

THE MiNDSTEp TRANSIT PROJECT: current status

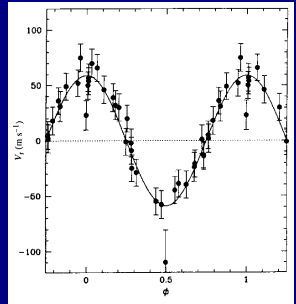
John Southworth

(Advanced Fellow)

Keele University, UK

Extrasolar planets – a history

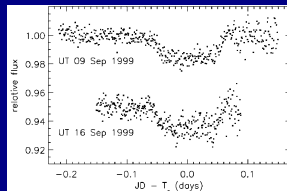
- 1995: first extrasolar planet: 51 Peg
 - Mayor & Queloz (1995)



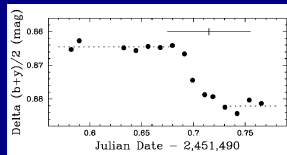
51 Peg velocity curve

Extrasolar planets – a history

- 1995: first extrasolar planet: 51 Peg
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- 1999: First transiting one: HD 209458
 - Charbonneau et al. (2000)
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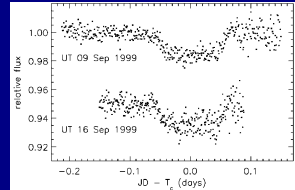
Charbonneau et al.



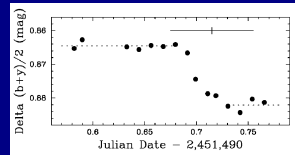
Henry et al.

Extrasolar planets – a history

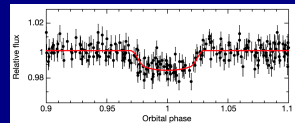
- 1995: first extrasolar planet: 51 Peg
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- 1999: First transiting one: HD 209458
 - Charbonneau et al. (2000)
 - Henry et al. (2000)
- 2002: First planet discovered from its transits: OGLE-TR-56
 - Konacki et al. (2003)
- Current census: ~ 1800 planets



Charbonneau et al.



Henry et al.



OGLE-TR-56

Transiting planets – current status

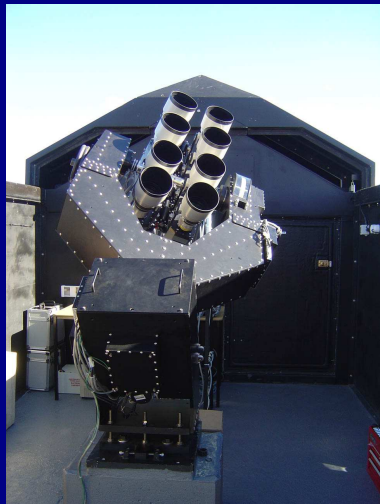
- Roughly 1100 known



WASP-South installation (South Africa)

Transiting planets – current status

- Roughly 1100 known
- Dedicated ground-based transiting planet surveys:
 - SuperWASP: 85 published
 - HAT: 46 published
 - XO: 5 published
 - TrES: 5 published
 - HAT-South: 5 published
 - KELT: 4 published



WASP-South installation (South Africa)

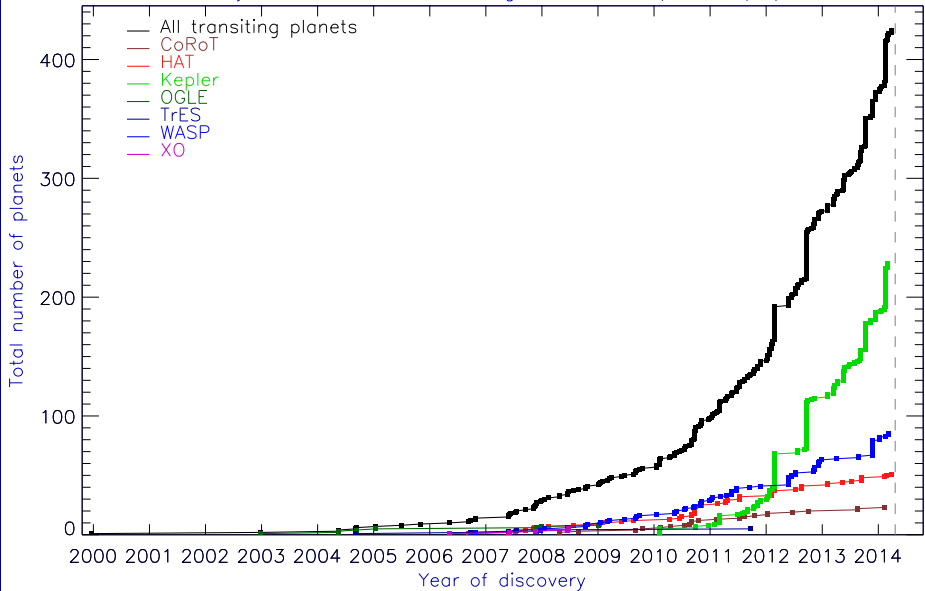
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 - HAT-South: 5 published
 - KELT: 4 published
- Dedicated space-based surveys:
 - CoRoT: 24 published
 - *Kepler*: ~900 ...

