Title: Kicking the tires on picolensing as a probe of primordial black hole dark matter

Speakers: Michael Fedderke

Collection/Series: Particle Physics

Subject: Particle Physics

Date: October 08, 2024 - 1:00 PM

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Abstract:

Primordial black hole (PBH) dark matter can be probed by "picolensing". Widely spatially separated gamma-ray detectors near Earth would observe parallax of an intervening PBH lens with respect to a cosmologically distant gamma-ray burst (GRB). This parallax can be of order the Einstein angle of the lens, resulting in differential magnification of the source as viewed from the two detectors. Simultaneous brightness measurements of the same GRB made by two detectors is sensitive to this effect. Two recent studies in the literature have shown this approach could be a promising way to search for PBH dark matter in part of the "asteroid mass window", roughly (few) * 1e-15 < M_{PBH} / M_{Sun} < (few) * 1e-11. In this talk, I will discuss some ongoing work to explore the robustness of this signal to various uncertainties not previously carefully accounted for: e.g., uncertainties in the transverse extent of the GRB emission region, its intensity profile, detector background rates, sensitivity of the projection to outlier GRB events, etc. I'll show that, while the large GRB source size uncertainties do degrade previous projections somewhat, it is still possible to probe most of the PBH DM asteroid mass window with a mission that employs two Swift/BAT-class detectors separated by a distance on the order of an AU. Depending on the total number of GRBs that such a mission ultimately observes, it may even be possible to robustly probe new subcomponent dark-matter parameter space at PBH masses above the window, potentially as high as (few) * 1e-6 M_{Sun}.

Kicking the tires on picolensing as a probe of primordial black hole DM

Particle Theory Seminar
Perimeter Institute
Waterloo, ON, Canada

October 8, 2024

Ongoing work [241x.yyyzz]
M.A.F. and Sergey Sibiryakov

Michael A. Fedderke

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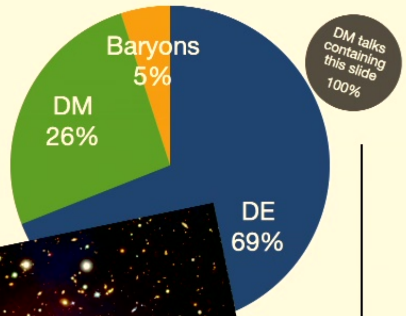
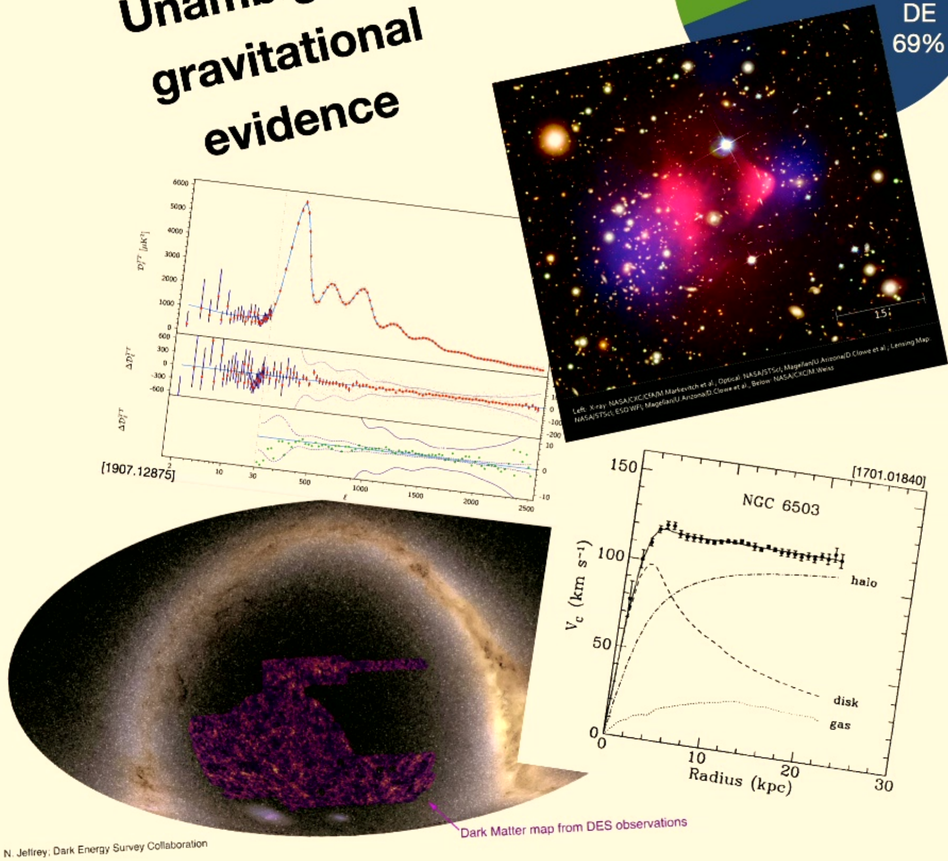
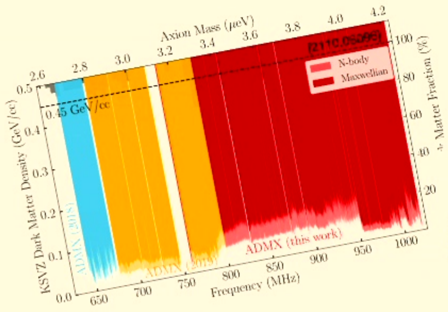
PERIMETER INSTITUTE

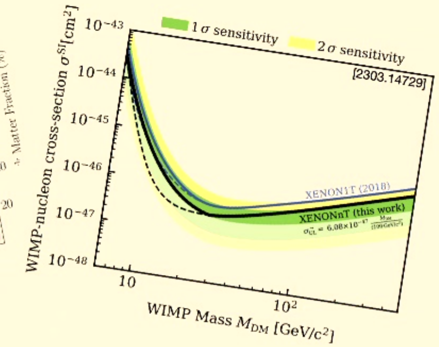
Dark Matter



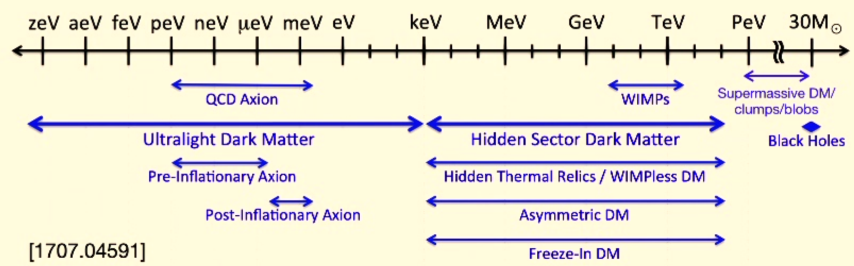
Unambiguous gravitational evidence







No direct, non-gravitational evidence … yet



[1707.04591]

Huge number of possibilities, over many orders of magnitude in mass

Michael A. Fedderke [Perimeter]

Primordial black holes (PBH)

GRAVITATIONALLY COLLAPSED OBJECTS OF VERY LOW MASS

Stephen Hawking

For the purposes of this talk: sub-solar mass black holes $M_{PBH} \ll M_\odot$

Production in the early universe via:

$$M \sim \frac{c^3 t}{G} \sim 10^{15} \left(\frac{t}{10^{-23}\,\mathrm{s}}\right) \mathrm{g}.$$

- Sharp features in the inflationary power spectrum. When these re-enter, direct collapse to BH ensues if density perturbation is large enough $\beta \approx \mathrm{Erfc}\left[\frac{\delta_c}{\sqrt{2}\,\sigma}\right].$
  see also [2410.03451]
- Collisions of bubble walls from primordial first-order phase transitions
- … many other variations on these themes

agnostic to the production mechanism

Annu. Rev. Nucl. Part. Sci. 2020. 70:355–94
Bernard Carr[1] and Florian Kühnel[2]

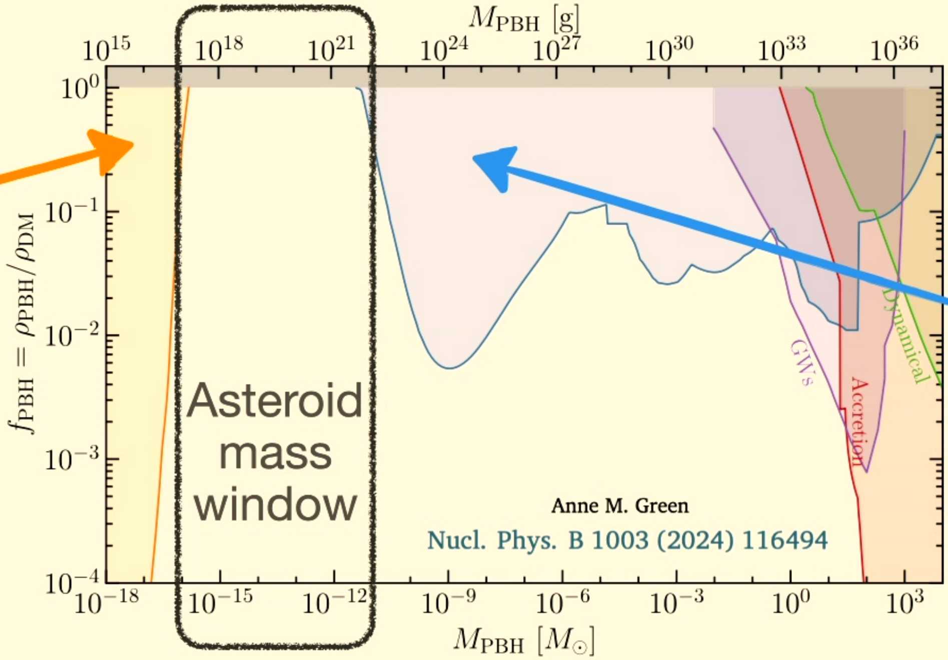
Nucl. Phys. B 1003 (2024) 116494
Anne M. Green

A. Escrivà, F. Kuhnel and Y. Tada, *Primordial Black Holes*, arXiv:2211.05767.

A. M. Green and B. J. Kavanagh, *Primordial Black Holes as a dark matter candidate*, *J. Phys. G* 48 (2021) 043001 [arXiv:2007.10722].

PBH dark matter

These objects are dark, and are still allowed to be 100% of the DM in certain mass ranges



Hawking Evaporation

- Lifetime [PRD 13 (1976) 198, ...]
- γ/x-ray flux [ApJ 206 (1976) 1; 1906.10113; 2004.00627, ...]
- 511 keV [1906.07740, ...]
- etc.

Microlensing [ApJ 304 (1986) 1]

Transient brightening of distant stars by single-lensing [ApJ 499 (1988) L9, astro-ph/0011506, 1701.02151, 1901.07120, 2007.12697,...]

