# Microlensing and Gaia

## Opportunity for a Black Hole search

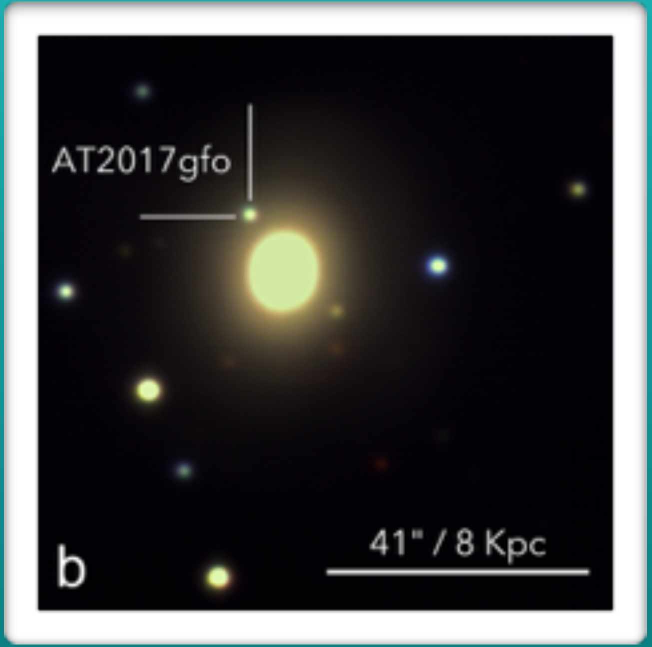
Kris Rybicki
Warsaw University Observatory

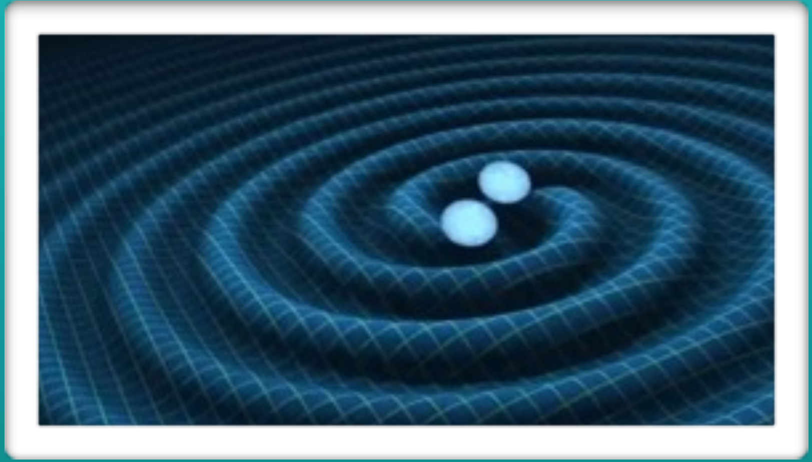
PhD supervisor: Łukasz Wyrzykowski

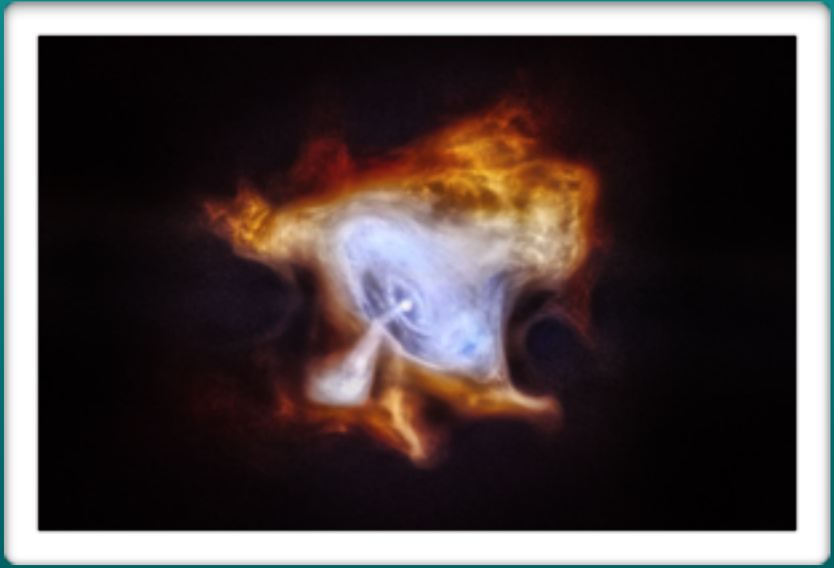
Gaia Science Alerts Workshop,
Vipava, 09.10.2018

# Dark remnants so far

- Around 30 in X-ray binaries
- Few known from GW signal detection
- Young, γ-emitting NSs
- Pulsars
- GW170817 - neutron stars
- Cooled down, isolated NSs
- Stellar origin, isolated BHs