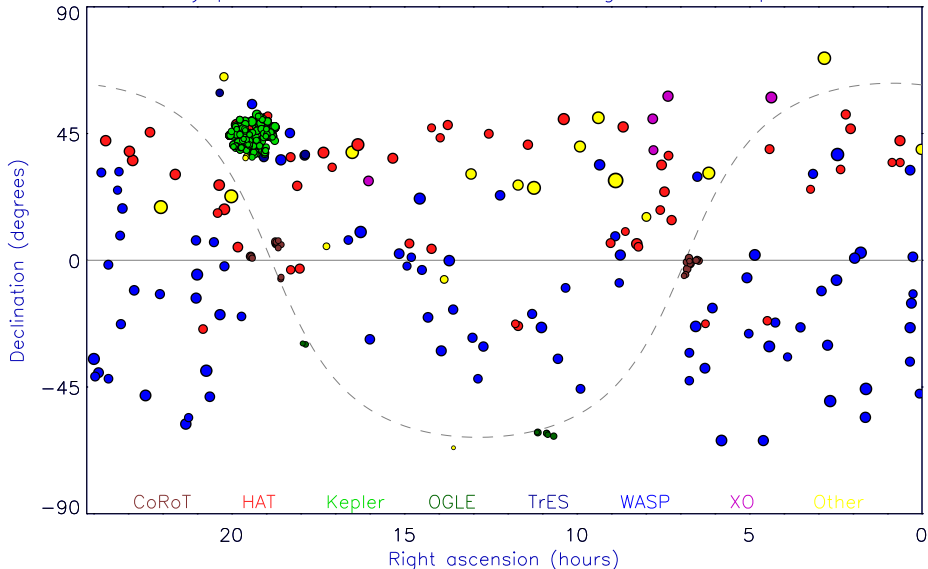


WASP-South installation (South Africa)

Discovery rate of the transiting extrasolar planet population

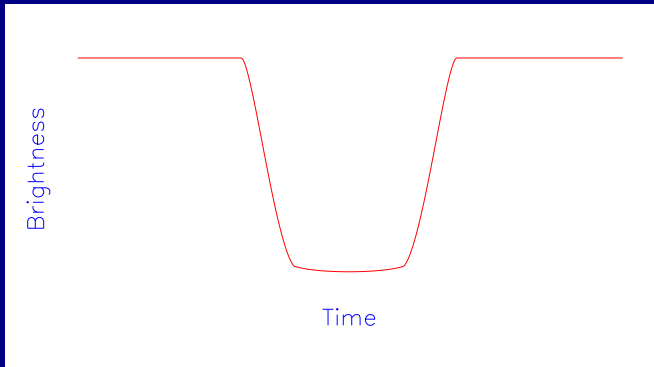


Sky positions of the known transiting extrasolar planets



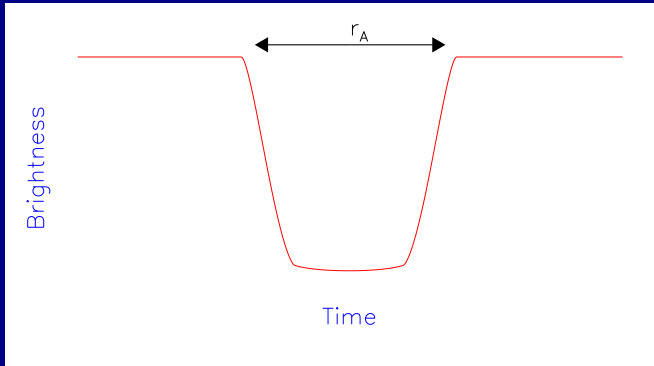
The symbol size is larger for the brighter systems (roughly proportional to the apparent V magnitude)

Anatomy of a transit light curve



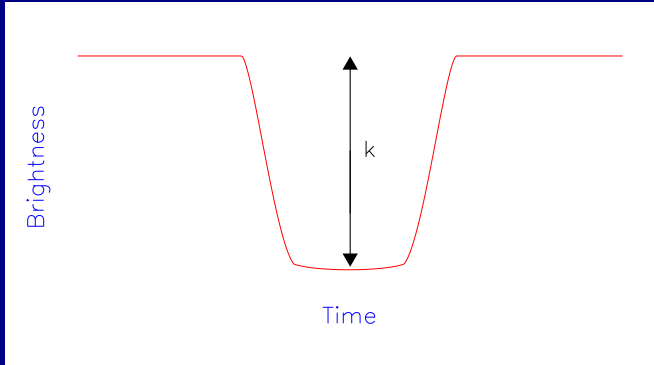
Light curve gives: P_{orb} orbital period

