Observational Techniques: Ground-based Transits

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Work funded by:

Why ground-based observations?

Space-based observations:

Pros: - Avoid atmospheric noise
- Sensitive to larger wavelength range

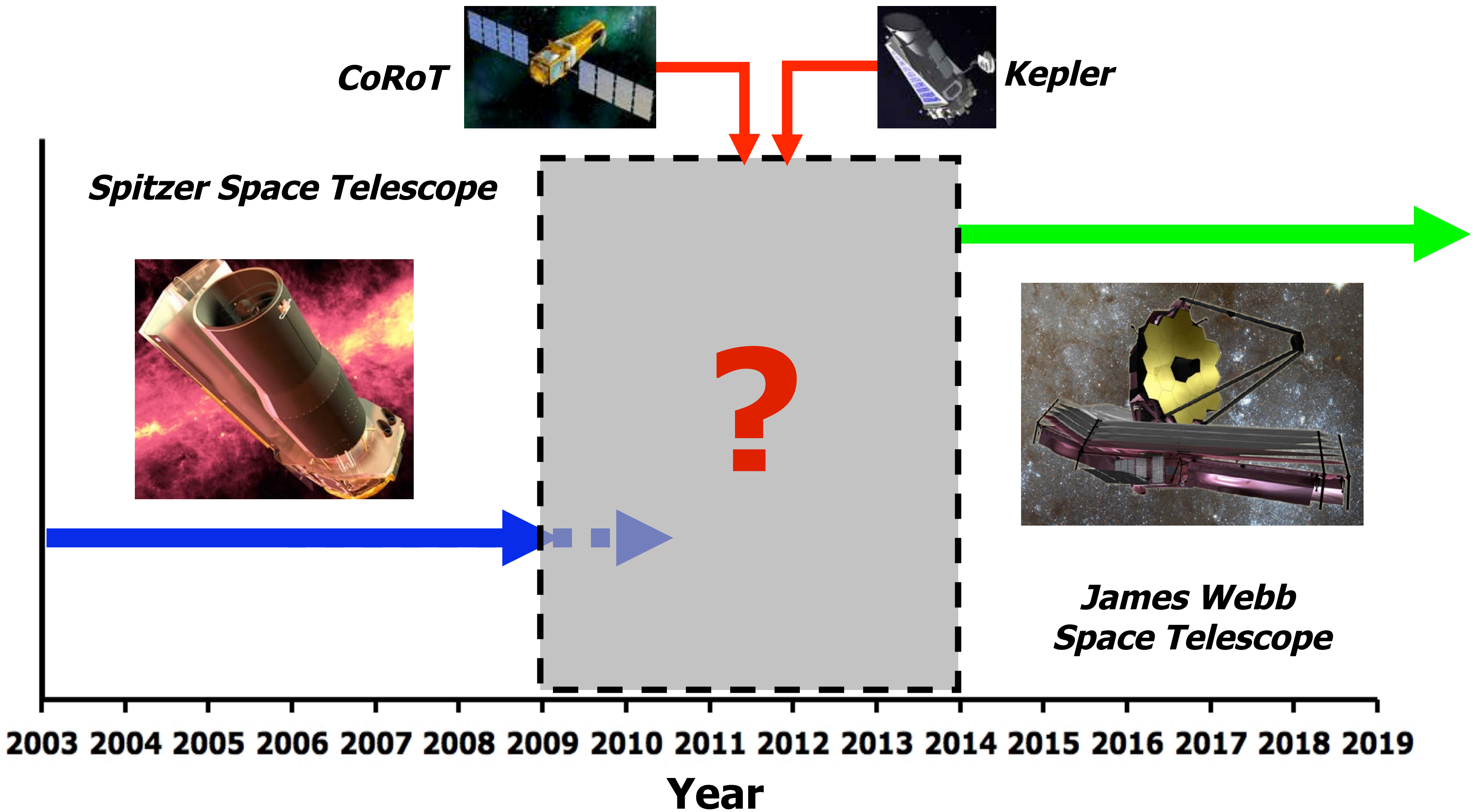
Cons: - Higher competition for telescope time
- Not many missions available

Ground-based observations:

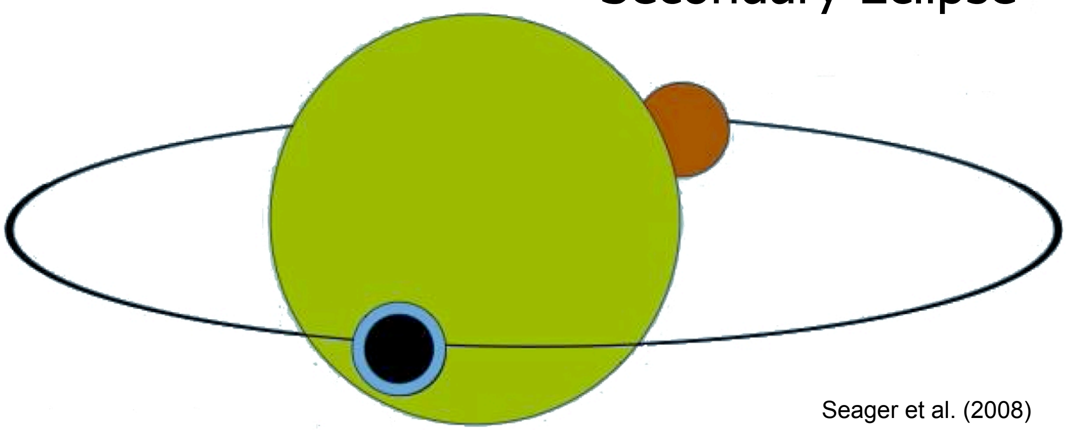
Pros: - More telescopes/instrument available

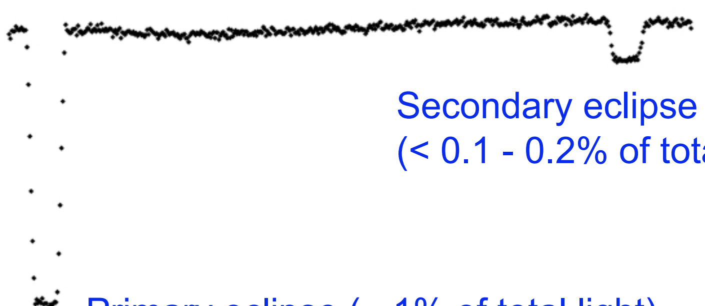
Cons: - Earth atmosphere constraints
(see P. Deroo's talk)

