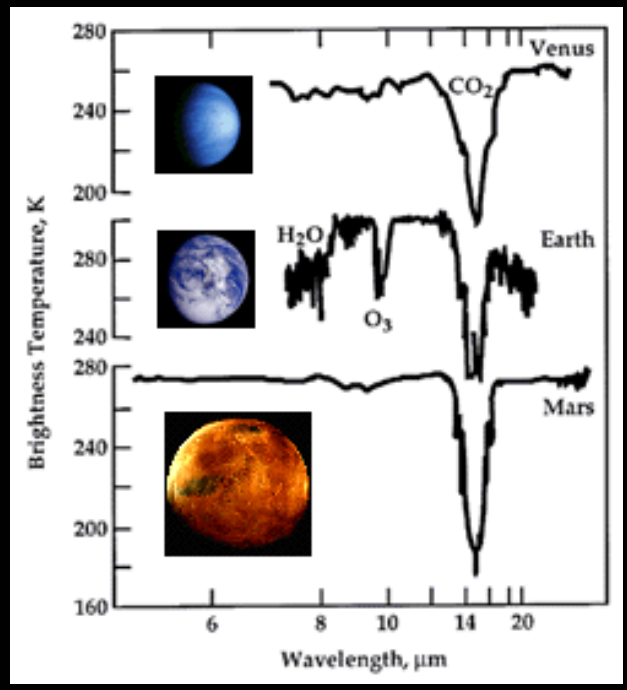
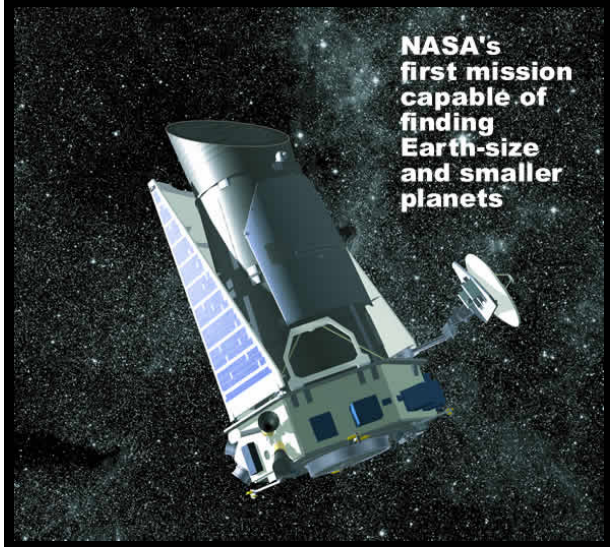
From exoplanets to astrobiology





Yasushi Suto *Department of Physics, the University of Tokyo*

The 2nd Yonsei-Tokyo joint workshop on physics

- high-energy particle and nuclear physics -

Yonsei University, October 30, 2008

YONSEI UNIVERSITY

東京大学 THE UNIVERSITY OF TOKYO

Recent work of Observational Cosmology Group, University of Tokyo (1)

- **Large-scale structure of the universe**
  - constraints on the deviation from Newton's law of gravity from SDSS galaxy power spectrum (Shirata et al. 2005, 2007)
  - prospects to constrain modified gravity models from future surveys (Yamamoto et al. 2006, 2007)
  - bispectrum and nonlinear biasing of galaxies (Nishimichi et al. 2007)
  - precise modeling of baryon acoustic oscillations for dark energy survey (Nishimichi et al. 2007,2008)
  - Galactic dust map against SDSS galaxy surface density (Yahata et al. 2007)

Recent work of Observational Cosmology Group, University of Tokyo (2)

- **Dark halos and galaxy clusters**
  - triaxial modeling of dark matter halos (Jing & Suto 2002; Oguri, Lee & Suto 2003; Lee, Jing & Suto 2005)
  - log-normal model for intra-cluster gas fluctuations and its impact on X-ray and SZ observations (Kawahara et al. 2006, 2007,2008)
- **WHIM:Warm/hot intergalactic medium**
  - proposing oxygen emission line survey with a dedicated satellite (Yoshikawa et al. 2003, 2004)
  - feasibility of an absorption line search with XEUS along bright quasars and GRB afterglow (Kawahara et al. 2006)

Recent work of Observational Cosmology Group, University of Tokyo (3)

- **Spectroscopy of transiting extrasolar planets**
  - constraints on planetary atmosphere
    (Winn et al. 2004; Narita et al. 2005)
  - detection of the spin-orbit (mis)alignment via the Rossiter effect
    (Ohta, Taruya & Suto 2005, 2009; Winn et al. 2005, 2006, 2007; Narita et al. 2007)
  - feasibility study to detect vegetation/plant signatures on exoplanets
    (Fujii et al. in preparation)

A brief history of extrasolar planets

- **1995 :** the first extrasolar planet around the main sequence star 51 Pegasi
- **1999 :** the first transit planet around HD209458
- **2001 :** the first detection of atmosphere of HD209458b
- **2005:** the first detection of the spin-orbit misalignment via the Rossiter effect
- **2007:** habitable super-Earth ? (Udry et al.)
- ***>300 extrasolar planets* are reported (October 2008)**

http://exoplanets.org/

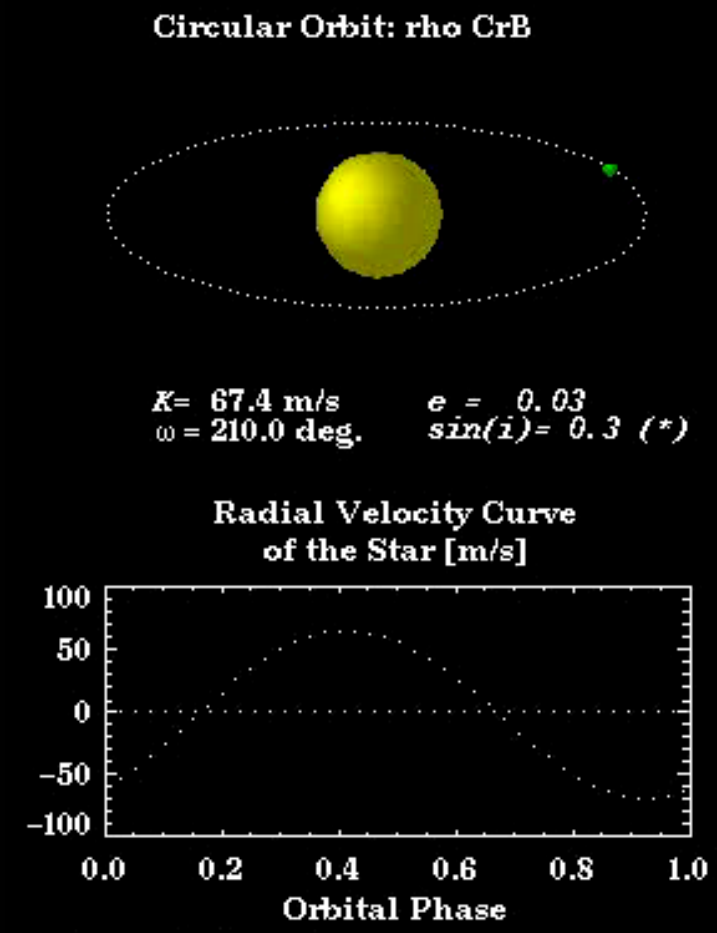
Search for extrasolar planets

- the ***final*** goal: ***Are we alone ?***
  - origin of the earth
  - origin of the Solar System
  - ***habitable*** planets ⇒ origin of life
  - signature of *extra-terrestrial life* ?
  - ***extra-terrestrial intelligence ?***

"Where are they ?" E.Fermi (1950)

