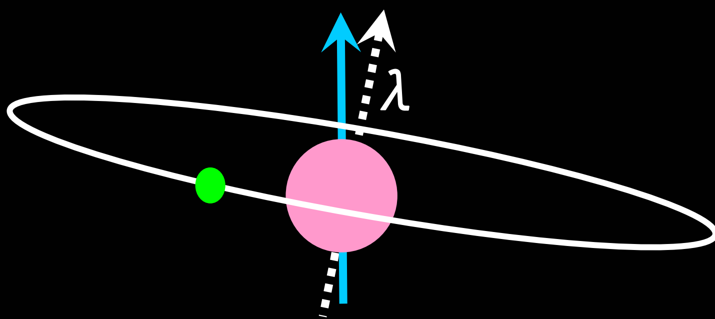
Predicting signatures of planetary rings around extrasolar transiting planets



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The 2nd KIAS Workshop on
COSMOLOGY AND STRUCTURE FORMATION
Sept. 20-21, 2006, KIAS, Seoul

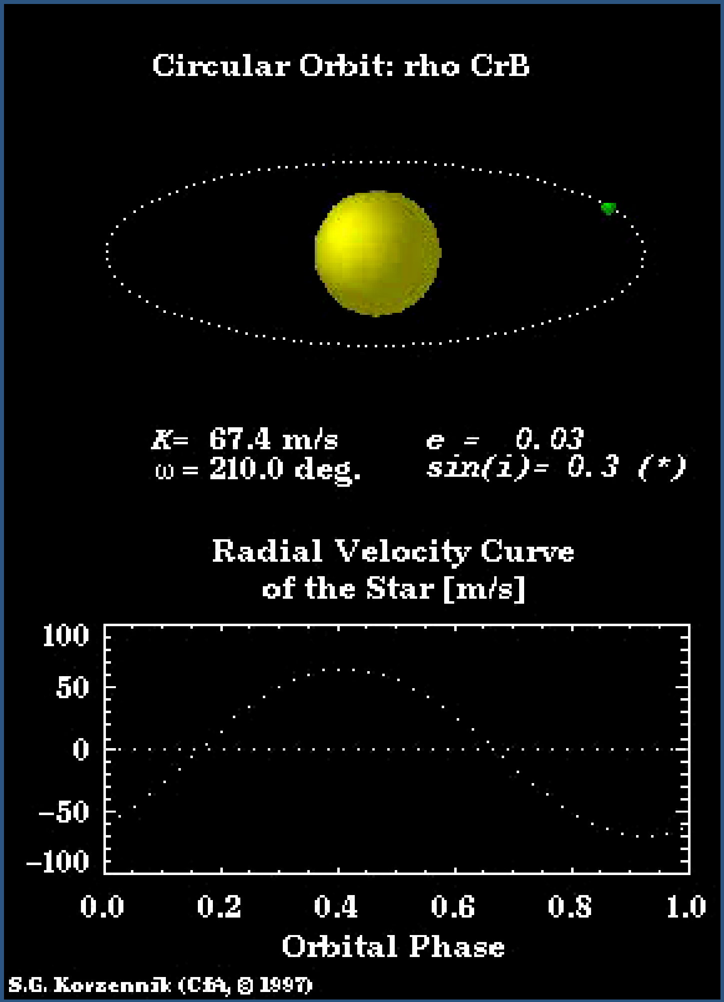
A brief history of the discovery of extrasolar planets

- **1995 :** the first extrasolar planet around the main sequence star 51 Pegasi (Mayor & Queloz)
- **1999 :** transit of a known planet around HD209458 (Charbonneau et al., Henry et al.)
- **2001 :** Na in the atmosphere of HD209458b
- **2003 :** first discovery of a planet by transit method *alone* (1.2 day orbital period: OGLE)
- **2005:** spin-orbit misalignment via the Rossiter effect
- *200 extrasolar planets* are reported (Sept. 2006)

http://exoplanets.org/

Radial velocity of a star perturbed by a planet

Even if planets are not directly observable, their presence can be inferred dynamically



velocity modulation of the Sun:

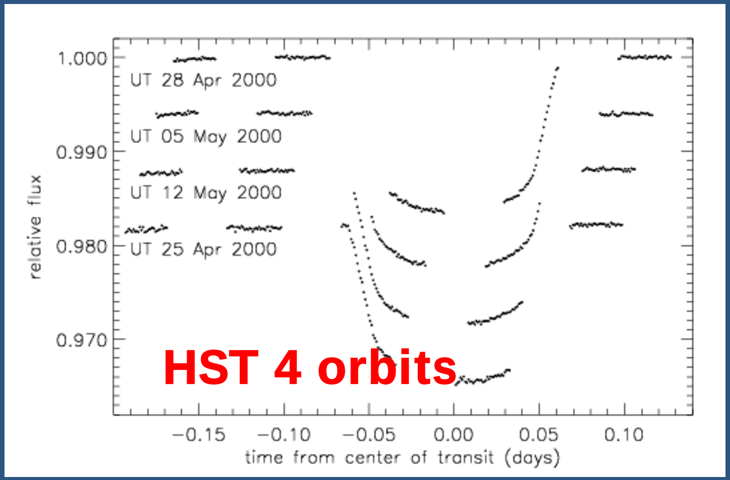
12.5 m/s（Jupiter）

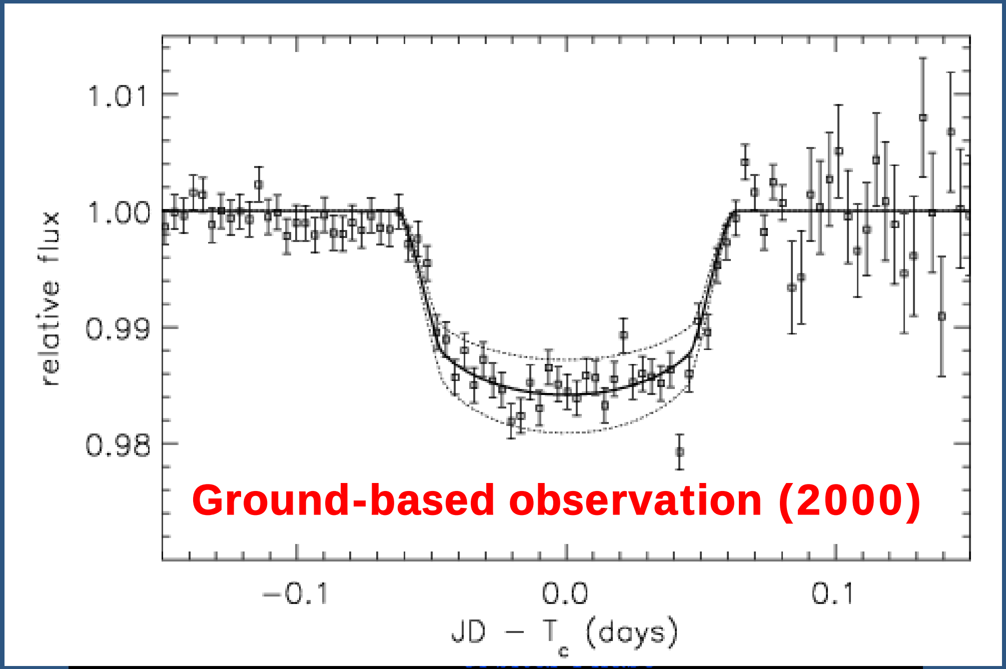
0.1 m/s（Earth）

an accuracy of 1m/s achieved from the ground observation
⇒ the current major method in search for Jupiter-sized planets

the first discovery of the transit of a planet: HD209458

- detected the light curve change at the phase consistent with the radial velocity (Charbonneau et al. 2000, Henry et al. 2000)





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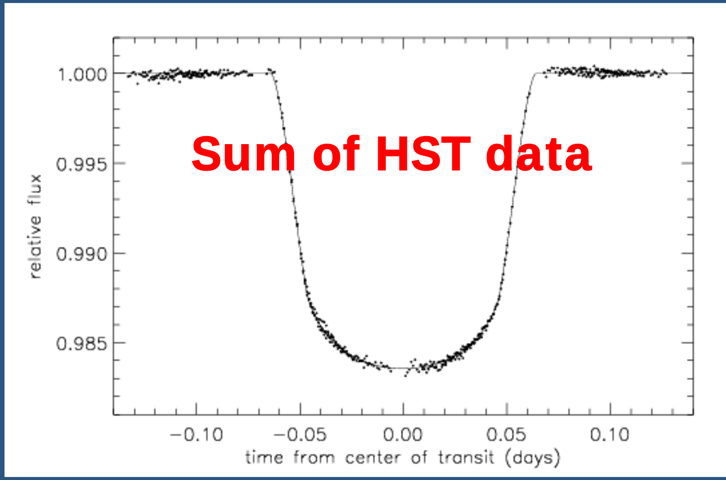
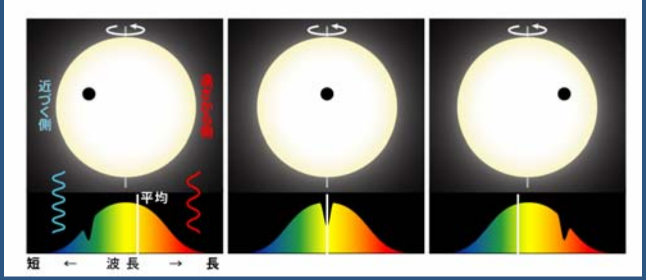


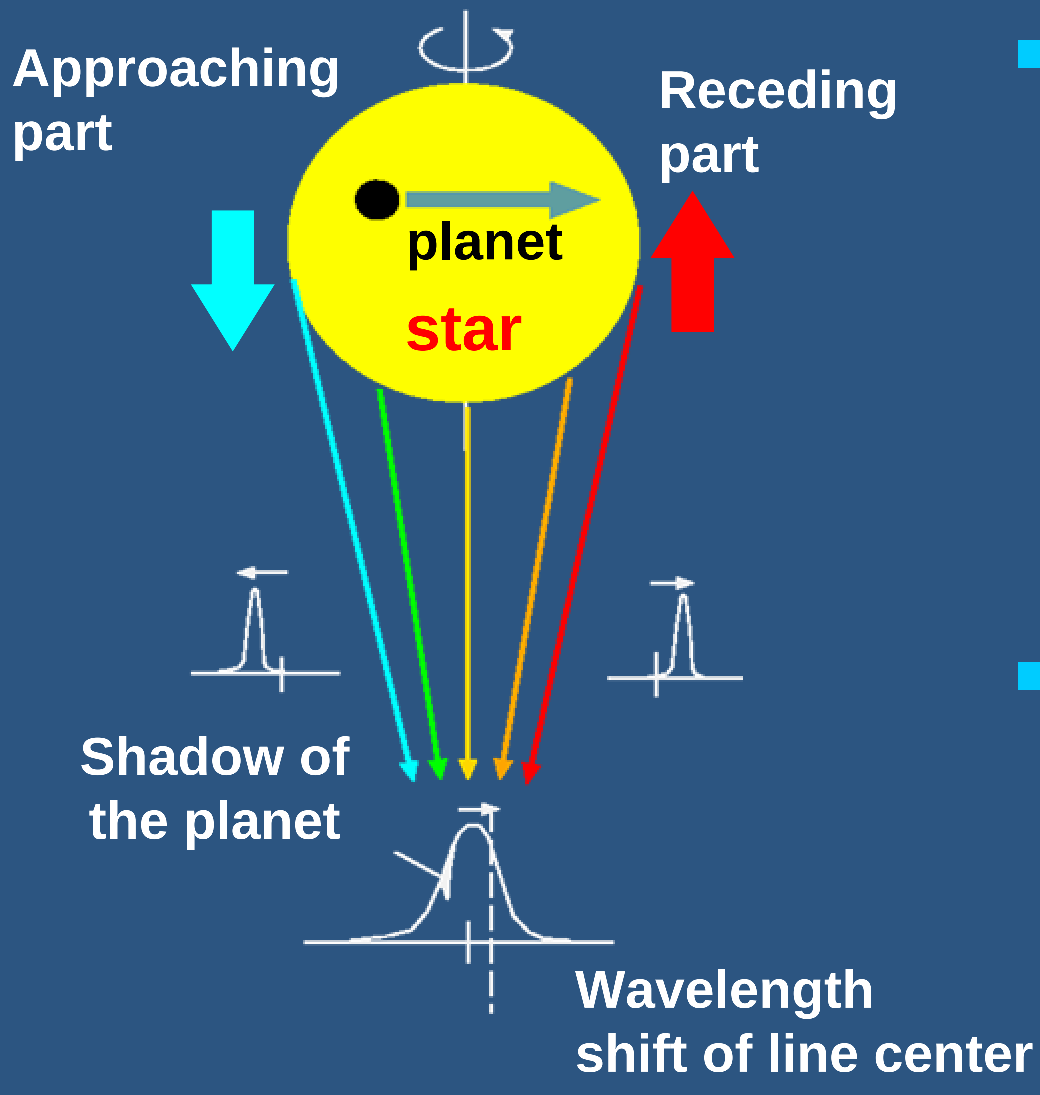
Brown et al. (2001)

