SPICA for Transiting Exoplanets: Which SPICA instruments are useful?

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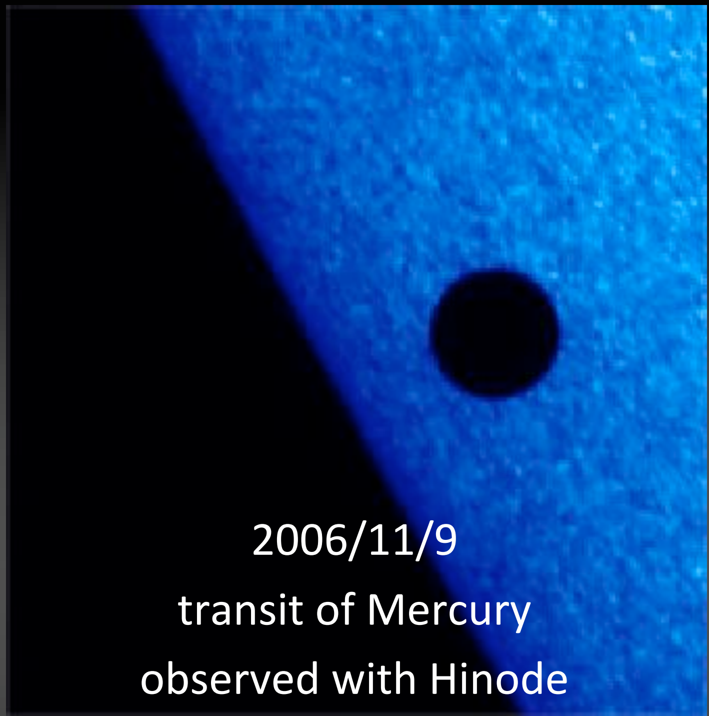
Outline

- Overviews of transit related sciences
  - Transit, secondary eclipse, temporal variation
  - Rings
  - Desired instrument specifications
- JWST instruments
  - NIRSpec, MIRI
- Strong/Weak points of SPICA instruments
- Summary

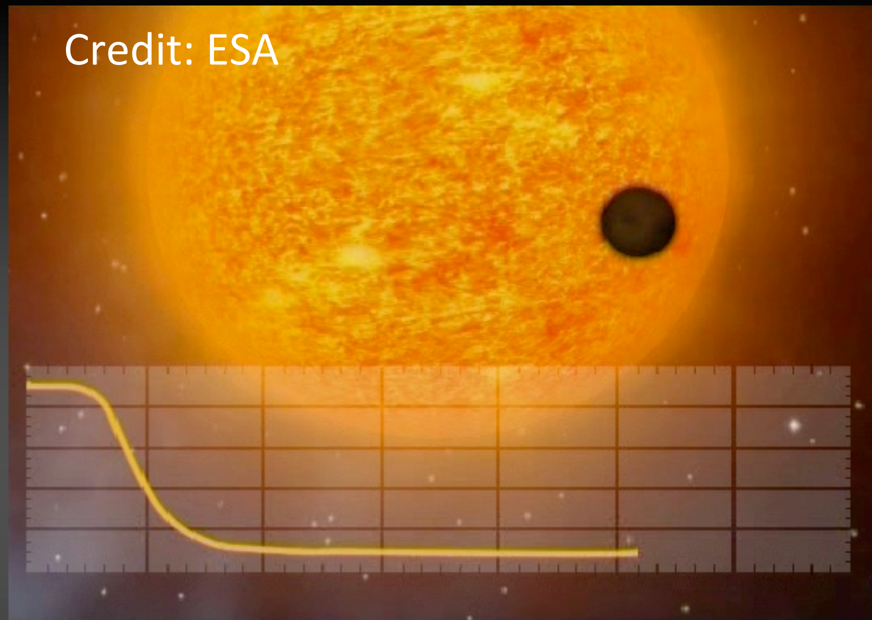
Planetary Transits

transit in the Solar System



transit in exoplanetary systems

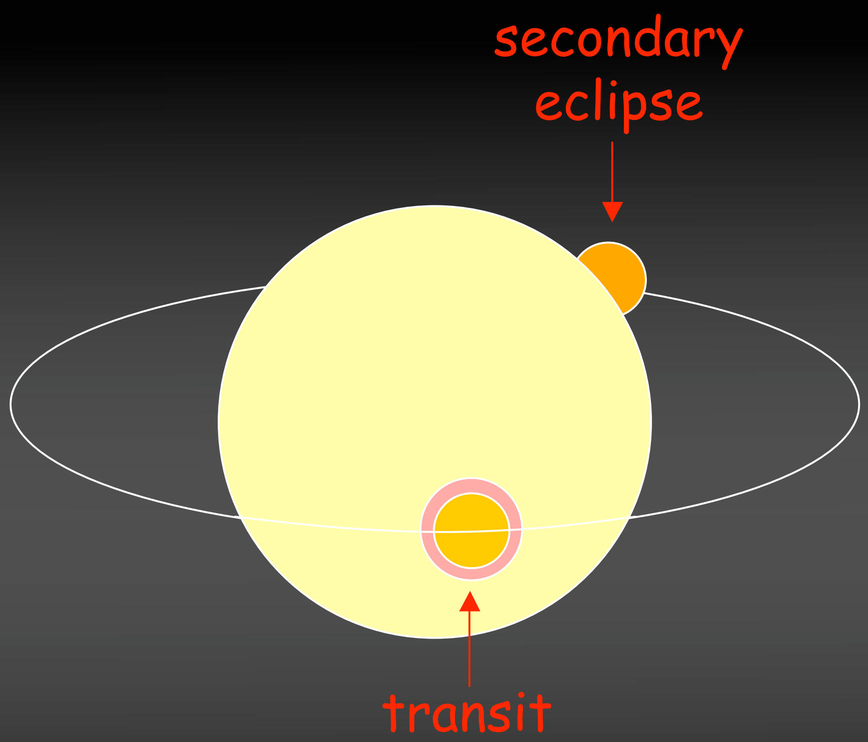
(we cannot spatially resolve)

