
Characterizing Exoplanets
Ray Jayawardhana
University of Toronto
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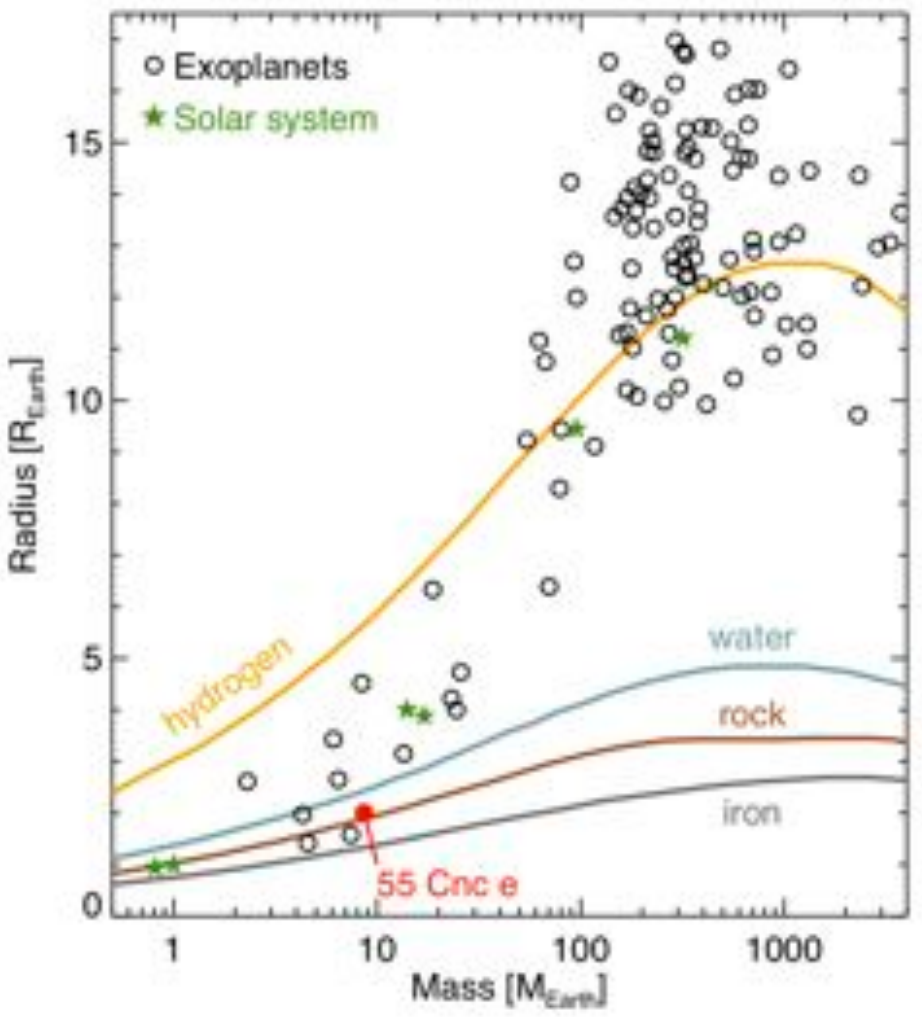
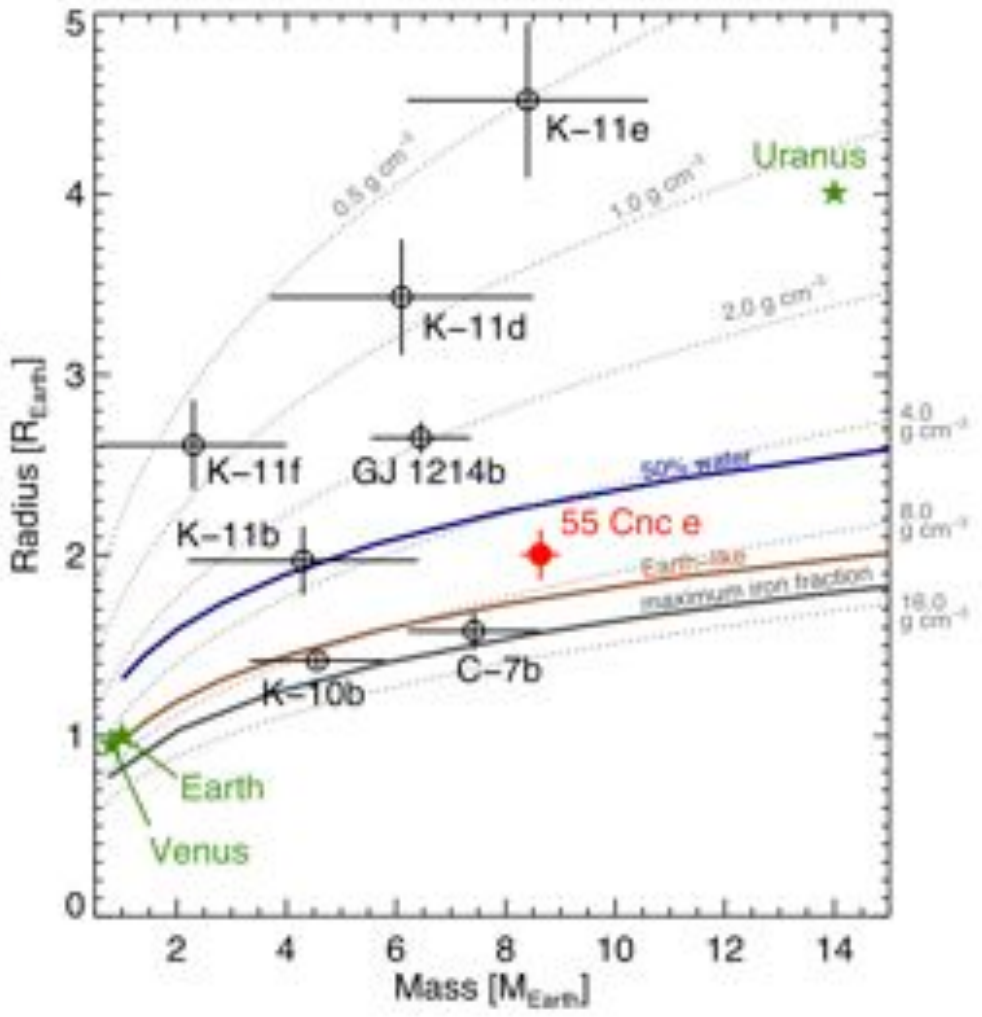
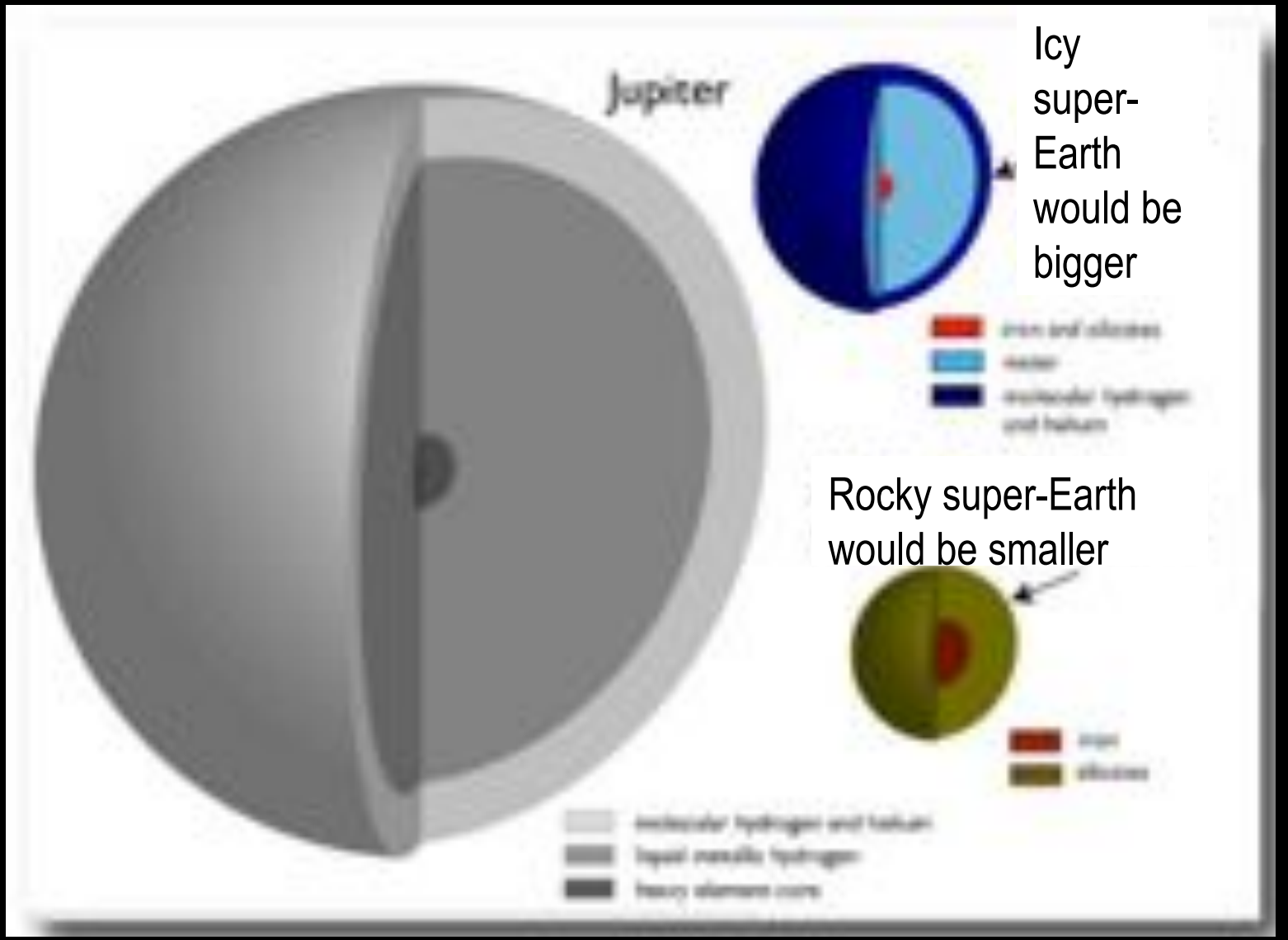
RV+Transit → Mass-Radius Diagram



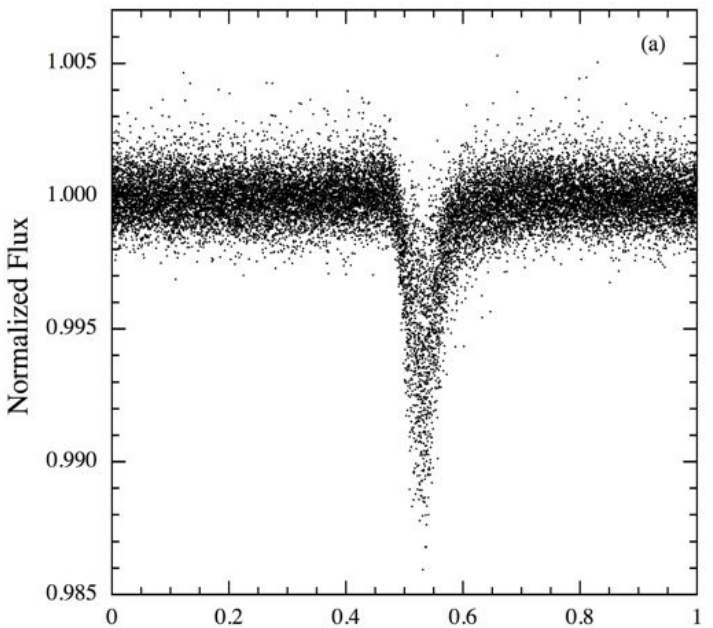


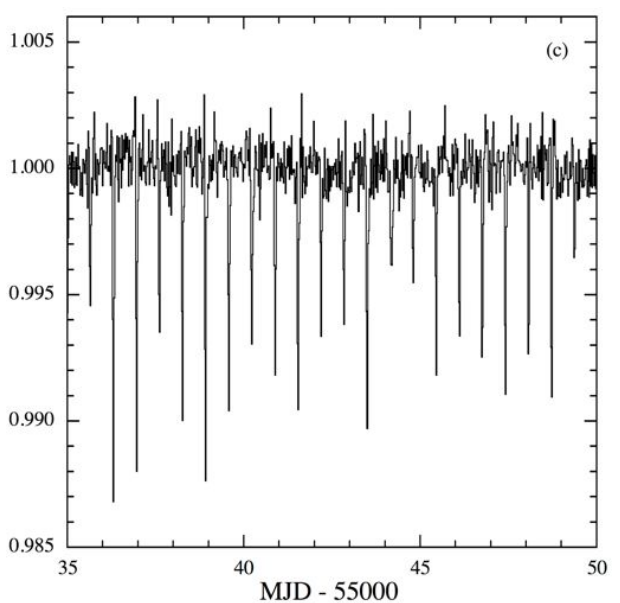
Winn et al. (2011)

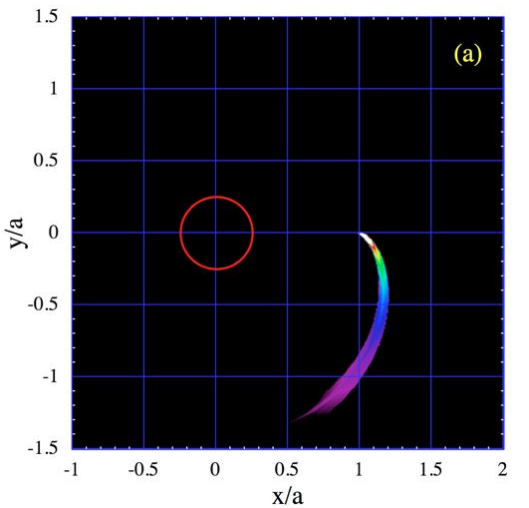
Super-Earths: Icy or Rocky?

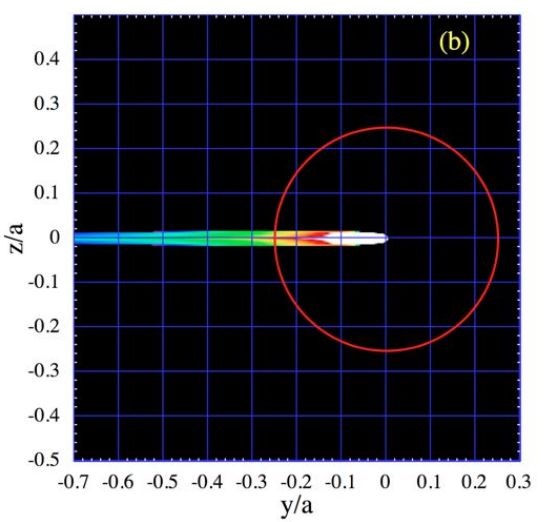


Evaporating Super-Mercury?

