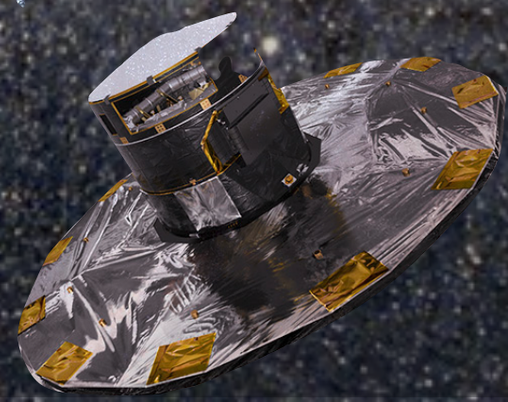
OPTICON TIME-DOMAIN

Łukasz Wyrzykowski

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

Warsaw University Astronomical Observatory, Poland



10th OPTICON Gaia Science Alerts Workshop
Catania, 2019

TEAM

Warsaw University Astronomical Observatory

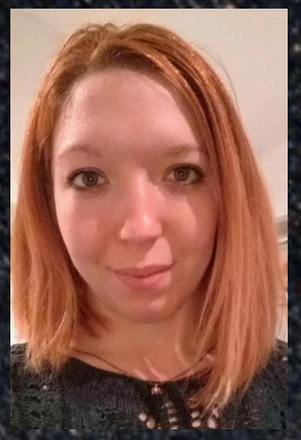
Paweł Zieliński
(postdoc)

Ilknur Gezer
(postdoc)

Kris A. Rybicki
(PhD student)

Katarzyna Kruszyńska
(PhD student)

Algita Stankevičiūtė
(PhD student)



Nada Ihanec
(PhD student)

Zosia Kaczmarek
(BSc student)

TEAM

Warsaw University Astronomical Observatory

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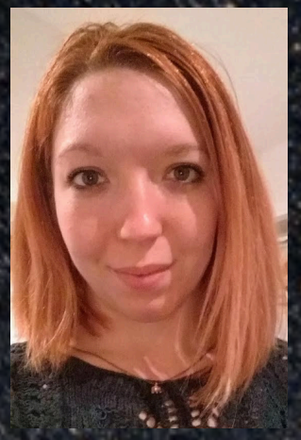


Nada Ihanec
(PhD student)

Zosia Kaczmarek
(BSc student)

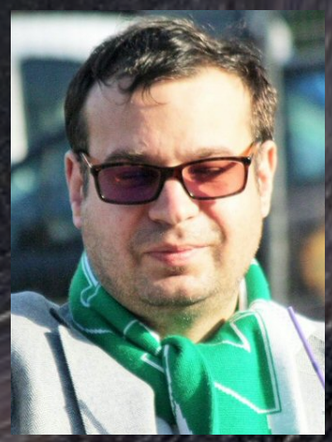
Institute of Theoretical Physics and Astronomy, University of Vilnius

Marius Maskoliūnas

Erika Pakštienė

Rimvydas Janulis

Justas Zdanavičius



Vytautas Čepas

Kotryna Šiškauskaitė
(BSc student)

Zuzanna Kostrzewa-Rutkowska (Utrecht)
Grzegorz Wiktorowicz (Beijing)
Simon Hodgkin (Cambridge)
Peter Jonker (Utrecht)
Iair Arcavi (Tel Aviv)

Institute of Astronomy
UNIVERSITY OF CAMBRIDGE

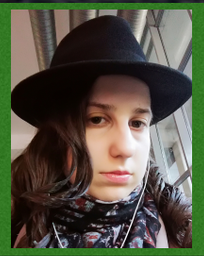
Gaia DPAC (alerts, micro)




OGLE

Astrometric lensing





Photometric follow-up



+ Agnieszka Gurgul
+ Oliwia Ziółkowska
+ Przemek Mikołajczyk

Gaia DPAC

Spectroscopy

National Science Centre Poland

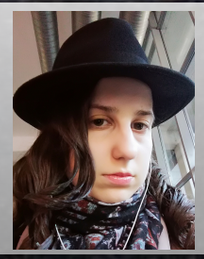
OPTICON

GW, TDE, lensQSO



+ Mateusz Bronikowski

Adaptive optics engineering



NCN DAINA 2017/27/L/ST9/03221
NCN UWERTURA 2017/24/U/ST9/00077
NCN HARMONIA 2012/06/M/ST9/00172
NCN HARMONIA 2015/18/M/ST9/00544
NCN HARMONIA 2018/30/M/ST9/00311
EC H2020 730890 OPTICON

TIME-DOMAIN ASTRONOMY (TDA) IN OPTICON

since 2013

- network of small- and mid-sized telescopes (<2m)

Łukasz Wyrzykowski

TIME-DOMAIN ASTRONOMY (TDA) IN OPTICON

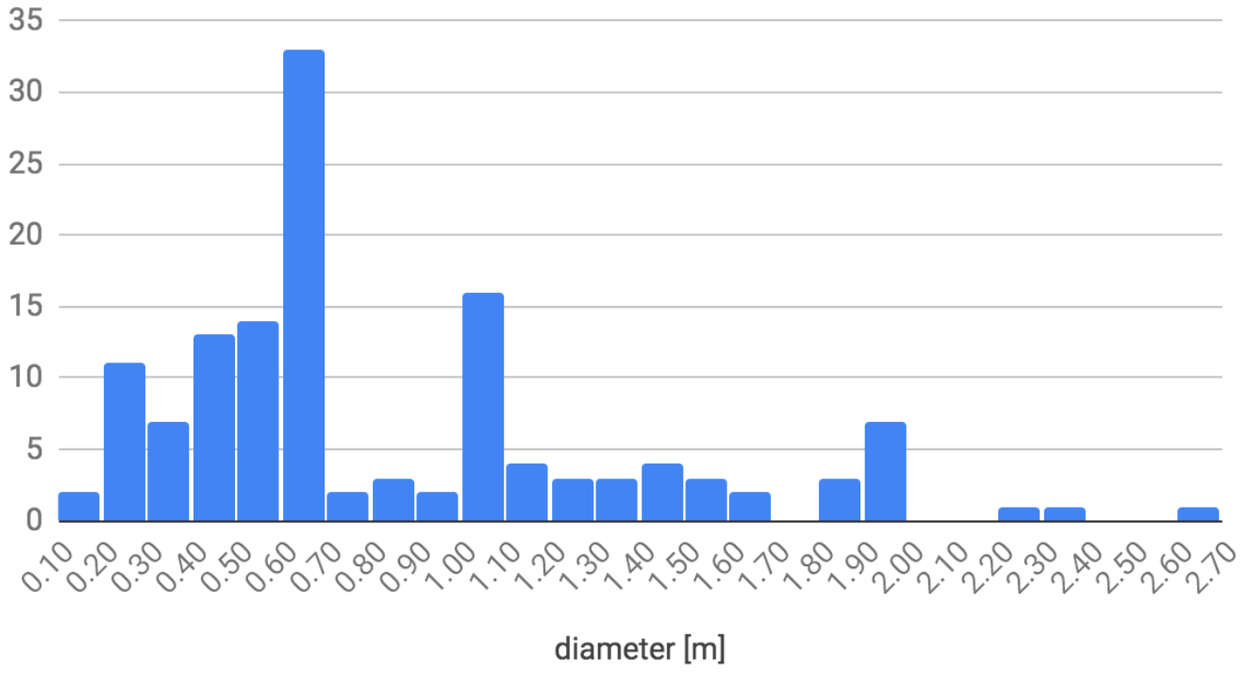
since 2013

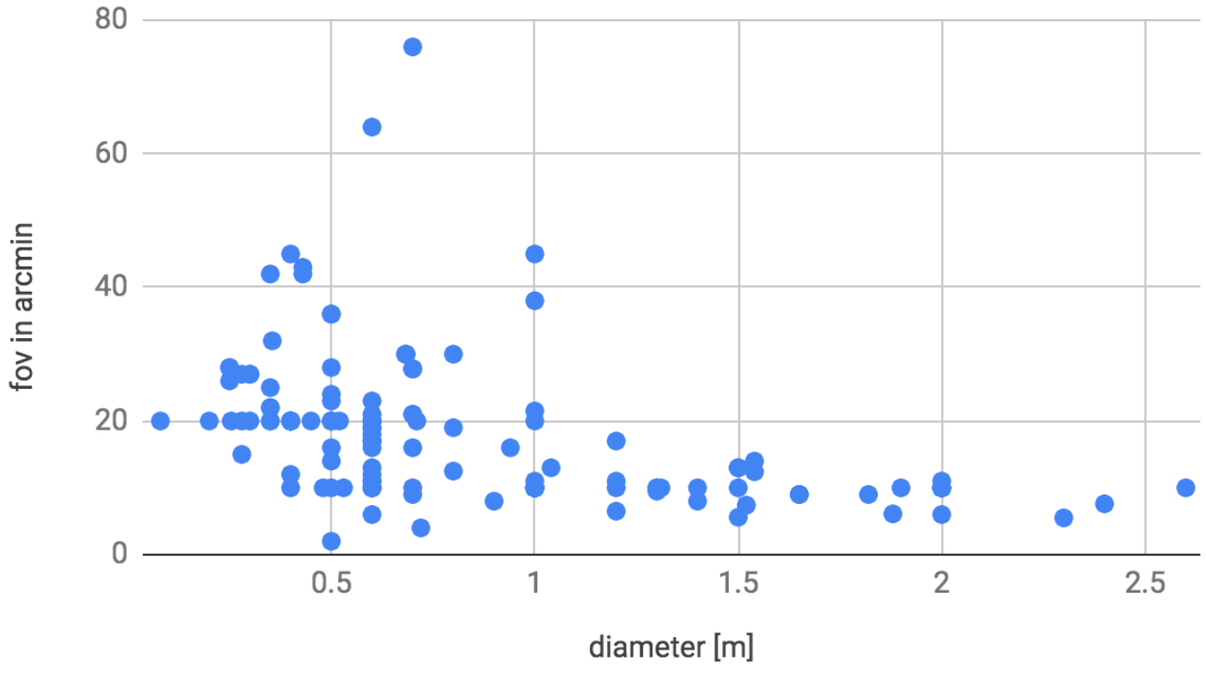
- network of small- and mid-sized telescopes (<2m)

TIME-DOMAIN ASTRONOMY (TDA) IN OPTICON

since 2013

- network of small- and mid-sized telescopes (<2m)
- voluntary time allocation or via local proposals
- most with very small field-of-view (10-20 arcmin)
- robotic (~50) and manual (~50) (+10 controled remotely)

