SPICA Science for Transiting Planetary Systems

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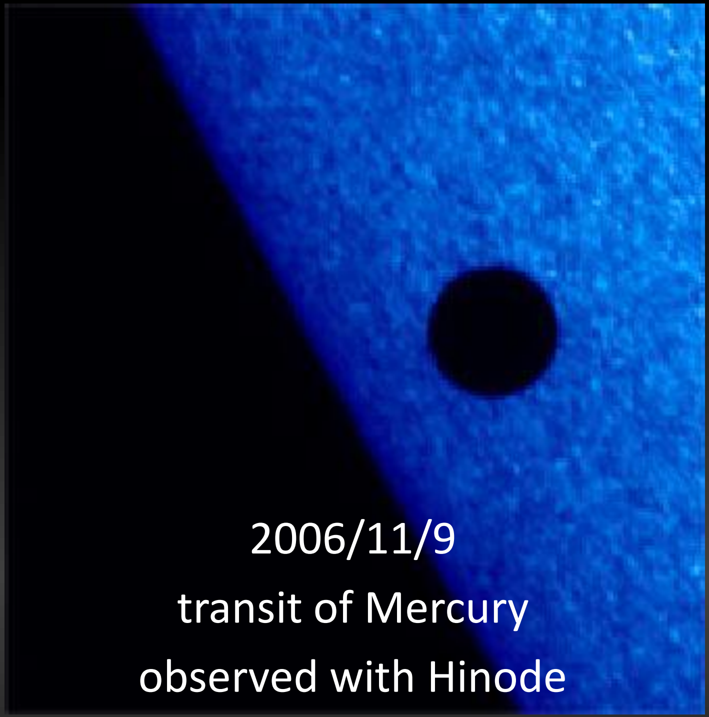
Outline

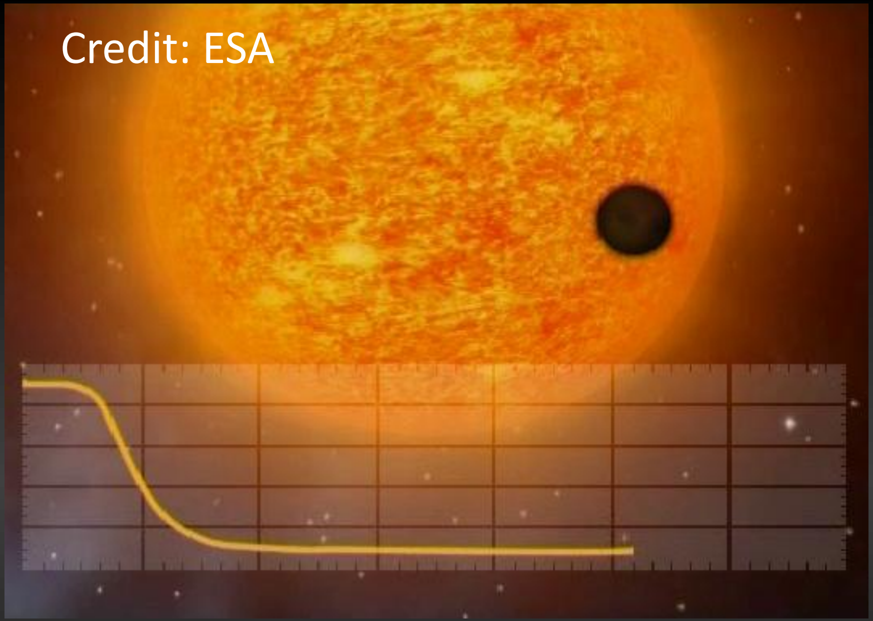
- For Terrestrial/Jovian Planets
  1. Probing Planetary Atmospheres
- For Jovian Planets
  2. Planetary Rings
  3. Phase Function and Diurnal Variation
- Summary and Requirements

