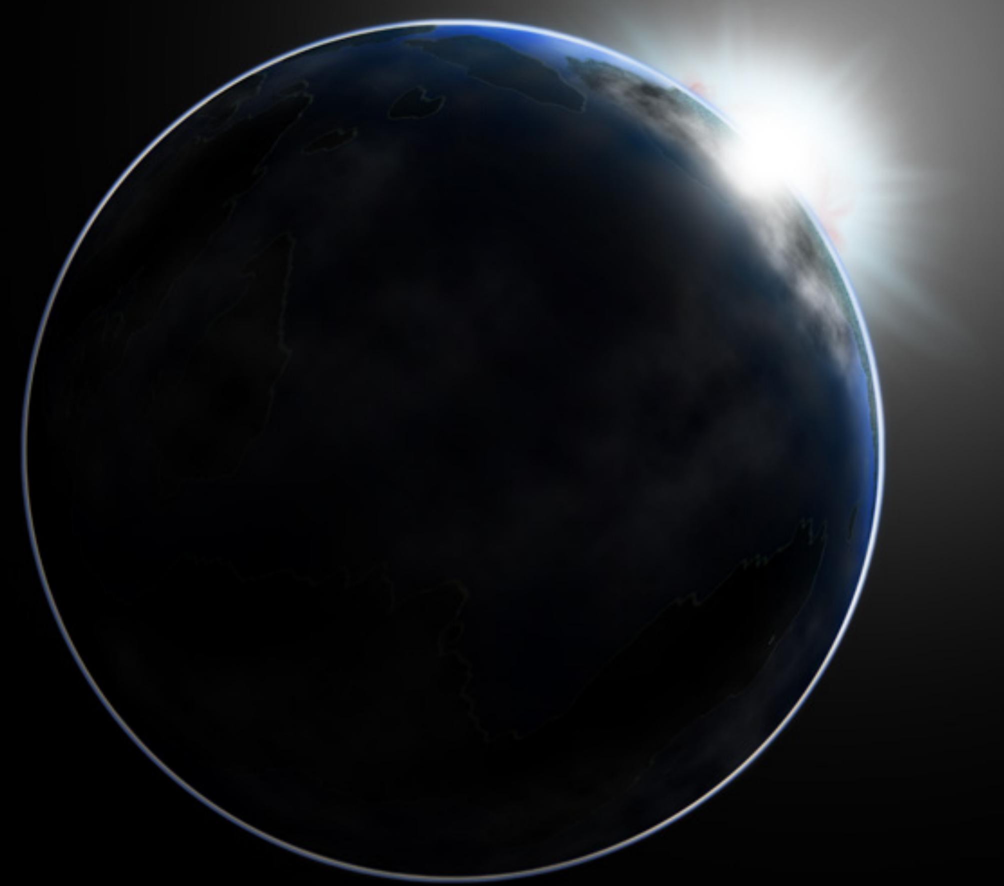
Transmission Spectroscopy of a Transiting Super-Earth GJ1214b



Norio Narita (NAOJ)

Outline

- Brief Introduction of Super-Earths
- Transmission Spectroscopy of Transiting Super-Earths
- Case for GJ1214b
- Subaru Capability and Future Plans

What is "Super-Earths?"

- There is no official definition by IAU
- Planets with the mass and radius between Earth and Uranus/ Neptune (No corresponding planet in Solar System)
  - Mass : 1-15 M_Earth
  - Radius : 1-4 R_Earth
- Not necessarily rocky planets
  - large Earth / mini-Neptune
  - the boundary is still unclear

Importance of Super-Earths

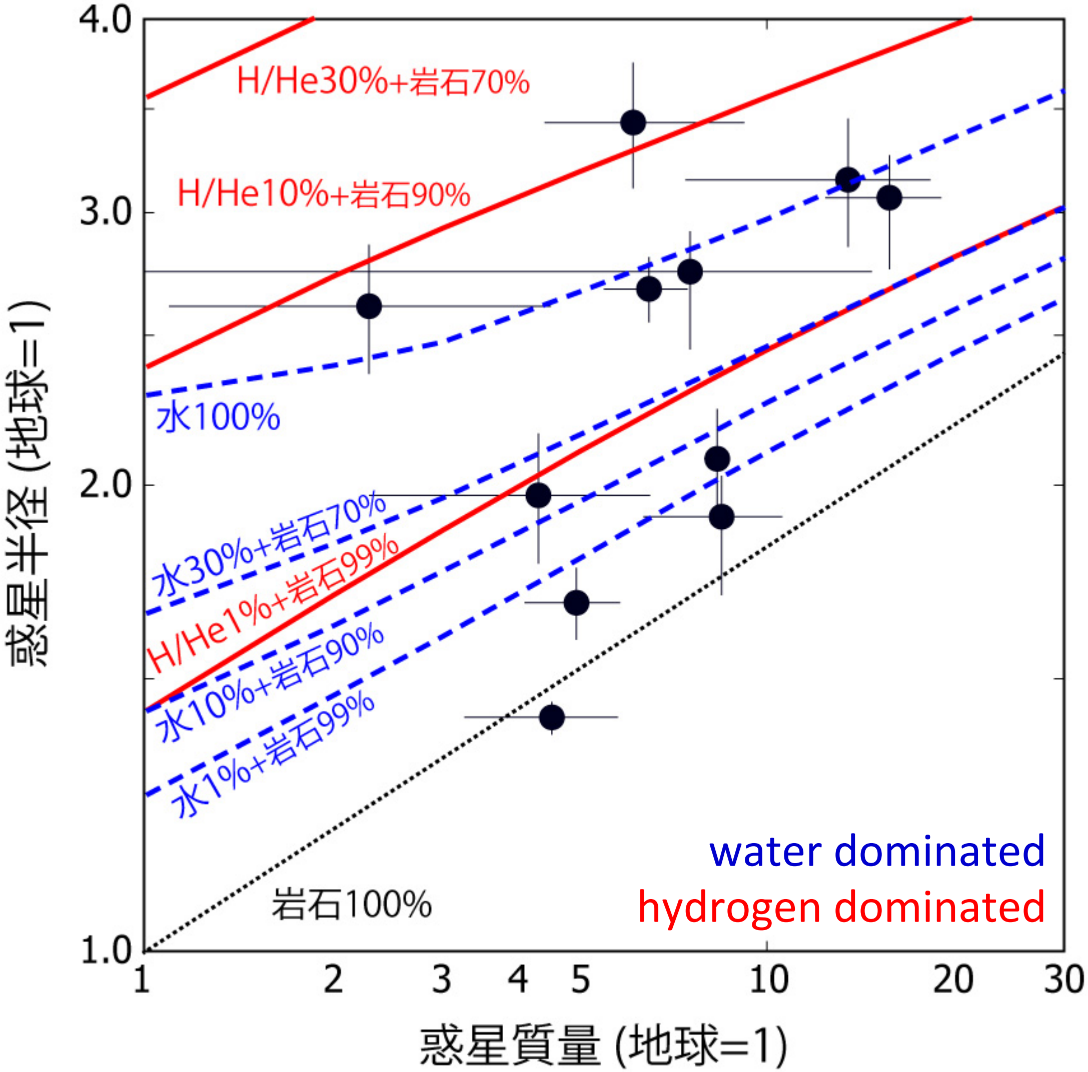
- A new class of planets
  - No corresponding planet in the Solar System
- Many unknowns
  - Formation mechanisms
  - Migration mechanisms
  - Planetary structures
  - Atmospheres
- Important targets toward Earth-twin planets

