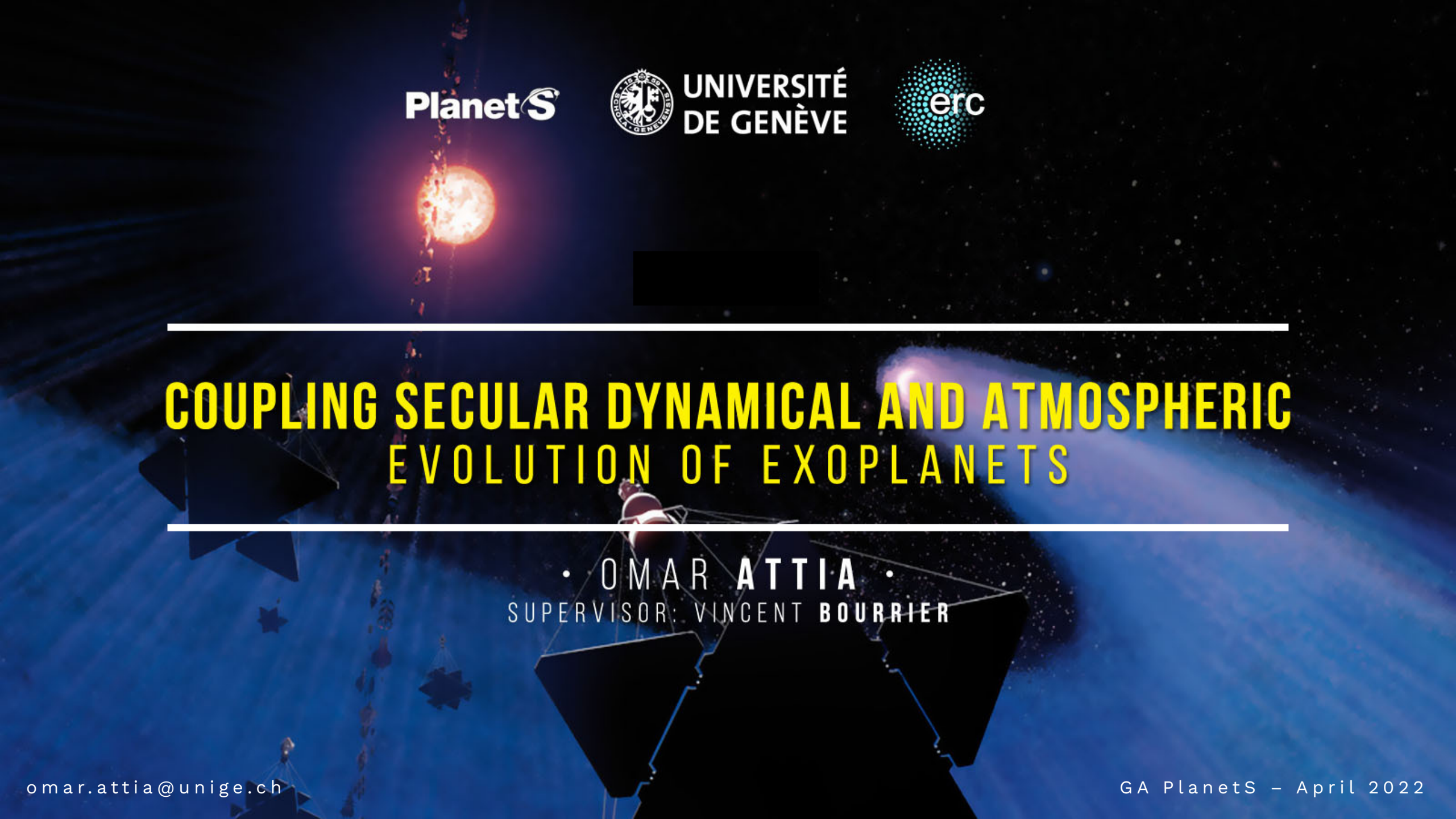

COUPLING SECULAR DYNAMICAL AND ATMOSPHERIC EVOLUTION OF EXOPLANETS

· OMAR **ATTIA** ·

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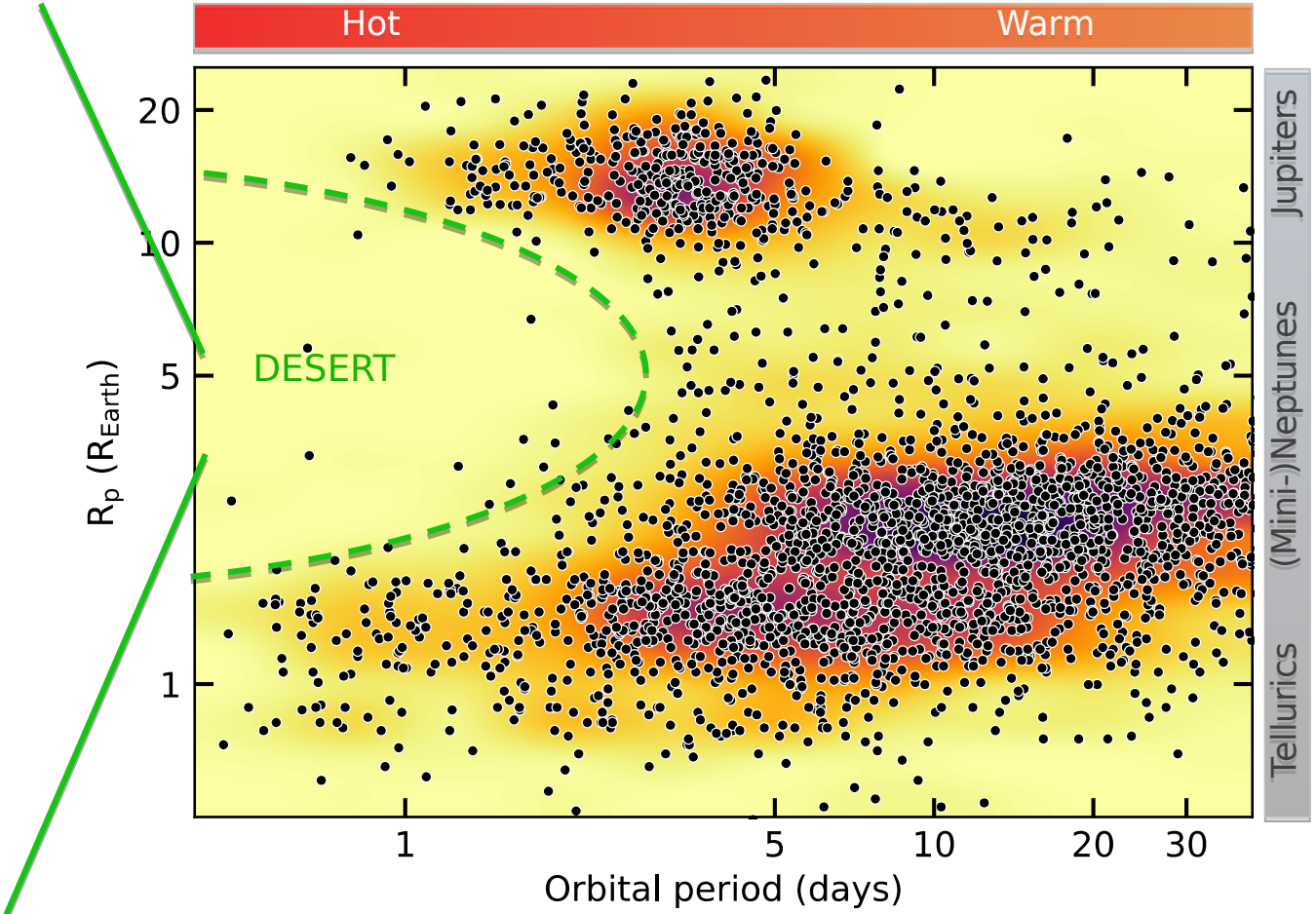
GA PlanetS – April 2022

INTRODUCTION

A DESERT OF HOT NEPTUNES

Role of evaporation supported by theoretical studies
(e.g. Lopez+2012, Jin+2014, Kurokawa+2014, Owen+2017)



BUT:

Role of orbital migration
(e.g. Mazeh+2016, Bourrier+2018)

