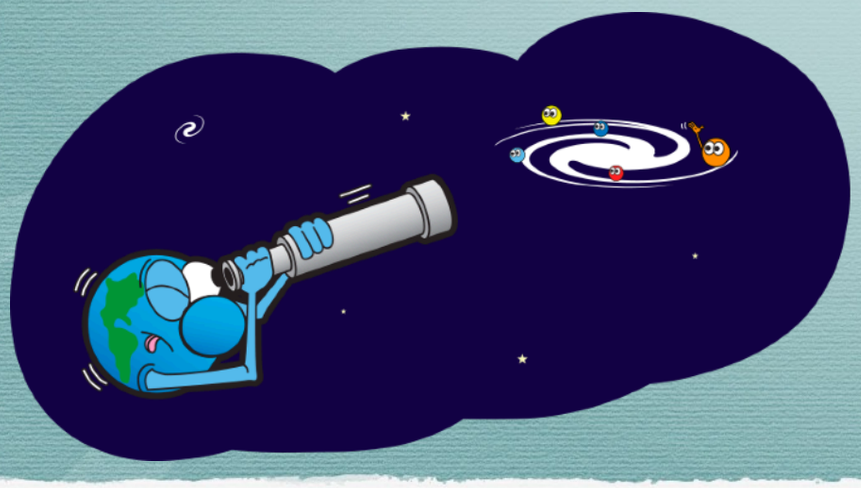
Friends of planetary systems

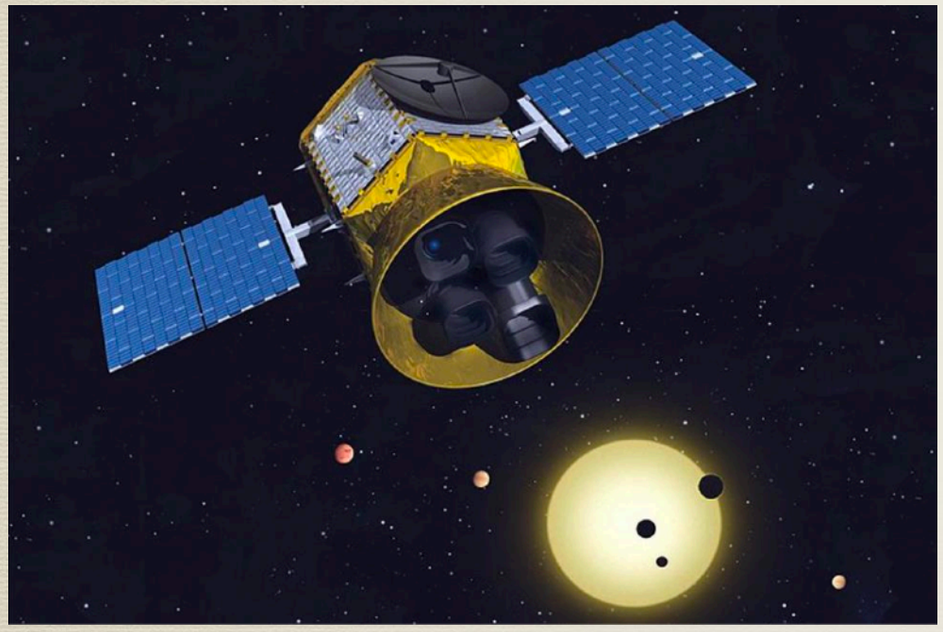
Hidden and apparent companions for multi and lonely planets around hot (or not) stars

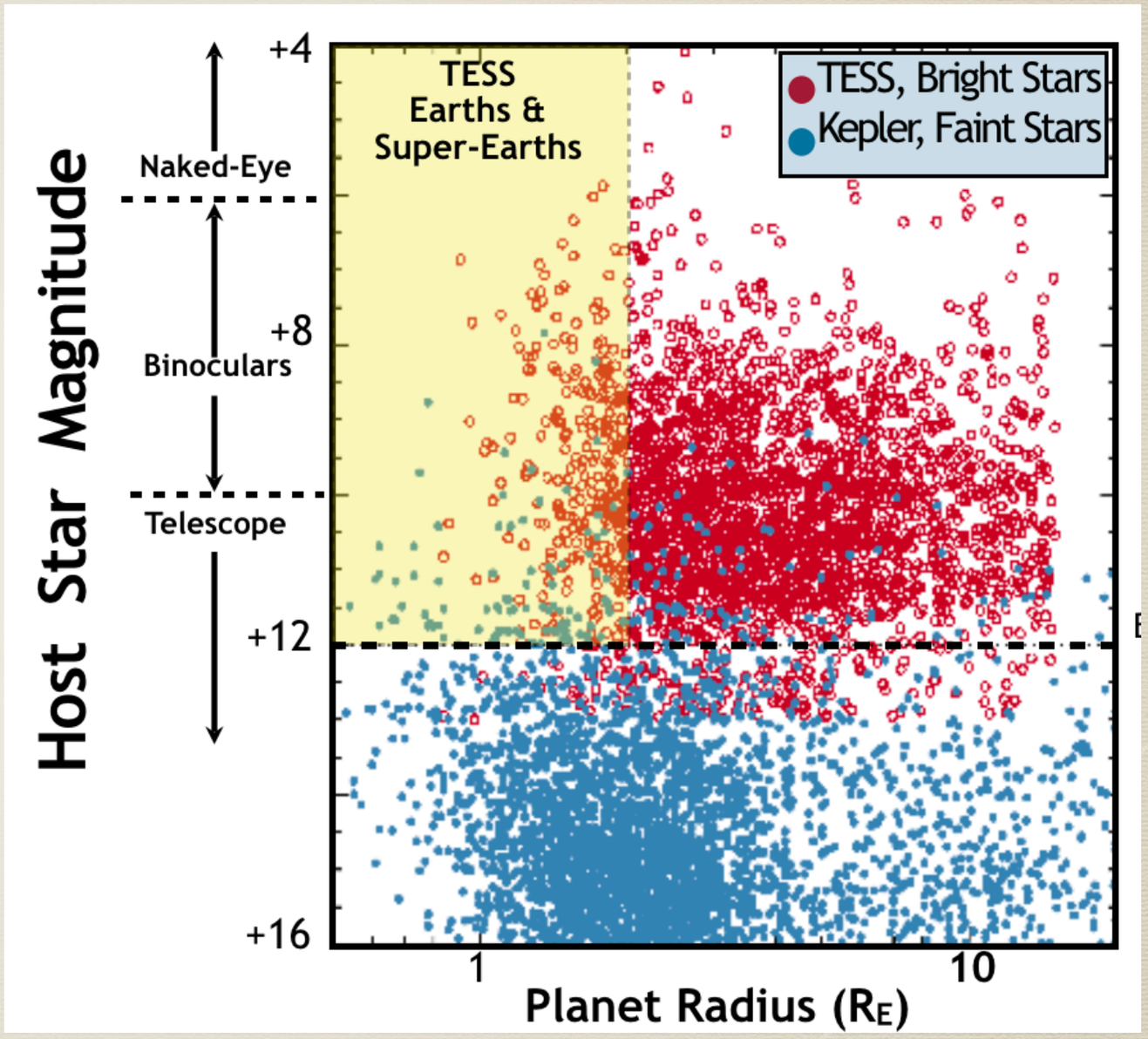
Smadar Naoz

Planet-Star Connections in the Era of TESS and Gaia



The TESS Connection





Credit: MIT's Kavli Institute for Astrophysics and Space Research TESS/NASA, adaptation of Beichman et al (2014) based on simulations from Sullivan et al (2014)

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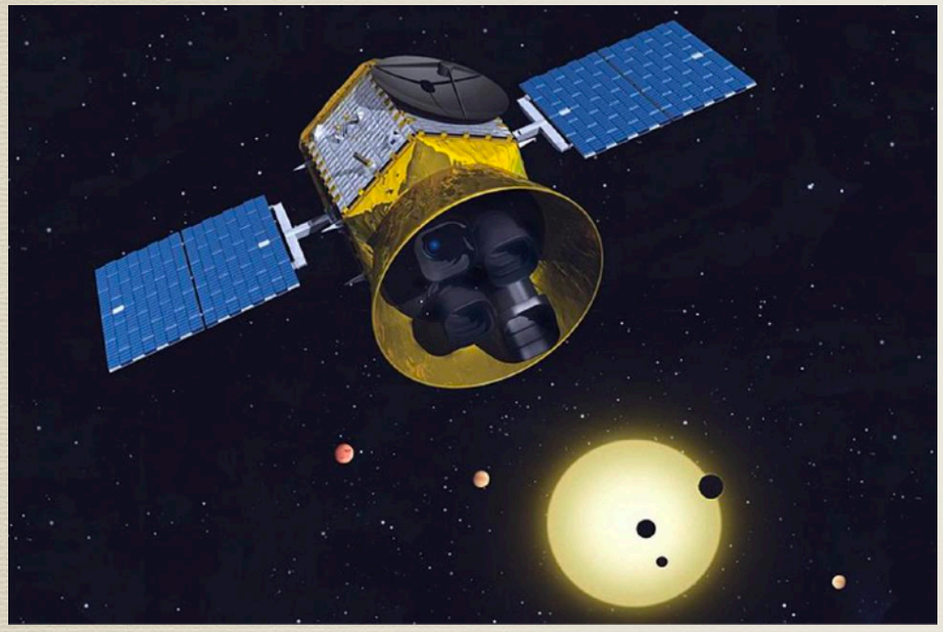

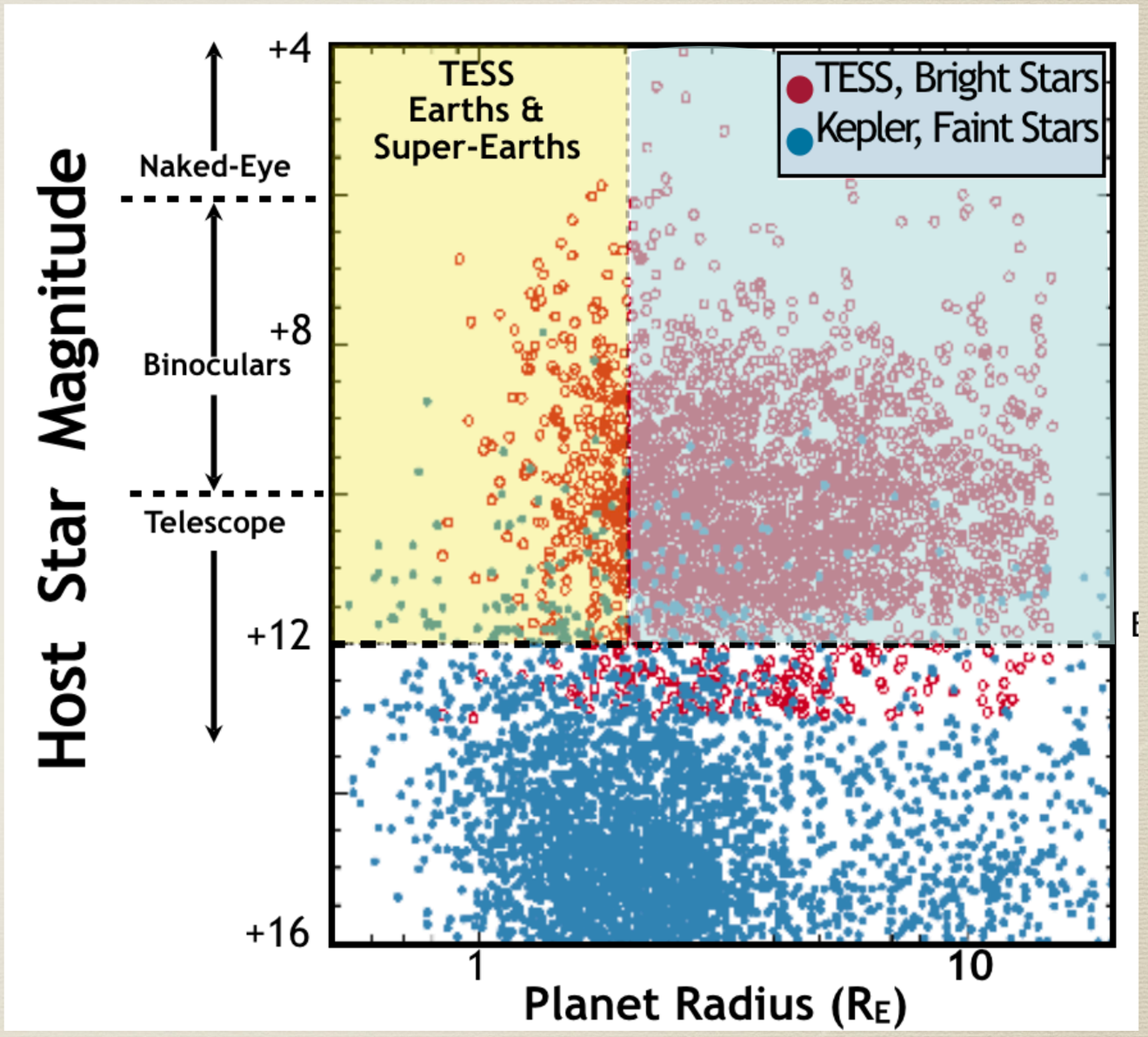

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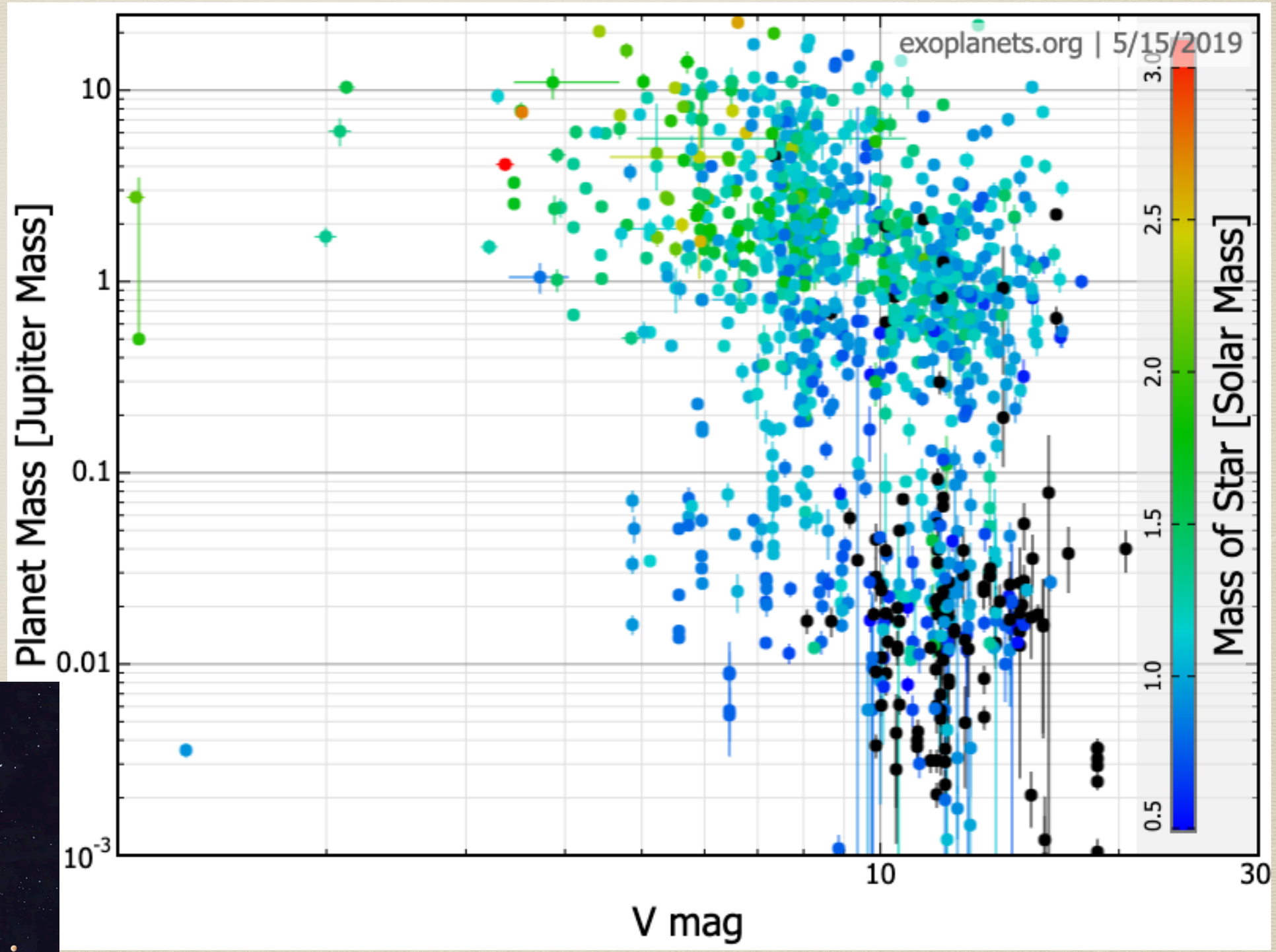
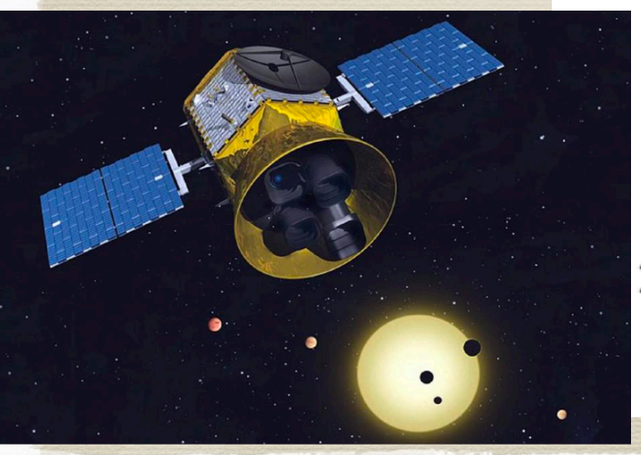
Bright stars

The TESS Connection

TESS surveys the brightest stars





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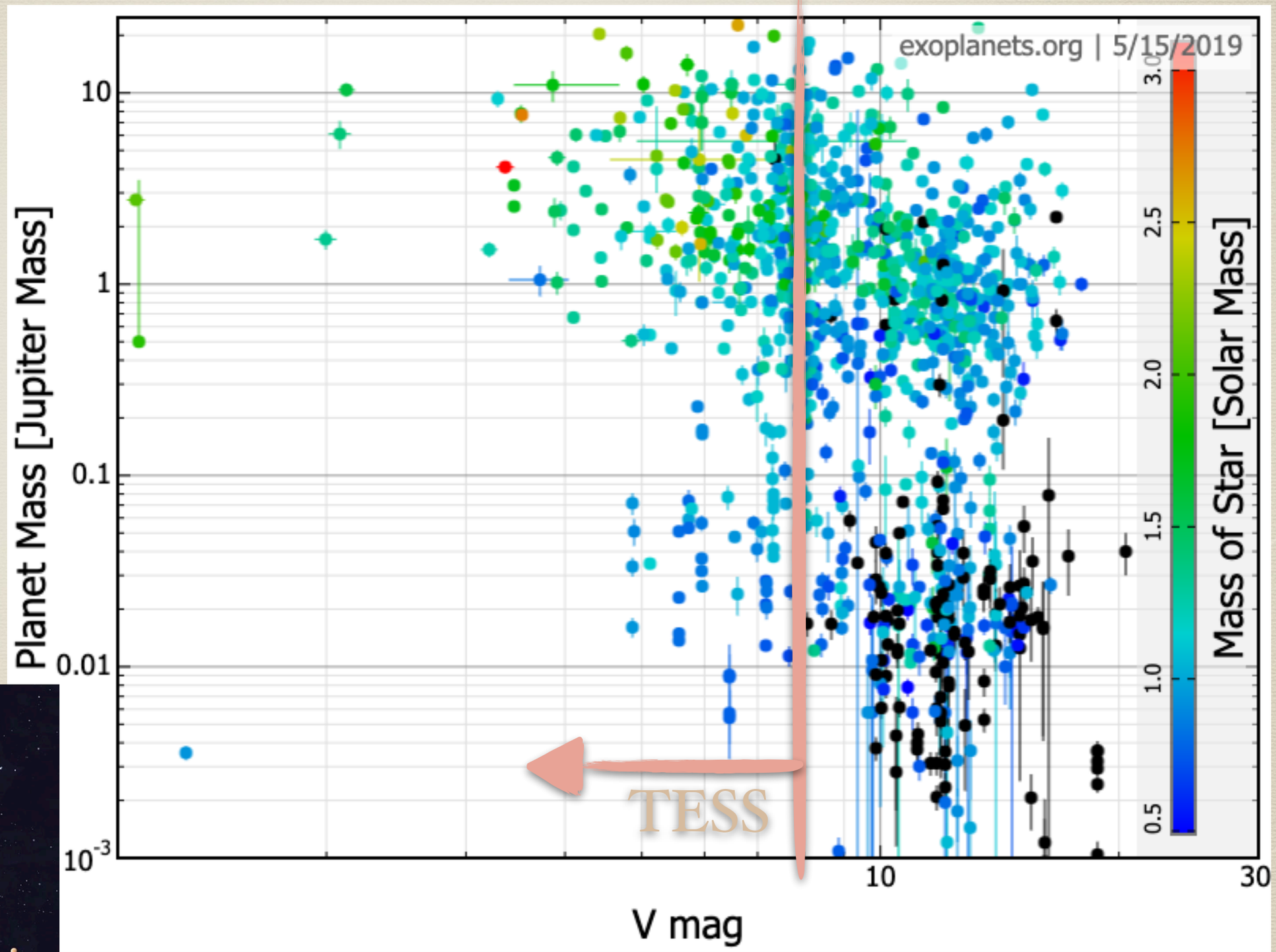

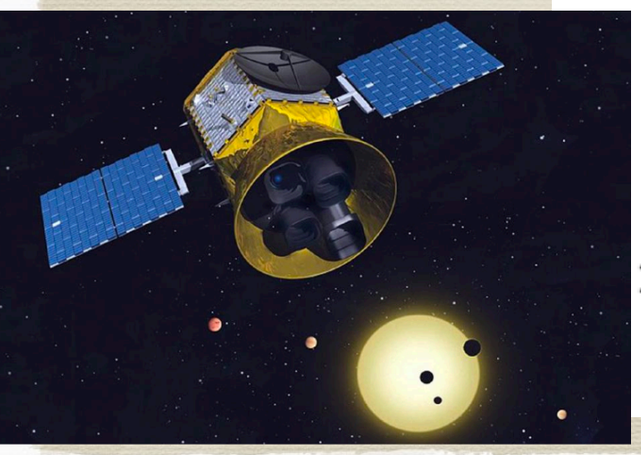

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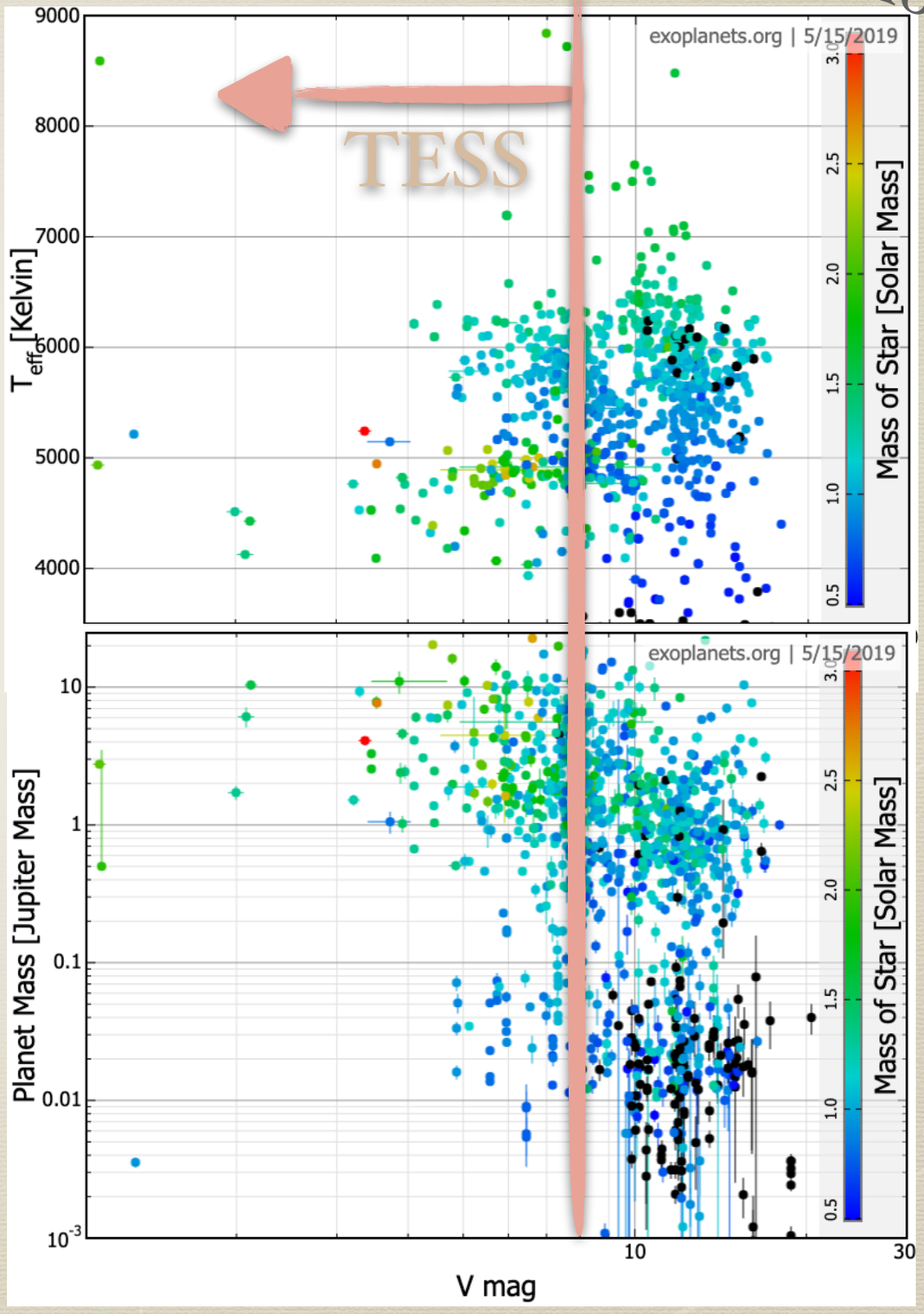

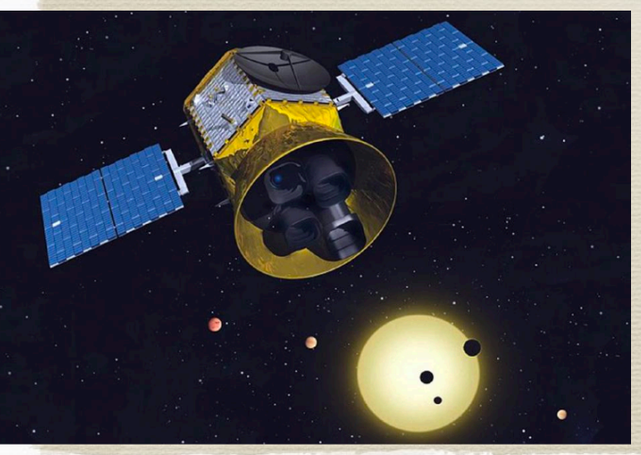

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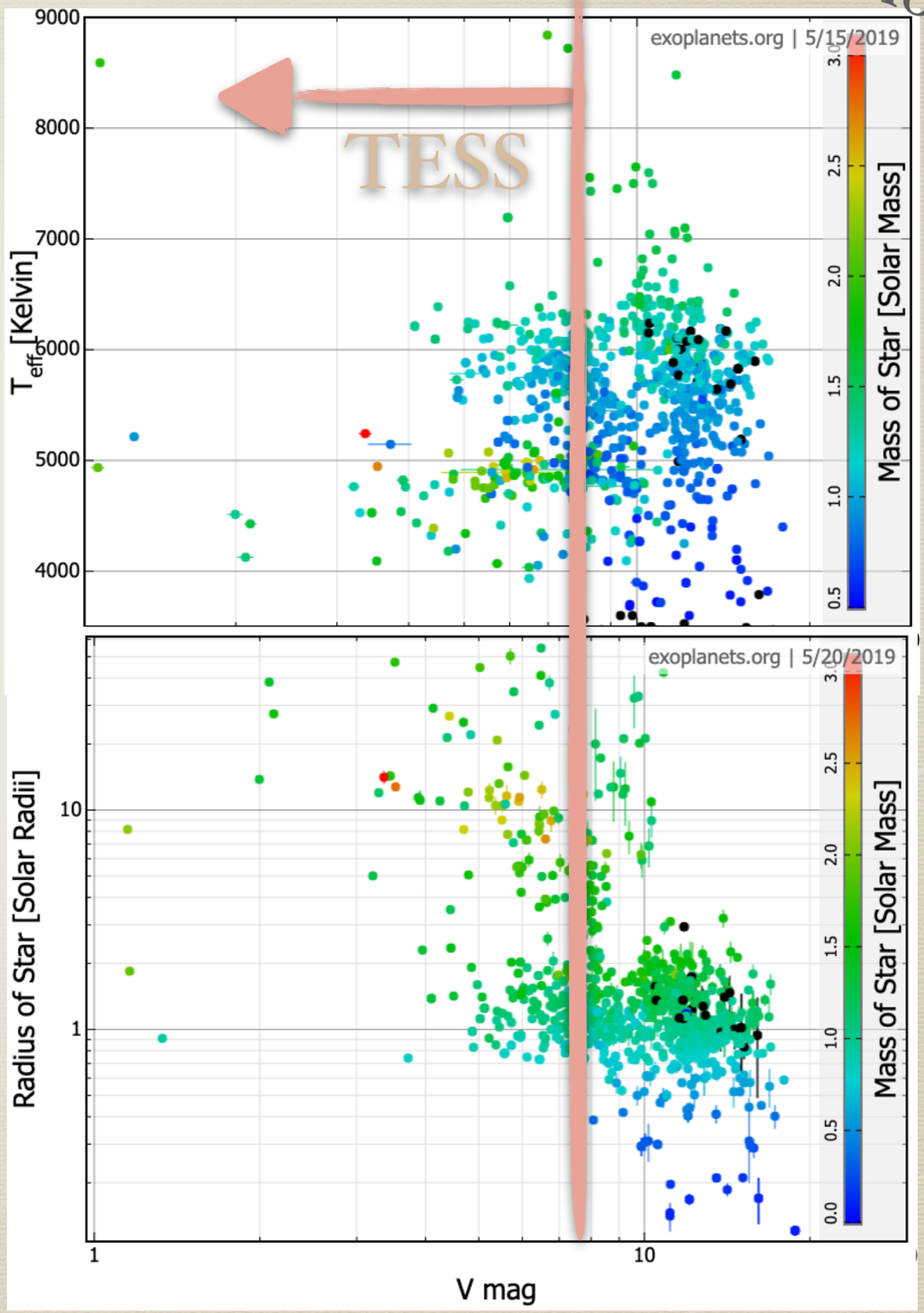