How to Characterize Transiting Planets

- Transiting planets allow us to probe
  - internal structure of planets
  - atmospheric composition of planets
  - orbital migration history of planets
- Transmission spectroscopy can give us useful clues

Mass-Radius Relation for "Super-Earths"

Courtesy of M. Ikoma

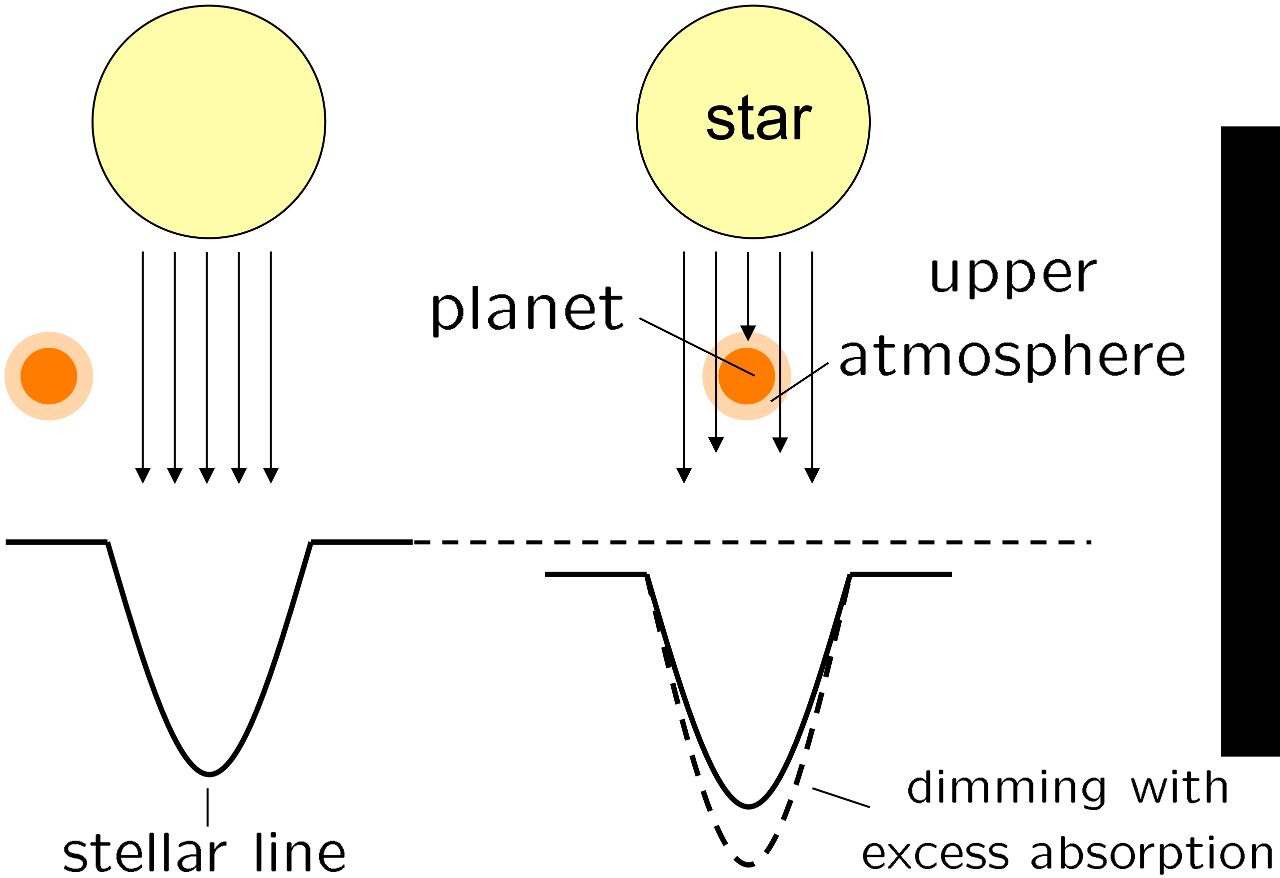


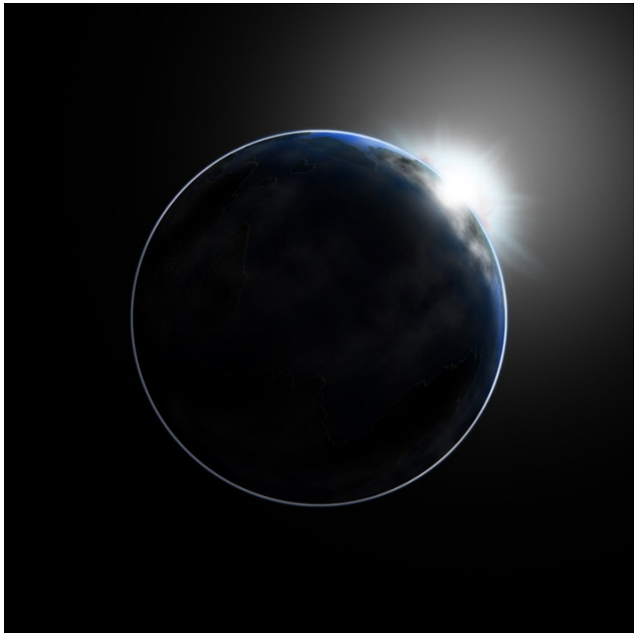
There is a wide diversity of structures of super-Earths.

Theoretical models can predict mass-radius relation for a variety of bulk compositions, but models are often degenerated.

We need further information to solve the degeneracy.

