Photometric Gravitational Microlensing observed by Gaia

Katarzyna Kruszyńska, Łukasz Wyrzykowski, M. Gromadzki, P. Zieliński,
K. Rybicki, M. Zieliński (Astronomical Observatory, University of Warsaw)

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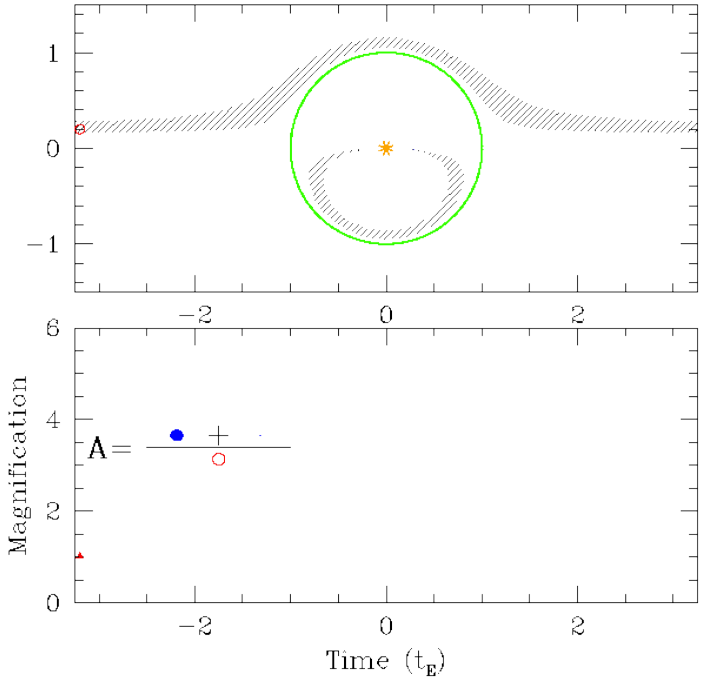
Gravitational Microlensing

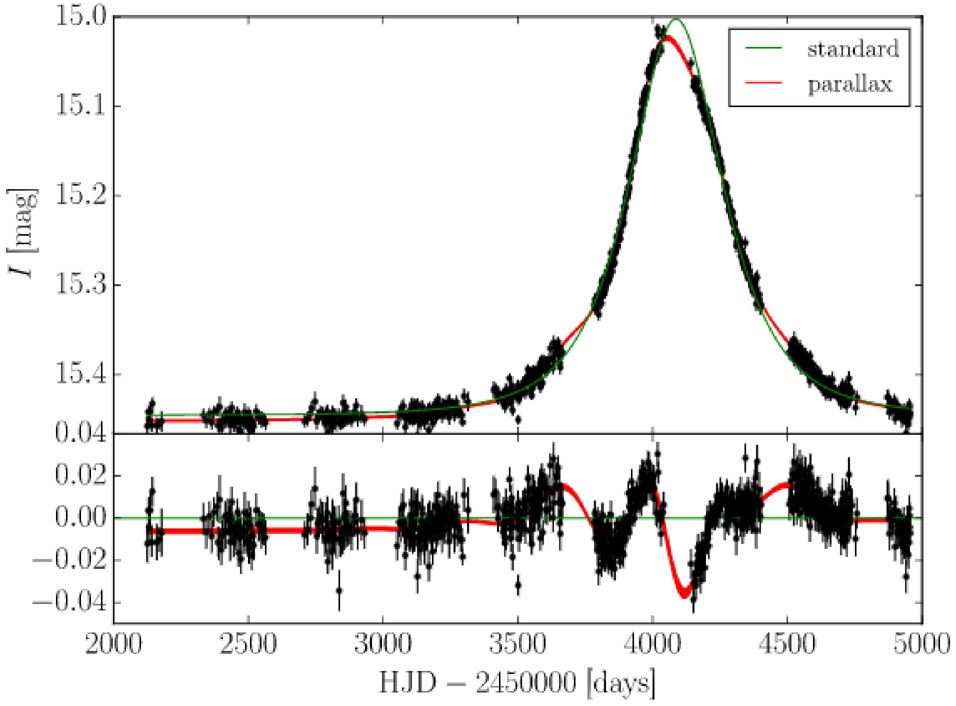
- **Theoretical lightcurve**
  →Paczynski curve
  (Paczynski 1986, 1996)
- **Model parameters for single lens:**
  - impact parameter u_0
  - time of maximum t_0
  - timescale of event t_E (Einstein time)



Source: S. Gaudi,
http://www.astronomy.ohio-state.edu/~gaudi/movies.html

Why care about microlensing?

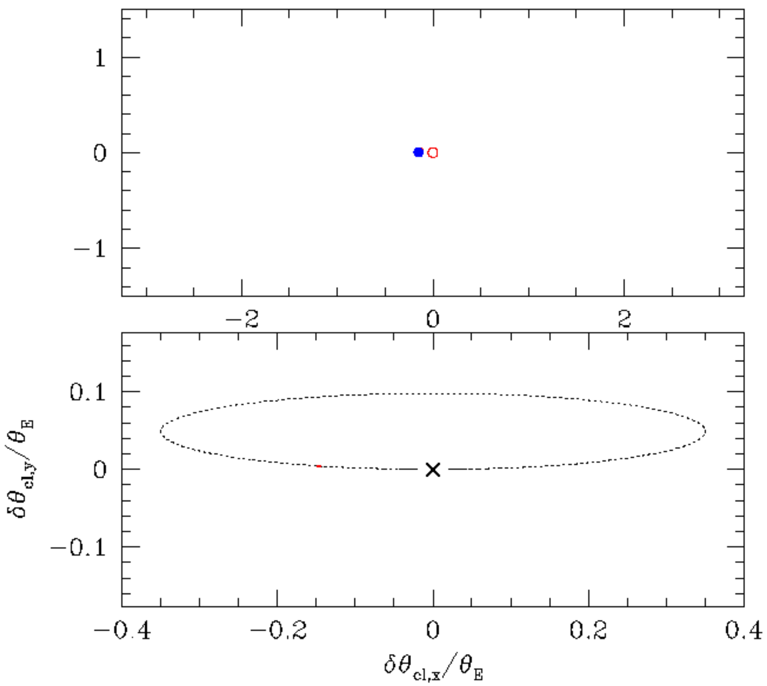
- **Micolensing does not require for the lens to emit light → possible detection of:**
  - Planets
  - Black holes, neutron stars and white dwarfs
- **It is also allows us to analyze the structure of the Milky Way**