Exoplanet atmosphere observations in upcoming years



Transiting planets





Real data for HD 189733b (Knutson et al. 2007)

From Primary eclipse:

- Radius of Planet
- Density
- Chemical composition

From Secondary eclipse:

- Albedo
- Winds
- Temperature
- Chemical composition

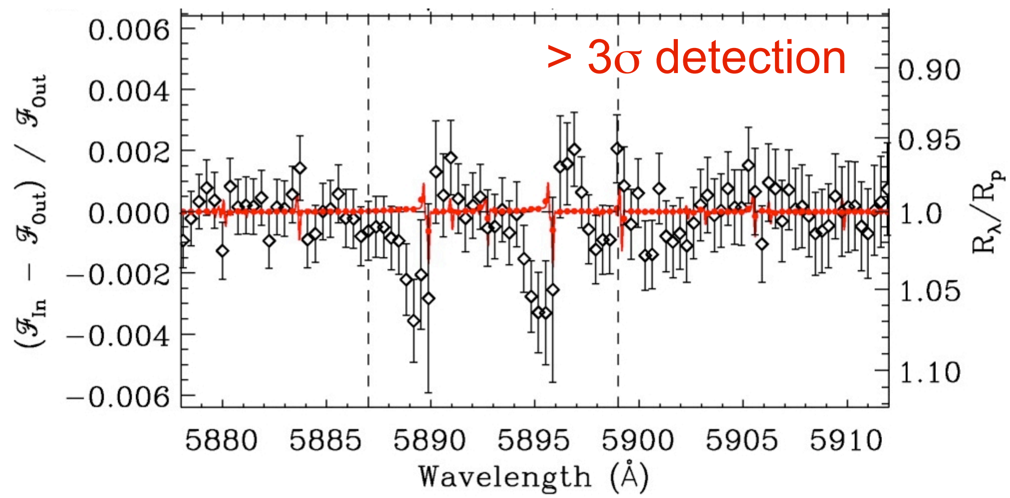
Observational Bias:

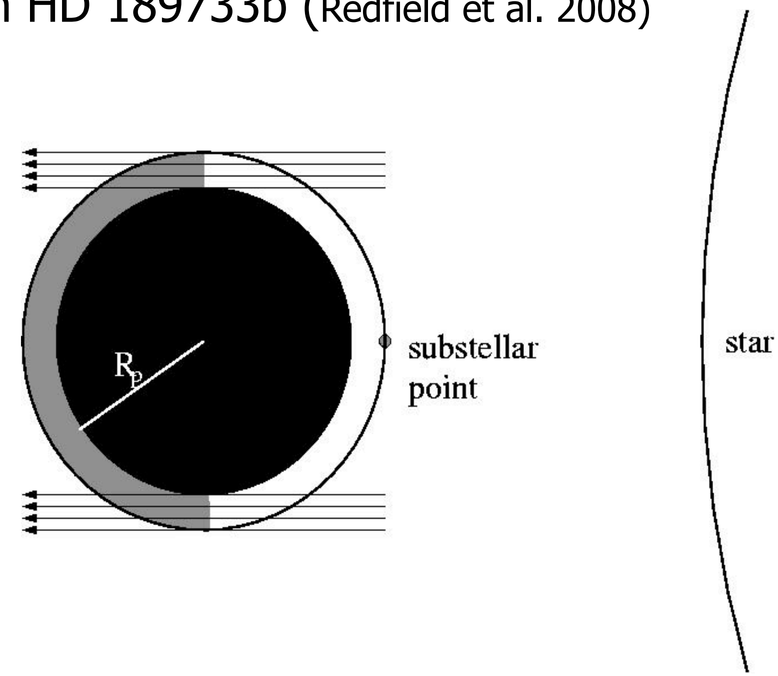
- $M_p \sim M_{jup}$
- $a < 0.09$ AU
- $T_p > 1000$ K

HOT JUPITERS

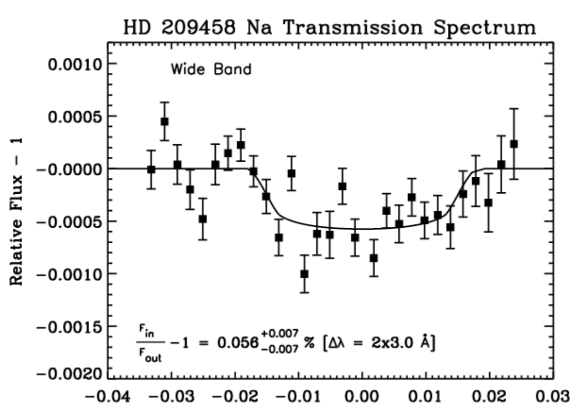
Primary Eclipses: Transmission Spectra

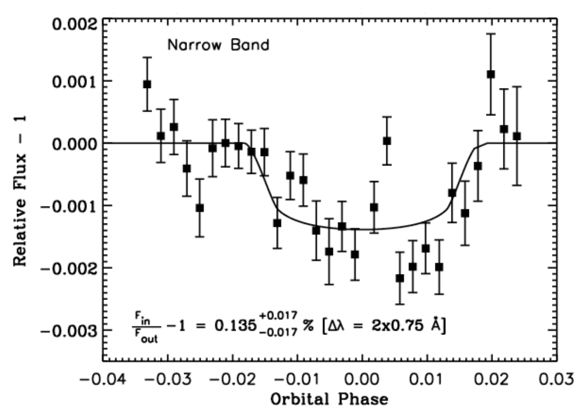
January 2008: Ground-based detection of **Sodium** in HD 189733b (Redfield et al. 2008)





August 2008: Ground-based confirmation of **Sodium** in HD 209458b (Snellen et al. 2008)





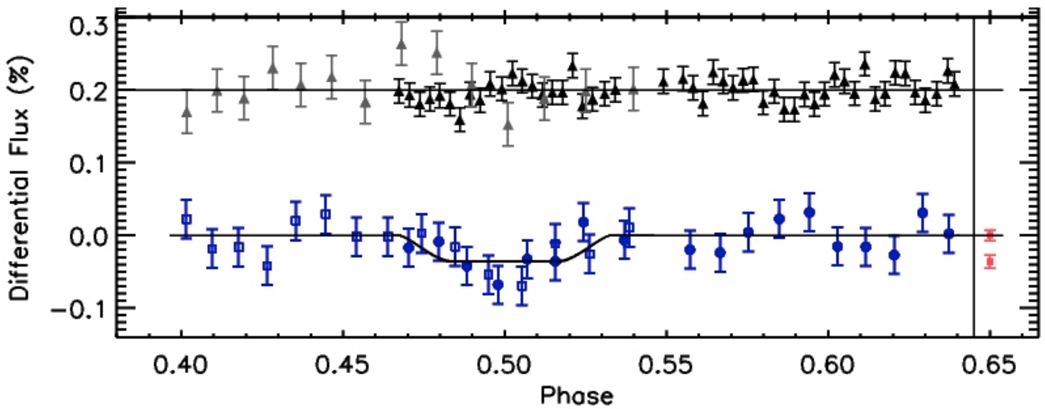
$\Delta\lambda$ = 3.0 Å → Depth = 0.056%