Anatomy of a transit light curve



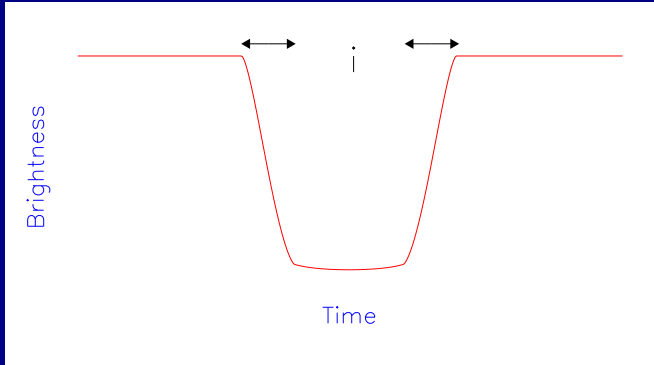
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 $r_A = R_A/a$ fractional radius of star

Anatomy of a transit light curve



Light curve gives: P_{orb} orbital period
 $r_A = R_A/a$ fractional radius of star
 $k = r_b/r_A$ ratio of planet to star radius

Anatomy of a transit light curve



Light curve gives:

$$P_{\text{orb}}$$

orbital period

$$r_A = R_A/a$$

fractional radius of star

$$k = r_b/r_A$$

ratio of planet to star radius

$$i$$

inclination of the orbit

Getting the physical properties

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- Interpolate in stellar models:
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 - find most likely age for the system
- Get planet mass and radius
 - \Rightarrow surface gravity \Rightarrow atmosphere studies
 - \Rightarrow density \Rightarrow composition and core size
 - \Rightarrow composition and core size \Rightarrow formation scenario

TEPCat

TEPCat: Physical properties of transiting planets without errorbars

This table contains a summary of the physical properties for all known transiting extrasolar planetary systems. I include those systems for which a detailed study has been published in a refereed journal or on the arXiv preprint server. Most systems have been studied multiple times, so for these I select what I consider to be the best measurements. By necessity the results for many of the planetary systems have been assembled from multiple papers, so are not guaranteed to be internally consistent. I give a reference to the discovery paper and the paper from which most of the results were taken for each system.

A full table with errorbars included can be found [here](#) or by clicking on the table below (except for Firefox or IE). The full data can also be obtained in machine-readable [ascii](#) and [csv](#) formats.

Click [here](#) to return to the TEPCat main page.

System	Stellar properties						Planetary properties								Discovery reference	Main refer
	Teff (K)	[Fe/H] (dex)	Mass (Msun)	Radius (Rsun)	log(g) (cgs)	Density (psun)	Orbital period	Eccentricity	Semimjr axis (AU)	Mass (Mjup)	Radius (Rjup)	Gravity (m/s2)	Density (pjup)	Equil temp		
55-Cnc-e	5234	+0.31	0.94	0.95	4.43		0.737	0.057	0.01564	0.0251	0.190		3.4	arXiv:1105.0415	arXiv	
CoRoT-1	5950	-0.30	0.95	1.131	4.311	0.660	1.509	0.0	0.02536	1.03	1.551	10.65	0.259	1915	2008A+A...482L..17B	arXiv
CoRoT-2	5696	+0.03	1.018	0.907	4.530	1.362	1.743	0.0143	0.02854	3.62	1.470	41.5	1.066	1548	2008A+A...482L..21A	arXiv
CoRoT-3	6740	-0.02	1.403	1.575	4.191	0.359	4.257	0.0	0.05783	21.96	1.037	506	18.4	1695	2008A+A...491..889D	arXiv
CoRoT-4	6190	+0.05	1.194	1.148	4.396	0.790	9.202	0.0	0.09120	0.731	1.160	13.5	0.438	1058	2008A+A...488L..43A	arXiv

<http://www.astro.keele.ac.uk/~jkt/tepcat/>

TEPCat

TEPCat: Basic observable properties of transiting planets

This table contains basic observable quantities all known (published) transiting extrasolar planets. The quantities comprise the sky position (J2000), V magnitude, latest orbital ephemerides, and the transit duration and depth. Transiting planets are denoted with a "TEP" and transiting brown dwarfs with a "BD". The transit depth is only approximate as it varies with wavelength.

The full data can also be obtained in machine-readable [ascii](#) and [csv](#) formats.

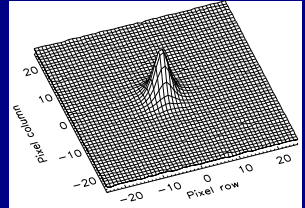
Click [here](#) to return to the TEPCat main page.

