The CHEOPS - K2 synergies

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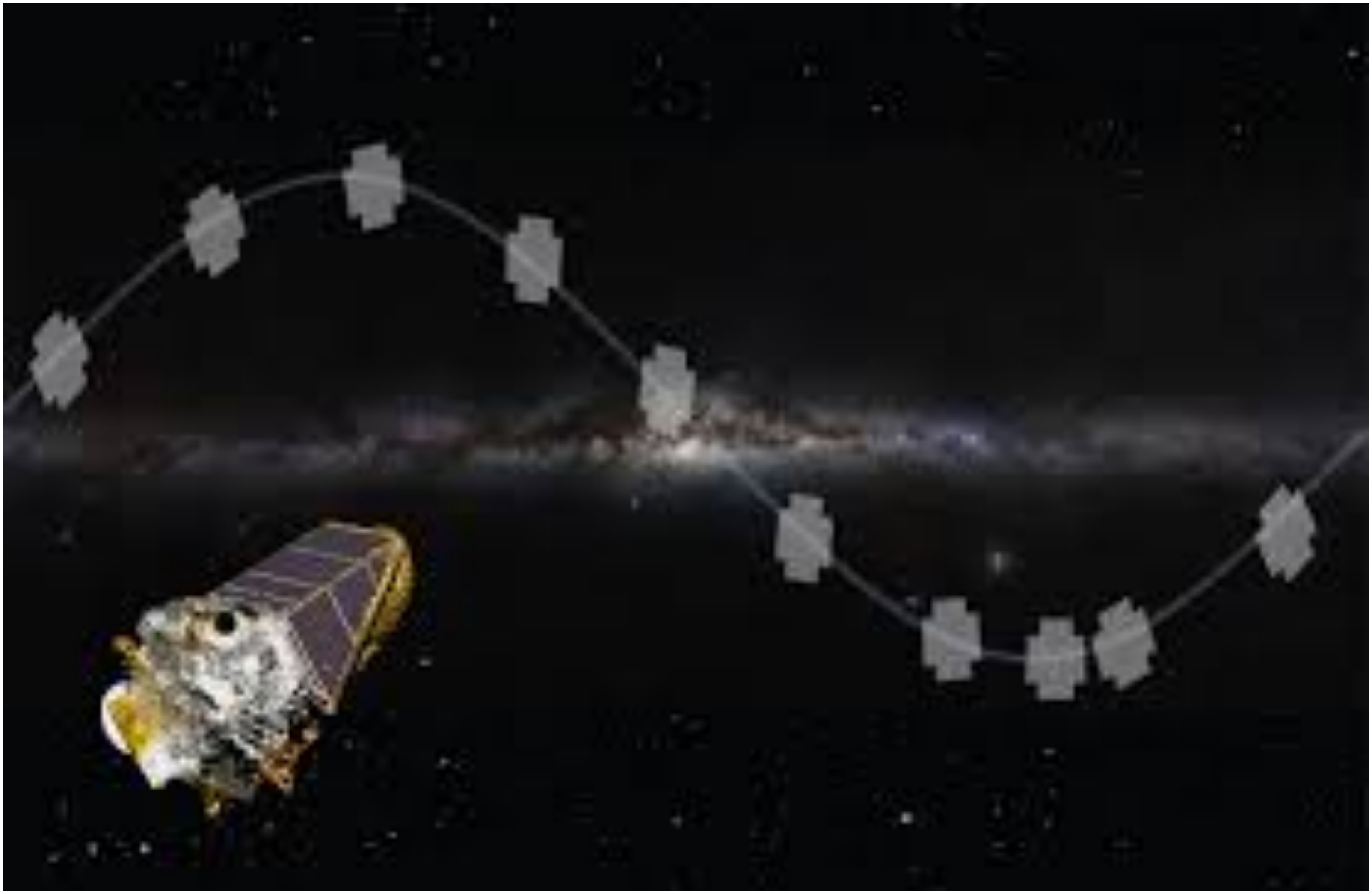
CHEOPS Science Workshop #3, Madrid

