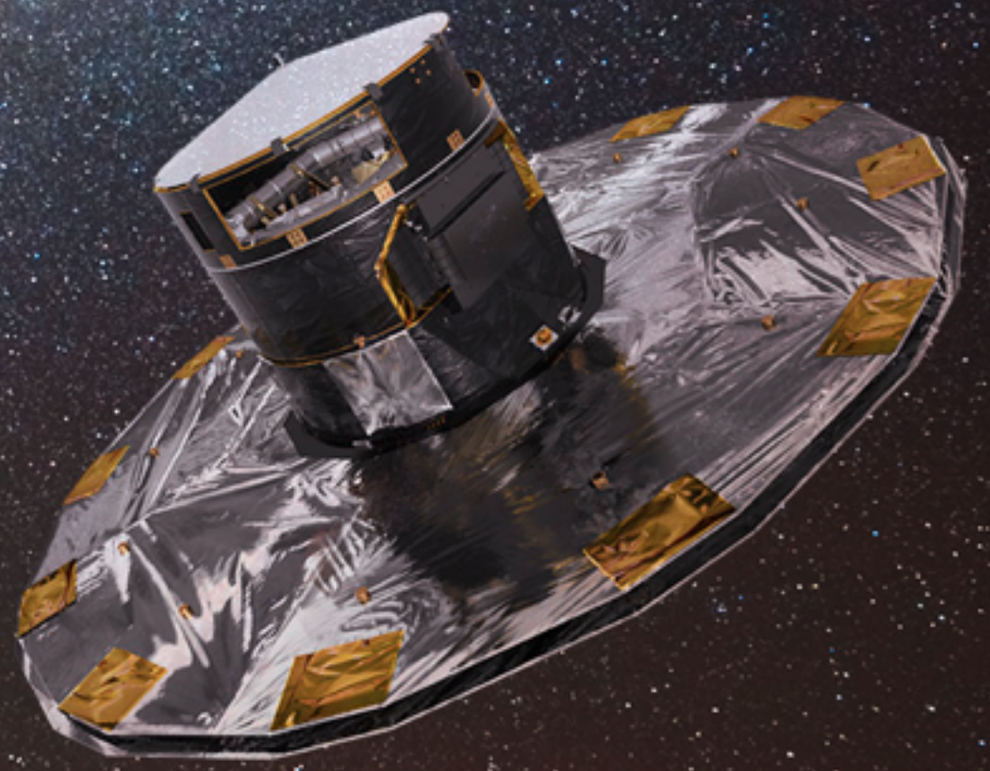
ASTROMETRIC MICROLENSING WITH GAIA

Łukasz Wyrzykowski

(pron: Woo-cash Vi-zhi-kov-ski)

Warsaw University Astronomical Observatory, Poland



Sagan Workshop, Pasadena, 10 August 2017

COLLABORATORS

here

Krzysztof Rybicki
(PhD student)

here

Kasia Kruszyńska
(PhD student)

Mariusz Gromadzki
(postdoc)

Zuzanna Kostrzewa-Rutkowska
(postdoc at SRON, NL)

Alex Hamanowicz
(Master student -> PhD @ ESO)

Gaia Alerts team in Cambridge (UK)

UNIVERSITY OF CAMBRIDGE

Gaia DPAC

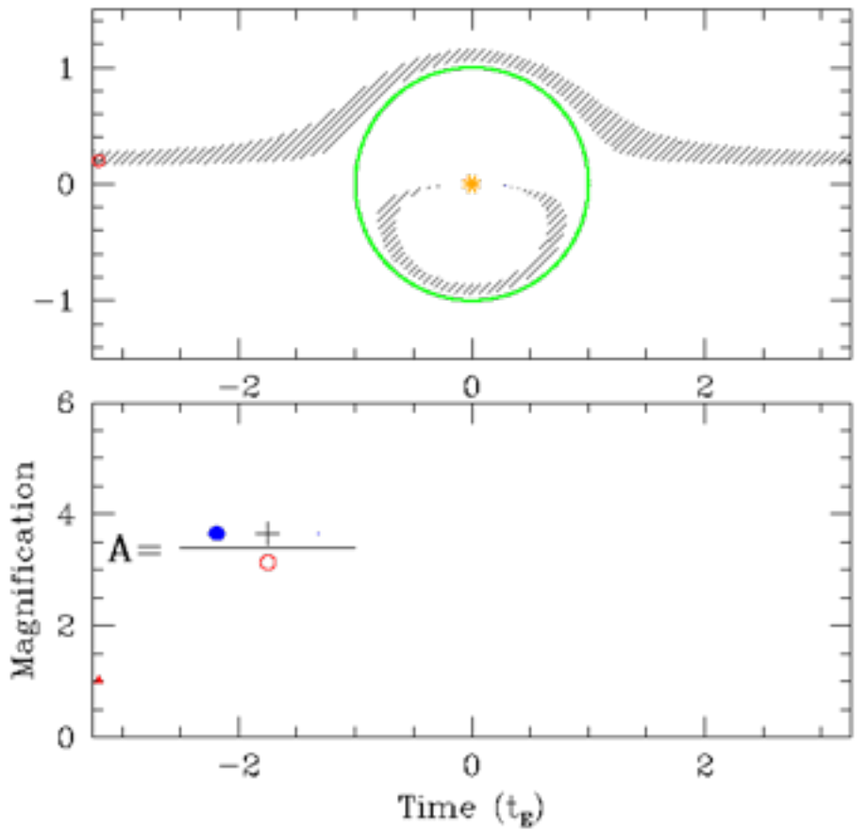
gaia

UNIVERSITAS VARSOVIENSIS

MICROLENSING

- Gravitational lensing by compact lenses (stellar or remnants)
- Mass range from Earth-like to ~100 MSun
- Sources: background stars (chance: 10^{-6} in the Bulge, 10^{-8} in the LMC)

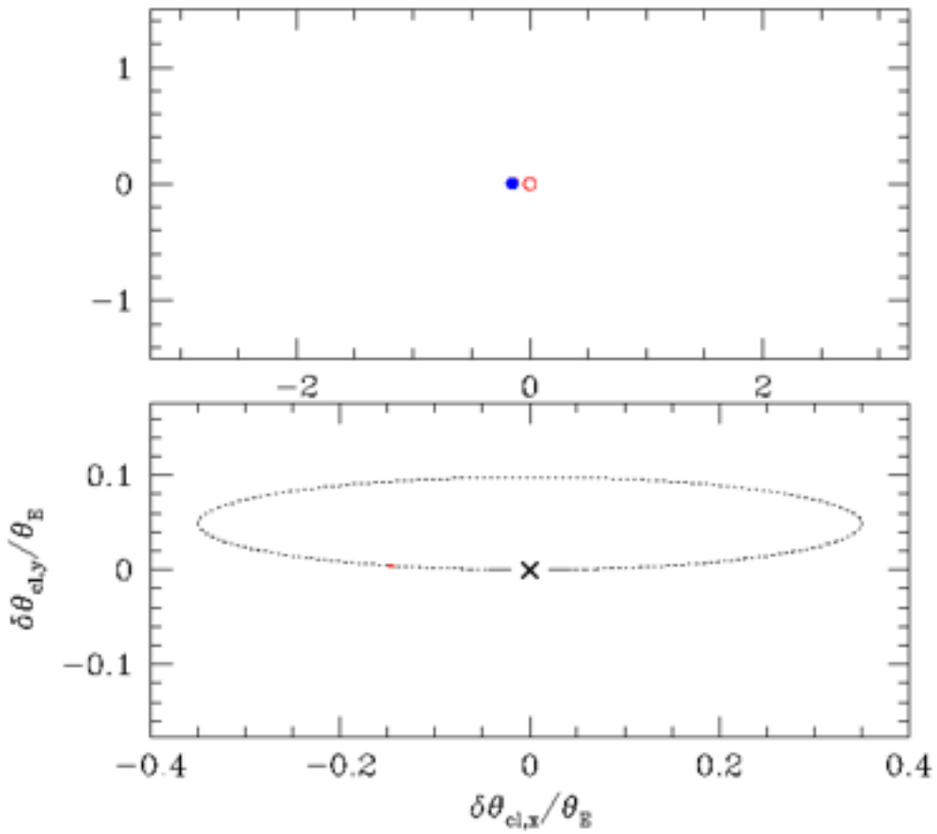
photometry (sum of images)



~1 month

animations by S.Gaudi

astrometry (centroid motion)



~1mas

http://www.astronomy.ohio-state.edu/~gaudi/movies.html

BLACK HOLES MICROLENSING

- About 0.8% of microlensing events should be due to Black Holes! (Gould 2000)
- 2000 events found every year -> ~16 black holes every year!!
- so, where are they?

$$M = \frac{\theta_E}{\kappa \pi_E}$$

high amplification events/finite source (rare)

astrometry (VLT/AO, HST, Gaia)

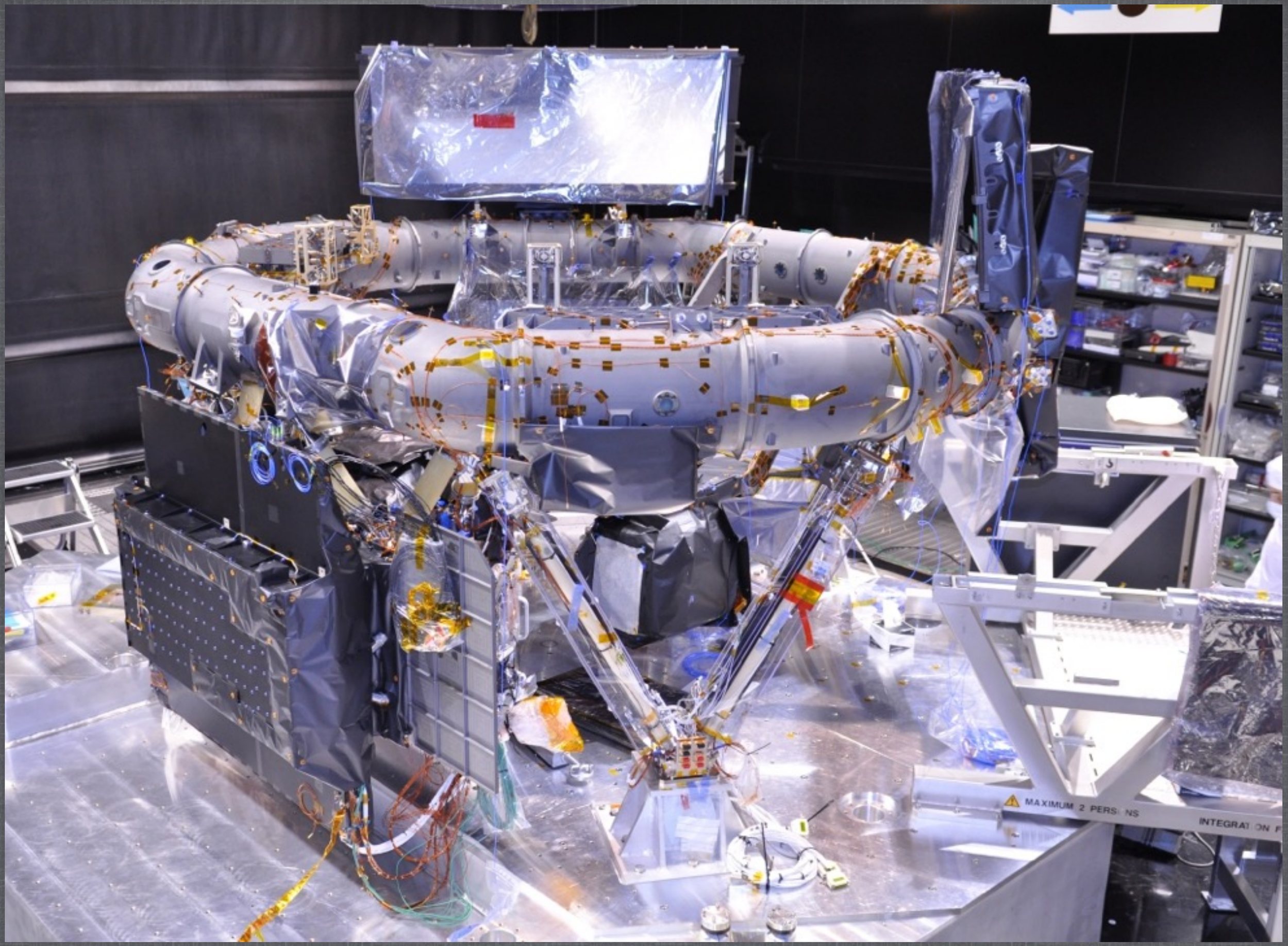
Earth parallax

space-based parallax (e.g., Earth-Spitzer)

