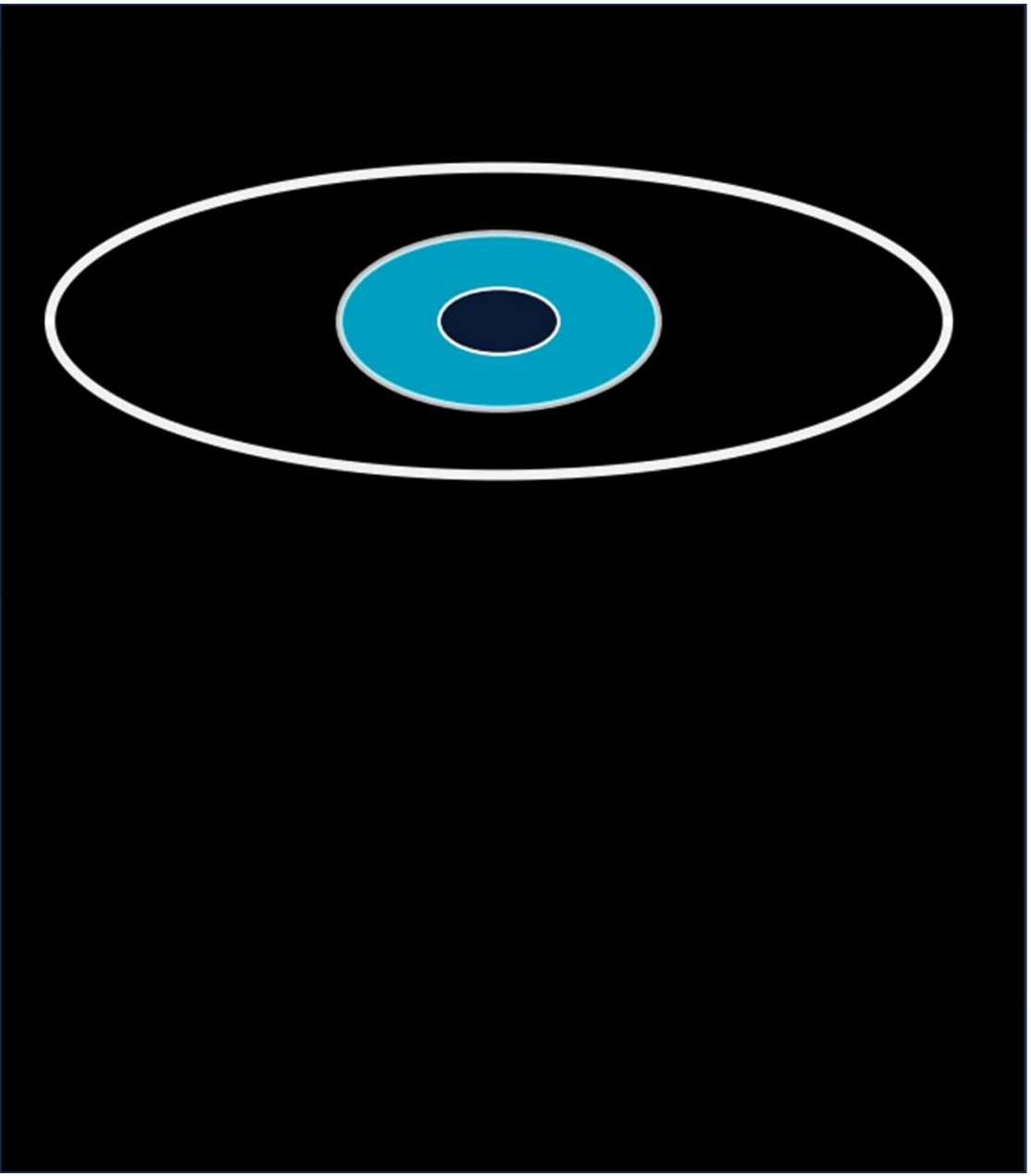

DIPS OjOS

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III ICTEA Research days, 01/06/26

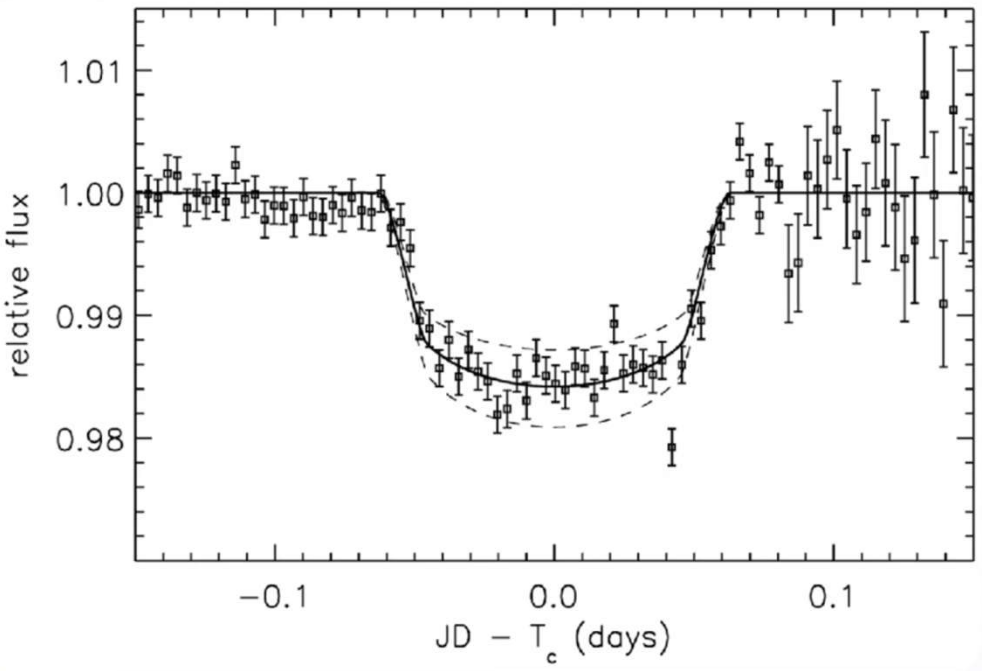
Universidad de Oviedo

ICTEA
Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias

The transit method

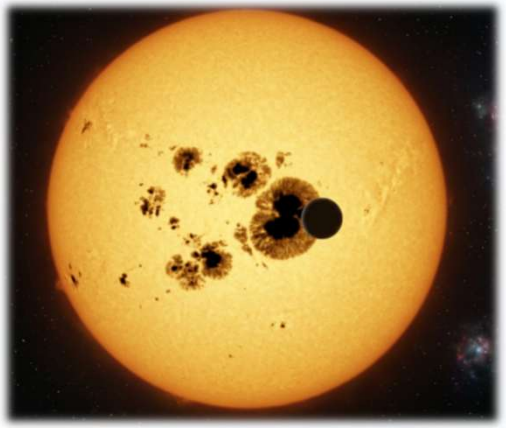
- In 1999 *HD 209458 b became the first exoplanet detected via the transit method* (Henry et al. 1999; Charbonneau et al. 1999).

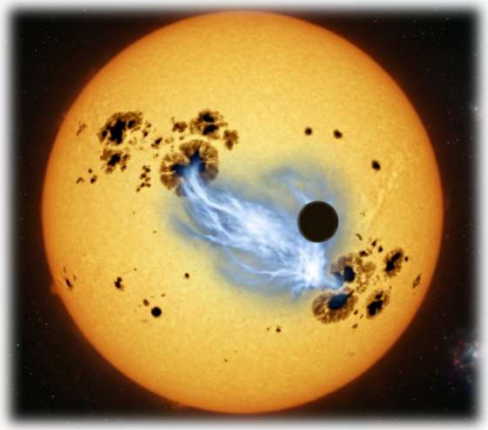
- As of May 2026, thanks to facilities such as *Kepler* and *TESS*, more than 4600 exoplanets have been confirmed using this method, accounting for about 74% of the total number of known exoplanets.



