Detailed analysis of Kepler-10: Synergy between asteroseismology and exoplanet research

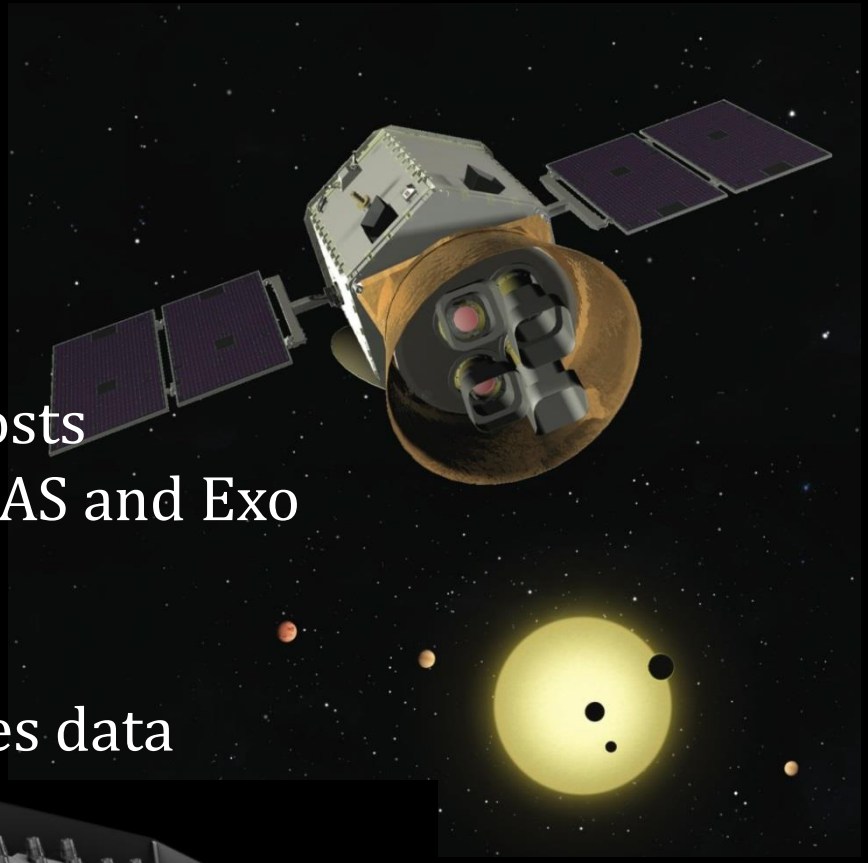
Kepler-10b (animation: NASA)

CoRot-7b
(Figure: ESO/L. Calçada)

Hans Kjeldsen

SAC
STELLAR ASTROPHYSICS CENTRE

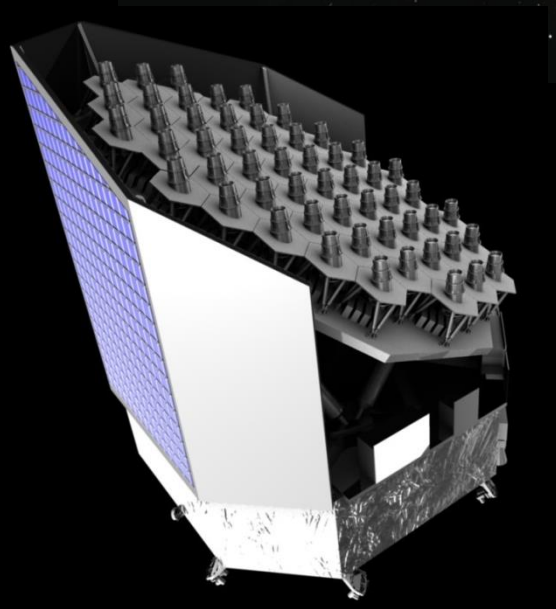
PLATO and TESS



- CoRoT: Separate AS and Exo
- Kepler: AS for selected planet hosts
- PLATO and TESS: Simultaneous AS and Exo

Accurate properties of exoplanets:

- SNR and length of the time series data
- Kepler-10:
  - Batalha et al. 2011: **275d**
  - All data to date: **850 d**



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KEPLER'S FIRST ROCKY PLANET: KEPLER-10b*

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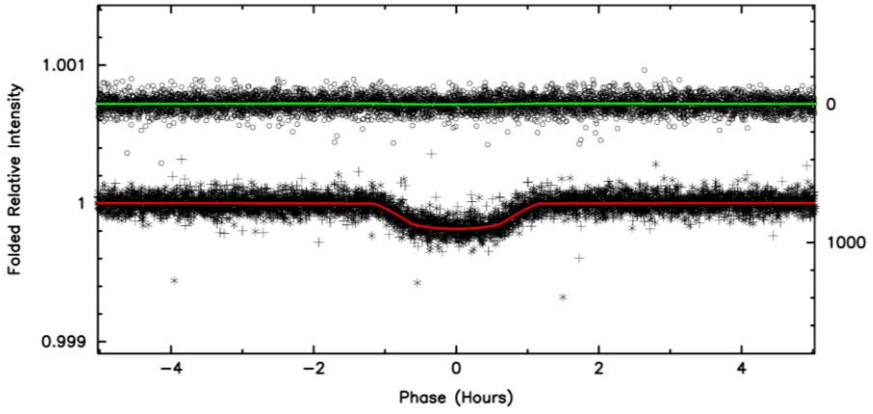
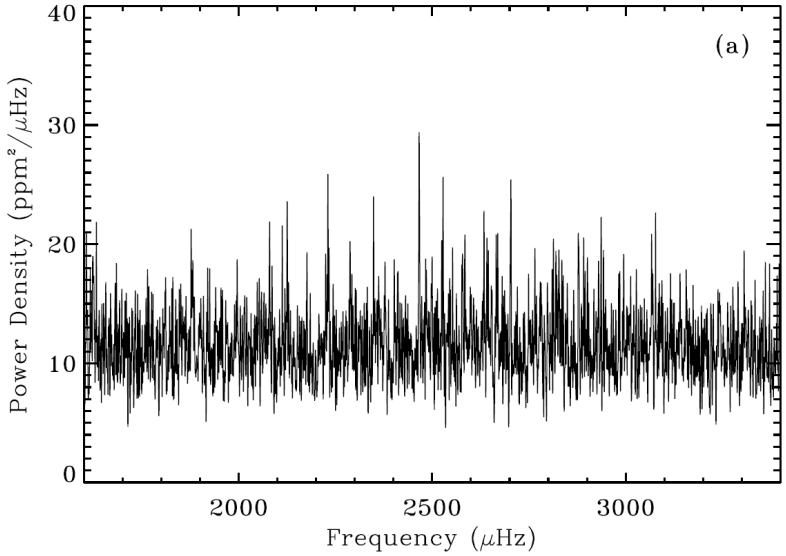
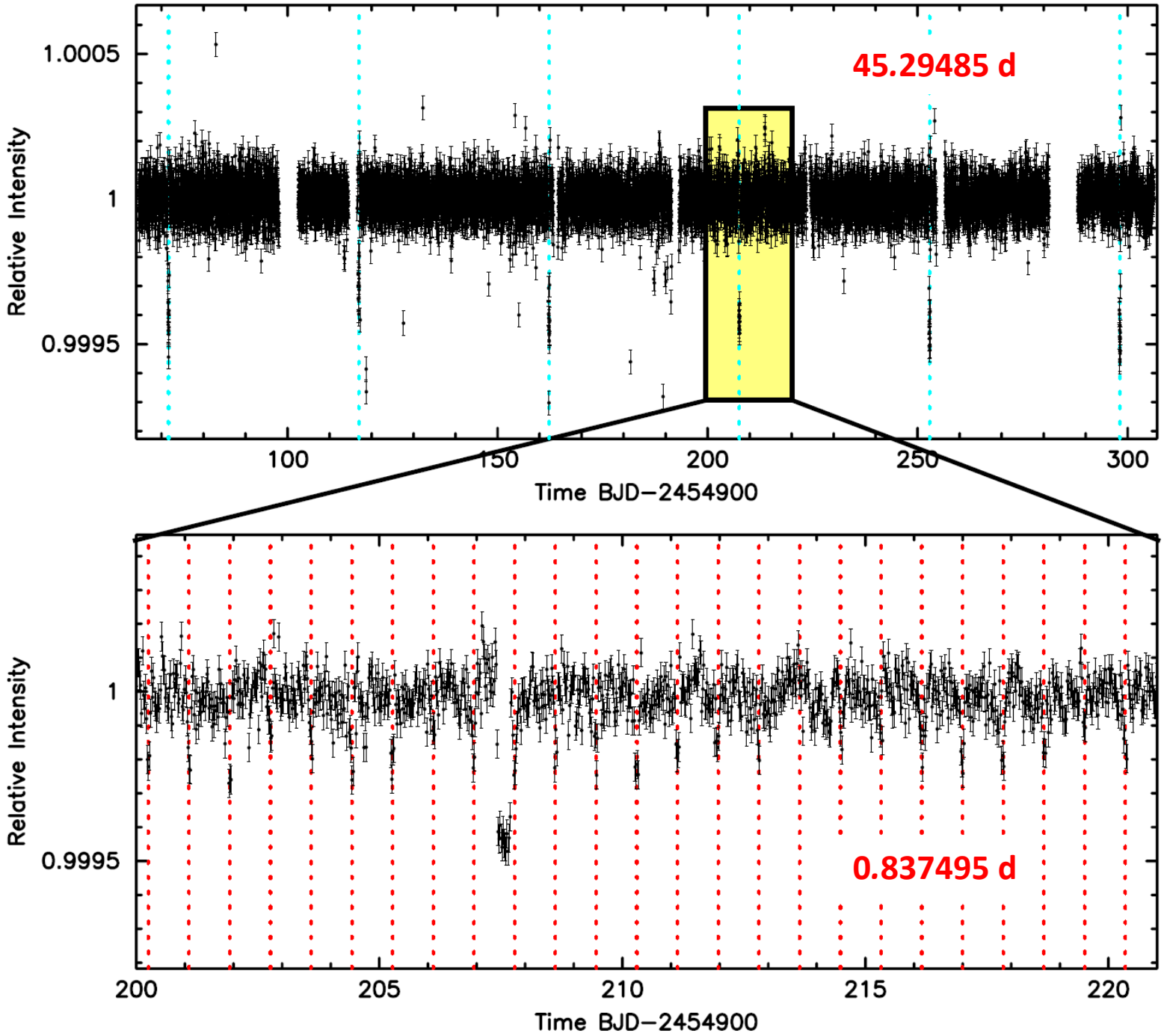
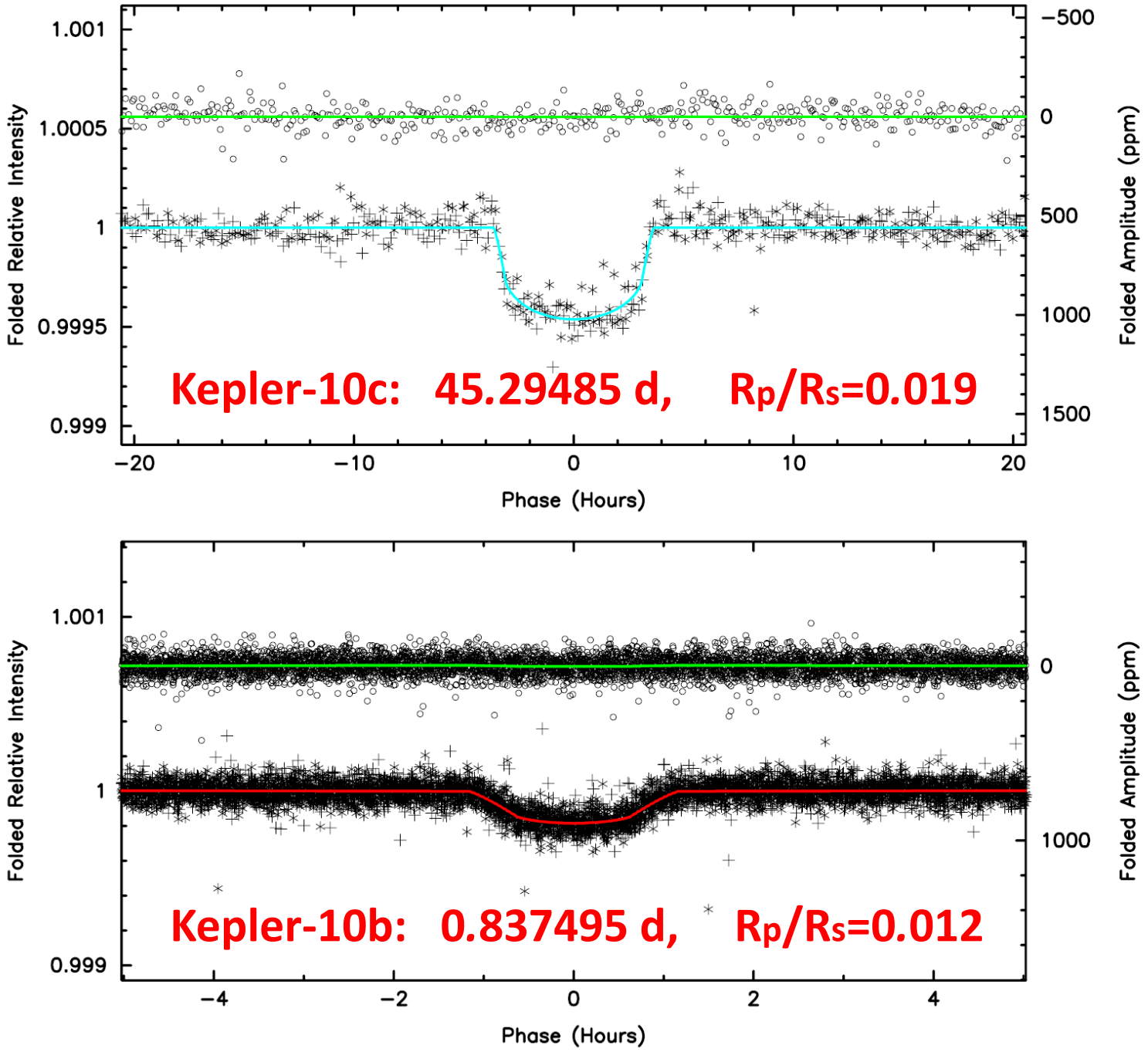
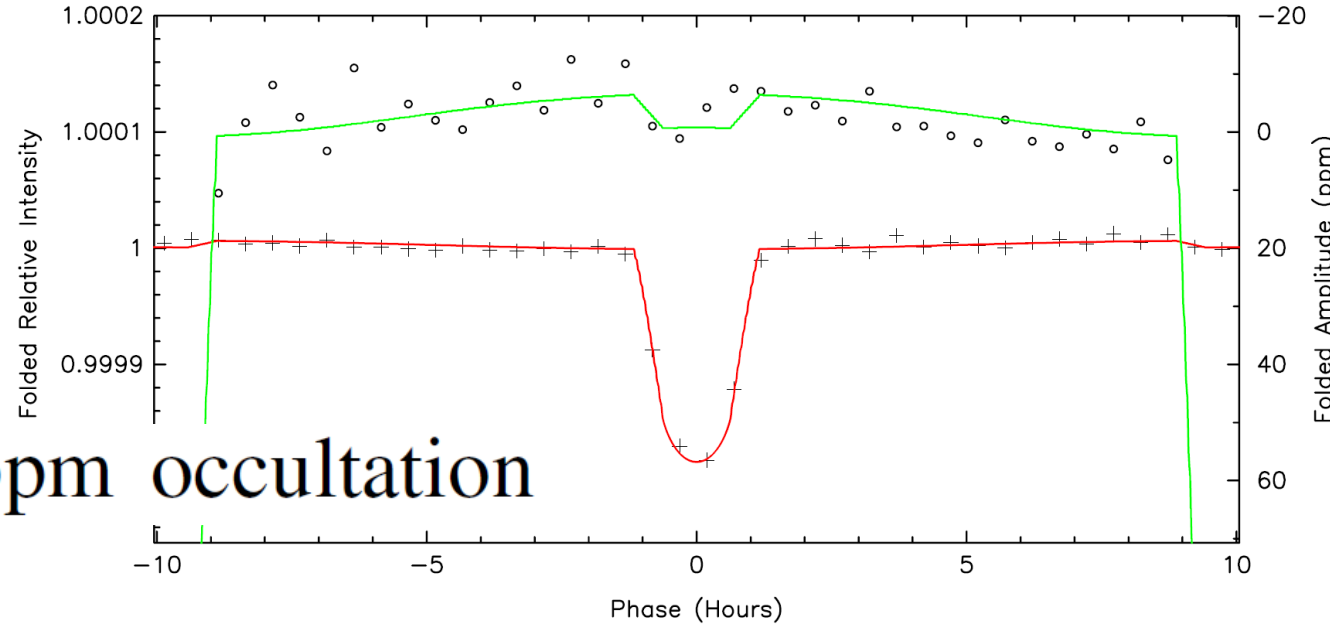




