Eris: The brightest (and most active?) Kuiper belt object. J. D. Hofgartner*[1], B. J. Buratti[1], P. O. Hayne[2], and L. A. Young[3], *Jason.D.Hofgartner@jpl.nasa.gov, [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [2]Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO, [3]Southwest Research Institute, Boulder, CO.

Eris 101: Eris is a large Kuiper belt object (KBO) that is similar to Pluto in several of its bulk properties.

Table 1: Properties of KBO Eris.

Orbit	38 – 98 AU, 557 year period, Aphelion in 1977, presently 96 AU
Mass	1.27 mass of Pluto [1]
Radius	0.98 radius of Pluto [2]
Visible Geometric Albedo	0.96, highest of any known KBO [2]
Volatiles	N_2 and CH_4 with bulk abundances of 9 N_2 : 1 CH_4 [3]
Satellites	Dysnomia [1]
Spin and Obliquity	Unknown & unknown, If tidally locked to Dysnomia: 16 days and 78^{O} with current subsolar latitude of ≈40^{O} [1]

Motivation - High Albedo Implies Activity: Eris is exceptionally bright with a visible geometric albedo of ≈0.96 [2], greater than any other known KBO. Its infrared reflectance spectrum is dominated by CH_4 [4], which should form tholins that darken the surface on timescales much shorter than the age of the solar system [5]. Thus one or more ongoing processes probably maintain its surface brightness.

Atmospheric freeze-out (collapse onto the surface) as Eris recedes from its perihelion distance of 38 AU to 98 AU at aphelion is a prevalent hypothesis to explain its anomalous albedo (e.g., [4]; [2]).

Global and Local, Collisional, Sublimation Atmospheres: We define a *sublimation atmosphere* (atm) as an atm where the primary constituent is in vapor pressure equilibrium (VPE) with solid-phase surface deposits (volatile-ice) on the surface. A *collisional atm* is defined as an atm where vapor particles interact with each other and do not follow ballistic trajectories. A *global, collisional, sublimation atm* is an atm with approximately uniform pressure everywhere around the globe (isobaric); VPE implies uniform volatile-ice temperature (isothermal). Mars, Triton, and Pluto have this type of atm. A *local, collisional, sublimation atm* is an atm where the condensation and/or sublimation rates exceed the rate of atmospheric transport and atmospheric transport cannot maintain a globally uniform pressure. The temperature of the volatile-ices are not held isothermal by VPE with an isobaric atm. A local atm occurs over the warmest (≈subsolar) volatile-ice covered region but the atmospheric pressure decreases over colder volatile-ices away from this region. The pressure gradients generate winds that transport the volatile away from the warmest region. Due to the significant decrease in pressure away from the warmest region, the transport may not include the whole globe. Io has this type of atm and several other KBOs are also predicted to have this type of atm [6].

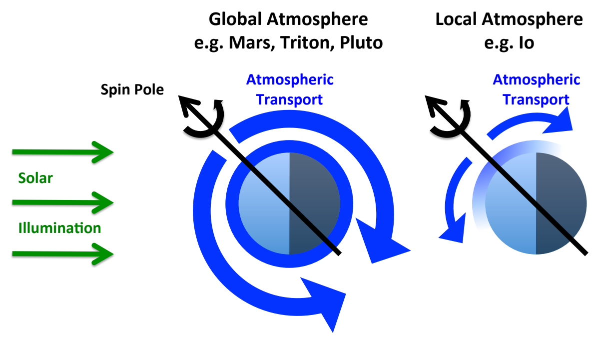

Figure 1: Conceptual diagrams of global (A.) and local (B.), collisional, sublimation atmospheres.

Eris's eccentric orbit is expected to result in two atmospheric regimes: (1) a period near perihelion when the atm is global and (2) a period near aphelion when only a local atm exists near the warmest (≈subsolar) region. In both regimes the atm is collisional (not ballistic) and maintained by VPE.

Coupled Thermal-Transport Numerical Model of Local, Collisional, Sublimation Atmospheres: Volatile transport (VT) in the global, collisional, sublimation atm regime has been modeled with a numerical thermal model that conserves energy and mass while maintaining VPE (e.g., [7]). These models assume a uniform pressure which implicitly incorporates transfer of energy and mass, so these models do not explicitly track the atmospheric transport.

VT in the local, collisional, sublimation atm regime has been modeled with a meteorological model that conserves energy, mass, and momentum [8]. The model prescribed the volatile-ice temperature distribution, did not include latent heat, and assumed symmetry about the subsolar/antisolar axis. As a result, both the thermal and temporal behavior were not explicitly modeled.

We combine elements of the two types of models discussed above to model local, collisional, sublimation atms with a coupled thermal-transport numerical model that conserves energy, mass, and momentum while maintaining VPE. This model does not include any of the assumptions noted above and is adaptable to any body with a local, collisional, sublimation atm.

Results - Significant Volatile Transport: Figures 2 and 3 show example results for Eris of the coupled thermal-transport numerical model.