~~Femtolensing~~ [1807.11495]

~~SNIa ignition~~ [1505.04444,1505.07464,1906.05950]

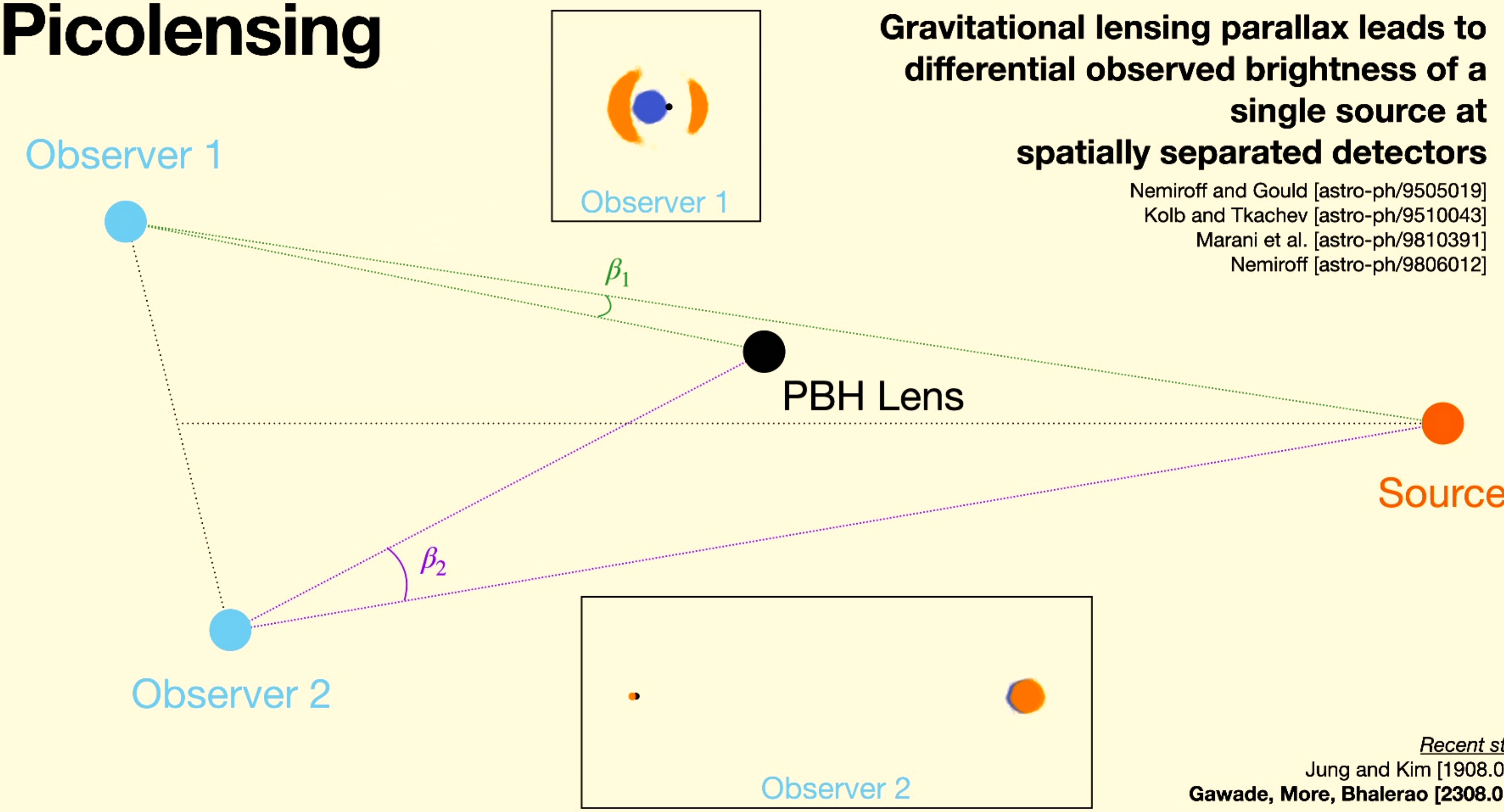
Solar system ephemeris [2312.17217]

$$M_{\circledast} \sim \frac{4\pi}{3}(2.5\text{g/cm}^3)(10\,\text{km})^3 \sim 10^{19}\,\text{g} \sim 5\times10^{-15}M_\odot$$

Picolensing

Gravitational lensing parallax leads to differential observed brightness of a single source at spatially separated detectors

Nemiroff and Gould [astro-ph/9505019]
Kolb and Tkachev [astro-ph/9510043]
Marani et al. [astro-ph/9810391]
Nemiroff [astro-ph/9806012]



Recent studies
Jung and Kim [1908.00078]
Gawade, More, Bhalerao [2308.01775]

NOT TO SCALE (think: a basketball at the outer edge of the Oort cloud)

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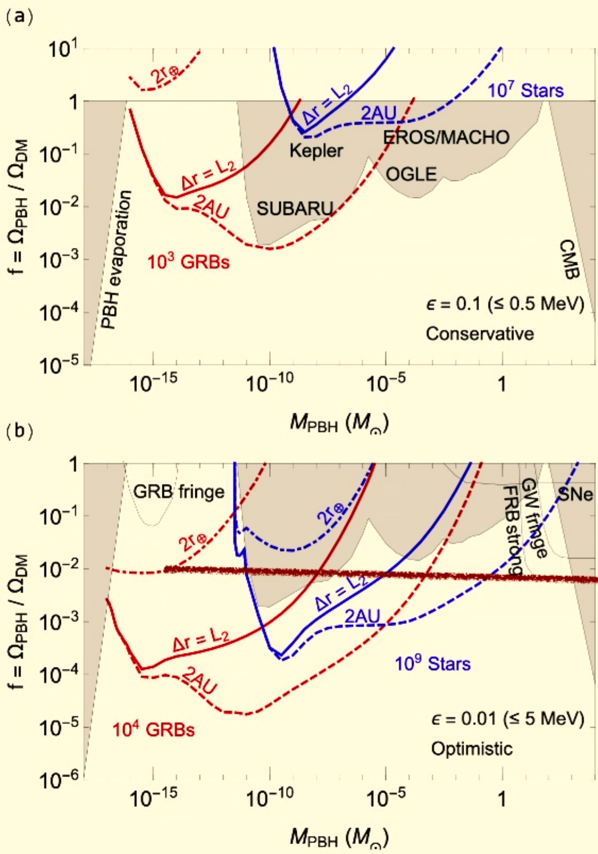
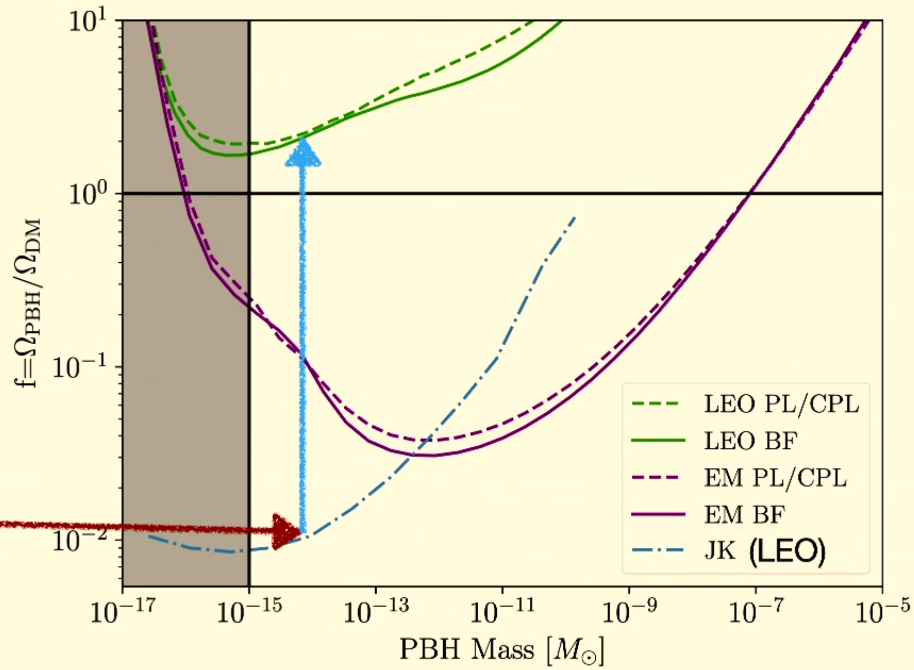
Michael A. Fedderke [Perimeter]

Current state of the literature



Jung and Kim [1908.00078]



Gawade, More, Bhalerao [2308.01775]

6

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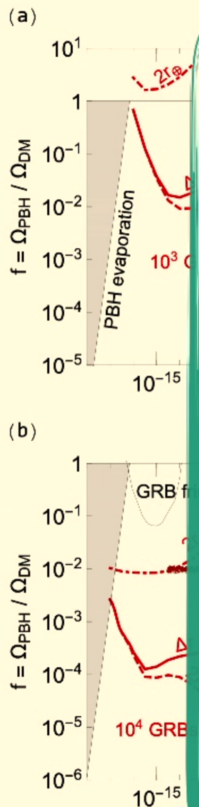
Current state of the literature



HOW ROBUST IS THIS SIGNAL?

SOURCE SIZE DISTRIBUTION UNCERTAINTIES

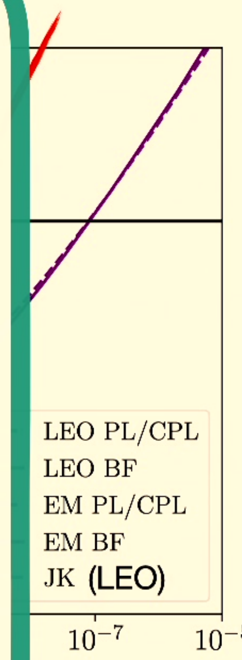
MINIMUM SOURCE SIZE

SOURCE PROFILE

BACKGROUND LEVEL

ALSO: LARGER DETECTOR SEPARATION DONE CAREFULLY?

of this paper



308.01775]

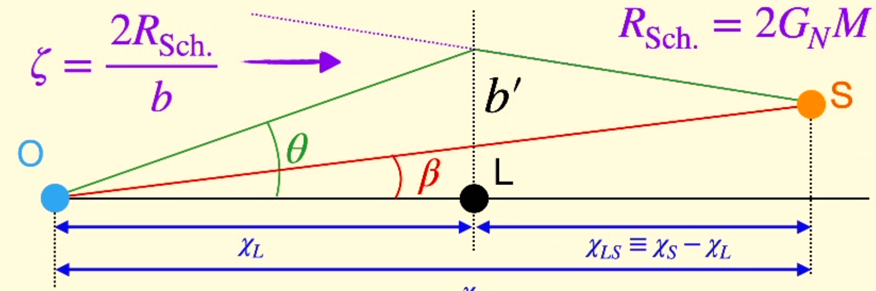
Jung and Kim [1908.00078]

Gravitational Lensing 101

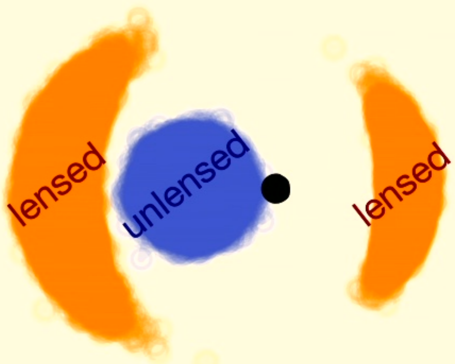
Lens Equation: $\theta - \beta = \dfrac{\theta_E^2}{\theta}$

$$\theta_E \equiv \sqrt{\frac{4G_N M(1+z_L)\chi_{LS}}{\chi_S \chi_L}}$$

Einstein Angle



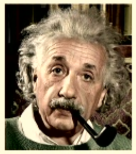
$b' = \chi_L \theta = (1+z_L) b$



Annalen der Physik 49 (1916): 769–822.

1. ***Die Grundlage der allgemeinen Relativitätstheorie;* von *A. Einstein.***

IN: *Koniglich Preußische Akademie der Wissenschaften* (Berlin) *Sitzungsberichte* (1915): 831–839.



