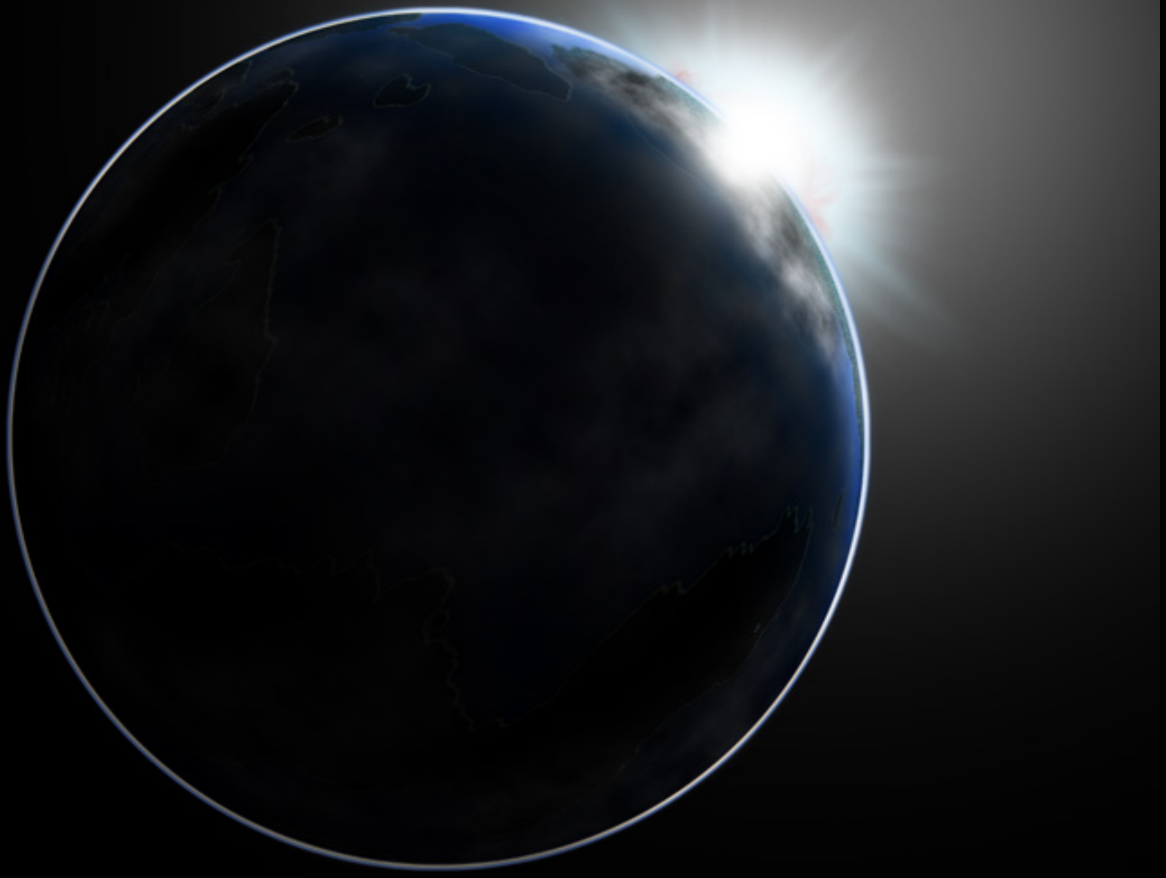
Exoplanetary Science with Multi-Object Spectrographs (and GLAO)



Norio Narita (NAOJ)

Outline

- Conclusion of My Considerations
- Current Status of Exoplanetary Science
  - Summary of Previous Discoveries
  - Future Prospects
  - Transmission Spectroscopy of Transiting Planets
  - Science Case and Possible Contribution
- Answers to the Questions

Brief Results of My Considerations

- Unfortunately, exoplanetary science will NOT be a key science for GLAO
- But Wide Field Imager & MOS will be useful for a kind of observations for exoplanets
- The purpose of this talk is to introduce such a science case and to discuss whether the exoplanetary science can contribute to this project

What is going on with Exoplanetary Science?

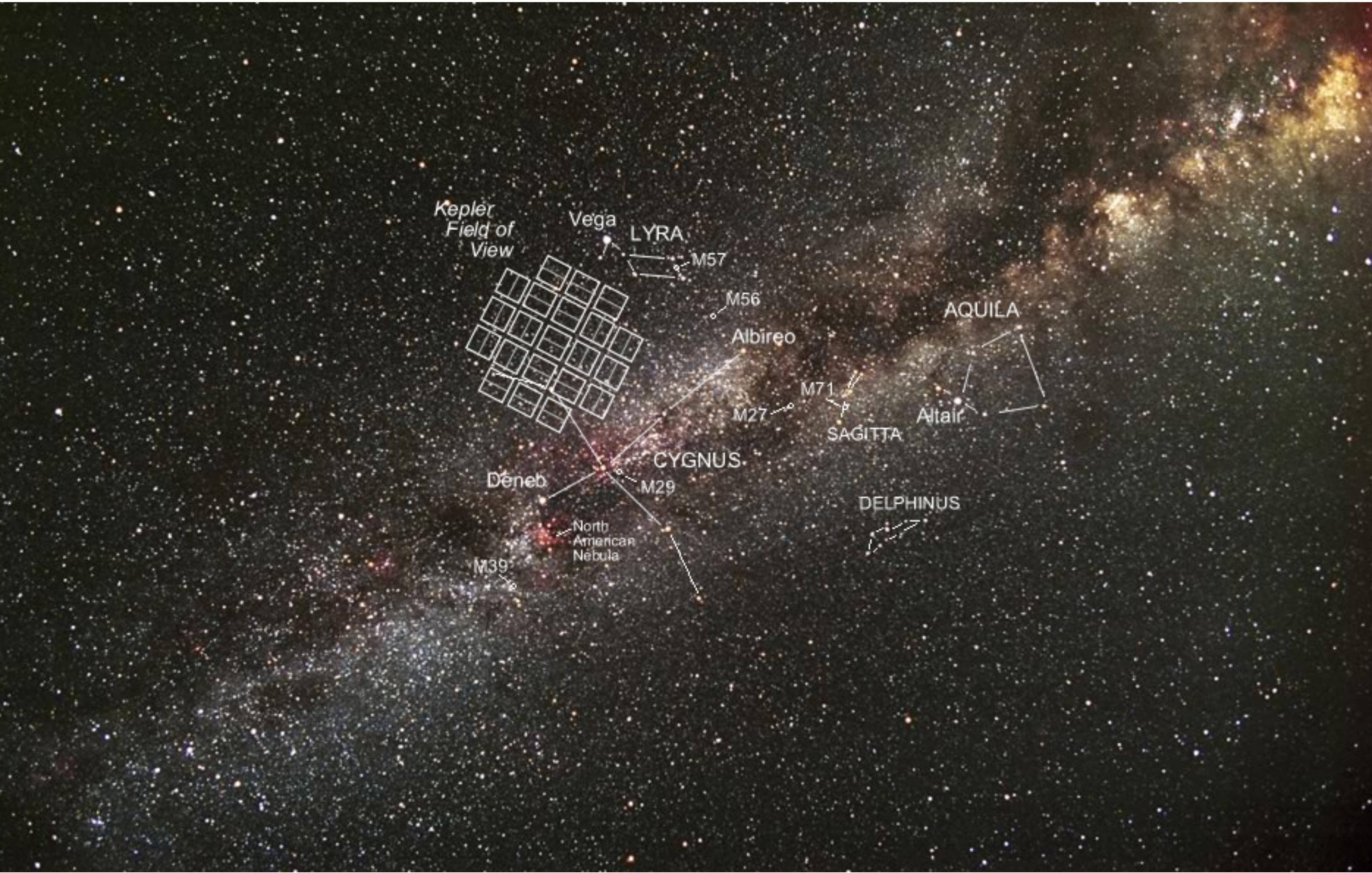
- over 850 planets confirmed by various methods
  - radial velocity, transit, microlensing, direct imaging, etc
- over 2500 planet candidates discovered by Kepler
  - habitable planets
  - Earth-size and even smaller-size planets
  - circumbinary planets
- diversity of planetary systems recognized
- planet occurrence frequency estimated

