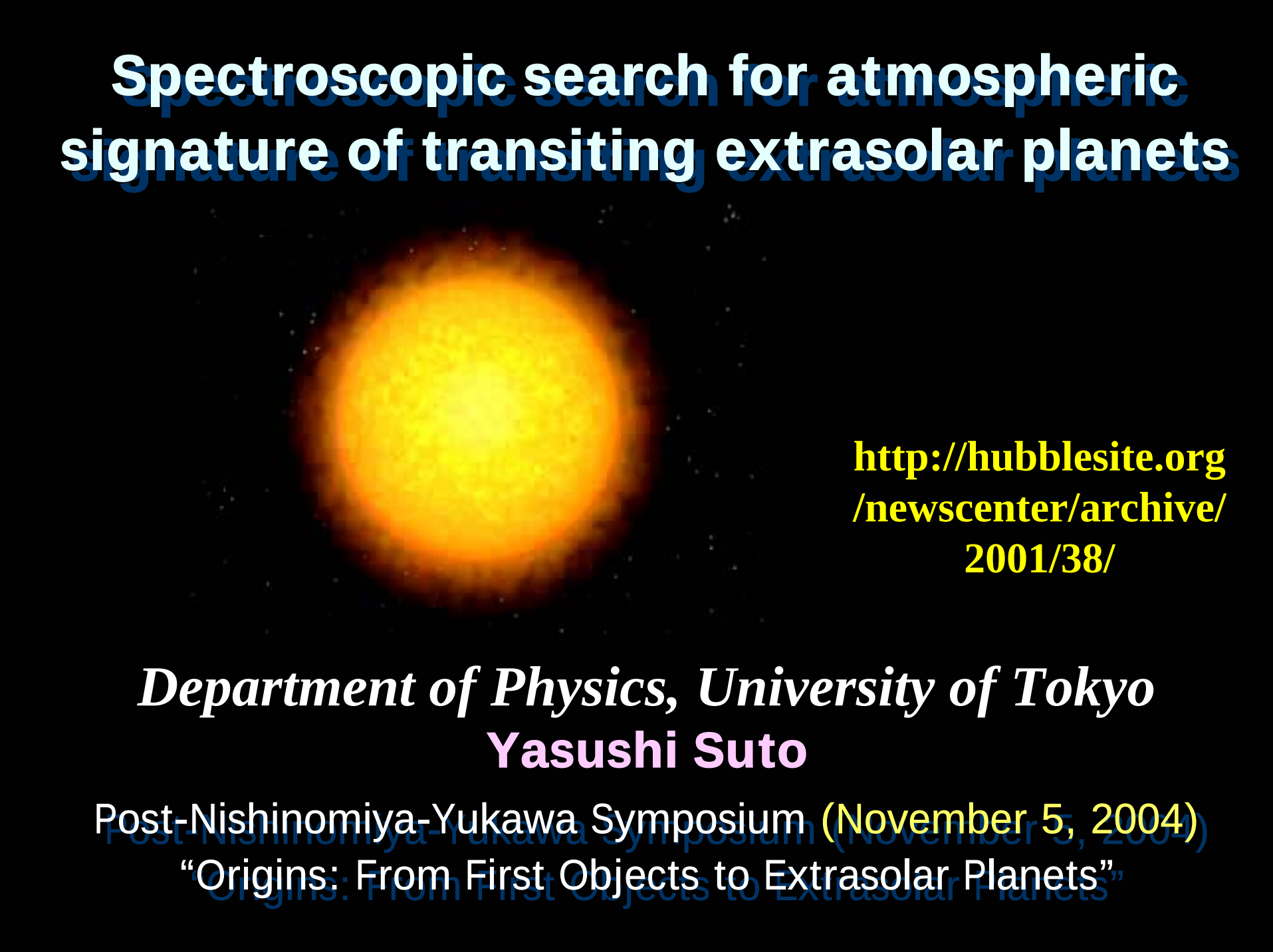
Spectroscopic search for atmospheric signature of transiting extrasolar planets

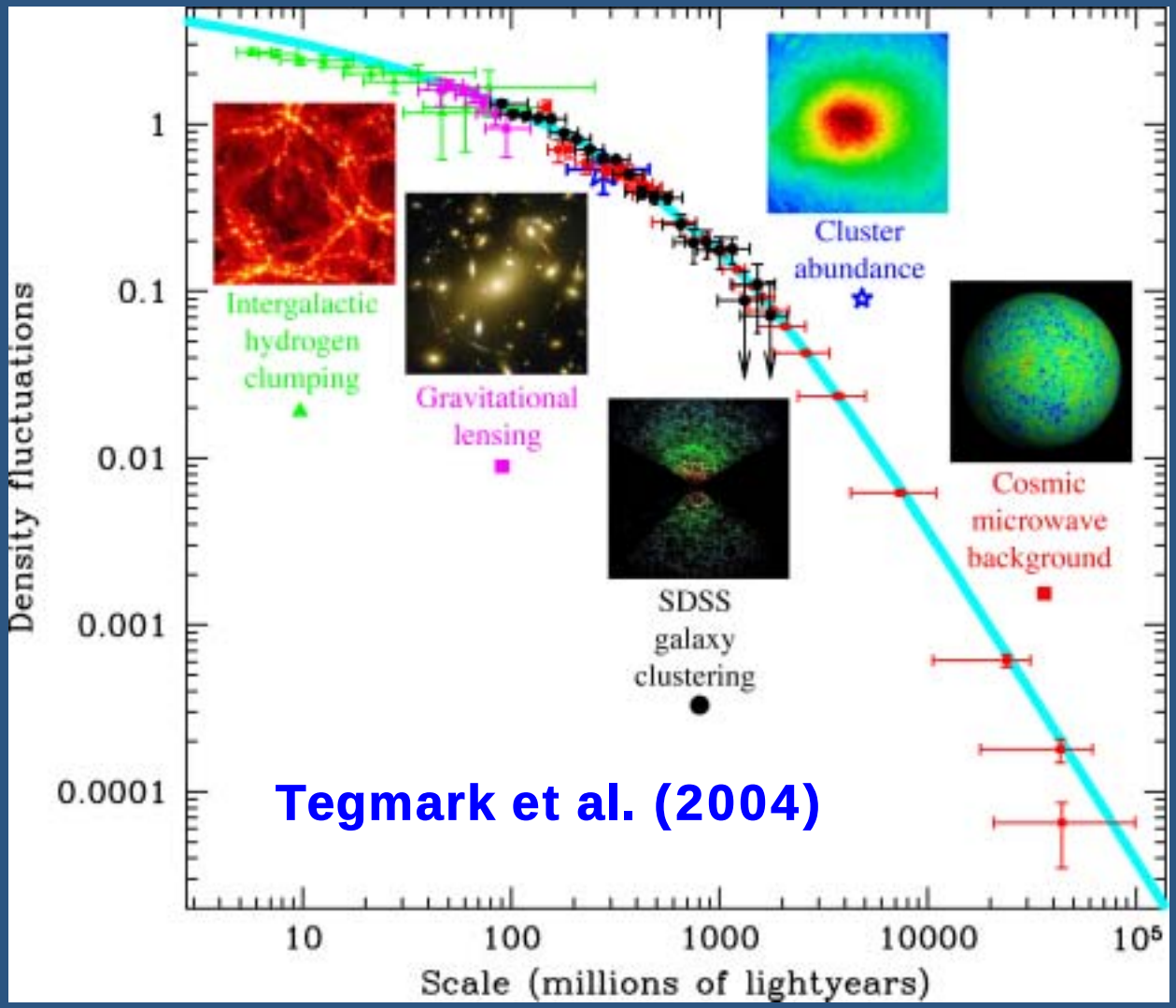


http://hubblesite.org/newscenter/archive/2001/38/

Department of Physics, University of Tokyo
Yasushi Suto

Post-Nishinomiya-Yukawa Symposium (November 5, 2004)
"Origins: From First Objects to Extrasolar Planets"

Non-trivial and amazing success of observational cosmology



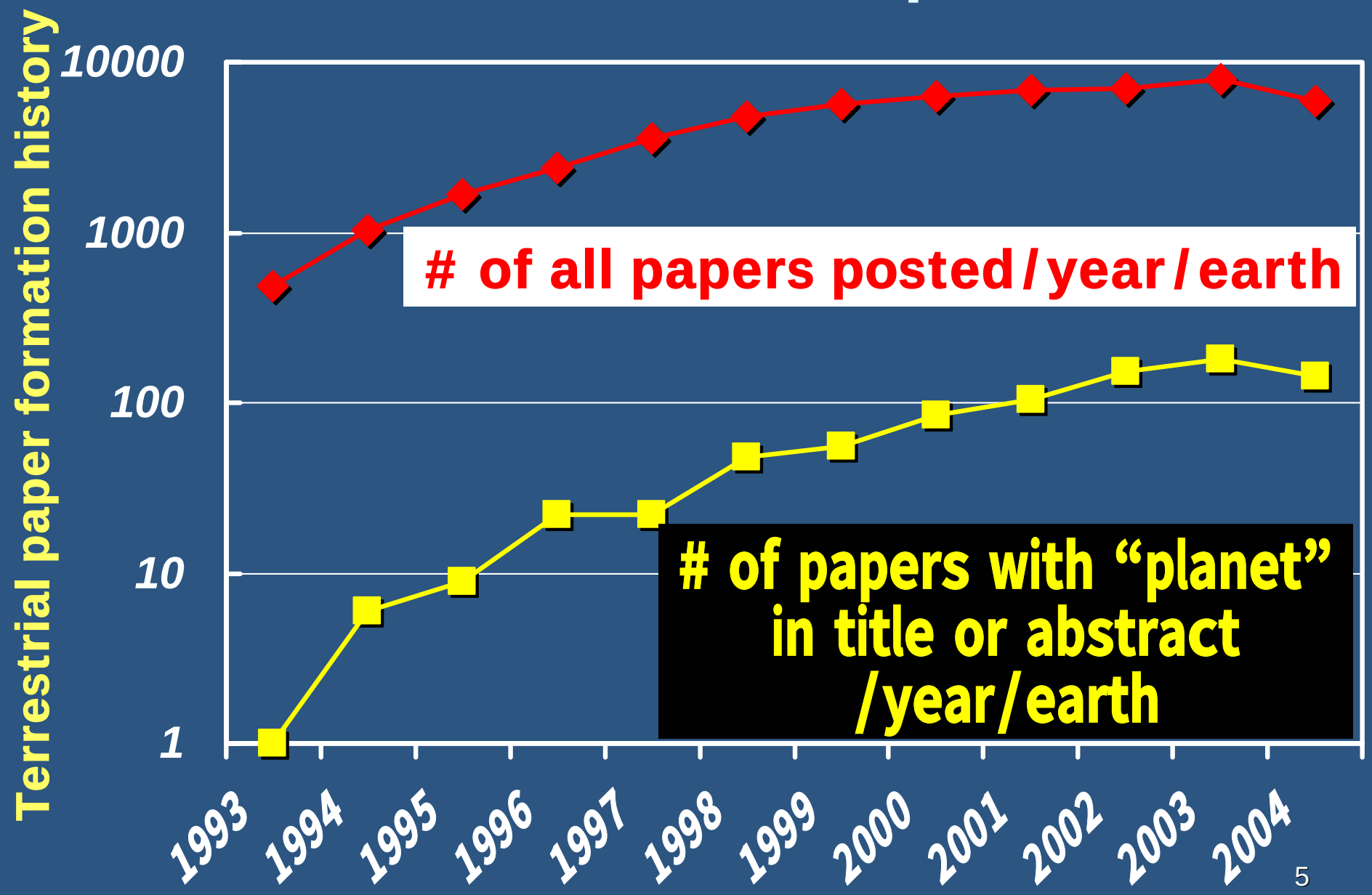
So what's next ?

