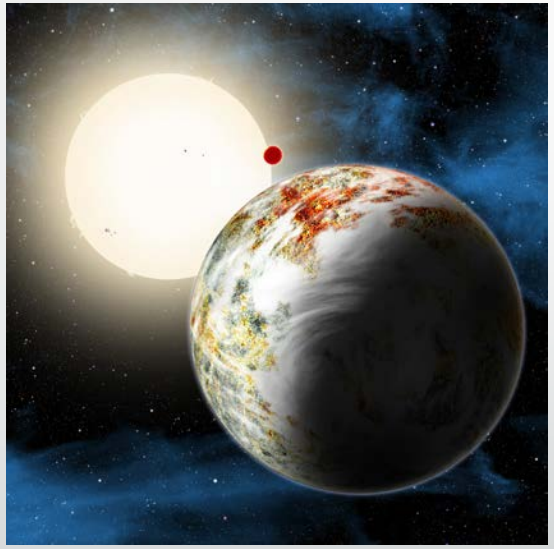
Exoplanet Pursuit



PLANet B

Kalpaxis Georgios

Vasilainas Athanasios

Vatistas Andreas

"We must continue to go into space for the future of humanity. I do not think we will survive another 1,000 years without escaping our fragile planet."

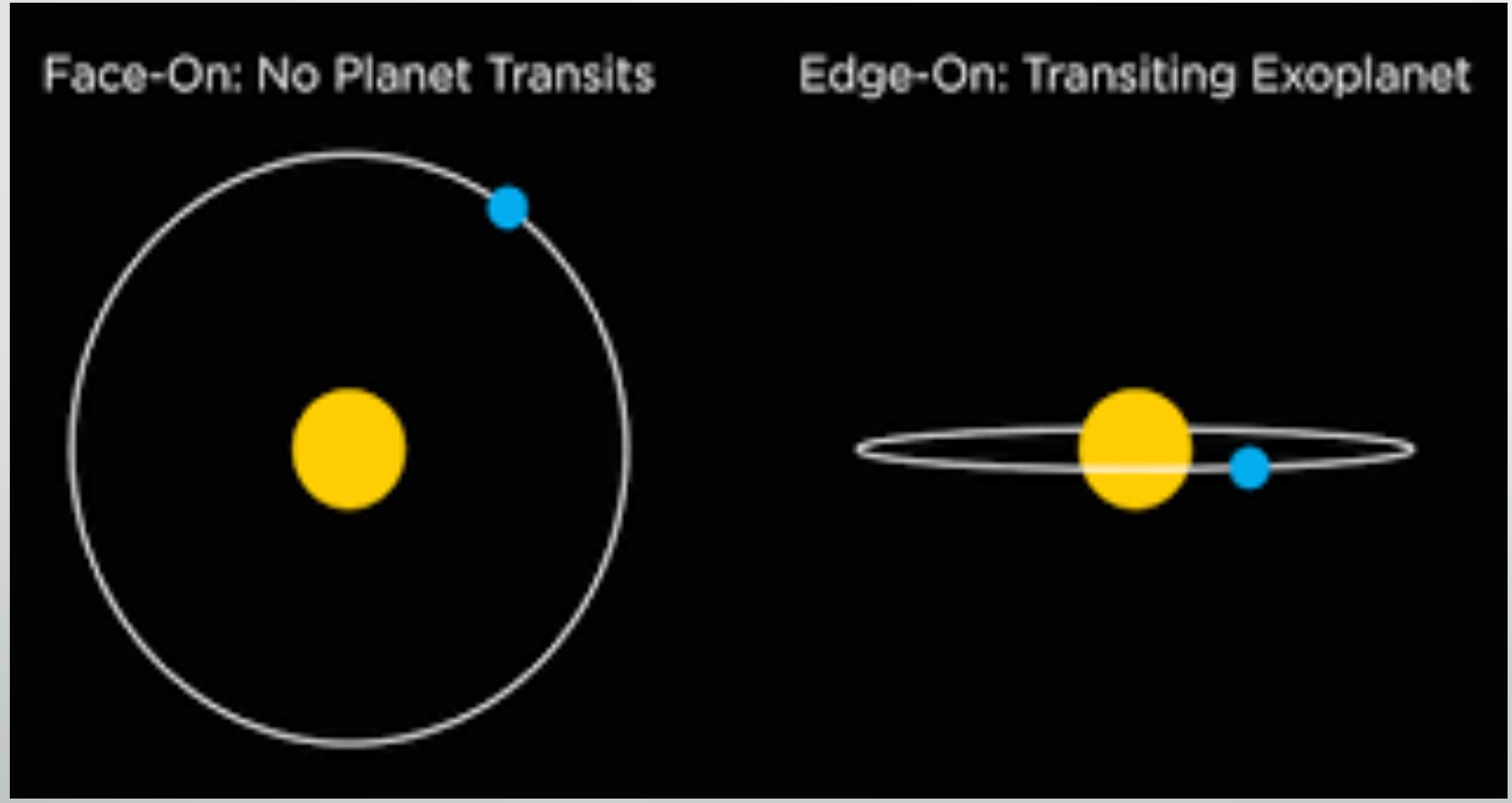
-Stephen Hawking

Project Goals

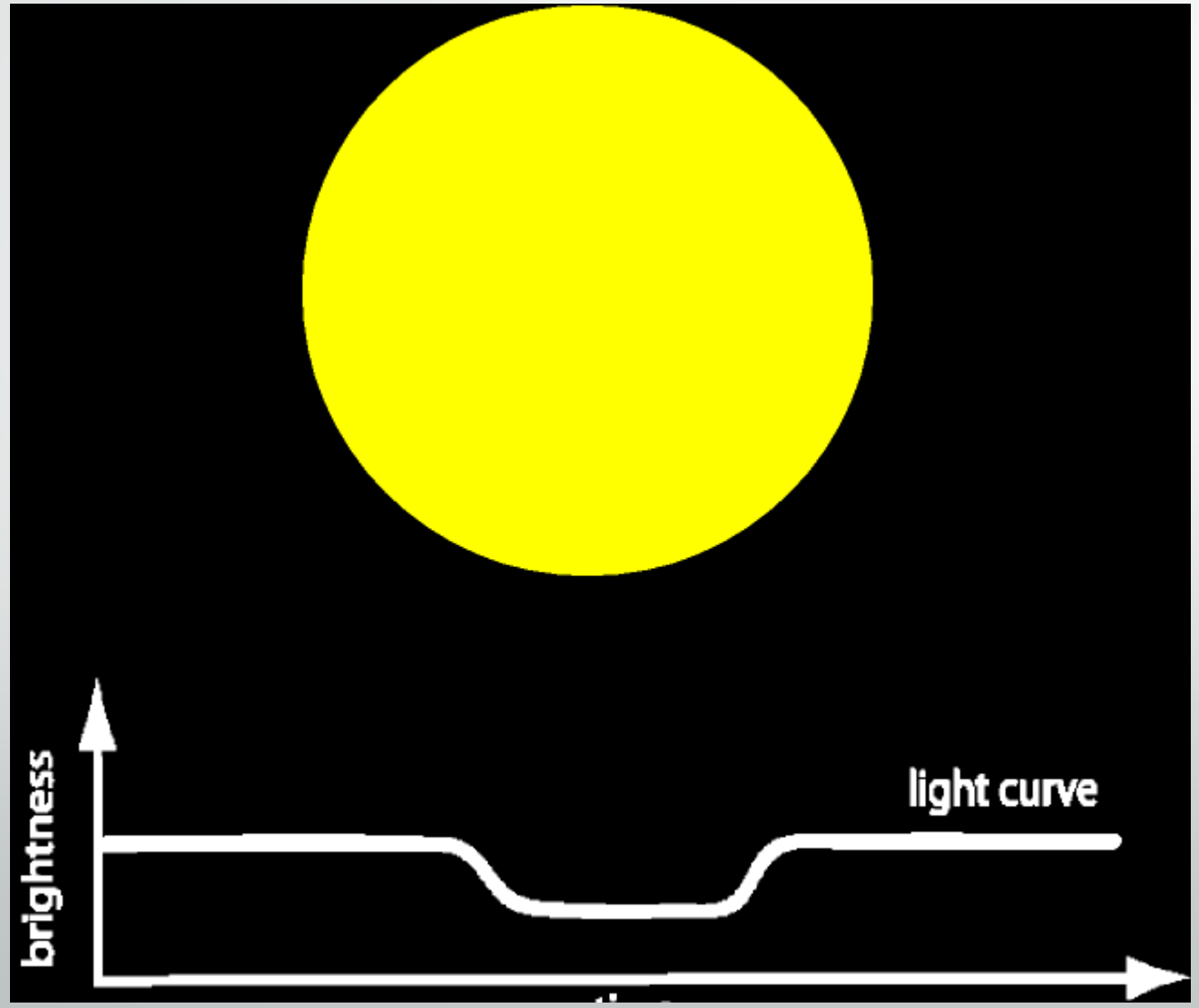
- Search for exoplanets using the Kepler Mission data and the transit method.
- Implement a new approach for this search, using two original computer programs written by us.
- Extract the orbital and transit parameters of the exoplanets.
- Explain the light variation in a case of other phenomena, like a pulsating variable star.

https://www.youtube.com/watch?v=51GnNtlzj6g&feature=youtu.be

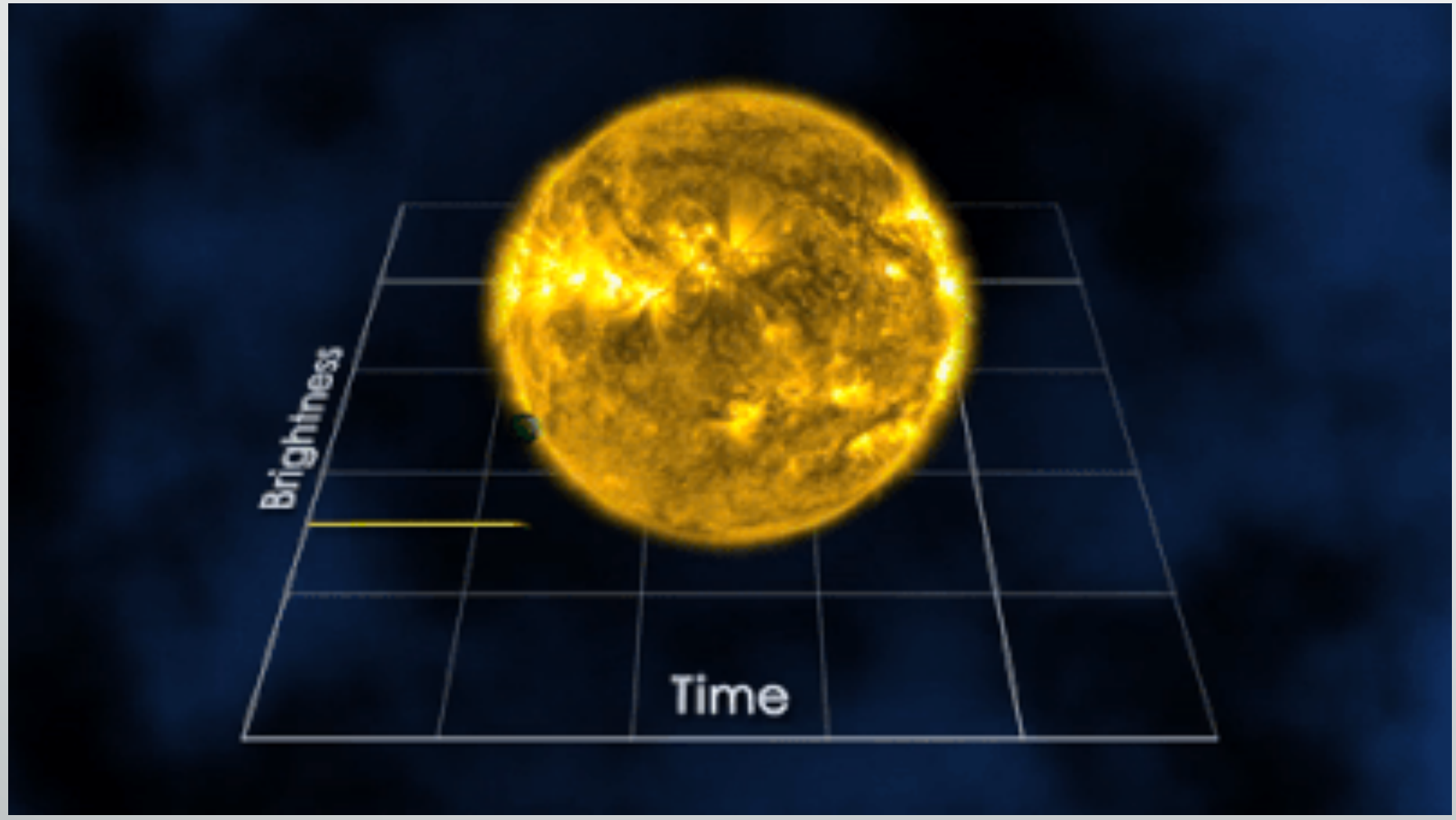
How does the transit method work?