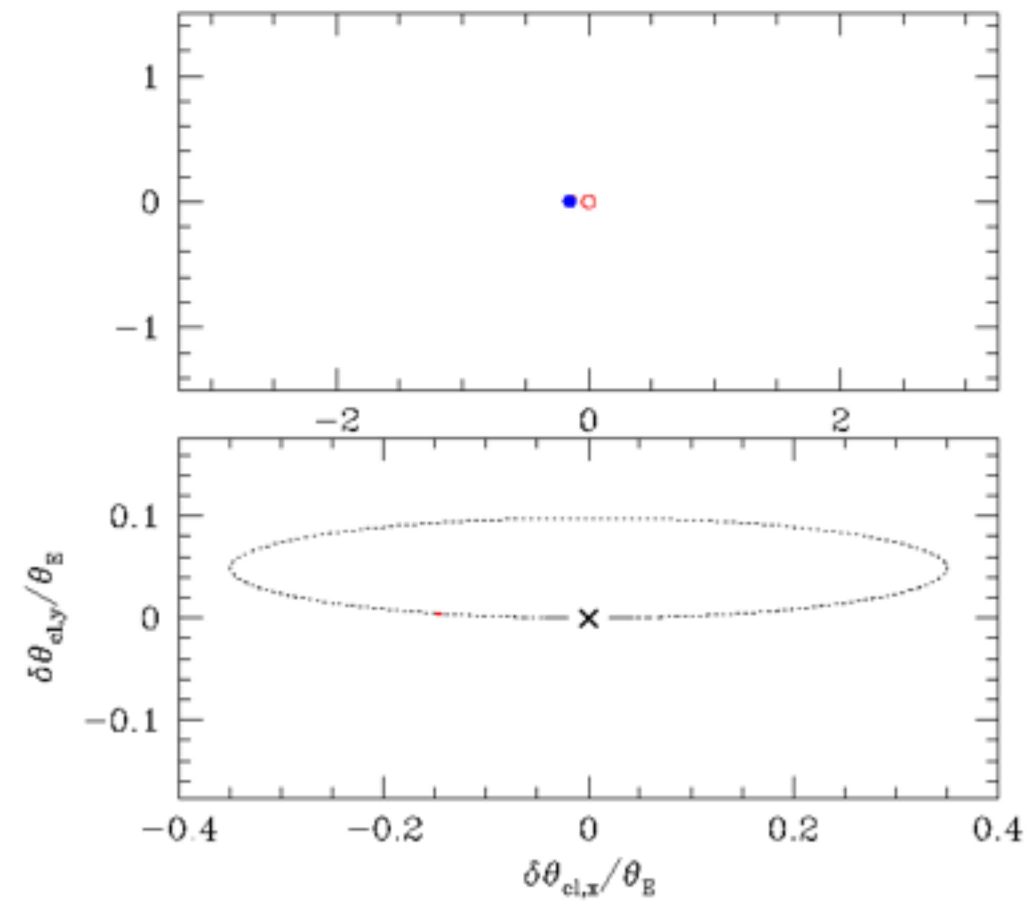




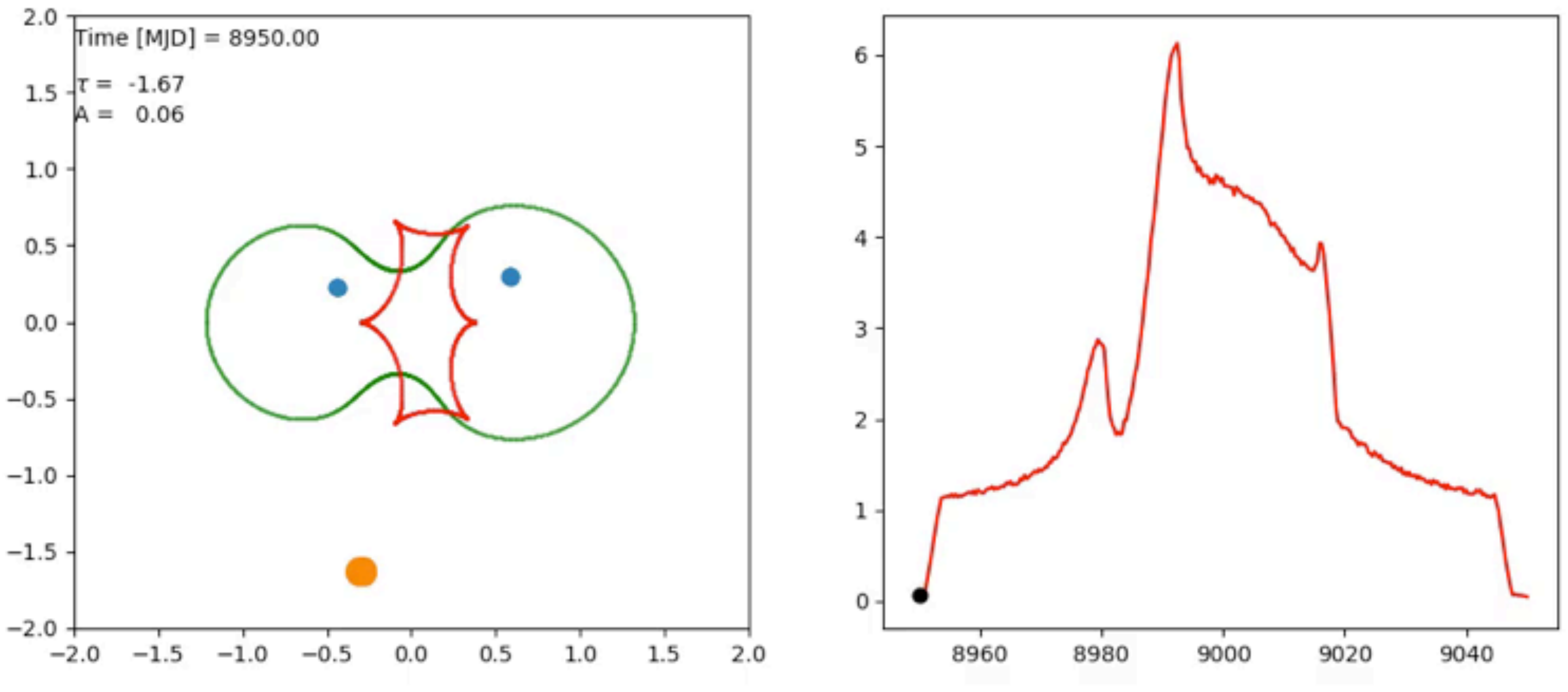
Özel et al. 2010, Kiziltan et al. 2013

# Microlensing



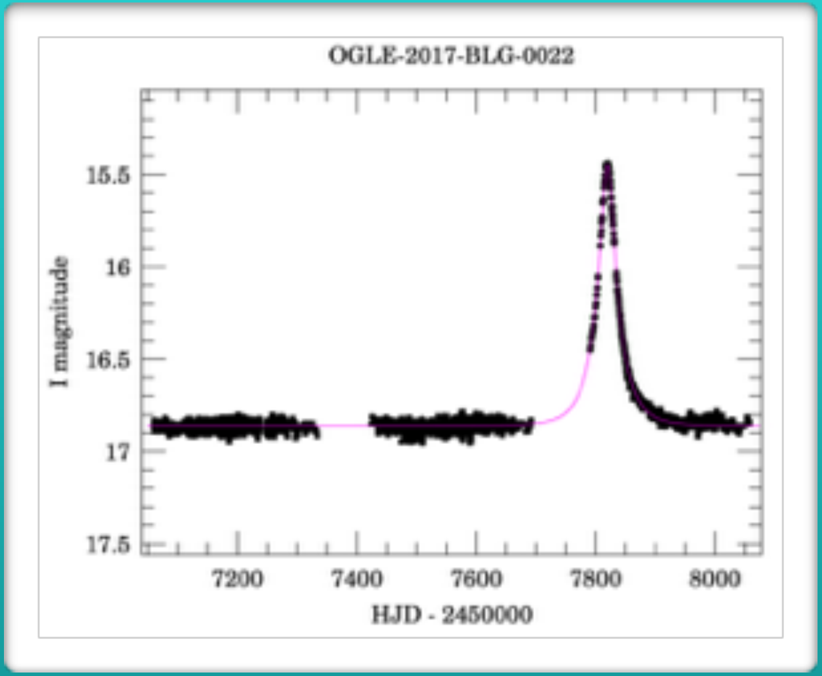

credit: Scott Gaudi

# Digression : binary lenses

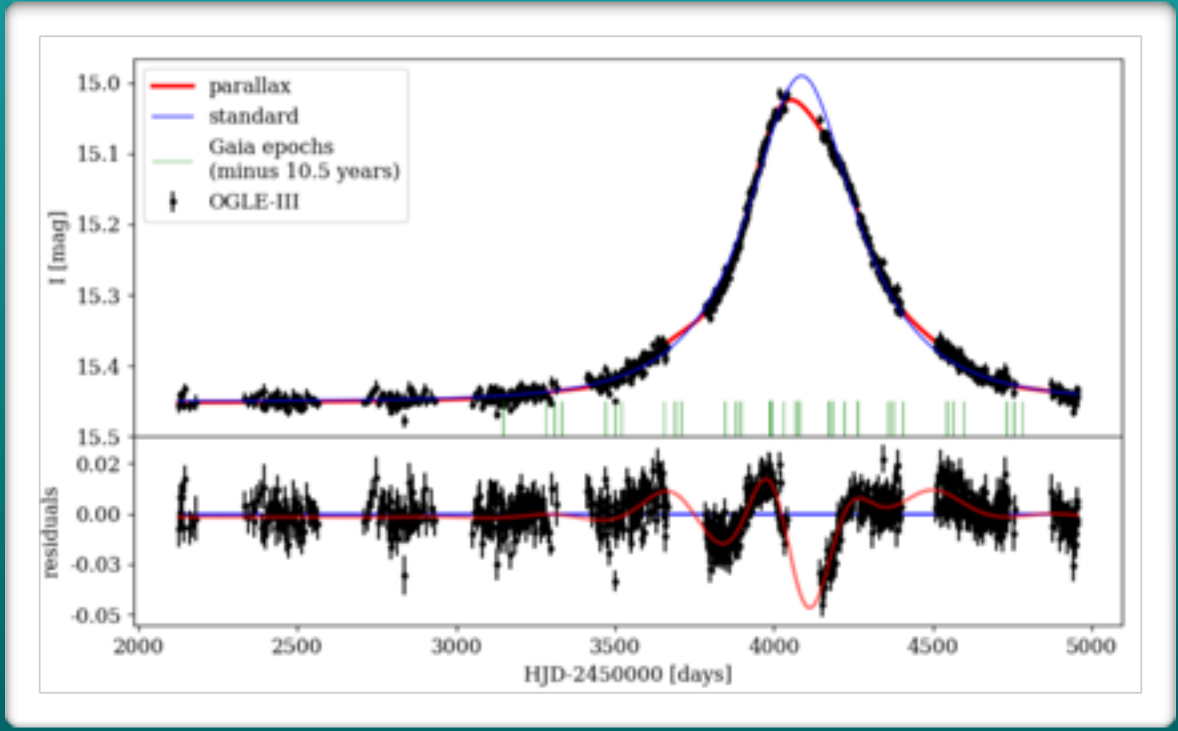


# What do we want from the microlensing?

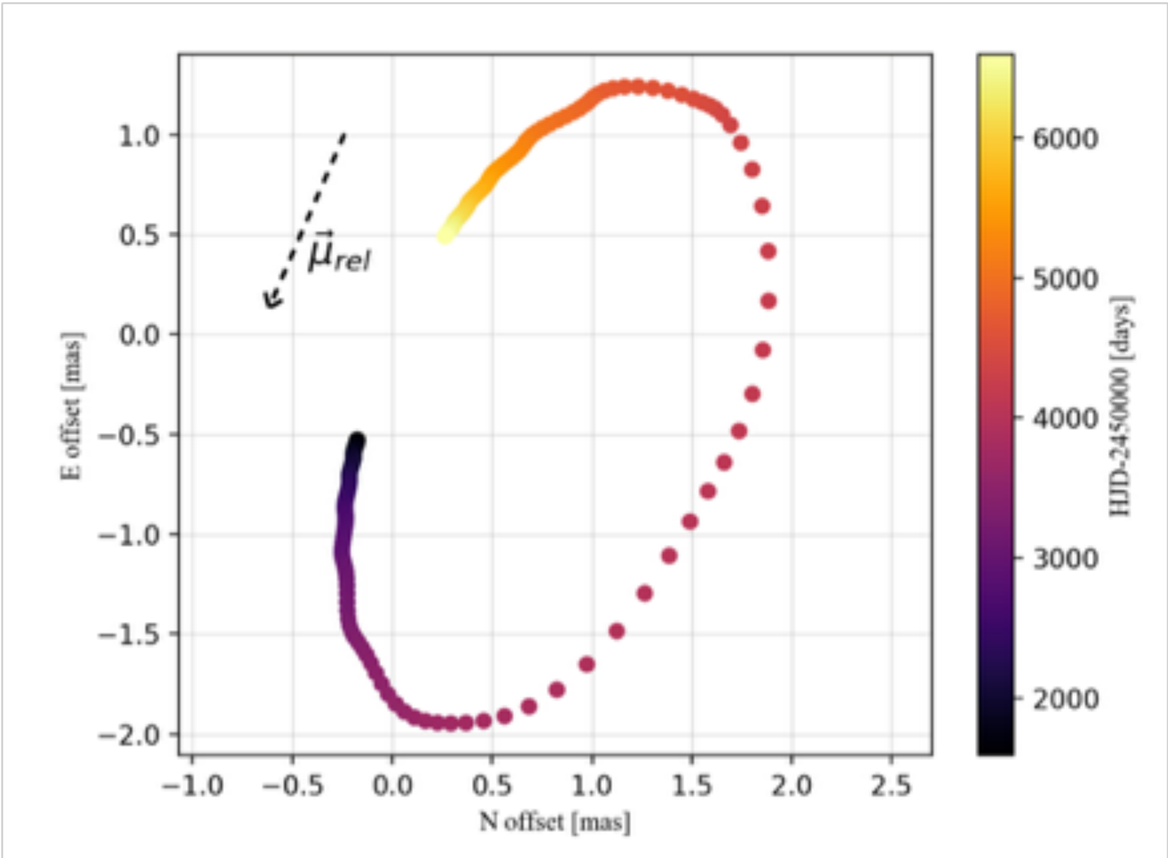
- **The simple PSPL model: $t_0$, $u_0$, $t_E$, $I_0$, $f_s=F_s/(F_s+F_{bl})$**
- **We know more if we measure microlensing parallax: $\pi_E=(\pi_{EN}, \pi_{EE})$**
- **It is still not enough, but we want to utilise the mass formula**




