Characterising planetary atmospheres with IRIS2 and HIPPI at the AAT

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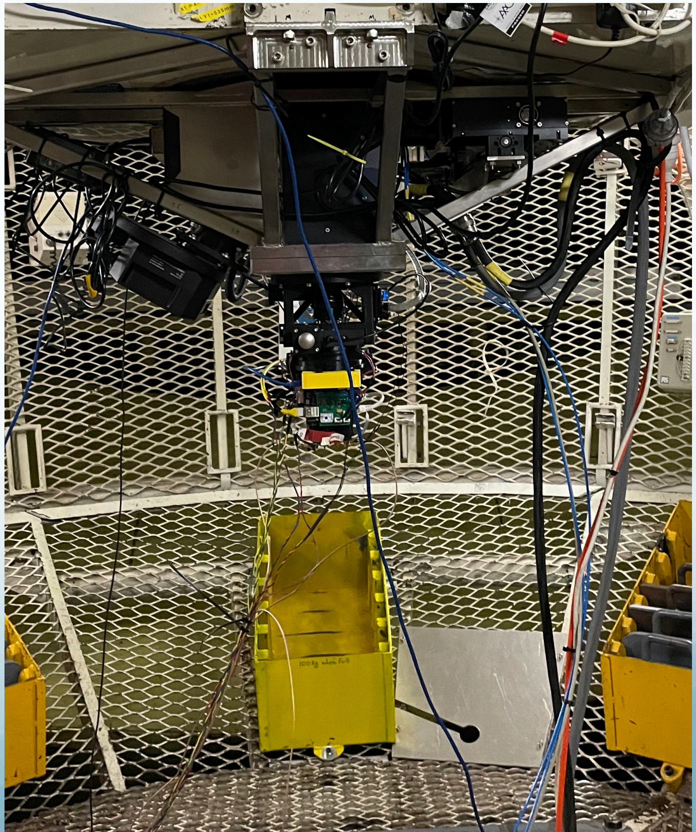
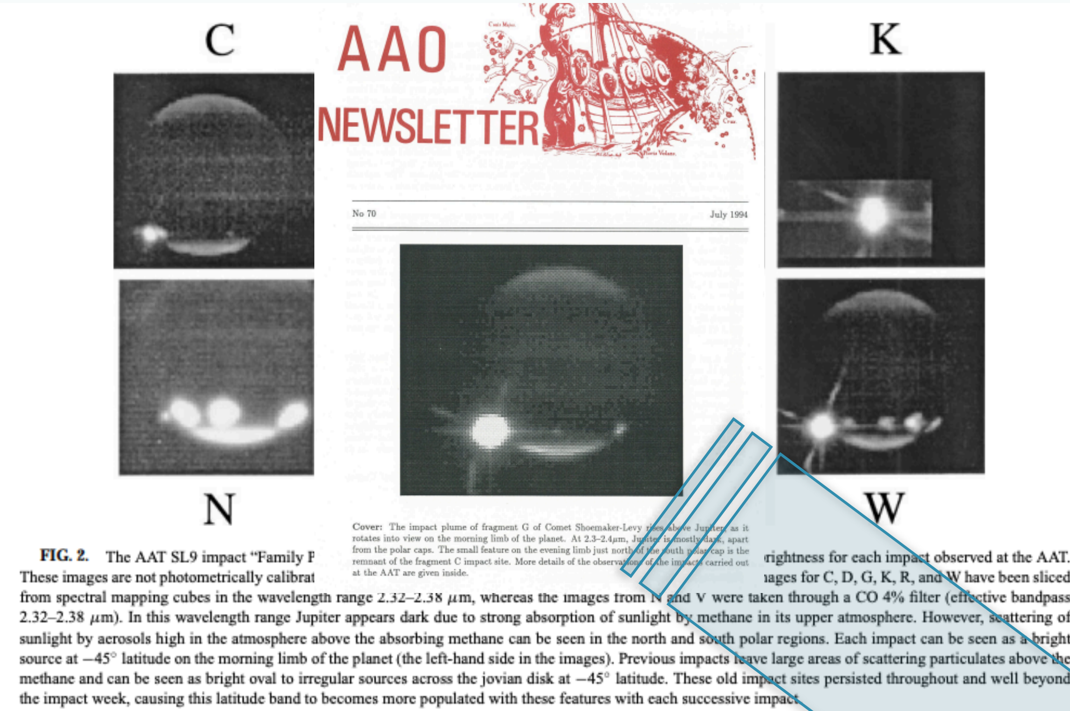
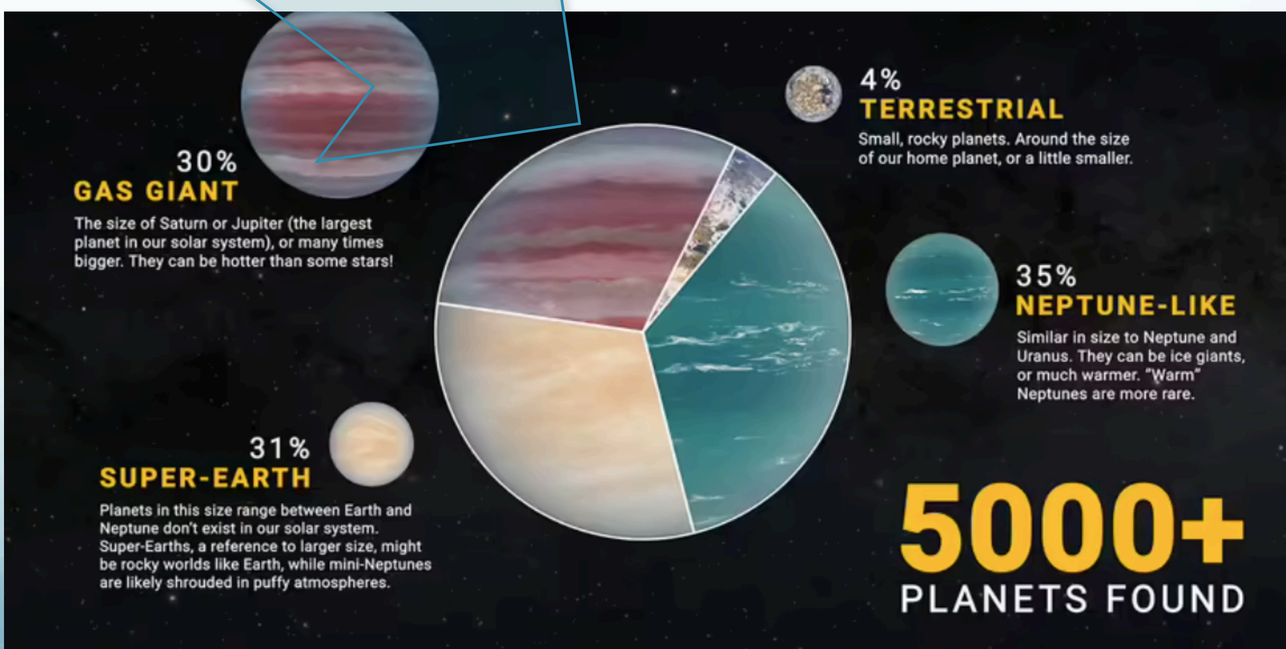




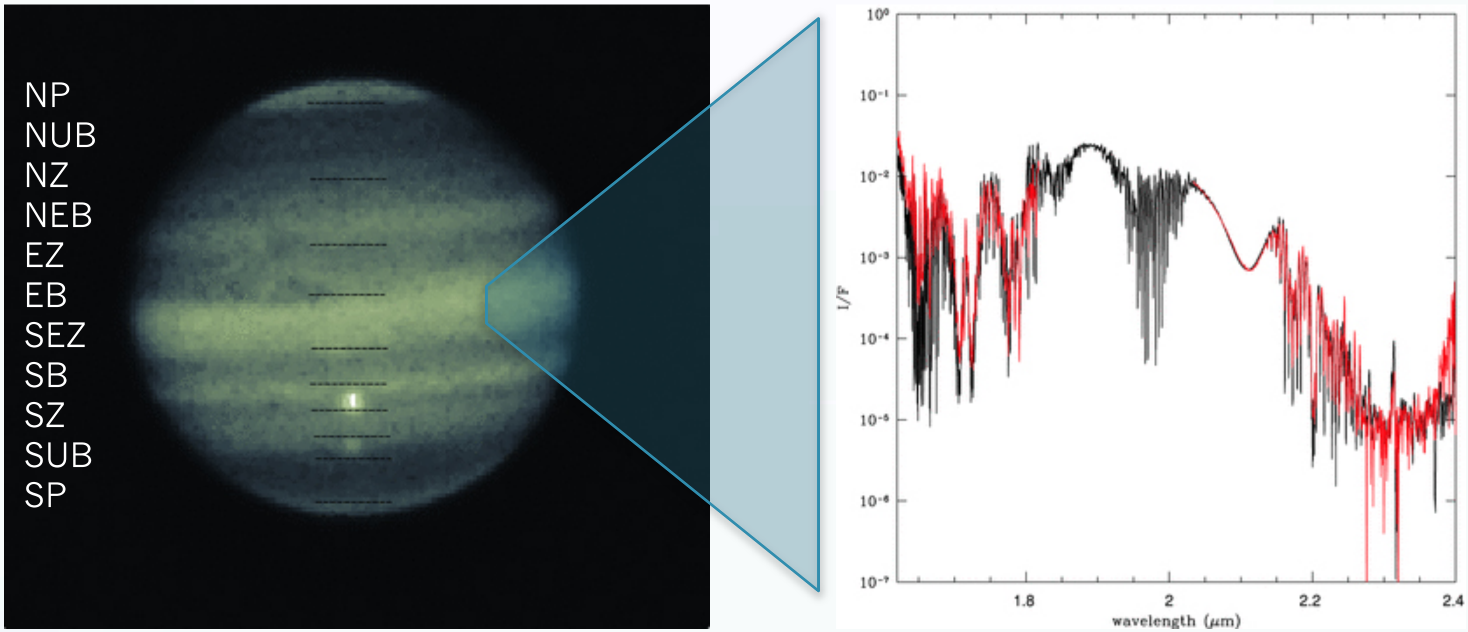
The Anglo-Australian Planet Search (AAPS) led by Chris Tinney started in 1998 using UCLES to measure Doppler shifts in the stellar spectra to discover giant planets around nearby Solar-type stars.