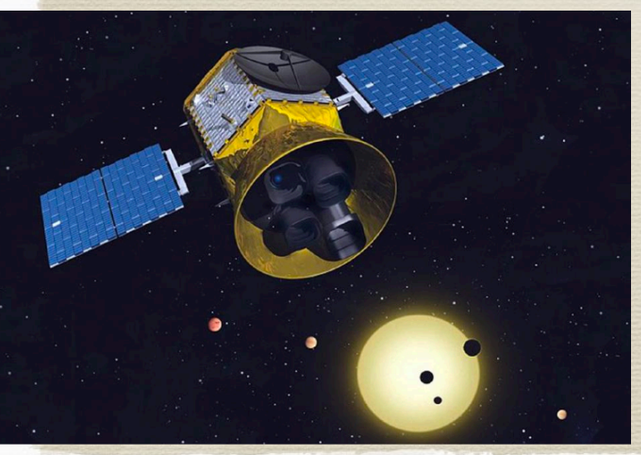

Bright stars

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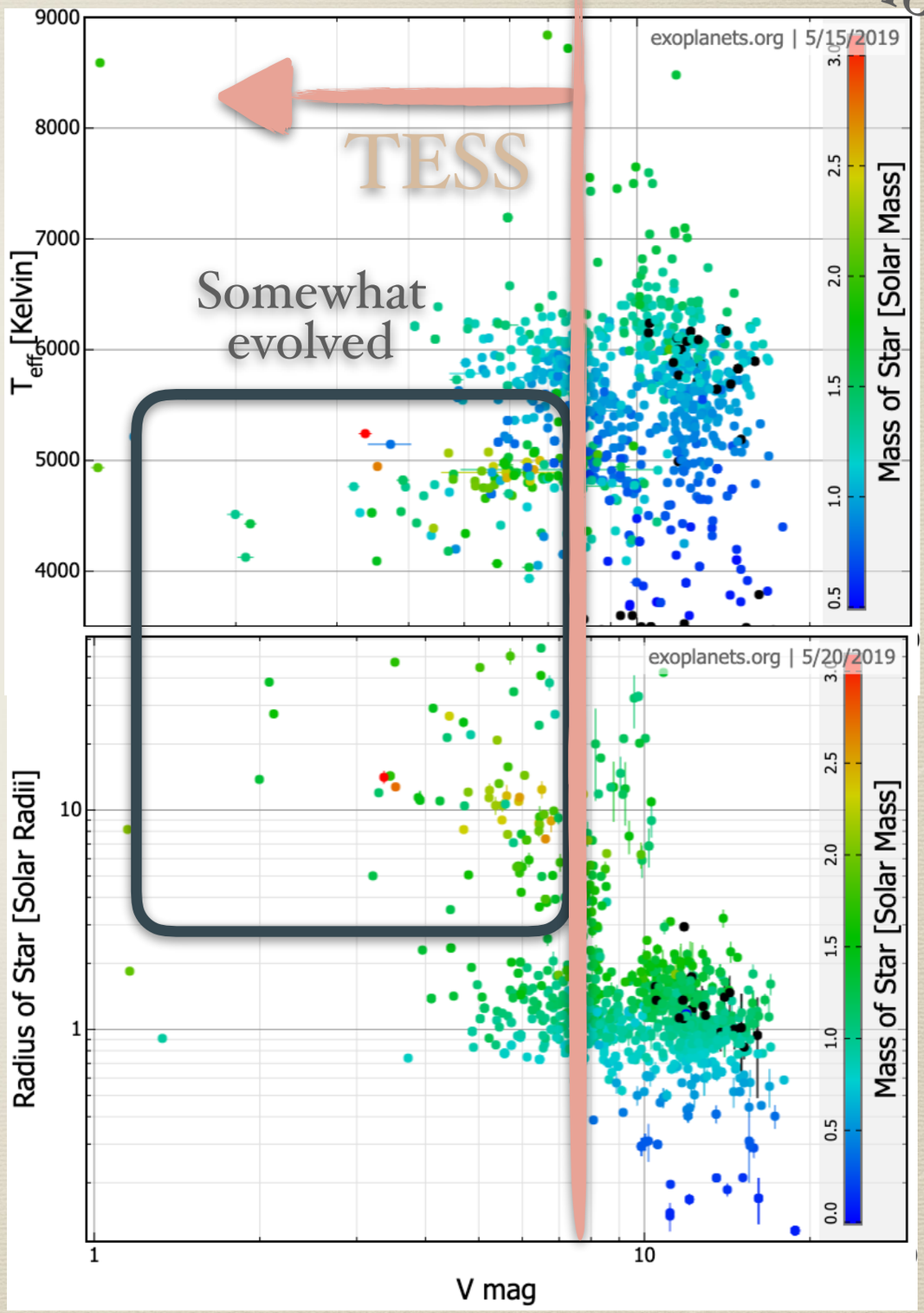
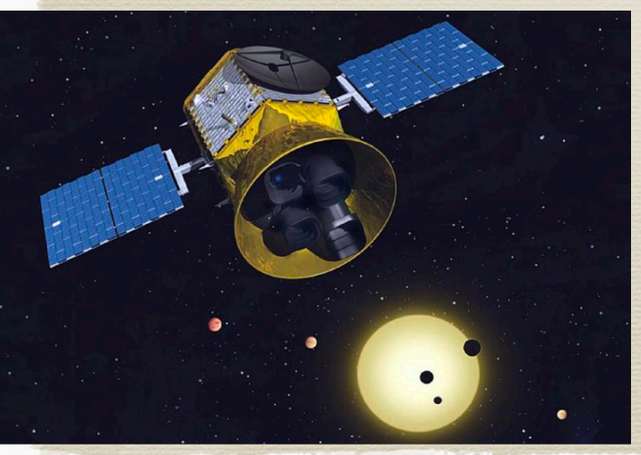
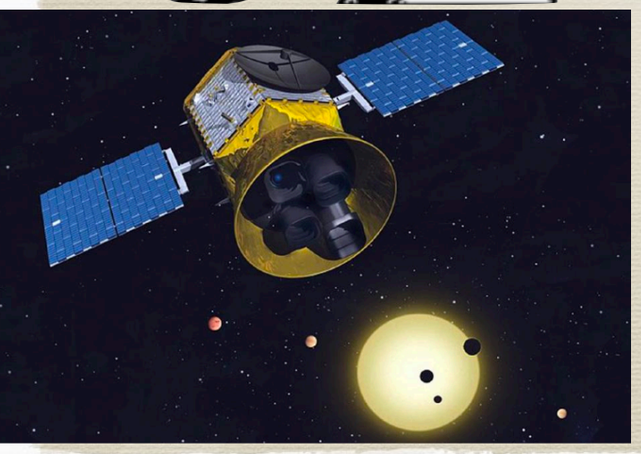




Bright stars

TESS surveys the brightest stars

Some are hot, some are cold
Some are young and some are old



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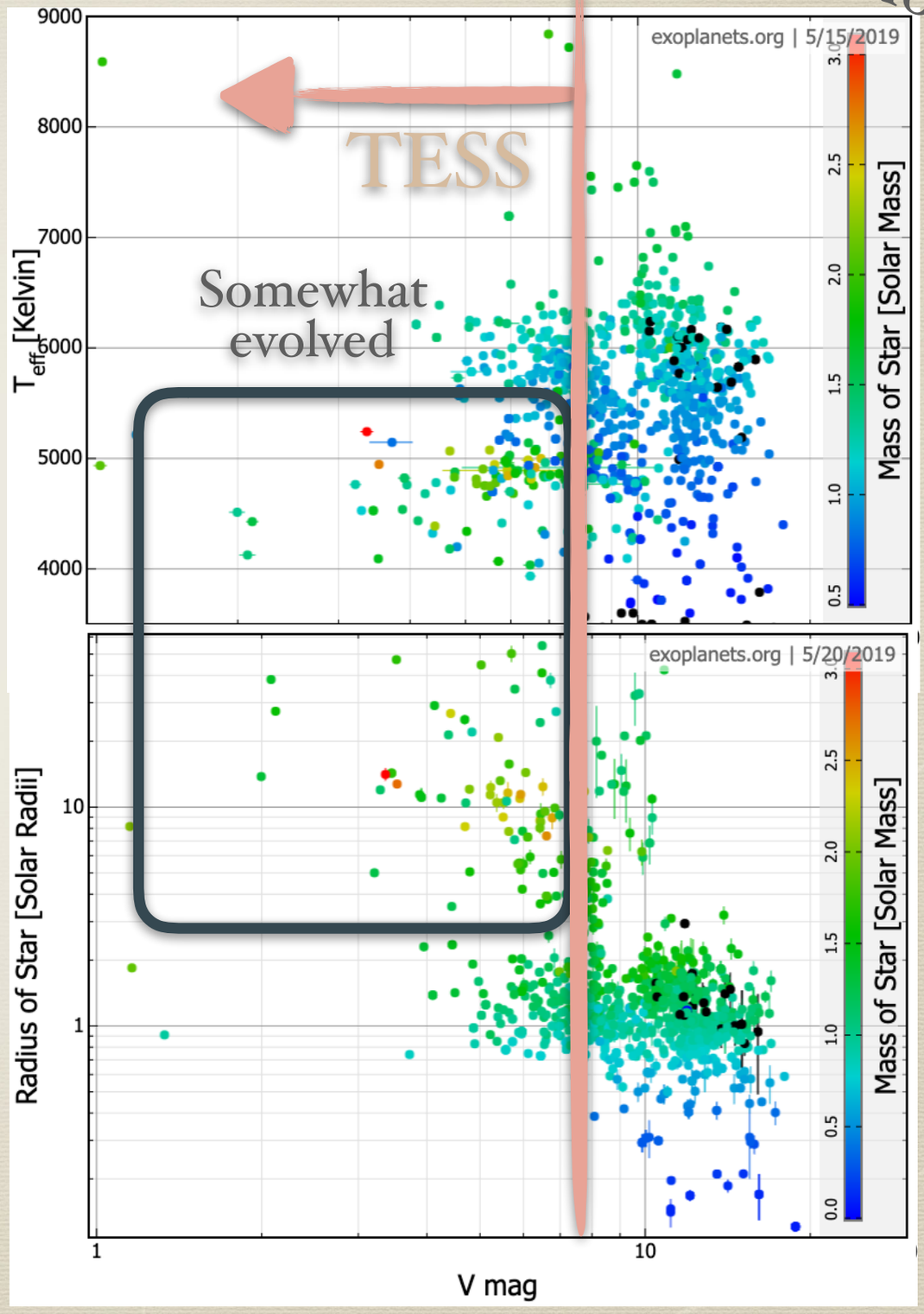

Binaries here and there

The majority of stars in *the field and clusters* are born in binaries or higher multiples, e.g., Ghez et al 1993, Sana et al 2012

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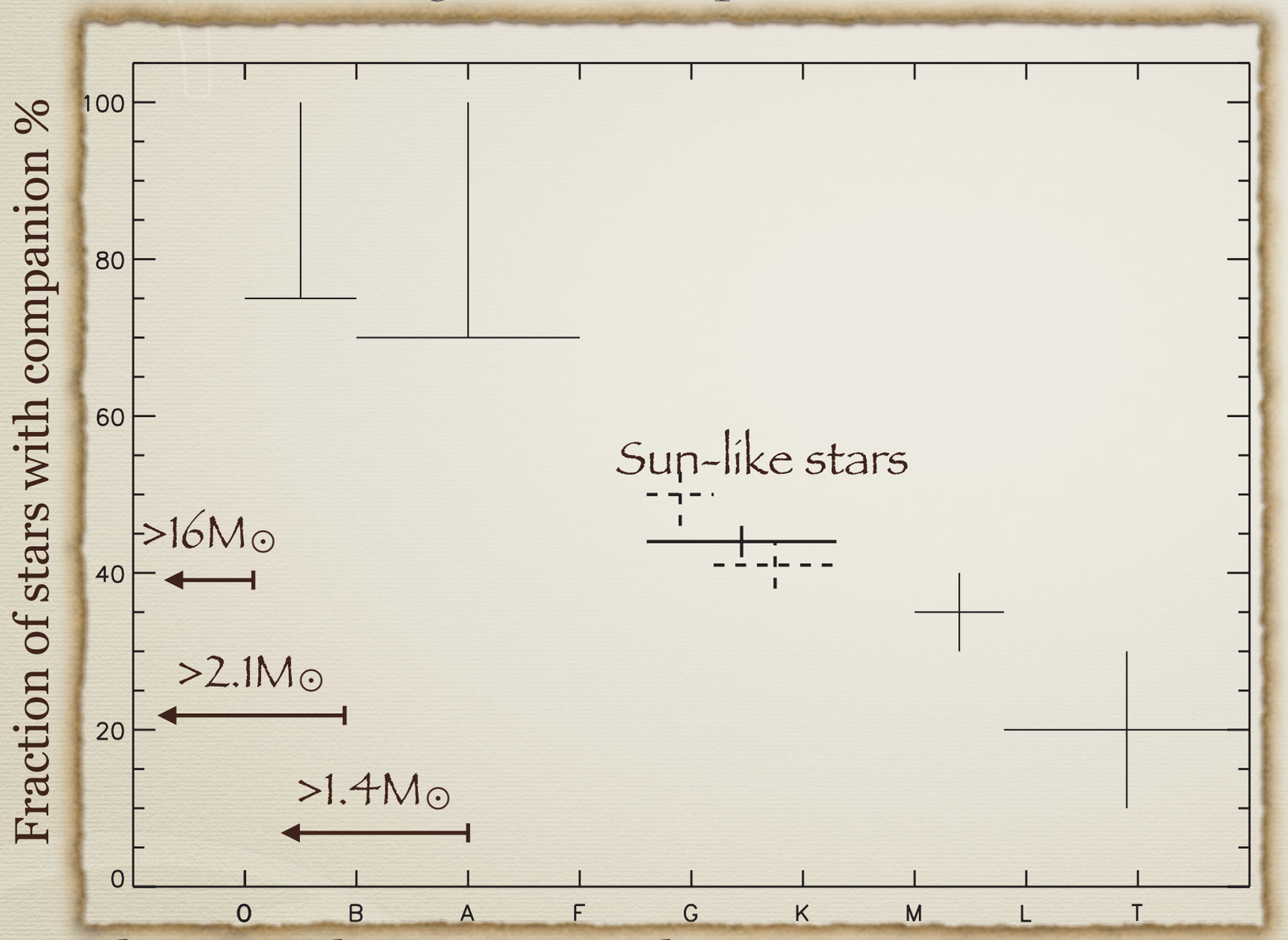

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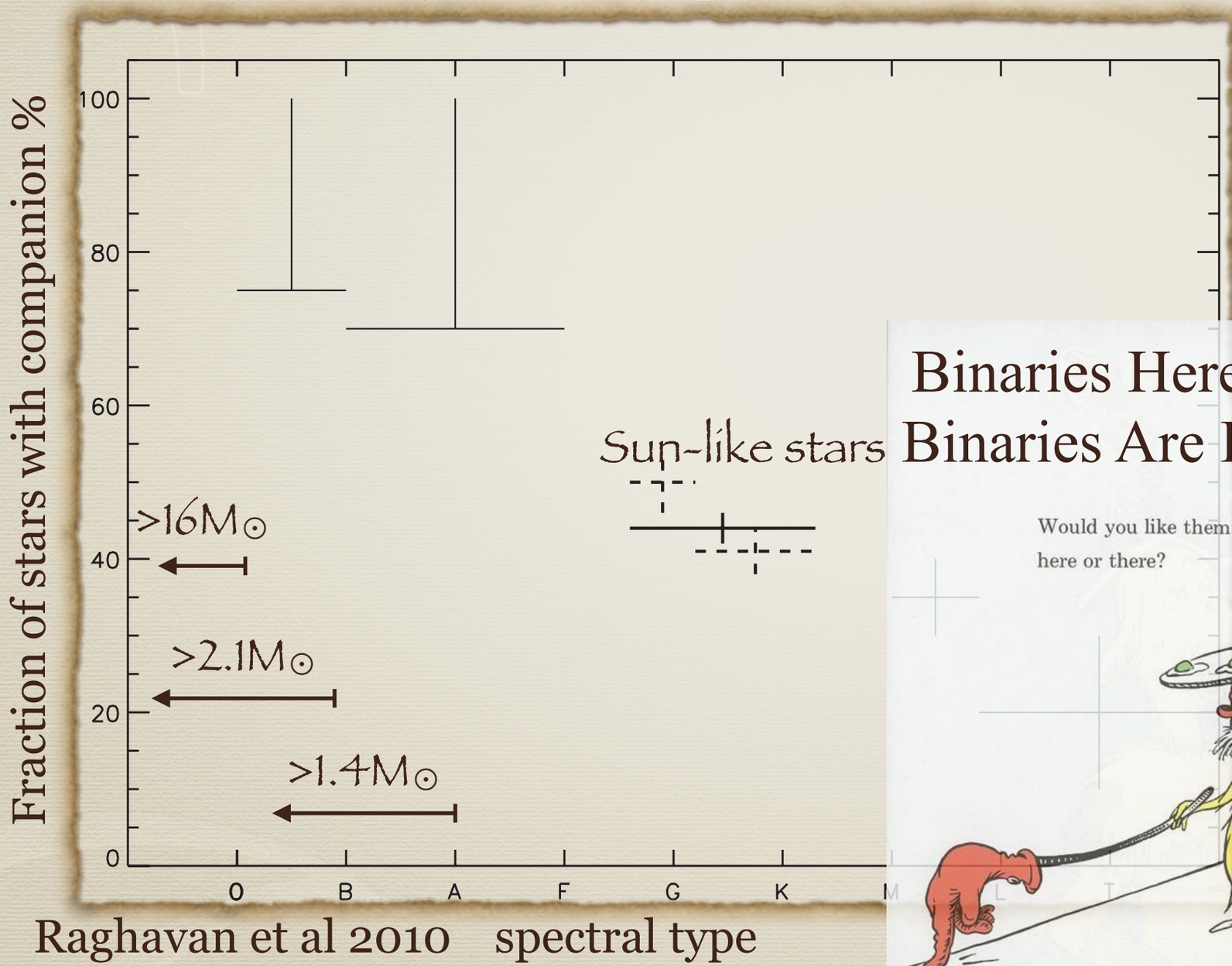
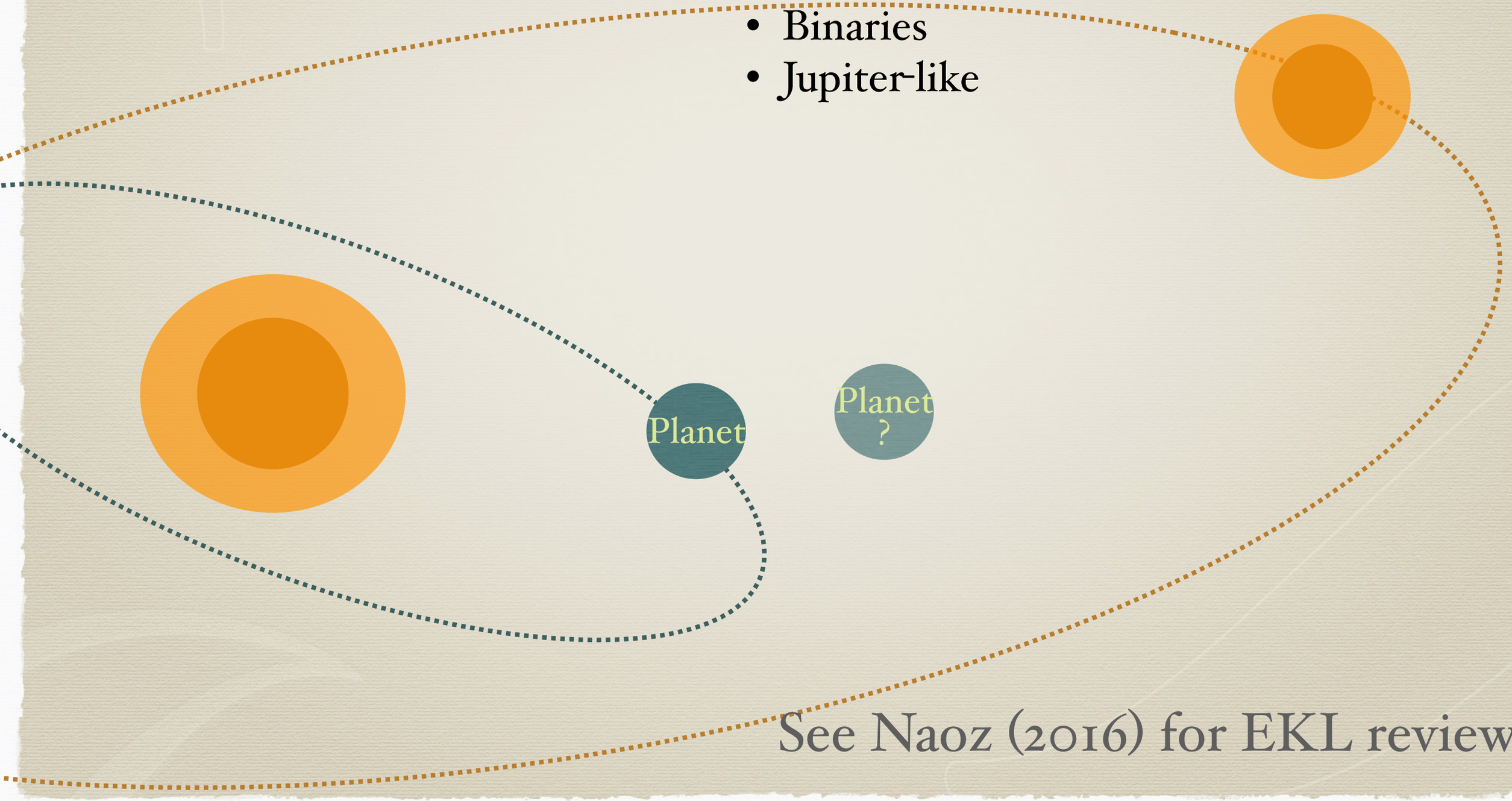


Raghavan et al 2010

The TESS Connection

A-type stars and their friends

- Binaries
- Jupiter-like



See Naoz (2016) for EKL review

The TESS Connection

A-type stars and their friends

- Binaries
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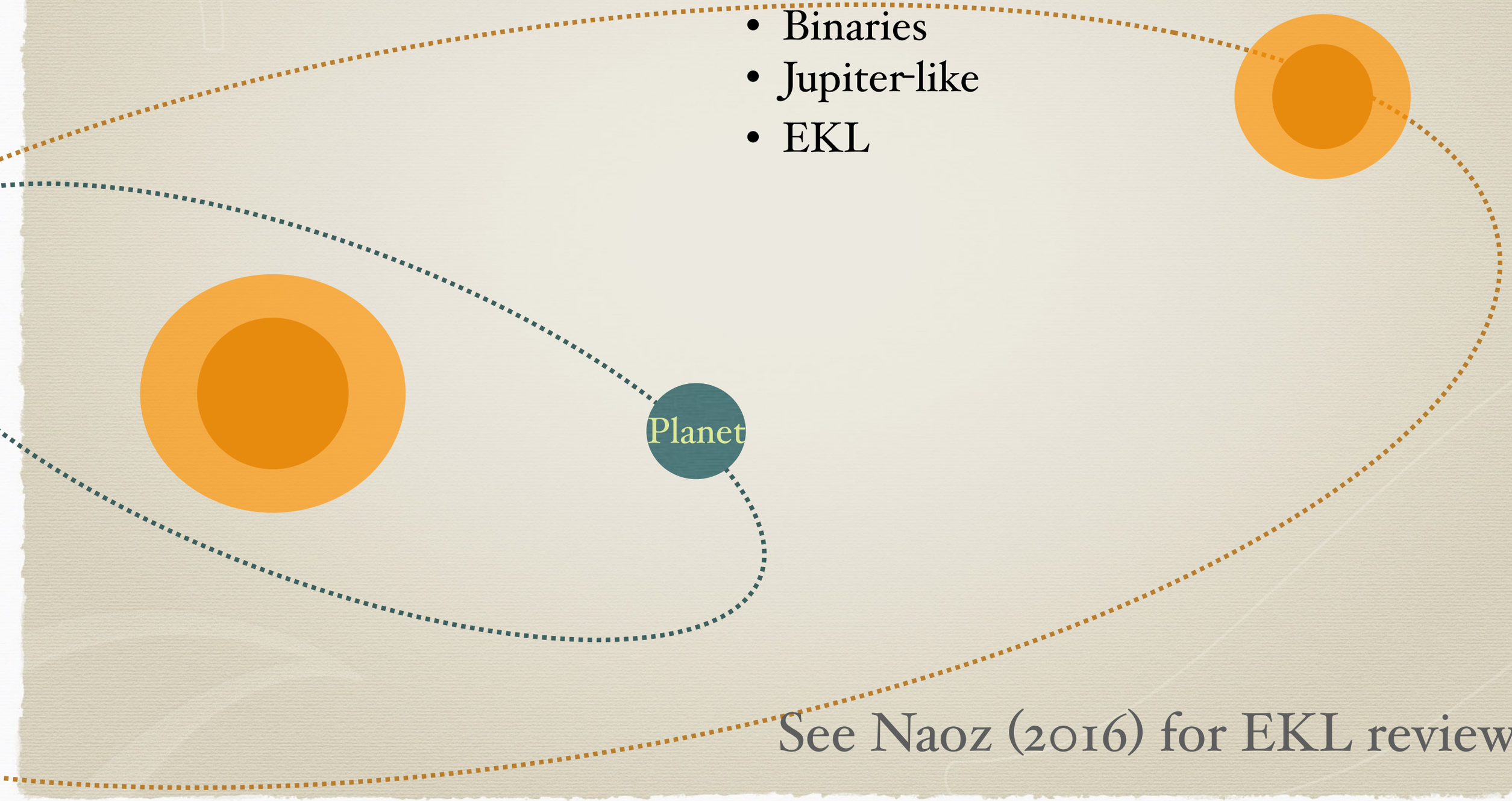
- EKL



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The TESS Connection

A-type stars and their friends

- Binaries
- Jupiter-like
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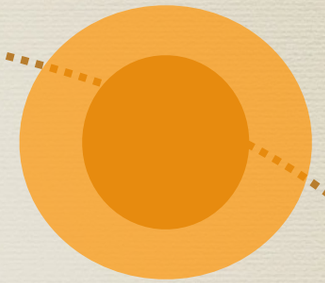
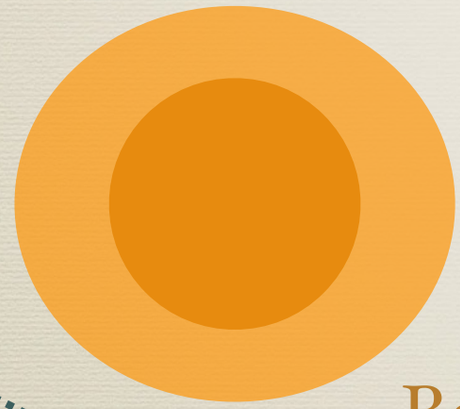
- MS Radiative stars





Planet

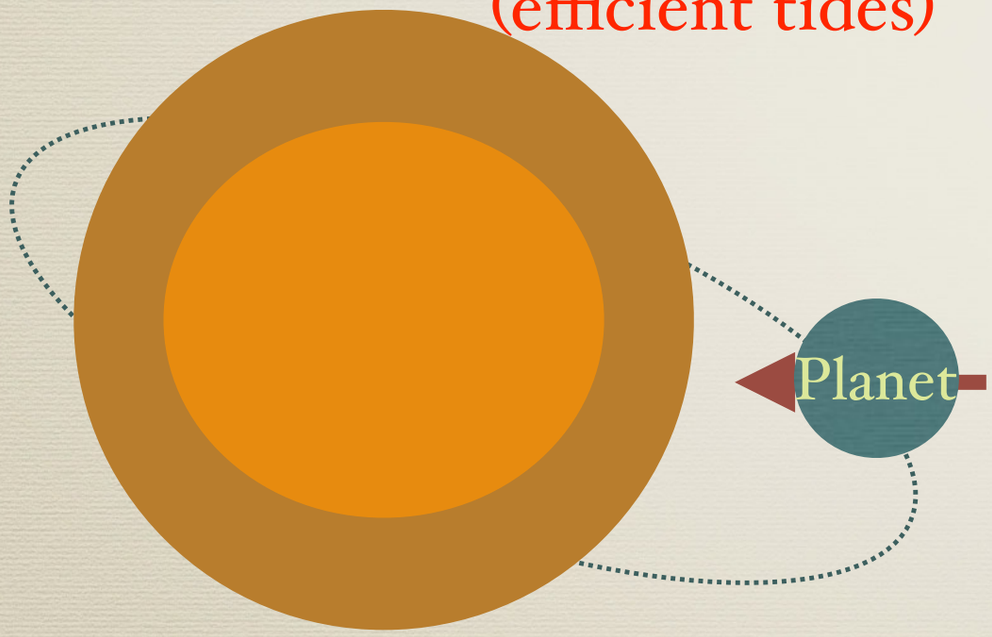
Radiative stars
(inefficient tides)

See Naoz (2016) for EKL review

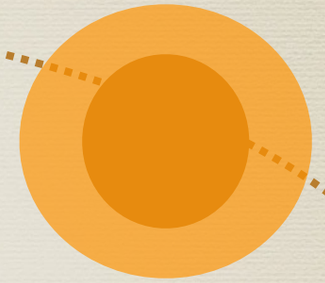
The TESS Connection

A-type stars and their friends

Convective red giants
(efficient tides)



- Binaries
- Jupiter-like
- EKL
- MS Radiative stars
- Convective red giant



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The TESS Connection

A-type stars and their friends

- Binaries
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- MS Radiative stars
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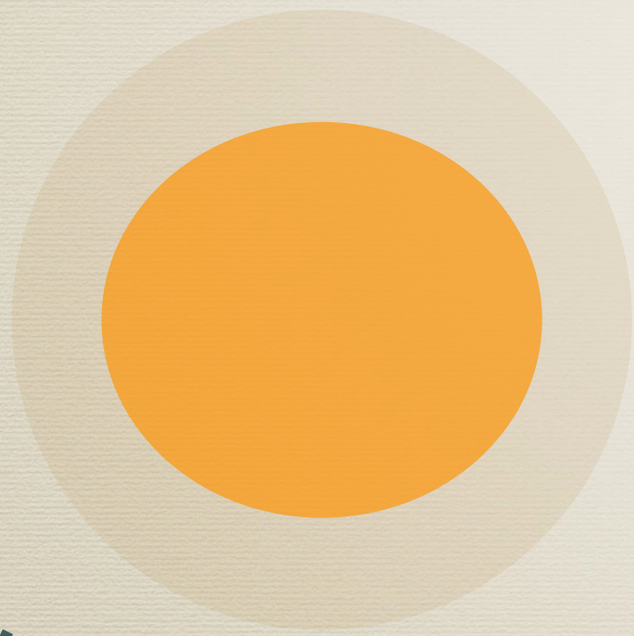
- Mass loss



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Bright stars, hot planets

Alexander Stephan

- ✓ Eccentric Kozai-Lidov (EKL)
- ✓ General Relativity
- ✓ Tides (convective + radiative)
- ✓ Rotation
- ✓ Stellar evolution*

Stephan, **Naoz** Zuckerman (2017), ApJ-Lett
Stephan, **Naoz** Gaudi (2018), ApJ

*following SSE
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See also talk by Dimitri Veras

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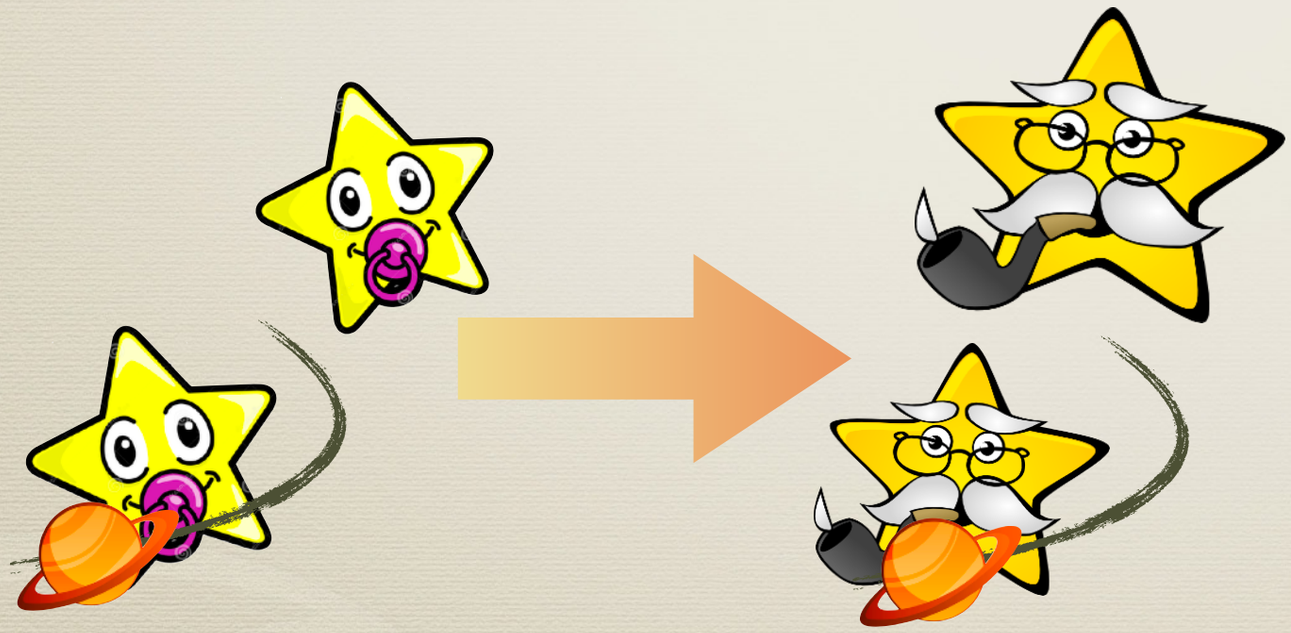

