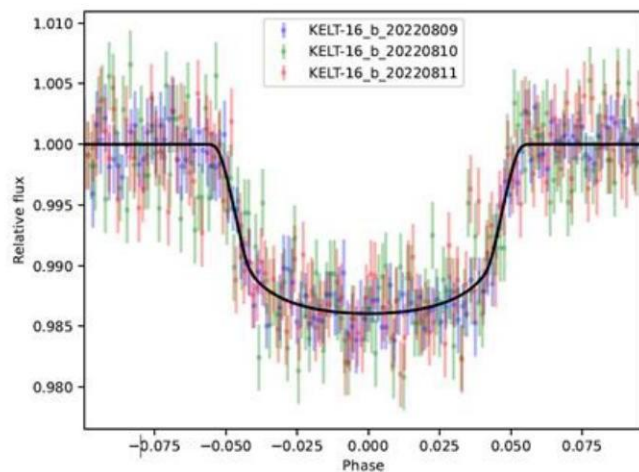


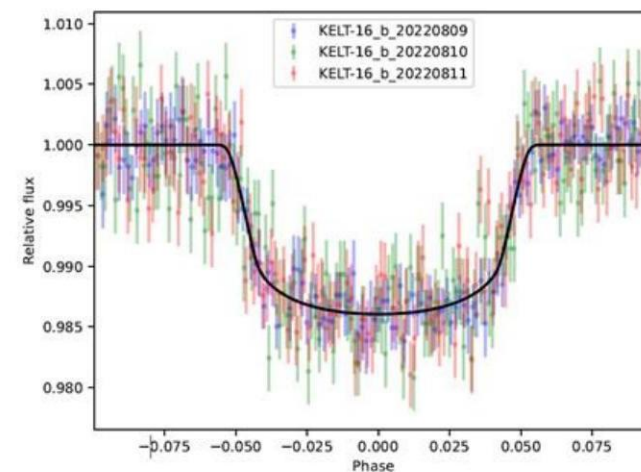
# Exoplanets

## Challenging Objects for Citizen Science

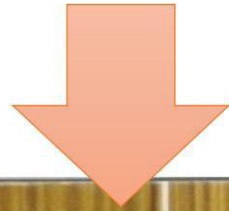


Pieter Vuylsteke  
(special thanks to Siegfried Vanaverbeke)

October 2022 – VVS weekend



# Who am I ?



- Variable stars in the 80's
- Started astronomy again at the end of 2020
- Astrophotography,  
and again : **variables**
- Author of **AstroPie** and **ExoPie** :  
astrophotometry with a bag of tricks.
- Don't like presentations, **but**  
**can't keep my mouth shut.**

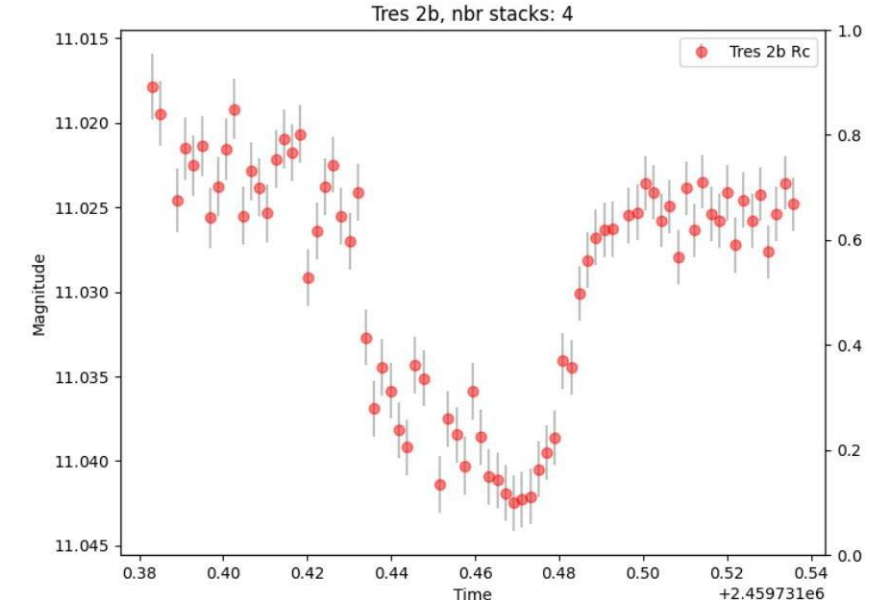


# Observe an exoplanet yourself ???

- Planet in front of the star -> star less bright.
- Effect : 0.040 to < 0.001 magnitude.
- In this example : 15 millimagnitude
- Duration of coverage : **a few hours**



Figure: NASA



# Why observe?

- Main reason : **THEREFORE.**
- Because it's not easy : challenge !
- Parameters to be deduced from the shape of the lightcurve : the radius of the planet, duration of a planetary year, duration of the eclipse
- ...

# Let's get to work ! But, um, when?

## Exoclock.space :

### Open Science :

- monitoring the ephemerides
- fostering the democratisation of science.

ExoClock Database Articles My Profile My Schedule My Lab Welcome Pieter! Logout

TheGardenToTheSkyFacility - TS ONTC 25cm f4.7 - QHY 268M  
Latitude: 50.0°, Longitude: 4.0°, Telescope size: 10.0°

Planet & ExoClock status	Star RA/DEC J2000	Mag mag	Transit Depth mmag	Duration hours	Observing times [ UTC+0.0 ] and target position				
					1h Before Ingress	Transit Start	Mid Transit	Transit End	1h After Egress
<b>Qatar-3b</b> Observ. Priority: LOW Total obs. (Recent): 5 (3) O-C minutes: 5.2±0.7	23:56:36.4831 +36:12:46.773	12.89	10.12	3.1	2022-09-02 18:49 Alt: 26° Azi: 64° (NE)	2022-09-02 19:49 Alt: 35° Azi: 74° (E)	2022-09-02 21:22 Alt: 50° Azi: 90° (E)	2022-09-02 22:55 Alt: 65° Azi: 112° (E)	2022-09-02 23:55 Alt: 73° Azi: 138° (SE)
Max counts increase during observation: R:12% V:25% Moon illumination: 40.9%, Moon distance: 128.3°									
<b>Qatar-7b</b> Observ. Priority: LOW Total obs. (Recent): 8 (8) O-C minutes: -24.3±0.5	23:54:03.6389 +37:01:18.584	13.02	15.92	3.58	2022-09-02 18:33 Alt: 28° Azi: 65° (NE)	2022-09-02 19:53 Alt: 37° Azi: 74° (E)	2022-09-02 21:41 Alt: 54° Azi: 93° (E)	2022-09-02 23:28 Alt: 70° Azi: 124° (SE)	2022-09-03 00:28 Alt: 76° Azi: 162° (S)
DRIFTING EPHEMERIS NOTE: a drift of -24.3 minutes has been applied to this prediction. Max counts increase during observation: R:11% V:22% Moon illumination: 41.0%, Moon distance: 127.6°									
<b>WASP-40b</b> Observ. Priority: LOW Total obs. (Recent): 7 (5) O-C minutes: 0.7±0.4	19:24:38.9615 +55:28:23.331	11.61	10.69	3.11	2022-09-02 20:24 Alt: 84° Azi: 354° (N)	2022-09-02 21:24 Alt: 79° Azi: 306° (NW)	2022-09-02 22:57 Alt: 66° Azi: 296° (NW)	2022-09-03 00:31 Alt: 53° Azi: 303° (NW)	2022-09-03 01:31 Alt: 45° Azi: 308° (NW)
Max counts increase during observation: R:0% V:0% Moon illumination: 41.6%, Moon distance: 89.3°									
<b>HAT-P-52b</b> Observ. Priority: LOW Total obs. (Recent): 9 (6) O-C minutes: -0.4±0.4	02:50:53.2003 +29:01:20.522	13.52	17.25	2.41	2022-09-02 22:48 Alt: 31° Azi: 81° (E)	2022-09-02 23:48 Alt: 41° Azi: 92° (E)	2022-09-03 01:00 Alt: 53° Azi: 108° (E)	2022-09-03 02:13 Alt: 63° Azi: 131° (SE)	2022-09-03 03:13 Alt: 68° Azi: 160° (S)
Max counts increase during observation: R:8% V:17% Moon illumination: 42.6%, Moon distance: 163.9°									
<b>HAT-P-32b</b> Observ. Priority: LOW Total obs. (Recent): 50 (14)	02:04:10.2775 +46:41:16.210	11.23	29.39	3.13	2022-09-02 22:59 Alt: 51° Azi: 71° (E)	2022-09-02 23:59 Alt: 60° Azi: 79° (E)	2022-09-03 01:33 Alt: 75° Azi: 95° (E)	2022-09-03 03:07 Alt: 86° Azi: 203° (SW)	2022-09-03 04:07 Alt: 78° Azi: 260° (W)