Transmission Spectroscopy



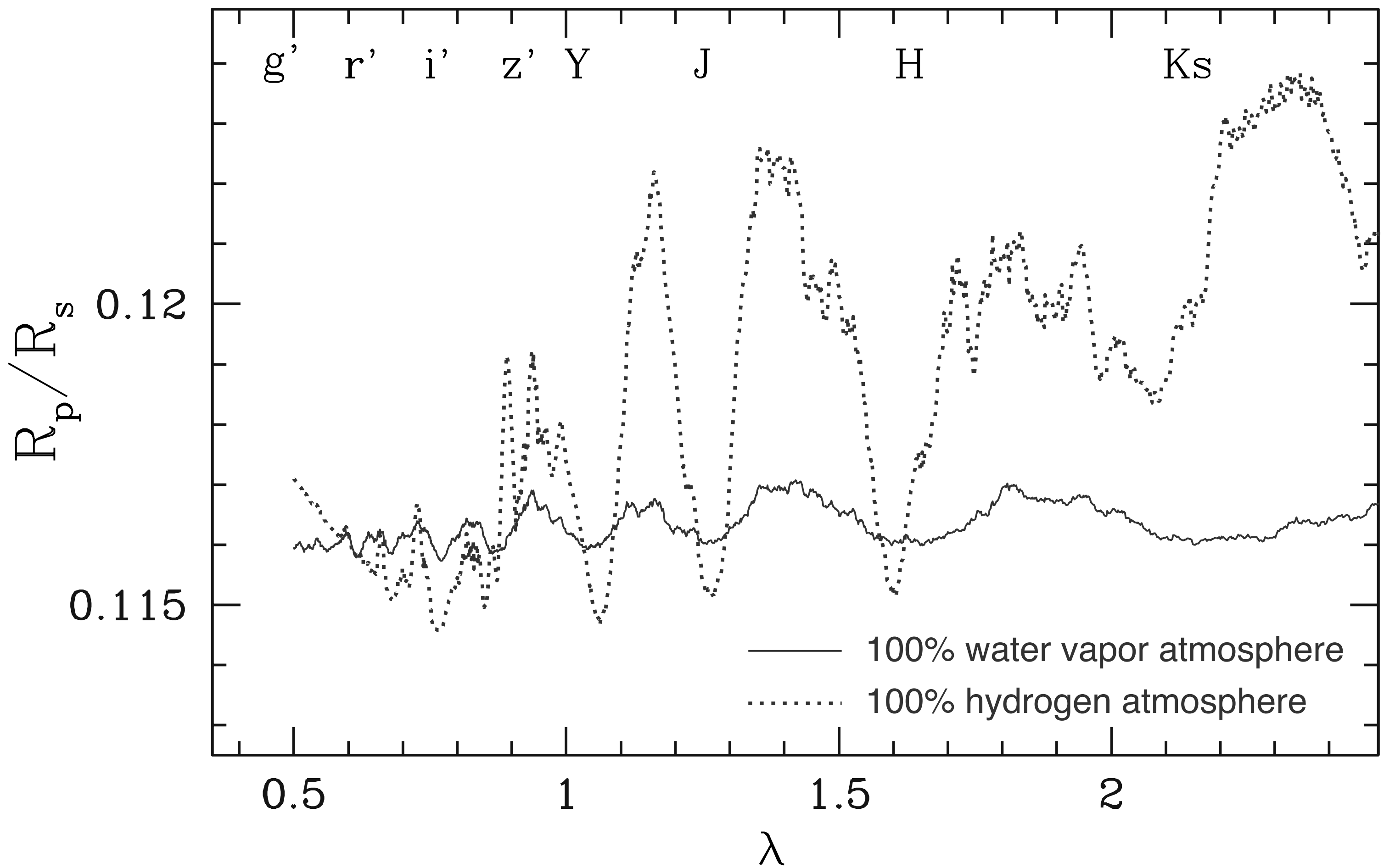


Transit depth depends on lines / wavelength

reflecting atmospheric compositions

Discriminating Major Component of Atmosphere

Multi-band observations are useful to distinguish the major composition



Model for super-Earth GJ1214b based on Miller-Ricci & Fortney (2010)

Various atmospheric models were calculated by Howe & Burrows (2012)

“Water” and Planet Formation and Migration

- Water ice is the major component of solid materials outer than the snow line
- Difficult to acquire *in situ* inner than the snow line

➢ Water is a useful diagnostic for planet formation and migration

- Statistical studies of the major component of inner super-Earths will give useful constraints on formation and migration mechanisms by comparison with planet population synthesis

Motivations for Transmission Spectroscopy

- Transmission spectroscopy of super-Earths enable us to
    1. determine the major component of atmospheres
    2. solve the degeneracy of the mass-radius relation, and allow us to determine the internal structure of planets
    3. constrain planetary formation / migration

Good Targets for Transmission Spectroscopy

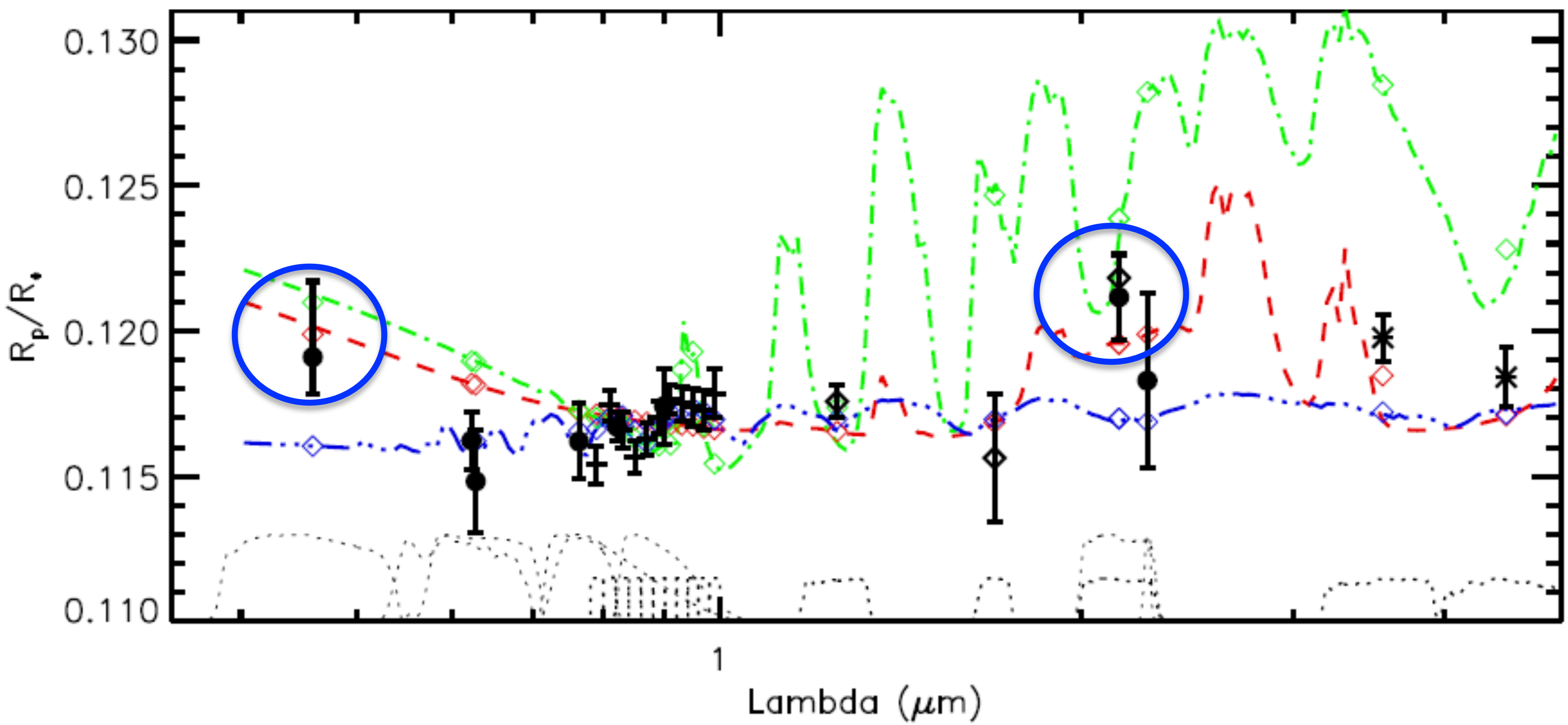
- Large transit depth (large R_p/R_s)
  - easy to see wavelength dependence
  - smaller host stars (M dwarfs) are favorable
- Bright host stars
  - give higher precision for R_p/R_s
  - nearby stars are brighter