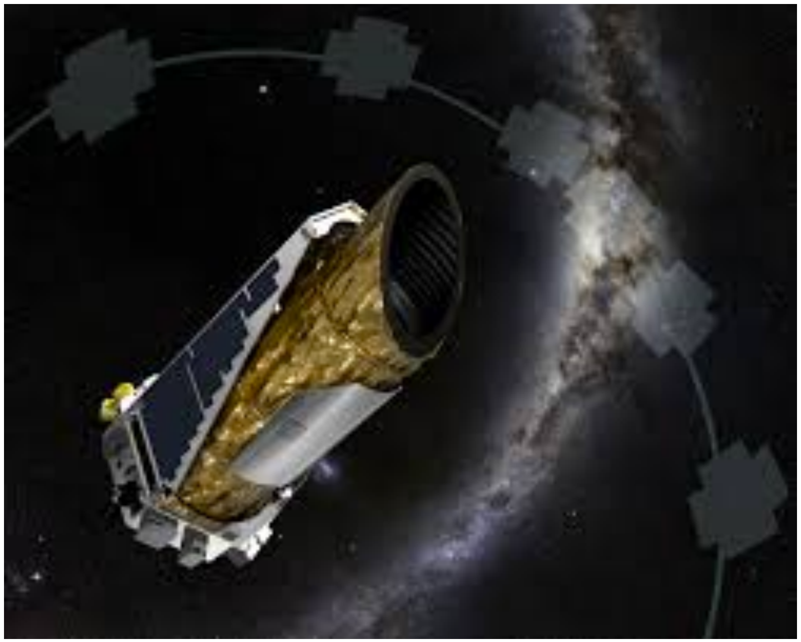
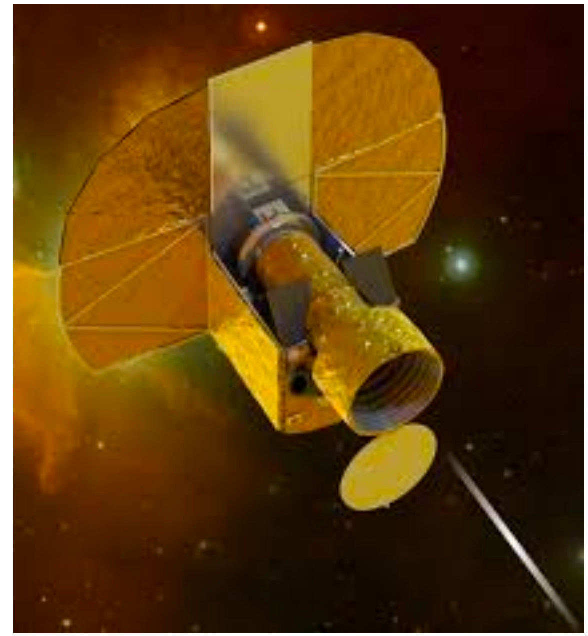
On behalf of :

- CHEOPS Science Team WG-A1 Activities

- ESPRINT collaboration

Kepler – K2 mission



Kepler (K2)	CHEOPS
	
Aperture 0.95 m	Aperture 0.32 m
FOV 105 deg^2	FOV: single star
Continuous data ≈80 days	*Repeated, scheduled visits over 3-5 years*

Exoplanet science cases K2 - Cheops

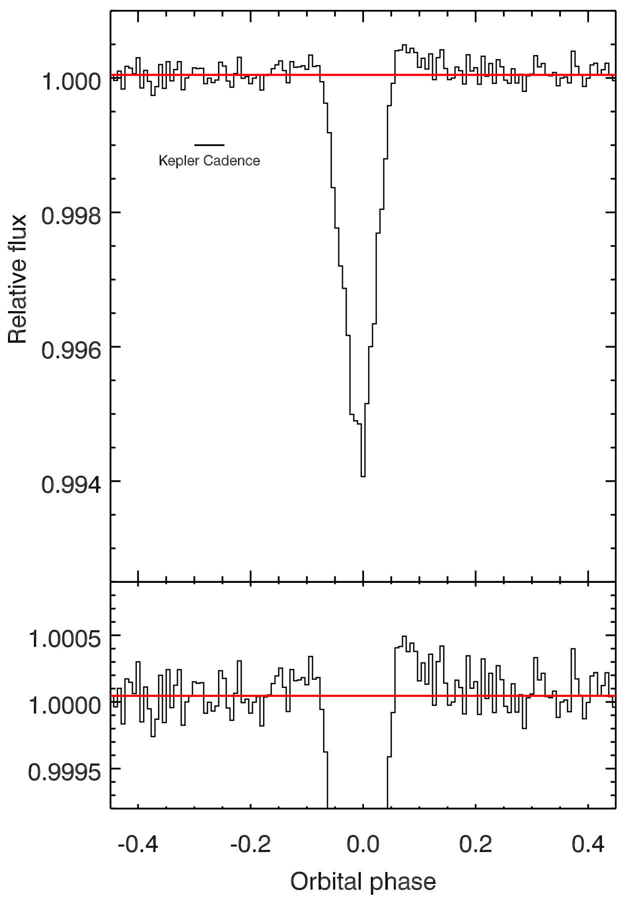
- More transits at lower precision
  - Re-observation of K2 planets with only 1 or 2 observed transits, to refine physical parameters
  - Ephemeris recovery for small depths.
  - Cumulative brute force