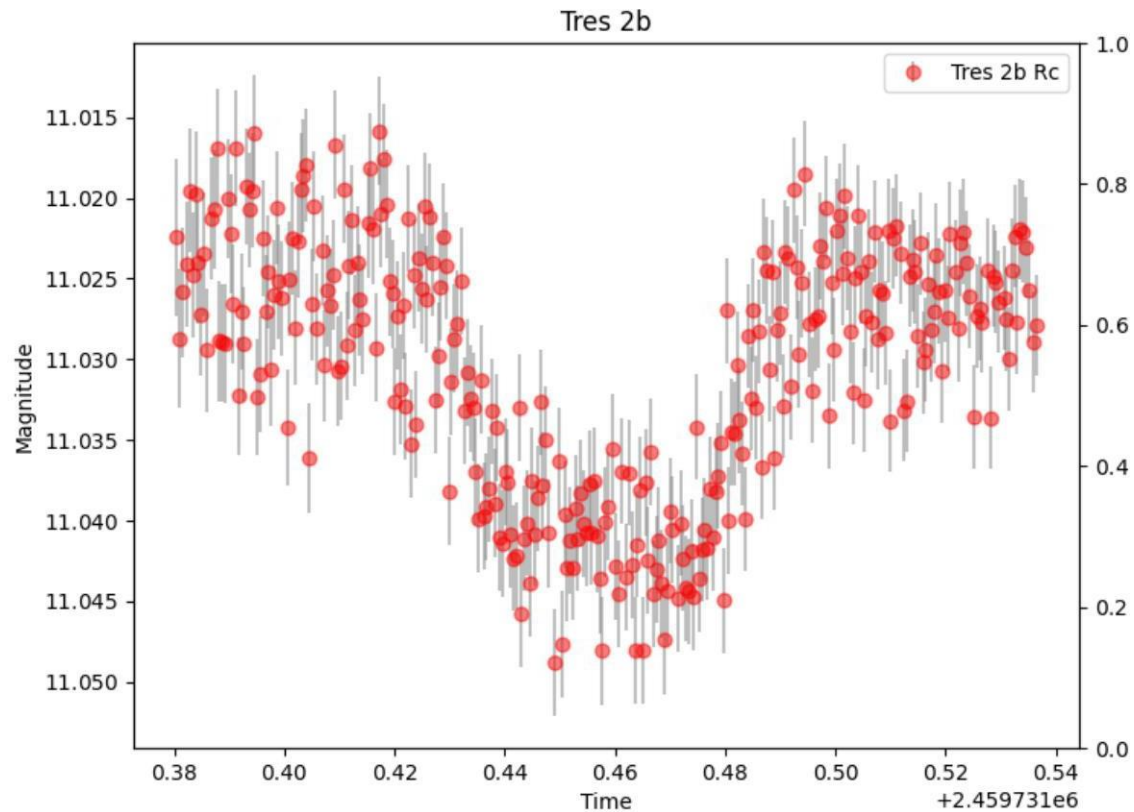
image008.png KELT-1b\_Vuylsteke\_...bt Alles bekijken

Typ hier om te zoeken





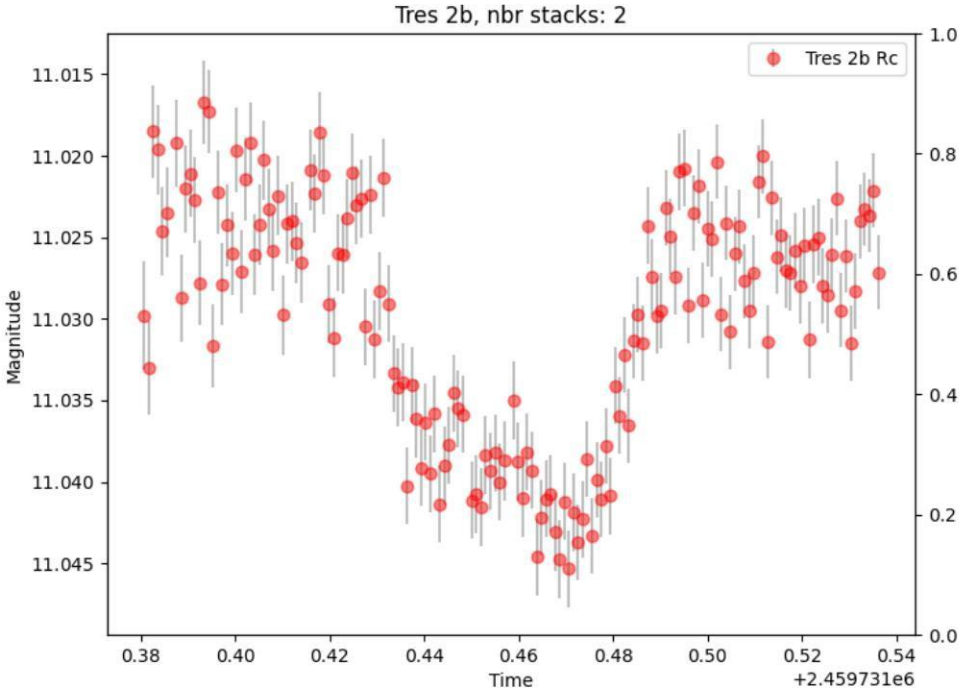
# Tres-2b, 31 May 2022



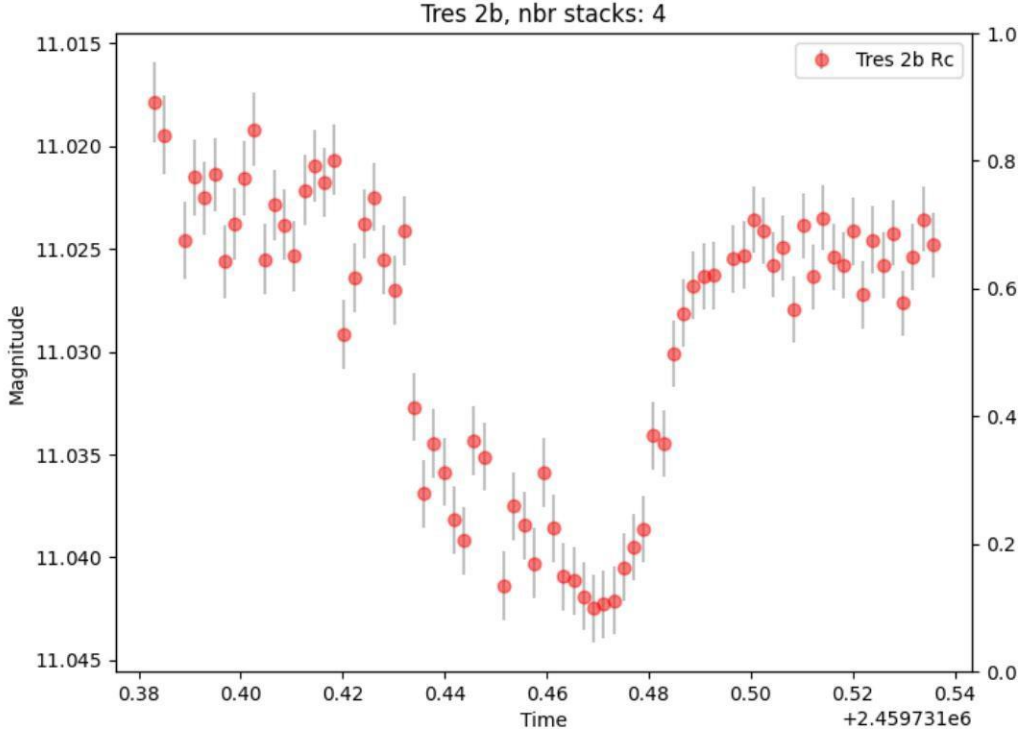
- Observation : 23h07 -> 2h52
- Red filter used
- 320 exposures of 40 seconds
- Keep the recording time of the exposures constant.
- Here 40 s,  
(today I chose 120 s)

