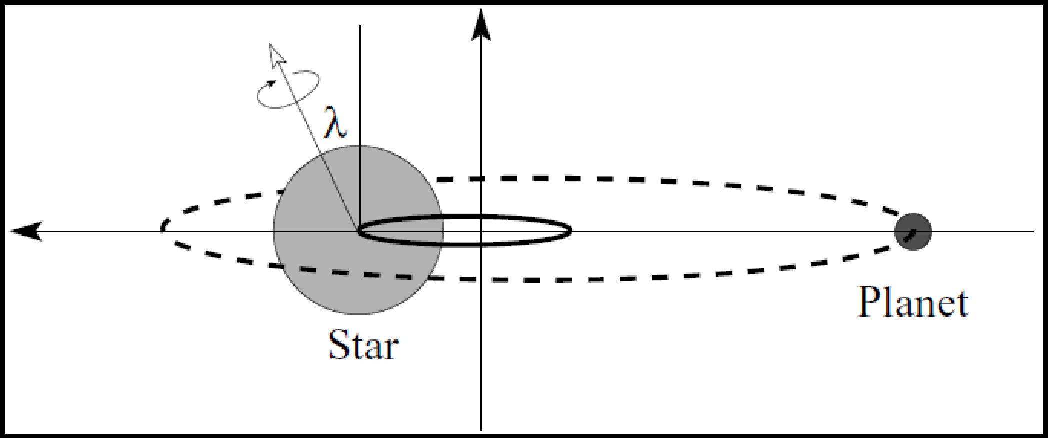
Investigation of the Rossiter effect of a transiting planet to determine the spin-orbit alignment



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

Yasushi Suto

Department of Physics, University of Tokyo

seminar @ Liverpool John Moores University (July 15, 2005)

Liverpool John Moores University and me

- Three collaborators in very different topics
  - Shiho Kobayashi (will arrive on Sep. 4, 2005)
    - 1995: correlation function of gamma ray bursts
    - 1996: angular-diameter vs redshift relation from SZ observations
  - Sabine Schindler (now in Univ. of Innsbruck)
    - 1998-2001: Sunyaev-Zel'dovich mapping of the most luminous X-ray cluster in mm and submm
  - Chris Leigh
    - 2005: ultra-high spectroscopy of extrasolar planets
- More to come, hopefully

Recent Activities in Observational Cosmology Group, University of Tokyo (1)

- **SDSS galaxy and quasar statistics**
  - topological analysis of galaxy distribution (Hikage et al. 2003, 2004; Park et al. 2005)
  - phase correlation statistics of SDSS galaxies (Hikage et al. 2005)
  - 3pt correlation functions of SDSS galaxies (Kayo, Suto, **Nichol** et al. 2004)
  - widest-separation lensed quasar from SDSS (Inada et al. 2003; Oguri et al. 2004)
  - 2pt correlation functions of SDSS quasars and dark energy (Yahata et al. 2005)
  - constraints on the deviation from Newton's law of gravity from SDSS galaxy power spectrum (Shirata, Shiromizu, Yoshida & Suto 2005)
  - testing the Galactic dust map against SDSS galaxy number counts (Yahata et al. in preparation)

Recent Activities in Observational Cosmology Group, University of Tokyo (2)

- **Dark halo and galaxy cluster**
  - triaxial modeling of dark matter halos (Jing & Suto 2002; Oguri, Lee & Suto 2003; Lee, Jing & Suto 2005)
  - highest-angular resolution SZ maps in submm and mm (Komatsu et al. 1999, 2001; Kitayama et al. 2004)
- **Warm/hot intergalactic medium (WHIM)**
  - a proposal of oxygen emission line search (Yoshikawa et al. 2003, 2004)
  - feasibility of an absorption line search with XEUS along a GRB afterglow (Kawahara et al. 2005)
- **Spectroscopy of transiting extrasolar planets**
  - constraints on planetary atmosphere (Winn et al. 2004; Narita et al. 2005)
  - first detection of the spin-orbit misalignment in an extrasolar planetary system with the Rossiter effect (Ohta, Taruya & Suto 2005; Winn et al. 2005)

Why extrasolar planets *now* ?

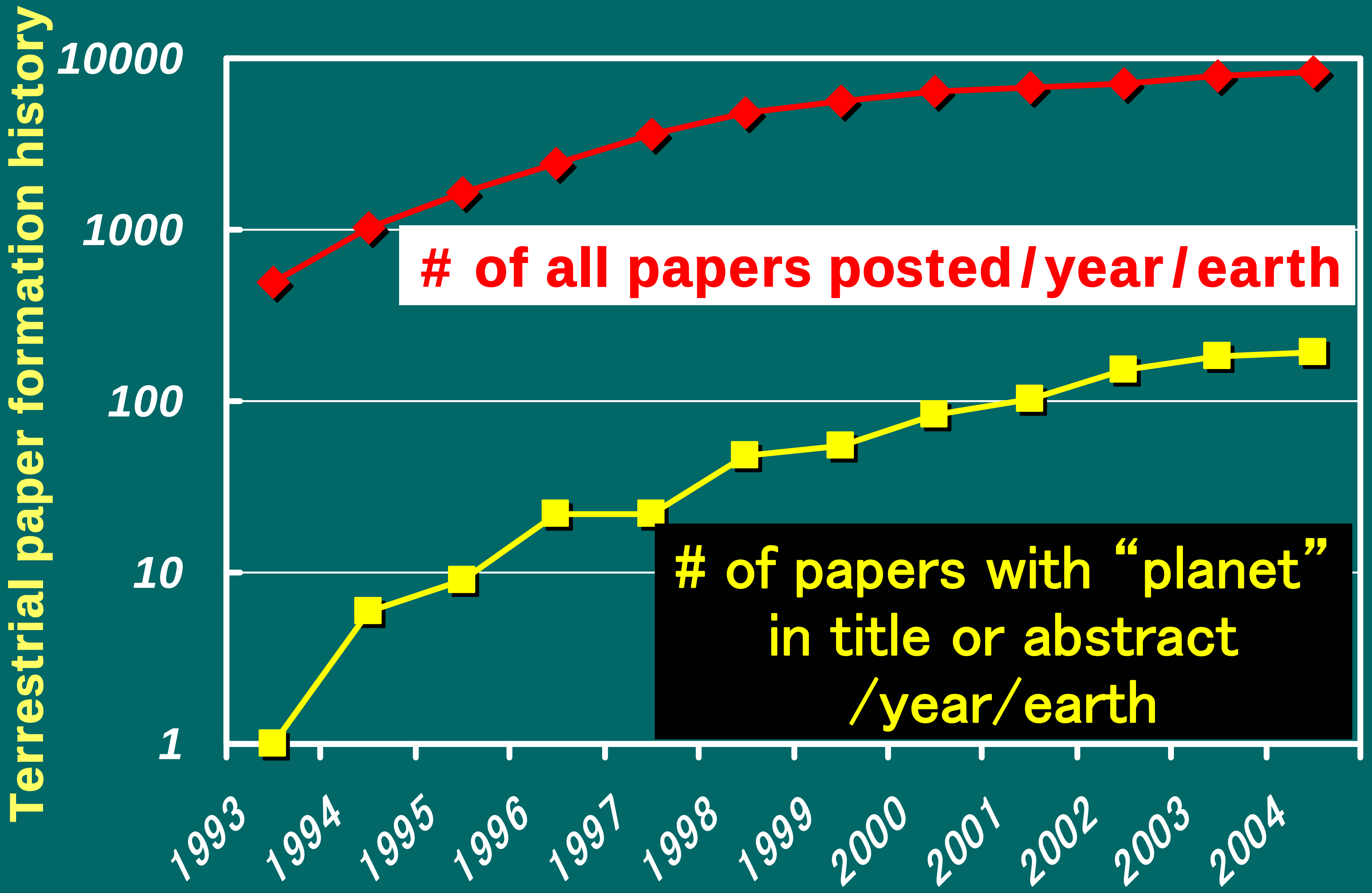
- **related to one of the most fundamental questions**
  - origin of life
- **Just started**
  - first discovery in 1995 !
- **easier to convince taxpayers**
  - other sciences became too detailed or too matured to achieve really fundamental contribution
- **Very few experts in this field, and quite interdisciplinary**
  - whatever experts in physics, planetary science, astronomy, geology, climate, and biology are welcome to join in many respects

