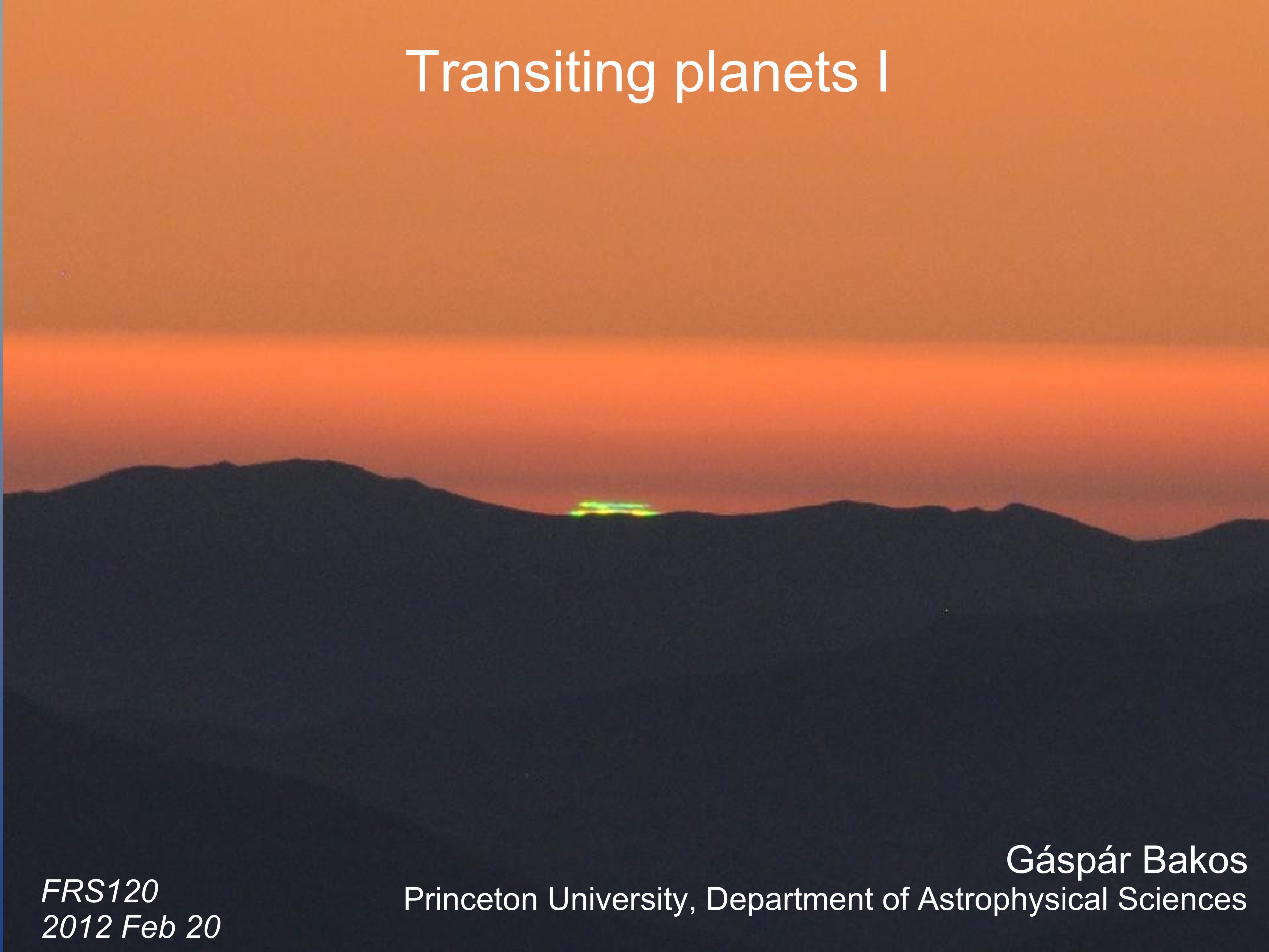
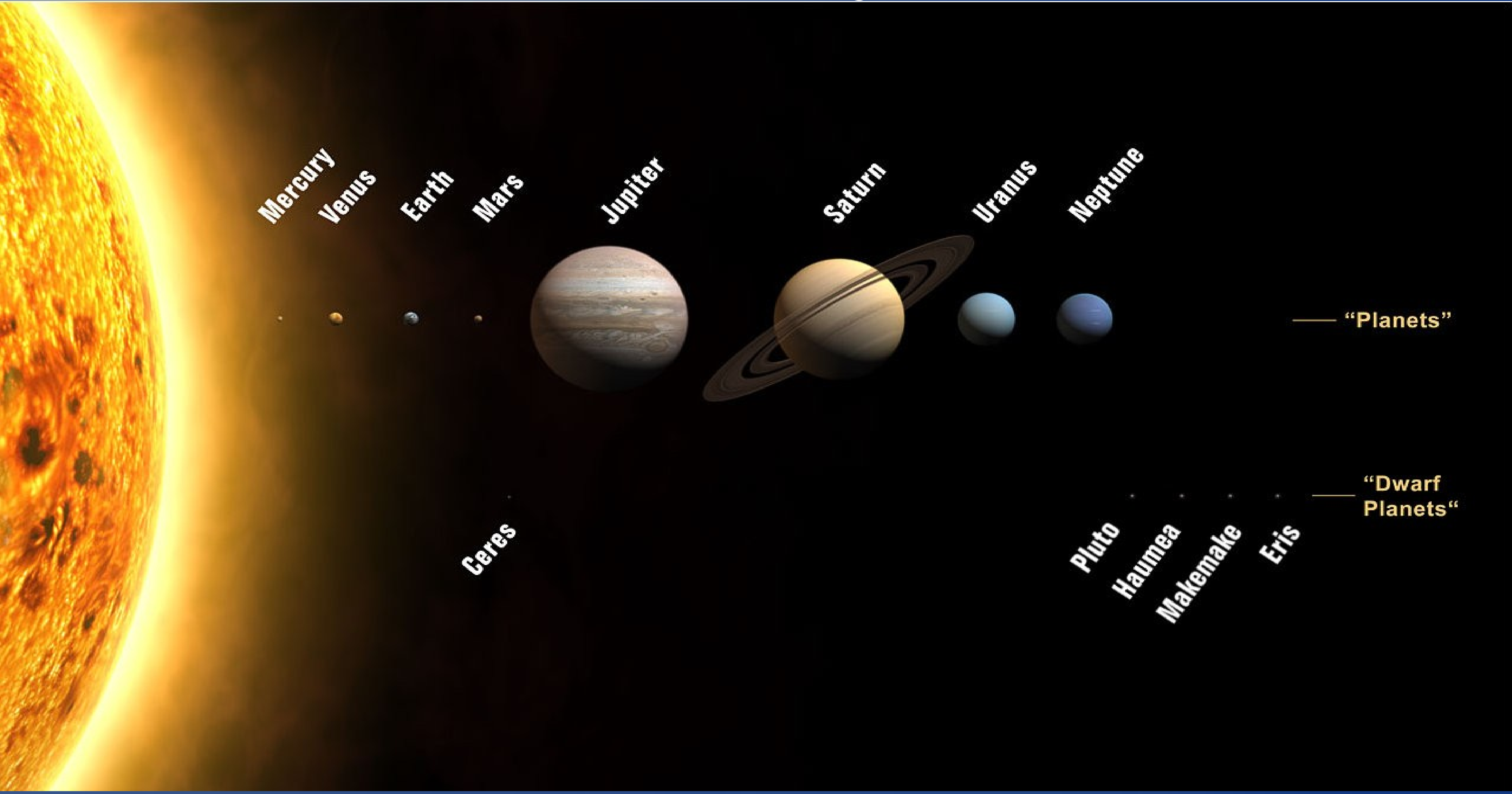


Transiting planets I

Gáspár Bakos
Princeton University, Department of Astrophysical Sciences

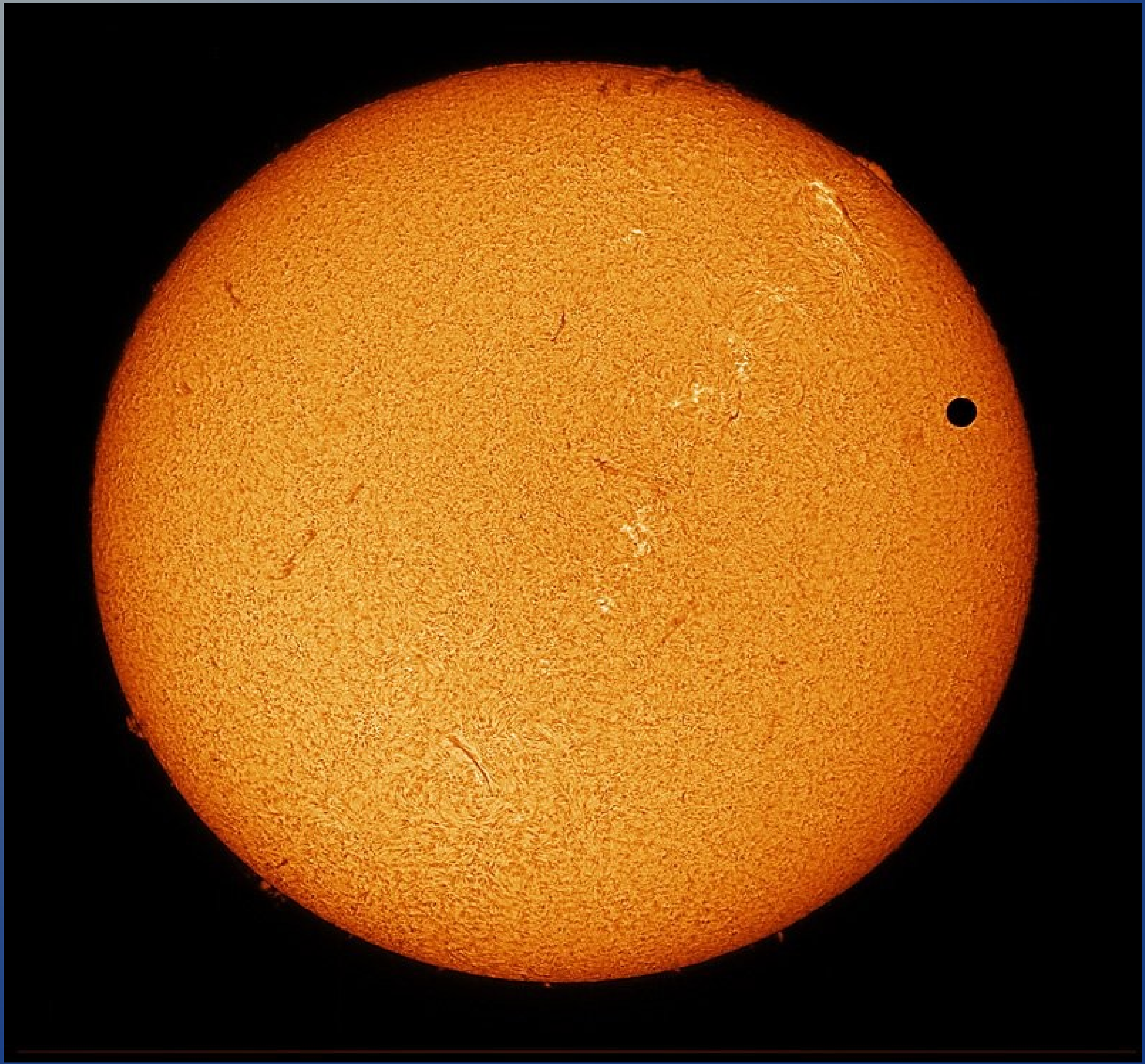
FRS120
2012 Feb 20

Our Solar system



Is the Solar system typical?
Are there other types of planets, and what is their frequency?
What is the occurrence of Earths and extraterrestrial life?
How do planets form and evolve and die?

Venus transiting the Sun (from Earth)

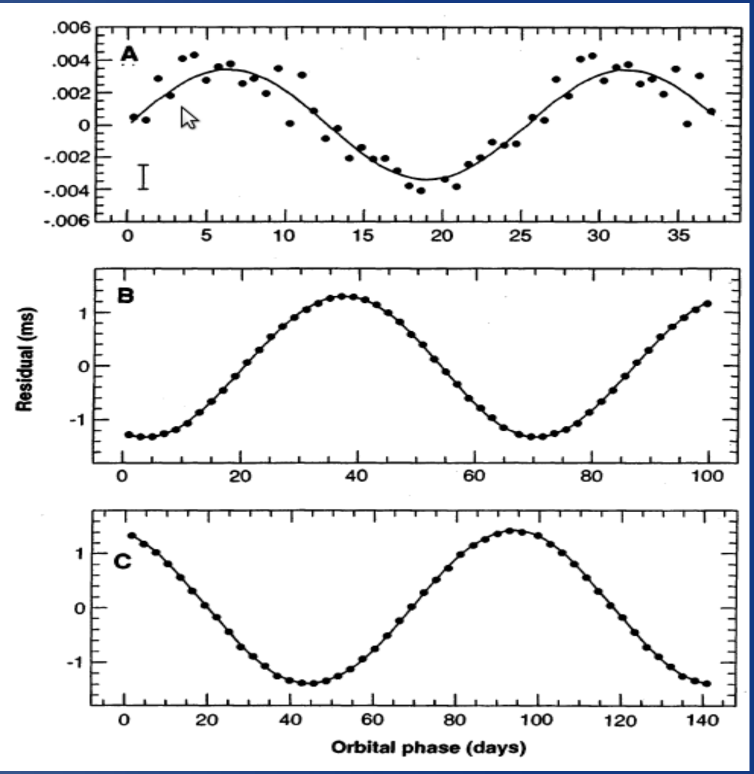


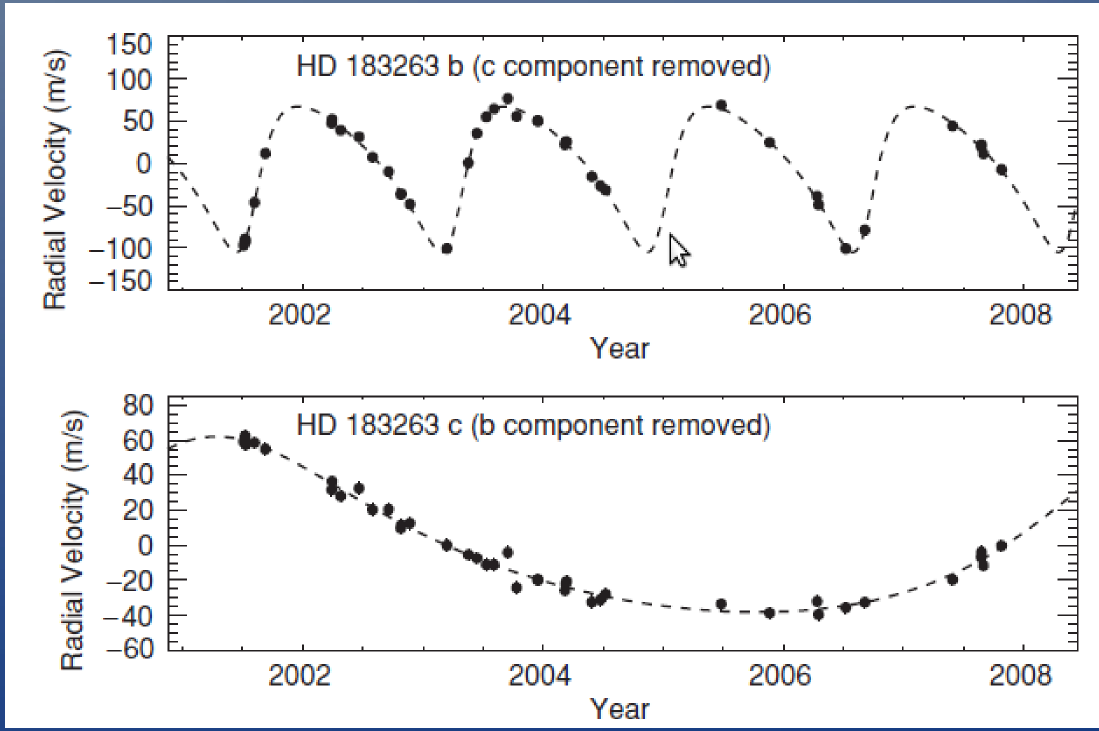
- 112 yr periodicity
- 1769: the first international scientific collaboration
- Measurement of the AU to 0.5% in 1769
- Discovery of Venus' atmosphere by Lomonosov