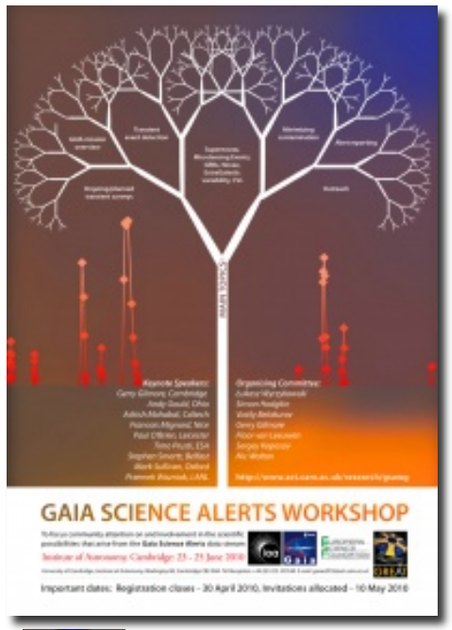




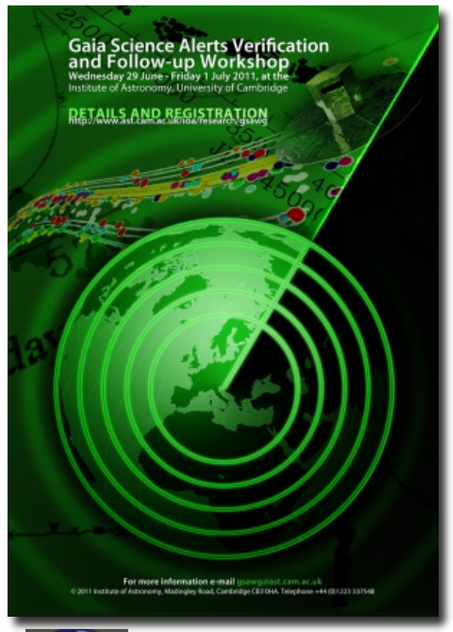
Łukasz Wyrzykowski

WORKSHOPS SINCE 2010

2010-Cambridge



2011-Cambridge

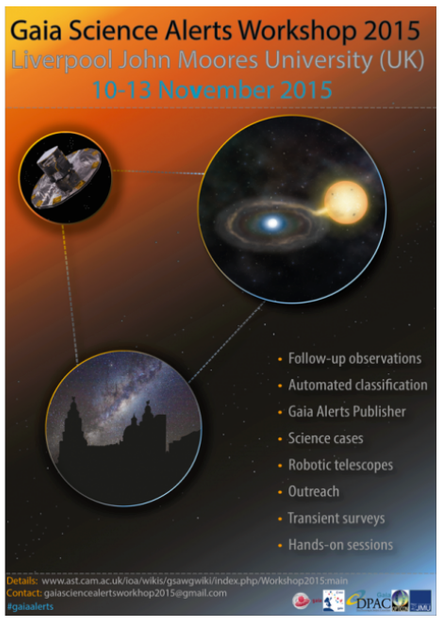


2012-Bologna

2013-Paris

2014-Warsaw

2015-Liverpool



2016-Utrecht

2017-Warsaw

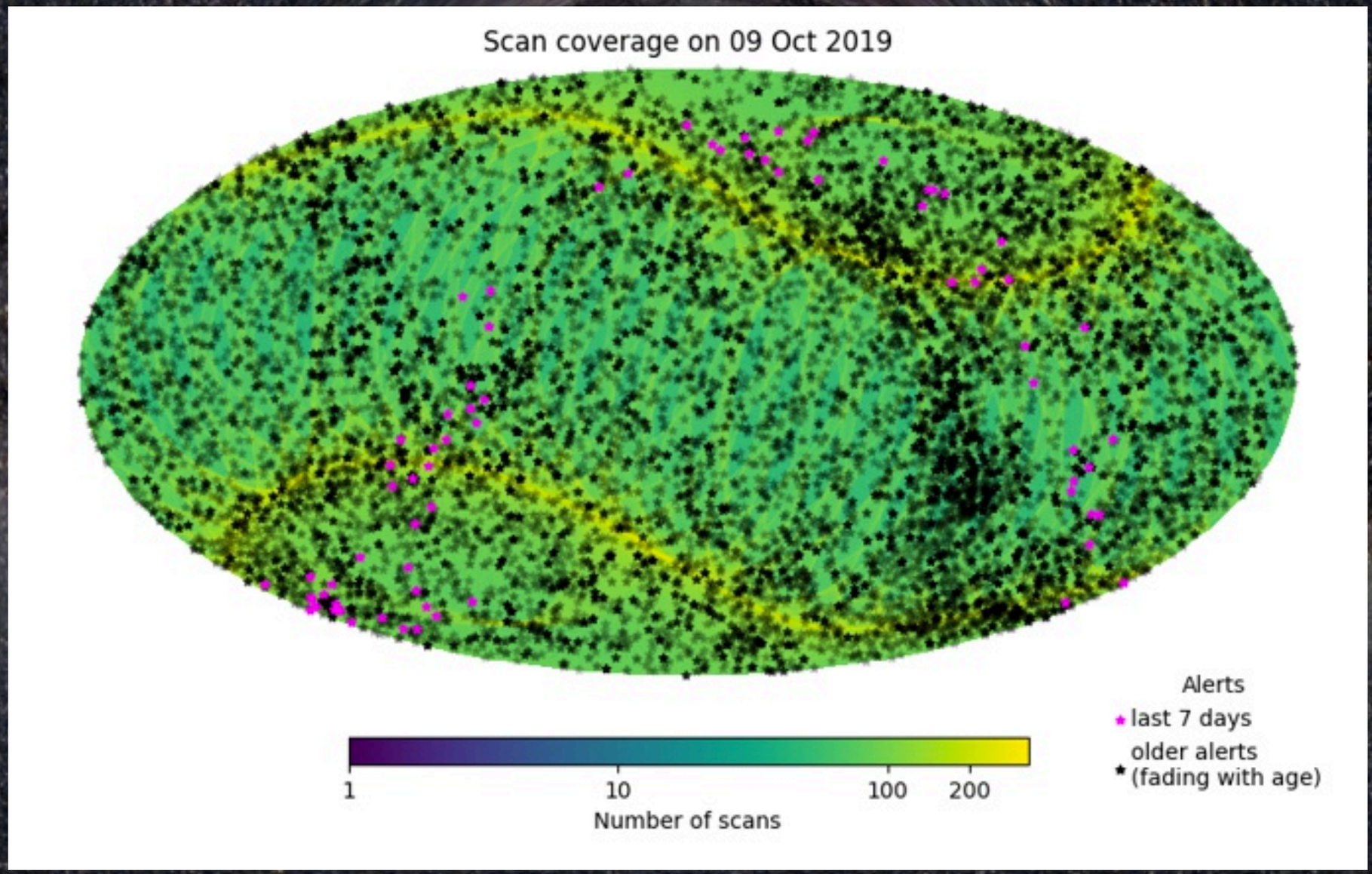
2018-Vipava

2019-Catania

ARCHIVE OF SLIDES AND VIDEOS: HTTP://WWW.AST.CAM.AC.UK/IOA/WIKIS/GSAWGWIKI

Gaia Photometric Science Alerts

10-20 alerts every day since 2014:
supernovae, CV, microlensing, TDE, PISNe, SLSNe,...



UNIVERSITY OF CAMBRIDGE

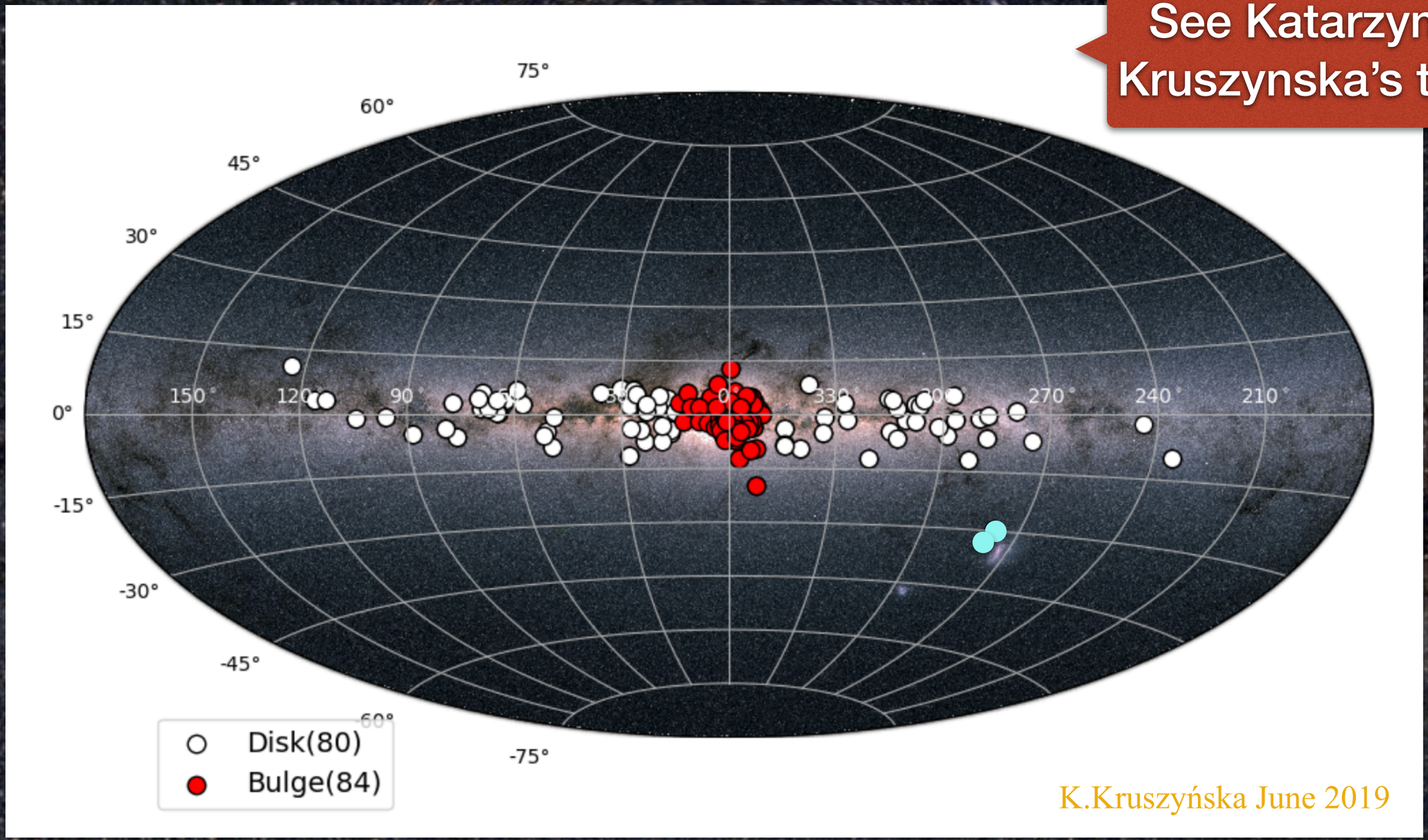
http://gsaweb.ast.cam.ac.uk/alerts/

Łukasz Wyrzykowski

MICROLENSING EVENTS IN GAIA ALERTS

160+ events since 2016

See Katarzyna Kruszynska's talk



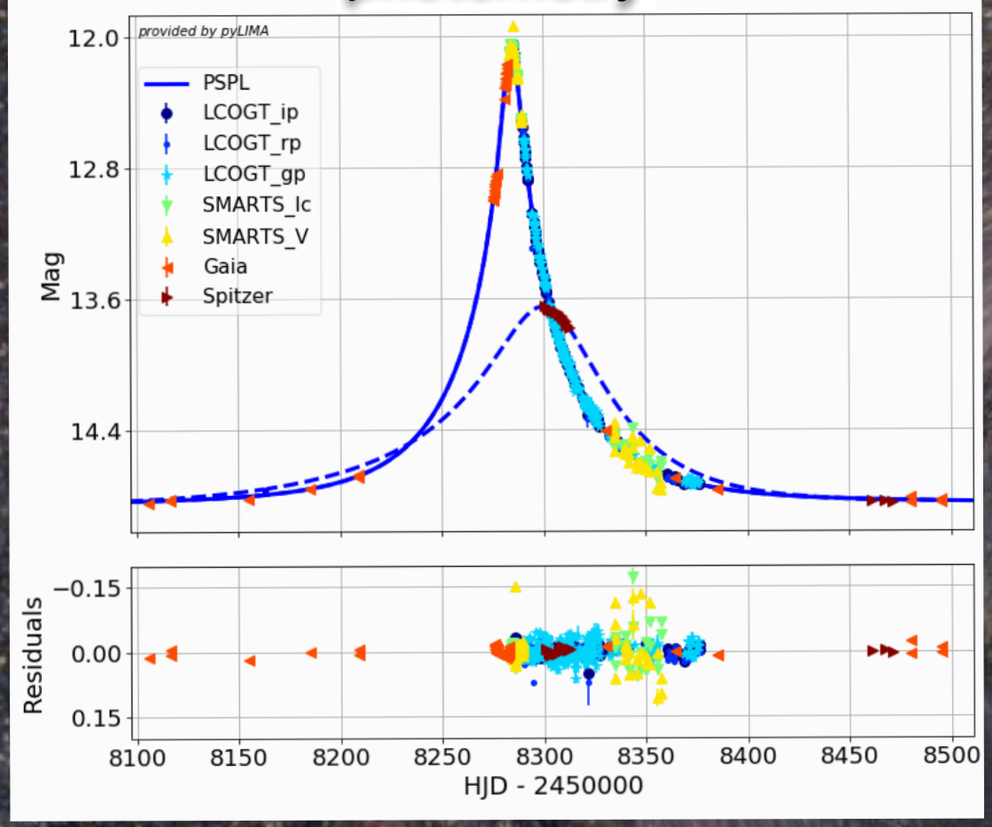
K.Kruszyńska June 2019

Łukasz Wyrzykowski

MICROLENSING BY BLACK HOLES

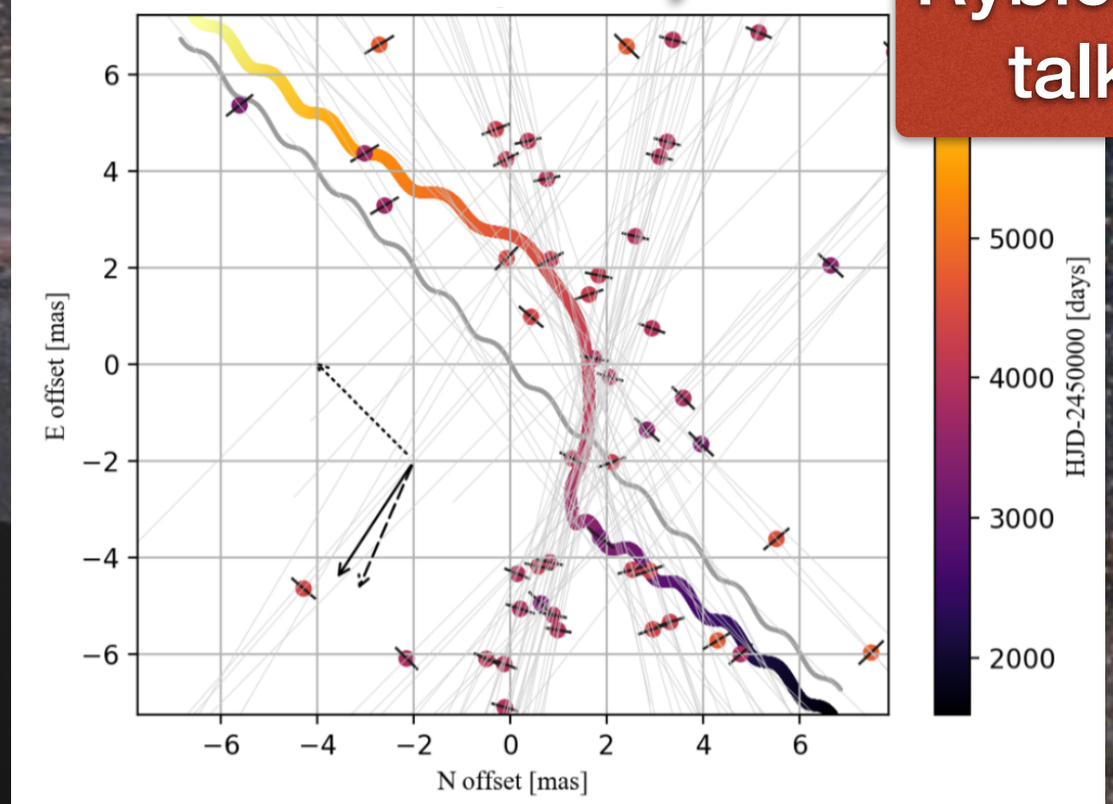
See Kris Rybicki's talk

photometry



Ground-based photometry
of currently on-going events

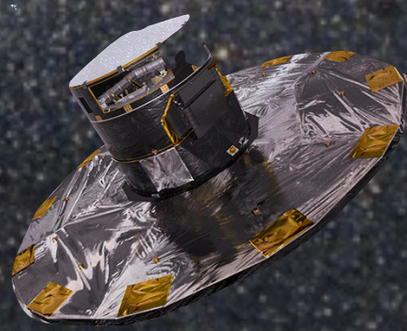
astrometry



predicted Gaia astrometry
(real data in 2023)

