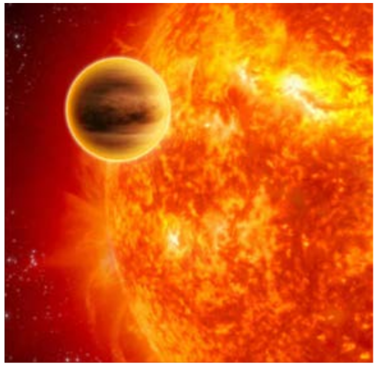


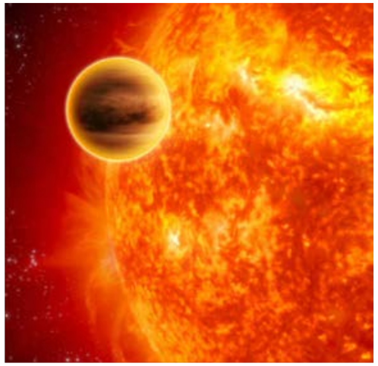
Summary of ground based (transit) surveys

Don Pollacco
University of Warwick

The Astrophysical Journal, 529:L41-L44, 2000 January 20

A Transiting "51 Peg-like" Planet[1]

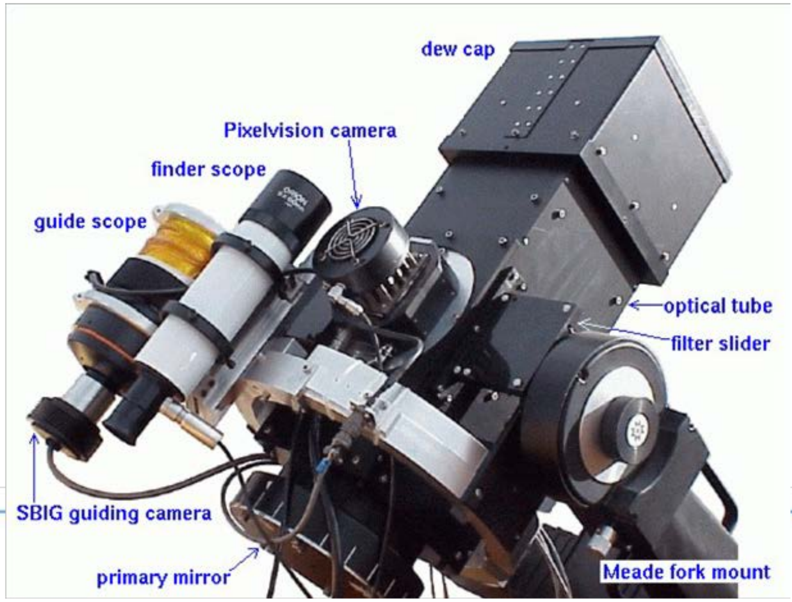
Gregory W. Henry,[2] Geoffrey W. Marcy,[3] R. Paul Butler,[4] and Steven S. Vogt[5]



THE ASTROPHYSICAL JOURNAL, 529:L45–L48, 2000 January 20

DETECTION OF PLANETARY TRANSITS ACROSS A SUN-LIKE STAR

DAVID CHARBONNEAU,[1,2] TIMOTHY M. BROWN,[2] DAVID W. LATHAM,[1] AND MICHEL MAYOR[3]
Received 1999 November 19; accepted 1999 November 23; published 1999 December 16



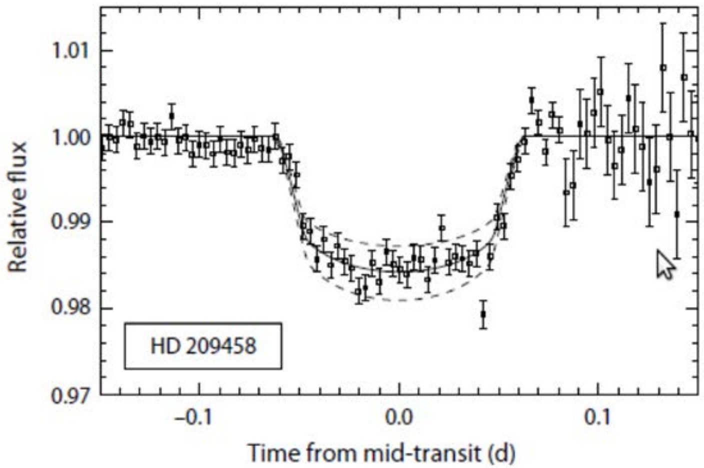
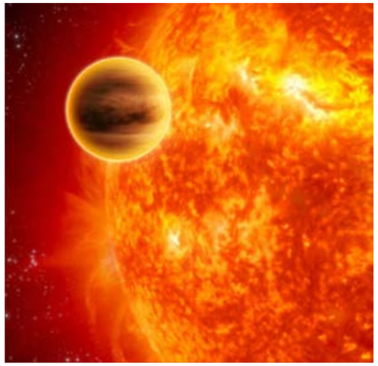


Figure 6.1: The first detected transiting exoplanet, HD 209458, showing the measured flux versus time. Measurement noise increases to the right due to increasing atmospheric air mass. From Charbonneau et al. (2000, Figure 2), reproduced by permission of the AAS.

Outline

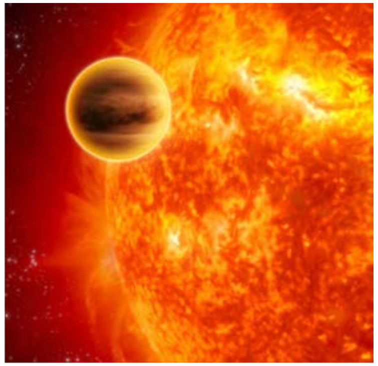


Why transits are important? Limitations of the technique

20 years since the first exoplanet transit - Results from historical surveys
- First generation
- Second generation

Current/future surveys – what are they doing?
– synergy with TESS

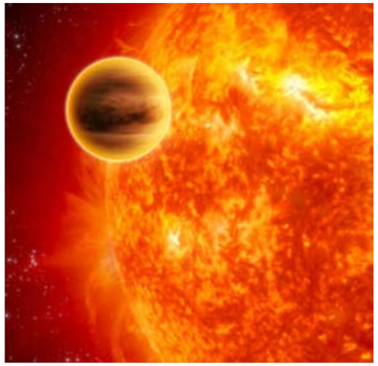
Why transit detections are so important



Accurate and (mostly) physics independent measurement of planetary radius
- Main limitation is our understanding of the physical properties of stars

Accurate and (mostly) physics independent measurement of orbital inclination
- Main limitation is our understanding of limb darkening

Scientifically - Atmospheres, bulk planetary parameters, RM etc

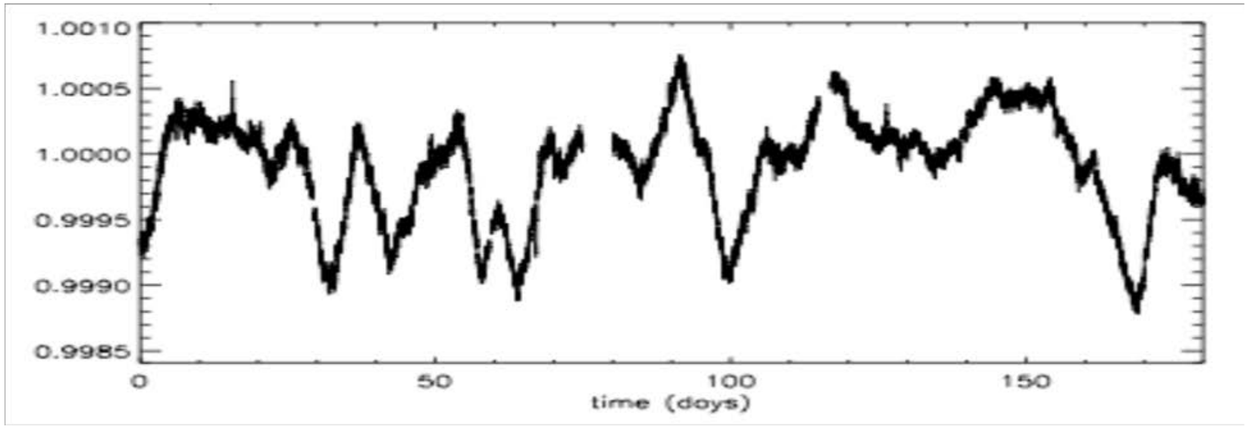


Transit survey limitations

Very inefficient – geometric probability low eg 4d -> ~10% probability

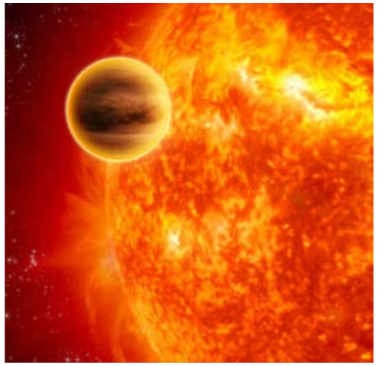
Mimics – additional observations needed to rule out

