Measuring Spin-Orbit Alignment of Transiting Exoplanets with Subaru/HDS

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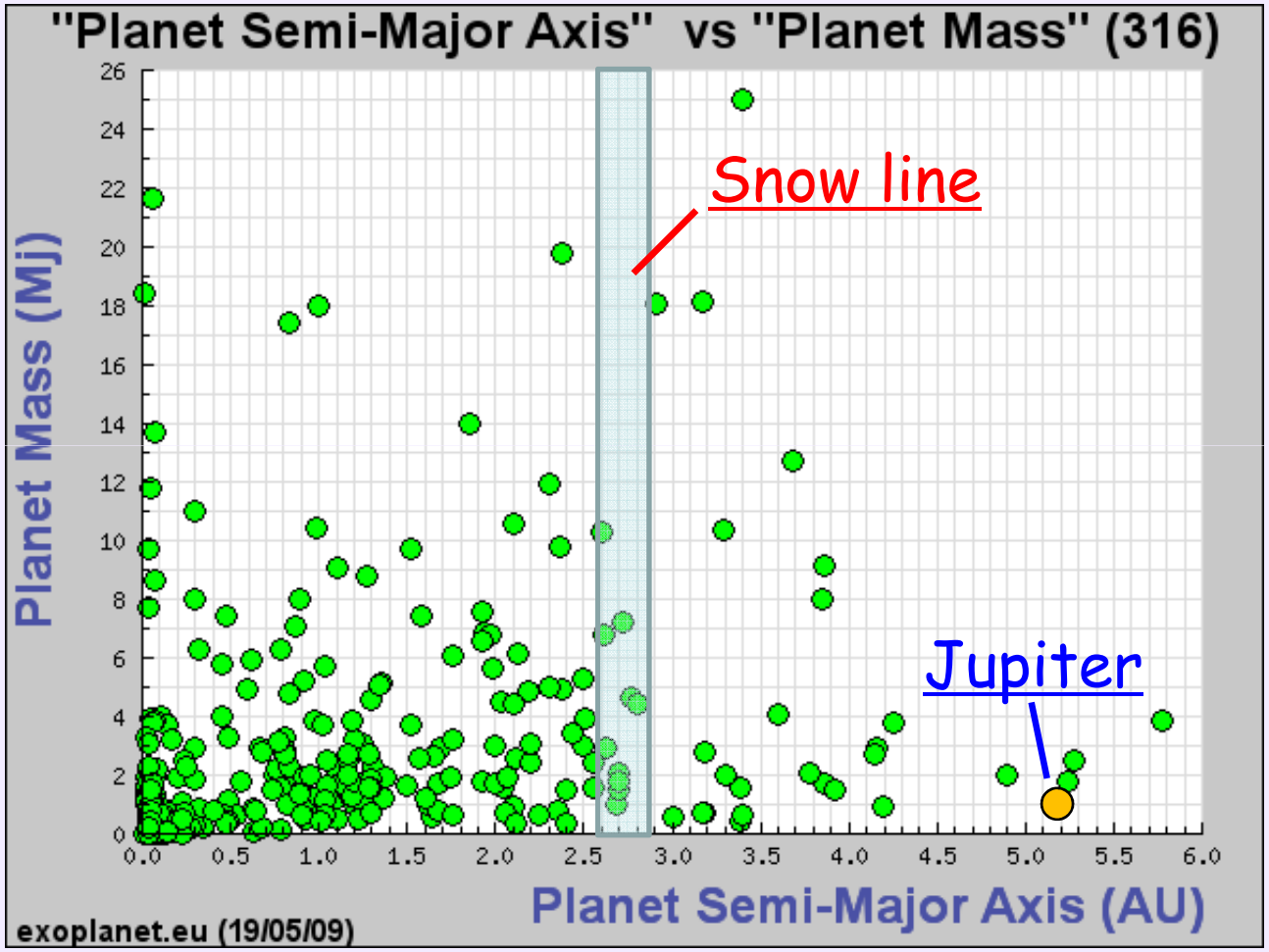
Outline

- Backgrounds
  - Planetary orbital distribution
  - Planetary migration models
  - The Rossiter effect
- Subaru observations and results
- Discussions and summary

