Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
Proceedings IAU Symposium No. 343, 2019
F. Kerschbaum, M. Groenewegen & H. Olofsson, eds.

doi:10.1017/S1743921318006609

Ammonia in C-rich stars

Bartosz Etmański, Mirosław R. Schmidt, Bosco H. K. Yung and Ryszard Szczerba

Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences,
Departament of Astrophysics, 87-140 Toruń, Rabiańska 8, Poland

Abstract. HIFI instrument onboard the Herschel satellite provided an unprecedented number of detections of rotational transitions of ammonia in circumstellar envelopes of evolved stars including massive red supergiants, Asymptotic Giant Branch (AGB), and post-AGB stars. The chemistry of ammonia formation in the circumstellar envelopes of evolved stars is poorly understood. The mechanisms proposed for its formation are processes behind the shock front, photochemistry in the inner part of the clumpy envelope, and formation on dust grains. We present results of the non−local thermodynamical equilibrium (non−LTE) radiative transfer modeling of ammonia transitions, mainly of the ground-state rotational one NH_3 $J_K = 1_0 - 0_0$ at 572.5 GHz, in selected AGB stars, aiming at the quantitative estimation of the NH_3 abundance. The model of ammonia includes IR radiative pumping via $v_2 = 1$ vibrational band at 10 μm.

Keywords. line: profiles - submilimeter: stars - stars: AGB and post-AGB - circumstellar matter

1. Introduction

Ammonia is the molecule which occurs in many different astrophysical objects, like dark clouds, merger remnants, massive star-forming regions, protoplanetary discs and in the circumstellar envelopes (CSE) around AGB stars. Its abundance found in CSE is much higher than predicted by models of stellar atmospheres of cool (super)giants, which is of order of 10^{-12}–10^{-10} relative to H_2 (Johnson & Sauval 1982). Abundances of ammonia in circumstellar environments of AGB stars are much higher ($\sim 10^{-6}$–10^{-7}). One of the explanations proposed to resolve this problem is dissociation of N_2 molecules by passage of shocks (Willacy & Cherchneff 1998). In C-rich stars, this process changes the abundance of ammonia only slightly (Gobrecht *et al.* 2016). Another explanation is that the clumpy CSE may be penetrated by the galactic background ultraviolet radiation even to the inner part of the envelope (Decin *et al.* 2010) producing atomic nitrogen. However, Li *et al.* (2016) have shown that N_2 may survive in inner regions due to self-shielding.

Recently, Schmidt *et al.* (2016) analysed all the lowest nine rotational transitions acquired with the HIFI instrument updated by observations of inversion lines of ammonia (Gong *et al.* 2015) in the very well studied C-rich AGB star CW Leo. Here, we follow their approach for the analysis of other C-rich objects.

2. Analysis and results

In Table 1, we present derived abundances of ortho-ammonia in five C-rich AGB stars together with their basic parameters. We estimate that the accuracy of determinations of ortho-ammonia abundances should be better than a factor of two.

For the modelling of molecular lines, we have applied the following procedure. The spectral energy distribution was modelled using MRT (Szczerba *et al.* 1997), and occasionally

Table 1. The basic parameters of analysed AGB stars and their CSE.

Object	P (days)	V_{LSR} (km s^{-1})	L_{star} (10^3 $L_\odot$)	T_{star} (K)	M_{loss} $M_\odot$ yr^{-1}	Distance (pc)	V_{exp} (km s^{-1})	f(o-NH_3)
V Cyg	421	15.0	6.6	1875	1.7×10^{-6}	458[1]	10.5	0.9×10^{-7}
CIT 6	640	−1.8	8.3	2470	5.2×10^{-6}	589[1]	16.5	1.8×10^{-7}
II Lup	580	−15.0	9.1	2000	1.5×10^{-5}	1917[1]	21.0	5.0×10^{-7}
LP And	614	−17.0	9.7	2040	2.2×10^{-5}	400	13.5	3.5×10^{-8}
V384 Per	535	−16.2	8.4	1820	4.2×10^{-6}	918[1]	14.5	2.2×10^{-7}

Notes:
[1]distance based on Gaia measurements (Brown *et al.* 2018)

DUSTY (Ivezic *et al.* 1999) codes. The thermal structure was derived using the code for computation of thermal structure THERMAL and modelling of CO transitions in the large velocity gradient approximation following Groenewegen *et al.* (1994). For modelling of molecular lines we have used the code for the solution of the multilevel radiative transfer problem in an expanding envelope, MOLEXCSE, applied earlier for analysis of emission lines of ammonia in CW Leo (Schmidt *et al.* 2016). The list of transitions and their strengths was extracted from the BYTe computations (Yurchenko *et al.* 2011) and compared with the list of lines in HITRAN database. The collisional data of rotational levels were adopted from the LAMDA database (up to 300 K). For more details of our approach, see Schmidt *et al.* (2016). The radius of NH_3 formation was fixed to the inner radius of the envelope. The photodissociation radius was calculated with CSENV (Mamon *et al.* 1988), while photodissociation rates were adopted from the website http://home.strw.leidenuniv.nl/ẽwine/photo/ (Heays *et al.* 2017).

Acknowledgements

The authors acknowledge support by the National Science Centre, Poland, under grant 2016/21/B/ST09/01626.

References

Brown, A.G.A., Vallenari, A., Prusti, T., de Bruijne, J.H.J, Babusiaux, C., & Bailer-Jones, C.A.L 2018, arXiv:1804.09365

Decin, L., Agndez, M., Barlow, M. J., Daniel, F., Cernicharo, J., Lombaert, R., De Beck, *et al.* 2010, *Nature* 467, 64

Gobrecht, D., Cherchneff, I, Sarangi, A., Plane, J.M.C., & Bromley, S.T. 2016, *A&A* 585, A6

Gong, Y., Henkel, C., Spezzano, S., *et al.* 2015, A&A, 574, A56

Heays, A. N., Bosman, A. D., & van Dishoeck, E. F. 2017, *A&A* 602, A 105

Ivezic, Z., Nenkova, M., & Elitzur, M. 1999, *http://www.pa.uky.edu/ moshe/dusty*

Johnson, H. R. & Sauval, A. J. 1982, *A&ASuppl.* 49, 77

Li, X., Millar, T.J., Heays, A. N., *et al.* 2016, *A&A* 588, A4

Mamon, G. A., Glassgold, A. E., & Huggins, P. J. 1988, *ApJ* 328, 797

Schmidt, M. R., He, J. H., Szczerba, R., Bujarrabal, V., Alcolea, J., Cernicharo, J., *et al.* 2016, *A&A* 592, A131

Szczerba, R., Omont, A., Volk, K., Cox, P., & Kwok, S. 1997, *A&A* 317, 859

Yurchenko, S. N., Barber, R. J., Tennyson, J. 2011, *New Astron. Revs* 46, 513

Willacy, K., & Cherchneff, I. 1998, *A&A* 330, 676

https://doi.org/10.1017/S1743921318006609 Published online by Cambridge University Press