Stellar activity



Activity a problem for detection but more serious for RV spectroscopy

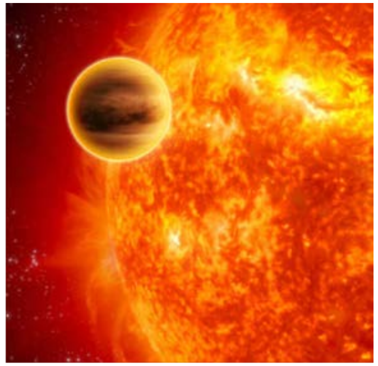
The scene in 2001…..

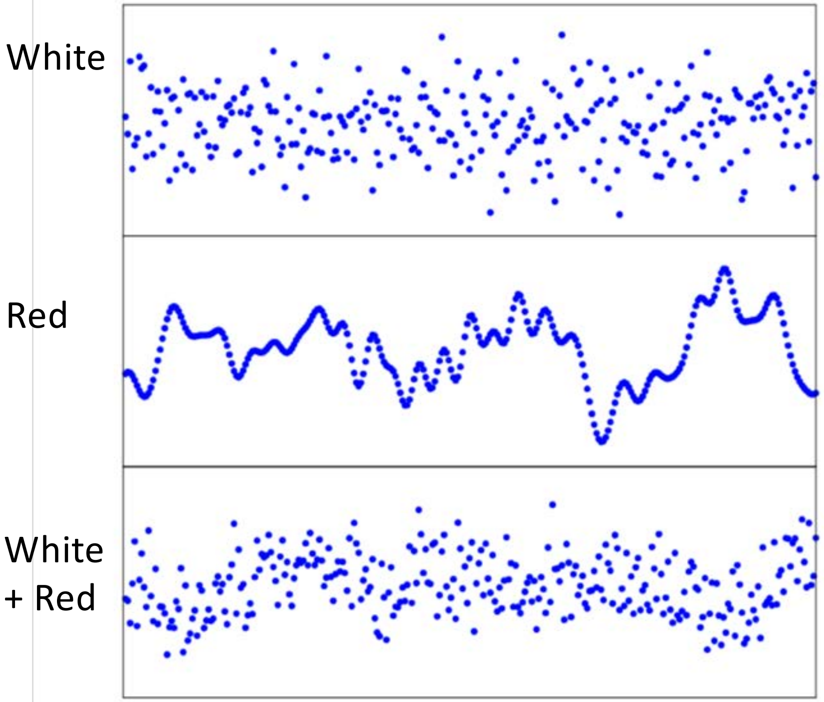


Programme		D (cm)	focal ratio	$\Omega^{0.5}$ (deg)	N_x (kpix)	N_y (kpix)	no. of CCDs	pixel (arcsec)	sky mag	star mag	d (pc)	stars ($x10^3$)	planets /month
1	PASS	2.5	2.0	127.25	2.0	2.0	15	57.75	6.8	9.4	83	18	6.3
2	WASP0	6.4	2.8	8.84	2.0	2.0	1	15.54	9.6	11.8	246	2	0.8
3	ASAS-3	7.1	2.8	11.21	2.0	2.0	2	13.93	9.9	12.0	272	5	1.7
4	RAPTOR	7.0	1.2	55.32	2.0	2.0	8	34.38	7.9	11.1	179	33	11.7
5	TrES	10.0	2.9	10.51	2.0	2.0	3	10.67	10.5	12.7	362	10	3.5
6	XO	11.0	1.8	10.06	1.0	1.0	2	25.00	8.6	11.9	258	3	1.2
7	HATnet	11.1	1.8	19.42	2.0	2.0	6	13.94	9.9	12.5	338	28	9.7
8	SWASP	11.1	1.8	31.71	2.0	2.0	16	13.94	9.9	12.5	338	74	26.0
9	Vulcan	12.0	2.5	7.04	4.0	4.0	1	6.19	11.6	13.4	497	12	4.1
10	RAPTOR-F	14.0	2.8	5.93	2.0	2.0	2	7.37	11.3	13.4	498	8	2.9
11	BEST	19.5	2.7	3.01	2.0	2.0	1	5.29	12.0	14.2	668	5	1.8
12	Vulcan-S	20.3	1.5	6.94	4.0	4.0	1	6.10	11.7	14.1	642	24	8.5
13	SSO/APT	50.0	1.0	5.05	2.9	3.1	2	4.20	12.5	15.5	1103	65	22.8
14	RATS	67.0	3.0	1.31	2.0	2.0	1	2.30	13.8	16.4	1548	12	4.2
15	TeMPEST	76.0	3.0	0.77	2.0	2.0	1	1.35	15.0	17.1	1944	8	2.9
16	EXPLORE-OC	101.6	7.0	0.32	2.0	3.3	1	0.44	17.1	18.4	2881	5	1.6
17	PISCES	120.0	7.7	0.38	2.0	2.0	4	0.33	17.1	18.6	3045	8	2.7
18	ASP	130.0	13.5	0.17	2.0	2.0	1	0.30	17.1	18.7	3125	2	0.6
19	OGLE-III	130.0	9.2	0.59	2.0	4.0	8	0.26	17.1	18.7	3125	20	7.1
20	STEPSS	240.0	0.0	0.41	4.0	2.0	8	0.18	17.1	19.5	3757	17	5.9
21	INT	250.0	3.0	0.60	2.0	4.0	4	0.37	17.1	19.5	3800	37	13.1
22	ONC	254.0	3.3	0.53	2.0	4.0	4	0.33	17.1	19.5	3817	30	10.5
23	EXPLORE-N	360.0	4.2	0.57	2.0	4.0	12	0.21	17.1	19.9	4196	46	16.2
24	EXPLORE-S	400.0	2.9	0.61	2.0	4.0	8	0.27	17.1	20.0	4313	58	20.1

Horne 2003

Correlated noise





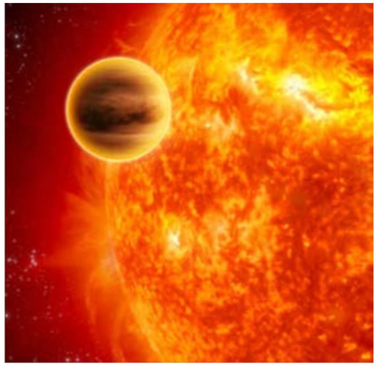
$$S_d \equiv d/\sigma_d = \frac{d}{\sigma_0} n^{1/2}$$

$$S_r \equiv \frac{d}{\sigma_d} = \frac{d}{\sqrt{\frac{\sigma_0^2}{n} + \frac{1}{n^2}\sum_{i \neq j} C_{ij}}}$$

Where C_{ij} is the covariance coefficients between the i^{th} and j^{th} measurements (during the transit)

