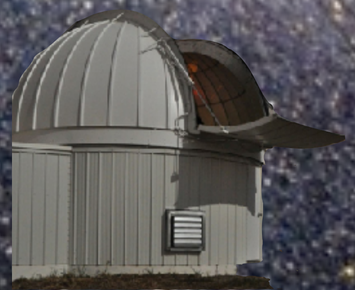
TIME-DOMAIN OPTICAL ASTRONOMY

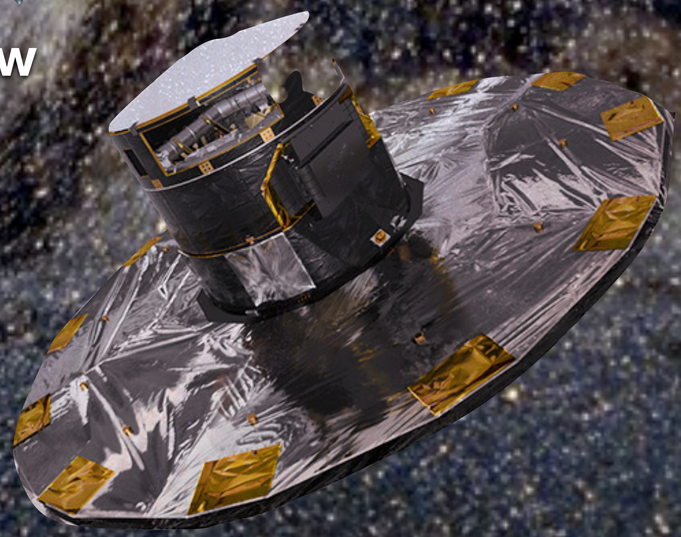
Łukasz Wyrzykowski

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

Astronomical Observatory, University of Warsaw

Poland





EGO, Pisa

10.October 2022

WARSAW UNIVERSITY ASTRONOMICAL OBSERVATORY

- Founded 1816 (before the Warsaw University!)
- Building completed 1825
- Best ranked Polish astronomical teaching and research institute (A+ award in 2022)
- Physics and Astronomy ranked 51-75 in Shanghai Ranking 2022
- Observing stations: Ostrowik near Warsaw (since 1953), Las Campanas, Chile (since 1996)

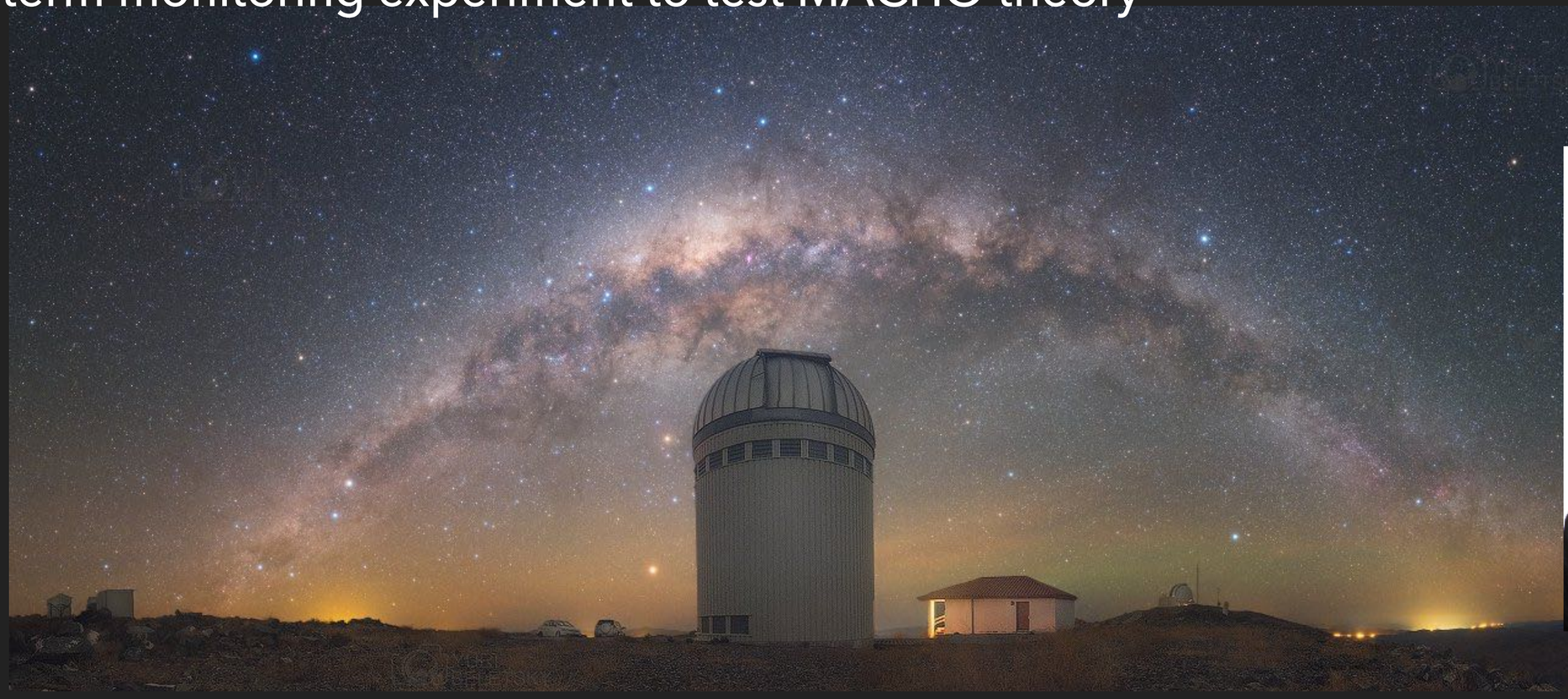
WARSAW UNIVERSITY ASTRONOMICAL OBSERVATORY

- Warsaw School of Photometry since 1950s with Ostrowik station
- Krzemiński (discovery of polars), Lick Observatory, Las Campanas, Carnegie (1960s)
- Smak, Czerny, Kruszewski, Stępień (variable stars, accretion disks)
- Paczyński:
  - Compact binaries - Common Envelope phase of stellar evolution (leading to GW mergers)
  - Gamma Ray Bursts at cosmological distances
  - Theory of Neutron Stars mergers (kilonovae)
  - Gravitational microlensing to probe Dark Matter (MACHOs)

Bohdan Paczyński
(1940—2007)

OPTICAL GRAVITATIONAL LENSING EXPERIMENT OGLE

- initated in 1992 by Bohdan Paczyński and Andrzej Udalski
- the longest running large-scale optical survey, currently in its 4th phase
- long-term monitoring experiment to test MACHO theory

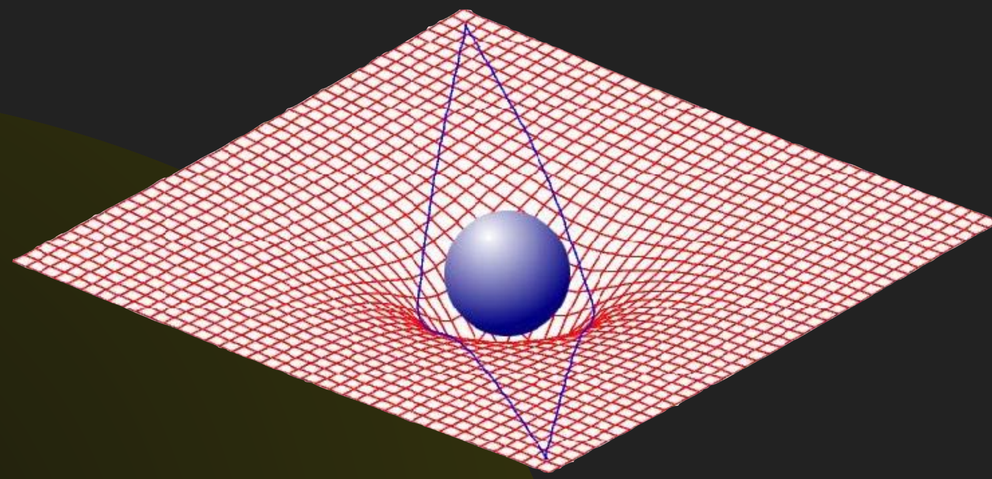


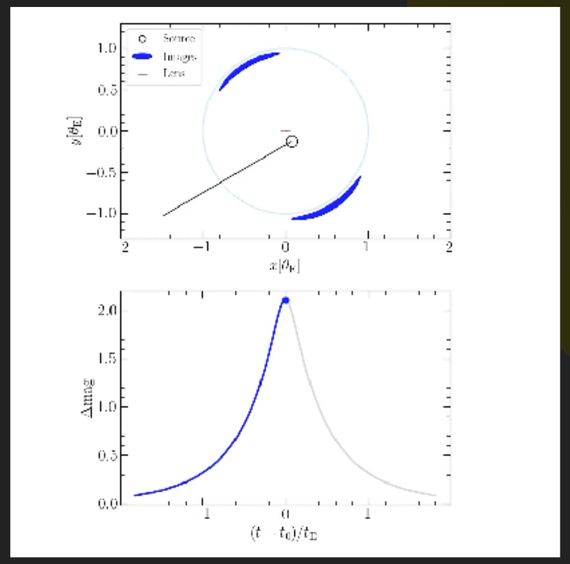
erc

Andrzej Udalski

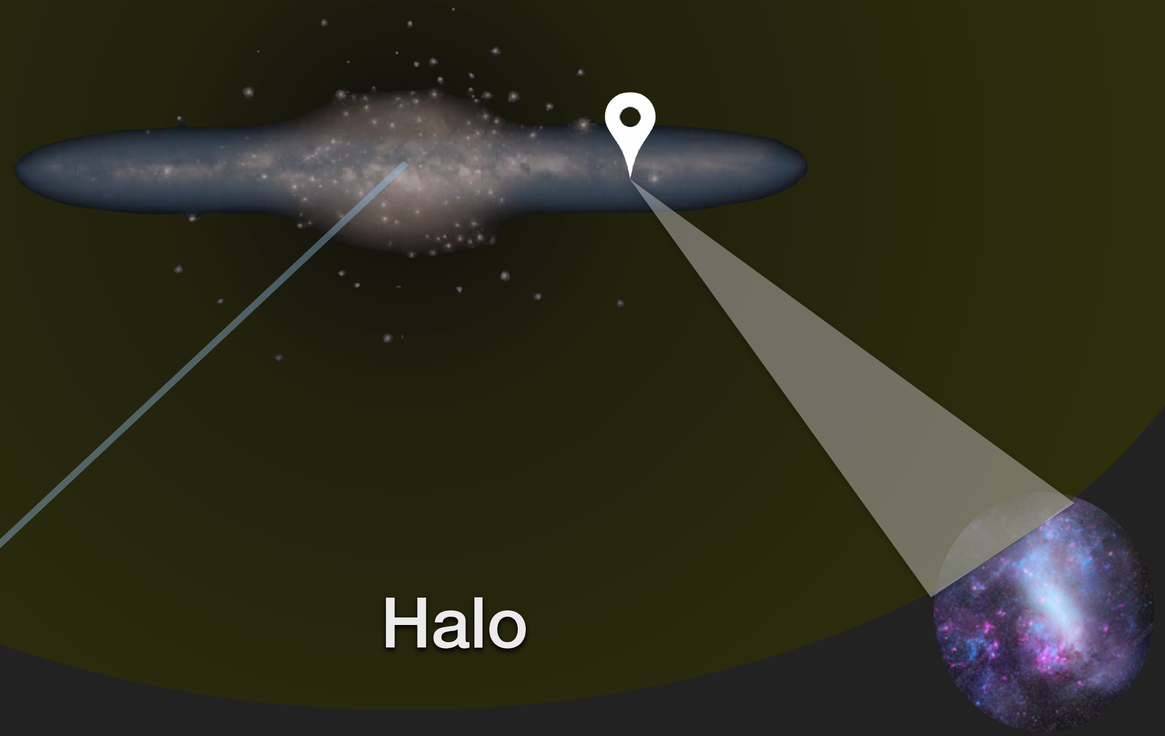
HOW TO FIND DARK MATTER WITH MICROLENSING?

- Massive Astrophysical Compact Halo Objects (MACHOs) if dominant in the Galaxy Halo could cause temporal lensing (brightenning) events on background stars



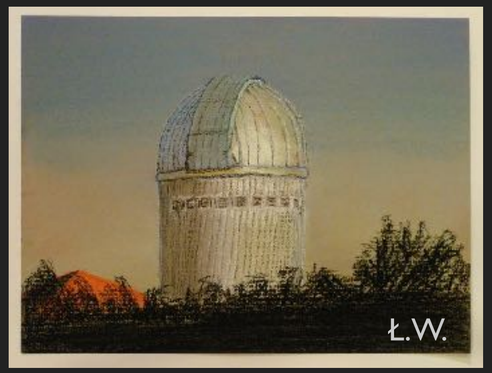


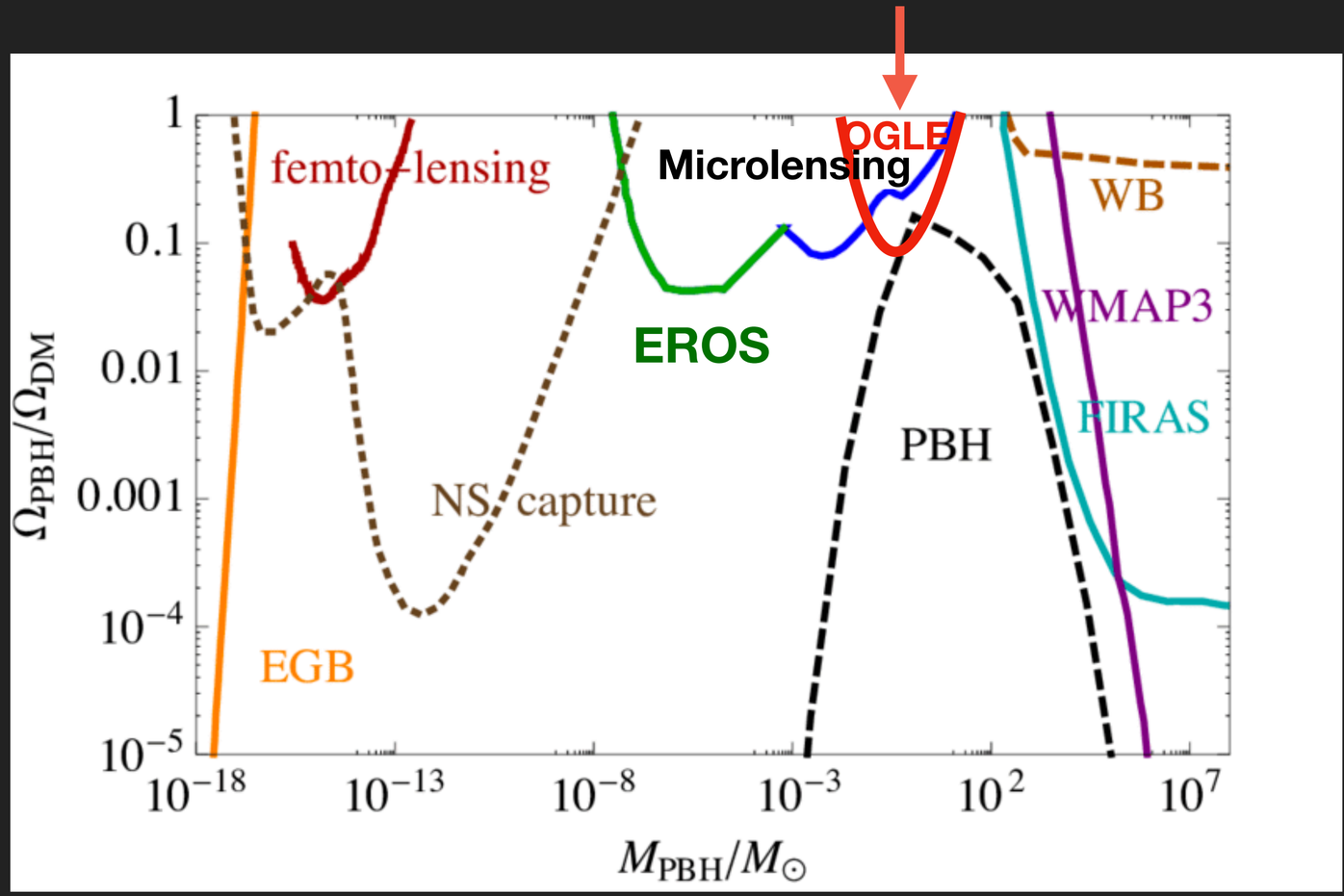
Paczyński curve



MICROLENSING CONSTRAINS ON THE HALO DARK MATTER (MACHO)

- OGLE data (1996-2009) was searched for time-varying changes in stars
- Dark Matter in form of primordial black holes (PBH) with monochromatic mass spectrum was ruled out to <~10 Solar Mass

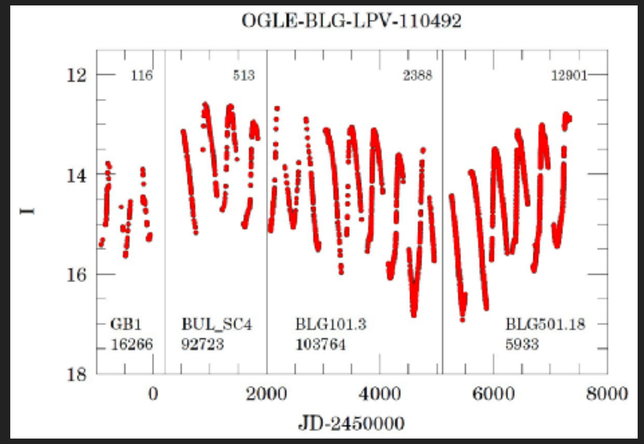




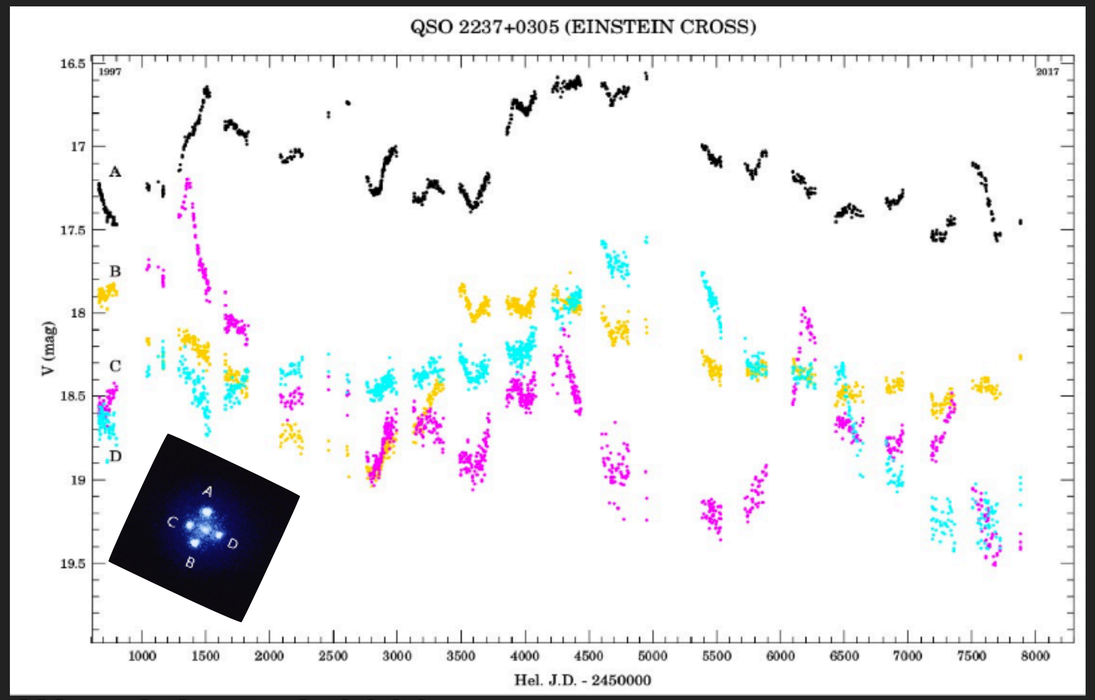
Garcia-Bellido & Clesse 2017
Wyrzykowski+ 2009,2010,2011a,2011b

OGLE AND OTHER TIME-DOMAIN ASTROPHYSICS

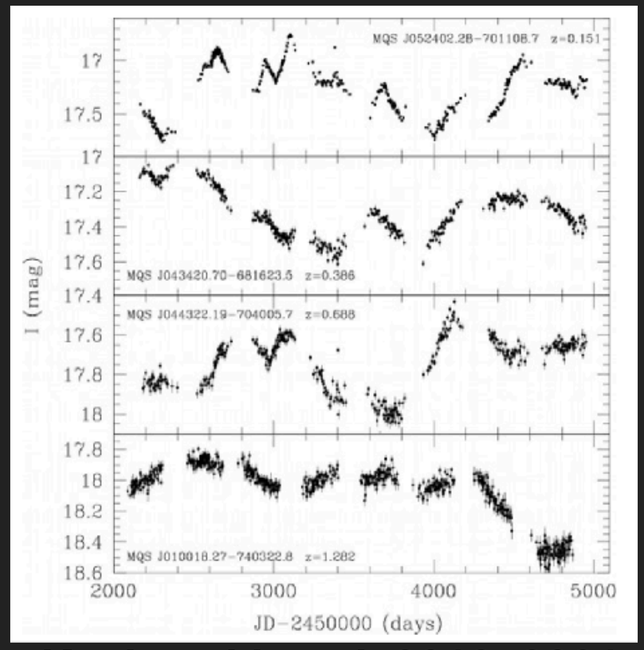
- 1 million variable stars
- 20,000 microlensing events
- new types of variable stars and rare stages of stellar evolution
- planets
- extragalactic science:
  quasars discovery (z>5)
  quasar monitoring
  (20 years)



