

The nature and impact of obliquity evolution on the habitability of Earth-like exoplanets

Astrophysics of Planetary Habitability

Vienna, Austria

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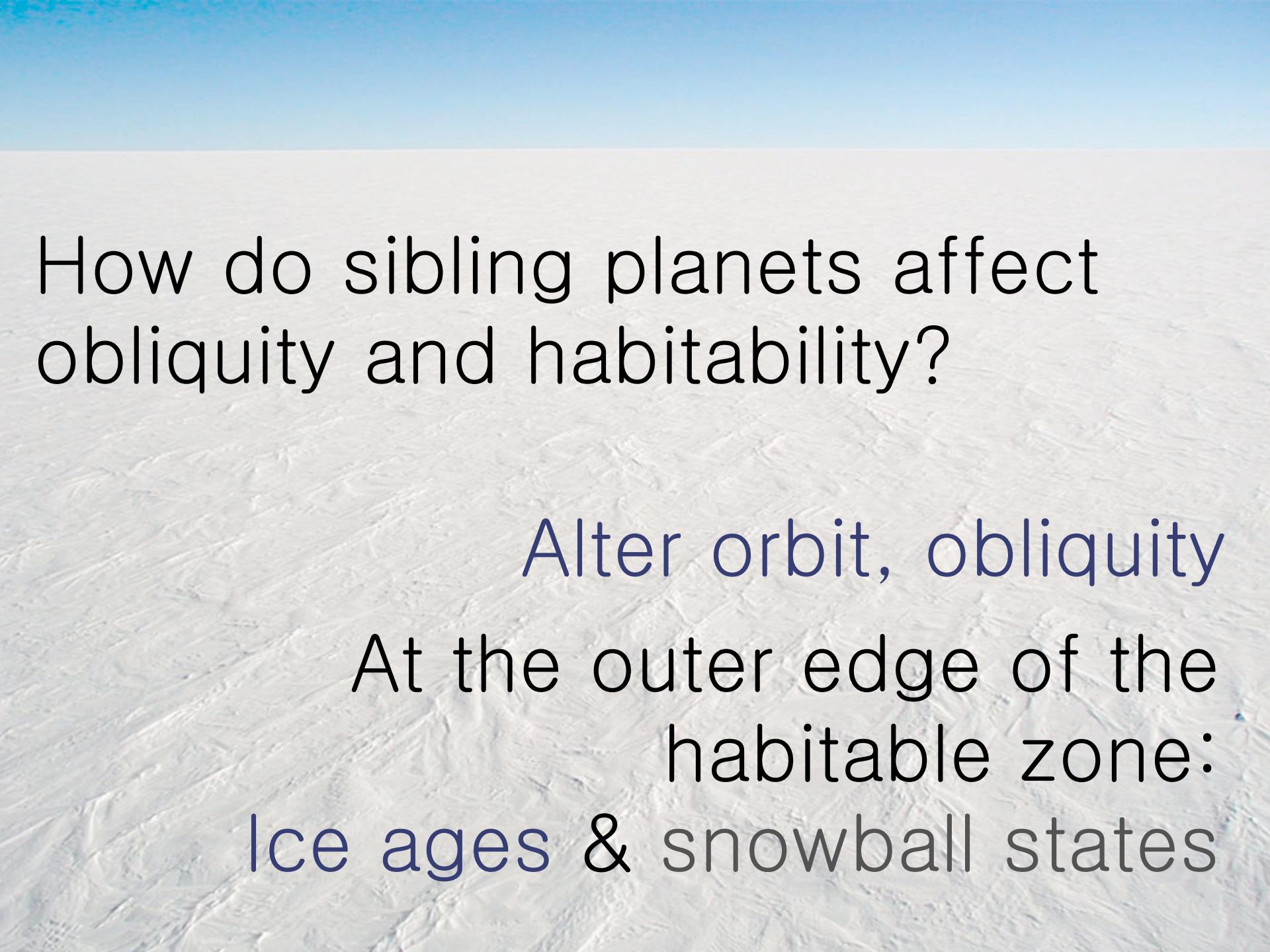
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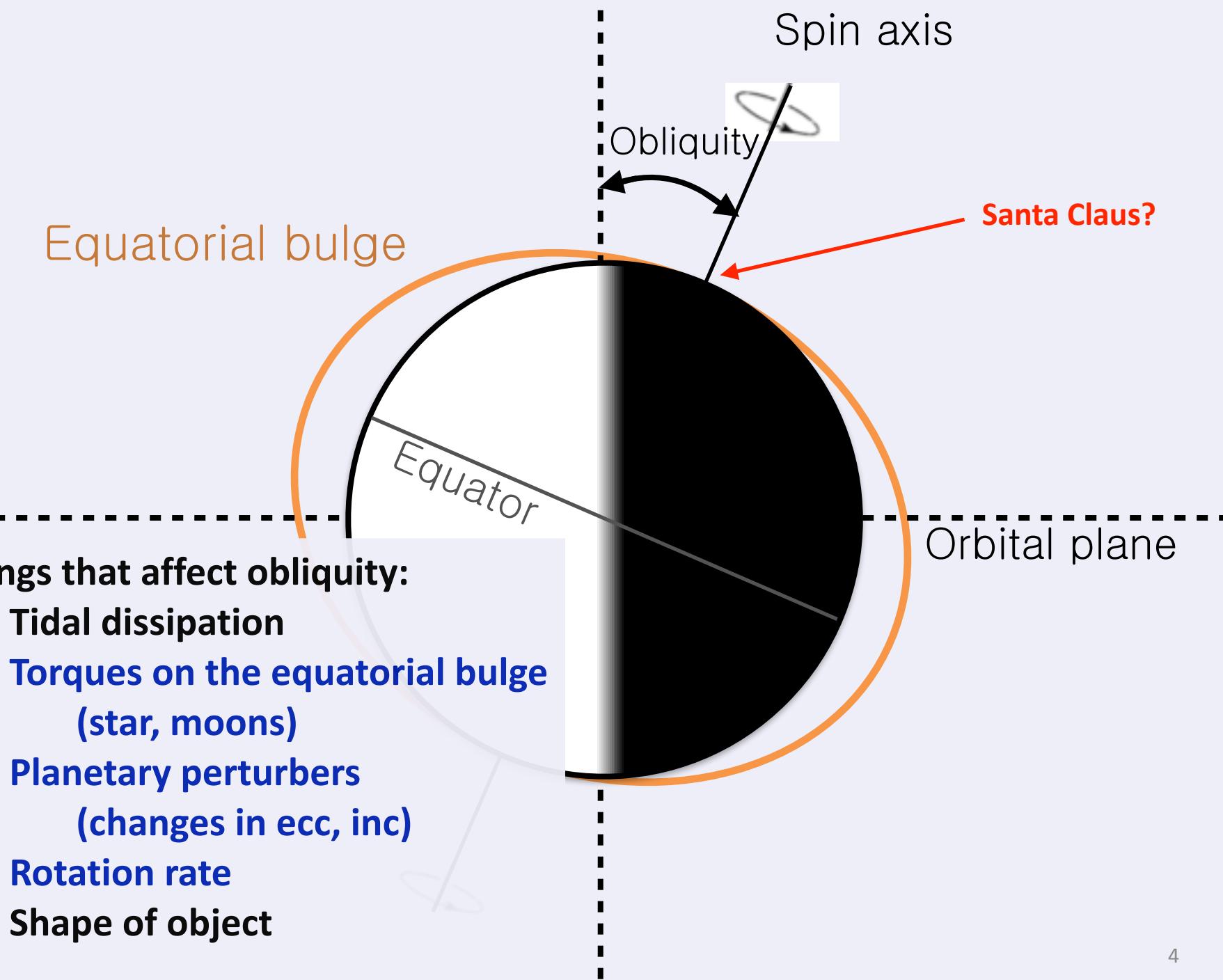
How do sibling planets affect obliquity and habitability?

Alter orbit, obliquity

At the outer edge of the
habitable zone:

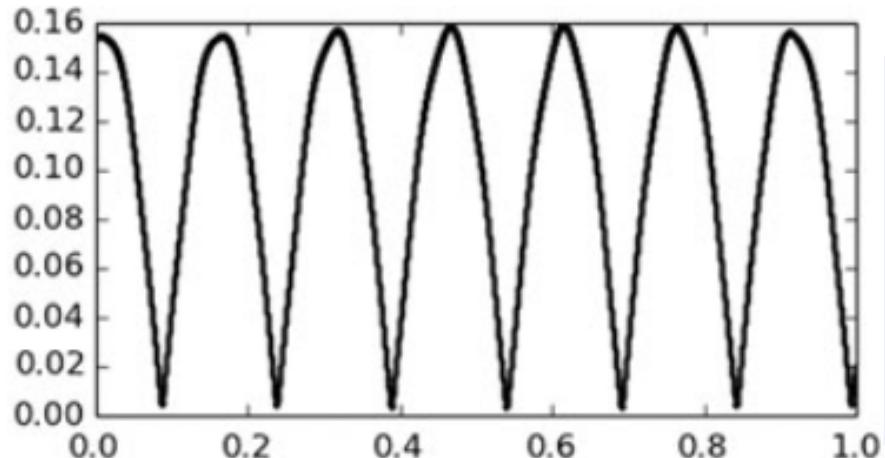
Ice ages & snowball states

**Earth's ice ages likely
linked to orbital and
obliquity variations**

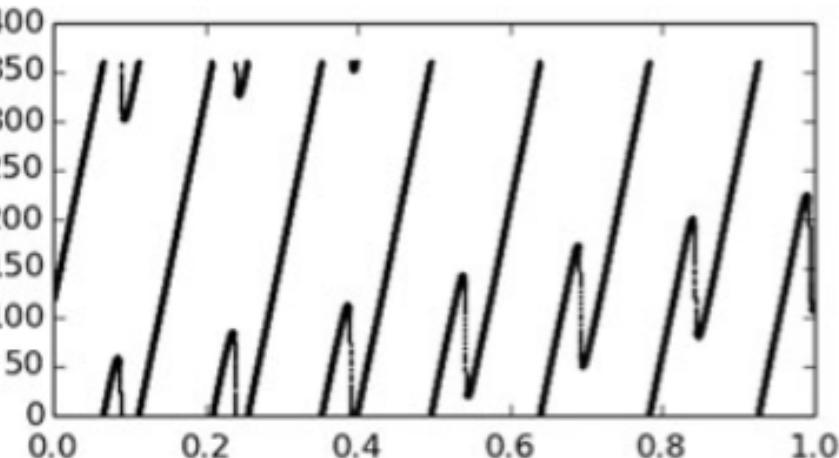


Eccentricity, inclination variations (due to other planets) can strongly affect obliquity