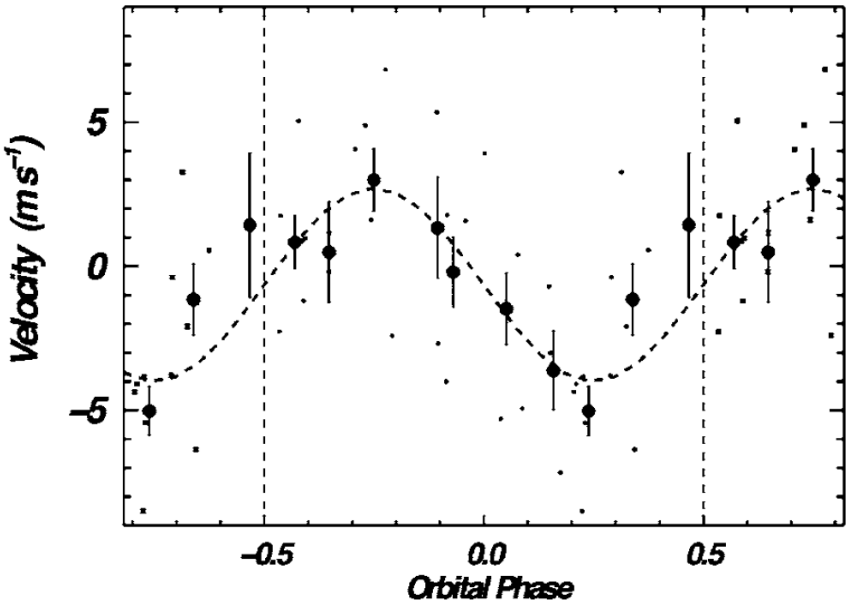

45.29485 d
1.0005
1
0.9995
Relative Intensity
100
150
200
250
300
Time BJD−2454900
0.837495 d
1
0.9995
Relative Intensity
200
205
210
215
220
Time BJD−2454900


Folded Relative Intensity
1.001
1.0005
1
0.9995
0.999
−500
0
500
1000
1500
Folded Amplitude (ppm)
−20
−10
0
10
20
Phase (Hours)
Kepler-10c: 45.29485 d, Rp/Rs=0.019
Folded Relative Intensity
1.001
1
0.999
0
1000
Folded Amplitude (ppm)
−4
−2
0
2
4
Phase (Hours)
Kepler-10b: 0.837495 d, Rp/Rs=0.012



