ON THE ATMOSPHERE OF 2060 CHIRON ; D.C. BOICE[1], S. ALAN STERN[1,2], and W.F. HUEBNER[1], [1]Southwest Research Institute, San Antonio, TX 78228, and [2]Visiting Scientist

Introduction. There has been much interest in 2060 Chiron since observations of comet-like activity and a resolved coma established that it is a comet. Its unusually large size for a comet (determinations of its radius range from 65 to 200 km) places Chiron in a unique class compared to bodies with atmospheres in the Solar System. The atmospheres of almost all of the planets and satellites are tightly bound in approximate hydrostatic equilibrium and thin compared to the size of the body, while comae of typical comets represent the other extreme of greatly extended size in free expansion. Chiron is intermediate to these two types of atmospheres. Under certain conditions it may gravitationally bind an atmosphere (depending on molecular weight, temperature, and heliocentric distance) that is thick compared to its size while a significant amount of gas will undergo hydrodynamic escape or even "blow-off" (1) to an extensive exosphere. Coupling this attribute with reports of sporadic outbursts at heliocentric distances larger than 12 AU and the identification of CN and CO^+ in the coma makes Chiron a challenging object to model. Simple models of gas production and the dusty coma have been recently presented by several investigators (see, e.g., 2-4) but a general concensus on basic features has not occurred. The objectives of this paper will be to conceptually outline a model currently under development to provide a more complete framework for understanding Chiron and its surrounding environment.

Gas Production. Throughout its orbit, Chiron remains too far from the Sun for direct sublimation of water to be important. CO, CO_2, and other volatile ices are likely candidates for gas production from Chiron (2). We present in Figure 1 the production rate of various volatiles throughout Chiron's orbit. The most volatile ices (CO and CH_4) exhibit activity throughout a complete orbit with a change in amplitude by a factor of about 6. A representative clathrate ($CH_4 \cdot X\ H_2O$) increases production rate by about two orders of magnitude to the same level of activity as CO and CH_4 near perihelion and CO_2 production only "turns on" about 10 years prior to perihelion. At perihelion, substantial amounts of a volatile like CO can be released even if only a small amount (few percent) of Chiron's surface is active, on the order of a Mg/sec. At these activity levels, the mean free path of a CO molecule at the surface is on the order of 100 m, so the sublimating gas is collisionally coupled. The extent of the collision region can only be determined by detailed modeling or observations but an upper limit can be estimated assuming free expansion (R^{-2} density distribution) and isotropic emission. In this limit, its size is roughly $3 \cdot 10^3$ km, about the same as P/Halley at perihelion. Under the influence of Chiron's gravity (a few to 10 cm s^{-2}), fluid dynamic conditions near the surface are even more favorable.

The sublimation of a volatile like CO results in cooling of the surface far below that of a blackbody. In the case of CO, the gas temperature is close to 30 K throughout Chiron's orbit (2). These conditions result in a thermal velocity that is comparable to the escape velocity (4), given uncertainities in the mass of Chiron. This situation may lead to a bound atmosphere with extensive exosphere as slower molecules in the Maxwellian cannot escape while those traveling faster than the escape velocity leave. The loss of these more energetic molecules results in substantial cooling of the remaining gas making it more tightly bound. However, slightly higher thermal velocities lead to hydrodynamic escape or "blow-off" of the atmosphere (1). This borderline situation will be investigated in a more detailed model.

Other processes can heat and cool the gas, including photo reactions (heating), collisions with grains that are hotter than the gas (heating), sublimation from icy grains, and expansion cooling of the gas. Each of these effects requires investigation with detailed modeling to assess their significance. In the case of photo destruction (ionization and dissociation) of CO, typical rates (5) scaled to 10 AU yield lifetimes on the order of 4.5 years, making this a minor source of energy and ions on smaller timescales.

Dust Coma. The sublimating gas will entrain dust particles as it leaves the surface. The dynamics of dust will be influenced by the gas flow, the gravity of Chiron, and its rotation within a sphere of influence given by (6),

$$R_{GS} = r_h (M_{Chiron}/2M_{Sun})^{1/3}.$$

At $r_h = 10$ AU and adopting a radius of 120 km and a density of 1 gm cm^{-3} for Chiron, $R_{GS} \approx 1500 R_{Chiron}$. Outside of this region, both solar gravity and radiation pressure must be taken into account. The maximum

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particle size that can be lifted by gas drag has been estimated to be on the order of 100 μm with CO sublimation (3). In a typical comet, the gas density decreases as R^{-2} and for large particles (with velocities much smaller than the gas) the ratio of the gas drag to gravity is constant (see 7). Once lifted off the nucleus, these particles will leave the comet. However, considering gas production from restricted active areas and the effects of gravity on the gas, the gas density will decrease more rapidly than R^{-2} and these larger particles may decouple from the gas drag before escape, traveling on bound orbits that may eventually fall back to the surface. The extent of the gas–dust interaction region depends on particle size and density. Its determination requires detailed modeling but estimates for typical comets are on the order of a few tens of nuclear radii (8).