Pont, Zucker, Queloz 2006

First Generation Surveys



HAT (62), Multi-site (longitude) 7 instruments

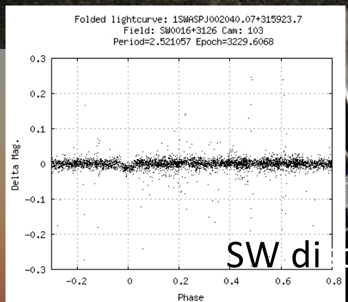
TRES (5),

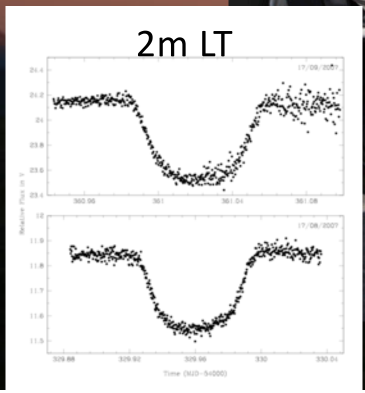
WASP (192), 1 facility in each hemisphere

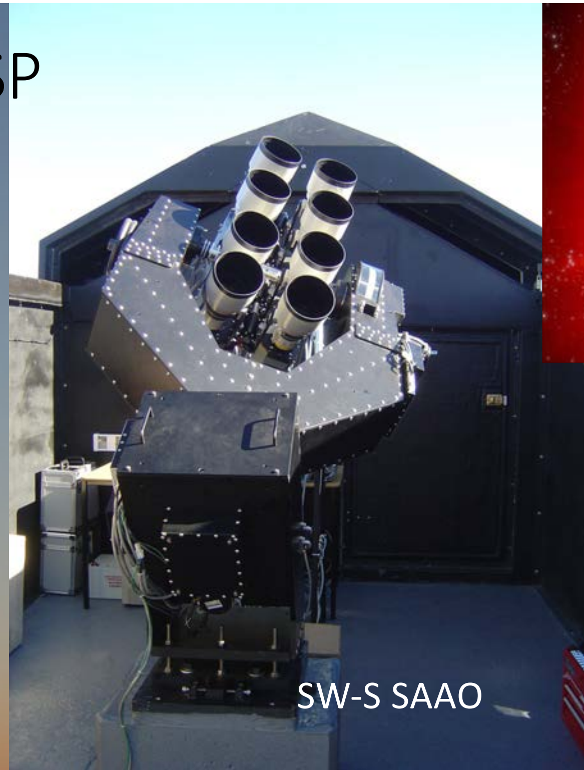
XO (7)

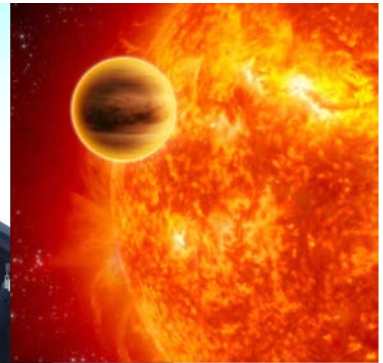
HAT/WASP/XO all used large aperture short focus camera lenses = > lots of systematics

Ground based transits: SuperWASP



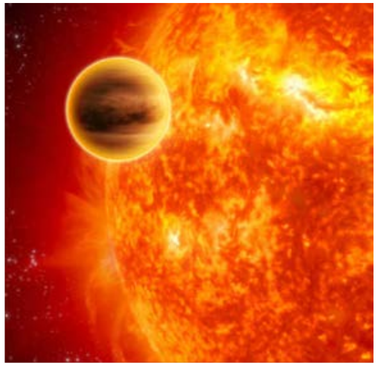






WASP project is the leading survey with >190 confirmed planets. Largest, lowest density, backward orbit, highest irradiation etc

Second Generation Surveys



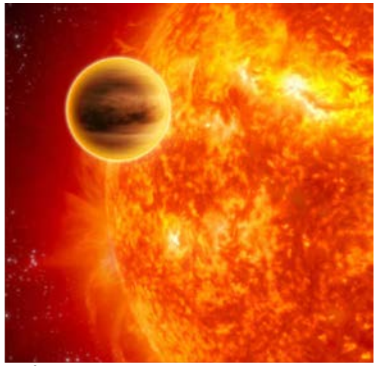
Surveys designed to look at low luminosity stars (red dwarfs)

MEarth M0-5 (3) North and South

Apache M0-5 (0)

Qatar K (10)

Mearth - Monitoring individual M dwarfs



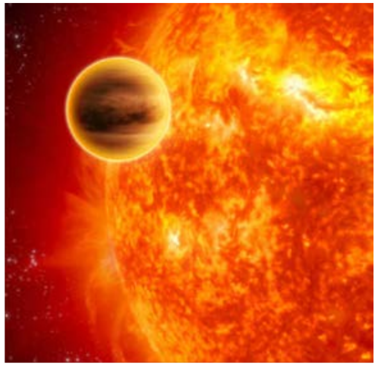
Quality not quantity….

GJ1214b 2.7 $R_{\oplus}$ Superearth

GJ1132b 1.2 $R_{\oplus}$

LHS1140b 1.7 $R_{\oplus}$

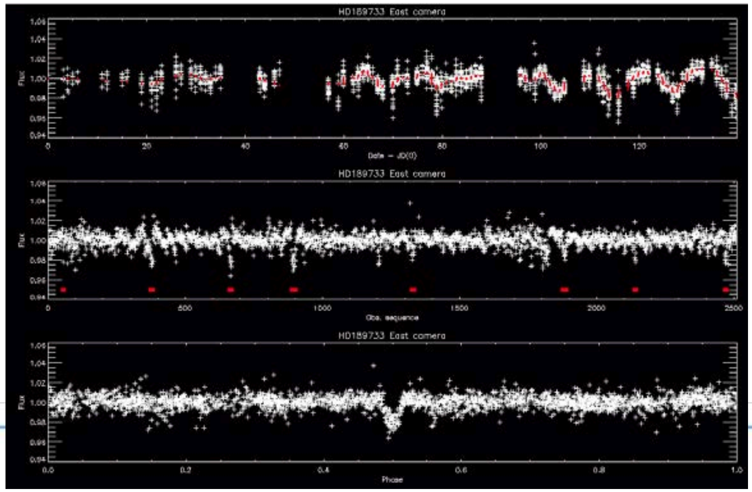
Second Generation Surveys



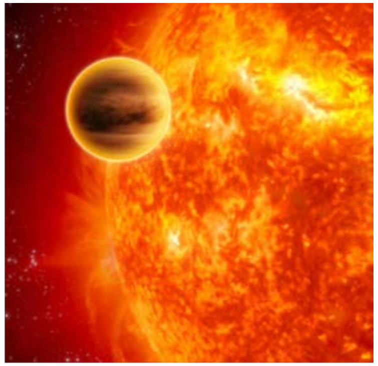
Surveys designed to look at at bright stars

KELT (23)

Mascara (4)



Current/Future Surveys



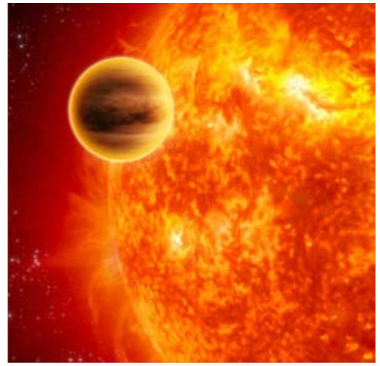
HAT-S (66)

NGTS K stars (10)

Trappist/Speculoos – Late M stars (pointed at individuals stars) (7)

HAT-PI (whole sky)

Push towards small stars: HATS



Another excellent survey from Bakos et al

3 sites: Chile, Namibia, Australia, operational since 2010

Smaller fov, fainter stars
66 Planets

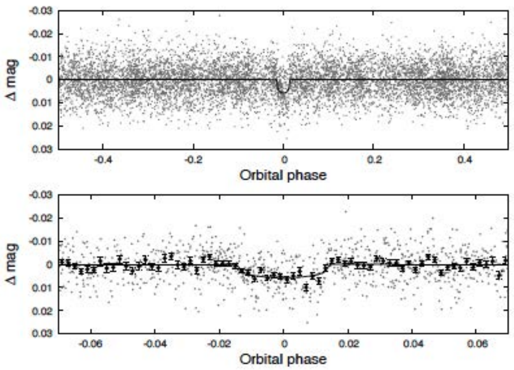


FIG. 1.— Unbinned instrumental r band light curve of HATS-7 folded with the period $P = 3.1853150$ days resulting from the global fit described in Section 3. The solid line shows the best-fit transit model (see Section 3). In the lower panel we zoom-in on the transit; the dark filled points here show the light curve binned in phase using a bin-size of 0.002.