IRIS observations of SL9 comet impacting Jupiter in July 1994

From SL9 Comet to Exoplanets



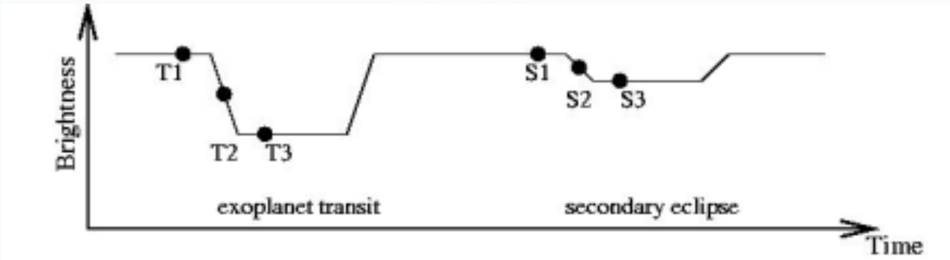
Chemistry of planetary atmosphere and clouds

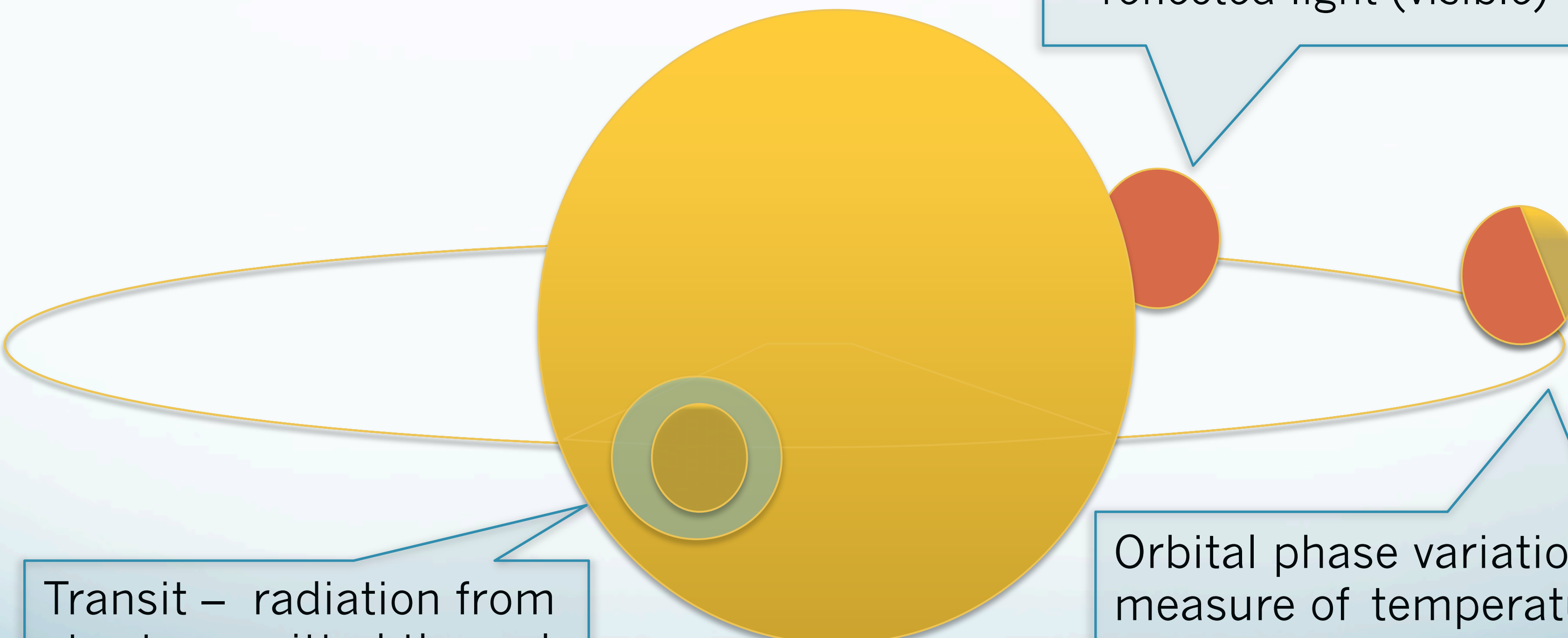


Modelling the near-infrared IRIS2 spectra of giant planets of Solar System using the VSTAR, modular line-by-line radiative transfer solver for light in a stratified atmosphere with a defined chemical composition and a specified size distribution of cloud particles

More about VSTAR - Modelling the spectra of planets, brown dwarfs and stars using VSTAR (*Bailey & Kedziora-Chudczer, 2012, MNRAS, 419, 1913)*

Transiting planets





Secondary eclipse – day side of the planet, thermal radiation (at infrared) and reflected light (visible)

Transit – radiation from star transmitted through the planet atmosphere – probe of planetary limb and upper atmosphere

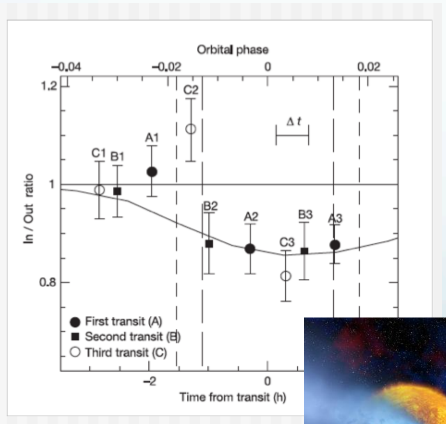
Orbital phase variations – measure of temperature gradient between day and night side of the planet (not only for transiting planets)

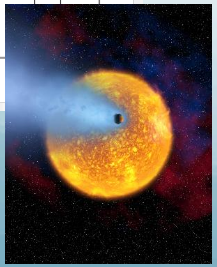
Transit spectrophotometry

UV **Probing low pressures** Visible **Probing high pressures** IR

H Lyman-α 121.6 nm feature
In HD 209458b
(15% absorption)

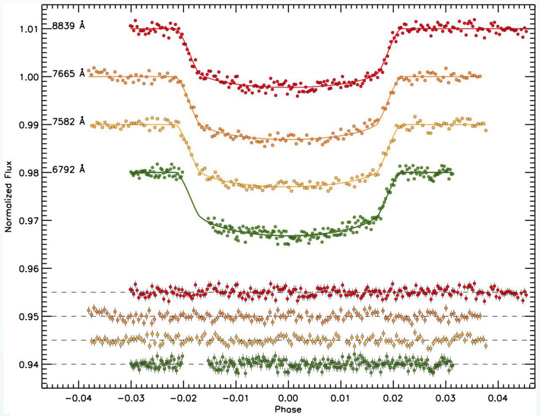
- Atmospheric mass loss
- Cometary tail of H gas

