Why Galaxies Care About AGB Stars: A Continuing Challenge through Cosmic Time
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Separation of gas and dust in the winds of AGB stars

Lars Mattsson[1], Christer Sandin[1] and Paolo Ventura[2]

[1]Nordita, Roslagstullsbacken 23, SE-106 91 Stockholm, Sweden
email: lars.mattsson@nordita.org

[2]INAF-Osservatorio Astronomico di Roma, Monteporzio, Italy

Abstract. We present first results from a project aiming at a better understanding of how gas and dust interact in dust-driven winds from Asymptotic Giant Branch (AGB) stars. We are at the final stage of developing a new parallelised radiation-hydrodynamics (RHD) code for AGB-wind modelling including a new generalised implementation of drift. We also discuss first results from high-resolution box simulations of forced turbulence intended to give quantitative "3D corrections" to dust-driven winds from AGB stars. It is argued that modelling of dust-driven winds of AGB stars is a problem that may need to be treated in a less holistic way, where some parts of the problem are treated separately in detailed simulations and are parameterised back into a less detailed (1D spherically symmetric) model describing the entire picture.

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1. Background

The current state-of-the-art codes used to model AGB winds include time-dependent dust-grain growth and frequency-dependent radiative transfer, but assume direct position coupling between gas and dust, i.e., there is no drift between the two phases in the model (see, e.g., Mattsson *et al.* 2010, Mattsson & Höfner 2011, Höfner *et al.* 2016). It is well established, though, that kinetic drag and drift is indeed an essential part of the wind-formation mechanism in AGB stars (Krüger *et al.* 1994, Sandin & Höfner 2003a, Sandin & Höfner 2003b, Sandin & Höfner 2004).

Three dimensional (3D) models for the inner (convective) part of AGB atmospheres are now being used instead of a simple piston boundary to account for pulsation (see, e.g., Liljegren *et al.* 2018). But 3D inhomogeneous models of the wind region is still an inhibiting computational challenge. However, effects of relaxing the spherical-symmetry assumption in the wind region may be greater than the effects of replacing the simplistic piston boundary with simulations of large-scale convection in 3D. The reason for this is that in reality, turbulence is expected to develop and in the presence of turbulence, inertial dust grains will cluster, which significantly alters the radiative balance.

For the reasons given above, we have developed a new simulation code for AGB winds, which includes a new generalised implementation of drift as well as corrections for 3D effects in the wind region.

2. Towards a new improved AGB wind model

We are currently finalising the development of a new RHD code built upon the work by Sandin (2008). In comparison to existing codes, our improved code is based on modern powerful features in Fortran 90/95. Additionally, it has drastically improved numerics; the radiative transfer is parallelised, and the code is structured in such a way that it can easily be extended with more accurate physical descriptions. Currently the code can do gas-dust drift, as well as convection, but more features are added continuously. Below, we detail the new physics considered at present.

Radial drift. By having $1 + N$ momentum equations for the gas and N dust sizes/species we can model drift with rather generic approach, which does not necessarily require dust dynamics to be treated in terms of a "mean component", but actually allow a multidisperse dust component. This, combined with high-resolution frequency-dependent radiative transfer, leads to different rates of dust condensation and sublimation compared to models with position coupling as well as compared to models that include drift and *grey* radiative transfer.

3D effects. How long does the dust spend in low- and in high-density regions, respectively? As we hinted above, decoupled grains are more susceptible to radiative heating and sublimation. They also grow slower as they are less exposed to their growth-species molecules. Separation of gas and dust occurs not only in the radial direction and effects on the radiative transfer through the wind region can be significant. High-resolution box simulations of moderately forced turbulence in a local co-moving region of the wind provide quantitative "3D corrections" to the 1D radiative transfer, which have bearing on the wind formation and the efficiency of momentum transfer from radiation to gas via dust grains.

Grain clustering. One type of "3D correction" is particularly important: grains in a turbulent medium will cluster on scales shorter than that of the gas, which leads to an uneven dust-drag on the gas as the dust is accelerated by radiation pressure. Moreover, grain do not necessarily cluster where the gas is; the dust grains are exposed to more radiation as they are not shielded by the gas. It also means that the effective dust opacity (or optical depth) is less than it would be assuming a homogeneous mix of gas and dust.

3. Concluding remarks

Test models for carbon-rich AGB stars show that the decoupling of gas and dust leads to complex two-fluid dynamics, which suggest reduced mass-loss rates. The preferential (size-dependent) concentration and gas-drag acceleration of grains also create nontrivial size distributions, which in turn suggest an evolving grain-temperature distribution. This may be an important parameter in observational estimates of dust around AGB stars, just as well as it is in supernova remnants (Mattsson *et al.* 2015).

Finally, a thought-provoking question: *if dust-driven stellar winds are formed, as dust drags gas along – can we say we understand the formation of such winds before the gas-to-dust coupling is fully understood?*

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