Observable effects of tides on exoplanets

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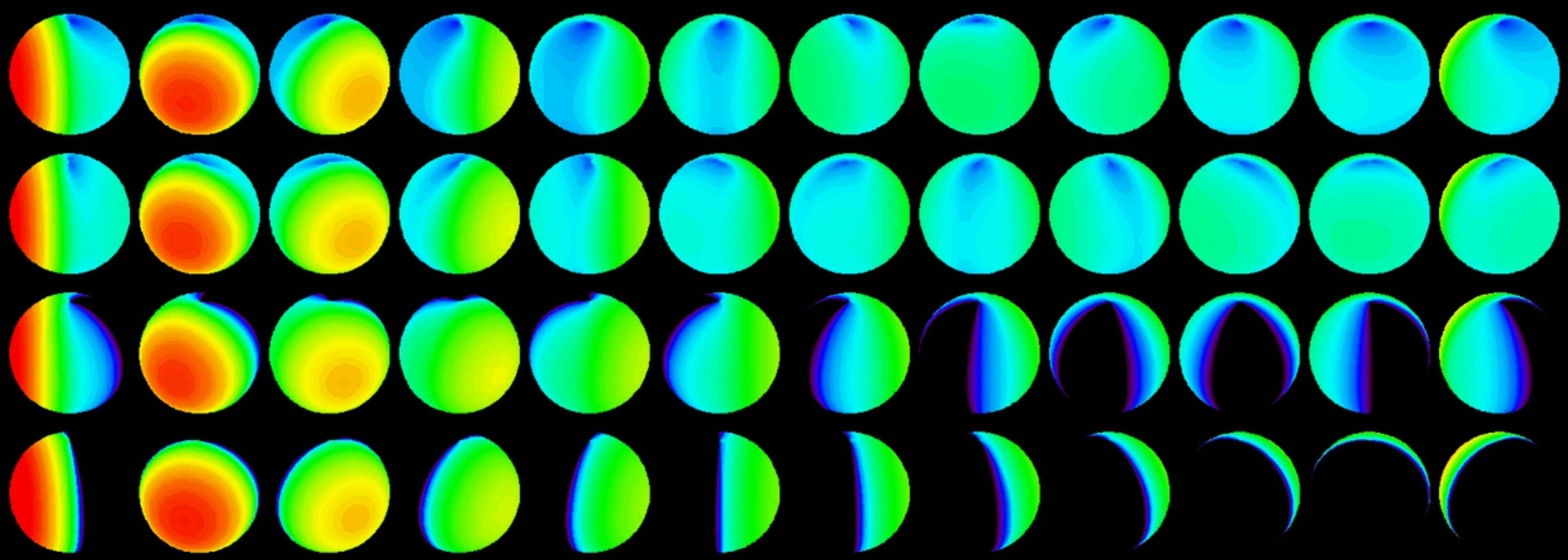
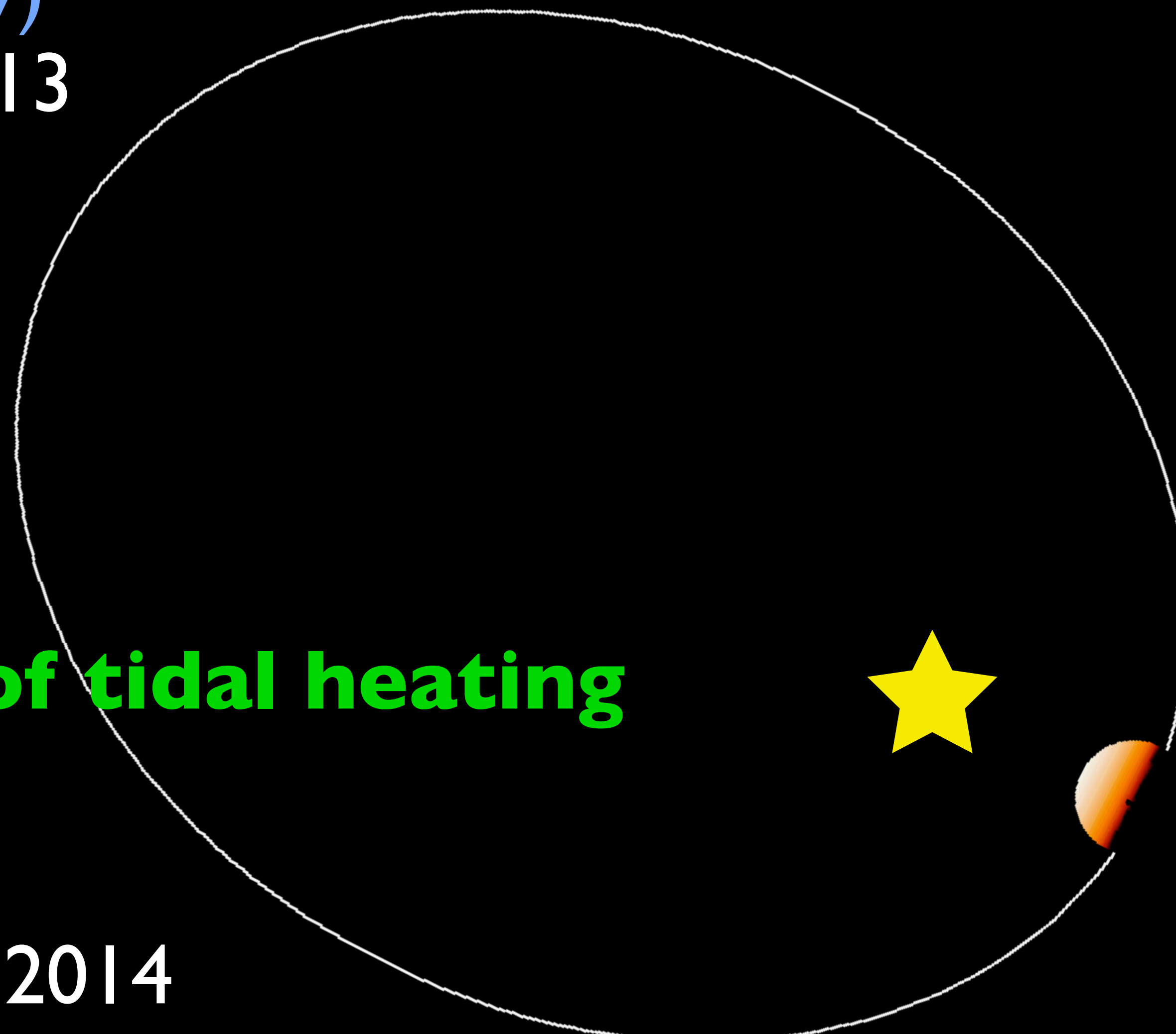
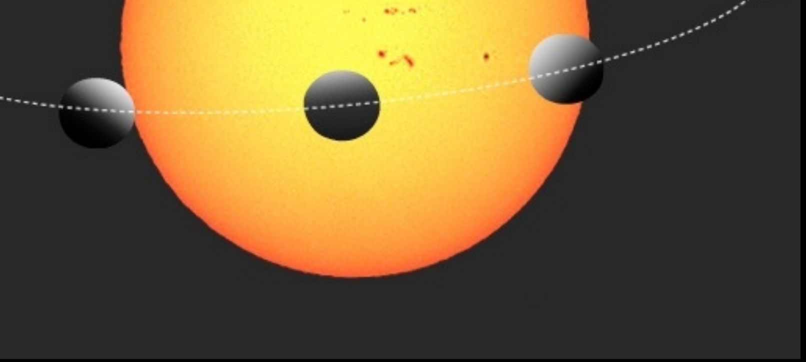


tidal luminosity
55 Cnc e
Bolmont et al., A&A, 2013

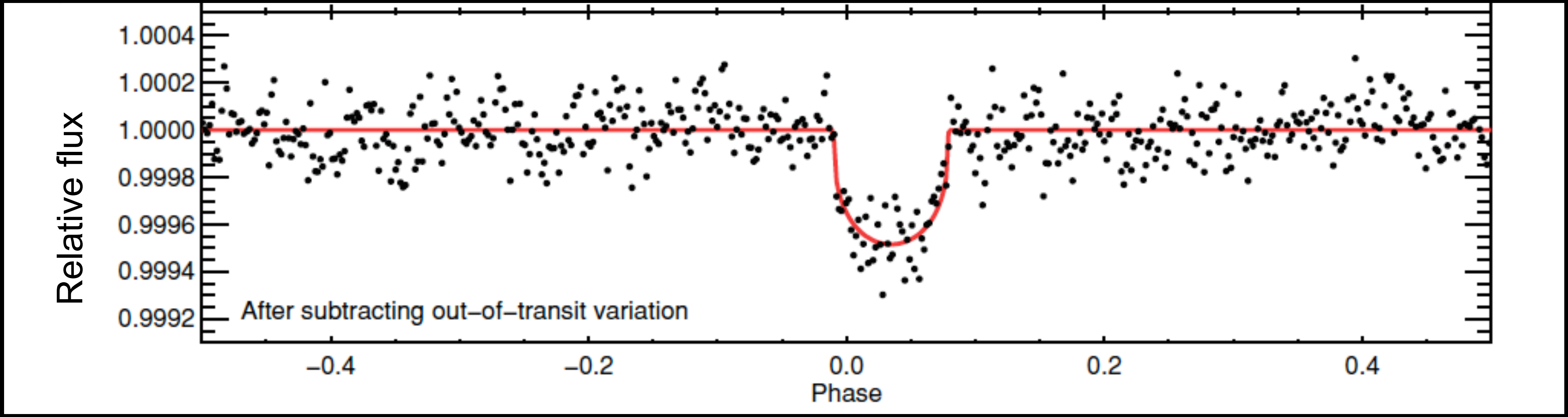
rotation
(and tidal luminosity)
Selsis et al, A&A, 2013



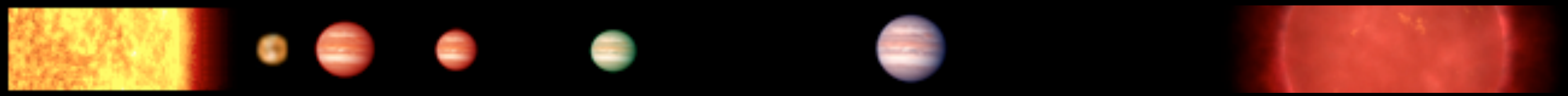
indirect effect of tidal heating (chemistry)
GJ 436 b
Agundez et al., ApJ, 2014