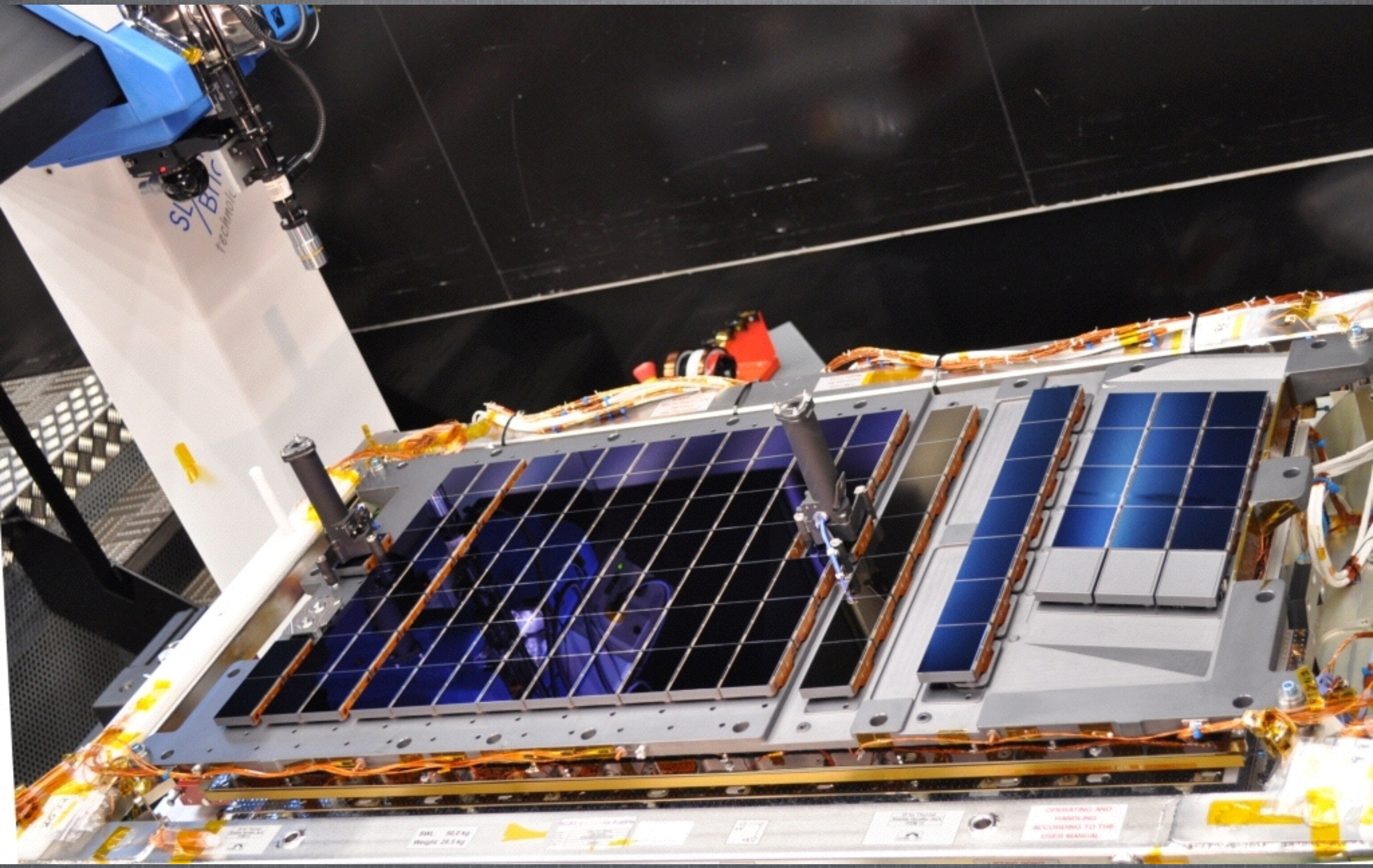
GAIA SPACE MISSION

19 DEC 2013 9:12 UT


esa
gaia


MAXIMUM 2 PERS NS
INTEGRATION F

GAIA FOCAL PLANE

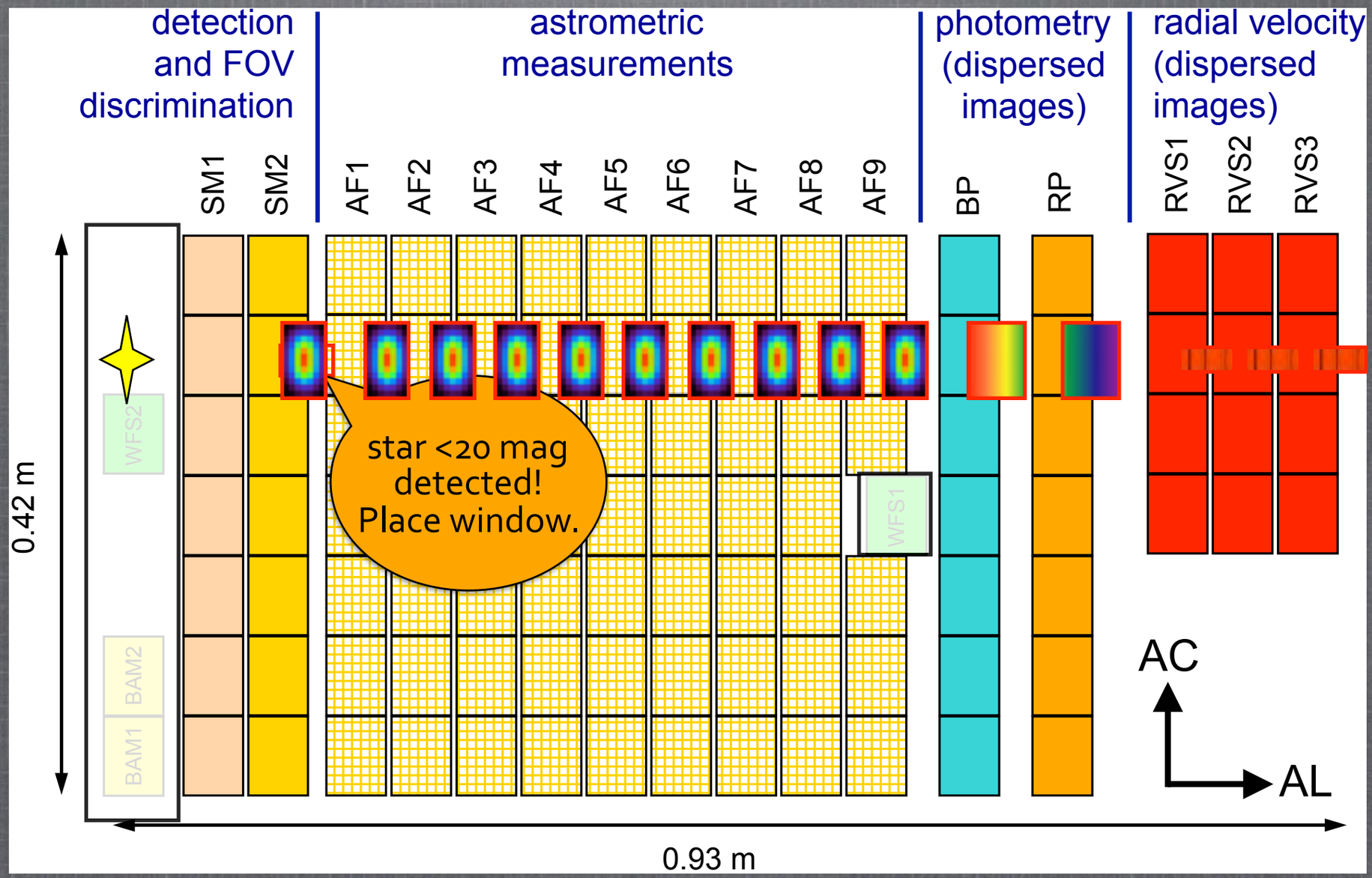


GAIA FOCAL PLANE

Camera:

0.75 deg^2

pixel size:
10x30 µm
(59x177 mas)



Animation by
Berry Holl, Geneva

windows observed:

→ ~4.4 sec

→ ~45 sec

GAIA SKY SCANNING PATTERN

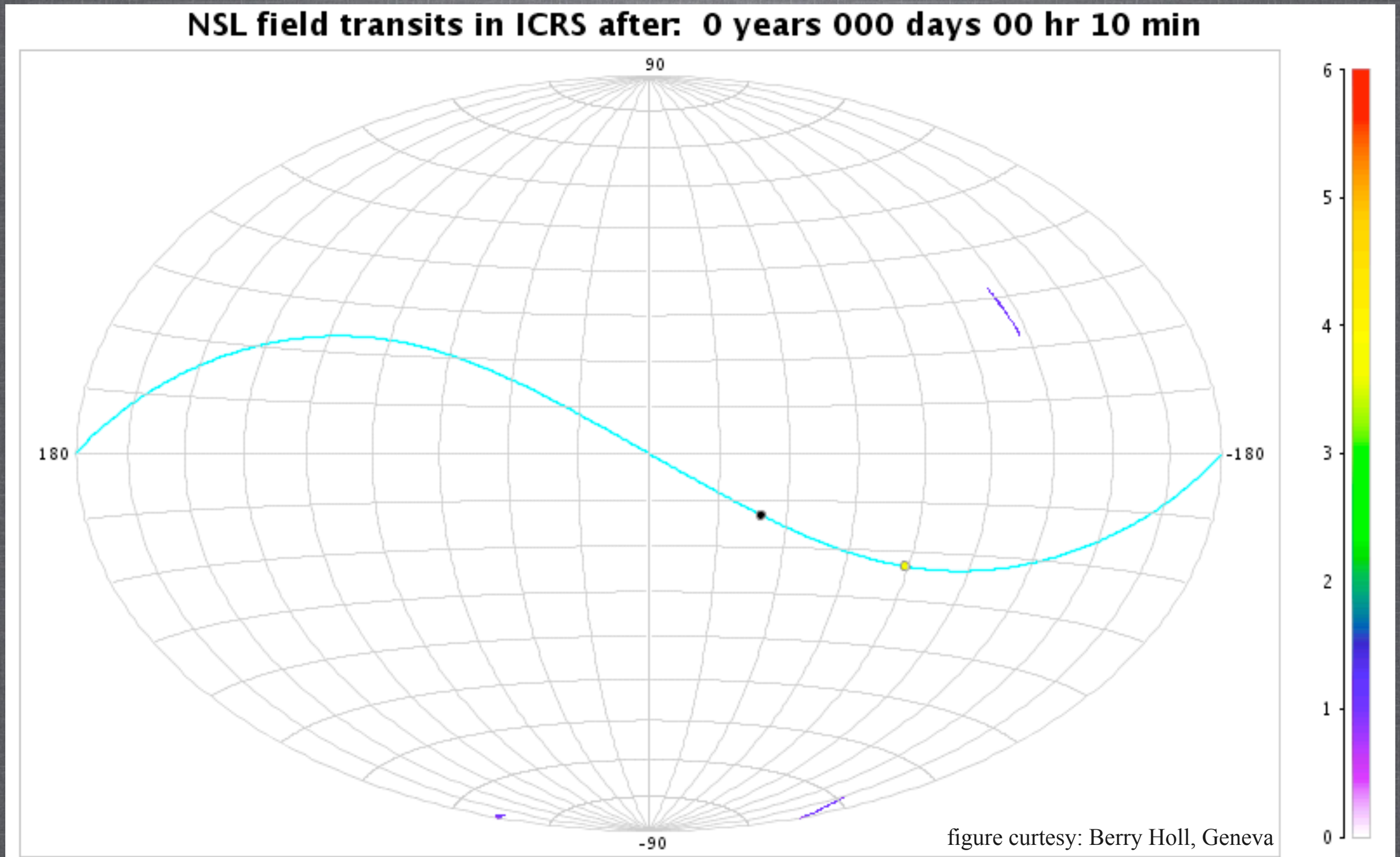
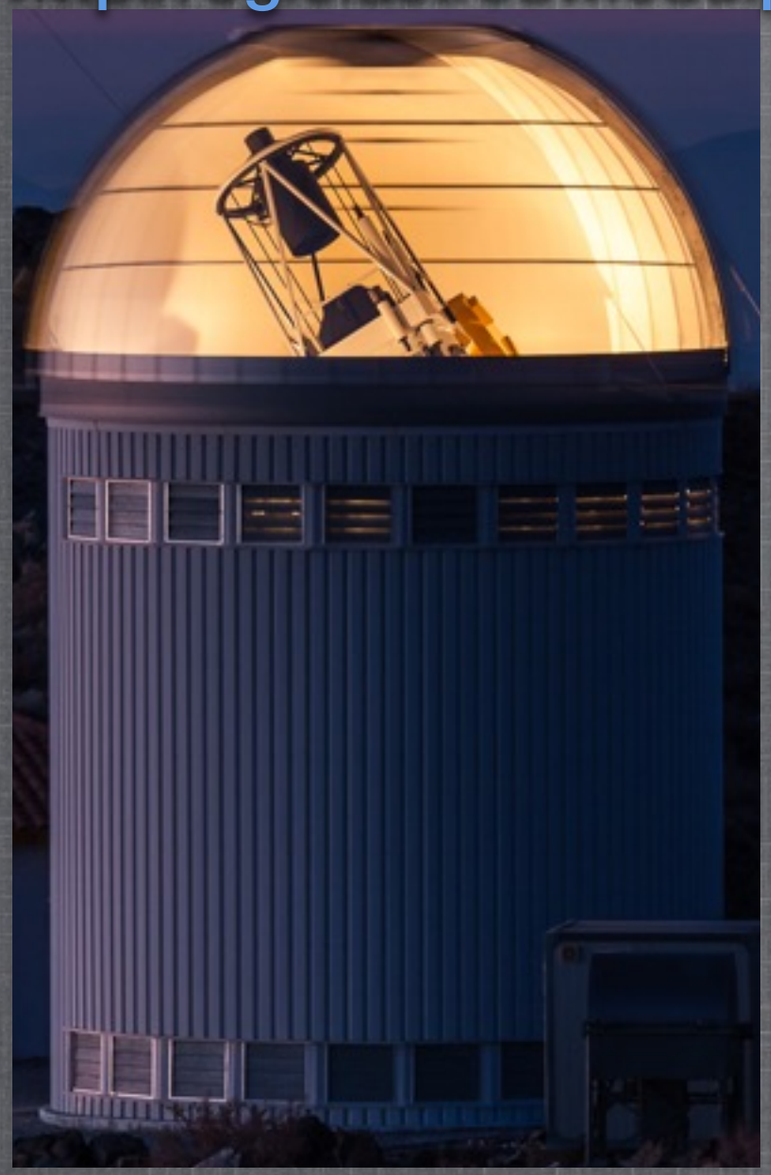


figure curtesy: Berry Holl, Geneva

HOW TO FIND BLACK HOLES?

OGLE

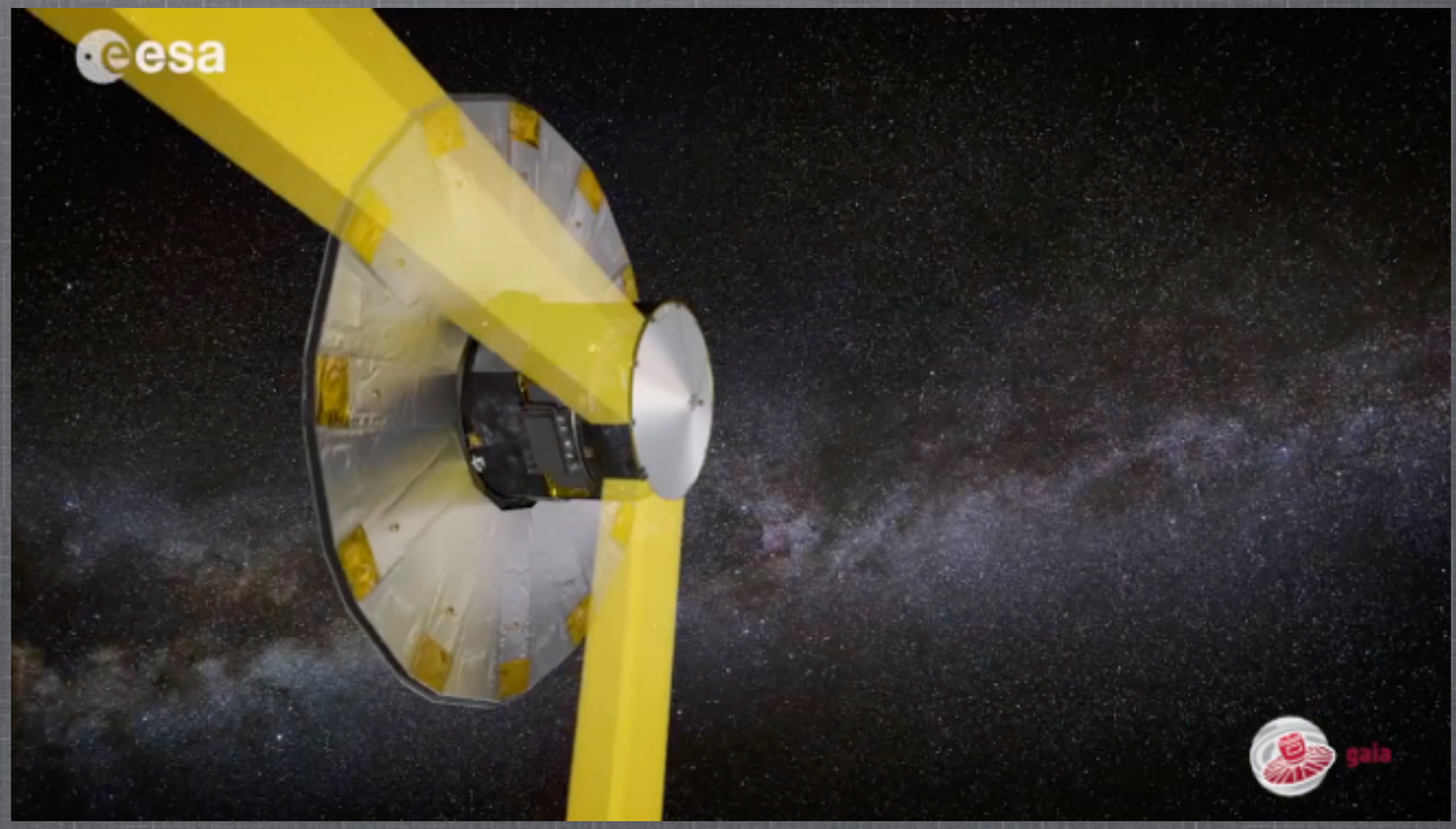
http://ogle.astrouw.edu.pl



Polish 1.3m dedicated telescope
in Las Campanas, Chile
Surveying continuously since 1992.

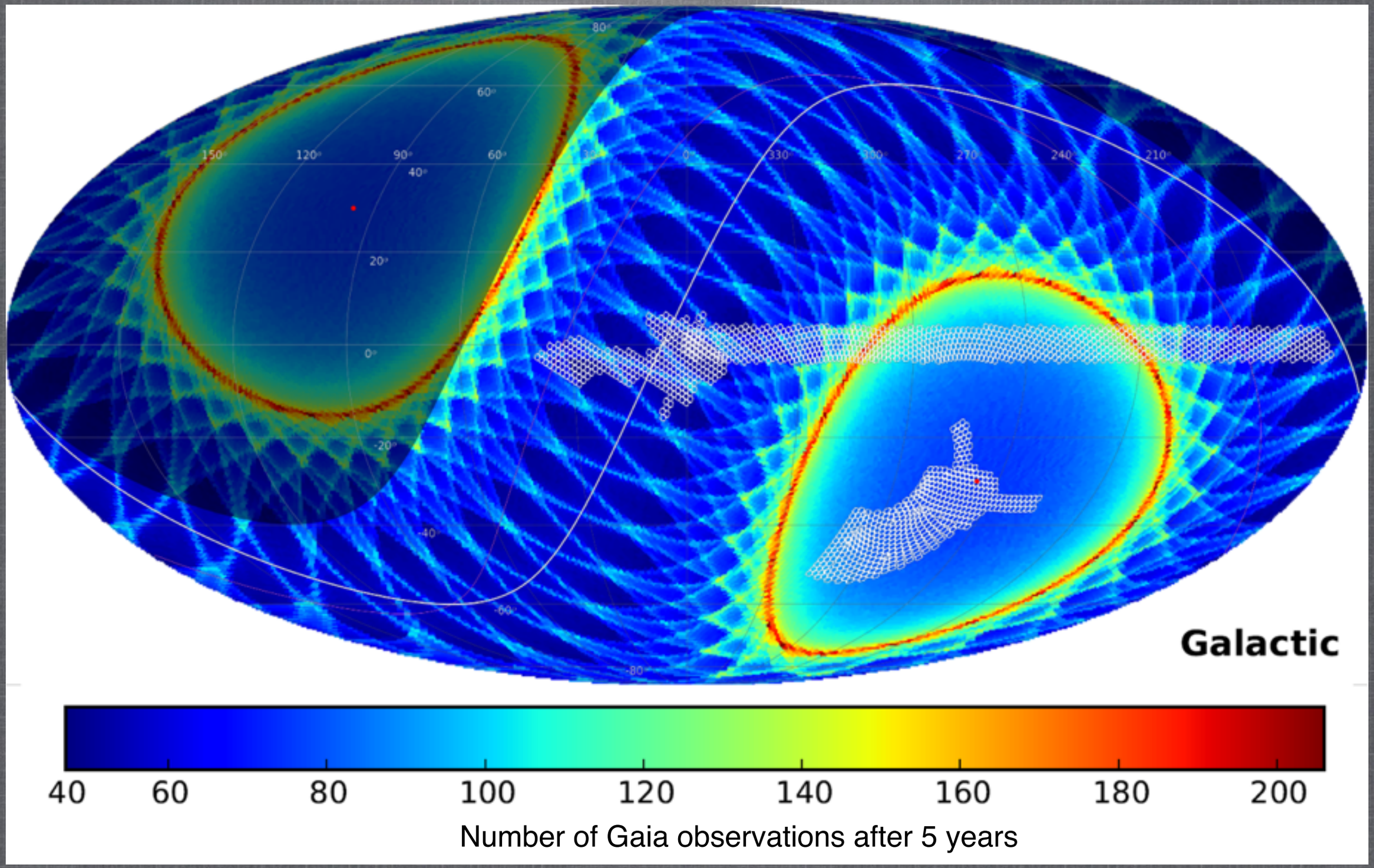
Gaia Science Alerts

http://gsaweb.ast.cam.ac.uk/alerts



ESA space mission with 2x1.4m telescopes located in L2.
In operation since 2014.