Planetary Transits

transit in the Solar System

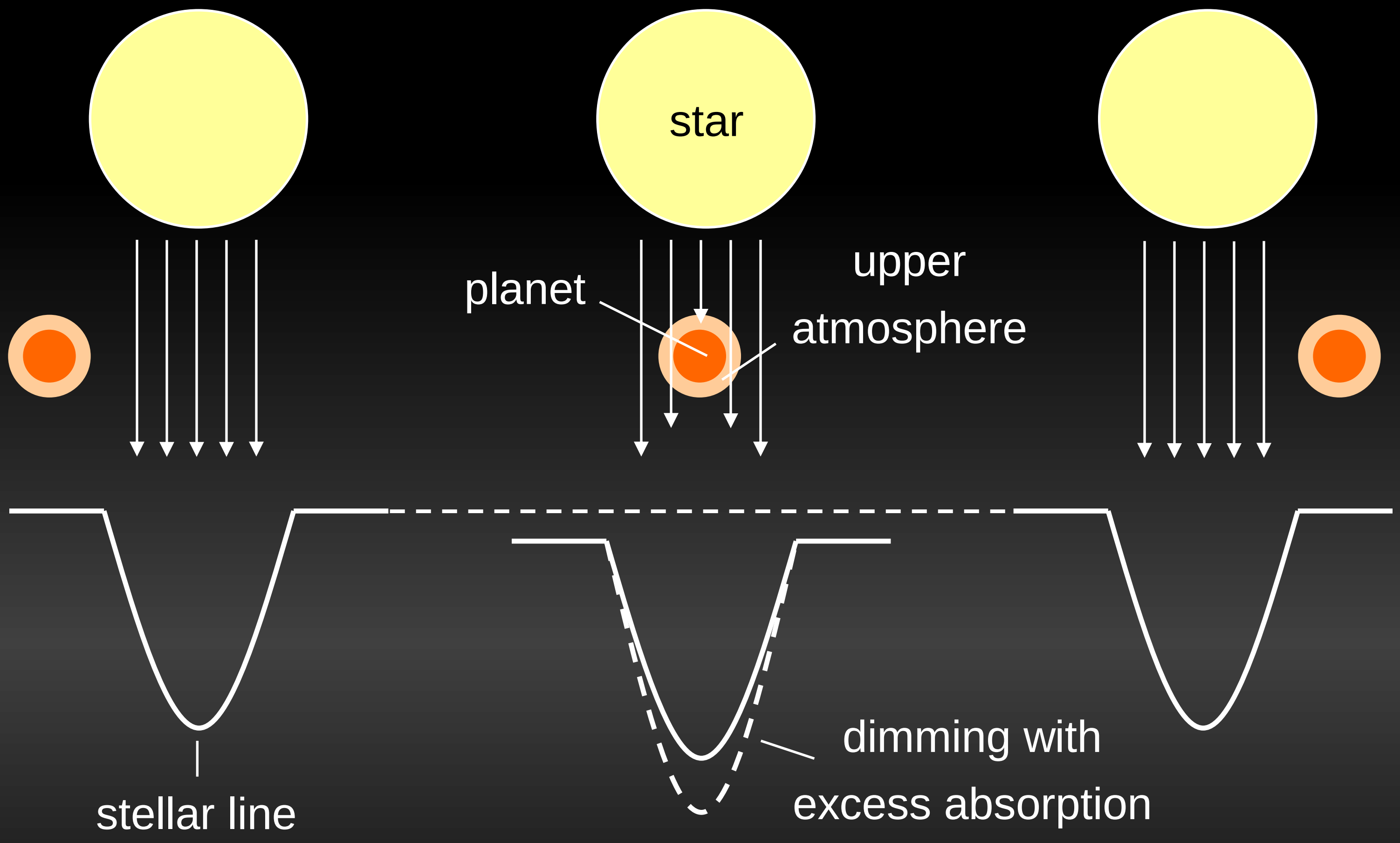


transit in exoplanetary systems
(we cannot spatially resolve)



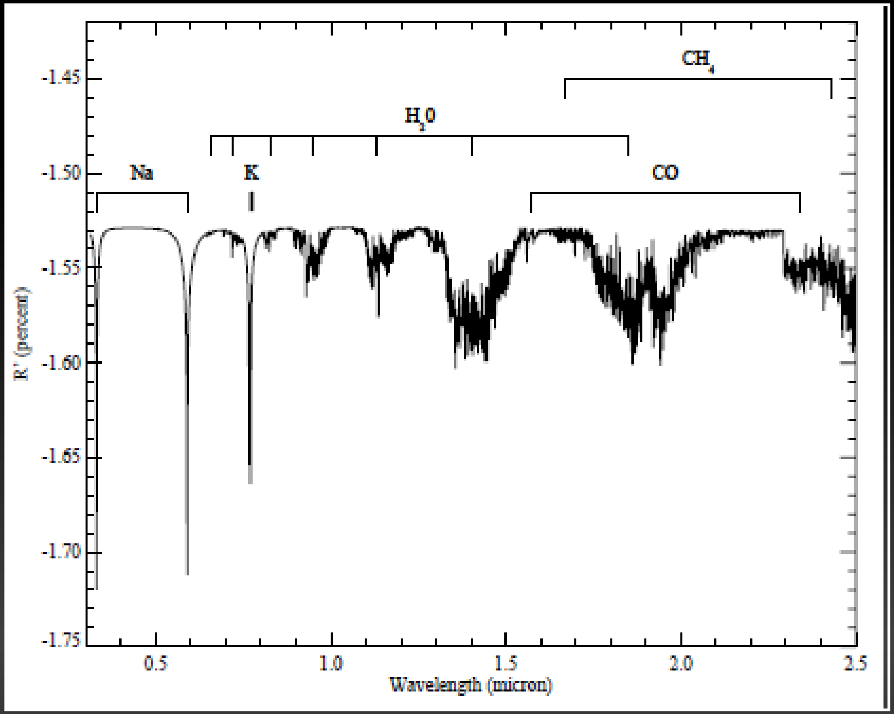
If a planetary orbit passes in front of its host star by chance, we can observe exoplanetary transits as periodical dimming.

Transmission Spectroscopy



A tiny part of starlight passes through planetary atmosphere.