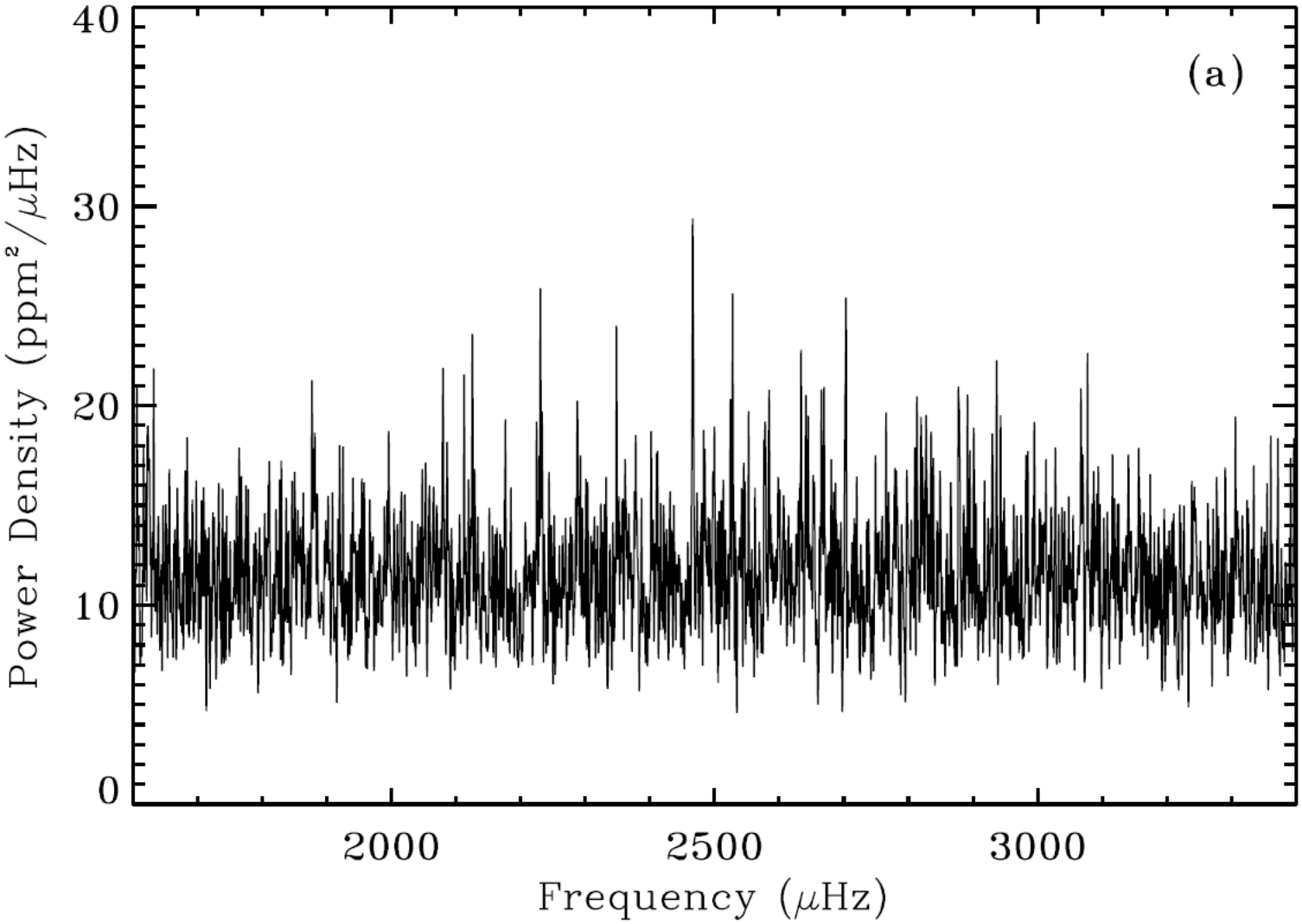
5.8 ± 2.5 ppm occultation

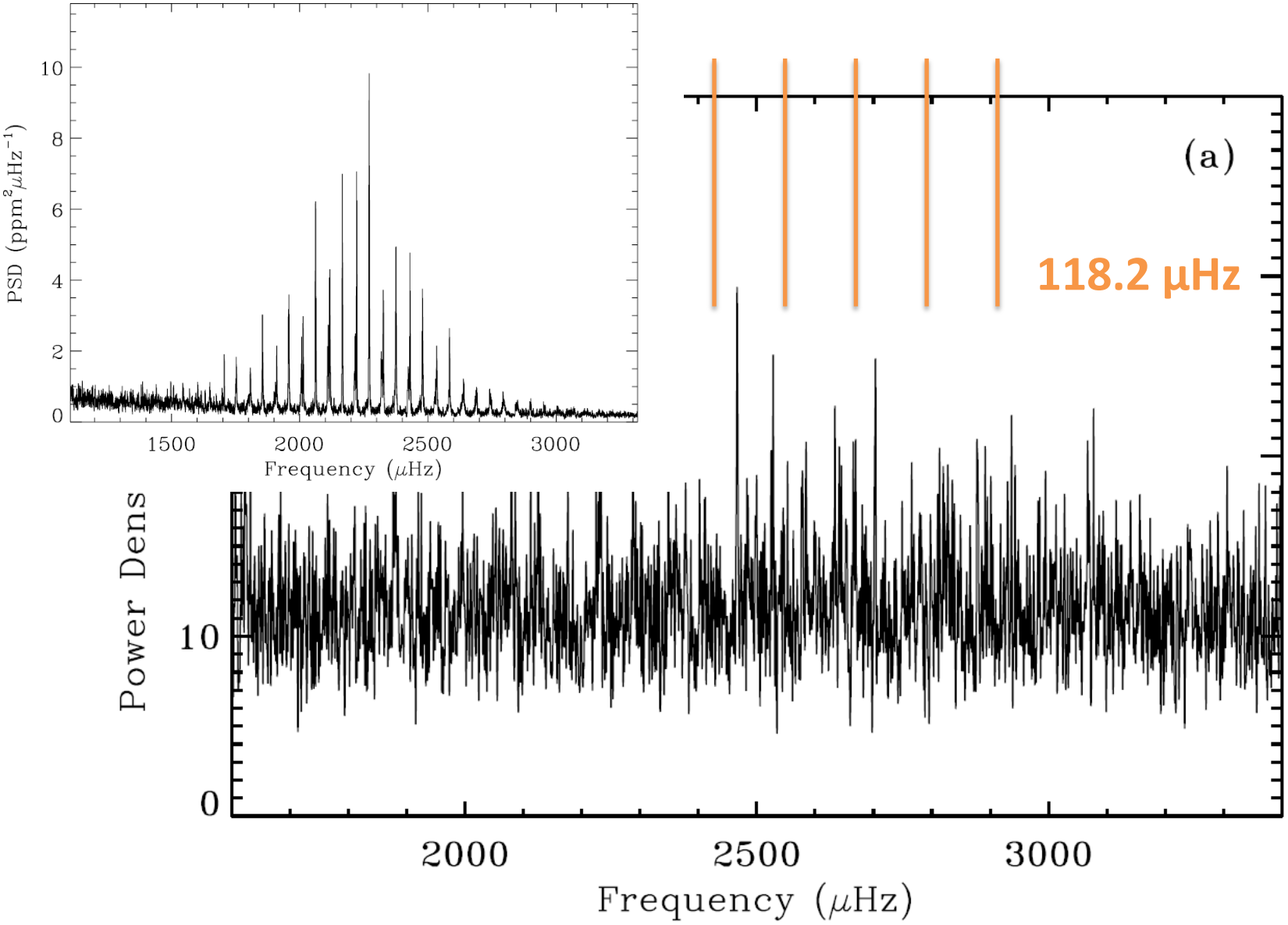
Kepler-10b: 0.837495 d, R_P/R_S=0.012



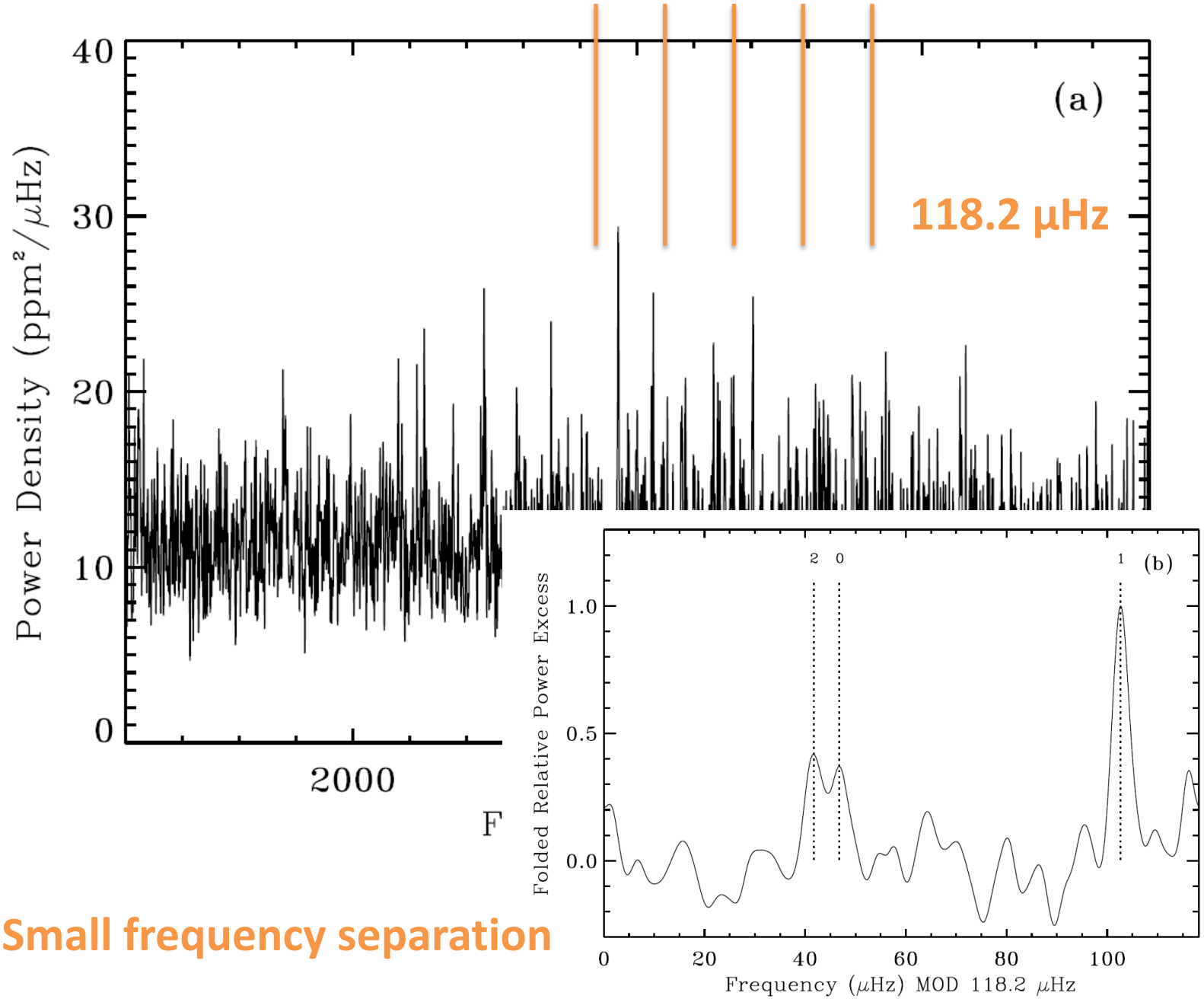
Mass, M_P ($M_\oplus$)

$4.56^{+1.17}_{-1.29}$


(a)
Power Density (ppm²/μHz)
0
10
20
30
40
2000
2500
3000
Frequency (μHz)