$$M = \frac{\theta_E}{\kappa \pi_E} = \frac{t_E \mu_{rel}}{\kappa \pi_E}$$



# Theta_E




$$a = \frac{1}{2\sqrt{u_0^2 + 2}} \theta_E$$

$$b = \frac{u_0}{2(u_0^2 + 2)} \theta_E$$

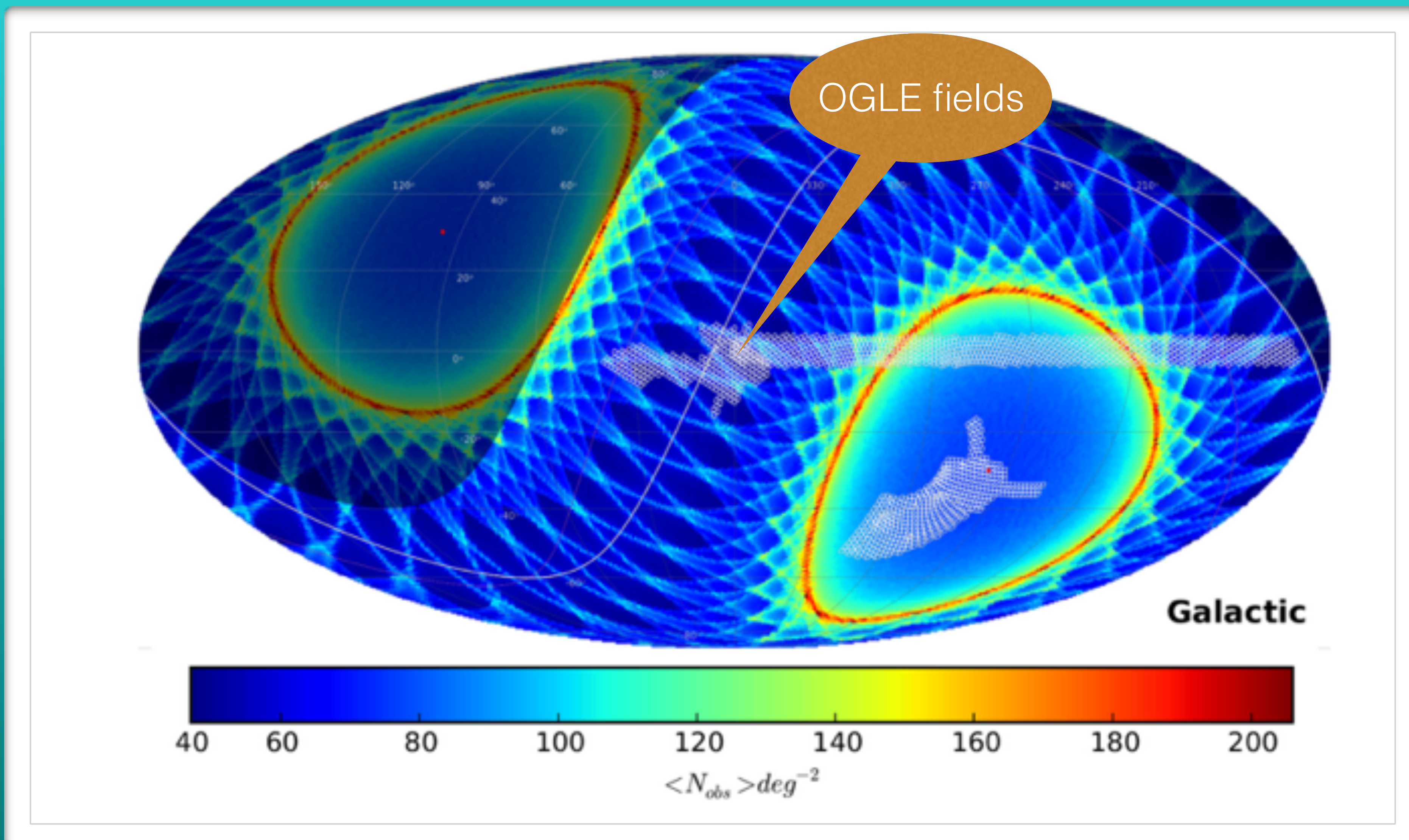
Gaia astrometric time series

ground based photometry/satellite

$$M = \frac{\theta_E}{\kappa \pi_E}$$ + $$f_s \approx 1$$ → BH or not BH?

**Dominik & Sahu 2000; Belokurov & Evans 2002**

# Gaia not designed for that…




Gaia Collaboration et al. 2016

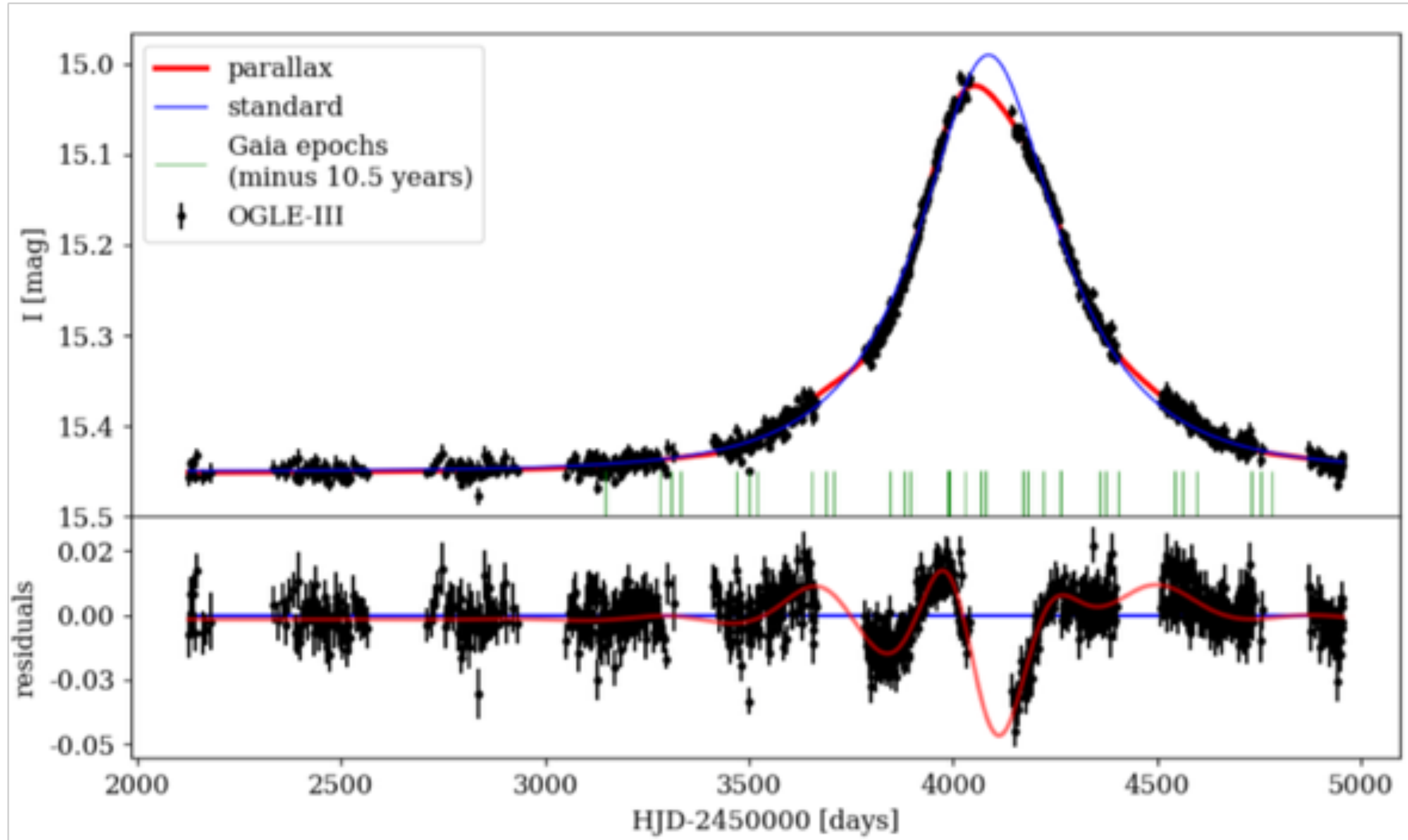
**Pros**

- The most precise astrometry in the history

**Cons**

- Data not available yet
- 1D astrometry
- Dramatic decrease of accuracy with brightness
- Low cadence in Bulge