Radial velocity of a star perturbed by a planet

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

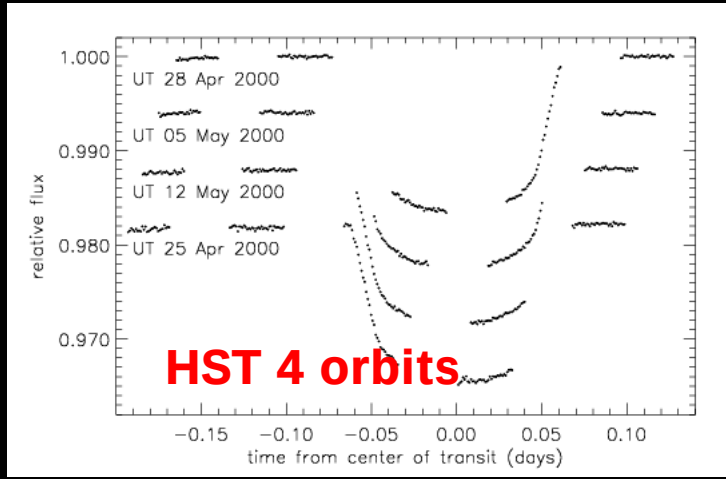


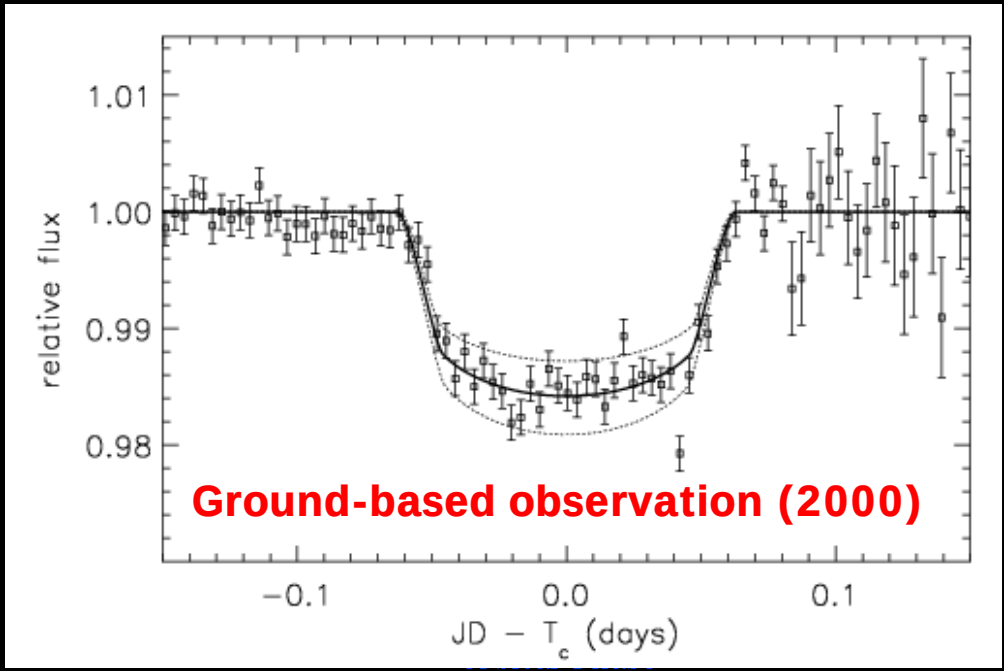
- velocity modulation of the Sun:
  - 12.5 m/s（Jupiter）
  - 0.1 m/s（Earth）
- an accuracy of 0.3m/s now achieved from the ground observation

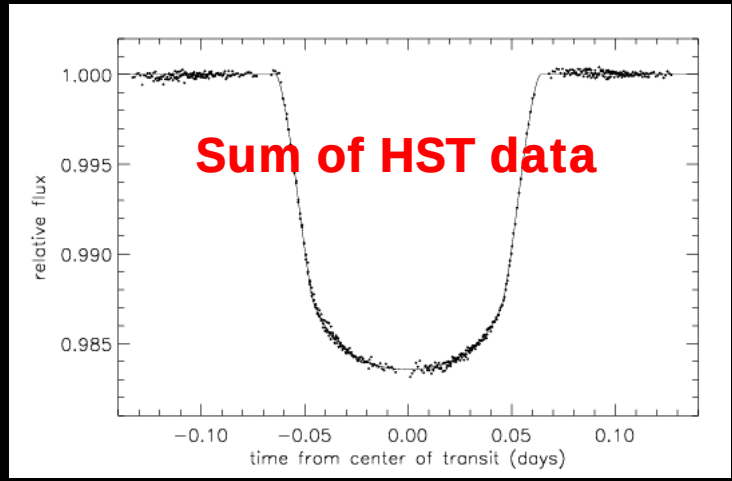
⇒ the major method of (Jovian) planet search

the first discovery of a transiting planet: HD209458

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





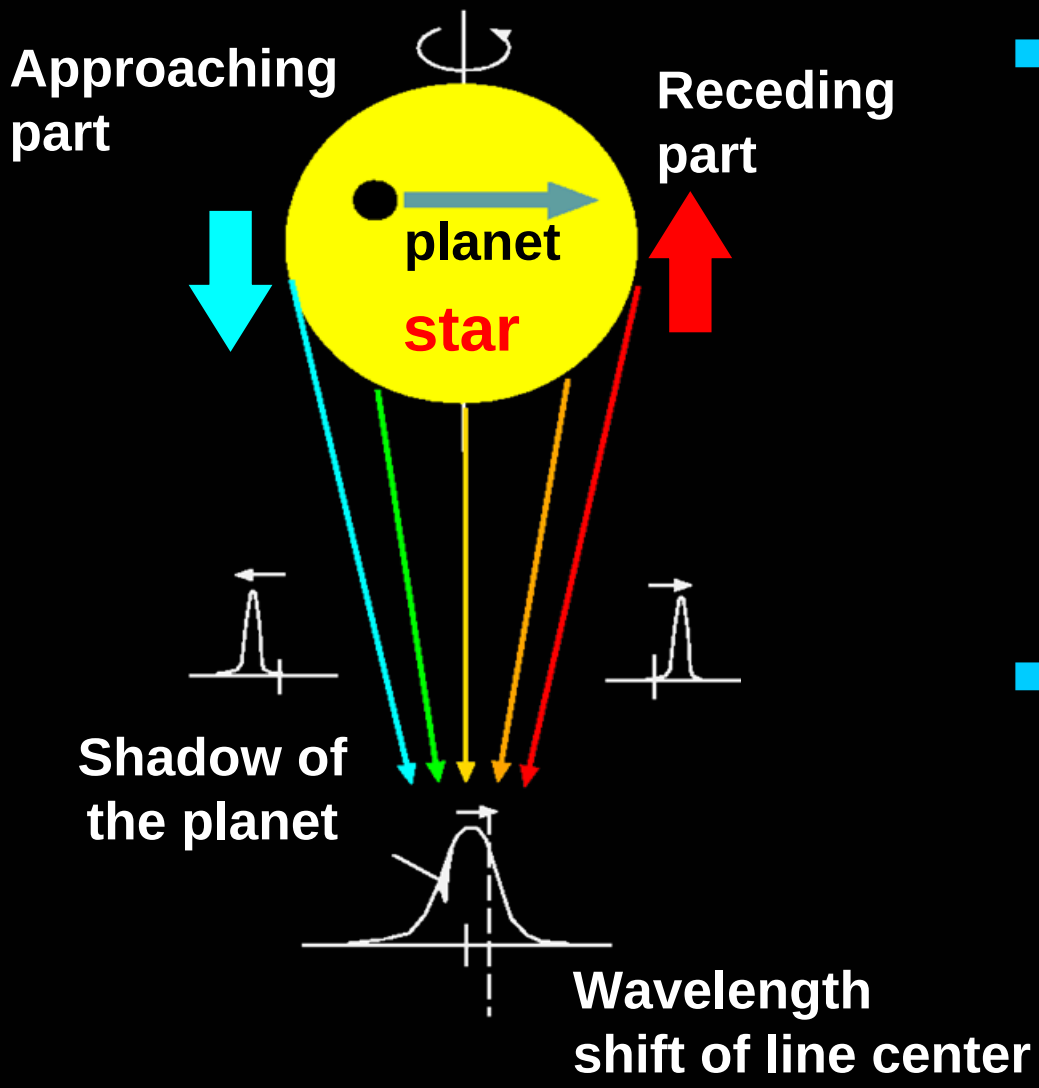


Brown et al. (2001)