Soszynski et al. 2015, 2016



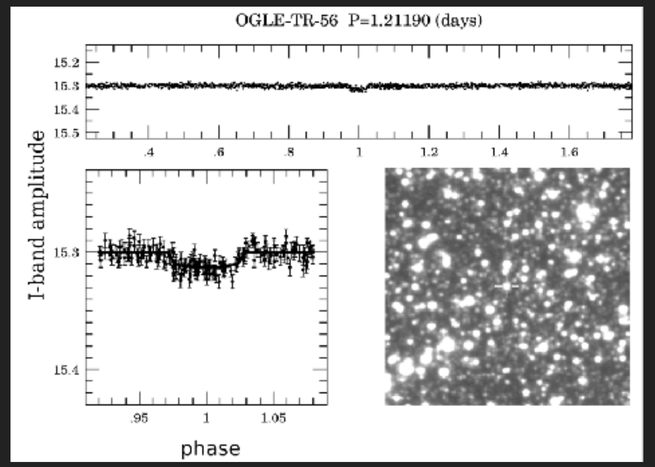
Wozniak et al. 2000

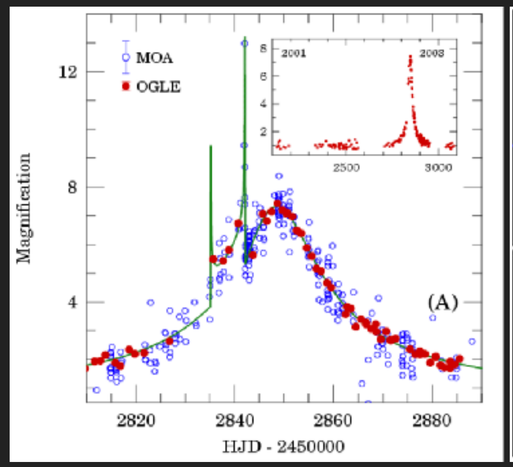


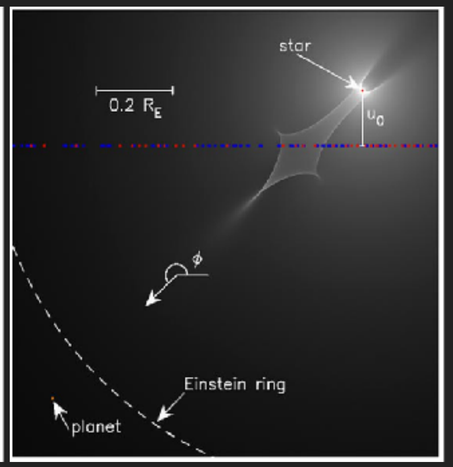
Kozlowski et al. 2013, 2021

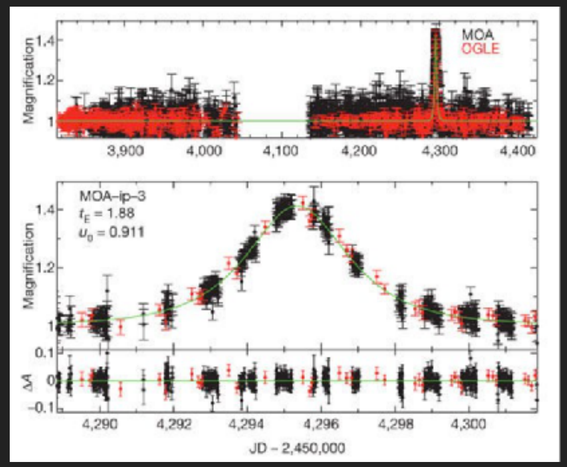
PLANETS

- Planet abundance: 17% Jupiters, 52% Neptunes, 62% Super-Earths
- Free-floating planets (no stellar host) - challenge for planet formation theory
- Different methods:
  - microlensing (short perturbations to Paczynski curve, ~hours)
  - transits (dimming of the host star)





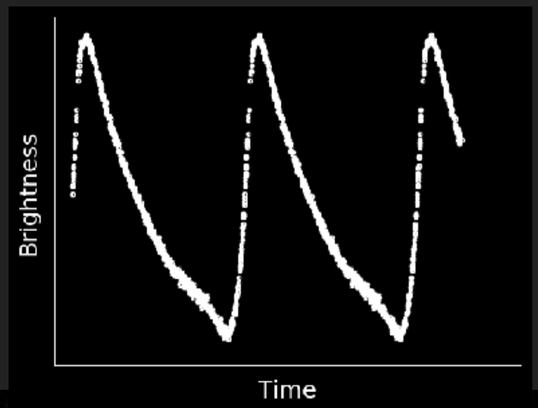




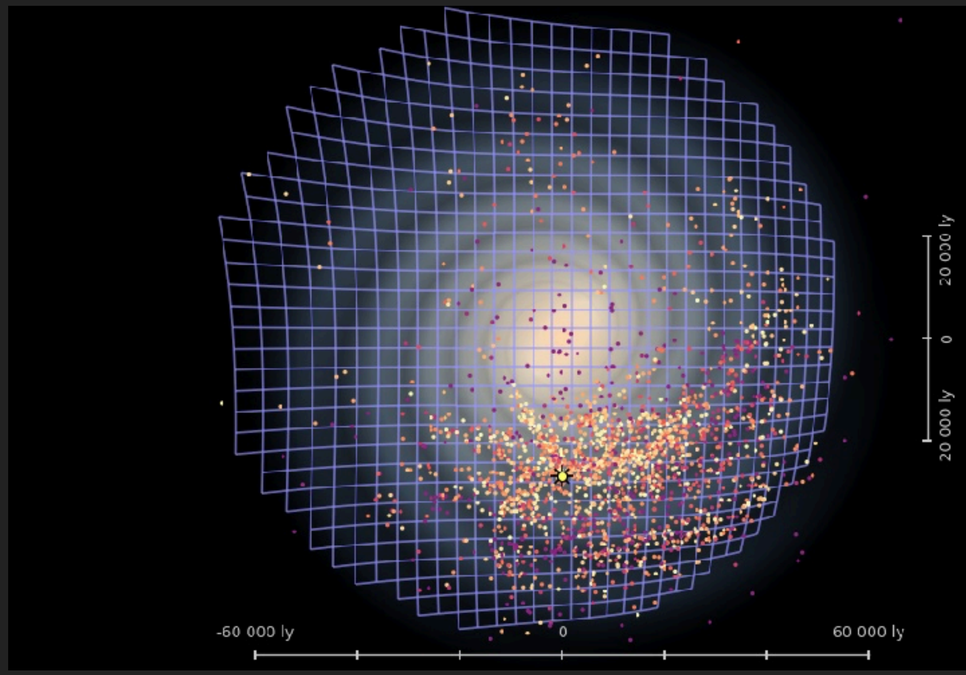
Udalski et al. 2002, Bond et al. 2004, Cassan et al. 2012, Sumi et al. 2011, Mroz et al. 2017

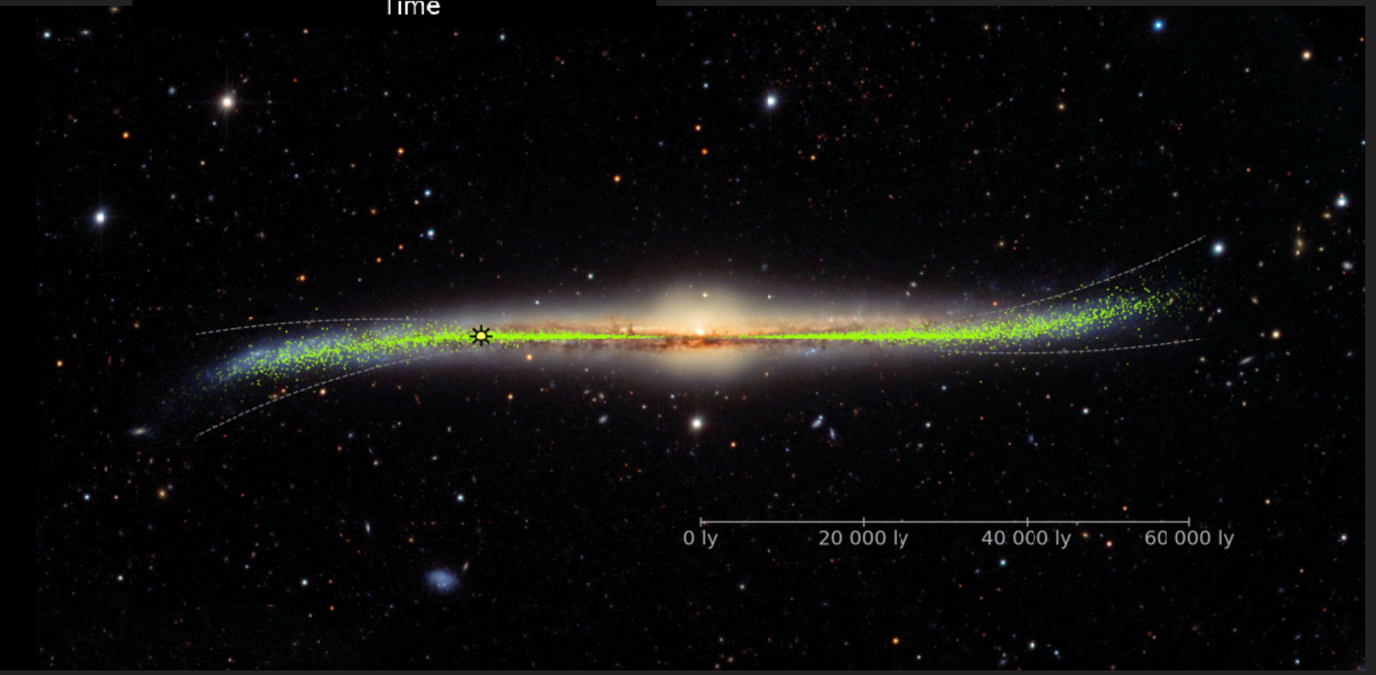
CEPHEIDS AS TRACERS OF THE GALAXY STRUCTURE

- Well-calibrated distance tracers
- 3D structure of the Galaxy
- Warping of the Disk discovered



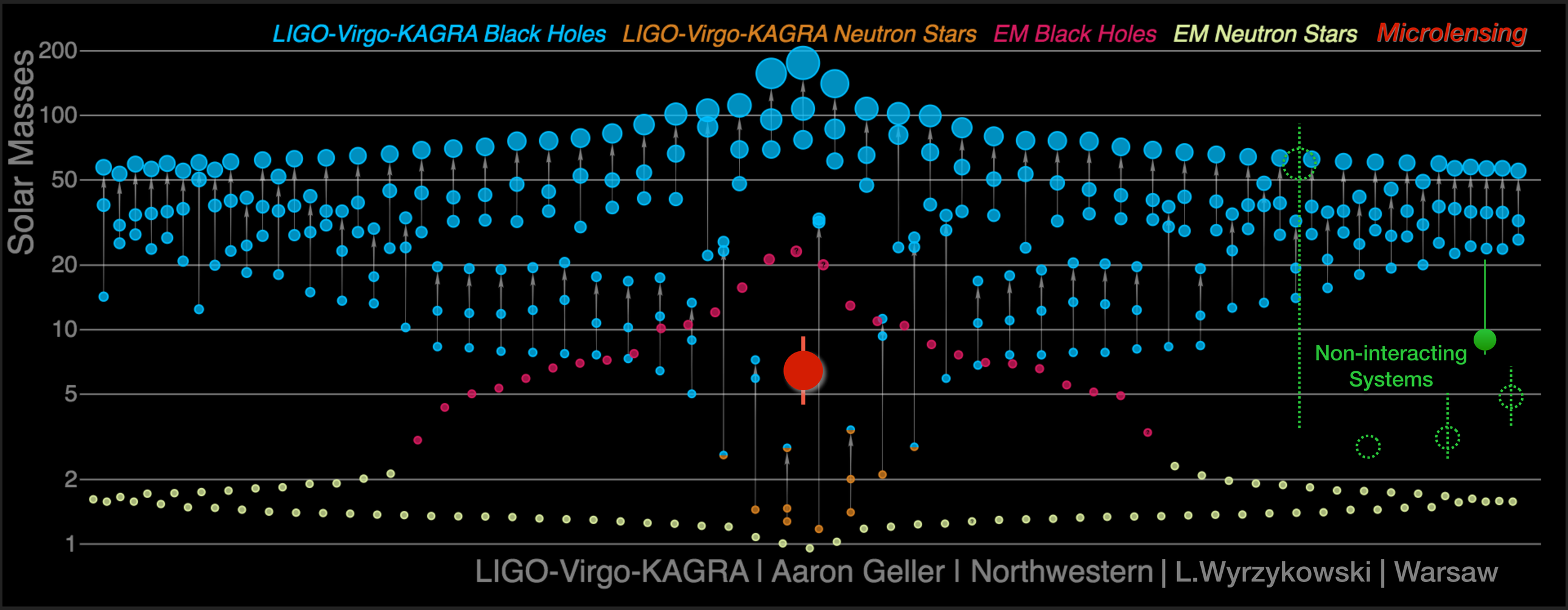
Dorota Skowron





Skowron et al. 2020

MASSES OF BLACK HOLES AND NEUTRON STARS



Abbott+2021 *Thompson et al. 2019, Liu+2020, Shenar+2022* *Sahu+2022*
Corral Santana+2016 *Rivinius+2020, Jayasinghe+2021* *Lam+2022, Mróz+2022*

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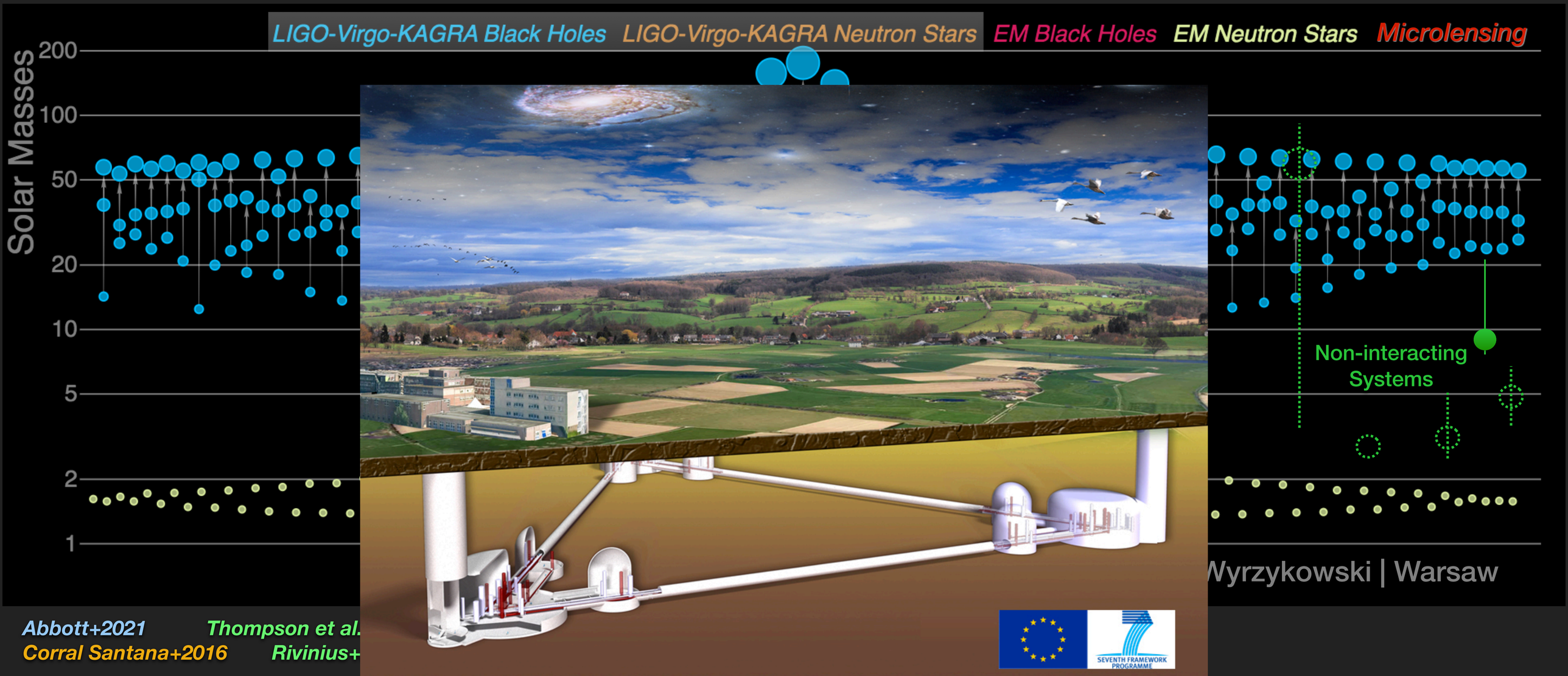

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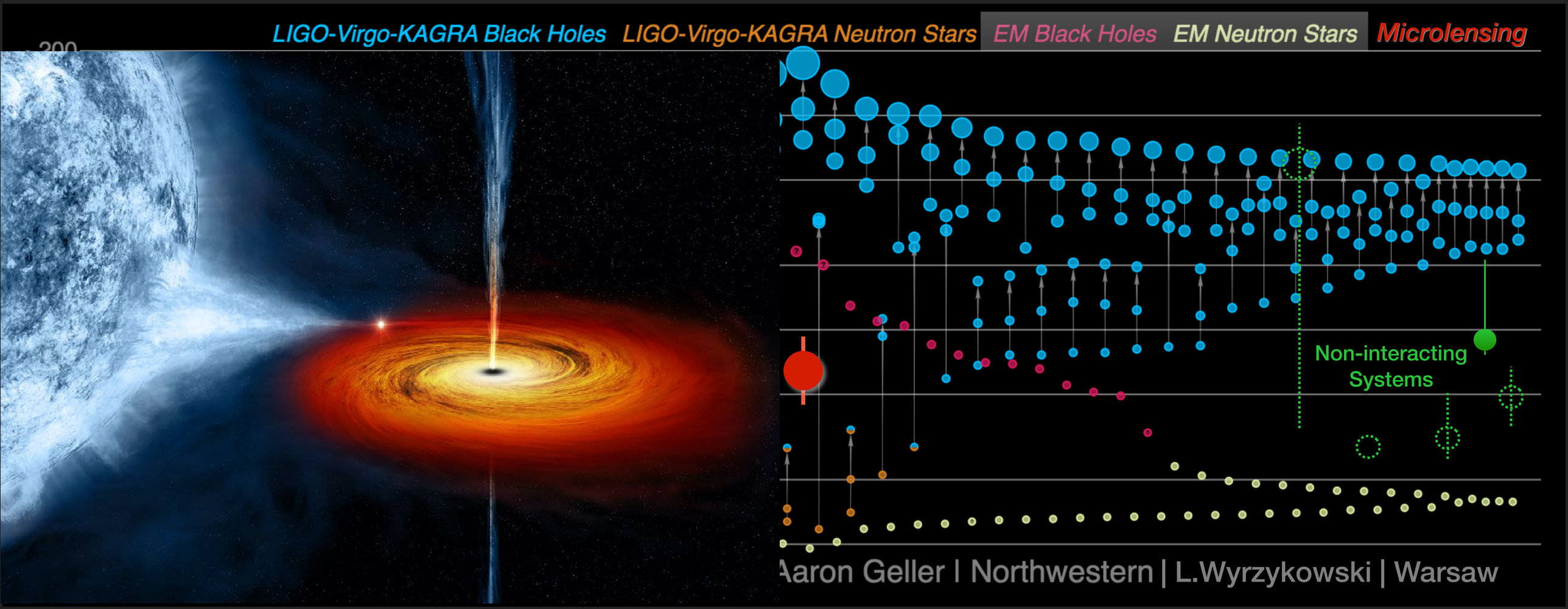

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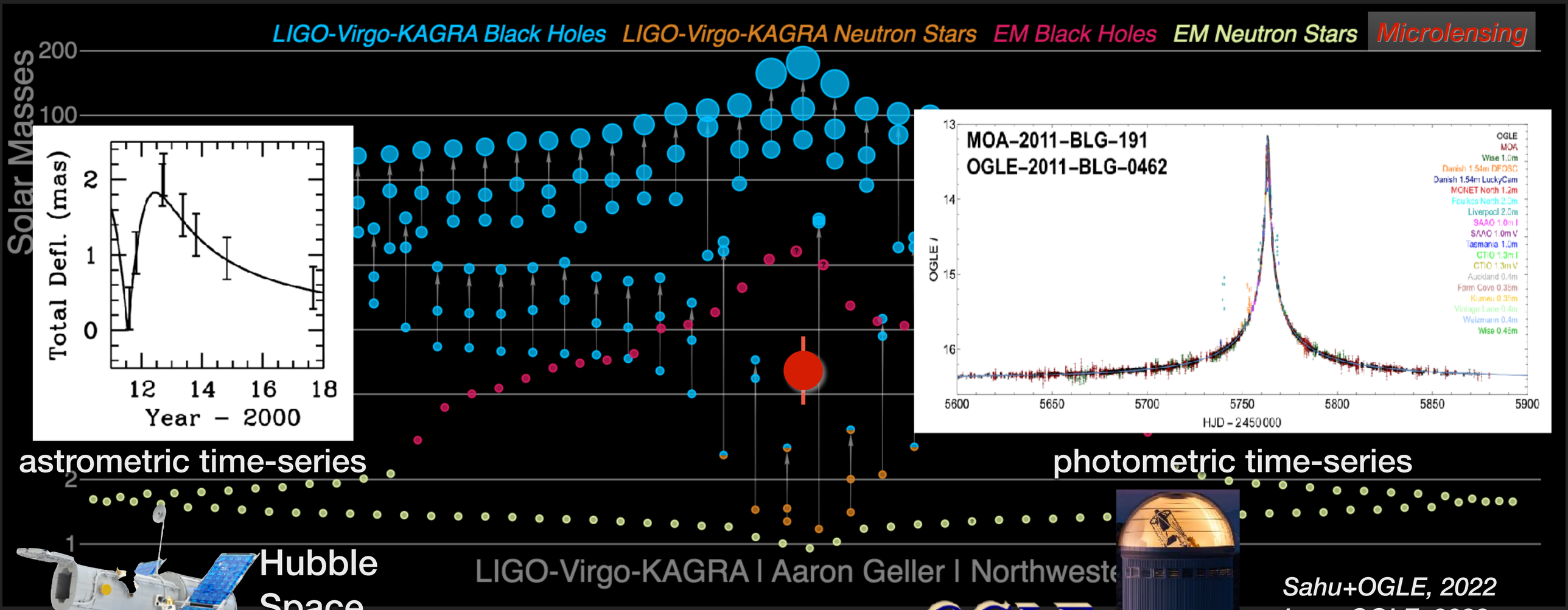
MASSES OF BLACK HOLES AND NEUTRON STARS

