Uniting MEarth and TESS

KRISTO MENT

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

MEarth Team:
David Charbonneau,
Jonathan Irwin,
Jen Winters, et al.

the David & Lucile Packard FOUNDATION

NASA

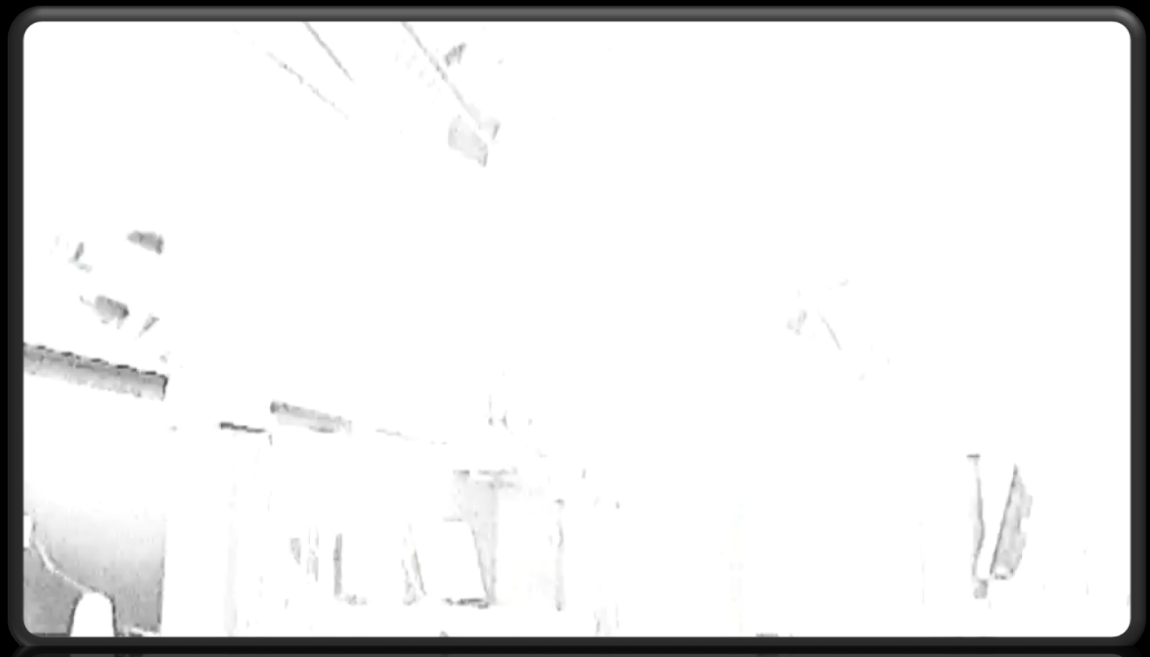
NSF

JOHN TEMPLETON FOUNDATION

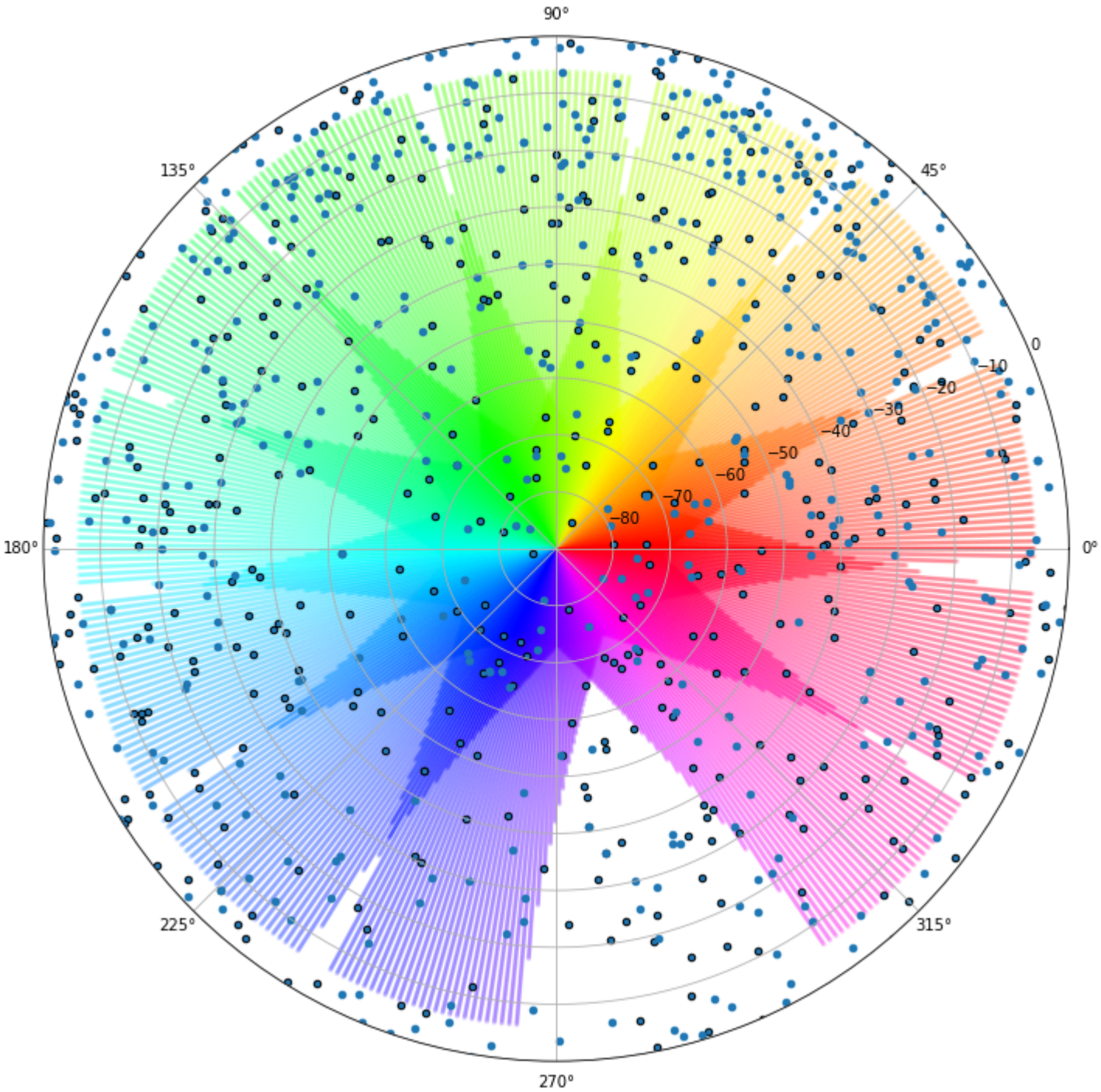
Image: SpaceX

MEarth-South
Cerro Tololo, Chile

MEarth-North
Mt Hopkins, AZ



MEarth Targets in Sectors 1-12

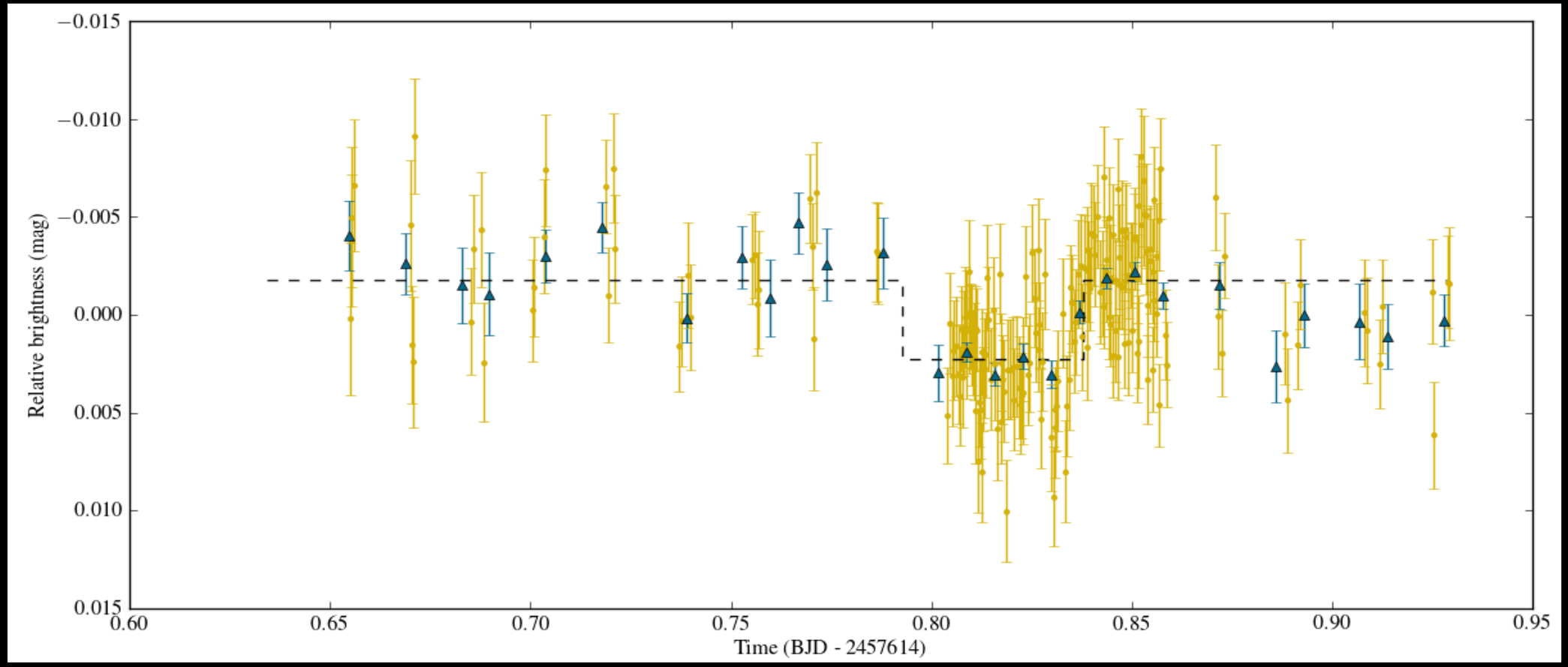


MEarth & TESS

- MEarth data modeling
- MEarth planets in Sectors 1-12
- MEarth contribution to TESS discoveries
- TESS vetting of MEarth targets of interest

