National Aeronautics and Space Administration

JPL

Atmospheric profiling of extrasolar planets through combined light measurements

THESIS

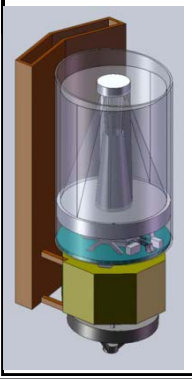
THESIS – The Terrestrial and Habitable-zone Exoplanet Spectroscopy Infrared spacecraft: *a joint NASA/ESA exoplanet characterization mission concept*

Pieter Deroo

(Jet Propulsion Laboratory, California Institute of Technology)

&

Mark Swain (JPL), Thomas Henning (MPIA), Drake Deming (GSFC), Gautam Vasisht (JPL), Carl Grillmair (Cal. Tech.), Jeroen Bouwman (MPIA), Rachel Akeson (Cal. Tech.) + others



Combined light characterization

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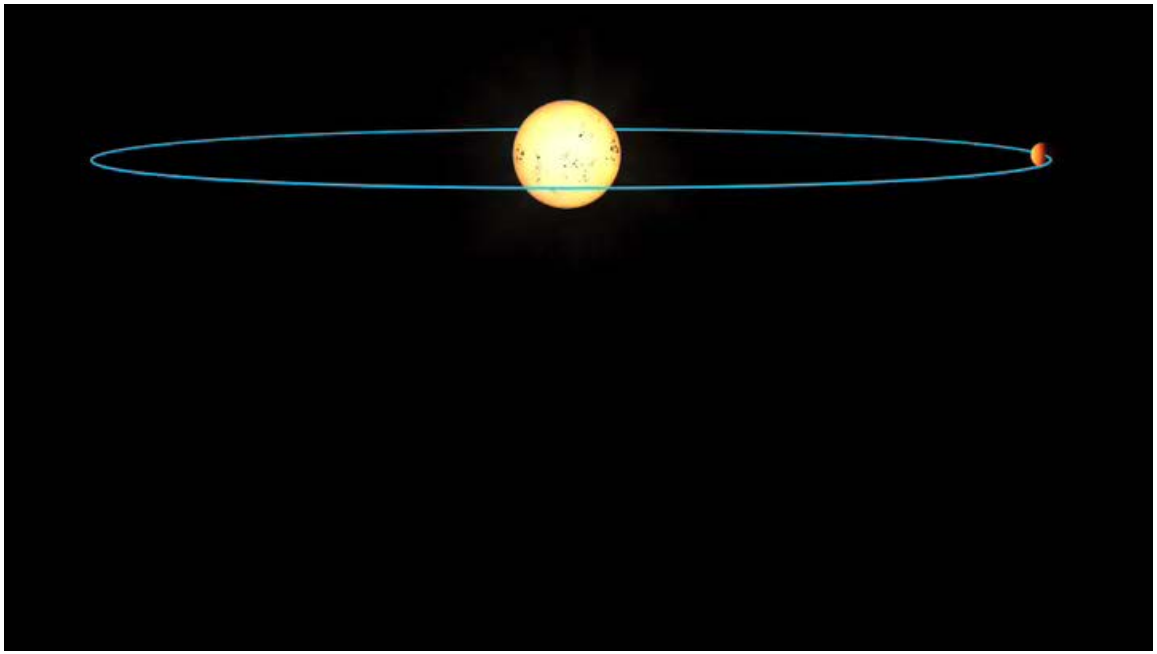
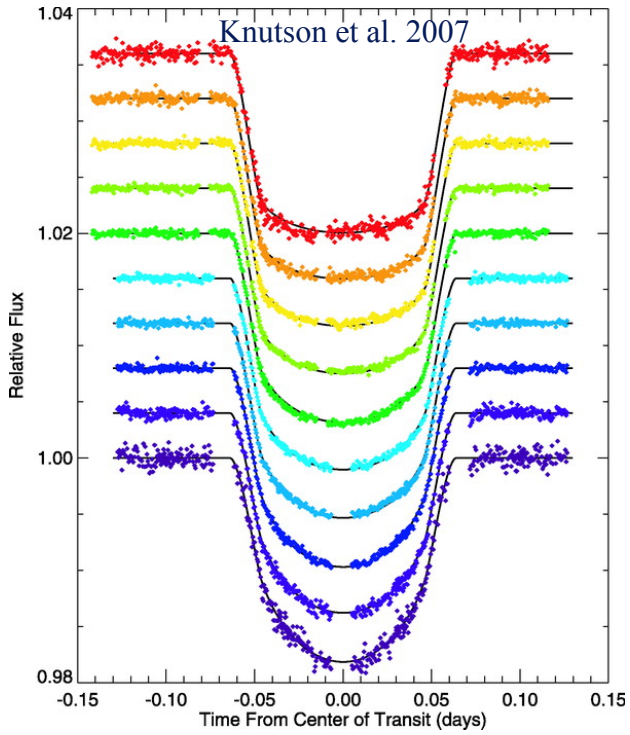
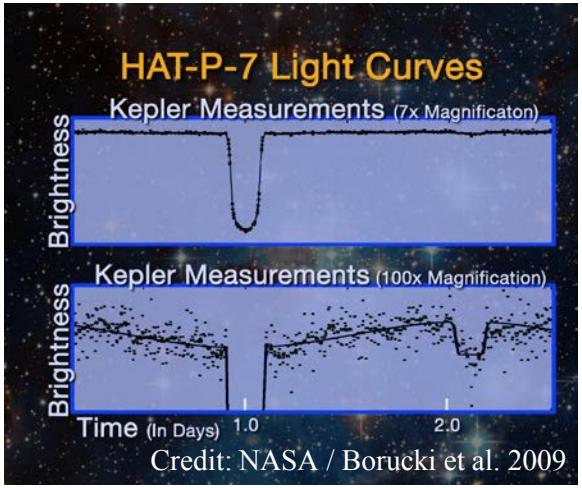
Measurement = modulation of combined light