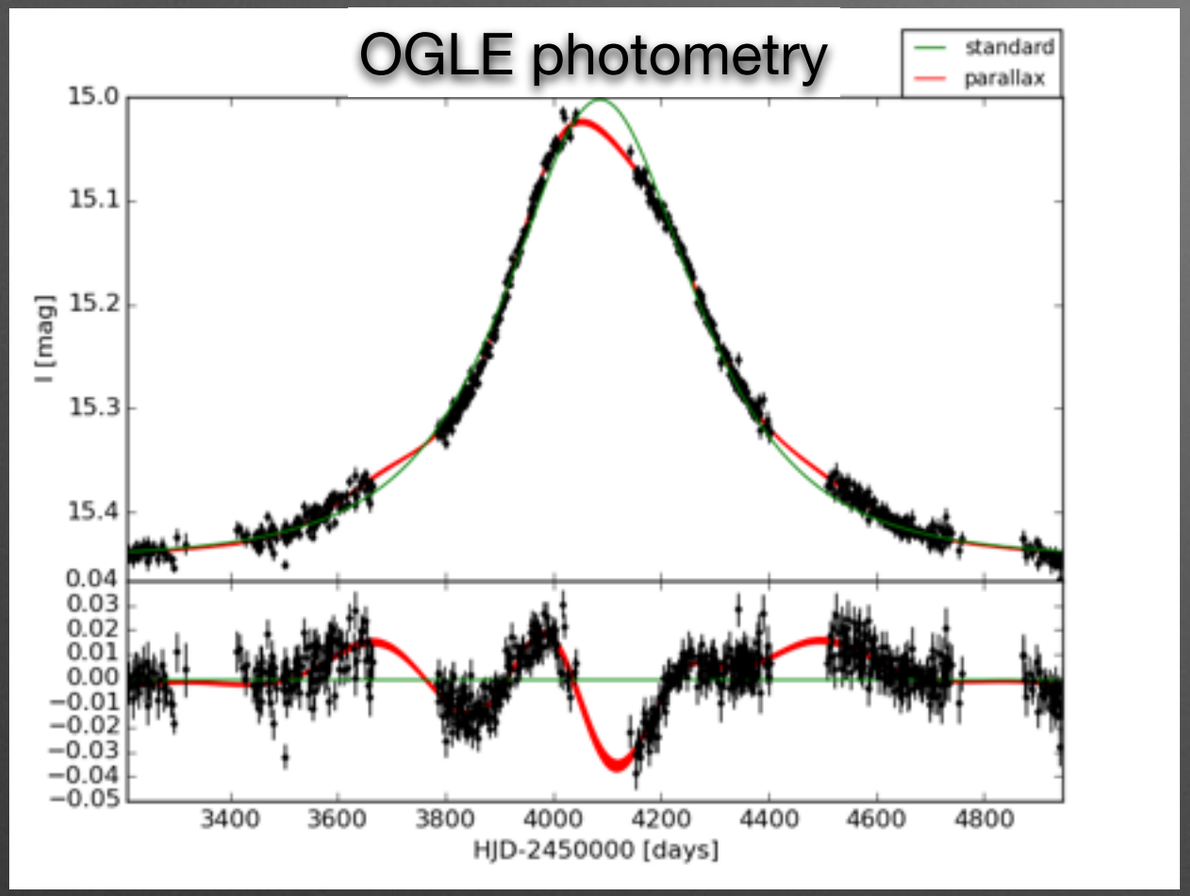
OGLE-GAIA SKY

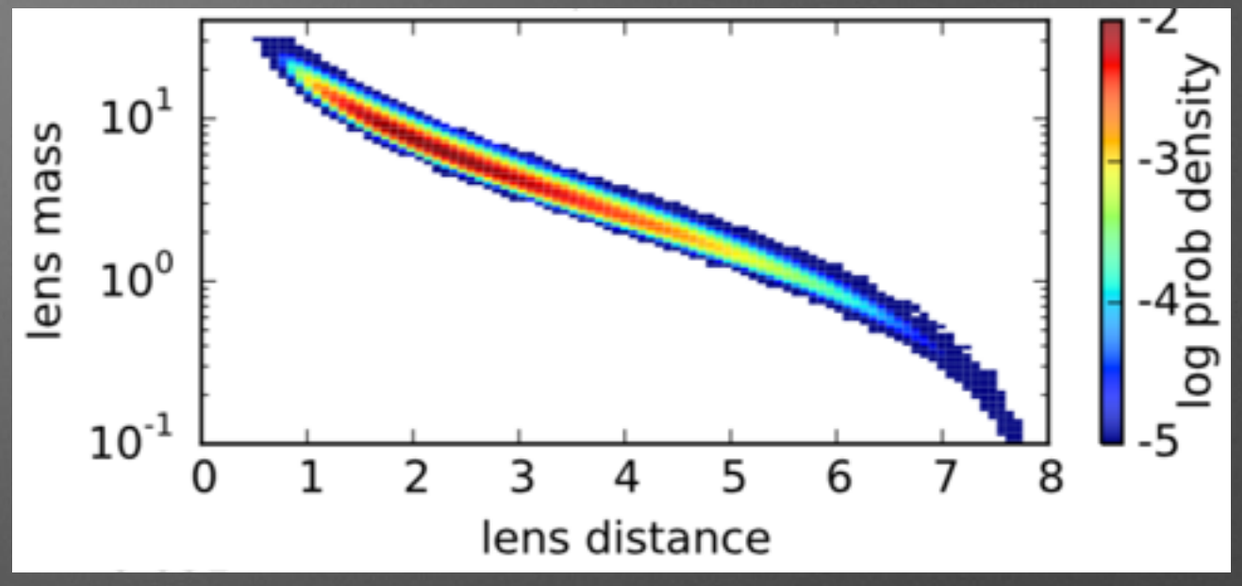


Gaia figure by Nadia Blagorodnova, OGLE fields by Jan Skowron

STELLAR-MASS BLACK HOLES

OGLE3-ULENS-PAR-02 - candidate ~9MSun BH





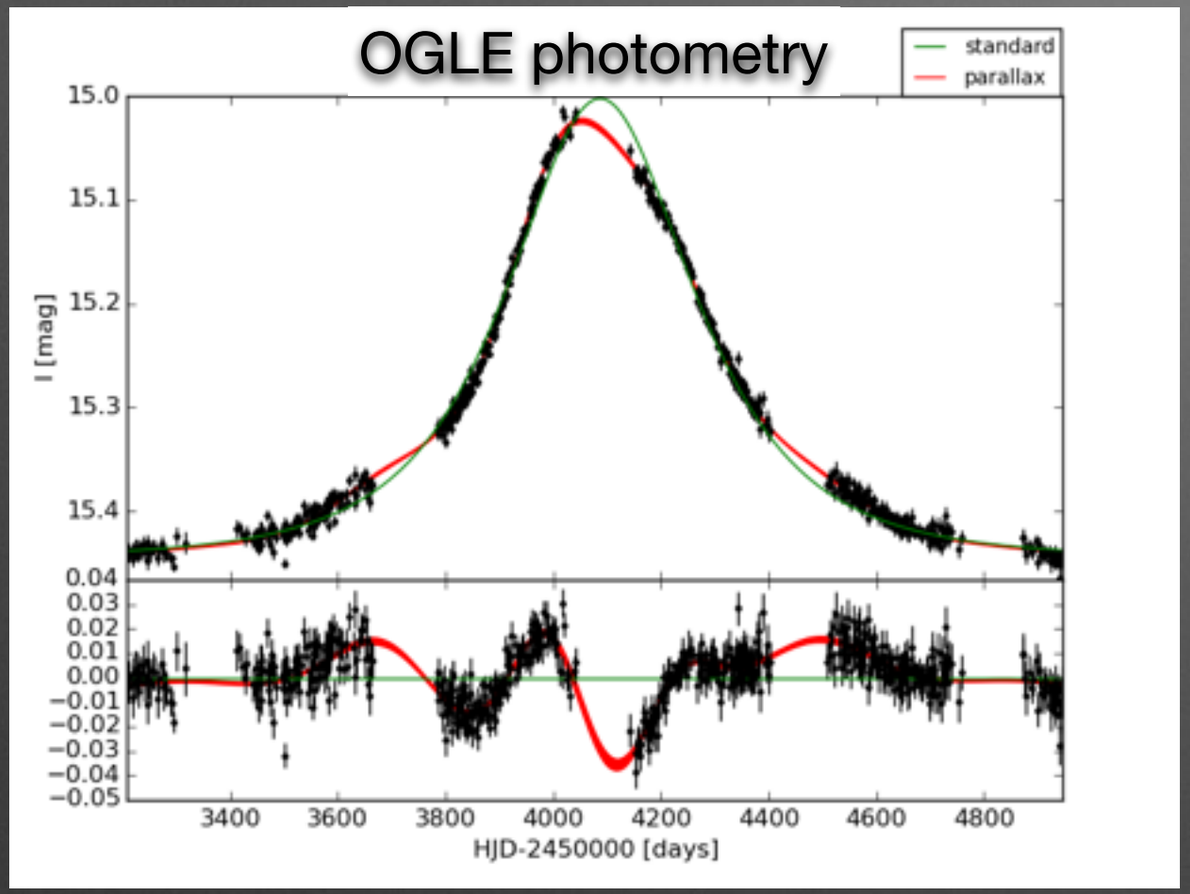
OGLE photometry
from 2001-2008
and microlensing model

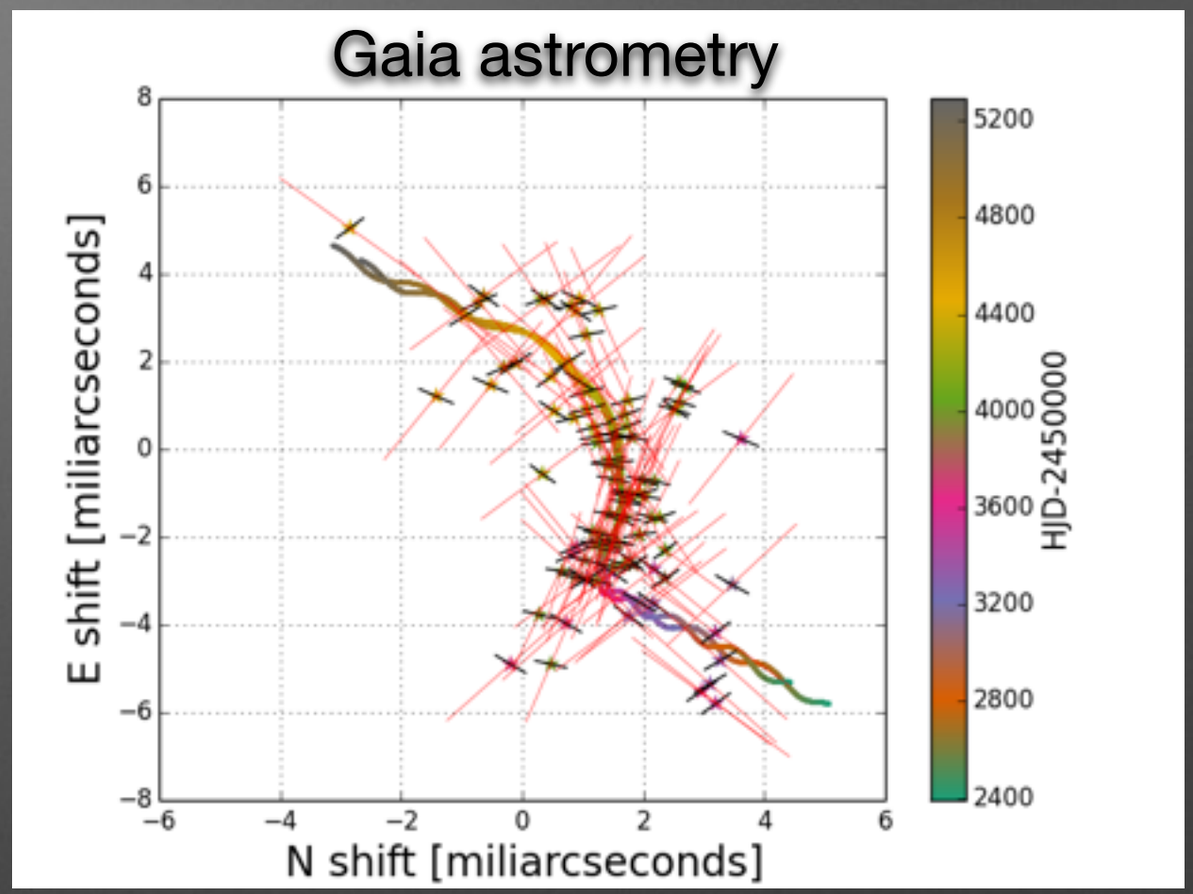
probability distribution
for the proper motion
based on observed PM

Mass, Distance estimate only

STELLAR-MASS BLACK HOLES

OGLE3-ULENS-PAR-02 - candidate ~9MSun BH





OGLE photometry
from 2001-2008
and microlensing model

predicted
Gaia astrometry
for similar event

Mass, Distance

Rybicki in prep.

ASTROMETRIC PRECISION IN GAIA

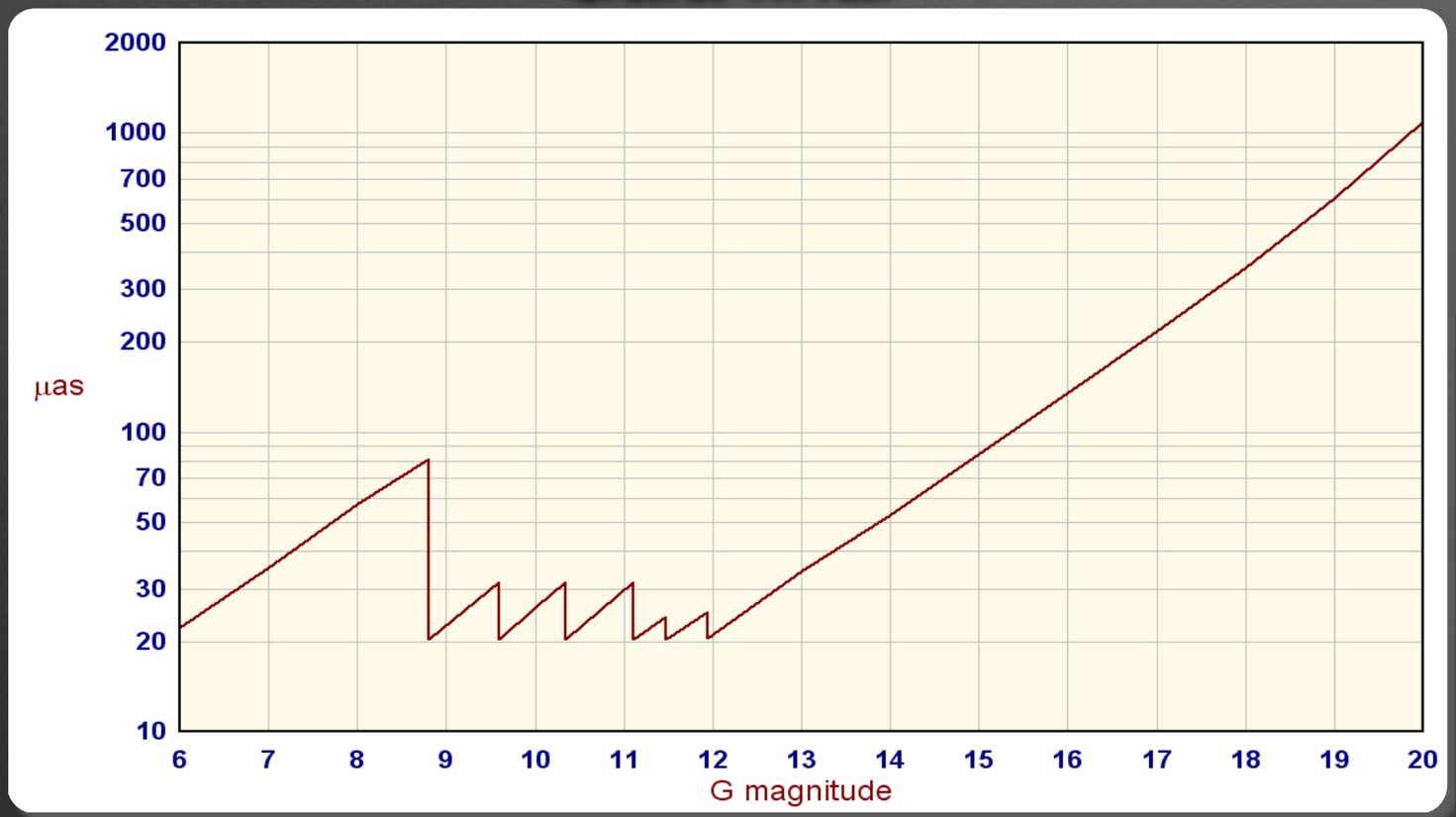
50 mas : daily calibrations

0.1 mas : fortnightly calibrations

final precision (in 2022):

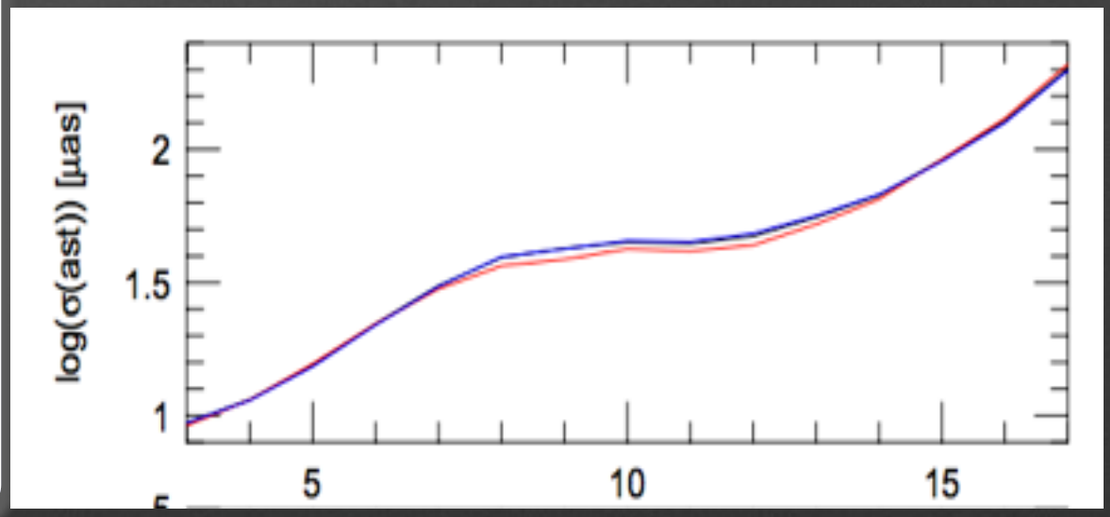
1D precision!