# Stacking.

Number of stacked photos : 2

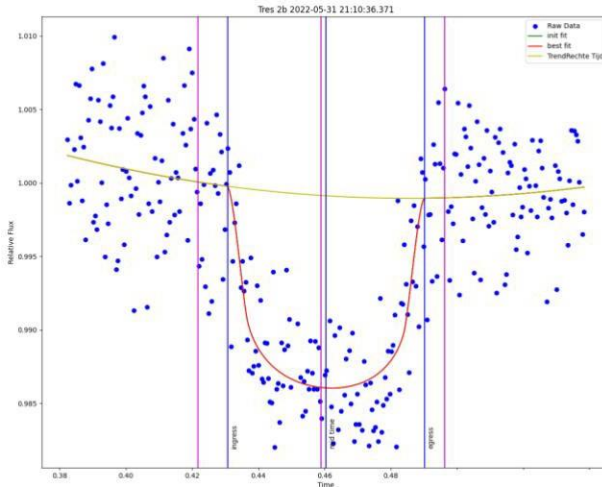


Number of stacked photos = 4





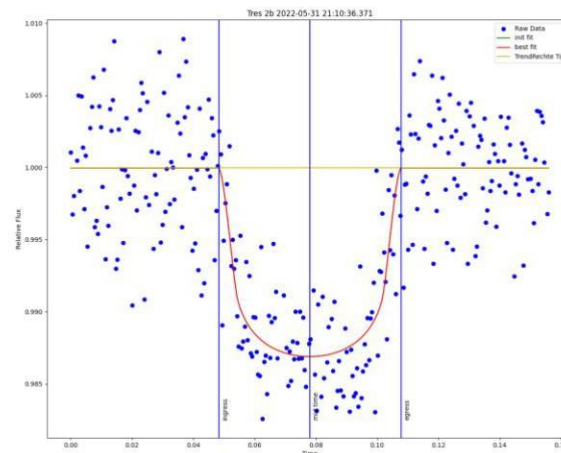
# What do we learn today ?



Raw data

Detrended data :

influence of atmosphere removed



Parameters are calculated by optimizing the variables in the theoretical formulas so that everything fits best.

## Step 1 : the atmosphere (detrending)

Airmass, ...

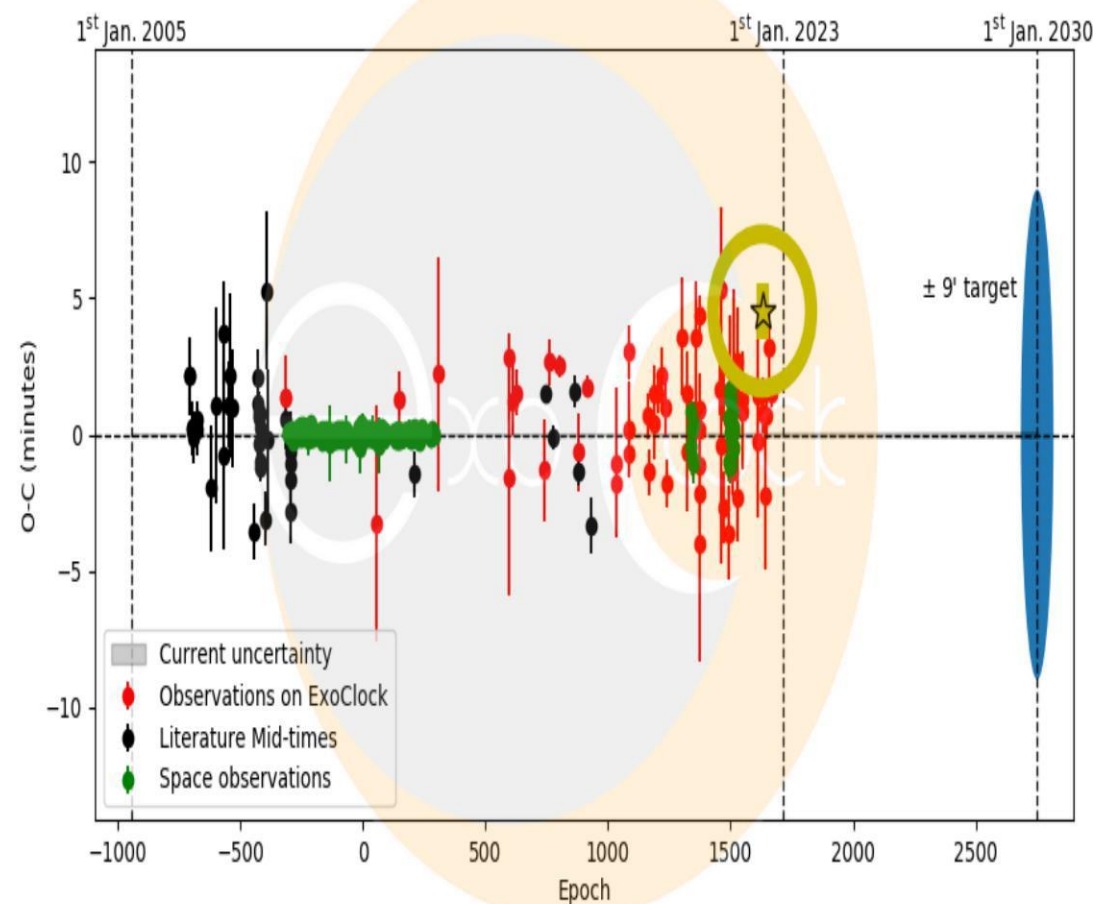
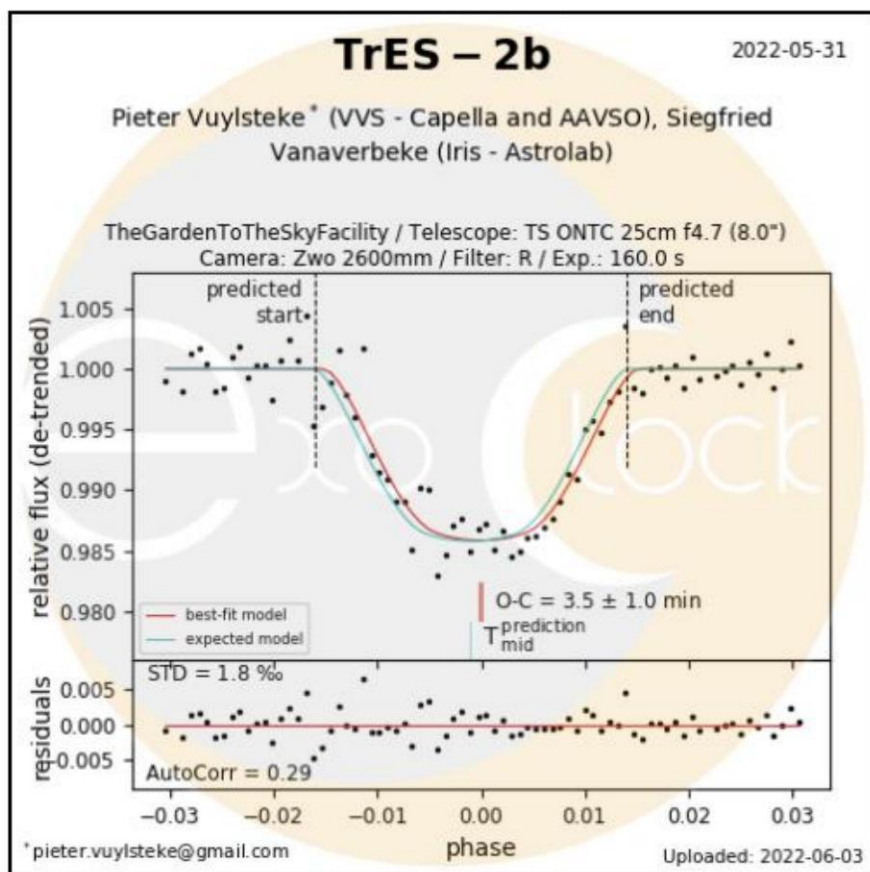
## Step 2 : The planetary system

Eclipse duration, planet size, orbital inclination, dark edges of the star(limb darkening), ...