The transit method

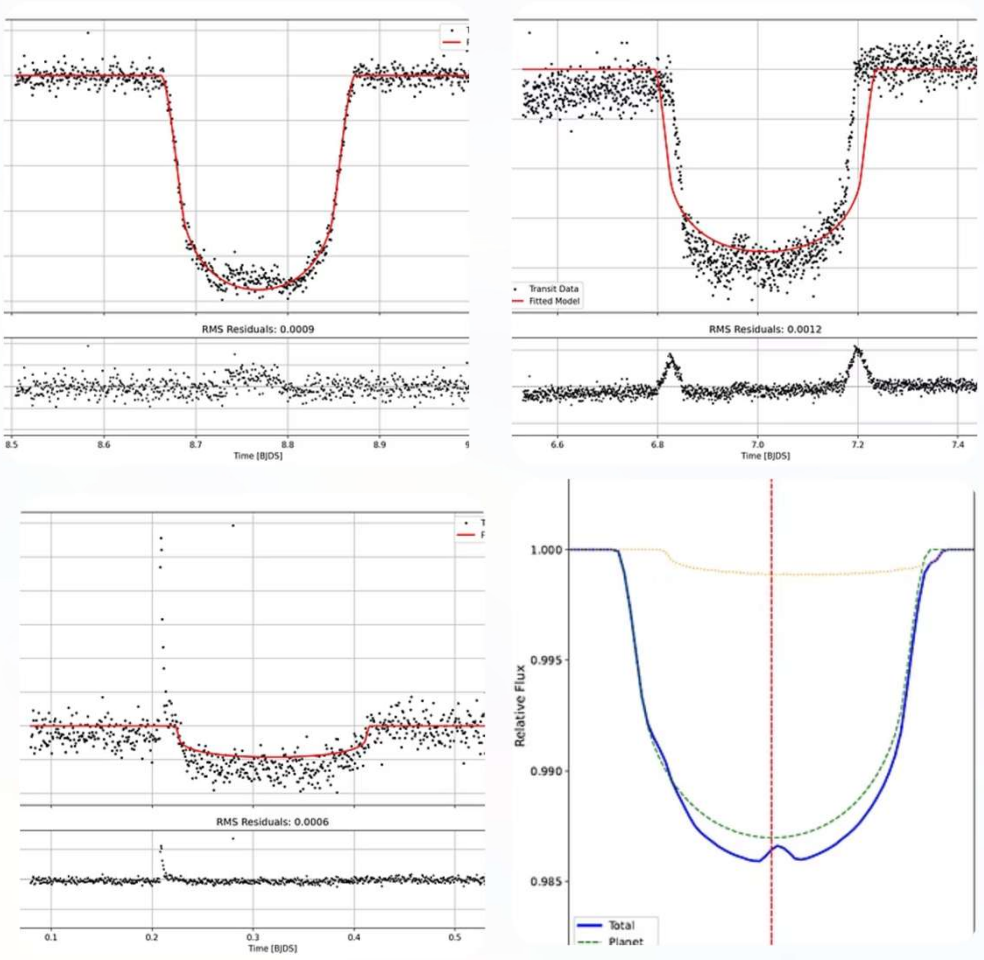
- In the big data era, automatic detection algorithms are essential
- Many subtle signals within the transits remain undetected by these algorithms
- We work with a team of trained collaborators capable of detecting these signals.
- This led to the creation of the DIPS OjOS project (Detecting Irregular Photometric Signals Ojimetro Survey)





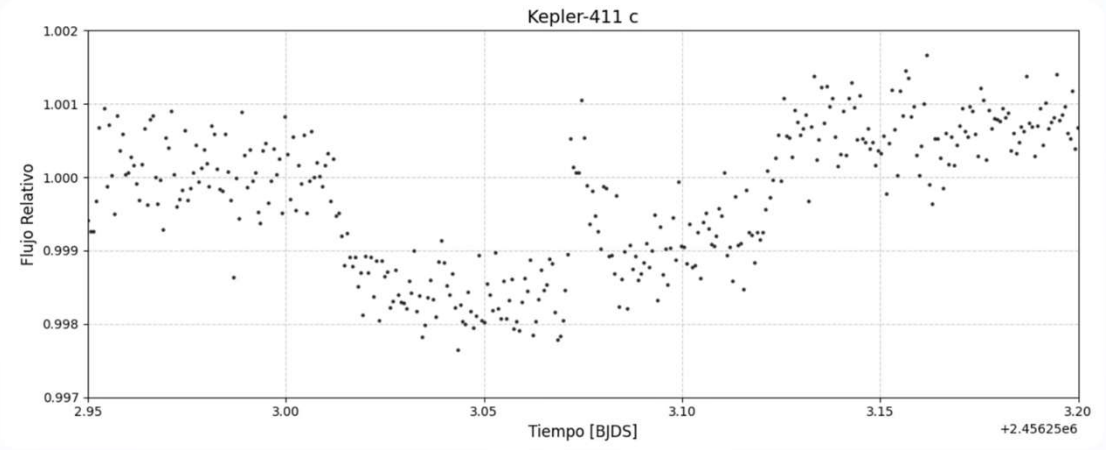
Transits

- **Starspot – crossing events (SSCEs):** star spot maps, magnetic activity, radial velocity surveys...
- **Flares:** star – planet magnetic interactions, atmospheric photoevaporation.
- **Transit duration variations (TDVs):** additional bodies (non transiting planets, moons), incorrect parameters.
- **Others:** rings, dust / debree, mutual phenomena, exomoons...