$B = \dfrac{2\alpha}{\Delta} \overset{?}{=} \dfrac{\varkappa M}{4\pi\Delta}$ $\qquad g_{44} = 1 - \dfrac{\alpha}{r}$

Lichtstrahl

$\alpha = R_{\rm Sch.}$

Wir untersuchen die Krümmung, welche ein Lichtstrahl erleidet, der im Abstand Δ an einer Masse M vorbeigeht.

gesamte Biegung B des Lichtstrahles

https://einsteinpapers.press.princeton.edu

Hilariously, there's a factor-of-2 typo in the German version of the **1916** review article Einstein wrote…

ergibt, wobei K die gewöhnlich als Gravitationskonstante bezeichnete Konstante $6{,}7 \cdot 10^{-8}$ bedeutet. Durch Vergleich

$(K \equiv G_N)$ $\qquad \varkappa = \dfrac{8\pi K}{c^2}$

$\alpha \overset{?}{=} \dfrac{\varkappa M}{8\pi}$ $\qquad (\alpha \overset{?}{=} G_N M = R_{\rm Sch.}/2)$

BUT: Biegung von 1,7″,

The English translation correctly gives

$\alpha = \dfrac{\kappa M}{4\pi},$

7

Michael A. Fedderke [Perimeter]

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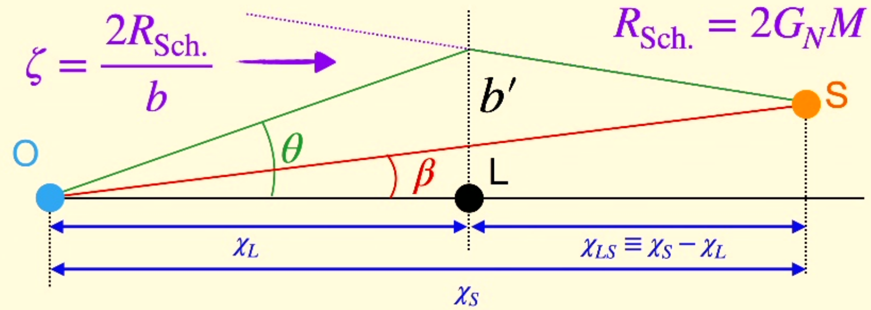
Lens Equation: $\theta - \beta = \dfrac{\theta_E^2}{\theta}$

$$\theta_E \equiv \sqrt{\frac{4G_N M(1+z_L)\chi_{LS}}{\chi_S \chi_L}}$$ Einstein Angle

$$\theta_E \sim 2\,\text{picoarcsec} \times \sqrt{\frac{M}{10^{-12}M_\odot}}$$

$[z_S = 1, \chi_L/\chi_S = 0.5\ (z_L = 0.43)]$

$\zeta = \dfrac{2R_{\text{Sch.}}}{b}$ $R_{\text{Sch.}} = 2G_N M$



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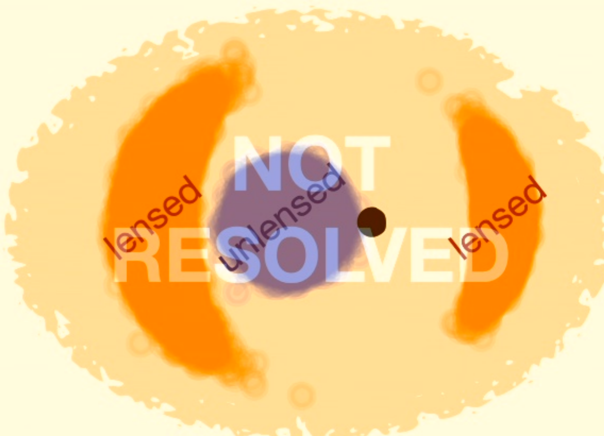

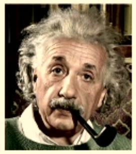

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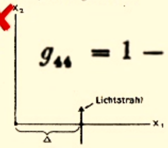

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Michael A. Fedderke [Perimeter]

Finite Sources

$$\mu(y) = \frac{y^2 + 2}{\sqrt{y^2(y^2+4)}}$$

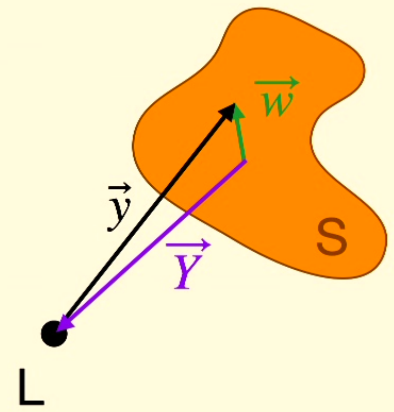
But all sources have a finite extent!

$$\bar{\mu}(\vec{Y}) = \iint d^2w \, \mathcal{I}(\vec{w}) \cdot \mu\left(y = |\vec{Y} - \vec{w}|\right)$$

Source-averaged magnification for lens at location $\vec{Y}$ relative to source centroid

Source brightness profile at location $\vec{w}$ relative to the source centroid

small-angle/
flat-sky approx



We'll consider both Gaussian and flat disk source profiles

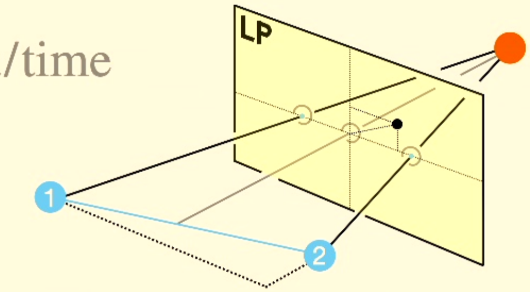
Generally, sources sizes $\theta_S \ll \theta_E$ behave as point-like…

…while those with $\theta_S \gg \theta_E$ have suppressed magnifications

…but those with $\theta_S \sim \theta_E$ can be more favourably lensed vs. point sources

Picolensing signal

f = fluence = photons/area/time



Signal photons: $\langle N_S^i \rangle = \bar{\mu}_i f_s^i A_s^i T^i \longrightarrow \langle N_S^i \rangle = \bar{\mu}_i f_s A_s T$

Background: $\langle N_B^i \rangle = f_b^i A_b^i T^i \longrightarrow \langle N_B \rangle = f_b A_b T$

- other sources on the sky
- detector dark counts, etc.

Assume identical detectors, except for magnification

Per-detector observable is $N_i = N_S^i + N_B^i$.

Could generalise and talk instead about background-subtracted measured source apparent luminosity (factoring out effective area, integration time, background)

Expected value: $\langle N_i \rangle = \langle N_S^i \rangle + \langle N_B \rangle = \bar{\mu}_i f_s A_s T + f_b A_b T$

Uncertainty: $\sqrt{\langle N_i \rangle}$

The picolensing signal is $\Delta N = | N_2 - N_1 |$.

$\langle \Delta N \rangle = | \langle N_S^1 \rangle - \langle N_S^2 \rangle |$.

after: Gawade, More, Bhalerao [2308.01775]

Picolensing SNR

$$\Delta N = |N_2 - N_1| .$$

$$\langle \Delta N \rangle = |\langle N_S^2 \rangle - \langle N_S^1 \rangle| .$$

$$\rho = \frac{\langle \Delta N \rangle}{u[\Delta N]}$$

$$= \frac{|N_S^1 - N_S^2|}{\sqrt{2N_B + N_S^1 + N_S^2}}$$

$$N_i = N_S^i + N_B^i$$

$$= \frac{|\bar{\mu}_1 - \bar{\mu}_2| \sqrt{A_s f_s T}}{\sqrt{2(A_b/A_s)(f_b/f_s) + (\bar{\mu}_1 + \bar{\mu}_2)}} \propto |\Delta \bar{\mu}|$$

after: Gawade, More, Bhalerao [2308.01775]

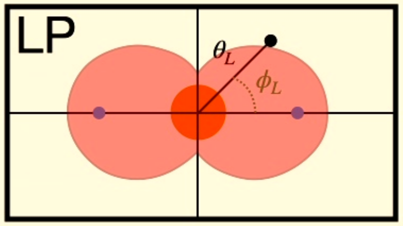
Michael A. Fedderke [Perimeter]

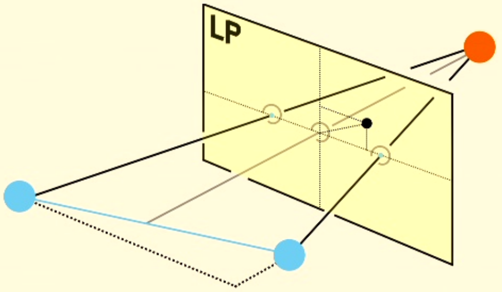
Picolensing cross-section

$\rho = \rho(\{\theta_L, \phi_L, z_L, M\}, \{z_S, \theta_S, f_s\}, \{R_O, \theta_O, A_b, A_s, f_b, T\})$

Fix: lens distance, lens mass, source parameters, observer parameters.

SNR $\rho = \rho(\theta_L, \phi_L)$.





Is any lens detectable at some threshold SNR ρ_*?

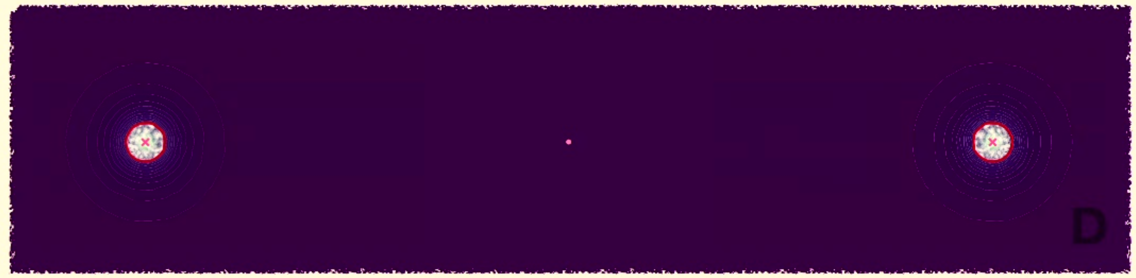
$\rho \geq \rho_*$ defines region in the lens plane where lensing is detectable. Can be multiple disjoint regions!

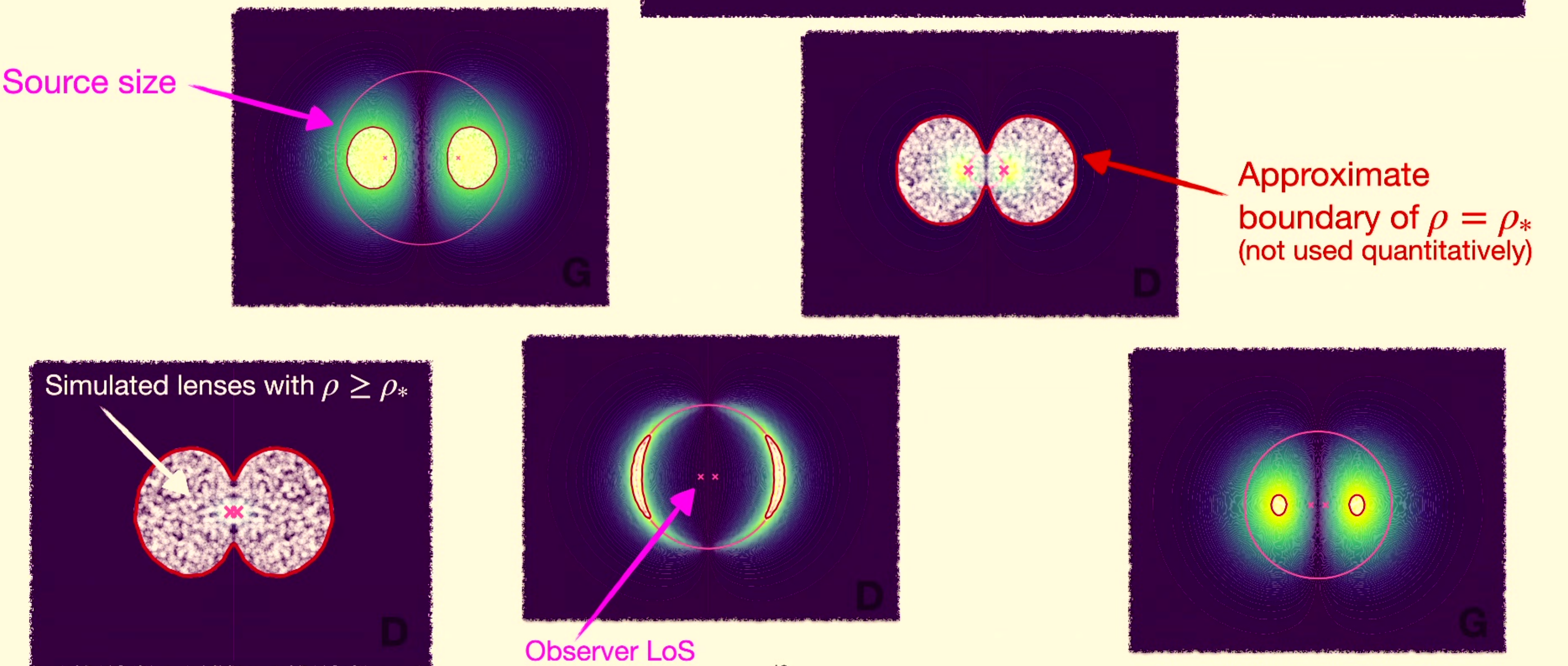
Lensing cross-section σ is the area of that region (comoving): $\sigma = \sigma(\rho_*)$