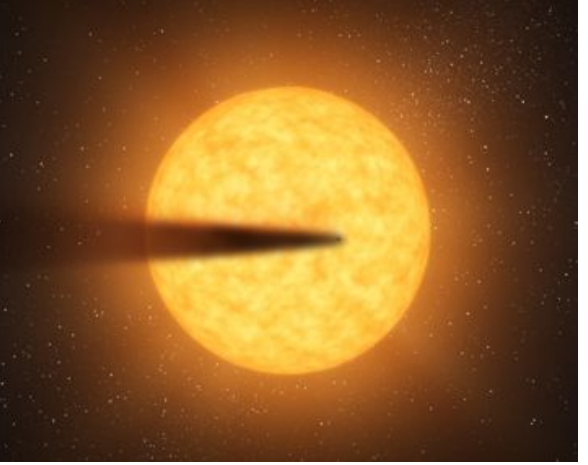




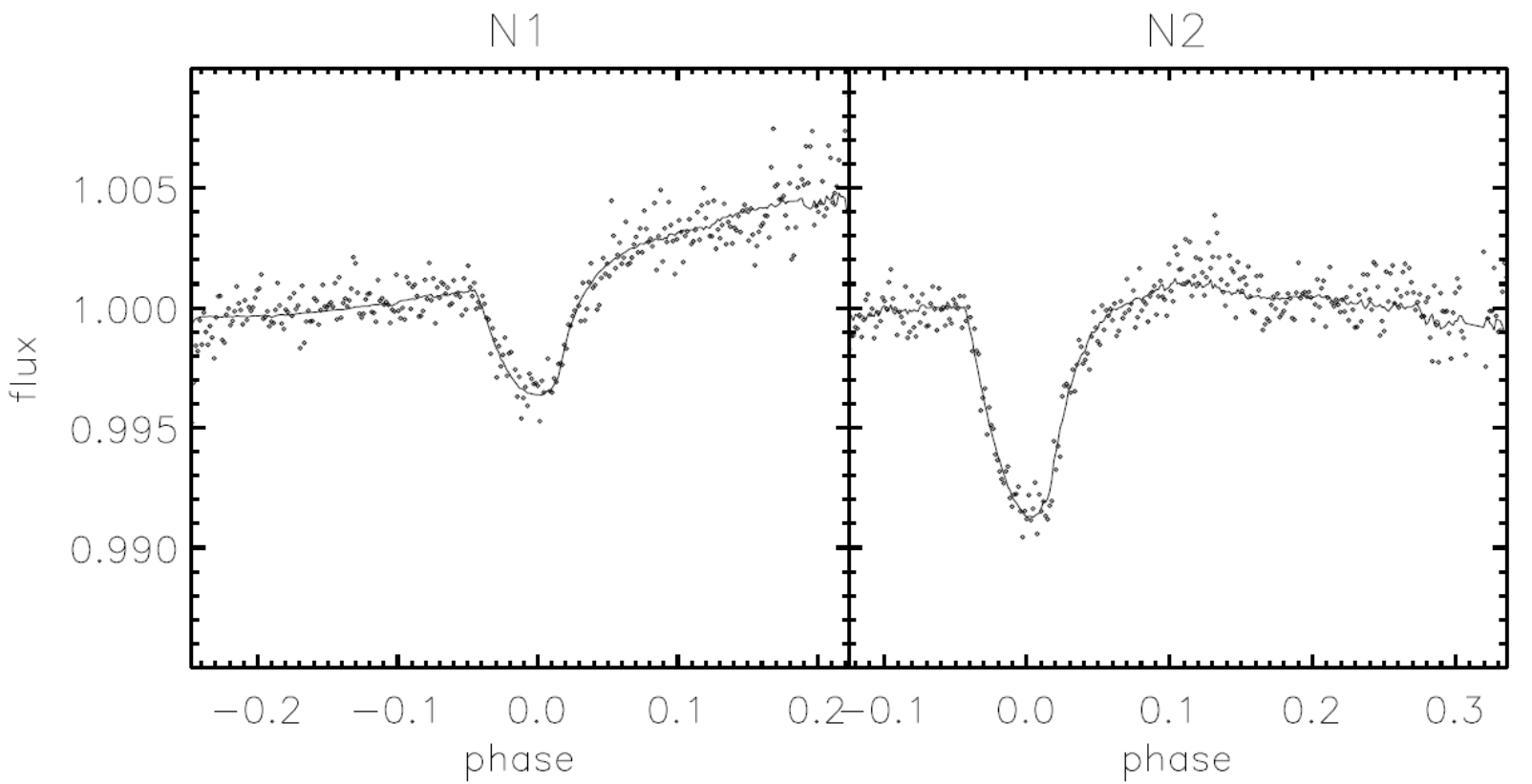




Rappaport et al. (2011)

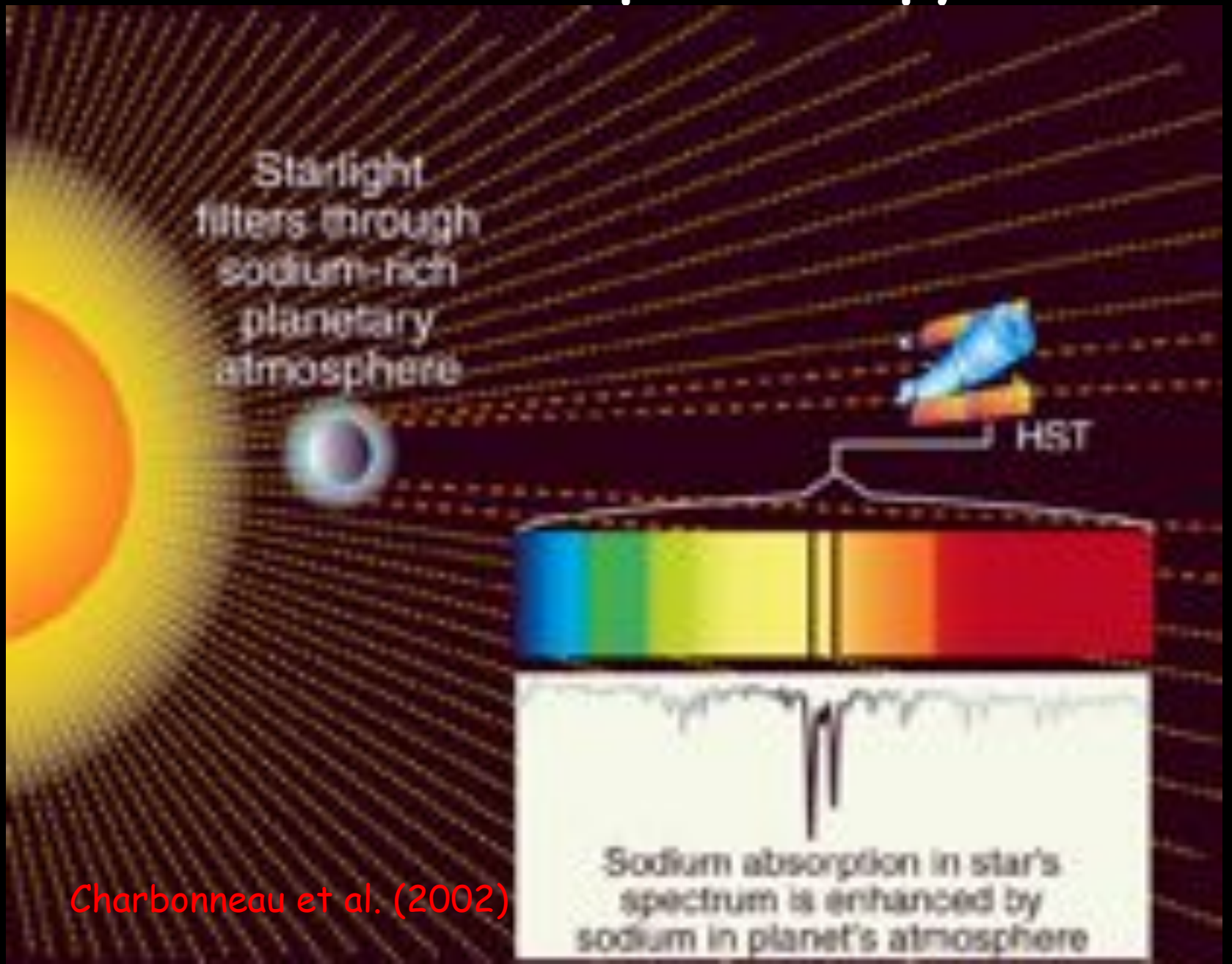


Differential Spectrophotometry with Gemini North



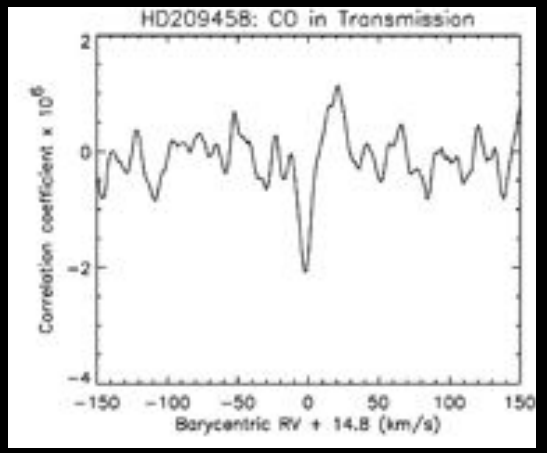
de Mooij, Silburt, Jayawardhana et al. (in prep)

Transmission Spectroscopy



Charbonneau et al. (2002)

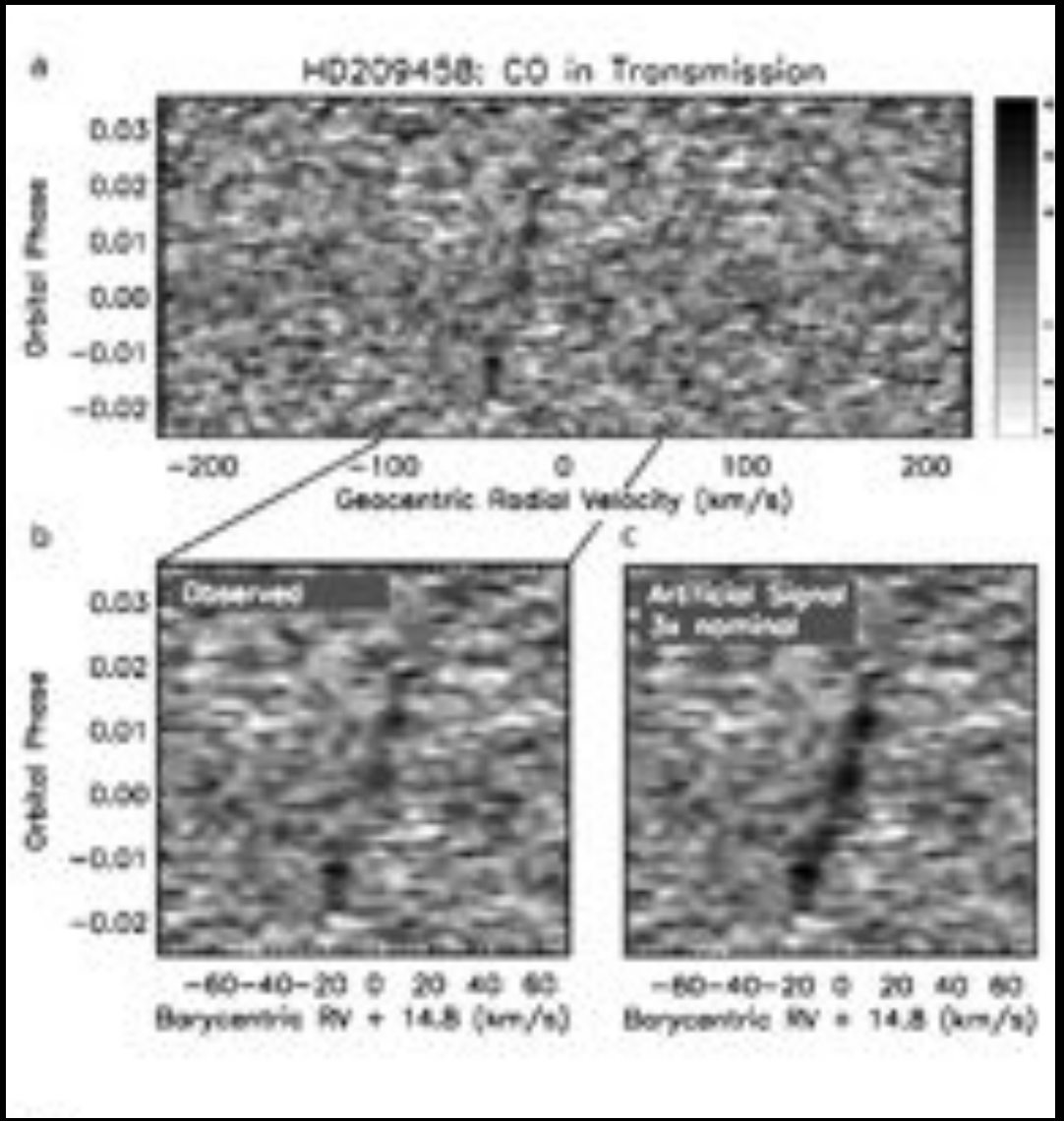
Transmission Spectroscopy



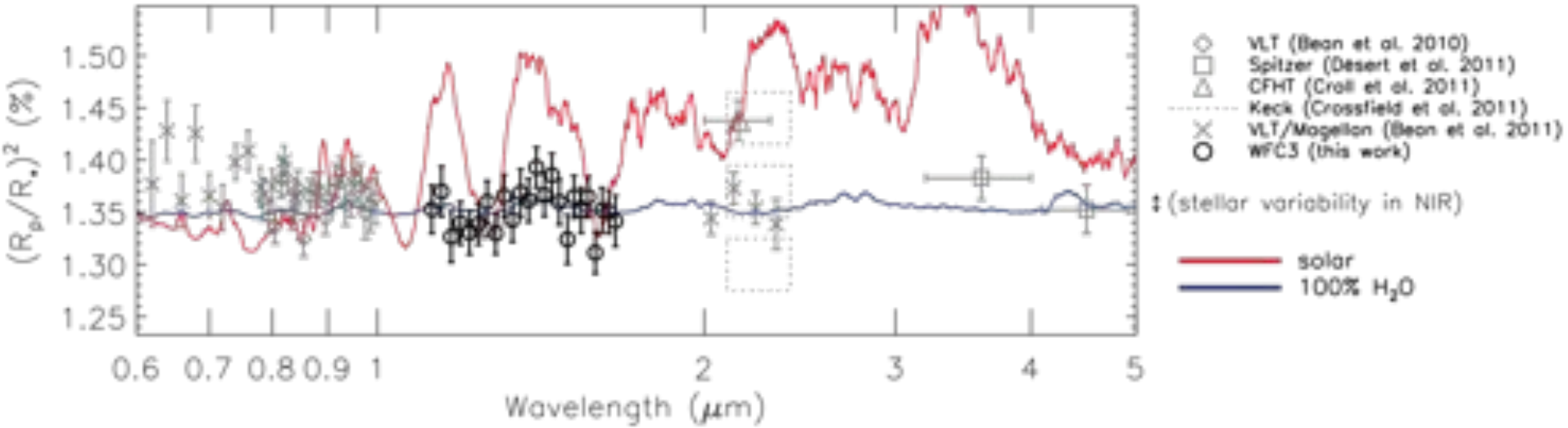
Planet's Orbital Velocity from CO line

Snellen et al. (2010)

