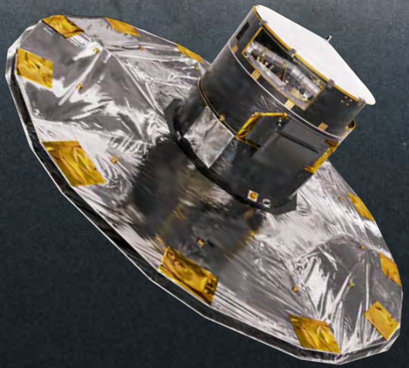
Dark microlensing event candidates found in Gaia

Katarzyna Kruszyńska,
(pronunciation: Ka-ta-zhi-na Kru-shyn-ska)

Łukasz Wyrzykowski, Kris Rybicki, Kornel Howil,
Maja Jabłońska, Zofia Kaczmarek, Marius Maskoliunas,
Mateusz Bronikowski, Uliana Pylypenko

Las Cumbres Observatory, USA



26th International Microlensing Conference, 2024

Supported by the NSF under Grant No. 2209852

Black holes (and other dark remnants): What Do We Know? Do We Know Things?? Let's Find Out!

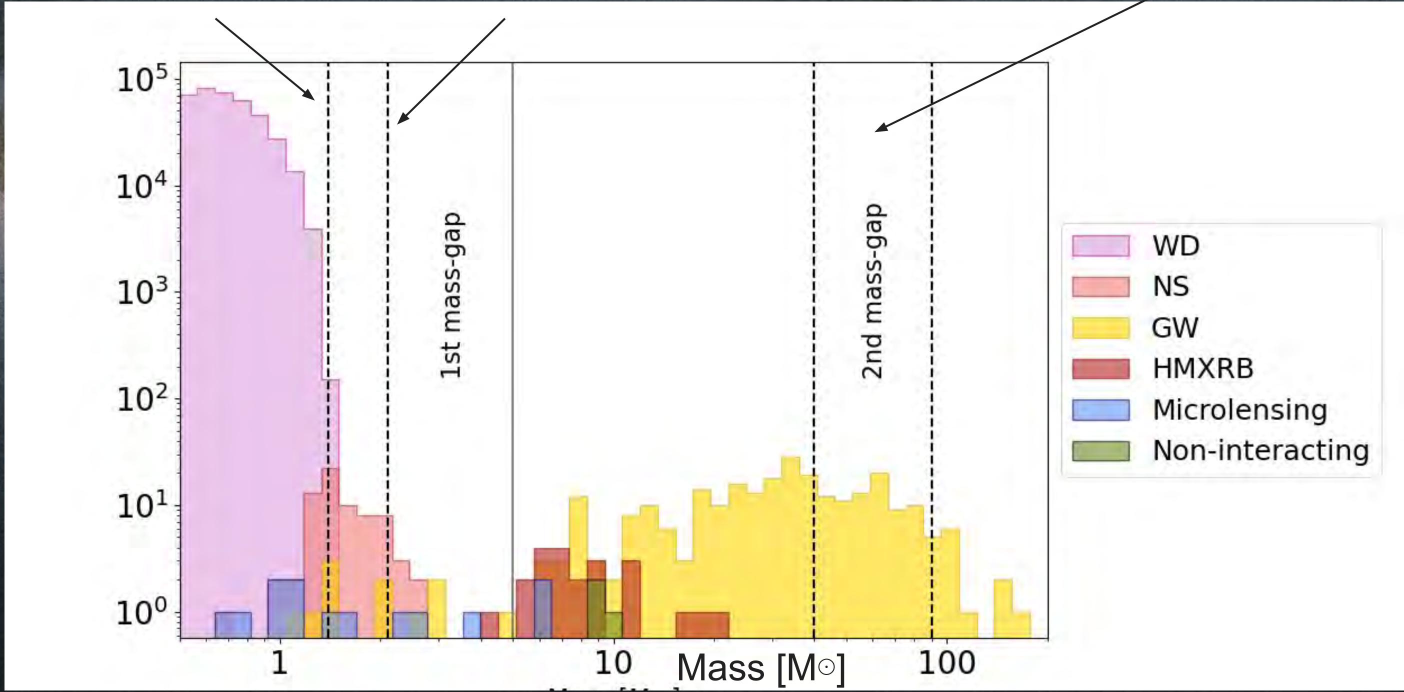
- Problem 1: Stellar remnants mass distribution.
    - How massive can the remnants get?
    - Does mass gap exist?
- Problem 2: Stellar remnants velocity distribution.

