Looking for Primordial Black Holes
in the spectra of GRBs and FRBs

Wei Xue

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Phenomenology 2020

UF | UNIVERSITY of FLORIDA

with A. Katz, J. Kopp, S. Sibiryakov
arXiv: 1807.11495, 1912.07620

Outline

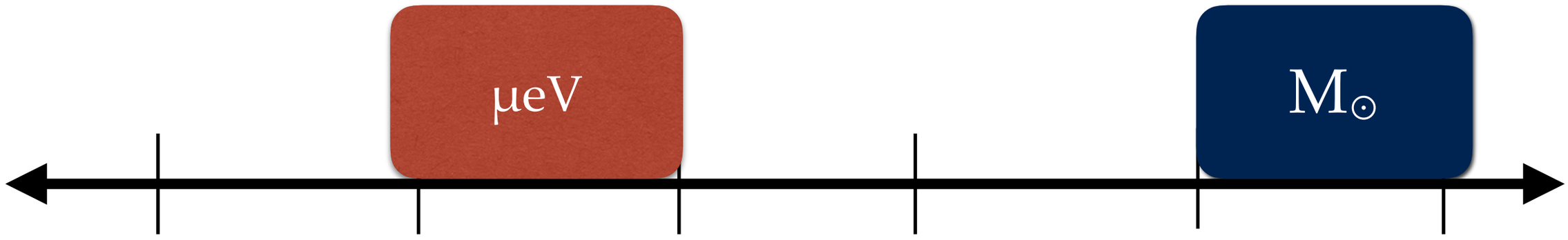
- diffractive lensing by PBHs with GRBs (femtolensing)
  Introduce diffractive lensing
  how the parameter space is recovered

arXiv: 1807.11495

- diffractive lensing by PBHs with FRBs (nanolensing)
  radio wave, scintillation

arXiv: 1912.07620

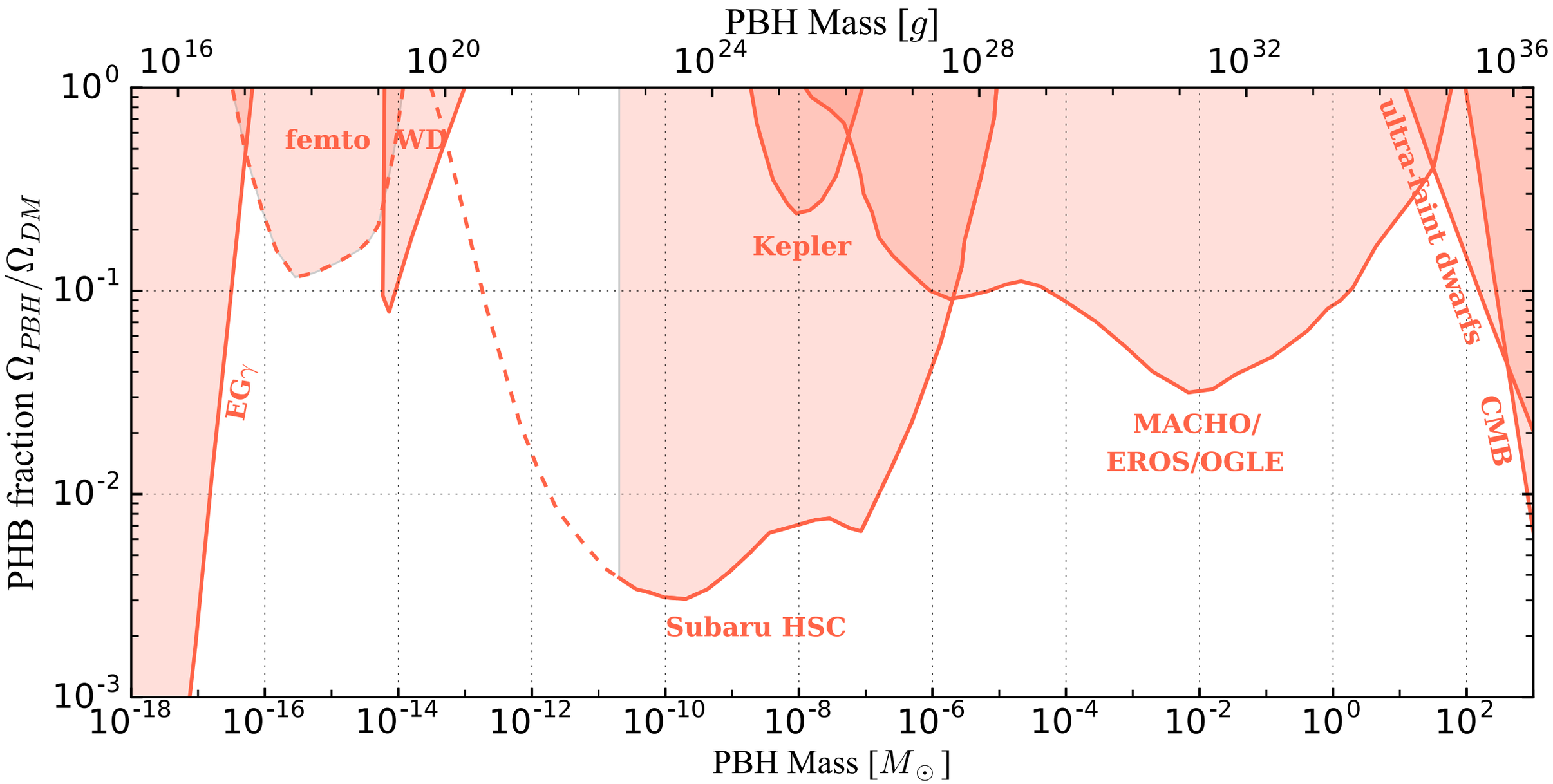
Massive Compact Halo Objects (MACHOs)



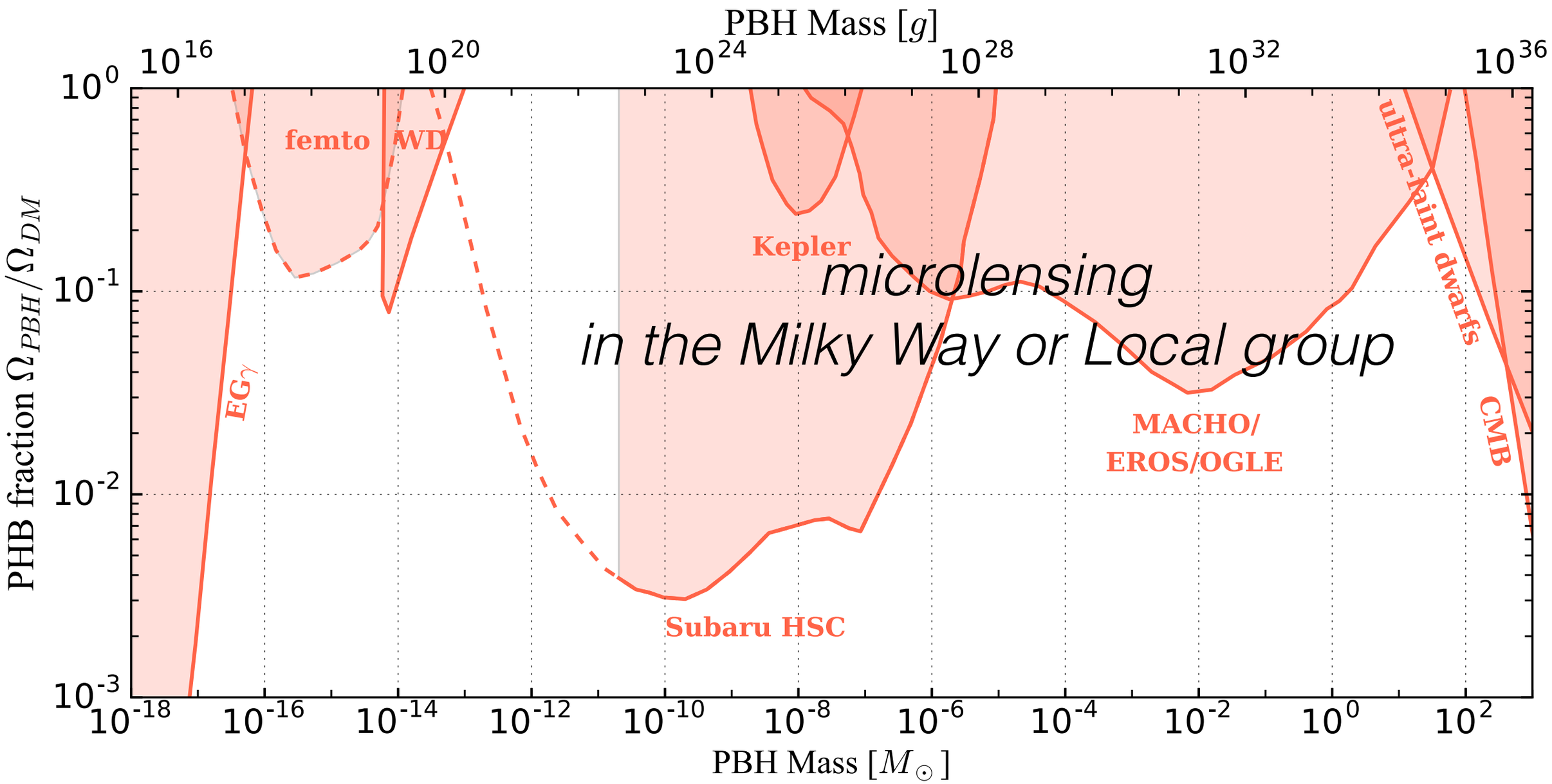
- primordial black holes
  from inflationary perturbations