Semi-Major Axis Distribution of Exoplanets



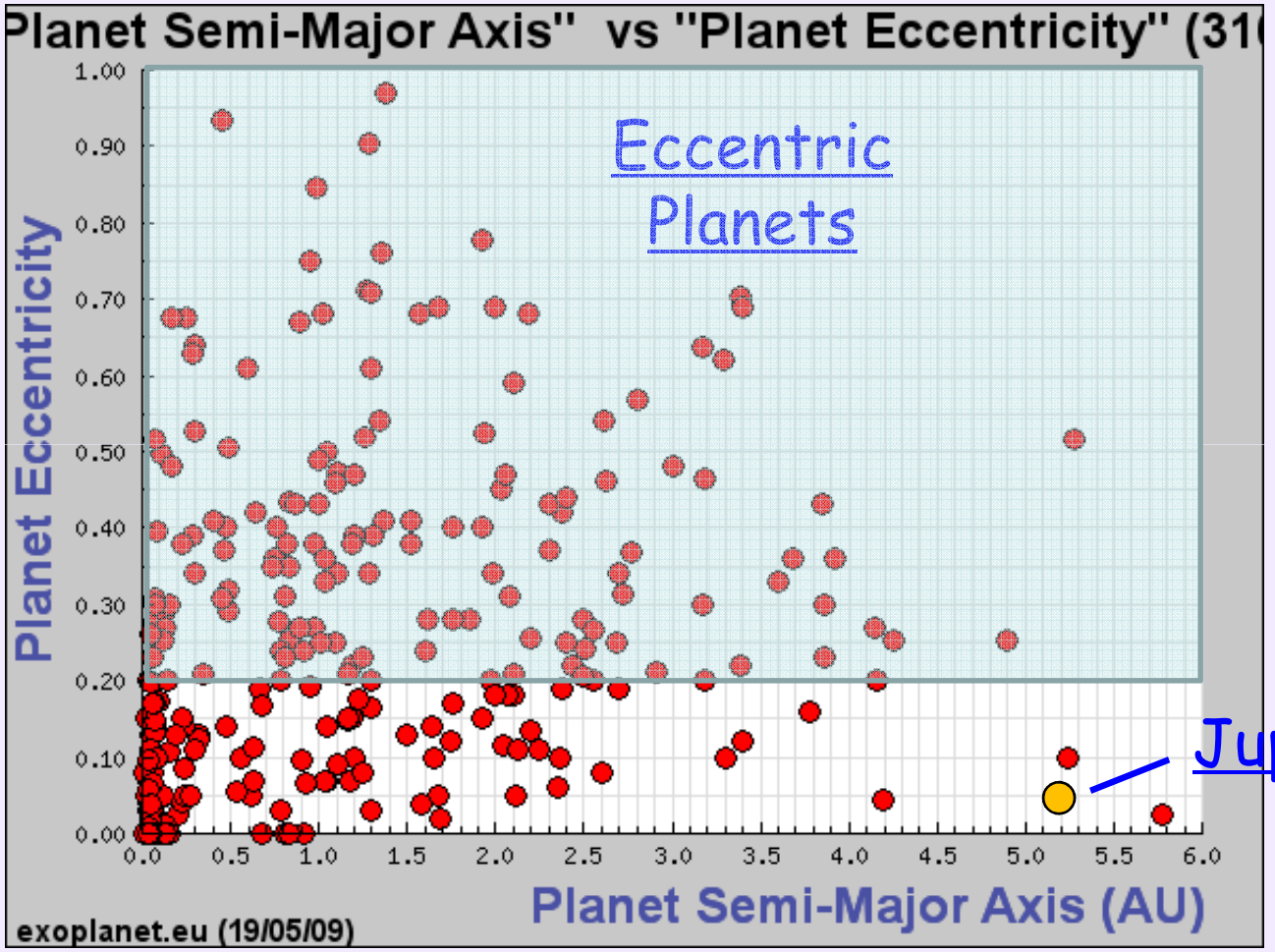
Need planetary migration mechanisms!