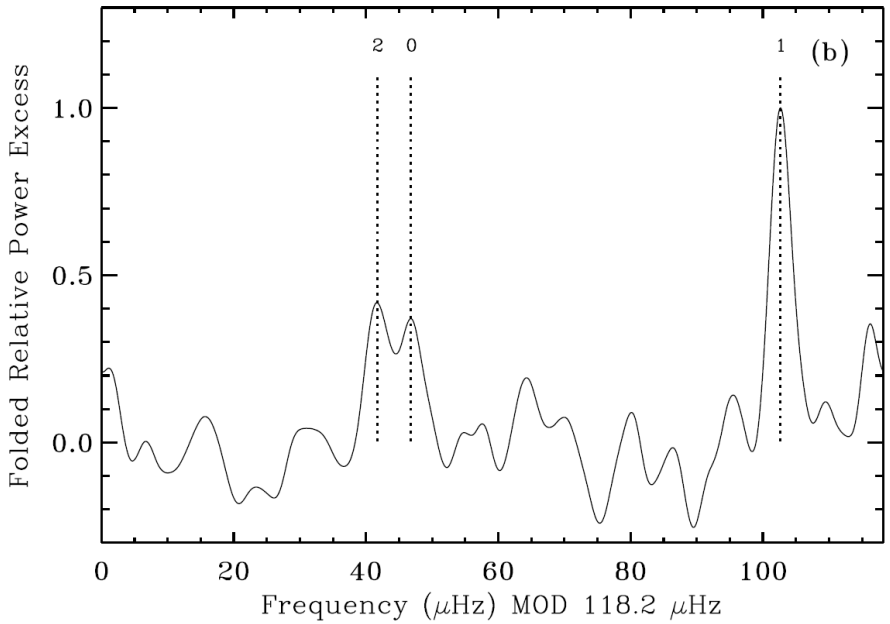
Large frequency separation



Small frequency separation

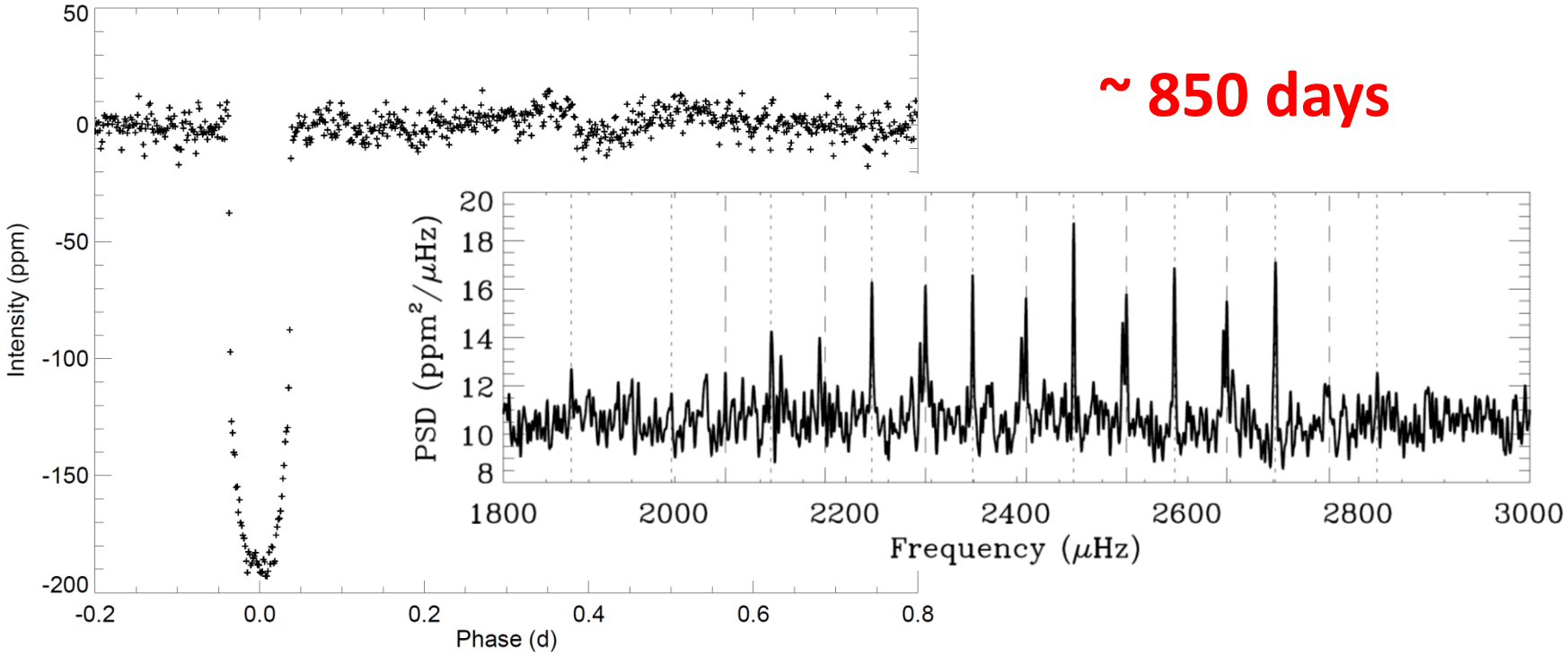
Mass (Msun)	0.995 ± 0.060	(6%)
Radius (Rsun)	1.056 ± 0.021	(2 %)
Age (Gyr)	11.9 ± 4.5	(38%)

- Batalha et al. 2011

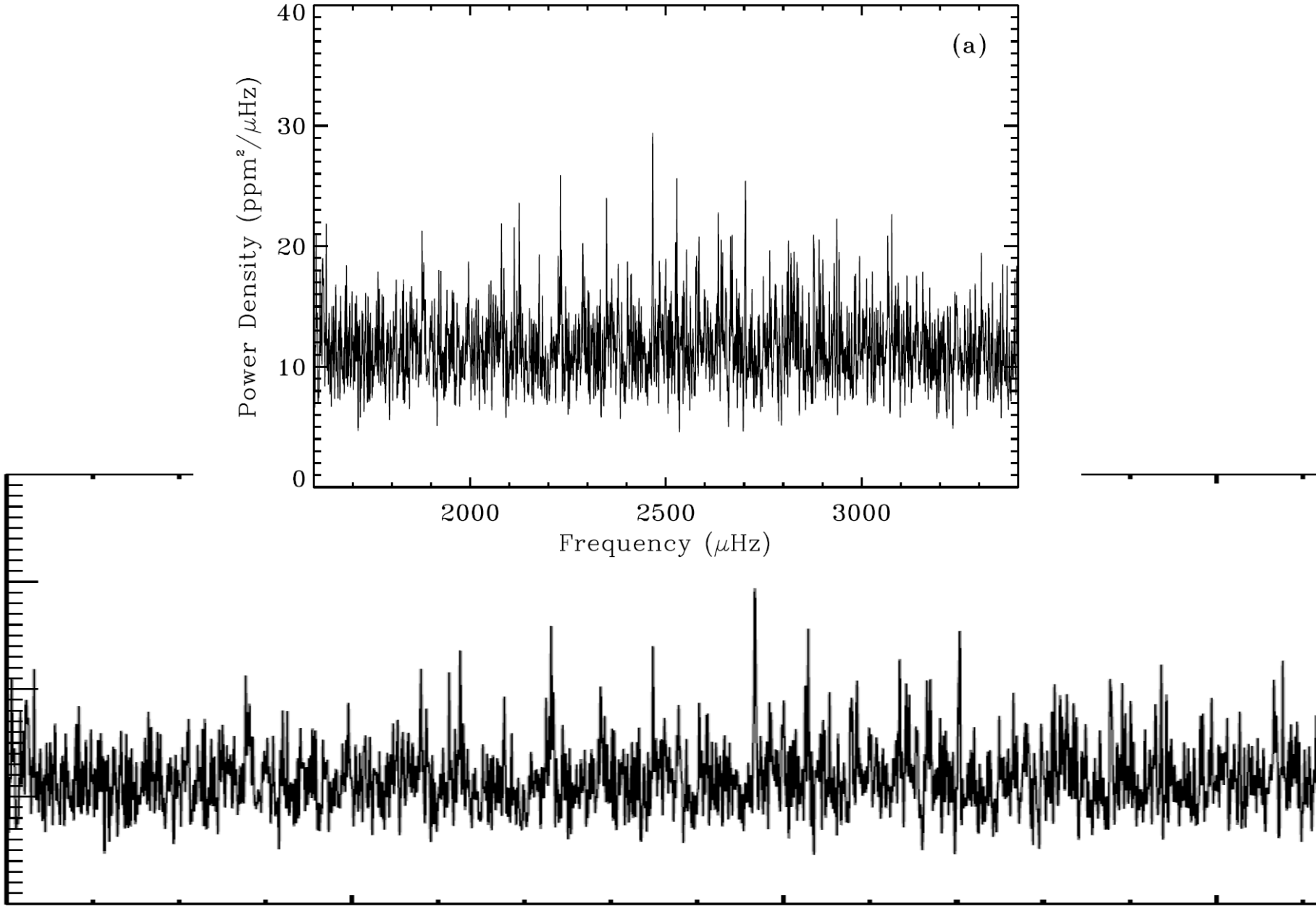


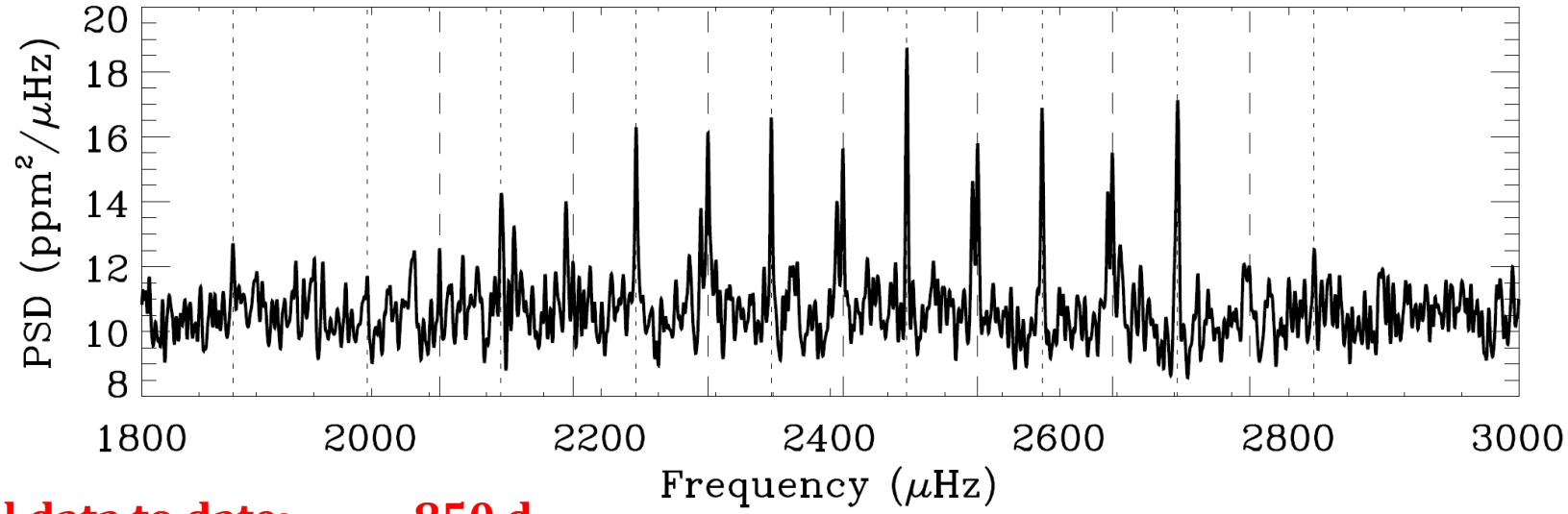
Analysis of more than two years of data….

Alexandra Fogtmann-Schulz, Brian Hinrup, Vincent Van Eylen, Jørgen Christensen-Dalsgaard, Hans Kjeldsen, Victor Silva Aguirre and Brandon Tingley
Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Denmark.