- axion miniclusters
  from QCD phase transition

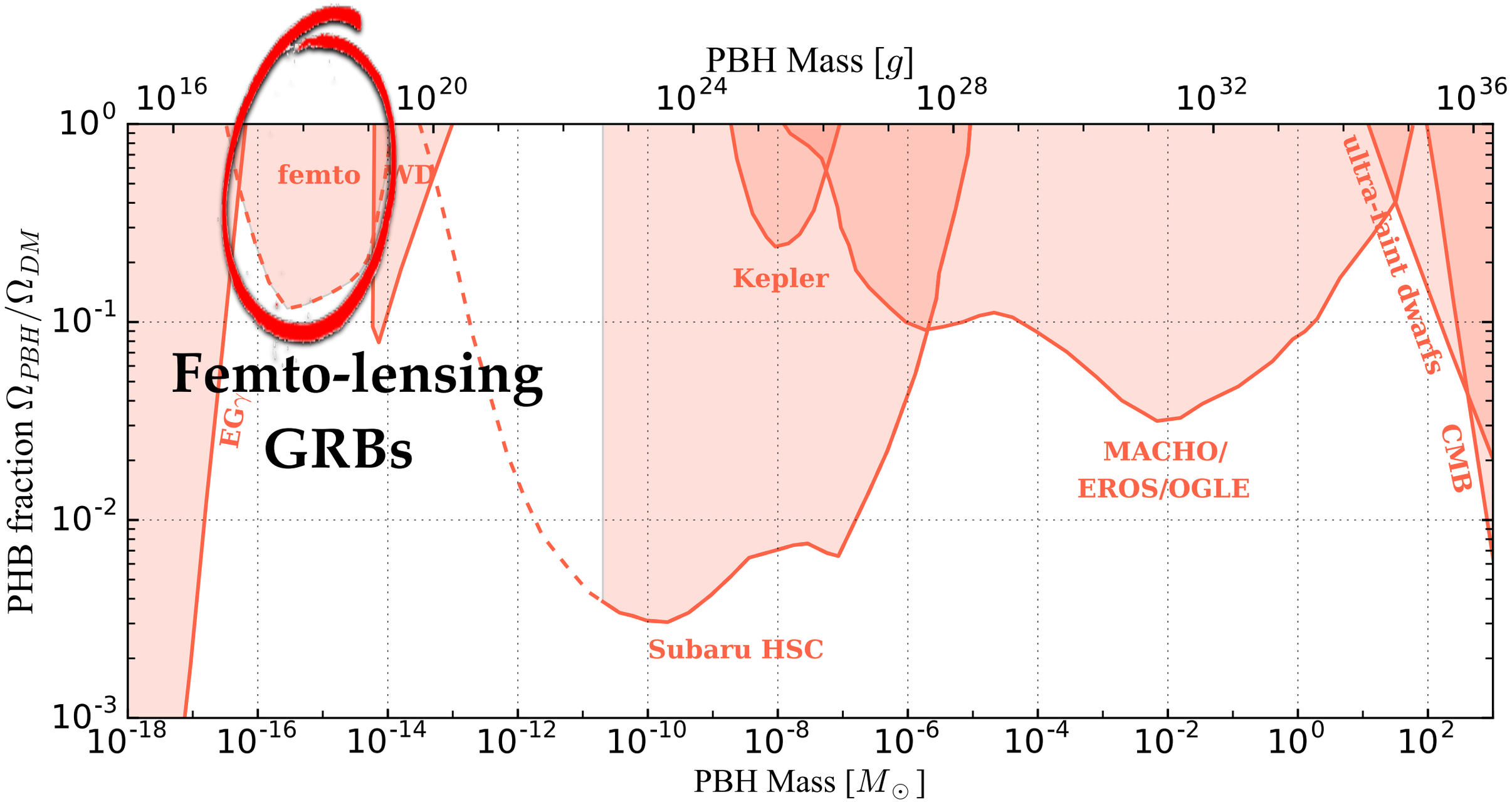
Primordial Black Hole Abundance



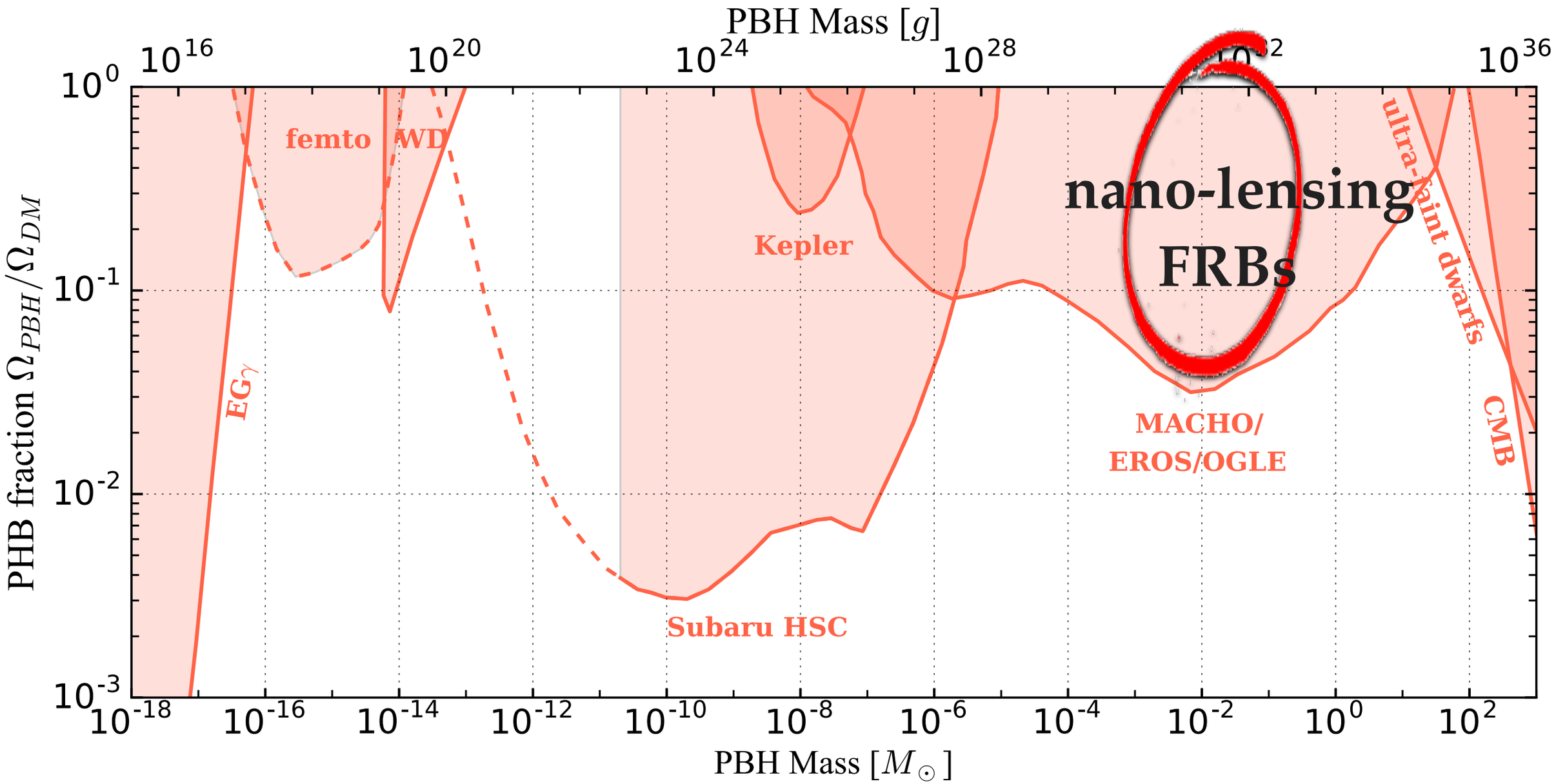
Primordial Black Hole Abundance



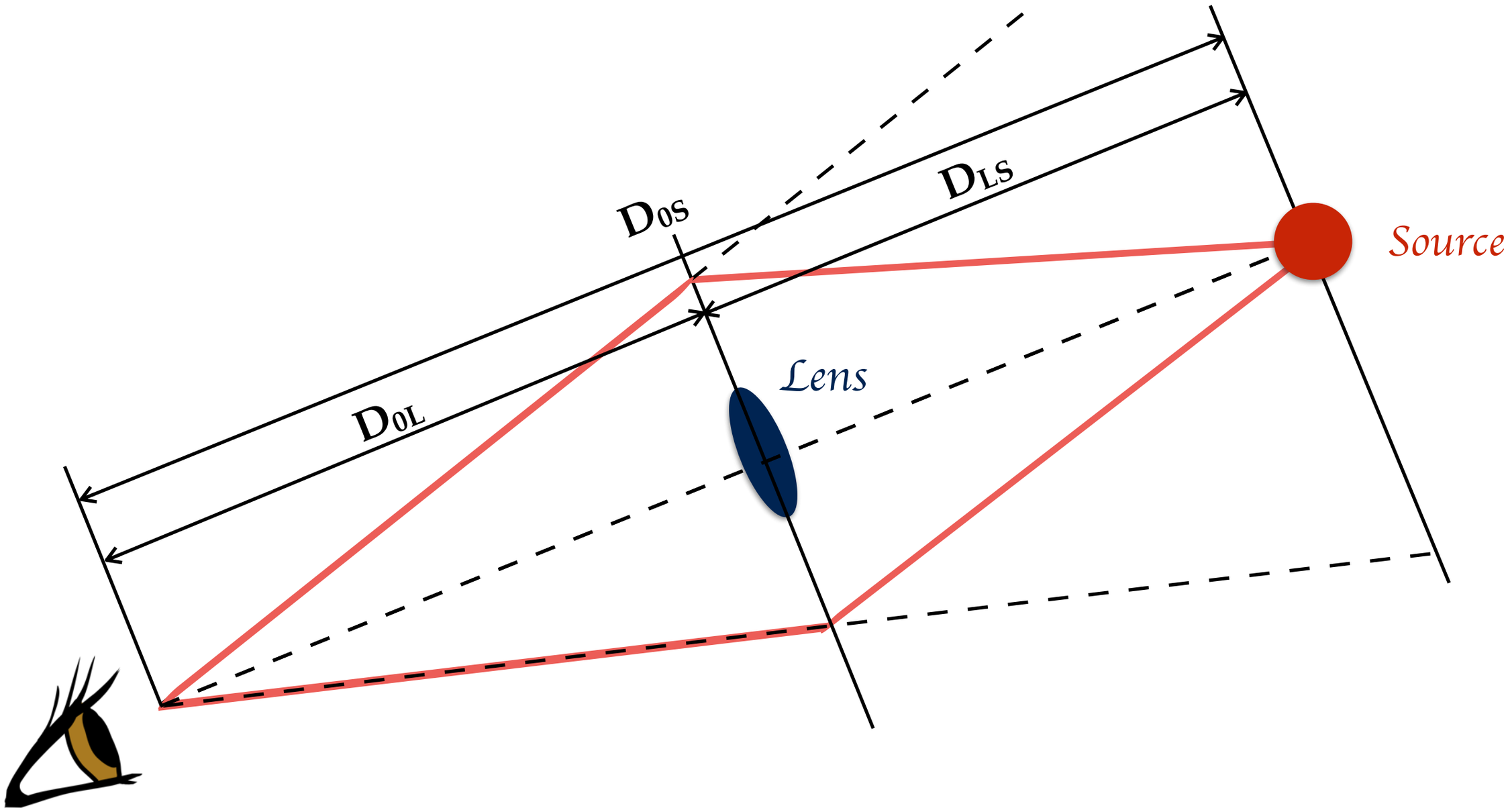
Diffractive Lensing (femto-lensing)



Diffractive Lensing (nano-lensing)



Einstein Radius r_E



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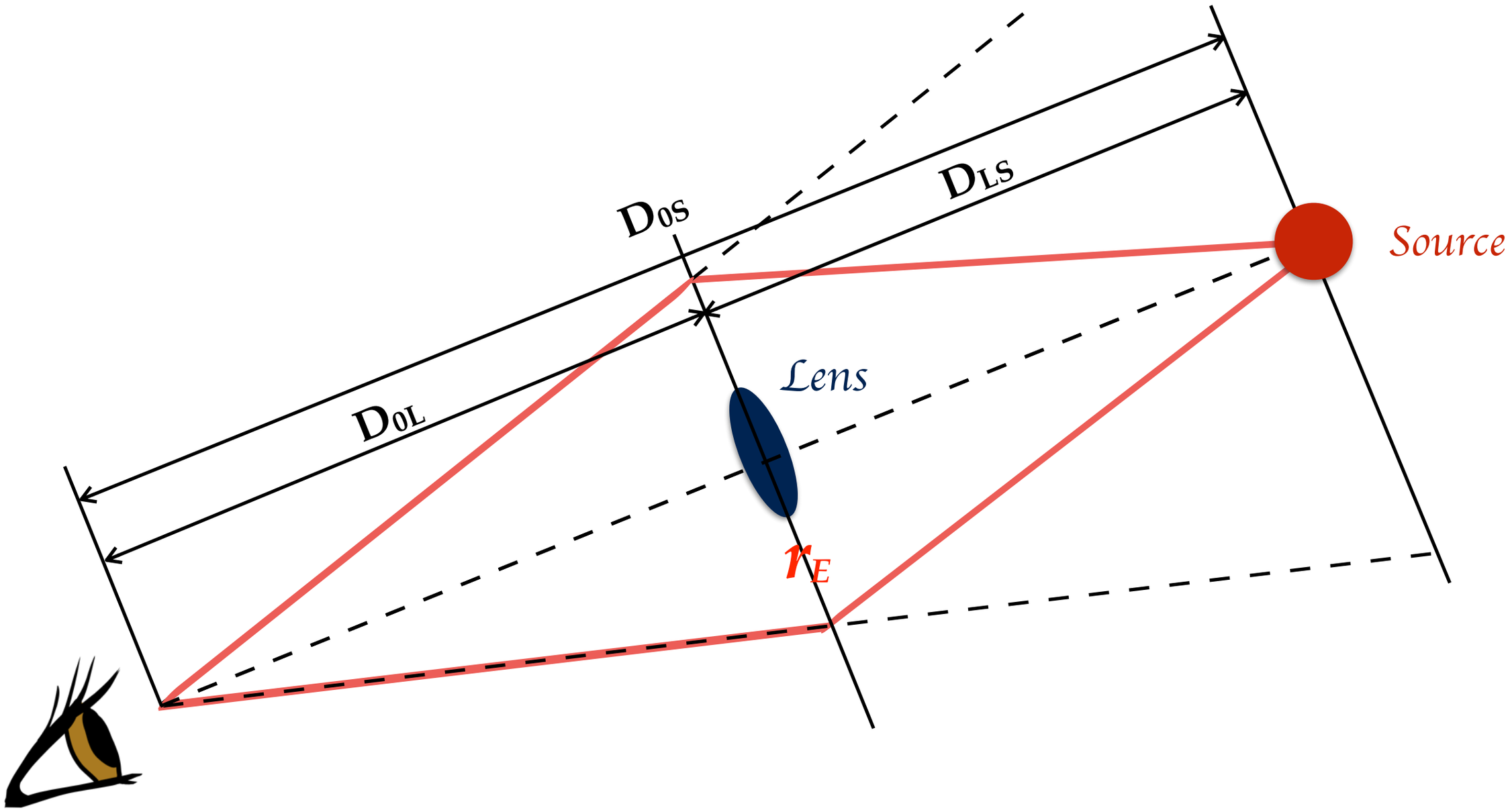

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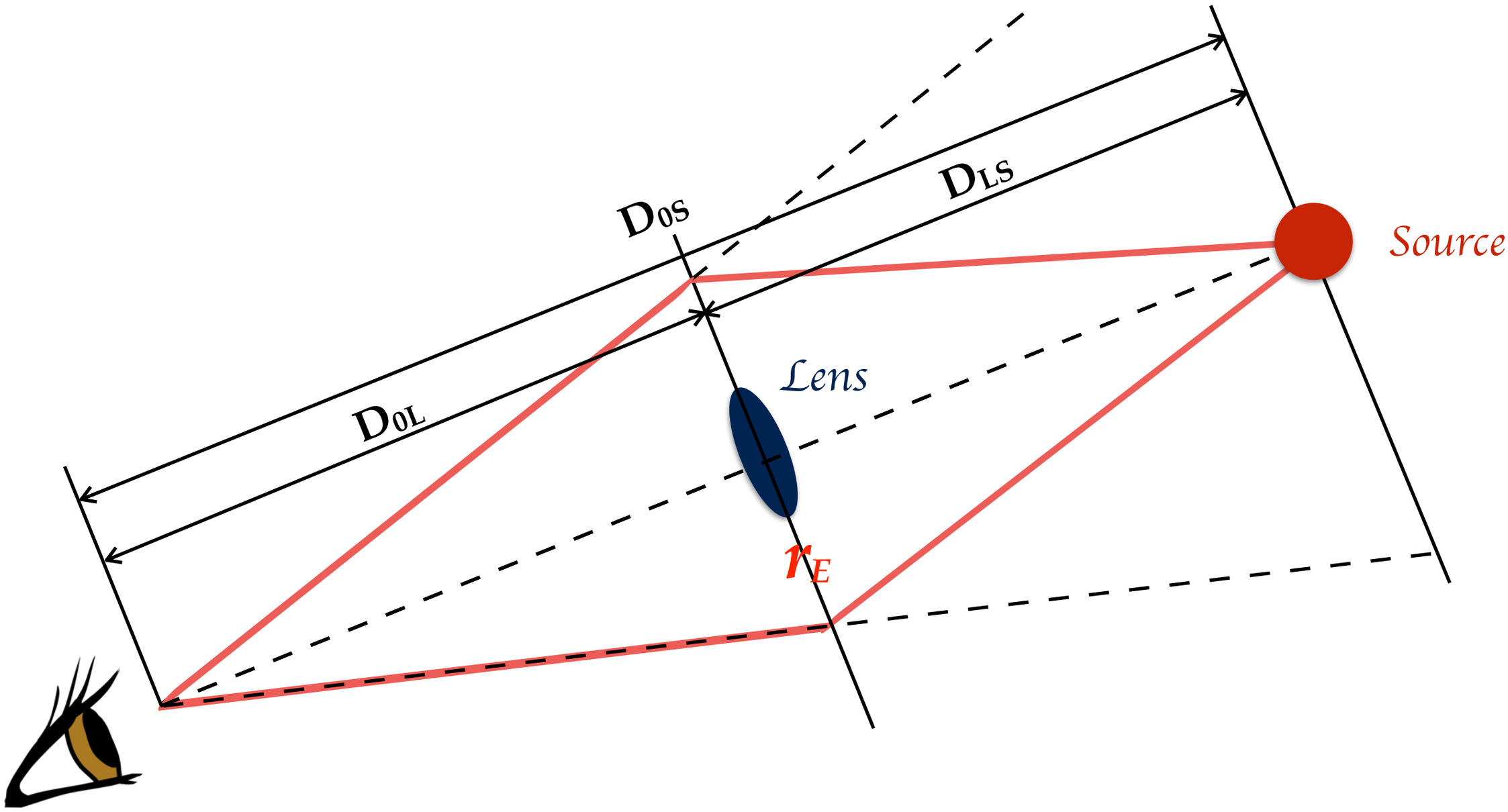
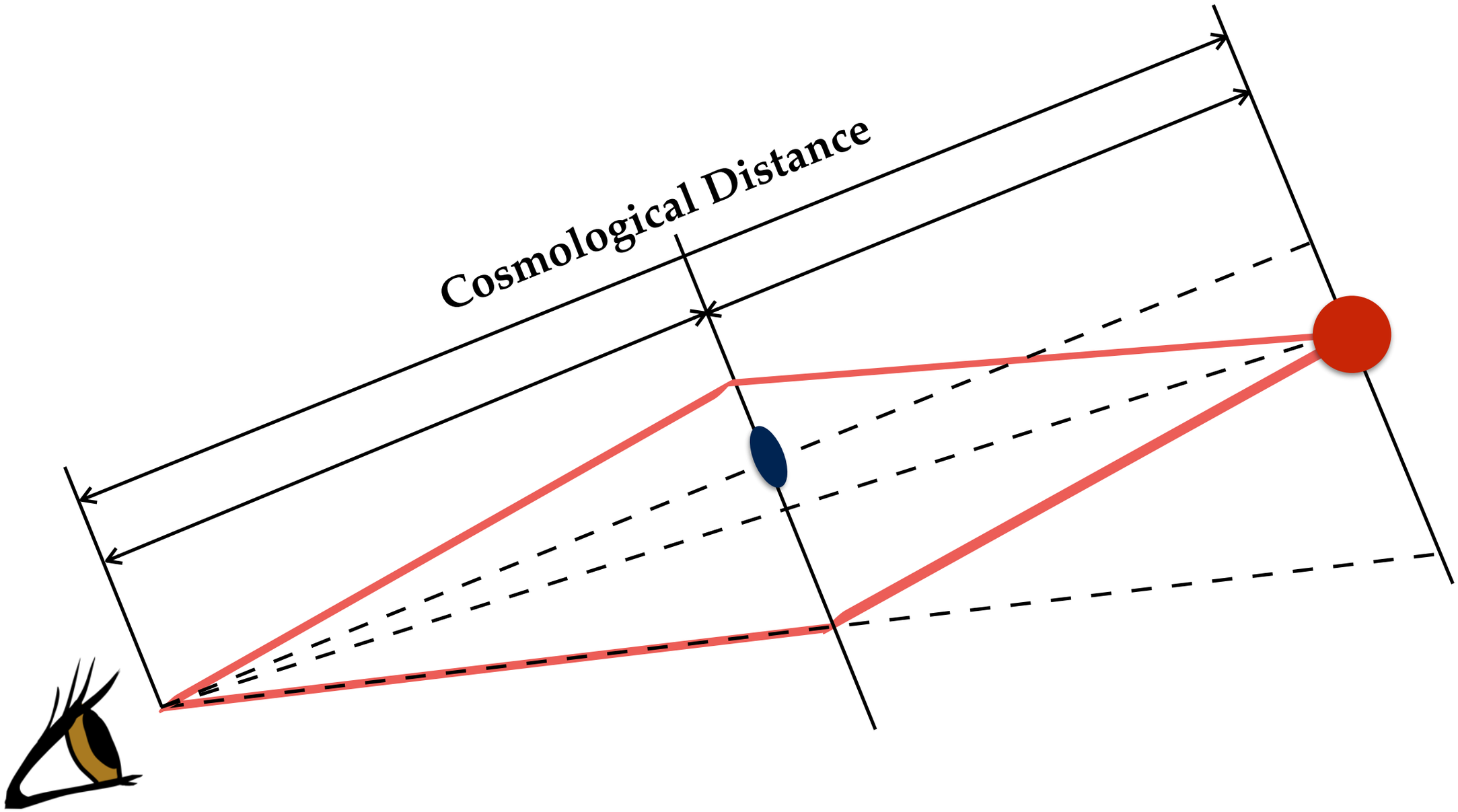