Gaia final



G-band mag

WFIRST



H-band mag

Gould+2017

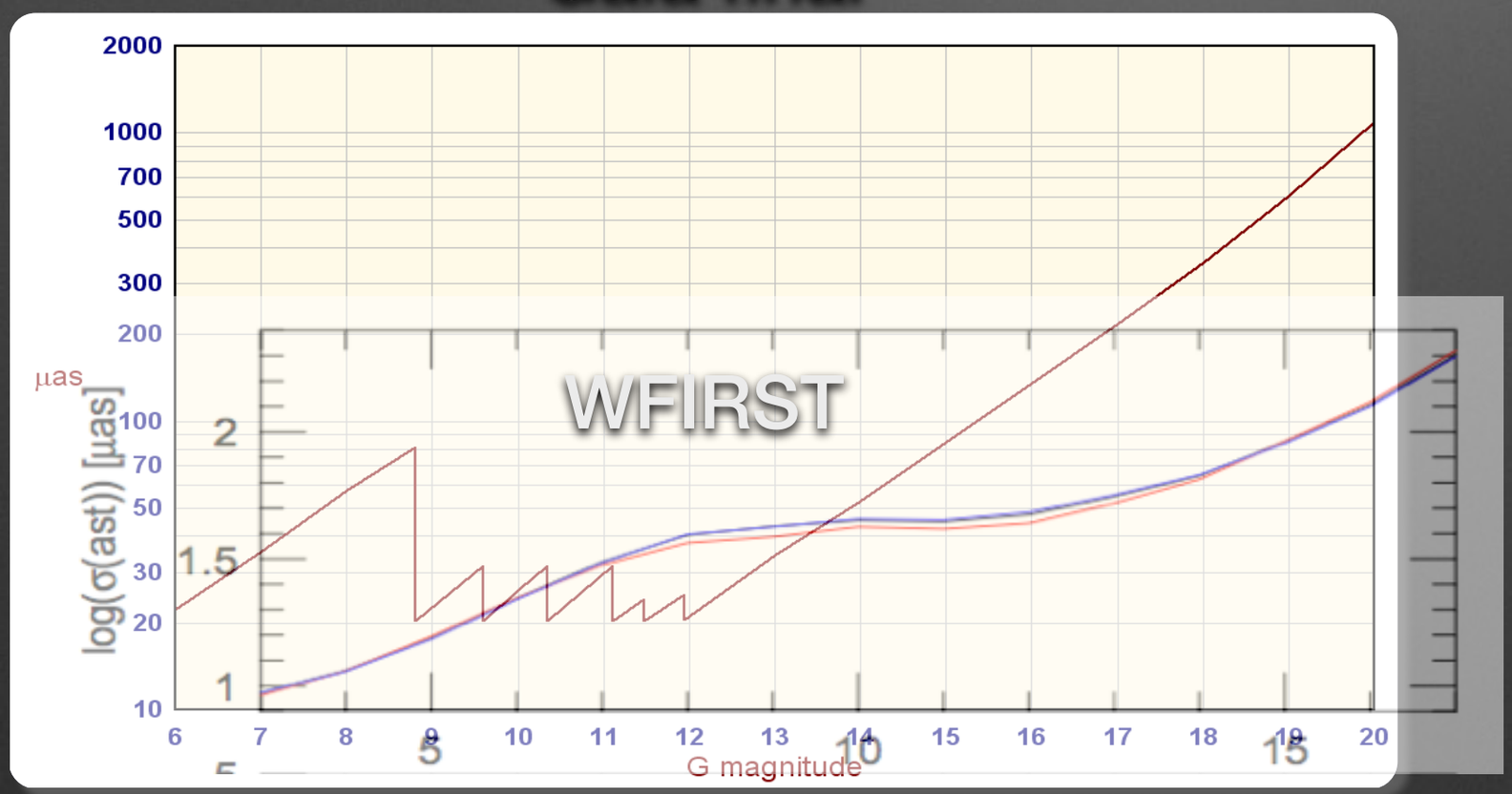
ASTROMETRIC PRECISION IN GAIA

50 mas : daily calibrations

0.1 mas : fortnightly calibrations

final precision (in 2022):

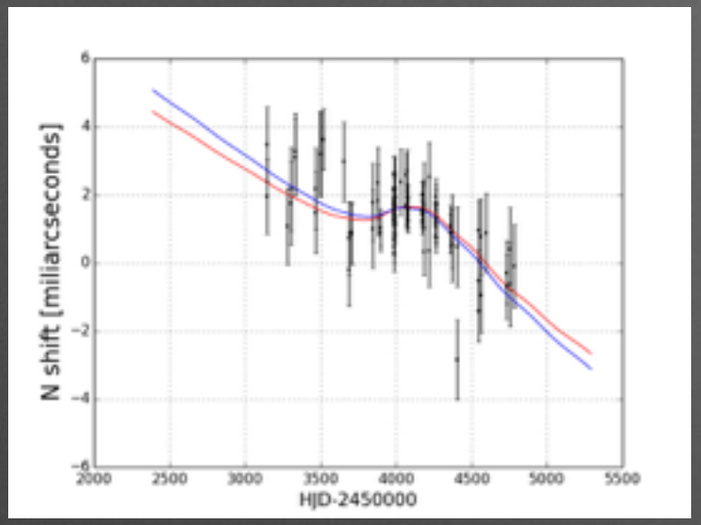
1D precision!

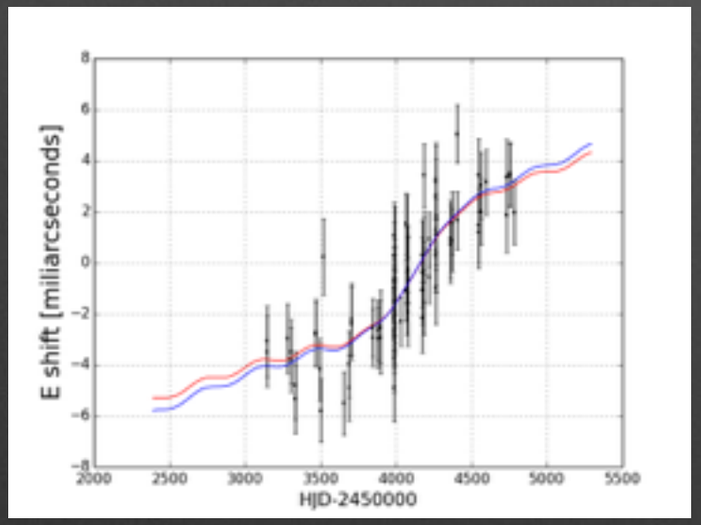


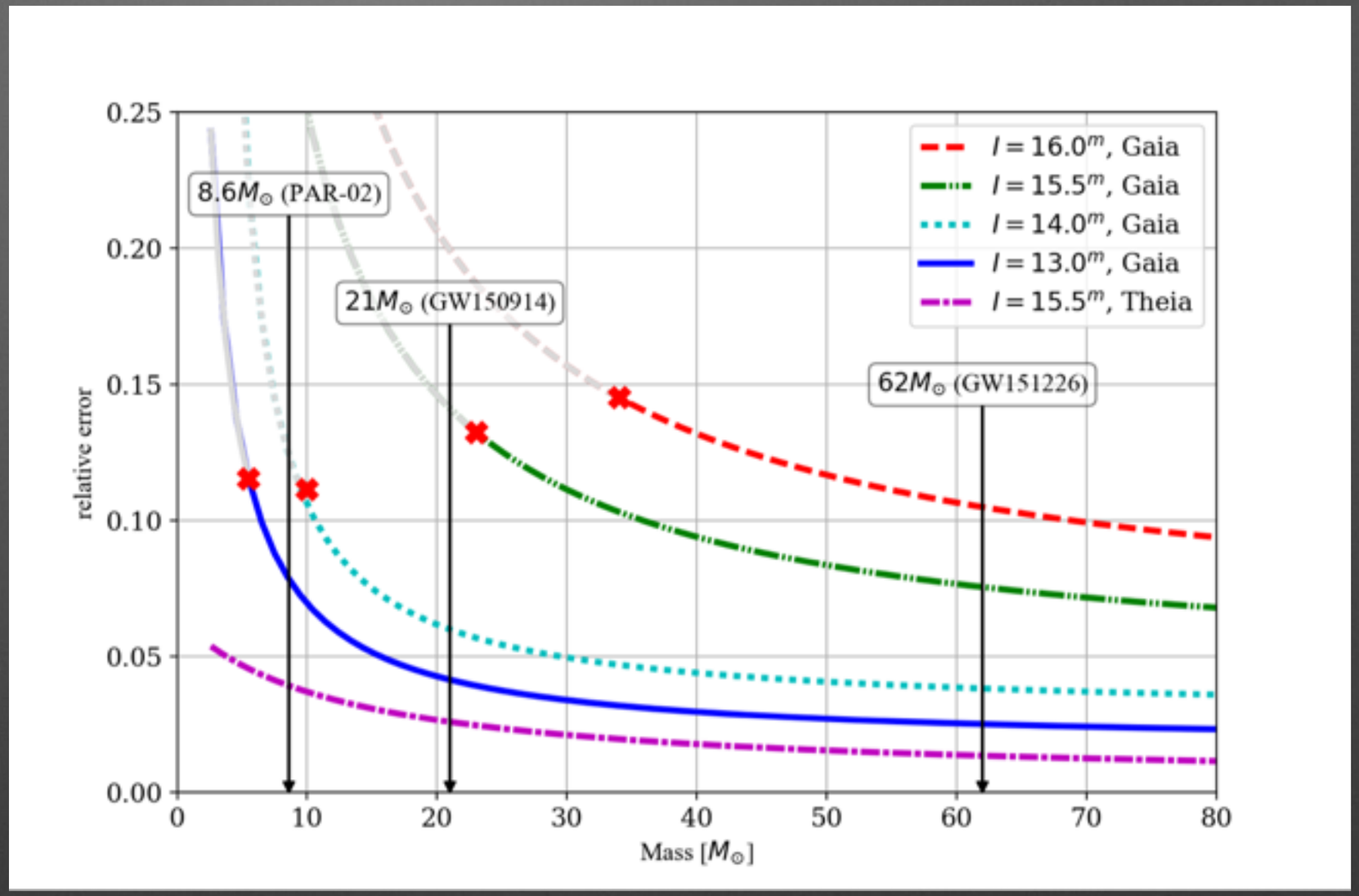
Gould+2017

STELLAR-MASS BLACK HOLES

OGLE3-ULENS-PAR-02 - candidate ~9MSun BH







Combination of ground-based photometry and Gaia astrometry for long events will yield masses of black holes accurate to ~10% percent (brightness dependent)

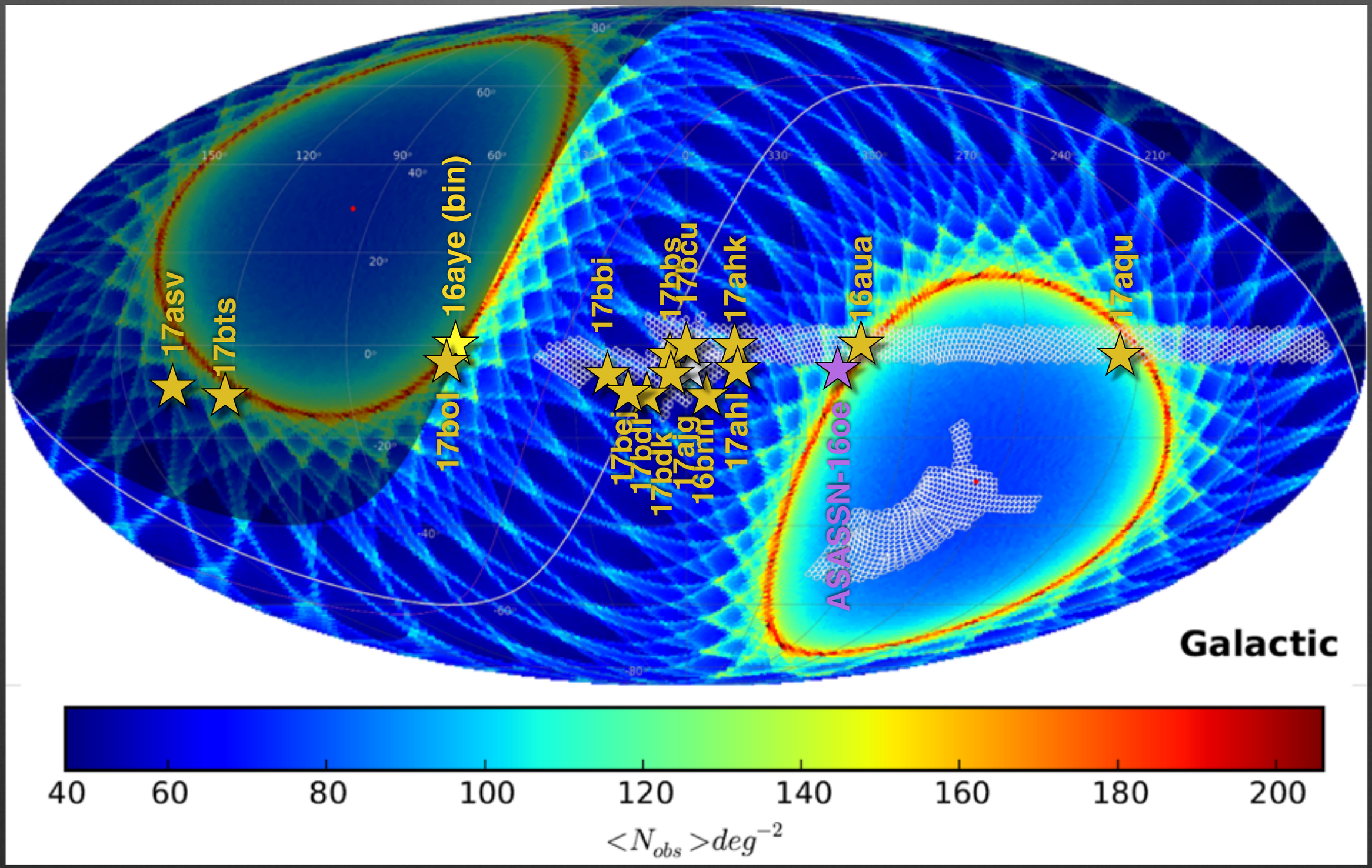
see Kris Rybicki's POP

Rybicki in prep.

short break :)