Compute this using Monte Carlo methods (sample LP area with lenses randomly)

after: Gawade, More, Bhalerao [2308.01775]

Examples

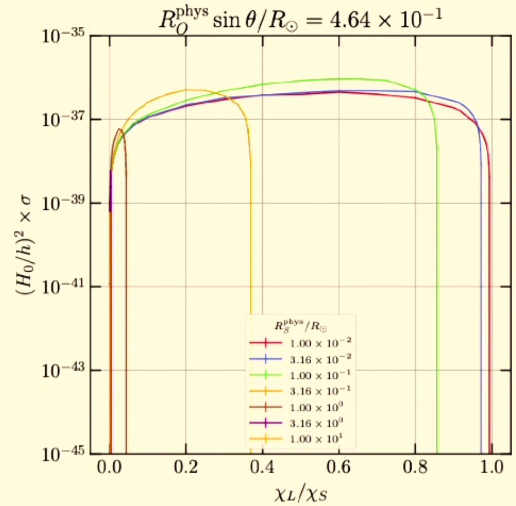




after: Gawade, More, Bhalerao [2308.01775]

Michael A. Fedderke [Perimeter]

Picolensing volume & optical depth



$\sigma = \sigma(\chi_L; \rho_*, \ldots)$ is a function of χ_L, the distance to the lens!

At zeroth order, don't care *where* the lens is.

We only want to know whether (any) picolensing has $\rho \geq \rho_*$.

Define a co-moving picolensing volume: $\mathscr{V} = \int_0^{\chi_S} \sigma(\chi_L) d\chi_L$

Requires large number of σ evaluations on $S \sim 50 - 100$ slices of χ_L; dynamically chosen

PBHs: can assume a uniform co-moving lens number density n_0**

Optical depth to source j is $\tau_j = n_0 \mathscr{V}_j$

Number of expected observable lenses between observers and the source. Need $\tau \ll 1$ for validity.

Average optical depth to all $\aleph$ sources: $\bar{\tau} = \frac{1}{\aleph}\sum_{j=1}^{\aleph} n_0 \mathscr{V}_j \equiv n_0 \bar{\mathscr{V}}$

****Jung and Kim [1908.00078] looked at clustering; impact not significant for $\bar{\tau} \ll 1$, $\tau_{\rm halo} \ll 1$**

after: Gawade, More, Bhalerao [2308.01775]

Michael A. Fedderke [Perimeter]

$\omega^0_{\rm DM} \equiv \Omega^0_{\rm DM} h^2 \sim 0.12$

Lensing Probability

No detectable lenses at $\rho \geq \rho_*$ for single source j:

$$\Pr[\text{no lensing}, j] = e^{-\tau_j}$$

Poisson statistics; also only works for $\tau_j \ll 1$, otherwise the signal SNR we computed is wrong!

Jung and Kim [1908.00078]

No lenses for $\aleph$ sources:

$$\Pr[\text{no lensing}; \aleph] = \Pi_{j=1}^{\aleph} e^{-\tau_j} = \exp\left[-\sum_{j=1}^{\aleph} \tau_j\right] = \exp\left[-\aleph \bar{\mathscr{V}} n_0\right].$$

Exclusion on n_0 at confidence level α: $\Pr[\text{no lensing}; \aleph] = (1-\alpha) \Rightarrow n_0^\alpha = -\dfrac{\ln(1-\alpha)}{\aleph \bar{\mathscr{V}}}$.

$$f^\alpha_{\rm DM} = -\frac{\ln(1-\alpha)}{\omega^0_{\rm DM}\aleph} \frac{4\pi (H_0/h)^{-2}(2G_N M)}{3\bar{\mathscr{V}}}$$

$H_0^{-1} \sim 4.5\,\text{Gpc}$ $\quad R_S(M = 10^{-12} M_\odot) = 3\,\text{nm}$

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OR

DISCOVERY SPACE!

$H_0^{-1} \sim 4.5\,\text{Gpc}$ $\quad R_S(M = 10^{-12} M_\odot) = 3\,\text{nm}$

14

after: Gawade, More, Bhalerao [2308.01775]

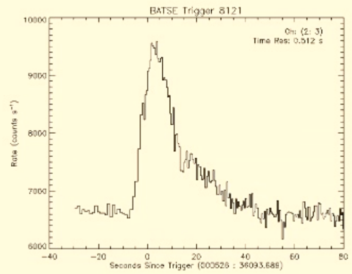
Michael A. Fedderke [Perimeter]

Sources?

$H_0^{-1} \sim 4.5\,\mathrm{Gpc}$ $R_S(M = 10^{-12} M_\odot) = 3\,\mathrm{nm}$

Must be cosmologically distant, else $H_0^{-2} G_N M \gg \bar{\mathscr{V}}$

But also still visible, else $\rho \propto \sqrt{f_s} \ll 1$



Gamma-ray bursts!

Most violent explosions in the universe

Transient. Two classes: long (>2s) and short (<2s)

Some uncertainty as to *what* these are

Long: associated with supermassive stellar supernovae

Short: NS mergers, …?

Observable at short wavelengths

(geometrical optics)

Extremely distant: $\bar{z}_S \sim 2$ (long) … $\chi_S \sim 5\,\mathrm{Gpc}$; $\mathscr{D}_S \sim 2\,\mathrm{Gpc}$; $\mathscr{D}_S^{\mathrm{lumi}} \sim 16\,\mathrm{Gpc}$

Isotropic *equivalent* energy release as large as (long) $E_{\mathrm{iso}} \sim 10^{55}$ erg $\sim 6 M_\odot$

Highly beamed! $\Gamma \sim 10^2$. Actual energy release $E_{\mathrm{beam}} \sim \Gamma^{-2} E_{\mathrm{iso}} \lesssim 3 \times 10^{51}$ erg

$\sim (2-3) \times E_{\mathrm{SNIa}}$

Observations

x-rays / γ-rays: must be observed from space. Vela (1967).

Many thousands have now been seen (INTEGRAL, BATSE, etc.)

***Swift*/BAT:** $\sim$ few $\times\, m^2$ CdZnTe detector plane. 15-150 keV.
$\sim 12\%$ instantaneous sky coverage.
Catalogue of ~ 1600 GRBs [2004-present].

***Fermi*/GBM:** NaI (~few keV - MeV) / BGO (1 - 30 MeV).
$\sim$70% sky coverage (all non-Earth-occulted). Smaller effective area.
Catalogue of $\gtrsim 2400$ GRBs [2008-2018 (-present)].

2308.01775 looked at a possible future ISRO project Daksha ($2 \times \sim$ Swift/BAT-class detectors in space, but each with Fermi/GBM sky coverage)

We will assume similar parameters to $2 \times \sim$ *Swift*/BAT $\sim$ Daksha

Michael A. Fedderke [Perimeter]

Source characteristics I

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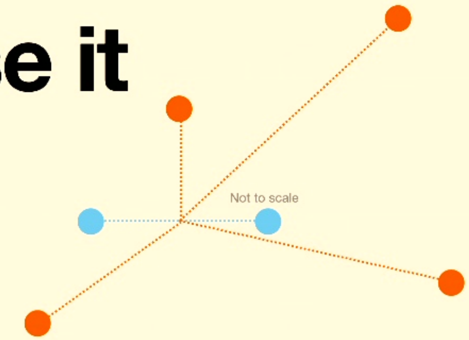
Source characteristics I

Need to know: duration (T), distance (z_S), source fluence (f_s), source size (θ_S)

Swift/BAT catalogue and how we use it



> 1600 GRBs in catalog

409 GRBs have all necessary characteristics known

We use these real GRBs to make projections [following 2308.01775]

For each GRB, we assume 4 observation angles θ_O to average over spacecraft orientations / orbital phase wrt ~isotropic GRB distribution.

$\aleph = 4 \times 409 = 1636$ effective GRB parameter sets to simulate.

Use these to compute $\bar{\mathscr{V}}$

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Source characteristics II

Need to know: duration (T), distance (z_S), source fluence (f_s), source size (θ_S)

Duration: T_{90}, 90% of measured intensity

Distance: z_S, known for ~400 GRBs

Source fluence: Band function in source frame. In detector frame, fit as a power law (PL) or cut-off power law (CPL)

$$f_{\rm PL}(E) \equiv K_{50}^{\rm PL} \left(\frac{E}{50\,\text{keV}} \right)^{\alpha_{\rm PL}} \qquad f_{\rm CPL}(E) \equiv K_{50}^{\rm CPL} \left(\frac{E}{50\,\text{keV}} \right)^{\alpha_{\rm CPL}} \exp\left[-\frac{E(2+\alpha_{\rm CPL})}{E_{\rm CPL}^{\rm peak}} \right]$$

$$f_s = \int_{E_{\rm min}}^{E_{\rm max}} f_{\rm (C)PL}(E)\, dE$$

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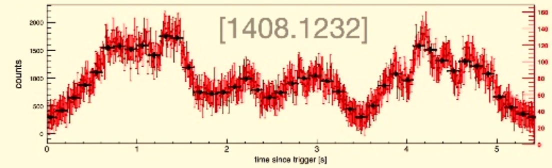
GRB sizes: general considerations



Indirectly inferred from "minimum variability timescale" $\Delta t_{\rm var}$

$$D' \sim \frac{\Gamma^2 \times \Delta t_{\rm var}}{1+z_S}$$

$$D_{\rm obs} \sim \frac{D'}{\Gamma} \sim \frac{\Gamma \times \Delta t_{\rm var}}{1+z_S}$$

Physical size of emi … ed size (beaming)

THIS IS ALL VERY APPROXIMATE

EMPIRICALLY: $T_{90} \sim \Gamma \Delta t_{\rm var}$

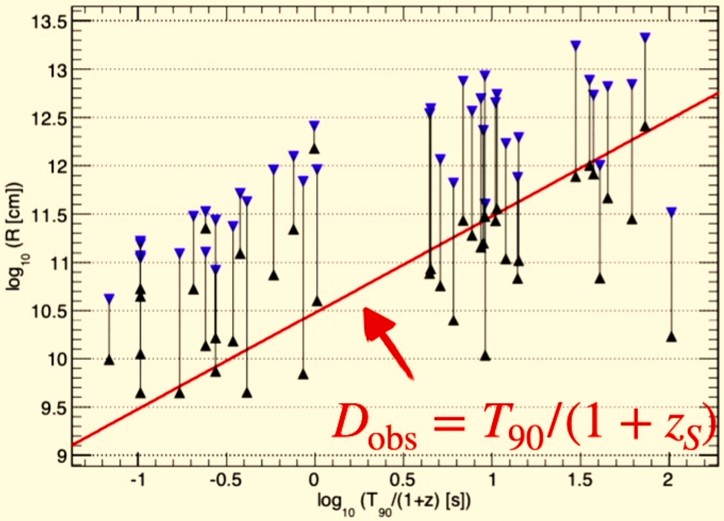
Commonly used size estimate: $D_{\rm obs} \sim \dfrac{T_{90}}{1+z_S} \quad \Rightarrow \quad \theta_S = \dfrac{D_{\rm obs}}{\mathscr{D}_S} = \dfrac{T_{90}}{\chi_S}$