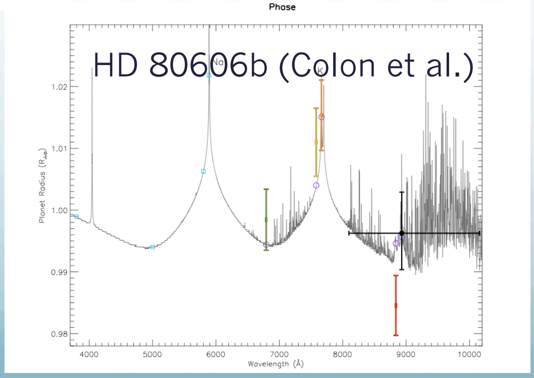




Absorption of Na,K, TiO

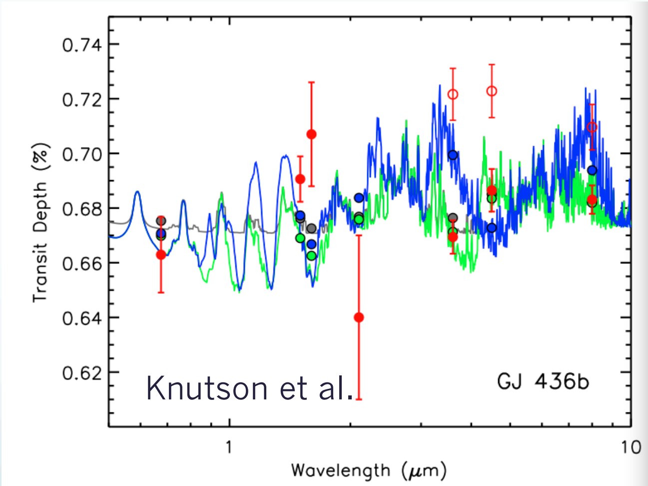
- Constraints on metallicity, clouds and rainout of condensates





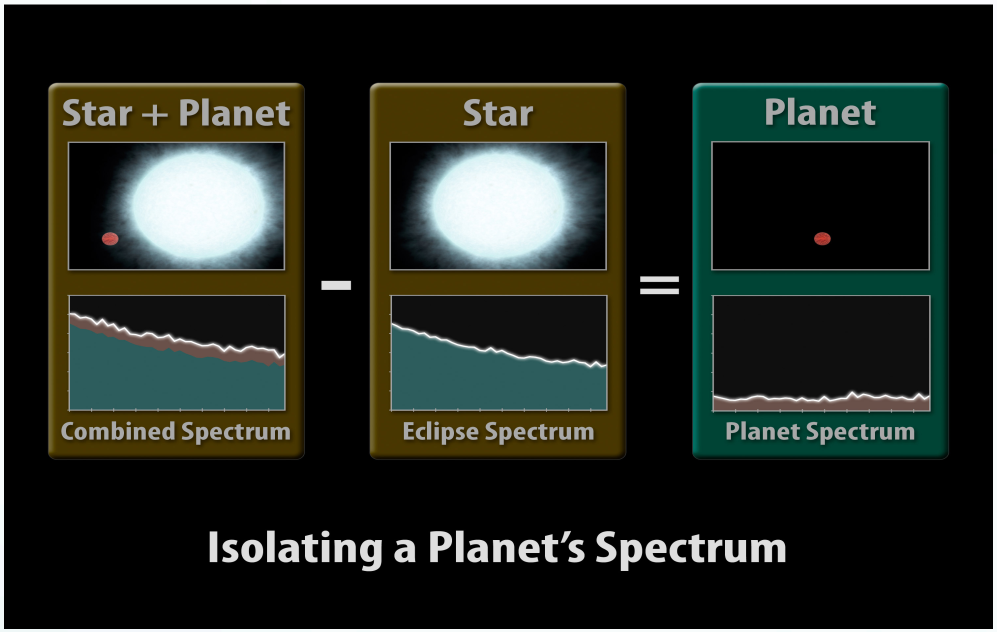
Absorption of CO, CO_2, H_2O, CH_4

- Atmospheric composition

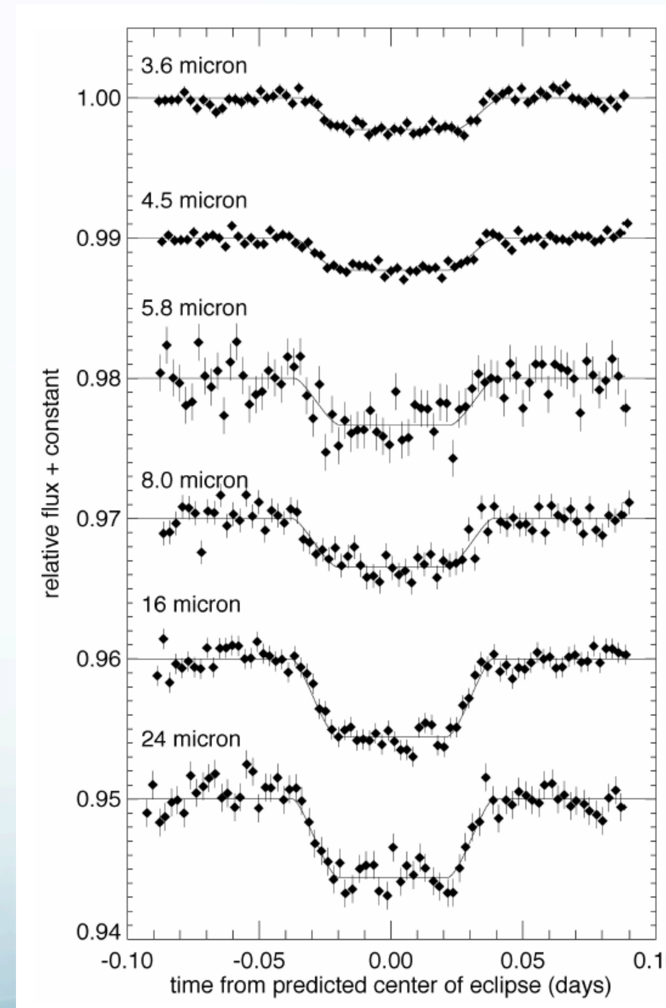


Eclipse spectrophotometry

UV **Probing reflectivity –albedo** Visible IR **Probing temperature**



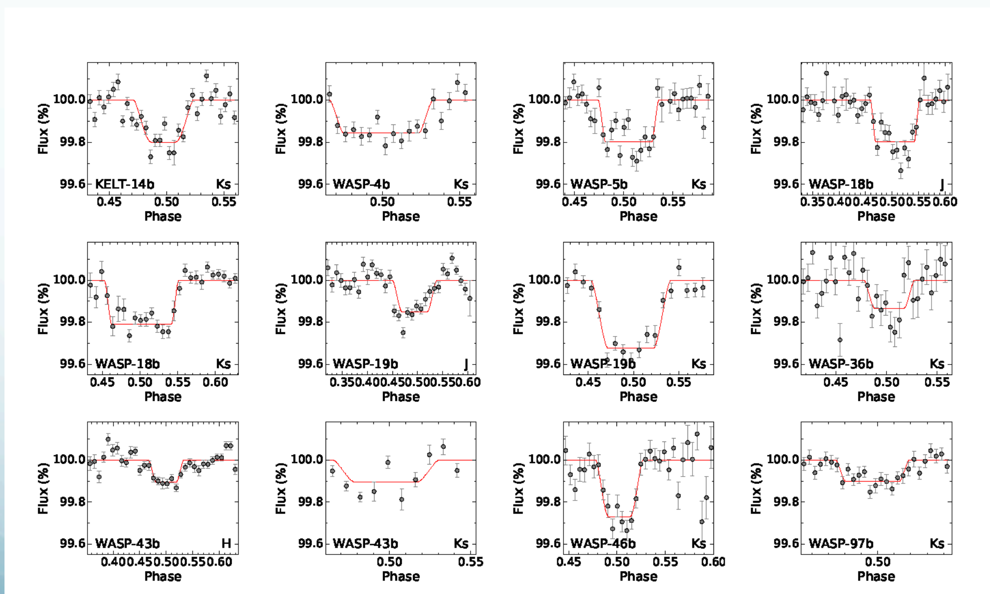
- First detections of planetary emission done by Spitzer space telescope in mid and far infrared (3.5 to 24 μm)

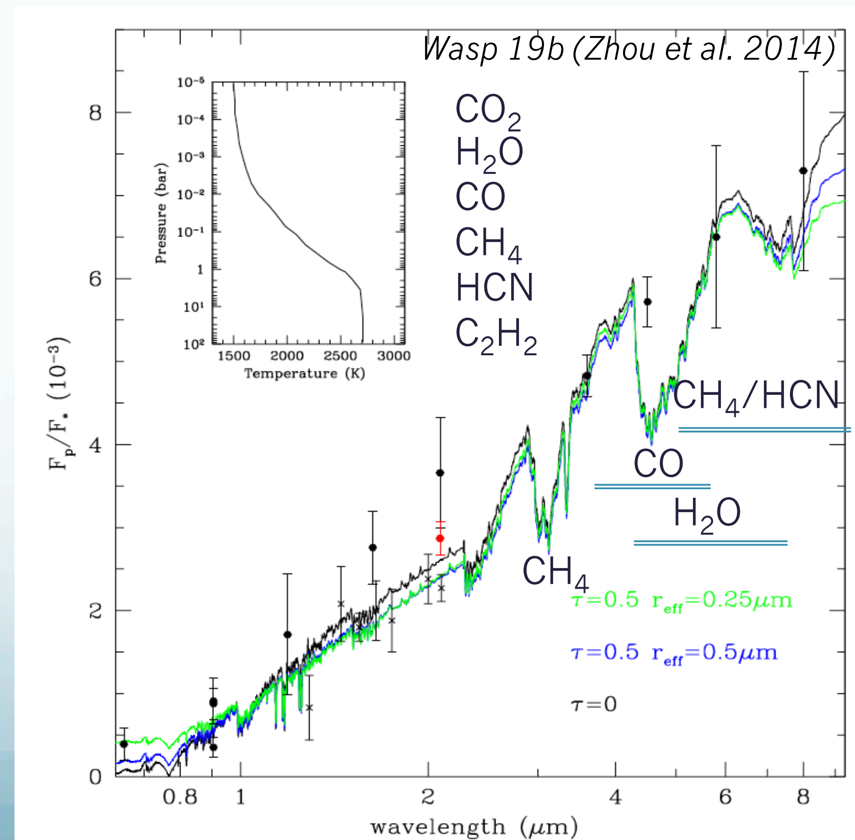


Spitzer observations of eclipses of HD189733b Charbonneau et al.