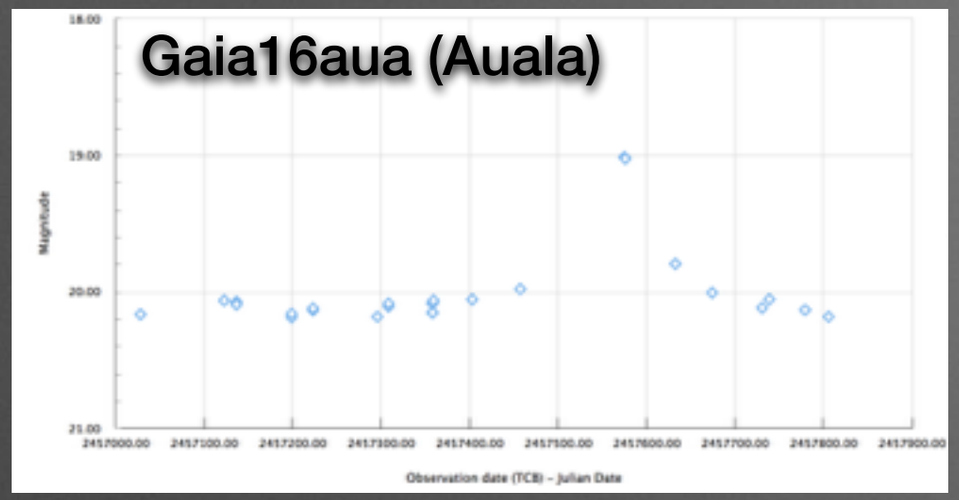
MICROLENSING EVENTS FROM GAIA

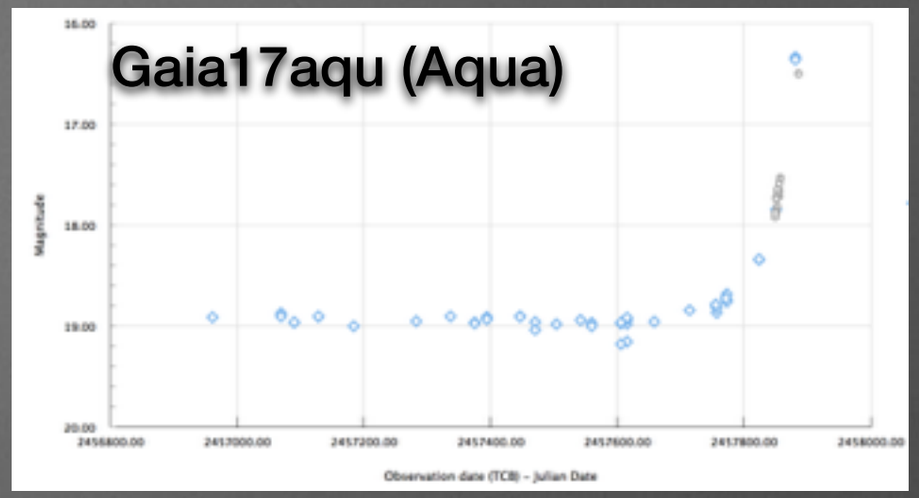
July 2016 - July 2017

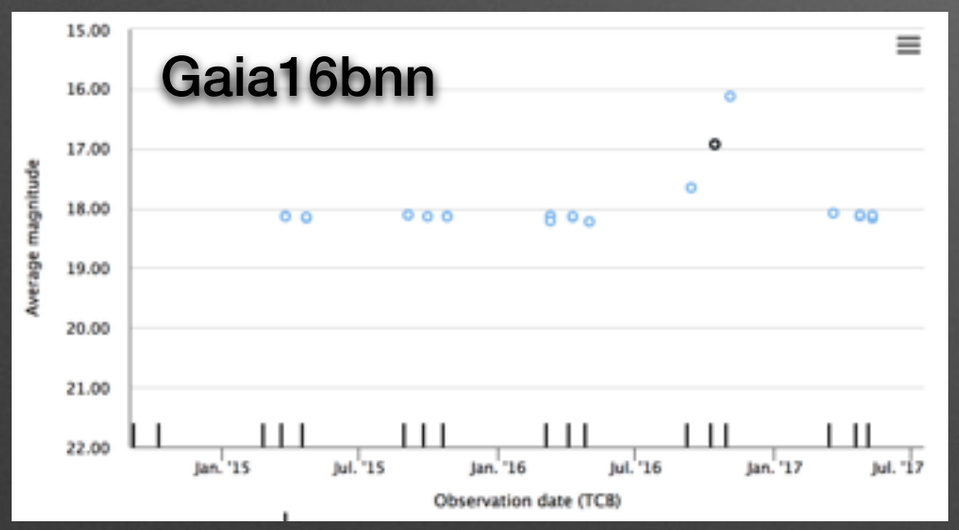


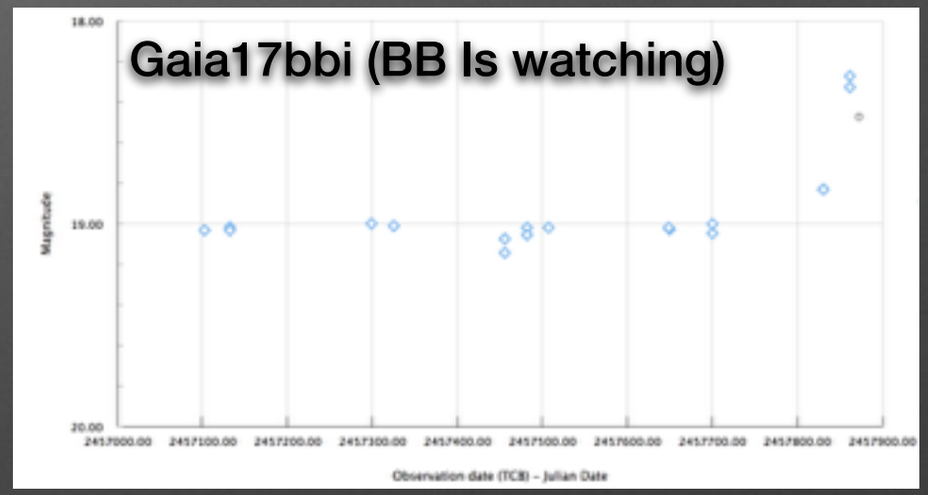
Gaia figure by Nadia Blagorodnova, OGLE fields by Jan Skowron

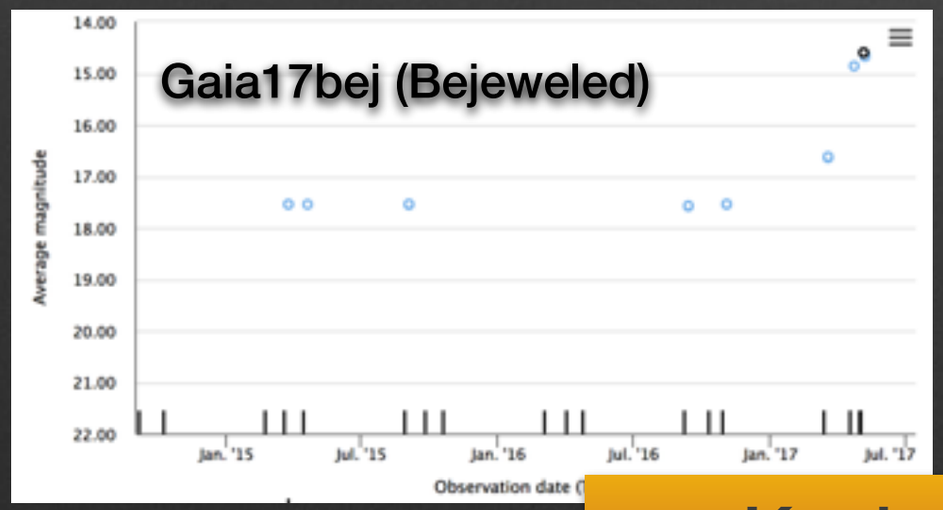
MICROLENSING EVENTS FROM GAIA

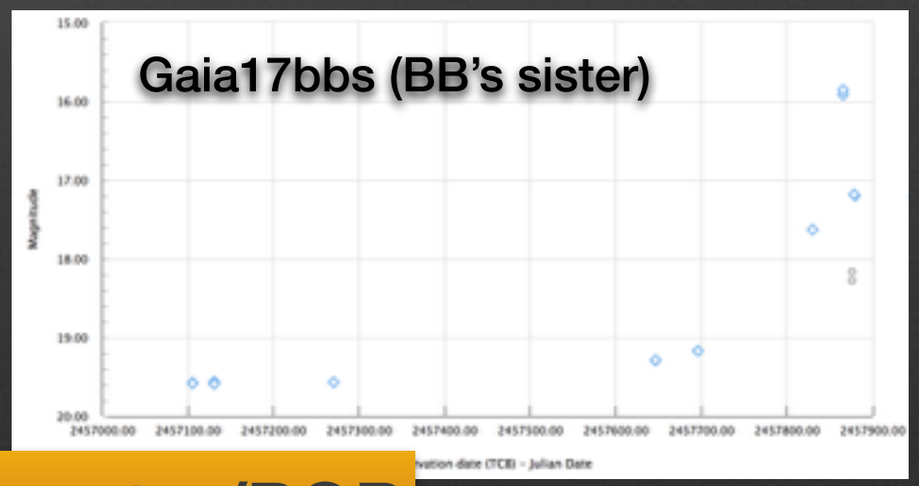






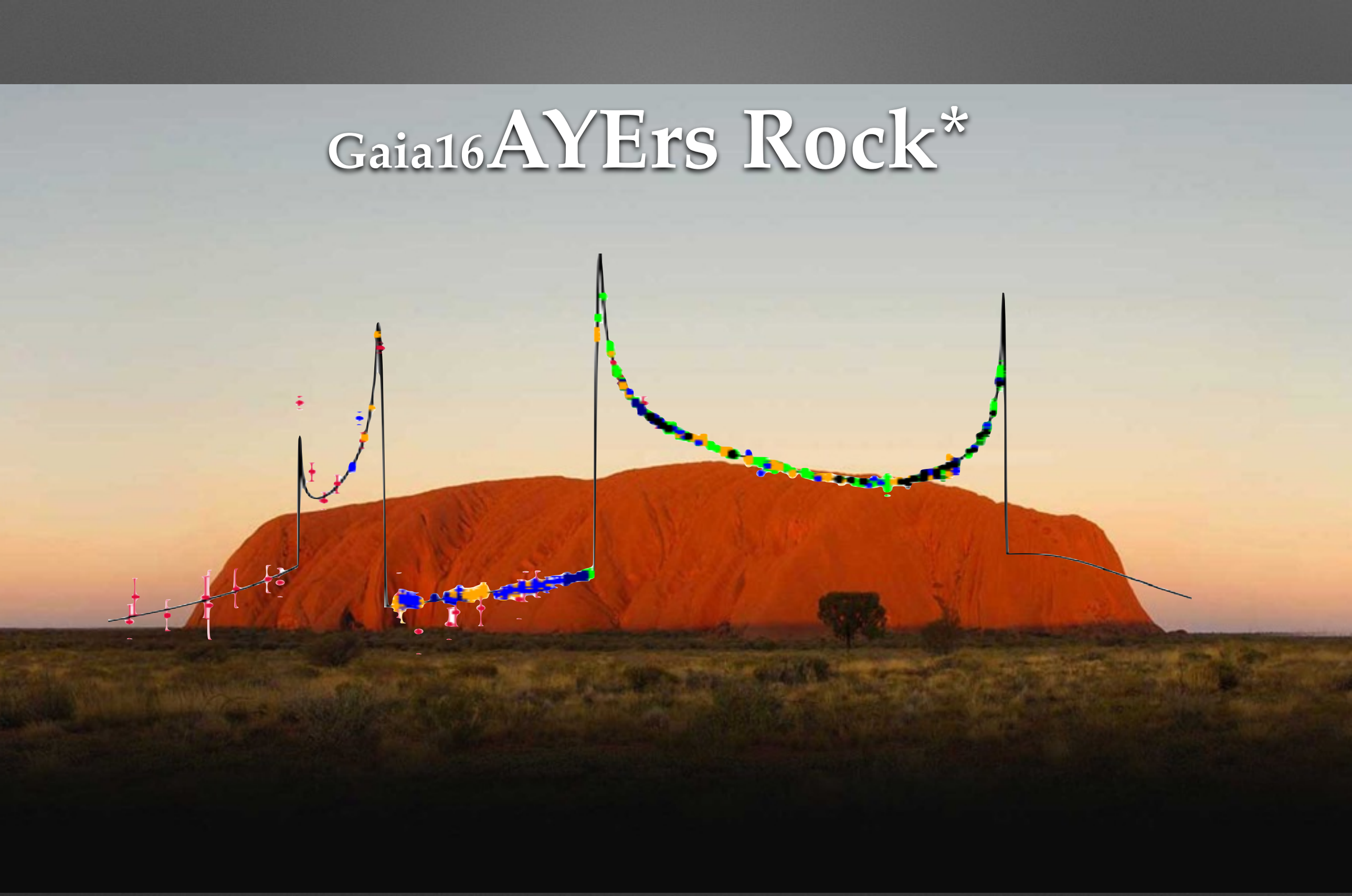






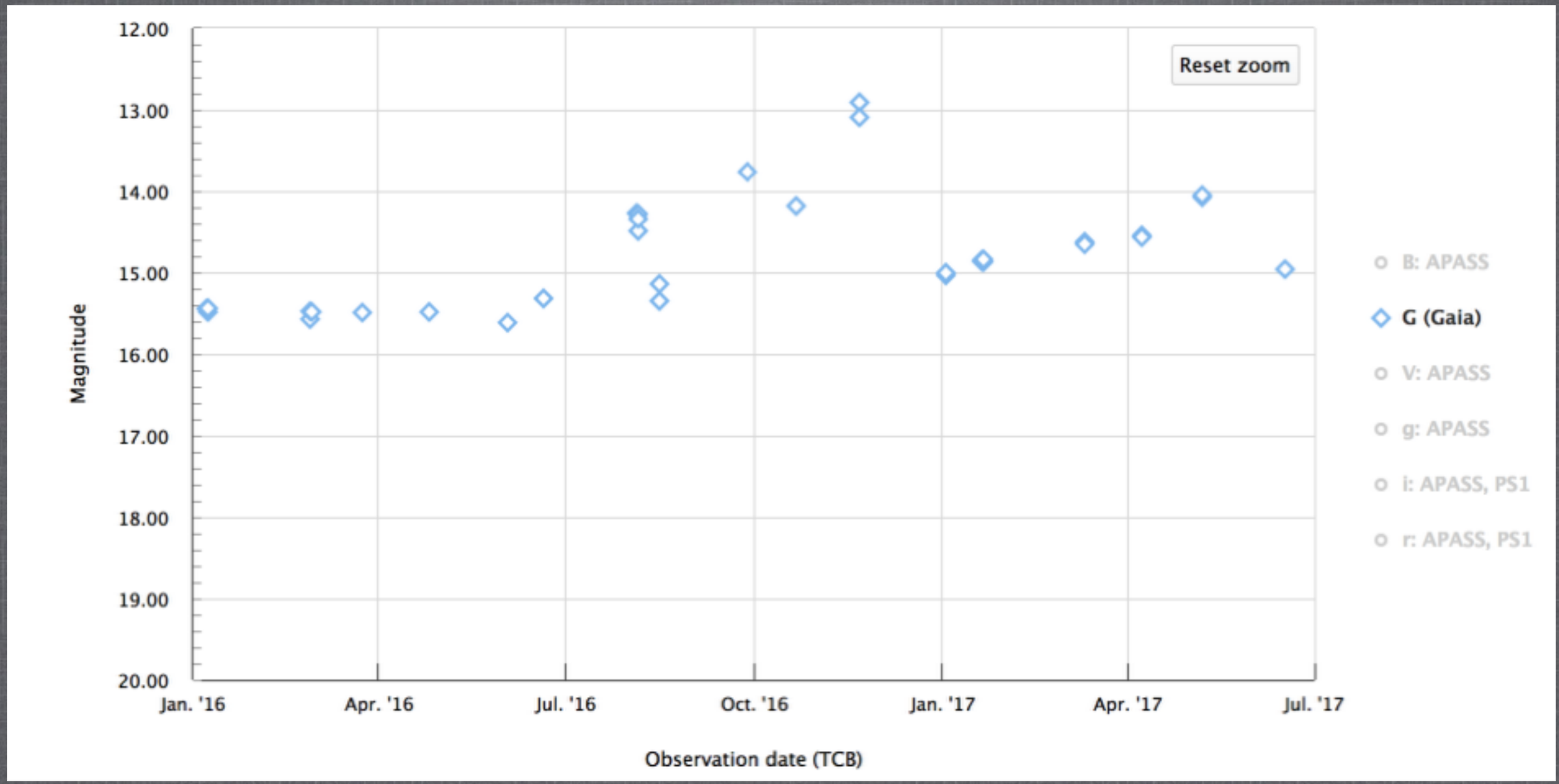
see Kasia Kruszynska's poster/POP

Gaia16AYErs Rock*



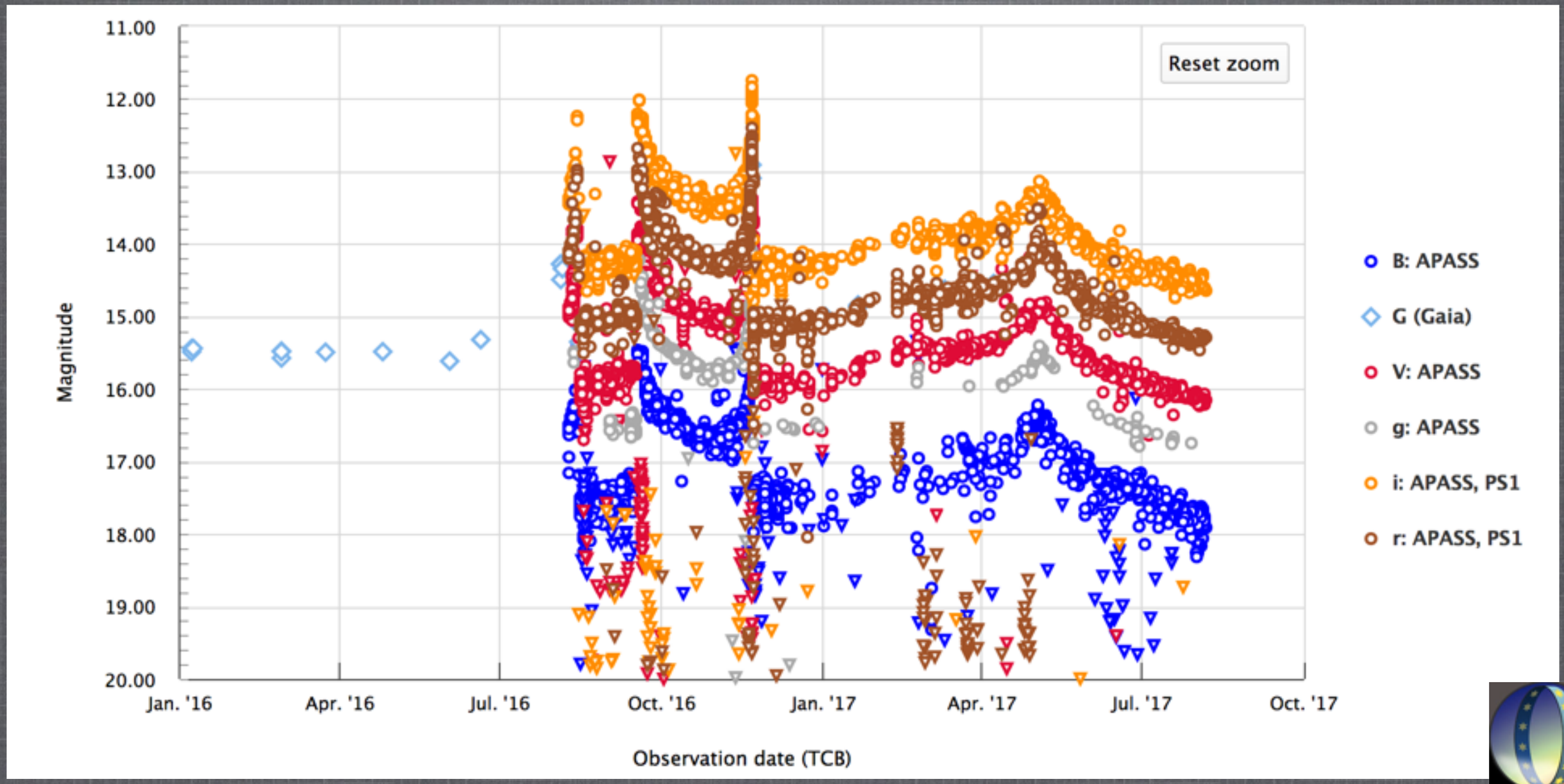
*Uluru

GAIA16AYE (AYERS ROCK)