FIRST ISOLATED BLACK HOLE FOUND WITH MICROLENSING



astrometric time-series

photometric time-series

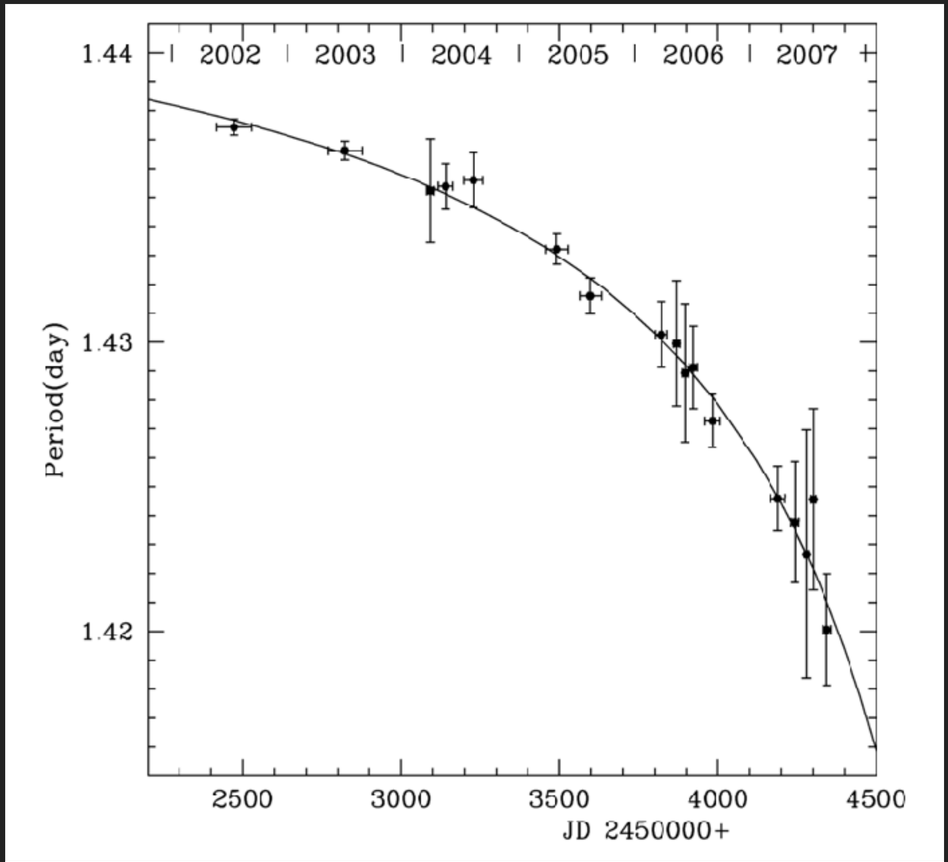
Hubble Space Telescope

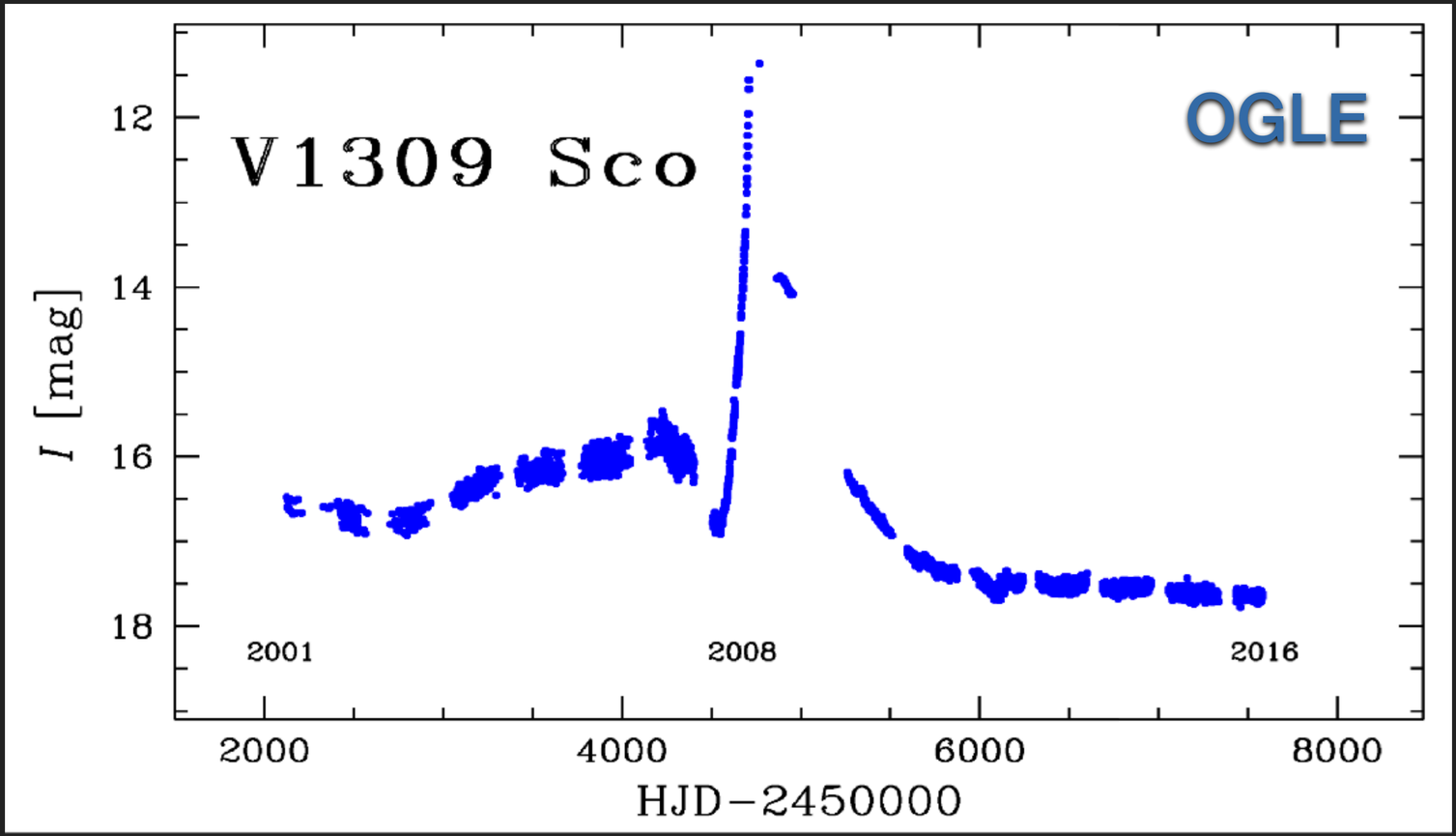
OGLE

Sahu+OGLE, 2022
Lam+OGLE, 2022
Mróz et al. 2022

FIRST EVER DETECTED STELLAR MERGER

- Flare (Red Nova) preceded with a period shortening
- Merger of two dwarf main-sequence stars with emission of graviational waves (not detected)

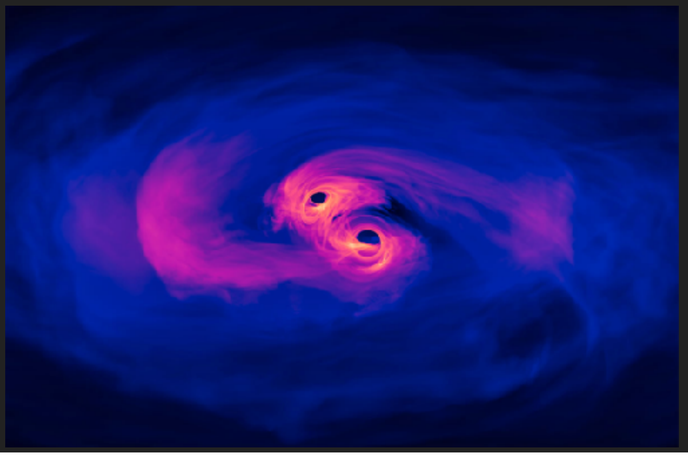


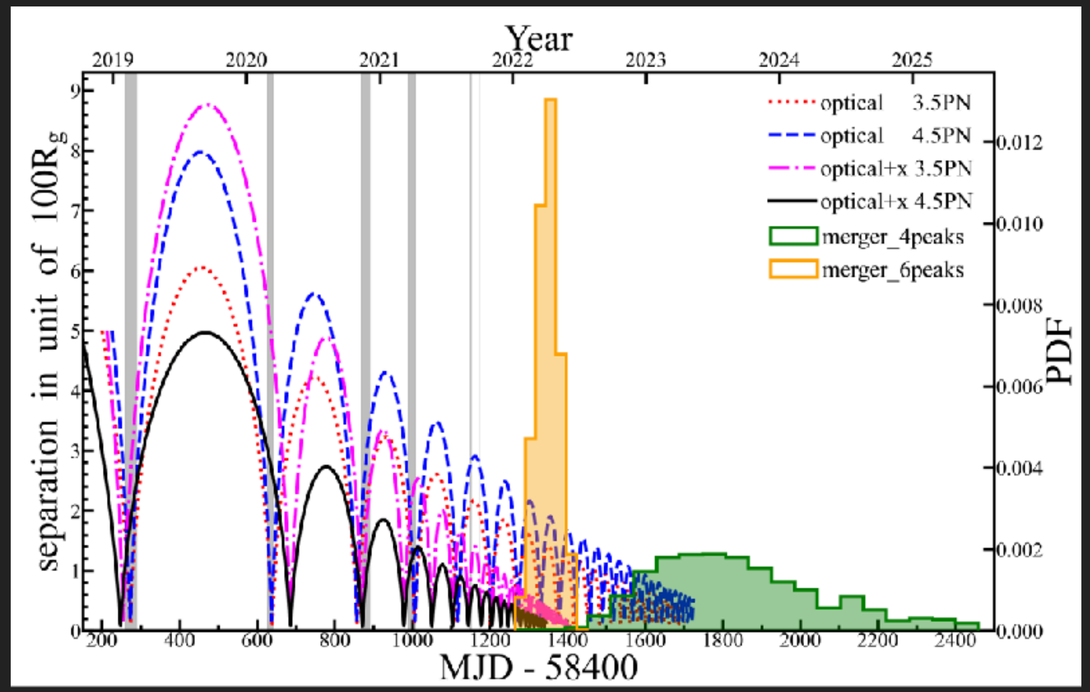


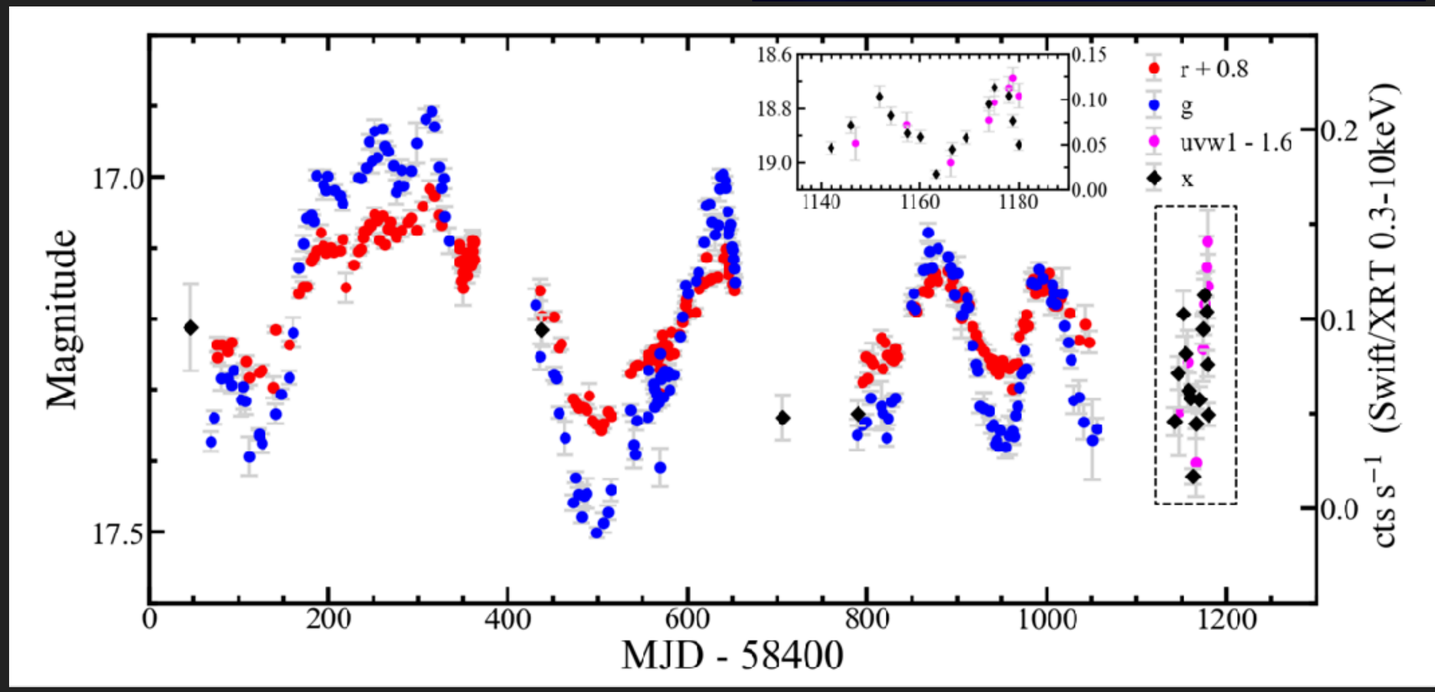
Tylenda et al. (2011)

SUPER-MASSIVE BLACK HOLE MERGER?

- Possible binary black hole merger in a distant galaxy
- Merger predicted to occur SOON!







Jiang et al. (2022)

OTHER TIME-DOMAIN SURVEYS

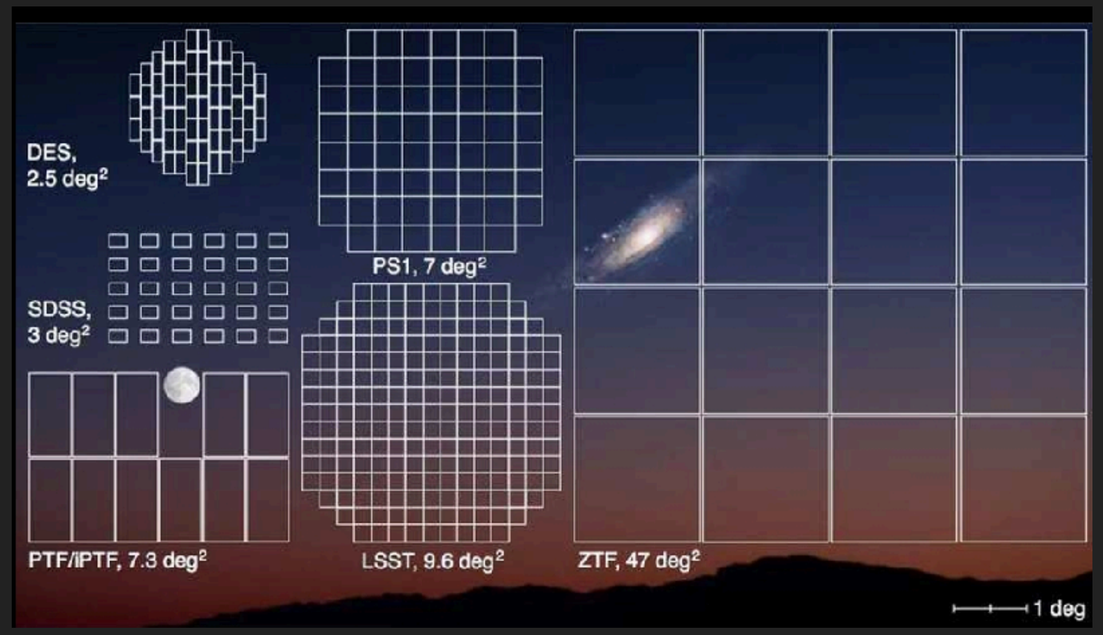
- Optical:
  - MACHO, EROS, MOA, KMTNet, Tomo-eGozen - long-term microlensing surveys, South
  - PTF->iPTF->ZTF - Northern all-sky survey (the largest single fov camera of 40deg^2)
  - ASAS (Warsaw), ASAS-SN (Ohio-Warsaw) - N+S, shallow (<15mag), supernovae
  - Pan-STARRS, CRTS, LINEAR - mostly for NEOs
  - ATLAS, SDSS, GOTO, MASTER, HATPI, ... - different goals, vast archives!
  - Gaia
- Ultraviolet: GALEX
- Infrared: WISE->NEOWISE, Spitzer, VVV
- X-ray: INTEGRAL, eROSITA
- ... probably many missed :)

FUTURE SURVEYS (2025+)

- Optical:
  - OGLE, ZTF, ASAS-SN, ATLAS, Pan-STARRS - ?
  - Vera Rubin Observatory (LSST) - 8m large fov Southern survey in Chile
  - GOTO, BlackGem, LAST,....
- Ultraviolet: UltraSAT
- Infrared:
  - Nancy Grace Roman Space Telescope, EUCLID
- ... probably many missed :)

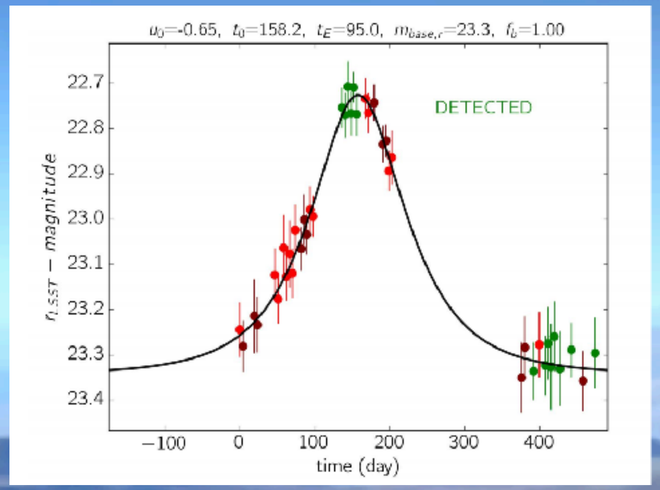
ZWICKY TRANSIENT FACILITY

- Caltech and partners
- Palomar factory: large-scale survey + follow-up (phot + spec)
- 1 million of alerts per night! (reports on changes on the sky)

