

Accepted Manuscript

The Origin and Evolution of a Differentiated Mimas

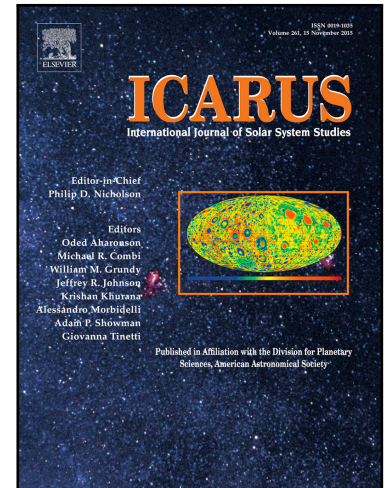
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PII: S0019-1035(16)30425-0
DOI: [10.1016/j.icarus.2017.06.011](https://doi.org/10.1016/j.icarus.2017.06.011)
Reference: YICAR 12495

To appear in: *Icarus*

Received date: 28 July 2016
Revised date: 2 March 2017
Accepted date: 5 June 2017

Please cite this article as: M. Neveu, A.R. Rhoden, The Origin and Evolution of a Differentiated Mimas, *Icarus* (2017), doi: [10.1016/j.icarus.2017.06.011](https://doi.org/10.1016/j.icarus.2017.06.011)



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The Origin and Evolution of a Differentiated Mimas

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Abstract

In stark contrast with its neighbor moon Enceladus, Mimas is surprisingly geologically quiet, despite an eccentric orbit and distance to Saturn prone to levels of tidal dissipation 30 times higher. While Mimas' lack of geological activity could be due to a stiff, frigid interior, libration data acquired using the *Cassini* spacecraft suggest that its interior is not homogeneous. Here, we present one-dimensional models of the thermal, structural, and orbital evolution of Mimas under two accretion scenarios: primordial, undifferentiated formation in the Saturnian sub-nebula, and late, layered formation from a debris ring created by the disruption of one or more previous moons. We find it difficult to reproduce a differentiated, eccentric Mimas under a primordial accretion scenario: either Mimas never differentiates, or the internal warming that leads to differentiation increases tidal dissipation, yielding runaway heating that produces a persistent ocean, thereby circularizing Mimas' orbit. Only if Mimas accretes very early (so that the decay of short-lived radionuclides initiates differentiation) but its rheology is not highly dissipative (in order to stop runaway tidal heating even if the eccentricity is not negligible) can the simulations match the observational constraints. Alternatively, a late, layered accretion scenario yields a present-day Mimas that matches observational constraints, independently of the magnitude of tidal dissipation. Consistent with previous findings, these models do not produce an ocean on Enceladus unless its orbital eccentricity is higher than today's value.

Keywords: Saturn, satellites; Satellites, formation; tides, solid body; interiors

1. Introduction

Mimas, Saturn's innermost mid-sized moon, displays a geologically old, inactive surface. This is puzzling, because one would expect Mimas to be prone to higher levels of tidal dissipation than its highly active neighbor moon Enceladus: Mimas is closer to Saturn (lower semi-major axis a), and its orbital eccentricity e is higher. The rate of tidal dissipation is proportional to $R^5 a^{-7.5} e^2$, where R is Mimas' radius (Peale, 1999; Wisdom, 2008). Since $R_{\text{Mimas}} \approx 0.8 R_{\text{Enceladus}}$, $a_{\text{Mimas}} \approx 0.8 a_{\text{Enceladus}}$, and $e_{\text{Mimas}} \approx 4.2 e_{\text{Enceladus}}$ (Table 1), the product $R^5 a^{-7.5} e^2$ is roughly 30 times higher for Mimas than for Enceladus. The surface expression of strong tidal heating would have likely been detected by *Cassini* instruments. Although a thermal anomaly was observed on

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