- Transits:
  - dayside emission spectrum
  - terminator region transmission spectrum
- Phase-curve:
  - longitudinal brightness distribution



NASA / Kepler / Borucki





Some highlights

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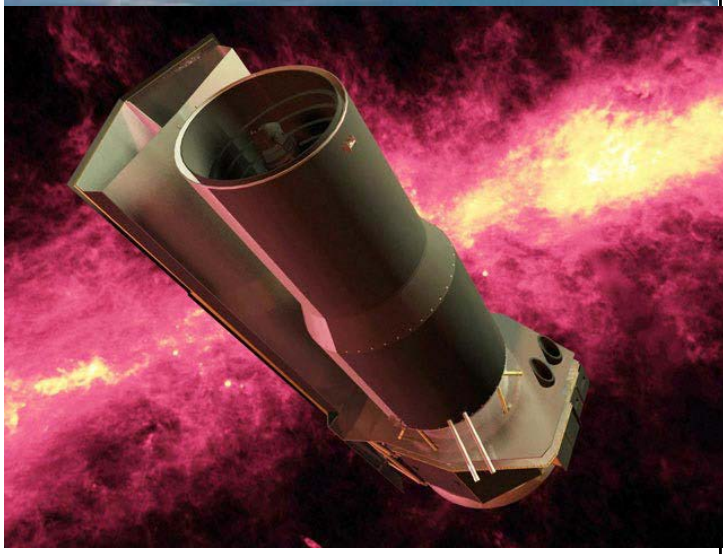
- 2002: first detection of an exoplanet atmosphere (Charbonneau)
- 2005: first detection of infrared emission of exoplanet (Deming; Charbonneau)
- 2006: first detection of day and night on exoplanet (Harrington)
- 2007: first emission spectrum of an exoplanet (Richardson; Grillmair)
- 2007: detection of H_2O in an exoplanet atmosphere (Tinetti)
- 2008: detection of an atmospheric temperature inversion (Knutson)
- 2008: detection of H_2O and CH_4 in an exoplanet (Swain)
- 2009: detection of H_2O, CH_4 and CO_2 in an exoplanet (Swain)
- 2009: detection of H_2O, CH_4 and CO_2 in a second exoplanet (Swain)
- 2009: detection of variability (Deroo)



A detailed characterization of exoplanet atmospheres is feasible, already with current technology!