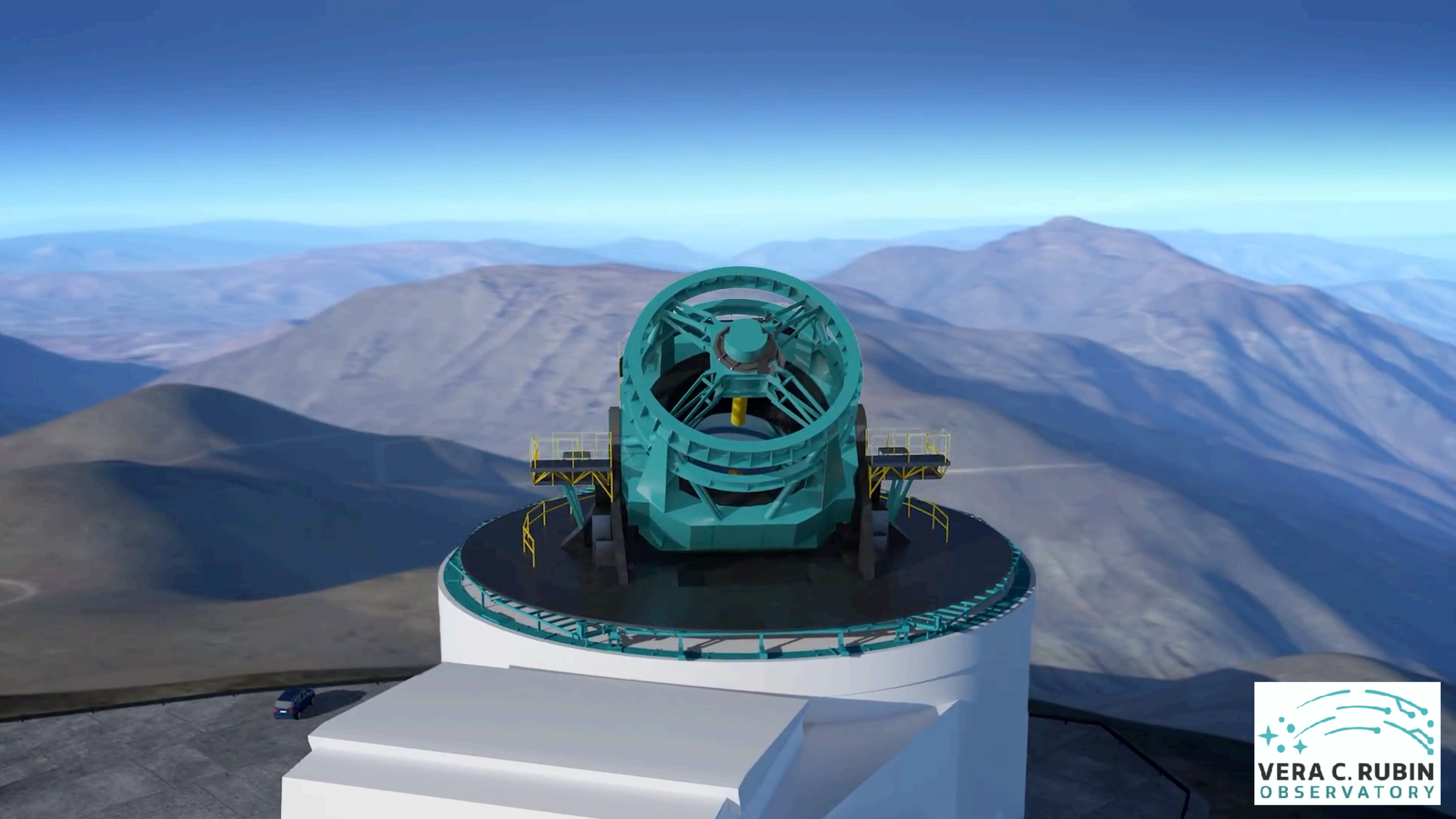


https://www.ztf.caltech.edu/

8-m survey telescope in Chile
multi-filter large fov camera
cadence: 3-30 days



VERA C. RUBIN
OBSERVATORY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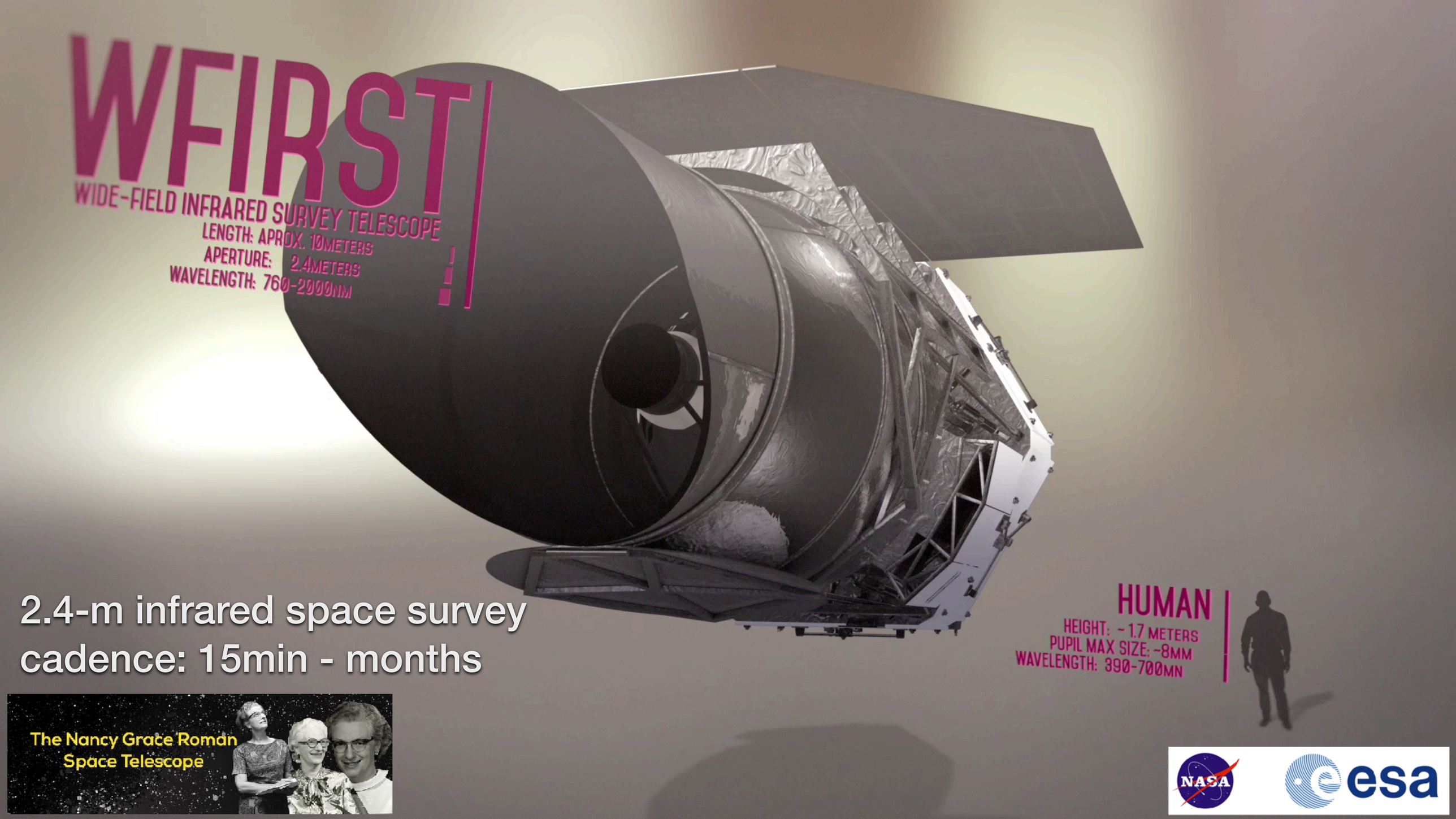
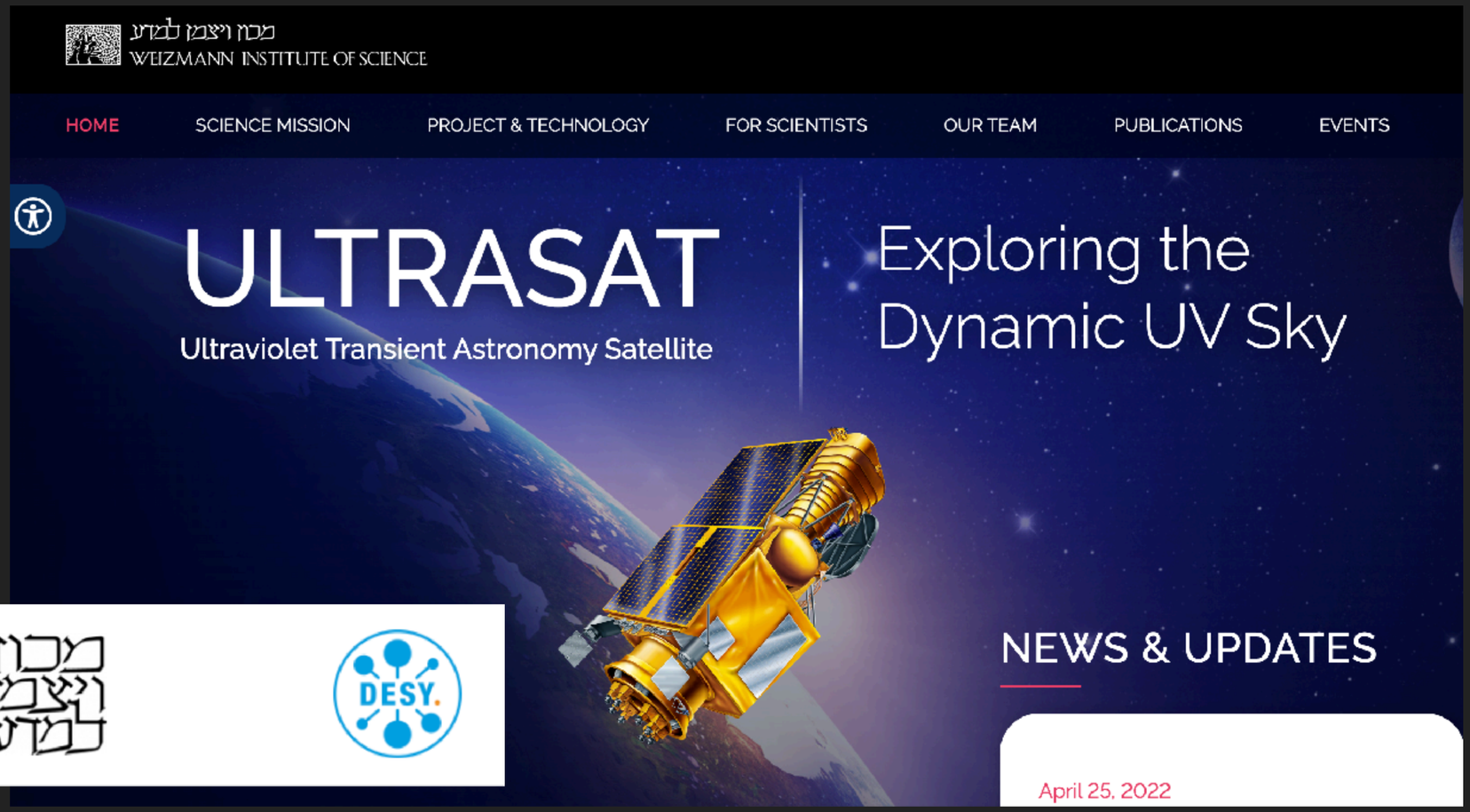


2.4-m infrared space survey
cadence: 15min - months

ULTRASAT – ULTRAVIOLET SPACE SURVEY

- Weizmann Institute (Israel) and partners (incl. DESY)
- Wide-field UV space survey
- Dedicted for transients:
  - TDE
  - supernovae
  - gamma-ray bursts

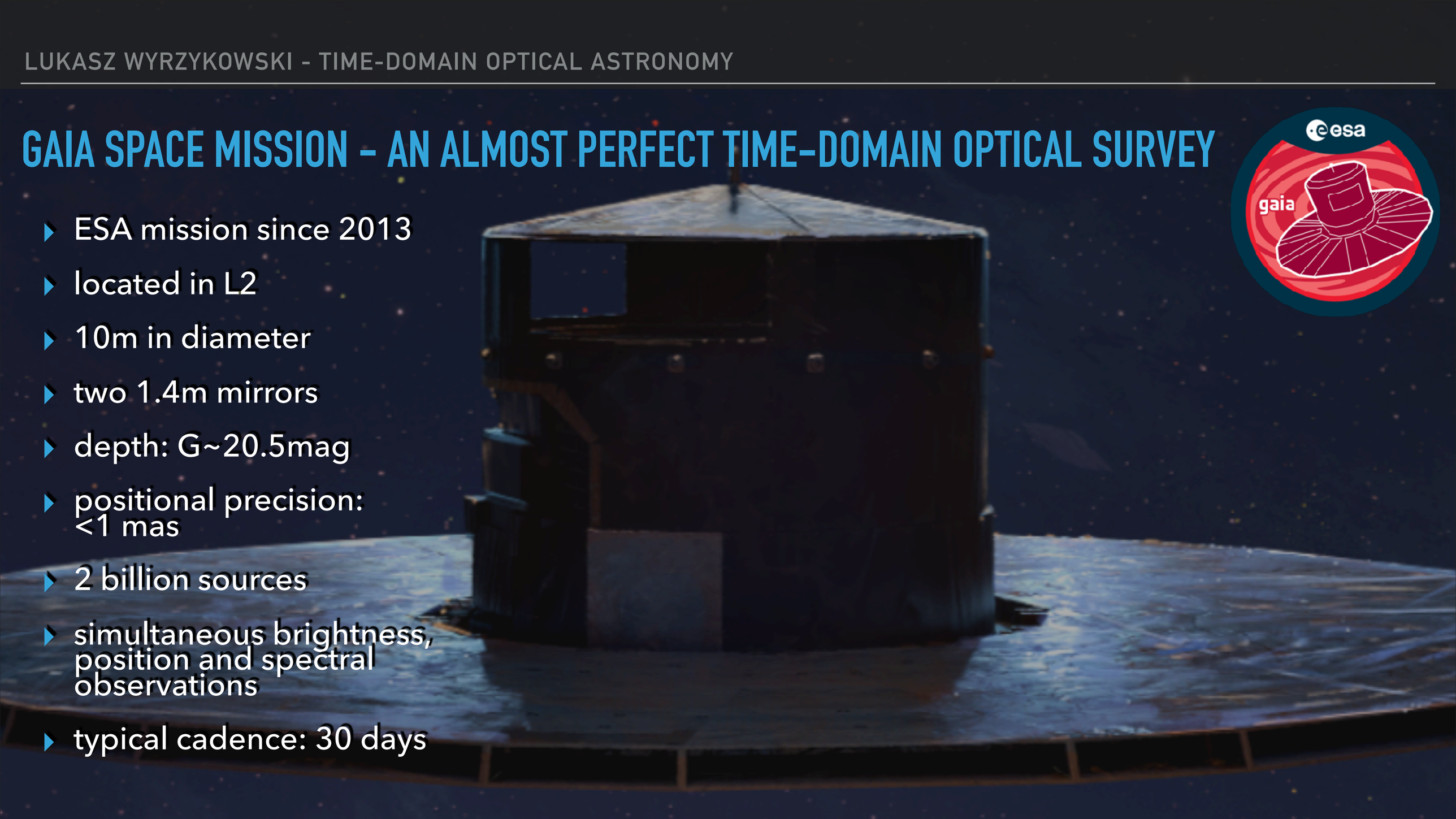


https://www.weizmann.ac.il/ultrasat/

GAIA SPACE MISSION

GAIA SPACE MISSION – AN ALMOST PERFECT TIME-DOMAIN OPTICAL SURVEY

GAIA SPACE MISSION – AN ALMOST PERFECT TIME-DOMAIN OPTICAL SURVEY



- ESA mission since 2013
- located in L2
- 10m in diameter
- two 1.4m mirrors
- depth: G~20.5mag
- positional precision: <1 mas
- 2 billion sources
- simultaneous brightness, position and spectral observations
- typical cadence: 30 days

GAIA SPACE MISSION – AN ALMOST PERFECT TIME-DOMAIN OPTICAL SURVEY

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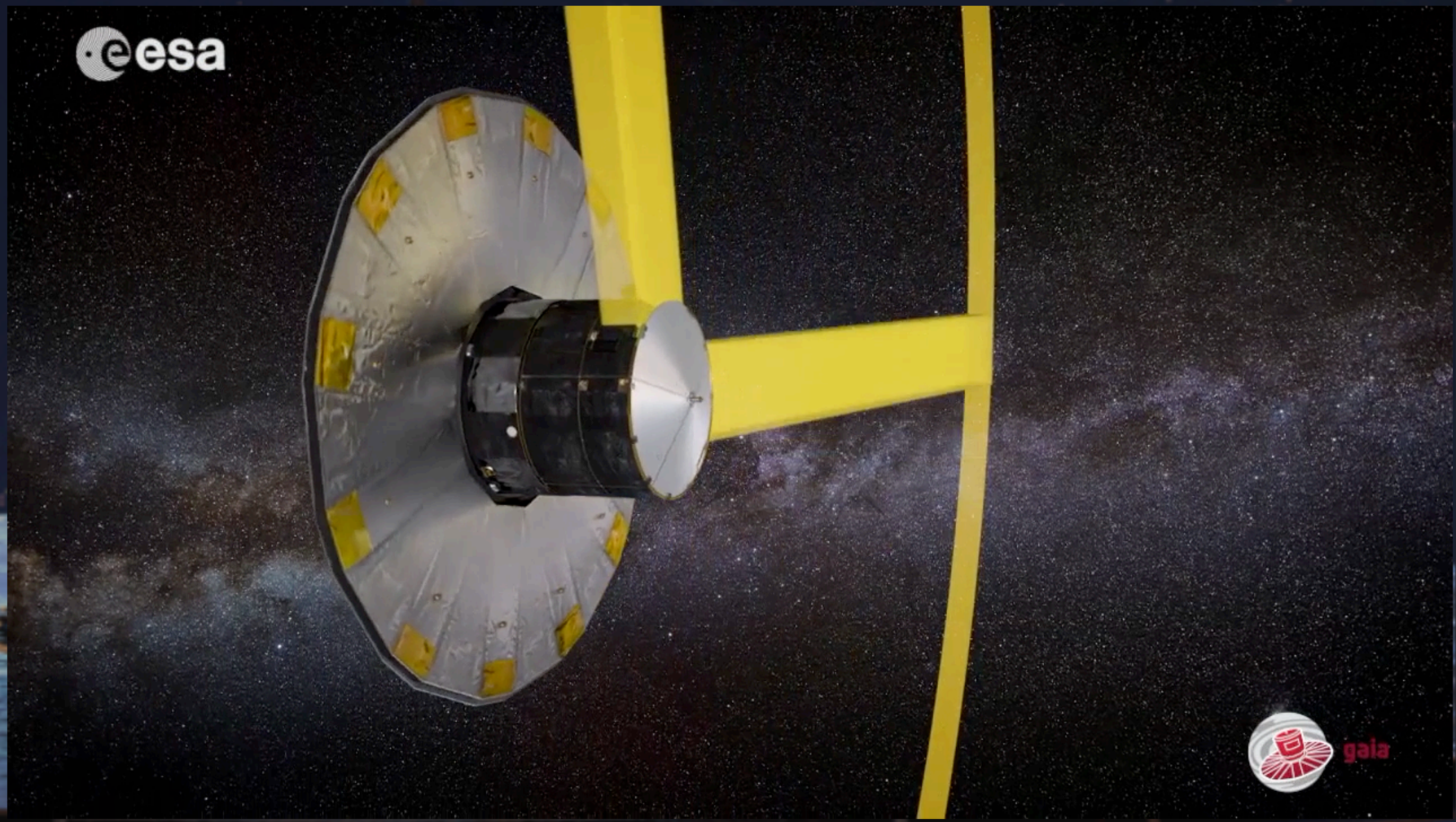
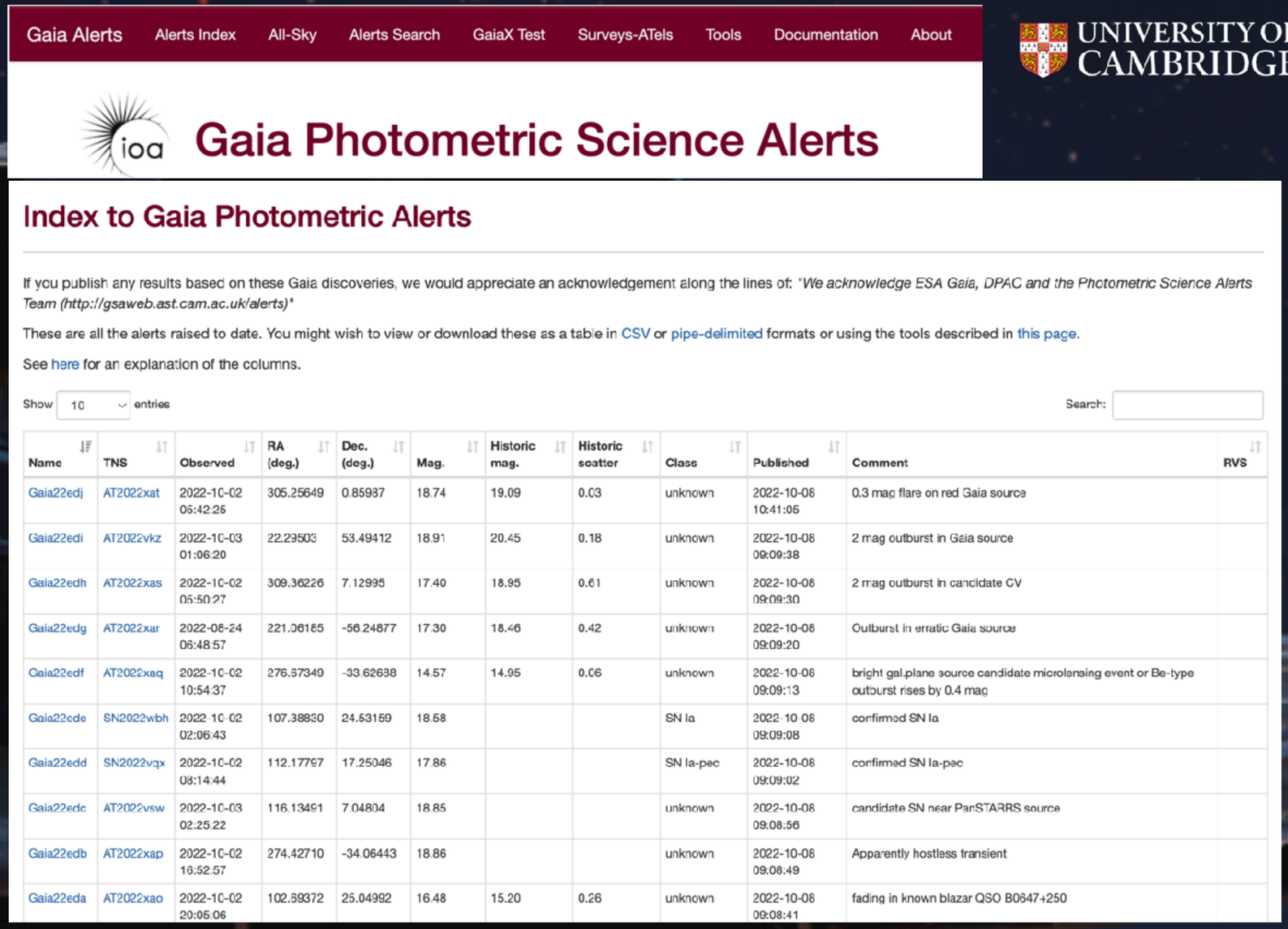


GAIA ALERTS

- in operation from 2014
- ~20,000 alerts
- ALL types of transients:
  - supernovae
  - tidal disruption events
  - super-luminous SNe
  - cataclysmic variables
  - dimming stars (RCrB)
  - young stellar objects
  - Be-type outbursts
  - microlensing events
  - quasars
- human-vetted,
  but automation is coming
- typical latency: 1-2 days

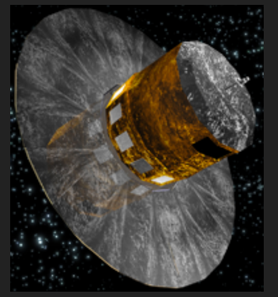


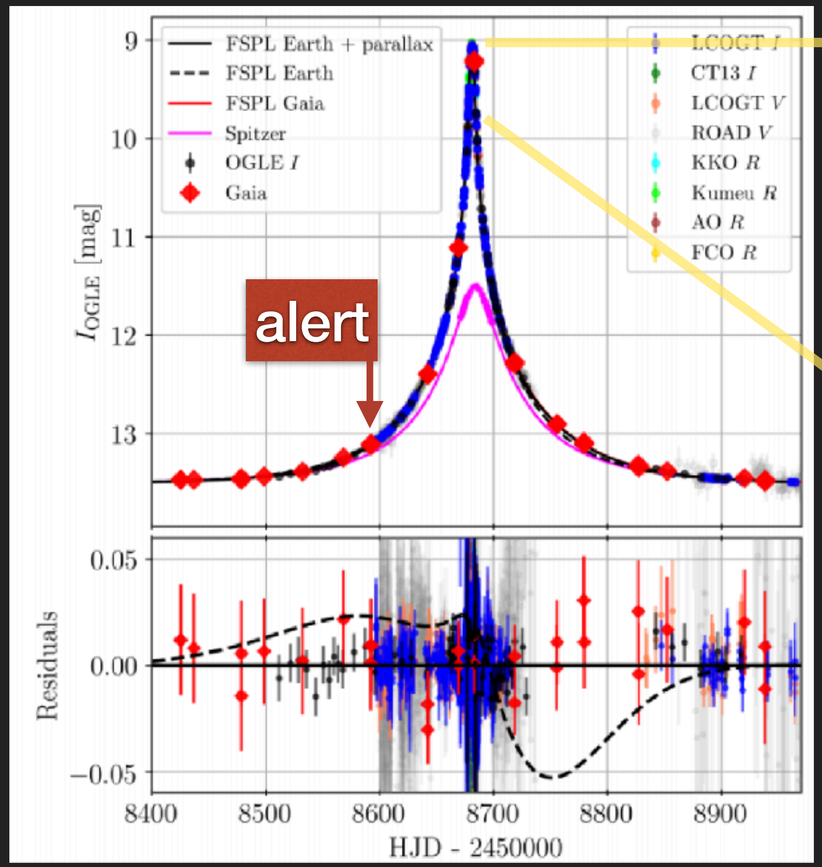
Name	TNS	Observed	RA (deg.)	Dec. (deg.)	Mag.	Historic mag.	Historic scatter	Class	Published	Comment	RVS
Gaia22edj	AT2022xat	2022-10-02 05:42:25	305.25649	0.85937	18.74	19.09	0.03	unknown	2022-10-08 10:41:05	0.3 mag flare on red Gaia source	
Gaia22edi	AT2022vkz	2022-10-03 01:06:20	22.29503	53.49412	18.91	20.45	0.18	unknown	2022-10-08 09:09:38	2 mag outburst in Gaia source	
Gaia22edh	AT2022xas	2022-10-02 05:50:27	309.36226	7.12995	17.40	18.95	0.61	unknown	2022-10-08 09:09:30	2 mag outburst in candidate CV	
Gaia22edg	AT2022xar	2022-08-24 06:48:57	221.06165	-56.24877	17.30	18.46	0.42	unknown	2022-10-08 09:09:20	Outburst in erratic Gaia source	
Gaia22edf	AT2022xaq	2022-10-02 10:54:37	276.57349	-33.62638	14.57	14.95	0.06	unknown	2022-10-08 09:09:13	bright gal.plane source candidate microlensing event or Be-type outburst rises by 0.4 mag	
Gaia22ede	SN2022wbh	2022-10-02 02:06:43	107.38830	24.53159	18.58			SN Ia	2022-10-08 09:09:08	confirmed SN Ia	
Gaia22edd	SN2022vqx	2022-10-02 08:14:44	112.17797	17.25046	17.86			SN Ia-pec	2022-10-08 09:09:02	confirmed SN Ia-pec	
Gaia22edc	AT2022vsw	2022-10-03 02:25:22	116.13491	7.04804	18.85			unknown	2022-10-08 09:08:56	candidate SN near PanSTARRS source	
Gaia22edb	AT2022xap	2022-10-02 16:52:57	274.42710	-34.06443	18.86			unknown	2022-10-08 09:08:49	Apparently hostless transient	
Gaia22eda	AT2022xao	2022-10-02 20:05:06	102.59372	25.04992	16.48	15.20	0.26	unknown	2022-10-08 09:08:41	fading in known blazar QSO B0647+250	

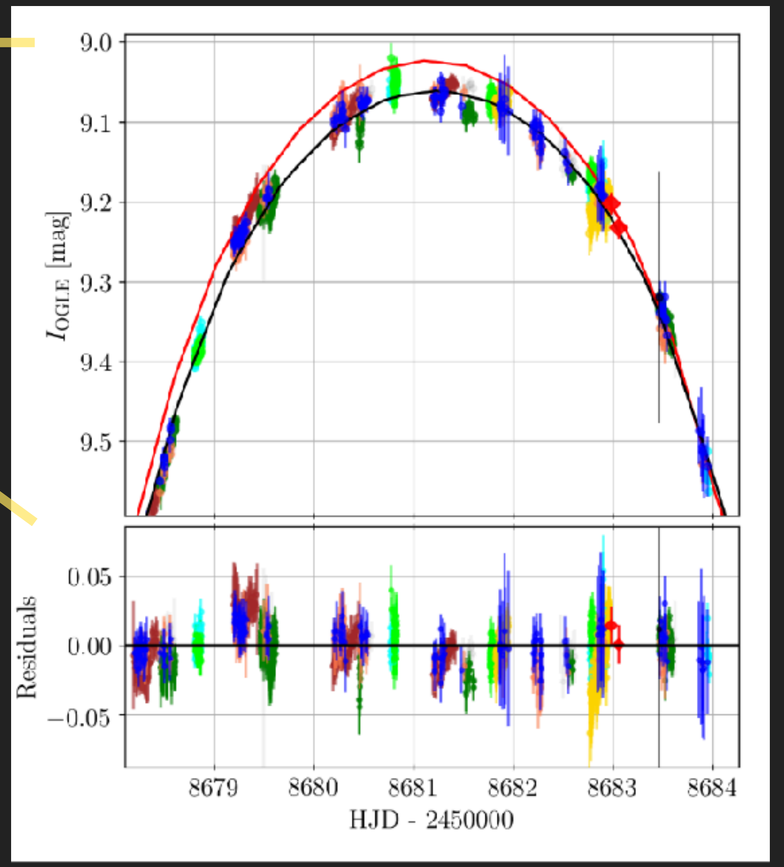
http://gsaweb.ast.cam.ac.uk/alerts/

GAIA19BLD ALERT

- High-magnification microlensing event with ~10,000 observations
- Dark lens identified, mass 1.13 MSun