exoplanet projects at Univ. of Tokyo

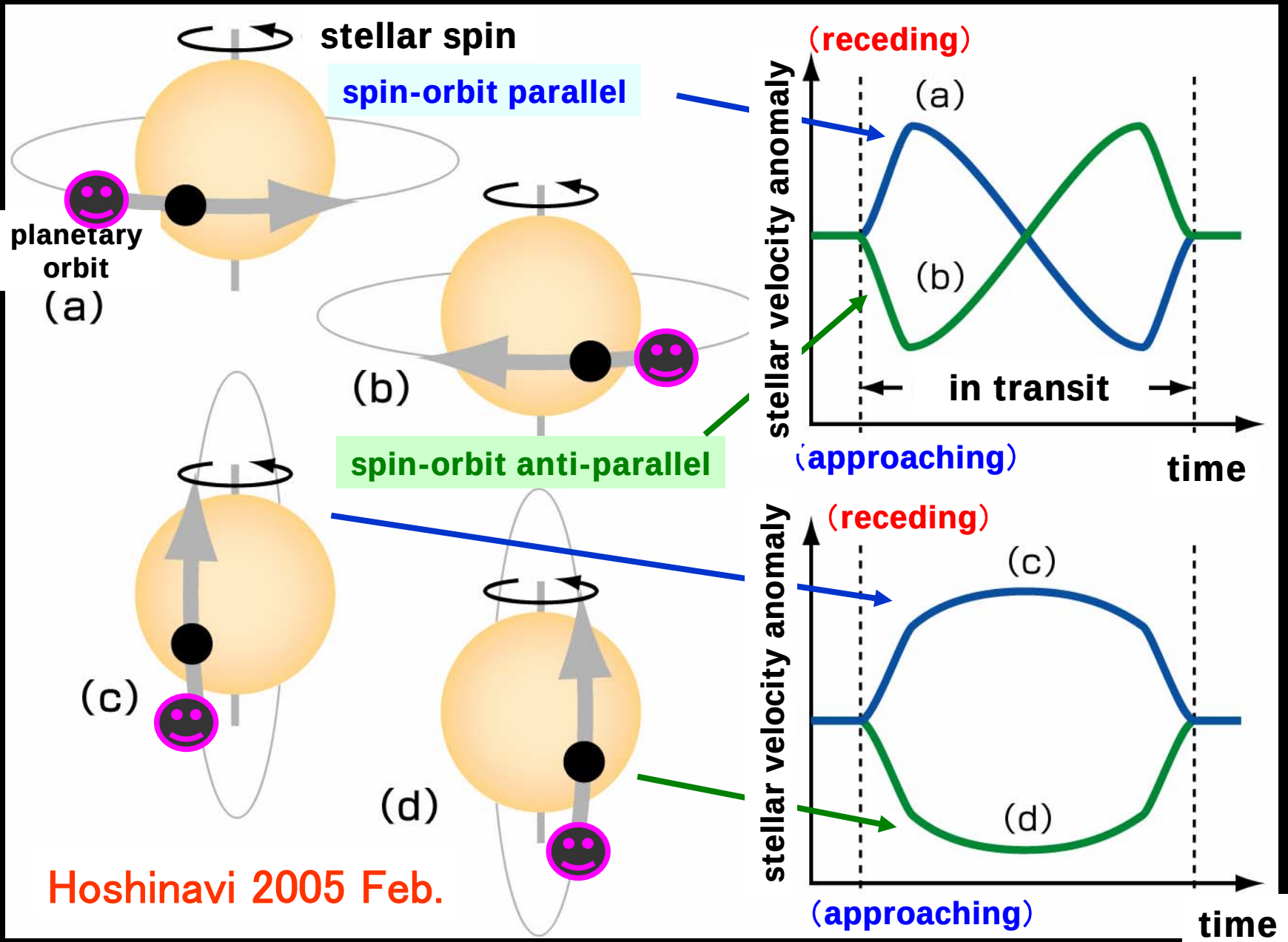
- **Search for the planetary atmosphere with Subaru**
  - the most stringent upper limits from ground-based obs.
  - Winn et al. PASJ 56(2004) 655 (astro-ph/0404469)
  - Narita et al. PASJ 57(2005) 471 (astro-ph/0504450)
- **Constraining the stellar spin and the planetary orbital axes from the Rossiter-McLaughlin effect**
  - New analytic formulae (Ohta et al. 2005, ApJ, 622, 1118)
  - First detection (Winn et al. 2005 ApJ, 631, 1215)
  - application to ring detection (Ohta et al. ApJ 2009, in press)
- **Search for reflected light from planets**
  - collaboration with Chris Leigh (Liverpool John Moores Univ.), E. Turner (Princeton Univ.)
- **Identification of red-edge of exoplants as a biomaker**
  - simulated photometry and spectroscopy for future (Fujii et al. in prep); a step toward astrobiology

Spectroscopic transit signature: the Rossiter-McLaughlin effect



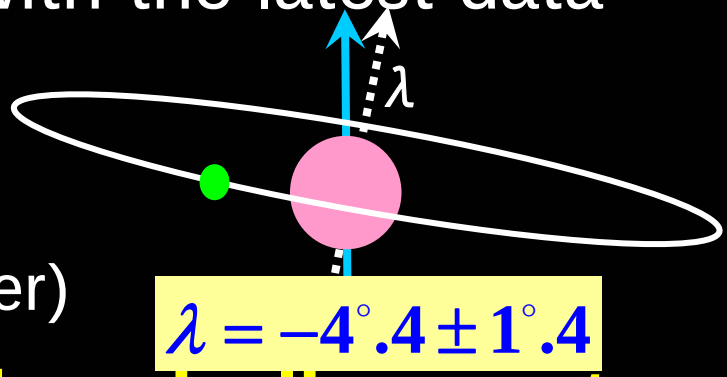
- Time-dependent asymmetry in the stellar Doppler broadened line profile
  - an apparent anomaly of the stellar radial velocity
- originally discussed in eclipsing binary systems
  - Rossiter (1924)
  - McLaughlin (1924)

Velocity anomaly due to the Rossiter effect



Precision analysis of the Rossiter-McLaughlin effect for HD209458

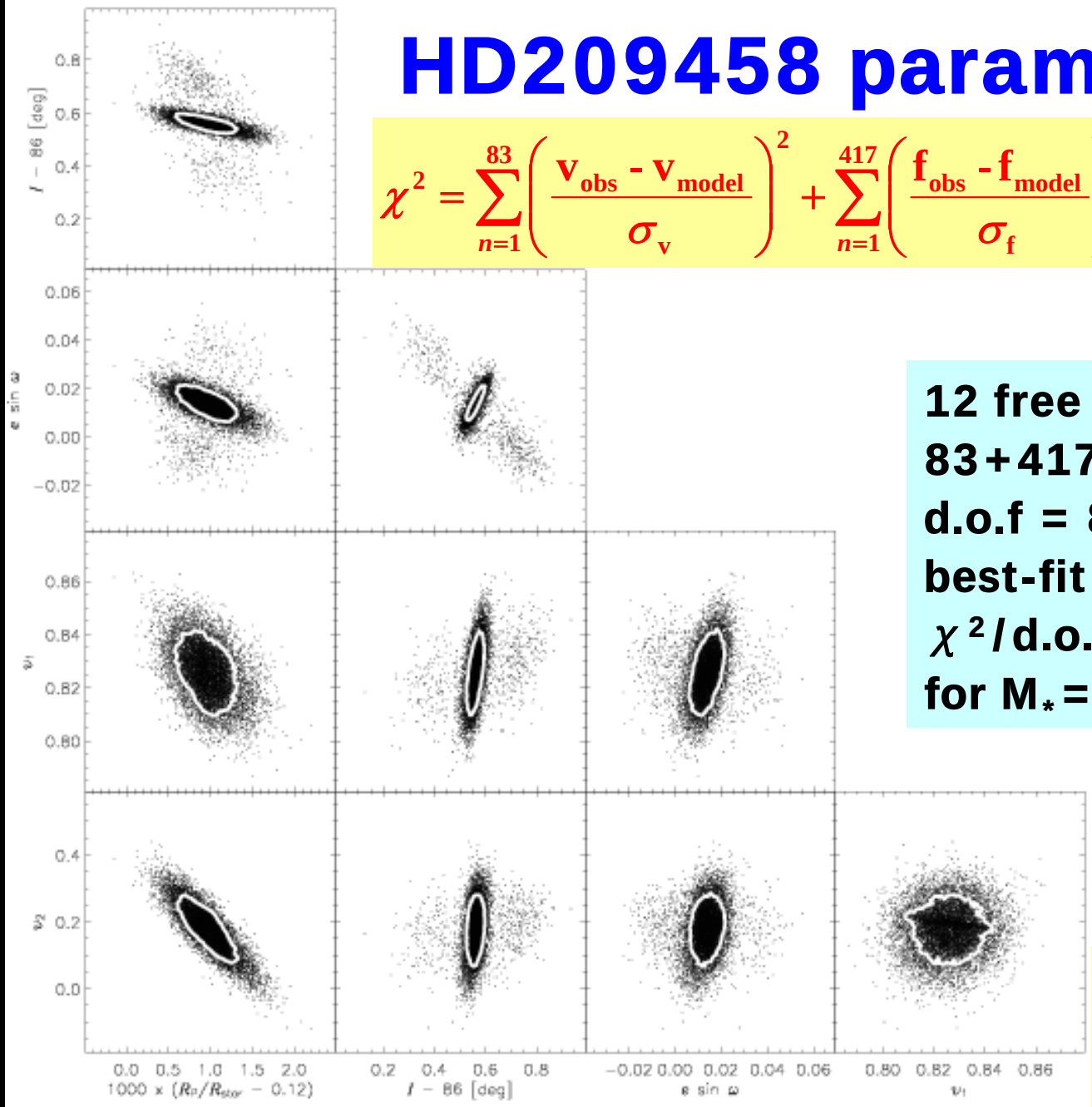
- perturbation formula by Ohta et al. (2005)
- HD209458 re-examined with the latest data
  - radial velocity data (Keck)
  - optical photometry (HST)
  - infrared photometry (Spitzer)