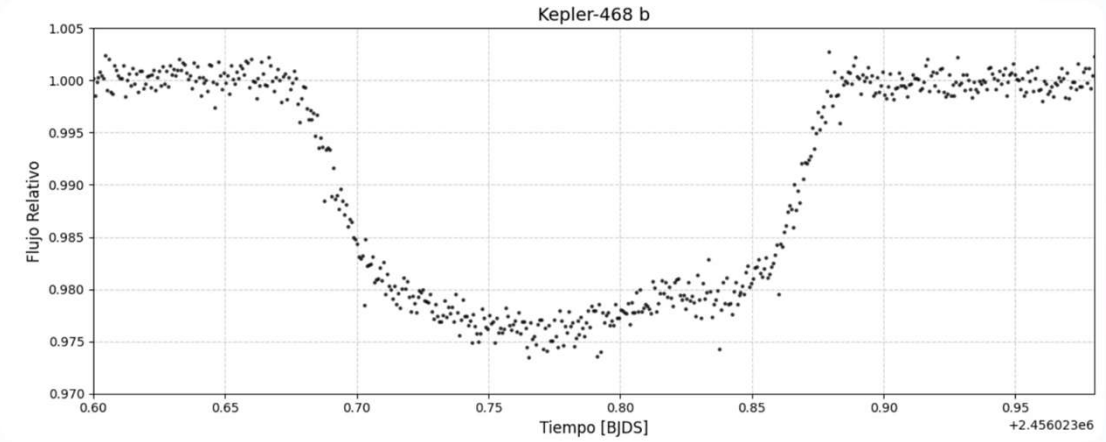


Transits

Sometimes obvious

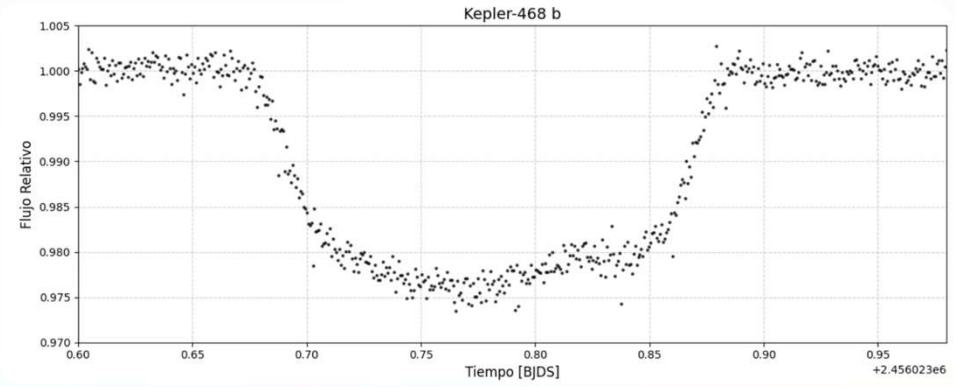


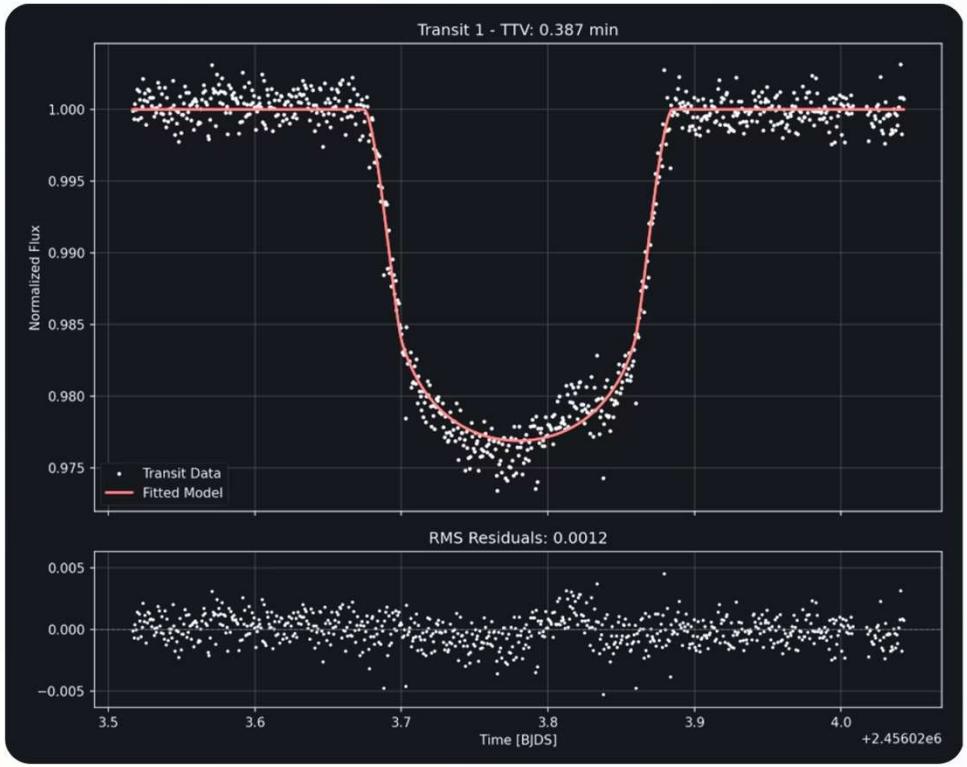
Sometimes no so much



Estrategy

To highlight these signals, each transit is displayed with its theoretical model overplotted, so that subtle features appear as deviations from the model.





Real sample

In this pilot phase we analyze a save sample of 51 exoplanets observed by *Képler*.

- Short cadence (1 min).
- mag < 14.
- δ > 1000 ppm.
- P_{orb} > 20 d.

Exoplanet	$R_p/R_\star$	$a/R_\star$	i (°)	P (d)	# Seg.	# Tr.
Kepler-11 e	0.0364	39.48	88.89	31.9996	6	40
Kepler-11 g	0.0290	94.40	89.87	118.3807	6	12
Kepler-79 d	0.0504	47.42	89.93	52.0902	6	25
Kepler-89 d	0.0680	23.80	89.97	22.3430	6	29
Kepler-89 e	0.0396	43.10	89.60	54.3203	4	10
Kepler-90 g	0.0615	127.30	89.89	210.6070	3	3
Kepler-90 h	0.0866	180.70	90.00	331.6006	1	1
Kepler-103 c	0.0335	98.00	89.70	179.6098	2	5
Kepler-108 b	0.0375	28.73	89.94	49.1839	3	8
Kepler-108 c	0.0330	70.81	89.40	190.3235	1	2
Kepler-111 c	0.0568	141.00	89.76	224.7783	2	4
Kepler-199 b	0.0295	37.08	89.97	23.6376	2	2
Kepler-199 c	0.0310	76.61	90.00	67.0934	1	1
Kepler-209 c	0.0371	21.43	87.50	41.7499	3	11
Kepler-289 c	0.1030	108.95	89.78	125.8723	5	5
Kepler-396 b	0.0302	72.95	90.00	42.9940	4	12
Kepler-396 c	0.0524	96.10	90.00	88.5050	4	5
Kepler-411 b	0.0266	9.86	87.40	3.0052	6	128
Kepler-411 c	0.0449	22.21	88.61	7.8344	5	49

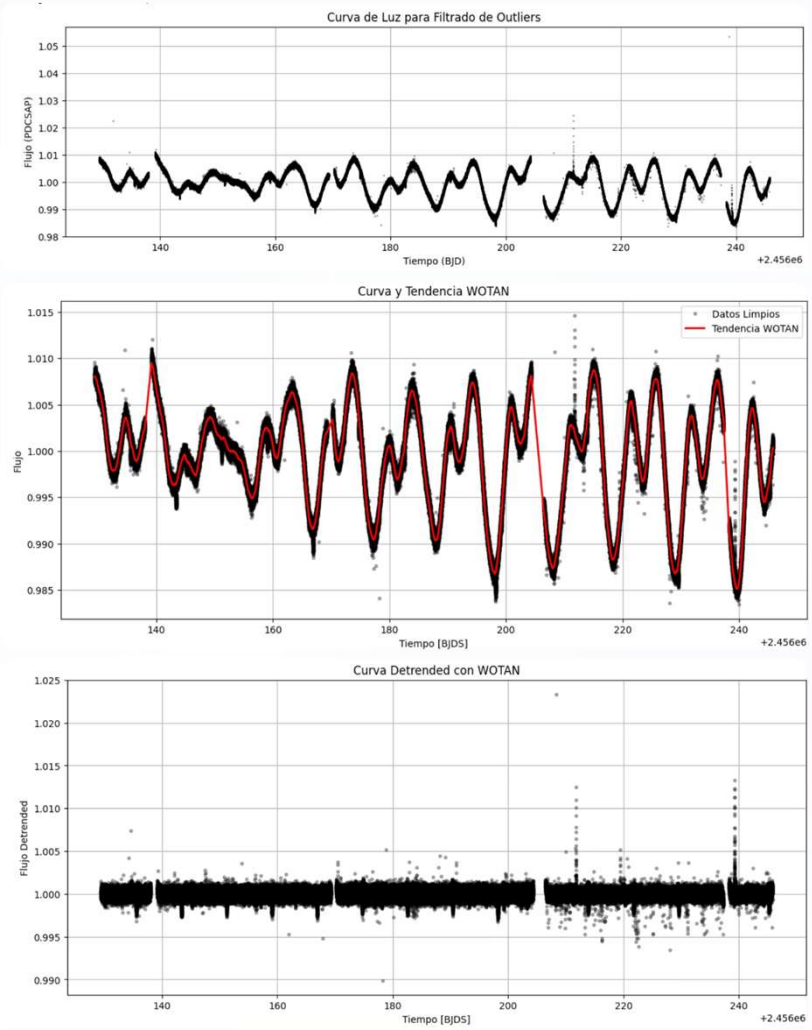
Real sample

Processing (Kepler 411)

Raw segment

Outliers and trends extraction (Wotan)