# OGLE-ULENS-PAR-02: photometry



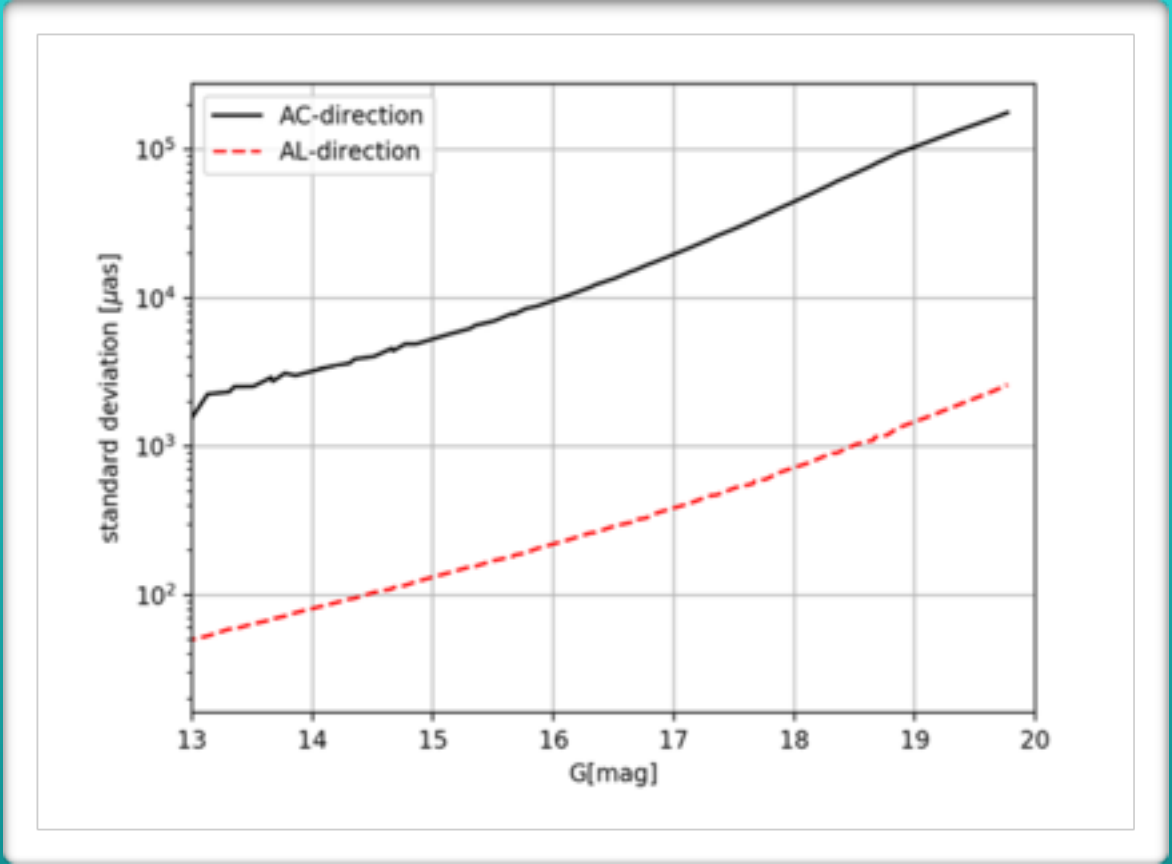

| solution No. [−] | $t_0$ [$days$] | $t_E^{helio}$ [$days$] | $u_0$ [$\theta_E$] | $\pi_{EN}$ [−] | $\pi_{EE}$ [−] | $f_s$ [−] | $I_0$ [$mag$] |
|---|---|---|---|---|---|---|---|
| 1. | $4091.98^{+0.32}_{-0.30}$ | $254.50^{+10.80}_{-7.86}$ | $-0.870^{+0.055}_{-0.044}$ | $0.0322^{+0.0012}_{-0.0012}$ | $-0.0742^{+0.0049}_{-0.0041}$ | $1.023^{+0.102}_{-0.117}$ | $15.4522^{+0.0006}_{-0.0006}$ |
| 2. | $4090.72^{+0.26}_{-0.28}$ | $296.52^{+8.22}_{-7.42}$ | $0.664^{+0.027}_{-0.027}$ | $0.0293^{+0.0011}_{-0.0010}$ | $-0.0529^{+0.0026}_{-0.0025}$ | $0.635^{+0.042}_{-0.042}$ | $15.4529^{+0.0006}_{-0.0006}$ |

**Wyrzykowski et al. 2016, Rybicki et al. 2018**

# Gaia data simulations

- **Per epoch accuracies!**
- **$\sigma_{AC}$ >> $\sigma_{AL}$**
- **AL from AFs and AC from SM**

| I-band [mag] | G-band [mag] | V-band [mag] | $\sigma_{AL}$ [mas] | $\sigma_{AC}$ [mas] |
|---|---|---|---|---|
| 12 | 13.3 | 14.2 | 0.056 | 2.31 |
| 13 | 14.3 | 15.2 | 0.089 | 3.54 |
| 14 | 15.3 | 16.2 | 0.145 | 5.91 |
| 15 | 16.3 | 17.2 | 0.244 | 10.97 |
| 16 | 17.3 | 18.2 | 0.430 | 23.03 |
| 17 | 18.3 | 19.2 | 0.818 | 52.84 |



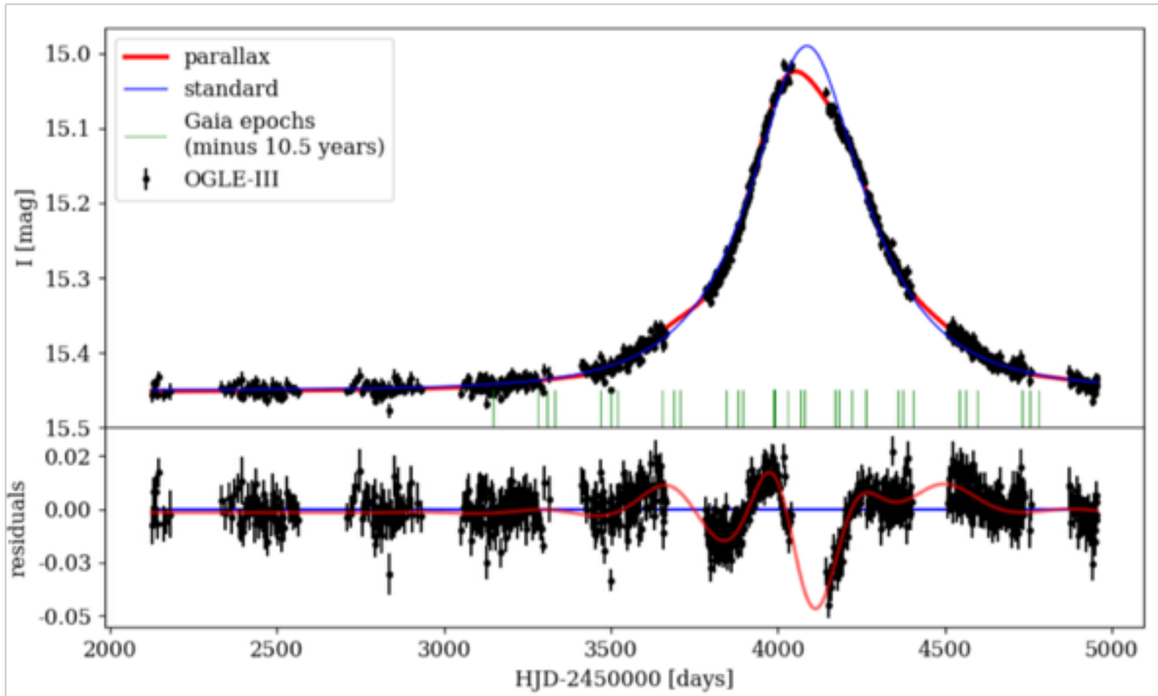

Adopted per transit astrometry:

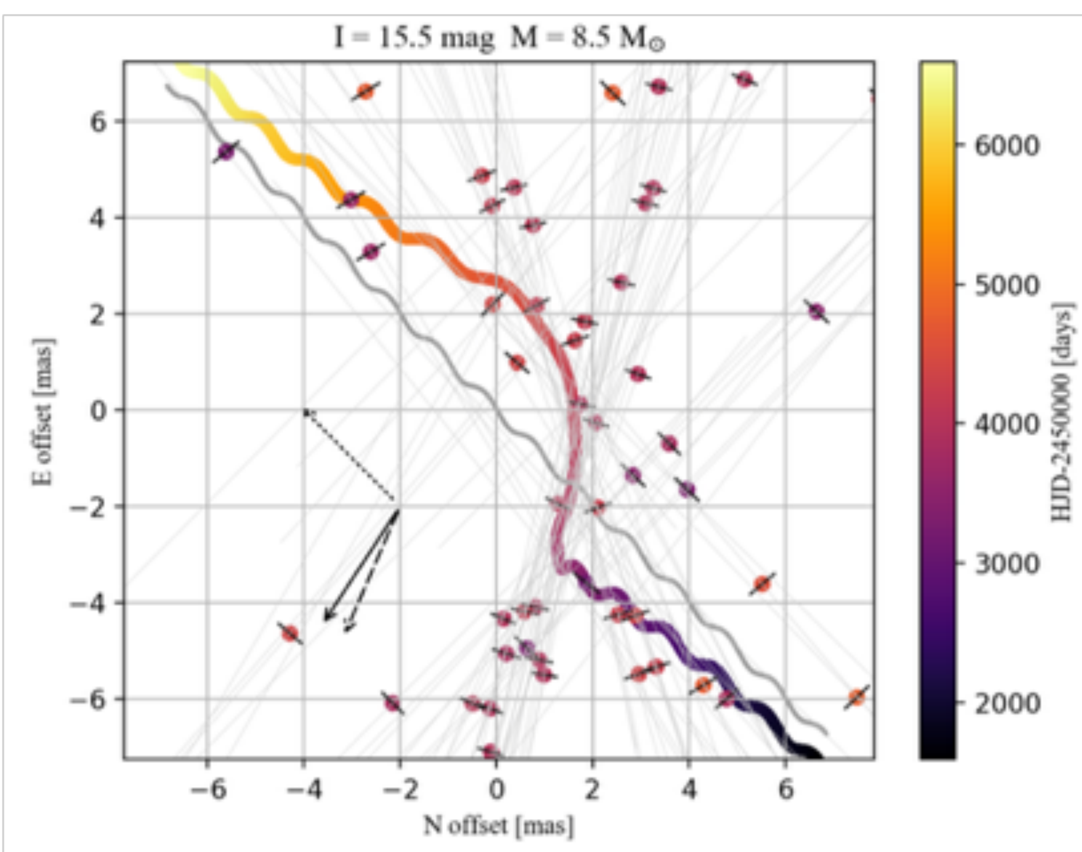
On-CCD centroiding errors estimated by Jos de Bruine