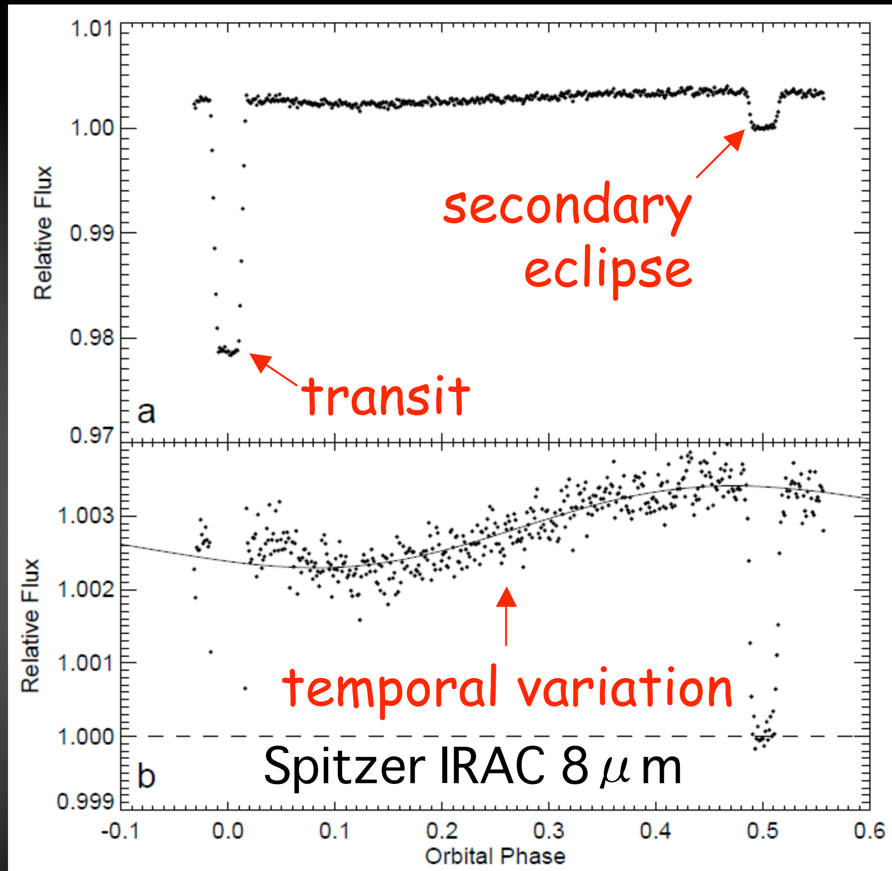


If a planetary orbit passes in front of its host star by chance, we can observe exoplanetary transits as periodical dimming.

Transit Related Sciences at a glance

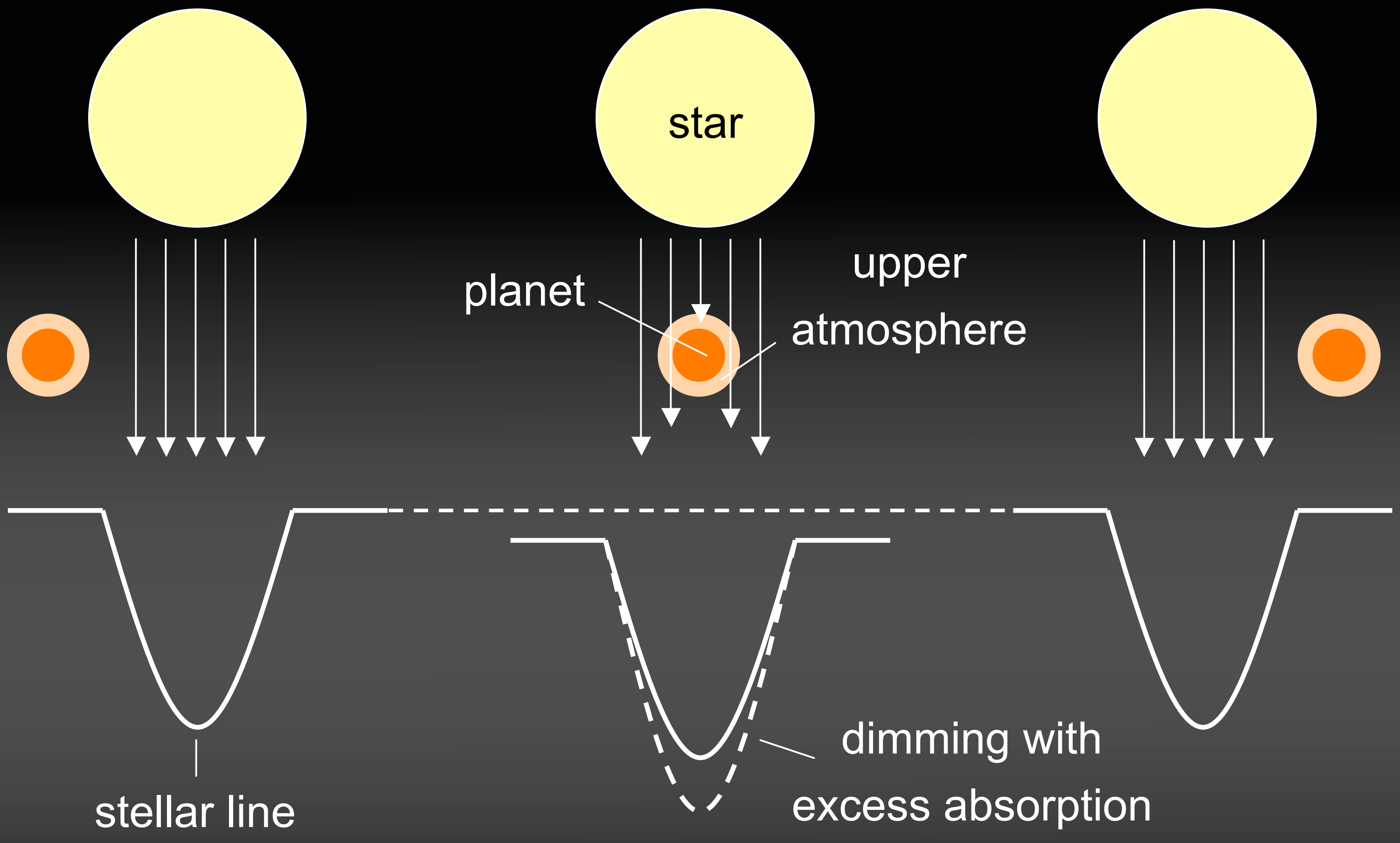
They provide fruitful information about their atmospheres





