THE MiNDSTEp TRANSIT PROJECT: current status

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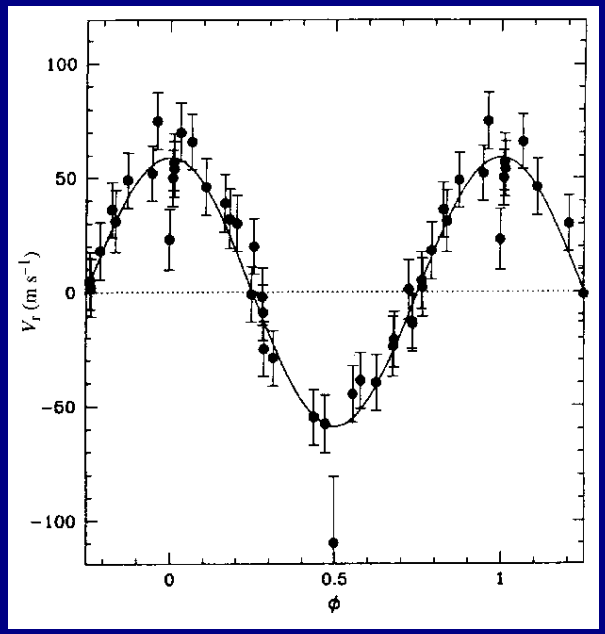
Extrasolar planets – a history

- 1995: first extrasolar planet found: 51 Peg
  - Mayor & Queloz (1995Natur.378..355M)



51 Peg velocity curve

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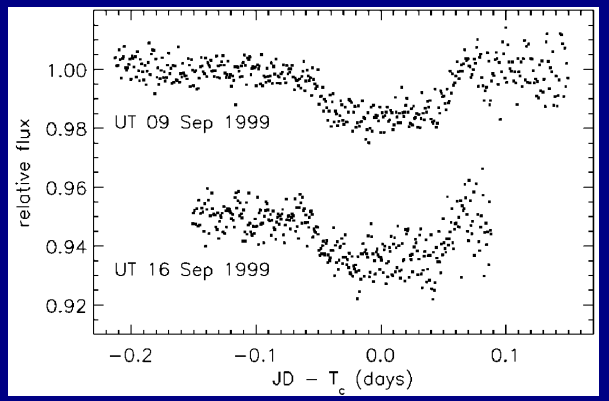

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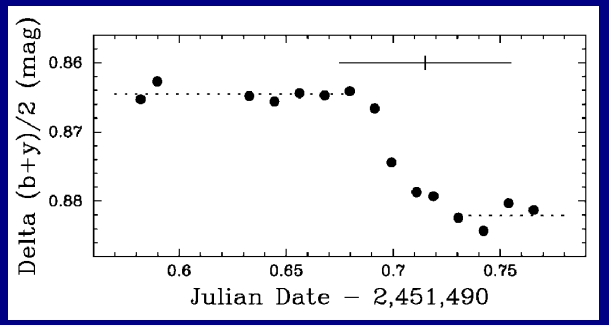

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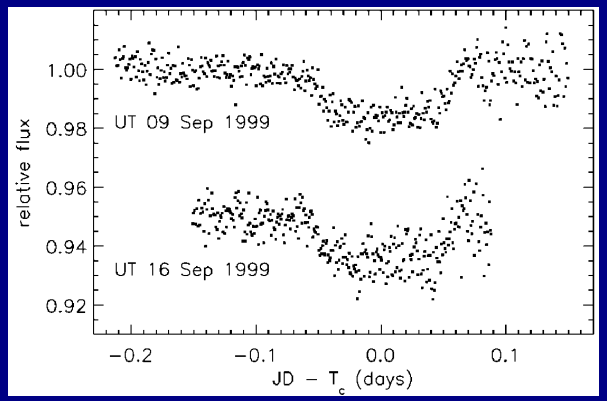
- 2002: First planet discovered by its transits: OGLE-TR-56
  - Konacki et al. (2003Natur.421..507K)
- Current census: ∼700



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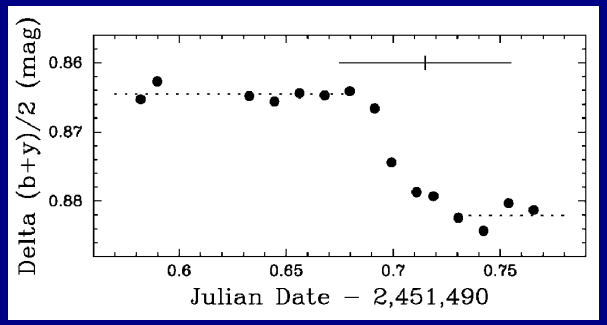

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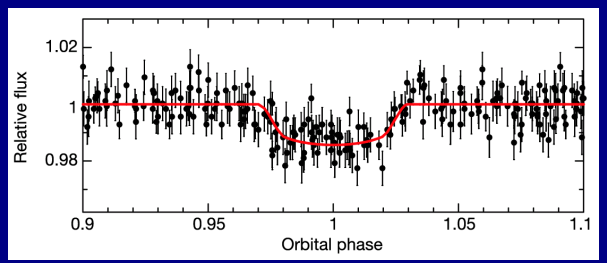

OGLE-TR-56

Transiting planets – current status

- Roughly 150 known transiting extrasolar planets

WASP-South installation (South Africa)

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- Dedicated ground-based transiting planet surveys:
  - SuperWASP: 41 published
  - HAT: 32 published
  - XO: 5 published (ish)
  - TrES: 5 published
  - Qatar: 2 published

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  - HAT: 32 published
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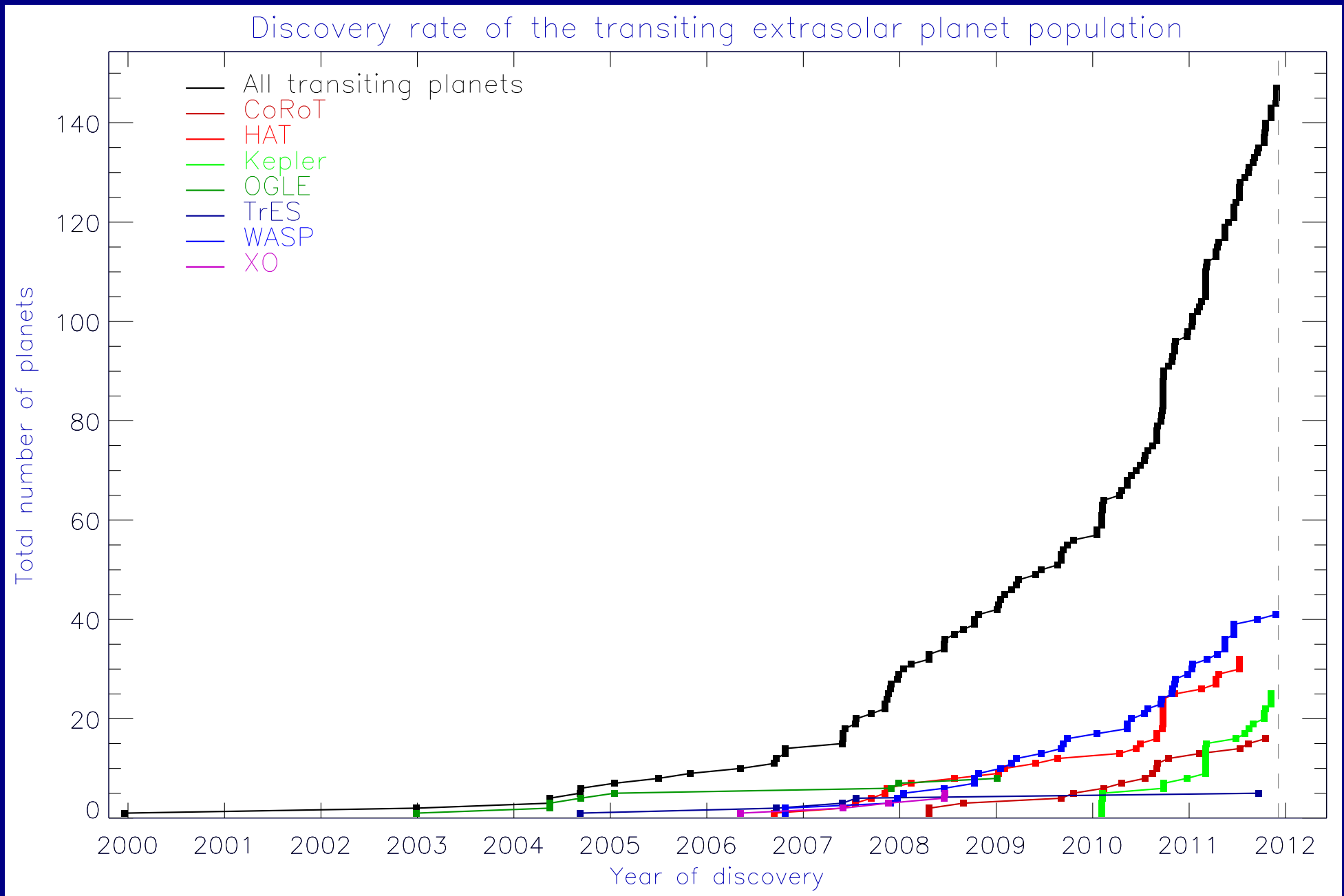
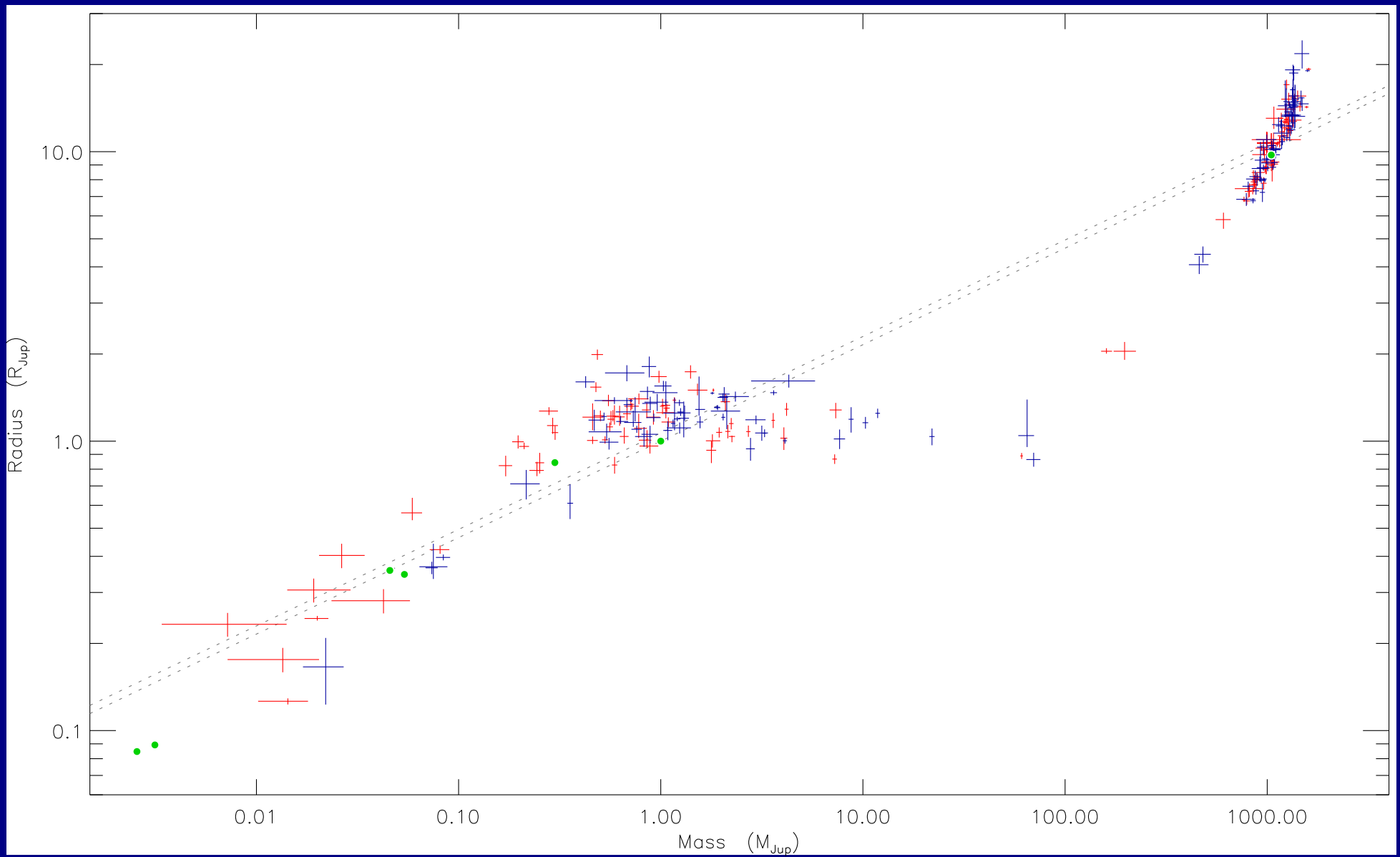
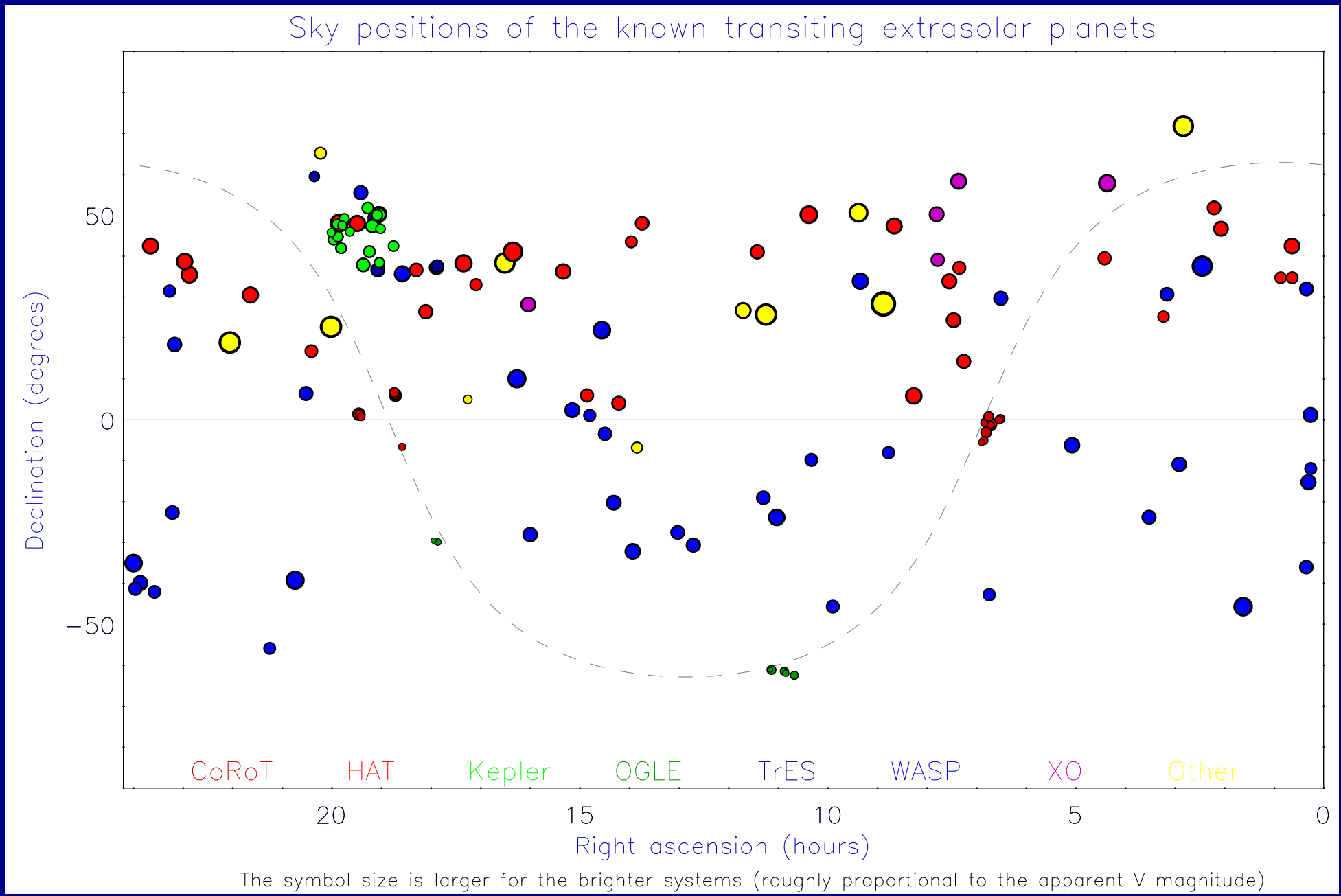
  - Qatar: 2 published
- Dedicated space-based surveys:
  - CoRoT: 16 published + 6 more
  - *Kepler*: 30 published + 1200 candidates