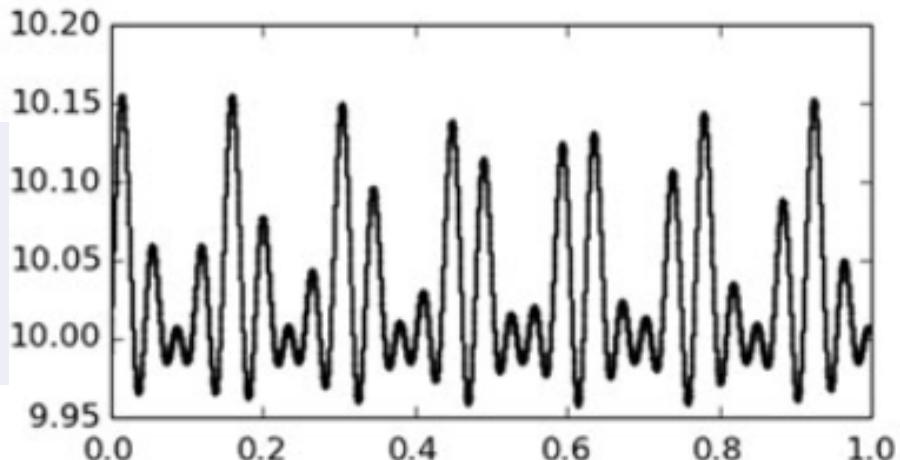
eccentricity



long. perihelion

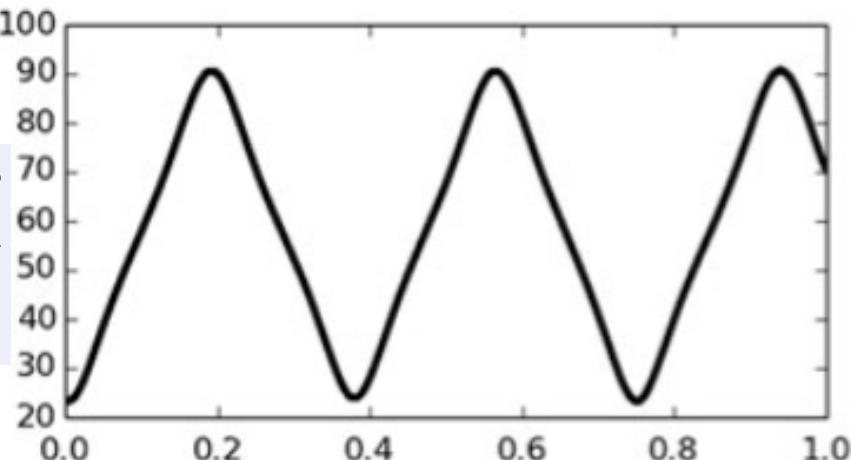


inclination

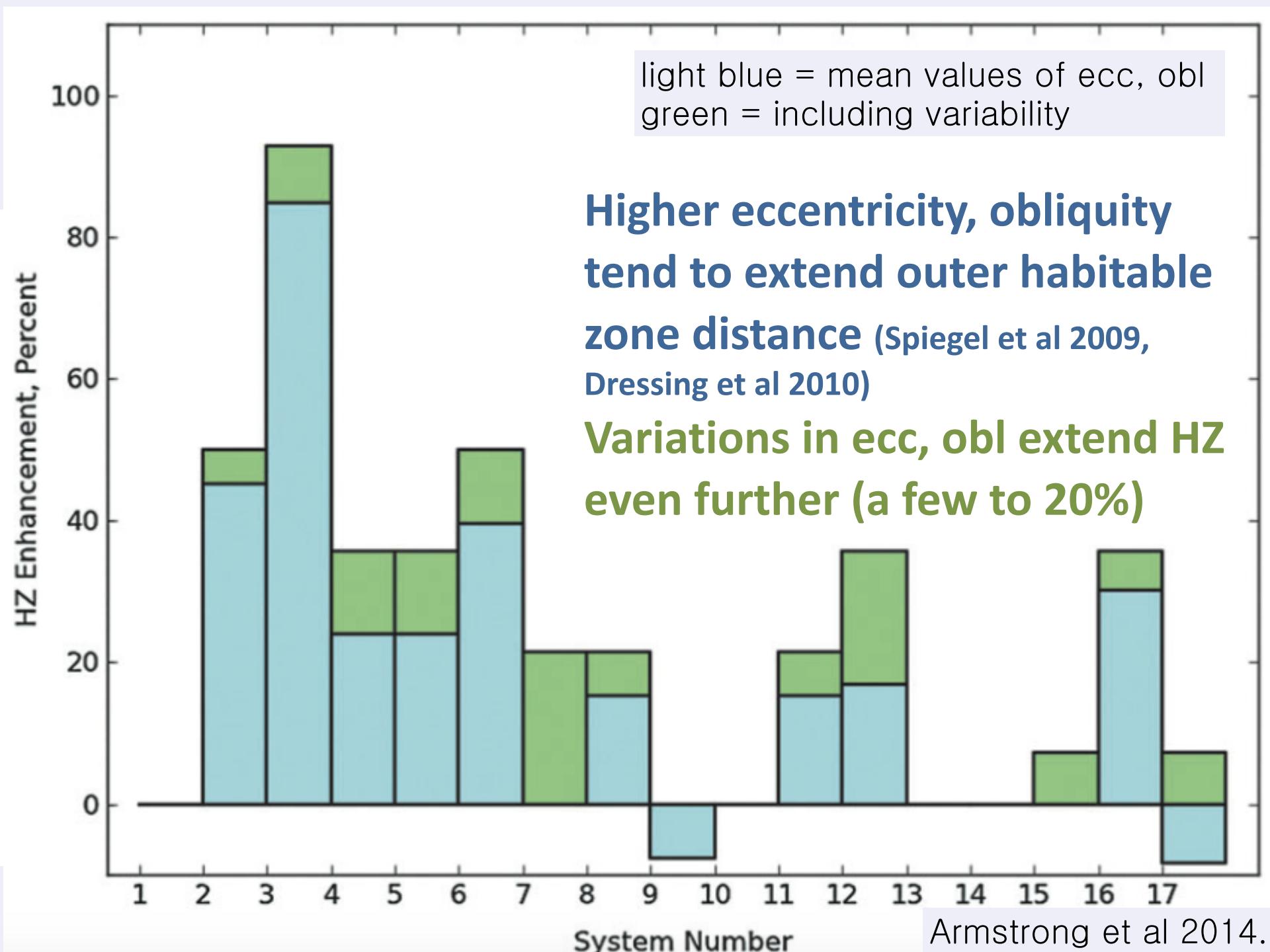


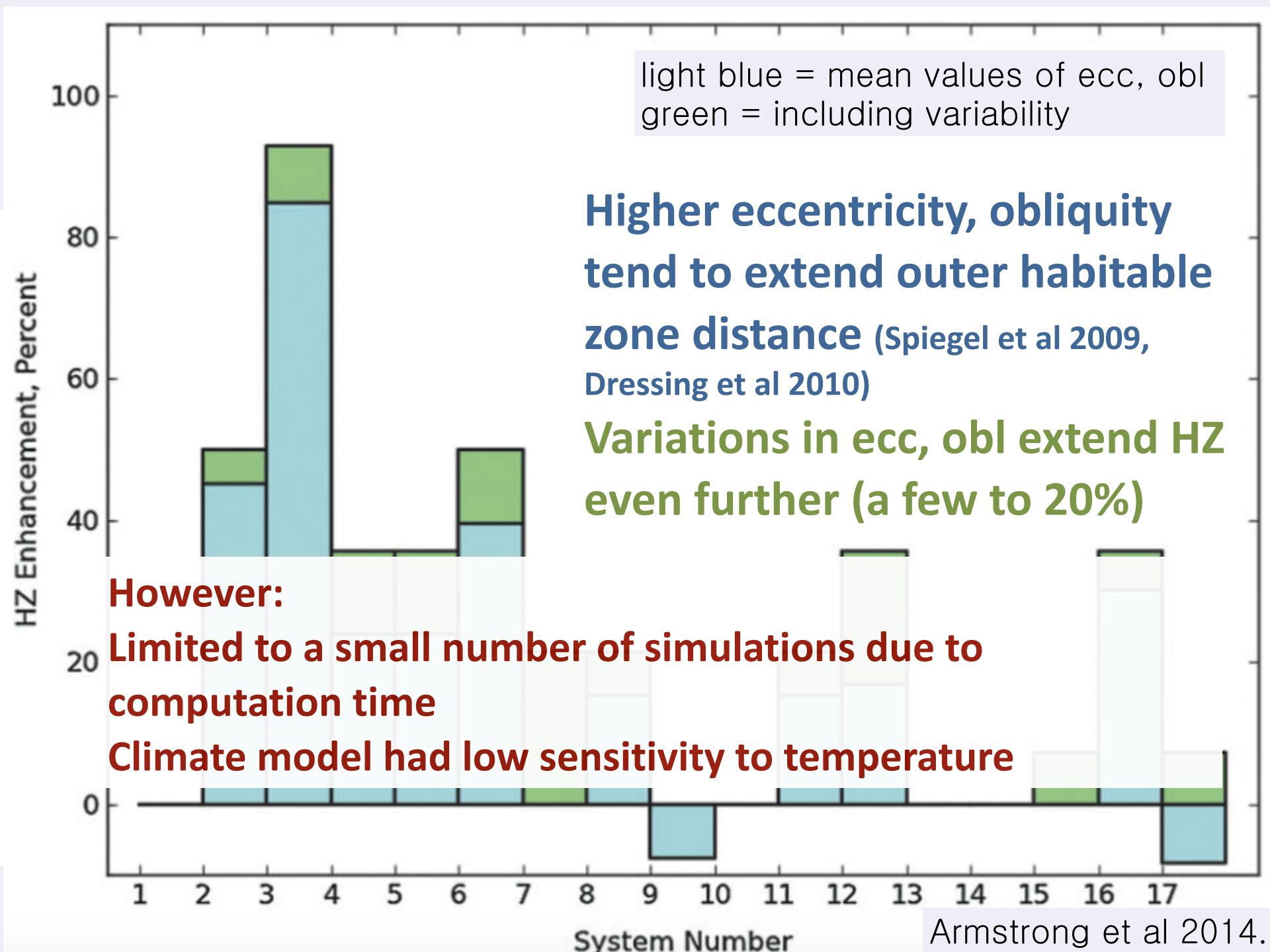
Time [Myr]

obliquity



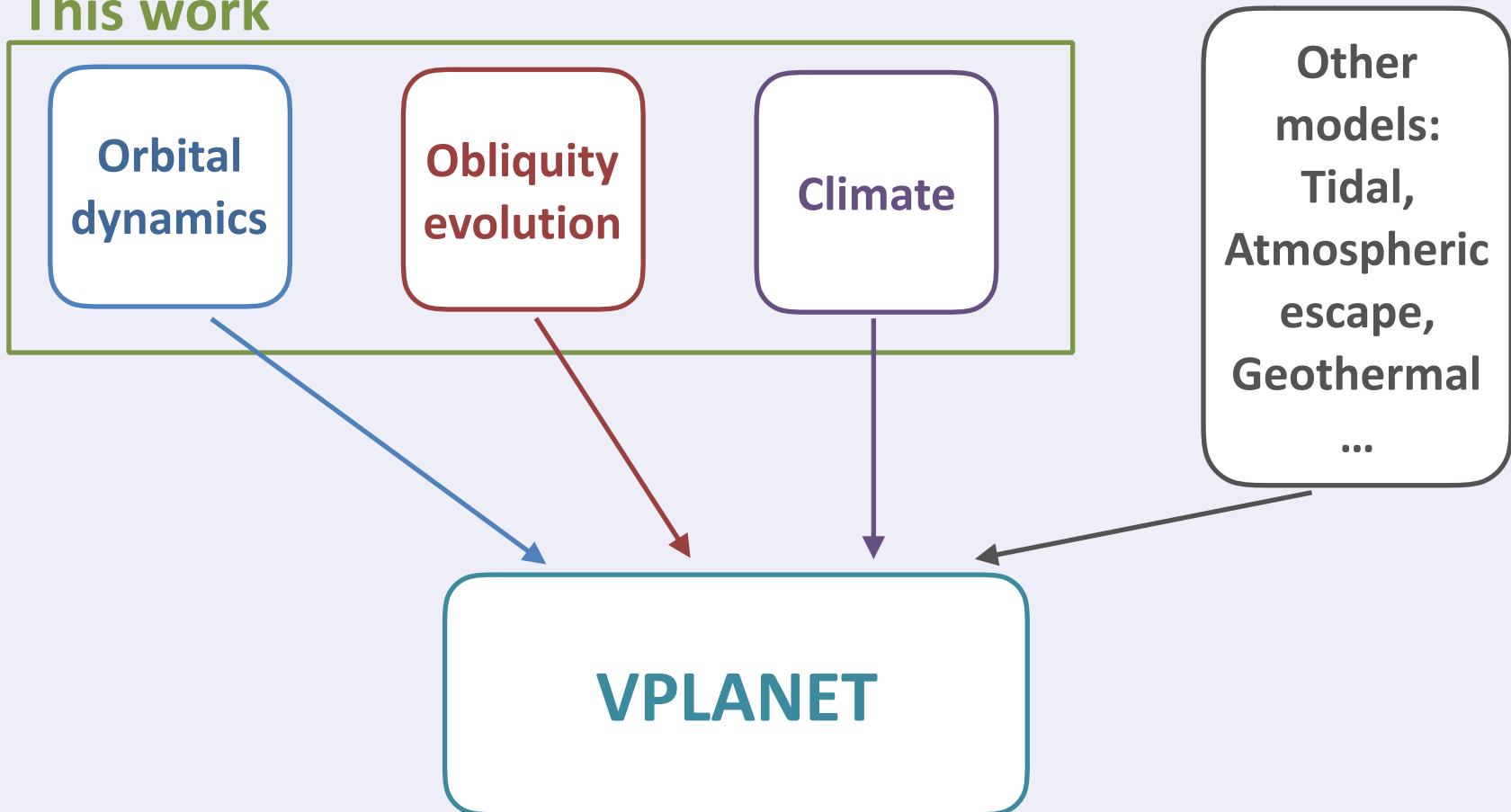
Time [Myr]