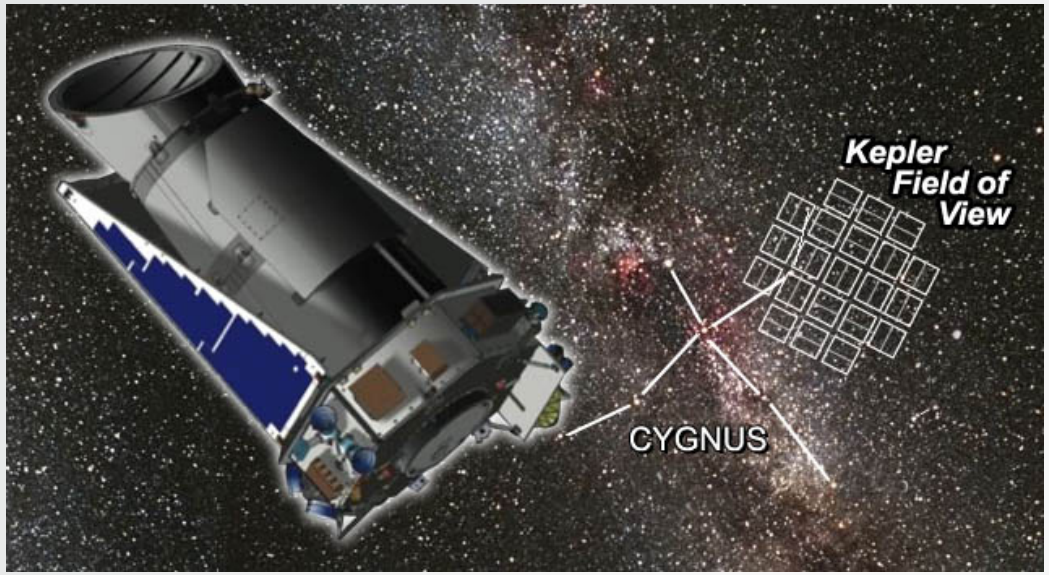


How does the transit method work?



Light curve is a graph of light intensity of a star as a function of time

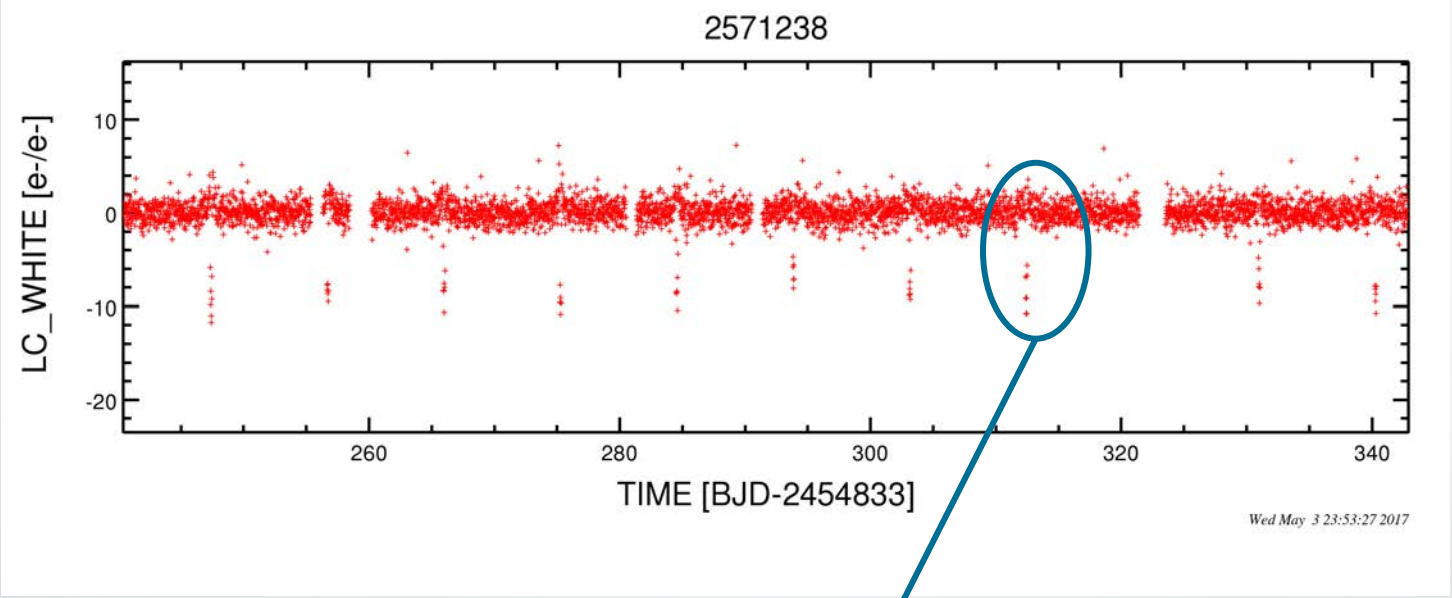

Brightness
Time

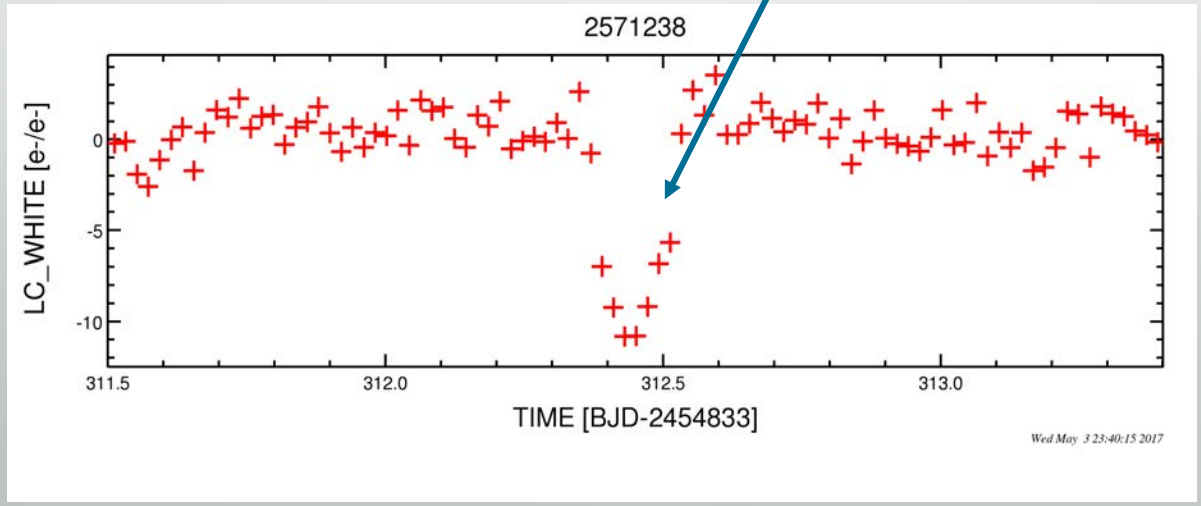


We used the data from the **Kepler Mission** and retrieved from the **NASA Exoplanet Archive**.

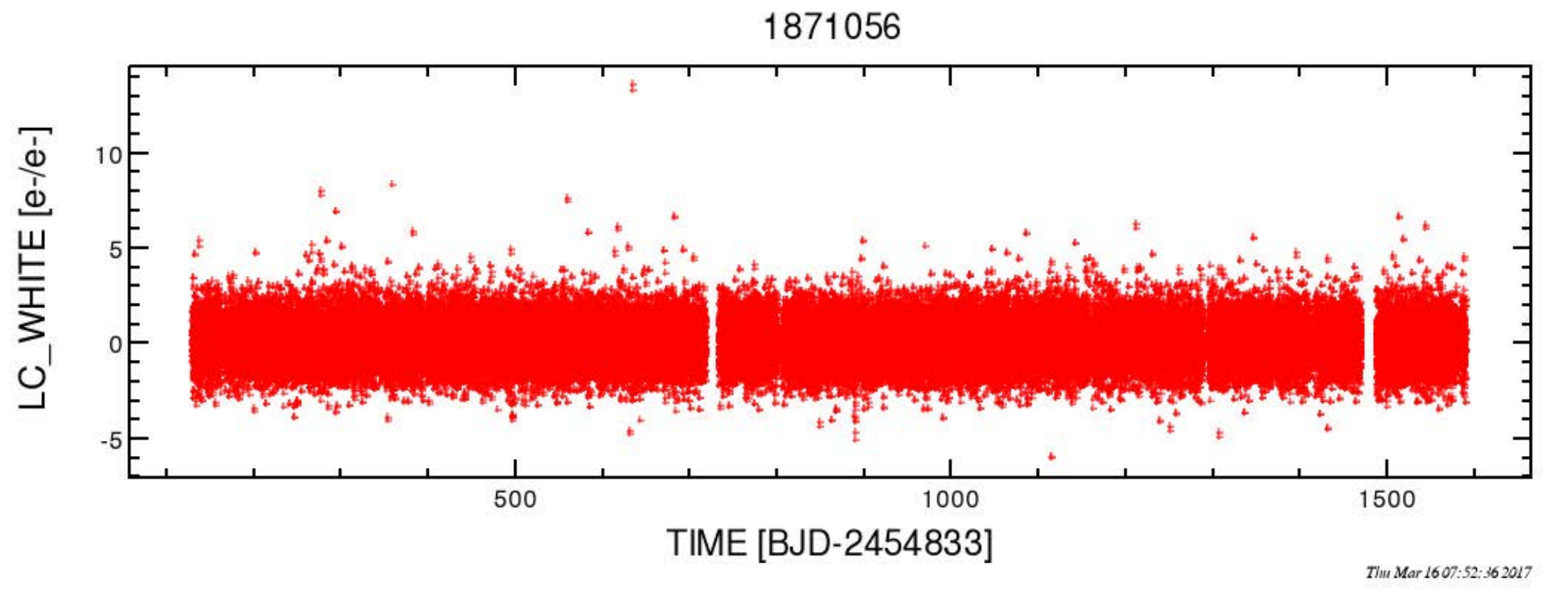
https://exoplanetarchive.ipac.caltech.edu/

