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Hyperfine Splitting of [Al VI] 3.66 μm and the Al Isotopic Ratio

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Abstract. Spectra of [Al VI] 3.66 μm $^3P_2 \leftarrow ^3P_1$ in the coronal region of PN NGC 6302, obtained with Phoenix on Gemini-South at resolving powers of up to 75000, resolve the line into five hyperfine components separated by 20 to 60 km s^{-1} due to the coupling of the $I = 5/2$ nuclear spin of ^{27}Al with the total electronic angular momentum J. ^{26}Al has a different nuclear spin of $I = 5$, and a different hyperfine structure (HFS), which allows us to place a 3 σ upper limit on the ^{26}Al/^{27}Al ratio of 1/33. We measure the HFS magnetic-dipole coupling constants for [Al VI], and provide the first observational estimates of atomic electric-quadrupole HFS coupling constants.

Keywords: atomic data – atomic processes – line: identification – line: profiles – ISM: abundances – platenary nebulae: individual: NGC 6302
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The 1.8 MeV gamma-ray emission due to the decay of ^{26}Al into ^{26}Mg has been the object of extensive surveys: with a half-life of 7.2 10^5 yr, ^{26}Al is a signpost of recent nucleosynthesis. But the ^{26}Al/^{27}Al isotopic abundance ratio has never been measured in any astrophysical source, and the precise origin of ^{26}Al remains elusive.

The interaction between the electronic wave-function and a non-zero nuclear magnetic dipole splits a fine-structure level $\{L,J\}$ into hyperfine levels. The electric-quadrupole corrections to the electric field introduce an additional correction, which is neglected in photospheric model line profiles, but which dominates over magnetic dipole HFS in molecules.

While hyperfine transitions are common in the radio range, at shorter wavelengths atomic hyperfine structure (HFS) has seldom been resolved in emission.

We observed NGC 6302 with Phoenix on Gemini South on 5 nights of May and July 2003, obtaining the spectra shown on Fig. 1.

We fit the [Al VI] line profile F_λ with a parametrised model, consisting of 2 Gaussians per hyperfine component for both isotopes. ^{27}Al/^{26}Al is a free parameter. We obtain $R_{\rm iso} < \langle R_{\rm iso} \rangle + 3\sigma = 3.0\ 10^{-2}$, or ^{27}Al/^{26}Al$<1/33$. The B HFS coupling constants lift a statistical bias that affects the A constants; their inclusion improves the significance of the fits. The accuracy of the magnetic-dipole measurement surpass the theory by a factor of $\sim$3.

We are short of quantifing ^{26}Al production in AGB stars through ^{25}Mg(p,γ)^{26}Al. The expected isotopic ratio at the tip of the AGB is at most 1/37, from the ratio of the ^{26}Al and ^{27}Al yields in the 6 $M_\odot$ models of Forestini & Charbonnel (1997).

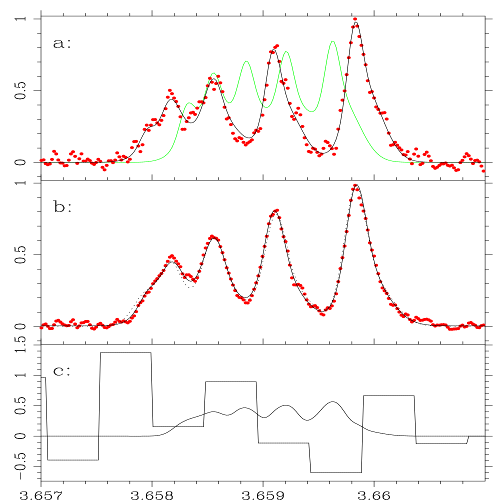

FIGURE 1. a) Points: collapsed spectrum of [Al VI] from 30-06-2003, with the optimal extraction aperture. Solid line: the best fit with two Gaussians per component, without contribution from ^{26}Al. Grey solid line: the profile of ^{26}Al, had it been present at a level giving an isotope ratio of 1. b) Points: coadded spectrum. Solid-line: combined model. Dotted-line: combined model without electric-quadrupole hyperfine splitting. c) Histogram: binned residuals, excluding the ^{26}Al fits. Solid line: combined ^{26}Al fit.

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