DOES CHARON HAVE AN ATMOSPHERE? J. L. Elliot and Leslie A. Young, Department of Earth, Atmospheric, and Planetary Sciences, M. I. T., Cambridge, MA 02139

Pluto and its satellite Charon are products of past and present conditions in the region of the solar system between 30 and 50 au from the sun. According to current ideas, the bulk density of Pluto-Charon, 2.03 ± 0.04 gm cm^{-3} [1], is high enough to imply that Pluto and Charon formed in the solar nebula, rather than in a protoplanetary nebula with a subsequent escape into a solar orbit [2, 3]. We can hope to make progress in understanding Pluto and Charon by pursuing comparative studies of their physical properties—such as atmospheres—that would be indicative of their composition and processes occurring near their surfaces. Pluto's atmosphere has been probed at high spatial resolution with stellar occultation observations [4, 5]. Although there is evidence that an atmosphere on Charon has been also revealed in occultation data [6], here we shall use the more conservative interpretation of these data and use the upper limits that have been derived from them. In this work we summarize the current observational limits that can be placed on an atmosphere of Charon and discuss the prospects for improving these in the near future.

The ability of a body to retain an atmosphere depends on the ratio of its gravitational potential to the thermal energy of the gas. This is usually expressed in terms of the parameter λ, the ratio of the gravitational potential of a molecule to kT, where k is Boltzmann's constant and T is the gas temperature. The rate of escape (whether Jeans or hydrodynamic) goes inversely with λ, which could be larger at the exobase for Charon than Pluto. If Charon's density is as great as 3.0 gm cm^{-3}, its surface gravity would be 0.8 that of Pluto's. This, coupled with a higher mean molecular weight and lower exobase temperature would make escape from Charon more difficult than from Pluto—and we know that Pluto has a detectable atmosphere. Since we do not know the individual densities and temperatures of these bodies, we cannot dismiss the possibility that Charon has an atmosphere.

Limits on the amount of CH_4 atmosphere that could surround Charon have been derived from mutual event data by differencing a spectrum of the combined light of Pluto and Charon and a spectrum of Pluto alone. This shows no CH_4 features (to a limit of 30 cm-amagat [7]), but evidence for H_2O ice [8, 9]. The spectrum of Pluto shows CH_4 bands arising from a combination of gas and solid [10], but no H_2O bands. Whether these spectral differences between Pluto and Charon result from different initial compositions, or are merely superficial differences due to subsequent evolution is not known.

Another approach to detecting gas surrounding a body is through the technique of stellar occultations, in which the starlight dims through the processes of differential refraction. Since the observed stellar flux depends on refractivity gradients in the atmosphere of the occulting body, it is sensitive to any gas. A single stellar occultation by Charon has been observed by Walker [11]. Elliot and Young [6] have reanalyzed these stellar occultation data and established upper limits for several gases by fitting a model to Walker's light curve for each gas with the molecular weight fixed and the temperature fixed at 52 °K. Their upper limits are given in the table. Atmospheres of gaseous CO_2 and H_2O are ruled out because their vapor pressure would be too low at any plausible surface temperature for Charon.

In order to use the upper limits on the noble gases to estimate depletion factors for these gases for Charon, we have computed the maximum amount of noble gases that could exist as an atmosphere of Charon under these optimistic assumptions: (i) all noble gases in the solar nebula were accreted in proportion to their cosmic abundances relative to Si [12]; (ii) Charon is a combination of half "cosmic ice," $\rho = 1.0$ gm cm^{-3}; 0% Si, and "cosmic rock," $\rho = 3.0$ gm cm^{-3}; 17% Si, [13], and (iii) all noble gas within Charon has outgassed into its atmosphere. Using these maximum amounts and the upper limits on the column heights obtained from the occultation data, we have placed upper limits on the depletion factor for noble gases, which are given in the table. Depletion factors for other gases would depend on the chemical model adopted for Charon [14].

