OBSERVATIONS OF CARBON MONOXIDE IN (2060) CHIRON. M. Womack, *Penn State Erie, Erie PA, 16563-0203, USA, maria@jibitoo.bd.psu.edu*, S.A. Stern, *Southwest Research Institute, Boulder CO, 80302, USA.*

(2060) Chiron is among the small population of large, outer solar system objects called Centaurs. Chiron's unusual, 51-year orbit ranges in distance from 8.5 to just over 19 AU, and exhibits an inclination to the ecliptic plane of 8.5 degrees. Recent dynamical studies (Levison & Duncan 1994; Dones, Levison, & Duncan 1996) show this orbit is unstable to giant planet perturbations on timescales of $< 10^6$ years, indicating that it is a recent addition to the planetary region. This provides strong evidence that Chiron is an escaped object from the Kuiper Disk. Chiron receives much more intense insolation than objects in the Kuiper Disk experience, which generates surface activity, as revealed by a highly-variable coma (Hartmann, Cruikshank, & Tholen 1989; Meech & Belton 1990).

Chiron's activity has been puzzling because the comet is so far from the Sun. Varying levels of activity detected in Chiron from 1988 to 1993 occurred while the object was between 9 and 11 AU from the Sun. Conditions at these distances are too cold for H_2O and CO_2 ices to sublimate, which generate the comae of most comets in the inner solar system. Further, the activity detected in archival images of Chiron made from 1969 to 1972, (Bus et al. 1993), while Chiron was near aphelion at 19 AU, provide additional evidence that its activity is not driven by H_2O-ice or CO_2-ice sublimation. One suspects that Chiron's gas coma is generated by one of the very few, relatively-abundant low-temperature sublimators called supervolatiles, such as CO, N_2, CH_4, or possibly S_2 (Stern 1989; Mumma, Weissmann & Stern 1993).

We searched for carbon monoxide through its well-known rotational band at 2.6 mm (115 GHz) during 1995 Jun 10-12 UT the National Radio Astronomy Observatory 12-m telescope at Kitt Peak, Arizona. The backends were two 128-channel filterbanks, each with two polarizations. Spectral resolutions of 100 kHz and 250 kHz per channel were used, which correspond to velocity resolutions of 0.26 km s^{-1} and 0.65 km $s,^{-1}$ respectively. Temperature scales were established in terms of T_R^*/η_c by a standard chopper-wheel method. The pointing accuracy of the telescope was measured to be $\sim 5''$ during the observing period and Chiron's ephemeris was estimated to be accurate to within 2 arcsec (D.J. Tholen, pers. comm.); this is very small compared to the half-power beamwidth of the telescope of $54''$ at 115 GHz.

The CO J=1-0 rotational transition was detected in both polarizations of each of the two different resolution spectra. The CO line is present in the filterbank spectra obtained for each day on June 10, 11, and 12, and maintains a consistent linewidth and intensity as the data are co-added and the signal-to-noise ratio increases. The spectra from the two parallel filterbank spectrometers are shown in Figure 1. Although the S/N ratio is somewhat low in the separate spectra, the simultaneous detection of this feature in both polarizations of both spectrometer backends is strong evidence that the detection is real. We verified that the signal did not arise from a background galactic cloud and checked for the presence of systematically bad channels in the telescope's receiver that could have created a spurious detection at the frequency of the J=1-0 CO emission.

Analysis of the higher-resolution 100 kHz spectrum indicates that the CO feature was marginally resolved in this filter bank with a FWHM of 150 ± 100 kHz, corresponding to a velocity width of 0.39 ± 0.26 km s^{-1}. Although this is large compared to the $\sim$0.1 km s^{-1} thermal velocity of pure CO gas freely sublimating at 8.5 AU, it is in good agreement with the coma model predictions for a dusty CO coma surrounding Chiron (Boice et al. 1993). At our velocity resolution of $\approx$0.3 km s^{-1}, no measurable redshift or blueshift of the CO feature from the predicted geocentric velocity of Chiron was observed. This indicates that to within our velocity resolution, the CO molecules in Chiron's coma at the time of these observations were not strongly beamed along or away from the Chiron-Sun line.

A total CO column density of N(CO)=(9 ± 4)x10^{12} cm^{-2} was calculated for the data, assuming an optically thin gas and a rotational temperature of 10 K, as is expected from CO observations of other distant, active comets (Crovisier et al. 1995). A production rate of Q(CO)=(2 ± 1)x10^{28} s^{-1} was calculated using a photodissociation decay model (Haser 1957) assuming that the CO sublimates directly from the nucleus with a velocity of 0.2 km s^{-1} (equal to half the estimated linewidth). An independently estimated production rate of CO assuming the simple, isotropic expansion of molecules through the telescope beam is Q(CO)=(0.9 ± 0.5)x10^{28} s^{-1}. Averaging these two production rate estimates, we obtain a CO production rate of Q(CO)=(1.5 ± 0.8)x10^{28} s^{-1}. These calculations assume that the CO emission fills the telescope beam size of $53\,''$. If the CO emission region is smaller than this, then the values for the column density and production rates will be higher.

