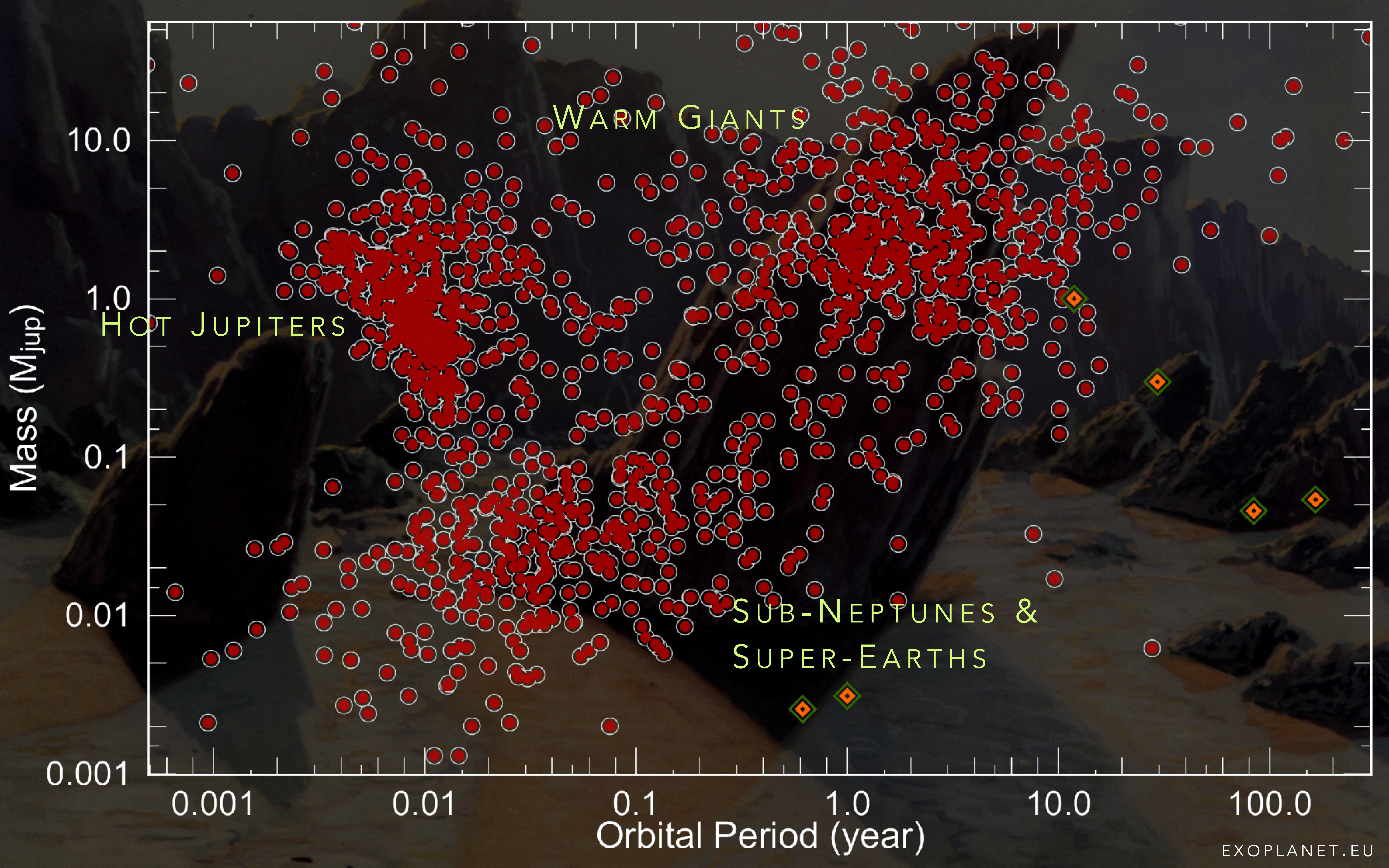
Low-Mass Binaries & Circumbinary planets

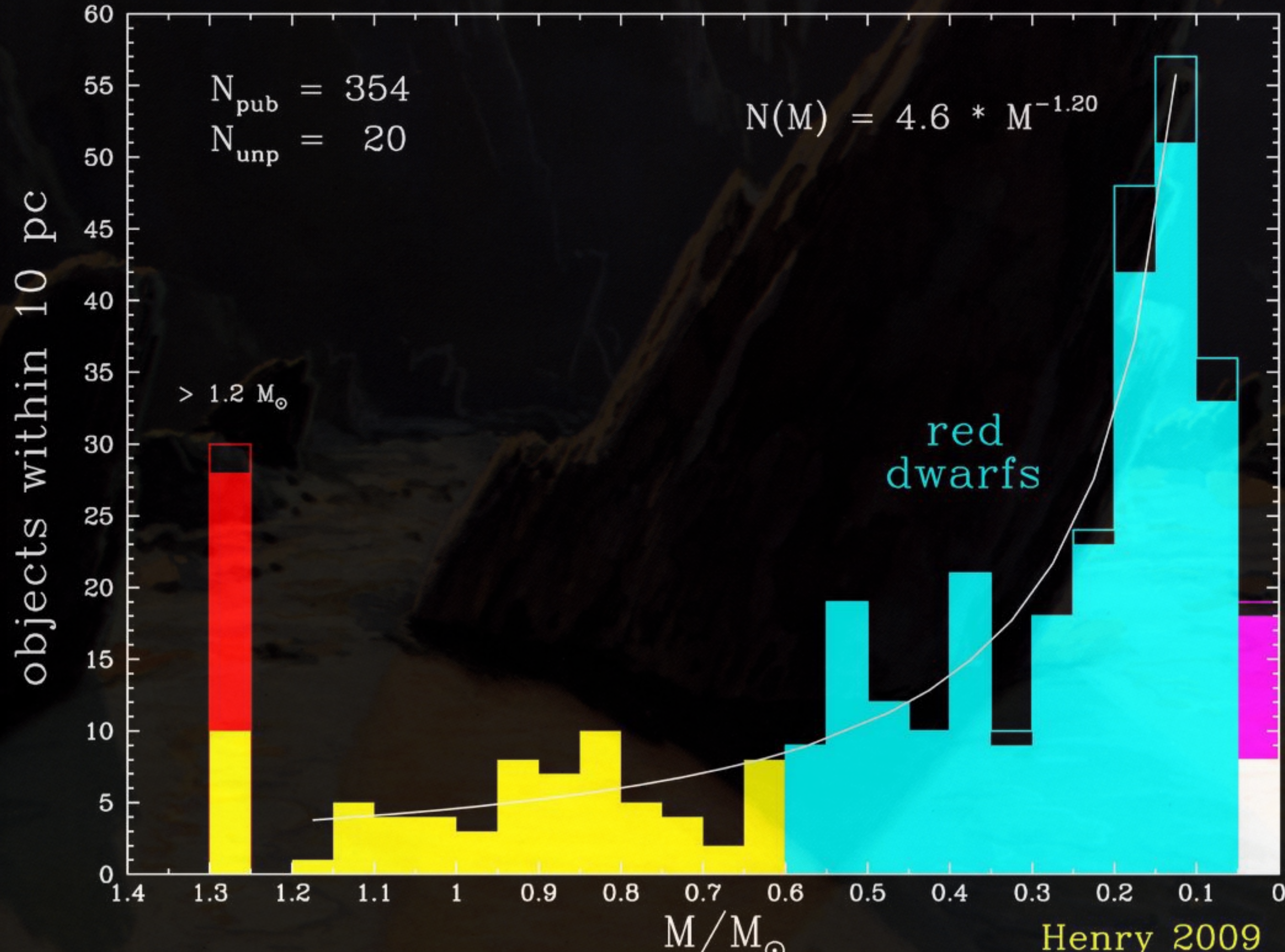
Amaury H.M.J. Triaud

University of Birmingham
European Research Council
Established by the European Commission
Leverhulme Trust
Science & Technology Facilities Council



Warm Giants
Hot Jupiters
Sub-Neptunes &
Super-Earths
Mass (Mjup)
10.0
1.0
0.1
0.01
0.001
0.001
0.01
0.1
1.0
10.0
100.0
Orbital Period (year)
EXOPLANET.EU

DIFFERENT STELLAR TYPES



RECONS.ORG

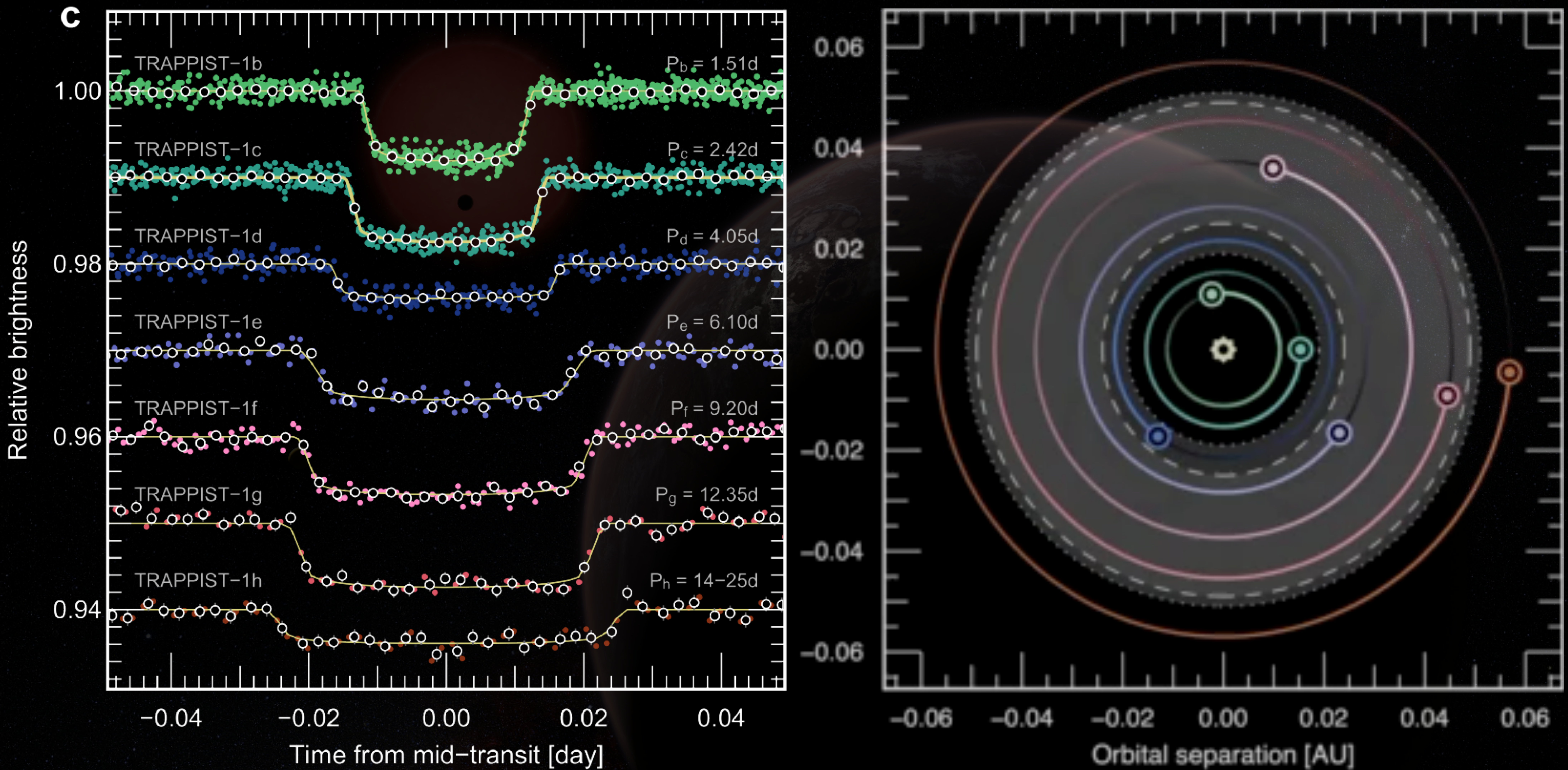
The TRAPPIST-1 system

Gillon et al. 2016, 2017, Nature

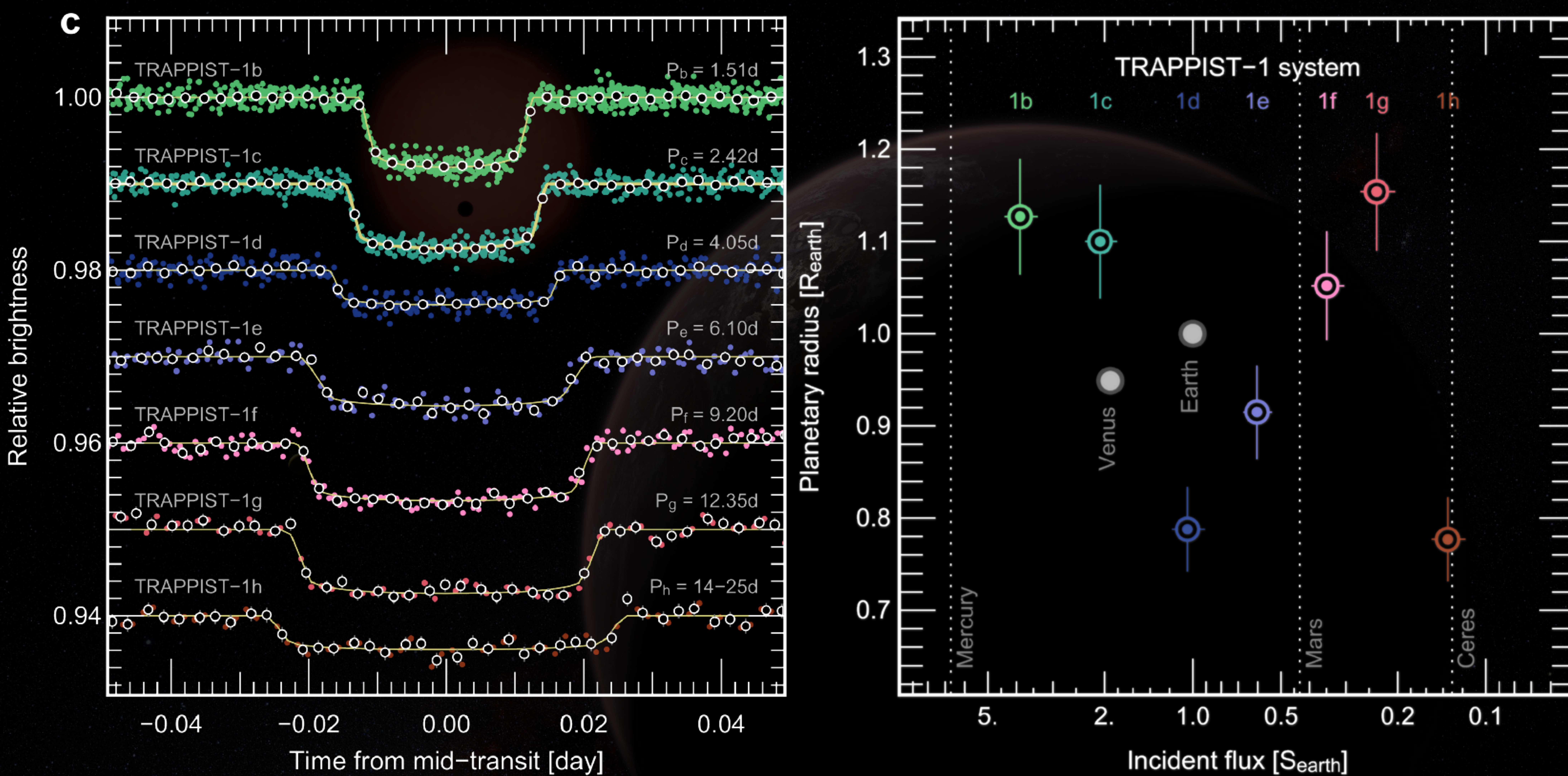
van Grootel et al. 2018, ApJ
Delrez et al. 2018, MNRAS
Grimm et Al. 2018, A&A