Rybicki+ 2018

Mass, Distance, Luminocity
(nature of the lens)



HOW TO FIND BLACK HOLES?

alerts about
on-going
microlensing events

OGLE

ZTF

Gaia Science Alerts

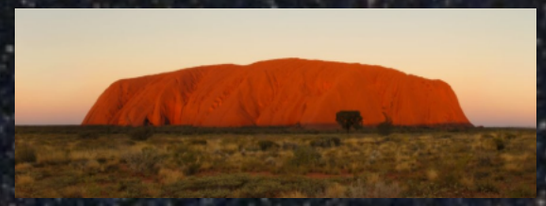
ASAS-SN

follow-up

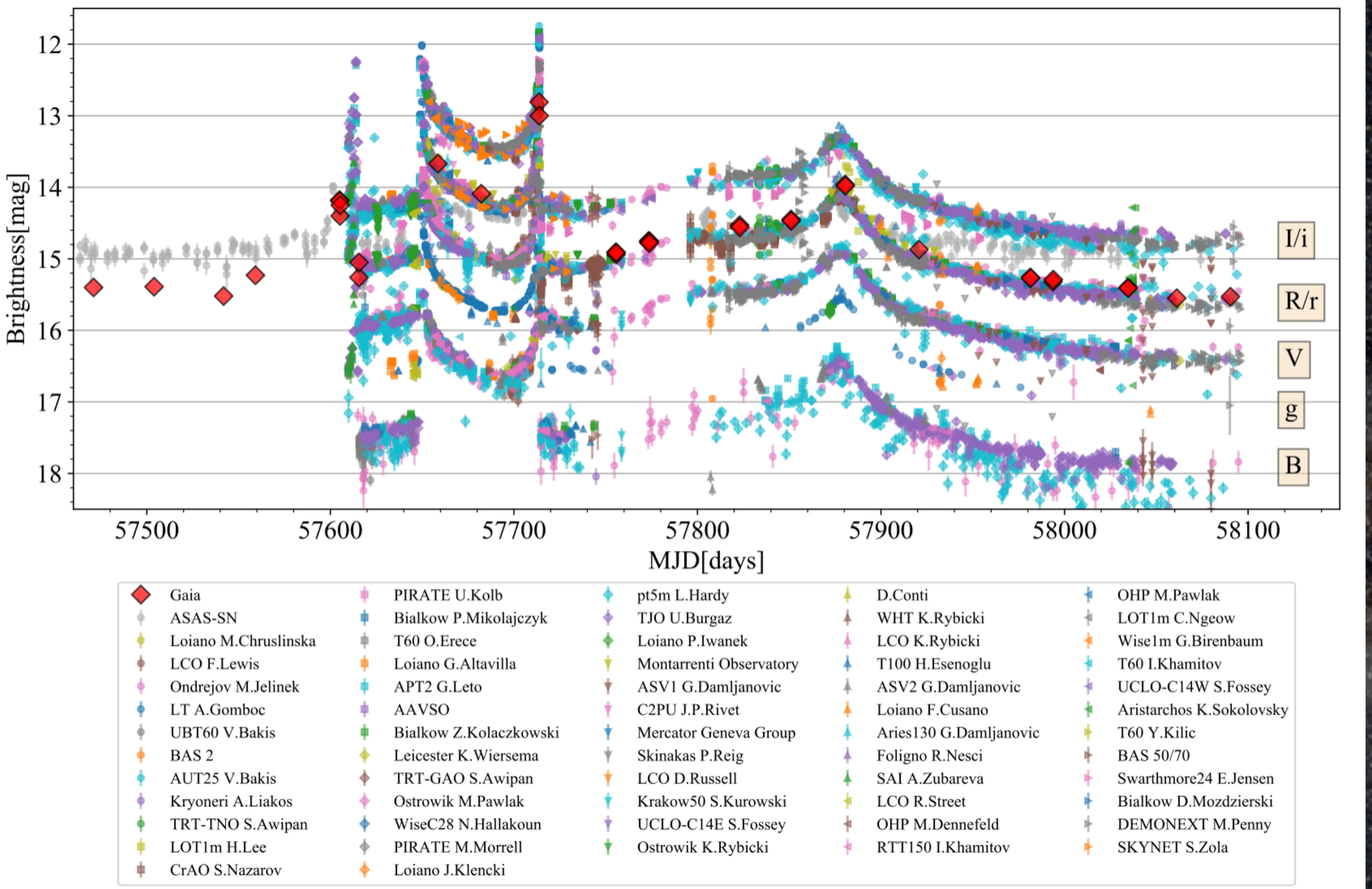
- light curves (network of telescopes)
- spectra (VLT, Gemini, SALT)
- space observations (Spitzer)

astrometric
time-series (Gaia DR4)

GAIA16AYE *(aka AYErs Rock)*



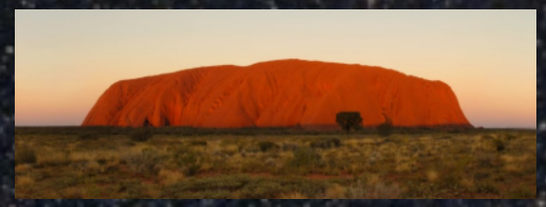
20,000 follow-up observations over 2 years



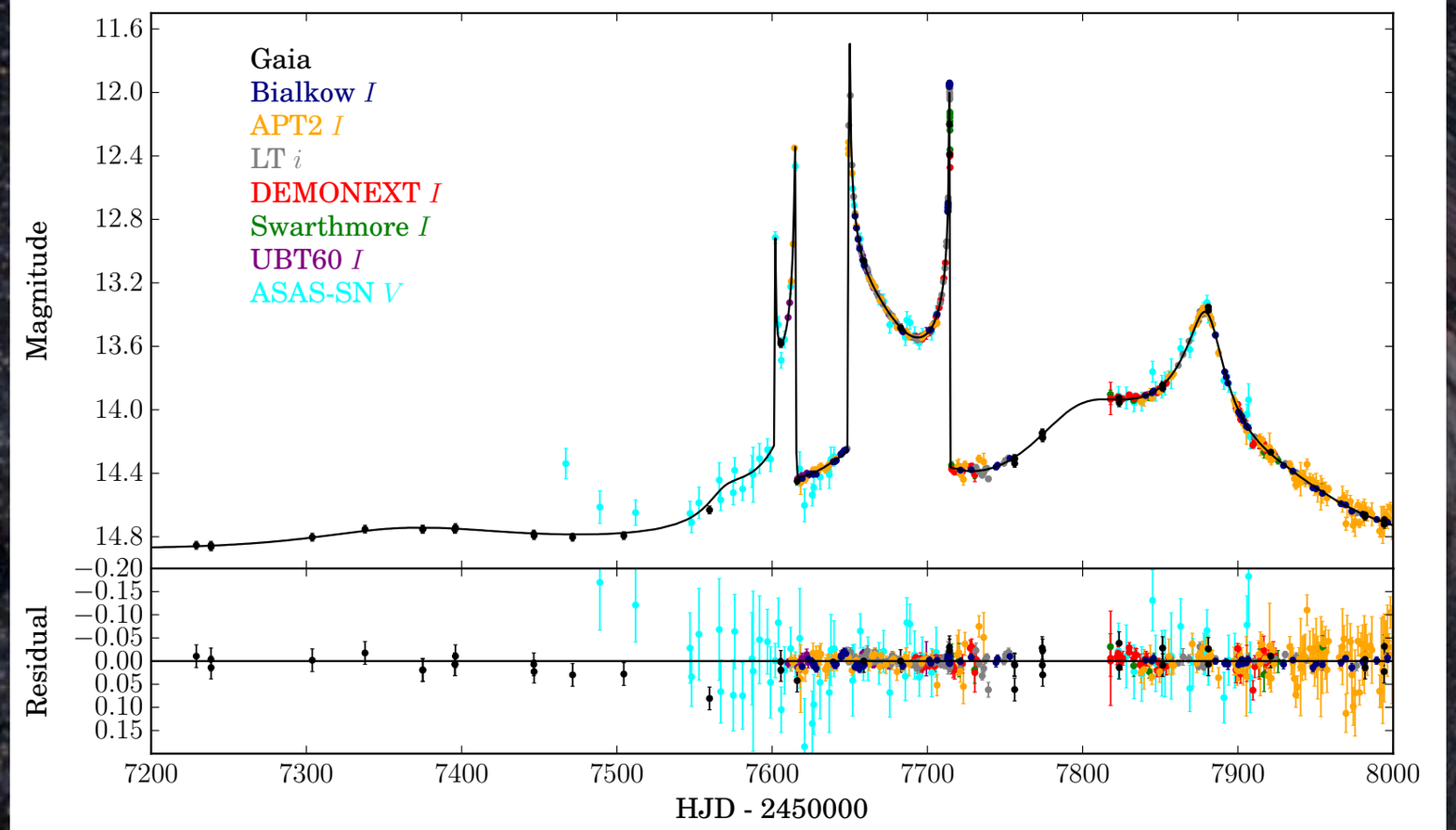
Wyrzykowski+2019(2020), accepted!

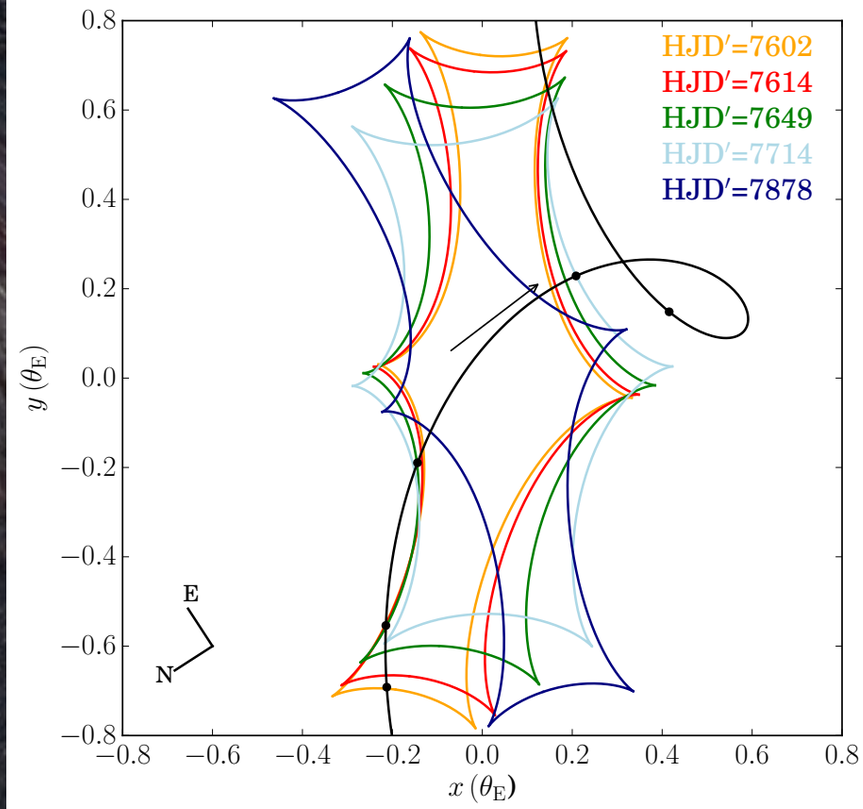
Łukasz Wyrzykowski

GAIA16AYE *(aka AYErs Rock)*



20,000 follow-up observations over 2 years





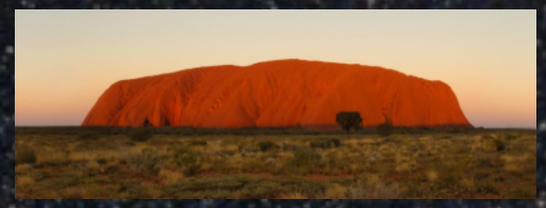
model by Przemek Mroz and Jan Skowron, OAUW

- all possible microlensing effects: parallax, finite source, binary rotation
- first ever need to use the full Keplerian motion model of the lens orbit
- impossible to solve without long-term ground-based follow-up

Wyrzykowski+2019(2020), accepted!

Łukasz Wyrzykowski

GAIA16AYE *(aka AYErs Rock)*



lens

source

~15kpc

0.8kpc

2.0AU

K3 giant
R=~31 R_{Sun}

full orbital solution!