HD 209458b with VLT

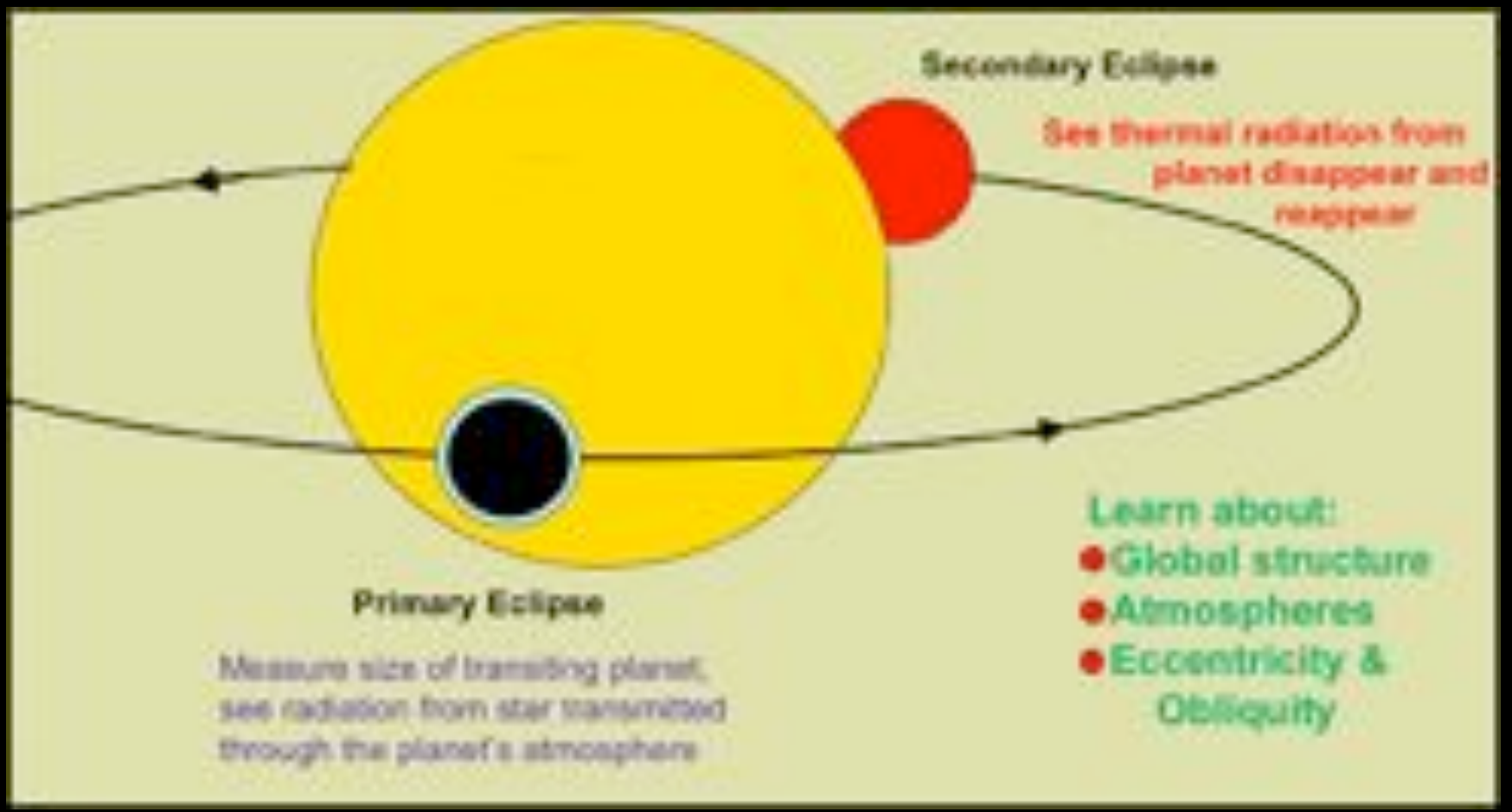


Characterizing GJ 1214b

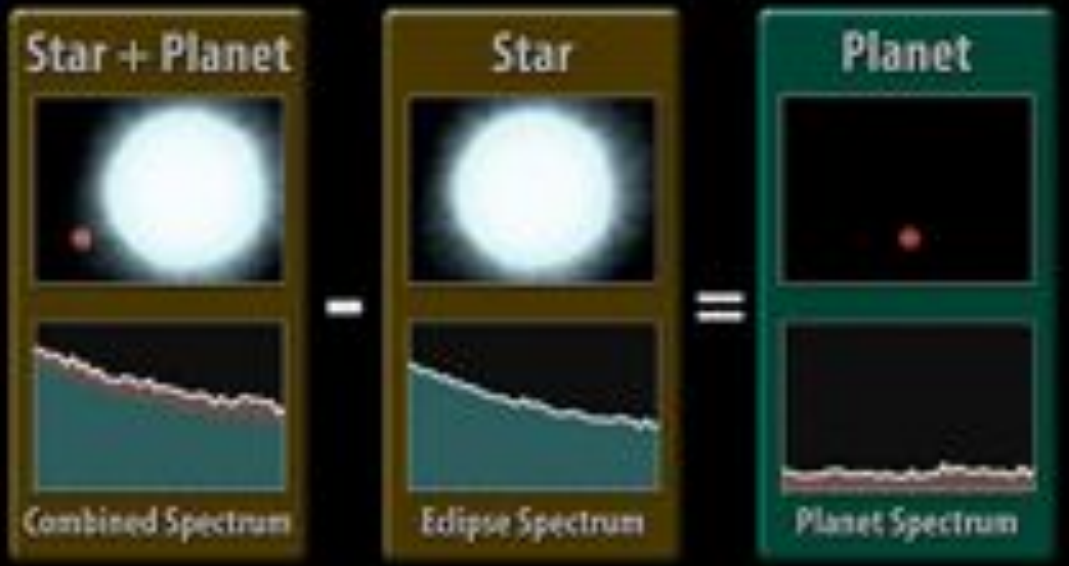


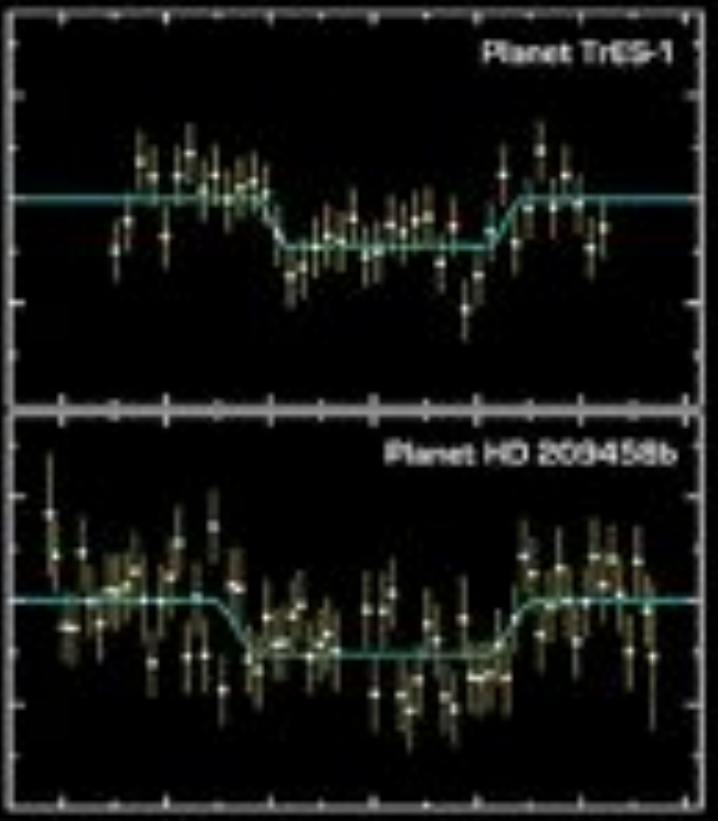
Bean et al. (2011); Desert et al. (2011); Croll et al. (2011);
Berta et al. (2012); de Mooij et al. (2013)

Characterizing Transiting Planets

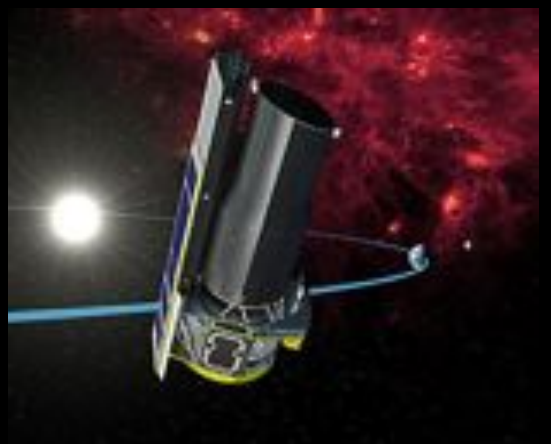


Secondary eclipse: when the planet goes behind the star





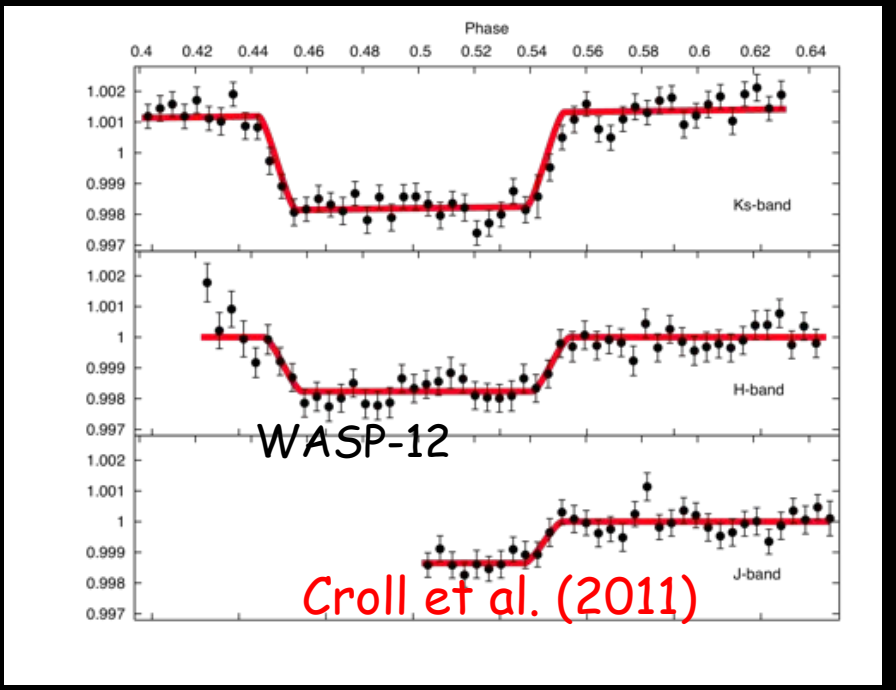
Isolating a Planet's Spectrum

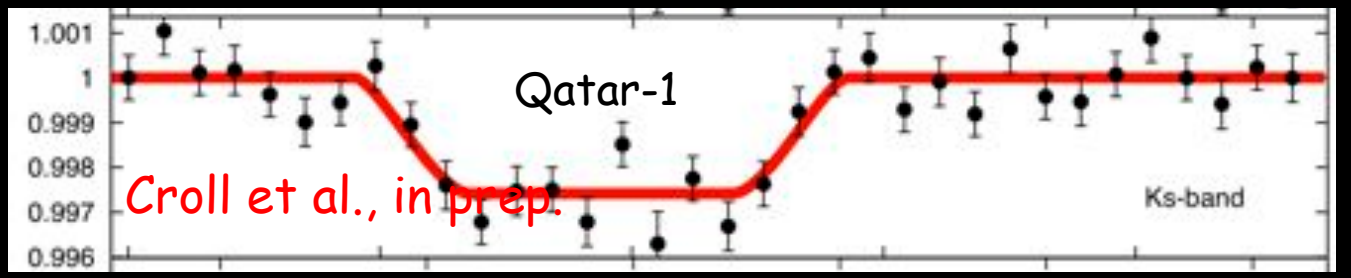


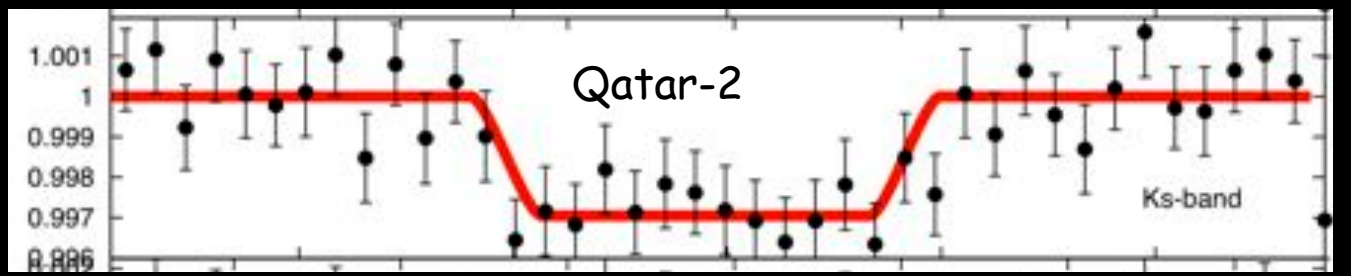
Planetary Eclipses Spitzer Space Telescope • IRAC • MIPS