- Precision **xxx**, not yet ?
  - We have to move on; determine all the cosmological parameters within 0.1% accuracy, for instance.
  - For what ? Really interesting ? Can convince taxpayers ?
- Beyond precision **xxx** ?
  - Stop playing with the *values of parameters*, but try to understand *their meaning*, i.e., matter context in the universe
    - Nature of dark matter and dark energy
    - Highest redshift objects, First objects in the universe
    - initial conditions (physical model of inflation)...
  - Revisit the cosmological observations in a more general framework
    - Equation of state of the universe
    - Validity of the cosmological principle
    - Validity of the general relativity on cosmological scales
- Or simply beyond **xxx** itself !
  - Religion (i.e., Anthropic principle), ***Extrasolar planet***, ,,,

A naive point of view of a simple-minded cosmologist for extrasolar planet study

- **Just started**
  - first discovery in 1995 !
- **easier to convince taxpayers**
  - other sciences became too detailed or too matured to achieve really fundamental contribution
  - What fraction of people can appreciate M-theory ?
- **directly related to one of the most fundamental questions**
  - origin of life
  - ***Maybe not during my lifetime, but this is exactly why I am attracted by this field***

“Evolution” of extra-solar planet science



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

- Astro-ph/9309052
- C.Alock 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…***
  - A seminal paper, but not a planet paper indeed

Subaru observation

“Spectro-photometric search for scattered light from HD209458b”

S02B-16 on October 24 and 26, 2002

Yasushi Suto, Norio Narita (Univ. of Tokyo)

Toru Yamada, Wako Aoki (National Ast. Obs. Japan)

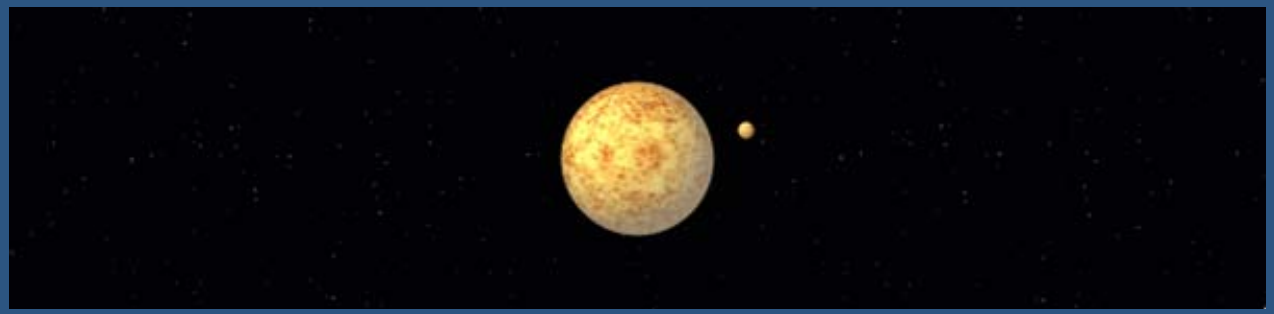
Bun-ei Sato (Kobe Univ.)

Edwin L. Turner , Brenda Frye (Princeton Univ.)

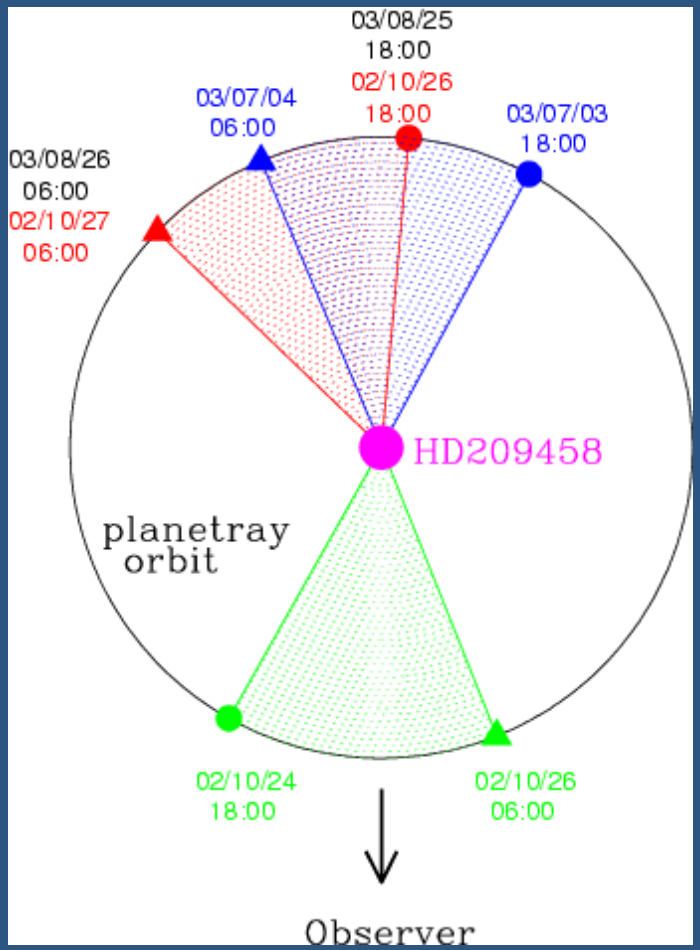
Josh Winn (Harvard Univ.)

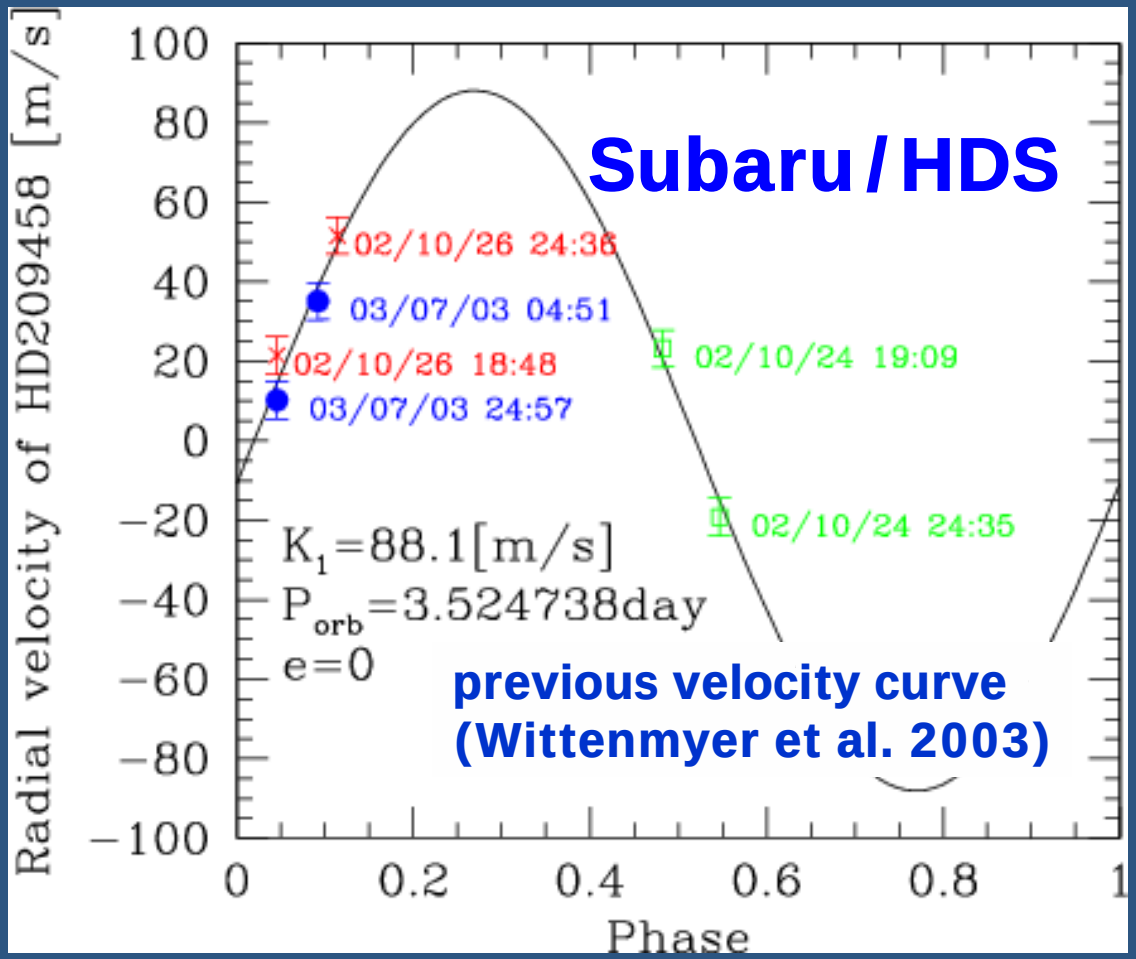
On-going three projects with HDS

- **Search for the planetary atmosphere from the ground observation**
  - Hα absorption analysis completed; upper limit $\sim$0.1%
  - Winn et al. PASJ 56(2004) 655 (astro-ph/0404469)
  - Analysis of other lines in progress (Narita et al. 2004)
- **Constraining the stellar spin and the planetary orbital axes from the Rossiter-McLaughlin effect**
  - New analytic formulae (Ohta, Taruya & Suto 2004; astro-ph/0410499)
- **Search for reflected light from planets**
  - Just started collaboration with a group at St. Andrews University (A. Cameron, C. Leigh, …)