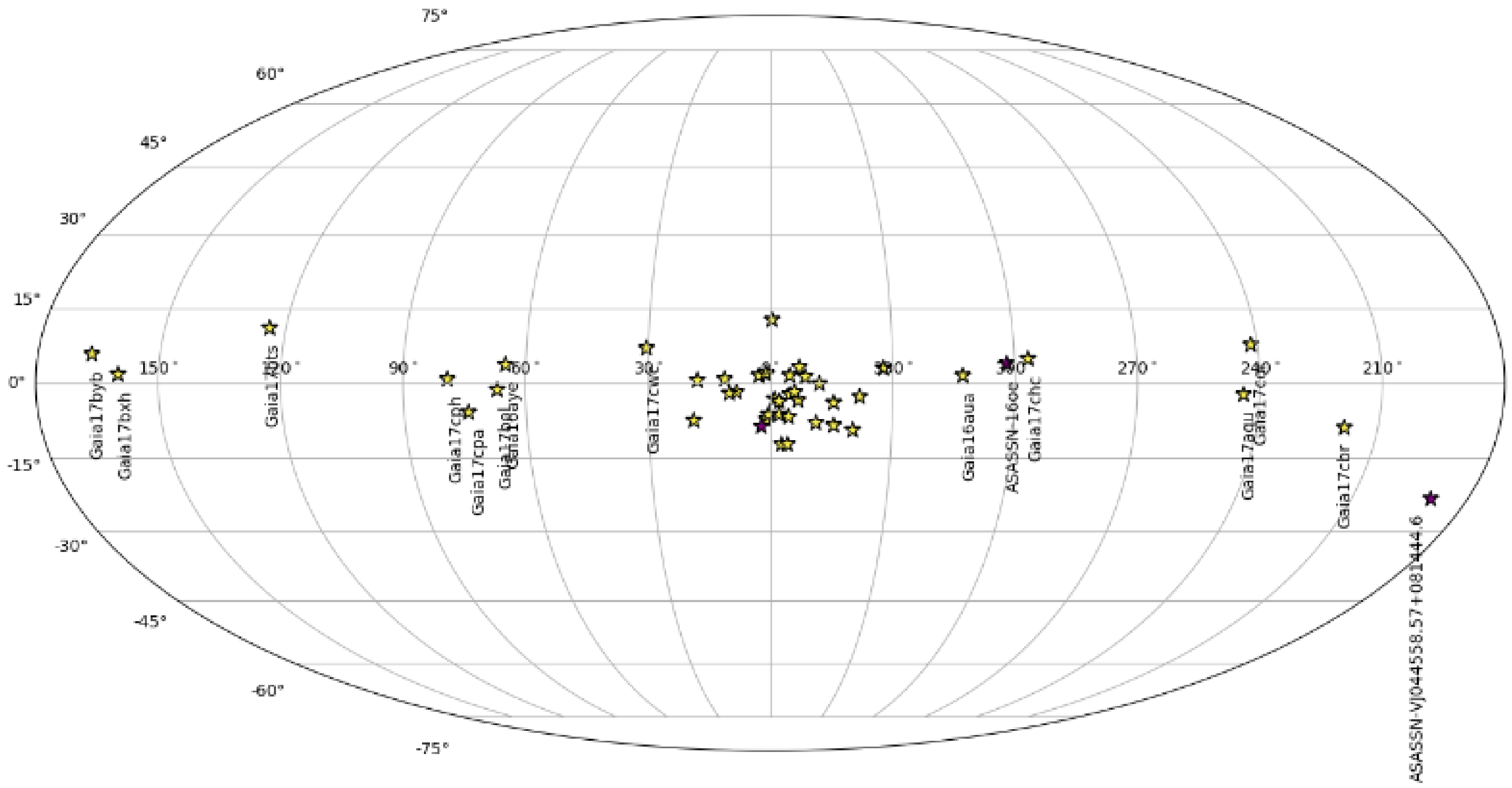
Souce: Wyrzykowski et al. 2016

Why Gaia is important for microlensing?

- **Microlensing:**
  - Photometric
  - Astrometric
- **Gaia is an astrometric mission!**
- **Possible detection of astrometric microlensing for stars brighter than G=15.5 (see: Kris Rybicki's presentation)**

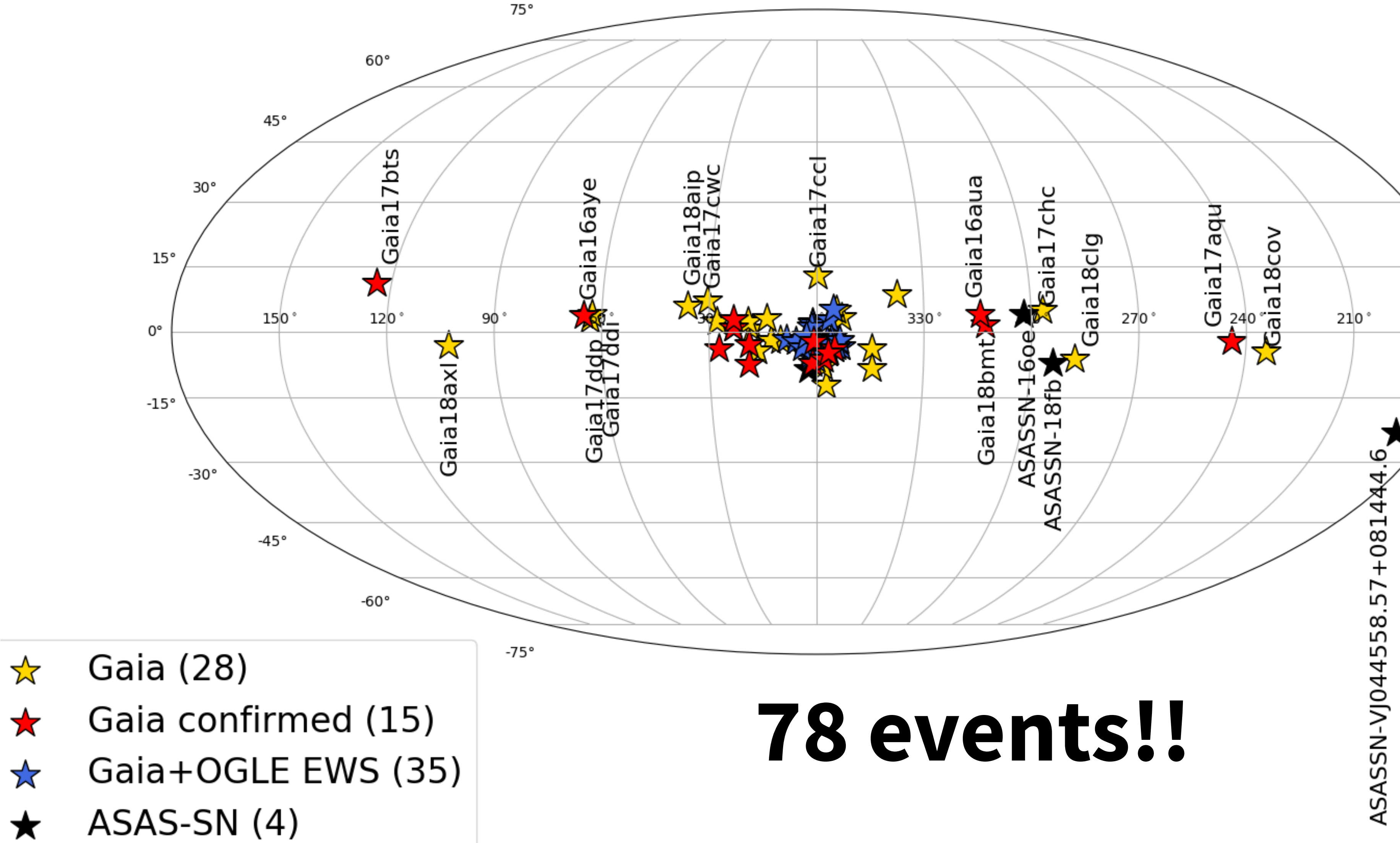


Microlensing observed by Gaia (last year)



~30 events

Microlensing observed by Gaia (most recent)