System	Type	Right ascension	Declination	V mag	Transit length (d)	Transit depth	Time of mid-transit	Orbital period (d)	Ephemeris reference
55-Cnc-e	TEP	08 52 36.13	+28 19 53.0	5.95	0.0734	0.045 %	2455607.0553 ± 0.0026	0.736540 ± 0.000003	arXiv:1104.5230
CoRoT-1	TEP	06 48 19.17	-03 06 07.8	13.6	0.10439	2.3 %	2454524.6231 ± 0.0002	1.5089686 ± 0.0000006	2009A+A...506..359G
CoRoT-2	TEP	19 27 06.50	+01 23 01.4	12.57	0.09446	3.2 %	2454237.53556 ± 0.00021	1.7429935 ± 0.0000010	2010A+A...511A...3G
CoRoT-3	BD	19 28 13.27	+00 07 18.6	13.29	0.153	0.25 %	2454283.13388 ± 0.00024	4.2567994 ± 0.0000035	2009A+A...506..377T
CoRoT-4	TEP	06 48 46.72	-00 40 22.0	14.0	0.184	1.3 %	2454141.36416 ± 0.00089	9.20205 ± 0.00037	2008A+A...488L..43A
CoRoT-5	TEP	06 45 06.54	+00 48 54.9	14.0	0.117	1.4 %	2454400.19885 ± 0.00002	4.0378962 ± 0.0000019	2009A+A...506..281R
CoRoT-6	TEP	18 44 17.40	+06 39 47.4	13.91	0.170	1.5 %	2454595.6144 ± 0.0002	8.886593 ± 0.00004	2010A+A...512A..14F
CoRoT-7	TEP	06 43 49.47	-01 02 46.9	11.67	0.0469	0.024 %	2454388.0769 ± 0.0015	0.853585 ± 0.000024	2009A+A...506..287I

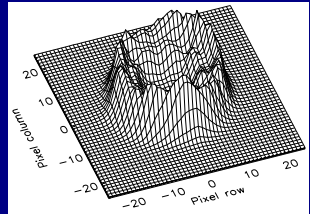
<http://www.astro.keele.ac.uk/~jkt/tepcat/>

DEFOCUSSED PHOTOMETRY

- Look at a bright star with a large telescope:
 - long exposure times: 120s maximum
 - defocus PSF to cover thousands of pixels



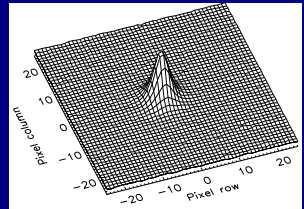
Focused PSF for WASP-5



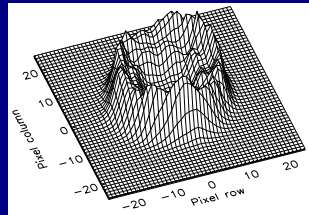
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- Advantages:
 - large PSF \Rightarrow low flatfielding noise
 - long exposure times \Rightarrow less time lost to CCD readout
 - less CCD readout \Rightarrow more photons, less scintillation



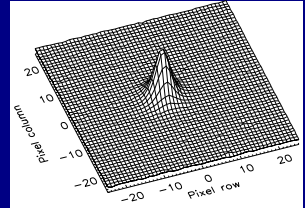
Focused PSF for WASP-5



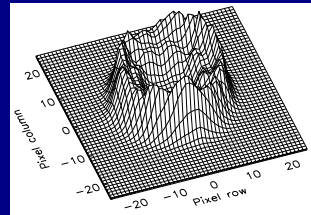
Defocused PSF for WASP-5

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 - large PSF \Rightarrow low flatfielding noise
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- Disadvantages:
 - lower time resolution \Rightarrow 120s is good enough for planets
 - higher background \Rightarrow not important for bright stars

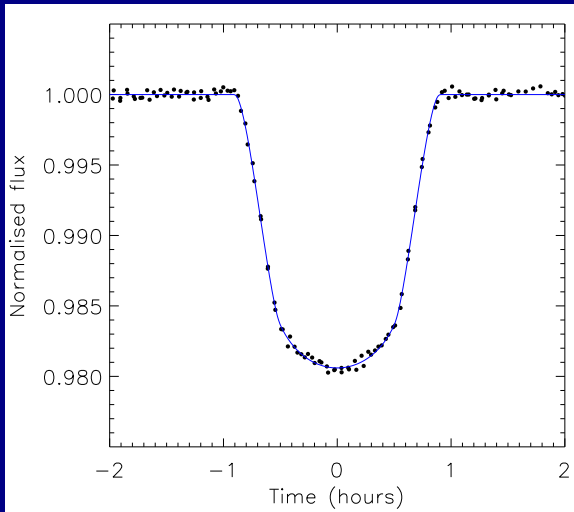


Focused PSF for WASP-5



Defocused PSF for WASP-5

WASP-50 with the NTT

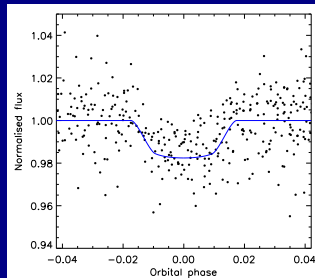


- NTT/EFOSC2
- Scatters 0.22 and 0.26 mmag
- Tregloan-Reed & Southworth (2013MNRAS.431..966T)