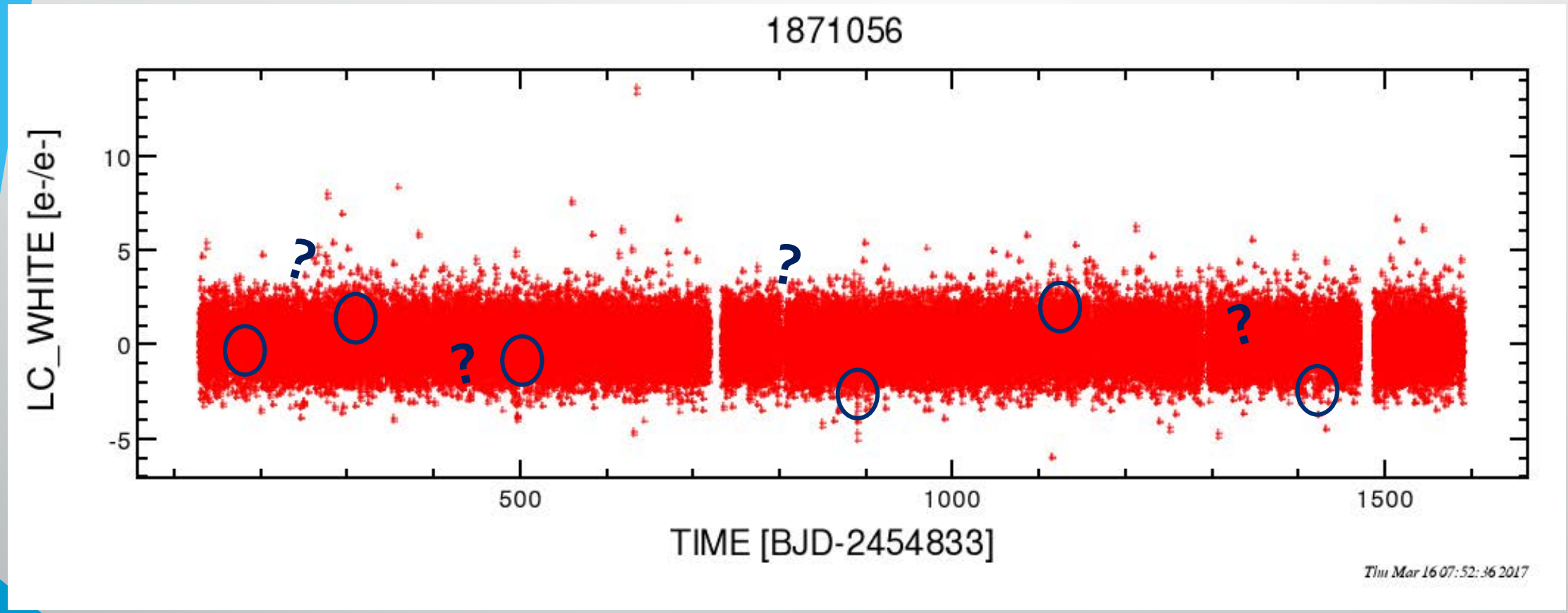
Some Light curves

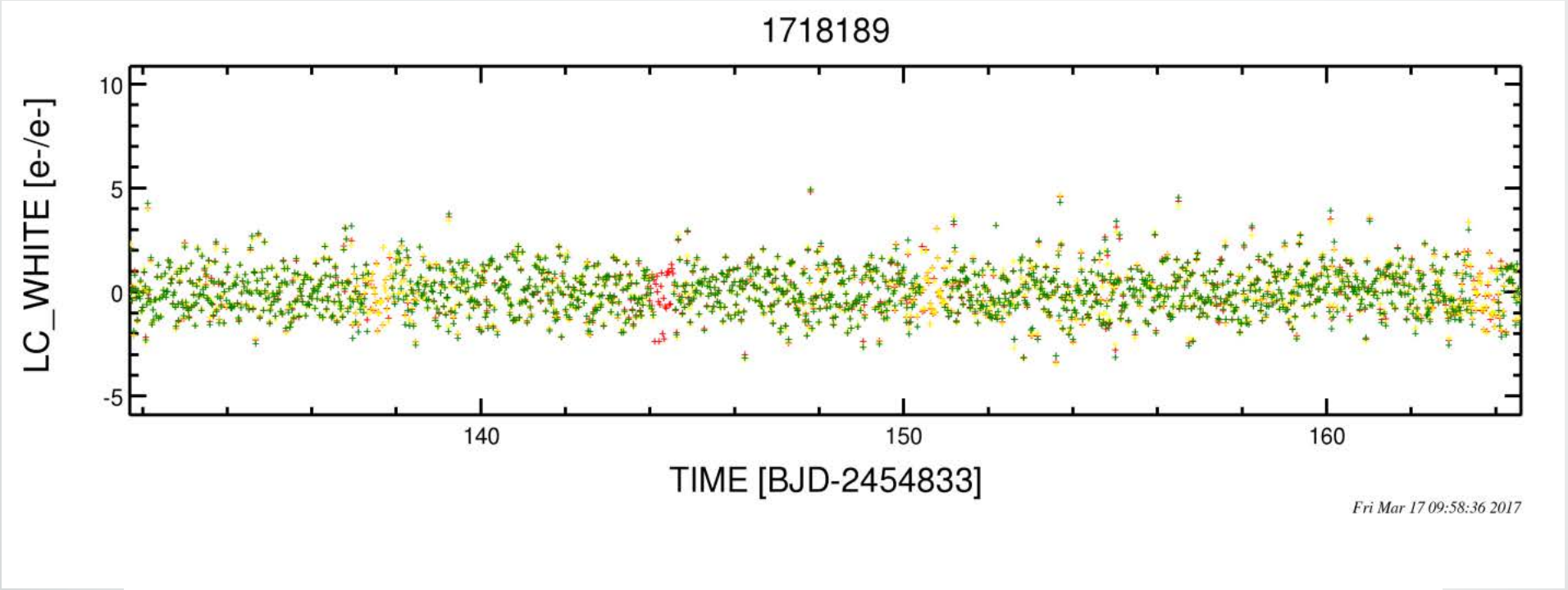


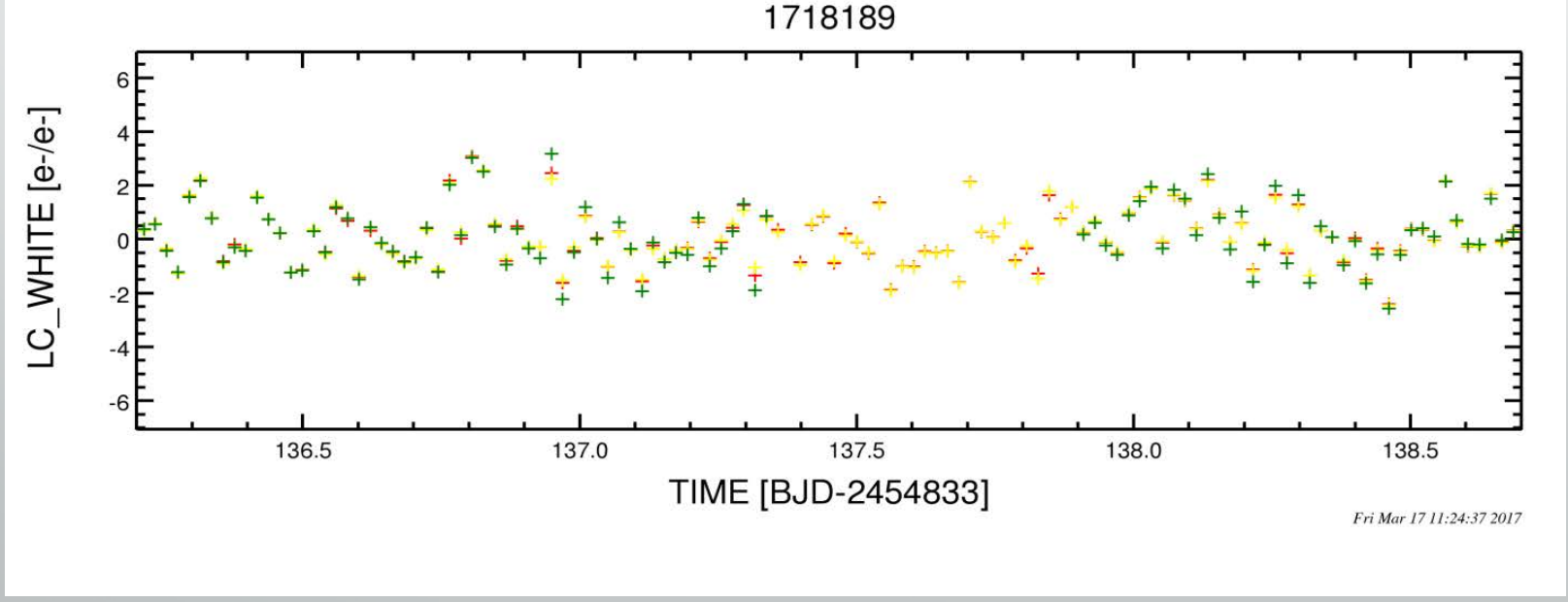


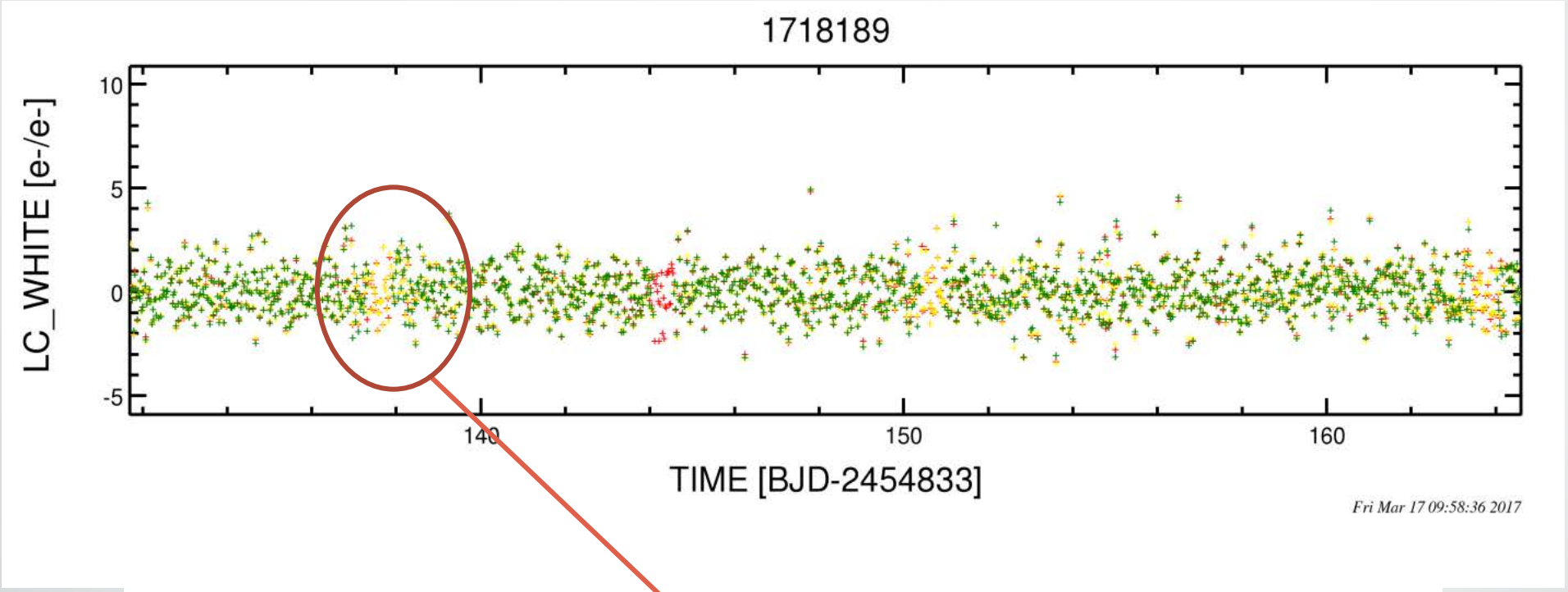
The major difficulty

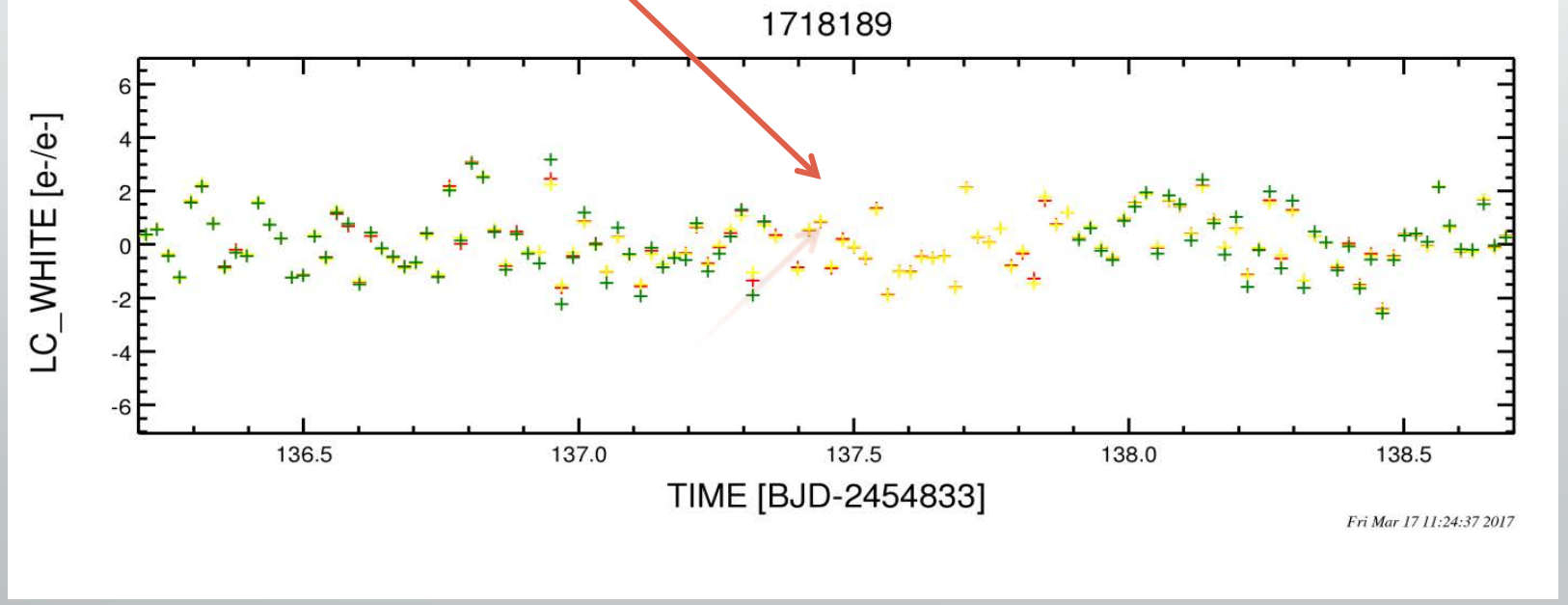



1871056
LC_WHITE [e-/e-]
10
5
0
-5
500
1000
1500
TIME [BJD-2454833]
Thu Mar 16 07:52:36 2017


1718189
LC_WHITE [e-/e-]
10
5
0
-5
140
150
160
TIME [BJD-2454833]
Fri Mar 17 09:58:36 2017


1718189
LC_WHITE [e-/e-]
6
4
2
0
-2
-4
-6
136.5
137.0
137.5
138.0
138.5
TIME [BJD-2454833]
Fri Mar 17 11:24:37 2017


1718189
LC_WHITE [e-/e-]
10
5
0
-5
140
150
160
TIME [BJD-2454833]
Fri Mar 17 09:58:36 2017


1718189
LC_WHITE [e-/e-]
6
4
2
0
-2
-4
-6
136.5
137.0
137.5
138.0
138.5