Standard Migration Models

Type I and II migration mechanisms

- consider gravitational interaction between
  - ✓ proto-planetary disk
  - ✓ planets
    - Type I: less than 10 Earth mass proto-planet
    - Type II: more massive case
- well explain the semi-major axis distribution
  - ✓ e.g., a series of Ida & Lin papers
- predict small eccentricities for migrated planets

Eccentricity Distribution



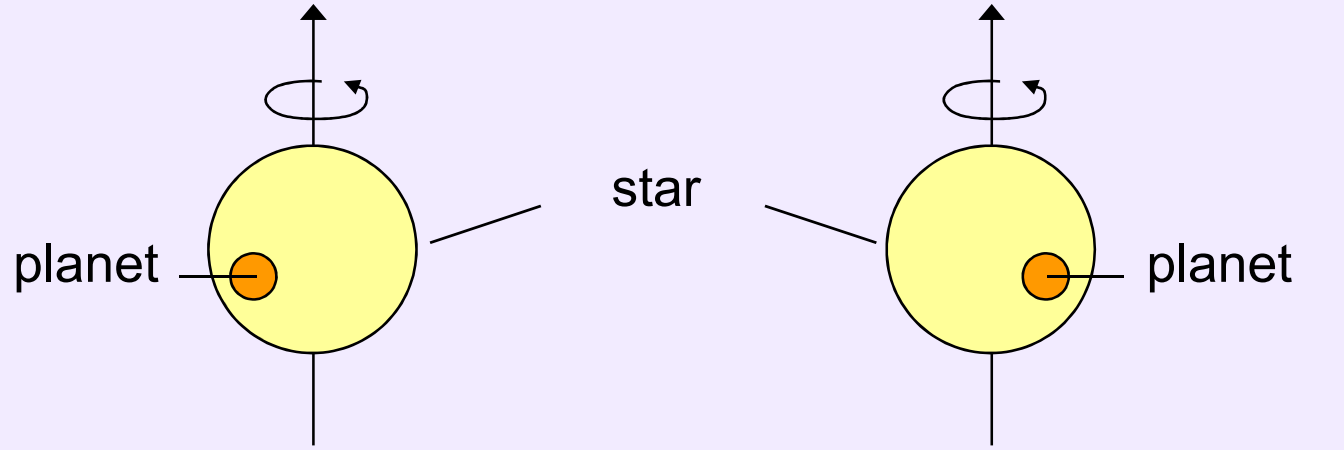
Cannot be explained by Type I & II migration model.

Migration Models for Eccentric Planets

- consider gravitational interaction between
  - ✓ planet-planet (planet-planet scattering models)
  - ✓ planet-binary companion (the Kozai migration)
    - Cf. Kozai-san = the first NAOJ director
- may be able to explain eccentricity distribution
  - ✓ e.g., Nagasawa+ 2008, Chatterjee+ 2008
- predict a variety of eccentricities and misalignments between stellar spin and planetary orbital axes
- How can we confirm these models by observations?