GAIA16AYE (AYERS ROCK)

More than 20,000 data points collected in multiple bands
by a network of volunteering observatories

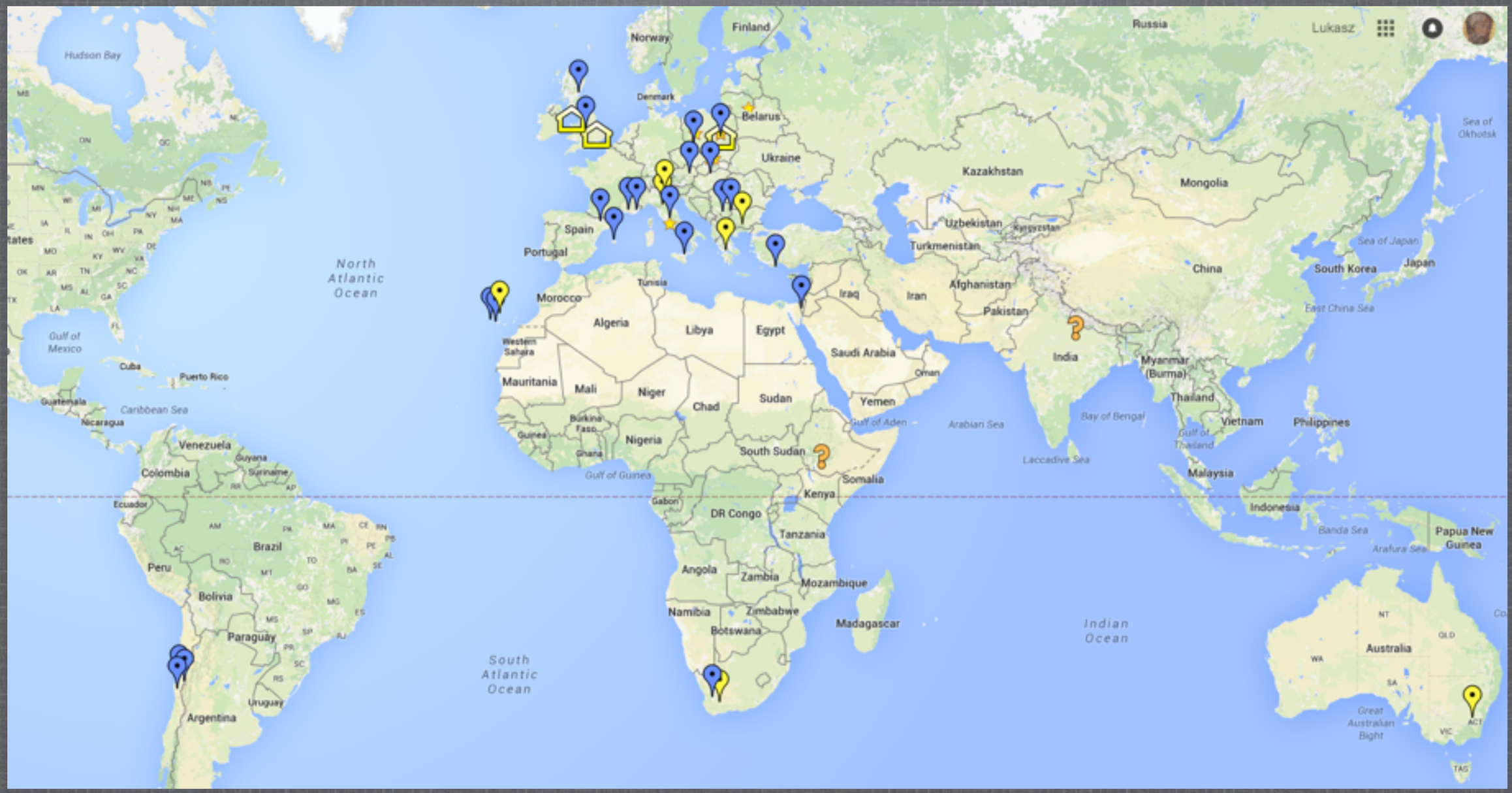


OPTICON

GAIA ALERTS FOLLOW-UP NETWORK

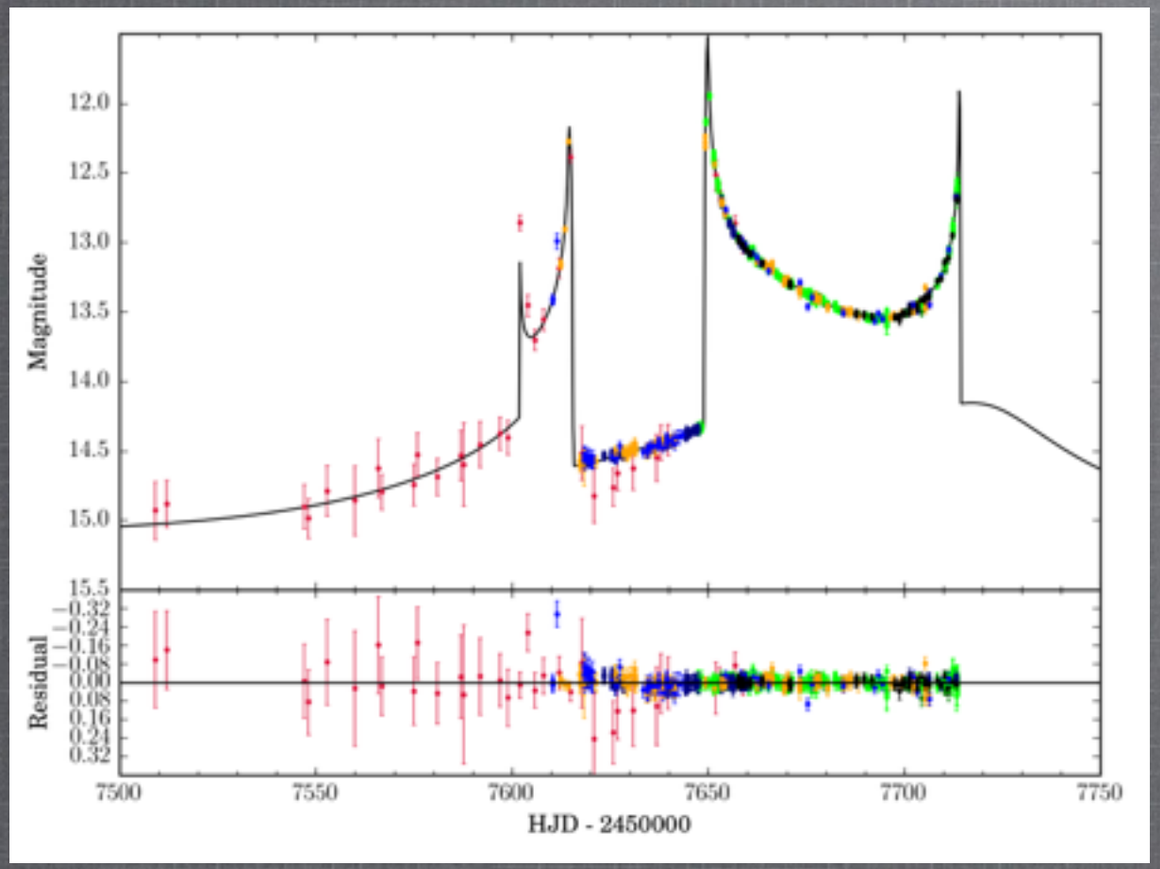
~20 active partners, ~30000 data points collected 2014-2016

2017-2020: continuation under OPTICON H2020



GAIA16AYE (AYERS ROCK)

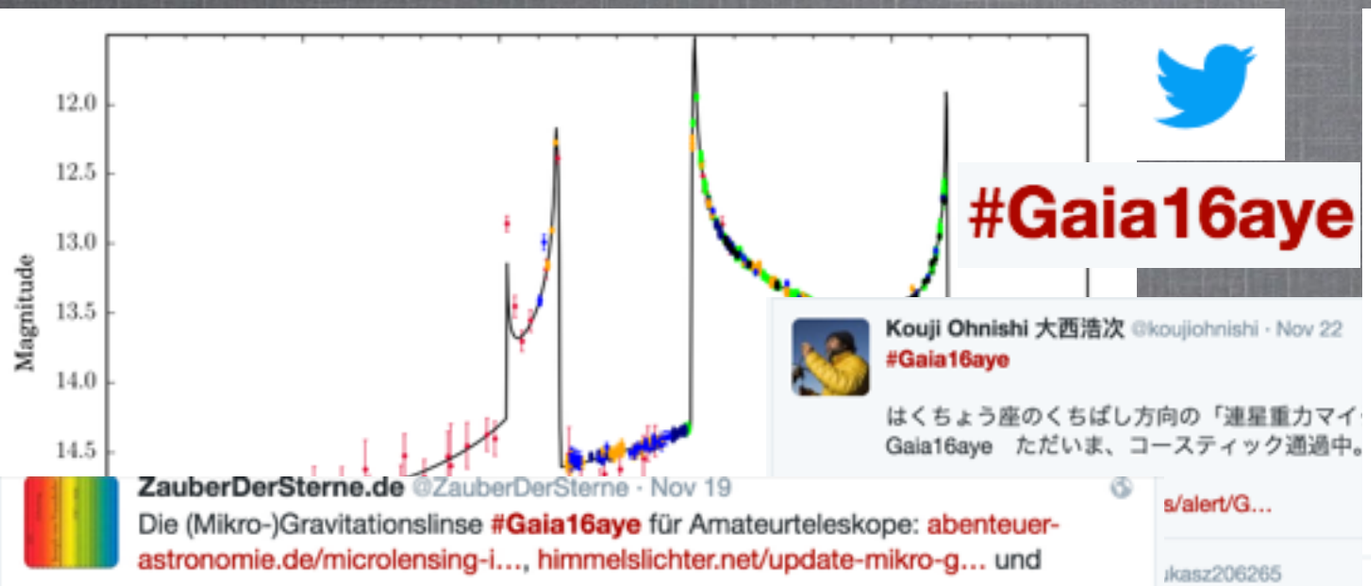
Catching the 4th caustic exit



Model prediction
Caustic exit 21 November 2 am UT

GAIA16AYE (AYERS ROCK)

Catching the 4th caustic exit



#Gaia16aye

Kouji Ohnishi 大西浩次 @koujiohnishi · Nov 22
#Gaia16aye

はくちょう座のくちばし方向の「連星重力マイ
Gaia16aye　ただいま、コースティック通過中。

ZauberDerSterne.de @ZauberDerSterne · Nov 19
Die (Mikro-)Gravitationslinse #Gaia16aye für Amateurteleskope: abenteuer-astronomie.de/microlensing-i..., himmelslichter.net/update-mikro-g... und

Gaia16aye: Seltenes Microlensing-Ereignis mit Ans...
Zurzeit ereignet sich im Schwan nahe des hellen Sterns phi Cyg ein spektakuläres Himmelsphänomen. Das Microlensing-Ereignis Gaia16aye (Spitzname Ayers Ro...
zauberdersterne.wordpress.com

2　2

Gaia-GOSA and 2 others follow

Jan Hattenbach @JanHattenbach · Nov 19
Morgen abend gibt's Gravitationslinse: himmelslichter.net/update-mikro-g... #Gaia16aye

Update: Mikro-Gravitationslinse Gaia16aye soll Son...
Ein neues Modell sagt das vierte und letzte Aufleuchten der Mikro-Gravitationslinse Gaia16aye für Sonntag, den 20. November kurz vor 22 Uhr MEZ (20,8 UT) voraus. ...
himmelslichter.net

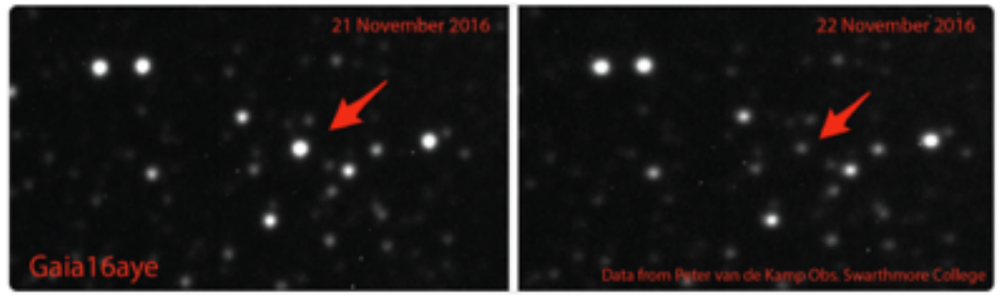
1　6　3

Jos de Bruijne Retweeted

Jan Hattenbach @JanHattenbach · Nov 18

Simon Hodgkin and 3 others Retweeted

Eric Jensen @elnjensen · Nov 23
What a difference a day makes! #Gaia16aye fades dramatically as caustic crossing part of microlensing event ends. #GaiaMission



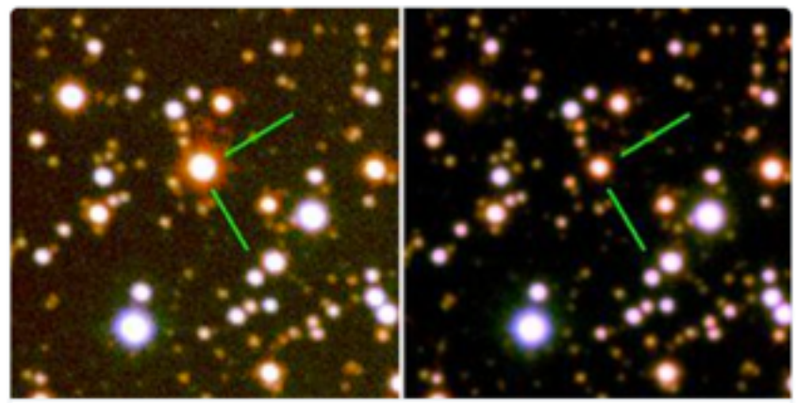
18　15

Daniel Fischer @cosmos4u · Nov 22
Light curve from Turkey could nail down peak time of the final #Gaia16aye caustic crossing: astronomerstelegram.org/?read=9780 - 17:54 UTC yesterday.

Lukasz Wyrzykowski @lukasz206265 · Nov 22
#Gaia16aye magnitude drop by 2.5 from last night - clearly the caustic crossing is over!