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*** **:** discovery of Na in the atmosphere of HD209458b
- **2003**: first discovery of a planet by transit method *alone* (1.2 day orbital period: OGLE)
- *154 extrasolar planets* are reported (June, 2005)

http://exoplanets.org/

“Evolution” of extra-solar planet research

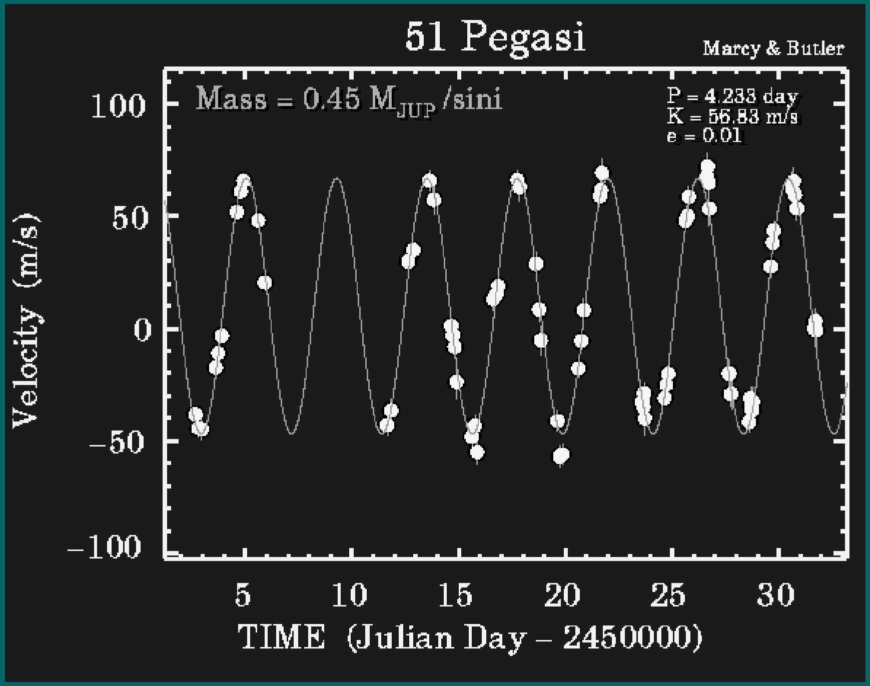


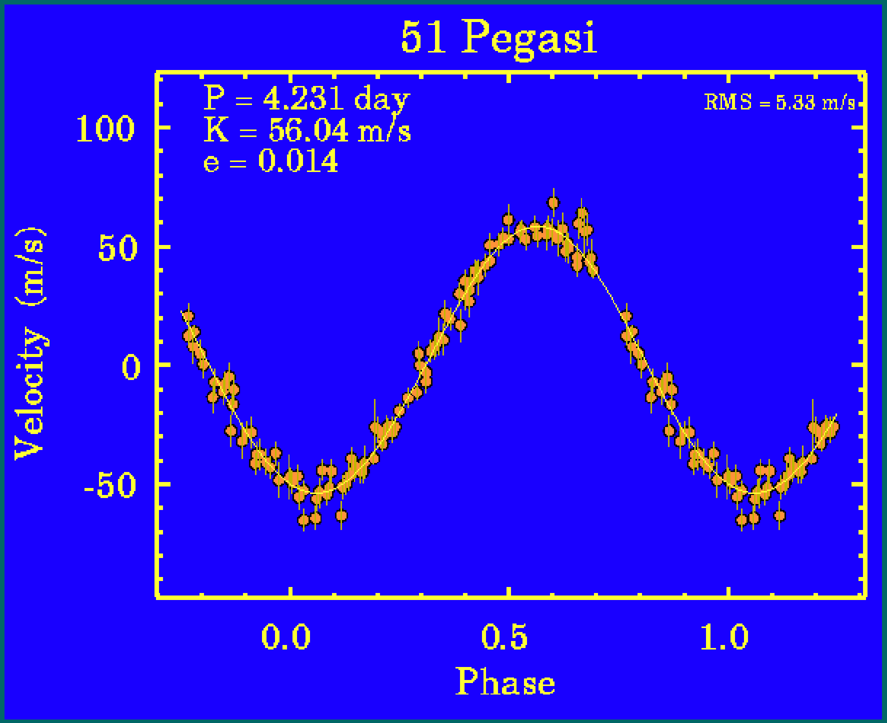
The first astro-ph paper with a word “planet” in its abstract

- Astro-ph/9309052
- MACHO discovery paper by C.Alcock et al.
- **Possible Gravitational Microlensing of a Star in the Large Magellanic Cloud**
  - … A less exotic alternative is normal matter in the form of bodies with masses ranging from that of a large planet to a few M_{sun}…
- ***Needs better criteria to remove false-positives in the analysis of the last page…***
  - A seminal paper, but not a planet paper indeed

51 Pegasi b: the first discovered planet around a main-sequence star

- discovered from the periodic change of the radial velocity of the central star (Mayor & Queloz 1995)