The Rossiter Effect for Transiting Planets

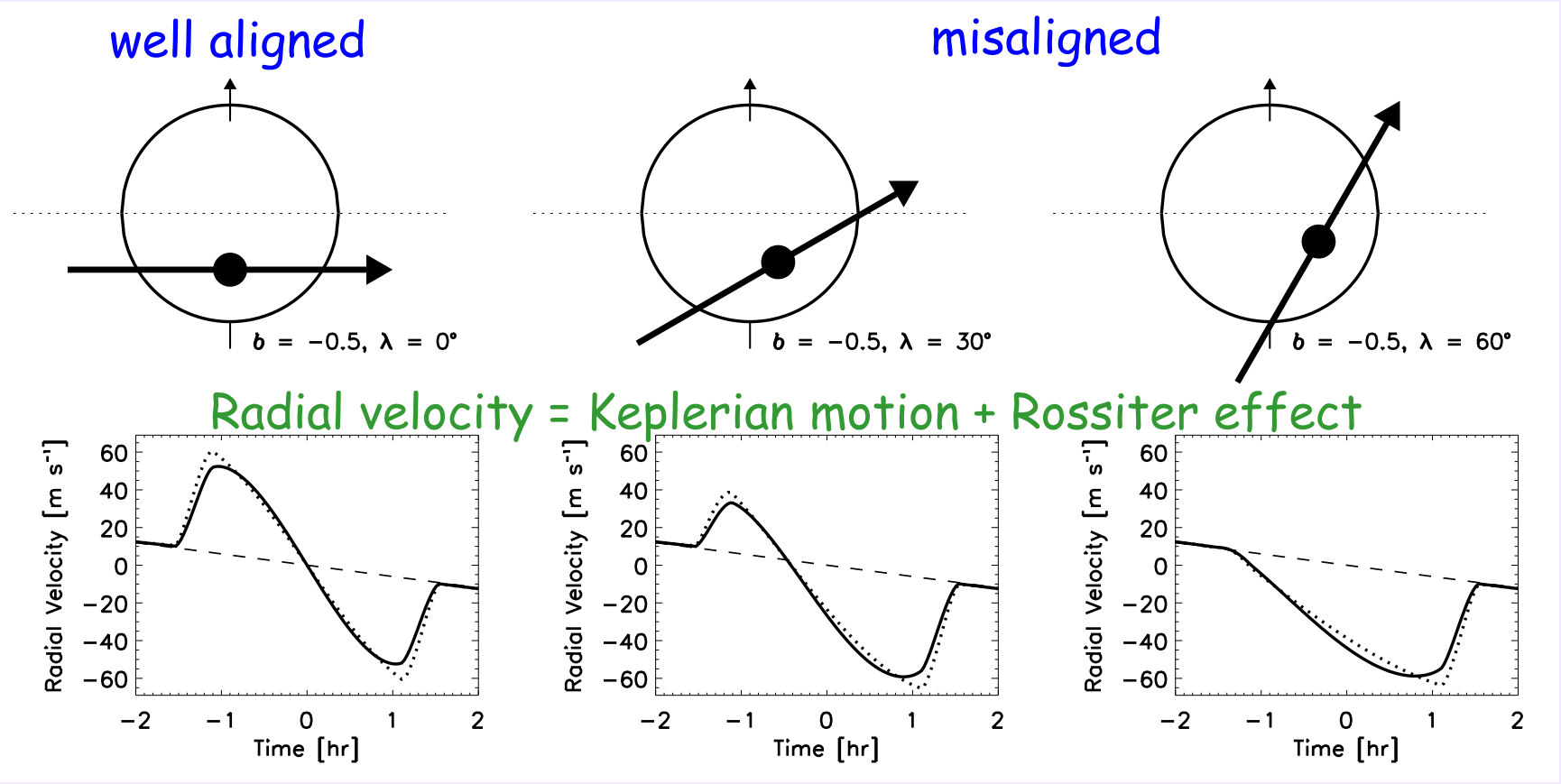
When a transiting planet hides stellar rotation,



radial velocity of the host star would show an anomaly.