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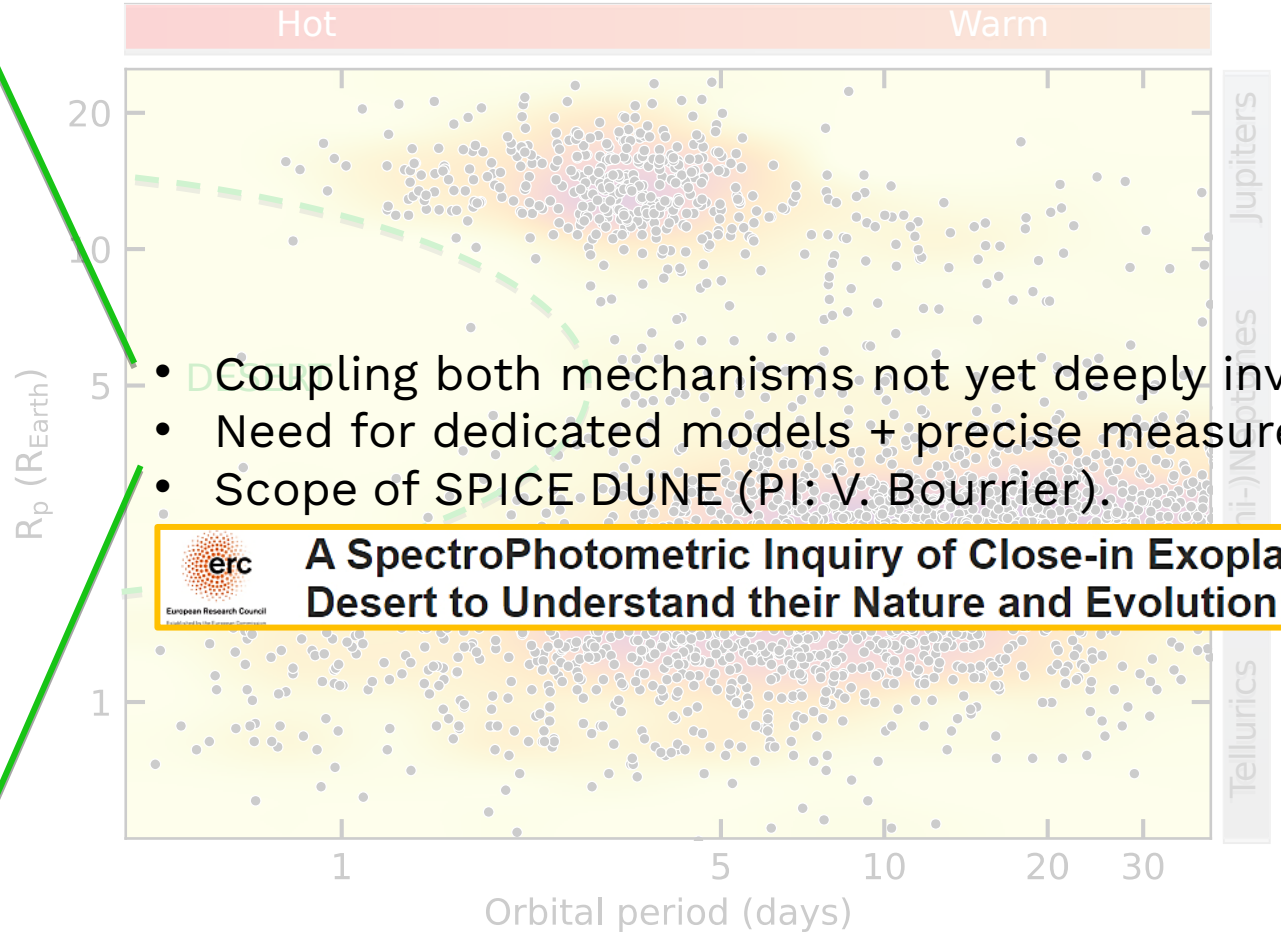


- Coupling both mechanisms not yet deeply investigated.
- Need for dedicated models + precise measurements.
- Scope of SPICE DUNE (PI: V. Bourrier).

A SpectroPhotometric Inquiry of Close-in Exoplanets around the Desert to Understand their Nature and Evolution

BUT:

Role of orbital migration
(e.g. Mazeh+2016, Bourrier+2018)