Extrasolar planet projects at Univ. of Tokyo

- **Search for the planetary atmosphere with Subaru**
  - the most stringent upper limits from ground-based obs.
  - Winn et al. PASJ 56(2004) 655 (astro-ph/0404469)
  - Narita et al. PASJ 57(2005) 471 (astro-ph/0504450)
- **Constraining the stellar spin and the planetary orbital axes from the Rossiter-McLaughlin effect**
  - New analytic formulae (Ohta, Taruya & Suto 2005, ApJ, 622, 1118)
  - First detection (Winn et al. 2005 ApJ, 631, 1215)
- **Search for reflected light from planets**
  - collaboration with Andrew Cameron (St. Andrews Univ.) & Chris Leigh (Liverpool John Moores Univ.)

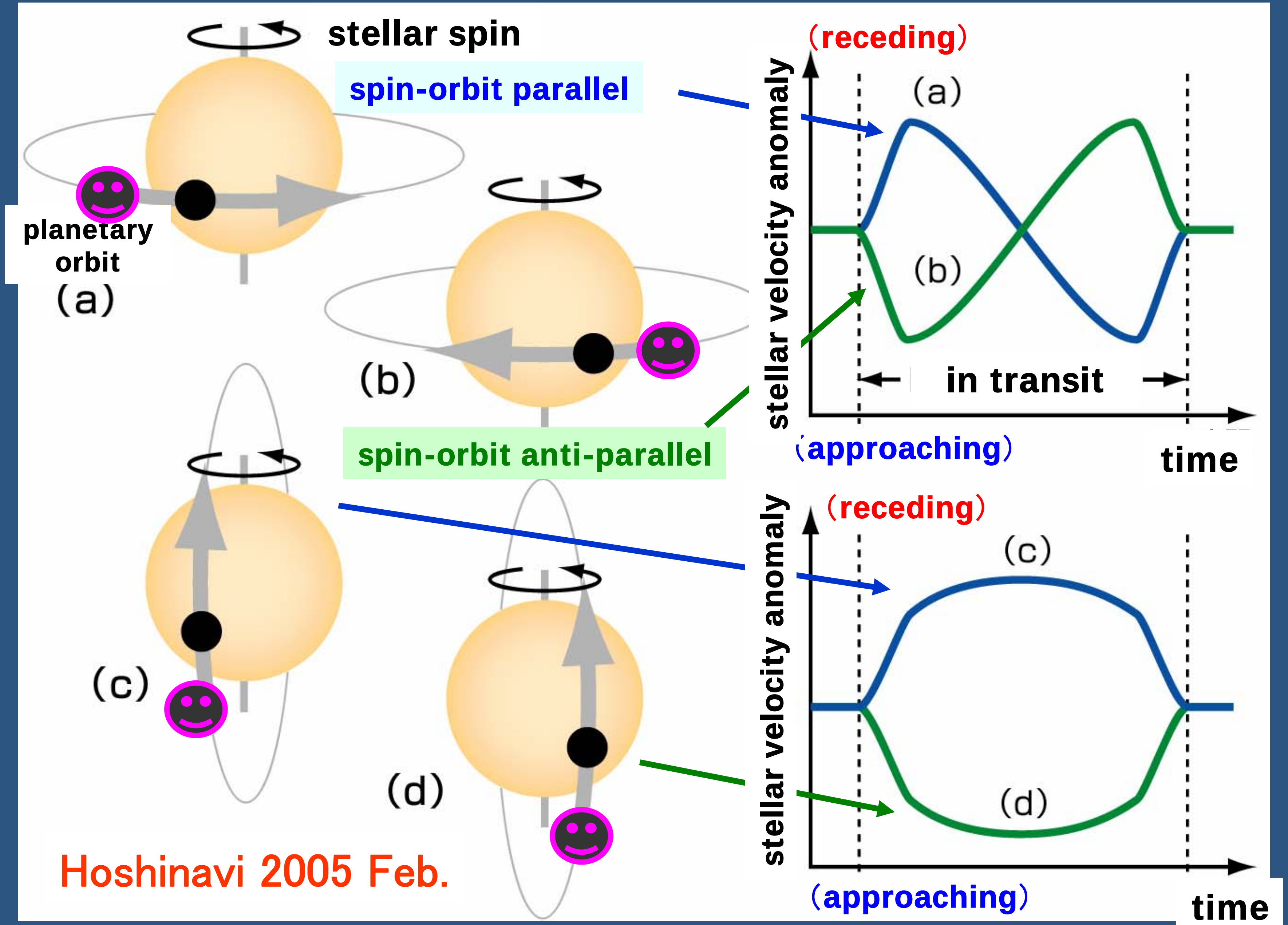


Spectroscopic transit signature: the Rossiter-McLaughlin effect



- Time-dependent asymmetry in the stellar Doppler broadened line profile
  - an apparent anomaly of the stellar radial velocity
- originally discussed in eclipsing binary systems
  - Rossiter (1924)
  - McLaughlin (1924)