- **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

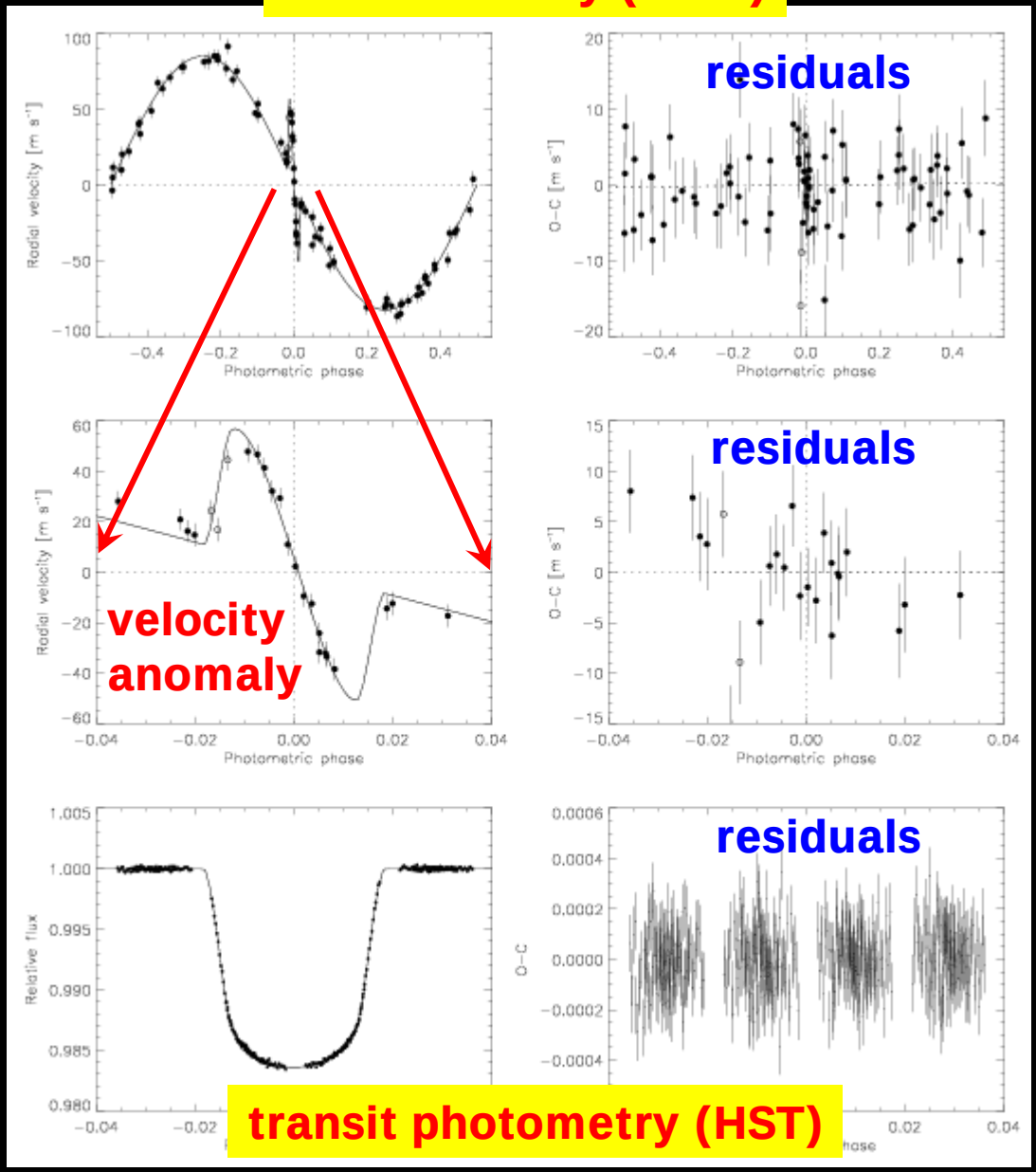
$$\chi^2 = \sum_{n=1}^{83}\left(\frac{v_{obs} - v_{model}}{\sigma_v}\right)^2 + \sum_{n=1}^{417}\left(\frac{f_{obs} - f_{model}}{\sigma_f}\right)^2 + \left(\frac{t_{2nd,obs} - t_{2nd,model}}{\sigma_t}\right)^2$$



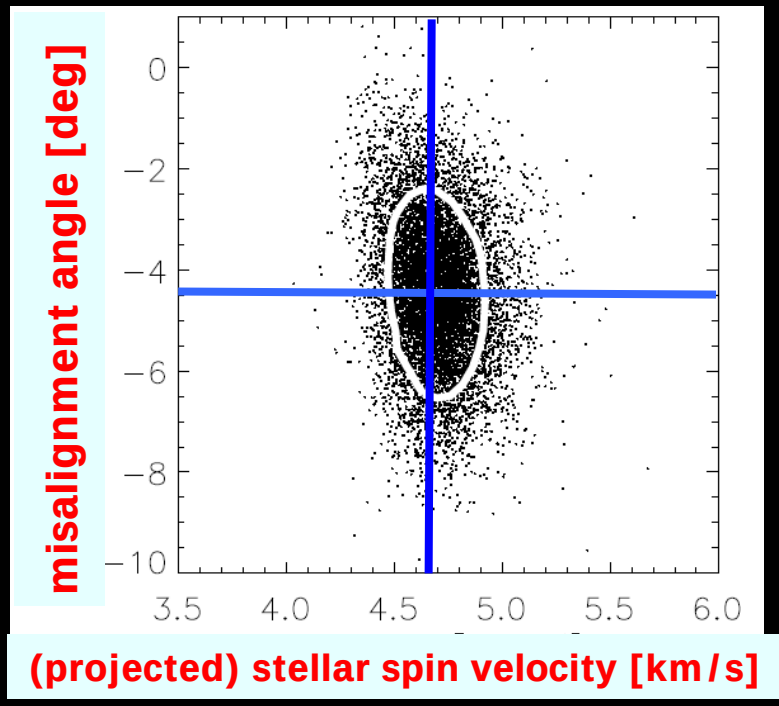
12 free parameters
83+417+1 data points
d.o.f = 83+417+1-12=489
best-fit :
χ^2/d.o.f=528/489=1.08
for $M_* = 1.06 M_{sun}$

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

radial velocity (Keck)



first detection of small misalignment !