Molecular Spectroscopy

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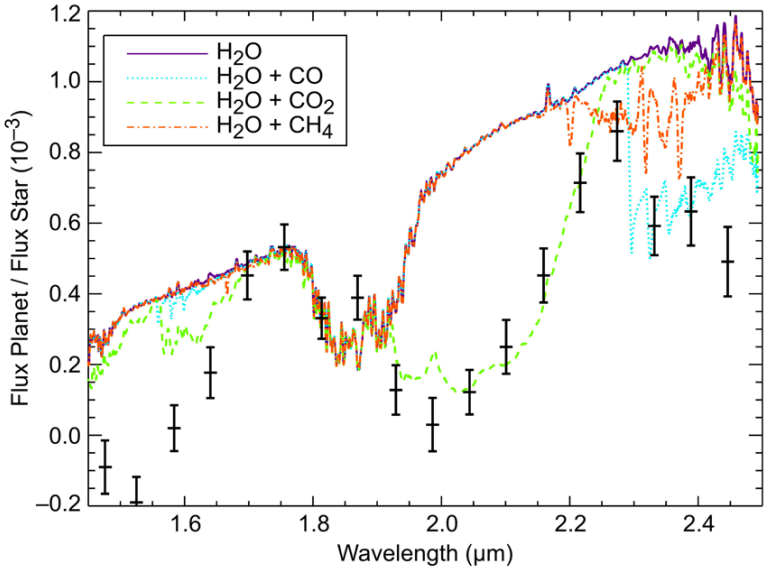
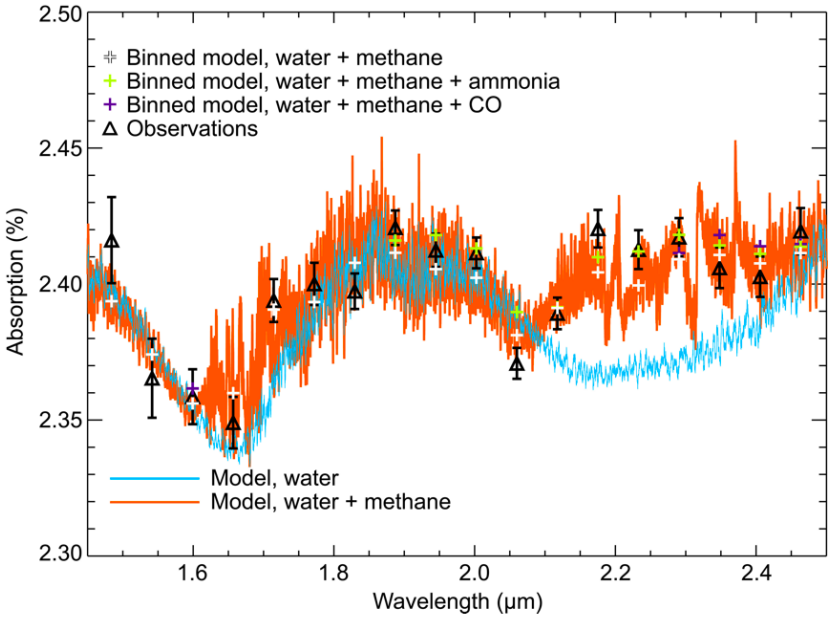
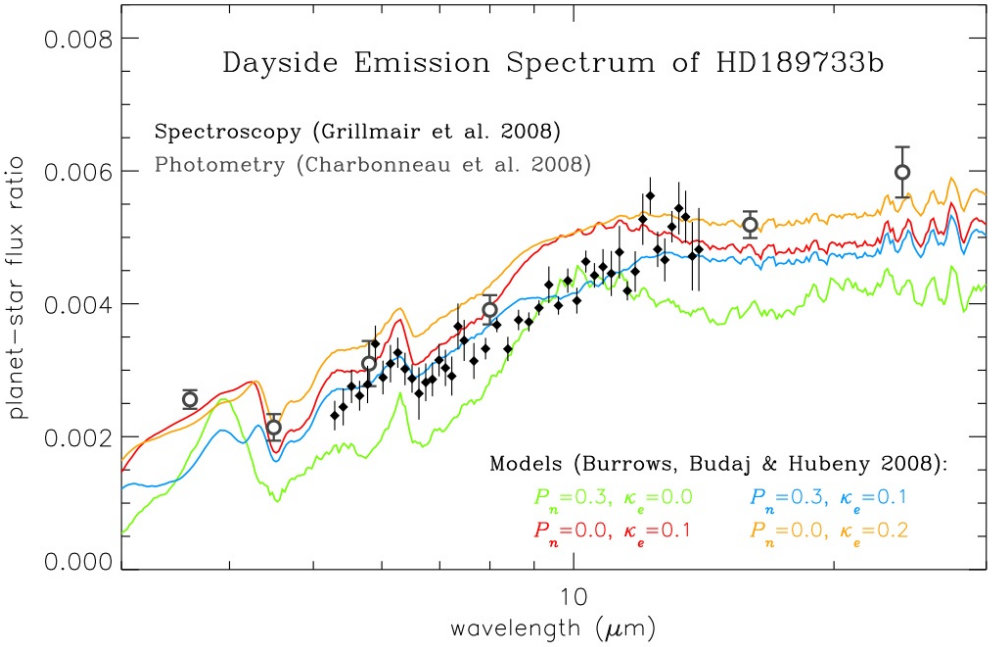
- Molecules with pre-biotic and biological significance H2O, CH4, CO2, & CO detected in the “hot-Jupiter” HD 189733b via infrared spectroscopy.
- Detections with primary and secondary eclipse with both Hubble and Spitzer (Swain et al. 2008, Grillmair et al. 2008, Swain et al. 2009).