Processed segment

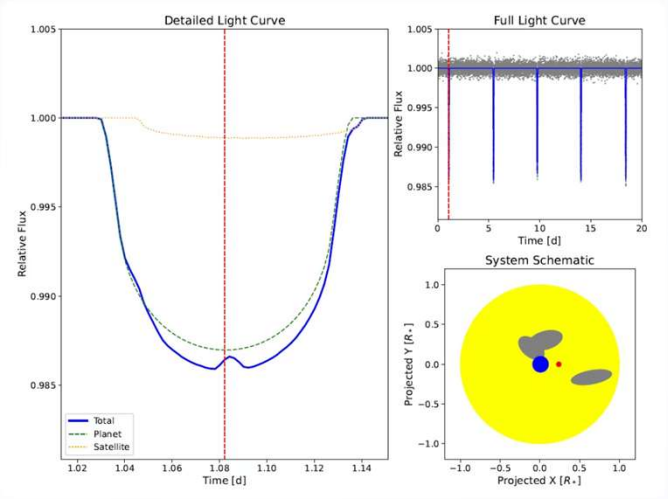


Simulated sample

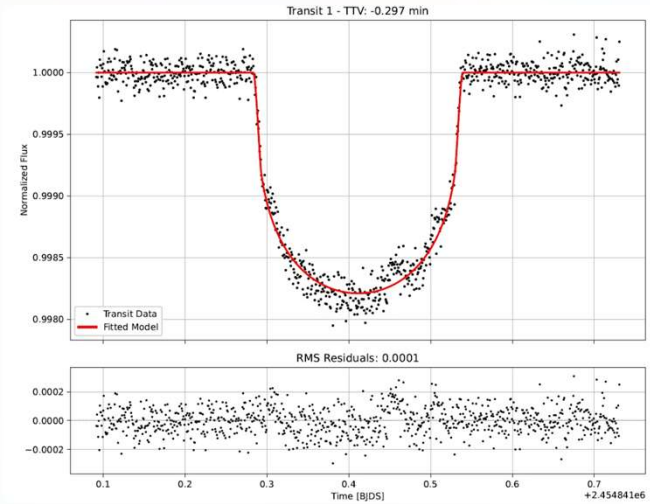
We developed a simulation code capable of injecting stellar spots, exomoons and TTVs.

Same parameters as the real sample (cadence, SNR, δ, *P*orb...).

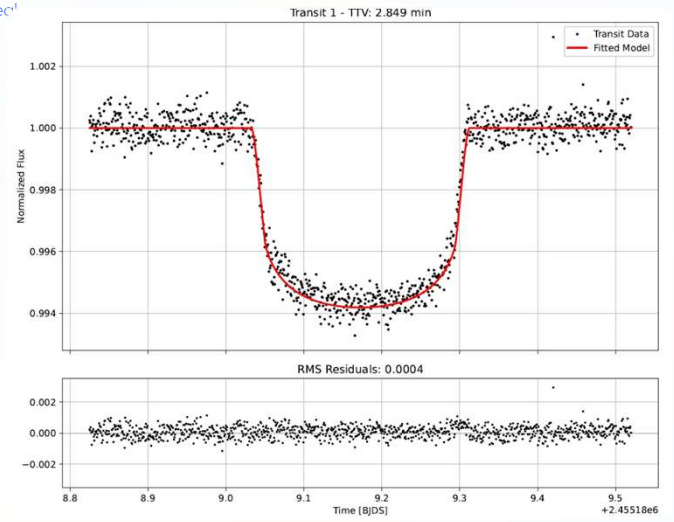
We generated 100 simulated curves analogous to the real sample



Sim



Rec



Final sample

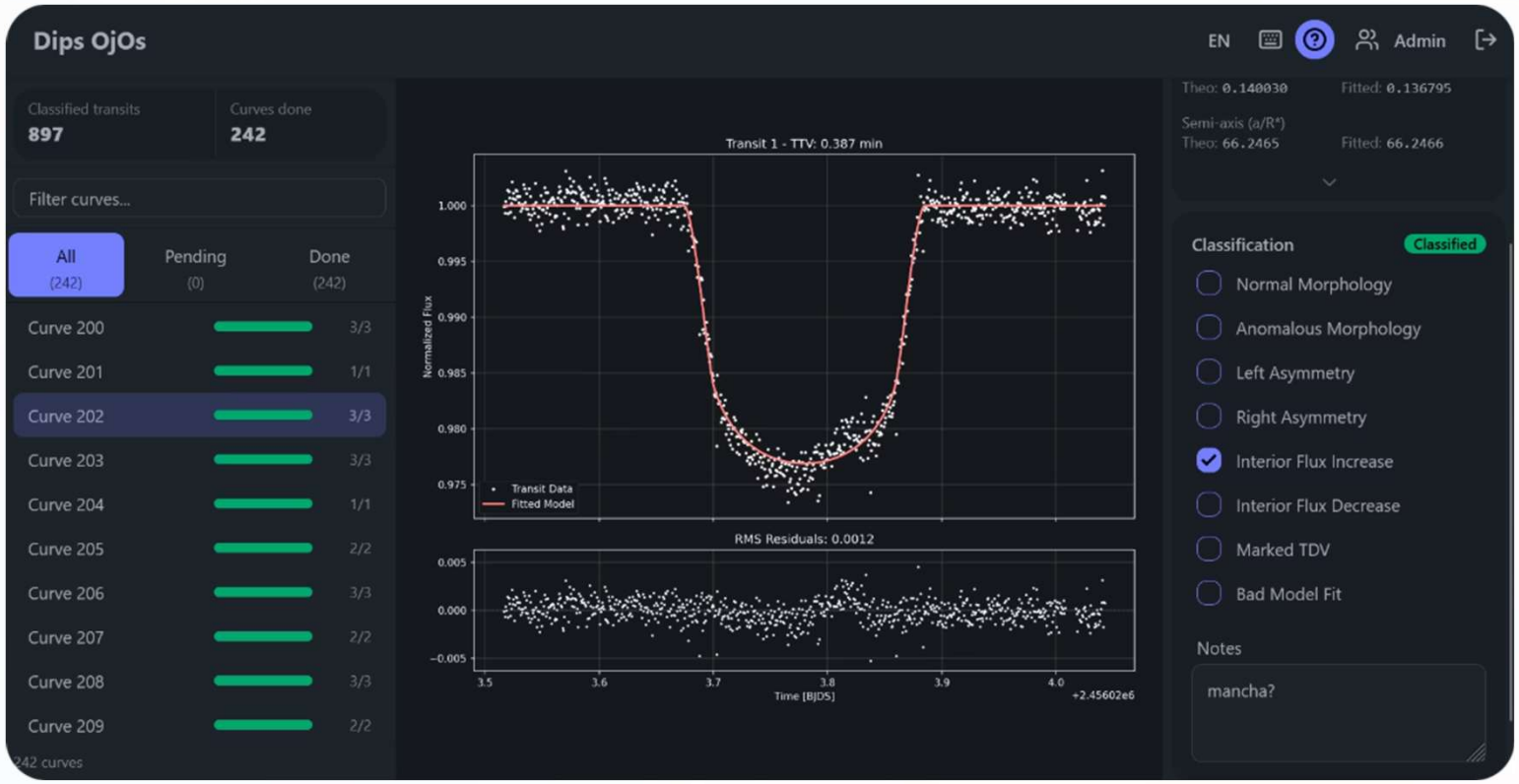
- Final real sample: 140 segments comprising 555 transits from 51 Kepler exoplanets.
- Final simulated sample: 100 curves comprising 362 transits.
- 40 null case curves.
- 10 null case curves (with injected TTVs ranging from 5 to 15 minutes).
- 40 curves with SSCEs.
- 10 curves with exomoons.
- Fall – Winter 2025/26, 12 trained collaborators blindly analyzed the final sample .

Analysis code

- Loads each processed segment.
- Computes the position of each transit from t_0 and P_{orb} (accounting for TTVs).
- Fixing the inclination (i), the code iterates over a and R_p, fits each transit with a Mandel & Agol model and identifies the $a - R_p$ pair that best fits the full set of transits.

