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# Signs of rotating equatorial density enhancements around SRb pulsators

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**Abstract.** We observed the circumstellar environments (CSEs) of the semiregular AGB stars L2 Puppis, R Doradus and EP Aquarii with ALMA. (1) The molecular emission in the $L_2$ Pup nebula reveals an edge-on rotating disk. (2) PV diagrams of the $^{28}$SiO emission in the inner CSE of R Dor expose a pattern pointing to an inclined rotating disk. (3) The CO emission in the CSE of EP Aqr reveals a nearly face-on equatorial density enhancement (EDE). The inner EDE strongly resembles theoretical wind-Roche-lobe-overflow models. The SiO emission points to a potential companion. The combination of (1), (2) and (3) suggests that a link may exist between the type of AGB pulsations and the morphological nature of the CSE.

**Keywords.** stars: AGB and post-AGB stars, circumstellar material, stars: mass loss, stars: imaging, submillimeter

## 1. Introduction

Asymptotic giant branch (AGB) stars are the evolutionary stage of low- and intermediate-mass stars before they turn into the planetary nebulae. These CSEs exhibit large-scale sphericity, but generally display a rich spectrum of smaller scale structural complexities. Hydrodynamic models show that perturbation of the AGB wind by the local gravity field of a non-giant binary companion may play a crucial role in explaining various deviations from spherical symmetry (Mastrodemos & Morris 1999). This should not not come as a surprise, as the multiplicity frequency of the main sequence (MS) predecessors of AGB stars is found to exceed 50% (Raghavan *et al.* 2010). Considering that recent studies show that on average every star in the Milky Way (Cassan *et al.* 2012) possesses one or more planets, this frequency can only be considered a lower limit. In this manuscript we briefly present high-resolution ALMA observations of three different M-type SRb AGB stars: $L_2$ Puppis, R Doradus and EP Aquarii.

## 2. Observations

**$L_2$ Puppis** (Homan *et al.* 2017) We obtained spatially resolved ALMA band 7 observations of the CSE of $L_2$ Pup. The data shows an edge-on differentially rotating gas disk (Kervella *et al.* 2016). The Keplerian motion of the gas allowed us to accurately determine the central mass of the $L_2$ Pup system. A significant asymmetry in the continuum emission of the disk points towards the presence of a binary companion. We modelled the observed emission of the $^{12}$CO and $^{13}$CO rotational transition $J=3-2$ with LIME (Brinch & Hogerheijde 2010) which allowed us to constrain the (thermo)dynamical and morphological properties of the circumstellar gas. This permitted us to deduce the mass

of the disk. The angular momentum (AM) in the disk was found to be excessive compared to the host star's AM. We calculate that a binary companion of ∼1 Jupiter mass would be sufficient to explain the AM contained in the disk.

**R Doradus** (Homan *et al.* 2018a) A spectral scan of the CSE of R Dor was acquired with ALMA at a spatial resolution of ∼ 150 mas (Decin *et al.* 2018). Many molecular transitions show a distinct spatial offset between the blue and red shifted emission in the central 1" × 1". We constructed position-velocity diagrams of the compact $^{28}$SiO v=1 emission, whose dynamical signature resembles that of a nearly edge-on rotating disk. We model the emission using the radiative transfer code `LIME`, and reproduce the morpho-kinematical emission features by assuming a compact disk. We calculate the mass of the disk and estimate that its AM exceeds the AM of the host star. An object with a mass of at least ∼2.5 earth masses at a distance of 6 AU, the tentative disk inner rim location, could explain the AM contained within the disk, though its mass may be substantially higher.

**EP Aquarii** (Homan *et al.* 2018b) EP Aqr was observed with ALMA band 6 in cycle 4, probing the molecular emission of $^{12}$CO , $^{28}$SiO , and $SO_2$ emission. The spatially resolved CO emission reveals a bi-conical outflow with a bright central spiral structure-harbouring EDE. The EDE is extremely confined in velocity-space. The innermost regions of the CO emission exhibit a morphology that strongly resembles the wind Roche-lobe overflow (WRLOF) simulations of the Mira AB system. The SiO emission exhibits a localized emission void, located about 0.5" west of the continuum brightness peak in the red-shifted portion of the emission, located where the WRLOF simulations predict it to be. This feature may be a local environment caused by the presence of a companion, and estimate its to be at most ∼0.1 $M_\odot$ based on its non-detection in the continuum. Finally, the $SO_2$ emission shows a clear sign of (co)rotation, with a maximum projected velocity amplitude of ∼1 km s$^{-1}$. The odd nature of the spiral/EDE and the deprojected rotation speeds of the $SO_2$ gas favours the hypothesis that the equatorial matter is contained within a large face-on differentially rotating disk.

## 3. Concluding hypothesis

Observations/Modeling of the inner wind of these three oxygen-rich SRb-type AGB stars show strong indications for the presence of binary companions. Furthermore, it seems that the dominating velocity field of the equatorial matter in the inner CSE is tangential, resulting in the formation of a stable disk. High-resolution observation of mira-type carbon stars show that these typically possess spiral-shaped features in their winds, with no indications of rotation. We hypothesize that there may be a relation between the nature of the surface pulsations of the AGB star, and the resulting companion-induced wind morphology.

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