The simplest origin for the CO gas detected in Chiron's coma is from the direct sublimation of solid state CO on, or in thermal contact with, Chiron's surface. The sublimation of a pure CO-ice surface completely covering Chiron is estimated to generate $\approx$3x10^{31} CO molecules per second (Stern et al. 1994). Our observation of Q(CO)$\sim$1.5x10^{28} s^{-1} indicates that $<$5x10^{-4} of Chiron's surface area is sublimating. If concentrated in one area, this would correspond to a circular spot with a radius of just 4 km($R_{chiron}/90$ km) (Dones et al. 1996), where R_{chiron} is Chiron's true radius (90 km is the best present radius estimate (Campins et al. 1994)). Of course, several smaller spots distributed on the surface with a combined active area near this estimate would also suffice. Although uncertainties in Chiron's surface emissivity and radius could change the estimated active surface fraction by a factor of several, the detected CO column density and production rate clearly indicate that much less than 1% of Chiron's surface is freely sublimating CO.

The fact that the estimated production rate of CO derived from our mm-wavelength detection corresponds to one or more very small sublimating patches, as opposed to a large fraction of the surface, suggests that the narrow, highly-localized particulate plumes and archlike structures described in the stellar occultation experiment (Elliot et al. 1995) may be CO-driven vents or geysers. This inference is supported by the surprisingly-warm surface temperature measurements of Chiron (Campins et al. 1994). Given the small apparent sublimation fraction of the surface derived above, it now becomes clear why Chiron's surface is found to be so much warmer than a broadly-distributed surface sublimation would predict. Latent-heat cooling of the surface is restricted to a surface area fraction far less than 1%, so most of the surface will reach radiative equilibrium temperatures near 100 K, as observed (Campins et al. 1994) rather than the ∼35-55 K temperature indicative of a uniformly-sublimating surface consisting of CO or another of the supervolatiles (e.g., N_2, CH_4).

Chiron and the similarly-sized Kuiper Disk objects are logarithmically intermediate in scale between short period comets (with radii of 10 km and less) and Pluto/Triton (with radii of 1150-1350 km). All of these objects are thought to have originated in the region between 20 and 50 AU (Weissman & Levison 1996). However, whereas the surface ices and atmospheres of Triton and Pluto are dominated by N_2, with only a trace of CO (Cruikshank, et al. 1996), cometary comae exhibit $CO/N_2 >> 1$. The origin of this chemical dichotomy is not understood. We suggest that an important clue to the nature of Chiron and its largish cohorts lies in whether the CO/N_2 ratio of Chiron and related-type objects in the trans-Neptunian region is comet-like, or Pluto/Triton-like.

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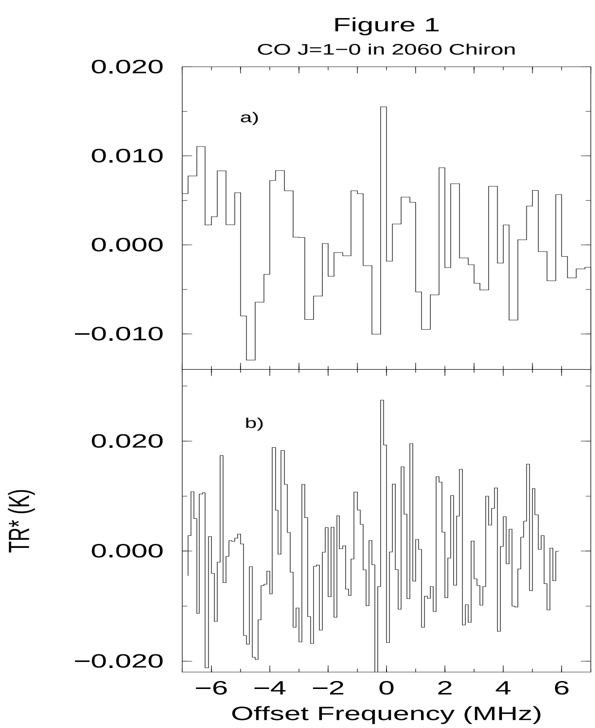

Figure 1. Spectrum of the CO J=1−0 transition in Chiron with a) 250 kHz and b) 100 kHz/channel resolution obtained Jun 10−12, 1995 UT at the NRAO 12−m telescope. The frequency scale is referenced to Chiron's velocity, so an isotropic CO emission would produce a feature at zero MHz. The spectrum is a result of 110 co−added scans of 6 minutes each, with a total integration time of 39,600 sec.