Gawade, More, Bhalerao [2308.01775] used this

GRB sizes: what do the data say?

$$D_{\text{obs}} \sim \frac{D'}{\Gamma} \sim \frac{\Gamma \times \Delta t_{\text{var}}}{1 + z_S}$$

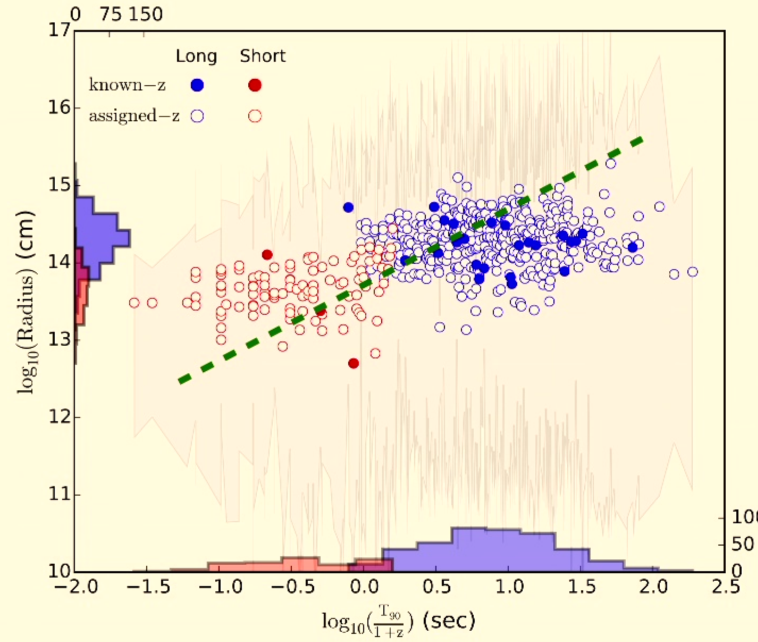
$$D' \sim \frac{\Gamma^2 \times \Delta t_{\text{var}}}{1 + z_S}$$



Note that this line is not attempting to fit the constraints from the data

Barnacka, Loeb [1409.1232]

y-axes differ by $\Gamma \sim 10^2$

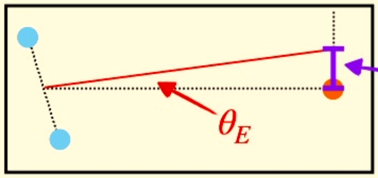


Golkhou et al [1501.05948]

GRB sizes: can this matter?

$M_{\text{PBH}} = 10^{-12} M_\odot$ $z_S = 1$

χ_L/χ_S	z_L	θ_E [arcsec]	Plane	$R_E^{\text{proj.}}/R_\odot$
0.25	0.20	2.9×10^{-12}	Source	1.1
			Lens	0.45
			Observer	0.72
0.50	0.43	1.9×10^{-12}	Source	0.68
			Lens	0.47
			Observer	1.4
0.75	0.69	1.1×10^{-12}	Source	0.42
			Lens	0.38
			Observer	2.5



$\chi_E^S = (1 + z_S) R_E^S$

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GRB sizes: can this matter? YES!

$M_{\rm PBH} = 10^{-12} M_\odot$ $\quad z_S = 1$

χ_L/χ_S	z_L	θ_E [arcsec]	Plane	$R_E^{\rm proj.}/R_\odot$
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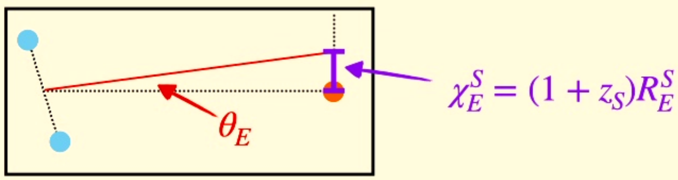

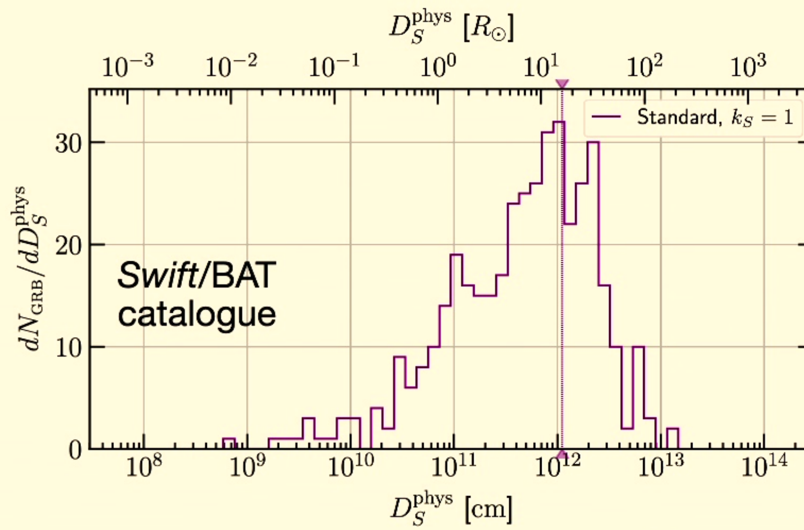

$$D_{\rm obs} \equiv \frac{k_S T_{90}}{1 + z_S}$$

Source sizes can be significant compared to the Einstein radius!

Could make the lensing signal very sensitive to source size uncertainties!

Given enormous uncertainties, we bracket: $k_S = 0.1,\ 1,\ 10,\ 10^{\mathcal{U}[-1,1)}$

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RESULTS

$\rho_* = 5$ $\alpha = 0.95$

95% confidence exclusions of any 5-sigma lensing events

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Comparison to 2308.01775

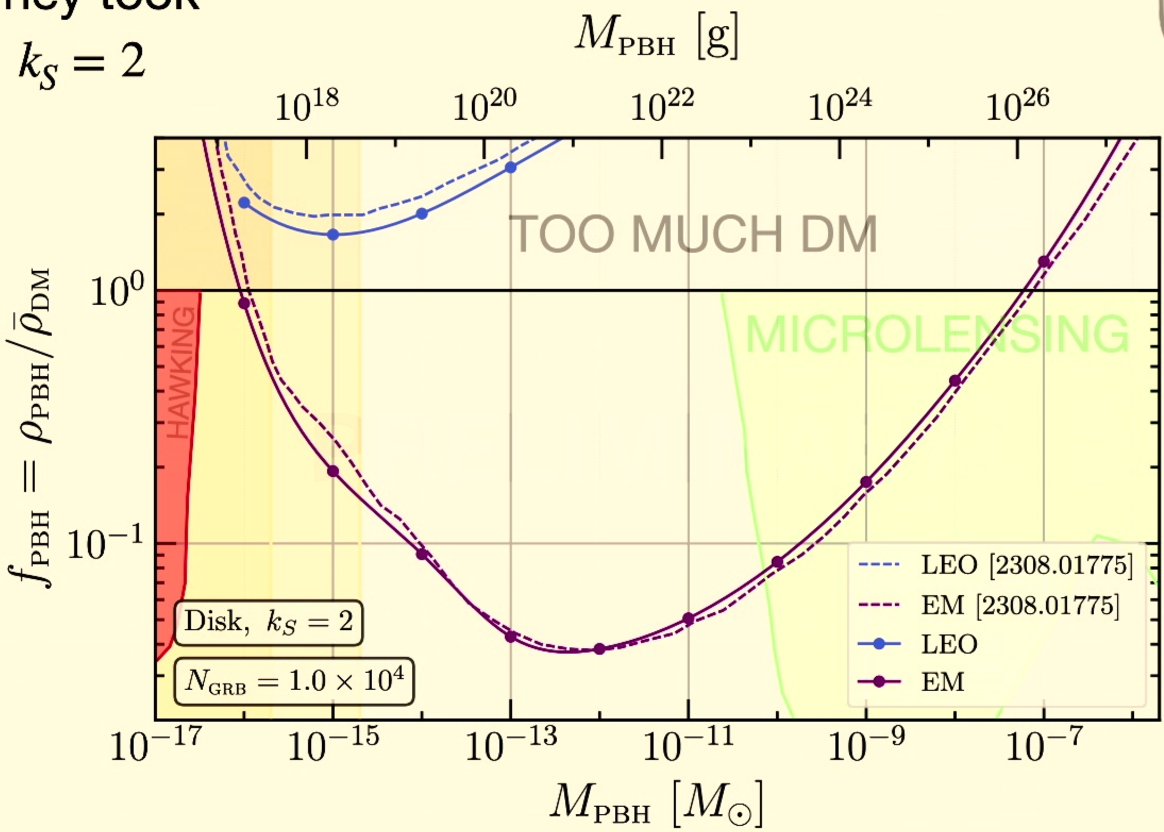
They took

$k_S = 2$

$A_b = 2400\,\mathrm{cm}^2 \quad A_s = 1300\,\mathrm{cm}^2$

$f_b = 10\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

~Swift/BAT



Scenario	Abbrev.	Baseline R_O	$R_O/R_\odot$
Low Earth Orbit	LEO	1.40×10^4 km	0.020
Earth–Moon	EM	3.84×10^5 km	0.55

Minor difference in assumed energy range (15-150keV [us] vs. 20-200 keV [them]); makes little difference

*markers are computed; lines are log-log cubic spline interpolants

Comparison to 2308.01775

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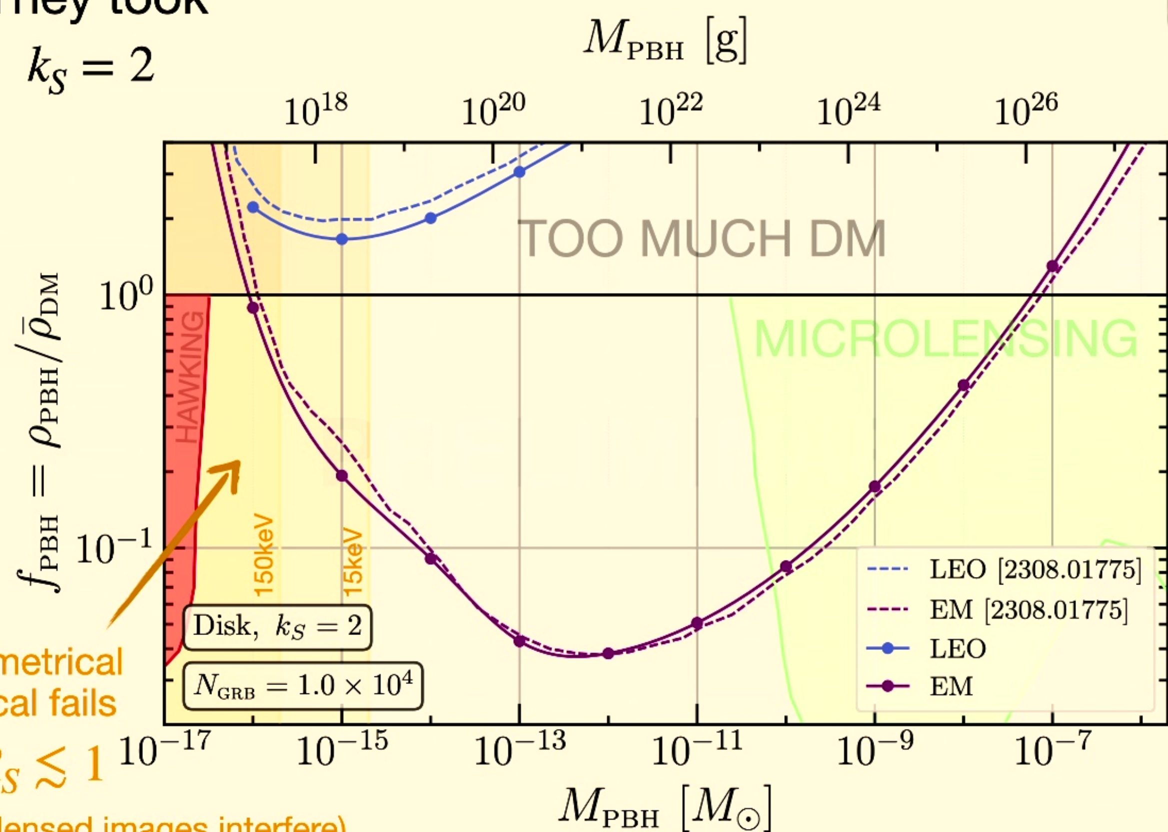