Spectroscopy with Spatial Resolution

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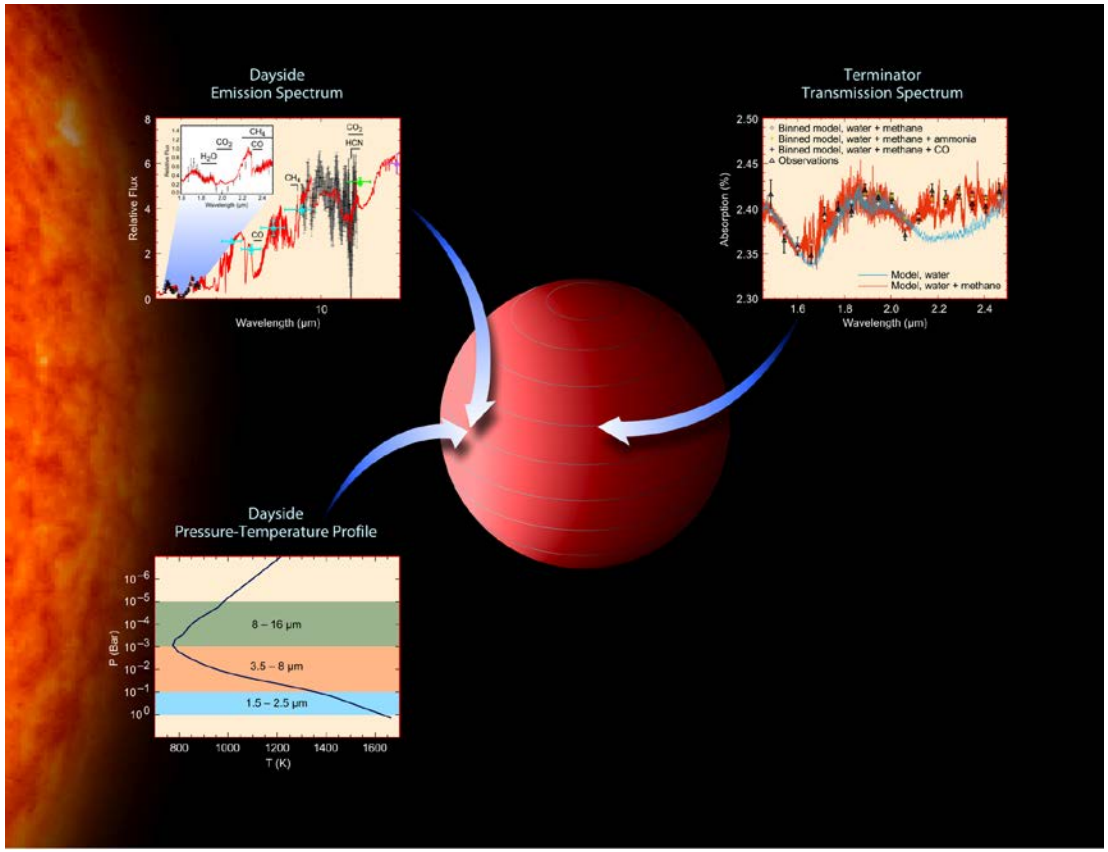
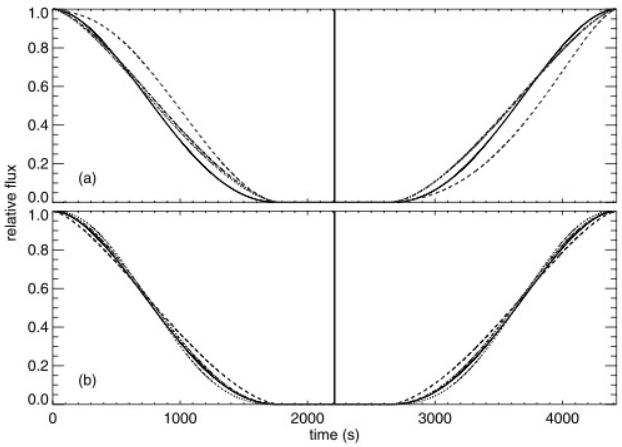
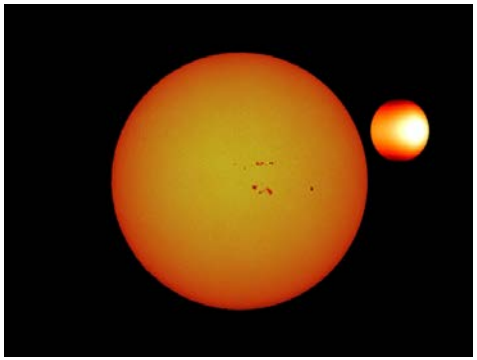
- Transmission and emission spectroscopy/photometry.
- Ingress/Egress light curve measurements (discussed Deming et. al. 2006)