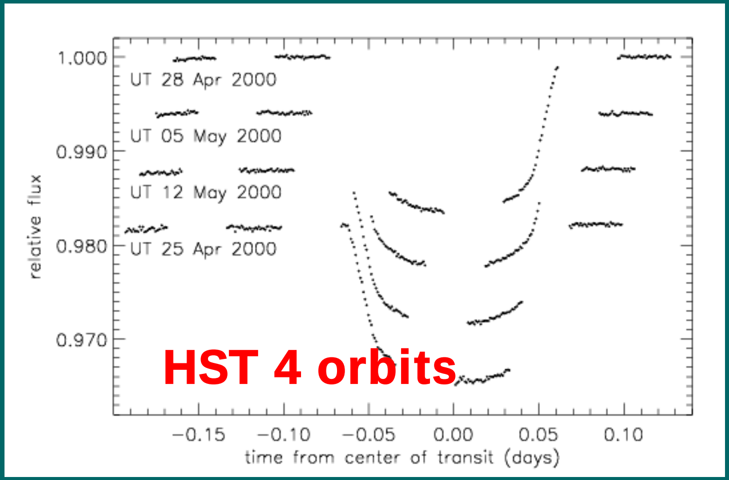


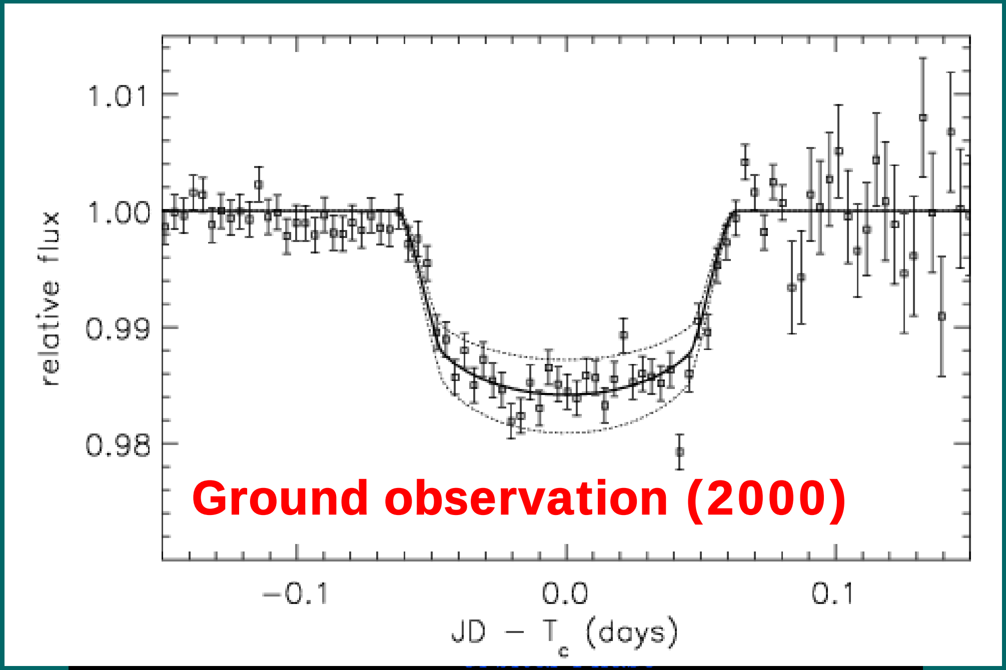


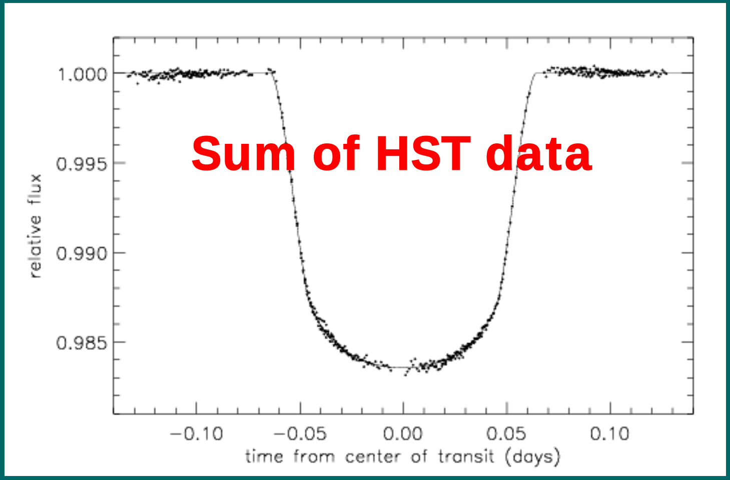
P=4.2 days !

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)



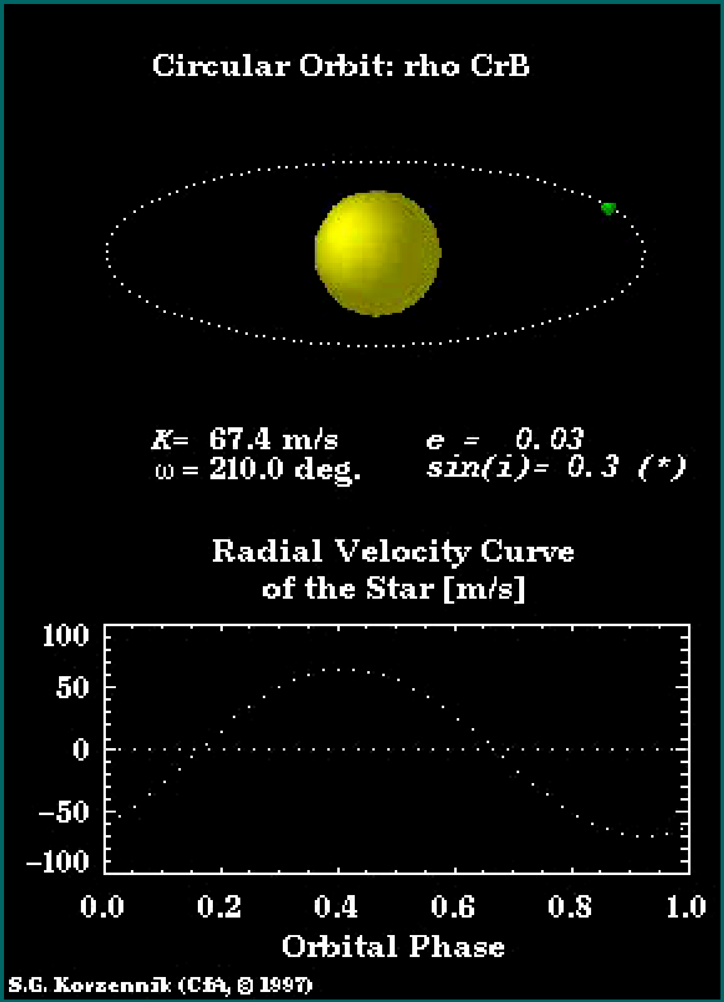




Brown et al. (2001)

Radial velocity of a star perturbed by a planet

Even if a planet is not directly observable, its 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

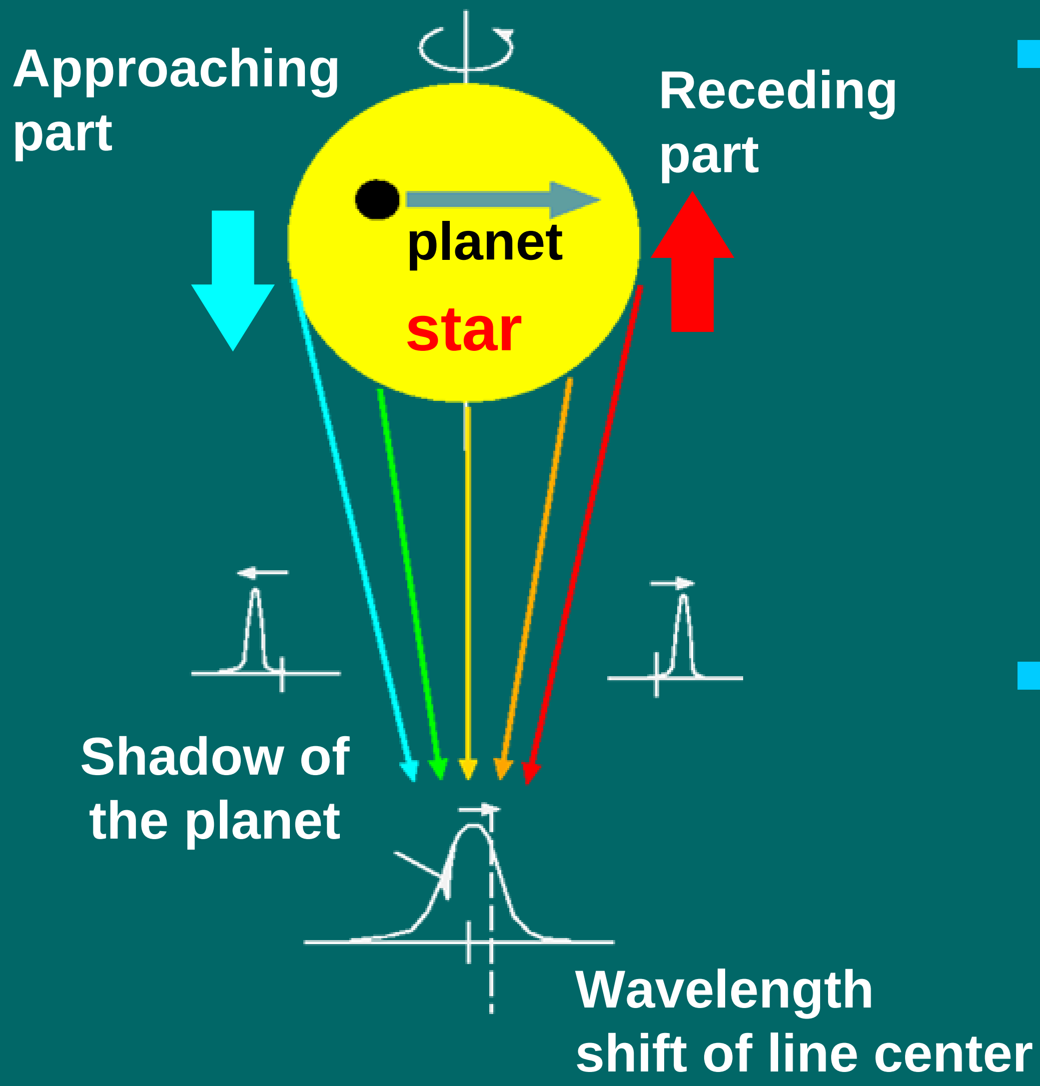
On-going projects at Univ. of Tokyo

- **Search for the planetary atmosphere with Subaru**
  - the most stringent upper limits from ground
  - 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 in press)
- **Search for reflected light from planets**
  - collaboration with Andrew Cameron (St. Andrews Univ.) & Chris Leigh (Liverpool John Moores Univ.)