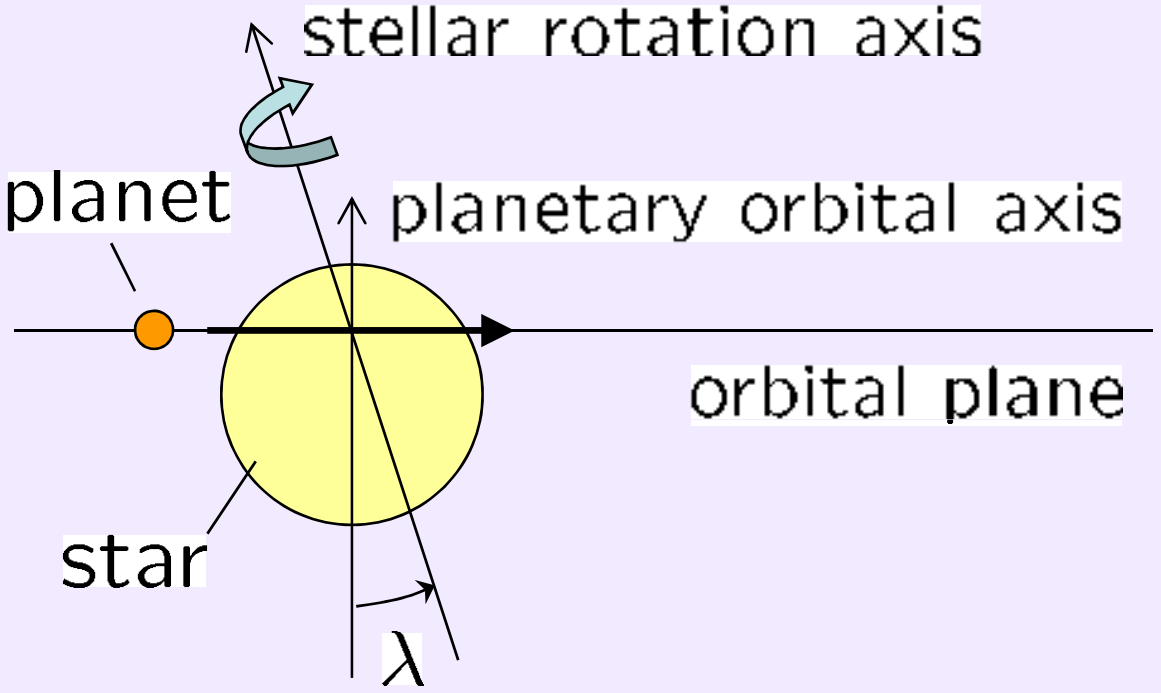
What can we learn from the effect?

The shape of the Rossiter effect
depends on the trajectory of the transiting planet.



Gaudi & Winn (2007)

Spin-Orbit Alignment



λ : sky-projected angle between

the stellar spin axis and the planetary orbital axis

(e.g., Ohta et al. 2005, Gimentz 2006, Gaudi & Winn 2007)