Dedicated Space Mission for Transit Survey

NASA’s Kepler

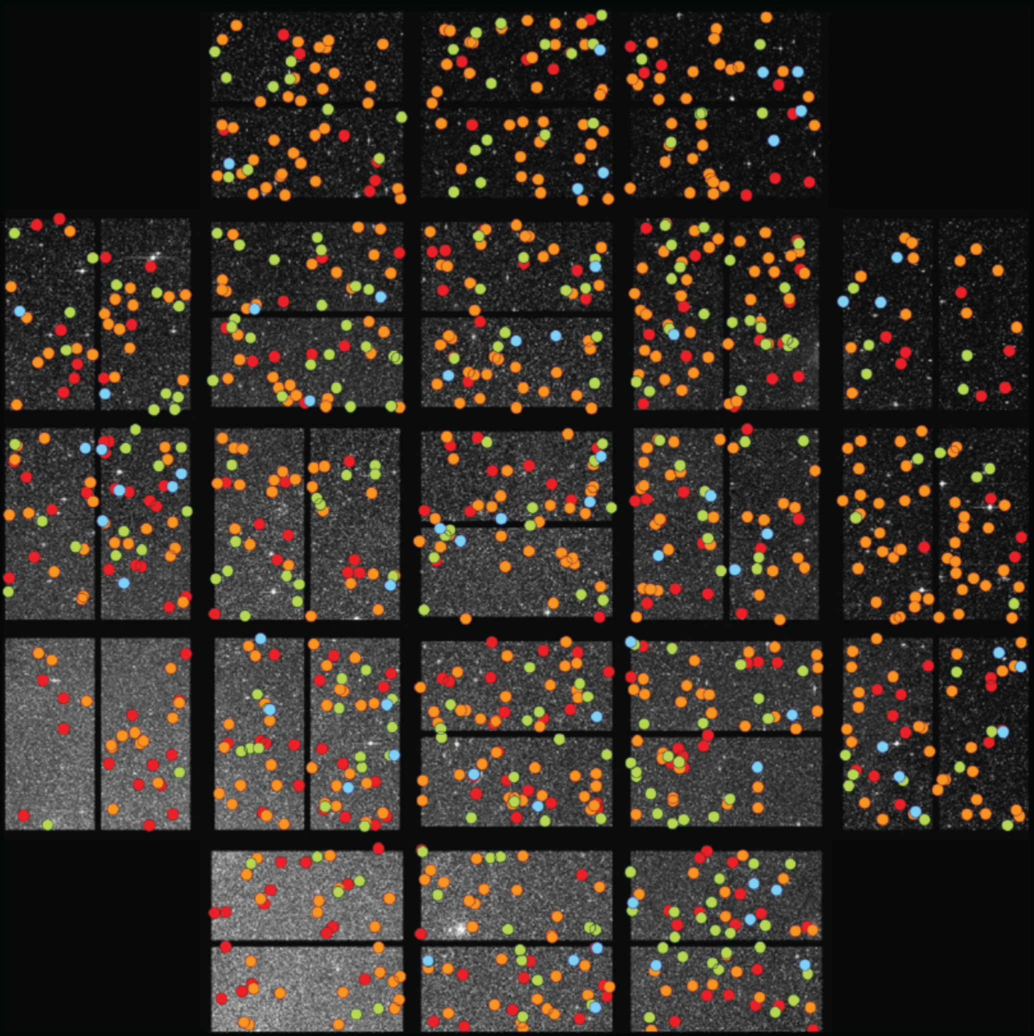
launched 2009/3/6, out of order 2013/5/16

Kepler Field of View



First 4 Month Kepler Planet Candidates

- ● Earth-size
  <1.25 R_E
- ● Super-Earth size
  1.25 - 2.0 Earth-size
- ● Neptune-size
  2.0 - 6.0 Earth-size
- ● Giant-planet size
  6.0 - 22 Earth-size



