Identification of Rocky Exoplanets and Characterization of Their Surfaces

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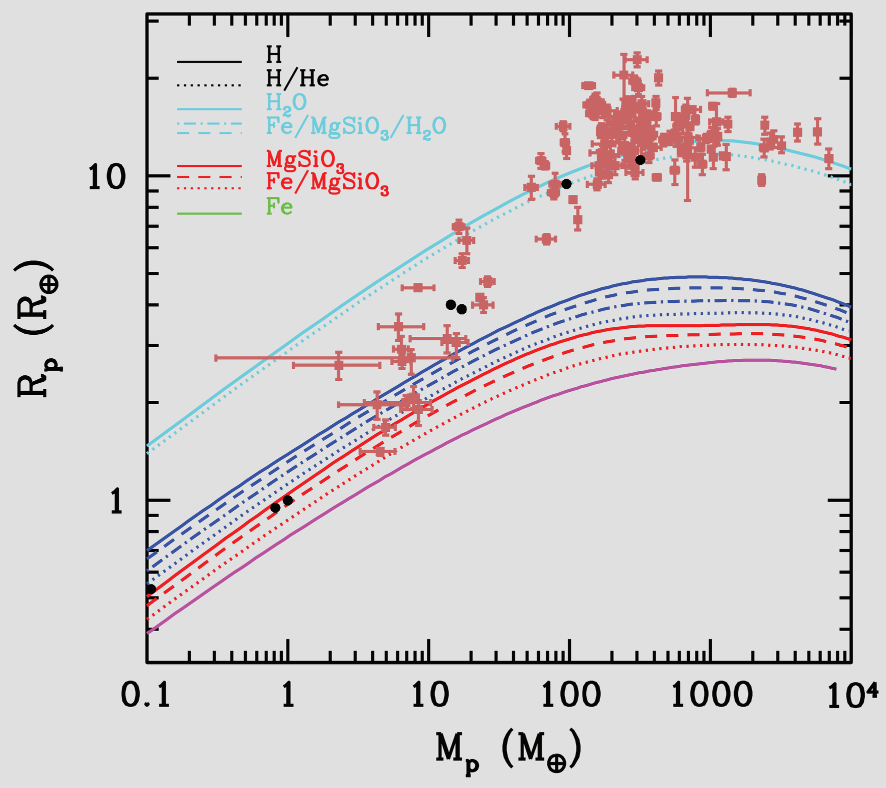
Objective

The search for exoplanets has resulted in discoveries of a large number of low-mass and small planets that can be rocky.

- Degeneracy between rocks and volatiles in the planetary mass-radius relationship prevents identification of rocky exoplanets in some cases.
- Characterization of rocky surfaces on exoplanets is instrumental for our understanding of the interior and the evolution history of low-mass exoplanets.



We here propose that characterization of solid surfaces of exoplanets is possible via infrared spectroscopy.

Model

Potential Crustal Compositions of Rocky Exoplanets:

Type	Mineral Composition	Spectrum Source	Indication	Solar System Examples
Metal-rich	Pyrite	Sample[a]	Primary crust with mantle ripped off	N/A
Ultramafic	60% olivine, 40% enstatite	Modeled[b]	Primary crust with mantle overturn; or secondary crust from hot lavas	Primary Earth and Mars; and early Earth lavas
Feldspathic	97% Fe-plagioclase, 3% augite	Sample[c]	Primary crust without mantle overturn	Lunar highlands
Basaltic	76% plagioclase, 8% augite, 6% enstatite, 5% glass, 1% olivine	Sample[d]	Secondary crust	Lunar mare and locations on current Earth
Granitoid	40% K-feldspar, 35% quartz 20% plagioclase, 5% biotite	Modeled[b]	Tertiary crust	Current Earth
Clay	50% Mg-smectite, 50% serpentine	Modeled[b]	Aqueously altered crust	Locations on current Earth and Mars
Ice-rich silicate	50% water ice, 50% basalt	Modeled[b]	Ice-rich silicate mantle	Locations on current Earth and Mars
Fe-oxidized	50% nanophase hematite, 50% basalt	Modeled[b]	Oxidative weathering	Current Mars

Notes. NIR spectra were defined for eight notional exoplanet surface types from laboratory measurement of rock powders (sample) or radiative-transfer modeling combining endmember mineral samples measured in the laboratory (modeled).
[a] Clark et al. (2007).
[b] Spectra are synthesized from the measured spectra of each endmember minerals in Clark et al. (2007).
[c] Lunar anorthosite, sample 15415, Cheek et al. (2009).
[d] Basalt sample 79-3b from Wyatt et al. (2001).