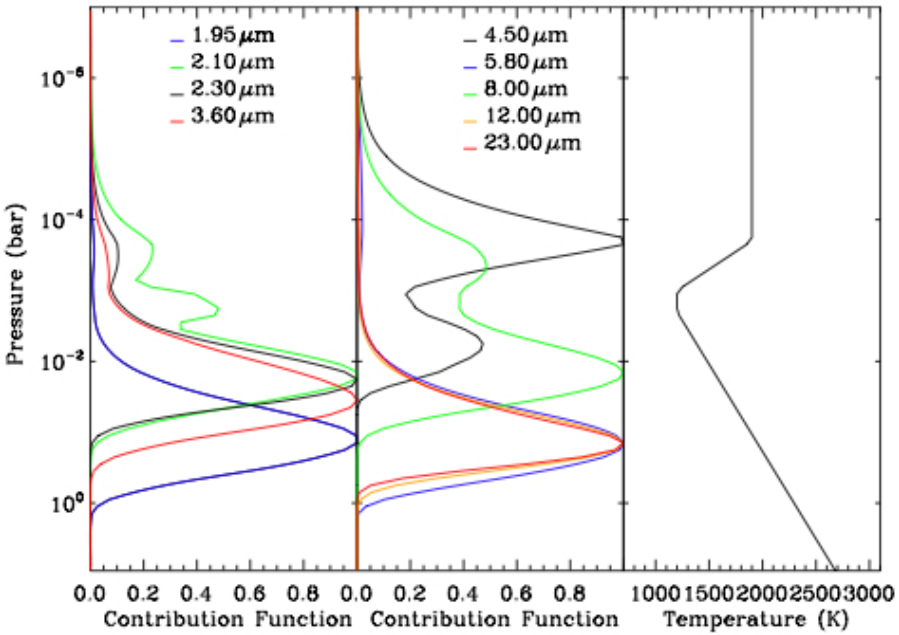


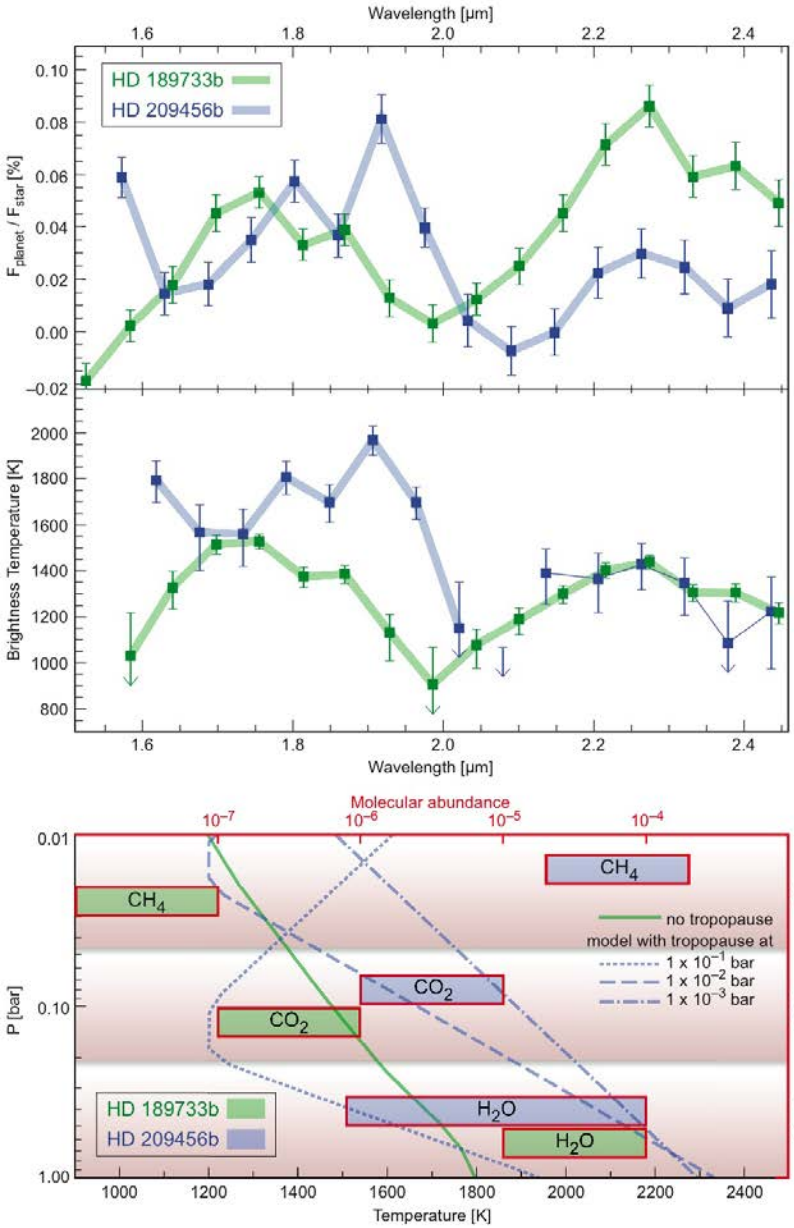
Rauscher et al. 2007





Atmospheric profiling





Swain et al. 2009

Science – Key Questions

Exoplanet spectroscopy:

- What are the conditions, composition, and chemistry of exoplanet atmospheres?
- How do dynamics affect atmospheric composition and chemistry?
- Are biologically important molecules present in habitable-zone rocky or ocean worlds?

THESIS overview

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- 1.4 m telescope with passive cooling
- Falcon launch to L2 orbit (1250 kg injected mass)
- 3 + 3 year mission life
- Cryo-cooler for IR FPAs
- R~2000 continuous spectroscopy from 0.4 to 14 microns
- No filter wheels or optics repositioning
- Calibration for long term stability
  - Periodic observations of a network of calibrator stars to tie-in data over mission life
  - Simultaneous visible observations to remove variations from star spots

Key Aspects

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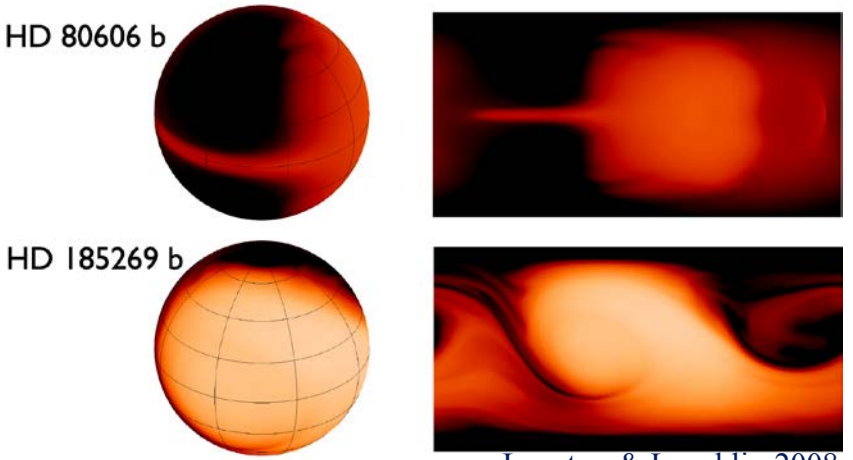
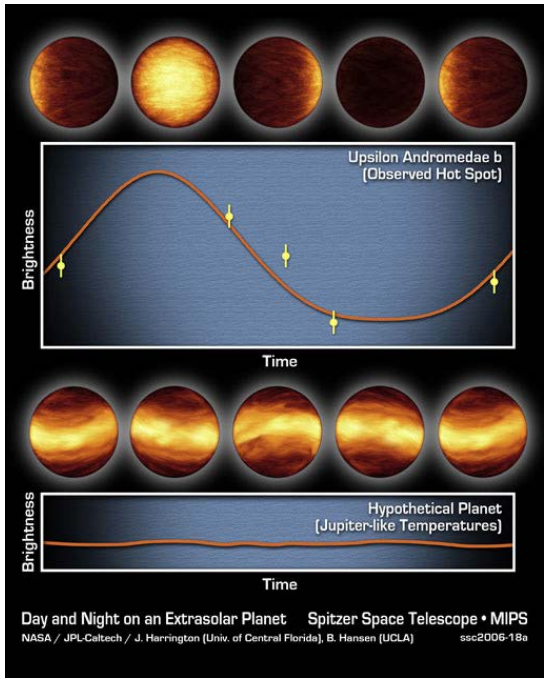
- Low technical risk
- Observational method proven with Hubble and Spitzer
- Simultaneous broad spectral coverage (0.4-14 microns “all at the same time”)
- Long term stability (near photon noise calibrated stability over the mission life)
- Enables a large sample of exoplanets to be characterized
- Highly complimentary to JWST.