So far highlight is HATS-7b (Bakos et al), 8b (Baylis et al) - Super-Neptunes

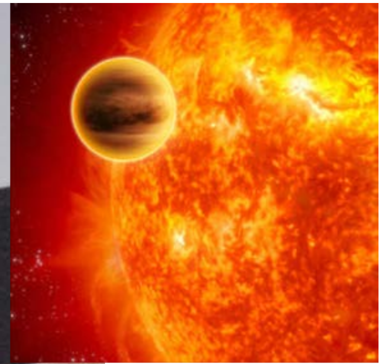
Depths are 0.5-1%. HATNET/WASP have few similar depth objects

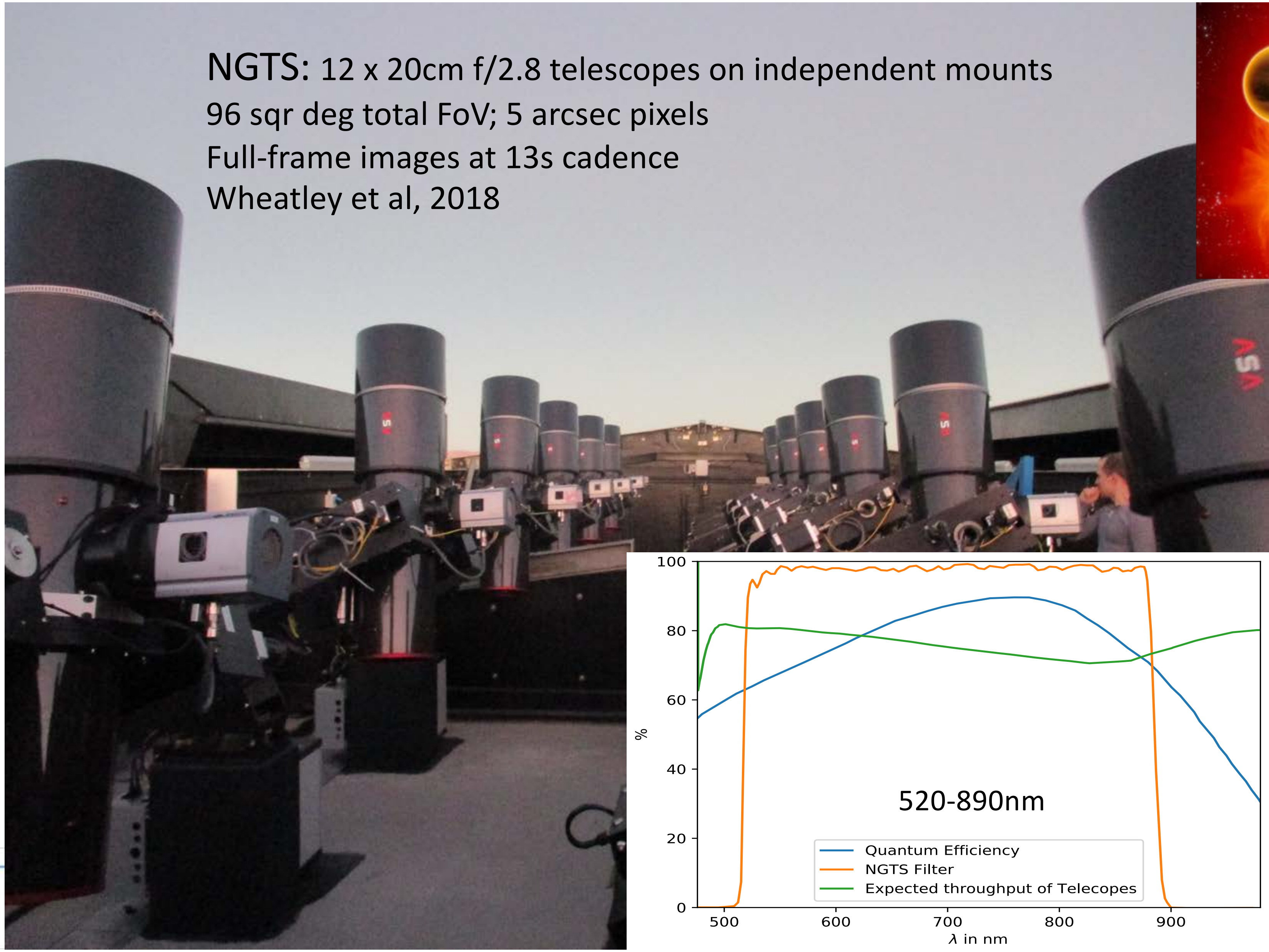
NGTS: 12 x 20cm f/2.8 telescopes on independent mounts