Measurement of Spin-Orbit Alignment in an Extrasolar Planetary System

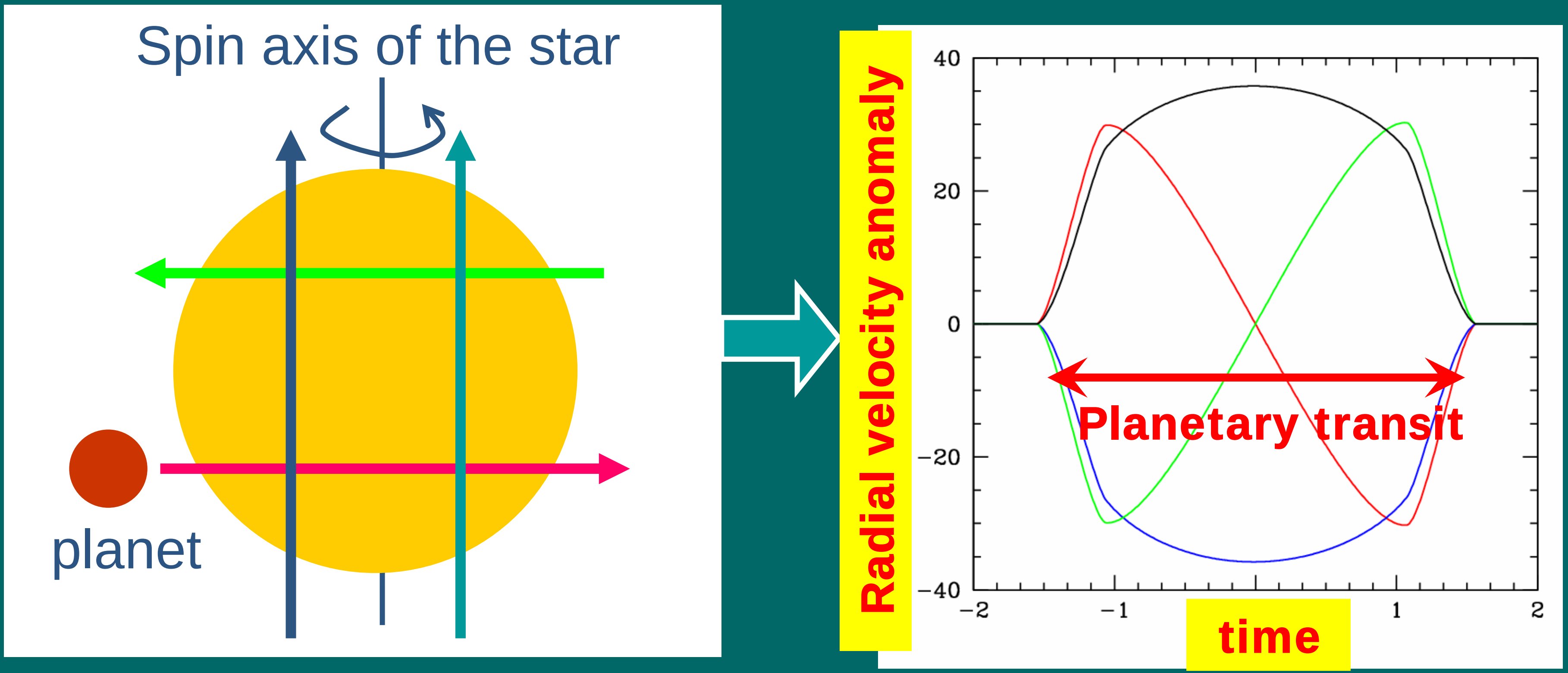
- Joshua N. Winn (CfA→MIT), R.W. Noyes, M.J. Holman, D.B. Charbonneau, Y. Ohta, A. Taruya, Y. Suto, N. Narita, E.L. Turner, J.A. Johnson, G.W. Marcy, R.P. Butler, & S.S. Vogt
- astro-ph/0504555 (ApJ 2005, in press)

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)

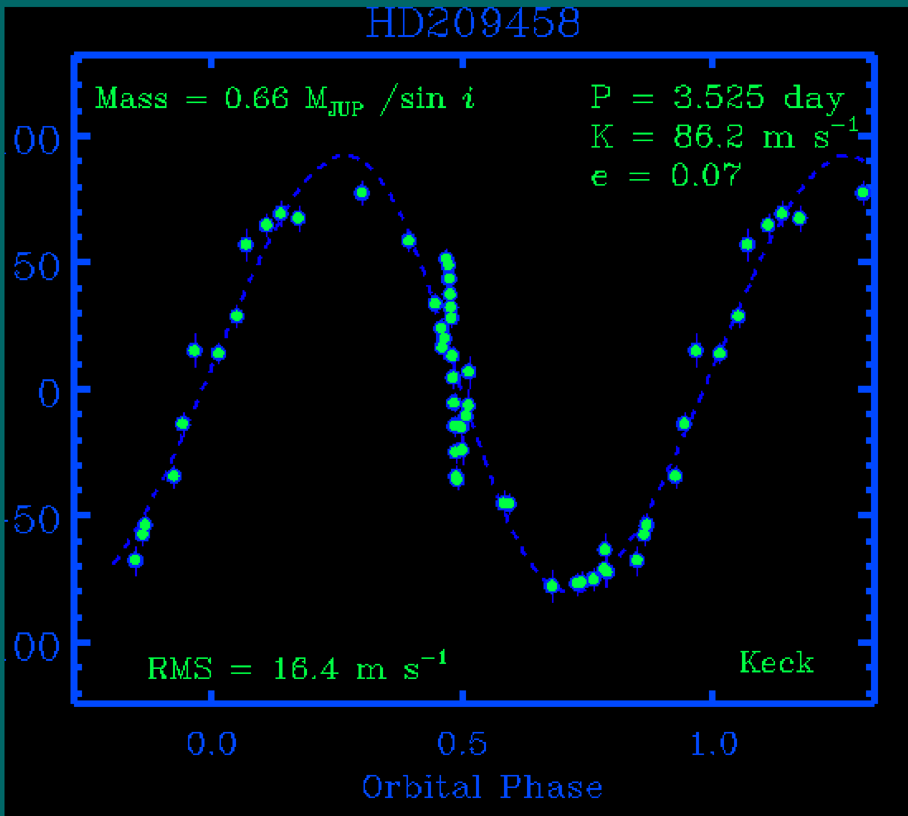
Radial velocity anomaly due to the Rossiter-McLaughlin effect

