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DETECTION OF ATOMIC IRON AND OTHER METALS IN THE CIRCUMSTELLAR ENVELOPE OF IRC+10216

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Abstract. We report the detection of several metals in atomic form in the gas phase of the envelope of IRC+10216, the archetype of evolved carbon-rich AGB stars. By observing with VLT-UVES a background star located behind the envelope at 35 arcsec from center, optical absorption lines of Na, K, Ca, Fe and Cr are revealed. It is the first time that circumstellar Fe is detected in a dusty envelope. The column densities of the circumstellar metals are derived. Then, the abundances of these metals are obtained with a model treating the photoionization of these elements in the outer envelope. The fraction of these metals present in the gas phase can be obtained, and a strong depletion of Fe and Ca onto grains is derived. The atomic abundances can also be compared to the abundance of metals carried by molecules. Our observations suggest that in the gas phase, the metals are much more abundant in atomic form than in molecular form. Our results are also consistent with metal depletions in planetary nebulae.

Keywords: AGB stars, mass-loss, circumstellar matter

1 Introduction

This research grew out of several earlier investigations on the colors and the structure of the envelope of IRC+10216 (Mauron et al. 2003; Mauron & Huggins 1999). UBV imaging of the envelope had been carried out to study the reflection of the Galactic light by the dust. A by-product of the photometry of field stars was the realization that a background star, located at about 1400 pc behind IRC+10216, could be used as a target for optical absorption line investigations. Its angular offset with respect to IRC+10216 is 35 arcsec, and it is a G-type star with V=16.0. The first investigations of this star were done with a VLT-UVES 2-hour exposure to search for diffuse bands (Kendall et al. 2002). No such bands were found, but we detected remarkable absorption lines of NaI and KI. Because IRC+10216 is at high galactic latitude, there is little interstellar matter on the line of sight, and in view of the central wavelength and characteristic profiles, these lines are of circumstellar origin. Then, it was realized that in principle, one could search for other elements in absorption in this spectrum, like CaII 3933-3968, CaI 4226, FeI 3820, and other resonance lines. In practice, the difficulty is that the star spectrum is not flat like for an OB star, but is solar-like with many photospheric absorption lines. We could resolve this problem because: 1) the spectrum of the target is very similar to the solar spectrum; and 2) its radial velocity is favourable: the circumstellar resonance lines are centered at -19.3 km s^{-1} (heliocentric center of mass velocity of IRC+10216), while the corresponding photospheric lines of the target are at +52 km/s. Therefore, the template spectrum of the Sun can be used and, after a small velocity shift, fitted on the target spectrum to search for any circumstellar feature. Eventually, we detected lines of KI 7665-7699, NaI 5890-5896 and 3300, CaI 4226, CaII 3933-3968, FeI 3860-3720 and several weak lines CrI in the blue, and measured their equivalent widths. We also searched for lines of AlI, TiI, TiII, MnI, and SrII, and put limits on their strengths.

2 Results and conclusions

From the profiles and equivalent widths, we determined the column densities of each element. It is then possible to interpret them quantitatively with the model of Glassgold & Huggins (1986) which includes photoionization

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and recombination of metal atoms and ions in an expanding envelope. The gas temperature and electronic density were taken from Cordiner et al. (2007). This model allows us to determine ratios like N(FeI) / N(FeII) on the line of sight, and correct our column densities for ionization to obtain abundances of each element, or upper limits.

The results are the following: Ca and Fe are depleted in the circumstellar gas phase, i.e. only about 5/1000 of Fe is in gas, and only 3/1000 of Ca. For Na, K, and Cr, the fractions in gas are 20 percent, 4 percent and 2.5 percent respectively. These results suggest that most of the metallic elements are in dust, either through condensation or through adsorption. However, some of the elements, like Na, are only slightly depleted. We could also put useful limits to Ti and Mn: we find that their fractions in the gas phase are lower than 3.5 percent and 1.6 percent.

The abundances of these metals in atomic form can be compared to their abundances in molecular form. It appears that the latter are smaller by an order of magnitude. For example, NaCl and NaCN have been observed, and their summed relative abundance (with respect to the total number of Na nuclei) is 4/1000. This is much lower than the 20 percent mentioned above for atomic Na. The same is true for K (3/1000 in KCN, 4 percent in atoms and ions). Therefore, it is unlikely that the metallic atoms and ions that we observe have their origins in the photodissociation of metal-bearing molecules. More probably, the metal-bearing molecule formation is not complete.

It is also possible to compare the depletions in IRC+10216 to those found in the ionized region of NGC 7027, a carbon-rich planetary nebula. We find that iron and calcium are more depleted in the AGB envelope (5/1000 and 3/1000, for Fe and Ca resp.) than in NGC7027 (2 percent and 18 percent, respectively). In contrast, Na and K are more volatile elements with low depletions: 20 percent of Na and 4 percent of K are in the 10216 gas phase, while these elements are essentially not depleted in NGC 7027. This suggests the following evolutionary effects in the transition from AGB to PN: nearly complete evaporation of the volatile species Na and K, and partial erosion of more refractory species Ca, and possibly Fe.

3 Conclusions

In conclusion, our results directly constrain the condensation efficiency of metals in a carbon-rich circumstellar envelope and the mix of solid and gas phase metals returned by the star to the interstellar medium. The abundances of the uncondensed metal atoms that we observe are typically larger than the abundances of the metal-bearing molecules detected in the envelope. The metal atoms are therefore the major species in the gas phase and likely play a key role in the metal chemistry. More details can be found in Mauron & Huggins (2010).

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