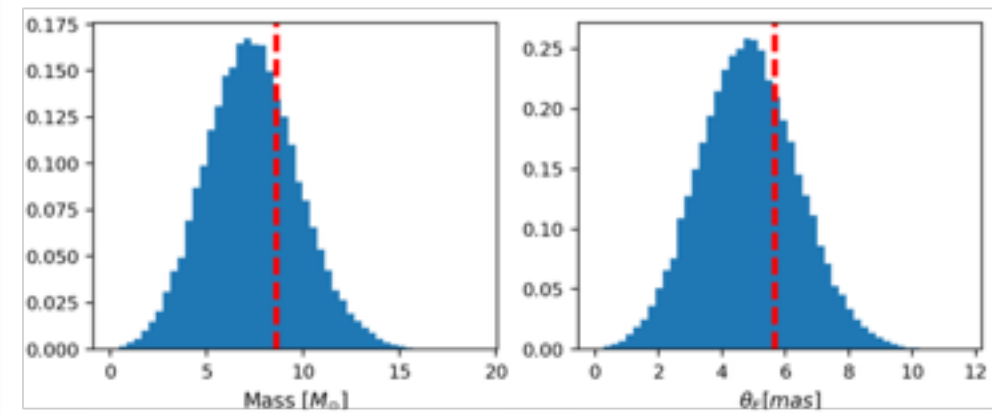
$\sigma_{AL} = \sigma_{ctrAF} / 2$

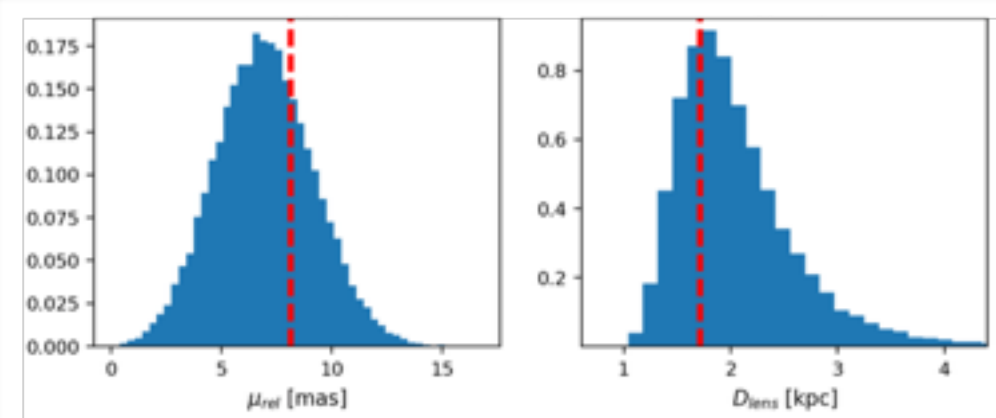
$\sigma_{AC} = 2*\sigma_{ctrSM}$

# Fitting joined model



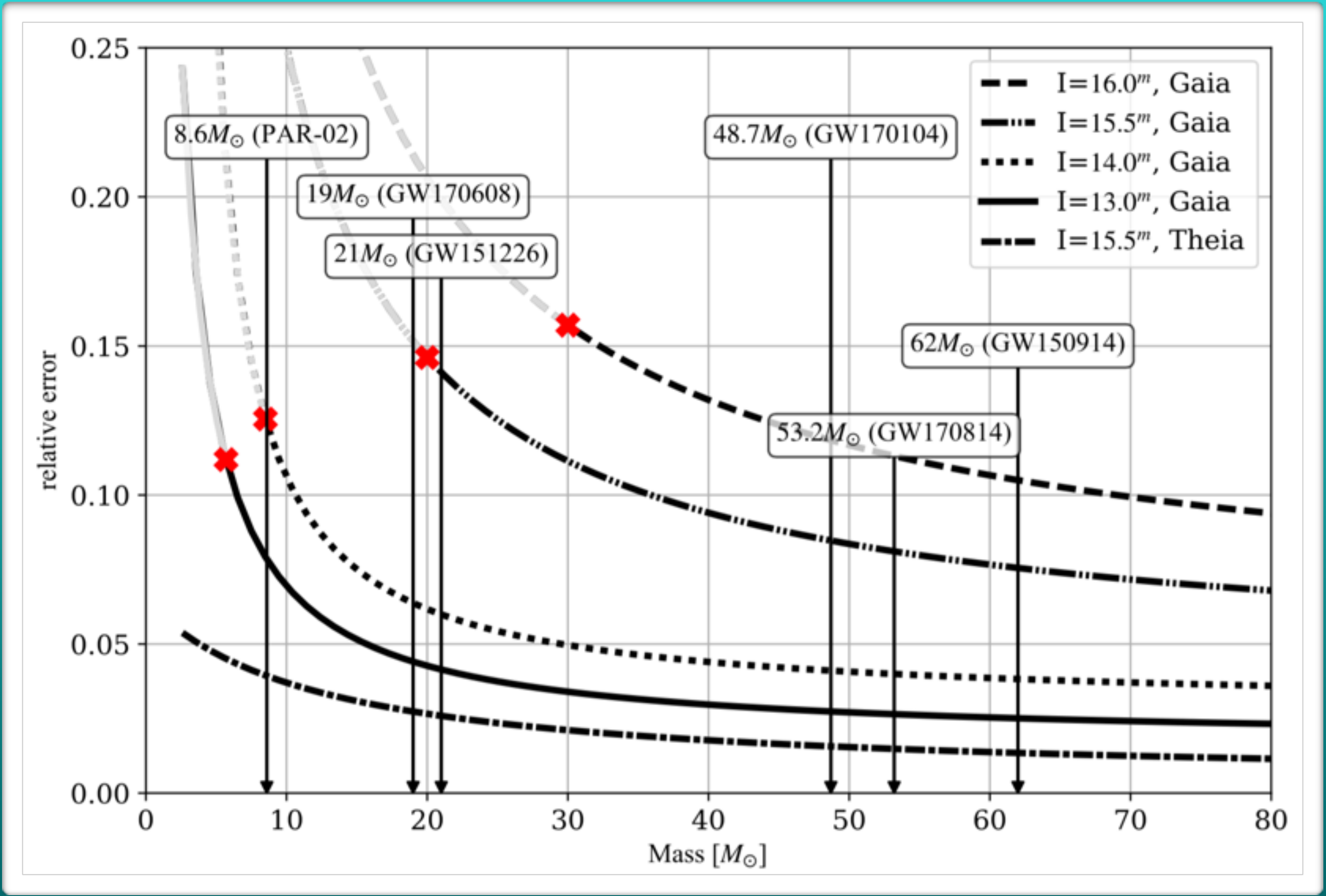




It can be done, but…

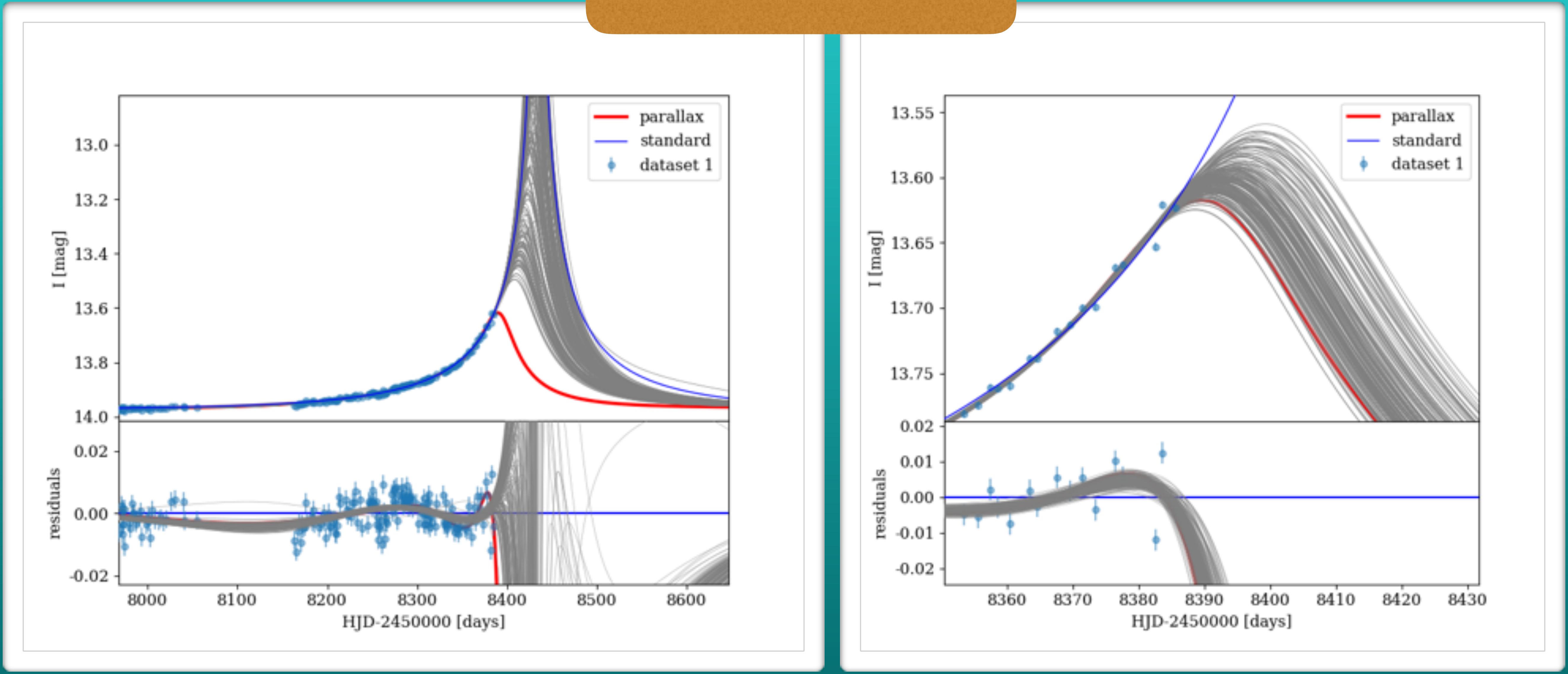
# Extension to other cases



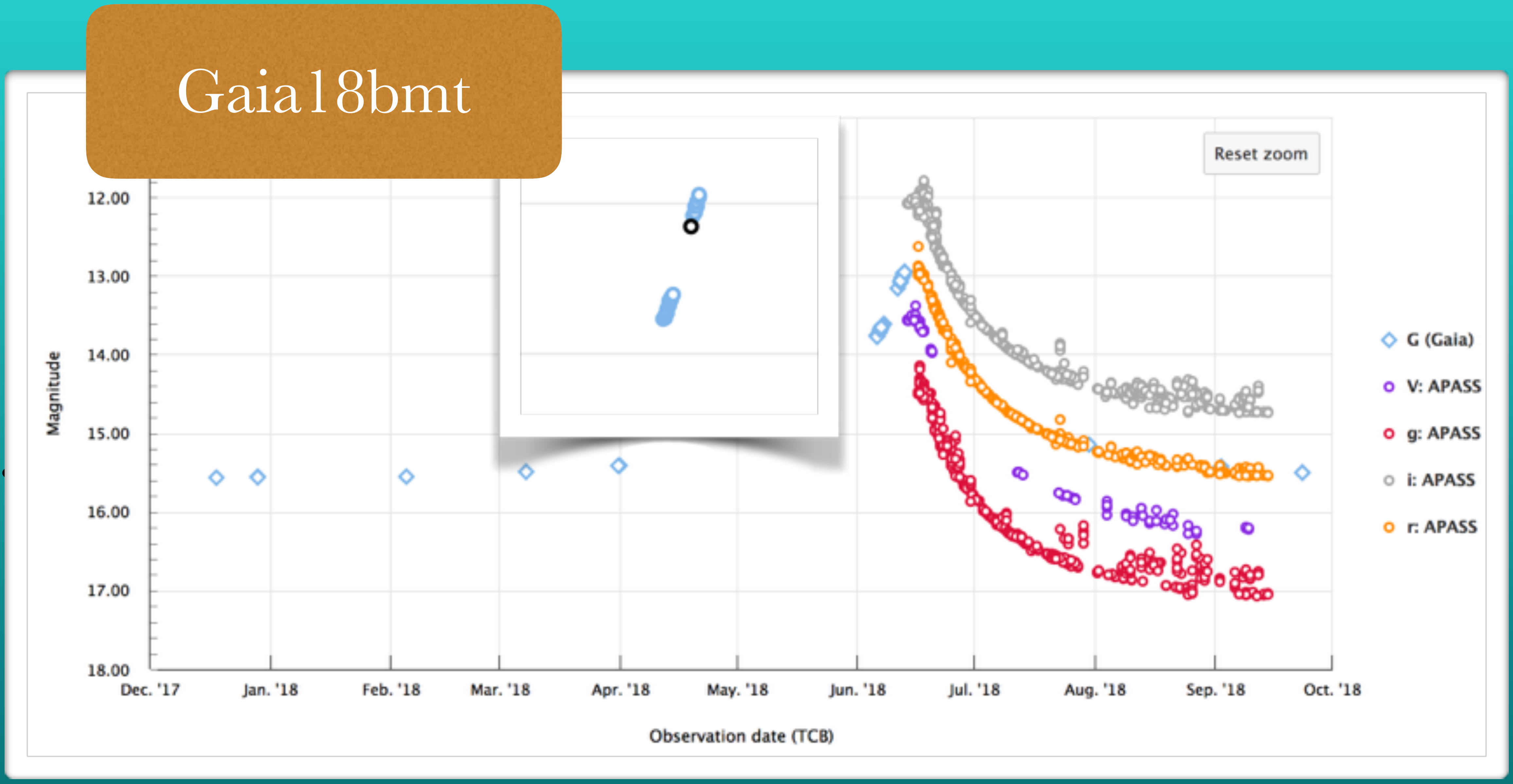

**Rybicki et al. 2018**

# Importance of continuous follow-up

Gaia18ces



# Importance of continuous (and rapid!) follow-up

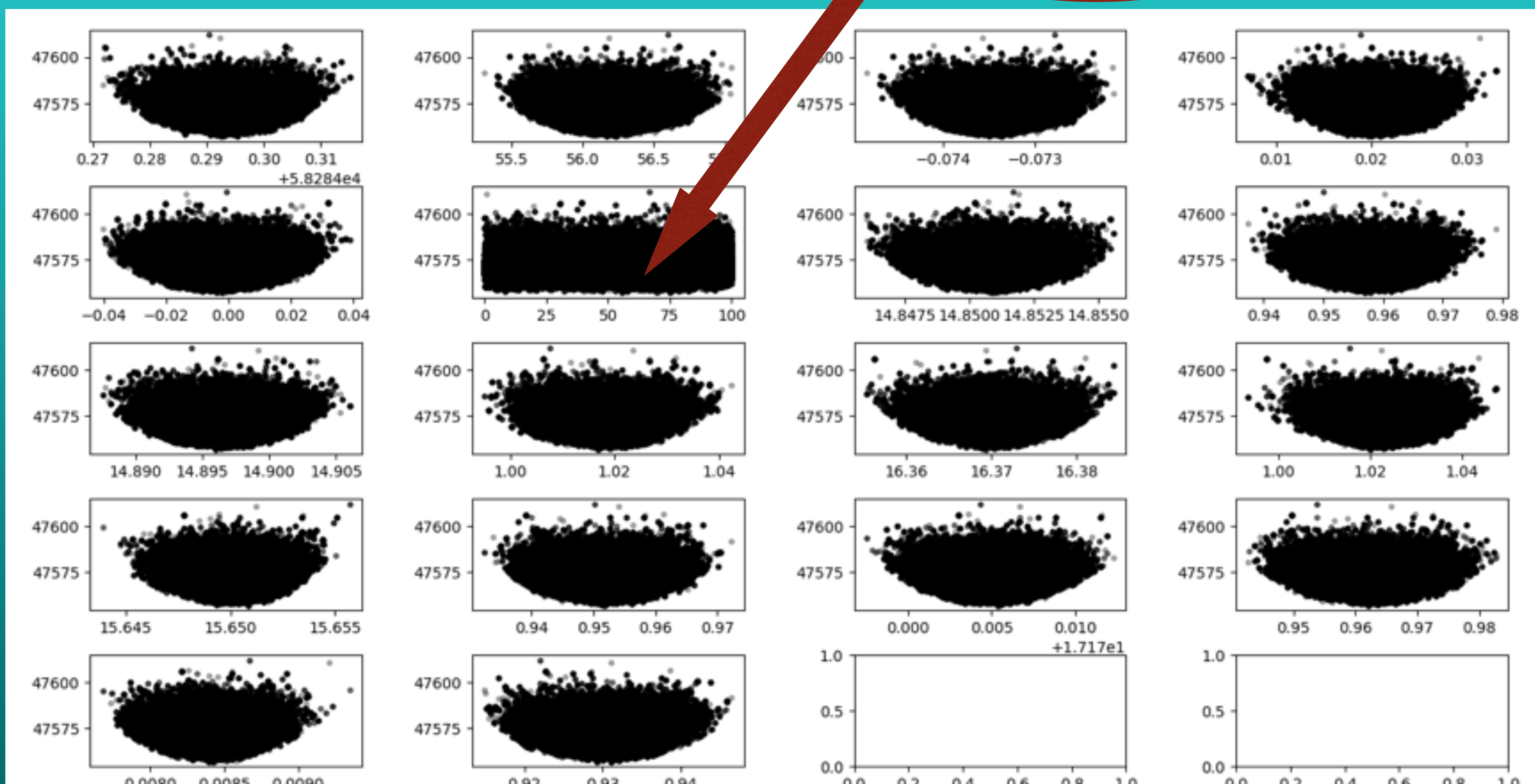



Relatively long + low parallax signal + no blending = BH???