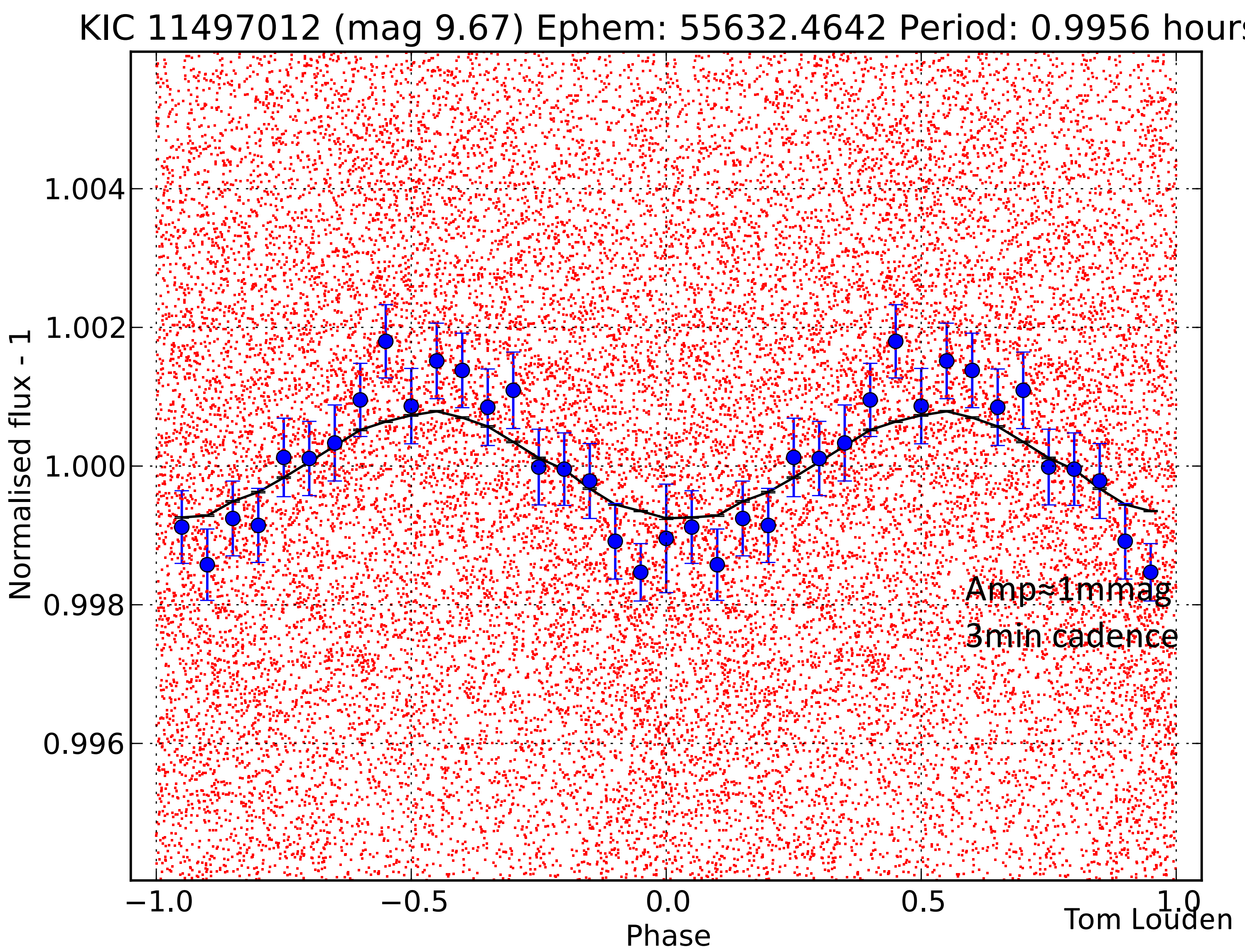
96 sqr deg total FoV; 5 arcsec pixels

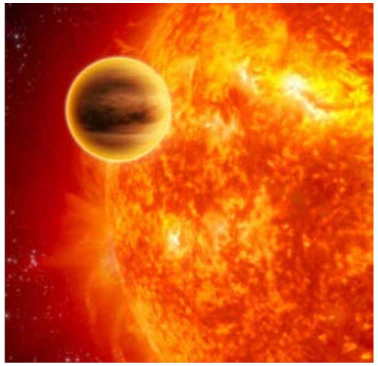
Full-frame images at 13s cadence

Wheatley et al, 2018



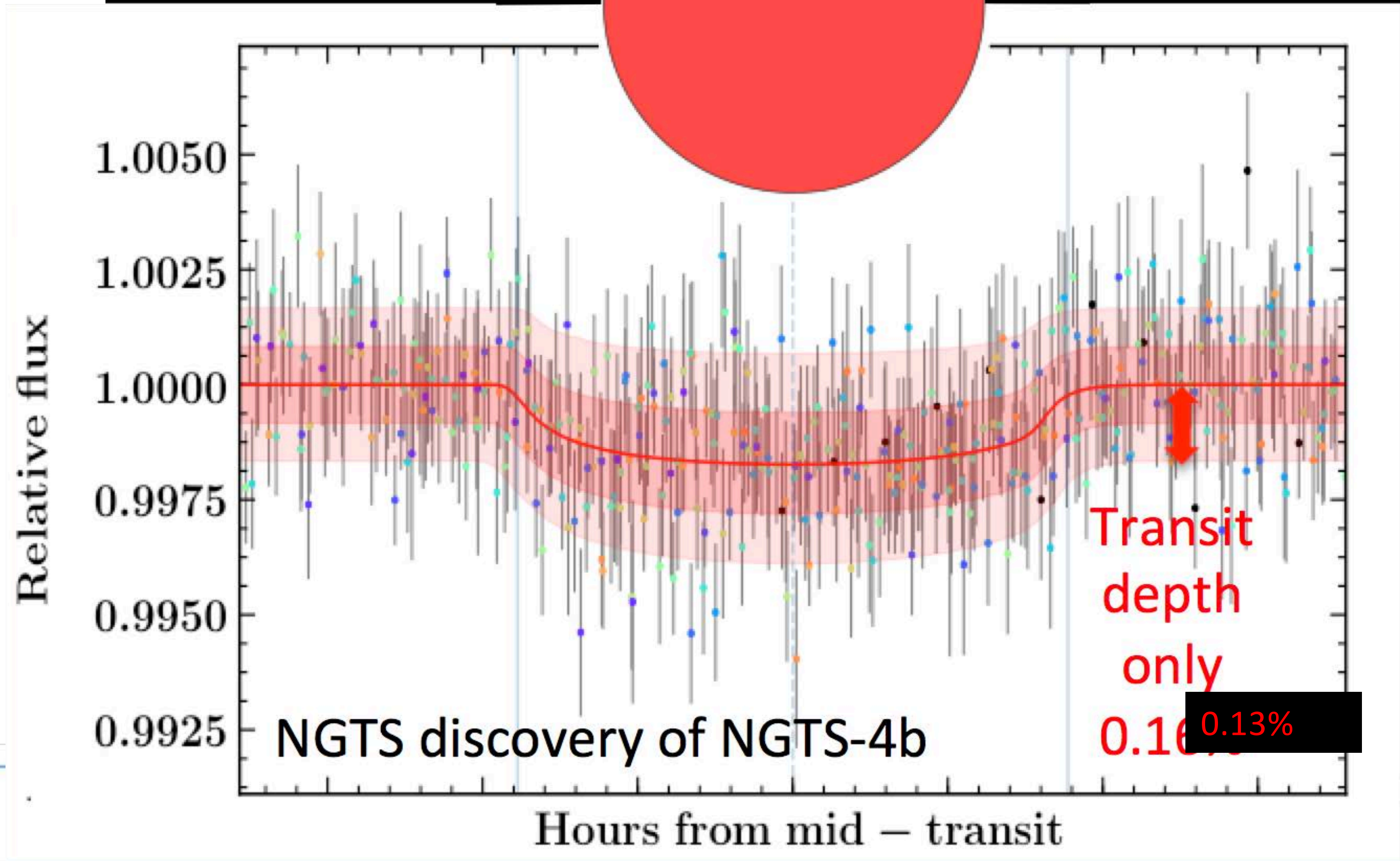


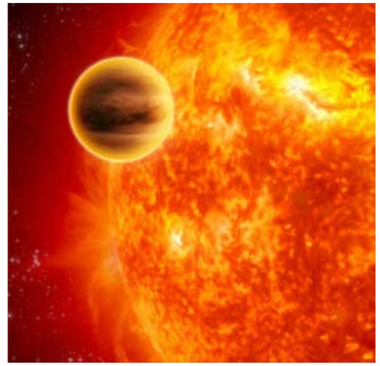

KIC 11497012 (mag 9.67) Ephem: 55632.4642 Period: 0.9956 hours
Normalised flux - 1
1.004
1.002
1.000
0.998
0.996
−1.0
−0.5
0.0
0.5
1.0
Phase
Amp≈1mmag
3min cadence
Tom Louden



NGTS-4b West et al. 2019

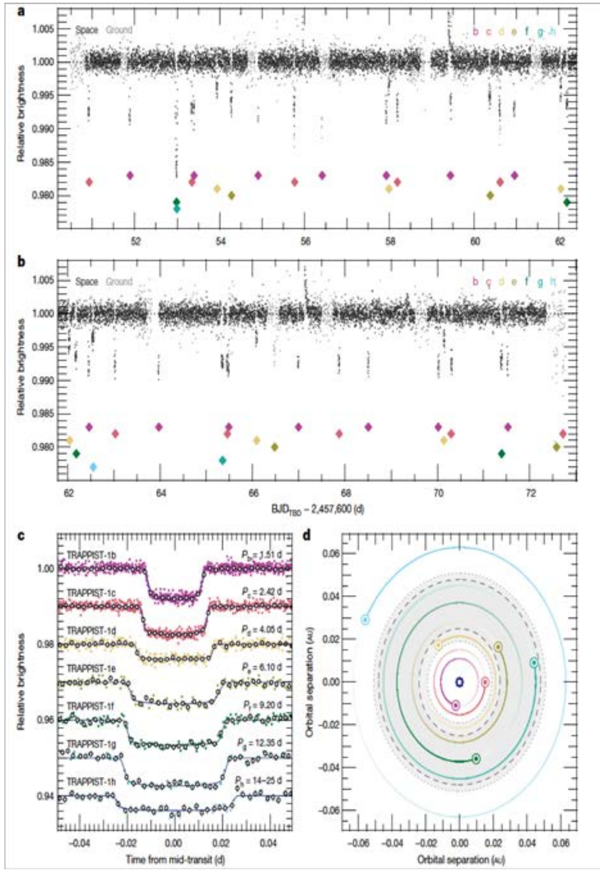
3 Earth radius sub-Neptune
in the Neptunian desert