## Result for Tres 2b, 31 May 2022 :

- Planet radius :  $0.107 (0.1254) \times \text{stellar radius}$
- Eclipse duration : 1h52m ( 1h47m)

# Then upload the data in Exoclock



# Fine Tuning Needed!

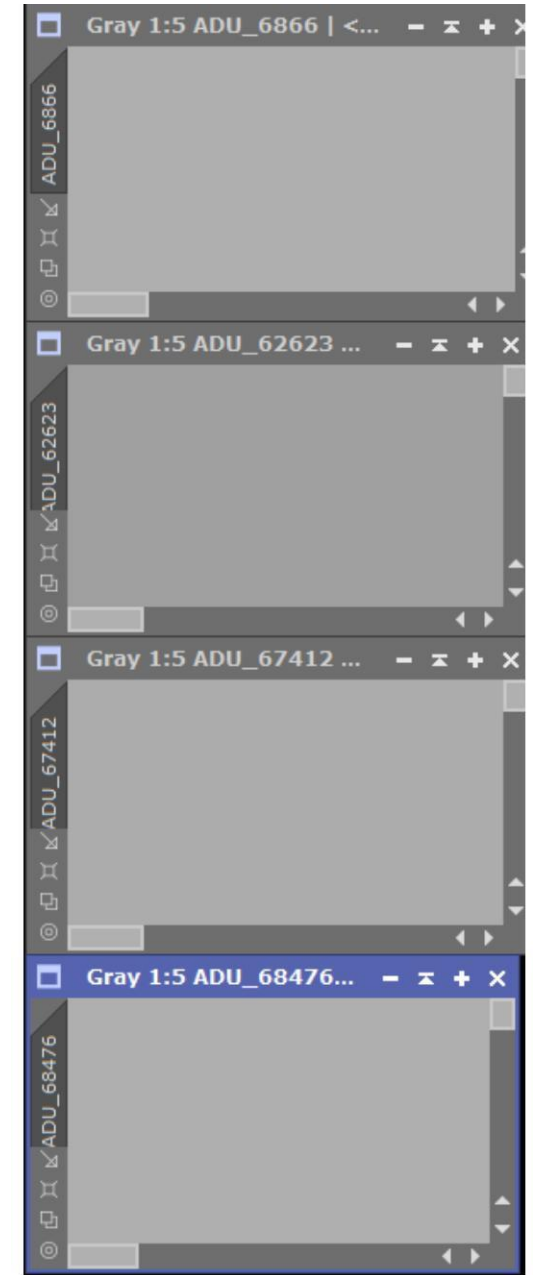
- **Visual** estimate of the brightness of a star :  
accuracy of about **0.100 magnitude**.
- Photometry of a star, with amateur equipment: accuracy of  
about **0.020 magnitude**
- Photometry of a star, with amateur  
equipment, and bag of  
tricks : accuracy to **a few millimagnitudes**
- $m_1 - m_2 = -2,5 \log_{10} (\text{Flux}_1 / \text{Flux}_2)$

Basis

0.1 quantity

0.020 quantity

0.003 quantity



# Problem 1: the garden.

- My observatory, **TheGardenToTheSkyFacility**, is (unsurprisingly) in my garden
- Altitude above sea level : 70 meters
- Wind: yes.  
When the wind blows.
- Dark : at night, sometimes.  
can't really complain, 20.4 SQM

## Solutions :

- A Johnson-Cousins RED filter,
- Staying high above the horizon (airmass < 2.0)

# Problem 2: the telescope

My scope is a 25 cm f4.7 Newton, with a 2.5" Coma Corrector.

No matter how well you adjust it, a photo will always contain traces of:

- Remaining Coma
- Tilt
- Collimation errors
- Tracking errors
- Vignetting
- Changing focus

## **Solutions :**

- Larger mirror -> more stable curve
- "Aperture photometry", and no "PSF photometry".
- 2.5" focuser and APS-C sensor for the camera (more comparison stars)
- AstroPie's box of tricks

# Problem 3: The camera

Photometry can only be as accurate as the quality of the camera's recordings.

## **Systematic errors Include :**

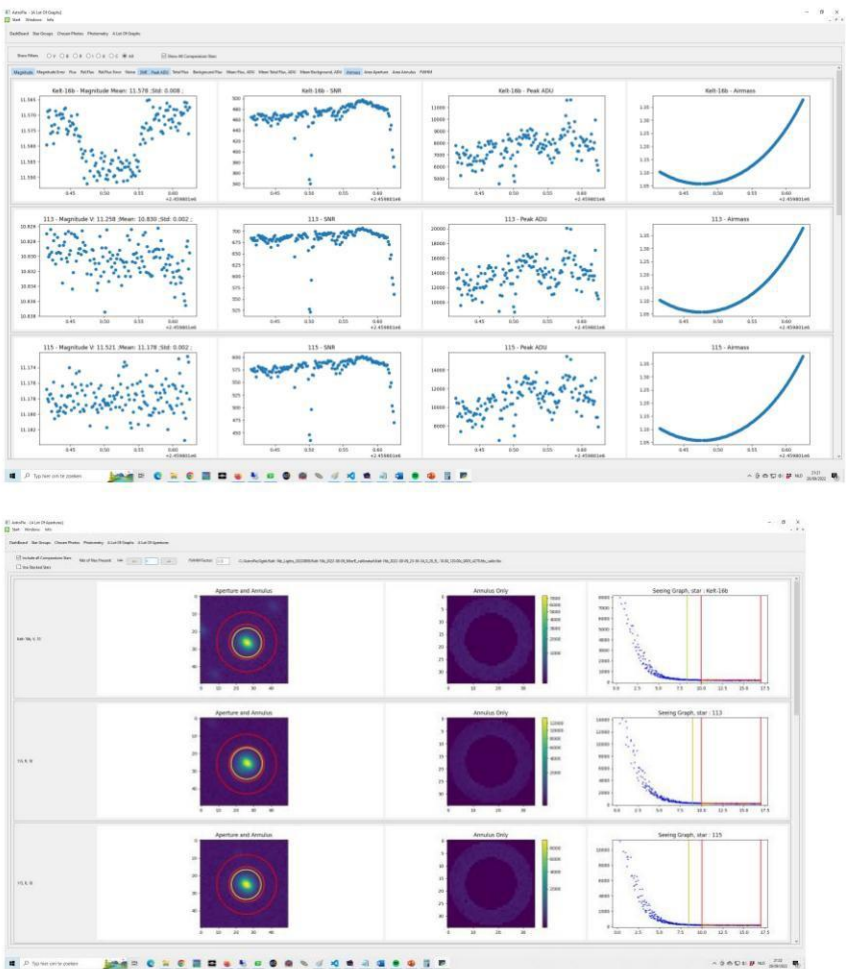
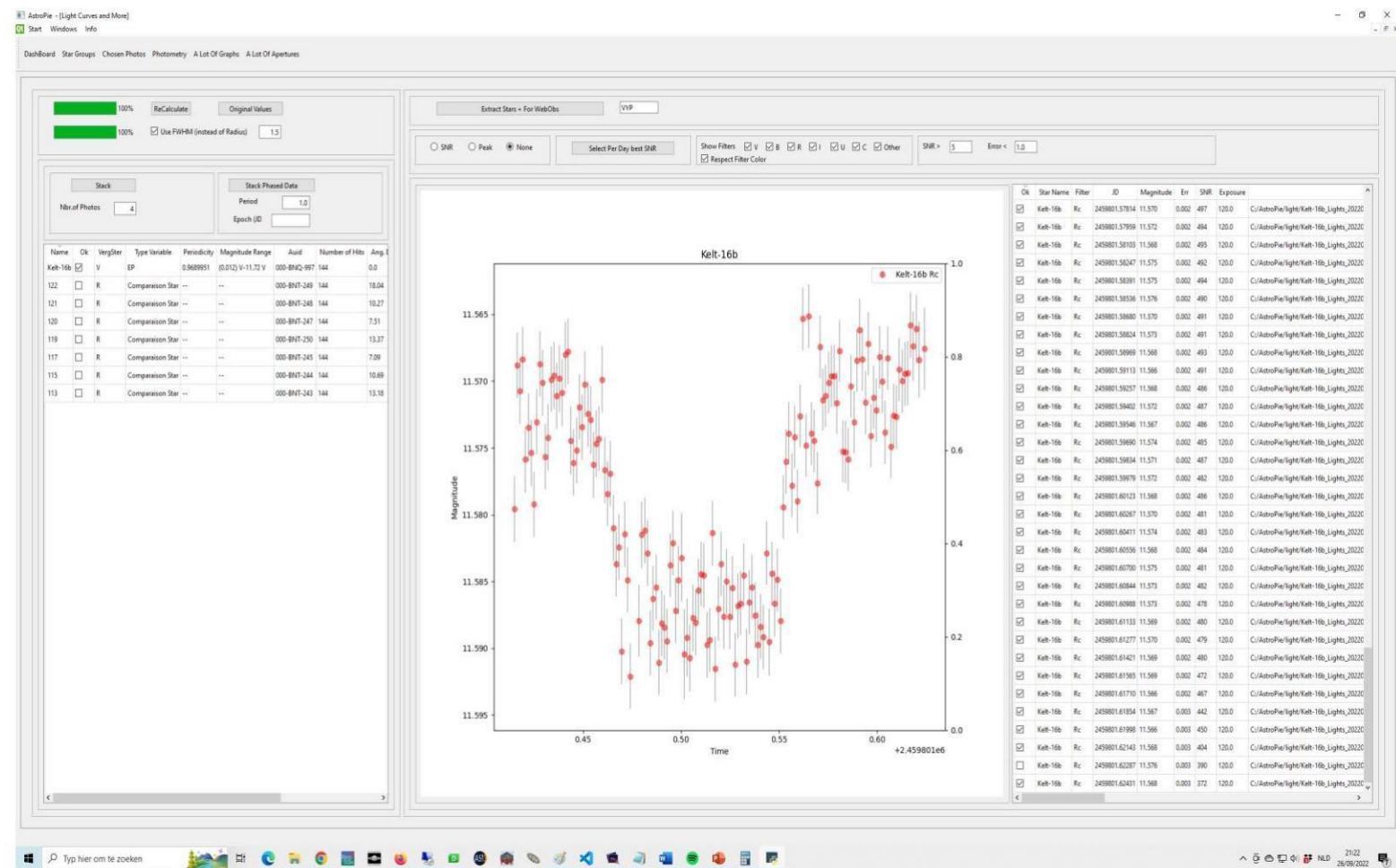
noise, warm pixels, cold pixels, hot pixels, bad lines, vignetting, satellite trails, airplanes, ...