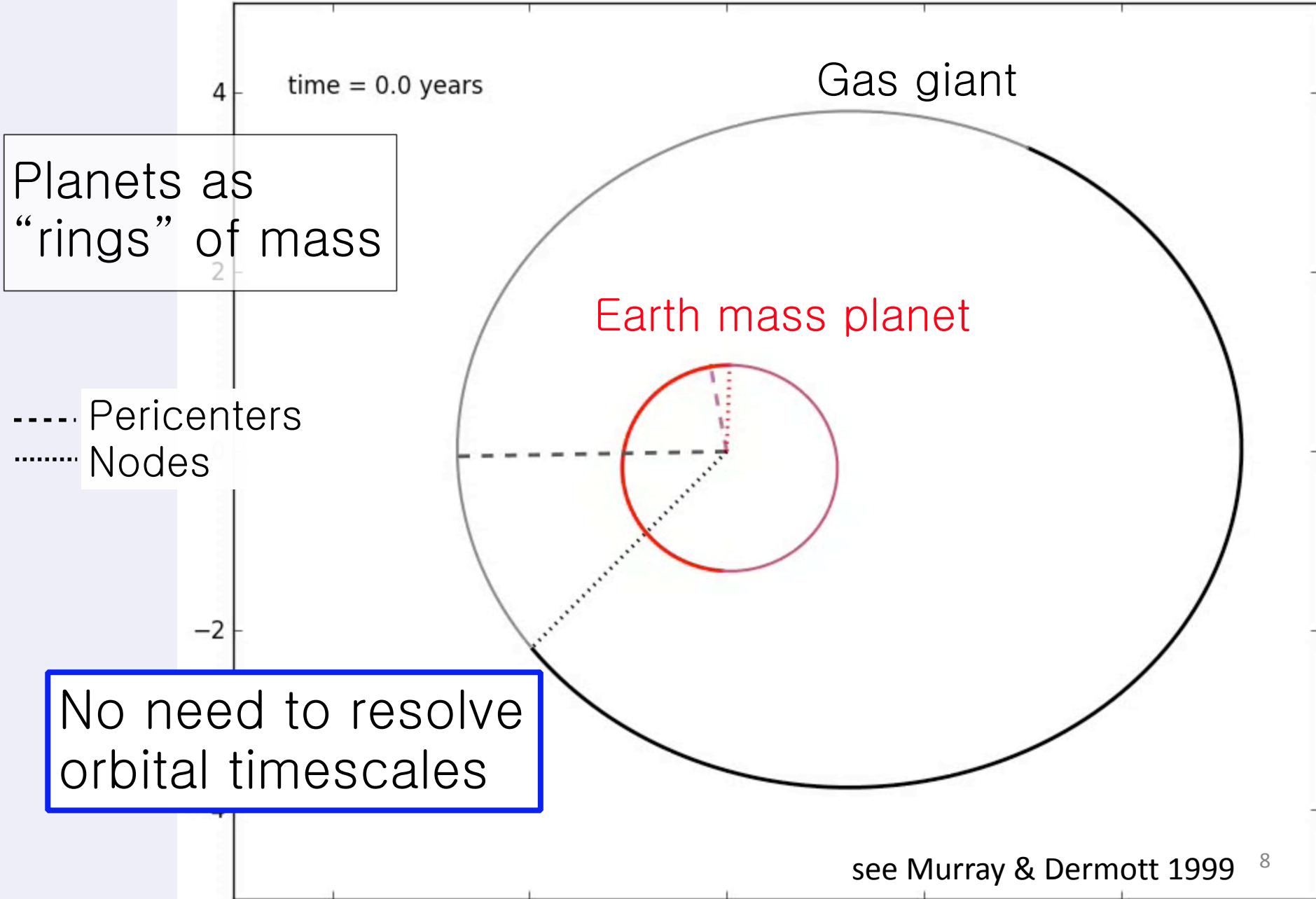


We need a fast, fully-coupled model to explore parameter space

This work



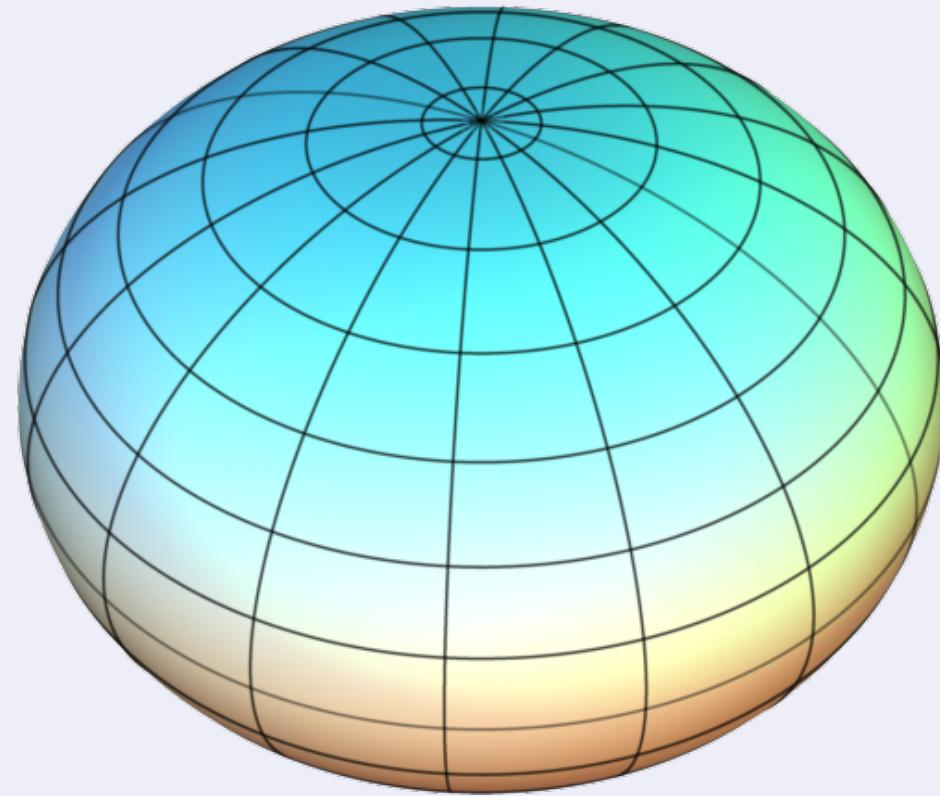
4th order secular model



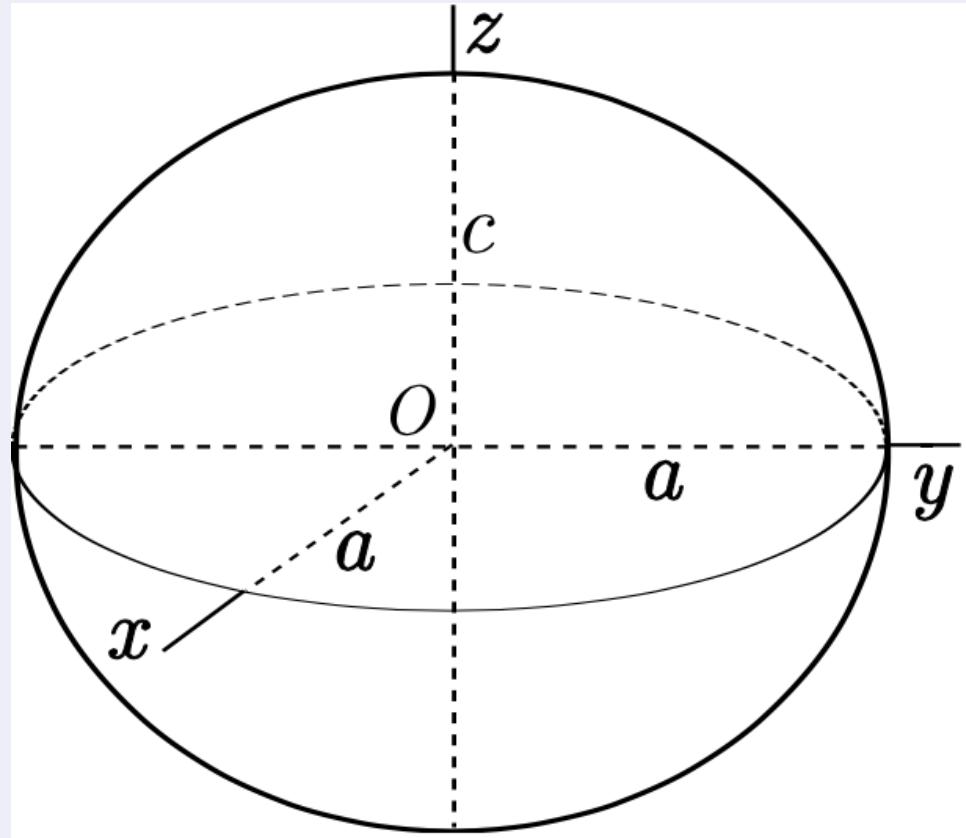
Obliquity model

Kinoshita 1975, 1977

Planets are oblate spheroids



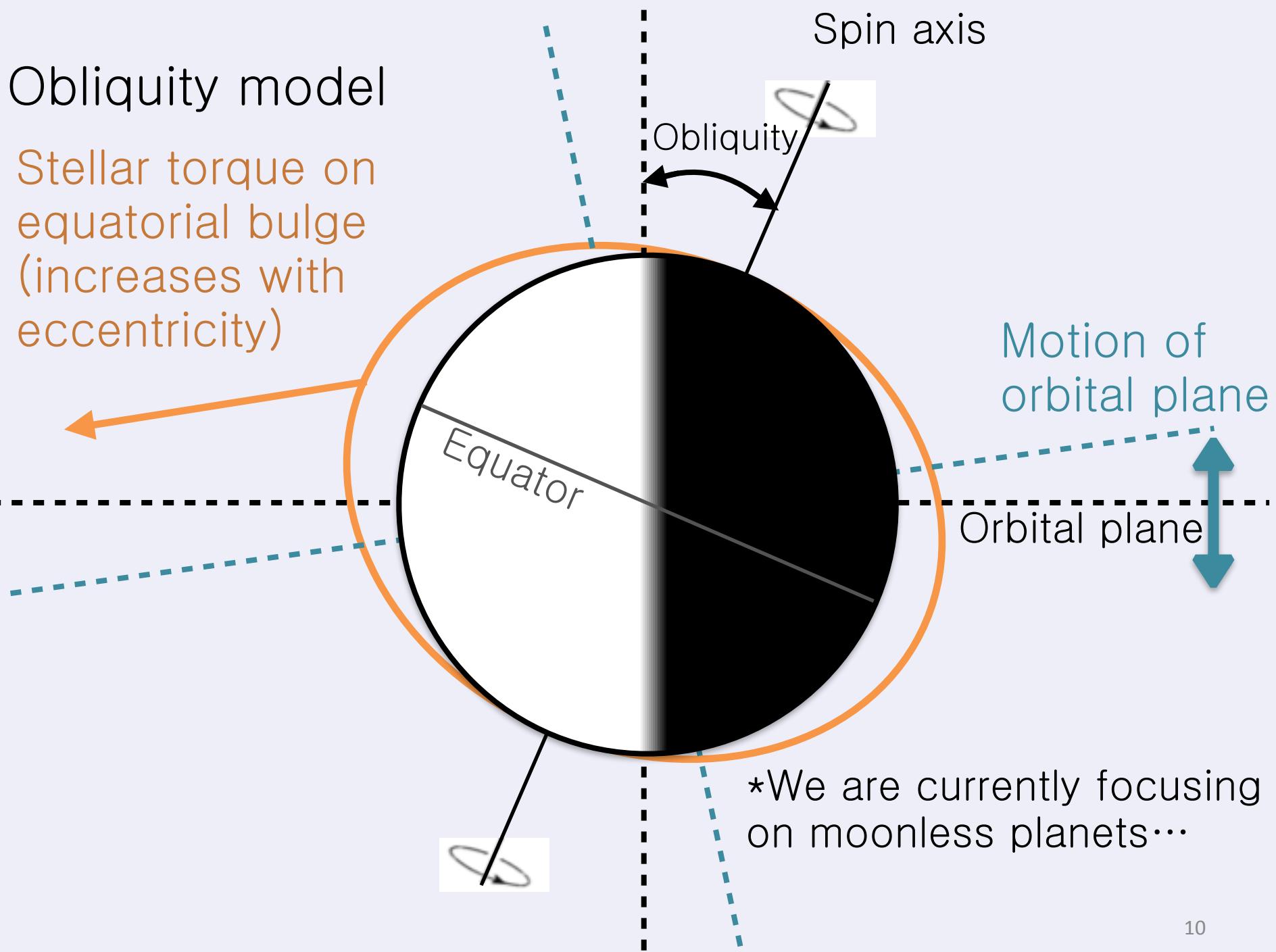