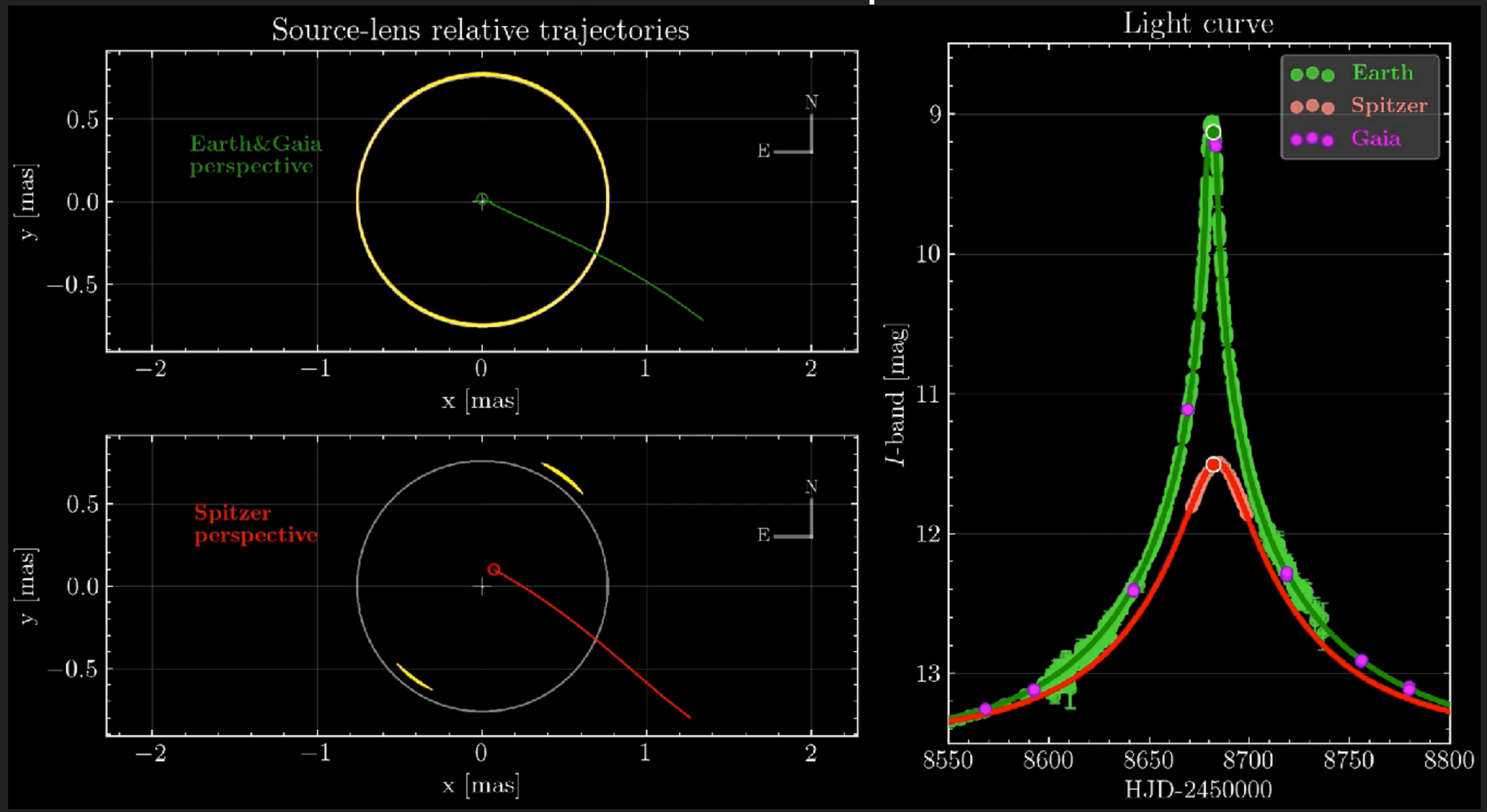


Rybicki et al. 2022
Bachelet et al. 2022
Cassan et al. 2022

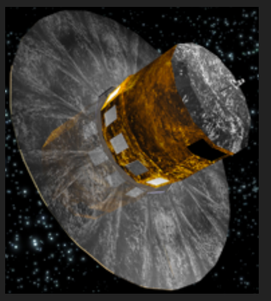
animation by Kris Rybicki

GAIA19BLD ALERT

- observed from Gaia, Earth and Spitzer satellite



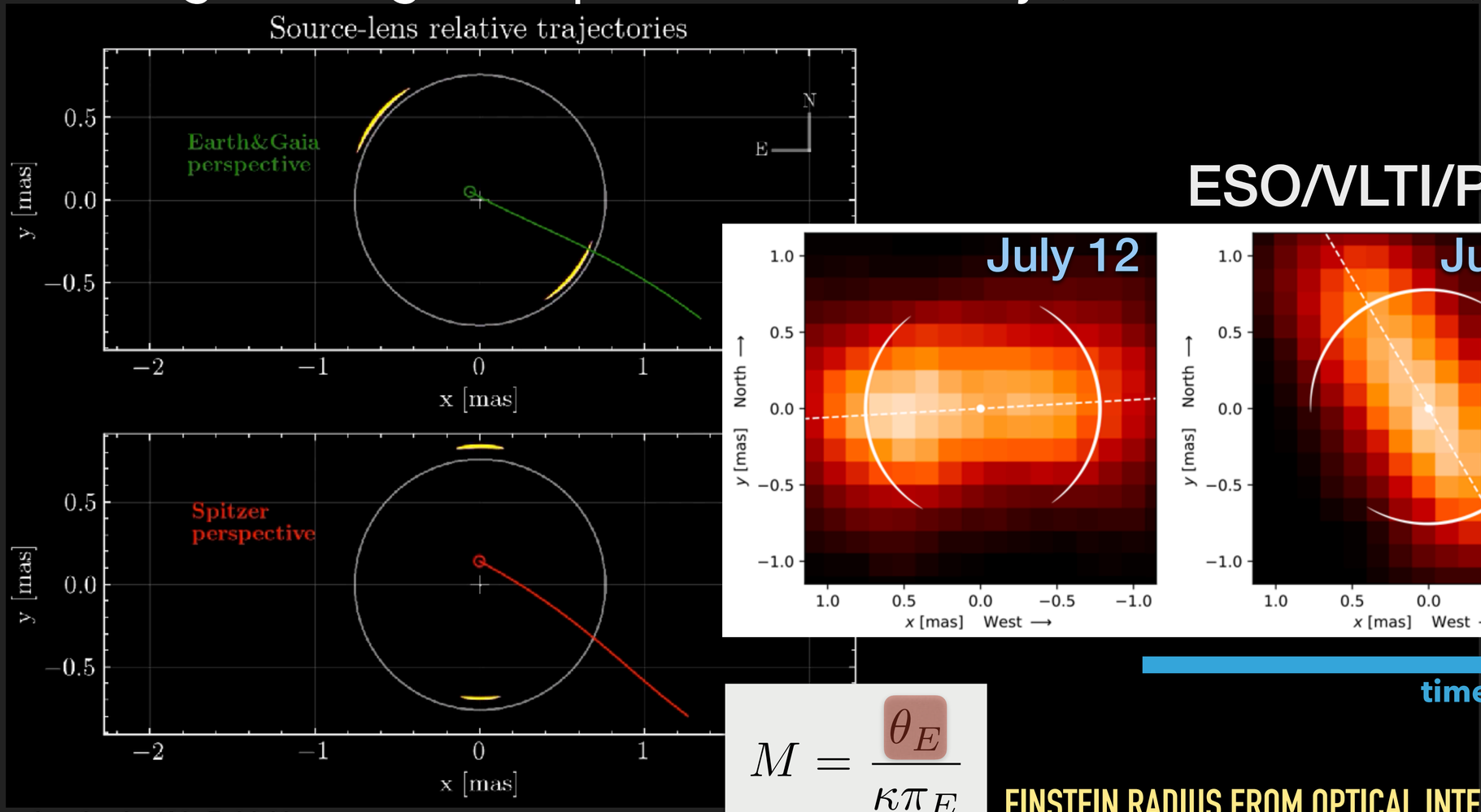
animation by Kris Rybicki



Rybicki et al. 2022
Bachelet et al. 2022
Cassan et al. 2022

GAIA19BLD ALERT

- bright enough for optical interferometry (second case ever)



animation by Kris Rybicki

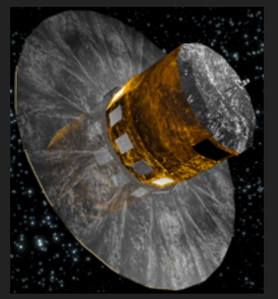
time

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

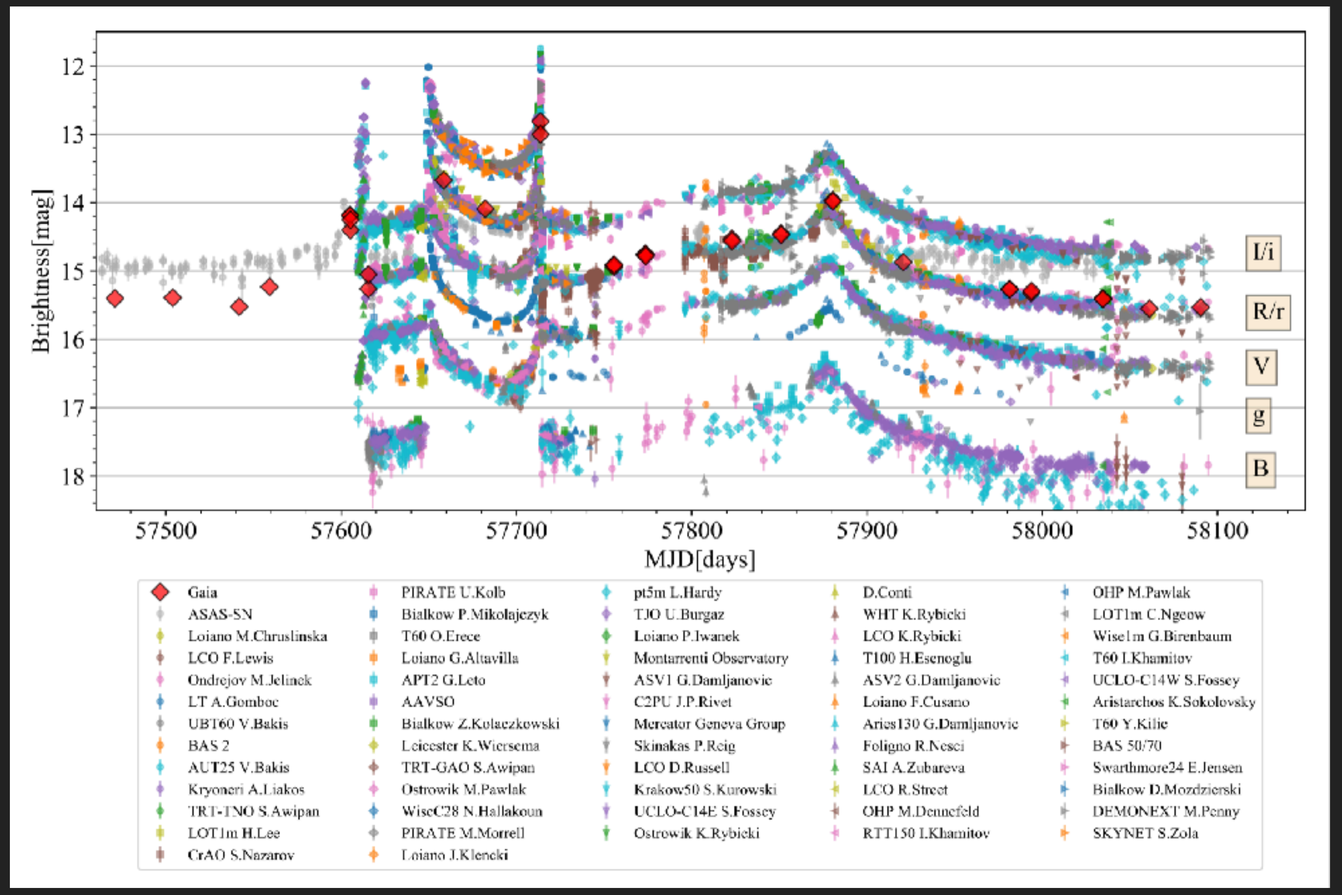
EINSTEIN RADIUS FROM OPTICAL INTERFEROMETRY

Cassan et al. 2022
(Nature Astronomy)

GAIA16AYE ALERT



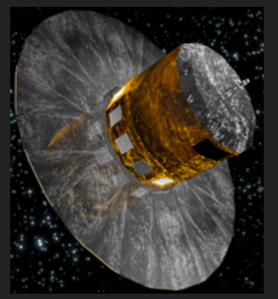
- Gaia16aye – the most complex microlensing event !
- 20,000 ground-based follow-up observations from 51 observatories



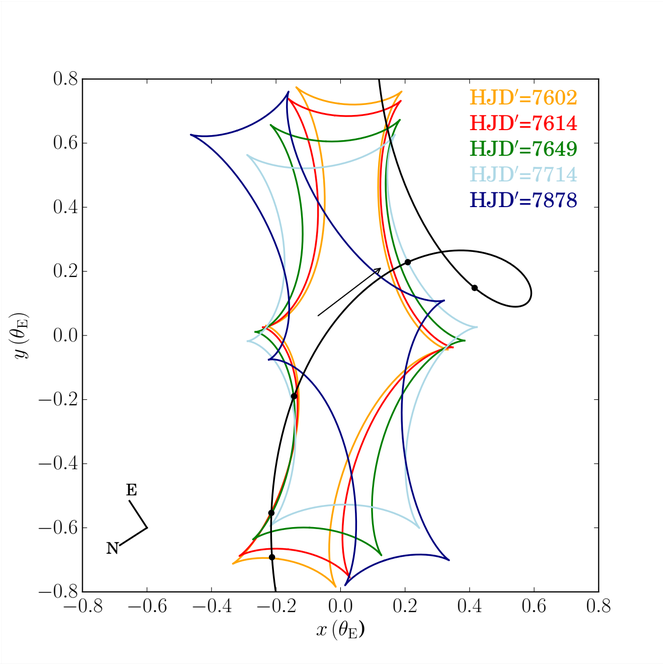
#gaia16aye

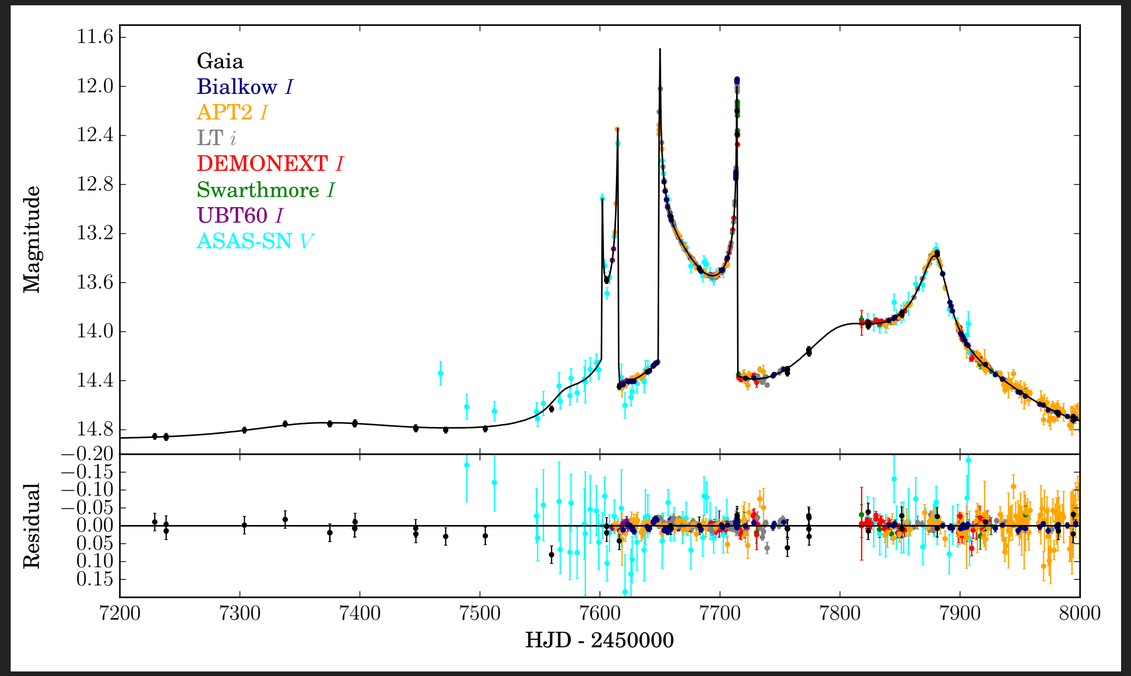
Wyrzykowski et al. 2020

GAIA16AYE ALERT



- Gaia16aye – the most complex microlensing event !
- 20,000 ground-based follow-up observations from 51 observatories
- full-orbital solution found for the invisible MS star binary system (0.6+0.4 MSun) at 800pc



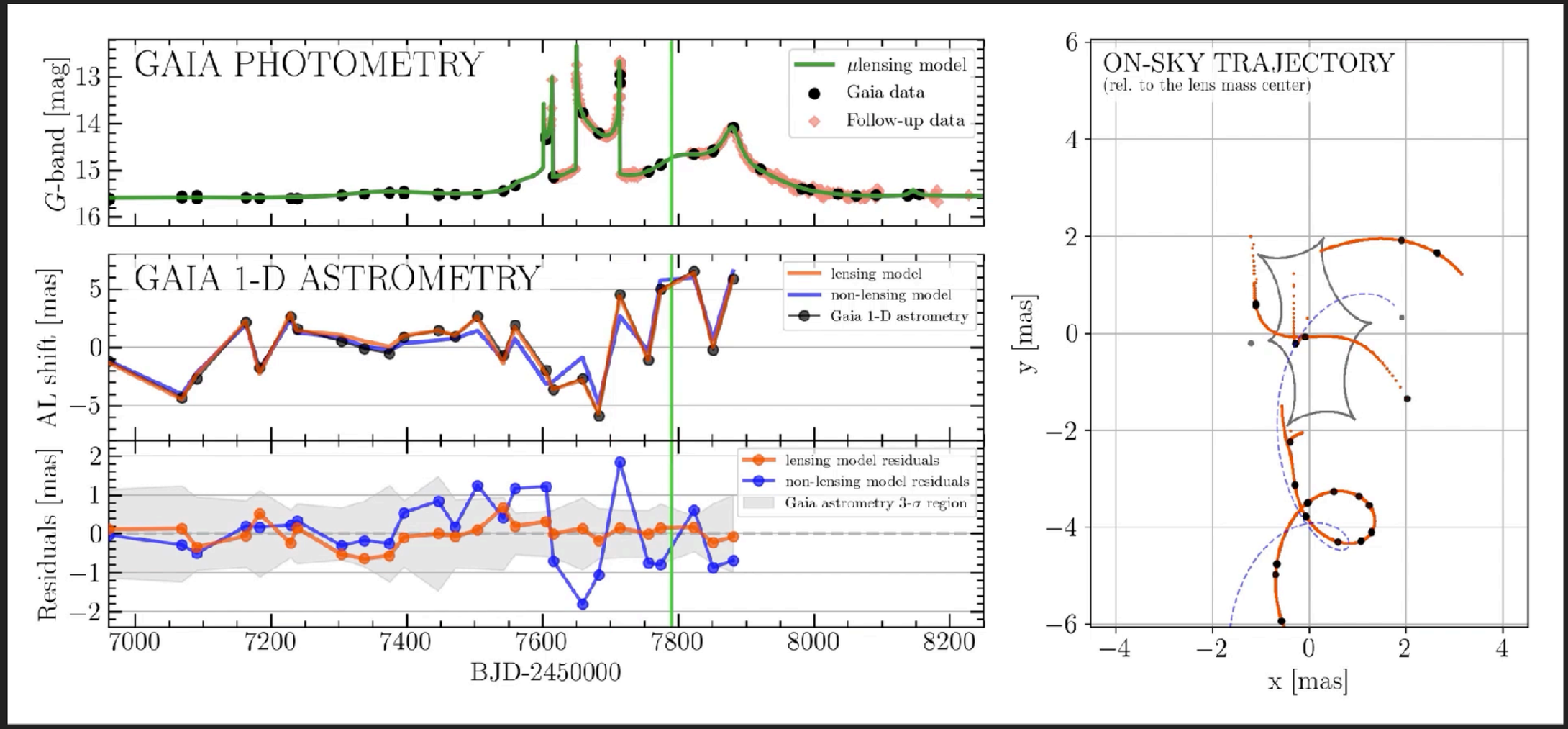


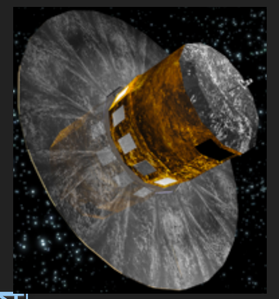
Wyrzykowski et al. 2020

#gaia16aye

GAIA16AYE ALERT

- Gaia astrometric time-domain - new domain to be openned by Gaia in 2025!