MEarth finds terrestrial planets in real time

Discovery of LHS 1140 c on 14 Aug 2016

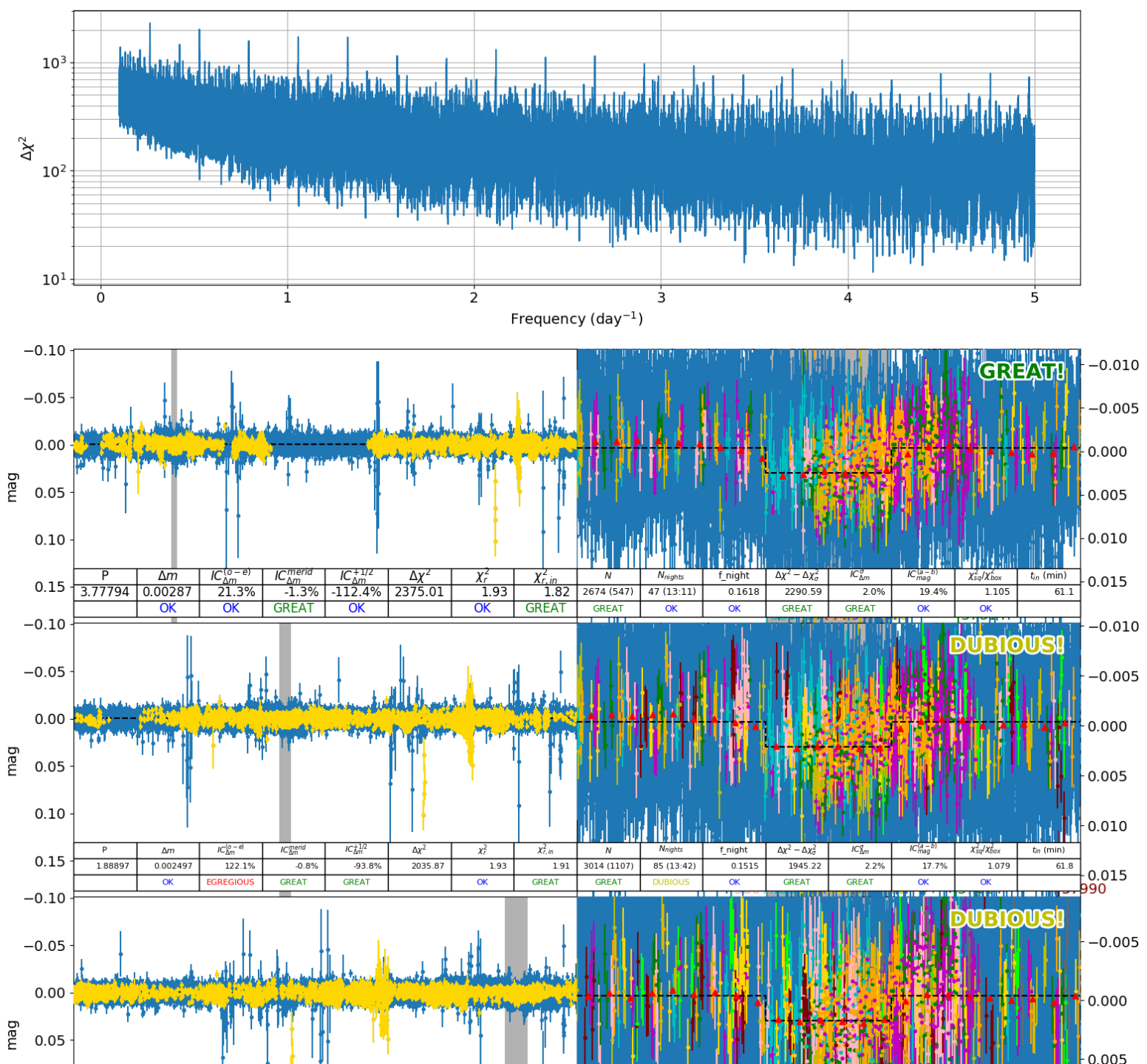


Ment et al 2019

We also use an Advanced

BLS

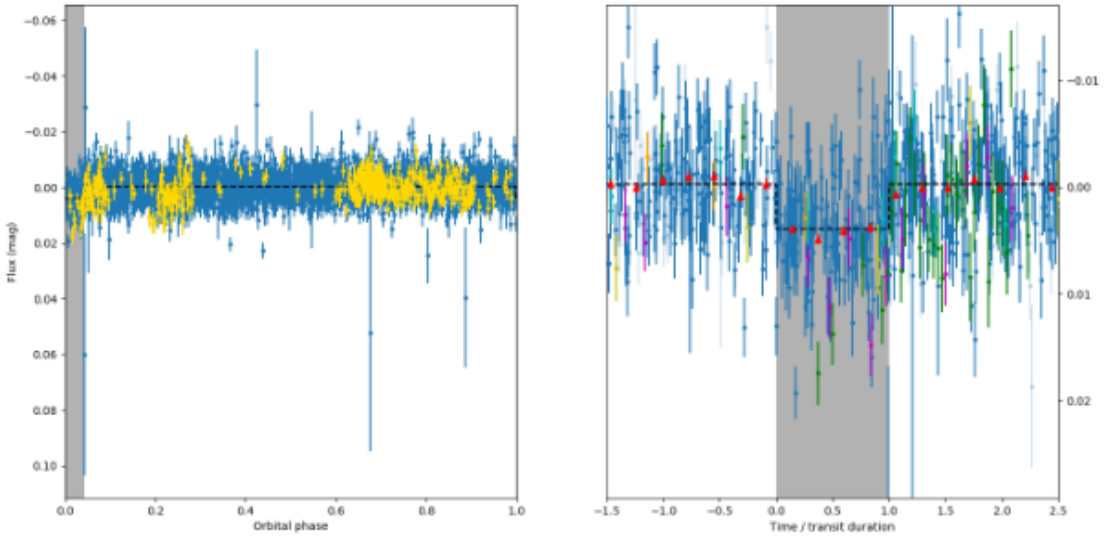
Search



Advanced BLS Vetting with 15 parameters

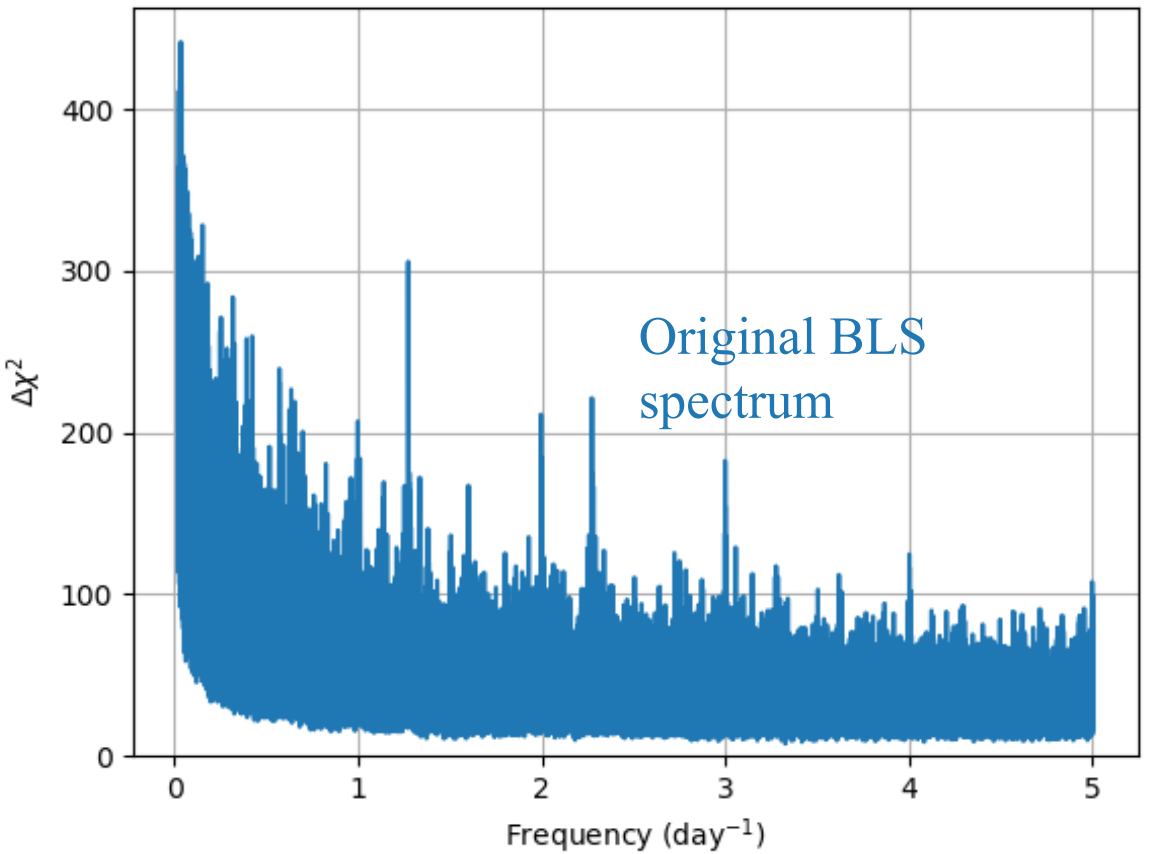
2	M-580.R6.2		OK
P	0.462932	$\Delta\chi^2$	353.16	276.47

1	Transit midpoint	JD 57397.97267	
2	Transit duration	28.98 min	GREAT
3	Transit depth	4.2 mmag	OK
4	Reduced $\Delta\chi^2$	2.67	DUBIOUS
5	Reduced $\Delta\chi^2$ (in-transit)	2.91	GREAT
6	Max. night contribution	14.2%	OK
7	# of in-transit data (exp)	158 (152)	GREAT
8	# of in-transit nights (sig:insig)	101 (17:34)	OK
9	Depth IC odd-even	6.3%	GREAT
10	Depth IC meridian flips	-2.7%	GREAT
11	Depth IC trigger nights	-9.4%	GREAT
12	Depth IC half-phase	-116%	OK
13	Depth IC noise	5.2%	OK
14	Ingress/egress baseline IC	6.3%	GREAT
15	Frac. $\Delta\chi^2$ of quadratic fit	1.165	OK



