DARK MATTER AND BLACK HOLES FROM MICROLENSING IN OGLE, GAIA AND LSST

Łukasz Wyrzykowski

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

Warsaw University Astronomical Observatory, Poland

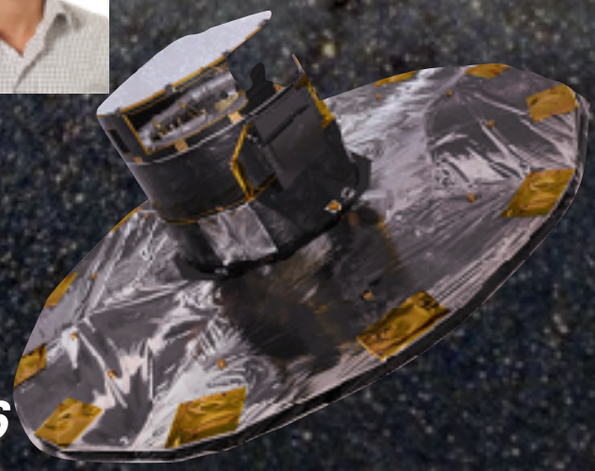
LCO (Goleta, CA) September - December 2019

with

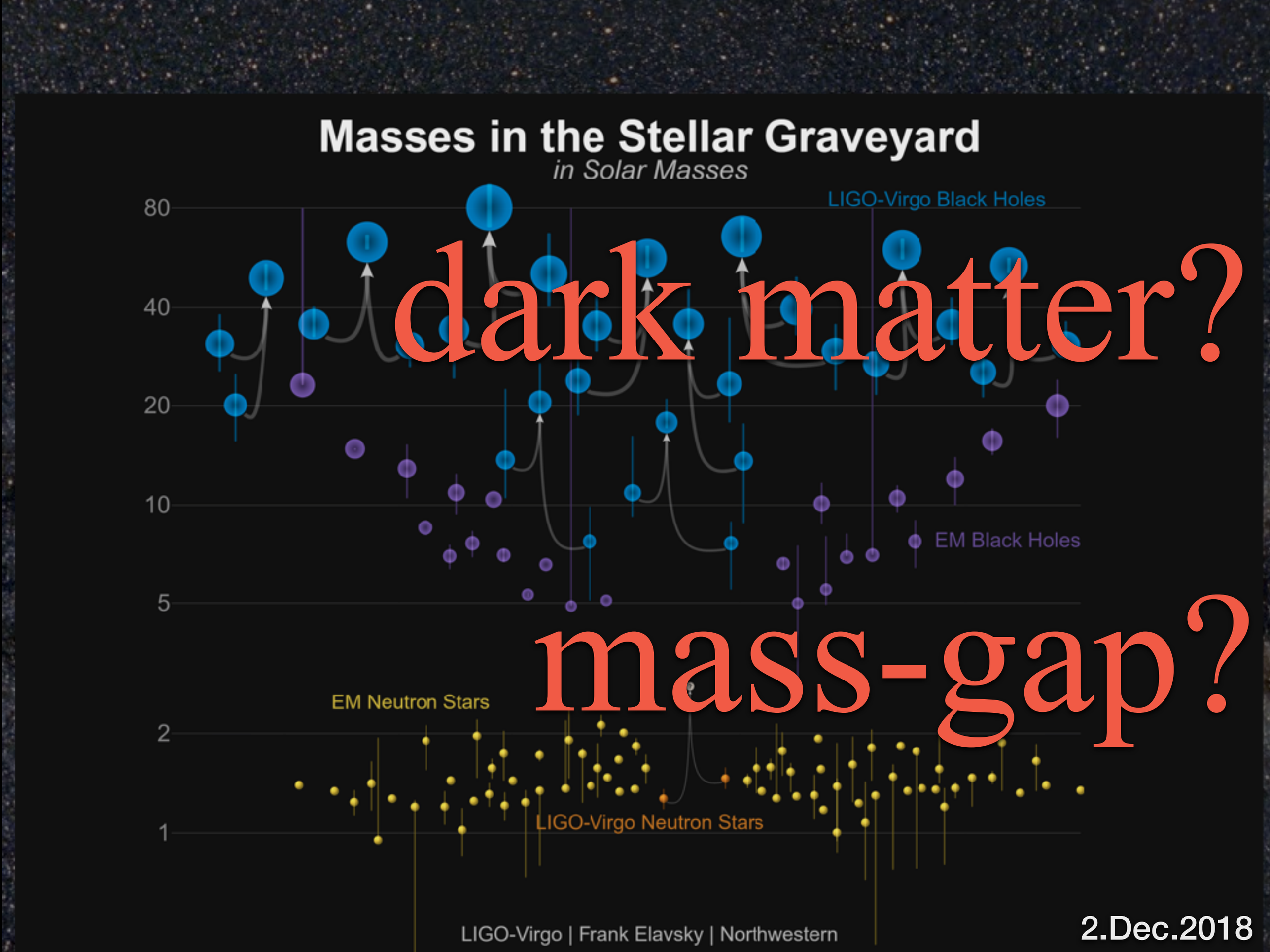
Katarzyna Kruszyńska, Kris A. Rybicki

Large Synoptic Survey Telescope

Polish Consortium



LSST Dark Matter Workshop, KICP Chicago 2019 Aug 6


Masses in the Stellar Graveyard
in Solar Masses
80
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2
1
LIGO-Virgo Black Holes
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars
LIGO-Virgo | Frank Elavsky | Northwestern
dark matter?
mass-gap?
2.Dec.2018

HOW TO FIND DARK MATTER?

Massive Astrophysical Compact Halo Objects

Mon. Not. R. astr. Soc. (1971) **152**, 75–78.

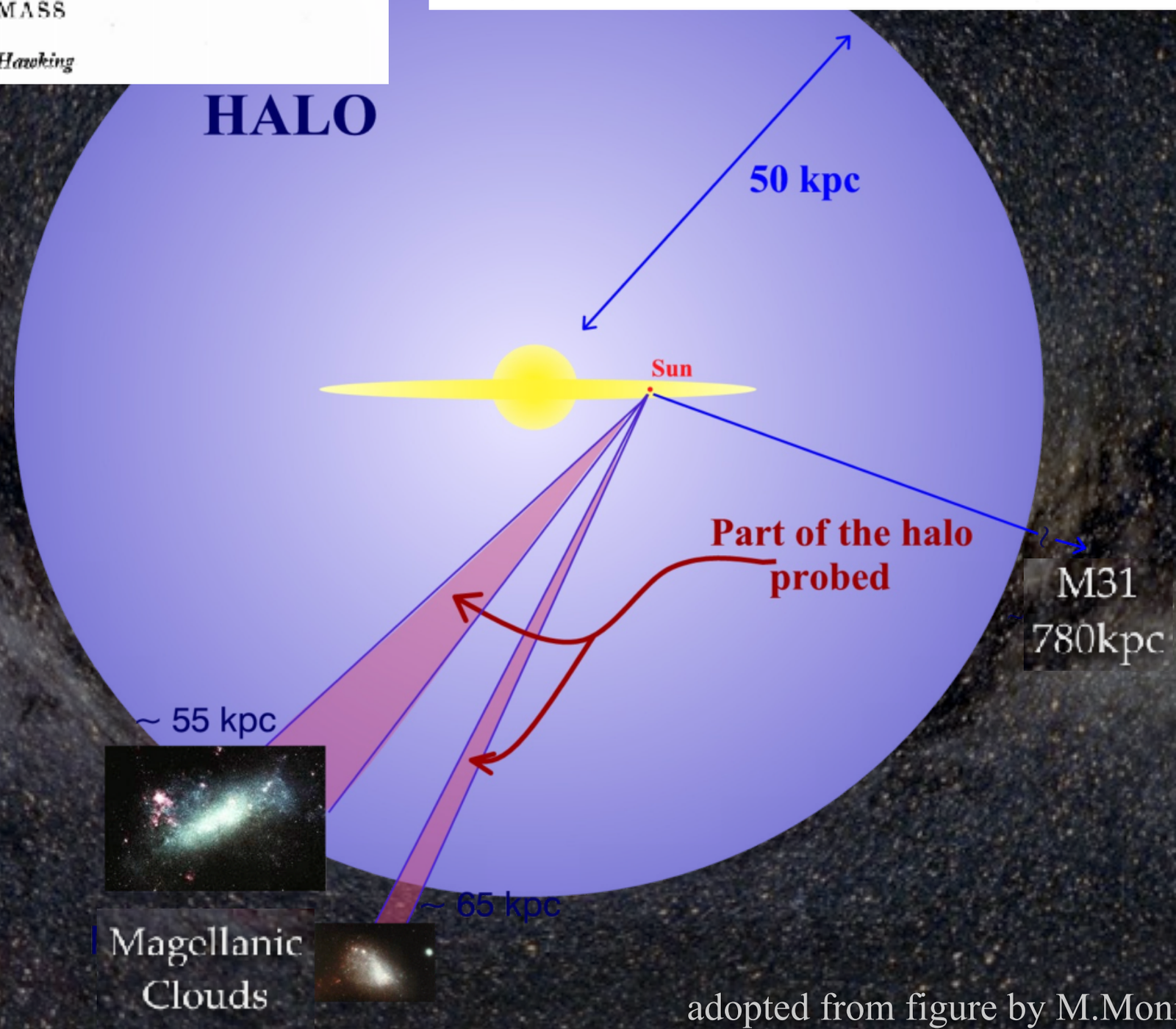
GRAVITATIONALLY COLLAPSED OBJECTS OF VERY LOW MASS