➢ Super-Earths around nearby M dwarfs are the most favorable targets

The First Good Target: GJ1214b

- Transiting super-Earth around M4.5V star (Charbonneau et al. 2009)
- Planet Radius: ~2.7R_{Earth}, Mass: ~6.5M_{Earth}, Period: ~1.58 days
- Transit depth is ~1.5% due to small host star's radius ~0.2R_{Sun}
- only ~13 pc away
- B=16.4, V=14.67, J=9.75, H=9.09, Ks=8.78
- The first (and only by 2012 June) super-Earth for which one can characterize planetary atmosphere in detail

What Previous Observations Found



de Mooij et al. (2012)

Green: H dominated with solar metallicity

Red: H dominated with sub-solar metallicity and cloud layer at 0.5 bar

Blue: Vapor dominated atmosphere

Our Strategies

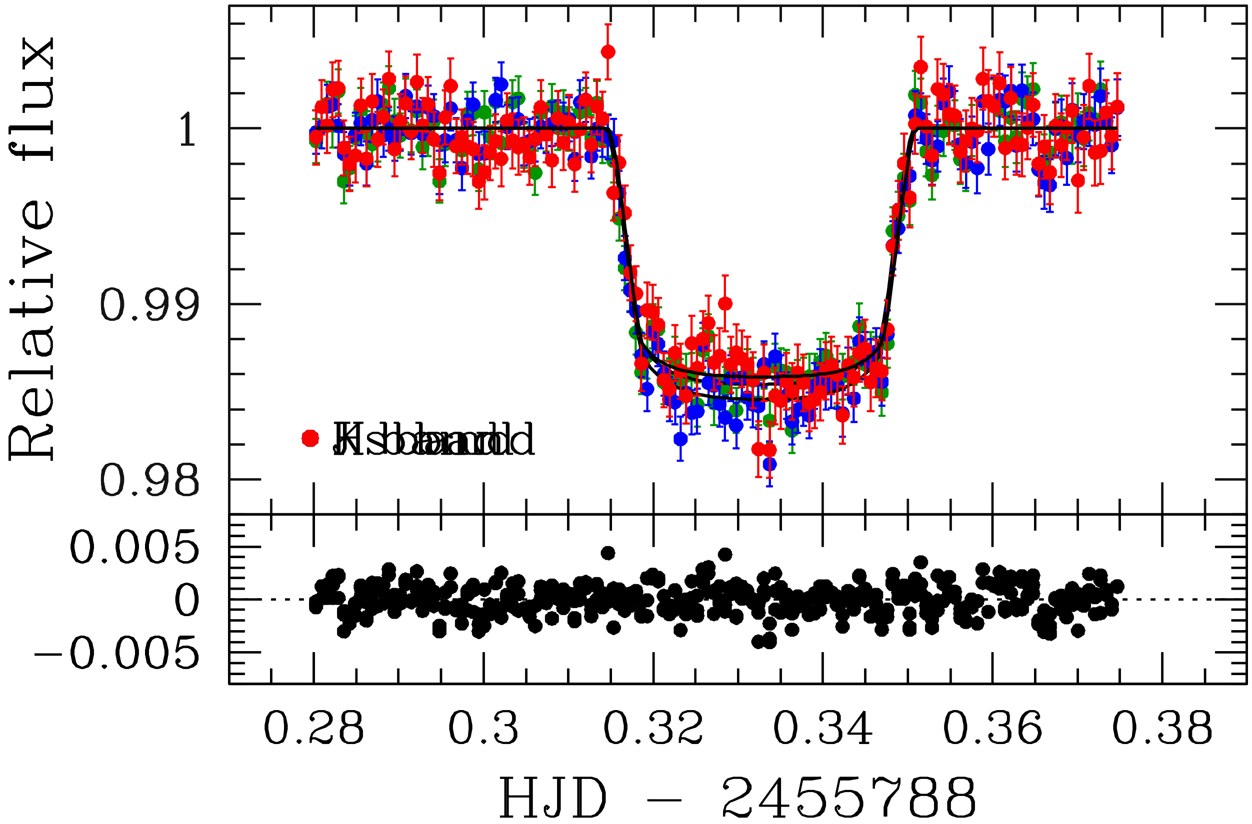
- To confirm or refute the hydrogen dominated atmosphere, we proposed to confirm a deeper transit in Ks and blue wavelength region

- IRSF/SIRIUS for JHKs band in 2011 and 2012
- Subaru/S-Cam and FOCAS for B band in 2012

JHKs Simultaneous Transit Photometry with IRSF

- IRSF is 1.4m telescope located at Sutherland, South Africa
- equips SIRIUS camera, which can take JHKs band images simultaneously
- Obs. date: 2011 Aug 14
- The first NIR 3-color simultaneous transit photometry in the world