$$r_E = \sqrt{\frac{4GM}{c^2}\frac{D_{OL}D_{LS}}{D_{OS}}}$$

Diffractive Lensing (unresolved images)



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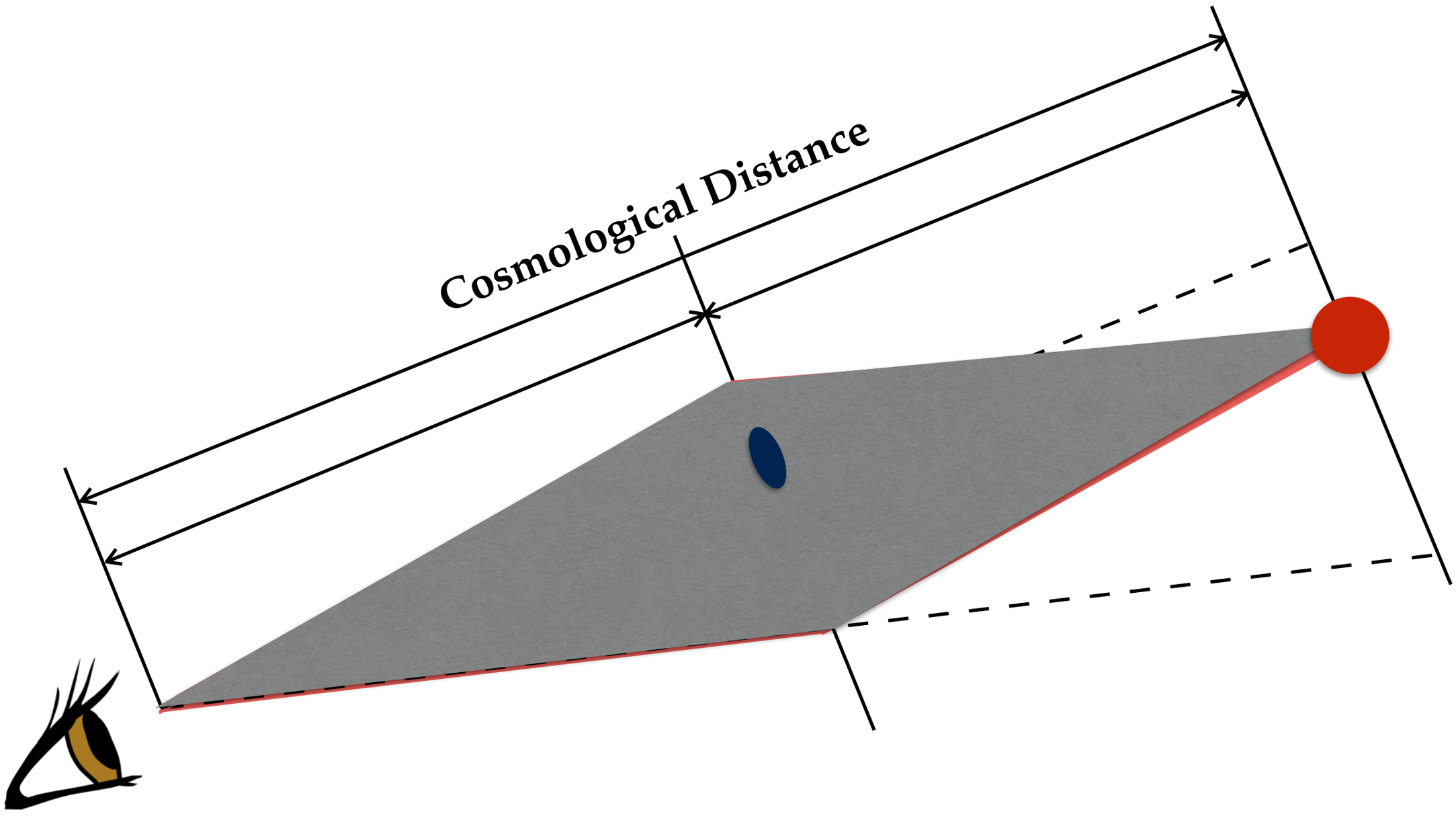
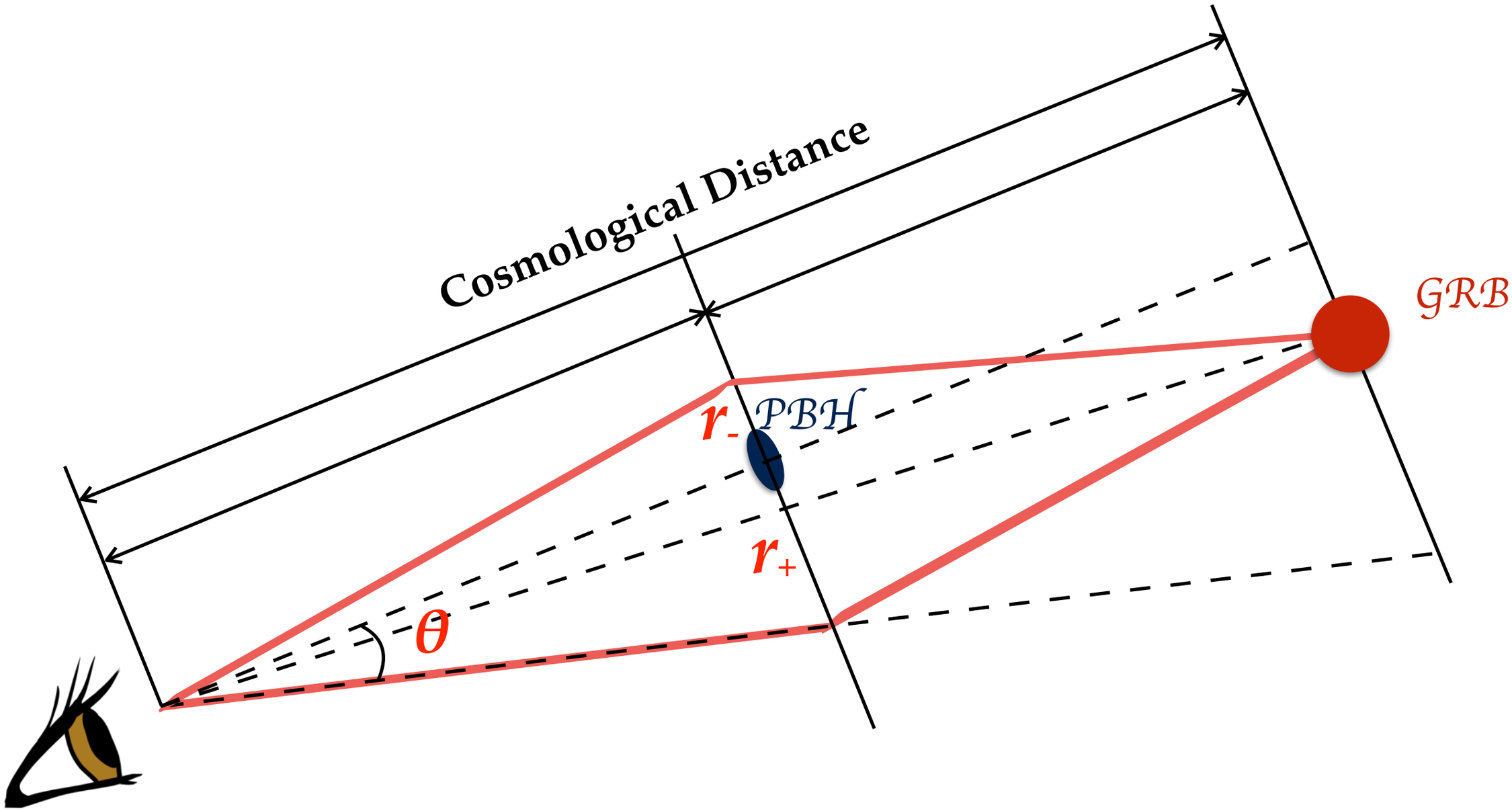


Femtolensing (unresolved images)

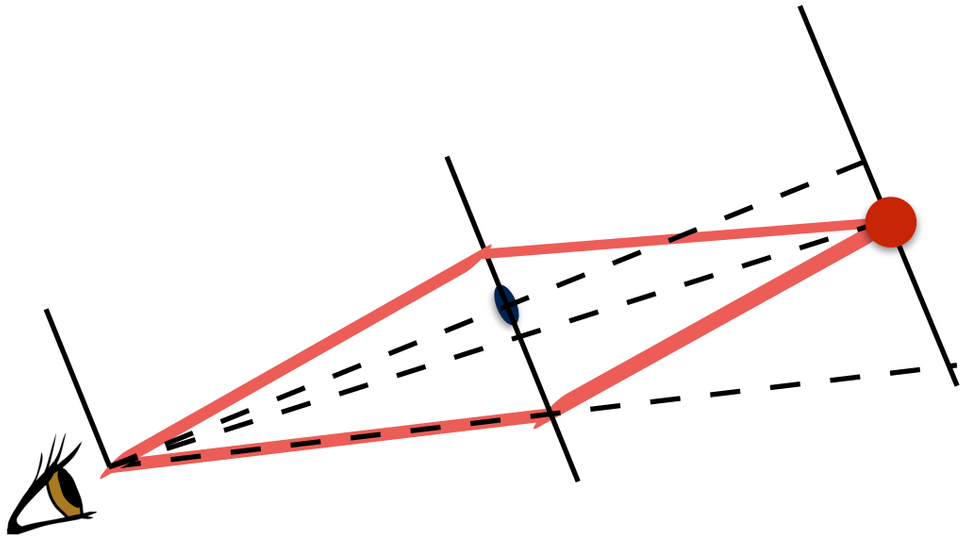


$\theta \sim$ *femto-arcsec*

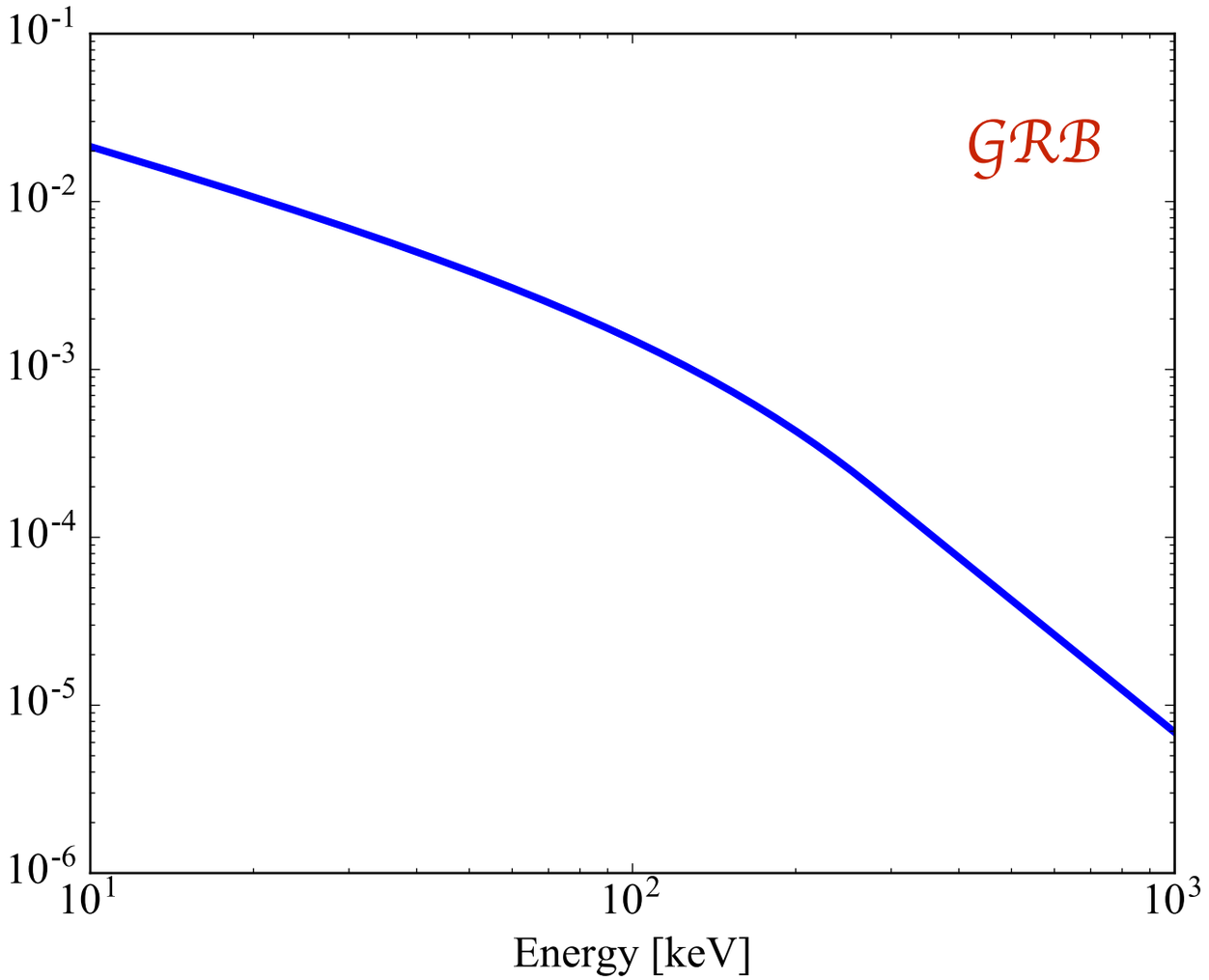
$r_\pm \sim \theta \times Gpc \sim 10^7$ *cm*

