SPICA's Capability for Studying Transiting Super-Earths

Norio Narita,[1] Keigo Enya,[2] and Takuya Yamashita[1]

[1]*National Astronomical Observatory of Japan, Japan*
[2]*Institute of Space and Astronautical Science, JAXA, Japan*

ABSTRACT

Super-Earths are potentially important targets for the *SPICA* mission, which has a great capability to reveal the nature of super-Earths via transit observations. Measurements of atmospheric transmission spectra during planetary transits enable us to infer compositions of atmospheres and thereby internal structures of super-Earths. Dozens of good targets of transiting super-Earths are expected to be discovered by TESS (Transiting Exoplanets Survey Satellite) by the launch of the *SPICA*. We propose to reveal the diversity of natures of super-Earths with the *SPICA* in the 2020s.

1. SUPER-EARTHS AND IMPORTANCE OF TRANSMISSION SPECTROSCOPY

Super-Earths are an emerging population of extrasolar planets whose masses and radii lie between those of the Earth and the Uranus or Neptune. Although there is currently no official definition for super-Earths, we regard such planets with 1–4 $R_\oplus$ or 1–15 $M_\oplus$ as super-Earths in this manuscript. As super-earths do not exist in our Solar System, uncovering the nature of super-earths is one of the most important studies in both planetary and exoplanetary science in terms of comparative planetology.

Transiting super-earths are thus the most fascinating targets, because one can learn the true mass, radius, and density for transiting planets. However, it is still difficult to determine a unique solution for the planetary structure, since some different solutions of planetary structures are degenerated at the same mass and radius. Figure 1 shows a current summary of the mass and radius of super-Earths and indicate the degeneracy of planetary structures. To solve this degeneracy and find a unique solution, one need to determine planetary atmospheric compositions via an independent way.

During a planetary transit, a part of starlight transmits through the planetary upper atmosphere (optically thin region). For this reason, transit depths depend on wavelength according to planetary atmospheric compositions. Thus measurements of atmospheric transmission spectra during planetary transits enable us to infer compositions of planetary atmospheres. This methodology is referred to as transmission spectroscopy.

It is thus quite important to conduct transmission spectroscopy for super-Earths to uncover not only the atmospheric compositions but also infer the internal structures of this type of planets.

2. POTENTIAL CAPABILITY OF *SPICA*

Figure 2 shows transmission spectra of two representative atmospheric models for super-Earths. The figure assumes parameters of GJ 1214b, which is one of the well-known super-Earths at this point.

The differences of the two atmospheric models are whether the planet has a low molecular weight (hydrogen dominated) atmosphere or a high molecular weight atmosphere (e.g., H_2O, CH_4, CO_2, etc). The molecular weight determines a scale height of a planetary atmosphere. The high molecular weight atmosphere has small wavelength dependence in transit depths, while the low molecular weight atmosphere shows large dependence. The difference can be easily differentiated by transmission spectroscopy with a good precision and wide wavelength coverage in near-to-mid infrared wavelength.

Among the *SPICA*'s planned instruments, the MCS (Mid-infrared Camera and Spectrometer) and the SCI (*SPICA* coronagraphic instrument: Enya et al. 2011) are potentially useful for transmission spectroscopy of transiting super-Earths,. Both instruments have low-to-medium resolution spectroscopic capability in mid-infrared wavelength. Thus the instruments can determine a likely atmosphere model for super-Earths with a single transit observation with *SPICA*.

3. CURRENT PROBLEMS

As of September 2013, only two transiting super-Earths (GJ 1214b and GJ 3470b) have been discovered around bright host stars. The brightness is important because host stars need to be very bright to do transmission spectroscopy with a good precision, which is important to discriminate atmospheric models at a high confidence level.

For the case of GJ 1214b, various observations for transmission spectroscopy were conducted with ground-based telescopes and the two space-based telescopes (*Hubble* and *Spitzer*). At this point, a unique atmospheric model has not yet been determined, mainly due to uncertainties of the transit depths and lack of wide wavelength coverage up to mid-infrared wavelength. From the previous observations, we have learned that not only optical and near-infrared region but also mid-infrared region are important. The warm *Spitzer* is still useful, but very weak for determining a likely atmosphere model. Thus one needs a space-based telescope which can observe mid-infrared wavelength with a high precision for transmission spectroscopy of transiting super-Earths.