Velocity anomaly due to the Rossiter effect

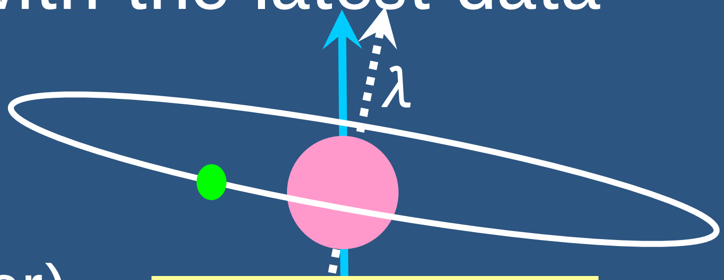


Measurement of Spin-Orbit alignment in an Extrasolar Planetary System

- Joshua N. Winn (MIT), R.W. Noyes, M.J. Holman, D.B. Charbonneau, Y. Ohta, A. Taruya, Y. Suto, N. Narita, E.L. Turner, J.A. Johnson, G.W. Marcy, R.P. Butler, & S.S. Vogt
  - ApJ 631(2005)1215 (astro-ph/0504555)

Precision analysis of the Rossiter-McLaughlin effect for HD209458

- perturbation formula by Ohta et al. (2005)
- HD209458 re-examined with the latest data
  - radial velocity data (Keck)
  - optical photometry (HST)
  - infrared photometry (Spitzer)

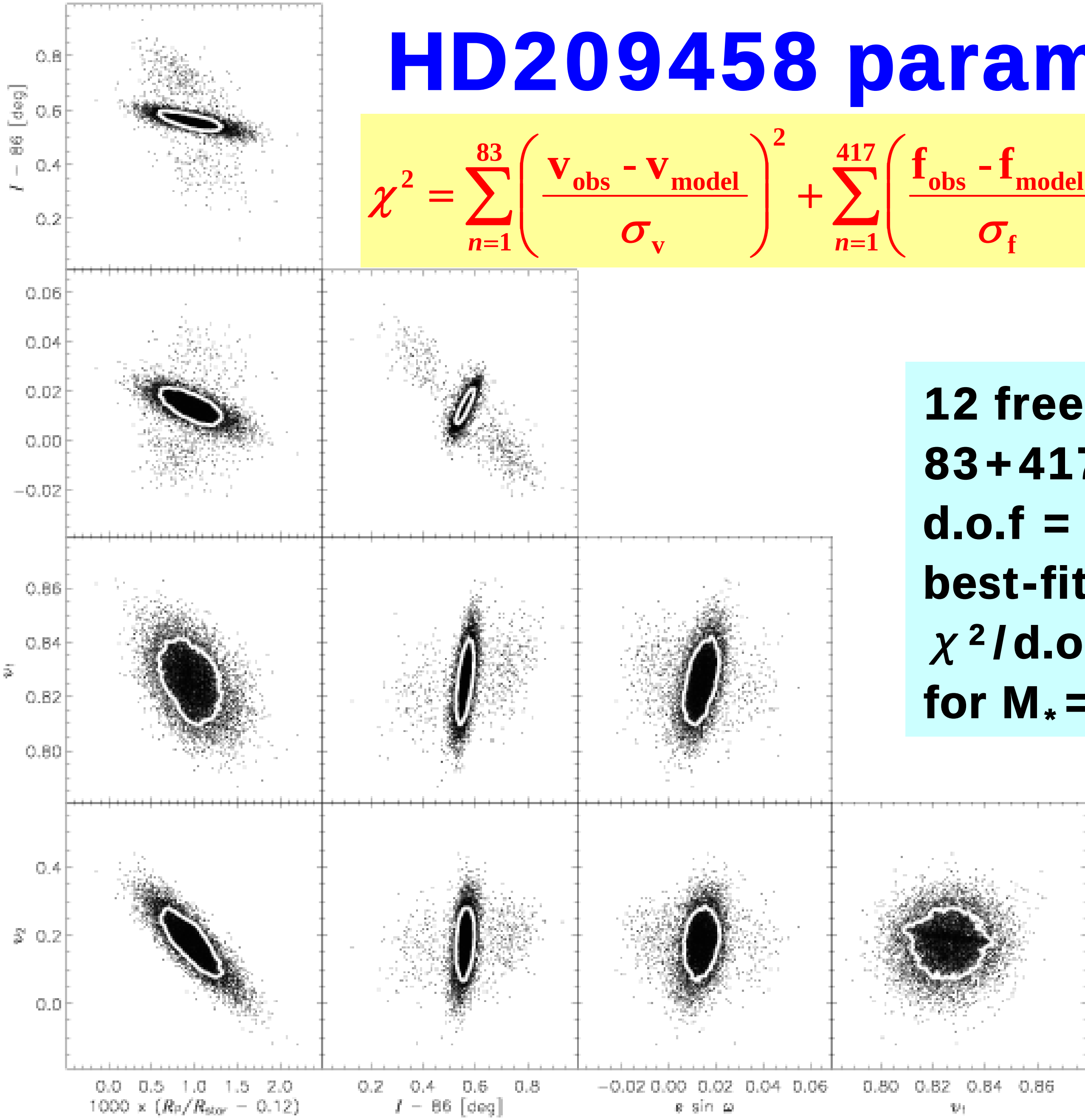


$$\lambda = -4^{\circ}.4 \pm 1^{\circ}.4$$

- **the first detection of the misalignment between the stellar spin and the planetary orbital axes by (−4.4±1.4)deg**
  - more than an order-of-magnitude improvement of the previous error-bar (maybe useless but impressive result !)
  - c.f., 6 degree misalignment for the Solar system

