Astrometric Microlensing of Primordial Black Holes with *Gaia*

[arXiv:2208.14460]

IITB-Hiroshima workshop in HEP

Himanshu Verma
(184123004)
Ph.D. 5th year, Department of Physics
IIT Bombay, India
Ph.D. Supervisor: Prof. Vikram Rentala

Feb 22, 2023

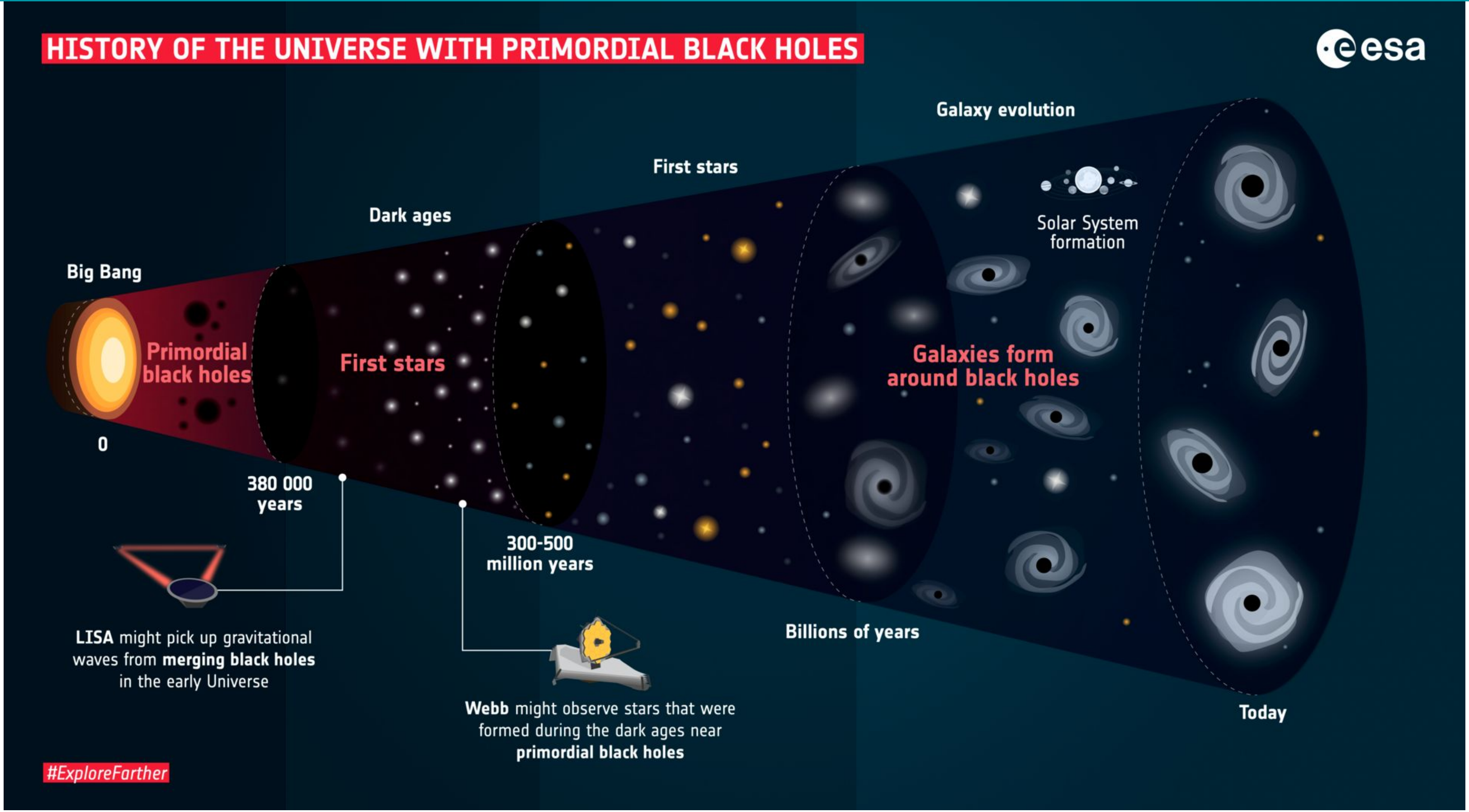
How many **Primordial Black Holes** (PBHs) can be detected by **Gaia Telescope** using the method of **Astrometric Microlensing**?

Assumption: PBHs are Dark matter

Plan

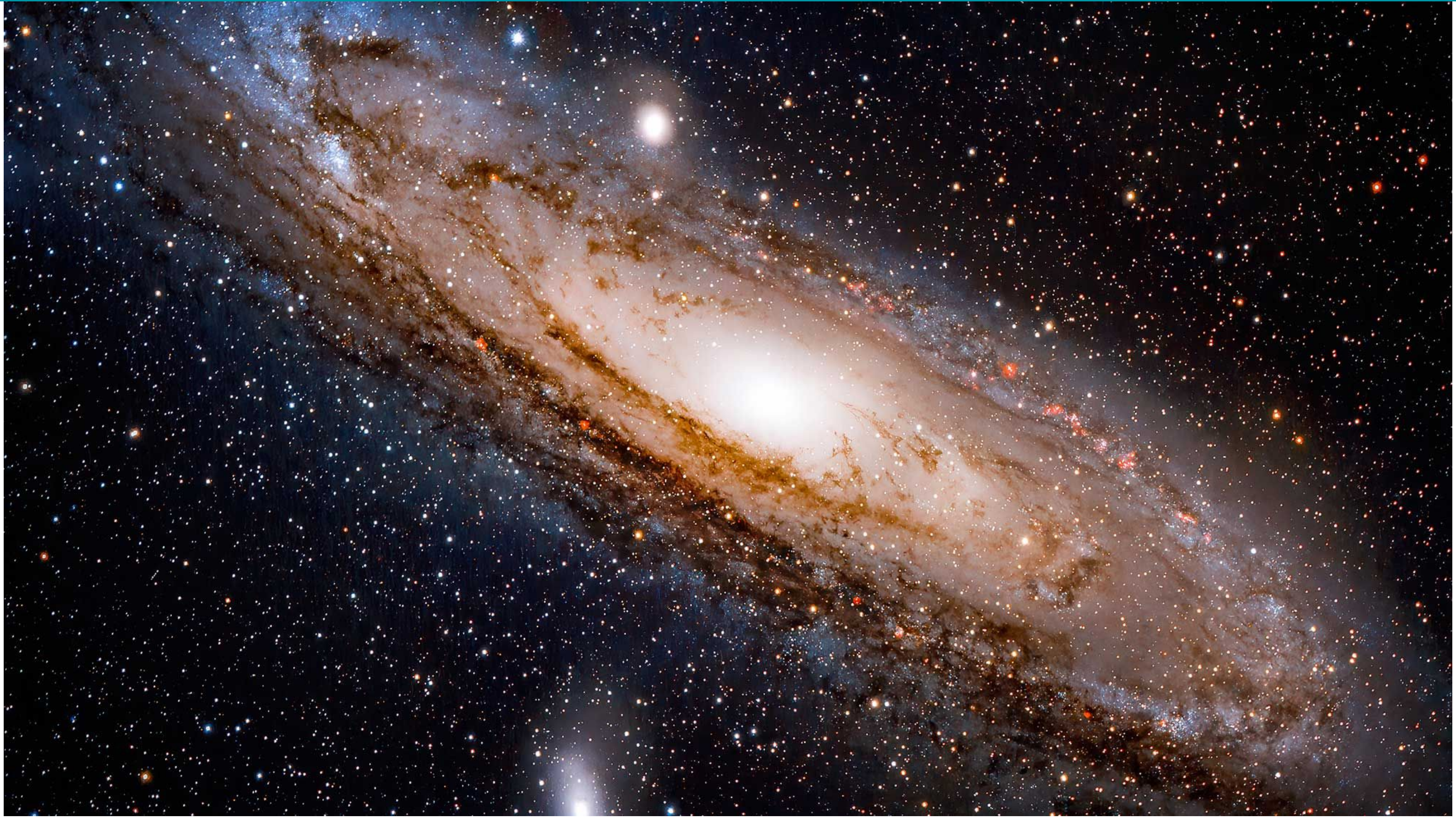
1. Primordial Black Holes (PBHs)
2. Astrometric Microlensing
3. Gaia Telescope
4. Number of PBHs observed by Gaia
5. Potential Constraints