1235 Planet Candidates

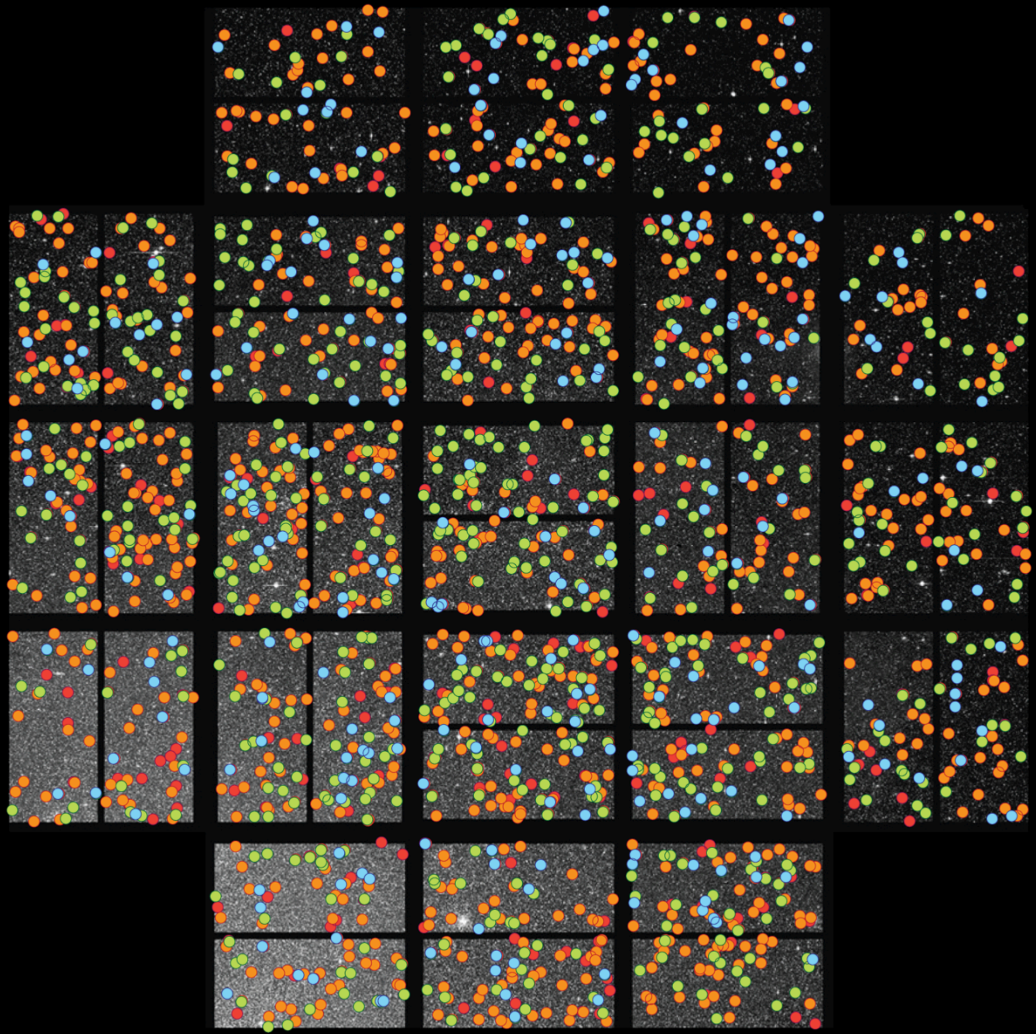
Planet Candidates as of Jan 2013

🔵 Earth-size
<$1.25\ R_E$

🟢 Super-Earth size
1.25 - 2.0 Earth-size

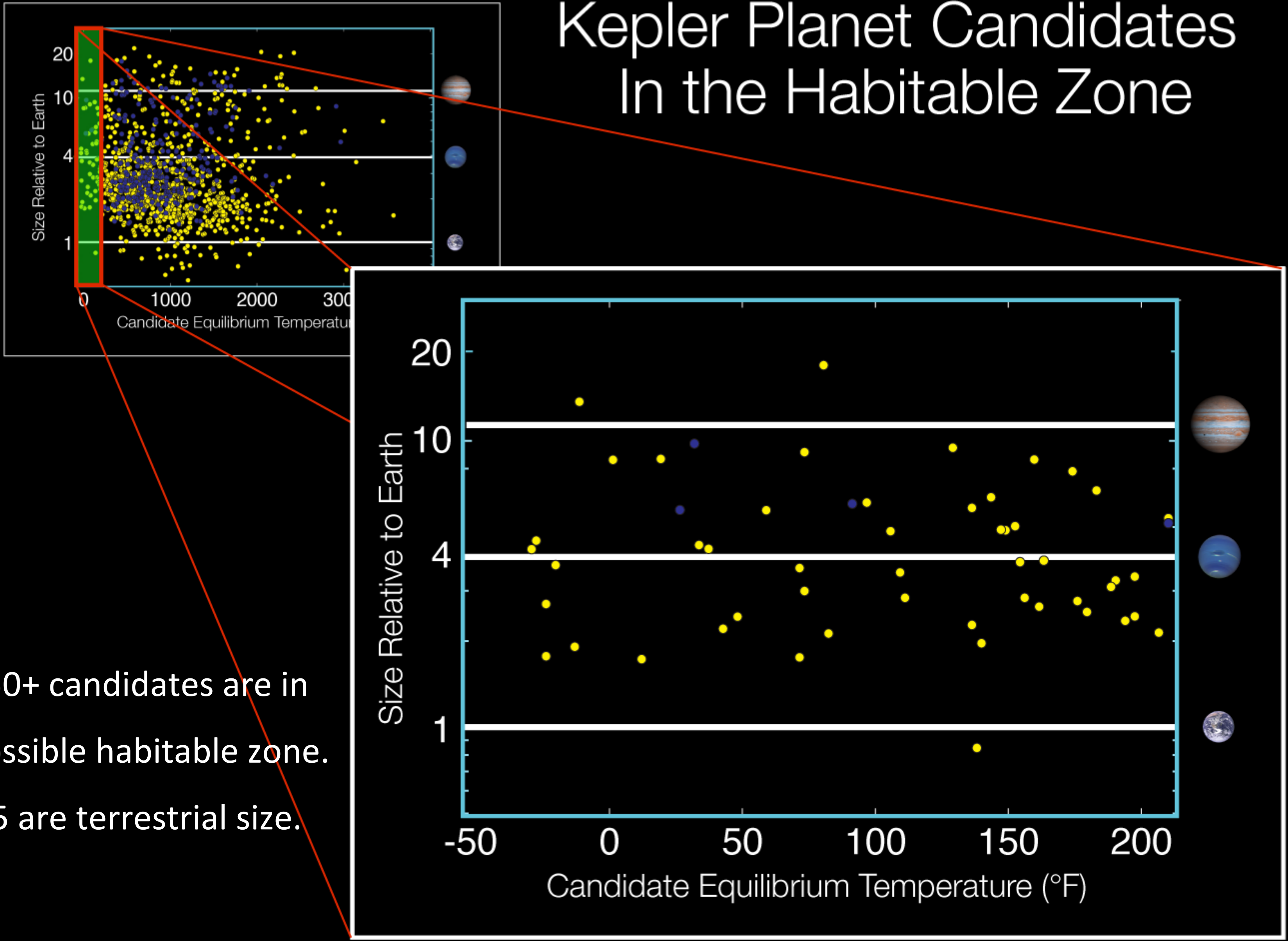
🟠 Neptune-size
2.0 - 6.0 Earth-size

🔴 Giant-planet size
6.0 - 22 Earth-size



2740 planet candidates

Kepler Planet Candidates
In the Habitable Zone

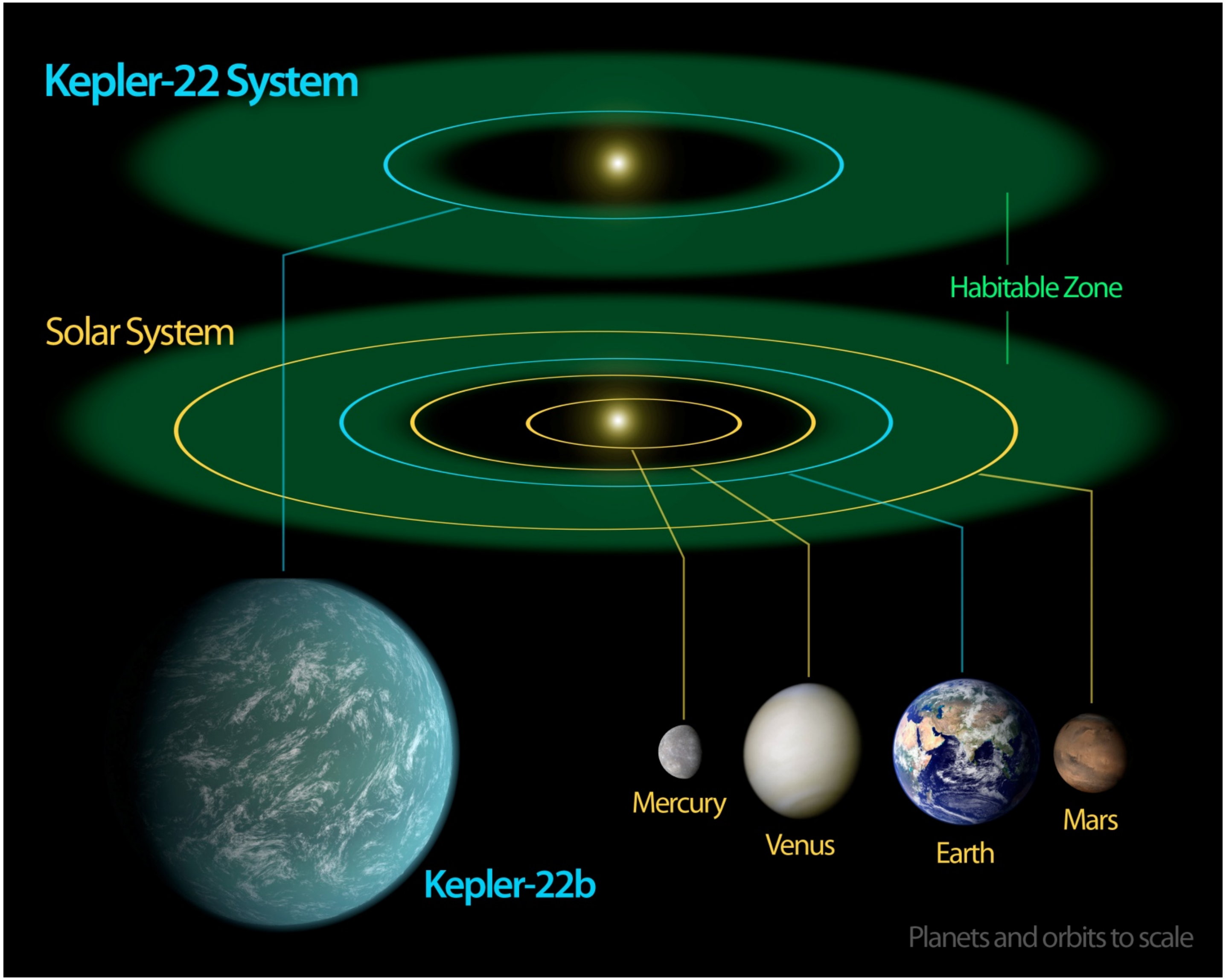


50+ candidates are in

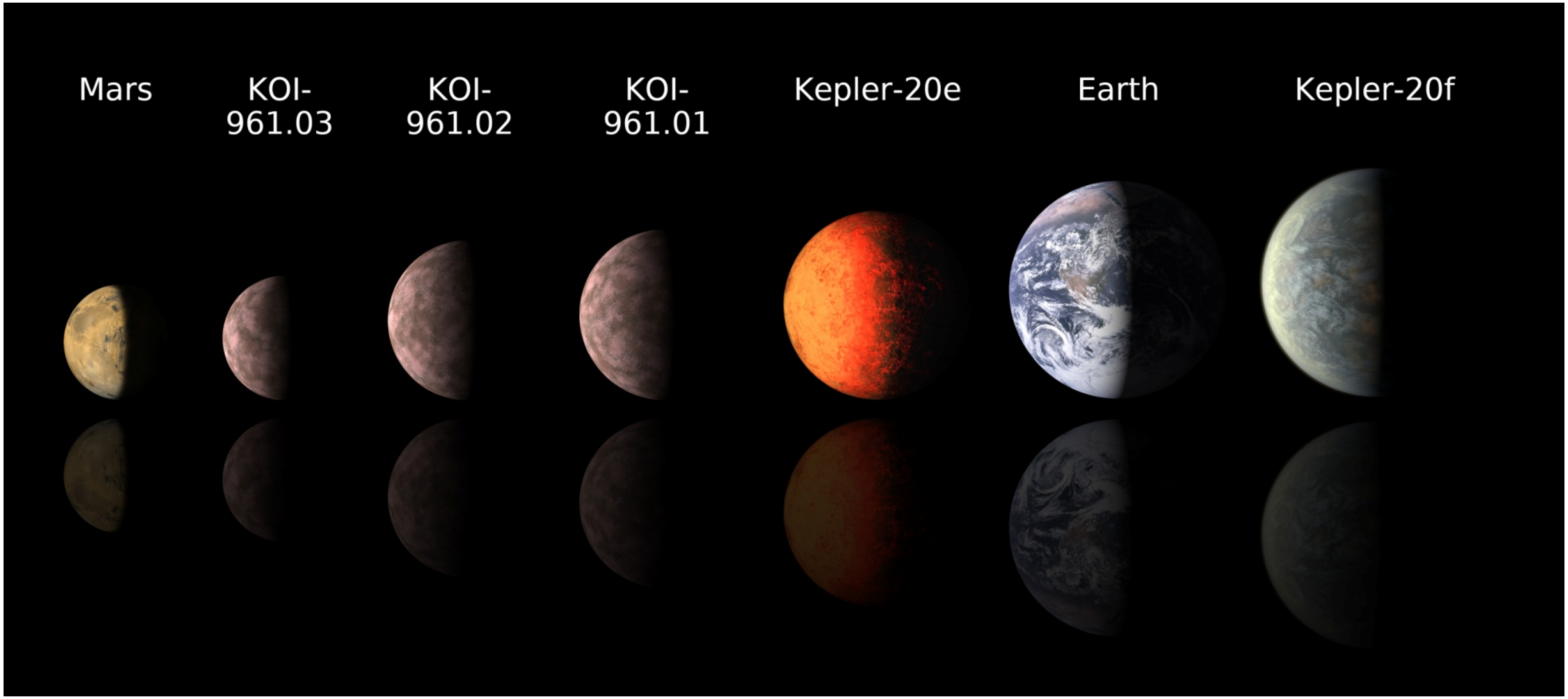
possible habitable zone.

5 are terrestrial size.