HD209458 parameter fit

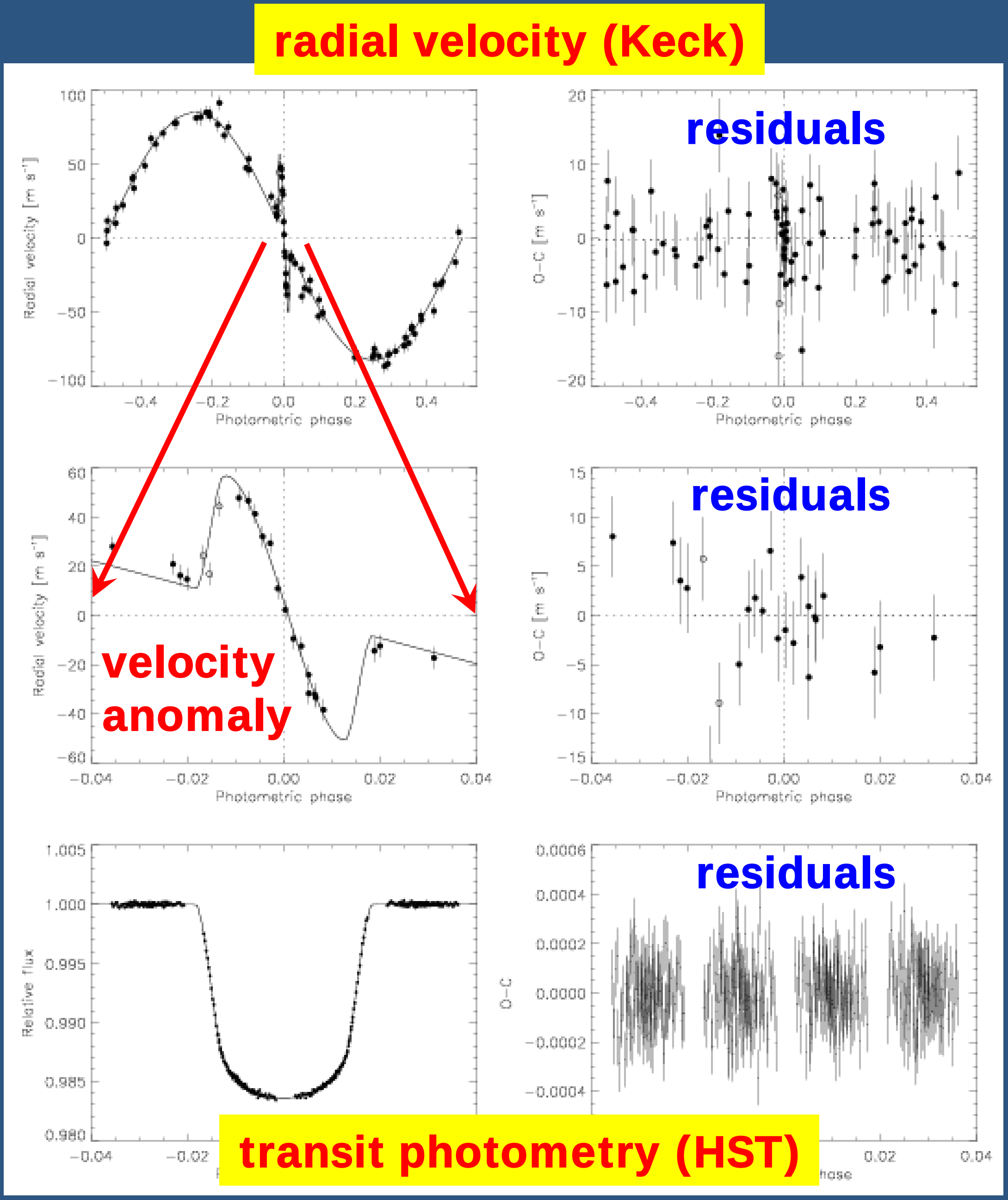
$$\chi^2 = \sum_{n=1}^{83}\left(\frac{v_{obs} - v_{model}}{\sigma_v}\right)^2 + \sum_{n=1}^{417}\left(\frac{f_{obs} - f_{model}}{\sigma_f}\right)^2 + \left(\frac{t_{2nd,obs} - t_{2nd,model}}{\sigma_t}\right)^2$$

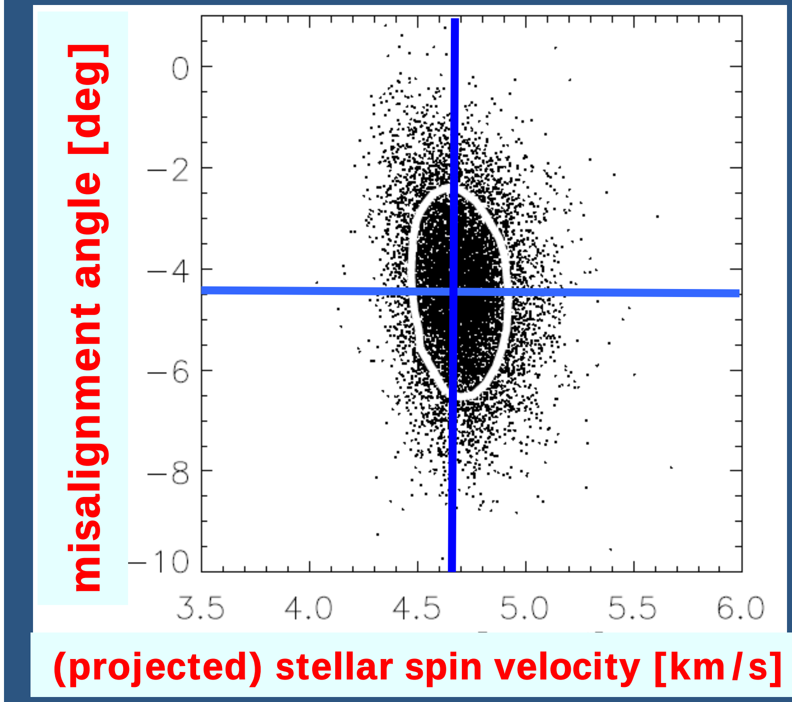


12 free parameters
83+417+1 data points
d.o.f = 83+417+1-12=489
best-fit :
χ^2/d.o.f=528/489=1.08
for $M_* = 1.06 M_{sun}$

Winn et al.
astro-ph/0504555
ApJ 631(2005)1215

first detection of non-zero λ !