$\Delta\lambda$ = 0.75 Å → Depth = 0.135%

> 5σ detection

Secondary Eclipse: Thermal + Reflected Emission

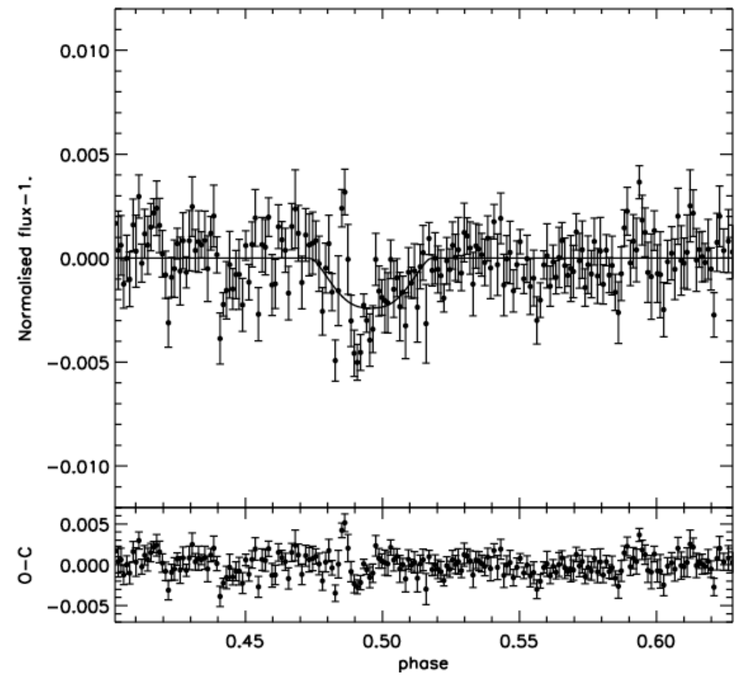
Ogle-TR-56b (Sing & López-Morales 2009)



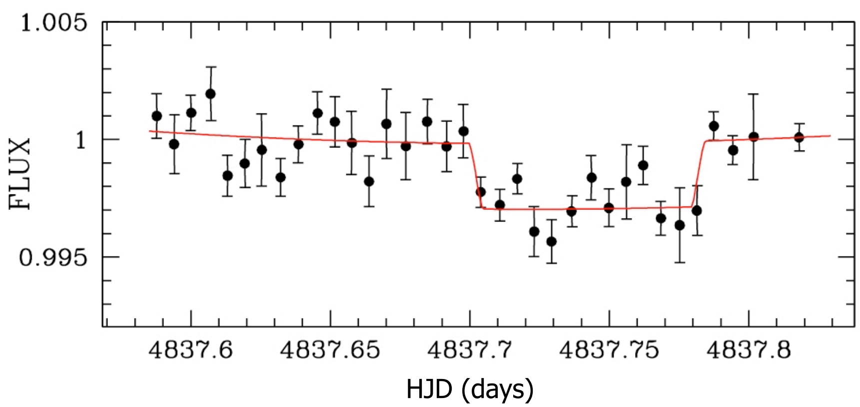
z'-band (0.9 Å) → Depth = 0.036% (3.6σ)

K-band (2.2 Å) → Depth = 0.241% (~6σ)

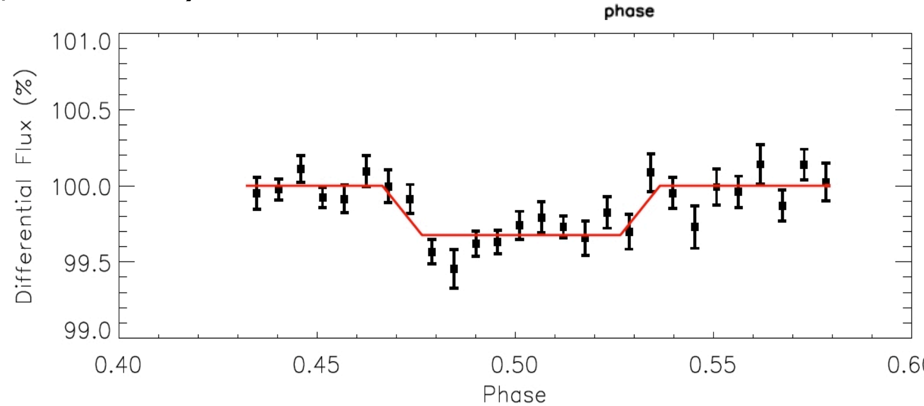
TrES-3b (de Mooij & Snellen 2009)



CoRoT-1b (Gillon et al. 2009; Rogers et al., submitted)