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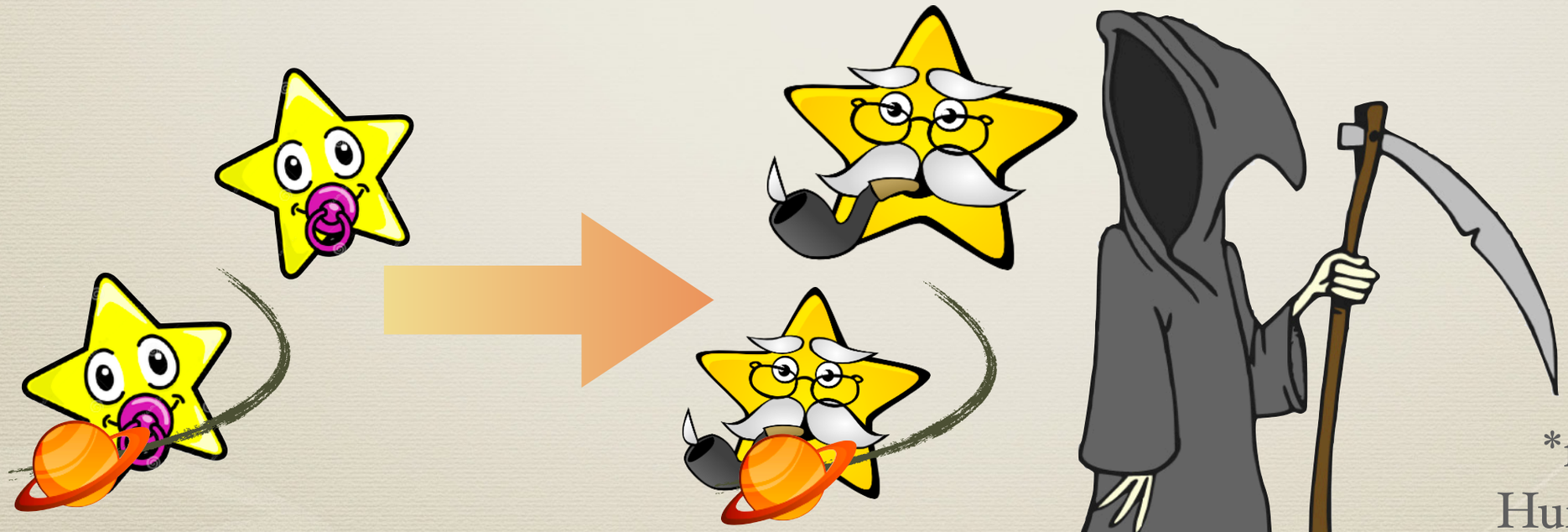

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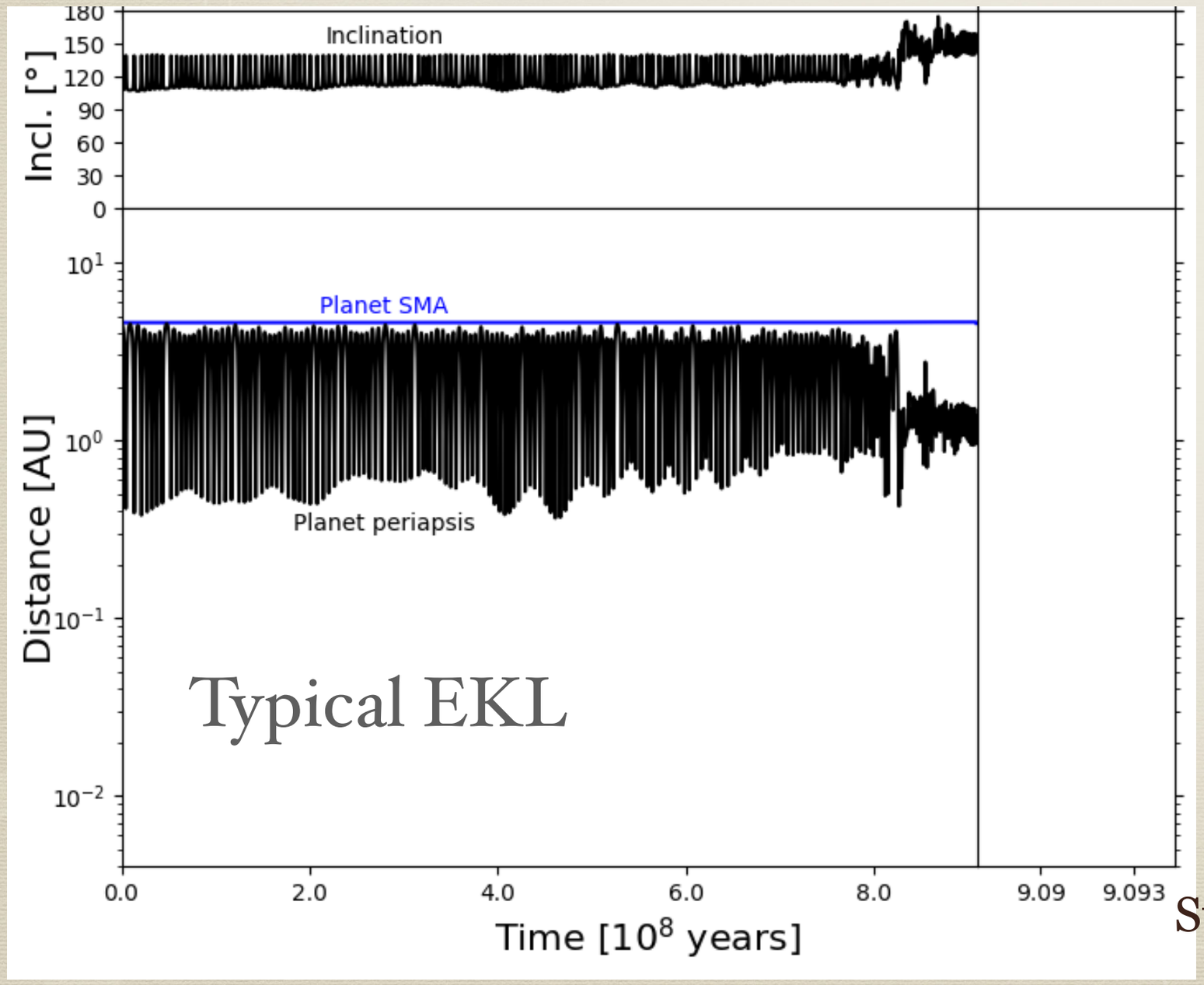

Typical EKL

m_1=2.39 $M_\odot$, m_2=1.95 $M_\odot$,
a_1=4.58 au, a_2=601.6 au,
e_1=0.01, e_2=0.587, i=108°.2

Stephan, **Naoz** Gaudi (2018), ApJ

Bright stars, hot planets

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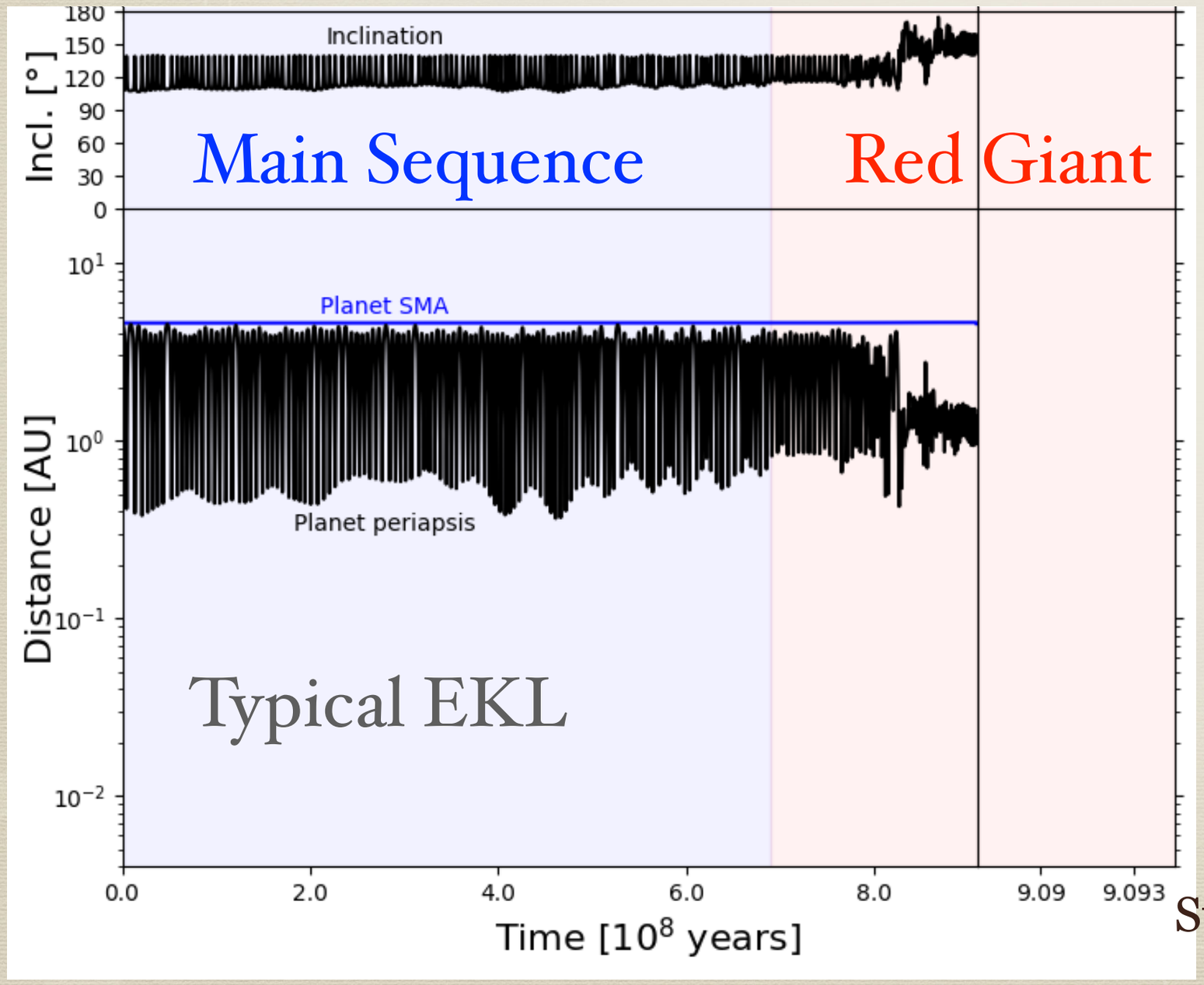

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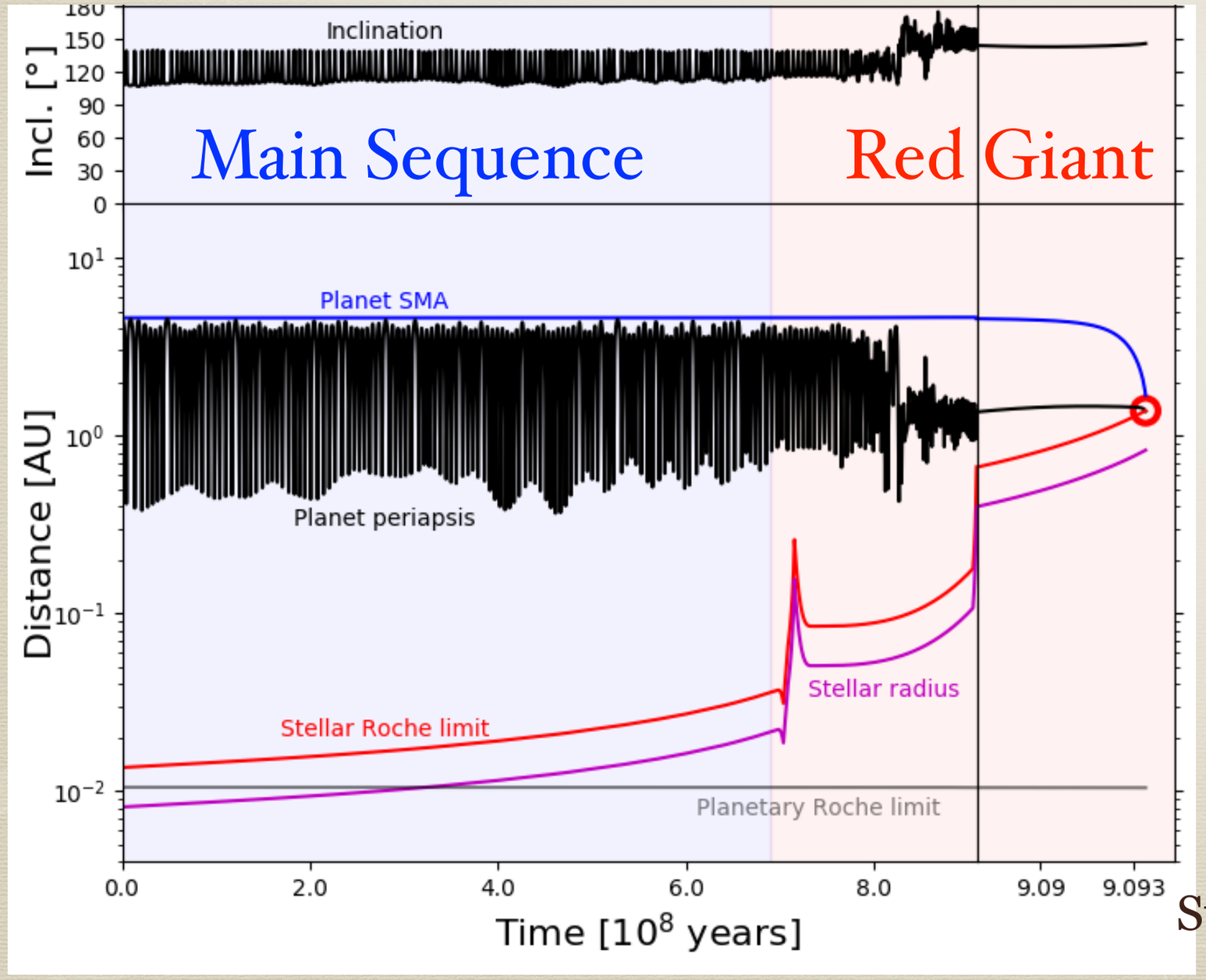

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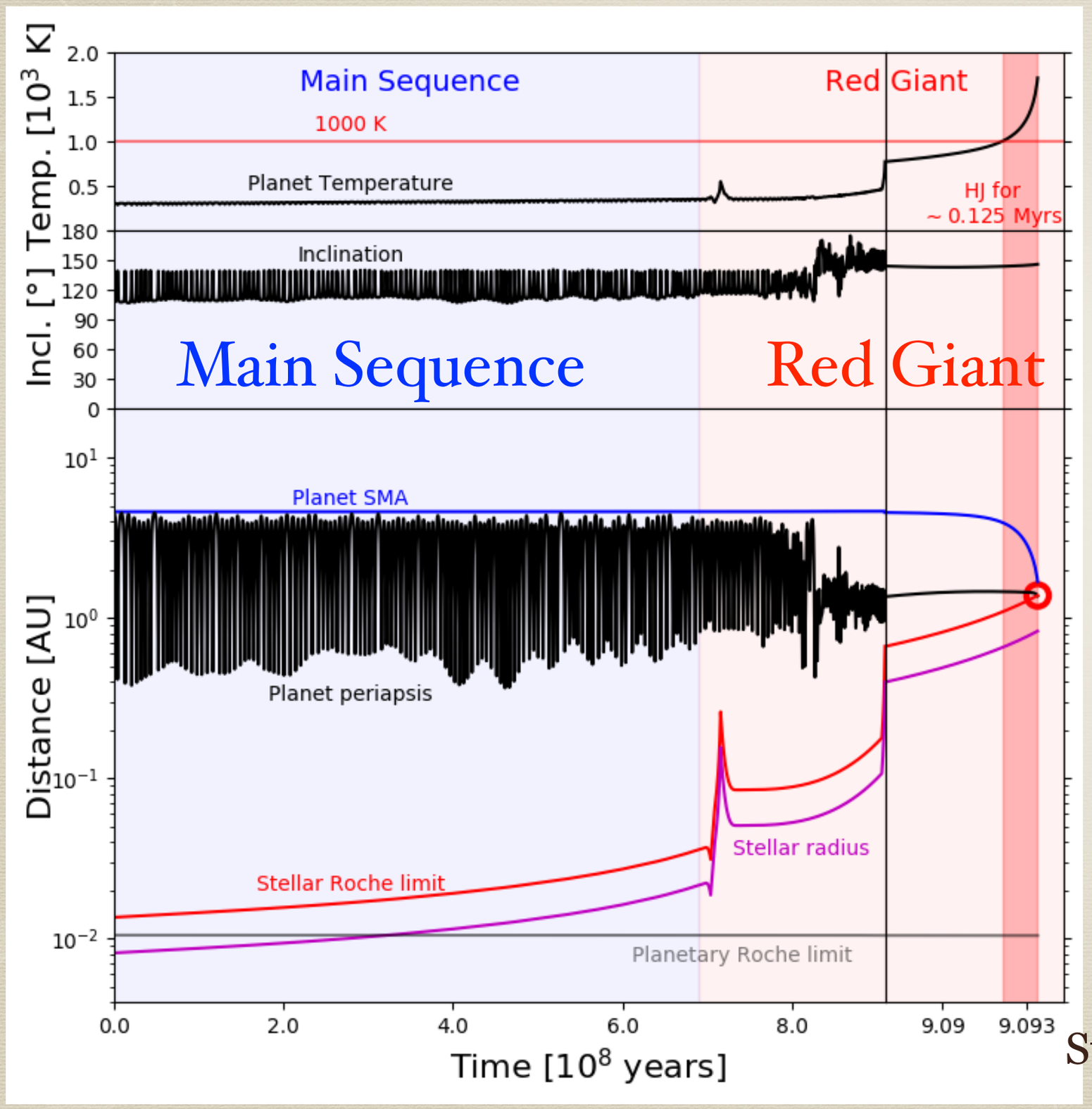

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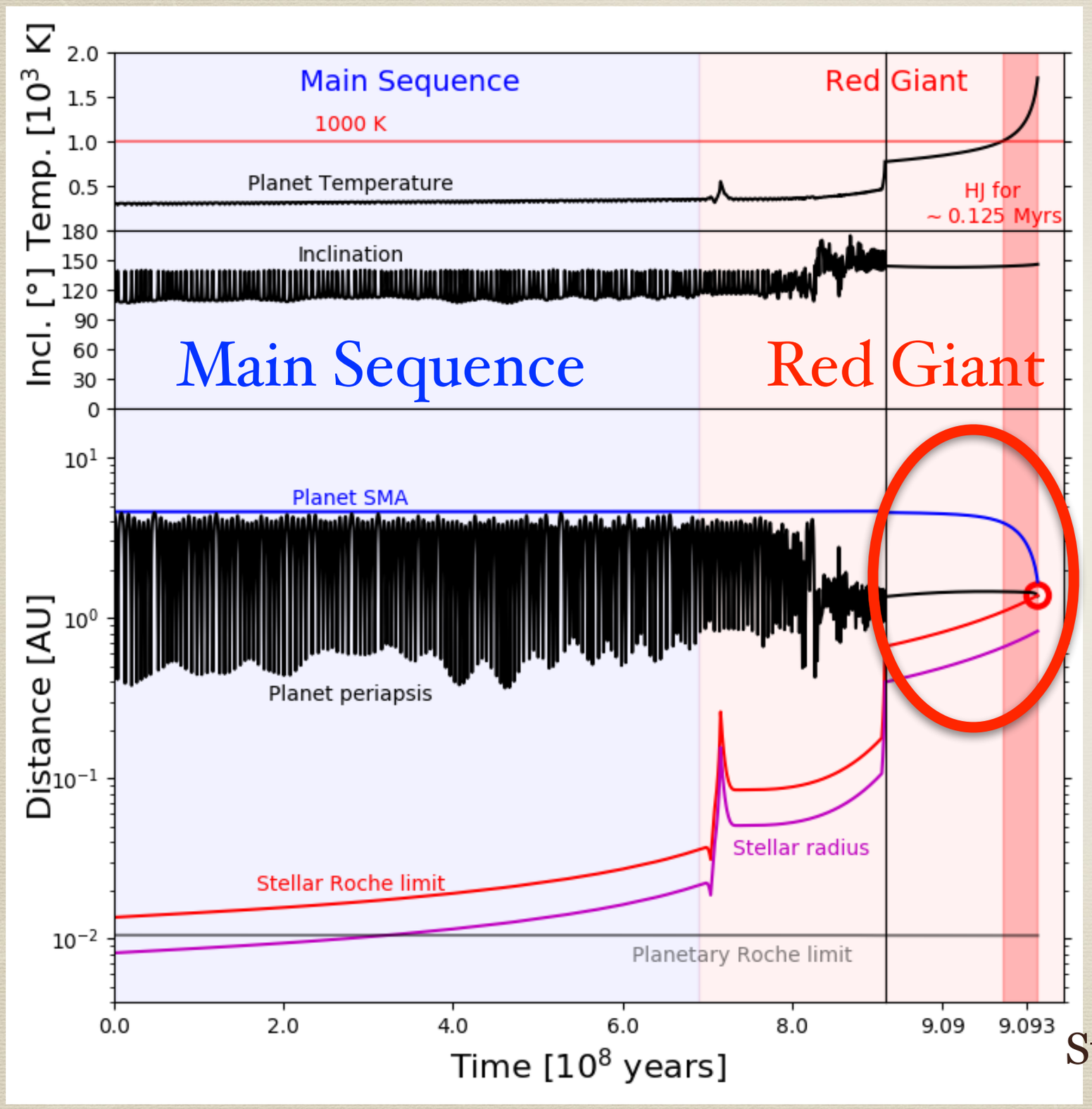

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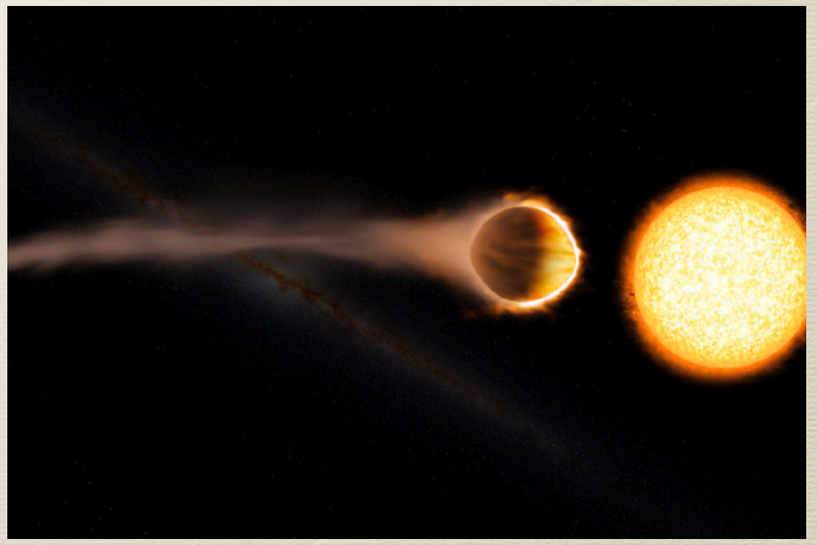
“Temporary” Hot Jupiter



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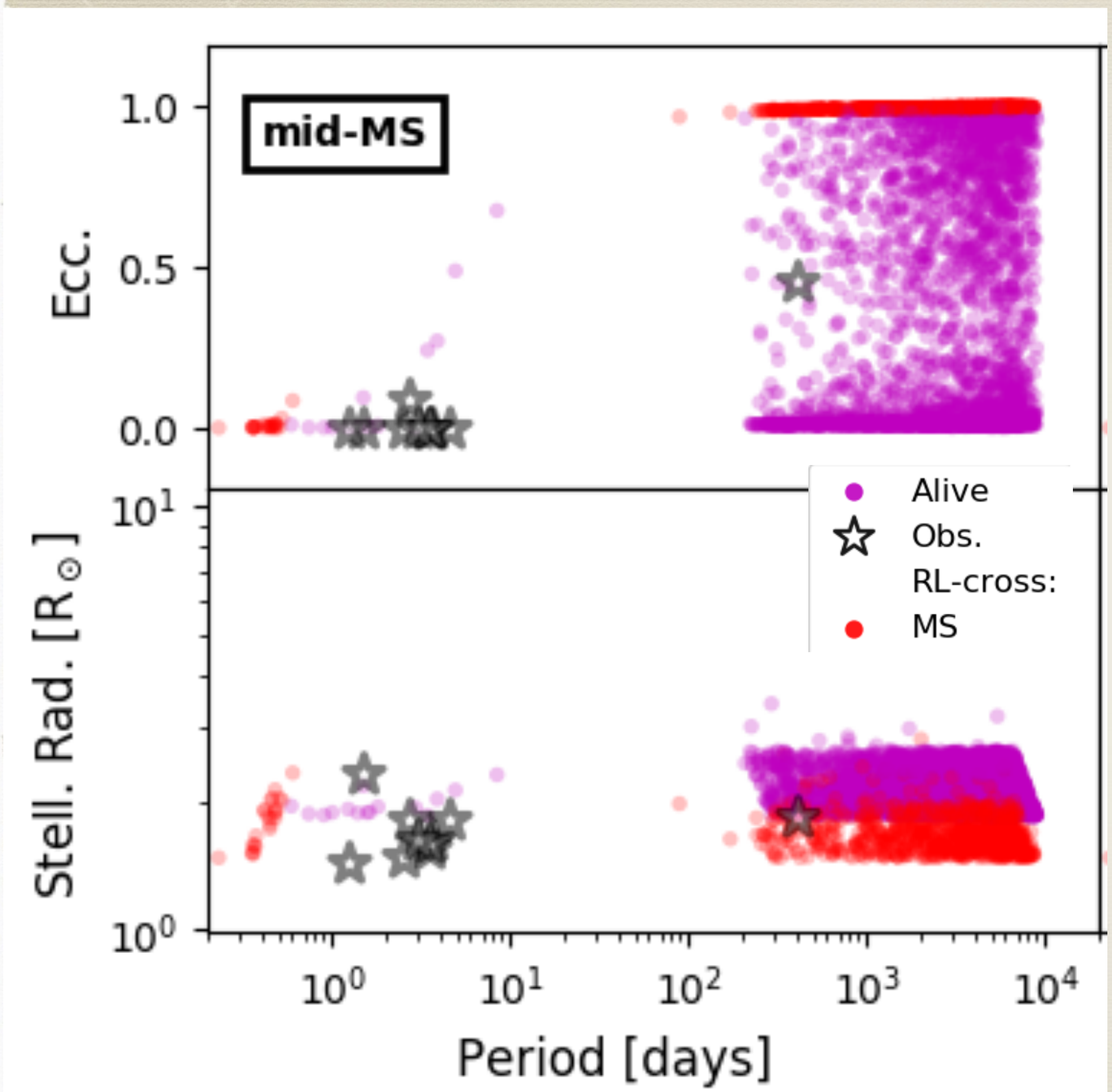

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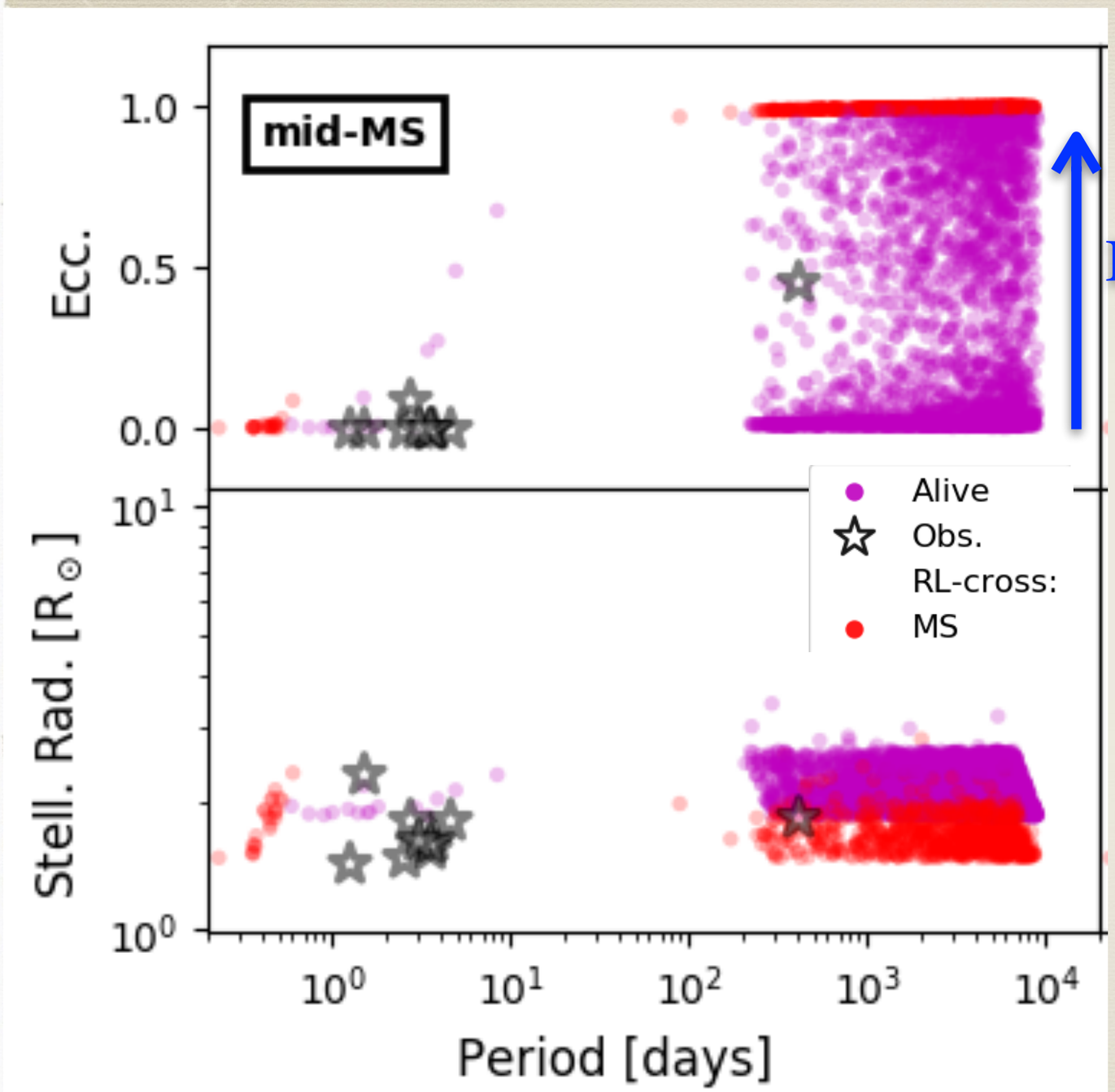
$M_\star \in [1.6,3] M_\odot$