WASP-South installation (South Africa)

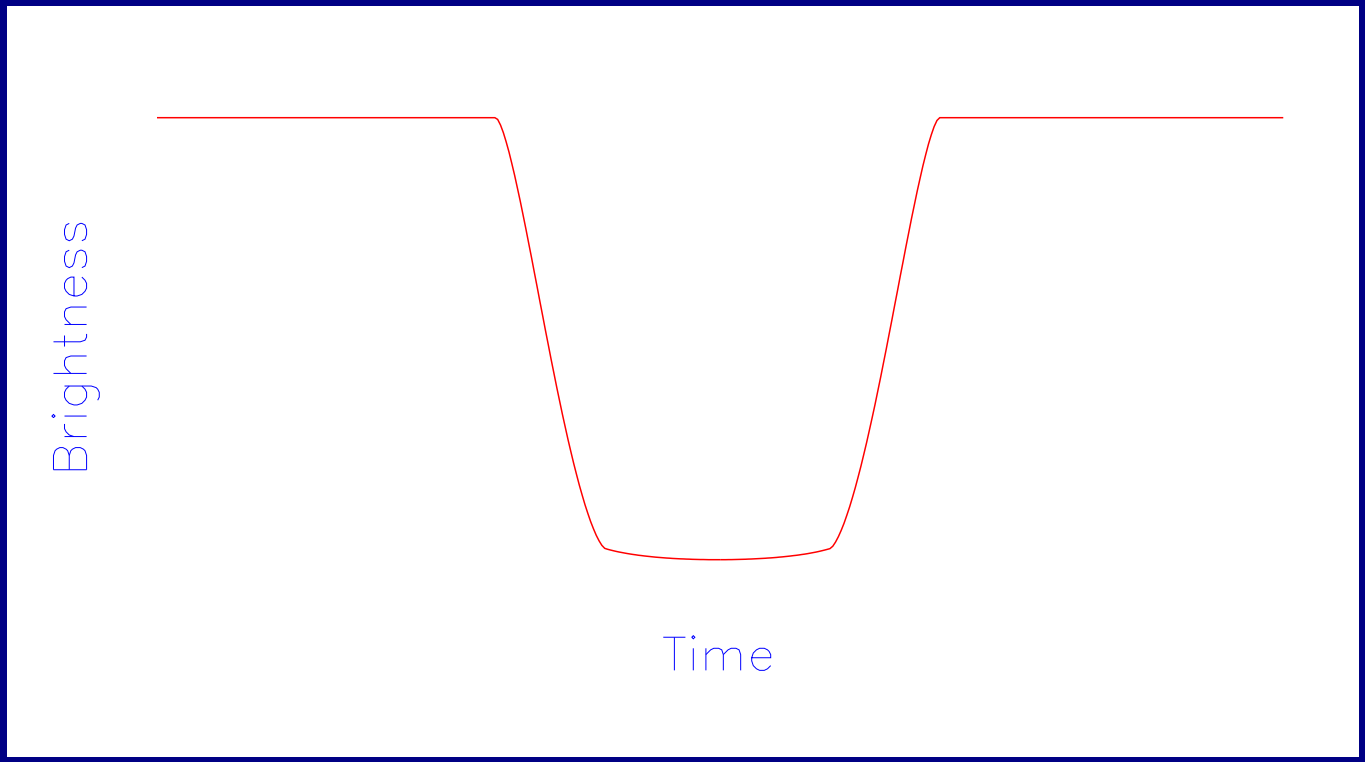

Discovery rate of the transiting extrasolar planet population
All transiting planets
CoRoT
HAT
Kepler
OGLE
TrES
WASP
XO
Total number of planets
0
20
40
60
80
100
120
140
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year of discovery



Mass versus radius – planets on the left, host stars on the right


Sky positions of the known transiting extrasolar planets
50
0
−50
Declination (degrees)
CoRoT
HAT
Kepler
OGLE
TrES
WASP
XO
Other
20
15
10
5
0
Right ascension (hours)
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: $P_{\rm orb}$ orbital period

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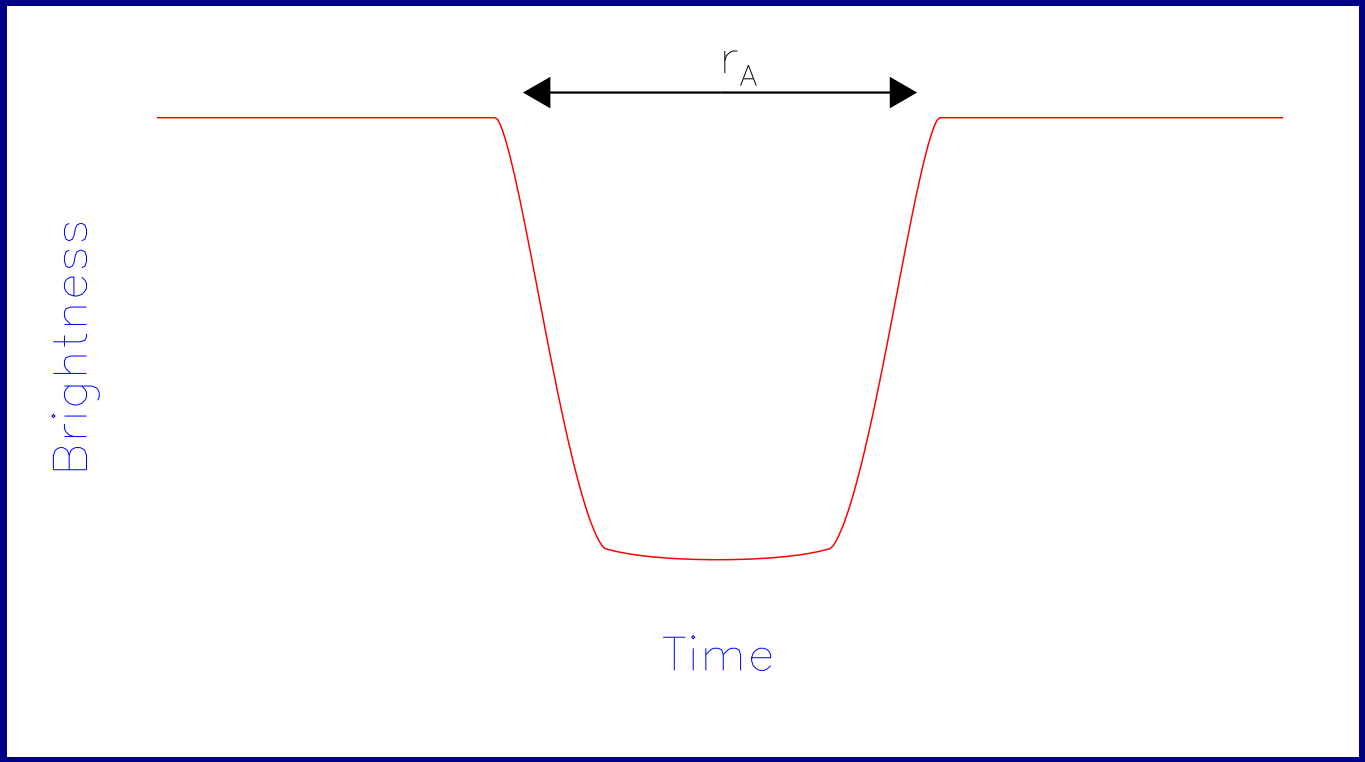

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$r_{\rm A} = R_{\rm A}/a$	fractional radius of star

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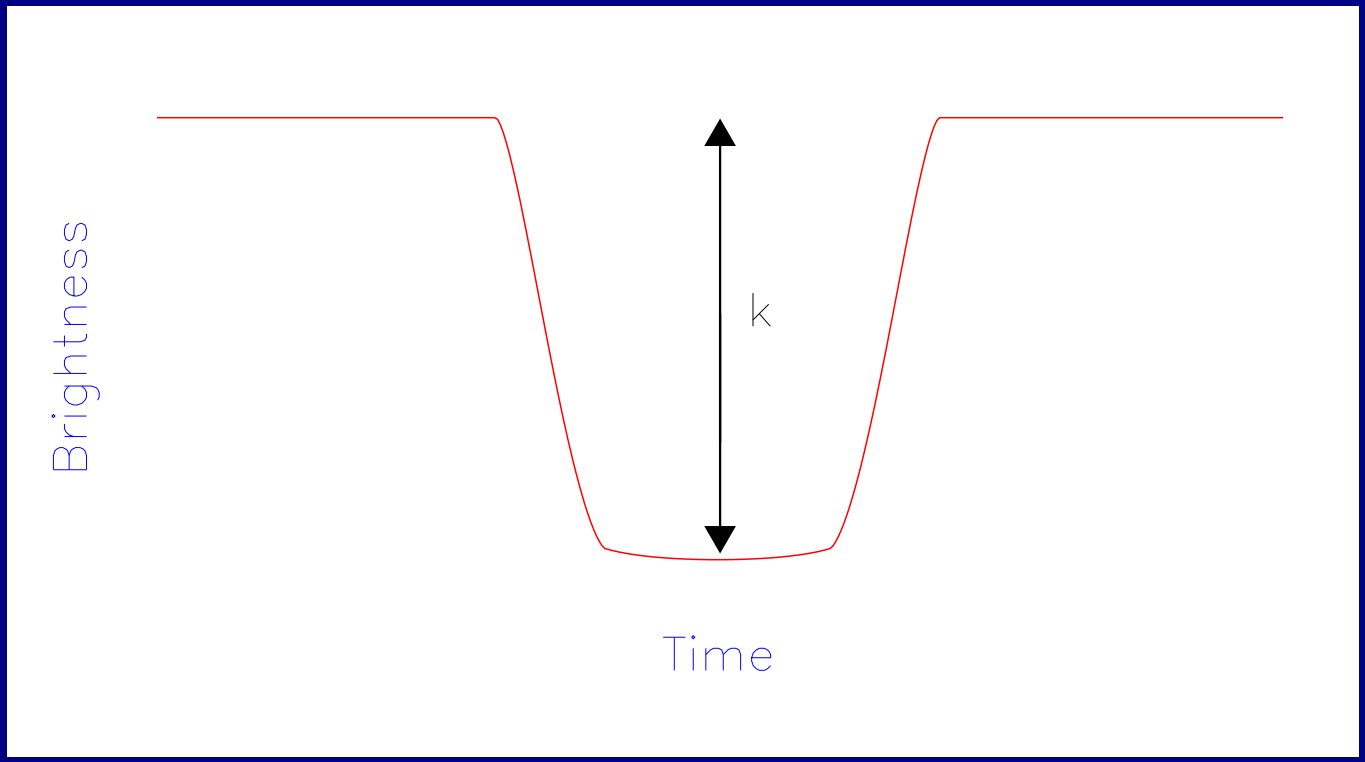