ERIC AGOL
YASEEN ALMLEAKY
THOMAS BARCLAY
GEERT BARENTSEN
KHALID BARKAOUI
ZOUHAIR BENKHAKLDOUN
EMELINE BOLMONT
VINCENT BOURRIER
ARTEM BURDANOV
ADAM BURGASSER
MATTHEW BURLEIGH
SEAN CAREY
ALEKSANDER CHAUSHEV
CHRIS COPPERWHEAT
KATHERINE DECK
LAETITIA DELREZ
BRICE-OLIVER DEMORY
JULIEN DE WIT
DAVID EHRENREICH
DANIEL FABRYCKY
CATARINA FERNANDES
DANIEL FOREMAN-MACKEY
MICHAËL GILLON
SIMON GRIMM
KEVIN HENG
DANIEL HOLDSWORTH
JAMES INGALLS
EMMANUËL JEHIN
ENRICO KOTZE
ETHAN KRUSE
JÉRÉMY LECONTE
SUSAN LEDERER
NIKOLE LEWIS
RODRIGO LUGER
PIERRE MAGAIN
BRETT MORRIS
JAMES OWEN
DIDIER QUELOZ
SEAN RAYMOND
FRANCK SELSIS
MARKO SESTOVIC
VLADA STAMENKOVIC
AMAURY TRIAUD
MARTIN TURBET
VALÉRIE VAN GROOTEL
JEFF VALENTI
HANNAH WAKEFORD
PETER WHEATLEY

ESO



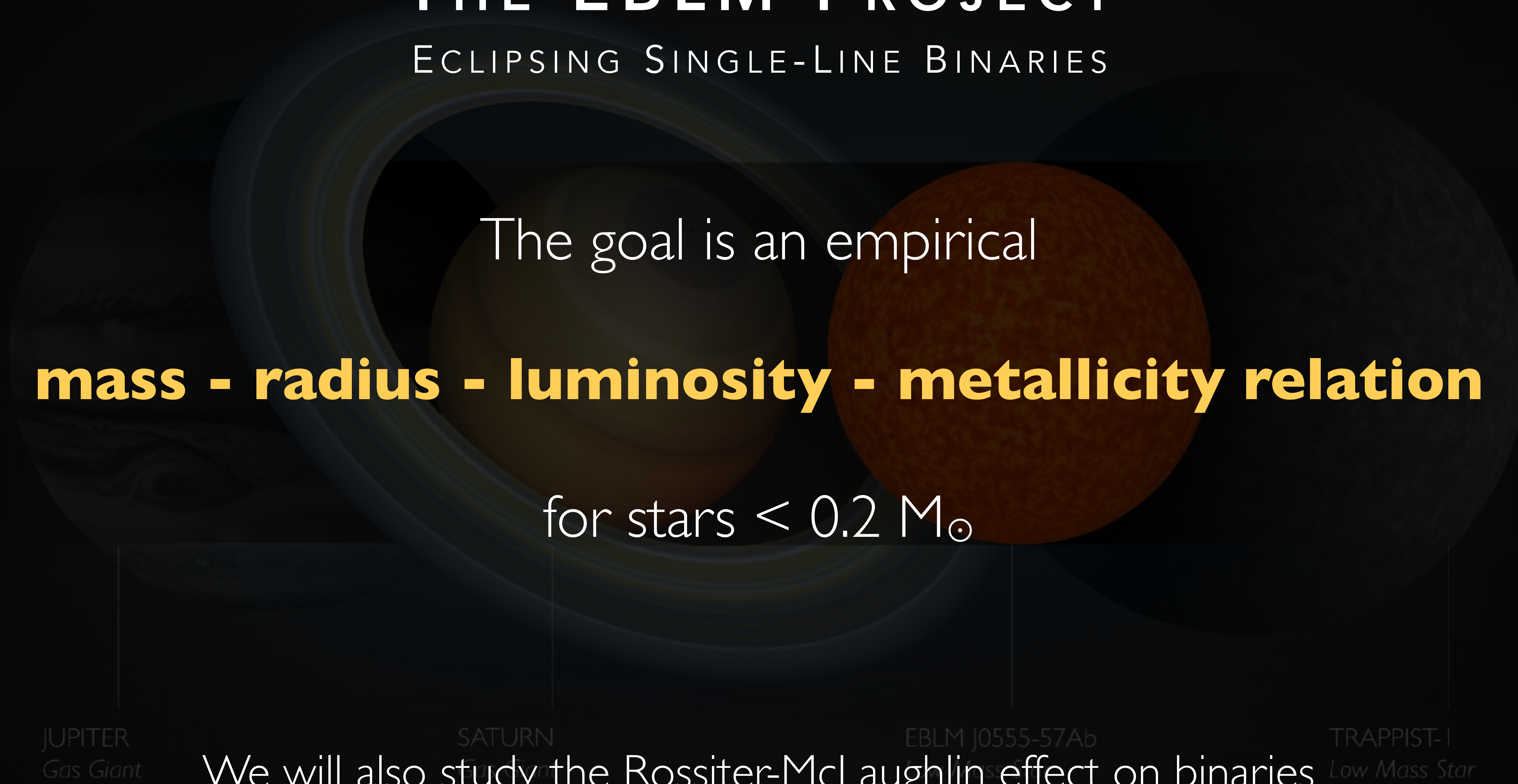
GILLON, TRIAUD ET AL. 2017



Delrez, Gillon et al. 2018

The EBLM Project

Eclipsing Single-Line Binaries



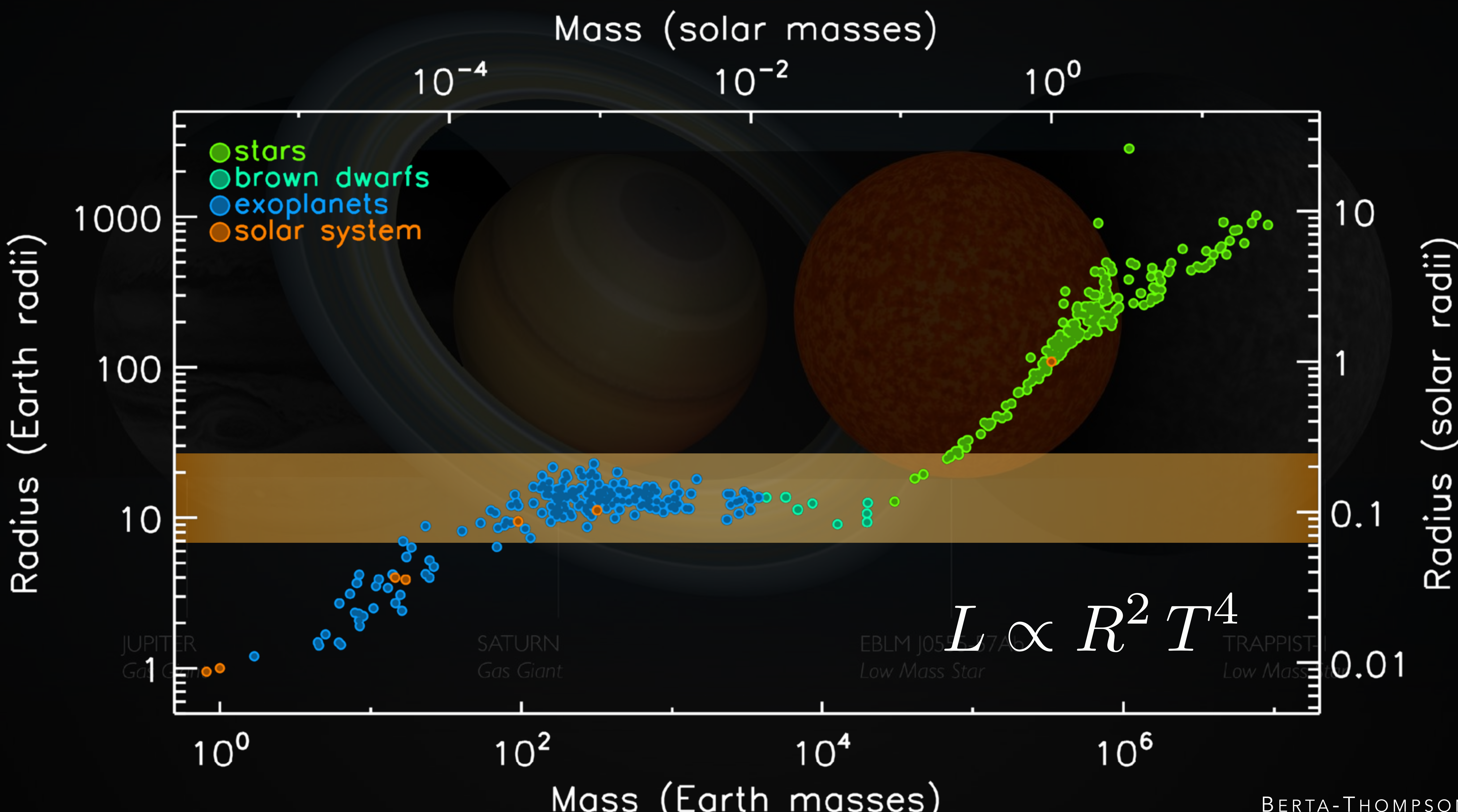
The goal is an empirical

mass - radius - luminosity - metallicity relation

for stars $< 0.2\ M_{\odot}$

We will also study the Rossiter-McLaughlin effect on binaries

The EBLM Project: Eclipsing Single-Line Binaries



$$L \propto R^2 T^4$$

Berta-Thompson

The EBLM Project: Eclipsing Single-Line Binaries

campaign rules

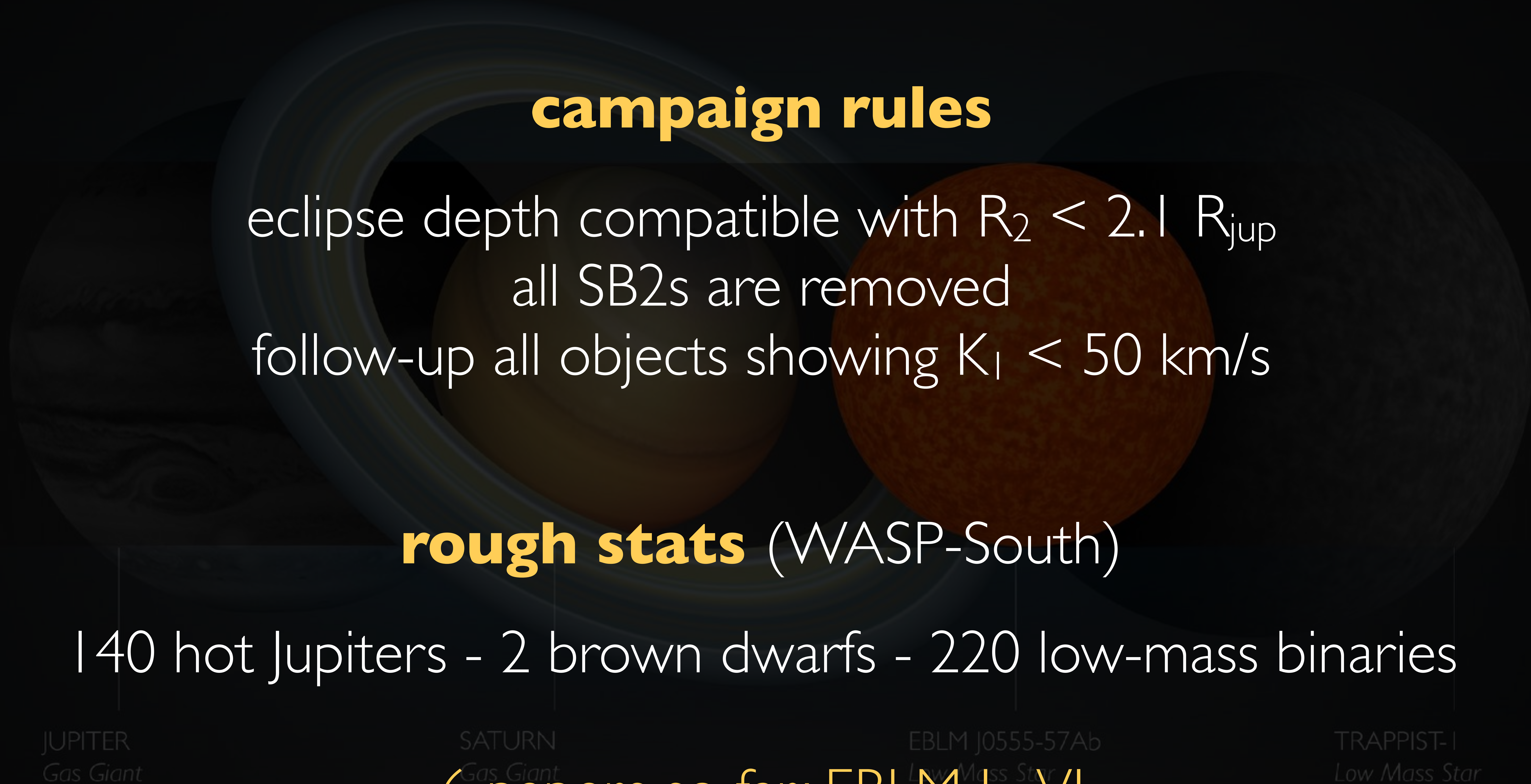
eclipse depth compatible with $R_2 < 2.1\ R_{jup}$

all SB2s are removed

follow-up all objects showing $K_1 < 50$ km/s

rough stats (WASP-South)

140 hot Jupiters - 2 brown dwarfs - 220 low-mass binaries

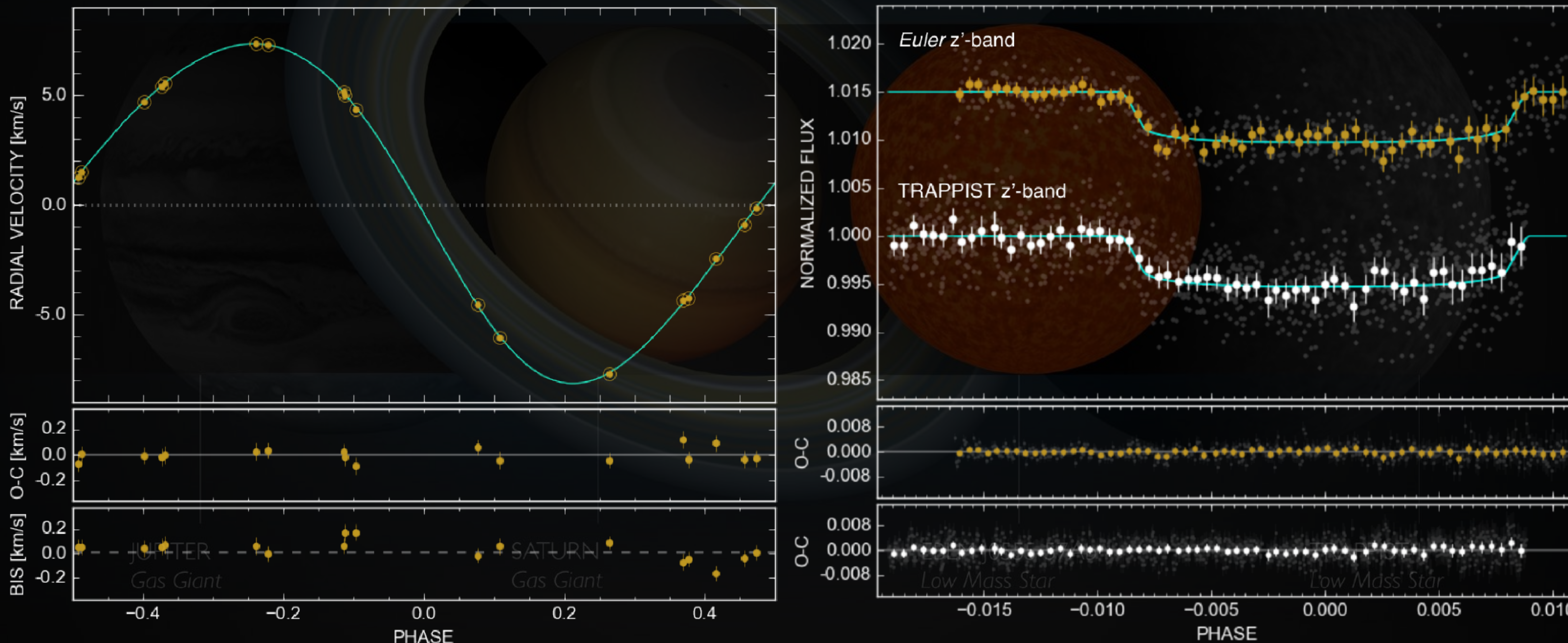


6 papers so far: EBLM I - VI

Triaud+2013, Gomez Maqueo Chew+ 2014, von Boetticher+ 2017,
Triaud+ 2017, von Boetticher+ 2019, Gill+2019