Only an atmosphere of the heaviest gases would be in the Jeans escape mode. Assuming a density of 2.0 gm cm^{-3} for Charon and an exobase temperature of 100 °K, we calculate that a quarter of the upper limit on Xe would escape in 3×10^7 years from an exobase at 950 km; for Kr, the corresponding values are 650 years and 1900 km. Lighter gases would be in hydrodynamic escape. The mass loss over the age of the solar system for the lightest gas that we considered, CH_4, would deplete only 4% of Charon's mass, under the assumptions of Trafton *et al.* [15].

LIMITS FOR CANDIDATE GASES

Gas	Molecular Weight (amu)	Spectroscopic Upper Limit (cm-amagat)	Occultation Upper Limit* (cm-amagat)	Upper Limit† on Depletion Factor $\frac{N[\text{atmosphere}]}{N[\text{cosmic}]}$
CH_4	16.0	30	13.	...
Ne	20.2	...	57.	1.4×10^{-9}
N_2	28.0	...	7.7	...
Ar	39.9	...	5.0	1.8×10^{-7}
CO	28.0	...	6.9	...
Kr	83.8	...	1.5	6.0×10^{-5}
Xe	131.3	...	1.0	4.7×10^{-4}

*Upper limits are 3σ and apply for fits of an isothermal model, with sub-occultation temperature $T = 52 \pm 12$ °K and $\rho = 2.0 \pm 0.4$ gm cm^{-3} [6].

†See text for assumptions.

Even though the mutual event season has ended, anticipated improvements in the image quality for telescopes at the best ground-based sites may well permit the recording of additional spectra of Charon that would improve the spectroscopic limit for CH_4 and perhaps other gases. Also, future stellar occultations by Charon of sufficiently bright stars [16, 17] might reveal an atmosphere or would improve the current limits. The answer to the question posed by this paper should prove valuable for testing ideas concerning the formation and evolution of bodies in the remote parts of our solar system, because of the comparable sizes of Pluto and Charon.

REFERENCES

1. Tholen, D. J. and M. W. Buie. Bull. Amer. Astr. Soc. **21**(3): 981-982, 1989.
2. McKinnon, W. B. Astrophys. J. (Letters). **344**: L41-L44, 1989.
3. Simonelli, D. P. and R. T. Reynolds. Geophys. Res. Letters. **16**(11): 1209 - 1212, 1989.
4. Elliot, J. L., E. W. Dunham, A. S. Bosh, S. M. Slivan, L. A. Young, L. H. Wasserman and R. L. Millis. Icarus. **77**: 148-170, 1989.
5. Hubbard, W. B., D. M. Hunten, S. W. Dieters, K. M. Hill and R. D. Watson. Nature. **336**: 452-454, 1988.
6. Elliot, J. L. and L. A. Young. Icarus. : in press, 1991.
7. Fink, U. and M. A. DiSanti. Astron. J. **95**(1): 229-236, 1988.
8. Buie, M. W. and U. Fink. Icarus. **70**: 483-498, 1987.
9. Marcialis, R. L., G. H. Rieke and L. A. Lebofsky. Science. **237**: 1349-1351, 1987.
10. Spencer, J. R., M. W. Buie and G. L. Bjoraker. Icarus. **88**(2): 491-496, 1990.
11. Walker, A. R. Mon. Not. Roy. Astron. Soc. **192**: 47p-50p, 1980.
12. Cameron, A. G. W. "Elementary and nuclidic abundances in the solar system." Essays in Nuclear Astrophysics. Barnes, Clayton and Schramm ed. 1982 Cambridge University Press. Cambridge.
13. Ozima, M. and F. A. Podosek. "Noble Gas Geochemistry." 1983 Cambridge University Press. Cambridge.
14. Prinn, R. G. and B. Fegley Jr. Astrophys. J. **249**: 308-317, 1981.
15. Trafton, L., S. A. Stern and G. R. Gladstone. Icarus. **74**: 108-120, 1988.
16. Mink, S. J., A. R. Klemola and M. W. Buie. Astron. J. : in press, 1991.
17. Dunham, E. W., S. W. McDonald and J. L. Elliot. Bull. Amer. Astron. Soc. **22**(3): 1129, 1990.