Secondary Eclipses

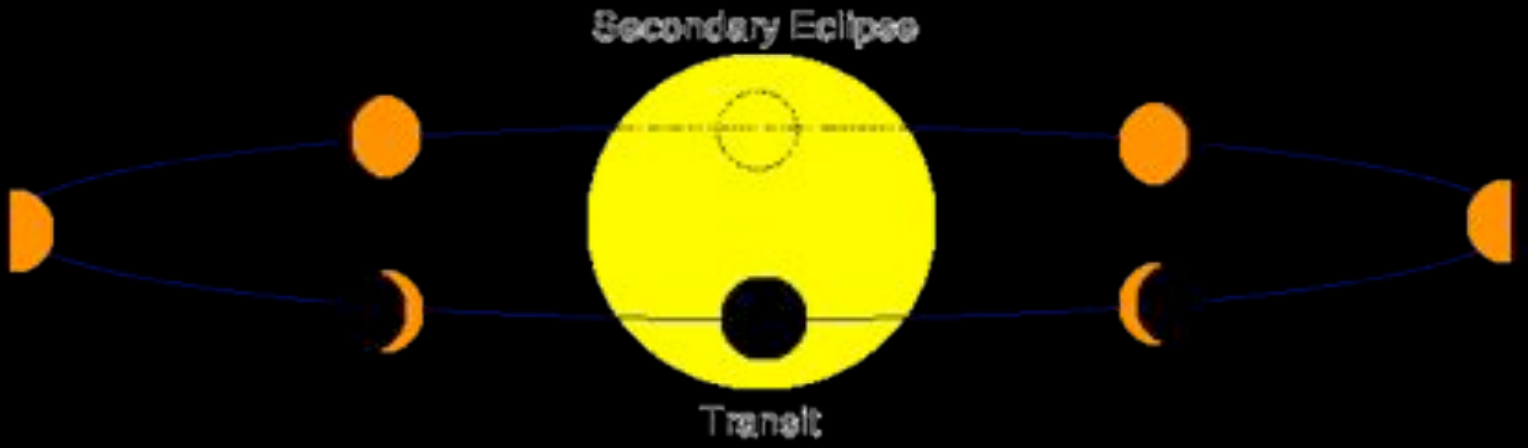
Canada-France-Hawaii Telescope

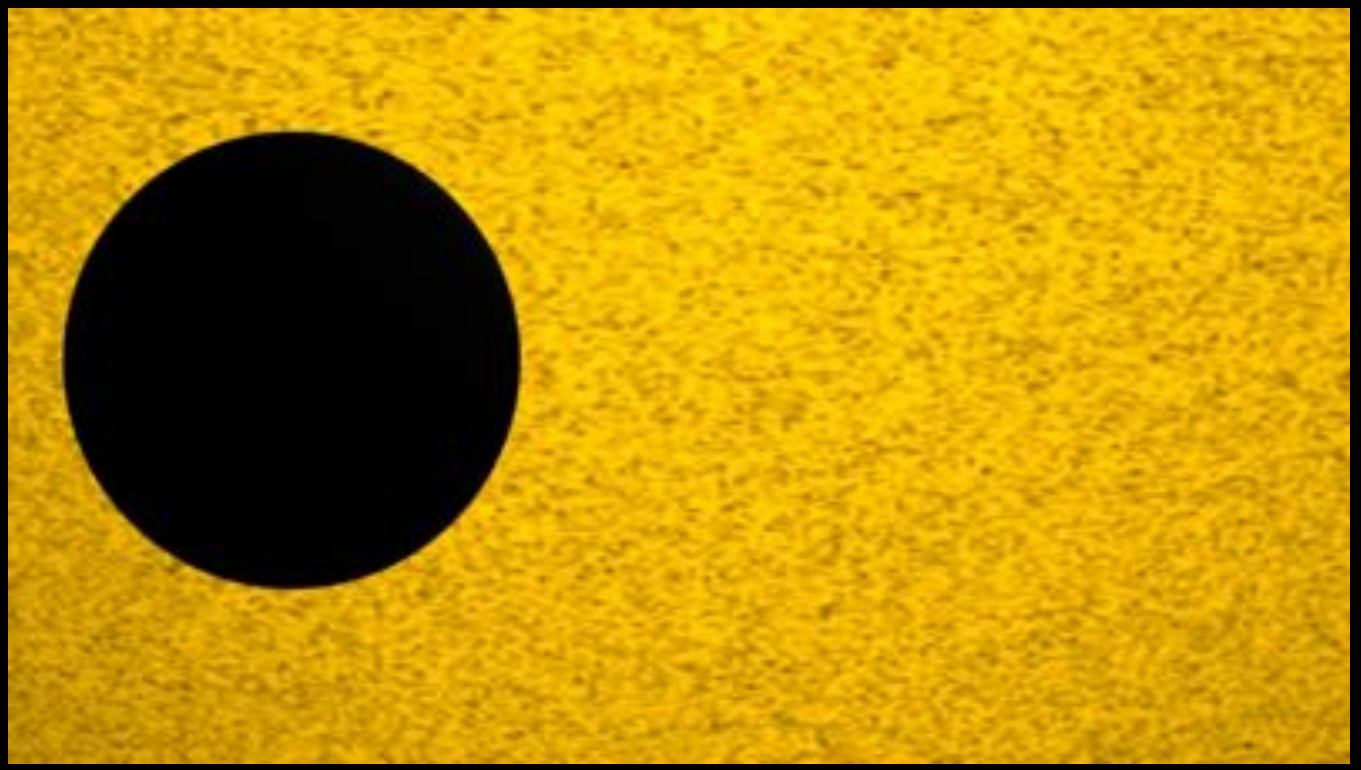




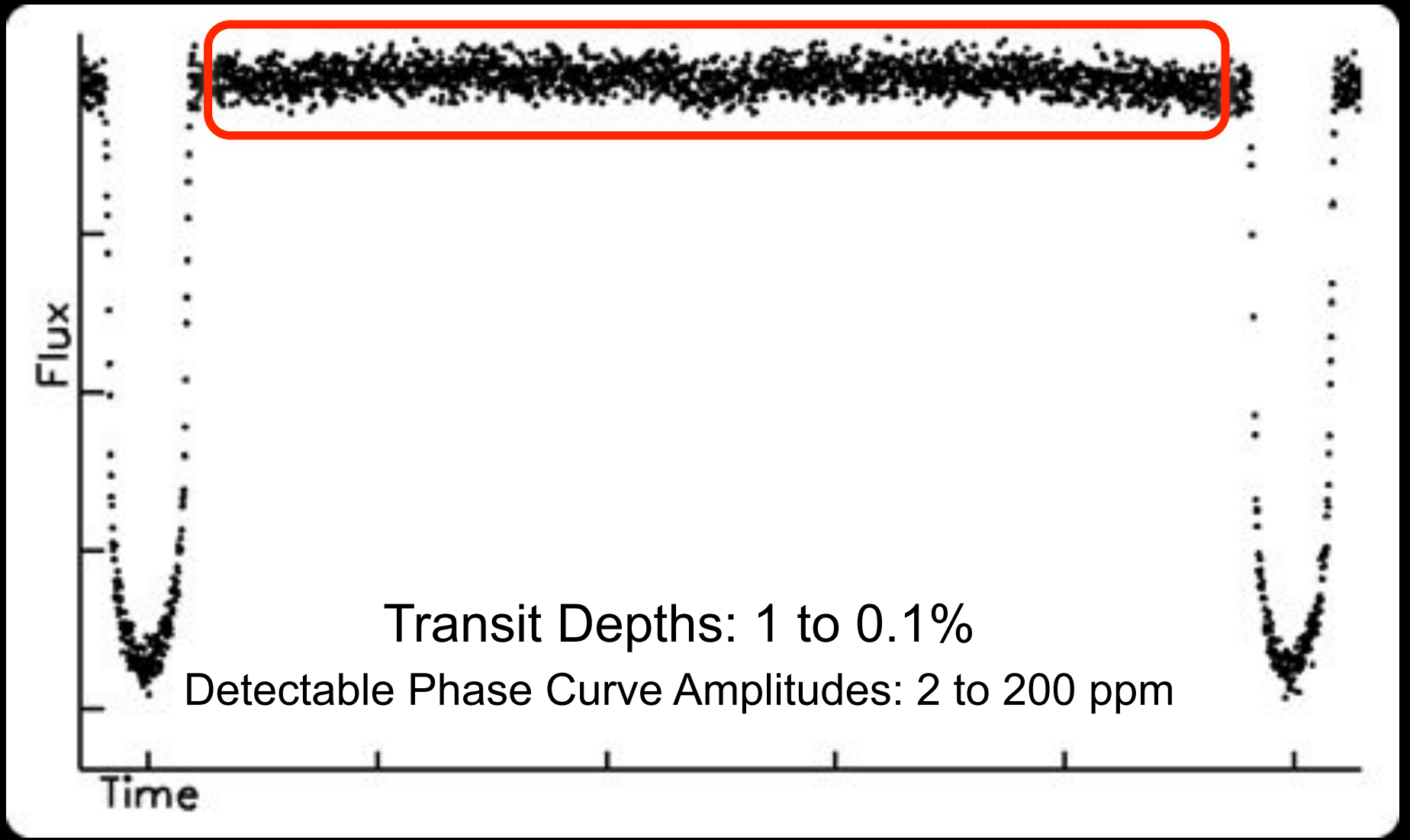


Phase Curves of Transiting Planets

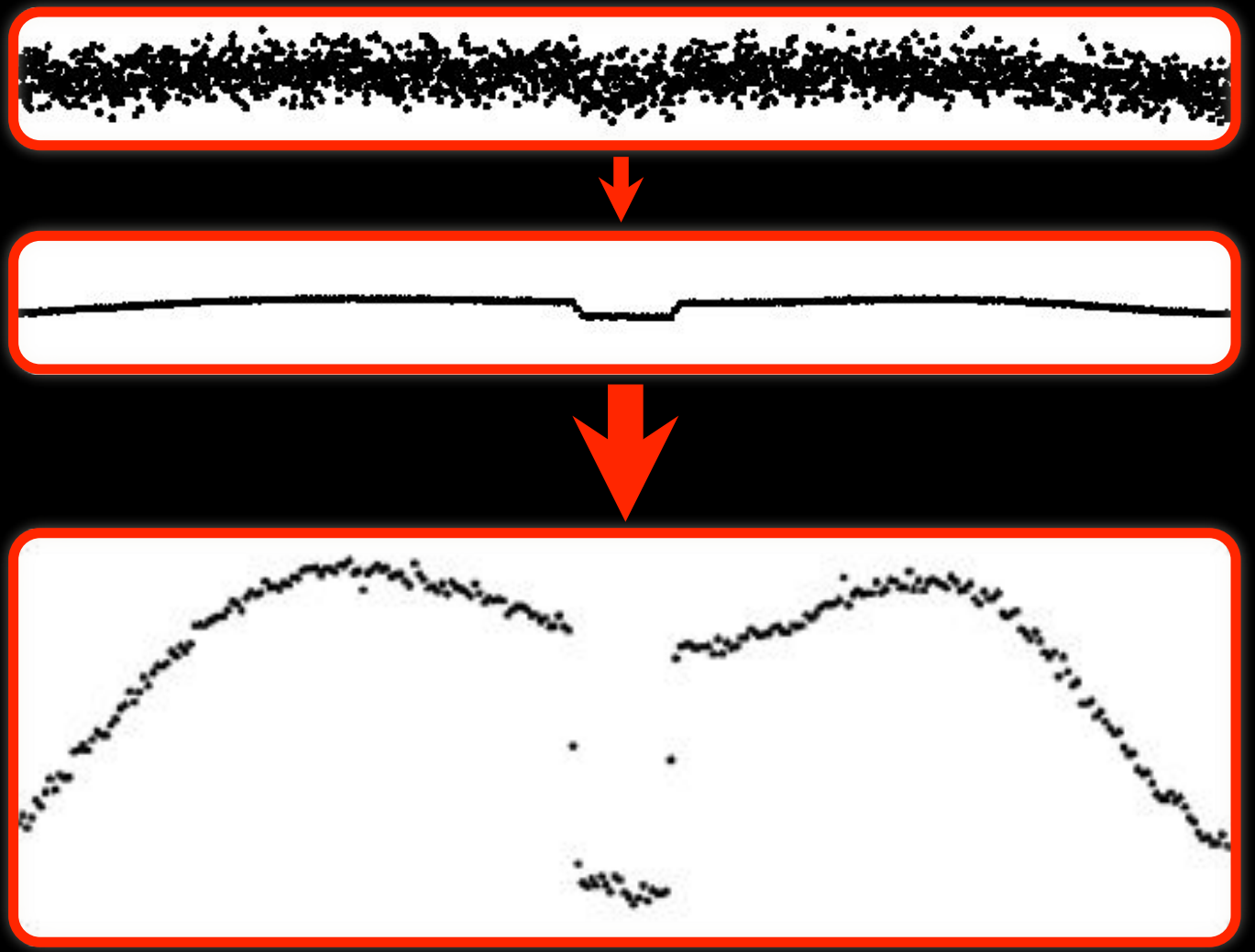




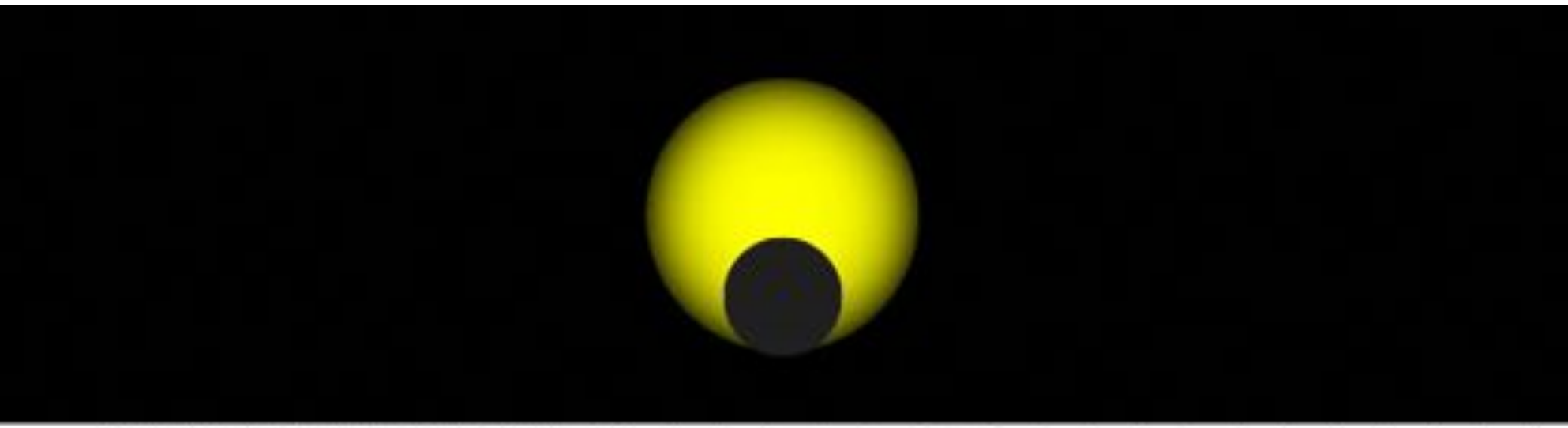
Light Curve from Kepler

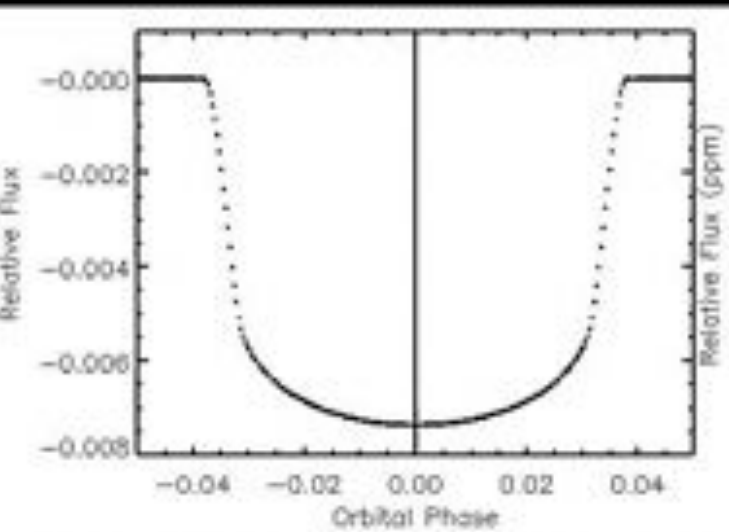


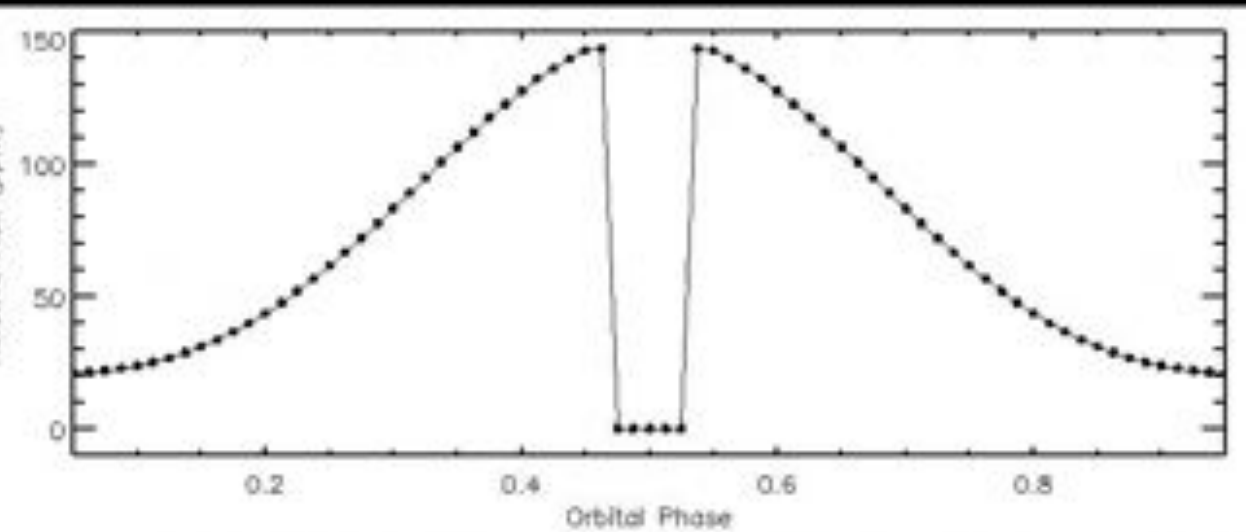
Phase Curve



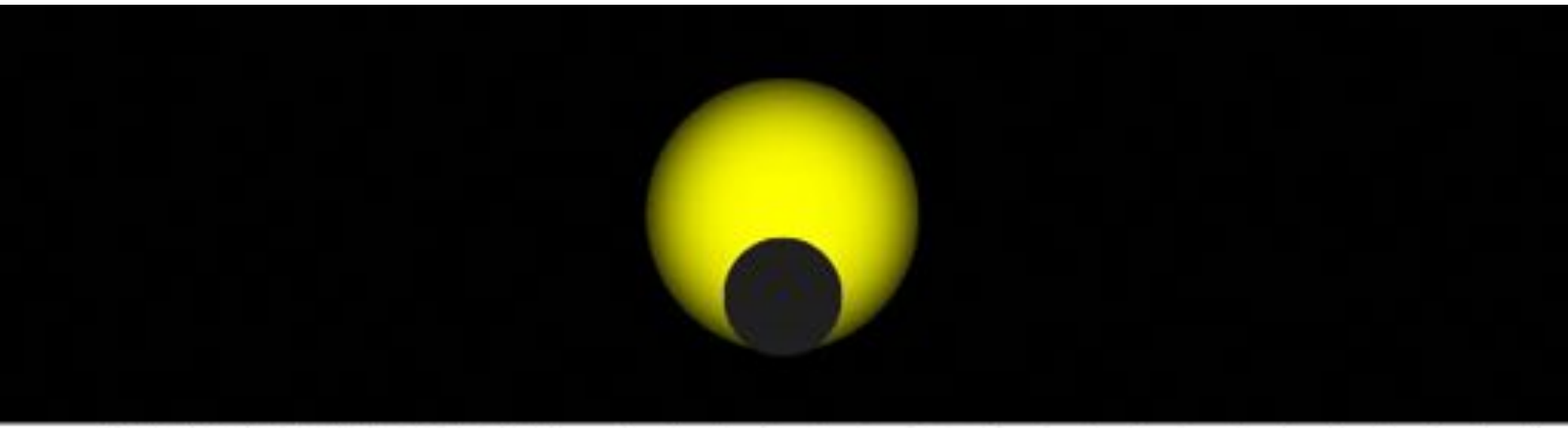
Secondary Eclipse
and
Reflected Light/Thermal Emission