Primordial Black Holes



PC: European Space Agency

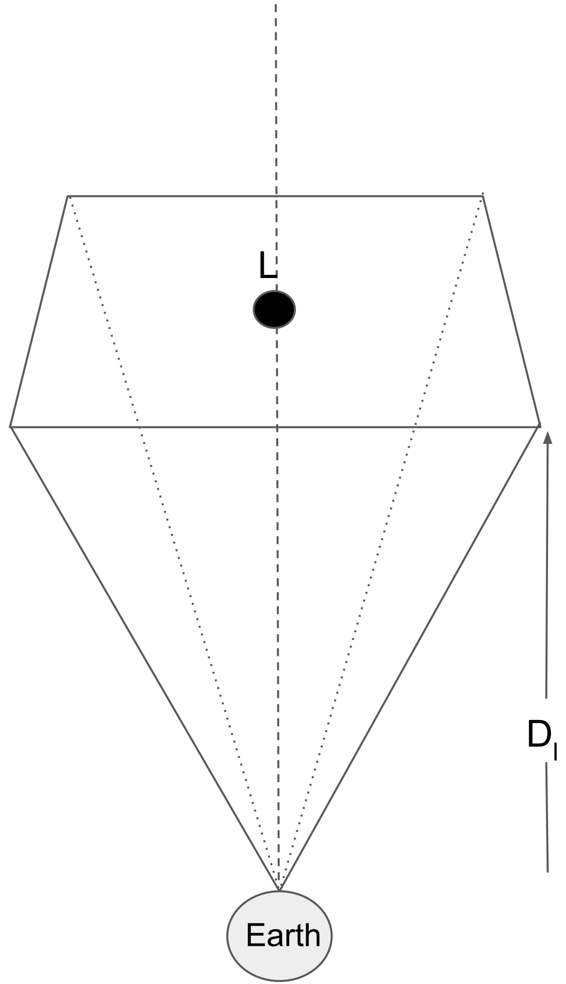
Primordial Black Holes as Dark Matter?