Web analysis tool

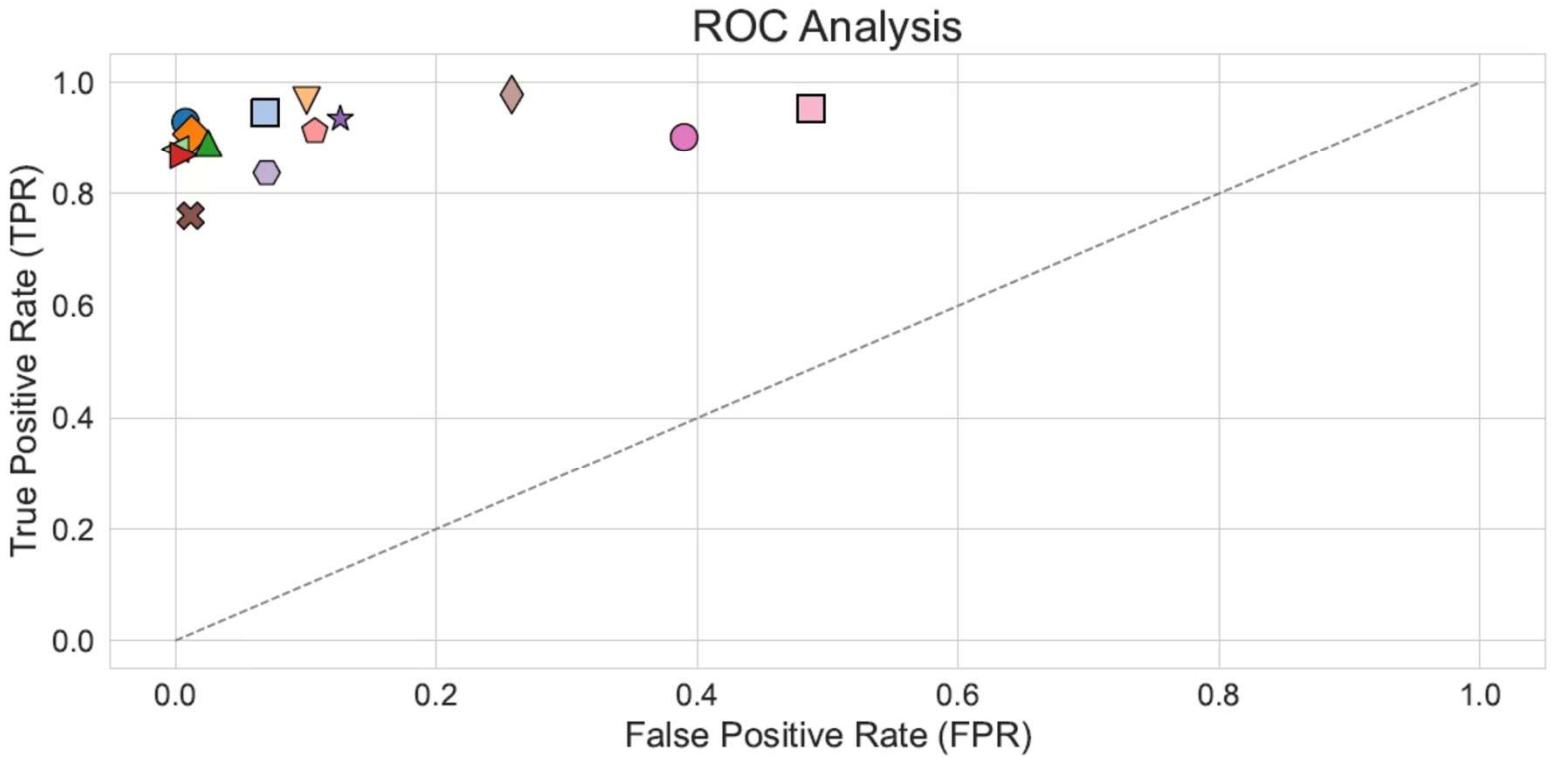
- Classifying Categories.
- SQLite database.
- https://dipsojos.uniovi.es (us:public, pw: public).



SCAN ME

Eficiency

- Simulated curves → True Positive Rate (<TPR> = 86%) and False Positive Rate (<FPR>=15%).
- We weight each observer's classifications according to their efficiency to reduce the number of real transits requiring expert vetting.



Results

Of the 555 real transits, 363 were flagged by the collaborators, and 88 remained after expert vetting.

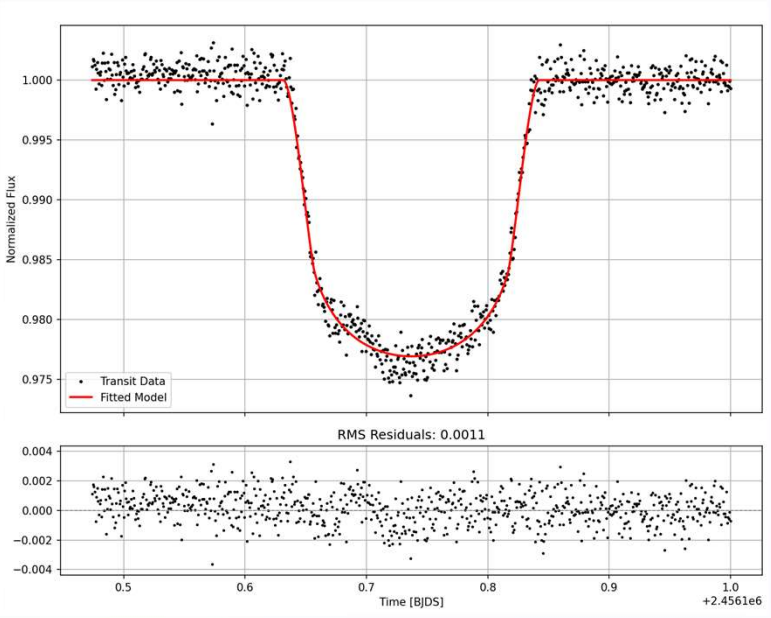
Exoplaneta	Curva	Tránsito ID	T0_esperado	Principal Caract	Fenómeno [veredicto]	Confianz	Acción	Notas
Kepler-289 c	3	0	2456202,52400	Inc_flux_int	Mancha	Alta	Publicar	Mancha, rotación clara de la est
Kepler-289 c	92	0		Inc_flux_int	Mancha	Alta	Publicar	Mancha
Kepler-1656 b	15	0	2455136,45400	Right_asimetry	Ruido	Alta	Publicar	Es ruido. En todo caso se ve que
Kepler-419 b	17	0	2456284,67600	Dec_flux_int	Mal ajuste	Alta	Publicar	TTV de -749 minutos. Lo detectó
Kepler-1656 b	19	0	2455578,32200	Dec_flux_int	Mal ajuste	Alta	Publicar	Es ruido. En todo caso se ve que
Kepler-1656 b	19	1	2455609,88400	Dec_flux_int	Mal ajuste	Alta	Publicar	Es ruido. En todo caso se ve que
Kepler-89 e	20	0	2455211,51900	Inc_flux_int	Transitos solapados	Alta	Publicar	Se aprecia fenómeno mutuo cor
Kepler-11 e	26	0		Bad_model_fit	Incompleto	Alta	Publicar	Faltan datos. También se apreci
Kepler-11 e	29	1		TDV	Ruido	Alta	Publicar	Interesante porque se aprecian
Kepler-11 e	29	4		Dec_flux_int	Ruido	Alta	Publicar	Interesante porque se aprecian
Kepler-11 e	29	5		Anomalous_morphology	Incompleto	Alta	Publicar	Interesante porque se aprecian
Kepler-11 e	29	8		Anomalous_morphology	Incompleto	Alta	Publicar	Interesante porque se aprecian
Kepler-11 e	29	10		Dec_flux_int	Ruido	Alta	Publicar	Interesante porque se aprecian
Kepler-11 e	29	11		Dec_flux_int	Mal ajuste	Alta	Publicar	erró el código al ajustar porque
Kepler-11 e	29	12		Anomalous_morphology	Ruido	Alta	Publicar	Interesante porque se aprecian
Kepler-11 e	29	13		TDV	Ruido	Alta	Publicar	Interesante porque se aprecian
Kepler-89 d	31	1	2455591,34400	Anomalous_morphology	Transitos solapados	Alta	Publicar	A la sealida se ve que empieza a
Kepler-450 b	38	4	2455493,43900	Anomalous_morphology	Mal ajuste	Alta	Publicar	No está el tránsito
Kepler-450 b	39	0		TDV	Incompleto	Alta	Publicar	Faltan algunos puntos dentro de
Kepler-289 c	229	0		Inc_flux_int	Mancha	Alta	Publicar	SSCE
Kepler-396 b	69	0		Inc_flux_int	Mancha	Alta	Publicar	Este tránsito no lo marcó nadie