Orbital phase and radial velocity of HD209458b in our observing run





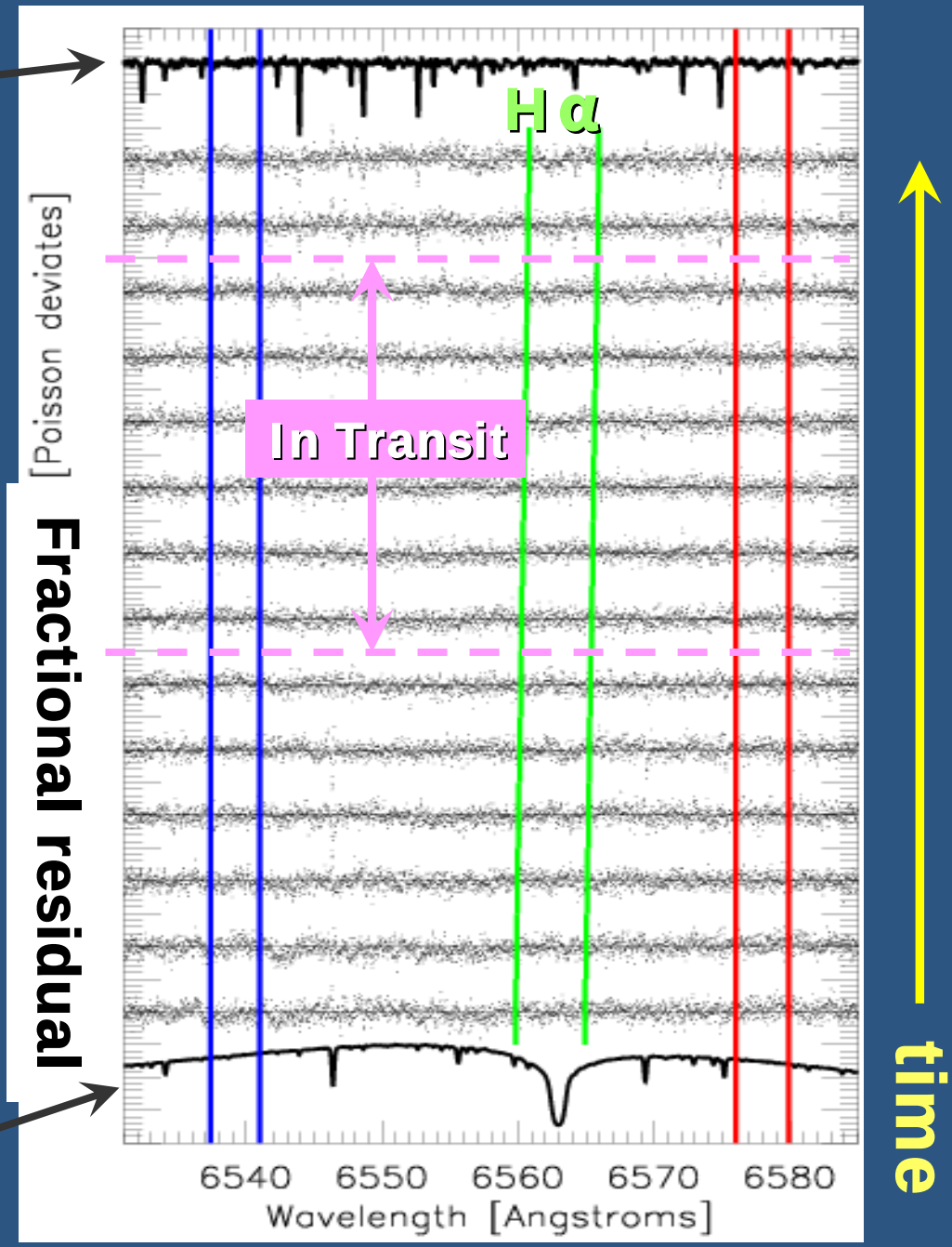
Winn et al. PASJ 56(2004) 655, astro-ph/0404469

Telluric spectrum

search for Hα absorption due to the atmosphere of HD209458b

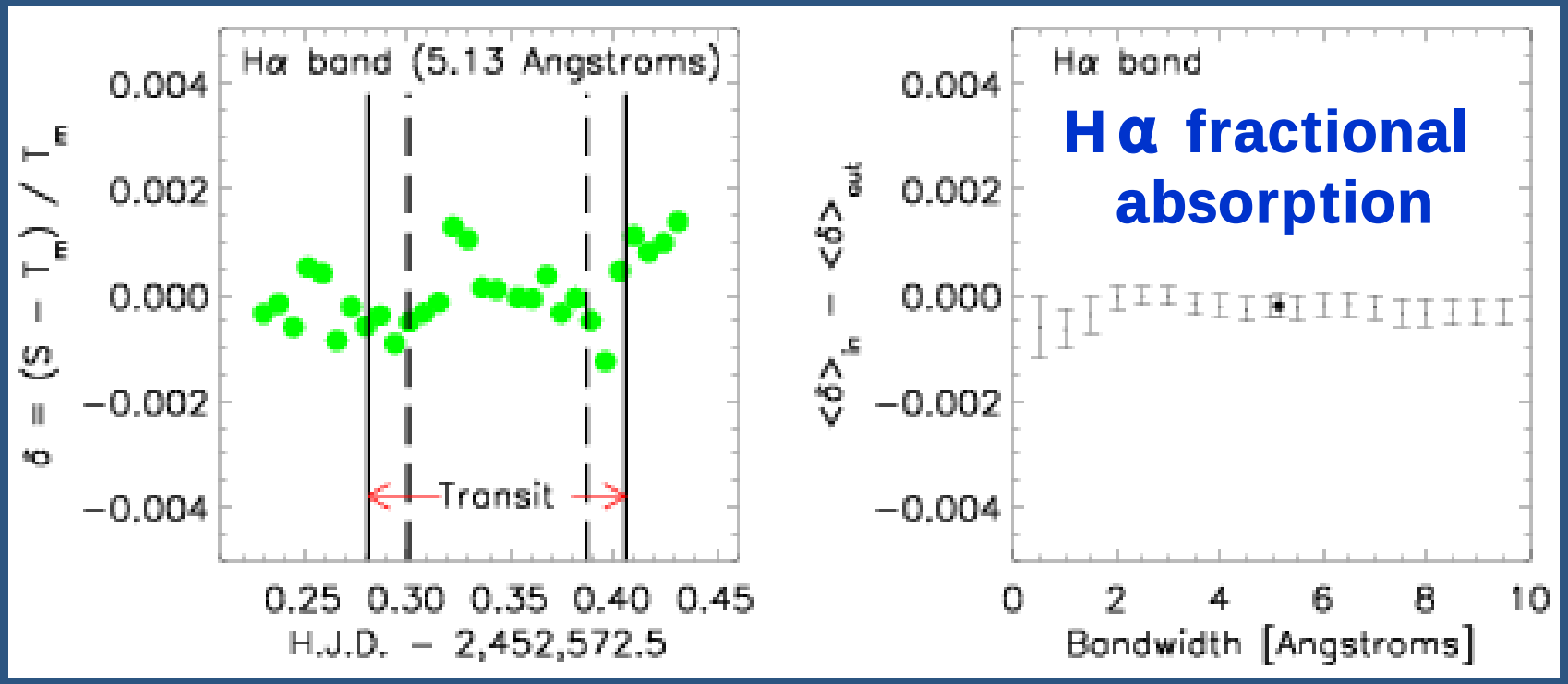
Na I (D2)	5889.97 Å
Na I (D1)	5895.94 Å
Hα	6562.81 Å
Hβ	4861.34 Å
Hγ	4340.48 Å

Template steller spectrum



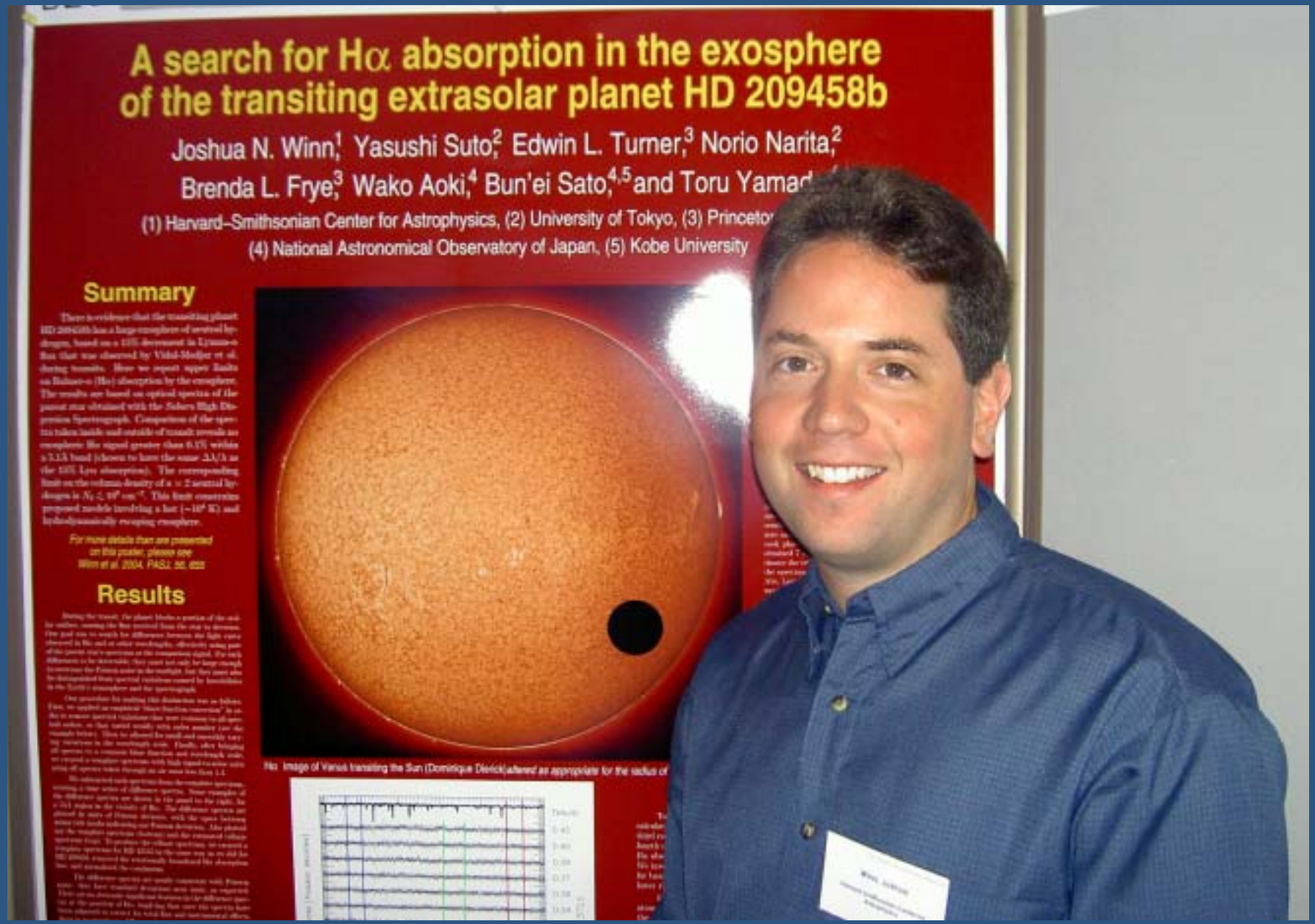
Winn et al. (2004)