"OblateSpheroid" from Wikipedia



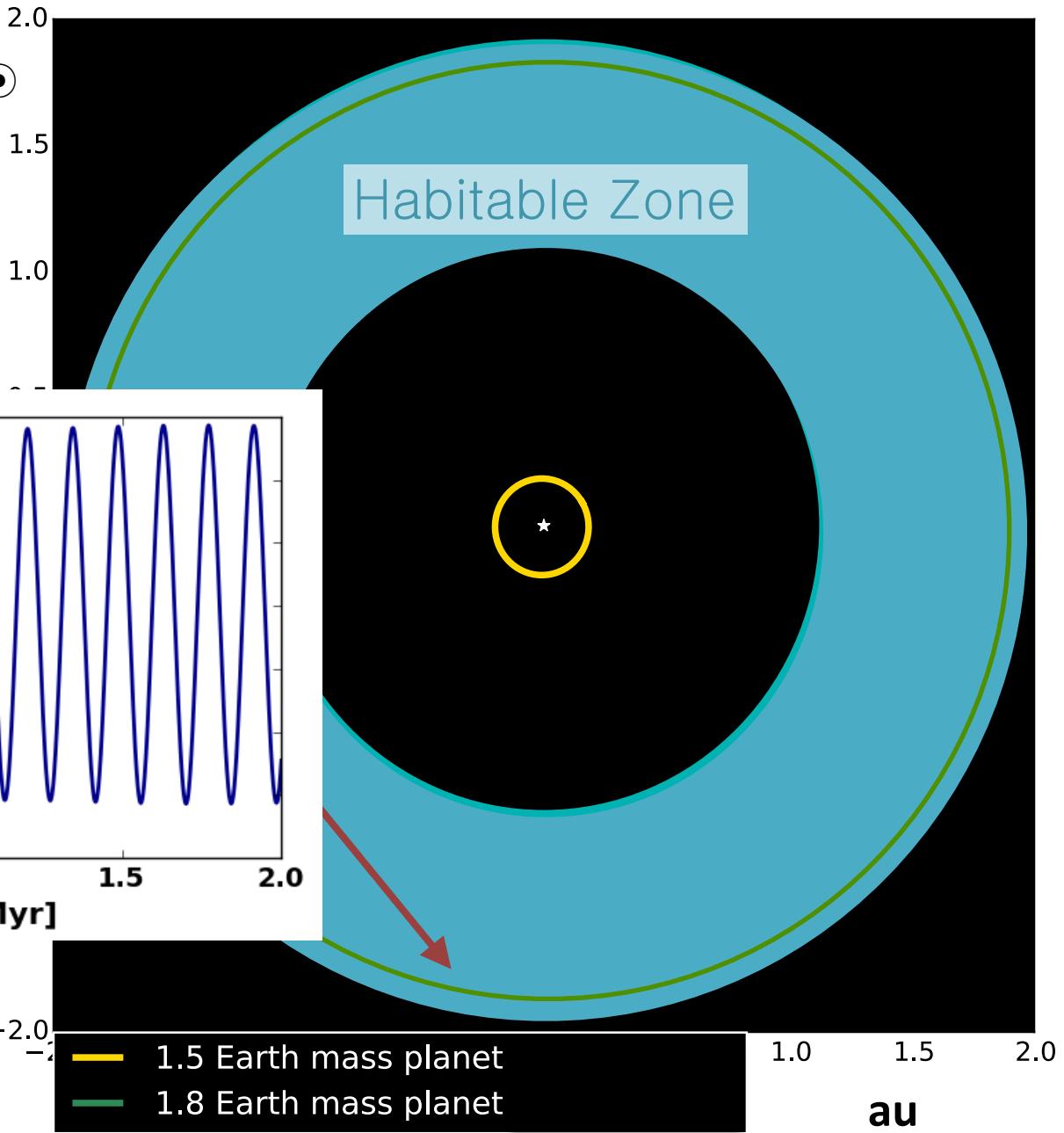
"Spheroid" by Peter Mercator

Obliquity model

Stellar torque on equatorial bulge
(increases with eccentricity)



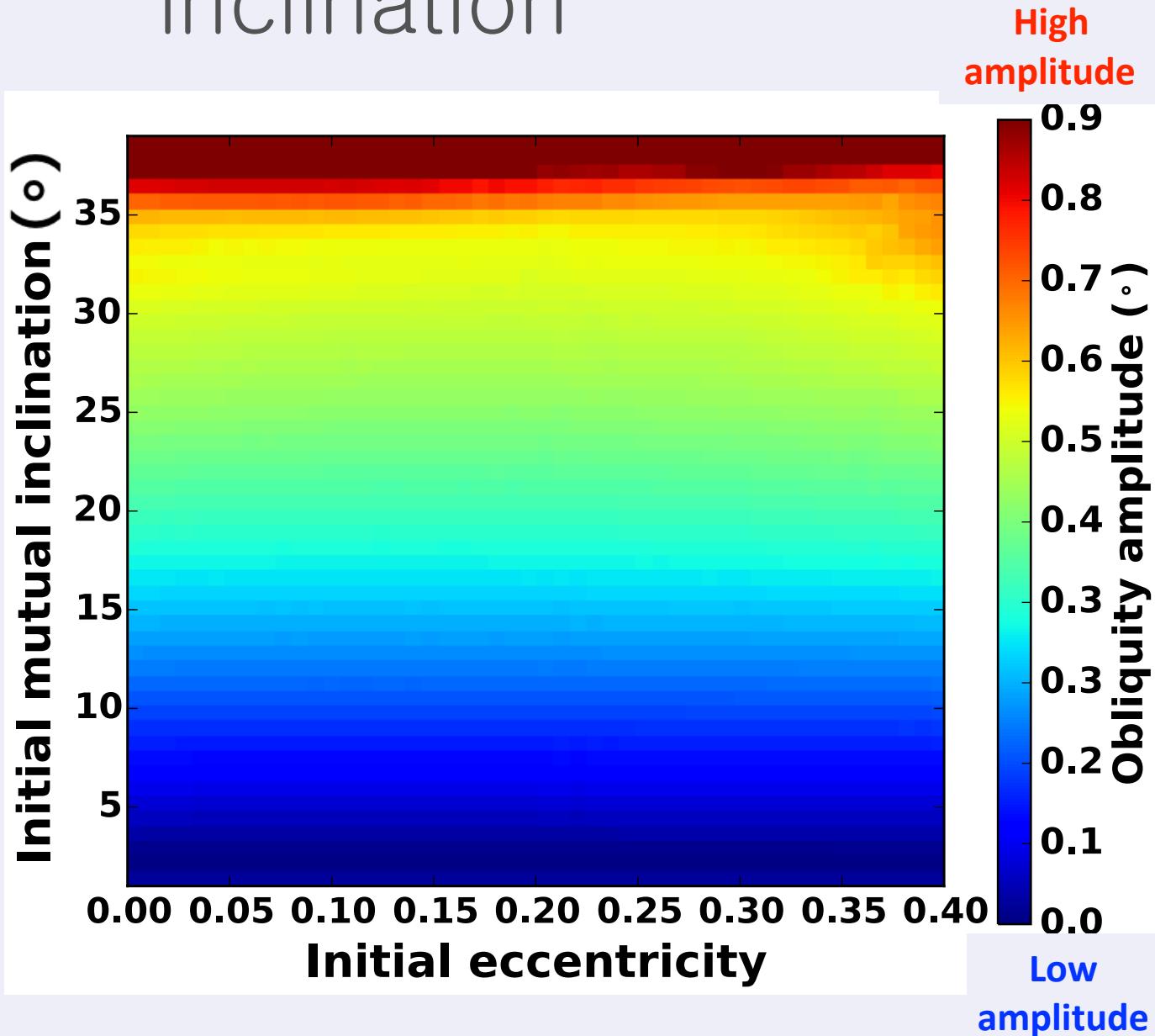
■ Star = $0.97 M_{\odot}$



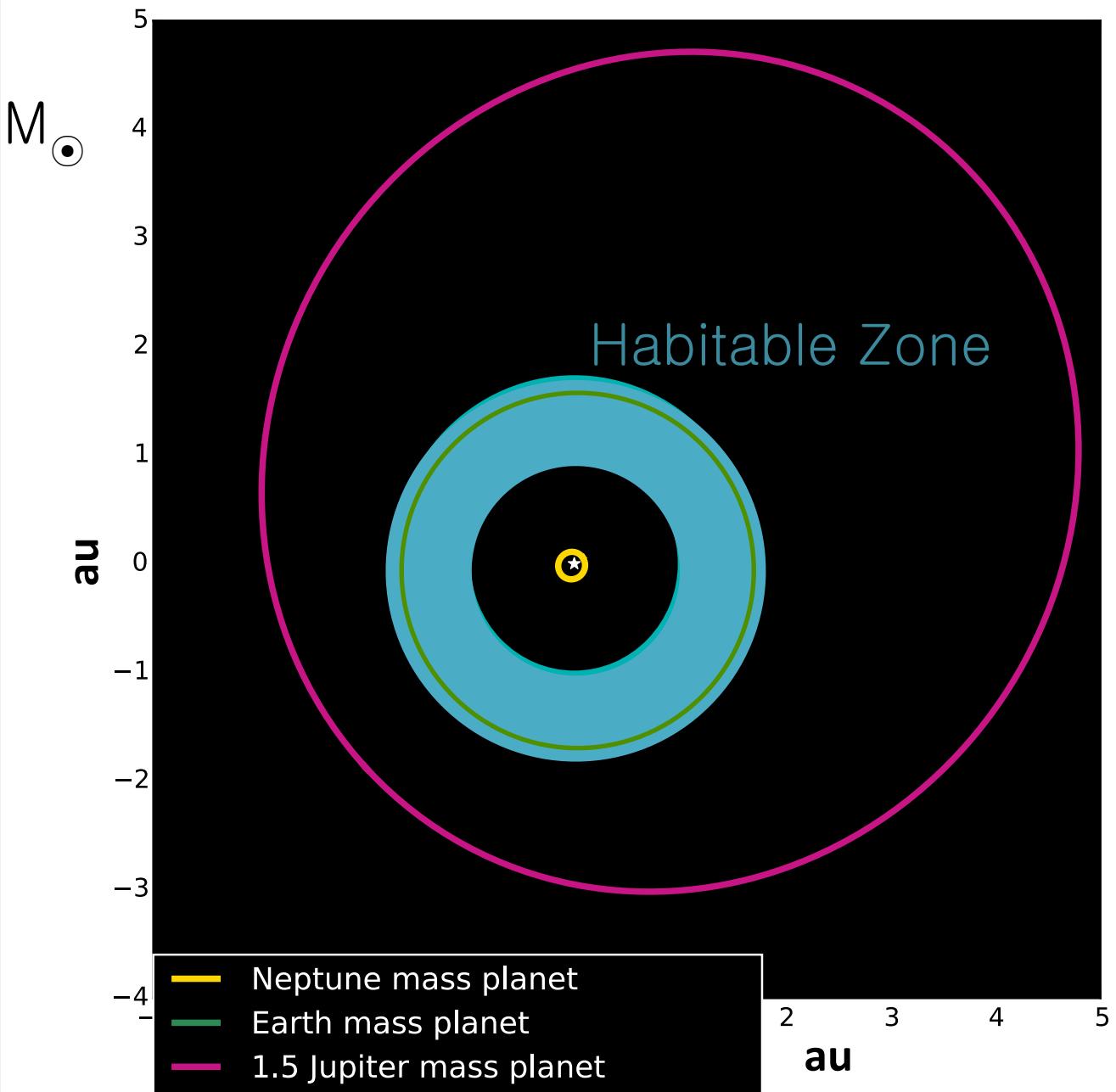
— 1.5 Earth mass planet
— 1.8 Earth mass planet