Stephen Hawking

GRAVITATIONAL MICROLENSING BY THE GALACTIC HALO

BOHDAN PACZYŃSKI[1]
Princeton University Observatory

Received 1985 August 1; accepted 1985 October 23

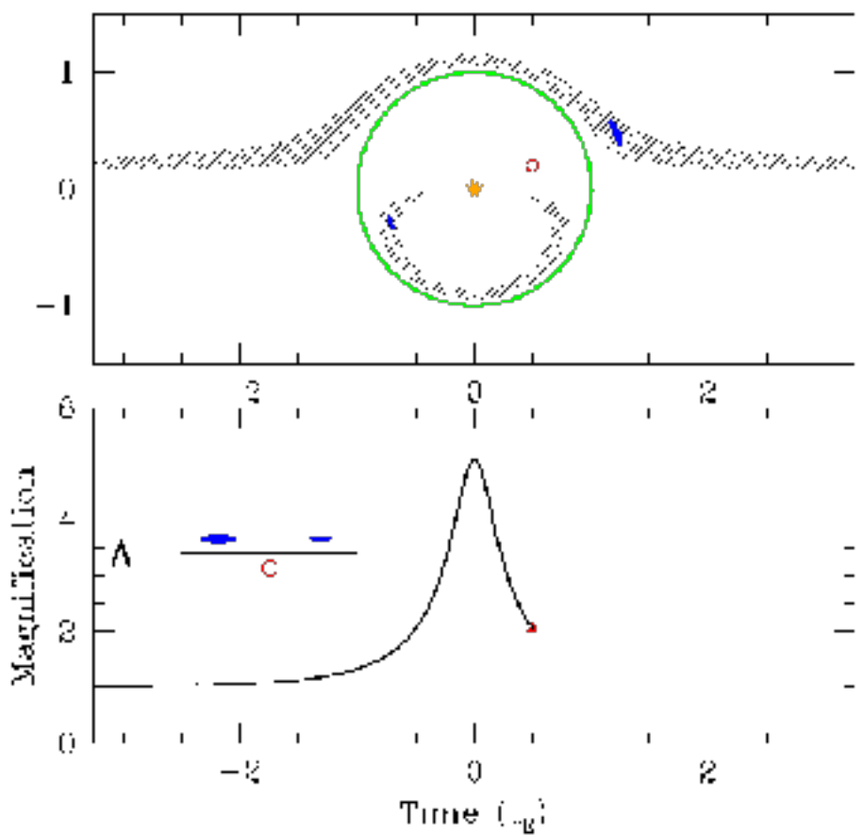


adopted from figure by M.Moniez

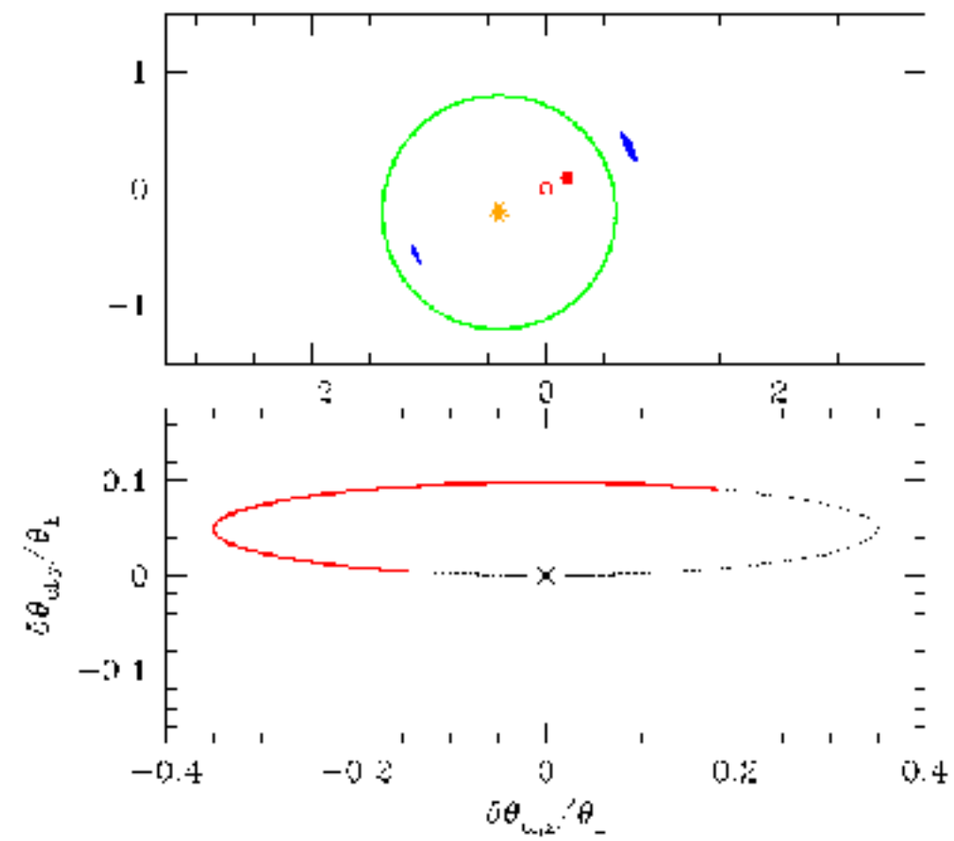
MICROLENSING

= strong lensing in an unresolved regime

photometry (sum of images)



astrometry (centroid motion)



animations by S.Gaudi

~1 month

~1mas

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

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HOW TO FIND BLACK HOLES?

OGLE

http://ogle.astrouw.edu.pl

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

HOW TO FIND BLACK HOLES?

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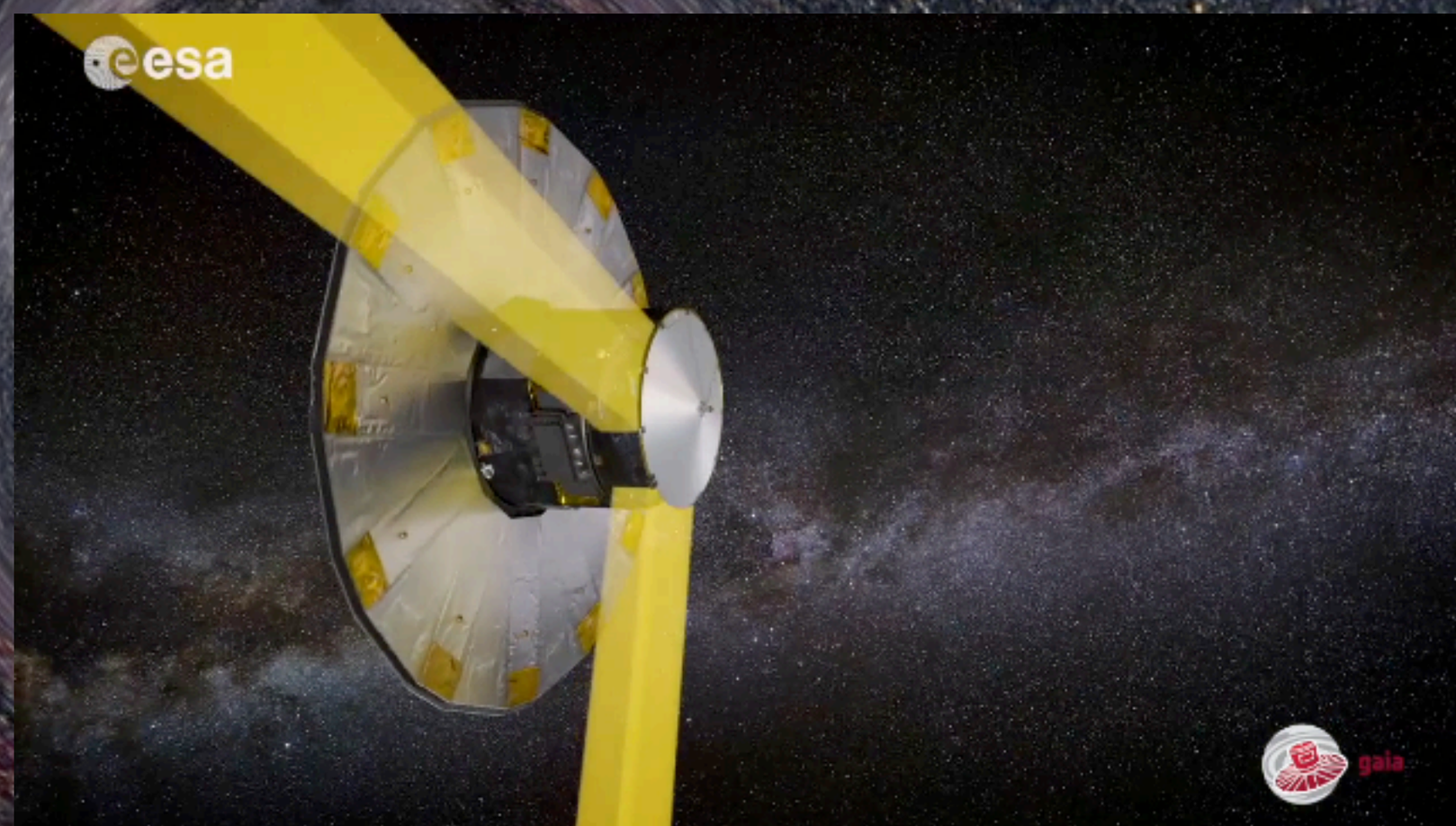
Gaia Science Alerts