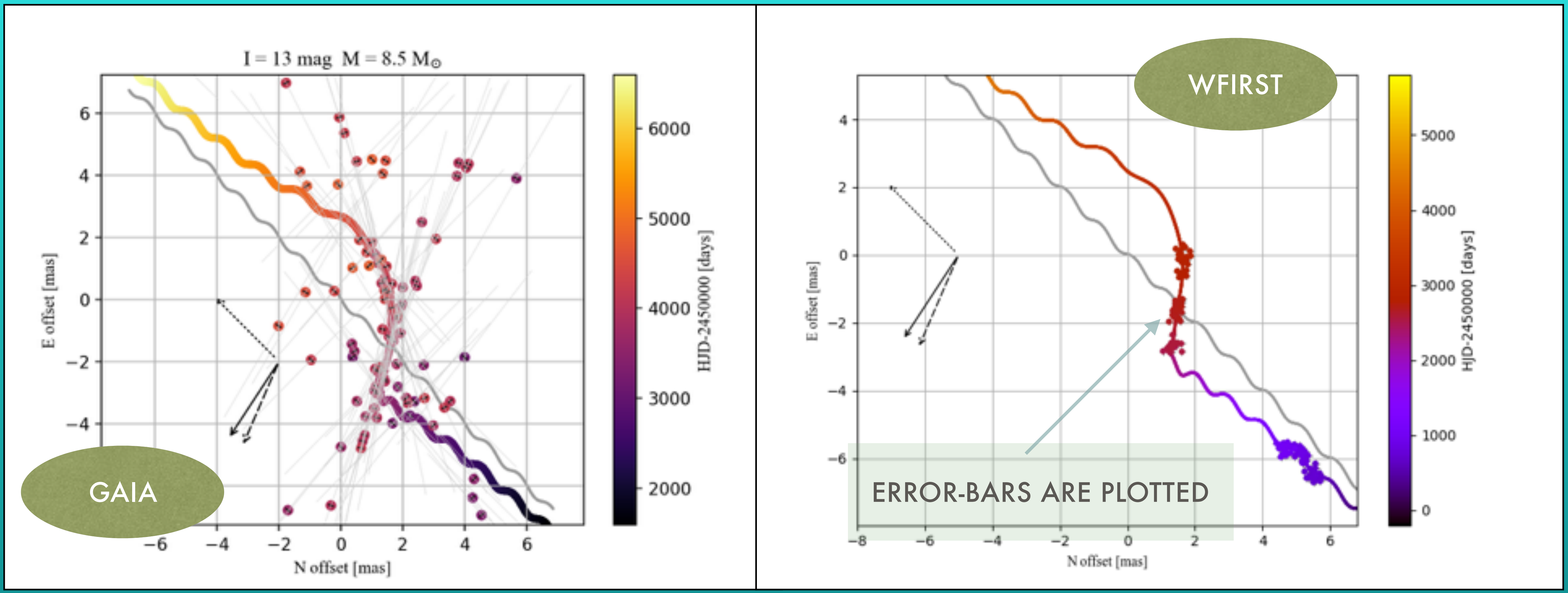
# Simulations not too promising so far…

Gaia18bmt

$\mu_{rel}$… :'(



# WFIRST compared to the expected performance of Gaia




WHY IS WFIRST SO MUCH BETTER?

- **Gaia not designed to accurately cover transients, especially astrometric ones**
- **Gaia provides good accuracy only along the scan direction**
- **Cadence: 15min vs >30days**
- **Main problem for Gaia: precision drops dramatically with brightness**

# Conclusions

It may be possible to detect BHs by simultaneous observation of the microlensing event in Gaia and from the ground

Brightness of the source is a crucial thing as Gaia astrometric accuracy drops significantly for faint targets

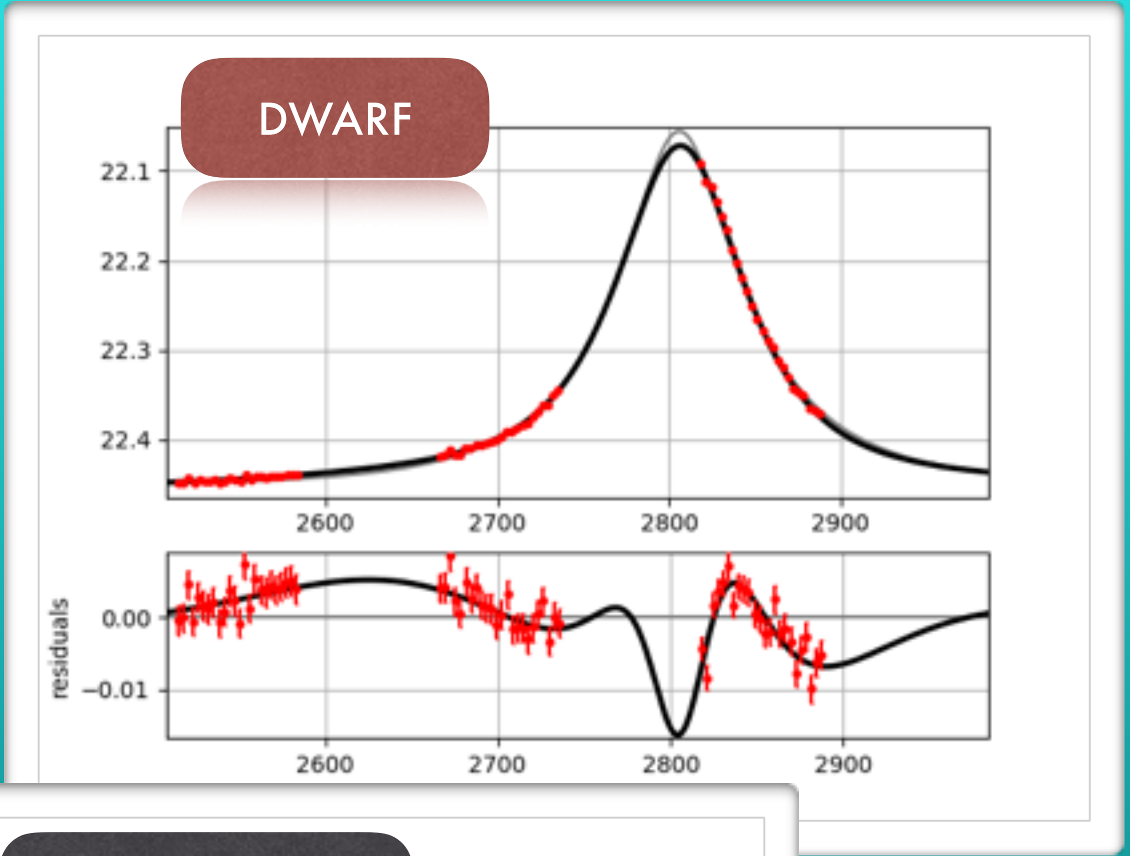
Basing on crude rates estimates, we expect few BHs to be observed by Gaia and possible to identify, **if followed-up sufficiently from the ground**