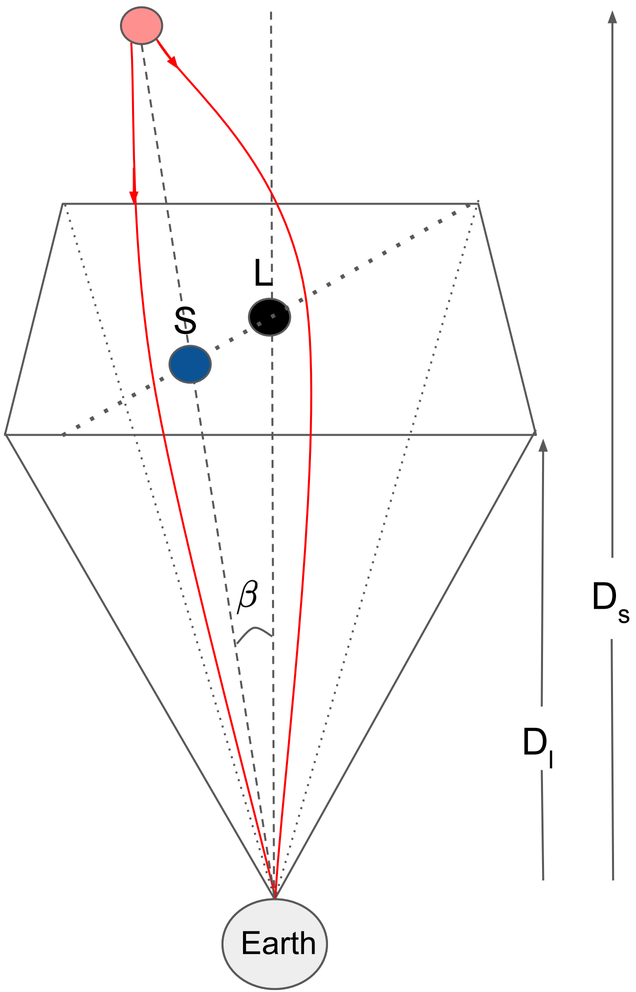
PC: Iván Éder; HST ACS/HRC

Phenomenon of Astrometric Microlensing

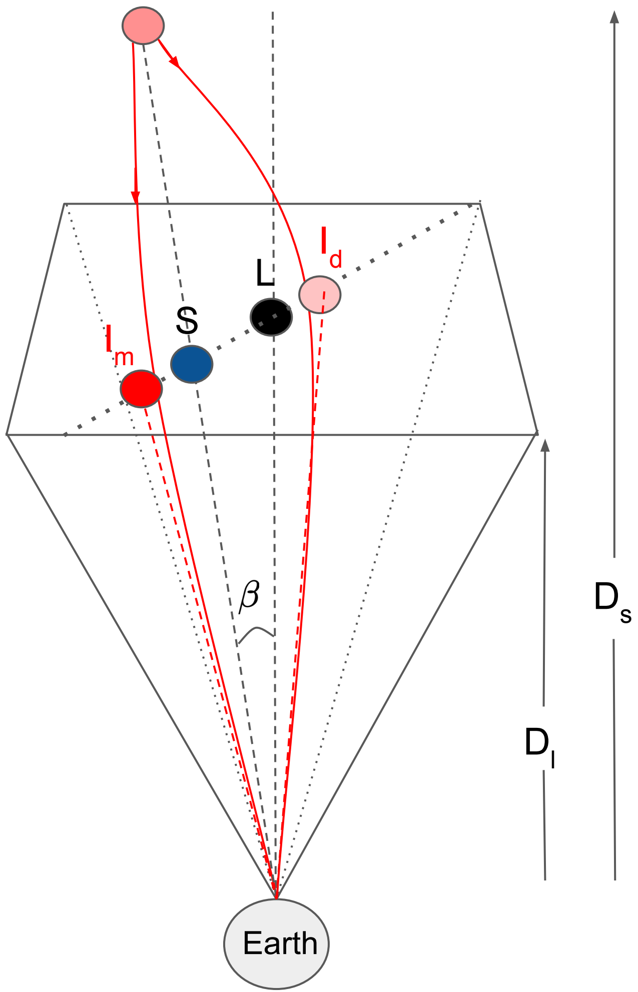
Phenomenon of Astrometric Microlensing



Phenomenon of Astrometric Microlensing



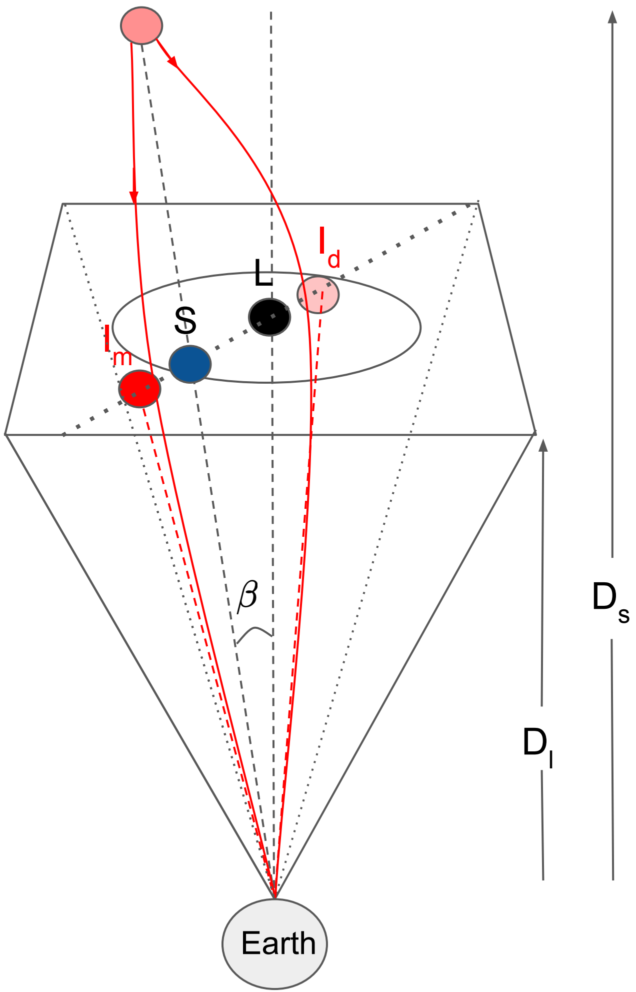
Phenomenon of Astrometric Microlensing



Phenomenon of Astrometric Microlensing

Einstein Angle

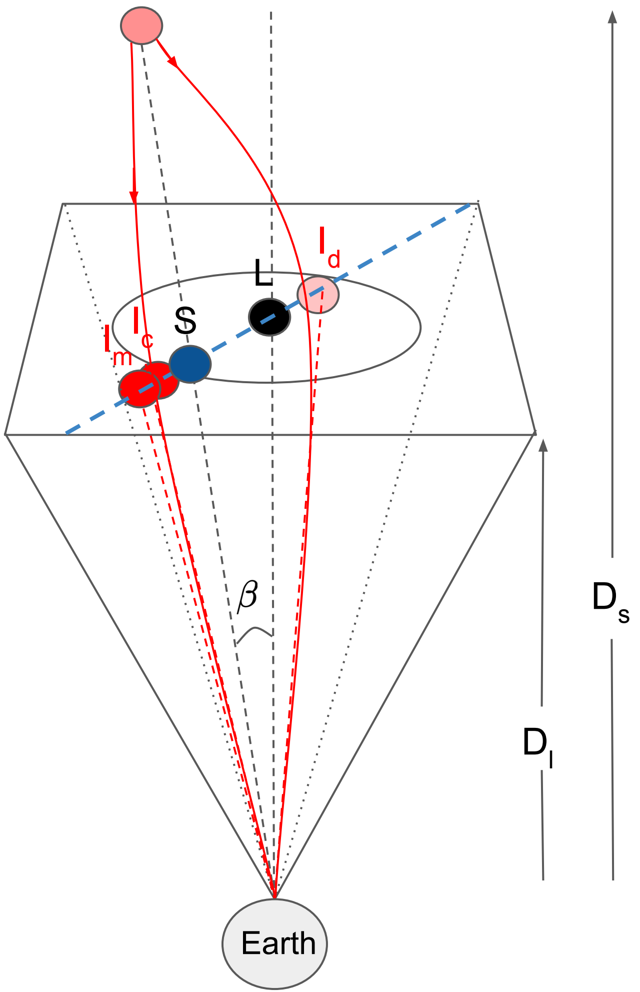
$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10\ \mathrm{M}_\odot} \frac{10 \text{ kpc}}{D_s} \left(\frac{D_s}{D_l} - 1\right)}$$



Phenomenon of Astrometric Microlensing

Einstein Angle

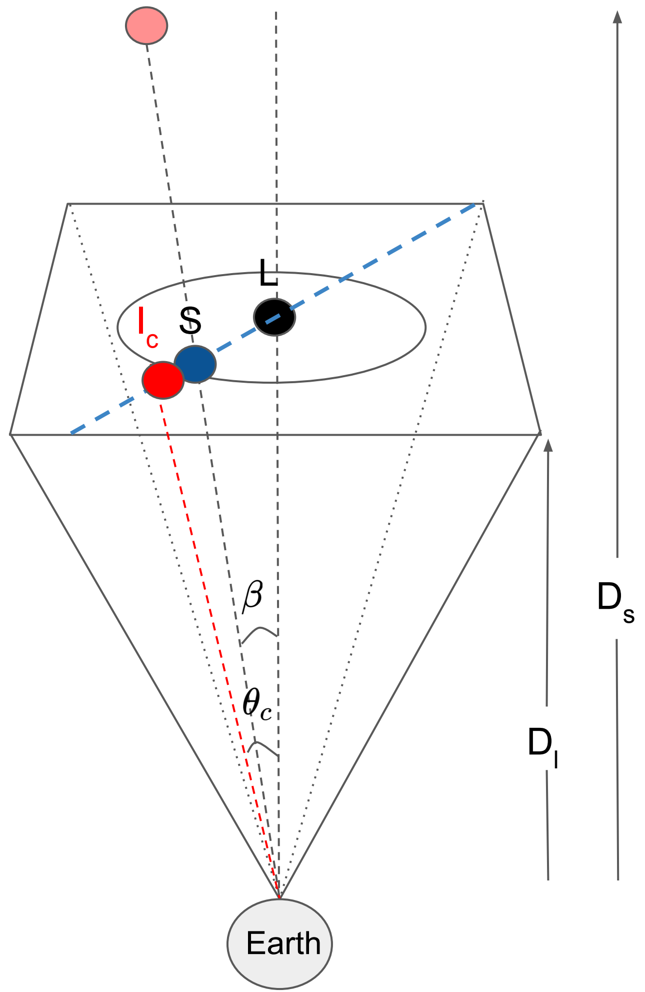
$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10\ \mathrm{M}_\odot} \frac{10 \text{ kpc}}{D_s} \left(\frac{D_s}{D_l} - 1\right)}$$



Phenomenon of Astrometric Microlensing

Einstein Angle

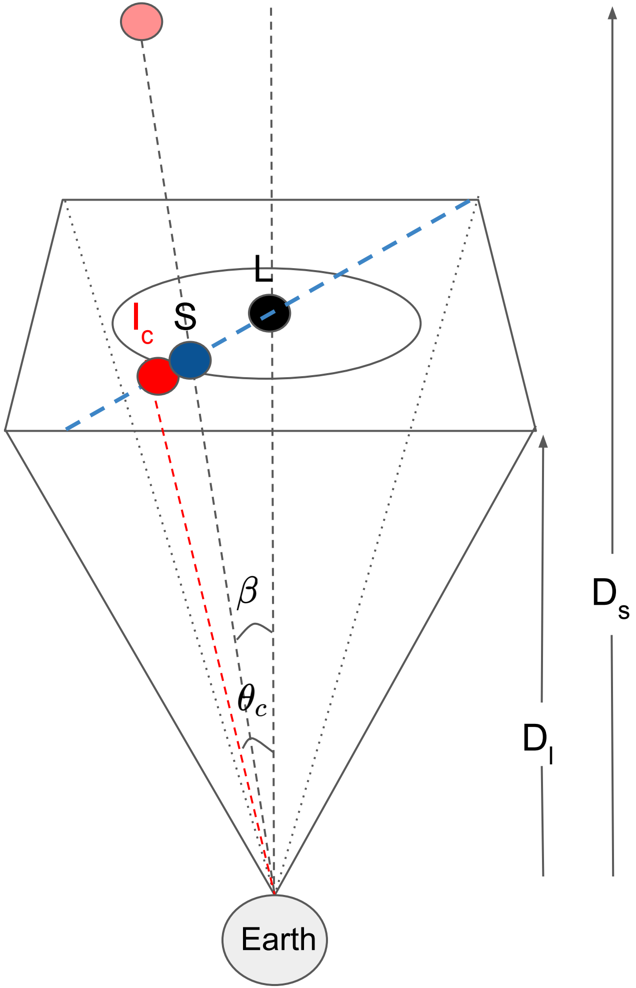
$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10 \text{ M}_\odot} \frac{10 \text{ kpc}}{D_s} \left(\frac{D_s}{D_l} - 1 \right)}$$