Results (SSCEs)

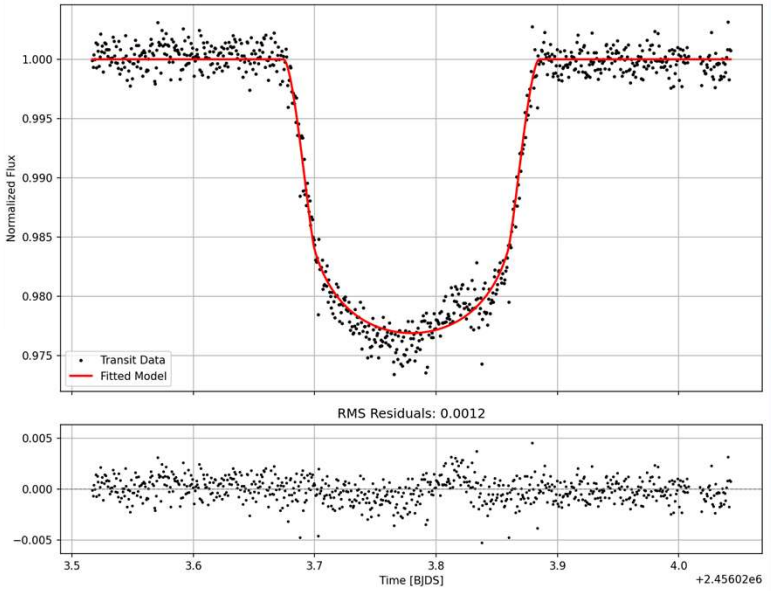
26 event (8 exoplanet), 23 *new.*

Table 2: List of SSCE-like signals detected, along with their estimated center times (t_c), p-values, and corresponding curve and transit IDs for the processed curves. The (†) symbol labels events not found in previous studies.

Exoplanet	t_c (BKJD)	p-value	Curve ID	Transit ID
Kepler-89 d (†)	1518.032	0.011	171	1
Kepler-289 c (†)	865.920	0.017	229	0
Kepler-289 c (†)	1369.499	0.043	3	0
Kepler-289 c (†)	1495.264	0.036	92	0
Kepler-396 b (†)	1323.334	0.145	69	0
Kepler-396 c (†)	1156.298	< 0.001	231	0
Kepler-396 c (†)	1333.349	0.033	93	0
Kepler-396 c (†)	1421.786	0.037	14	0
Kepler-396 c (†)	1510.286	< 0.001	232	0
Kepler-411 c (†)	1044.013	< 0.001	112	5
Kepler-411 c (#1)	1051.825	< 0.001	197	6
Kepler-411 c (#2)	1051.857	0.006	197	6
Kepler-411 c	1083.167	0.013	197	10
Kepler-419 b (†)	893.353	0.239	221	1
Kepler-468 b (†)	305.757	0.033	124	1
Kepler-468 b (#1, †)	459.662	0.270	124	5
Kepler-468 b (#2, †)	459.706	0.049	124	5
Kepler-468 b (†)	498.142	0.022	124	6
Kepler-468 b (†)	1190.816	0.032	202	0
Kepler-468 b (†)	1229.303	0.040	202	1
Kepler-468 b (†)	1267.694	0.048	202	2
Kepler-539 b (†)	1383.969	0.159	201	0
Kepler-539 b (†)	1509.552	0.031	59	0
KOI00130.01 (†)	394.671	0.145	147	3
KOI00130.01 (†)	497.227	0.068	147	6
KOI00130.01 (†)	531.418	0.161	147	7



Kepler-468 b



Results

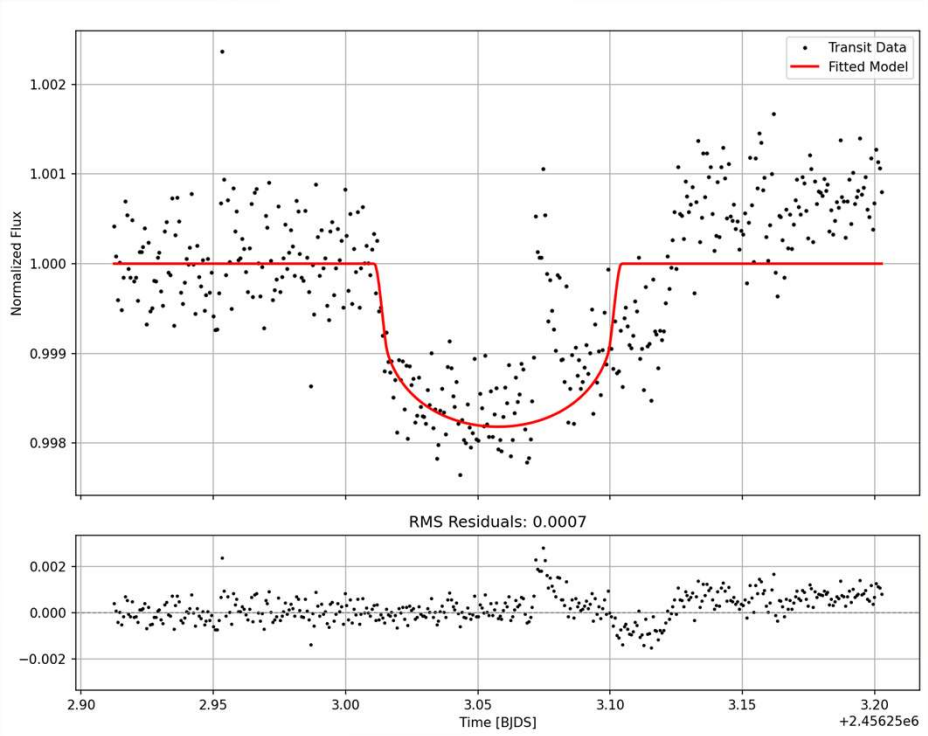
(Flares)

7 events (3 exoplanets), 4 *new.*

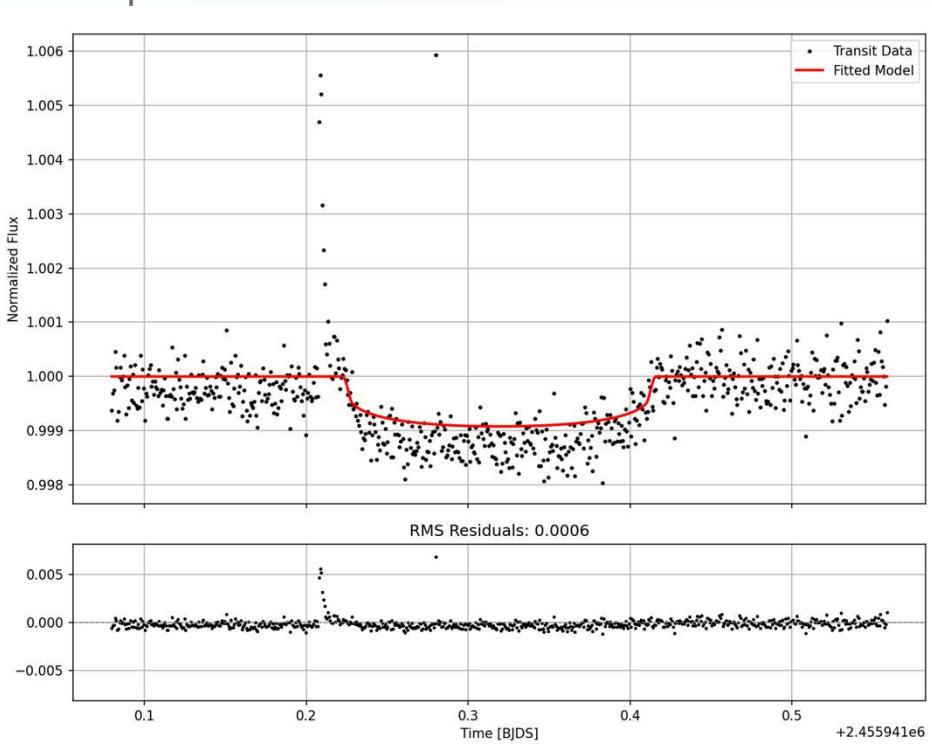
Table 3: List of transits with stellar flares occurring shortly before, during, or immediately after detected in this work.