Langton & Laughlin 2008



Broad Spectral Coverage

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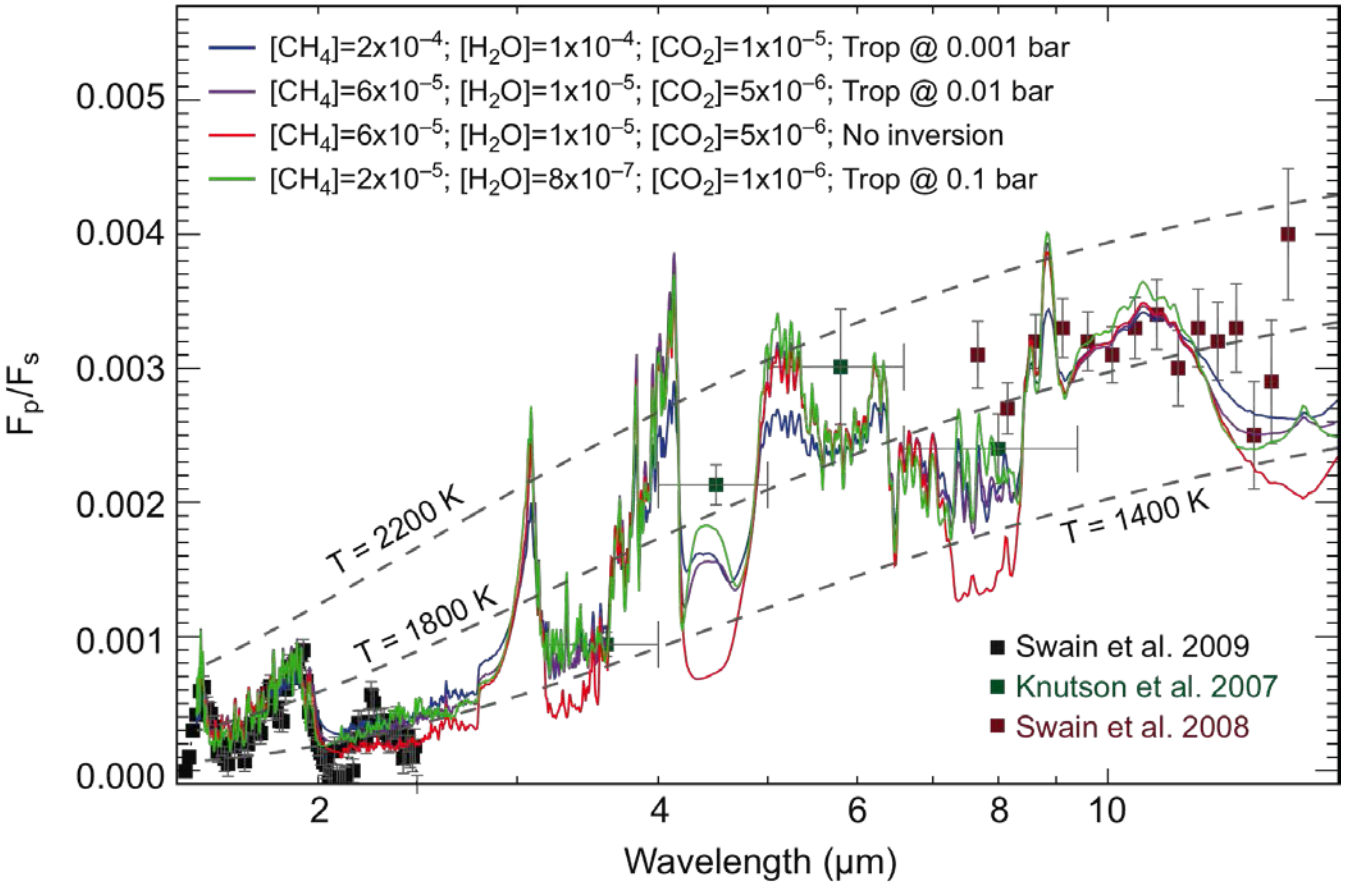
Emission spectra require broad spectral coverage to remove the temperature/composition ambiguity