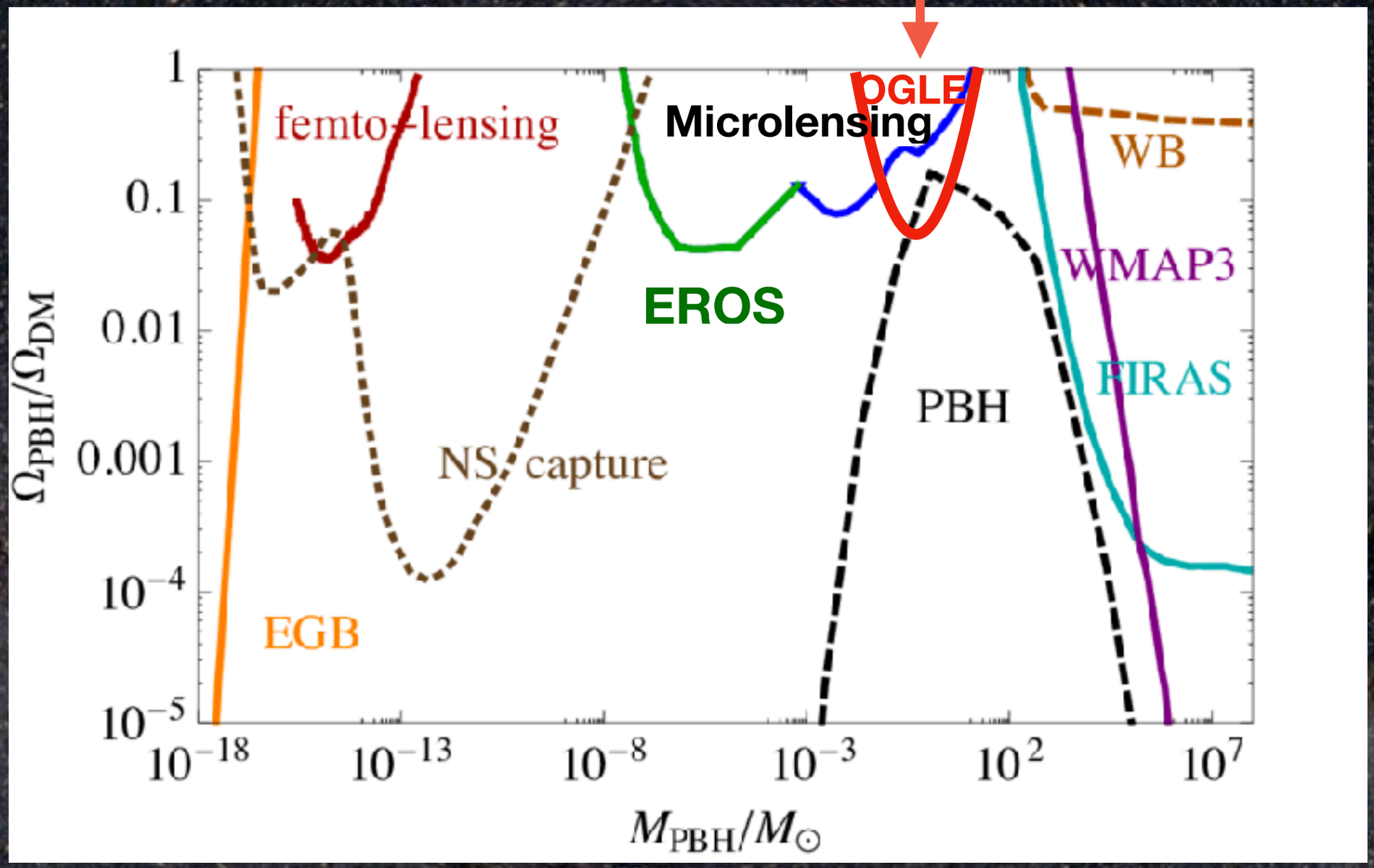
http://gsaweb.ast.cam.ac.uk/alerts



ESA space mission with 2x1.4m telescopes located in L2.
In operation since 2014. Extended until 2020+
DR1 in Sepember 2016,
DR2 in April 2018

MICROLENSING CONSTRAINS ON HALO DARK MATTER

OGLE data (1996-2009) ruled out PBH M<1 MSun



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

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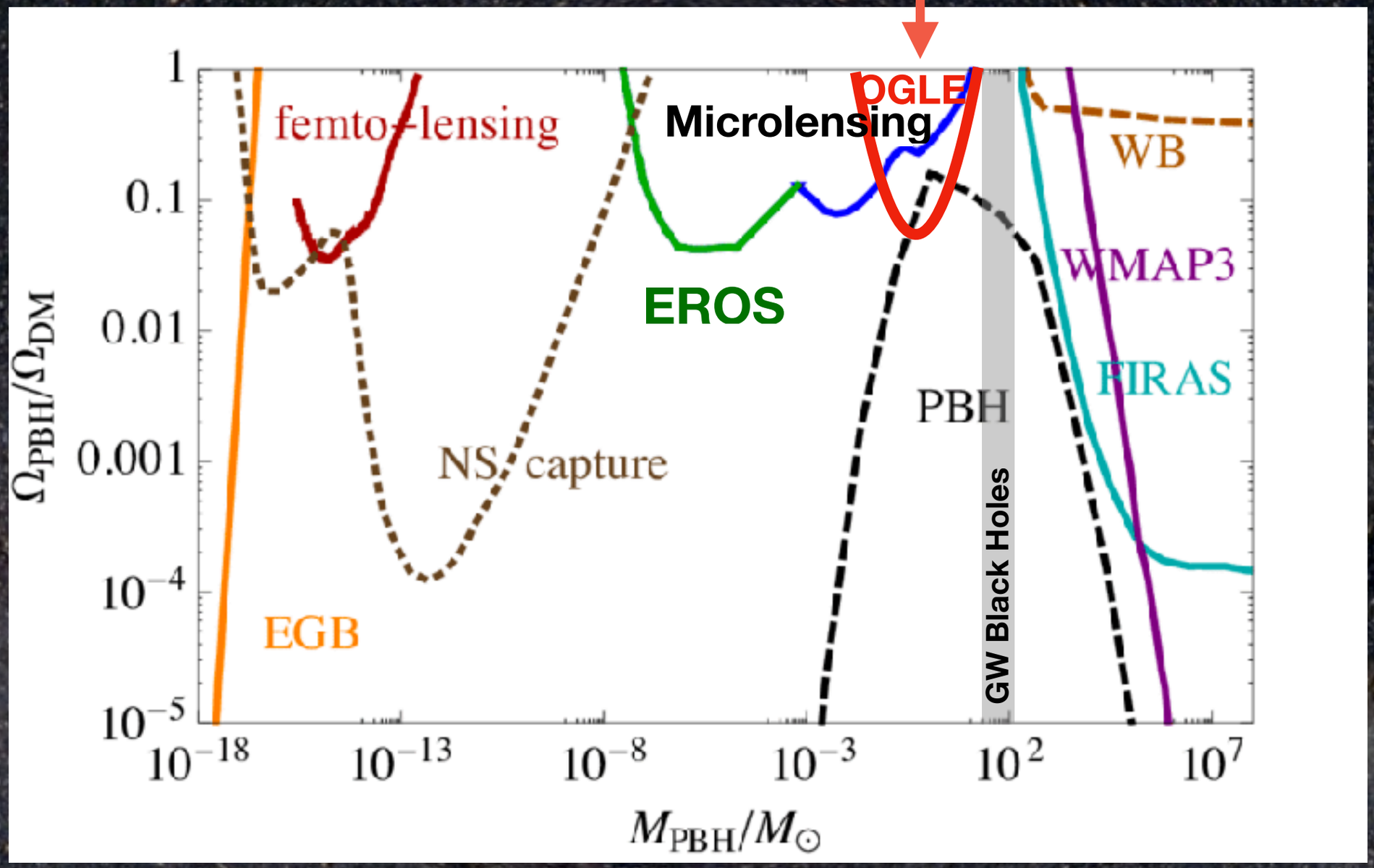

Garcia-Bellido & Clesse 2017 Wyrzykowski+ 2009,2010,2011a,2011b

The only window for Primordial Black Holes coincides with the GW black holes!

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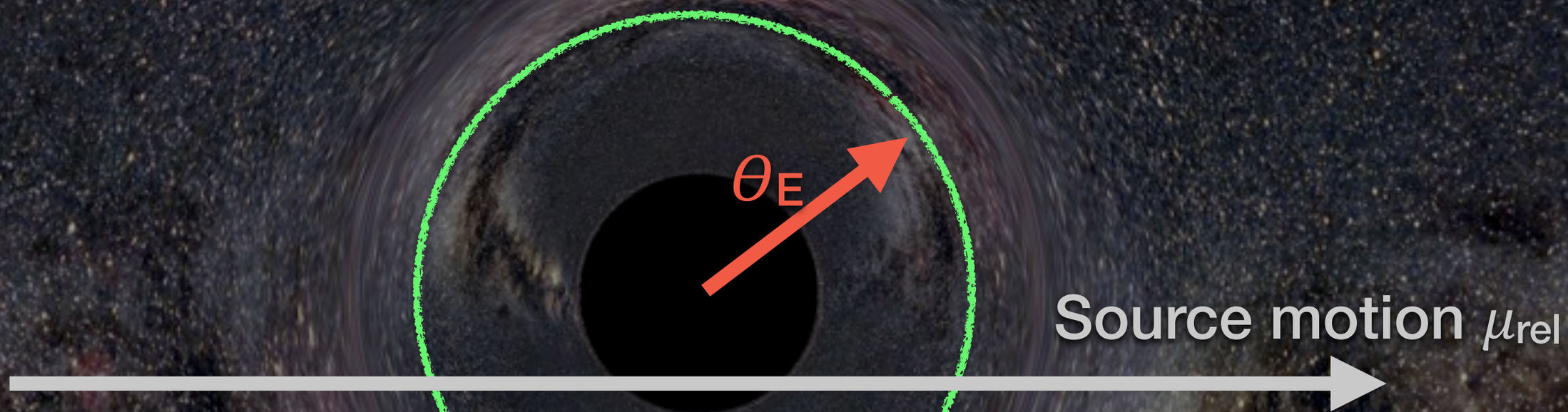
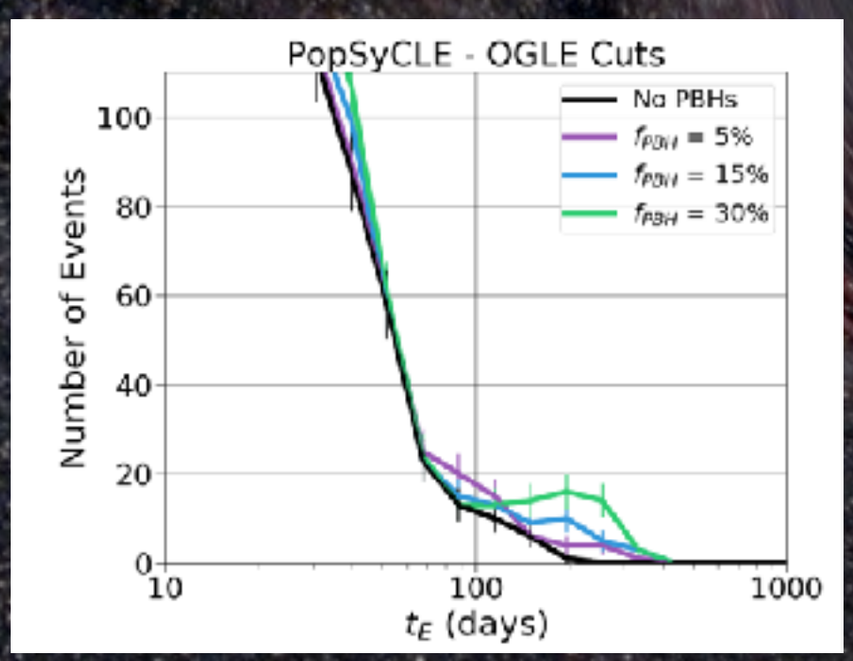
BLACK HOLES AS LENSES IN THE DISK