Theoretical Transmission Spectra for Hot Jupiters

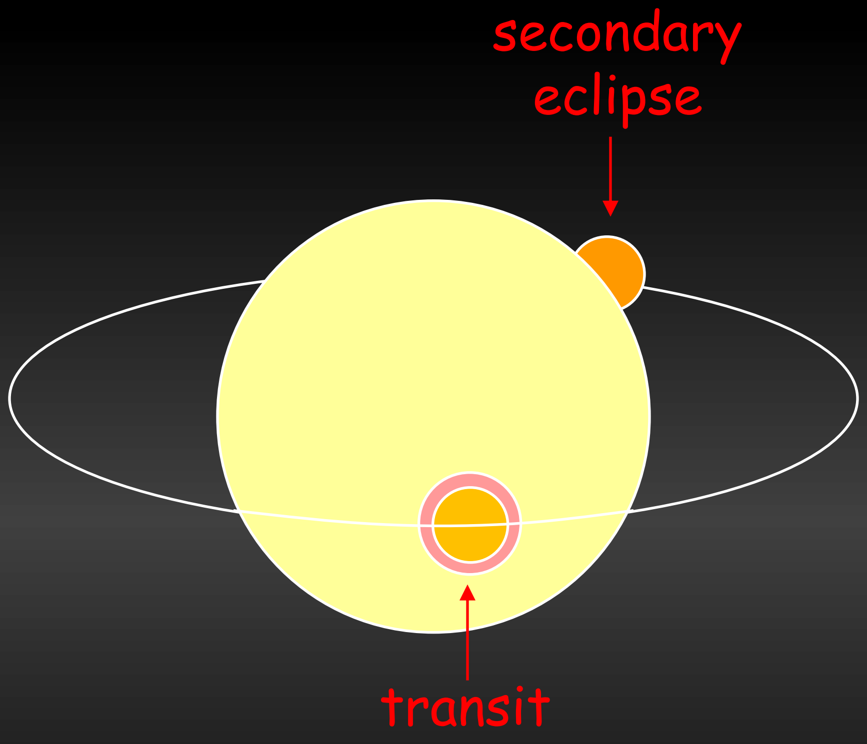


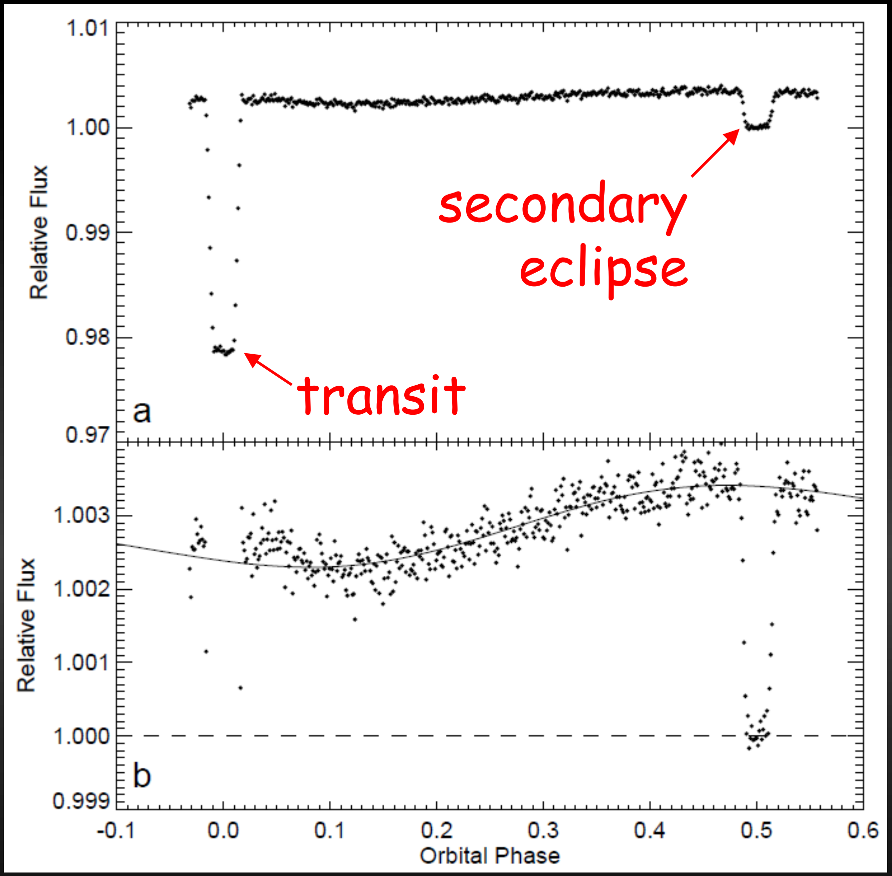
Brown (2001)

Strong excess absorptions were predicted especially in alkali metal lines and molecular bands

Secondary Eclipse

provides 'dayside' thermal emission information

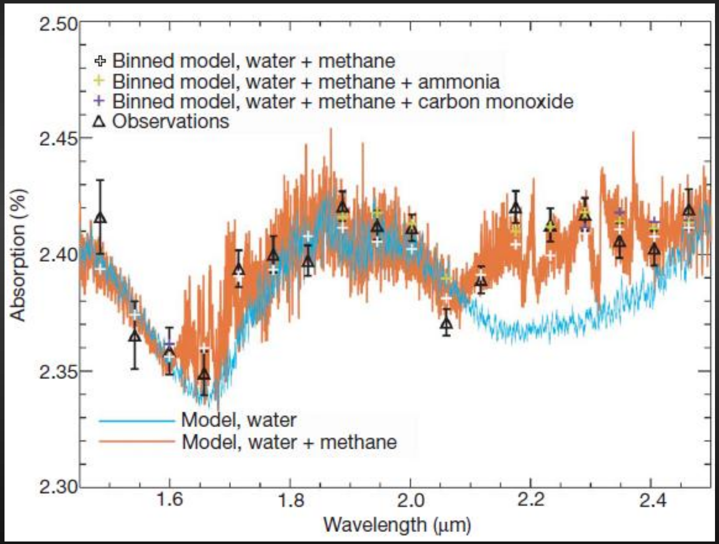




Knutson et al. (2007)

Components reported so far

- Sodium: Charbonneau+ (2002), Redfield+ (2008), etc
- Vapor: Barman (2007), Tinetti+ (2007)
- CH_4: Swain+ (2008)
- CO, CO_2: Swain+ (2009)



▲ : HST/NICMOS observation

red : model with methane+vapor

blue : model with only vapor

Swain et al. (2008)

SPICA Transit/SE Spectroscopy

Main (Difficult) Targets

- Possible habitable terrestrial planets
  - ✓ around nearby M stars: TESS, MEarth
  - ✓ (around nearby GK stars: Kepler, CoRoT)