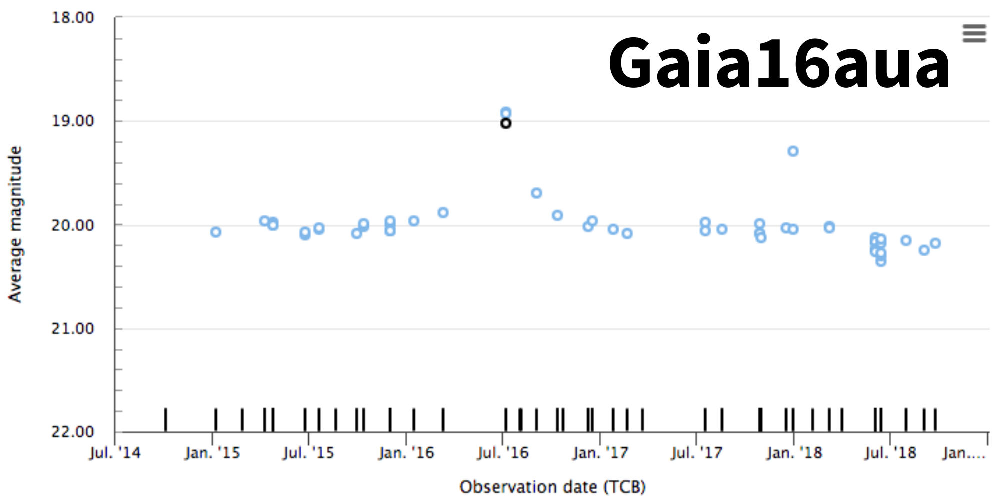


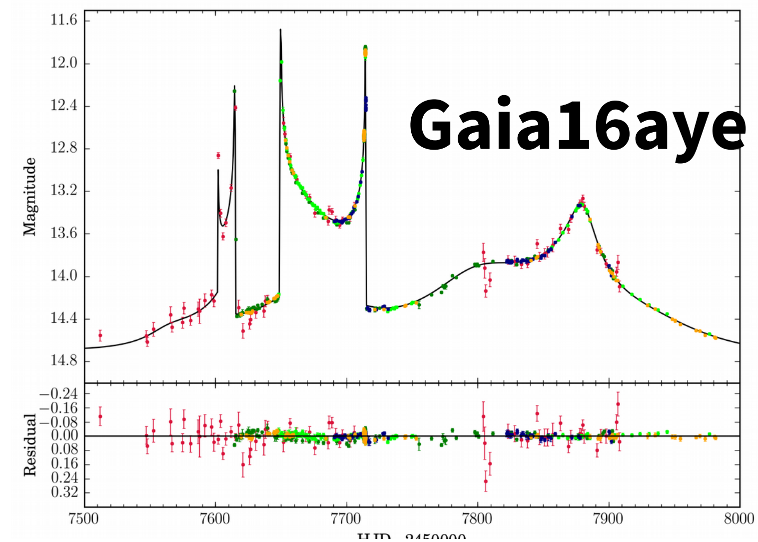
78 events!!

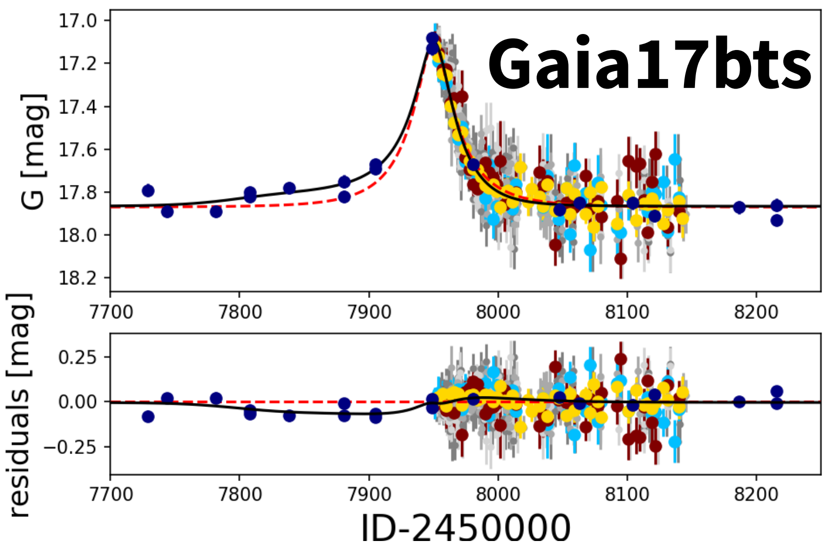
Microlensing in Gaia: overall

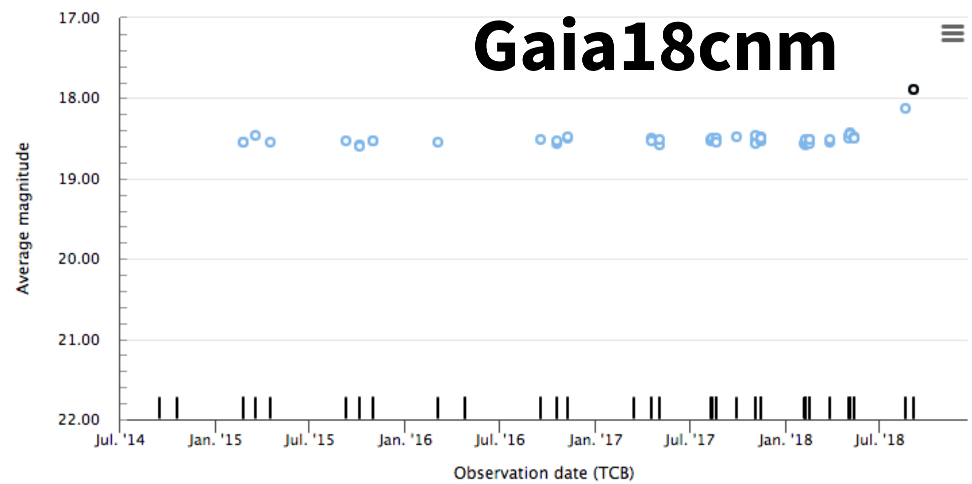
- **Promising candidates get a high resoultion spectrum done with VLT or Gemini-North**
- **We have:**
  - 15 spectroscopially confirmed candidates
  - 28 candidates
  - 35 candidates, that were also observed by OGLE (EWS)
- **5 events have been missed (that we know of…)**
  - 1: Kojima event, found by an amateur astronomer
  - 4: detected by ASAS-SN

Highlights

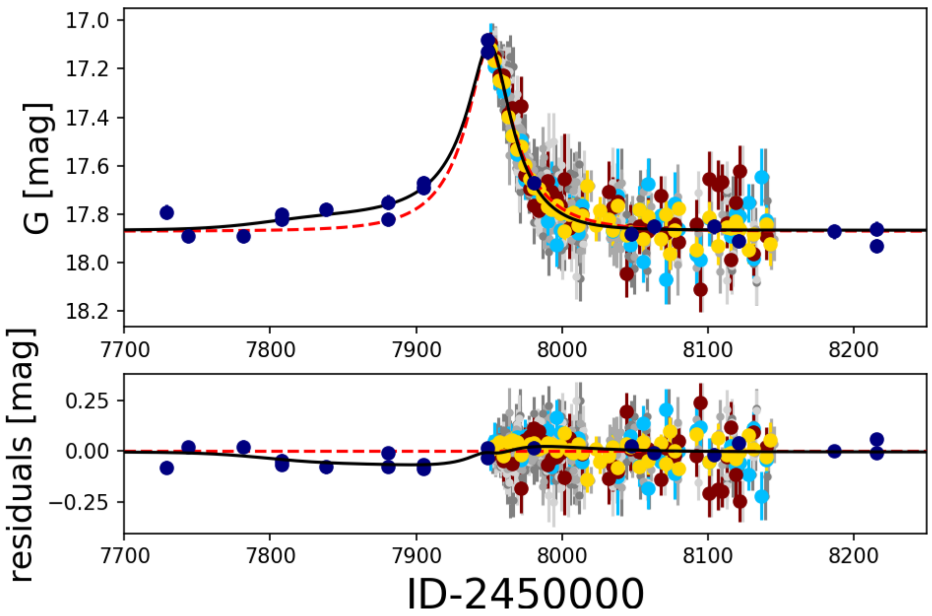

Gaia16aua
Average magnitude
18.00
19.00
20.00
21.00
22.00
Jul. '14
Jan. '15
Jul. '15
Jan. '16
Jul. '16
Jan. '17
Jul. '17
Jan. '18
Jul. '18
Observation date (TCB)