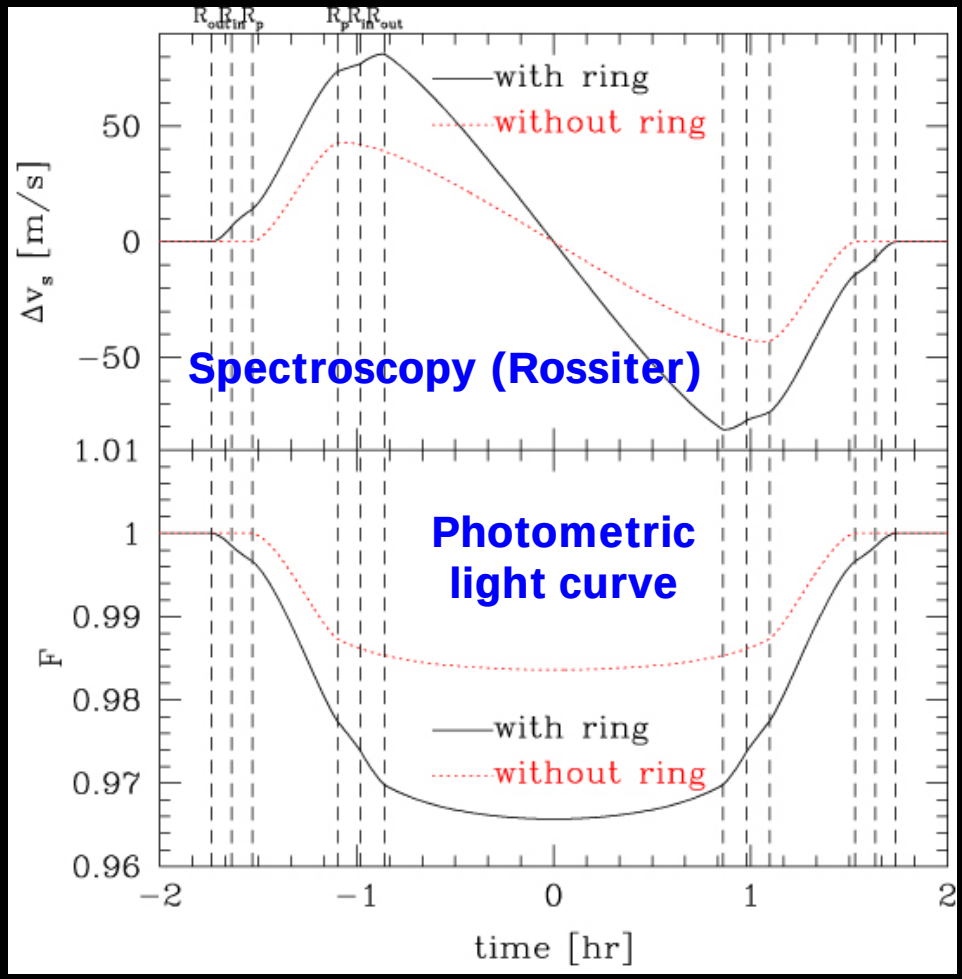


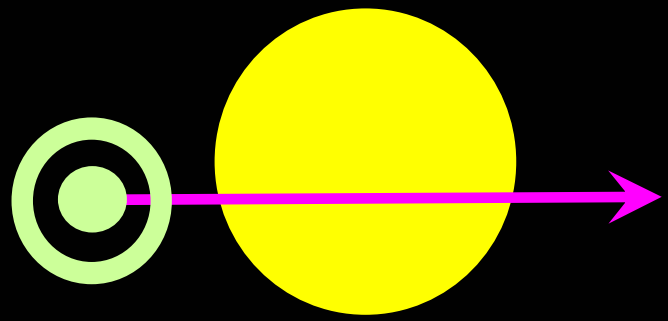
$$\lambda = -4^{\circ}.4 \pm 1^{\circ}.4$$

3 σ detection !