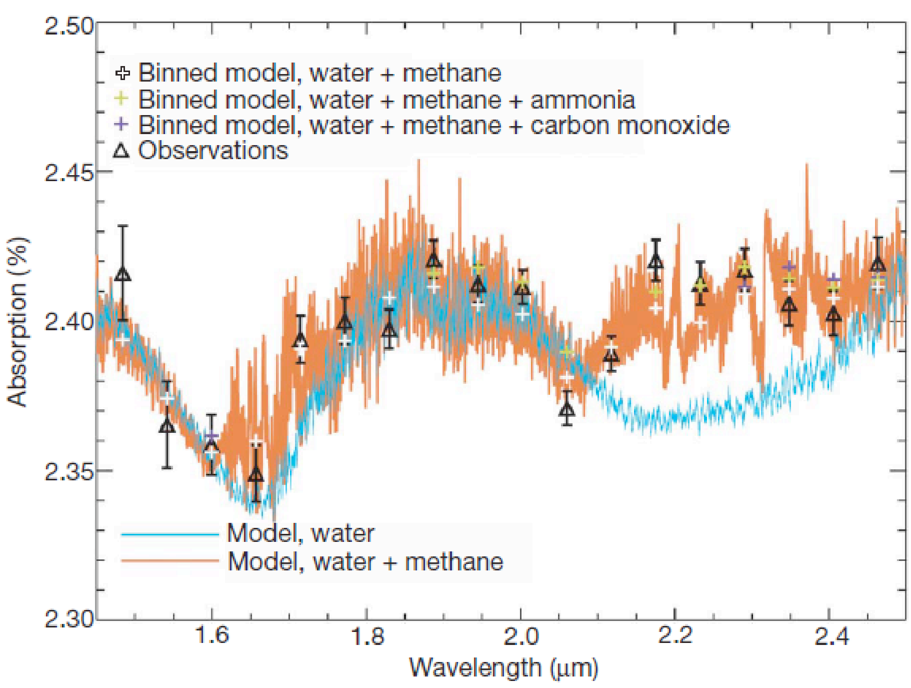
Knutson et al. (2007)

Transmission Spectroscopy



A tiny part of starlight passes through planetary atmosphere.

Example of Molecular Detection



▲ : HST/NICMOS observation

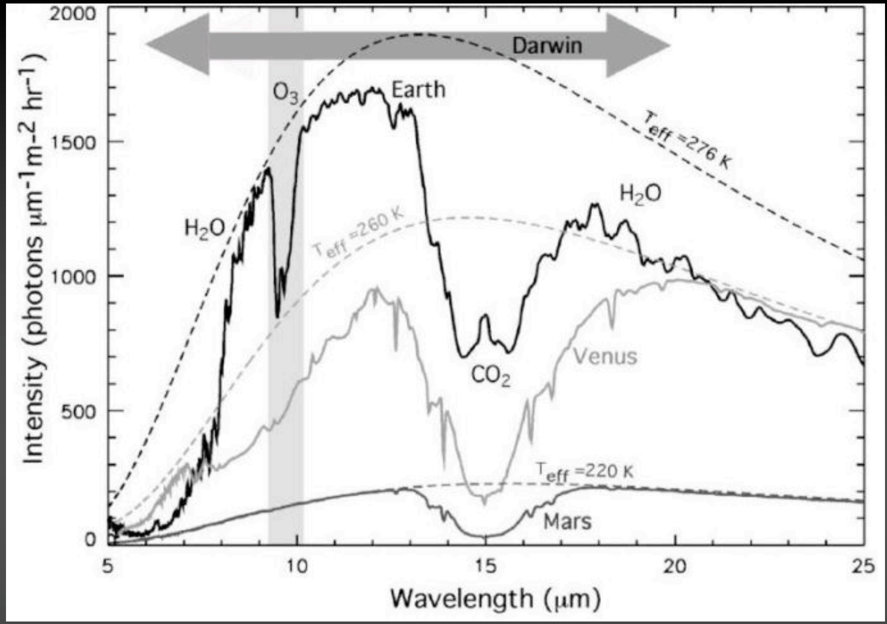
red : model with methane+vapor

blue : model with only vapor

Swain et al. (2008)