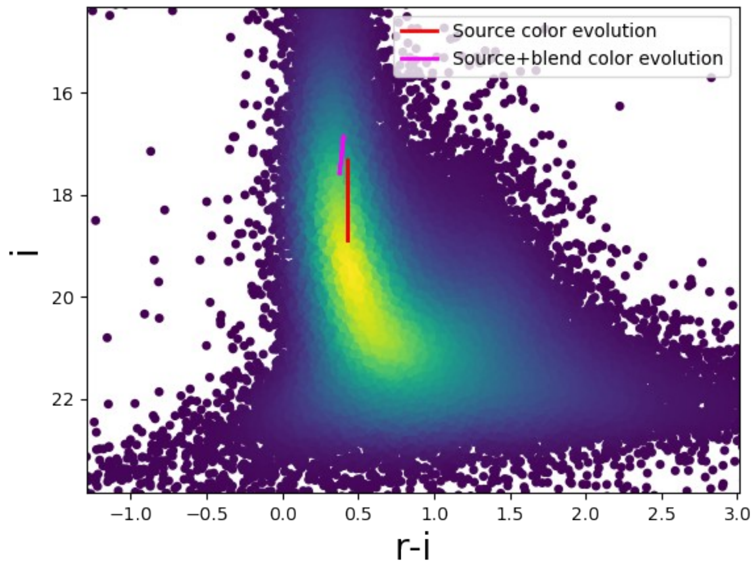

Gaia16aye
Magnitude
Residual
7500
7600
7700
7800
7900
8000


Gaia17bts
G [mag]
17.0
17.2
17.4
17.6
17.8
18.0
18.2
residuals [mag]
0.25
0.00
−0.25
7700
7800
7900
8000
8100
8200
ID-2450000


Gaia18cnm
Average magnitude
17.00
18.00
19.00
20.00
21.00
22.00
Jul. '14
Jan. '15
Jul. '15
Jan. '16
Jul. '16
Jan. '17
Jul. '17
Jan. '18
Jul. '18
Observation date (TCB)

Highlights: Gaia17bts



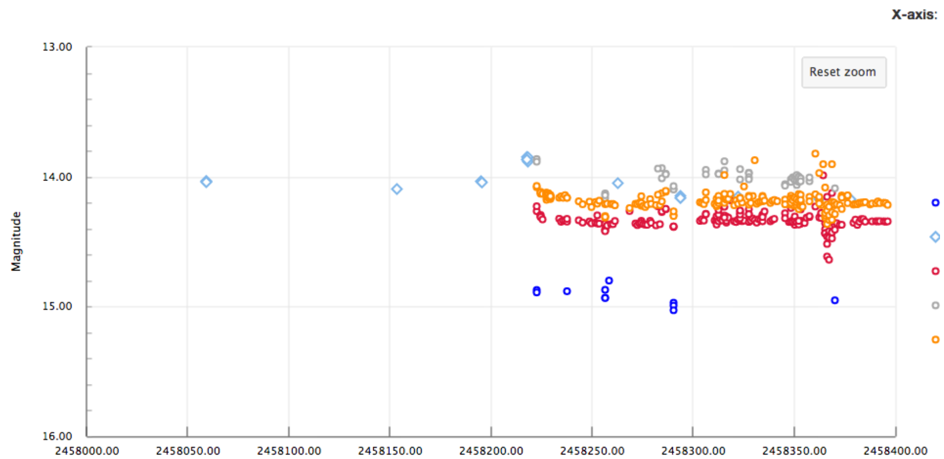


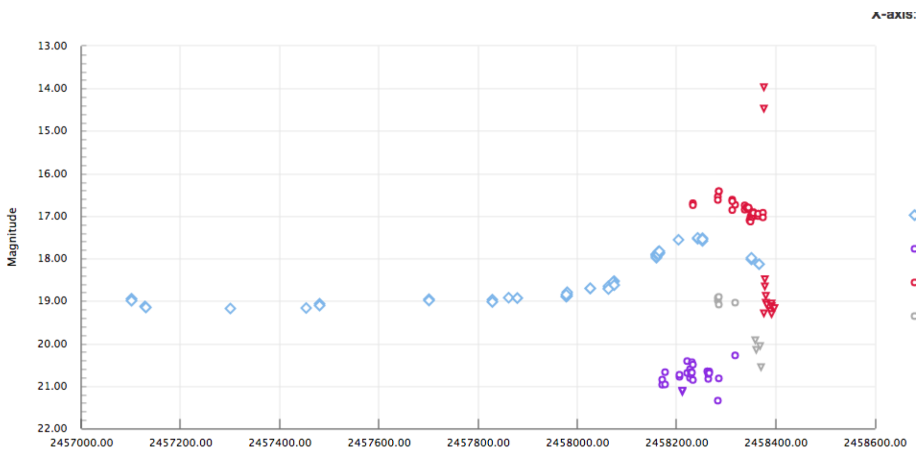
- **Latest model:**

  t_0 = 2457950.18, u_0 = 0.274, t_E = 43.81 d, I_{01} = 17.87, f_{sGaia} = 0.37, f_{sV} = 0.35

- **Very noisy follow-up data…**
- **Minor parallax effect can be seen in Gaia data, but not in the follow-up**