Problem 1: Dark remnant mass distribution

Chandrasekhar limit
1.4 M☉

TOV limit
2.1 M☉

Pair-instability SN
40 - 90 M☉
(Farmer et al. 2020)



Gentille-Fusillo et al. 2021

Lattimer 2012,
Antoniadis 2013

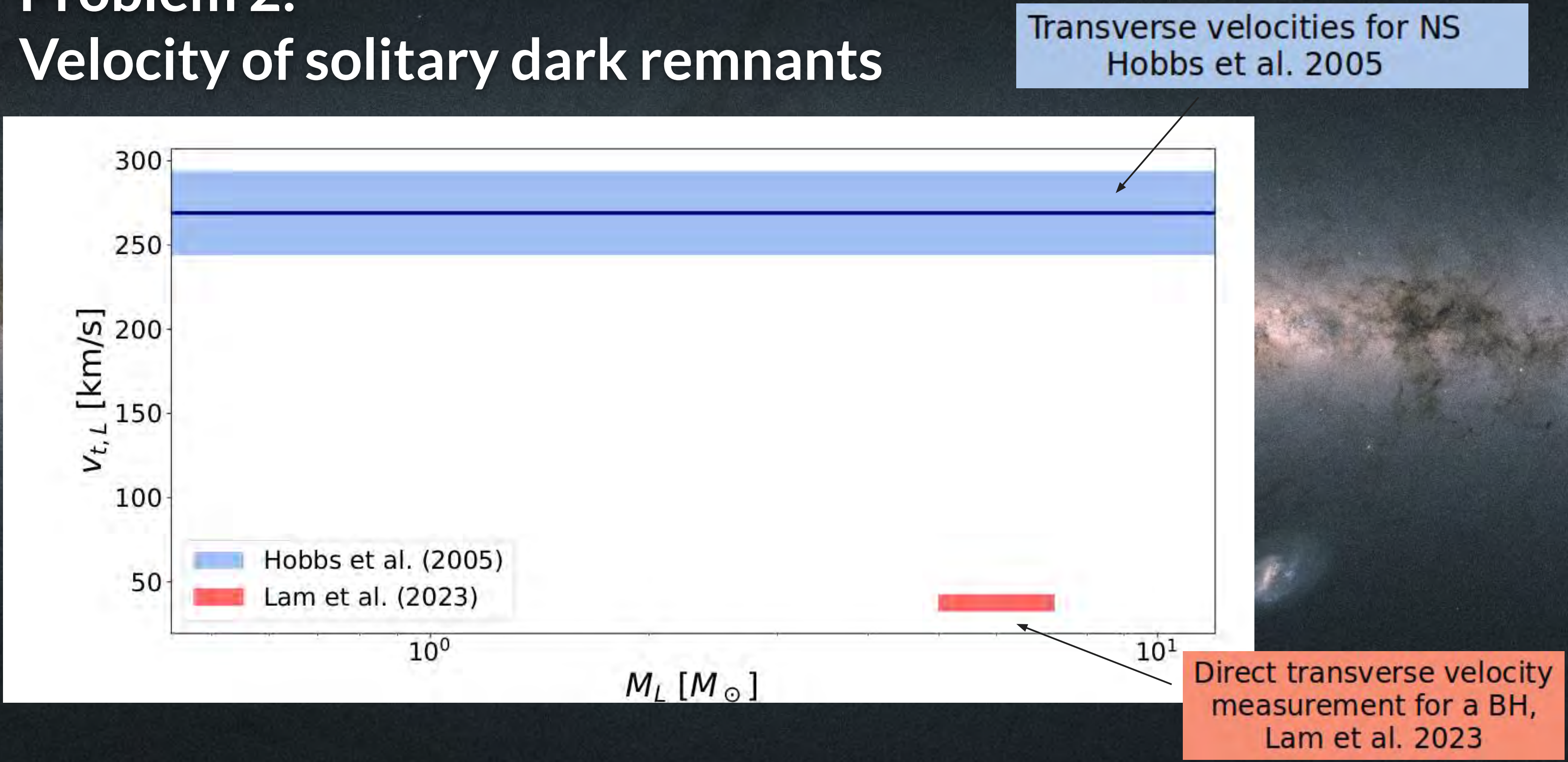
Abbott et al. 2019, 2021a, b

Orosz et al. 2007, 2009, 2014,
Val-Baker et al. 2007,
Corral-Santana et al. 2016,
Miller-Jones et al. 2021