## **Solutions :**

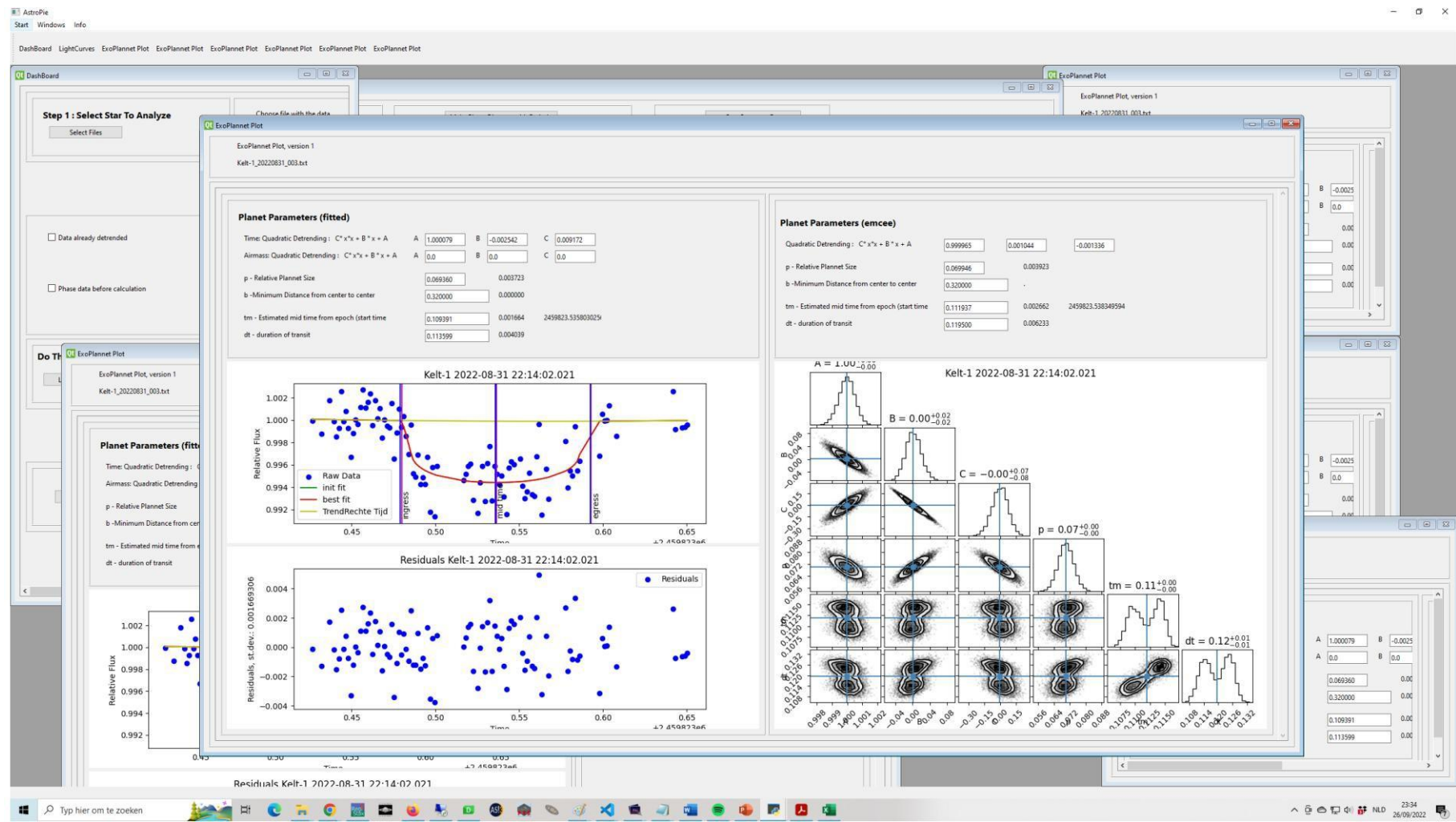
- Cooled modern 16 bit mono camera with a CMOS sensor
- Meticulous calibration
- AstroPie's bag of tricks