Stephan, **Naoz** Gaudi (2018), ApJ

Bright stars, hot planets



EKL

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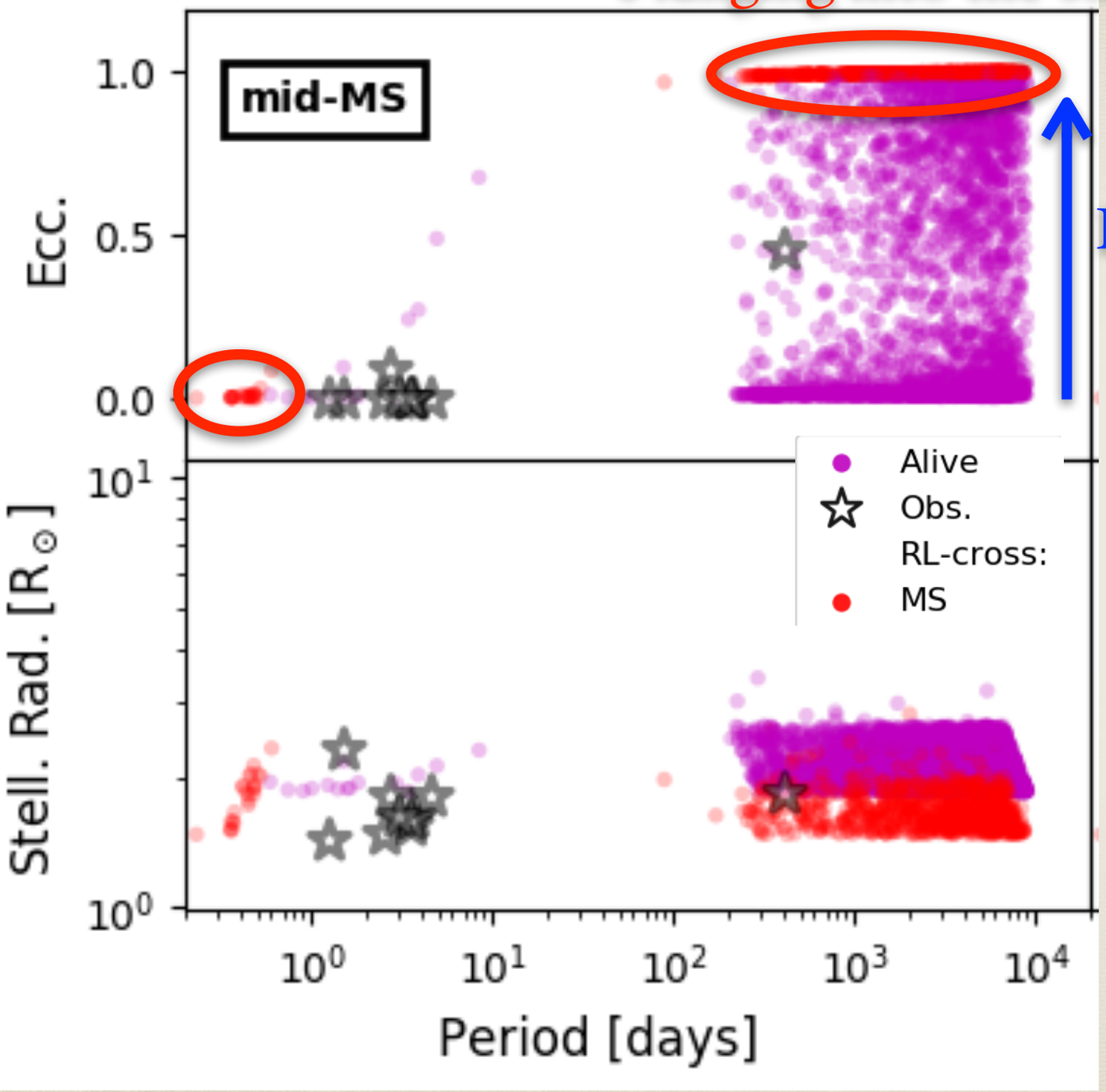
Stephan, **Naoz** Gaudi (2018), ApJ

Bright stars, hot planets

Plunging into the star



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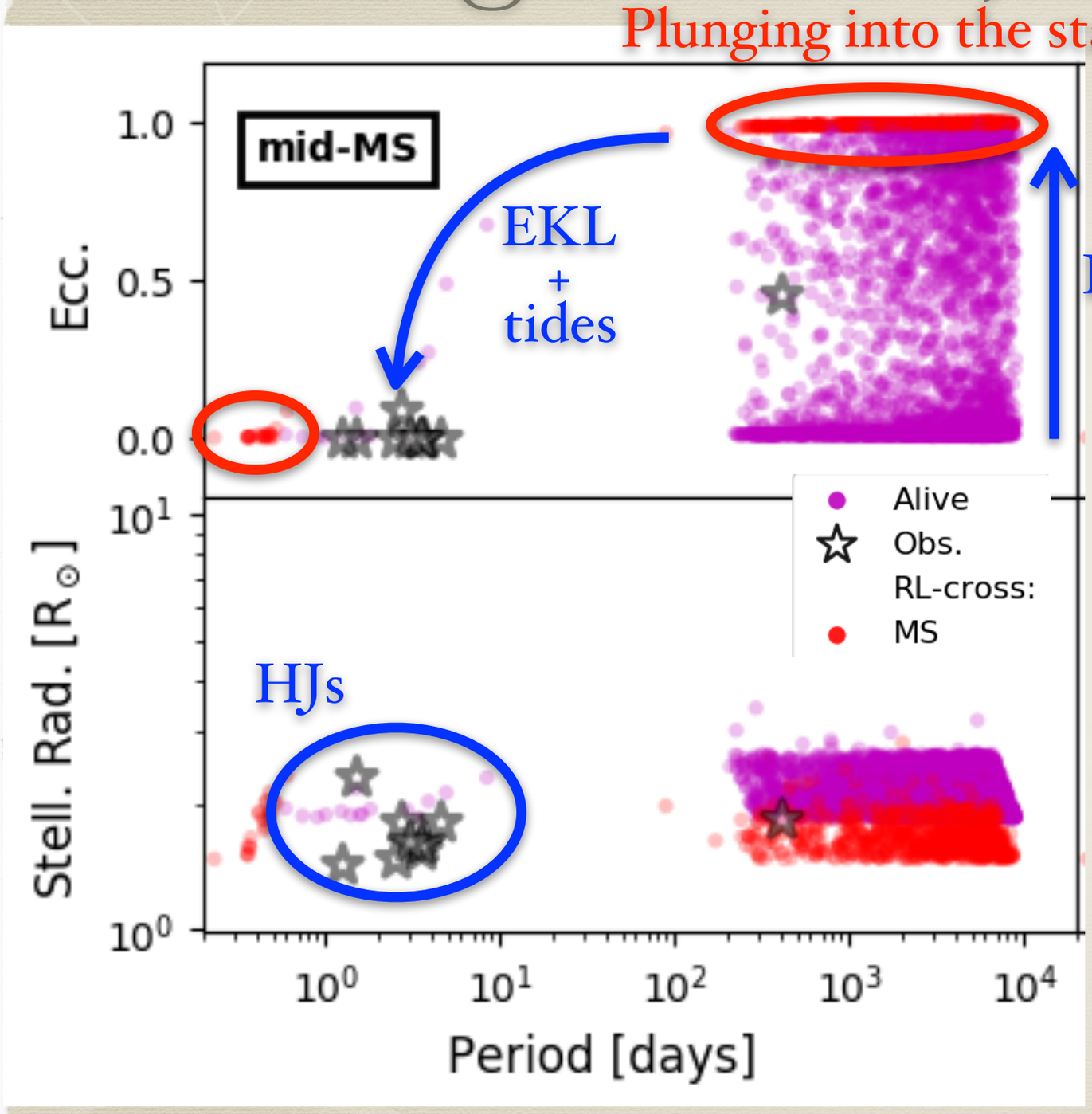

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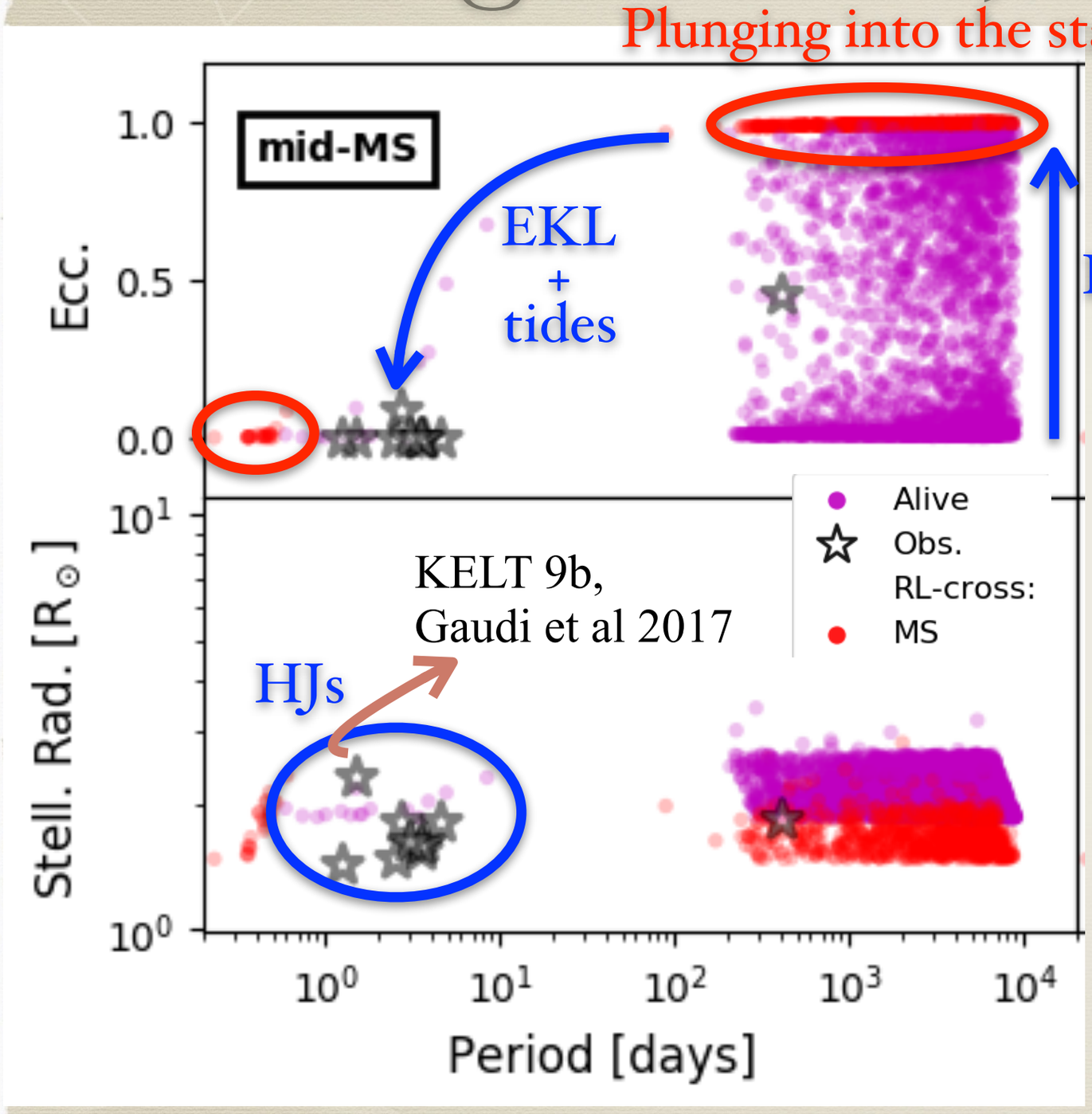

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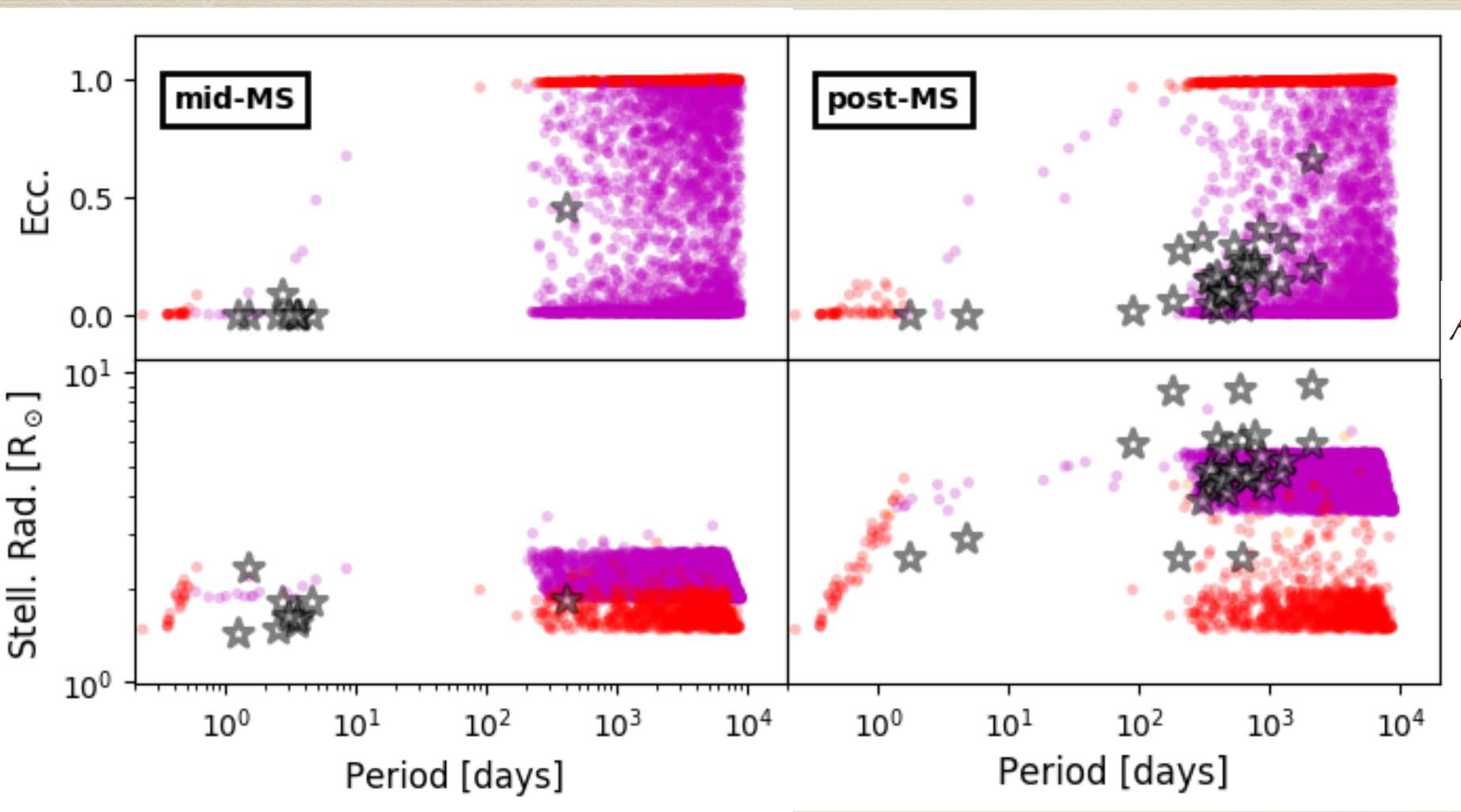

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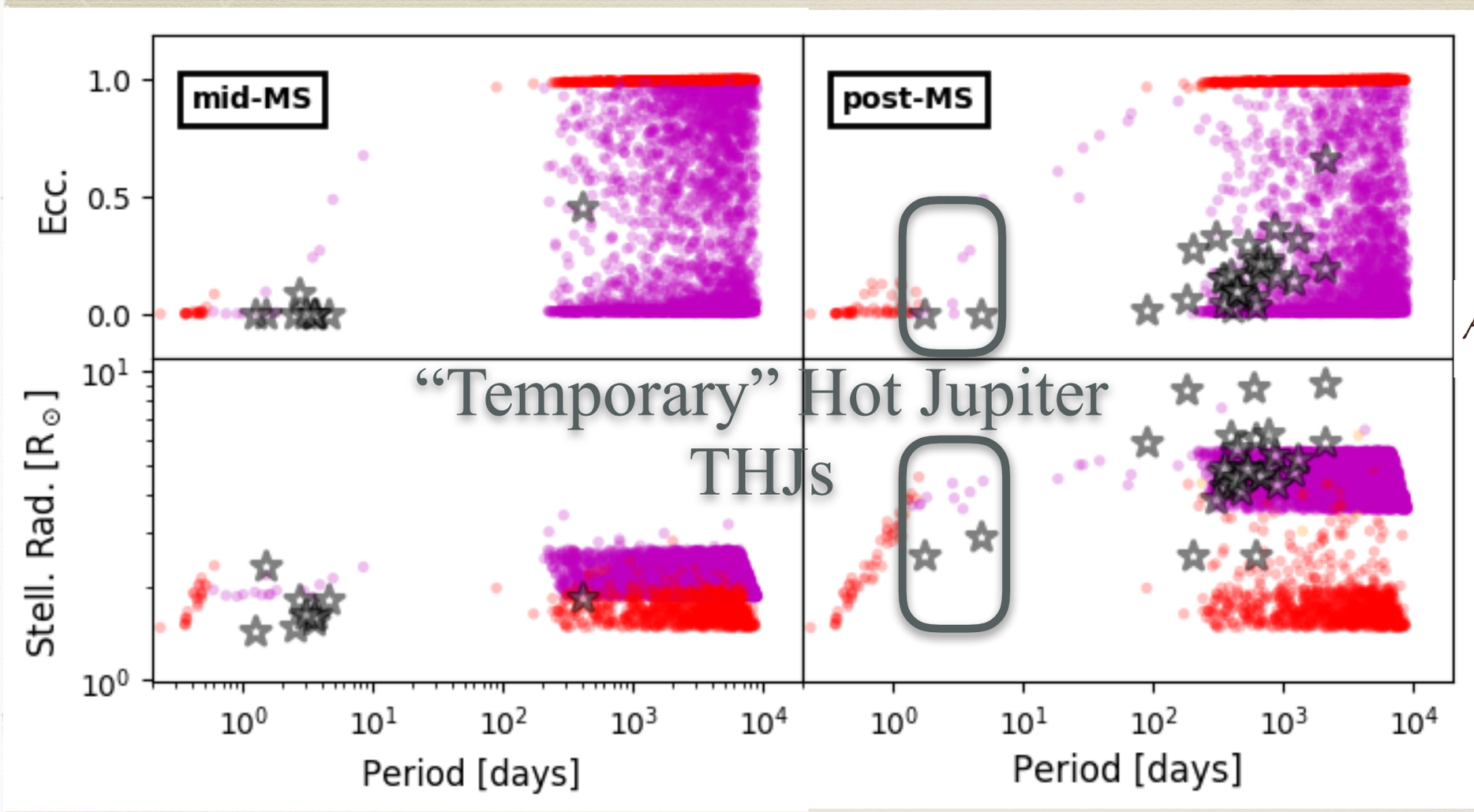

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"Temporary" Hot Jupiter

THJs

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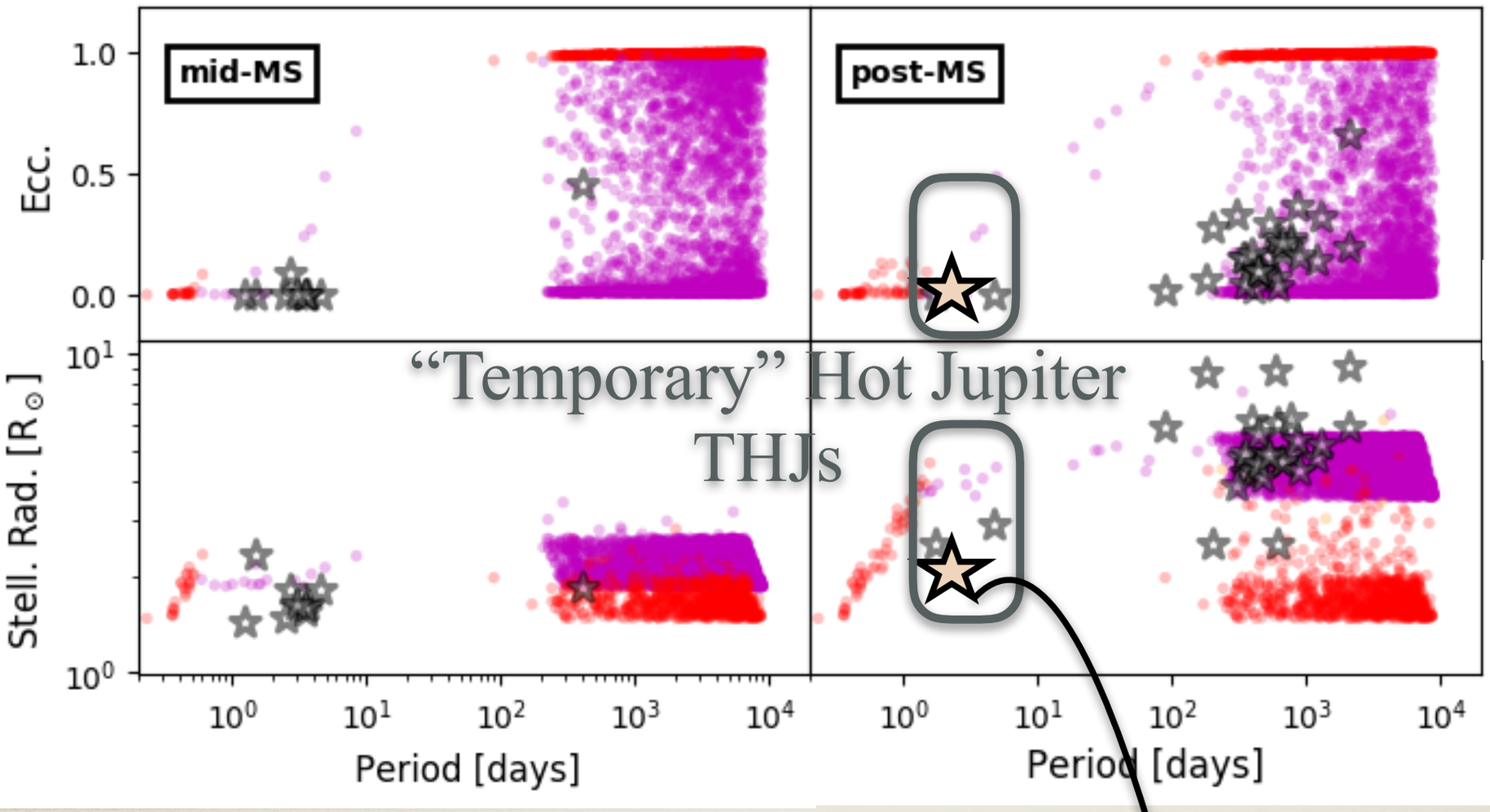

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"Temporary" Hot Jupiter

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HD 202772A b: A THJ in a binary, TESS observation, Wang et al (2018)

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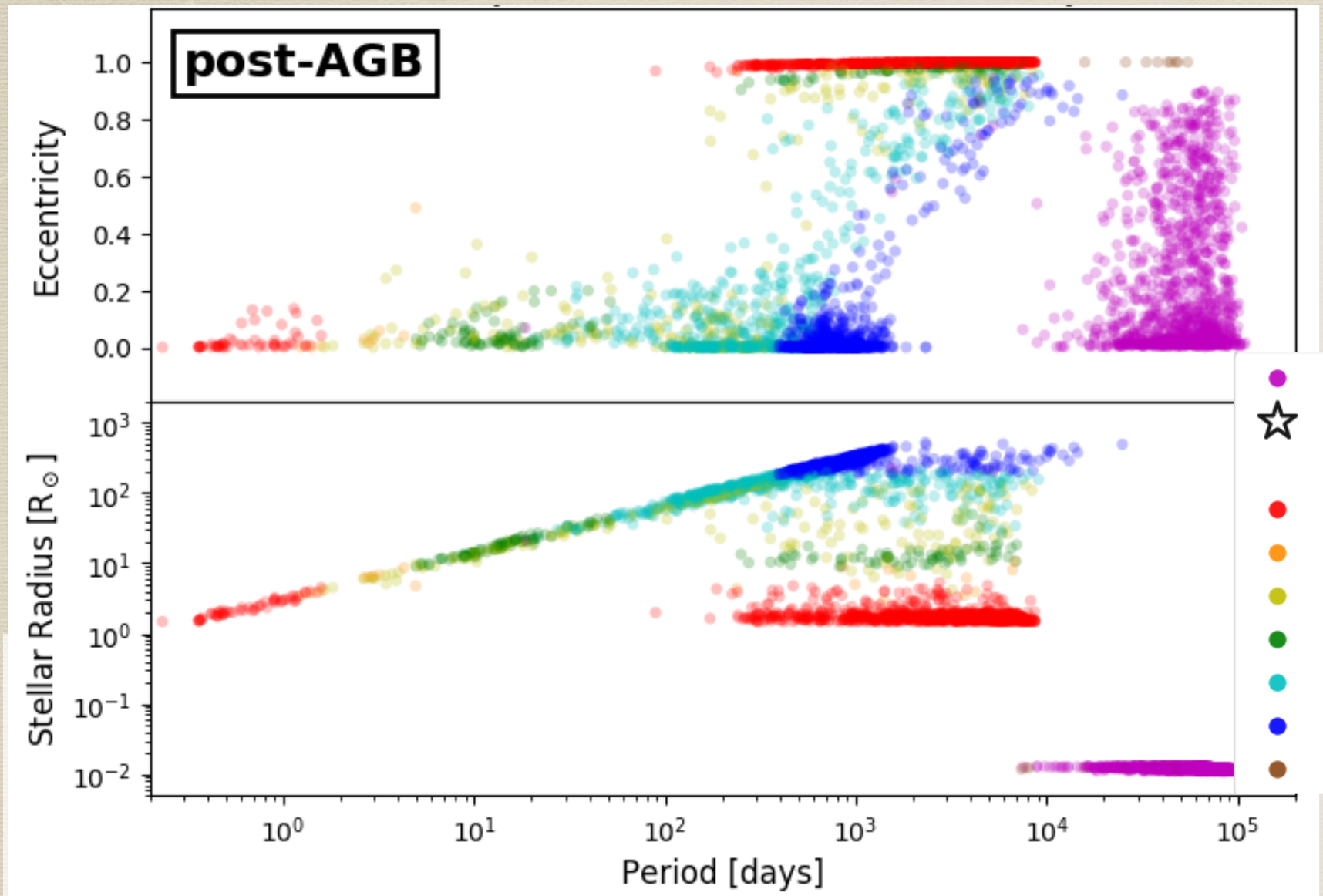

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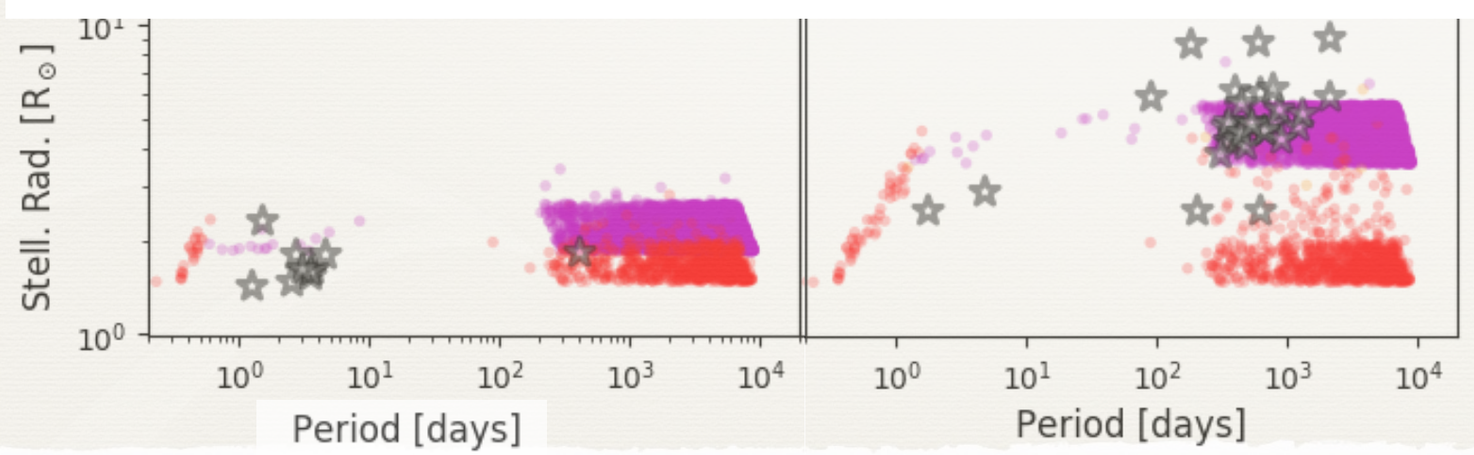


THJs:

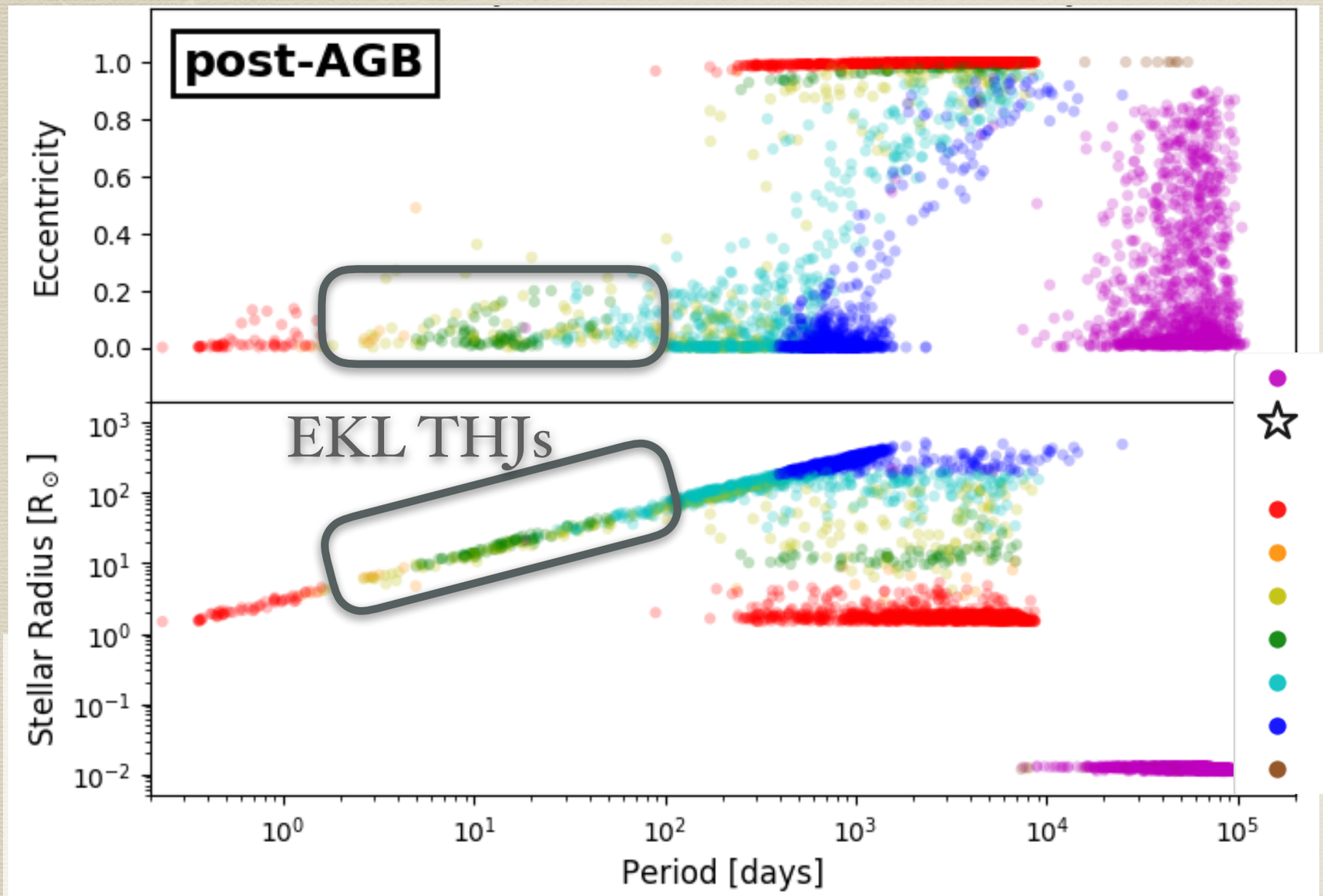
★Evolved star

★e-ish

★Large period

Stephan, **Naoz** Gaudi (2018), ApJ

Bright stars, hot planets



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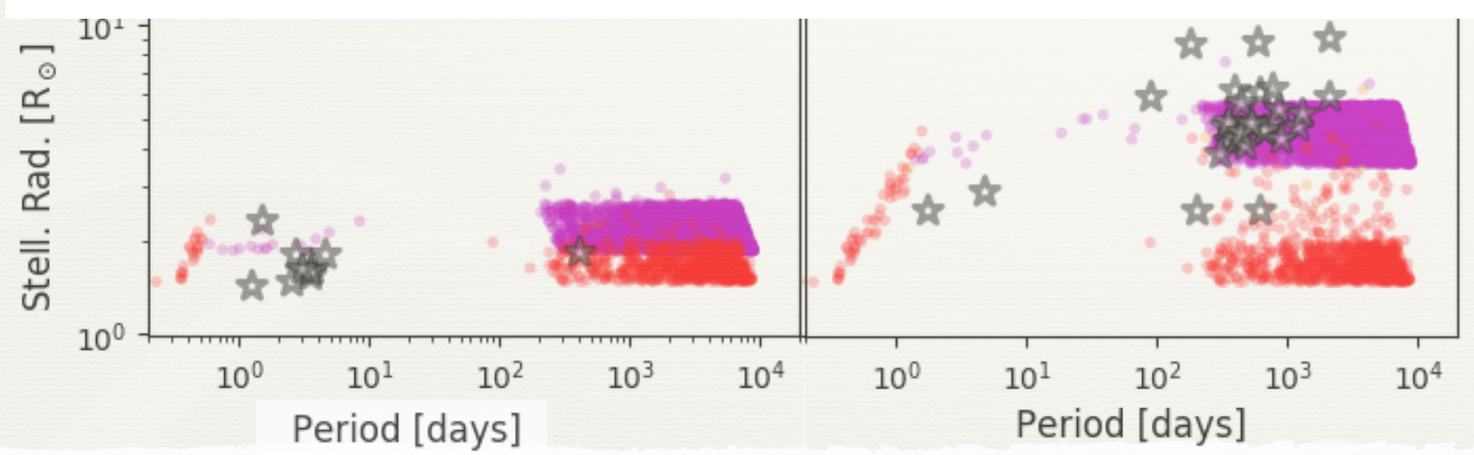