Exoplanet discovery methods

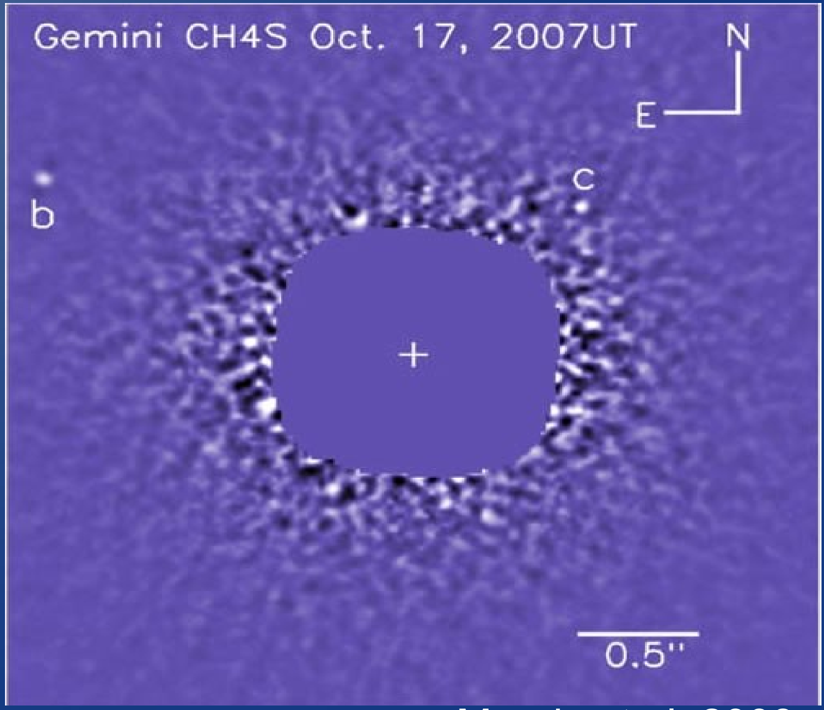
- Pulsar timing
- Reflex motion of the host star (RV)
- Transits
- Microlensing
- Direct imaging

Wolszczan 1994



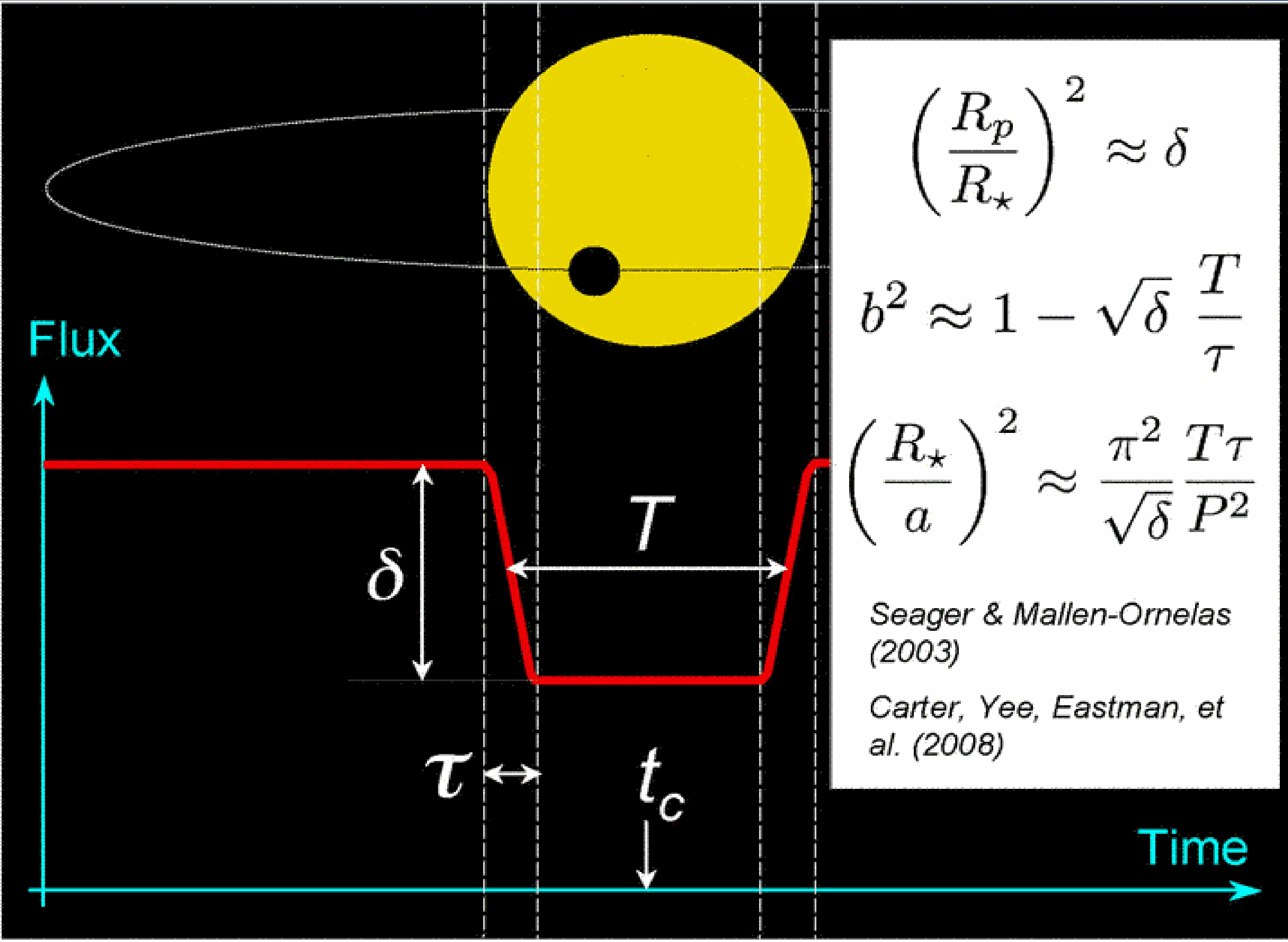


Wright et al. 2010



Marois et al. 2008

Transit parameters versus physical parameters



Courtesy J. Winn

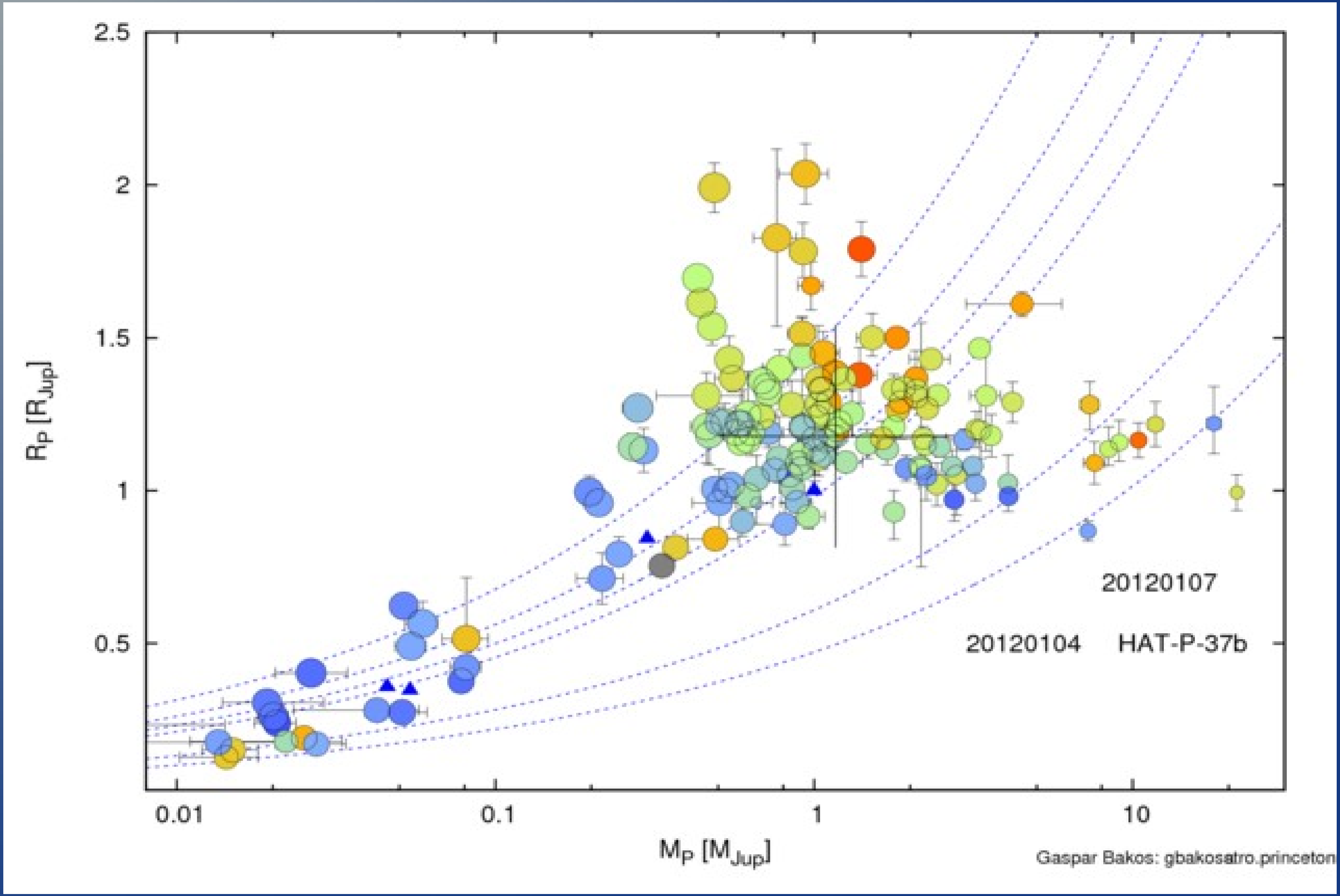
Transits: The "royal way" of understanding planetary systems.

Note complementarity to other discovery methods (RV, microlensing)

$$\rho_\star \approx \frac{3P}{\pi^2 G}\left(\frac{\sqrt{\delta}}{T\tau}\right)^{3/2}$$

$$g_p \approx \frac{2K_\star P\sqrt{\delta}}{\pi T\tau \sin i}$$

Planetary mass — radius diagram



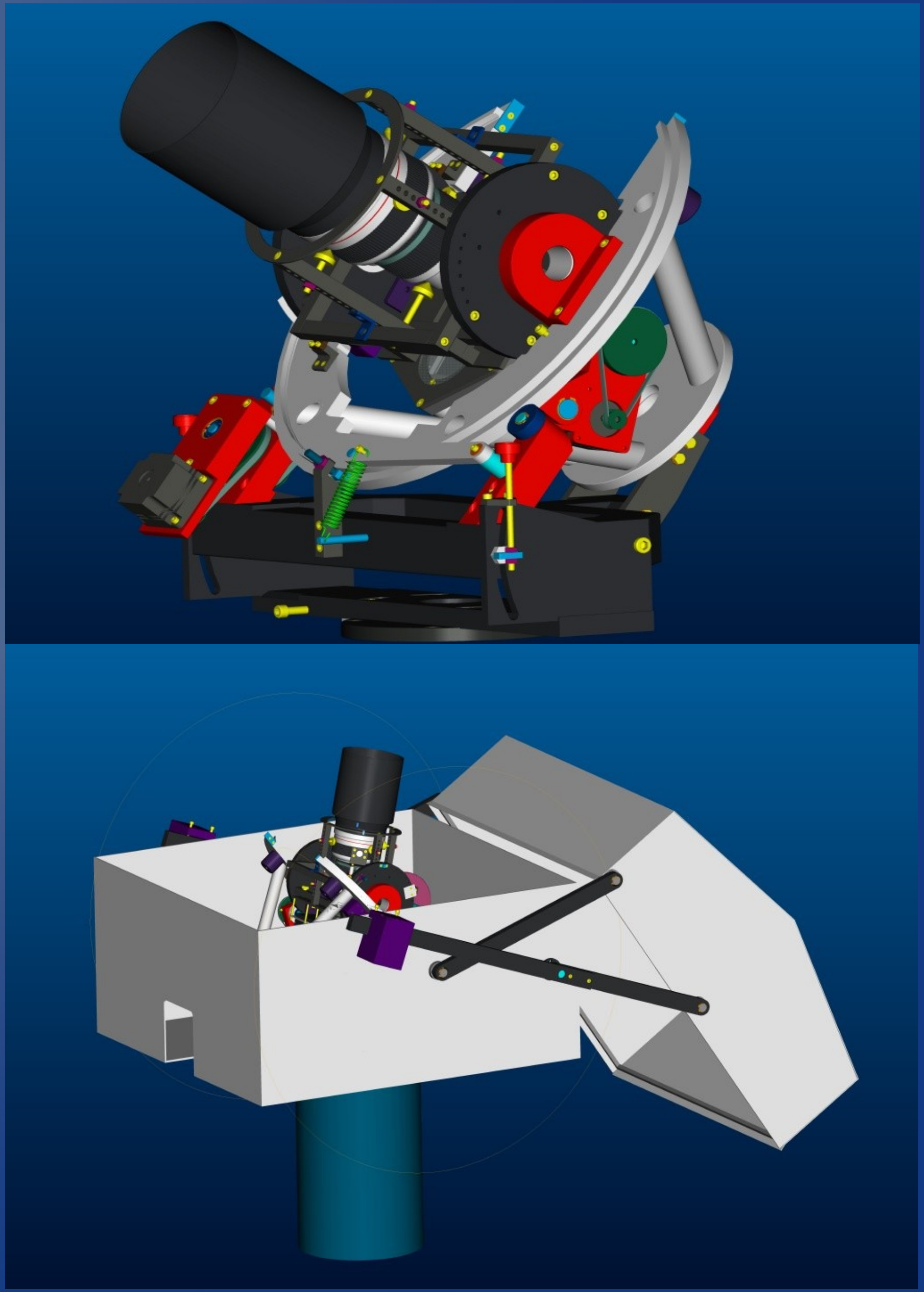
What can be learned for a transiting exoplanet?

- Known inclination, true mass, radius (if stellar radius and mass are known*) → density, structure [~130]
- Detection of planetary atmospheres via transmission spectroscopy or occultation spectroscopy (and potentially, biomarkers).
- Measurements of planetary brightness temperature via the occultation of the planet (Spitzer). [30+]
- Sky projected angle of stellar spin axis and planetary orbital normal via the RM-effect → formation [40+]
- Transit timing variations → perturber bodies, and masses [few]
- Transit (through a/R_*) refines stellar parameters (note: eccentricity and argument of periastron also required)
- Orbital evolution? Tidal dissipation constants. Moons.

The HATNet project

Goals:

- Discover many transiting extrasolar planets.
- Carry out their accurate *initial* characterization, explore their diversity
- Focus on planets around bright stars to enable detailed follow-up (community effort)
- Investigate relations between planetary and host star parameters.
- Contribute to the understanding of their formation, migration, evolution, and physics.
- Find odd-balls.