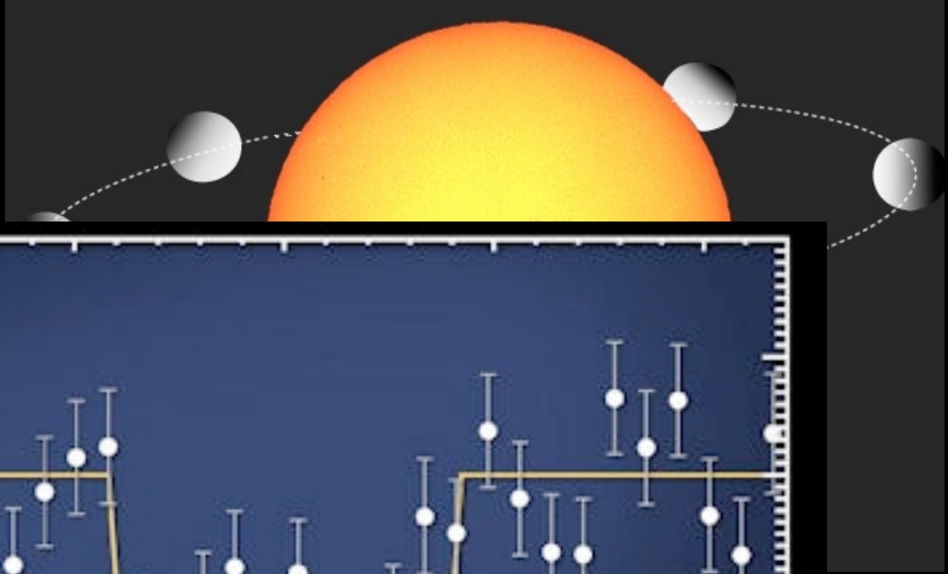
55 Cancri

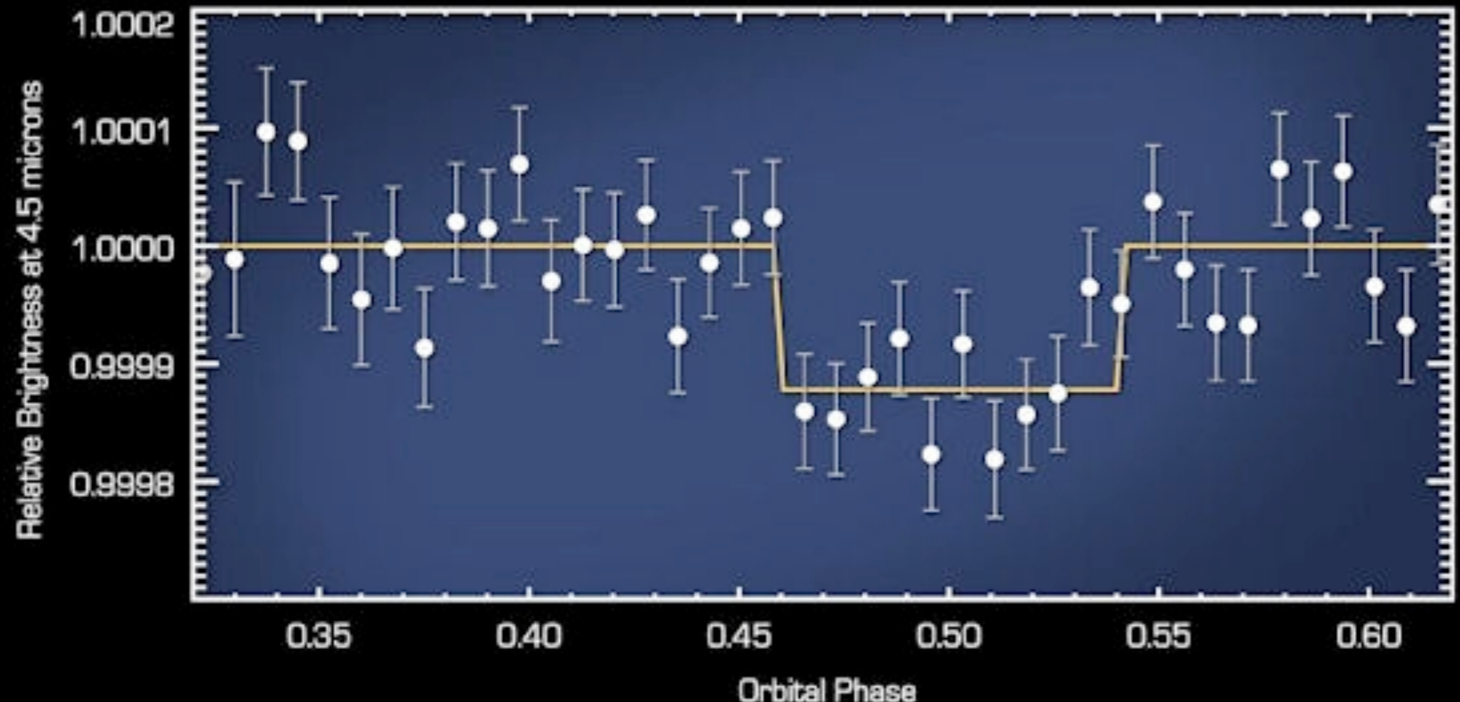


Winn et al., 2011, Demory et al., 2011, Gillon et al., 2012

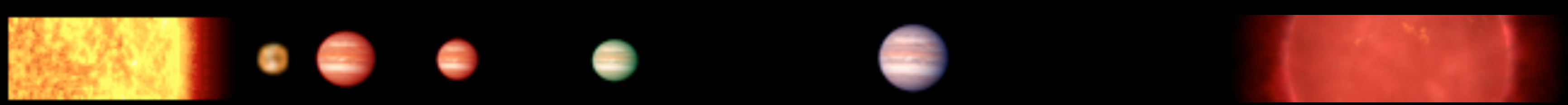


55 Cancri





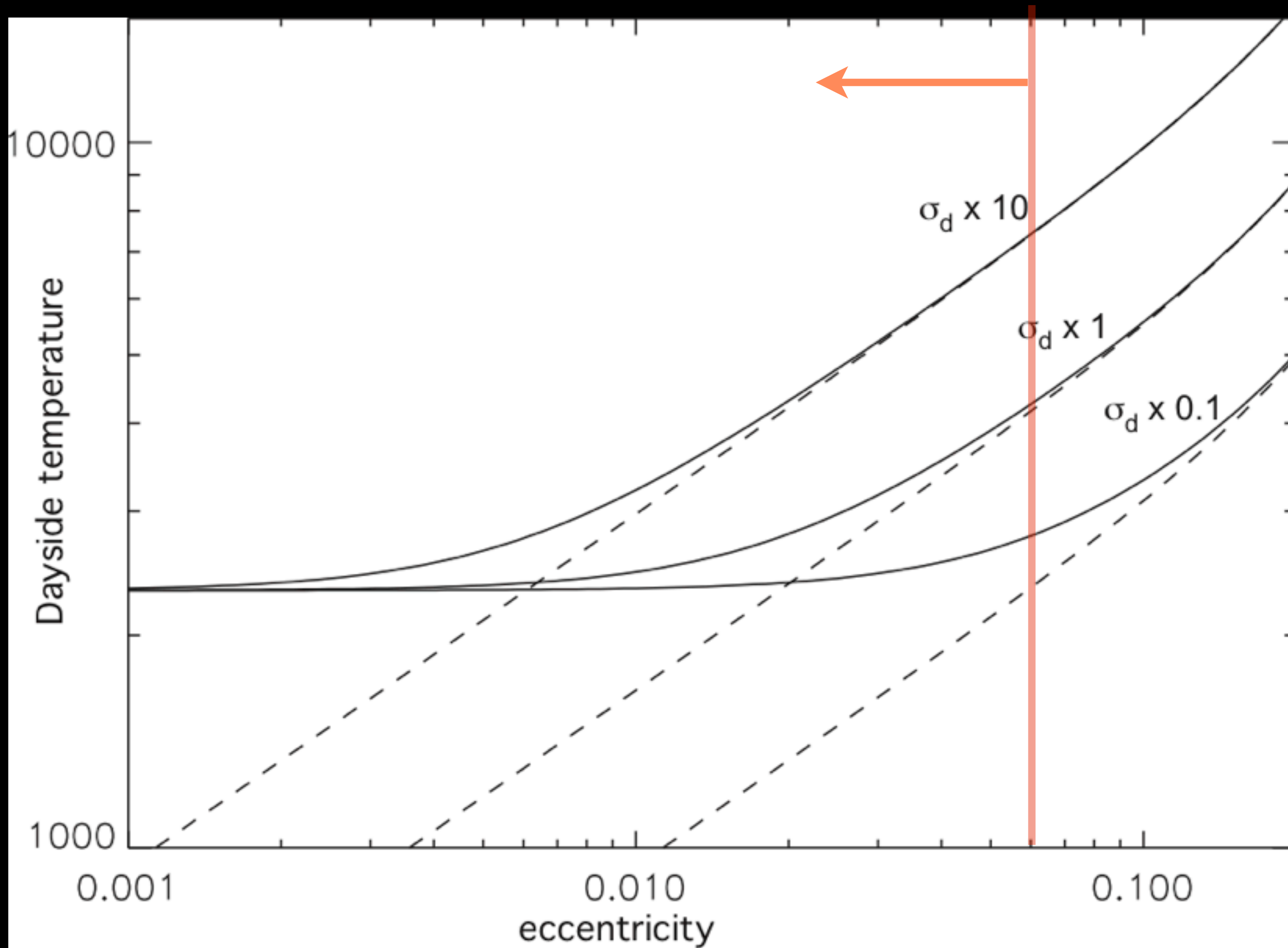
Demory et al., 2012



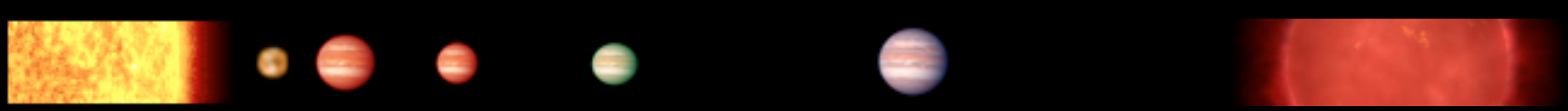
55 Cancri e - secondary eclipse depth (4 µm) implies a low albedo

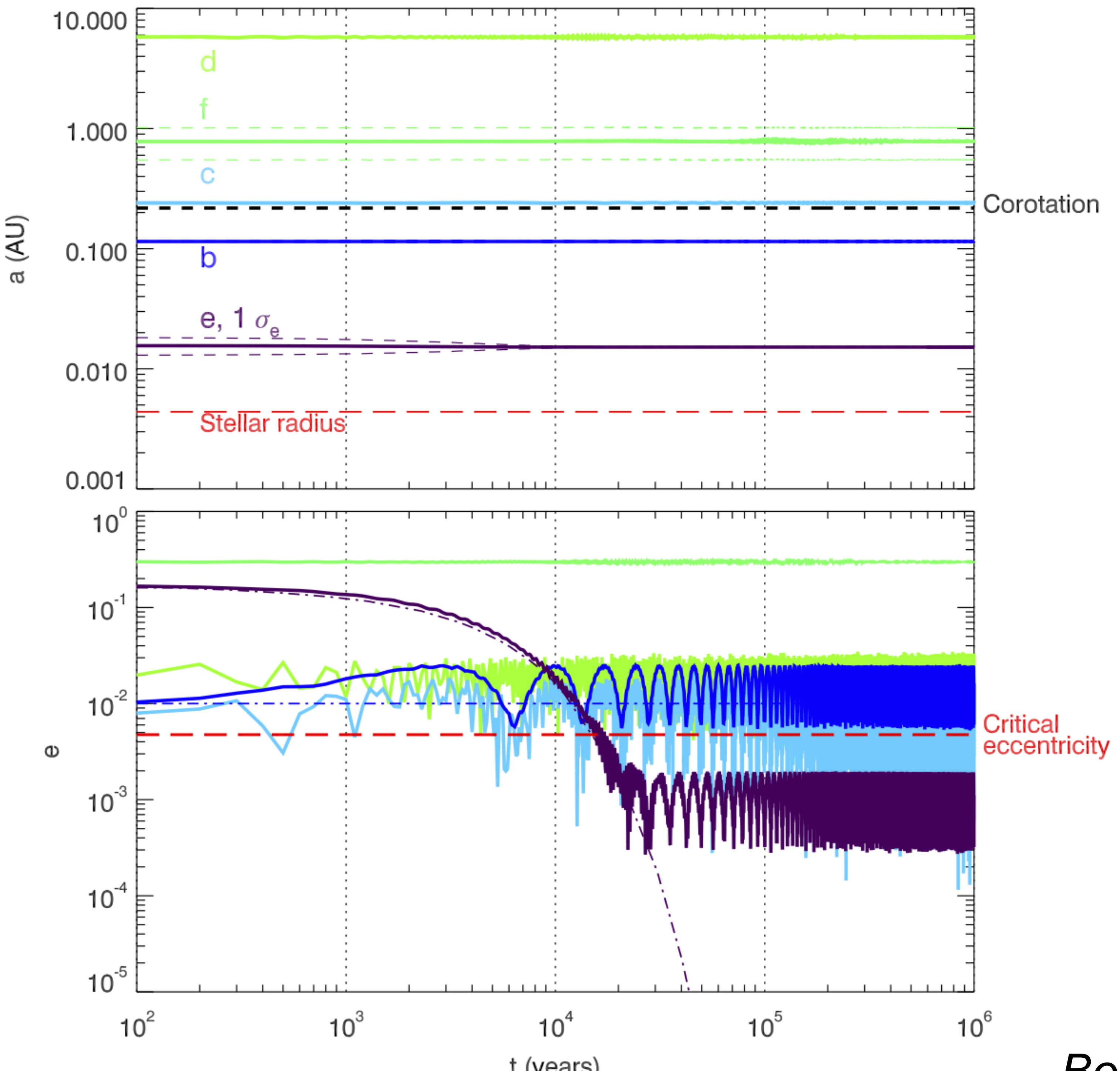
Kepler 10 b - primary transit depth (0.4-0.9 µm) implies a high albedo

55 Cancri

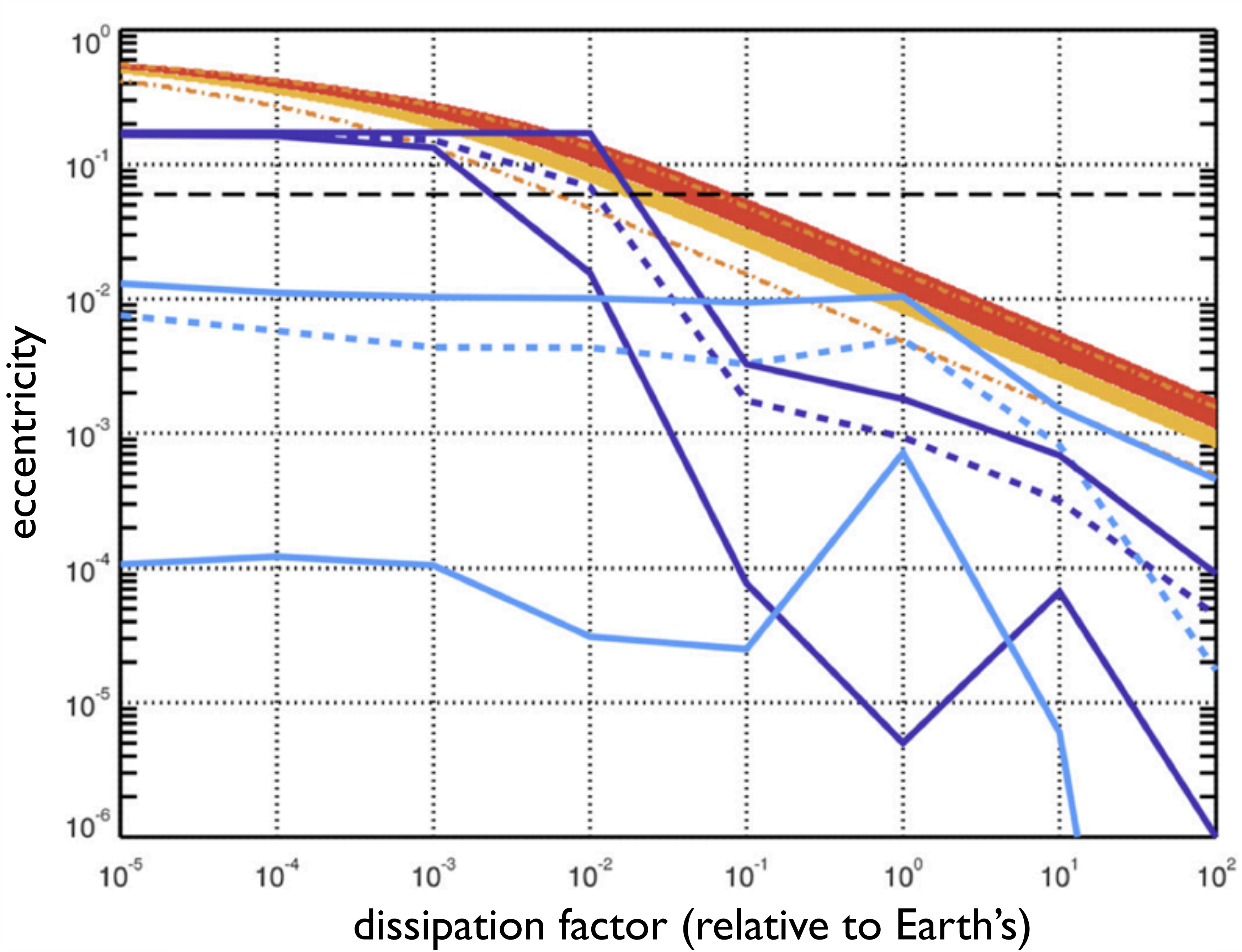


10000
1000
Dayside temperature
0.001
0.010
0.100
eccentricity
σ_d x 10
σ_d x 1
σ_d x 0.1