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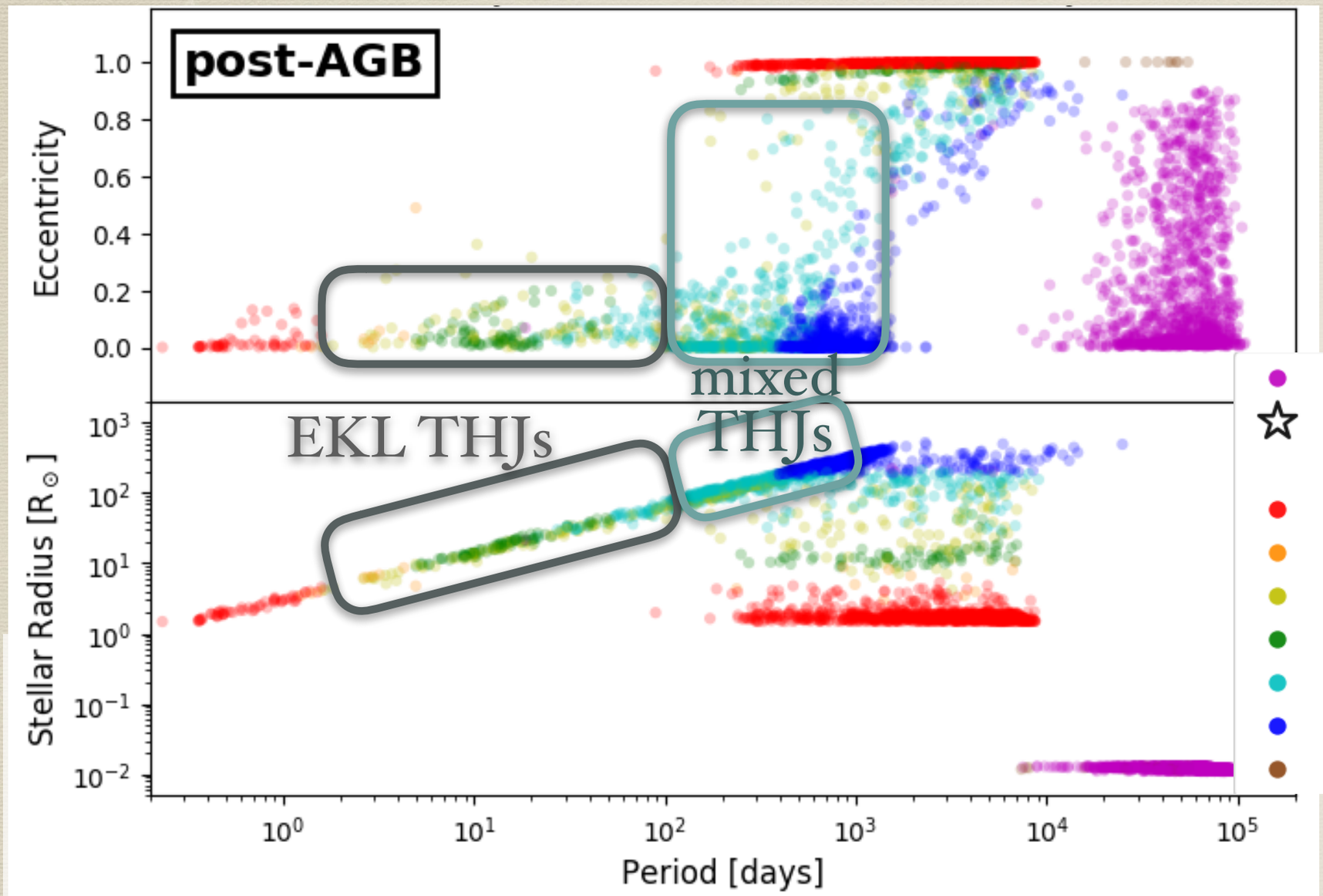

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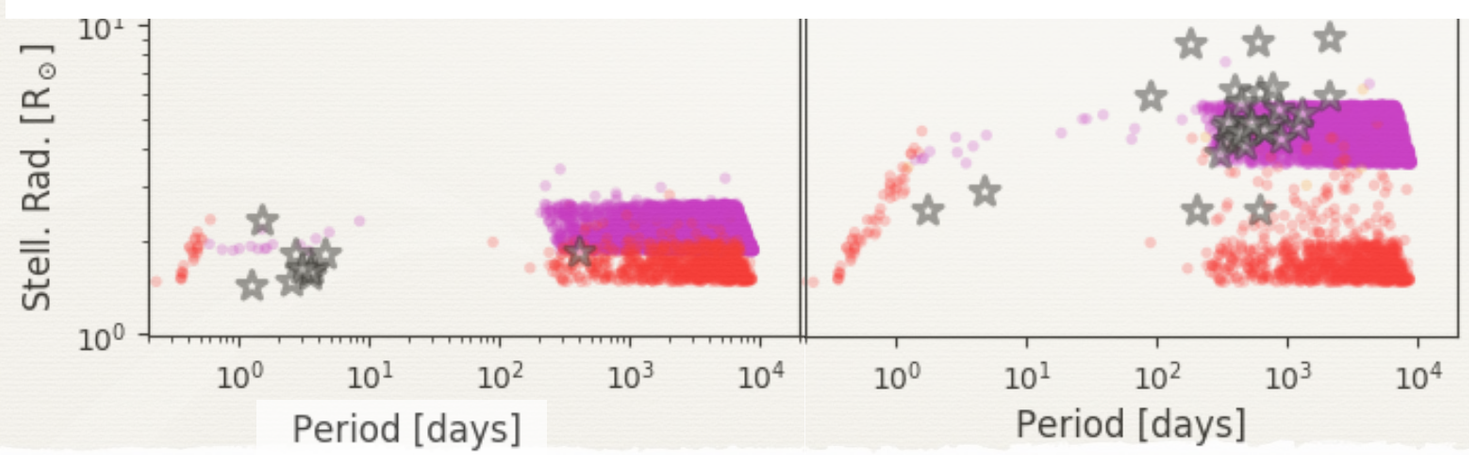

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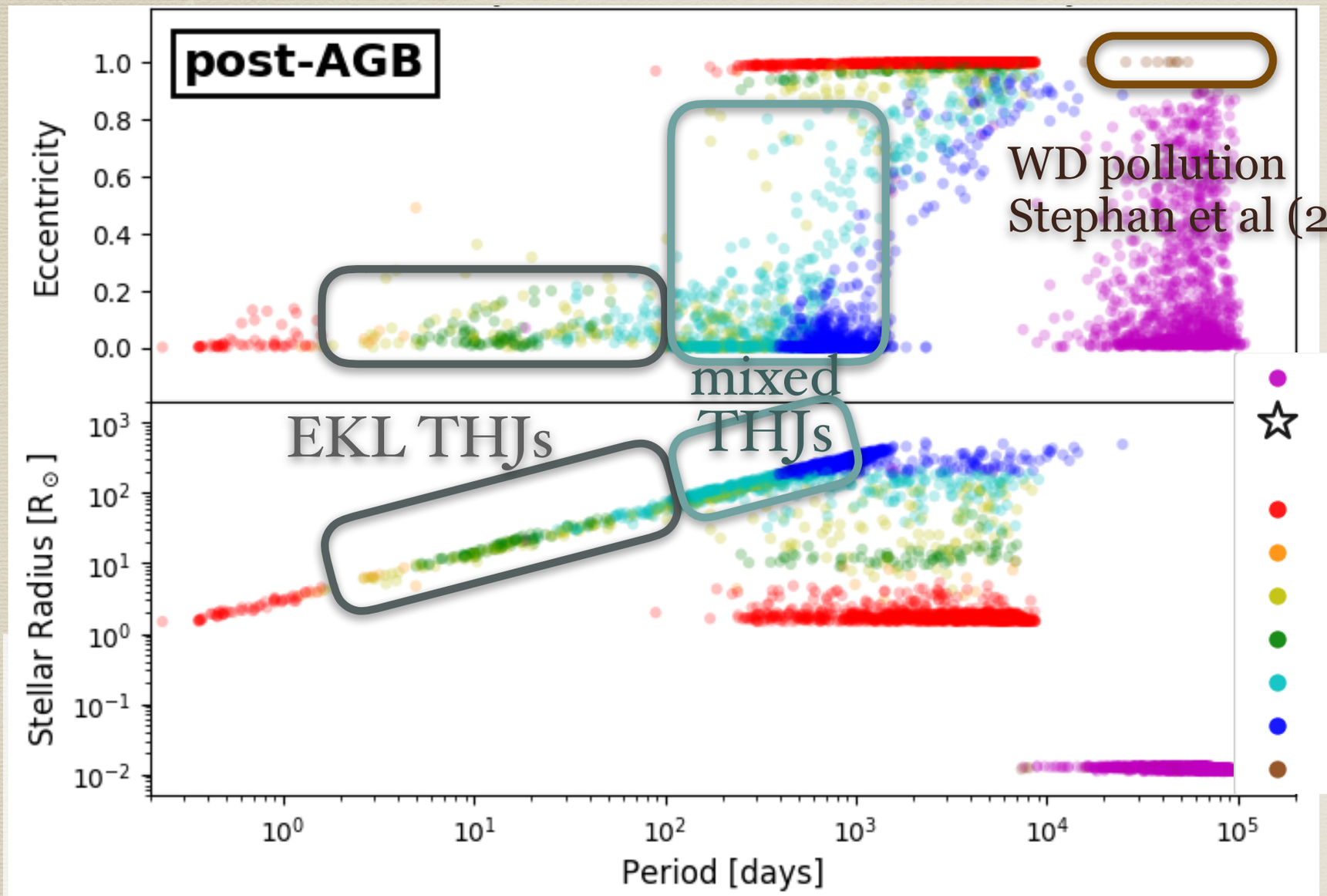

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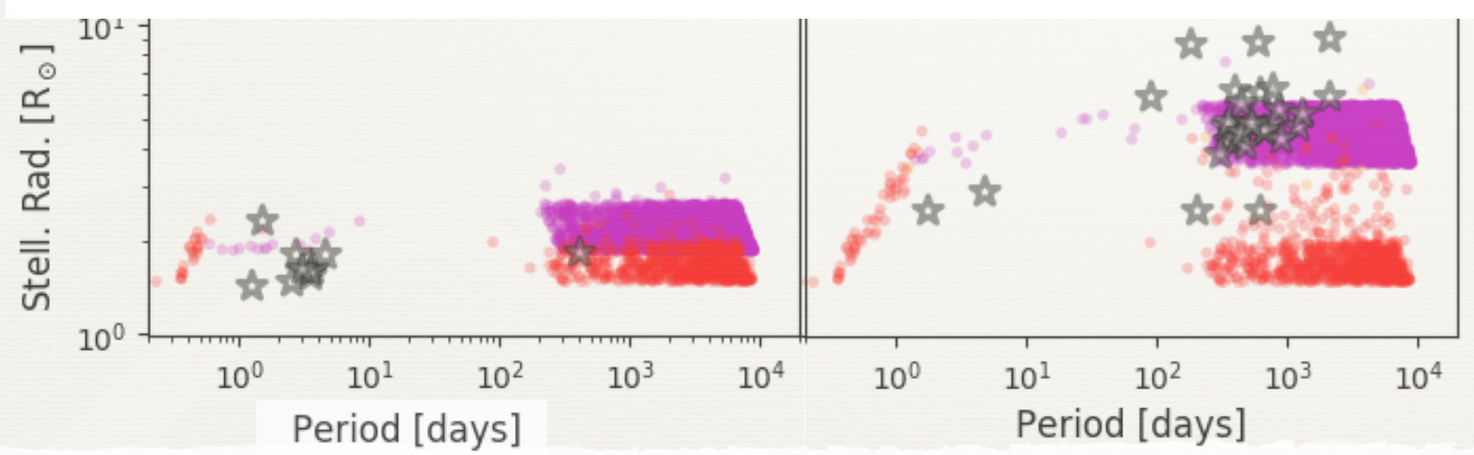

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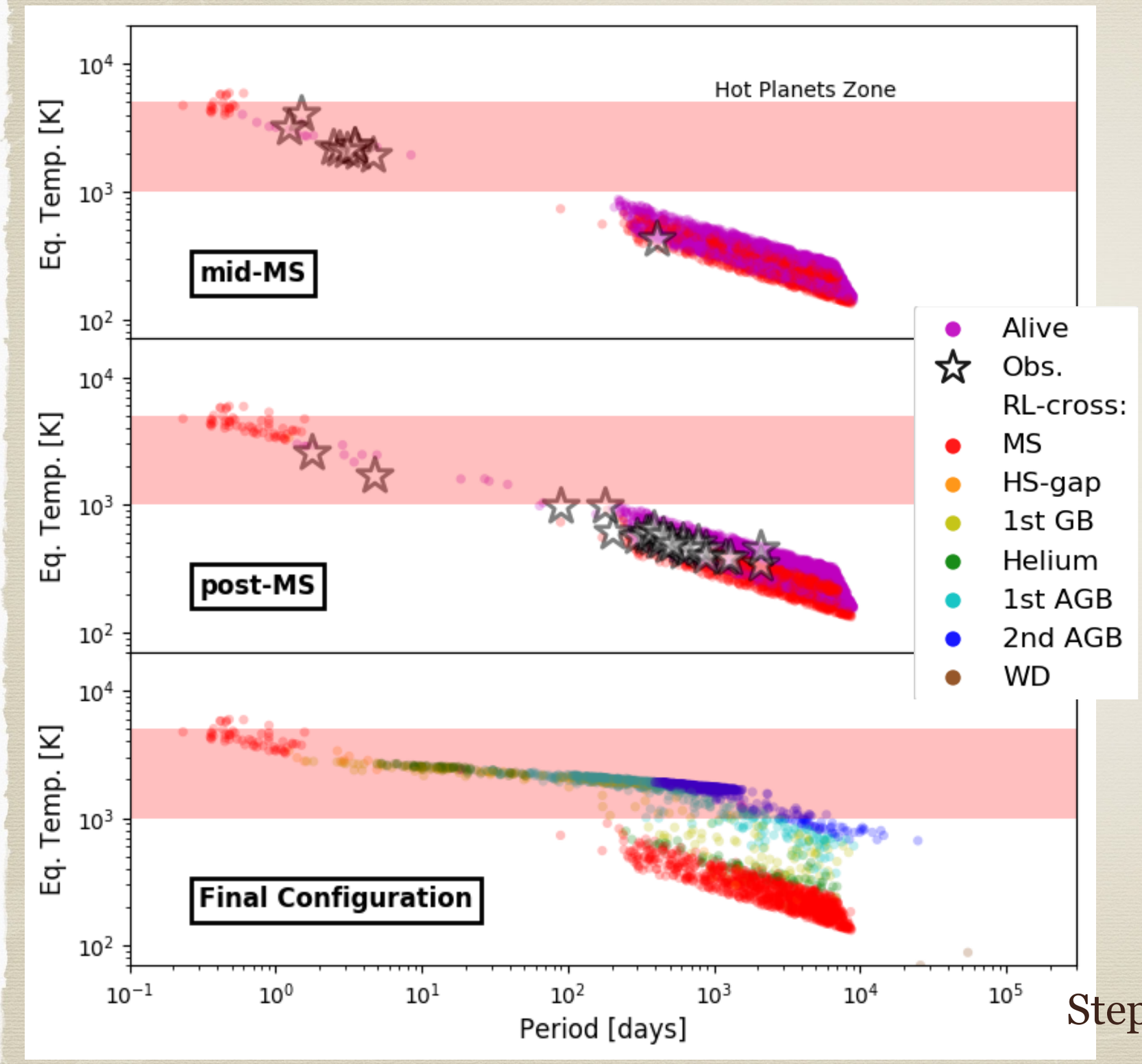

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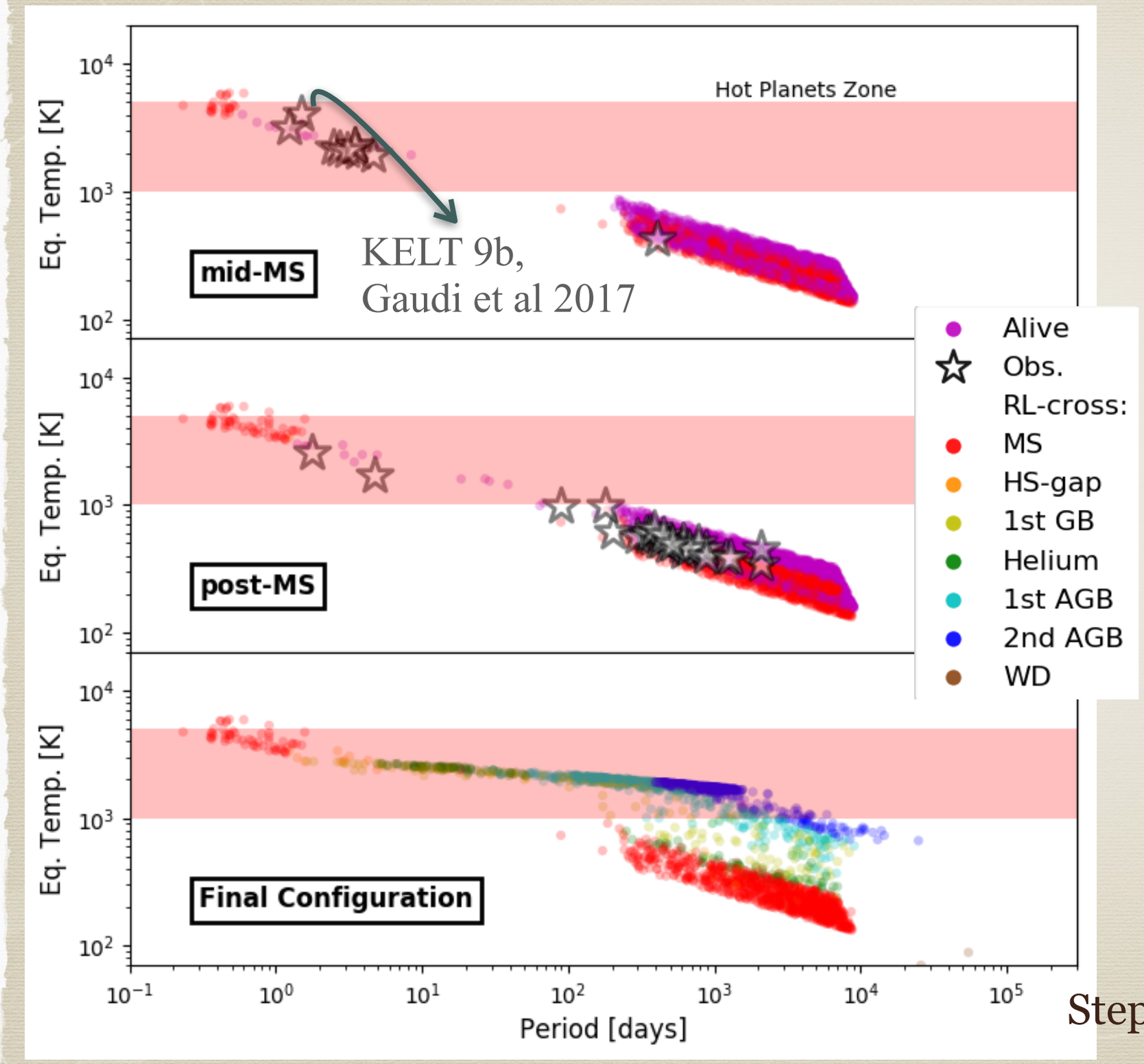

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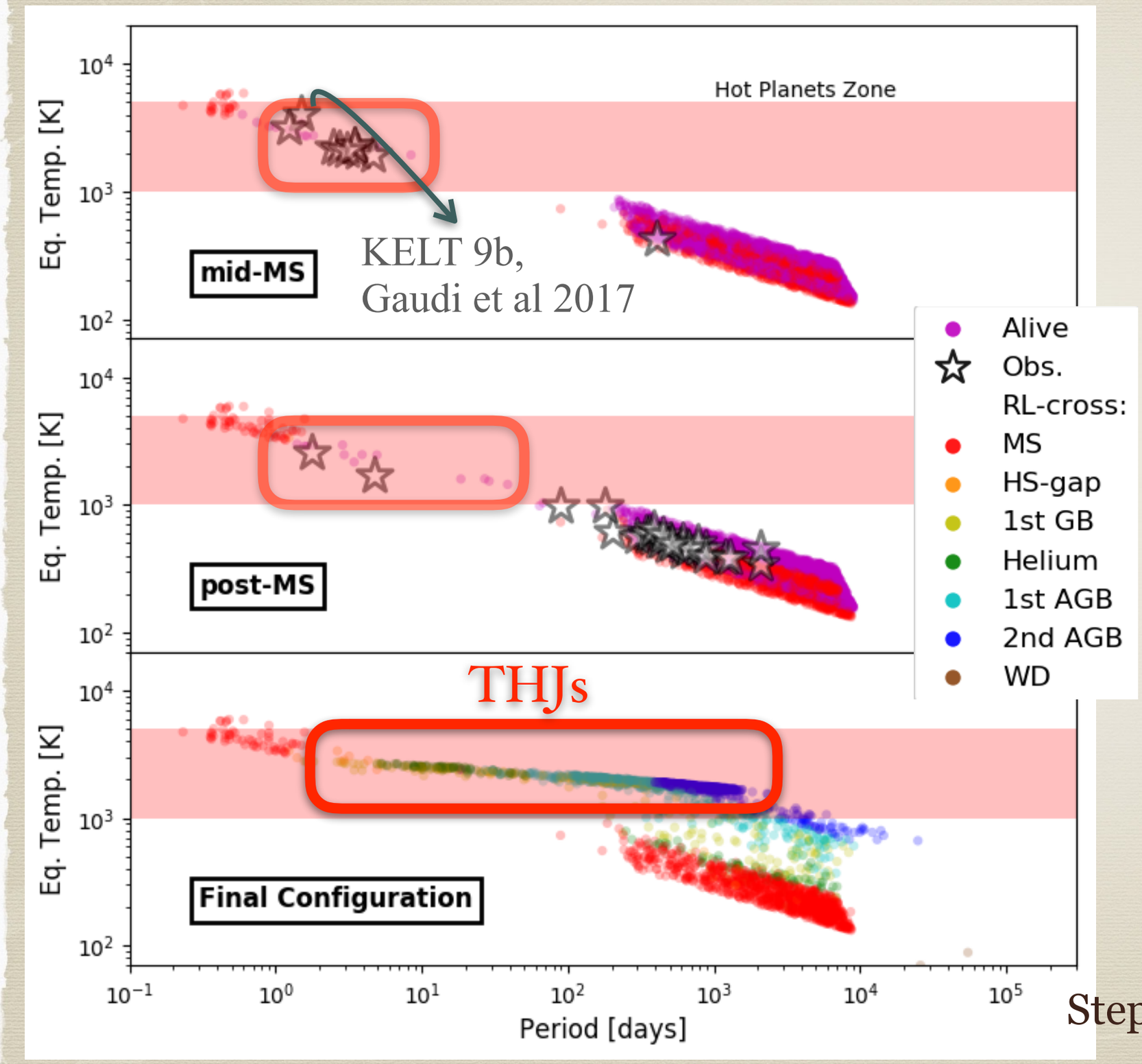

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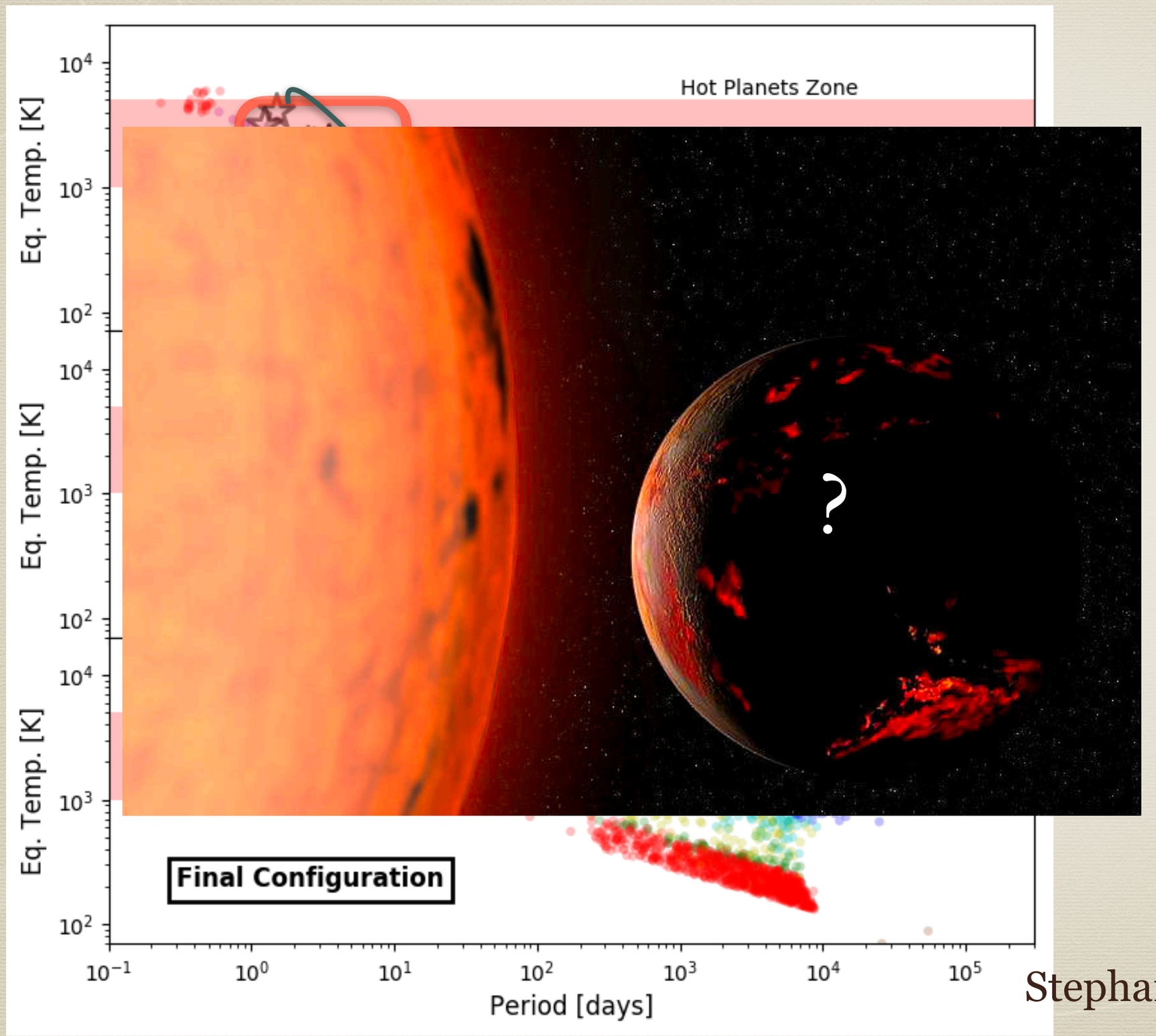

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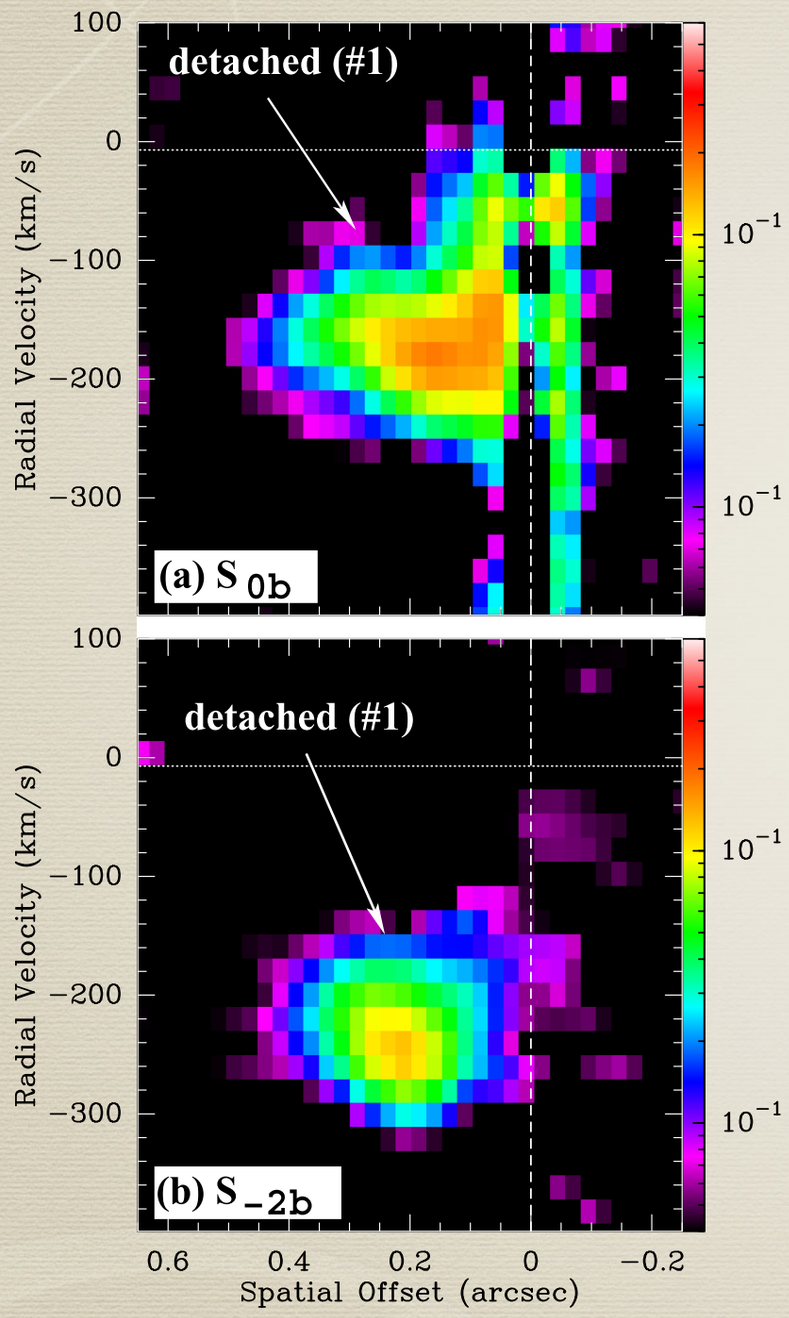
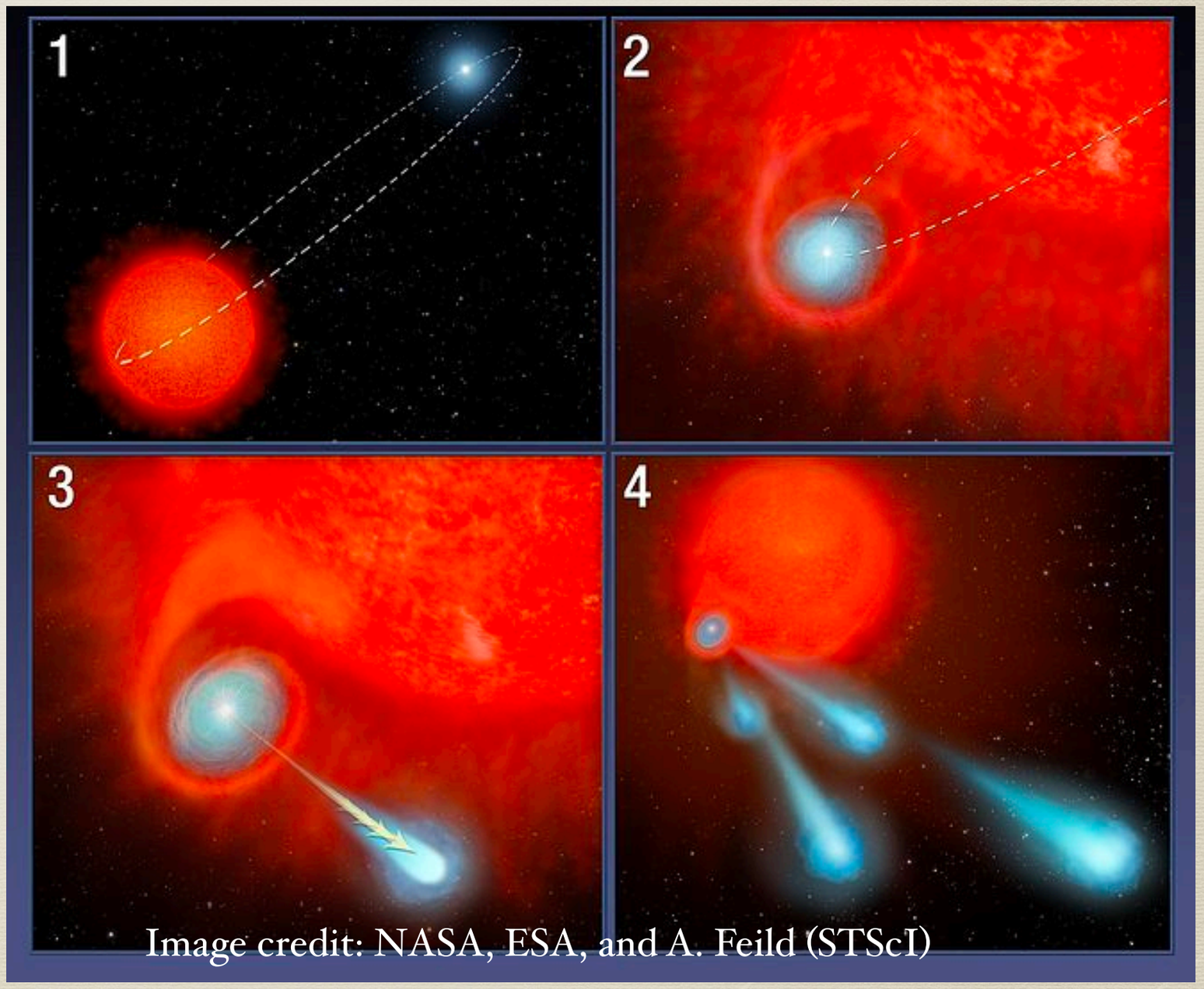
The death of THJ