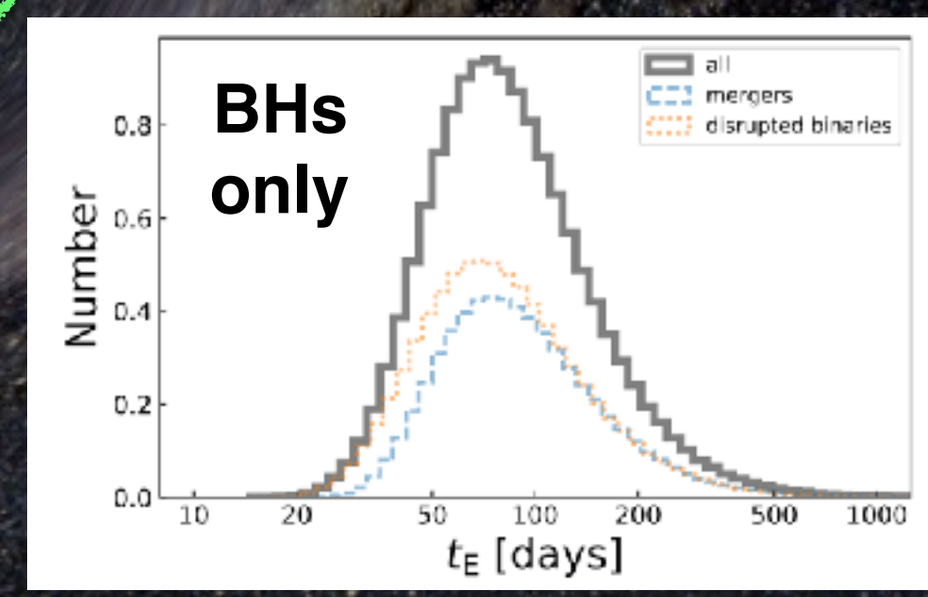
M_{BH} = 10 $M_\odot$ at ~kpc —> θ_E=~5mas, μ_{rel} = 5mas/yr

—> t_E > 1 yrs





Lu+2019 arxiv:1904.01771

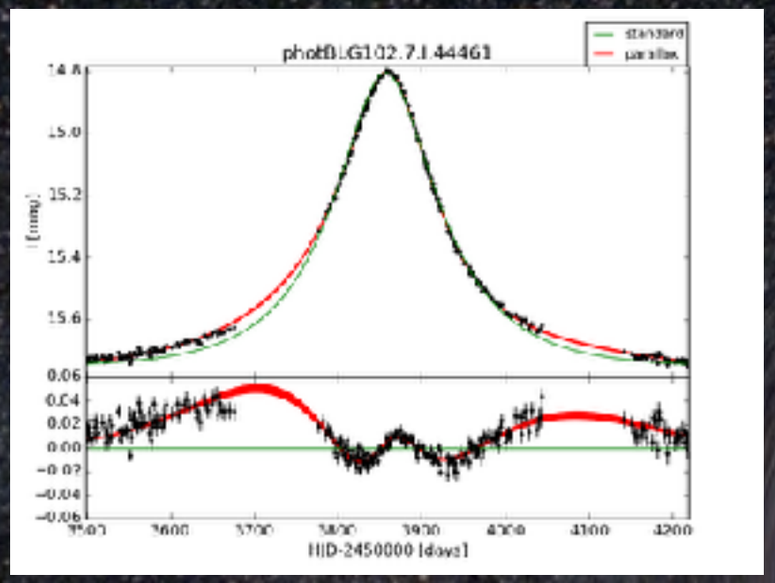


Wiktorowicz, LW+2019 arxiv: 1907.11431

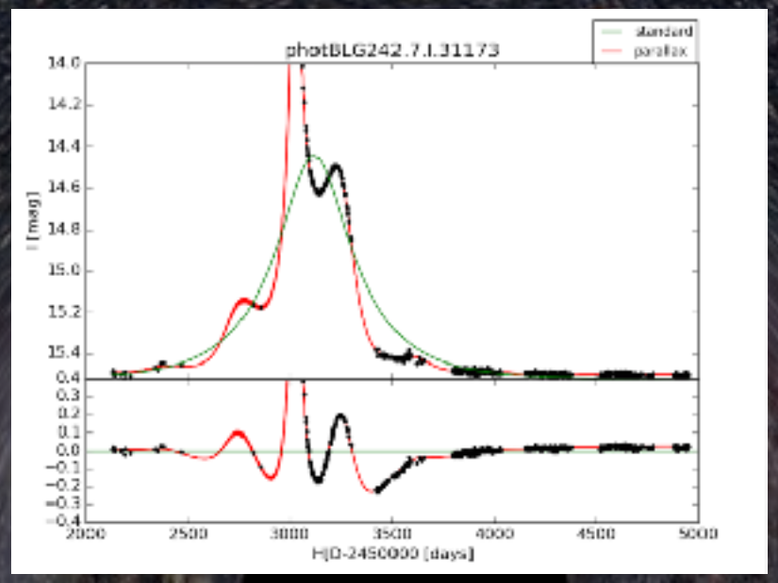
DARK LENS CANDIDATES IN THE MILKY WAY

OGLE-III 2001-2009 Bulge 150 million stars

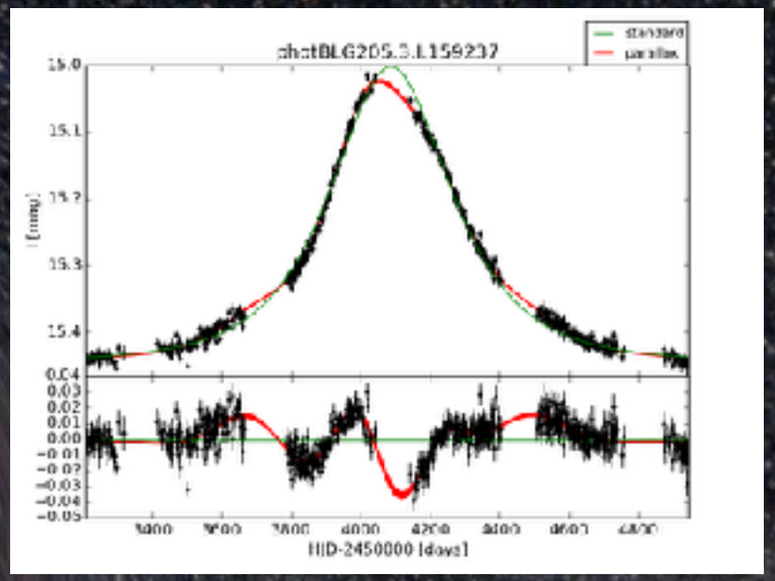
PAR-07 (Notec)



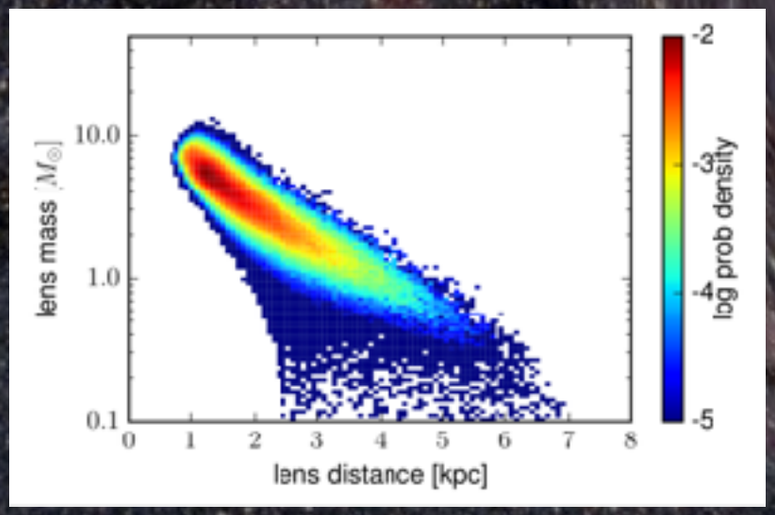
PAR-03 (Warta)