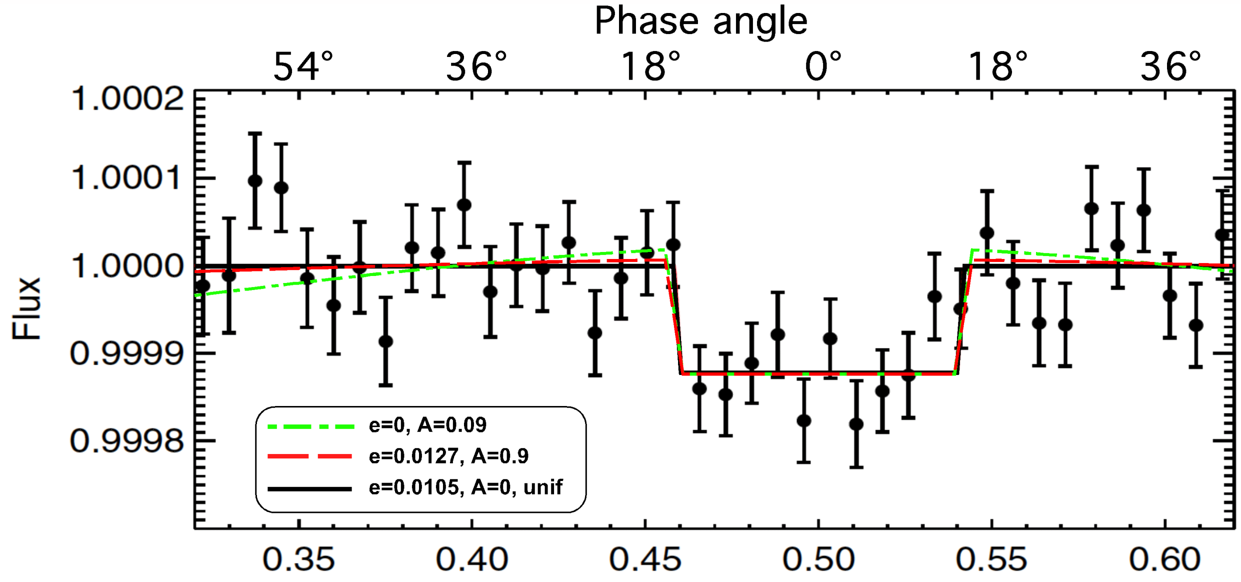




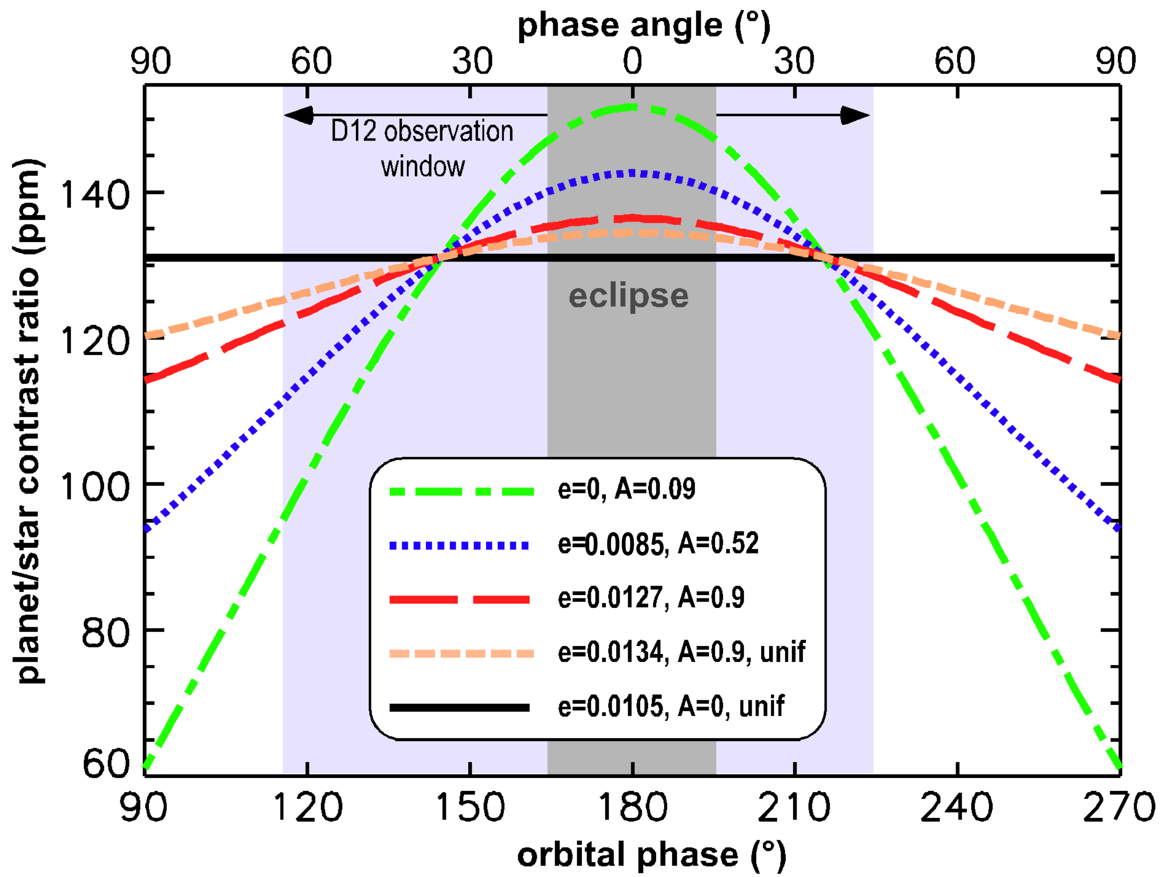
Bolmont et al., 2013

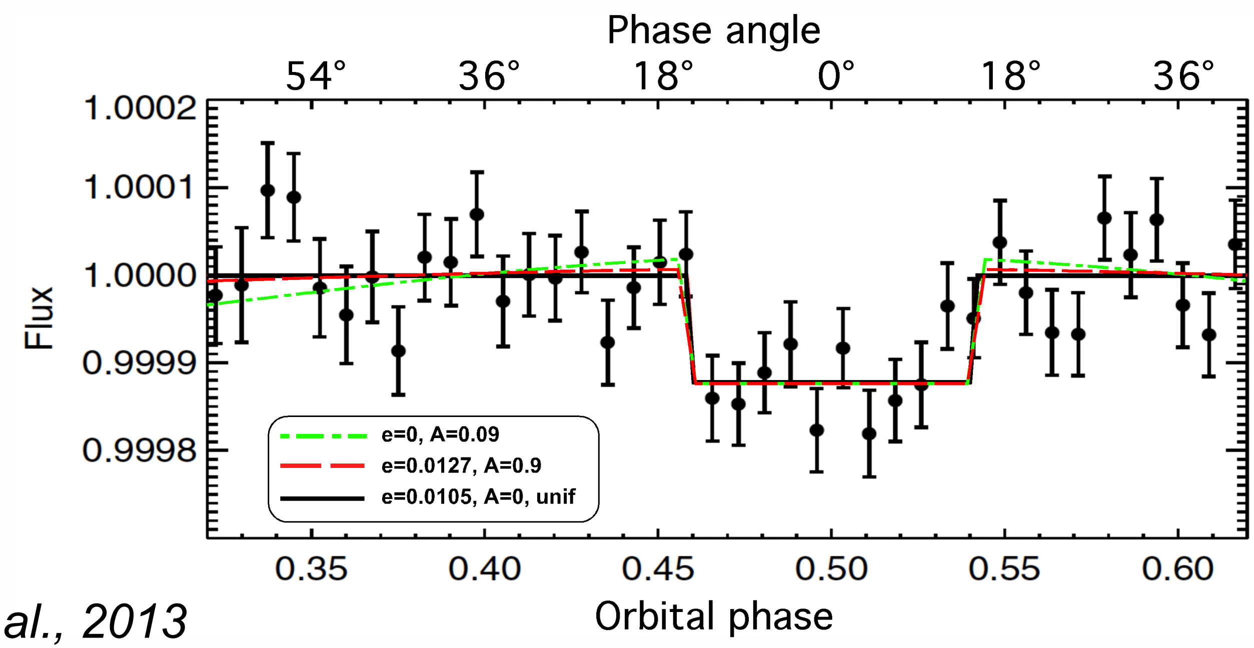


Bolmont et al., 2013



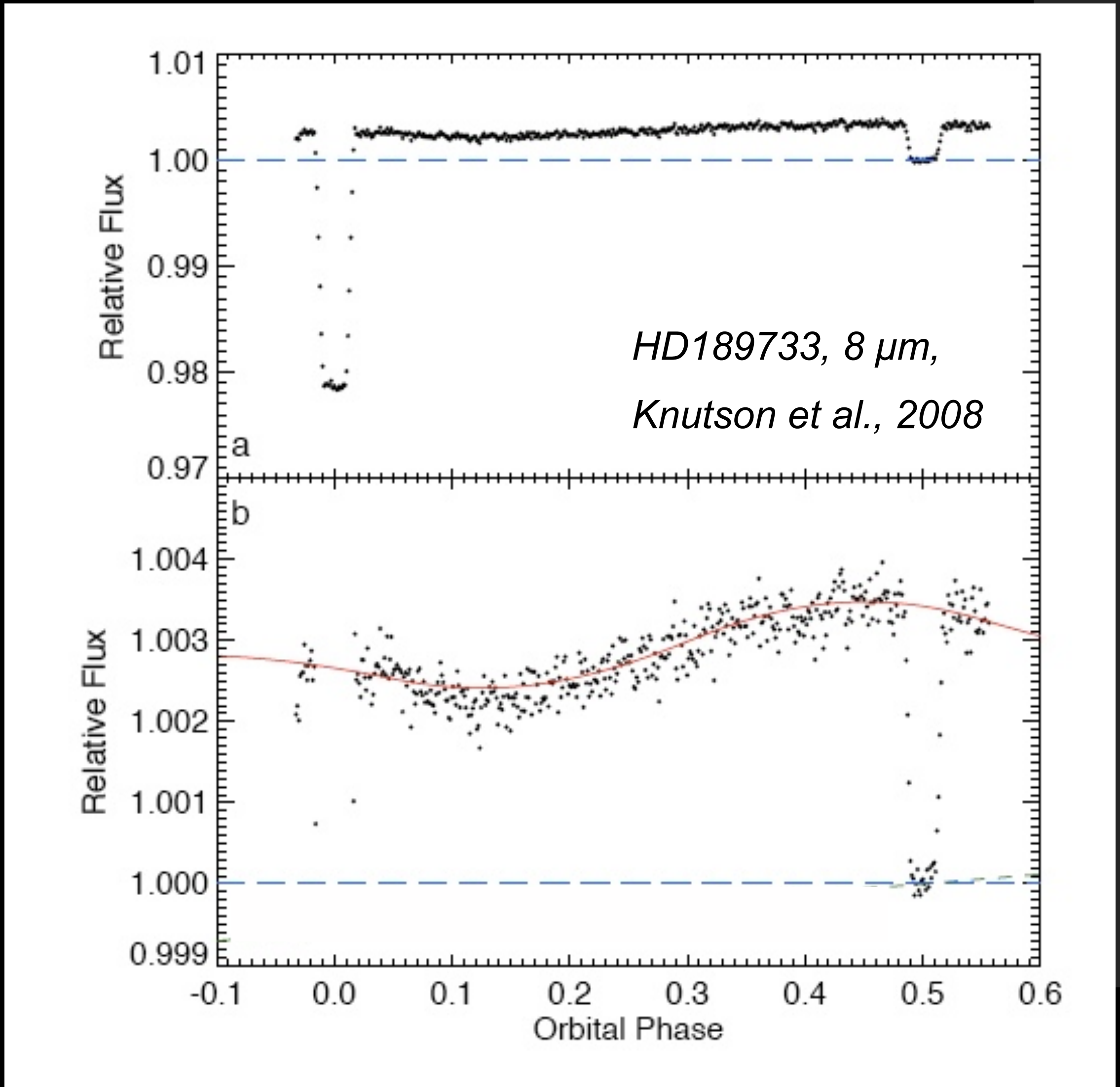
Bolmont et al., 2013

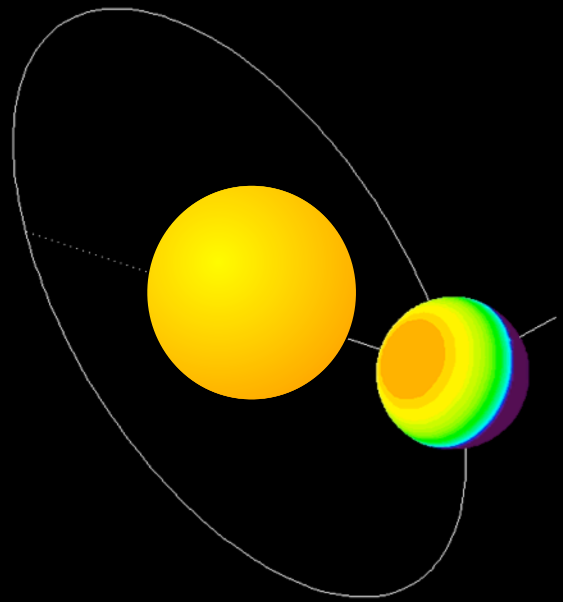




Bolmont et al., 2013

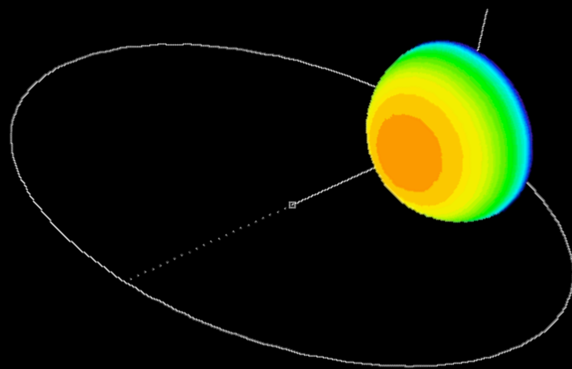
What can be the influence of tides on orbital IR photometry ?



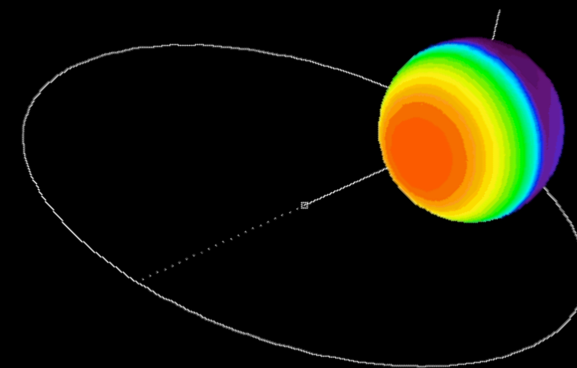


- IR excess
- rotation
- combination of both

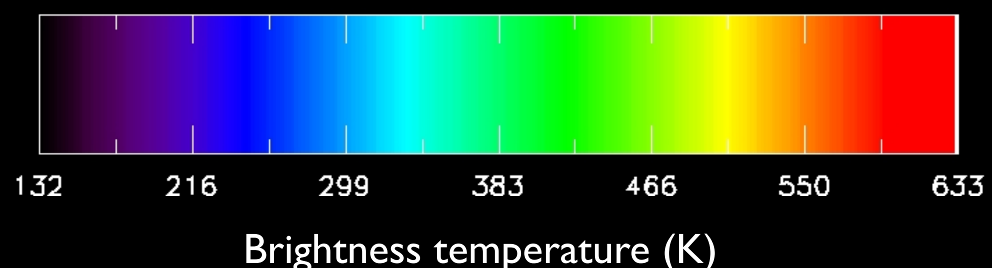
8.7 microns

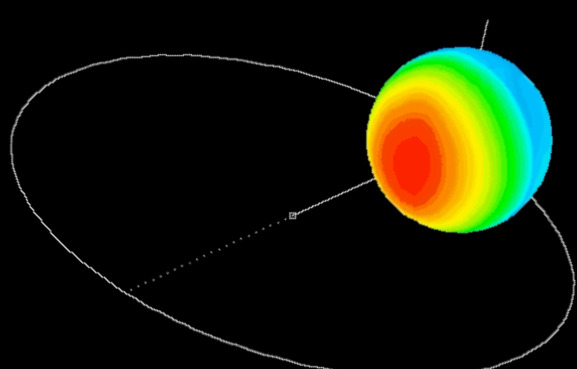


no atmosphere