Interference $\Delta\phi = \omega\, \delta t \sim \mathcal{O}(1)$

$$\delta t \sim MeV^{-1} \; - \; keV^{-1}$$



$$|\mathcal{A} + \mathcal{B}|^2 \propto 1 + \mathcal{O}(1)\cos(\Delta\phi)$$



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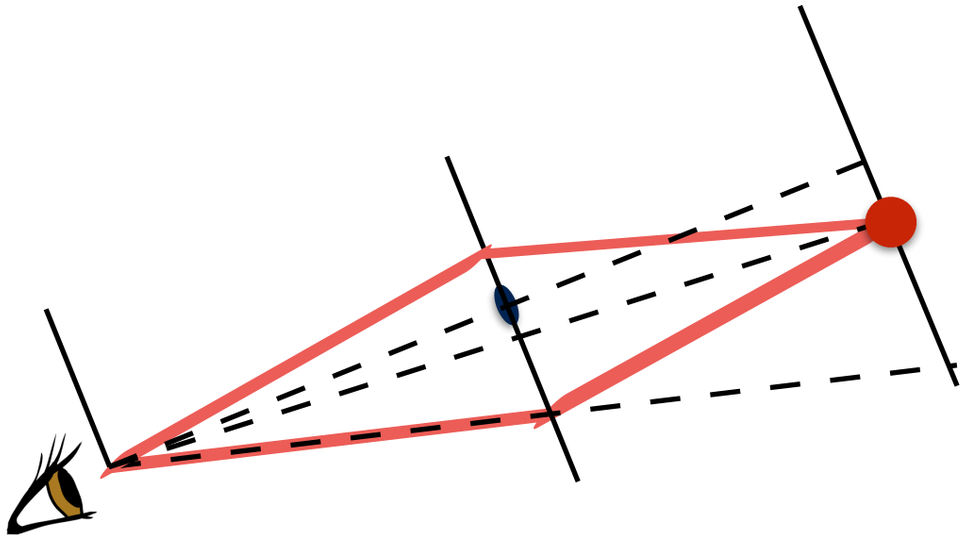

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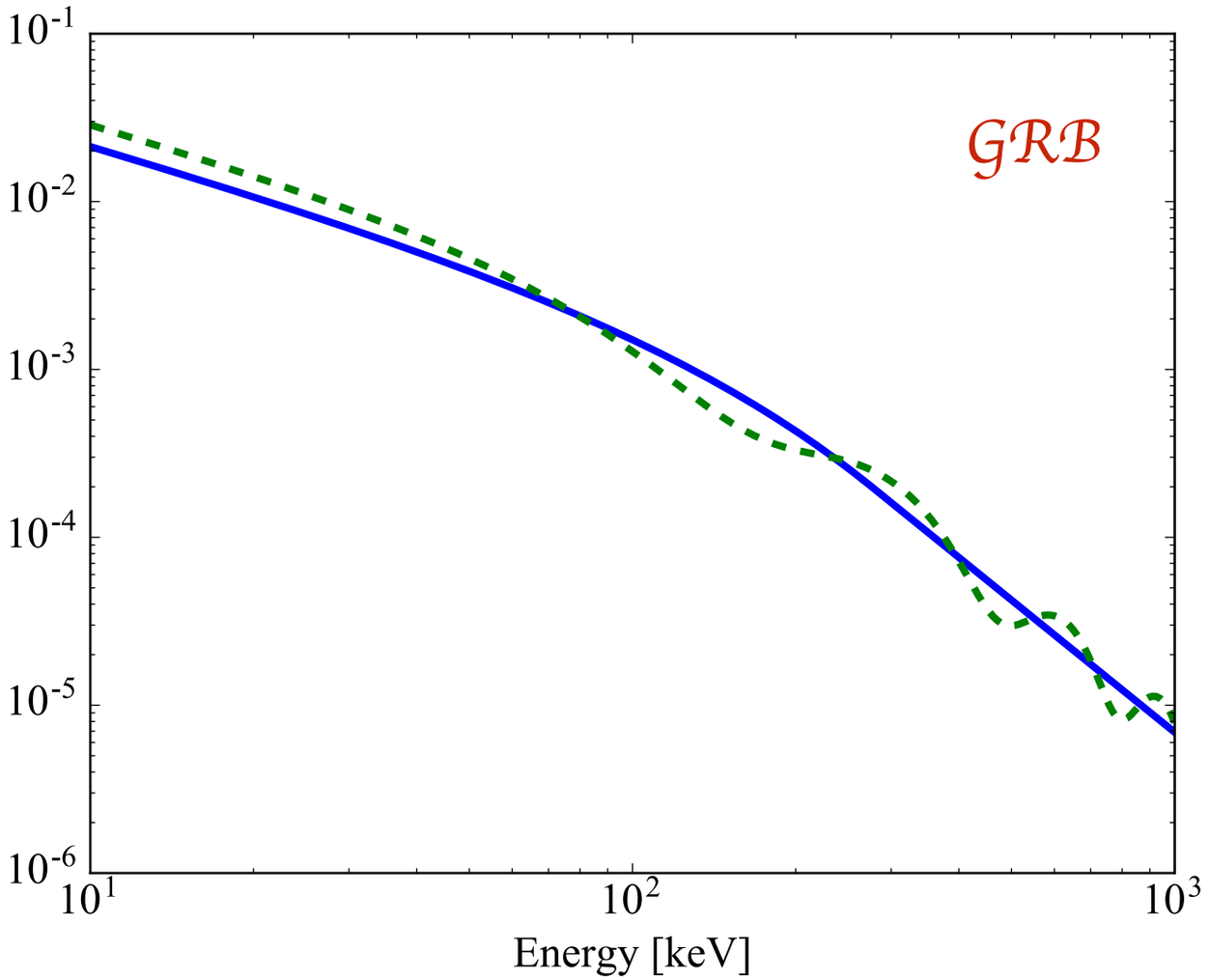
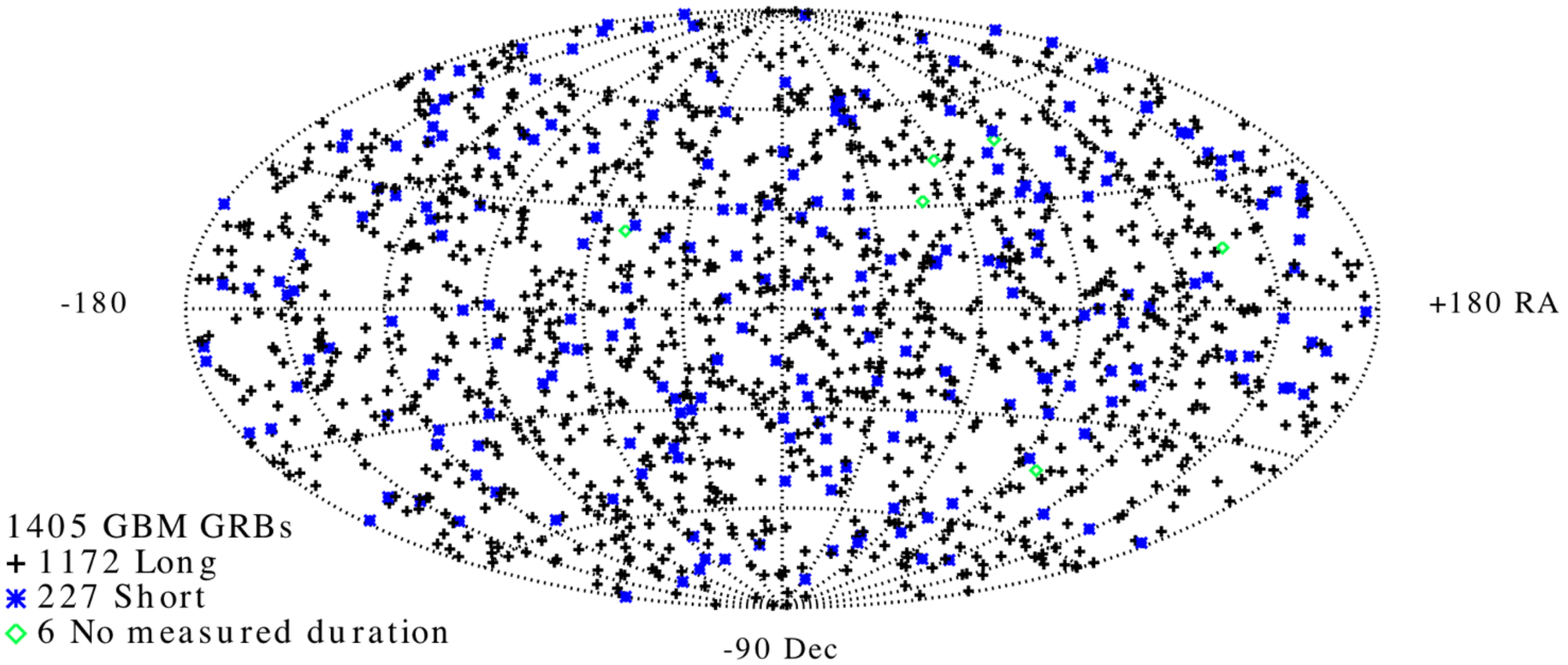


Previous Work with Fermi GBM



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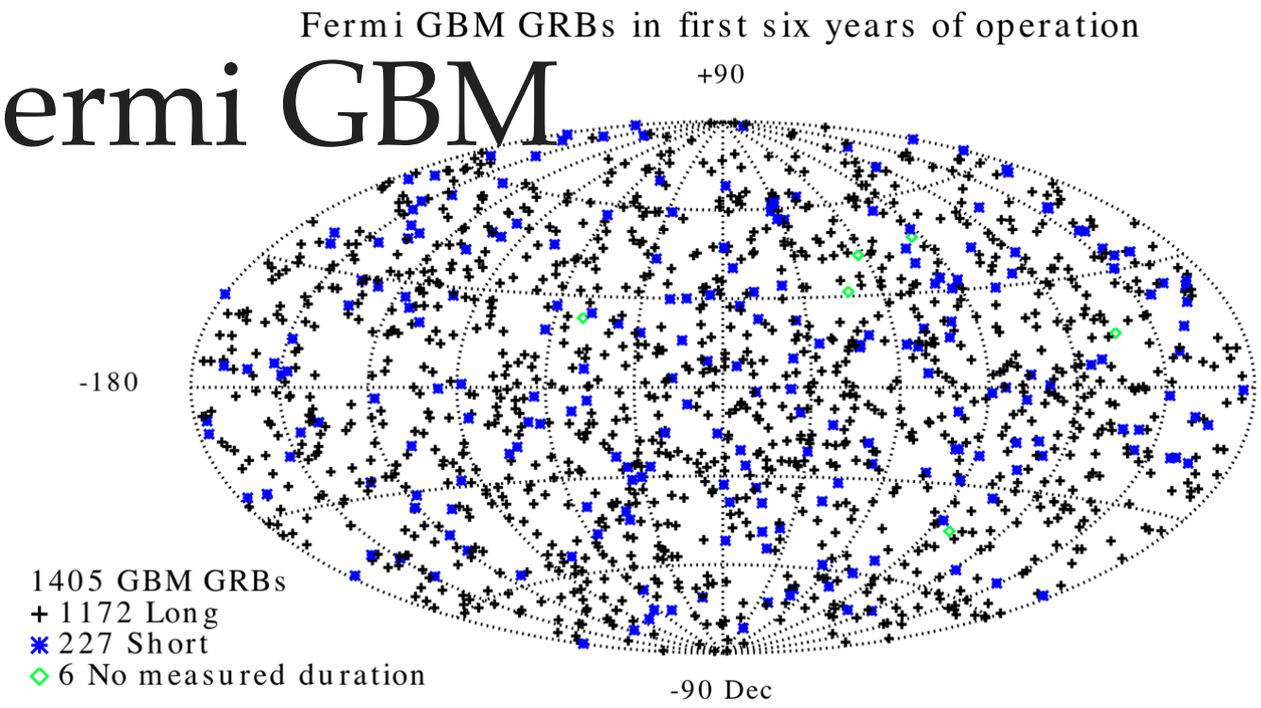
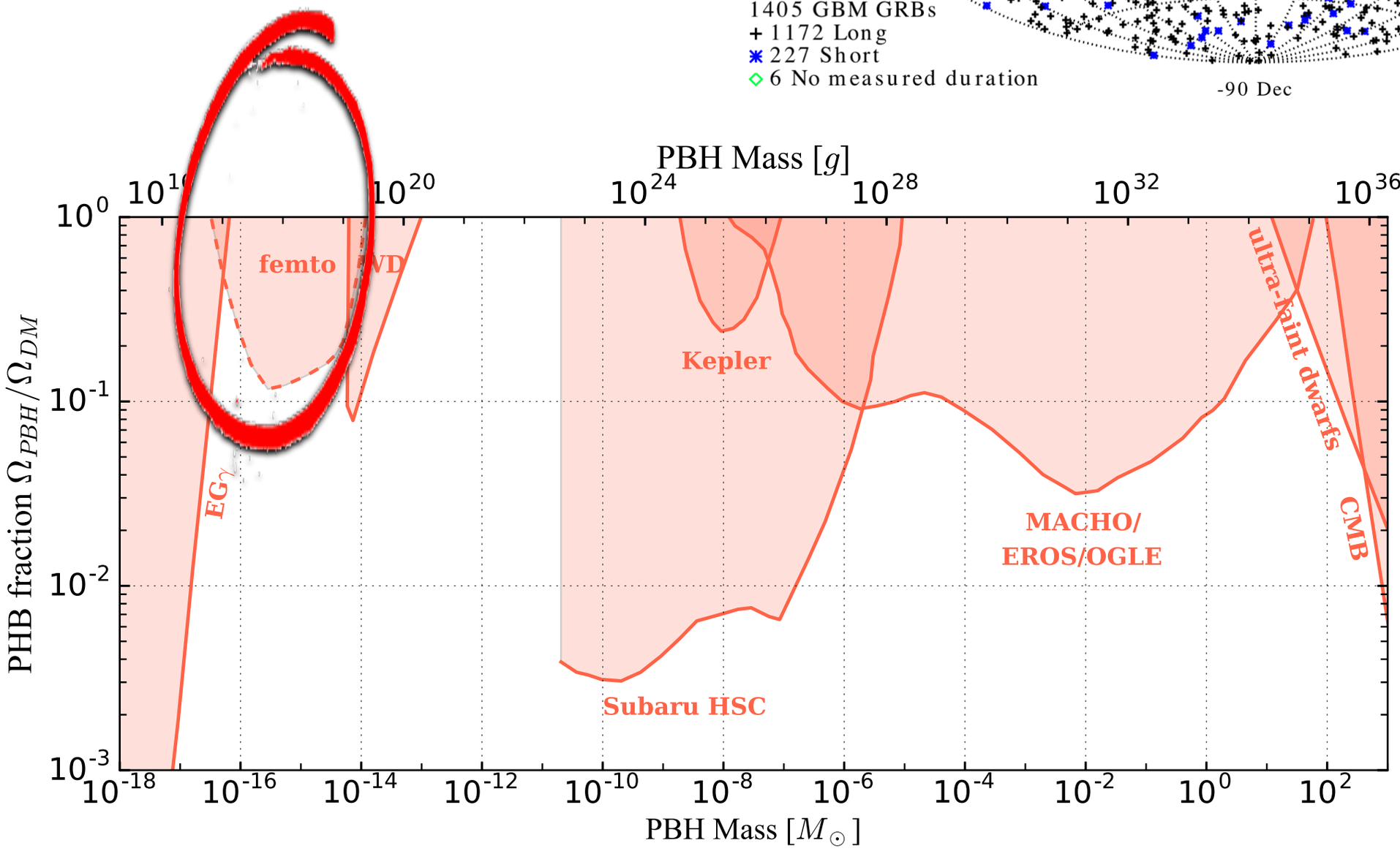