- Longer observing baseline/ Objects with transient properties
  - “Evaporating” planets (KIC 1225792b; Rappaport et al 2013)

THE K2-ESPRINT PROJECT I: DISCOVERY OF THE DISINTEGRATING ROCKY PLANET WITH A COMETARY HEAD AND TAIL EPIC 201637175B

R. SANCHIS-OJEDA[1,2], S. RAPPAPORT[3], E. PALLÈ[4,5], L. DELREZ[6], J. DEVORE[7], D. GANDOLFI[8,9], A. FUKUI[10], I. RIBAS[11], K. G. STASSUN[12,13], S. ALBRECHT[14], F. DAI[3], E. GAIDOS[15], M. GILLON[5], T. HIRANO[16], M. HOLMAN[17], A. W. HOWARD[18], H. ISAACSON[1], E. JEHIN[6], M. KUZUHARA[16], A. W. MANN[19,20], G. W. MARCY[1], P. A. MILES-PÁEZ[4,5], P. MONTAÑÉS-RODRÍGUEZ[4,5], F. MURGAS[21,22], N. NARITA[23,24,25], G. NOWAK[4,5], M. ONITSUKA[23,24], M. PAEGERT[12], V. VAN EYLEN[14], J. N. WINN[3], L. YU[3].

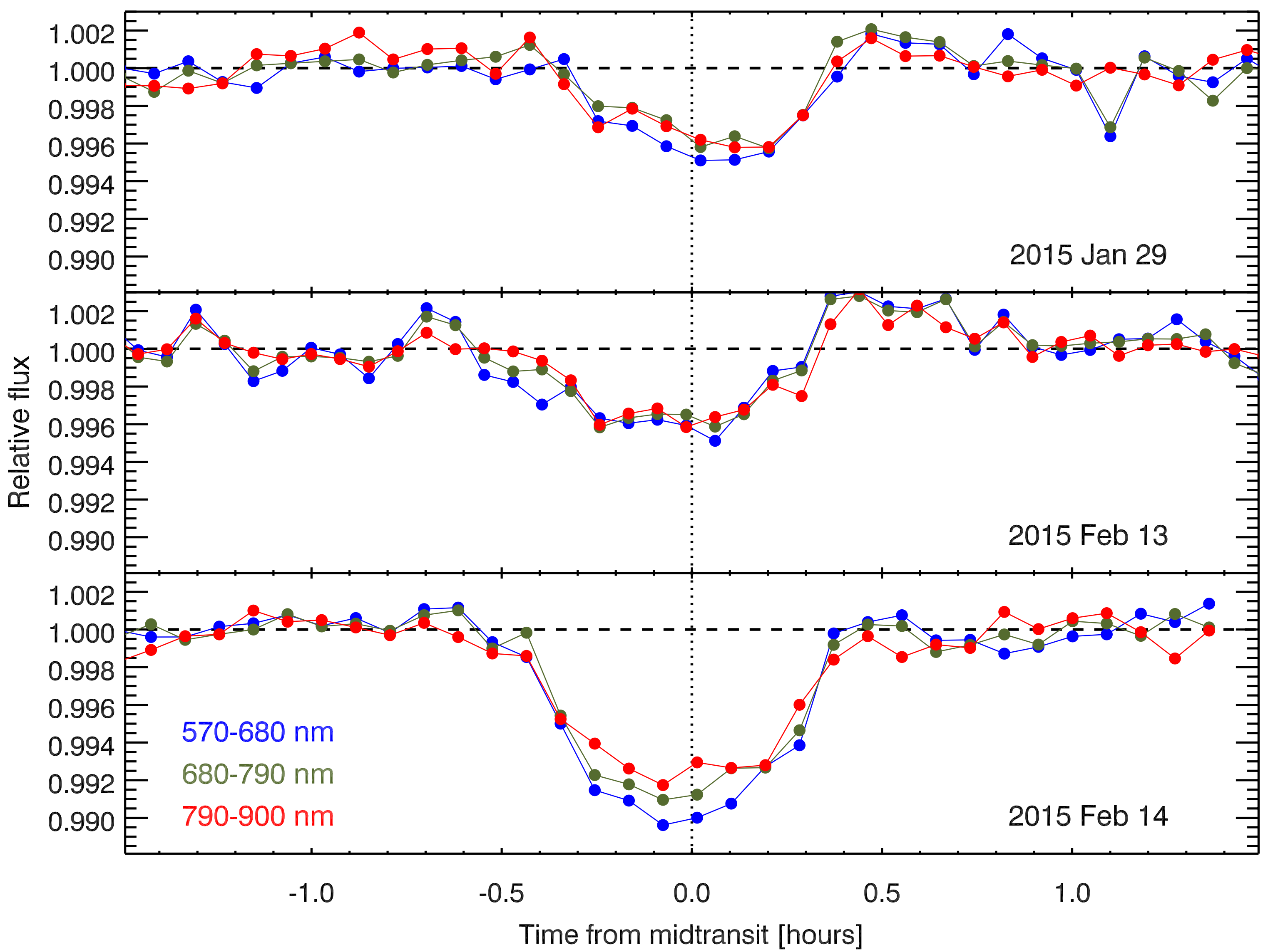
Submitted to the Astrophysical Journal, 2015 April 9