TIME [BJD-2454833]
Fri Mar 17 11:24:37 2017

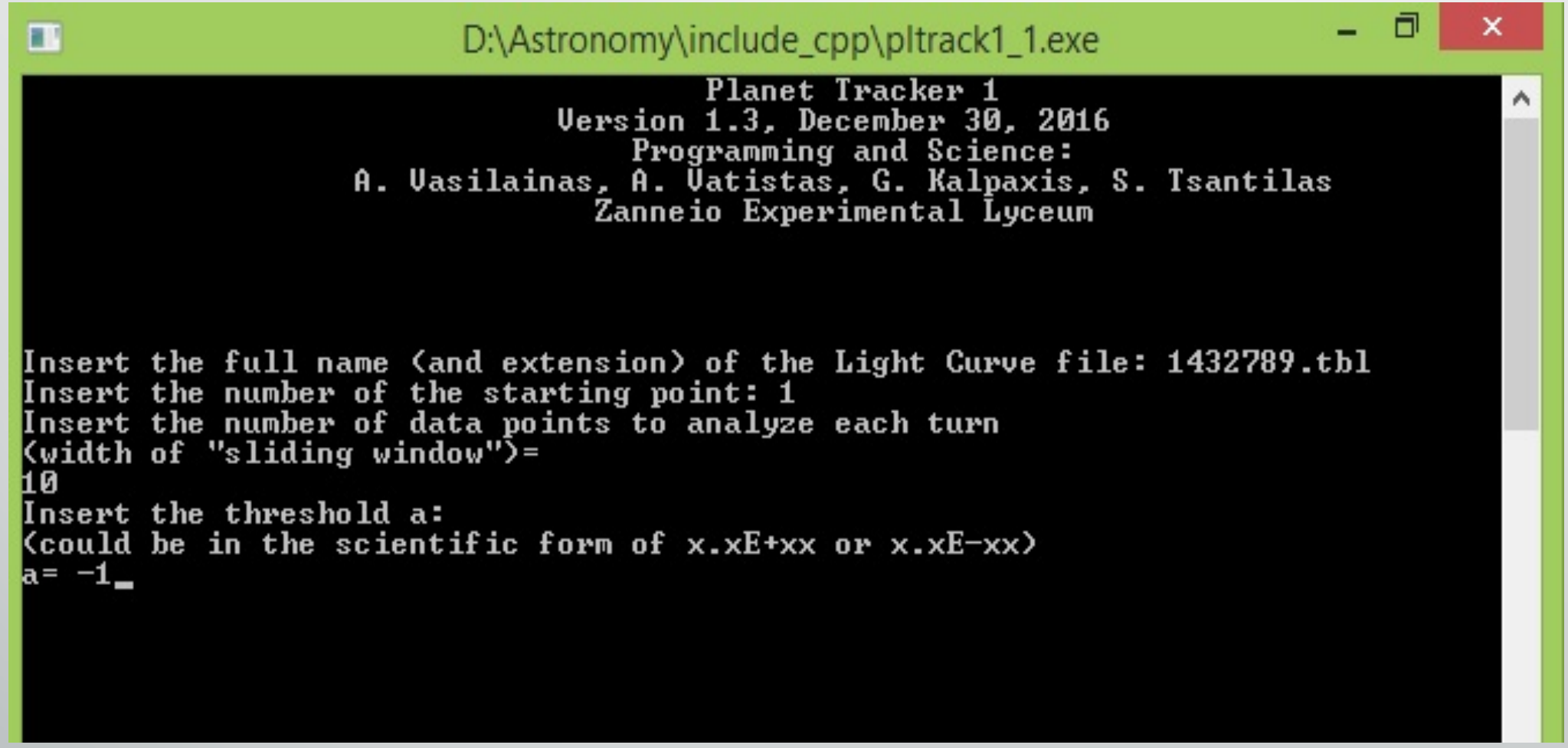
So we thought about developing a program!

pltrack1.cpp

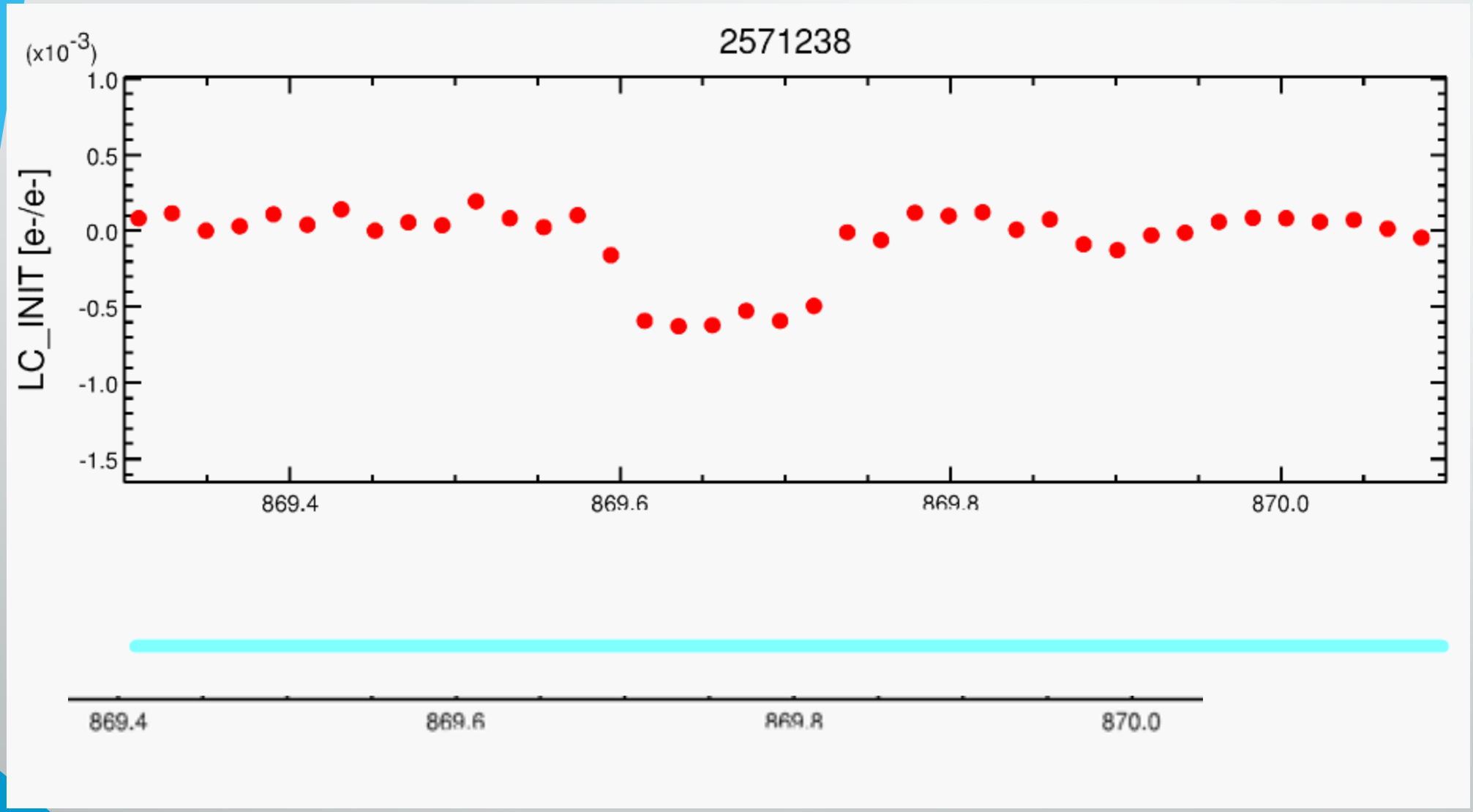
```
62    out << "\n";
63  }
64
65  void outputfile2()
66  //Enallaktikh epilogh gia to out.dat
67  {
68    out.width(12);
69    out.precision(10);
70    out << epoch[gyros];
71    out << "    ";
72    out.width(12);
73    out.precision(10);
74    out << 0;
75    out << "\n";
76  }
77
78  void outputfile()
79  //Enallaktikh epilogh gia to out.dat
80  {
81    out.width(12);
82    out.precision(10);
83    out << epoch[gyros];
84    out << "    ";
85    out.width(12);
86    out.precision(10);
```

pltrack1

PLANET TRACKER 1.3 (pltrack 1.3)

