

Giant Impact Ejecta Can Drive Significant Atmospheric Erosion on Terrestrial Planets

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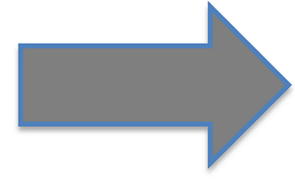
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Introduction

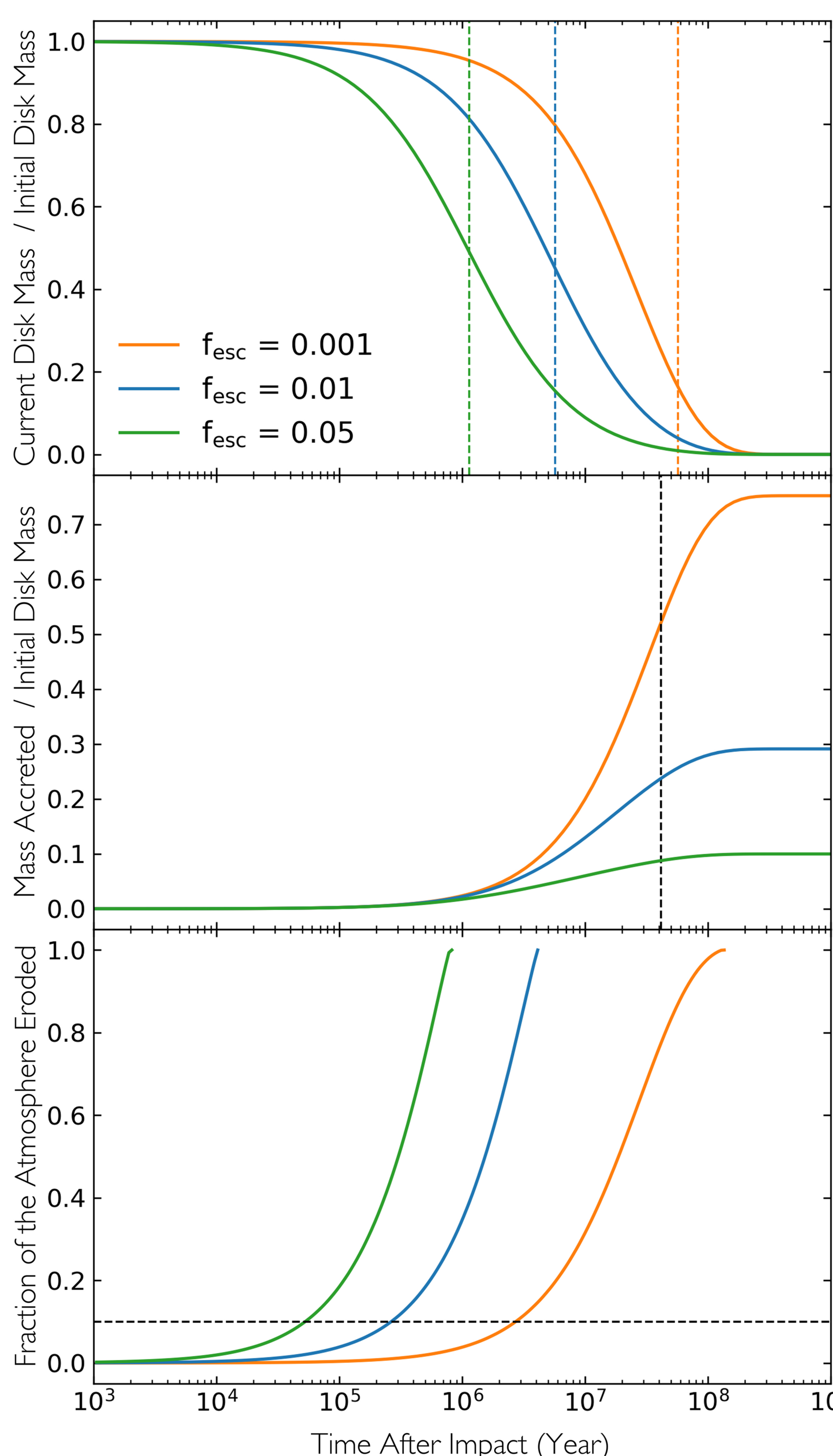