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

Signatures of planetary rings





- 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

Ohta, Taruya & YS: astro-ph/0611466
ApJ, in press

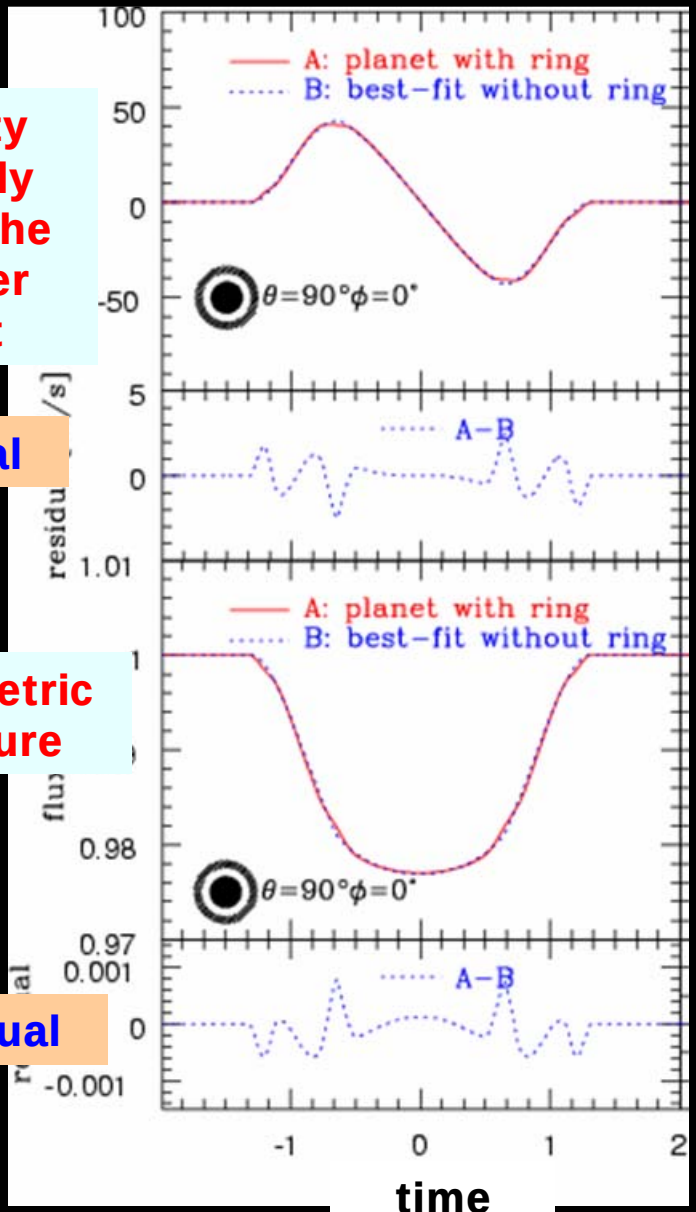
Detectability of a ring via anomaly

Velocity anomaly due to the Rossiter effect

residual

Photometric signature

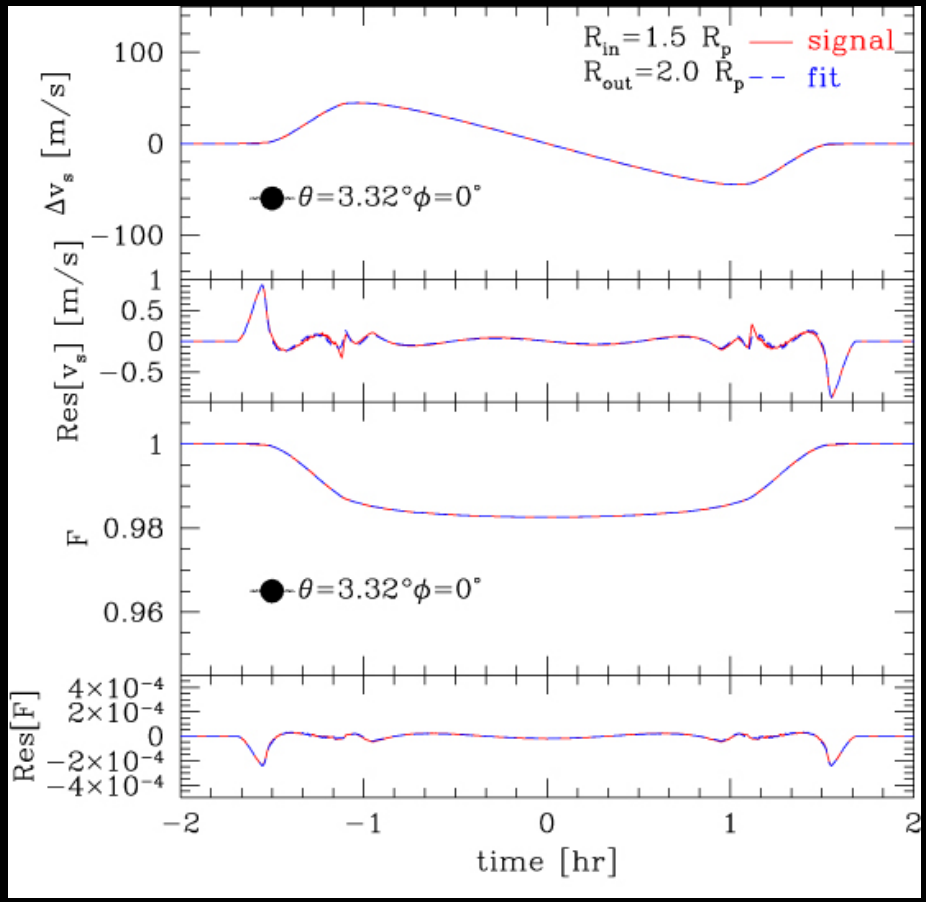
residual

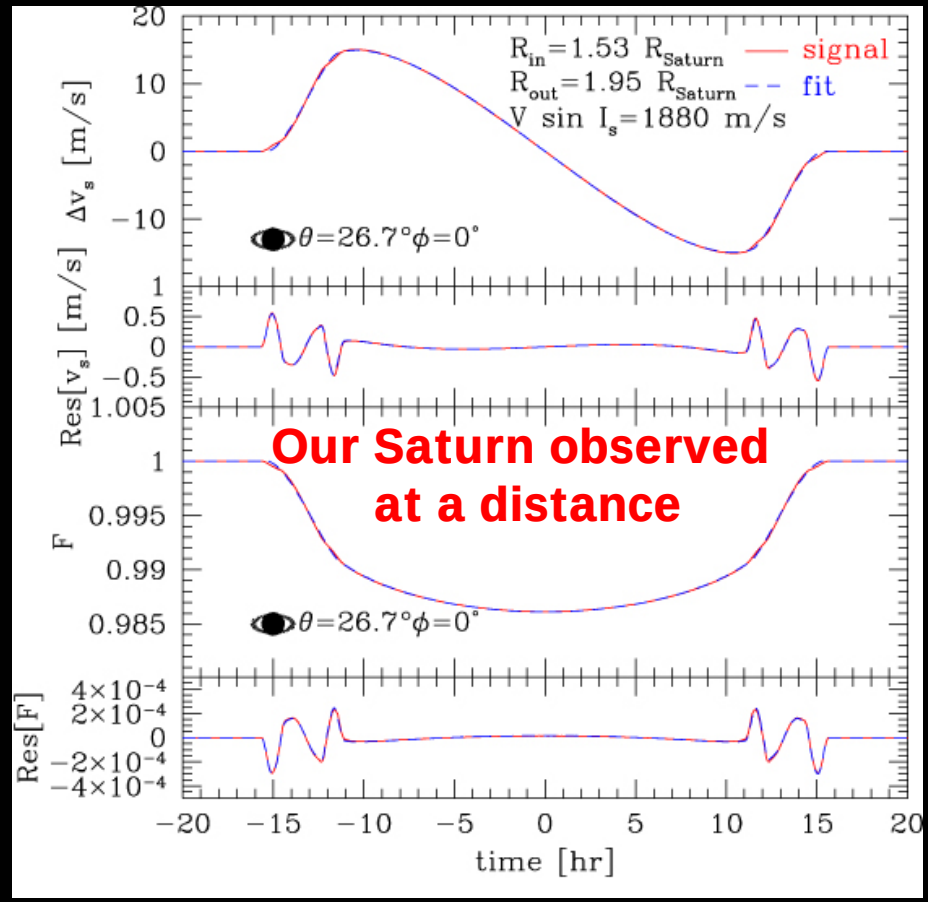


- a hypothetical ring around HD209458
  - $1.5R_{pl} < R_{ring} < 2R_{pl}$
  - deviation from a best-fit single planet
  - $\delta v \sim 1 m/s$
  - $\delta F/F \sim 0.1\%$
- marginally detectable level even with the current technology

Ohta, Taruya & YS: astro-ph/0611466, ApJ in press

How about hot Jupiter and Saturn rings ?





Ohta, Taruya & YS: astro-ph/0611466, ApJ in press

- **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)**

A possible roadmap of sciences of extrasolar planets

- Discovery phase of gas giant planets (1995-)
- Discovery of planetary atmosphere (2002)
- Detailed spectroscopic study of planets
- Discovery of IR emission of planets (2005)

- Discovery of visible reflection light
- Discovery of planetary ring
- Discovery of extrasolar planetary satellite
- Discovery of terrestrial planets

- ***Discovery of habitable terrestrial planet***
- ***Identifying biomarker***
  - Red-edge of extrasolar plant ?
- ***Discovery of extraterrestrial life***

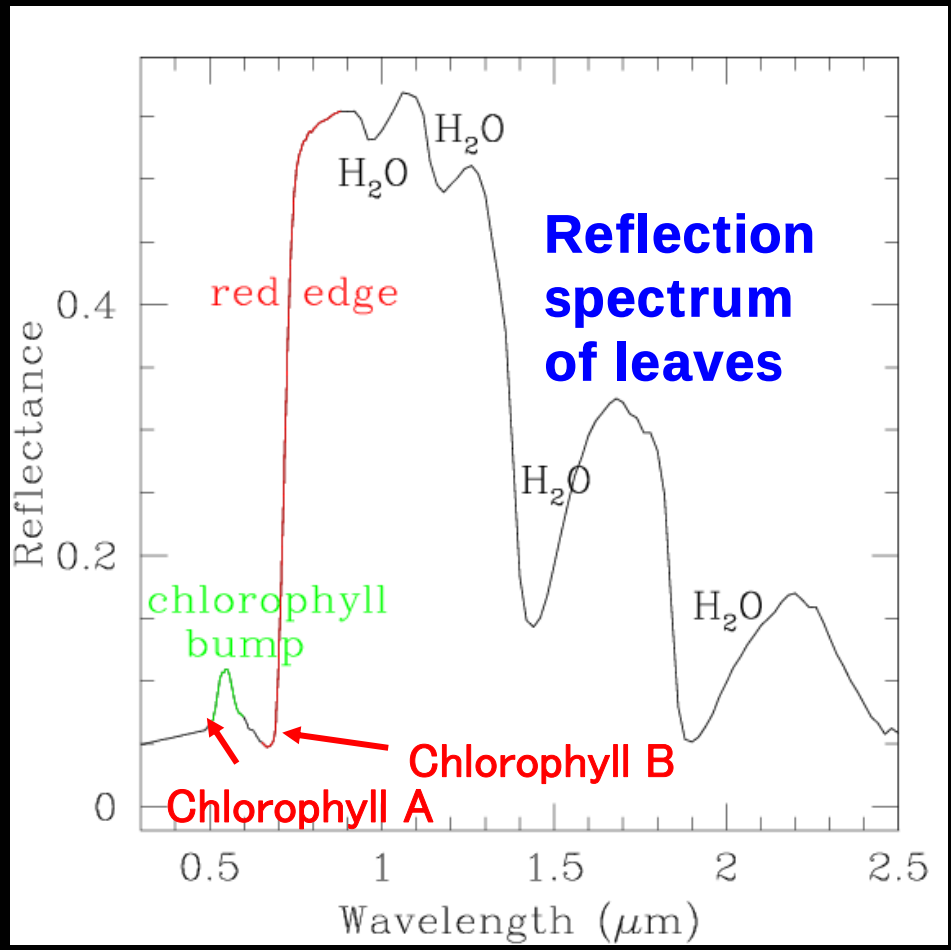
Astrobiology ? Not yet

- Discovery of extrasolar planets is a wonderful breakthrough in astronomy (and philosophy)
- 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 ?

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

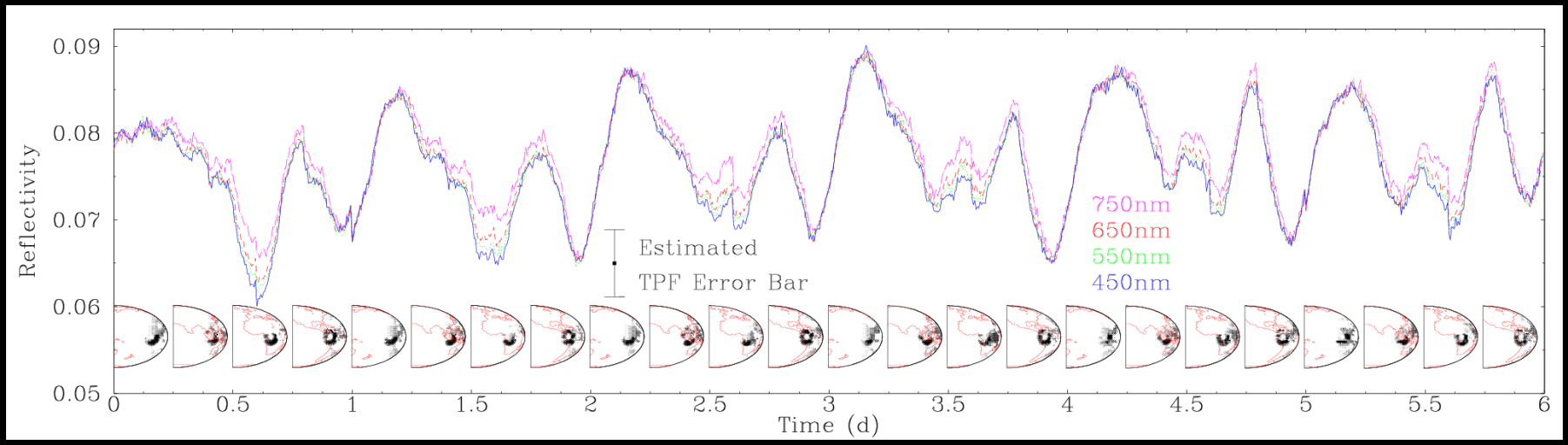
Red edge of *(extrasolar) plants:* a biomarker in *extrasolar planets*

- Significant reflectivity of leaves of terrestrial planets for $\lambda > 7500$ Å
- An interesting (maybe unique) candidate for a biomarker ?
- ***extrasolar plants*** as a biomarker in *extrasolar planets*