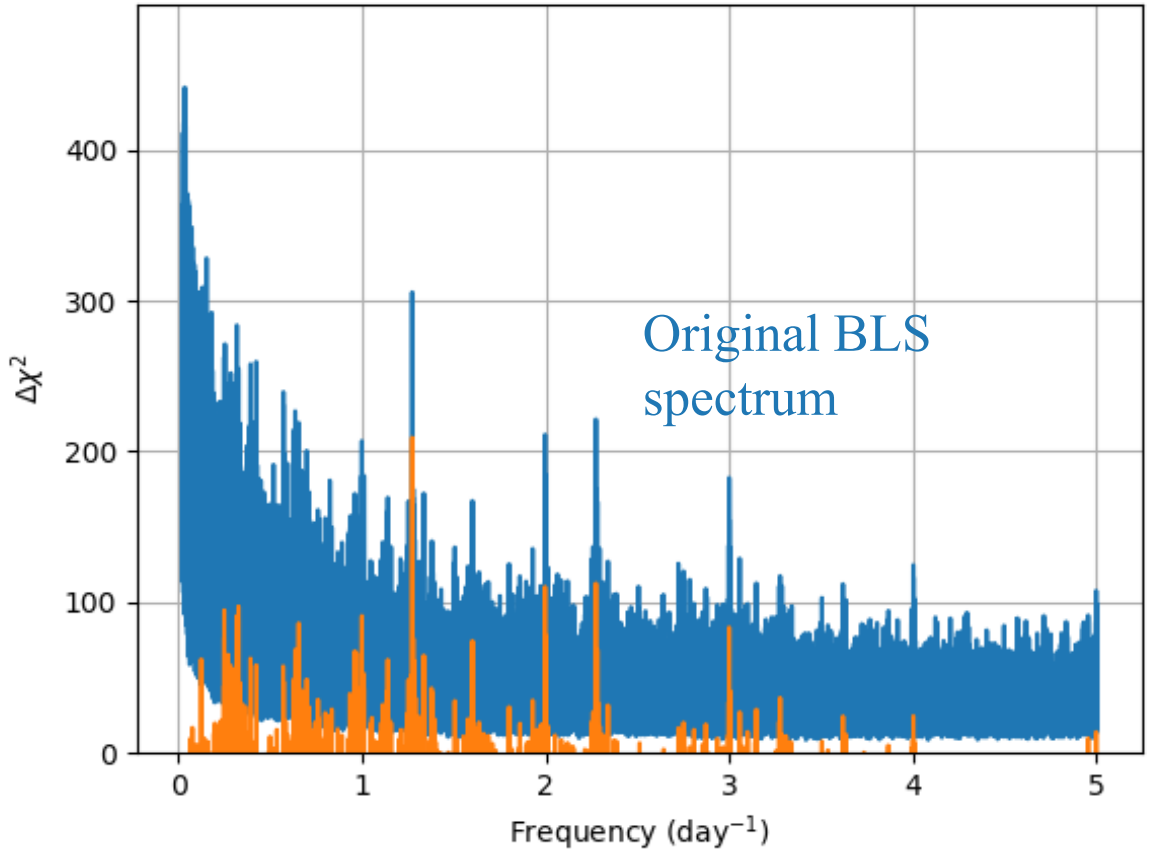
Advanced BLS

Noise Spectrum



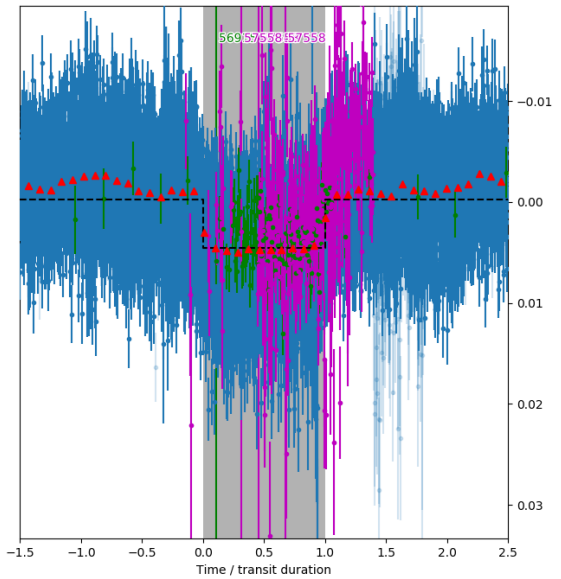
Advanced BLS

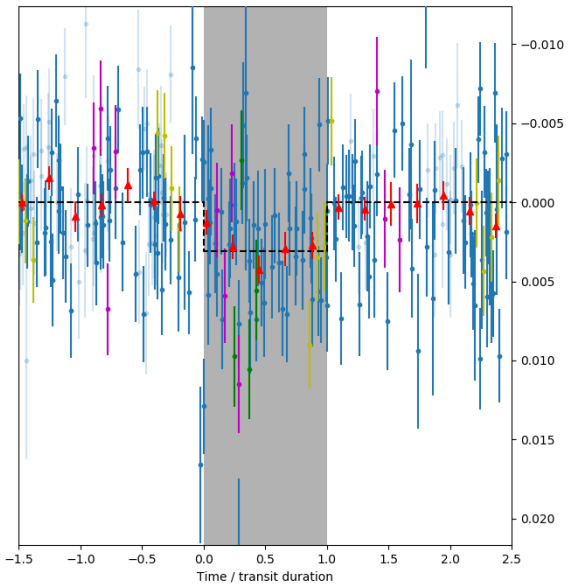
Noise Spectrum

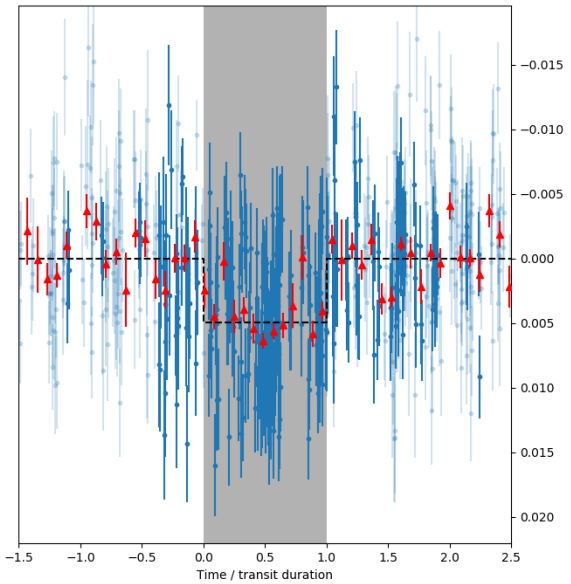


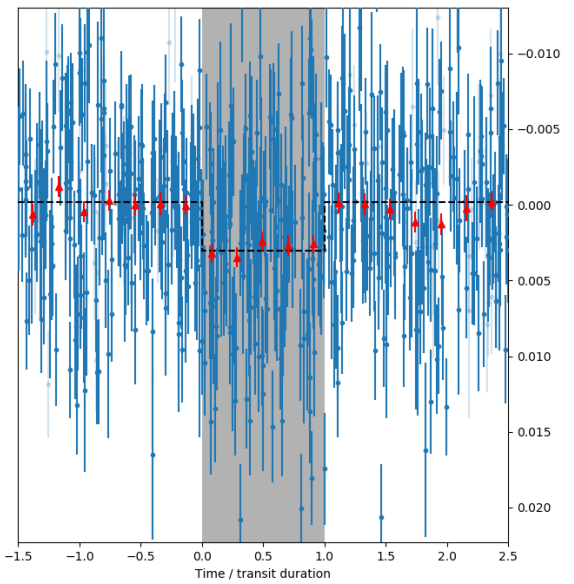
Residual BLS spectrum after subtracting “noise”