Example: WASP-2

Discovery light curve
(Collier Cameron et al. 2007)

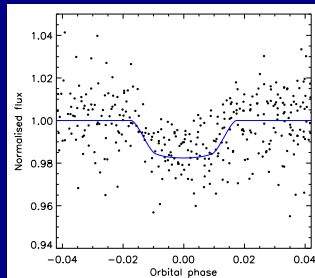
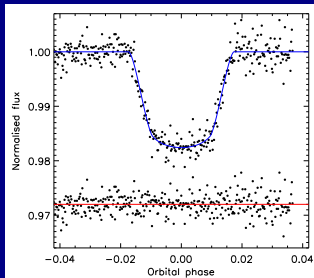
$\sigma = 10$ mmag



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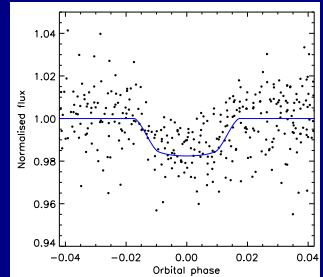
Charbonneau et al. (2007)

$\sigma = 1.9$ mmag

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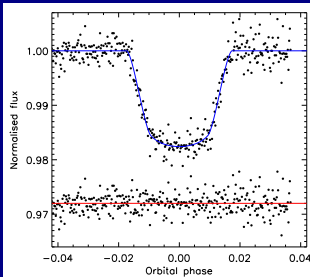
Discovery light curve
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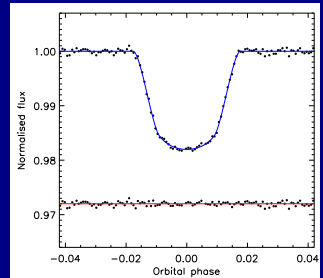
Charbonneau et al. (2007)

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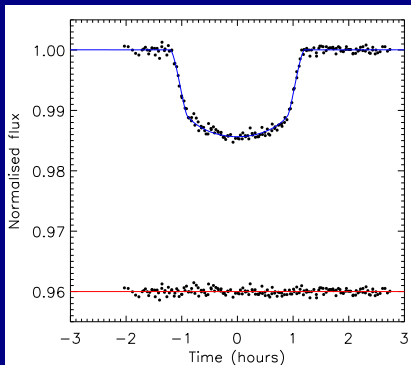
Defocused-photometry light curve
(Southworth et al. 2009)

$\sigma = 0.46$ mmag



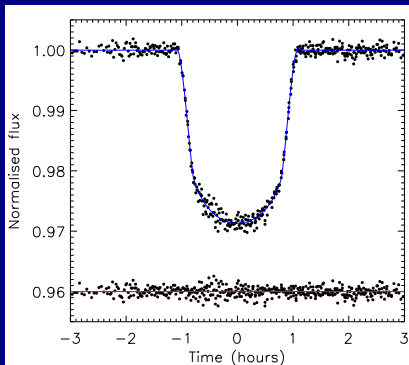
MiNDSTEp transit project: current status

- WASP-5 (2009MNRAS.396.10235)
 - Two transits with scatters 0.50 and 0.59 mmag



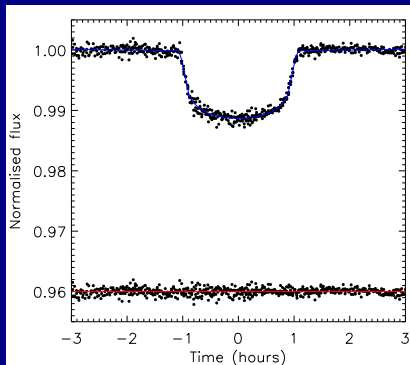
MiNDSTEp transit project: current status

- WASP-5 (2009MNRAS.396.1023S)
- WASP-4 (2009MNRAS.399..287S)
 - Four transits with scatters 0.84, 0.88, 0.75 and 0.60 mmag



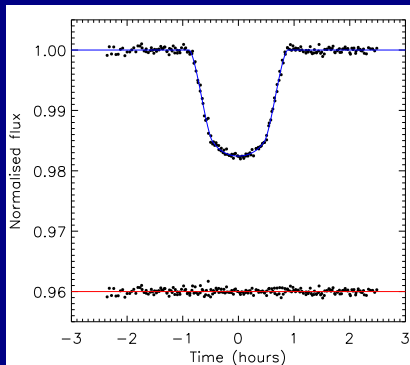
MiNDSTEp transit project: current status

