The obliquities of the planetary systems detected with PLATO

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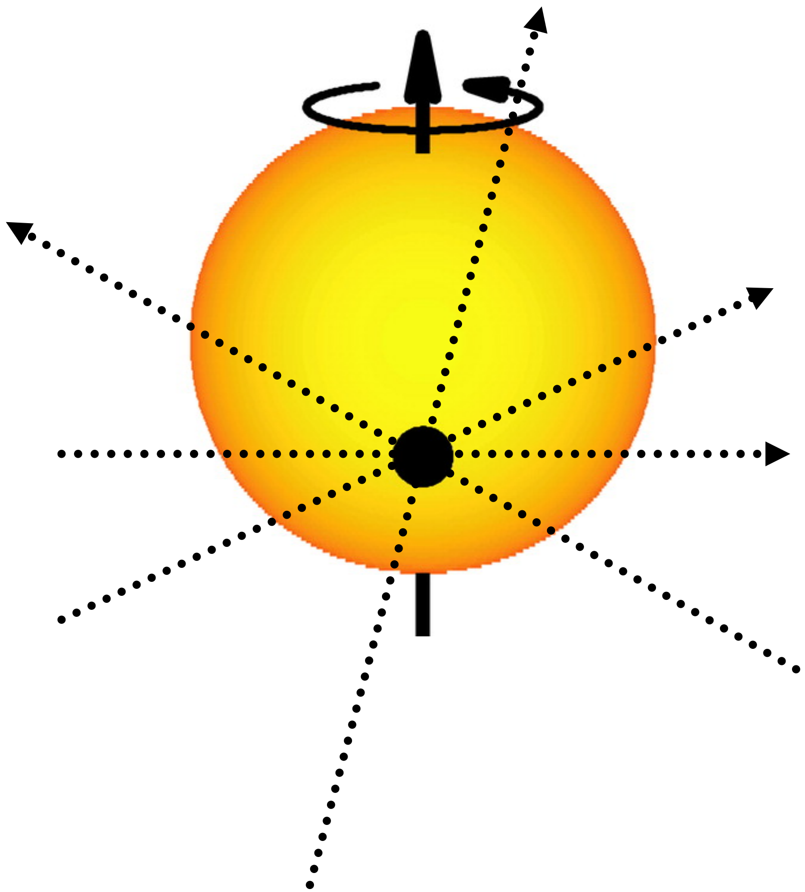
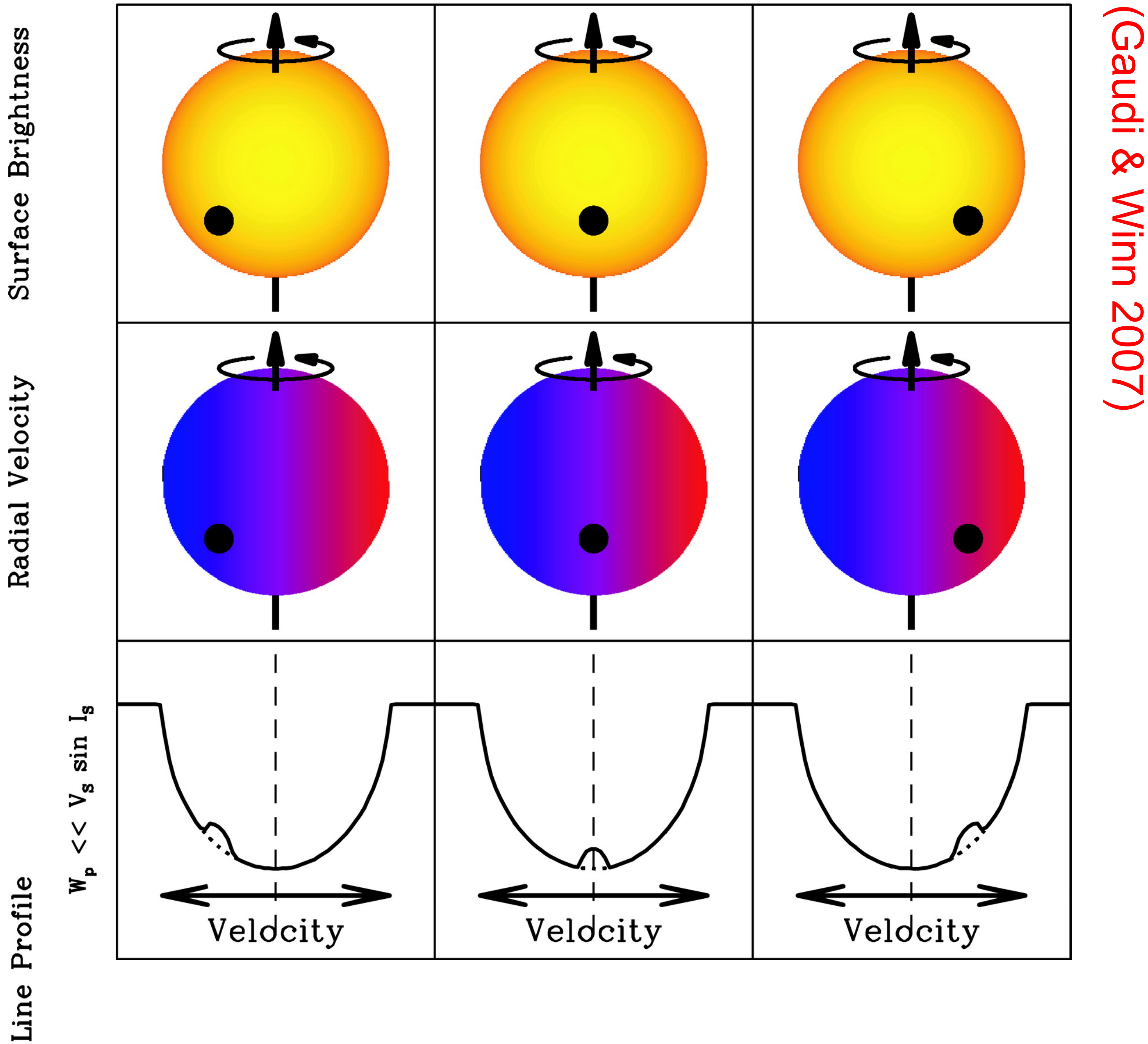
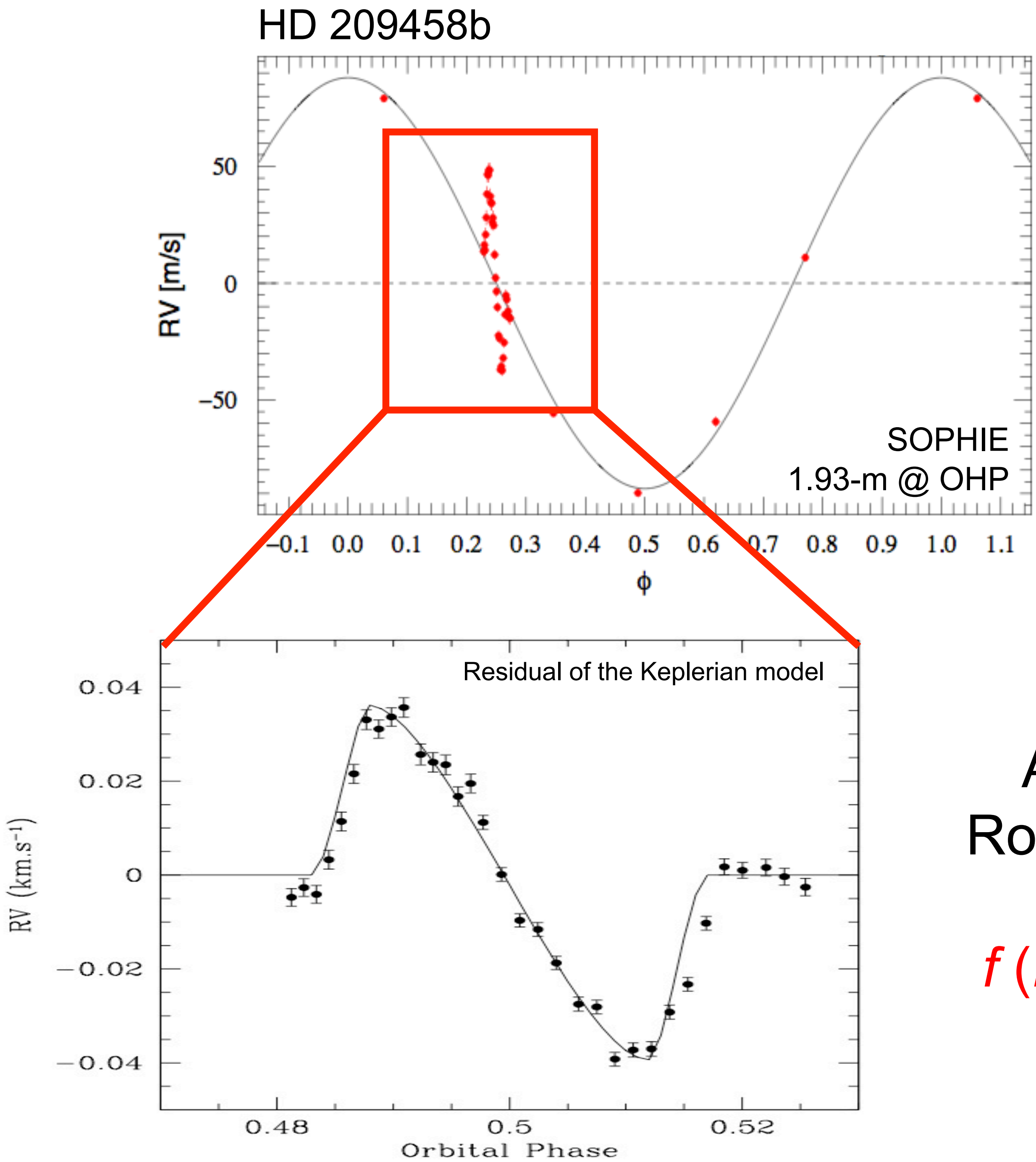
The obliquity is the spin-orbit angle