Beyond the gas–dust interaction region, the dust trajectories are increasingly influenced by radiation pressure and can be approximated by the fountain model. Micrometer-sized particles follow parabolic orbits confined within an envelope which is a paraboloid with focus in the nucleus and apex in the sunward direction. The standoff distance can be roughly estimated for these particles, using typical parameters for Chiron, to be on the order of 100 R_{Chiron}. At distances still further, the solar gravity and the Poynting-Robertson effect influence the dust dynamics. Other effects that may need to be considered in a realistic model of the dust coma include grain-grain collisions and charging of particles by solar wind, secondary electron emission, or coma plasma.

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References. **(1)** Hunten D.M. and Watson (1982) *Icarus* **51**, 666. **(2)** Stern S.A. (1989) *PASP* **101**, 126. **(3)** Luu J.X. and Jewitt D.C. (1990) *Astron. J.* **100**, 913. **(4)** Meech K.J. and Belton M.J.S. (1990) *Astron. J.* in press. **(5)** Schmidt H.U. et al. (1988) *Comp. Phys. Comm.* **49**, 17. **(6)** Öpik E. (1963) *Adv. Astron. Astrophys.* **2**, 219. **(7)** Grün E. and Jessberger E.K. (1990) In *Physics and Chemistry of Comets*, W.F. Huebner (ed.), Chapter 4. **(8)** Gombosi T.I. et al. (1986) *Rev. Geophys.* **24**, 667.

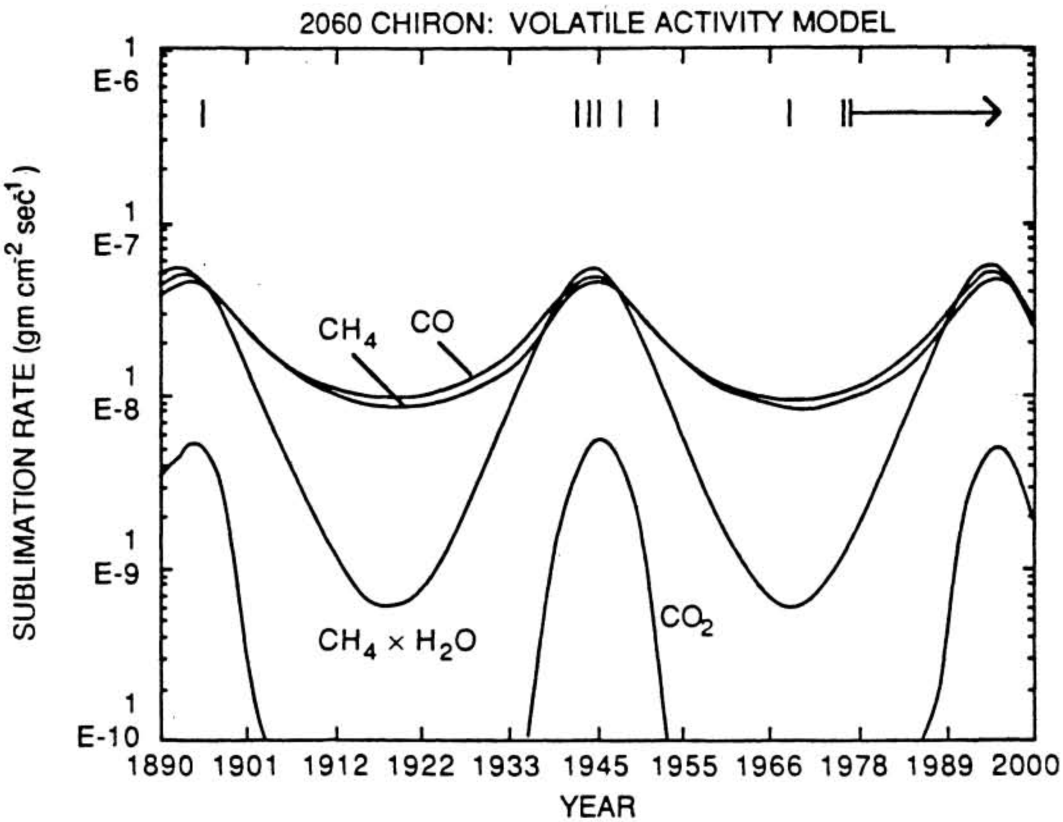

Figure 1. Sublimation rates for various volatiles throughout the orbit of Chiron (2). The energy balance calculation was performed by a global average, assuming no mantle and an albedo of 0.1.