- WASP-5 (2009MNRAS.396.1023S)
- WASP-4 (2009MNRAS.399..287S)
- WASP-18 (2009ApJ...707..167S)
 - Five transits on consecutive nights (scatters 0.83, 0.68, 0.51, 0.56 and 0.47 mmag)



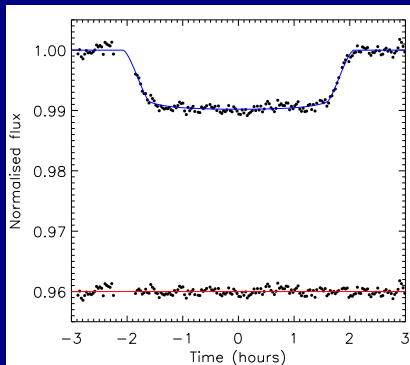
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- WASP-4 (2009MNRAS.399..287S)
- WASP-18 (2009ApJ...707..167S)
- WASP-2 (2010MNRAS.408.1680S)
 - Two transits with lowest scatters yet: 0.42 and 0.47 mmag



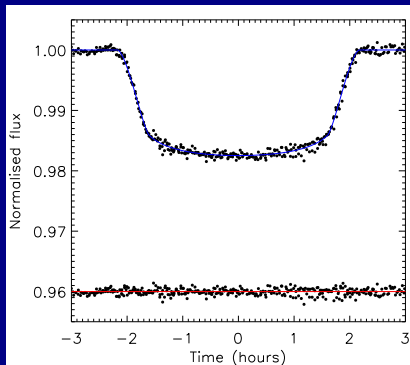
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- WASP-18 (2009ApJ...707..167S)
- WASP-2 (2010MNRAS.408.1680S)
- WASP-7 (2011A+A...527A...8S)
 - Only one transit (0.68 mmag), the first one for WASP-7
 - Planet radius $0.915^{+0.046}_{-0.040} R_{\text{Jup}}$ from WASP data
 - Planet radius $1.330 \pm 0.093 R_{\text{Jup}}$ from our data



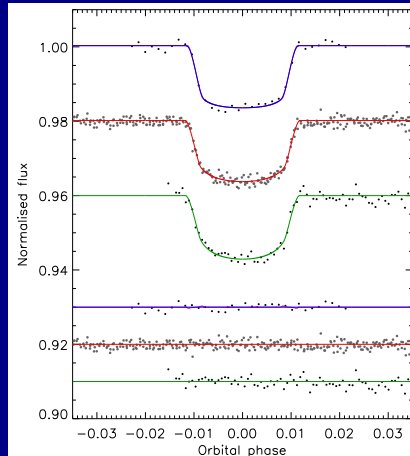
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- WASP-2 (2010MNRAS.408.1680S)
- WASP-7 (2011A+A...527A...8S)
- WASP-17 (2012MNRAS.426.1338S)
 - Remains the biggest known planet, at $1.932 \pm 0.052 R_{\text{Jup}}$!
 - Four transits with scatters 0.56, 0.76, 0.53, 0.48 mmag



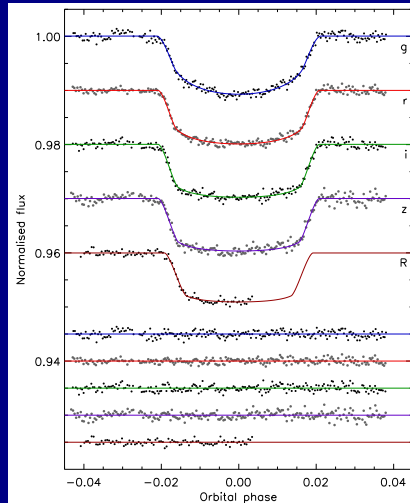
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- WASP-7 (2011A+A...527A...8S)
- WASP-17 (2012MNRAS.426.1338S)
- GJ-1214 (Harp e et al. 2013A+A...549A..10H)
 - Included DFOSC observations of three transits



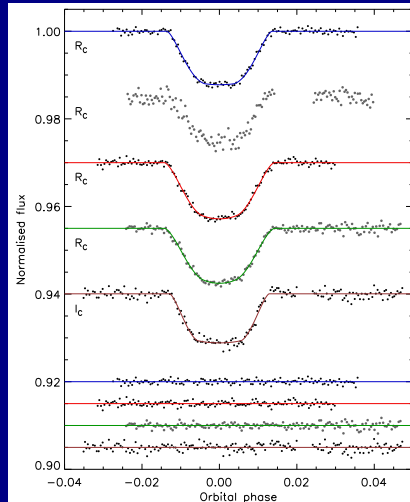
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- WASP-7 (2011A+A...527A...8S)
- WASP-17 (2012MNRAS.426.1338S)
- GJ-1214 (Harpsoe et al. 2013A+A...549A..10H)
- WASP-15 and WASP-16 (2013MNRAS.434.1300S)
 - WASP-15 mainly based on GROND data of one transit in *griz*