Past Subaru Observations

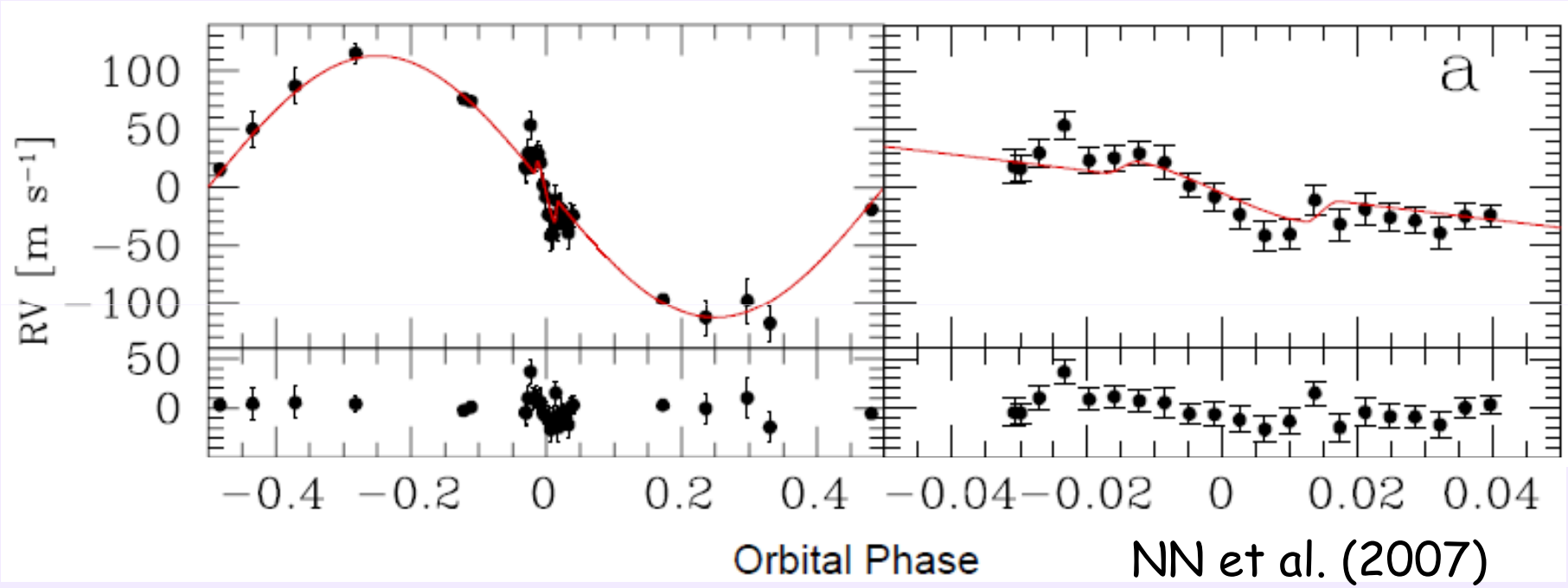
Proposals and target list

- S06A-029: TrES-1
- S07A-007: TrES-4
- S07B-091: TrES-3, WASP-1, WASP-2, HAT-P-1
- S08A-021: XO-2, HAT-P-7
- S08B-086: XO-3
- S08B-087: HD17156

Blue: Planets in Binary System / Green: Eccentric Planets

TrES-1: Slow Rotation and Faint Target

Our first observation with Subaru/HDS – difficult target



NN et al. (2007)

Thanks to Subaru, clear detection of the Rossiter effect.

We confirmed a prograde orbit and alignment of the planet.

TrES-3: Slower and Fainter Target

More difficult target

NN et al. in prep.

Very weak detection of the Rossiter effect.

This planet also orbits in a prograde and aligned way.

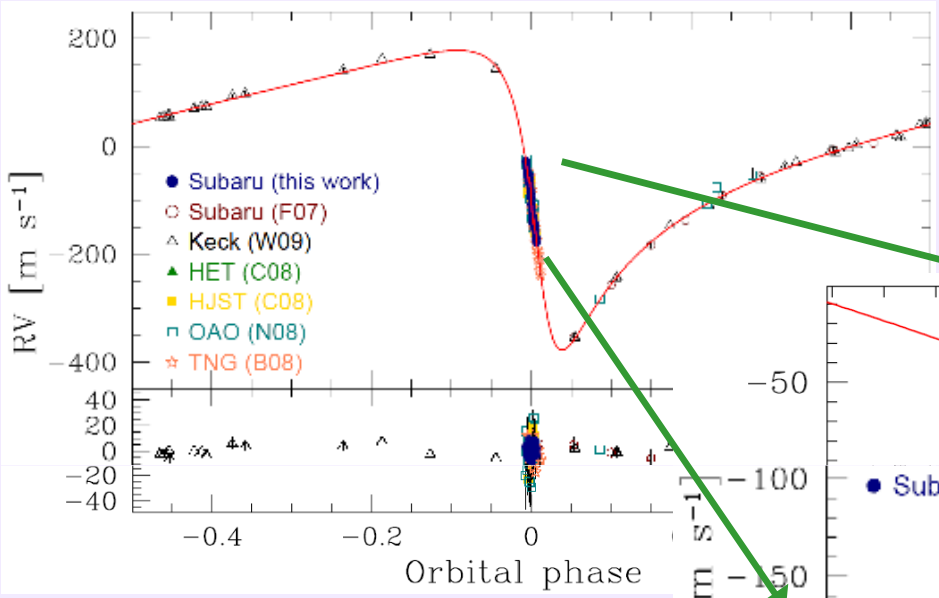
TrES-4: Fast Rotating Binary Target

The Rossiter effect is greater than the Keplerian motion!