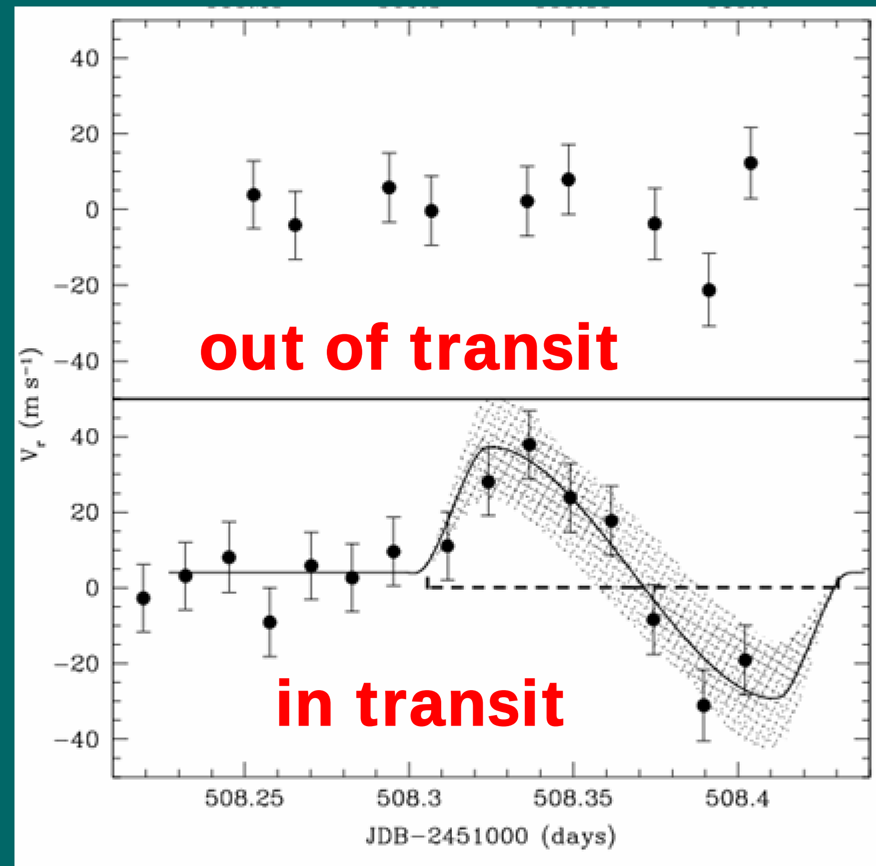


- **Planetary orbital axis with respect to the stellar spin axis**
  - **origin of planets and of the angular momentum**

Previous result of the Rossiter-McLaughlin effect for an extrasolar transit planetary system HD209458

Origin of angular momentum





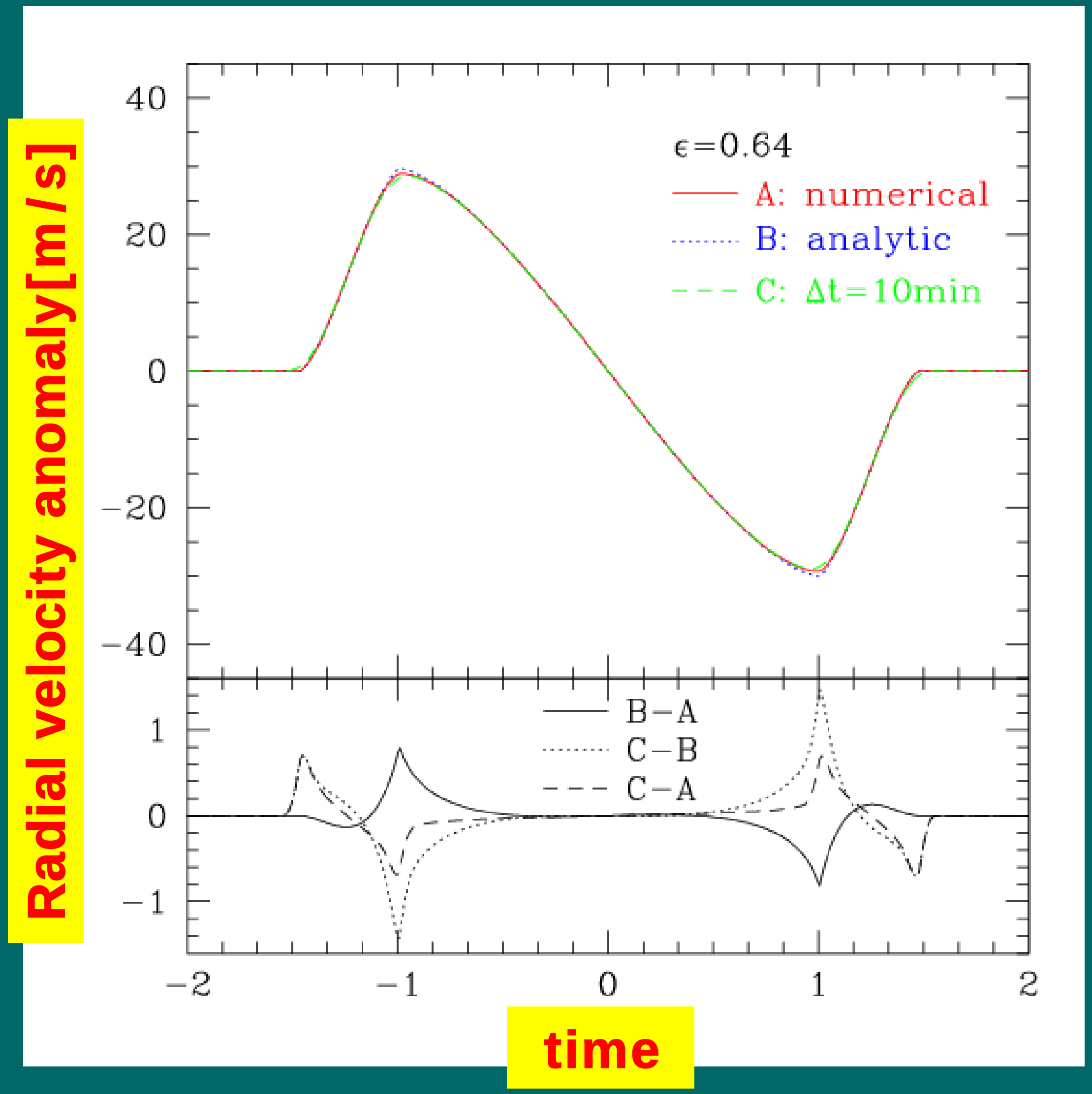
HD209458 radial velocity data
http://exoplanets.org/

Stellar rotation and planetary orbit
Queloz et al. (2000) A&A 359, L13
ELODIE on 193cm telescope

Analytic templates for the velocity anomaly due to the Rossiter -McLaughlin effect

Limb darkening:
$B = 1 - \varepsilon\,(1 - \cos\theta)$

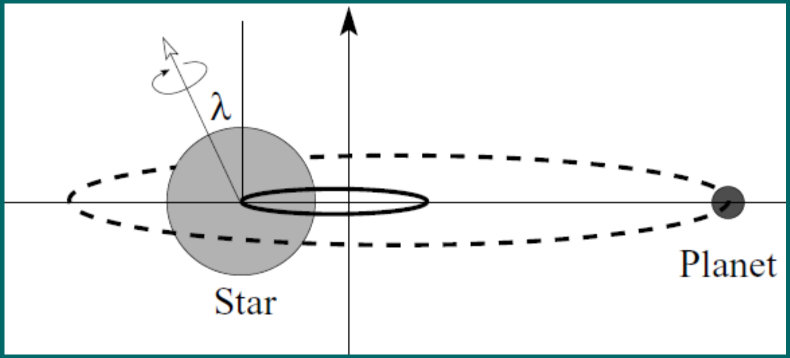
First analytic formula using perturbation theory



Ohta, Taruya & Suto
(ApJ 2005, 622, 1118)