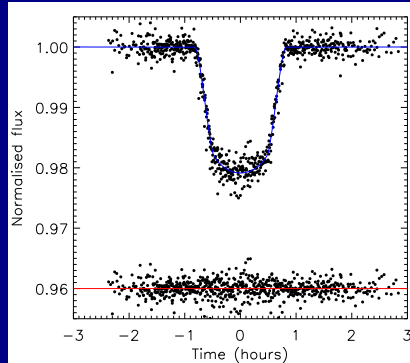
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- GJ-1214 (Harpsoe et al. 2013A+A...549A..10H)
- WASP-15 and WASP-16 (2013MNRAS.434.1300S)
 - WASP-16: four DFOSC transits



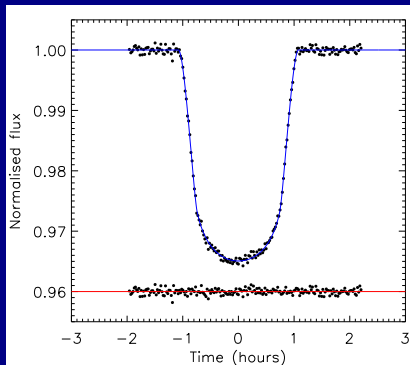
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- WASP-17 (2012MNRAS.426.1338S)
- GJ-1214 (Harpsoe et al. 2013A+A...549A..10H)
- WASP-15 and WASP-16 (2013MNRAS.434.1300S)
- WASP-19 (Mancini et al. 2013MNRAS.436....2M)
 - DFOSC data for eight transits



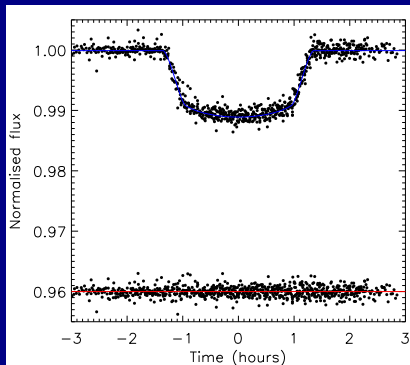
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- WASP-19 (Mancini et al. 2013MNRAS.436....2M)
- WASP-80 (Mancini et al. 2014A+A...562A.126M)
 - DFOSC and GROND observed the same transit



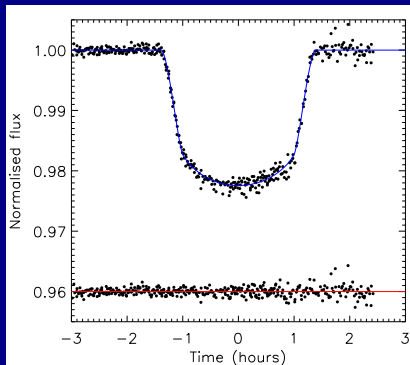
MiNDSTEp transit project: current status

- WASP-5 (2009MNRAS.396.1023S)
- WASP-4 (2009MNRAS.399..287S)
- WASP-18 (2009ApJ...707..167S)
- WASP-2 (2010MNRAS.408.1680S)
- WASP-7 (2011A+A...527A...8S)
- WASP-17 (2012MNRAS.426.1338S)
- GJ-1214 (Harpstøe et al. 2013A+A...549A..10H)
- WASP-15 and WASP-16 (2013MNRAS.434.1300S)
- WASP-19 (Mancini et al. 2013MNRAS.436....2M)
- WASP-80 (Mancini et al. 2014A+A...562A.126M)
- WASP-24, WASP-25 and WASP-26
 - Draft of paper completed



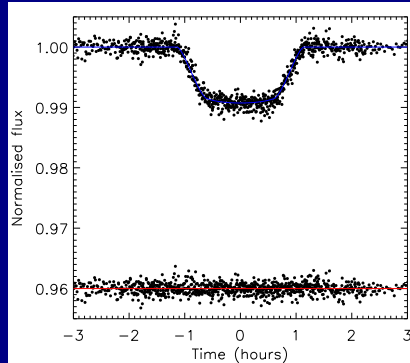
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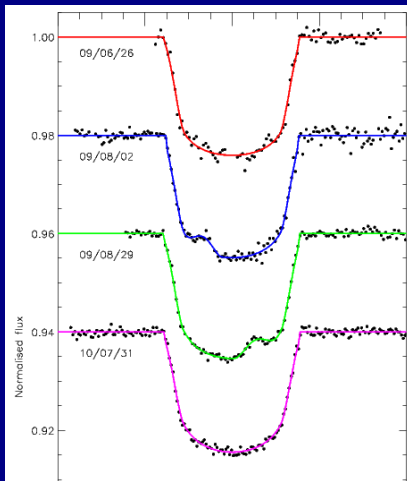
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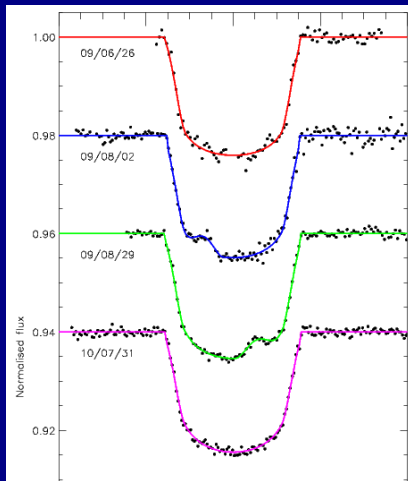
MiNDSTEp transit project: work in progress