V Hydrae star



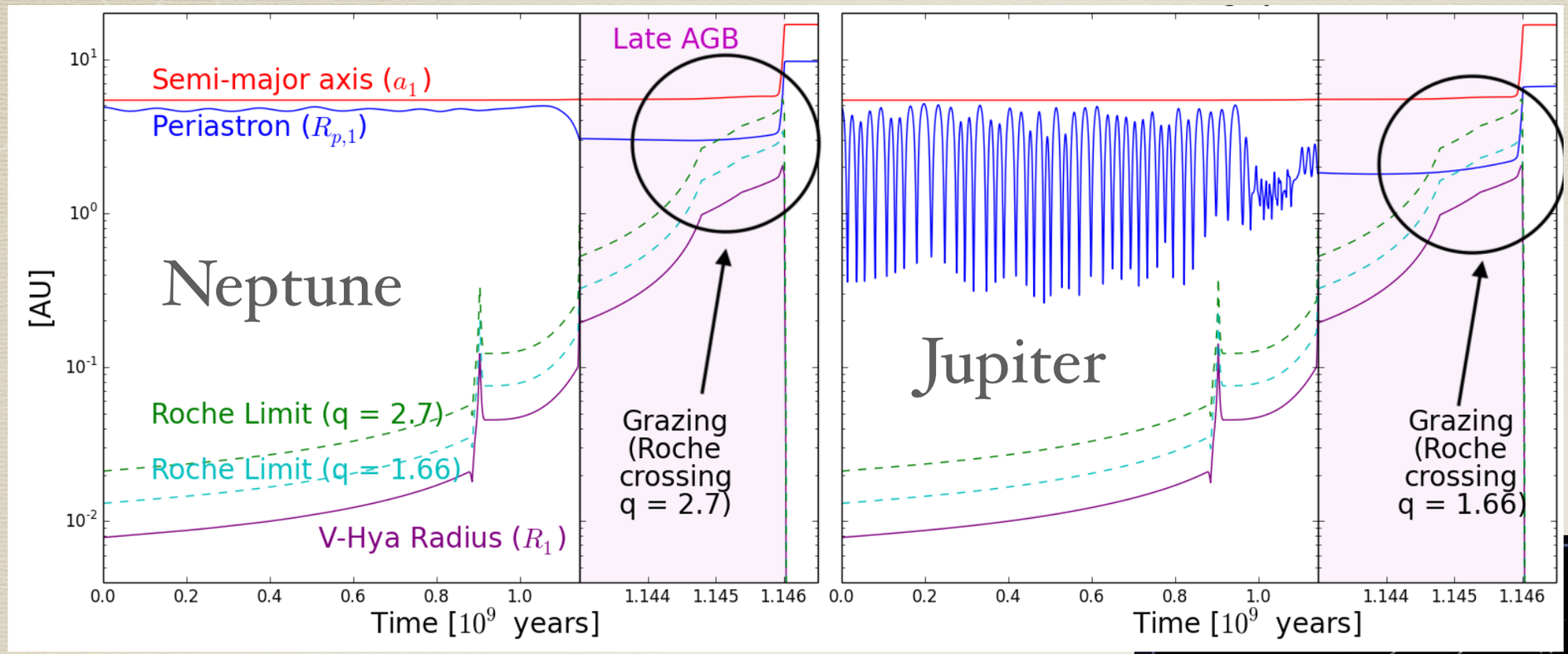
2002 STIS[S II]/4069.7 line emission color-bar intensities erg s^{-1} cm^{-2} Å^{-1} $arcsec^{-2}$

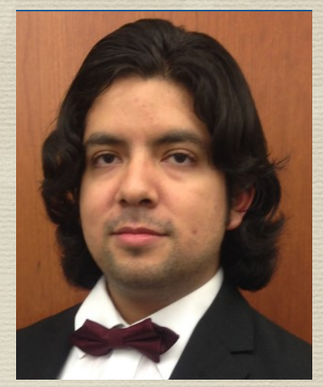


Sahai et al. 2016

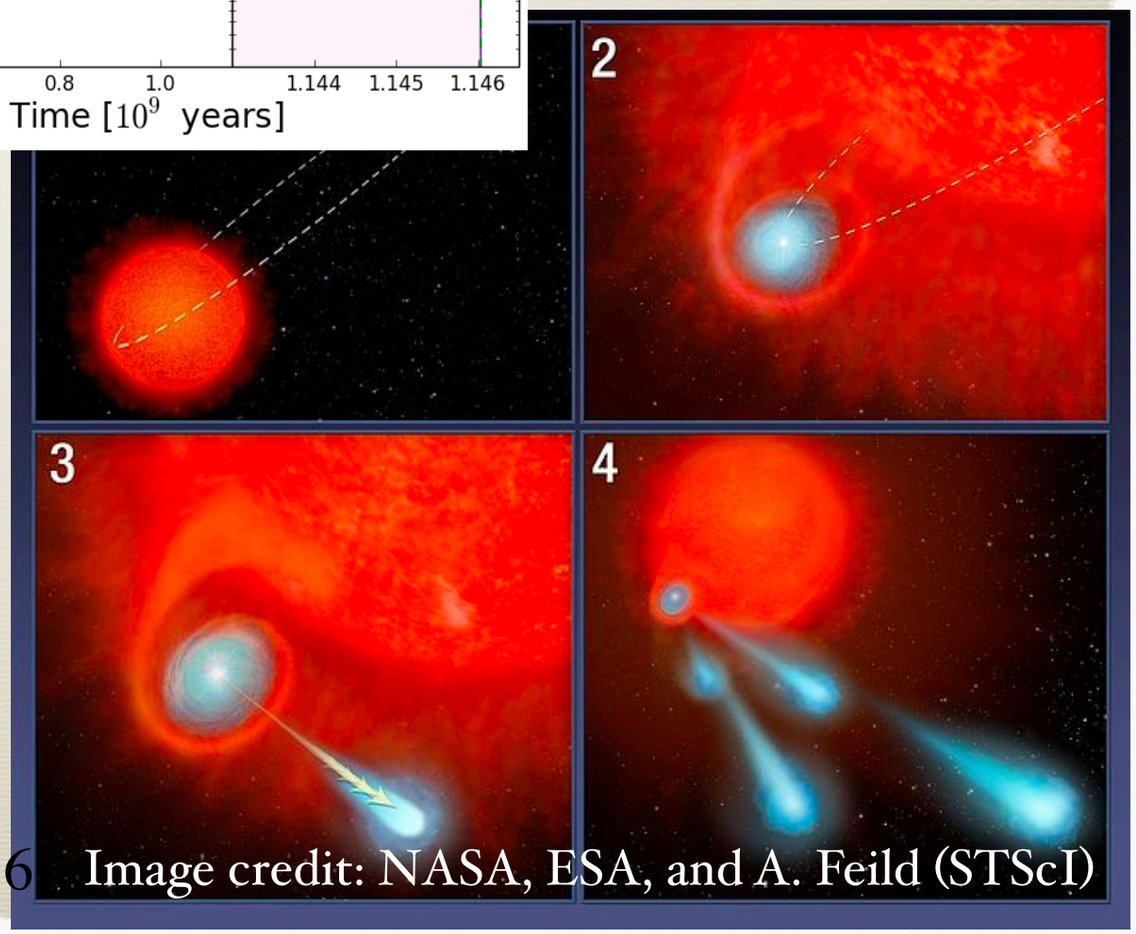
The death of THJ

V Hydrae star





Jesus Salas



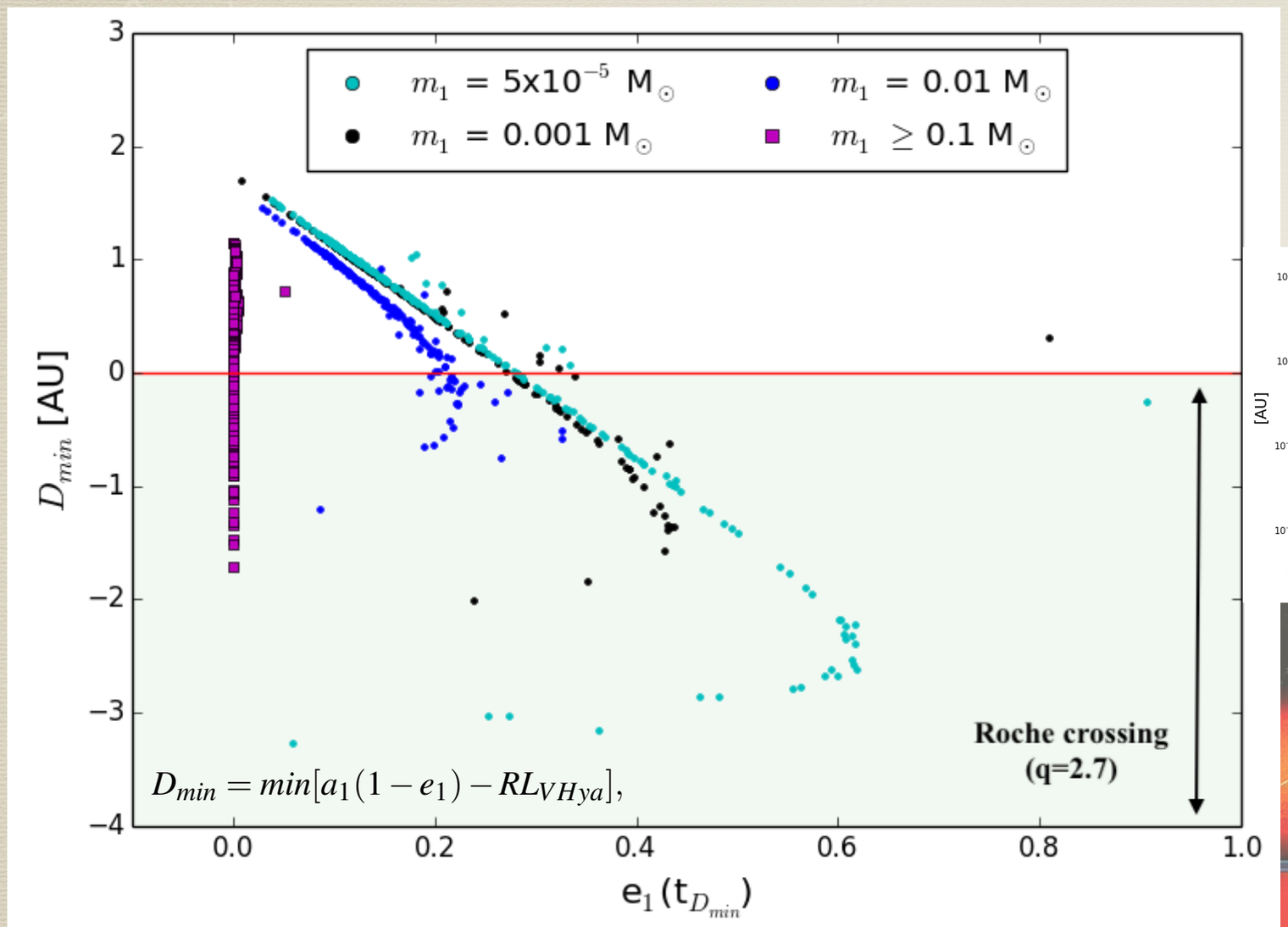
Salas, **Naoz** et al (2019)

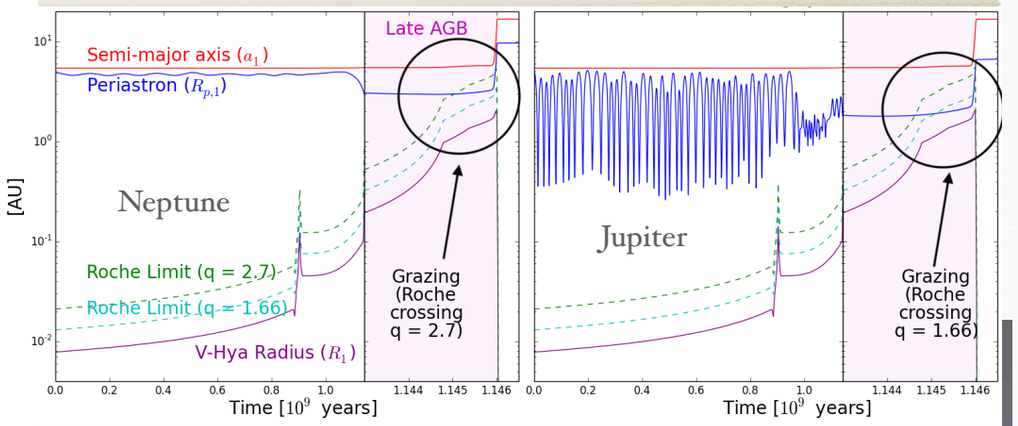
e.g., Sahai et al. 2016

The death of THJ

V Hydrae star

Jesus Salas





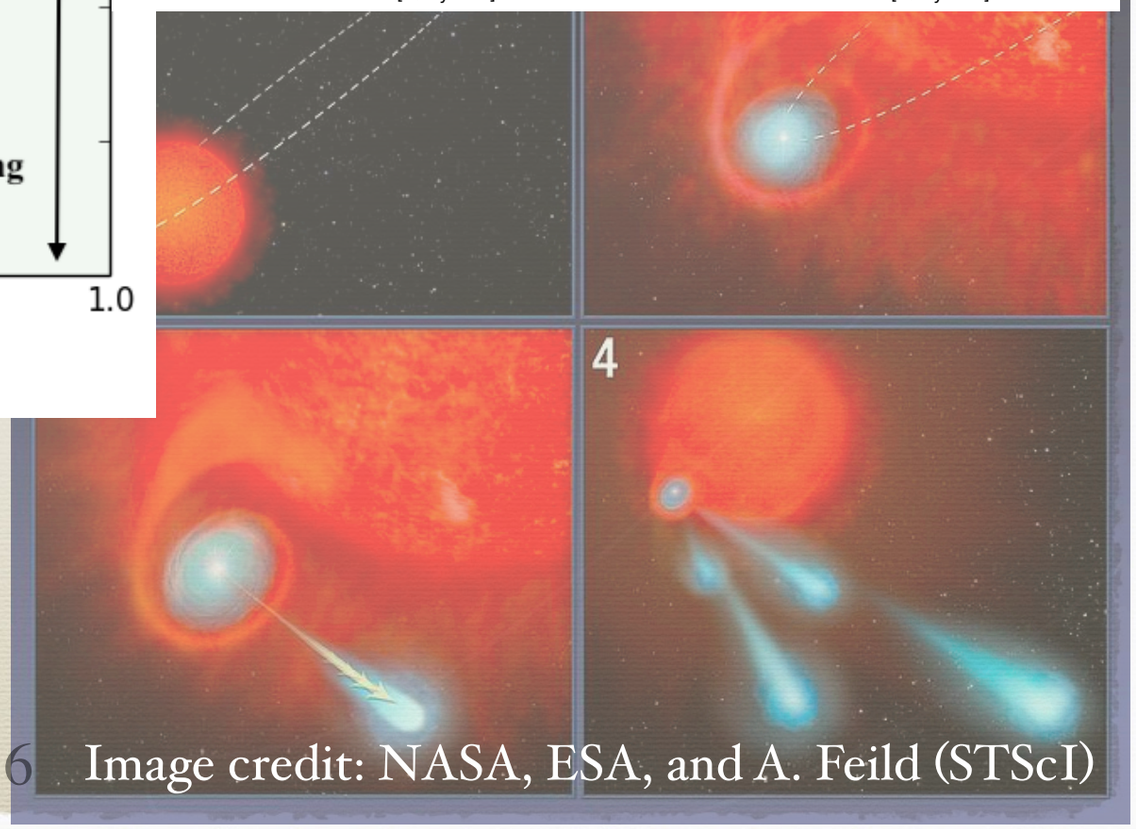


Image credit: NASA, ESA, and A. Feild (STScI)

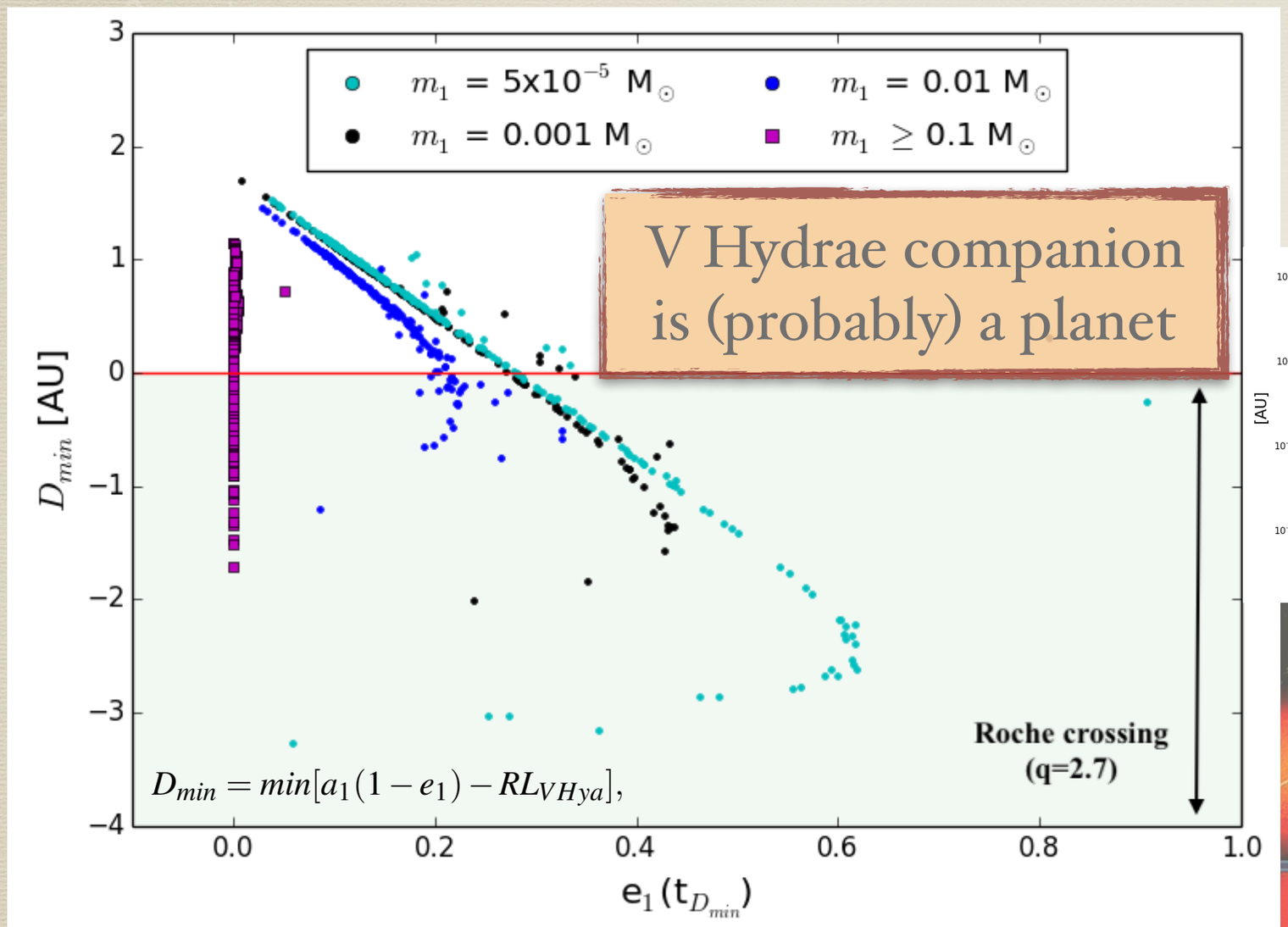
Salas, **Naoz** et al (2019)

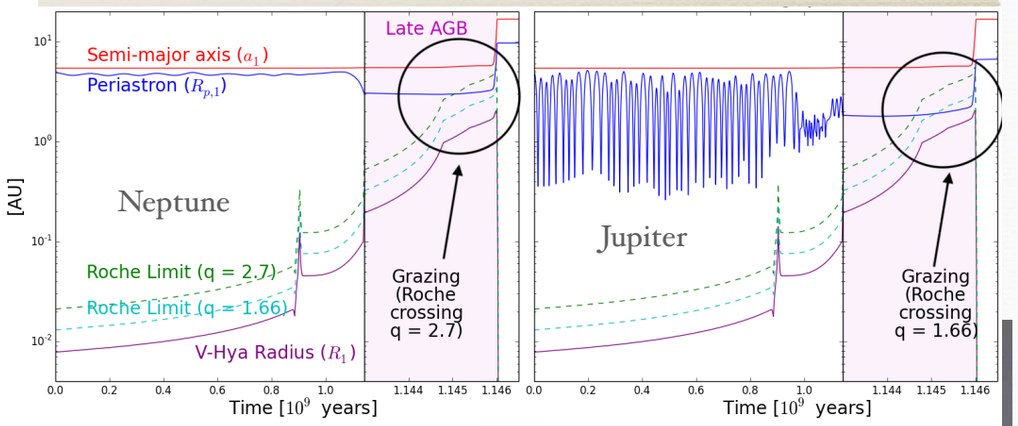
e.g., Sahai et al. 2016

The death of THJ

V Hydrae star

Jesus Salas





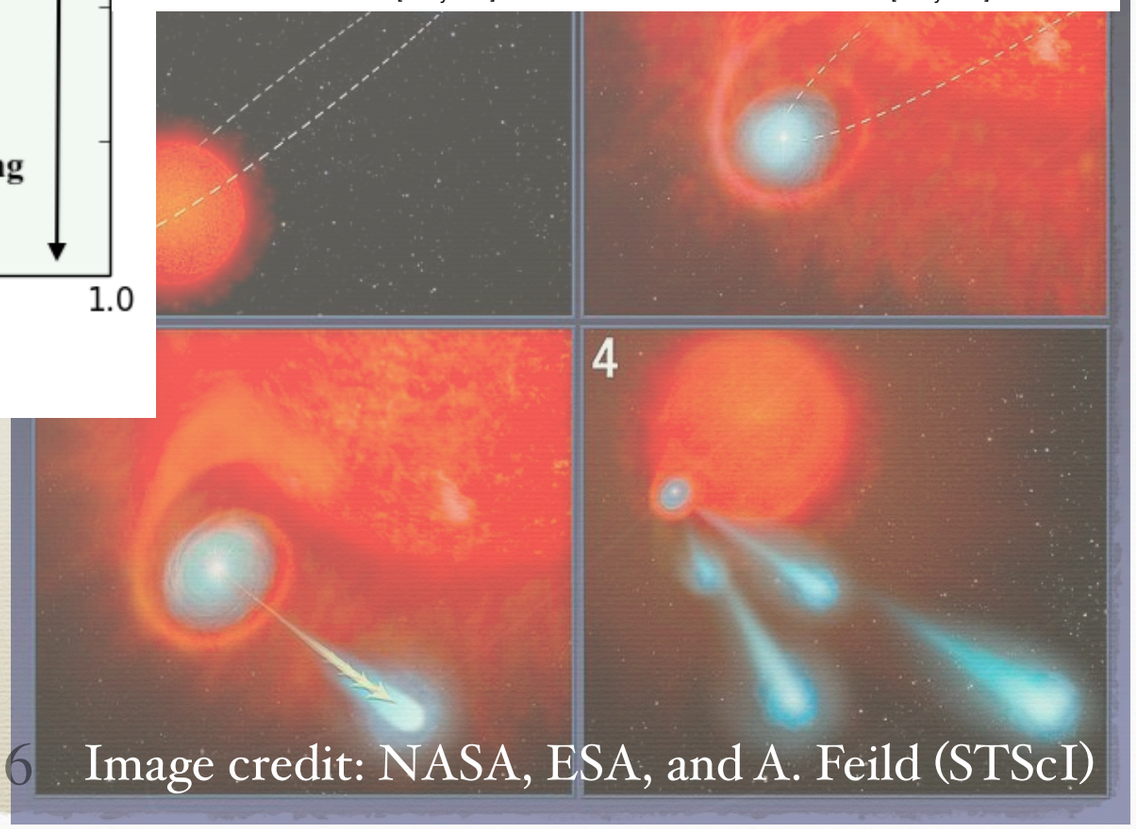
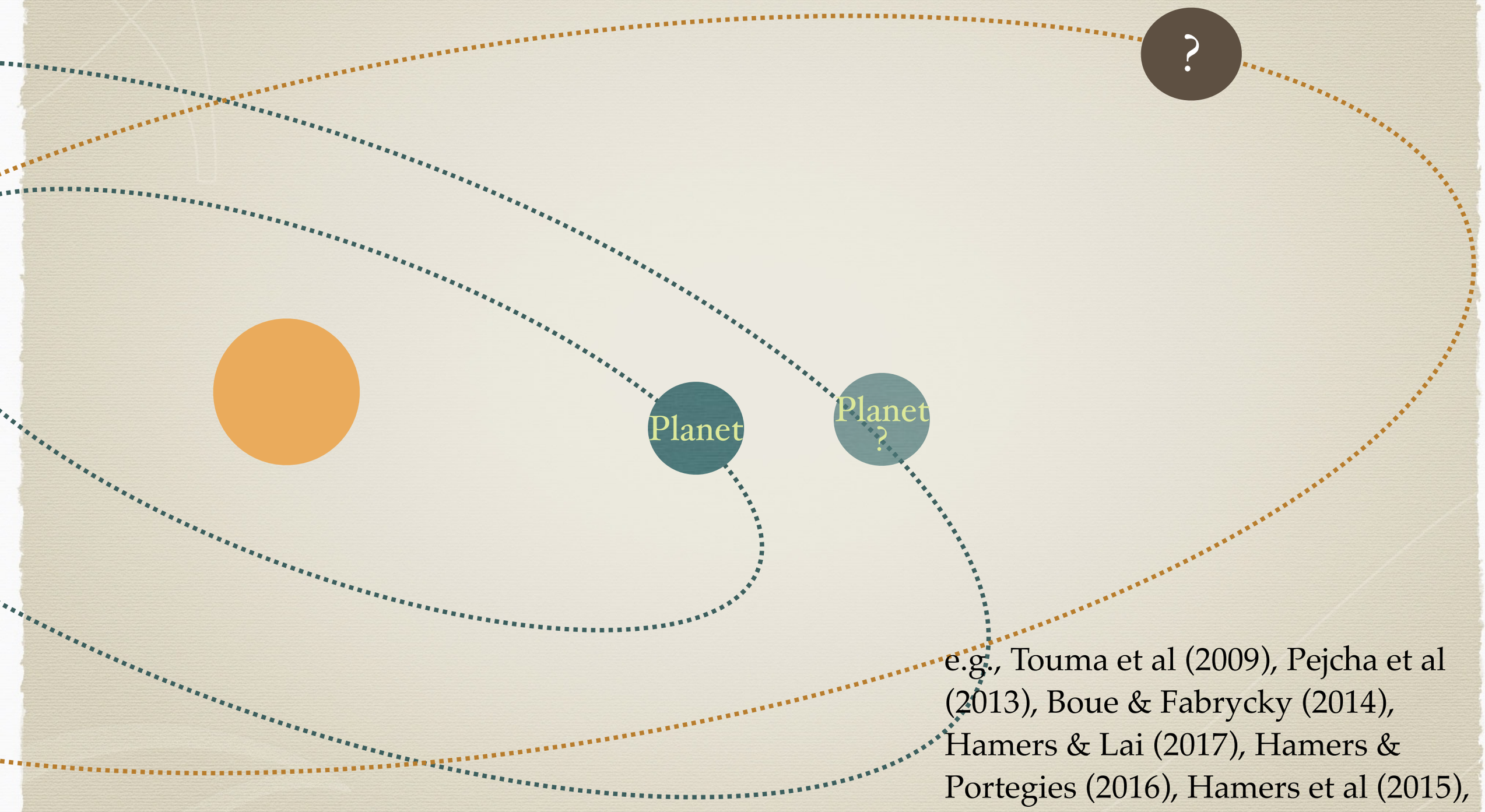


Image credit: NASA, ESA, and A. Feild (STScI)

Salas, **Naoz** et al (2019)

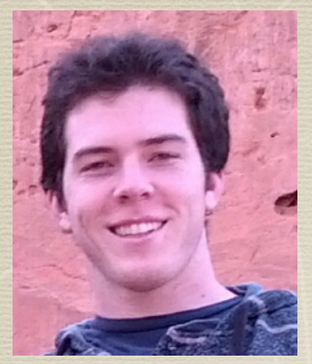
e.g., Sahai et al. 2016

Planet and stellar friends



e.g., Touma et al (2009), Pejcha et al (2013), Boue & Fabrycky (2014), Hamers & Lai (2017), Hamers & Portegies (2016), Hamers et al (2015), Nesvold, **Naoz** et al (2016), Pu & Lai (2018), Denham, **Naoz** et al (2018)

Planet and stellar friends

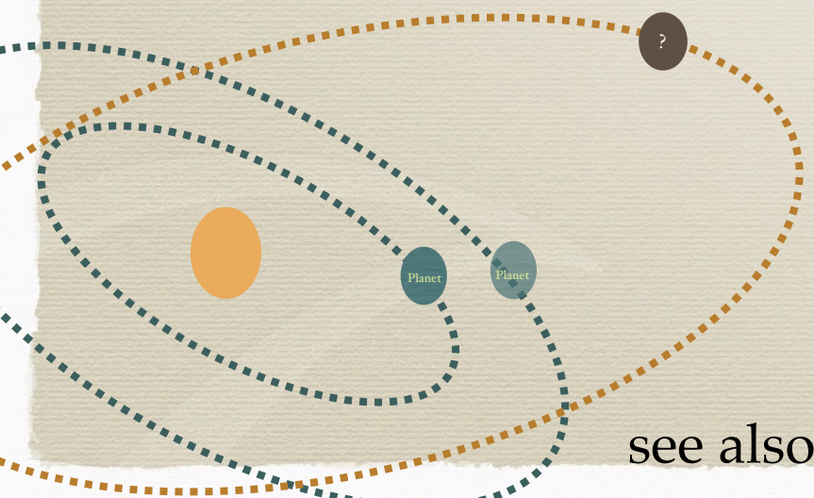


Paul Denham

Alexander Stephan

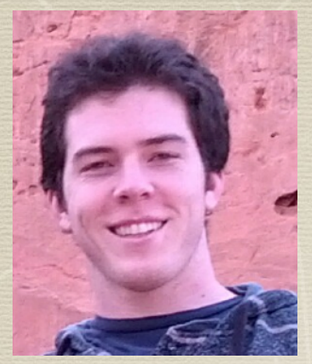
Bao-Minh Hoang

Denham, **Naoz** et al (2019)



see also Lai & Pu (2017) Pu & Lai (2018)