Phenomenon of Astrometric Microlensing

Einstein Angle

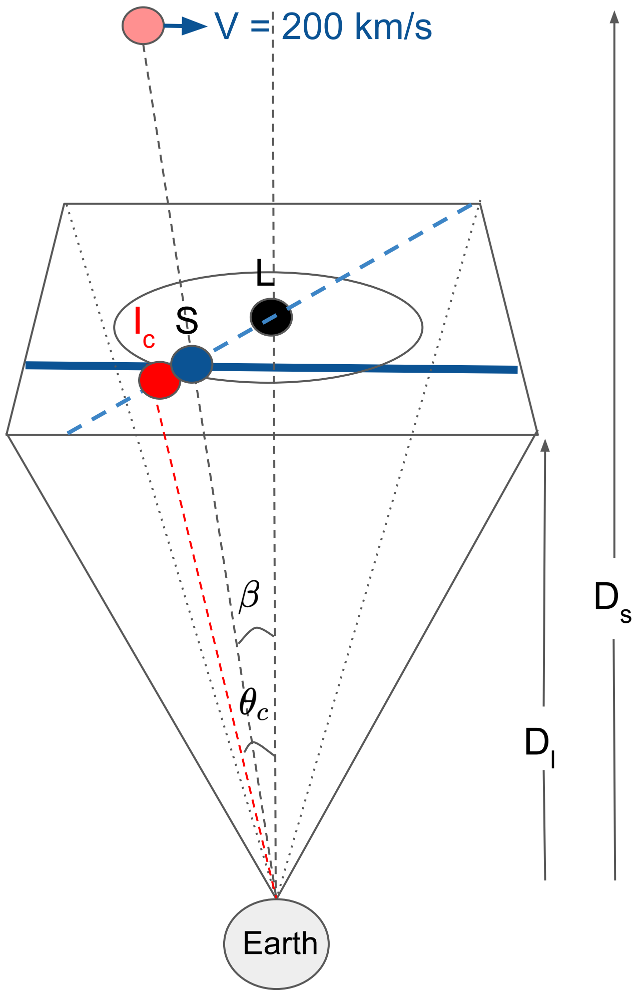
$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10\ \mathrm{M}_\odot} \frac{10\ \mathrm{kpc}}{D_s} \left(\frac{D_s}{D_l} - 1\right)}$$



Phenomenon of Astrometric Microlensing

Einstein Angle

$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10\ \mathrm{M}_\odot} \frac{10 \text{ kpc}}{D_s} \left(\frac{D_s}{D_l} - 1\right)}$$



Phenomenon of Astrometric Microlensing

Astrometric Microlensing

Time varying Angular Shift in the Centroid

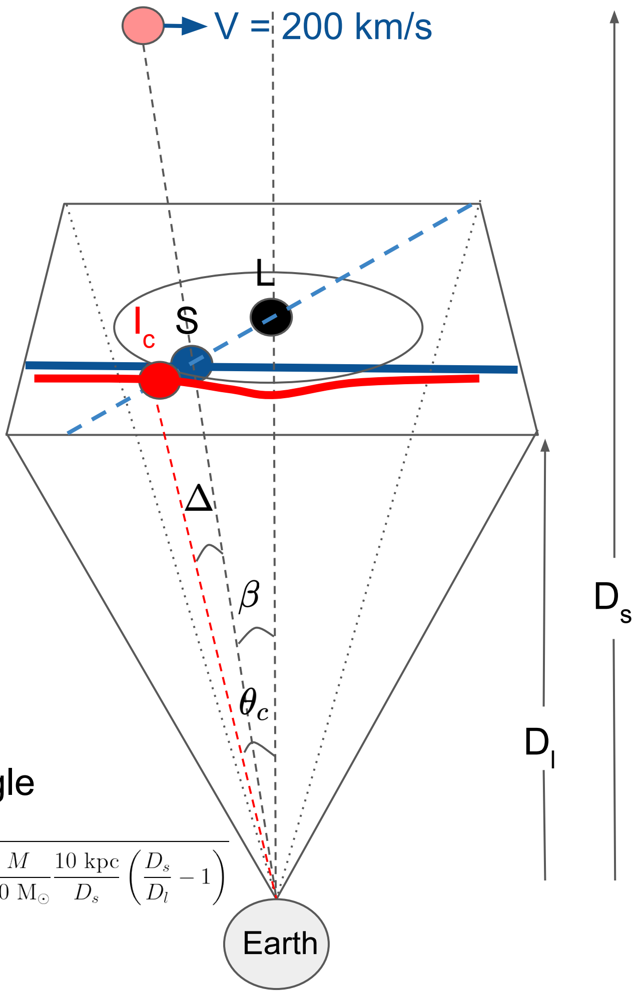
$$\vec{\Delta}(t) = \frac{\theta_E^2 \vec{\beta}(t)}{2\theta_E^2 + \beta(t)^2}$$

$$\vec{\beta}(t) = \frac{v}{D_l} t\,\hat{x} + \theta_0 \hat{y}$$

$$\mu_c(t) - 1 = \frac{\beta(t)^2 + 2\theta_E^2}{\beta(t)\sqrt{\beta(t)^2 + 4\theta_E^2}} - 1$$

Time varying change in the Magnification of Centroid

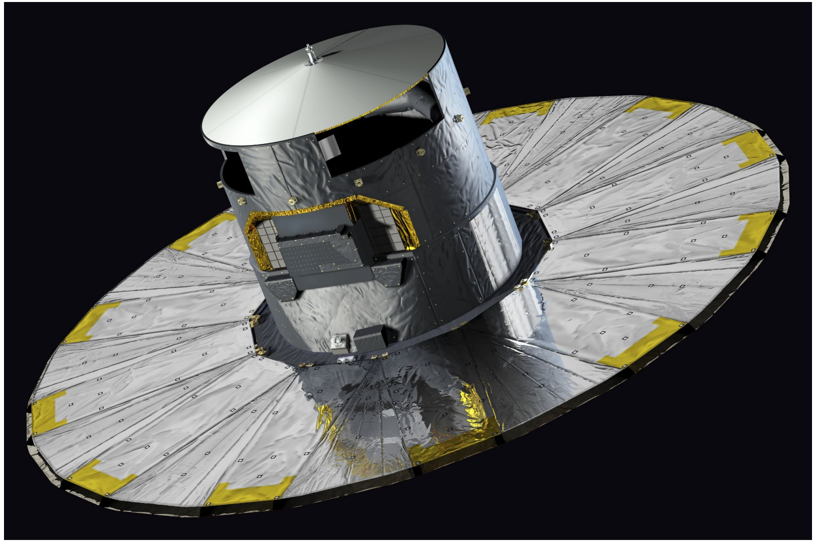
Photometric Microlensing

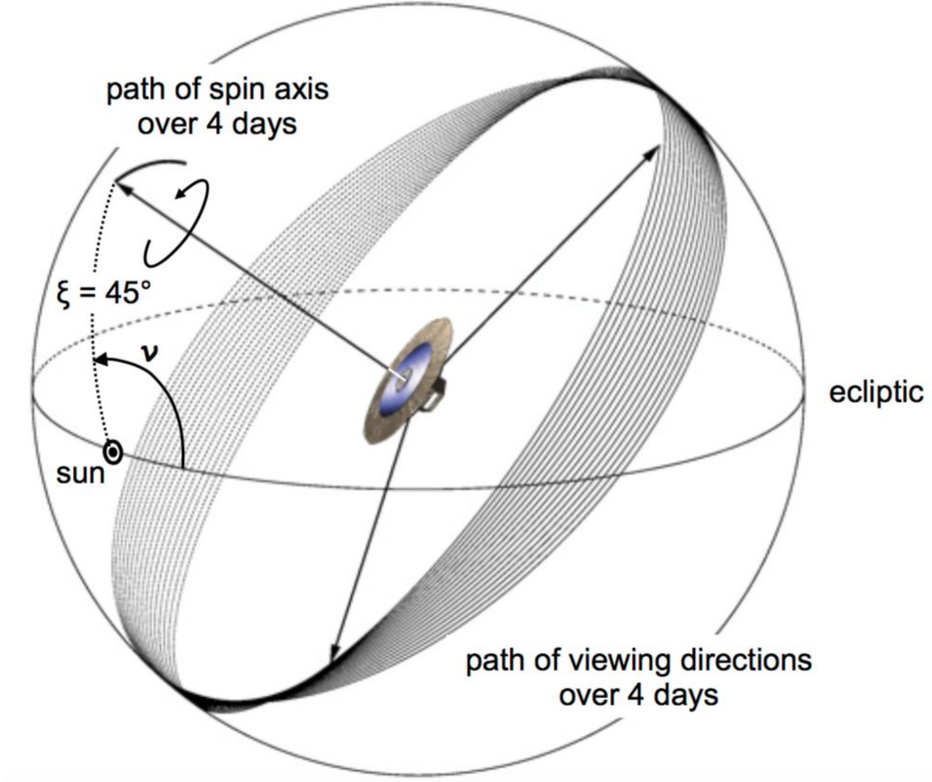


Einstein Angle

$$\theta_E \approx 2.854 \text{ mas} \sqrt{\frac{M}{10\ M_\odot} \frac{10 \text{ kpc}}{D_s} \left(\frac{D_s}{D_l} - 1\right)}$$