INTRODUCTION

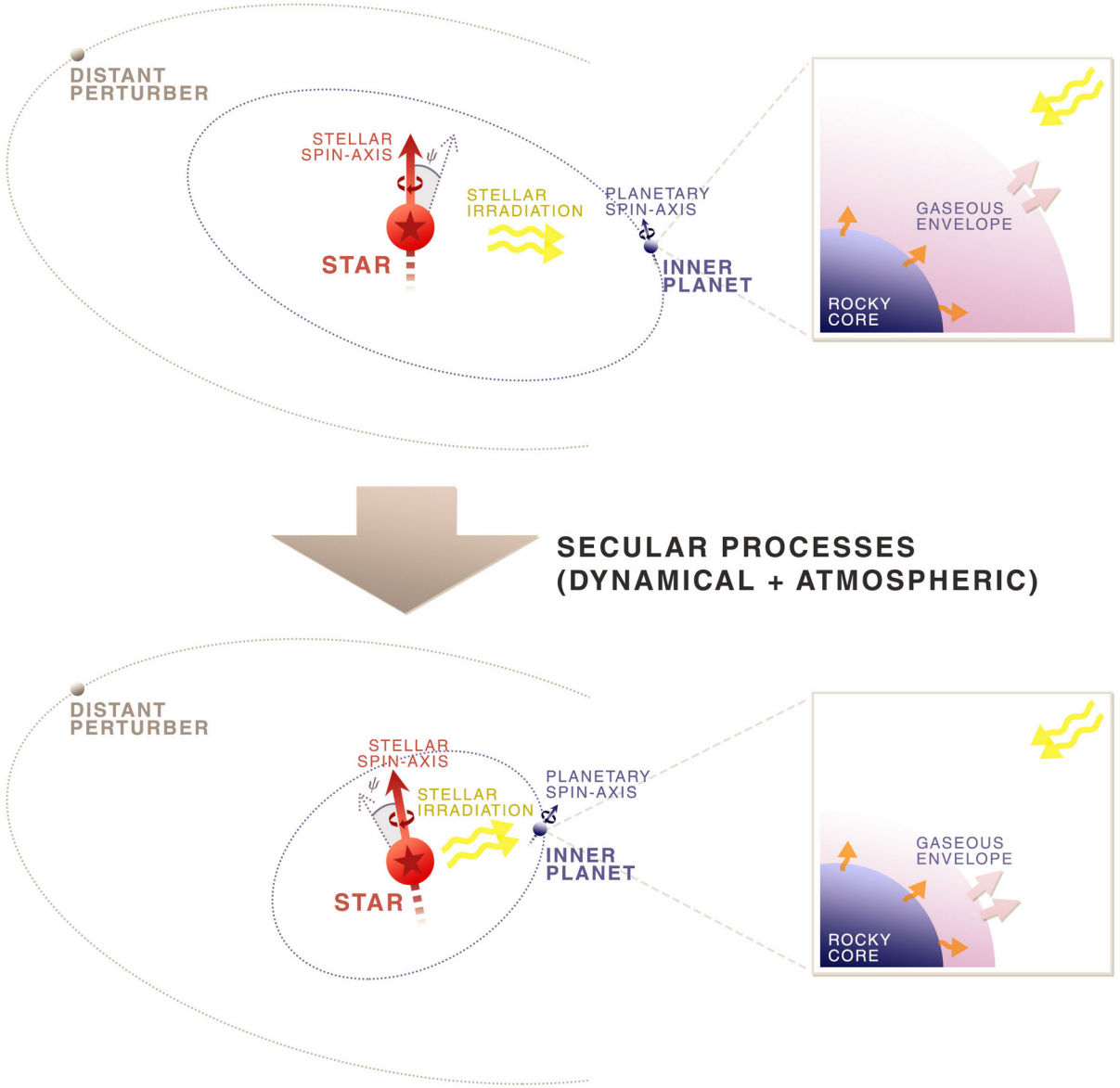
THE JADE CODE

APPLICATION

CONCLUSION

THE JADE CODE

PRESENTATION

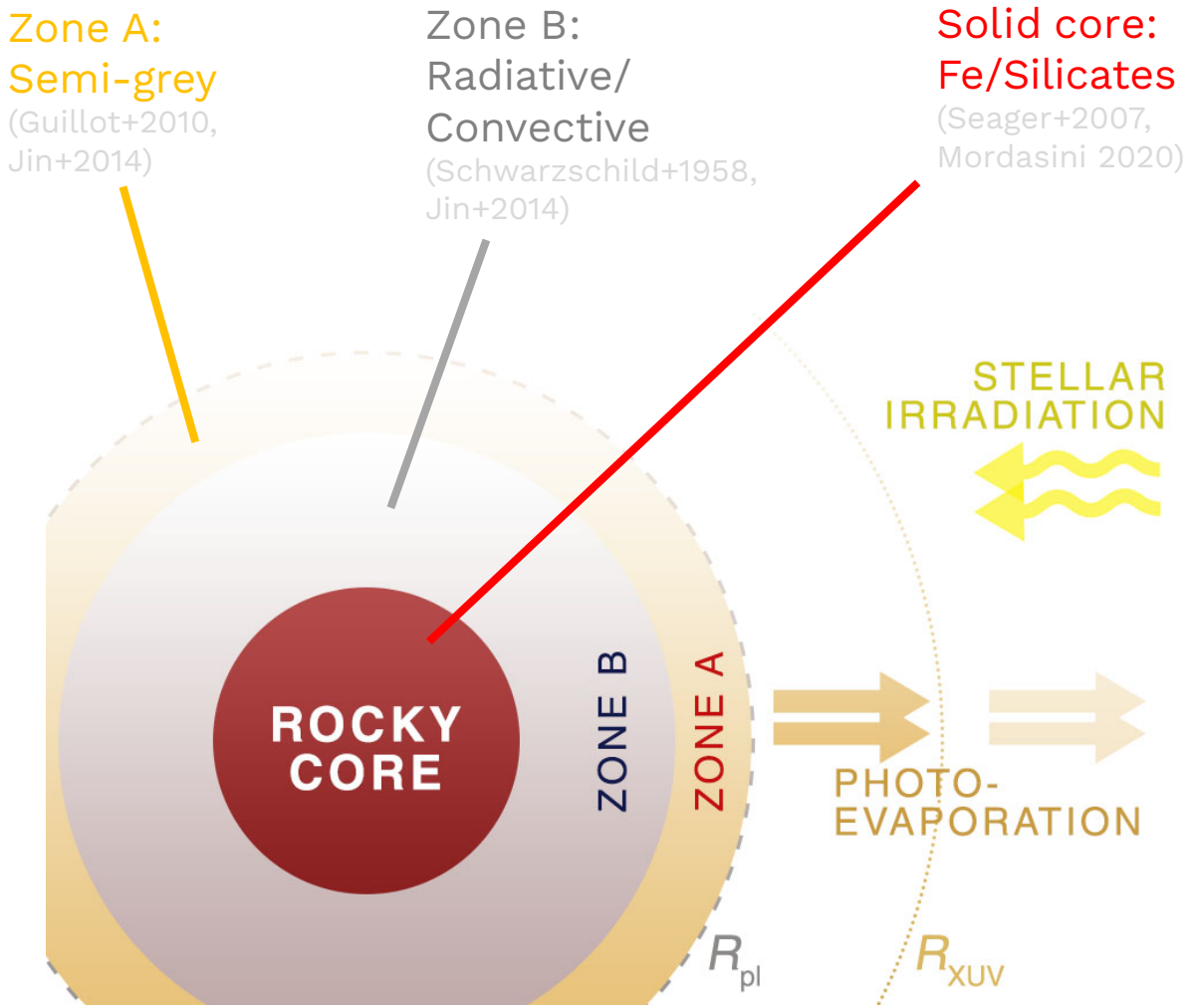


Attia+2021

ENCODED FEATURES

Dynamical features	Atmospheric features	Stellar features
• Perturbing distant body	• Atmospheric integrator	• Evolving luminosity
• Tidal effects	• Photo-evaporation	• Evolving spin vector
• Relativistic precession	• Planetary inner-heating	• Contraction (WIP)

ATMOSPHERIC STRUCTURE



Atmospheric features

- Layer-by-layer atmospheric integrator
  → Detailed atmospheric structure
- XUV photo-evaporation
  → Mass loss
- Internal planetary luminosity
  → Atmospheric heating

APPLICATION

GJ436

- High eccentricity (~ 0.15) despite advanced age (6 Gyr).

e.g. Butler+2006, Torres+2008, Beust+2012, Bourrier+2018

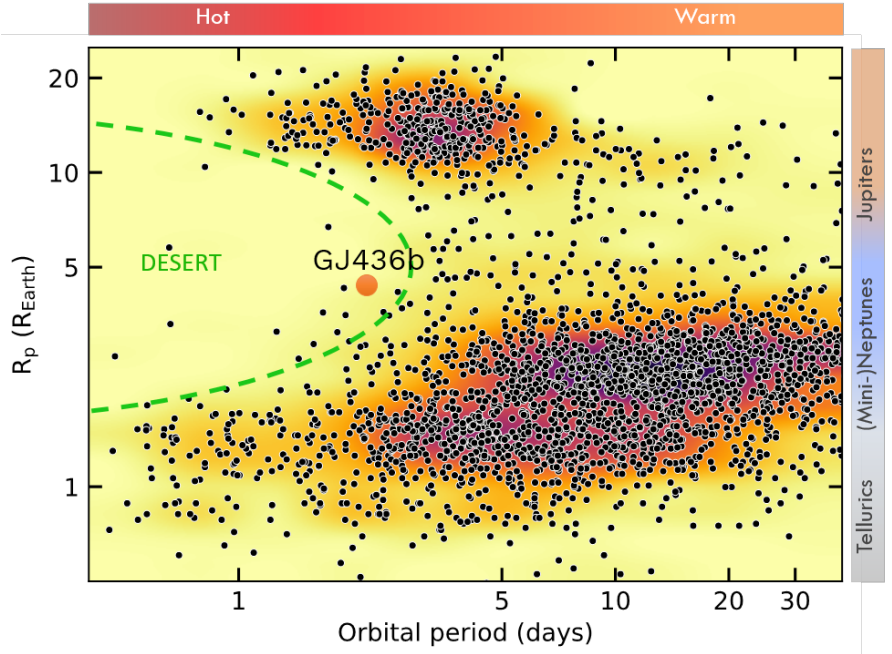
- Highly misaligned orbit (~ 100 deg).

Bourrier+2018, Bourrier,...,Attia+2022

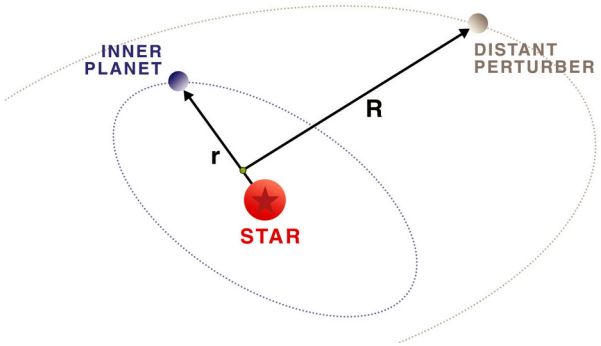
- Evaporating atmosphere.

e.g. Kulow+2014, Ehrenreich+2015, Bourrier+2016, Lavie+2017

- ... and it is inside the desert!
- How could it have survived?