Obliquity amplitude increases with inclination

- $0.97 M_{\odot}$
 - $1.5 M_{\odot}$
 - $1.8 M_{\odot}$
(in Hz)
- 

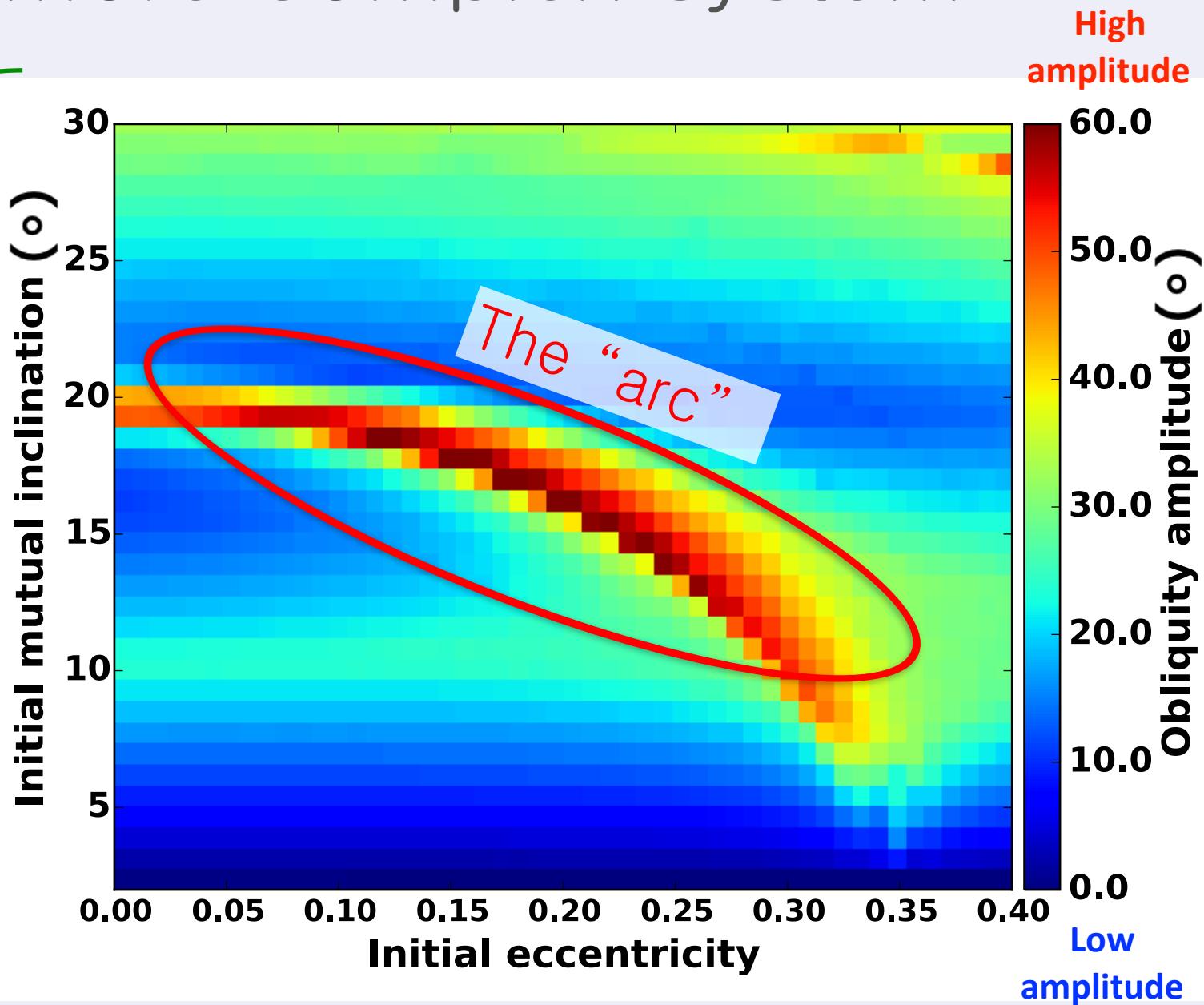


- Star = $0.98 M_{\odot}$



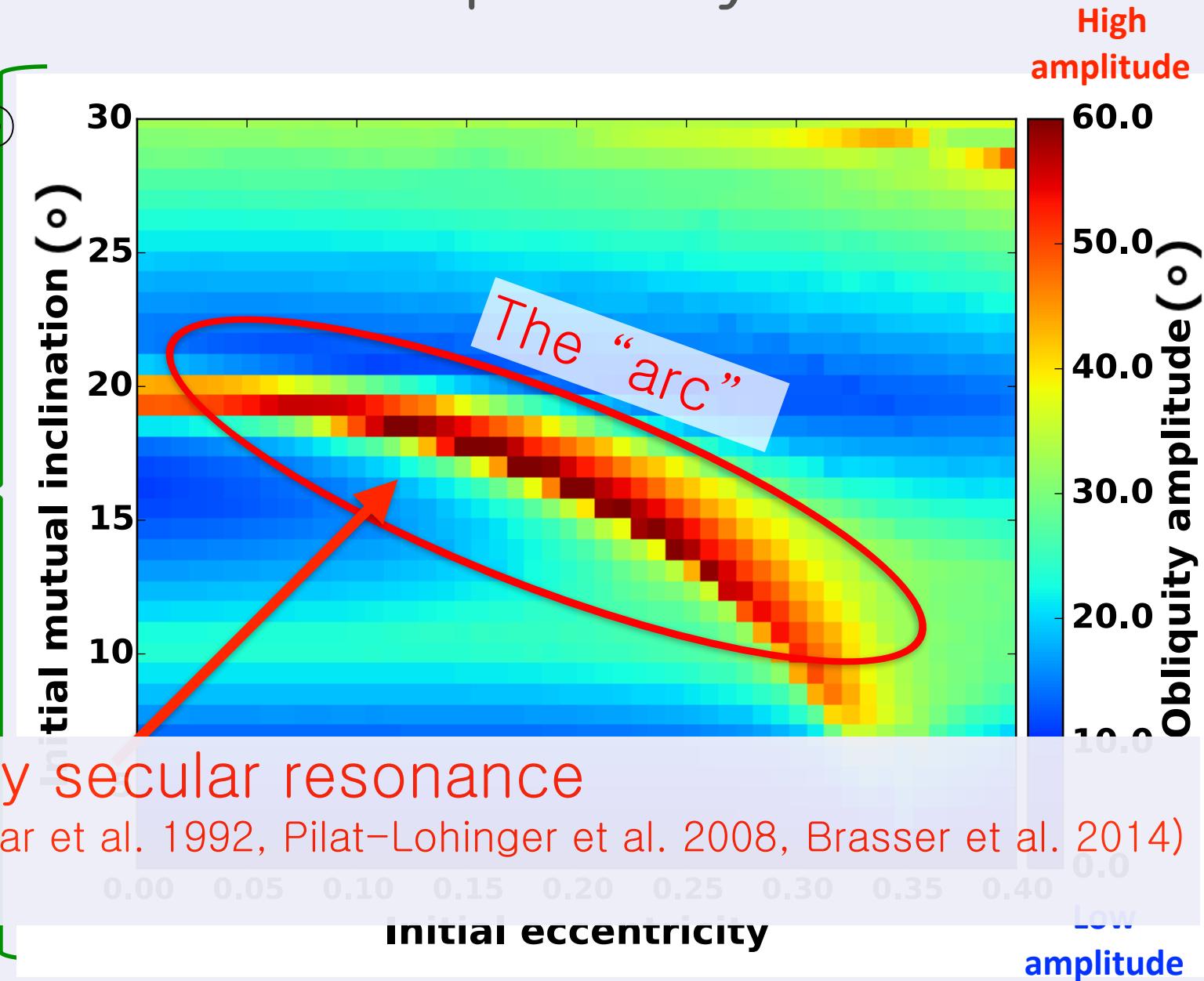
A more complex system

- $0.98 M_{\odot}$
- $19 M_{\odot}$
- $@0.13 \text{ au}$
- $1 M_{\odot}$
- (in Hz)
- $1.5 M_J$
- $@3.8 \text{ au}$



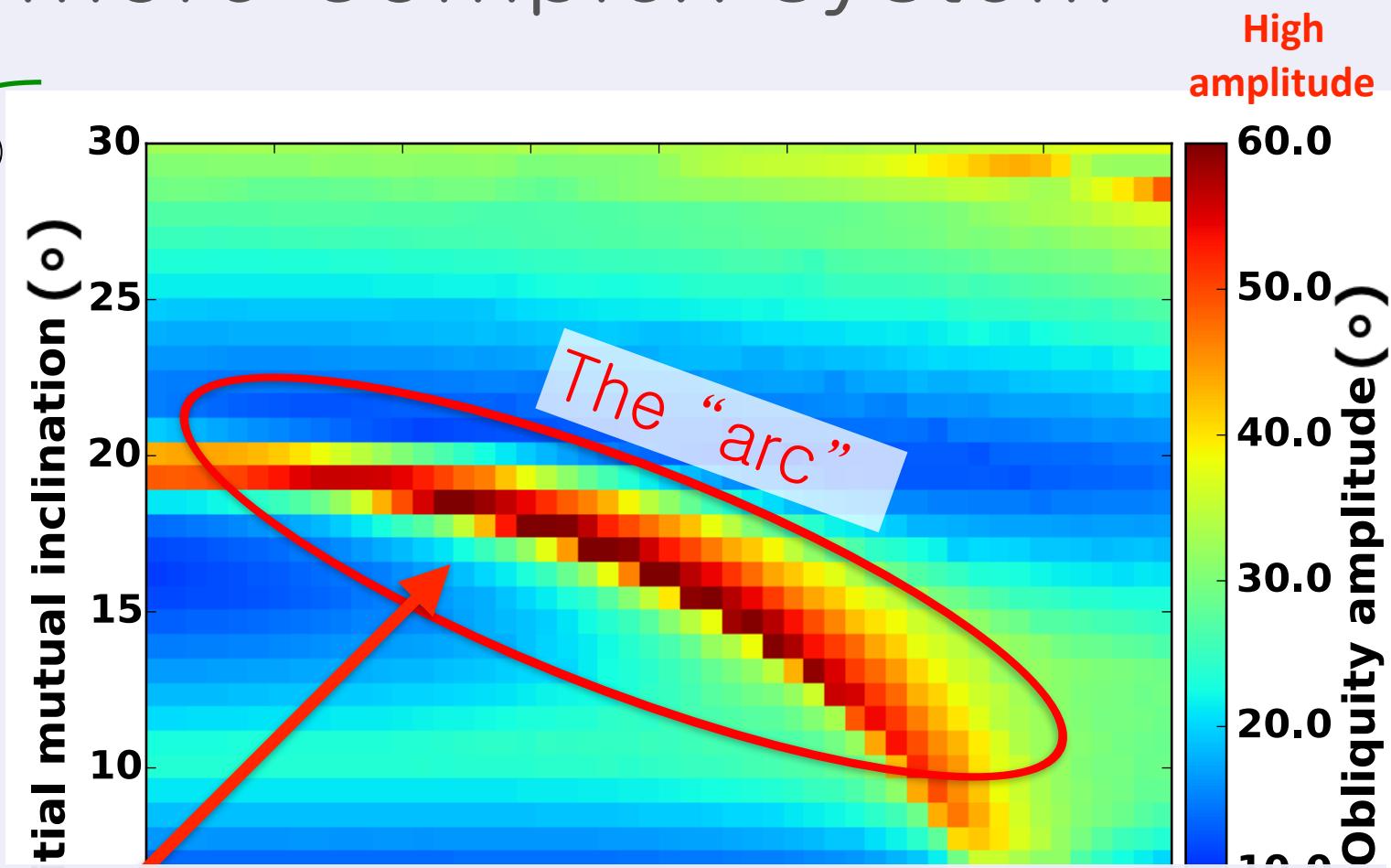
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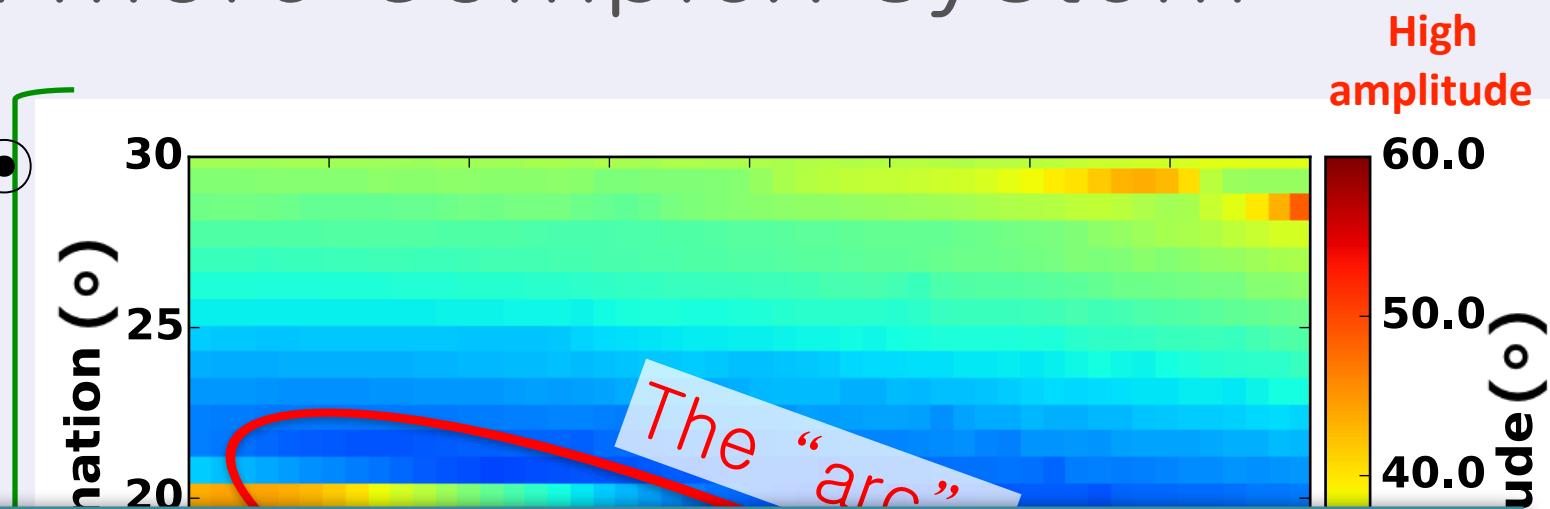
Caused by secular resonance