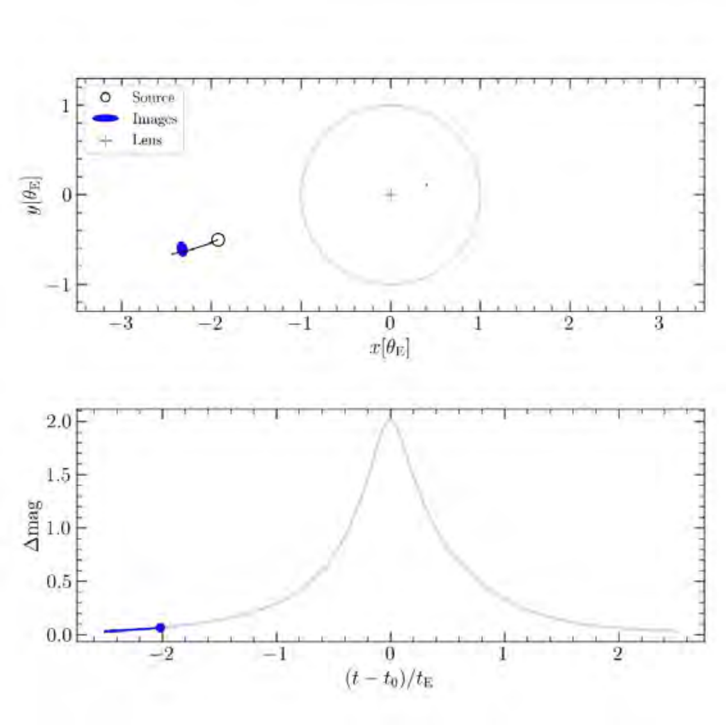
Mróz&Wyrzykowski 2021,
Kaczmarek et al. 2021,
Kruszyńska et al. 2022,
Sahu et al. 2022,
Lam et al. 2022, 2023
Mróz et al. 2022,
Jabłońska et al. 2022

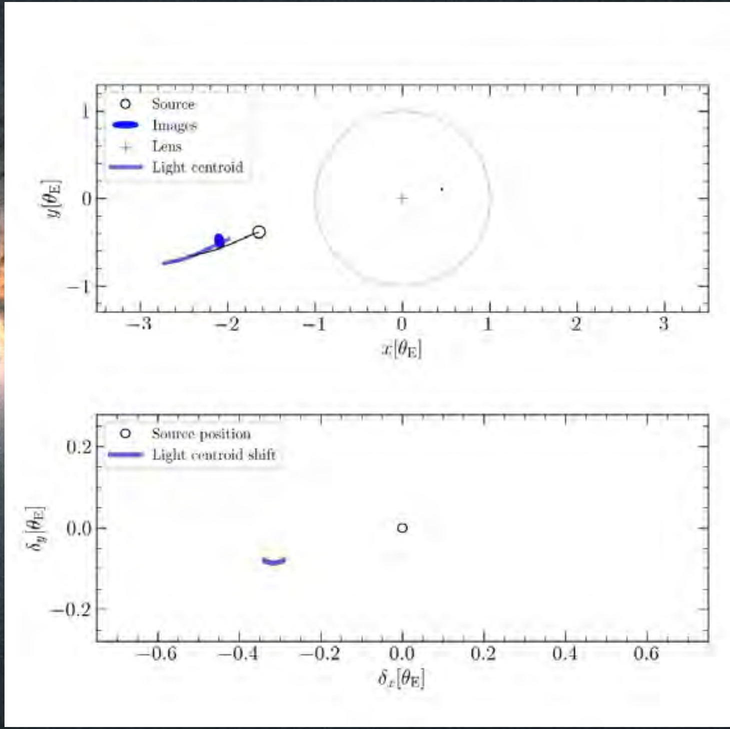
Shenar et al. 2022,
El-Badry et al. 2022, 2023