IR Survey of Eclipses in 30 Hot Jupiters with IRIS2

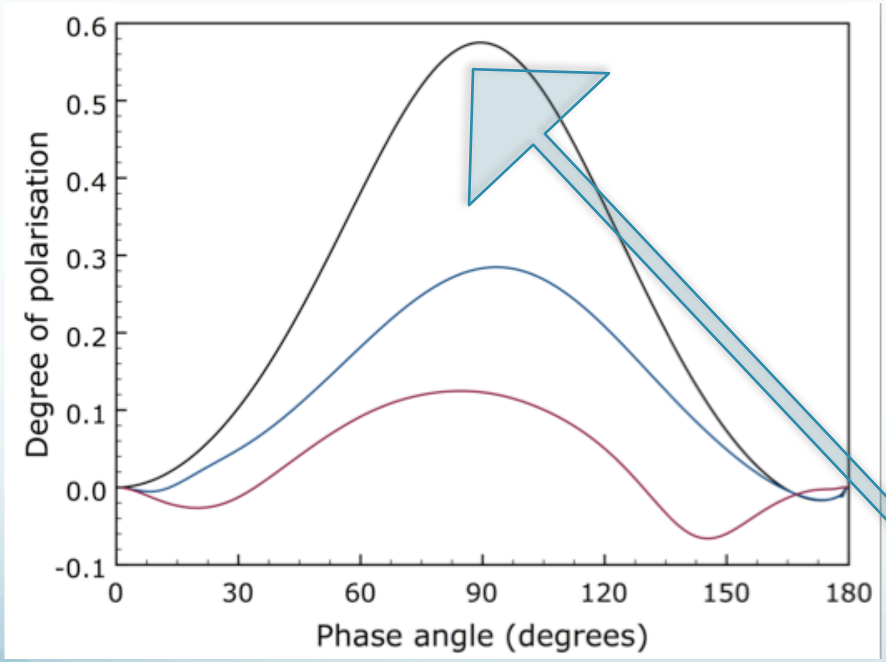
- Broad band measurements at Ks (2.1μm), J (1.2μm) and H (1.6μm)
- Achieved 10^{-3} magnitude precision infrared photometry over typically 5 hours
- To double the number of planets with measured temperature and probe atmospheres of individual sources (when there is good spectral coverage in other bands)
- Exploring the population of hot Jupiters with colour-magnitude diagrams

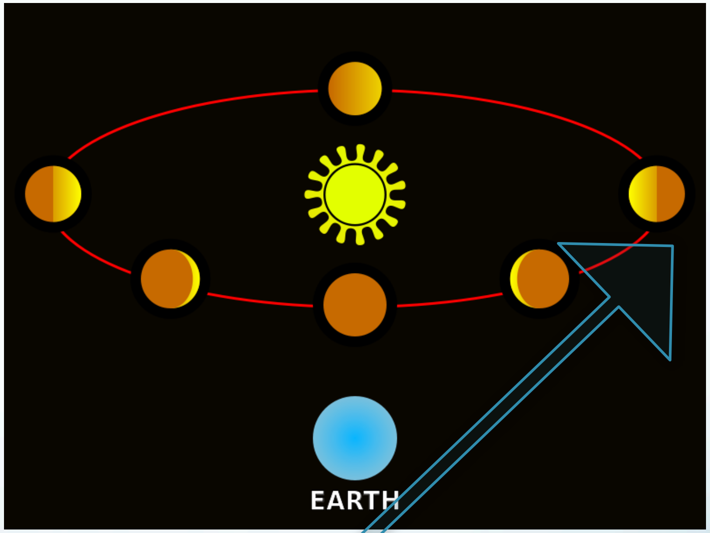




Polarization of exoplanets

- Currently - Detection of Rayleigh scattering by molecules and Mie scattering by larger particles and aerosols (both are polarised)
- Future - Pathway to detection of liquid water:
  - droplets in atmosphere (from rainbow polarization)
  - or on surfaces of oceans (glint)

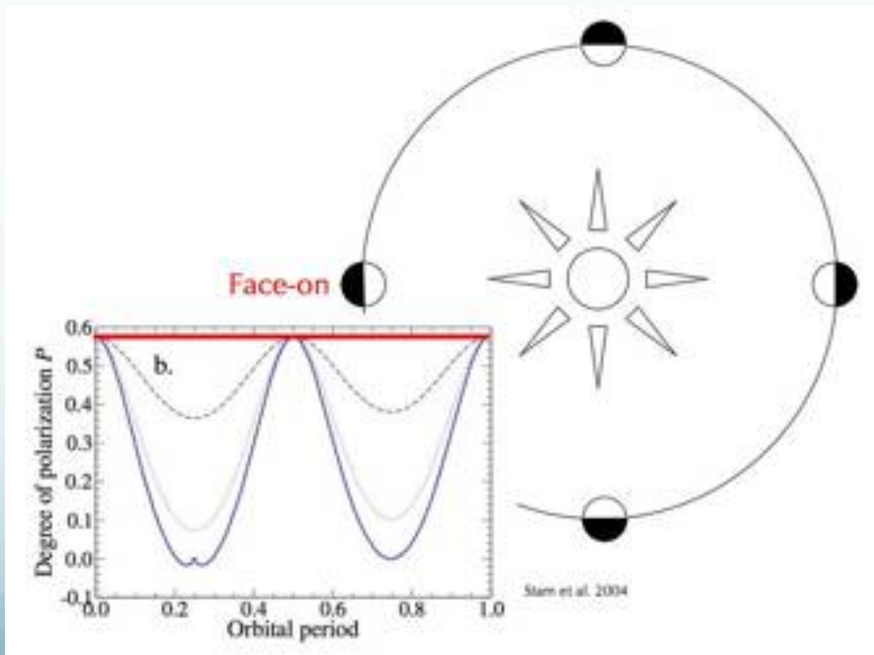


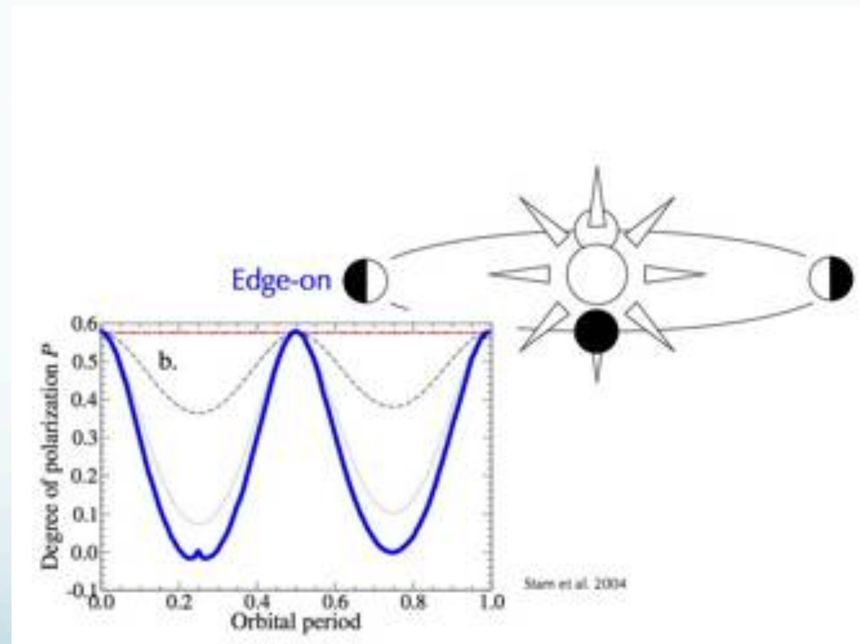


Maximum polarization at phase angle of 90^{o} due to Rayleigh scattering

What else can we learn from polarisation

- Inclination of orbit from variation of polarization and position angle at different orbital phases
- Albedo and radius can be modelled from the peak polarization
- Size and composition of scattering particles modelled from phase of peak polarization.