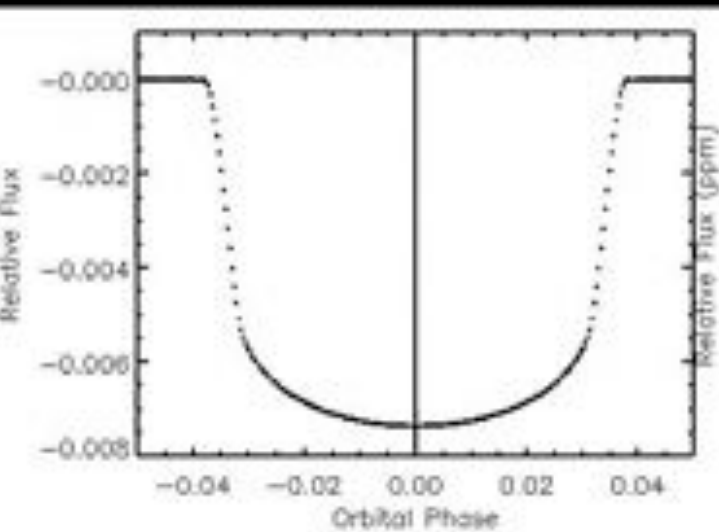


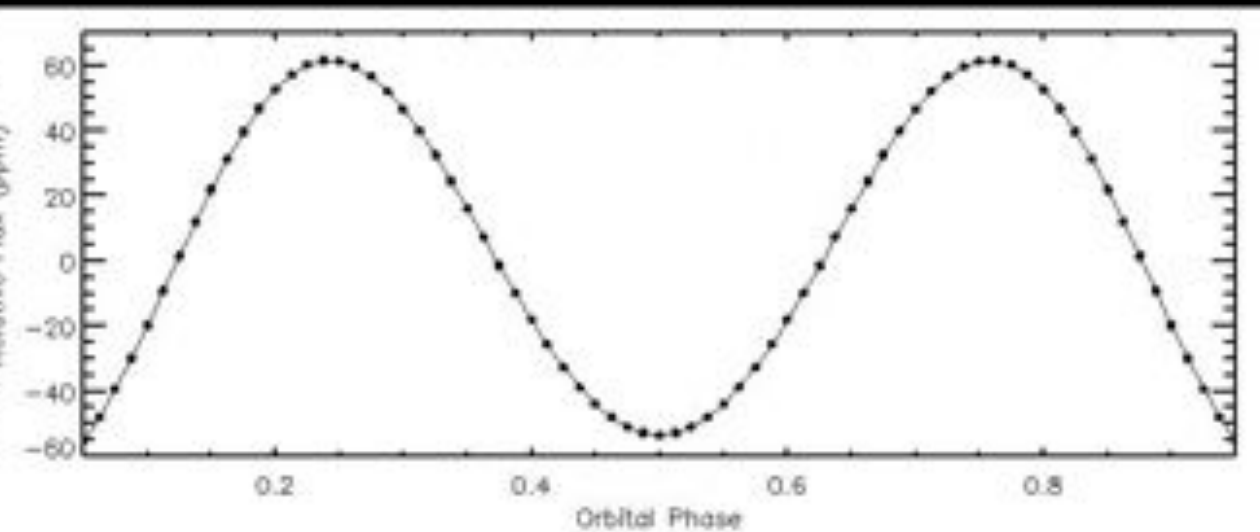




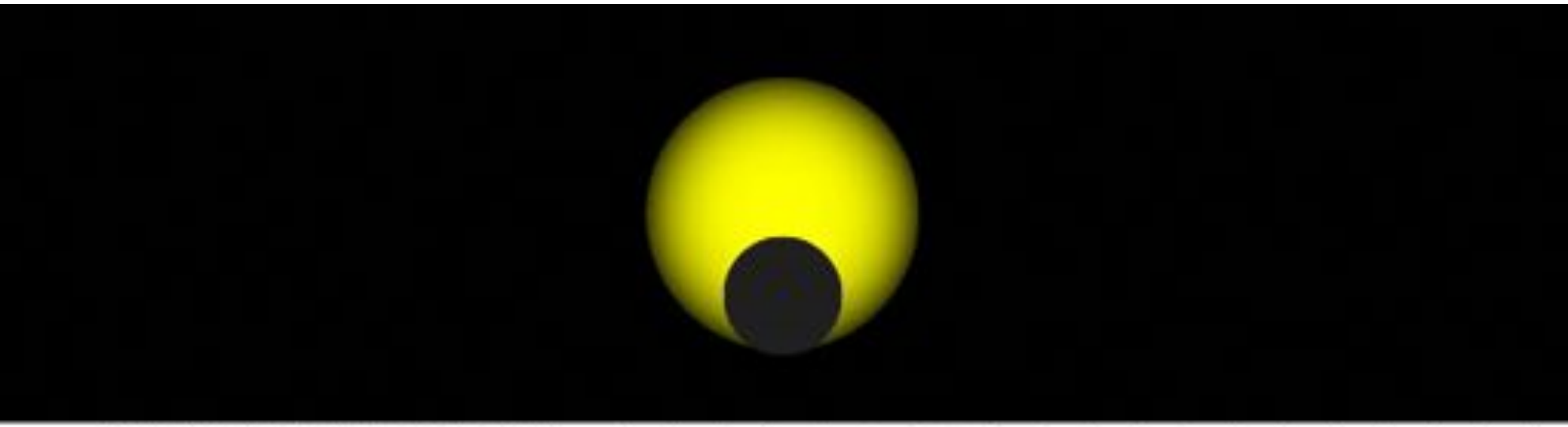
Ellipsoidal Variations

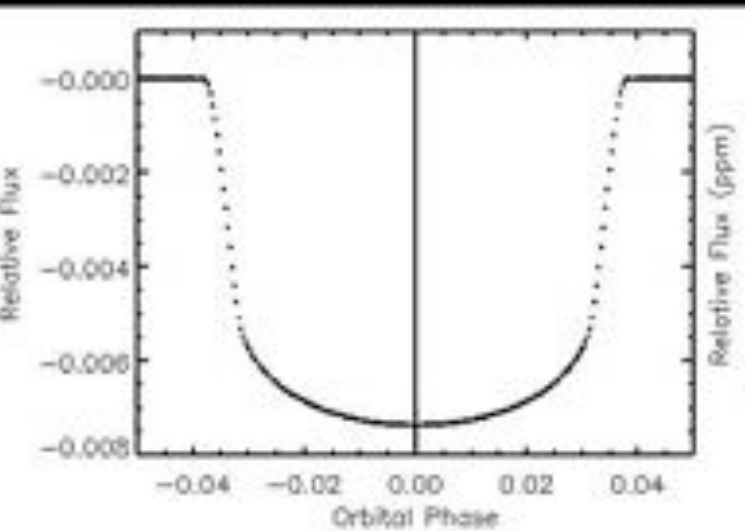


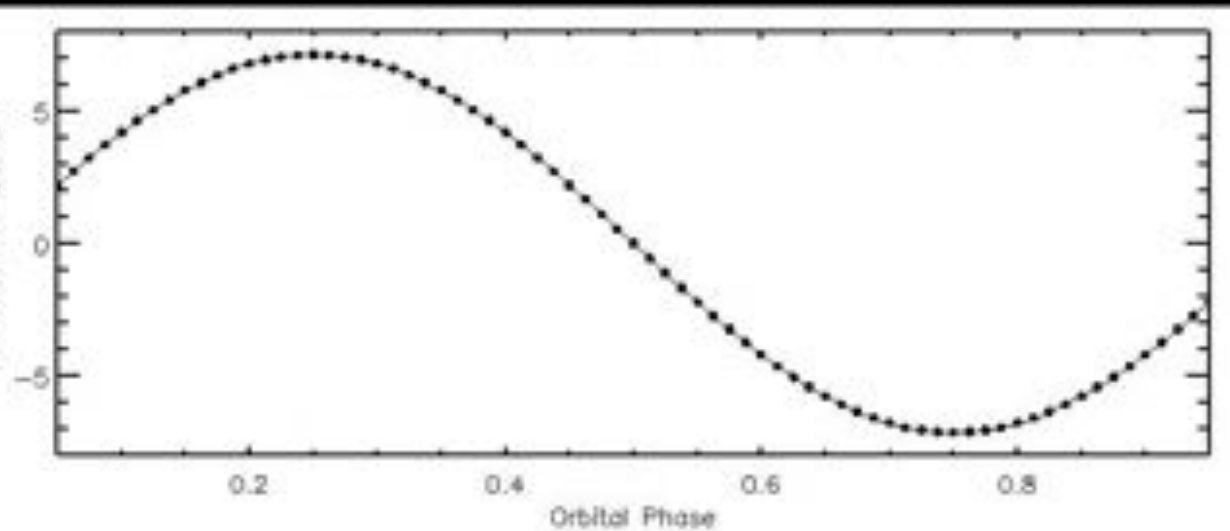




Doppler Beaming





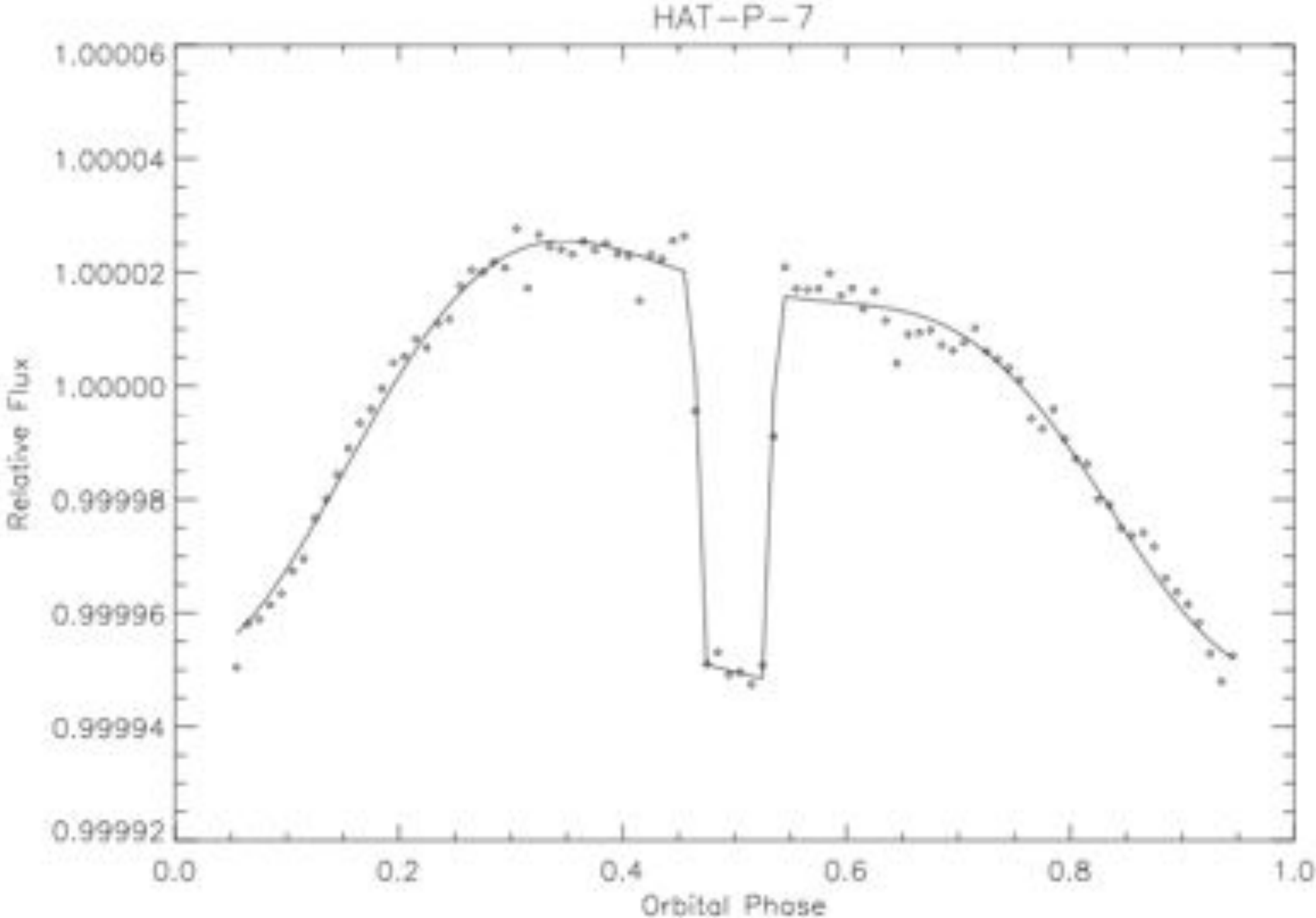


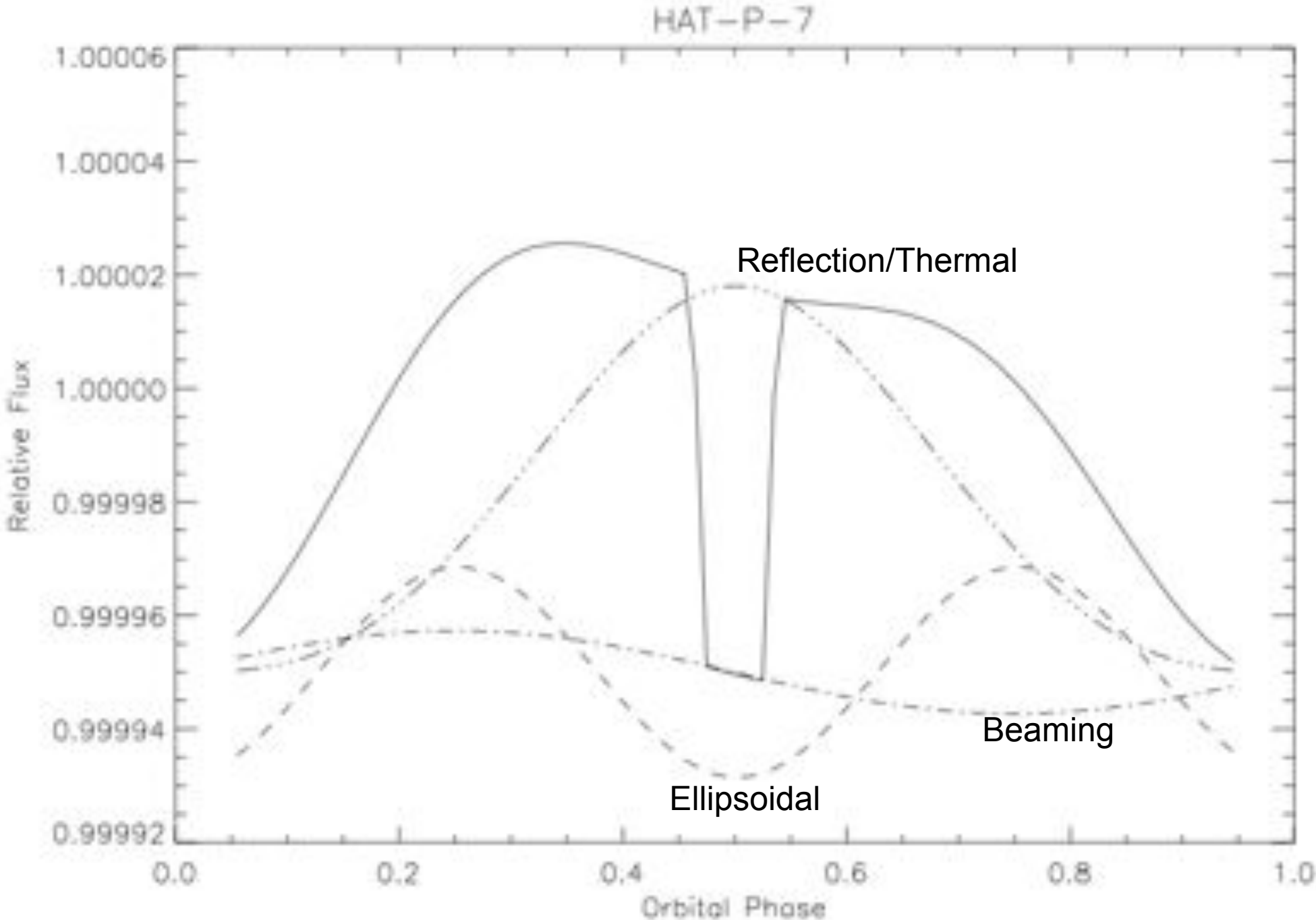
Phase Curve

1. Planetary Light
   - Reflected Light/Thermal Emission
   - Secondary Eclipse
2. Ellipsoidal Variations
3. Doppler Beaming