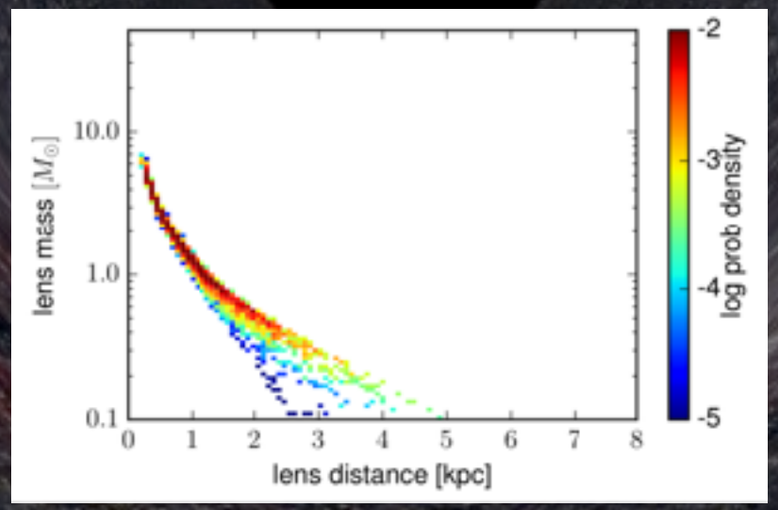
PAR-02 (Odra)



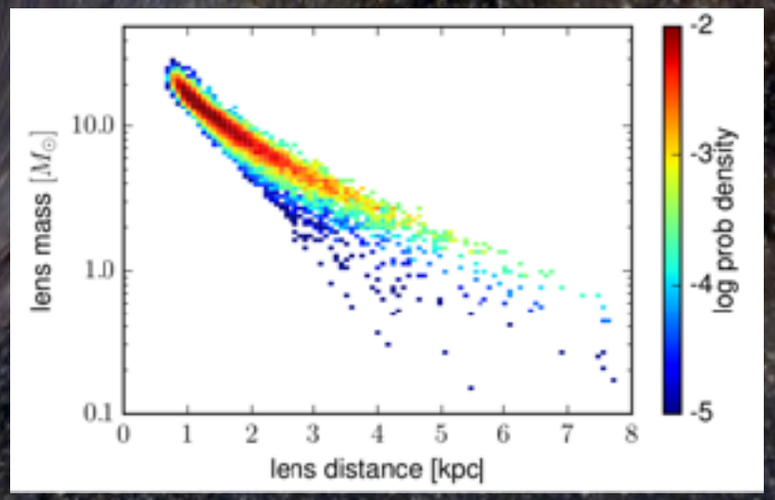
4.5±1.8 M⊙



1.7±1.0 M⊙



11.9±5.2 M⊙



WARNING: Photometry-only leaves mass-distance degenracy

Wyrzykowski+2016, Wyrzykowski&Mandel 2019

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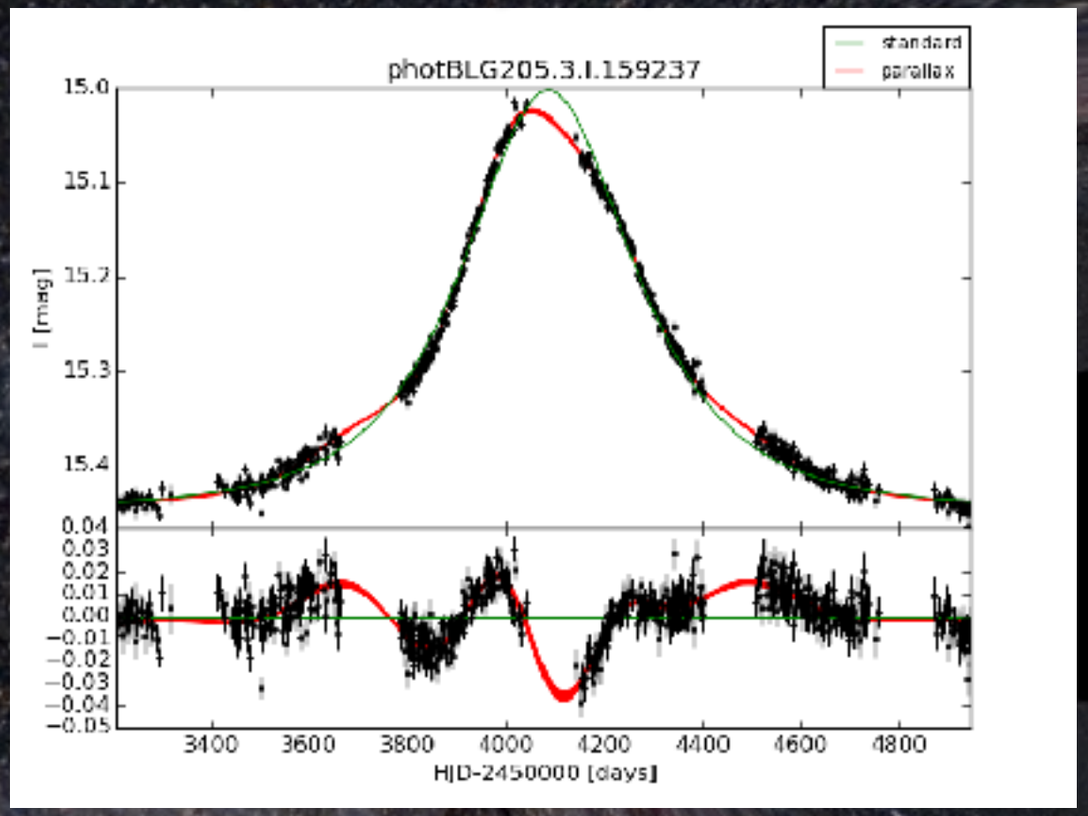
HOW TO RECOGNISE A BLACK HOLE LENS?

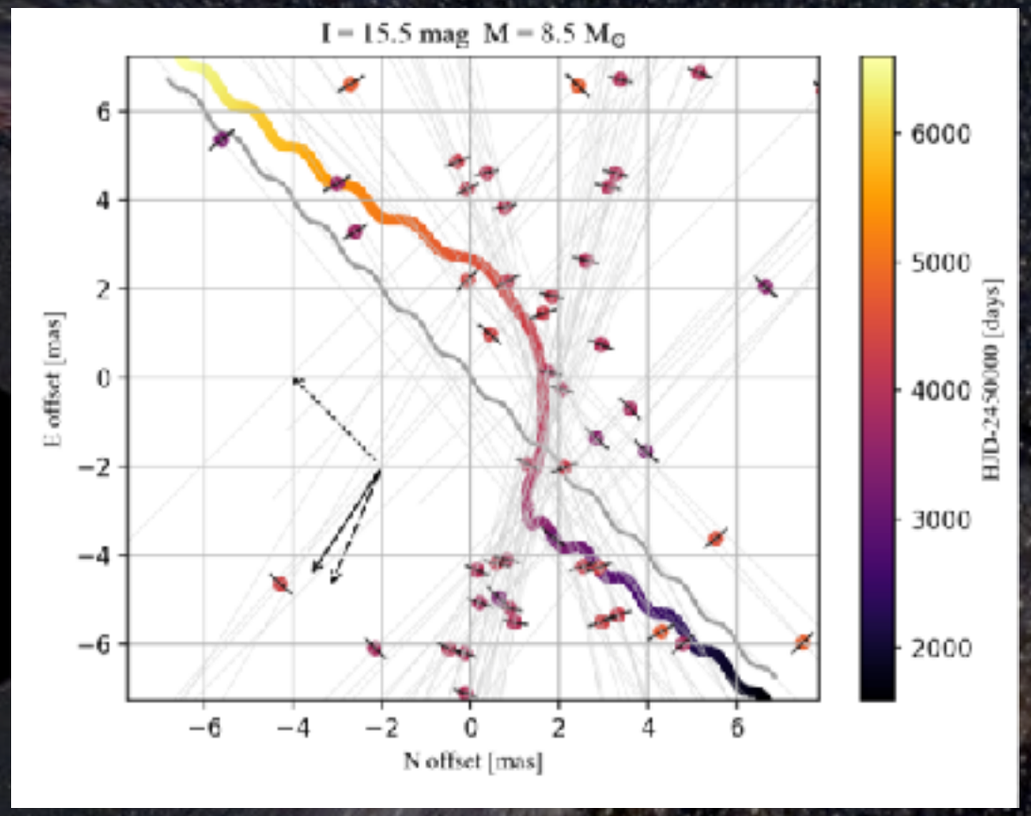
example: OGLE3-ULENS-PAR-02 ~11M_{Sun} BH candidate