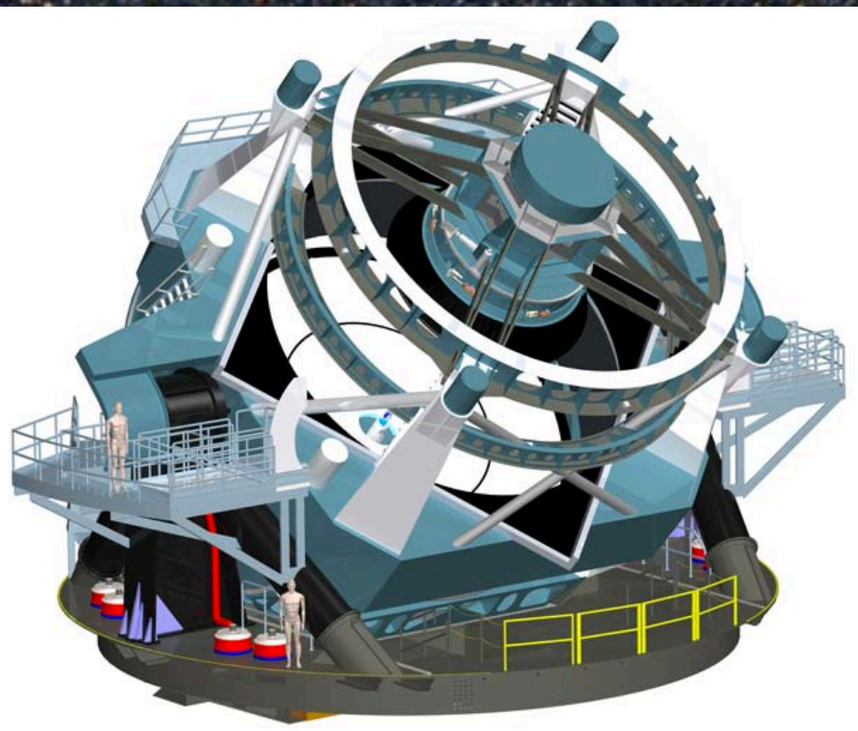
M_1 = 0.4 M_{Sun}
M_2 = 0.6 M_{Sun}
P = 2.9 yrs
incl = 66 deg
ecc = 0.3

Wyrzykowski+2019

LSST

Large Synoptic Survey Telescope

8.4m mirror, 10 sq.deg. ~25mag survey



Large Synoptic Survey Telescope

The Diverse Science Return from a Wide-Area Survey of the Galactic Plane

R.A. Street, M.B. Lund, S. Khakpash, M. Donachie, W.A. Dawson, N. Golovich, L. Wyrzykowski, P. Szkody, T. Naylor, M. Penny, N. Rattenbury, M. Dall'Ora, W.I. Clarkson, D. Bennett, J. Pepper, M. Rabus, M.P.G. Hundertmark, Y. Tsapras, R. Di Stefano, S. Ridgway, M. Liu, E. Lin, with the support of the LSST Transient and Variable Stars Collaboration.

Nov 2018

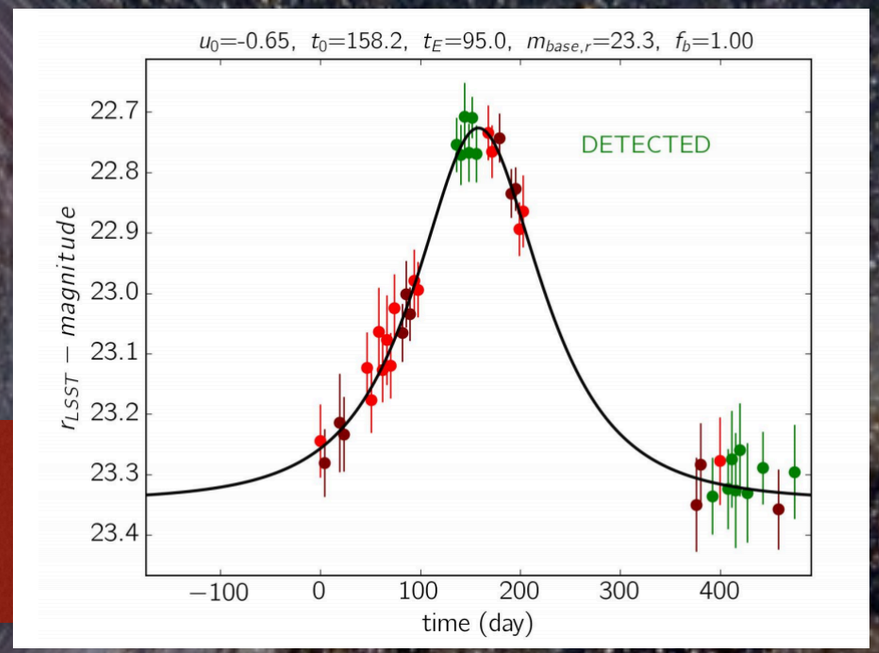
Street+2018, arxiv:1812.03127

PREDICTION ON DETECTION AND CHARACTERIZATION OF GALACTIC DISK MICROLENSING EVENTS BY LSST

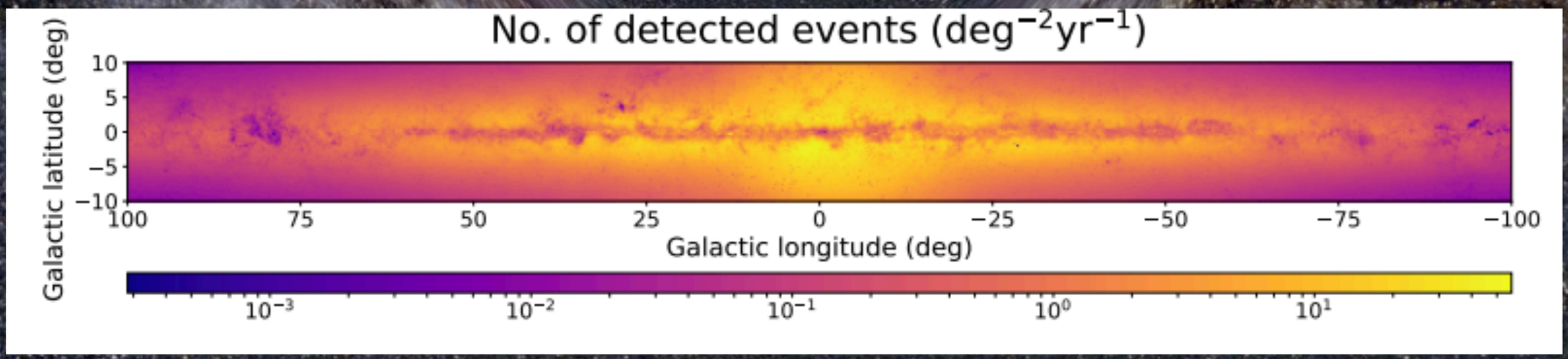
SEDIGHE SAJADIAN [1,2], RADOSŁAW POLESKI [3]

Draft version June 19, 2018

Sajadian,Poleski arXiv:1806.06372

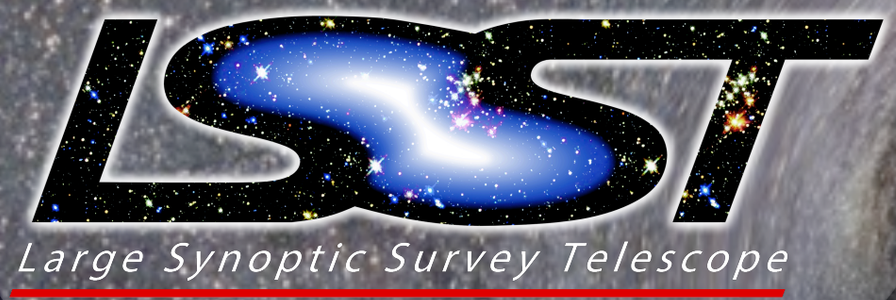


LSST will detect 10,000s of microlensing events yielding 100s of BHs



HOW TO FIND BLACK HOLES WITH LSST?

alerts about
on-going
microlensing events



follow-up

- light curves (network of >2m telescopes)
- spectra (ESO/VLT, Gemini, SALT)
- space (WFIRST?)

astrometric
time-series
(WFIRST?, JWST?
GaiaNIR*)

*Hobbs+2019
arXiv:1907.12535

CALIBRATION SERVER 1.0

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

AUTOMATED PHOTOMETRY STANDARDIZATION TOOL

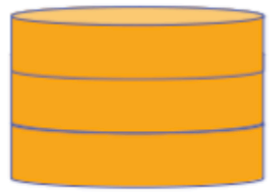
Network
of telescopes

PHOTOMETRY
AND
ASTROMETRY

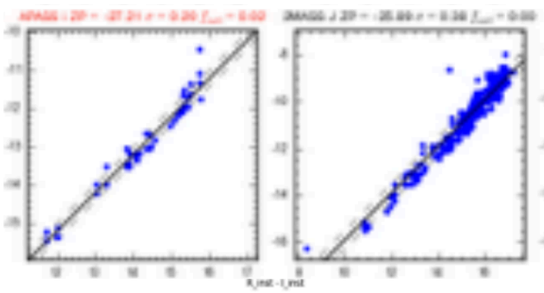
CPCS 1.0

in operation since 2013

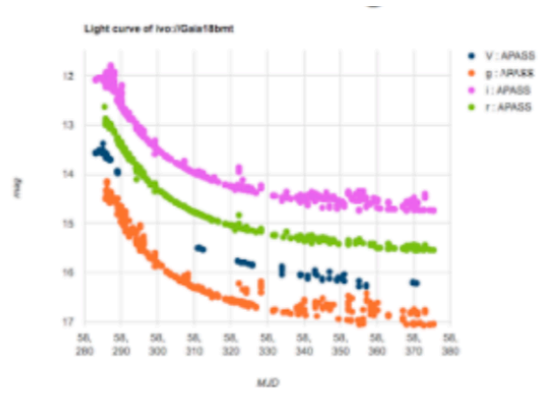
Data storage



Zero-point calibration
and automated
best filter determination



Quasi-homogenous lightcurves



PYTHON
FLASK
JSON
CURL API

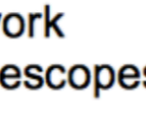
developed by Sergey Koposov and ŁW

Łukasz Wyrzykowski

CALIBRATION SERVER 2.0

AUTOMATED PSF-PHOTOMETRY AND ASTROMETRY TOOL

Network of telescopes



FITS IMAGES

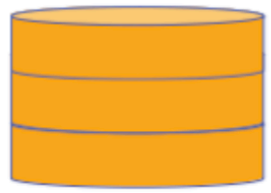
home-made ccdphot

CPCS 2.0

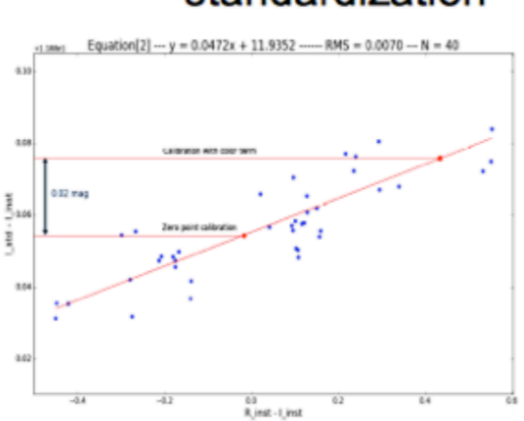
in Beta version
under extensive tests

but under development
since 2016...