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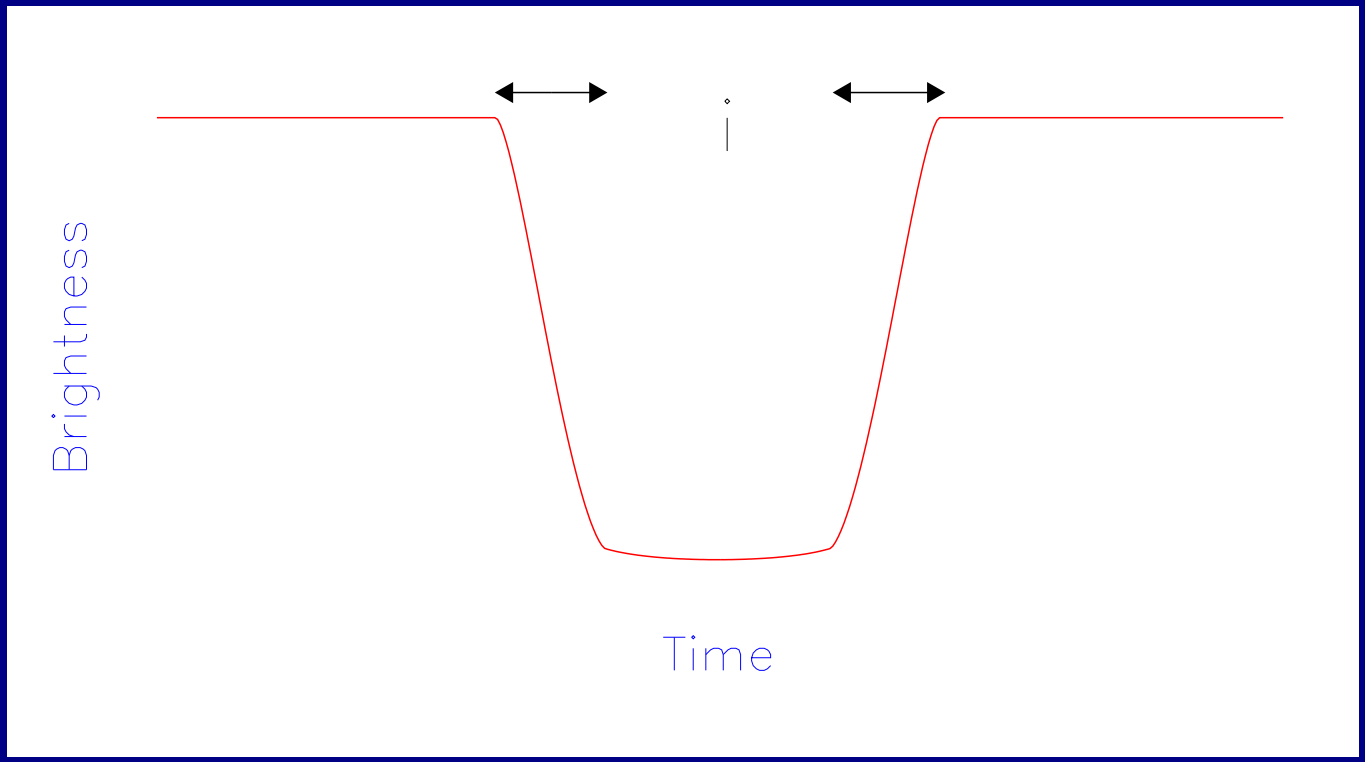

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	i	inclination of the orbit

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- 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

Homogeneous studies of transiting planets

- Light curve fit: JKTEBOP
- Limb darkening: five laws
- Statistical errors: Monte Carlo algorithm
- Correlated noise: residual-permutation algorithm
- Contaminating light: included in JKTEBOP
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- Extra constraint: five different theoretical models
- Empirical constraint: eclipsing binary relations

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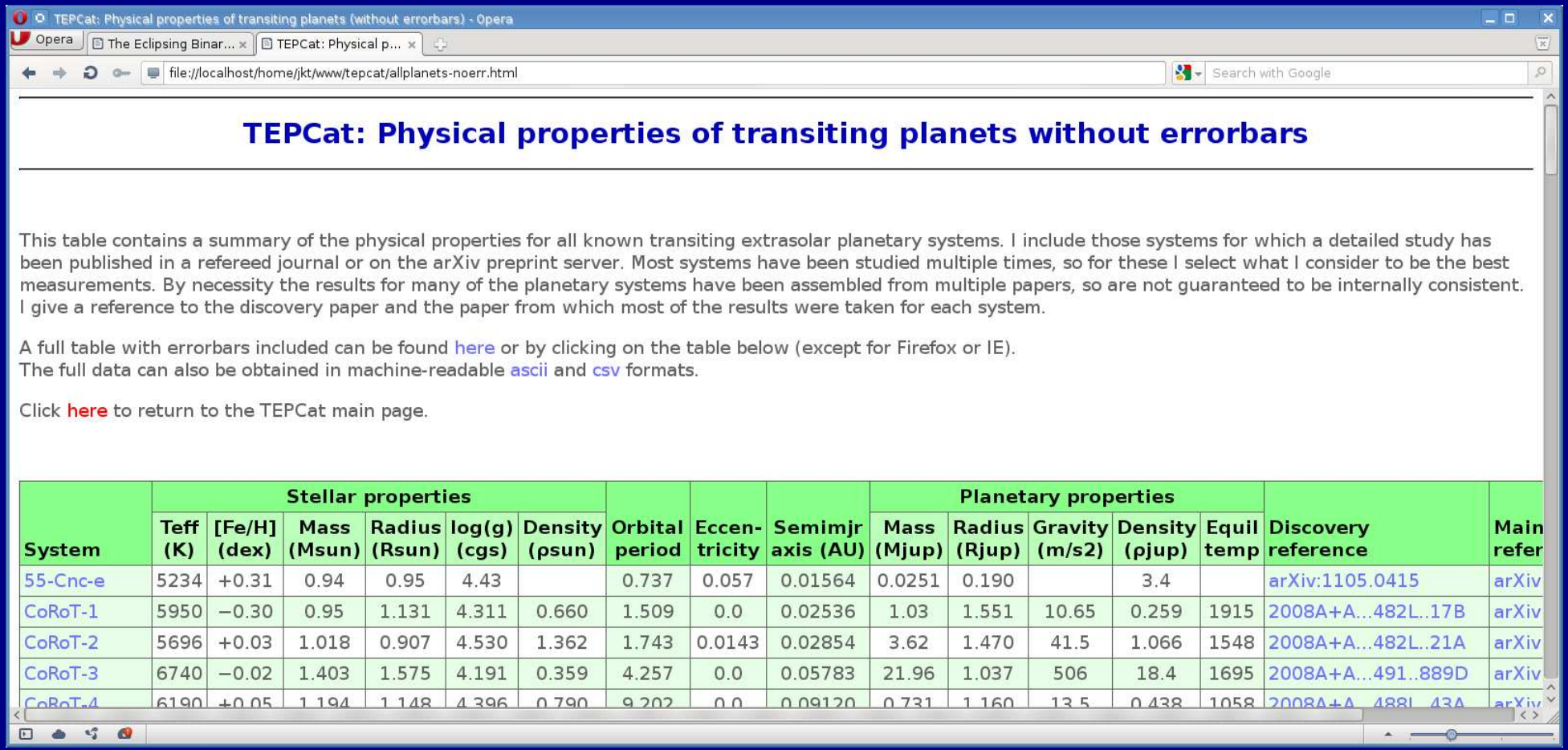
- Southworth (2008, 2009, 2010, 2011)
- TEPCat: http://www.astro.keele.ac.uk/∼jkt/tepcat/

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						Orbital period	Eccen-tricity	Semimjr axis (AU)	Planetary properties					Discovery reference	Main refer
	Teff (K)	[Fe/H] (dex)	Mass (Msun)	Radius (Rsun)	log(g) (cgs)	Density (ρsun)				Mass (Mjup)	Radius (Rjup)	Gravity (m/s2)	Density (ρjup)	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

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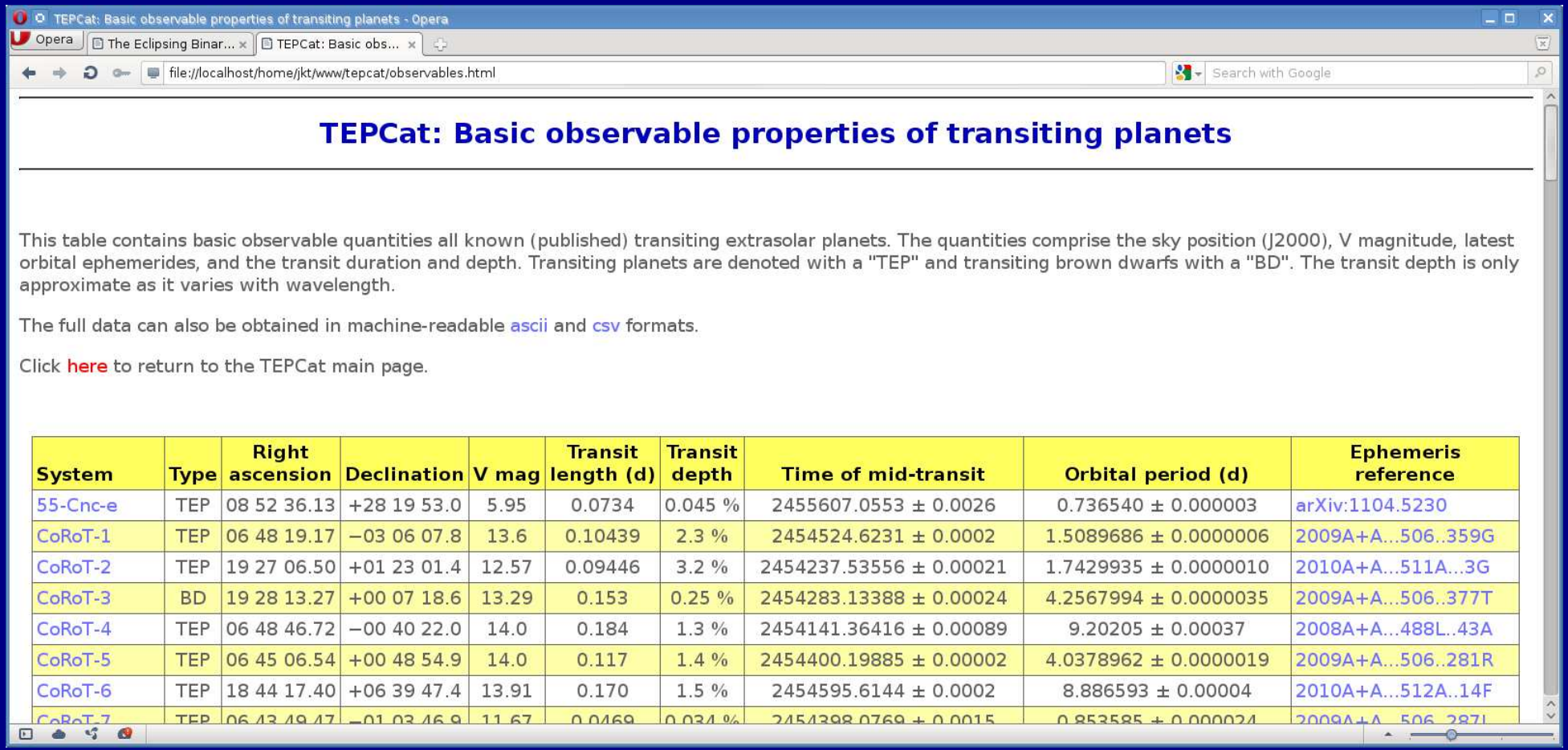
TEPCat



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.