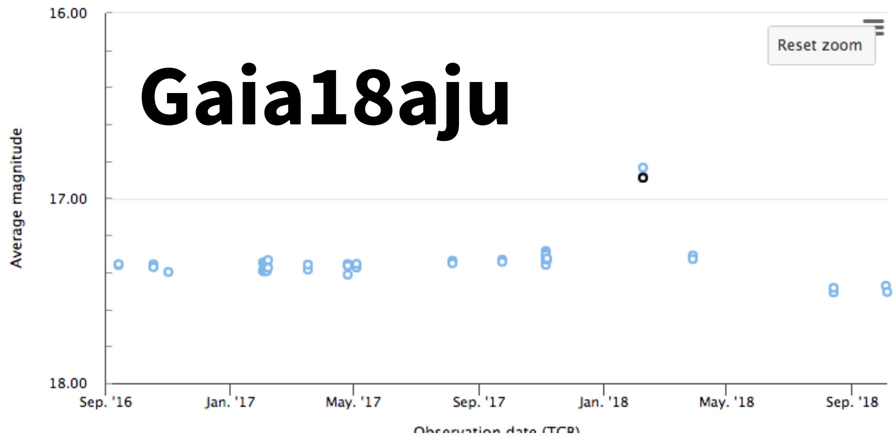
Highlights: Gaia18axl and Gaia18ajz

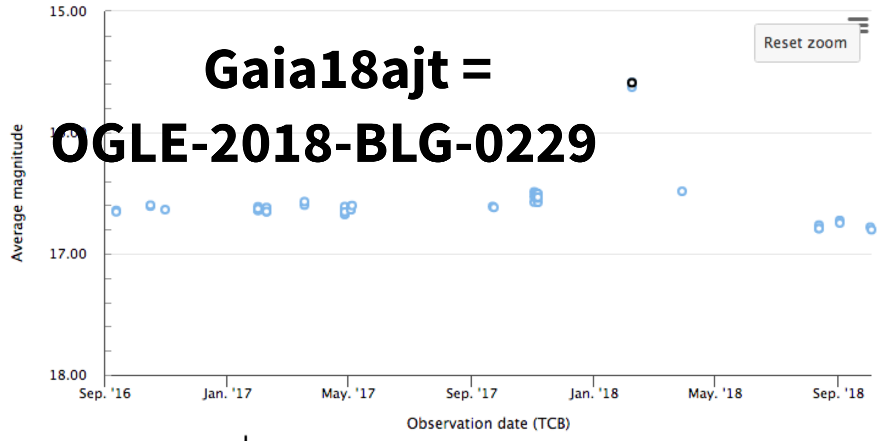


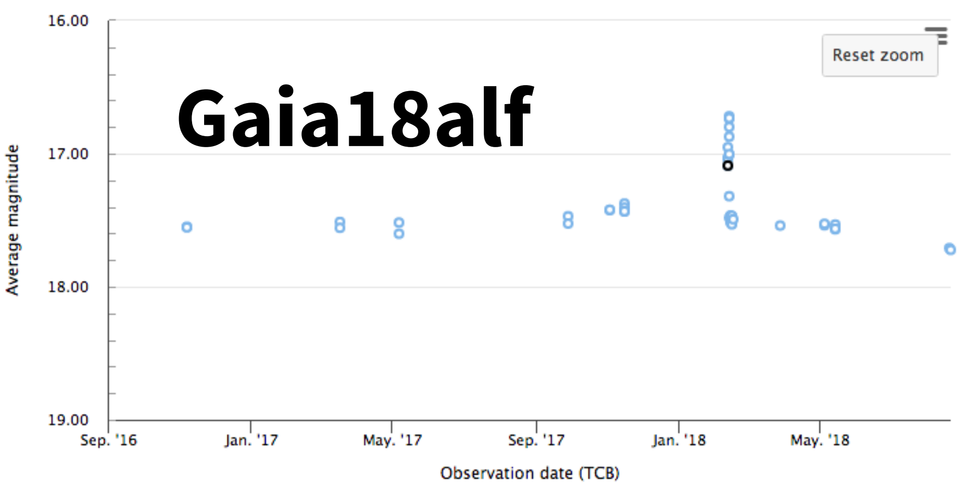


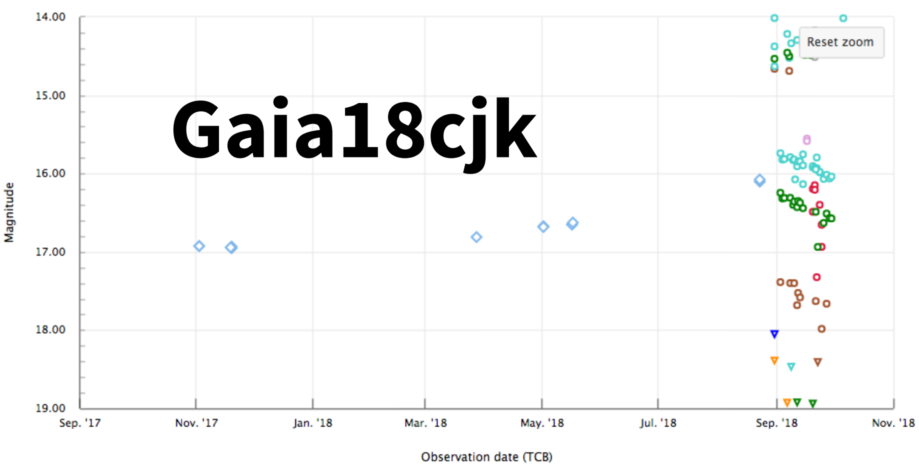
- **Gaia18axl:**
  - A short microlensing event candidate in the Northern part of Milky Way
- **Gaia18ajz:**
  - A long microlensing event (confirmed!) in the Southern part of the Milky Way (outside Bulge)