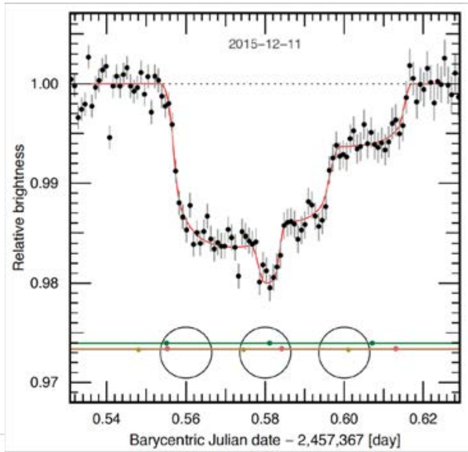


Trappist-1 System

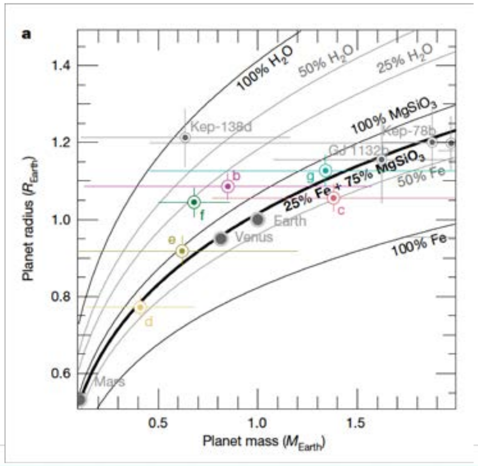
- host star: M dwarf (M8), Teff = 2550 K
- HZ is at a period of a few days.
- discovered by Gillon et al (2015) to be a 4 planet system and more recently found to have 7 earth sized planets (Gillon et al 2017).
- **2-3 planets are in the HZ.**
- Masses very uncertain (from TTV)



Light curve showing multiple transits from planets



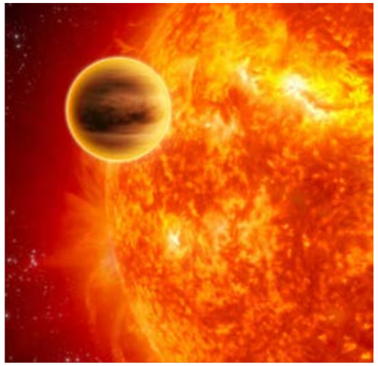
Wow!



M v’s r

Speculoos – late M dwarfs

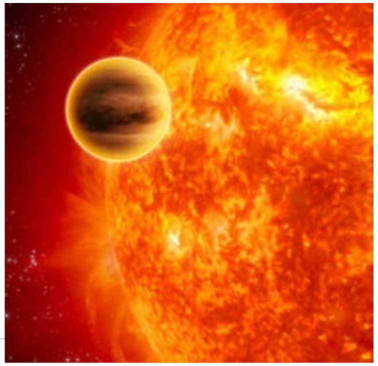
4x 1m Paranal, being extended to northern hemisphere



Searching for more Trappist-1 type systems.

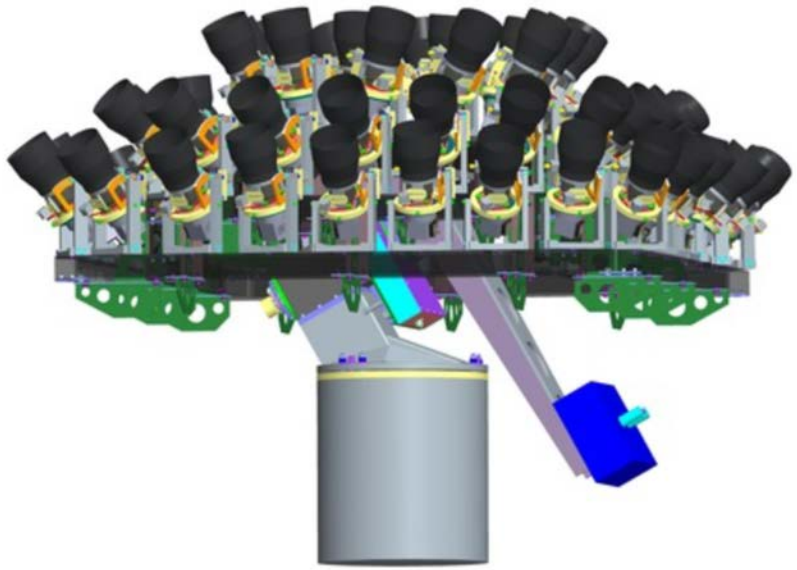
HAT-PI

Bakos et al



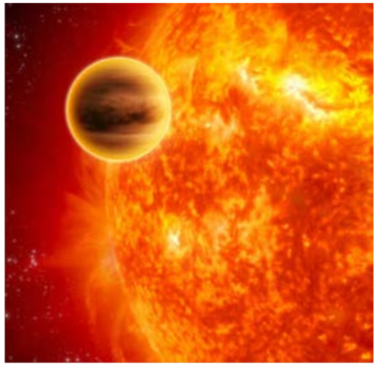
Currently commissioning.
Monitoring 75% of the Las Campanas sky down to 14^{th} mag

Whole sky every 30sec.



"HATPI is expected to discover ~200 long period and/or small radius planets, many of which would not be found by other surveys, including some within the habitable zones of their host stars, and some beyond the snow line (a distance from the host star of great importance in planet formation theories)."

What are these surveys doing in the era of TESS?

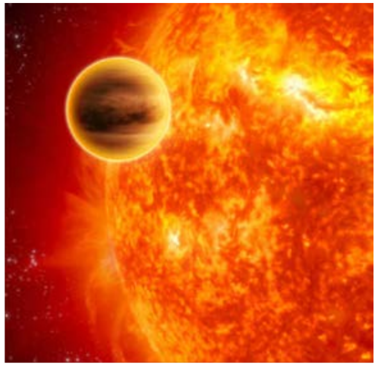


Fair to say that normal surveys will not be competitive with TESS

However, at least some of the pointed Surveys are largely unaffected by TESS eg Spectuloos

Others have aligned their strategies with TESS

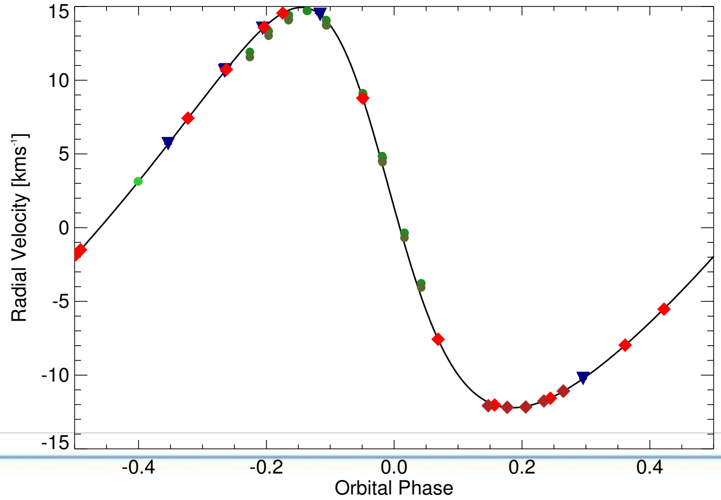
Long-period transiting exoplanets from TESS mono-transit candidates