First ESPRINT paper out

Arxiv: http://arxiv.org/abs/1504.04379

GTC spectro-photometry data

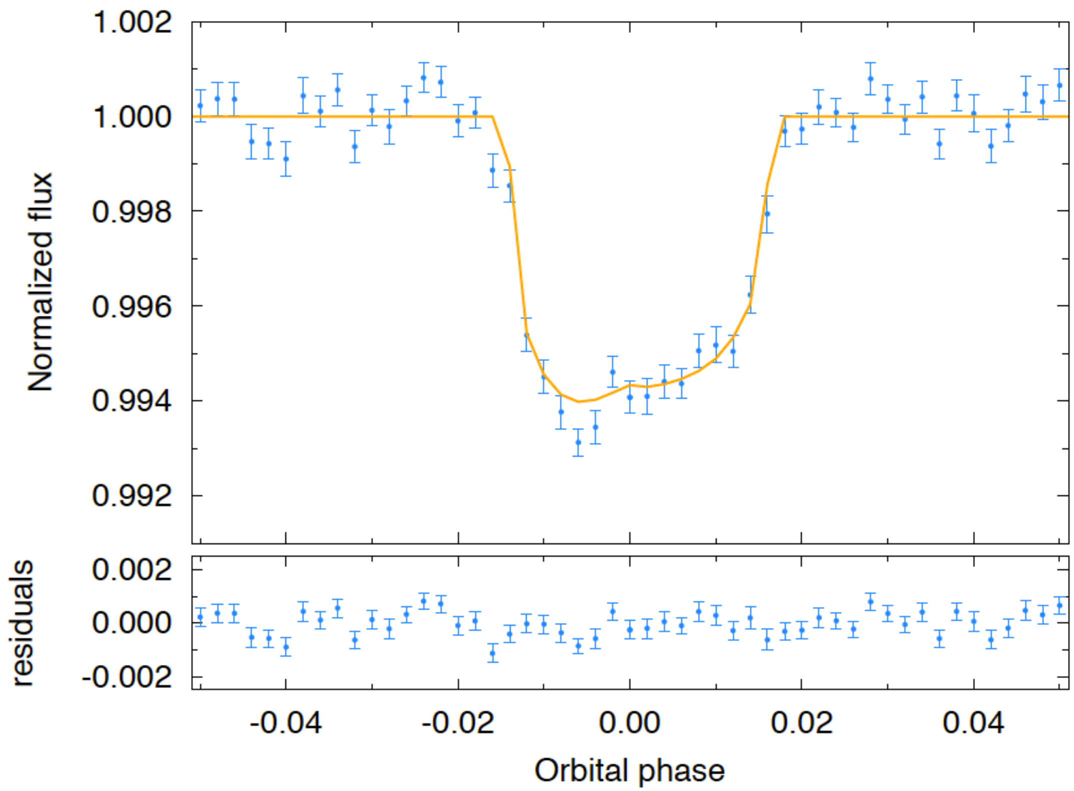


Exoplanet science cases K2 - Cheops

- More transits at lower precision
  - Re-observation of K2 planets with only 1 or 2 observed transits, to refine physical parameters
  - Ephemeris recovery for small depths.
  - Cumulative brute force

