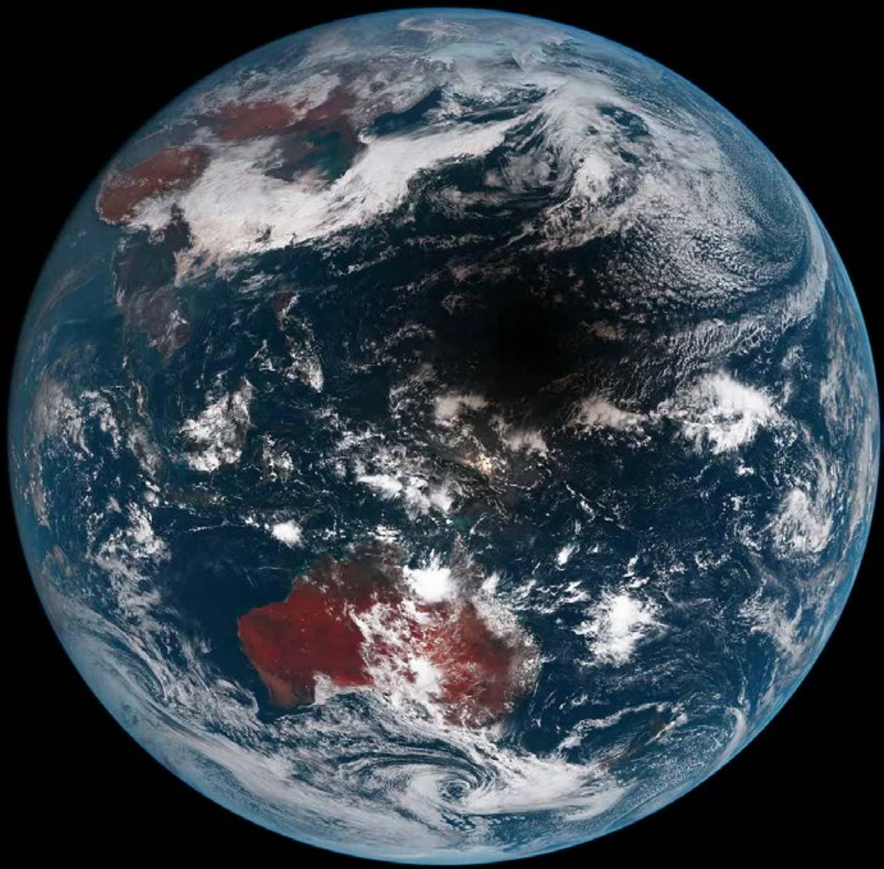
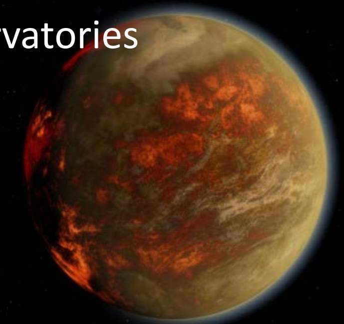
Sniffing Alien Atmospheres

Exoplanet Spectrophotometry from Ground-, Airborne- and Space-based Observatories





Credit: NICT

@dan_anger

Dr. Daniel Angerhausen

(CSH, Uni Bern)

SOFIA tele talk

31/1/2018

My journey

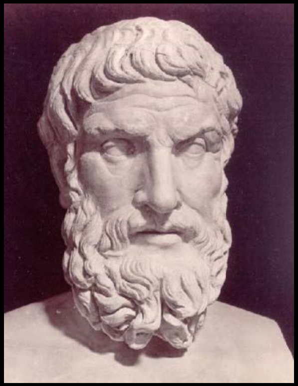
Currently:
Center for Space and Habitability Fellow at Bern University
Founder and Executive Director `explainables.org` Science Communication

-University Cologne (Diploma)
-Caltech/ NASA-JPL (DAAD fellow)
-German SOFIA Institute (Phd)

-Hamburg Observatory (1 y PD)
-RPI, NY NAI Center for Astrobiology (2y PD)
-NASA postdoctoral program (2 y)

Exoplanets: A very old question

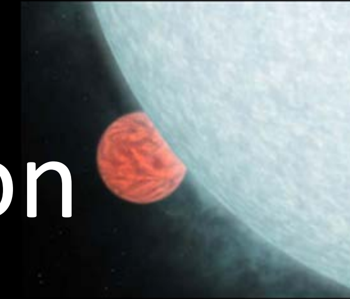
Epicurus (341-270 BC):
"...there are infinite worlds both like and unlike this world of ours."



Giordano Bruno (1584):
"...there are countless suns and countless earths all rotating around their suns."

Isaac Newton (1713): "And if the fixed stars are the centers of similar systems, they will all be constructed according to a similar design ..."

Exoplanets: A very old question



Move over, Tatooine! Amateurs discover planet with four suns

By **Ed Payne**, CNN
updated 6:10 PM EDT, Tue October 16, 2012

'Saturn on Steroids': 1st Ringed Planet Beyond Solar System Possibly Found

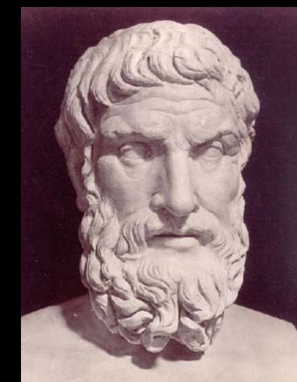
by Charles Q. Choi, Space.com Contributor | January 12, 2012 07:47am ET

Is the Nearest Alien Planet Proxima b Habitable? 'It's Complicated'

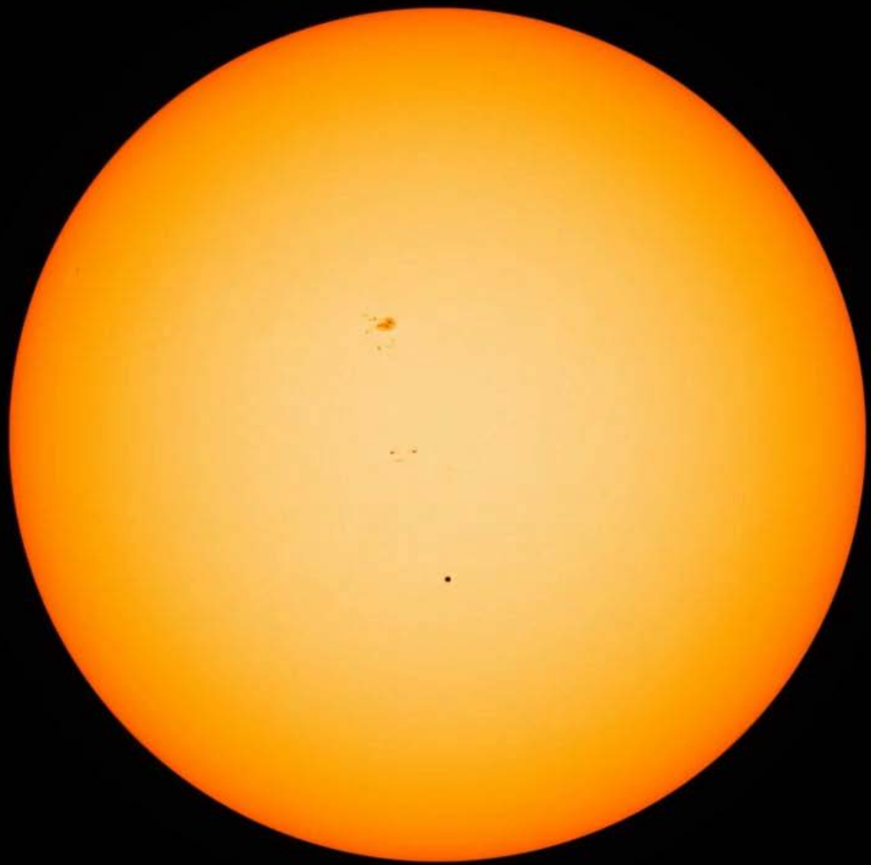
By Jesse Emspak, Space.com Contributor | August 31, 2016 01:27pm ET

Population of Known Alien Planets Nearly Doubles as NASA Discovers 715 New Worlds

By Mike Wall, Senior Writer | February 26, 2014 01:01pm ET



Why is it so difficult?