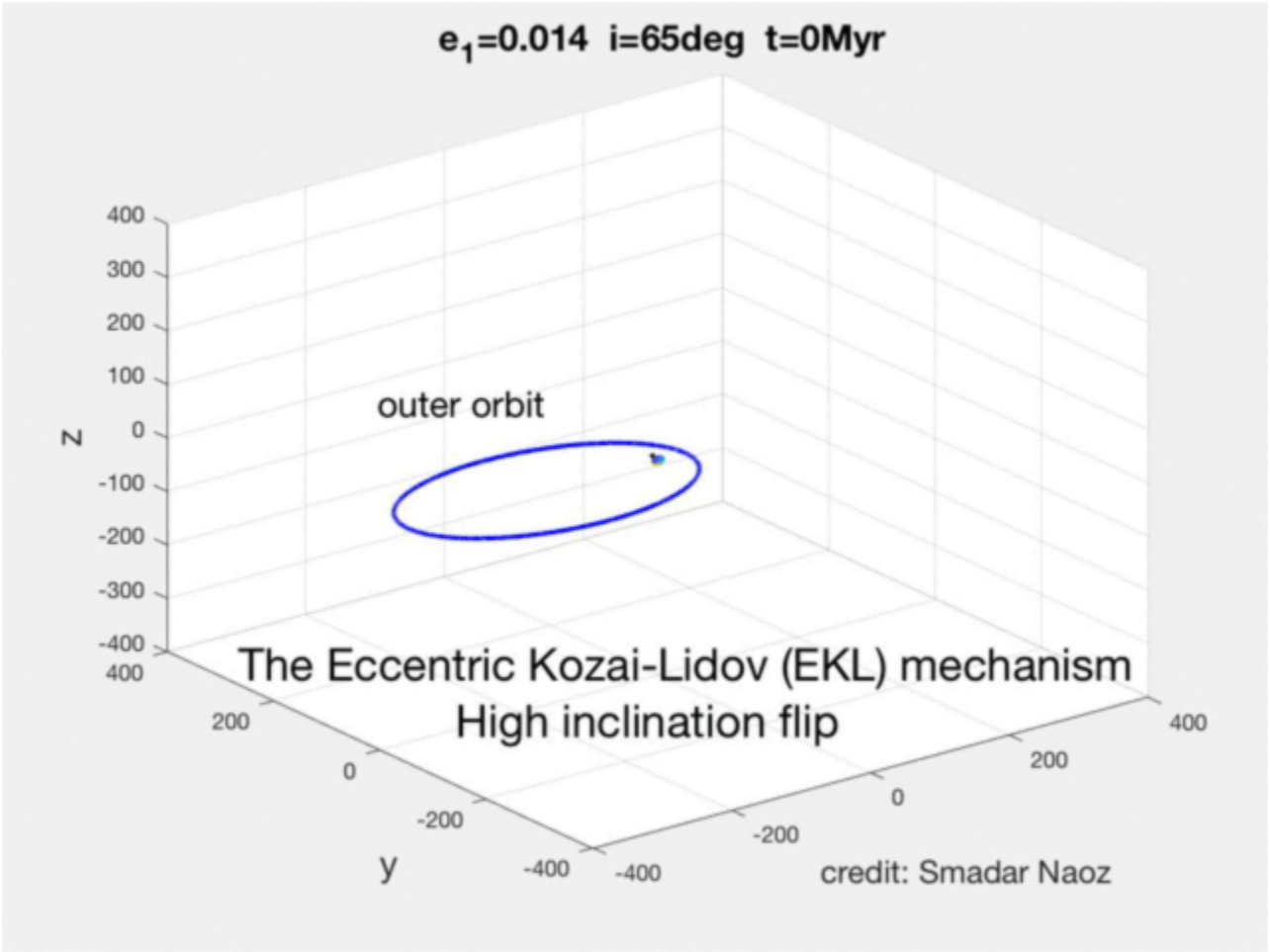


GJ436

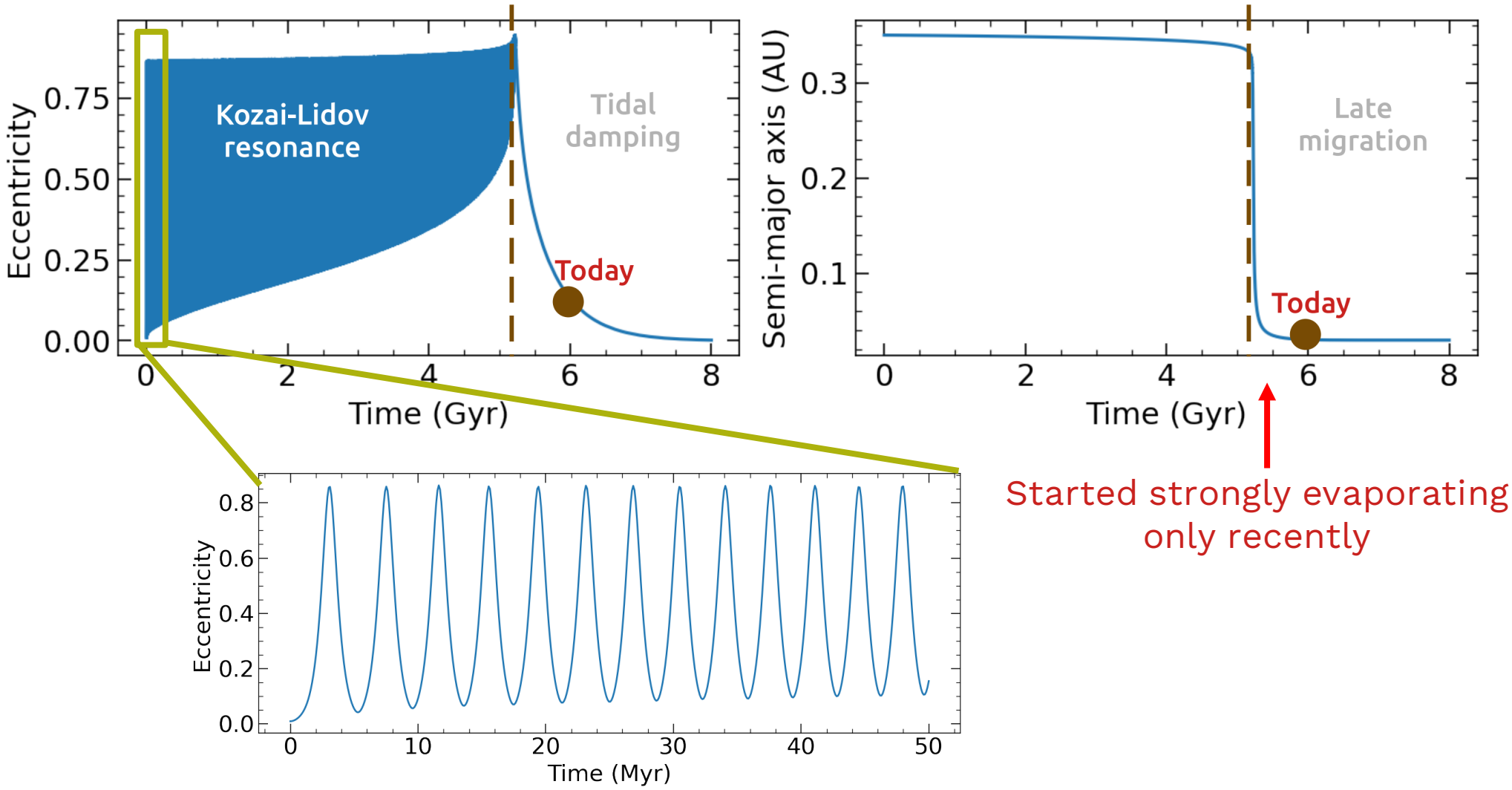


Solution to eccentricity problem: Kozai-Lidov mechanism... Featuring GJ436c

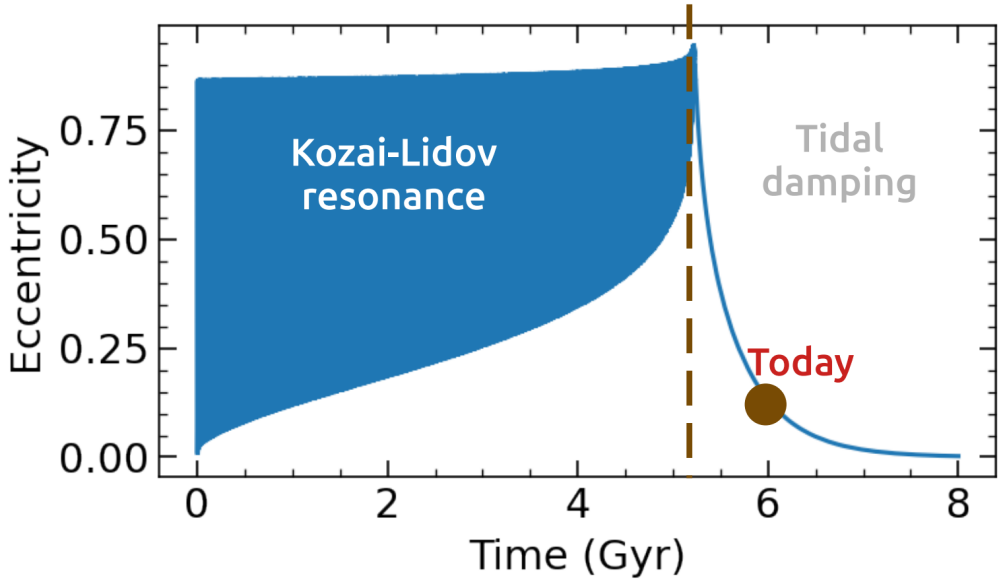
Beust+2012, Bourrier+2018

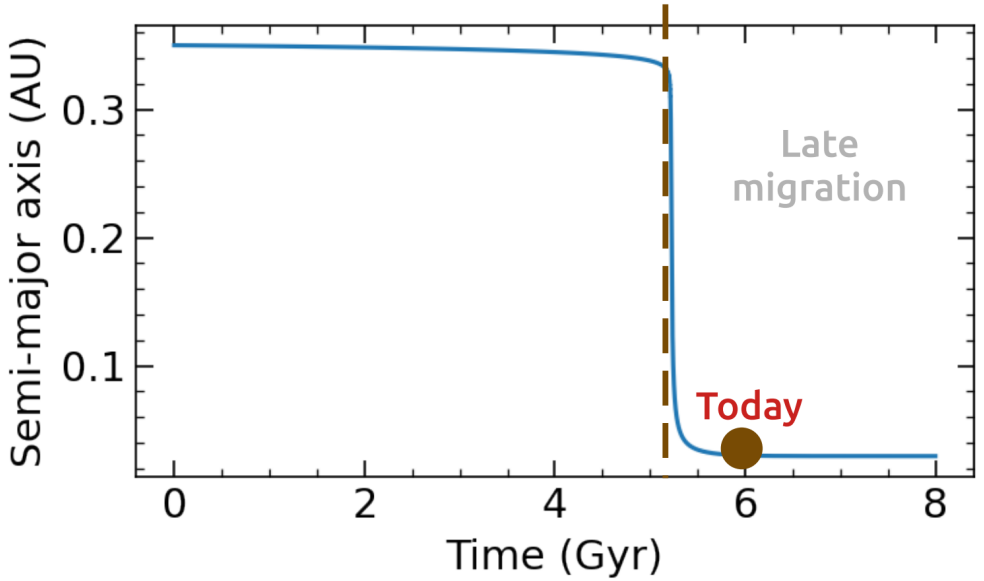


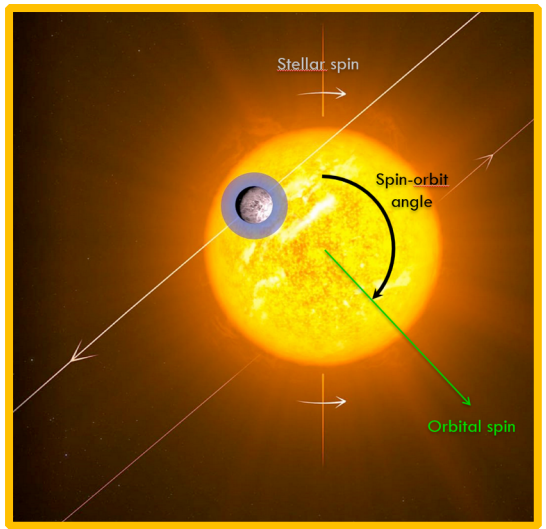
GJ436

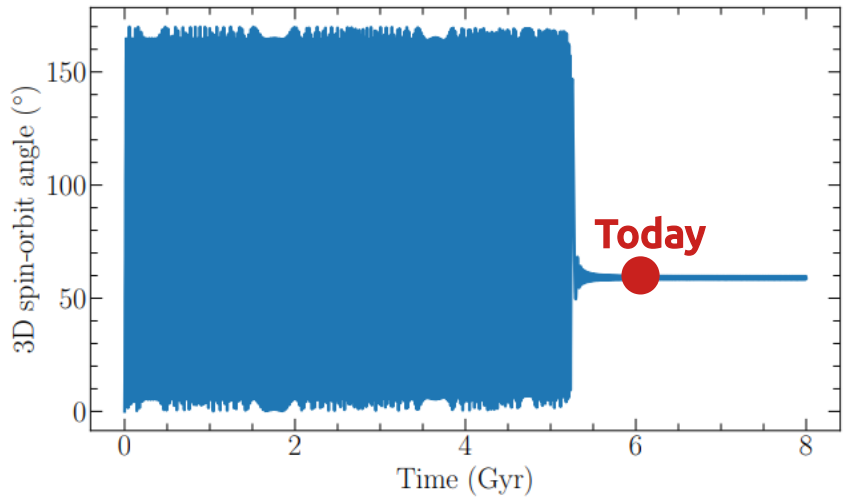

Eccentricity
0.75
0.50
0.25
0.00
Kozai-Lidov resonance