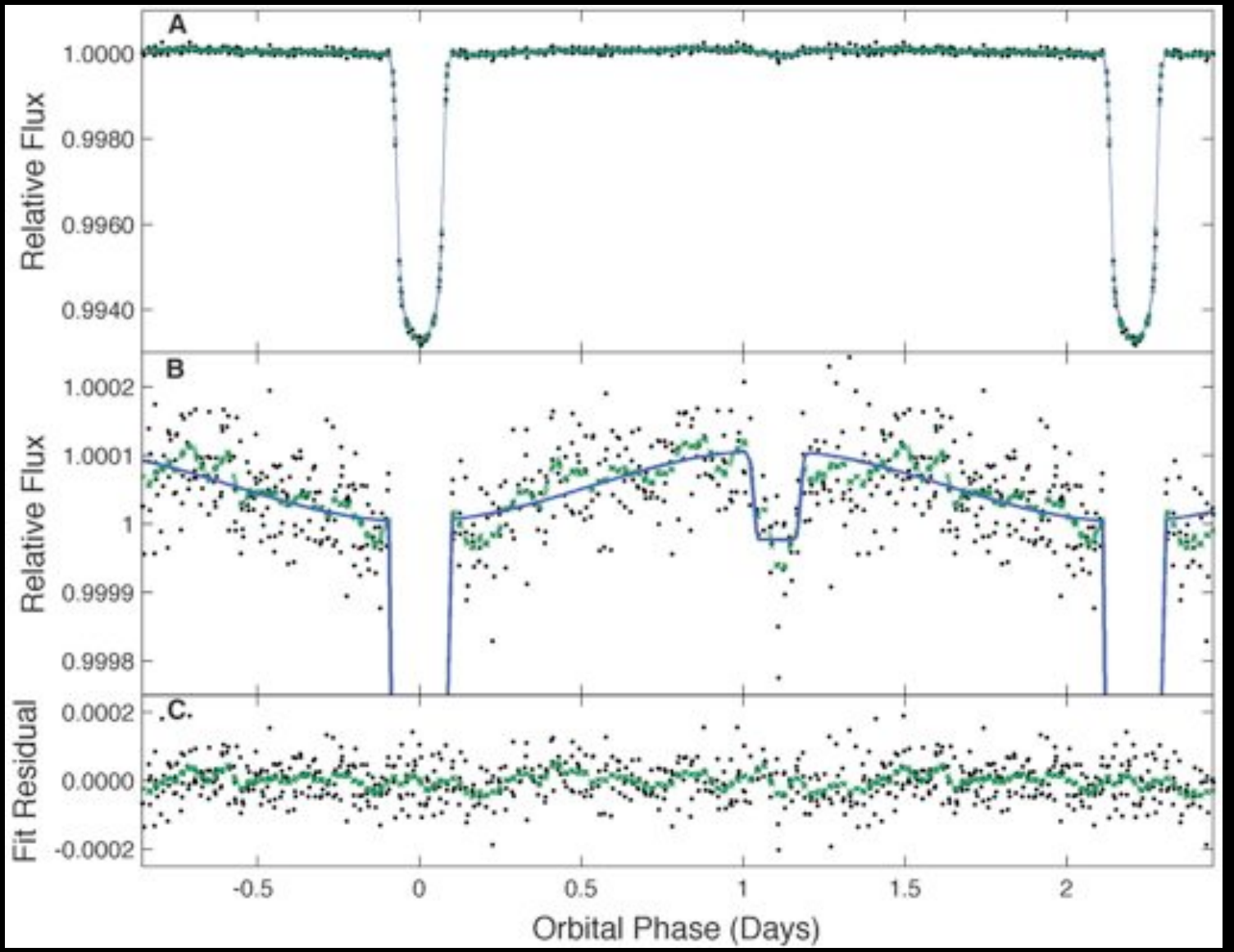
- **Albedo**
- **Temperature**
- **Heat Distribution**

Mass


HAT−P−7
1.00006
1.00004
1.00002
1.00000
0.99998
0.99996
0.99994
0.99992
Relative Flux
0.0
0.2
0.4
0.6
0.8
1.0
Orbital Phase

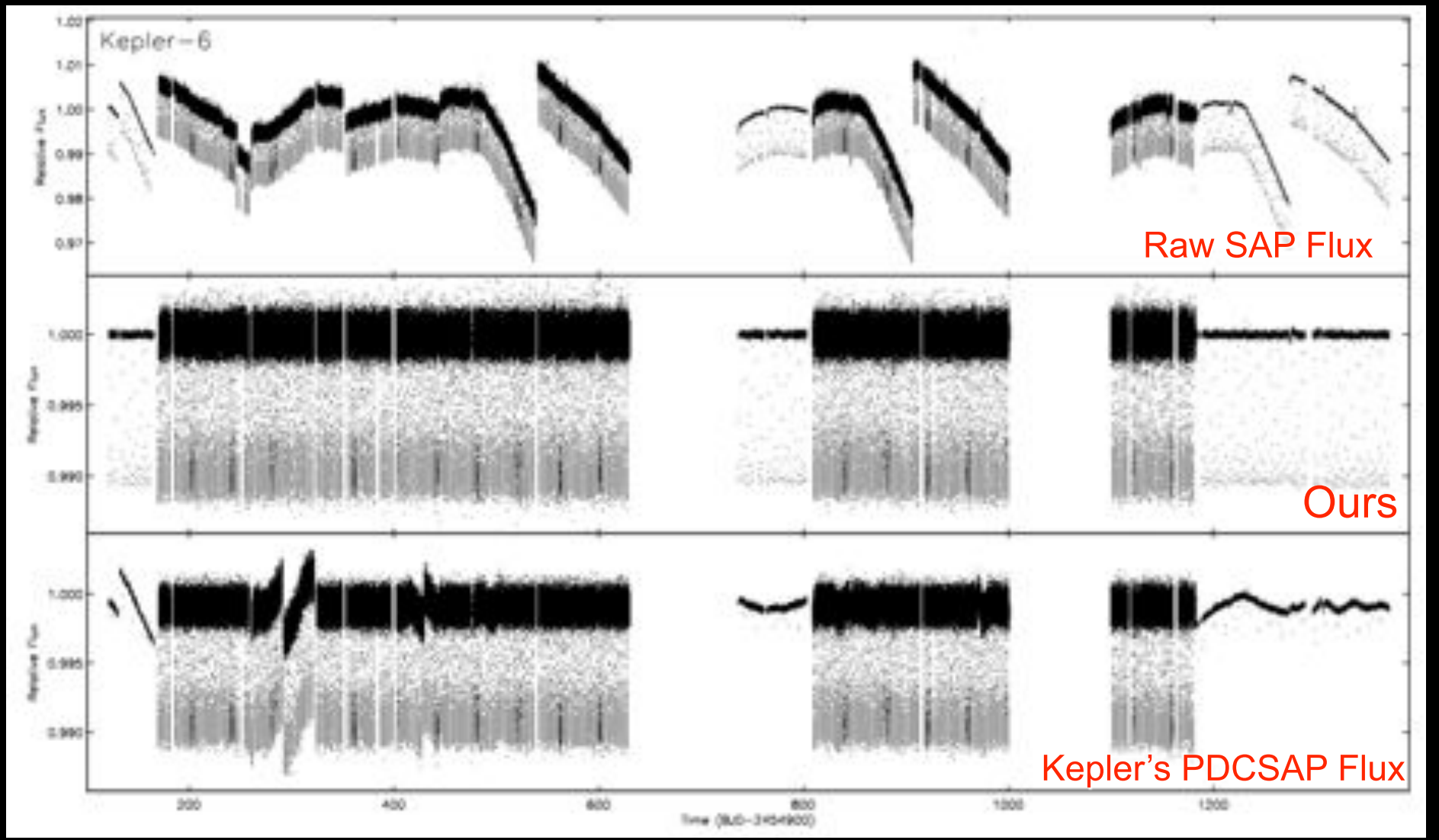

HAT-P-7
1.00006
1.00004
1.00002
1.00000
0.99998
0.99996
0.99994
0.99992
Relative Flux
0.0
0.2
0.4
0.6
0.8
1.0
Orbital Phase
Reflection/Thermal
Beaming
Ellipsoidal

HAT-P-7b

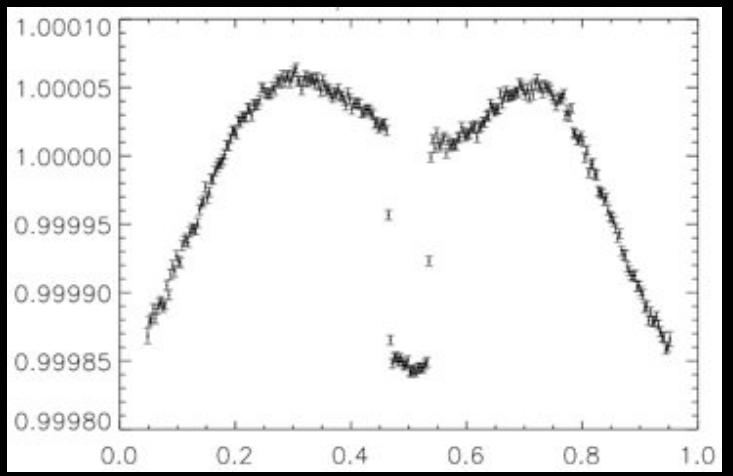


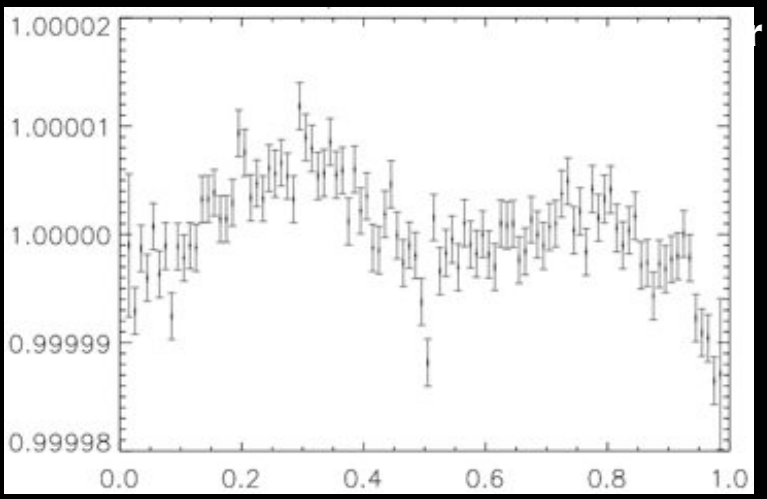
Borucki et al. (2009)

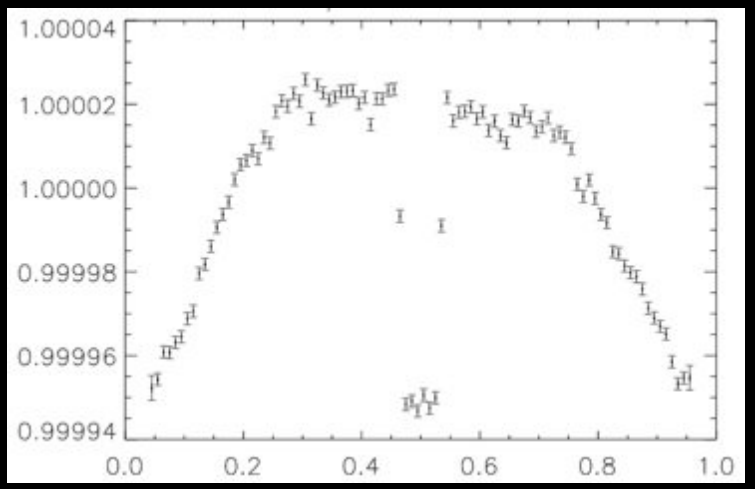
Removal of Systematics

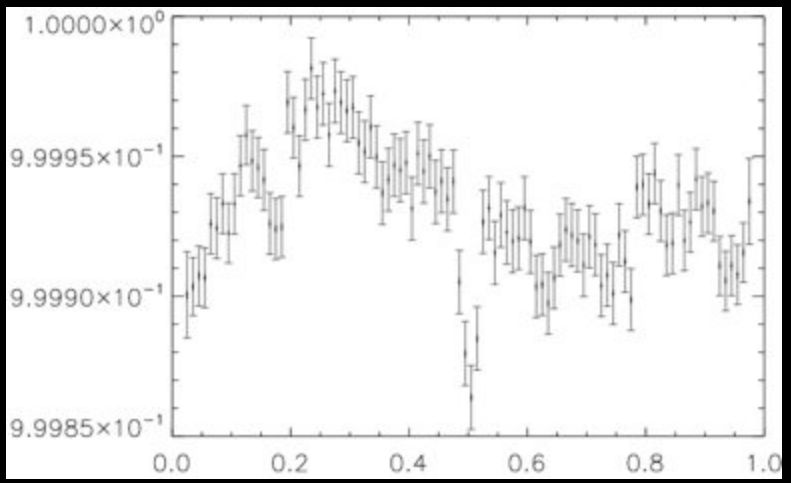


Phase Curves of Kepler Planets

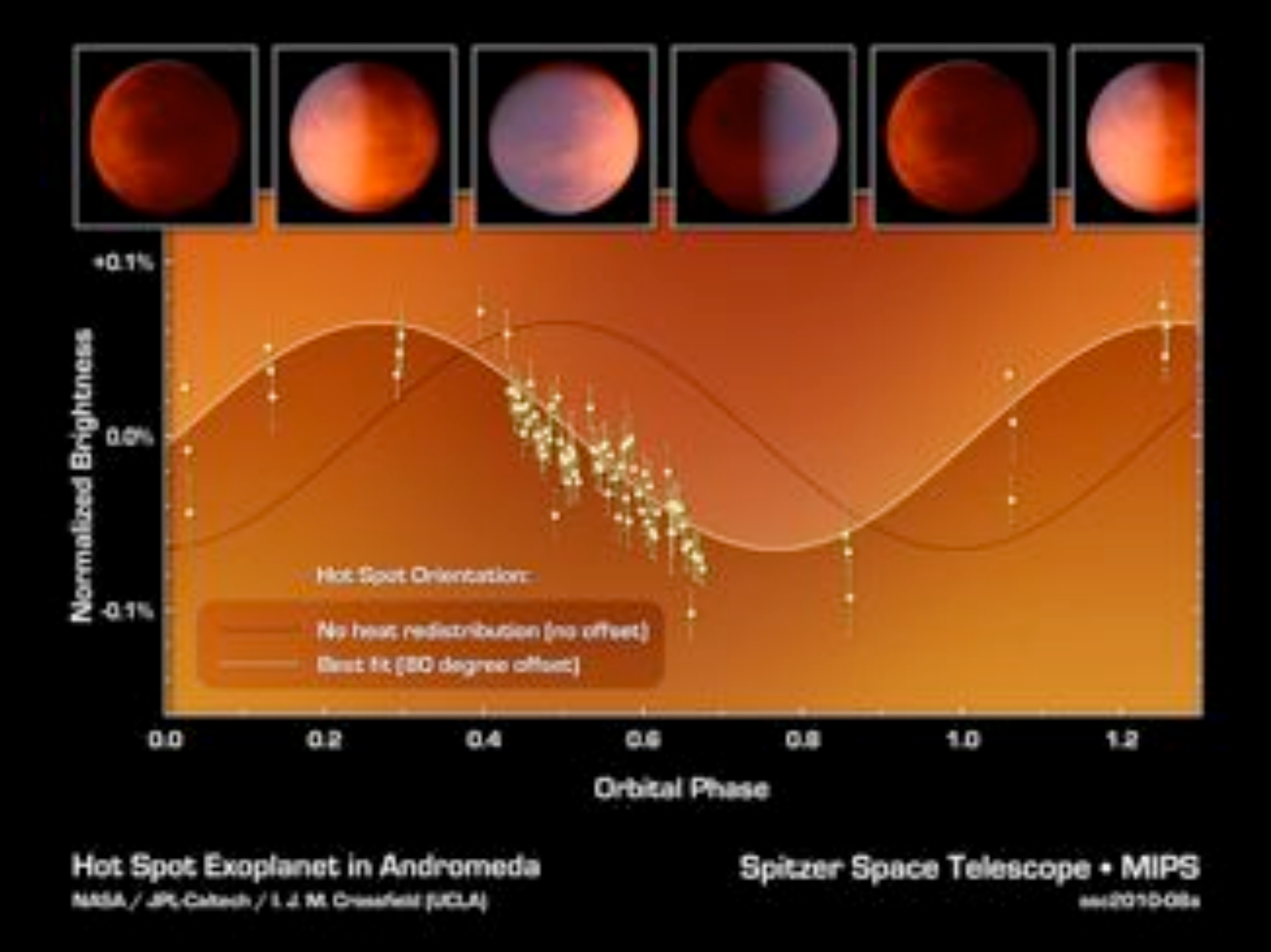








Esteves, de Mooij & Jayawardhana (in press)