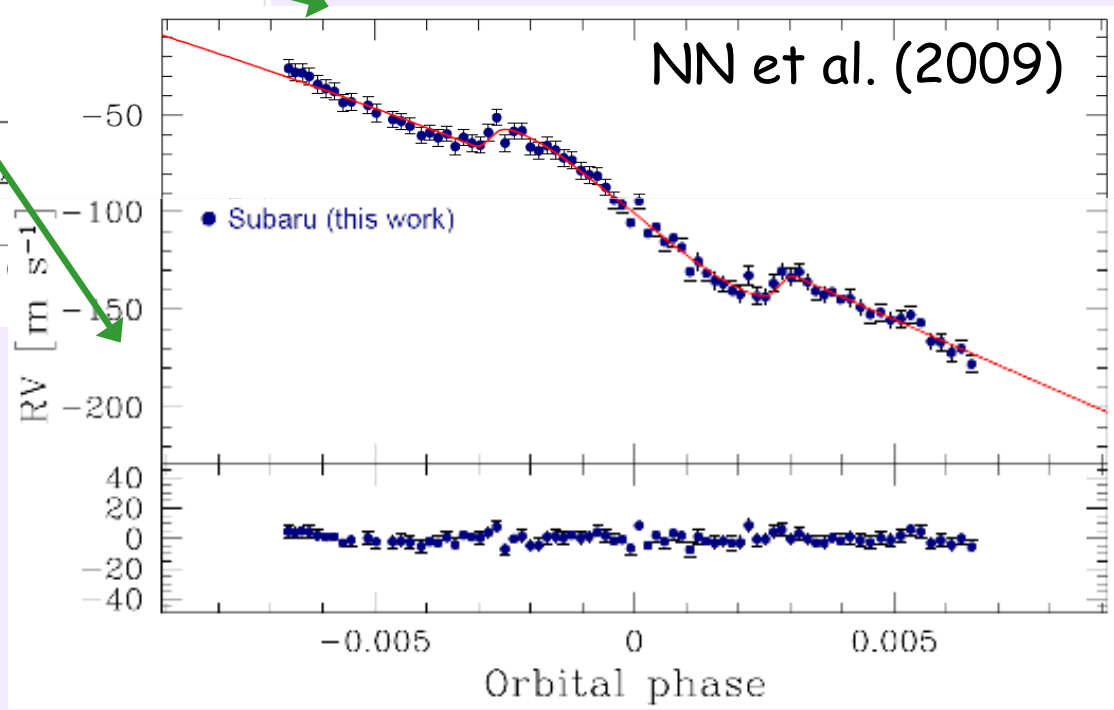
NN et al. in prep.

Well aligned in spite of its binarity.

HD17156: Eccentric Target

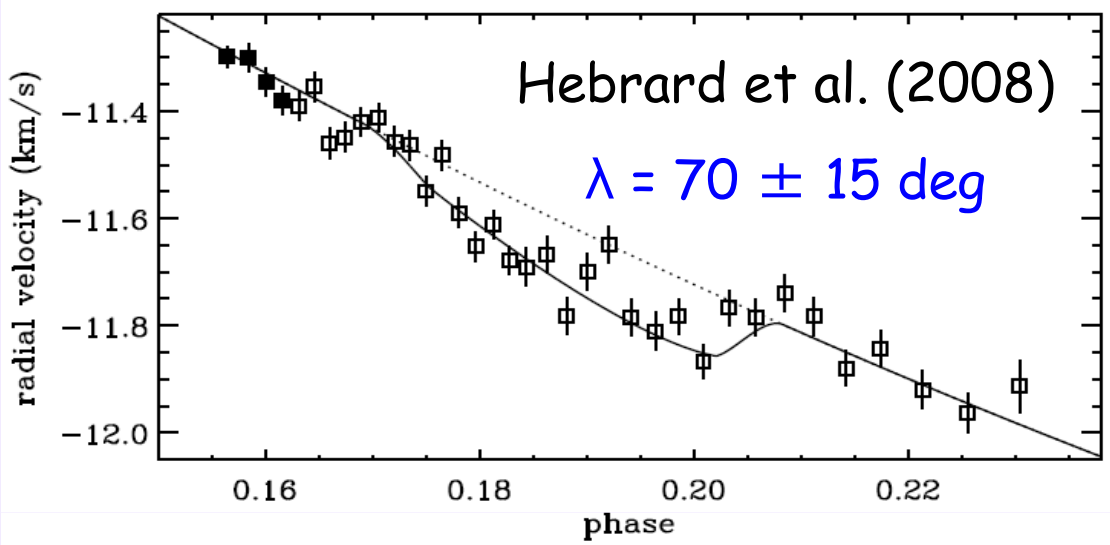


Eccentric planet with the orbital period of 21.2 days.