The most stringent upper limit on the Hα absorption in the atmosphere of HD209458b

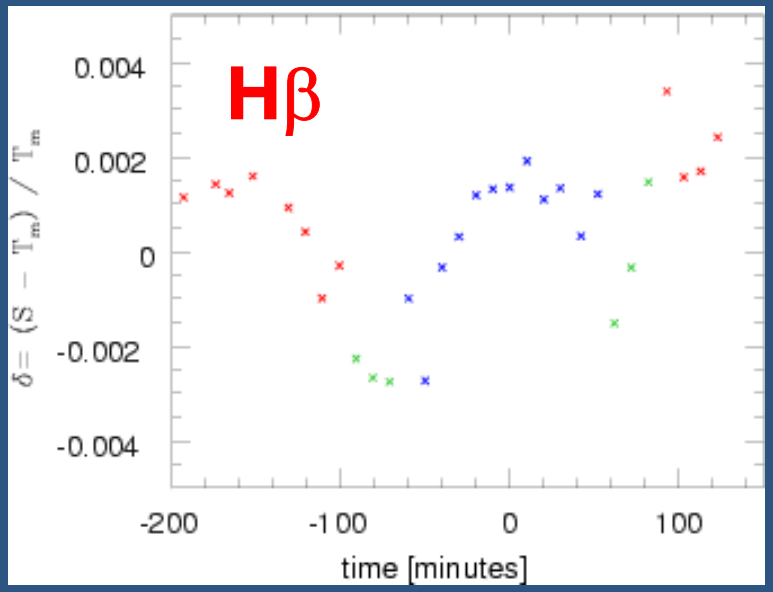


- Hα absorption <0.1% (3σ) (Winn et al. 2004)
- Ly α absorption=15% (Vidal-Madjar et al. 2003)
  - $T_{excitation}$< (0.6-1.3)eV (***heavily*** model-dependent)

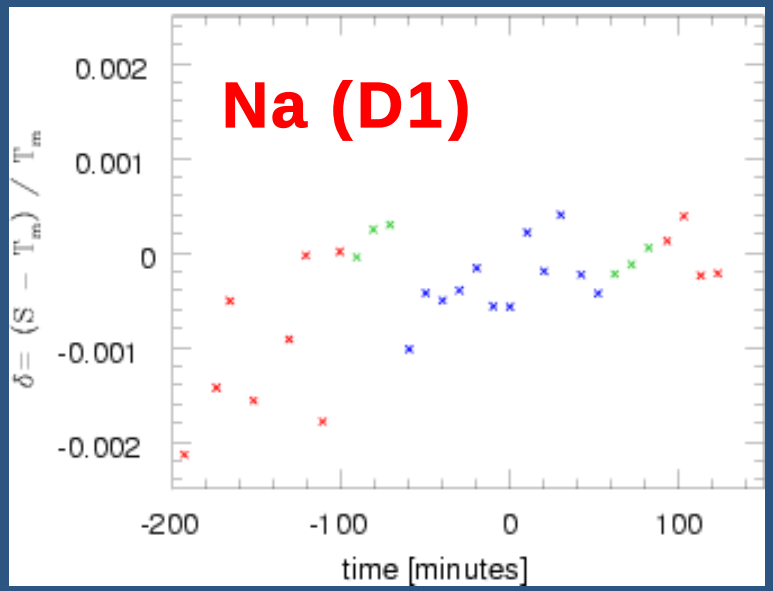
See poster B20 (Josh Winn) for details

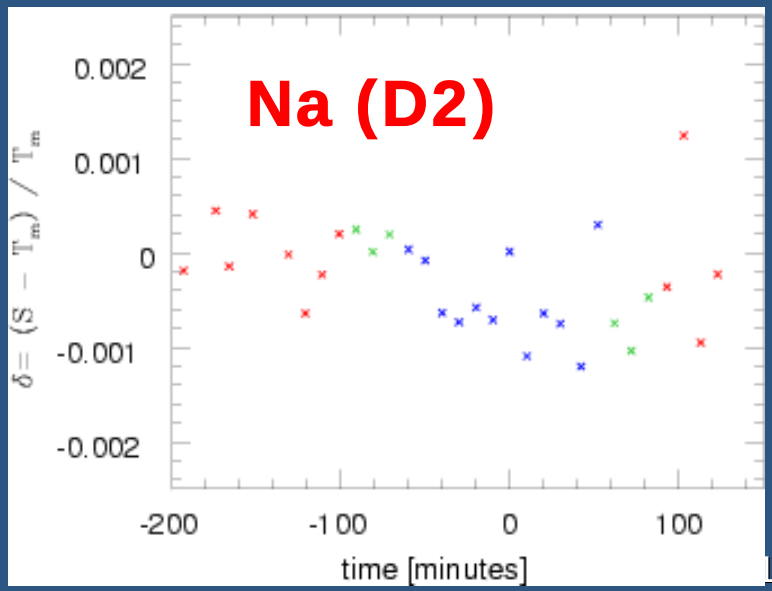


Other lines (preliminary results)

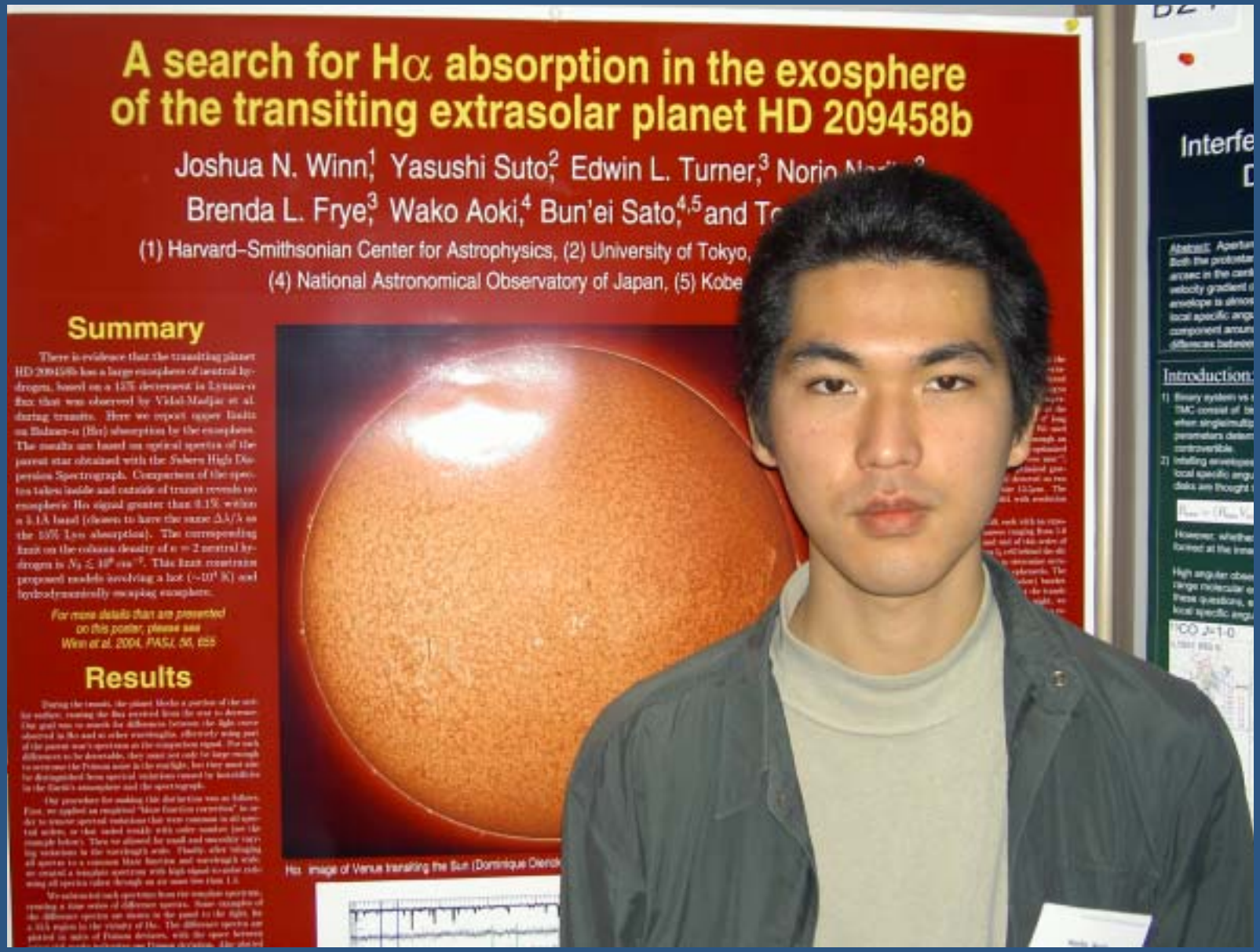


- No robust additional absorption signatures detected so far.
- fractional upper limits 0.1-0.3%
  - Narita et al. (2004), in preparation