Geometrical optical fails

$\omega R_S \lesssim 1$

(two lensed images interfere)

Pretty good agreement (5-10%)

Validates our implementation

Confirms previous literature under their assumptions

Scenario	Abbrev.	Baseline R_O	$R_O/R_\odot$
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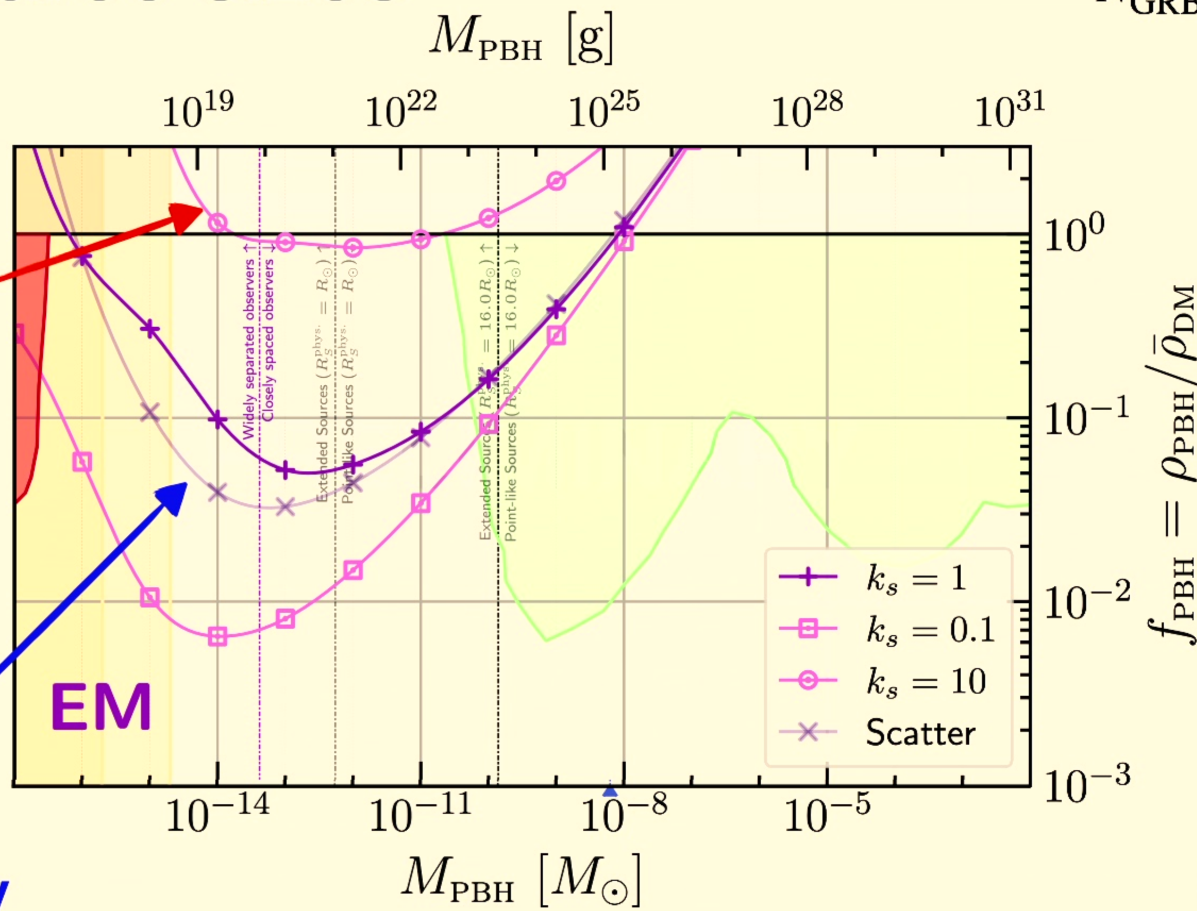
Vary the source sizes

$N_{\rm GRB} = 3 \times 10^3$

Questionable whether you can robustly rule out $f_{\rm DM} = 1$ with this baseline if GRB sources are systematically off



But the scatter may not be an issue

$$D_{\rm obs} \equiv \frac{k_S T_{90}}{1 + z_S}$$

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*markers are computed; lines are log-log cubic spline interpolants

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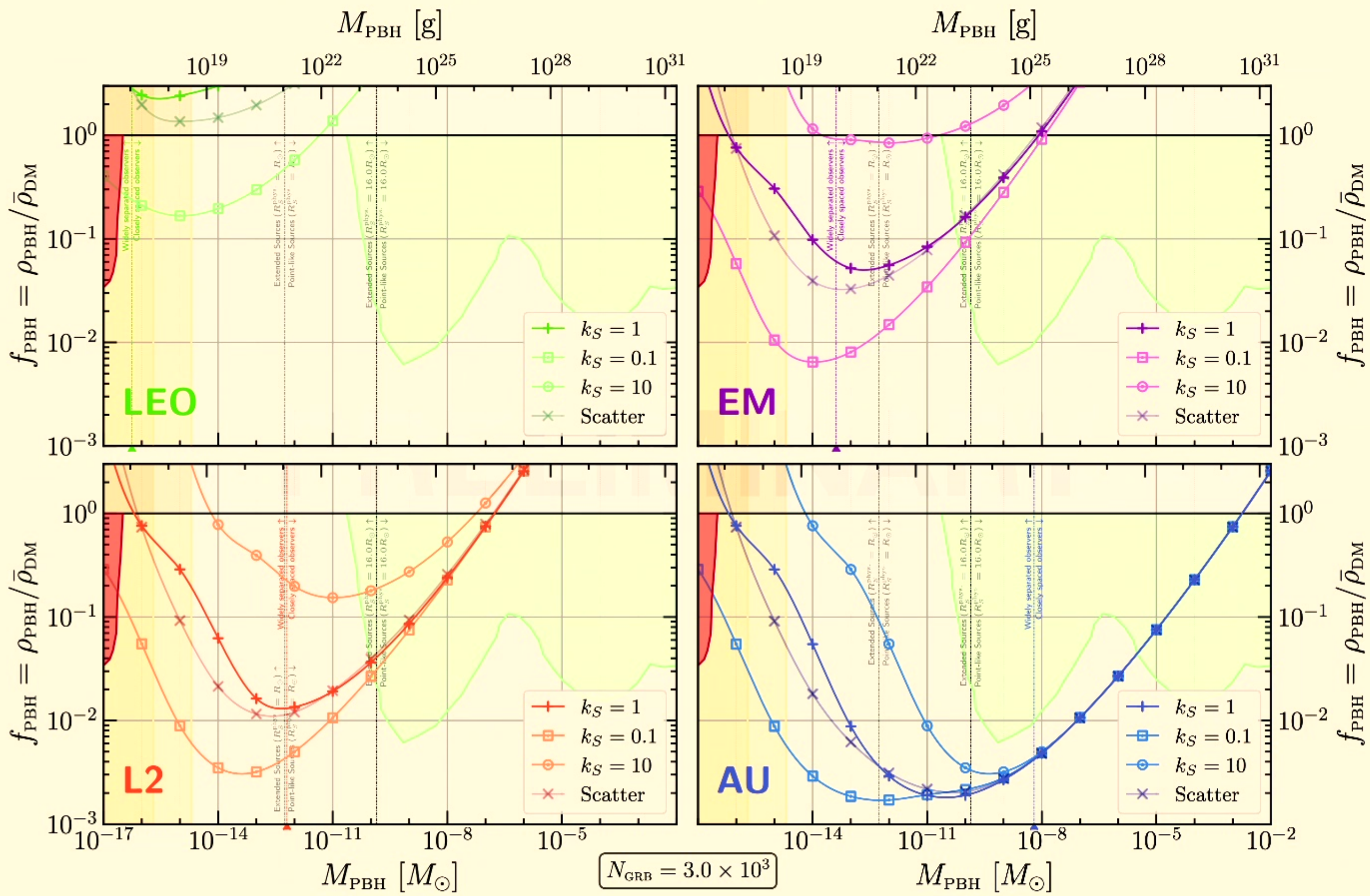
Vary the source sizes for other baselines

ROBUST EXCLUSIONS FOR L2, AU

LARGE-MASS REACH AT AU INDEPENDENT OF SOURCE UNCERTAINTIES!



Scenario	Abbrev.	Baseline R_O	$R_O/R_\odot$
Low Earth Orbit	LEO	1.40×10^4 km	0.020
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Lagrange Point 2	L2	1.50×10^6 km	2.15
Astronomical Unit	AU	1.50×10^8 km	215

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*markers are computed; lines are log-log cubic spline interpolants

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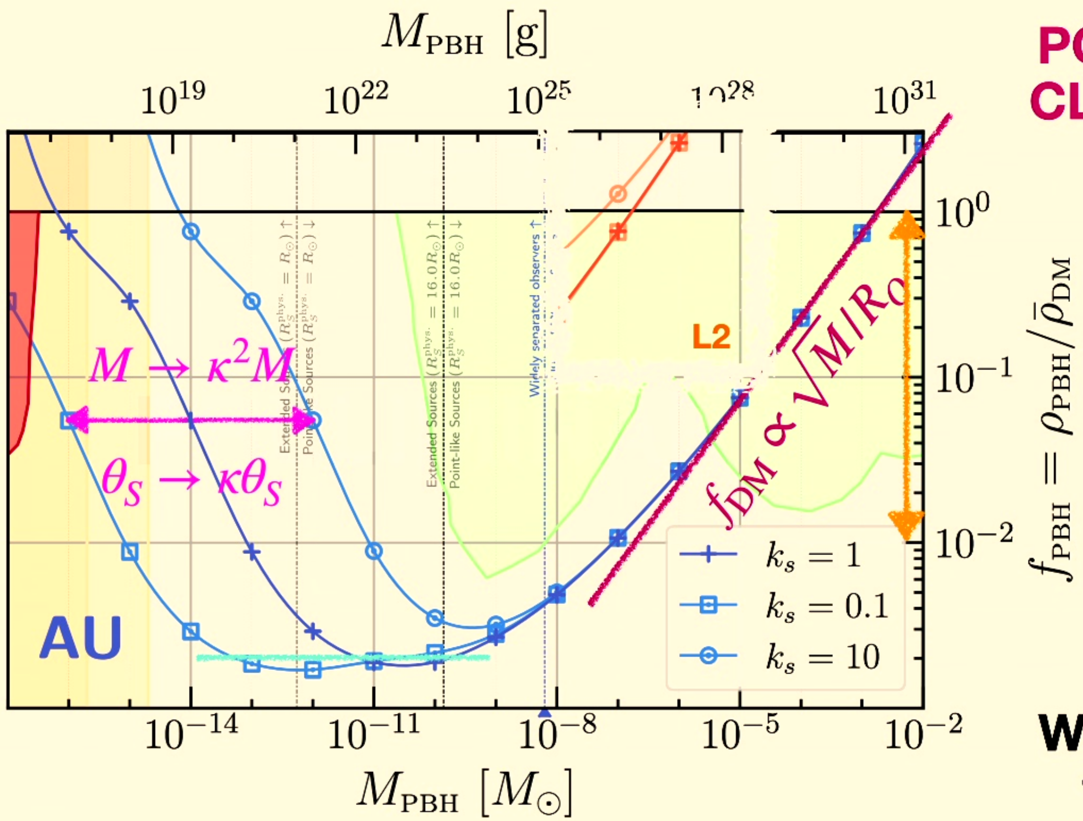
Scalings



POINT SOURCES, CLOSELY SPACED OBSERVERS

EXTENDED SOURCE, WIDELY SEPARATED OBSERVERS

$R_{\rm L2} \sim 10^{-2}$AU

POINT SOURCES, WIDELY SEPARATED OBSERVERS

We understand all these features analytically

(ask me after!)