Tidal damping
Today
0
2
4
6
8
Time (Gyr)
Semi-major axis (AU)
0.3
0.2
0.1
Late migration
Today
0
2
4
6
8
Time (Gyr)
Started strongly evaporating only recently
Eccentricity
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
Time (Myr)

GJ436





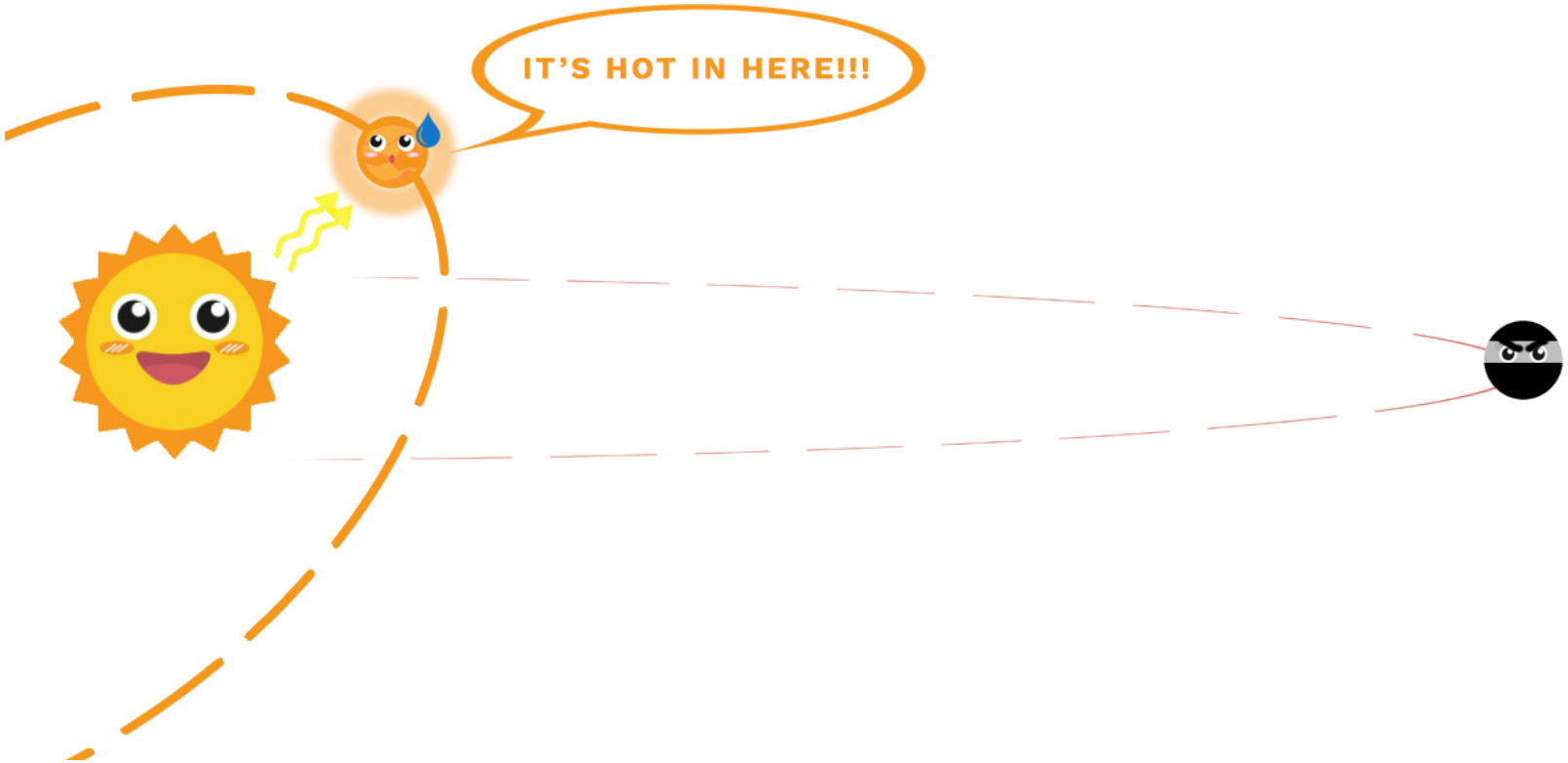




Still locked on a misaligned orbit

GJ436

- Adding an accurately-modelled atmosphere largely changes the results.