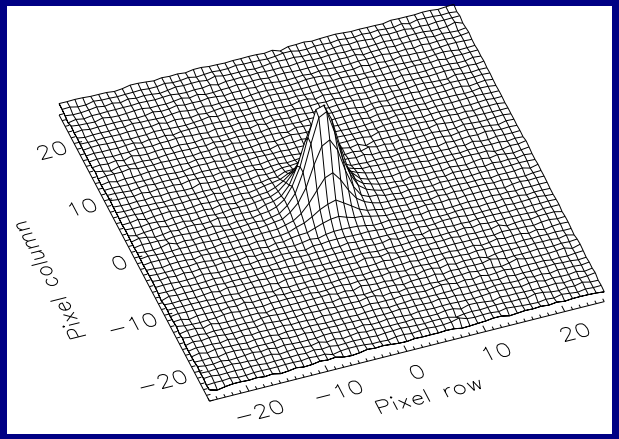
Click here to return to the TEPCat main page.

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 03 46.9	11.67	0.0469	0.034 %	2454398.0769 ± 0.0015	0.853585 ± 0.000024	2009A+A...506..287L

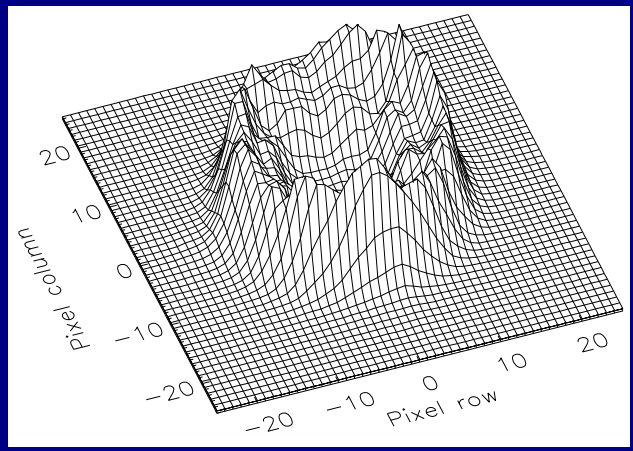
http://www.astro.keele.ac.uk/∼jkt/tepcat/

DEFOCUSSED PHOTOMETRY

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



Focussed PSF for WASP-5



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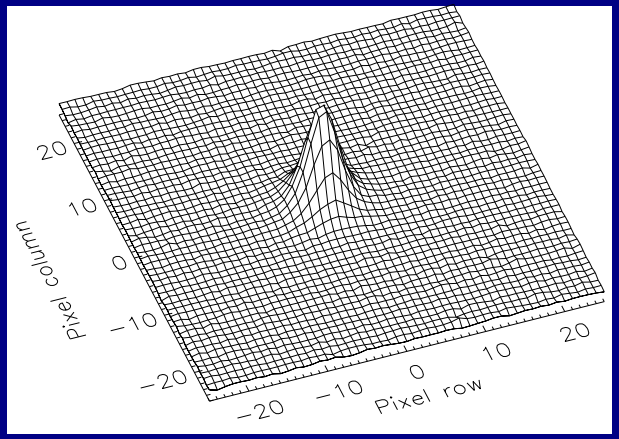

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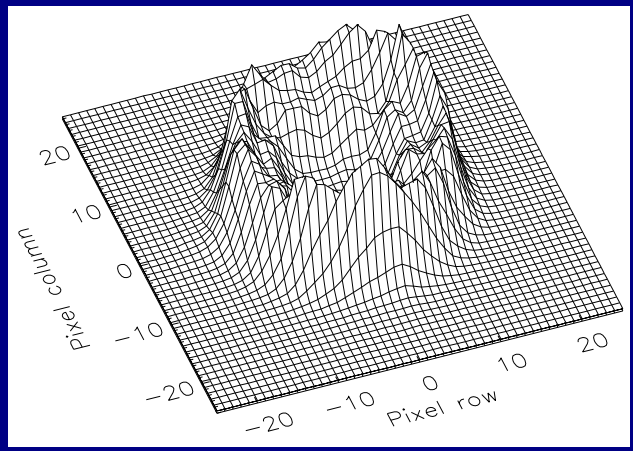

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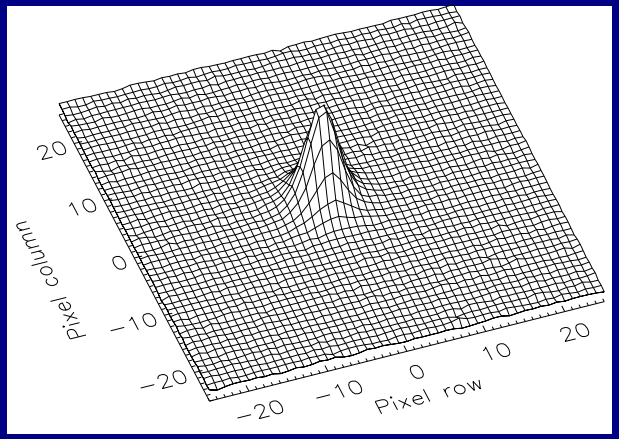
- Disadvantages:
  - lower time resolution $\Rightarrow$ 120 s is good enough for planets
  - higher background $\Rightarrow$ not important for bright stars



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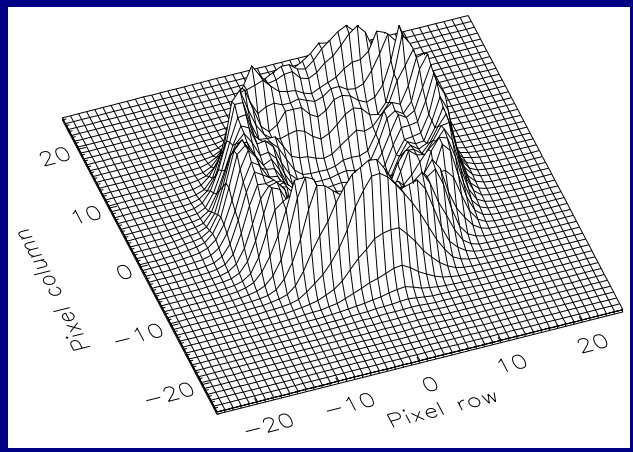
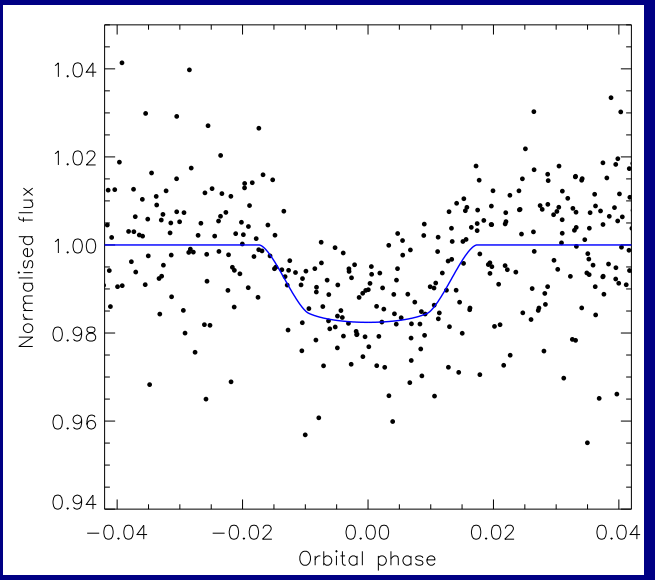


Defocussed PSF for WASP-5

Example: WASP-2

Discovery light curve (Collier Cameron et al., 2007MNRAS.375..951C)

$\sigma = 10\,\mathrm{mmag}$



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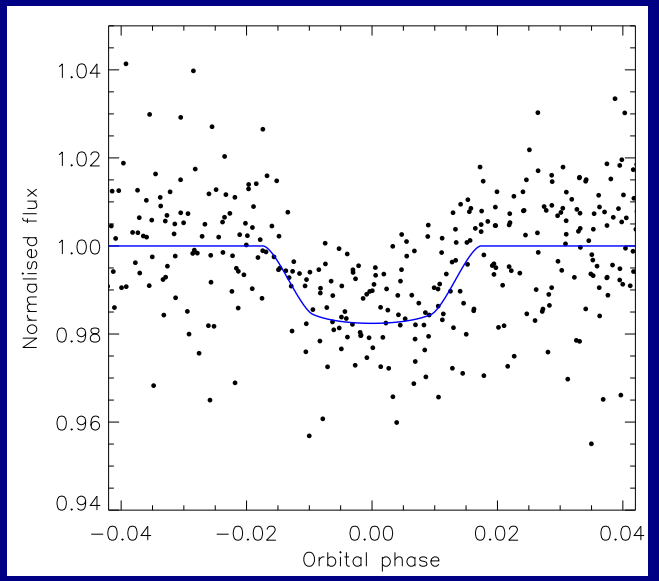

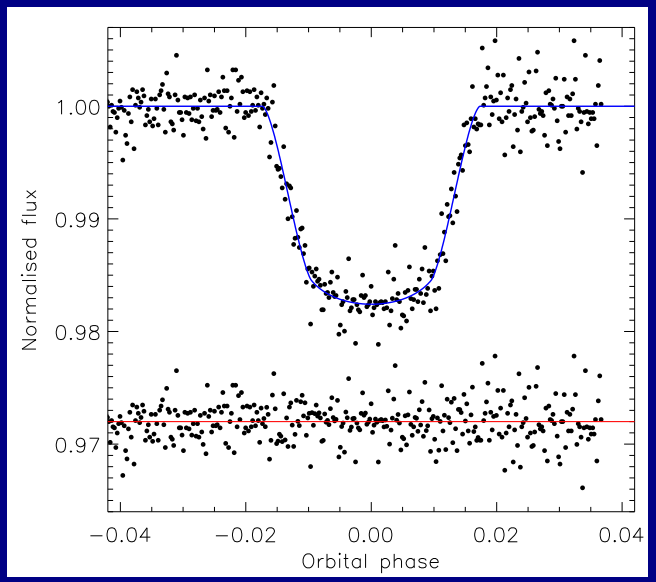

Charbonneau et al. (2007ApJ...658.1322C)

$\sigma = 1.9\,\mathrm{mmag}$

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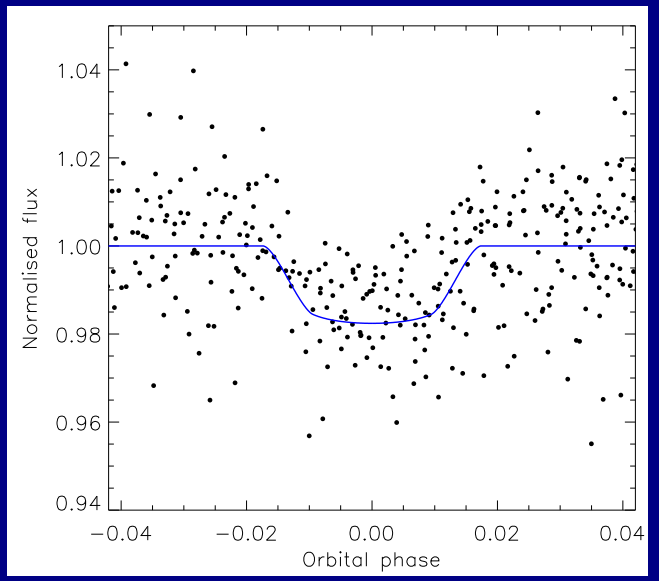
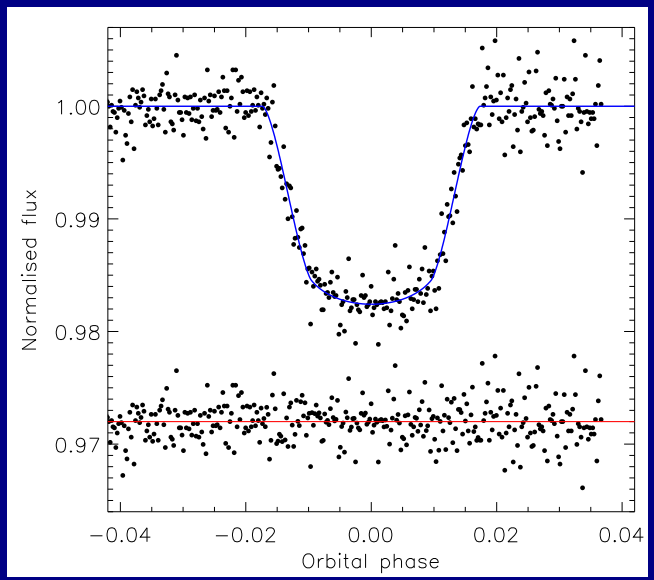