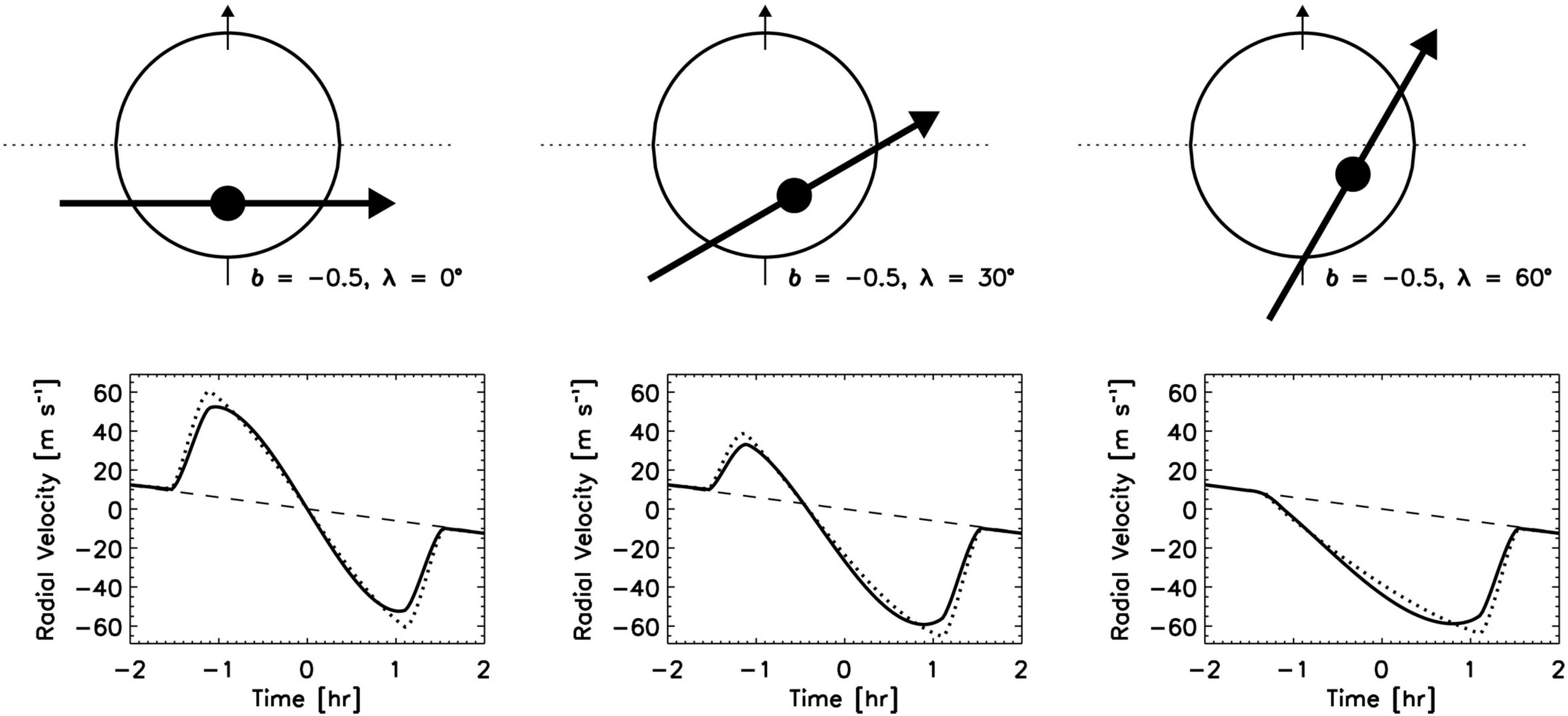


Rossiter-McLaughlin effect (1924)
(see also Holt 1893)