THE EBLM PROJECT: ECLIPSING SINGLE-LINE BINARIES

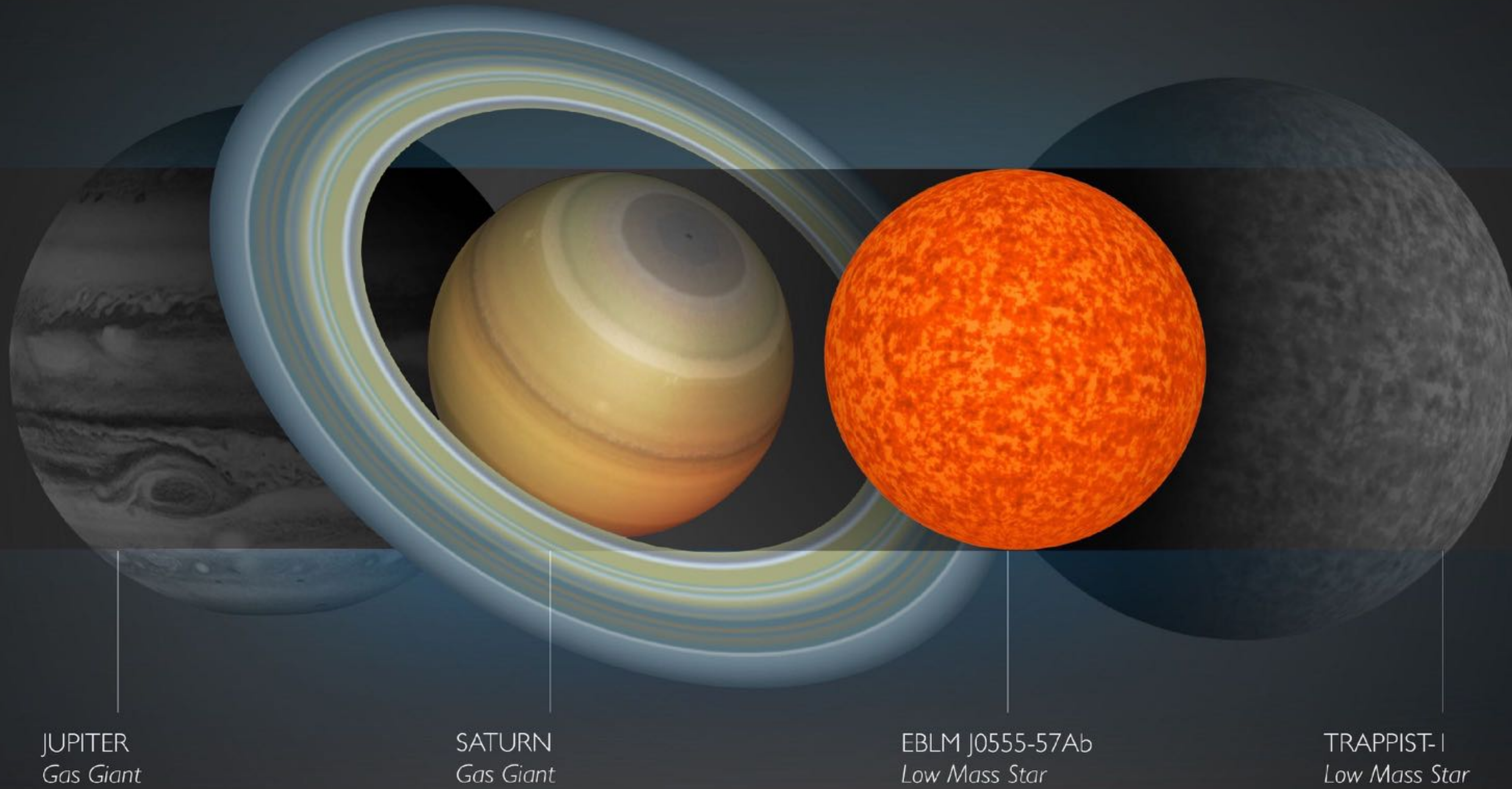
EBLM J0555-57 0.081 $M_\odot$ (85 M_{jup}) - 0.084 $R_\odot$ (0.84 R_{jup})



Adjusted using the **ELLC** model (Maxted 2016) and the **EMCEE** MCMC sampler (Foreman-Mackey 2013)

VON BOETTICHER, TRIAUD ET AL. 2017

The EBLM Project: Eclipsing Single-Line Binaries

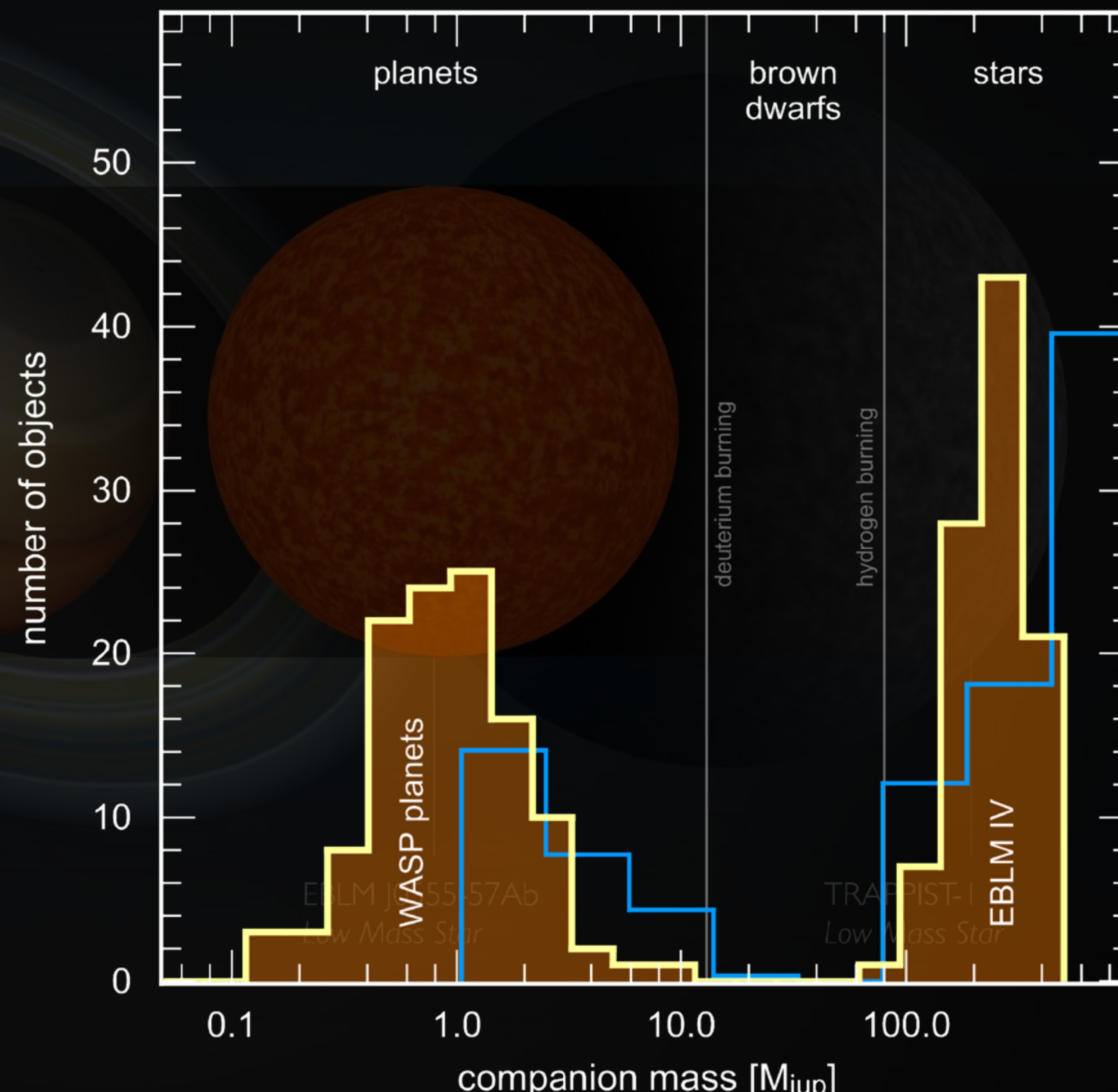


IoA/A. Smith

The EBLM Project: Eclipsing Single-Line Binaries

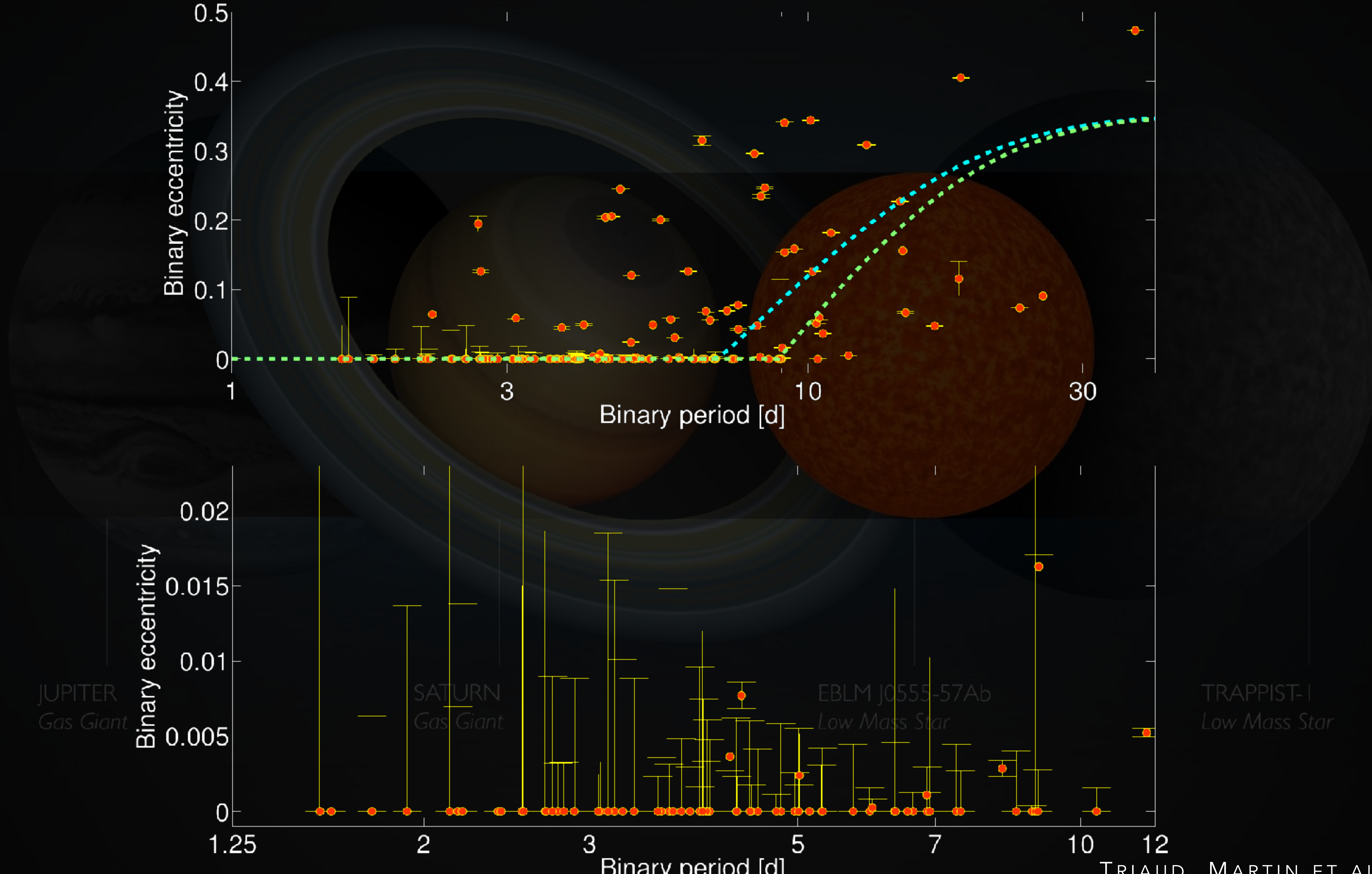
Update on the Brown Dwarf Desert

& spectroscopic orbits for 118 binary systems composed of a Sun-like star, and a very low-mass star



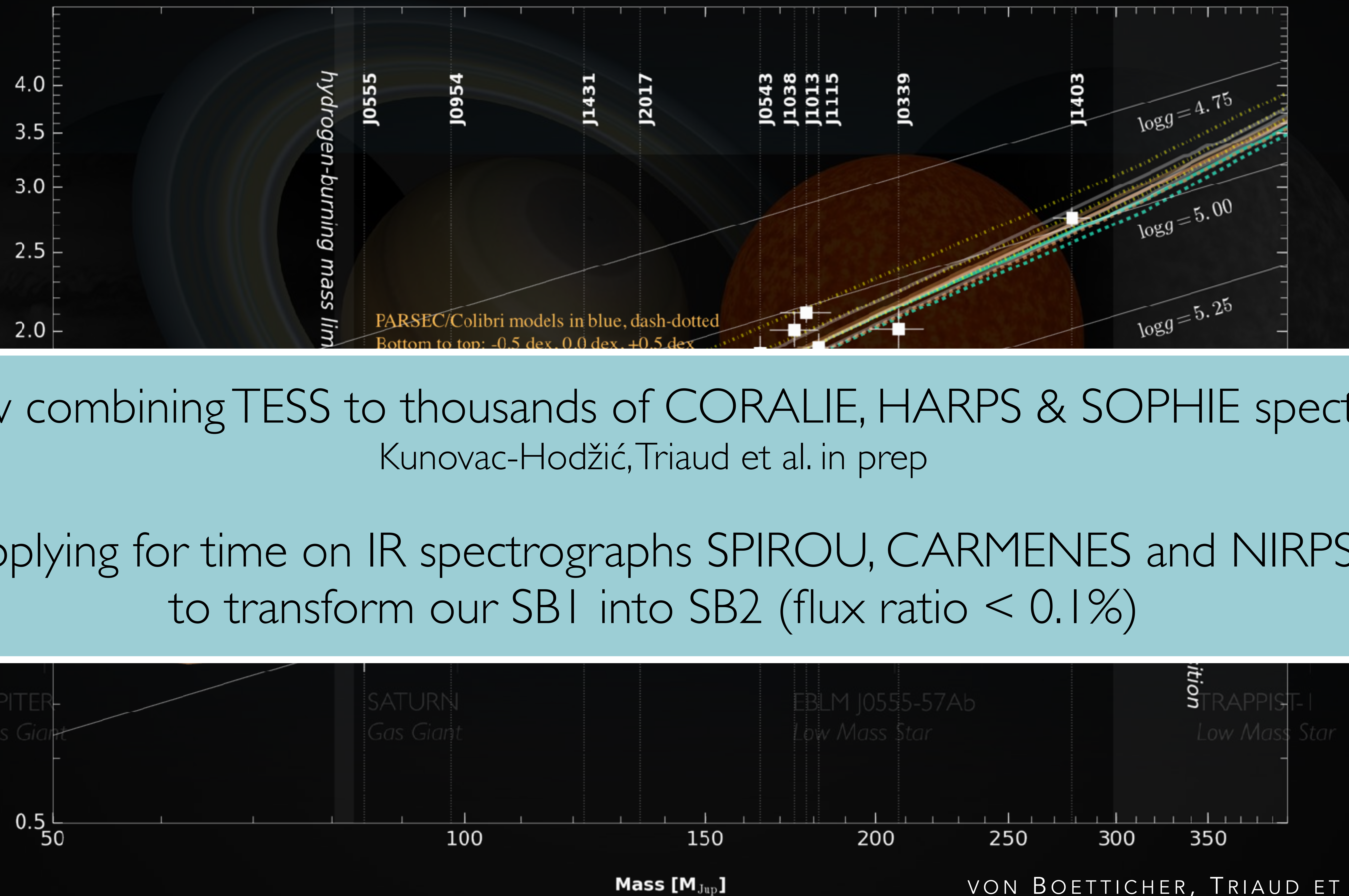
Triaud, Martin et al. 2017

The EBLM Project: Eclipsing Single-Line Binaries



Triaud, Martin et al. 2017

The EBLM Project: Eclipsing Single-Line Binaries



Now combining TESS to thousands of CORALIE, HARPS & SOPHIE spectra

Kunovac-Hodžić, Triaud et al. in prep

Applying for time on IR spectrographs SPIROU, CARMENES and NIRPS to transform our SB1 into SB2 (flux ratio < 0.1%)

von Boetticher, Triaud et al. 2019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SUPPORTED BY: EUROPEAN RESEARCH COUNCIL, SIMONS FOUNDATION, MERAC FOUNDATION, STFC