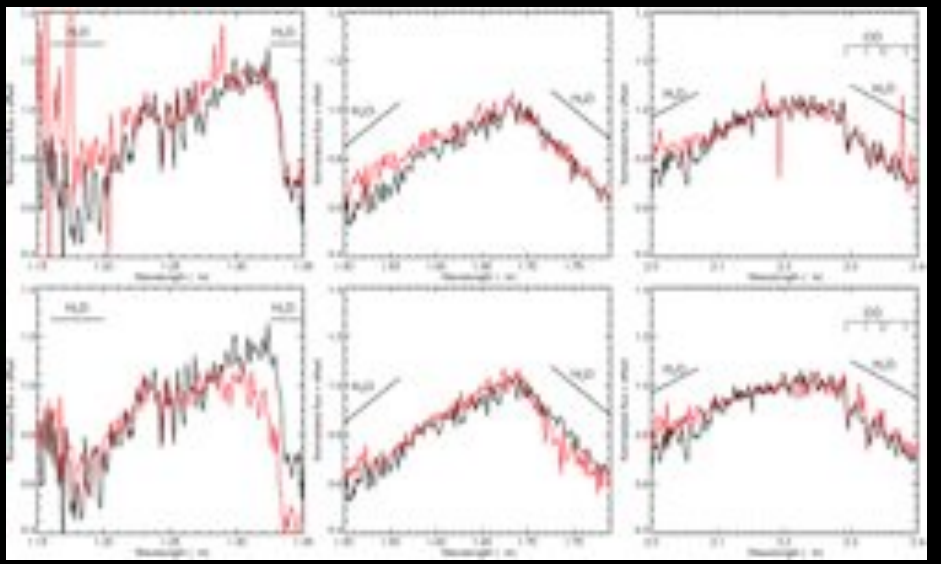
Hot Spot Exoplanet in Andromeda

NASA / JPL-Caltech / I. J. M. Crossfield (UCLA)

Spitzer Space Telescope • MIPS

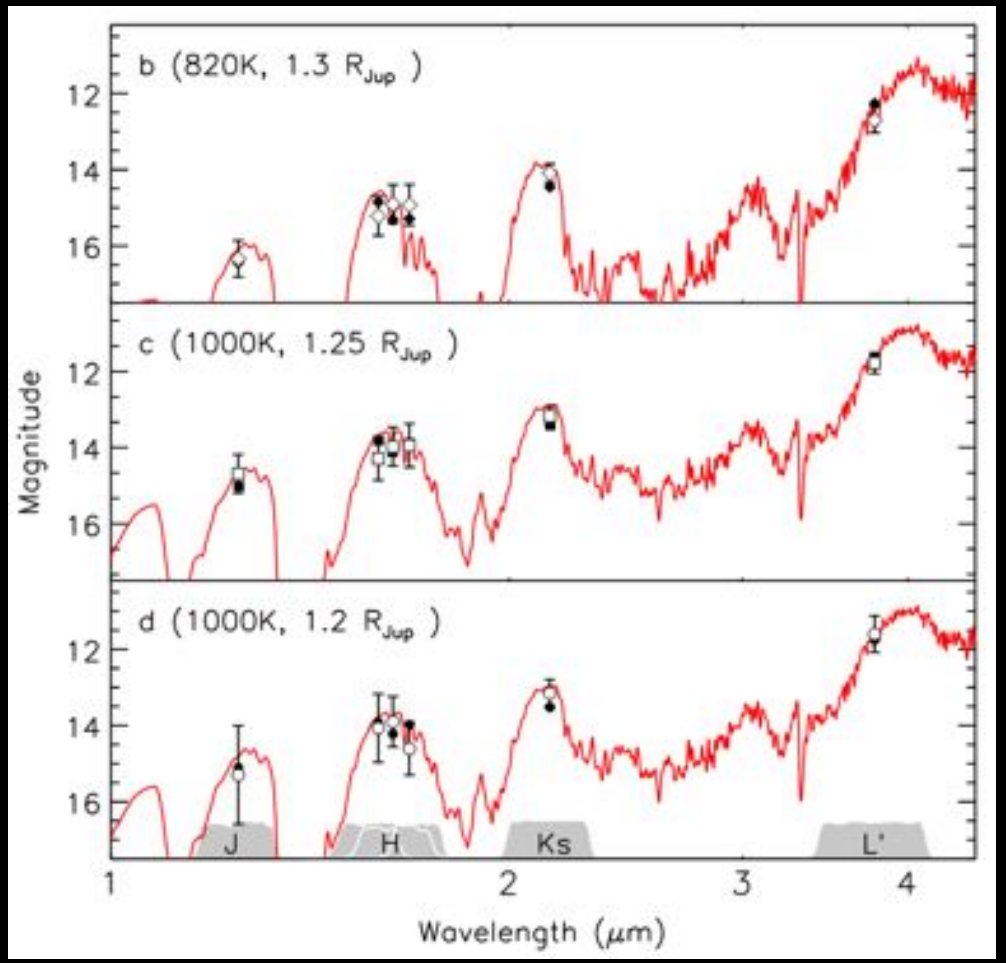
ssc2010-08a

Directly Imaged Exoplanets

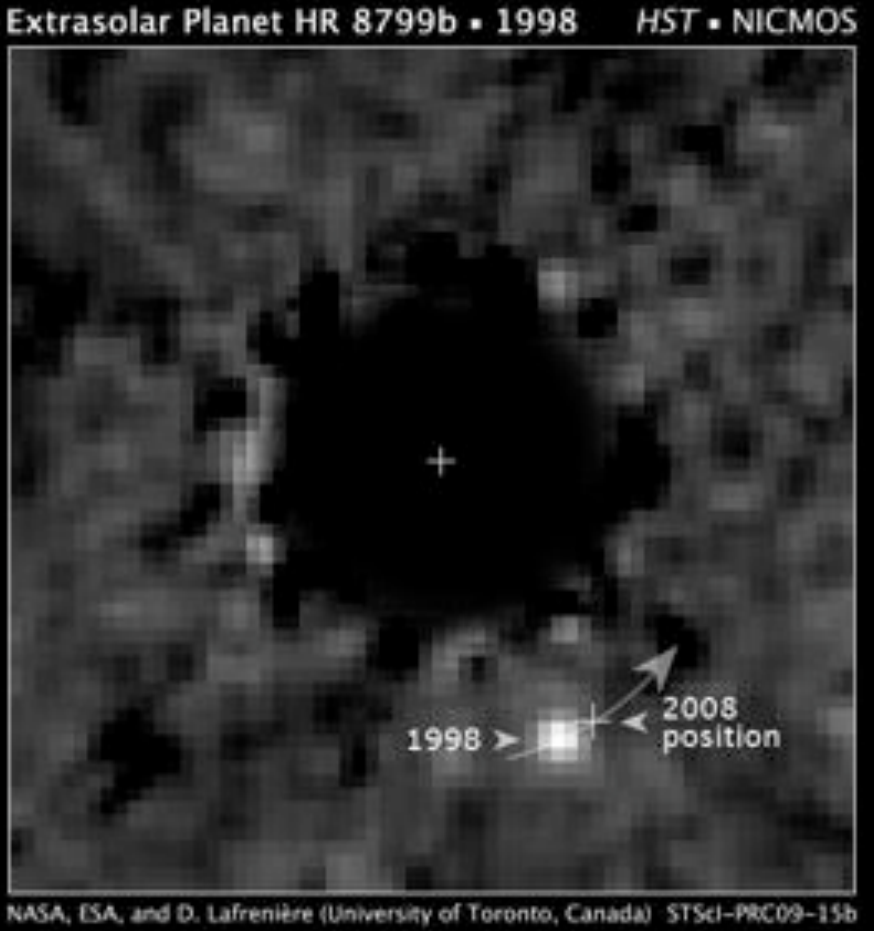


Lafreniere, Jayawardhana & van Kerkwijk (2008, 2010)

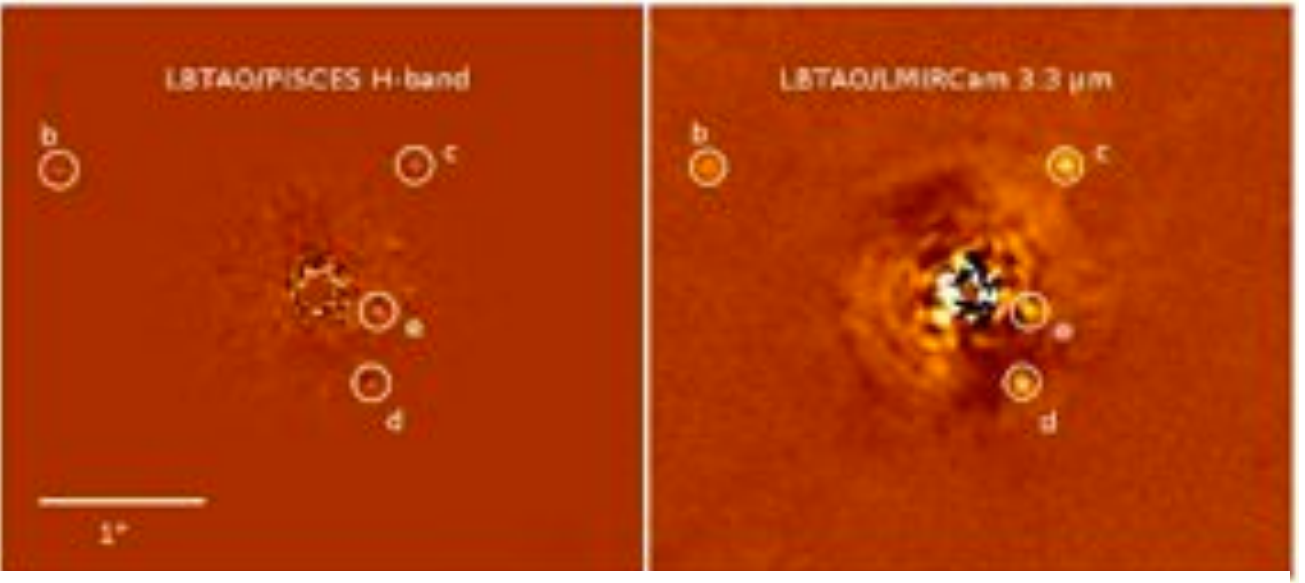
HR 8799 Planets

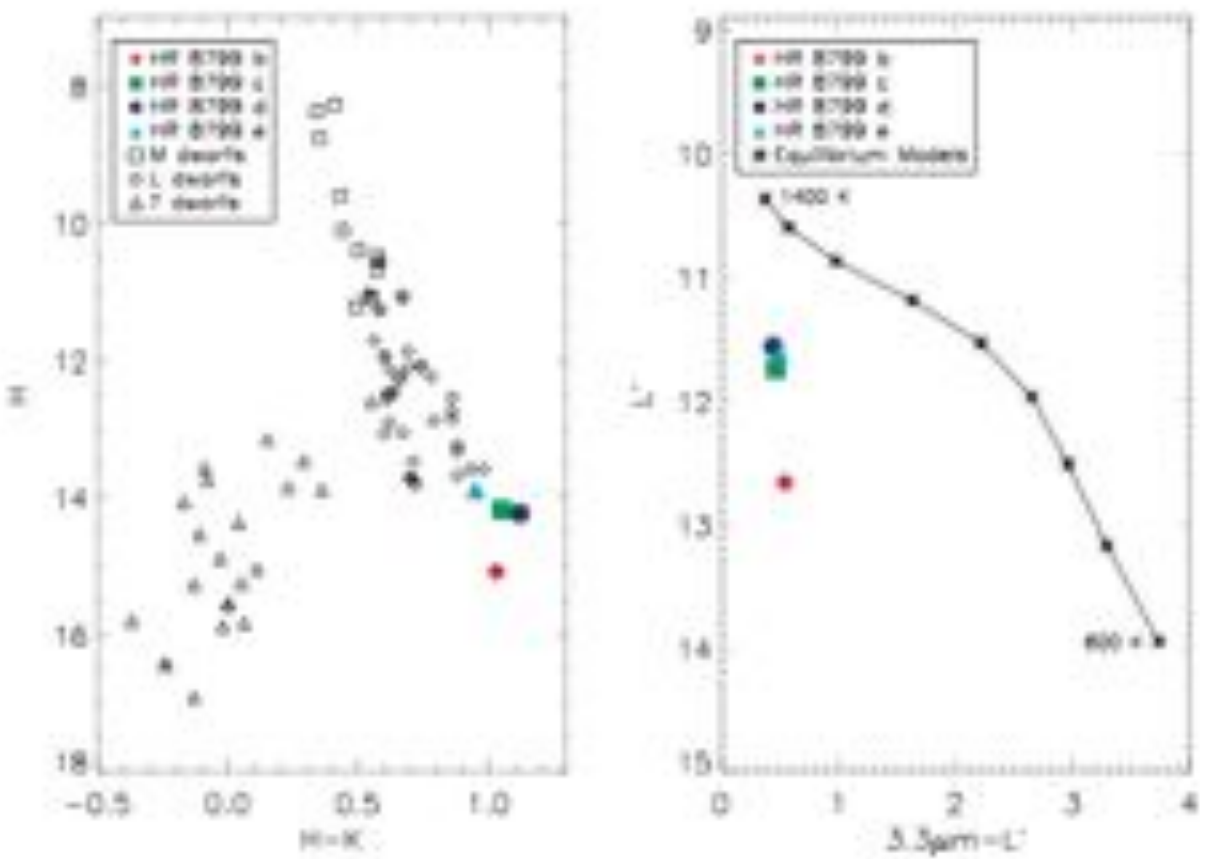


Marois et al. (2008)



Lafreniere et al. (2009)