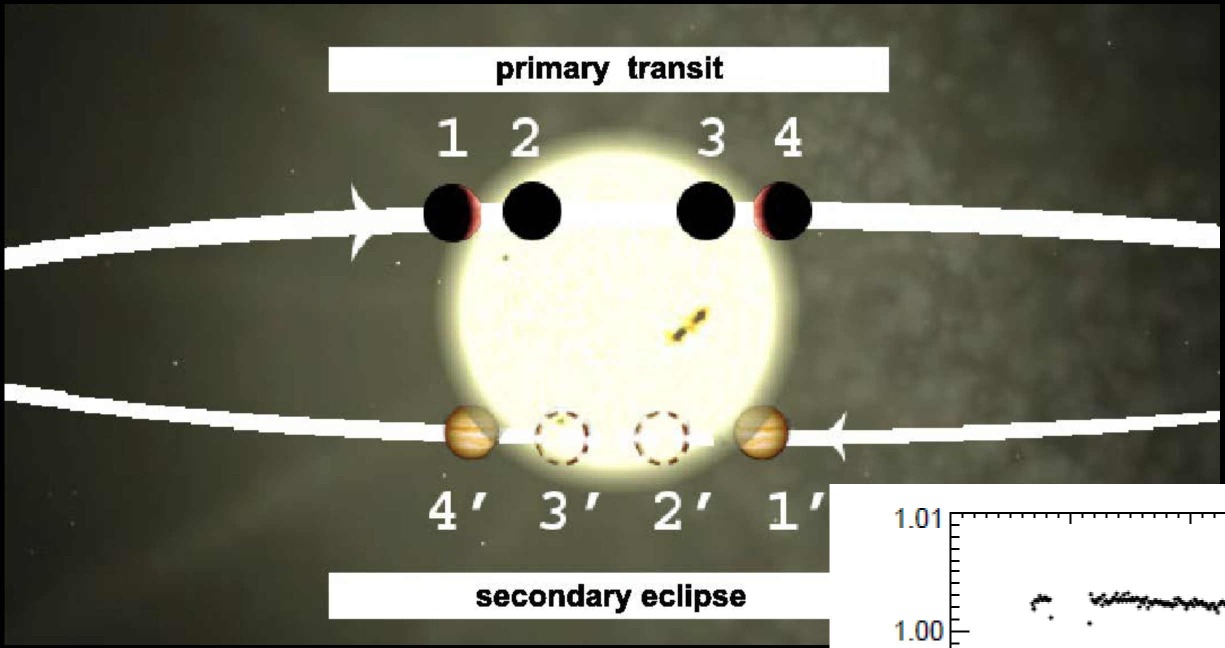


Stars are
larger
brighter
than planets

>>> indirect methods or methods that cancel out the stellar contribution

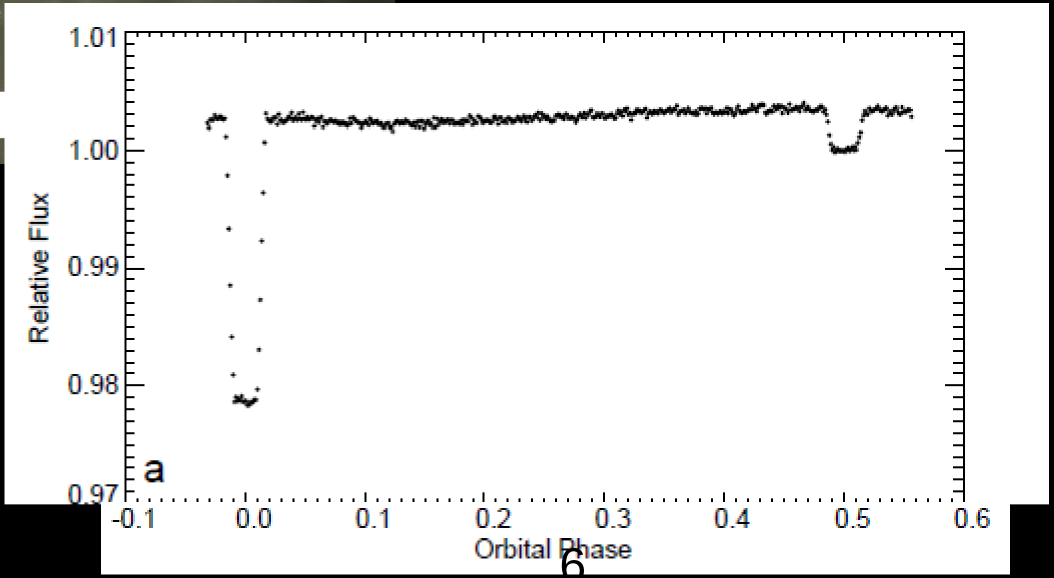
Credit: NASA Heliophysics

Differential photometry

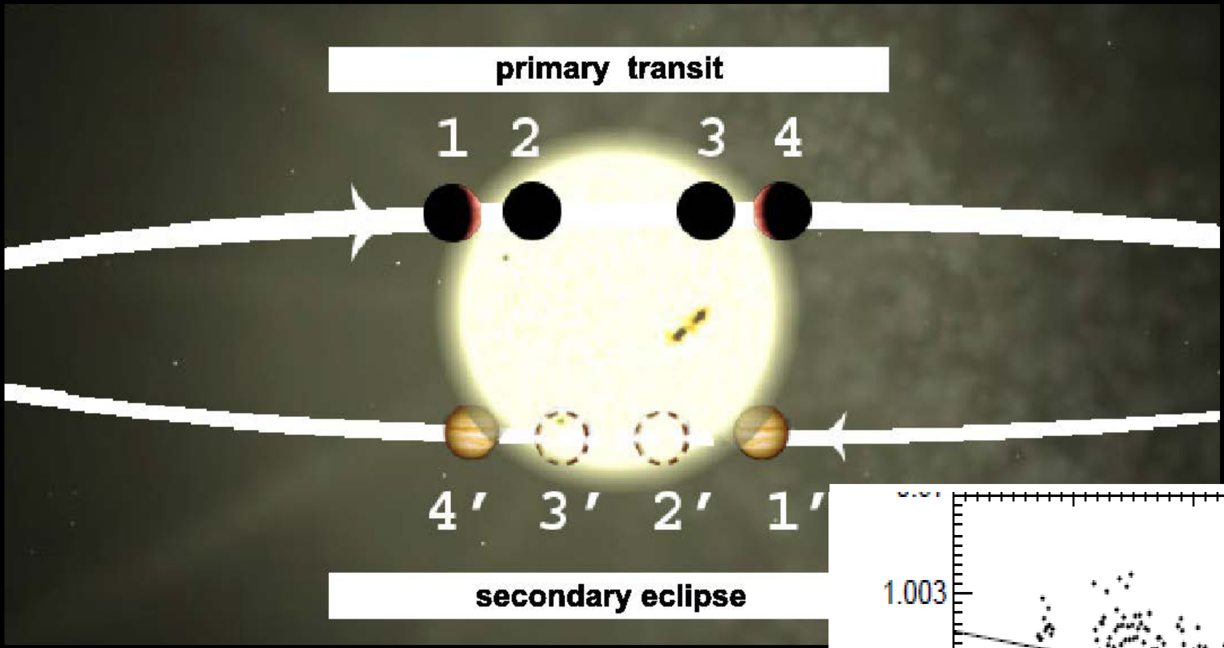


Differences between observations in and out of occultation reveal information about the planet

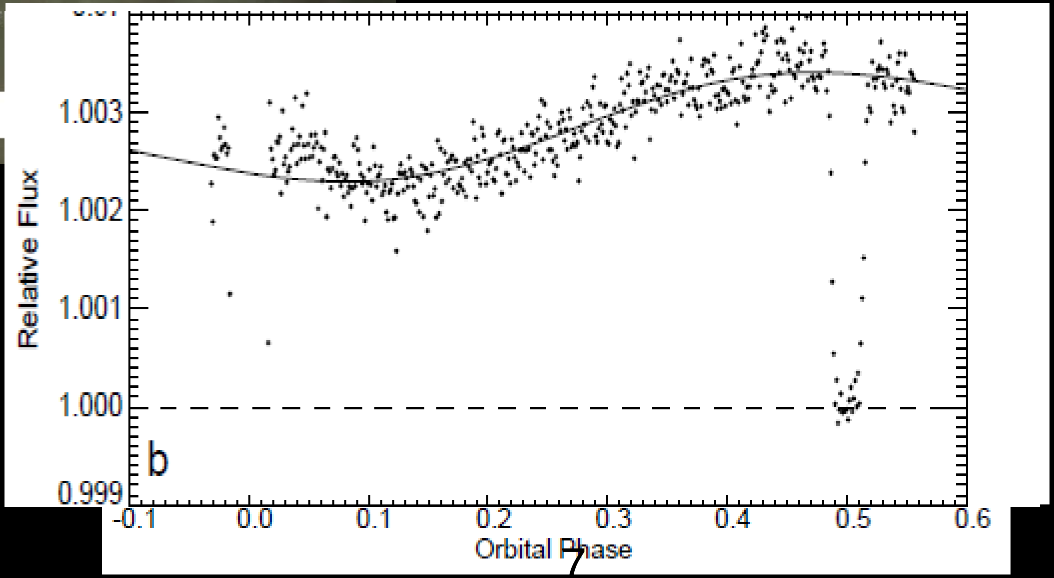
Example: half-orbit lightcurve of HD189733b at 8 micron with Spitzer (Knutson et al. 2007)



Differential photometry



Differences between observations in and out of occultation reveal information about the planet



Example: half-orbit lightcurve of HD189733b at 8 micron with Spitzer (Knutson et al. 2007)

Space-based: *Kepler*

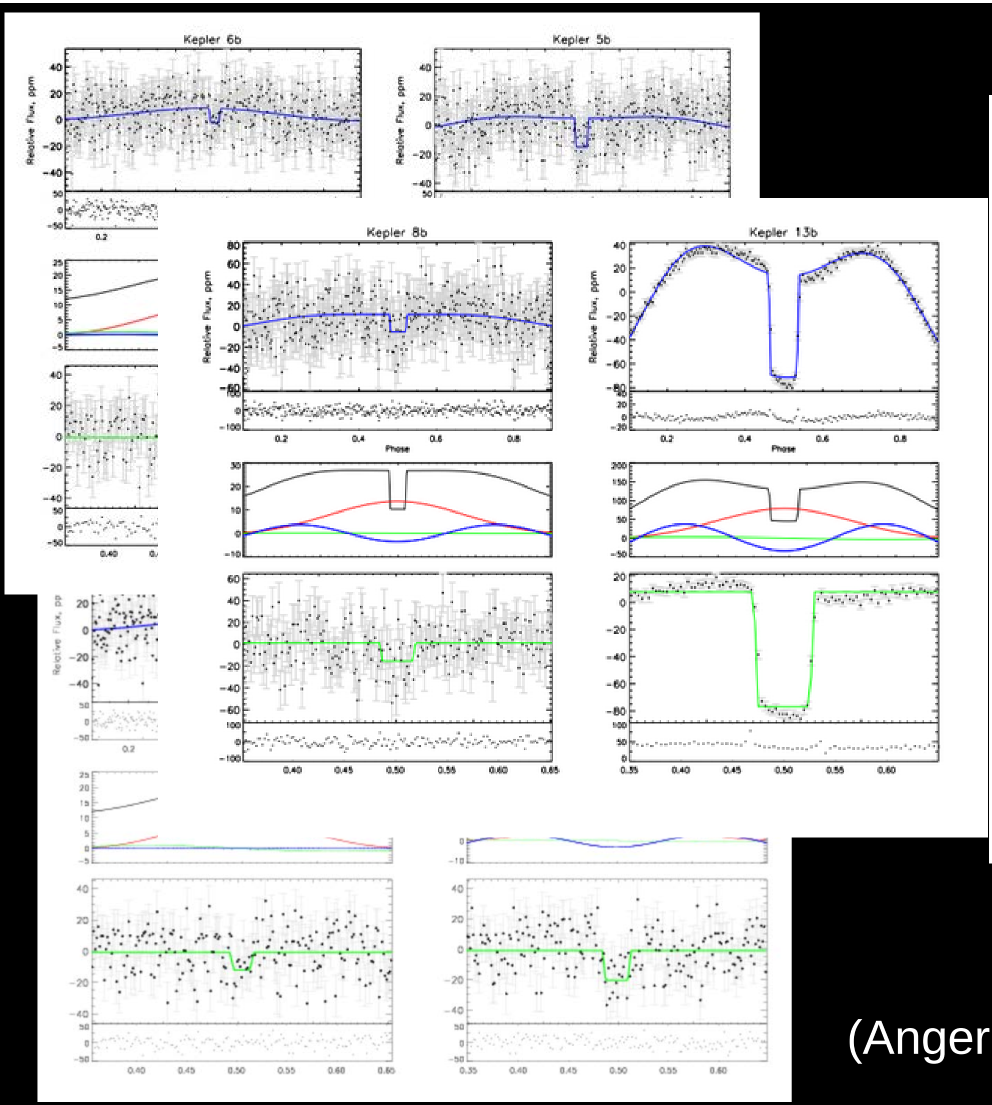
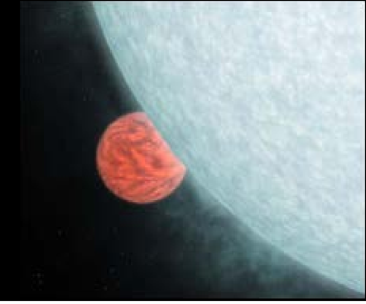


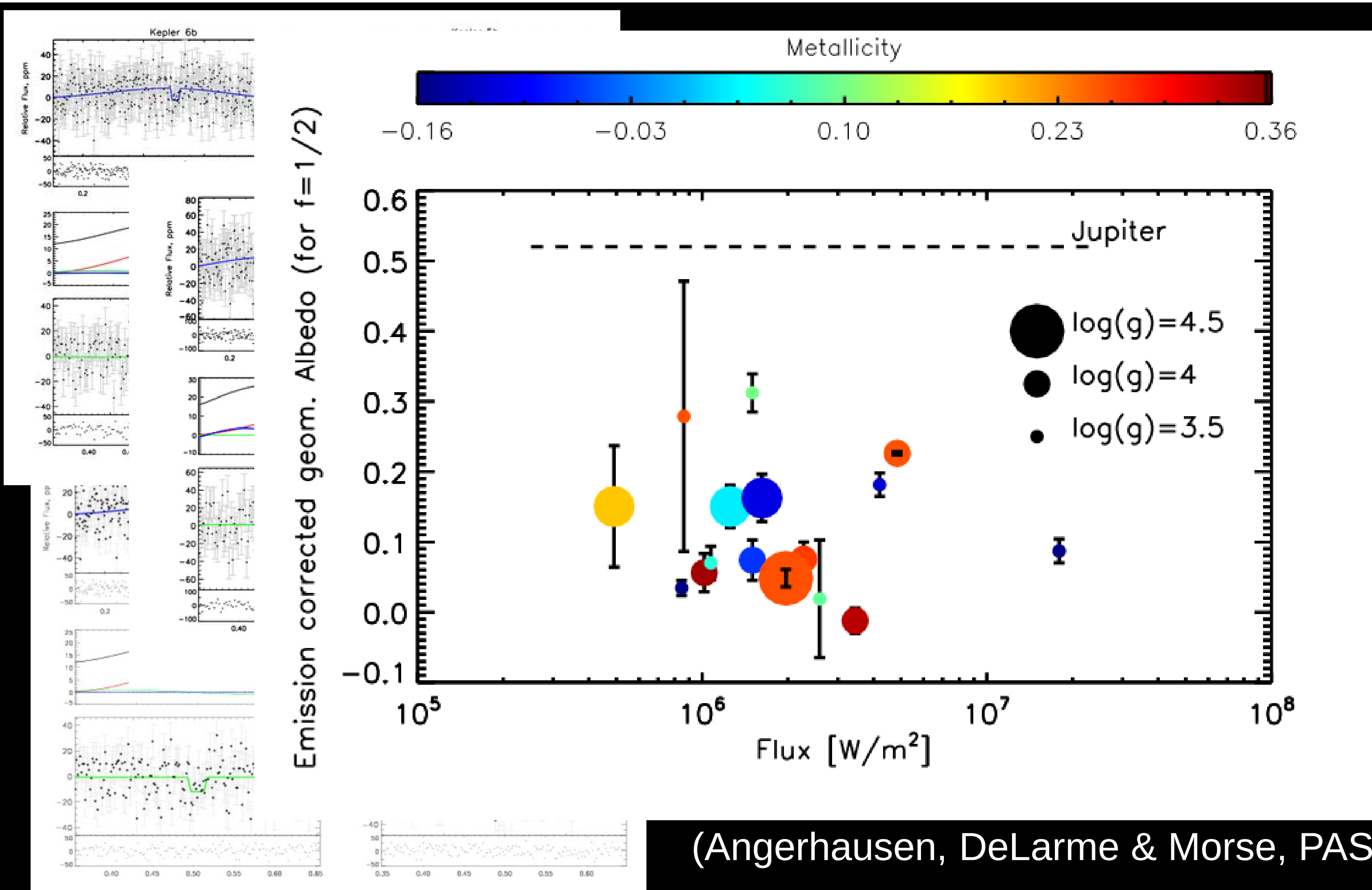
Table 5
Derived brightness temperatures (T_b), geometric and bond albedos (A_g,A_b), equilibrium temperatures T_{eq} for $f = \frac{1}{4}$ and $\frac{2}{3}$ and night-side temperature T_{night}