Highlights: Confirmed events

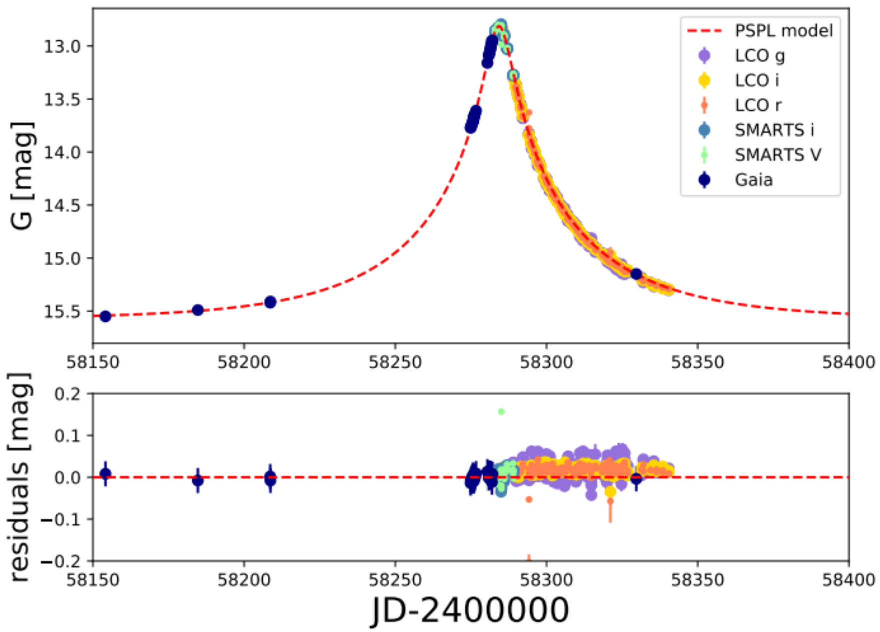








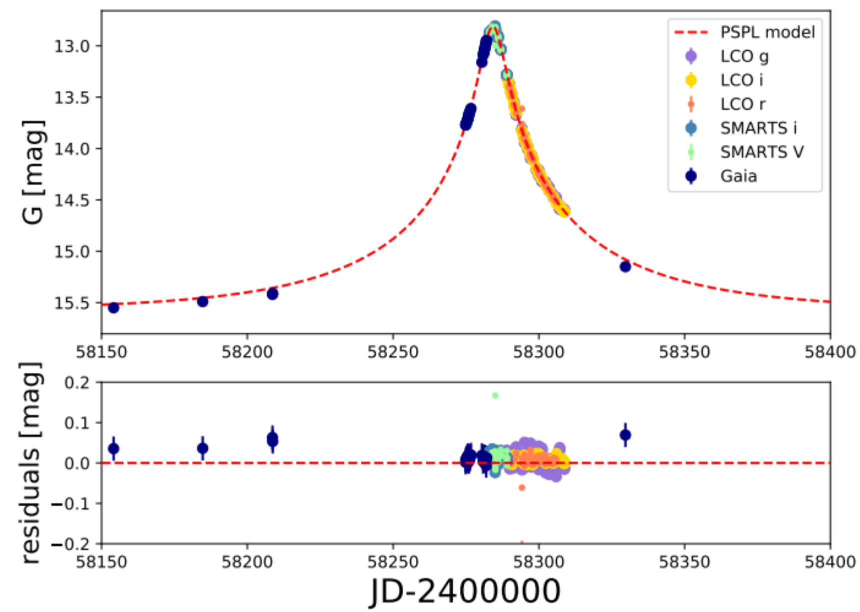
Why follow-up is important



$t_0 = 58284.29$ $I_{01} = 15.58$

$\underline{u_0 = 0.074}$ $\mathbf{f_{s1} = 0.94}$

$\underline{t_E = 55.81}$



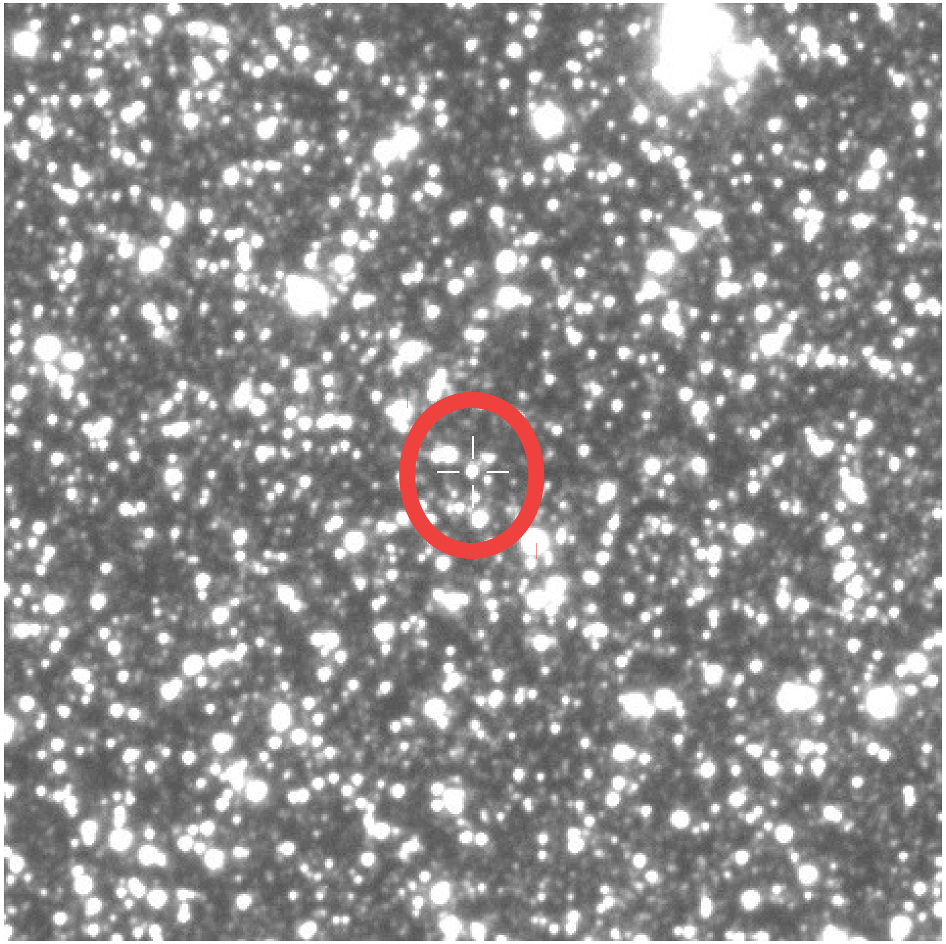
$t_0 = 58284.23$ $I_{01} = 15.58$

$\underline{u_0 = 0.053}$ $\mathbf{f_{s1} = 0.66}$

$\underline{t_E = 76.11}$

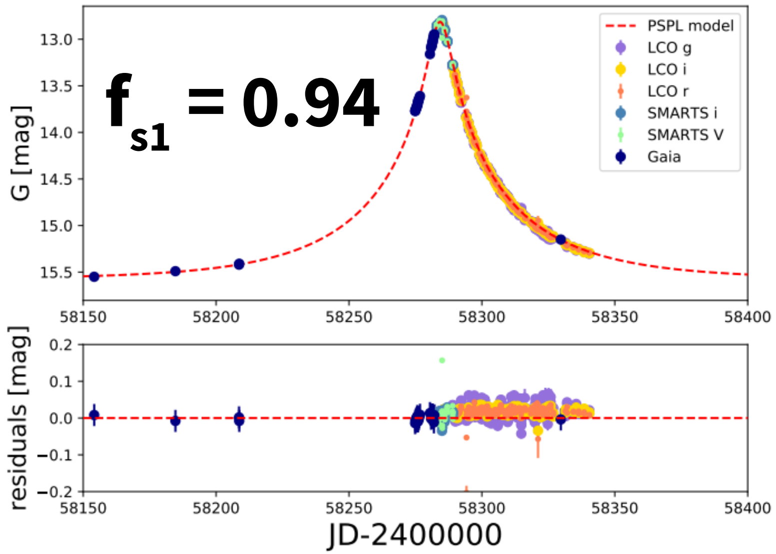
Why follow-up is important: what is blending?

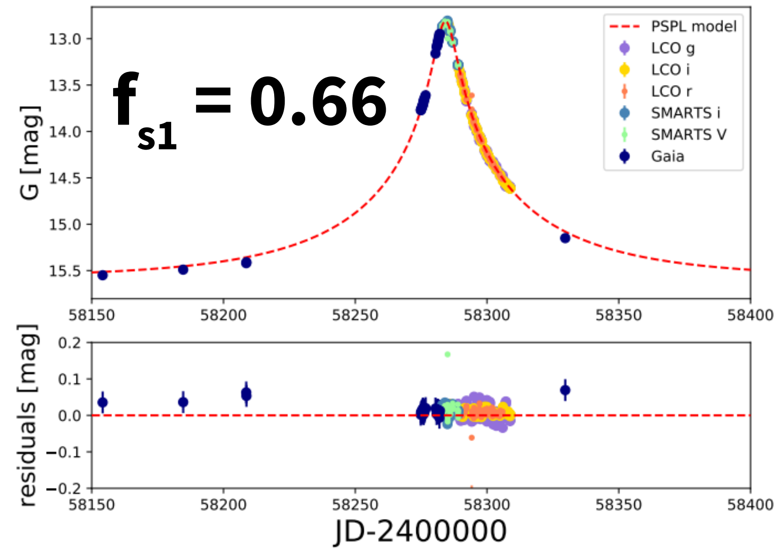
- **In crowded fields, the classical model needs to be expanded**
- **Additional parameter: blending (f_s) →** represents the „third light” coming from the stars surrounding the source
- **Low f_s => lens is a black hole? Or a planet?**



Source: OGLE, http://ogle.astrouw.edu.pl/ogle4/ews/blg-0034.html

Why follow-up is important





- **Parameters of an event depend heavily on the amount of acquired data**
- **Least robust parameter is blending!!! t_E and u_0 are also fragile!**

Additional way of finding microlensing in Gaia?

- **Looking at a 10^9 lightcurves is impossible…**
- **Maybe using some statistics will help?**
  - Skewness of the histogram of brightness
  - Eta or Abbe value (Eta = 2 Abbe)
- **Abbe and skewness were calculated for 0.5mln stars in DR2!**

the variance,

$$s^2 = \frac{1}{n}\sum_{\mu=1}^{n}(x_\mu - \bar{x})^2,$$

and also the mean square successive difference

$$\delta^2 = \frac{1}{n-1}\sum_{\mu=1}^{n-1}(x_{\mu+1} - x_\mu)^2.$$

The reasons for the study of the distribution of the mean square successive difference δ^2, in itself as well as in its relationship to the variance s^2, have been set forth in a previous publication[2], to which the reader is referred. The distribution of δ^2, and in particular its moments, were also studied there. The present paper is devoted to the investigation of the ratio