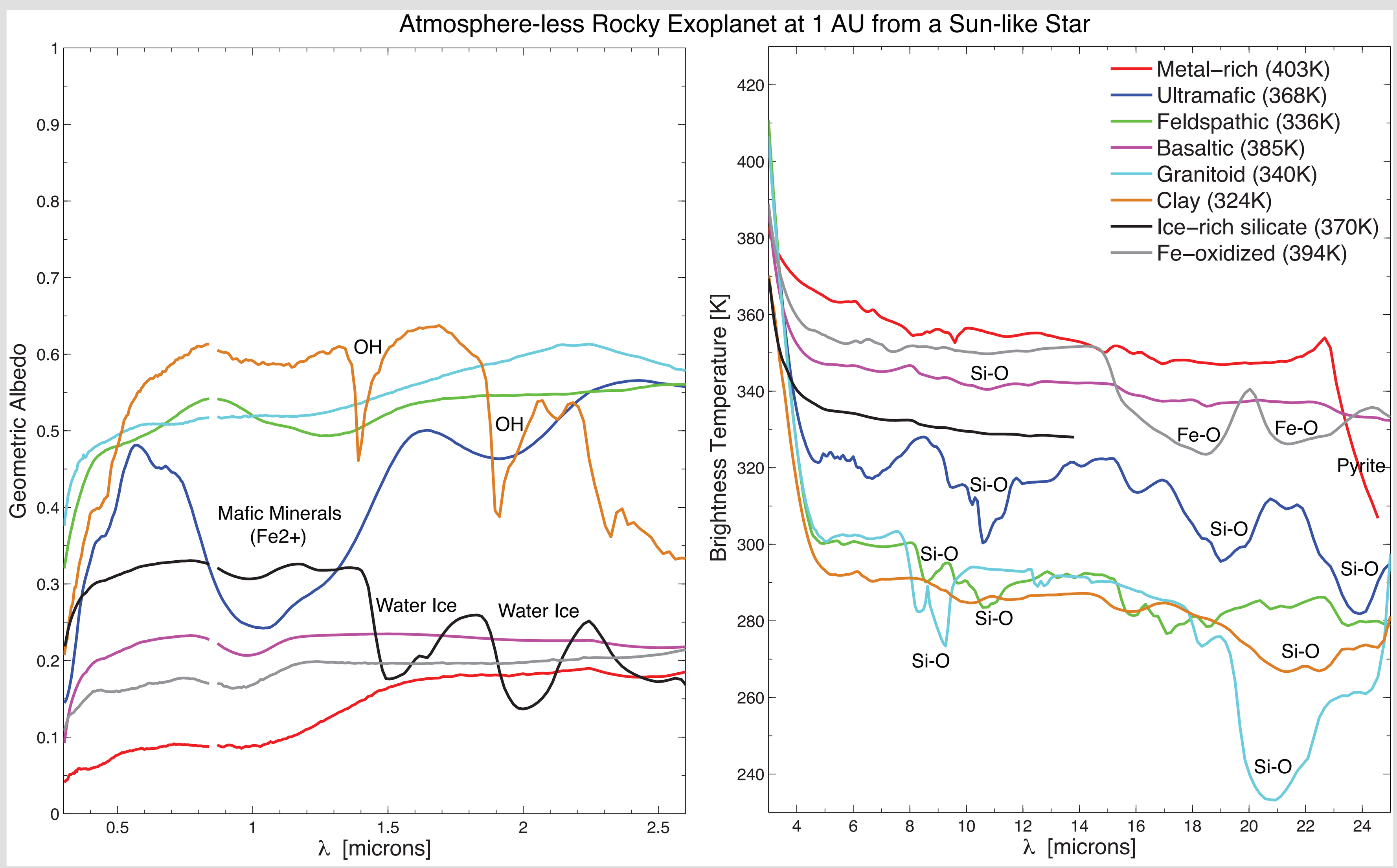
We have developed a theoretical framework to compute disk-integrated spectra of airless rocky exoplanets that self-consistently treats reflection of stellar radiation and planetary thermal emission.

We used the laboratory measured reflectance for endmember minerals in the USGS Digital Spectral Library (Clark et al. 2007) and the RELAB Spectral Database (2010).

We extended the laboratory measured reflectance for any incidence and scattering angles using a radiative transfer model for planetary regolith (Hapke 2002).