Swain et al. 2009, Ap J. accepted

Simultaneous Measurements

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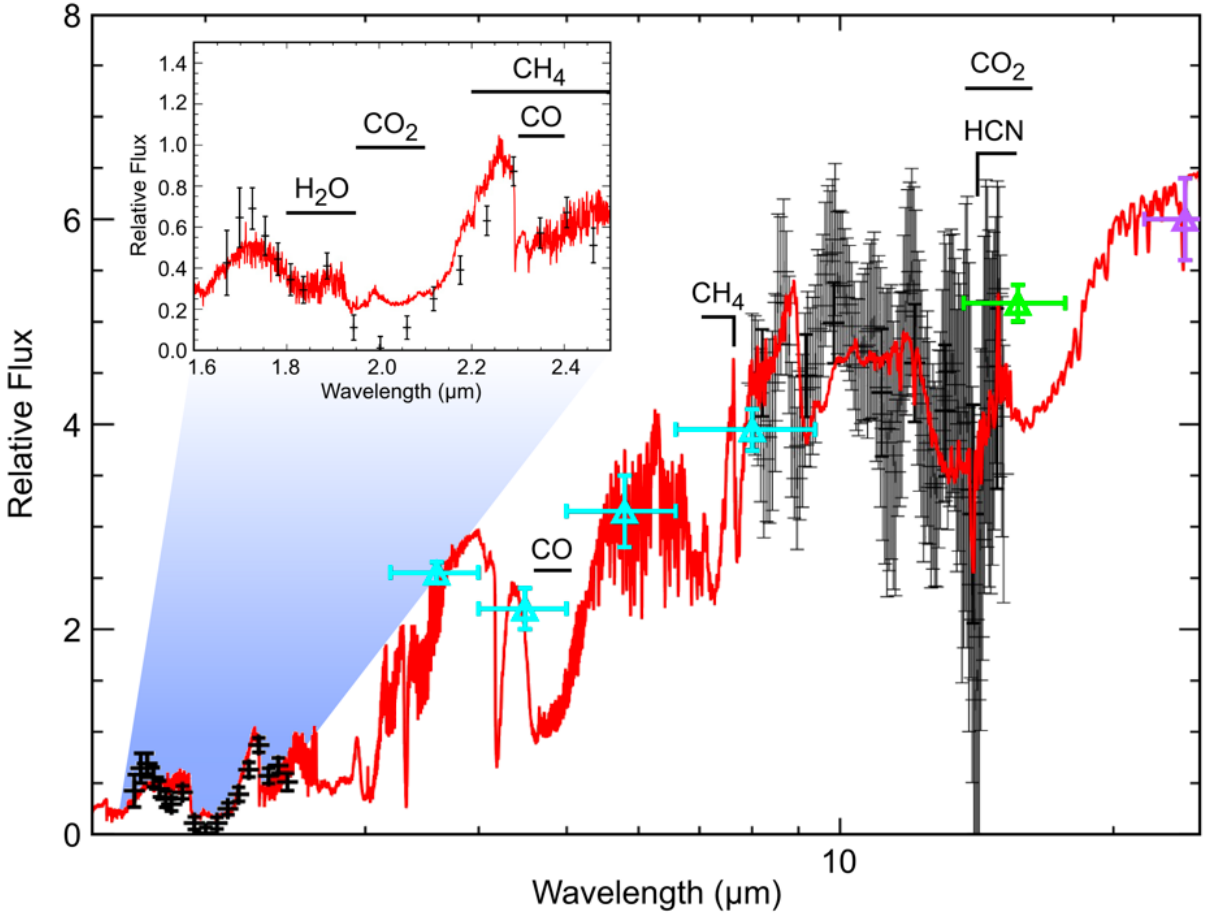
Simultaneous measurements are needed because of variability (which probes dynamical processes).



Near-IR (Swain et al. 2009), blue (Charbonneau et al. 2008), mid-IR (Grillmair et al. 2008), green (Deming et al. 2006), purple (Knutson et al. 2008)

THESIS/JWST Partnership

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- Focuses on “the big picture” of many planets, the atmospheric conditions and composition, and dynamics.
- Characterizes non-transiting planets including a “super Earth” orbiting an M dwarf in the habitable zone.

JWST

- Obtains the highest possible SNR spectra for a specific wavelength/events in high-priority targets.
- This could be important for obtaining the best possible abundance estimates where molecules have overlapping bands.

Cost & Schedule

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- JPL Team-X exercise with instrument inputs from ASPIRE instrument.
- Launch vehicle cost excluded.
- Phase A->F cost 520 M

- 8 year project
- 4.5 years from starting project to launch
- 0.25 year commissioning
- 3.25 years science operations
- Extended mission possible

Item	Cost ($M 2009)*
Management, Systems Eng., Mission Assurance	35
Payload System	155
-- Telescope	80
-- Instrument	70
-- Payload I&T	5
Flight System	110
Mission Ops/Ground Data System	45
Launch Vehicle	
Assembly, Test, Launch Operations	15
Science	40
Education and Public Outreach	5
Mission Design	5
Reserves	110
Total Project Cost (not including launch vehicle)	520

Science objectives

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" Virtually everything we know about the physical nature of exoplanets has come from a combination of radial velocity and transit measurements. "

Exoplanet Community Report (2009)

Time to take exoplanet characterization to the next level with a dedicated mission:

- Does non-equilibrium chemistry play a significant role in determining atmospheric composition?
- What dynamical processes are present, and how do they influence atmospheric composition and chemistry through mechanisms such as quenching or vertical transport?
- What is the extent and origin of temporal and spatial variability?
- What are the elemental abundances, and how do they constrain the formation and evolution histories?
- What are the conditions on habitable-zone "super-Earths," and is there potential for generating and sustaining life?
- What do exoplanets reveal about the origin, evolution, and destiny of the planets in our solar system?