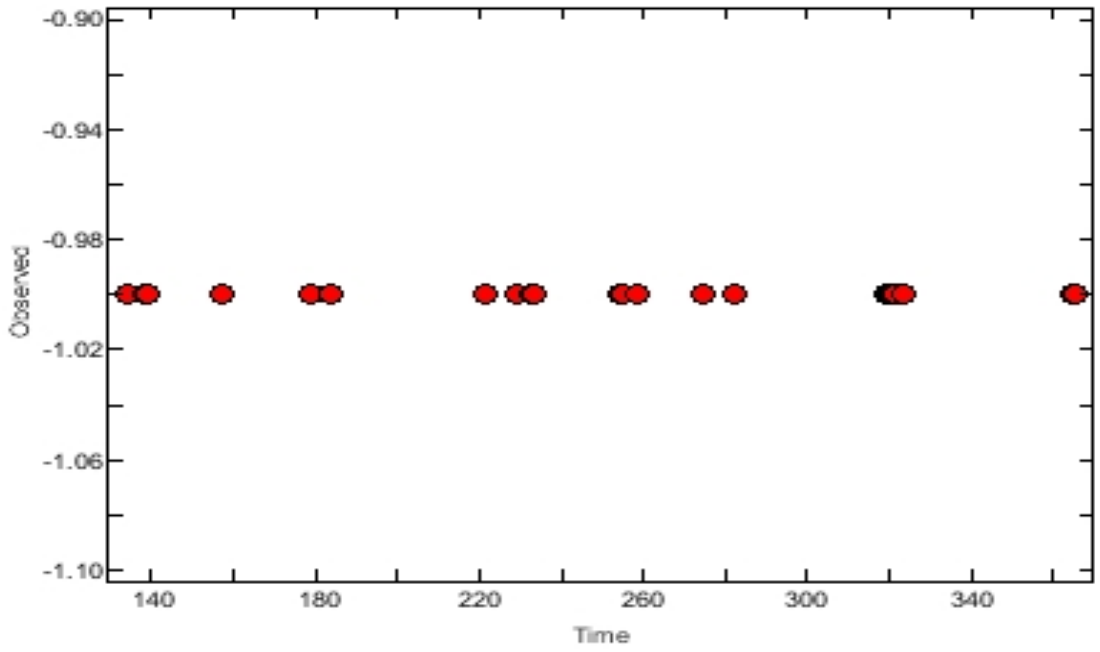


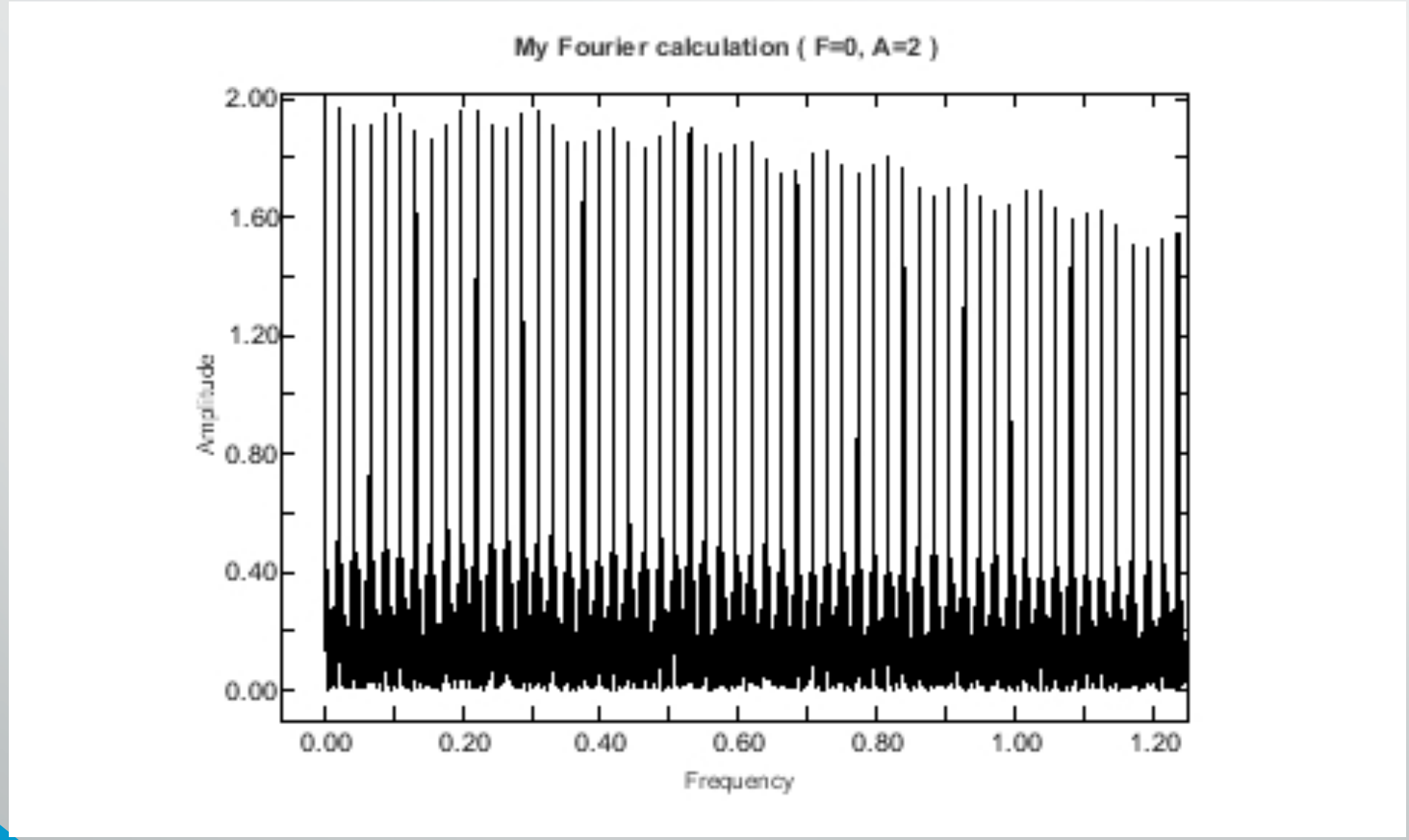
- Sliding Window
- Threshold


2571238
(x10-3)
1.0
0.5
0.0
-0.5
-1.0
-1.5
LC_INIT [e-/e-]
869.4
869.6
869.8
870.0
869.4
869.6
869.8
870.0

The produced file (named out.dat) and its graph

134.0461541	-1
134.1483252	-1
138.459936	-1
138.4803702	-1
138.5008045	-1
138.5212386	-1
138.5416727	-1
138.5621069	-1
138.5825411	-1
138.6029752	-1
138.6234094	-1
138.6438436	-1
138.6642777	-1
138.6847119	-1
138.705146	-1
138.7255802	-1
138.7460144	-1
157.0958529	-1
178.9397796	-1
178.9602135	-1
178.9806473	-1
179.0010813	-1
179.0215152	-1
179.041949	-1
183.7417392	-1
183.762173	-1
183.7826069	-1
183.8030408	-1



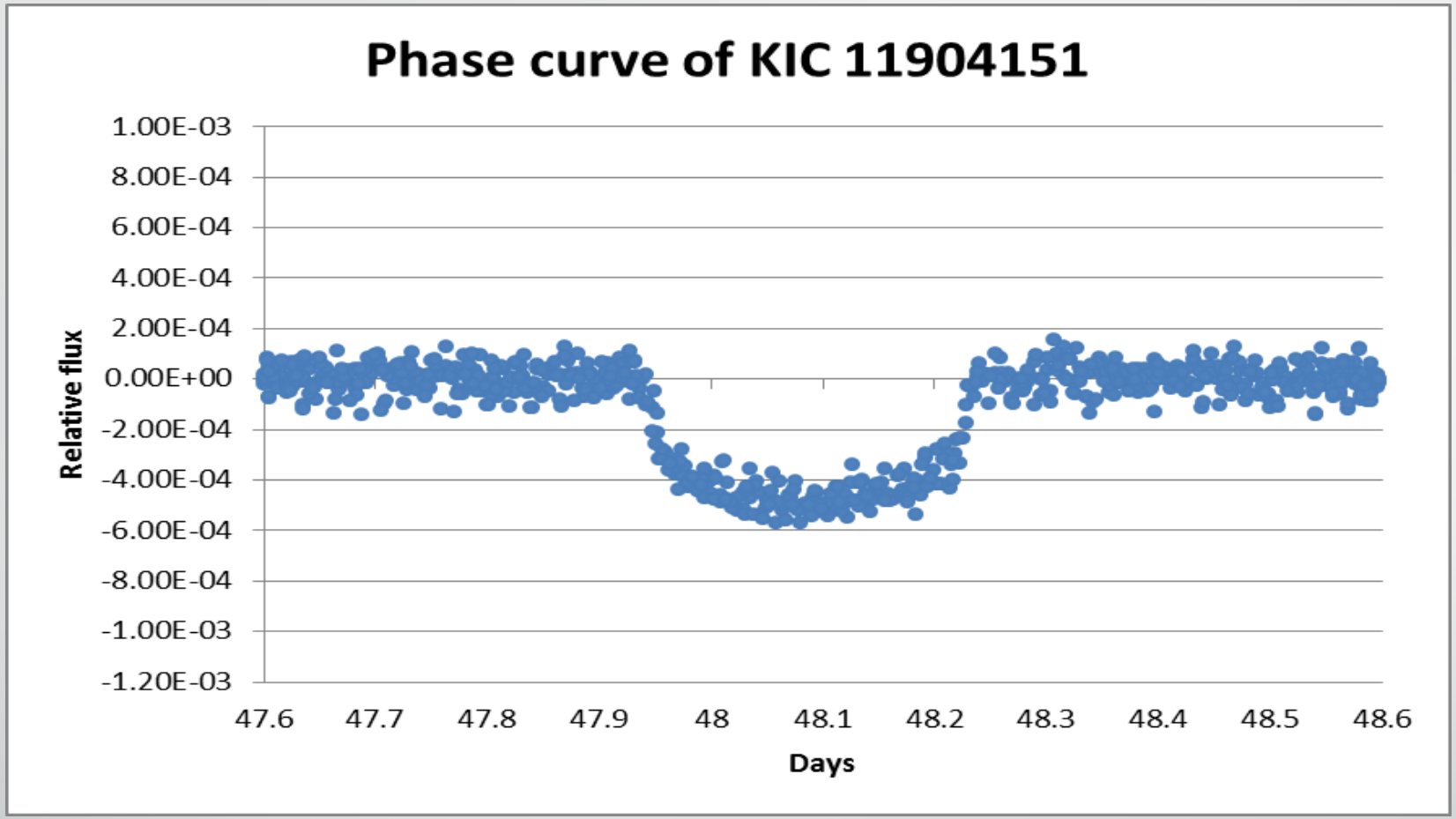

My Fourier calculation (F=0, A=2)
2.00
1.60
1.20
0.80
0.40
0.00
Amplitude
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Frequency

Pltrack2

```
                                Planet Tracker 2
                            Version 2.5, January 24, 2017
                                Programming and Science:
                        A. Vasilainas, A. Vatistas, G. Kalpaxis, S. Tsantilas
                                Zanneio Experimental Lyceum



Insert the full name (and extension) of the Light Curve file: 1432789_det.tbl
Insert the number of the starting point: 1
Insert the number of data points for binning:  30
Insert the period:  9.93493
```



The shape of Kepler-10c transit (KIC 11904151).

Theoretical Background

The equations we used to extract the transit and orbital parameters are (Seager & Mallén, 2003):

1. The transit depth ΔF , with F defined as the total observed flux, and R_p , R_* the planetary and stellar radii respectively

$$\Delta F = \frac{F_{no\ transit} - F_{transit}}{F_{no\ transit}} = \left(\frac{R_p}{R_*} \right)^2$$

2. Kepler's Third Law, assuming a circular orbit, where P is the orbital period, G is the universal gravitational constant, M_p , M_* the planetary and stellar masses, and a the orbital radius,

$$P^2 = \frac{4\pi^2 a^3}{G(M_* + M_p)}$$

3. The impact parameter b that defines the shape of the transit, where t_T, t_F is the total duration of the eclipse and the duration of the flat part,

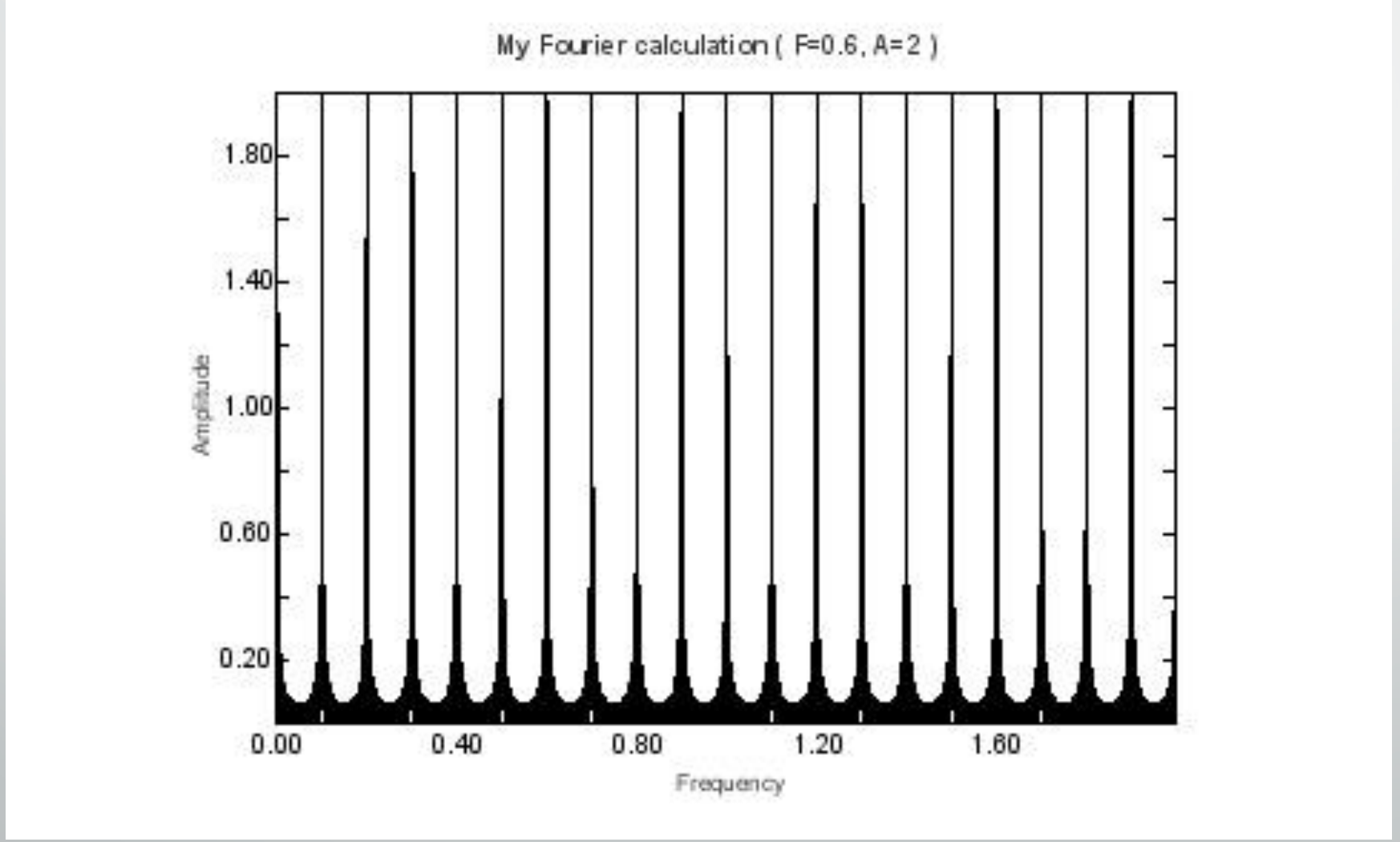
$$b = \left[\frac{\left(1 - \sqrt{\Delta F}\right)^2 - \left(\frac{t_F}{t_T}\right)^2 \left(1 + \sqrt{\Delta F}\right)^2}{1 - \left(\frac{t_F}{t_T}\right)^2} \right]^{1/2}$$