- Longer observing baseline/ Objects with transient properties
  - "Evaporating" planets (KIC 1225792b; Rappaport et al 2013)
  - Orbital decay candidates
  - Transit timing/duration variation monitoring
  - Buildup of SNR for asymmetric transits (gravity darkening)

Science cases K2 Cheops



CoRoT-29b (Cabrera et al, 2015)

How many targets can K2 provide for Cheops ?

Three different estimations:

- From models (+ Kepler)
- From Kepler statistics
- From real observations, K2 campaigns 0 to 2

1. Model populations

- Evaluate the exoplanet yield from K2 with specific magnitude cuts
- Consider all late-type stars with good transit performance:
  - F8 to M-type stars
  - Dwarfs and subgiants
  - V < 12 & V < 10
- Consider period intervals to evaluate occurrence rate of transits of:
  - Heavily irradiated planets (P < 10 d)
  - Mildly irradiated planets (10 < P < 40 d)
  - Planets with 2 transits detected by K2 (40 < P < 80 d)
  - Planets with 1 (or 0!) transit detected by K2 (P > 80 d)

Star counts

- Use of Besançon Galaxy model (Robin et al. 2003 & updates)
  - F8-M9 stars; luminosity class IV & V; V<12
- Tests also with TRILEGAL (Girardi et al. 2005 & updates)
- Results show 60-70% dwarfs & 30-40% subgiants

- Consistency checks
  - Field 0:
    - Model: All stars to V<12 ⇨ 13752
    - EPIC catalog to Kp < 12 ⇨ 14501
  - Field 1:
    - Total K2 targets ⇨ 21650
    - K2 Targets with Kp < 12 ⇨ 3100
  - Kepler field:
    - KIC catalog: $T_{eff} < 6200$, $\log g > 3.5$, Kp < 12 ⇨ 2381
    - Besançon model V< 12 ⇨ 1700
    - TRILEGAL model Kp < 12 ⇨ 1320*

K2 Field #	Nstars (V < 12)	Nstars (V < 10)
0	1476	128
1	1285	104
2	1717	137
3	1407	121
4	1495	136
5	1404	118
6	1423	125
7	1312	107
8	1740	119
9	1710	137
TOTAL	**14969**	**1232**

Kepler statistics & planet classes

- Planet counts from Kepler statistics using Fressin et al. prescription but updated with new results (Burke catalog & Kepler detection model)
- No geometric bias correction, i.e., direct planet detection rates
- Assume same distribution with stellar mass (seems OK comparing with Dressing & Charbonneau 2013)

Planet type	Radius ($R_{\oplus}$)	<Radius> ($R_{\oplus}$)
Super-Earths (SE)	1.4-2.2	1.8
Small Neptunes (SN)	2.2-3.0	2.6
Neptunes (N)	3.0-6.0	4.0
Jupiters (J)	6.0-22.0	10.0

Number of transiting planets

Type	Nplanets (V < 12)	Nplanets (V < 10)
H_Irrad SE	70.15	5.88
L_Irrad SE	61.48	5.08
2_Transits SE	17.54	1.44
1_Transit SE	14.71	1.21
H_Irrad SN	23.37	1.92
L_Irrad SN	36.93	3.04
2_Transits SN	12.86	1.06
1_Transit SN	8.55	0.70

Type	Nplanets (V < 12)	Nplanets (V < 10)
H_Irrad NE	12.95	1.07
L_Irrad NE	17.74	1.46
2_Transits NE	7.00	0.58
1_Transit NE	7.82	0.64
H_Irrad JU	6.66	0.55
L_Irrad JU	4.79	0.39
2_Transits JU	3.28	0.27
1_Transit JU	7.01	0.58

- Total planets V < 12 ⇨ 313
- Total planets V < 10 ⇨ 26
- Overall 2.09% transiting planet occurrence

2. Kepler extrapolation

- Use of KOI catalog of candidates (last vet update 30-10-2014)
- Currently 3196 KOIs as candidates OR confirmed
- Number of observed stars 206150
- Nstars (kepmag <12) = 15878
- Nstars (kepmag <10) = 2117