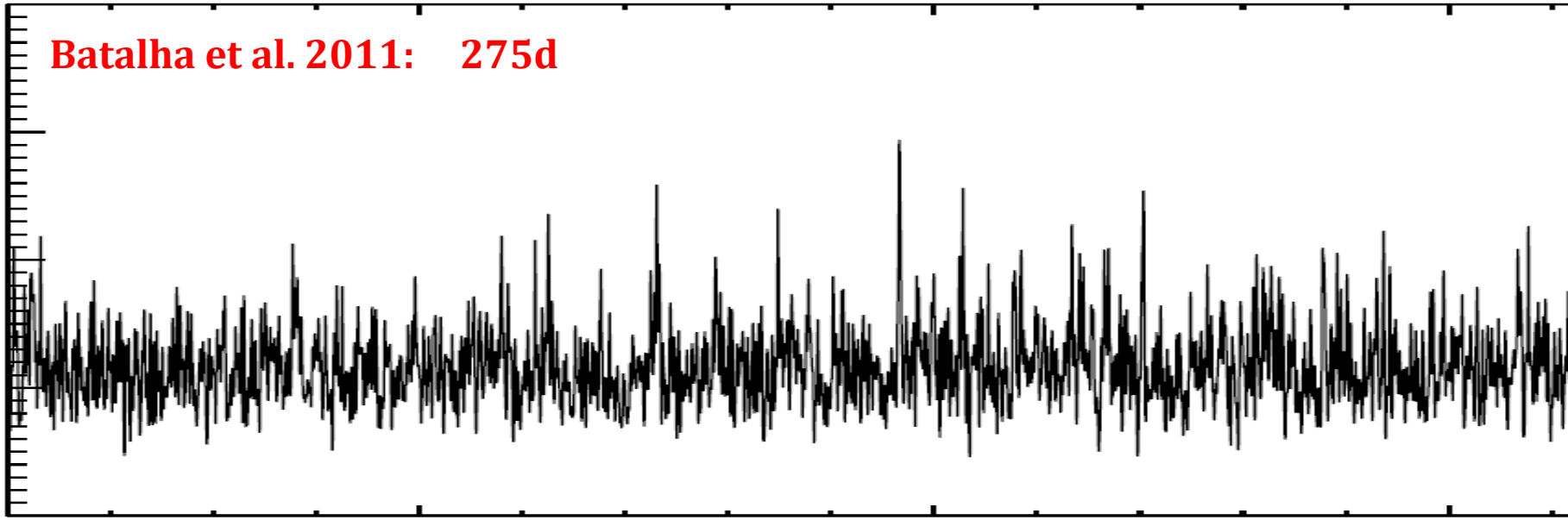
~ 850 days

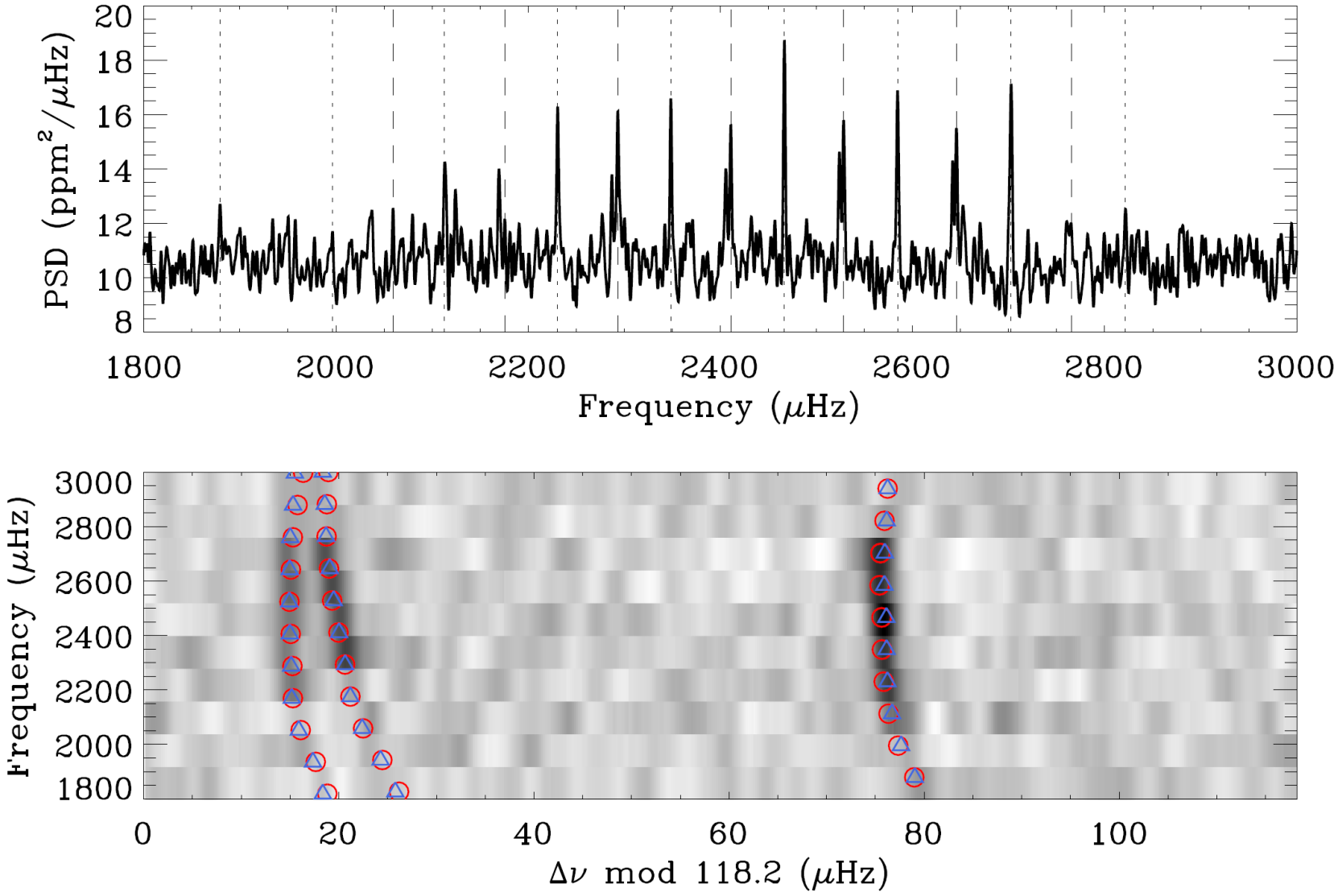

(a)
Power Density (ppm²/μHz)
0
10
20
30
40
2000
2500
3000
Frequency (μHz)



All data to date: 850 d

Batalha et al. 2011: 275d



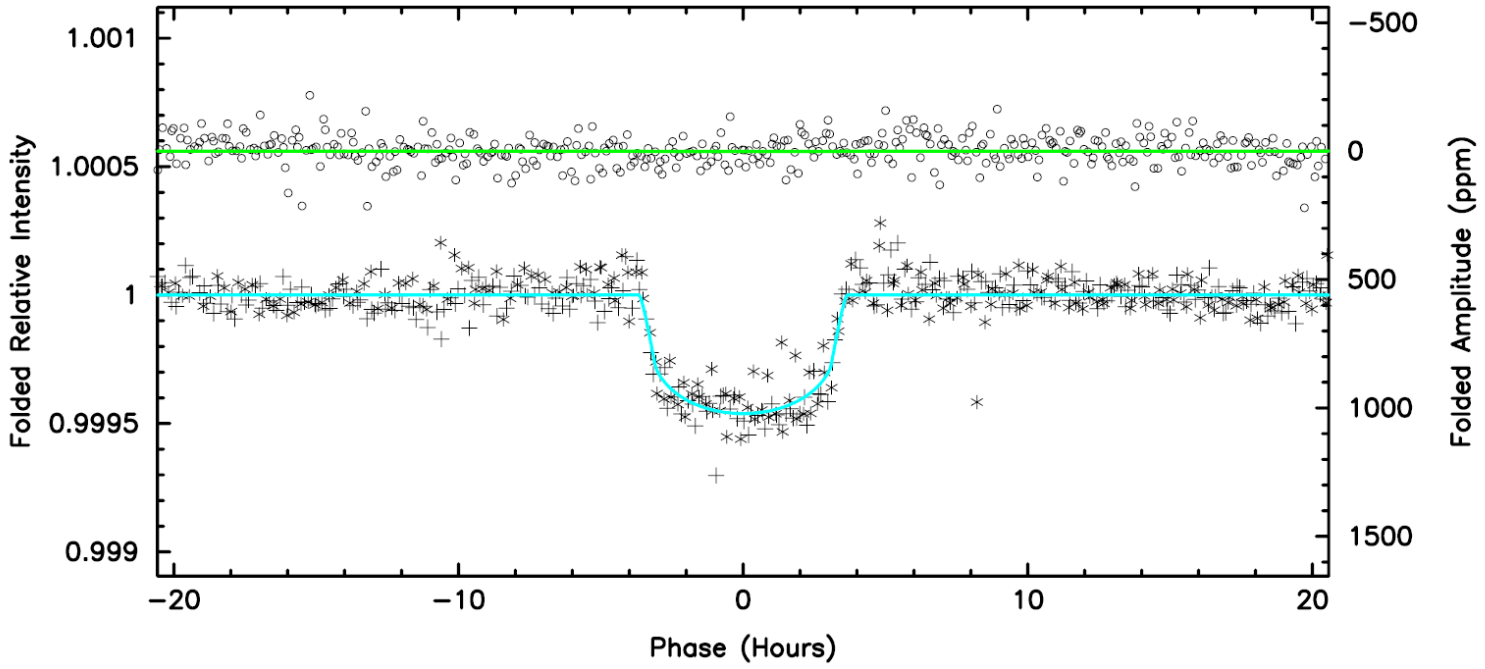

PSD (ppm²/μHz)
20
18
16
14
12
10
8
1800
2000
2200
2400
2600
2800
3000
Frequency (μHz)
Frequency (μHz)
3000
2800
2600
2400
2200
2000
1800
0
20
40
60
80
100
Δν mod 118.2 (μHz)

