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Molecular gas chemistry in NGC 1068

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Abstract. We have studied how the active nucleus of the Seyfert 2 galaxy NGC 1068 influences the chemistry of its 200 pc circumnuclear disk of molecular gas (CND). Results from new observations made with the IRAM 30m telescope have served for deriving abundances of molecular species such as SiO, CN, HCO^+, HOC^+, $H^{13}CO^+$ and HCO. These estimates are complemented with a re-evaluation of abundances of HCN, CS and CO, based on previously published observations. We report on the first detection of significant SiO emission in the CND of NGC 1068. We also report on the first extragalactic detection of the reactive ion HOC^+. Our conclusions favour an overall scenario where the CND of NGC 1068 has become a giant X-ray Dominated Region (XDR).

Active Galactic Nuclei (AGN) are able to inject vast amounts of energy into their host galaxies, carried by nuclear winds and strong X-rays fields. In particular, X-ray dominated regions (XDR) could become the dominant sources of emission for molecular gas in the circumnuclear disks (CND) of AGN. The first evidence of a 'peculiar' chemistry in the CND of AGN was found by Sternberg *et al.* (1994), who measured an abnormally high HCN/CO abundance ratio in the nucleus of NGC 1068 ($\sim 10^{-3}-10^{-2}$). Different explanations have been advanced to account for this anomalous HCN chemistry. The selective depletion of gas-phase oxygen in the dense molecular clouds could enhance the HCN-to-CO abundance ratio (Sternberg *et al.* 1994). Alternatively, an increased X-ray ionization of molecular clouds near the AGN could be at work Lepp & Dalgarno (1996).

While the aforementioned scenarios reproduce the measured enhancement of HCN relative to CO in NGC 1068, their predictions about other molecular species differ. In order to constrain observationally the choice of the optimum scenario, we have obtained with the IRAM 30m mm-telescope new spectra of 6 molecular species: SiO, HCO, $H^{13}CO^+$, HCO^+, HOC^+ and CN (see Usero *et al.* 2004). We have also included in our analysis the results from previous observations of CO (Schinnerer *et al.* 2000), HCN (Tacconi *et al.* 1994), and CS (Tacconi *et al.* 1997). This database has served for estimating the abundances of eight molecular species in the CND of NGC 1068, using LVG calculations. While models invoking oxygen depletion in molecular gas successfully fit the HCN/CO ratio measured in the CND, they fail to account for our estimates of the HCN/HCO^+ and CN/HCN abundance ratios. On the contrary, XDR models can satisfactorily fit these values. The detection of SiO and HOC^+ emission in the CND of NGC 1068 (Fig. 1) gives further support to the XDR chemistry scenario.

The large overall abundance of SiO estimated in the CND ($\sim$(5-10)$\times 10^9$) cannot be explained by shocks driven by star formation on molecular gas, as there is counter-evidence of a recent starburst in the nucleus of NGC 1068. The processing of 10 Å dust grains by X-rays, as a mechanism to enhance Si chemistry in the gas phase, would explain the large SiO abundances of the CND. The observation of HOC^+ in the CND

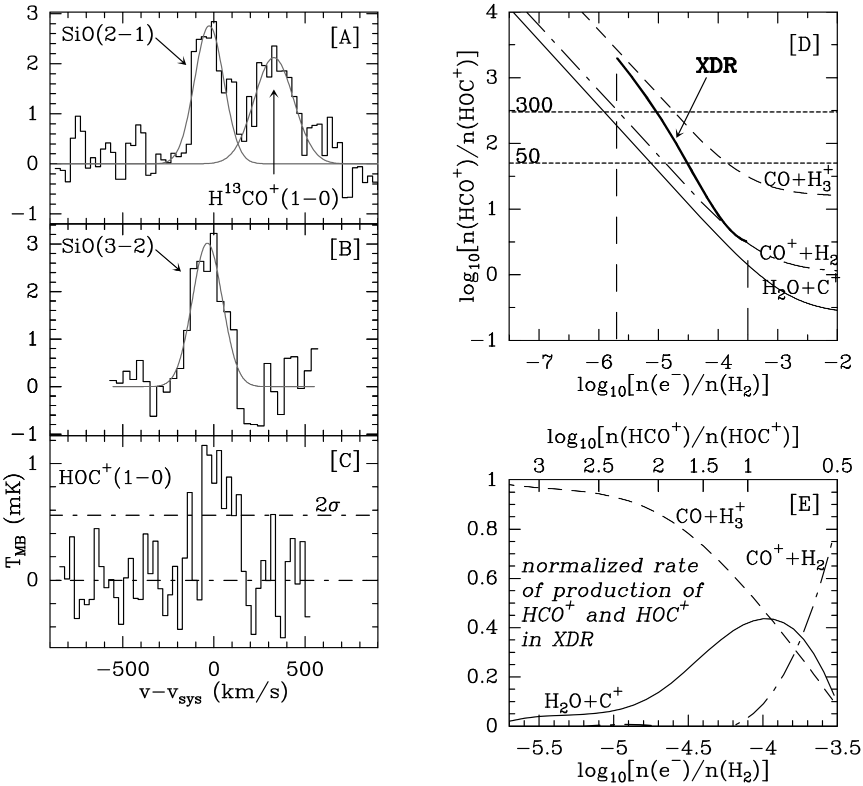

Figure 1. *Panels A, B and C:* SiO(J=2–1 and J=3–2) and HOC^+(J=1–0) spectra observed towards the nucleus of NGC 1068. *Panel D:* HCO^+/HOC^+ abundance ratio vs. ionization degree predicted for a XDR chemistry. *Panel E:* fraction of HCO^+ and HOC^+ molecules formed along each chemical path in a XDR chemistry (adapted from Usero *et al.* 2004).

of NGC 1068 is the first extragalactic detection of this reactive ion; most remarkably, the estimated HCO^+/HOC^+ abundance ratio, ∼30–80, is the smallest ever measured in molecular gas. We have shown that such low ratios can be explained if molecular clouds have the high ionization degrees typical of XDR ($X(e^-) \sim 10^{-6}$-10^{-4}) (Fig. 1, *panel D*). An examination of the different formation paths of HOC^+ suggests that reactions involving H_2O and CO^+ would be the predominant precursors of HOC^+ in XDR (Fig. 1, *panel E*; see also Usero *et al.* 2004 for details).

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