Problem 2:
Velocity of solitary dark remnants



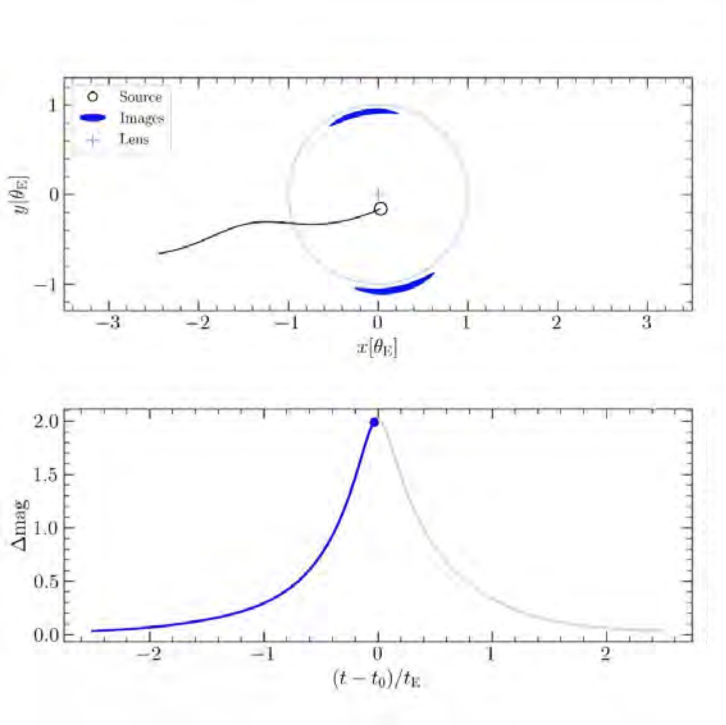
Photometric and astrometric effect

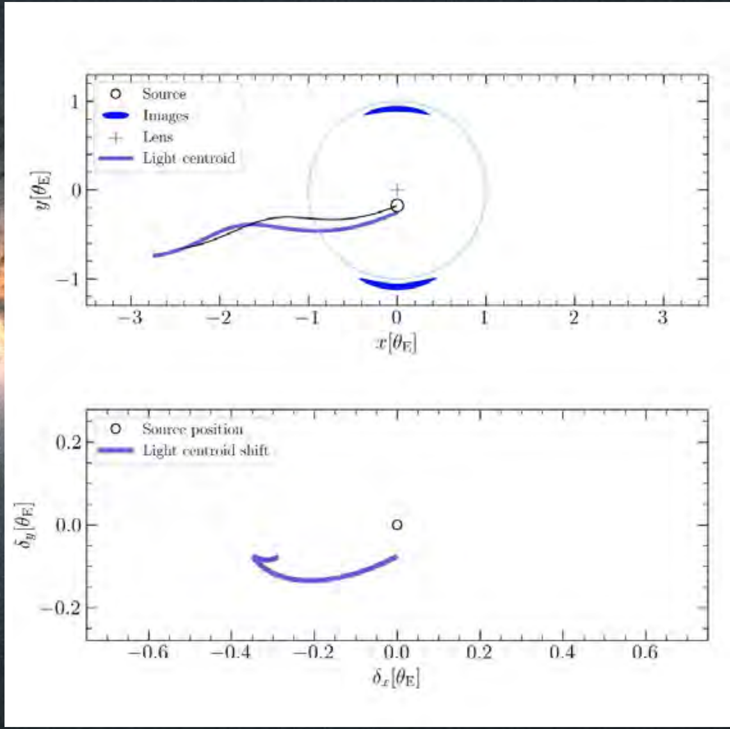




Source: K. A. Rybicki, https://www.astrouw.edu.pl/~krybicki/animations.php

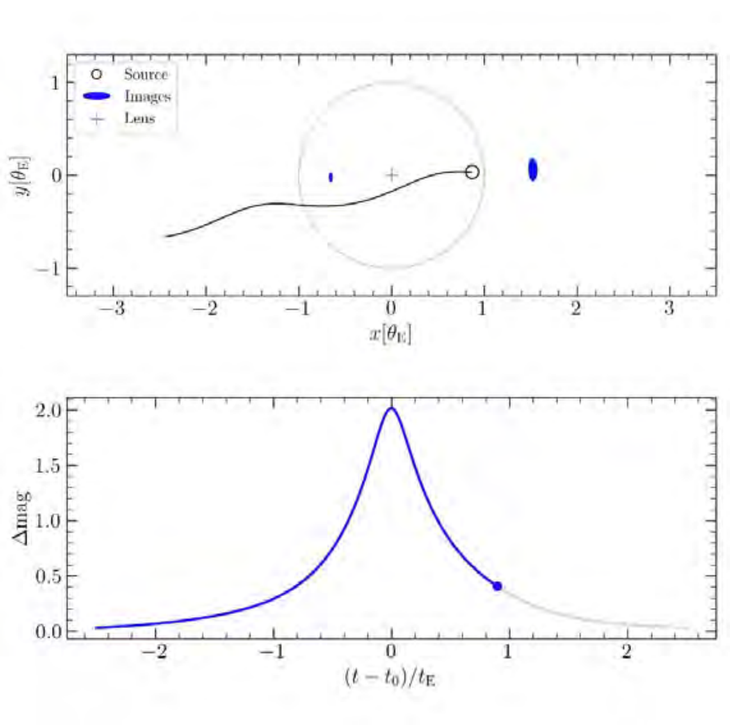
Photometric and astrometric effect

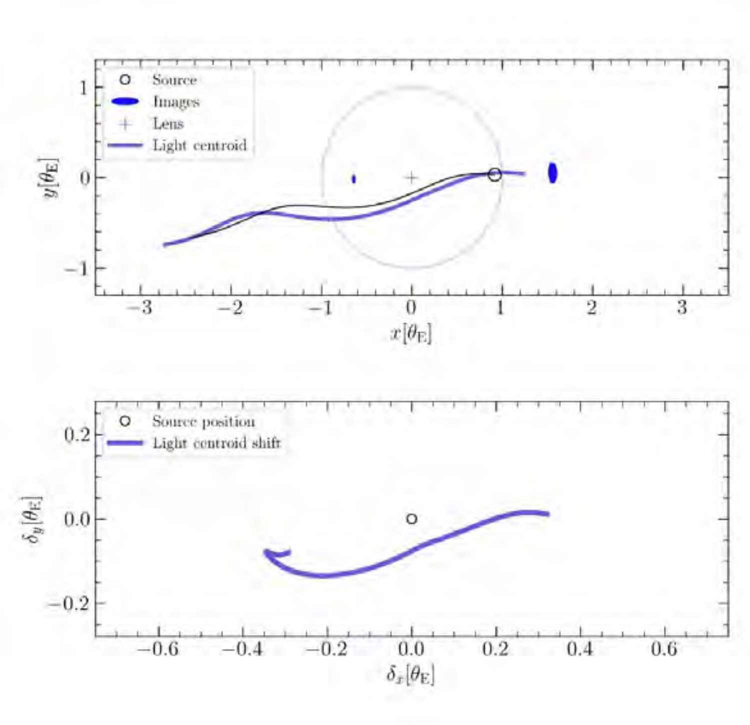