Purpose

- Search for molecular signatures
  - ✓ possible bio-signatures (e.g., O_2)
  - ✓ evidence of temperature homeostasis by green house effect gas (e.g., CO_2)

SPICA Transit/SE Spectroscopy

Sub (Secure) Targets

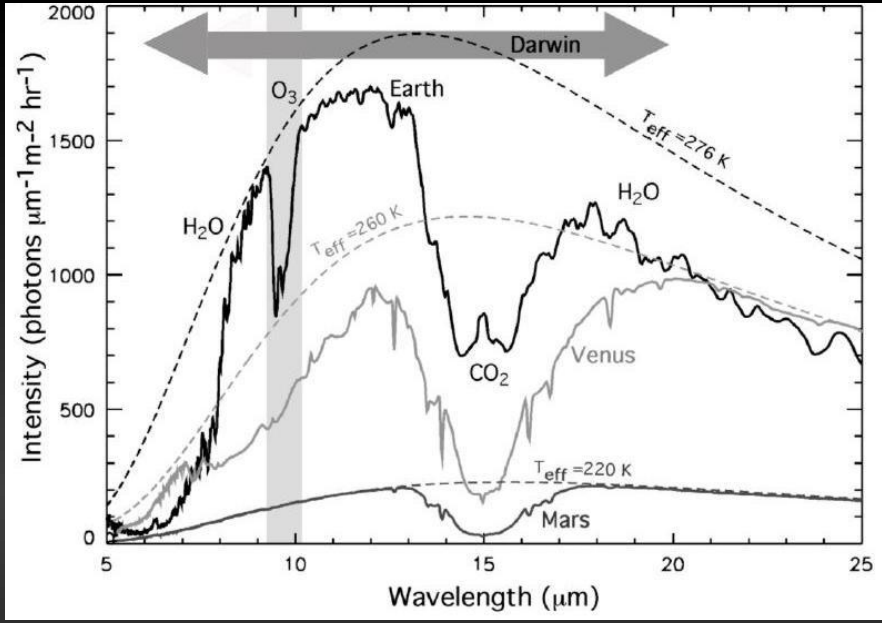
- Jovian planets
  - ✓ Many targets will be available
  - ✓ Variety of mass, semi-major axis, eccentricity, etc

Purpose

- Detailed studies of atmospheric compositions
  - ✓ To learn the diversity of Jovian planetary atmospheres

Spectral Features

- Atmospheric spectral features
  - CO_2: 1.06μm (weak), 4.7μm, 15μm (strong and wide)
  - CH_4: 0.88μm, 1.66μm, 3.3μm, 7.66μm
  - H_2O: many features at NIR-MIR
  - O_2 : 0.76μm
  - O_3 : 0.45 - 0.74μm, 9.6μm
- Which wavelength is important ?
  - MIR (strong O_3 , CO_2)
  - NIR also contains important features (CO_2, CH_4)
  - Need optical wavelengths for oxygen detection



Darwin proposal

Case Studies

- If a transiting terrestrial planet in HZ around a M5V star at 5pc is discovered
  - Total number of stars at d < 5pc = 74 (44 for M type stars)
  - Host star: 5.3mag at 10μm (near O_3 band)
  - Transit spectroscopy (R=20)
    - Depth of excess absorption: 5.2 μJy (1.6×10^{-5}), S/N = 0.7/hr
  - Secondary Eclipse Spectroscopy (R=20)
    - Thermal emission of Super Earth: 8.8 μJy, (2.8×10^{-5}), S/N = 1.1/hr
  - a = 0.1 AU, Period: 25.2 days, Transit duration: 2.3 hr
  - Observable time: 35 hr/yr → 105 hr/3yr → S/N ratio ~ 10x
    - Marginal, even if every chance will be observed for 3 years

Feasibility and Summary

- Needs large dynamic range
  - Planet signals are very weak compared to the host star
    - Atmospheres of Jovian planets
      - ~10^{-3} (transits) and less than ~10^{-3} (secondary eclipses)
      - Fairly secure and we can investigate detailed atmospheric composition for many targets
    - Atmospheres of terrestrial planets in habitable zone
      - 10^{-5} ~ 10^{-6} (for both transits and secondary eclipses)
      - Marginal and depends on stellar distance and planetary environment
      - Needs stability of instruments and precise calibration