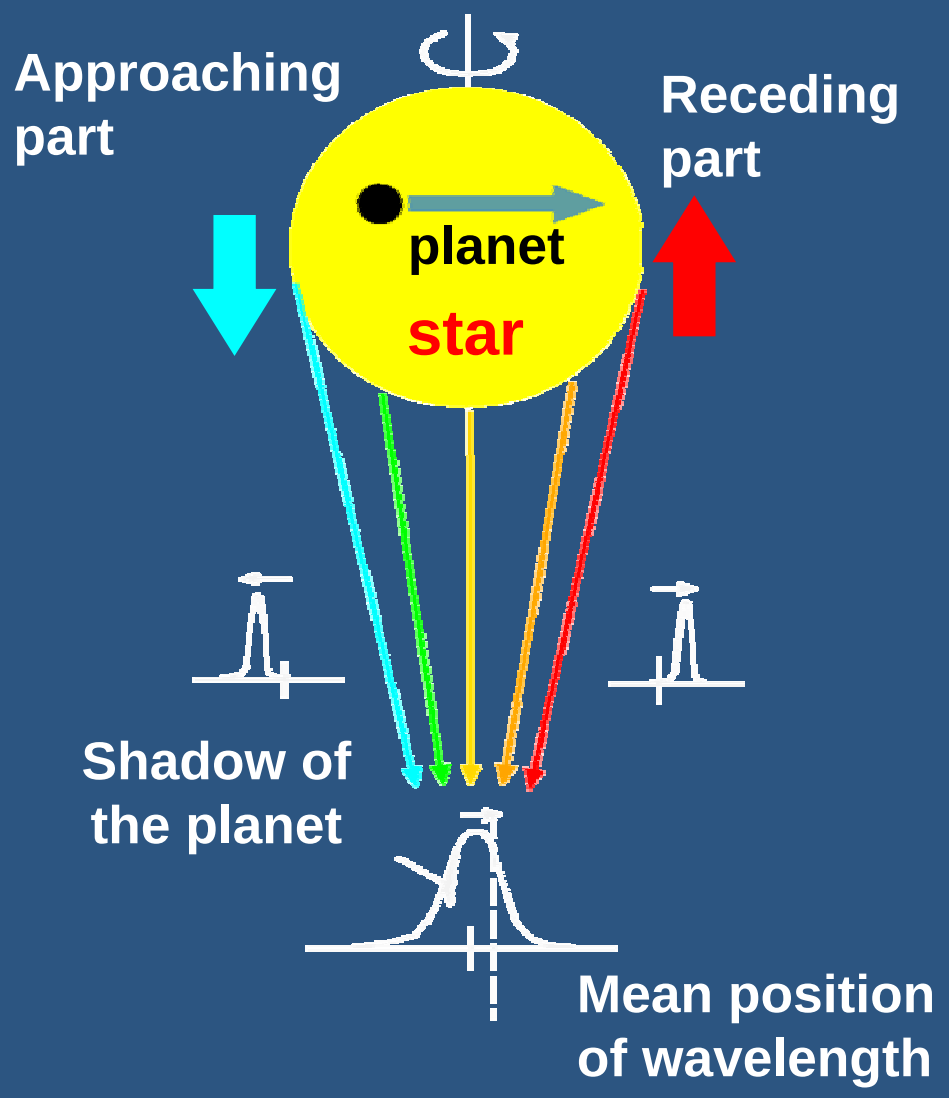




Ask Norio Narita for details

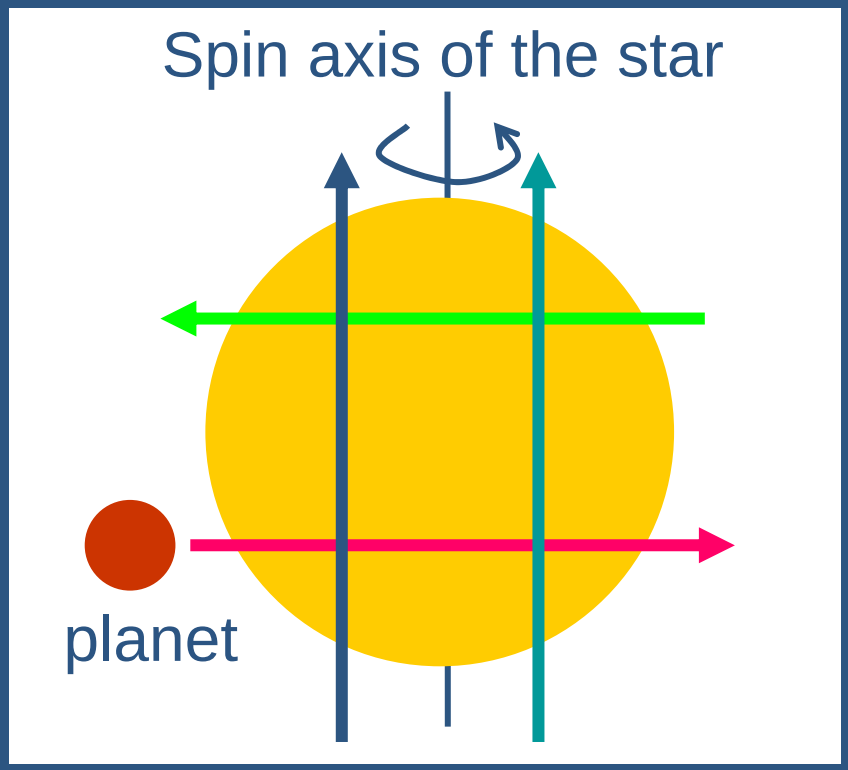


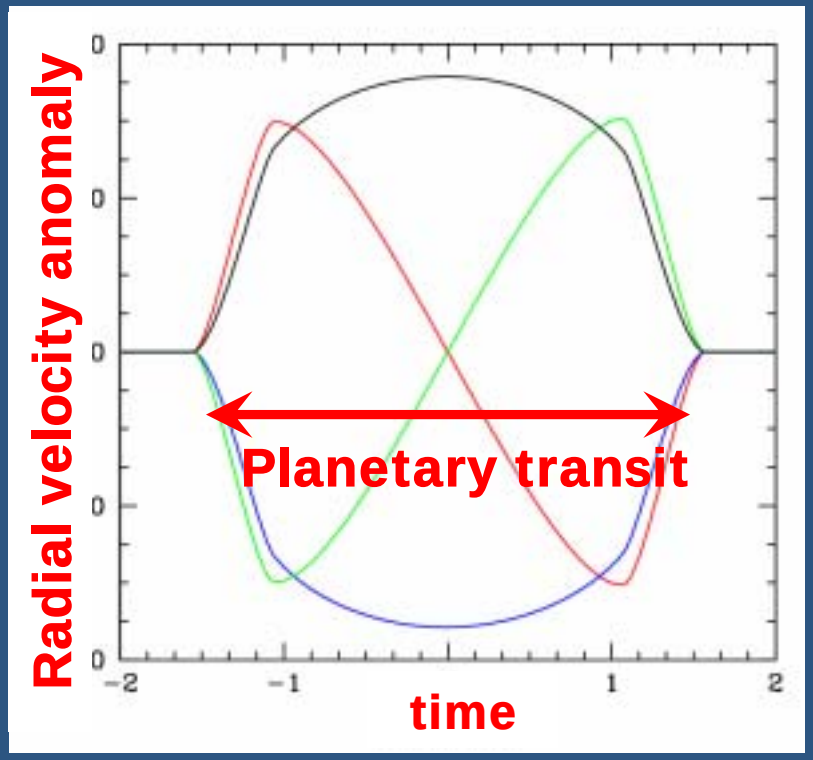
The Rossiter-McLaughlin effect



- 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

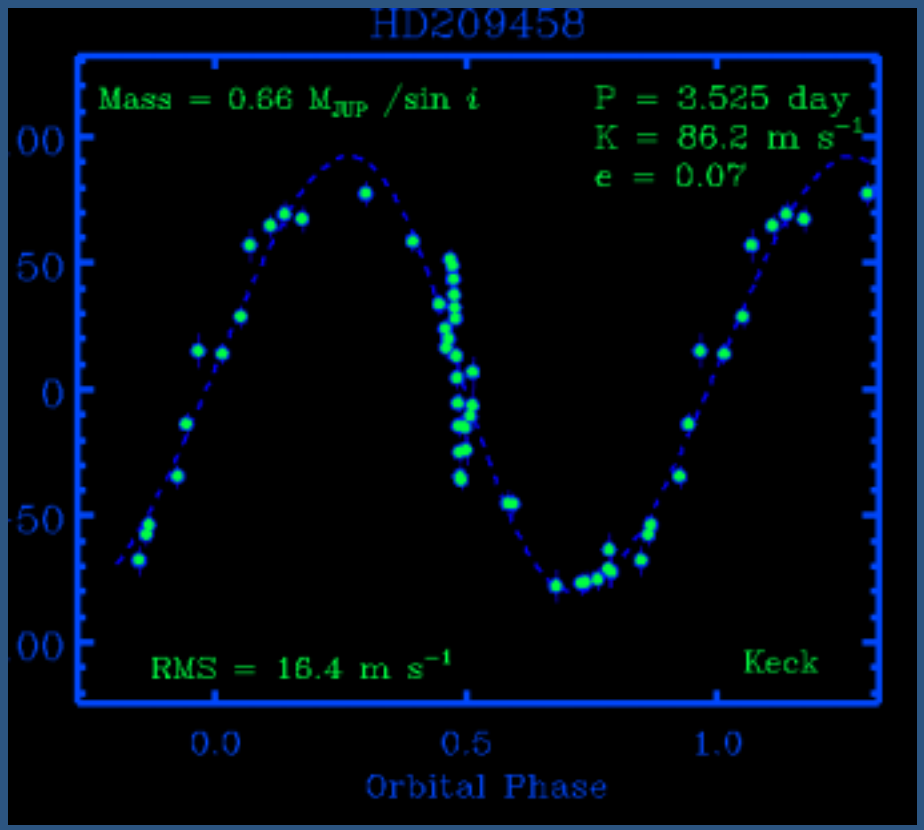


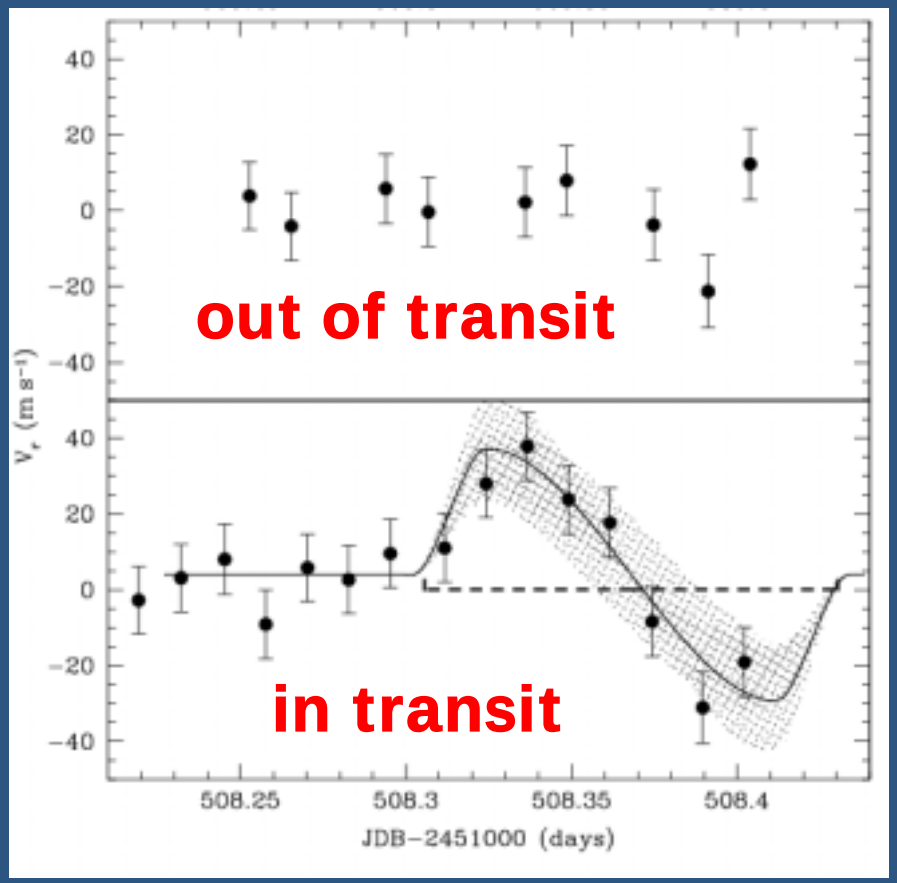


- Planetary orbital axis with respect to the stellar spin axis
  - They are parallel in the case of HD209458
  - How about the other transiting planets ?