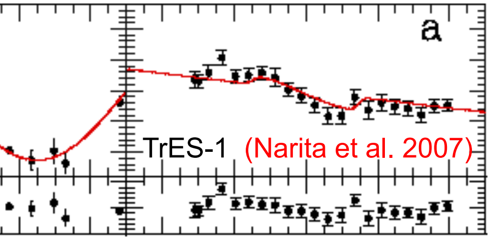
Amplitude of the Rossiter-McLaughlin anomaly:

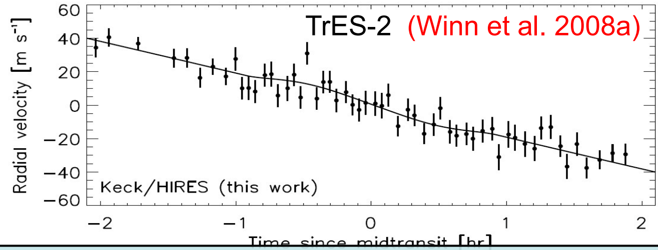
$f\,(R_p/R_\star,\ v \sin i_\star,\ b)$

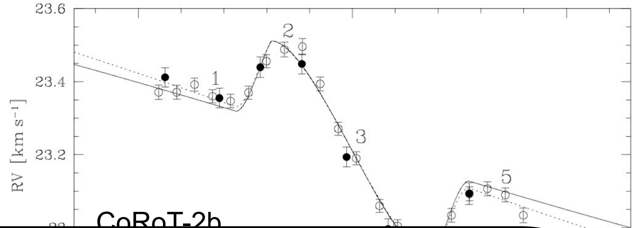


λ = 0°   λ = 30°   λ = 60°

Gaudi & Winn (2007)



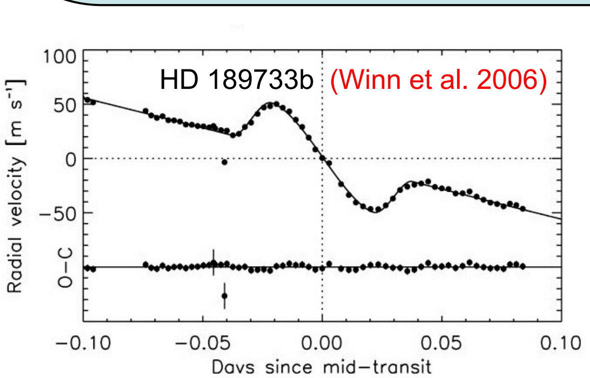


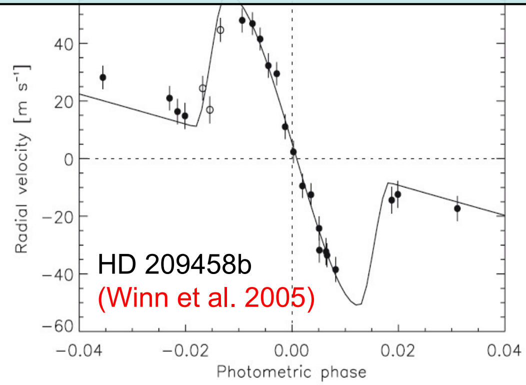


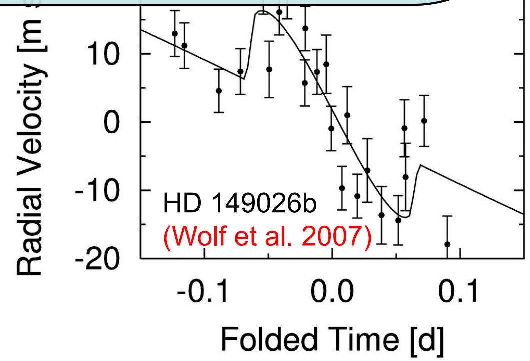
2008: ~ 10 observed spectroscopic transits over ~ 50 known transiting planets

All well aligned and prograde

Validation of planetary formation and evolution models where a single giant planet migrates in a proto-planetary disk (perpendicular to the stellar spin axis)