Seager, Ford & Turner
astro-ph/0210277

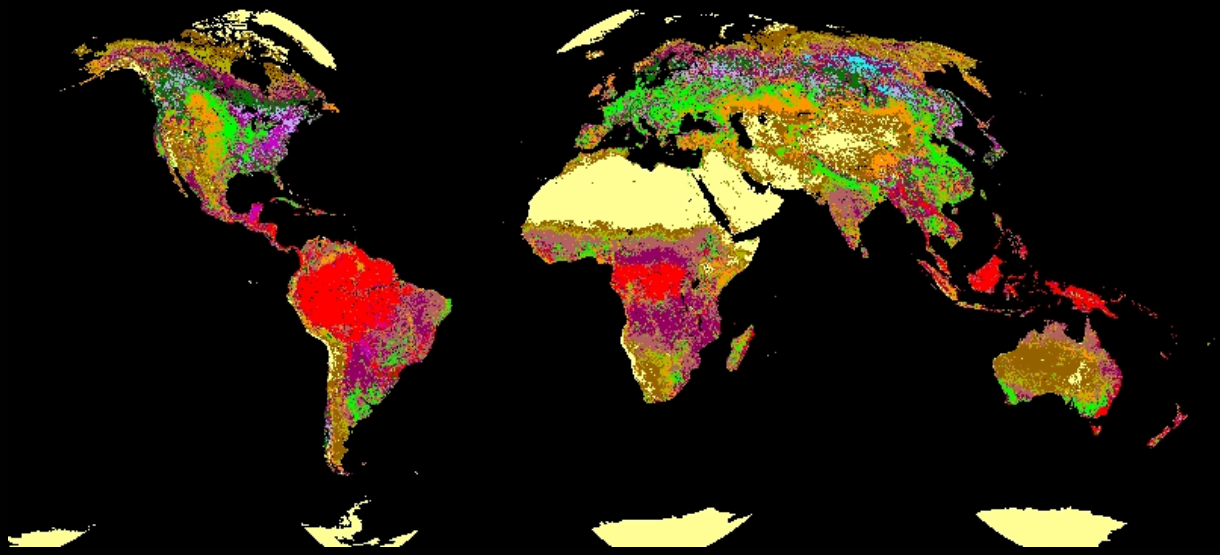
Expected daily change of the reflected light from the earth



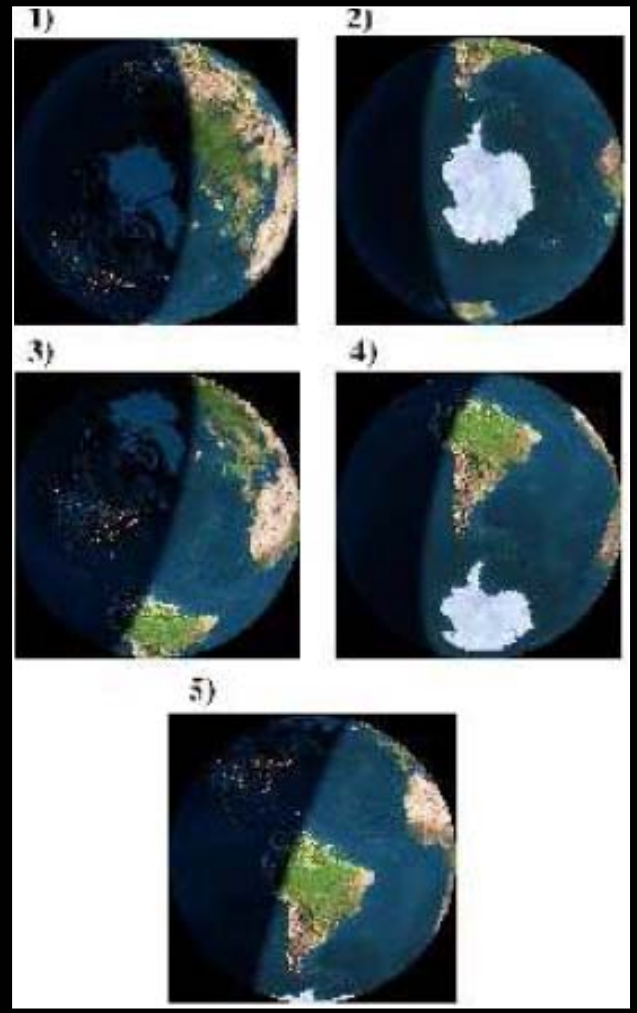
Ford, Seager & Turner: Nature 412 (2001) 885

- ***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 !***

feasibility of identifying rotation period of extrasolar Earth-like planets from photometric observation



mock photometric data from real observations of Earth

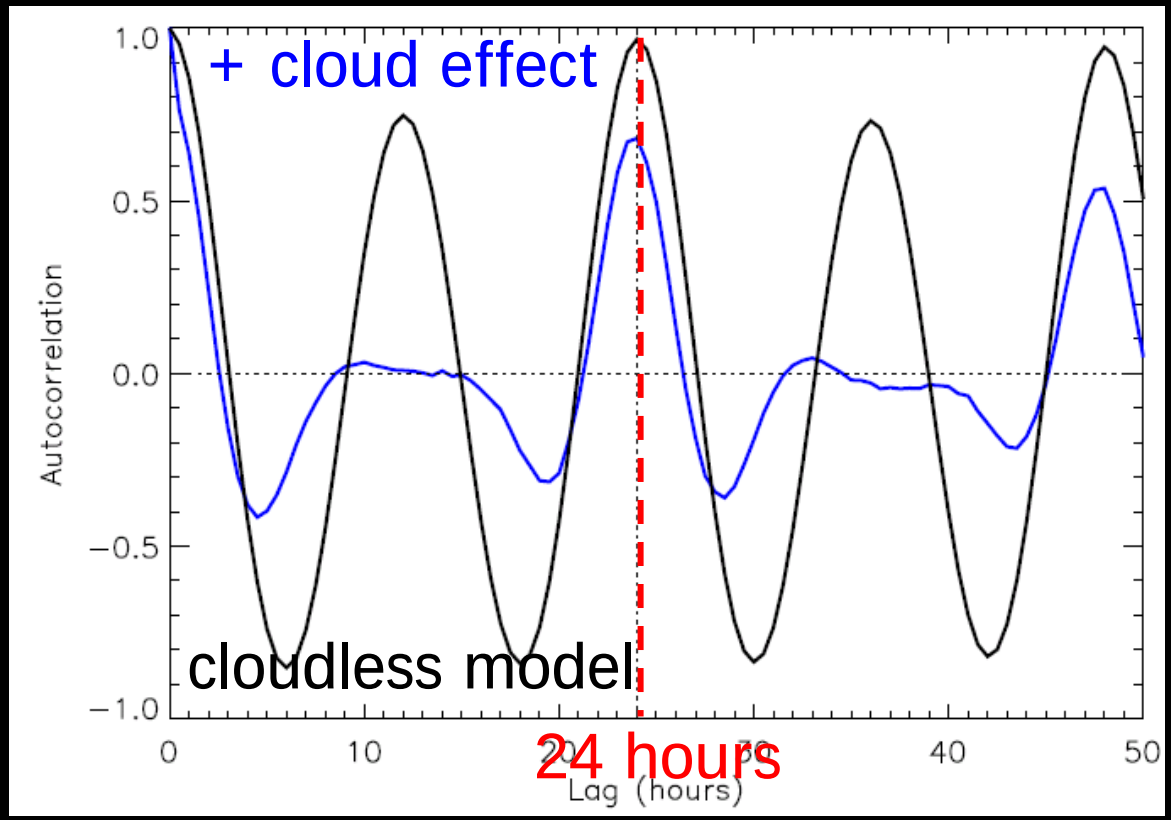


Palle et al. arXiv:0802.1836

identifying rotation period of Earth by autocorrelation w/wo cloud

Palle et al. arXiv:0802.1836

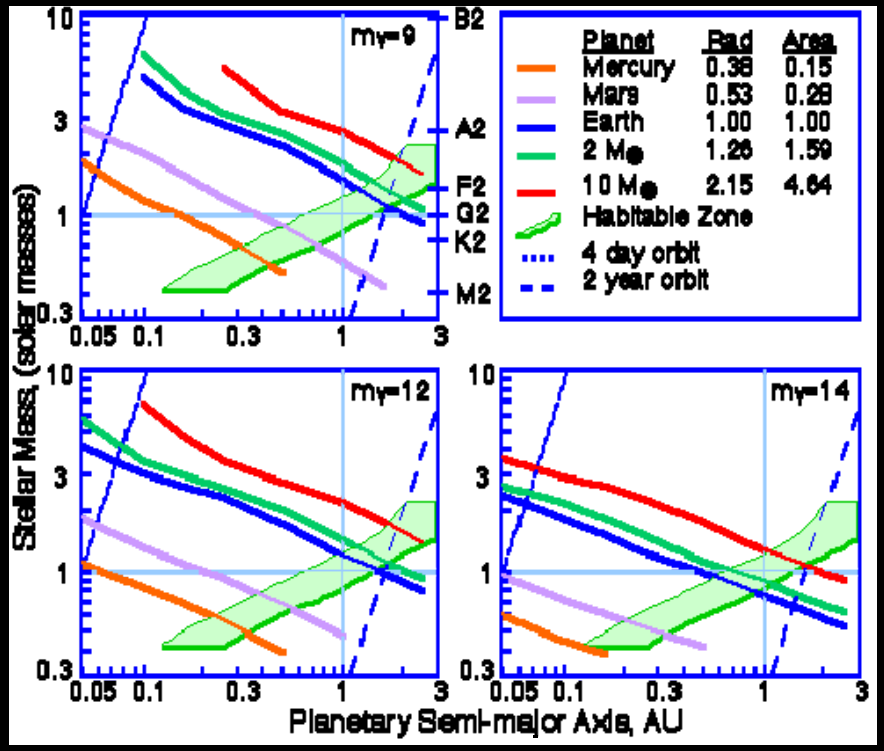
- inclination: 90°
- S/N : 40
- exposure time: 0.1 hour
- Earth's actual cloud data selected randomly in 1985