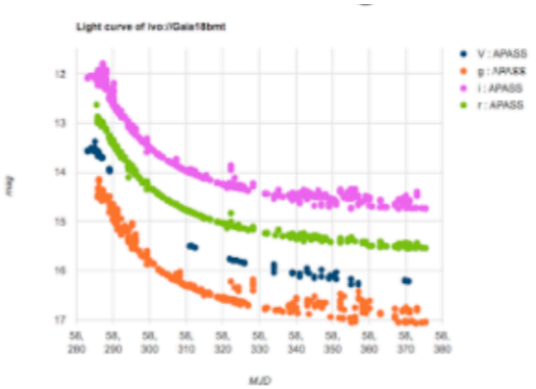
Data storage



Photometric standardization



Science-ready light curves

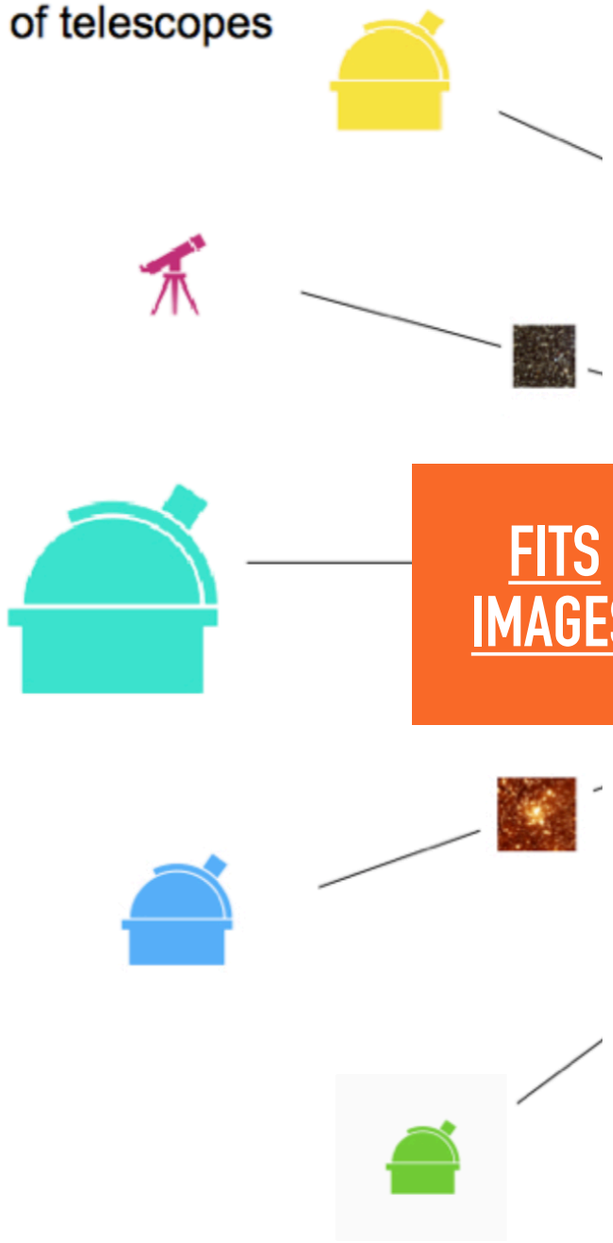


developed by Z.Kołaczkowski, P.Mikołajczyk, P. Zieliński

Łukasz Wyrzykowski

BLACK HOLE TOM

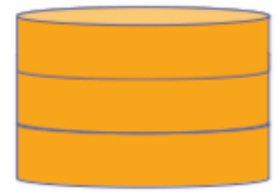
Network
of telescopes



FITS
IMAGES

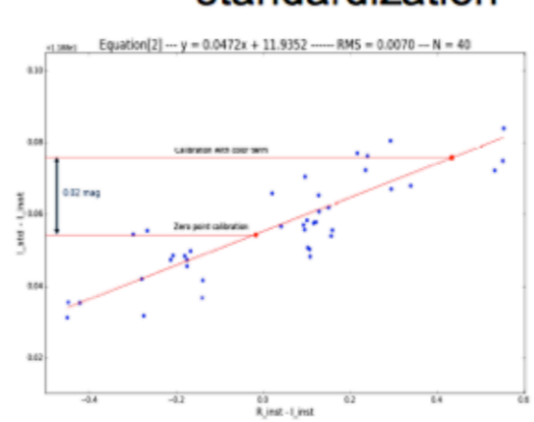
TOM TOOLKIT Las Cumbres Observatory LCO

Data storage

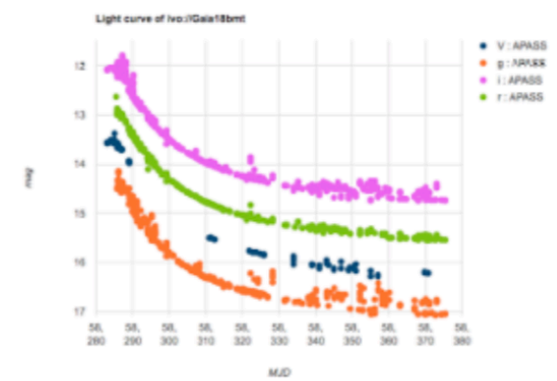


CPCS 2.0

Photometric
standardization



Science-ready light curves



Łukasz Wyrzykowski

BLACK HOLE TOM

Multi-telescope Observing requests

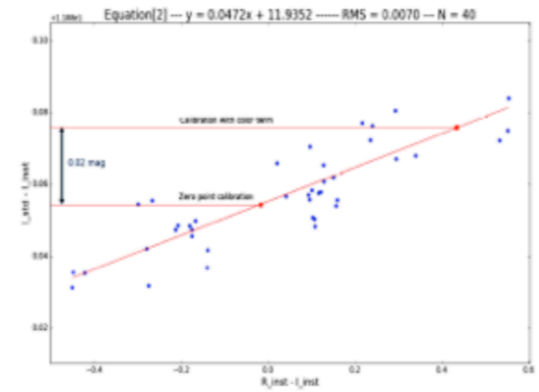
TOM TOOLKIT Las Cumbres Observatory LCO

Data storage

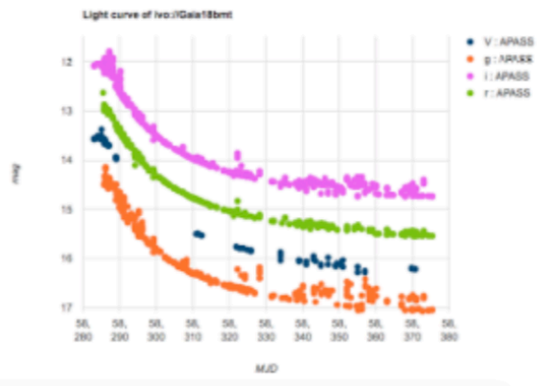
FITS IMAGES

CPCS 2.0

Photometric standardization



Science-ready light curves



Łukasz Wyrzykowski

BLACK HOLE TOM

Multi-telescope Observing requests

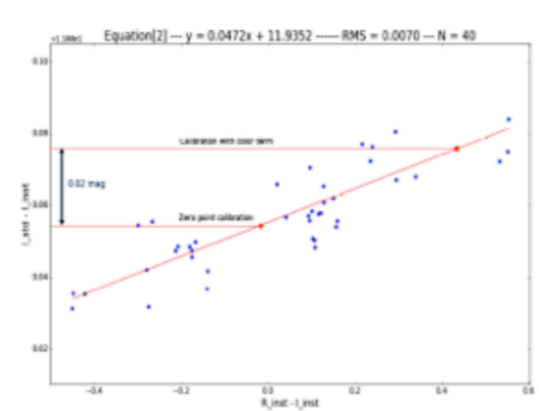
TOM TOOLKIT Las Cumbres Observatory LCO

Data storage

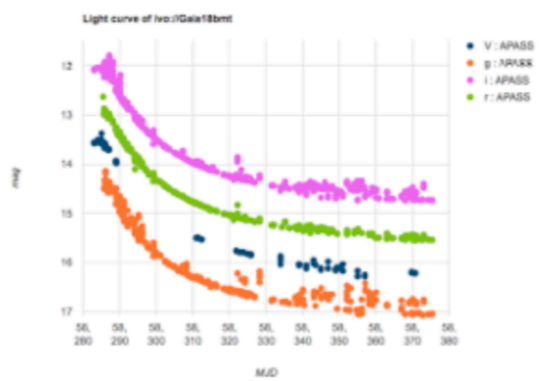
FITS IMAGES

CPCS 2.0

Photometric standardization



Science-ready light curves

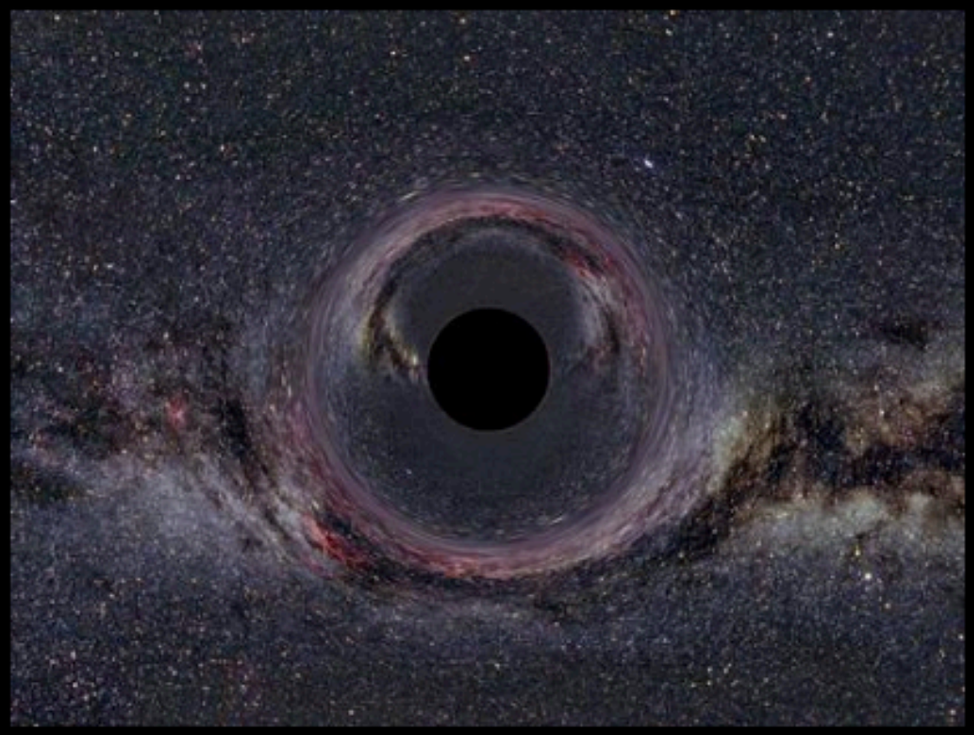


Łukasz Wyrzykowski

http://visata.astrouw.edu.pl:8080

BHTOM Targets Target Grouping About User 2 Logout

Black Hole TOM



(Image courtesy of Ute Kraus.)

Welcome to Black Hole TOM, built using the TOM Toolkit. Github here. To build your own TOM (Target Observation Manager), check out the getting started guide.

The Black Hole TOM 1.0 is an interface for viewing and sharing observational data of microlensing events, and for requesting and managing observations with the LCO network and OPTICON telescopes.

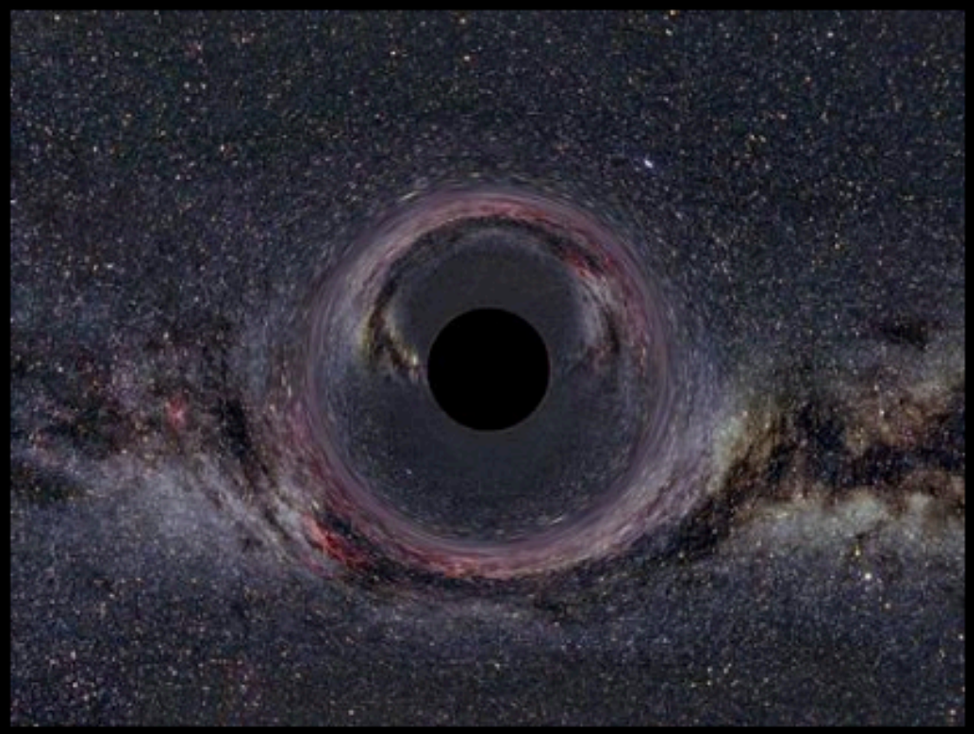
acknowledging help from LCO Santa Barbara staff

http://visata.astrouw.edu.pl:8080

BHTOM Targets Target Grouping About User 2 Logout

main list of targets

Black Hole TOM



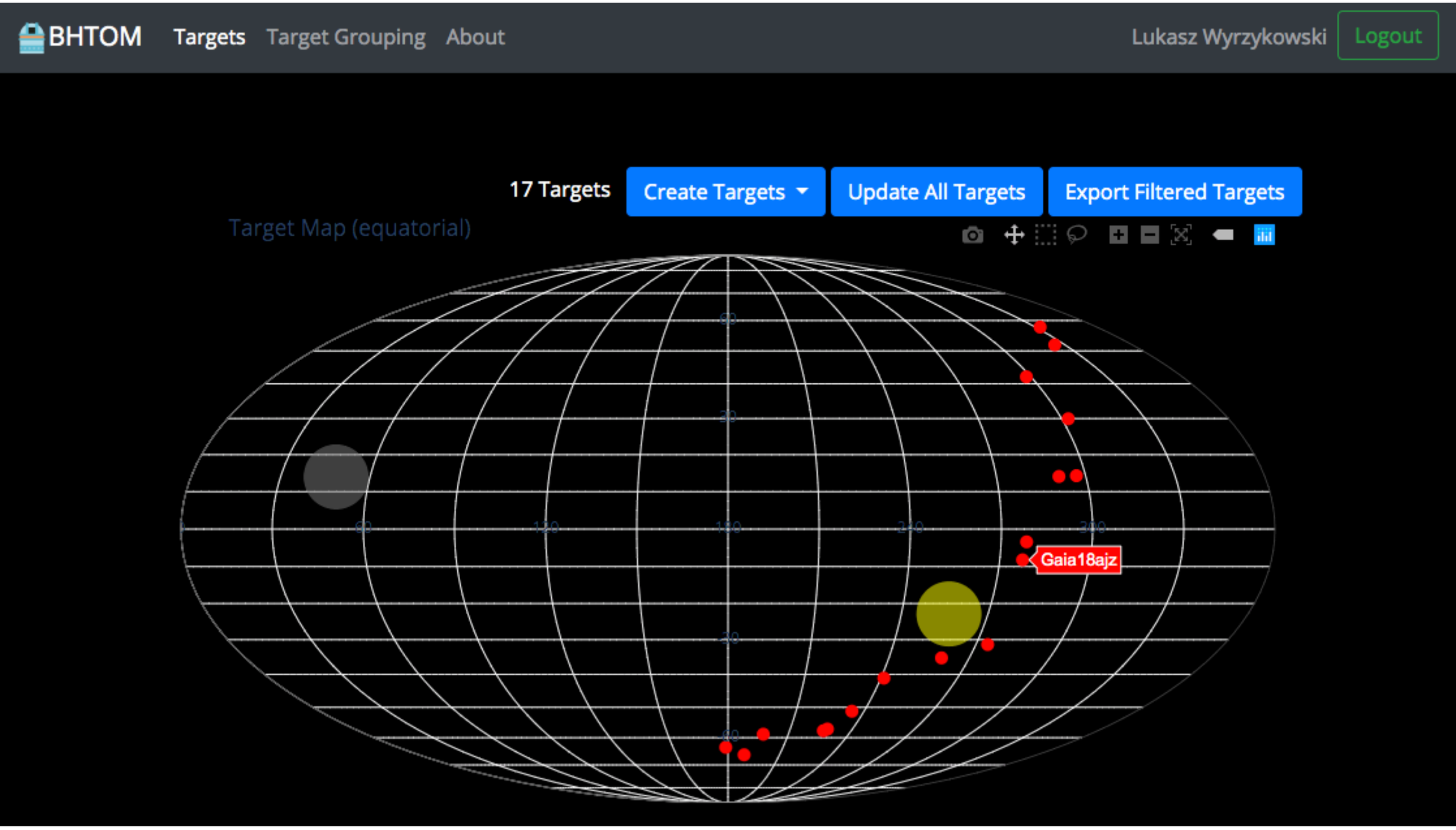
(Image courtesy of Ute Kraus.)