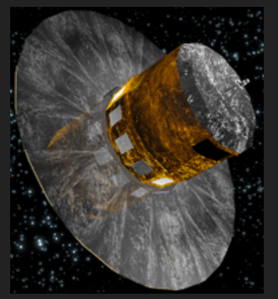


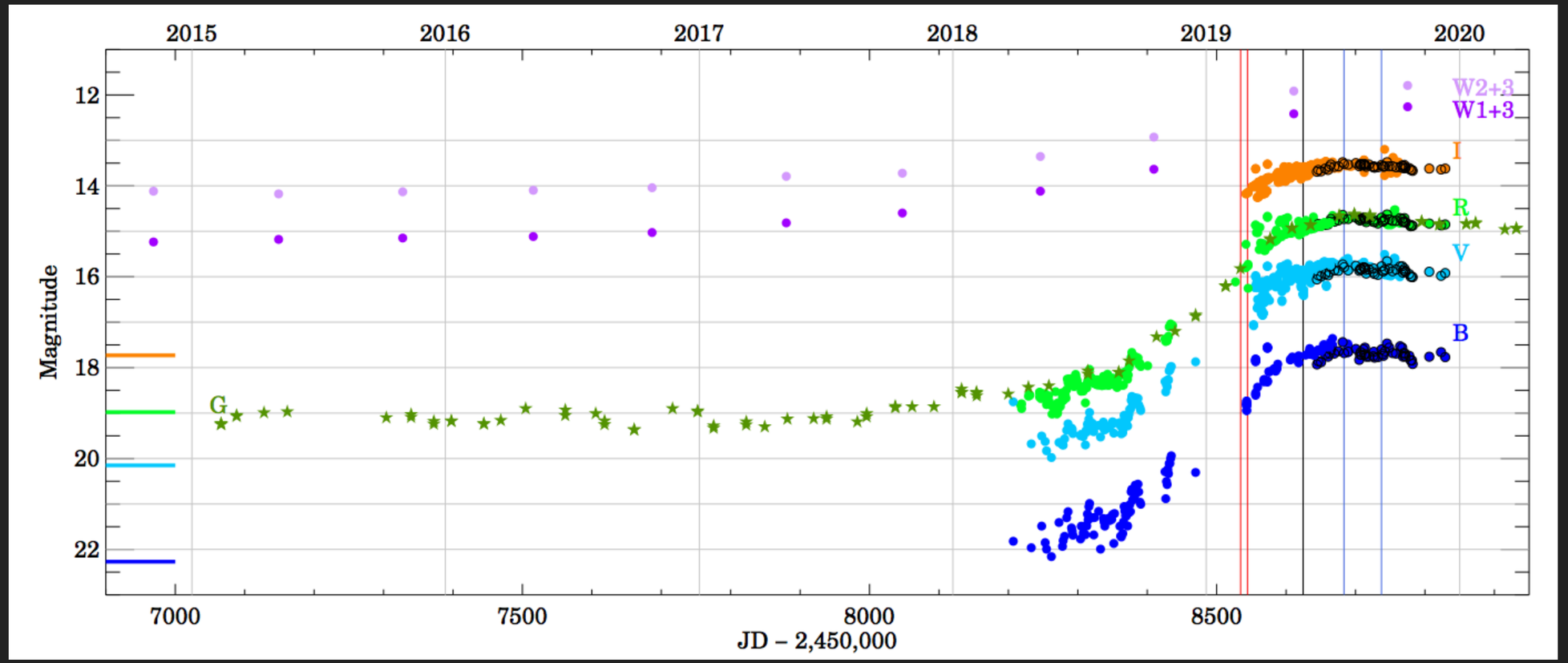
https://www.cosmos.esa.int/web/gaia/iow_20210924

Gaia
Image of the Week
24 Sep.2021

GAIA18DVY ALERT

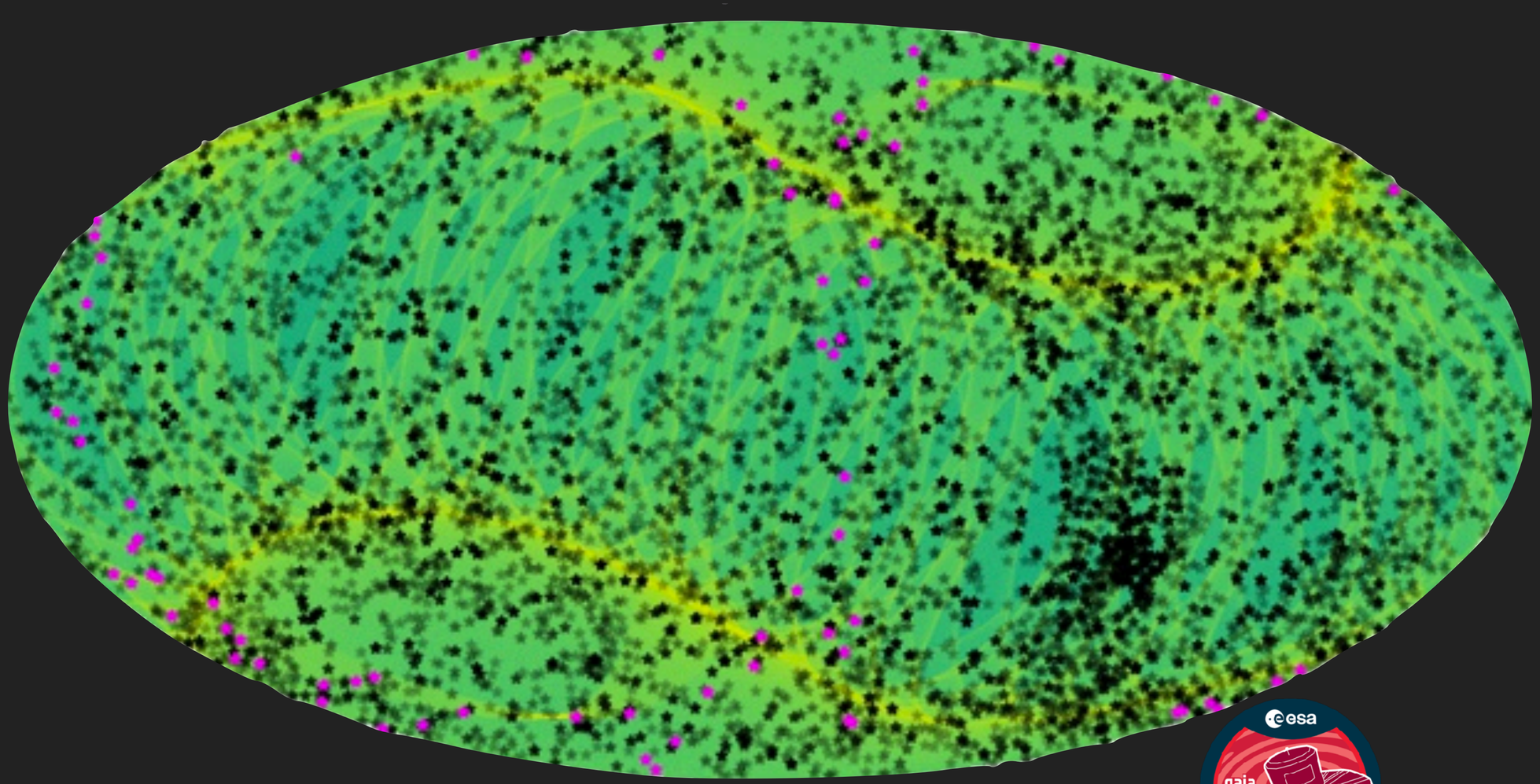
- New example of rare FU Ori young stellar object in outburst
- Optical + Infrared time-series





Szegedi-Elek et al. 2020

THERE IS ALWAYS A TIME-DOMAIN INTERESTING OBJECT VISIBLE ON THE SKY



UNIVERSITY OF CAMBRIDGE

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

esa gaia

PROPERTIES OF AN ULTIMATE EM TIME-DOMAIN INSTRUMENT:

- *All sky (North, South)*
- *Space (no weather problems, unlimited transmission)*
- *(at least) Two observatories separated by 1 AU (avoiding Sun)*
- *Large Field-of-View (many tens square degrees)*
- *High temporal cadence in repeating observations (ms-s-min-hours-weeks-months-years)*
- *Multi-wavelength: radio-optical-ultraviolet-X-gamma*
- *High- and low-resolution spectroscopy (spaxels?)*
- *High-angular resolution for μas/mas astrometry*
- *Polarimetry*

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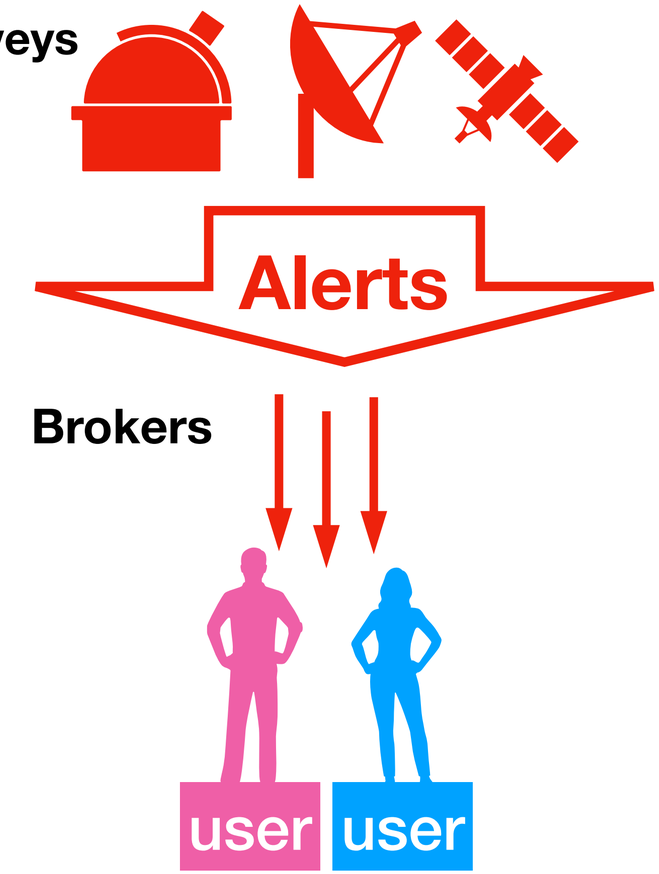
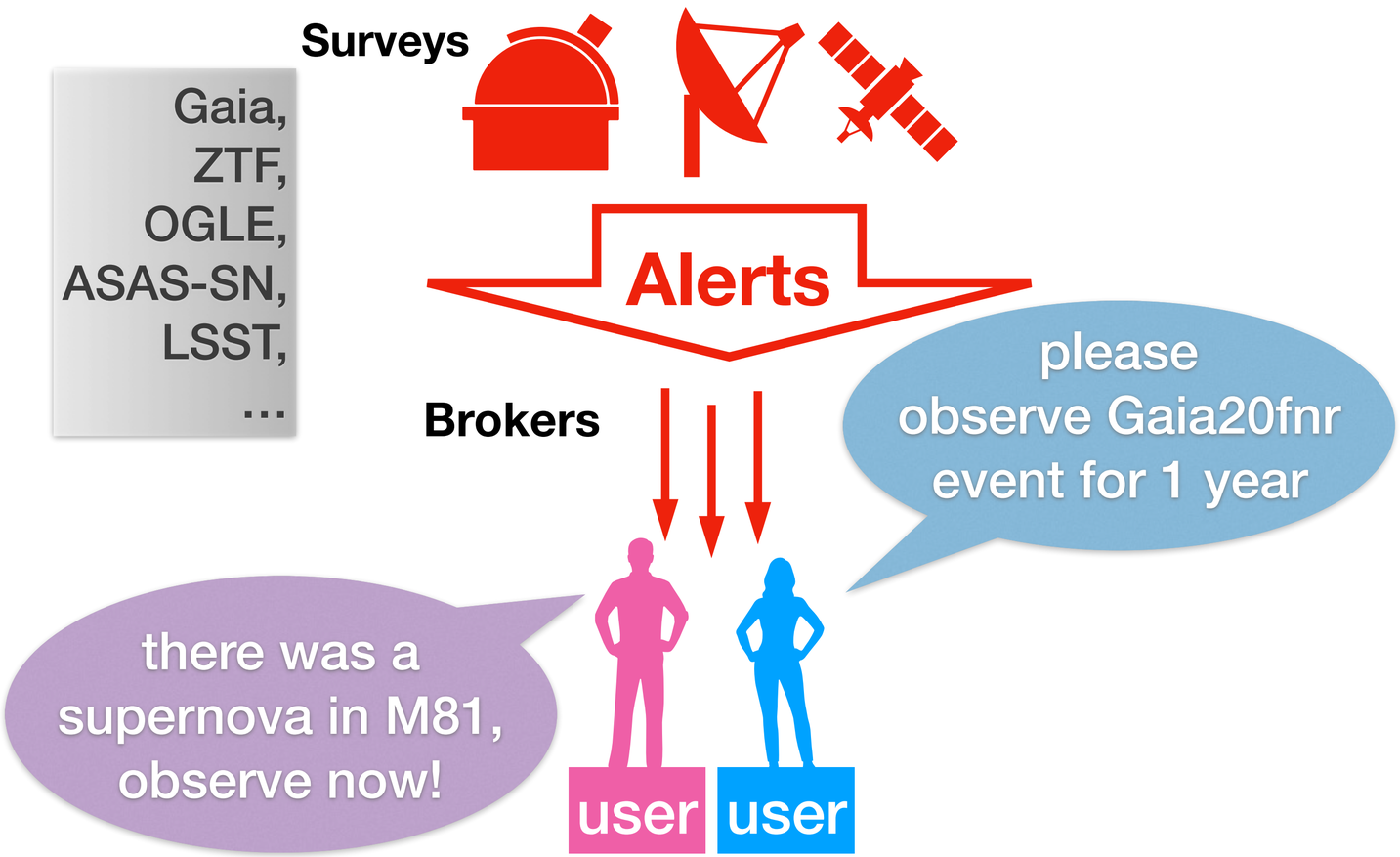
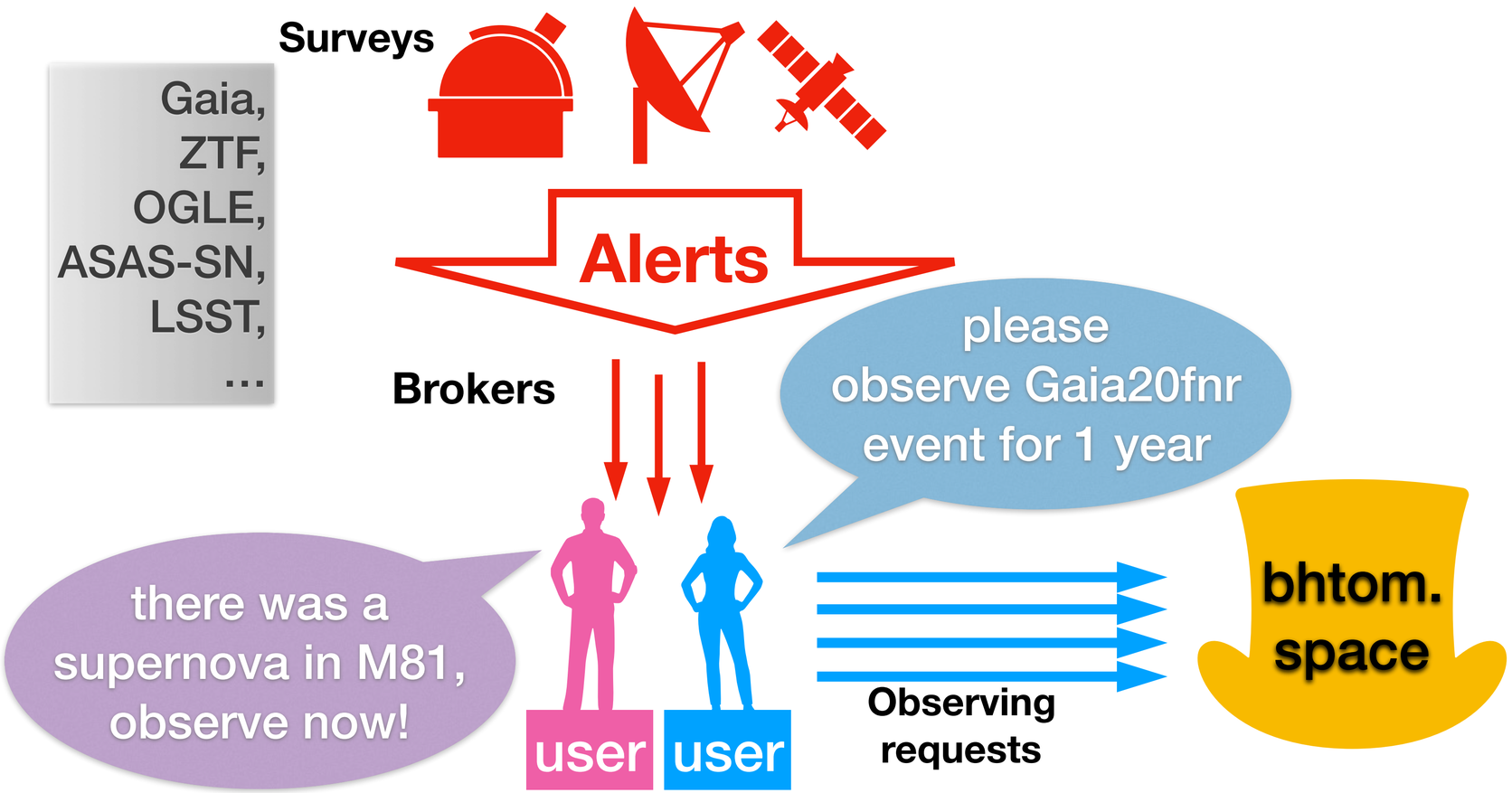
Surveys

Gaia,
ZTF,
OGLE,
ASAS-SN,
LSST,
...

Gaia,
ZTF,
OGLE,
ASAS-SN,
LSST,
…




Surveys
Gaia,
ZTF,
OGLE,
ASAS-SN,
LSST,
…
Alerts
Brokers
please
observe Gaia20fnr
event for 1 year
there was a
supernova in M81,
observe now!
user
user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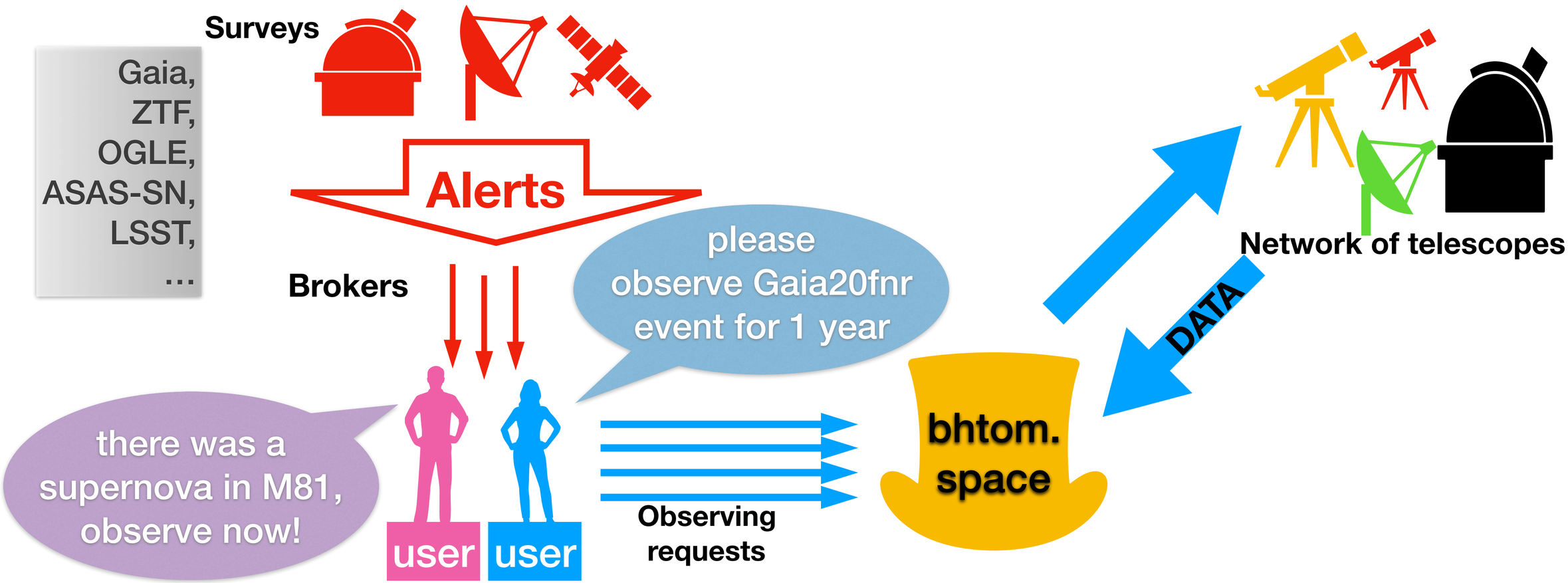
user
user
Observing
requests
bhtom.
space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ZTF,
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LSST,
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user
Observing
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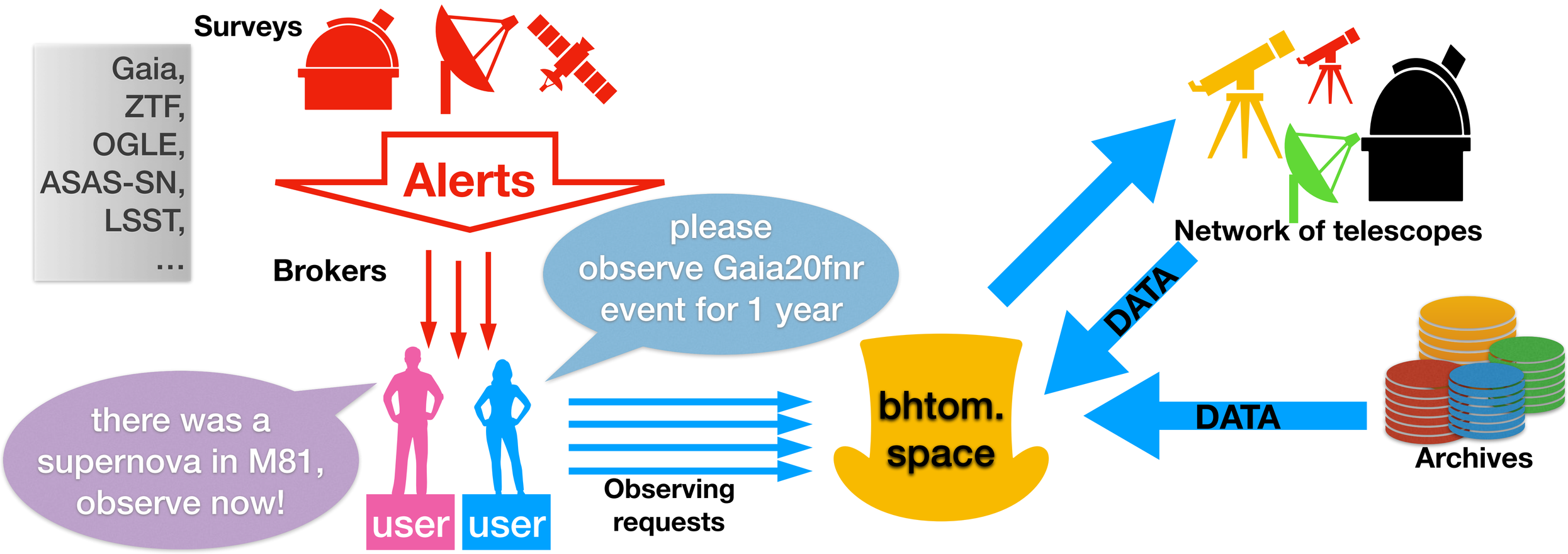
bhtom.
space
DATA
Network of telescopes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space
DATA
Network of telescopes
DATA
Archives

Surveys

Gaia,
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OGLE,
ASAS-SN,
LSST,
…

Alerts

Brokers

please observe Gaia20fnr event for 1 year

there was a supernova in M81, observe now!

user user

Observing requests

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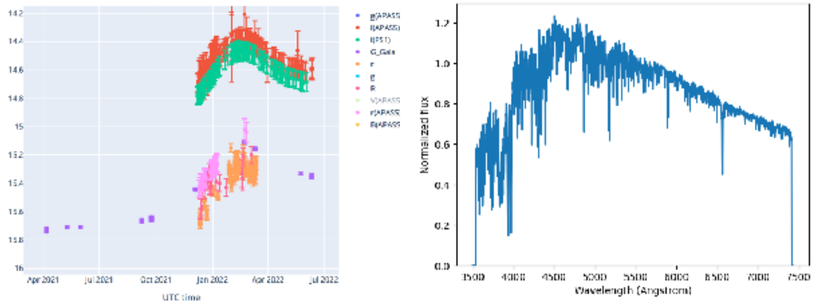
DATA

DATA

Archives



Science-ready data products

Surveys

Gaia,
ZTF,
OGLE,
ASAS-SN,
LSST,
…

Alerts

Brokers

please observe Gaia20fnr event for 1 year

there was a supernova in M81, observe now!