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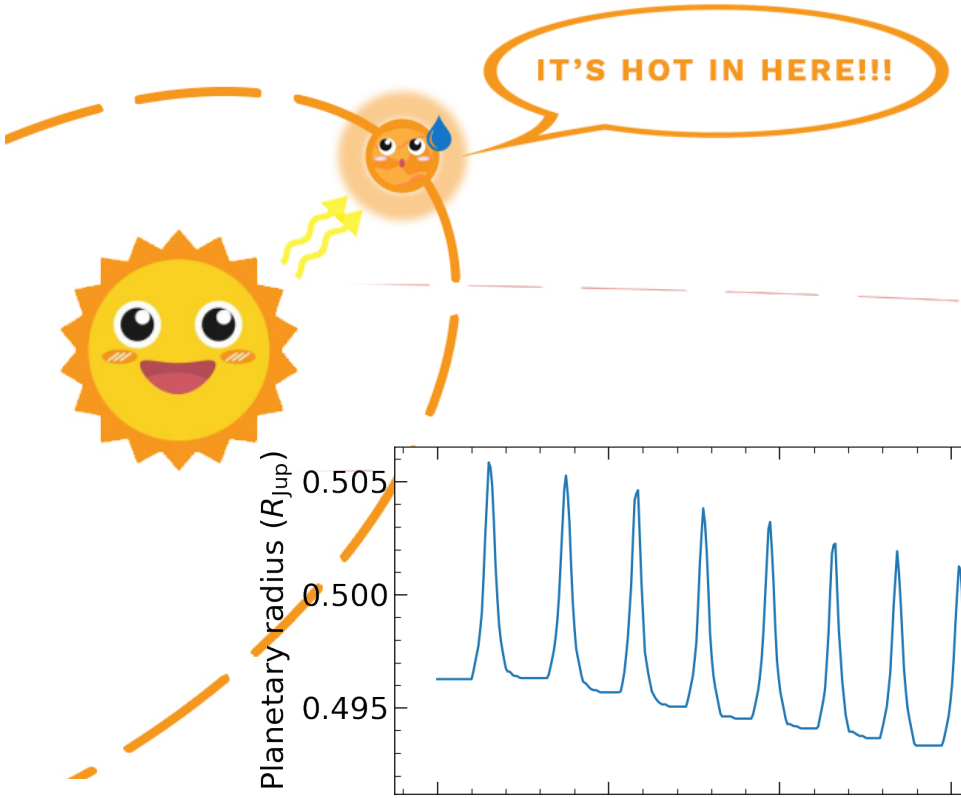

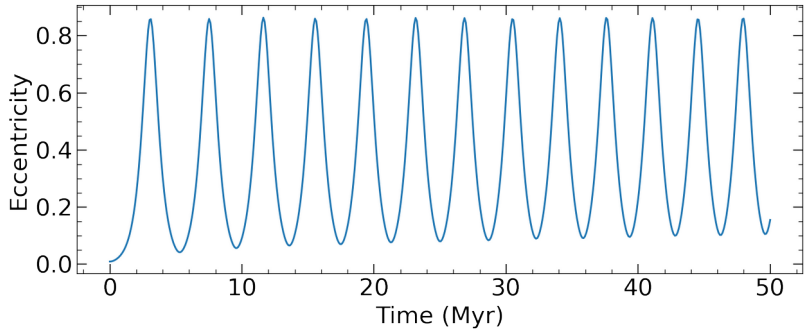

<u>Coupling</u>
dynamics/atmosphere:
Radius pulsations
in tune with
Kozai—Lidov cycles

GJ436

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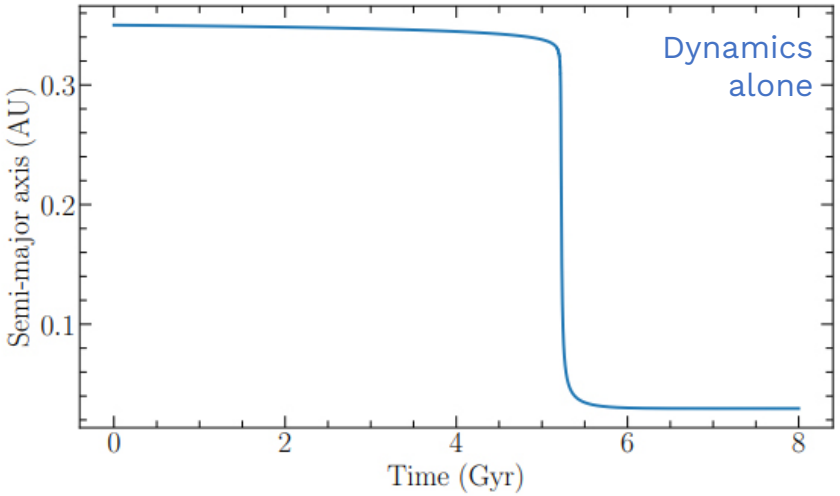

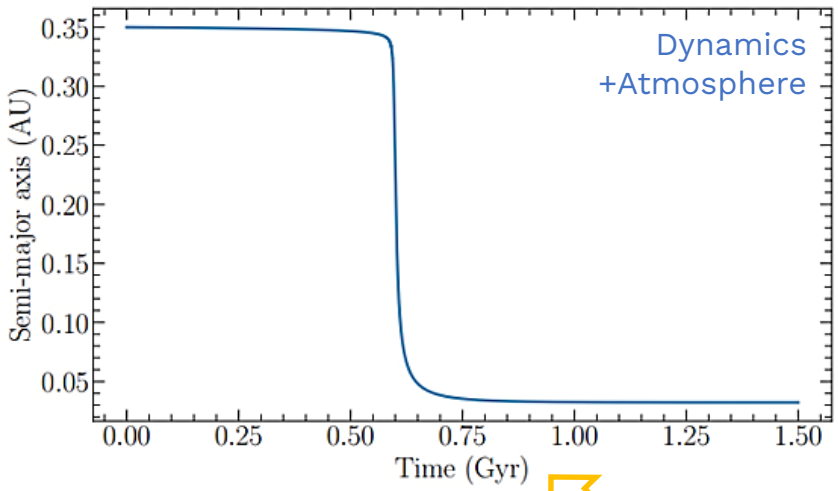

Coupling dynamics/atmosphere:
Earlier migration due to stronger tides (larger radius)

(Much) shorter timescales

$$\tau_{tide} \propto M_{pl}/R_{pl}^{5}$$

TOI-177

Almenara,...,Attia+ submitted

- Planet b: recently-detected hot mini-Neptune around an M-dwarf.
- Interior characterization: ~ 4% H/He.

Table 6. Inferred interior structure properties of TOI-177 b.

Constituent	4-layer	No H-He	No H_2O	No Fe
M_{core}/M_{total}	$0.44^{+0.14}_{-0.23}$	$0.18^{+0.09}_{-0.07}$	$0.45^{+0.21}_{-0.20}$	-
M_{mantle}/M_{total}	$0.37^{+0.21}_{-0.18}$	$0.24^{+0.14}_{-0.11}$	$0.51^{+0.23}_{-0.22}$	$0.84^{+0.04}_{-0.07}$
M_{water}/M_{total}	$0.17^{+0.14}_{-0.11}$	$0.57^{+0.12}_{-0.13}$	-	$0.15^{+0.06}_{-0.04}$
M_{atm}/M_{total}	$0.019^{+0.006}_{-0.007}$	-	$0.043^{+0.009}_{-0.008}$	$0.009^{+0.005}_{-0.004}$

- Could it have kept a primordial H/He envelope after ~ 1 Gyr on such a short orbit (P ~ 3 days)?