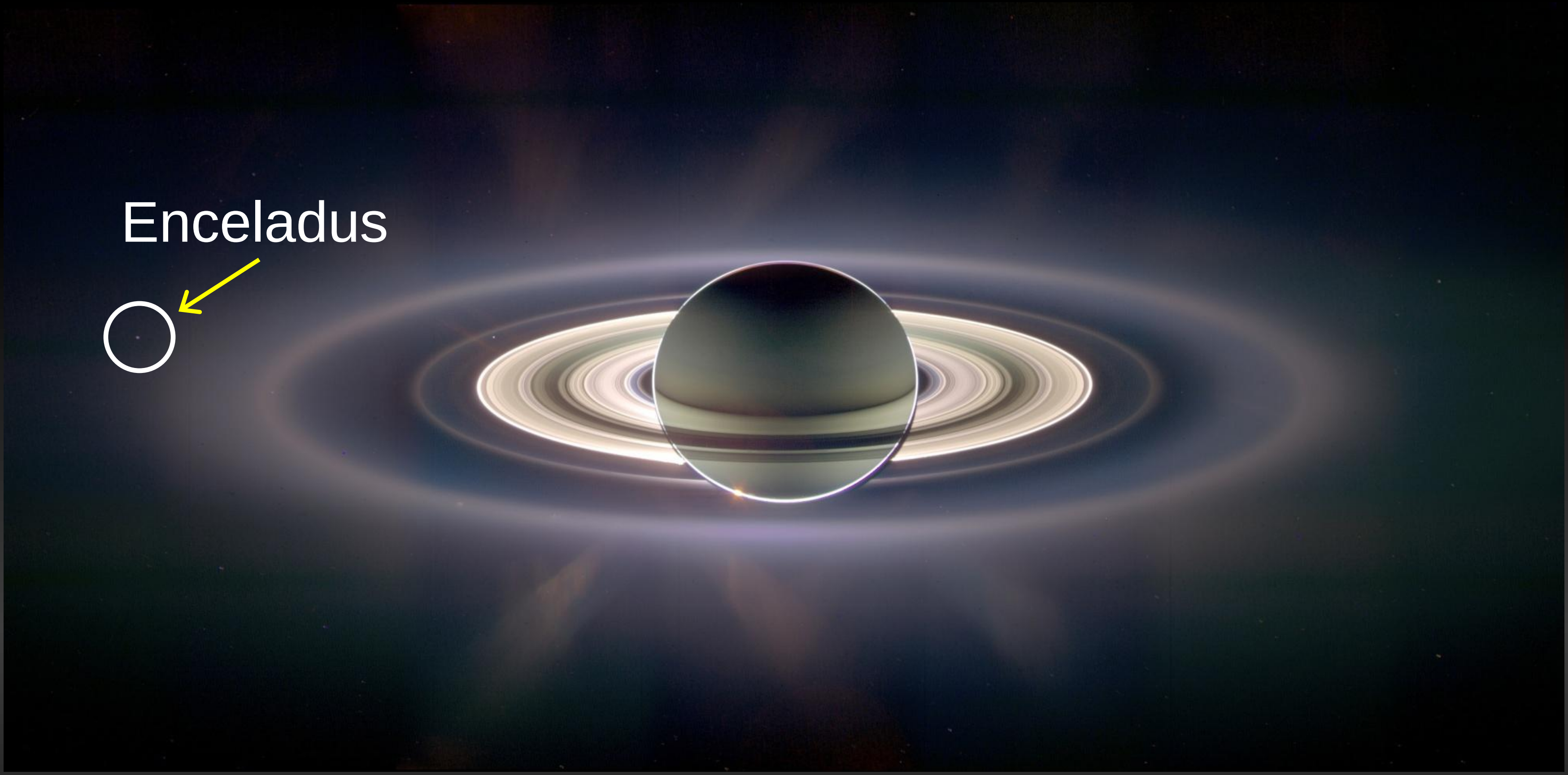
SPICA Science for Transiting Jovian Planets

Considered Topics

- Ring Survey & Characterization
- Moon Survey & Characterization
- Phase Function and Diurnal Variation
- (Trojan Asteroid Survey)

We focus on colored topics to utilize SPICA's NIR~FIR capability.

The Saturn transiting the Sun

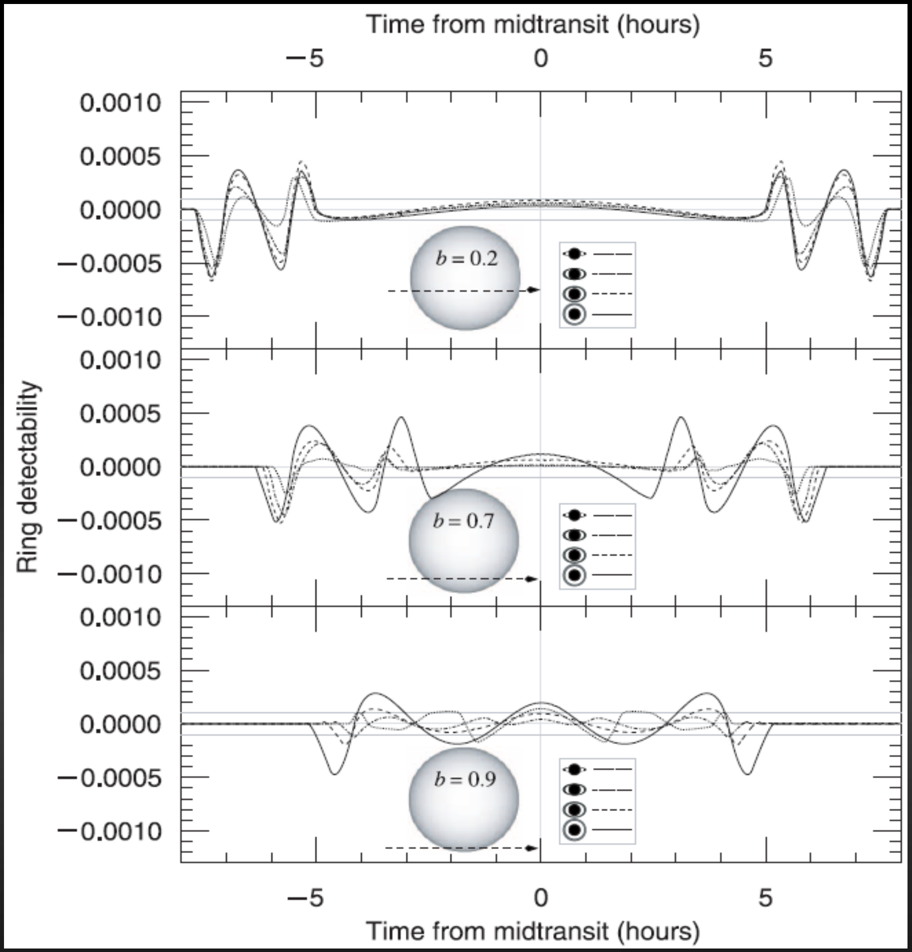


Taken by the Cassini spacecraft on September 15, 2006
(Credit: NASA/JPL/Space Science Institute)