Precision analysis of the Rossiter-McLaughlin effect for HD209458

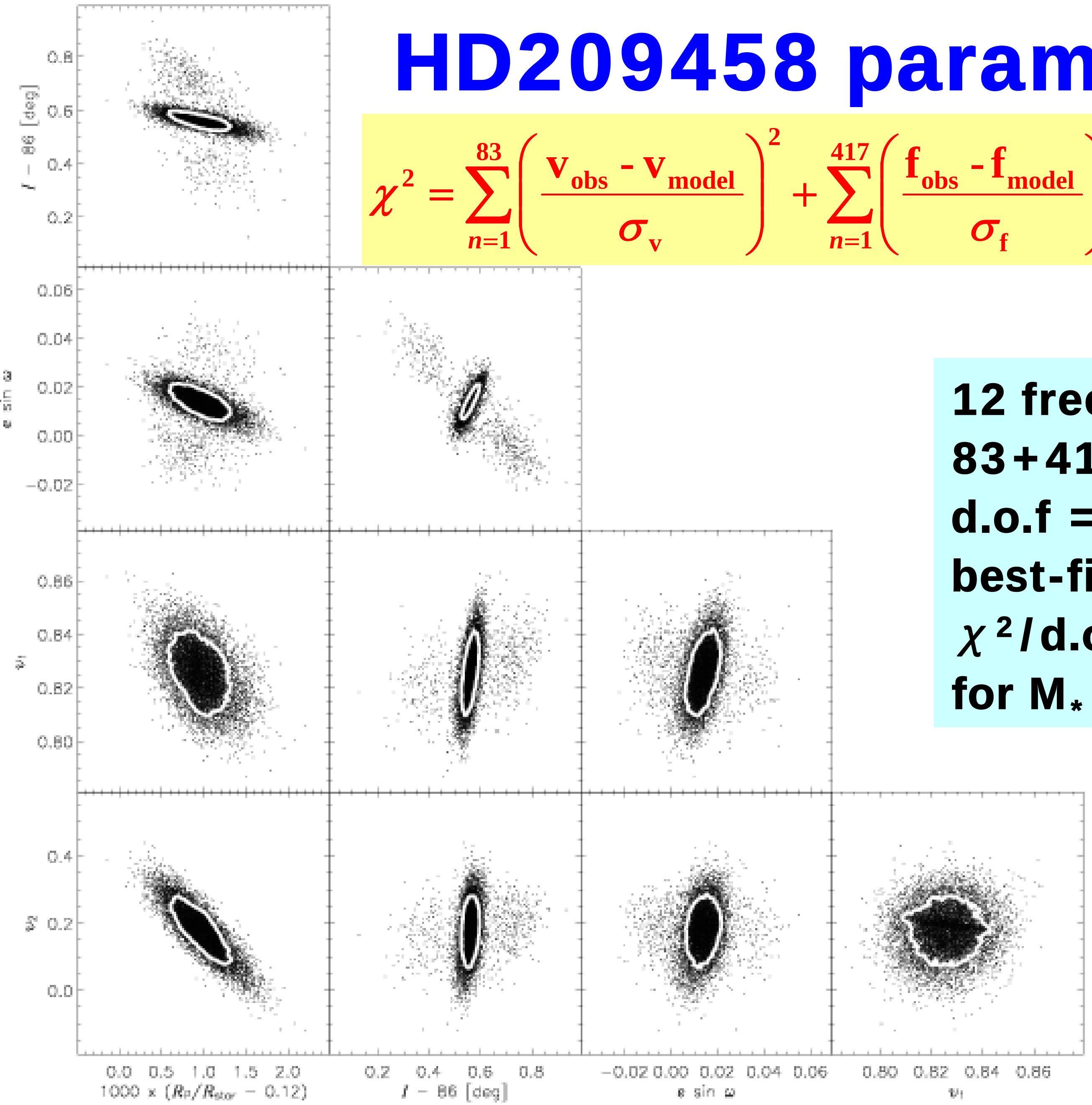
- Ohta et al. (2005) stimulated Josh Winn
- Josh re-examined HD209458 with the best data available
  - radial velocity data (Keck)
  - optical photometry (HST)
  - infrared photometry (Spitzer)



- **the first detection of the misalignment between 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 lovely result !)
  - c.f., 7 degree misalignment for the Solar system
- **$\lambda \neq 0$ problem other than in cosmology !**