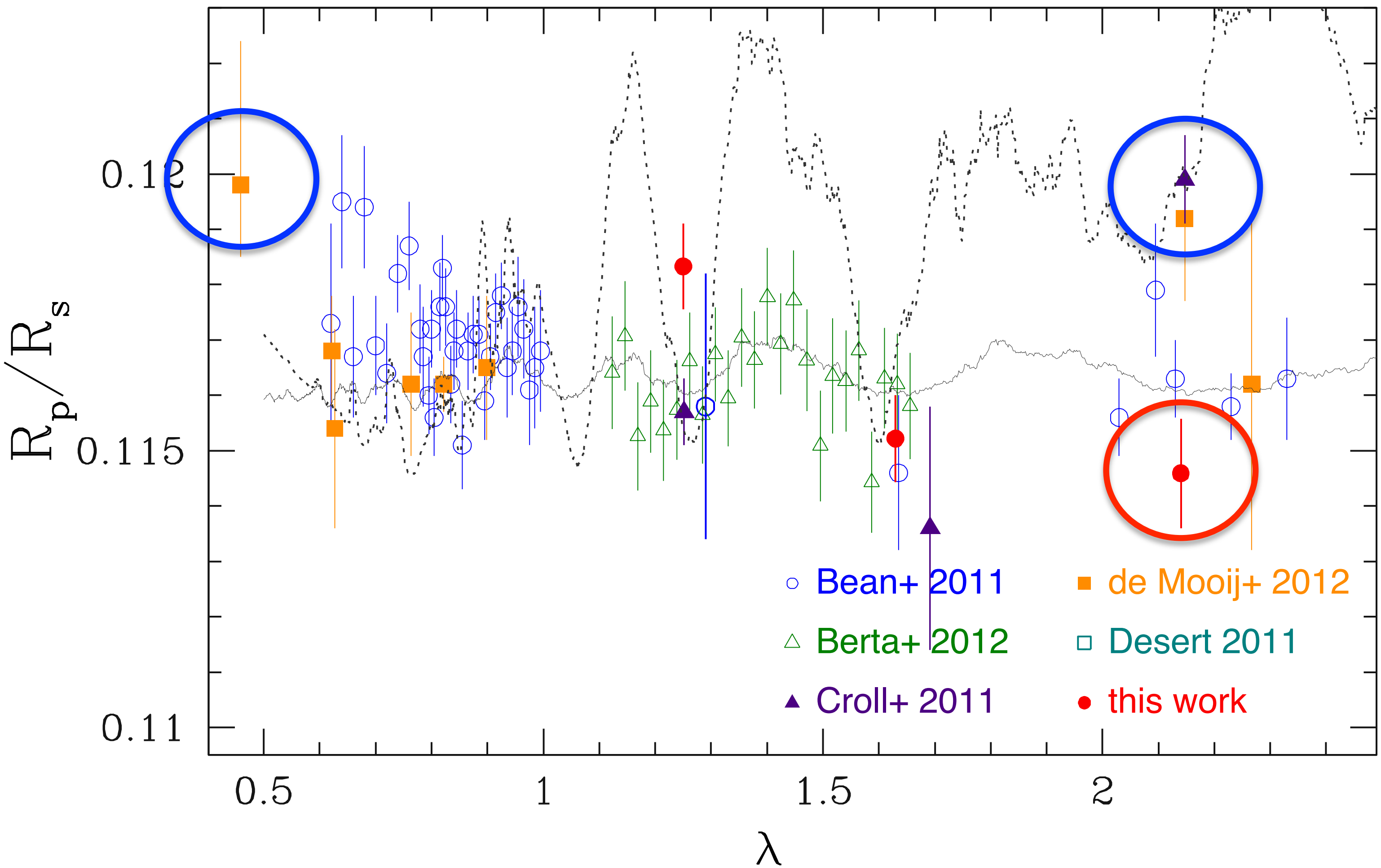
Results@IRSF



Photometric precision was ~0.13% (JH band) / ~0.15% (Ks band)

(Narita et al. 2013, PASJ in press)

Results@IRSF



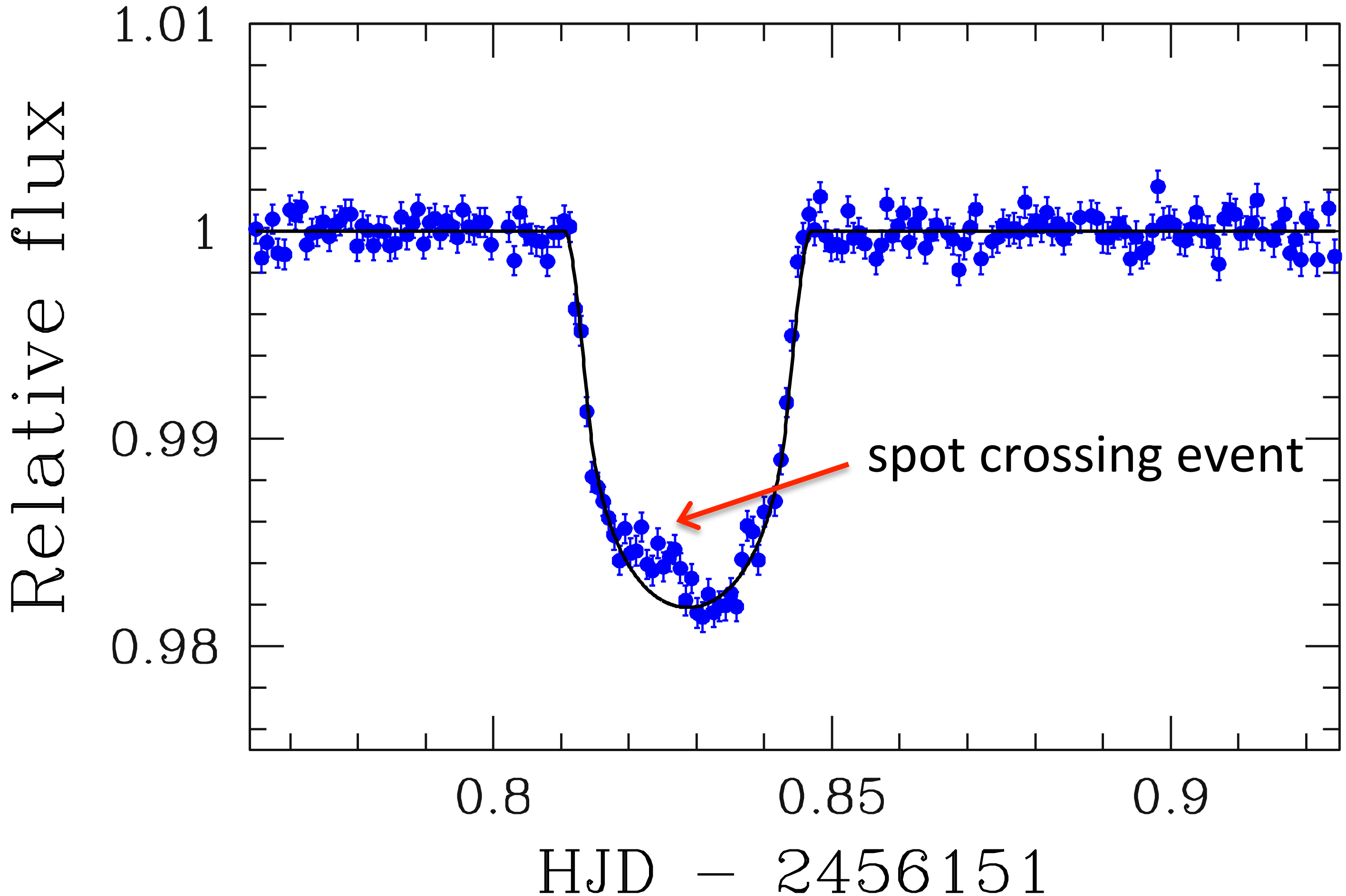
Shallower transit in Ks band, supporting water dominated atmosphere

(Narita et al. 2013, PASJ in press)

Subaru Observations

- accepted as S12B-017
- August 11, 2012 with S-Cam
  - B band (GJ1214 -> B = 16.4 mag)
  - Auto-guider trouble (-> but no problem)
  - exposure time: 40 sec, dead time: 30 sec
- October 7, 2012 with FOCAS + IRM2
  - B band (effect of IRM2 is still unclear)
  - exposure time: 40 sec, dead time: 23 sec
  - twilight and low elevation