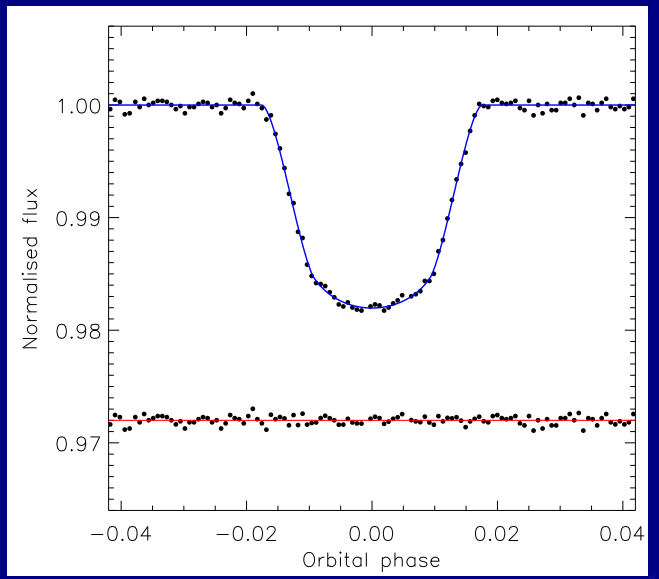


Charbonneau et al. (2007ApJ...658.1322C)

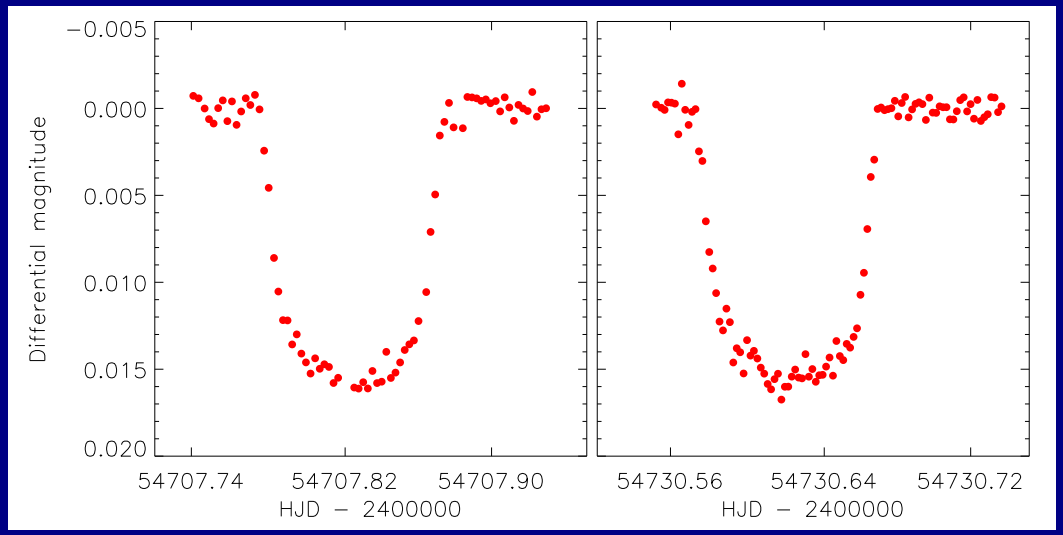
$\sigma = 1.9\,\mathrm{mmag}$

Defocussed-photometry light curve (DK1.5, 2009/06/02)

$\sigma = 0.46\,\mathrm{mmag}$

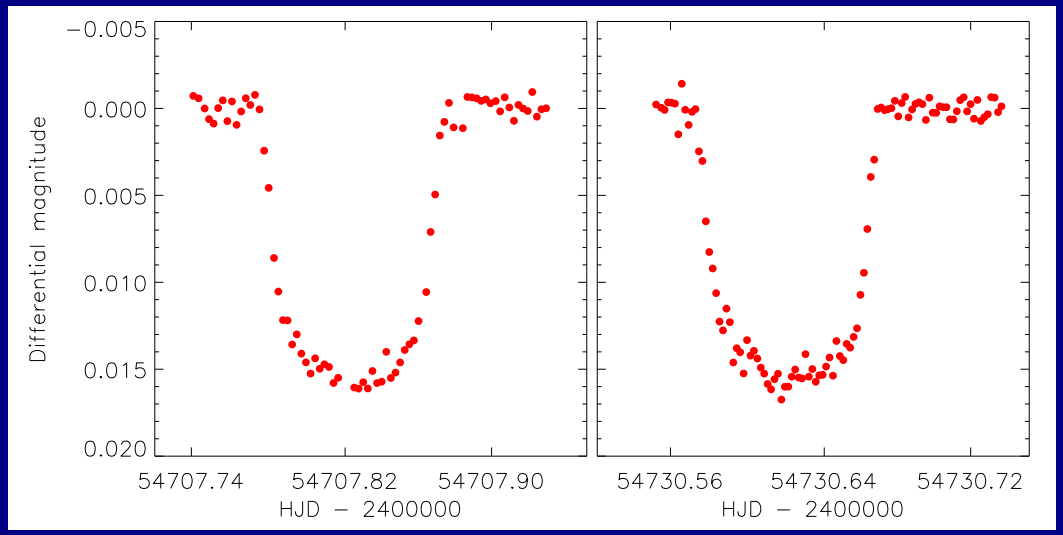


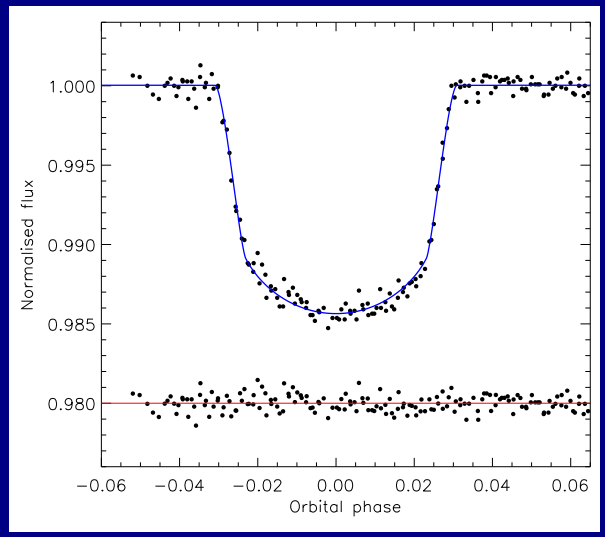
MiNDSTEp 2008 season. I. WASP-5



- Two transits, R filter, $t_{\mathrm{exp}} = 120\,\mathrm{s}$, PSF diameter 46 px (16″)

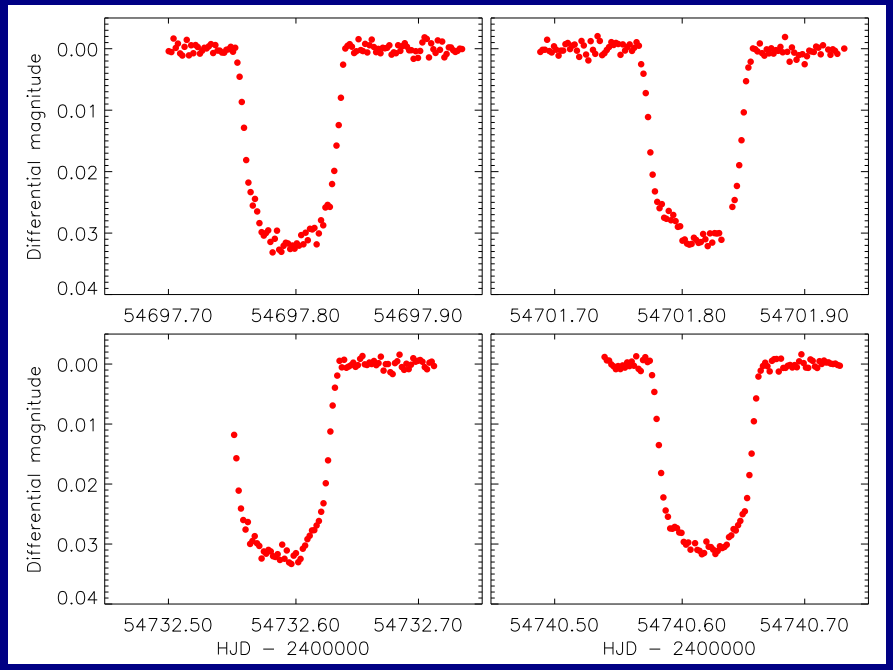
MiNDSTEp 2008 season. I. WASP-5





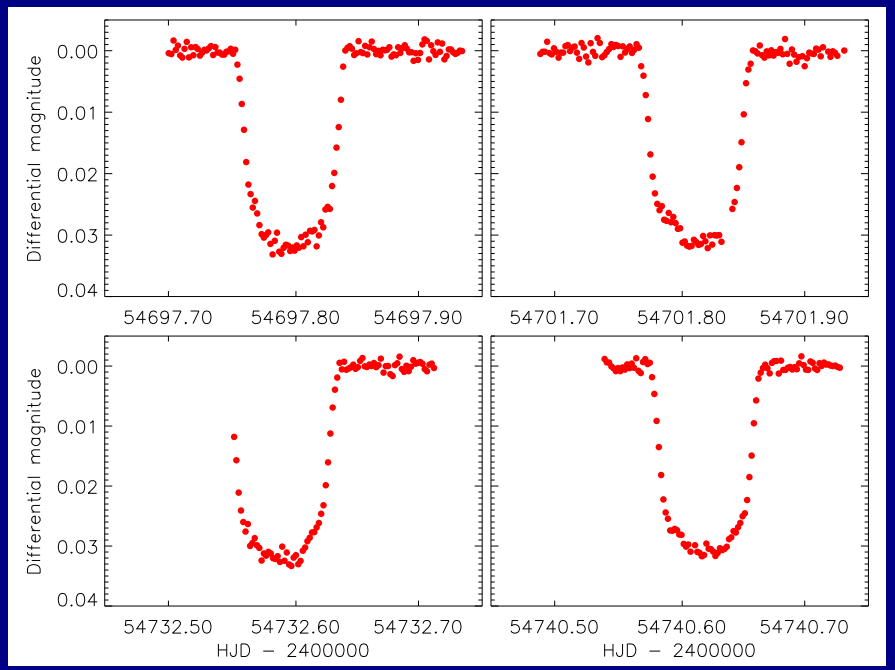
- Two transits, R filter, $t_{\rm exp} = 120\,\mathrm{s}$, PSF diameter 46 px (16″)
- JKTEBOP fit + stellar models (2009MNRAS.396.1023S):
  - planet mass $M_{\rm b} = 1.637 \pm 0.075 \pm 0.033\,\mathrm{M_{Jup}}$
  - planet radius $R_{\rm b} = 1.171 \pm 0.056 \pm 0.012\,\mathrm{R_{Jup}}$
  - surface gravity $g_{\rm b} = 29.6 \pm 2.8\,\mathrm{m\,s^{-2}}$ (empirical)

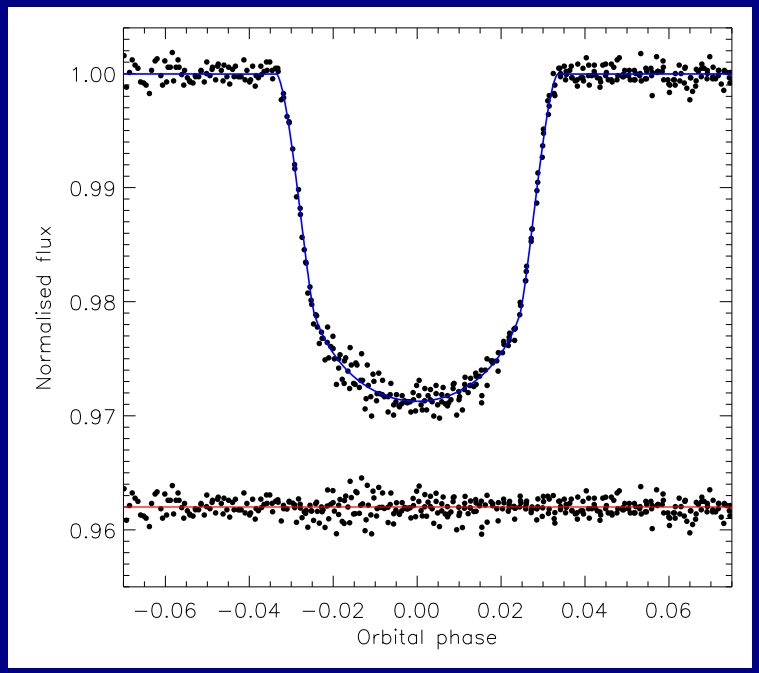
MiNDSTEp 2008 season. II. WASP-4



- Four transits from the Danish, V filter, $t_{\rm exp} = 120\,{\rm s}$
  - two Magellan transits (Winn et al. 2009AJ....137.3826W)
  - one VLT transit (Gillon et al. 2009A&A...496..259G)