TOI-177

Almenara,...,Attia+ submitted

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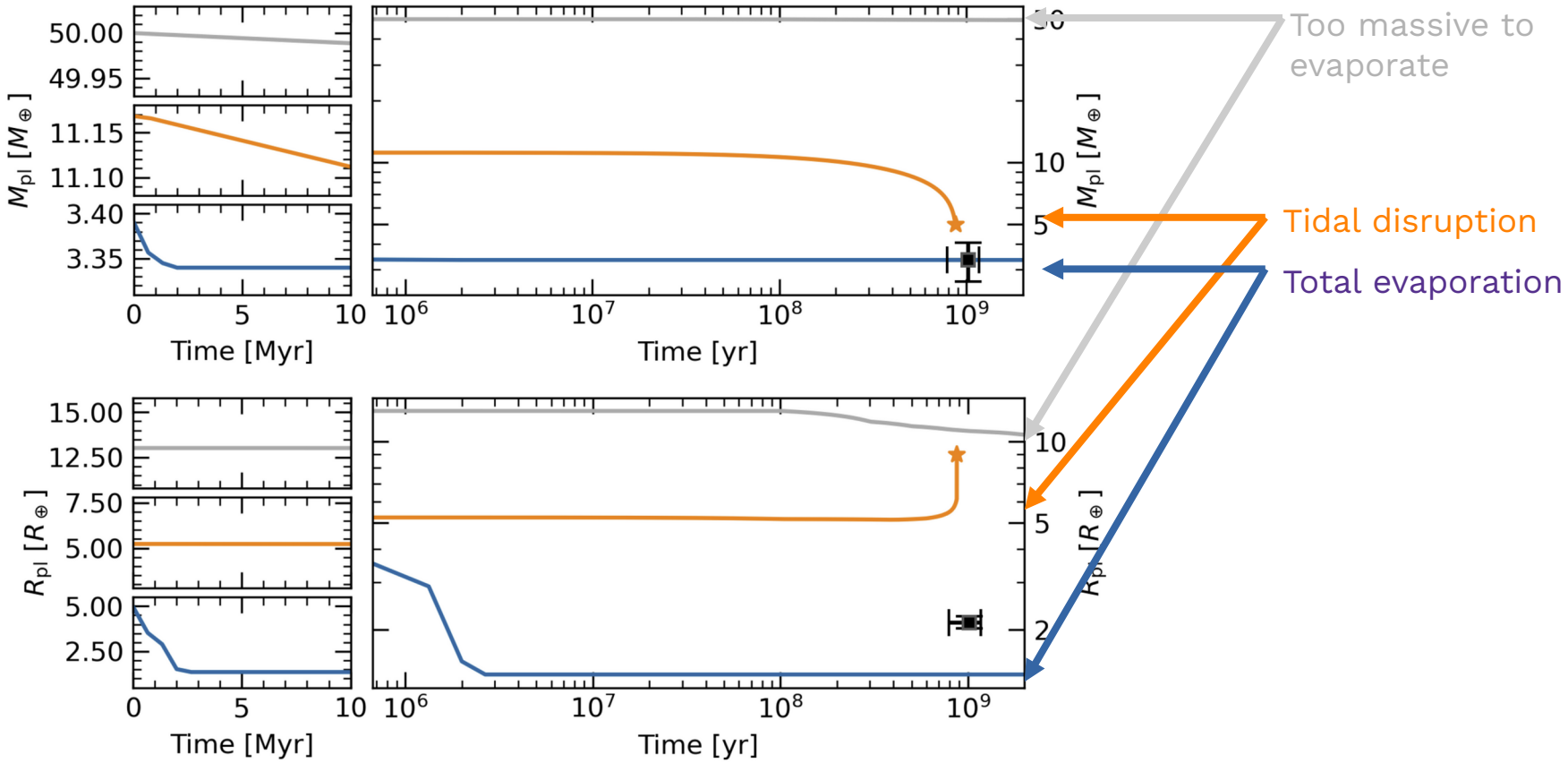

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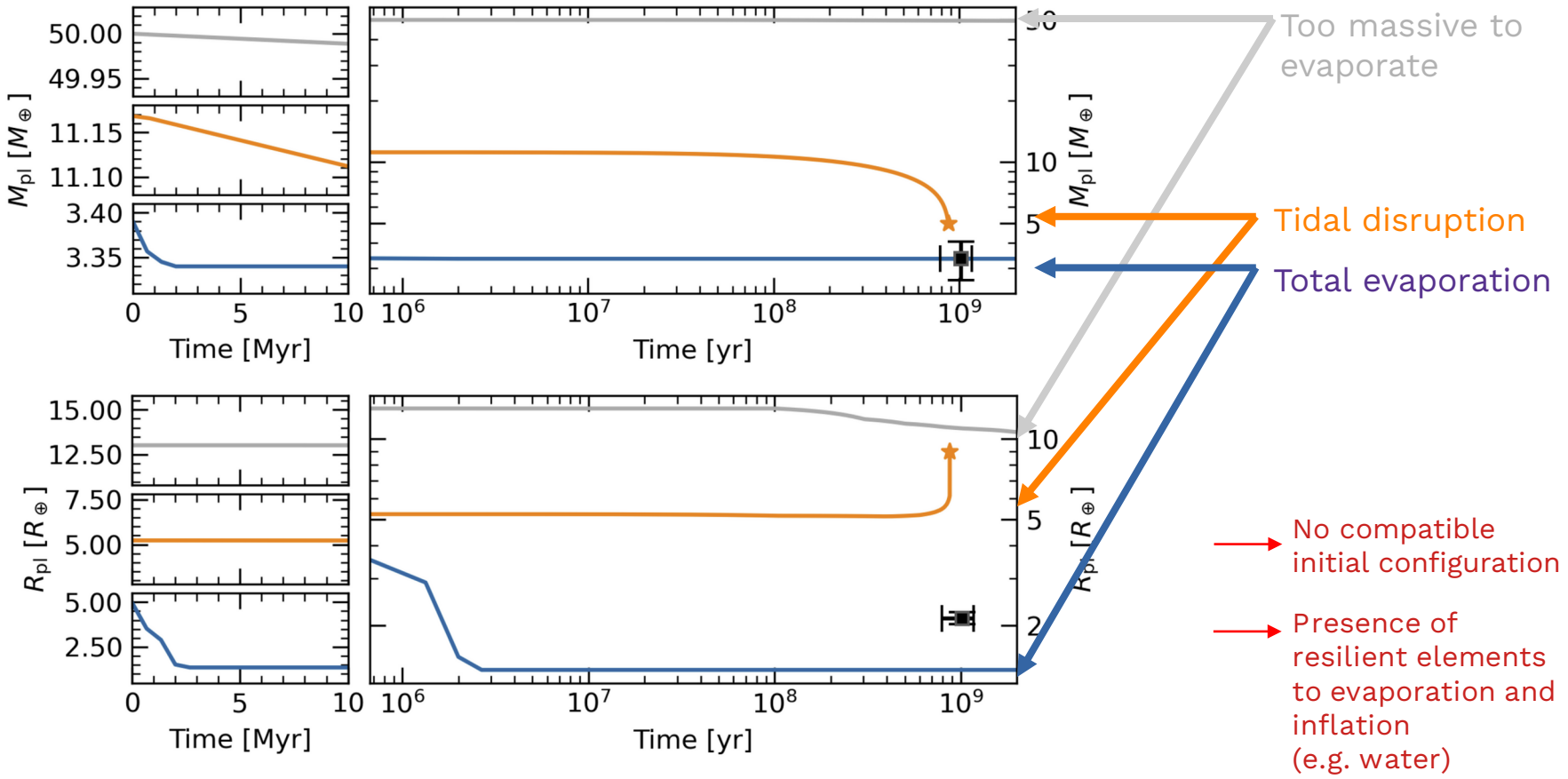