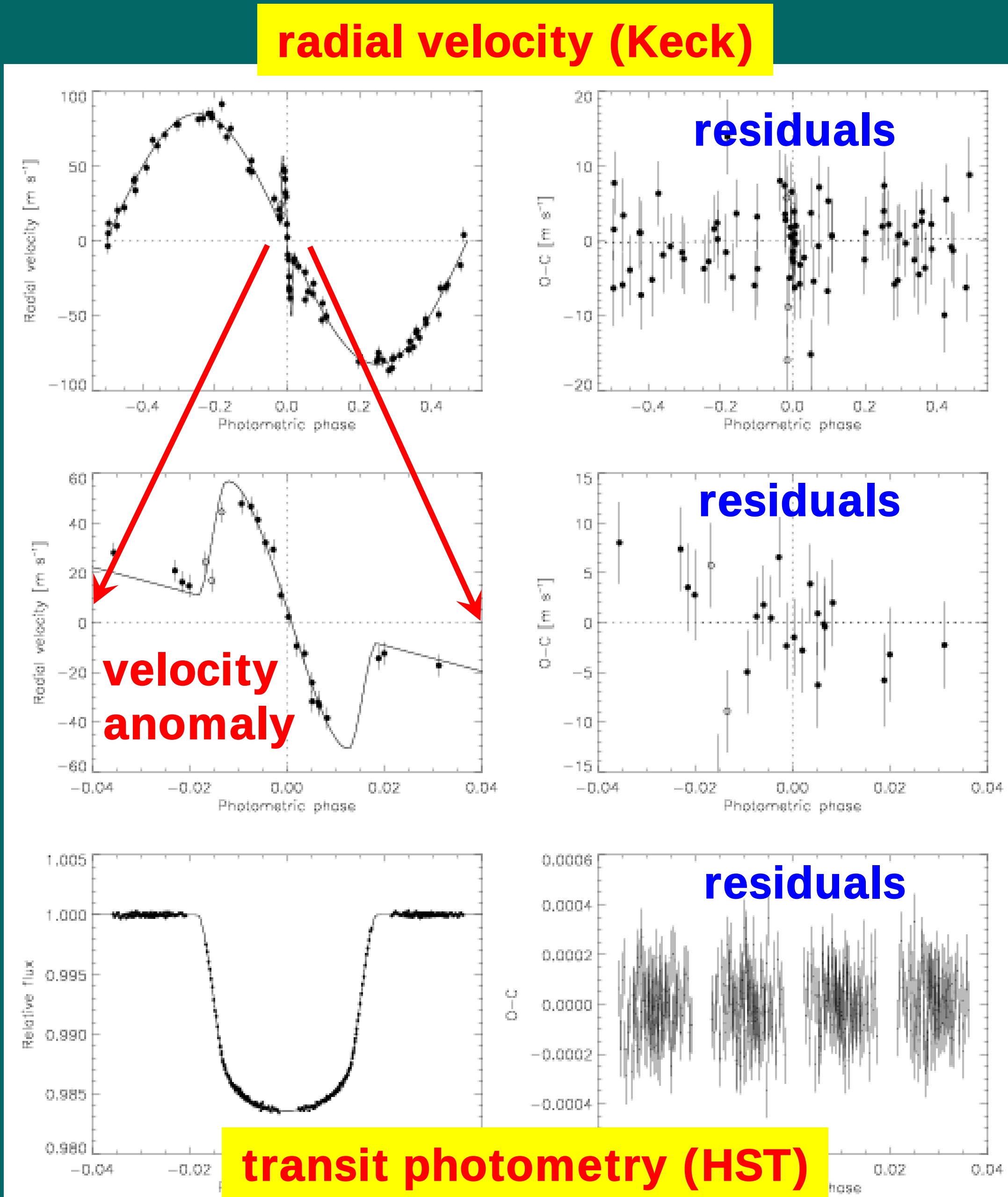
HD209458 parameter fit

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

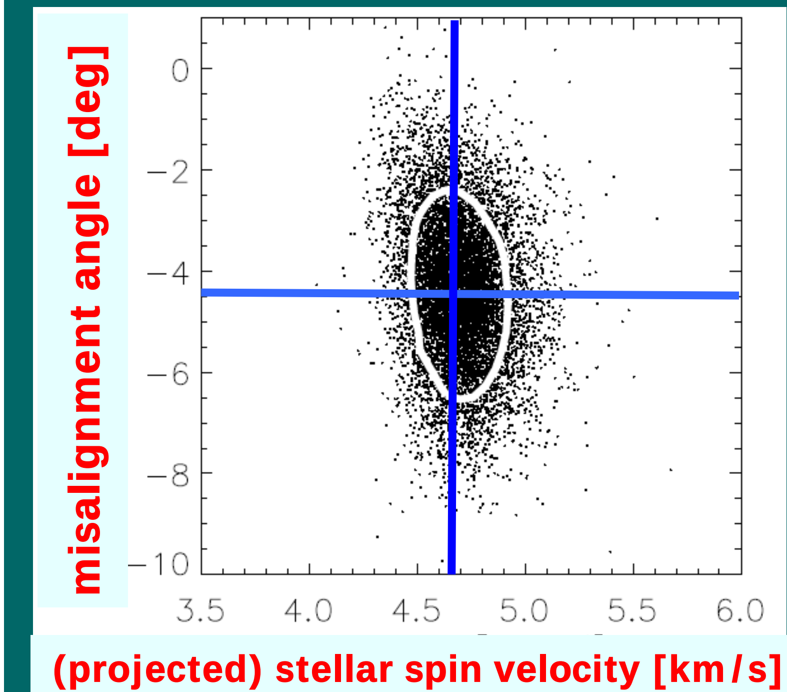


12 free parameters
83+417 data points
d.o.f = 83+417-12=489
best-fit :
χ^2**/d.o.f=528/489=1.08**
for $M_* = 1.06 M_{sun}$

Winn et al.
astro-ph/0504555
ApJ 2005, in press



first detection of non-zero λ !



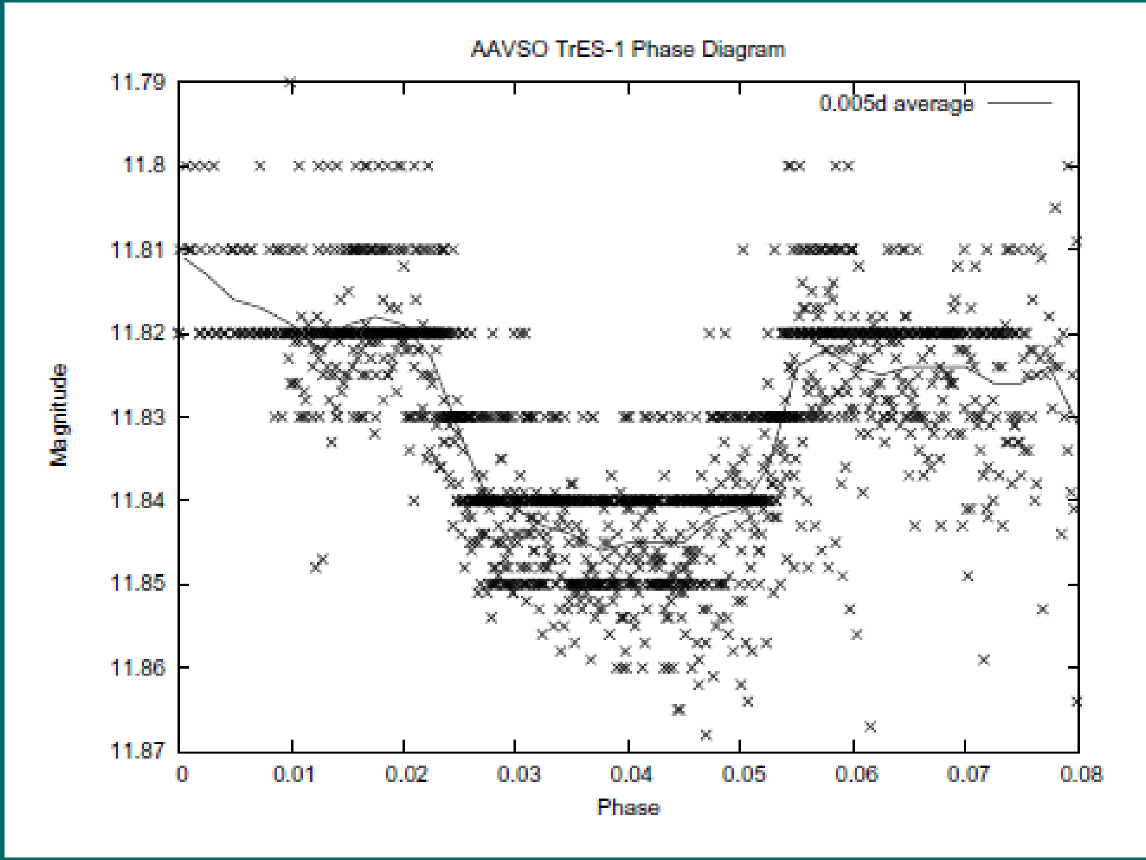
$$\lambda = -4^{\circ}.4 \pm 1^{\circ}.4$$

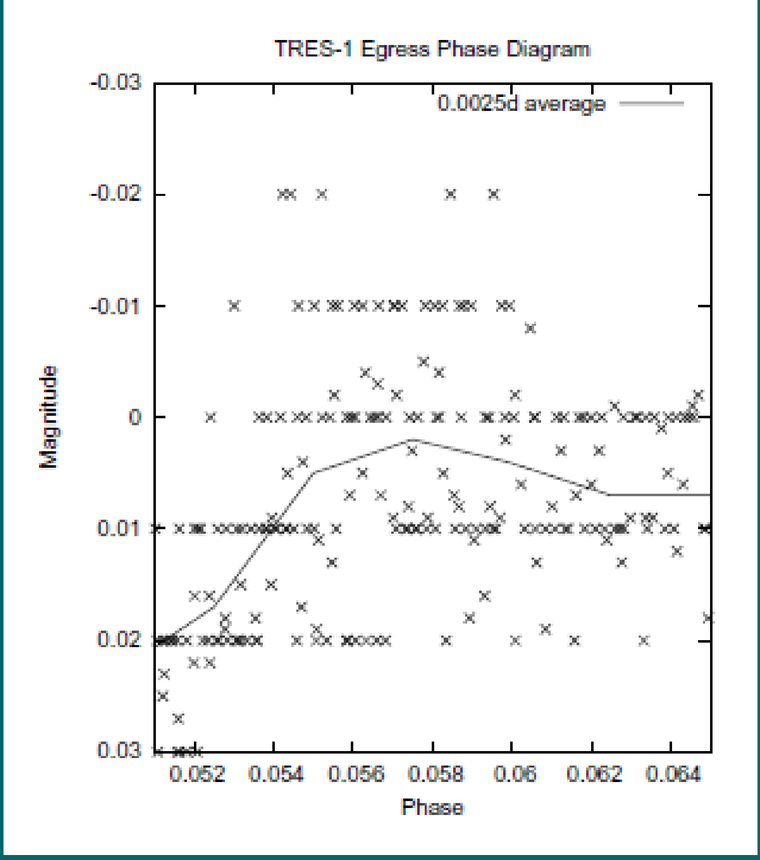
3σ detection !

Winn et al. astro-ph/0504555 ApJ 2005, in press

Another transit planet: TrES-1

- intriguing photometric signatures ? (Bissinger et al. astro-ph/0412463)
- ring around the planet ? (Ohta, Taruya & Suto 2005)
- need more reliable datasets; an interesting target for the JMU Liverpool telescope !





