

LOWELL OBSERVATORY
COMET 96/P MACHHOLZ 1 BACKGROUND

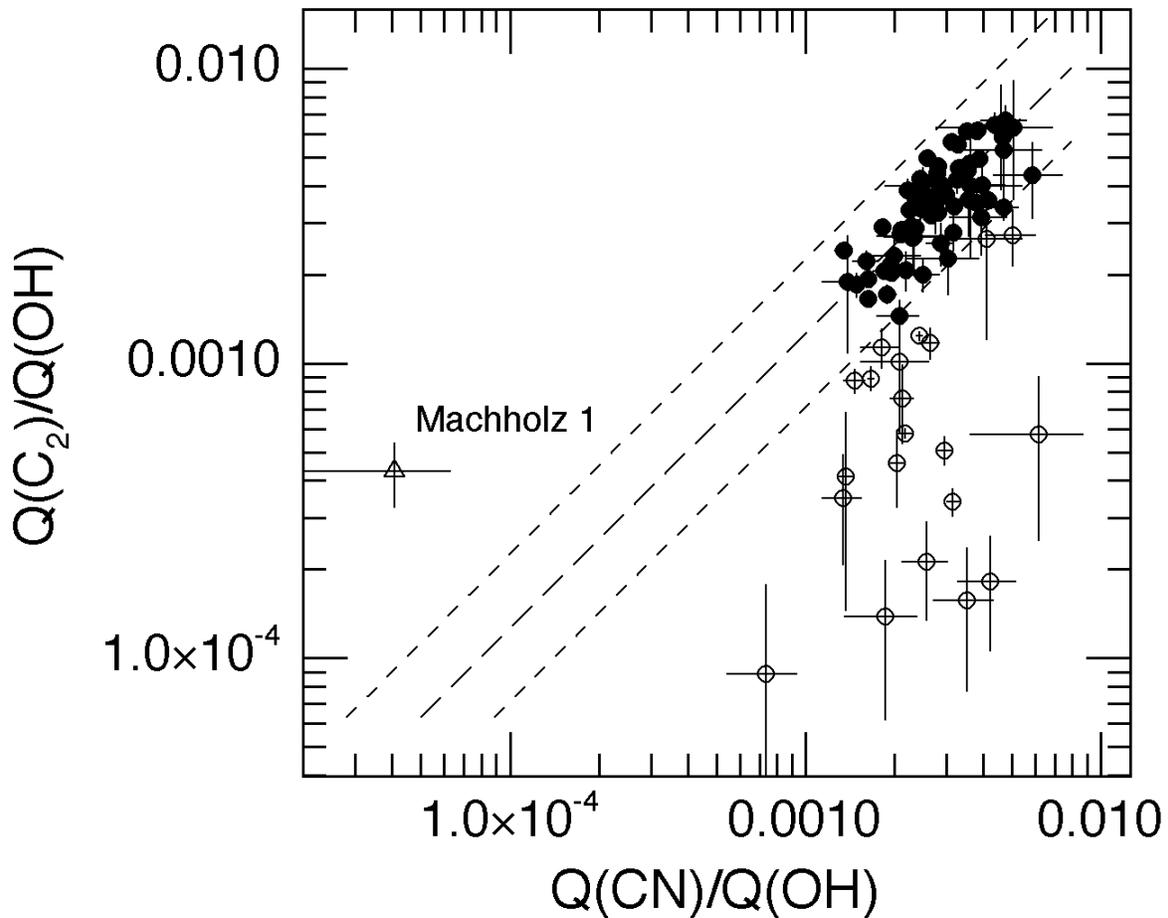


FIGURE CAPTION: Abundance ratios for C₂-to-OH vs CN-to-OH based on compositional measurements of the well-determined subset of 93 comets from the Lowell database. The majority of comets, in the “typical” class (shown as filled symbols), exhibit a strong correlation (the diagonal band) in the abundances of C₂ and CN. A smaller group of comets, to the lower right (open circles) have lower relative abundances of C₂ with respect to CN and are members of the “carbon-chain depleted” class. Comet Machholz 1 (open triangle to the far left in this logarithmic plot) is extremely depleted in CN with respect to OH or water, by about a factor of 72 or only just over 1% of the average CN-to-OH ratio.