Welcome to Black Hole TOM, built using the TOM Toolkit. Github here. To build your own TOM (Target Observation Manager), check out the getting started guide.

The Black Hole TOM 1.0 is an interface for viewing and sharing observational data of microlensing events, and for requesting and managing observations with the LCO network and OPTICON telescopes.

acknowledging help from LCO Santa Barbara staff

Target Map


BHTOM
Targets
Target Grouping
About
Lukasz Wyrzykowski
Logout
17 Targets
Create Targets
Update All Targets
Export Filtered Targets
Target Map (equatorial)
60
120
180
240
300
-30
-60
Gaia18ajz

The target list can be viewed without loging-in!

BHTOM Targets Target Grouping About Lukasz Wyrzykowski Logout

Event Name/Aliases	RA	Dec	Number of Observations	Last Gaia [mag]	Target Importance	Time from last obs [days]	Required Cadence [days]	Observing Priority	Sun distance [deg]
Gaia18cbf	241.1619	-41.10483	337	18.54	10.0	68.6	1.0	686.0	22
Gaia19cnm	227.93683	-57.0571	89	17.85	10.0	54.8	1.0	547.9	40
Gaia19bir	234.64341	-51.24145	24	20.56	5.0	56.9	1.0	284.3	33
Gaia18dif	197.55161	-58.80407	3667	18.28	5.0	52.0	1.0	260.2	55
Gaia19bsy	296.90816	14.2932	9173	14.07	10.0	14.9	1.0	148.8	54
Gaia19cmd	226.43808	-57.63583	63	18.38	5.0	54.5	4.0	68.2	41
Gaia19bpg	325.46012	51.9293	4643	13.37	8.0	8.1	1.0	64.7	96
Gaia19dak	302.36516	29.93588	245	17.65	9.0	6.6	1.0	59.6	69
Gaia19flk	332.27348	57.74831	192	14.3	9.0	3.1	1.0	27.9	102
Gaia19duw	298.19944	42.07147	2038	17.04	5.0	7.2	3.0	12.0	76
Gaia19apc	290.98676	14.08804	8071	16.12	5.0	9.4	5.0	9.4	50

The target list can be viewed without loging-in!

BHTOM Targets Target Grouping About Lukasz Wyrzykowski Logout

sort by any of the columns

default sort by observing priority

Event Name/Aliases	RA	Dec	Number of Observations	Last Gaia [mag]	Target Importance	Time from last obs [days]	Required Cadence [days]	Observing Priority	Sun distance [deg]
Gaia18cbf	241.1619	-41.10483	337	18.54	10.0	68.6	1.0	686.0	22
Gaia19cnm	227.93683	-57.0571	89	17.85	10.0	54.8	1.0	547.9	40
Gaia19bir	234.64341	-51.24145	24	20.56	5.0	56.9	1.0	284.3	33
Gaia18dif	197.55161	-58.80407	3667	18.28	5.0	52.0	1.0	260.2	55
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Gaia19flk	332.27348	57.74831	192	14.3	9.0	3.1	1.0	27.9	102
Gaia19duw	298.19944	42.07147	2038	17.04	5.0	7.2	3.0	12.0	76
Gaia19apc	290.98676	14.08804	8071	16.12	5.0	9.4	5.0	9.4	50

Filter targets

Define your filter below the list

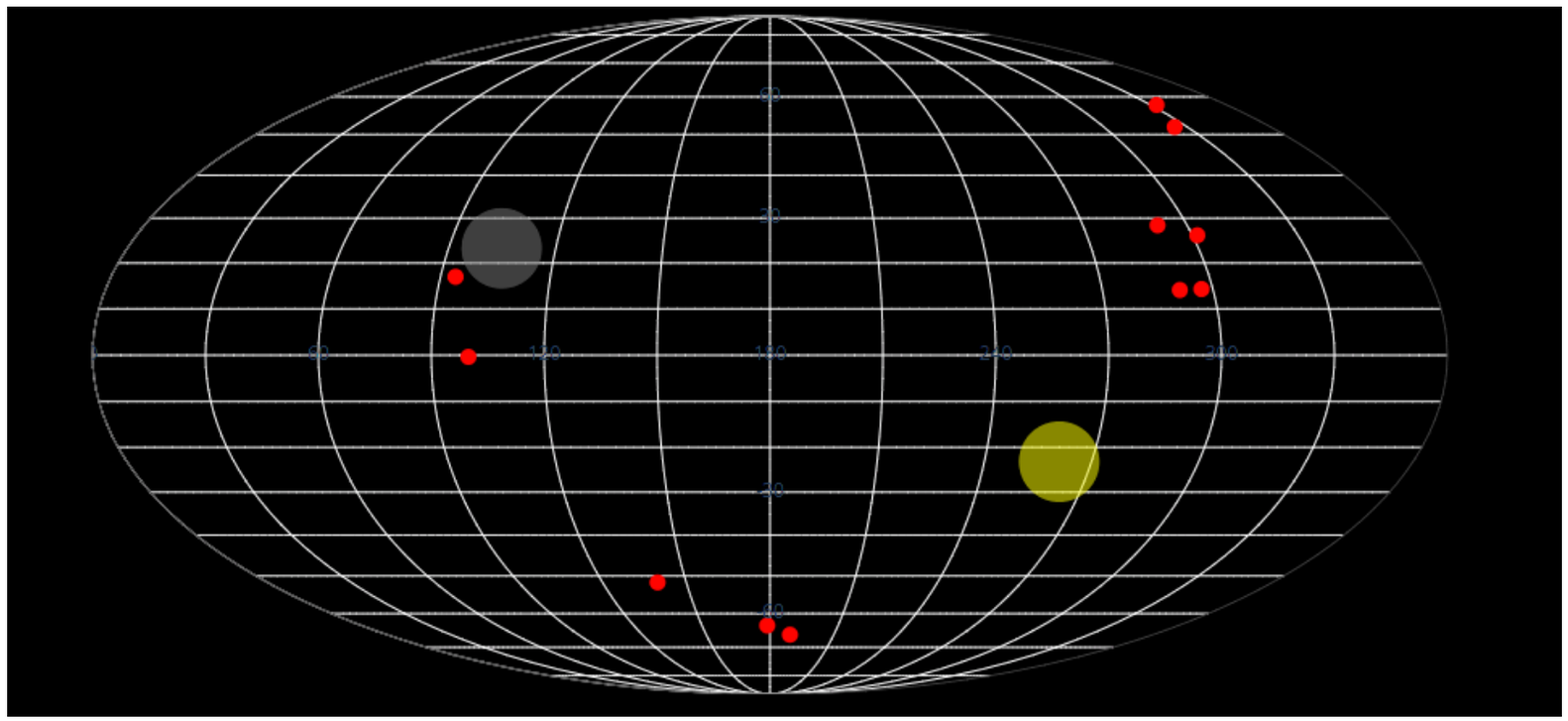
Filter targets

Sun separation

min	30
max	1000

Maglast

min	0
max	17



only 6 important targets currently visible and brighter than 17 mag

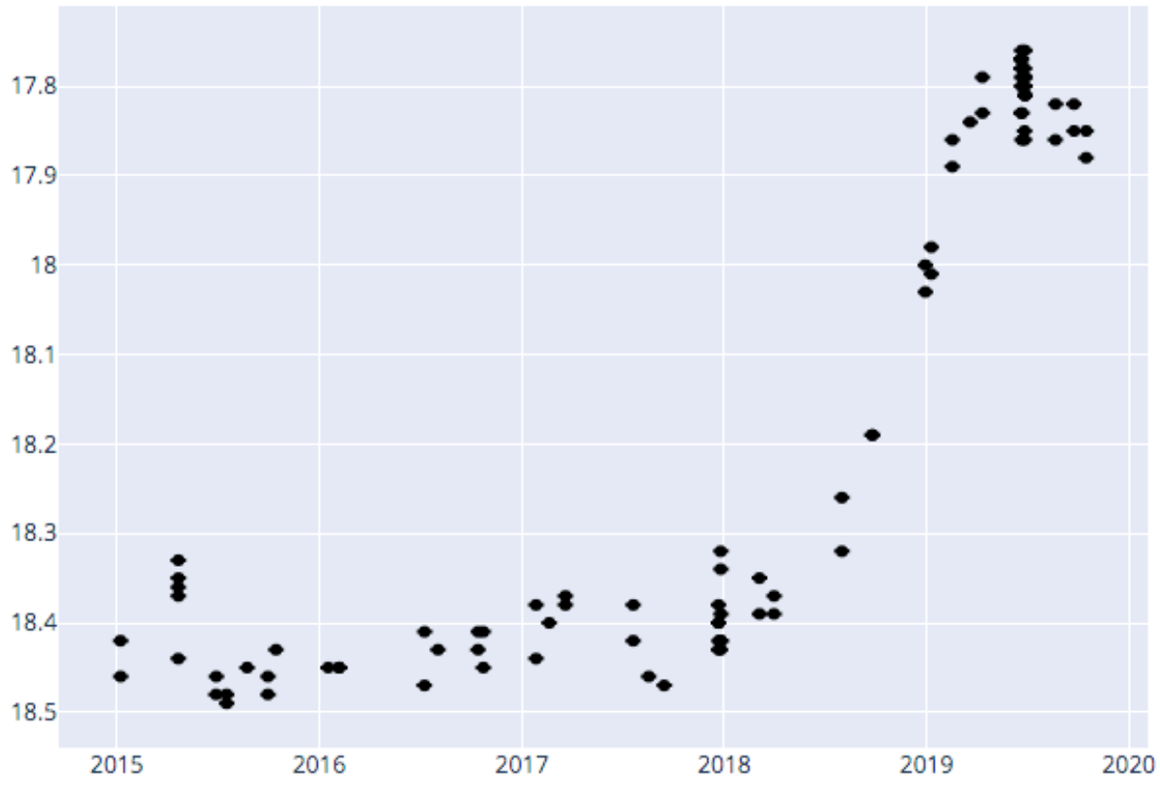
Time

	Event Name/Aliases	RA	Dec	Number of Observations	Last Gaia [mag]	Target Importance	Time from last obs [days]	Required Cadence [days]	Observing Priority	Sun distance [deg]
☐	Gaia19drp	94.11385	16.96586	3679	13.76	10.0	9.9	1.0	98.9	166
☐	Gaia19ewo	139.74432	-51.67762	88	16.97	7.0	8.3	1.0	58.1	89
☐	Gaia19dqe	99.85635	-0.36987	55	12.76	4.0	19.6	3.0	26.1	150
☐	Gaia19dmj	301.39949	26.16769	391	13.84	3.0	33.9	5.0	20.3	63
☐	Gaia19flk	332.27348	57.74831	193	14.3	9.0	1.9	1.0	17.1	100
☐	Gaia19apc	290.98676	14.08804	12473	16.12	5.0	13.4	5.0	13.4	48
☐	Gaia19bsy	296.90816	14.2932	14106	14.07	10.0	0.9	1.0	9.0	52
☐	Gaia19bld	189.38565	-66.11136	57732	14.67	5.0	4.0	3.0	6.7	61