Motivation

- Jovian planets in the Solar System have rings (+ moons): Why not in exoplanetary systems?
- Many transiting Jovian planets (TJPs) with a wide variety of system parameters (e.g., semi-major axis/age) will be discovered with CoRoT/Kepler/TESS
- We can search and characterize rings with SPICA
  - Ring existence vs planetary semi-major axis/stellar age relation
  - particle size of rings
- We can learn the diversity of Jovian planetary rings

Methodology of Ring Detection

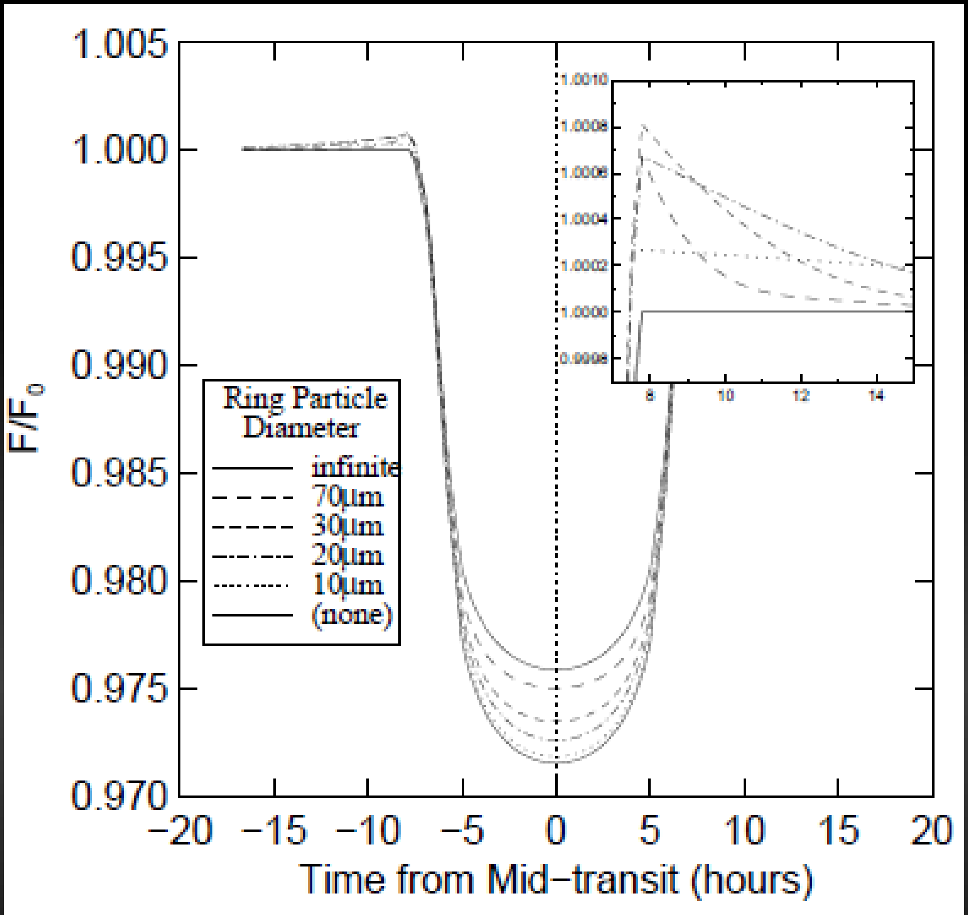


Barnes & Fortney (2004)

- Transit light curves for ringed planets are slightly different from those for no-ring planets
- Residuals between observed light curves and theoretical planetary light curves are ring signals
- Signals are typically ~10^{-4} level
  - Detectable with HST/Kepler
- We can learn configuration of rings with high precision photometry

Characterization of Particle Size of Rings

- Diffractive forward-scattering depends on ring's particle size and causes difference in
  - ✓ depth of transit light curve
  - ✓ ramp just before and after transits
- Multi-wavelength observations would be useful to characterize distribution of particle size
- SPICA's wide wavelength coverage is useful to probe wide variety of particle size



Barnes & Fortney (2004)
(for 0.5 micron observations)

SPICA Ring Studies

Purposes and Targets

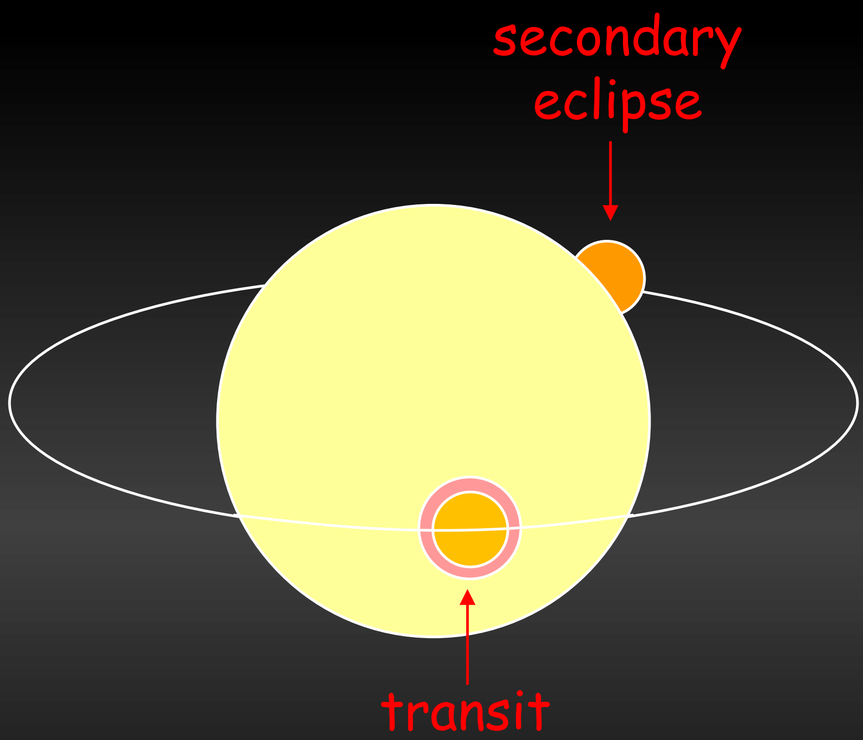
- Characterization of planetary rings
  - ✓ Ringed Jovian planets detected with Kepler
  - ✓ Multi-wavelength transit photometry
  - ✓ To learn particle size of planetary rings
- Ring survey is still interesting
  - ✓ For TESS Jovian planets (over 1000?)
  - ✓ Variety of stellar/planetary parameters