- WASP-6
 - 2 transits show clear evidence of starspot occultations
 - Jeremy Tregloan-Reed has written code (PRISM and GEMC) to model transits with starspots



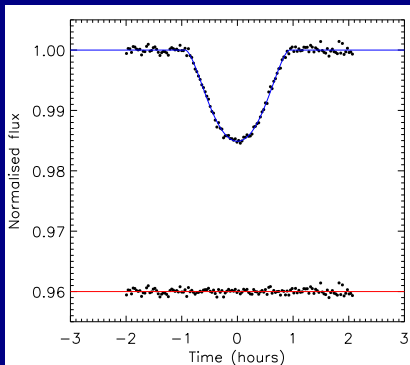
MiNDSTEp transit project: work in progress

- WASP-6
 - 2 transits show clear evidence of starspot occultations
 - Jeremy Tregloan-Reed has written code (PRISM and GEMC) to model transits with starspots
 - Result: orbital obliquity $\lambda = 6.4 \pm 2.3$ degrees
 - Currently thesis chapter, will become a paper



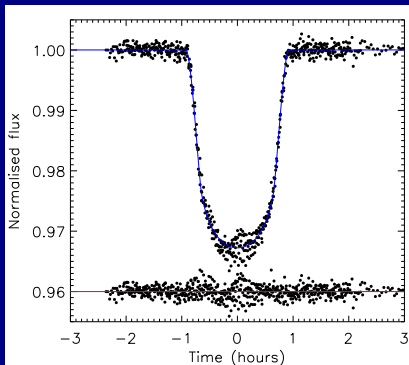
MiNDSTEp transit project: work in progress

- WASP-6
 - Starspots in 2 transits
 - Jeremy is writing the paper
- WASP-67
 - Only a partial eclipse
 - *Kepler* K2 target in field 7
 - Luigi is leading this work



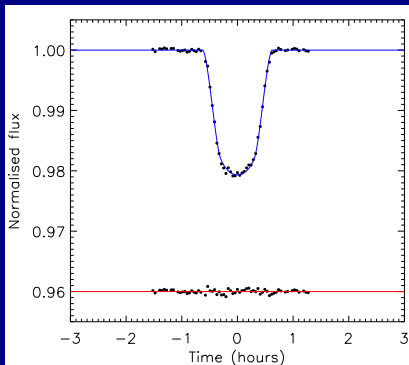
MiNDSTEp transit project: work in progress

- WASP-6
 - Starspots in 2 transits
 - Jeremy is writing the paper
- WASP-67
 - Partial eclipse, *Kepler* target
 - Luigi is leading this work
- Qatar-2
 - 6 transits in 2012-3
 - Aim for 3 more in 2014
 - Second planet now retracted
 - Toby is leading this work



MiNDSTEp transit project: work in progress

- WASP-6
 - Starspots in 2 transits
 - Jeremy is writing the paper
- WASP-67
 - Partial eclipse, *Kepler* target
 - Luigi is leading this work
- Qatar-2
 - Got 6 transits, want 9
 - Toby is leading this work
- WASP-45 and WASP-46
 - 2 DFOSC transits for WASP-45
 - 3 DFOSC transits for WASP-46
 - One NTT transit for WASP-45
 - Luigi is leading this work



MiNDSTEp transit project: future plans

- WASP-103
 - Very short period (0.92 days): tidal effects will be important
 - Will be VLT and *Spitzer* target
 - 12 transits visible in 2014 season

MiNSTEp transit project: future plans

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 - WASP-30 is a $60 M_{\text{Jup}}$ brown dwarf
 - Have 2 + 2 + 2 transits
 - Want one more each

MiNDSTEp transit project: future plans

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 - WASP-30 is a $60 M_{\text{Jup}}$ brown dwarf
 - Have 2 + 2 + 2 transits
 - Want one more each
- WASP-4 and WASP-5 revisited
 - Well studied (73 and 55 ADS references)
 - We published 2 + 4 transits
 - We have 3 + 4 more transits
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MiNDSTEp transit project: future plans

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- WASP-4 and WASP-5 revisited
 - Well studied (73 and 55 ADS references)
 - We published 2 + 4 transits
 - We have 3 + 4 more transits
 - Want 2 more each
- Partial data on WASP-22, WASP-42 and WASP-55



HARDY

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