 5876 and [OIII] 5007 of a spherical nebula with central star with disk-like wind.

Is the proposed scenario possible?
It is intuitively clear that an axi-symmetric radiation field will produce an axi-symmetric ionization structure, if the contrast between polar and equatorial flux is large enough. The question is, could the stellar remnant which is in the way to became CSPN rotates fast enough to produce the contrast? This question is very difficult. Based on observation of CaII K line, Berger et al. (2005) showed that the DA white dwarfs rotate very slowly. Suijs et al. (2008) had studied the evolution of a rotating star from MS to WD phase. The authors obtained that the non magnetic white dwarf produced from 3 Msun main sequence star will rotate with 220 km/s. Magnetic reconnection were suggested to additionally reduce the angular momentum and to reconcile the model with the observed values of Vrot. These results seems to discard any effect caused by rapid rotation simply because the rotation does not exist.

On the other hand the conclusions are not so simple. There are several bipolar PN (Lamers et al., 1998; Arrieta et al, 2009) with B[e] characteristics. Sahai et al (2002) obtained high resolution images of the B[e]/compact PN object He 2-90 (Fig. 4). A disk-like structure is clearly visible and the spectrum of the object is typical for a B [e] star. If we assume that the B[e] phenomenon is caused by rapid rotation, then at least in the above mentioned object, the central star do conserve its angular momentum, form an equatorial disk and emits axi-symmetric radiation. In these cases our scenario should work and indeed our model 2 resemble the image of He2-90.

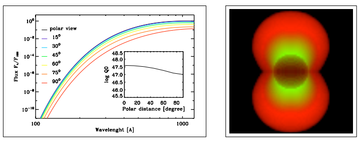

Figure 4. Flux at different polar angles for Model 1. The radiation field is a weighted summ of Black bodies with differet temperatures. The changes in the flux are result of both temperature and projected surface changes. Note that the contrast between polar and quatorial Q0 is about 6, which is sufficient to create the bipolar structure.

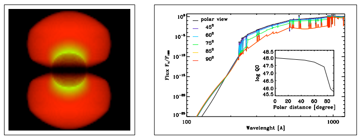

Figure 5. Flux at different polar angles for Model 2. The radiation field is calculated with 2D radiation transfer code Astaroth. The changes in the flux are result of the ionization structure of the wind. Note that the contrast between polar and quatorial Q0 is almost 100.

Discussion:

1) *We suggest that in the early stages of the evolution of a planetary nebula, its central star increases its rotational velocity and due to the gravitational darkening and possible formation of an equatorial disk creates a bipolar ionization structure in the expelled spherical AGB shell. The polar and equatorial regions of that structure will evolve in different way due to the difference in their physical conditions. The cold, neutral equatorial region may form the dust torus observed in several objects. The polar regions will expand more rapidly elongating the structure and eventually forming a bipolar planetary nebula.*
2) *If one assume that objects with similar spectral characteristics are formed by similar physical mechanisms then, at least for the CSPN with B[e] classification, the angular momentum survives the AGB evolution leading to a fast post-AGB rotator. How these stars loose their momentum to became a slowly rotating DA or do they evolve to a different kind of white dwarfs is an open question.*

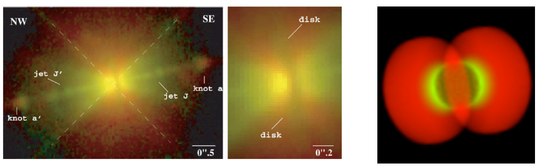

Figure 6. HST composit image of He 2-90 taken from Sahai et al. 2002. Pseudo color made from F502N (green) and F658N (red) images. The disk-like structure is clearly seen and the low ionisation hallo (red) is similar to the Halpha image obtained from our model 2. The right panel shows the composit image from Model 2. Again Halpha is in red and [OIII] 5007 is in green. There is clear resemblance between two images.

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