Spectroscopic transit signature: the Rossiter-McLaughlin effect

Origin of angular momentum





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

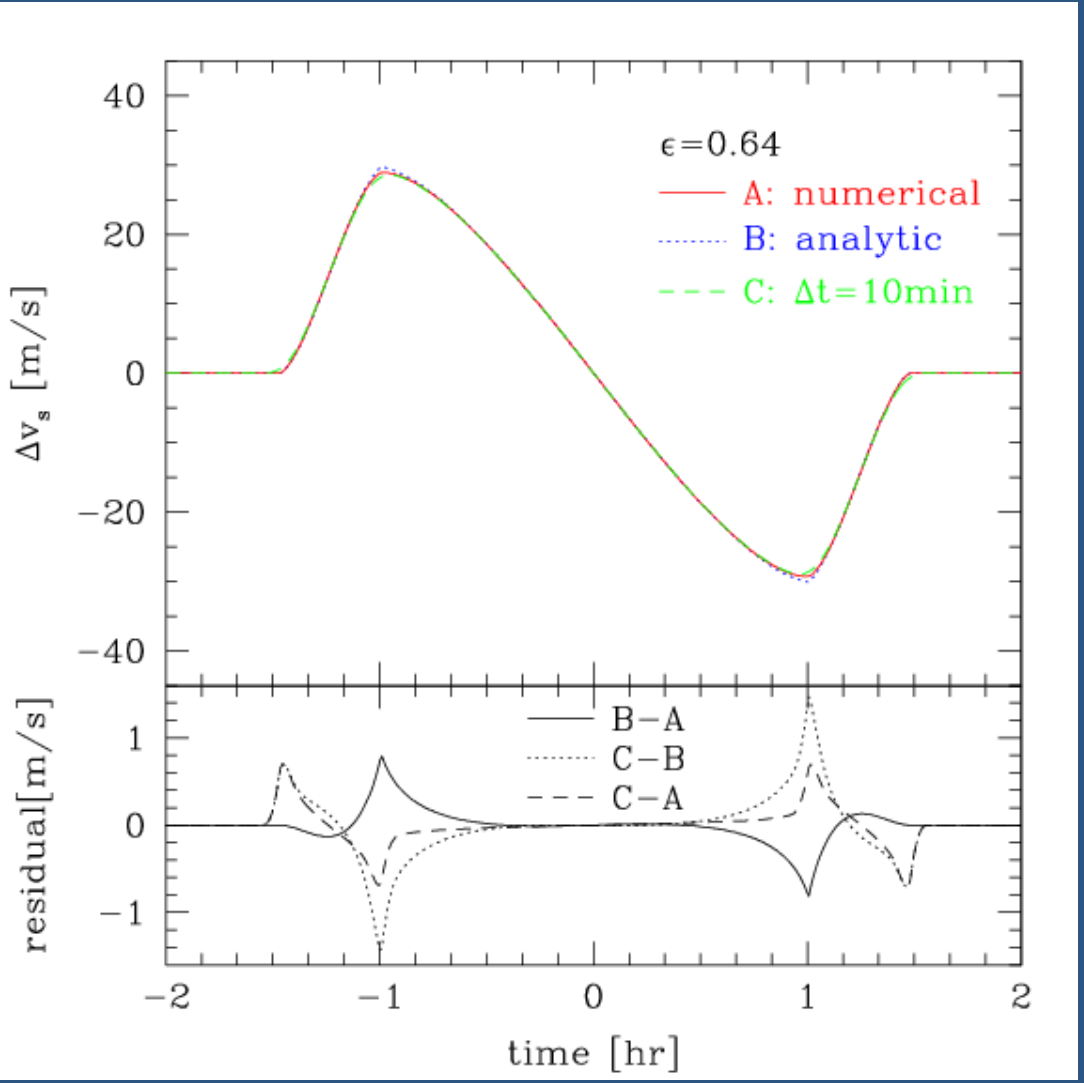
Stellar rotation and planetary orbit
Queloz et al. (2000) A&A 359, L13
ELODIE on 193cm telescope

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

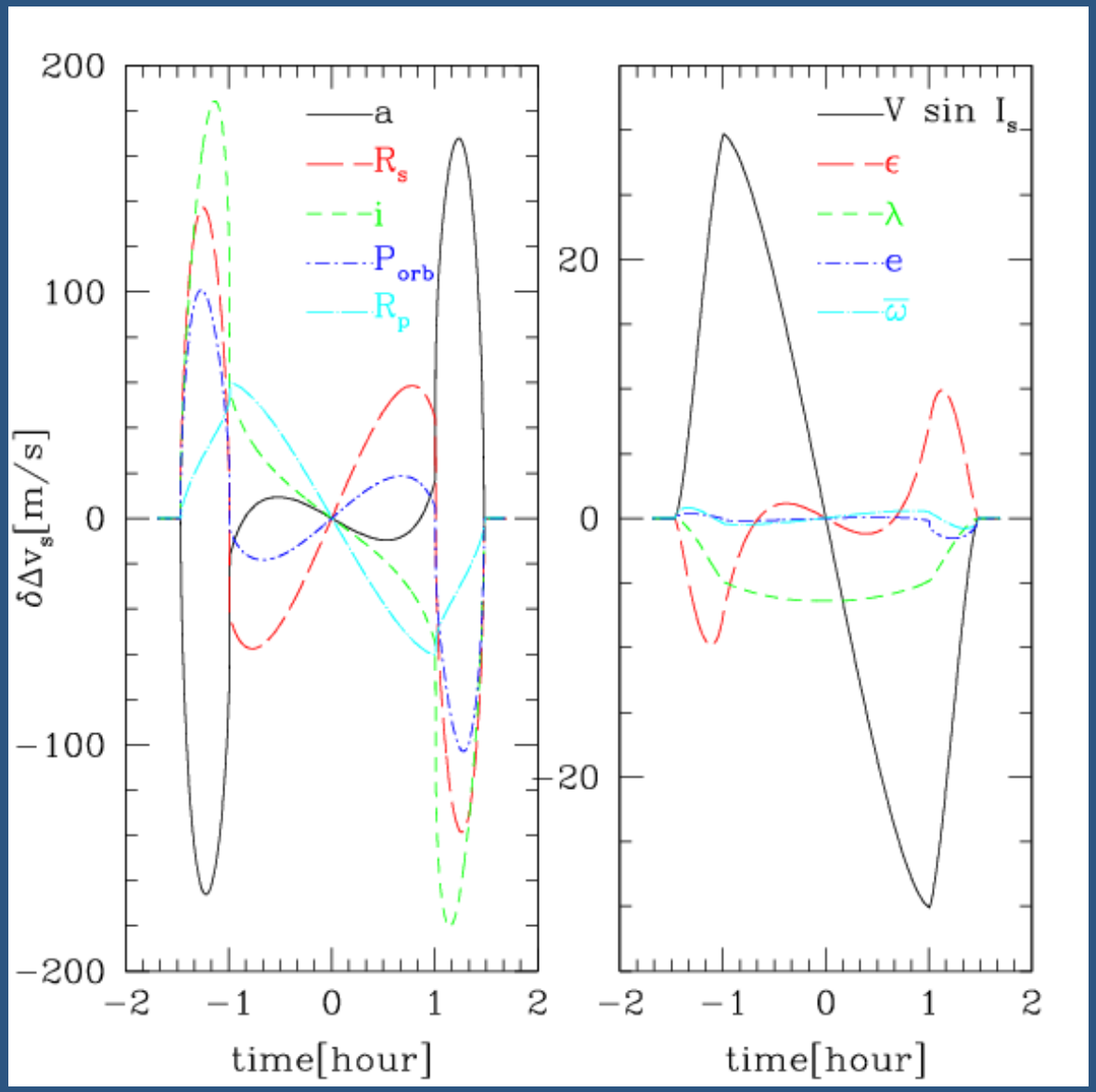
Limb darkening:
B= 1- ε (1-cos θ)

Accurate analytic formula using perturbation theory

Ohta, Taruya & Suto (astro-ph/0410499)