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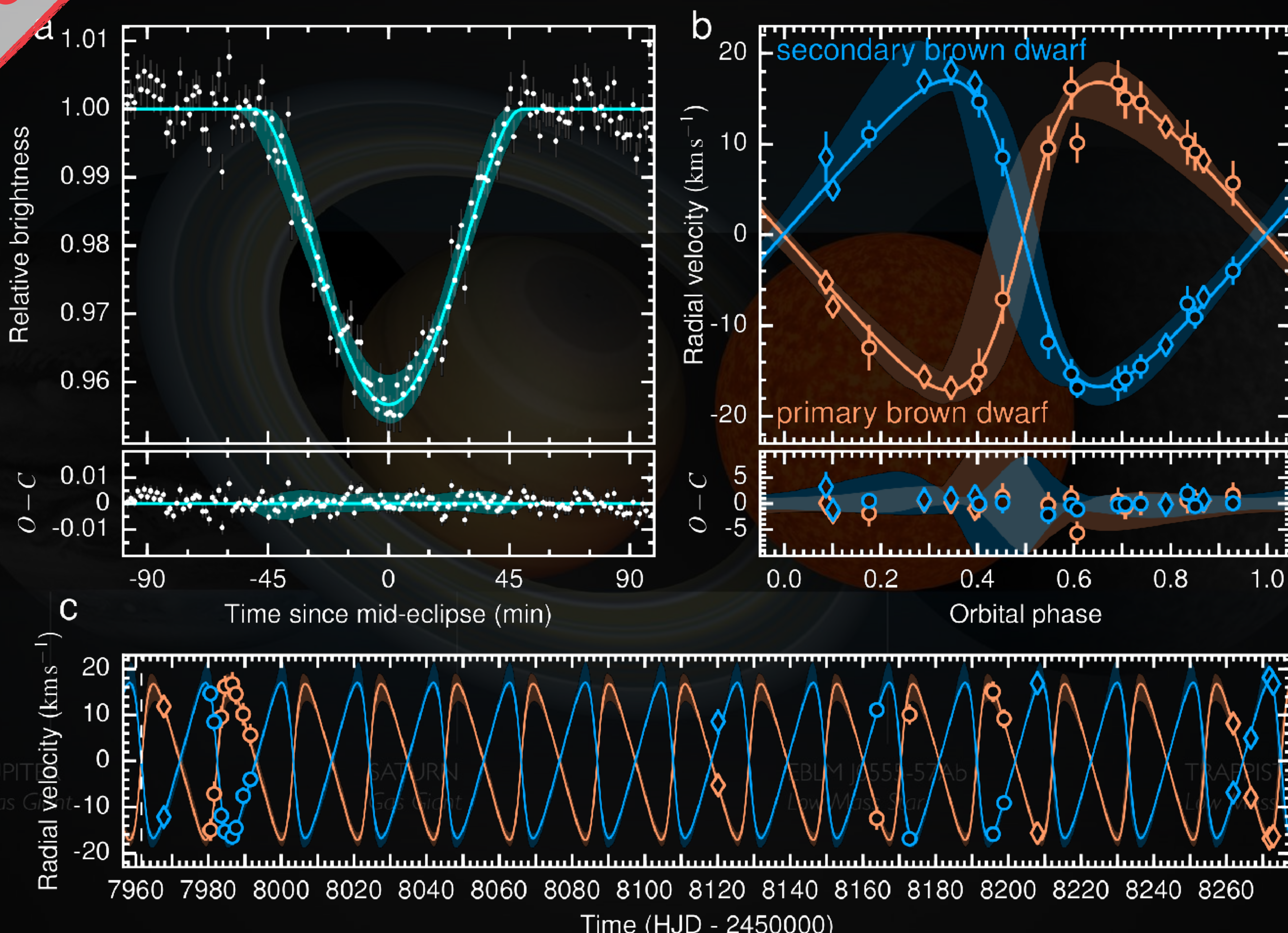
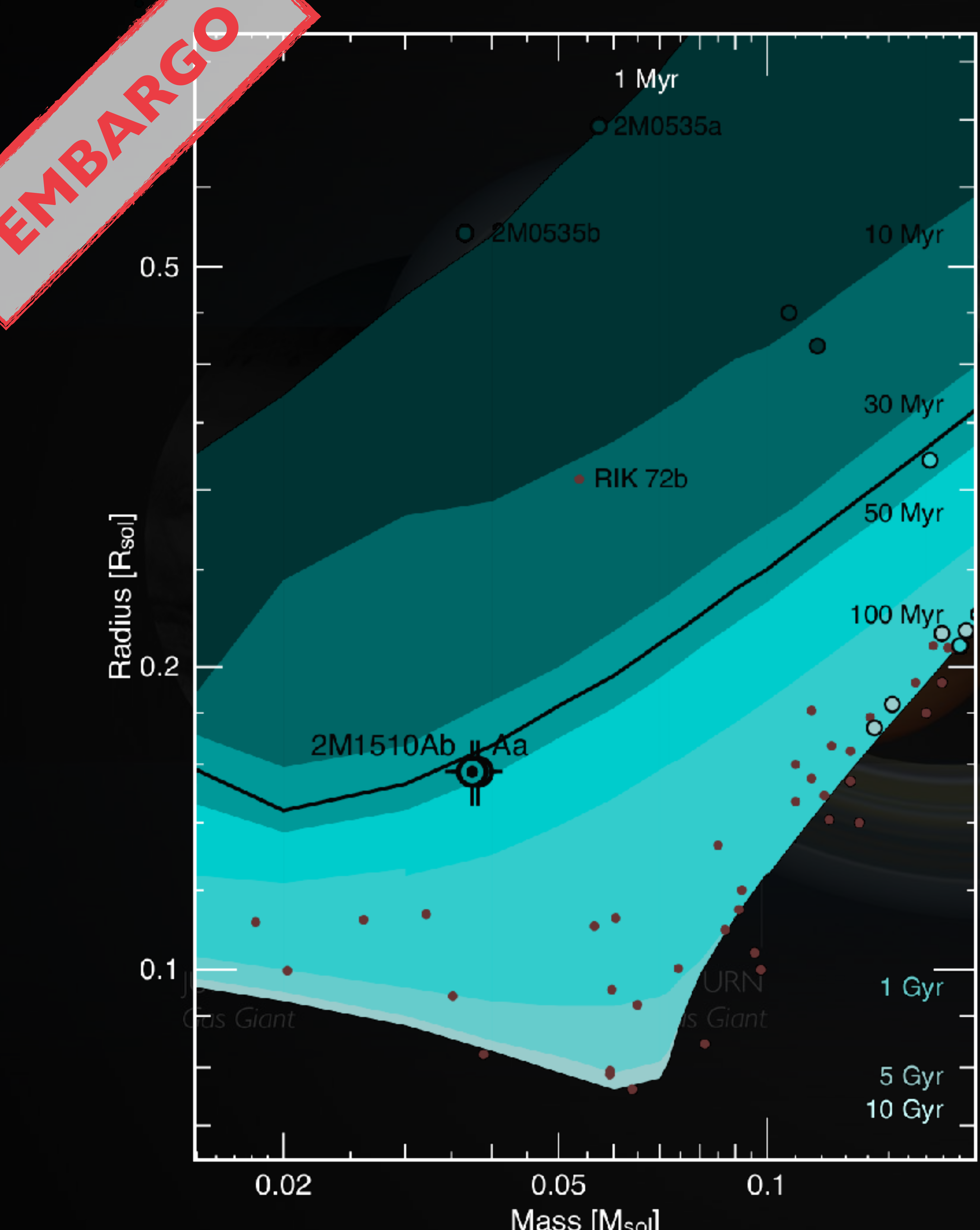


Triaud, Burgasser et al. under review



2M1510

0.038 $M_\odot$
0.16 $R_\odot$

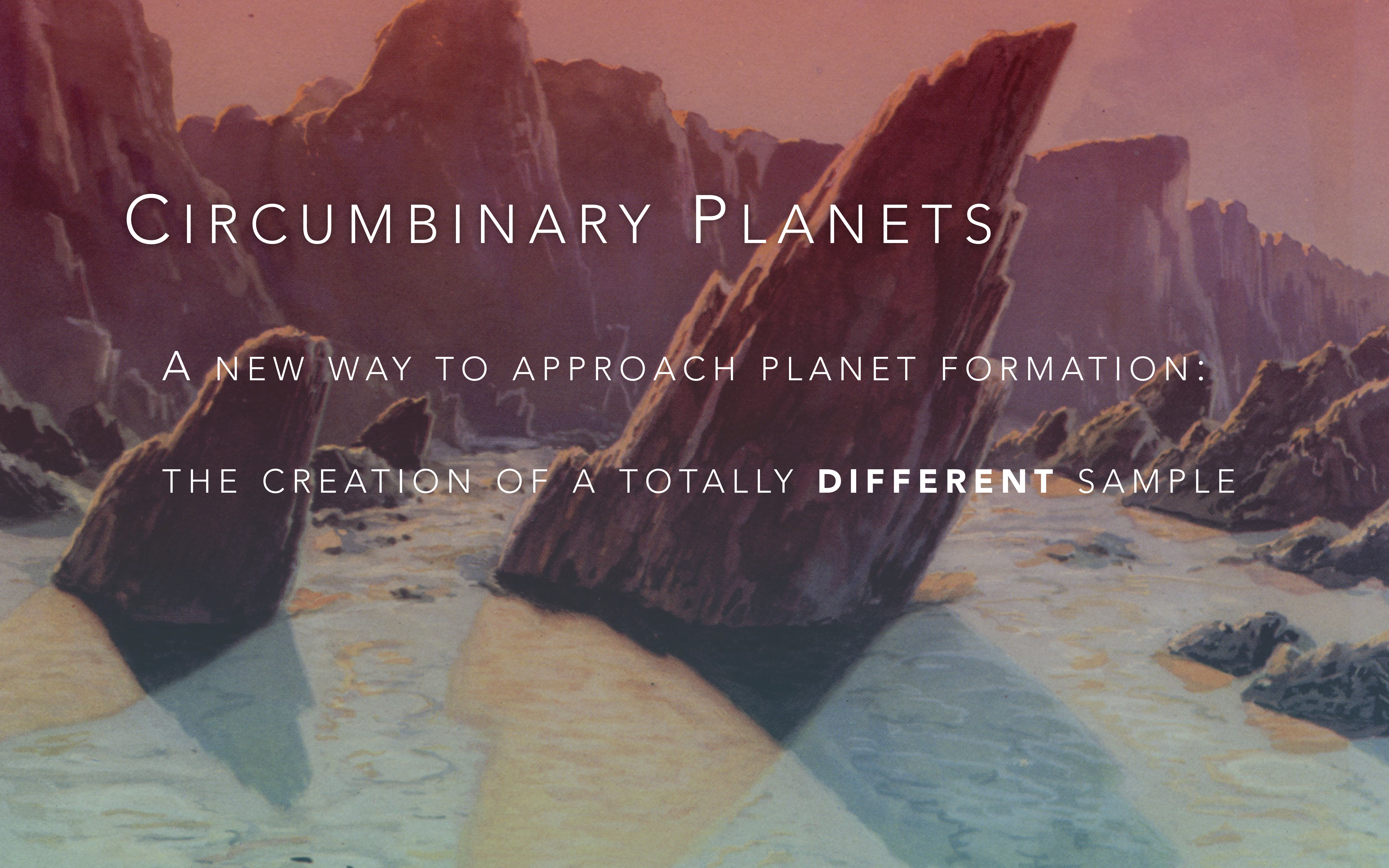
20.90 days

spectra show indication of youth

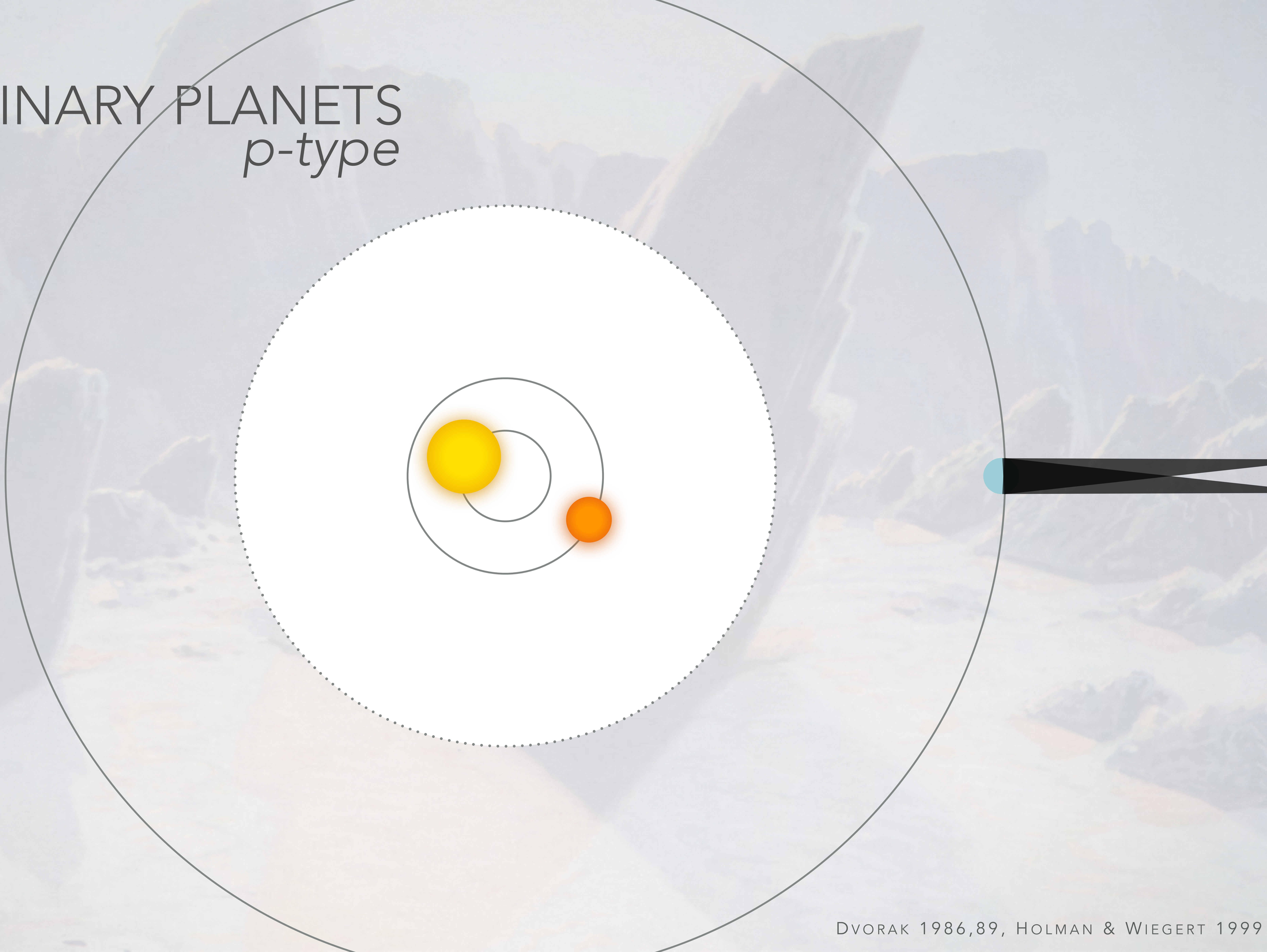
kinematics make it a member of Argus young moving group

45±5 Myr

TRIAUD, BURGASSER ET AL. UNDER REVIEW


Circumbinary Planets
A new way to approach planet formation:
the creation of a totally **DIFFERENT** sample