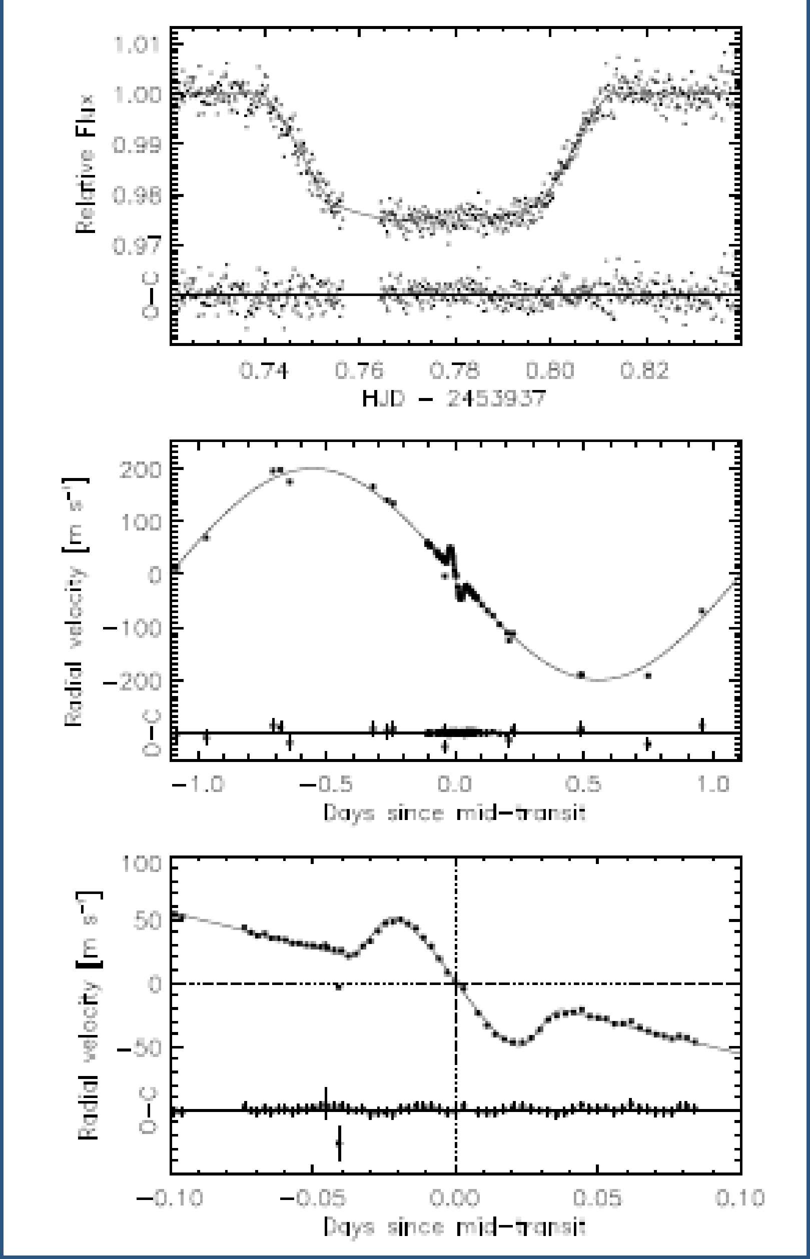


$$\lambda = -4^{\circ}.4 \pm 1^{\circ}.4$$

3σ detection !