Mass (Msun)	0.995 ± 0.060
Radius (Rsun)	1.056 ± 0.021
Age (Gyr)	11.9 ± 4.5

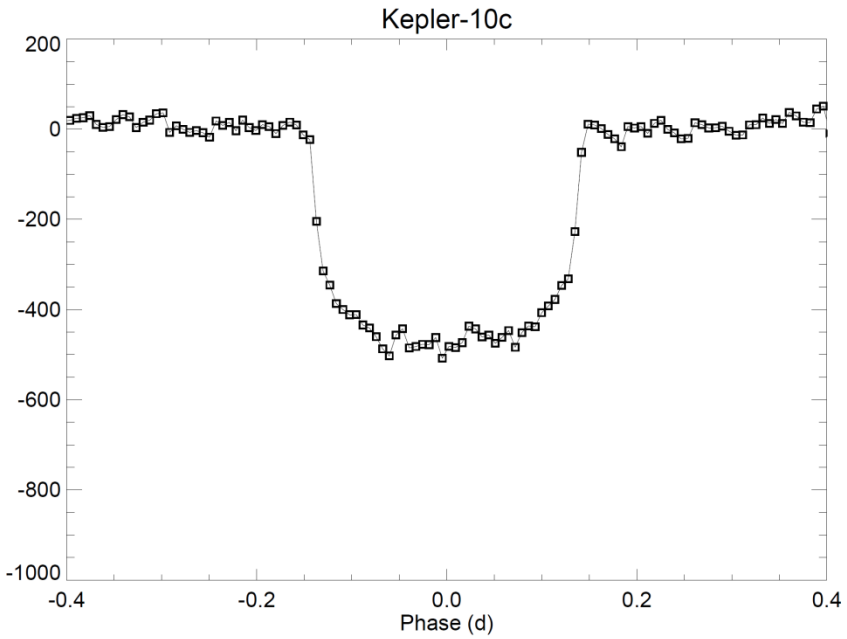
- Batalha et al. 2011

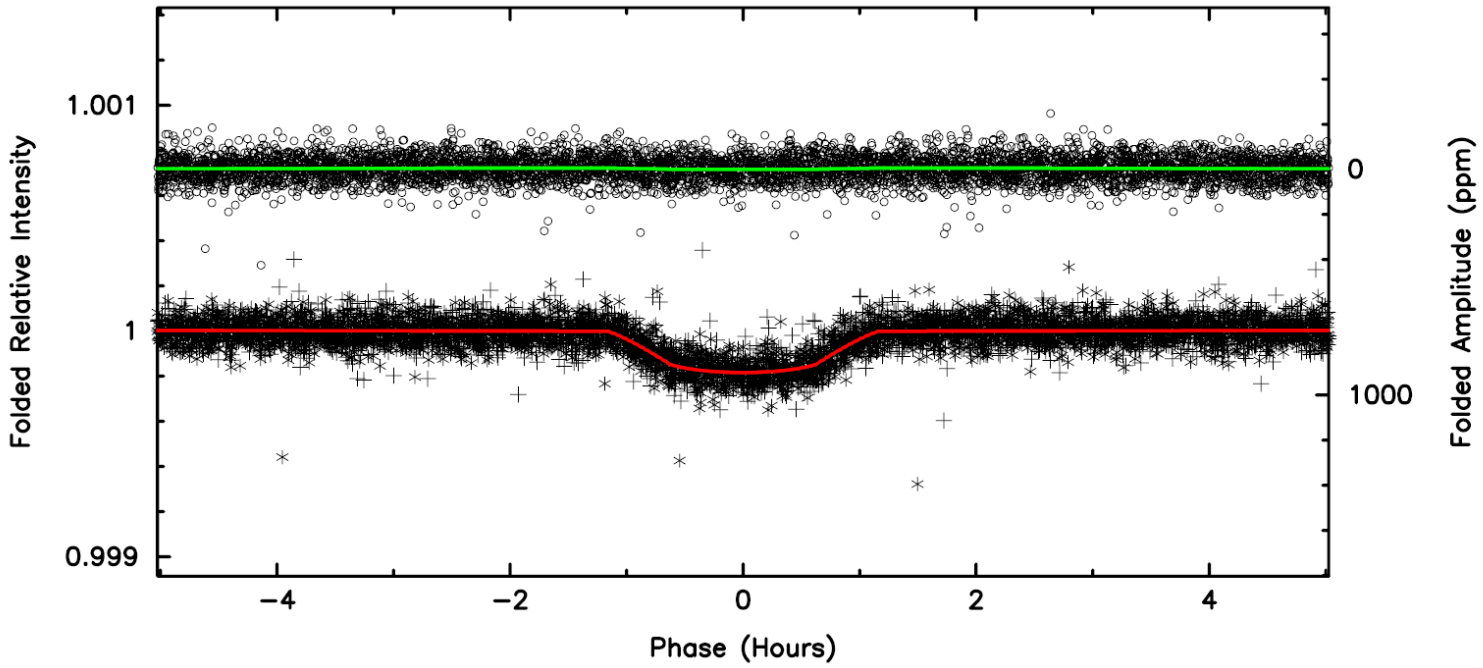
Mass (Msun)	0.913 ± 0.022
Radius (Rsun)	1.065 ± 0.009
Age (Gyr)	10.4 ± 1.4

- All data to date

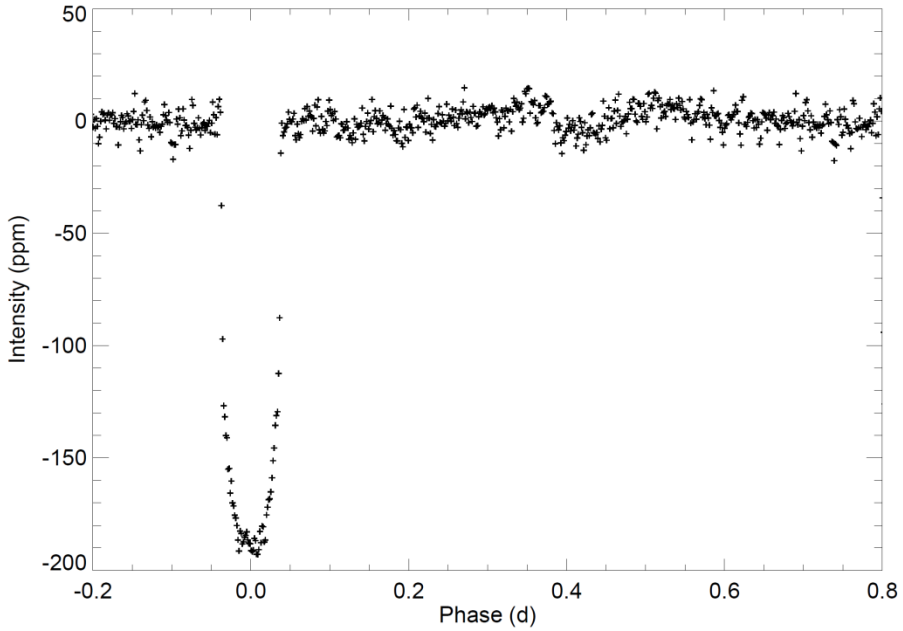

1.001
1.0005
1
0.9995
0.999
Folded Relative Intensity
−500
0
500
1000
1500
Folded Amplitude (ppm)
−20
−10
0
10
20
Phase (Hours)

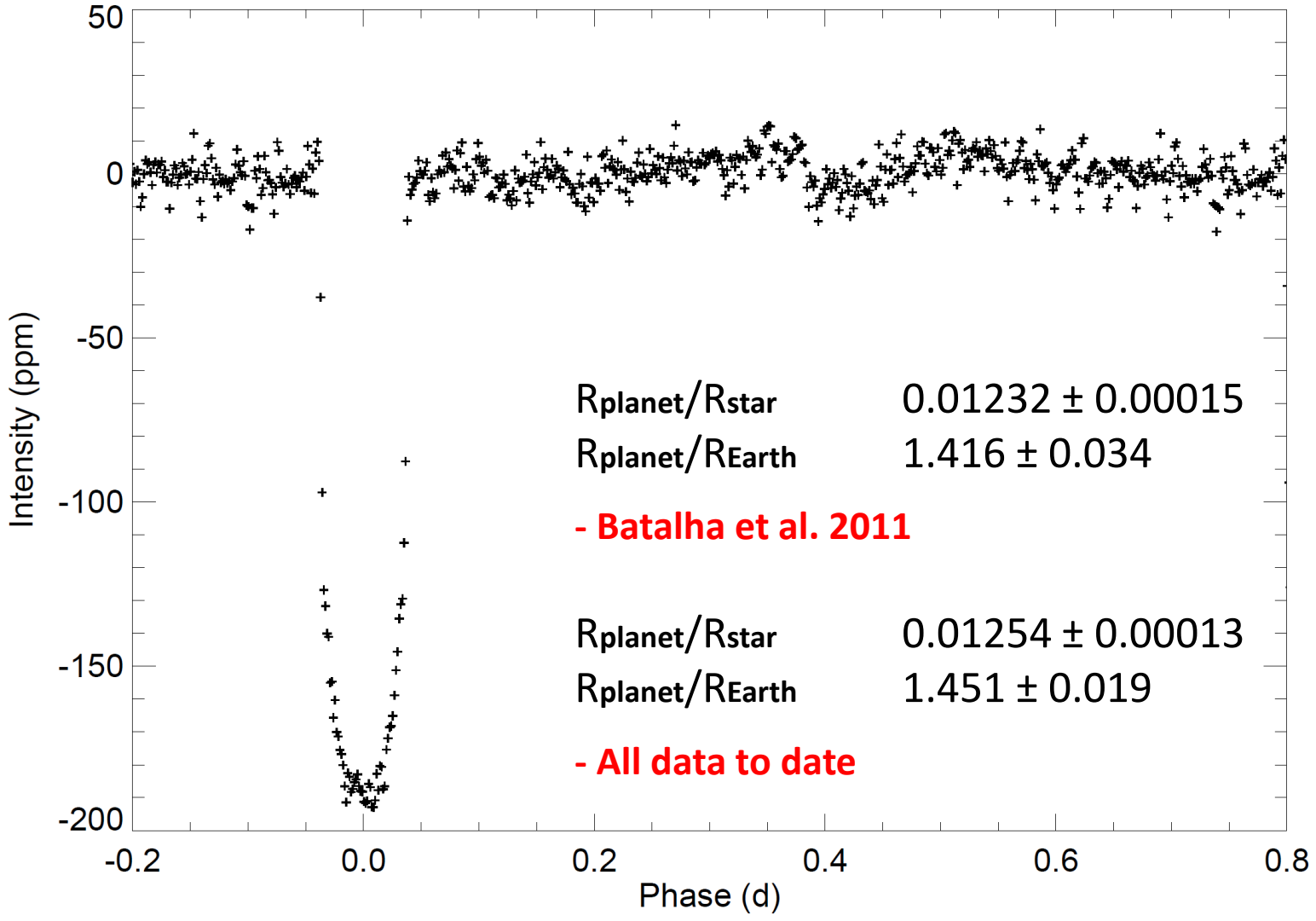
Kepler-10c


Kepler-10c
200
0
-200
-400
-600
-800
-1000
-0.4
-0.2
0.0
0.2
0.4
Phase (d)

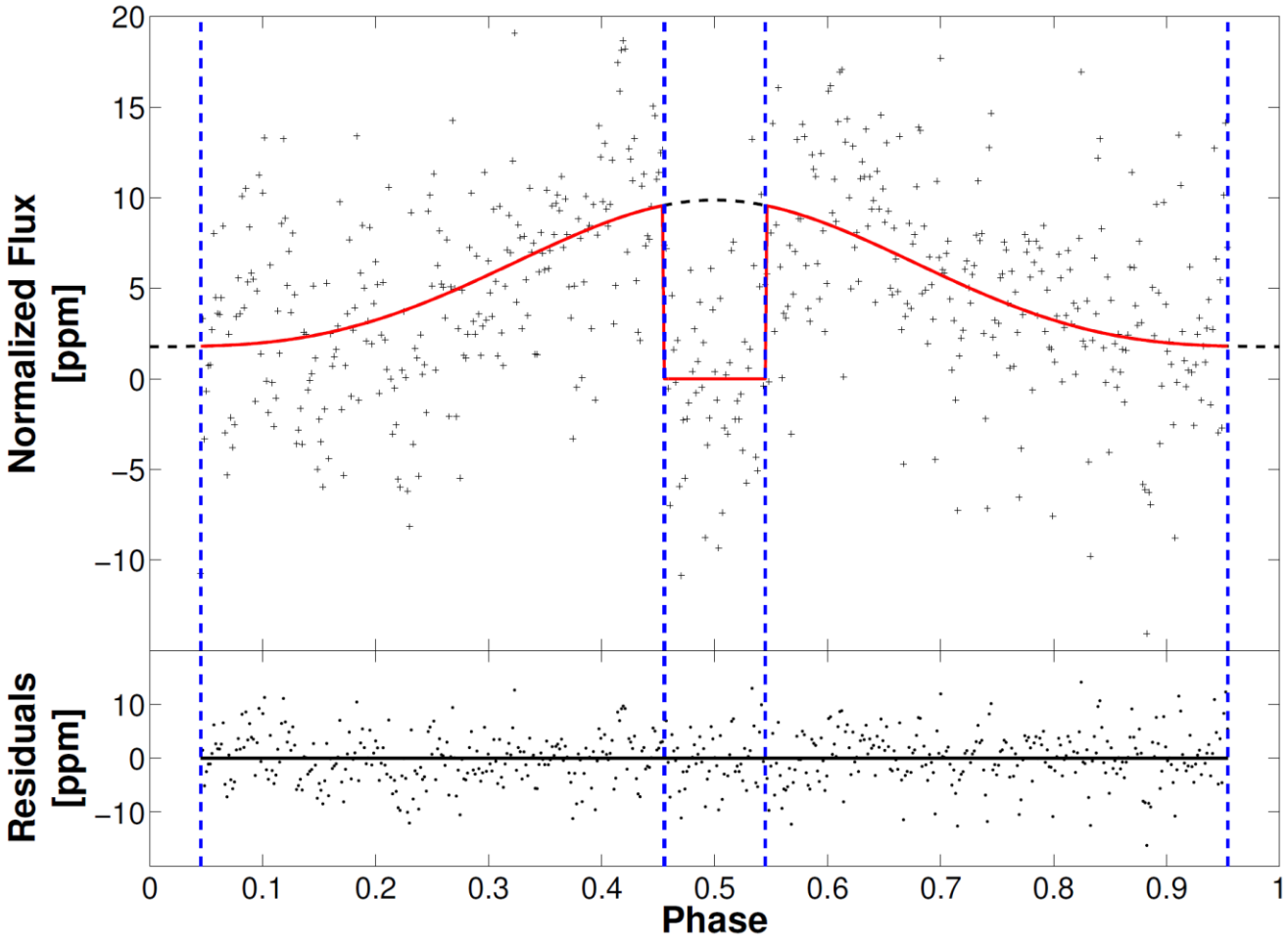

Folded Relative Intensity
1.001
1
0.999
−4
−2
0
2
4
Phase (Hours)
0
1000
Folded Amplitude (ppm)

