Complete transmission spectrum of an exoplanet from UV to IR

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HD 189733b
prototype non-inflated hot gas giant

HST programmes

STIS low-res UV/visible
STIS mid-res visible
ACS low-res visible
NICMOS low-res IR
NICMOS filters IR
WFC3 low-res IR

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Transit spectroscopy

Deriving $R_{\text{planet}}(\lambda)$ by measuring the transit depth at many $\lambda$

(example from ACS, Pont et al. 2008)
TRANSMISSION SPECTRUM OF HD 189733b

Tinetti & Beaulieu, 2008

Na
K
water

Observations
Model, water + methane
Model, water+clear sky
Model, water+hazes
TRANSMISSION SPECTRUM OF HD 189733b

Challenges:

**Infrared**: complex instrumental systematics

**Visible**: star spots

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Tinetti & Beaulieu, 2008

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Ehrenreich et al. 2008,
Desert et al. 2009,

Tinetti & Beaulieu, 2008
TRANSMISSION SPECTRUM OF HD 189733b

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Infrared: complex instrumental systematics

Visible: star spots

Ehrenreich et al. 2008,
Desert et al. 2009,

Pont et al. 2009 on GJ436

Tinetti & Beaulieu, 2008

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Our runs on HD189733 after Servicing Mission 5 on the HST:

GO-11740 (16 orbits)  + re-analysis of NICMOS data
STIS 3000-5500 Å (Sing et al. 2011)   (Gibson et al. 2010)
WFC 1-2 μ (Gibson et al. 2011)

GO-11572 (16 orbits)
STIS 5893 Å Na (Huitson et al. 2011)
Star spot monitoring

Monitoring of HD189733 over 6 years by G. Henry with APT

Gaussian process analysis (see talk by S. Aigrain)
Star spot monitoring

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Gaussian process analysis (see talk by S. Aigrain)
+ many spot crossings during HST measurements
TRANSMISSION SPECTRUM OF HD 189733b

new results with refurbished HST

ACS 600nm-1μ (Pont et al. 2008)
TRANSMISSION SPECTRUM OF HD 189733b

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ACS 600nm-1μ (Pont et al. 2008)

STIS 300-600 nm (Sing et al. 2011)
TRANSMISSION SPECTRUM OF HD 189733b

new results with refurbished HST

ACS 600nm-1μ (Pont et al. 2008)

STIS 300-600nm (Sing et al. 2011)

STIS Na-D line (Huitson et al. 2011)

Poster

Ground (Redfield et al. 2008)
TRANSMISSION SPECTRUM OF HD 189733b

new results with refurbished HST

ACS 600nm-1μ (Pont et al. 2008)

potassium line

STIS 300-600nm (Sing et al. 2011)

STIS Na-D line (Huitson et al. 2011)

Poster

Ground (Redfield et al. 2008)
TRANSMISSION SPECTRUM OF HD 189733b

- NICMOS narrow-band (Sing et al. 2009)
- WFC3 grism (Gibson et al. 2011)

Radius vs. Wavelength

- 300 nm to 8 μm

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Rayleigh scattering: slope gives scale height, temperatures
Haze with mixture of silicate grains shows correct behaviour
Over >5 scale heights

Visible opacity determines the deposition of stellar energy (Heng, Hayek, Pont, Sing 2011)
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TRANSMISSION SPECTRUM OF HD 189733b

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Rayleigh scattering by silicate grains?
Lecavelier et al. (2008)

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Conclusions
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A “best-guess” picture of the atmosphere of HD189733b near the limb from HST transit spectroscopy:

Dominated by haze scattering, possibly by silicate grains

Temperature rising above photosphere to ~2000 K thermosphere

Alkali metal abundances far above solar

Photosphere and deposition of heat high in the atmosphere (10-100 mbars)
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see you in Aspen!