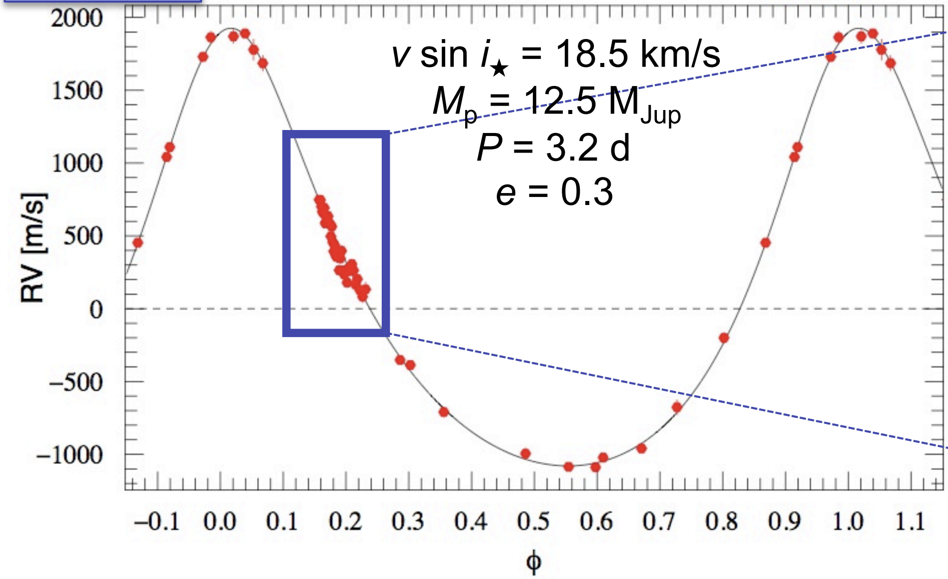


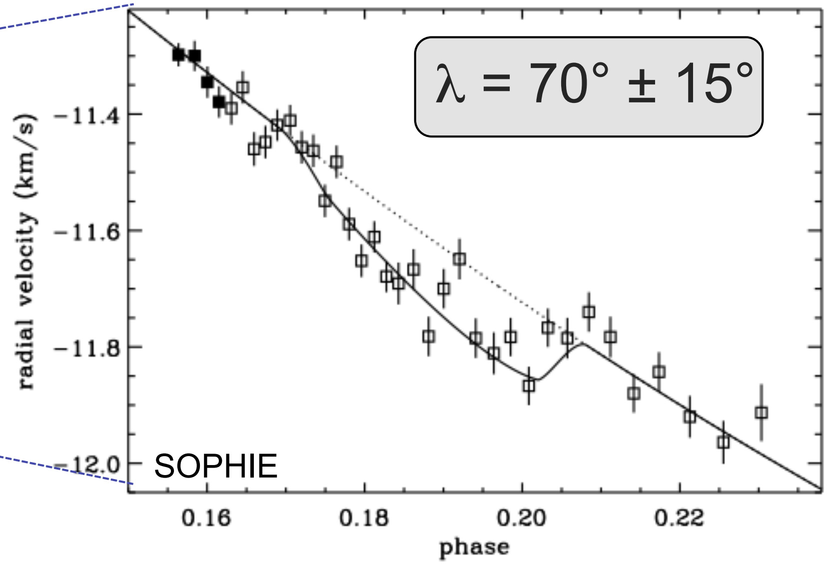


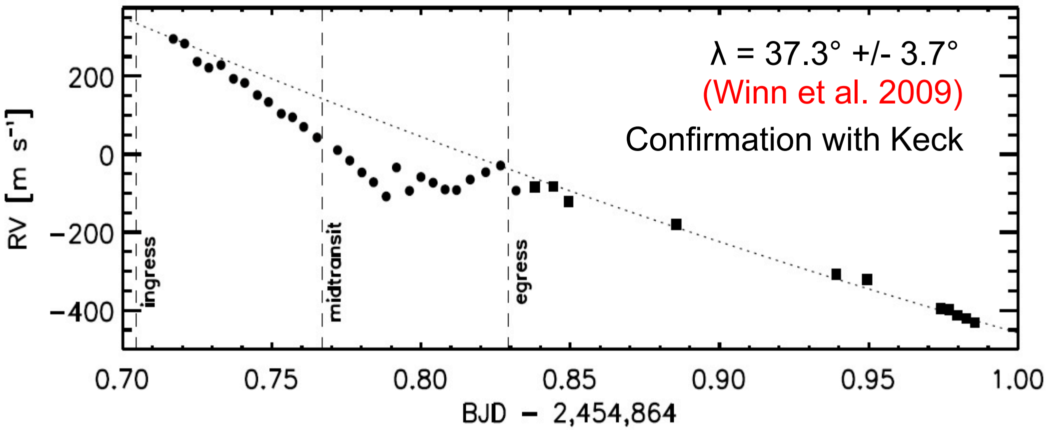
2008: First case of spin-orbit misalignment

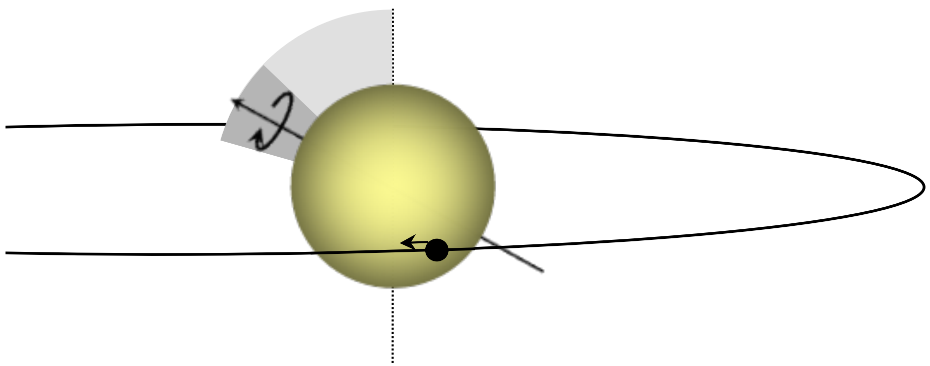
XO-3

Hébrard et al. (2008)