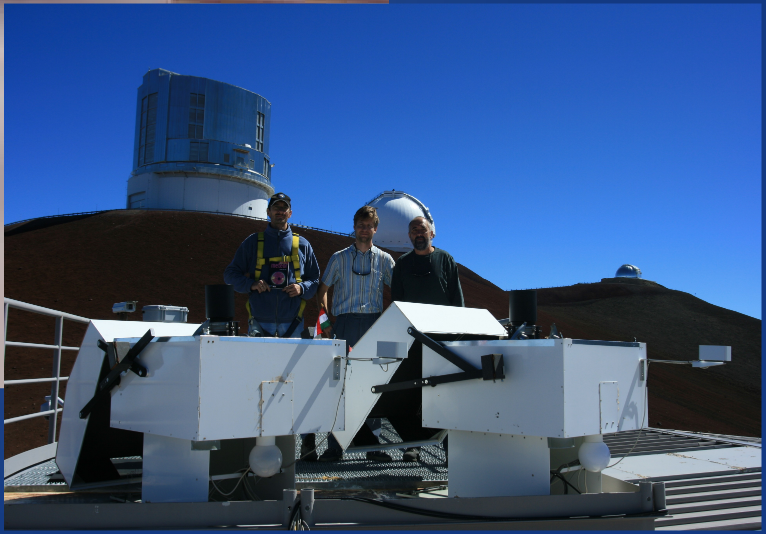


The HAT telescope – in real

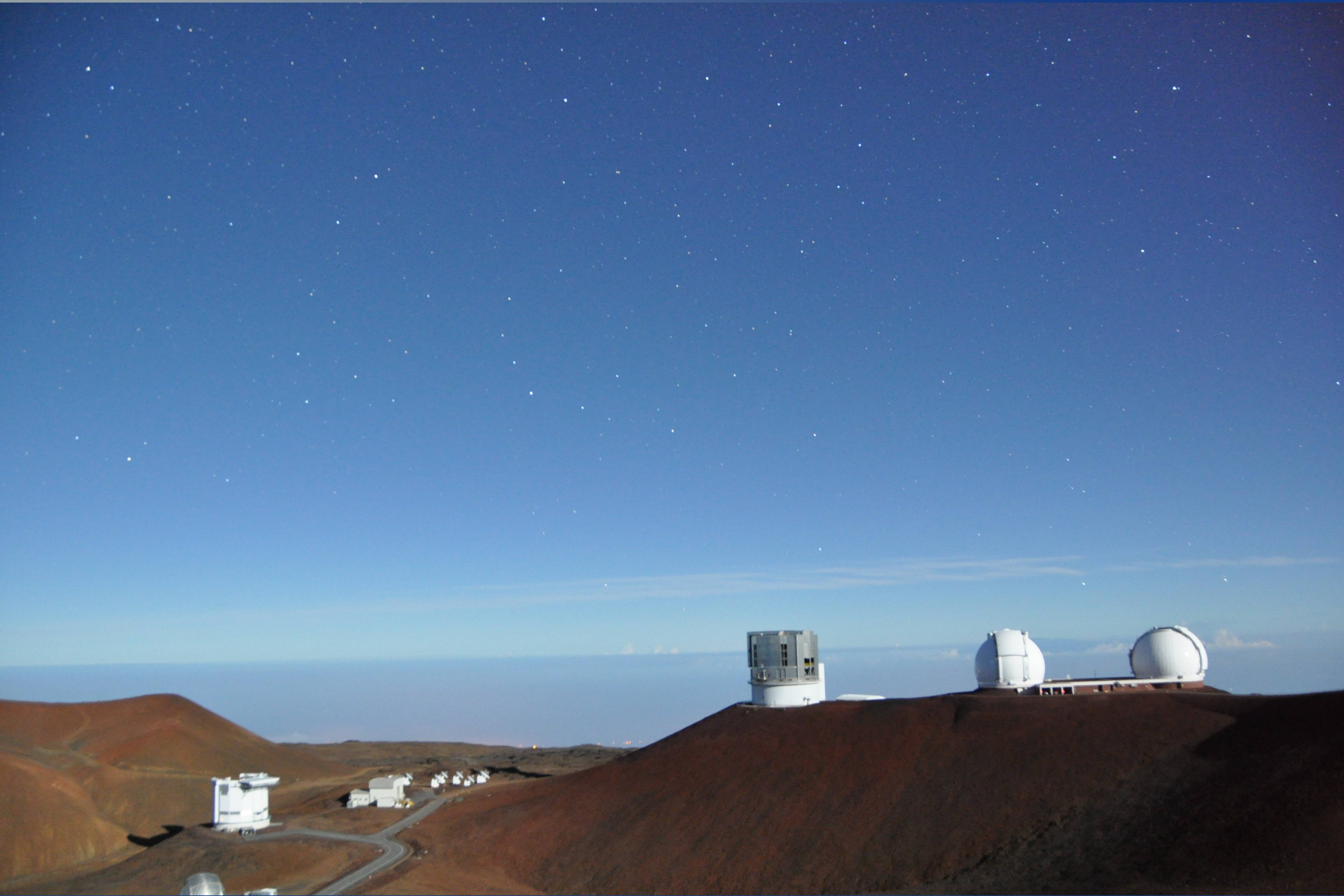
- f=200mm
- f/1.8
- D=110mm
- FOV=10°
- scale10”/pix
- Sloan r filter
- 4K x 4K Kodak FI chip
- Fully automated with all components: dome, telescope, CCD