Possible Habitable Planet Kepler-22b



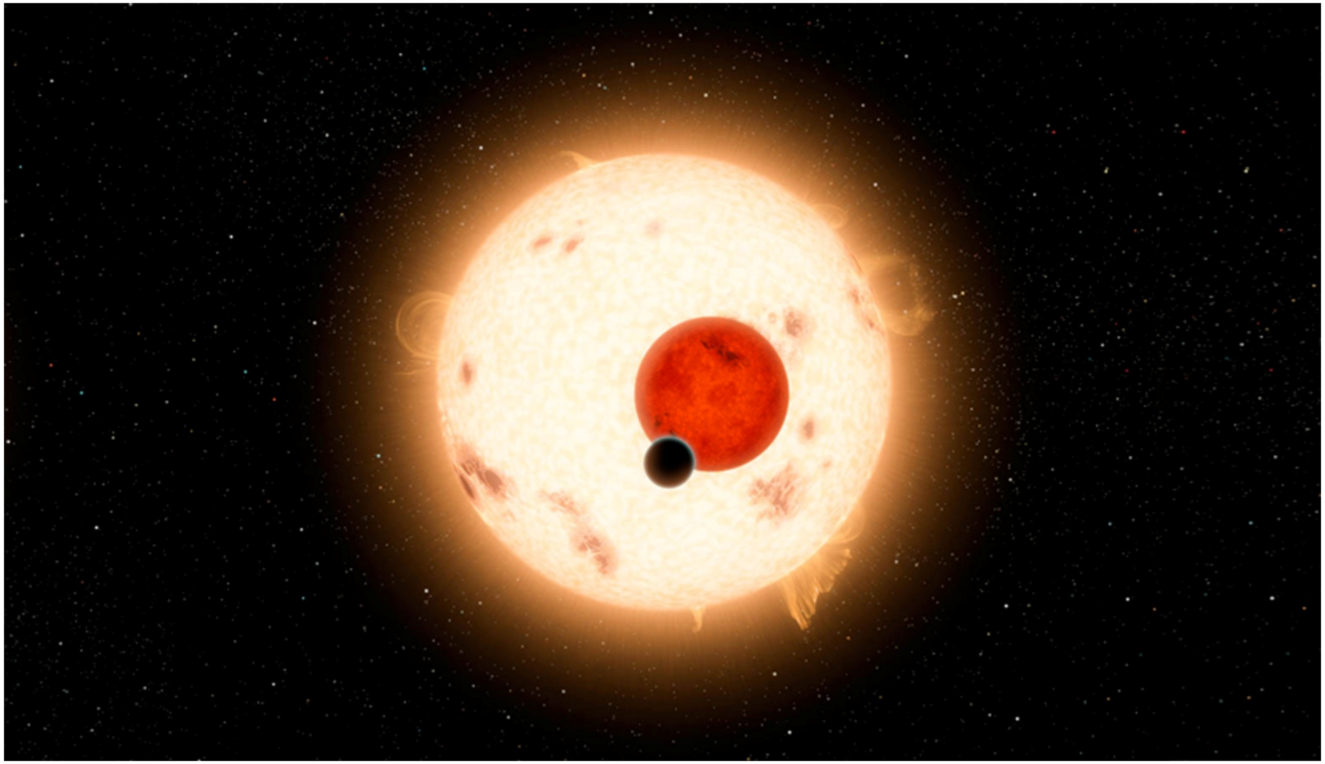
(Sub-)Earth-sized Planets



Earth–sized planet Kepler–20f

Mars–sized planet KOI–961.03 (renamed as Kepler–42d)

Now Not a Science Fiction



Planetary Systems with Two Suns: Kepler-16, 34, 35, 47
→ Tatooine-like (in Star Wars) planets

Summary of Current Status

- Various (diverse) exoplanets have been discovered
  - hot Jupiters
  - hot Nuptunes
  - super Earths
  - habitable planets
  - Tatooine-like planets
- Each star has more than 1 planet on average
- What’s next?

Kepler’s Weakness

- Kepler’s targets are relatively faint and far
  - Although over 2500 candidates discovered, RV follow-ups for all targets are difficult
  - Further characterization studies are also difficult

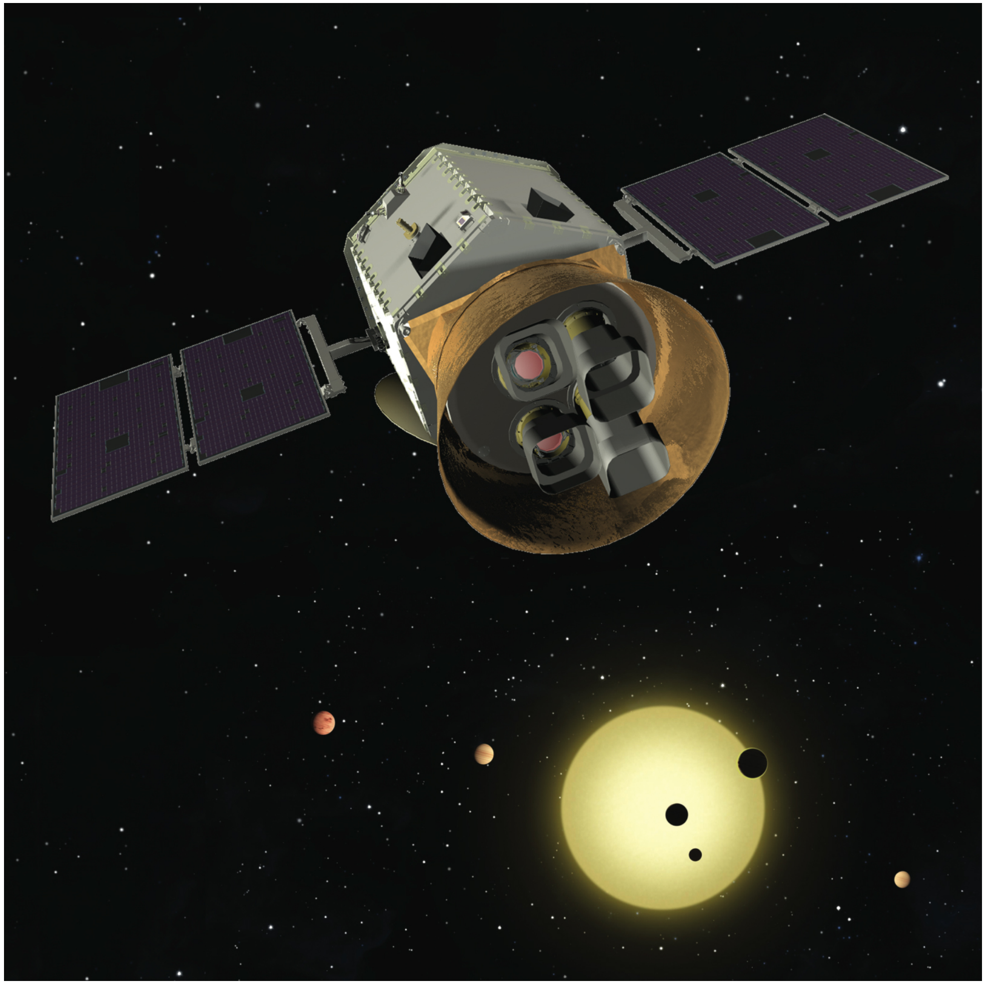
➢ Kepler is good for statistical studies, but not for characterization studies for each planet

Strategy of Future Transit Survey

- Future planet surveys will target nearby bright stars to detect smaller (Earth-like or super-Earth) planets, especially in the habitable zone

- Space-based all-sky transit survey for bright stars
  - TESS (Transiting Exoplanet Survey Satellite) by MIT team
- Ground-based transit survey for nearby M dwarfs
  - MEarth lead by D. Charbonneau at Harvard
  - Other teams all over the world
  - Japanese IRD transit group

All-Sky Transit Survey: TESS



Approved by NASA in April 2013.

TESS will be launched in 2017.

Table F-17: TESS Science Team Co-Investigators

Name	Institution	TESS Responsibility
G. Ricker[N]	MIT	Principal Investigator
R. Vanderspek[N]	MIT	Deputy PI; TESS SOC Manager
D. Latham[C,K]	CfA	Director, Science Office; Follow-up Task lead
J. Winn[N,K]	MIT	Deputy Director, Science Office; TOI Task lead
J. Villasenor[N]	MIT	MIT Payload Scientist; POG lead
G. Bakos[N]	Princeton	False positive rejection
T. Brown[C,K]	LCOGT	LCOGT follow-up; asteroseismology
D. Charbonneau[N,K]	CfA	MEarth follow-up; TOI identification
J. Christiansen-Dalsgaard[C,K]	Aarhus	Asteroseismology
M. Clampin[N]	NASA GSFC	JWST follow-up
D. Deming[N]	U. Maryland	JWST and ground-based follow-up
J. Doty[N]	Espace/MIT	Transit detection strategy; POG staff
E. Dunham[N,K]	Lowell Obs.	Camera ground testing; SOFIA follow-up
M. Holman[C,K]	CfA	Transit timing variation analyses
J. Jenkins[N,K]	SETI Inst.	Adaptation of Kepler methodology; DPG lead
G. Jernigan[N]	Espace/MIT	Transit detection algorithms; SEO Science
L. Kaltenegger[C]	MPIA	Modeling of super-Earth atmospheres
G. Laughlin[N]	UCSC	Optimization of follow-up strategy
A. Levine[N]	MIT	Survey simulations; TOI identification
D. Lin[N]	UCSC	Population synthesis for survey planning
J. Lissauer[N,K]	NASA Ames	Planet formation theory
P. McCullough[N]	STScI	MAST liaison, HST follow-up
S. Rinehart	GSFC	Project Scientist
D. Sasselov[N,K]	CfA	Exoplanet interior modeling
S. Seager[N,K]	MIT	Exoplanet atmosphere modeling
K. Stassun[N]	Vanderbilt	Target catalog preparation
A. Szentgyorgyi[N]	CfA	HARPS-N follow-up coordination
G. Torres[N,K]	CfA	Catalog preparation; False positive rejection
S. Udry[C]	Geneva Obs.	Coralie and HARPS-S follow-up

