THE PROPENSITY OF PLATE TECTONICS ACROSS THE GALAXY. V. Stamenković[1], D. Breuer[2], T. Höink[3], and A. Lenardic[3], [1]MIT (54-1726, 77 Massachusetts Avenue, Cambridge, MA 02139, rinsan@mit.edu), [2]DLR German Aerospace Center (Rutherfordstrasse 2, 12489 Berlin, Germany), [3]Rice University (Houston, TX).

Introduction: Both the time and the location of planet formation shape a rocky planet's mass, interior composition and structure, and hence also its tectonic mode. The tectonic mode of a planet can vary between two end-member solutions, plate tectonics and stagnant lid convection, and does significantly impact outgassing and biogeochemical cycles on any rocky planet.

Therefore, estimating how the tectonic mode of a planet is affected by a planet's age, mass, structure, and composition is a major step towards understanding habitability of exoplanets and geophysical false positives to biosignature gases. This type of research moreover also helps to gain a more fundamental insight into the drivers of plate tectonics, volcanism, and the deep water cycle on Earth, Venus, and Mars.

Methods: We use 3D mantle convection evolution models with a sub-lithospheric low-viscosity channel using CitcomS to explore which stress component initiates plate tectonics. The connection to the specific stress component that initiates failure ties to a debate regarding plate tectonics on super-Earths ([1]). We then combine our 3D numerical results with our 1D thermal evolution model ([1]) to explore how the specific type of stress impacts the dependence of plate tectonics (initiation and maintenance) on planet mass, composition, structure, and initial conditions. We especially account for the current wide range of uncertainties in mantle rheology and initial conditions.

Finally, we connect our geophysical results to astronomy in order to explore how we could identify and where we could find planet candidates with optimized conditions for plate tectonics across the Galaxy.

Results: Although initial conditions and the specific history of a planet critically shape its tectonic mode, we can still build a probabilistic method to quantify the propensity of plate tectonics occurring on a given planet.

We find that shear stresses are responsible for initiating plate tectonics from a stagnant lid state. Based on our best model estimates, we predict that the ideal targets for plate tectonics are silicate (solar system like) rocky planets of ~1 Earth mass with surface oceans, large metallic cores (~Mercury-structured, rocky body densities of ~7000kgm^{-3}), and with small mantle concentrations of iron (~0%), water (~0%), and radiogenic heat sources (~10 times less than Earth). Super-Earths, undifferentiated planets, and especially hypothetical carbon planets, speculated to consist of SiC and C, are not optimal for the occurrence of plate tectonics.

Moreover, the results indicate that plate tectonics might have never existed on planets formed soon after the Big Bang—but instead is favored on planets formed from an evolved interstellar medium enriched in iron but depleted in silicon, oxygen, and especially in Th, K, and U relative to iron. This allows for the first time to discuss the tectonic mode of a rocky planet from a practical astrophysical perspective.

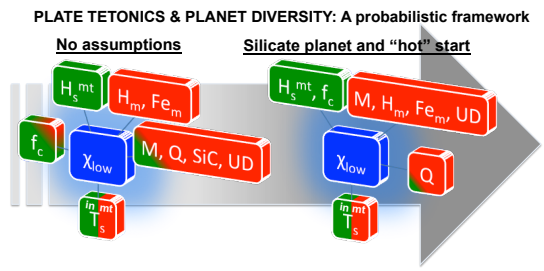

Figure 1: Schematic representation how surface temperature, planet mass, composition, structure, and differentiation impact the propensity of plate tectonics, when no assumptions about composition, structure, and initial conditions are made and when we focus on silicate planets assuming they form molten – which is plausibly the best approximate representation of Earth and solar system like rocky planets. Red (green) represents that an increase in the specific property always decreases (increases) the propensity of plate tectonics. Intermediate colorings indicate that the effects on the propenisty of plate tectonics are non-unique and depend on specific conditions (the degree of increasing/decreasing the propensity of plate tectonics scales with the ratio of green/red shading). The abbreviations are M for planet mass, T_s for surface temperature, H_m for water within the bulk mantle, H_s for surface water, Fe_m for mineralogically bound iron within mantle rock, Q for radiogenic heat sources, f_c for the mantle core ratio, SiC for carbon planets in relation to silicate analogs, and UD for undifferentiated planets in relation to differentiated analogs. The symbols "in" represent initiation and "mt" maintainenece of plate tectonics – this distinction only matters for the effects of surface temperature on plate tectonics, and for the result that surface water only affects the maintenance and not the initiation of plate tectonics (hence H_s^{mt}). All other trends are identical for initiation and maintenance.

References:

[1] Stamenković V. and Breuer D. (2014) *Icarus, 234*, 174-193.