4. The orbital inclination i ,

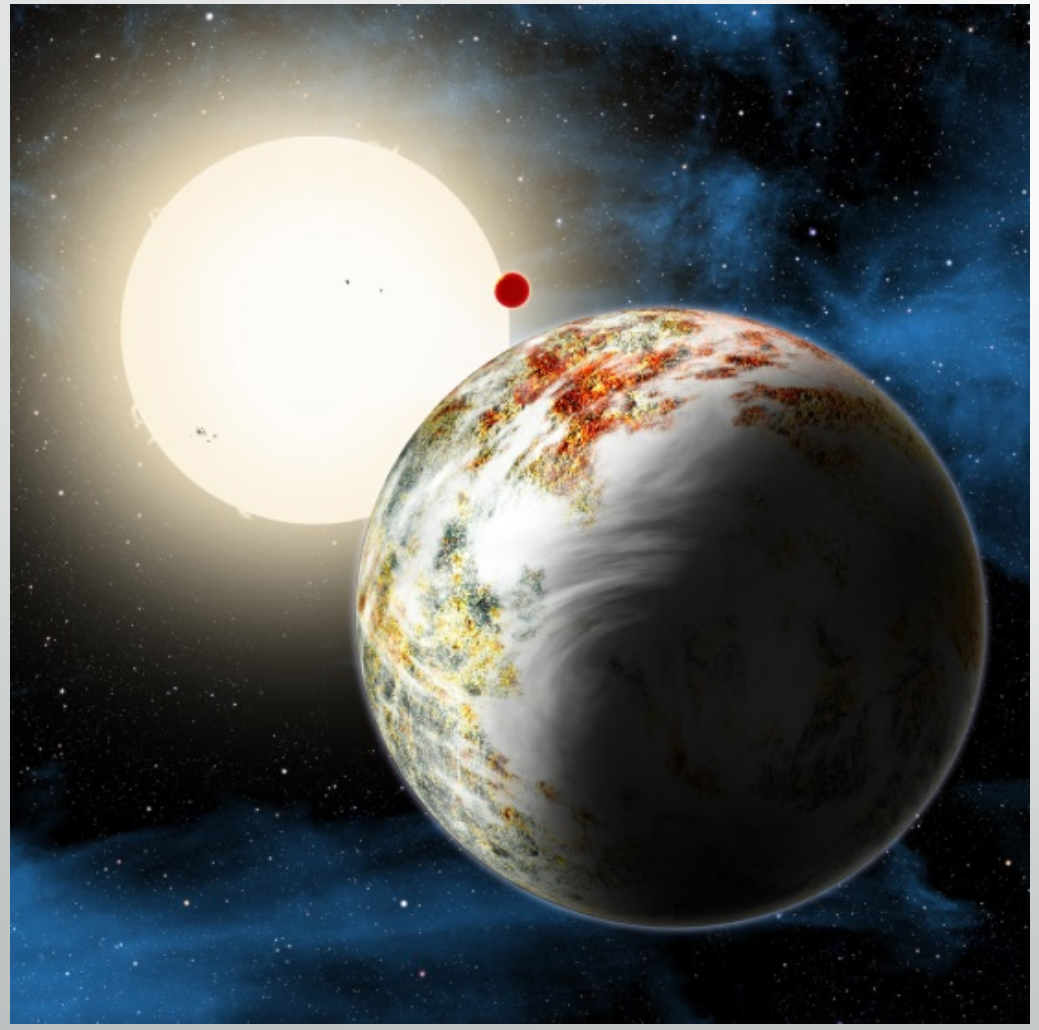
$$i = \cos^{-1}\left(b \frac{R_*}{a}\right)$$

ANALYSIS

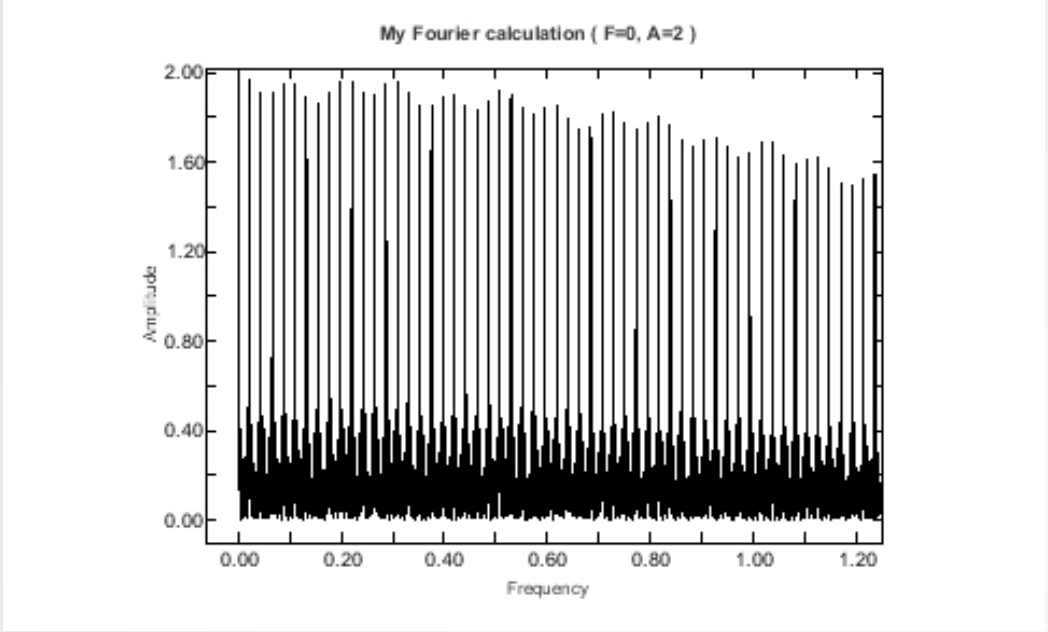
Artificially created data

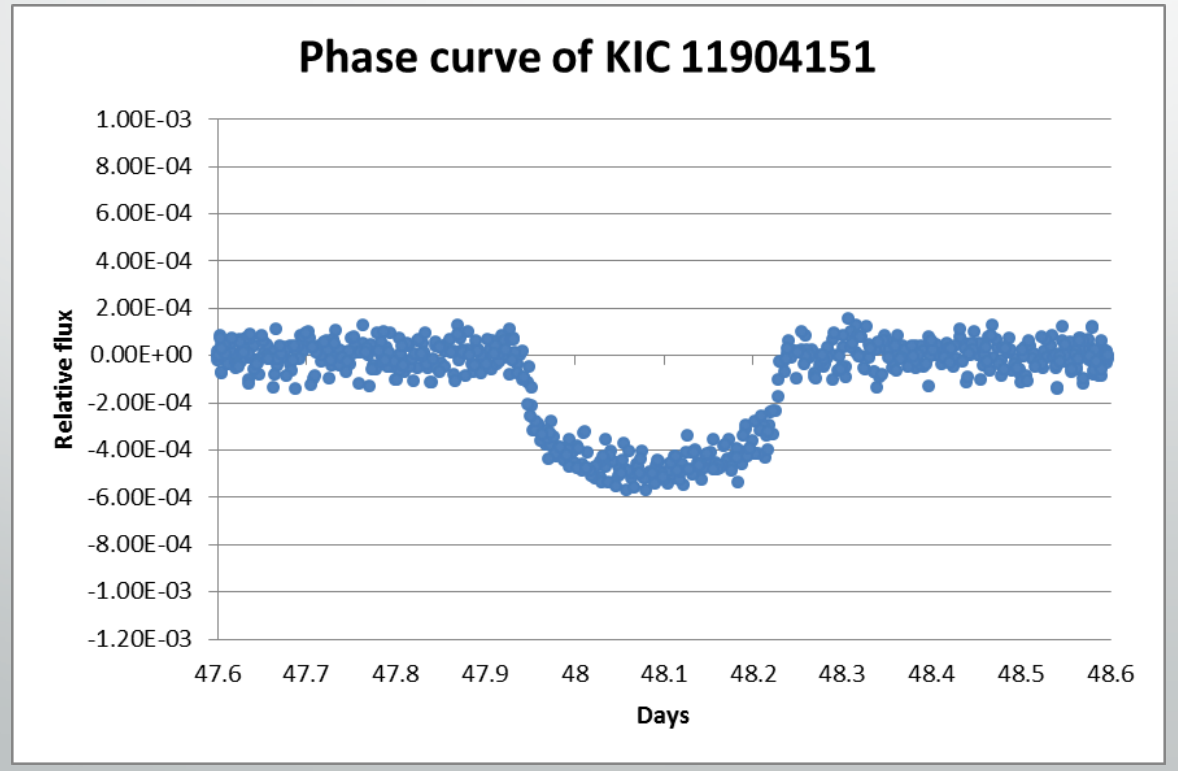


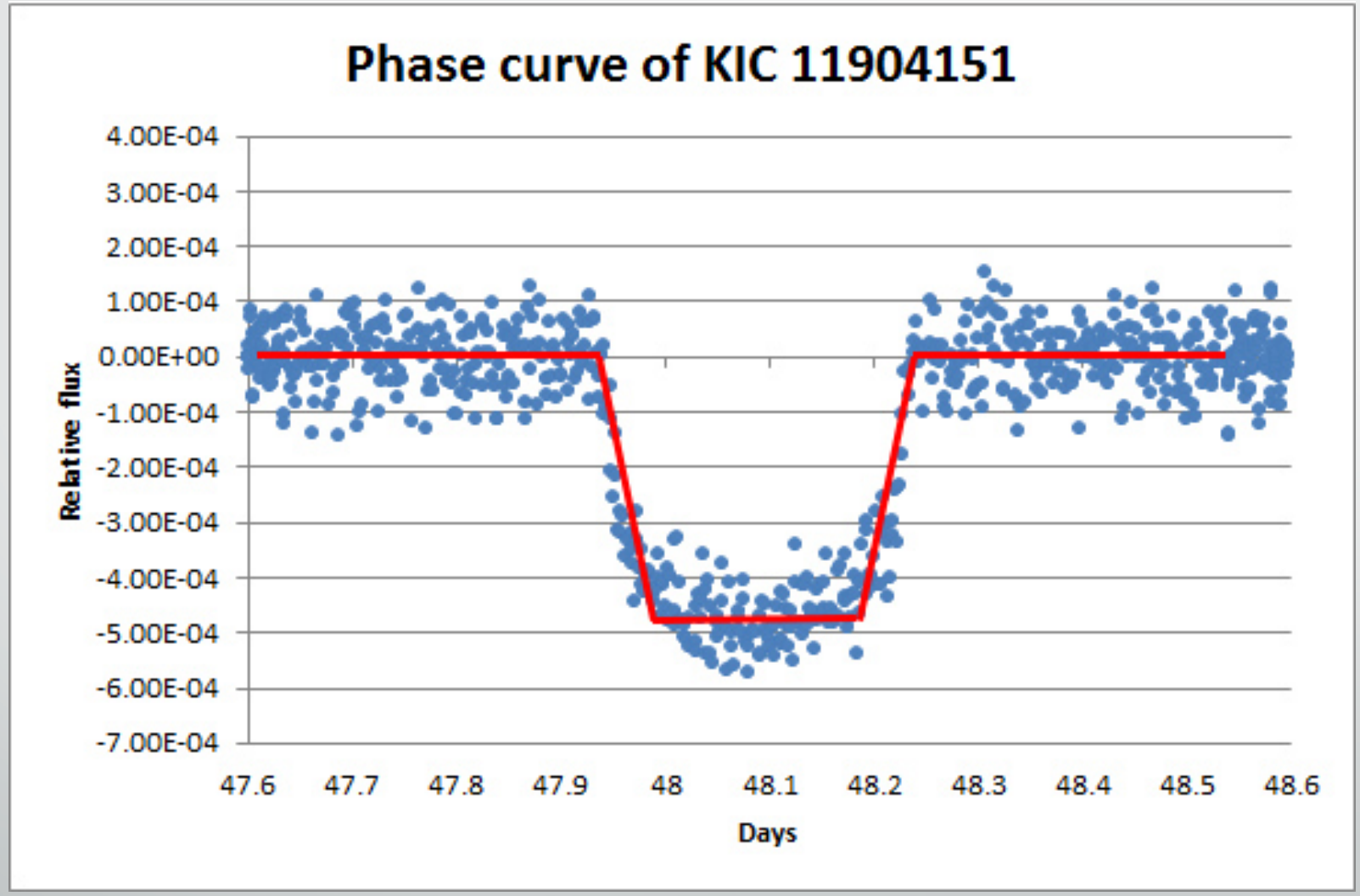
Kepler-10 (KIC 11904151)



An artist concept shows the Kepler-10 system, home to two rocky planets.