Observing priority

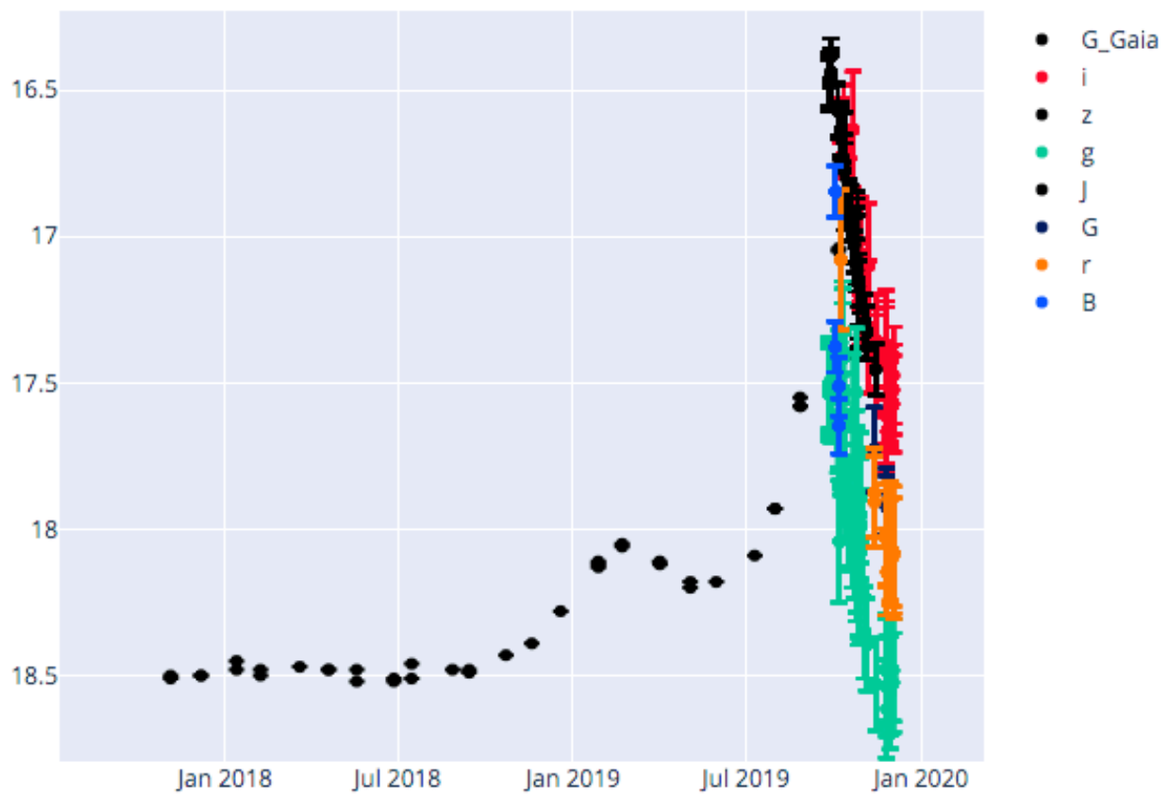
Gaia19cnm
Target Importance (Priority) = 10 (very high)
Required cadence (Cadence) = 1 day
Last data point taken (Dt) = 54.8 days ago!

Observing priority = (dt/cadence)*priority = 548



Gaia19duw
Target Importance (Priority) = 5 (medium)
Required cadence (Cadence) = 3 day
Last data point taken (Dt) = 7.2 days ago

Observing priority = (dt/cadence)*priority = 12



Target grouping

BHTOM Targets Target Grouping About Lukasz Wyrzykowski Logout

display groups of targets

Event Name/Aliases	RA	Dec	Number of Observations	Last Gaia [mag]	Target Importance	Time from last obs [days]	Required Cadence [days]	Observing Priority	Sun distance [deg]
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Gaia19cuh	197.55161	-58.80407	3667	18.28	5.0	52.0	1.0	260.2	55
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Gaia19dak	302.36516	29.93588	245	17.65	9.0	6.6	1.0	59.6	69
Gaia19flk	332.27348	57.74831	192	14.3	9.0	3.1	1.0	27.9	102

select targets and add to your groups

add to existing groups or create a new one

Add/Remove from grouping | Targets for spectroscopy | Add | Remove

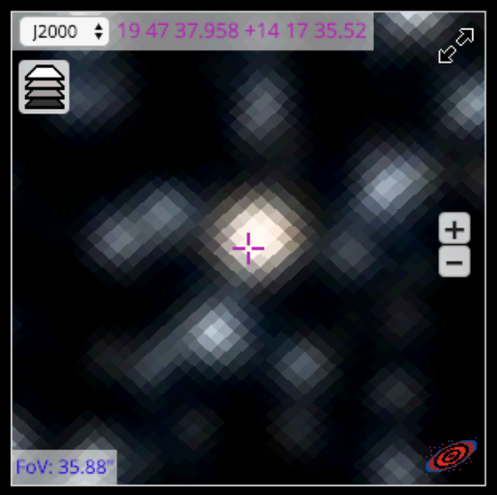
BHTOM Targets Target Grouping About Lukasz Wyrzykowski Logout

Gaia19bsy

Update Target | Delete Target

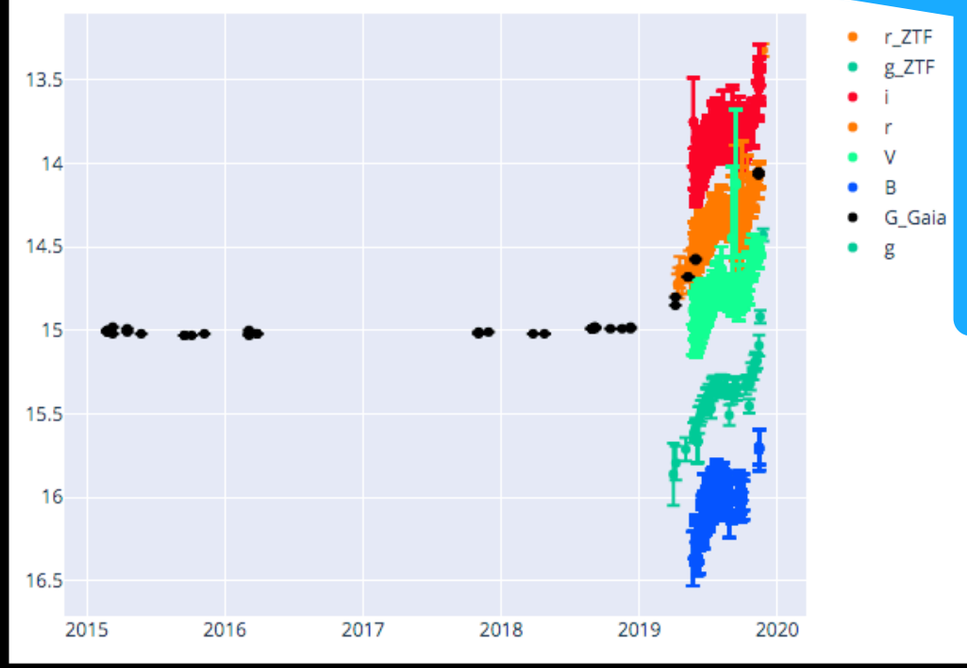
Names	Gaia19bsy
Target Type	SIDEREAL
Right Ascension	296.90816
	19:47:37.958
Declination	14.2932
	+14:17:35.520
Epoch Of Elements	2000.0
gaia_alert_name	Gaia19bsy
calib_server_name	ivo://Gaia19bsy
ztf_alert_name	ZTF18aczojlw
gaiadr2_id	4317386033190228864
classification	Microlensing with parallax effect or binary lens
tweet	False
jdlastobs	2458812.6227315
maglast	14.07
priority	10.0
cadence	1.0
Sun_separation	54.4753044756923

Tags

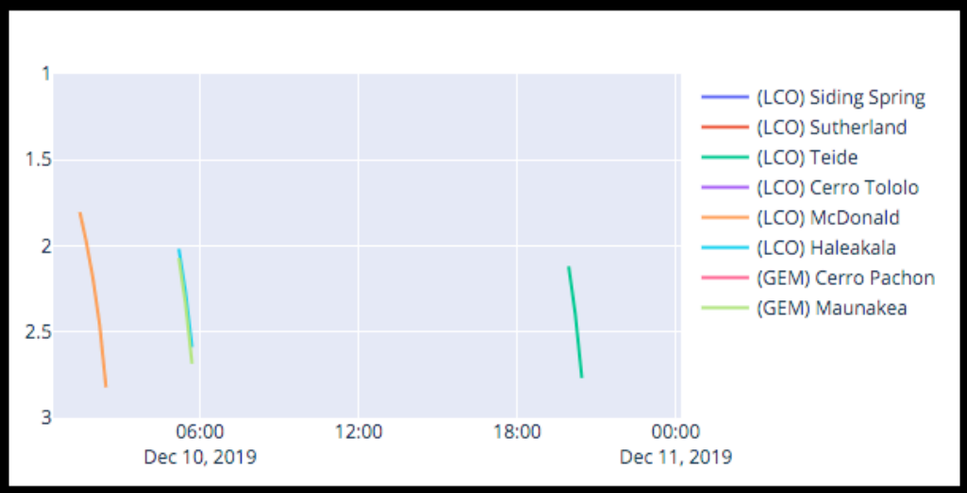


Overview | Spectra | Images | Data | Schedule Observations

Check for new data



Current Visibility of the target



Comments

No comments yet.

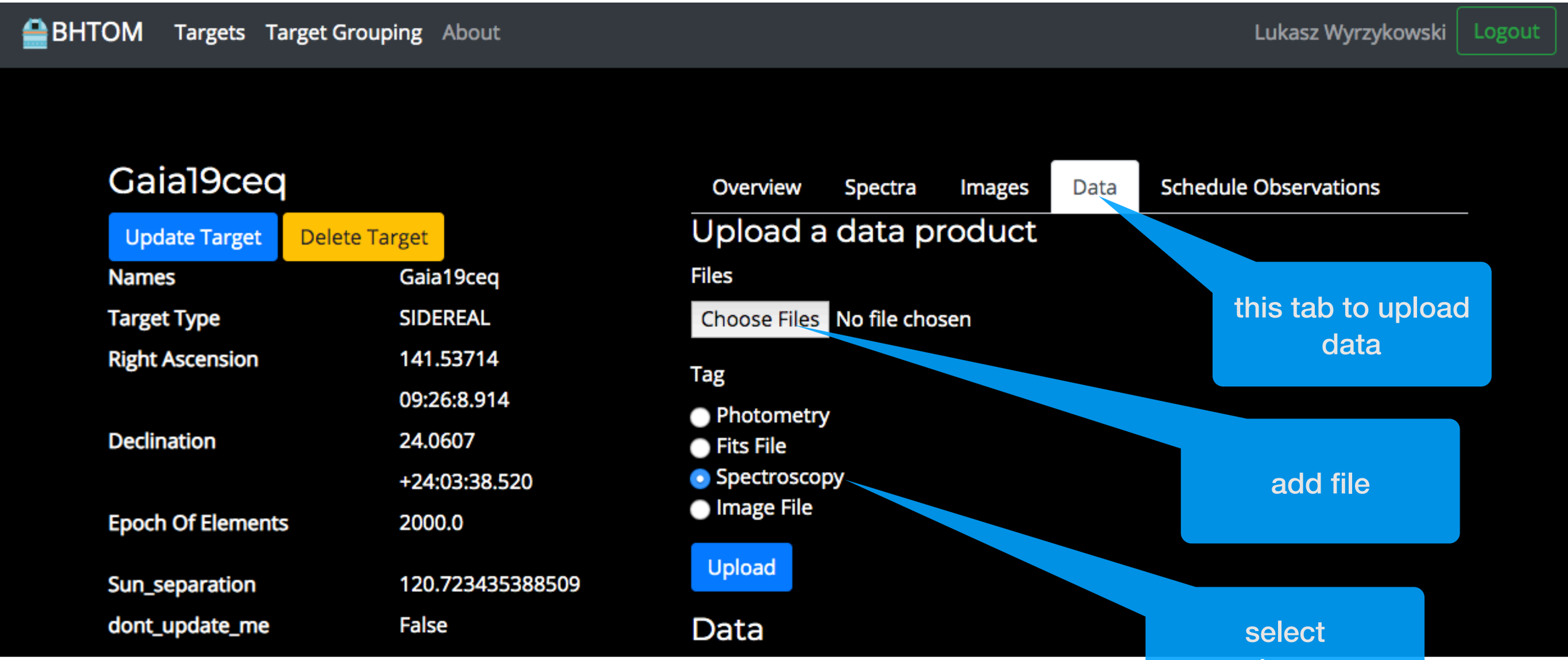
Comment

Comment

update fields, but only edit priority and cadence

click here to download any new photometric points from Gaia, ZTF, CPCS

Spectra uploading



example text file

```
# DATE-OBS: 2019-12-09
wavelength flux
3341.26928710937  1.464014E-16
3345.34836769104  1.447222E-16
3349.4274482727  7.000821E-17
3353.50652885437  4.936740E-17
3357.58560943603  7.570946E-17
```