OGLE photometry and parallax model



Wyrzykowski+2016

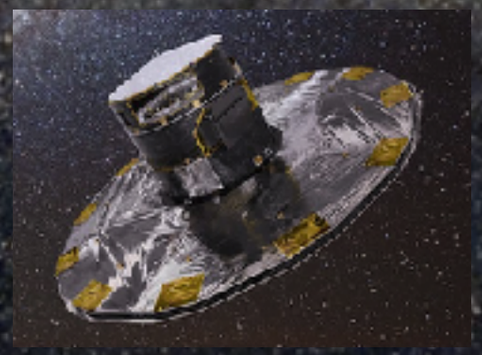
simulated Gaia astrometry



Rybicki+2018

Photometry + astrometry = mass, distance, luminosity

Gaia will provide <1mas astrometric time-series for events brighter than G=16mag



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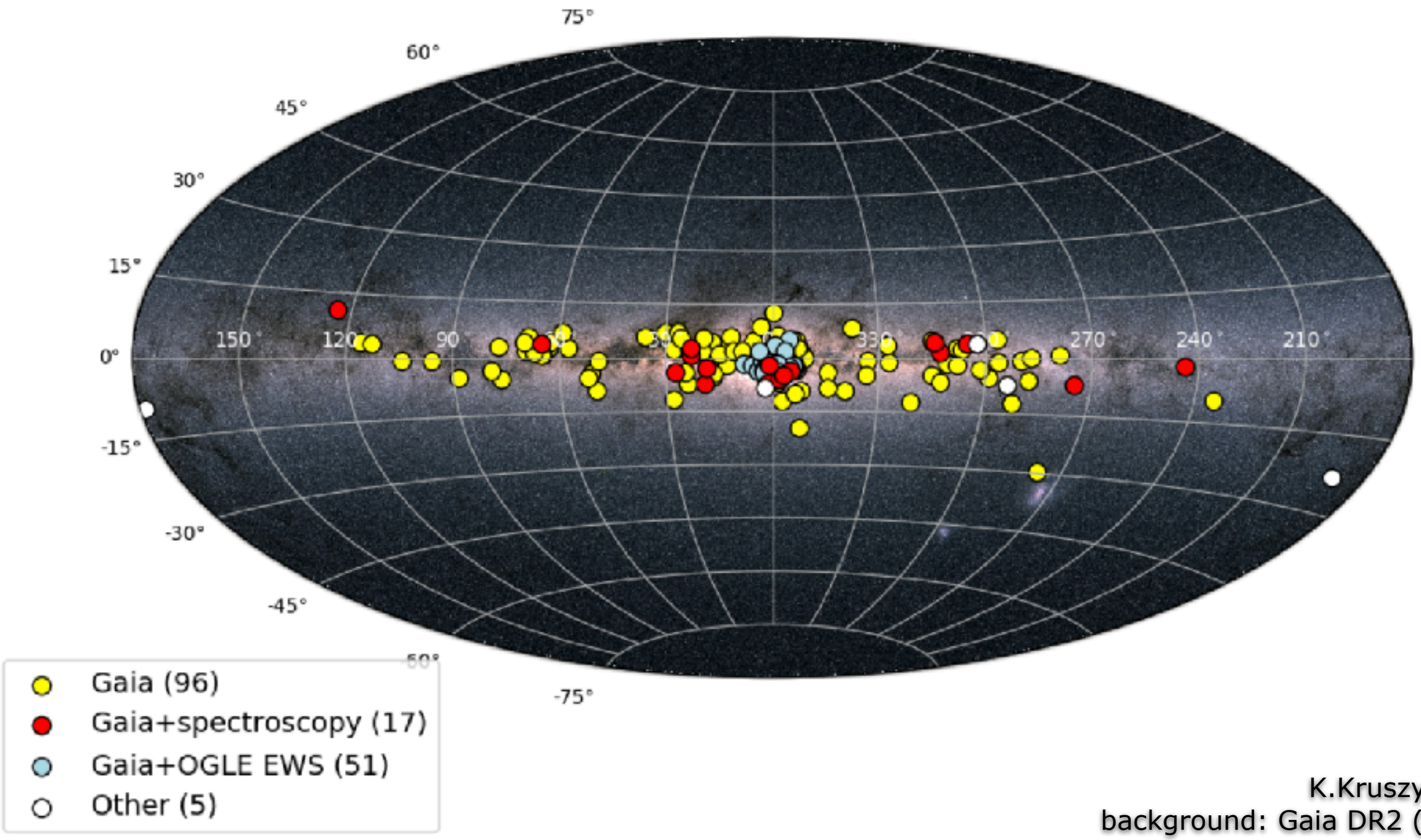
MICROLENSING EVENTS FROM GAIA

since 2016



K.Kruszynska
background: Gaia DR2 (ESA)

HOW TO FIND BLACK HOLES?

alerts about
on-going
microlensing events

OGLE

Gaia Science Alerts

ASAS-SN

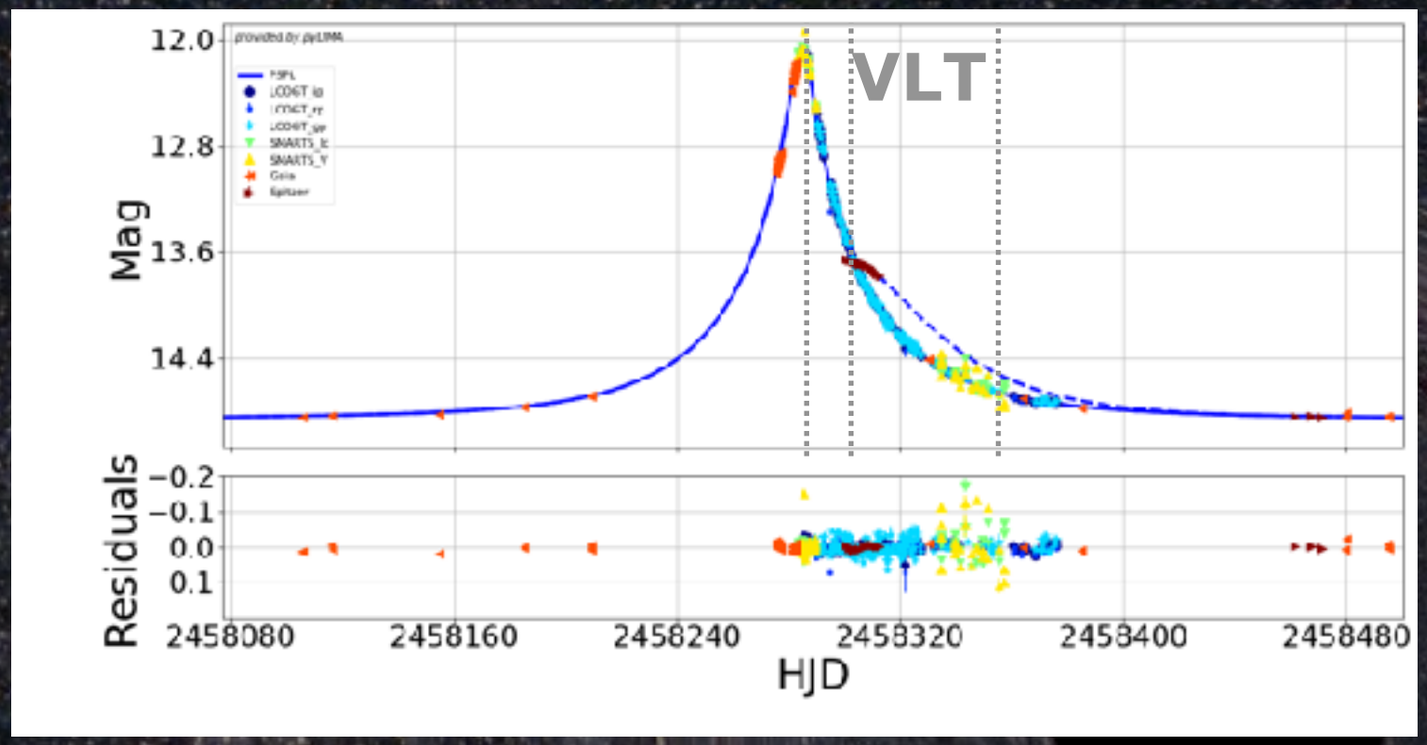
follow-up

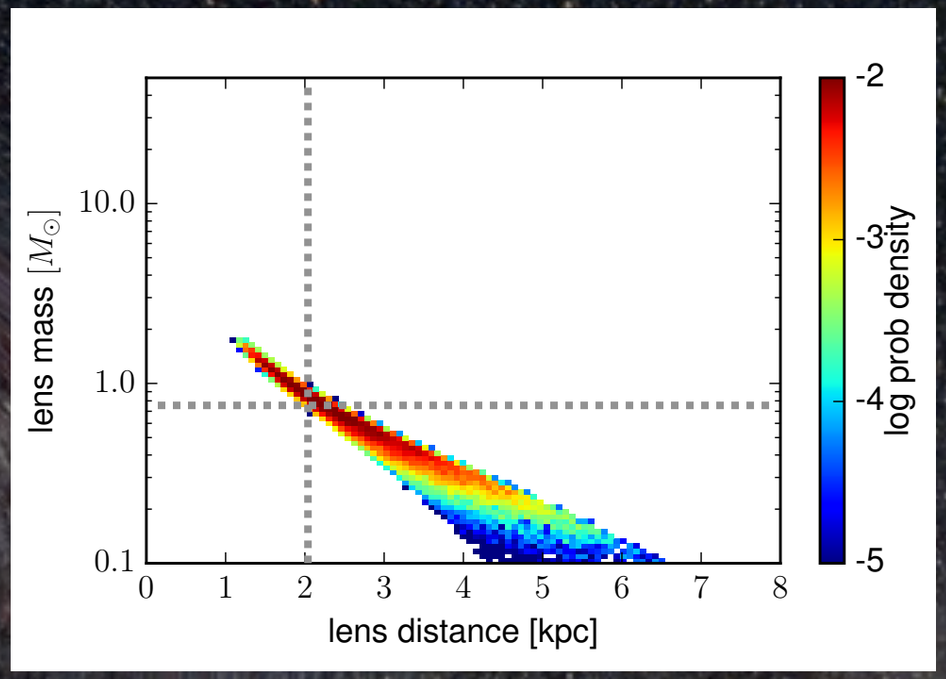
light curves (~20 telescopes)
spectra (VLT, Gemini, SALT)
space observations (Spitzer)