KOI	T_b	A_g	A_b	$T^{eq}_{1/4}$	$T^{eq}_{2/3}$	T_{night}
1	1901^{+27}_{-31}	0.05± 0.01	0.08± 0.02	1363	1742	1885.00
2	2897^{+3}_{-4}	0.27 0± 0. 0	0.4± 0. 0	1892	2418	2235.00
3	1382^{+0}_{-0}	0.01± 0. 0	0.01± 0. 0	825	1054	0. 0
7	1713^{+562}_{-1614}	0.01± 0.11	0.01± 0.16	1624	2075	0. 0
10	2241^{+61}_{-77}	0.11 0± 0.03	0.16 0± 0.04	1536	1963	1859.00
17	2060^{+70}_{-95}	0.07± 0.03	0.11 0± 0.04	1413	1806	1719.00
18	2305^{+46}_{-52}	0.16 0± 0.03	0.25 0± 0.05	1429	1826	2169.00
20	2121^{+54}_{-67}	0.09± 0.02	0.14 0± 0.04	1422	1817	1711.00
97	2547^{+26}_{-28}	0.32 0± 0.03	0.48 0± 0.04	1364	1743	0. 0
98	2146^{+96}_{-148}	0.06± 0.03	0.09± 0.04	1634	2089	2139.00
128	1861^{+177}_{-1762}	0.05± 0.07	0.07± 0.11	1234	1577	1857.00
135	2296^{+73}_{-95}	0.06± 0.02	0.09± 0.03	1930	2467	0. 0
137	1948^{+831}_{-1849}	0.24 0± 5.	0.35 0± 7.5	854	1092	1938.00
196	2395^{+50}_{-58}	0.18 0± 0.03	0.27 0± 0.05	1513	1933	0. 0
203	2247^{+35}_{-40}	0.08± 0.01	0.13 0± 0.02	1660	2121	2229.00
204	2348^{+149}_{-279}	0.28 0± 0.19	0.42 0± 0.29	1217	1555	2347.00
428	2331^{+193}_{-626}	0.09± 0.08	0.13 0± 0.13	1774	2267	2327.00

(Angerhausen, DeLarme & Morse, PASP, 2015)

Space-based: *Kepler*

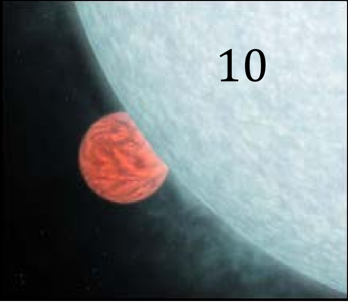




dos (A_g,A_b),
temperature

eq 2/3	T_{night}
742	1885.00
118	2235.00
054	0. 0
075	0. 0
063	1859.00
306	1719.00
326	2169.00
317	1711.00
743	0. 0
089	2139.00
577	1857.00
467	0. 0
092	1938.00
033	0. 0
121	2229.00
555	2347.00
267	2327.00

(Angerhausen, DeLarme & Morse, PASP, 2015)



Space-based: *Kepler*

-collaboration with
SUNY Albany
(Ben Placek, now: WIT)

-bayesian phase curve
modelling & retrieval code
EXONEST

The Astrophysical Journal, 795:112 (15pp), 2014 November 10 doi:10.1088/0004-637X/795/2/112

EXONEST: BAYESIAN MODEL SELECTION APPLIED TO THE DETECTION AND CHARACTERIZATION OF EXOPLANETS VIA PHOTOMETRIC VARIATIONS

Ben Placek[1], Kevin H. Knuth[1,3], and Daniel Angerhausen[2]
[1] Physics Department, University at Albany (SUNY), Albany, NY 12222, USA; bplacek@albany.edu, kknuth@albany.edu
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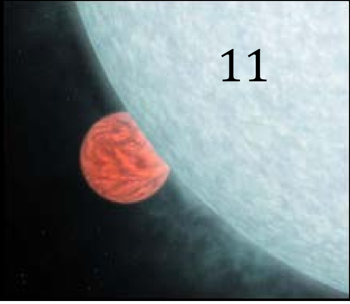
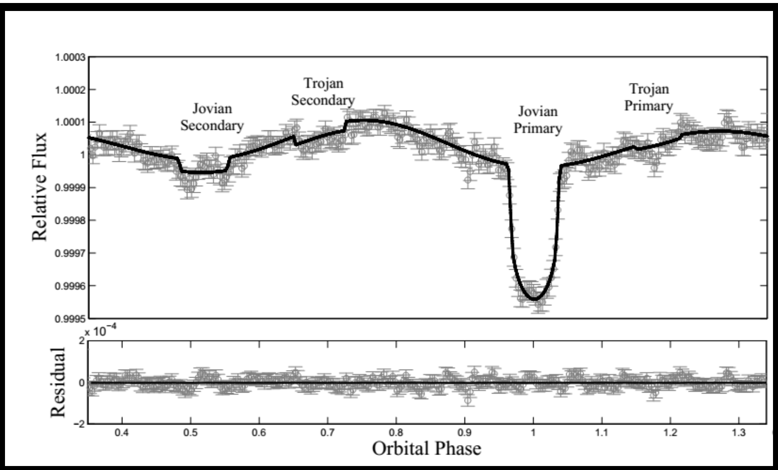
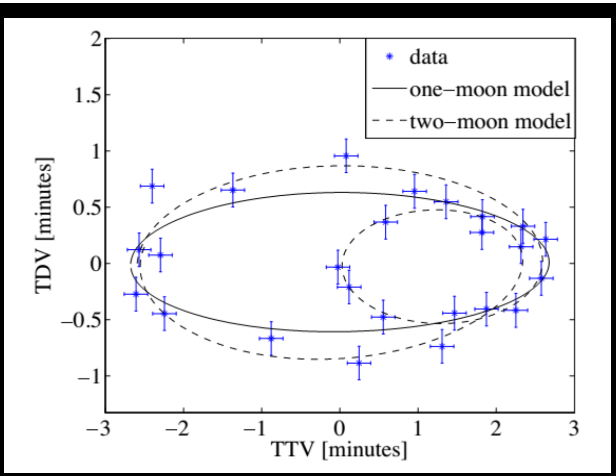
Received 2013 October 24; accepted 2014 August 13; published 2014 October 20

EXONEST

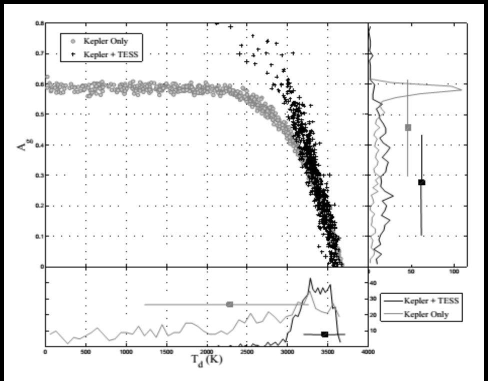




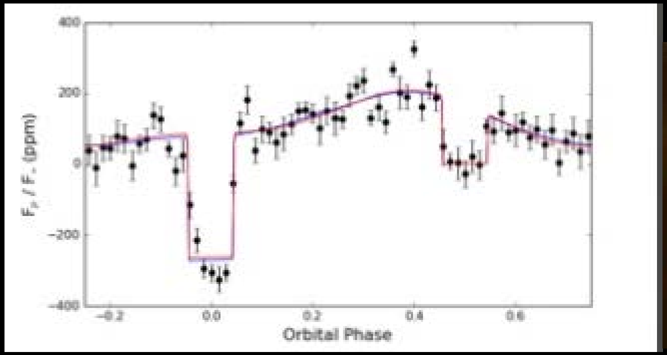
Kepler-91b; Placek, Knuth & Angerhausen, ApJ, 2015b



Exo-moons; Heller et al., A&A, 2016

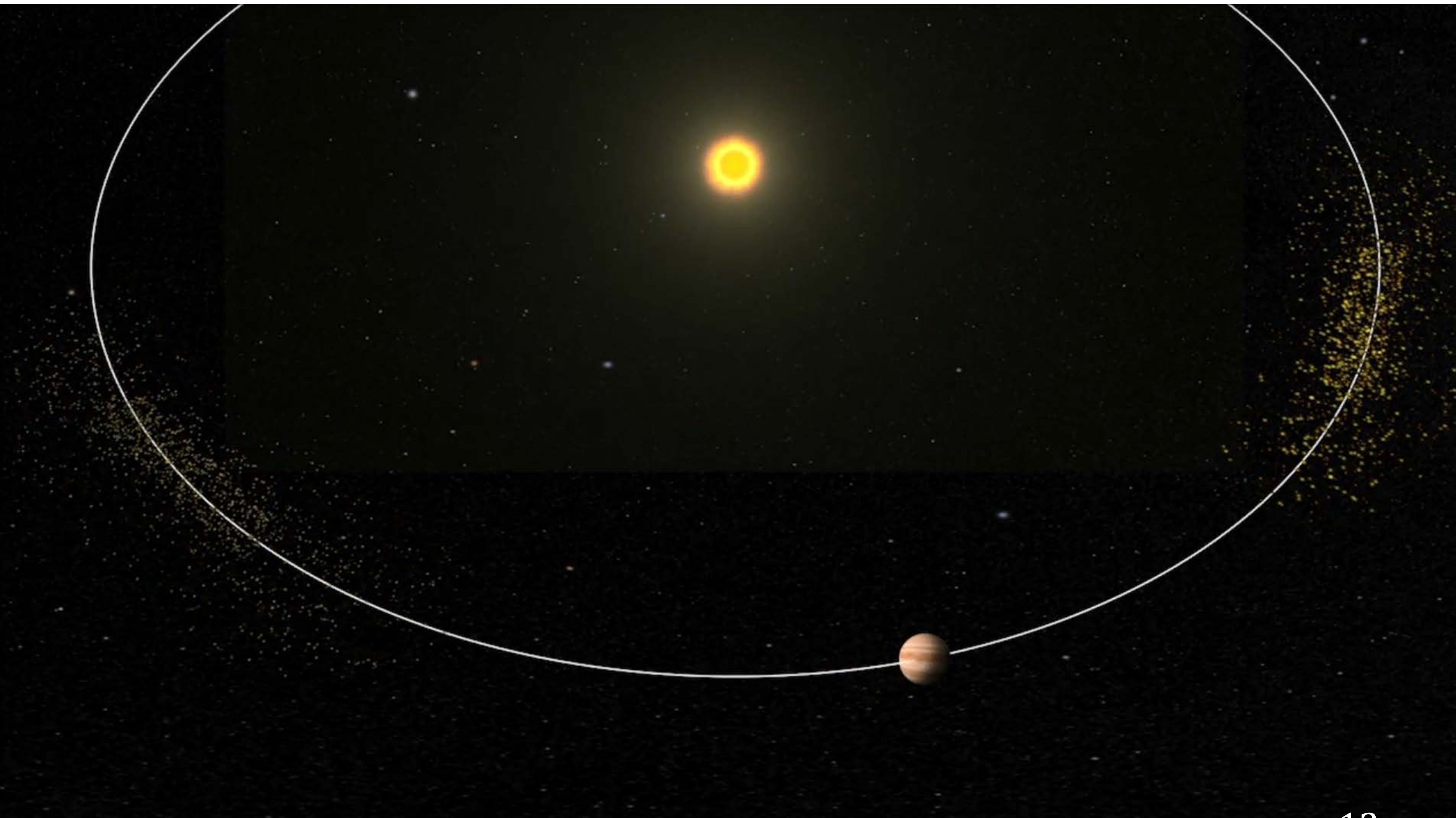


TESS + Kepler; Placek, Knuth & Angerhausen, ApJ, 2016

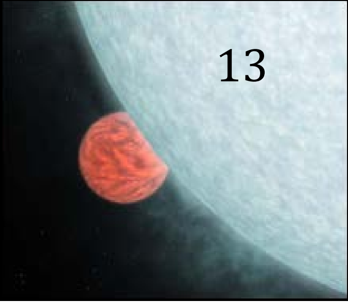


'Beachball' mapping; Chontos, Angerhausen & Placek, in prep

Statistical evidence for 'Exo-Trojans'