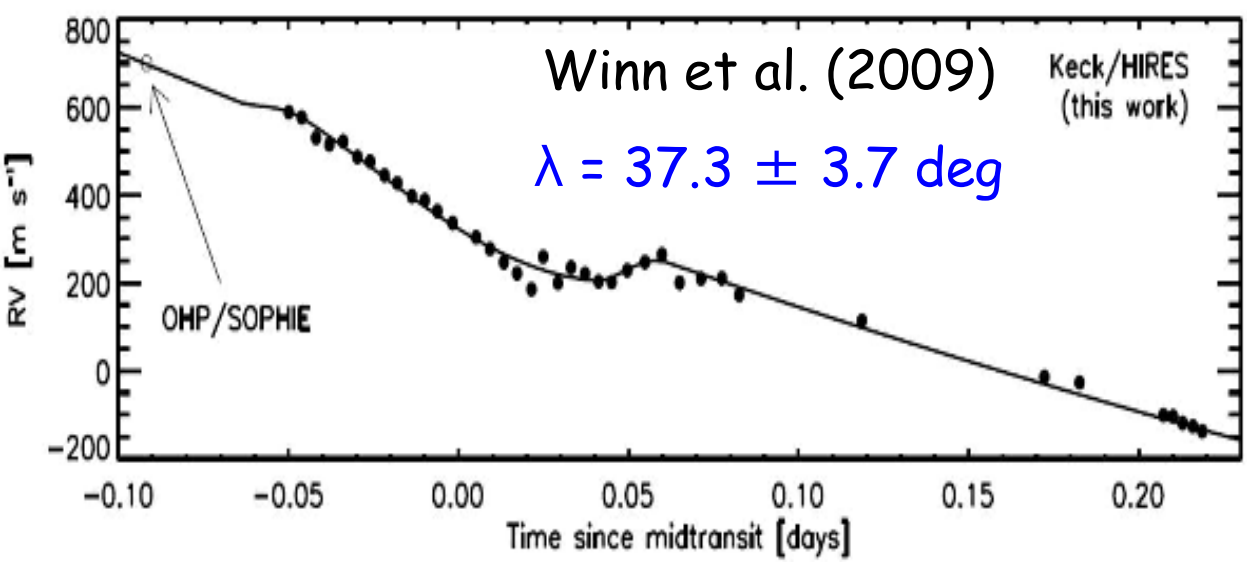


Aligned in spite of its eccentricity.

XO-3: Another Eccentric Target



Large misalignments
were reported,
but not yet confirmed.
(2σ discrepancy)



Unfortunately
S08B Subaru
observation
failed due to
bad weather.

List of Previous Studies

- HD209458 Queloz et al. 2000, Winn et al. 2005
- HD189733 Winn et al. 2006
- TrES-1 NN+ 2007
- HAT-P-2 Winn et al. 2007, Loeillet et al. 2008
- HD149026 Wolf et al. 2007
- HD17156 NN+ 2008,2009, Cochran+ 2008, Barbieri+ 2009
- TrES-2 Winn et al. 2008
- CoRoT-Exo-2 Bouchy et al. 2008
- HAT-P-1 Johnson et al. 2008
- XO-3 Hebrard et al. 2008, Winn et al. 2009
- WASP-14 Joshi et al. 2008
- (TrES-3, 4, WASP-1, 2, HAT-P-7, XO-2 NN+ in prep.)

Statistical Study

- Fabrycky and Winn (2009) considered two models,
  - A perfectly aligned (with large dispersion) distribution
    - Corresponding to Type II migration model
  - Aligned distribution + partly isotropic distribution
    - Corresponding to a combination of migration models
- Winn et al. (2009) reported
  - The second model is preferred with a confidence of 96.6%
- But it is not robust because XO-3 is the only one sample
  - More samples needed

Summary and Future Prospects

- So far almost all planets show no large misalignment
  - consistent with standard Type II migration models
  - HD17156b (eccentric planet) also show no misalignment
- Only 1 exception is XO-3b
  - $\lambda = 70 \pm 15$ deg (Hebrard et al. 2008)
  - $\lambda = 37.3 \pm 3.7$ deg (Winn et al. 2009)
  - formed through planet-planet scattering?
- Statistical study is just beginning
  - More samples (especially eccentric planets) needed
  - The Rossiter effect is useful to study planet migration!