*markers are computed; lines are log-log cubic spline interpolants

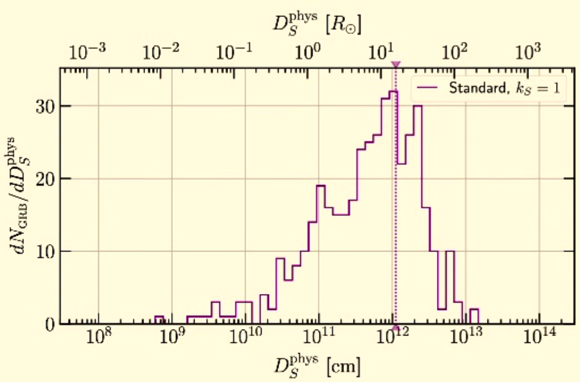
Vary the minimum source size

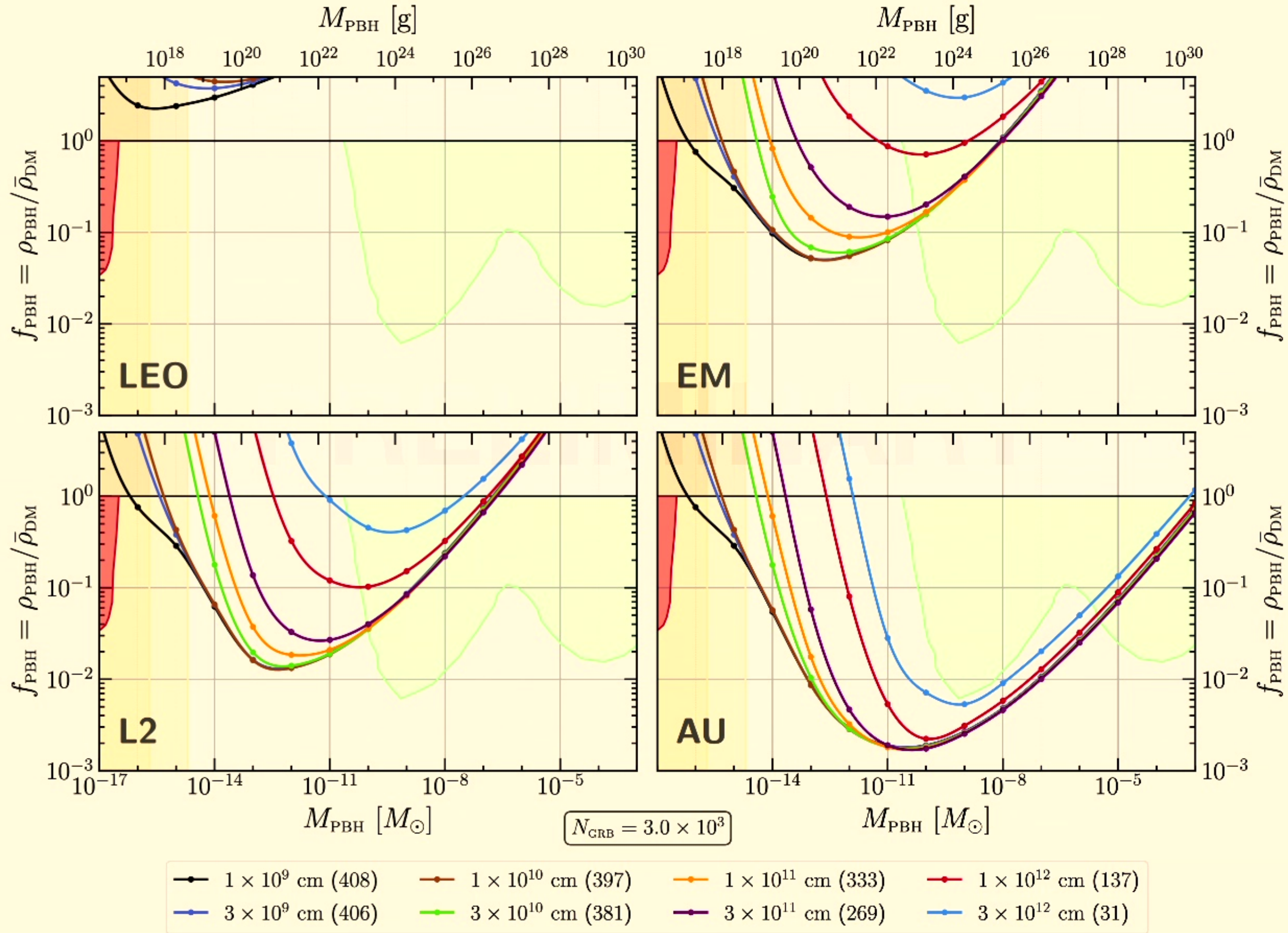
$$k_S = 1 \qquad D_{\rm obs} \equiv \frac{k_S T_{90}}{1 + z_S}$$

Recall:

$$R_\odot \sim 7 \times 10^{10}\,\mathrm{cm}$$

Quite robust to excluding $\lesssim R_\odot$ sources





*markers are computed; lines are log-log cubic spline interpolants

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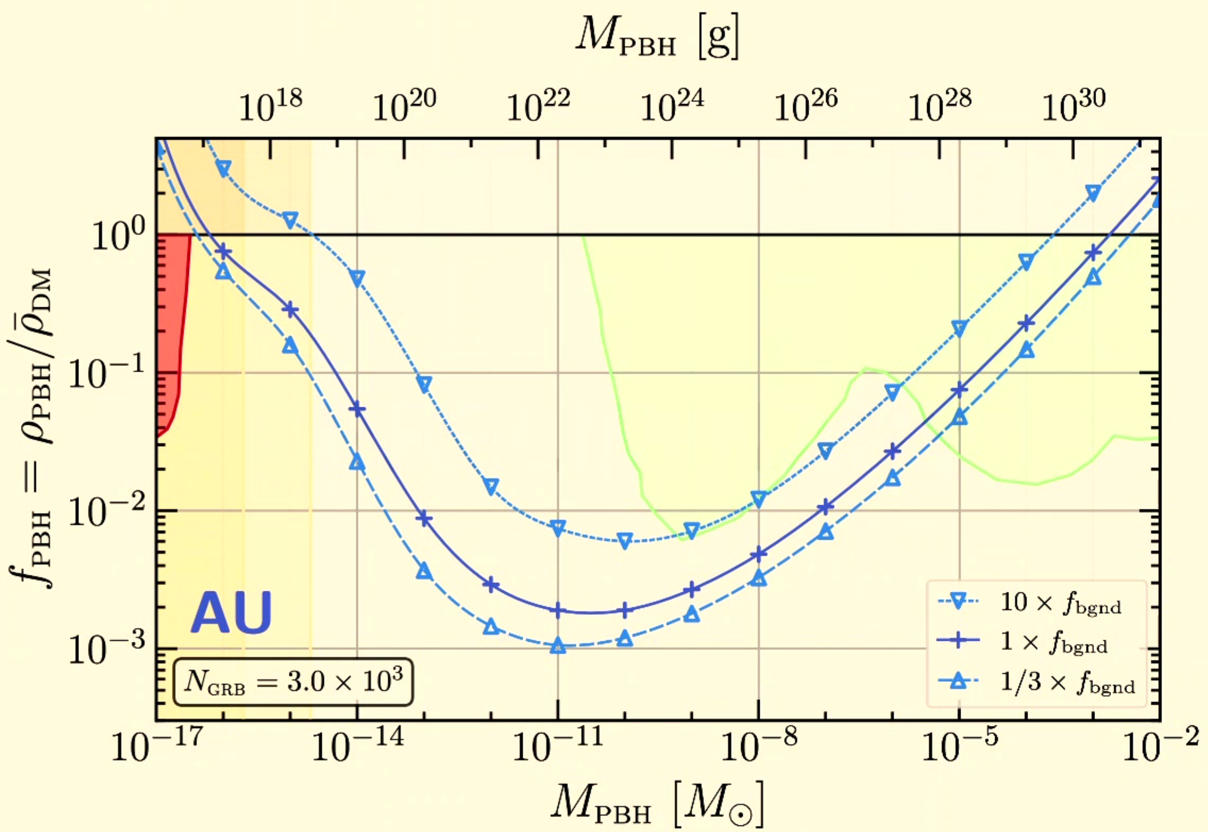
Vary the background level

Higher backgrounds once out of LEO?

Some x-ray detection backgrounds from HE particles hitting detector / spacecraft



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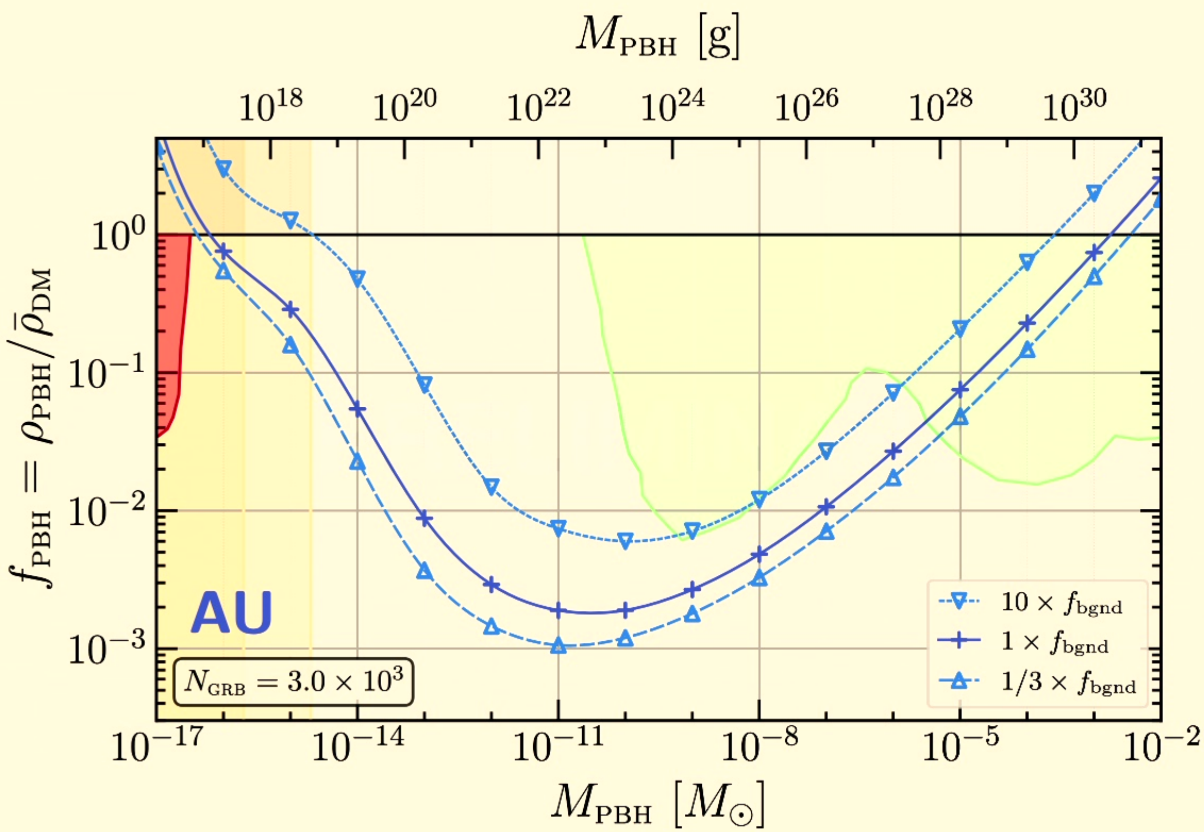