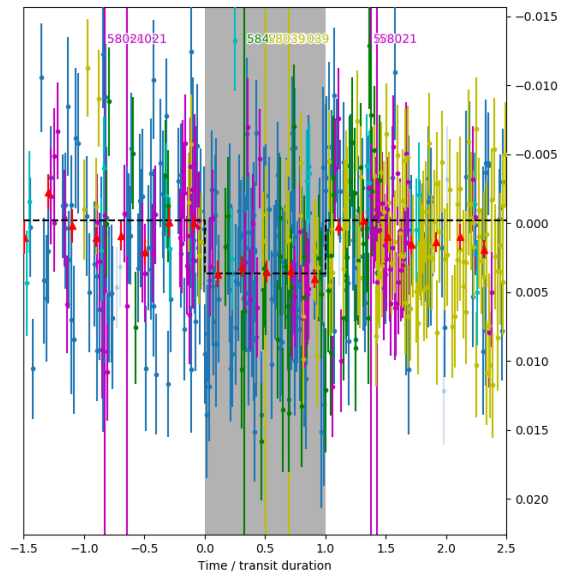
Shortlist of MEarth planet candidates

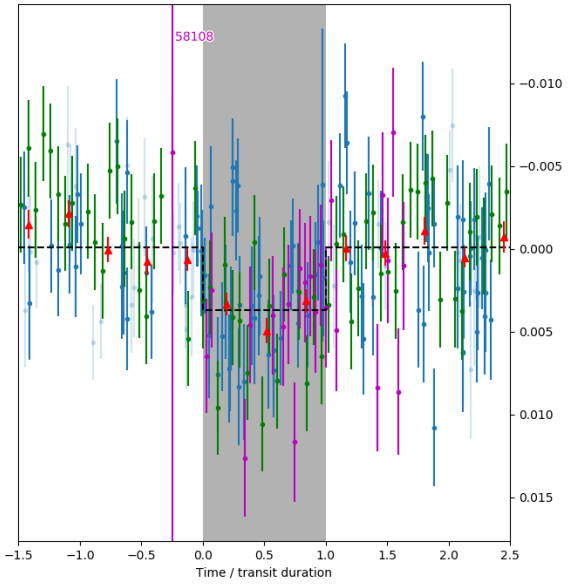


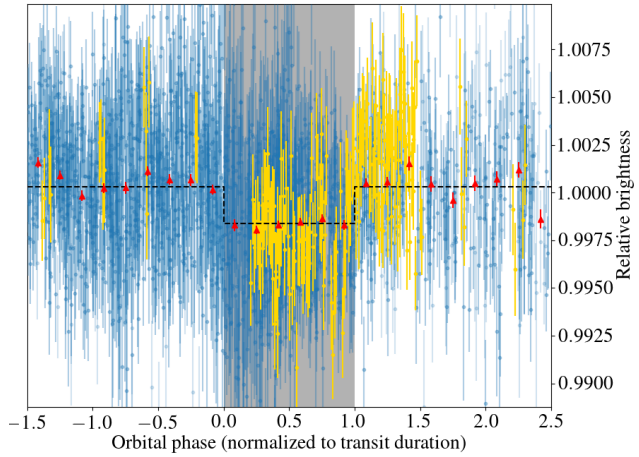


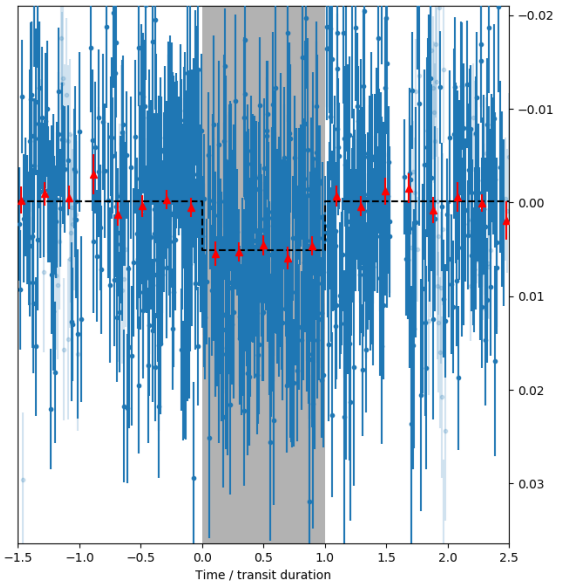




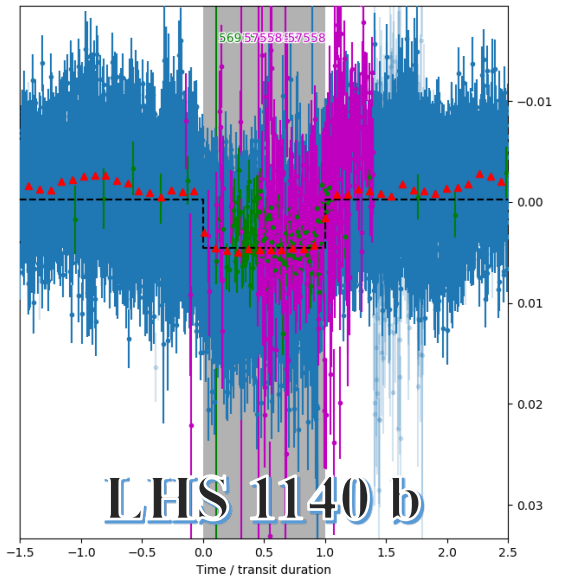


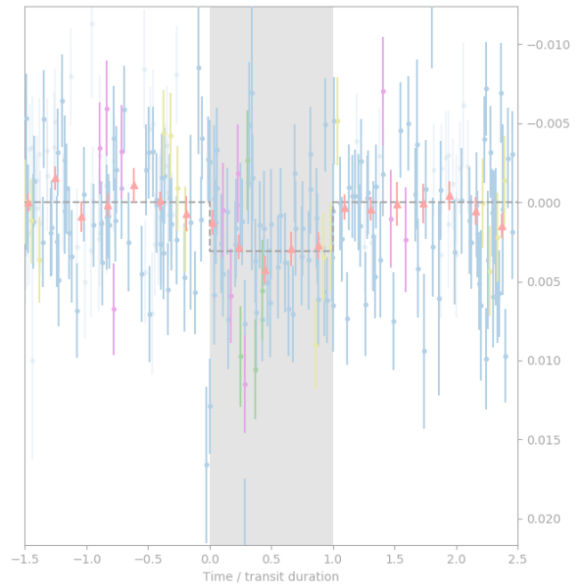


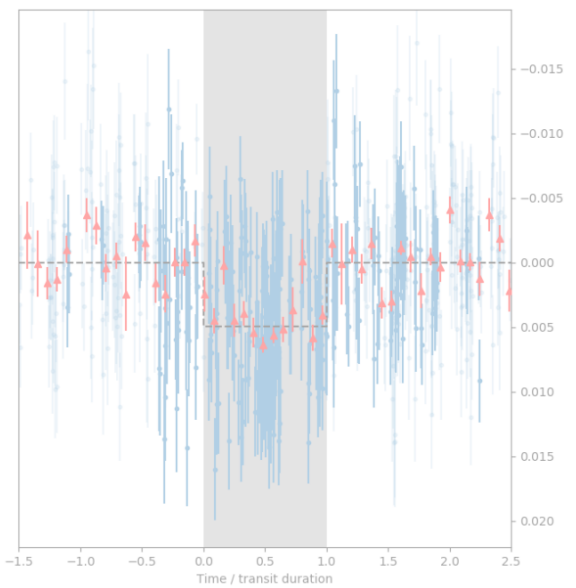


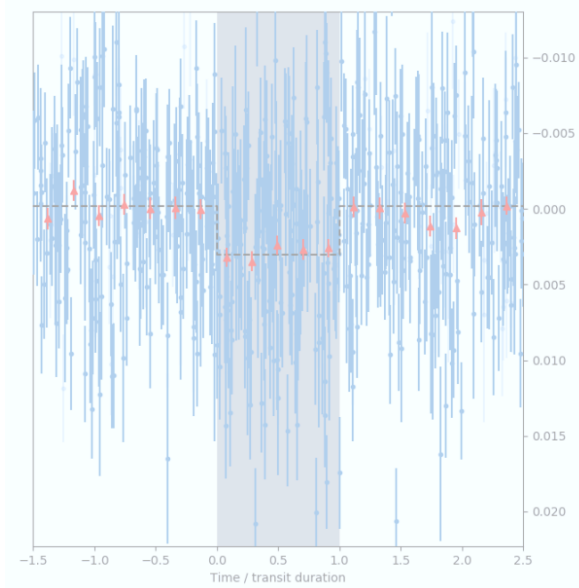


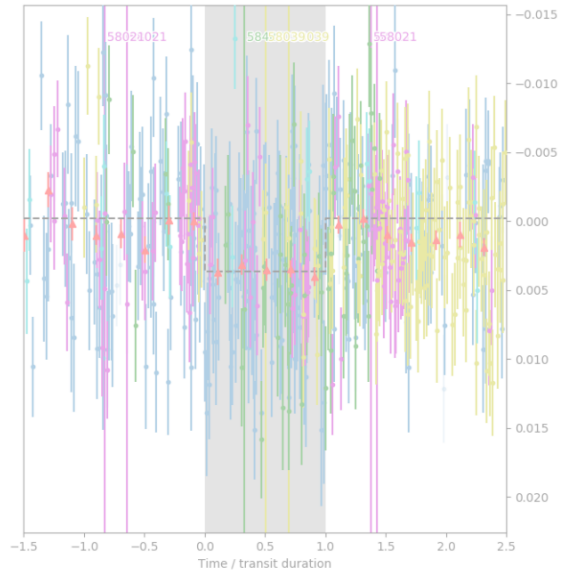
Shortlist of MEarth planet candidates

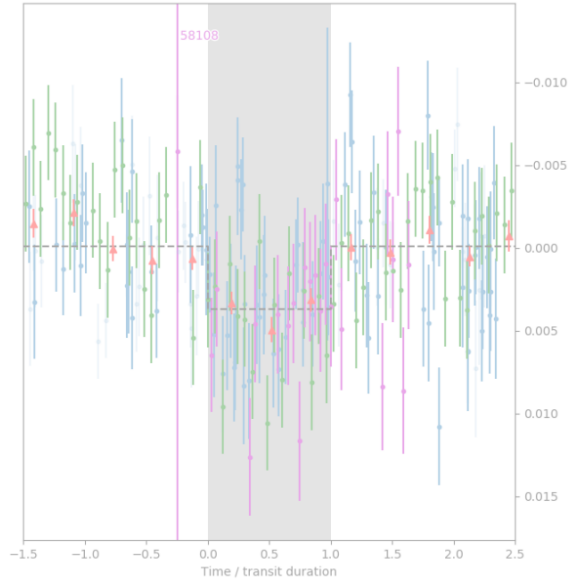


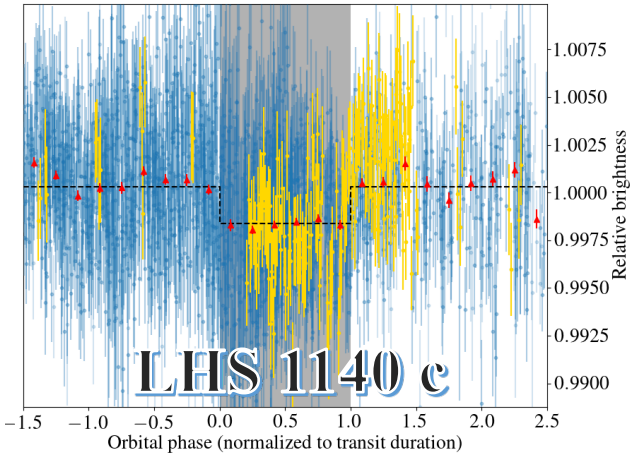


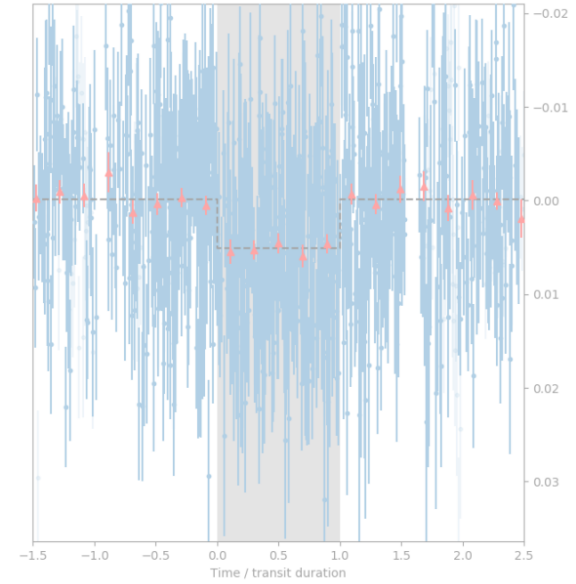












MEarth & TESS

- MEarth data modeling has produced a series of new planets and potential candidates
- MEarth planets in Sectors 1-12
- MEarth contribution to TESS discoveries
- TESS vetting of MEarth targets of interest

MEarth & TESS

- MEarth data modeling has produced a series of new planets and potential candidates
- MEarth planets in Sectors 1-12
- MEarth contribution to TESS discoveries
- TESS vetting of MEarth targets of interest

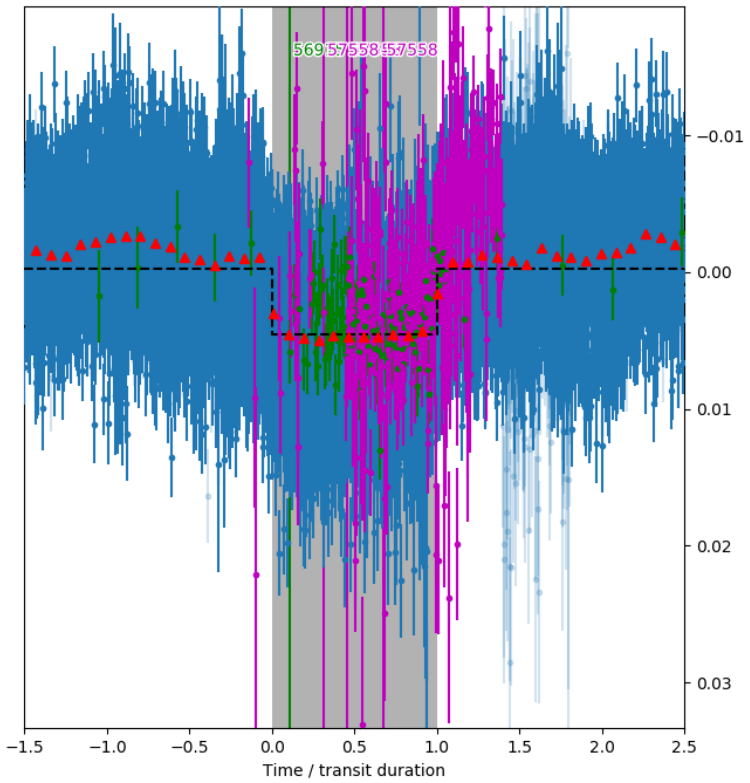
M4.5 V type
15.0 pc away

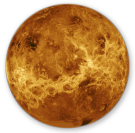
LHS 1140 b

P = 24.73696 days
7.0 ± 0.9 M_{Earth}
1.73 ± 0.03 R_{earth}

within HZ

MEarth



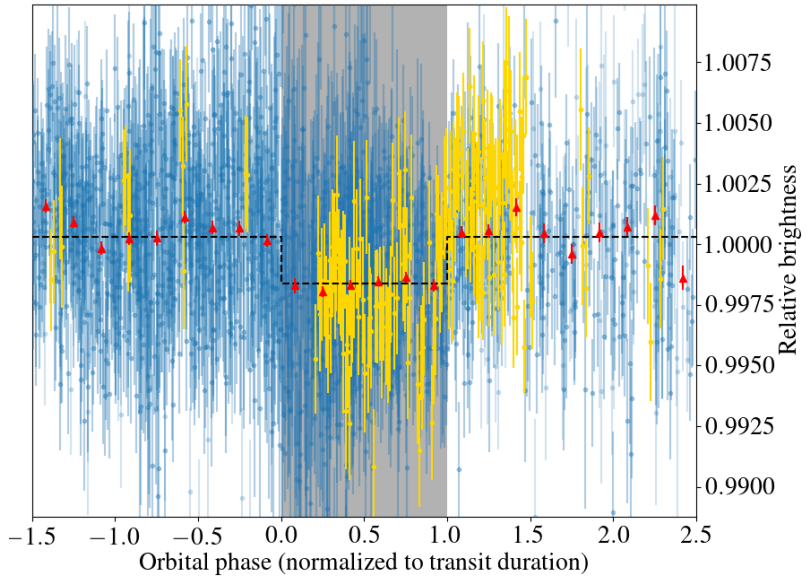


LHS 1140 c

P = 3.77797 days
1.8 ± 0.4 M_{Earth}
1.28 ± 0.02 R_{earth}

T ~ 440 K

MEarth

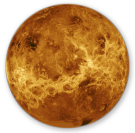


M4.5 V type
15.0 pc away

LHS 1140 b

P = 24.73696 days
$7.0 \pm 0.9\ M_{Earth}$
$1.73 \pm 0.03\ R_{earth}$

within HZ

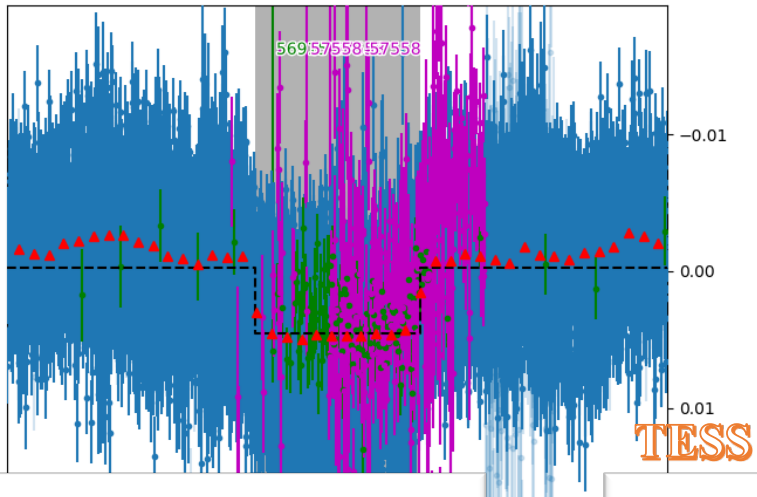


LHS 1140 c

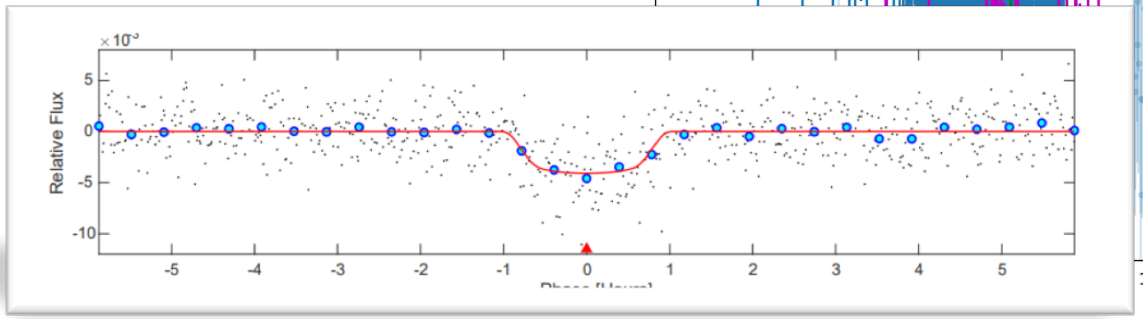
P = 3.77797 days
$1.8 \pm 0.4\ M_{Earth}$
$1.28 \pm 0.02\ R_{earth}$