[A. Barnacka, J. Glicenstein and R. Moderski, PRD 2012]

Assumptions

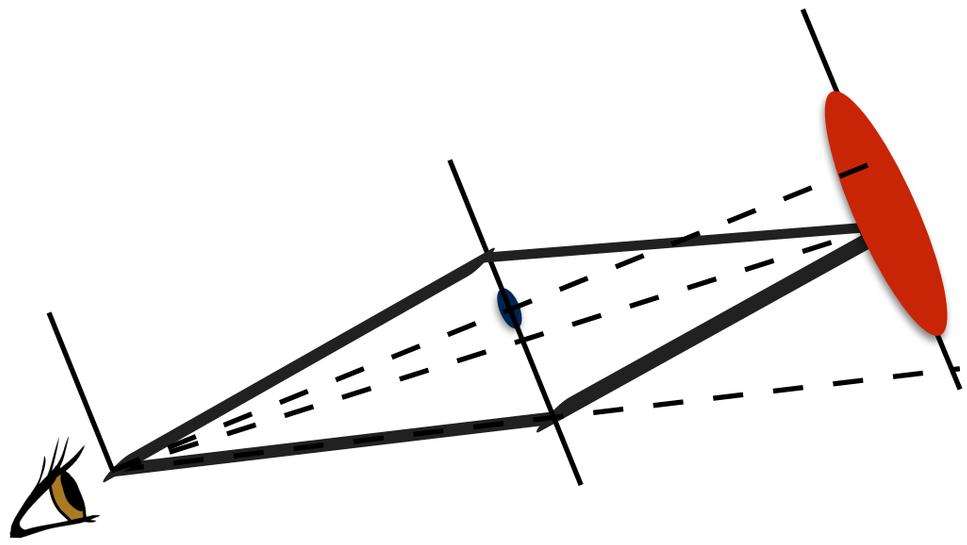
- the limit of geometric optics (?)

$$\omega\,\Delta t_0 \gg 1$$

but interference $\omega\Delta t_0 \sim 1$

- sources should be point-like (?)

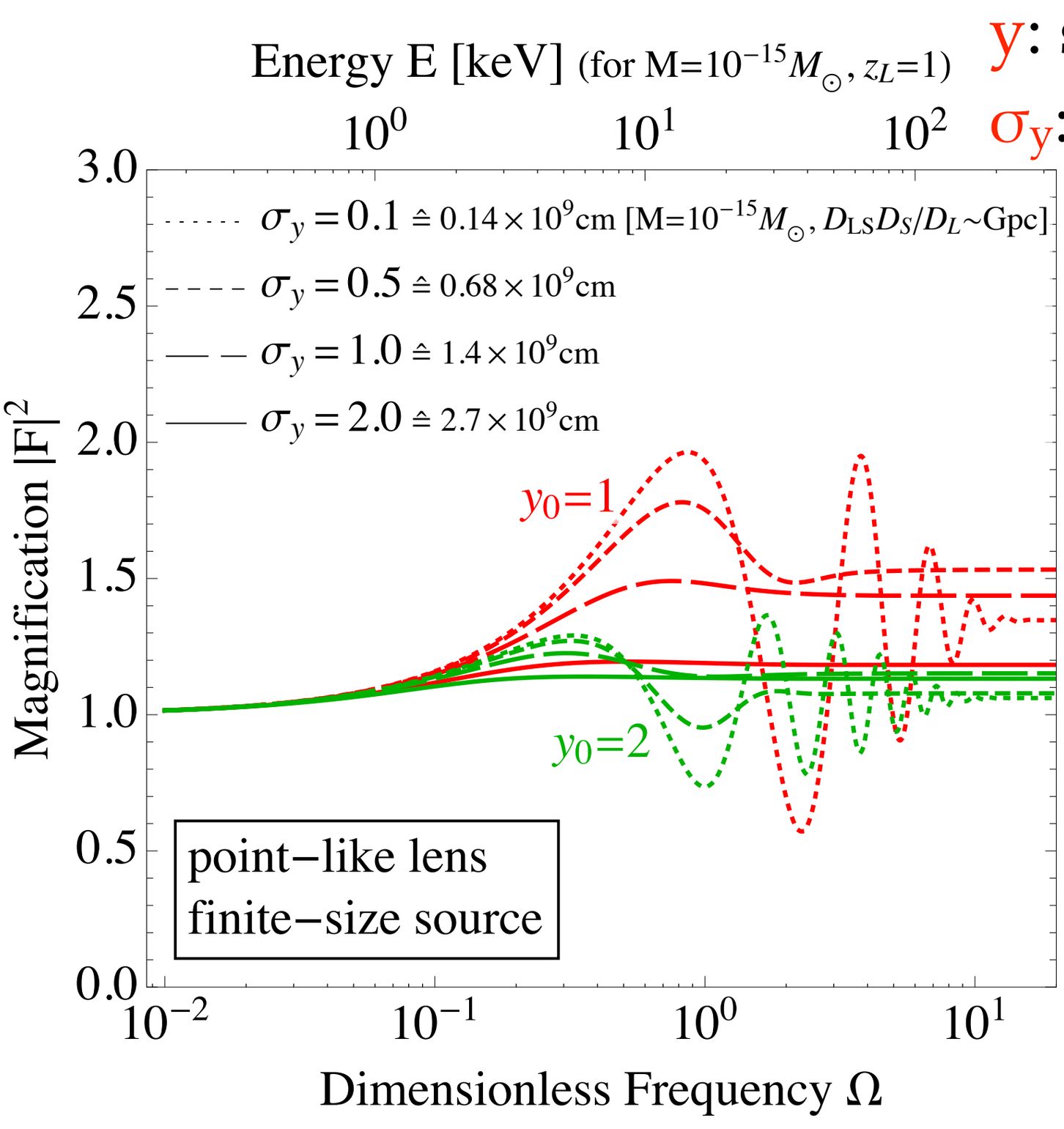
(source size in the lens plane) $\ll R_E \sim 10^7$ - 10^8 cm



Extended Sources

y: source position / r_E

σ_y: source size / r_E



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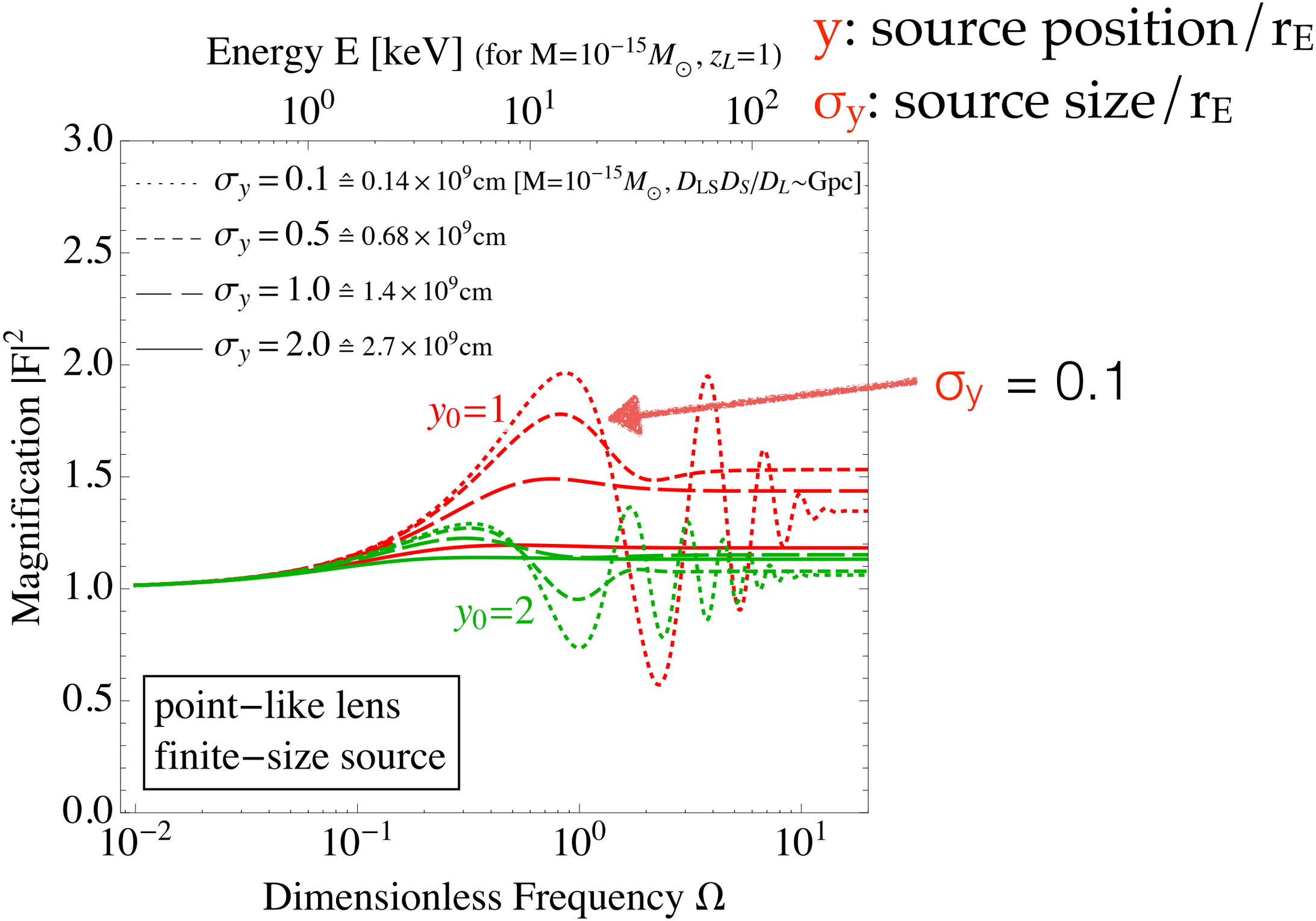

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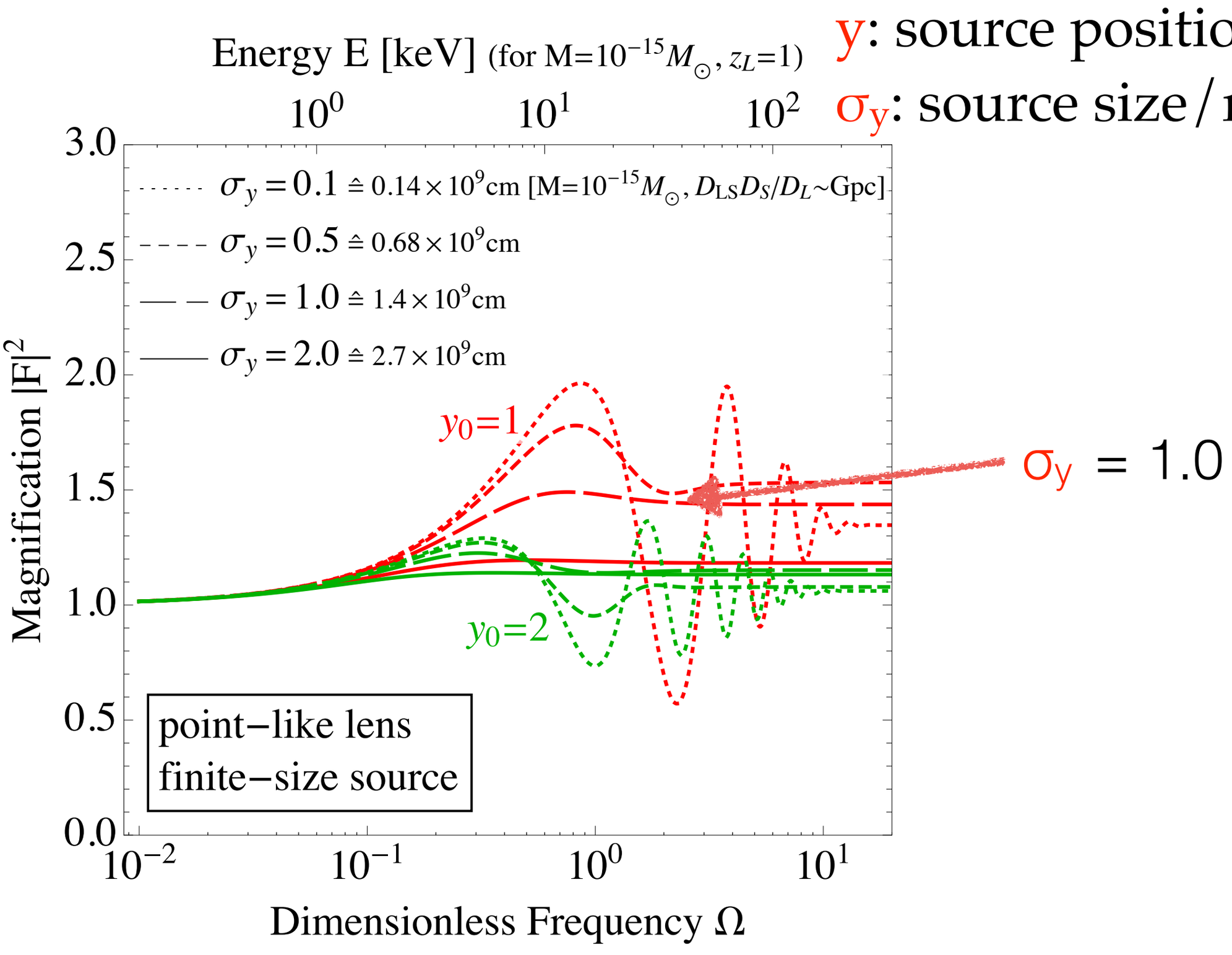

