Characterising exoplanet atmospheres

Ernst de Mooij

Department of Astronomy & Astrophysics
University of Toronto
Exoplanets

• More than 1000 planets known to date, most discovered by radial velocity surveys
• RV planets great for statistics on masses and orbital parameters but little information about planets themselves
• More than 400 confirmed planets that transit their star
Transiting planets
Transiting planets

\[ \left( \frac{R_p}{R_*} \right)^2 \]
Transiting planets

• Measure the inclination → combine with RV measurement to get true mass
• Able to measure planet's mean density
Density provides information on composition
Transiting planets

- Measure the inclination $\rightarrow$ combine with RV measurement to get true mass
- Able to measure planet's mean density
- Also: investigate the star & orbit
  - Starspots
Starspots

Sing et al. 2011
Transiting planets

• Measure the inclination → combine with RV measurement to get true mass
• Able to measure planet's mean density
• Also: investigate the star & orbit
  – Starspots
  – Alignment with stellar rotation axis and the planet's orbit
Rossiter-McLaughlin effect

Source: NAOJ
Transiting planets

• Measure the inclination → combine with RV measurement to get true mass
• Able to measure planet's mean density
• Also: investigate the star & orbit
  – Starspots
  – Alignment with stellar rotation axis and the planet's orbit
• STUDY THE PLANET'S ATMOSPHERE
Transit:
Atmosphere in transmission
Sensitive to composition and atmospheric scale-height
Transmission spectroscopy
Ground-based detection of sodium

Ground-based detection of sodium

Rayleigh scattering

Sing et al. 2011, MNRAS 416, 1443
Rayleigh scattering

Sing et al. 2011, MNRAS 416, 1443
Transit:
Atmosphere in transmission
Sensitive to composition and atmospheric scale-height

Secondary eclipse:
Emission from the planet
Sensitive to composition and temperature structure
Structure of the atmosphere: inversion layers
Structure of the atmosphere: inversion layers
Structure of the atmosphere: inversion layers
Structure of the atmosphere: inversion layers

Madhusudhan and Seager (2010), ApJ 725, 261
The GROUSE project III: The secondary eclipse of WASP-33b

• Host-star:
  – A-type star
  – $T_{\text{eff}}=7430$K
  – Star shows pulsations ($\delta$ Scuti)

• Very hot Jupiter
  – Incident radiation: $1.2\cdot10^{10}$ erg/sec/cm$^2$
  – Equilibrium temperature: 3300K

De Mooij et al. (2013)
The secondary eclipse of WASP-33b

August 2010

September 2010

De Mooij et al. (2013)
The secondary eclipse of WASP-33b

De Mooij et al. (2013)
Transit:
Atmosphere in transmission
Sensitive to composition and atmospheric scale-height

Secondary eclipse:
Emission from the planet
Sensitive to composition and temperature structure

Phase curve:
Atmosphere in emission. Sensitive to composition and energy redistribution across day- and night-side
All measurements require high precision

- Transit of a planet around a solar type star:
All measurements require high precision

- Transit of a planet around a solar type star:
All measurements require high precision

- Transit of a planet around a solar type star:
All measurements require high precision

- Transit of a planet around a solar type star:
  - Jupiter: ~1%
  - Earth: ~0.008%
All measurements require high precision

- Transit of a planet around a solar type star:
  - Jupiter: ~1%
  - Earth: ~0.008%

Model by R.J. de Kok

Snellen et al. 2013
All measurements require high precision

• Transit of a planet around a solar type star:
  Jupiter: ~1%
  Earth: ~0.008%

• Secondary eclipse of a typical hot-Jupiter:
  Near-Infrared: ~0.1-0.3%
  Optical (~z): ~0.01%
All measurements require high precision

• Transit of a planet around a solar type star:
  Jupiter:  $\sim 1\%$
  Earth:  $\sim 0.008\%$

• Secondary eclipse of a typical hot-Jupiter:
  Near-Infrared:  $\sim 0.1-0.3\%$
  Optical ($\sim z$):  $\sim 0.01\%$

• Very tiny signals, not possible with absolute photometry from the ground $\rightarrow$ use differential measurements
Differential photometry
Remove most trends with reference star
Star 3 / (average of other stars)
The atmosphere of GJ1214b
The advantage of M-dwarfs

Solar type star

$R_* = 1 \ R_{\text{sun}}$
The advantage of M-dwarfs

Solar type star

\( R_\ast = 1 \ R_{\text{sun}} \)

Earth
The advantage of M-dwarfs

Solar type star

$R_*=1\ R_{\text{sun}}$

$(R_p/R_*)^2=0.0084\%$

M-dwarf

$R_*=0.2\ R_{\text{sun}}$

$(R_p/R_*)^2=0.205\%$
GJ1214b: the first super-Earth transiting an M-dwarf

• GJ1214b
  – $M_p = 6.55 \pm 0.98 \, M_{\text{Earth}}$
  – $R_p = 2.678 \pm 0.13 \, R_{\text{Earth}}$

• GJ1214
  – $M^* = 0.157 \pm 0.019 \, M_{\text{Sun}}$
  – $R^* = 0.2110 \pm 0.0097 \, R_{\text{Sun}}$

• $\Delta F \sim 1.35\%$

Charbonneau et al, Nature 2009
The super-Earth GJ1214b
Structure of GJ1214b

• 3 different models for structure
  – Water-world
    • Atmosphere dominated by water
  – Rocky planet with thick, gas rich envelope
    • Atmosphere dominated by Hydrogen
  – Mini-Neptune
    • Atmosphere dominated by Hydrogen and Helium

• Hydrogen/Helium dominated atmospheres have large scaleheight → Atmospheric signatures could be detectable

Rogers & Seager, 2010
Model spectra for GJ1214b
First results: No extended atmosphere

Bean et al. 2010
New results: atmosphere could be extended
Search for Rayleigh scattering: observations at blue optical wavelengths

• ACAM data of GJ1214b in g-band
• 1 night of observations
Search for Rayleigh scattering: observations at blue optical wavelengths

- ACAM data of GJ1214b in g-band
- 1 night of observations
Selecting reference stars
Selecting reference stars
Selecting reference stars
Selecting reference stars
Selecting reference stars
The GJ1214 lightcurve
Characterising the atmosphere of a super-Earth: GJ1214b

De Mooij et al. 2013
Characterising the atmosphere of a super-Earth: GJ1214b

De Mooij et al. 2013
Transmission spectrum of GJ1214b
60 orbits of HST covering 15 transits!
Transmission spectrum of GJ1214b

Kreidberg et al. 2014, Nature 505, 69
Current projects
Differential spectrophotometry

- Photometry only allows one band at a time → use differential spectrophotometry
- Require wide slit to avoid (differential) slit losses
The transit of 55Cnc e:
Slitless differential spectrophotometry with ALFOSC@NOT
The transit of 55Cnc e:
New data: differential spectrophotometry with ALFOSC@NOT
KIC12557548b

P = 0.65356 days (15.7h)
The End