HATNet at FLWO 2010-01-24 08:33:00

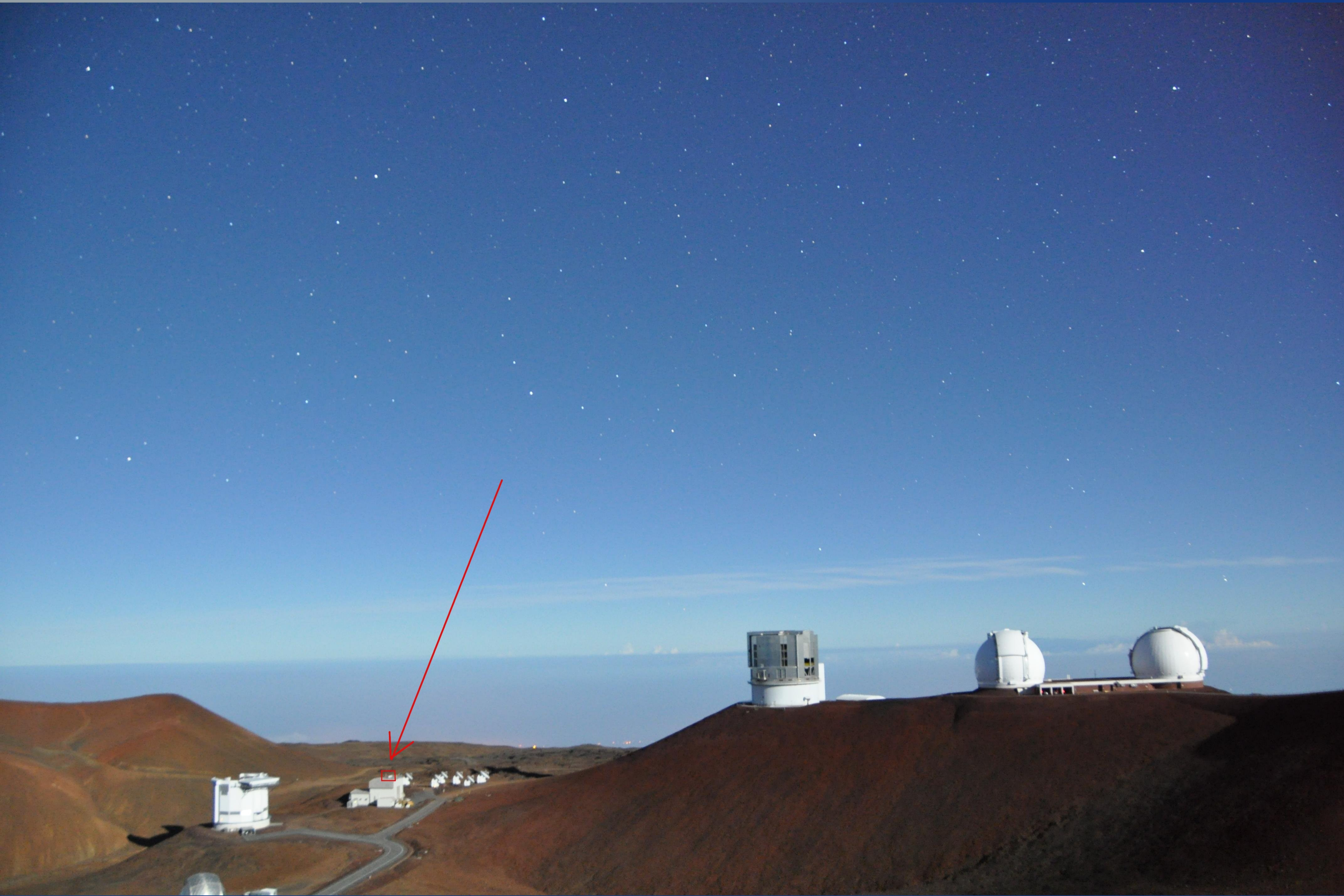
HATs at Mauna Kea



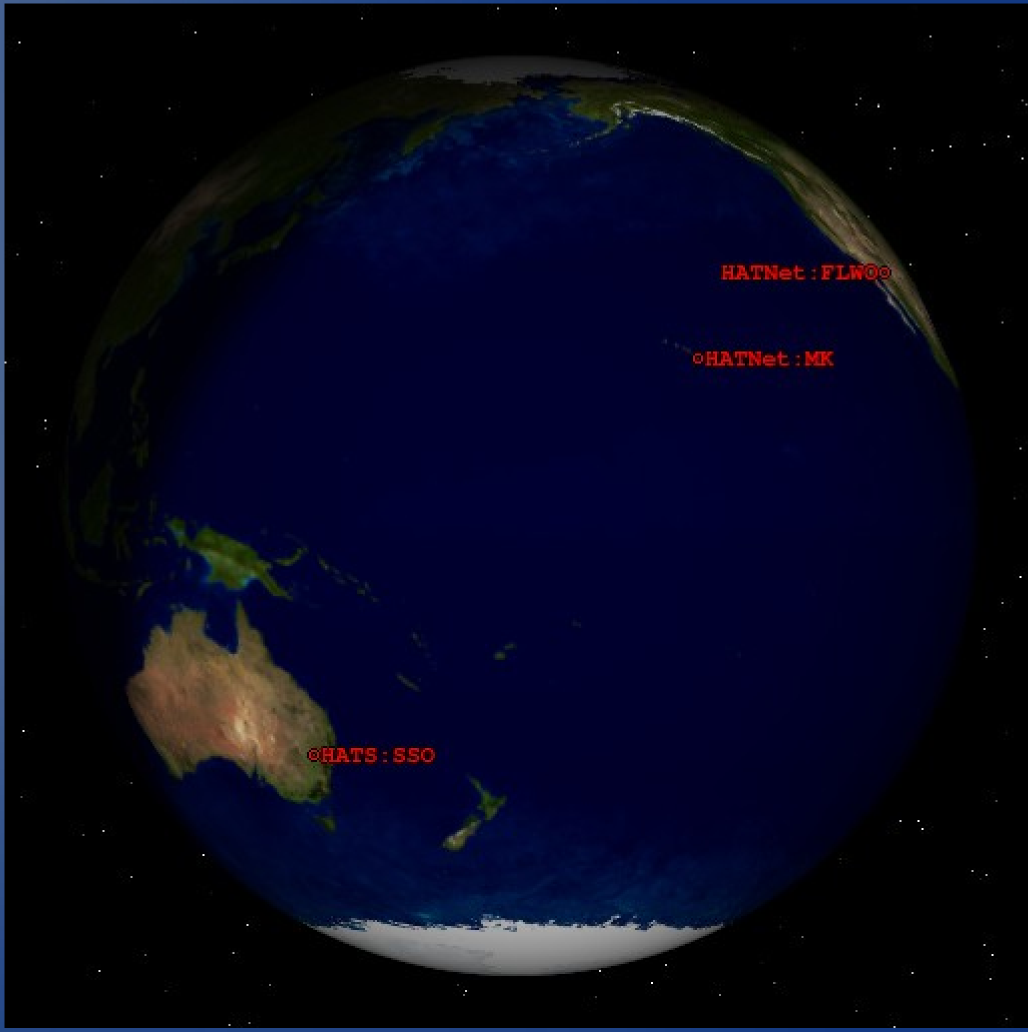
HATs at Mauna Kea



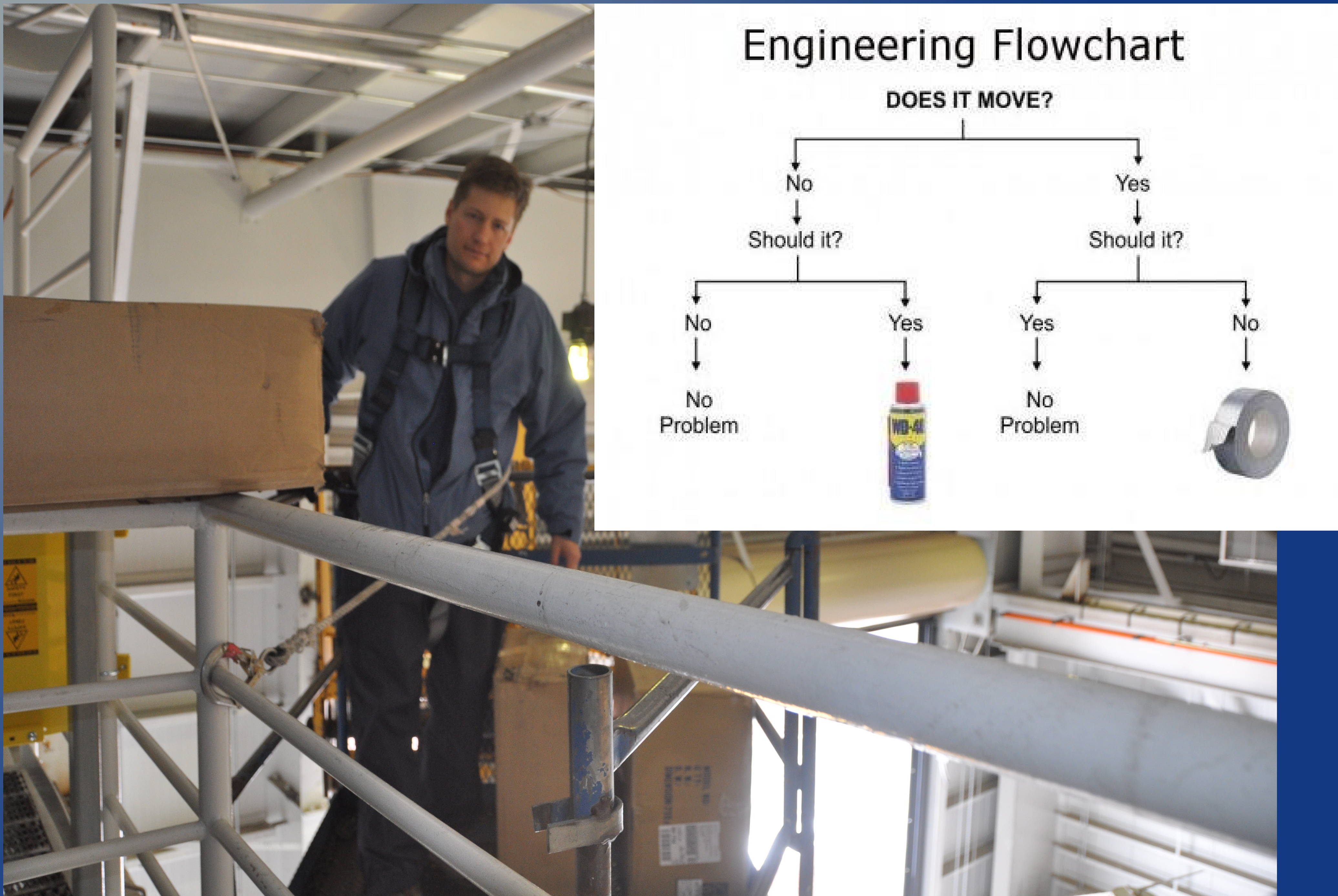
HATs at Mauna Kea



A network spread in longitude

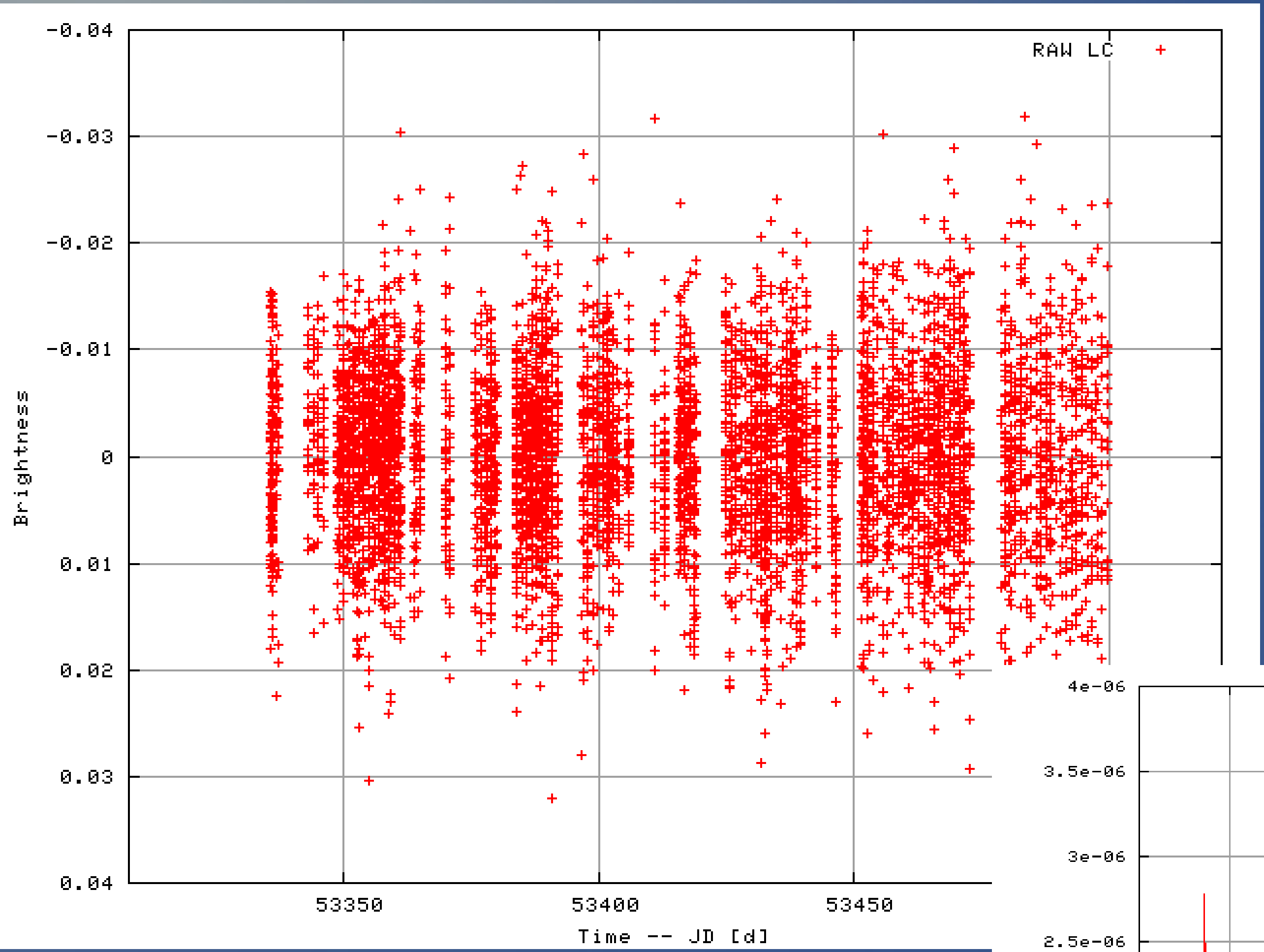


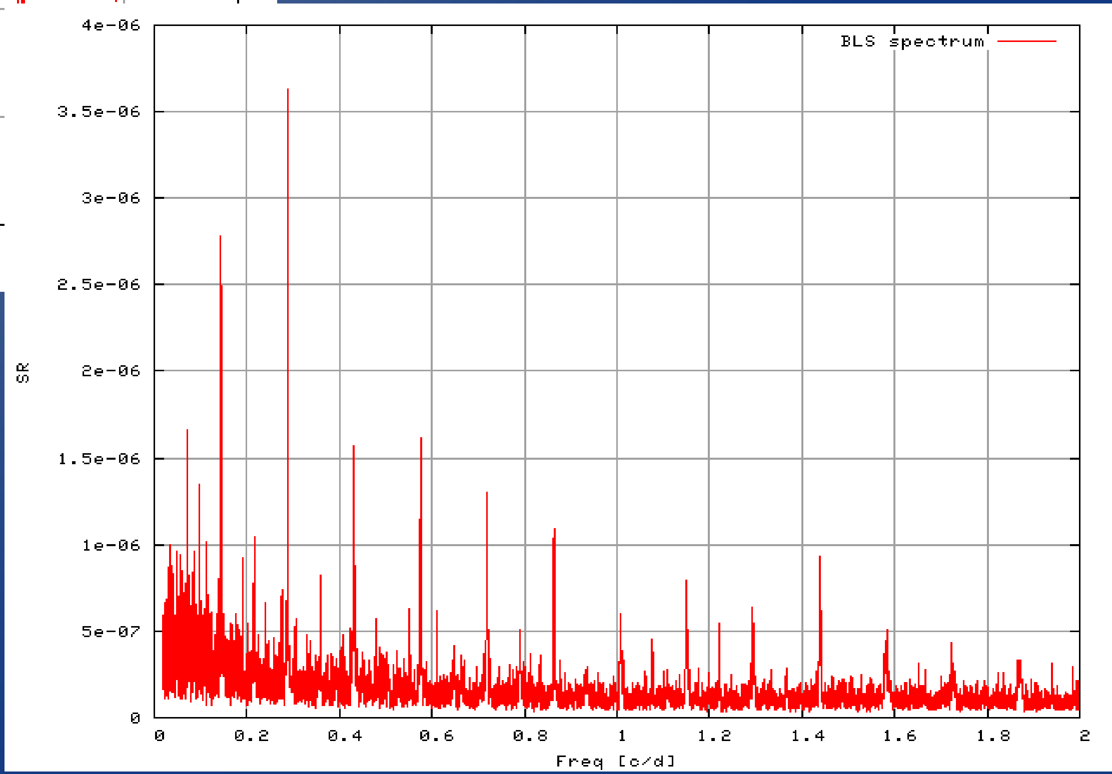
Servicing, repairs and maintenance



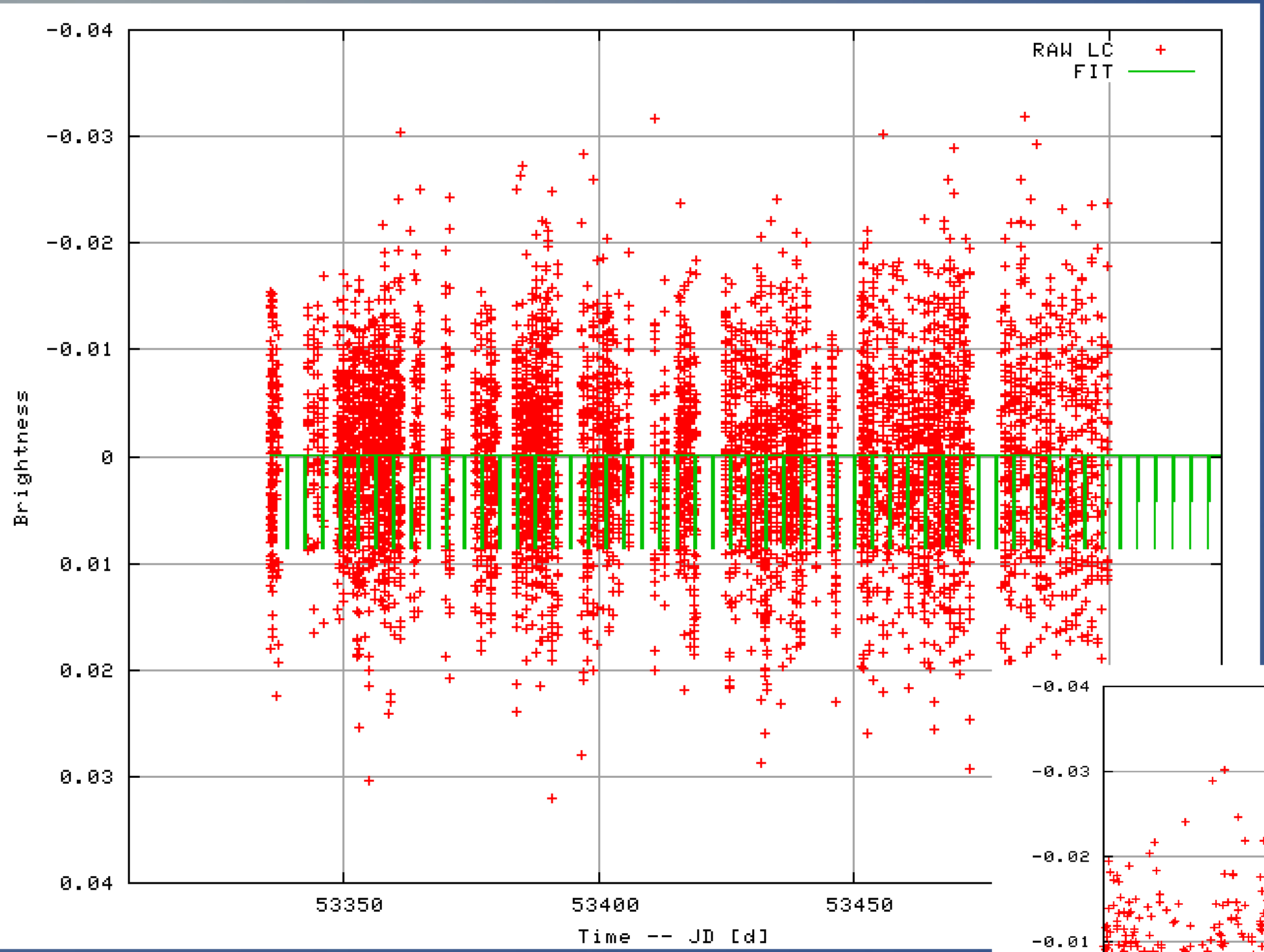
HATNet and HATSouth computers

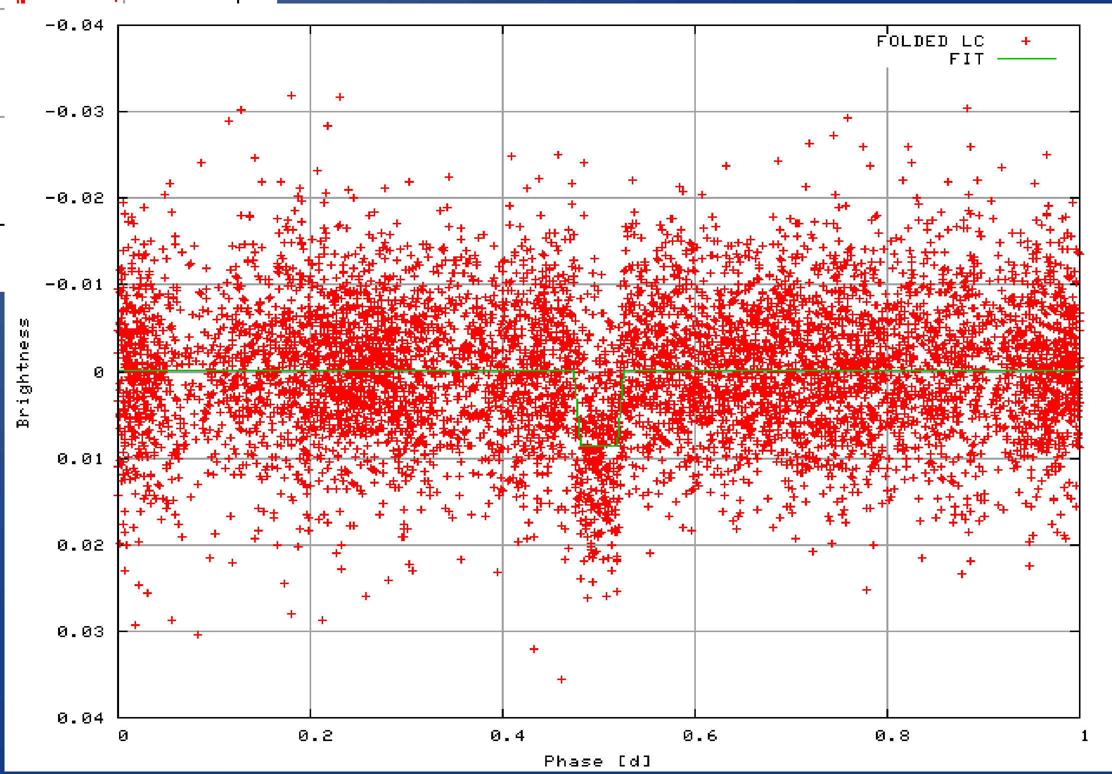
Search for transits





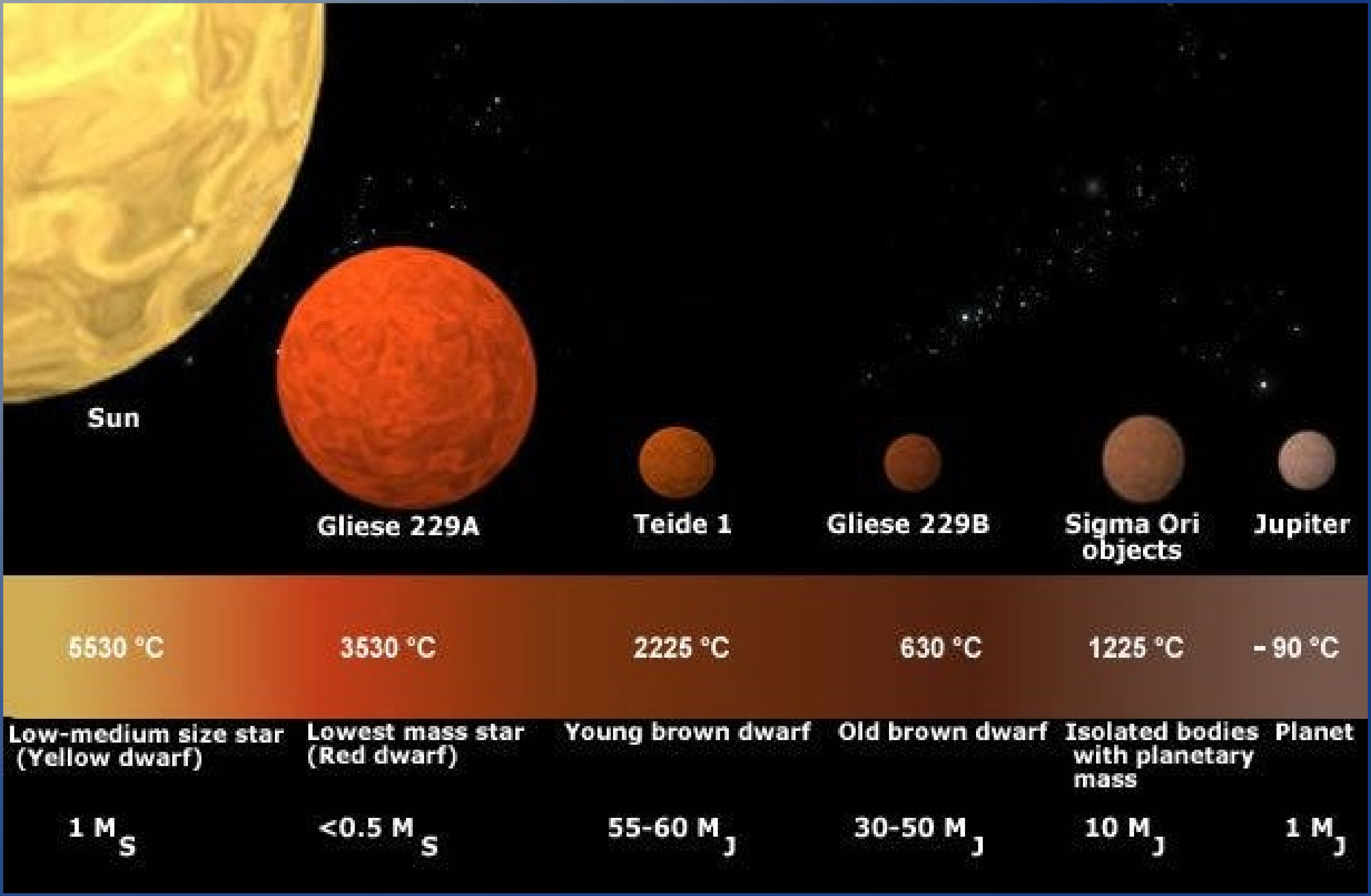