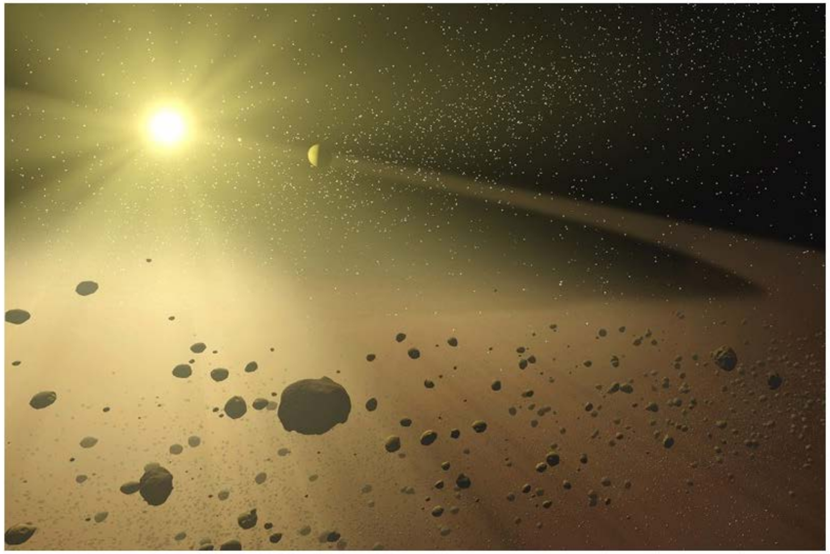


Hippke & Angerhausen, ApJ, 2015



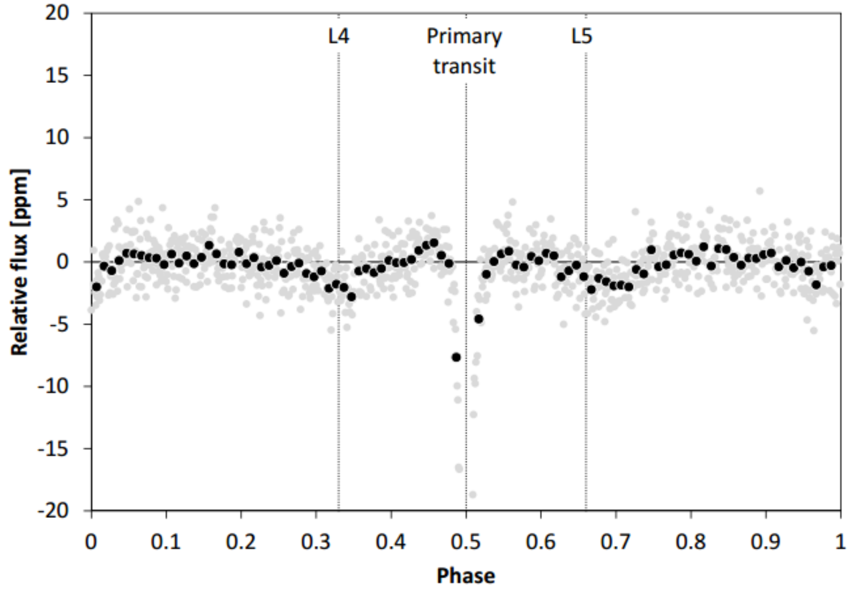
Space-based: *Kepler*

Kepler sees hints of asteroids pursuing planets near other stars



(Image: NASA/JPL-Caltech/T. Pyle (SSC)) New Scientist

-First evidence for "Exo-Trojans"
(Hippke & Angerhausen, ApJ, 2015)



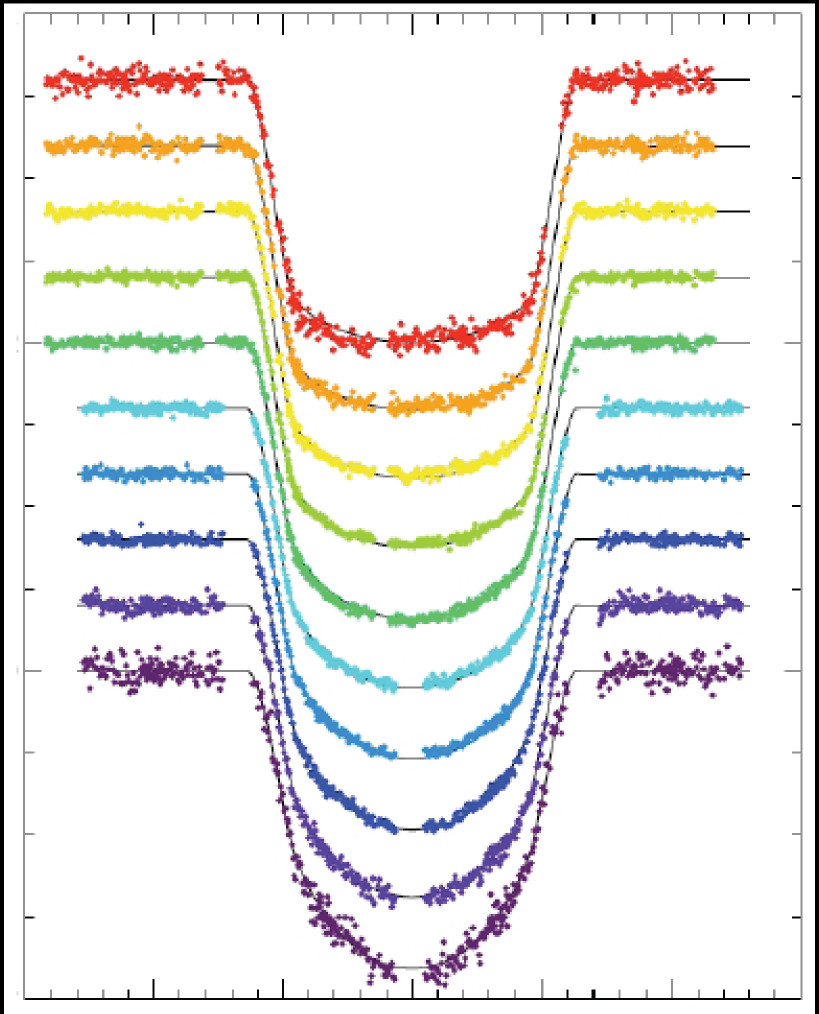
A STATISTICAL SEARCH FOR A POPULATION OF EXO-TROJANS IN THE KEPLER DATASET

MICHAEL HIPPKE
Luiter Straße 21b, 47506 Neukirchen-Vluyn, Germany

DANIEL ANGERHAUSEN
NASA Postdoctoral Program Fellow, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

Draft version August 4, 2015

(NIR-) Spectrophotometry



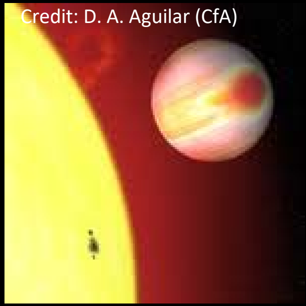
(Knutson 2008)

Primary transit:

Probing terminator

Broadband depth: ~ 1 %

Spectral features: ~ 10^{-4}



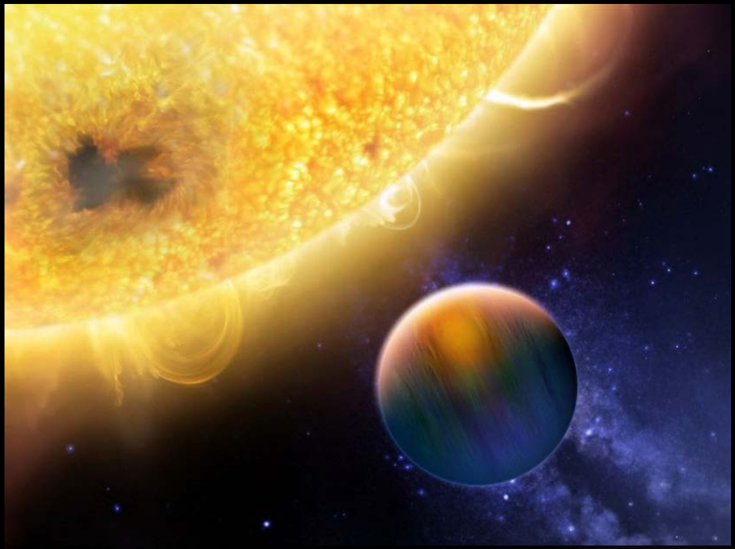
Secondary eclipse:

Probing dayside

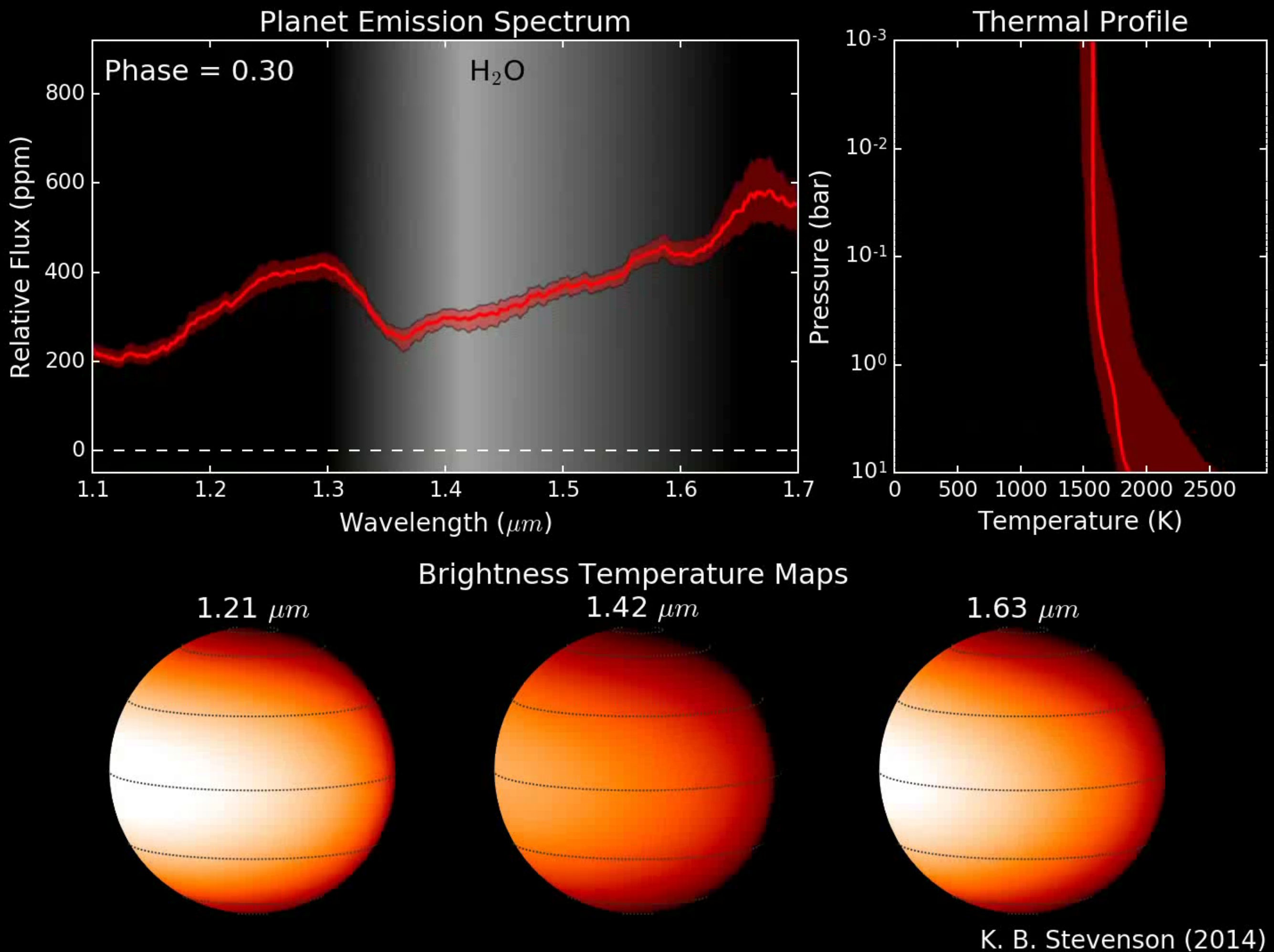
Broadband depth: ~ 0.1 %

Spectral features: ~ 10^{-4}

Hot Jupiters



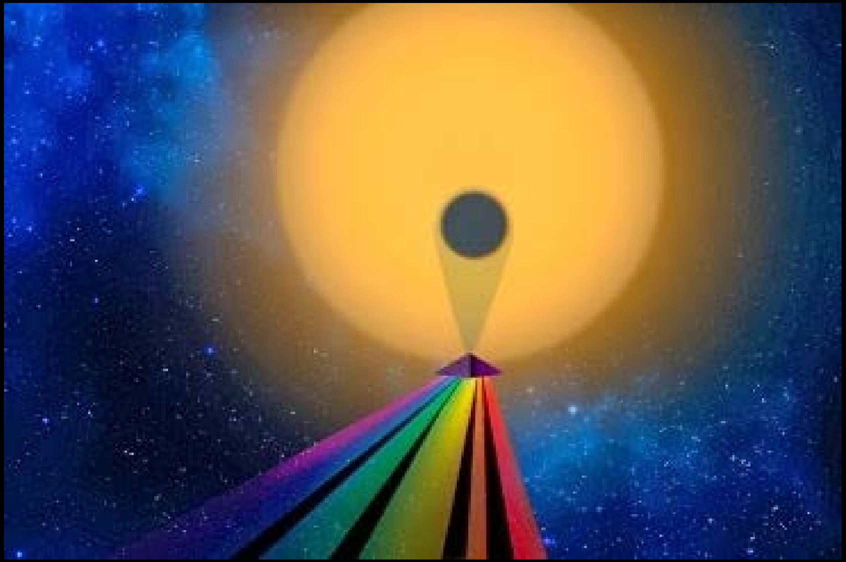
Hot Jupiters



Phase-resolved emission spectrum of WASP-43b
61 orbits with HST-WFC3

Super Earth vs Mini Neptun

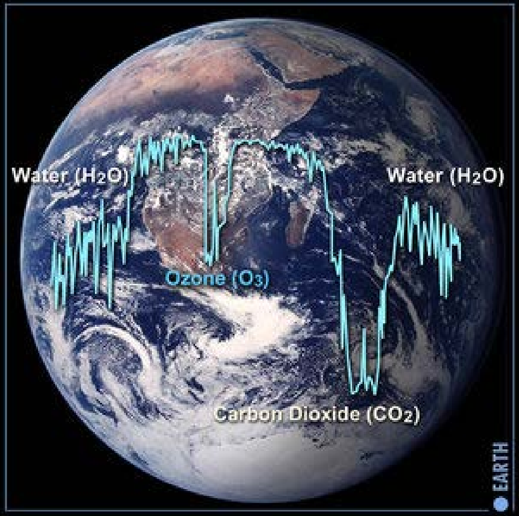
Future: Biomarkers



Most promising:
Oxygen and methane

….like gradstudents and pizza

(credit: Shawn DG)