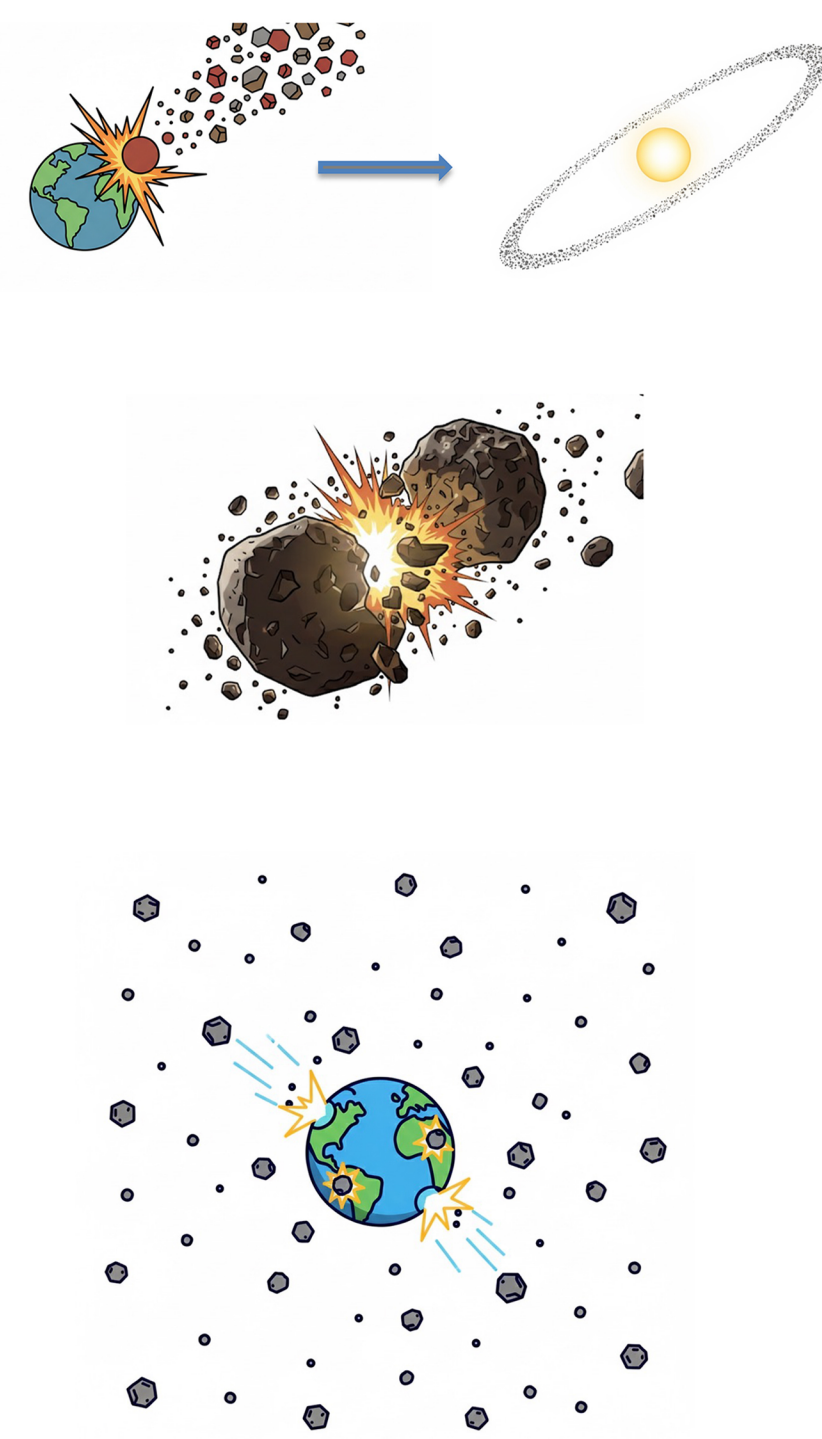
- Terrestrial planets form through giant impacts between newly formed protoplanets
- These impacts eject large amounts of debris into space and produce a circumstellar debris disk
- Some of the debris falls back and gradually erode terrestrial atmospheres via secondary impacts