user user

Observing requests

bhtom. space

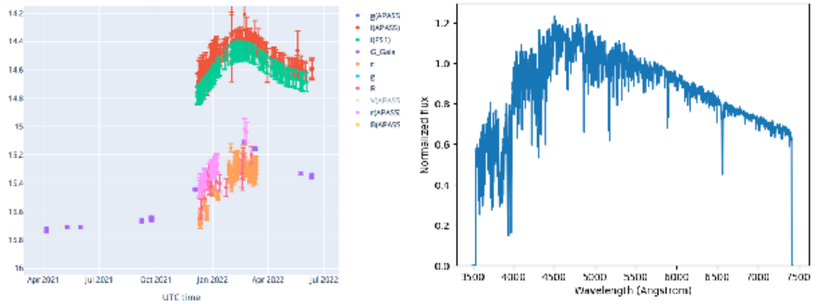
Network of telescopes

DATA

DATA

Archives

publications

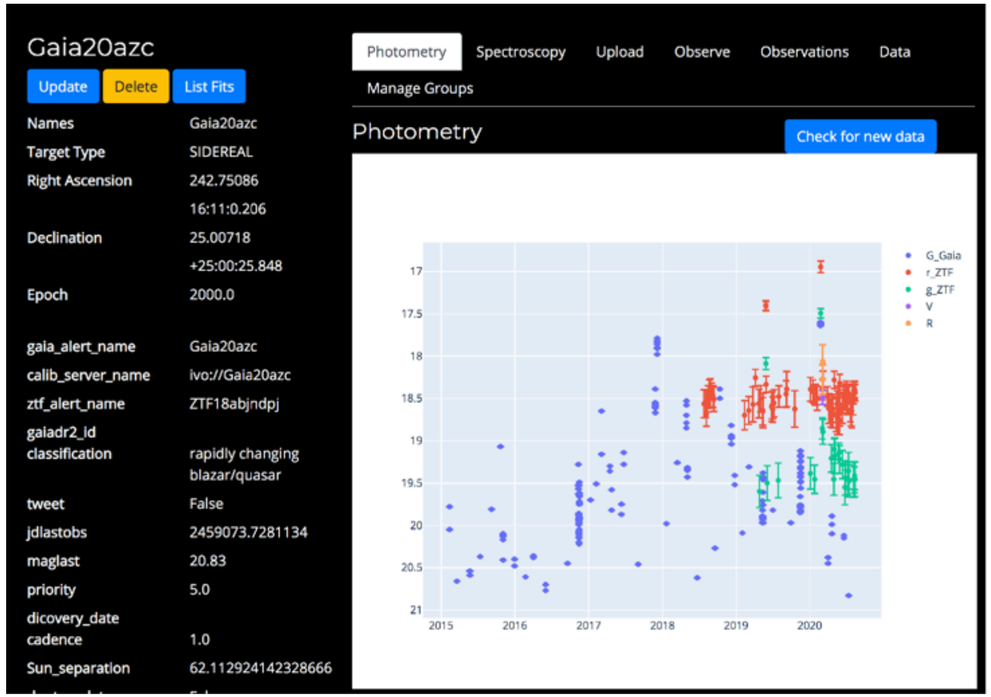


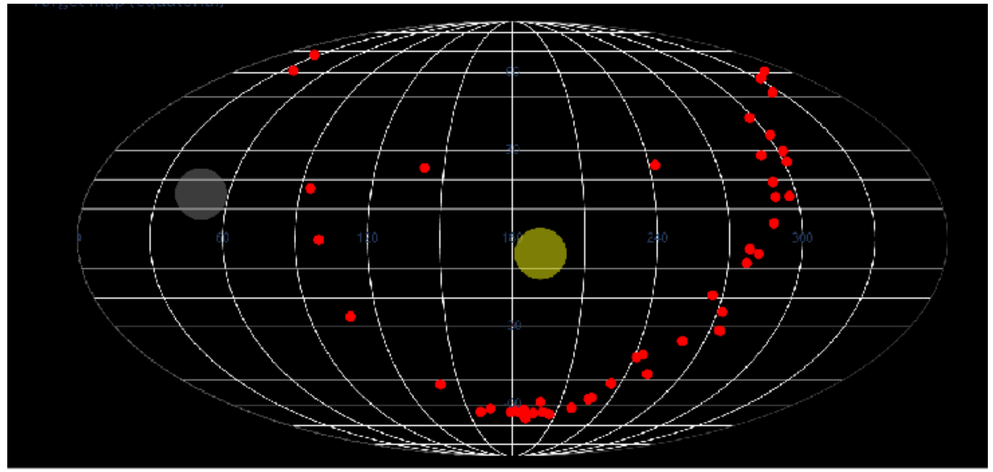
Science-ready data products

OPTICON RadioNet Pilot

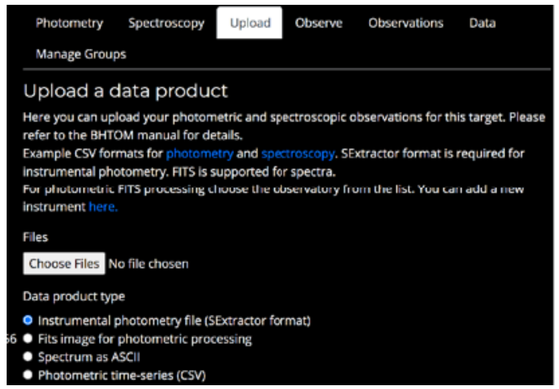
BLACK HOLE TOM

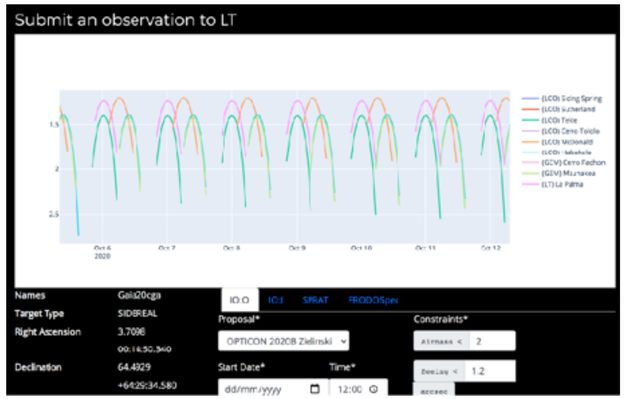
https://bhtom.space





	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	3164	20.13	10.0	29.9	1.0	299.1	64
☐	Gaia20azc	242.75086	25.00718	444	20.83	5.0	34.1	1.0	270.6	62
☐	Gaia20bof	184.61816	-63.49726	10852	15.7	8.0	13.9	0.5	223.0	61
☐	Gaia19dak	302.36516	29.93588	3316	18.98	9.0	24.3	1.0	219.1	115
☐	Gaia20cek	343.03385	60.66898	3333	12.46	10.0	16.1	1.0	160.6	119
☐	Gaia20bgu	205.559	-64.31565	92	16.57	9.0	11.9	1.0	107.4	54
☐	Gaia19cnm	227.93683	-57.0571	5396	18.03	10.0	9.4	1.0	94.3	65





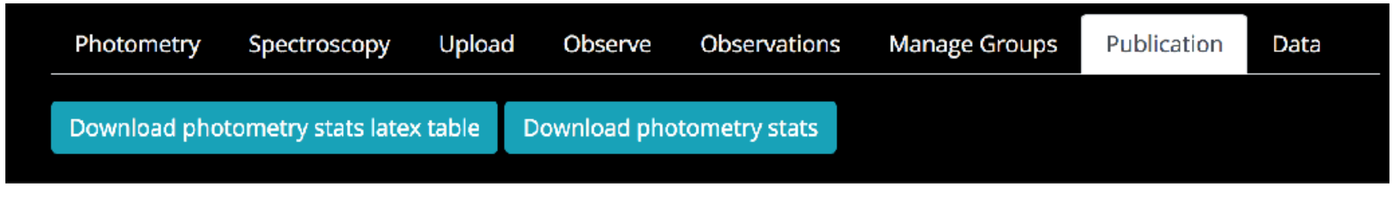
TOM TOOLKIT Las Cumbres Observatory LCO

///AkondLab.

OPTICON RadioNet Pilot

BLACK HOLE TOM

https://bhtom.space



The Astrophysical Journal, 899:130 (8pp), 2020 August 20
https://doi.org/10.3847/1538-4357/aba129

Gaia 18dvy: A New FUor in the Cygnus OB3 Association

E. Szegedi-Elek[1], P. Ábrahám[1,2], Ł. Wyrzykowski[3], M. Kun[1], Á. Kóspál[1,2,4], L. Chen[1], G. Marton[1,2], A. Moór[1,2], C. Kiss[1,2], A. Pál[1,2,5], L. Szabados[1], J. Varga[1,6], E. Varga-Verebélyi[1], C. Andreas[7], E. Bachelet[8], R. Bischoff[7], A. Bódi[1,9], E. Breedt[10], U. Burgaz[11,12], T. Butterley[13], J. M. Carrasco[14], V. Čepas[15], G. Damljanovic[16], I. Gezer[3], V. Godunova[17], M. Gromadzki[3], A. Gurgul[3], L. Hardy[18], F. Hildebrandt[7], S. Hoffmann[7], M. Hundertmark[19], N. Ihanec[3], R. Janulis[15], Cs. Kalup[1], Z. Kaczmarek[3], R. Könyves-Tóth[1], M. Krezinger[1], K. Kruszyńska[3], S. Littlefair[18], M. Maskoliūnas[15], L. Mészáros[1], P. Mikołajczyk[20], M. Mugrauer[7], H. Netzel[21], A. Ordasi[1], E. Pakštienė[15], K. A. Rybicki[3], K. Sárneczky[1], B. Seli[1], A. Simon[22], K. Šiškauskaitė[15], Á. Sódor[1], K. V. Sokolovsky[23,24,25], W. Stenglein[7], R. Street[8], R. Szakáts[1], L. Tomasella[26], Y. Tsapras[19], K. Vida[1,2], J. Zdanav[illegible]

Full orbital solution for the binary system in the northern Galactic disc microlensing event Gaia16aye*

Łukasz Wyrzykowski[1,**], P. Mróz[1], K. A. Rybicki[1], M. Gromadzki[1], Z. Kołaczkowski[45,79,***], M. Zieliński[1], P. Zieliński[1], N. Britavskiy[4,5], A. Gomboc[35], K. Sokolovsky[19,3,66], S.T. Hodgkin[6], L. Abe[89], G.F. Aldi[20,80], A. AlMannaei[62,100], G. Altavilla[72,7], A. Al Qasim[62,100], G.C. Anupama[8], S. Awiphan[9], E. Bachelet[63], V. Bakis[10], S. Baker[100], S. Bartlett[80], P. Bendjoya[11], K. Benson[100], I.F. Bikmaev[76,87], G. Birenbaum[12], N. Blagorodnova[24], S. Blanco-Cuaresma[15,74], S. Boeva[16], A.Z. Bonanos[19], V. Bozza[20,80], D.M. Bramich[62], I. Bruni[25], R.A. Burenin[84,85], U. Burgaz[21], T. Butterley[22], H. E. Caines[34], D. B. Caton[93], S. Calchi Novati[83], J.M. Carrasco[23], A. Cassan[29], V. Čepas[56], M. Cropper[100], M. Chruślińska[1,24], G. Clementini[25], A. Clerici[35], D. Conti[91], M. Conti[48], S. Cross[63], F. Cusano[25], G. Damljanovic[26], A. Dapergolas[19], G. D'Ago[80], J. H. J. de Bruijne[27], M. Dennefeld[29], V. S. Dhillon[30,4], M. Dominik[31], J. Dziedzic[1], O. Erece[32], M. V. Eselevich[86], H. Esenoglu[33], L. Eyer[74], R. Figuera Jaimes[31,53], S. J. Fossey[34], A. I. Galeev[76,87], S. A. Grebenev[84], A. C. Gupta[99], A. G. Gutaev[76], N. Hallakoun[12], A. Hamanowicz[1,36], C. Han[2], B. Handzlik[37], J. B. Haislip[94], L. Hanlon[102], L. K. Hardy[30], D. L. Harrison[6,88], H.J. van Heerden[103], V. L. Hoette[95], K. Horne[31], R. Hudec[39,76,40], M. Hundertmark[41], N. Ihanec[35], E. N. Irtuganov[76,87], R. Itoh[42], P. Iwanek[1], M.D.Jovanovic[26], R. Janulis[55], M. Jelínek[39], E. Jensen[92], Z. Kaczmarek[1], D. Katz[101], I.M. Khamitov[44,76], Y.Kilic[32], J. Klencki[1,24], U. Kolb[47], G. Kopacki[45], V. V. Kouprianov[94], K. Kruszyńska[1], S. Kurowski[37], G. Latev[16], C-H. Lee[17,18], S. Leonini[48], G. Leto[49], F. Lewis[50,59], Z. Li[63], A. Liakos[13], S. P. Littlefair[30], J. Lu[51], C.J. Manser[52], S. Mao[53], D. Maoz[12], A.Martin-Carrillo[102], J. P. Marais[103], M. Maskoliūnas[56], J. R. Maund[30], P. J. Meintjes[103], S. S. Melnikov[76,87], K. Ment[31], P. Mikołajczyk[45], M. Morrell[42], N. Mowlavi[74], D. Moździerski[45], D. Murphy[102], S. Nazarov[90], H. Netzel[1,79], R. Nesci[67], C.-C. Ngeow[51], A. J. Norton[42], E. O. Ofek[55], E. Pakštienė[56], L. Palaversa[6,74], A. Pandey[99], E. [illegible] Penprase[58], A. Piascik[59], J. L. Prieto[96,97], J. K. T. Qvam[98], C. [illegible], P. Reig[61,75], L. Rhodes[30], J.-P. Rivet[89], G. Rixon[6], D. Roberts[47], [illegible] Scarpetta[20,82], G. Seabroke[100], B. J. Shappee[69], R. Schmidt[41], Y. [illegible]vska[1,77,79], C. Snodgrass[46], P. S. Soares[34], B. van Soelen[103], Z. T. [illegible]. Street[63], J. Strobl[39], E. Strubble[95], H. Szegedi[103], L. M. Tinjaca [illegible], S. Villanueva Jr.[57], O. Vince[26], J. Wambsganss[41,42], I. P. van der [illegible]. Wilson[22], A. Yoldas[6], R.Ya. Zhuchkov[76,87], D. G. Zhukov[76], J. Zola[37,38], and A. Zubareva[73,3]

Single lens mass measurement in the high magnification microlensing event Gaia19bld located in the Galactic Disk

K. A. Rybicki,*[1] Ł. Wyrzykowski,[1] E. Bachelet,[2] A. Cassan,[3] P. Zieliński,[1] A. Gould,[4,5] S. Calchi Novati,[6] J.C. Yee,[7] Y.-H. Ryu,[8] M. Gromadzki,[1] P. Mikołajczyk,[9] N. Ihanec,[1] K. Kruszyńska,[1] F.-J. Hambsch,[10,11] S. Zola,[12] S. J. Fossey,[13] S. Awiphan,[14] N. Nakharutai,[15] F. Lewis,[16,17] F. Olivares E.,[18] S. Hodgkin,[19] A. Delgado,[19] E. Breedt,[19] D. L. Harrison.[19,20] M. van Leeuwen,[19] G. Rixon,[19] T. Wevers,[19] A. Yoldas,[19] A. Udalski,[1] M. K. Szymański,[1] I. [illegible]icz,[1] S. Kozłowski,[1] J. Skowron,[1] R. Poleski,[1] K. Ulaczyk,[21,1] P. Mróz,[1,22] P. Iwanek,[1] M. [illegible] Tsapras,[23] M. Hundertmark,[23] M. Dominik,[24] C. Beichman,[6] G. Bryden,[6] S. Carey,[6] B.S. [illegible],[5] Y. Shvartzvald,[25] W. Zang,[26] W. Zhu,[27] G.W. Christie,[28] J. Green,[29] S. Hennerley,[29] J. [illegible]nard,[31] T. Natusch,[28,32] R.W. Pogge,[5] I. Gezer,[1] A. Gurgul,[1] Z. Kaczmarek,[1] M. C. Lam,[1,17] [illegible]liunas,[33] E. Pakstiene,[33] A. Stankeviciute,[1] J. Zdanavicius,[33] O. Ziółkowska[1]

SN 2018zd: An Unusual Stellar Explosion as Part of the Diverse Type II Supernova Landscape

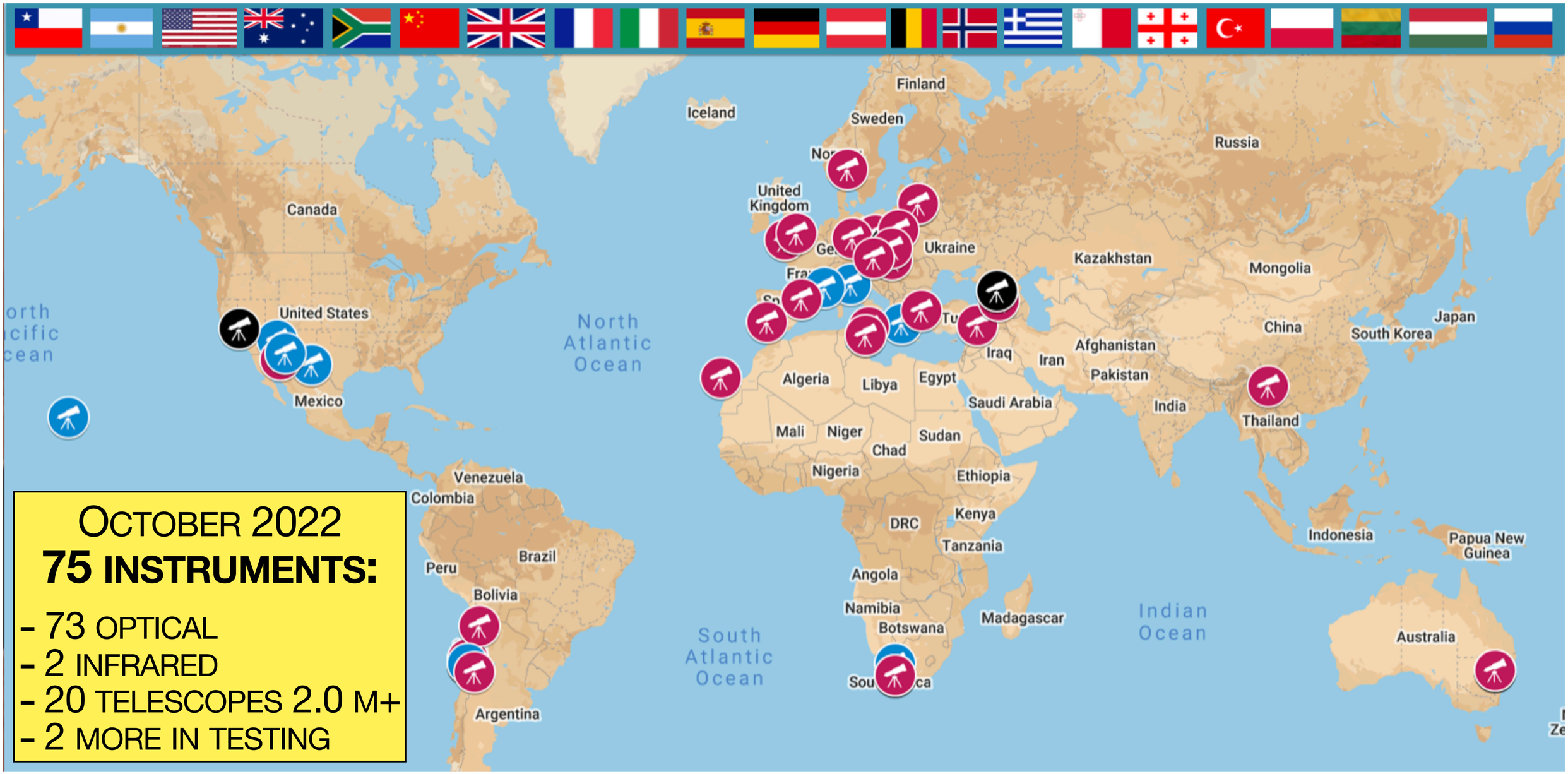
Jujia Zhang,[1,2,3,4★] Xiaofeng Wang,[5,6] József Vinkó[7,8,9] Qian Zhai,[1,2,3,4] Tianmeng Zhang,[10] Alexei V. Filippenko,[12,13] Thomas G. Brink,[12] WeiKang Zheng,[12] Łukasz Wyrzykowski,[14] Przemysław Mikołajczyk,[14] Fang Huang,[15] Liming Rui,[5] Jun Mo,[5] Hanna Sai,[5] Xinhan Zhang,[5] Huijuan Wang,[10,11] James M. DerKacy,[16] Eddie Baron,[16] K. Sárneczky,[7] A. Bódi,[7,18] G. Csörnyei,[7,8] O. Hanyecz,[7] B. Ignácz,[7] Cs. Kalup,[7,8,18] L. Kriskovics,[7,8] R. Könyves-Tóth,[7,8] A. Ordasi,[7] A. Pál,[7,8,17] Á. Sódor,[7,18] R. Szakáts,[7] K. Vida,[7,8,18] G. Zsidi[7,8,19]

OPTICON RadioNet Pilot

BLACK HOLE TOM – OPPORTUNITIES

https://bhtom.space

- for scientists:
  - virtual tool for long-term monitoring, 24h coverage
  - global telescope
  - we will observe your target and help write your paper!
- for telescopes:
  - we will tell you which target is of interest for observing
  - we will process your data
  - we can operate your robotic telescope!



OCTOBER 2022

75 INSTRUMENTS:

- 73 OPTICAL
- 2 INFRARED
- 20 TELESCOPES 2.0 M+
- 2 MORE IN TESTING

OPTICON RadioNet Pilot

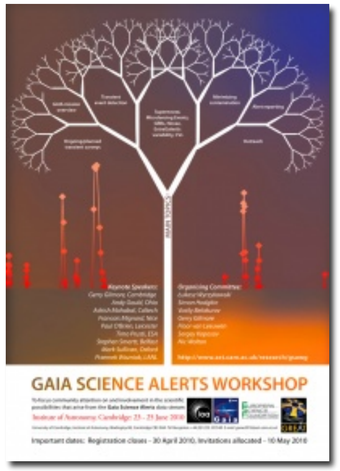
BLACK HOLE TOM – PLANS:

https://bhtom.space

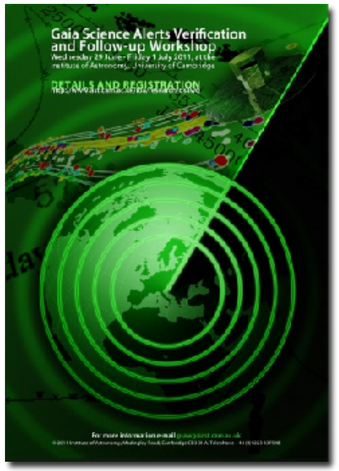
- expand the network with new telescopes
- connect radio telescopes
- automated observation requests
- more data processing tools (model fitting, etc)
- automated connection to alerts stream (already build-in)
- spectroscopic data processing
- expand the use of the archival data
- multi-wavelength (radio+optical) time-domain observations, e.g. quasar monitoring, transients

WORKSHOPS SINCE 2010

2010-Cambridge



2011-Cambridge



2012-Bologna

2013-Paris

2014-Warsaw

2015-Liverpool

2016-Utrecht

2017-Warsaw

2018-Vipava

2019-Catania

2020 - on-line

2021 - Crete

2022 - Sardinia

2023 - ???