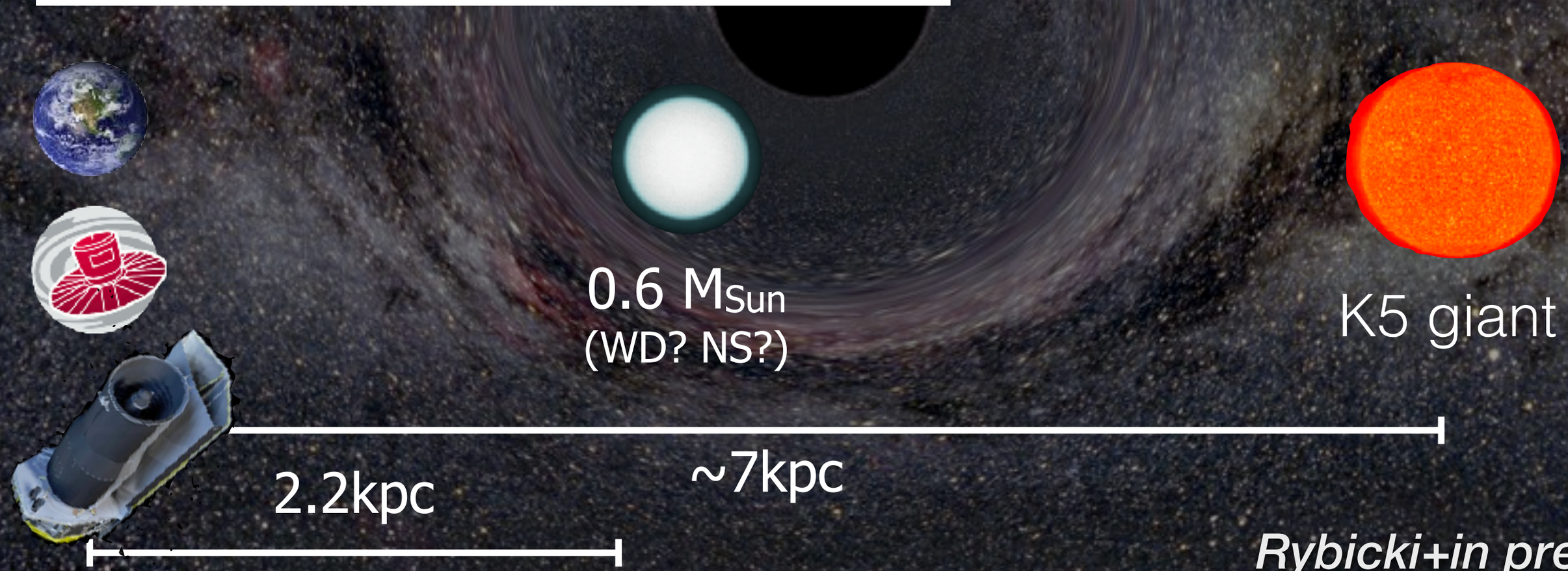
astrometric
time-series (Gaia DR4)

GAIA DARK LENSES: GAIA18BMT

photometry: Gaia, ground (LCO), Spitzer



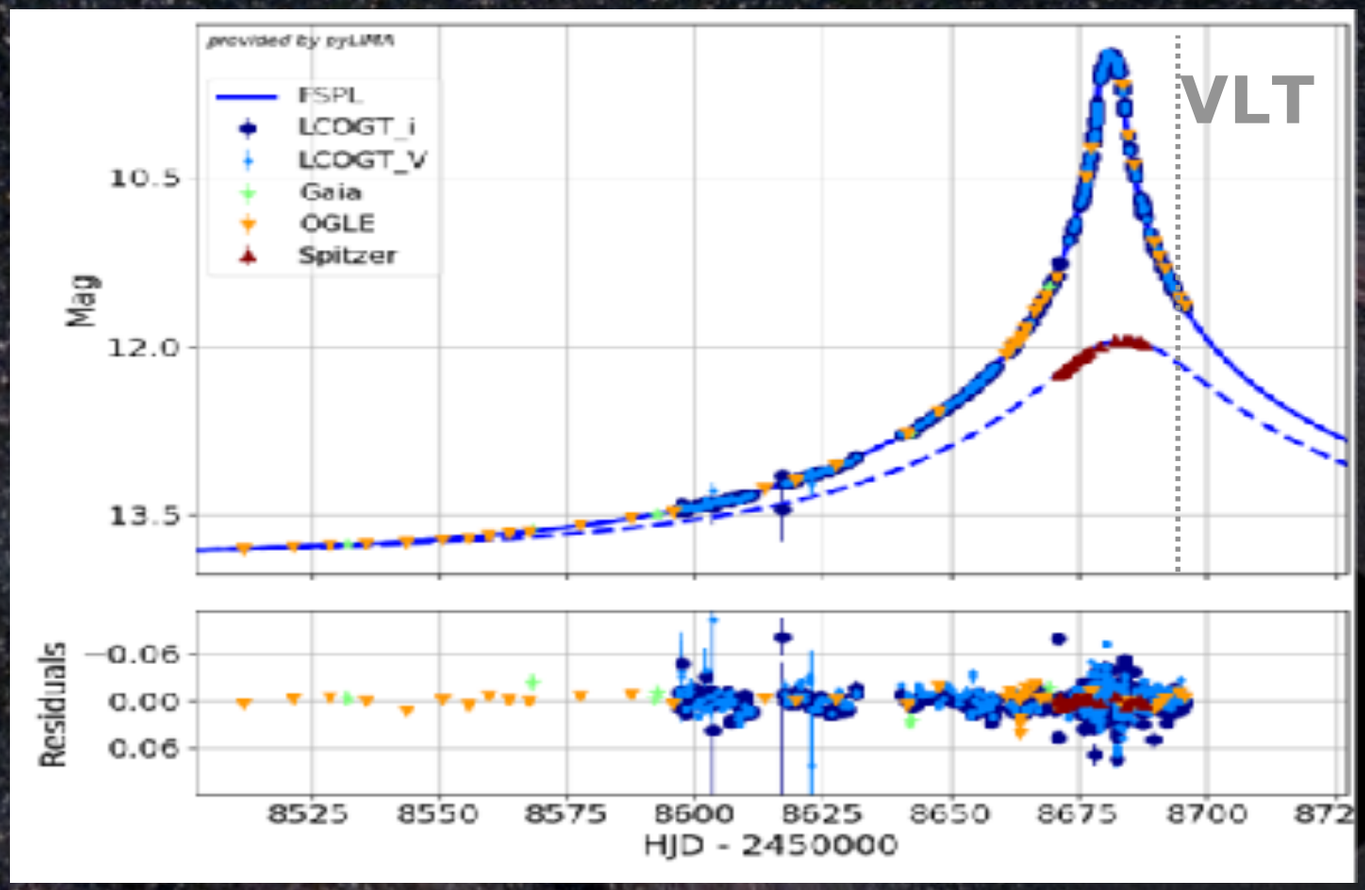


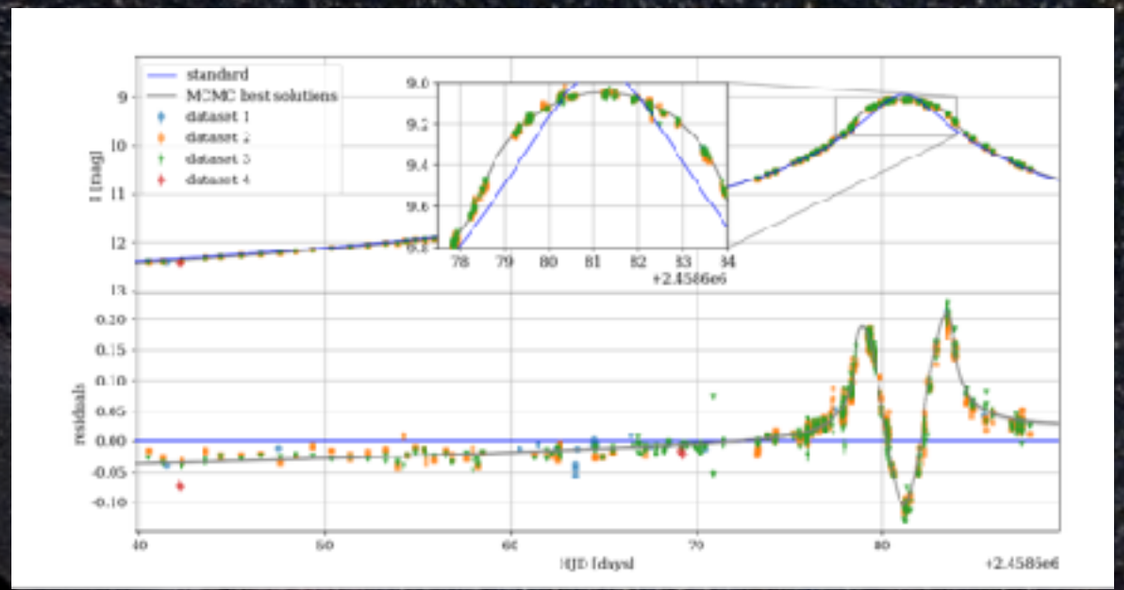


Rybicki+in prep.

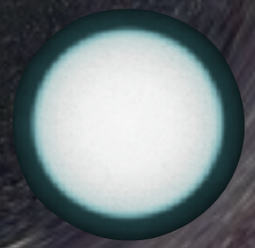
GAIA DARK LENSES: GAIA19BLD

photometry: Gaia, ground (LCO), Spitzer

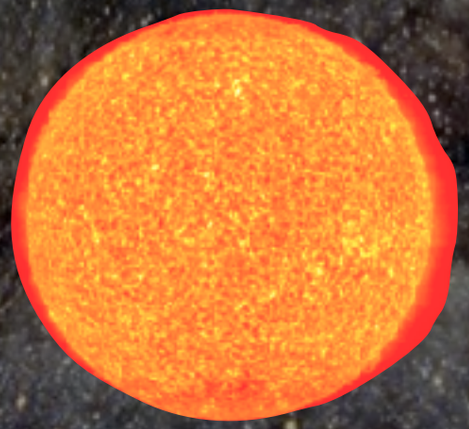




finite source effect gives thetaE -> M-D degeneracy broken!



0.9 M_{Sun}
(WD? NS?)



K3 supergiant

~3kpc

2.6kpc

Rybicki+in prep

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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. Lin, E. Lin,
with the support of the
LSST Transient and Variable Stars Collaboration.