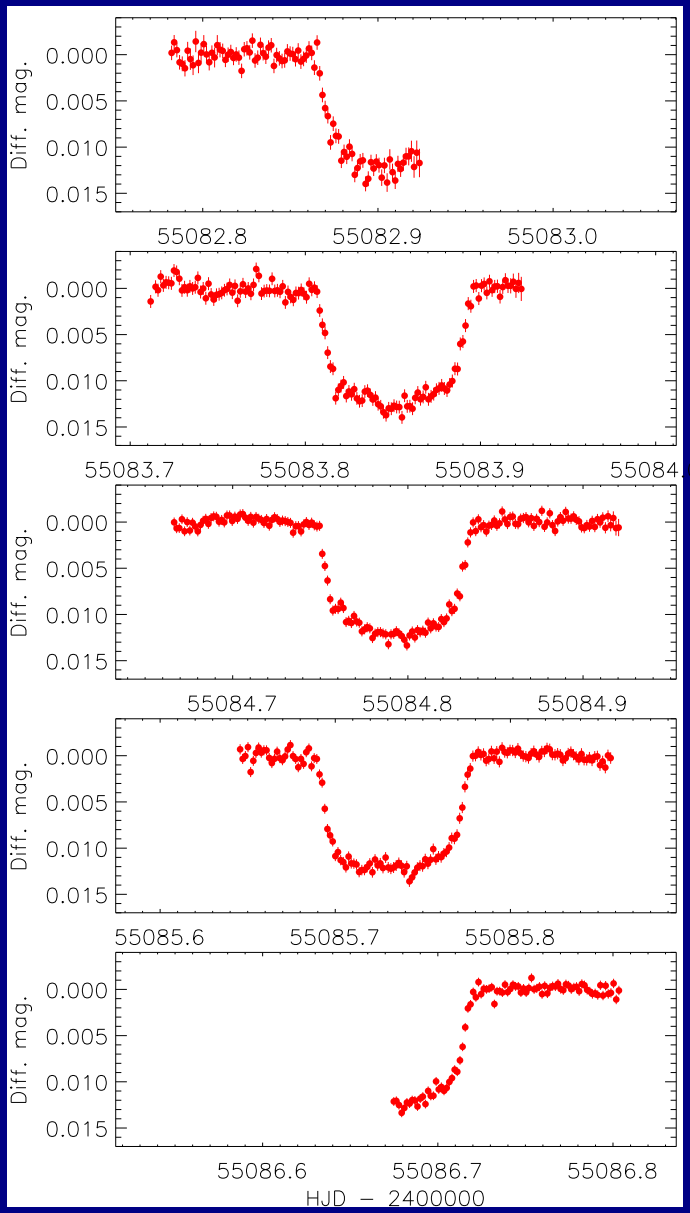
MiNDSTEp 2008 season. II. WASP-4





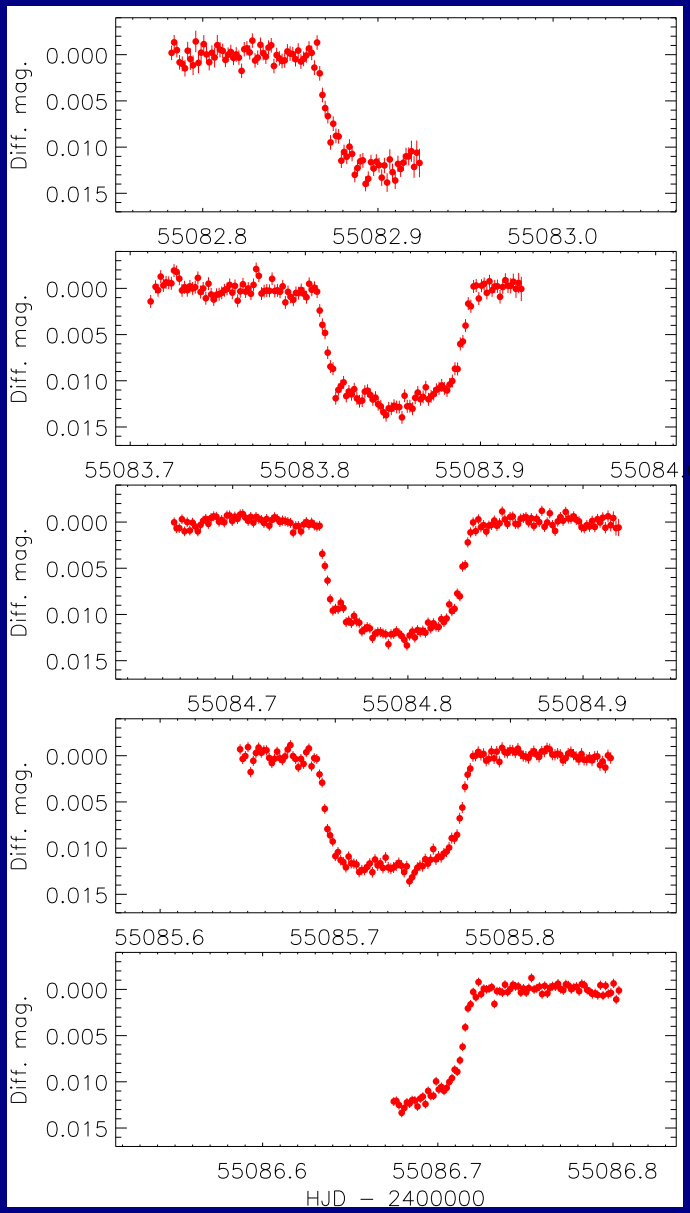
- Four transits from the Danish, V filter, $t_{\rm exp} = 120\,{\rm s}$
  - two Magellan transits (Winn et al. 2009AJ....137.3826W)
  - one VLT transit (Gillon et al. 2009A&A...496..259G)
- Analyse all data in standard way (2009MNRAS.399..287S):
  - planet mass $M_{\rm b} = 1.289\,^{+0.090\ +0.039}_{-0.090\ -0.000}\ {\rm M_{Jup}}$
  - planet radius $R_{\rm b} = 1.371\,^{+0.032\ +0.021}_{-0.035\ -0.000}\ {\rm R_{Jup}}$

MiNDSTEp 2009 season. I. WASP-18

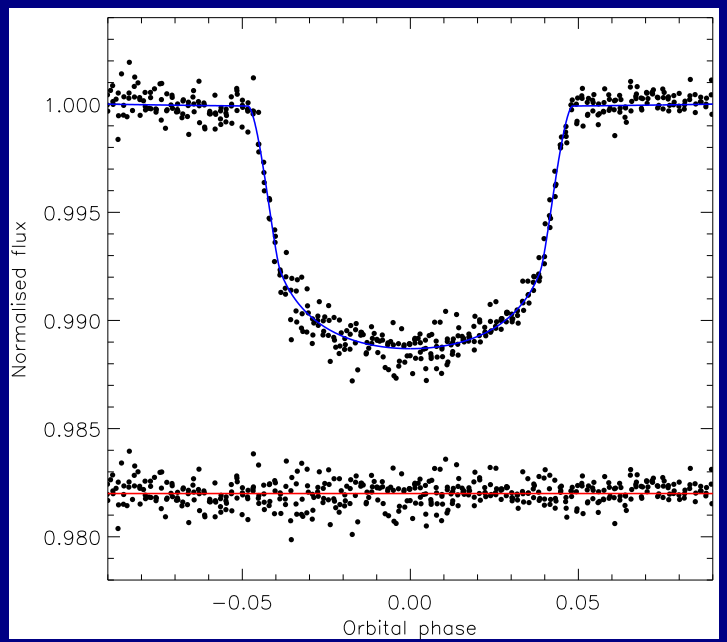


- Mass $10\,\mathrm{M_{Jup}}$, period 0.94 days
- Five transits on consecutive nights

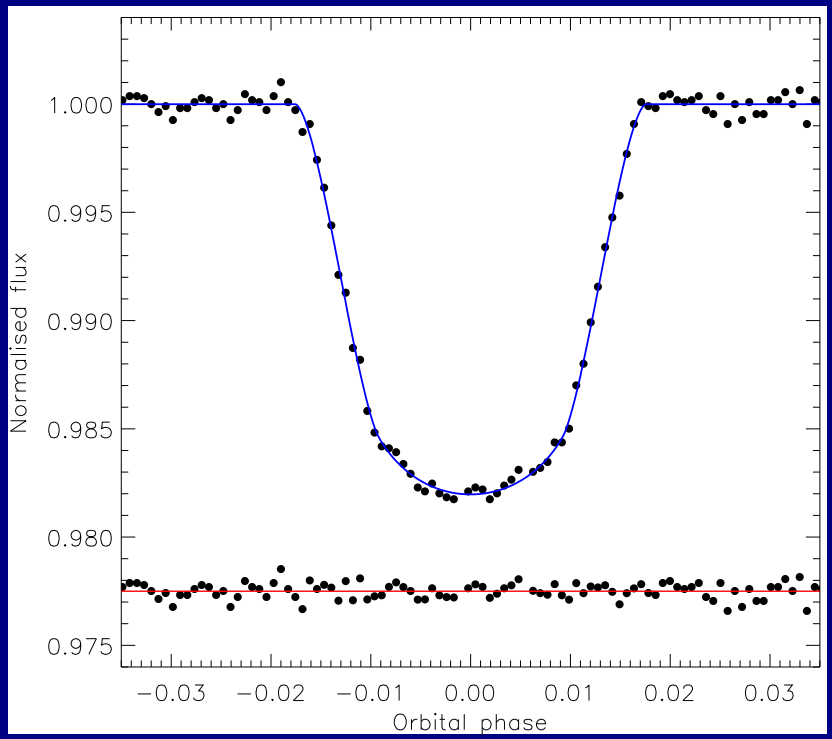
MiNDSTEp 2009 season. I. WASP-18

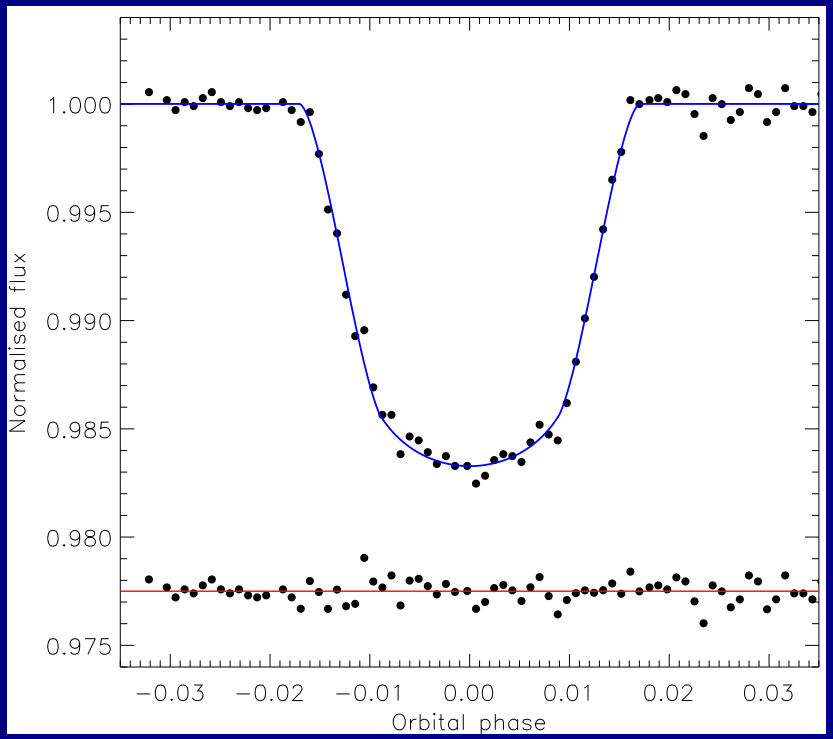


- Mass $10\,\mathrm{M_{Jup}}$, period 0.94 days
- Five transits on consecutive nights
- Standard analysis (2009ApJ...707..167S)
  - $M_\mathrm{b} = 10.43 \pm 0.30 \pm 0.24\,\mathrm{M_{Jup}}$
  - $R_\mathrm{b} = 1.165 \pm 0.055 \pm 0.014\,\mathrm{R_{Jup}}$
  - $g_\mathrm{b} = 191 \pm 17\,\mathrm{m\,s^{-2}}$



MiNDSTEp 2009 season. II. WASP-2

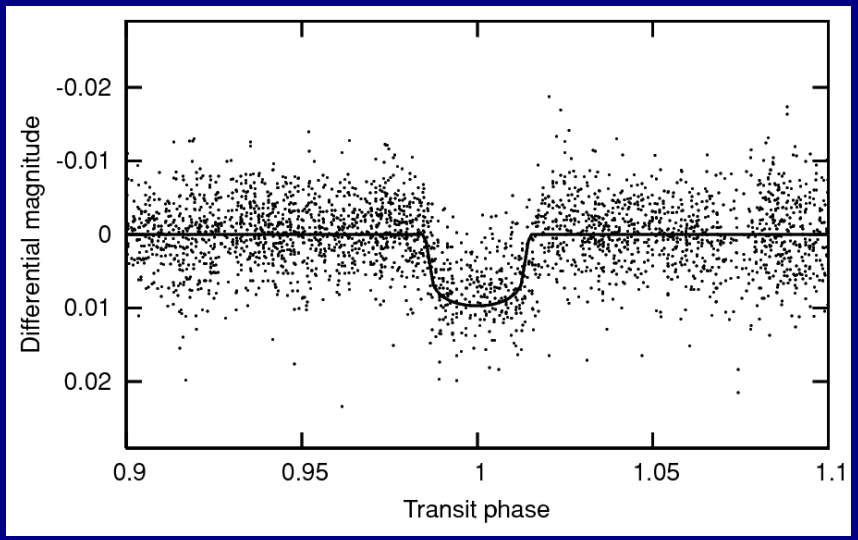




- Two transits of WASP-2 ($\sigma = 0.42$ and 0.48 mmag)
- Standard analysis (2010MNRAS.408.1680S):
  - $M_{\rm b} = 0.846 \pm 0.055 \pm 0.023\,{\rm M_{Jup}}$
  - $R_{\rm b} = 1.043 \pm 0.029 \pm 0.015\,{\rm R_{Jup}}$
  - $g_{\rm b} = 19.32 \pm 0.80\,{\rm m\,s^{-2}}$