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

Łukasz Wyrzykowski

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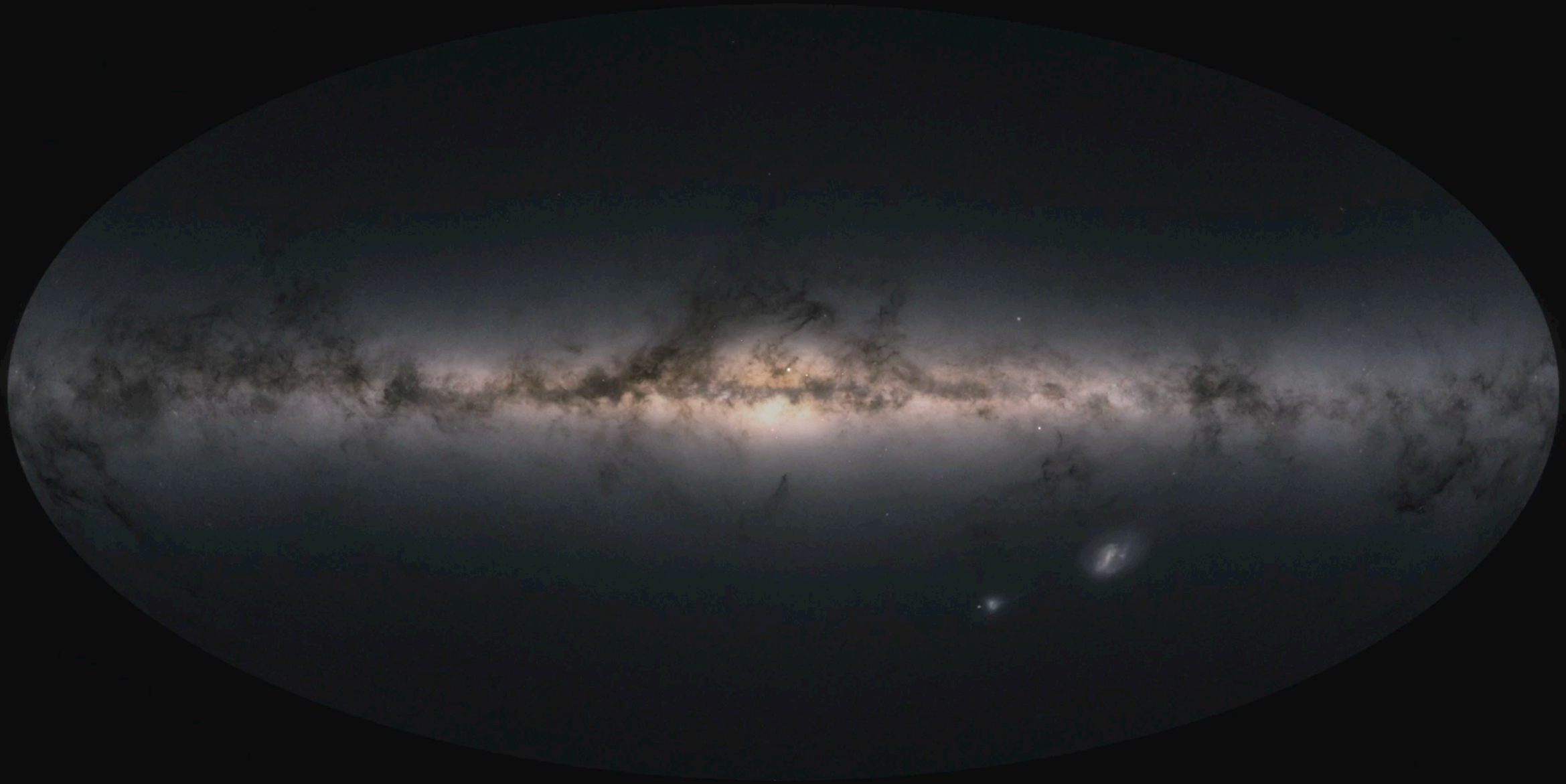
MICROLENSING EVENTS IN GAIA DR3 (2014–2018)



2014.1

https://youtu.be/o17MoMTbwy0

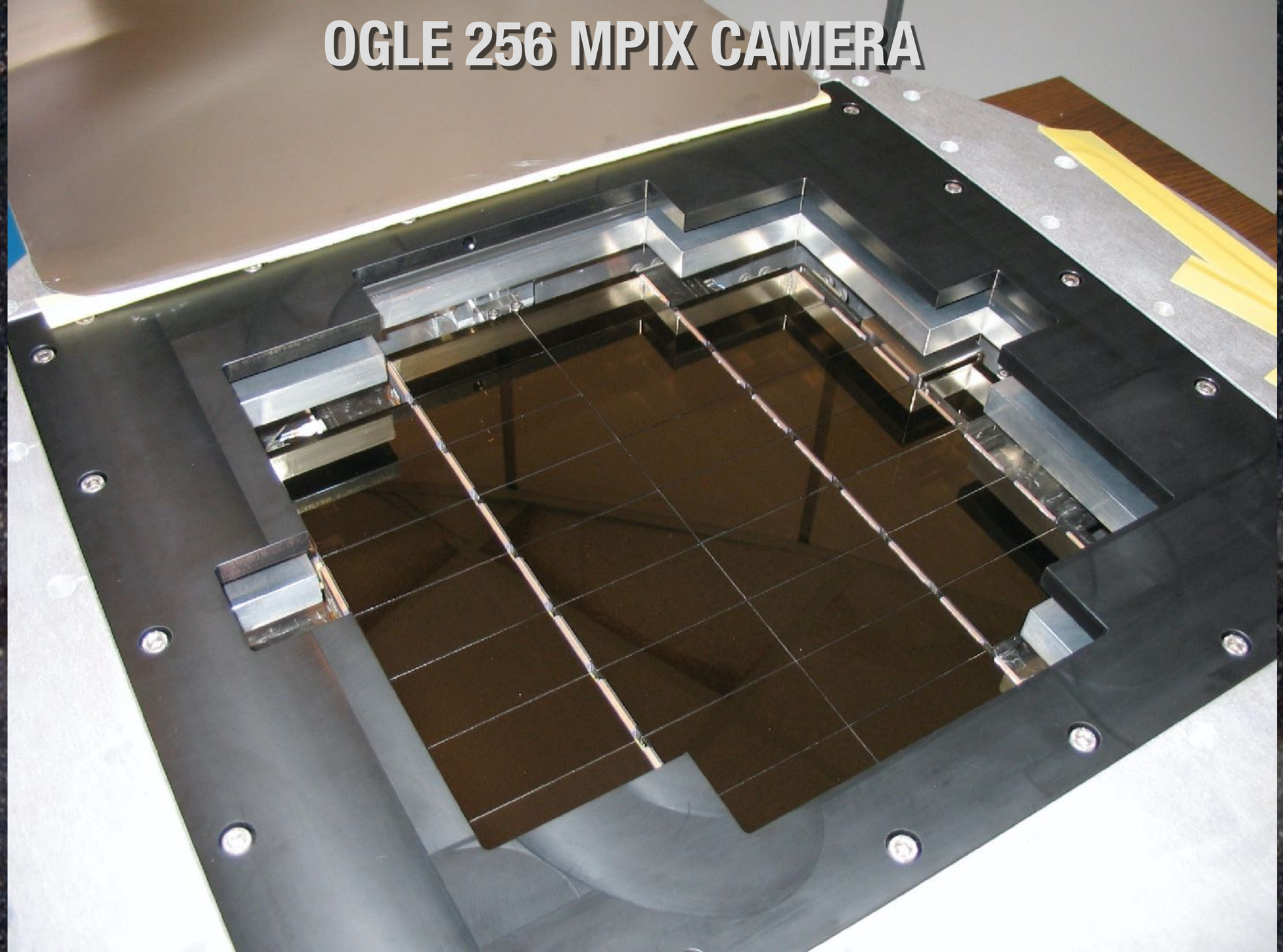
Maja Jabłońska, Andrzej Krupka, LW

extra slides

OPTICAL GRAVITATIONAL LENSING EXPERIMENT
SINCE 1992

Łukasz Wyrzykowski

OGLE 256 MPIX CAMERA



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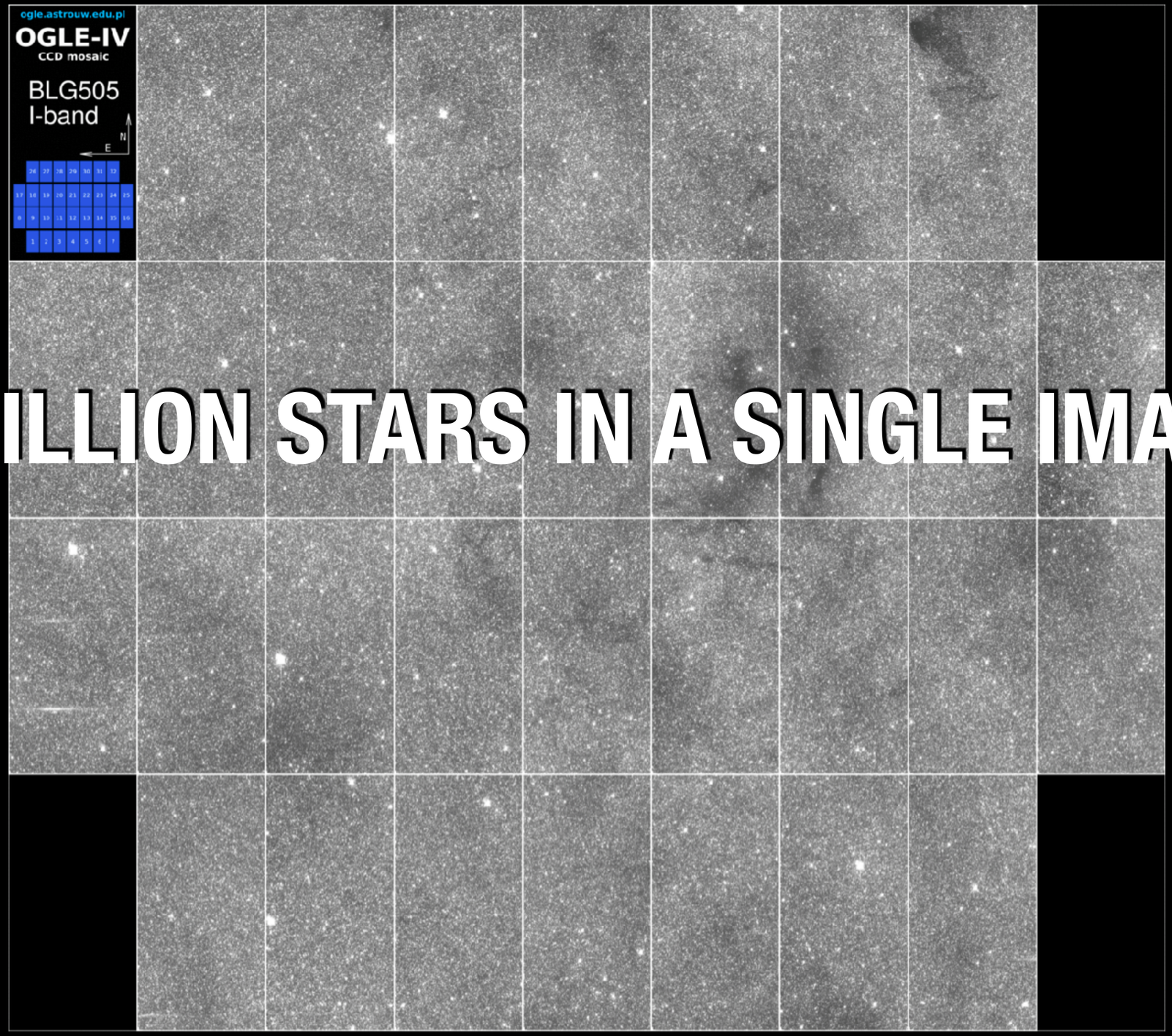
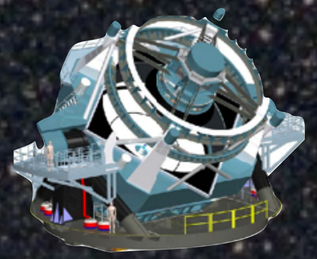
OGLE 256 MPIX CAMERA
= 21 X IPHONE 11

Łukasz Wyrzykowski

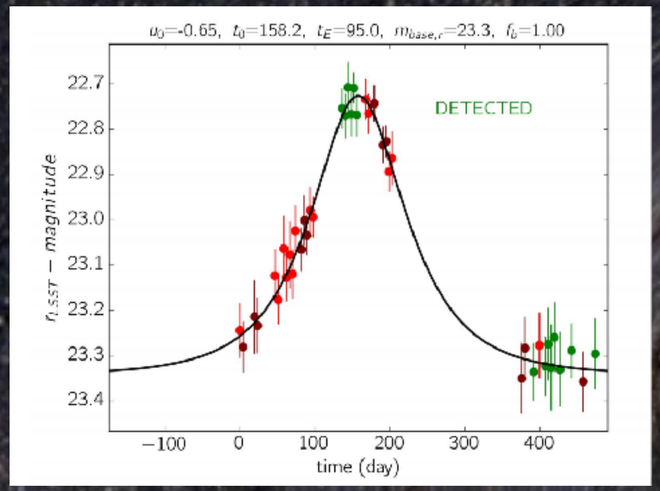


5 MILLION STARS IN A SINGLE IMAGE!



VERA RUBIN OBSERVATORY/LSST

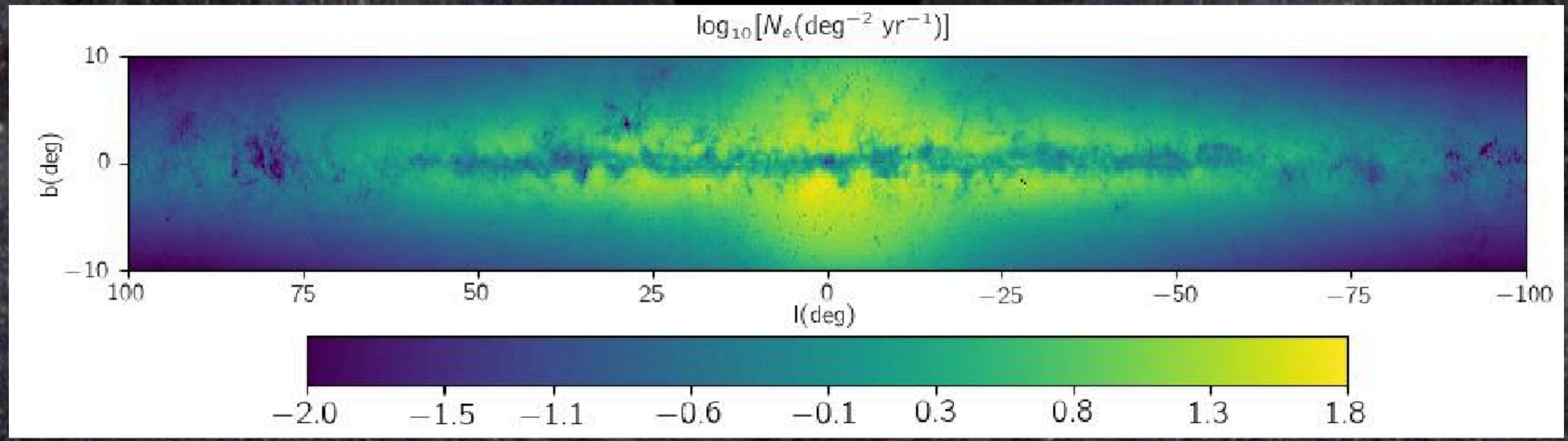
$$M = \frac{\theta_E}{\kappa \pi_E}$$



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

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

number of events per year per sq.deg.



Street+2018, arxiv:1812.03127

Sajadian&Poleski 2019

Łukasz Wyrzykowski

GAIA VARI

esa

Citizen science project by the European Space Agency supporting Gaia Variable stars classification

- → Building community around ESA's Gaia mission through science engagement
- → Engaging citizens in classification of the time-series dataset for interesting variable star cases
- → Possibility of co-authorship of scientific publications (Data Release 4)
- → Collaboration with Zooniverse – the biggest platform for citizen science projects
- → Gamification strengthening of the engagement of general public
- → Inviting open community to discussion and knowledge sharing
- → Attractive storytelling through appealing graphics and illustrations
- → New social media channels

sednai

science now.

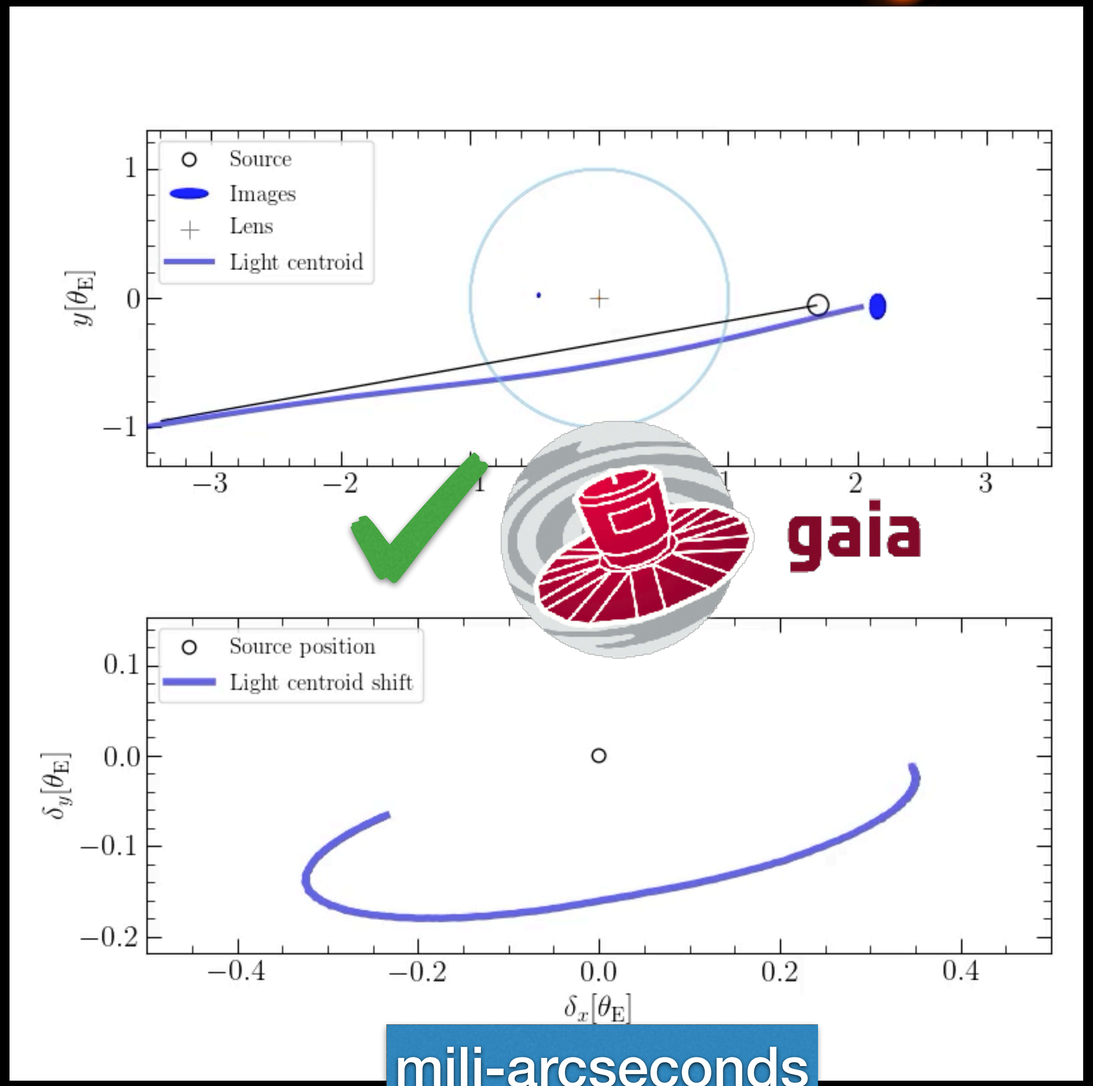
More to come! Stay tuned!

www.gaiavari.space

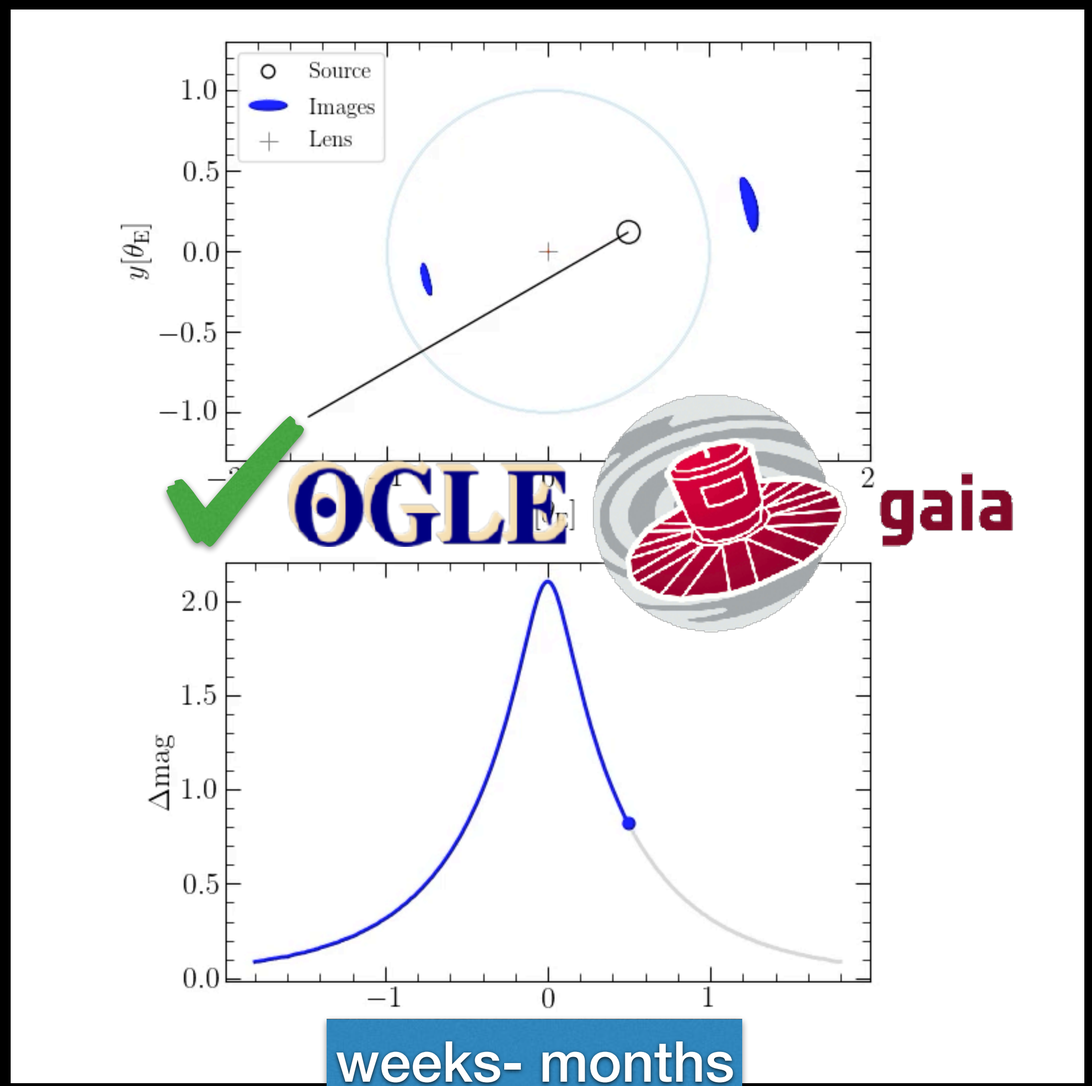
MICROLENSING BLACK HOLES

shift

brightening



mili-arcseconds



weeks- months