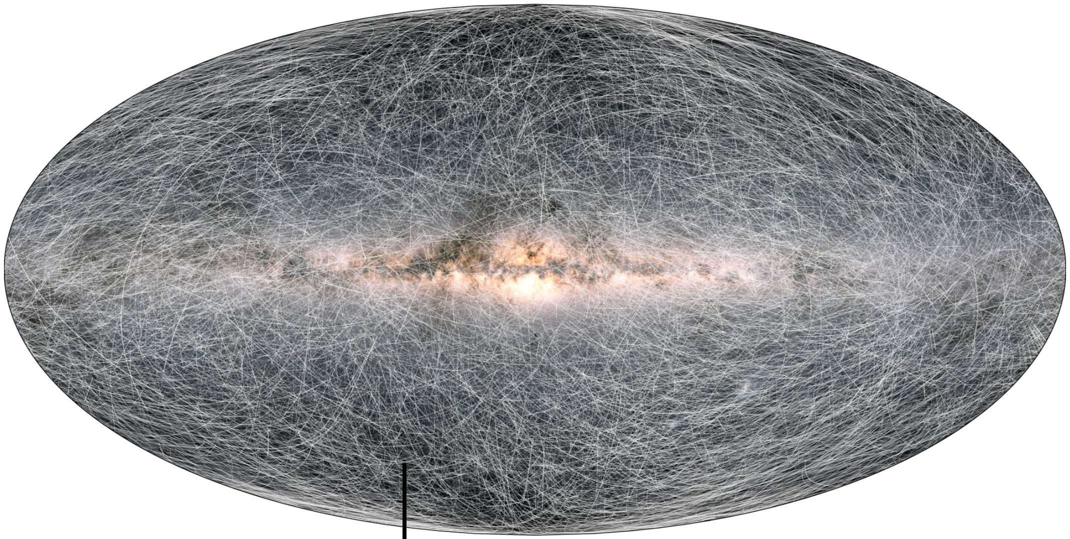
Gaia (Global Astrometric Interferometer for Astrophysics) Telescope





PC: Gaia ESA

Output of Gaia Telescope

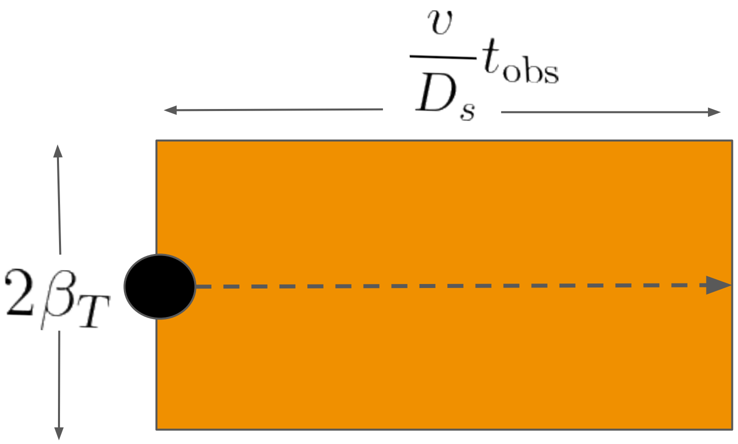


Time Series data of more than **a billion** stars

PC: Gaia ESA

Number of PBHs potentially observed by Gaia

Sensitive area around PBHs

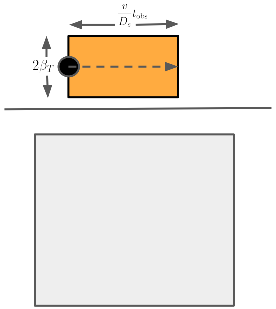


Probability of a star to be detected with AML signal

Fixing a PBH dark matter hypothesis $\left(f=\frac{\rho_{\mathrm{PBH}}}{\rho_{\mathrm{DM}}}, M\right)$

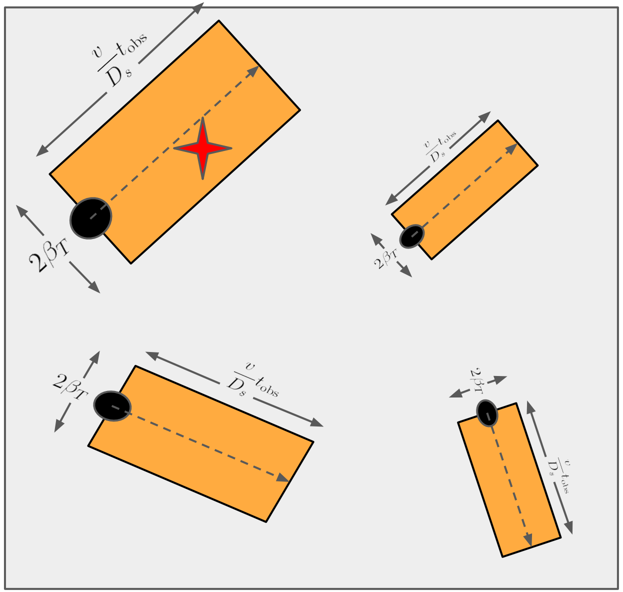
For each star with properties $(D_s,\ \alpha,\ \delta,\ m_G)$

$P_{star} = \sum_{D_l=0}^{D_s}$

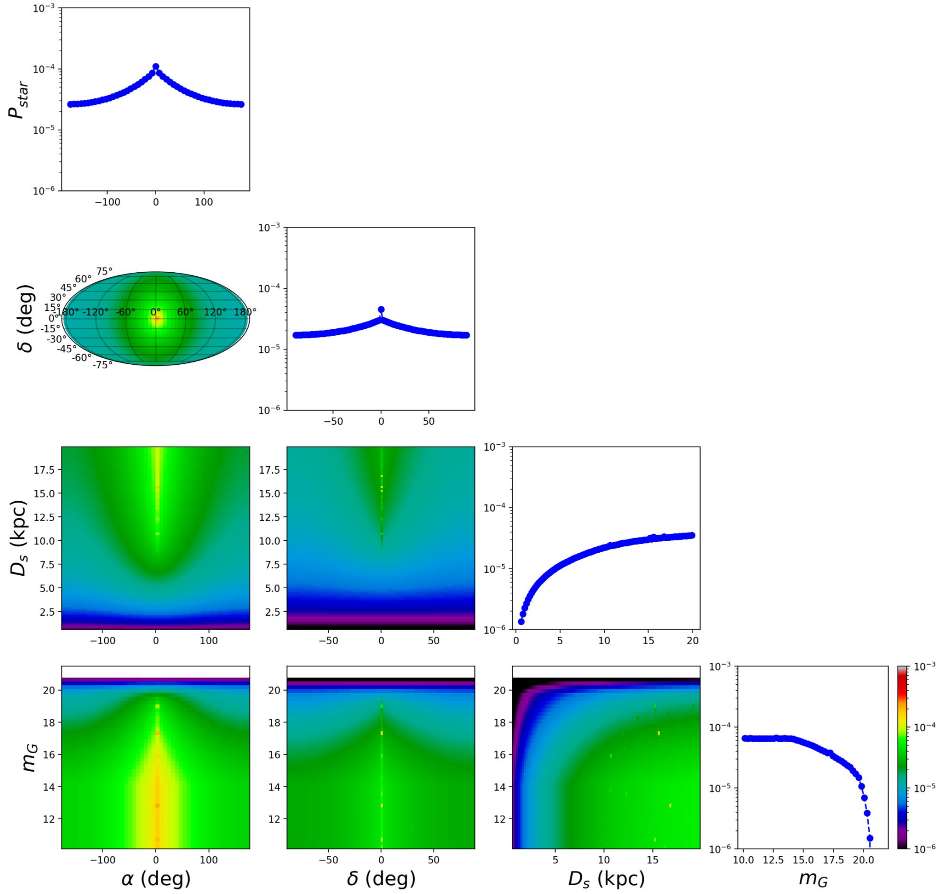


$$= \int_0^{D_s} \Delta\Omega\, dD_l D_l^2 \frac{f}{M}\rho_{DM}(D_s,\alpha,\delta)\frac{2\frac{v}{D_s}t_{\mathrm{obs}}\beta_T}{\Delta\Omega}$$

Counting # of lenses in between us and the star at (D_s, α, δ)