Search for transits





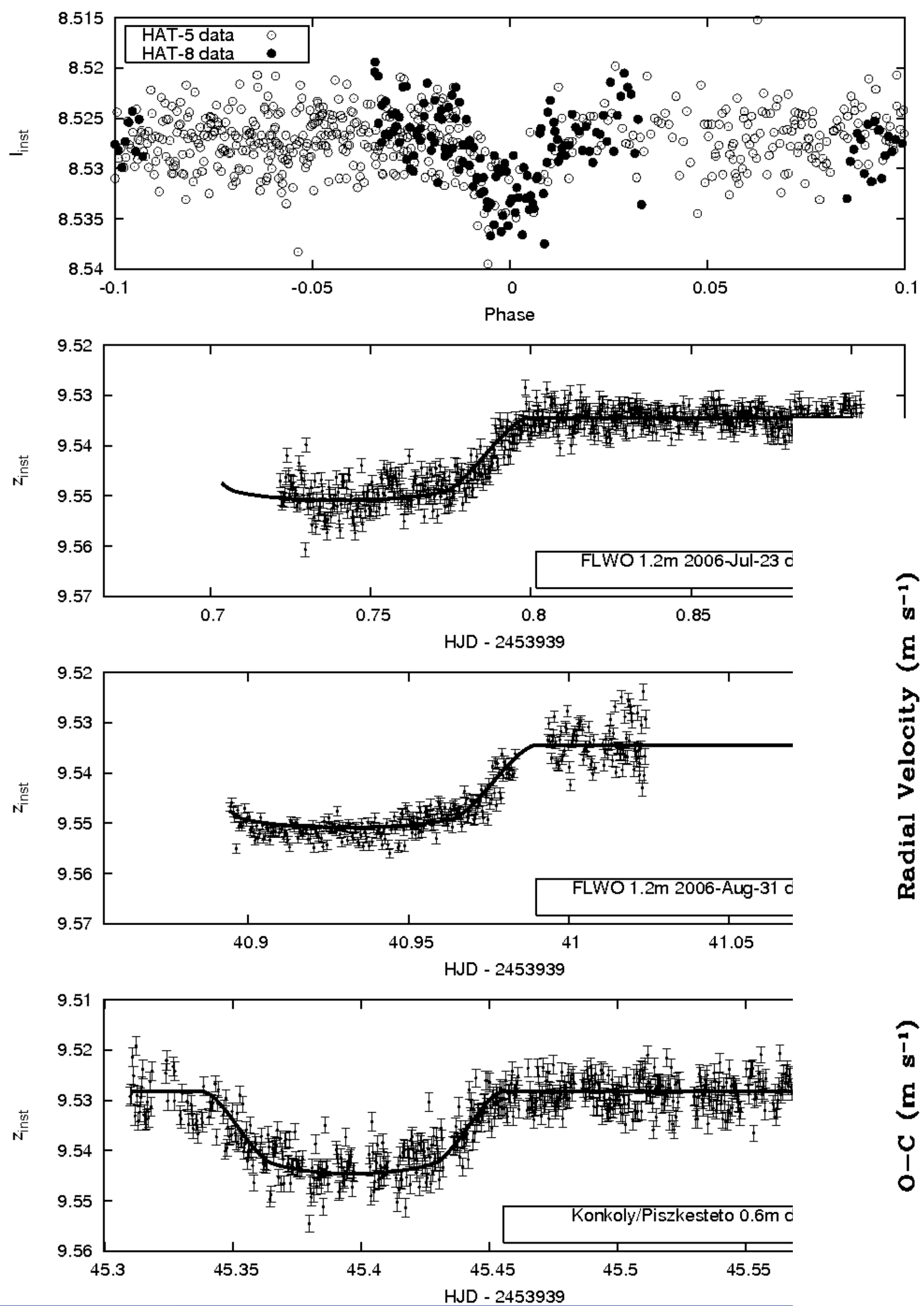
HAT-P-33b
Hartman et al., 2011

Not all that glitters is gold



Courtesy ESA

Highlights – HAT-P-1b



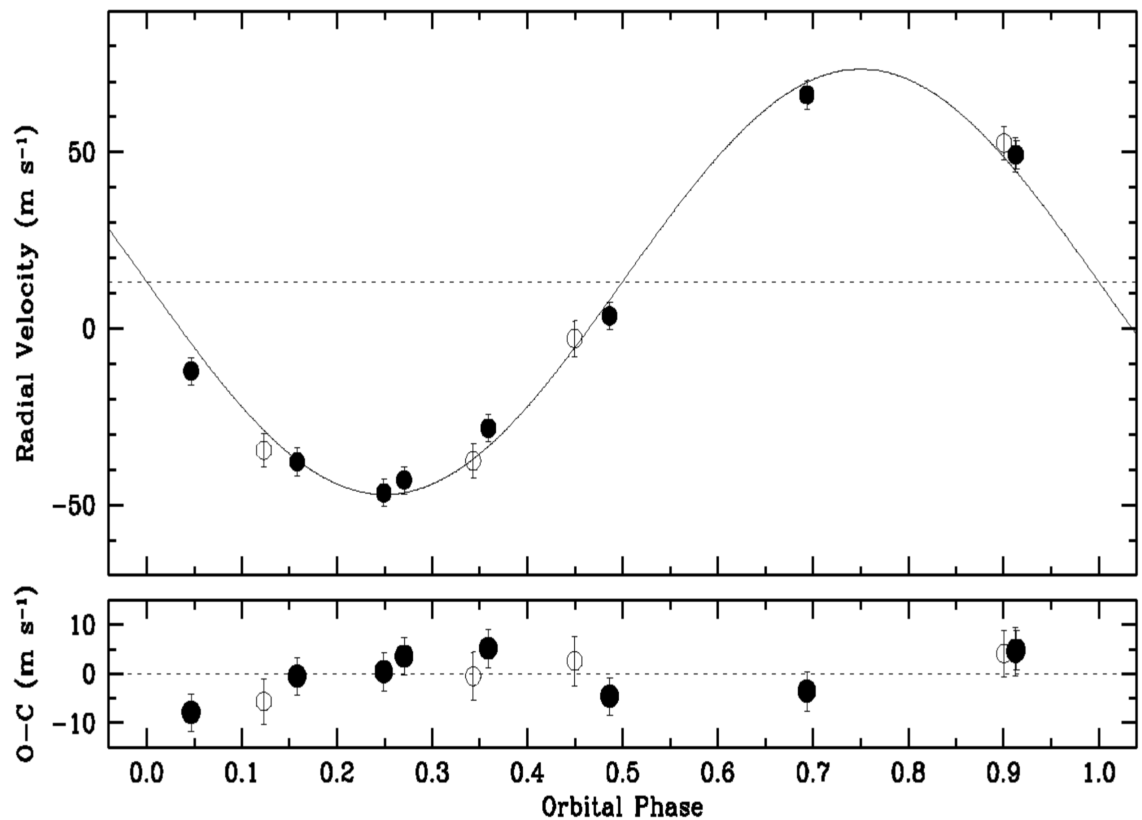
$R = 1.2R_J$ $M = 0.53M_J$

$\rho = 0.37$ g/cm^3

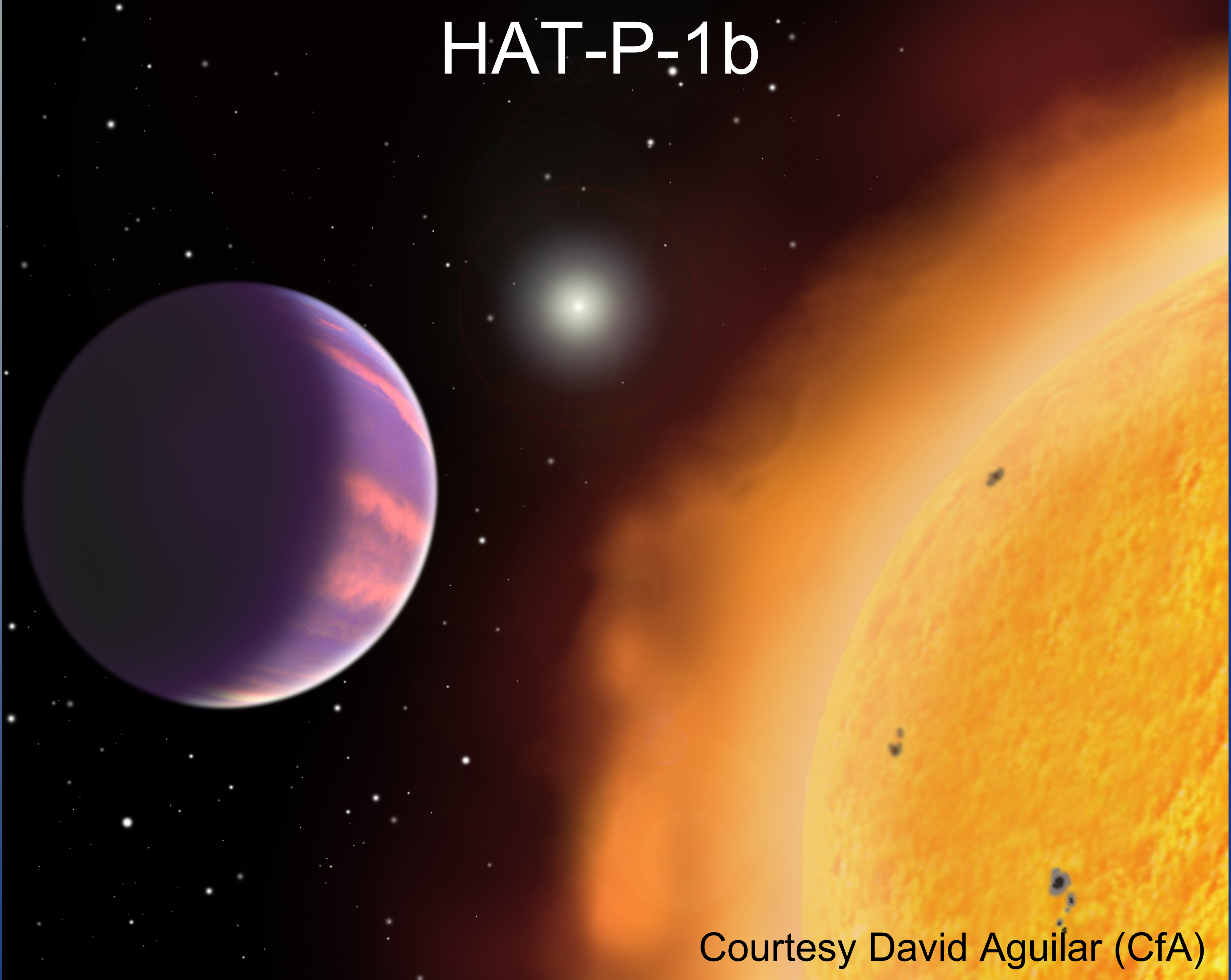
Inflated, low-mass hot Jupiter around one member of a binary star.

See Bakos et al. 2007,ApJ

Inflated radius: Burrows et al. 2007, ApJ

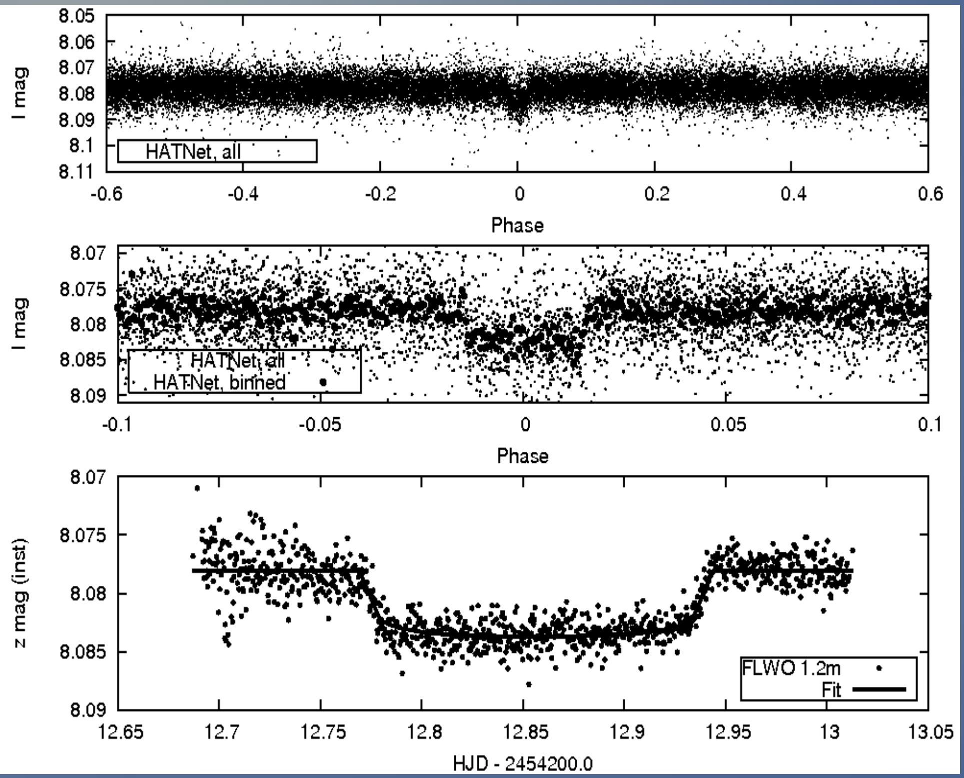


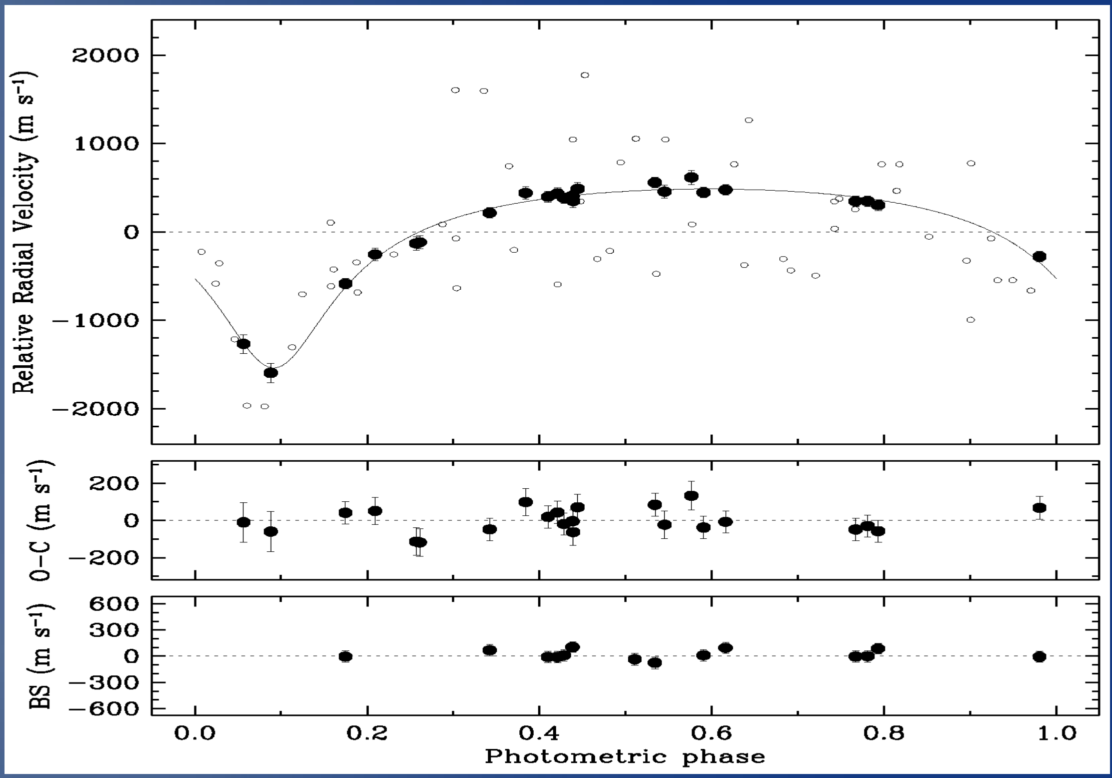
HAT-P-1b



Courtesy David Aguilar (CfA)