Future: Biomarkers

NExSS Exoplanet Biosignatures Workshop-Without-Walls
5 Review papers:

Title: Exoplanet Biosignatures: Observational Prospects

Short title: Observational Prospects for Biosignatures

Yuka Fujii[1,2], Daniel Angerhausen[3], Russell Deitrick[4,5], Shawn Domagal-Goldman[5,6], John Lee Grenfell[7], Yasunori Hori[8], Enric Palle[9,10], Nicholas Siegler[11,12], Karl Stapelfeldt[11,12], Heike Rauer[7,13]

White paper for the National Academies of Science (NAS) Astrobiology Science Strategy for the Search for Life in the Universe

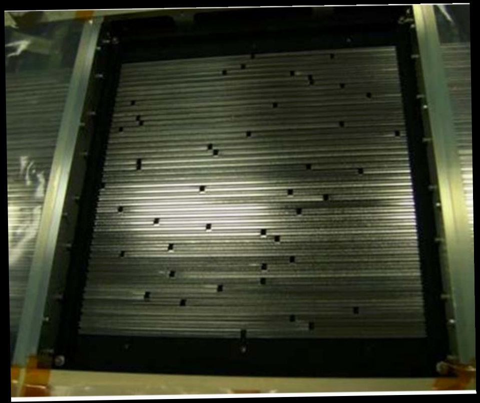
Life Beyond the Solar System: Remotely Detectable Biosignatures

Shawn Domagal-Goldman [1], Nancy Y. Kiang [2], Niki Parenteau [3], David C. Catling [4], Shiladitya DasSarma [5], Yuka Fujii [6], Chester E. Harman [7], Adrian Lenardic [8], Enric Pallé [9], Christopher T. Reinhard [10], Edward W. Schwieterman [11], Jean Schneider [12], Harrison B. Smith [13], Motohide Tamura [14], Daniel Angerhausen [15], Giada Arney [1] , Theresa Fisher [13] , Hilairy E. Hartnett [13] , Yasunori Hori [16], Betul Kaçar [17], Timothy Lyons [11] , Norio Narita [18], Heike Rauer [19], Sarah Rugheimer [20], Nick Siegler [21], Evgenya L. Shkolnik [13] , Karl R. Stapelfeldt [22]

Ground-Based

Hawaii Chile

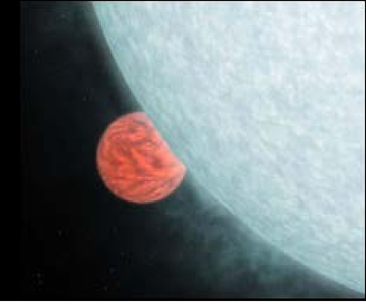
Ground-Based



~2006 - first generation IFU:
SINFONI @ VLT
OSIRIS @ Keck

Since 2015 - New MOS:
KMOS @ VLT
MOSFIRE @ Keck

Airborne-based: SOFIA



<u>Advantages for transit-observations:</u>

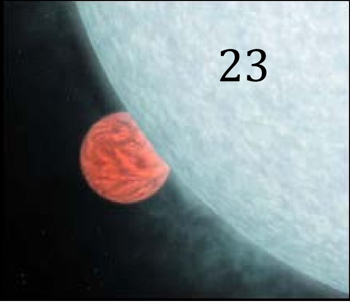
-wavelength regime

-mobility

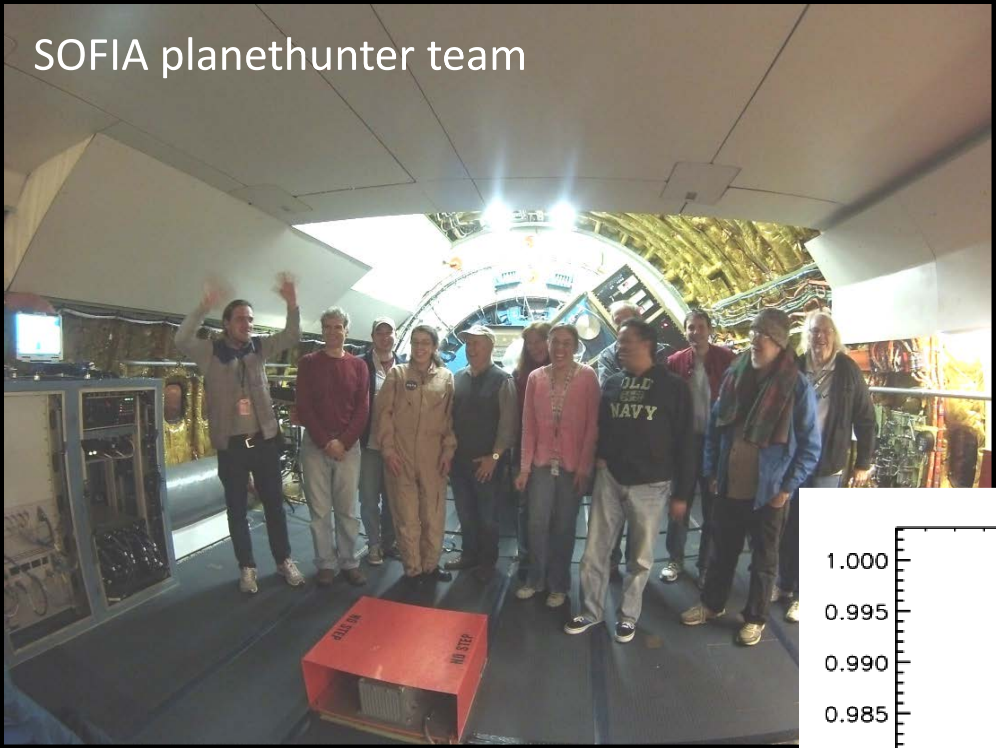
-less atmosphere

-dedicated instrumentation

(Angerhausen et al. 2011, McElwain et al. 2013)



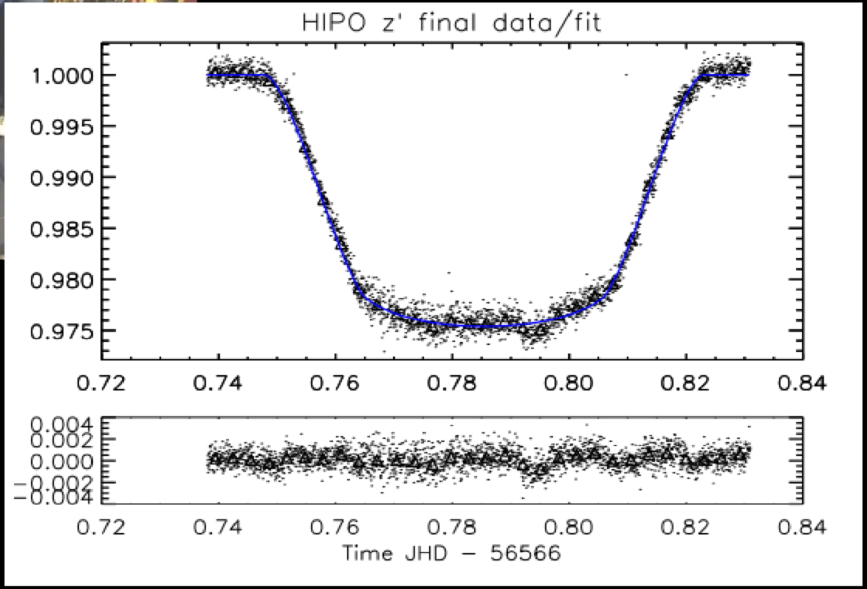
SOFIA – first transit



-First exoplanet observation:
1 October 2013 with
FLIPO (FLITECAM & HIPO)

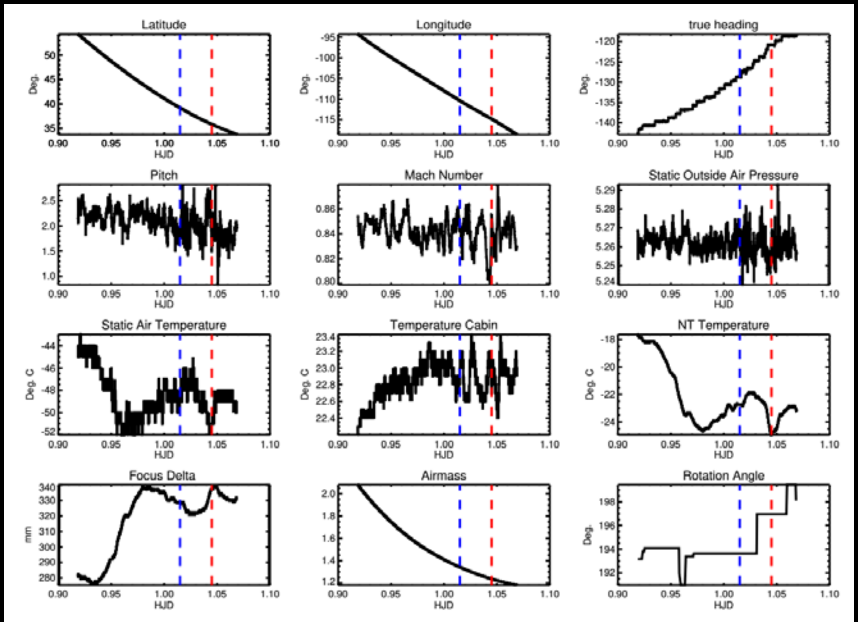
-transit of HD189733b

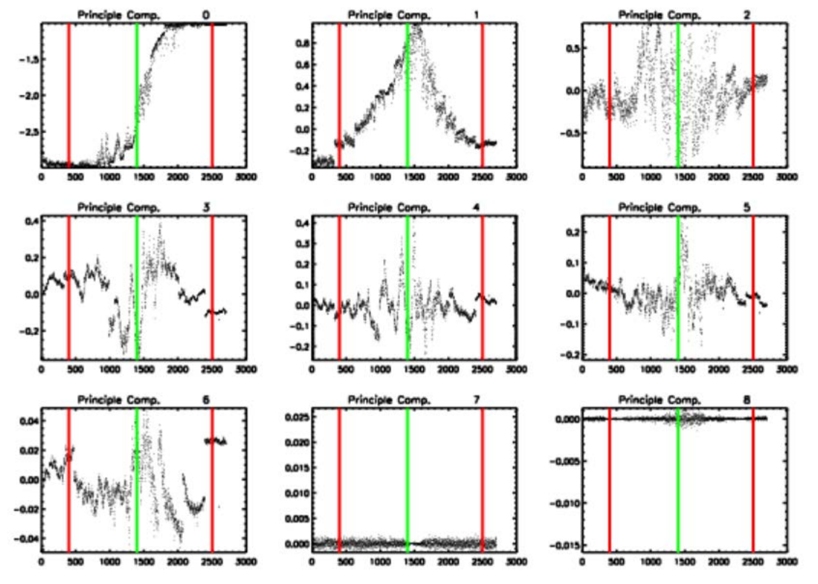
-"space based" quality



Decorrelation via PCA

observational Parameters → principle components
(PSF, “weather”, telemetry etc.)