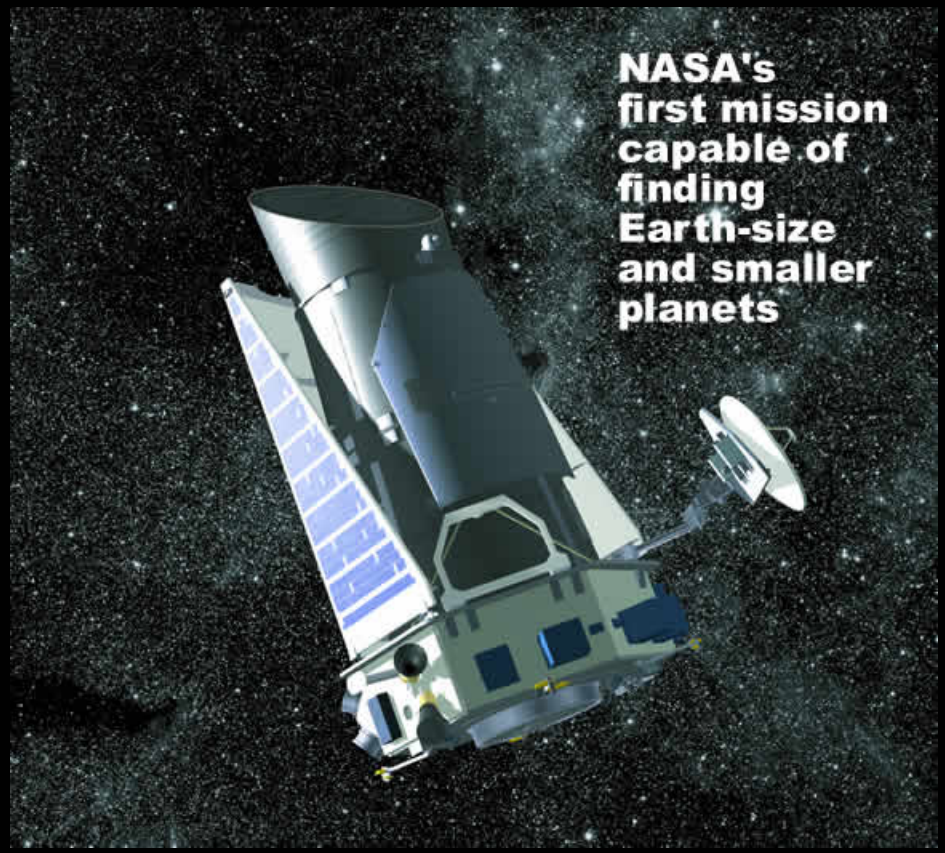


more elaborate analysis in collaboration with planetary/climate/plant scientists is in progress at Univ. of Tokyo (Fujii et al. in prep.); *interdisciplinary*

Kepler mission (Feb. 2009 launch?)

differential photometry survey of transit planets
expect to discover > 50 terrestrial planets in 4 years ?

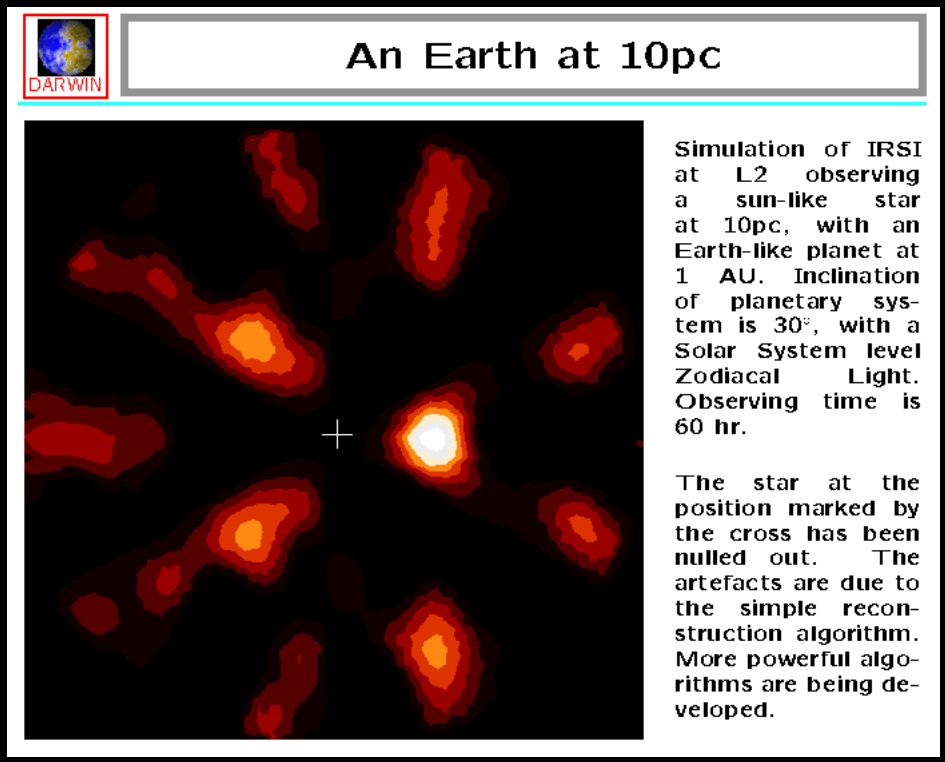




http://kepler.nasa.gov/

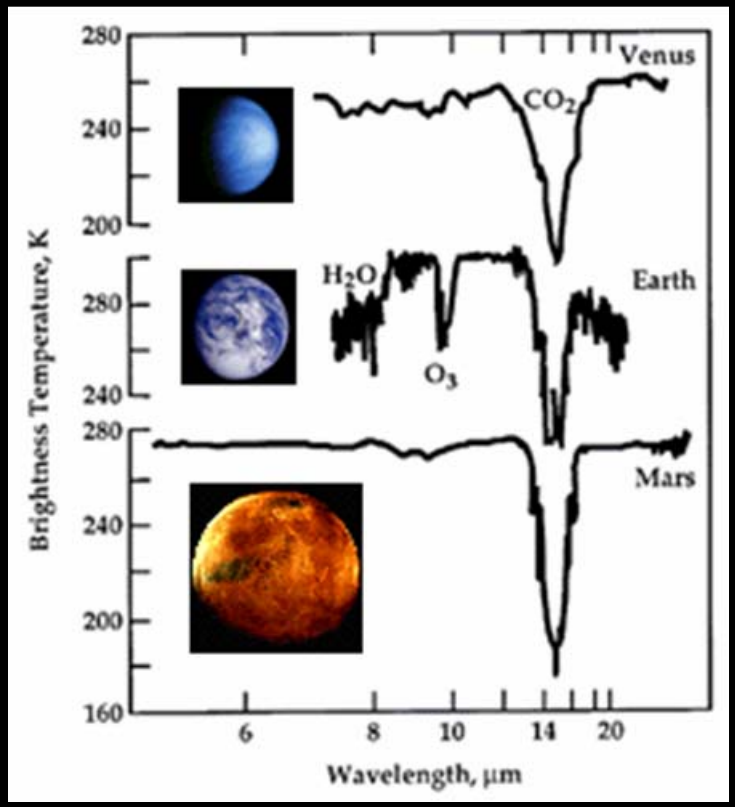
Darwin (ESA: launch after 2015)

infra-red space interferometry: imaging and spectroscopy



http://ast.star.rl.ac.uk/darwin/

Prospects in the 21st century: from exoplanets to exoplants



- Gas planets: from discovery phase to "characterization" phase
  - to understand origin, formation and evolution
- Discovery of terrestrial planets
- Discovery of habitable planets
  - the presence of liquid water
- **Ultra-precise spectroscopy**
  - Separate the planetary emission/reflection/absorption spectra from those of stars

How to convince ourselves of the presence of extra-terrestrial life from remote observations ? Biomarker !!!