My Fourier calculation (F=0, A=2)
Amplitude
2.00
1.60
1.20
0.80
0.40
0.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Frequency

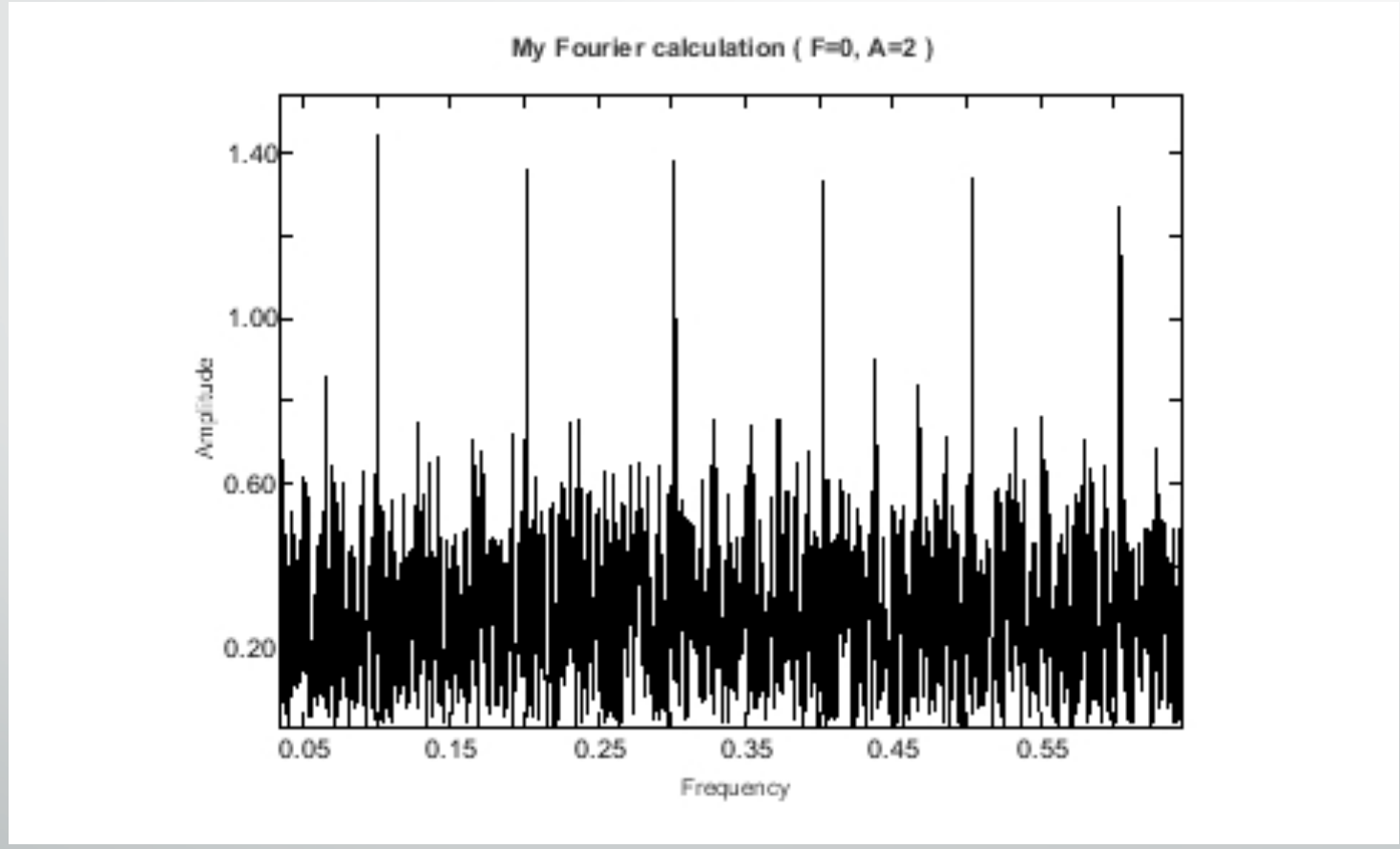

Phase curve of KIC 11904151
Relative flux
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
-2.00E-04
-4.00E-04
-6.00E-04
-8.00E-04
-1.00E-03
-1.20E-03
47.6
47.7
47.8
47.9
48
48.1
48.2
48.3
48.4
48.5
48.6
Days

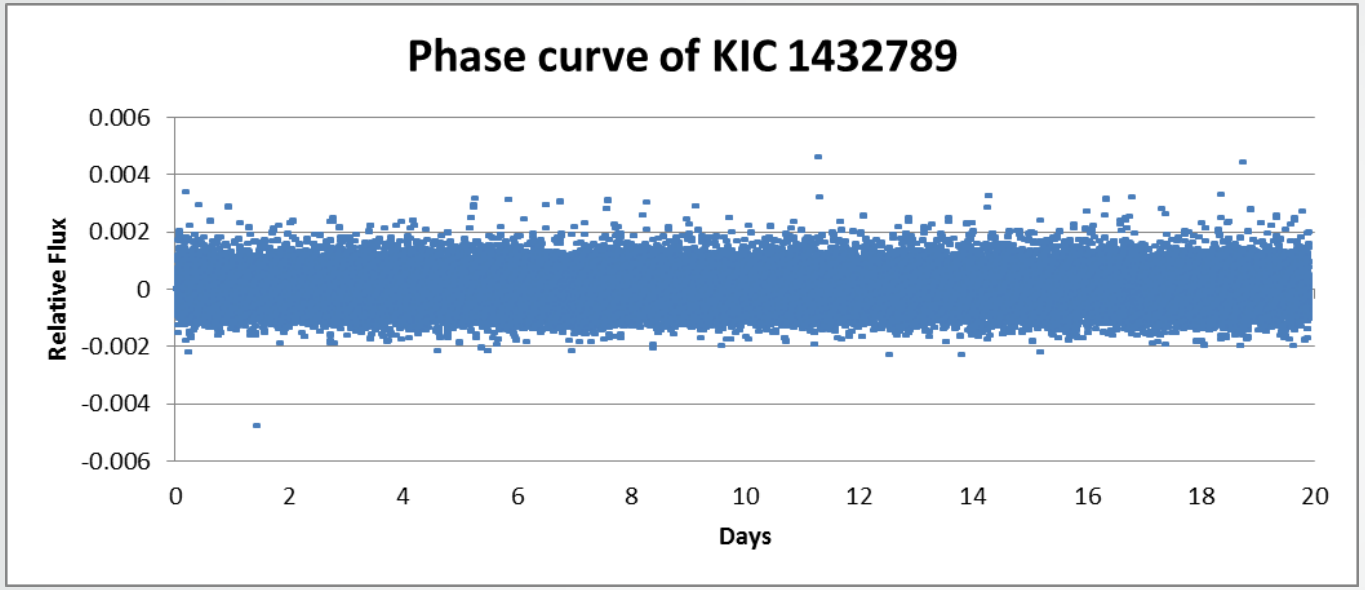

Phase curve of KIC 11904151
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
-1.00E-04
-2.00E-04
-3.00E-04
-4.00E-04
-5.00E-04
-6.00E-04
-7.00E-04
Relative flux
47.6
47.7
47.8
47.9
48
48.1
48.2
48.3
48.4
48.5
48.6
Days

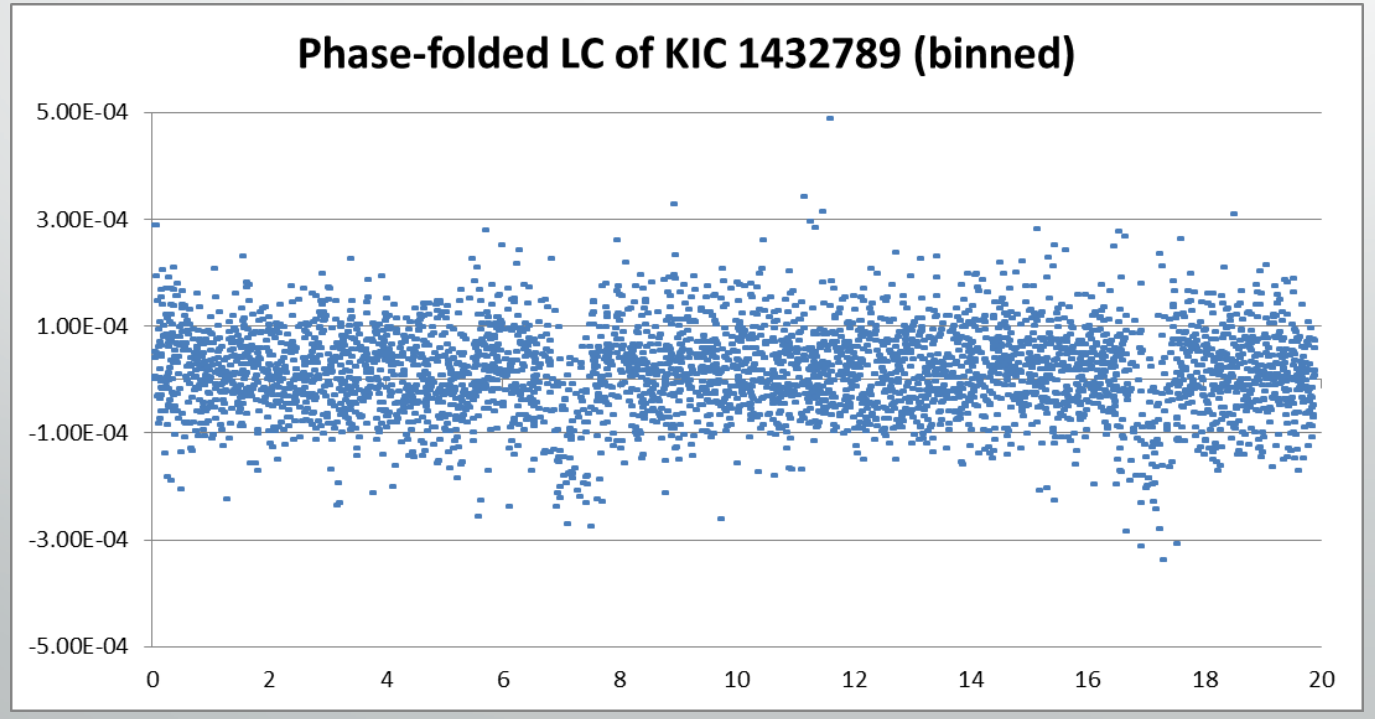
Kepler-10c	
Transit and orbital parameters	
Orbital period P (days)	45.29601 (45.29430)
Transit duration (hours)	7.392 (6.868)
Radius ratio (R_p/R_*)	0.021679 (0.02019)
Inclination i (deg)	88.8 (89.59)
Distance to stellar radius Ratio, a/R_*	48.71 (47.9)
Impact parameter b	0.9516 (0.36)
Planetary parameters	
Planet mass M_p (Earth masses)	- (17.2)
Planet radius R_p (Earth radii)	2.5212 (2.35)
Orbital semi-major axis a (AU)	0.2413 (0.2372)

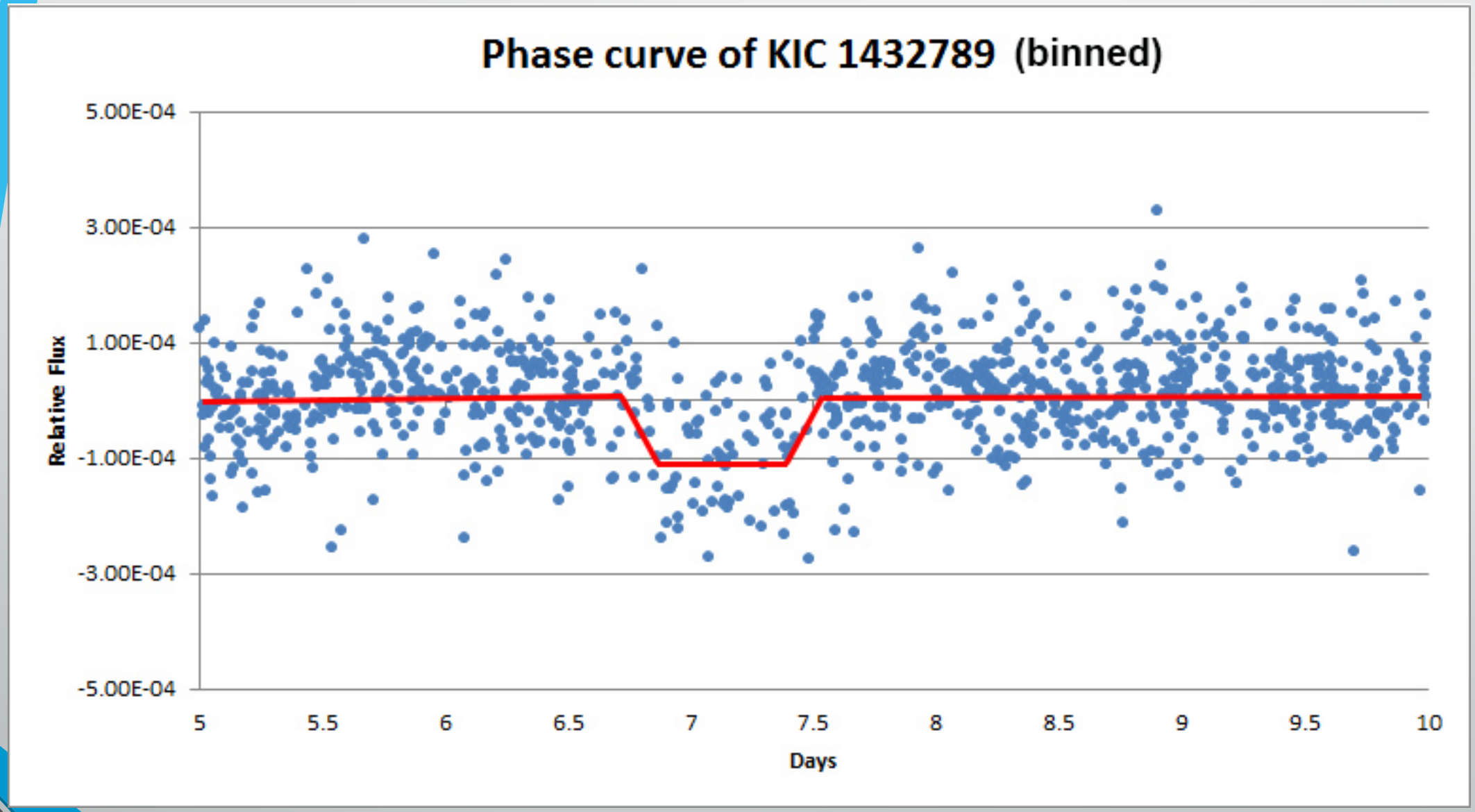
Table. Transit, orbital and planetary parameters of Kepler-10c. Values in parenthesis are taken from the literature.