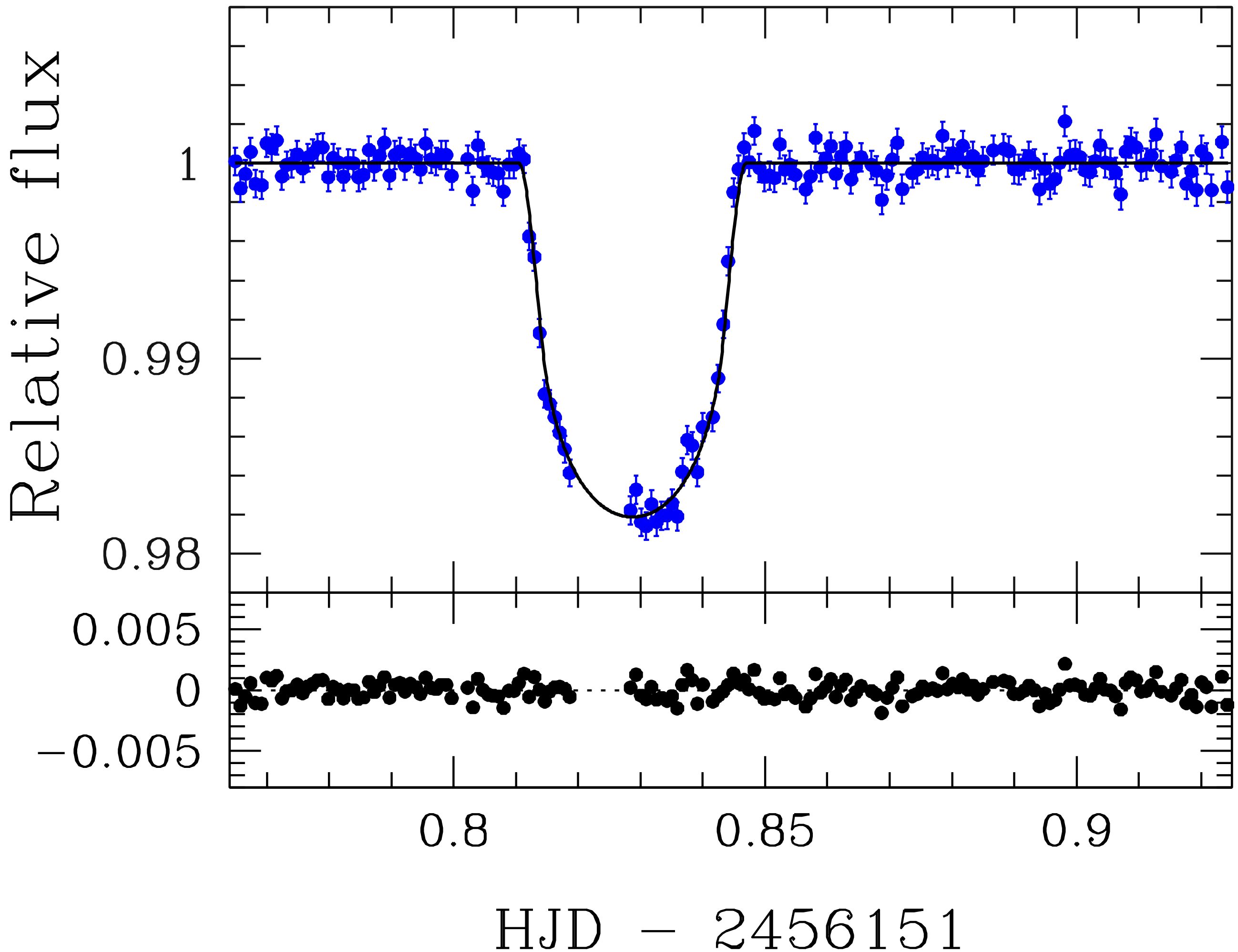
Result with Subaru S-Cam



Photometric precision was 0.08% at B band

(Narita et al., in prep.)

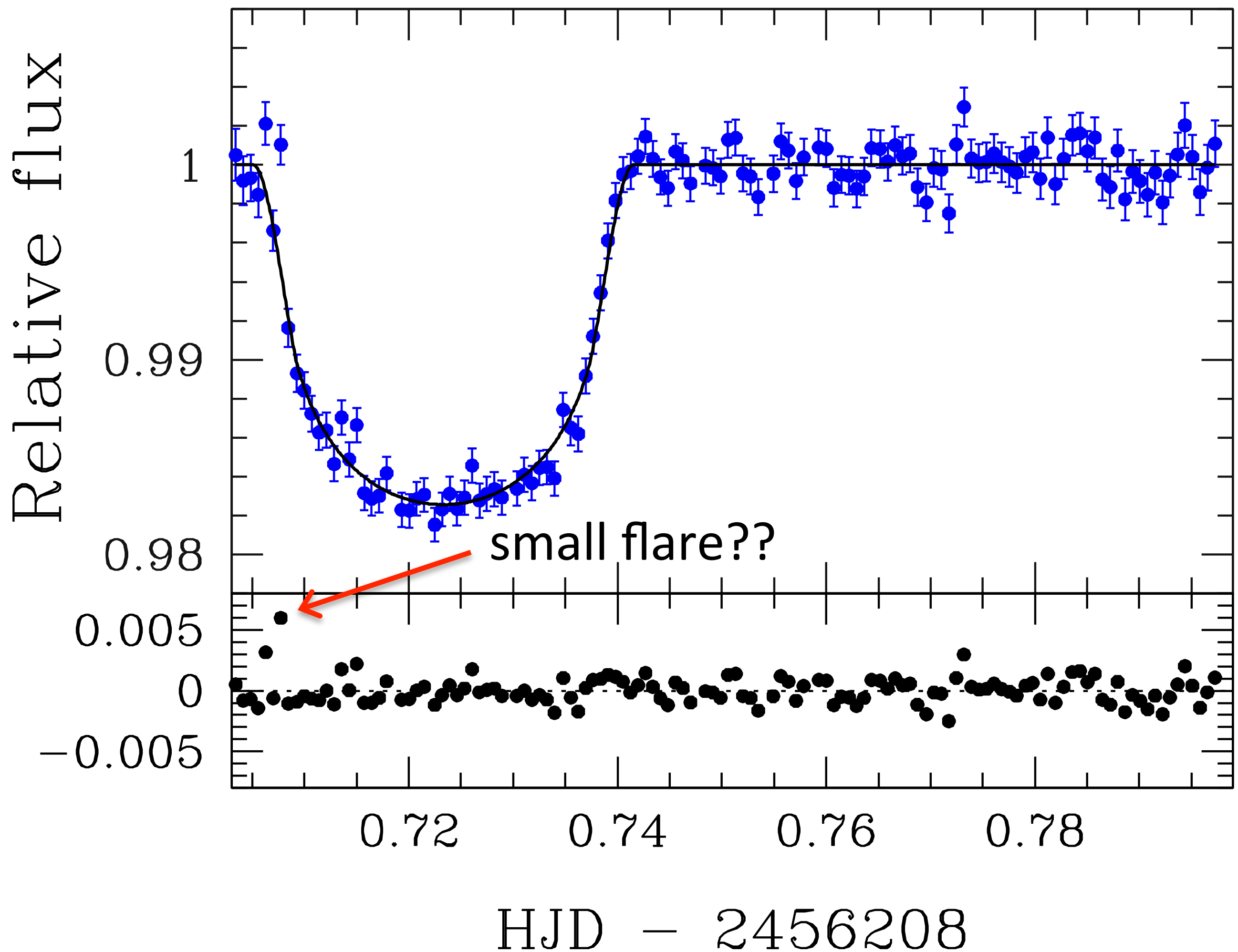
Result with Subaru S-Cam



Photometric precision was 0.08% at B band

(Narita et al., in prep.)