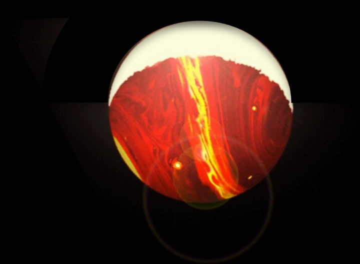




Aperture Polarimetry

Unpolarised

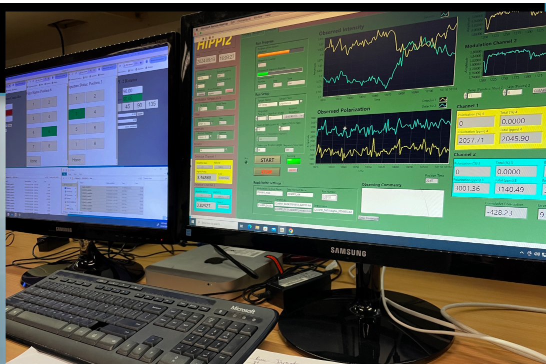
10^{-5} *polarised*



5-50% *polarised*

$F < 10^{-4}\, F_{Star}$

.... Polarization signatures ... are well under the current limits of detectability which is a few x 10^{-4} in fractional polarization" –(Seager et al. 2000).



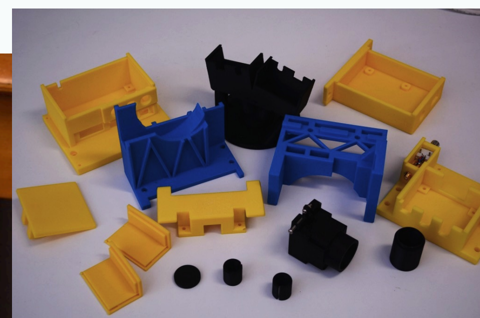
$$P_{max} = f\,(A_g\,,(R_p/a)^2)$$

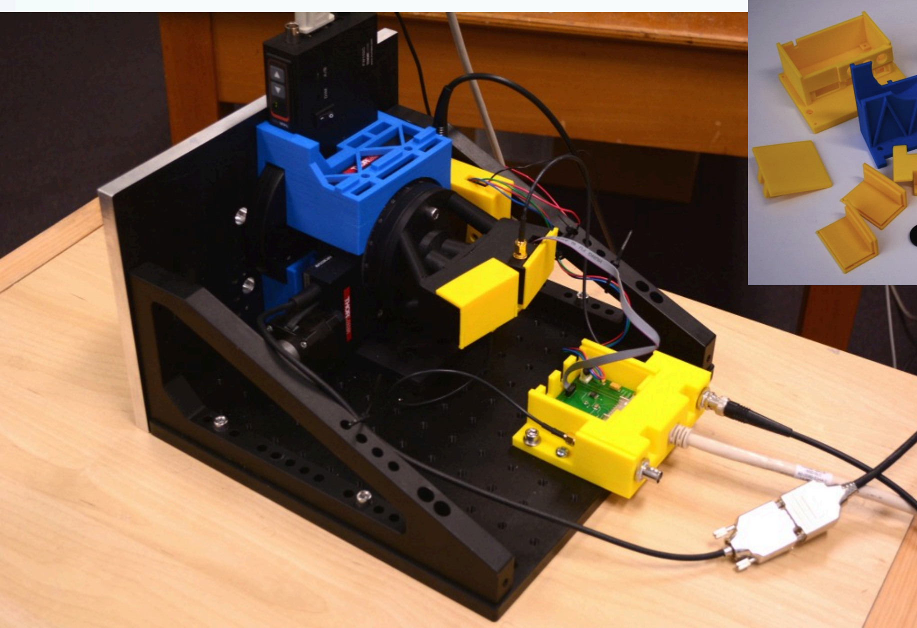
High Precision Polarimetric Instrument (HIPPI)

- Designed to measure **linear polarisation** with maximised sensitivity in blue

Best in the world precision of 4.3 x 10^{-6} (4.3 ppm) in fractional polarization.

- Built locally at UNSW
- Used on the AAT since May 2014
- Easy to transport - Light weight with 3D printed components



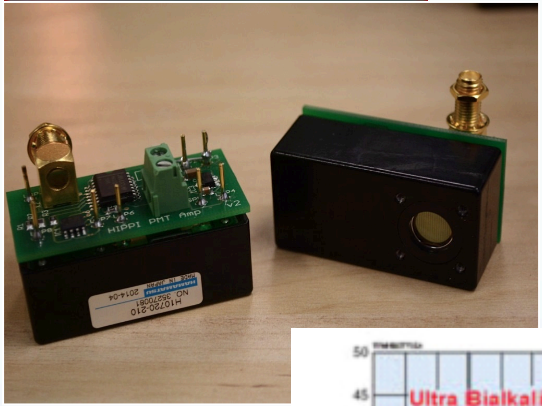


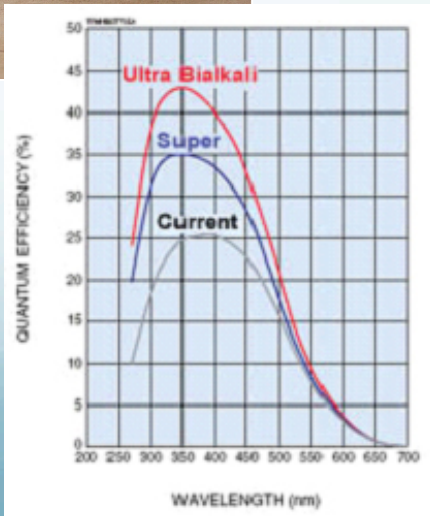
Jeremy Bailey,
Daniel Cotton,
Kim Bott,
Jim Hough,
Phil Lucas

HIPPI - Important design components

Super fast switch of polarisation:
Ferroelectric Liquid Crystal modulator (~500 Hz) allows to minimise systematics due to 'seeing'

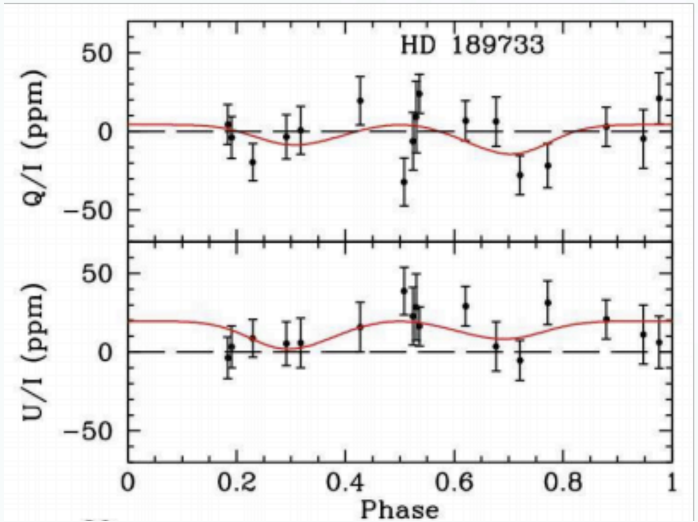
Detectors:
High sensitivity, compact, low noise Ultra-Bialkali Photomultipliers with adjustable gain
Peak Quantum Efficiency (43%) in blue light where the peak polarisation due to Rayleigh scattering expected.

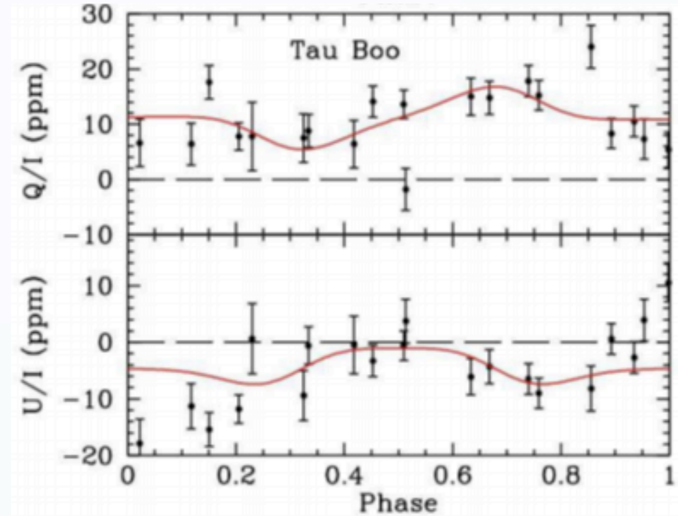


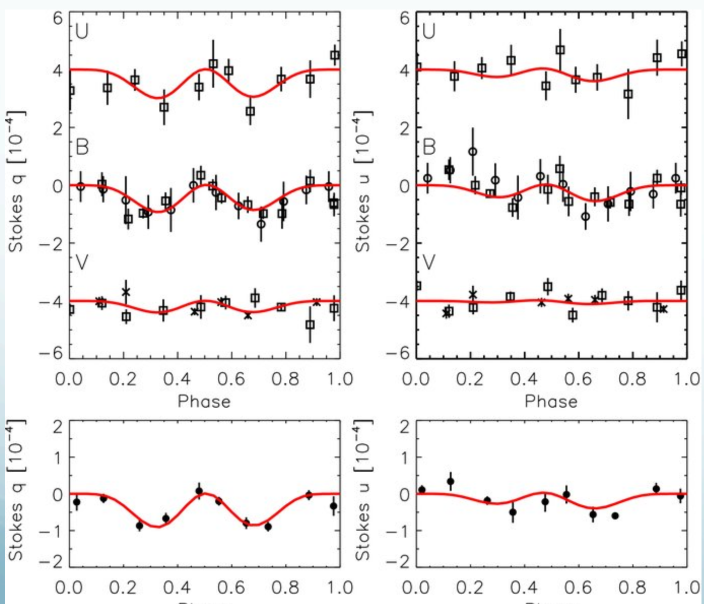


Rotation around optical axis to remove instrumental polarisation: 3-stage modulation for HIPPI and 2-stage for HIPPI-2