Kepler Field	Period (d)	Radius (R_e)	N total	N (kep < 12)	N (kep < 10)	N (kep<12 & sigma ind>7
2_Transit SE	40-80	1.4-2.2	71	3	0	0
1_Transit SE	80-160	1.4-2.2	50	4	0	0
2_Transit SN	40-80	2.2-3.0	78	2	0	0
1_Transit SN	80-160	2.2-3.0	56	3	0	0
2_Transits N	40-80	3.0-6.0	52	5	1	1
1_Transit N	80-160	3.0-6.0	106	4	0	0
2_Transits JU	40-80	6.0-22.0	38	2	0	0
1_Transit JU	80-160	6.0-22.0	40	4	1	0

- Assume same number of bright targets for all 10 K2 fields → x10
- Assume same fraction of giants, same success in selection of dwarfs (!)
- Assume same detection efficiency in K2 as in Kepler (!)

Kepler Field	Period (d)	Radius (R_e)	N (kep < 12)	N (kep < 10)	N (kep<12 & sigma ind>7	S/N in CHEOPS (V = 12)	S/N in CHEOPS (V = 10)
2_Transit SE	40-80	1.4-2.2	30	0	0	Bad	Limit
1_Transit SE	80-160	1.4-2.2	40	0	0	Bad	Limit
2_Transit SN	40-80	2.2-3.0	20	0	0	Limit?	OK
1_Transit SN	80-160	2.2-3.0	30	0	0	Limit?	OK
2_Transits N	40-80	3.0-6.0	50	10	10	OK	OK
1_Transit N	80-160	3.0-6.0	40	0	0	OK	OK
2_Transits JU	40-80	6.0-22.0	20	0	0	OK	OK
1_Transit JU	80-160	6.0-22.0	40	10	0	OK	OK

Probably feasible from ground

Feasible from ground

- Total planets kep < 12 (1 or 2 transits) ⇨ 270
- Total planets kep < 10 (1 or 2 transits) ⇨ 20
- Small number statistics, especially in kep<10
- Number of targets where ONLY CHEOPS can help: ≈100 (*very* optimistic)

3. Real observations from K2

- Several programs on-going on to search for transits in the K2 Mission data releases (*Data here only from one*)
- Field 0, 1 & 2 data already explored for planet detections, all stars included.
- False positives not completely accounted for but expected low
- Total of 62 planet candidates
- Systems with 1 transits unaccounted for

Results Field 0

Kepler Field	Radius (R_e)	N (kep>12)	N (kep < 12)	N (kep < 10)	S/N in CHEOPS (V = 12)	S/N in CHEOPS (V = 10)
>2_Transit SE	1.4-2.2	2	0	0	Bad	Limit
>2_Transit SN	2.2-3.0	2	0	0	Limit?	OK
>2_Transit N	3.0-6.0	2	1	0	OK	OK
>2_Transit JU	6.0-22.0	6	3	0(1)	OK	OK

Results Field 1

Kepler Field	Radius (R_e)	N (kep>12)	N (kep < 12)	N (kep < 10)	S/N in CHEOPS (V = 12)	S/N in CHEOPS (V = 10)
>2_Transit SE	1.4-2.2	11	0	0	Bad	Limit
>2_Transit SN	2.2-3.0	6	0	0	Limit?	OK
>2_Transit N	3.0-6.0	7	0	0	OK	OK
>2_Transit JU	6.0-22.0	5	2	0	OK	OK

Results Field 2

Kepler Field	Radius (R_e)	N (kep>12)	N (kep < 12)	N (kep < 10)	S/N in CHEOPS (V = 12)	S/N in CHEOPS (V = 10)
>2_Transit SE	1.4-2.2	1	2	0	Bad	Limit
>2_Transit SN	2.2-3.0	3	0	0	Limit?	OK
>2_Transit N	3.0-6.0	3	2	0	OK	OK
>2_Transit JU	6.0-22.0	3	1	0	OK	OK

A total of 16, **31**, 15 candidates in 3 fields (extrapolating x10 during the mission to 310)

Summary

Estimation from three different methods give us an idea of how many interesting target for CHEOPS can K2 provide:

- #planets Kp<12 313, 270, 20(-50)
- #planets Kp<10 26, 20, 0(-10)

Summary

On the other hand, so far K2 provides ***really interesting*** planets:

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- M star with 3 planets (Crossfield et al, 2015)