HAT-P-2b



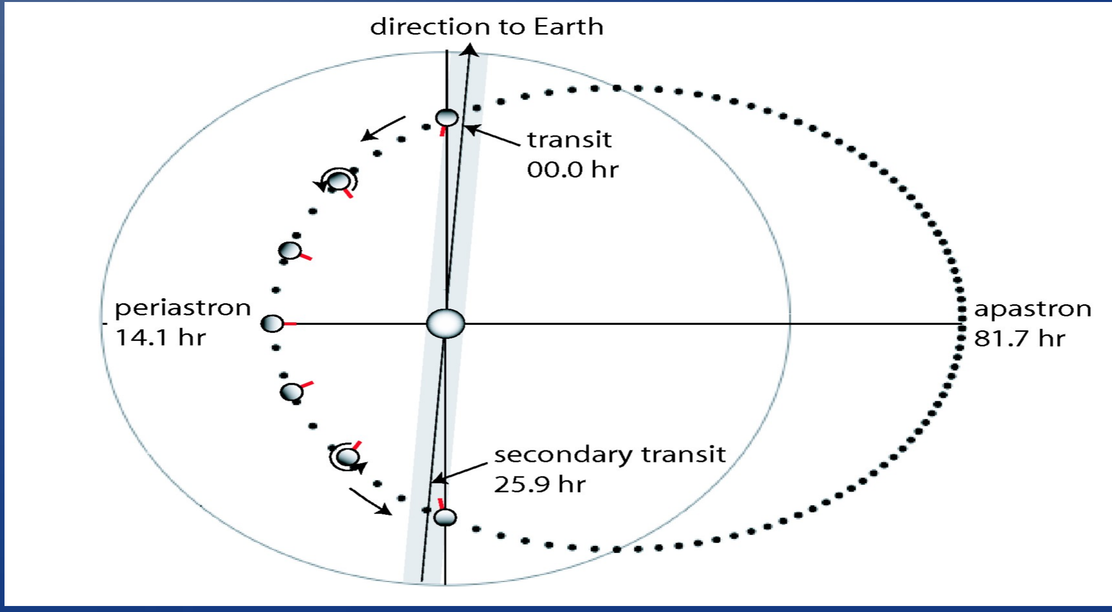


R = 1.16 R_J M = 9.09 M_J

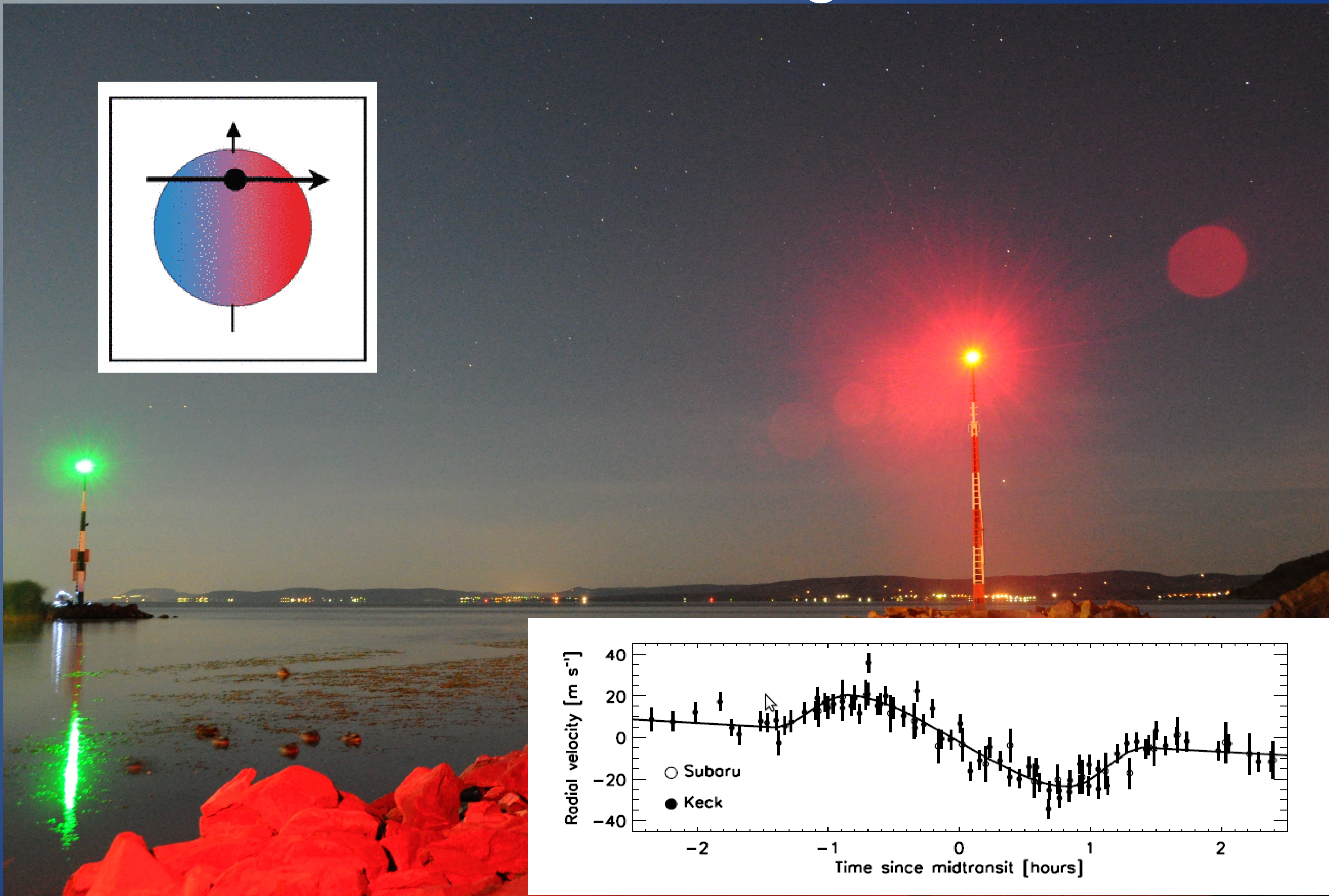
ρ = 7.6g/cm^3 P = 5.6d, e = 0.5

Super-massive, compact hot Jupiter

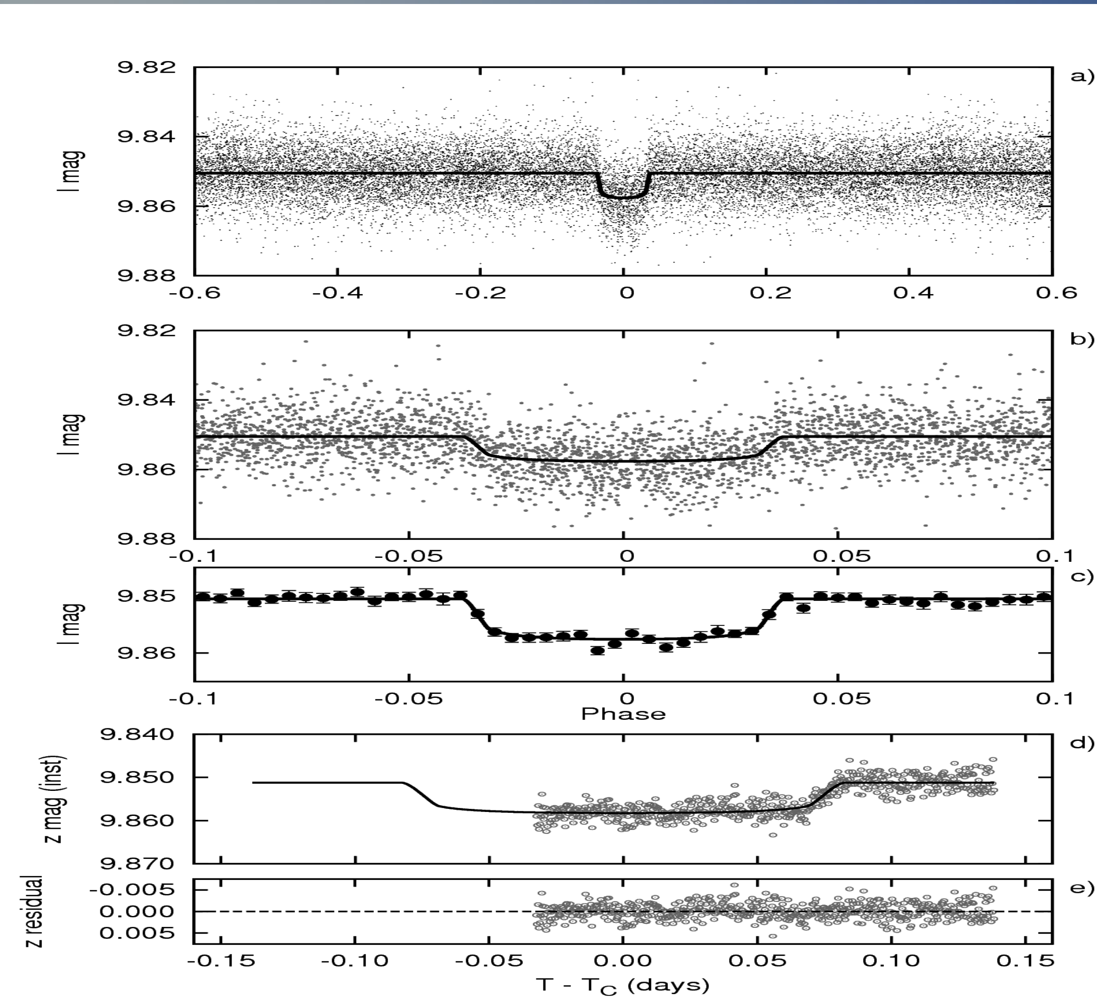
See Bakos et al. 2007, ApJ



The Rossiter-McLaughlin effect

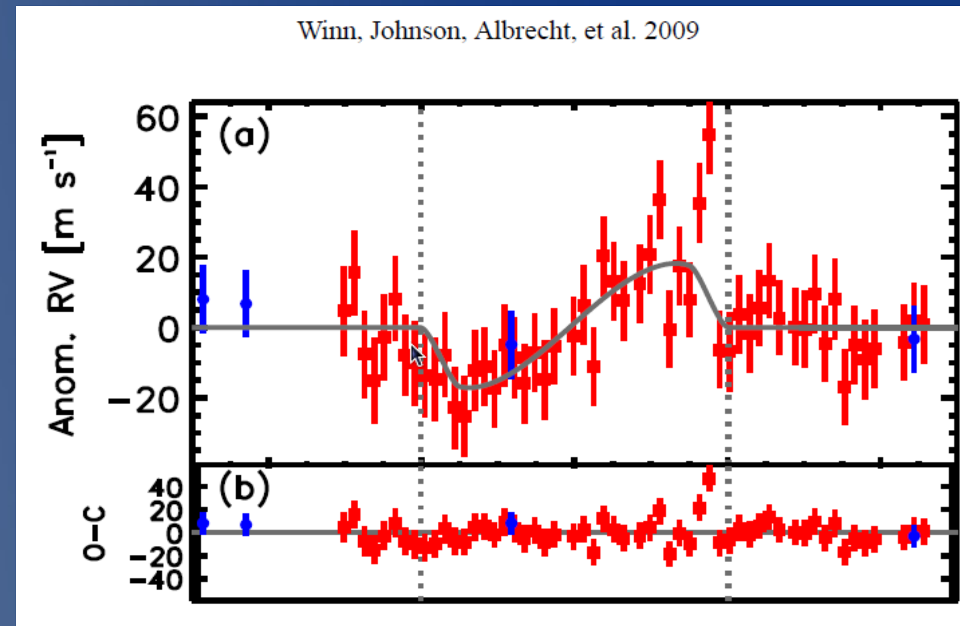


HAT-P-7b

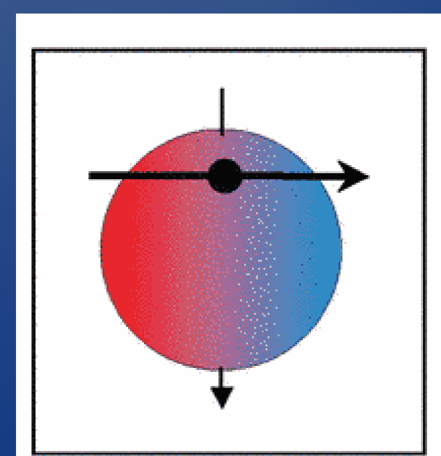


R = 1.36 R_J M = 1.78 M_J
ρ = 0.87 g/cm^3 P = 2.2 d
Very hot Jupiter (2700 K), in Kepler's field.
(Pál et al. 2008)

Retrograde or pole-on orbit!
(Winn et al. 2009, Narita et al. 2009)



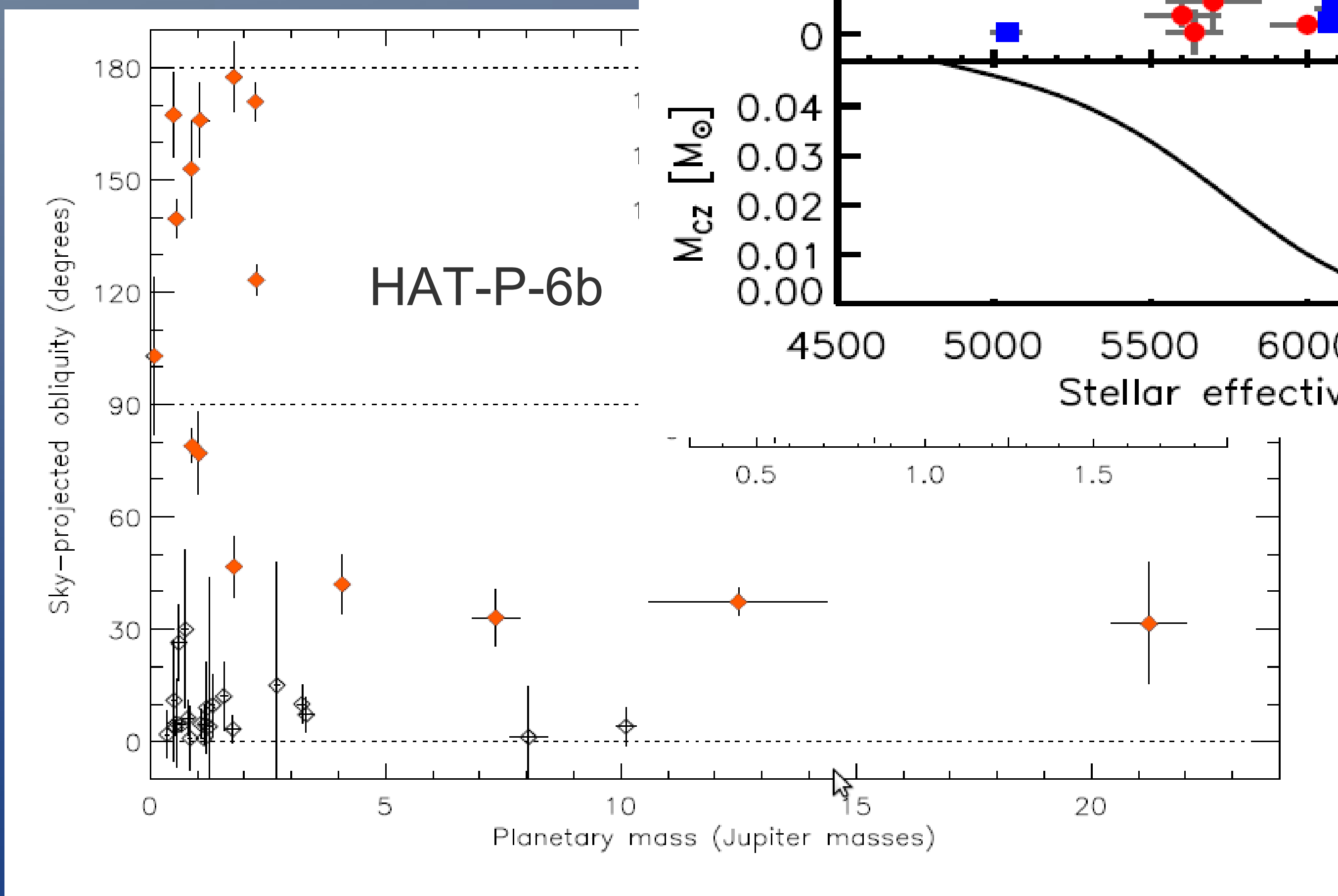
Retrograde or pole-on orbit!
(Winn et al. 2009, Narita et al. 2009)