A possible roadmap of sciences of extrasolar planet

- Discovery phase of gas giant planets
- Discovery phase of planetary atmosphere
- Detailed spectroscopic study of planets
- Discovery of terrestrial planets
- ***Identifying Biomarker***
  - Red-edge of extrasolar plant ?
- ***Discovery of Habitable planet***
- ***Discovery of Extraterrestrial life***

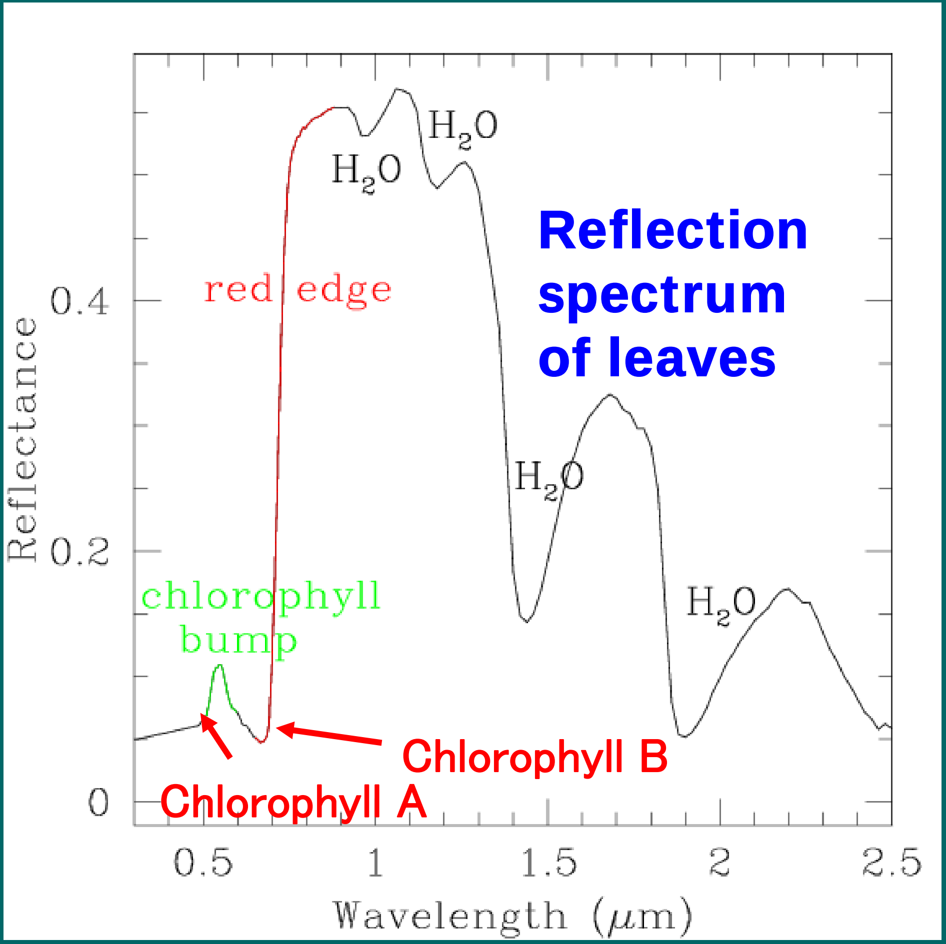
Astrobiology ?   Not yet

- Discovery of extrasolar planets is a wonderful breakthrough in astronomy (and philosophy, maybe)
- But mere discovery has no biological information
- **How can we identify the signature of life ?**
  - **Biomarker**
- Suppose our earth is  located at 10pc away. Can we identify any signature of life from photometric and spectroscopic data alone ?
  - **Earth-shine**

http://modarch.gsfc.nasa.gov/
http://www.nasa.gov/home/index.html

Red edge of *(extrasolar) plants:* a biomarker in *extrasolar planets*

- Significant reflectivity of leaves of terrestrial planets for λ >7000 Å
- An interesting (maybe unique) candidate for a biomarker ?
- ***extrasolar plants*** as a biomarker in *extrasolar planets*



Seager, Ford & Turner astro-ph/0210277

Vesto Melvin Slipher (1875–1969)

Red-edge as a biomarker (at least) in 1924 !

- Discovered redshifts of "spiral nebulae" now known as galaxies
- Essential contribution for Hubble's discovery of expanding universe

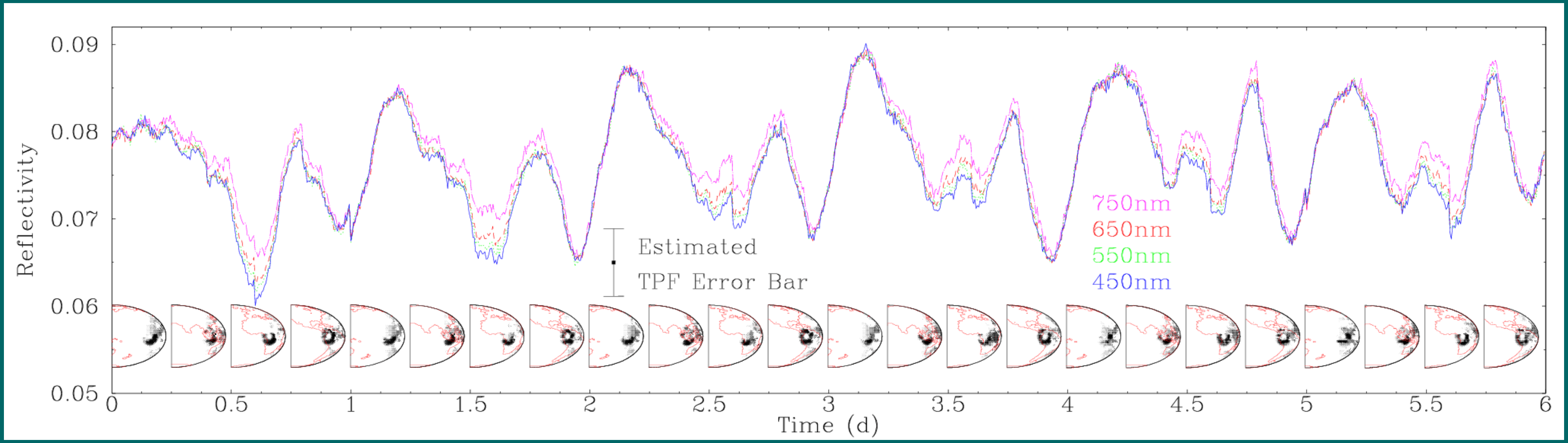
"Observations of Mars in 1924 made at the Lowell Observatory: II spectrum observations of Mars"

PASP 36(1924)261

reflection spectrum. The Martian spectra of the dark regions so far do not give any certain evidence of the typical reflection spectrum of chlorophyl. The amount and types of vegetation required to make the effect noticeable is being investigated by suitable terrestrial exposures.

Astrobiology indeed in 1924 !

Expected daily change of the reflected light from the earth



Ford, Seager & Turner: Nature 412 (2001) 885

- ***Assume*** **that the earth's reflected light is completely separated from the Sun's flux !**
  - **TPF (Terrestrial Planet Finder) in (10～20) years from now ?**
- ***Periodic change of 10％ level*** **due to different reflectivity of land, ocean, forest, and so on**
- **Cloud is the most uncertain factor:** ***weather forecast !***

From astronomy to astrobiology ?

- **We are in the most exciting epoch for extrasolar planet research**
  - **Just like cosmology in 1965 (Penzias and Wilson) or in 1992 (COBE)**
  - **Simply 10-40 years behind ?**
- **What if we discover more than 1000 terrestrial planets in the next decade ?**
  - **Just like cosmology in 2003 (WMAP+others) ?**
- ***How to convince ourselves of the presence of extra-terrestrial life simply from remote observations ?***
  - **Precision extrasolar planet research ?**
  - **Go back to SETI after all ?**
  - **Ultra-precise spectroscopy is the key !**

Thanks

This presentation PDF file is located at
http://www-utap.phys.s.u-tokyo.ac.jp
/~suto/mypresentation_2005e.html