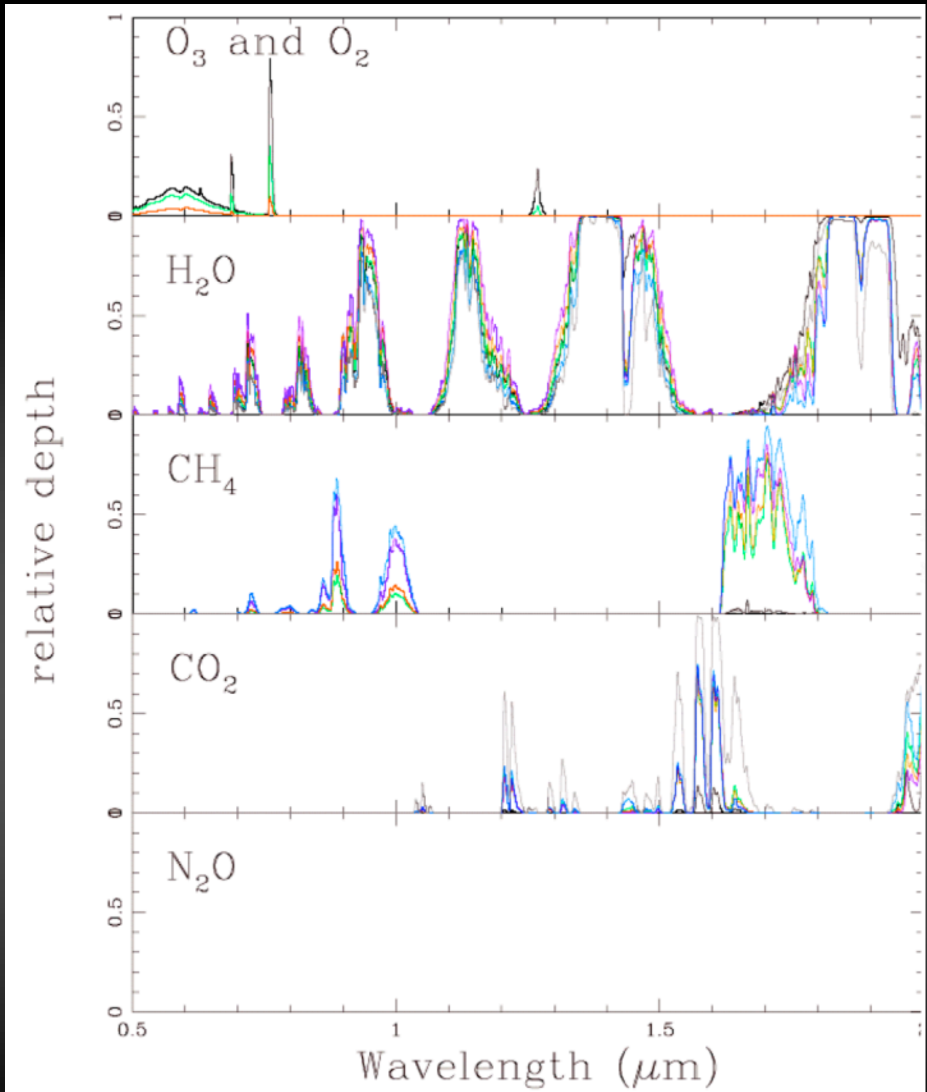
Spectral Features

- Atmospheric spectral features
  - CO_2: 1.6 μm, 4.7 μm, 15 μm (strong and wide)
  - CH_4: 0.88 μm, 1.66 μm, 3.3 μm, 7.66 μm
  - H_2O: many features at NIR-MIR
  - O_2 : 0.76 μm
  - O_3 : 0.45 - 0.74 μm, 9.6 μm
- 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

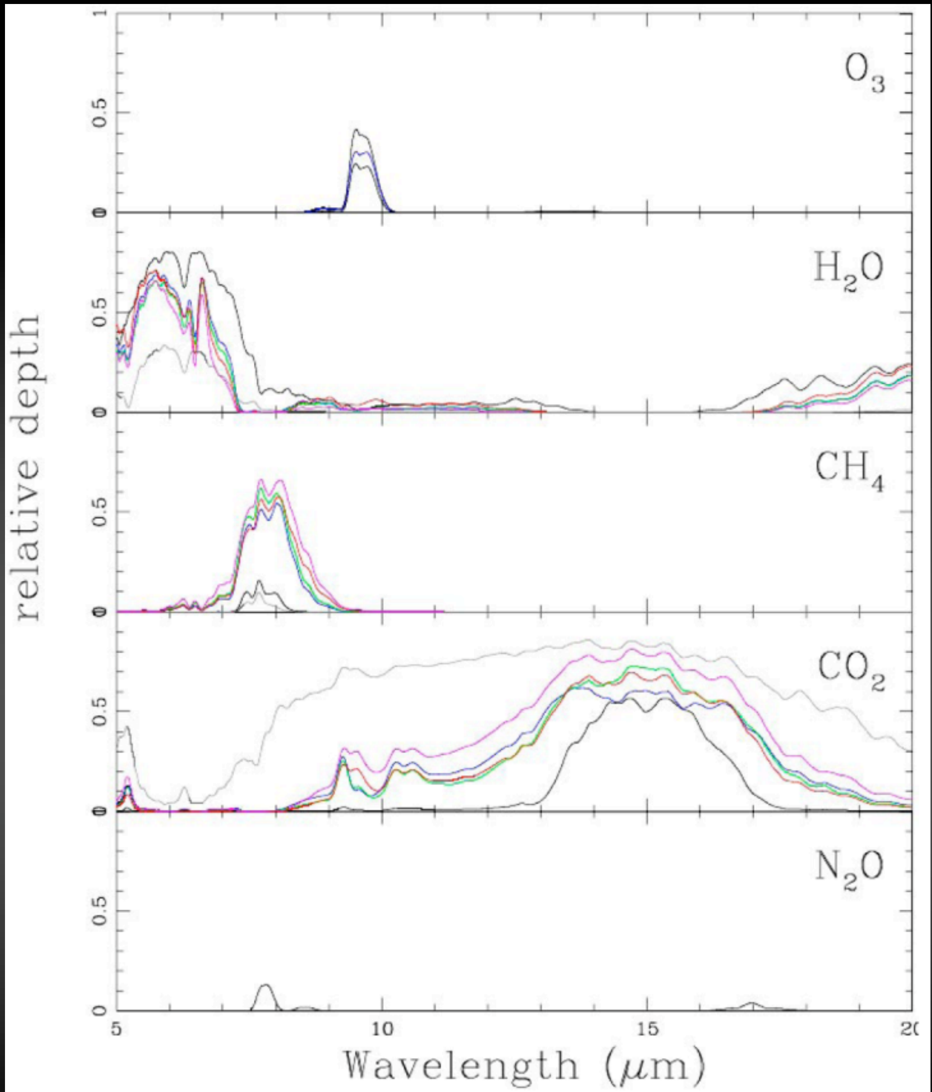
Near-Infrared Features (0.5-2 μm)



- Molecular features
  - CO_2: 1.6 μm
  - CH_4: 0.88 μm, 1.66 μm
  - H_2O: many features
  - O_2: 0.76 μm
- Necessary spectral resolution
  - ✓ ~200 to avoid blending

Kaltenegger et al. (2007)

Mid-Infrared Features (5-20μm)