Circumbinary planets
p-type



Dvorak 1986,89, Holman & Wiegert 1999

LESS EFFICIENT FORMATION

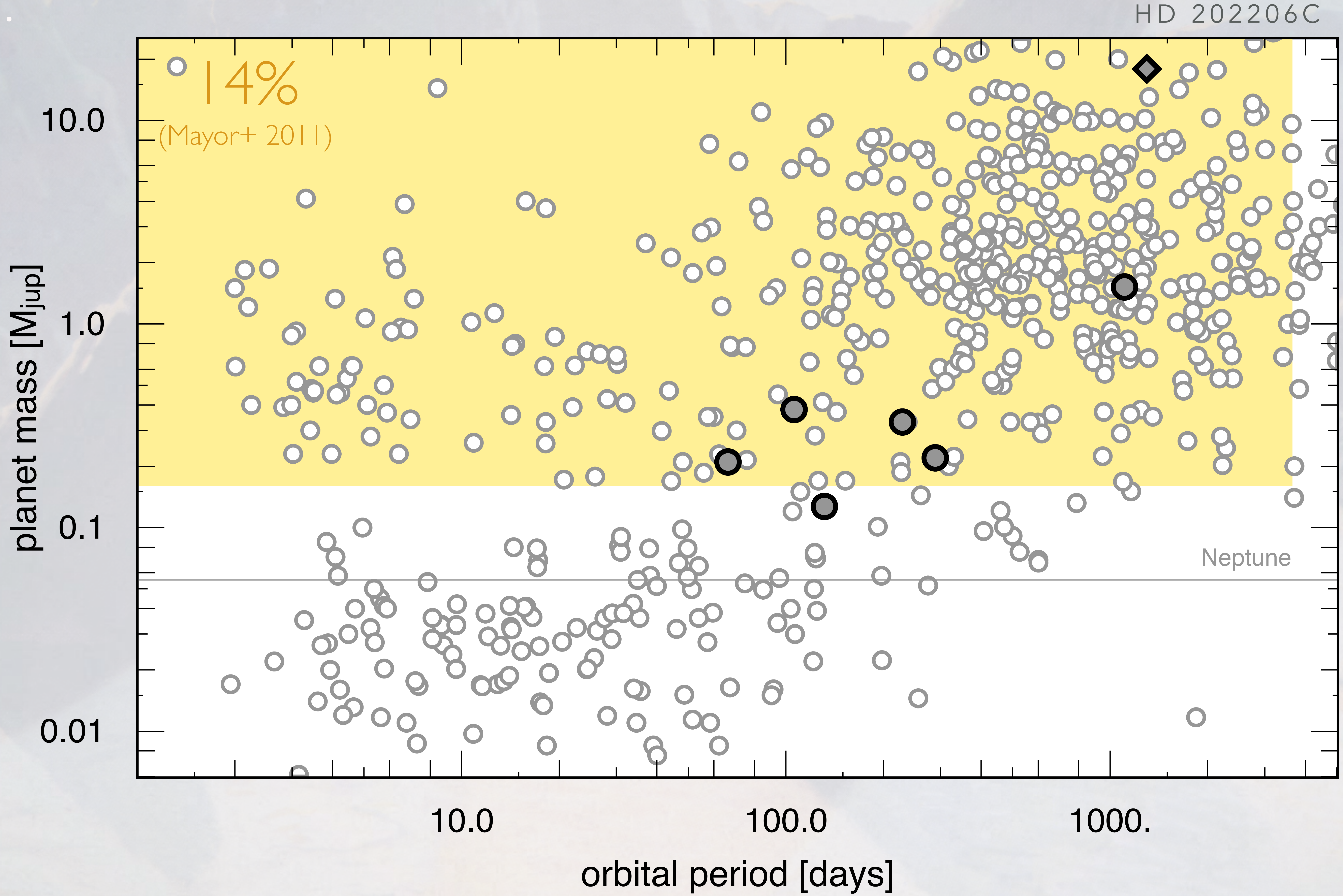
Meschiari 2012 a&b
Paardekooper+ 2012
Rafikov+ 2013

planetesimal accretion if > 50 binary separation

$$\frac{dm}{dt} = \frac{1}{2}\,\Sigma\,\Omega\,\pi\,r^2\,(1+\Theta) \qquad \text{with} \qquad \Theta = \frac{v_{\rm esc}^2}{v^2}$$

(DISC MIGRATION: Pierens & Nelson 2007,13 ; Kley & Haghighipour 2014,15)

THE DATA


HD 202206C
14%
(Mayor+ 2011)
Neptune
10.0
1.0
0.1
0.01
planet mass [Mjup]
10.0
100.0
1000.
orbital period [days]

Circumbinary gas-giant occurrence*

> 0.15 Mjup, >8 Rearth

Assuming coplanarity (ΔI = 0° ± 0°)

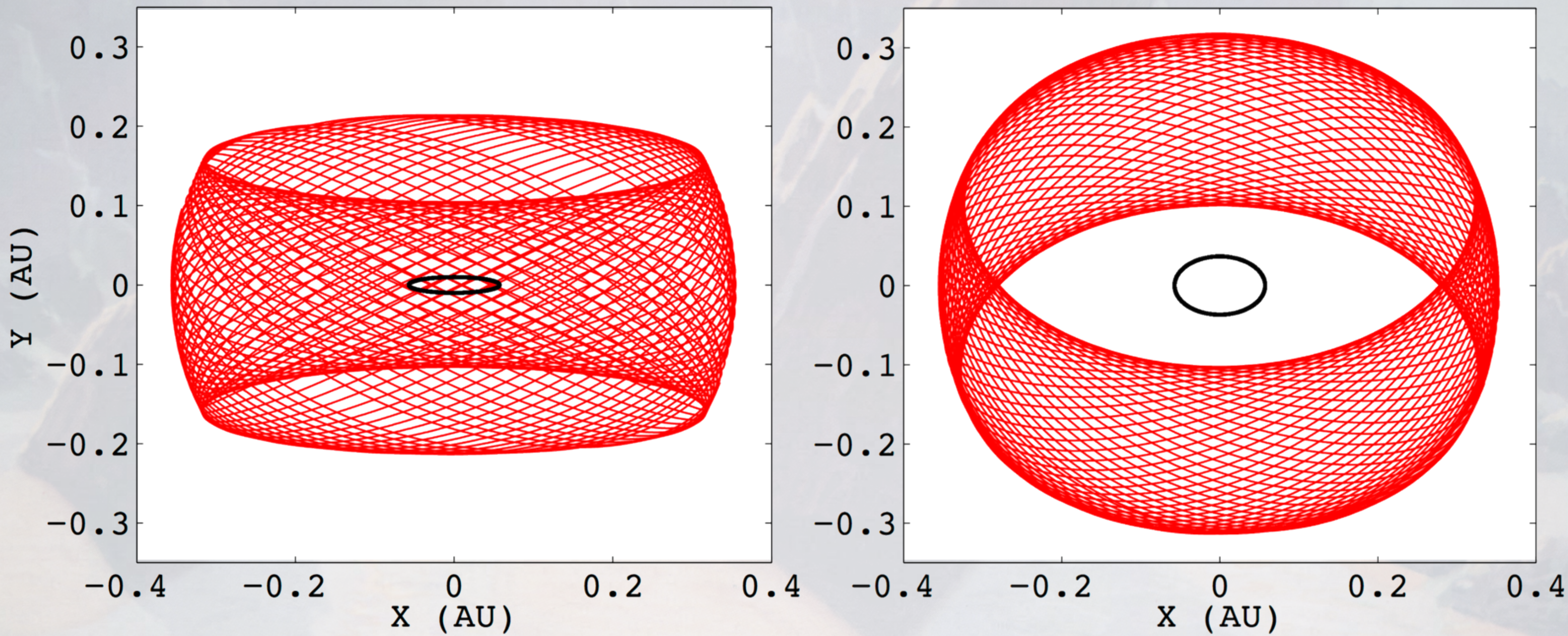
Armstrong et al. 2014:	~9.8% (P< 300 days)
Martin & Triaud 2014:	~15% (P< 10 years)

Single Sun-like stars:

Mayor+ 2011:	13.7% (P< 10 years)
	5.4% (P< 400 d)
Santerne+ 2016:	4.6% (P< 400 d)