Dependence on 10 parameters

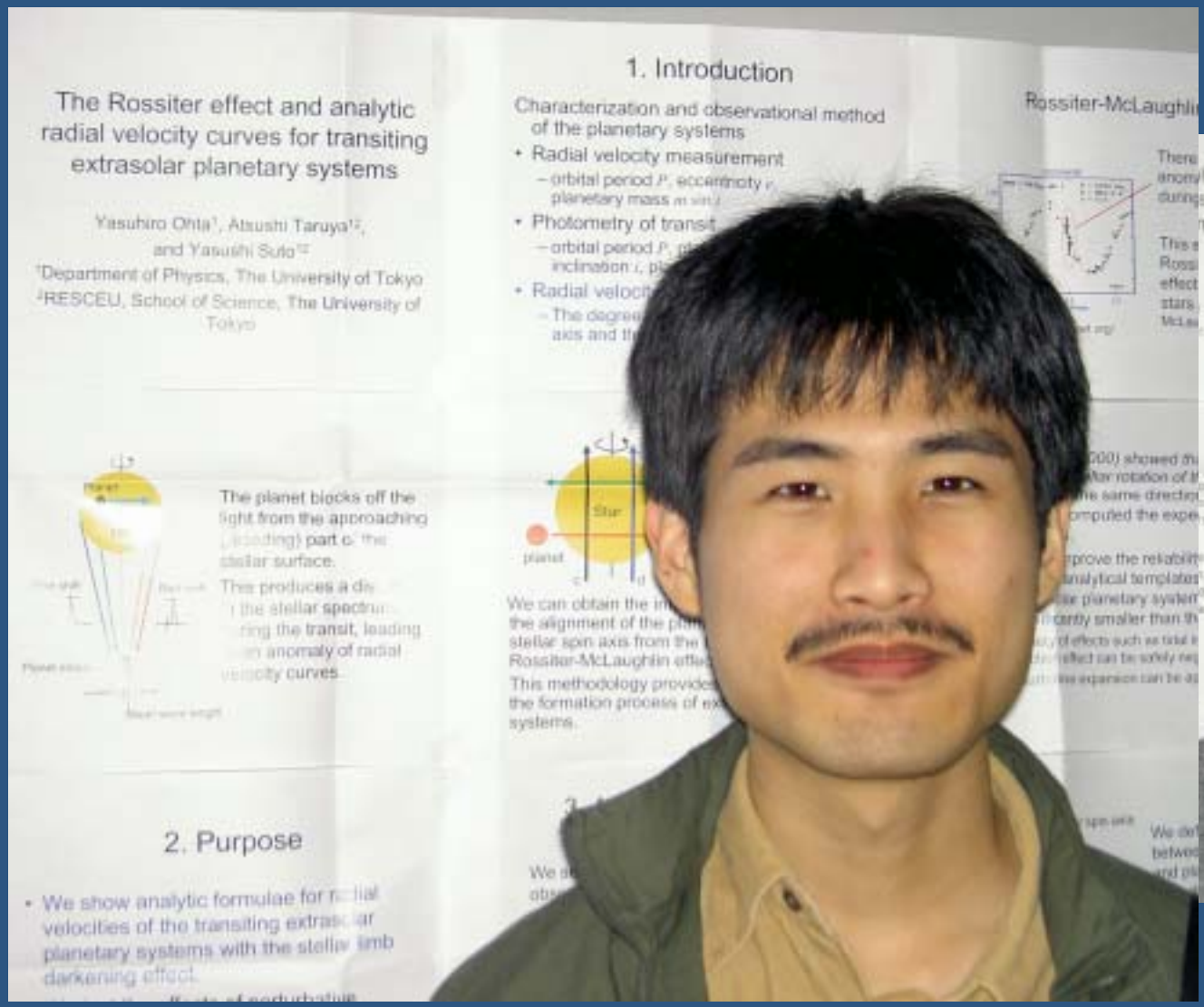


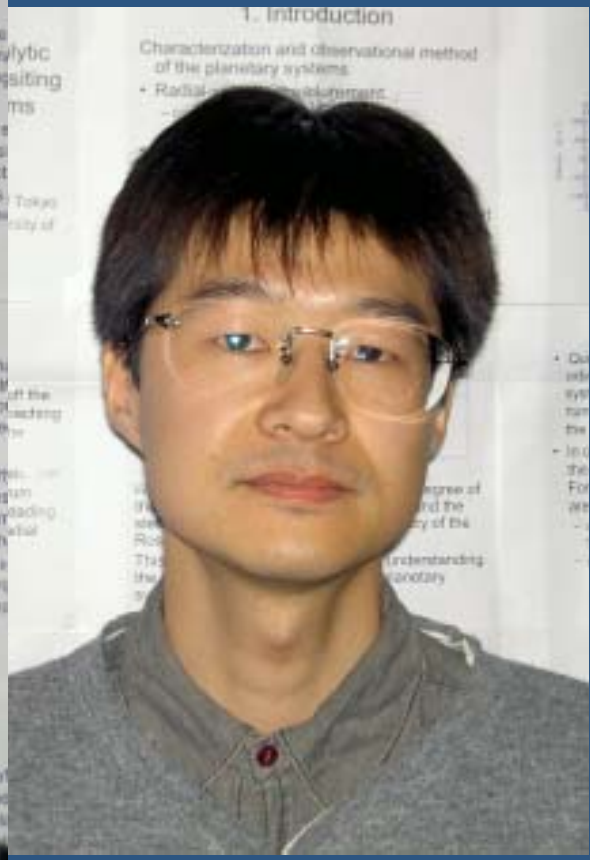
Example for HD209458

Velocity anomaly divided by the fractional uncertainty of each parameter

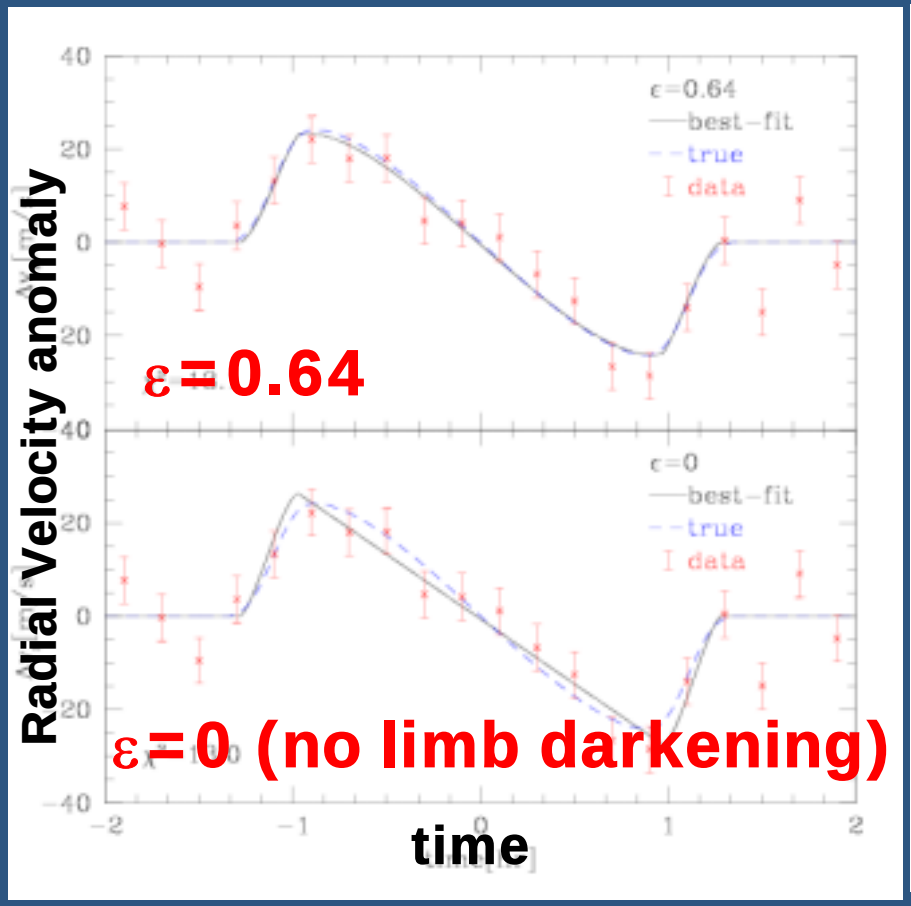
(Ohta, Taruya & Suto 2004)

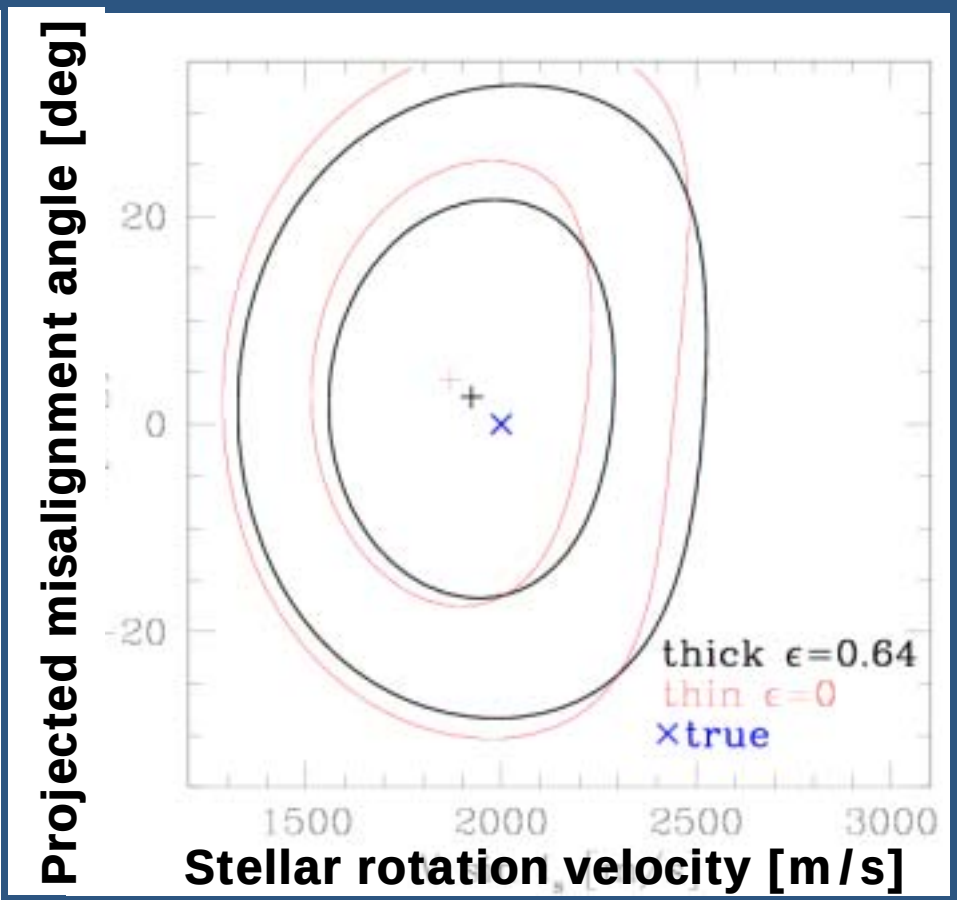
For further details, see poster B13 by Yasuhiro Ohta and Atsushi Taruya