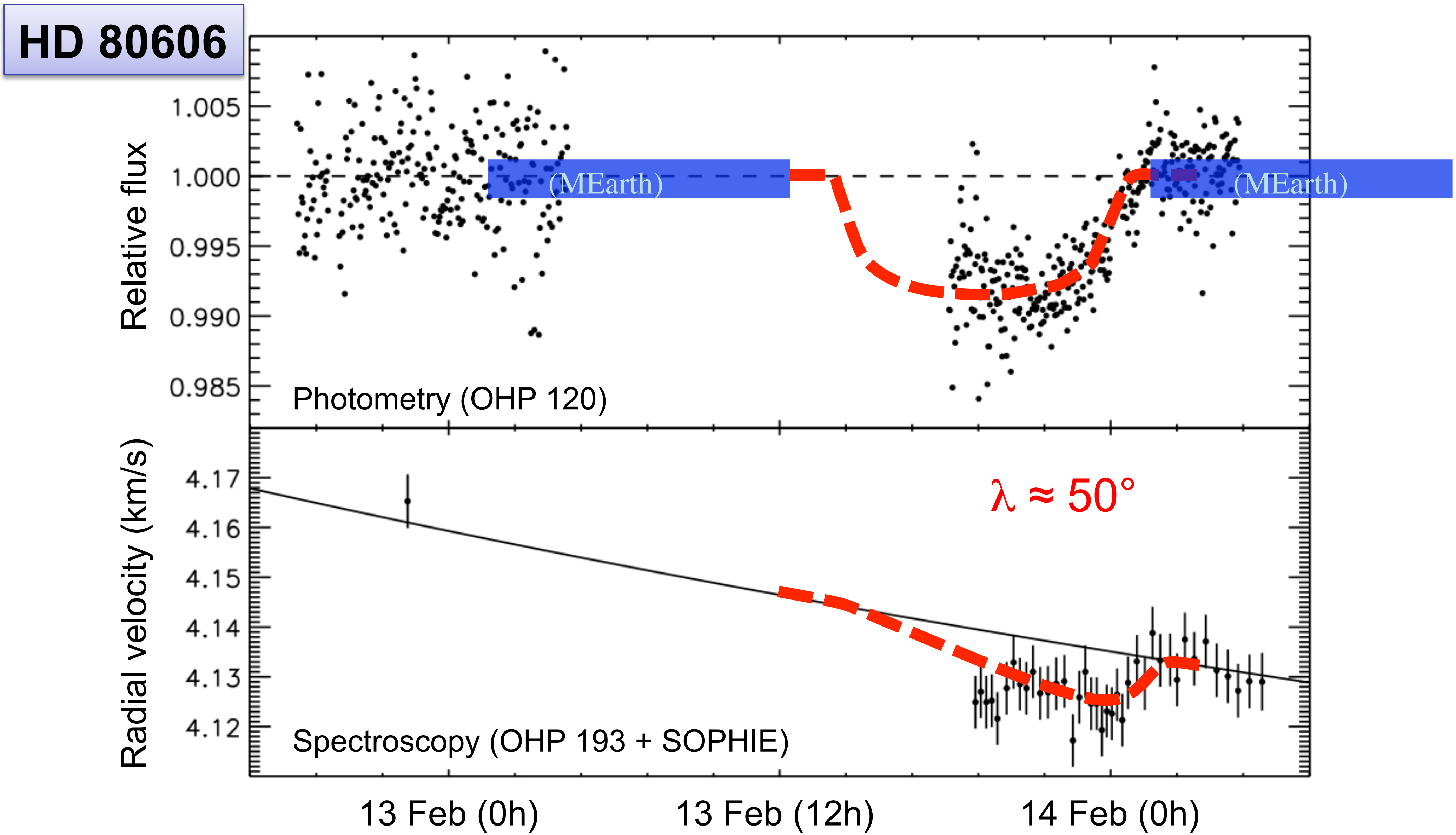








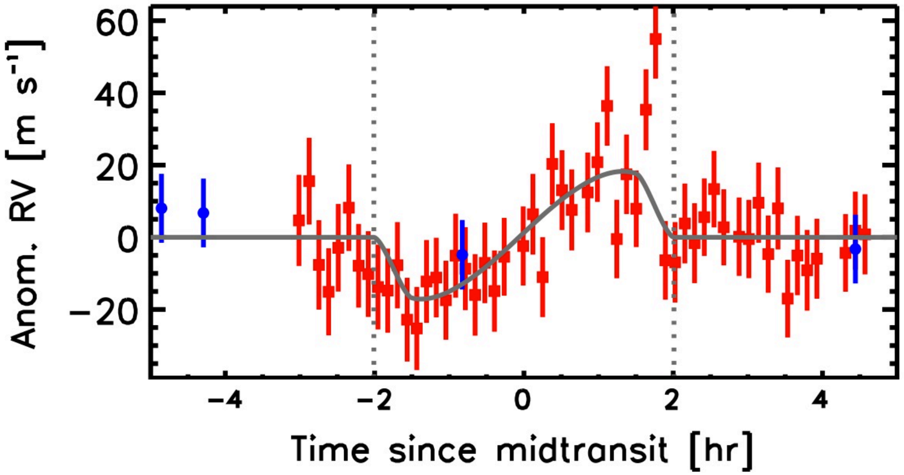
2009: Second case of spin-orbit misalignment



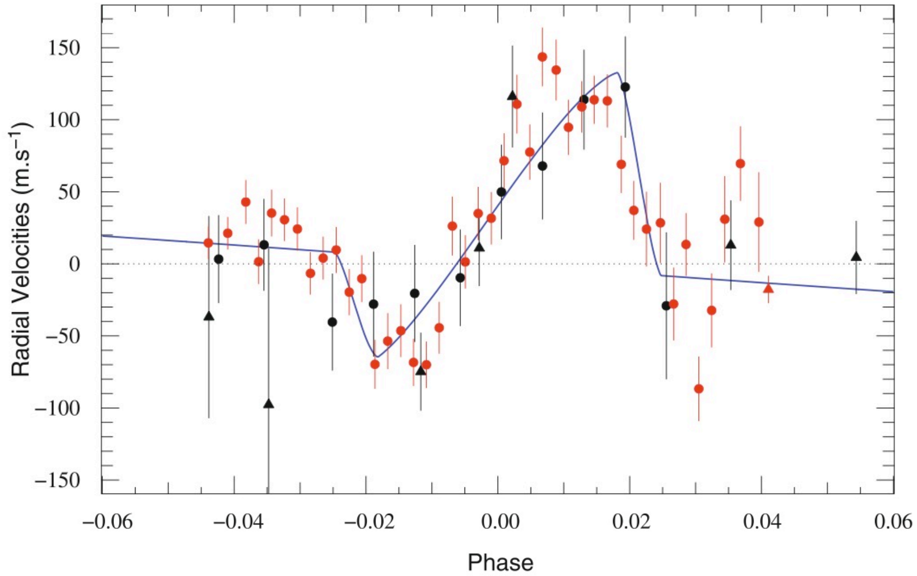
Moutou et al. (2009), Pont et al. (2009)

Examples of retrograde orbits

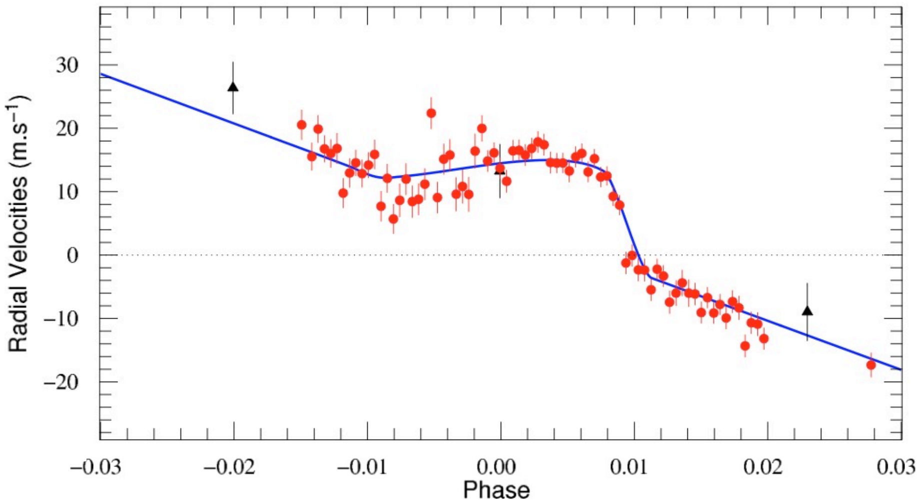
HAT-P-7 (Winn et al. 2009)
λ = 182.5° +/- 9.4°



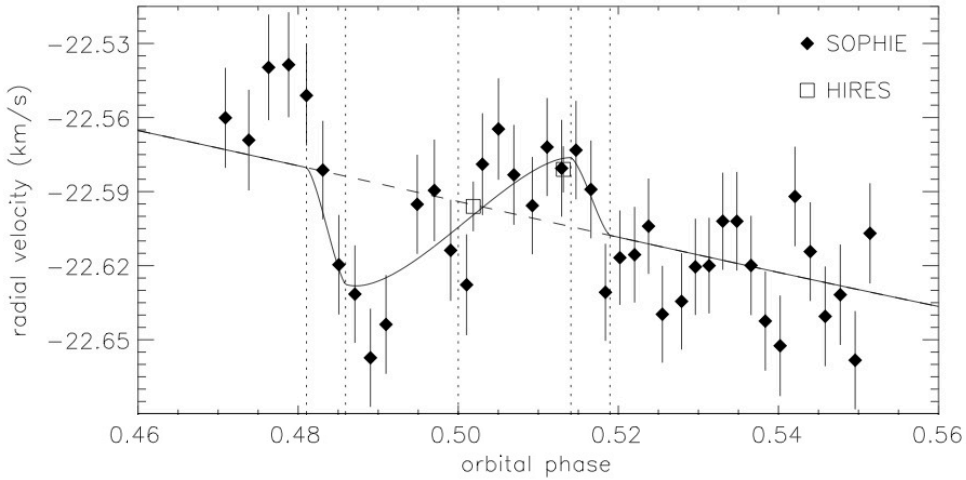
WASP-17 (Triaud et al. 2010)
λ = -148.5° +/- 4.7°