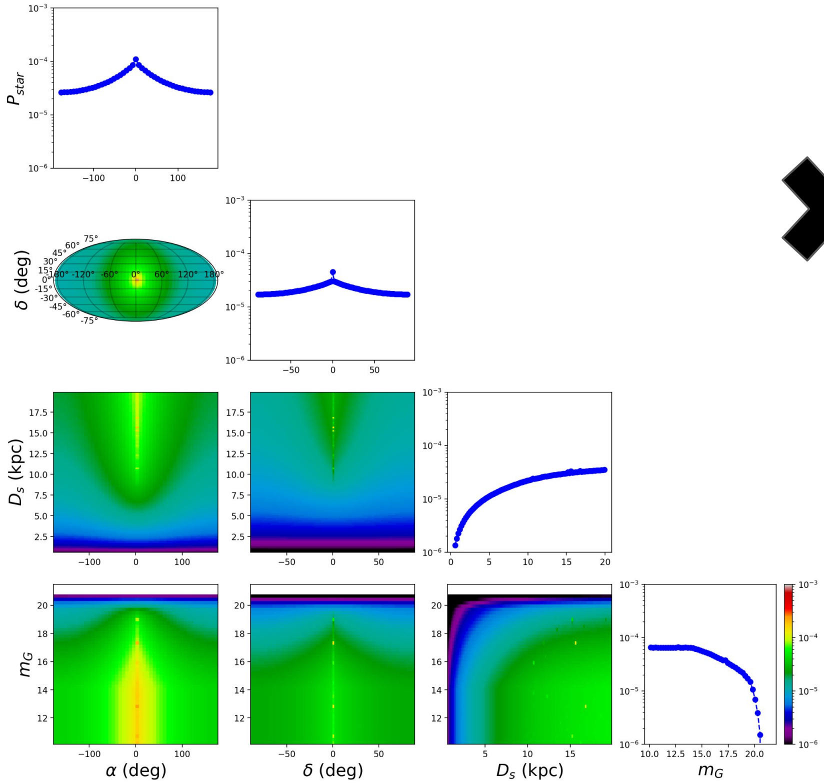


$$P_{\rm star}(f=1,\ M\ =\ 14\,M_{\odot};D_s\ ,\alpha,\ \delta,\ m_G)$$



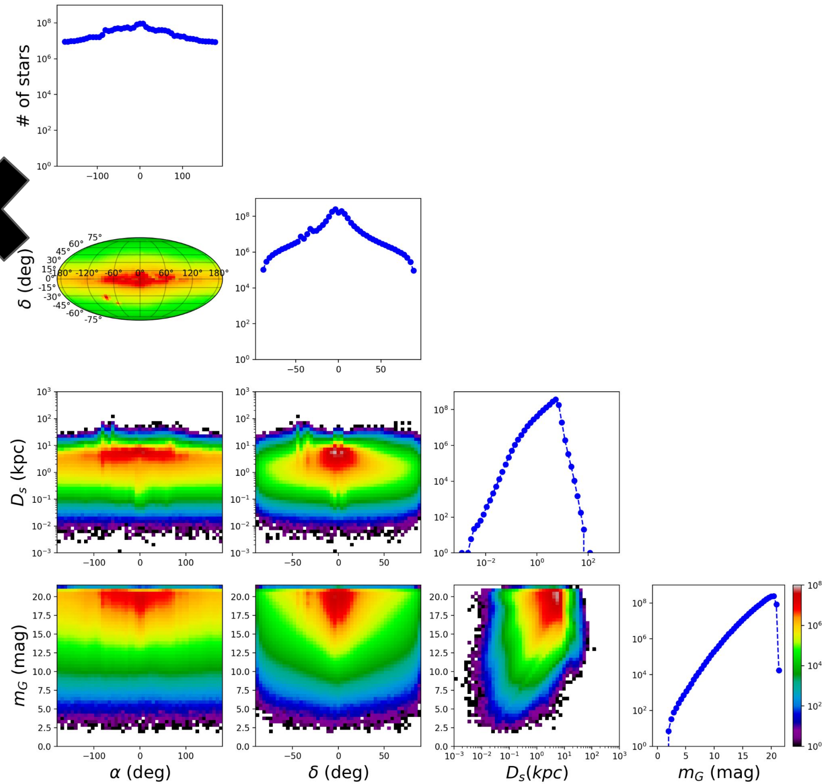
ArXiv: 2208.14460

Calculated probability



$$P_{\rm star}(f=1,\ M\ =\ 14\,M_{\odot};D_s\ ,\alpha,\ \delta,\ m_G)$$

Observed Gaia eDR3 catalog

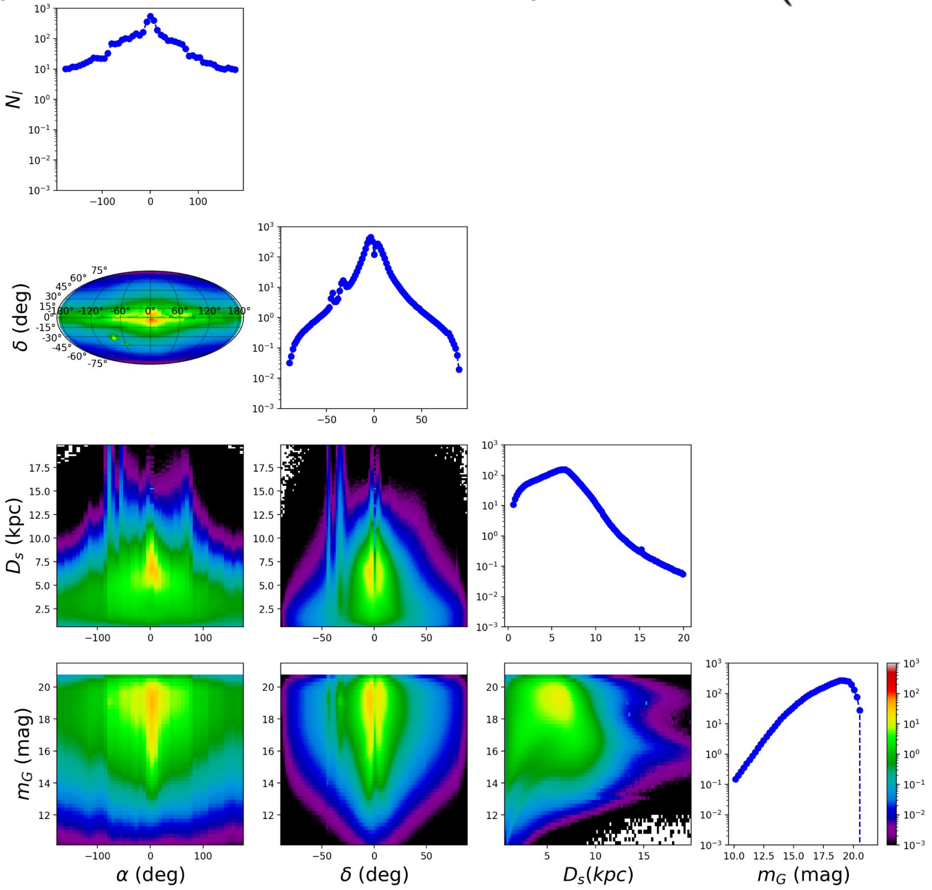


$$N_{\rm star}^{\rm eDR3}(D_s,\ \alpha,\ \delta,\ m_G)$$