T ~ 440 K

MEarth

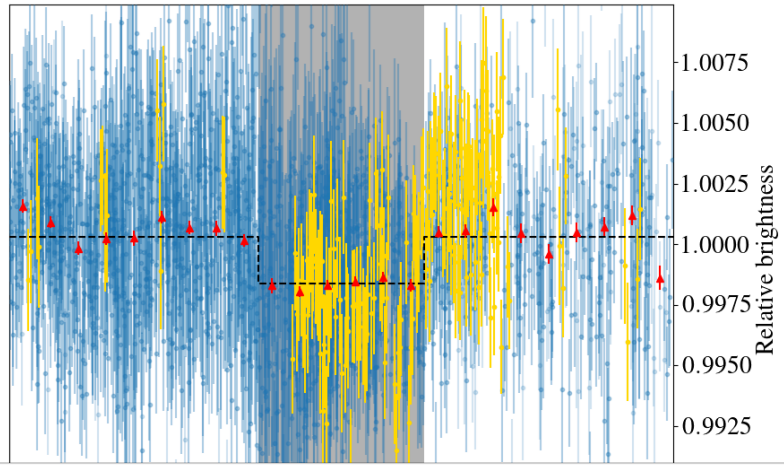


TESS

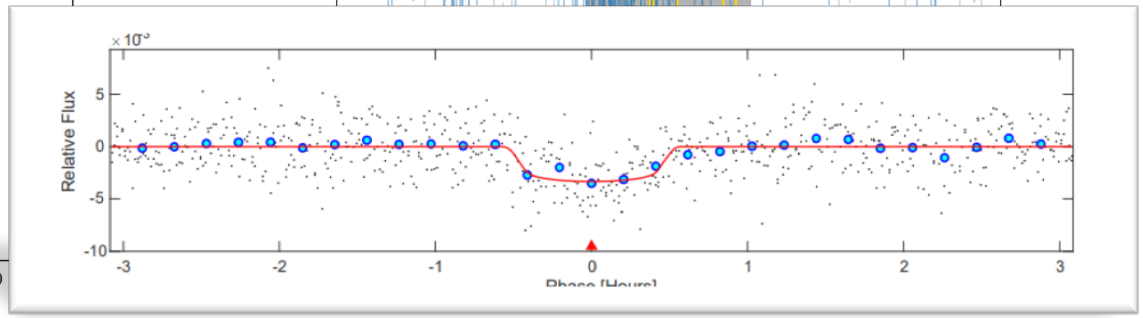


Source: SPOC

MEarth



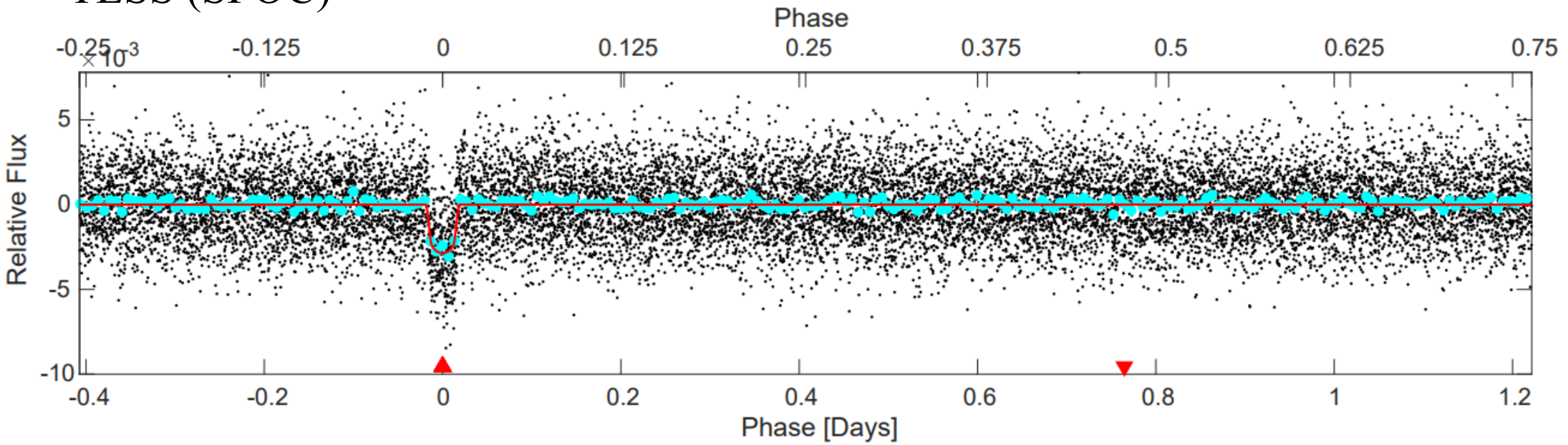
TESS



Source: SPOC

GJ 1132 b

TESS (SPOC)



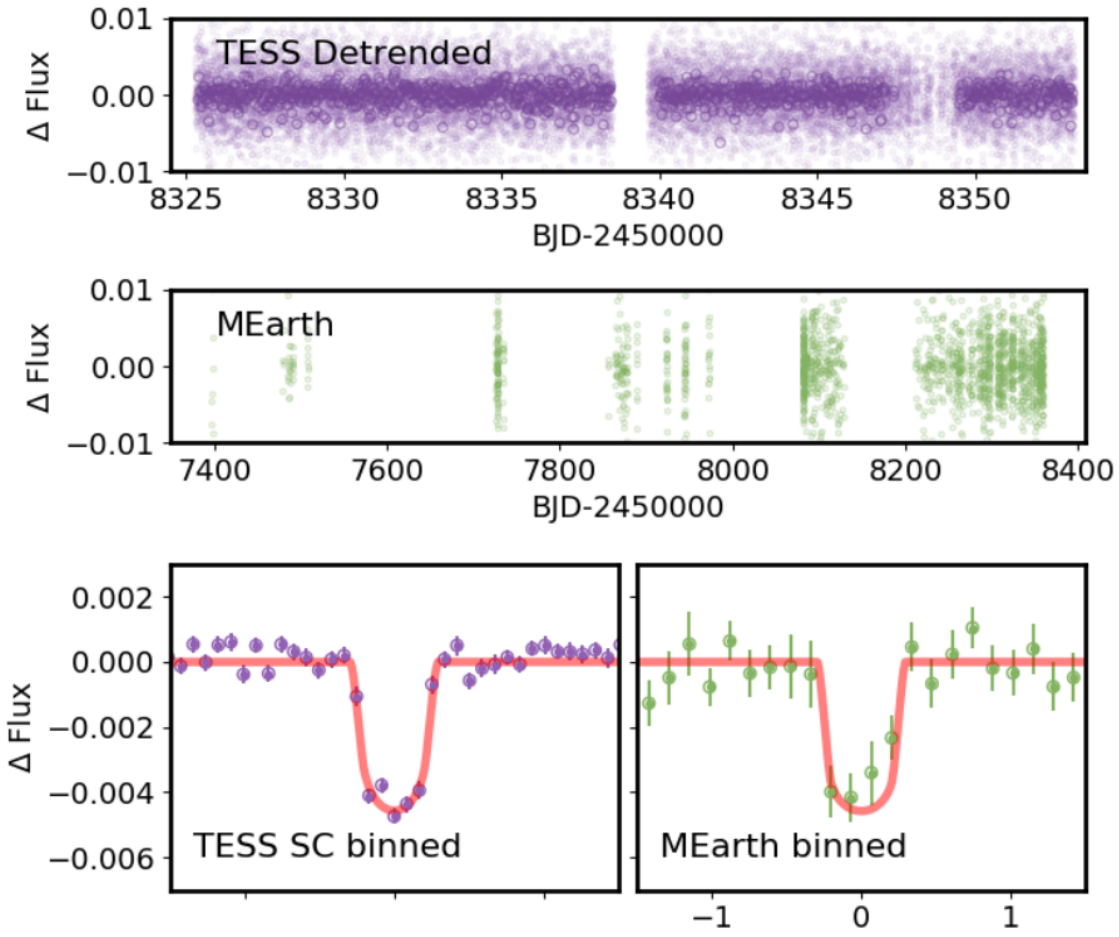
MEarth & TESS

- MEarth data modeling has produced a series of new planets and potential candidates
- All 3 MEarth planets in Sectors 1-12 have been observed and confirmed by TESS
- MEarth contribution to TESS discoveries
- TESS vetting of MEarth targets of interest

MEarth & TESS

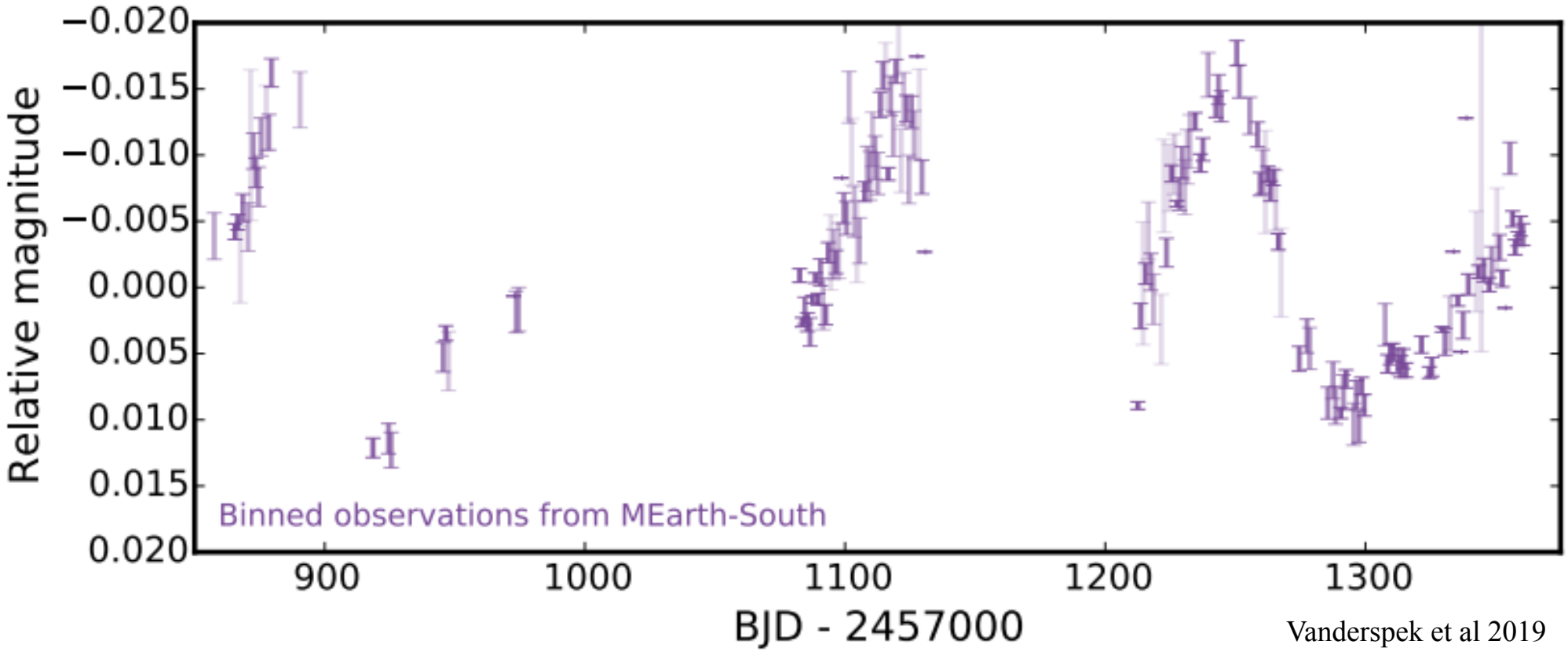
- MEarth data modeling has produced a series of new planets and potential candidates
- All 3 MEarth planets in Sectors 1-12 have been observed and confirmed by TESS
- MEarth contribution to TESS discoveries
- TESS vetting of MEarth targets of interest