Nov 2018

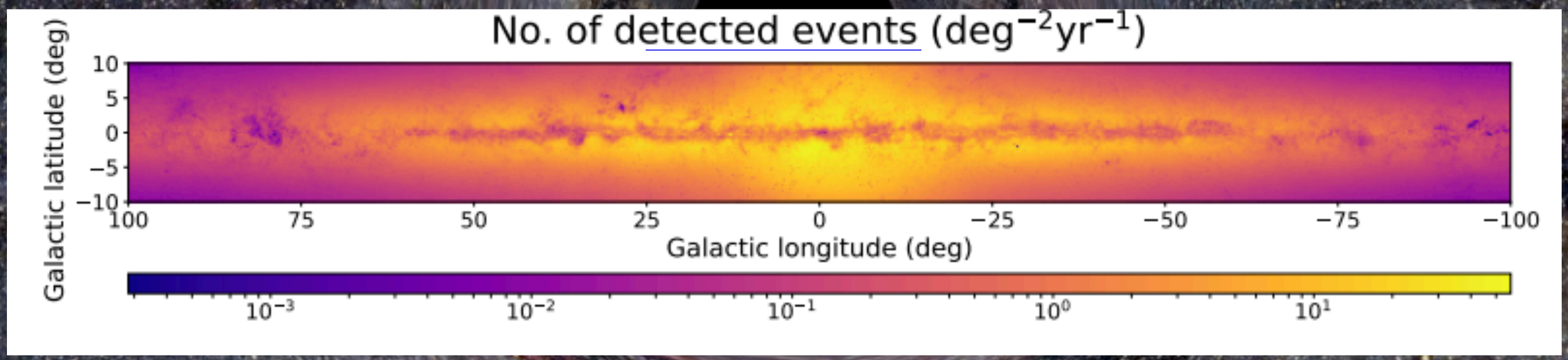
Street+2018, arxiv:1812.03127

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

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

Draft version June 19, 2018

Sajadian,Poleski arXiv:1806.06372



LSST will detect 10000s of microlensing events yielding 100s of BHs

HOW TO FIND BLACK HOLES WITH LSST?

alerts about
on-going
microlensing events

Large Synoptic Survey Telescope

follow-up

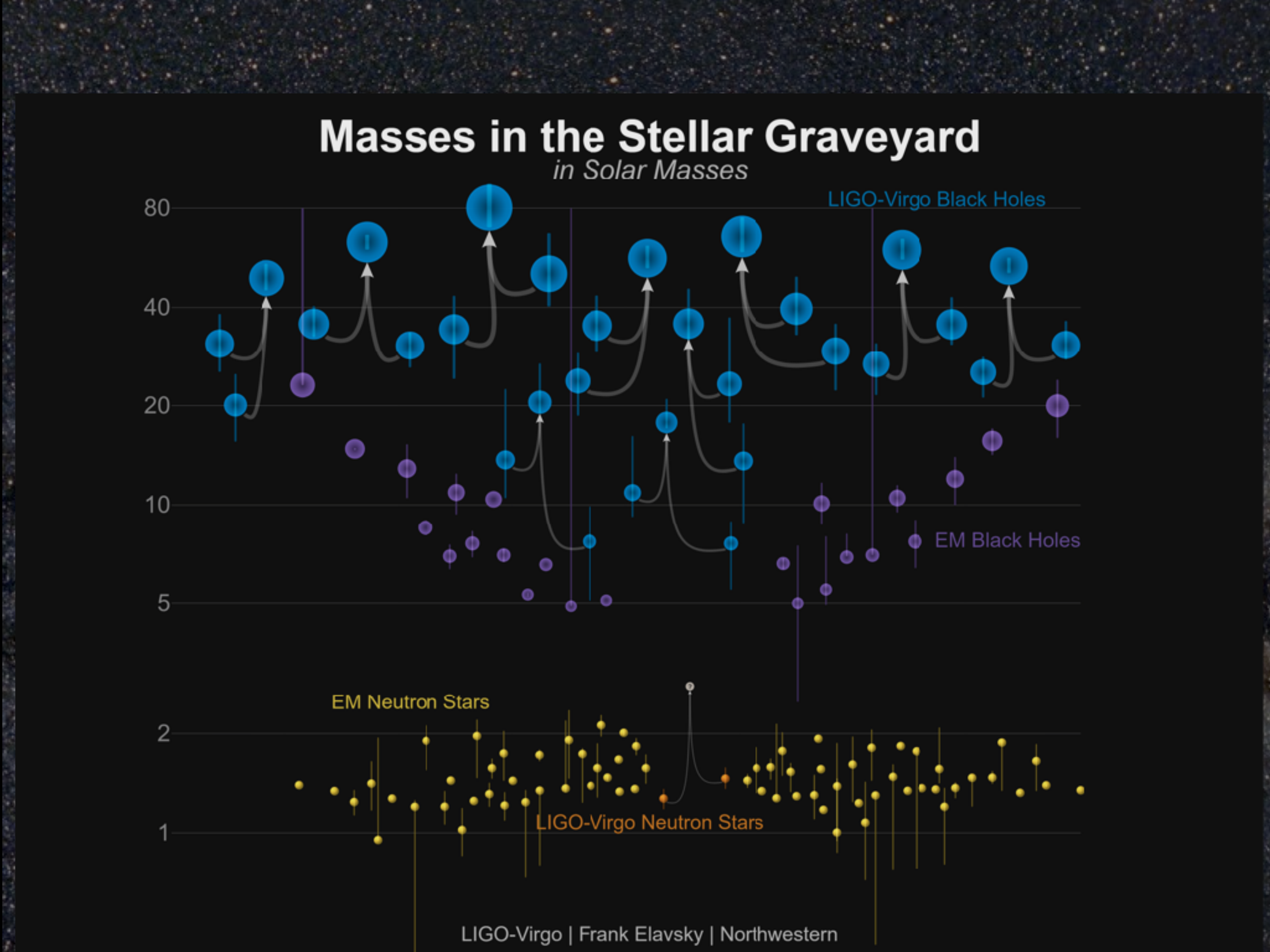
light curves (>2m telescopes)
spectra (ESO/VLT, Gemini, SALT)
+ space (WFIRST?)

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

*Hobbs+2019
arXiv:1907.12535

SUMMARY

- Microlensing can discover low and high mass black holes, including the primordial ones
- Strong limits below <1 MSun for the content of the Milky Way Halo
- OGLE Black holes in the Galactic Disk may fill the Mass-Gap
- Gaia astrometry necessary for accurate lens masses of currently on-going microlensing events, but only for bright rare events
- Individual dark Gaia events from the Galactic Disk will have lens masses measured
- LSST: 100s of lensing BHs!
- JWST, WFIRST, GaiaNIR, ELT - high astrometric precision (2020s)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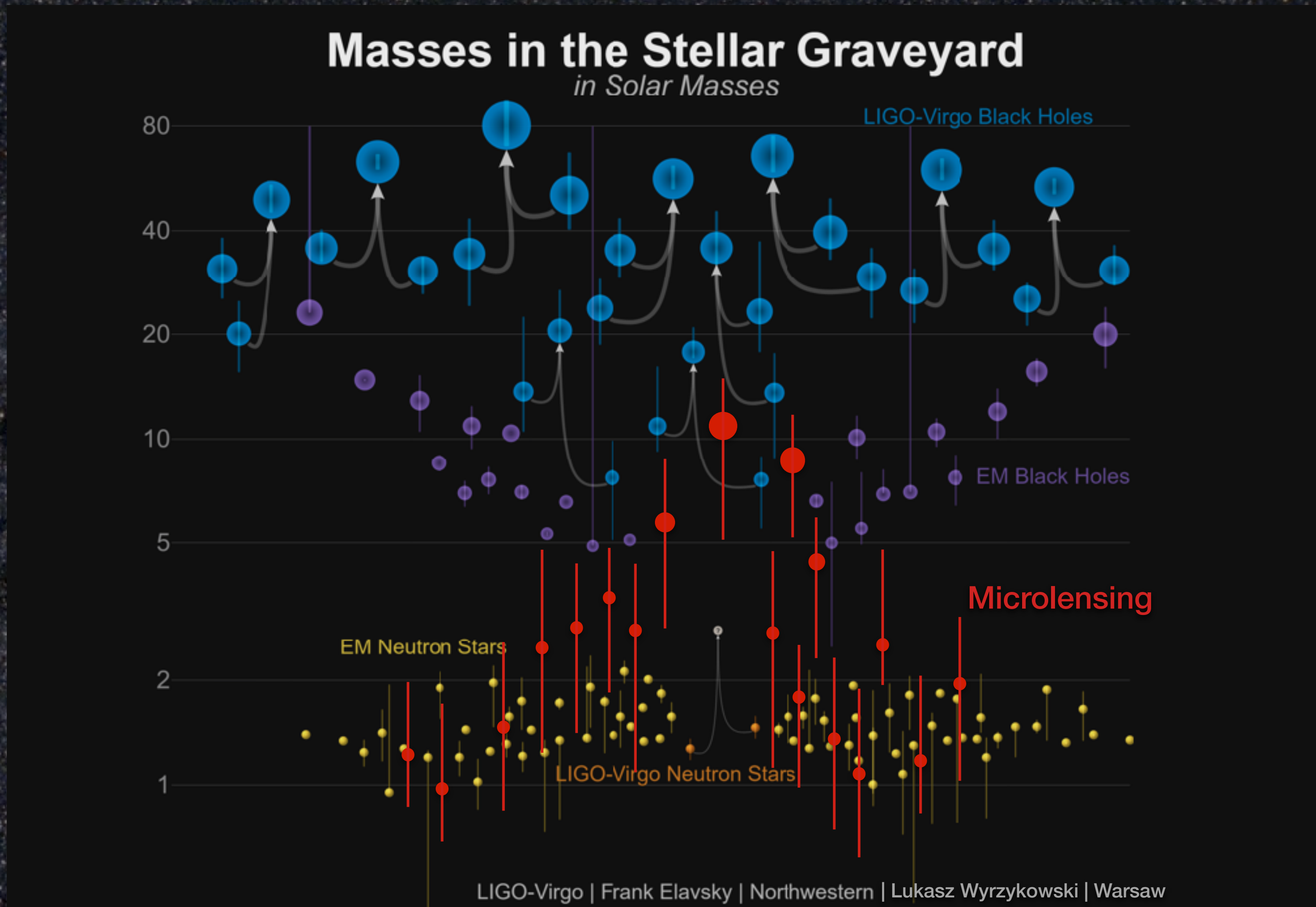
LIGO-Virgo | Frank Elavsky | Northwestern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LIGO-Virgo | Frank Elavsky | Northwestern | Lukasz Wyrzykowski | Warsaw