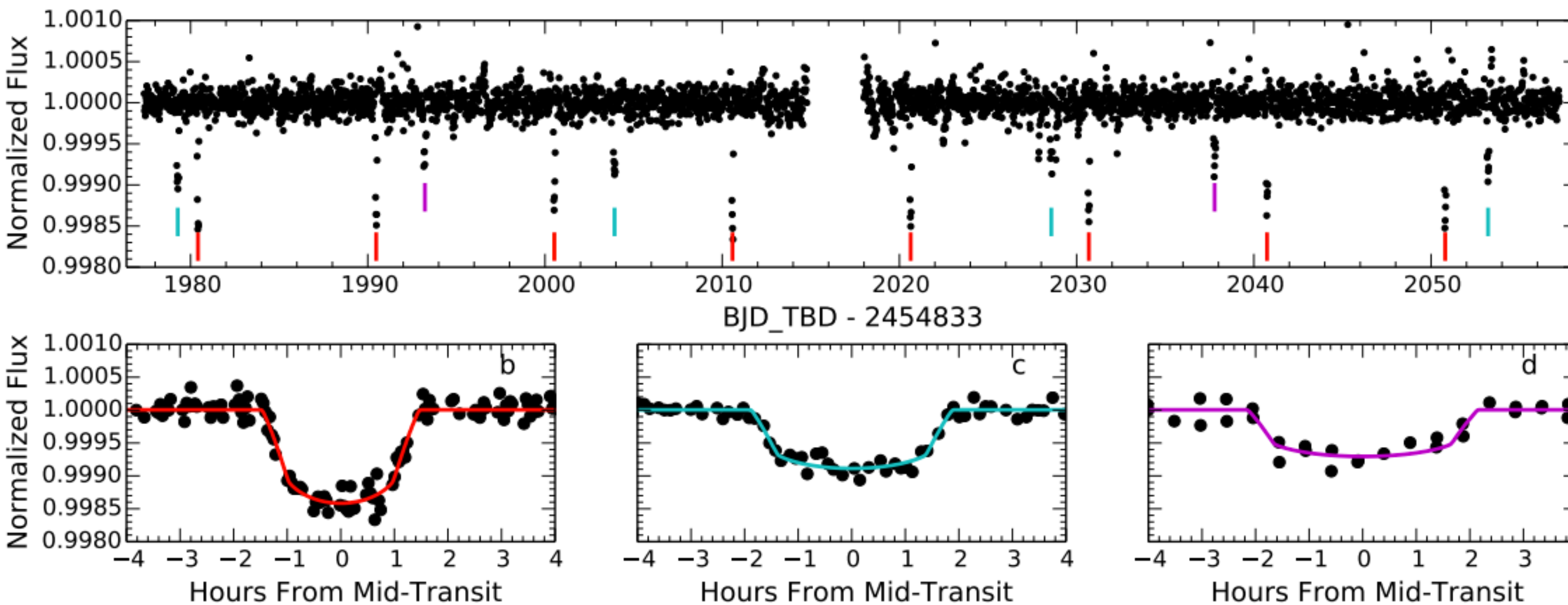
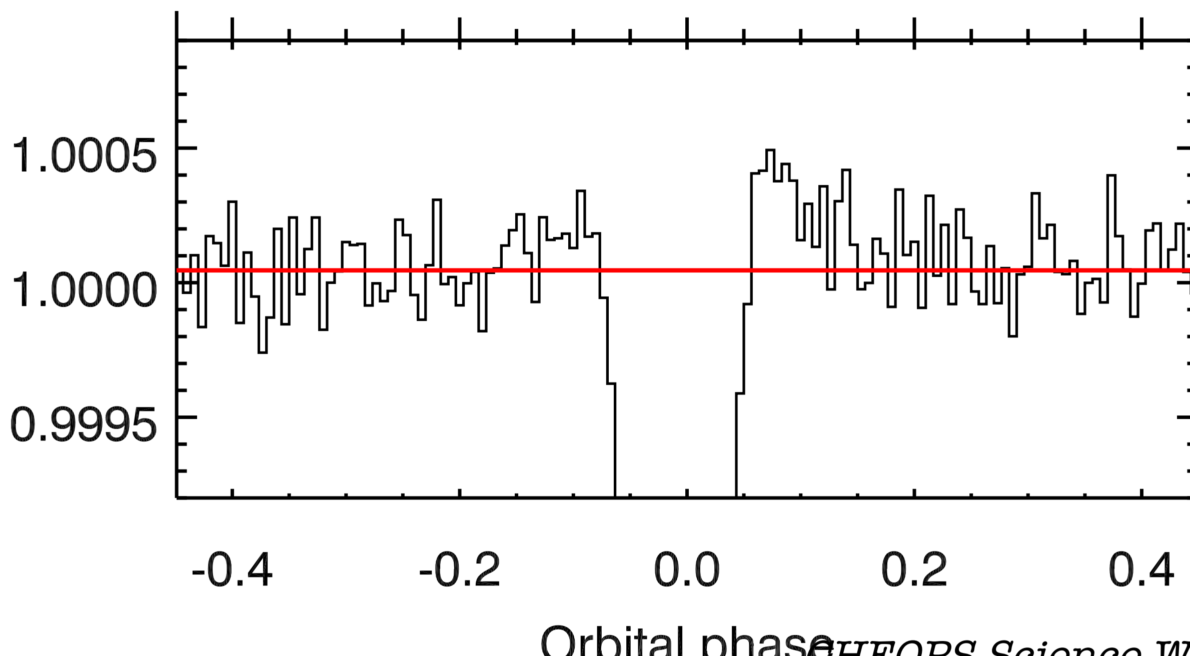