What are the long-term implications of debris re-accretion on planetary atmospheres?

Modeling Long-Term Debris Impacts

- Giant Impact Debris** : A fraction of the planet's mass ($f_{\text{esc}} \times m_p$) is ejected, which spreads out to form a debris disk orbiting the host star (Jackson & Wyatt 2012)
- Debris Disk Evolution** : Debris will collide with each other (also with the planet) till it is ground down to dust and eventually removed by radiation pressure or Poynting-Robertson drag
- Re-accretion and Atmospheric Erosion**: A fraction of the debris will re-impact the planet and be re-accreted onto the planet. As the smaller ($\sim$ km-sized) impacts are much more efficient at eroding atmospheres (Shuvalov 2009, Schlichting et al 2015), the secondary impacts from the debris result in significant atmospheric erosion over time.



Evolution of the debris disk mass over time following a potential Moon-forming impact (1 Earth mass planet at 1 au). Vertical dashed lines indicate the collisional depletion timescale for each f_{esc} . Assuming largest debris = 100 km.

Mass of debris re-accreted onto the planet as a function of time. The black dashed vertical line indicates the re-accretion timescale

Atmospheric mass loss due to the re-accretion of debris, assuming an initial atmosphere like present day Earth. The dashed line represents the atmospheric loss expected from a canonical Moon-forming impact (Kegerreis et al. 2020)

Re-accreted debris can erode more atmosphere than that the primary impact itself

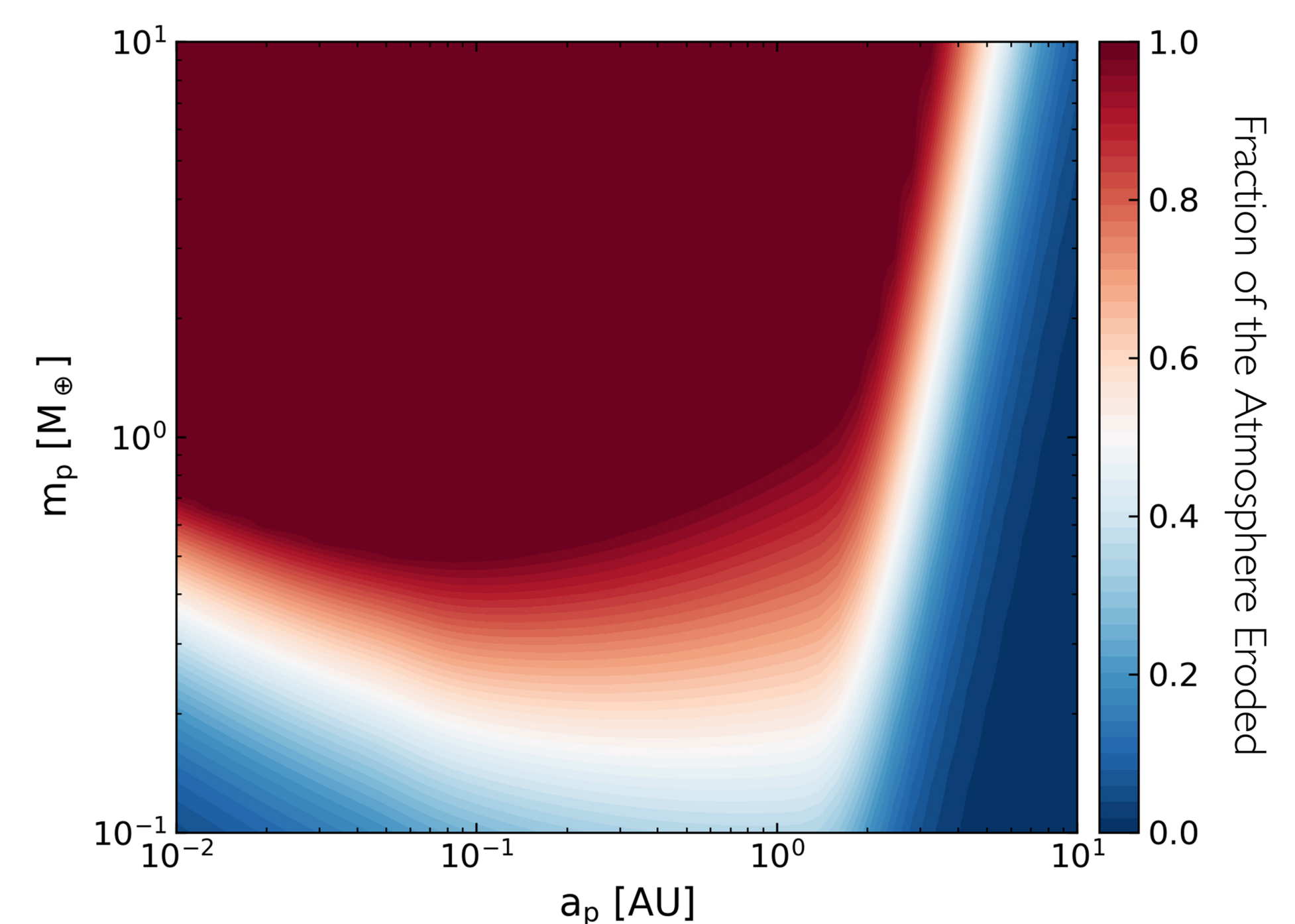
How does atmospheric erosion depend on planet mass and orbit?

Assuming :

- $f_{\text{esc}} = 0.01$, Largest debris = 100 km
- Initial atmosphere = 5 $\times$ Earth's present atmosphere

Our results suggest :

- Planets growing via giant impacts within 2 au are likely to experience significant atmospheric erosion.



Atmospheric erosion due to re-accretion of debris as a function of planet mass (m_p) and semi-major axis (a_p). Colors represent the fraction of the initial atmospheric mass lost within 1 Gyr.

Summary & Conclusions

- The re-accretion of giant-impact-ejecta, a previously overlooked process, can erode a substantial fraction of terrestrial planets' atmosphere, making giant impacts significantly more erosive than previously considered.
- Planets growing via giant impacts within 2 au are likely to experience significant atmospheric erosion from the re-accreting debris continuing for millions of orbits after the primary impact.
- This process may cause repeated volatile loss and replenishment cycles, influencing atmospheric composition and surface conditions that determine planetary habitability.
- Extensive atmospheric erosion by re-accreted debris may help explain isotope fractionations and noble gas depletions observed in Earth's mantle and atmosphere

For more details...

Ghosh T., Wyatt M., Shorttle O. 2025 (MNRAS, submitted)



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