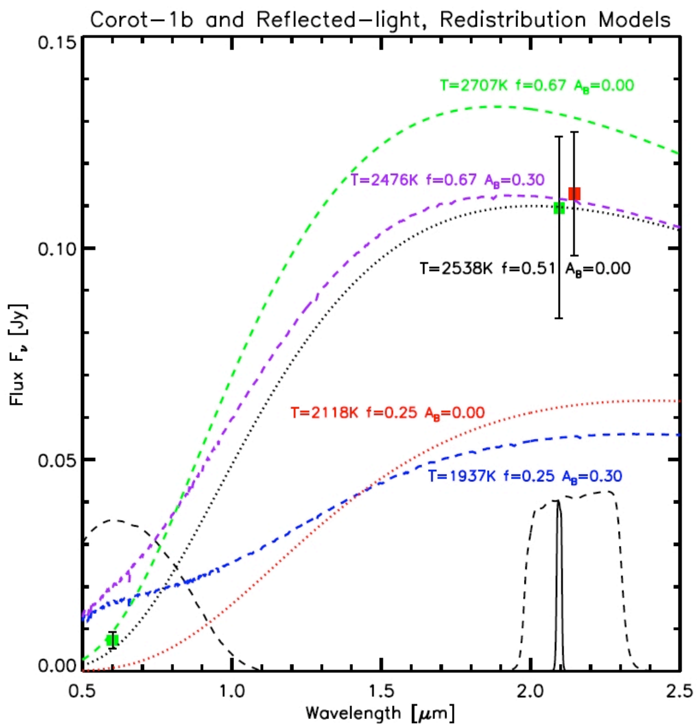


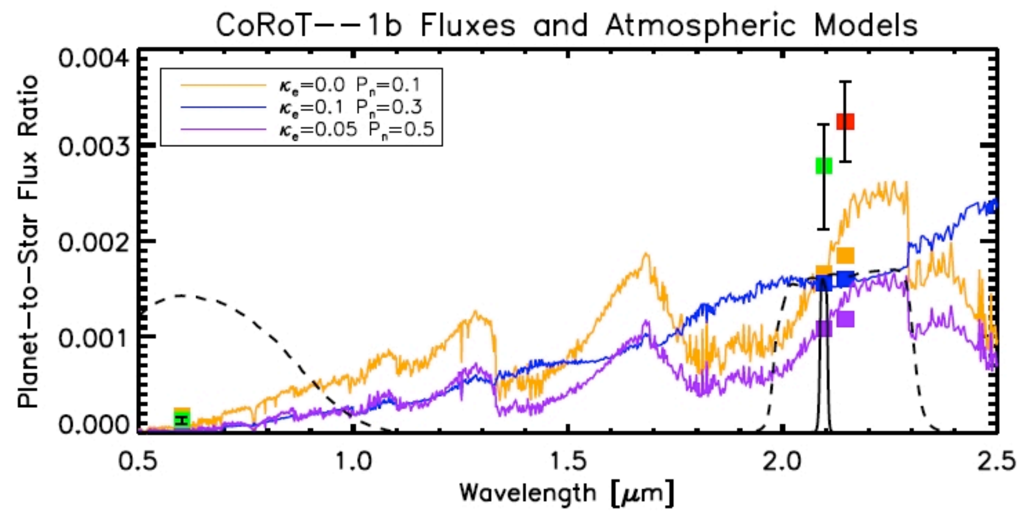
NB2090 (2.09 Å) → Depth = 0.278% (~5σ)

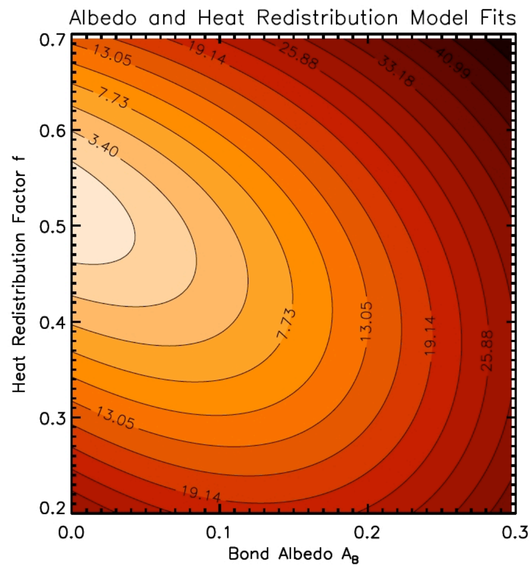


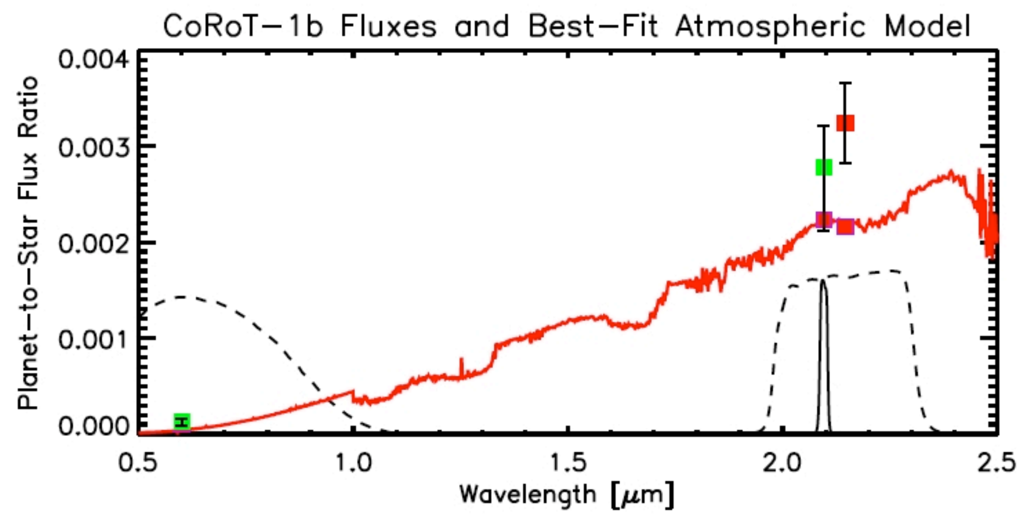
K-band (2.2 Å) → Depth = 0.324% (7.7σ)

First optical-near-IR study of a hot Jupiter's atmosphere









(Rogers et al., submitted)

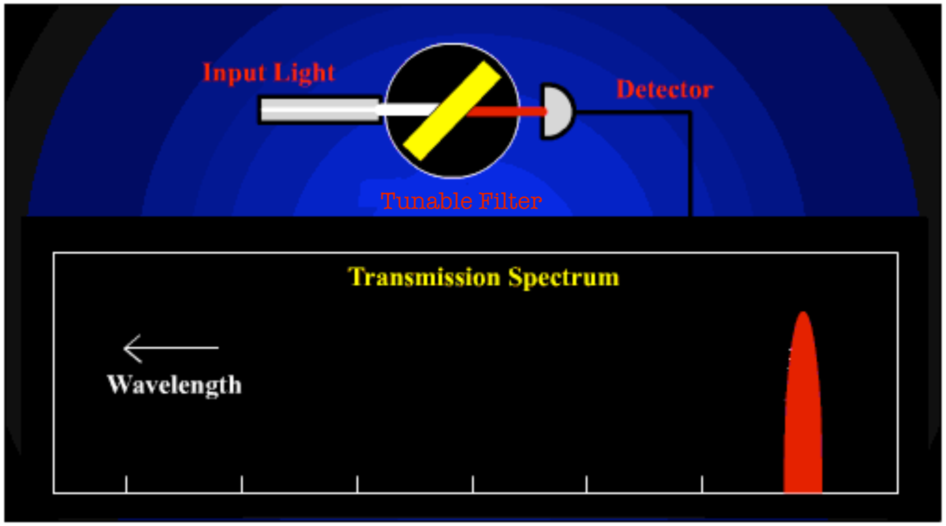
** Atmospheric models generated by co-author A. Burrows