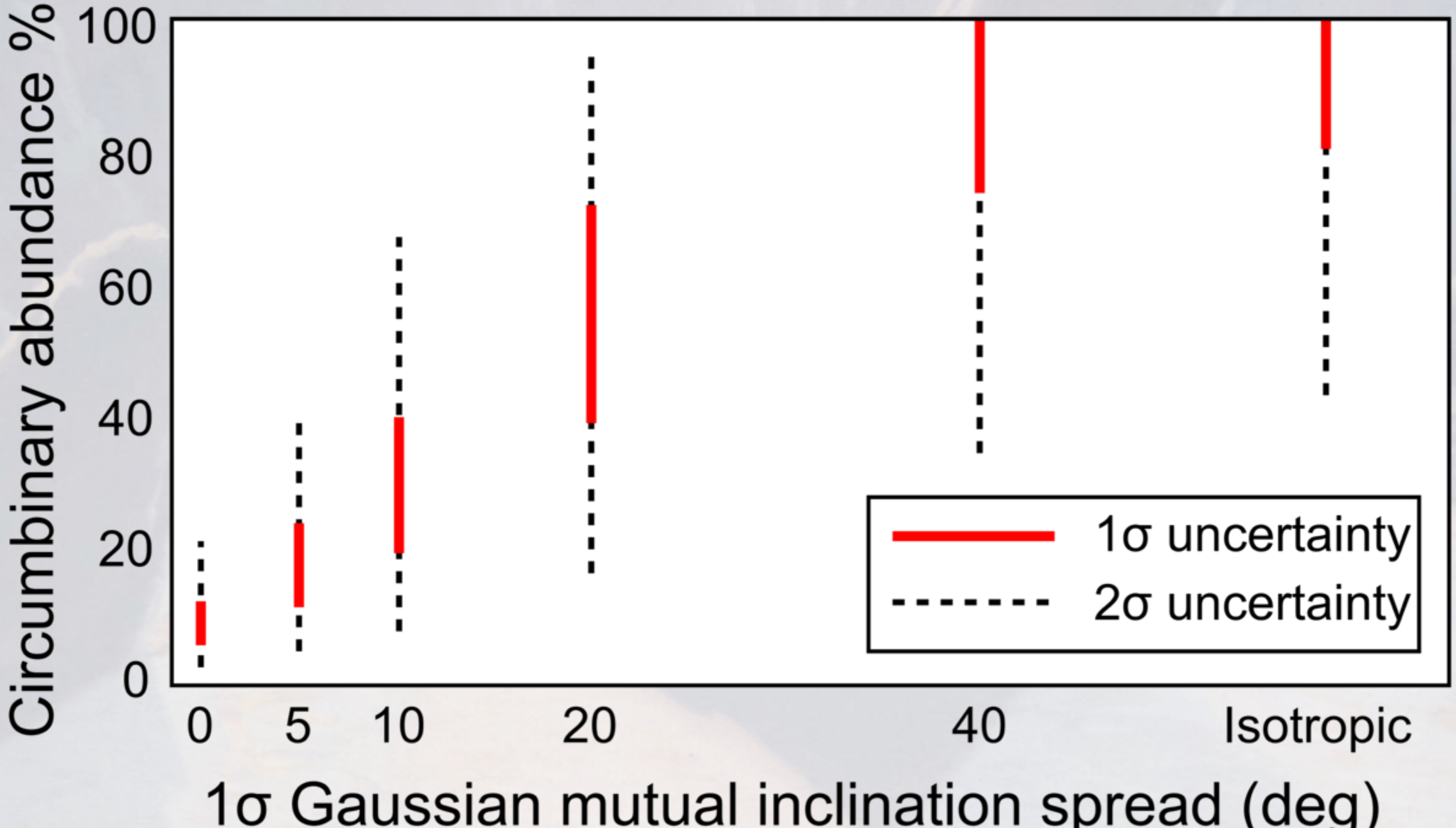
*after removing triples

Effect of orbital inclination



Martin & Triaud 2014

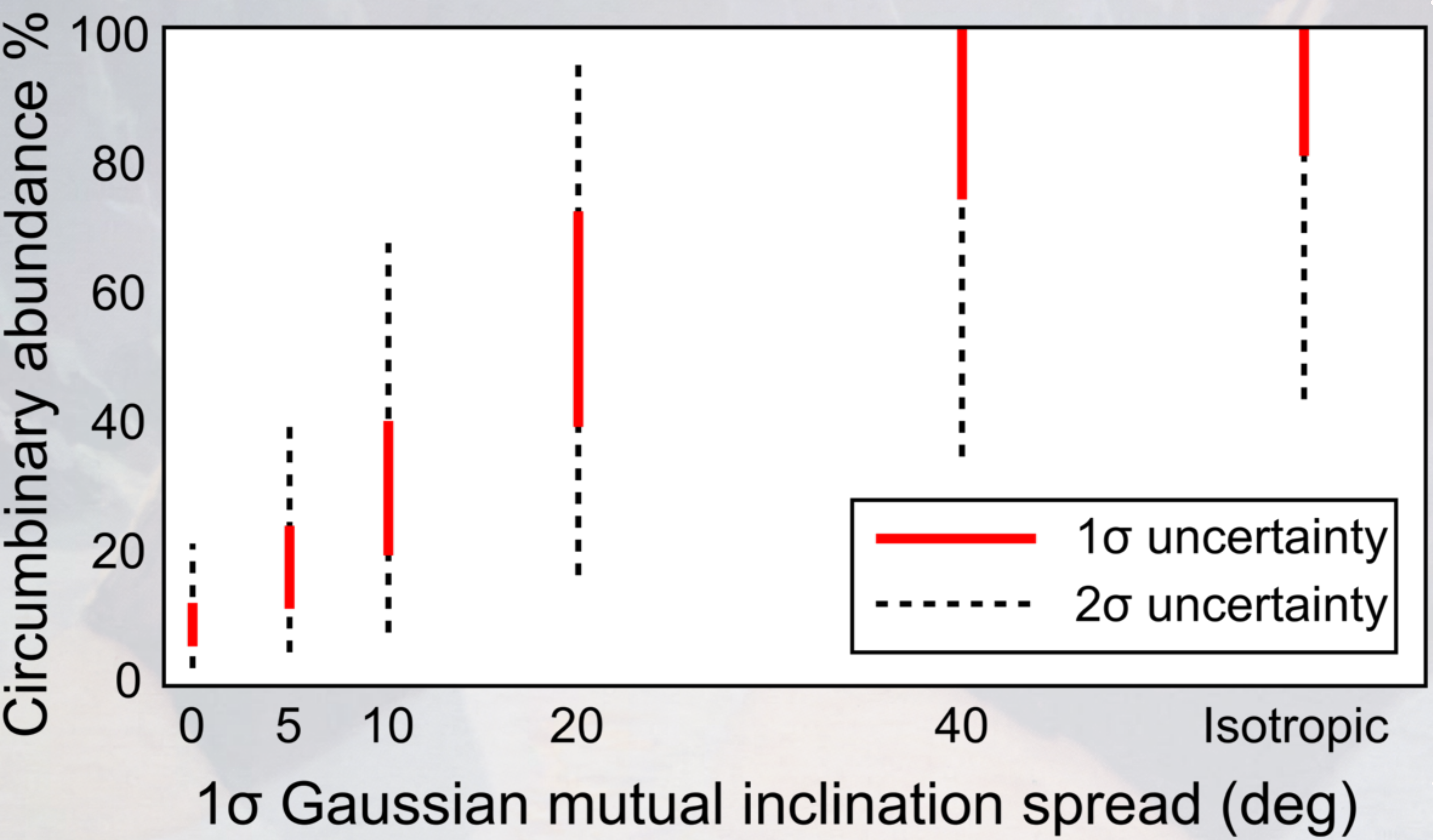
Effect of orbital inclination

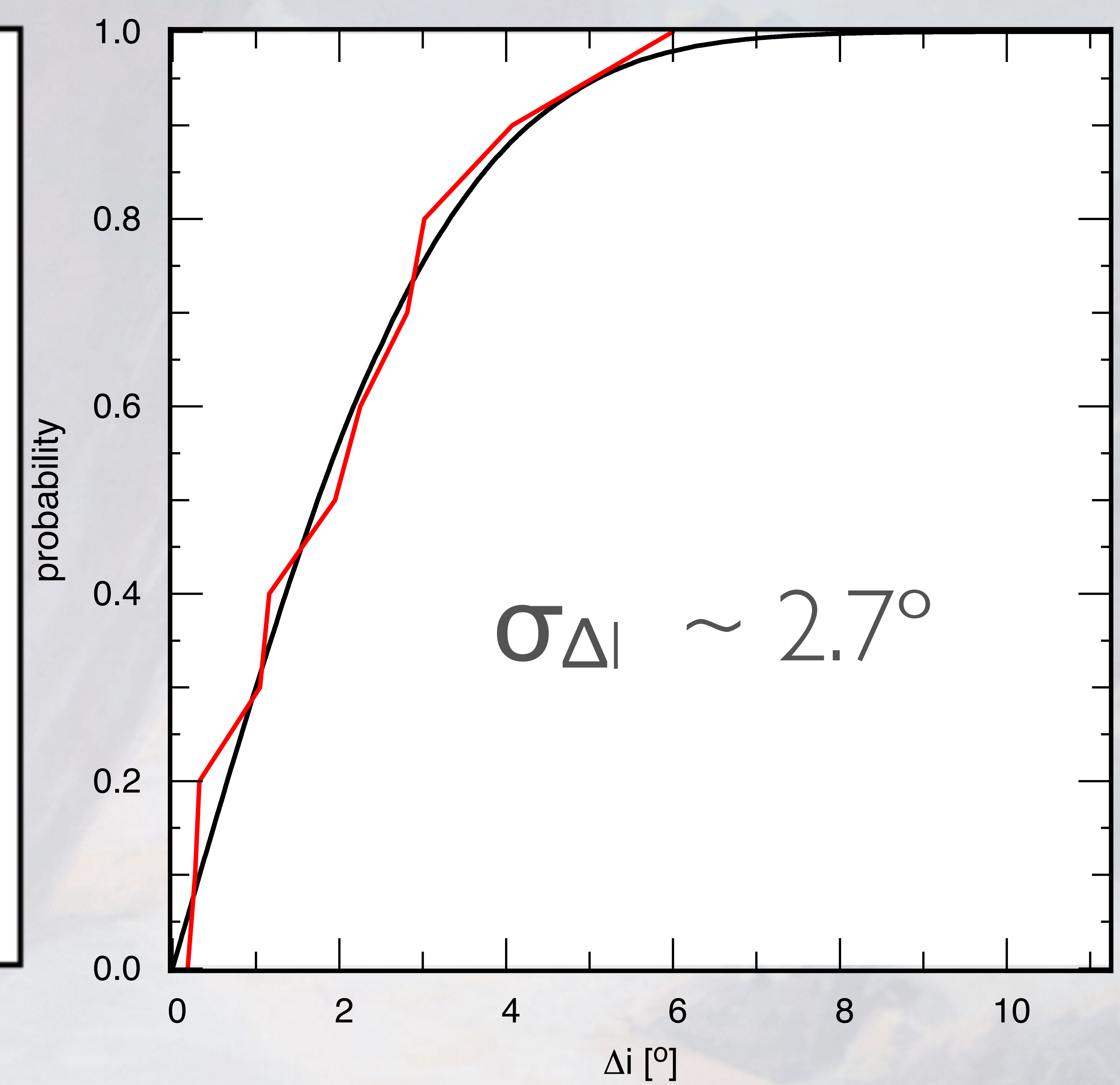


Reproduced from Armstrong+ 2014

Martin & Triaud 2014,15, Armstrong+ 2014, Li+ 2016

Effect of orbital inclination

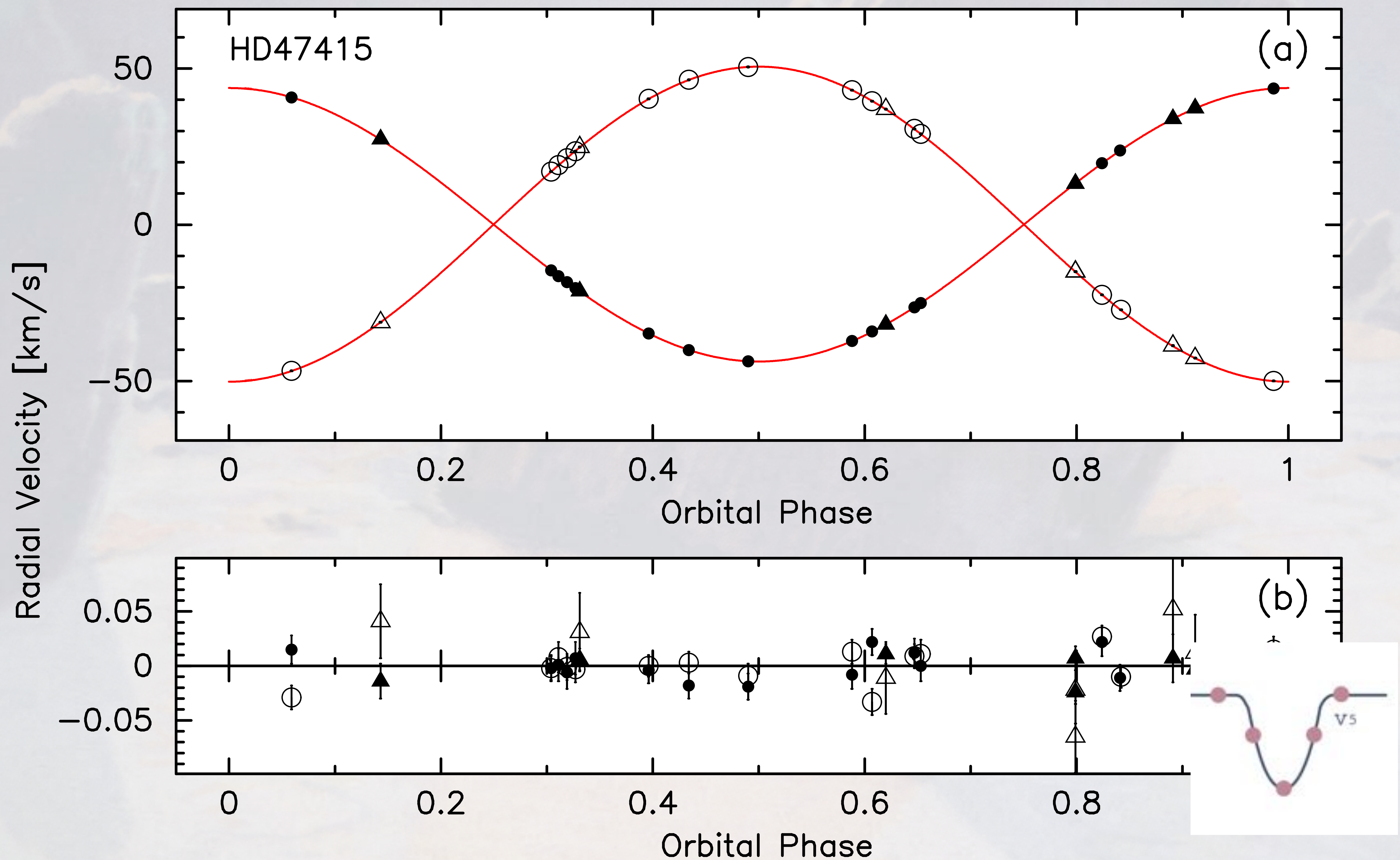




Martin & Triaud 2014,15, Armstrong+ 2014, Li+ 2016

LET'S SEARCH CIRCUMBINARIES FROM THE GROUND

RVs are more efficient, however, problem with SB2s
A noise floor of 15-20 m/s is found (Konacki+ 2009)



Problems solved by considering single line binaries.

Let's search circumbinaries from the GROUND

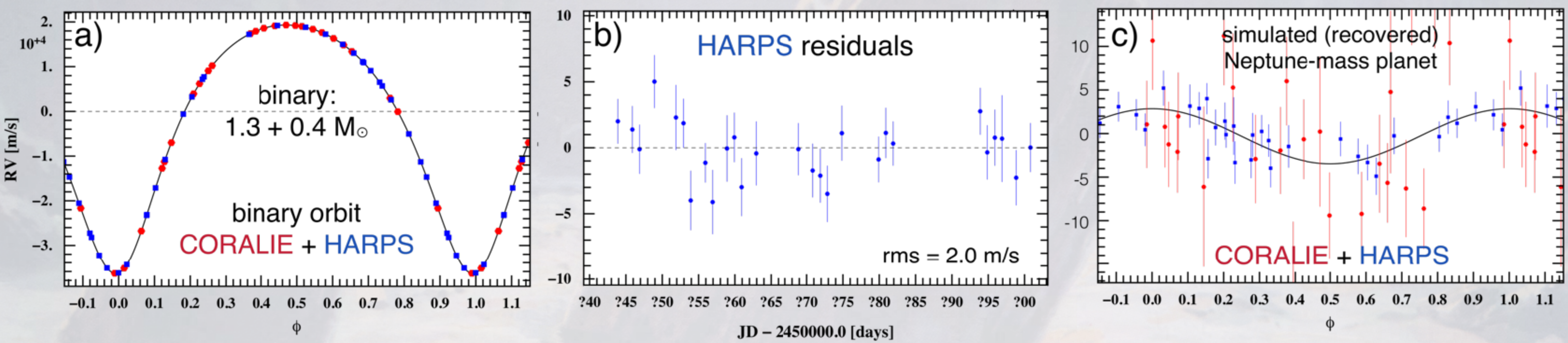
From Konacki et al. 2010

Current state-of-the-art precision is at the level of ~ 1 m s^{-1}. It is however important to note that such a precision refers to single stars or at best single-lined spectroscopic binaries where the influence of the secondary spectrum can be neglected. In

can be determined. It is quite surprising that the RV precision of double-lined binary stars on average has not improved much over the last 100 years (see Figure 1). With the exception of our previous work (Konacki 2005, 2009), the RV precision for such targets typically varies from ~ 0.1 km s^{-1} to ~ 1 km s^{-1} and clearly is much worse than what has been achieved for stars with planets or single-lined binary stars. The main problem with

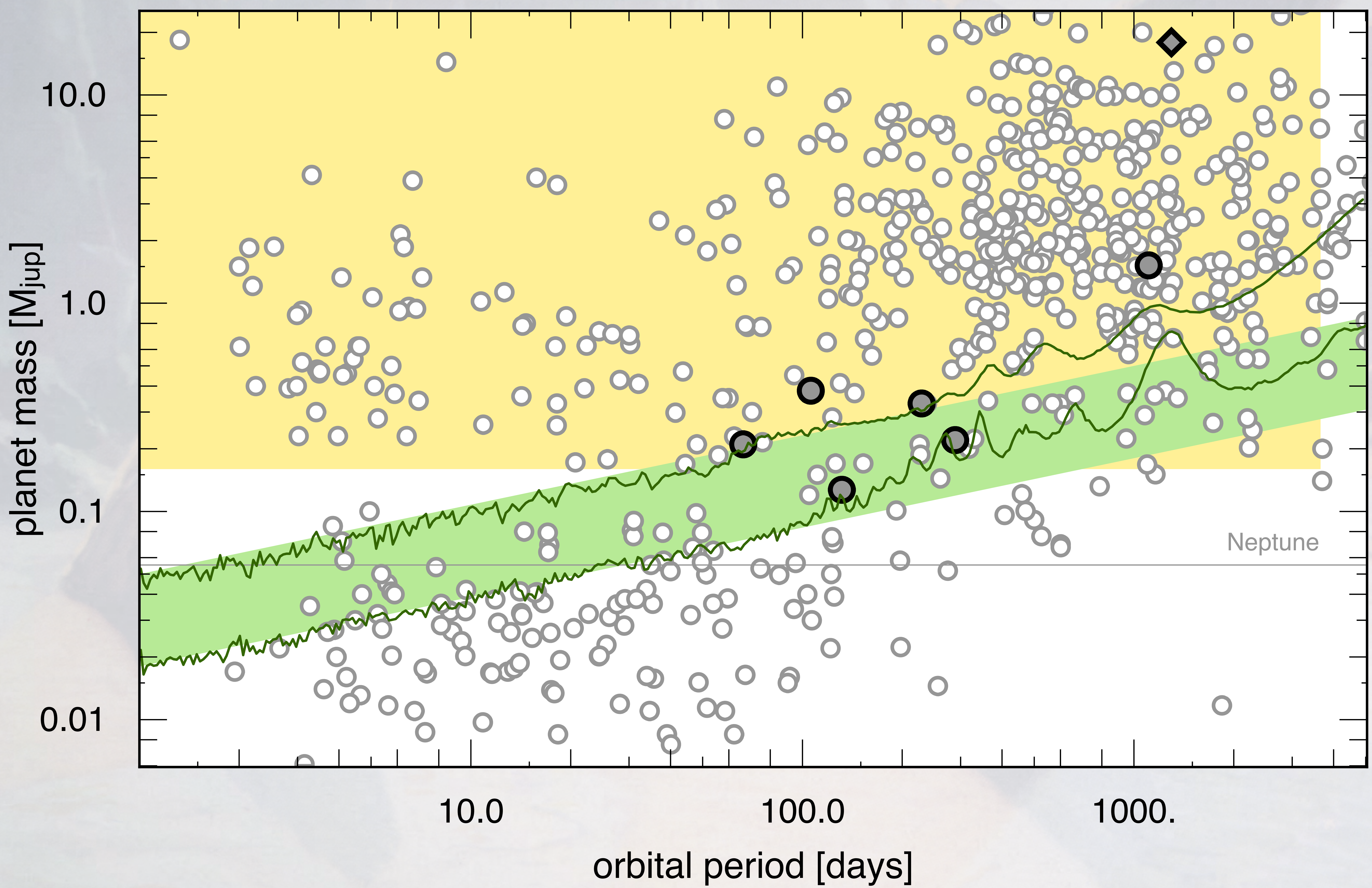
Problems solved by considering single line binaries.

