Exoplanet Spectra with WFIRST
Cool Planets, Exciting Sciences

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Cool, Gaseous Planets

Transits

WFIRST

M sin(i) [Jupiter Mass]

Semi-Major Axis [Astronomical Units (AU)]

Exoplanets.org, 8/8/2015
Reflection from Gas and Clouds

Burrows et al. 1997; Sudarsky et al. 2000; Cahoy et al. 2010; Marley et al. 2014
Photochemical Haze

Model Jupiter at 5 AU, 3x, 0 deg
Karkoschka 1994

Geometric Albedo

Wavelength, $\mu$m

Cahoy et al. 2010
Photochemical Haze

Geometric Albedo

Wavelength [nm]

No Haze
Haze $\tau \sim 1$
Haze $\tau \sim 2$
Karkoschka (1998)

CH$_4$
NH$_3$
H$_2$O

Hu 2014
Beyond the Solar Composition

Model

- $f_{\text{CH}_4} \times 0.01$
- $f_{\text{CH}_4} \times 0.1$
- $f_{\text{CH}_4} \times 3$
- $f_{\text{CH}_4} \times 10$

Data

Beyond the Solar Composition, in prep.

$\text{NH}_3$ Ice Cloud

$\text{H}_2\text{O}$ Ice Cloud

Hu 2016, in prep.
Degeneracy!

![Graph showing geometric albedo vs. wavelength](image)

- 0.2 bar, $X_{\text{CH}_4} = 3 \times 10^{-4}$
- 0.09 bar, $X_{\text{CH}_4} = 1 \times 10^{-3}$

Hu 2014
Detectability of Cloud and Gas

Cloud top pressure

Mixing ratio of methane

Hu 2014
Detectability of Cloud and Gas

Hu 2014

Cloud top pressure

Mixing ratio of methane

Hu 2014
Detectability of Cloud and Gas

\[ \chi^2 \] can be defined as the difference between a model and all adjacent models, for specified spectral resolution and SNR.

Hu 2014
Detectability of Cloud and Gas

SNR = 20

Cloud Top Pressure [Bars]

Mixing Ratio of Methane

Jupiter

HD 160691 e

Ups And e

$\chi^2$/dof

Hu 2014
Towards Imaging (Super-)Earths
Cool H$_2$O-rich Super Earths

Hu 2016, in prep.
Conclusion

Exciting scientific discoveries can be anticipated from imaging and characterizing cool, gaseous exoplanets by WFIRST.

Modeling groundwork is ongoing to fully recognize the science potential.

- Interplay between clouds and C, N, O abundances
- Haze Production in Photochemical Processes
- Evolved Neptunes and H$_2$O-rich Super Earths
- Spectral Degeneracies and Information Content
- ?


Thermal Evolution from the Cloud Pressure

HD 160691 e  Equivalent a = 3.8 AU

- $T_{\text{int}} = 110$ K, Ammonia Cloud
- $T_{\text{int}} = 60$ K, Ammonia Cloud
- $T_{\text{int}} = 20$ K, Water Cloud

Type and location of clouds depend on:

- Atmospheric composition
- Thermal evolution history
  and beyond 1-D models
- Updraft and downdraft

Deep liquid water clouds dissolving ammonia

Hu 2016, in prep.