What we'll be doing from the ground in the next few years

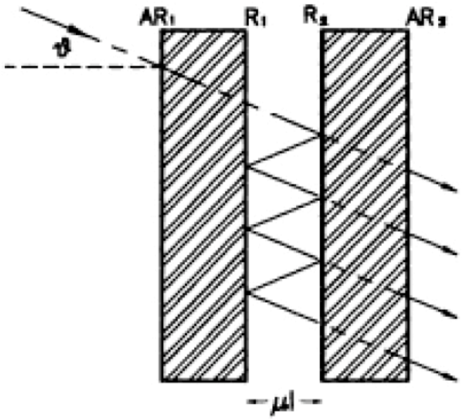
- From transits:
  - narrow-band transmission spectra with, e.g., tunable filters
  - higher resolution spectroscopy
    (M. Swain and P. Deroo's talks)

- From secondary eclipses:
  - Thermal emission/reflected light spectra with broad- and narrow-band filters

Transmission spectra with tunable filters



(Animated version at: http://en.wikipedia.org/wiki/File:Tunable_Filter.gif)



Fabry-Perot ethalon

For more info on ground-based telescopes with tunable filters:

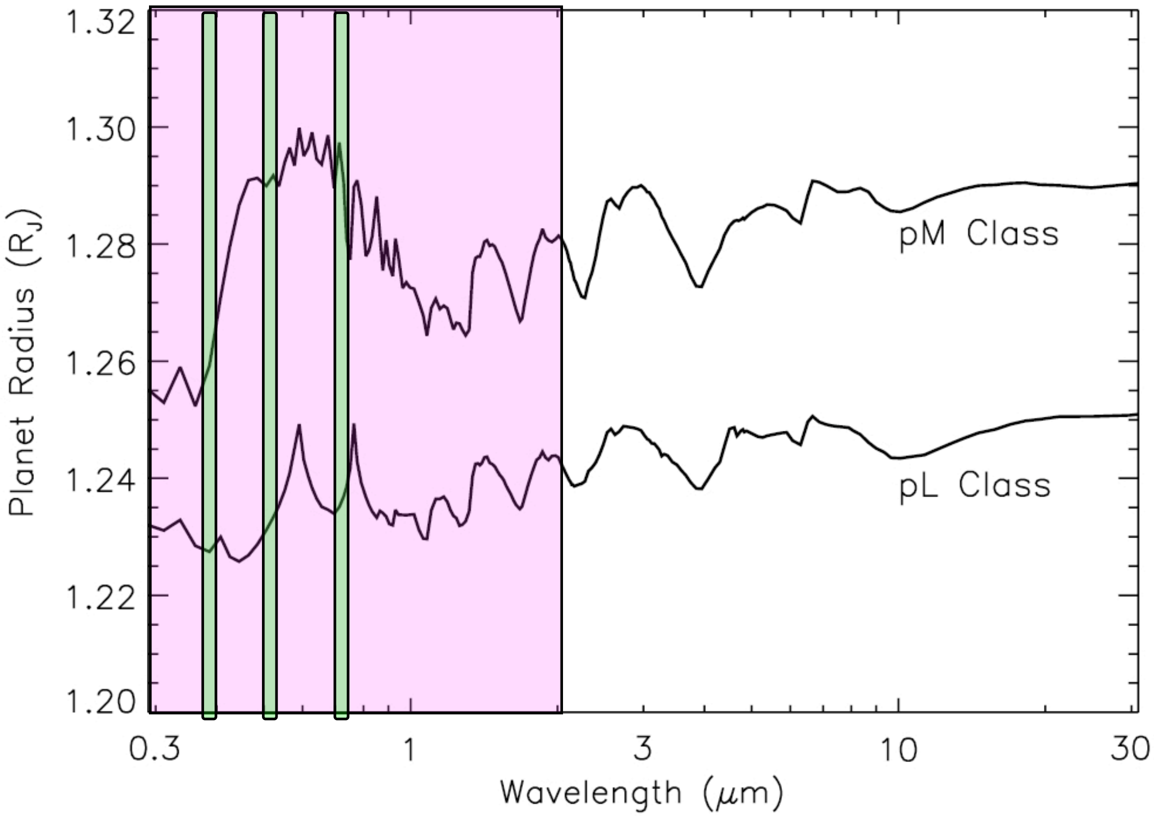
MMTF, Magellan (http://www.astro.umd.edu/~veilleux/mmtf/)

Osiris, GTC (http://www.iac.es/project/OSIRIS/)

RSS, SALT (http://www.sal.wisc.edu/pfis/)

TTF, formerly on AAT (http://www.aao.gov.au/local/www/jbh/ttf/)

Transmission spectra with tunable filters

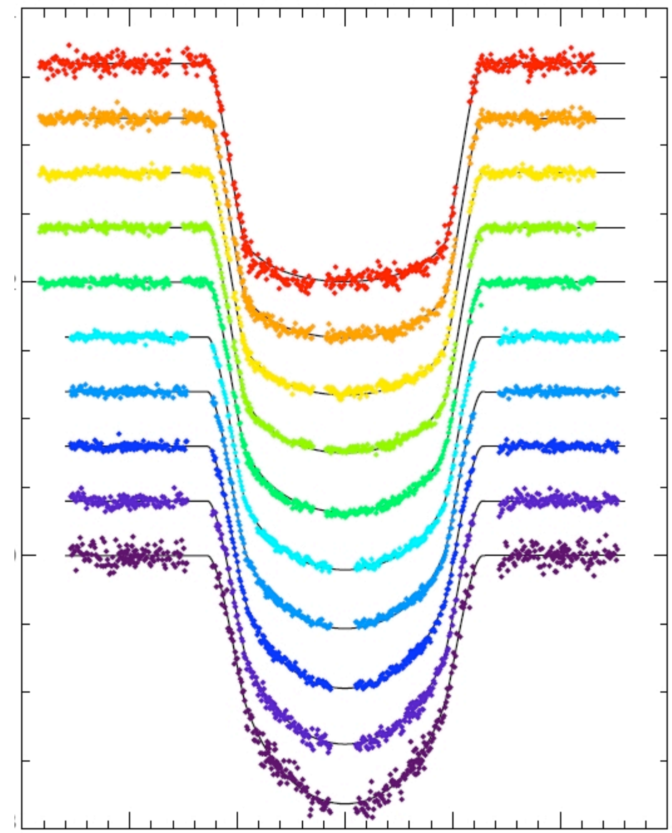


(Fortney et al. 2008; see also Burrows et al. 2007, ApJ, 668,171)