HIPPI – Polarimetry of hot Jupiters



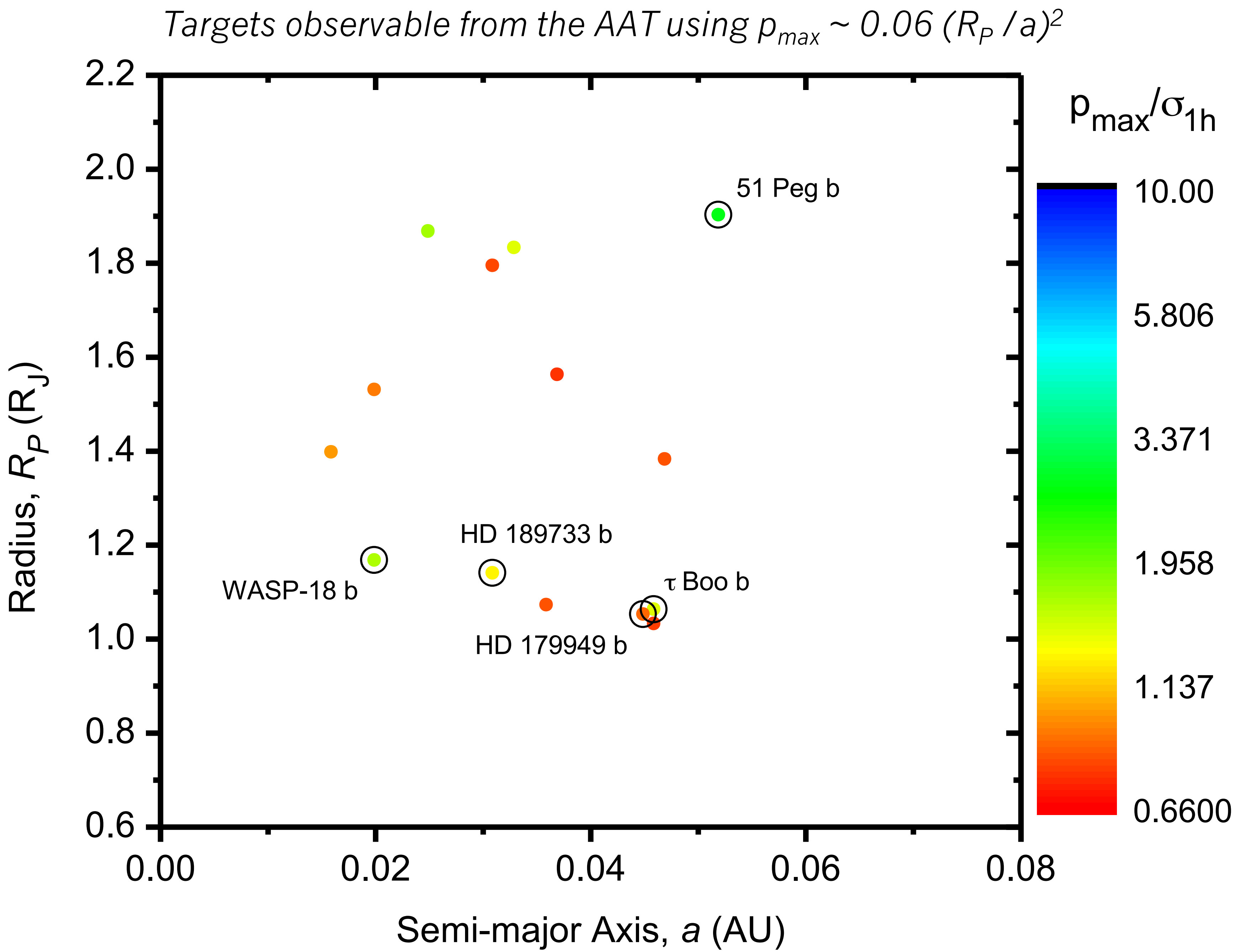




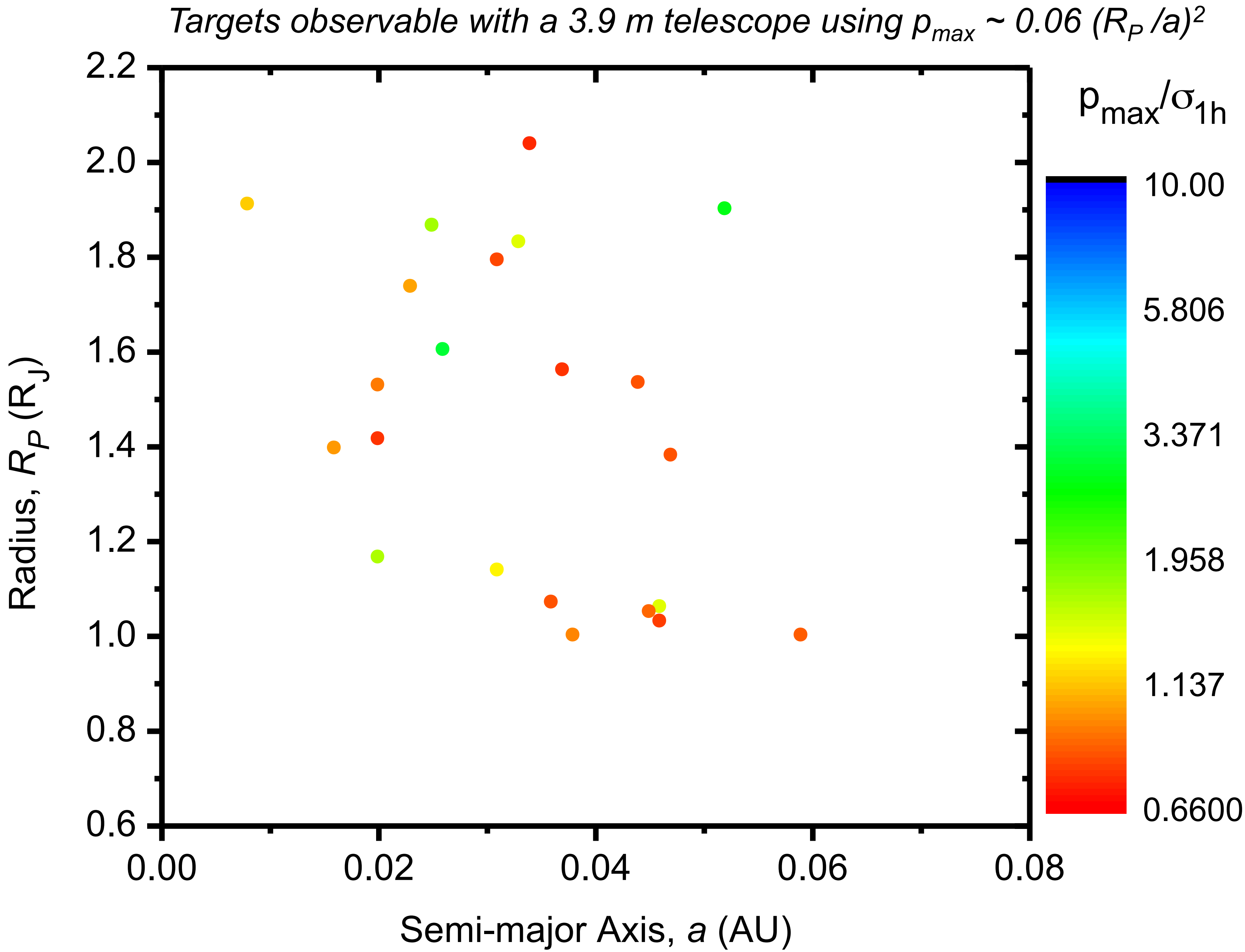
Polarimetry of HD 189733b (Berdyugina et al., 2011)

3-4 times higher than maximum expected from Rayleigh scattering models!!

