The Hydrodynamic Stability of Exomoon Atmospheres: Titan vs. Ganymede

Astrophysics Group **ASTR-Schulik-1**

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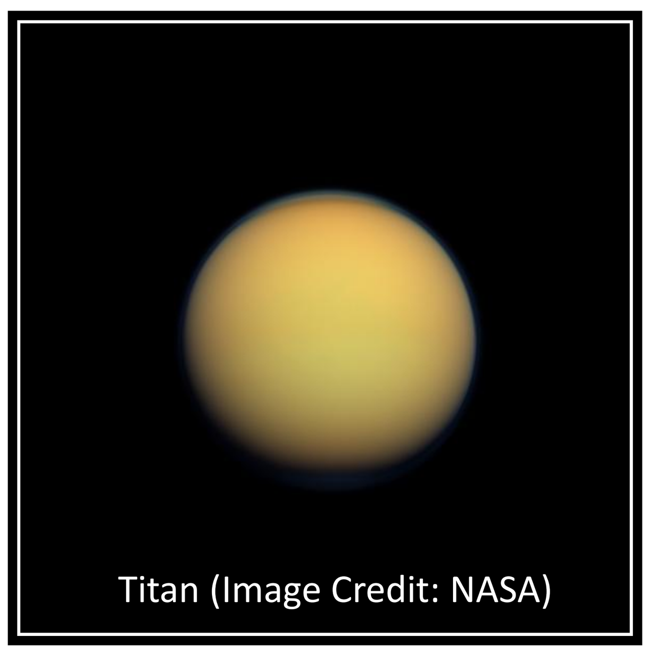
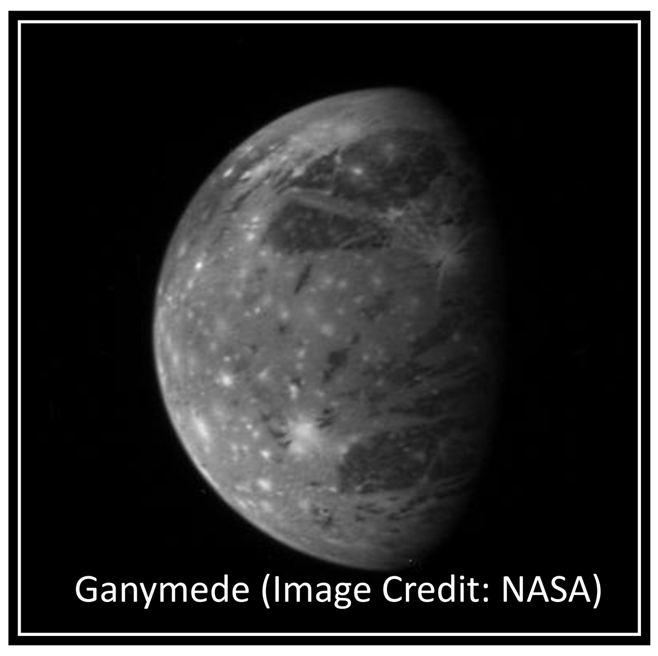
1. Introduction

Titan and Ganymede are moons of Saturn and Jupiter respectively. Despite the similarity in size, only Titan maintains a dense nitrogen-dominated atmosphere (Erkaev, 2020). Our goal is to affirm/annul key factors that may have distinguished the two moons, starting with:

1. If and when they experienced efficient hydrodynamic escape
2. The differences in host planets and potential changes in environment