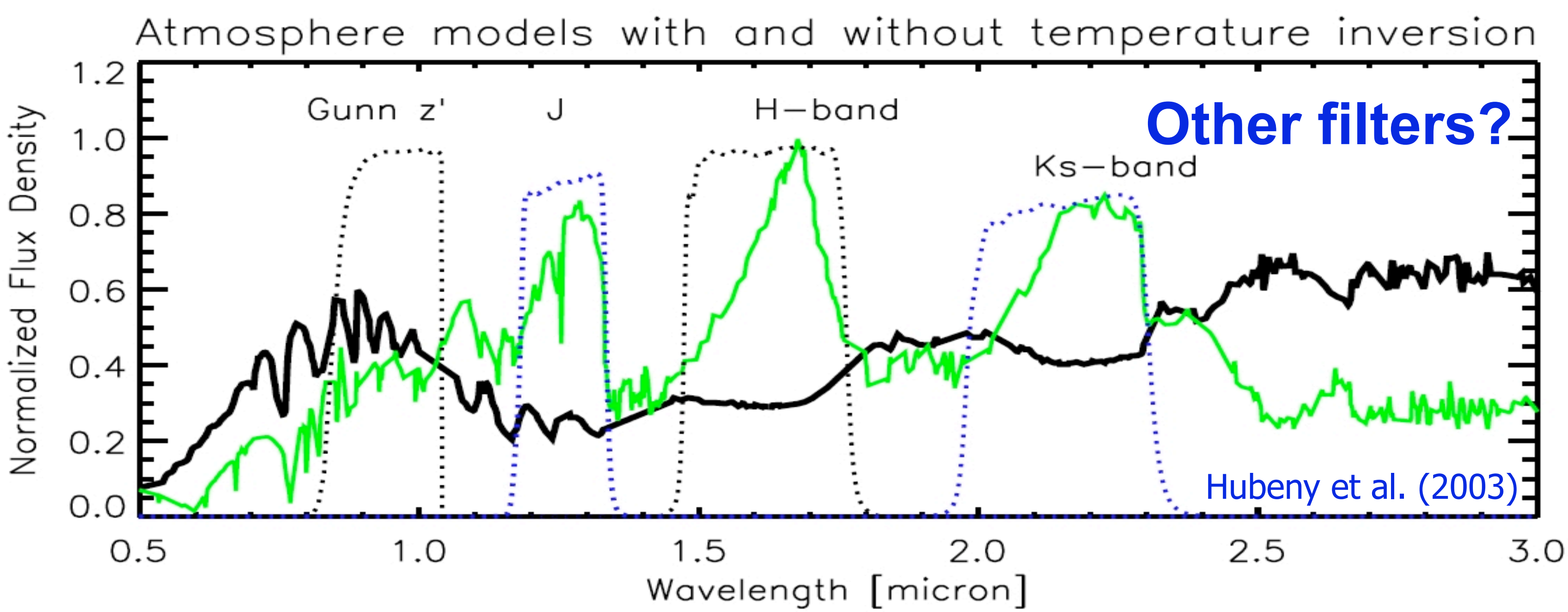
$$\frac{R_p}{R_{st}} = \sqrt{transit's\, depth}$$

Seager & Mallén-Ornelas (2003)

(Knutson et al. 2008)

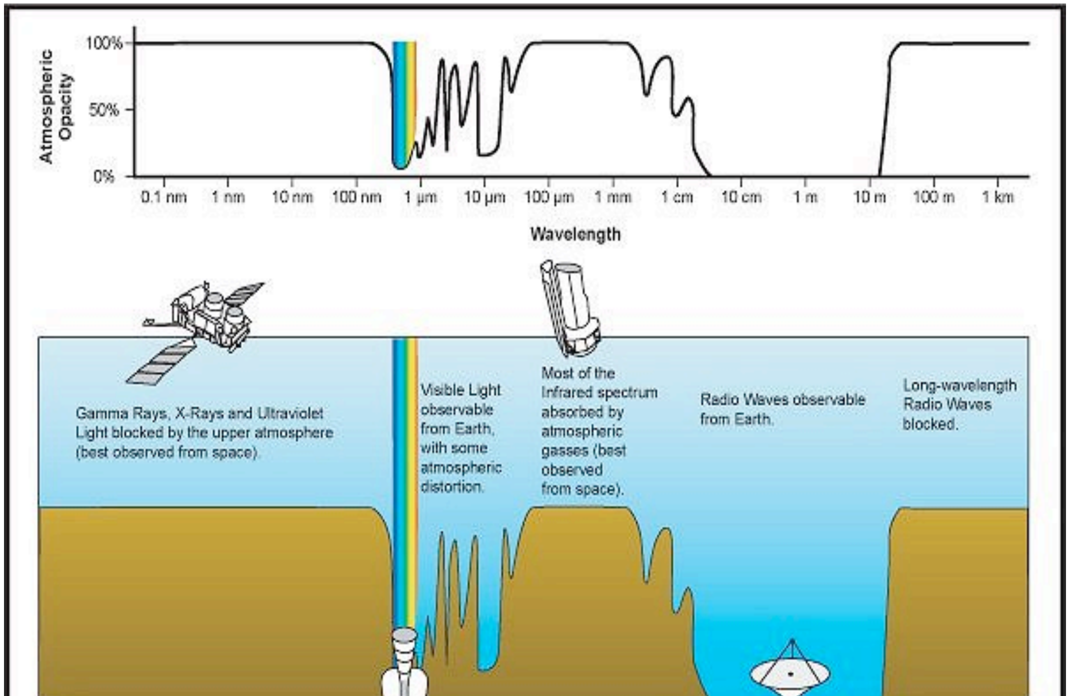


Thermal/reflected spectra with narrow- and/or broad-band filters



# of filters	Information about the planet's atmosphere
1	T_p and f
2	T_p , f and A_B if one of the colors is in the optical
3 or more	T_p , f , A_B , color and very low resolution spectral information

Latest “developments” on ground-based precision photometry



Credit: NASA/IPAC

- “Red Noise”
(see Pont et al. 2006,MNRAS,373,231)

- Elaborated photometric de-convolution analyses
(see e.g. Gillon et al. 2006,A&A,459,249)

- Sophisticated de-trending algorithms, e.g. Sys-Rem
(see Tamuz et al. 2005,MNRAS,356,1466)