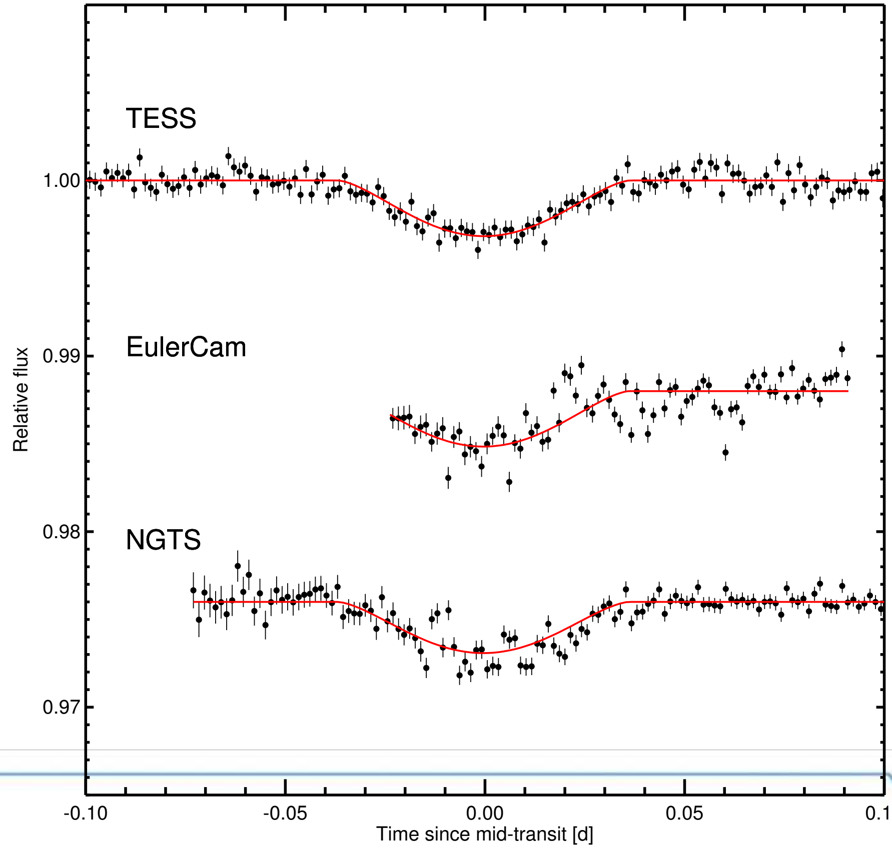
TOI-222 Lendl et al, 2019

34 day low-mass eclipsing binary

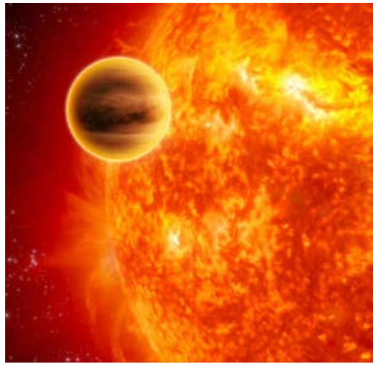
Coralie radial velocities

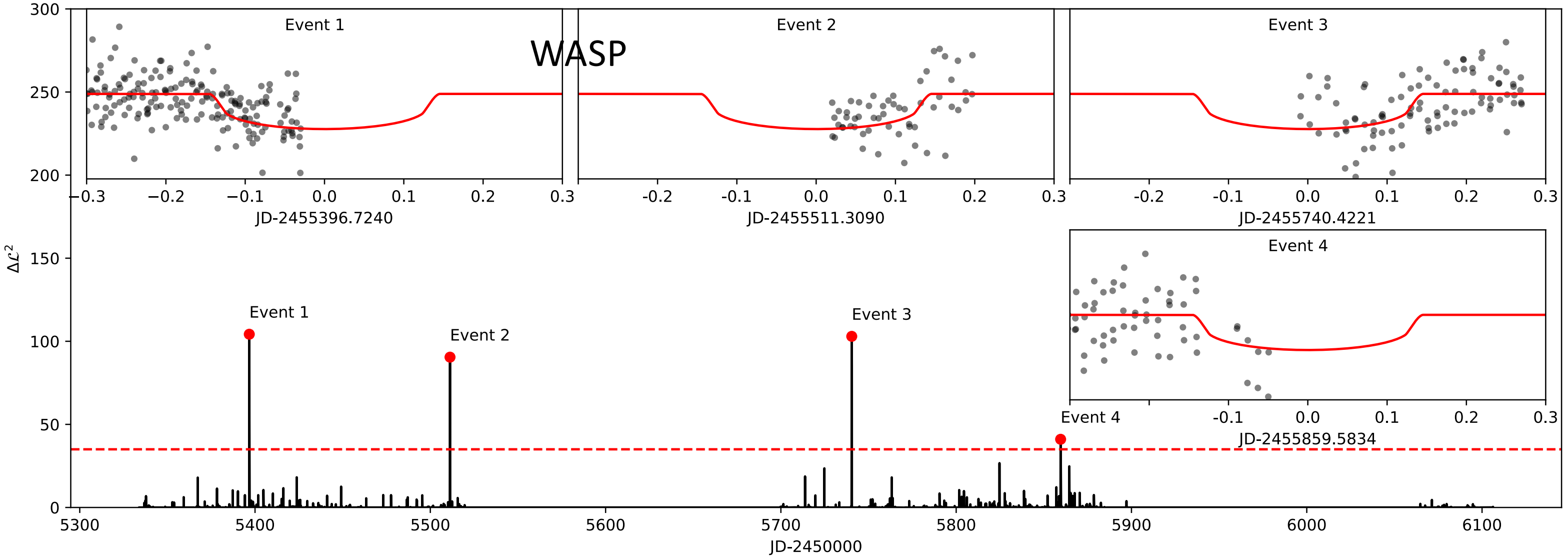


Photometry



Long-period transiting exoplanets from TESS mono-transit candidates
First generation surveys live again!