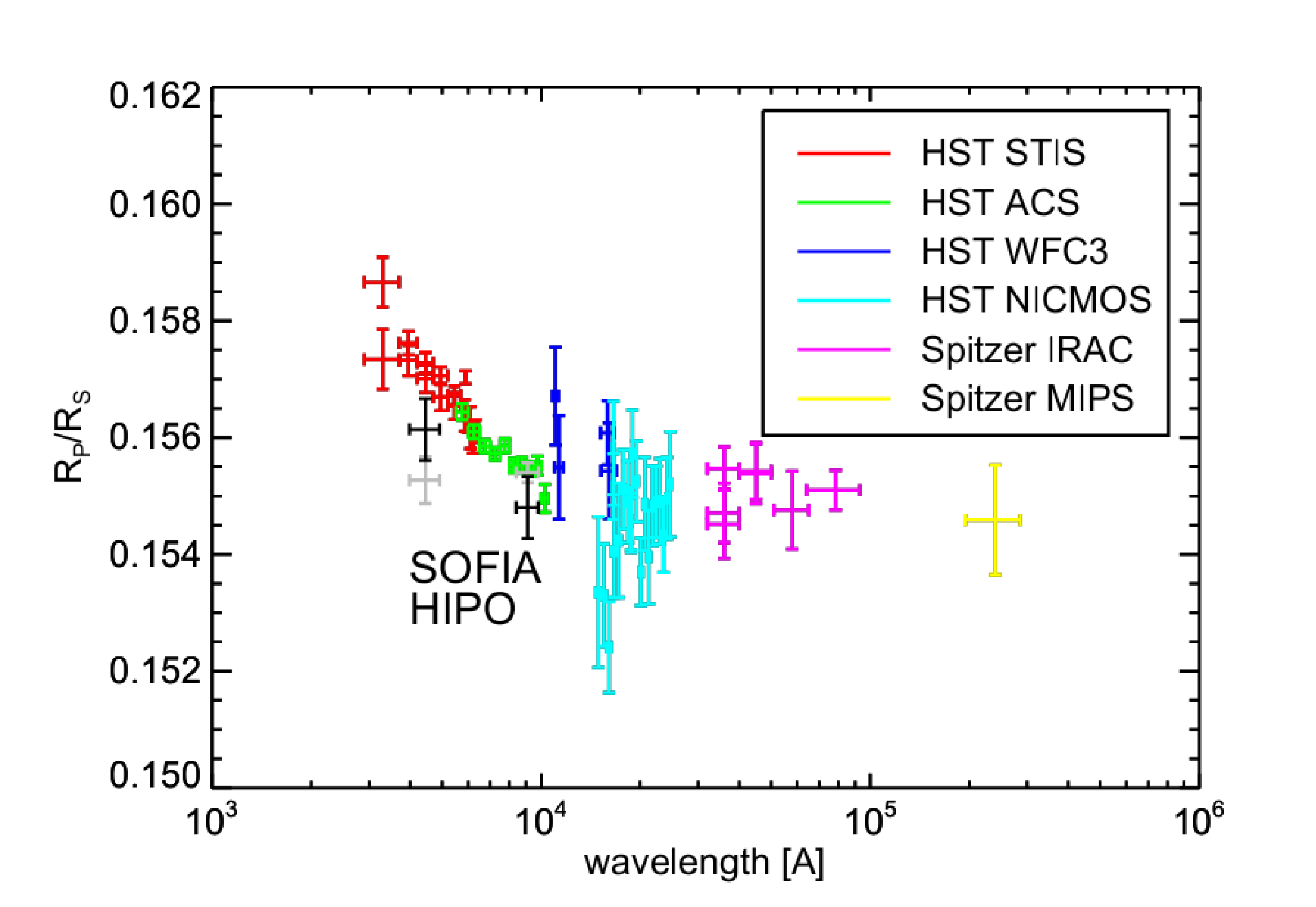




Advantages: solves degeneracies between parameters,
reduces number of fitting parameters

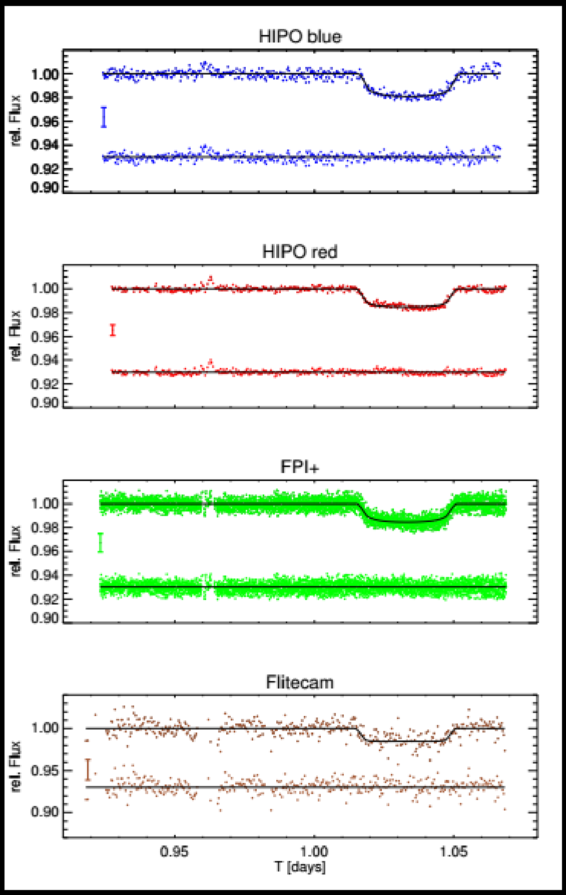
Disadvantage: loss of physical insight

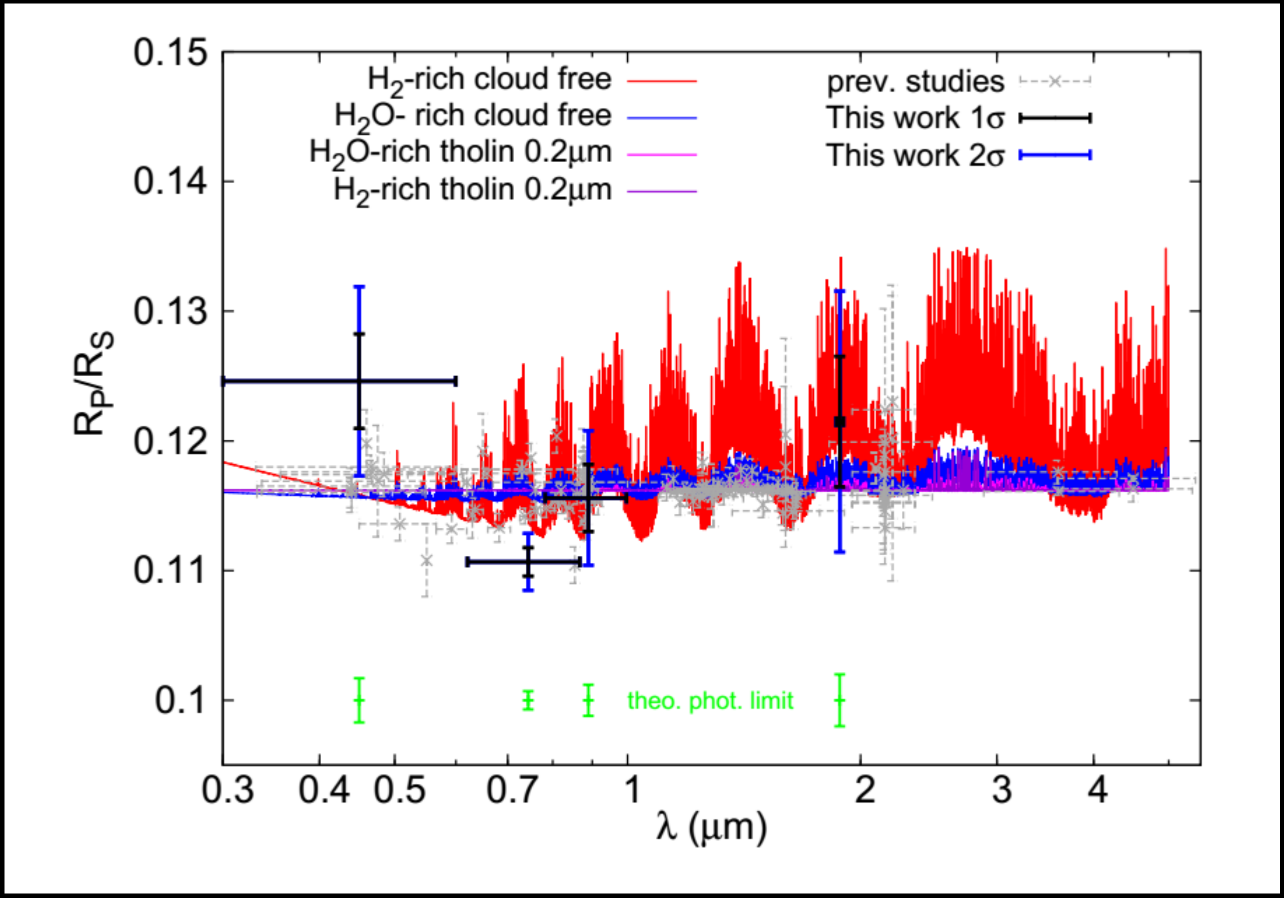
SOFIA – comparison



(~ 1.5 photon noise; 185/160 ppm: Angerhausen et al. JATIS, 2015)

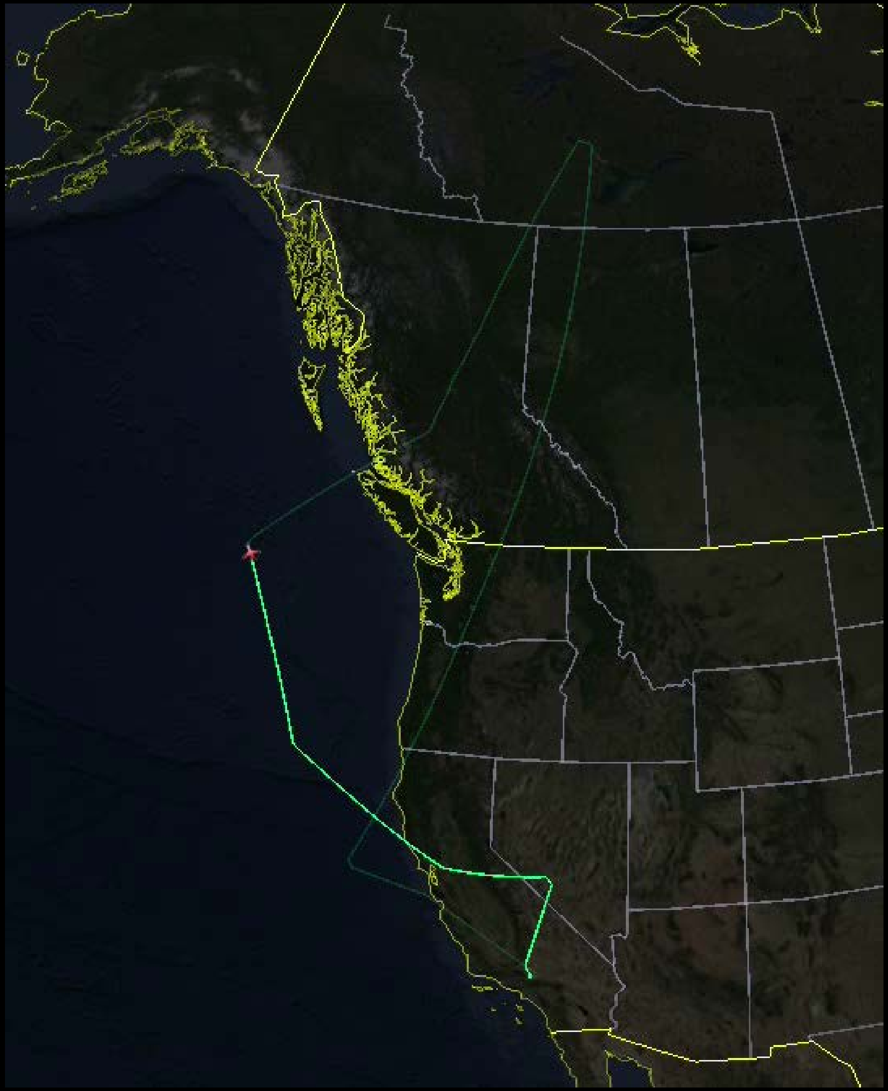
SOFIA – GJ 1214b





Transit spectrophotometry of GJ1214b (2.7 Re) in Paschen alpha
With FLITECAM Paschen alpha, red/blue with HIPO, I band with FPI+
(Angerhausen et al. 2017, A&A)