Planet and stellar friends



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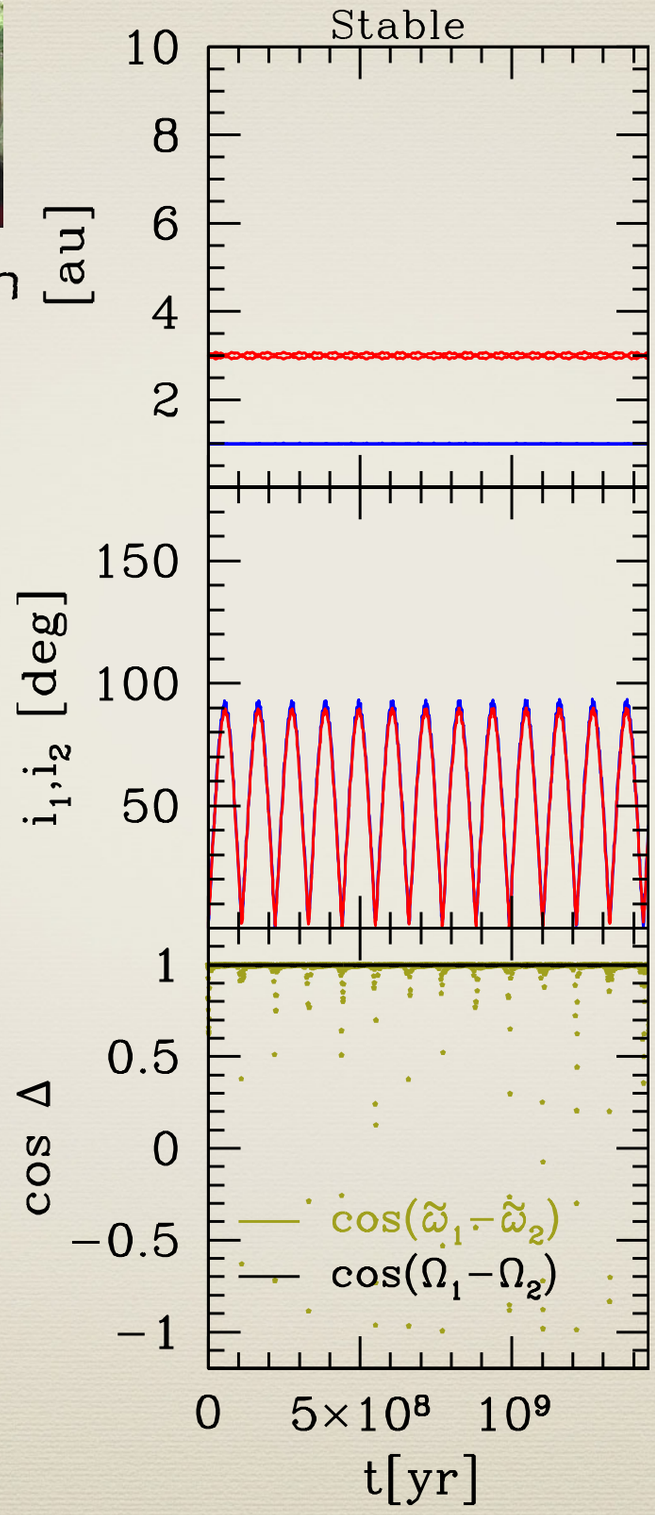

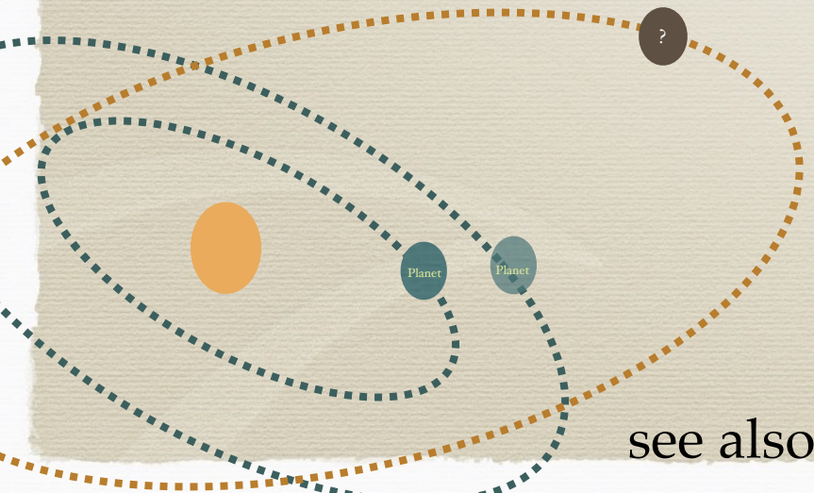

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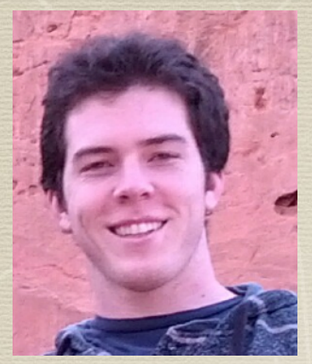
Planet and stellar friends



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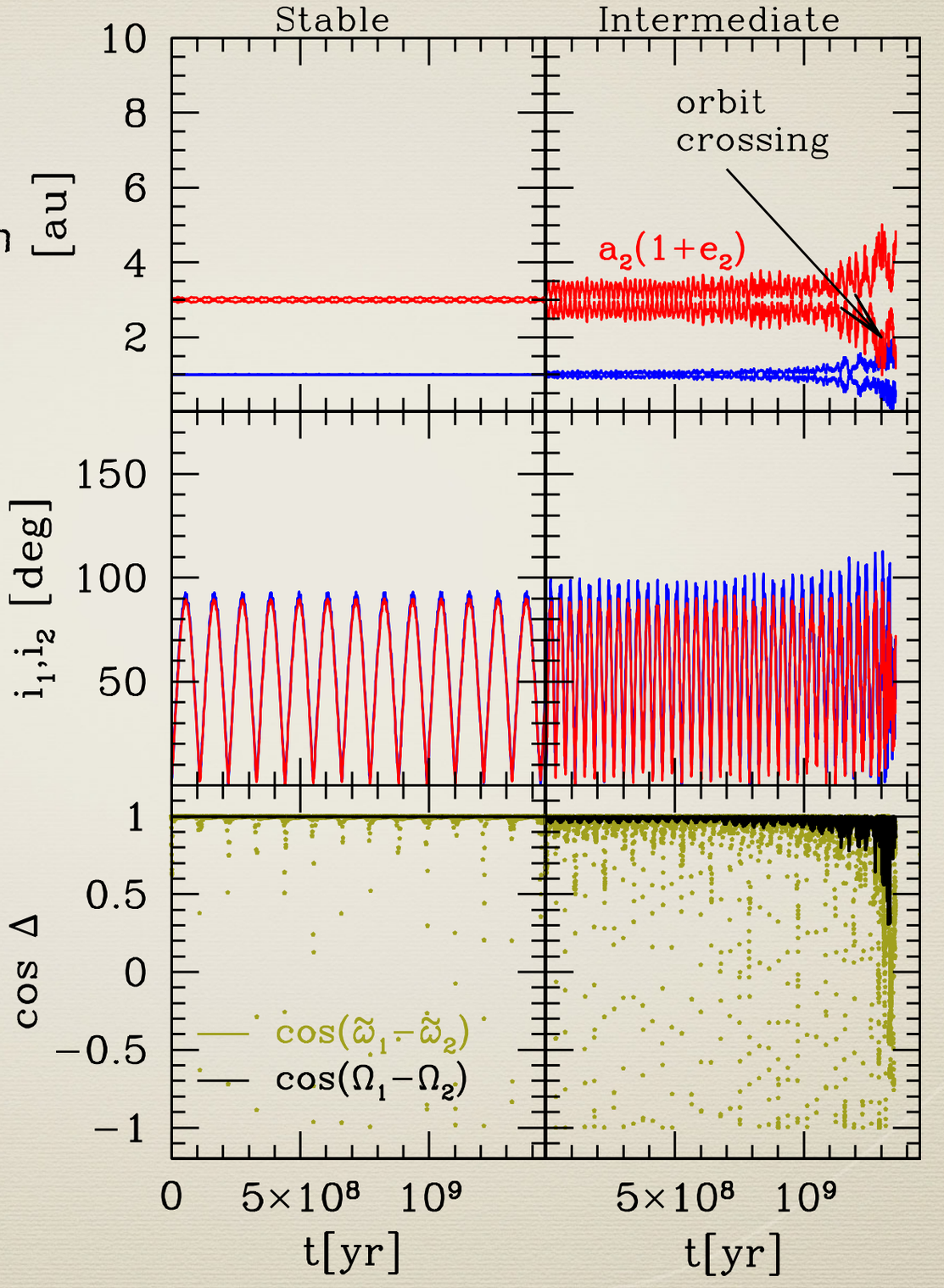

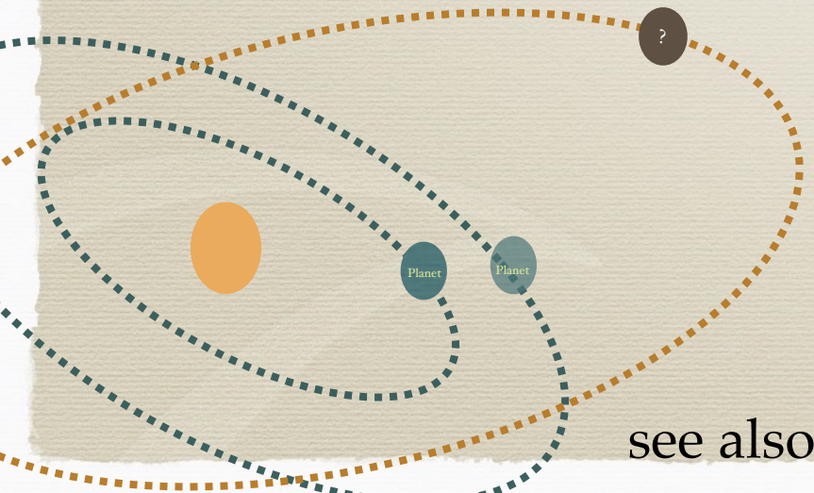

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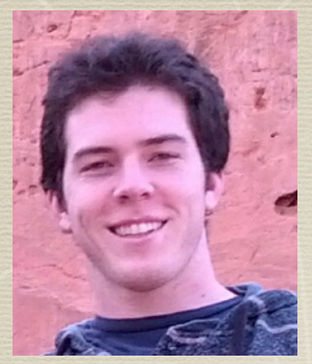
Planet and stellar friends



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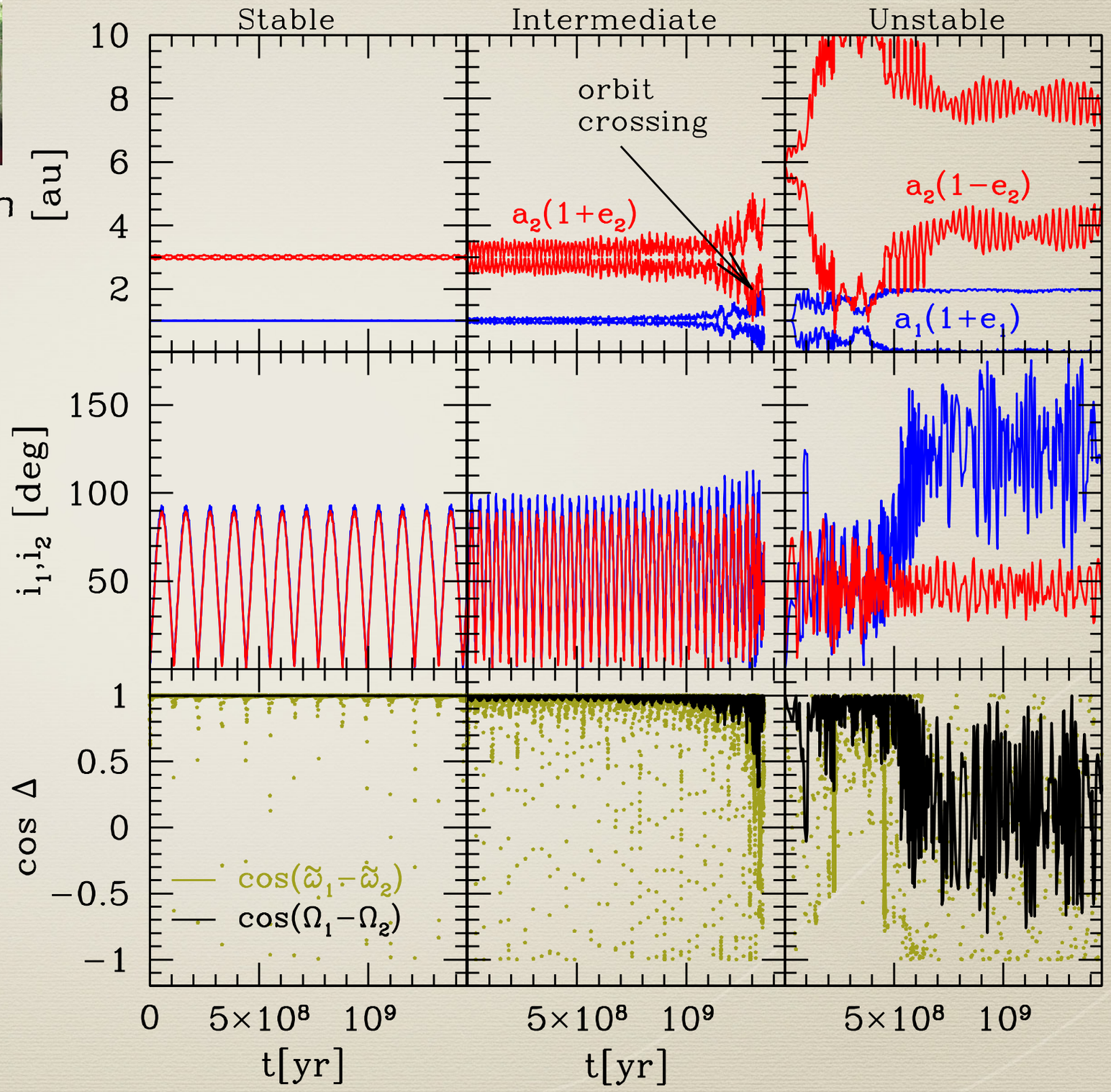

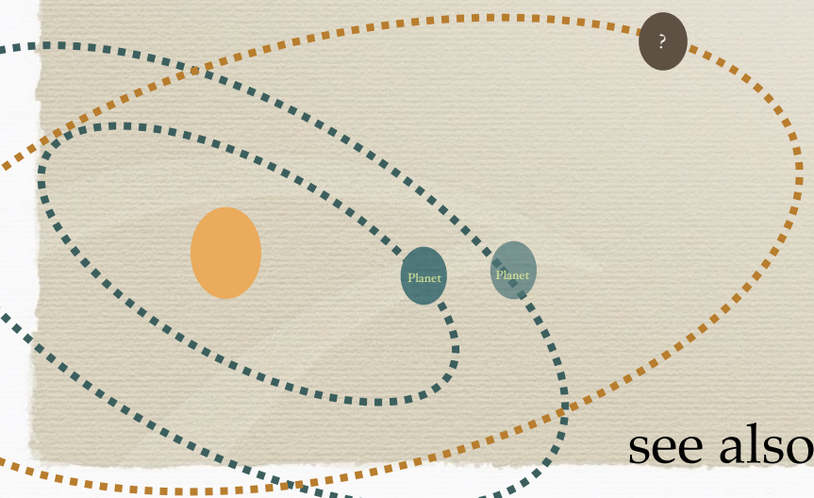

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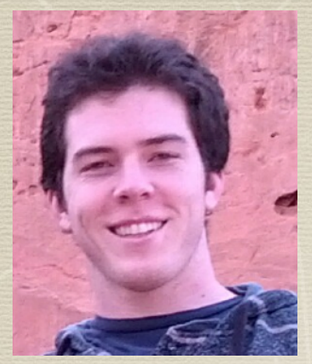
Planet and stellar friends



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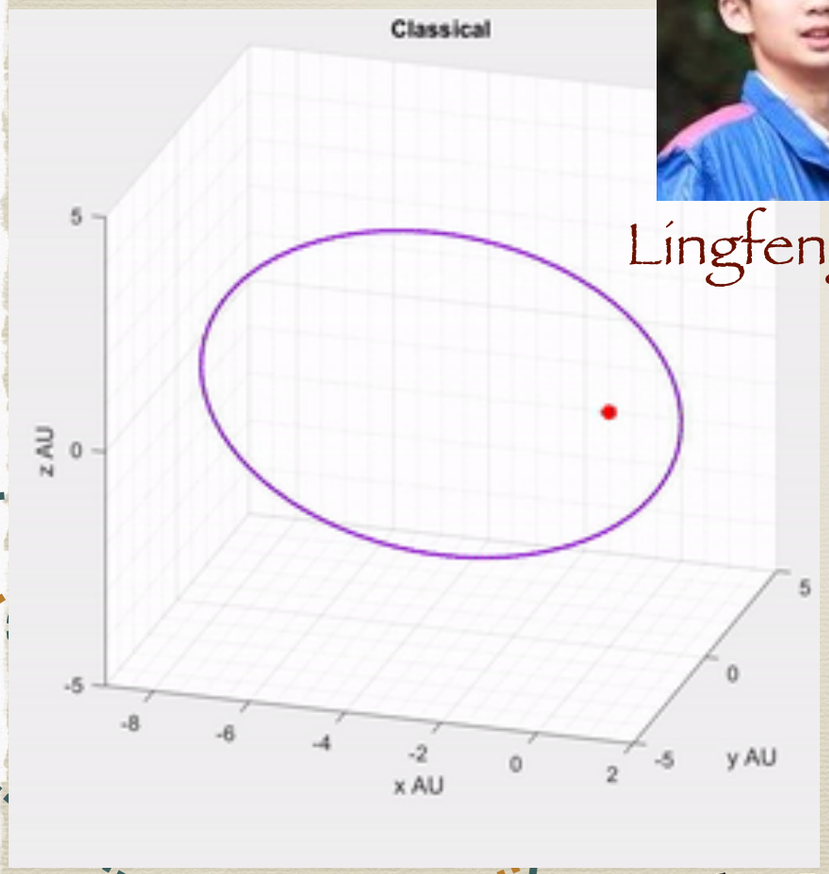
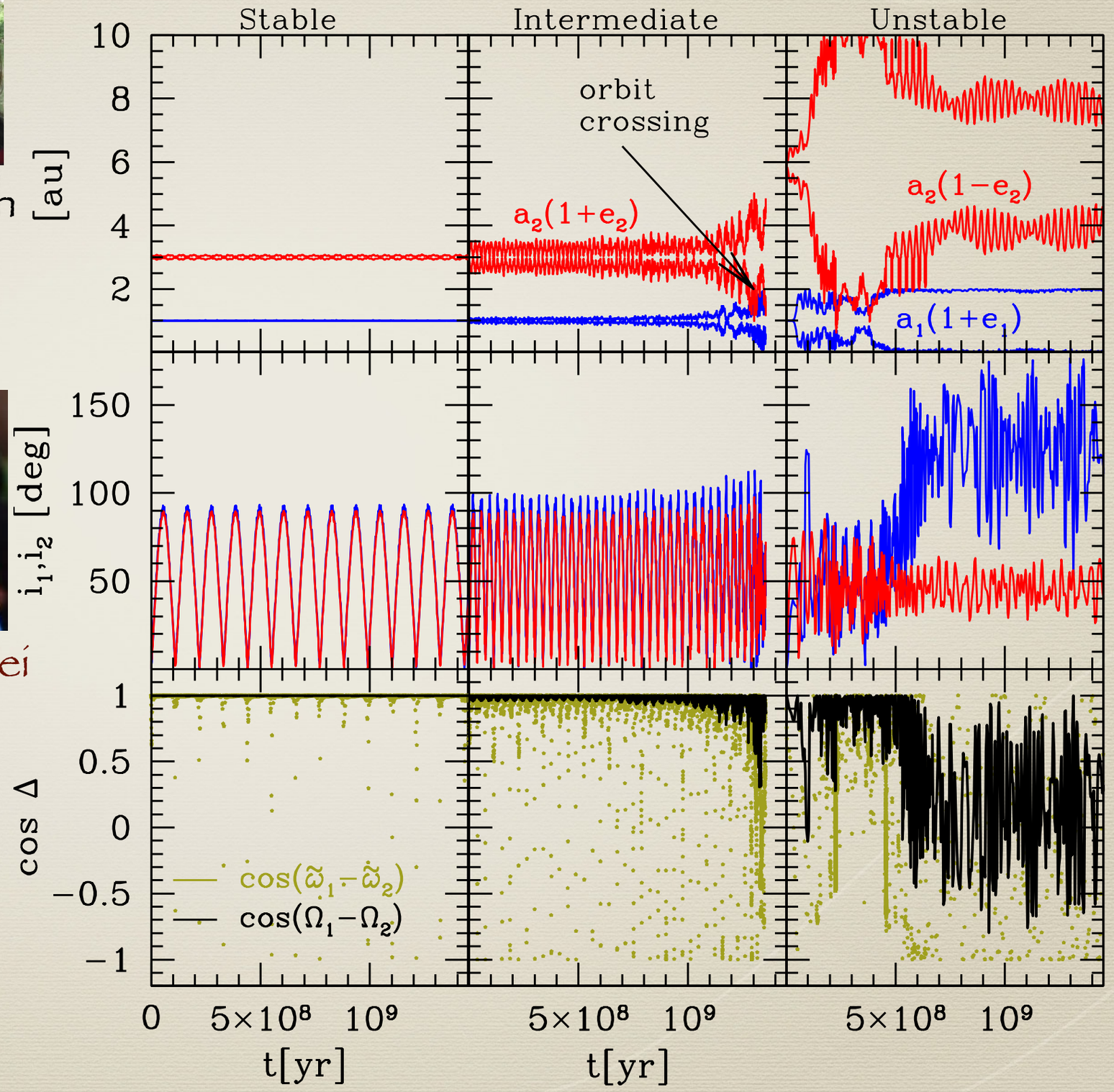
Lingfeng Wei





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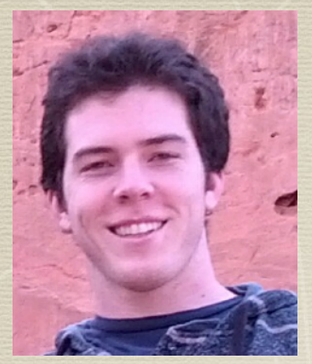

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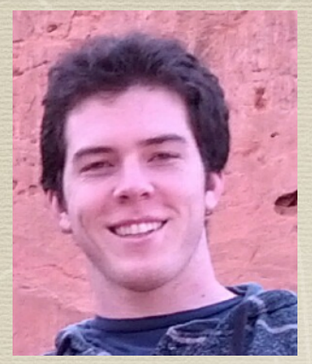
Planet and stellar friends



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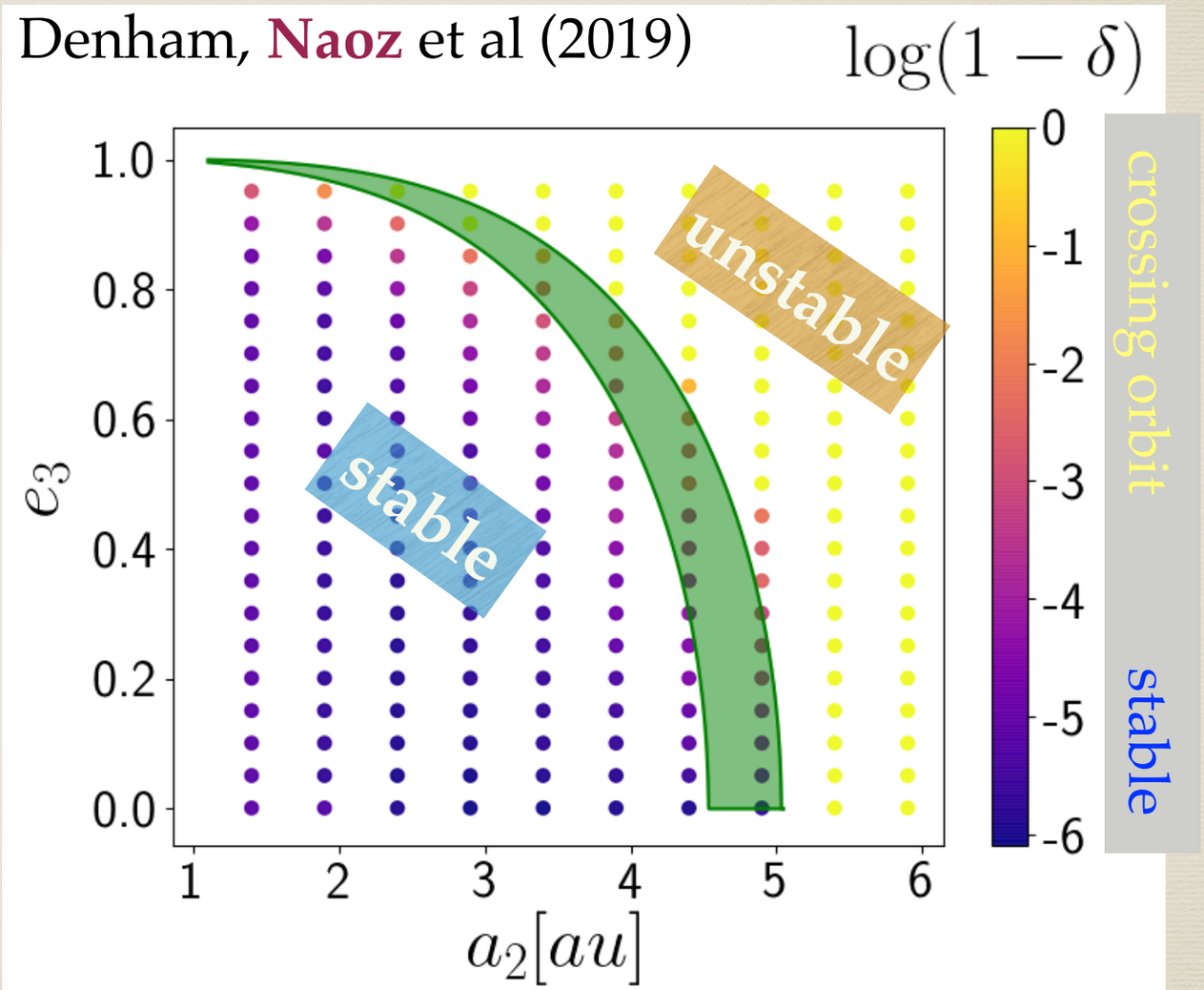

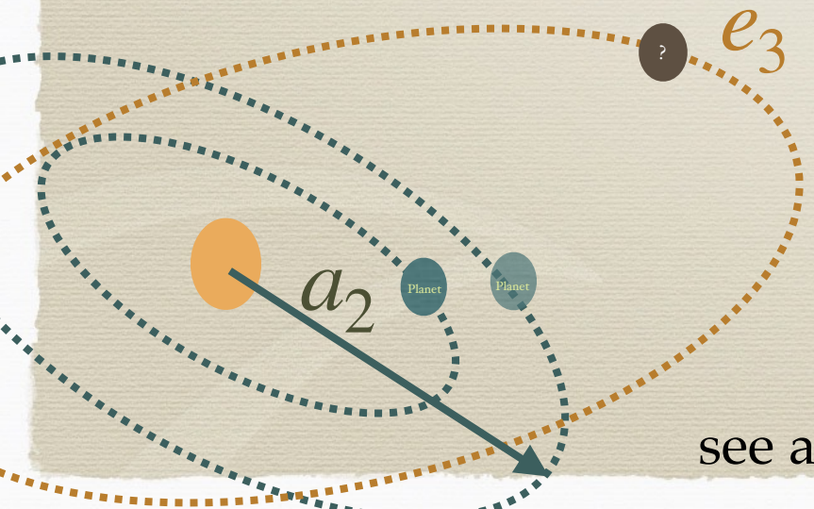

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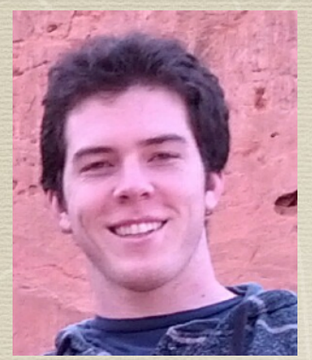
Planet and stellar friends



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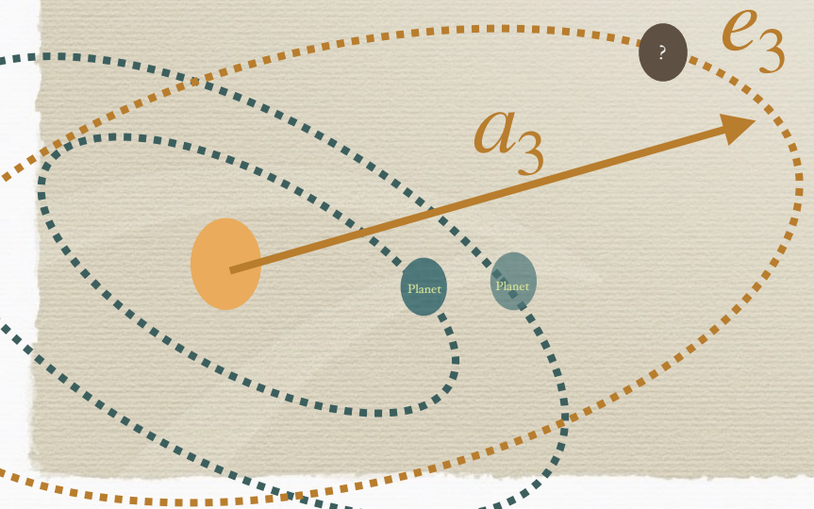
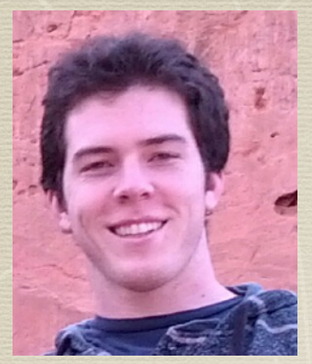
Hidden friends