Each gas species emits a unique set of spectral features, essentially a fingerprint of specific colors of light, which permit astronomers to determine not only which species exist in a comet's coma but also how many molecules of each species are present. Five molecular species are routinely measured as a part of the Lowell Observatory program of compositional studies of comets in the visible and near-ultraviolet portions of the spectrum. OH is the direct byproduct of water, H₂O, when water molecules dissociate (split apart) in space following their vaporization off of the surface of a comet's nucleus. Water is also the most abundant volatile species in

comets, and its abundance is therefore used for comparisons when determining the relative abundances of other species. NH is the resulting granddaughter of NH₃, ammonia, after NH₃ loses two hydrogen atoms during its dissociation. CN, cyanogen, is believed to primarily result from the dissociation of HCN. Finally, C₂, diatomic carbon, and C₃, triatomic carbon, are believed to be byproducts of several carbon-bearing compounds.

During its close apparition in May-June 2007, we discovered that Comet 96P/Machholz 1 exhibited extremely anomalous molecular abundances. Machholz 1 is shown to be depleted in CN (cyanogen) with respect to OH (a byproduct of water) by about a factor of 72 from average, while C₂ and C₃ are also low with respect to OH but “only” by factors of 10-20 from most comets. When comparing C₂ directly with CN, Machholz 1 is actually enhanced by about 5 times compared to “typical” composition, as defined by [¹]. In contrast to the extreme CN depletion, NH, the granddaughter of ammonia, is near the upper end of its normal range. The newly reported Lowell observations, having detections of OH, NH, CN, C₂, and C₃, permit the important determinations of the relative abundances of CN to C₂, and CN to water. Confirming but less constraining compositional information for Machholz 1 was also obtained by researchers at UC Santa Cruz in 2007, which showed that C₂ was depleted with respect to NH and NH₂, both byproducts of ammonia, while OH, CN, and C₃ were undetected [²].

This extremely low CN-to-OH ratio for Machholz 1 indicates that it is either compositionally associated with Comet Yanaka (1988r; 1988 Y1), which was strongly depleted in CN and C₂ but not NH₂ [³], or represents a new compositional class of comets, since Yanaka had a much greater depletion of C₂ (>100x) than does Machholz 1. It remains uncertain if these comets formed at a location in our Solar System with unusual conditions and a low probability of being gravitationally perturbed into the inner Solar System, or if one or both objects are interstellar interlopers.

The carbon-chain depleted class, believed to have originated from the Kuiper Belt region of our Solar System located beyond the planet Neptune, have previously been determined to be depleted in both C₂ and C₃ by between 2 and 20 times when compared to CN, while other comets have what is considered typical composition of C₂ and C₃ with respect to CN. In turn, the relative abundance of CN has almost always been between 0.13 percent and 0.5 percent that of water. The fact that CN had normal abundance in these objects implied that carbon was not depleted overall, leading A'Hearn et al. to conclude that the carbon in carbon-chain molecules was simply tied up in other compounds due to the colder temperatures which existed at larger distances in the Kuiper Belt during comet formation. In the case of this new compositional class, all three observed carbon-bearing species are strongly depleted, implying that, if Machholz 1 formed in the Kuiper Belt, it might have formed further out at an even colder temperature. This possibility can be investigated at the comet's next approach to Earth in 2012, when other carbon-bearing species can be measured in the optical and near-IR.

REFERENCES:

- [¹] A'Hearn, M. F., et al. (1995) *Icarus* 118, 223.
- [²] Langland-Shula and Smith (2007) *Ap. J.* 664, L119.
- [³] Fink, U. (1992) *Science* 257, 1926.