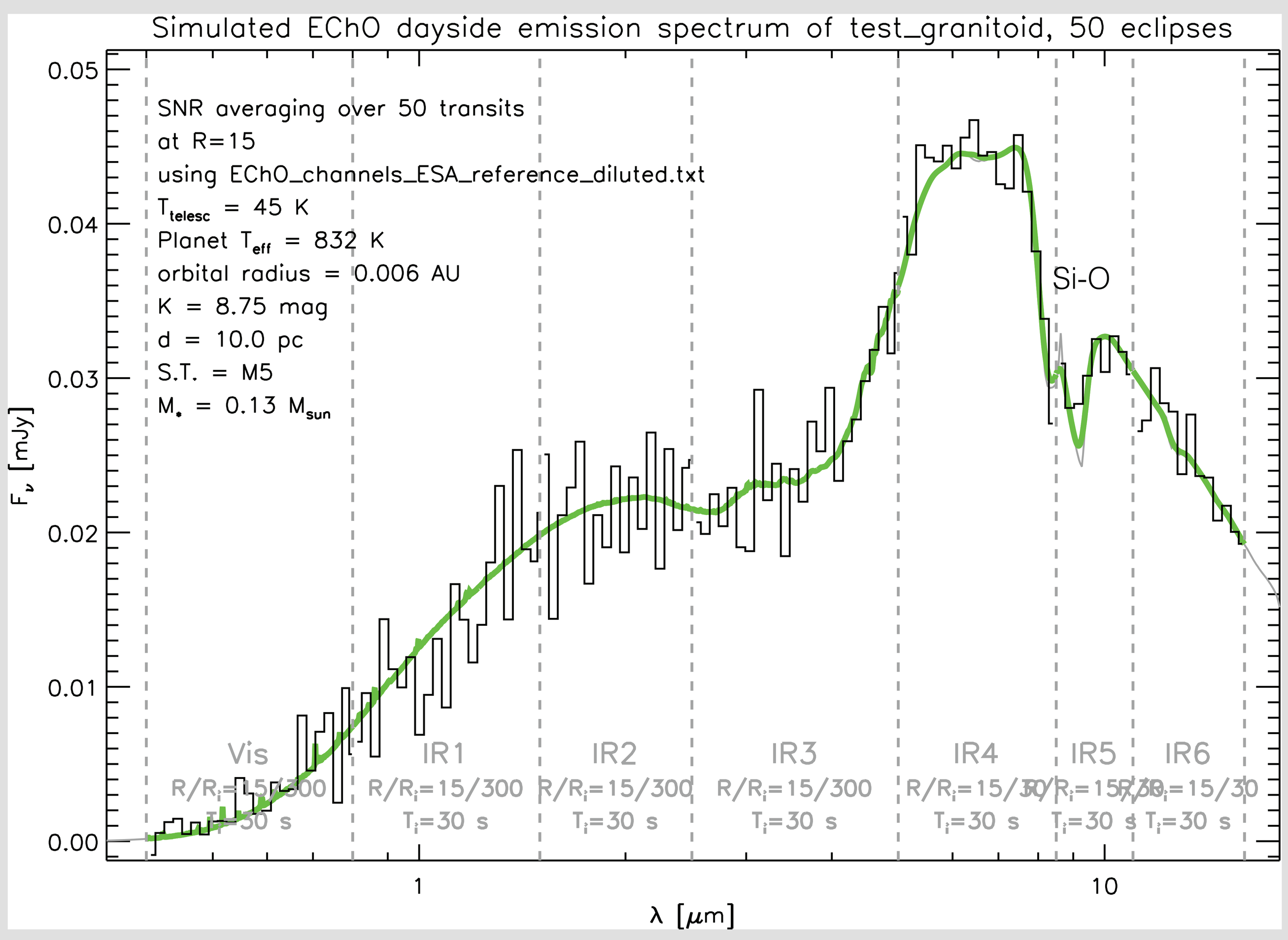
Results

- Silicate surfaces lead to unique features in planetary thermal emission at the mid-infrared wavelength due to strong Si-O vibrational bands (7 – 13 μm and 15 – 25 μm).
- The location of the emissivity maxima at the short-wavelength edge of the silicate feature (7 – 9 μm) can be used to distinguish different kinds of silicates.
- Planetary reflectance spectra in the near-infrared, if observable, will allow characterization of specific surface types including mafic minerals, water ice, and hydrated silicates.



Prospects

The silicate features in the planetary thermal emission are observable via transits for hot super-Earths around nearby low-mass stars.



Simulated observations with a 1.2-m space telescope of an exoplanet having a granitoid surface at 0.006 AU from an M5 star at 10 pc (courtesy of Joy van Boekel).

The surface features in reflection will be detectable with future space-based direct-imaging facilities.

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The Astrophysical Journal, 752, 7