Source: K. A. Rybicki, https://www.astrouw.edu.pl/~krybicki/animations.php

Photometric and astrometric effect

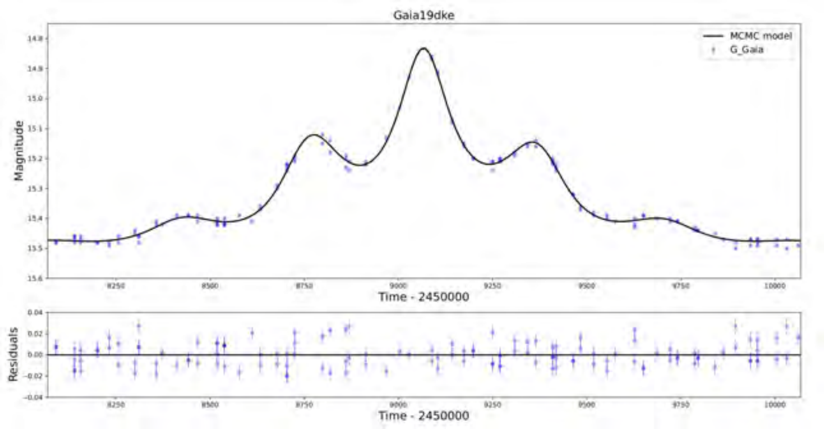




Source: K. A. Rybicki, https://www.astrouw.edu.pl/~krybicki/animations.php

Parallax effect

- Annual movement of the Earth is reflected in the light-curve
- For longer events → the lens might be massive (or moves slowly...)



