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The Relationship of HCN, NH_3, C_2H_6, H_2O, and Ammoniated Salts in Comets: A Key Clue to Origins.

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Abstract

1. We considered HCN, NH_3, C_2H_6, H_2O and related gases in 32 comets characterized at infrared wavelengths, along with seasonal and evolutionary behavior and evidence for salts and multiple ice phases within the cometary nucleus. Their behavior is consistent with the presence of abundant ammoniated salts, having profound implications for the origins of comets and of life.

2. Introduction

We consider HCN, C_2H_6, NH_3, and H_2O in 32 comets characterized by high resolution spectroscopy at infrared wavelengths, along with evidence for acids and salts in cometary nuclei. We present an integrating theme that largely reconciles the seemingly divergent data. We suggest that ammoniated salts comprise a large and important fraction of the cometary nucleus.

2.1 Correlation of HCN and Ethane

Production rates for HCN, C_2H_6, and H_2O reveal that, in 26 comets, HCN and C_2H_6 are correlated and group tightly along a trendline, with R = Q(HCN):Q(C_2H_6) = 0.33 (Fig. 1). We term these comets the "normal" group. Disrupting comets have R > 0.5, and all comets have R > 0.1. It is convenient (and appropriate) to remove H_2O from consideration, and show directly the mixing ratio of HCN/C_2H_6 for this sample; here we present it vs. the Tisserand invariant for each comet (T_j) (Fig. 2). Comets from both Oort cloud and Kuiper belt populations are found in the enriched group (R >0.5).

Figure 1. Q(HCN)/Q(H_2O) vs Q(C_2H_6)/Q(H_2O) — 32 comets

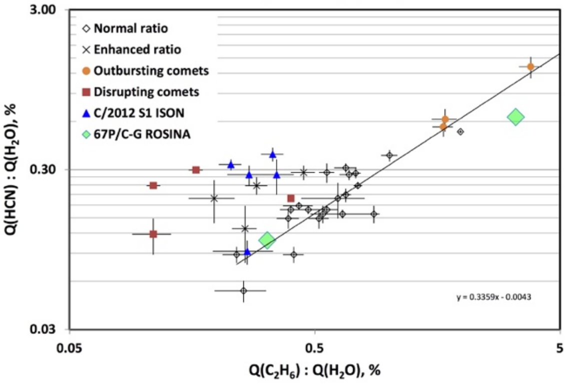


Figure 2. Rate Ratio (HCN:C_2H_6) vs. T_j — 32 comets

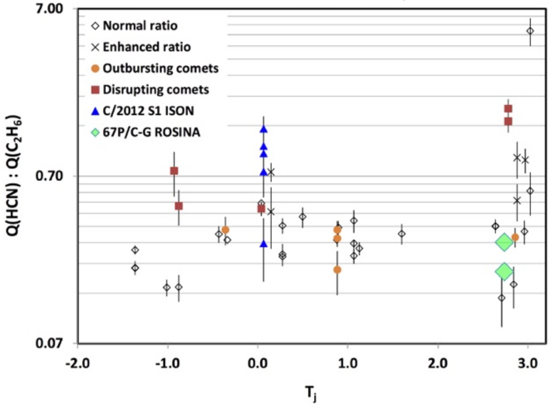
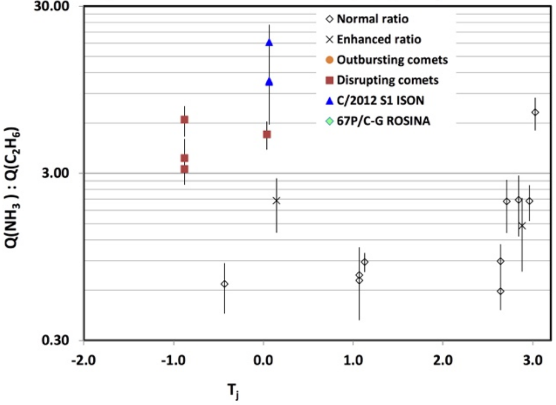


Figure 3. Production Rate Ratio (NH_3:C_2H_6) vs. T_j — 32 comets



NH_3 also correlates well with C_2H_6, and is seen to be enriched in disrupting comets (Fig. 3). Enriched production is seen in comets undergoing disruption within 1 AU of the Sun (Fig. 4), suggesting that NH_3 and excess HCN are produced by dissolution of small superheated dust grains.

Figure 4. Production Rate Ratio ($HCN:C_2H_6$) vs. R_h — 32 comets

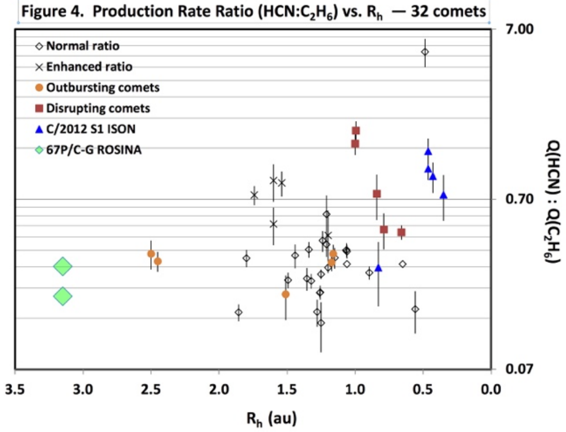
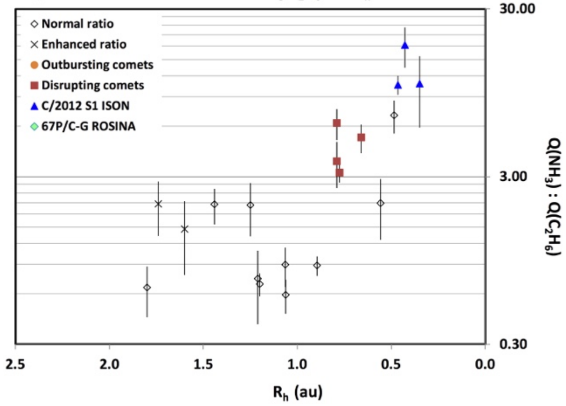


Figure 5. Production Rate Ratio $NH_3:C_2H_6$) vs. R_h — 32 comets



2.1 The ISM Origin of Ammoniated Salts

Ammoniated salts (NH_4CN & NH_4COOH) are produced at 10-15 K in lab simulations of ISM acid-base reactions [3,5]; once formed such salts will survive until warmed to 200K and higher. They can survive entry into a forming planetary system and be incorporated directly into pre-cometary materials, and the nucleus itself.

The ROSINA Team detected multiple salts of ammonia base and organic acids in micro-dust grains from 67P/C-G [1, 2, 4]. Our work suggests that such salts are common in comets and comprise a major component of the cometary nucleus, perhaps approaching 5% of the refractory mass. Ammoniated salts were abundant in the Orgeuil fresh-fall samples [6]. The extended sources of NH_3, HNC, glycine, HCOOH, and acetic acid seen in comets could be produced by dissolution of the ammoniated salts.

3. Summary and Conclusions

The implications are profound. First, we now know even less about comets than we thought [7]. And, the implications for carbonaceous chondrites are equally severe – what if most amino acids in them are stored as salts? Could an enantiomeric excess arise in the released chiral acids simply through the process of dissolution?

Second, if delivered to barren planets by comets, such salts could dissolve directly in the co-delivered abundant water, and create a rich broth amenable to formation of complex prebiotic compounds, thereby enabling the emergence of life. No need to worry about how to enrich tidal pools and the like – the enriched feedstock (and its own pool!) is delivered by comets.

Acknowledgements

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