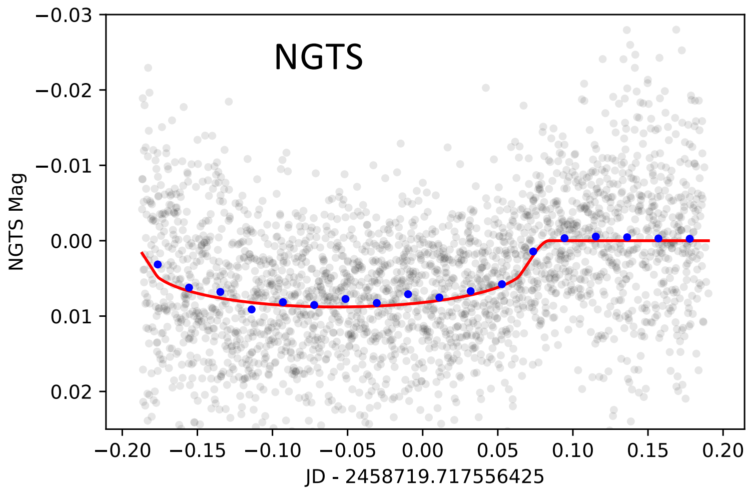




TIC-238855958

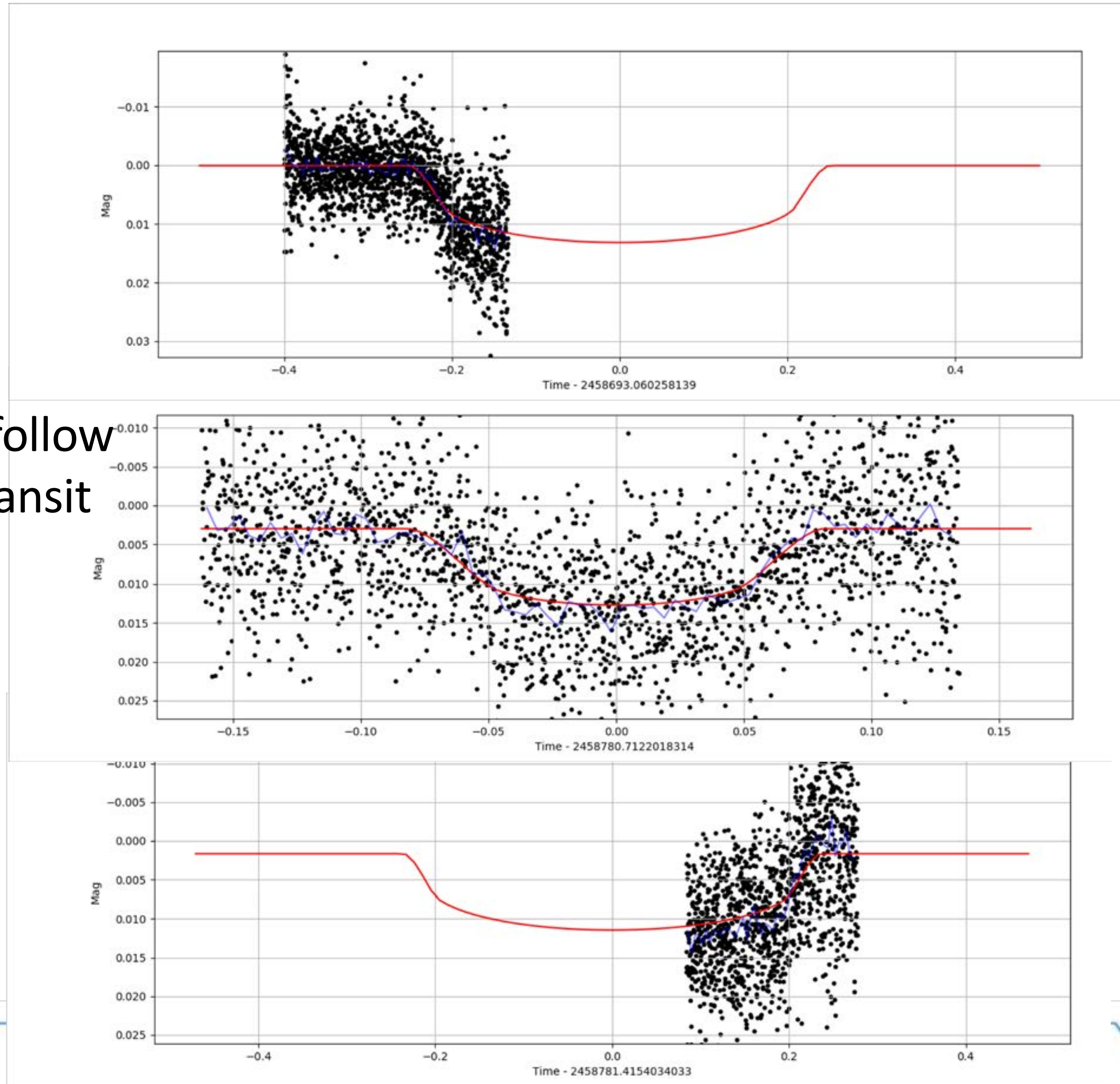
38 day low-mass eclipsing binary

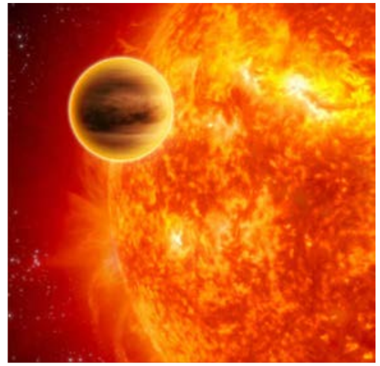
Gill et al, 2019



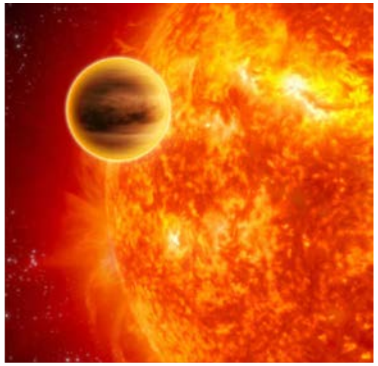
Long-period exoplanets

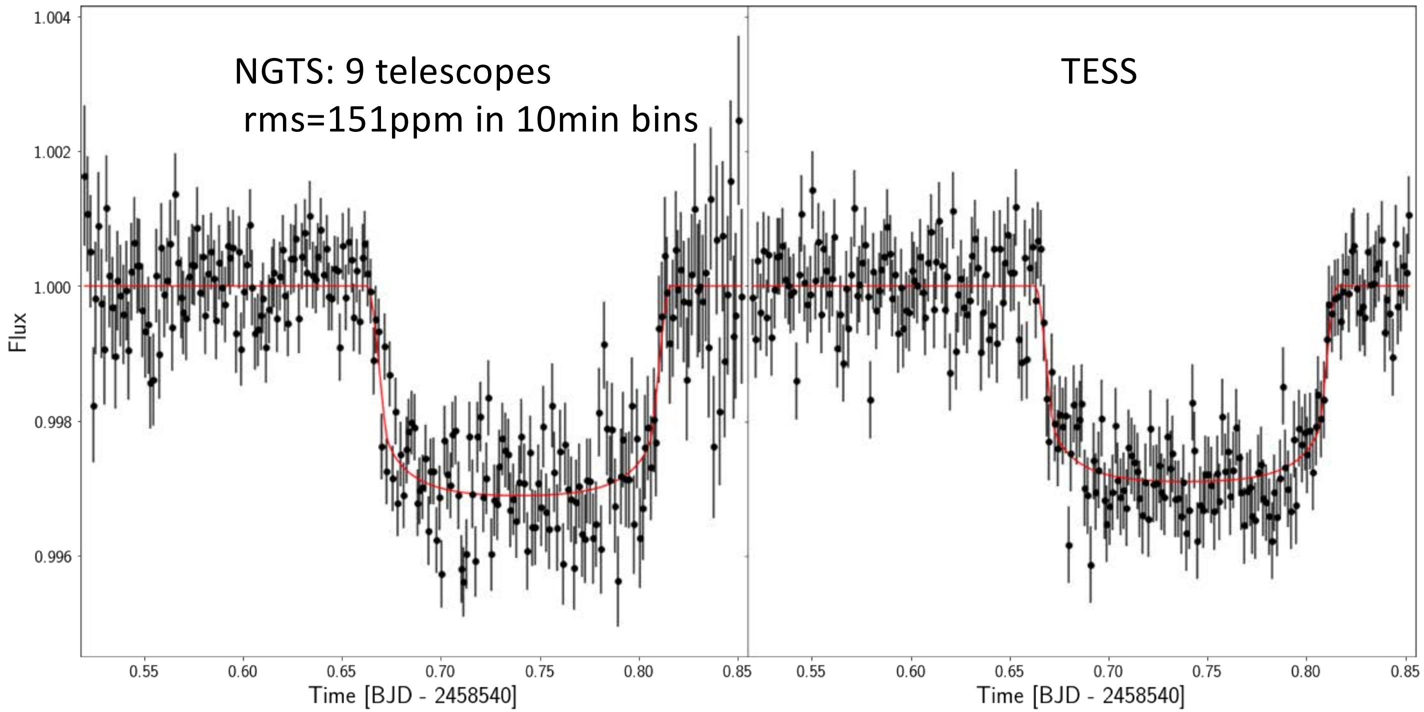
Photometric follow up of monotransit candidates



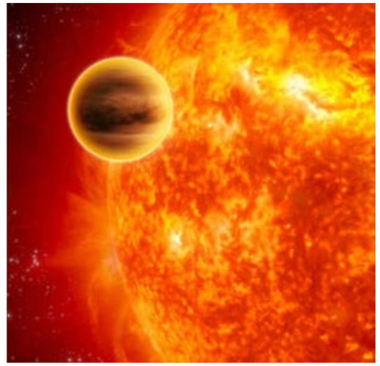


NGTS vs TESS - the light curves (WASP-166b)





The Numbers

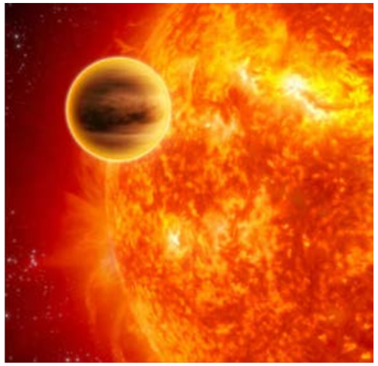


Exoplanet.eu lists (12/1/20) 4168 “confirmed’ planets in 3093 planetary systems

2982 discovered through transit detection (many have no mass estimate)

Of these <400 have been detected from ground based surveys: all have accurate photometry and nearly all have RV measurements

Census



From the ground - Earth and Superearth size planets available from M dwarf surveys only

A handful of <0.4 R_j size planets eg HAT-11b, NGTS-4b

The rest 0.8-2R_j
Periods <1 – 10d or so

A few low mass inflated planets

A handful of 1R_j planets around M dwarfs