(see e.g. Laskar et al. 1992, Pilat-Lohinger et al. 2008, Brasser et al. 2014)

Axial precession rate matches slow orbital frequencies
(Earth-mass and 1.5 Jupiter mass planets)

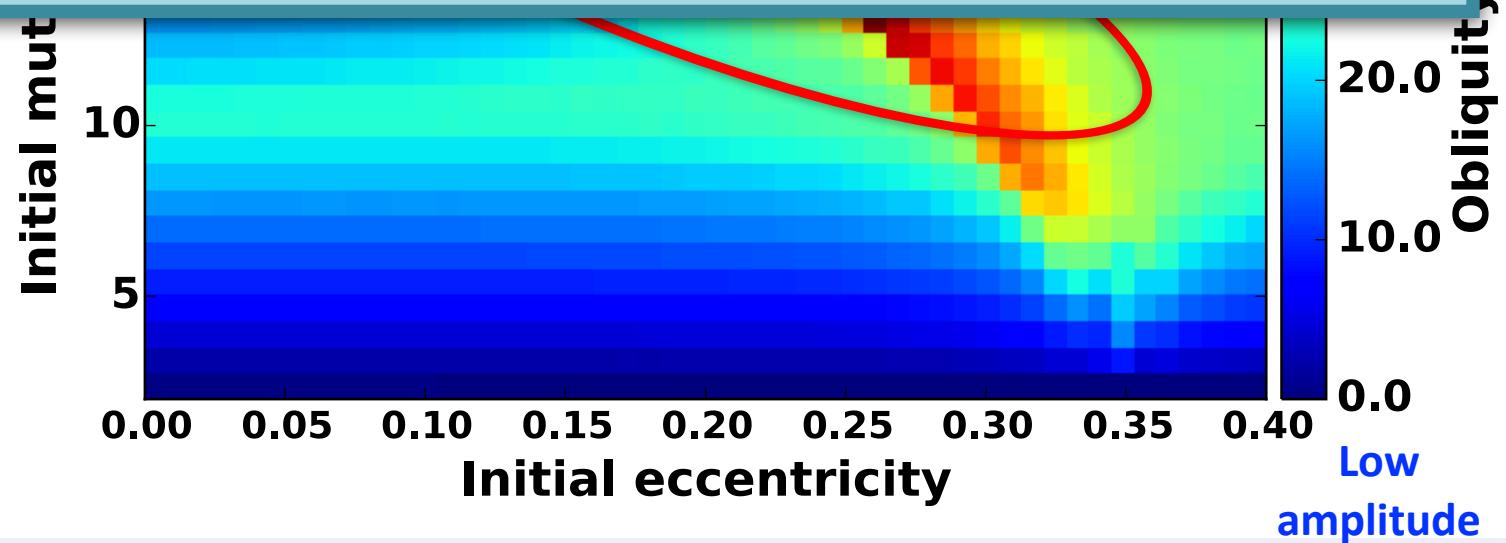
A more complex system

- $0.98 M_{\odot}$
- $19 M_{\odot}$
- @0.13 au

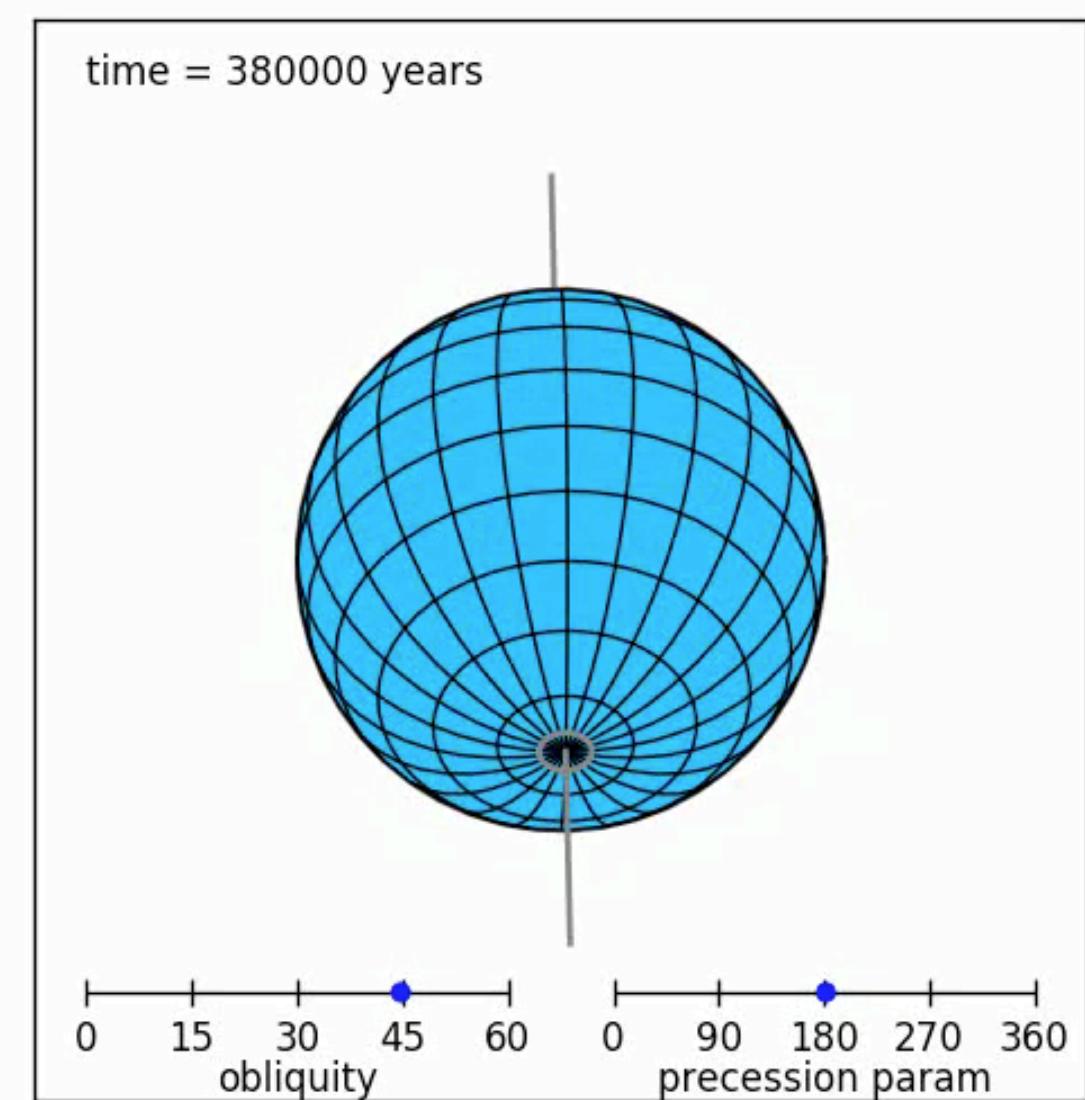


■ System architecture affects obliquity in complex ways → affects climate/habitability

- $1.5 M_J$
- @3.8 au



In the arc (secular resonance in effect)