SOFIA – challenges

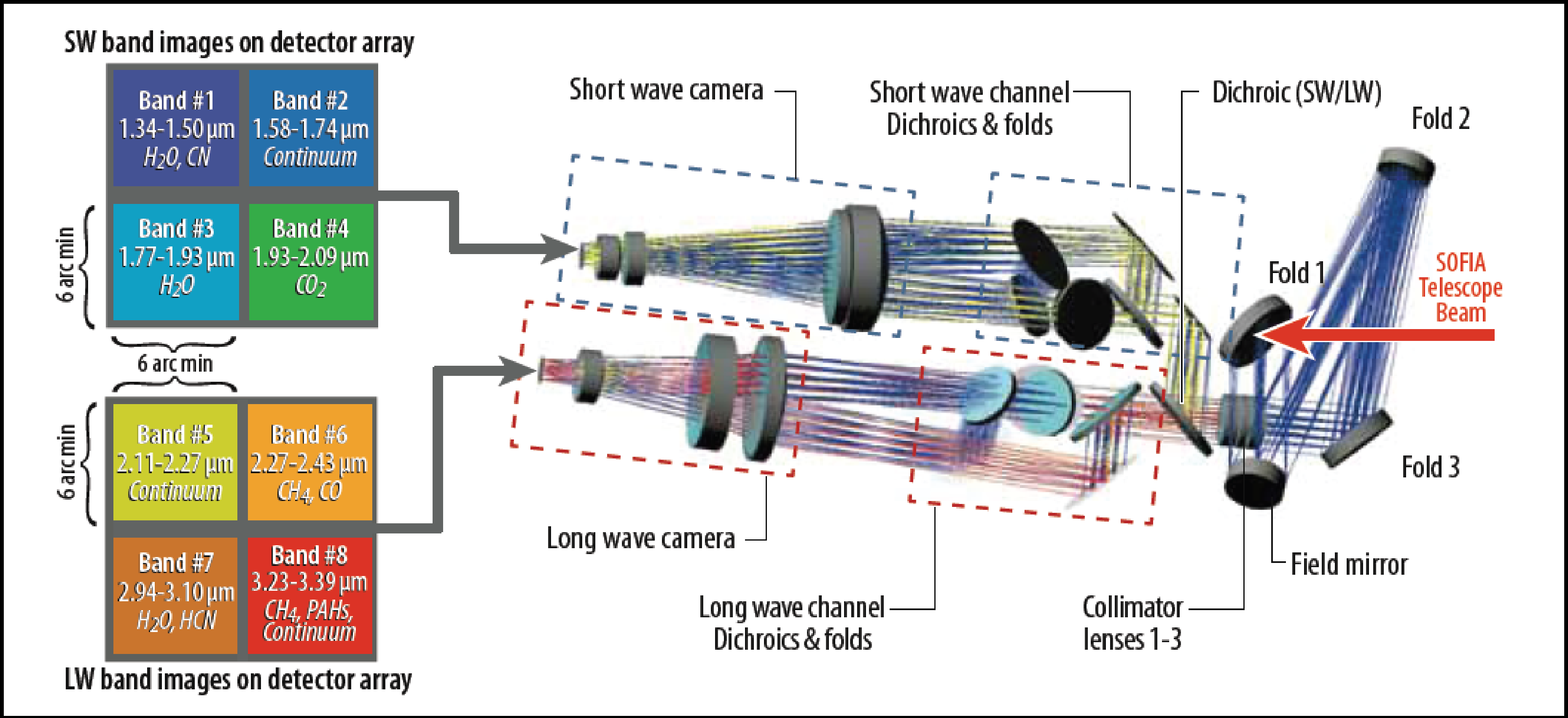


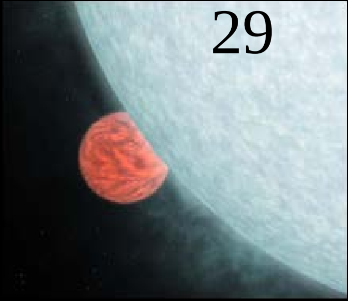
Sept 2015: transit of GJ3740b ('warm Uranus") in Paschen alpha with FLITECAM imager and I band with FPI

SOFIA observation in practice:
-flight planning constrains
-instruments not very well suited
-competition with MIR/FIR
-HIPO & FLITECAM n/a

NIMBUS

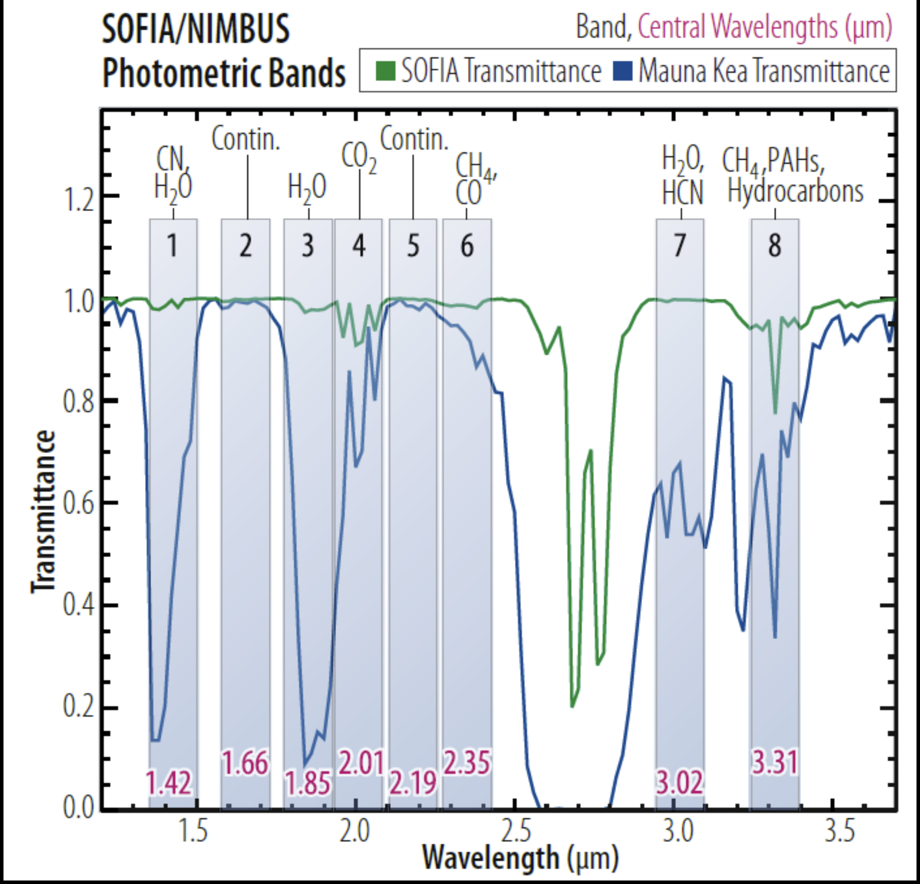
The Near-Infrared Multi-Band Ultraprecise Spectroimager for SOFIA

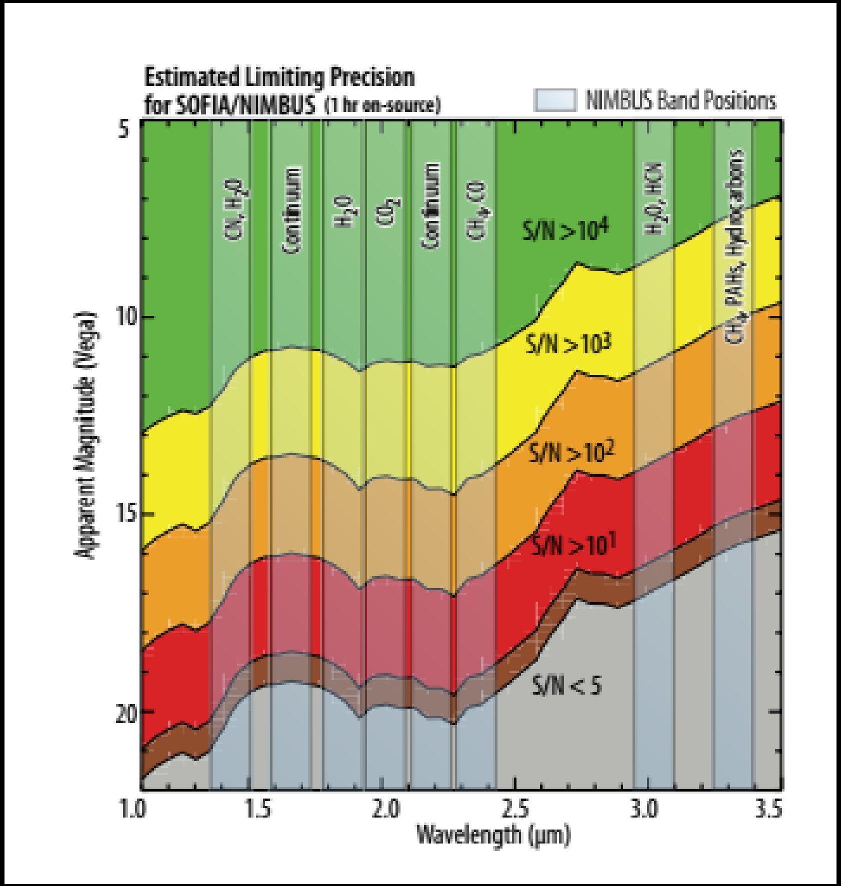




NIMBUS

The Near-Infrared Multi-Band Ultraprecise Spectroimager for SOFIA



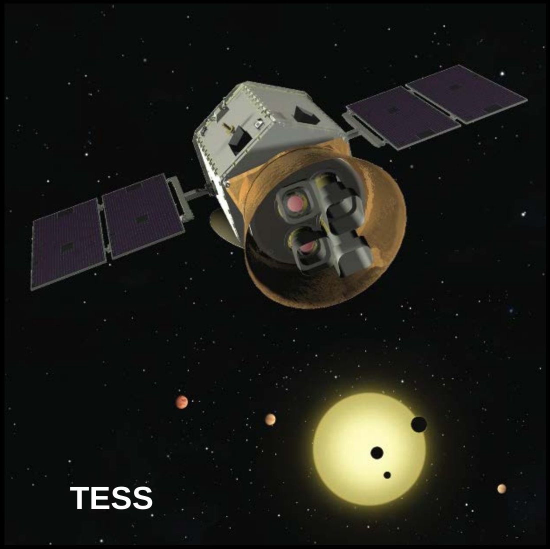


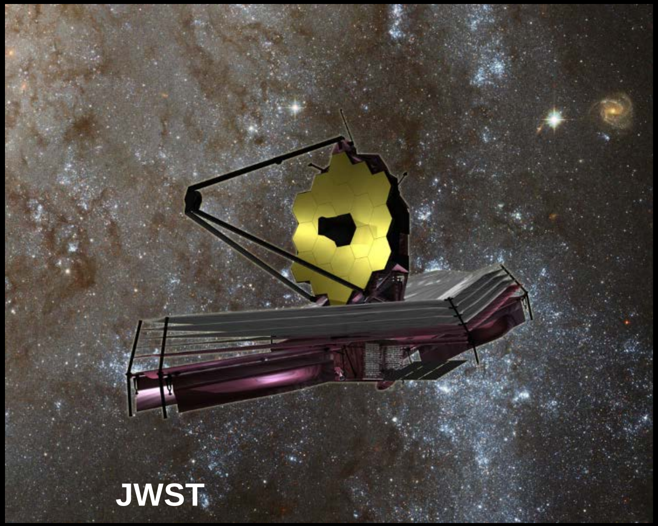
Future: What about a balloon?

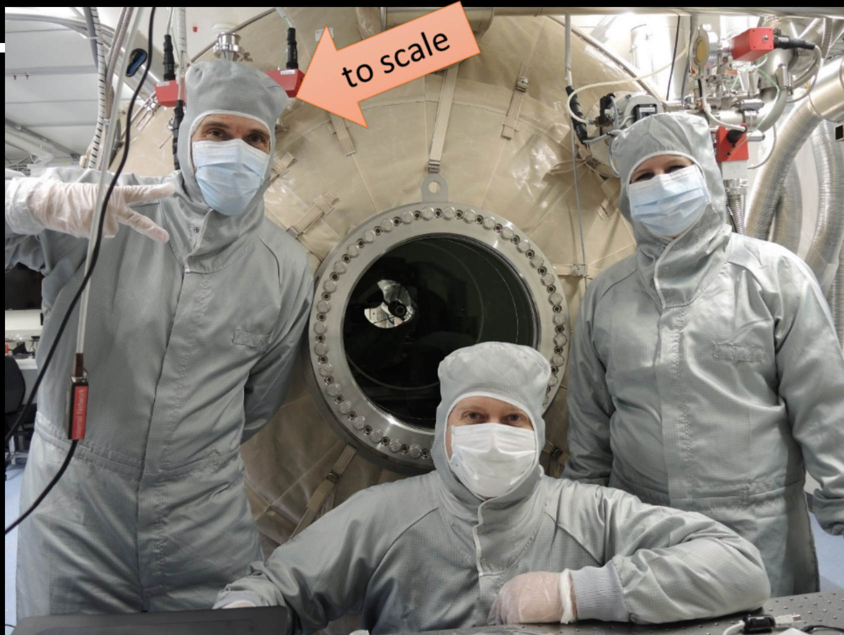
EX.TRA.BALL
EXOPLANET.TRANSIT.BALLOON

- -microwave kinetic inductance detector (MKID)
- -'pupil imager'
- -meter class balloon platform (ESBO)

Future: CHEOPS/TESS/JWST







CHEOPS
CHARACTERISING EXOPLANET SATELLITE

James Webb Space Telescope
JWST
NASA • ESA • CSA

From TESS/CHEOPS to JWST

'Exoplanet observations with SOFIA'
https://www.youtube.com/watch?v=y-W3xoOu0NE

Backup Slides

Kepler: Trojans

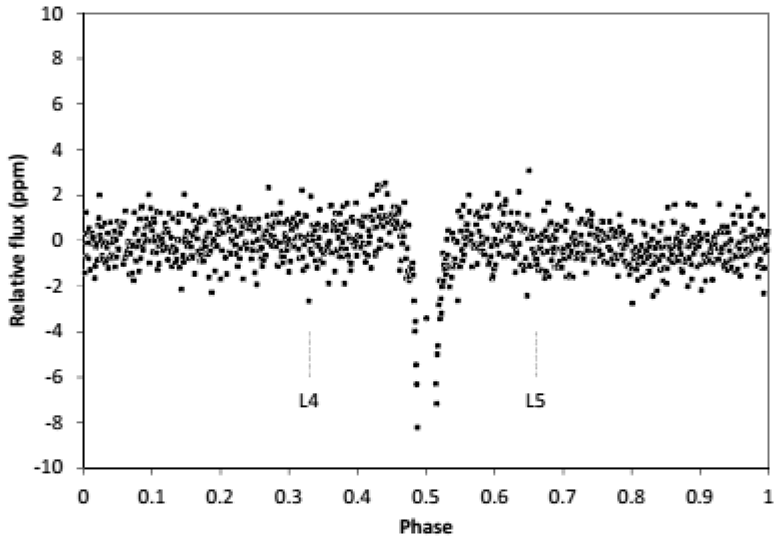


FIG. 2.— The initial superstack shows no significant dips at the Lagrangian points.