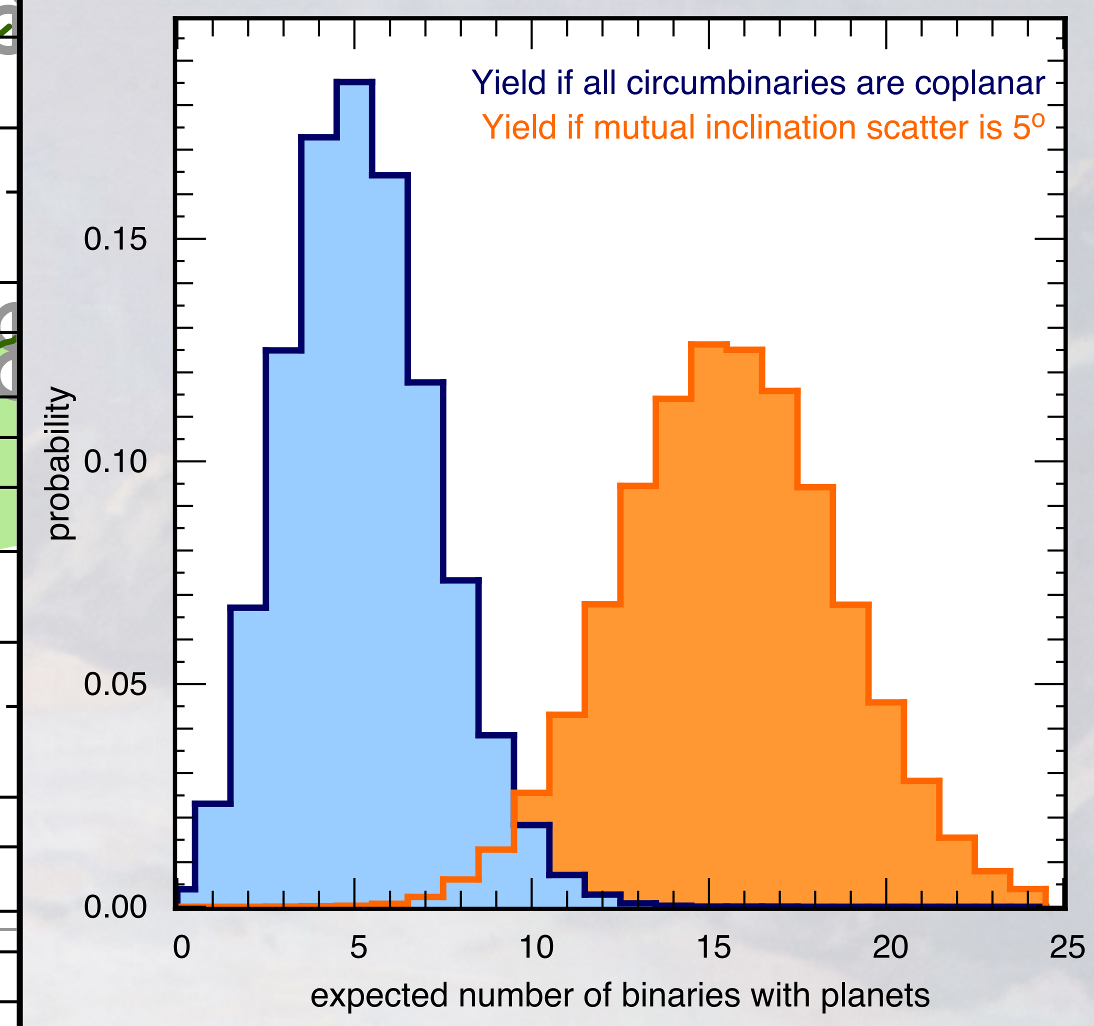
Proof-of-Concept: EBLMs



Triaud, Martin et al. in prep

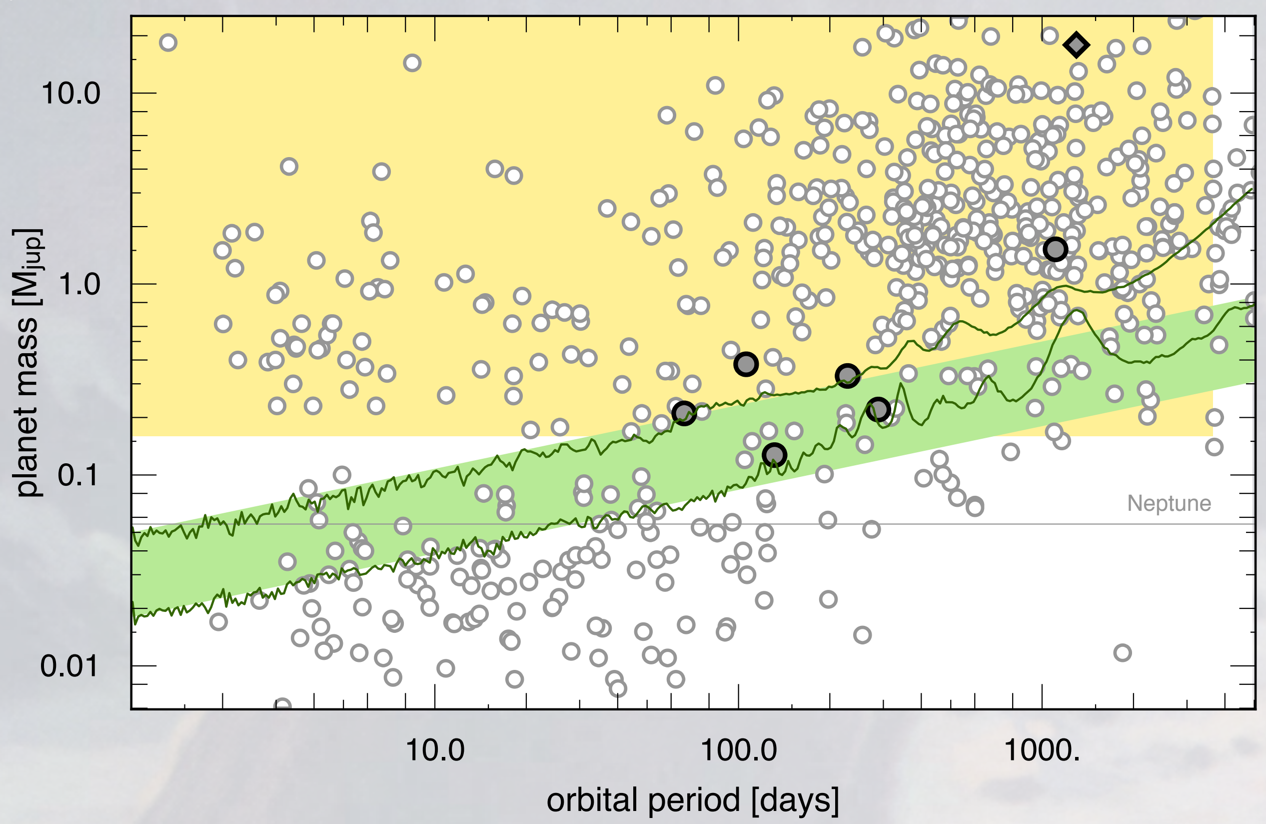
BEBOP Binaries Escorted by Orbiting Planets



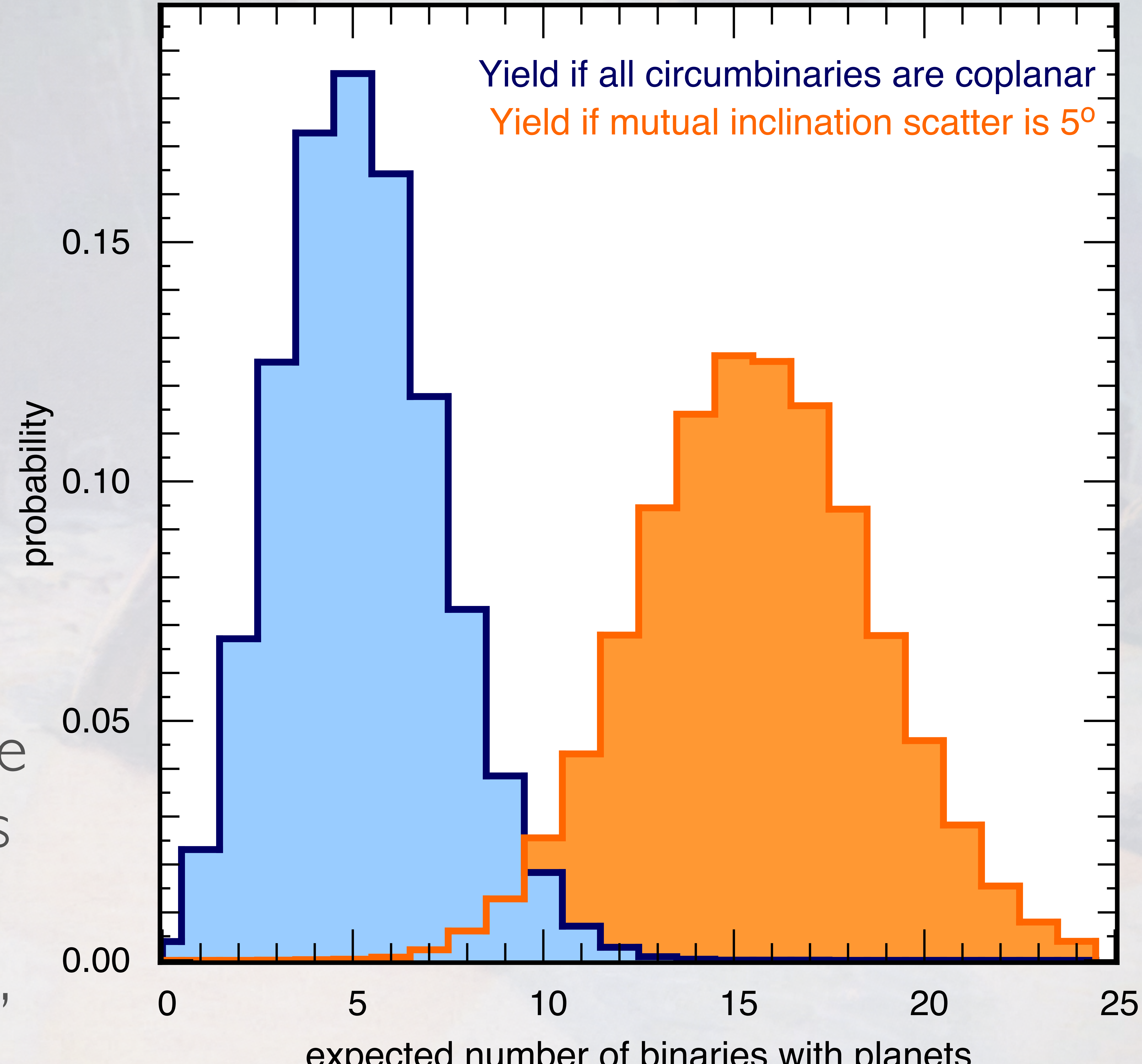


Triaud, Martin et al. in prep

BEBOP Binaries Escorted by Orbiting Planets



BEBOP might find more circumbinary gas giants than *KEPLER* using 2.5% of the time, and 0.2% of the cost



Accepted at ESO, observation started in April 2018

Want to compare 1:1 the distributions in

mass
period
eccentricity
inclination
multiplicity
metallicity

of gas-giants orbiting single Sun-like stars to close binaries including one Sun-like star.

data allocation

80 nights on HARPS @ ESO-3.6m
198 nights on SOPHIE @ OHP-193cm
photometric follow-up using an Antarctic telescope (ASTEP-400)
TESS short cadence

funding

European Research Council
Established by the European Commission
LEVERHULME TRUST
Science & Technology Facilities Council
UK Research and Innovation

The PLAN

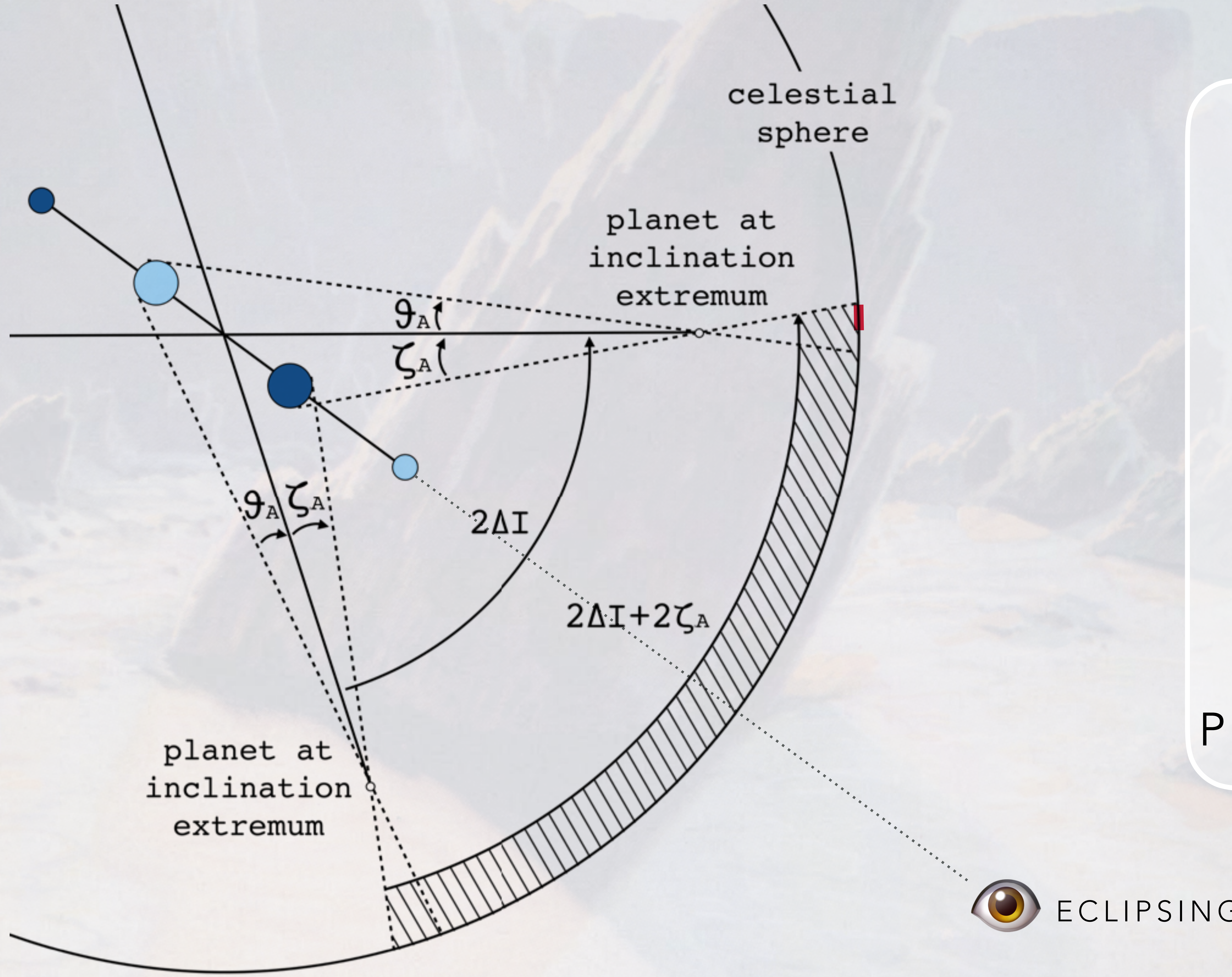
Find planets using the radial-velocity method
then
find them in transit, and recover their elemental abundance.

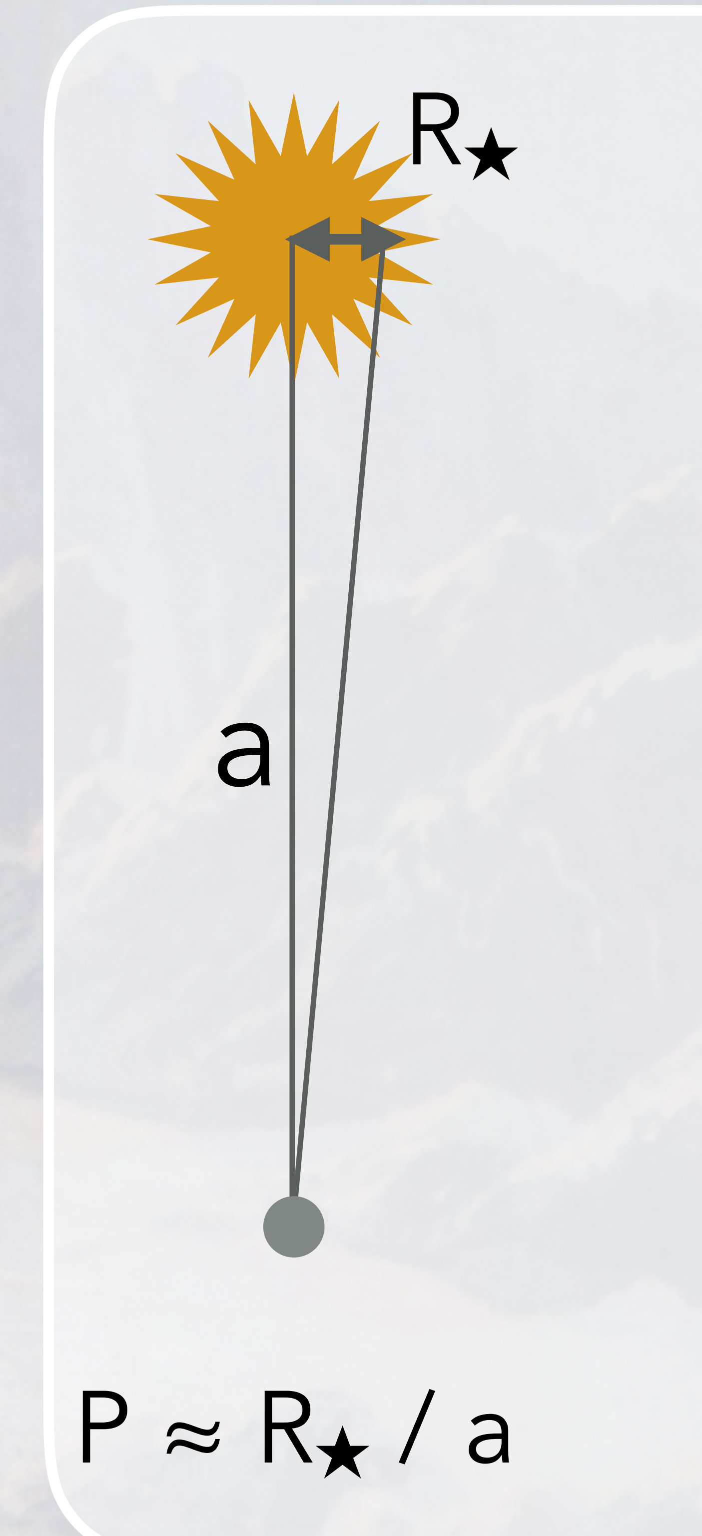
We expect that 95% of BEBOP discoveries will TRANSIT