LHS 3844 b



Vanderspek et al 2019

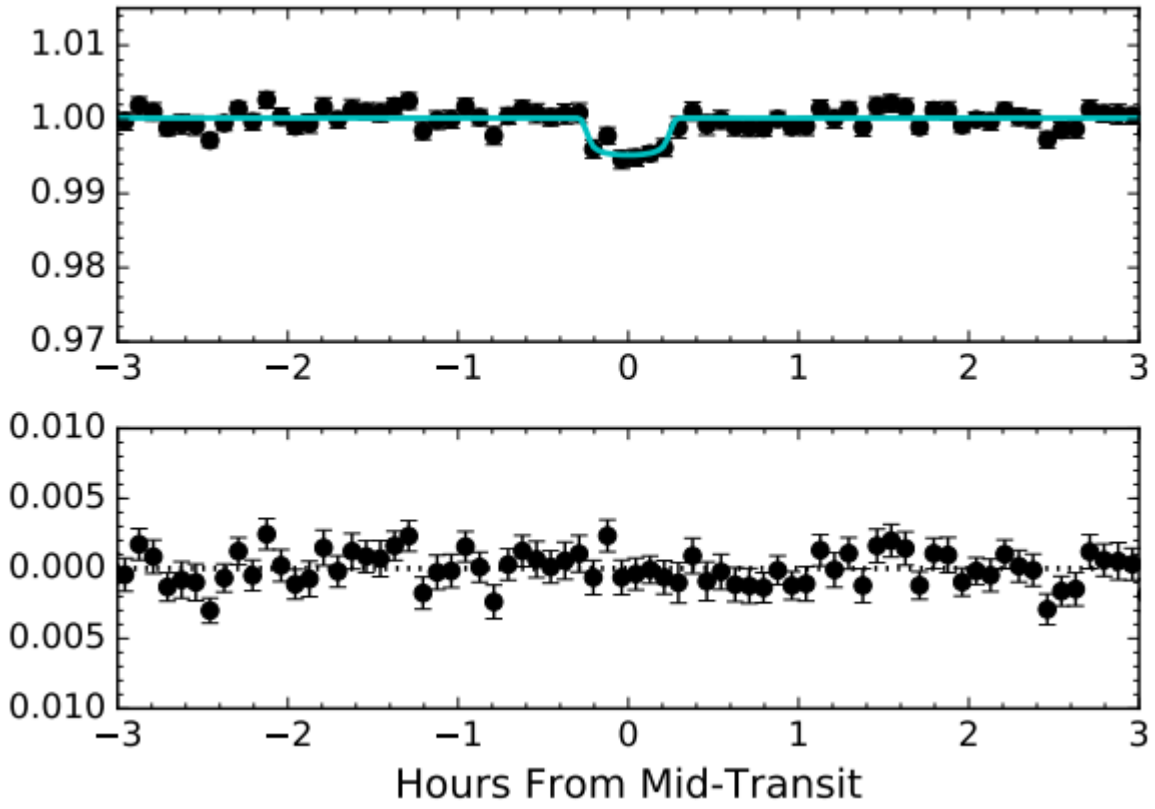
Rotational modulation of LHS 3844



Vanderspek et al 2019

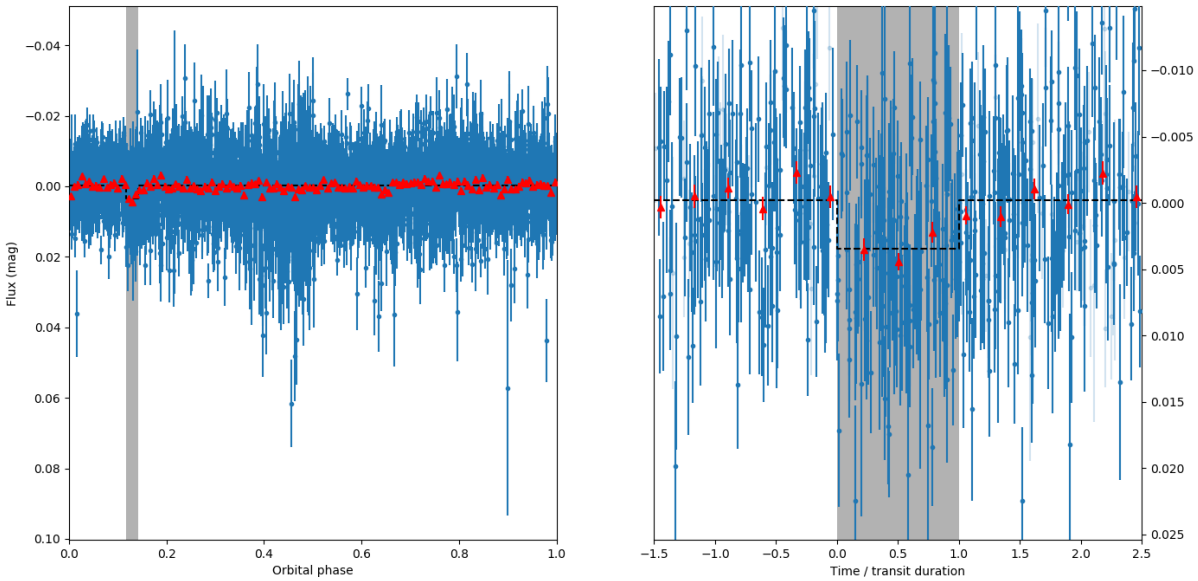
LP 791-18 b

TESS



Crossfield et al 2019
(submitted)

MEarth

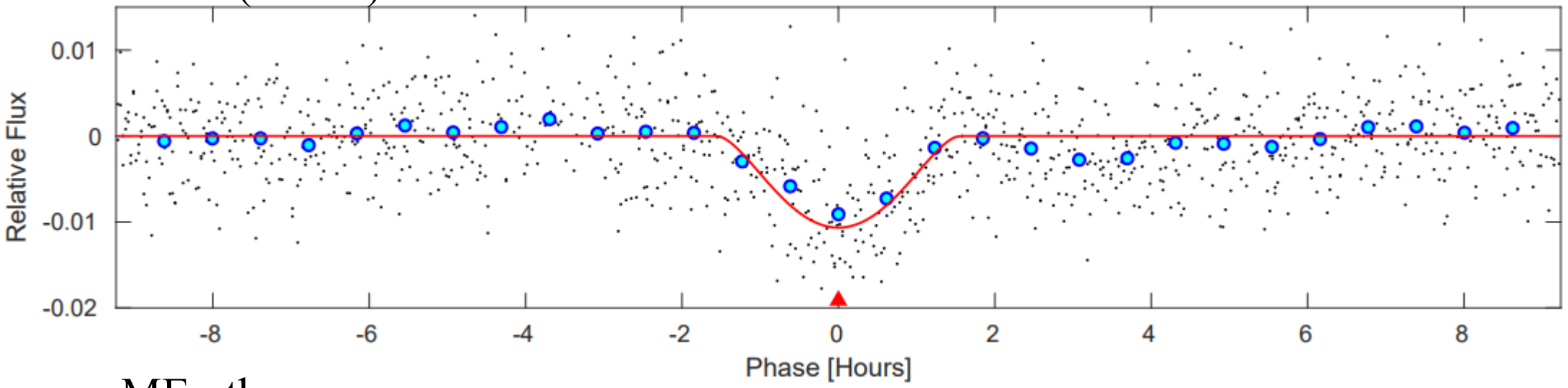


Orbital period: 0.9480050 ± 0.0000058 days

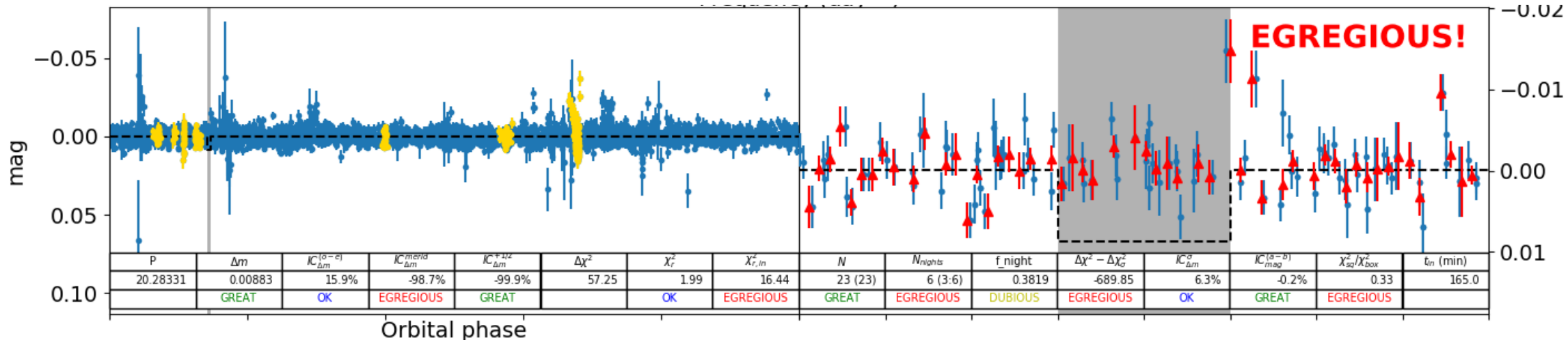
$R_p/R^* = 0.0604 \pm 0.0028$

LEHPM 5228 (TOI 226.01)

TESS (SPOC)