$$\eta = \frac{\delta^2}{s^2}.$$

Source: J. von Neumann, 1941

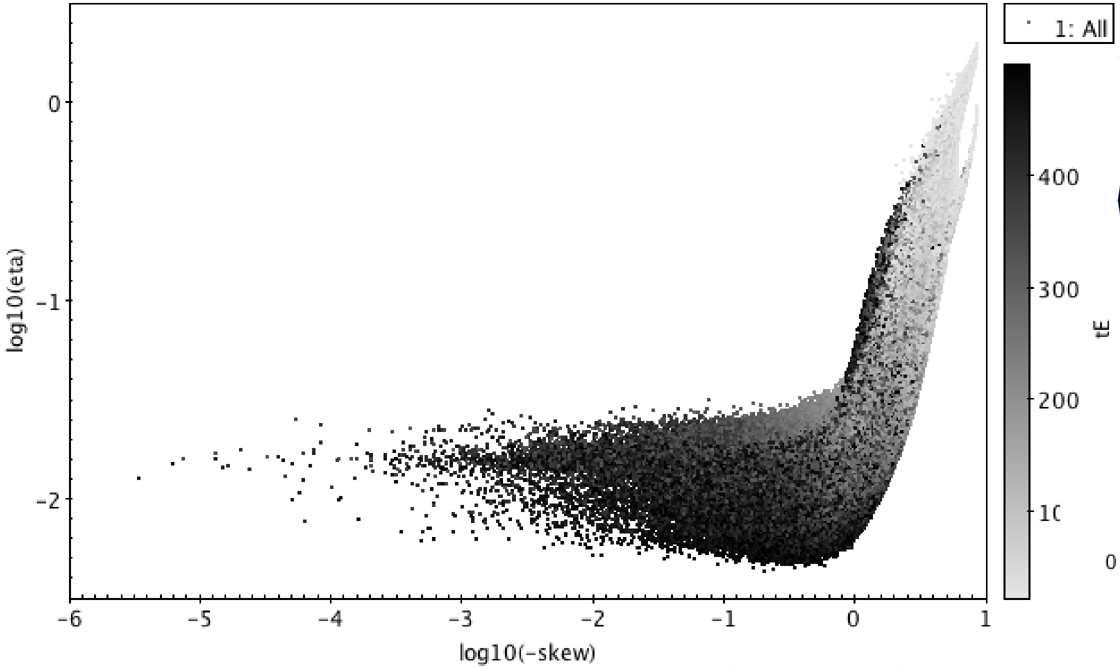
2. The method

We consider a time series $\{t_i, y_i\}$ of values y_i measured at times t_i, where i is an index running over the number of measurements n. The Abbe value $\mathcal{A}$ is defined as (von Neumann 1941, 1942)

$$\mathcal{A} = \frac{n}{2(n-1)} \frac{\sum_{i=1}^{n-1}(y_{i+1} - y_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}, \quad (1)$$