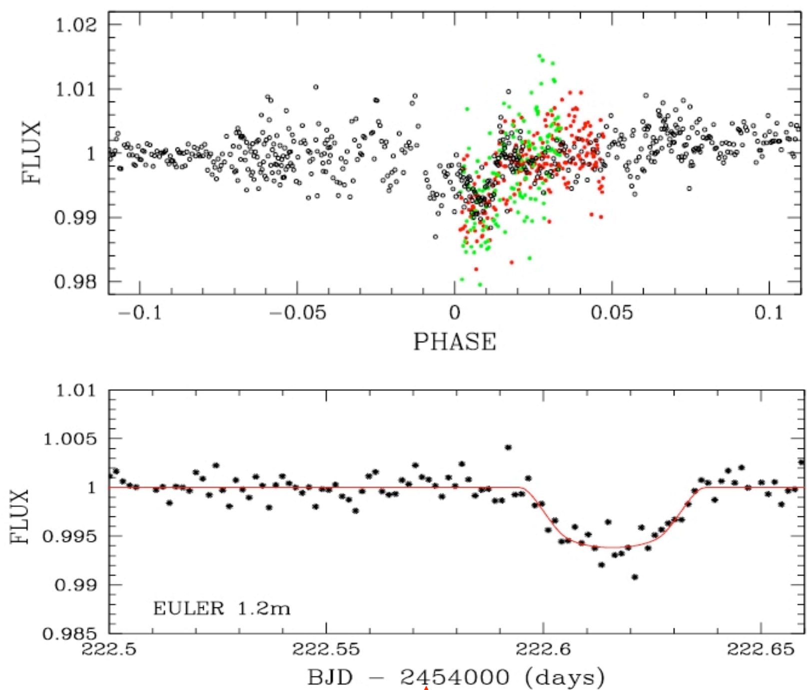
from space

from the ground

GJ 436b: The shallowest ground-based transit

Discovery data

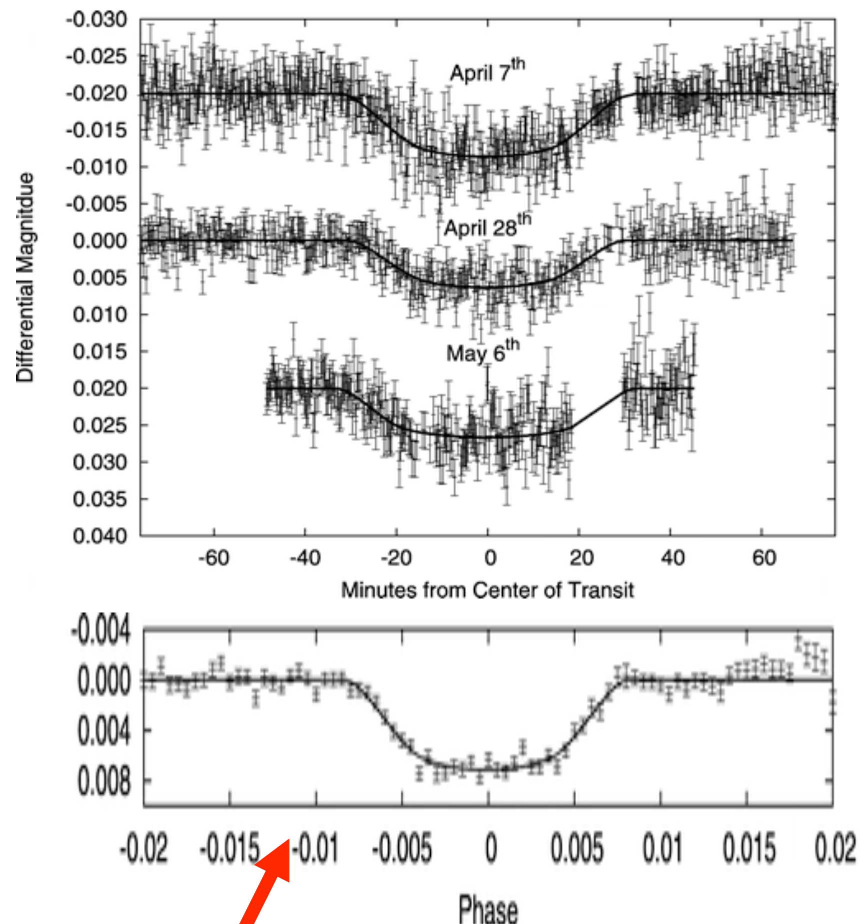
Gillon et al. (2007)



Top: < 0.6-m class telescopes data
Bottom: 1.2-m telescope
Filters: V-band
Sampling: 60 seconds per data point

Subsequent follow-up

Coughlin et al (2008)



Top: 3.5-m telescope
Filters: V-band
Sampling: 17 seconds per data point

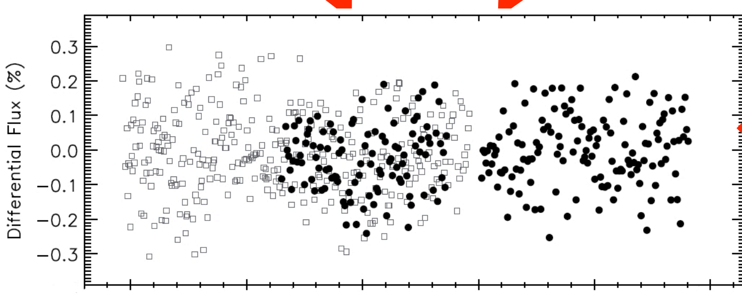
State-of-the-art ground-based photometry

CIW 6.5-m Magellans

ESO 8.5-m VLTs

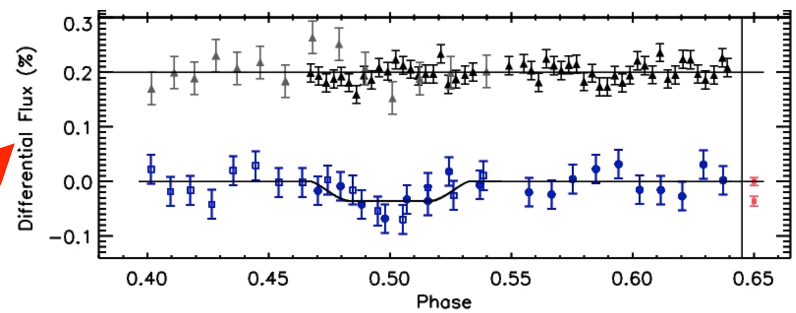
FORS2

MagIC-E2V



(Sing & López-Morales 2009)

Can find more about MagIC-E2Vat:
http://www.lco.cl/telescopes-information/magellan/instruments/magic/