Spectra uploading

BHTOM Targets Target Grouping About Lukasz Wyrzykowski Logout

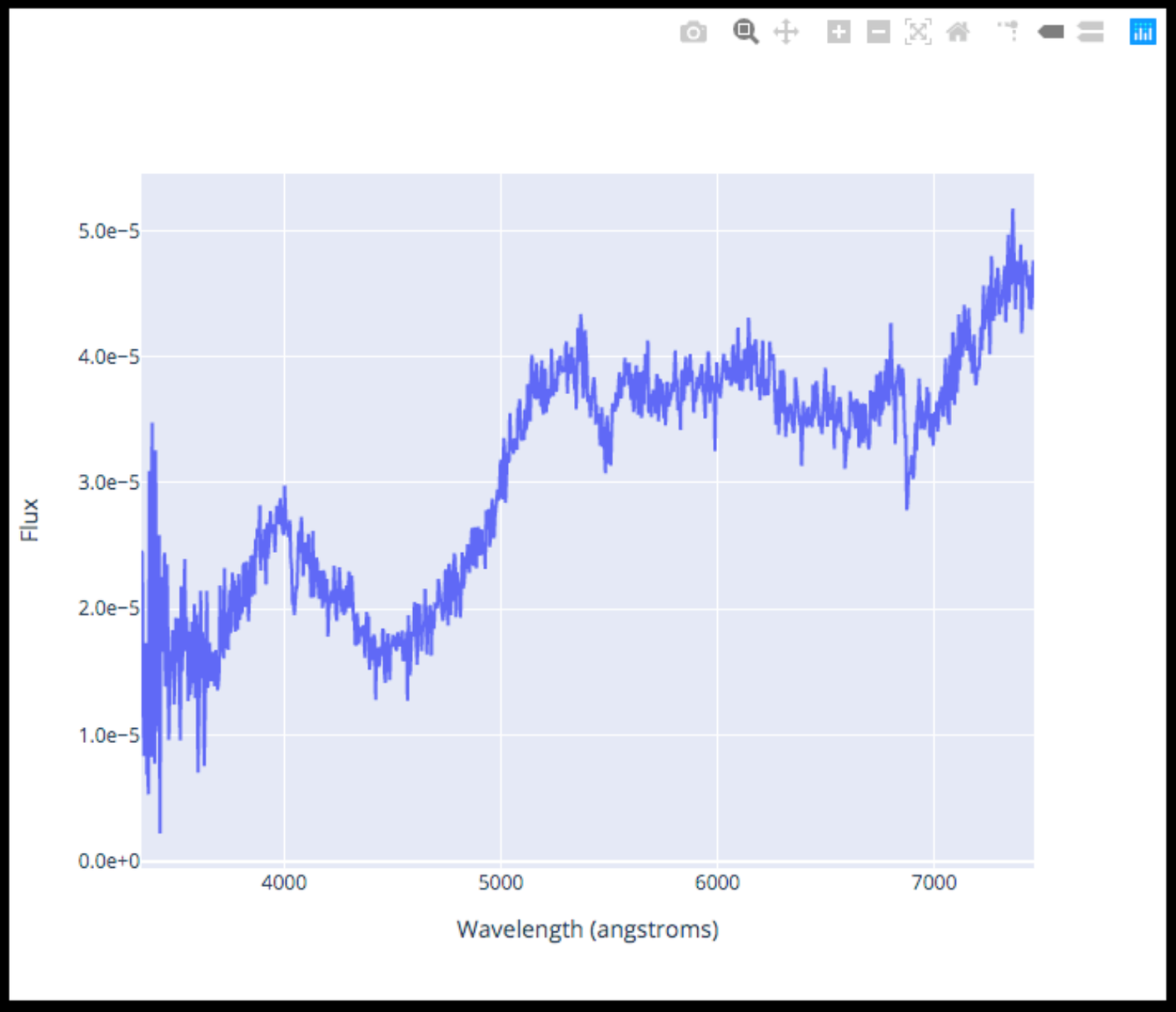
Gaia19ceq

Update Target Delete Target

Names	Gaia19ceq
Target Type	SIDEREAL
Right Ascension	141.53714
	09:26:8.914
Declination	24.0607
	+24:03:38.520
Epoch Of Elements	2000.0
Sun_separation	120.723435388509
dont_update_me	False
cadence	5.0
priority	3.0
maglast	18.27
jdlastobs	2458806.198
tweet	False
classification	Possible QSO, TDE
gaiadr2_id	
ztf_alert_name	ZTF18acpddav
calib_server_name	ivo://Gaia19ceq
gaia_alert_name	Gaia19ceq

Overview | Spectra | Images | Data | Schedule Observations

Spectra



Future functions

- upload fits image, psf photometry, send to Calib Server
- schedule observations with LCO, Gemini, LT and other robotic telescopes
- automated notification if target observed, data processed and calibrated
- send observing requests to manually operated OPTICON-TDA telescopes (email)
- each user/telescope has a dedicated list based on targets visibility
- different types of users: viewers, submitters, etc.
- robotic triggering of observations if target visible and with high priority
- triggering radio telescopes

Features wanted

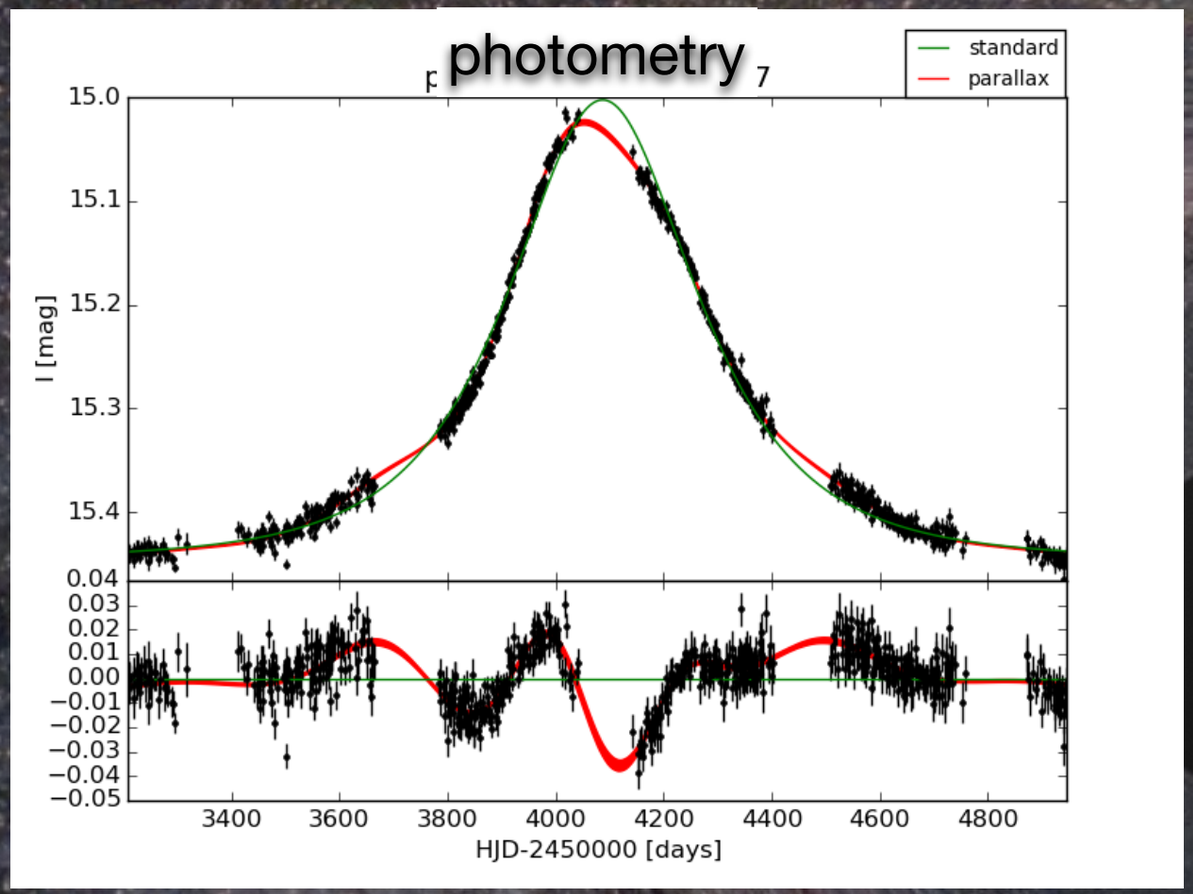
- switch between Ra-Dec and l-b map
- add Gaia DR2 image to the background on the map
- automatically query other surveys for their data on a target created, e.g. when creating Gaia Alert target, find if ZTF has an object there and request its data
- Gaia DR2 info pull
- auto generate finding charts (for observations and for papers)
- auto generate LaTeX table with data per target, with info on observatories and JDs (for papers)
- auto compute exposure time for a given facility
- weather display for all registered facilities
- read archival servers: target info, photometric time-series, spectra, radio (NED, CRTS, DASH, others)
- your ideas…

extra slides

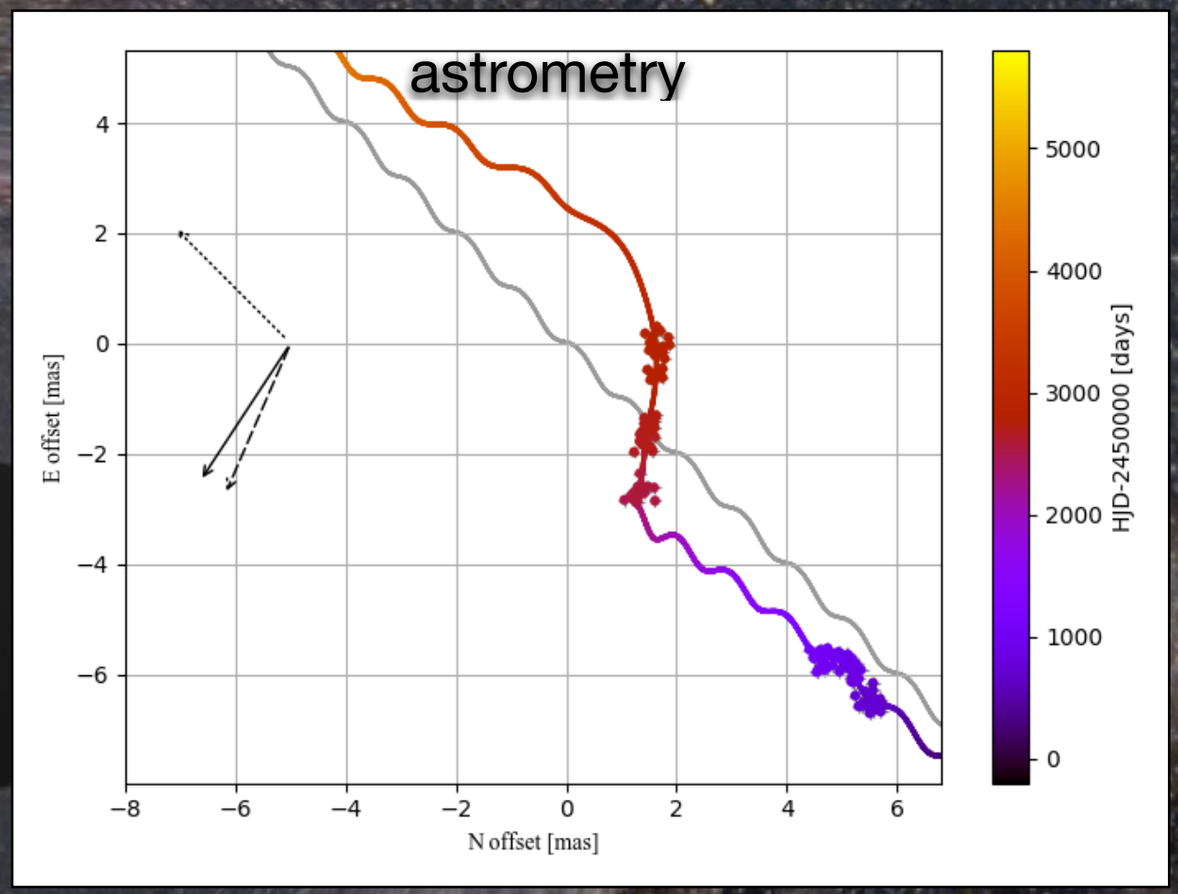
Łukasz Wyrzykowski

ASTROMETRY MICROLENSING

OGLE3-ULENS-PAR-02 - candidate ~12 MSun BH

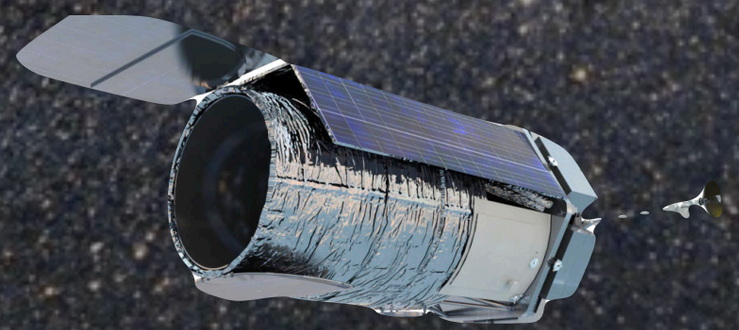


OGLE photometry from 2001-2008 and microlensing model



predicted WFIRST astrometry for similar event (2025?)

Mass, Distance



HOW TO FIND BLACK HOLES?

Black hole = large mass + dark object

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

$$\pi_L = \theta_E \pi_E + \pi_S$$

$$F_L = F_{obs}(t) - A(t) F_S$$

HOW TO FIND BLACK HOLES?

Black hole = large mass + dark object

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

Photometry

$$\pi_L = \theta_E \pi_E + \pi_S$$

Astrometry

$$F_L = F_{obs}(t) - A(t) F_S$$

Spectroscopy

HOW TO FIND BLACK HOLES?

Black hole = large mass + dark object

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

$$\pi_L = \theta_E \pi_E + \pi_S$$

$$F_L = F_{obs}(t) - A(t) F_S$$

Photometry

Gaia, OGLE, Spitzer, LCO *LSST

Astrometry

Gaia, VLTI, speckle imaging, *ELT, *JWST, *WFIRST

Spectroscopy

Gemini, SOAR, VLT, SALT, *ELT