MEarth

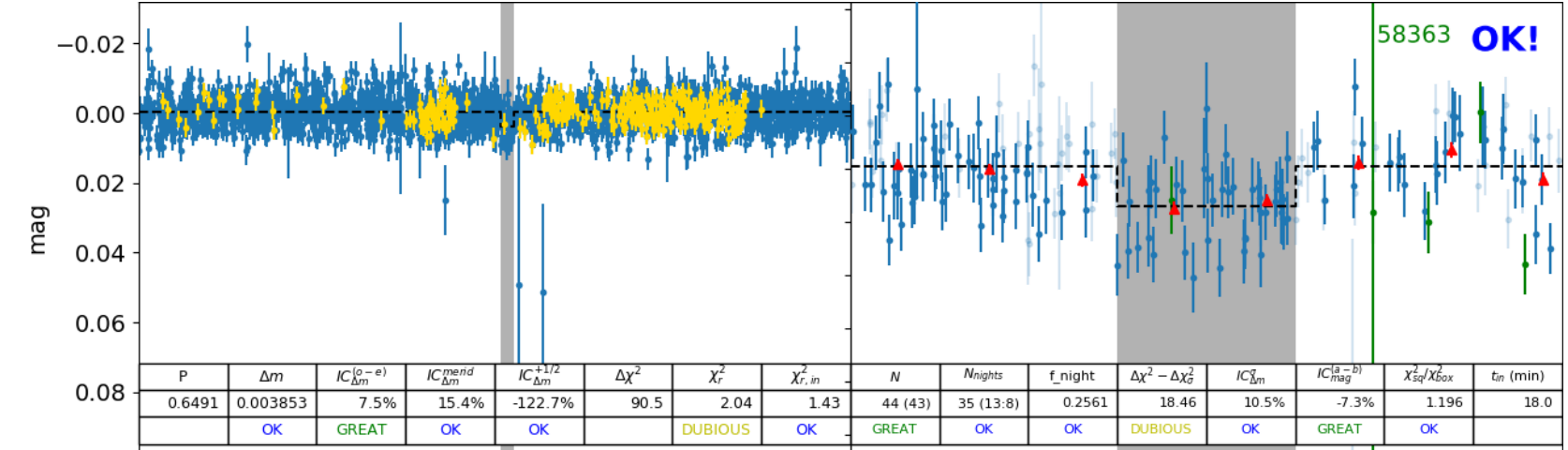


MEarth & TESS

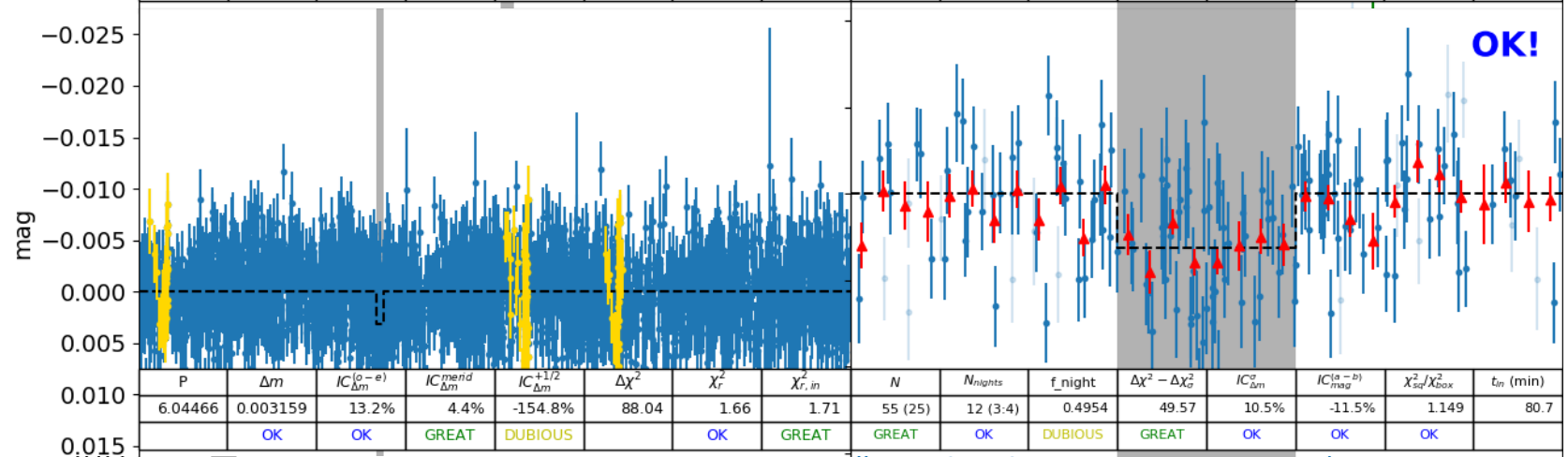
- MEarth data modeling has produced a series of new planets and potential candidates
- All 3 MEarth planets in Sectors 1-12 have been observed and confirmed by TESS
- MEarth has helped validate and further characterize several TESS discoveries (including LHS 3844 b and LP 791-18 b) and rule out a spurious TOI (226.01)
- TESS vetting of MEarth targets of interest

MEarth & TESS

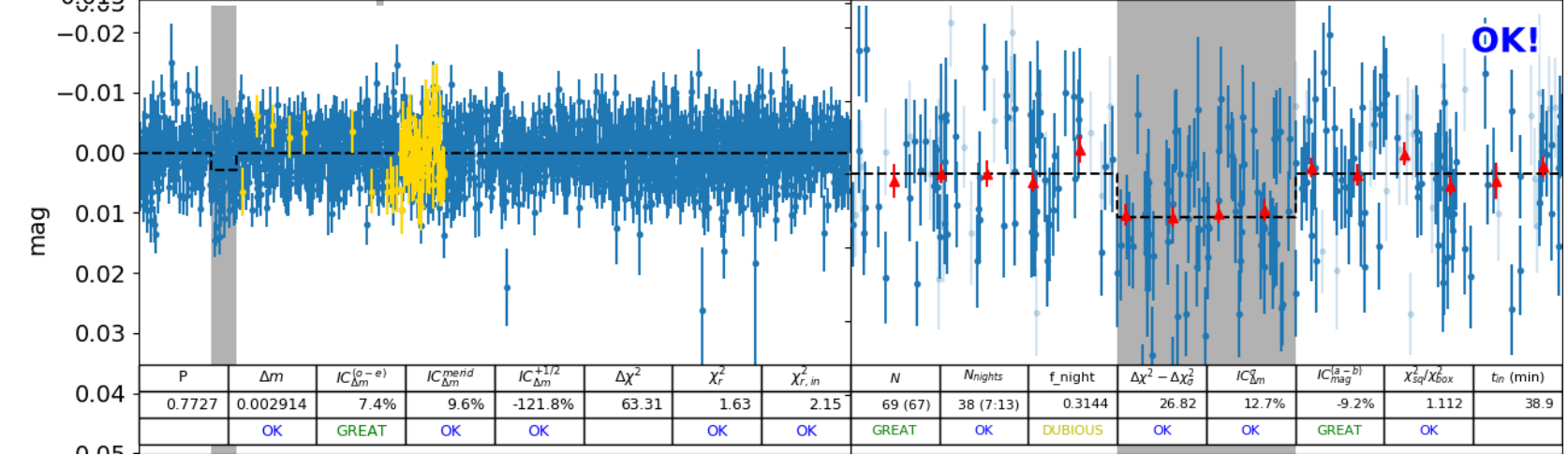
- MEarth data modeling has produced a series of new planets and potential candidates
- All 3 MEarth planets in Sectors 1-12 have been observed and confirmed by TESS
- MEarth has helped validate and further characterize several TESS discoveries (including LHS 3844 b and LP 791-18 b) and rule out a spurious TOI (226.01)
- TESS vetting of MEarth targets of interest



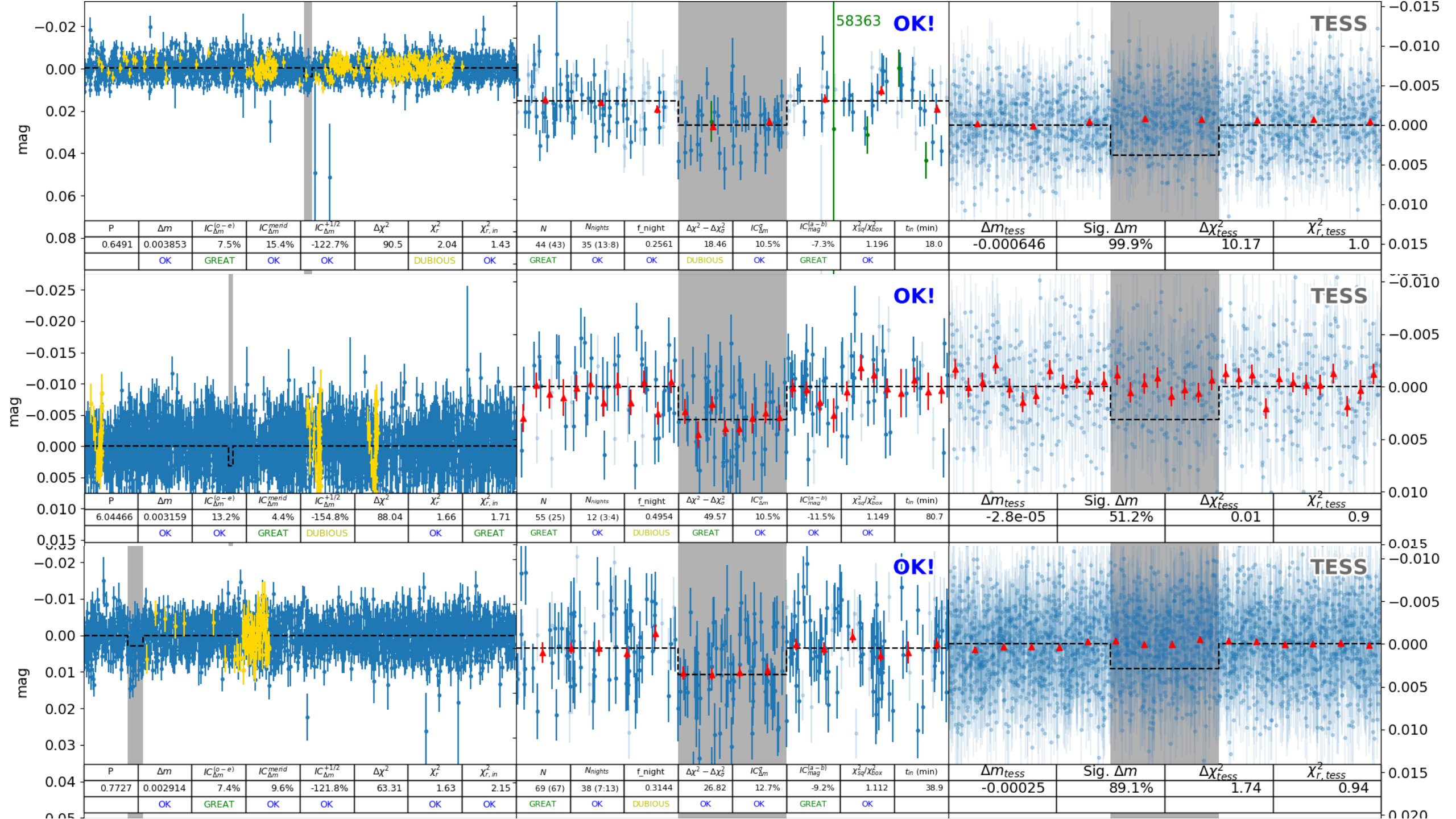
P	Δm	$IC^{[o-e)}_{\Delta m}$	$IC^{merid}_{\Delta m}$	$IC^{+1/2}_{\Delta m}$	$\Delta\chi^2$	χ^2_r	$\chi^2_{r,in}$	N	N_{nights}	f_night	$\Delta\chi^2-\Delta\chi^2_\sigma$	$IC^{\sigma}_{\Delta m}$	$IC^{(a-b)}_{mag}$	$\chi^2_{sqr}/\chi^2_{box}$	t_{in} (min)
0.6491	0.003853	7.5%	15.4%	-122.7%	90.5	2.04	1.43	44 (43)	35 (13:8)	0.2561	18.46	10.5%	-7.3%	1.196	18.0
	OK	GREAT	OK	OK		DUBIOUS	OK	GREAT	OK	OK	DUBIOUS	OK	GREAT	OK	



P	Δm	$IC^{[o-e)}_{\Delta m}$	$IC^{merid}_{\Delta m}$	$IC^{+1/2}_{\Delta m}$	$\Delta\chi^2$	χ^2_r	$\chi^2_{r,in}$	N	N_{nights}	f_night	$\Delta\chi^2-\Delta\chi^2_\sigma$	$IC^{\sigma}_{\Delta m}$	$IC^{(a-b)}_{mag}$	$\chi^2_{sqr}/\chi^2_{box}$	t_{in} (min)
6.04466	0.003159	13.2%	4.4%	-154.8%	88.04	1.66	1.71	55 (25)	12 (3:4)	0.4954	49.57	10.5%	-11.5%	1.149	80.7
	OK	OK	GREAT	DUBIOUS		OK	GREAT	GREAT	OK	DUBIOUS	GREAT	OK	OK	OK	



P	Δm	$IC^{[o-e)}_{\Delta m}$	$IC^{merid}_{\Delta m}$	$IC^{+1/2}_{\Delta m}$	$\Delta\chi^2$	χ^2_r	$\chi^2_{r,in}$	N	N_{nights}	f_night	$\Delta\chi^2-\Delta\chi^2_\sigma$	$IC^{\sigma}_{\Delta m}$	$IC^{(a-b)}_{mag}$	$\chi^2_{sqr}/\chi^2_{box}$	t_{in} (min)
0.7727	0.002914	7.4%	9.6%	-121.8%	63.31	1.63	2.15	69 (67)	38 (7:13)	0.3144	26.82	12.7%	-9.2%	1.112	38.9
	OK	GREAT	OK	OK		OK	OK	GREAT	OK	DUBIOUS	OK	OK	GREAT	OK	