ArXiv: 2208.14460

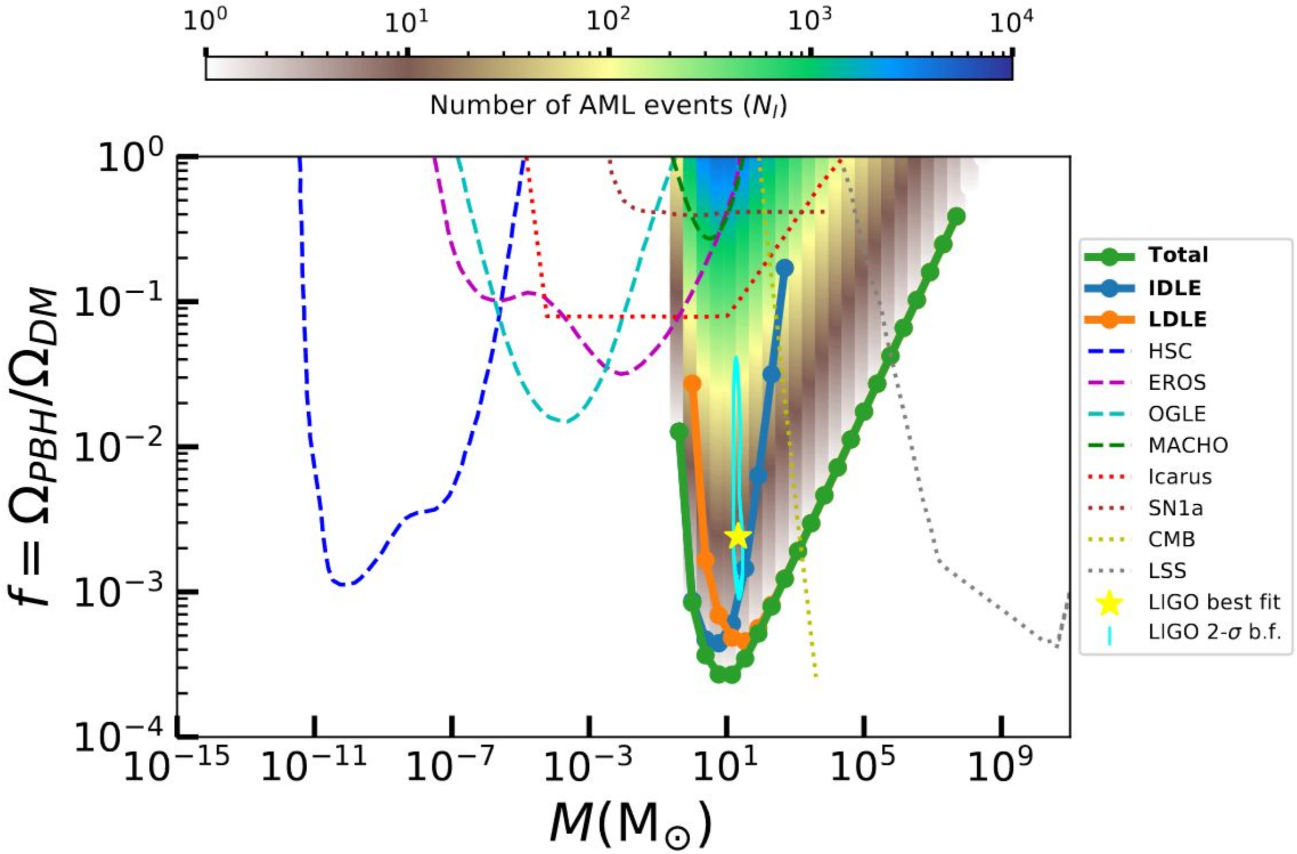
Number of PBHs potentially observed by Gaia

$$N_l(f = 1, M = 14\,M_\odot) = \Sigma_{\rm star}\left(P_{\rm star} \otimes N_{\rm star}^{\rm eDR3}\right)$$



ArXiv: 2208.14460

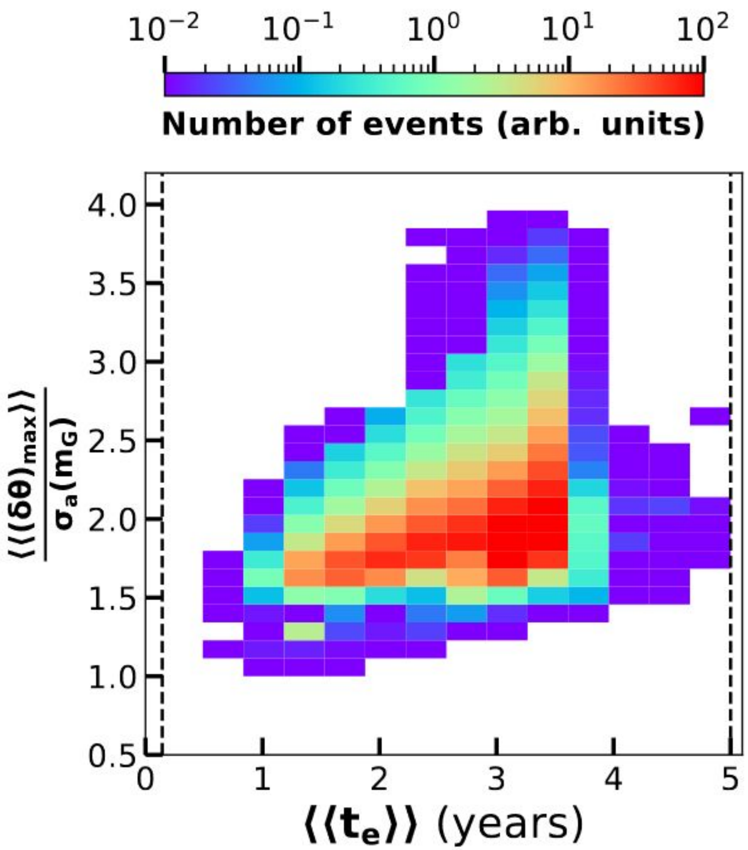
If any PBHs are NOT observed by Gaia: Potential Constraints



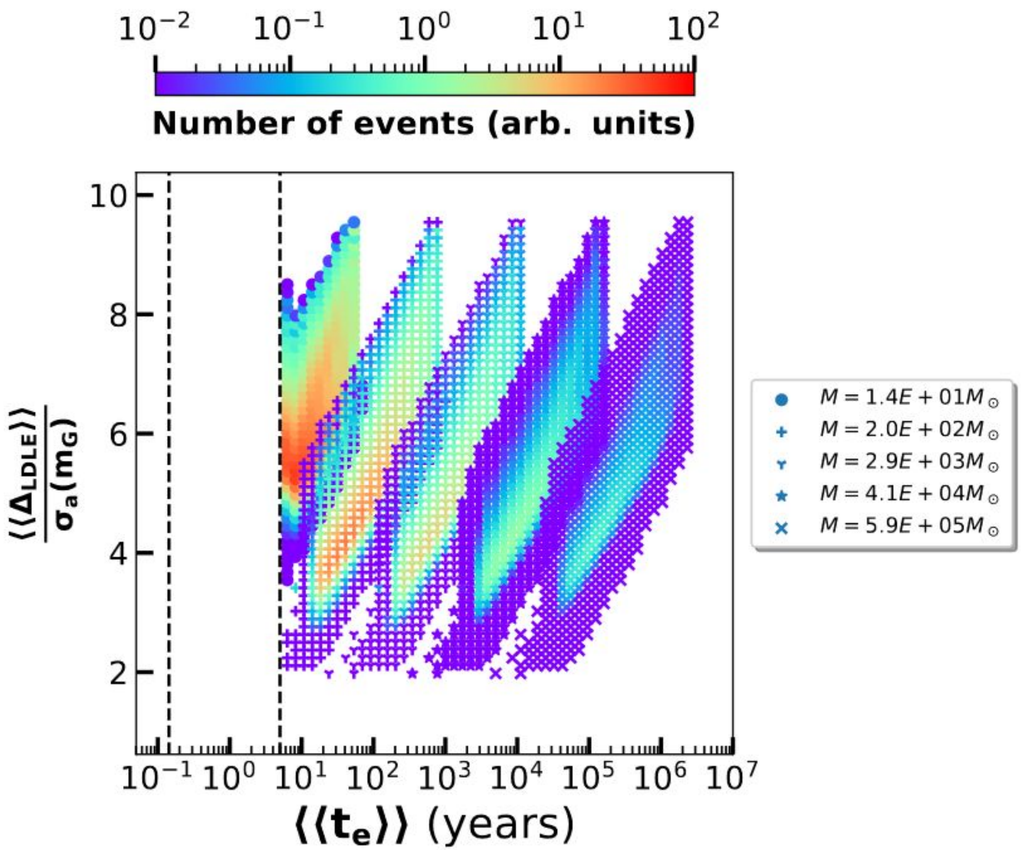
ArXiv: 2208.14460

Thank you!