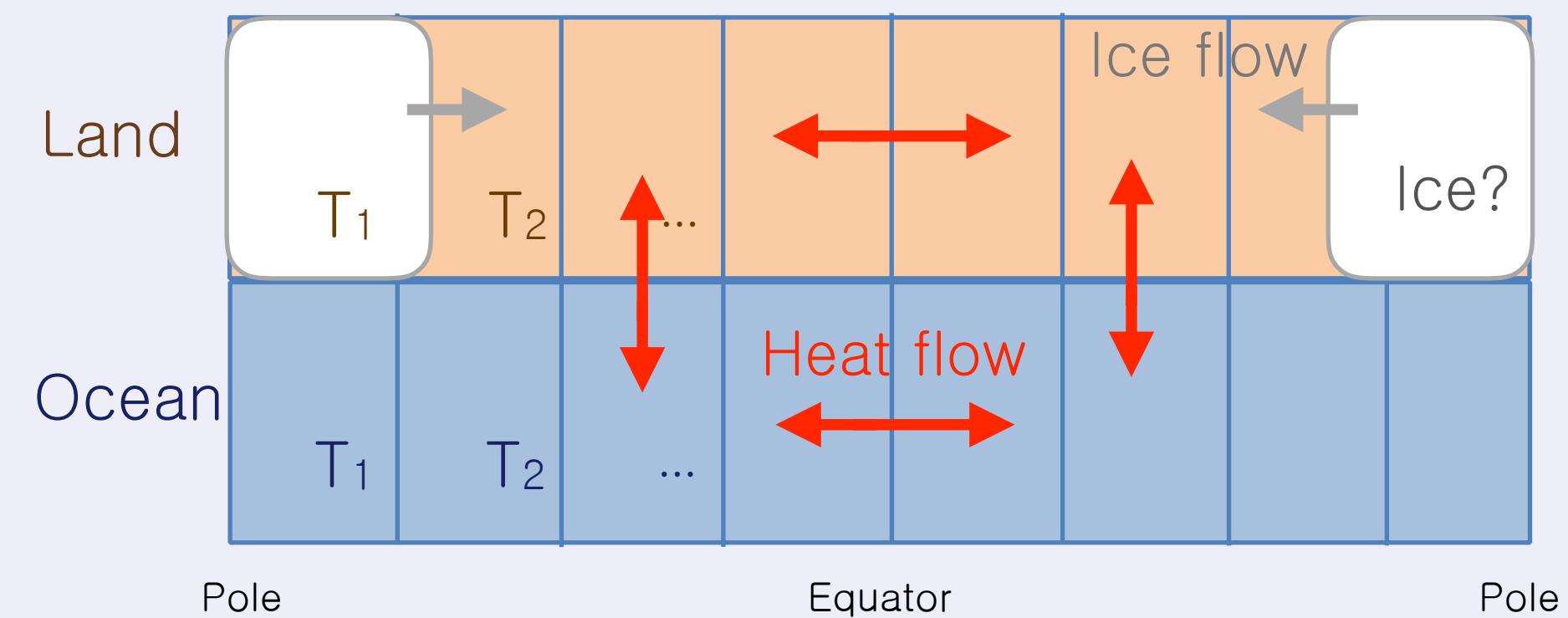


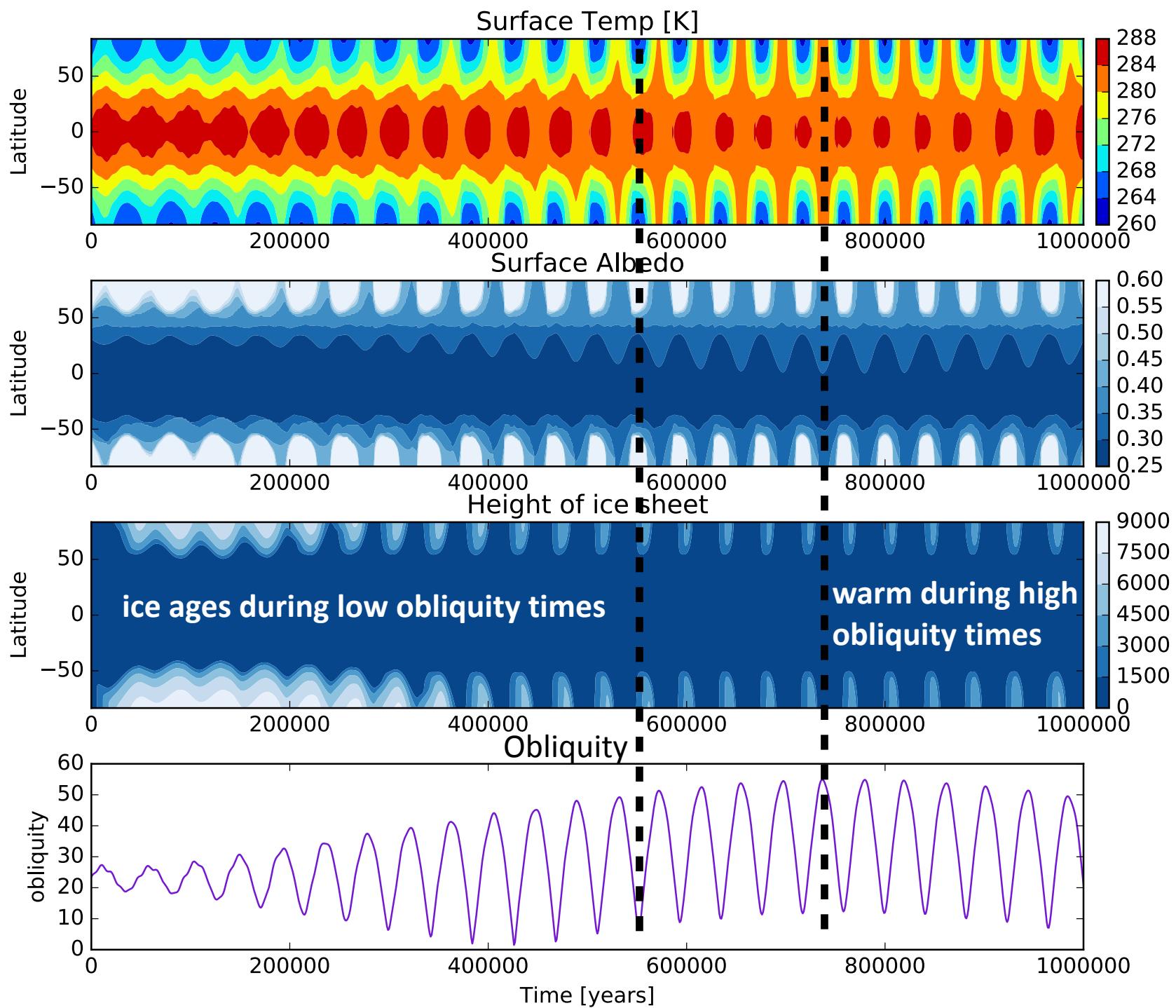
VPLanet's EBM

North & Coakley 1979

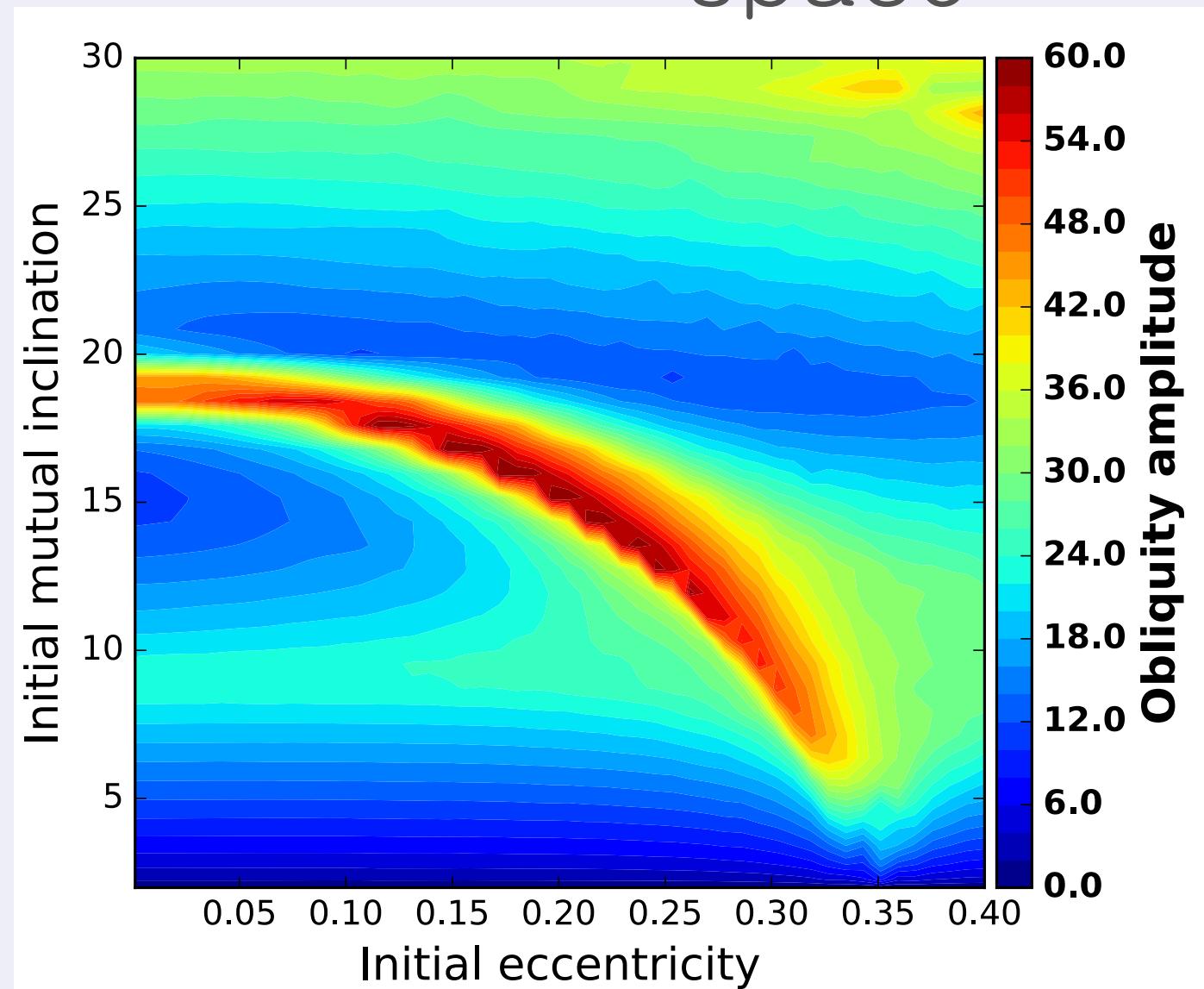
Insolation

* Snow */Melt

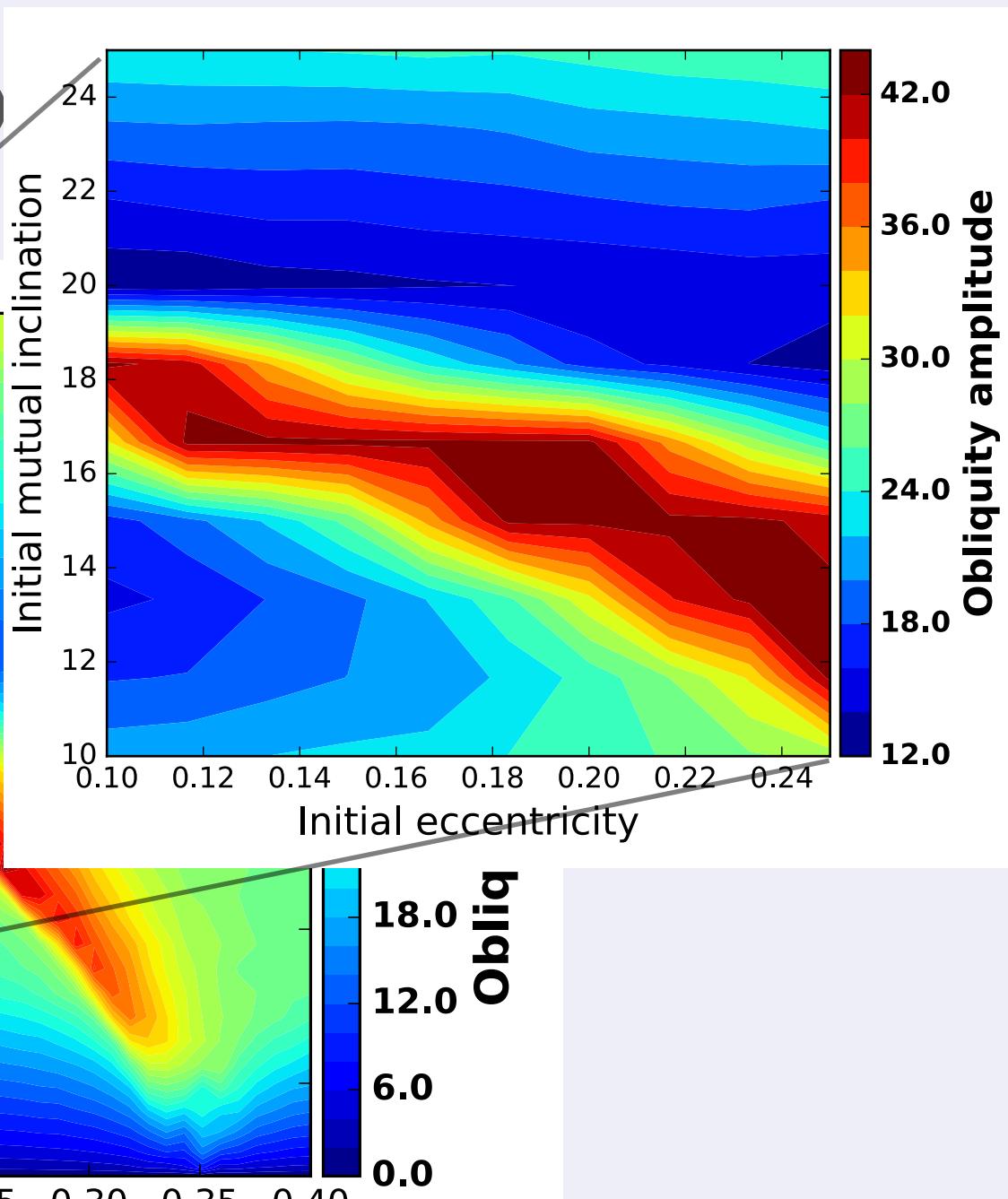
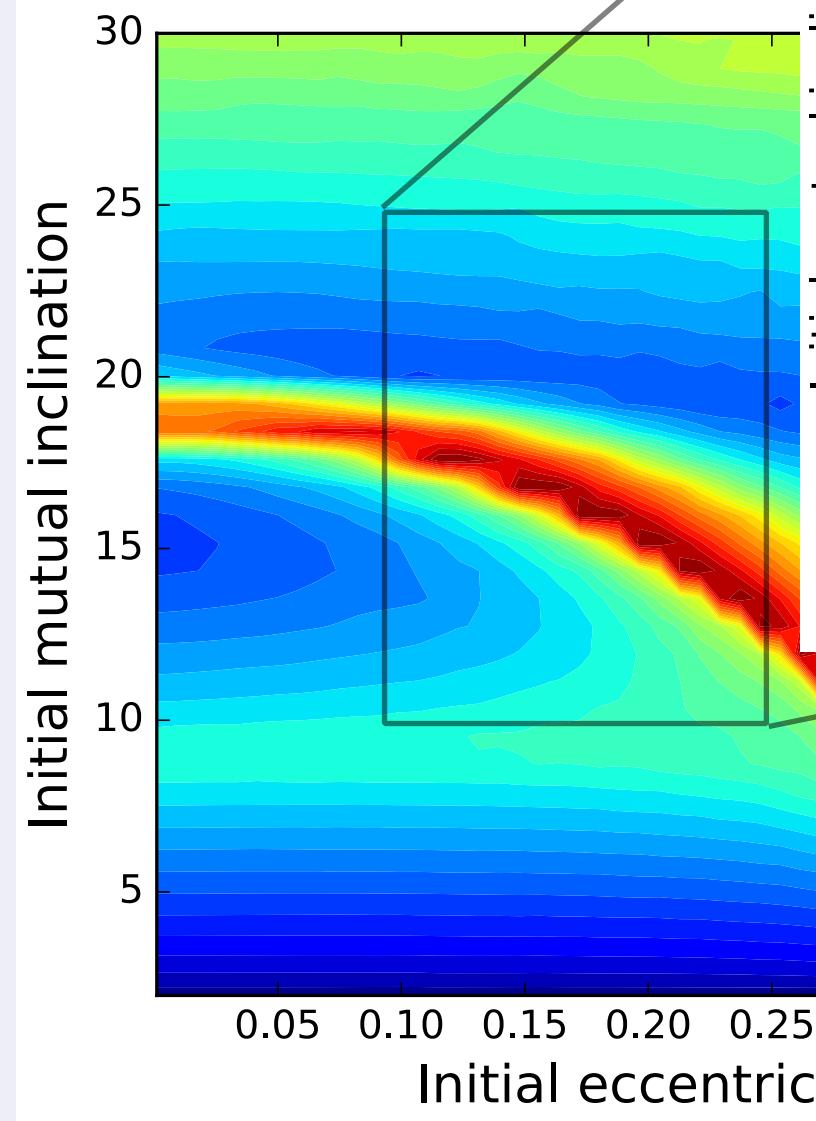