1

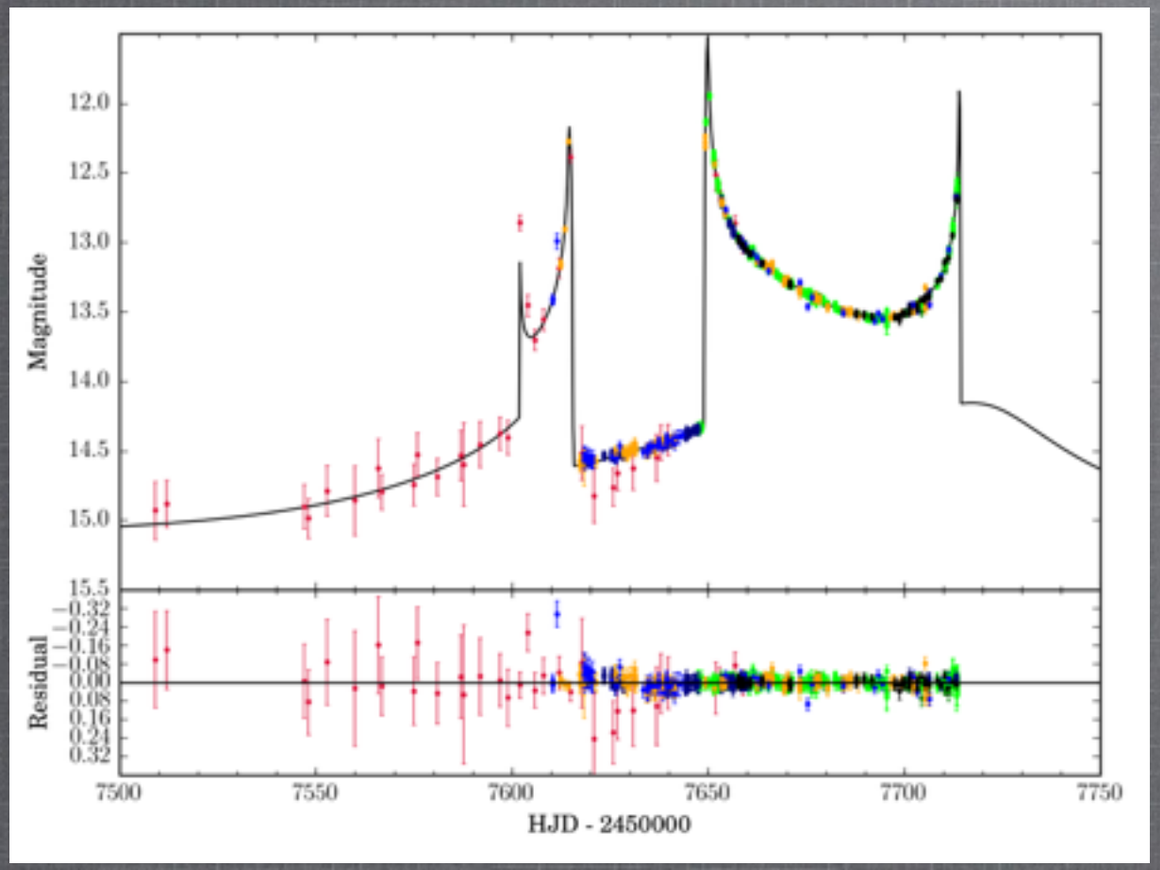
Daniel Fischer @cosmos4u · Nov 27
In Turkey they are celebrating their measurements (astronomerstelegram.org/?read=9780) of #Gaia16aye's final caustic crossing:



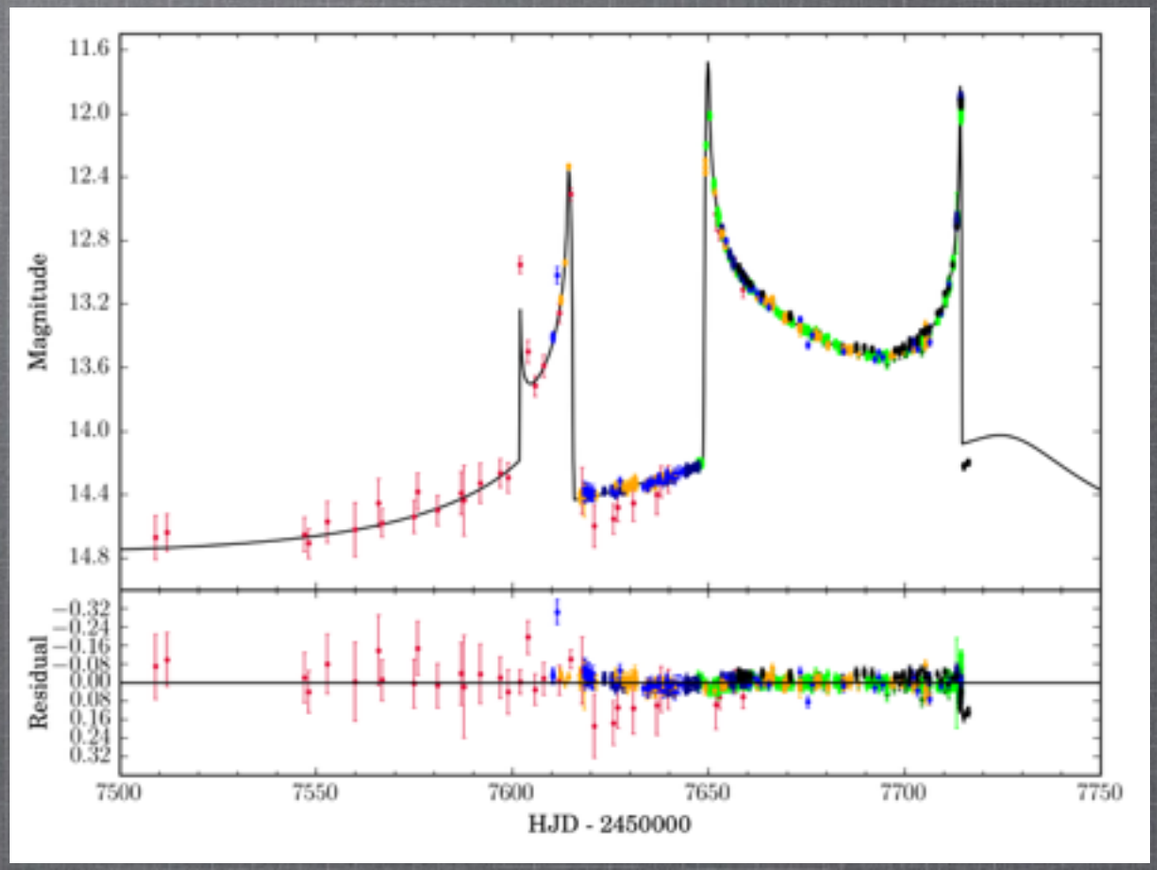
Parlayan yıldızın ışığını TÜBİTAK yakaladı
TÜBİTAK Başkanı Ergin, "TÜBİTAK Ulusal Gözlemevinin, coğrafi konum ve atmosferik koşullarının avantajını kullanarak, Gaia16aye isimli yıldızdan ...
aa.com.tr

GAIA16AYE (AYERS ROCK)

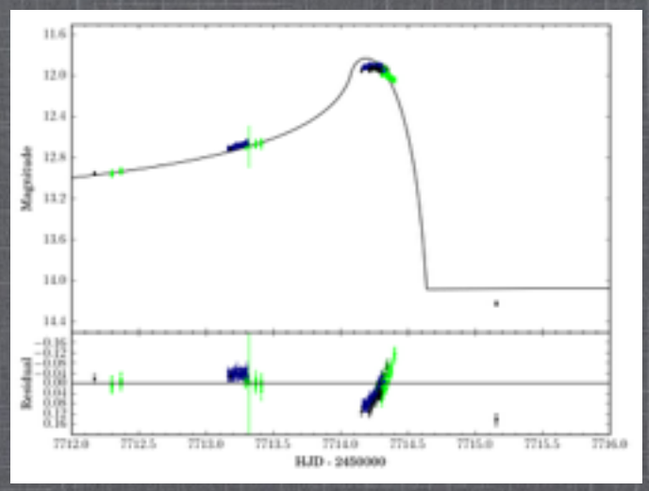
Catching the 4th caustic exit



Model prediction
Caustic exit 21 November 2 am UT

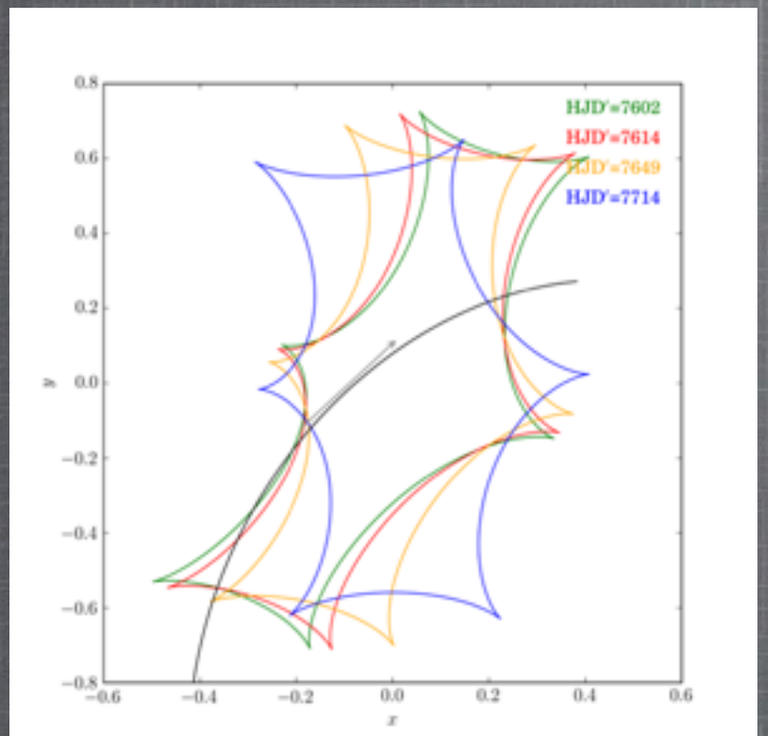


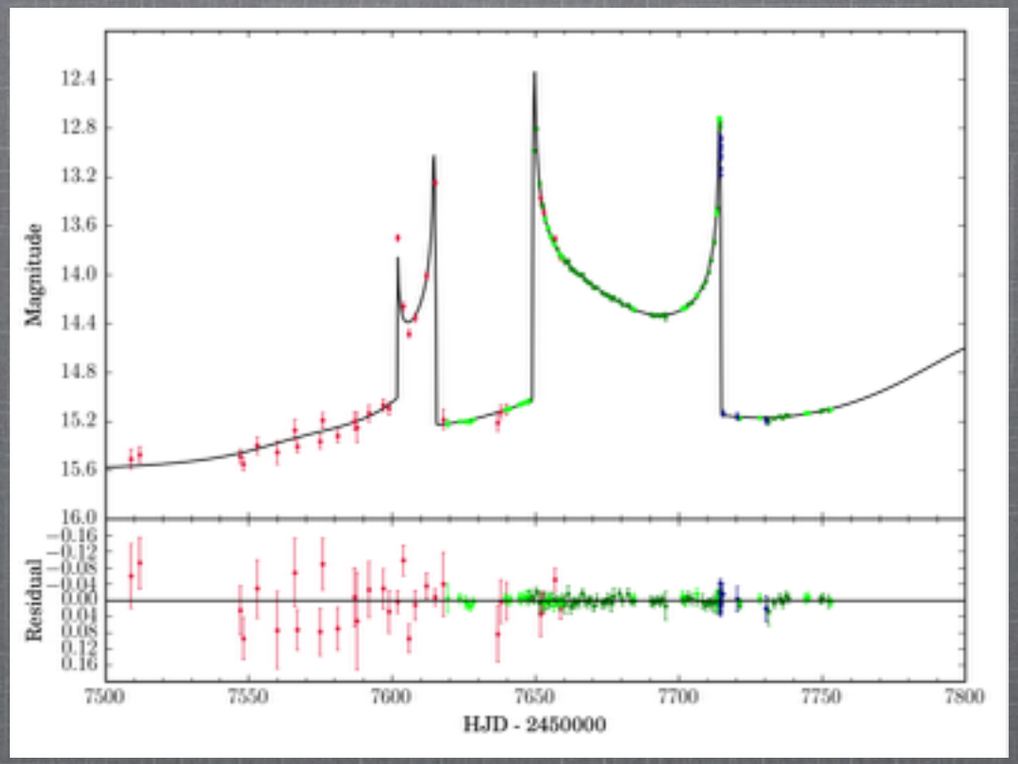
actual peak: 21 Nov ~16 UT



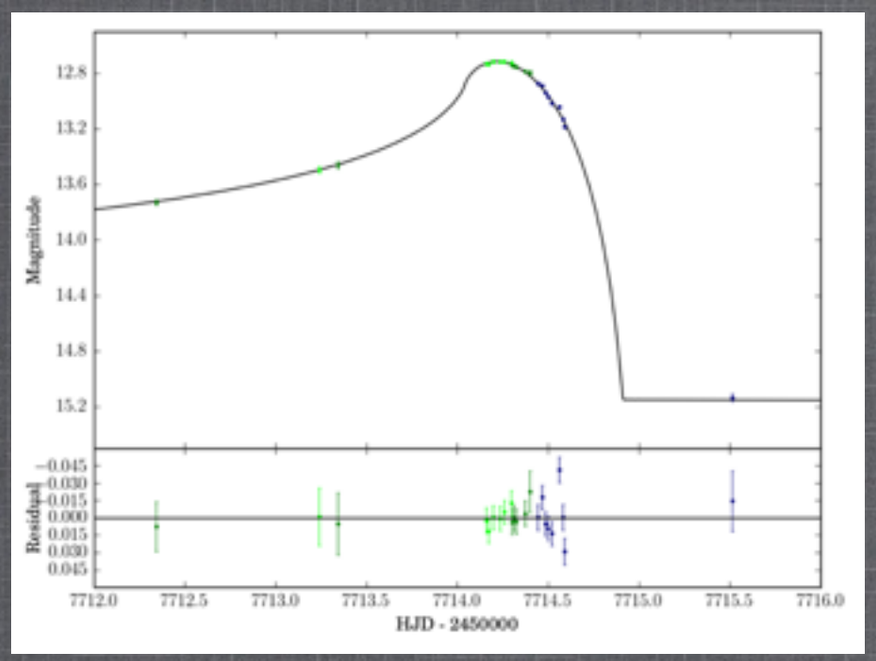
GAIA16AYE (AYERS ROCK)

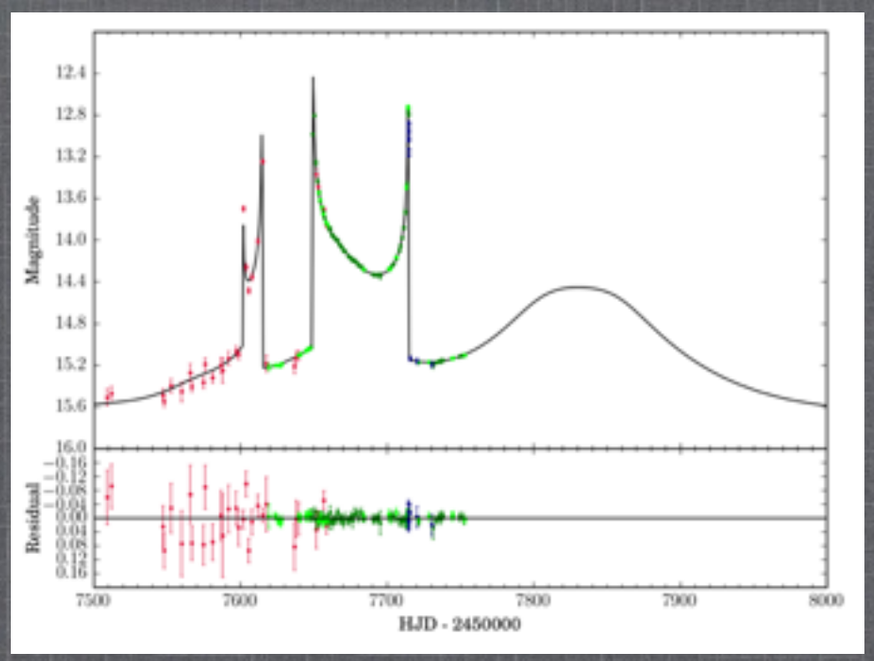
Preliminary full-Keplerian orbital solution of the binary lens