FIG. 1.— *Top*: Calibrated K2 photometry for K2-3. Vertical ticks indicate the locations of each planets' transits. *Bottom*: Phase-folded photometry and best-fit light curves for each planet.

Summary

On the other hand, so far K2 provides ***really interesting*** planets:

- M star with 3 planets (Crossfield et al, 2015)
- New, slightly brighter, “evaporating” system (Sanchis-Ojeda et al, 2015)



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- M star with 3 planets (Crossfield et al, 2015)
- Evaporating system (Sanchis-Ojeda et al, 2015)
- TTVs systems in resonance (Armstrong et al, 2015)

One of the closest planet pairs to the 3:2 Mean Motion Resonance, confirmed with K2 observations and Transit Timing Variations: EPIC201505350★

David J. Armstrong[1], Dimitri Veras[1], Susana C. C. Barros[2], Olivier Demangeon[2], James McCormac[1], Hugh P. Osborn[1], Jorge Lillo-Box[3], Alexandre Santerne[2,4], Maria Tsantaki[4], José-Manuel Almenara[5,6], David Barrado[3],

Summary

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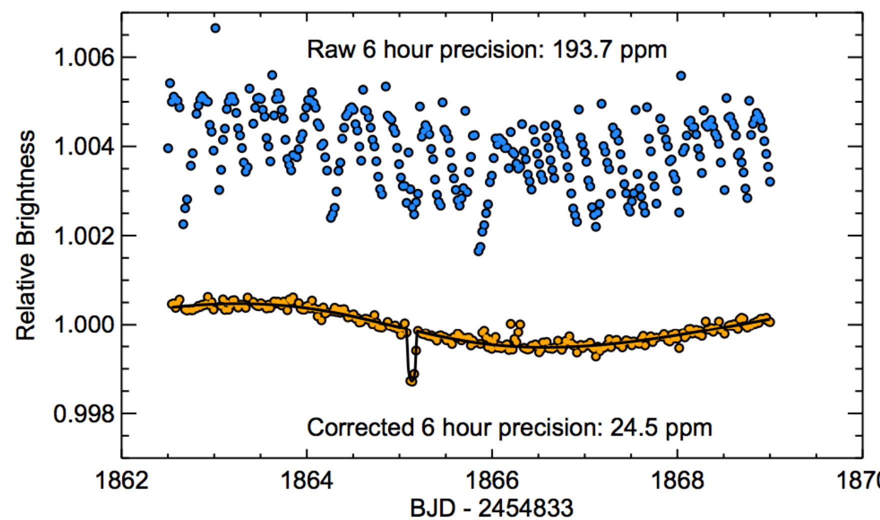
- M star with 3 planets (Crossfield et al, 2015)
- Evaporating system (Sanchis-Ojeda et al, 2015)
- TTVs systems in resonance (Armstrong et al, 2015)
- A Super Earth around a bright (V=10.1) nearby star (Vanderburg et al, 2015)



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- Evaporating system (Sanchis-Ojeda et al, 2015)
- TTVs systems in resonance (Armstrong et al, 2015)
- A Super Earth around a bright (V=10.1) neaby star (Vanderburg et al, 2015)
- A few planets to be announced