

The chemistry in clumpy AGB outflows

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Abstract. The chemistry within the outflow of an AGB star is determined by its elemental C/O abundance ratio. Thanks to the advent of high angular resolution observations, it is clear that most outflows do not have a smooth density distribution, but are inhomogeneous or “clumpy”. We have developed a chemical model that takes into account the effect of a clumpy outflow on its gas-phase chemistry by using a theoretical porosity formalism. The clumpiness of the model increases the inner wind abundances of all so-called unexpected species, i.e. species that are not predicted to be present assuming an initial thermodynamic equilibrium chemistry. By applying the model to the distribution of cyanopolynes and hydrocarbon radicals within the outflow of IRC+10216, we find that the chemistry traces the underlying density distribution.

Keywords. astrochemistry, molecular processes, stars: AGB and post-AGB stars, circumstellar material, stars: mass loss, stars: individual (IRC+10216)

1. Introduction

By using a theoretical porosity formalism (e.g., [Owocki *et al.* 2006](#); [Sundqvist *et al.* 2014](#)), we have developed a model of the gas-phase chemistry that takes into account the effects of clumpiness throughout the outflow. This model is the first model that includes the effect of both the increased penetration rate of interstellar UV photons (porosity) and the relative over-density within clumps (clumping). Porosity is taken into account by modifying the optical depth of the outflow. A crucial parameter for this is the porosity length h_* at the stellar surface, which can be seen as the local mean free path between two clumps. Clumping is achieved by splitting the outflow into an overdense clump component and a rarefied inter-clump component ([Van de Sande *et al.* 2018](#)).

2. Effect on the inner wind abundances

In the inner regions of AGB outflows, several molecules have been detected with abundances much higher than expected from thermodynamic equilibrium chemical models. Non-equilibrium chemical models that take into account the effect of shocks, induced by the pulsating AGB star, can account for the presence of most, but not all, of these so-called unexpected species, but not all. We found that a clumpy outflow influences the abundances of the unexpected species. They can all form close to the star, including species not formed by shock-induced non-equilibrium chemical models (e.g., NH_3). The largest increase is seen in outflows with a large clump overdensity and large porosity ([Van de Sande *et al.* 2018](#)). The effect of porosity on the abundances is illustrated in

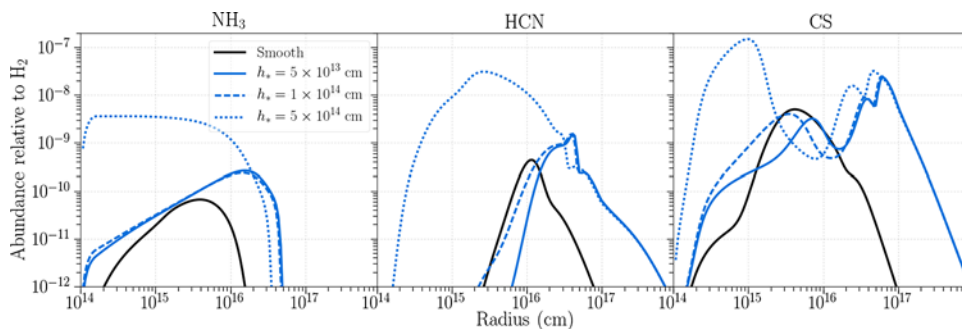


Figure 1. Abundance of NH_3 , HCN , and CS relative to H_2 throughout an O-rich outflow with a mass-loss rate of $10^{-5} M_{\odot} \text{ yr}^{-1}$. In the outflows shown here, all material is located inside the clumps (void inter-clump component) and the clumps take up 10% of the total volume.

Fig. 1. However, not all observed abundances can be reproduced. This can potentially be solved by combining shock-induced non-equilibrium chemistry and a clumpy outflow.

3. Cyanopolyynes and hydrocarbon radicals in IRC+10216

Cyanopolyynes, HC_{2n+1}N , and hydrocarbon radicals, C_{2n}H ($n = 1, 2, 3, \dots$), are located in molecular shells around IRC+10216. The HC_{2n+1}N shells show a radial sequence, which is expected from a bottom-up formation route. The C_{2n}H shells, however, are observed to be cospatial. The outflow of IRC+10216 is not smooth. Density-enhanced shells are present, which are moreover distinctly clumpy (e.g., Agúndez *et al.* 2017; Keller, *et al.* 2018). Previous chemical models have aimed to explain the discrepancy between the locations of the HC_{2n+1}N and the C_{2n}H families by either taking into account the effect of the density-enhanced shells (i.e. Cordiner & Millar 2009) or the increased UV radiation rate due to their clumpy nature (i.e. Agúndez *et al.* 2017). Both types of models found a cospatial distribution of both the HC_{2n+1}N and the C_{2n}H .

We used our clumpy model to quantify the effects of clumping and porosity on the locations of the molecular shells. We find that one model cannot reproduce the observed locations of both the HC_{2n+1}N and the C_{2n}H . Rather, we find two independent families of models. The family of solutions that best reproduce the locations of the HC_{2n+1}N are characterised by a larger mass-loss rate (corresponding to a larger overall density) and a lower porosity compared to the family of solutions of the C_{2n}H shells. This corresponds to the observed structure in the outflow: the HC_{2n+1}N are located inside a density-enhanced shell, whereas the C_{2n}H are located at the outer edge of the shell. The density distribution within the outflow can hence be traced by simple chemical models. However, to reproduce the locations of both the HC_{2n+1}N and the C_{2n}H , a more comprehensive model is needed. It is clear that such a model must also include the significant effects of clumping and porosity on the chemistry.

References

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 Van de Sande, M., Sundqvist, J. O., Millar, T. J. *et al.* 2018, *A&A*, 616, A106