WASP-8 (Queloz et al. 2010)
λ = -123.3° +/- 3.9°



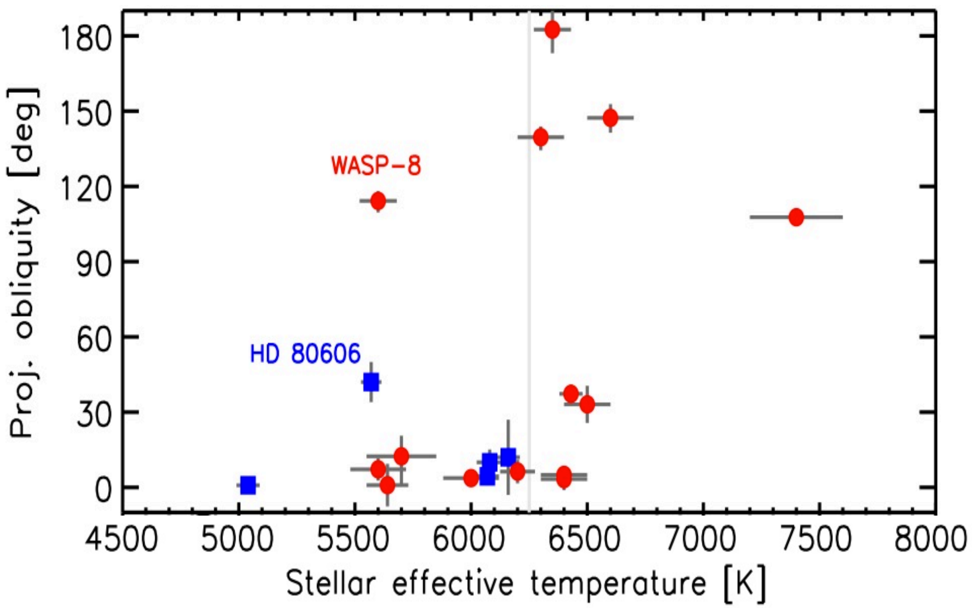
HAT-P-6 (Hébrard et al. 2011)
λ = 166° +/- 10°



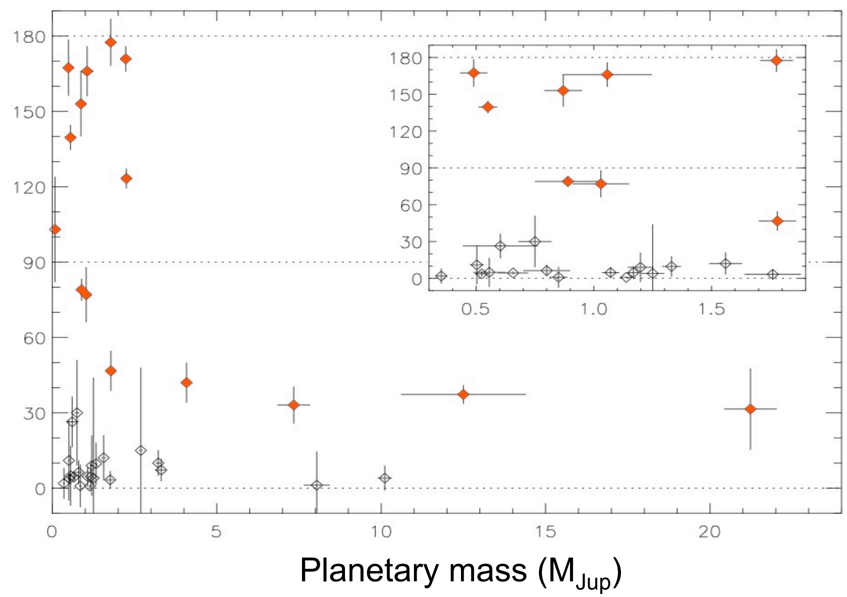
2011: ~ 40 observed spectroscopic transits over ~ 110 known transiting planets

15 misaligned systems, including 7 retrograde, 3 nearly polar

Winn et al. (2010)



Hébrard et al. (2011)



Why the obliquity of planetary orbit could change?

- **KT**: **K**ozai mechanism with **T**idal circularization (Fabrycky & Tremaine 2007)
45% to 85% of hot jupiters are misaligned (Triaud et al. 2010):
Most hot jupiters are formed from **KT** rather than migration in disk

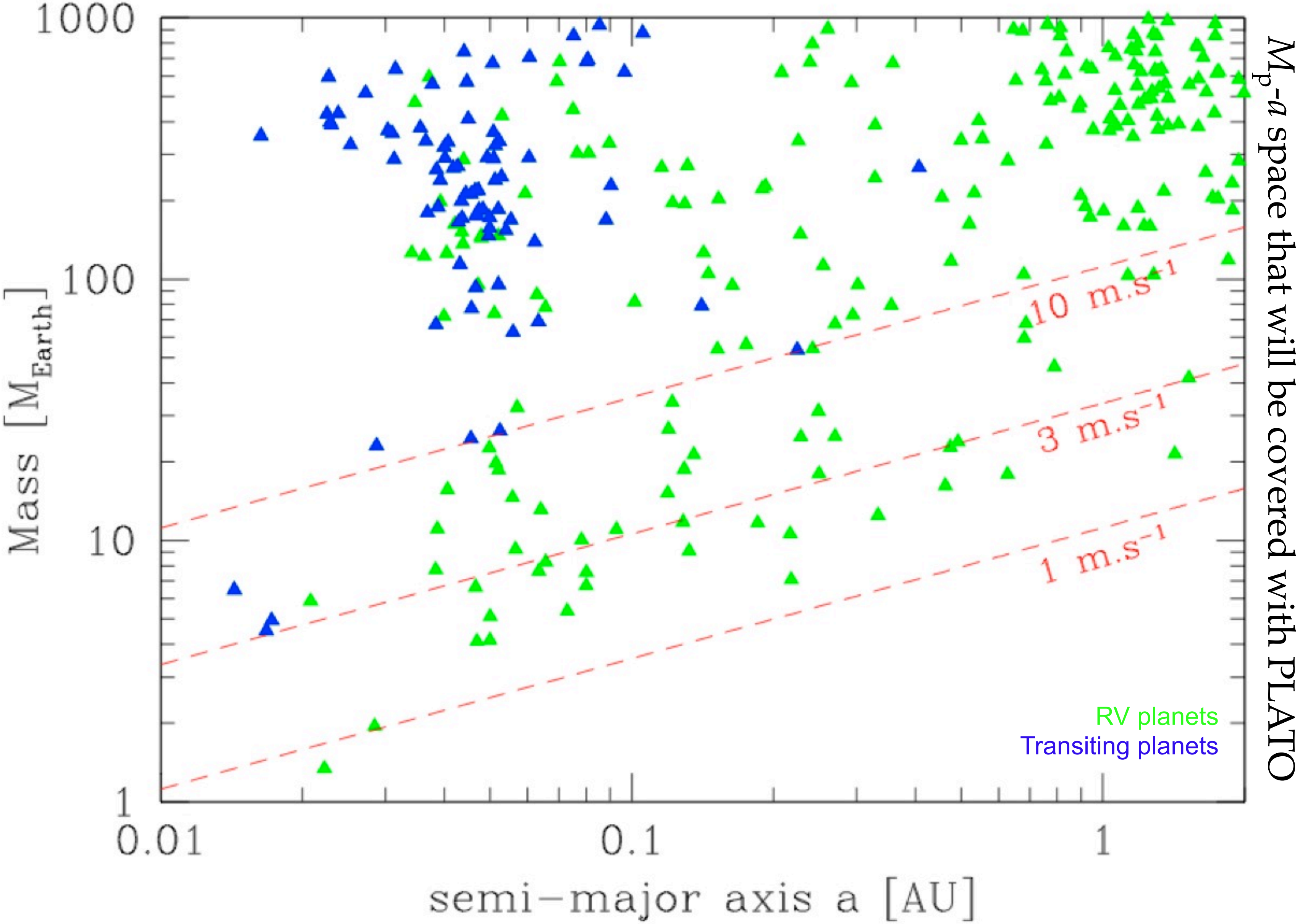
- **SKT**: planet **S**cattering, **K**ozai mechanism, and **T**idal circularization (Nagasawa et al. 2008)
2 modes (Morton & Johnson 2011): a part of planets migrated through **disk migration** (that preserve spin-orbit alignment) and another part (34% to 76%) migrated through **SKT**.