N=NASA-funded; C= Contributed; K=Kepler Team Member

Table F-18: TESS Science Team Collaborators

Name	Institution	TESS Responsibility
J. Andersen	NBI, Denmark	Follow-up observations
J. Bean	U Chicago	Follow-up observations
F. Bouchy	OHP, France	Follow-up spectroscopy
L. Buchhave	NBI, Denmark	Follow-up spectroscopy
P.I Butler	Carnegie/DTM	Follow-up spectroscopy
J. Carter	CfA	Transit detection algorithms; TOI ID
W. Cochran	U Texas	Follow-up spectroscopy
N. de Lee	Vanderbilt	Target catalog
M. Endl	U Texas	Follow-up spectroscopy
J. Ge	U Florida	Follow-up spectroscopy
T. Henning	MPIA/Heidelberg	Follow-up spectroscopy
A.Howard	U Hawaii	Follow-up spectroscopy
S. Ida	Tokyo Tech	Planet formation theory
J. Johnson	Caltech	Follow-up spectroscopy, imaging
N. Kawai	Tokyo Tech	Follow-up observations
G. Marcy	UC Berkeley	Follow-up spectroscopy
P. McQueen	U Texas	Follow-up spectroscopy
T. Morton	Caltech	False positive rejection
N. Narita	NAOJ, Japan	Follow-up spectroscopy
M. Paegert	Vanderbilt	Target catalog
F. Pepe	Geneva Obs.	Follow-up spectroscopy
J. Pepper	Vanderbilt	Target catalog
E. Palle	IAC-Spain	Follow-up spectroscopy
A. Quirrenbach	U Heidelberg	Follow-up spectroscopy
B. Sato	Tokyo Tech	Follow-up spectroscopy
A. Sozzetti	INAF, Italy	Target catalog, GAIA liaison

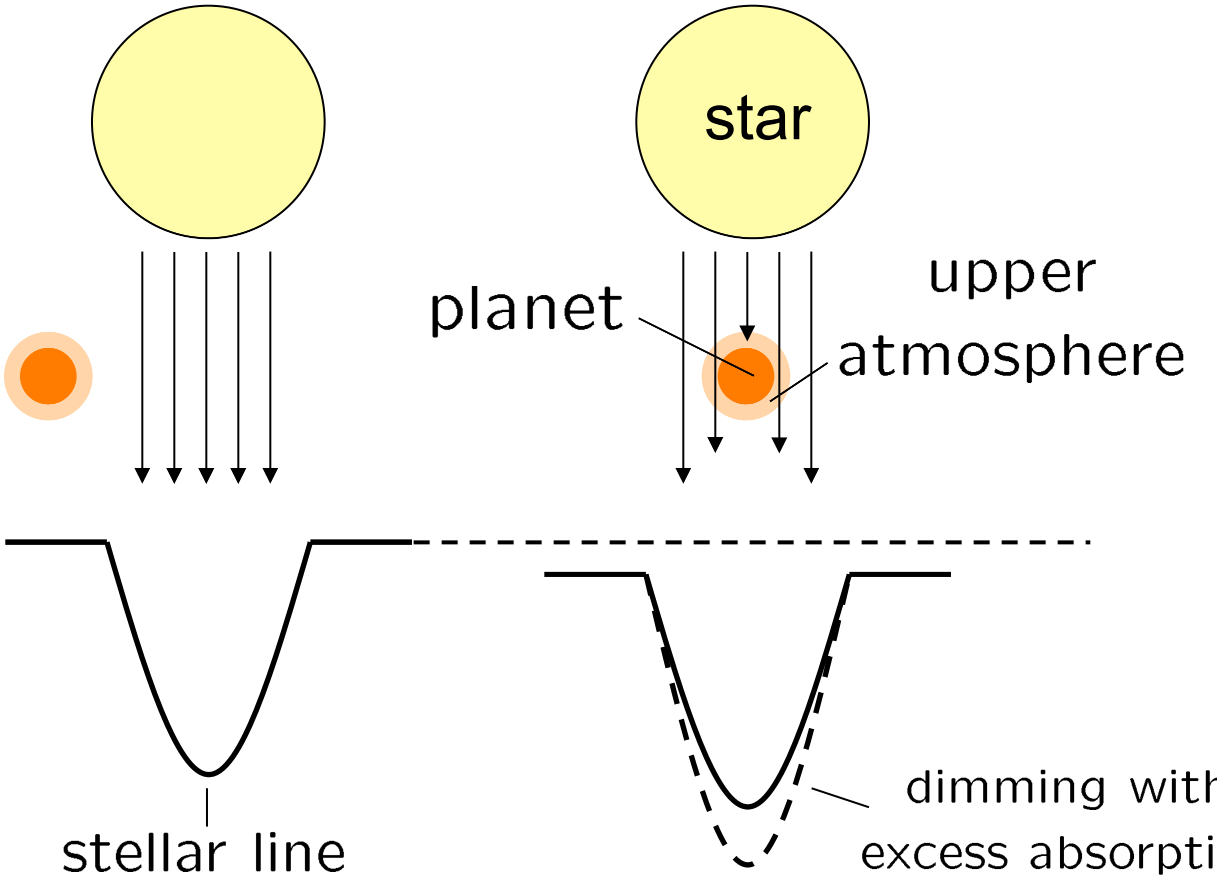
of $R<2.0\ R_E$ planets in the HZ as a 4-year Kepler mission, with the TESS planets occurring in systems with host stars that are 30-100 times brighter than are the Kepler host stars.

TESS Discovery Space

- Targets
  - Bright nearby stars with I = 4-12 mag (FGKM stars)
- Period of detectable planets
  - typically less than 10 days
  - up to ~60 days for JWST optimized fields
  - Planetary orbits with less than 10 (60) days period lie in habitable zone around mid (early) M stars
  - expected to discover ~500 Earths and super-Earths (including expected 5±2 habitable planets) by ~2020