Kepler-745 (KIC 1432789)




Phase curve of KIC 1432789
Relative Flux
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
0
2
4
6
8
10
12
14
16
18
20
Days


Phase-folded LC of KIC 1432789 (binned)
5.00E-04
3.00E-04
1.00E-04
-1.00E-04
-3.00E-04
-5.00E-04
0
2
4
6
8
10
12
14
16
18
20


Phase curve of KIC 1432789 (binned)
5.00E-04
3.00E-04
1.00E-04
-1.00E-04
-3.00E-04
-5.00E-04
Relative Flux
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
Days

Kepler-745b	
Transit and orbital parameters	
Orbital period P (days)	9.93493 (9.93144)
Transit duration (hours)	19.30 (5.659)
Radius ratio (R_p/R_*)	0.010954 (0.01922)
Inclination i (deg)	87.06 (-)
Distance to stellar radius Ratio, a/R_*	18.95 (-)
Impact parameter b	0.9728 (-)
Planetary parameters	
Planet mass M_p (Earth masses)	- (-)
Planet radius R_p (Earth radii)	1.24 (2.16)
Orbital semi-major axis a (AU)	0.0916 (-)

Table. Transit, orbital and planetary parameters of Kepler-745b. Values in parenthesis are taken from the literature.

$$l_{in} = \left(l_{in,sun} - a_{in}T_* - b_{in}T_*^2\right)\left(\frac{L}{L_{sun}}\right)^{1/2}$$

(Selsis et al, 2007)

$$l_{out} = \left(l_{out,sun} - a_{out}T_* - b_{out}T_*^2\right)\left(\frac{L}{L_{sun}}\right)^{1/2}$$

For Kepler 745 we calculated:

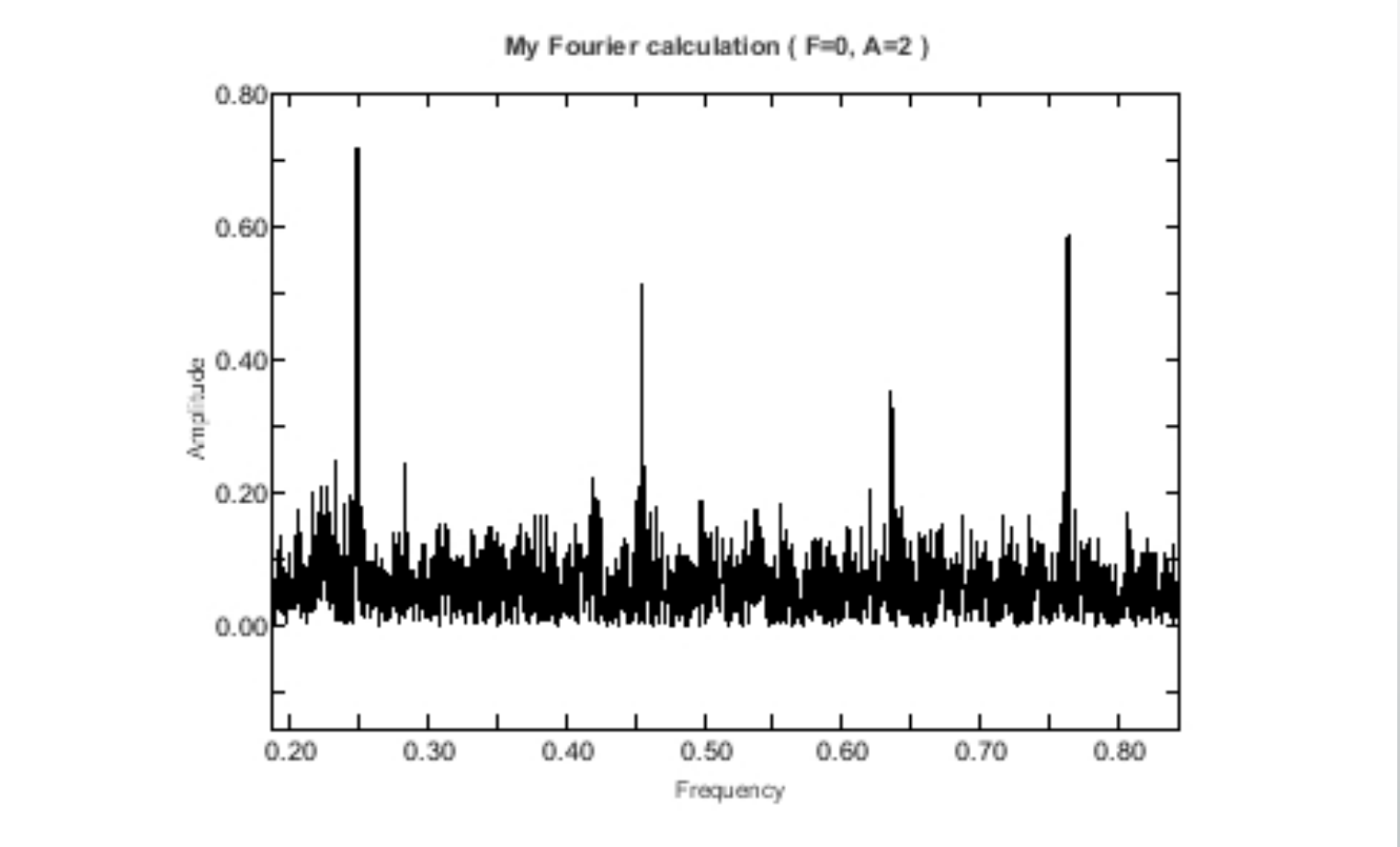
$$l_{in} = 0.7839\ AU \qquad l_{out} = 1.9158\ AU$$

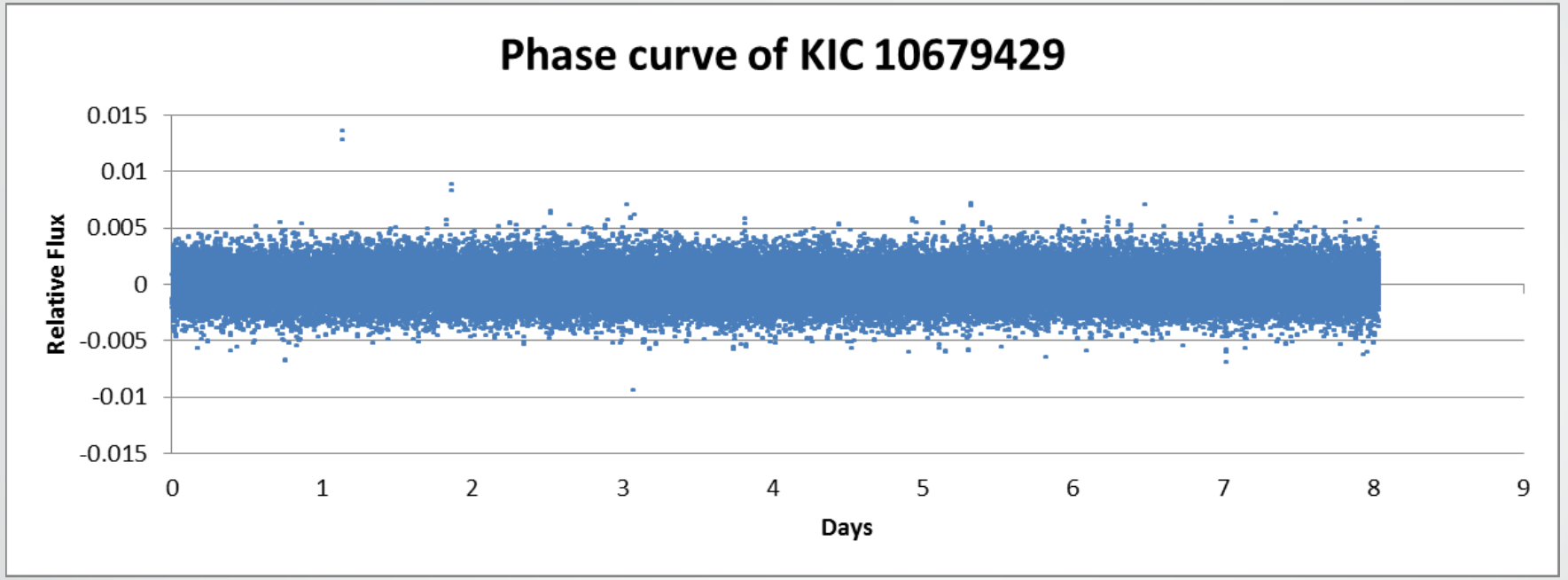
while Kepler's 745b semimajor axis:

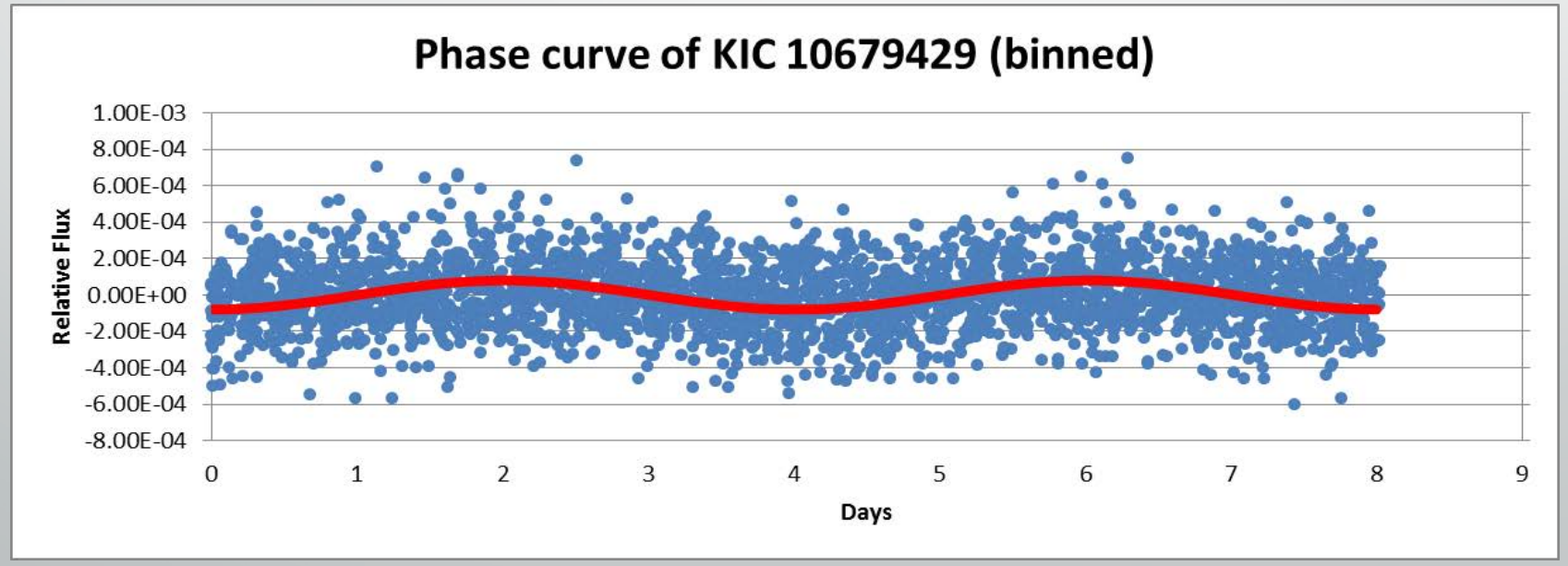
$$a = 0.0916\ \ AU$$

Artist’s concept of CoRoT 7b, a planet similar to Kepler-745b.

KIC 10679429




Phase curve of KIC 10679429
Relative Flux
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0
1
2
3
4
5
6
7
8
9
Days


Phase curve of KIC 10679429 (binned)
Relative Flux
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
-2.00E-04
-4.00E-04
-6.00E-04
-8.00E-04
0
1
2
3
4
5
6
7
8
9
Days

KIC 10679429	
Pulsation parameters	
Pulsation period P (days)	4.01568
Pulsation amplitude (relative flux)	$8 \cdot 10\uparrow{-5}$
Absolute magnitude	-3.02845
Distance (Kpc)	16.26

Table. Parameters of KIC 10679429 under the hypothesis of a Cepheid variable.

Future Plans

1. A more accurate method should be applied to define the critical event threshold.
2. Implement more complex models taking into account additional stellar phenomena like the limb darkening.
3. Expand our research to the CoRoT and the K2 Missions.

Thank you for your attention!!