Exoplanet	t_c (BKJD)	Curve ID	Transit ID
Kepler-396 b	1108.319	91	0
Kepler-411 b	1077.718	142	25
Kepler-411 b	1351.207	169	18
Kepler-411 b	1468.390	157	16
Kepler-411 b	1564.552	148	1
Kepler-411 b	1579.579	148	6
Kepler-411 c	1420.058	198	0

Kepler-396 b



Kepler-411 b

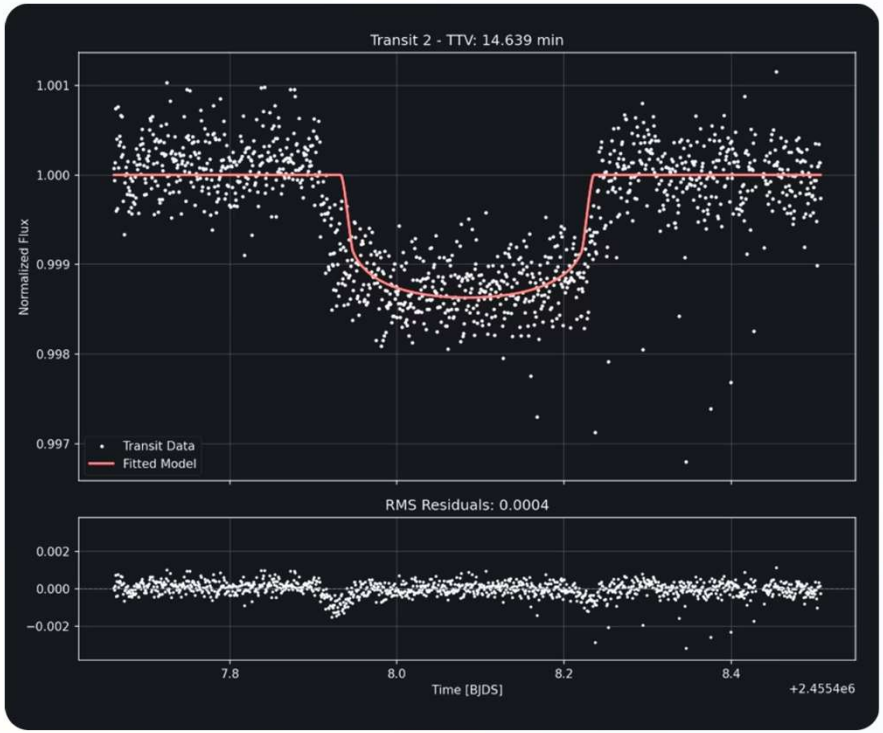


Results (TDVs)

Table 4: Best-fit parameters for systems exhibiting systematic TDVs. The rows corresponding to the planet names show the nominal parameters from the NEA. The label i_c denotes fits with the inclination fixed to the NEA value, whereas i_f indicates fits with the inclination left as a free parameter.

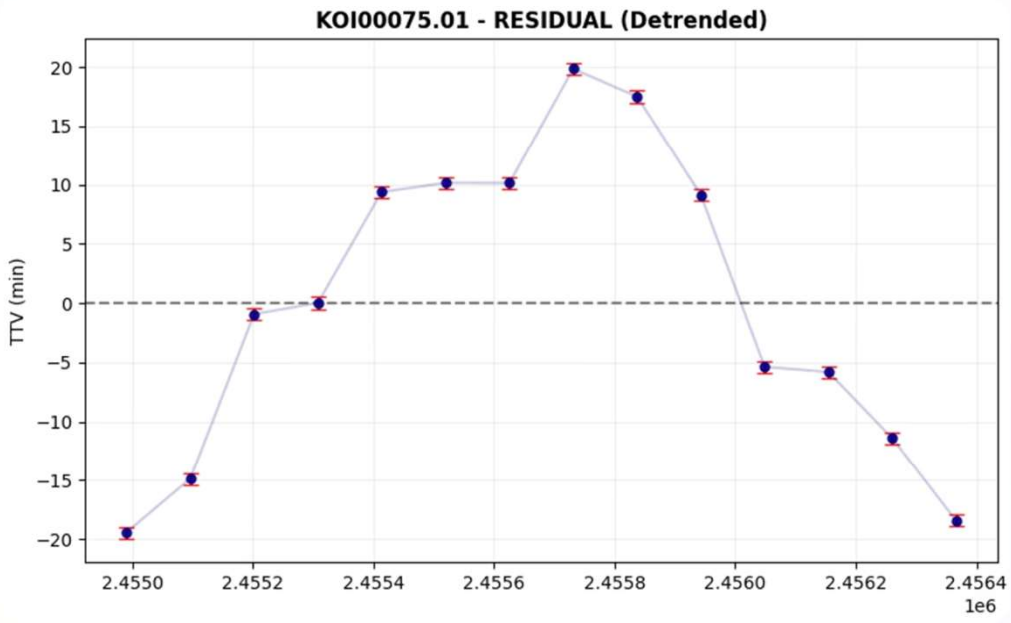
Planet / Curve #	Fit	i (°)	$a/R_\star$	$R_p/R_\star$	TDV (min)	χ^2
Kepler-108b	-	89.94	28.73	0.0375	–	–
# 81	i_c	89.94	28.73	0.0333	101.2	0.000 59
	i_f	89.56	32.40	0.0354	−3.8	0.000 50
# 139	i_c	89.94	28.73	0.0331	100.2	0.003 22
	i_f	88.94	28.73	0.0362	2.1	0.002 78
# 178	i_c	89.94	28.73	0.0328	101.1	0.001 09
	i_f	89.19	30.87	0.0358	−13.5	0.000 88
Kepler-450b	-	88.82	26.38	0.0346	–	–
# 38	i_c	88.82	26.38	0.0350	−60.6	0.001 31
	i_f	89.32	26.38	0.0335	−8.6	0.001 11
# 123	i_c	88.82	26.38	0.0374	−58.6	0.000 48
	i_f	89.32	26.38	0.0359	−7.6	0.000 38
# 135	i_c	88.82	26.38	0.0354	−61.6	0.000 32
	i_f	89.32	26.38	0.0343	−8.6	0.000 27
# 138	i_c	88.82	26.38	0.0354	−60.6	0.000 62
	i_f	89.25	26.38	0.0341	−13.5	0.000 52
Kepler-458c	-	88.27	10.28	0.0299	–	–
# 42	i_c	88.27	10.31	0.0254	261.5	0.023 85
	i_f	85.58	10.28	0.0254	−44.4	0.020 98
# 222	i_c	88.27	10.32	0.0254	261.5	0.005 78
	i_f	85.52	10.28	0.0254	−57.2	0.005 07
Kepler-533b	-	88.68	40.00	0.0431	–	–
# 11	i_c	88.68	40.00	0.0432	−126.6	0.001 46
	i_f	88.68	34.00	0.0434	−19.7	0.001 21
# 37	i_c	88.68	40.00	0.0432	−127.4	0.004 60
	i_f	88.68	34.00	0.0446	−18.7	0.003 70

Systematic TDVs suggest refined orbital parameters for 4 exoplanets.