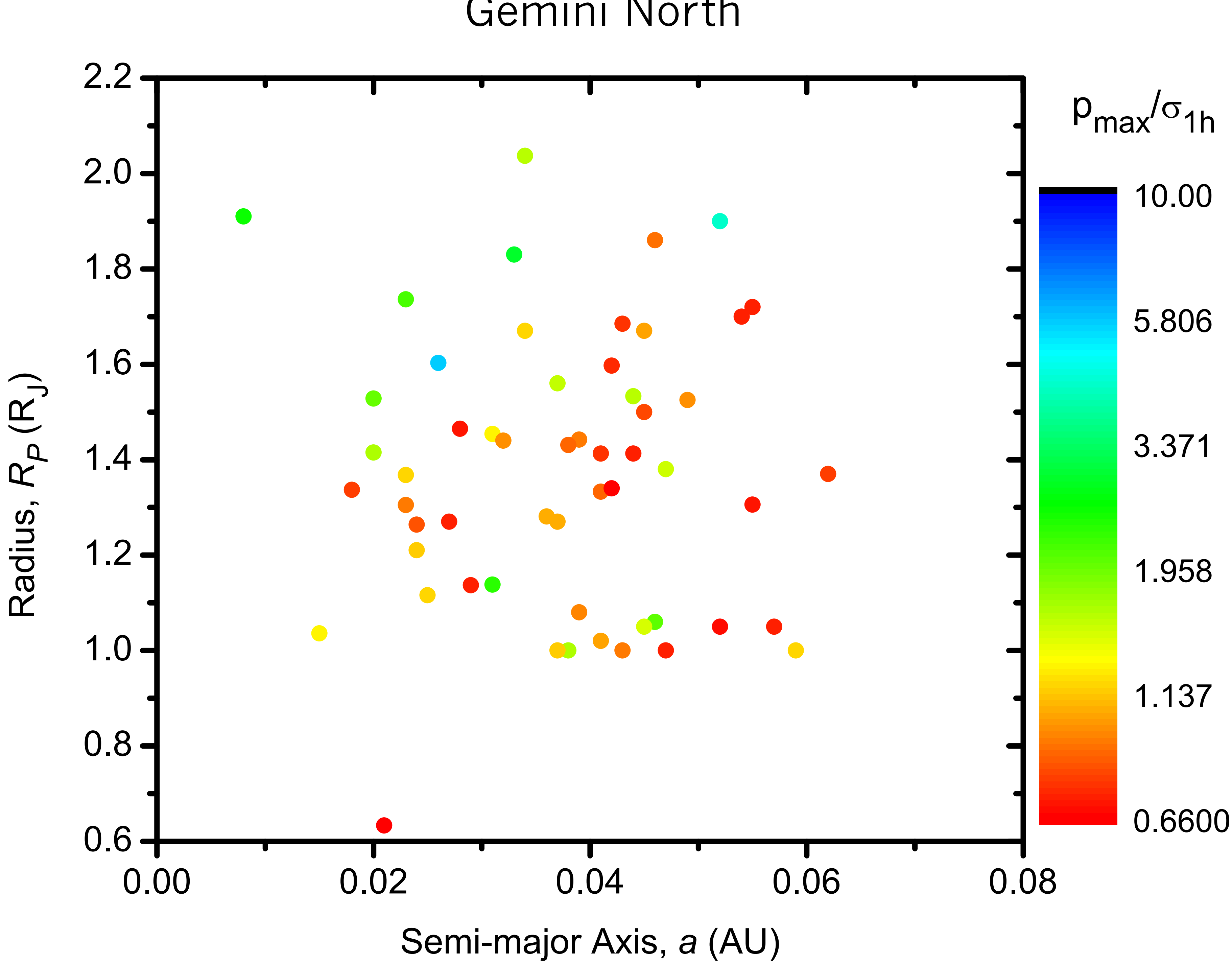
NOT seen in our data, nor that of Wiktorowicz, 2009 and Wiktorowicz et al., 2015



Targets observable from the AAT using $p_{max} \sim 0.06\,(R_P\,/\,a)^2$
Radius, R_P (R_J)
Semi-major Axis, a (AU)
p_{max}/σ_{1h}
51 Peg b
HD 189733 b
WASP-18 b
τ Boo b
HD 179949 b
10.00
5.806
3.371
1.958
1.137
0.6600
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.00
0.02
0.04
0.06
0.08



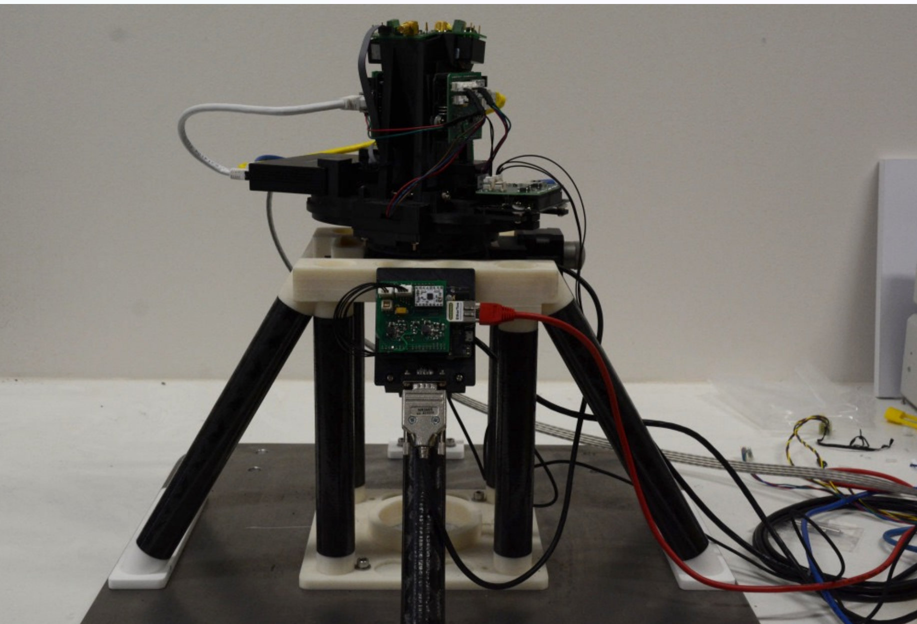
Targets observable with a 3.9 m telescope using p_{max} ~ 0.06 $(R_P/a)^2$
Radius, R_P (R_J)
Semi-major Axis, a (AU)
p_{max}/σ_{1h}
10.00
5.806
3.371
1.958
1.137
0.6600
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.00
0.02
0.04
0.06
0.08