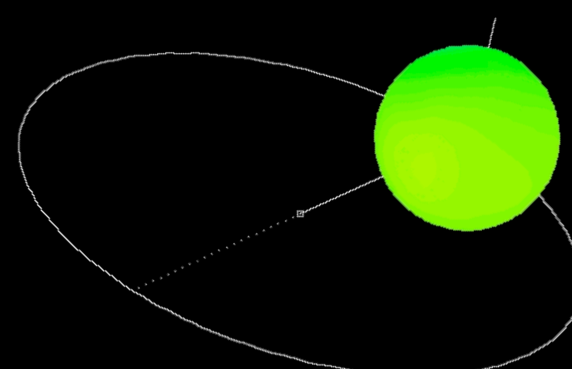


0.1 bar (CO_2)





1 bar (CO_2)



10 bar (CO_2)

default model parameters

$0.3\ M_{Sol}$
$R=2R_{Earth}$
P_{orb}=10 days
A=0.1
$Q_{tide}=Q_{tide,Earth}$
Γ_0=3000 SI (=rock)

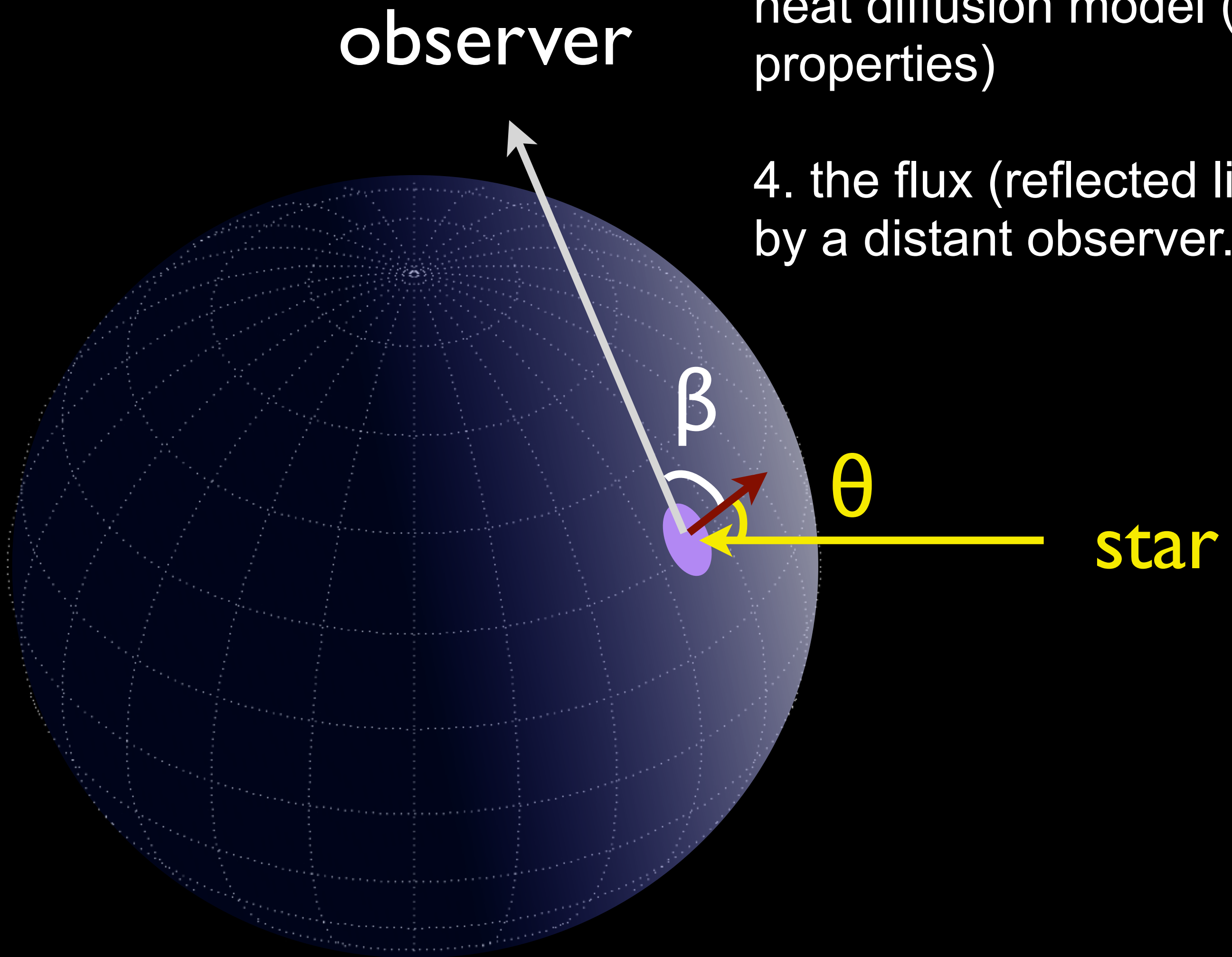
The model computes:

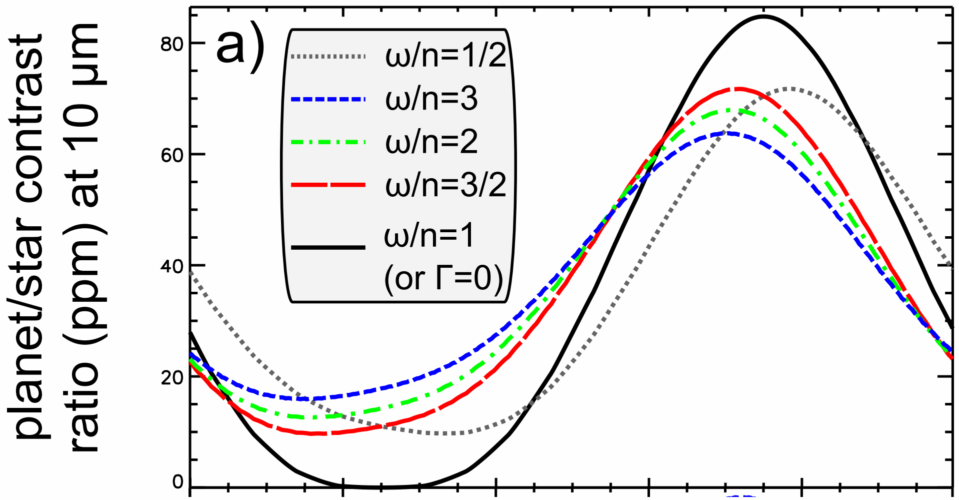
1. the time-dependent surface illumination for any Keplerian orbit and any rotation ω

2. the internal heat flow resulting from tidal dissipation

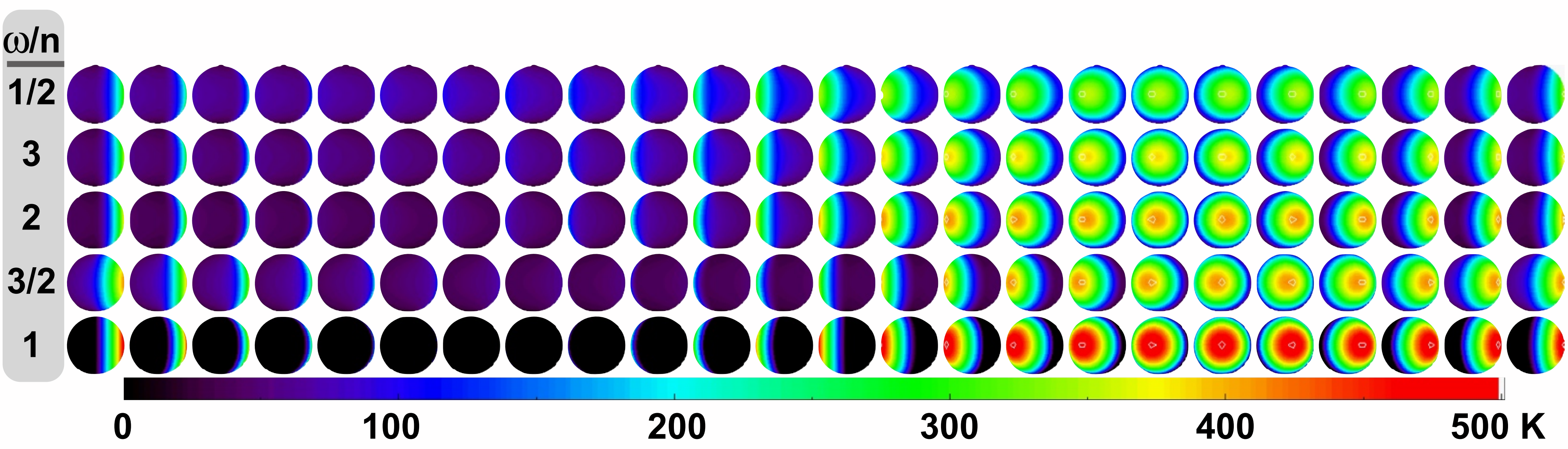
3. the time-dependent (sub)surface temperature with a heat diffusion model (assuming thermal surface properties)