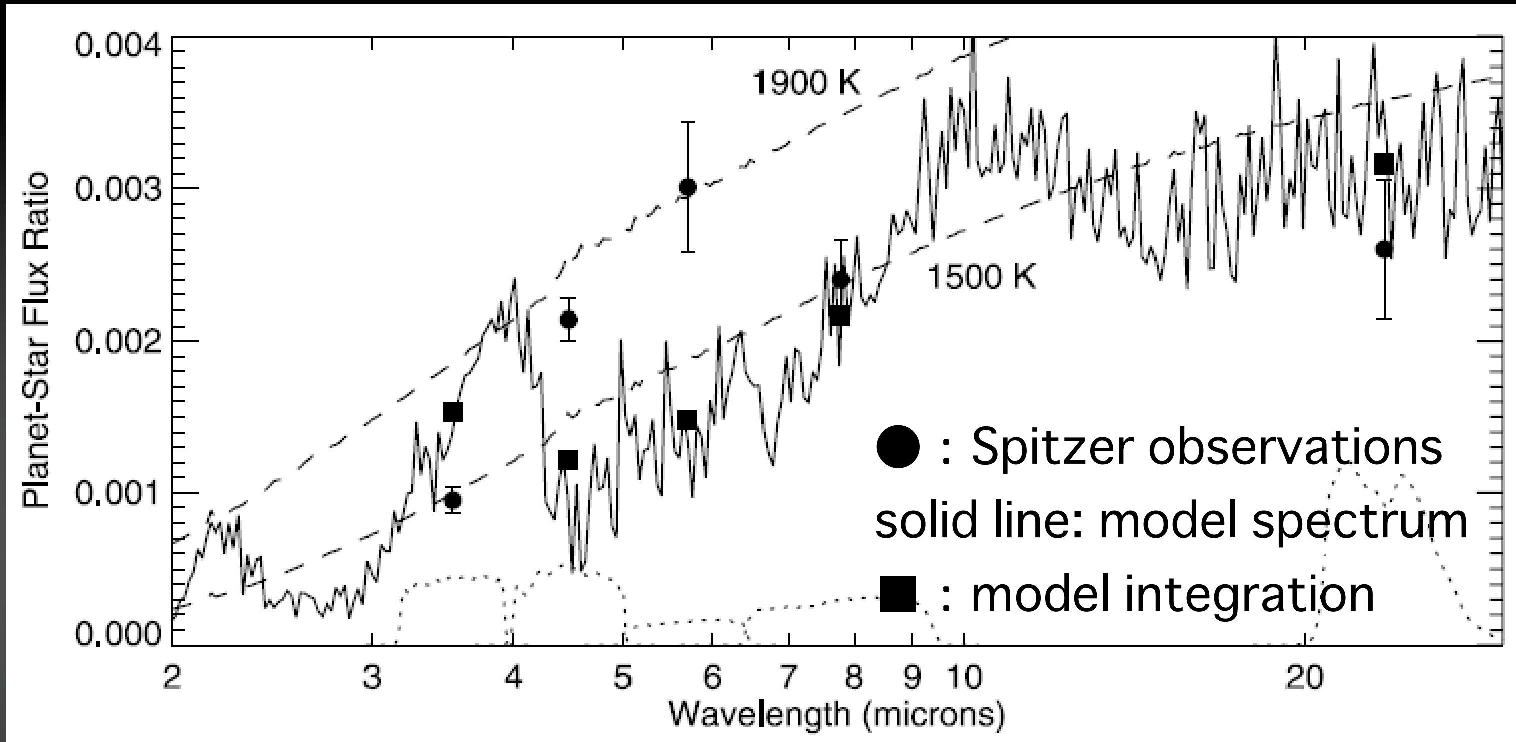


- Molecular features
  - CO_2: 15μm (wide)
  - CH_4: 7.8μm
  - H_2O: 6.5μm
  - O_3: 9.6μm
- Necessary spectral resolution
  - ✓ ~30 to avoid blending
  - ✓ higher is better to distinguish O_3 buried in CO_2

Kaltenegger et al. (2007)

Secondary Eclipses and Thermal Inversion

Secondary eclipses provide vertically-integrated dayside spectra.