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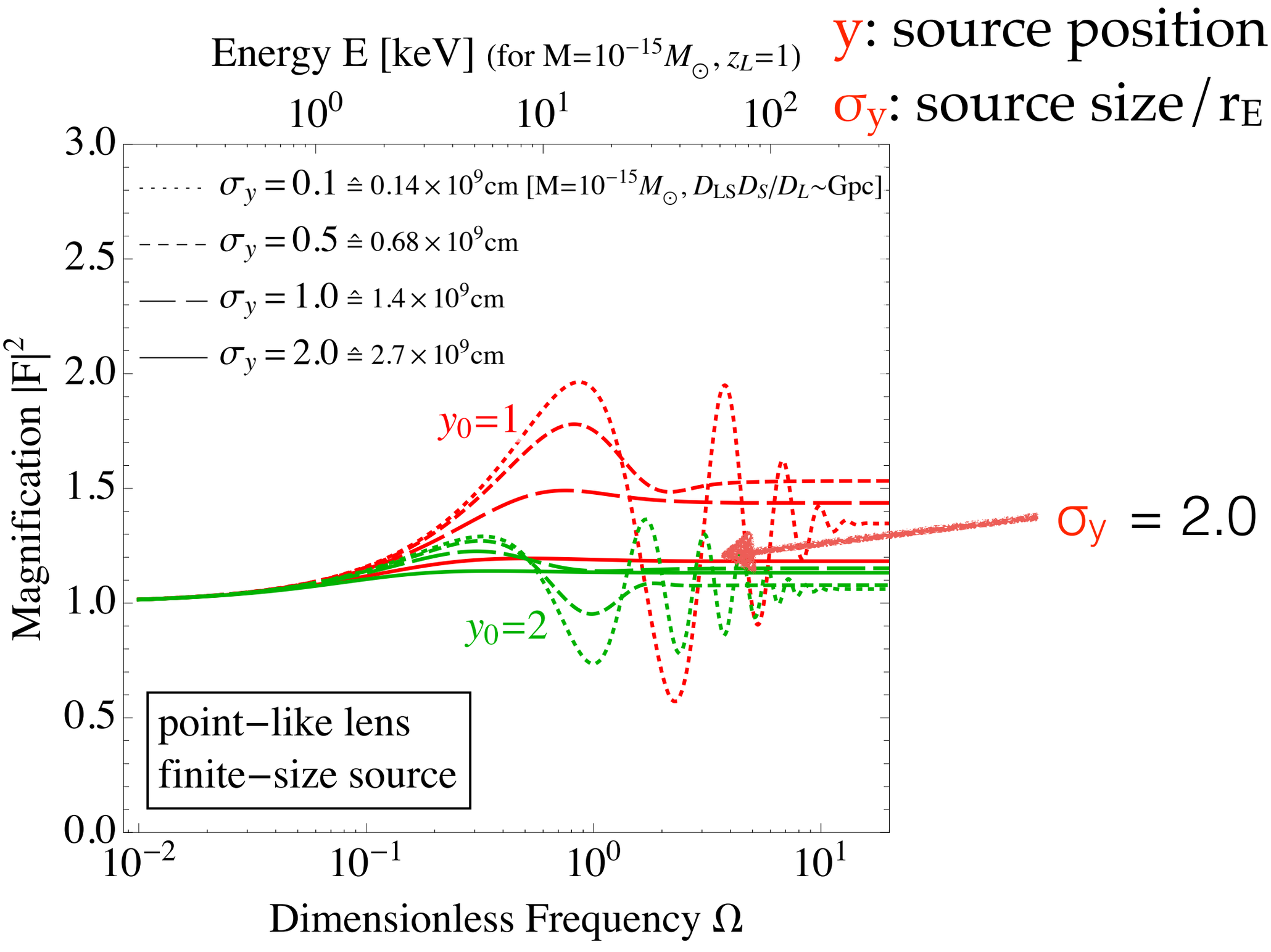
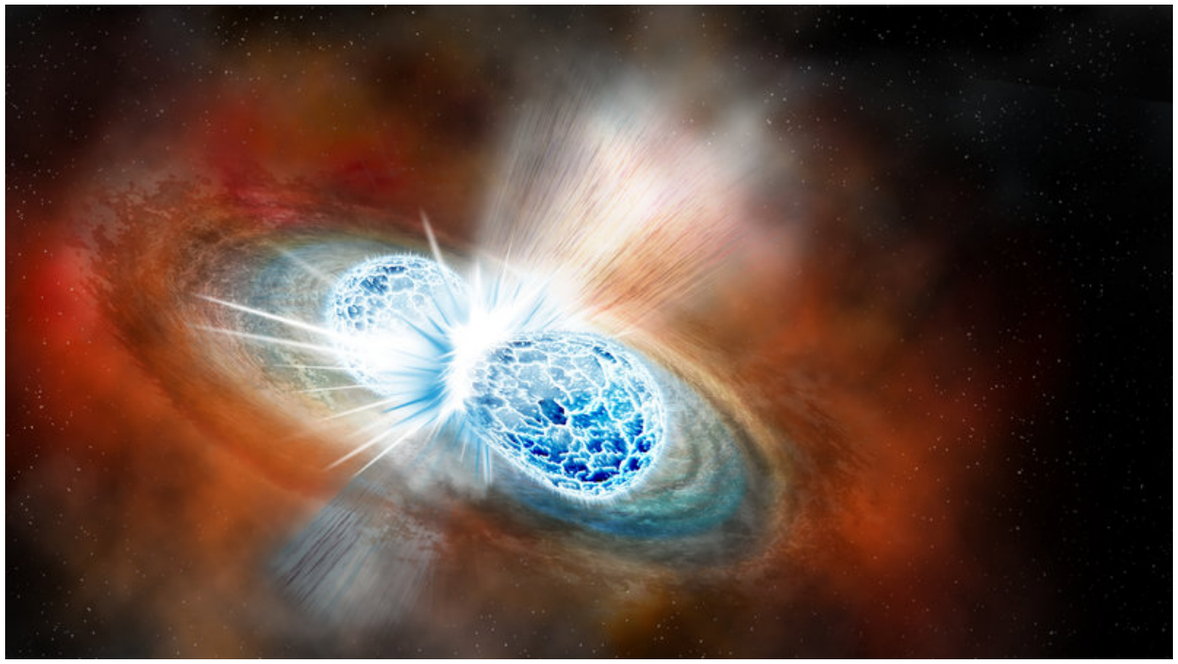


σ_y = 2.0

Size of Gamma Ray Burst

- Short GRB: NS and NS merge



- the estimated size

$$a_S \sim \frac{c\Gamma\, t_{\rm var}}{1+z_S} \simeq \frac{10^{11}\,{\rm cm}}{1+z_S} \times \left(\frac{t_{\rm var}}{0.03\,{\rm sec}}\right)\left(\frac{\Gamma}{100}\right)$$

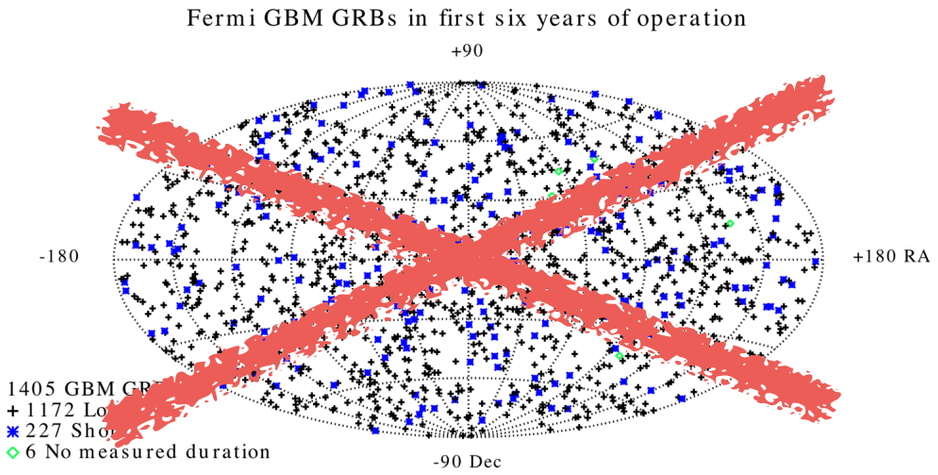
- 10^{11} cm $\gg 10^{8}$ cm

- The GRB size have some distribution

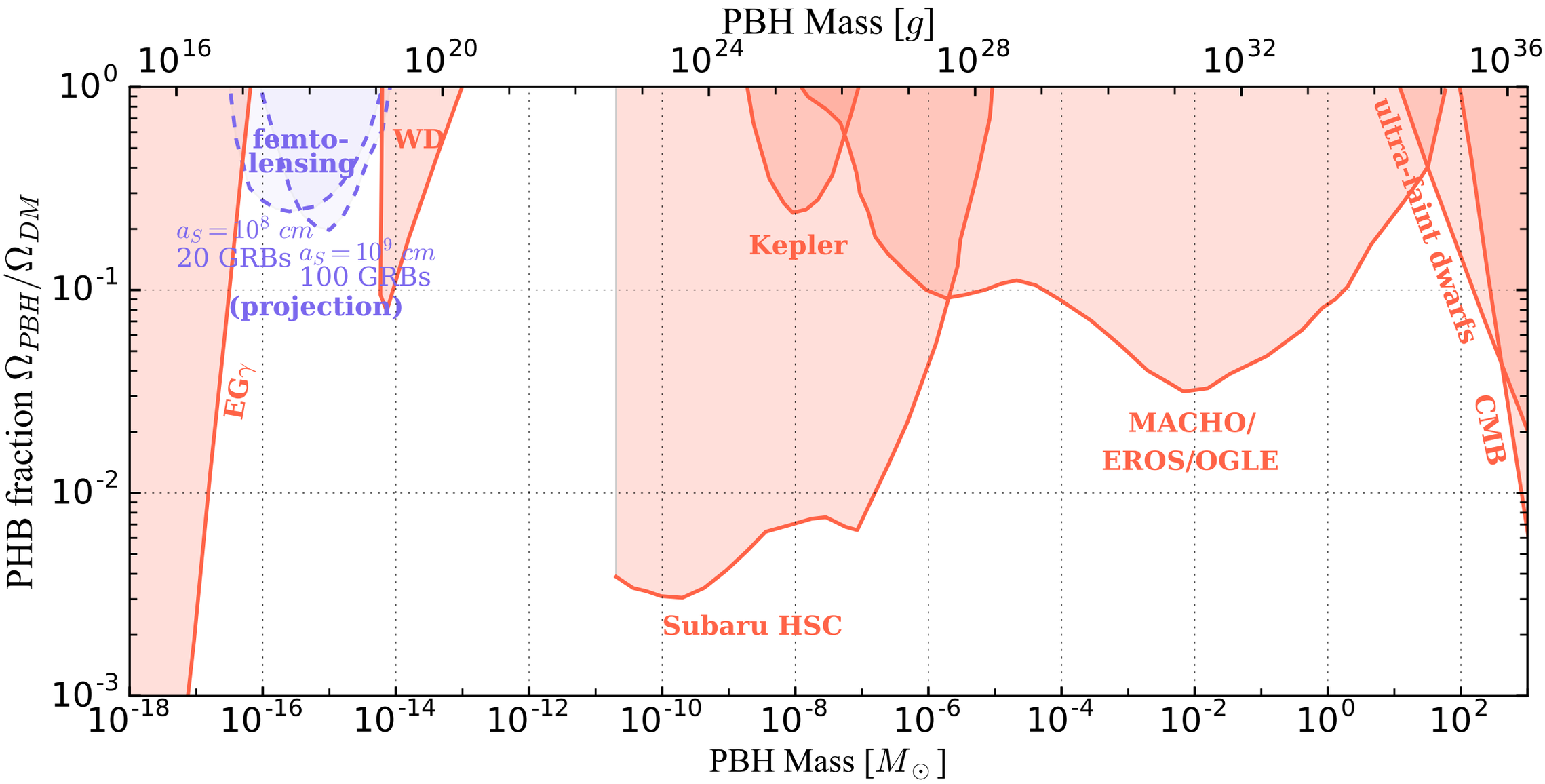
Size of Gamma Ray Burst (10^{11} cm)
>> R_E (10^8 cm)

Sensitivity Estimate

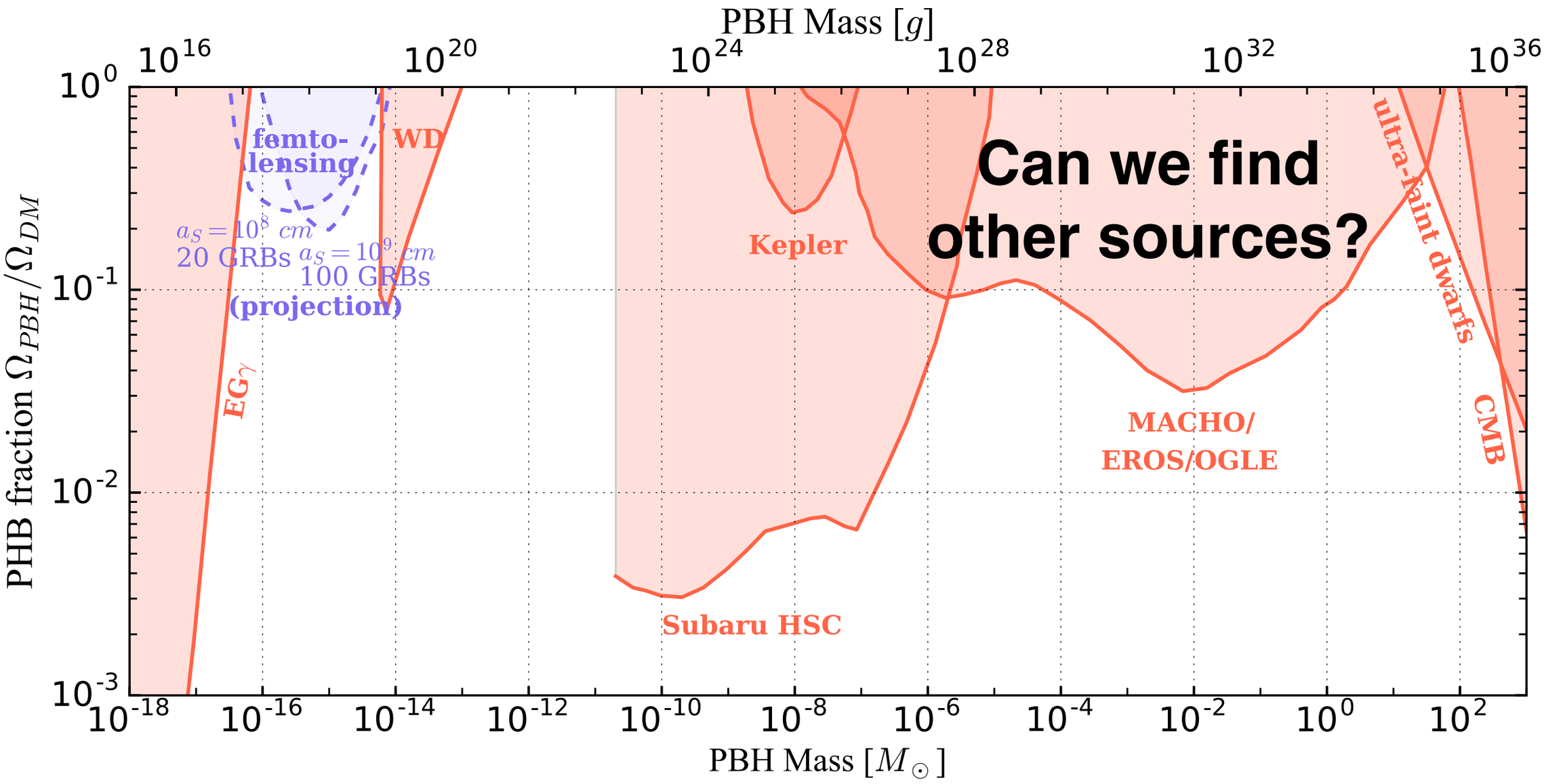
(not real data)