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

Angular Einstein ring radius

astrometry

Microlensing parallax

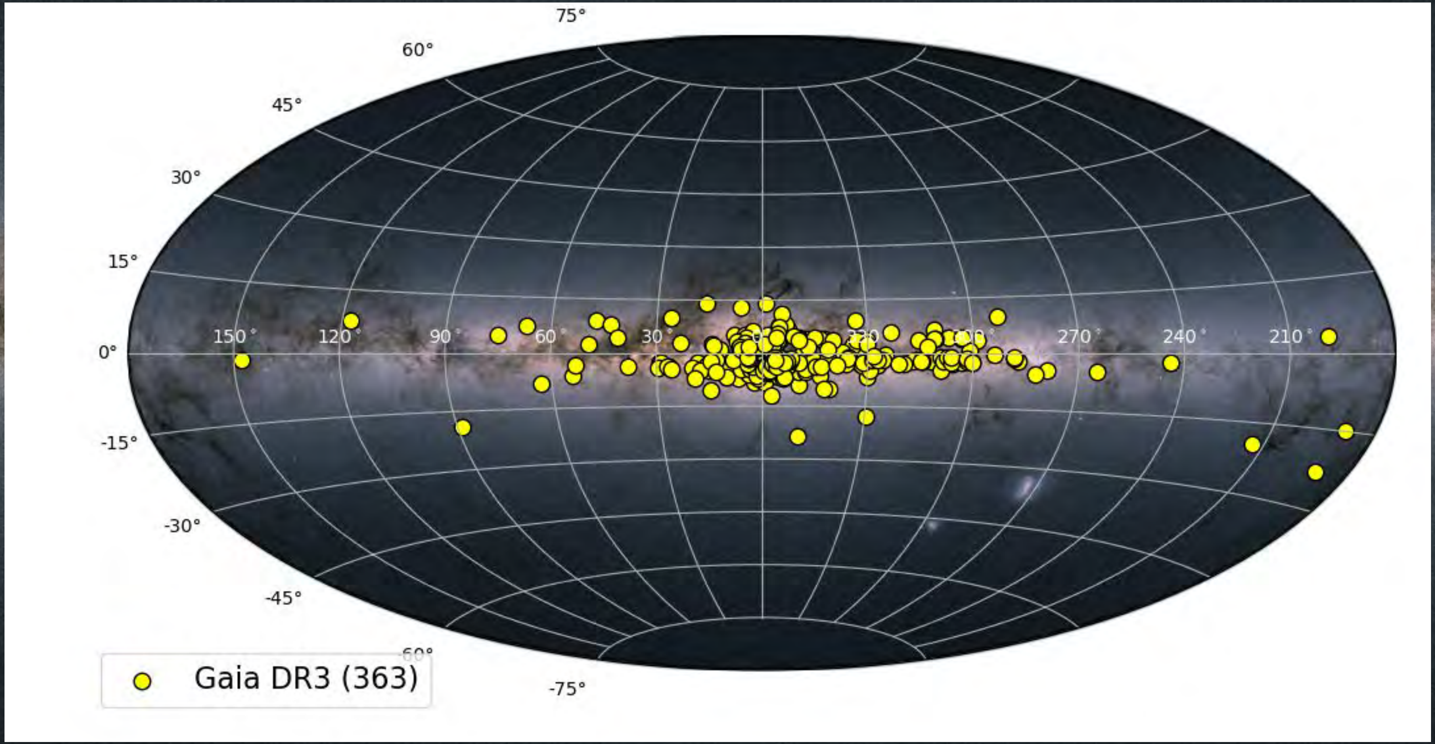
photometry

Source: Gaia19dke, Maskoliunas et al. 2023

Gaia

- European Space Agency satellite
- Launched on 19th December 2013
- End of mission in mid 2025
- Located in the L2 point
- Main goal: precise measurement of the positions and movement of 1 billion stars in the Milky Way
- >2025: DR4 – all data gathered until 2019, including astrometric time-series