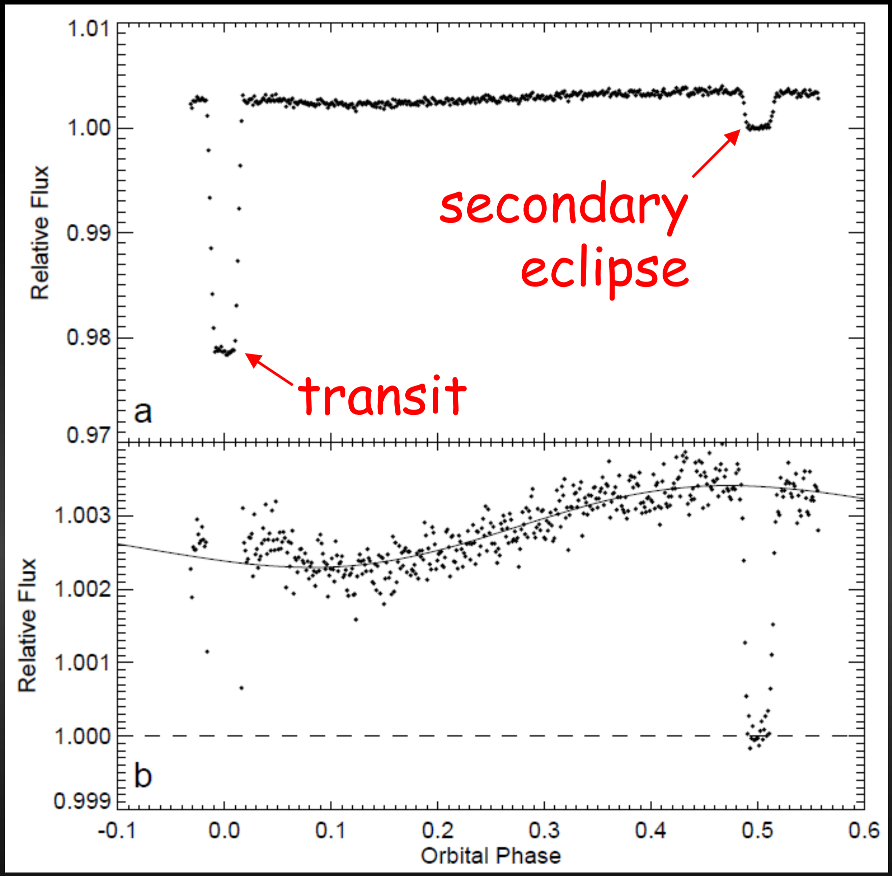
Feasibility and Summary

- photometric accuracy of $\sim 10^{-4}$ in a few minutes cadence is sufficient to detect rings and characterize their configurations
  - ✓ reasonable accuracy for Kepler/TESS main targets
- multichannel (NIR ~ FIR) & multiple observations would be useful to characterize particle size of rings
- observations for numbers of TJPs with a wide variety of system parameters are important to learn the diversity of ringed planets
- NIR~FIR capability may be one of a merits over JWST to characterize particle size of rings around TJPs

Around-the-Orbit Observations

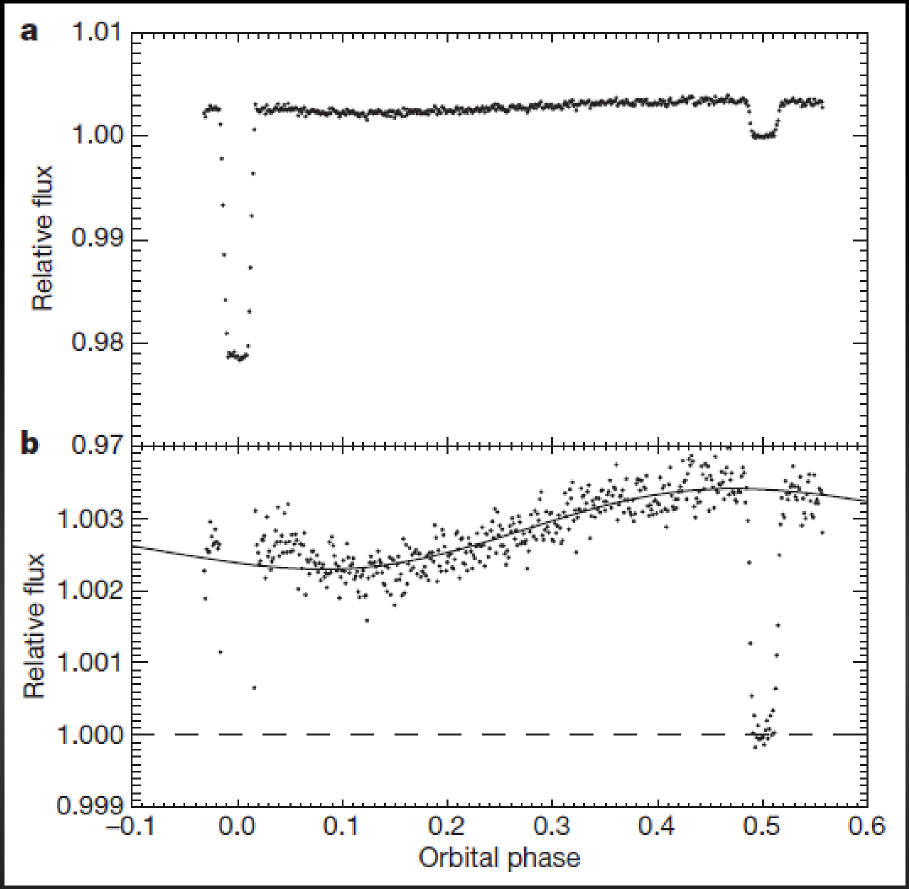
provide information of phase function and diurnal variations