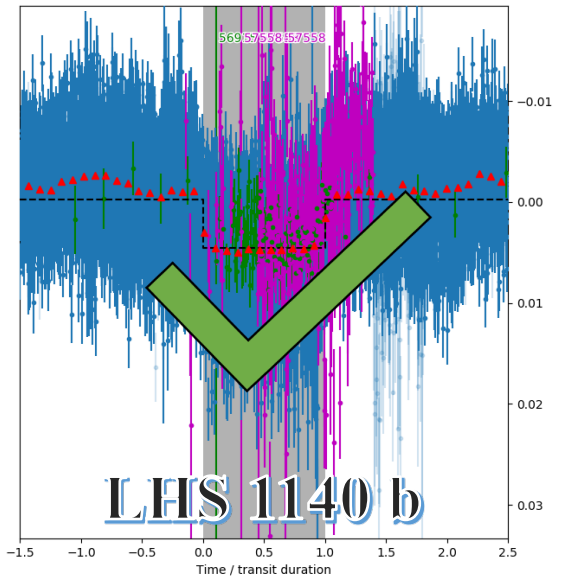


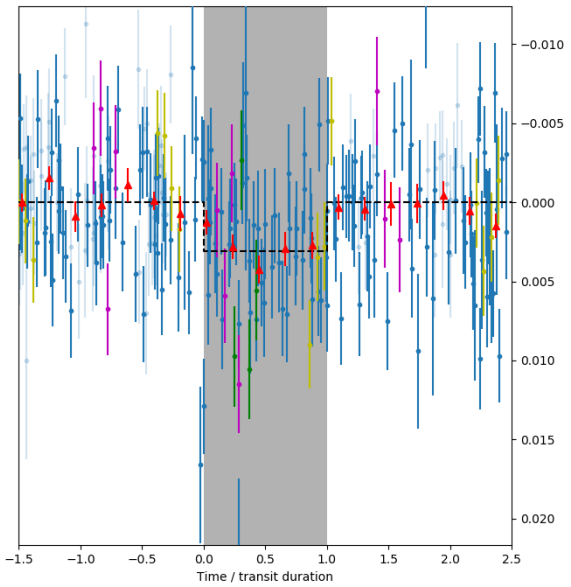
P	Δm	$IC_{\Delta m}^{(o-e)}$	$IC_{\Delta m}^{meri d}$	$IC_{\Delta m}^{+1/2}$	$\Delta\chi^2$	χ_r^2	$\chi_{r,in}^2$	N	N_{nights}	f_night	$\Delta\chi^2-\Delta\chi_\sigma^2$	$IC_{\Delta m}^{\sigma}$	$IC_{mag}^{(a-b)}$	χ_{sq}^2/χ_{box}^2	t_{in} (min)	Δm_{tess}	Sig. Δm	$\Delta\chi_{tess}^2$	$\chi_{r,tess}^2$
0.6491	0.003853	7.5%	15.4%	-122.7%	90.5	2.04	1.43	44 (43)	35 (13:8)	0.2561	18.46	10.5%	-7.3%	1.196	18.0	-0.000646	99.9%	10.17	1.0
	OK	GREAT	OK	OK		DUBIOUS	OK	GREAT	OK	OK	DUBIOUS	OK	GREAT	OK					

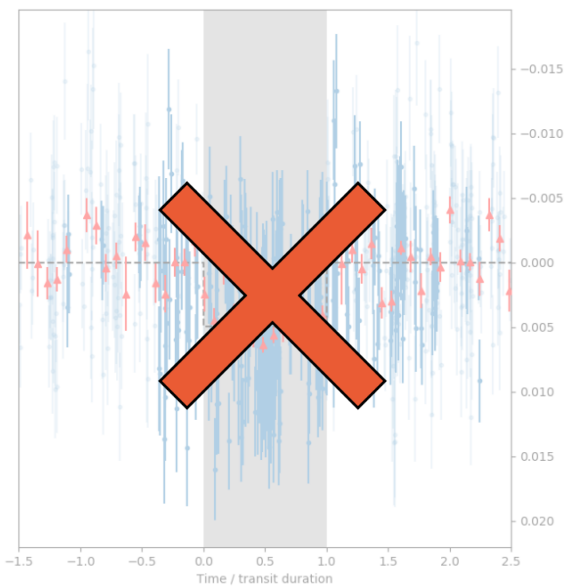
P	Δm	$IC_{\Delta m}^{(o-e)}$	$IC_{\Delta m}^{meri d}$	$IC_{\Delta m}^{+1/2}$	$\Delta\chi^2$	χ_r^2	$\chi_{r,in}^2$	N	N_{nights}	f_night	$\Delta\chi^2-\Delta\chi_\sigma^2$	$IC_{\Delta m}^{\sigma}$	$IC_{mag}^{(a-b)}$	χ_{sq}^2/χ_{box}^2	t_{in} (min)	Δm_{tess}	Sig. Δm	$\Delta\chi_{tess}^2$	$\chi_{r,tess}^2$
6.04466	0.003159	13.2%	4.4%	-154.8%	88.04	1.66	1.71	55 (25)	12 (3:4)	0.4954	49.57	10.5%	-11.5%	1.149	80.7	-2.8e-05	51.2%	0.01	0.9
	OK	OK	GREAT	DUBIOUS		OK	GREAT	GREAT	OK	DUBIOUS	GREAT	OK	OK	OK					

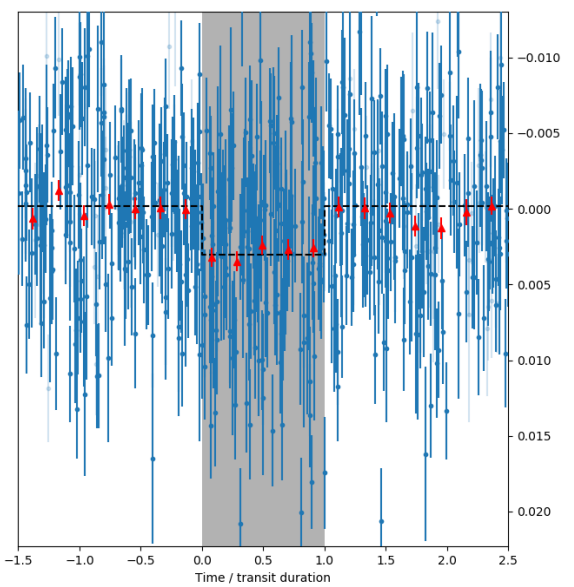
P	Δm	$IC_{\Delta m}^{(o-e)}$	$IC_{\Delta m}^{meri d}$	$IC_{\Delta m}^{+1/2}$	$\Delta\chi^2$	χ_r^2	$\chi_{r,in}^2$	N	N_{nights}	f_night	$\Delta\chi^2-\Delta\chi_\sigma^2$	$IC_{\Delta m}^{\sigma}$	$IC_{mag}^{(a-b)}$	χ_{sq}^2/χ_{box}^2	t_{in} (min)	Δm_{tess}	Sig. Δm	$\Delta\chi_{tess}^2$	$\chi_{r,tess}^2$
0.7727	0.002914	7.4%	9.6%	-121.8%	63.31	1.63	2.15	69 (67)	38 (7:13)	0.3144	26.82	12.7%	-9.2%	1.112	38.9	-0.00025	89.1%	1.74	0.94
	OK	GREAT	OK	OK		OK	OK	GREAT	OK	DUBIOUS	OK	OK	GREAT	OK					

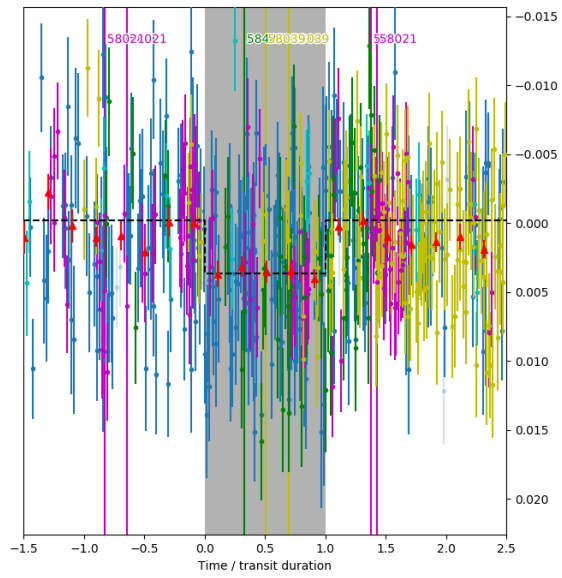
Shortlist of MEarth planet candidates

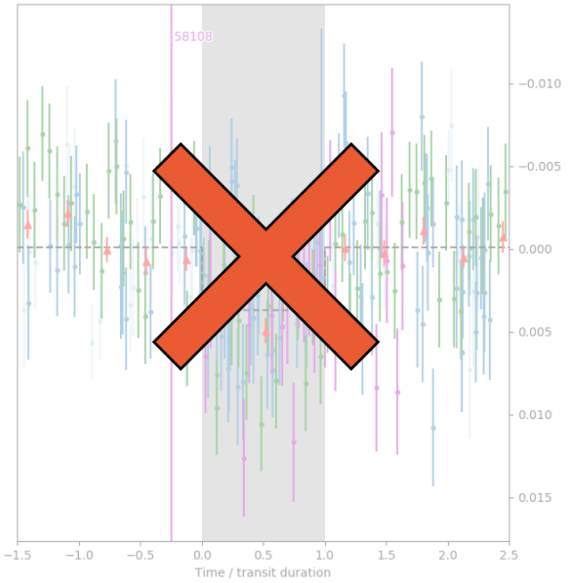


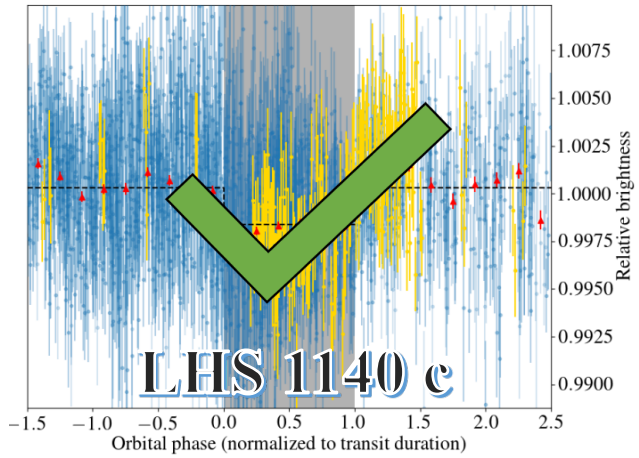


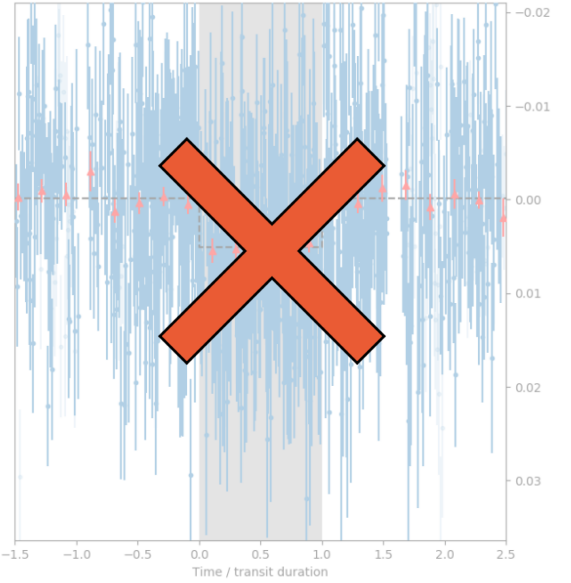












MEarth & TESS

- MEarth data modeling has produced a series of new planets and potential candidates
- All 3 MEarth planets in Sectors 1-12 have been observed and confirmed by TESS
- MEarth has helped validate and further characterize several TESS discoveries (including LHS 3844 b and LP 791-18 b) and rule out a spurious TOI (226.01)
- TESS has ruled out a dozen of MEarth candidates, and will provide definitive answers for many more in the remaining sectors

Uniting MEarth and TESS

KRISTO MENT

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Thank you for your attention!

MEarth Team:
David Charbonneau,
Jonathan Irwin,
Jen Winters, et al.

the David & Lucile Packard FOUNDATION

NASA

NSF

JOHN TEMPLETON FOUNDATION

Image: SpaceX