Gaia Data Release 3 Microlensing Catalogue

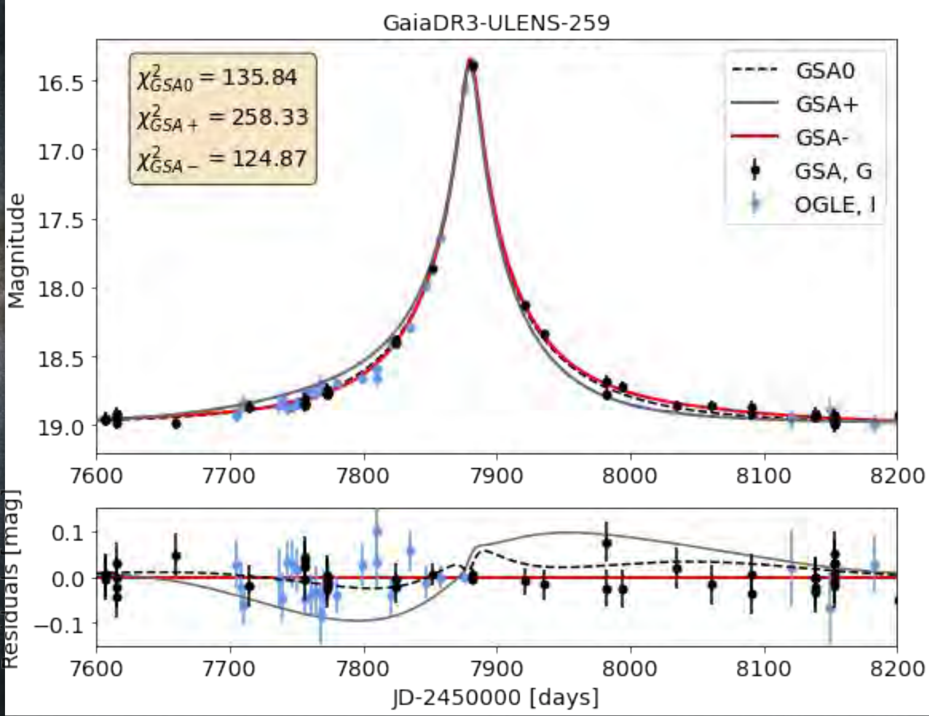


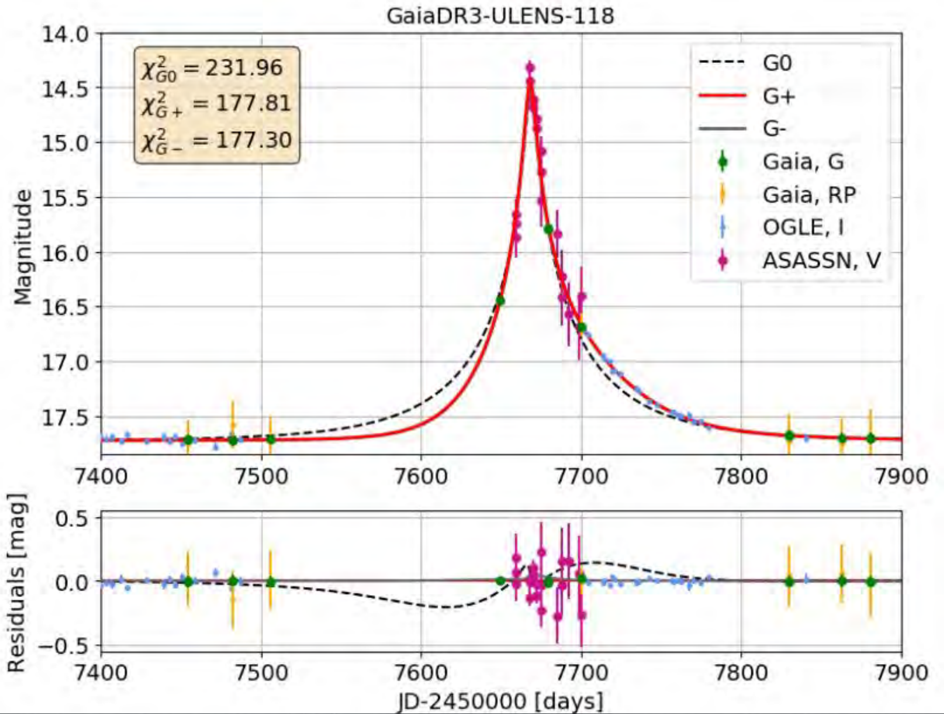
Source: Wyrzykowski et al. 2023

Analysis of selected 35 events

- 35 events from GDR3 microlensing catalog
  - 363 → 35
- Used data from other surveys:
  - OGLE, MOA, KMTNet, ASAS-SN,
- Dark Lens Code: Analysis of lens brightness and Bayesian posteriors for the lens mass and distance (see: Howil et al. in prep)
- 10 events: Lens brightness not consistent with an MS star
- Candidate dark lenses: 8 WD or NS, 2 mass-gap objects or light BH

Examples


GaiaDR3-ULENS-259
$\chi^2_{GSA0} = 135.84$
$\chi^2_{GSA+} = 258.33$
$\chi^2_{GSA-} = 124.87$
GSA0
GSA+
GSA-
GSA, G
OGLE, I
Magnitude
Residuals [mag]
JD-2450000 [days]