Result with Subaru FOCAS (+ IRM2)



Photometric precision was 0.1% at B band

(Narita et al., in prep.)

Speculations for GJ1214b

- The most plausible model is water-dominated atmosphere
- GJ1214b cannot acquire water *in situ* due to its close-in orbit (P=1.58 days)
  - migrated from outer region beyond the snow line?
  - acquisition by comet/asteroids bombardment?
- Migration process is still unknown
  - Need measurement of the Rossiter-McLaughlin effect with IRD

Subaru Capability and Future Prospects

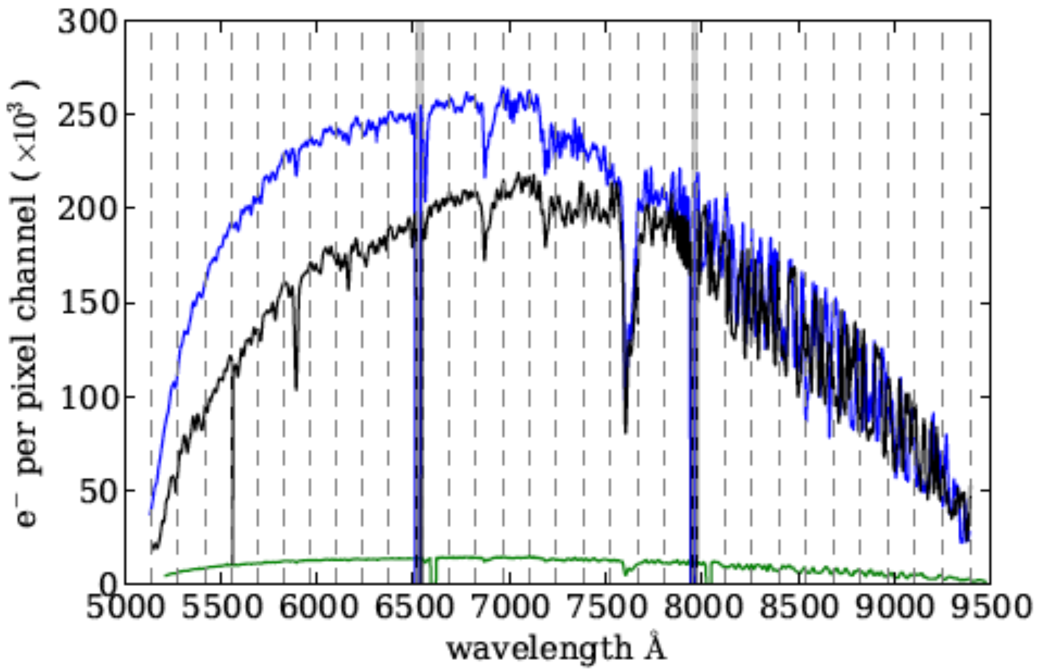
- New Observing method
- New targets

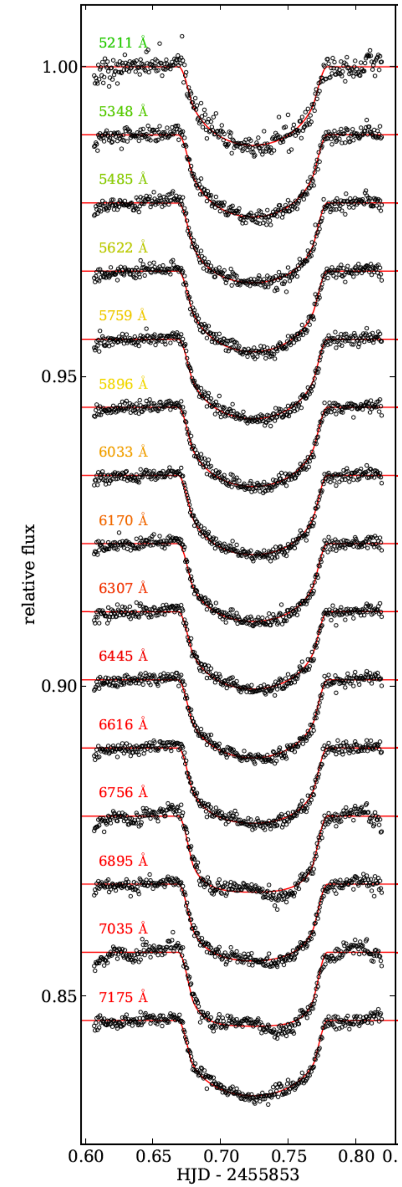
Transmission Spectroscopy by MOS

- One can do transmission spectroscopy using MOS (multi-object spectroscopy) instruments
  - e.g., VLT/ FORS2, Gemini/GMOS (Subaru/FOCAS, MOIRCS)
  - VLT/FORS2 and Gemini/GMOS already showed excellent results

- Simultaneously observe target and reference stars
  - using very wide slit (~10”) to avoid light-loss from slits
  - wide field of view is preferred to find good reference stars
  - integrate wavelength to create high precision light curves