# Photometry : AstroPie (written by myself)



# PlanetoCalculation : ExoPie.



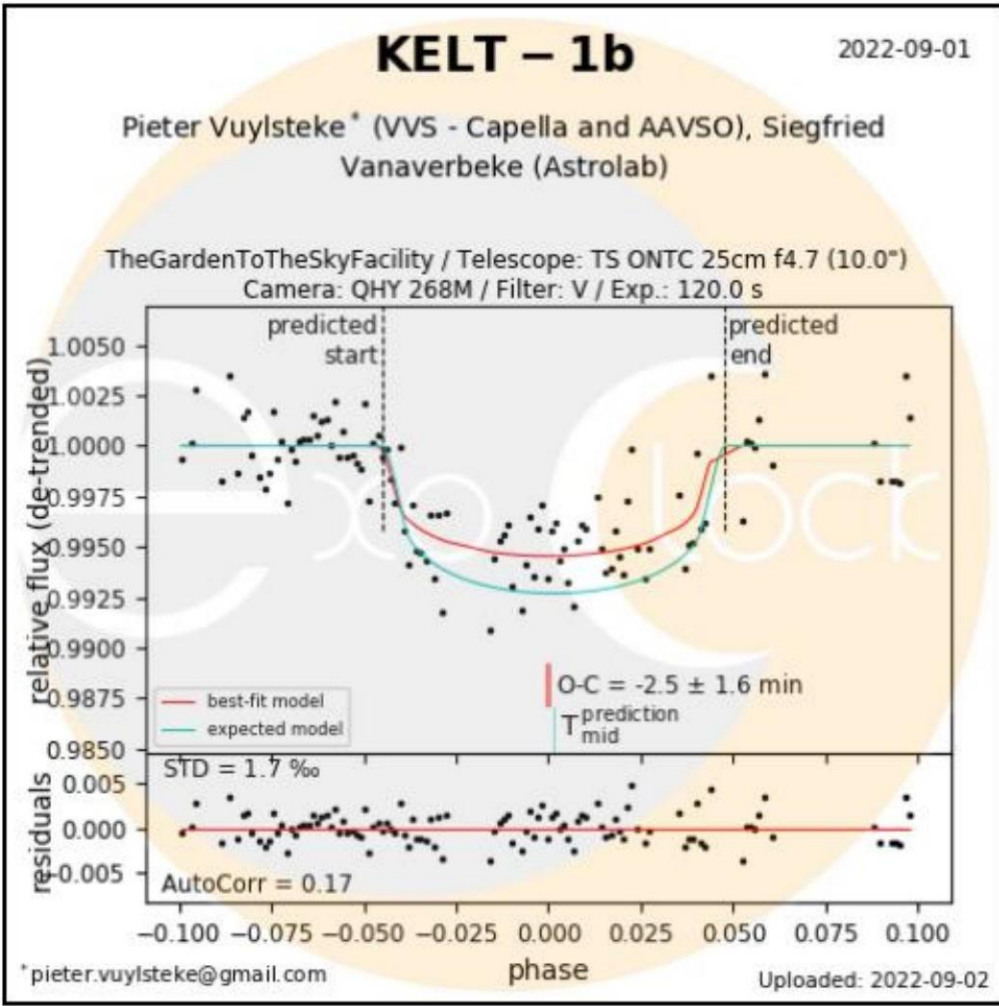
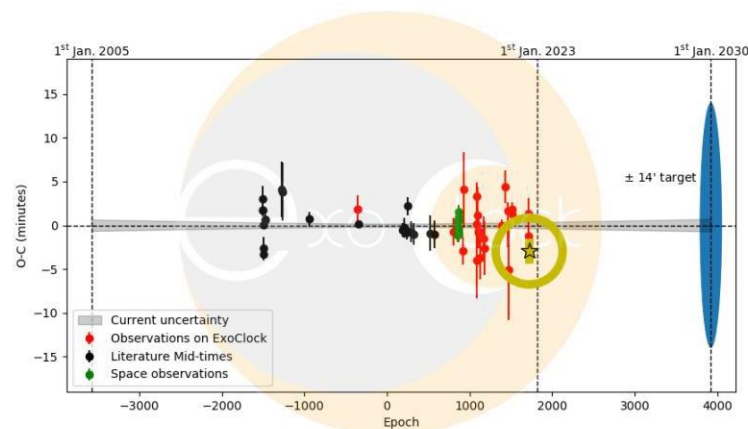
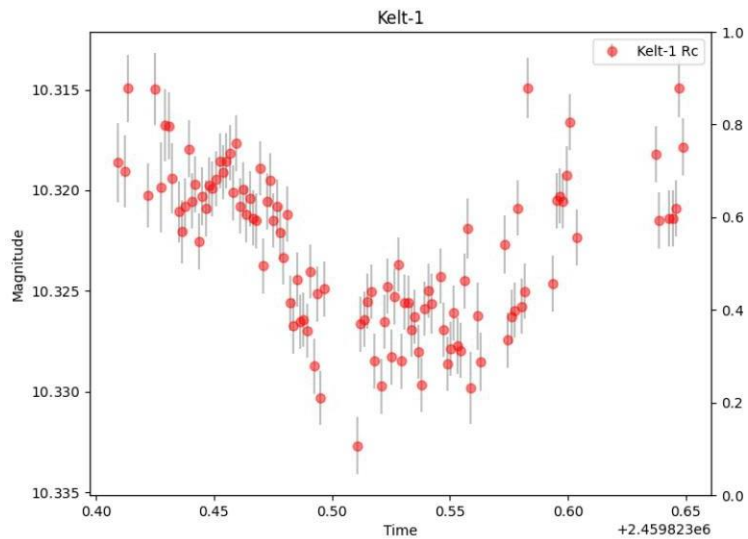
# Just call a helpline...

- Siegfried Vanaverbeke
- Franky Dubois
- Hubert Hautecler

With more people, more results !

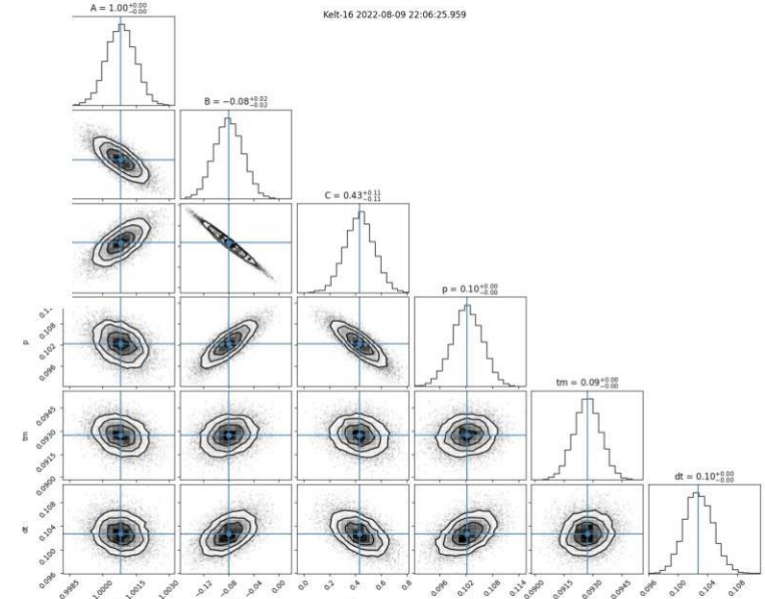
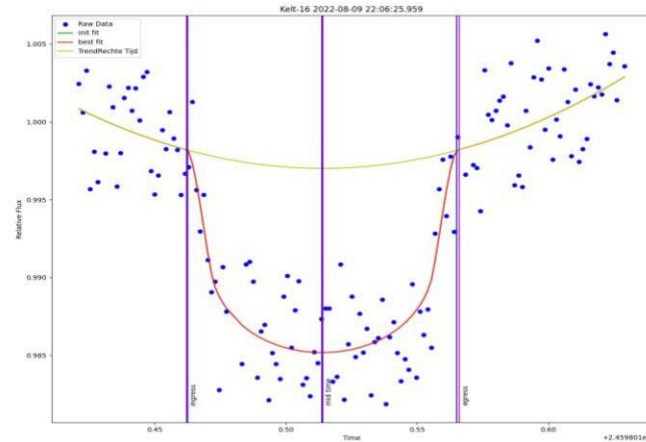
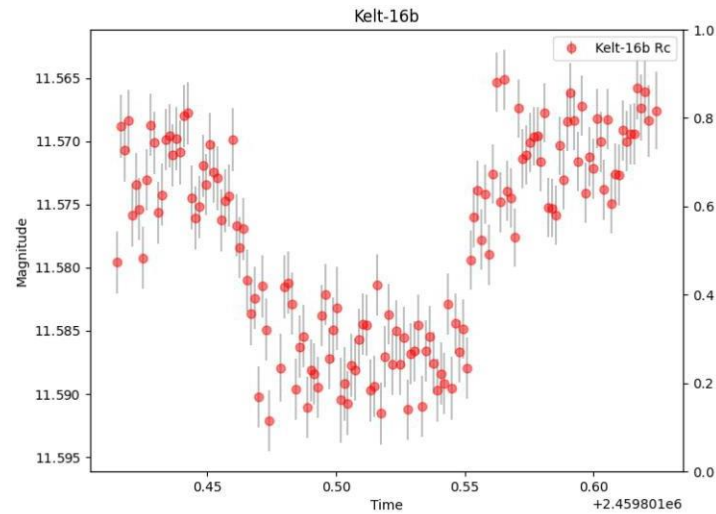
# Trial case : Kelt-1 : dip of 7 mmag ?