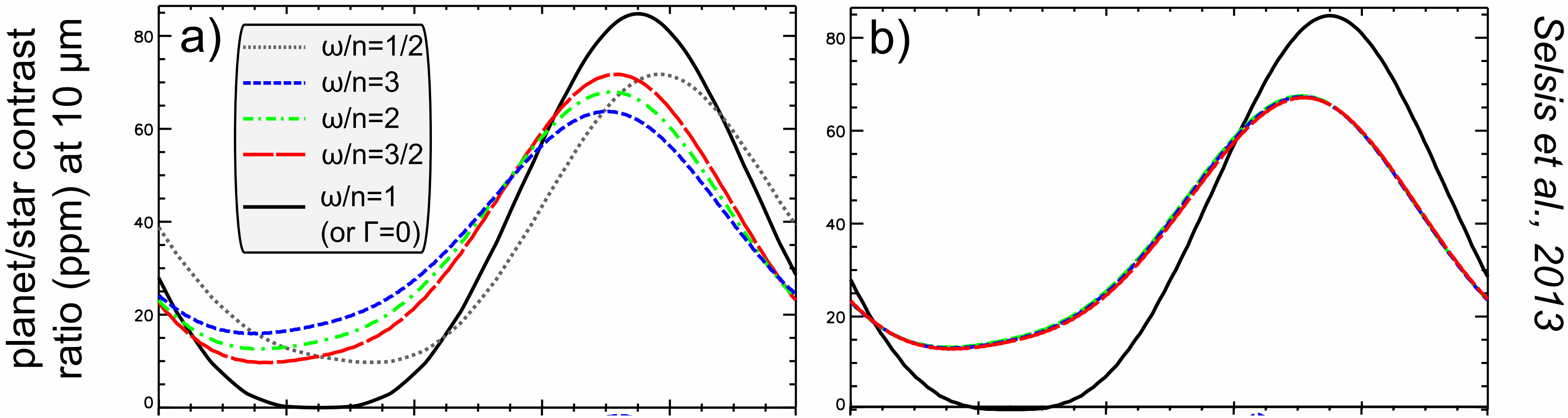
4. the flux (reflected light + thermal emission) received by a distant observer.



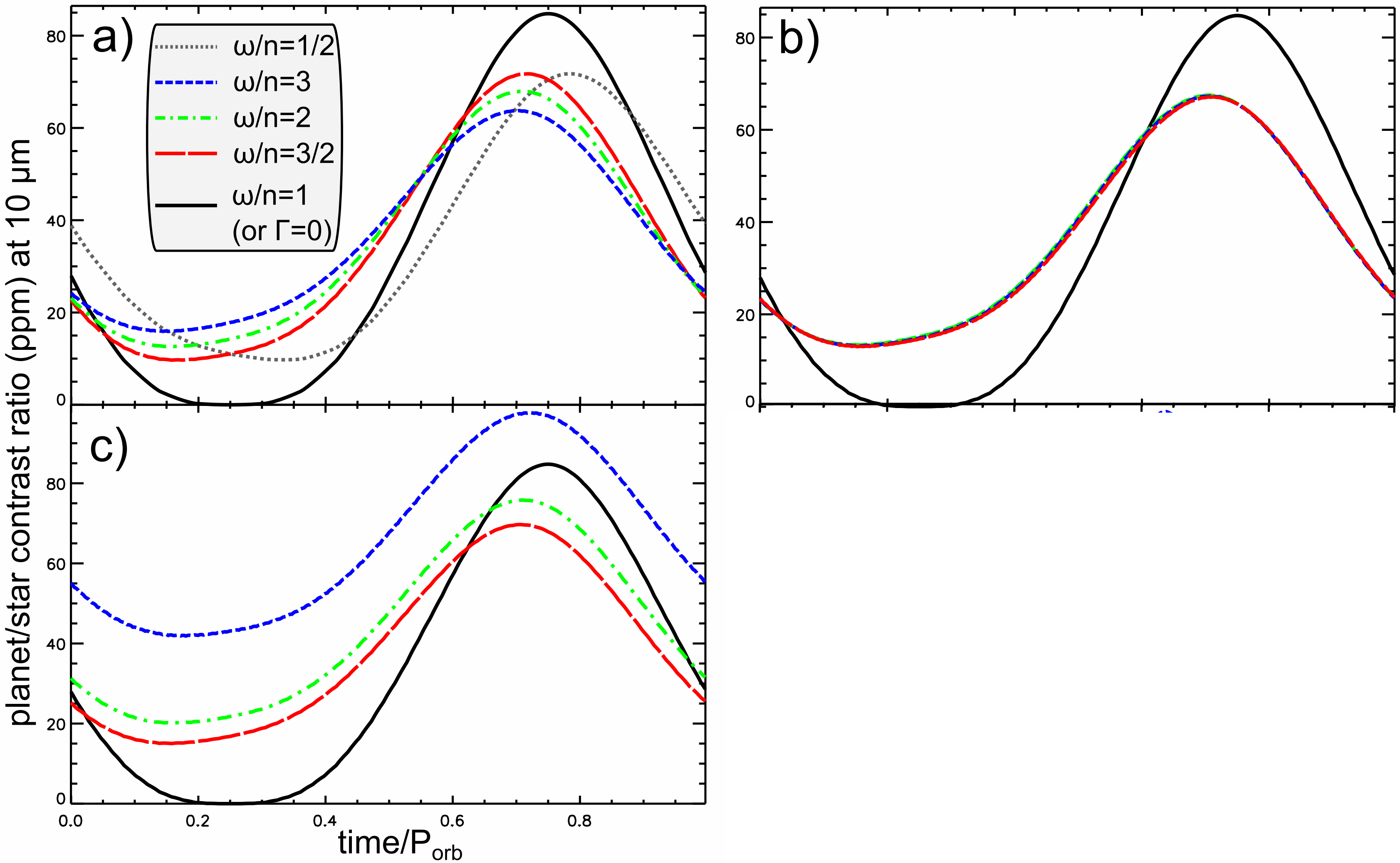


Selsis et al., 2013

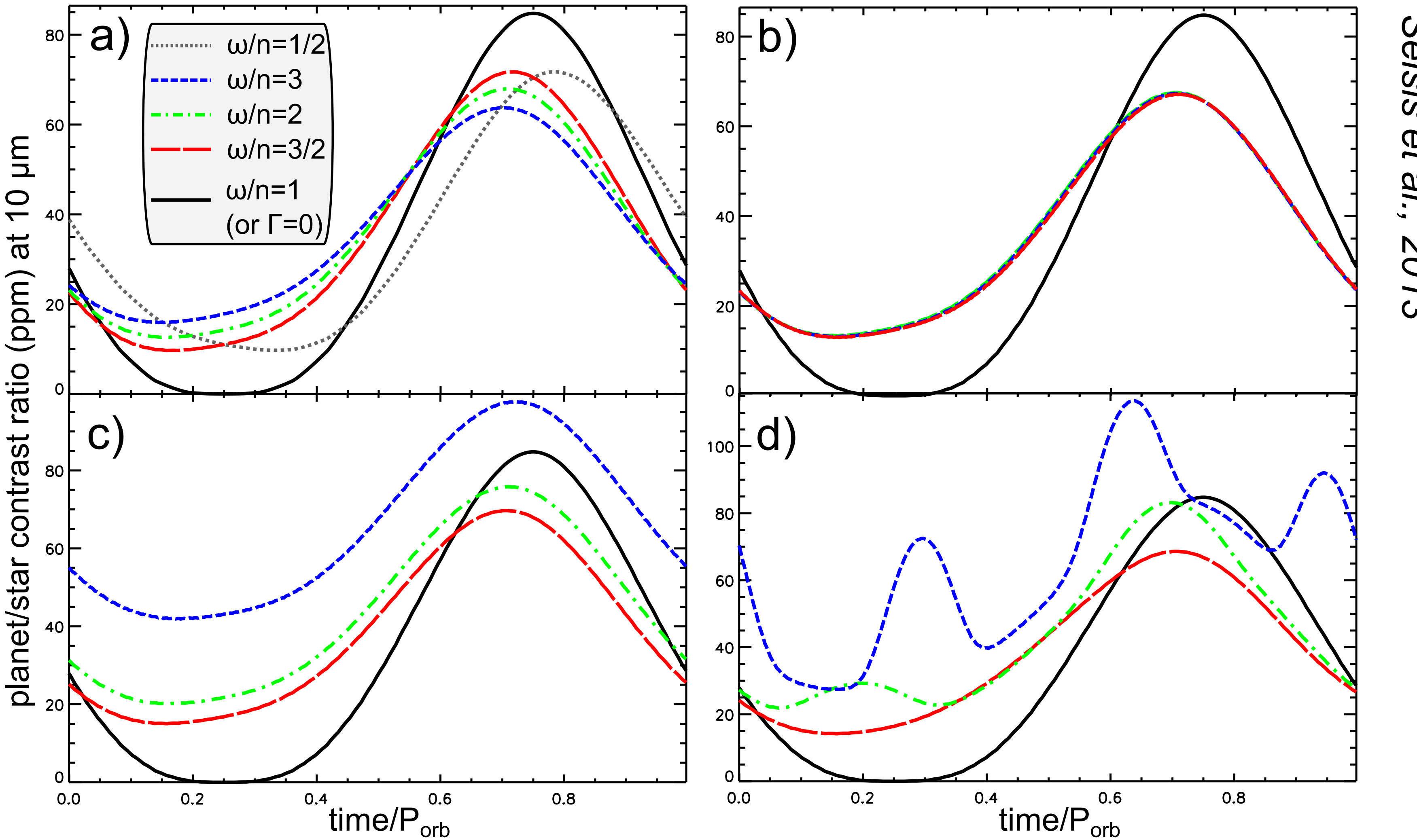




planet/star contrast ratio (ppm) at 10 μm
a)
ω/n=1/2
ω/n=3
ω/n=2
ω/n=3/2
ω/n=1
(or Γ=0)
b)
0
20
40
60
80
Selsis et al., 2013



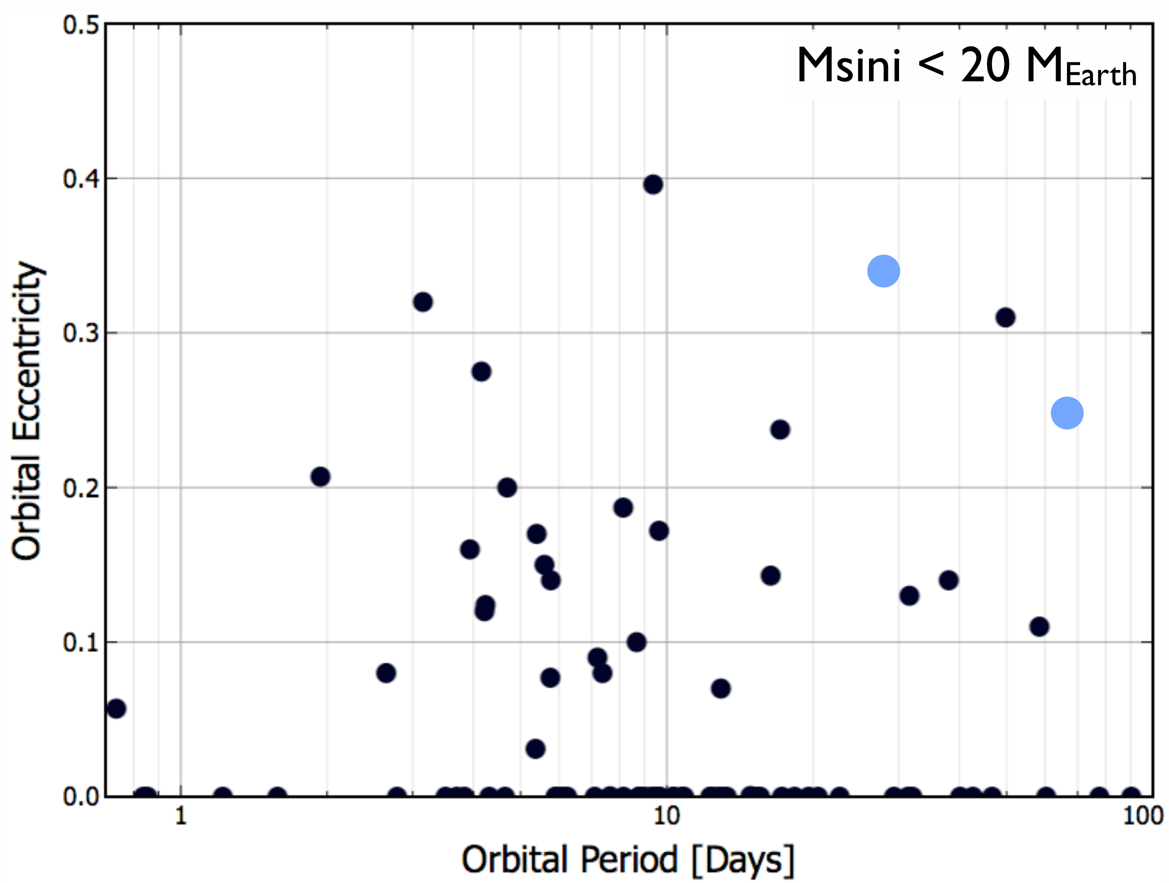
Selsis et al., 2013


a)
b)
c)
d)
ω/n=1/2
ω/n=3
ω/n=2
ω/n=3/2
ω/n=1
(or Γ=0)
planet/star contrast ratio (ppm) at 10 µm
time/P_orb
time/P_orb
Selsis et al., 2013

