Characterizing CH_4 Spin Temperature, Abundance, and CH_3D/CH_4 ratio in Comets: The Case of C/2004 Q2.

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Introduction: We present high-resolution, near-infrared NIRSPEC data of comet C/2004 Q2 (Machholz) to characterize the CH_4 abundance and spin temperature and search for CH_3D. Comets are remnants from the early solar system that retain the volatiles (ices) from the cold outer protoplanetary disk (beyond 5 AU) where they formed. Comet nuclei were among the first objects to accrete in the early solar nebula and many of them were subsequently incorporated into the growing giant planets. Gravitational scattering redistributed the remaining comet population by either sending them to the inner solar system, where they may have enriched the early biosphere, or scattering them into their present-day dynamical reservoirs. Since this early time, comets have been orbiting the Sun relatively untouched by processing mechanisms, until their orbits are perturbed (by various mechanisms) towards the inner solar system. As such, they are believed to be the most primitive objects in the solar system and may be representative of the material from which the solar system formed. Studying comets is therefore a vital link to understanding the origin and evolution of our planetary system. In this study we constrain the T_{spin} and D/H ratio for CH_4 in C/2004 Q2 as a first step in characterizing the origin and distribution of CH_4 in the early solar system.

Constraining the spin temperature of cometary methane. CH_4 has 3 different spin species designated A, E, and F. For statistical equilibrium A:E:F = 5:2:3. In our original work discussing CH_4 in Oort Cloud comets [3], we considered only the case of statistical equilibrium, corresponding to $T_{spin} > 40$ K. Recently, we have expanded our CH_4 fluorescence model considerations to take T_{spin} into account. For the heliocentric distances at which we typically observe comets, T_{rot} is generally ~50-150 K. At such temperatures, the R0 to R1 line ratio is much more strongly determined by T_{spin} than the relative intensities of other lines. Thus, with T_{rot} in the coma determined from other species (H_2O, HCN, H_2CO), the R0 and R1 line ratio may provide a useful constraint on the spin temperatures for CH_4.

CH_3D/CH_4 and the chemical formation temperature of cometary methane. We have the ability to perform a sensitive search for CH_3D (see Figure 1). The CH_3D/CH_4 ratio provides a diagnostic of the environment in which methane molecules condensed, before being incorporated into the ices of comet nuclei. Aikawa and Herbst (1999) predicted CH_3D/CH_4 = 9%-20%, assuming formation in dark 20%, assuming formation in dark molecular cloud at 10 K. Millar et al. (1989) predicted CH_3D/CH_4 = 2%, assuming dense molecular cloud at 30 K. Our preliminary results for C/2004 Q2 suggest $CH_3D/CH_4 < 0.01$, in support of [2].

References:

[1] Aikawa, Y., and Herbst, E. (1999) ApJ, 526, 314. [2] Millar, T. J., Bennett, A., and Herbst (1989) ApJ, 340, 906. [3] Gibb, E. L., Mumma, M. J., Dello Russo, N. DiSanti, M. A., and Magee-Sauer, K. (2003) Icarus, 165, 391.

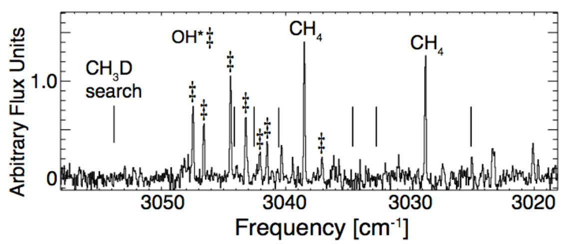

Figure 1 shows our preliminary search for CH_3D in comet C/2004 Q2 (Machholz) observed with NIRSPEC. Two bright CH_4 lines are clearly detected along with OH prompt emission (proxy for H_2O). Vertical lines indicate expected positions of CH_3D emission features. Although there is a line very close to the frequency of CH_3D emission near 3025 cm^{-1}, detection is not claimed because other emissions (e.g. near 3054 cm^{-1}) are expected to be stronger, but are not detected (after Bonev, Gibb et al., in preparation).