Or, why the inclination of the star could change?

- early on through magnetosphere-disk interactions (Lai et al. 2010)
- later through elliptical tidal instability (Cébron et al. 2011)

PLATO:

exploring the obliquity of low-mass and long-period planets



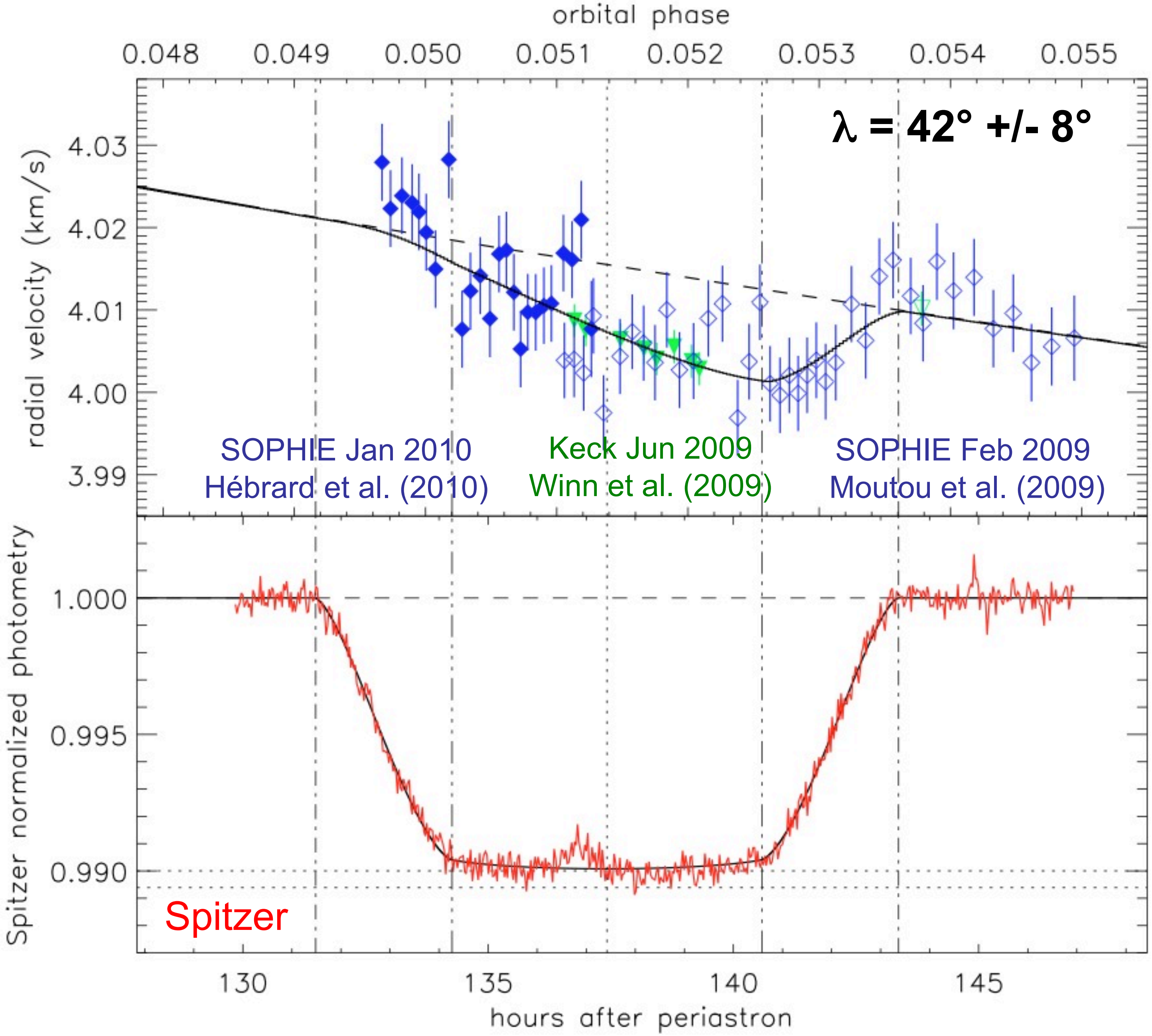
Long-period planets

Long-duration transit: longer than one observing night

HD 80606

Orbital period:
111 days

Transit duration:
11.88 hours

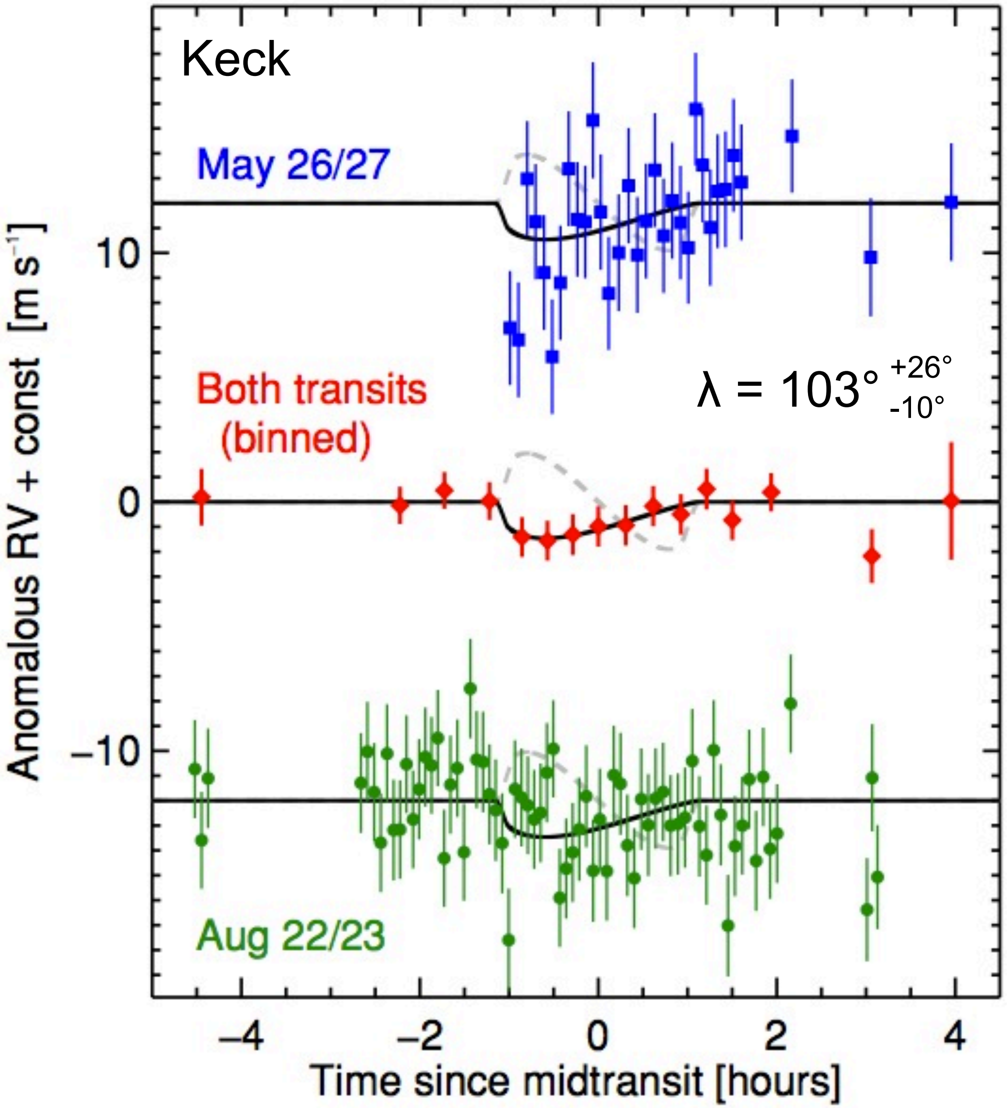


Hébrard et al. (2010)

Low-mass planets

HAT-P-11

Winn et al. (2010)



Small planetary radius:
Low-amplitude RM effect

RM anomaly amplitude: 1.5 m/s

P = 4.888 d

M_p = 26 M_{earth}

R_p = 4.7 R_{Earth}

$v \sin i_\star$ = 1.0 km/s

Low-mass planets

Kepler-11

Masses = [2.3 – 13.5] M_{Earth} Radii = [2.0 – 4.5] R_{Earth}

Planet	Transit duration (hours)	RM amplitude for *v*sin*i*=0.5km/s (m/s)	RM amplitude for *v*sin*i*=4.0km/s (m/s)	Keplerian amplitude *K* (m/s)	Orbital period (days)
Kepler-11b	4.0	0.1	1.1	1.3	10.3
Kepler-11c	4.6	0.3	2.8	3.8	13.0
Kepler-11d	5.6	0.4	3.3	1.4	22.7
Kepler-11e	4.3	0.7	5.7	1.7	32.0
Kepler-11f	6.5	0.2	1.9	0.4	46.7