(a lot of wind, some rising veil clouds)





# Kelt-16b, 09 August 2022 (dip: 14.77 mmag)

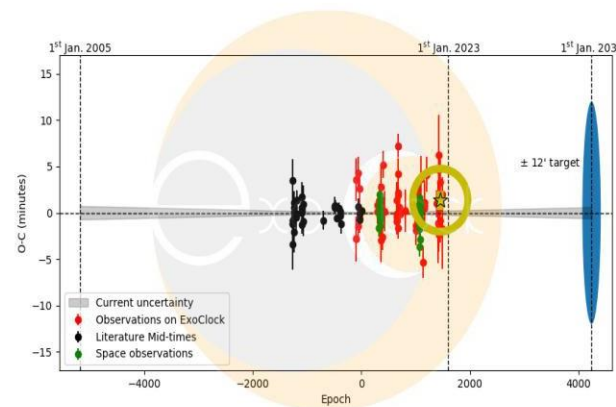


Planet Radius :  $0.102 R_{\text{star}} \pm 0.003$

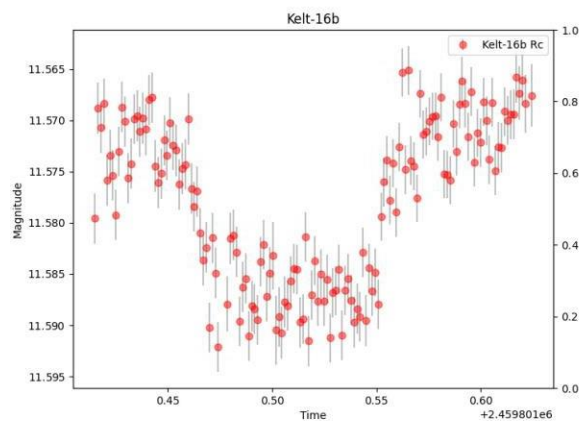
Literature :  $0.107 R_{\text{star}}$

Eclipse duration :  $2\text{h}28.32 \pm 0.48$

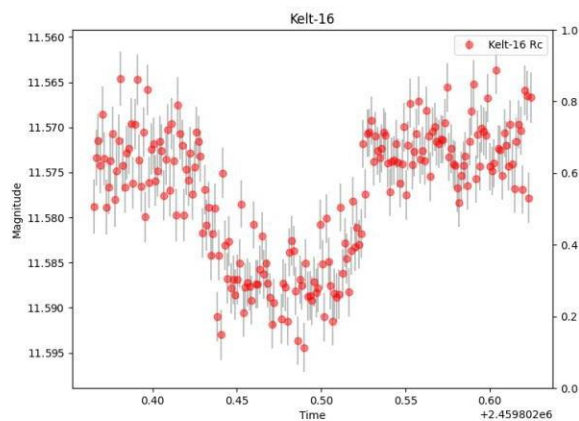
Literature :  $2\text{h}29.4$



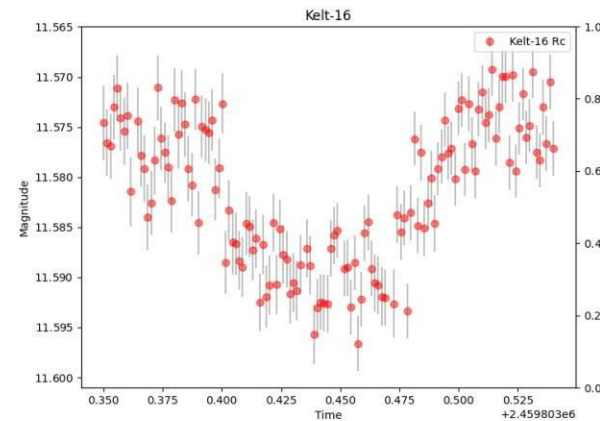
# Combining observations : 4x Kelt-16b



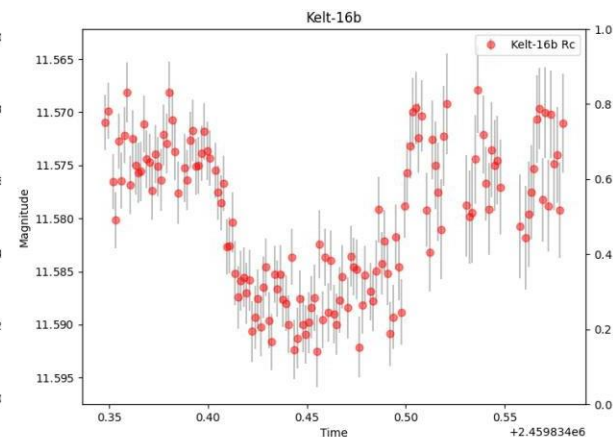
09 / 08 / 2022



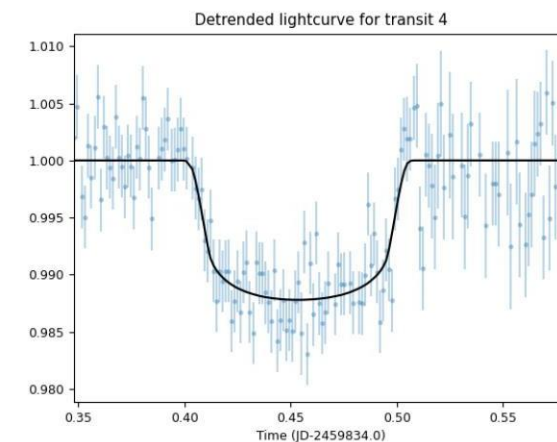
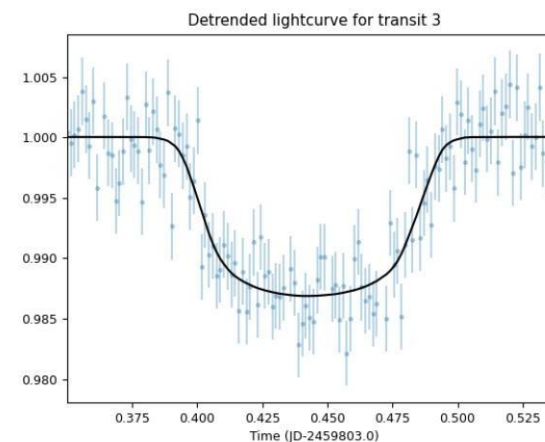
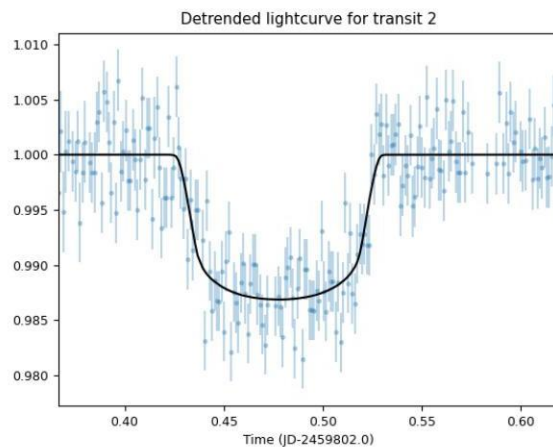
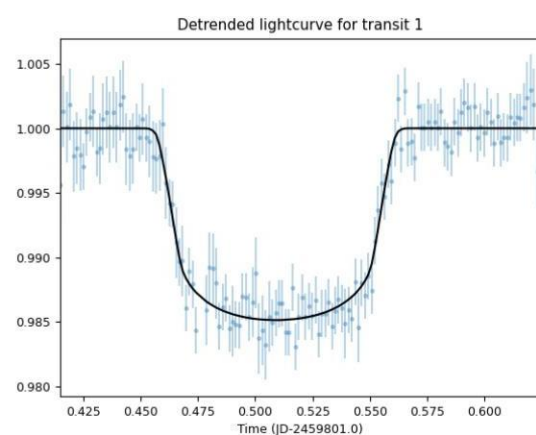
10 / 08 / 2022