Backup Slides



(a) IDLE observables



(b) LDLE observables

ArXiv: 2208.14460

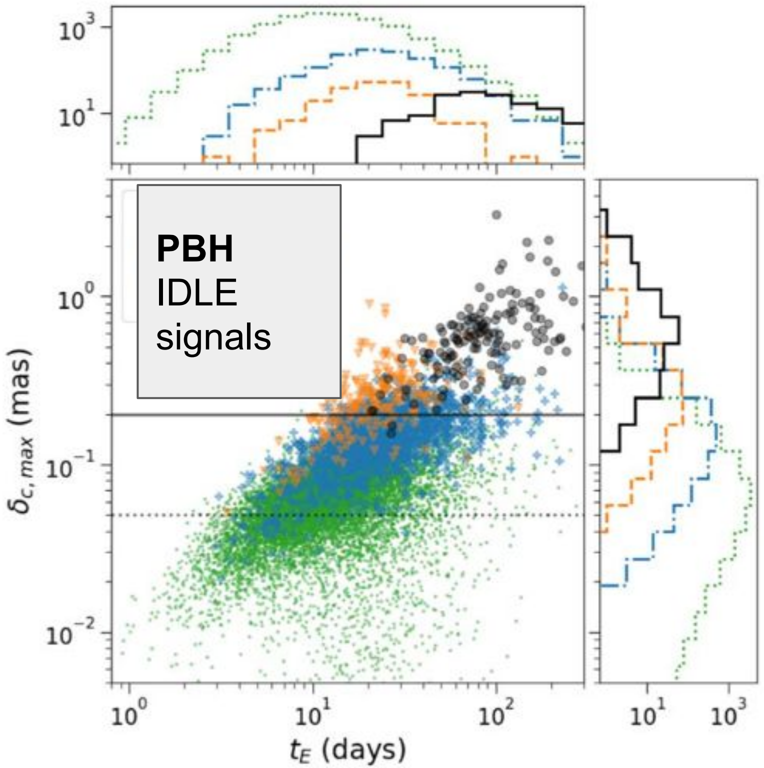
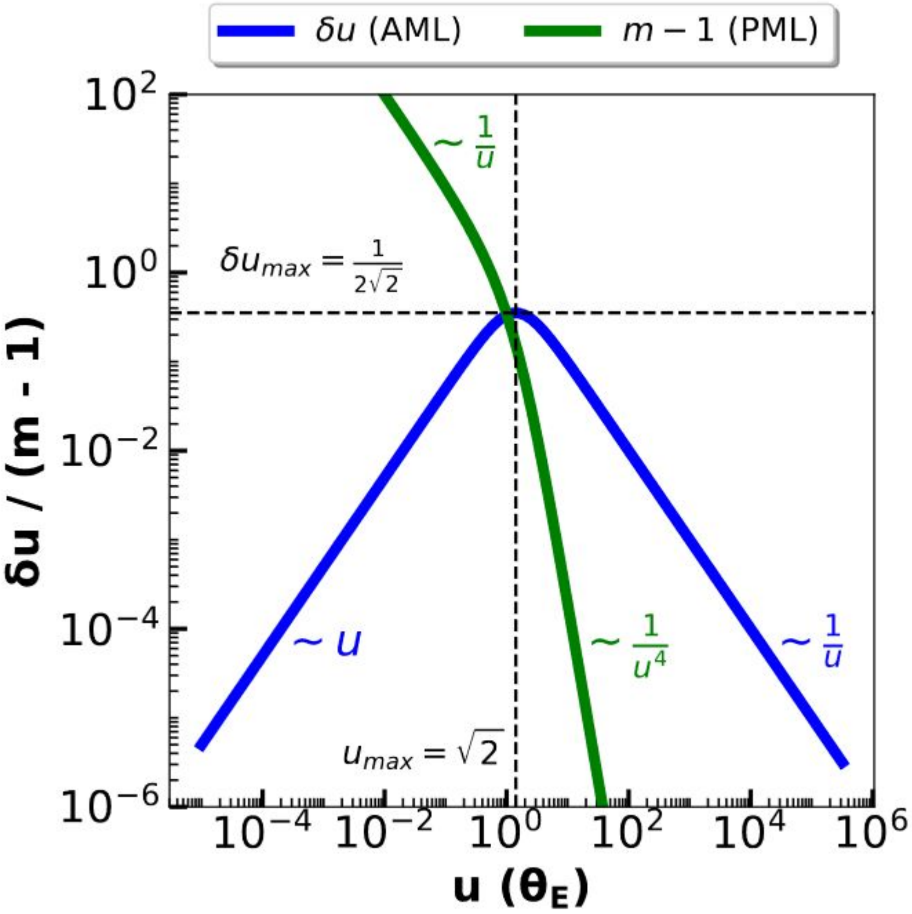
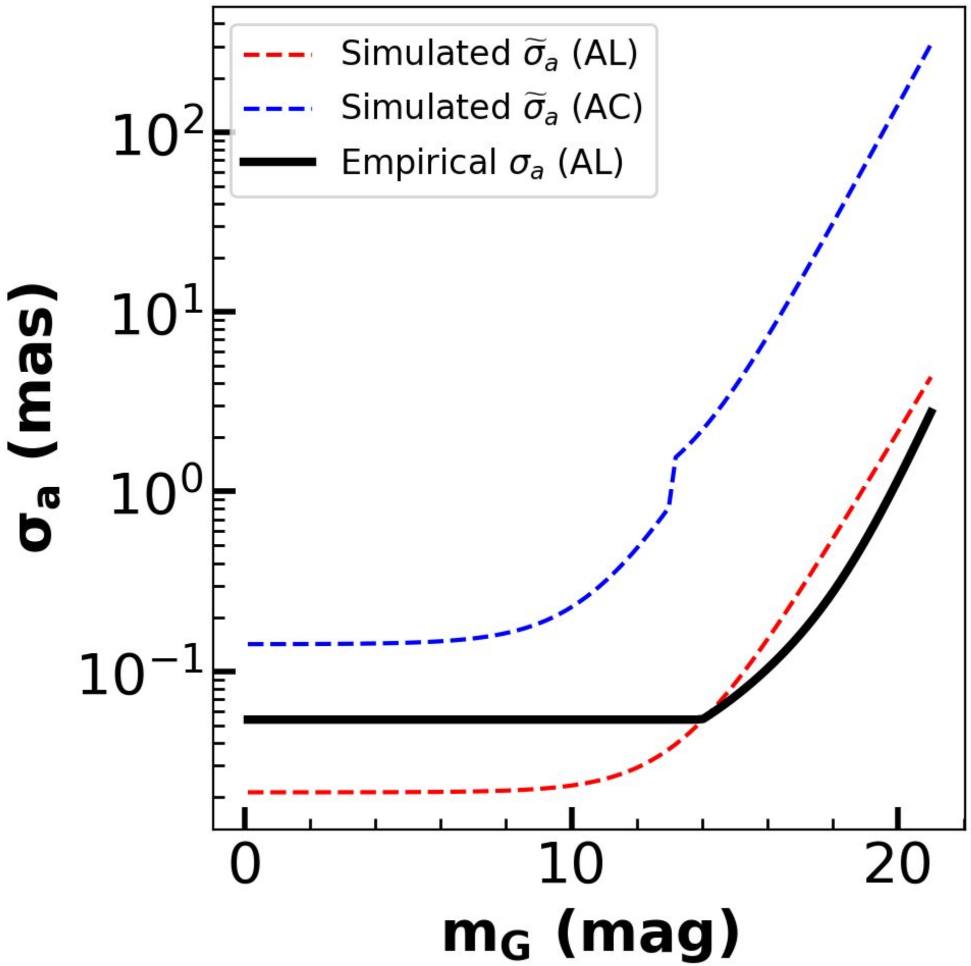


Figure 14. Maximum astrometric shift $\delta_{c,\mathrm{max}}$ vs. the Einstein crossing time t_E. We assume blending between the lens and source when calculating $\delta_{c,\mathrm{max}}$. The solid line denotes the achievable astrometric precision of ~0.2 mas using the Keck laser guide star adaptive optics system (Lu et al. 2016). The dotted line denotes anticipated astrometric precision achievable in the next decade (e.g., ~0.05 mas, using *WFIRST* or the Thirty Meter Telescope). The points correspond to microlensing events in the Mock EWS simulation.

Casey Lam & Jessica Lu et al. 2020



ArXiv: 2208.14460



ArXiv: 2208.14460