Kepler-10b

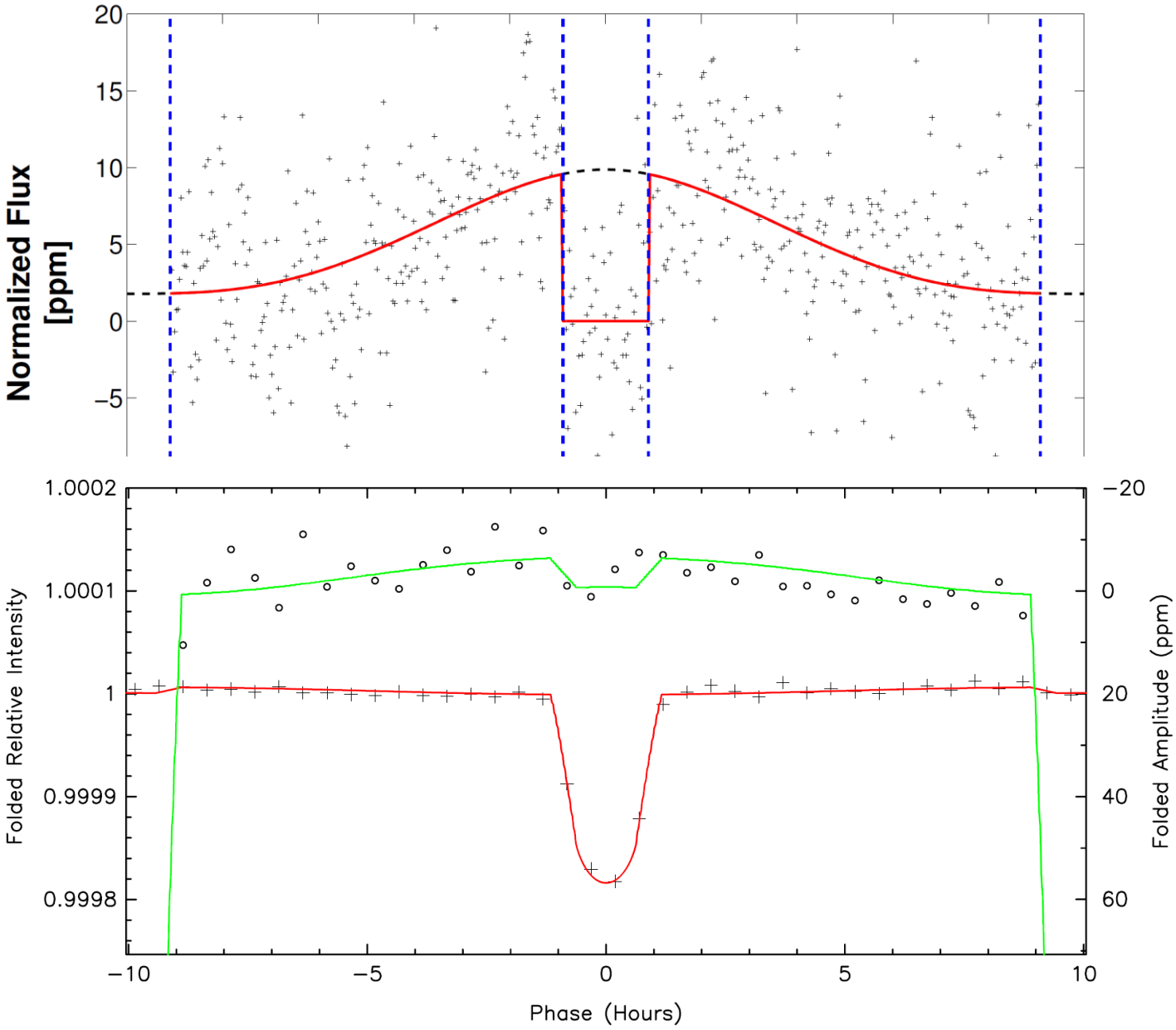

Intensity (ppm)
50
0
-50
-100
-150
-200
-0.2
0.0
0.2
0.4
0.6
0.8
Phase (d)


50
0
-50
-100
-150
-200
Intensity (ppm)
-0.2
0.0
0.2
0.4
0.6
0.8
Phase (d)
Rplanet/Rstar 0.01232 ± 0.00015
Rplanet/REarth 1.416 ± 0.034
- Batalha et al. 2011
Rplanet/Rstar 0.01254 ± 0.00013
Rplanet/REarth 1.451 ± 0.019
- All data to date

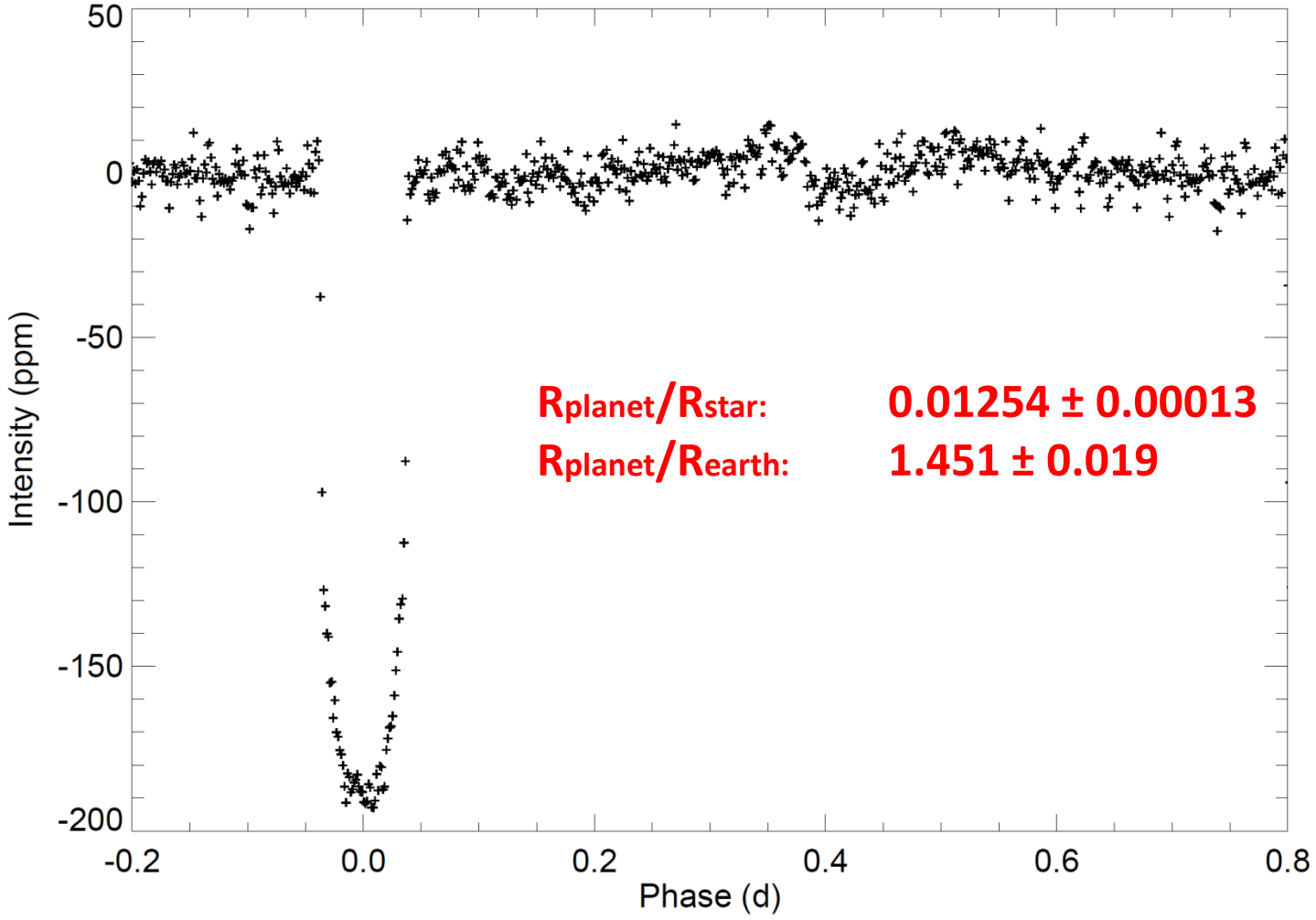
$\delta_{\mathrm{occultation}}$ (ppm) 9.9 ± 1.0



$\delta_{\mathrm{occultation}}$ (ppm) 9.9 ± 1.0



Are planet properties at the 1% level accurate or only precise?



Are planet properties at the 1% level accurate or only precise?

arXiv:1307.6959v1 [astro-ph.EP] 26 Jul 2013

Investigation of systematic effects in *Kepler* data: Seasonal variations in the light curve of HAT-P-7b