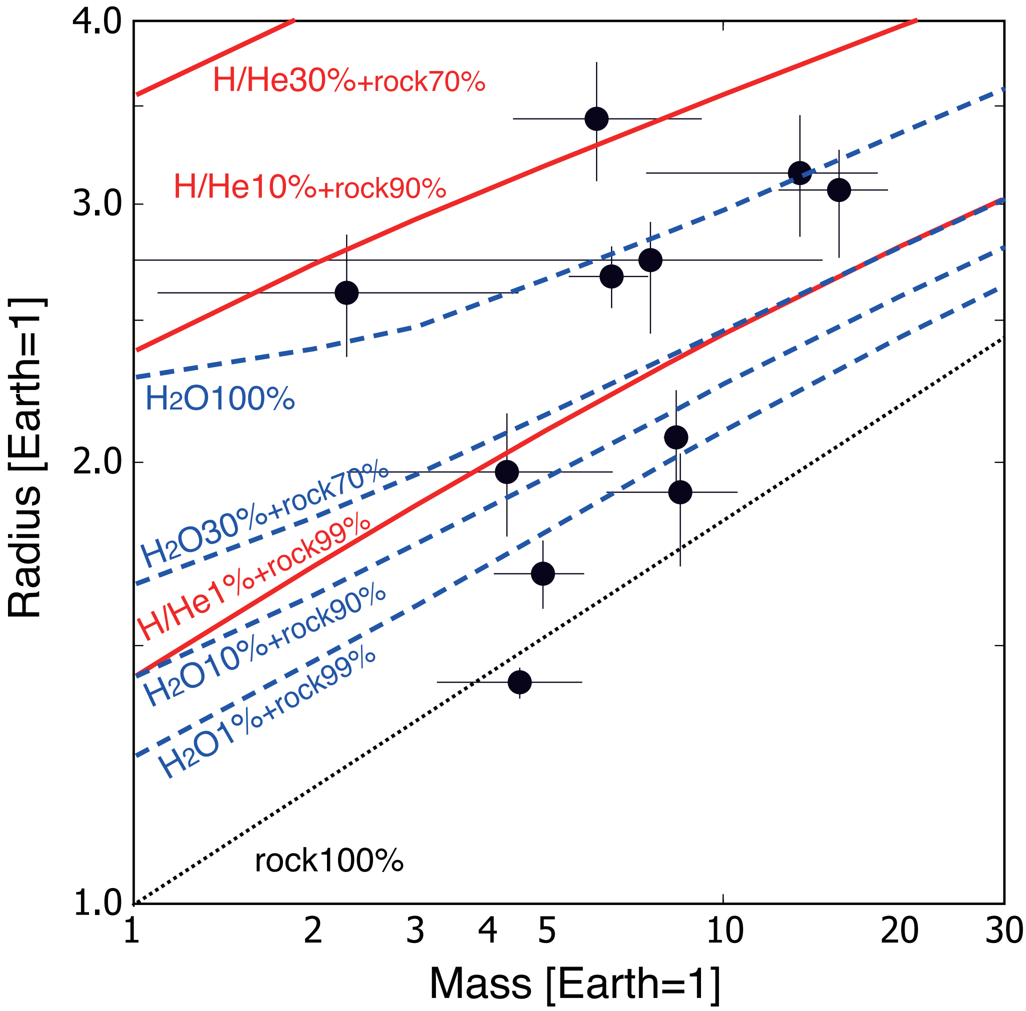

Figure 1. The mass (horizontal) - radius (vertical) relation of known super-Earths as of September 2013. The masses have large uncertainties because of the facts that most of the super-Earths are discovered by the *Kepler* satellite and that the masses are poorly constrained by radial velocities or transit timing variations due to the faintness of host stars. The red solid lines indicate mass-radius relations for hydrogen-dominated (low molecular weight) atmospheres, while the blue dashed lines show relations for water-dominated (high molecular weight) atmospheres. The black dotted line represents relation for rocky planets without atmosphere. Courtesy of Masahiro Ikoma.

4. POTENTIAL TARGETS FOR *SPICA*

In April 2013, *TESS* (Transiting Exoplanet Survey Satellite: Ricker et al. 2010) led by MIT is approved by NASA as an Explorer program. *TESS* is going to be launched in 2017, and is expected to discover hundreds of super-Earths around nearby stars, including dozens of super-Earths orbiting around M dwarfs, which are suitable for transmission spectroscopy.

For such super-Earths, *SPICA*'s SCI and MCS can measure transit depths covering wide wavelength regions (from near-infrared to mid-infrared) by spectro-photometry, with likely higher precision than *Spitzer*. The wide wavelength coverage allow us to pin down a likely atmospheric model.

We note that similar transmission spectroscopy studies can be done by ground-based telescopes. But potential targets for ground-based telescopes are very limited to transiting super-Earths around very bright late-M dwarfs. Thus one indeed needs a space-based telescope to extend potential targets for transmission spectroscopy and to reveal the diversity of super-Earths' atmospheres statistically.