Sub sample selection:
If "dip" at L4 take second half of lightcurve and vice versa

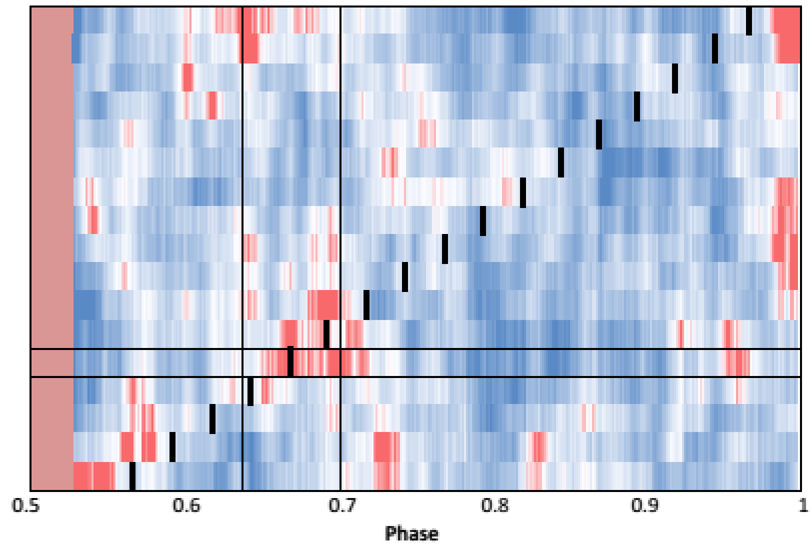
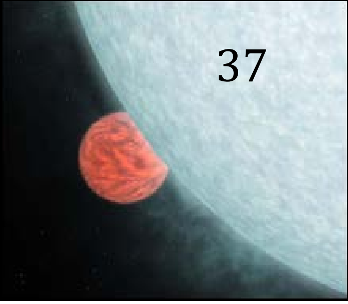
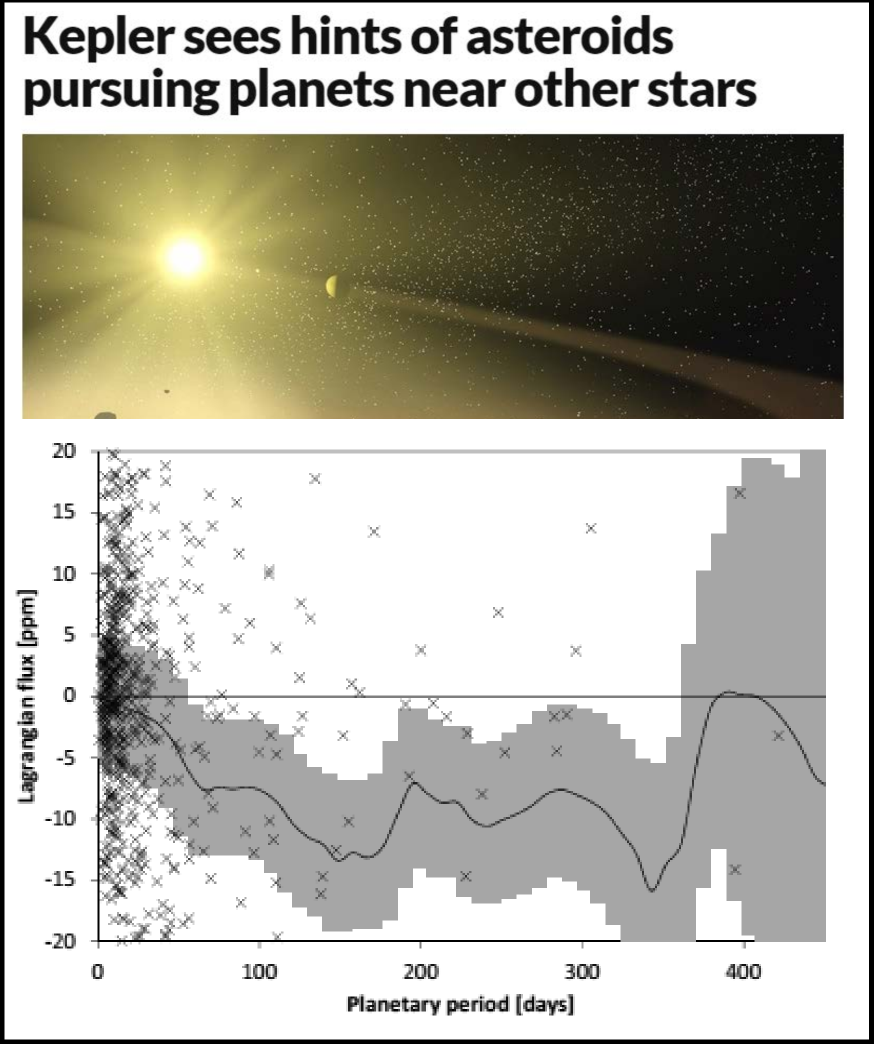


FIG. 4.— Cross-check of sub-sample selection artifacts. In each line, we select those data that have a dip on one side of phase space, and plot their flux only for the other half of phase space.

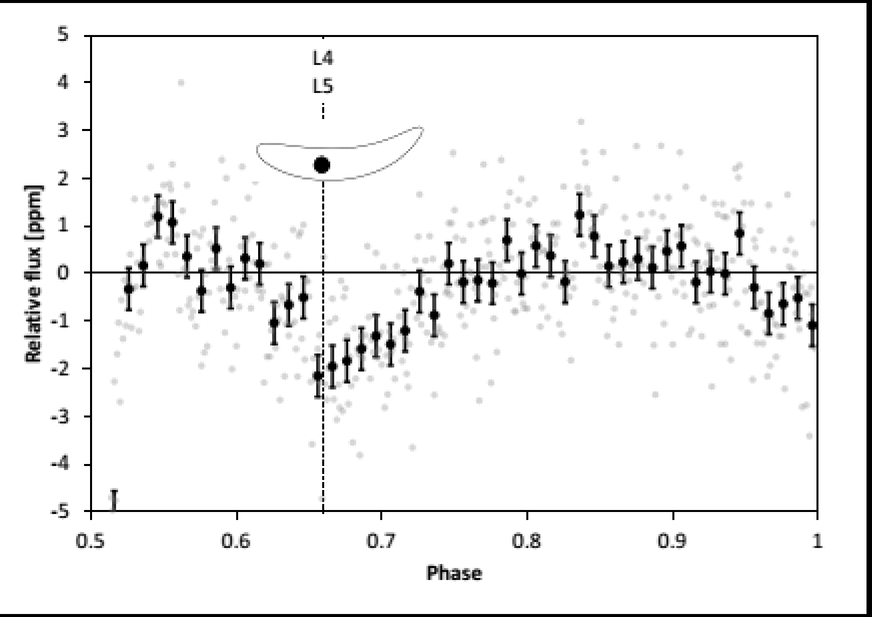
upper limit to the average Trojan transiting Area (per planet) corresponding to one body of radius < 460km



Kepler: Trojans



-First evidence for "Exo-Trojans"
(Hippke & Angerhausen, ApJ, 2015)



-sub-sample exhibits a clear dip at both L4 and L5, with a maximum depth of 2ppm (970km radius equivalent)

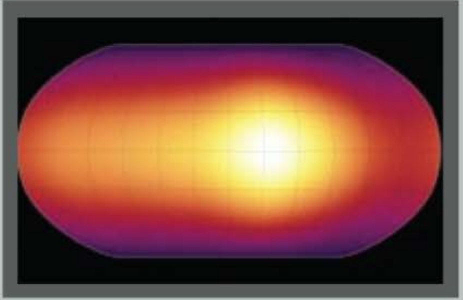
-weak distance correlation

CHEOPS/TESS/JWST connection

WEATHER ON HOT JUPITERS

1000+ TESS-provided sample

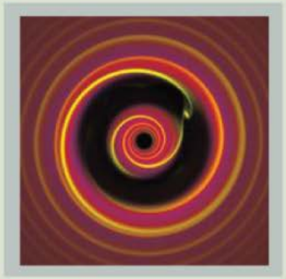
- Compare hot (~0.05AU) and cooler (0.1-0.2AU) systems
- Determine radiation time scales
- Measure temperature with altitude



FORMATION AND MIGRATION OF NEPTUNES

700+ TESS-provided sample

- Evaluate gas fraction vs. remnant core
- Differentiate atmospheric composition based on migration models



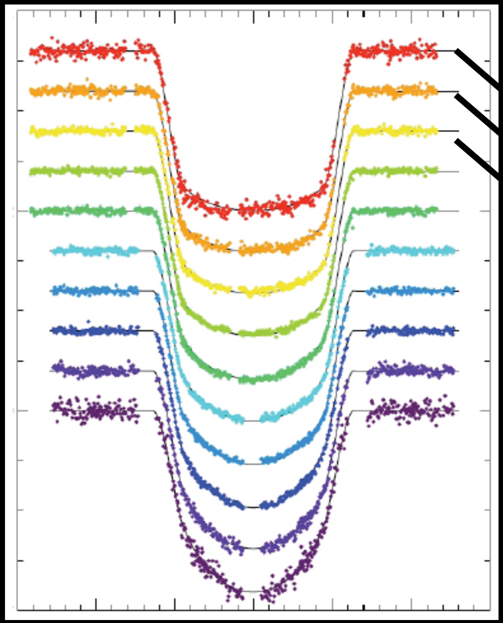
WET SUPER EARTHS

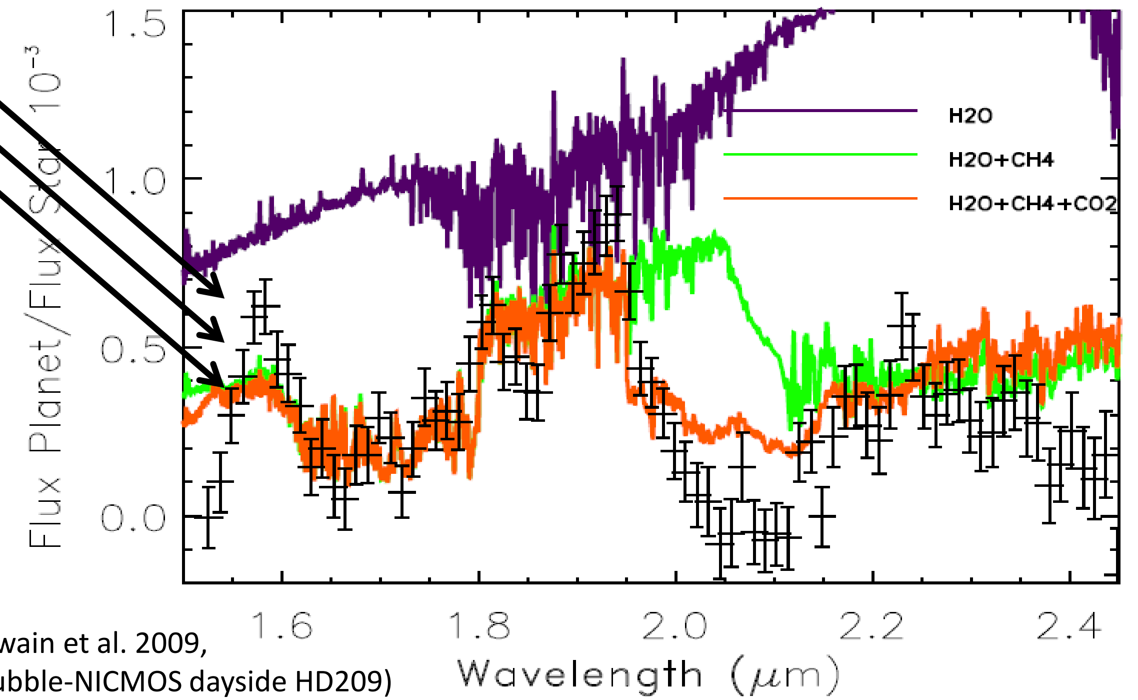
100+ TESS-provided sample

- Compare hot Super Earth's around the late type K stars and cooler Super Earths around mid-late M stars
- Investigate signs of habitability

(credit: Ricker, PI TESS)

(NIR-) Spectrophotometry





(Swain et al. 2009,
Hubble-NICMOS dayside HD209)

-every lightcurve represents the spectral value at its particular wavelength, putting them together reveals the spectrum

- "comparison" with models show molecule abundances and T-P profile of the planet