Some eccentric short-period planets (Msini <12 M_{Earth})

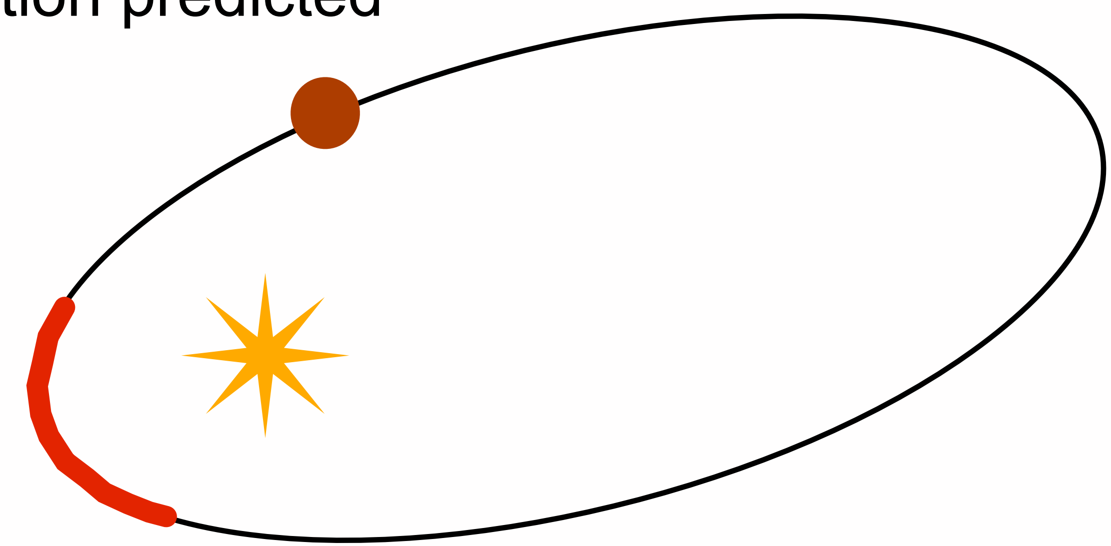
Planet	$M_\star$ ($M_\odot$)	$M \sin i$ ($M_\oplus$)	Period (d)	Eccentricity	Reference
HD 181433 b	0.78	7.5	9.37	0.396 ± 0.062	Bouchy et al. (2009)
GJ667C c	0.33	4.25	28.1	0.34 ± 0.1	Delfosse et al. (2013)
GJ581 e	0.31	**1.9**	3.14	0.32 ± 0.09	Forveille et al. (2011)
GJ581 d	0.31	6.1	66.6	0.25 ± 0.09	Forveille et al. (2011)
GJ876 d	0.3	6.83	1.93	0.257 ± 0.07	Rivera et al. (2010)
GJ674 b	0.3	11.1	4.7	0.20 ± 0.02	Bonfils et al. (2007)
HIP 57274 b	0.73	11.6	8.13	0.19 ± 0.1	Fischer et al. (2012)
μ Arae c	1.08	10.5	9.63	0.172 ± 0.040	Pepe et al. (2007)

Bolmont et al., 2013

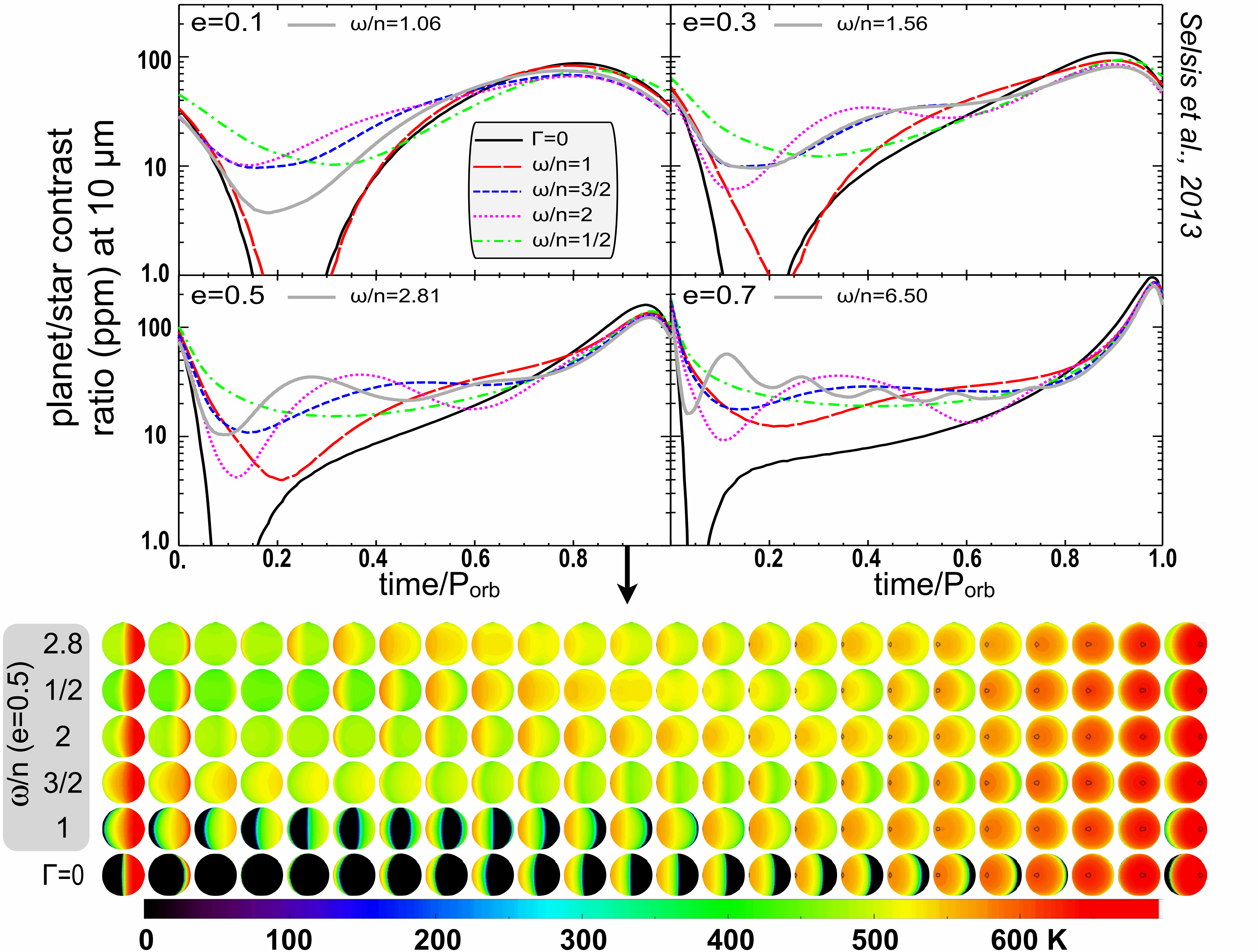


final rotation state for an eccentric planet

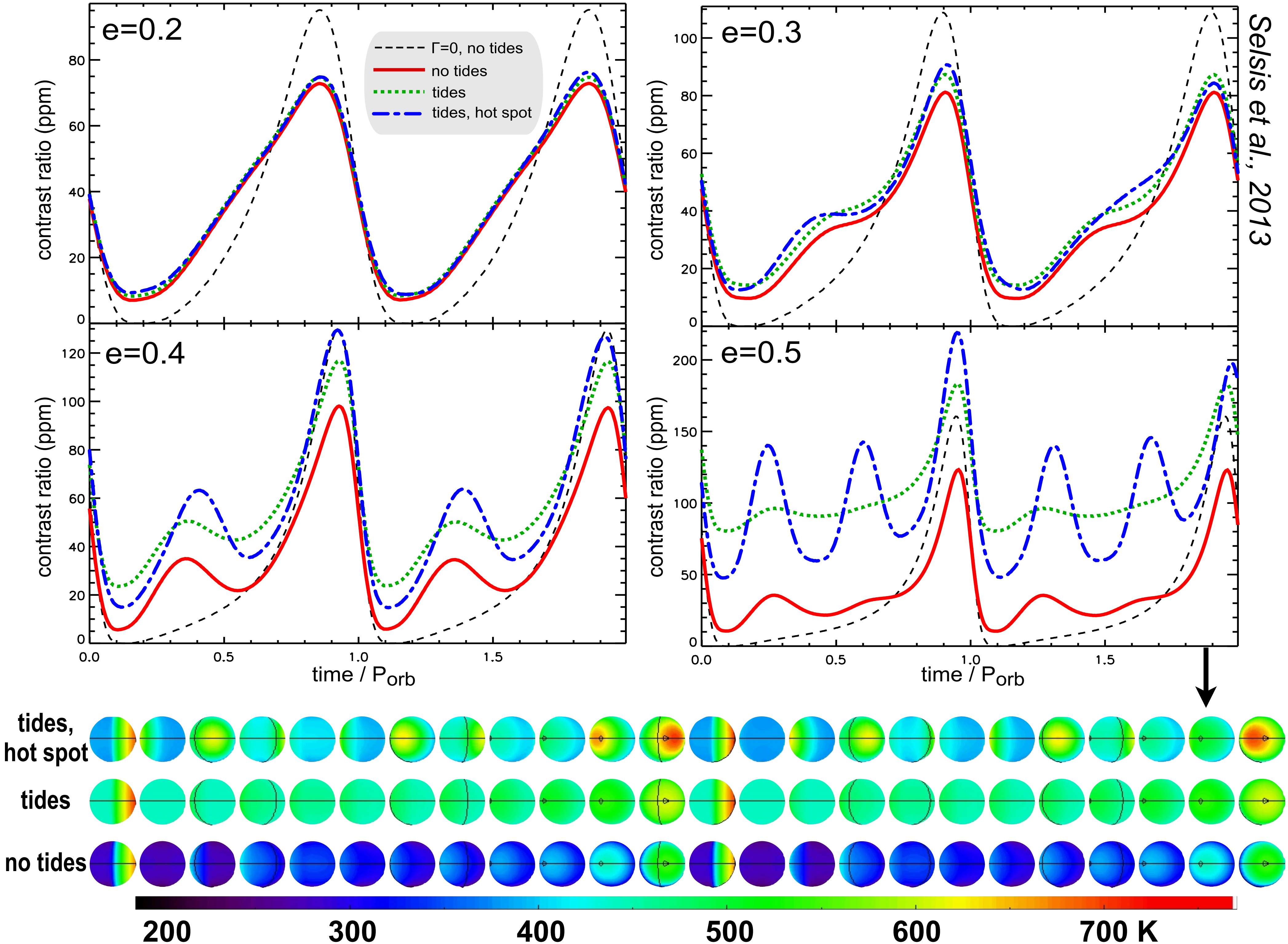
- pseudo-synchronization: f(e)
absolute minimum of the dissipation predicted
by (some) theories



- spin-orbit resonance (1:1, 2:1, 3:2,....)
local minimum of the dissipation
requires a preferential axis

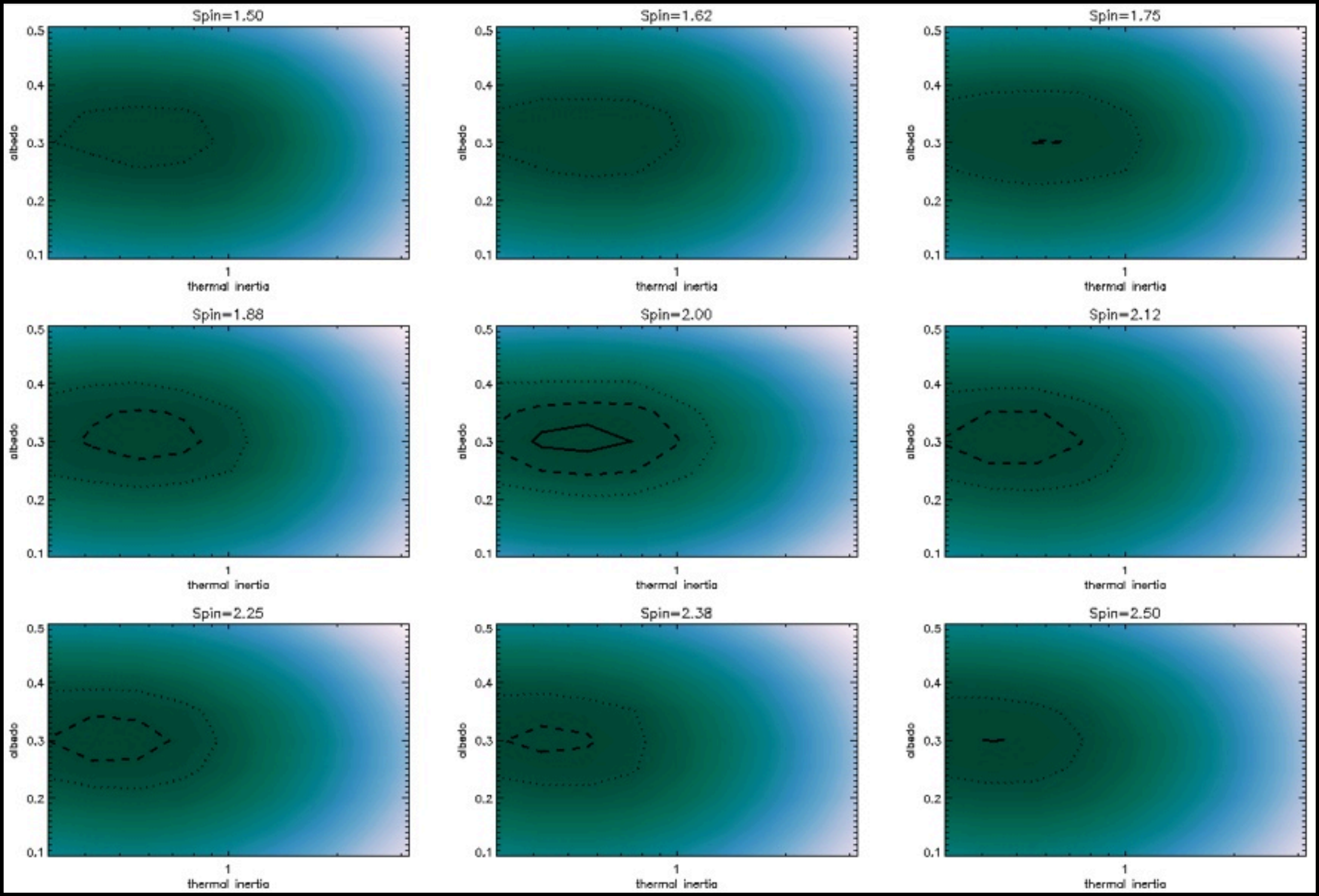


Selsis et al., 2013
e=0.1
ω/n=1.06
e=0.3
ω/n=1.56
e=0.5
ω/n=2.81
e=0.7
ω/n=6.50
Γ=0
ω/n=1
ω/n=3/2
ω/n=2
ω/n=1/2
planet/star contrast ratio (ppm) at 10 μm
100
10
1.0
0.
0.2
0.4
0.6
0.8
1.0
time/P_orb
ω/n (e=0.5)
2.8
1/2
2
3/2
1
Γ=0
0
100
200
300
400
500
600 K