5. SYNERGY WITH SCI'S CORONAGRAPHIC STUDY

SPICA's SCI can take spectra of direct imaged outer planets. This capability provide us very unique opportunities to investigate spectra of both inner transiting planets and outer direct imaged planets. Such a capability is very unique and one can study compositions of a whole planetary system. Thus *SPICA* can reveal "the whole recipe of planetary systems" with SCI.

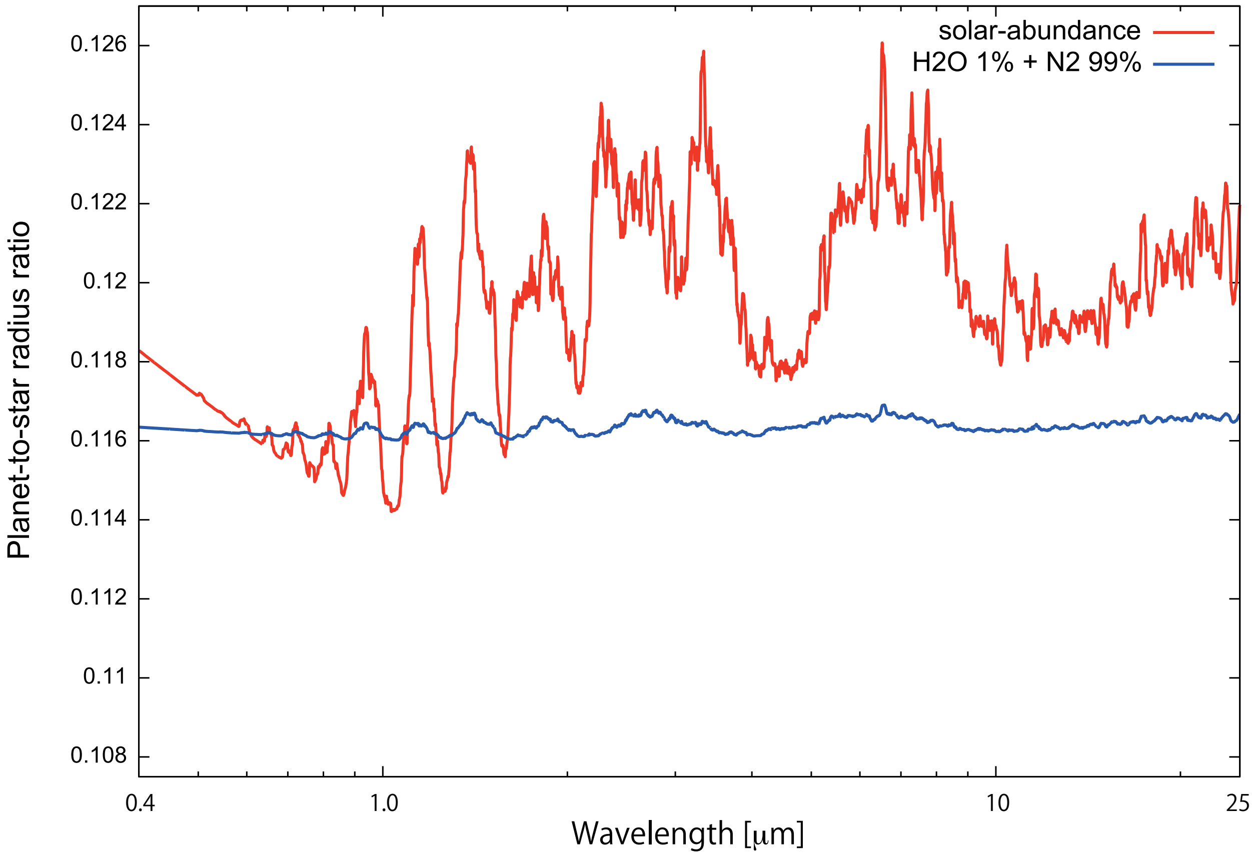

Figure 2. Two representative theoretical transmission spectra of GJ 1214b. The red line shows a case for a solar abundance (hydrogen-dominated) atmosphere, and the blue line does a case for a high molecular weight (water and nitrogen dominated) atmosphere. The major compositions determine the scale height of the planetary atmosphere. The largest differences are located in 2–4 μm and 6–8 μm. Courtesy of Yui Kawashima.

We greatly appreciate Masahiro Ikoma and Yui Kawashima for providing figures for this article. N.N. acknowledges supports by NAOJ Fellowship, NINS Program for Cross-Disciplinary Study, and Grant-in-Aid for Scientific Research (A) (No. 25247026) from the MEXT.

REFERENCES

Enya, K., et al. 2011, Advances in Space Research, 48, 323
Ricker, G. R., et al. 2010, BAAS, 42, 459