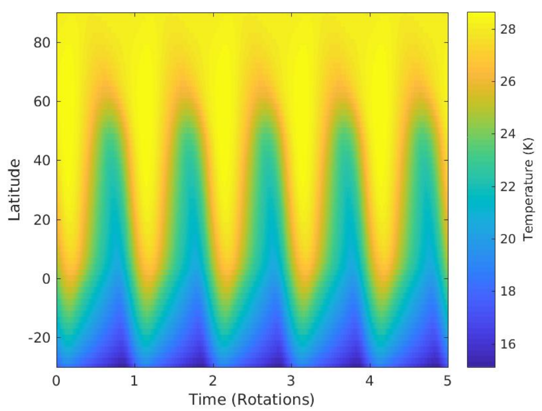

Figure 2: Volatile-ice temperature for bolometric Bond albedo of 0.6 [2] and emissivity of 0.9. There is a diurnal oscillation, the maximum is near the subsolar latitude (≈40^{O}) shortly after local noon, and the values are comparable to the planetary equilibrium temperature (≈23 K). This example demonstrates that the model results are reasonable.

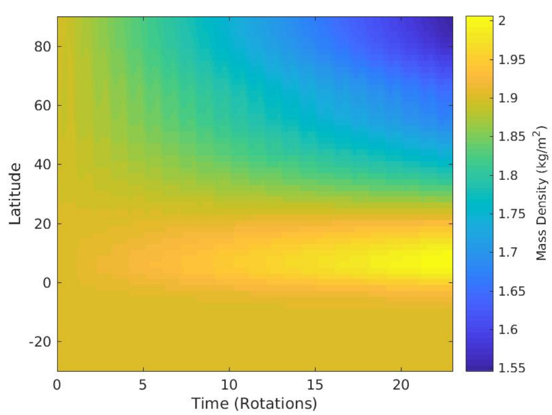

Figure 3: The volatile-ice mass per unit area for 23 rotation periods of ≈16-days each (≈1 Earth year). The initial volatile-ice mass is everywhere equal to the precipitable column of N_2 in Pluto's atm during the New Horizons encounter (the resultant volatile-ice if the Pluto atm collapsed uniformly over the globe); ≈2 mm thick N_2-ice layer. Eris is held at its aphelion distance, where the solar flux is a minimum, as a limiting case. After one year the pole has lost an appreciable amount (≈20%) of N_2-ice to the equator. In this simulation the pole of Eris is N_2-ice free after < 6 years. Thus even for the limiting case of aphelion, VT on Eris can alter the surface on decadal timescales.

Conclusions: 1. A coupled thermal-transport numerical model developed to simulate thermal and volatile evolution in the local, collisional, sublimation atm regime was introduced. The model conserves energy, mass, & momentum while maintaining VPE. It is adaptable to any local, collisional sublimation atm, an atmospheric regime that occurs on Io and is expected on several KBOS for parts of their orbits [6].

2. The model results indicate that VT on Eris, even at its aphelion distance of ≈100 AU, can be significant. The N_2-ice temperatures are < 30 K and vapor pressures are < 10 nbar but the significant pressure gradients in the local atm regime result in transport of N_2 mass, that integrated over the long timescales associated with such a distant orbit, can be significant as compared to the column mass of the atms of Triton and Pluto. Although Eris is 96 AU from the Sun in 2019, VT may result in changes in albedo or color that are observable.

3. Uniform collapse of a global sublimation atm, that presumably existed on Eris when it was near perihelion, is probably not the primary reason for its anomalously high albedo in the present epoch, when it is several decades past aphelion. This conclusion is true for most bolometric Bond albedos but since the VT depends sensitively on the thermal parameters, it does not hold for extremely high bolometric Bond albedos. The more general hypothesis of seasonal VT remains a plausible explanation for Eris's high albedo. Other geologic processes such as convection and glaciation that are now thought to be the primary processes renewing Pluto's brightest surfaces (e.g., [9]) are also plausible hypotheses for Eris's high albedo.

References: [1] Brown M. E. & Schaller E. L. (2007) *Science 316*, 1585. [2] Sicardy B. et al. (2011) *Nature 478,* 49. [3] Tegler S. C. et al. (2010) *ApJ 725,* 1296. [4] Brown M. E. et al. (2005) *ApJ 635*, L97. [5] Stern S. A. et al. (1988) *Icarus 75,* 485. [6] Young L. & McKinnon W. B. (2013) *AAS DPS Vol. 45* 507.02. [7] Hansen C. J. & Paige D. A. (1996) *Icarus 120*, 247. [8] Ingersoll A. P. et al. (1985) *Icarus 64,* 375. [9] Moore J. M. et al. (2016) *Science 351,* 1284.

This abstract is based on our publication: *Ongoing Resurfacing of KBO Eris by Volatile Transport in Local, Collisional, Sublimation Atmosphere Regime*, that is in press in *Icarus*.