PBH Reaches


PBH Mass [g]
10^{16}
10^{20}
10^{24}
10^{28}
10^{32}
10^{36}
10^{0}
10^{-1}
10^{-2}
10^{-3}
PHB fraction Ω_{PBH}/Ω_{DM}
femto-lensing
WD
$a_S = 10^8\ cm$
20 GRBs
$a_S = 10^9\ cm$
100 GRBs
(projection)
EG_γ
Kepler
ultra-faint dwarfs
CMB
MACHO/
EROS/OGLE
Subaru HSC
10^{-18}
10^{-16}
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
PBH Mass [$M_\odot$]

PBH Reaches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EG_γ
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Can we find other sources?
ultra-faint dwarfs
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10^{-18}
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10^{0}
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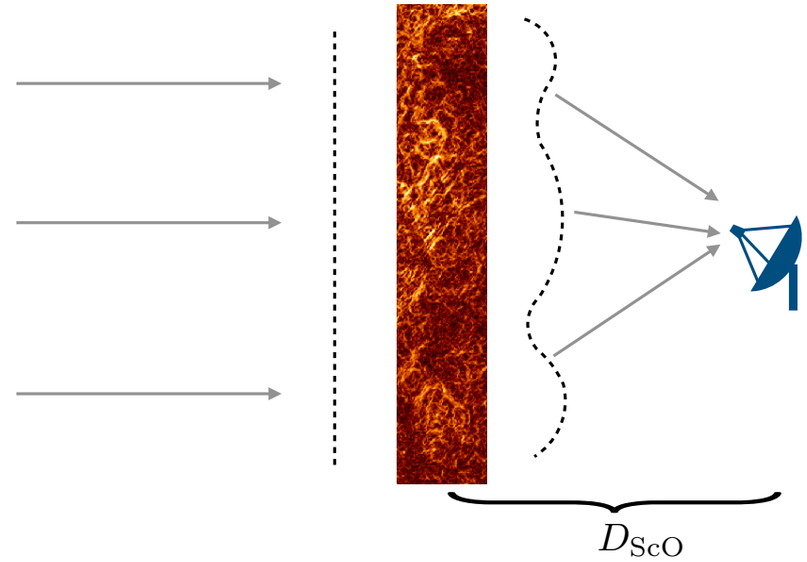
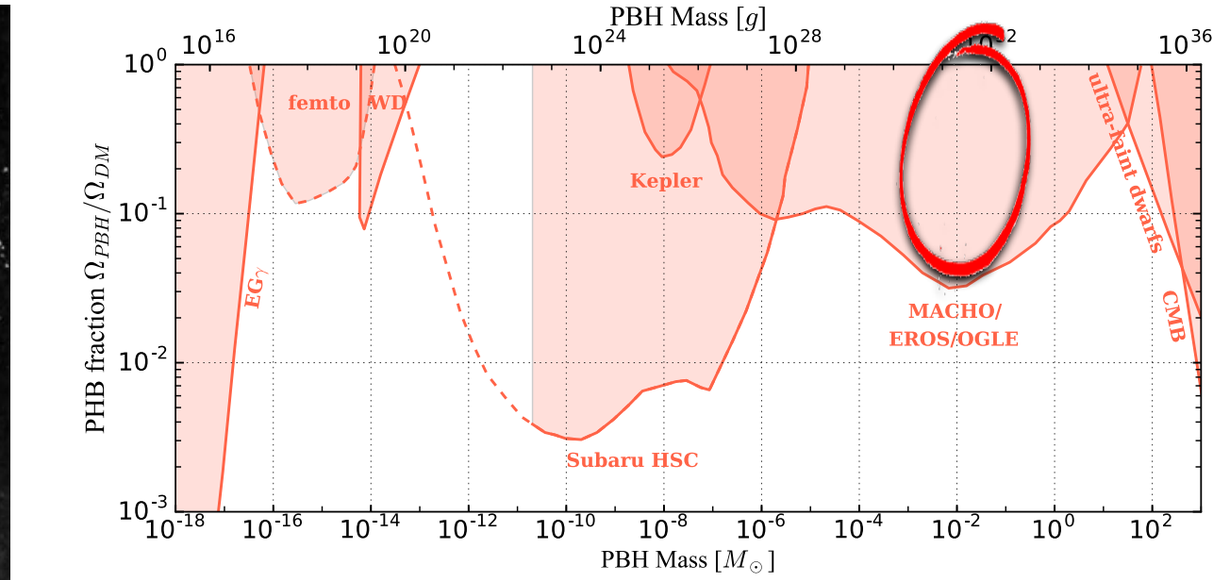
PBH Mass [$M_\odot$]

Diffractive Lensing (FRBs)



Fast Radio Bursts (FRBs)

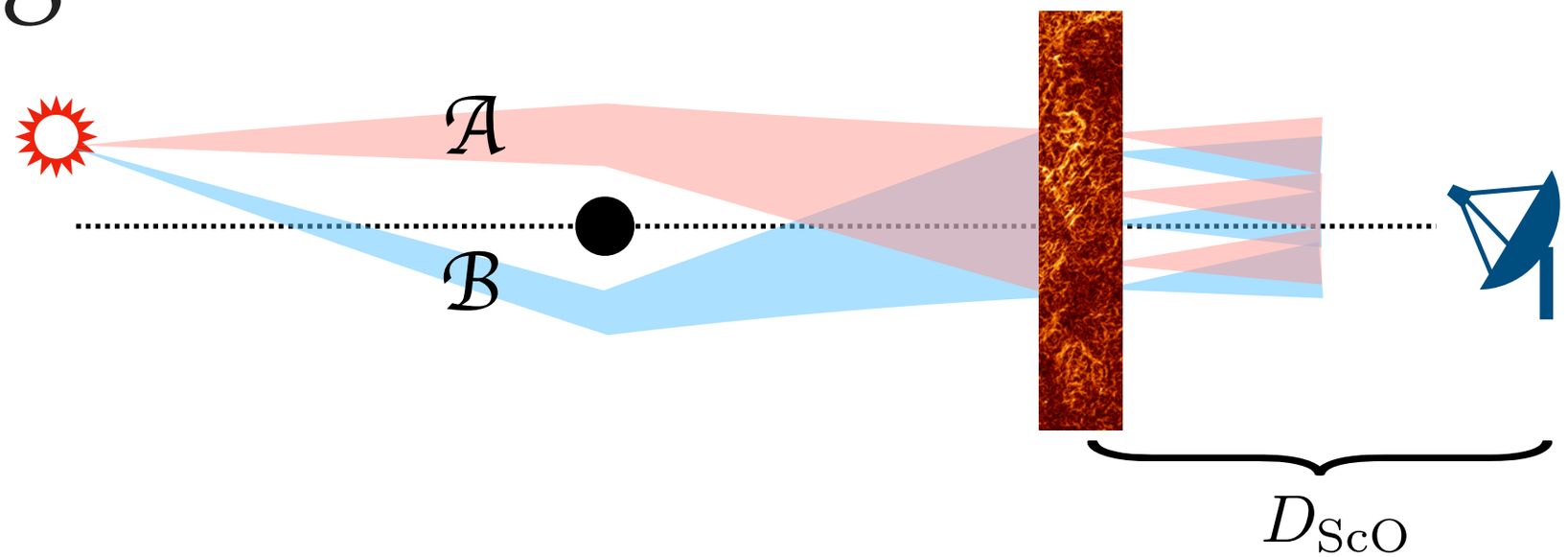


- **We do not know their origins**
- **CHIME is expected to detect FRB a few/day**
- **In the future, SKA a few tens/day**

GRBs vs FRBs

	GRB	**FRB**
frequency	MeV **gamma rays**	GHz (μeV) **radio waves**
Distance	Gpc **cosmological**	Gpc **cosmological**
R_E	10^7 cm **size problem**	10^{13} cm
PBH mass	10^{-15} M⊙	10^{-2} M⊙

Lensing and Scintillations



- signal

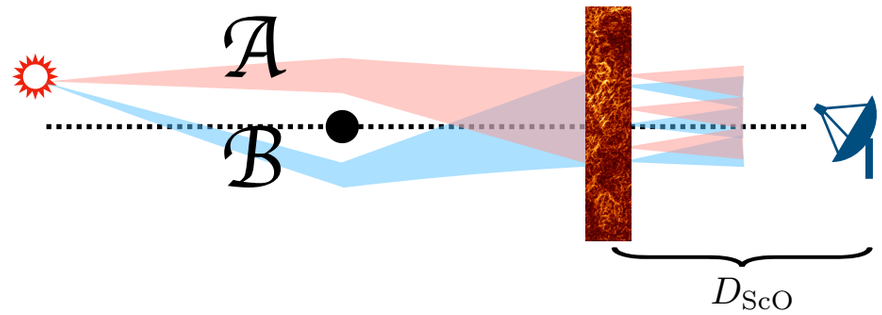
$$f(\omega) \propto \mathcal{A}(\omega) + \mathcal{B}(\omega)\, e^{i\omega\Delta t}$$

- intensity

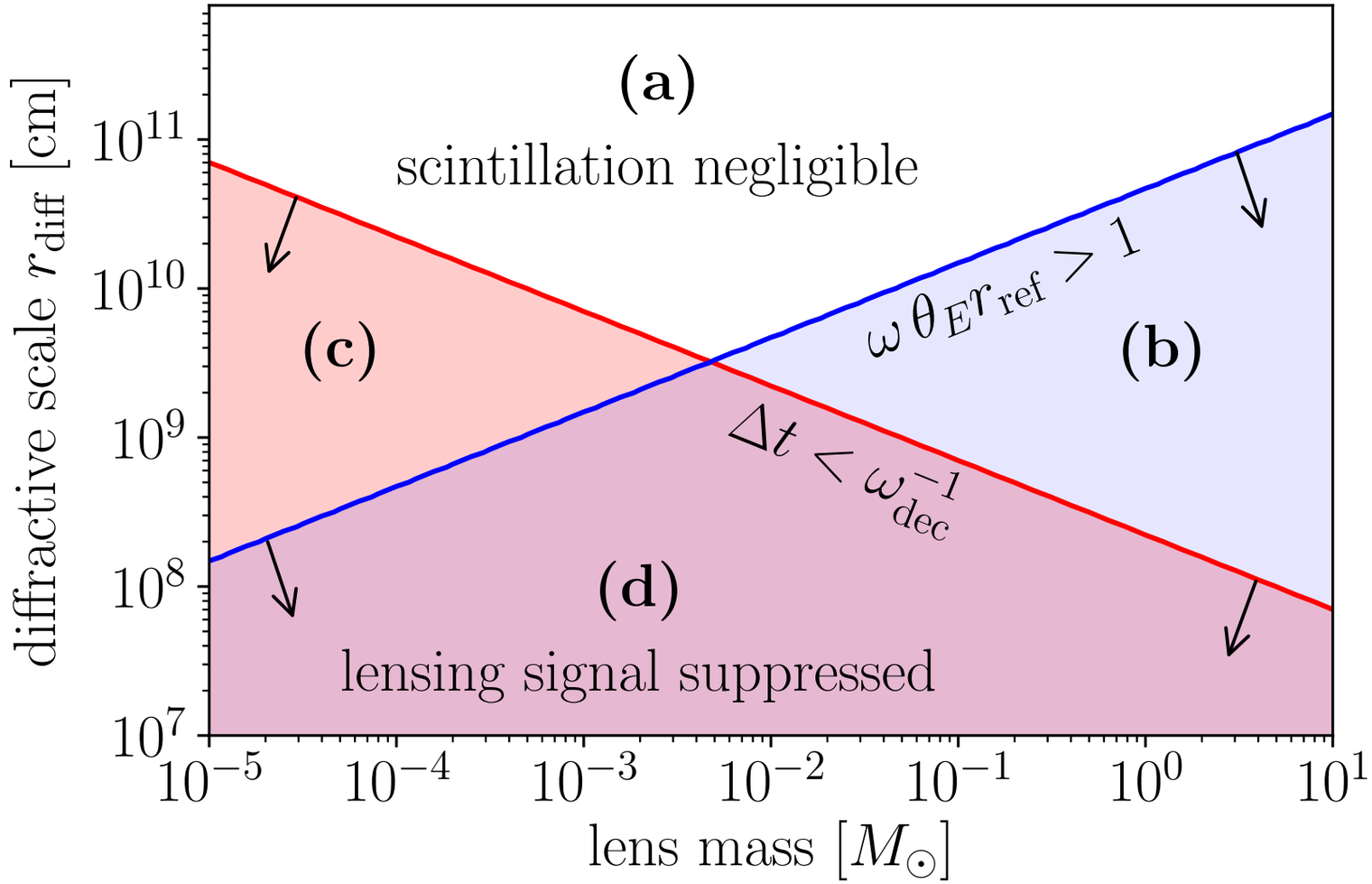
$$\mathcal{I}(\omega) = |f(\omega)|^2 \propto \left(|\mathcal{A}(\omega)|^2 + |\mathcal{B}(\omega)|^2 + \mathcal{A}^*(\omega)\mathcal{B}(\omega)\, e^{i\omega\Delta t} + \mathcal{A}(\omega)\mathcal{B}^*(\omega)\, e^{-i\omega\Delta t}\right)$$

- interference terms (oscillating intensity)
  "easy" method: Fourier transformation of the intensity
  peak due to the lensing time delay Δt

Autocorrelation Functions



- autocorrelation $\langle \mathcal{A}^*(\omega)\mathcal{A}(\omega')\rangle \langle \mathcal{B}(\omega)\mathcal{B}^*(\omega')\rangle + \langle \mathcal{A}^*(\omega)\mathcal{B}(\omega)\rangle \langle \mathcal{A}(\omega')\mathcal{B}^*(\omega')\rangle$
- (a&b) the amplitudes are correlated $\langle \mathcal{A}^*(\omega)\mathcal{A}(\omega')\rangle$
- (a&c) lensed images are distorted coherently $\langle \mathcal{A}^*(\omega)\mathcal{B}(\omega)\rangle$



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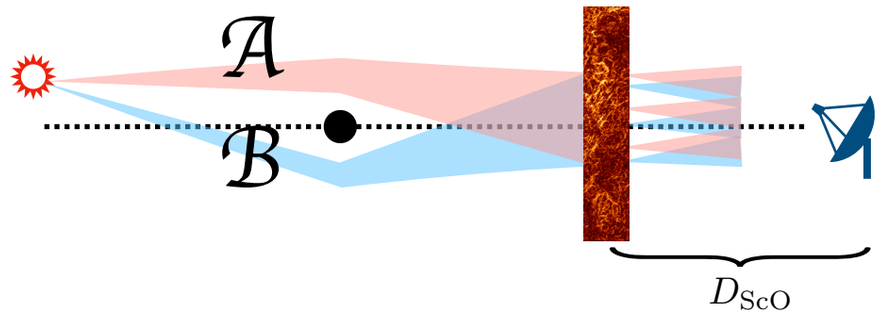