tE = 141d
piE= 0.39
thetaE=3 mas
mu_rel=7mas/yr
q=0.57
s=1.0
fs=0.75



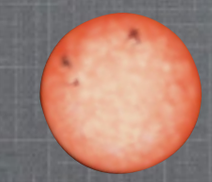


model by P.Mroz and J.Skowron

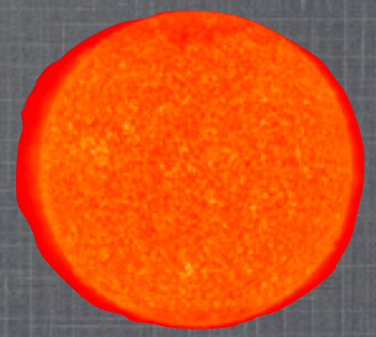
PRELIMINARY SOLUTION

~8kpc

0.8kpc



2.3AU

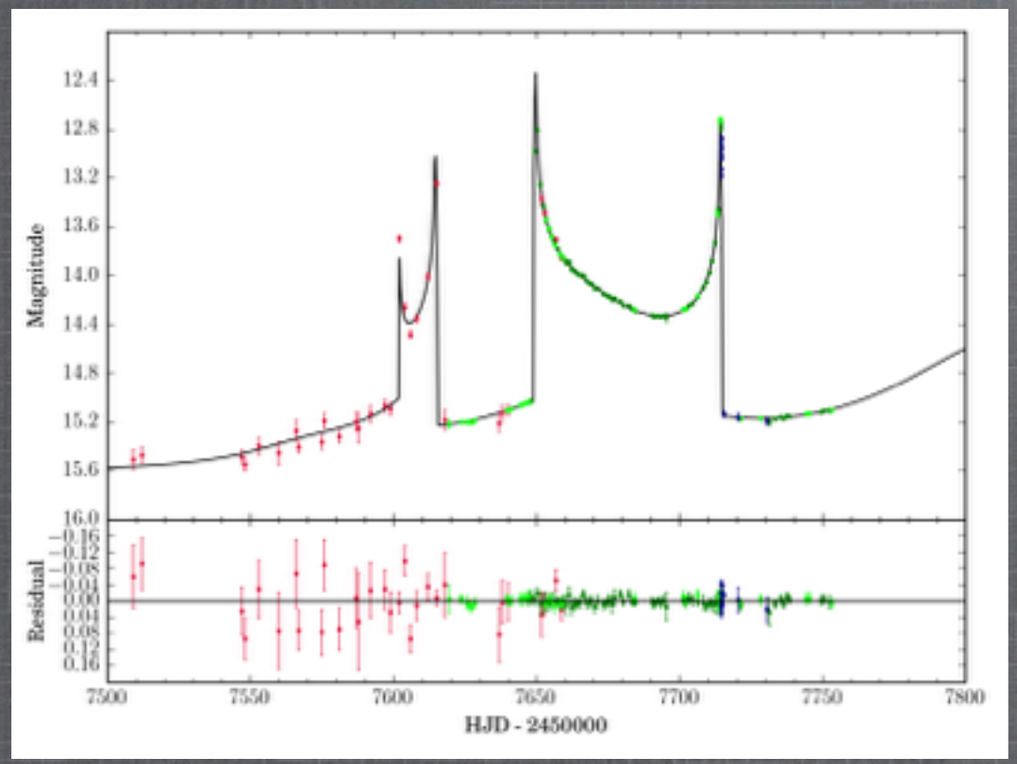


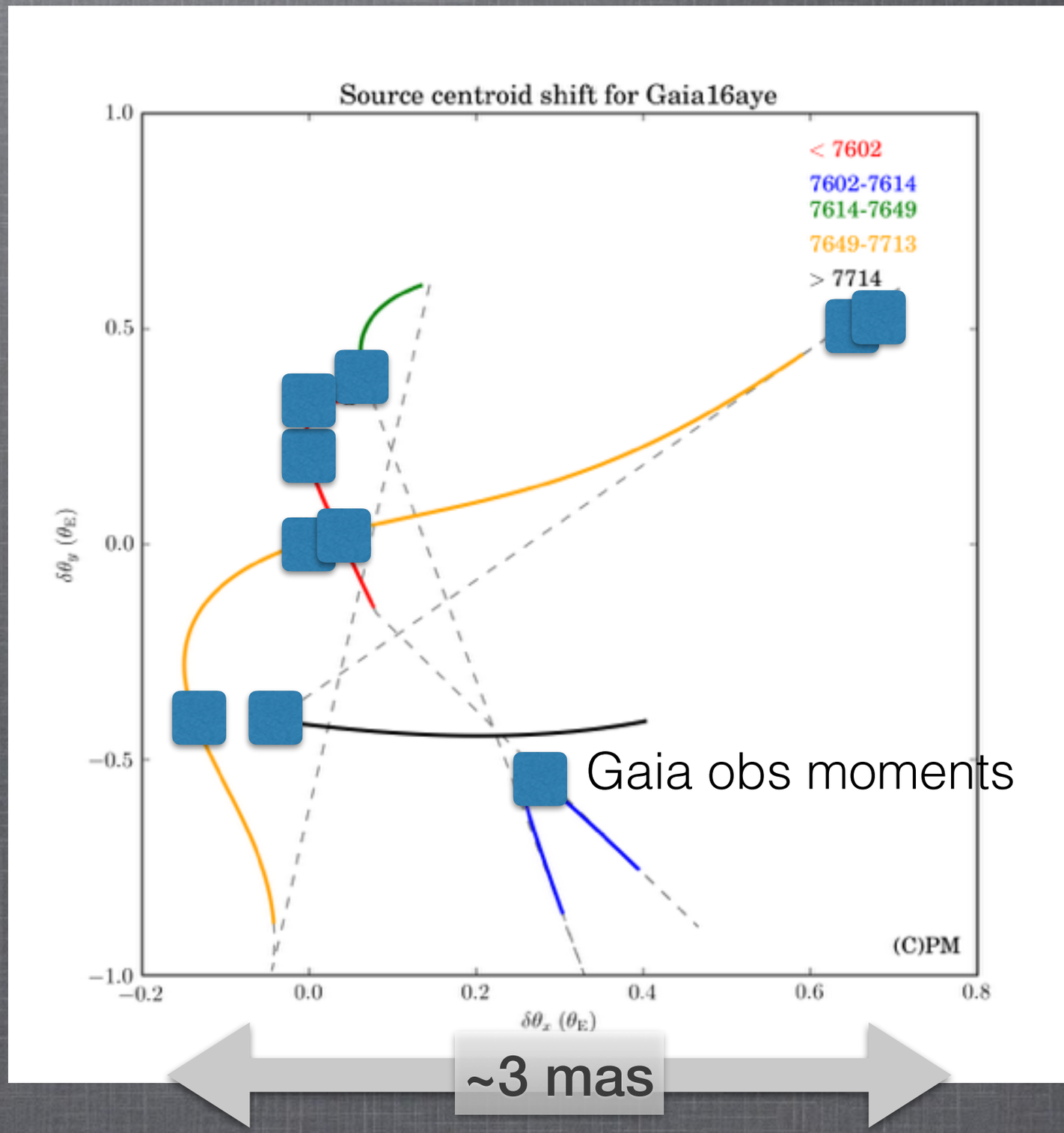
$M_1 = 0.4\ M_{Sun}$
$M_2 = 0.6\ M_{Sun}$
P = 3.4 yrs
incl = 60 deg
ecc = 0.473

K3 giant
$R = \sim 10\ R_{Sun}$

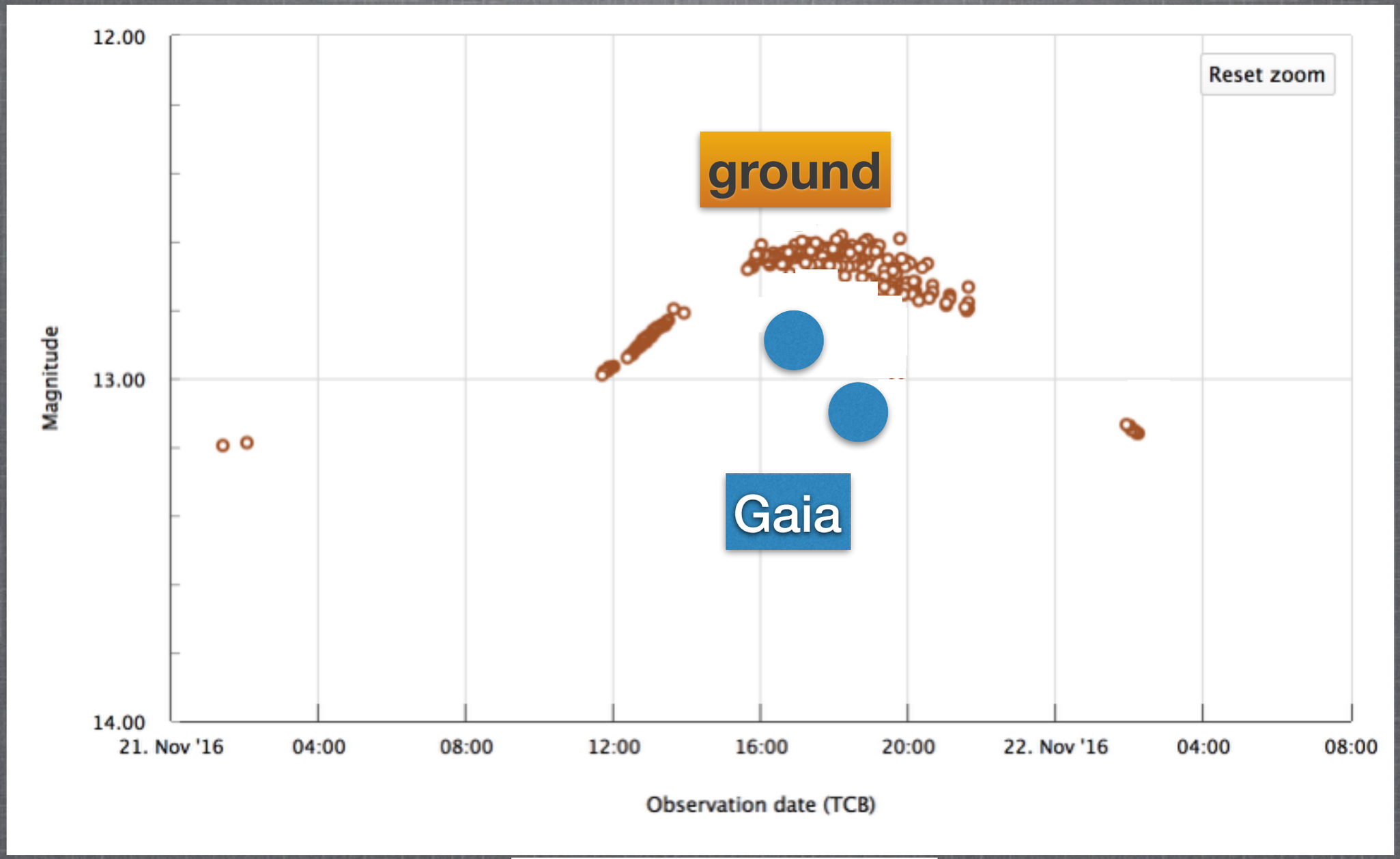
ASTROMETRY

First time ever chance to detect binary astrometric microlensing!





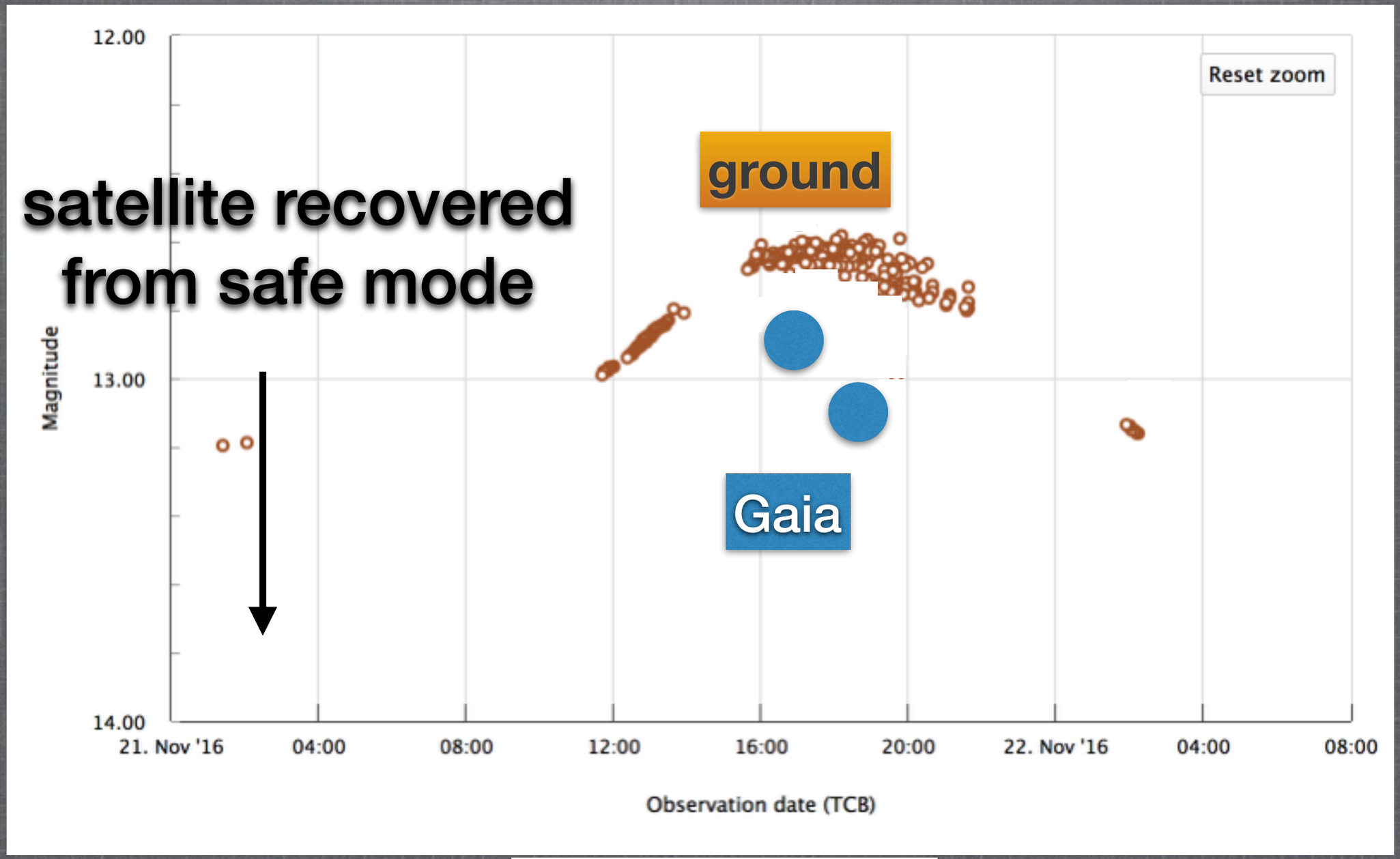
SPACE PARALLAX FROM GAIA?



$$\pi_{\rm E} = \frac{\rm AU}{D_\perp}\left(\frac{\Delta t_0}{t_{\rm E}}, \Delta u_0\right),$$

Offset in both time and mag between Earth-based and Gaia-based observations → microlensing parallax

SPACE PARALLAX FROM GAIA?

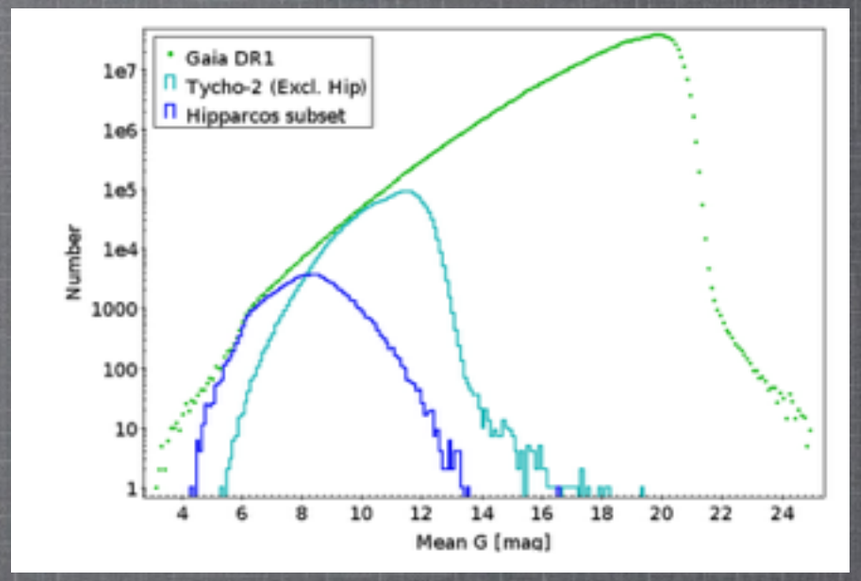


$$\pi_{\rm E} = \frac{\rm AU}{D_\perp}\left(\frac{\Delta t_0}{t_{\rm E}}, \Delta u_0\right),$$

Offset in both time and mag between Earth-based and Gaia-based observations → microlensing parallax

GAIA DATA RELEASES

www.cosmos.esa.int/web/gaia



DR1 14 September 2016:

- positions for 1 billion stars
- astrometric solution for 2 million stars (TGAS) (proper motion, parallax)

DR2 April 2018:

- astrometric solution for 1 biliion stars
- colors, temperatures, radial velocity

DR3 2020:

- improved astrometry
- low-resolution spectra for all objects
- radial velocity, variable stars
- non-single stars

DR4 (Final) 2022:

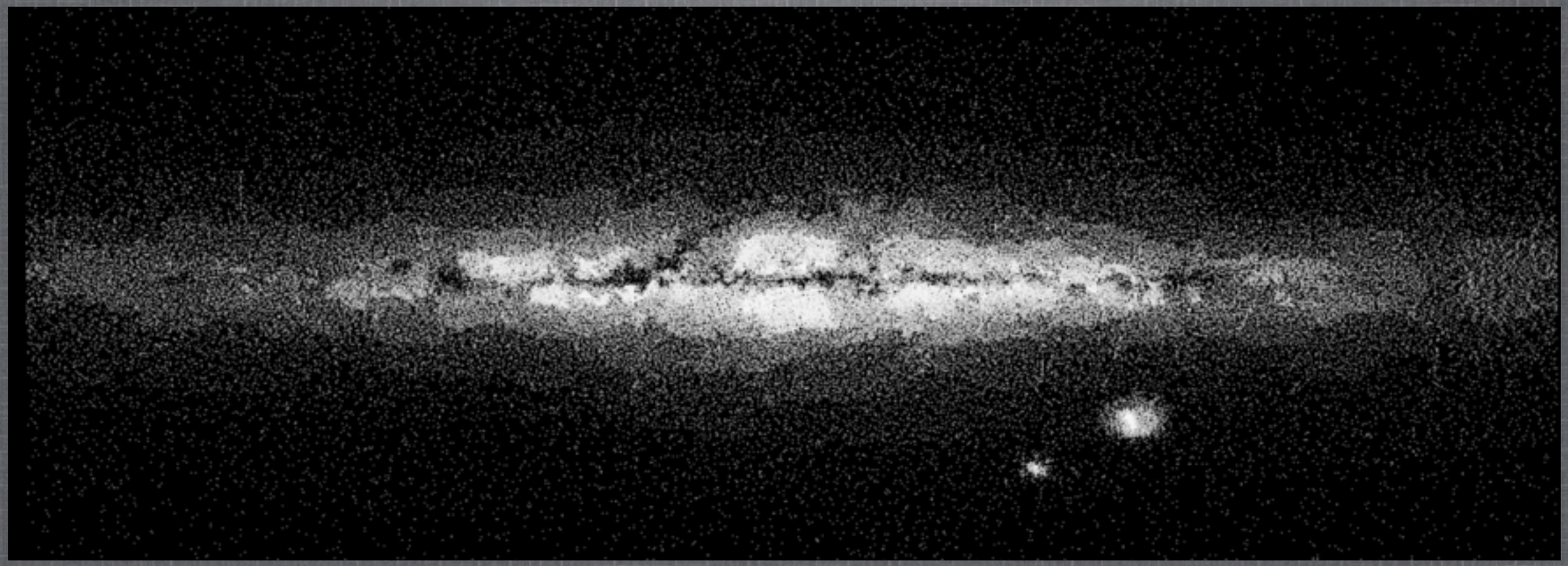
- Full astrometric, photometric and radial velocity catalogs
- All per-epoch astrometry and photometry
- Exo-planets

gaia

gaia archive

esa

https://gea.esac.esa.int/archive/



SUMMARY

- Gaia will soon provide 3D map of the Milky Way
- all data public in 2022 (after your PhD!)
- Gaia sampling in the Bulge is too poor for microlensing
- but Gaia finds microlensing in the MW Disk
- astrometric microlensing from Gaia only for brighter events
- space parallax possible Earth — Gaia (in L2)
- WFIRST should have astrometric microlensing capability — great for measuring theta_E for black hole lenses!