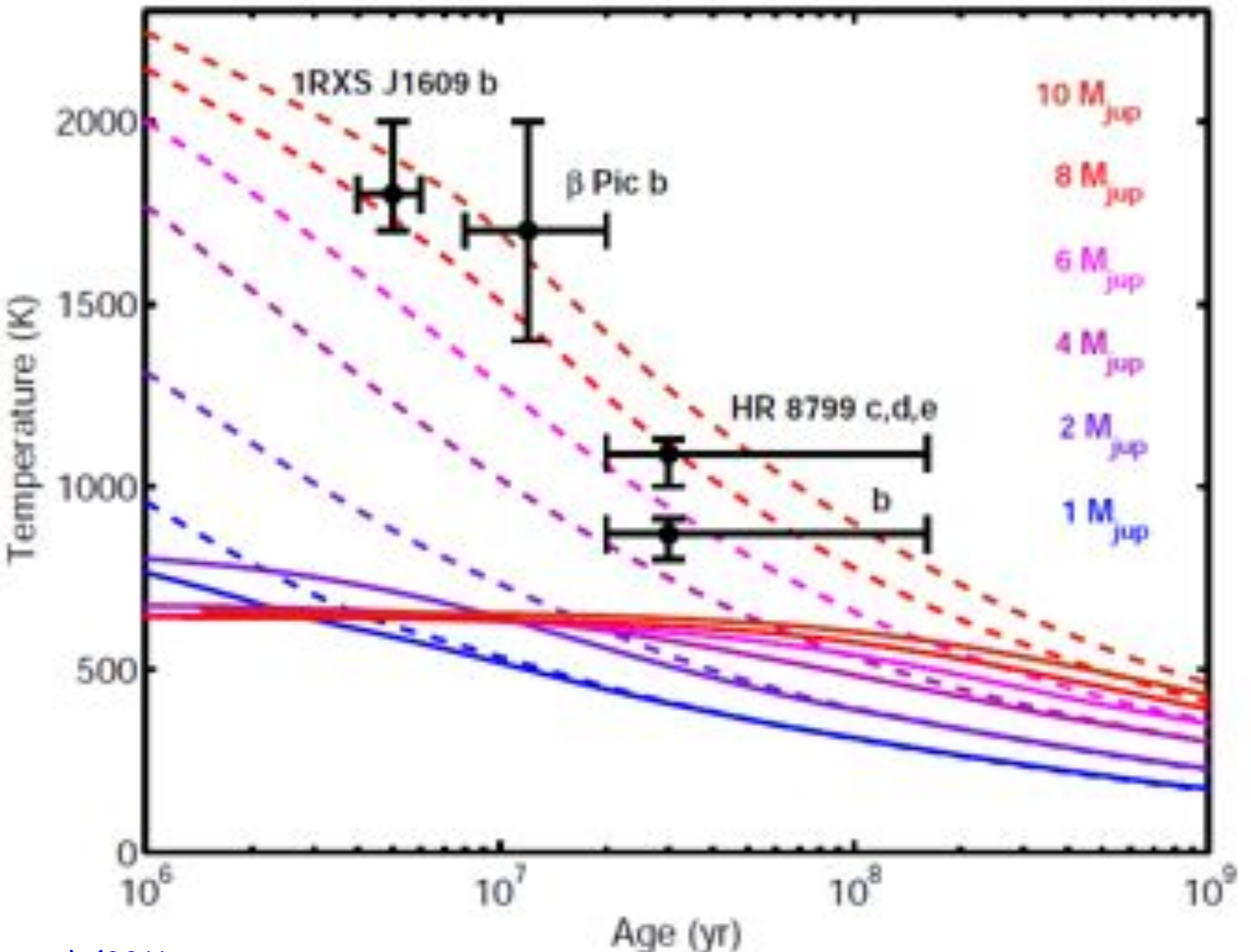




Multi-band imaging @ LBT– atmosphere characterization

Skemer et al. (2012)

`Hot Start' versus `Cold Start' Models

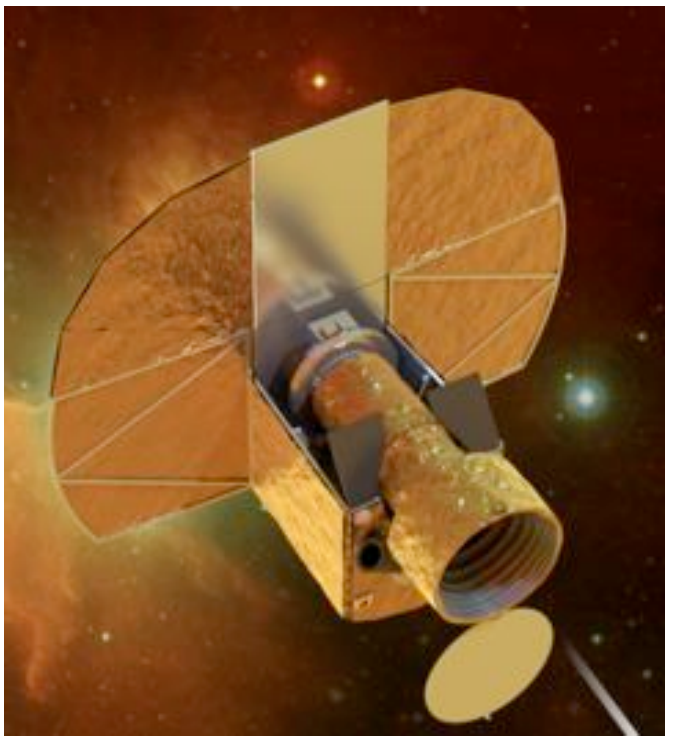


Janson et al. (2011;
based on Fortney et al., 2008)

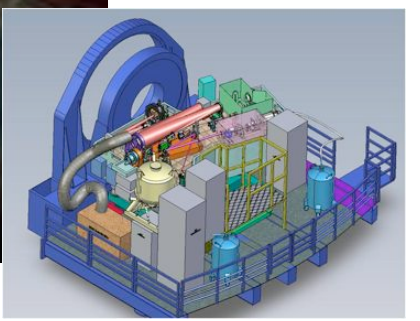
Coming Attractions

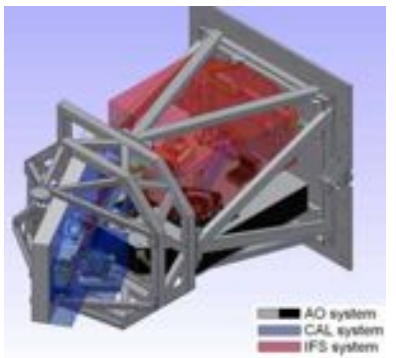
Transiting Exoplanet Survey Satellite (TESS, NASA, ~2017)

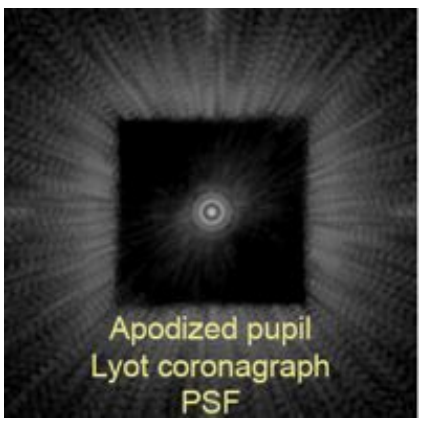
Characterising Exoplanets Satellite (CHEOPS, ESA, ~2017)



Extreme AO Imagers



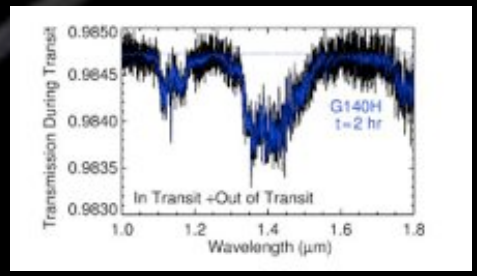


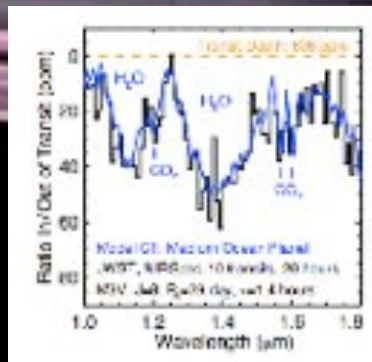


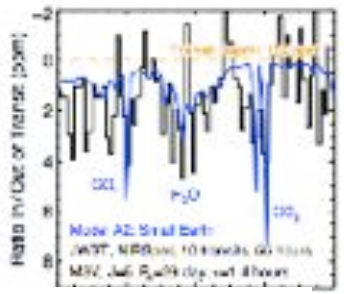
Direct imaging searches of nearest young stars for giant planets in wide orbits with extreme AO instruments on Gemini and VLT by ~2014

Better sense of planetary system diversity

James Webb Space Telescope ~2018

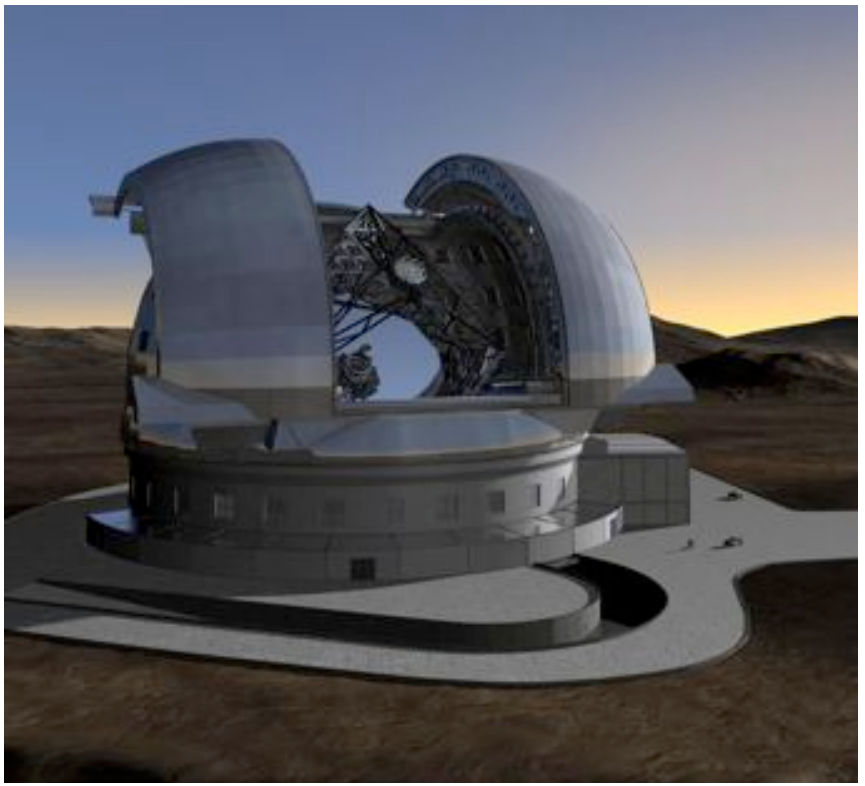






Seager et al.

In the longer term

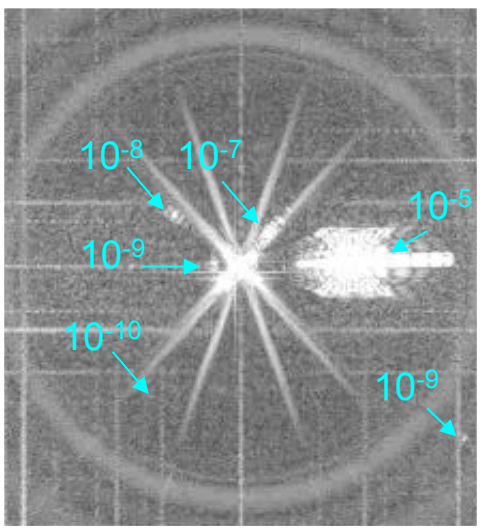


European Extremely Large Telescope (E-ELT)

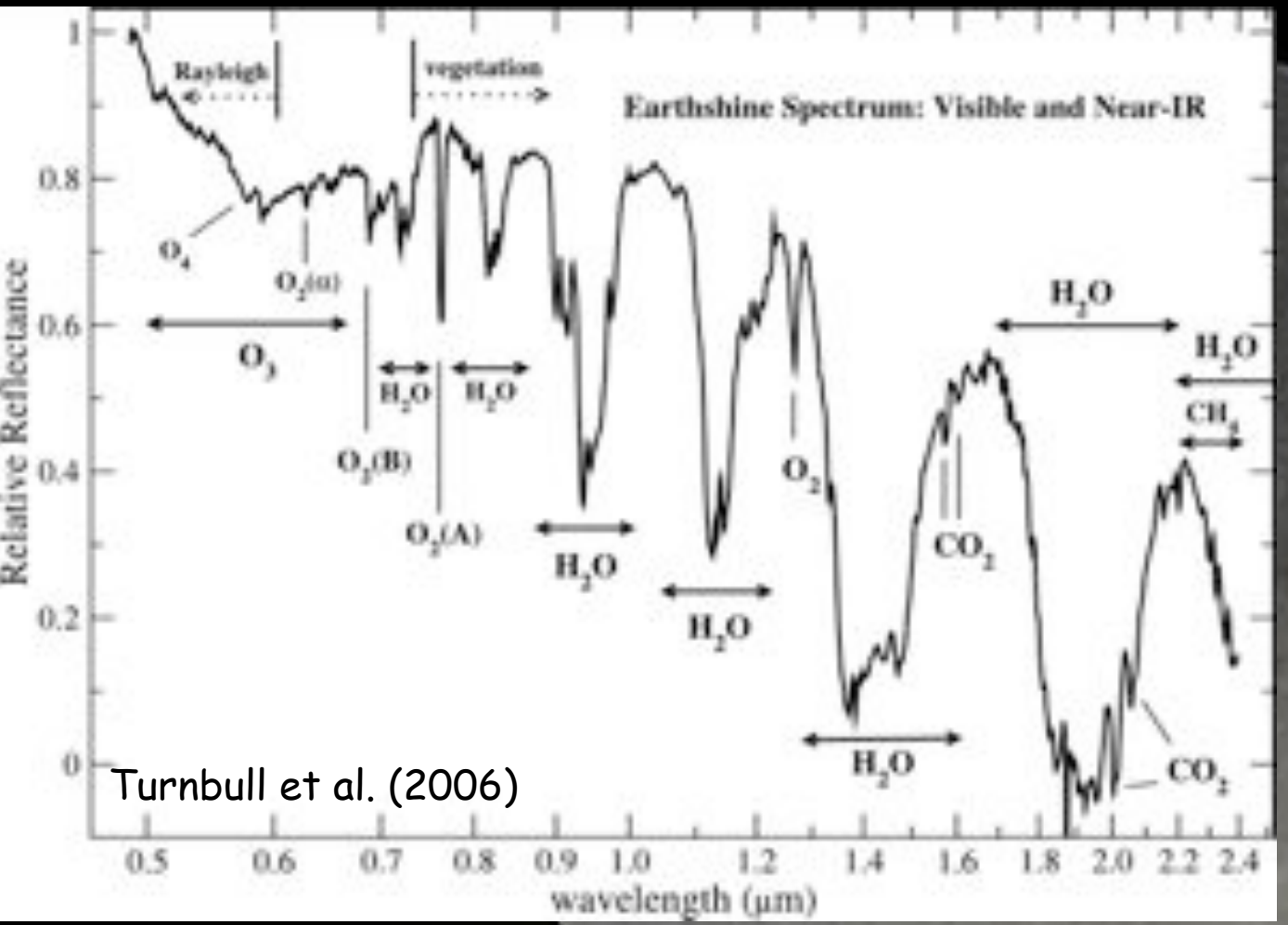
Instrument: Planet Imager and Spectrograph with Extreme Adaptive Optics (EPICS)

Thirty-Meter-Telescope (TMT)

Instrument: Planet Formation Imager (PFI)



Exo-planet imaging in J-band
Preliminary (EPICS team)



Turnbull et al. (2006)

Alan C. Tough

Alien Life, Coming Slowly Into View

By Ray Jayawardhana

New York Times

2011 March 27

The story of an unfolding revolution that could change the way we see ourselves and our place in the universe.

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