VLT: 0.037 +/- 0.016%
Magellan: 0.036 +/- 0.011%

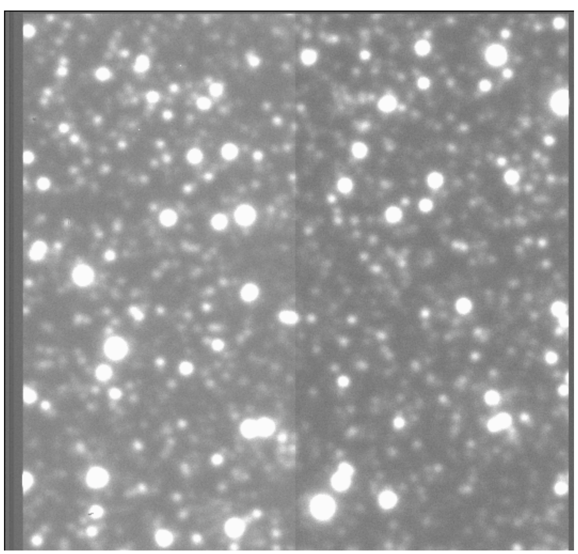
Reaching Poisson noise

IF blended images => need de-convolution,
psf, or image subtraction .. + de-trending

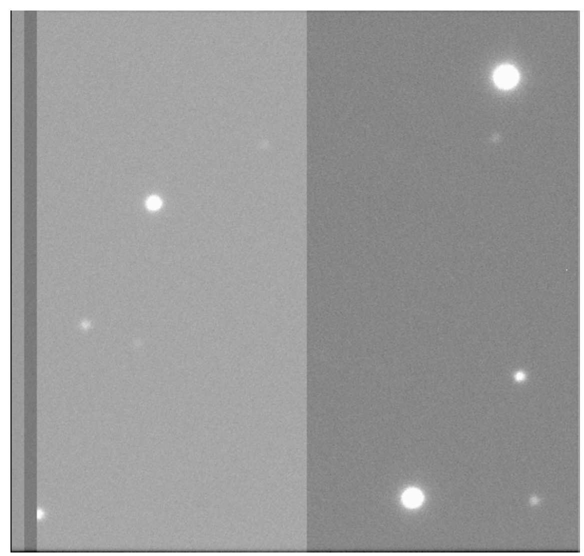
BUT, if no blends => aperture photometry + de-trending
is as good!

How to de-trend?

- Many stars in field => Algorithms like SysRem work
- If not many stars on the field => Need to de-trend "by-hand"

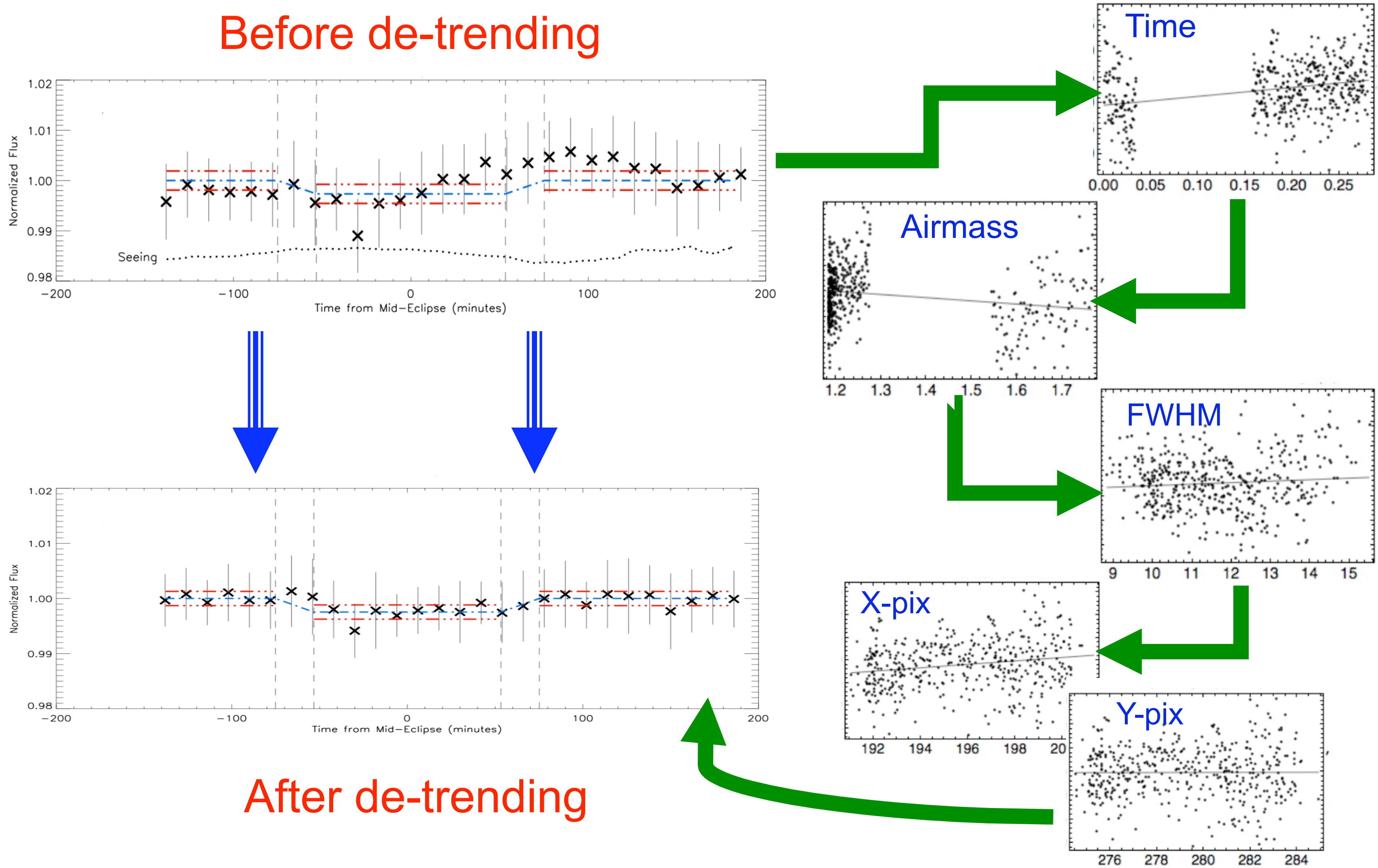


MagIC-e2V image of OGLE-56



MagIC-e2V image of CoRoT-1

De-trending "by-hand"



(Plots by Justin Rogers and Elisabeth Adams)