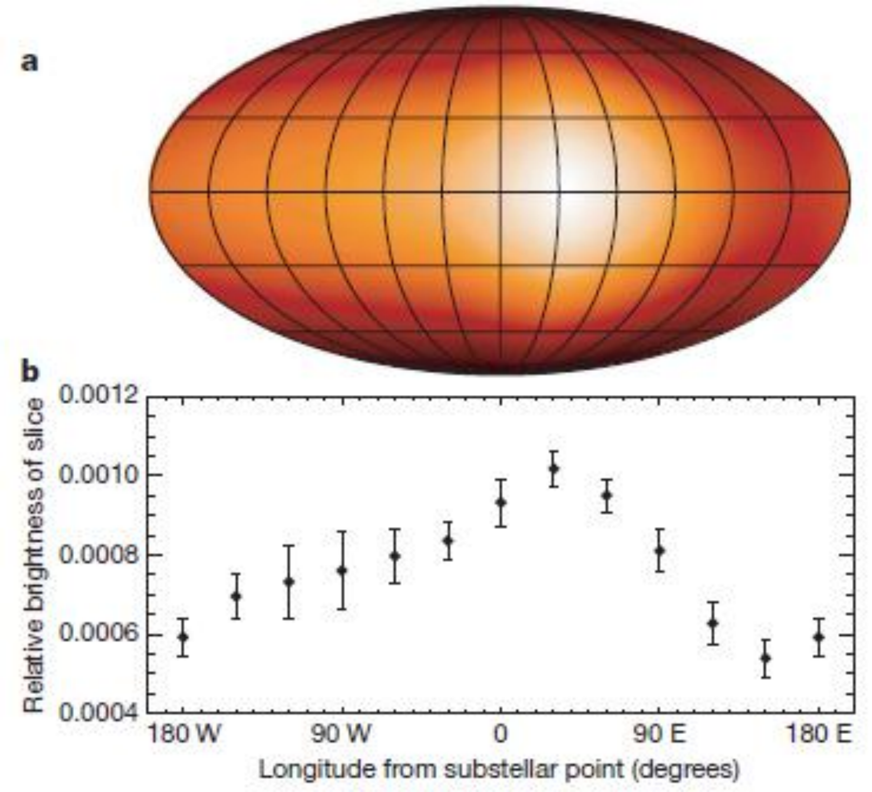




Knutson et al. (2007)

Temperature Map of a Jovian Planet





HD189733: 8 um IRAC / Spitzer Knutson et al. (2007)

Phase Function and Diurnal Variations

- Around-the-orbit observations provide clues for phase function and diurnal variations of TJPs
- Phase function is produced by difference in planet's day/night temperature
  - ✓ planets without atmosphere will exhibit maximum variations
  - ✓ efficient day-night heat transfer provides minimum variations
- Diurnal variations are caused by surface temperature inhomogeneity in TJPs and observed as modulation from phase function
- This kind of observations will also cover transit and SE
  - ✓ we can learn temperature of TJPs by SE detections

SPICA Around-the-Orbit Observations

Targets and Purposes

- Many warm/hot Jovian planets
  - ✓ will discovered with CoRoT/Kepler/TESS
- By measurements of secondary eclipses
  - ✓ planetary day-side temperature
- By measurements of phase function
  - ✓ effectiveness of heat transfer to night-side
- By detections of diurnal variations
  - ✓ rotation (spin) rate of Jovian planets

Feasibility and Summary

- SEs of warm Jovian planets are detectable by photometric accuracy of $\sim 10^{-4}$ in a few minutes cadence
- Variations due to difference of a few ten K in large surface area of planets would be detectable
  - Variations caused by a few hundred K difference in day/night side of hot Jupiters have already been detected with Spitzer's $\sim 1\times10^{-3}$ accuracy
- Detections of diurnal variations provide information of planetary rotation periods
- Hopefully feasible, but JWST will go ahead…

Overall Science Summary

- SPICA can study
  - ✓ atmospheres of terrestrial/Jovian planets
  - ✓ rings around Jovian planets
  - ✓ phase function and diurnal variations of Jovian planets
- Proposed studies of characterization of transiting Jovian planets are fairly secure
- It may be difficult to achieve proposed studies for terrestrial planets, but scientifically very important

Requirements

- Our targets are quite bright!
- Precise calibration sources are imperative
  - ✓ Stable flat-fielding
  - ✓ Lab tests for characterization of non-linearity of detectors
  - ✓ Effective read-out