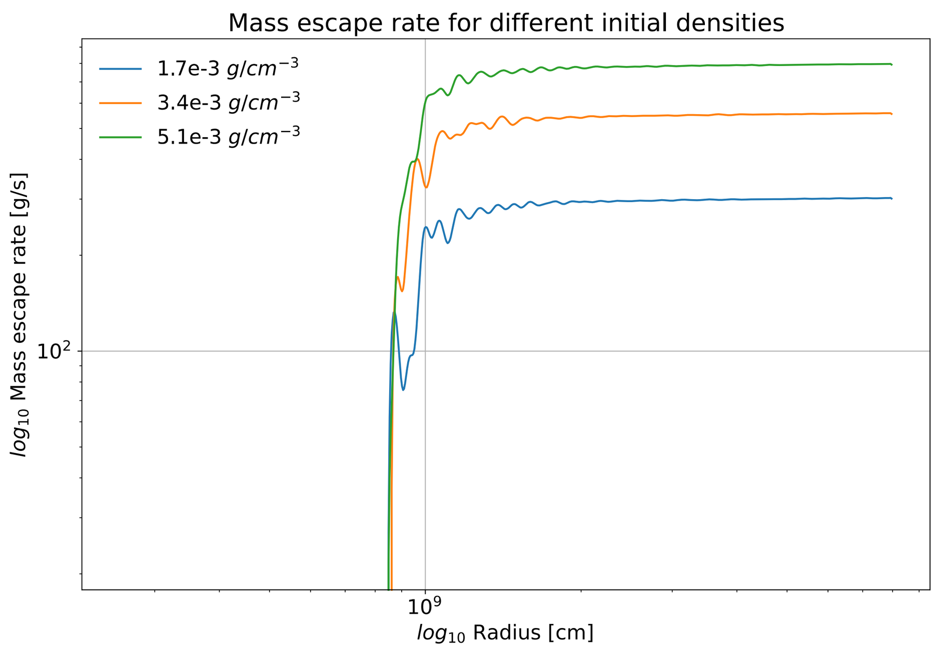


Titan (Image Credit: NASA)



Ganymede (Image Credit: NASA)

Simulation output:
Non-steady state mass escape rate profile on *Titan* for different initial densities

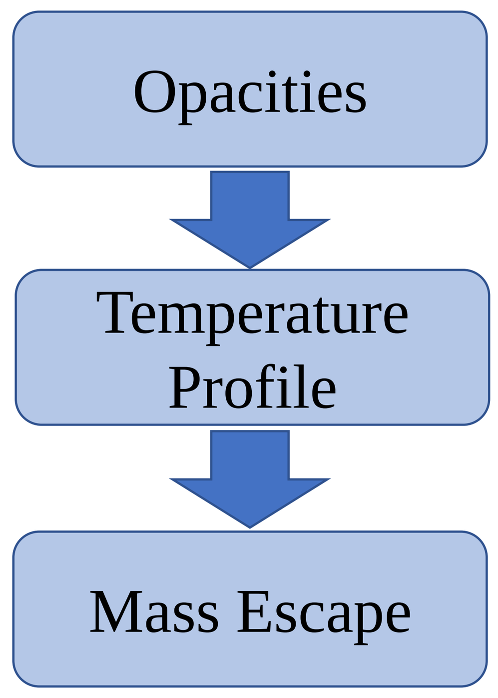


2. Method

We compute realistic mean opacities from databases and select parameters for Titan/Ganymede from the literature. Then solve hydrodynamic equations and radiative transfer equations numerically with the package `aiolos` to calculate mass escape rate.

Free parameters:

- Initial temperature/density profiles
- Luminosity curves (Burrows, 1997)



3A. Evolutionary Simulation

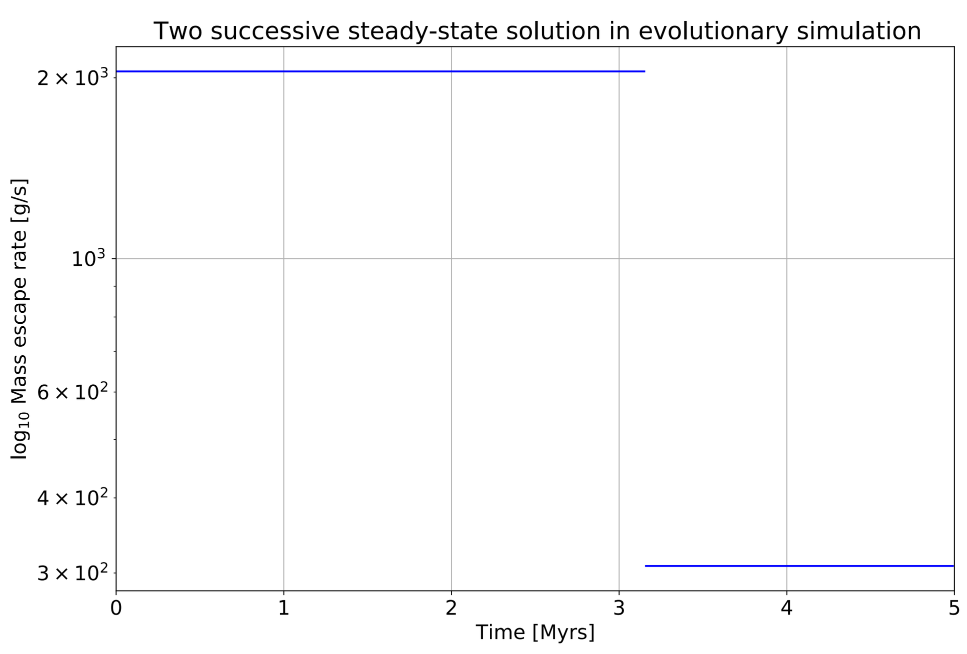
Methodology

- ”Jump” from one steady-state solution to the next after some time and repeat until we arrive at the solution for today
- Place constraints on the range of free parameters to make the simulation to be consistent with the observation today