Winn et al. astro-ph/0504555 ApJ 631(2005)1215

another example: HD189733

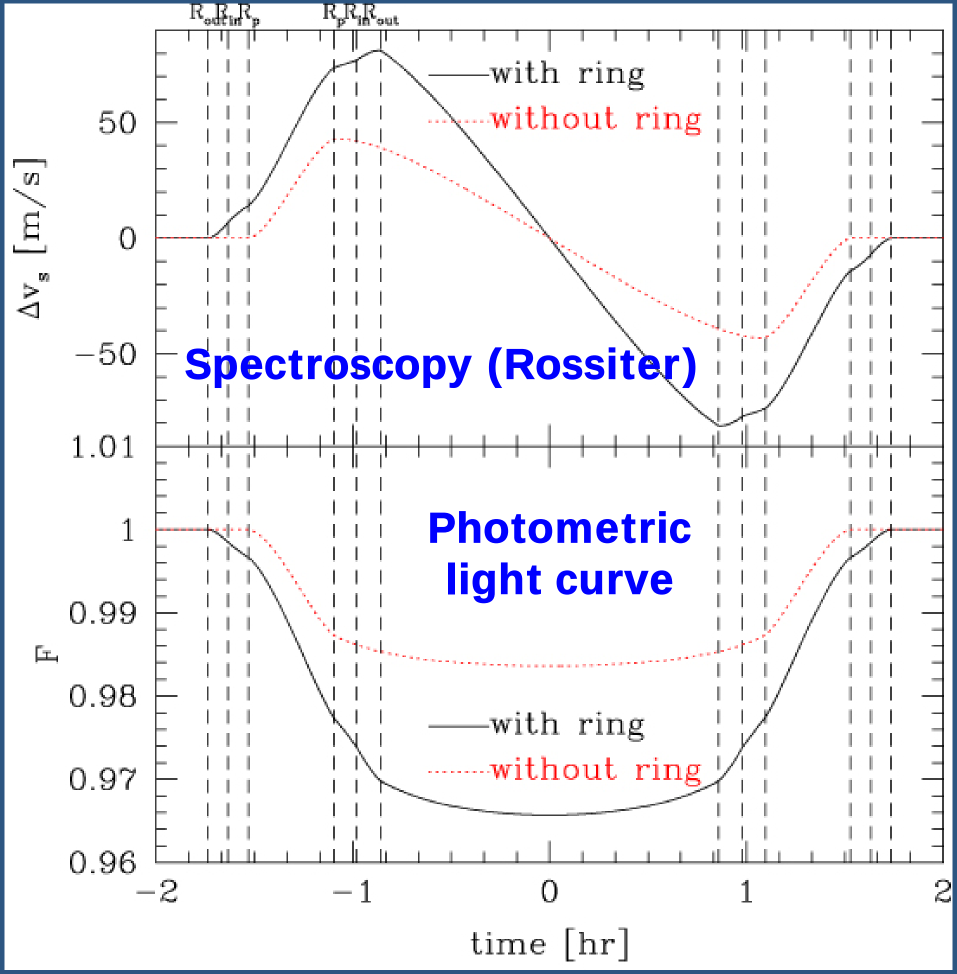


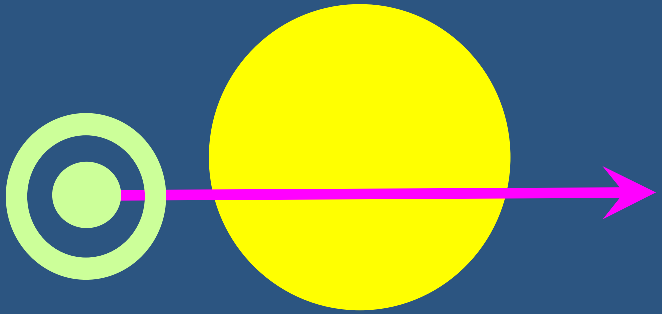
- **HD 189733**
  - Bouchy et al. (2005)
  - K-dwarf (V=7.7)+1.15$M_J$planet
  - 2.2 day orbital period
  - 2.5% photometric transit signal
- Winn et al. ApJL, submitted (astro-ph/0609506)
  - λ=-1.4° ±1.1°
  - consistent with zero

Discovery of the Uranus rings

- **Serendipitous discovery**
  - Uranus's transit against a background star (Elliot et al. 1977)
  - Neptune's ring was discovered also by transit technique in 1986
- **Transit proved to be useful in detecting rings of the Solar planets !**

Signatures of planetary rings

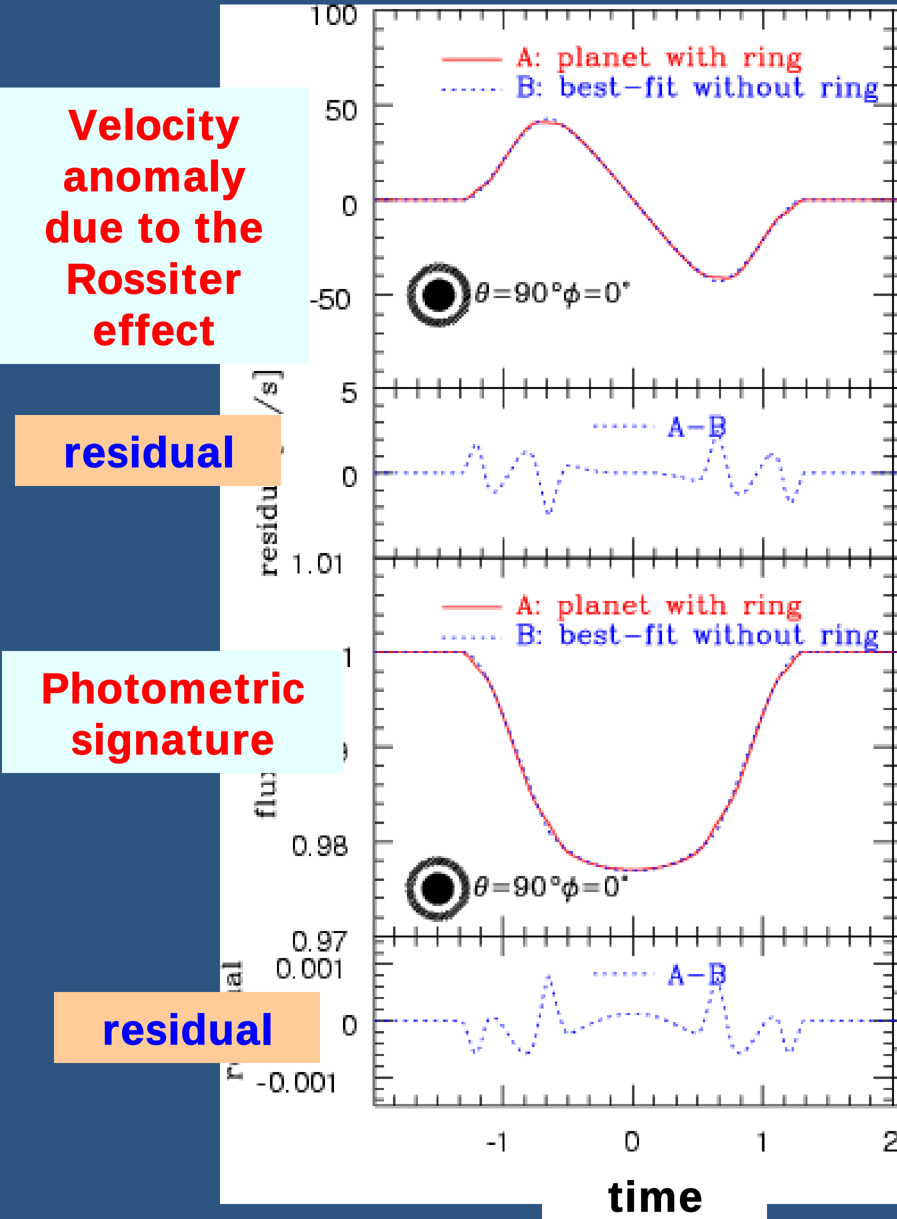




Ohta, Taruya & Suto, in preparation

- Ring's inner and outer radii, gap, planet's radius imprints strong features in the photometric and spectroscopic data
- Statistical analysis of the residuals with respect to the best-fit ringless model