Characterization of their Atmospheres

Transmission Spectroscopy



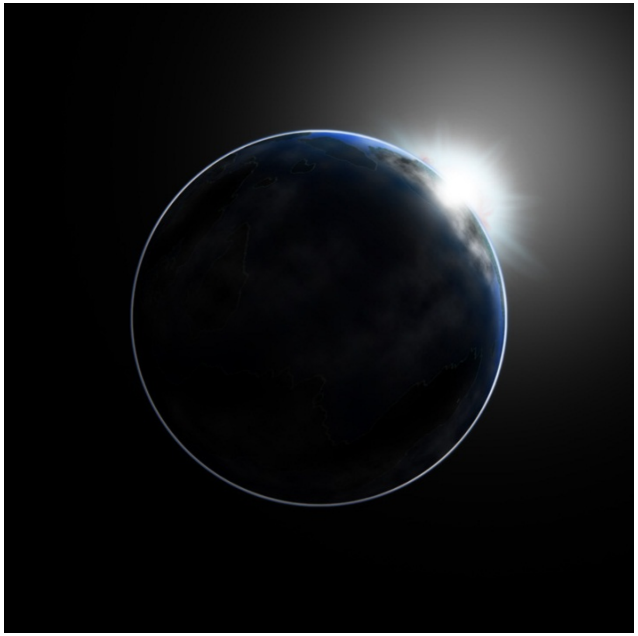
star

planet

upper atmosphere

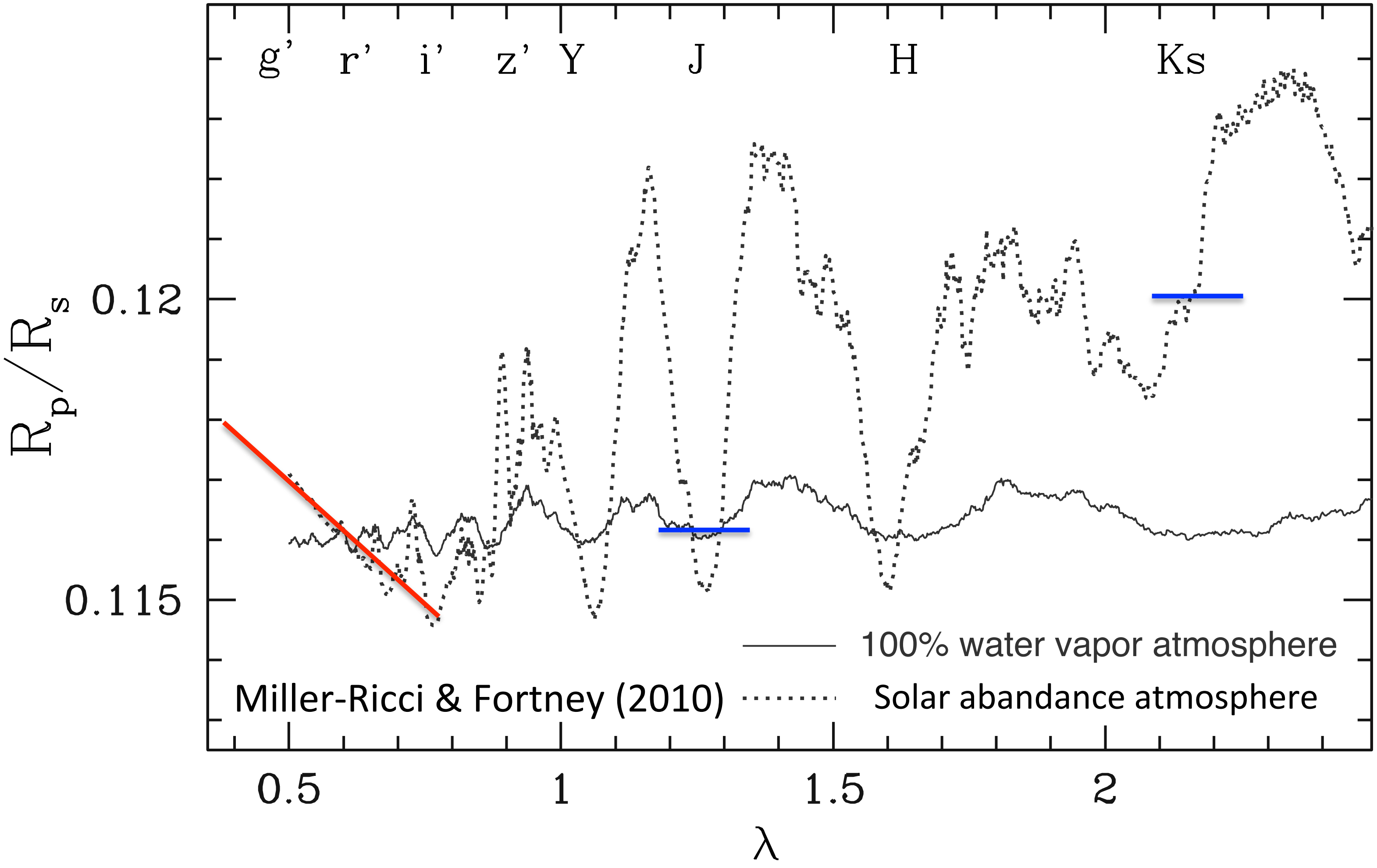
stellar line

dimming with excess absorption



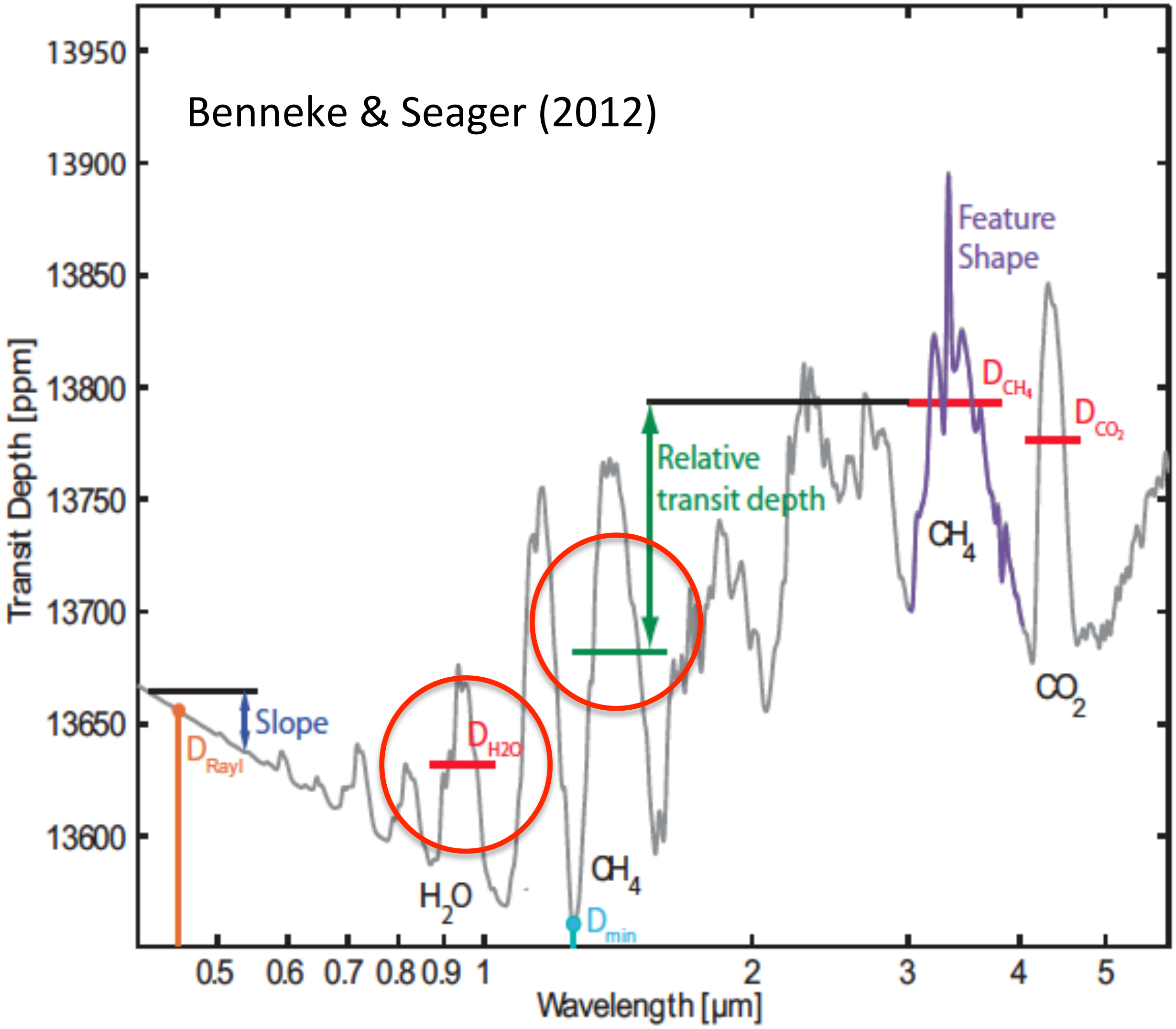
Transit depths depend on lines / wavelength reflecting atmosphere

Discriminating Major Components of Atmosphere



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

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

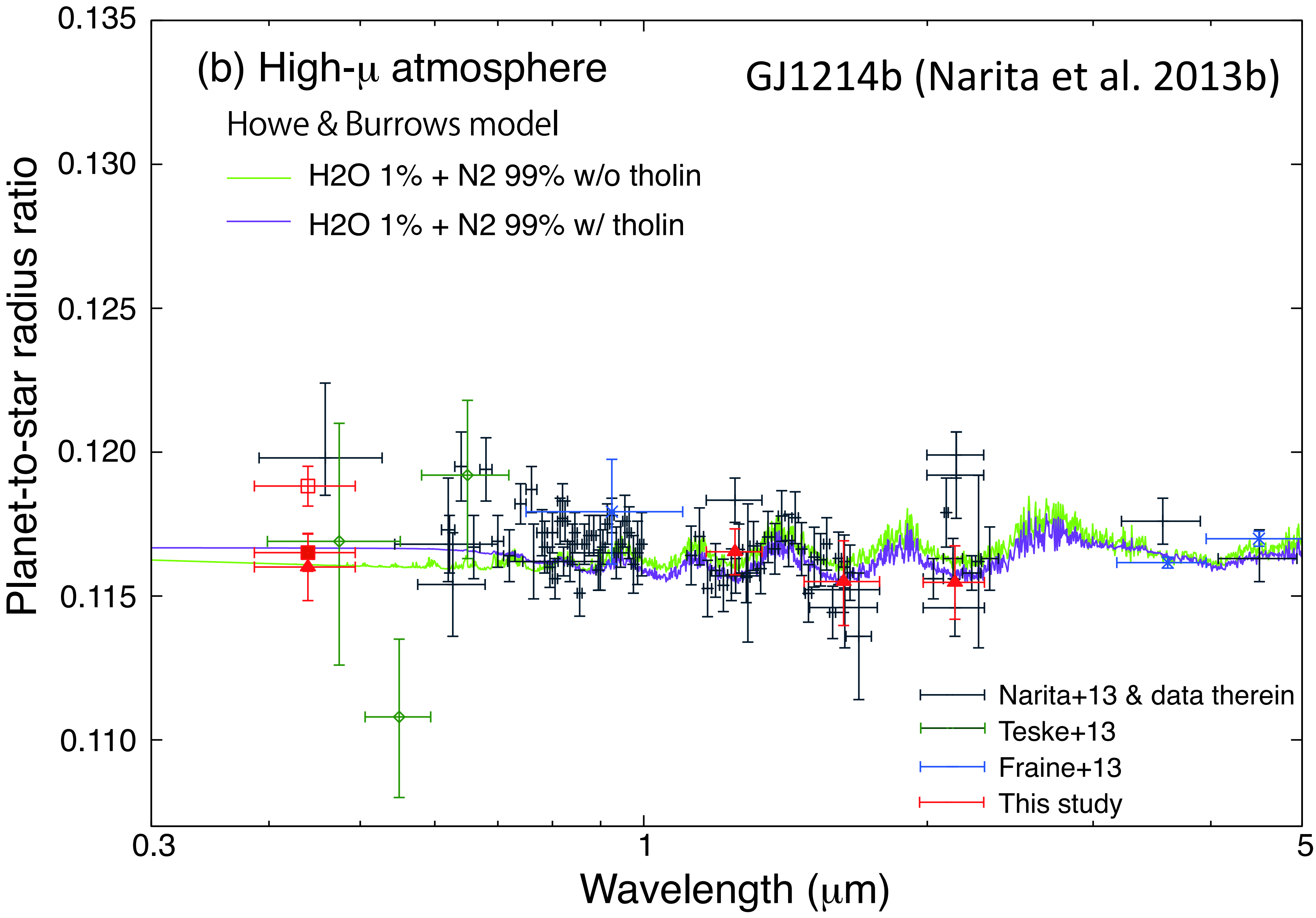


Benneke & Seager (2012)