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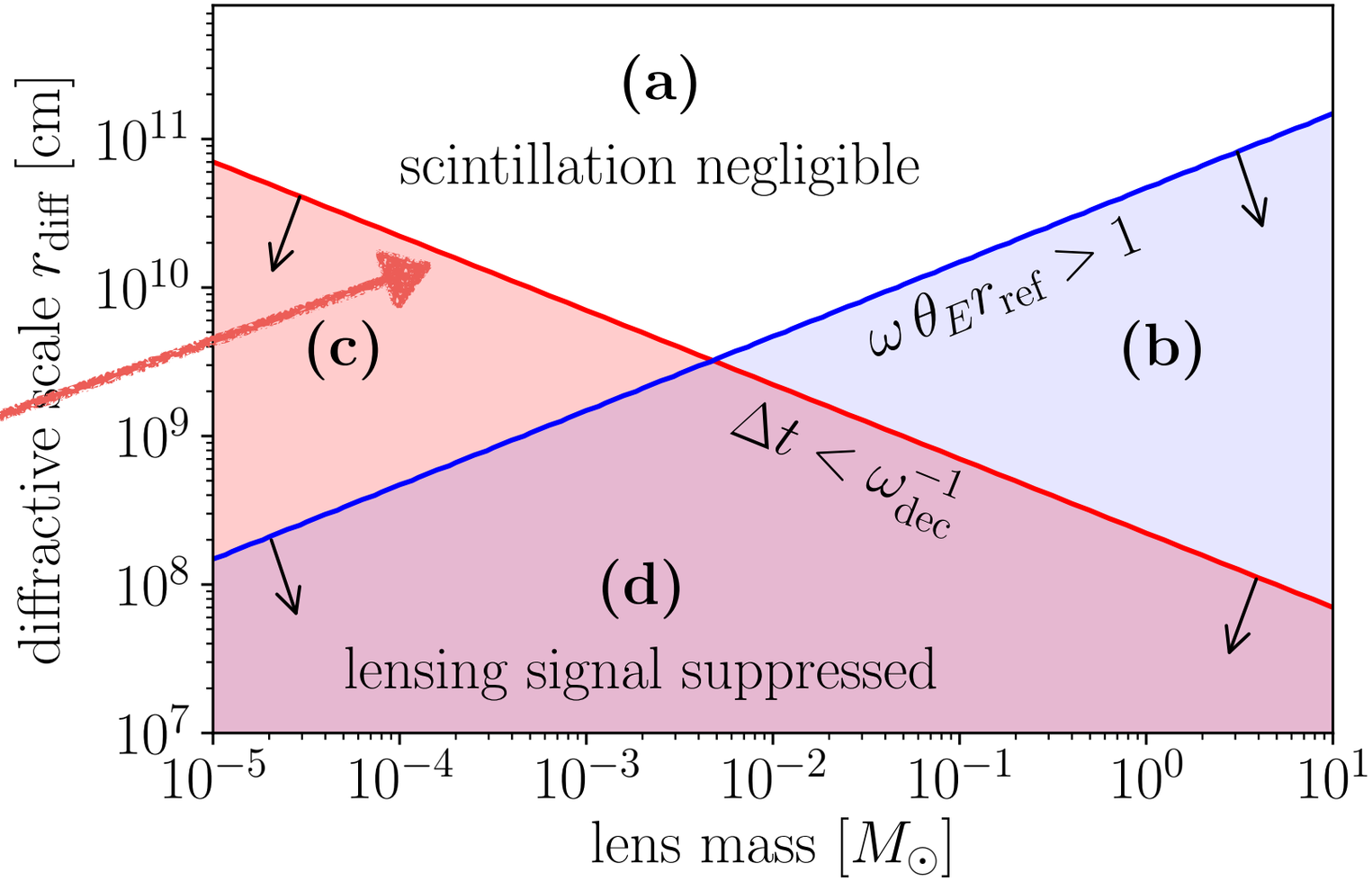
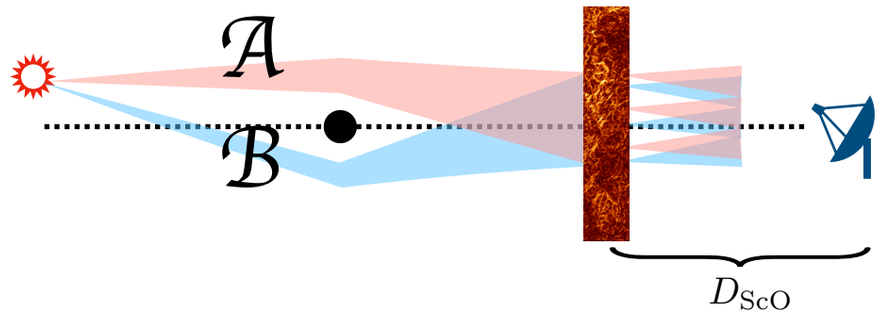


decorrelation bandwidth

Autocorrelation Functions



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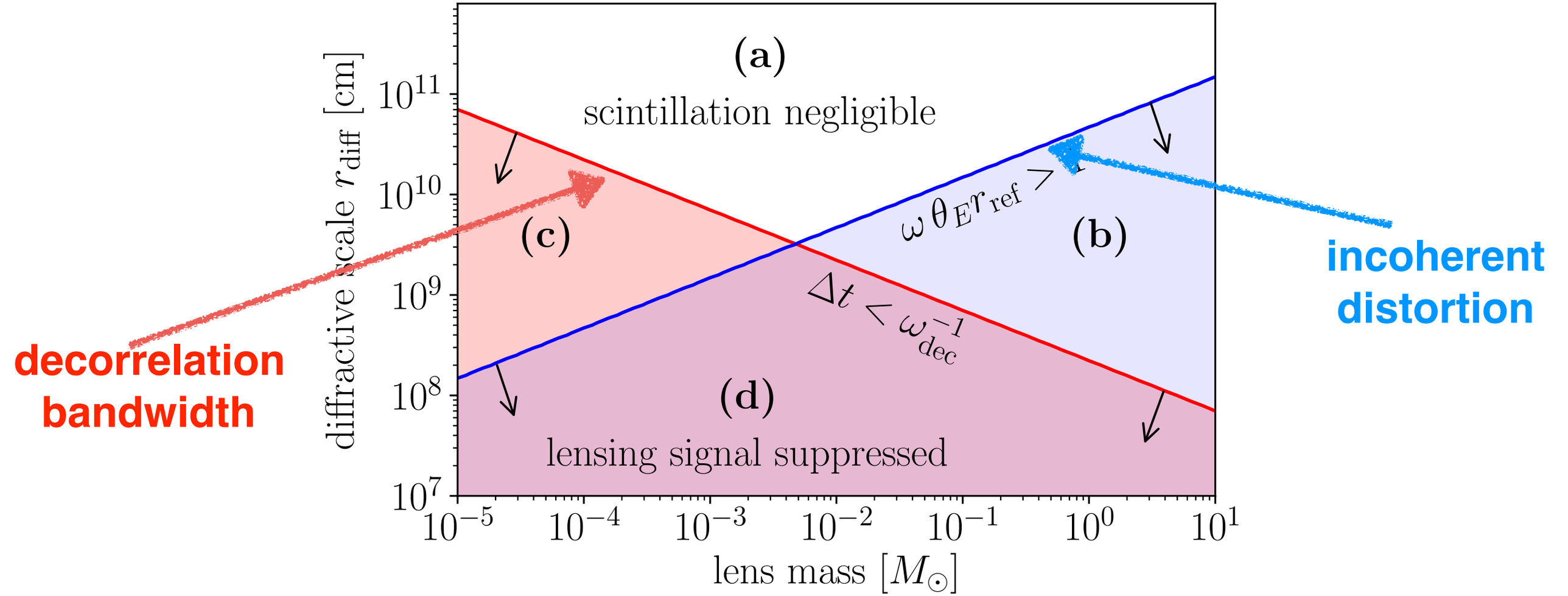

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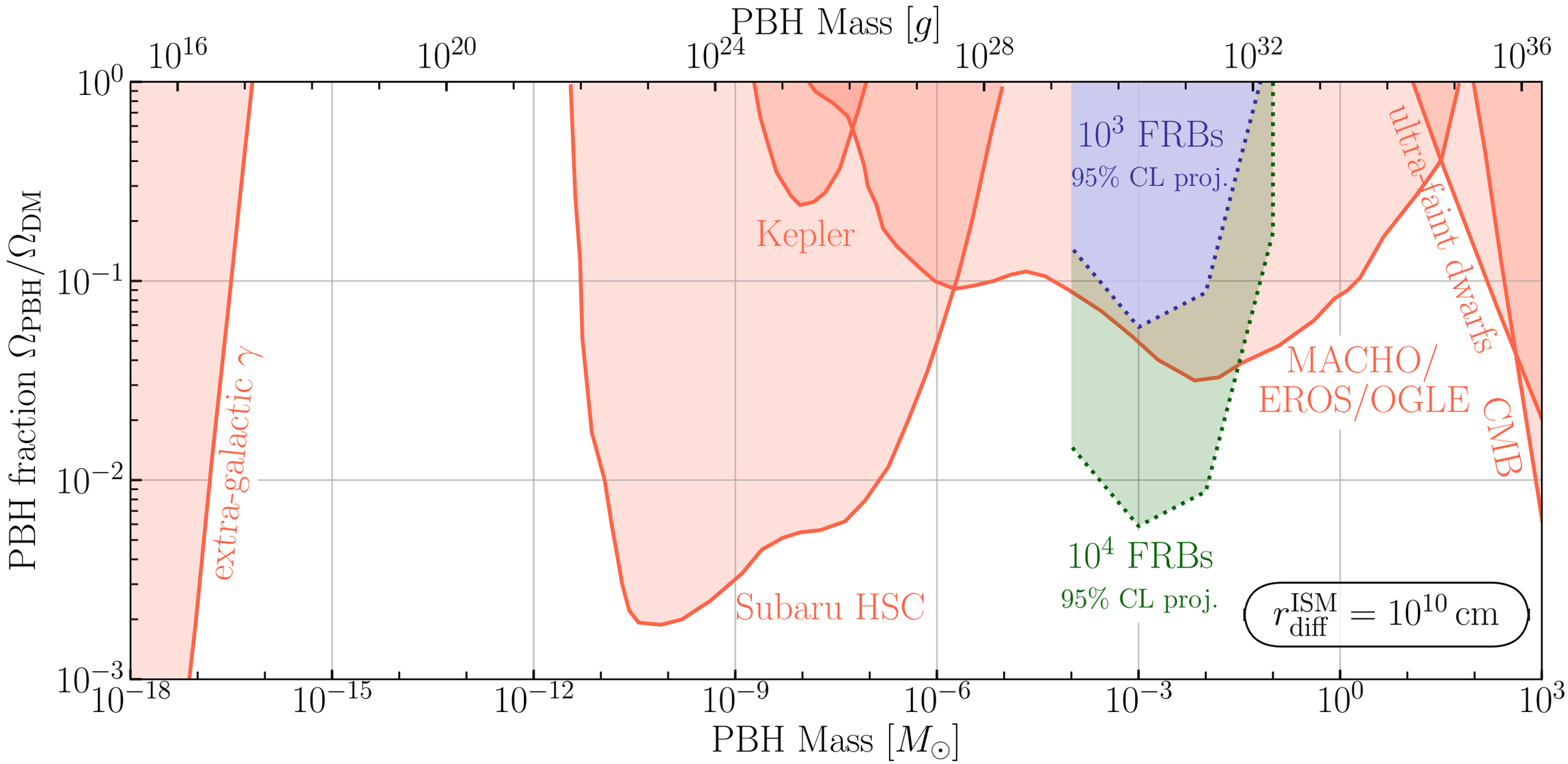
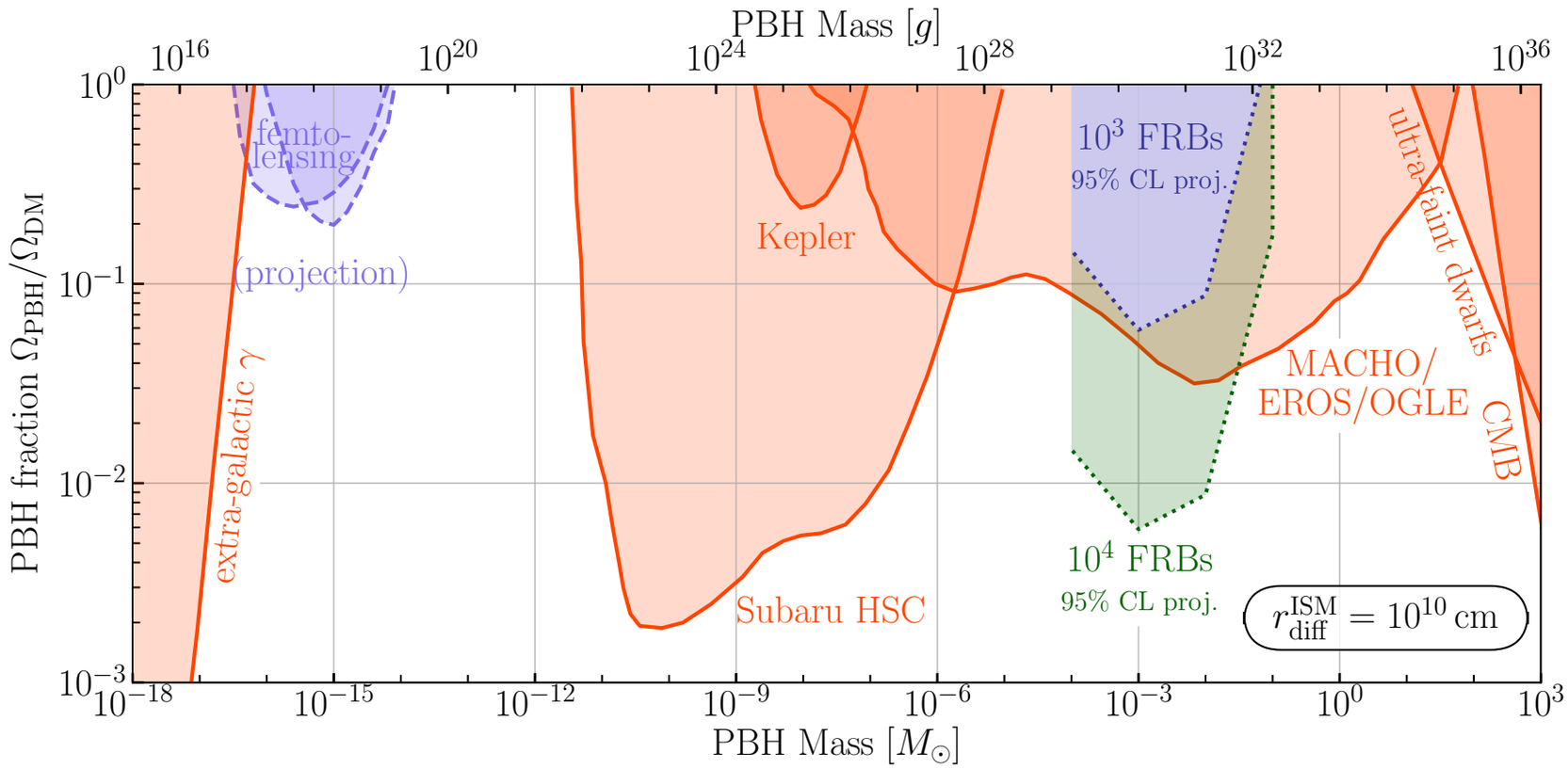


Summary



- diffractive lensing with GRBs
  finite source size and wave optics
  the parameter space is recovered

- diffractive lensing with FRBs
  scintillation
  point-like source & cosmological distances
  miniclusters

Thank you