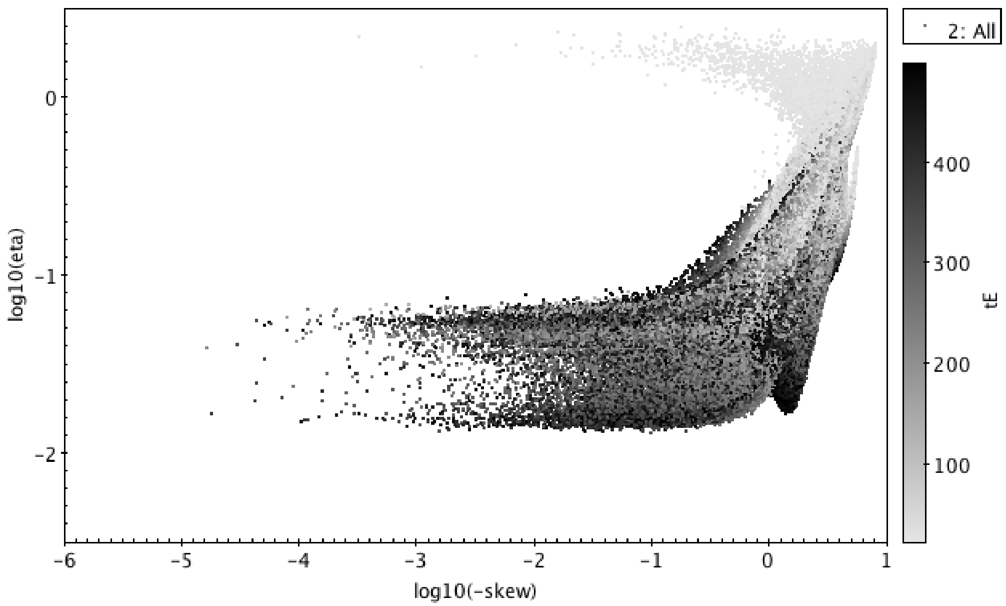
Souce: N. Molavi, 2014

Skew – Eta/Abbe parameter space

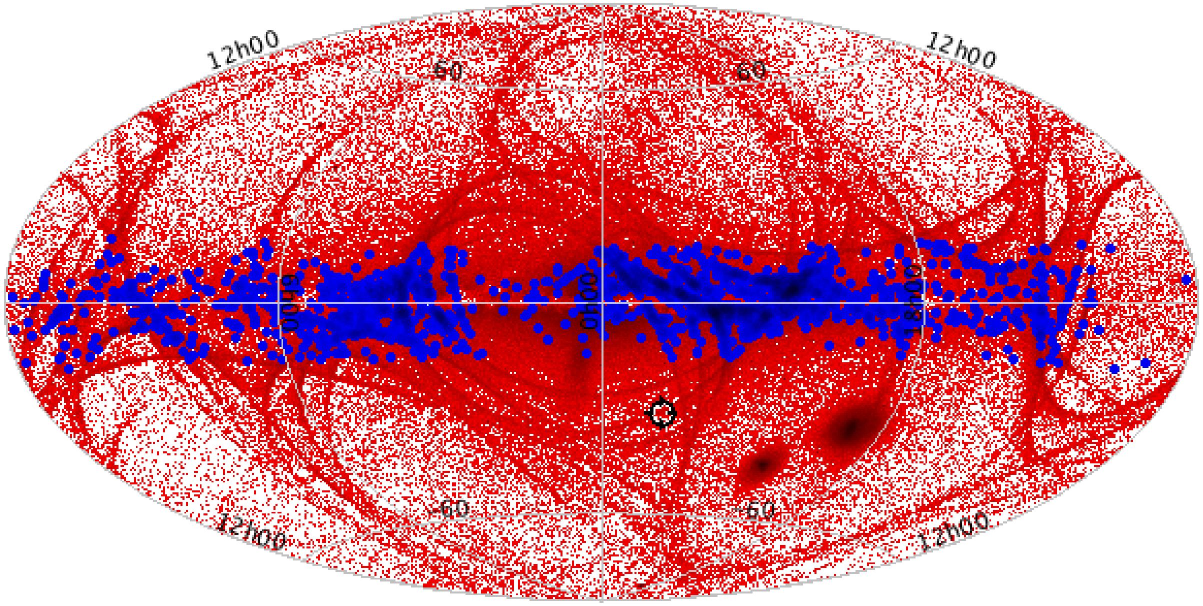


Frequently sampled field by Gaia

Field in Bulge

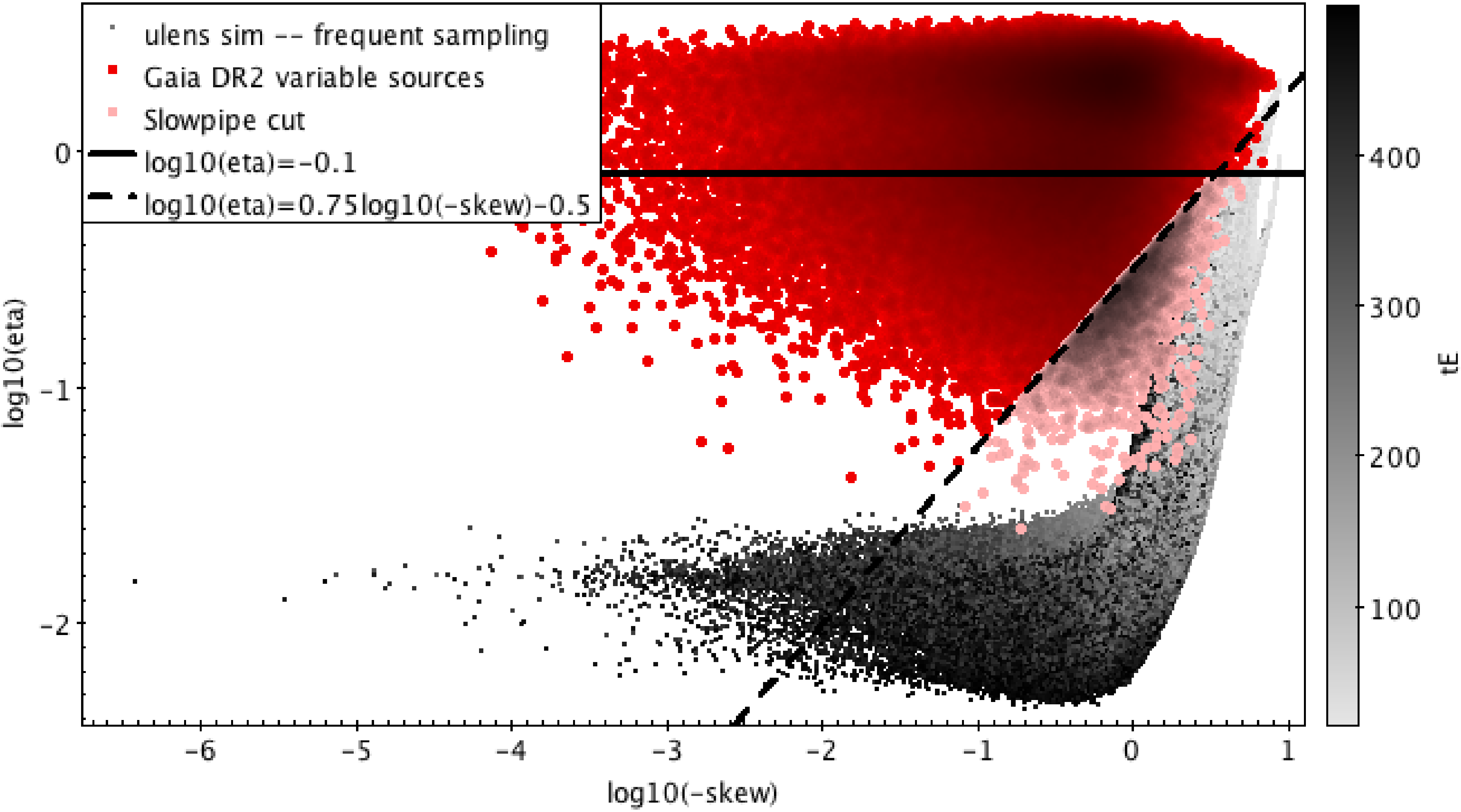


How does it look in DR2?

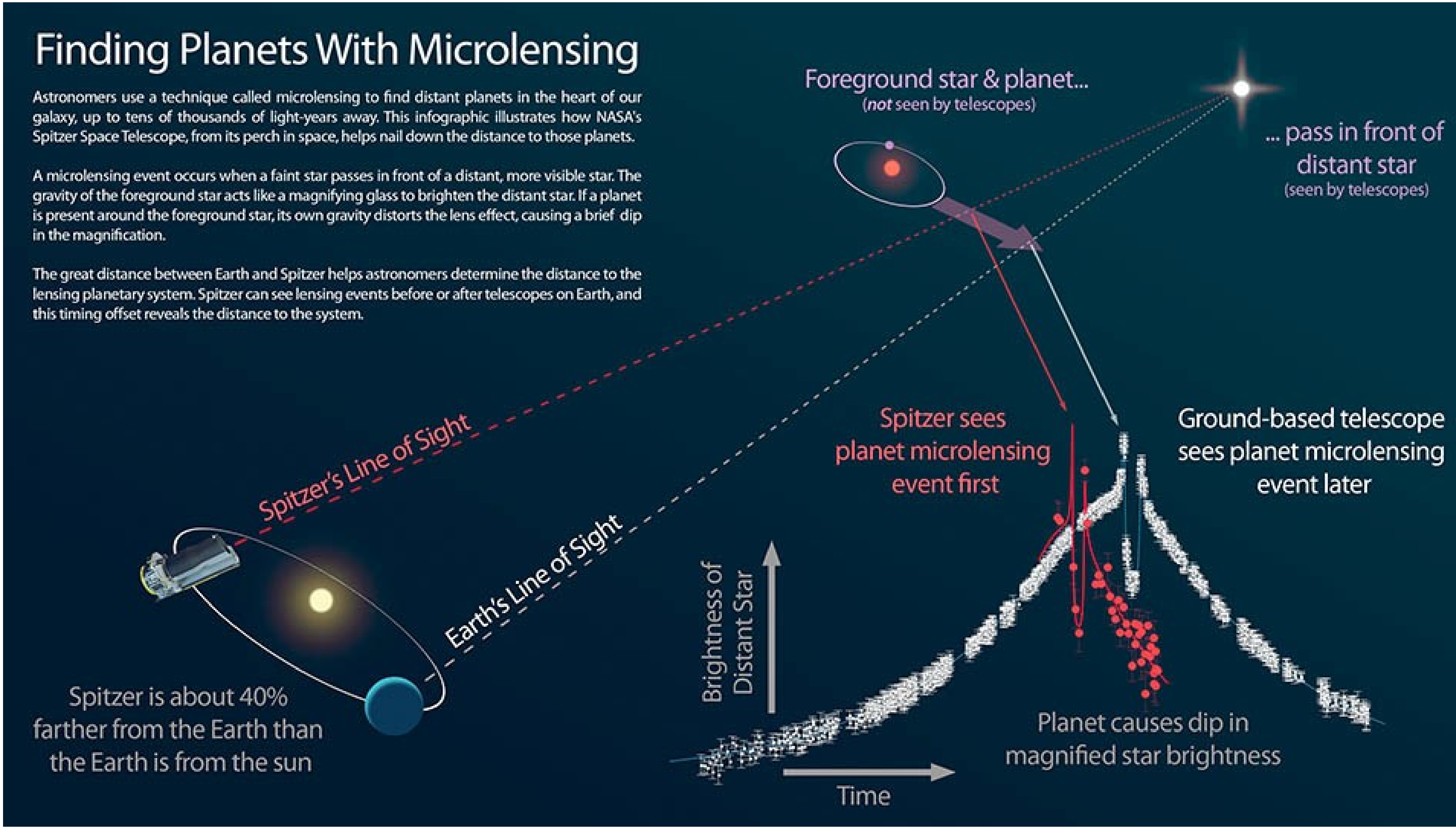


- All stars have to be within Galactic Plane (|b| < 15˚)
- Application of the initial cut left ~2200 candidates
- Additional restriction of G<15.5 (see: Rybicki et al. 2018) left ~1800 candidates

Skew – Eta/Abbe parameter space



New venture: Gaia microlenses and Spitzer



Source: NASA/JPL-Caltech/Warsaw University
http://www.spitzer.caltech.edu/images/6047-sig15-004-Infographic-Finding-Planets-With-Microlensing

Summary

- **Almost 80 candidates detected**
  - 15 events confirmed!
  - But at least 5 missed…
- **Follow-up always welcome! And it is very important!!**
- **New ways of looking for microlensing events**