Planet and stellar friends



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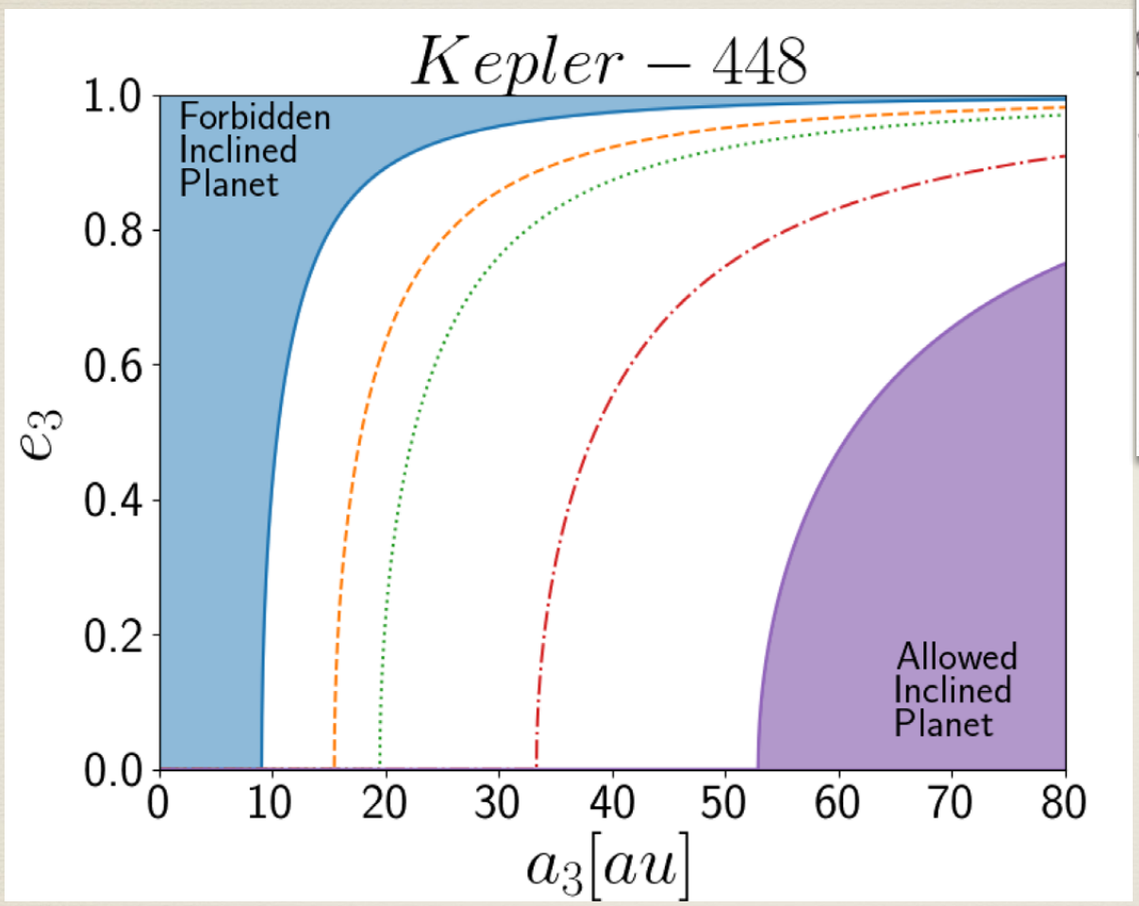
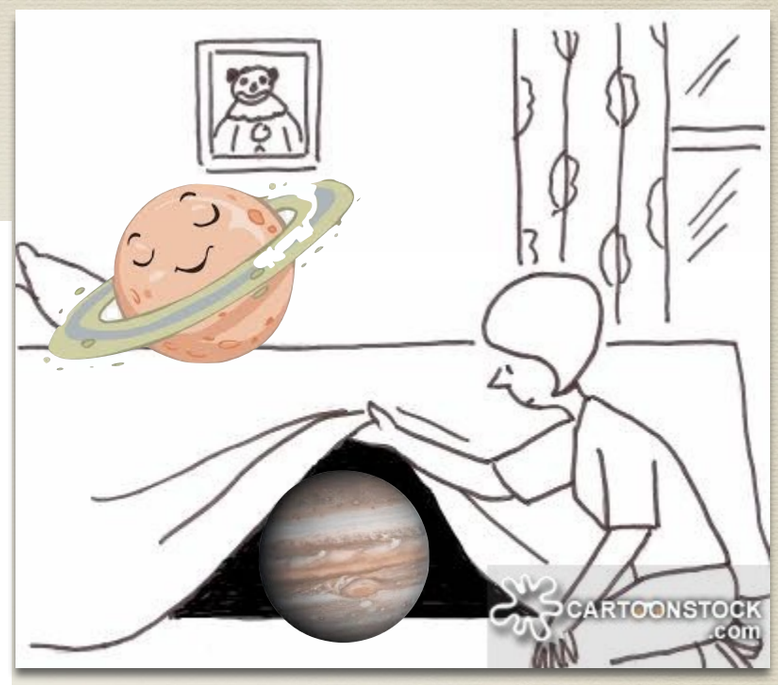
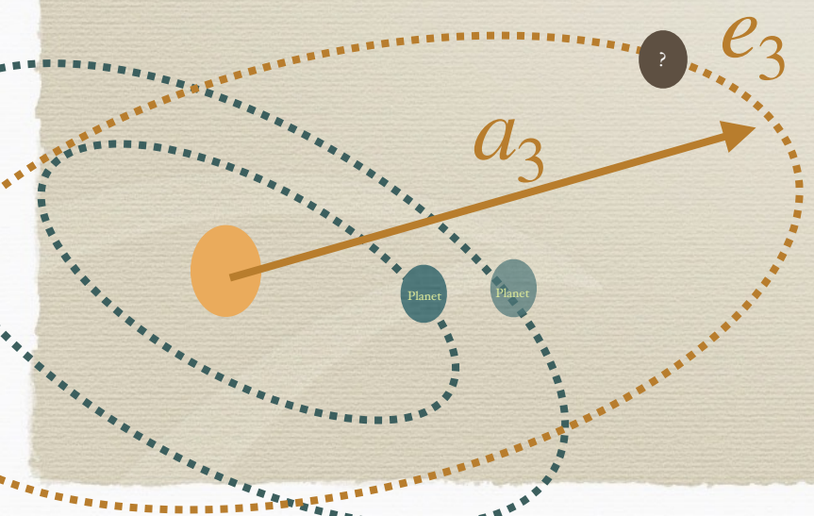


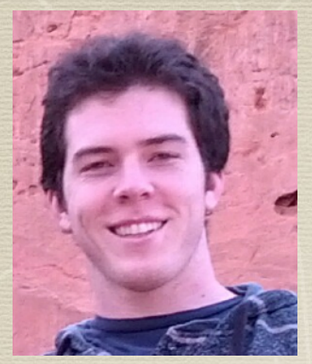




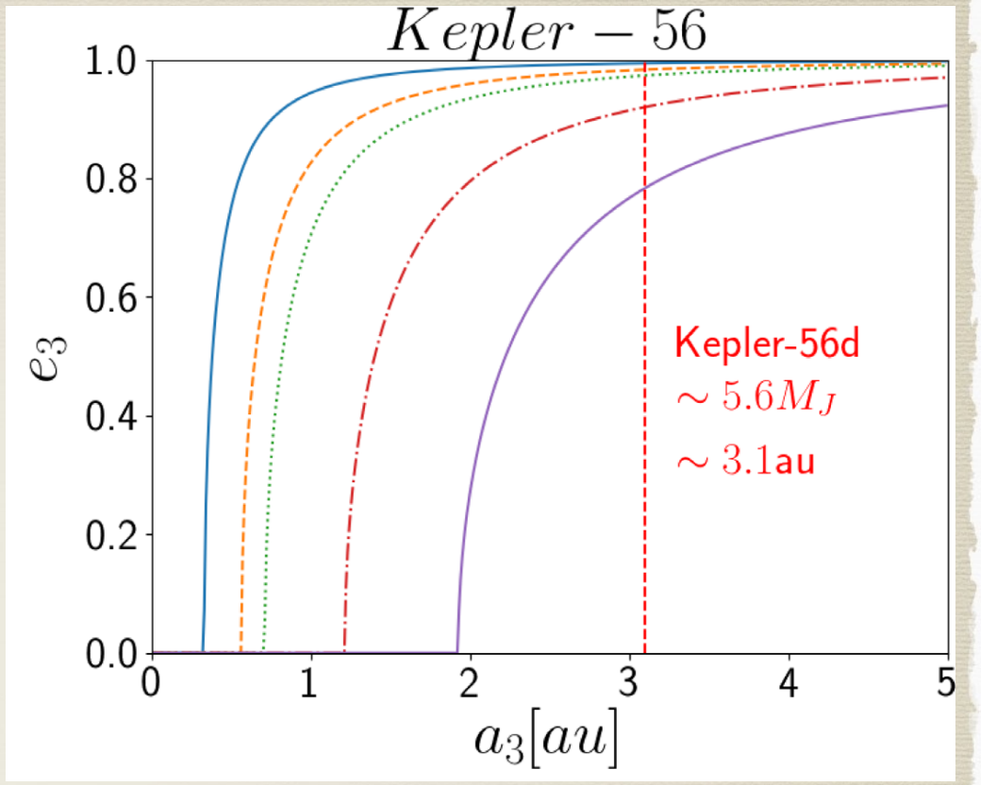
Denham, **Naoz** et al (2019)

Kepler 488:
$1.45M_\odot$ Bourrier et al. 2015; Johnson et al. 2017; Masuda (2017)
Planet 1: a=0.15au m=$10M_J$,e=0.34
Planet 2: a=4.2 m=$22M_J$ e=0.65

Planet and stellar friends



Paul Denham

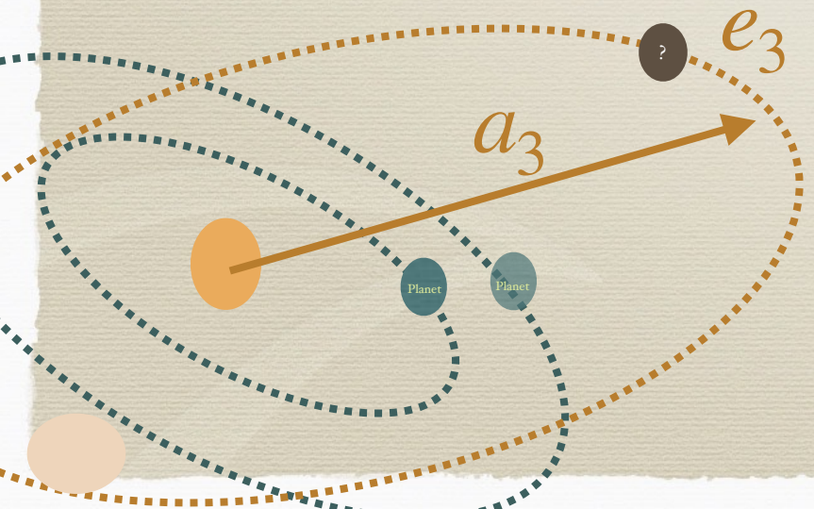


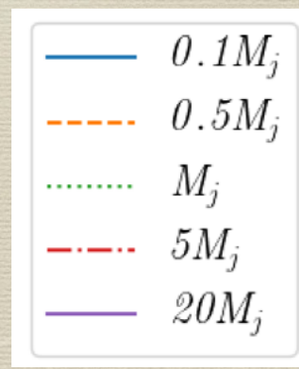
Denham, **Naoz** et al (2019)

Kepler 56: (slightly evolved star) $1.37M_{\odot}$; Huber et al. 2013, Otor et al. (2016)

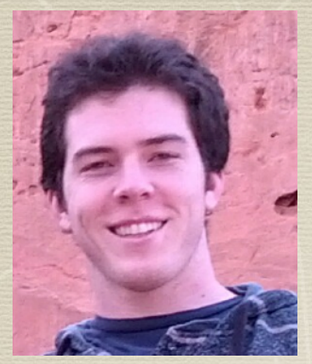
m_b=0.07M_J, a=0.103au

m_c=0.57M_J, a=0.17au



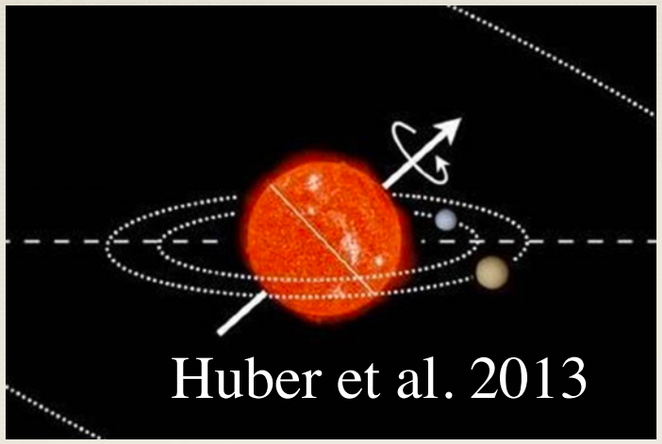


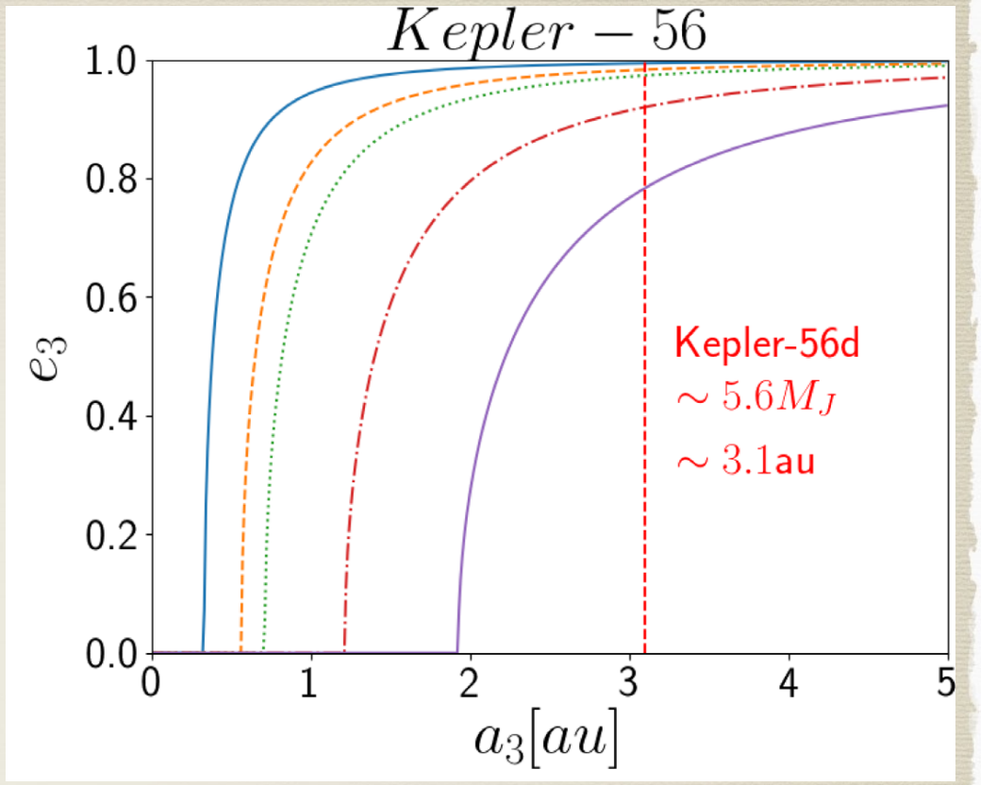
Planet and stellar friends



Paul Denham

Large obliquity





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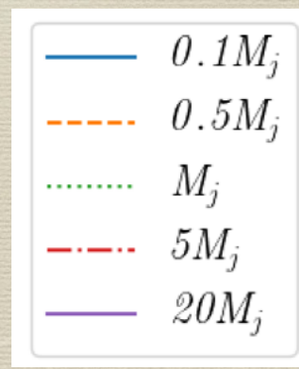
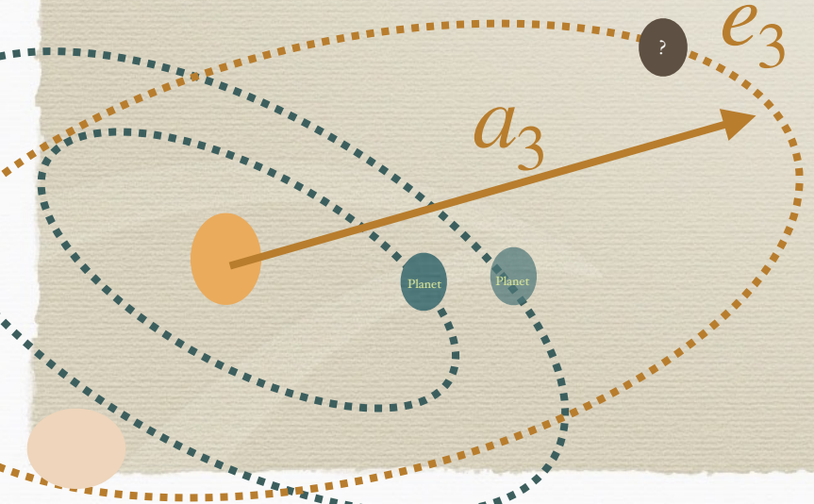
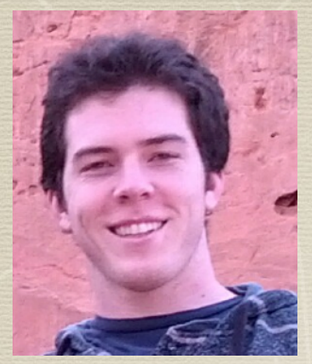


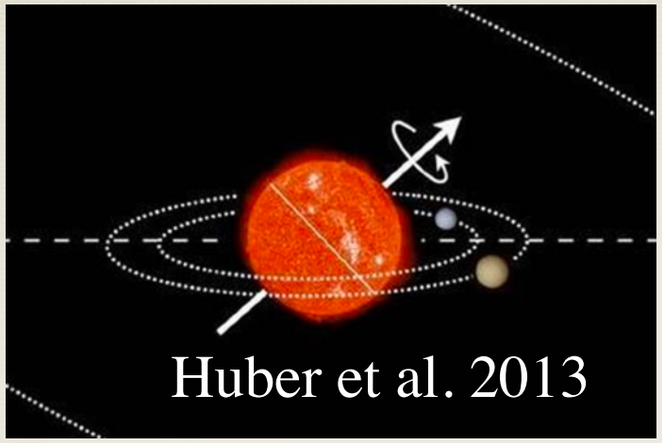


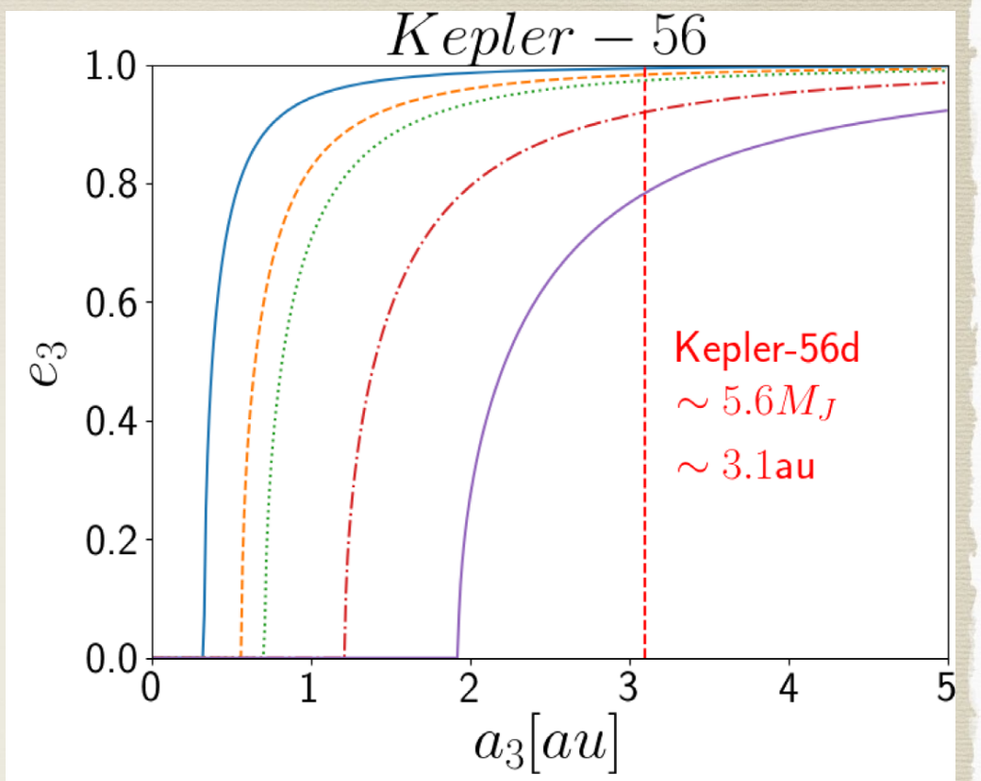
Planet and stellar friends



Paul Denham

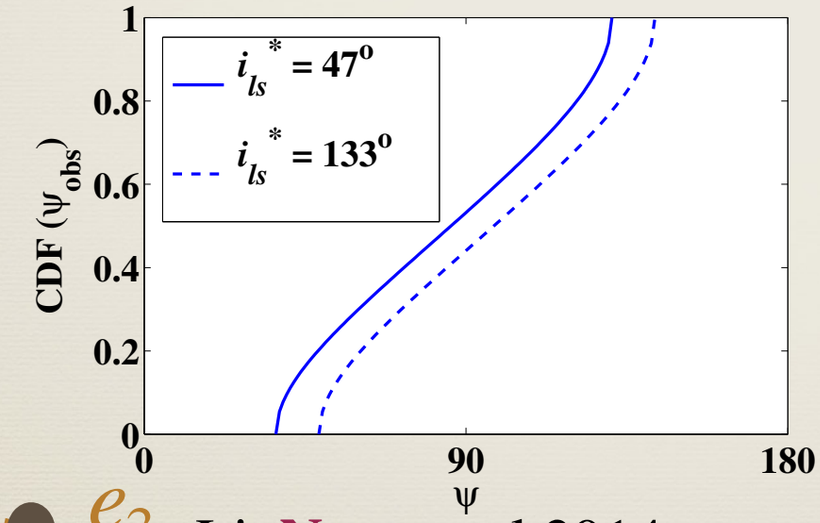
Large obliquity



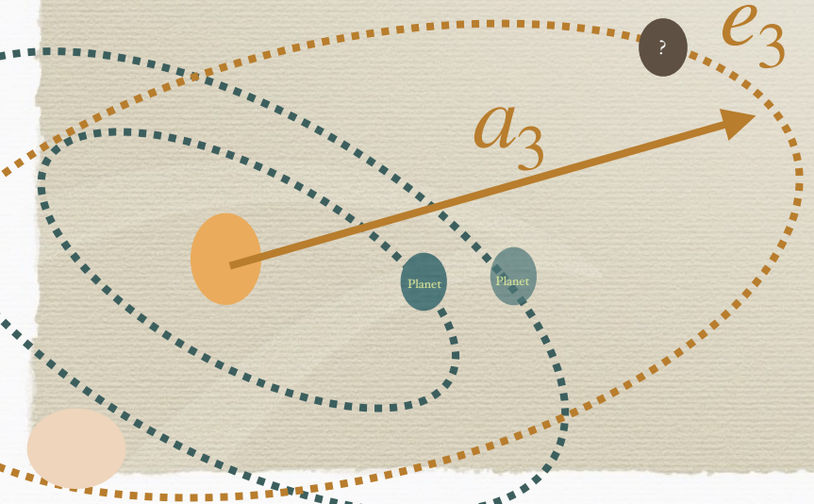


Denham, **Naoz** et al (2019)

Gongjie Li



Li, **Naoz** et al 2014



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m_c=0.57M_J, a=0.17au

Punchline

Bright stars (with the help of their friends) eat their planets

Punchline

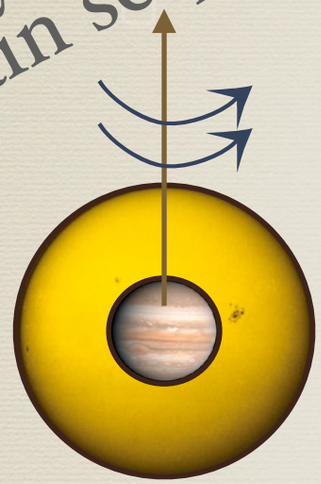
Bright stars (with the help of their friends) eat their planets

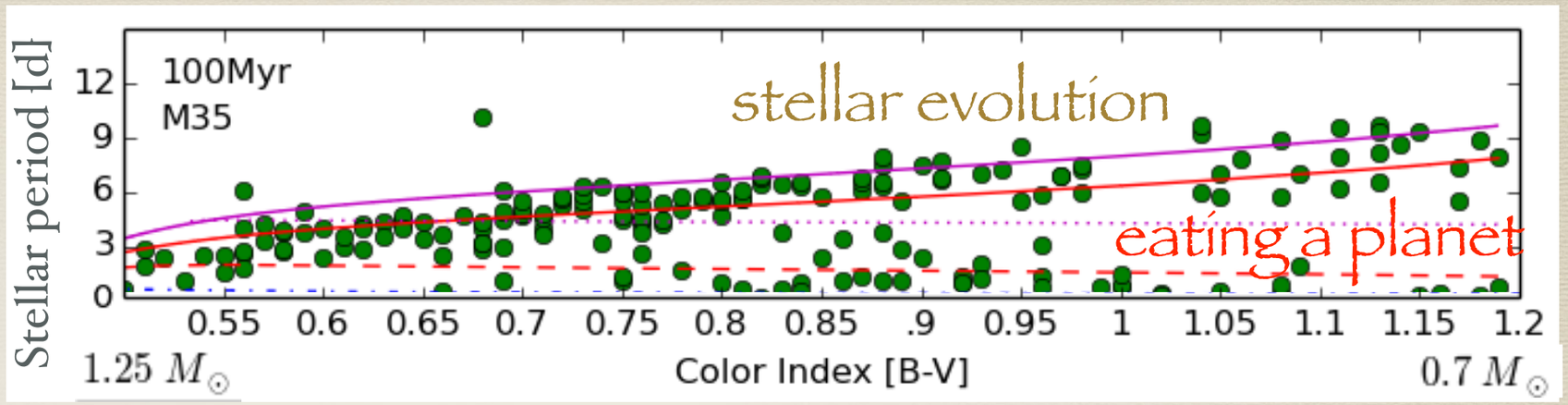
Hiding friends for multiple planets

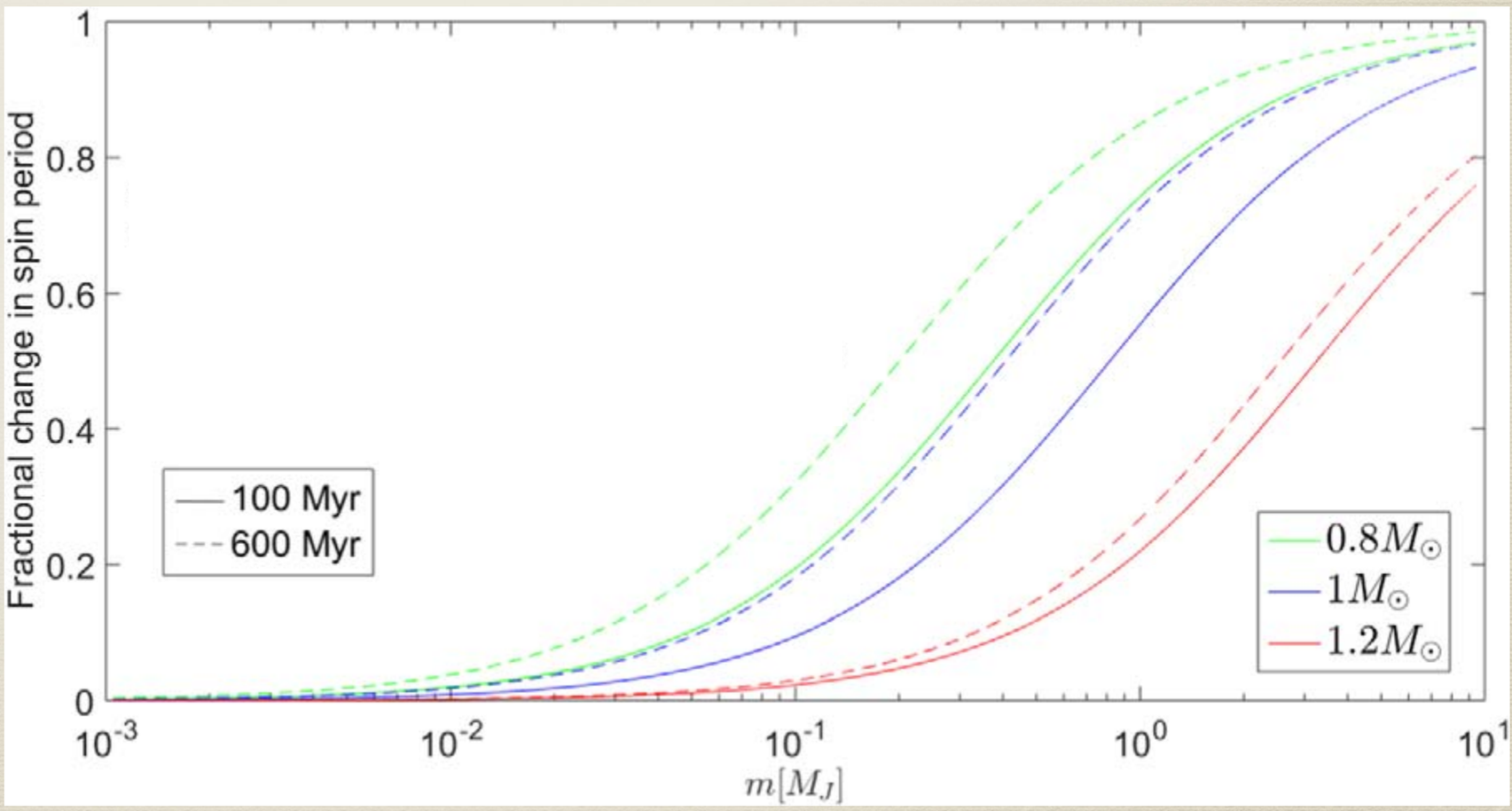
Planetary feast

Ahmed Qureshi

G-type Main sequence stars





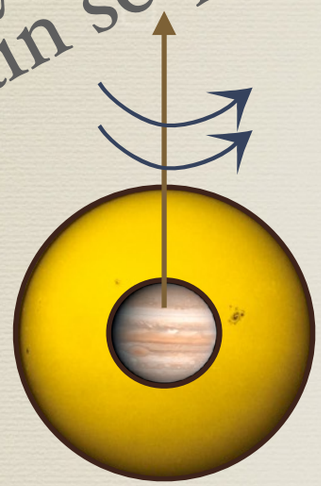


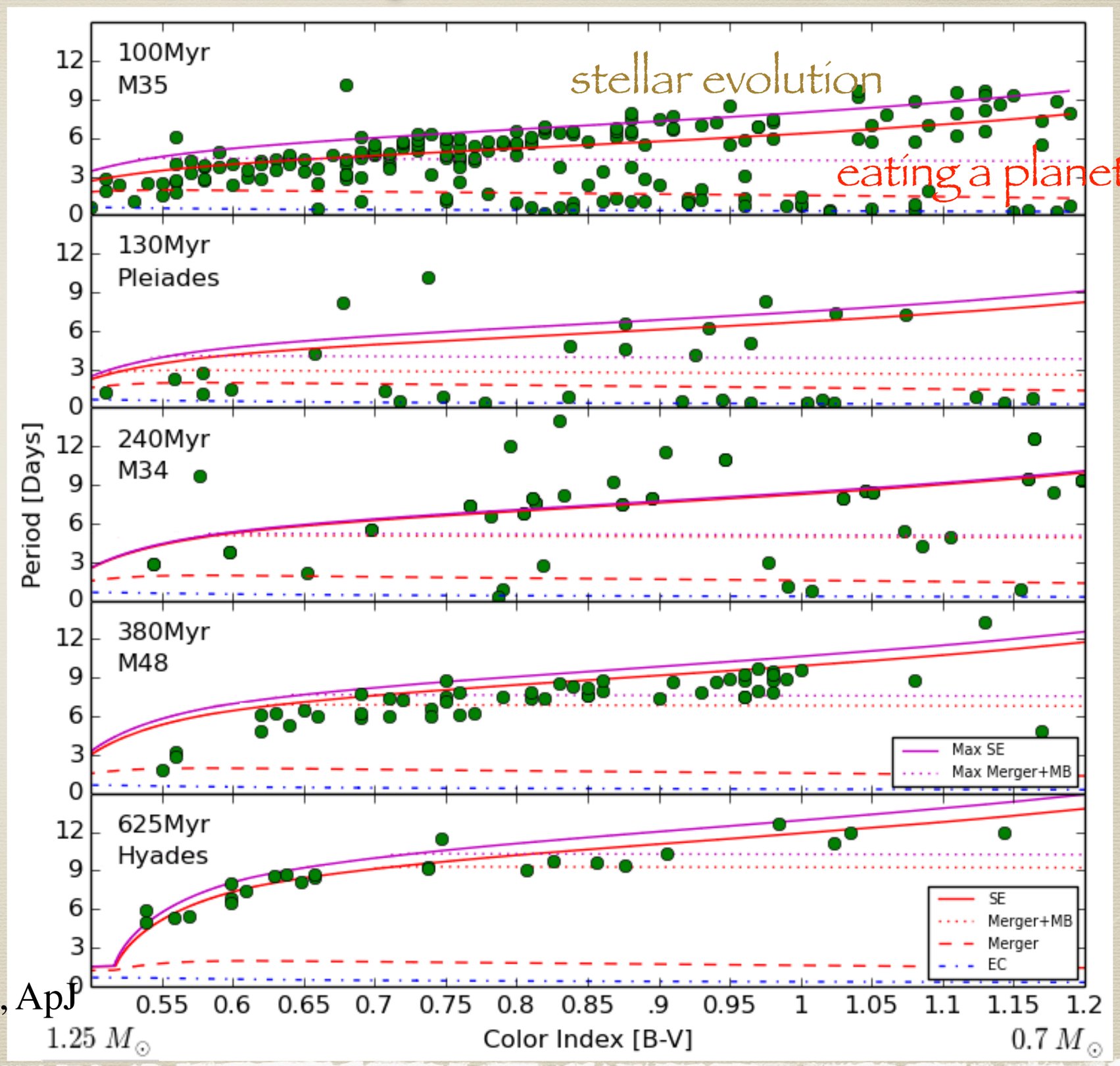
Qureshi, **Naoz**, Shkolnik, 2018, ApJ

Planetary feast

Ahmed Qureshi

G-type
Main sequence stars





Qureshi, **Naoz**, Shkolnik, 2018, ApJ