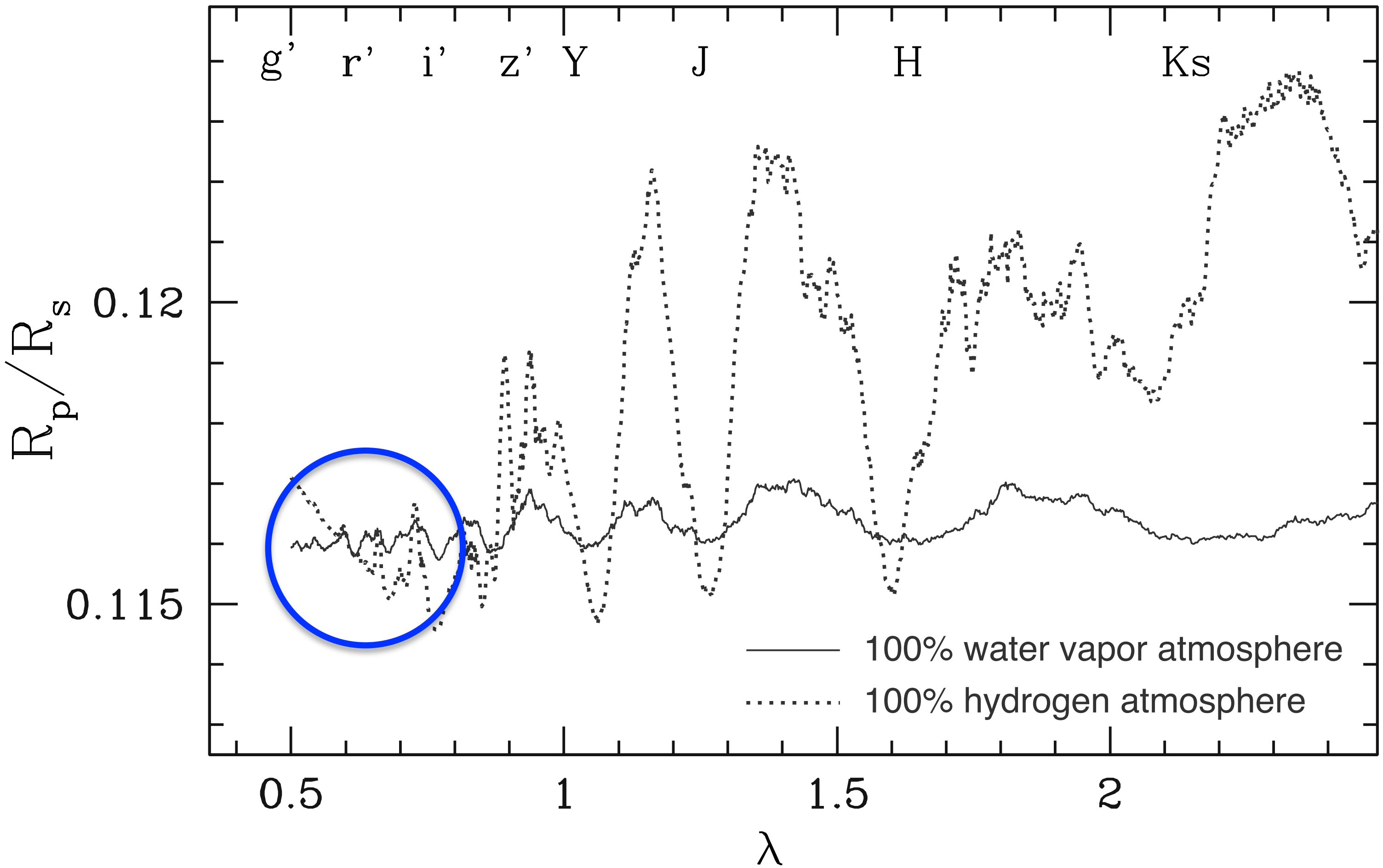
Recent Example by Gibson+ (2012)





- Instrument: Gemini South/GMOS
- Target: WASP-29 (V=11.3)
- Integration: about 15 nm (R ~ 40)
- Precision: ~400 ppm by 5 min binning

MOS is useful to see Rayleigh Scattering



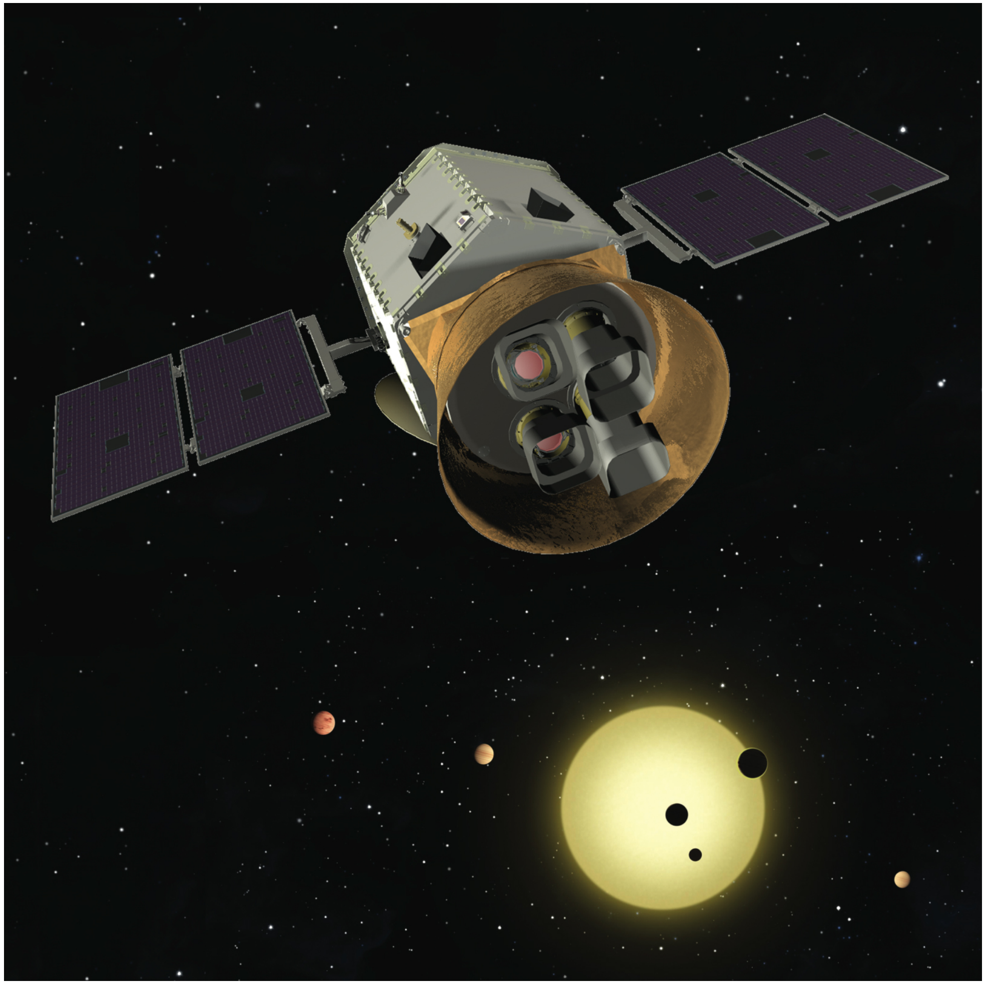
The slope reflects the strength of Rayleigh scattering of planetary atmosphere

Prospects for New Transiting Super-Earths

- Several teams in the world (including IRD team) aims to discover new transiting super-Earths around nearby M dwarfs
  - by both RV survey and transit survey

- Expected (realistic) number of targets for TS
  - several by IRD + transit follow-up
  - a few by ground-based transit survey and IRD follow-up
  - around 10 by 2016

All-Sky Transit Survey: TESS (by MIT/NASA)



Currently proposed to NASA. Selection result will be announced in Feb 2013.

If selected, TESS will be launched by 2016.

TESS Discovery Space

- Targets
  - Bright nearby stars with I = 0-12 mag (FGKM stars)
- Period of detectable planets
  - typically less than 10 days
  - up to ~60 days for specific fields
  - Planetary orbits with less than 10 (60) days period lie in habitable zone around mid (early) M stars
  - expected to discover ~500 super-Earths (around all-type stars and near-to-far) by 2020

Summary

- Subaru S-Cam / FOCAS have shown excellent photometric precision (sub-mmag) for GJ1214b
  - Suggesting water-dominated atmosphere of GJ1214b
- More targets will be available in near future
  - MOS capability is more useful for transmission spectroscopy
  - Subaru will become one of the most useful telescope for this kind of study