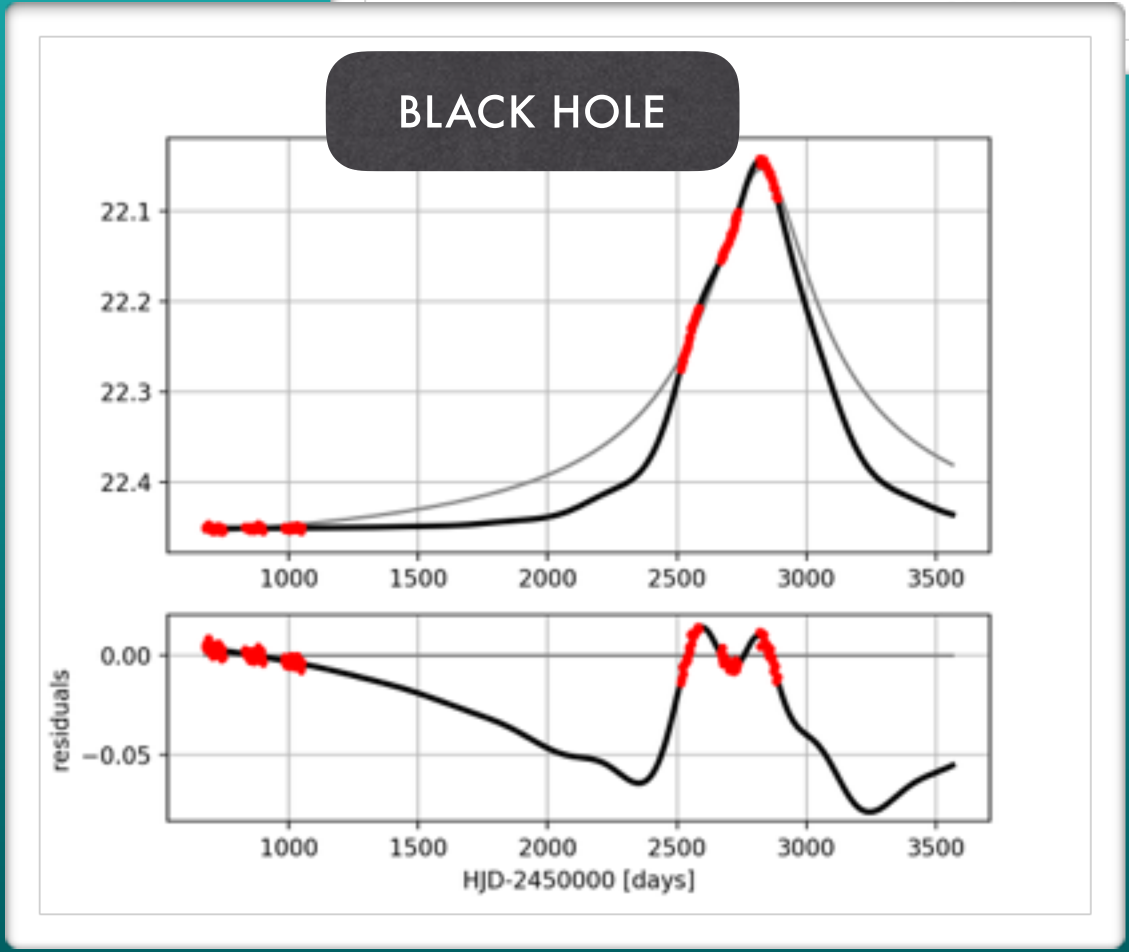
WFIRST (~2025?) is very promising in the context of astrometric microlensing

# Extra slides

# WFIRST data simulations

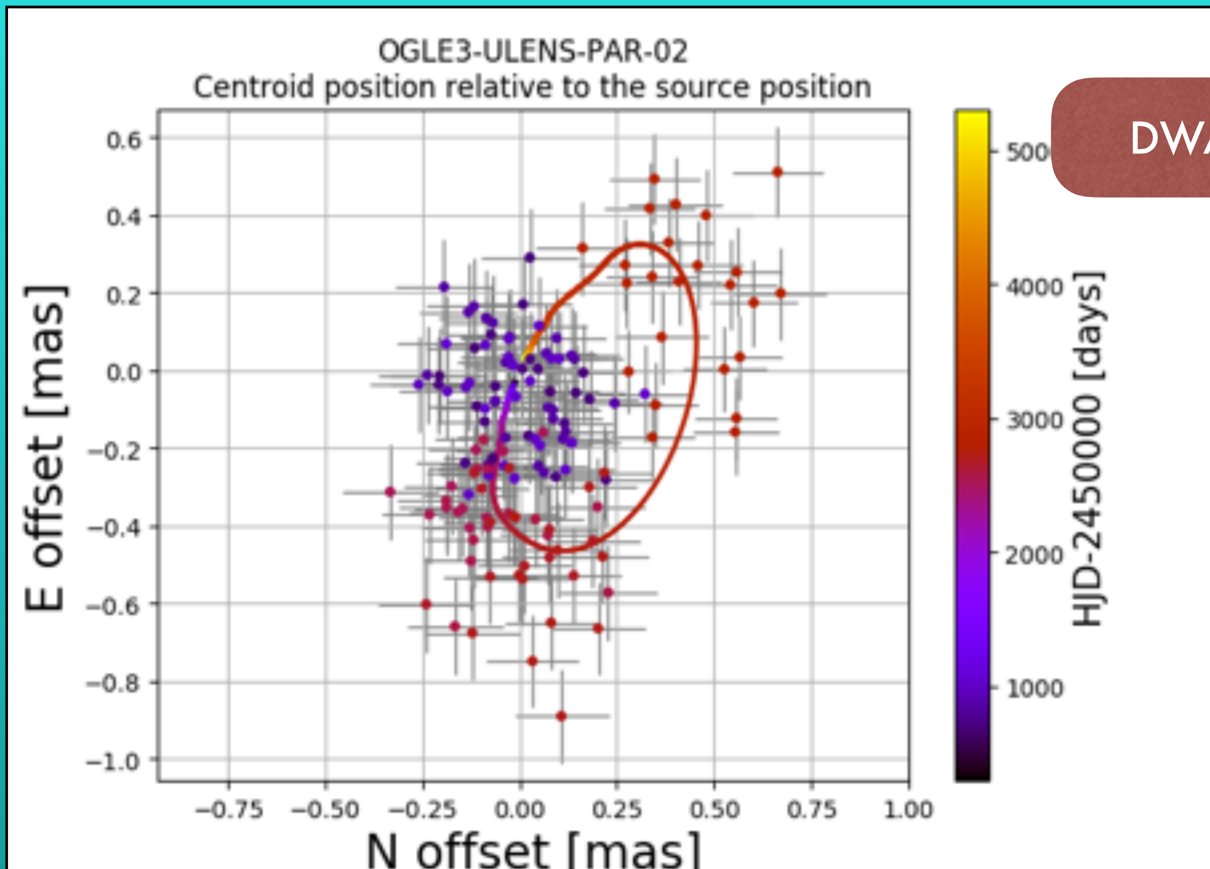
- centroiding error estimation for crowded regions
- 15 minute cadence adopted
- 3 seasons of observation at the beginning and the end of the 6-year mission
- each season 72-days long
- gaussian errors assumed
- averaging over 3 days - to see preliminary results

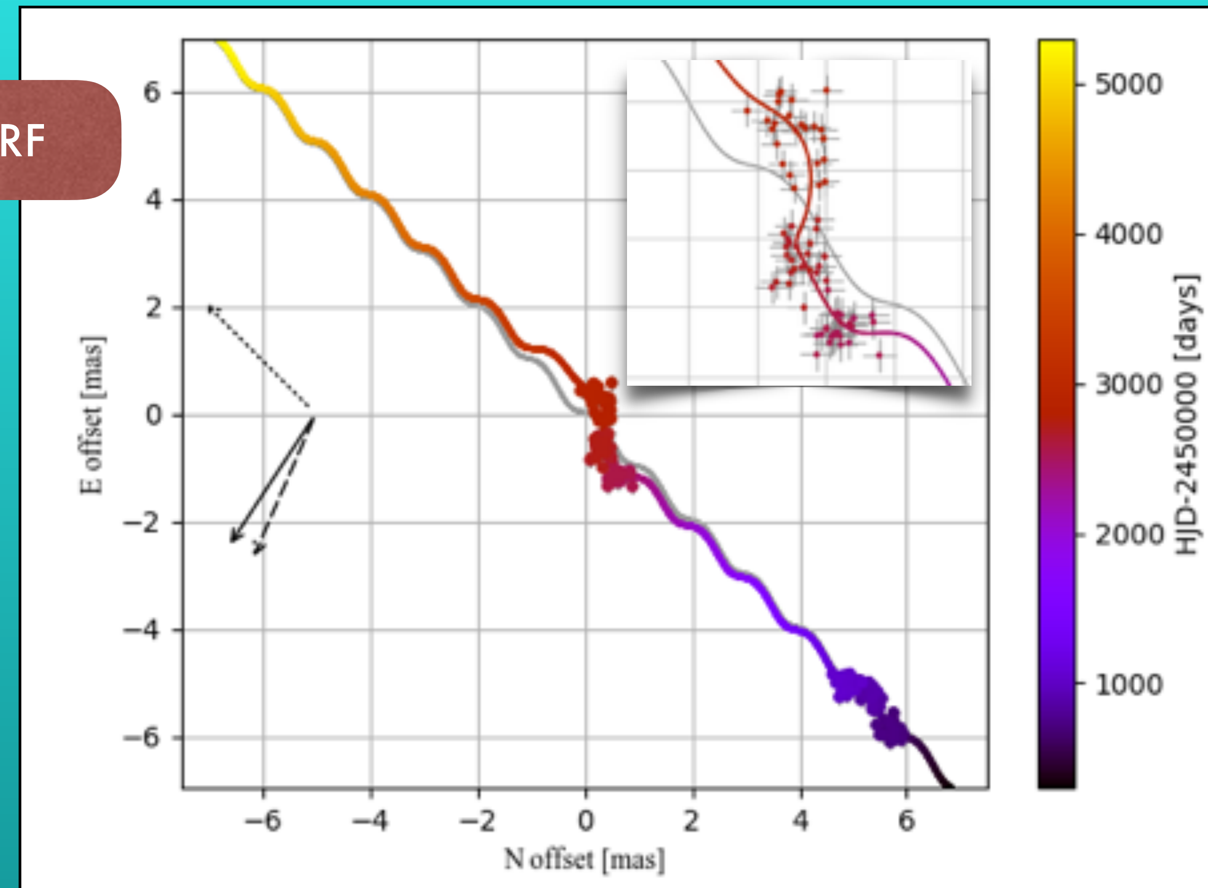


# Motion curves simulations

DWARF




BLACK HOLE