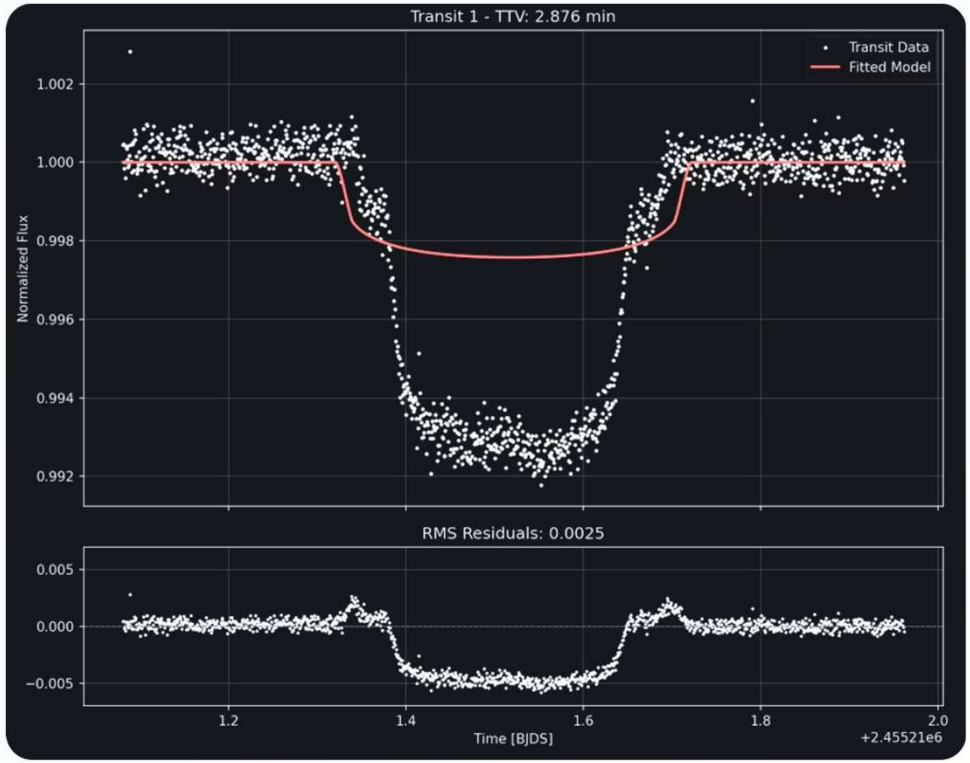


Results (TTVs)

KEPOI	*Kepler* ID	$TTV_{Holczer}$ (min)	$TTV_{thiswork}$ (min)
K01478.01	Kepler-858 b	12.0	5.0
K01474.01	Kepler-419 b	39.0	67.0
K00353.01	–	3.0	–
K01781.03	Kepler-411 d	40.0	42.0
K02672.01	Kepler-396 c	59.0	14.0
K02672.02	Kepler-396 b	32.0	6.0
K00345.01	Kepler-531 b	12.0	5.0
K01783.01	Kepler-1662 b	6.0	–
K00119.02	Kepler-108 c	11.0	–
K00319.01	–	13.0	16.0
K01271.01	–	85.0	–
K00139.01	Kepler-111 c	211.0	28.0
K00152.01	Kepler-79 d	9.0	17.0
K00318.01	Kepler-522 b	12.0	38.0
K01353.01	Kepler-289 c	9.0	66.0
K00075.01	–	20.0	20.0
K00672.02	Kepler-209 c	9.0	21.0
K01242.01	–	3.0	–
K00157.03	Kepler-11 e	6.0	100.0
K00372.01	Kepler-539 b	14.0	3.0
K00094.03	Kepler-89 e	9.0	10.0
K00638.01	Kepler-199 b	100.0	–
K00108.02	Kepler-103 c	15.0	10.0
K01335.01	Kepler-820 b	6.0	–



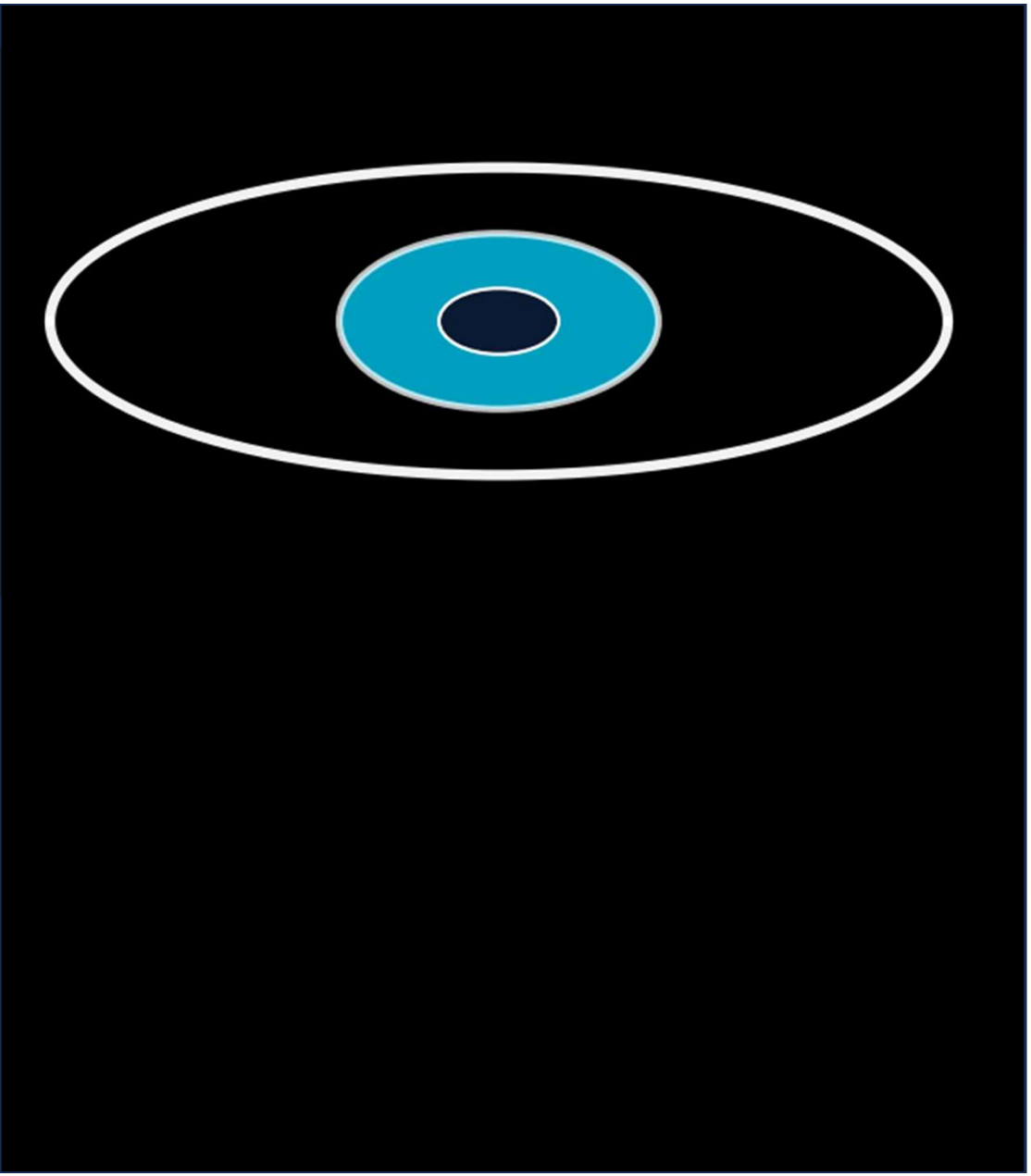
Results (mutual phenomena)



We recovered the event reported by Hirano et al. (2012) in Kepler-89 (planets e and d).

Future

- Scale the project to analyze the full sample from Kepler, TESS (PLATO...) .
- Needed more collaborators to inspect the larger number of curves.
- Bottleneck: real light curve reduction.



Thank you for your attention

Universidad de Oviedo

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