

# Nitrogen Isotope Ratios in Comets

Anita L. Cochran<sup>1</sup>, Emmanuël Jehin<sup>2</sup>, Jean Manfroid<sup>3</sup>, Damien Hutsemékers<sup>3</sup>, Claude Arpigny<sup>3</sup>, Jean-Marc Zucconi<sup>4</sup>, and Rita Schulz<sup>5</sup>

<sup>1</sup> University of Texas [anita@astro.as.utexas.edu](mailto:anita@astro.as.utexas.edu)

<sup>2</sup> ESO

<sup>3</sup> Institute d’Astrophysique et de Géophysique, Liège

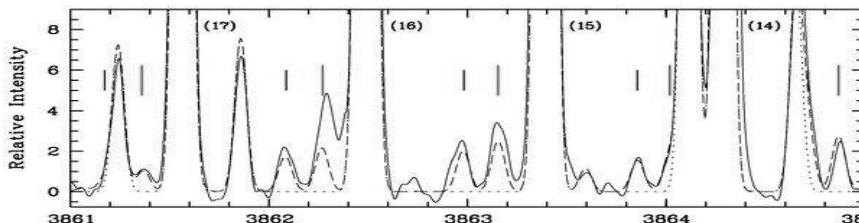
<sup>4</sup> Observatoire de Besançon

<sup>5</sup> ESTEC

We used high S/N, high spectral resolution observations to determine the isotope ratios  $^{12}\text{C}/^{13}\text{C}$  and  $^{14}\text{N}/^{15}\text{N}$  in comets. Observations were obtained with resolving powers  $R=\lambda/\delta\lambda \geq 60,000$  with telescopes at McDonald Observatory, VLT, NOT and Keck. We have now observed 13 comets on 20 different dates with heliocentric distances ranging from 0.6 au to 3.7 au. Most of these comets are from the Oort cloud; a few are members of the Jupiter family comets [2, 5, 4, 8, 6].

Cometary spectra consist of molecular emission from resonance fluorescence and a continuum resulting from sunlight scattered off dust. Before the emission spectrum may be modeled, the continuum must be removed accurately. Our isotope ratios are based on fluorescence models of the CN B-X (0,0) band [10]. The  $^{12}\text{C}^{14}\text{N}$ ,  $^{13}\text{C}^{14}\text{N}$  and  $^{12}\text{C}^{15}\text{N}$  are modeled as separate components. Only unblended lines within the R-branch are used for modeling the isotopes. Typically we have 6 – 10  $^{15}\text{N}$  lines observed for each comet.

We found that all of the comets have the same carbon and nitrogen isotope ratios:  $^{12}\text{C}/^{13}\text{C}=91\pm 21$  and  $^{14}\text{N}/^{15}\text{N}=141\pm 29$ . We find no difference in these ratios with dynamic type. Observations of comet Tempel 1 just prior to its impact with the Deep Impact spacecraft and in the following few hours show no change in these isotopic ratios, indicating that these ratios are the same in the interior and the mantle [6]. These values appear “universal” for comets.



**Fig. 1.** This figure shows data plus fits for comet 122P/de Vico [5]. The dotted line is the fit with only  $^{12}\text{C}^{14}\text{N}$  and the dashed line is the fit with the adopted isotope ratios. The long ticks mark  $^{13}\text{C}^{14}\text{N}$  lines; the short ticks mark  $^{12}\text{C}^{15}\text{N}$  lines. There is an unidentified line coincident with a  $^{13}\text{C}^{14}\text{N}$  at 3862.3Å.

Isotope ratios in comets offer important constraints on the physical and chemical conditions in the early solar nebula. From their study in different ob-

jects and from different molecules, we can determine the relationship between comets, the protosolar nebula and the interstellar medium. The fractionation history derived from these isotopes can tell us about the formation temperature, chemical processes and whether material has been chemically evolved within the early solar nebula.

The  $^{12}\text{C}/^{13}\text{C}$  ratio which we have found is the same as the Solar System value [1] and all bodies in the Solar System. The Solar System  $^{14}\text{N}/^{15}\text{N}$  is not currently known since it is difficult to measure in the Sun. The telluric value of 272 has historically been adopted as the Solar System reference value (but the Earth's is not a primary atmosphere).

$^{14}\text{N}/^{15}\text{N}$  from HCN was measured in comet Hale-Bopp at sub-mm wavelengths as  $323\pm 46$  [7] and  $330\pm 98$  [9]. Hale-Bopp is the only comet for which this HCN ratio was measured. Our value from CN of  $^{14}\text{N}/^{15}\text{N}=141\pm 29$  includes observations of Hale-Bopp and is significantly different than the HCN measurements. If the Hale-Bopp HCN value applies to other comets, HCN is not the sole parent of CN in comets. A potential parent for CN is  $\text{C}_2\text{N}_2$ , but it has no easily observed transitions. If there is another parent contributing to the  $^{14}\text{N}/^{15}\text{N}$  measured from CN, it must have a value which is significantly lower than the HCN value. Gas-grain effects can lead to significant  $^{15}\text{N}$  fractionation; a major reservoir for  $^{15}\text{N}$  in the early solar nebula might be  $\text{NH}_3$  [3]. One explanation for the different nitrogen isotope ratios in CN and HCN in comets could be that the high relative abundance of  $^{15}\text{N}$  originates from another source and is preferentially locked up in refractory organics.

Our observations of nitrogen isotope ratios in comets show the power of high-precision, high-spectral resolution observations for helping constrain conditions in the solar nebula.

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