Rationale

- Too computationally expensive to use `aiolos` for a complete evolutionary history of atmosphere
- Assume steady-state solutions can be maintained for long period (e.g. 1 Myrs), until luminosities change significantly

Preliminary Results:
Evolution of hydrodynamic escape rate on *Titan* over 2 steady-state solutions in 5 Myrs (with a floored temperature profile)



3B. Photochemistry

Extending past hydrodynamics to incorporate *photoionization* and *chemical reactions* within the atmosphere, by calculating new chemical abundances for each cell between each time step.

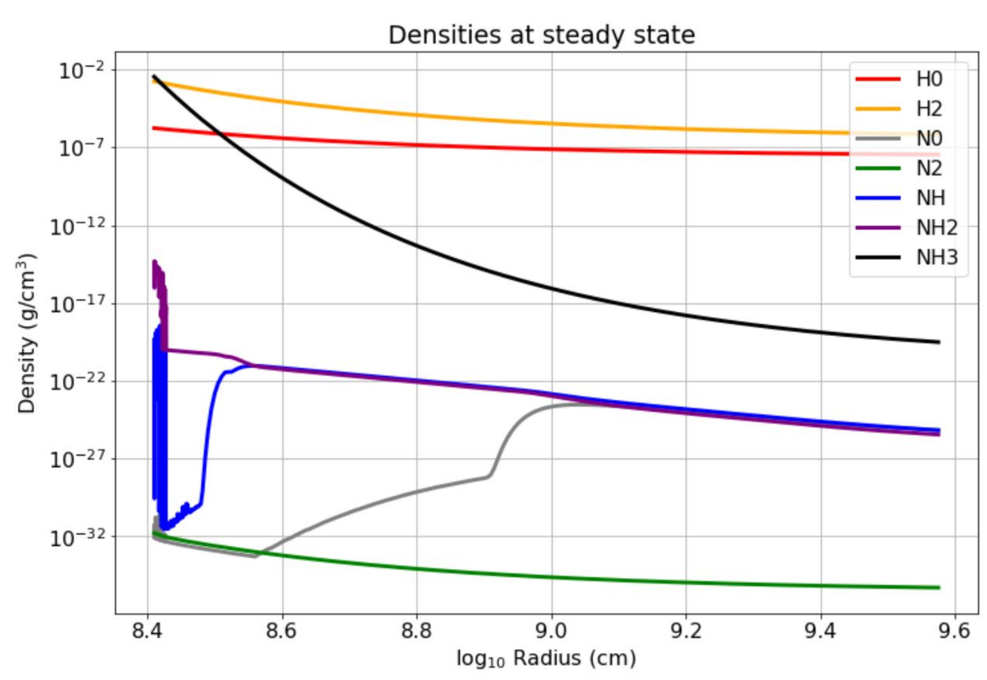
Reasoning for including chemistry:

- General consensus is that N_2 originated as NH_3, although the specific processes involved are unconfirmed (Mandt, 2014).
- A way to replenish depleted species, particularly relevant for heavier species that may be reliant on lighter species for escape via friction.

Methodology:

- Selecting reactions using sensitivity analysis (VULCAN).
- Building a self-contained chemical network of only N, H molecules.

Preliminary Results:
Density profiles of the different species on *Titan* (in a static atmosphere, and without complete opacity tables)



4. Outlook

The year 2022 remains an exciting time because *Dragonfly*, NASA’s rotorcraft relocatable lander, is planned to launch in 2027 — carrying our hopes and dreams to the hazy orange orb. Our next steps in the following month will be to:

- Proceed evolutionary simulations over a wider range of parameter space.
- Quantify the effects of; (a) moon/planet migration, (b) planet/stellar luminosity, (c) different photochemical reactions have on escape rate. Or at the very least, place constraints on theorized pathways for NH_3 to N_2 conversion.
- Compare the final state of our rudimentary models with current-day observations. And ideally, as a proof of success, perform a blind test on a similar moon within our solar system.

References:

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Erkaev N. V., Scherf M., Thaller S. E., Lammer H., Mezentsev A. V., Ivanov V. A., Mandt K. E., 2021, MNRAS, 500, 2020

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