ARGON-40 DEGASSING FROM TITAN AND ENCELADUS: A TALE OF TWO SATELLITES. William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130 (mckinnon@wustl.edu).

Introduction: One satellite is the best of Ar-degassers. One is about the worst. Measurements of the $^{40}Ar/H_2O$ ratio in Enceladus' plume vapor by the Cassini INMS (Ion and Neutral Mass Spectrometer) indicate an amount sufficient to deplete that satellite's maximum geologic inventory in under 1% of the age of the Solar System [1]. If the detection of ^{40}Ar is true and representative of Enceladus during periods of high geological activity, then the duty cycle for that activity is also less than 1%, which has important implications for the mechanism(s) of Enceladus' tidal heat release. In contrast, the ^{40}Ar abundance measured in Titan's atmosphere by the Huygens GCM indicates an integrated degassing efficiency of ~6% [2]. Despite a general picture of Titan as a major, active geological world [3], such a Mars-like degassing efficiency calls into question the degree of communication between the Titan's deeper interior and its surface and atmosphere.

Argon-40 Production: Estimating the production of ^{40}Ar over geologic time in a body is straightforward (estimating the ^{40}Ar loss rate to space or an atmosphere is not). Titan is about 55/45 rock/ice by mass, based both on structural models using the ICYMOON code [4] for Titan's density and preliminary moment-of inertia [5] and, simply, an average of Ganymede and Callisto models [4,6]. Titan's originally accreted rock was likely similar to carbonaceous chondrite (i.e., of solar composition and volatile-rich). The rock in a partially differentiated Titan today may still be partially hydrated. So taking 550 ppm K in CI carbonaceous chondrite [7] and correcting for some loss of water yields an estimate of 605 ppm in Titan-rock today. This number could be higher; [7] give 780 ppm K for H chondrites, through the relevance of ordinary chondrite compositions at Saturn is doubtful.

The present ratio of ^{40}K to total K in the Solar System today is low, 0.0117% [7], but with a half-life of 1.25 Gyr, there was originally 12.54 times as much. Titan thus contains about 1.345×10^{23} kg x 0.55 x 605 x 10^{-6} x $1.17 \times 10^{-4} = 5.25 \times 10^{15}$ kg of ^{40}K today; 11.54 times this has decayed, but only 10.5% to ^{40}Ar, the rest having gone to ^{40}Ca. Thus, Titan should have generated $\approx 6.4 \times 10^{15}$ kg of ^{40}Ar by now. Released to the surface, this 76 kg m^{-2} surface density of Ar could contribute ≈1 mbar of surface pressure. Given Titan's present atmosphere, this implies a potential $^{40}Ar/N_2$ ratio by mass of ≈0.07%, or 0.05% by mole. Compared with the GCM-measured value of 4.32 (± 0.1) x 10^{-5} [2], Titan is seen to be relatively poorly degassed in terms of ^{40}Ar. For comparison, the Earth is generally thought to be of order 50% degassed [e.g., 8].

How Active is Titan?: The release of ^{40}Ar on Earth is generally held to be the result of its partitioning into igneous melts and the ascent of these melts to the surface or near-surface where they degas [9]. On Titan, which is conventionally pictured as having a massive rock-iron core similar to that possessed by Ganymede, such volcanism would occur at great depths and pressures (>2 GPa). Even for favorable mineral-melt partition coefficients [10], at such pressures the modest amounts of ^{40}Ar in the melt are likely to remain there (no degassing) [11] unless they can be extracted by another process (such as hydrothermal leaching).

It thus may not be surprising that a fully differentiated Titan would have trouble releasing its ^{40}Ar to the atmosphere. The situation changes for a partially differentiated Titan, however. The announced value for Titan's normalized moment-of-inertia, 0.34 [5], when interpreted in terms of a hydrostatic structure, implies a Titan that is 40% differentiated if rock that separates from ice forms a core [12]. Greater degrees of differentiation are required if the separated rock remixes with primordial ice+rock. The upshot is that no more than 40% of Titan's rock may be in a separate core, and no more than 40% of Titan's K and ^{40}Ar may be so locked up. The rest of the rock, in a massive ice-rock layer that may extend to within ~300 km of Titan's surface, should be in more intimate contact with ice, and ^{40}Ar may enter the ice by simple diffusion (for sufficiently small rock particles [13]). The transfer of ^{40}Ar from a convecting ice-rock "mantle" to a separately convecting ice layer above is still a issue, but even the outer icy layer/ocean may have a dissolved silicate or K component [e.g., 14], so a "Mars-like" 6% ^{40}Ar degassing efficiency may (or may not) argue for a low outgassing efficiency overall (e.g., for NH_3 and CH_4). Impact erosion of the atmosphere during the Late Heavy Bombardment, in particular, could only have caused so much argon loss, because most ^{40}K would still have been live. Titan's outgassing efficiency can be contrasted to the situation at Enceladus, where the present ^{40}Ar degassing efficiency is $>10^3$ times as great as it is at Titan.

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