Strategy for TESS Follow-ups

- Medium-size telescopes with wide-field multi-color imager
  - wide wavelength coverage, broadband
  - e.g., ESO 2.2m / GROND, IRSF 1.4m / SIRIUS

- Larger telescopes with multi-object spectrographs
  - relatively narrow wavelength coverage, but detailed
  - e.g., Gemini / GMOS, VLT /FORS2, Magellan / MMIRS
  - Subaru / FOCAS & MOIRCS

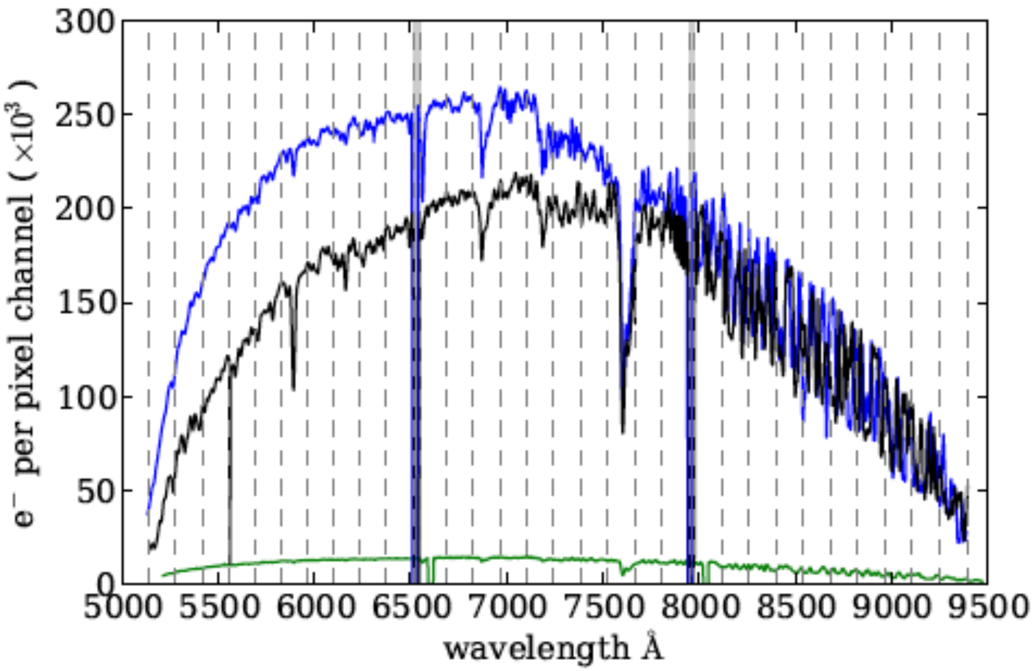

(b) High-μ atmosphere
GJ1214b (Narita et al. 2013b)
Howe & Burrows model
H2O 1% + N2 99% w/o tholin
H2O 1% + N2 99% w/ tholin
Narita+13 & data therein
Teske+13
Fraine+13
This study
Planet-to-star radius ratio
0.135
0.130
0.125
0.120
0.115
0.110
Wavelength (μm)
0.3
1
5

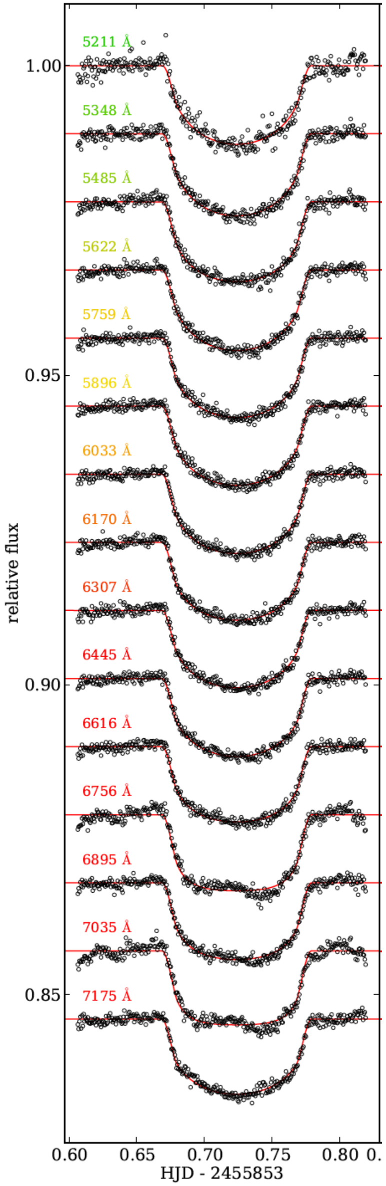
Transmission Spectroscopy by MOS

- One can do transmission spectroscopy using MOS (multi-object spectroscopy) instruments
  - VLT/FORS2, Gemini/GMOS, Magellan/MMIRS already reported excellent results

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

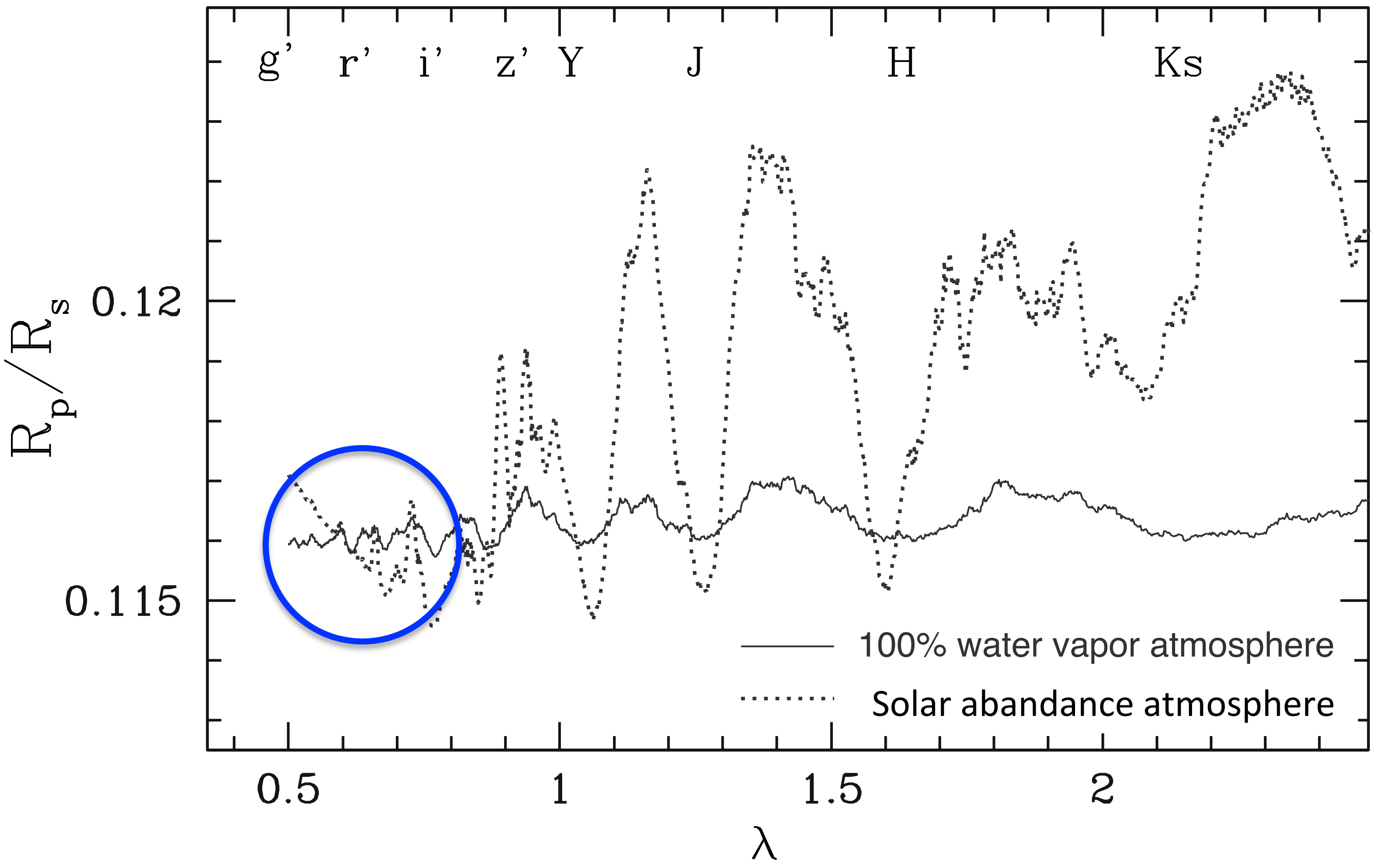
Recent Example by Gibson+ (2012)