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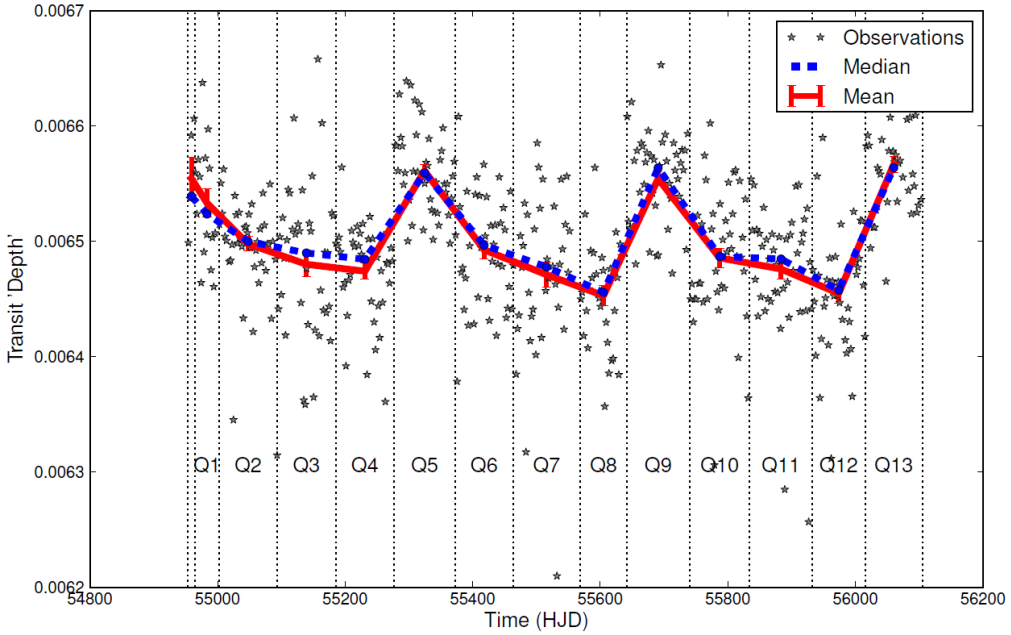
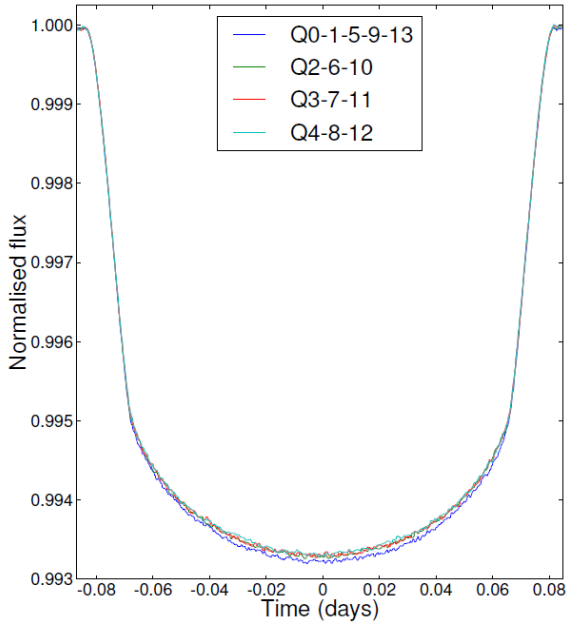
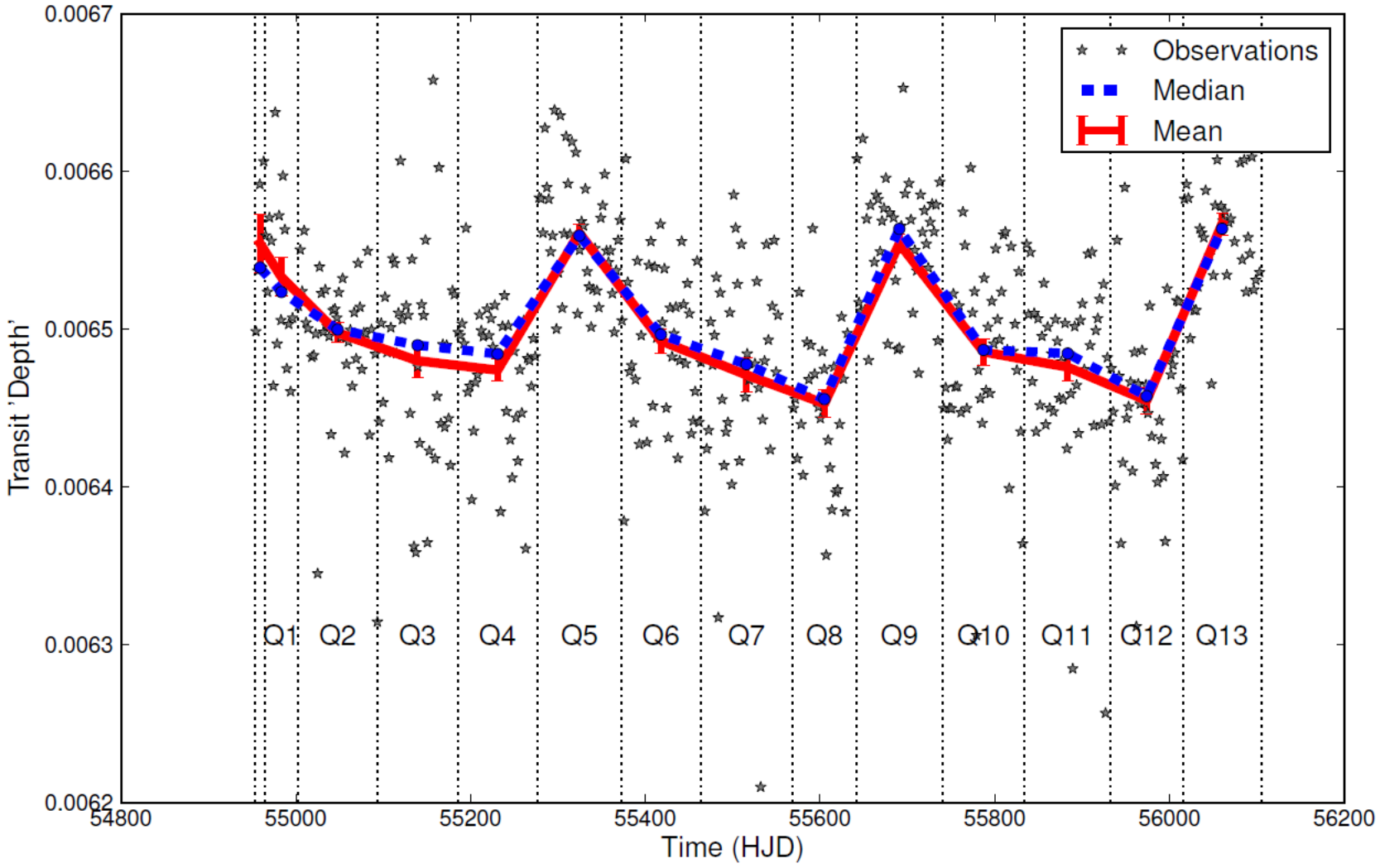
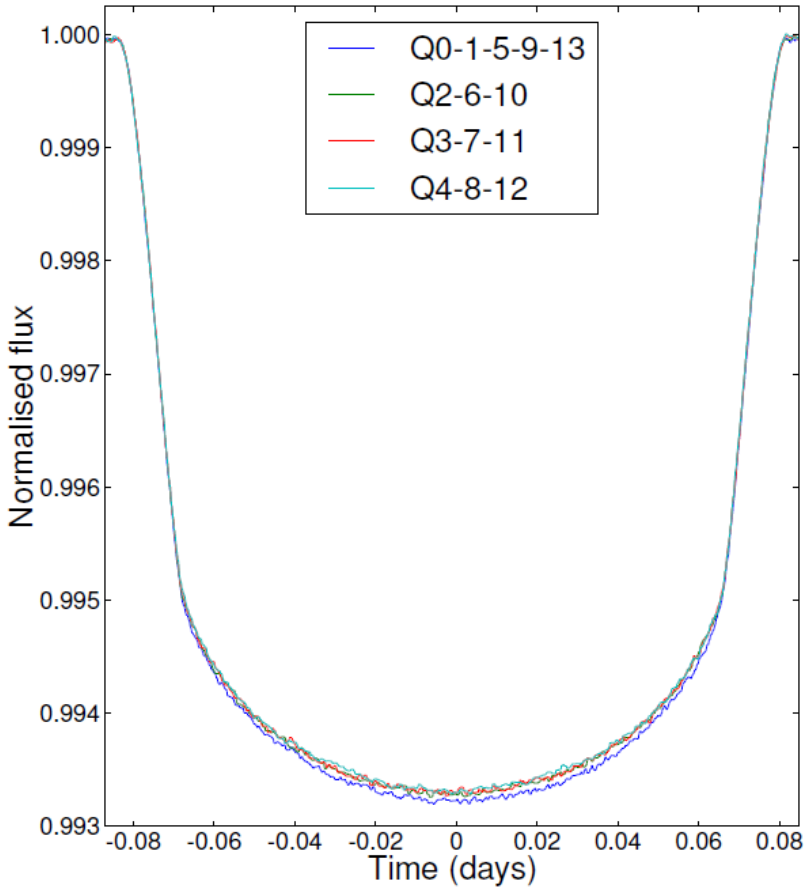
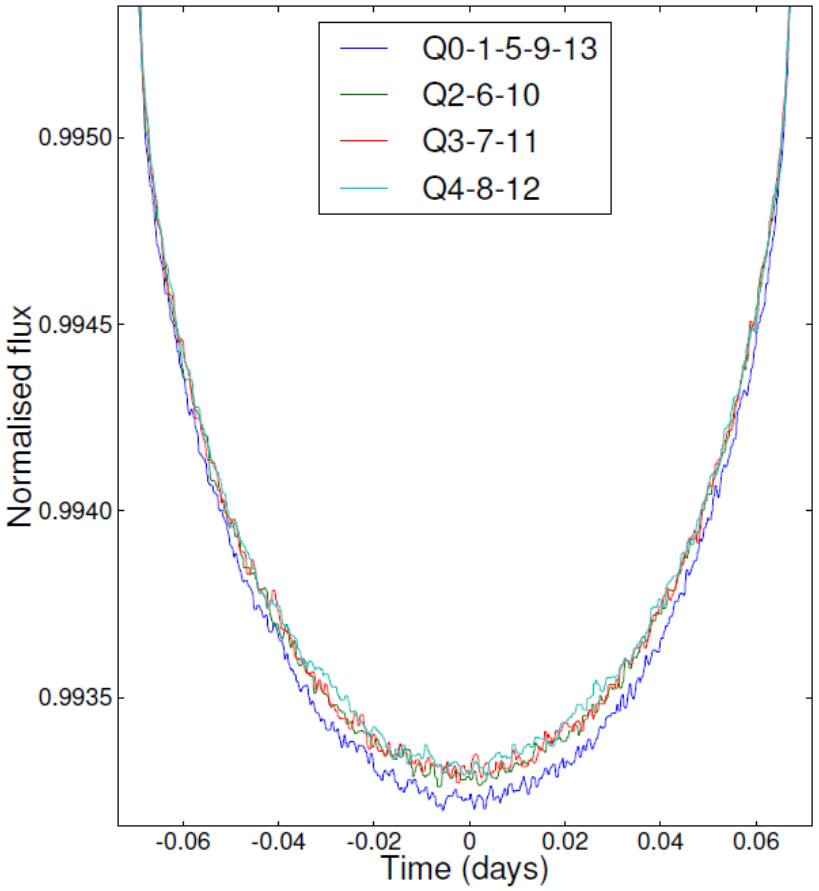
Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark.






Observations
Median
Mean
Transit 'Depth'
0.0067
0.0066
0.0065
0.0064
0.0063
0.0062
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
54800
55000
55200
55400
55600
55800
56000
56200
Time (HJD)





Season	Module	Channel	'Depth' (ppm)	Rel. 'depth'	'Depth' diff. (%)	$R_p/R_\star$
1	17	58	6557.2 ± 3.5	1.00869 ± 0.00054	0.869± 0.054	$0.077618\ ^{+0.000073}_{-0.000073}$
2	19	66	6491.8 ± 4.5	0.99863 ± 0.00068	-0.137± 0.068	$0.077355\ ^{+0.000035}_{-0.000035}$
3	9	26	6475.9 ± 6.0	0.99618 ± 0.00091	-0.382± 0.091	$0.077330\ ^{+0.000056}_{-0.000059}$
4	7	18	6461.1 ± 4.7	0.99392 ± 0.00071	-0.608± 0.071	$0.077229\ ^{+0.000044}_{-0.000043}$

Kepler-10:

Mass (Msun)	0.913 ± 0.022	(2.4%)
Radius (Rsun)	1.065 ± 0.009	(0.85%)
Age (Gyr)	10.4 ± 1.4	(13%)

Kepler-10b:

R_{planet}/R_{star}	0.01254 ± 0.00013	(1.0%)
R_{planet}/R_{Earth}	1.451 ± 0.019	(1.3%)

The key is to extend the length of the time series