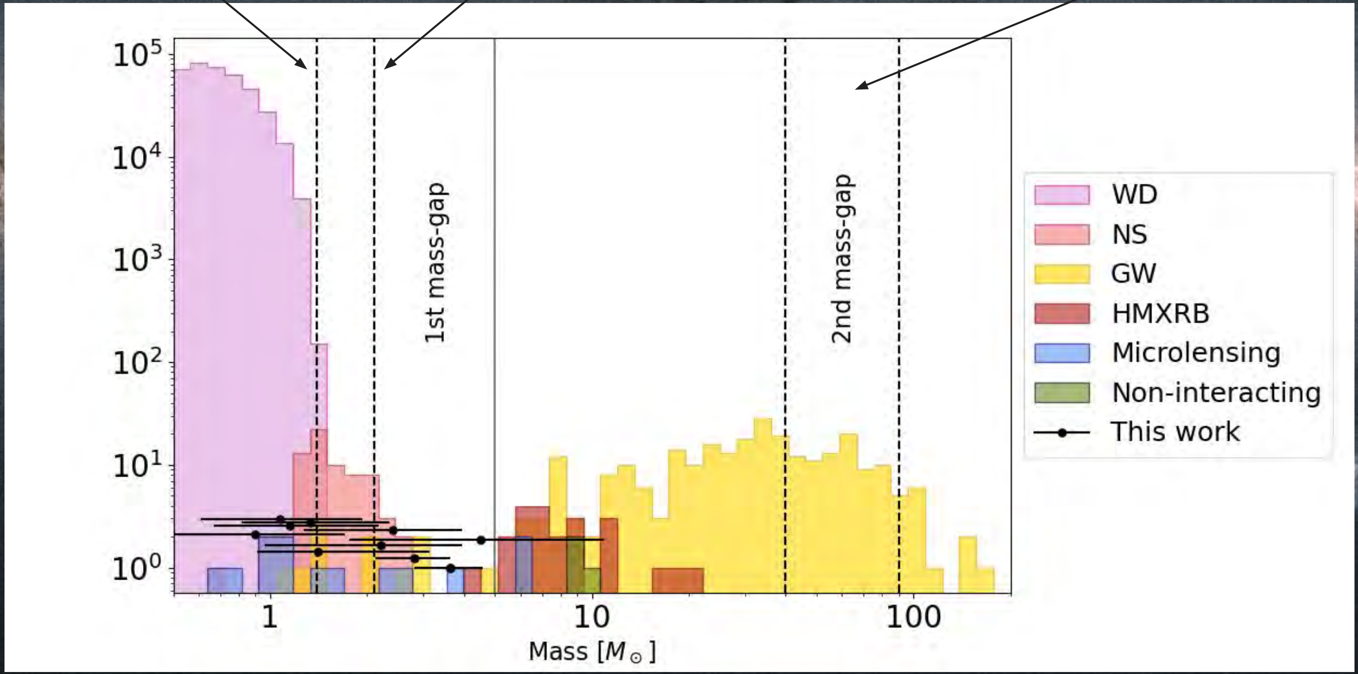

GaiaDR3-ULENS-118
$\chi^2_{G0} = 231.96$
$\chi^2_{G+} = 177.81$
$\chi^2_{G-} = 177.30$
G0
G+
G-
Gaia, G
Gaia, RP
OGLE, I
ASASSN, V
Magnitude
Residuals [mag]
JD-2450000 [days]

End results
Problem 1: Dark remnant mass distribution

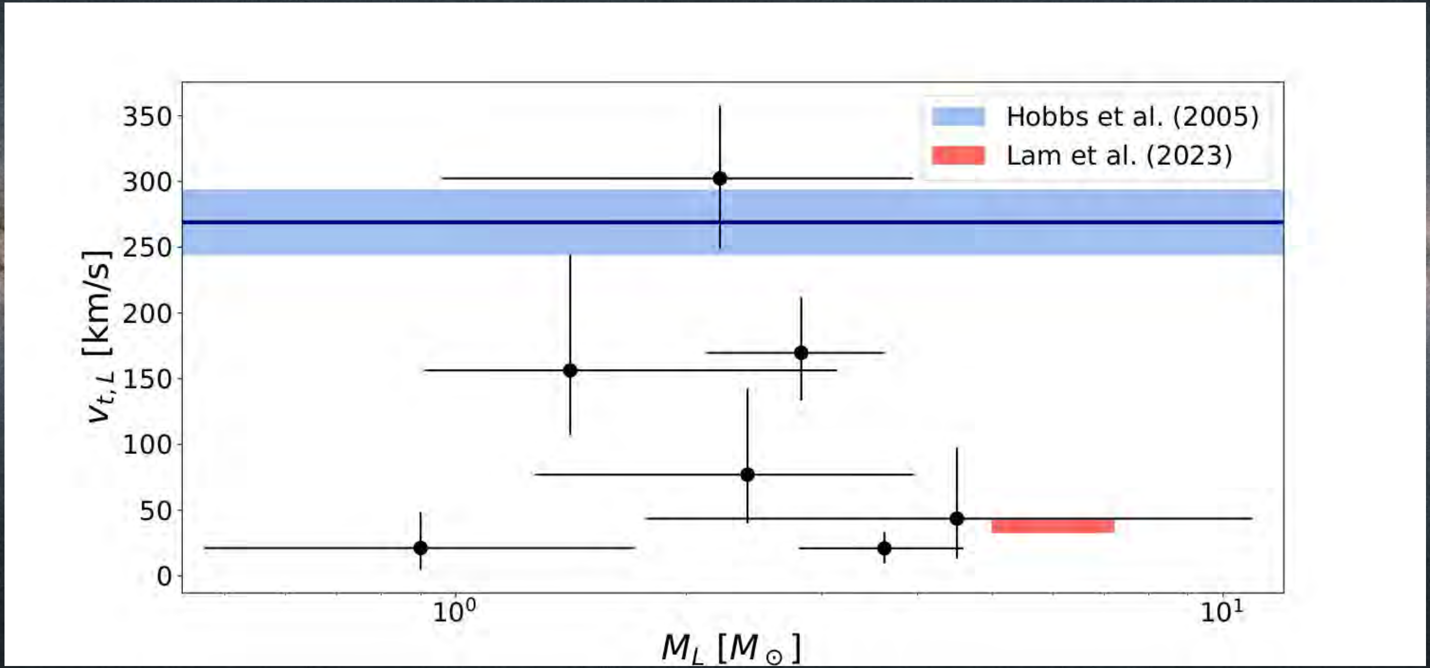
Chandrasekhar limit
1.4 M⊙

TOV limit
2.1 M⊙

Pair-instability SN
40 - 90 M⊙
(Farmer et al. 2020)



End results
Problem 2: Velocity of solitary dark remnants



The future

- Follow-up observations in different bands
  - X-ray, gamma, UV, etc.
- Analysis of astrometric signal in Gaia*
- Applying the same method of mass and distance determination to all events from Gaia Science Alerts

https://arxiv.org/abs/2401.13759