Martin & Triaud 2014

PROBABILITY OF TRANSIT REACHES 100%

FOR ΔI > 0.6°

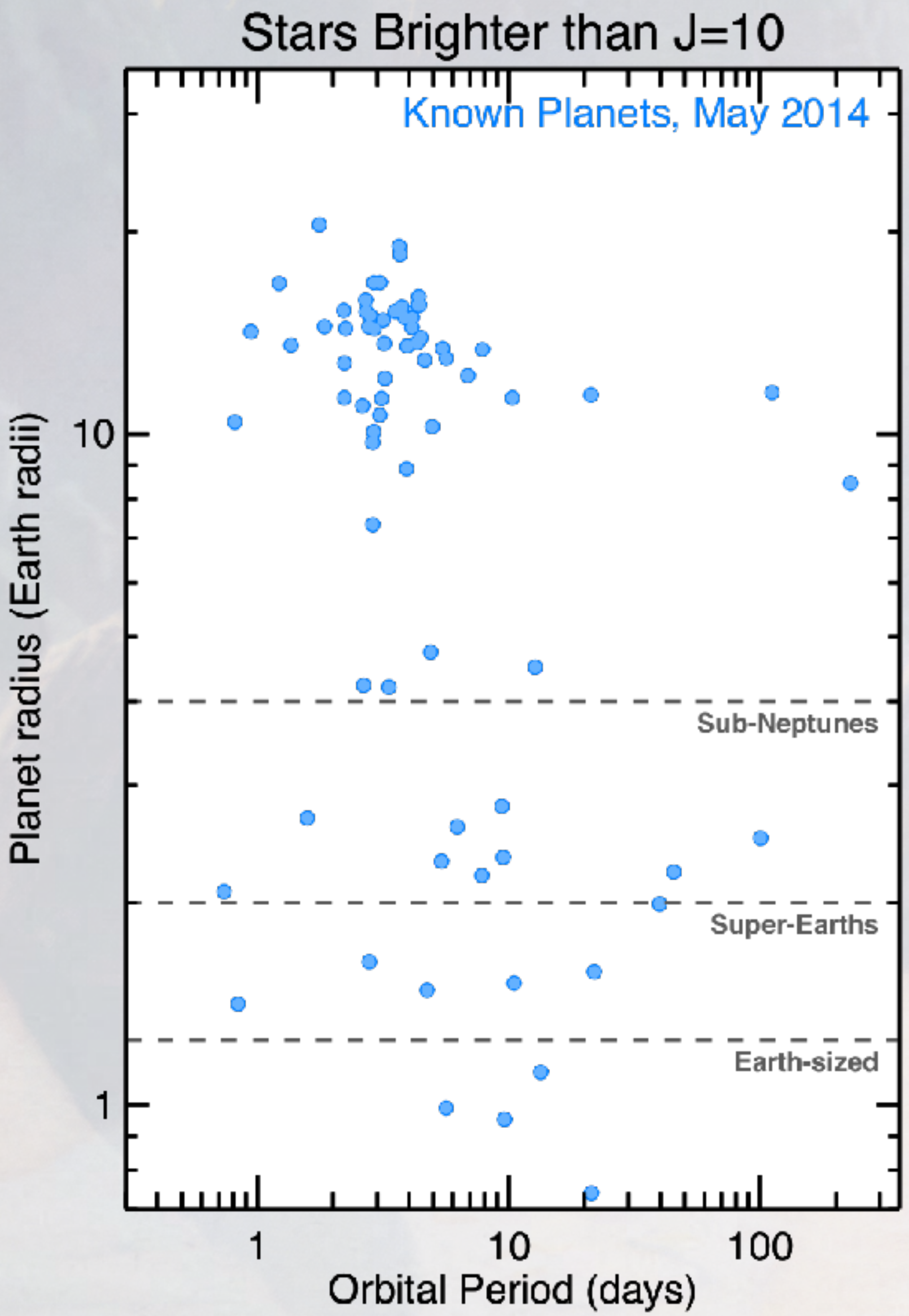




$P \sim \sin \Delta I$

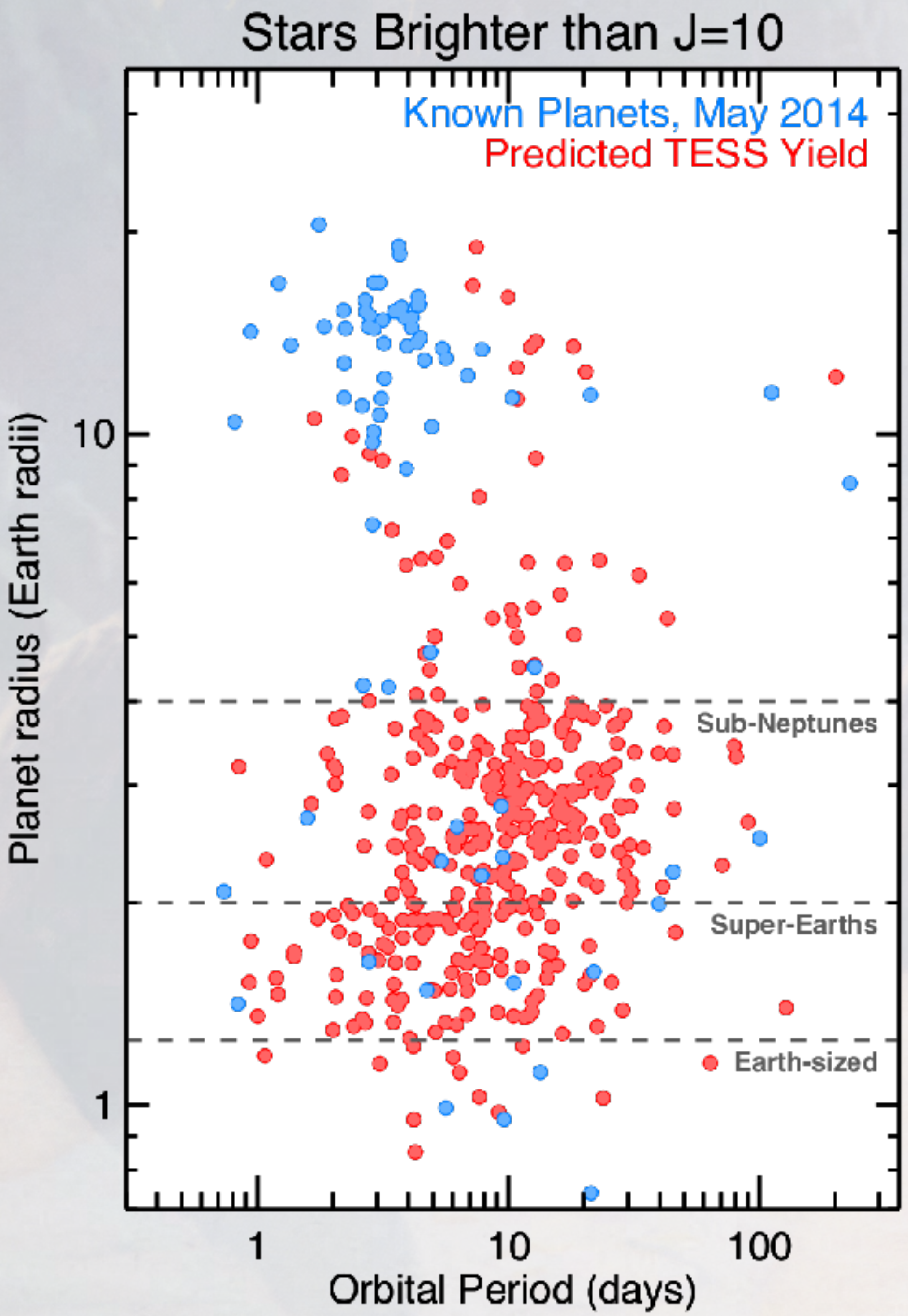
MARTIN & TRIAUD 2015

Accessing WARM Jupiters



Ricker+ 2014

ACCESSING WARM JUPITERS

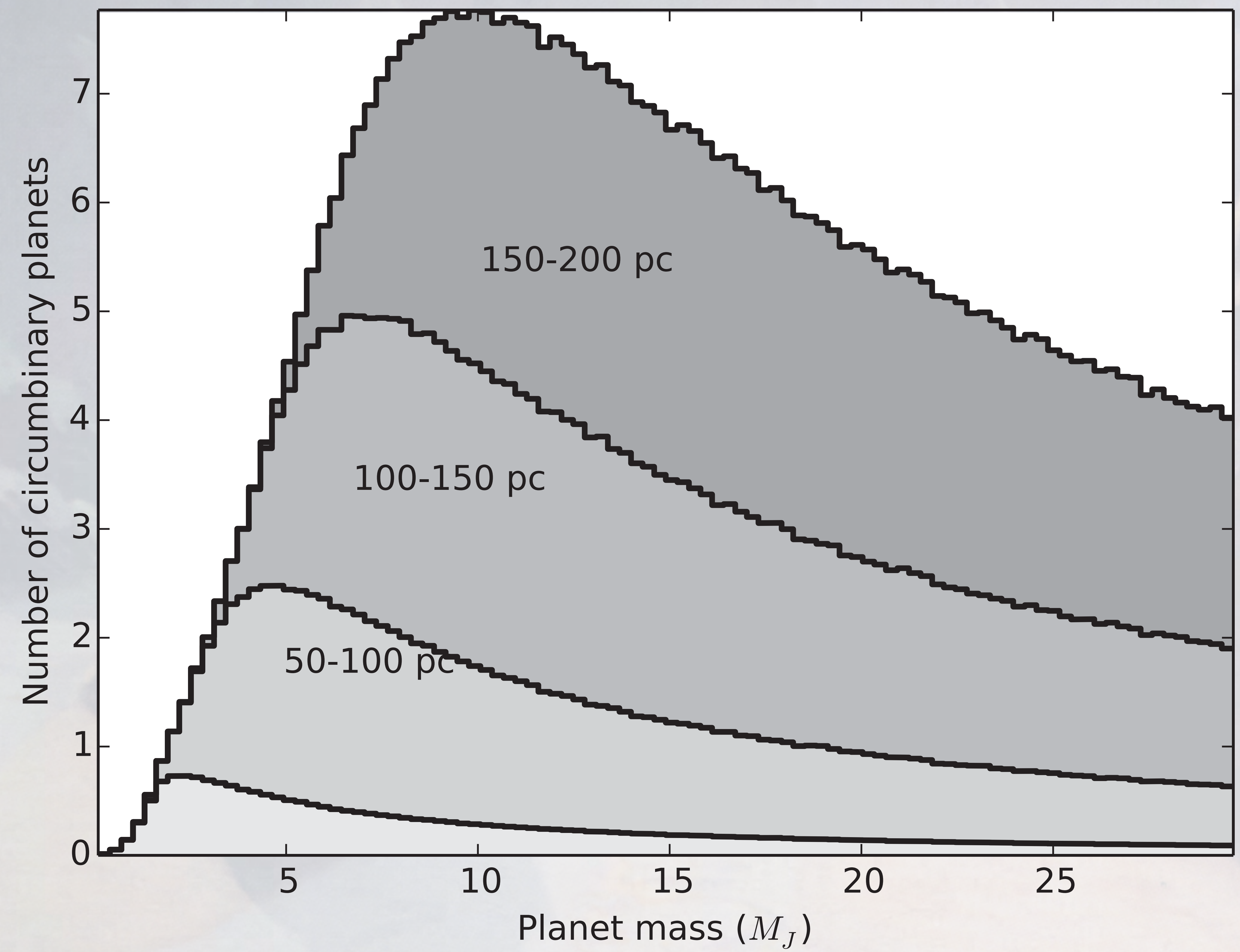


Projected results by TESS
very few warm giants for single stars

It may be that most bright transiting warm Jupiters will be circumbinary.

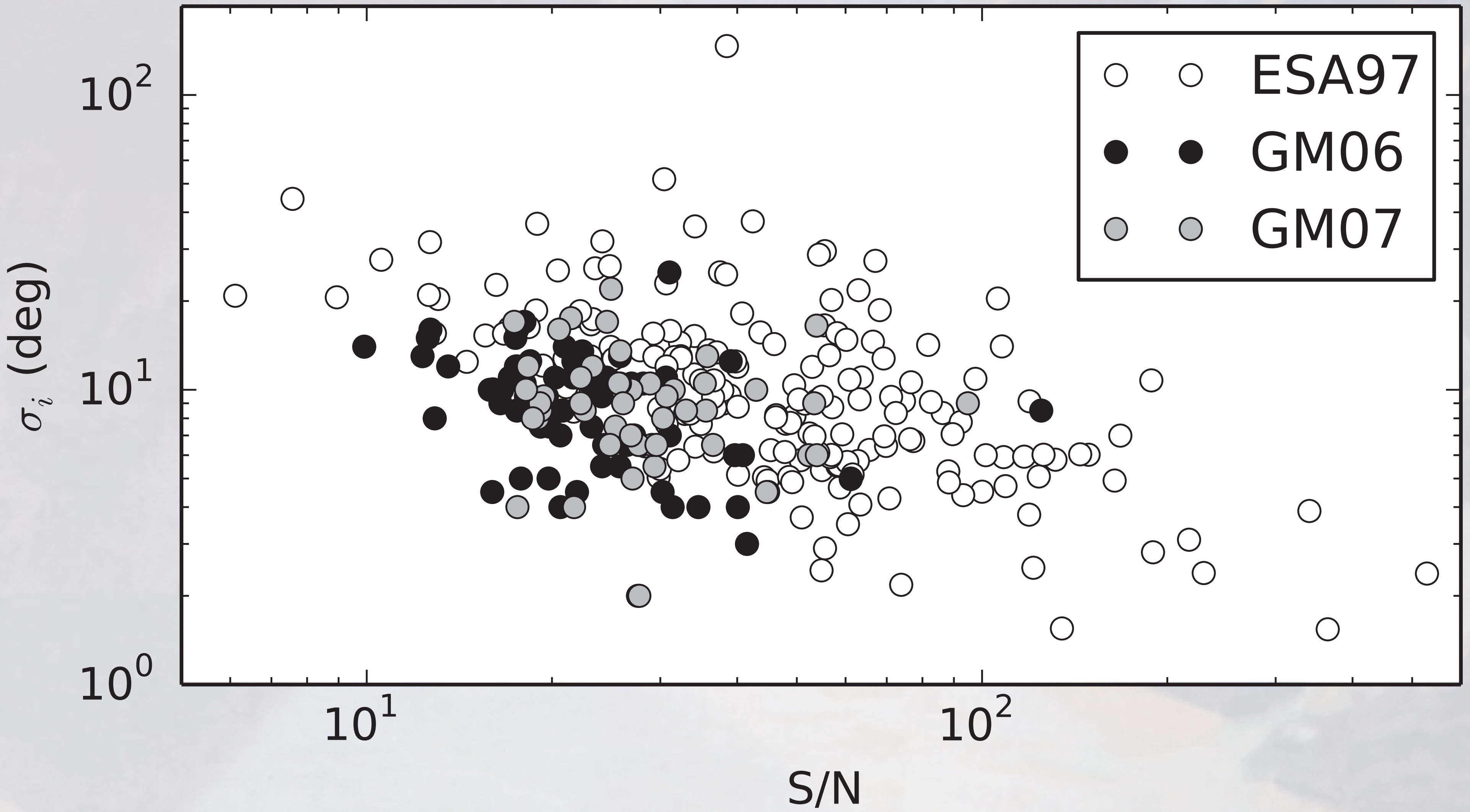
RICKER+ 2014

GAIA: A TRUE REVOLUTION



Identification of ~300-500 new systems

Mutual inclinations 1-10º



Sahlmann, Triaud & Martin 2015

We need observations
IN ALTERNATE ENVIRONMENTS
to single Sun-like stars

With BEBOP, we will be
DIRECTLY COMPARING
alternatives to single Sun-like stars

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