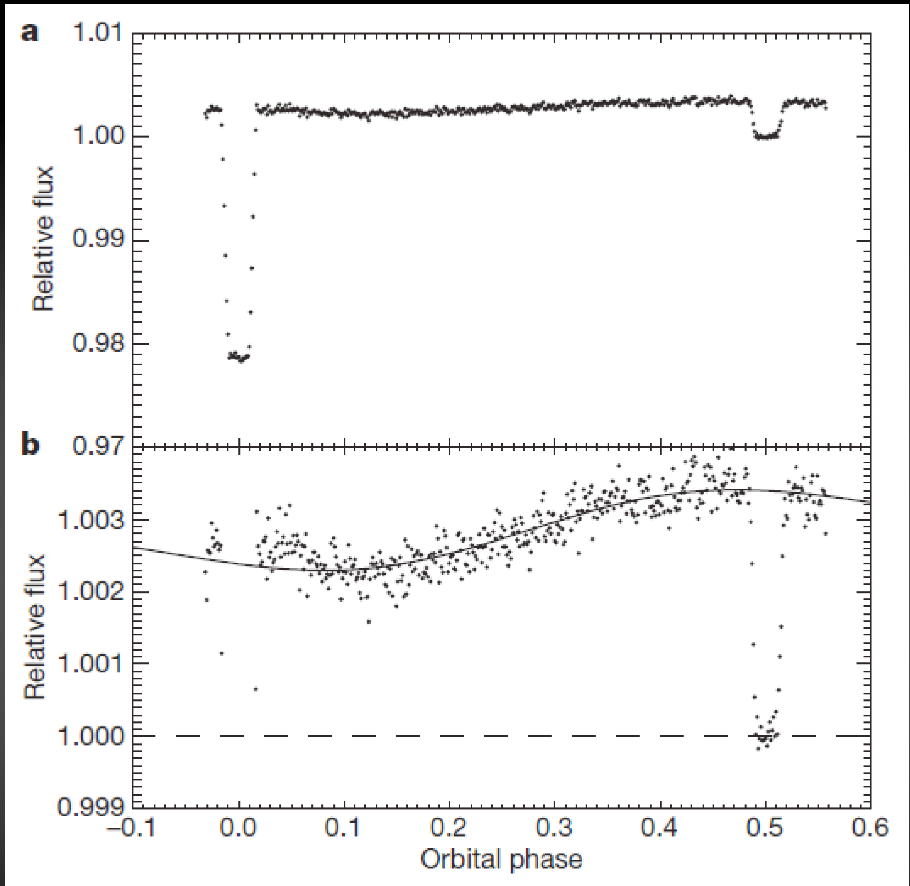


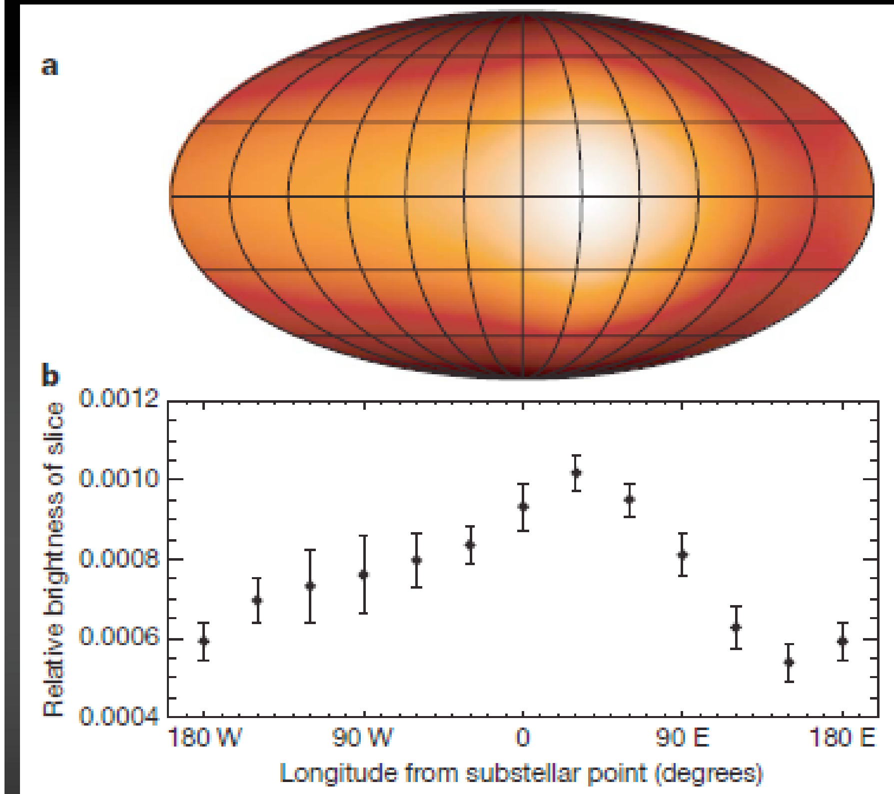
Knutson et al. (2008)

HD209458b has hot stratosphere and thermal inversion.

Temperature Map of a Jovian Planet

Temporal variations are related with planetary orbital phase and spin.

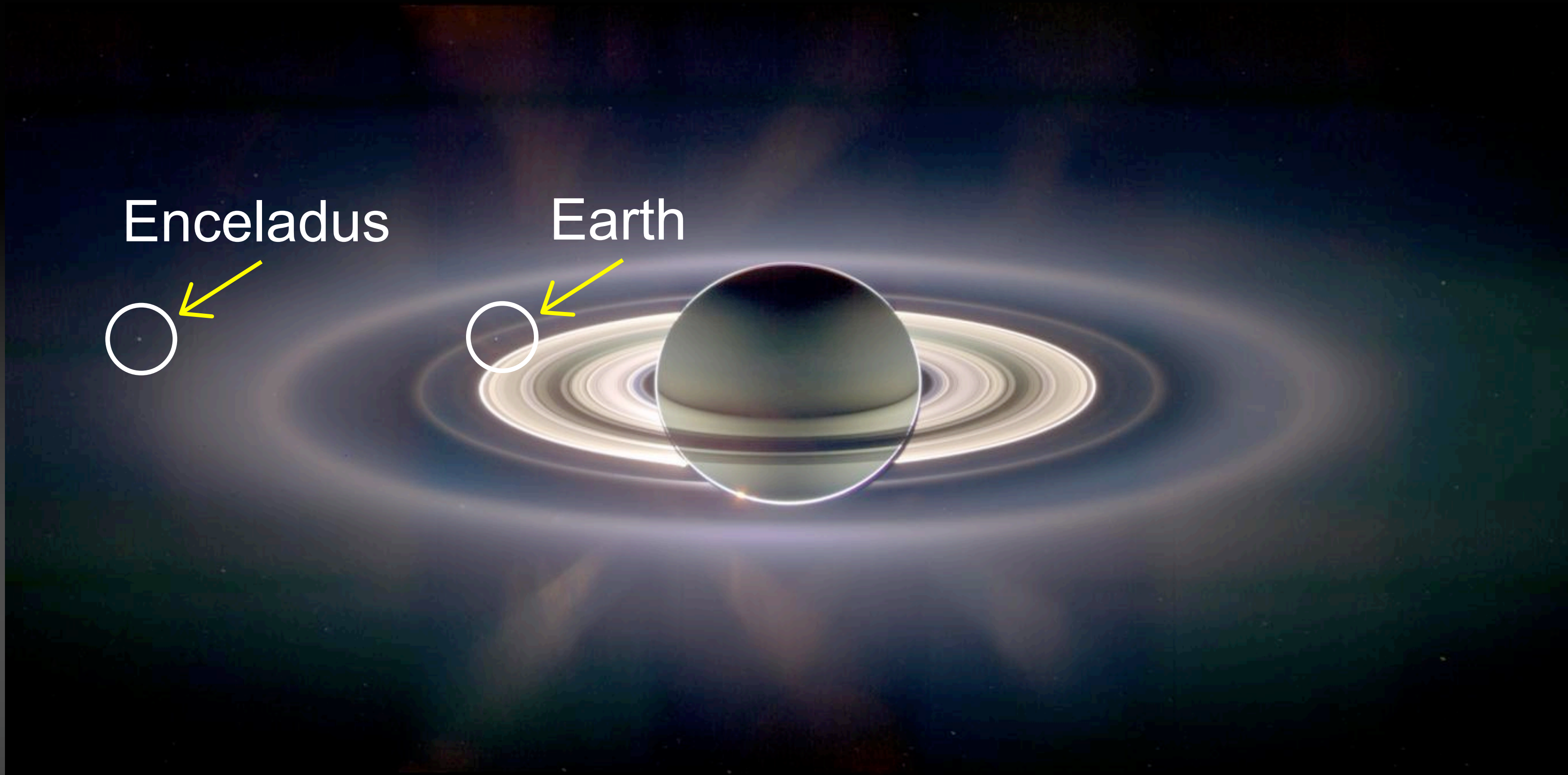




HD189733b: 8 μm IRAC / Spitzer Knutson et al. (2007)