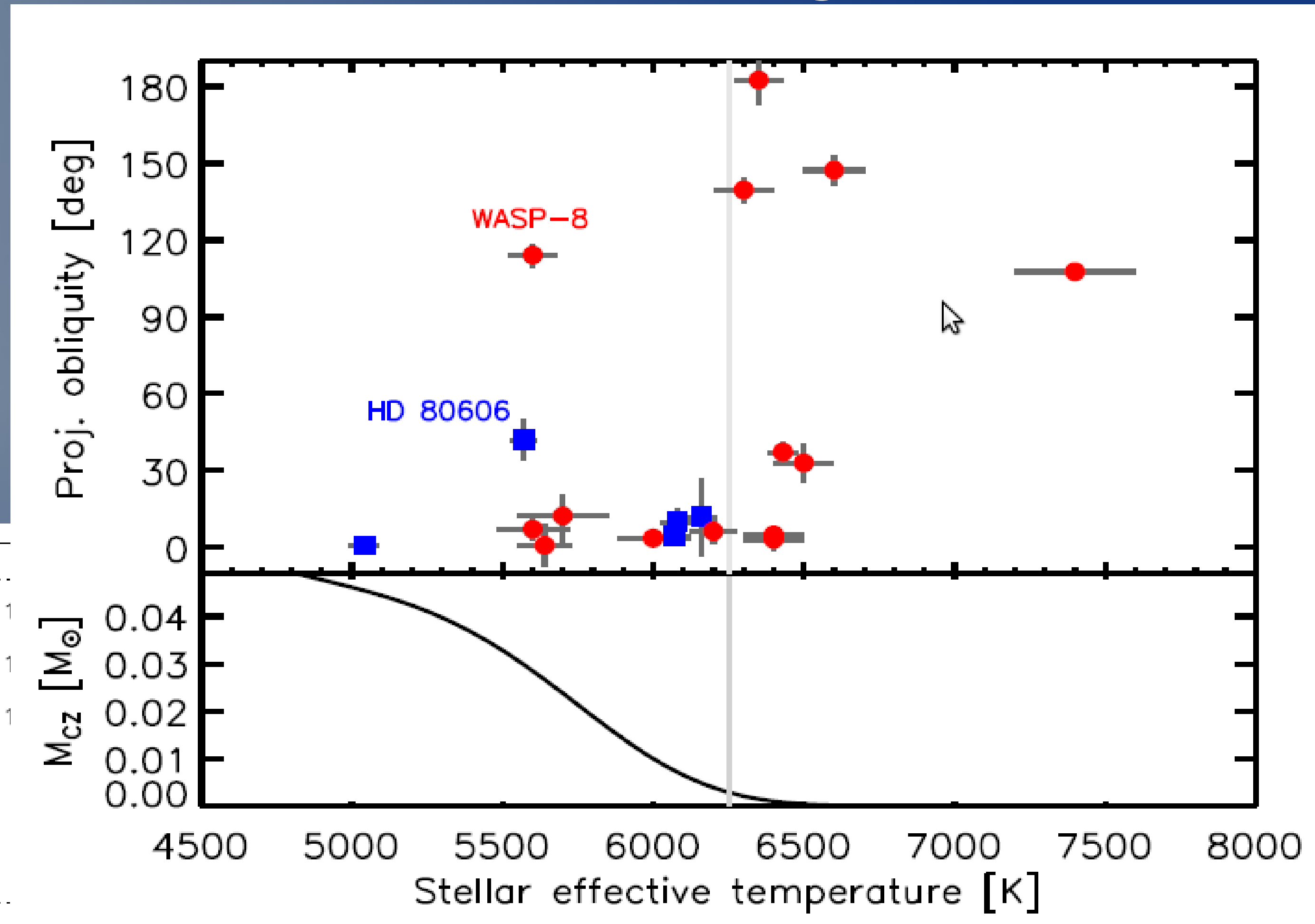


Hot stars with hot Jupiters have high obliquities

Winn, 2010
Schlaufman, 2010

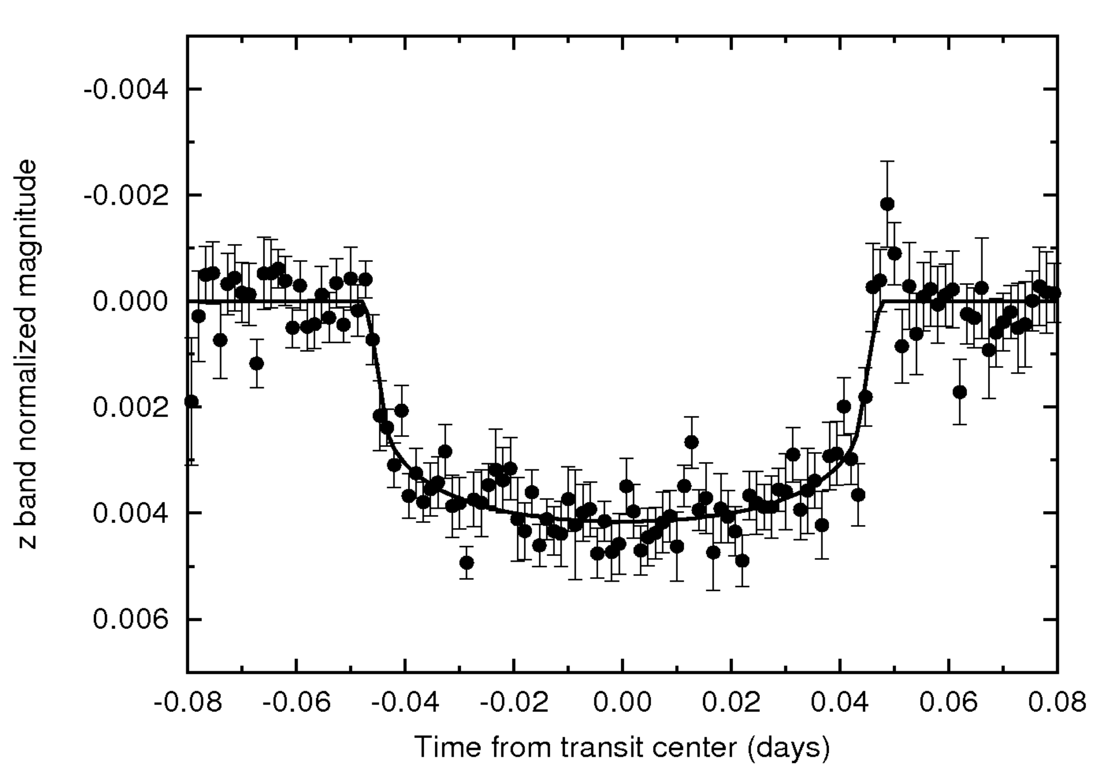
Hébrard, 2011

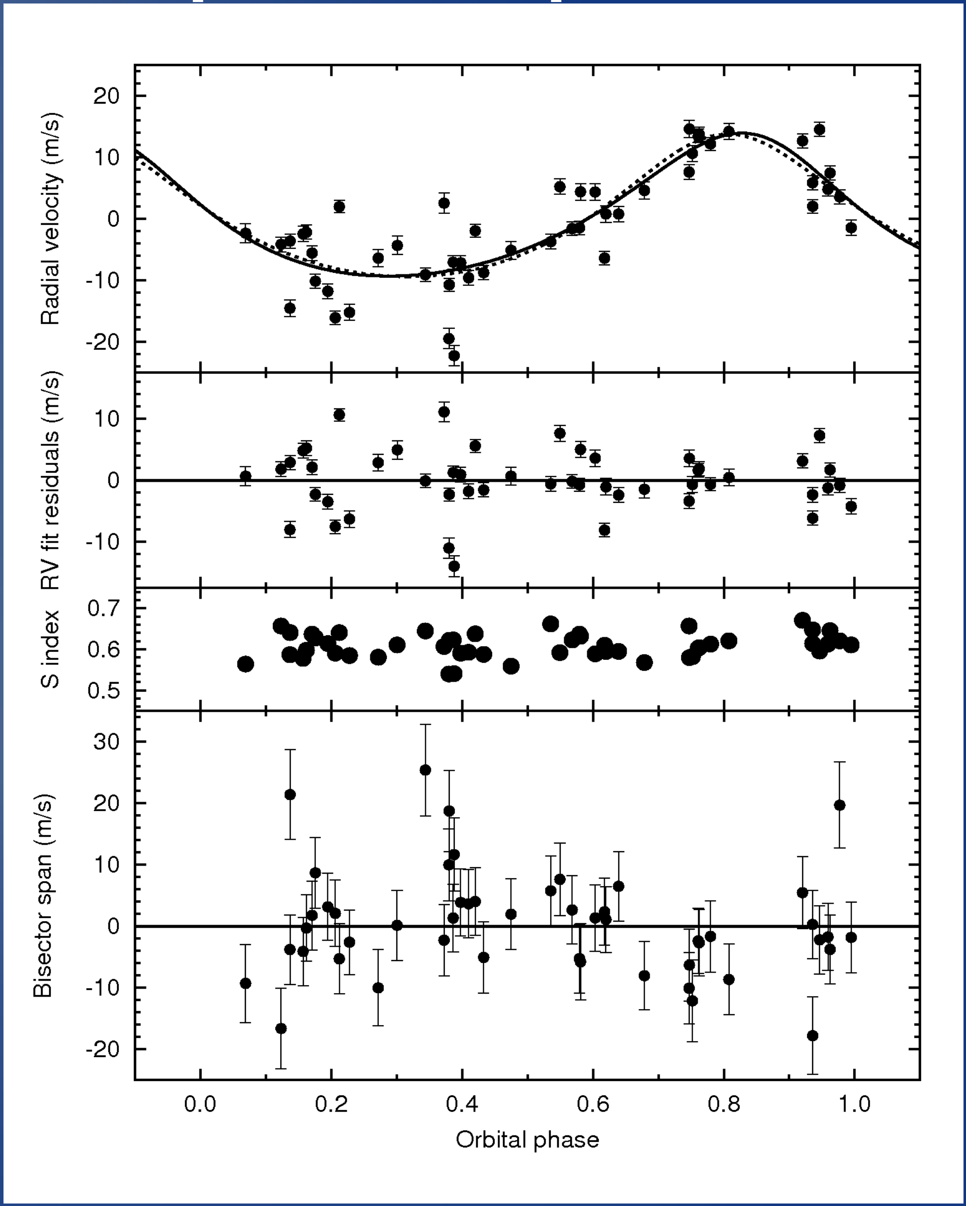




- Teff >6250 K → preferentially misaligned
- Retrograde → M < 3MJ?
- M>8MJ → misaligned?

HAT-P-11b: a warm super-Neptune





R = 0.4 R_J M = 0.08 M_J

ρ = 1.33 g/cm^3 P = 4.88 d

Warm super Neptune in Kepler's field orbiting a bright K dwarf.

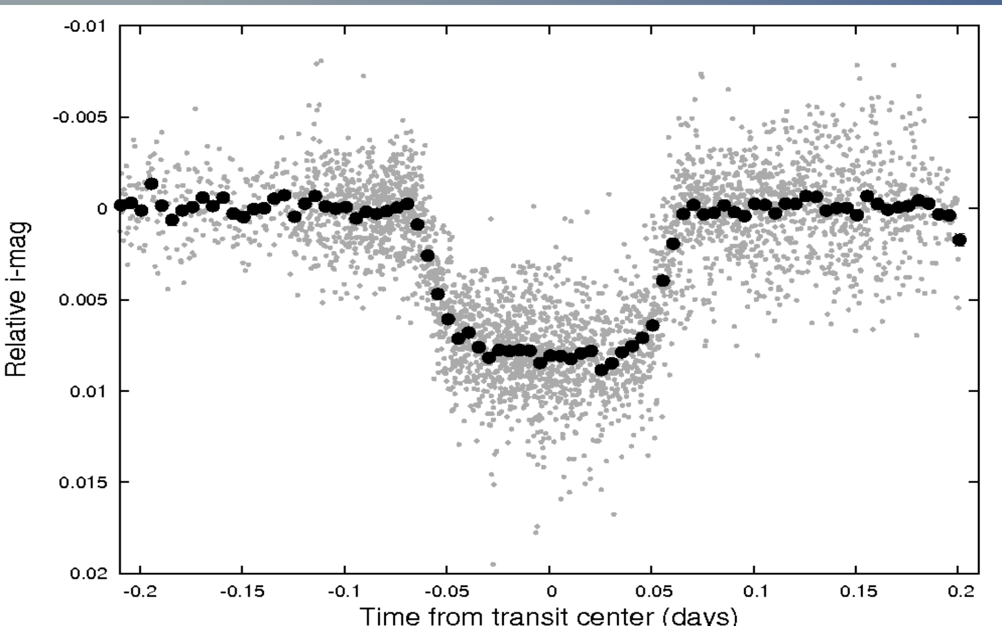
RV semi-amplitude: 11 m/s

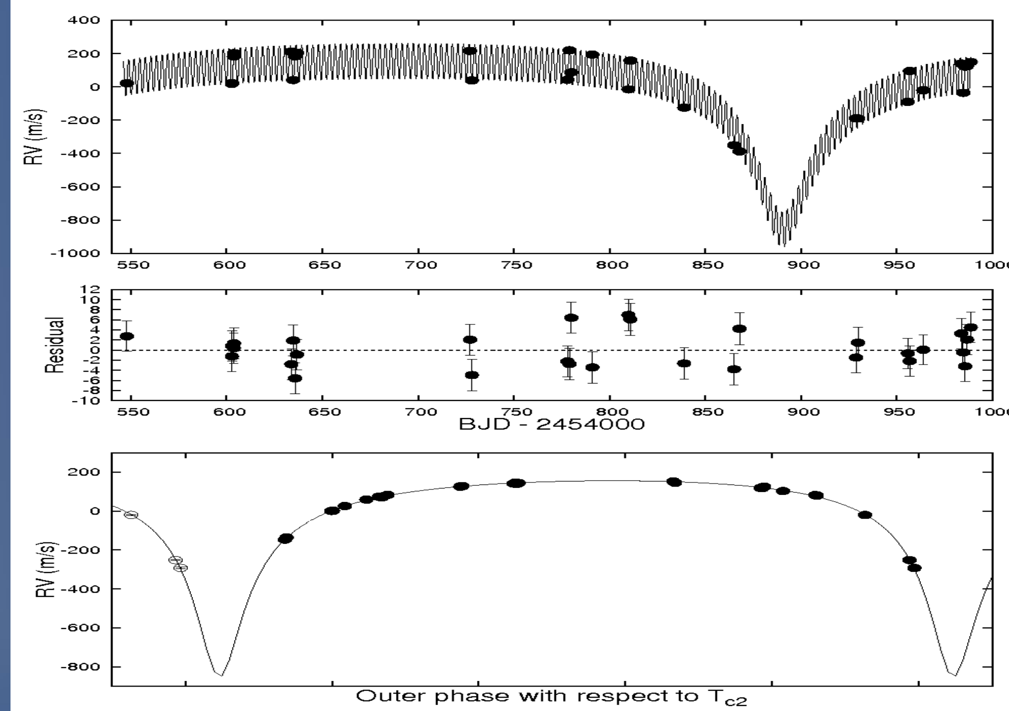
(Bakos et al. 2009)

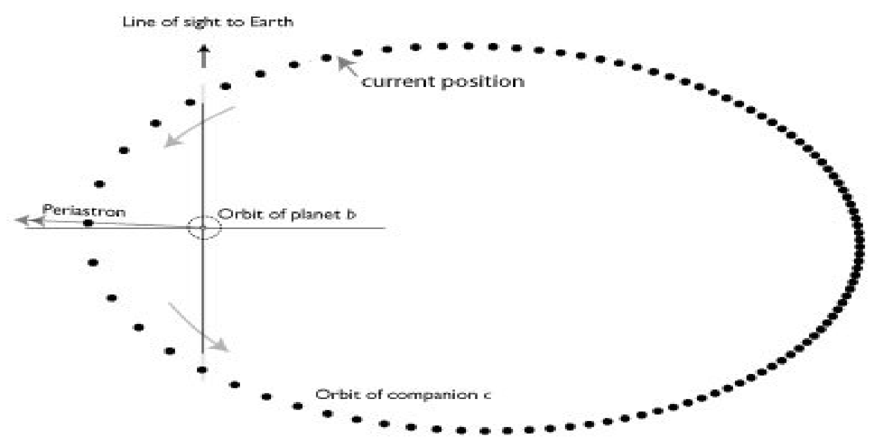
Tilted orbit w/respect to the stellar spin axis 103 ± 20 deg

(Winn et al. 2010)

HAT-P-13b,c: a double planet







HAT-P-13b: transiting HJ.
$M=0.85M_J$ $R=1.28R_J$ $\rho=0.5g/cm^3$ P=2.9d

HAT-P-13c: P=428d perturber on e=0.7 orbit, msini = 15.7 M_J *(Bakos et al. 2009)*

TTVs of “b” aid in refining parameters of “c”

Perturbation by “c” and tidal fixpoint configuration constrains structural parameters, Q and core-mass of “b” (Batygin 2009, Mardling, 2010)

Spin-orbit aligned, + 3^{rd} body: “d” (Winn, 2010)

Inflated planets – III

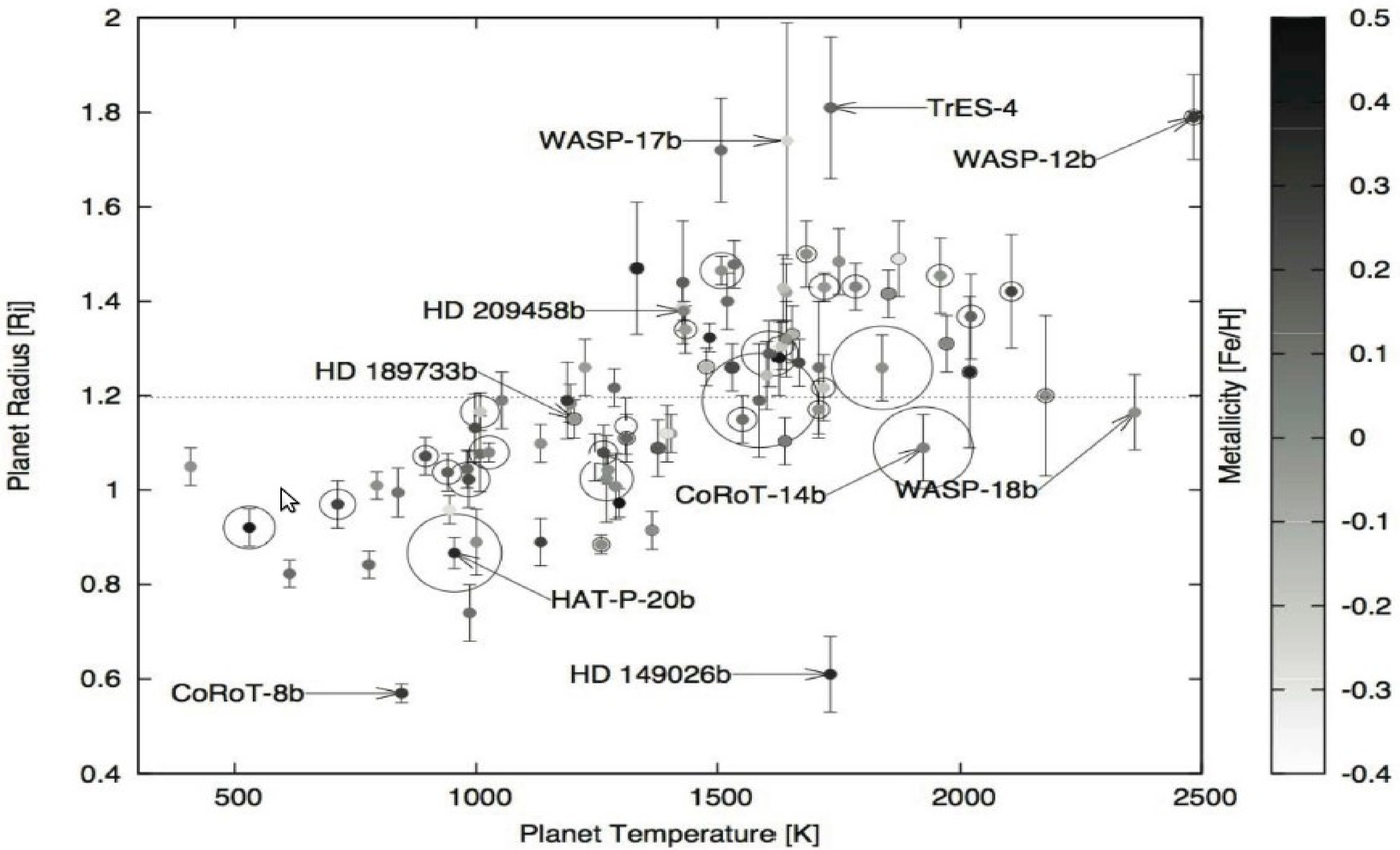
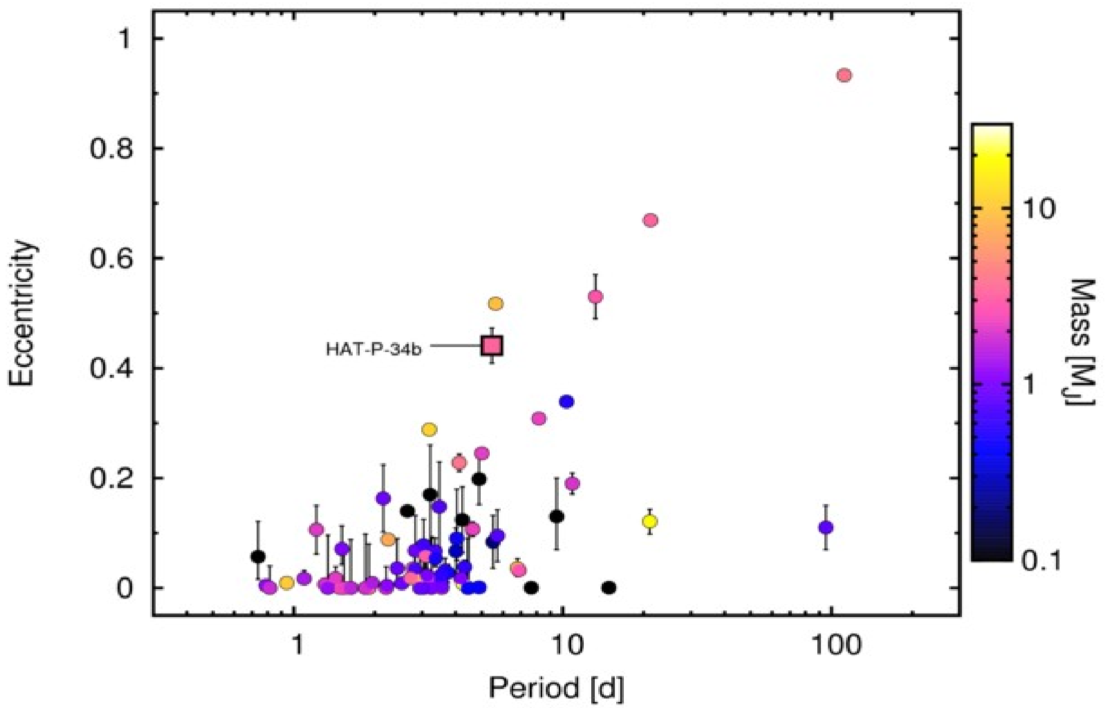


Fig. 1.— Radii and estimated effective temperatures for 90 transiting extrasolar planets with well-determined masses and radii. Circle size is in proportion to planetary mass, and the color of the inner circle indicates metallicity.