MiNDSTEp 2010 season: WASP-7

- Discovery paper had only SuperWASP photometry
  - Used a main-sequence prior for the star to get a result
  - $M_{\rm b} = 0.96^{+0.12}_{-0.18}\,{\rm M_{Jup}}$
  - $R_{\rm b} = 0.915^{+0.046}_{-0.040}\,{\rm M_{Jup}}$
  - $\rho_{\rm b} = 1.26^{+0.25}_{-0.21}\,\rho_{\rm Jup}$



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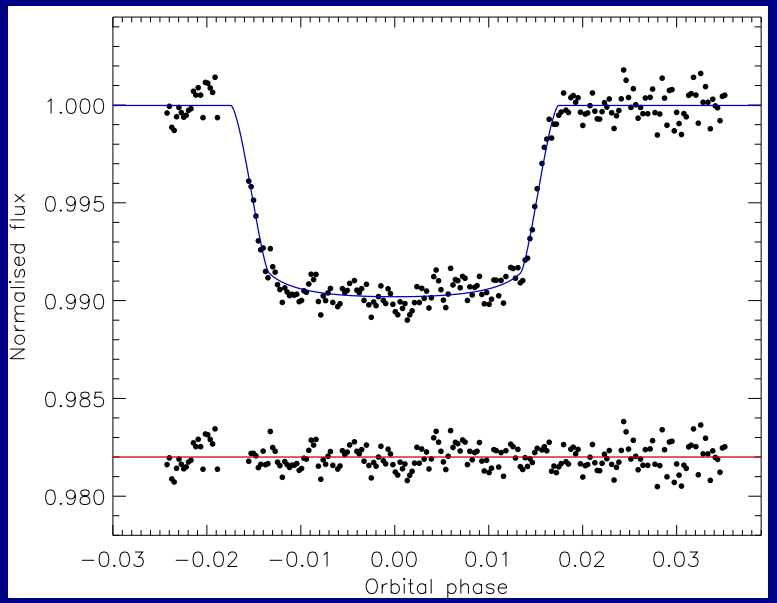

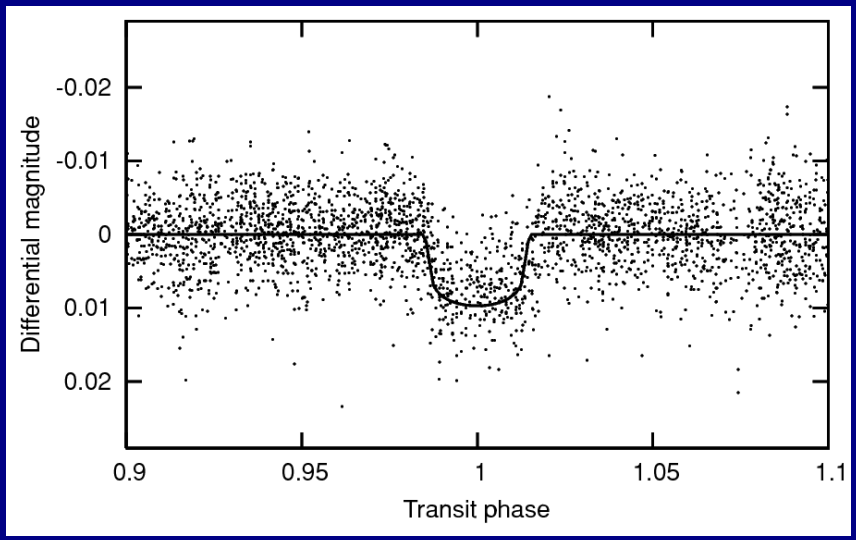

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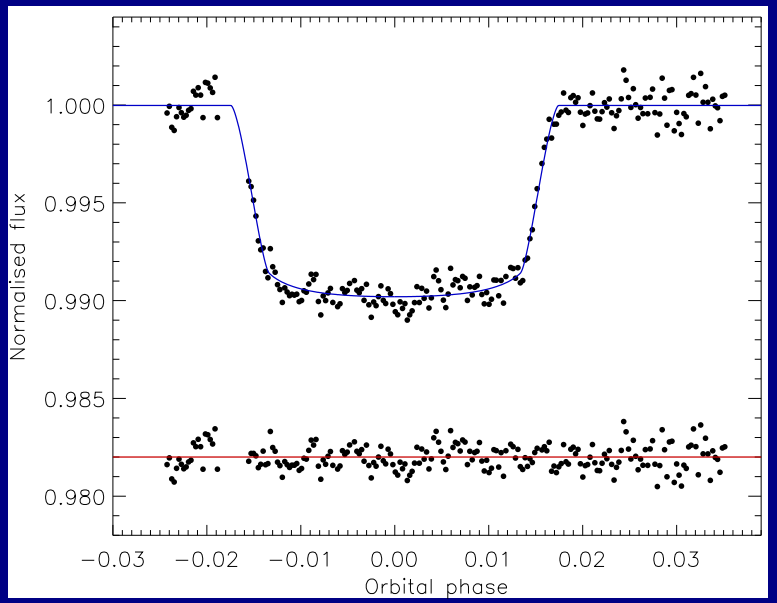
  - $\rho_\mathrm{b} = 1.26^{+0.25}_{-0.21}\,\rho_\mathrm{Jup}$
- One transit from the Danish 1.5 m (2011A+A...527A...8S):
  - $M_\mathrm{b} = 0.96 \pm 0.13\,\mathrm{M_{Jup}}$
  - $R_\mathrm{b} = 1.363 \pm 0.093\,\mathrm{R_{Jup}}$
  - $\rho_\mathrm{b} = 0.356 \pm 0.087\,\rho_\mathrm{Jup}$



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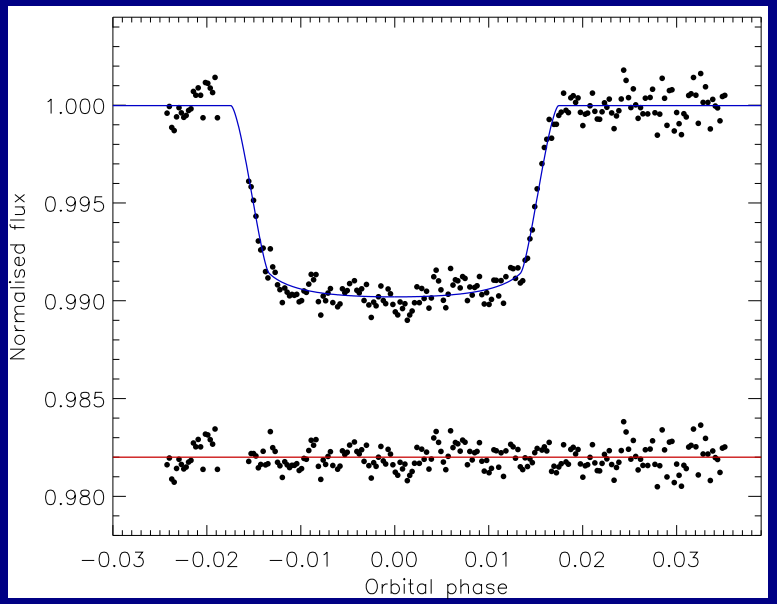
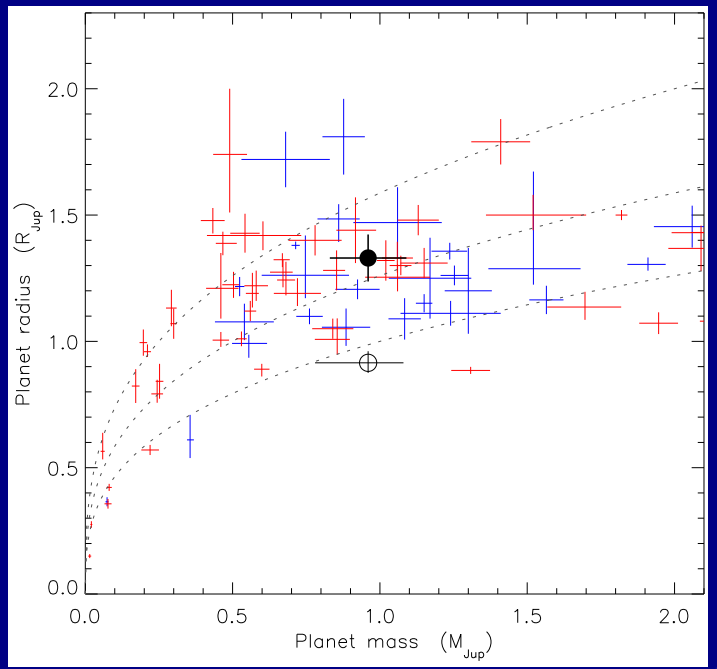
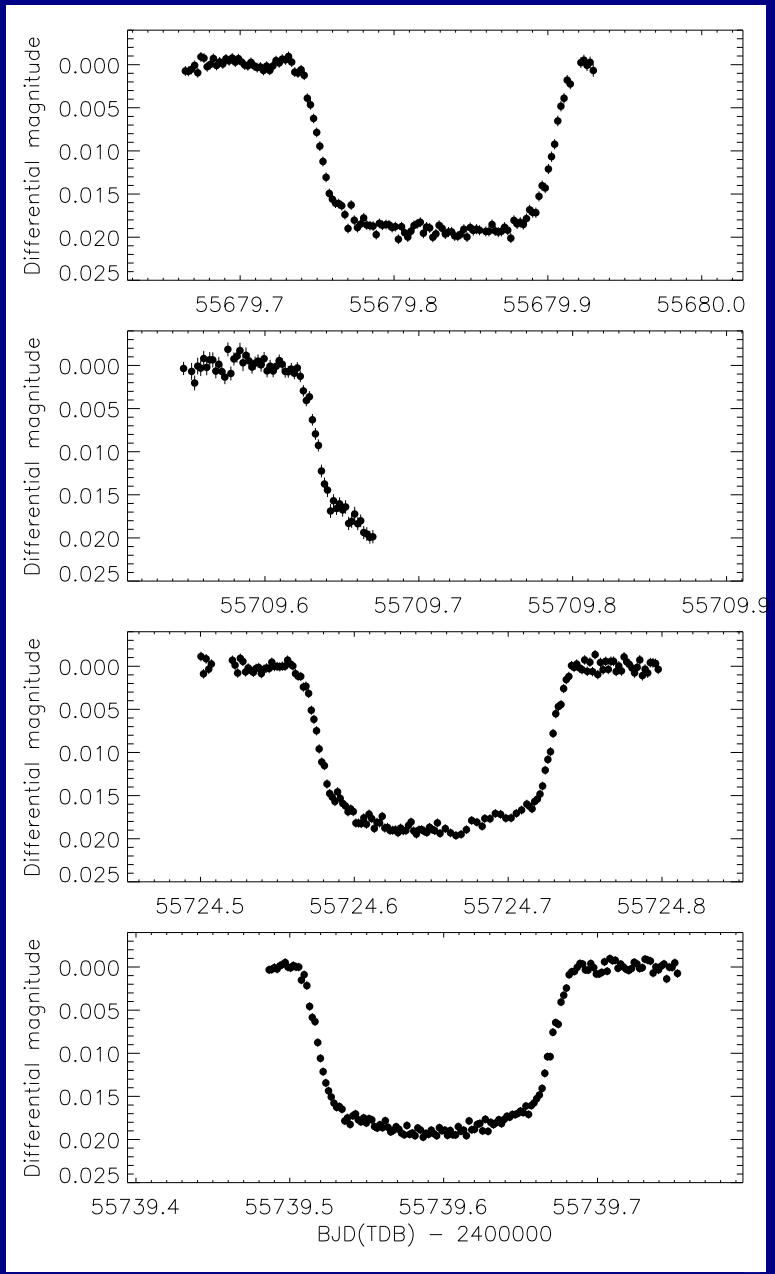
  - Density changes by factor of 3.5





MiNDSTEp 2011 season: WASP-17

- Biggest planet known
  - discovery paper: $R_{\rm b} = 1.5$–$2.0\,{\rm R_{Jup}}$
  - eccentricity $e = 0.129^{+0.106}_{-0.068}$
- Secondary eclipse observed with *Spitzer*
  - $e = 0.028$ (4σ significance)