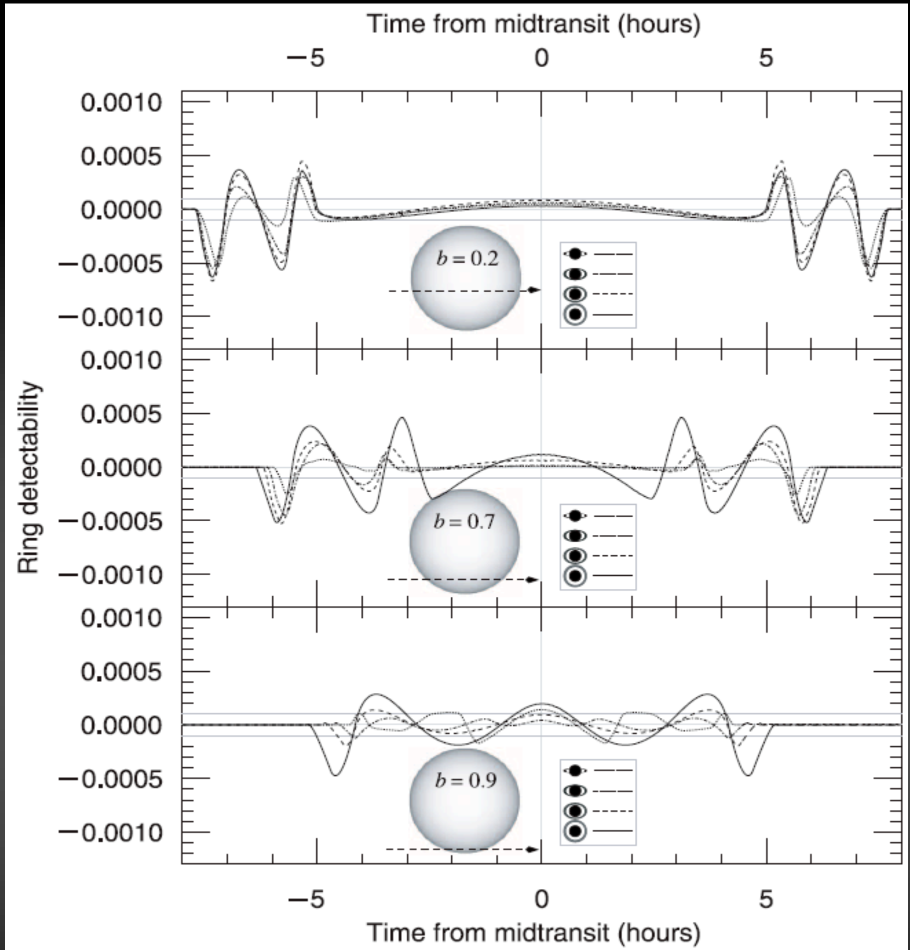
Items	Minimum Success	Full Success (achieve all the goals shown below)	Extra Success (achieve at least one of the goals shown below)
Technical Targets	In the orbit around Sun-Earth L2 point, spacecraft operation as well as the infrared observations shall be done for at least 6 months	In the orbit around Sun-Earth L2 point, spacecraft operation as well as the infrared observations shall be done for at least two years..	
Scientific Targets "Drama of Galaxy Formation"	Achieve at least two of the full-success level goals	(1)More than 80% of the cosmic far-infrared background light are resolved into the individual far-infrared objects. Multi-wavelength correlation functions of the cosmic far-infrared background light are measured. (2)The physical and chemical conditions of galaxies in the early universe (more than10 Gyrs ago) are measured based on the statistical study of various kind of galaxies up to redshifts of 2 or 3, through broad-band moderate resolution spectroscopy.	Over more than 90% of the history of universe (from ~12 Gyrs ago to the present), the physical and chemical conditions of galaxies are measured.
Scientific Targets: "transmigration of dust in the Universe"		(1) From the infrared spectroscopy of more than one dust forming SNe within 25Mpc during an initial few years after the explosion, the composition and the accurate amount of newly formed dust are measured. (2) From the resolved infrared spectro-imaging data of ~30 SNRs, the composition and the amount of formed dust in the SNRs are measured.	
Scientific Targets: "Recipe for Planetary Systems"		(1) More than 10 dust disks around nearby (<20pc) stars, including whose amount of dust is about 10 times as large as our solar system, are detected in order to resolve structure and evolution of the protoplanetary disk. (2) In order to reveal the evolutional history of outer solar system, thermal emission of more than five primitive objects up to the distance of 30-50 AU and radius of <100 km s-1 is measured.	From the spectroscopy of more than one exoplanets, composition of their atmospheres is measured.