e=0.2
e=0.3
e=0.4
e=0.5
Γ=0, no tides
no tides
tides
tides, hot spot
contrast ratio (ppm)
time / Porb
Selsis et al., 2013
tides, hot spot
tides
no tides
200
300
400
500
600
700 K

M_{Star}=0.3M_{Sun}, R_P=2R_{Earth}, e=0.3, P=20 days
transiting planet (R and i known) - 20 days of observation spread over 2 orbits
6-16 microns (10 bands) / noise=2*stellar photon noise / detector throughput=30%

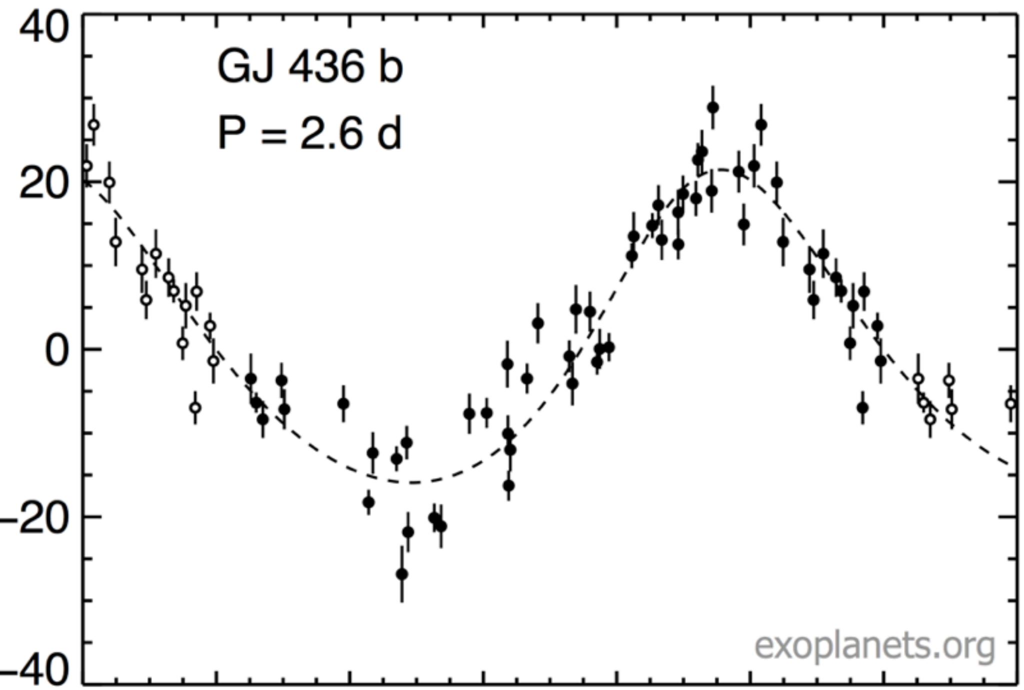


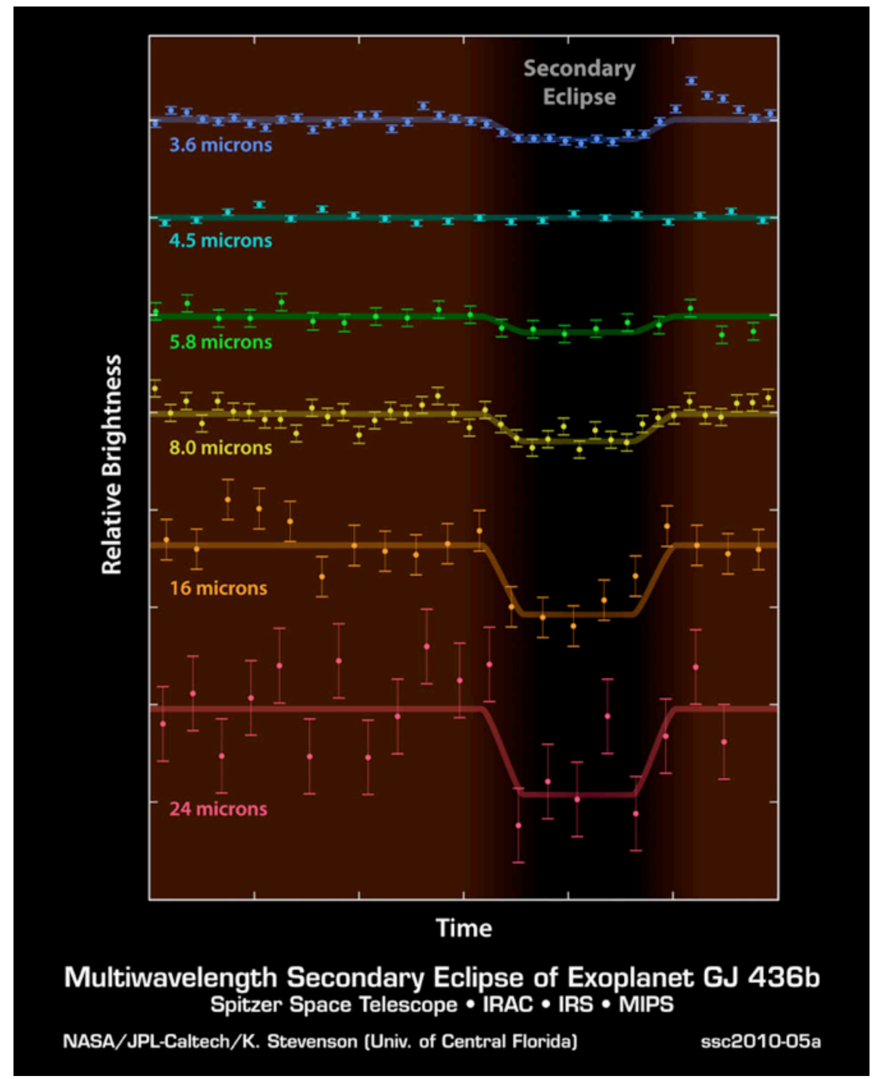
- rotation period of eccentric rocky planets can be measured by orbital spectro-photometry

- tested for planets witout an atmosphere, tbd for dense atmospheres (work in progress)