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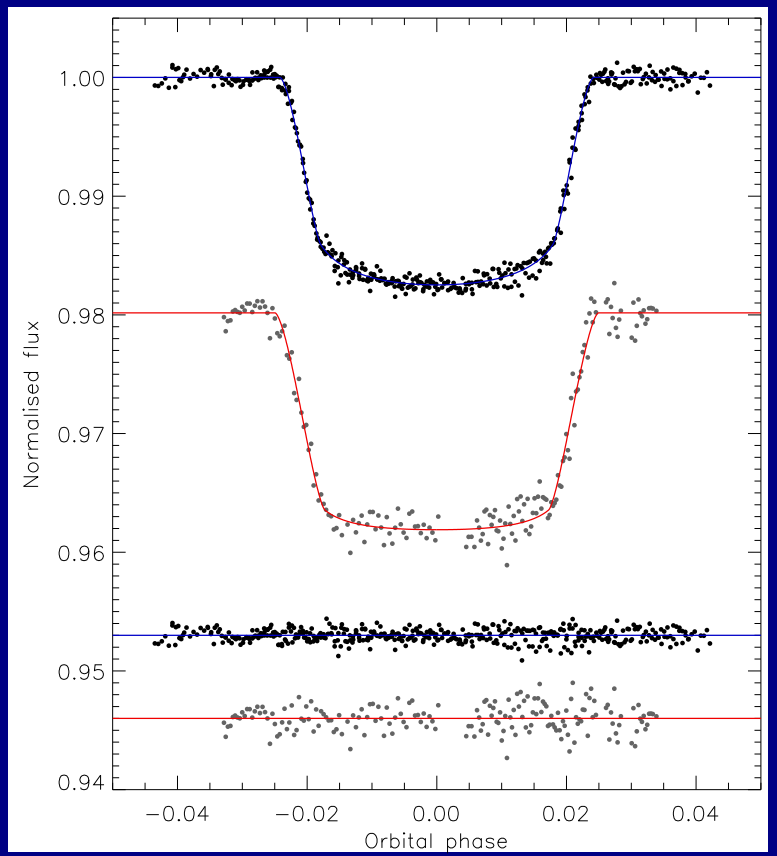
- Secondary eclipse observed with *Spitzer*
  - $e = 0.028$ (4σ significance)
- Four transits from the Danish 1.5 m:
  - scatter 0.56, 0.76, 0.53, 0.48 mmag!
  - longer $P_{\rm orb} \Rightarrow$ no eccentricity



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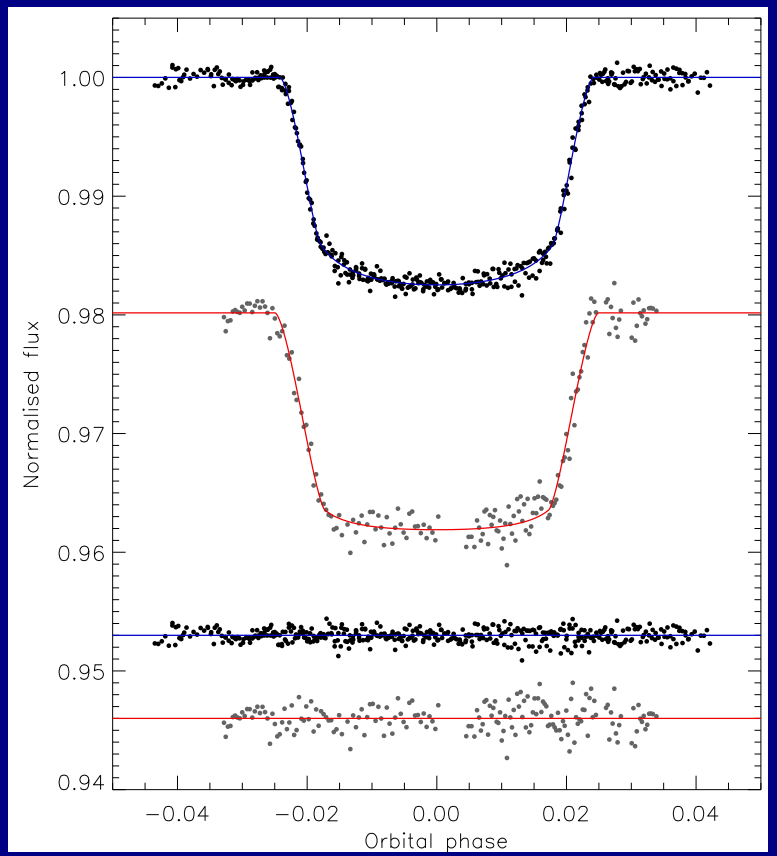
- Secondary eclipse observed with *Spitzer*
  - $e = 0.028$ (4σ significance)
- Four transits from the Danish 1.5 m:
  - scatter 0.56, 0.76, 0.53, 0.48 mmag!
  - longer $P_{\rm orb} \Rightarrow$ no eccentricity
  - $R_{\rm b} = 1.932 \pm 0.052 \pm 0.010\,{\rm R_{Jup}}$
  - $\rho_{\rm b} = 0.062 \pm 0.005\,\rho_{\rm Jup}$
- Paper in progress



Summary of objects

- WASP-5: published (2009MNRAS.396.1023S) + have more data
- WASP-4: published (2009MNRAS.399..287S) + have more data
- WASP-18: published (2009ApJ...707..167S) + have more data
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- WASP-7: published (2011A+A...527A...8S) + have more data

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- WASP-6: observations completed, paper assigned to Jeremy
- WASP-16: observations completed

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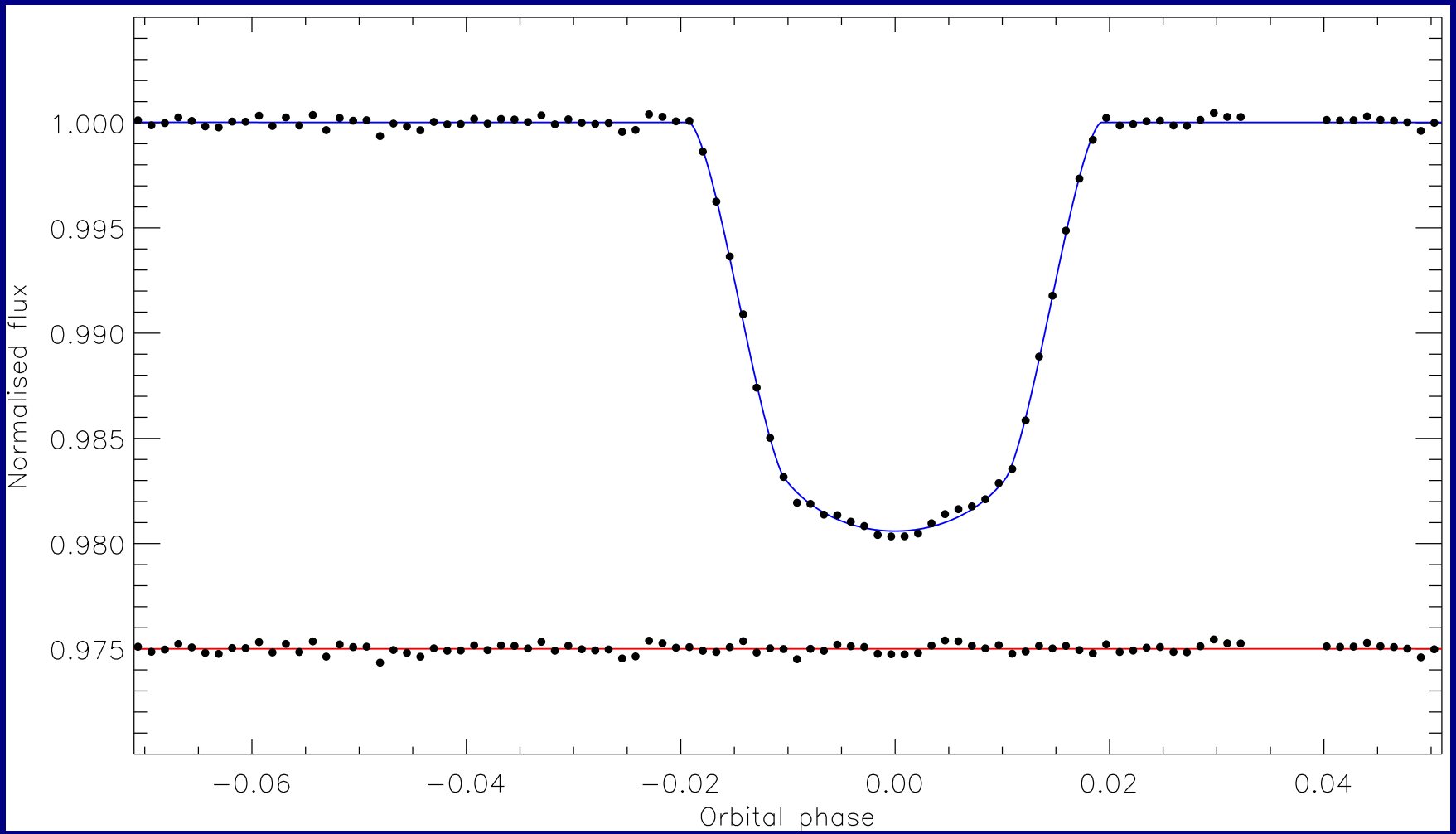
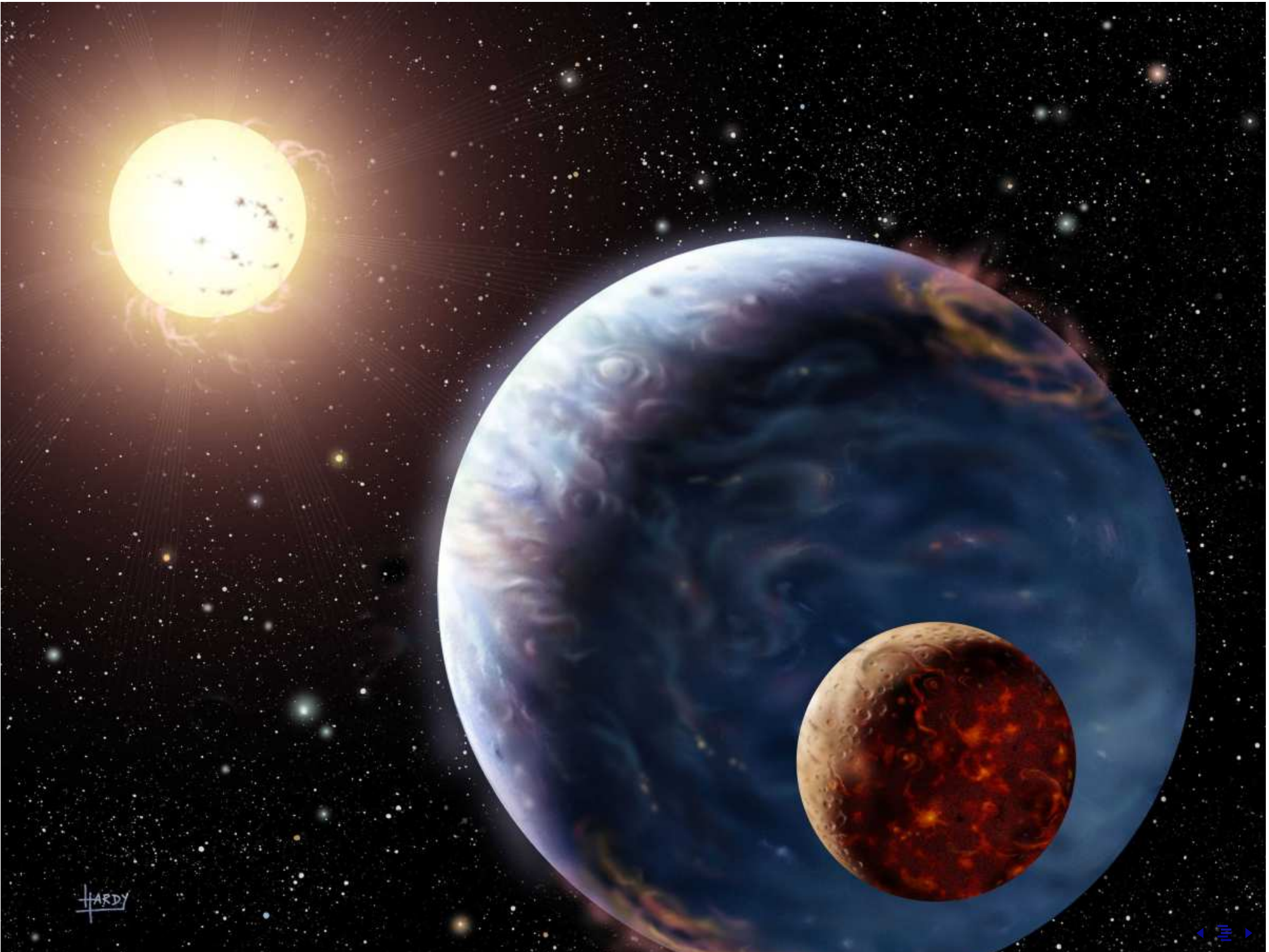
- WASP-16: observations completed
- 8 other systems with partial datasets
- 20–30 more possible targets

How far can we go?



To the NTT and beyond!

WASP-50: scatter 0.23 mmag?


HARDY