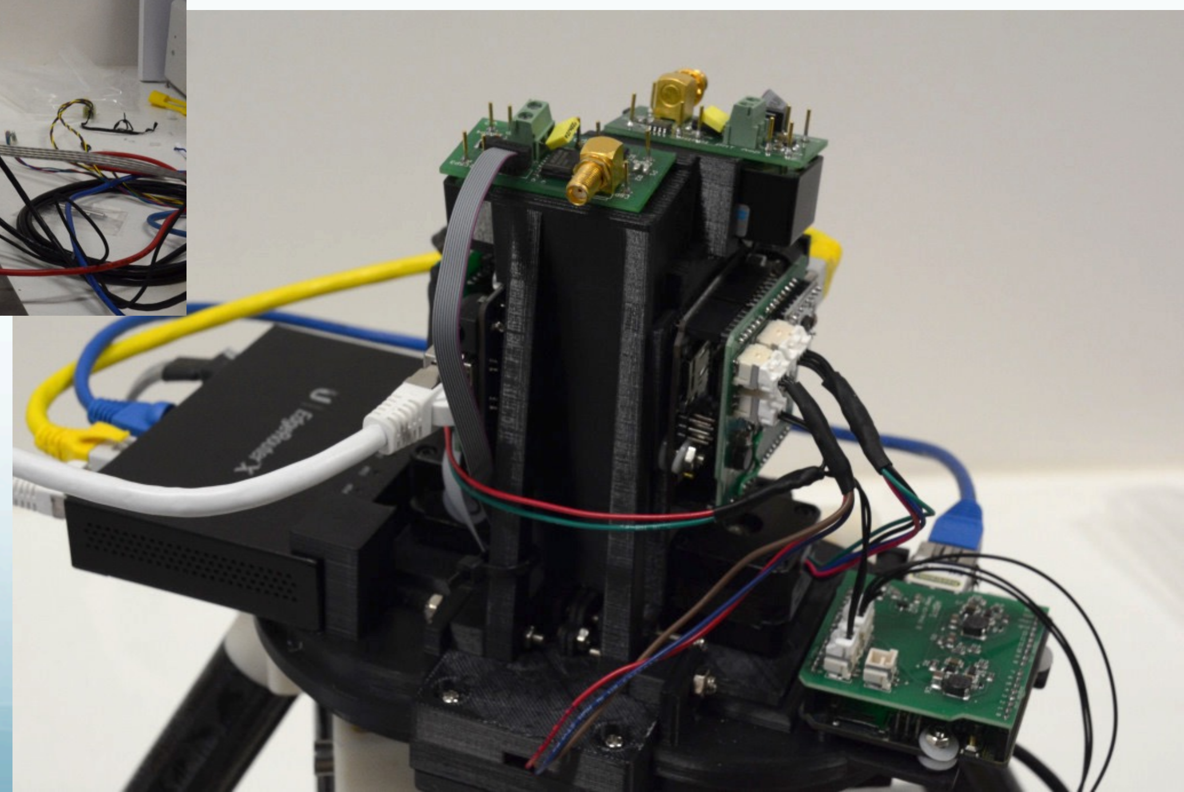


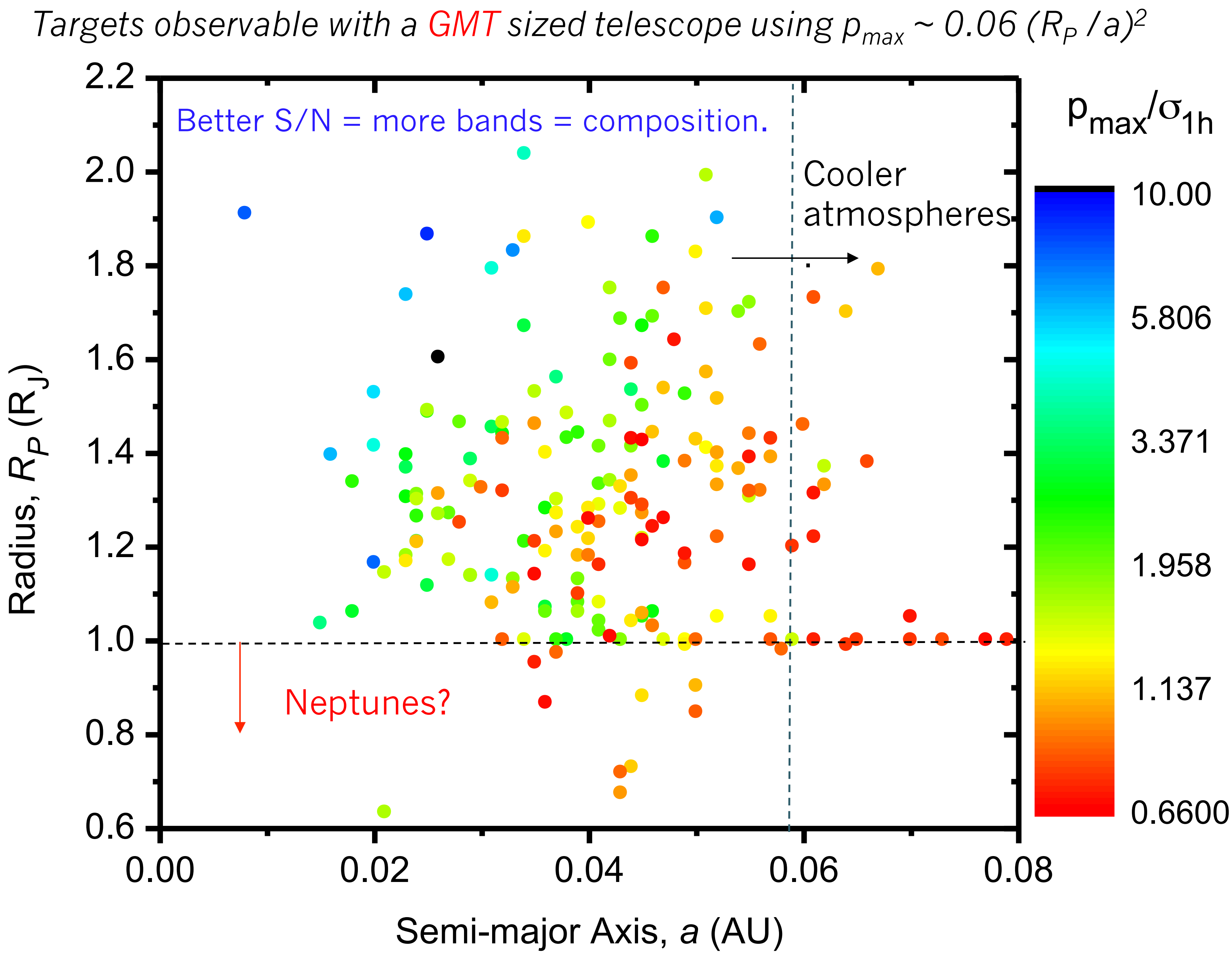
Gemini North
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
Radius, R_P (R_J)
0.00
0.02
0.04
0.06
0.08
Semi-major Axis, a (AU)
p_{max}/σ_{1h}
10.00
5.806
3.371
1.958
1.137
0.6600

HIPPI2 at Gemini North 8m telescope

Lightweight carbon fibre support structure-
“Internet of Things” control architecture

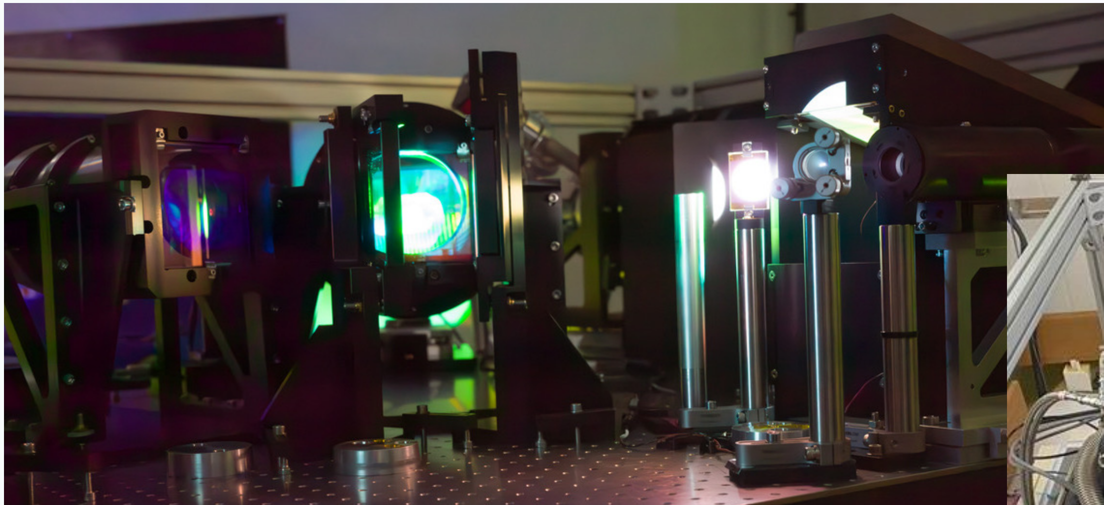


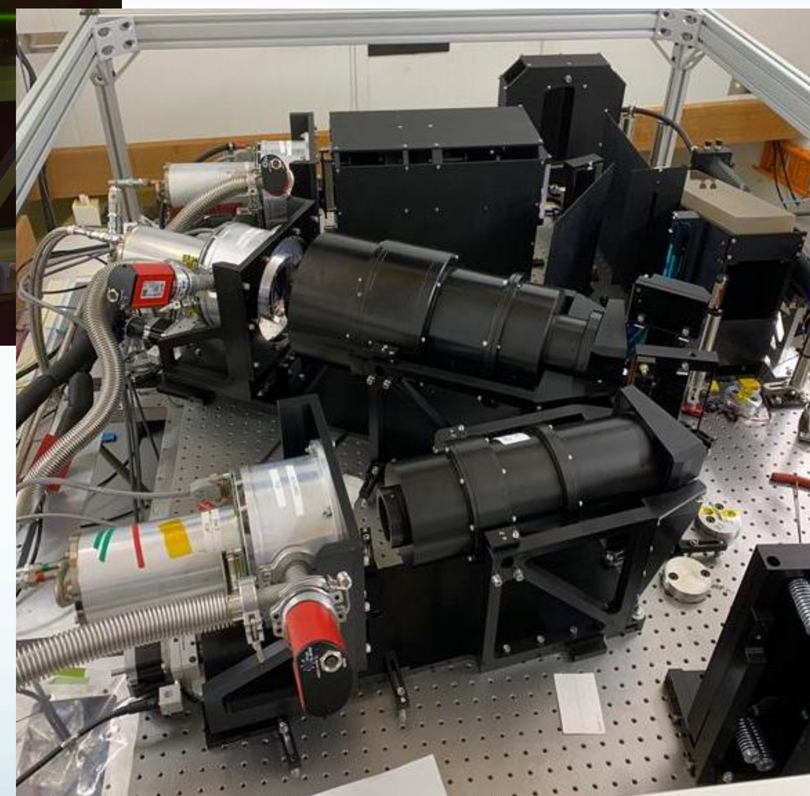




Targets observable with a GMT sized telescope using $p_{max} \sim 0.06\ (R_P / a)^2$
Better S/N = more bands = composition.
Cooler atmospheres
Neptunes?
p_{max}/σ_{1h}
10.00
5.806
3.371
1.958
1.137
0.6600
Radius, R_P (R_J)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.00
0.02
0.04
0.06
0.08
Semi-major Axis, a (AU)

Story of exoplanets on AAT is not finished…





- Upgraded Veloce echelle spectrograph: ~390-930nm at R~80,000
- Three cameras : Azzurro, Verde and Rosso
- Measure Doppler velocities for Sun-like and M-dwarf stars at sub-m/s precision.
- Derive masses of rocky exoplanets
- Cross-correlation techniques to detect molecular absorbers in planetary transit spectra