- the main obstacle is the intrisic variability of the star

Tides and chemistry
The case of GJ436b, a transiting eccentric *hot Neptune*

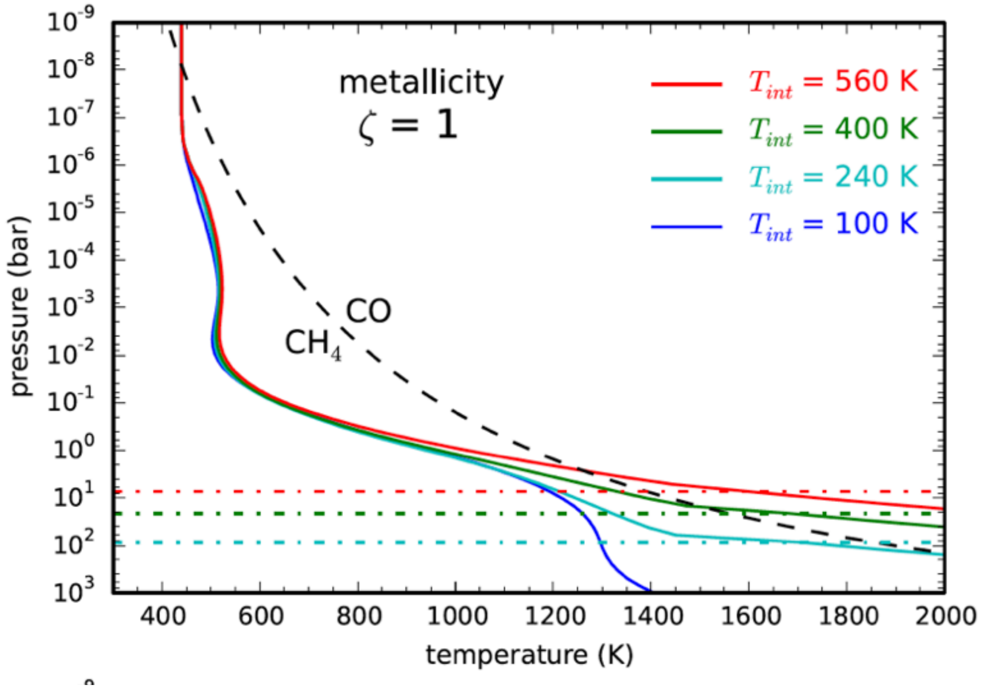


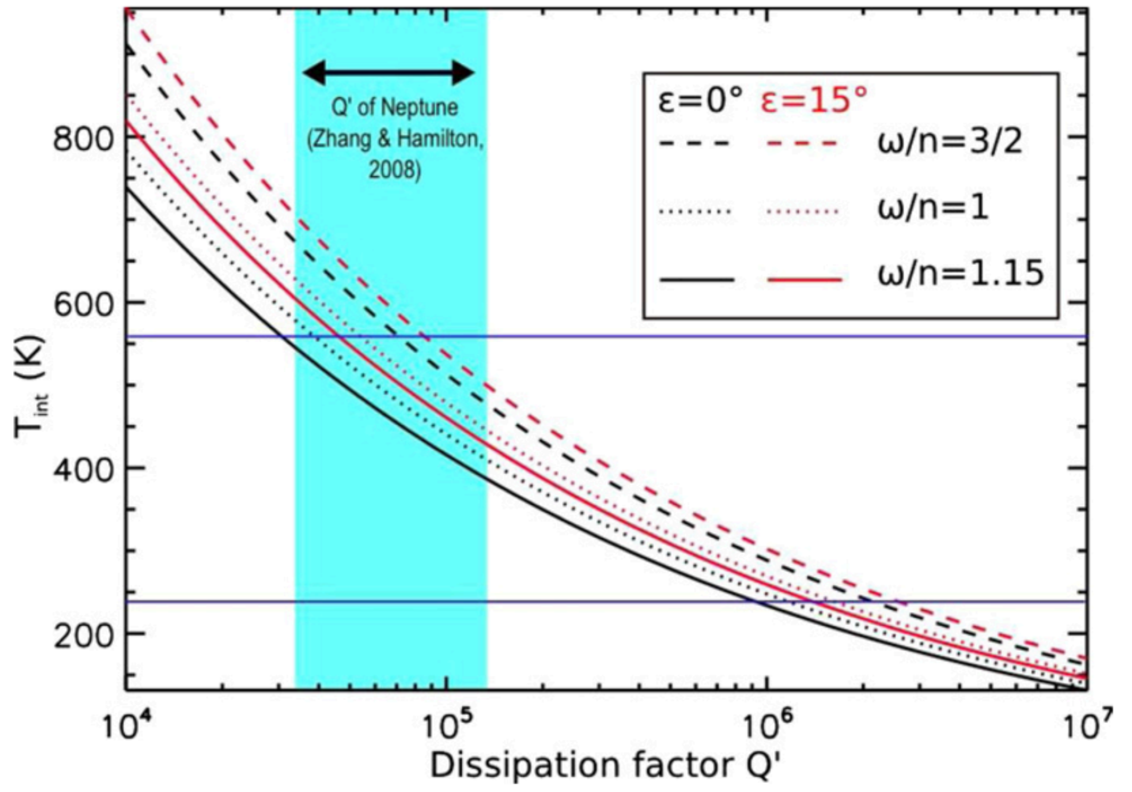


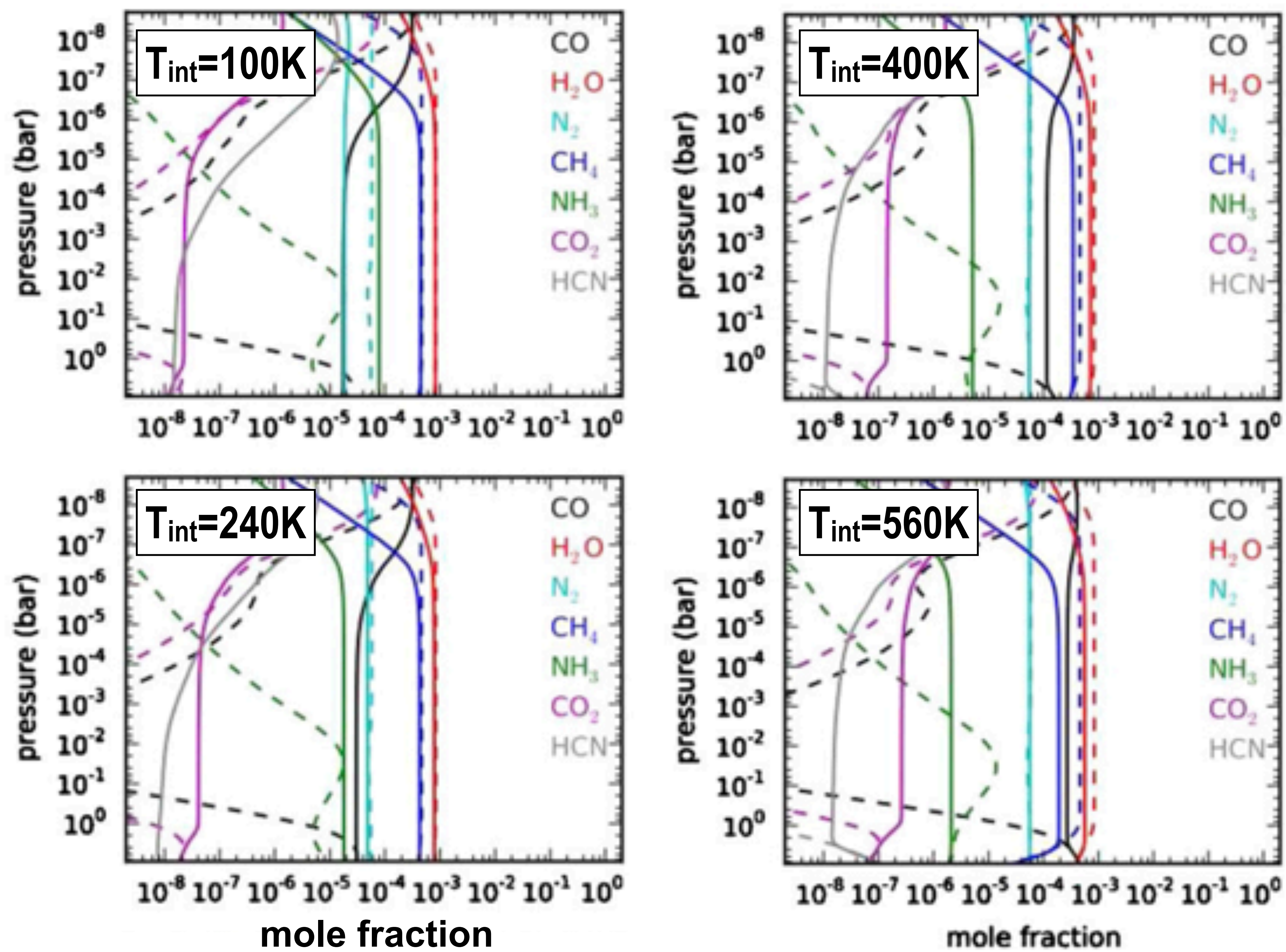
GJ 436b's Parameters

Parameter	Value
Stellar radius	$0.455 \pm 0.018\ R_{\odot}$ [a]
Stellar effective temperature	3416 ± 54 K [a]
Planetary radius	$4.09 \pm 0.20\ R_{\oplus}$ [b]
Planetary mass	$23.4 \pm 1.6\ M_{\oplus}$ [b]
Orbital semimajor axis	0.02887 ± 0.00089 AU [b]

Impact of tidal dissipation on the thermal profile

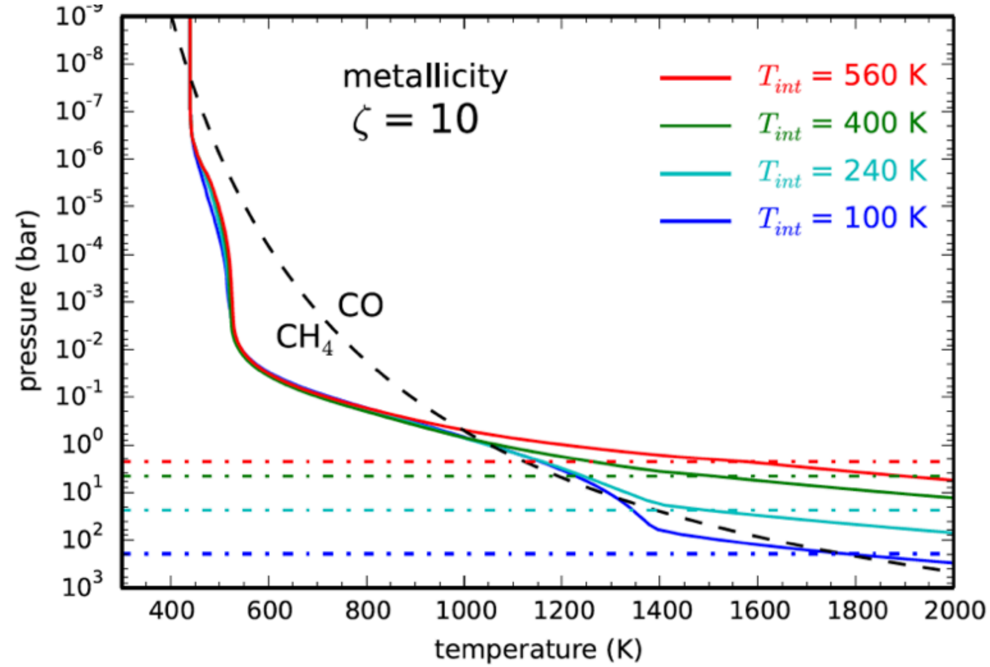


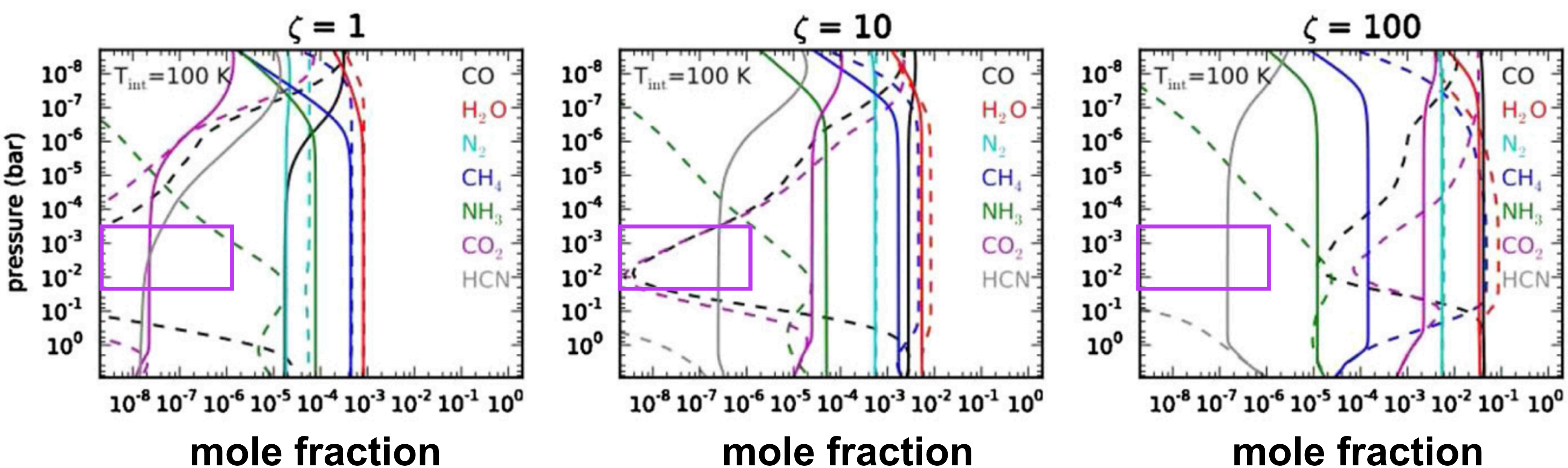




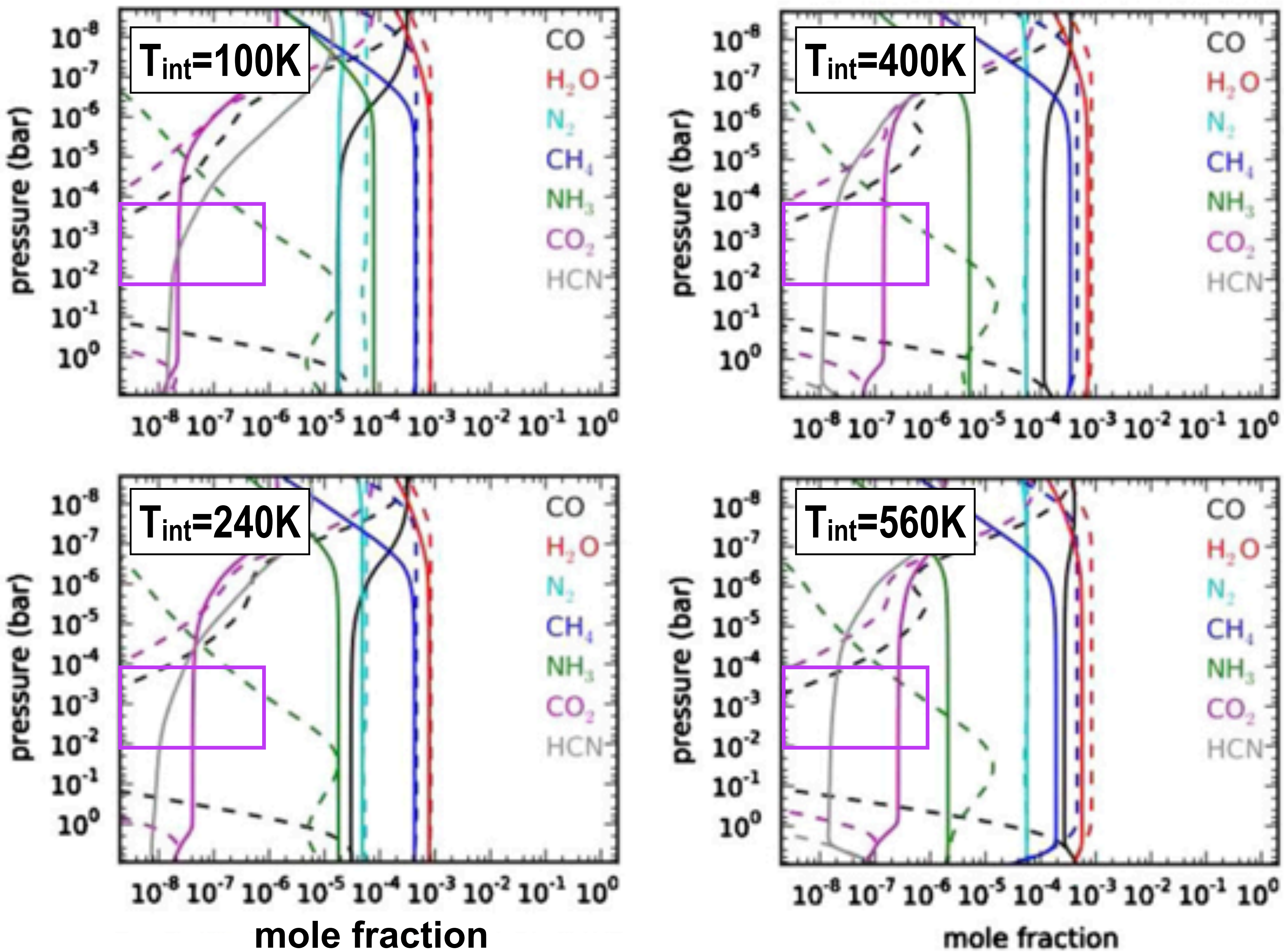
Tint=100K
Tint=400K
Tint=240K
Tint=560K
CO
H2O
N2
CH4
NH3
CO2
HCN
pressure (bar)
mole fraction

The CO/CH4 ratio can also be explained by a high metallicity without tidal heating





But CO2 is very sensitive to the metallicity and provides a strong constraint



T_int=100K
T_int=400K
T_int=240K
T_int=560K
CO
H2O
N2
CH4
NH3
CO2
HCN
pressure (bar)
mole fraction

Tidal heating can explain CO/CH4 > 1 simultaneously with a low CO2 abundance, and assuming reasonable dissipation

problems

- no scenario reproduce all observed spectral features
- problem with the model ? requires circulation ? high temperature opacities poorly known
- observations are debated

- But tidal heating can be revealed by indirect chemical consequences
- while the internal heating itself may not be observable
- GJ436b is a great target for future observations (JWST, ARIEL, E-ELT)

- the thermal emission and radiative budget of exoplanets can be affected by tides, even for very low eccentricities

- the IR tidal excess can be observed at secondary eclipse and by orbital photometry

- the rotation of eccentric planets can be constrained by orbital photometry