11 / 08 / 2022

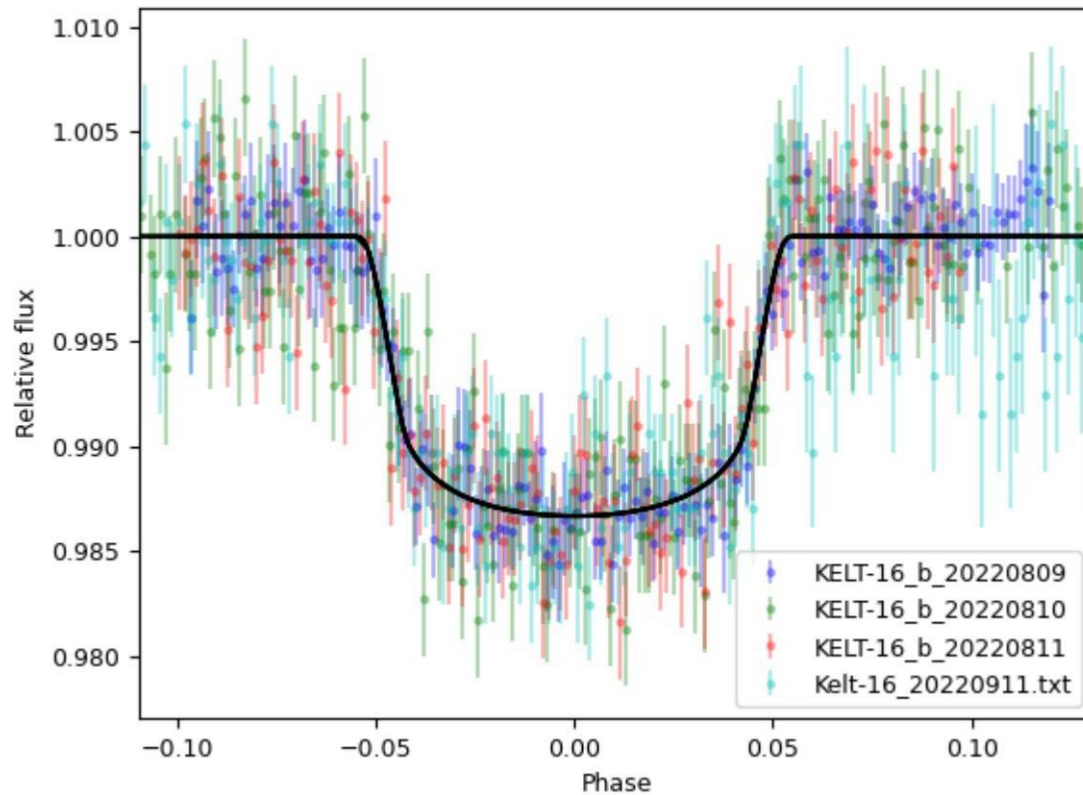


11 / 09 / 2022





# All together now (analyse by Siegfried Vanaverbeke )



- **Orbital period :**

$0.968\,995\,1 \pm 0.000\,002\,2$  days

literature value:

$0.968\,992\,962 \pm 0.000\,000\,097$  days

**so** : difference with literature =

$0.000\,002$  days = 0.17 seconds.

- **Planet radius :**

$1,4486 \pm 0,0197 / - 0.022$  (Jupiter radius)

**Planet Radius :**

$0.1070 \pm 0.0014$  (stellar radius)

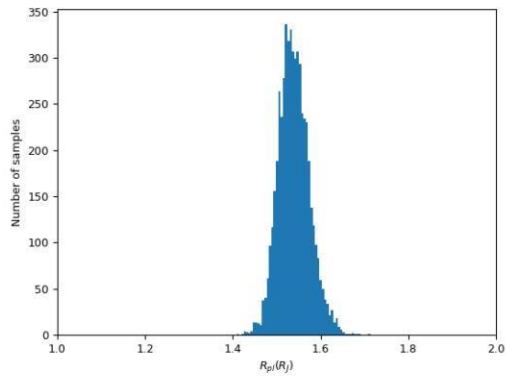
literature:  $0.107 \pm 0.0013$

- **Eclipse duration :**  $2.25 \pm 0.0024$  hours

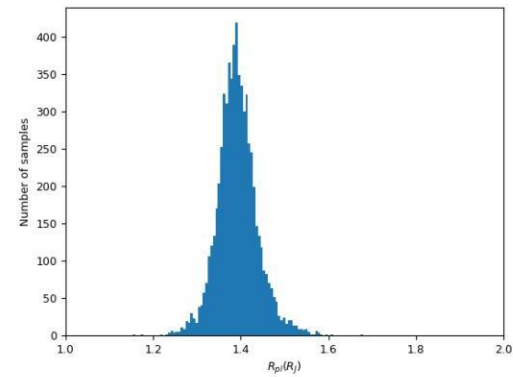
literature : 2.49 hours.

# Kelt-16b : planet diameter estimate

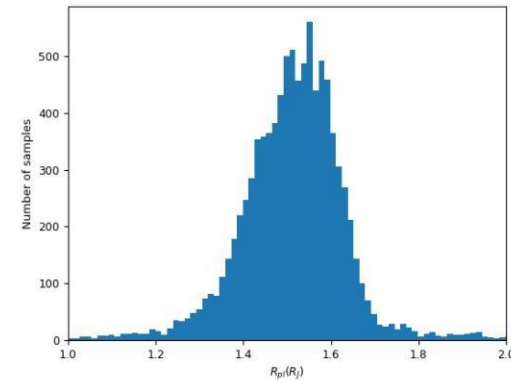
09/08/2022



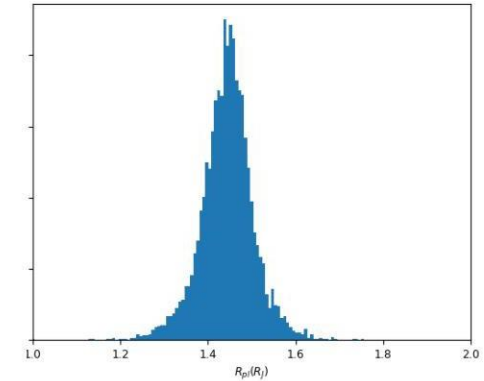
10/08/2022



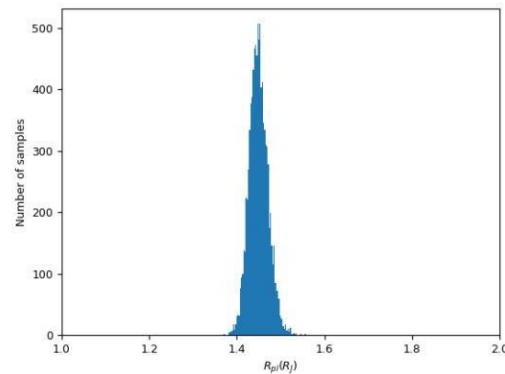
11/08/2022



11/09/2022



All together now

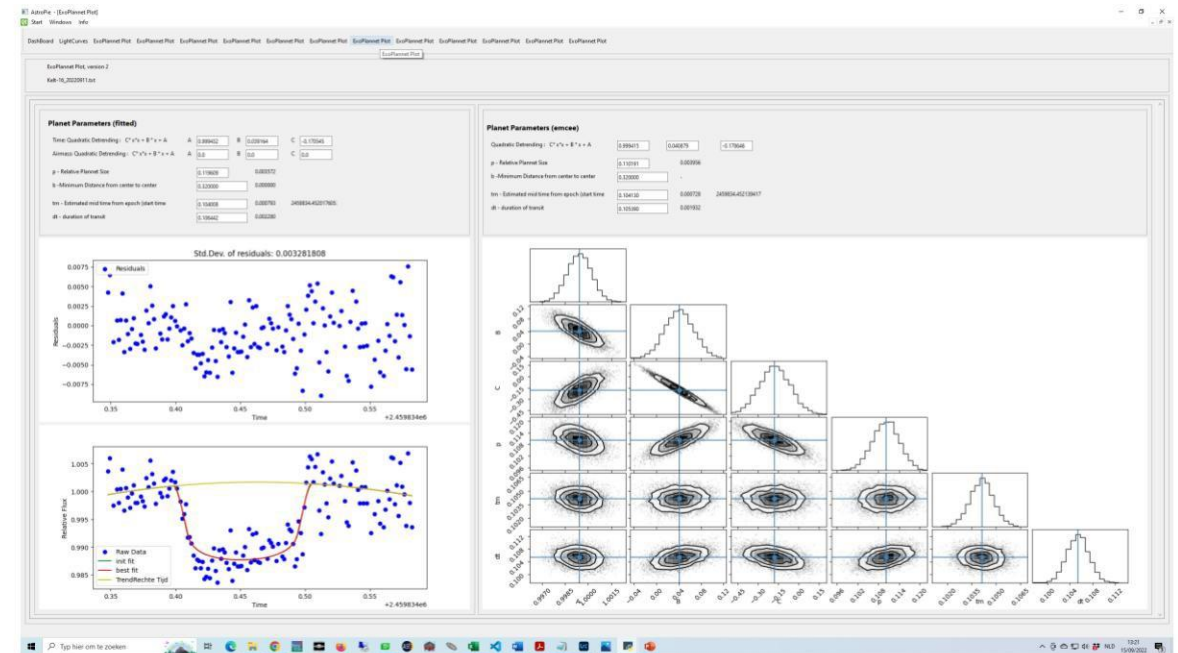


Combining lightcurves narrows down the planet radius !

# Future plans

- Engage amateur astronomers to participate in synchronous observing campaigns.
- Possibility to detect “Transit Timing Variations” • Interested in joining ?  
Mail : [pieter.vuylsteke@gmail.com](mailto:pieter.vuylsteke@gmail.com)

- 
- **The pleasure of the pudding is in the cooking, the eating, and the sharing.**



# The End.

Magn : 13.83, dip : 31.38 mmmag

Magn: 10,24, dip : 21,47mmag