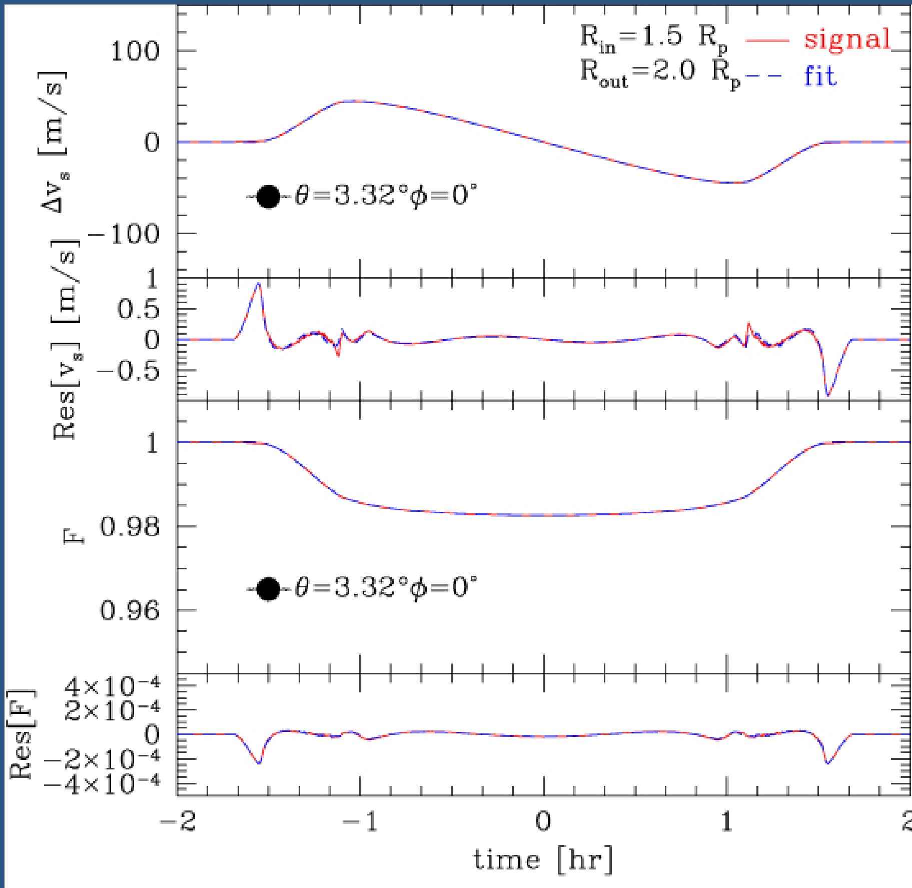
Detectability of a ring

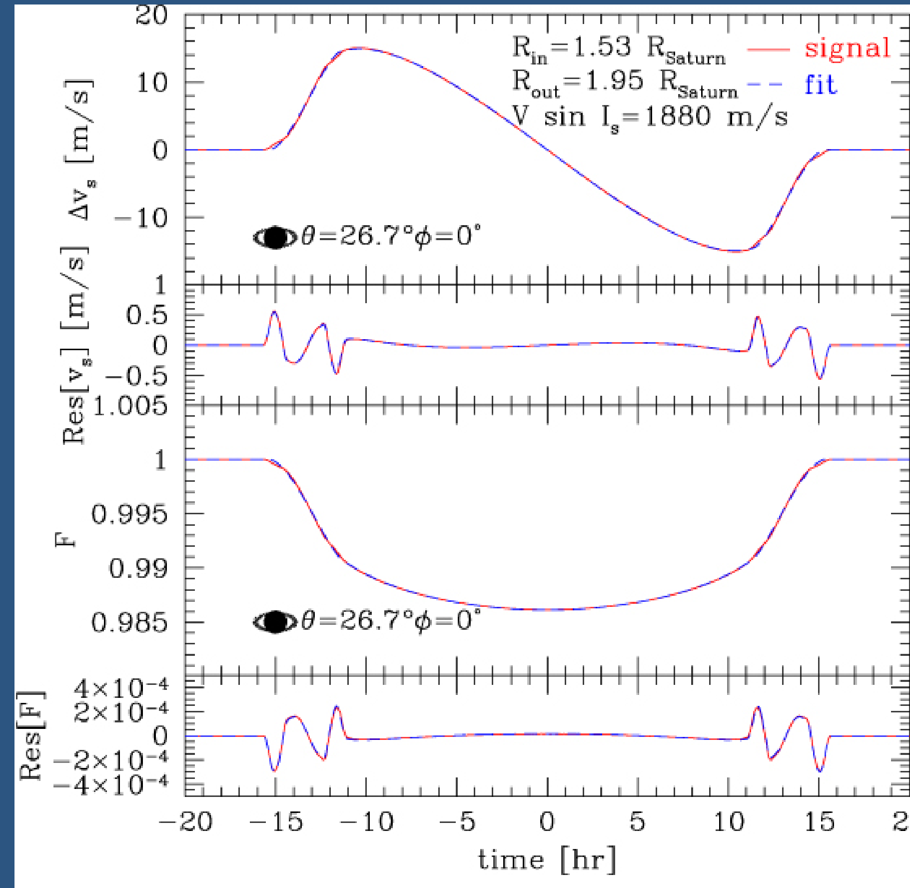


- a hypothetical ring around HD209458
  - $1.5R_{pl} < R_{ring} < 2R_{pl}$
  - deviation from a best-fit single planet
  - $\delta v \sim 1$ m/s
  - $\delta F/F \sim 0.1\%$
- marginally detectable level even with the current technology

Ohta, Taruya & Suto, in preparation

How about hot Jupiter and Saturn rings ?





Ohta, Taruya & Suto, in preparation

- **Hot Jupiter: edge-on rotation due to the tidal locking**
- **Saturn: 30 deg. inclined, but spin of the Sun is small**
- **Worse in either case, but still detectable potentially (S/N=1)**

Future of transiting planet research: follow Hantaro Nagaoka

- Nagaoka's Saturn model of atom
  - Nagaoka: Phil. Mag. 7(1904) 445
  - ⇒ quantum atomic physics
- Transit planets
  - Orbital angular momentum (**L**): radial velocity
  - Spin of star (**S**): Rossiter effect
  - Spin of planet (**s**): ring, satellite
- From planets to atomic physics
- From atomic physics to planets

写真 2：長岡半太郎（1865－1950）