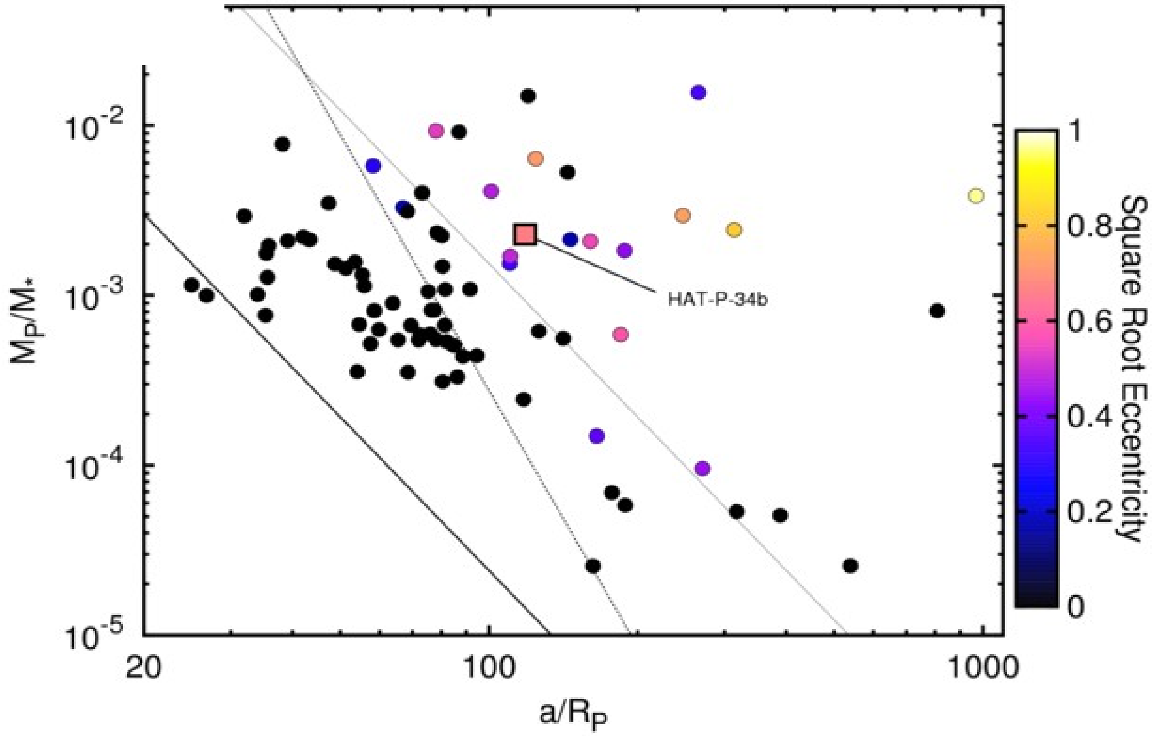
From Laughlin 2011

HAT-P-34b: an eccentric heavy mass planet



- P = 5.452 d
- M = 3.33 ± 0.2 M_J
- R = 1.20 ± 0.1 R_J
- ρ = 2.40 g cm^{-3}

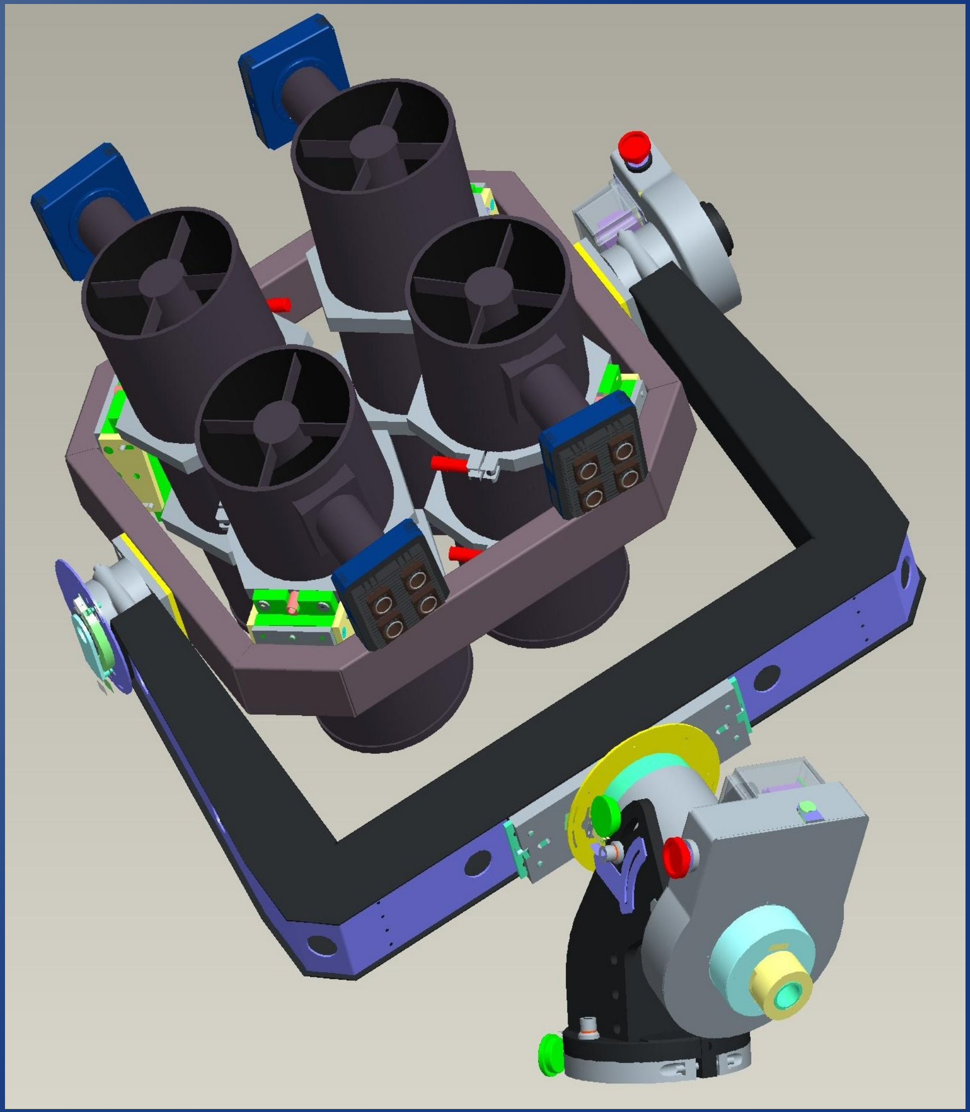
Bakos et al. 2012



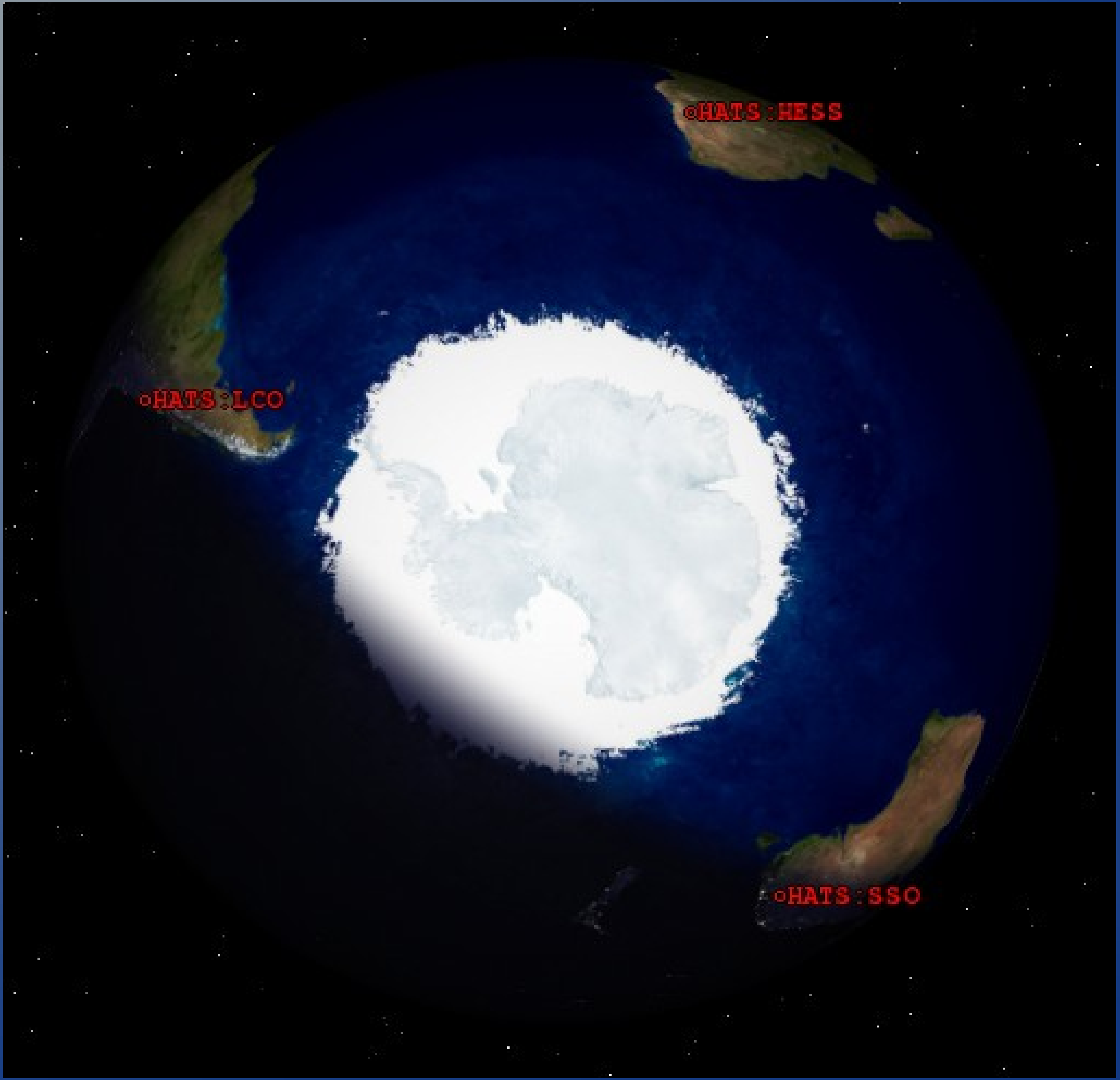
HAT-P-38b coming up soon!

The HAT-South project

- Longitudinally spaced global network of fully automated telescopes in the Southern hemisphere
- Almost 24 hour coverage
- 128 □° field of view per site
- Long period transits (up to P=20 days)
- Shallow transits: hot Neptunes and super Earths
- Joint effort of Princeton, PUC, ANU, MPIA.
- Estimate 1500 candidates/yr, up to 100 TEPs/yr (depending on follow-up)



HAT-South: the sites



The prototype at Pécel/Hungary

HAT-South installation in Namibia

HAT-South installation in Namibia

The HAT-South instrument close-up

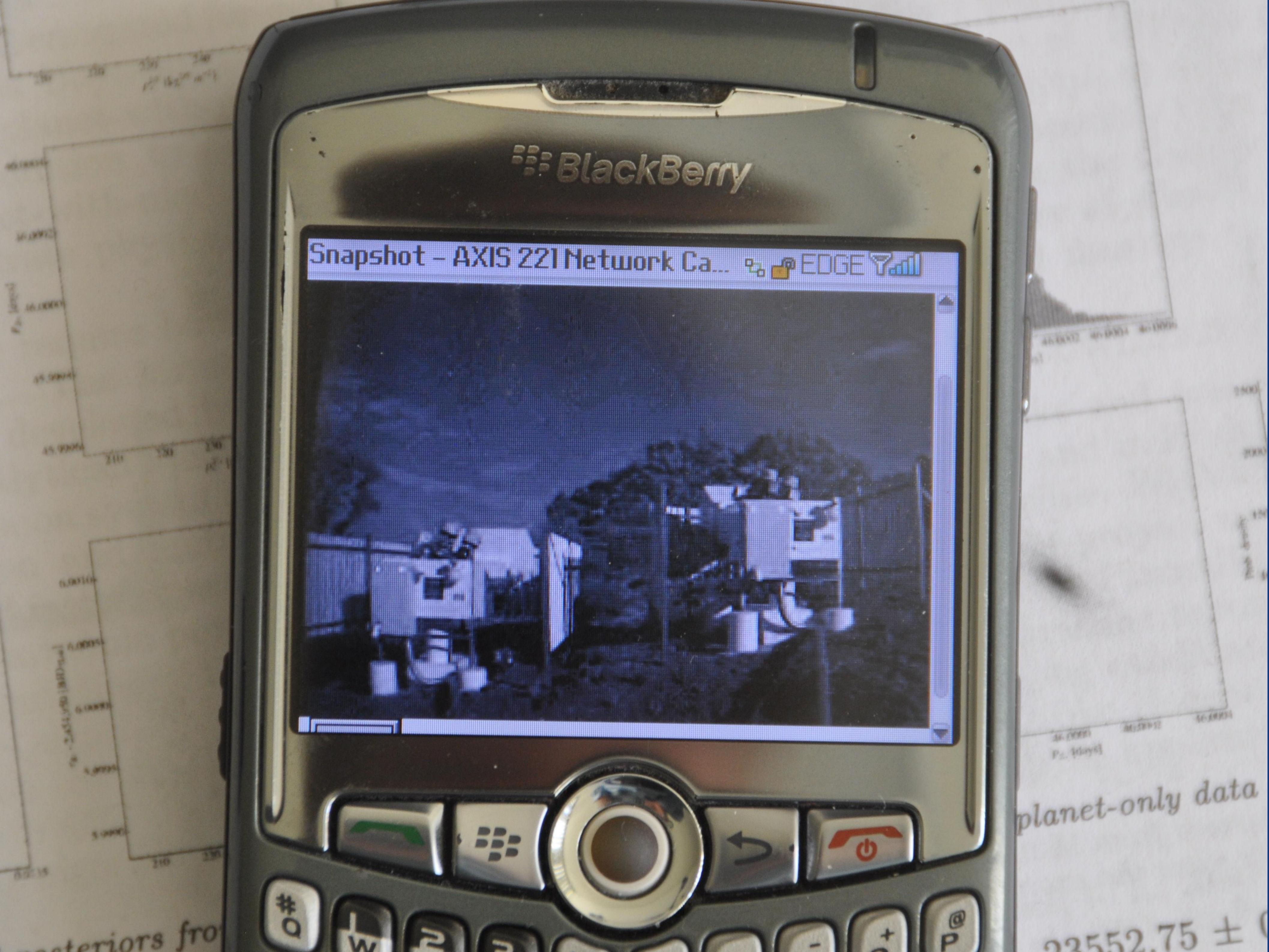
- 4x f/2.8 optics
- 4x 4Kx4K CCD
- 3.7 “/pixel
- 6” FWHM
- Sloan r
- 6 such instruments installed: 2-2-2 in Chile-Australia-Namibia

HAT-South first light image (1 chip out of 4)

HAT-South units at LCO


HAT-South in Namibia

HAT-South: Siding Springs Observatory


BlackBerry
Snapshot - AXIS 221 Network Ca...
EDGE
planet-only data

All-sky (fisheye) image