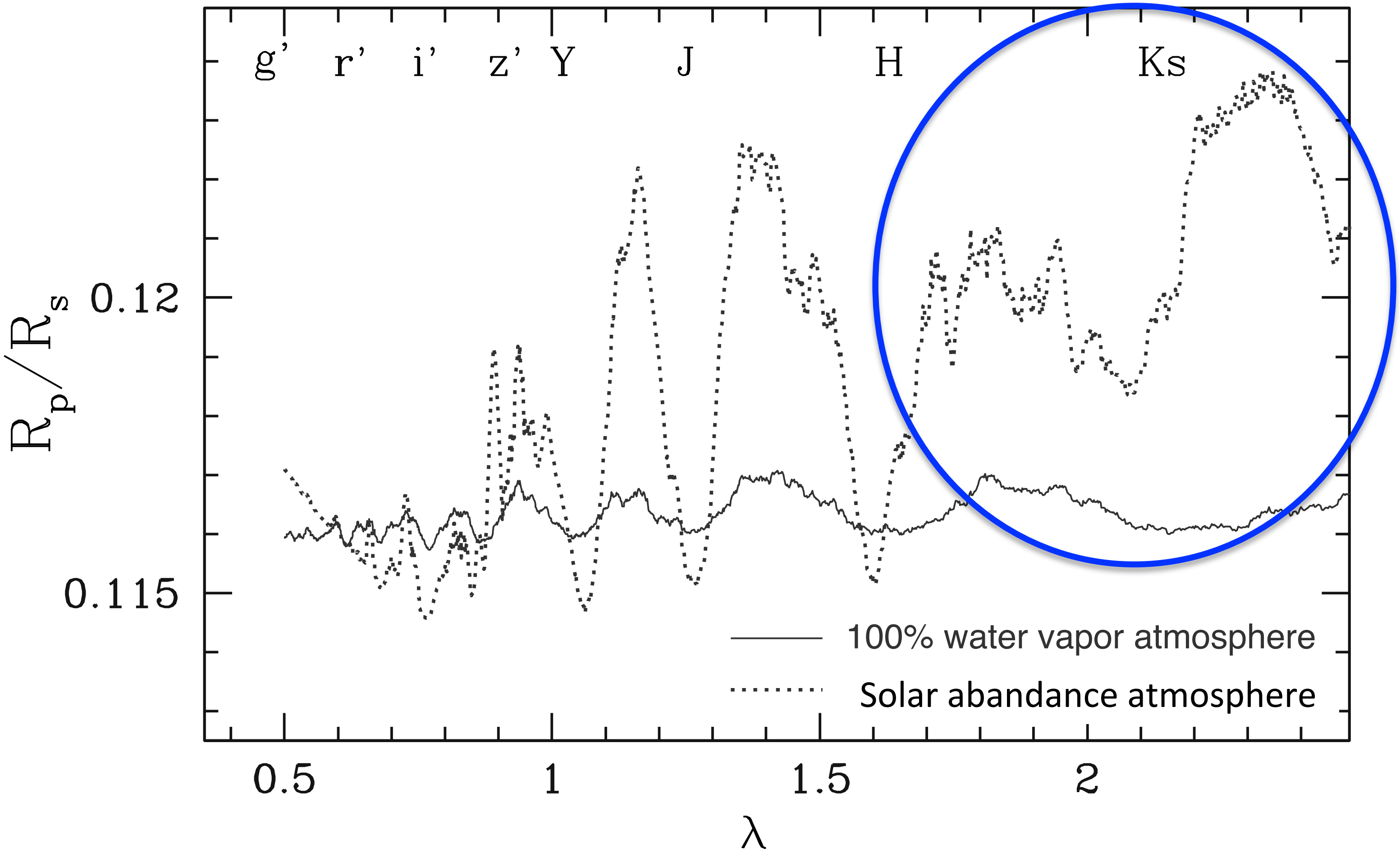
- Instrument: Gemini South/GMOS
- Target: WASP-29 (V=11.3)
- Integration: about 15 nm (R ~ 40)
- Precision: ~400 ppm by 5 min binning

Optical MOS is useful to see Rayleigh Scattering



The slope reflects the strength of Rayleigh scattering of planetary atmosphere

NIR MOS is useful to see molecule features



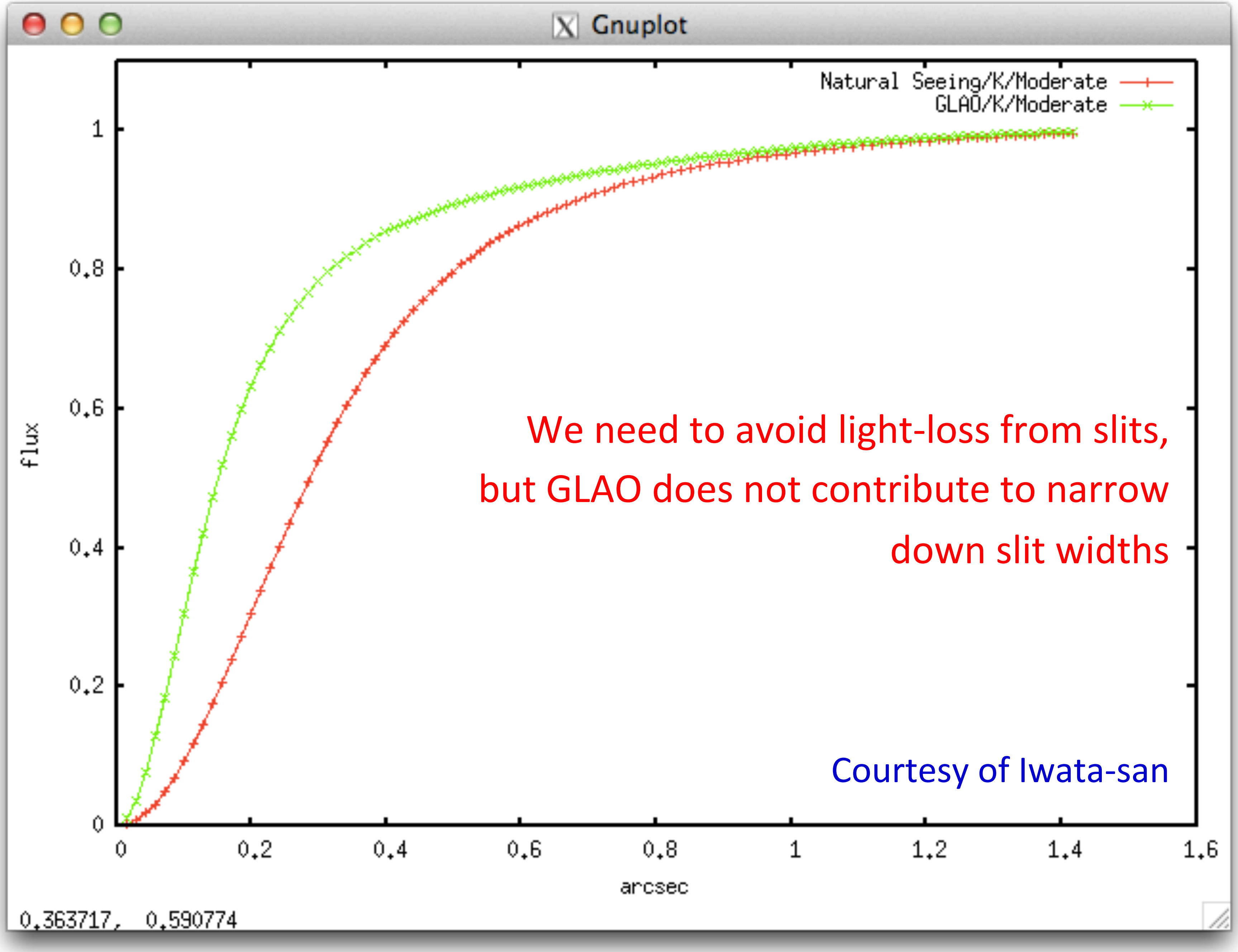
H and K bands are sensitive to molecules such as CH_4, CO, CO_2.

To achieve higher SNR, narrower slits are preferred to reduce sky backgrounds.

Relation with the GLAO Project

- Wide field imager and MOS are definitely useful for characterizing exoplanetary atmospheres
  - especially for TESS follow-ups

- But unfortunately, GLAO itself will not contribute to this science case



We need to avoid light-loss from slits, but GLAO does not contribute to narrow down slit widths

Courtesy of Iwata-san

Conclusions of My Considerations

- Unfortunately, exoplanetary science will not be a key science for GLAO
- But Wide Field Imager or MOS will be useful for a kind of observations for exoplanets
- We cannot contribute to the GLAO itself, but may contribute to one of key sciences of instruments (i.e., wide field imager & MOS)

Answers to the Questions

- (Q.1) In the baseline specifications of NIR instruments, we define three 'levels' of possible instruments: Which instrument is essentially important for your science cases?
  1. Wide-Field Near-IR Imager
  2. Wide-Field NIR Imager and Multi-Object Spectrograph
  3. Multi-Object Integral Field Spectrograph
- (A.1)
  - 2. Wide-Field NIR Imager and MOS

Answers to the Questions

- (Q.2) What is the optimal plate scale / FoV for your science cases?
- (A.2) Wider FOV (larger pixel scale) is preferred. If 10x10 arcmin^2 FOV is achieved, we can follow-up most of TESS targets. No other 8m class telescopes has such wide field capability.

Answers to the Questions

- (Q.3) Can you highlight synergies between this instrument and the TMT?
- (A.3) As IRMS (first light NIR instrument) has very narrow field of view, the wide field imager with MOS will be unique, until IRMOS will be installed on TMT

Answers to the Questions

- (Q.4) Does this instrument have competitive (or complementary) capabilities with planned Near-IR space missions?
- (A.4) It depends on whether one can achieve photon-noise limited data reduction & analyses. We need more practice for this method with current instruments. If one can do so, the sensitivity will be similar to JWST, but maybe JWST will be better due to atmospheric window (e.g., between J/H/K bands).

- (A.5&6) No legacy science is considered yet.