The Saturn transiting the Sun



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

Methodology of Ring Detection

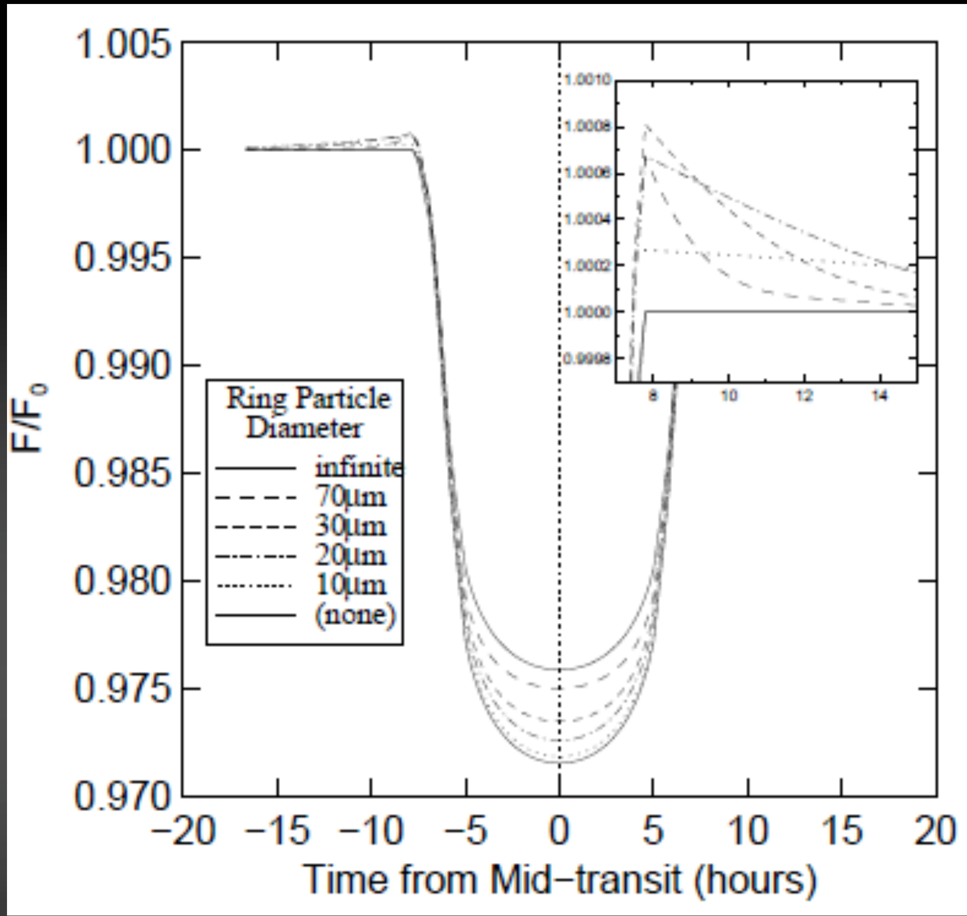


Barnes & Fortney (2004)

- 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)

Desired Instrument Specifications

- Transmission Spectroscopy
  - for both Jovian and terrestrial planets
  - special spectral features (0.76, 9.6, 15 μm) are very important for challenging cases (terrestrial planets)
  - wide wavelength coverage or higher spectral resolution are important to learn mixing-ratio (e.g., C/O) of atmospheres
  - low spectral resolution is useful, and higher resolution is effective for studying specific features
- Secondary eclipses, temporal variations, rings
  - for Jovian planets
  - wide wavelength coverage at one time

JWST Instruments: NIRSpec

- Specification
  - wavelength coverage: 0.6 - 5.0 μm
  - 3 spectroscopic modes
    - ✓ Micro-shutter assembly (simultaneous reference spectroscopy)
    - ✓ Integral-field spectroscopy
    - ✓ Slit spectroscopy
  - spectral resolution: 100, 1000, 2700
  - FoV: 3′ x 3′
- Science Cases
  - transmission spectroscopy of habitable terrestrial planets
  - NIRSpec can search for H_2O, CO_2, CH_4, O_2 in near-infrared

JWST Instruments: MIRI

- Specification
  - 9 photometric bands: 5-28 μm, R=5, imaging (FoV: 74" x 113")
  - low resolution: 5-14 μm, R=100@7.5 μm, slit
  - medium resolution: 4.9-28.8 μm, R=2070-3730, IFU
- Science Cases
  - transmission spectroscopy with medium resolution IFU
  - secondary eclipses, temporal variations, rings

SPICA Instruments

- SCI
- FPC-S
- WFC-S, WFC-L
- LRS-S, LRS-L
- MRS-S, MRS-L
- HRS-S, HRS-L
- SAFARI

SPICA Instruments: SCI

- SCI as simultaneous NIR-MIR low-res spectrograph
  - NIRSpec is better than SCI-short channel
  - MIRI is better than SCI-long channel
  - but JWST cannot use NIRSpec and MIRI simultaneously
- SCI covers all interesting molecular features
  - except for 0.76 μm O_2 feature -> option desirable
- If JWST/NIRSpec discover O_2 signatures, then SCI is very important for independent confirmation
  - ✓ no other instrument can confirm JWST results

SPICA Instruments: FPC-S

- FPC-S can be used for transit photometry
  - if simultaneous reference stars are within FoV
  - wider FoV than JWST/NIRCam
- But too long readout time (100-600 sec)
  - shorter (< 10 sec) readout would be useful

SPICA Instruments: WFC-S&L

- WFC-S&L are unique and strong instruments for transit photometry
  - wider FoV than JWST/MIRI
  - wider wavelength coverage than JWST/MIRI
  - especially useful if there are reference stars within FoV
- would be useful for detecting secondary eclipses, temporal variations, rings

SPICA Instruments: LRS-S&L

- LRS-S is somewhat similar to SCI-long channel
  - JWST/MIRI is better than LRS-S
- LRS-L or MRS-L?
  - MRS-L seems to be better for transits (very bright targets)
  - LRS-L may be interesting if the optional wavelength coverage (25-48 μm) is achieved
  - but SAFARI can cover the longer side?

SPICA Instruments: MRS-S&L

- MRS-S&L are useful for transmission spectroscopy
  - JWST/MIRI has a few higher spectral resolution
  - MRS-S&L have wider wavelength coverage than MIRI
  - but MRS-S is lacking O_3 spectral feature
  - ➢ desired to extend wavelength down to ~9.4 μm

SPICA Instruments: HRS-S&L

- HRS-S&L are unique high spectral resolution instruments
  - no other similar instrument
  - but very unfortunately, HRS-S&L do not cover interesting molecular features
  - may be useful if wavelength range changes
  - how about 5-10 μm?

SPICA Instruments: SAFARI

- SAFARI is unique and interesting
  - no other similar instrument so far
  - first challenge of transmission spectroscopy or other studies in FIR

- SCI: extend wavelength down to 0.7 μm
- FPC-S: shorter readout?
- WFC-S, WFC-L: if reference stars are within FoV
- LRS-S, LRS-L: can be trade-off with others?
- MRS-S, MRS-L: extend wavelength down to 9.4 μm
- HRS-S, HRS-L: wavelength change?
- SAFARI: first challenge