Kepler-11g	9.6	0.5	3.7	-	118.4
PLATO-??	12.8	0.04	0.34	0.09	365.3

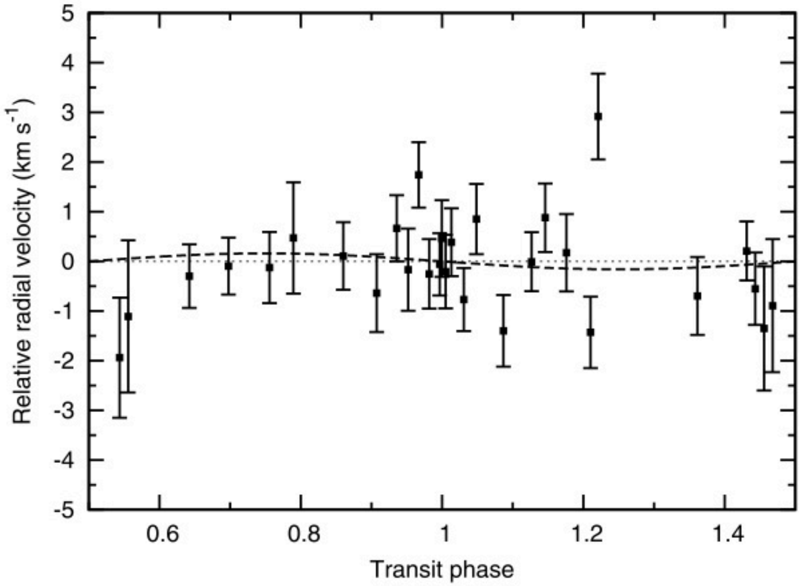
Spectroscopic transit for planet detection?

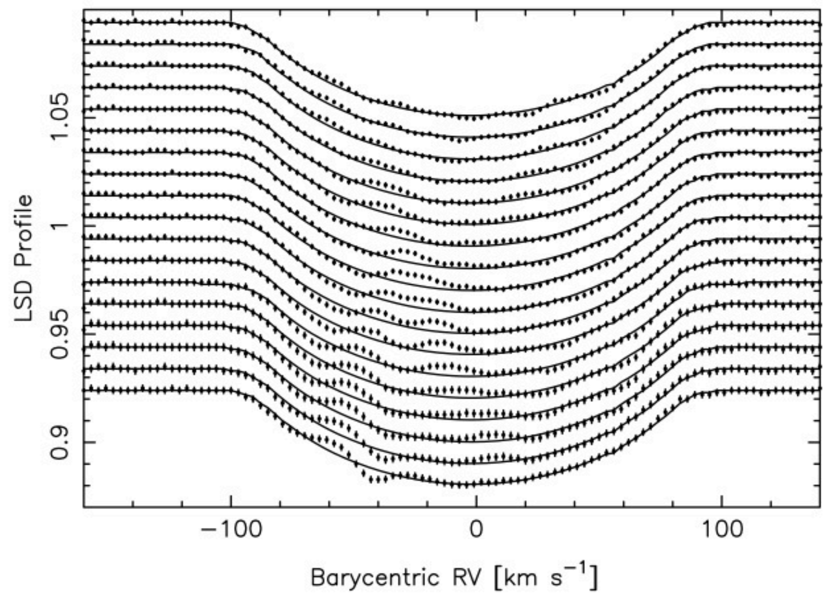
Radial velocity amplitude might be larger for the Rossiter-McLaughlin anomaly than for the Keplerian orbit.

And the duration of the event is shorter.

Doesn't depend on the semi-major axes: especially interesting for long-period planets.

One example: HD15082b (Collier Cameron et al. 2009)





Conclusions

- Obliquities constrain planetary formation and evolution models.

- Obliquities could be measured in spectroscopy through the Rossiter-McLaughlin anomaly.

- Available observations on hot jupiters jeopardizes disk migration as the standard/unique model explaining their origin.

- Obliquities measurements on PLATO planets will allow such studies to be extended on low-mass and long-period planets, and multiple-planets systems.

- It will require high-precision spectroscopic observations.

- Spectroscopic transits could be a way to establish the planetary nature of PLATO transiting objects in some cases where the Keplerian reflex motion is too low.