30

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Conclusions

Validated that picolensing is a useful way to probe asteroid-mass PBH DM

Source size uncertainties can have a significant impact on picolensing:
offset more important than scatter

Previous studies slightly too optimistic with shorter baselines (e.g., EM)

Mapped out that larger baselines (L2, AU) can overcome systematics issues with source sizes / minimum source sizes

Varying background levels not really a concern; ditto Gaussian vs Disk

Understood some qualitative scalings of results

Motivates work to understand GRB sources sizes in more detail

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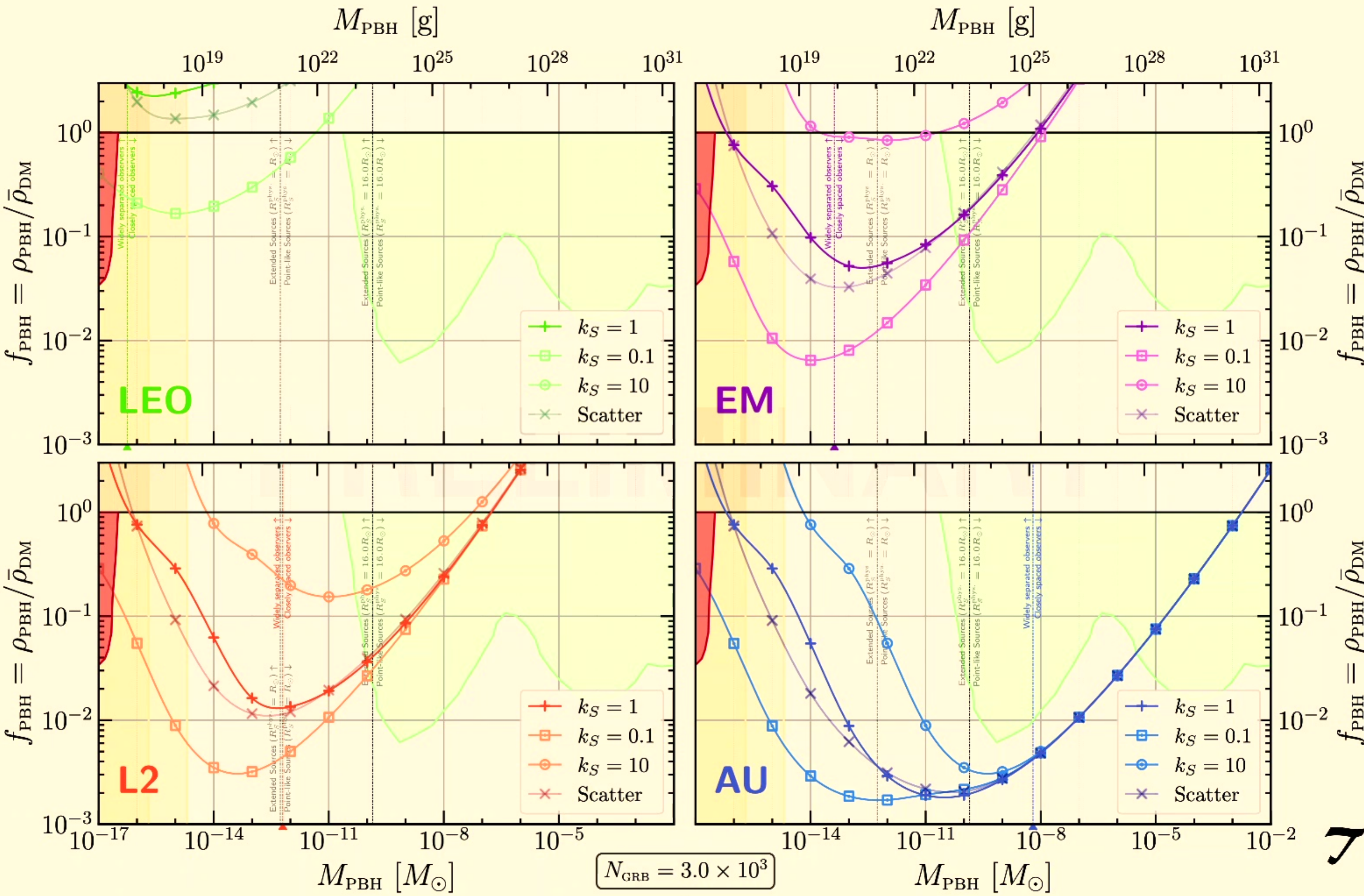

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Thanks!

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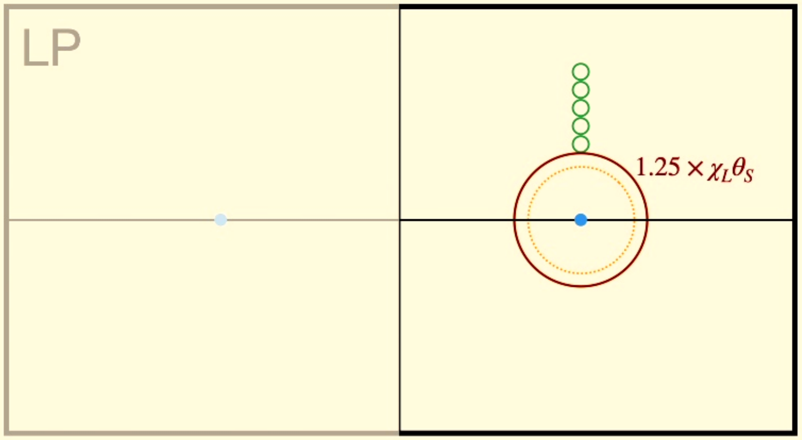
Computing σ

Monte Carlo methods

Pick an appropriate sample area in the positive half-plane of the lens plane



after: Gawade, More, Bhalerao [2308.01775]

Michael A. Fedderke [Perimeter]

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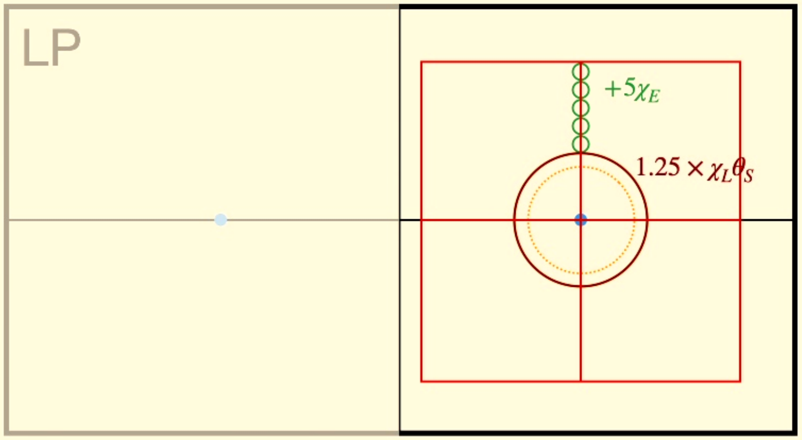

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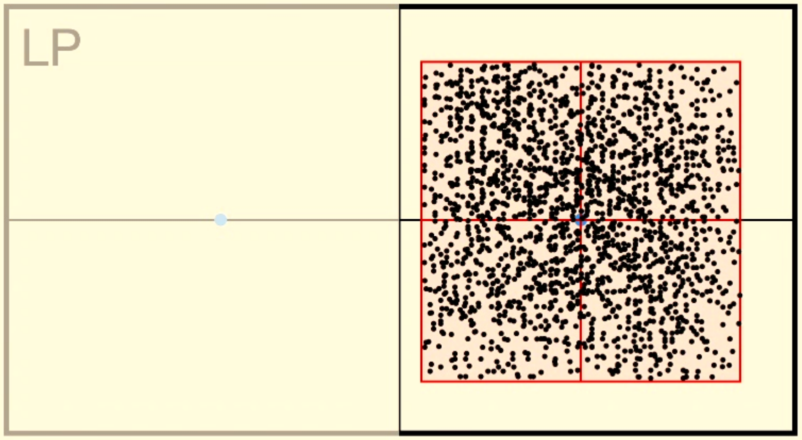
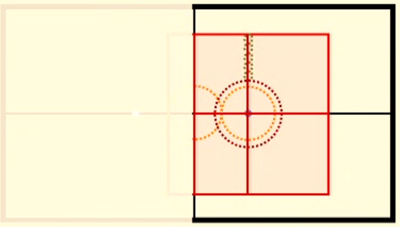




A_{sample} reduced if the box crosses the symmetry axis

Populate with N_{lens} lenses randomly sampled in 2D; $N_{\text{lens}} = 20000$ (100000 if needed)

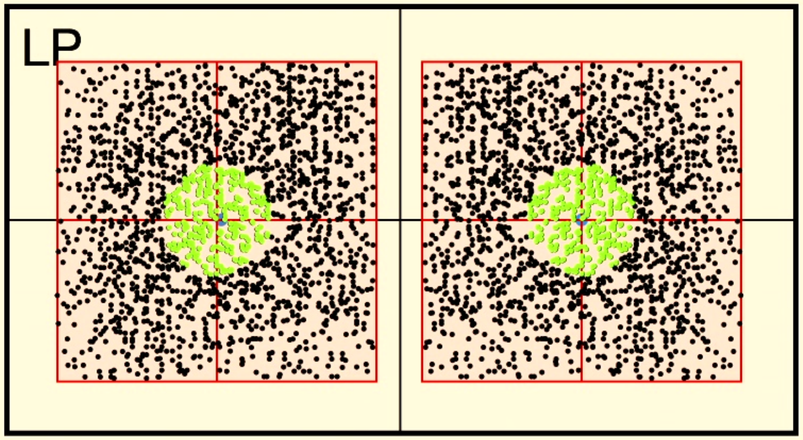
after: Gawade, More, Bhalerao [2308.01775]

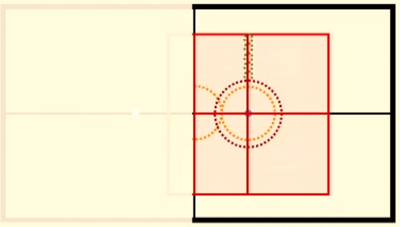
Michael A. Fedderke [Perimeter]

Computing σ

Monte Carlo methods

Pick an appropriate sample area in the positive half-plane of the lens plane





A_{sample} reduced if the box crosses the symmetry axis

Populate with N_{lens} lenses randomly sampled in 2D; $N_{\text{lens}} = 20000$ (100000 if needed)

Compute $\bar{\mu}_i^k$ for $i = 1,2$ and ρ^k for $k = 1,\ldots,N_{\text{lens}}$. Count the fraction f_ρ with $\rho^k \geq \rho_*$

Cross-section is $\sigma = 2A_{\text{sample}} \times f_\rho$ (the 2 accounts for the reflection symmetry)

We also test that no $\rho^k \geq \rho_*$ are too close to sample box edges

after: Gawade, More, Bhalerao [2308.01775]

Michael A. Fedderke [Perimeter]