CONCLUSION

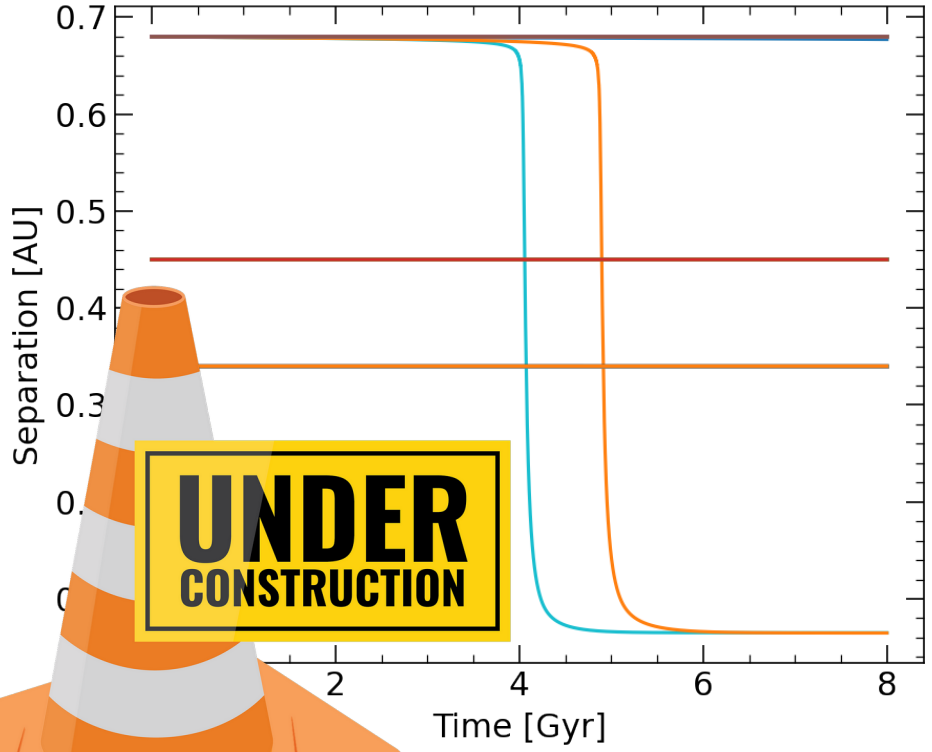
SUMMARY

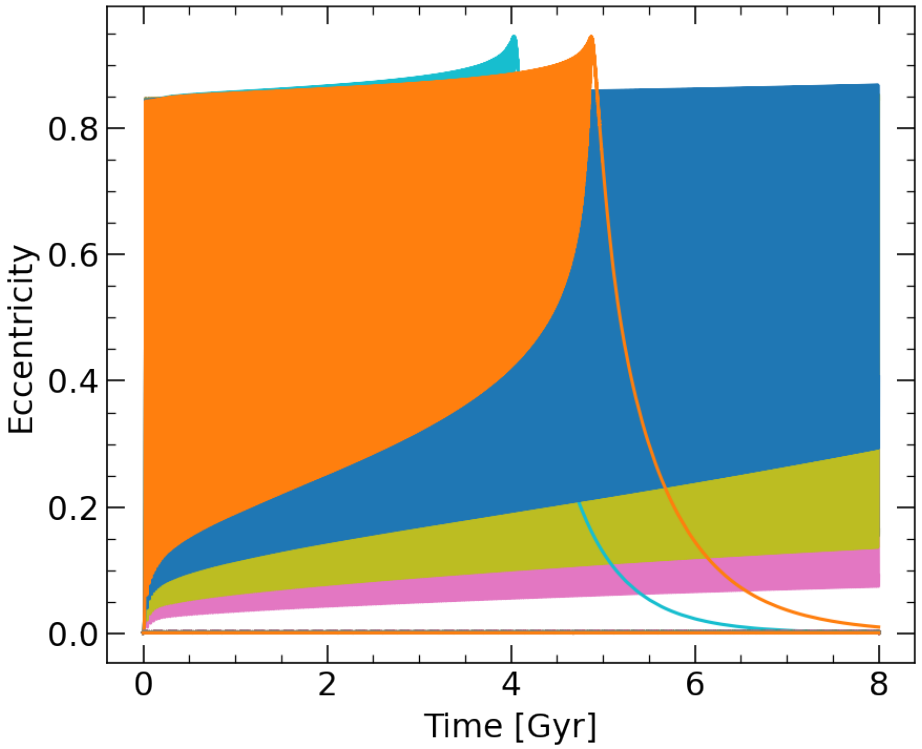
- 3-body simulations need to be refined with atmospheric processes.
- Change of paradigm about evaporation. It can be strongly active several Gyrs after formation due to late migration.
- Importance of both models and measurements to constrain plausible histories.

FUTURE WORK

Attia+ in prep.

- More JADE simulations. Exploration of the parameter space of GJ 436 b.

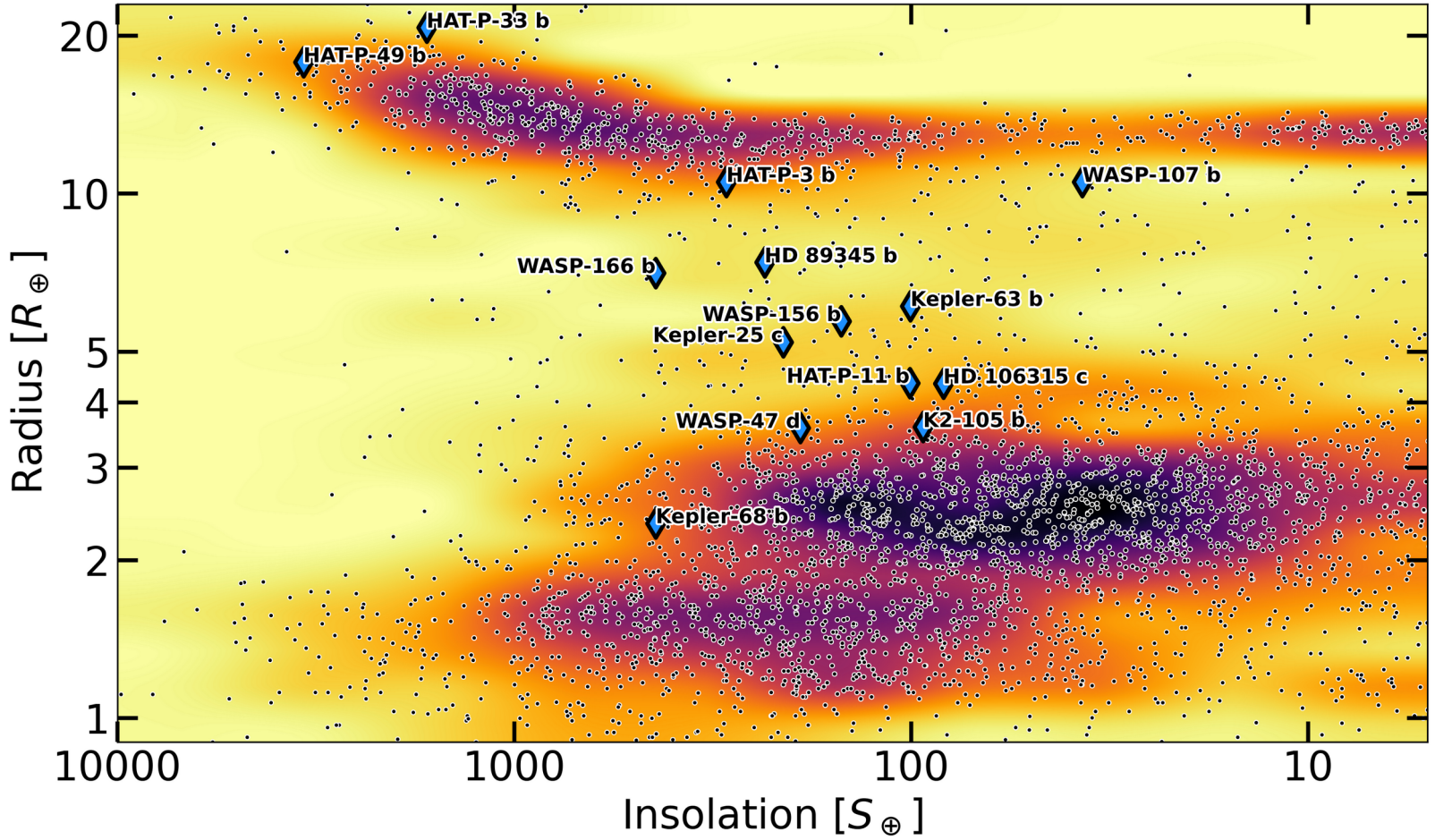




FUTURE WORK

Bourrier,Attia+ in prep.

- Also RM analyses to identify the most promising targets to simulate.



ADVERTISEMENT

- If you want coupled simulations for your favorite system, do not hesitate to contact us!