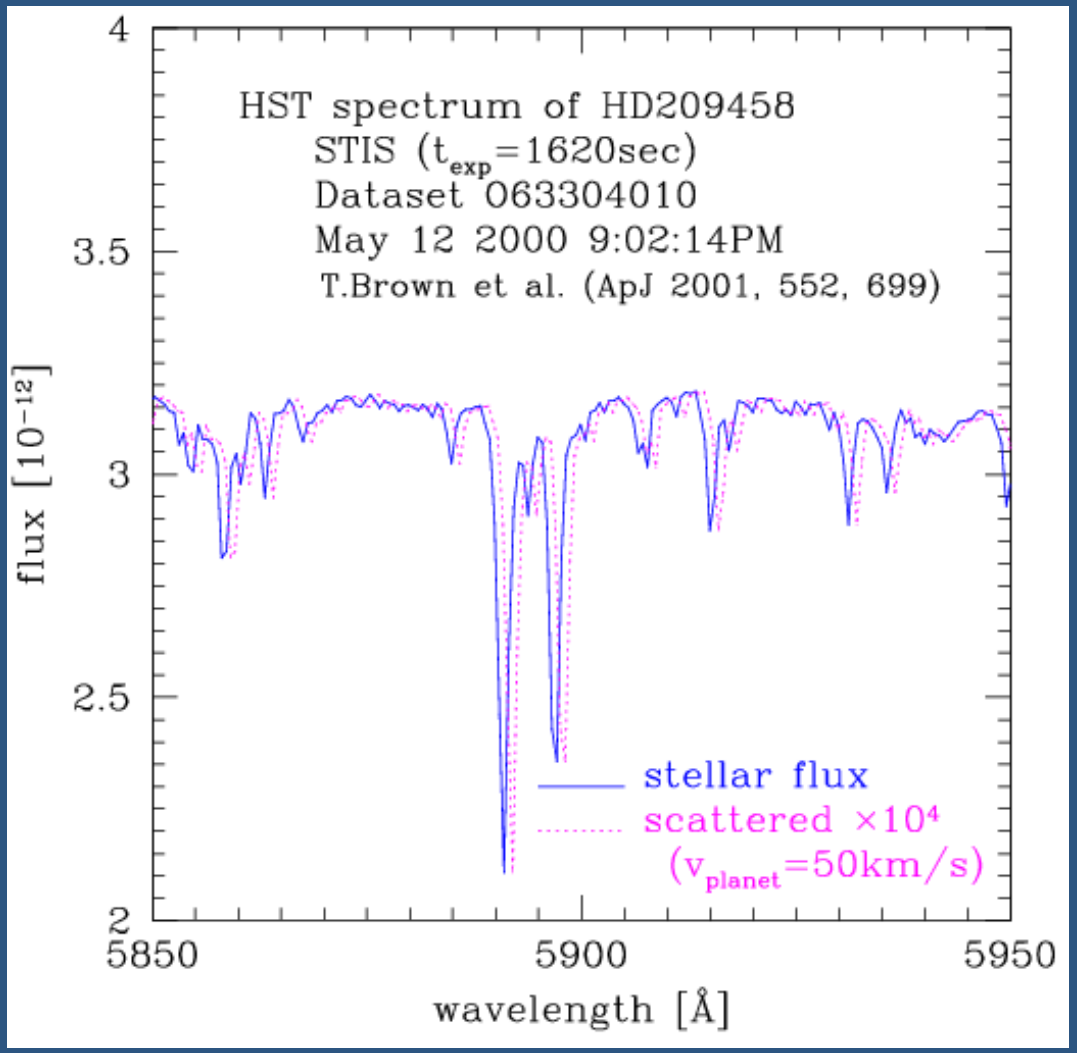
Possible constraints on TrES-1 system





- Proposal submitted to Subaru (PI: N.Narita)
- Mock data analysis using the parameters estimated by Alonso et al. (2004) and the analytic templates by Ohta, Taruya and Suto (2004)

Search for scattered light from HD209458b



- Statistical search for the scattered components Doppler-shifted at $v_p(t)$ from the stellar absorption lines.
- The spectral resolution of HDS ($\lambda/\Delta\lambda$=50000) is 10 times better than that of STIS, HST ($\lambda/\Delta\lambda$=5540).

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***

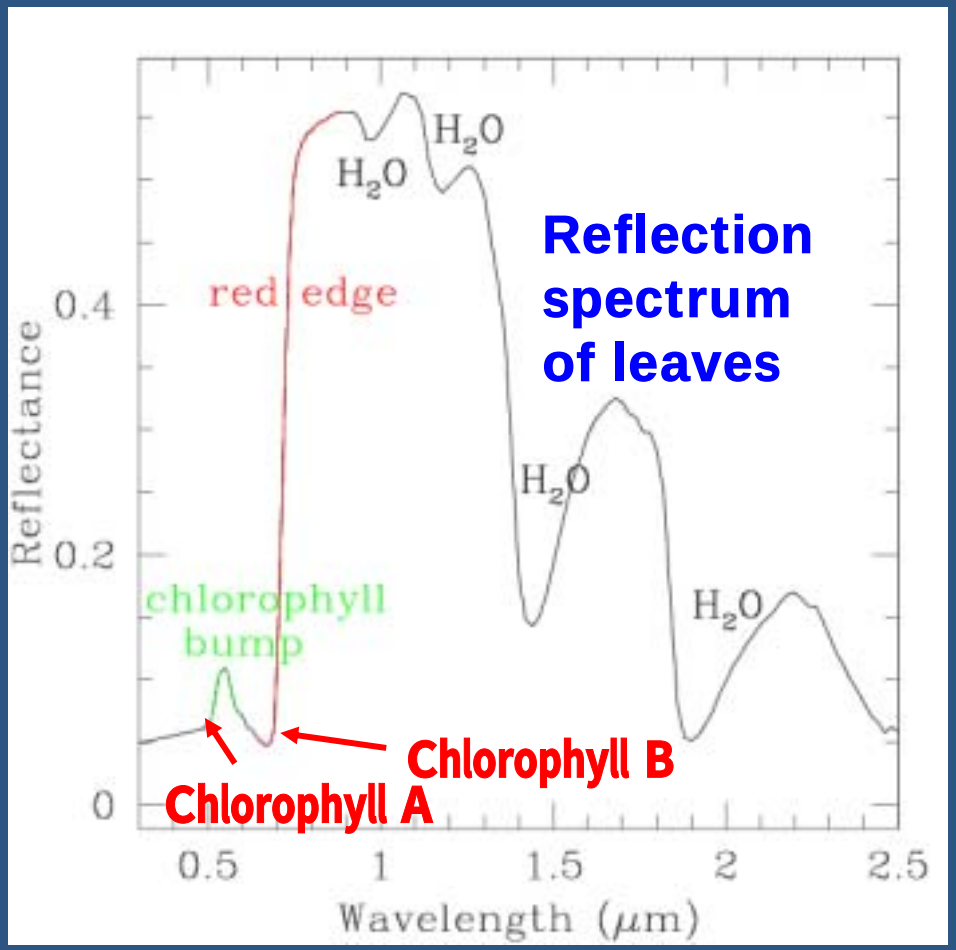
Astrobiology ? Not yet

- 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 $\lambda > 7000$ Å
- An interesting (maybe unique) candidate for a biomarker ?
- ***extrasolar plants*** as a biomarker in *extrasolar planets*



Seager, Ford & Turner
astro-ph/0210277

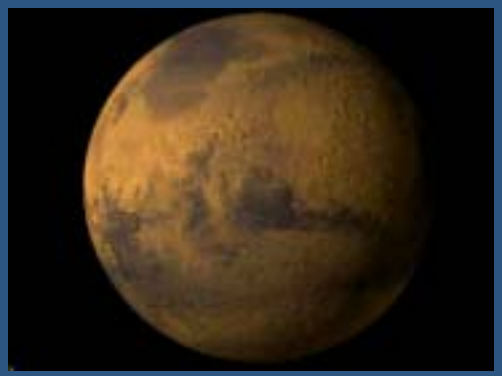
Vesto Melvin Slipher (1875-1969)

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’’

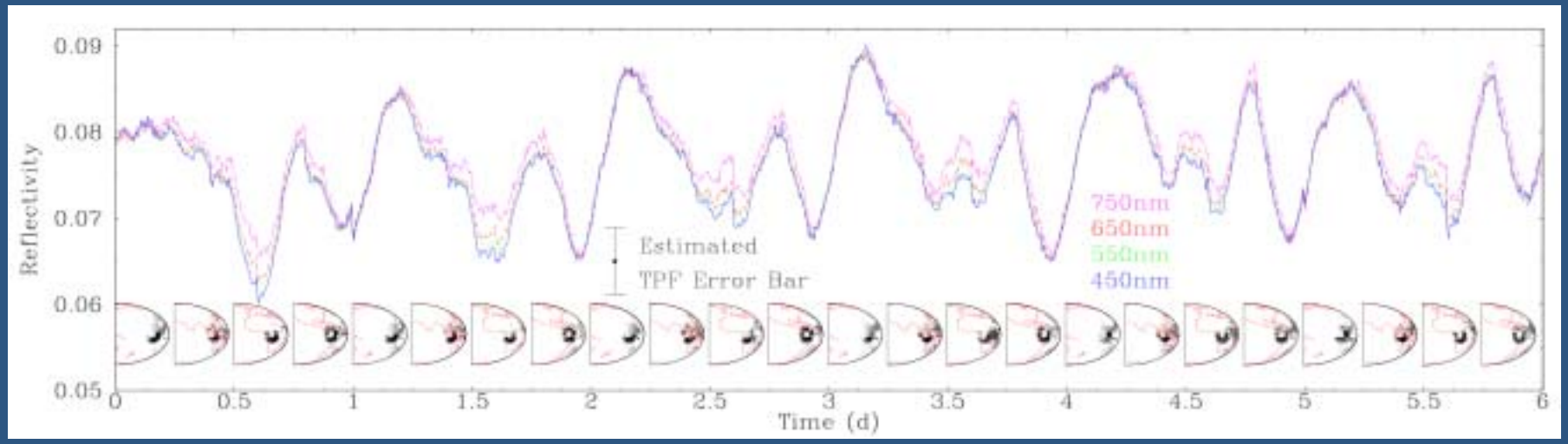
PASP 36(1924)261



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**

Let's thank a couple of great pioneers for attracting us to this exciting field !