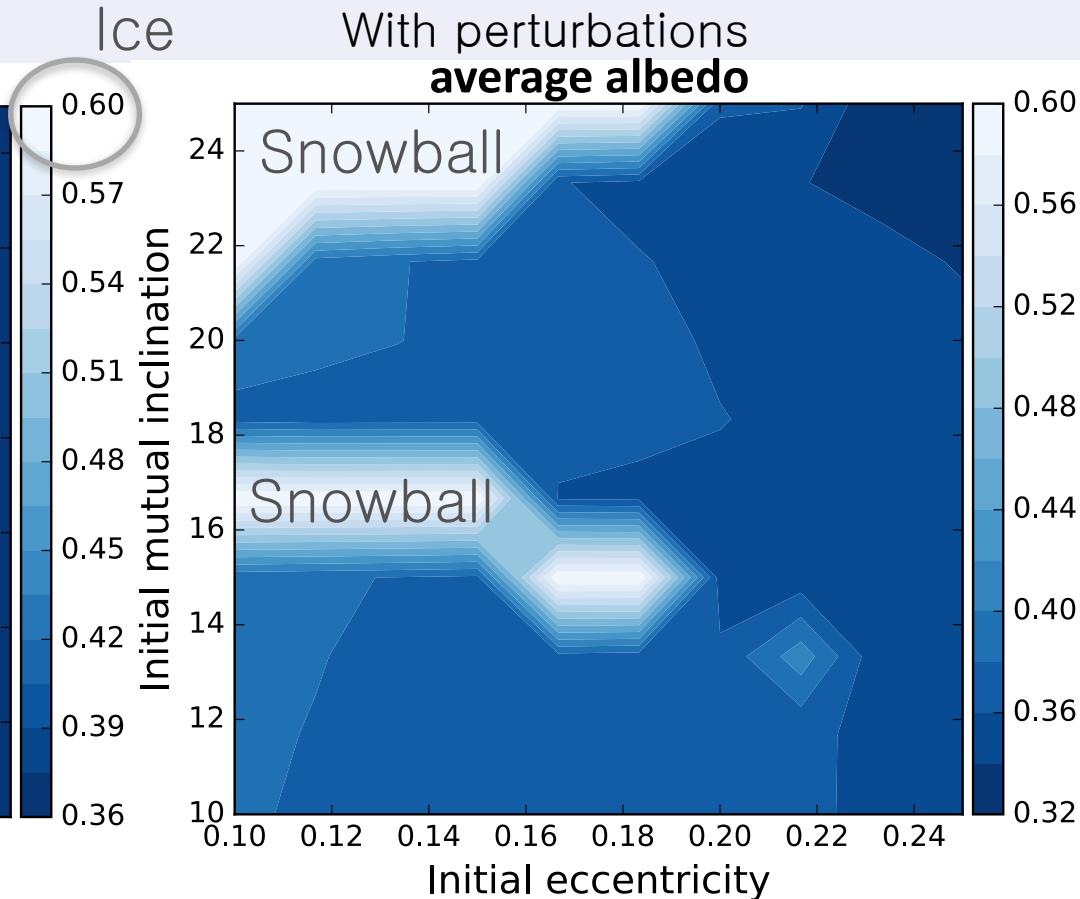
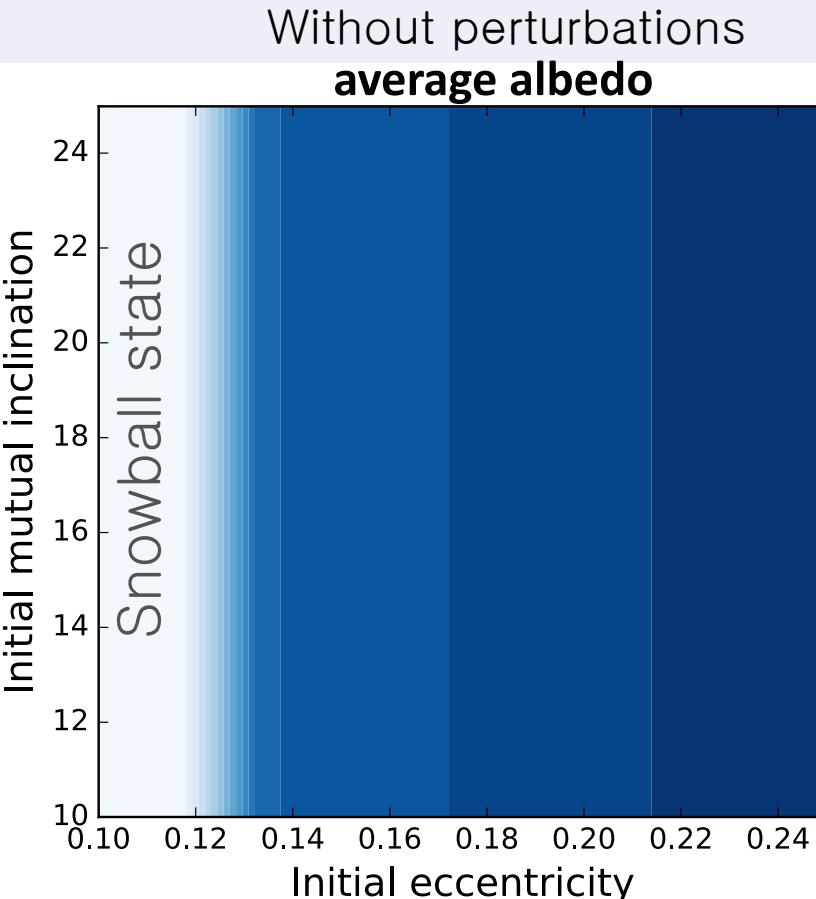
Another look at parameter space



Another lo



Revising the habitable zone

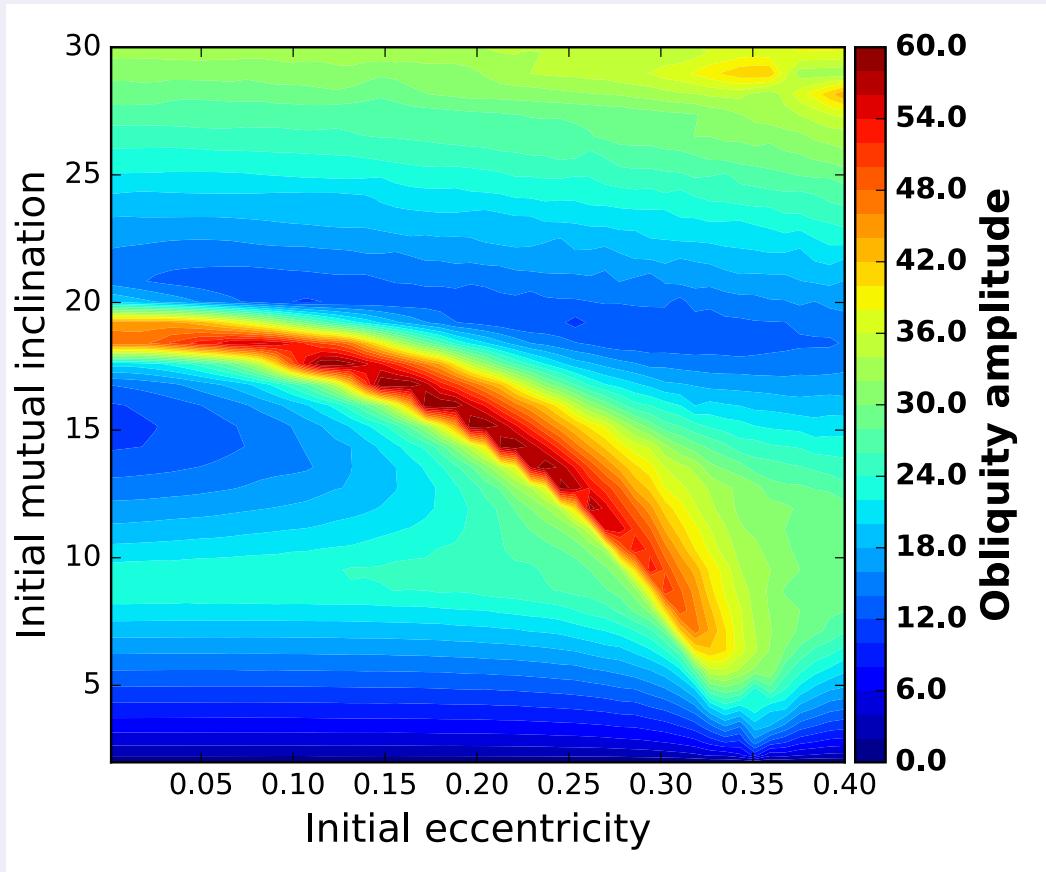


Dynamics, orbital parameters
may influence predictions/
interpretation of spectra

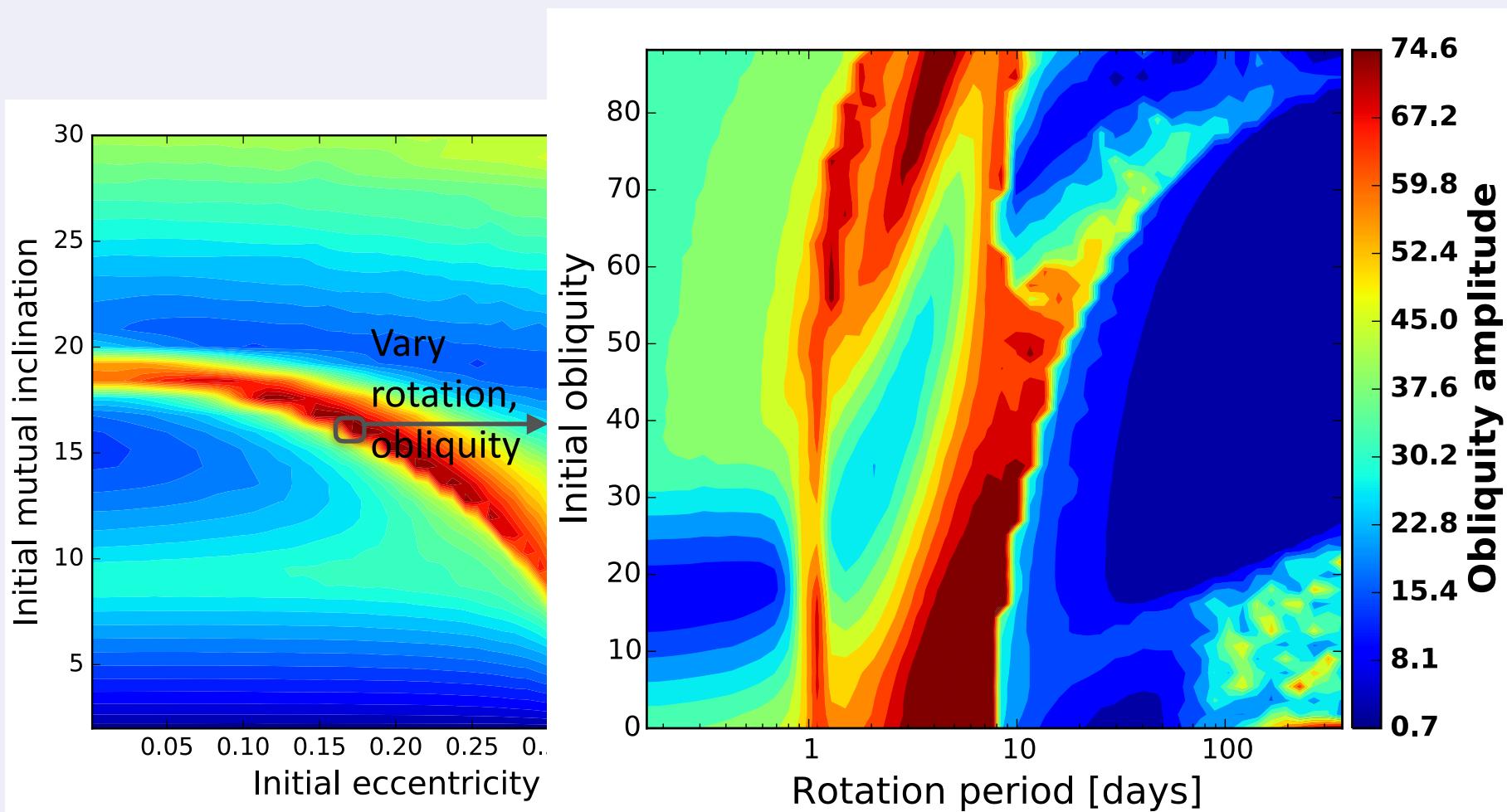
Outer edge of HZ can change by 2–3%

Similar to (or slightly smaller than) that found by Armstrong et al 2014

Secular resonances abound



Secular resonances abound

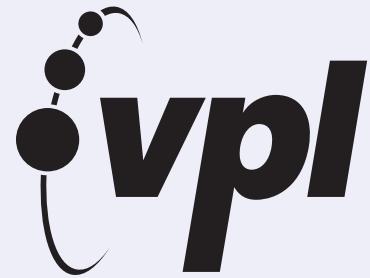


A complex set of factors can contribute to secular resonances:
orbital parameters, rotation rate, planet shape

Summary

- **Climate/surface conditions may be influenced by system architecture in complex ways (e.g. secular resonances)**
- Dynamics can modify the habitable zone boundary (roughly consistent with Armstrong et al. 2014)
- Orbital/obliquity evolution is a key aspect of planetary habitability

Danke!



- My co-authors: Rory Barnes, Cecilia Bitz, Tom Quinn, John Armstrong, Victoria Meadows, & Benjamin Charnay
- Virtual Planetary Laboratory and NASA Astrobiology Institute
- SOC and LOC
- …Everyone here today!