Cloudy with a Chance of Dark Matter

Leo Kim

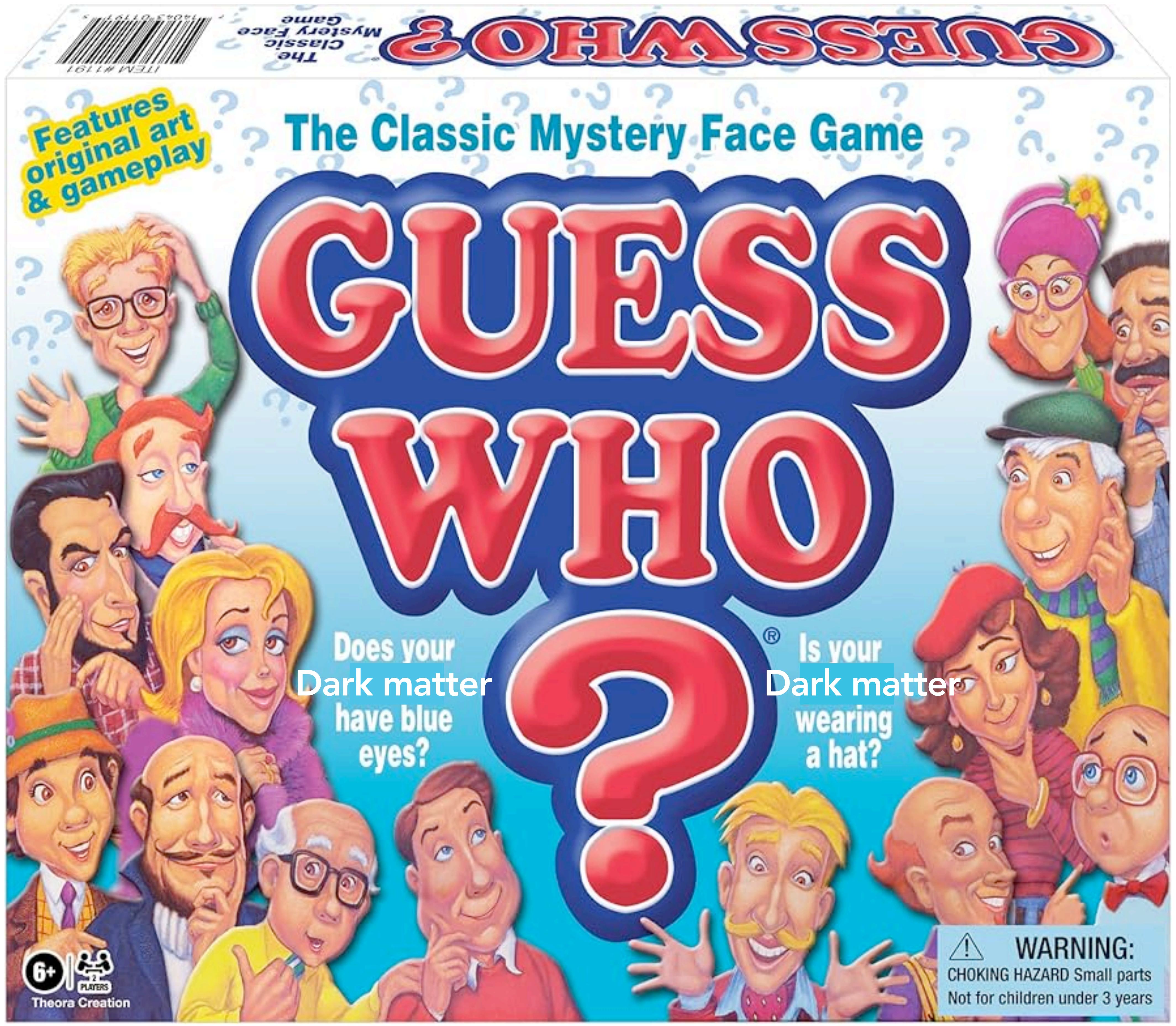
with Melissa Diamond & Joe Bramante

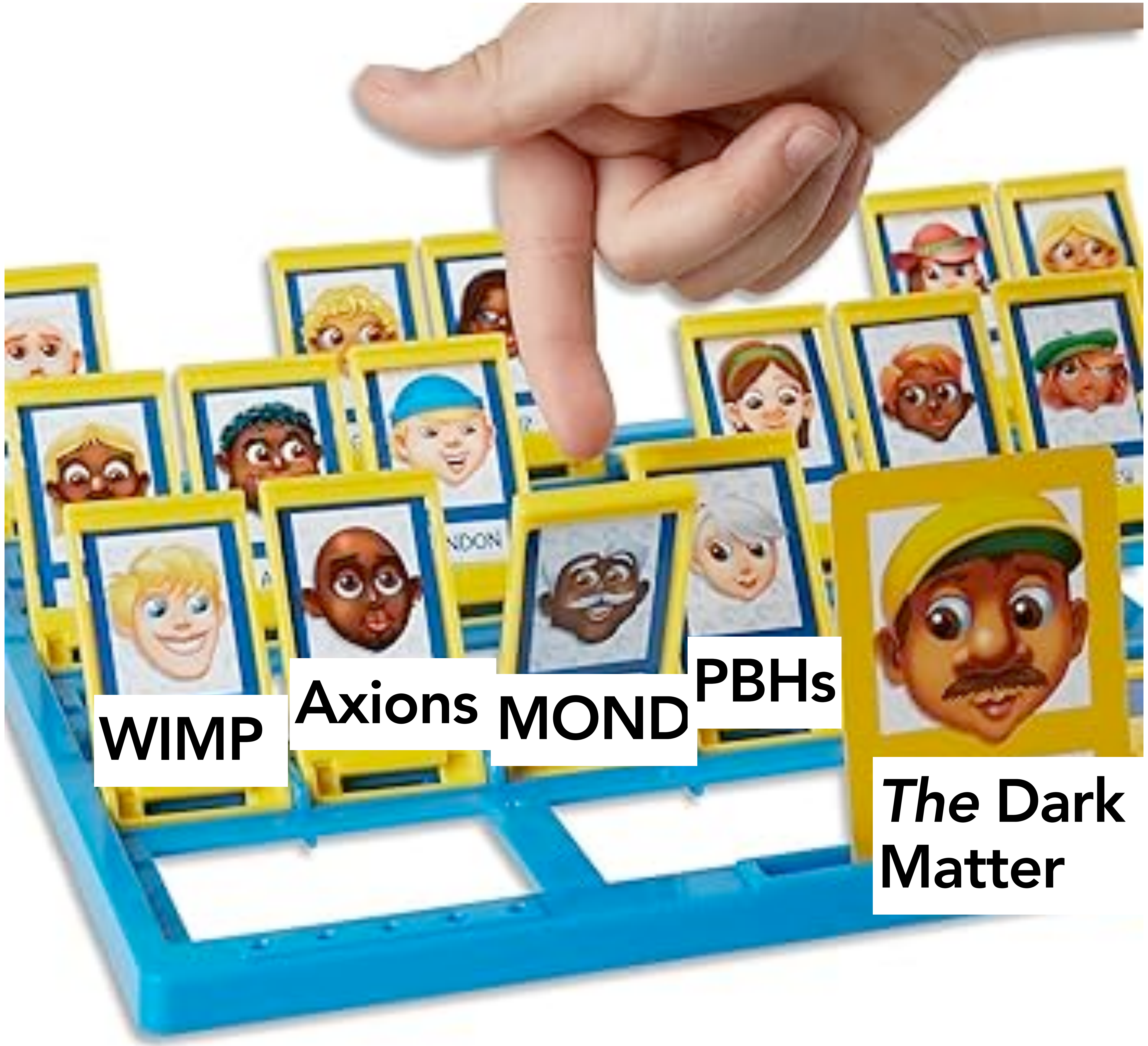
Based on 2409.08322

Dark Interactions 2024
Oct 18, 2024

Queen's University
Arthur B. McDonald Canadian Astroparticle Physics Research Institute

Dark matter?


GUESS WHO?
The Classic Mystery Face Game
Features original art & gameplay
GUESS WHO?
Does your Dark matter have blue eyes?
Is your Dark matter wearing a hat?
WARNING:
CHOKING HAZARD Small parts
Not for children under 3 years
6+
Theora Creation


WIMP
Axions
MOND
PBHs
The Dark Matter

Dissipative dark sectors

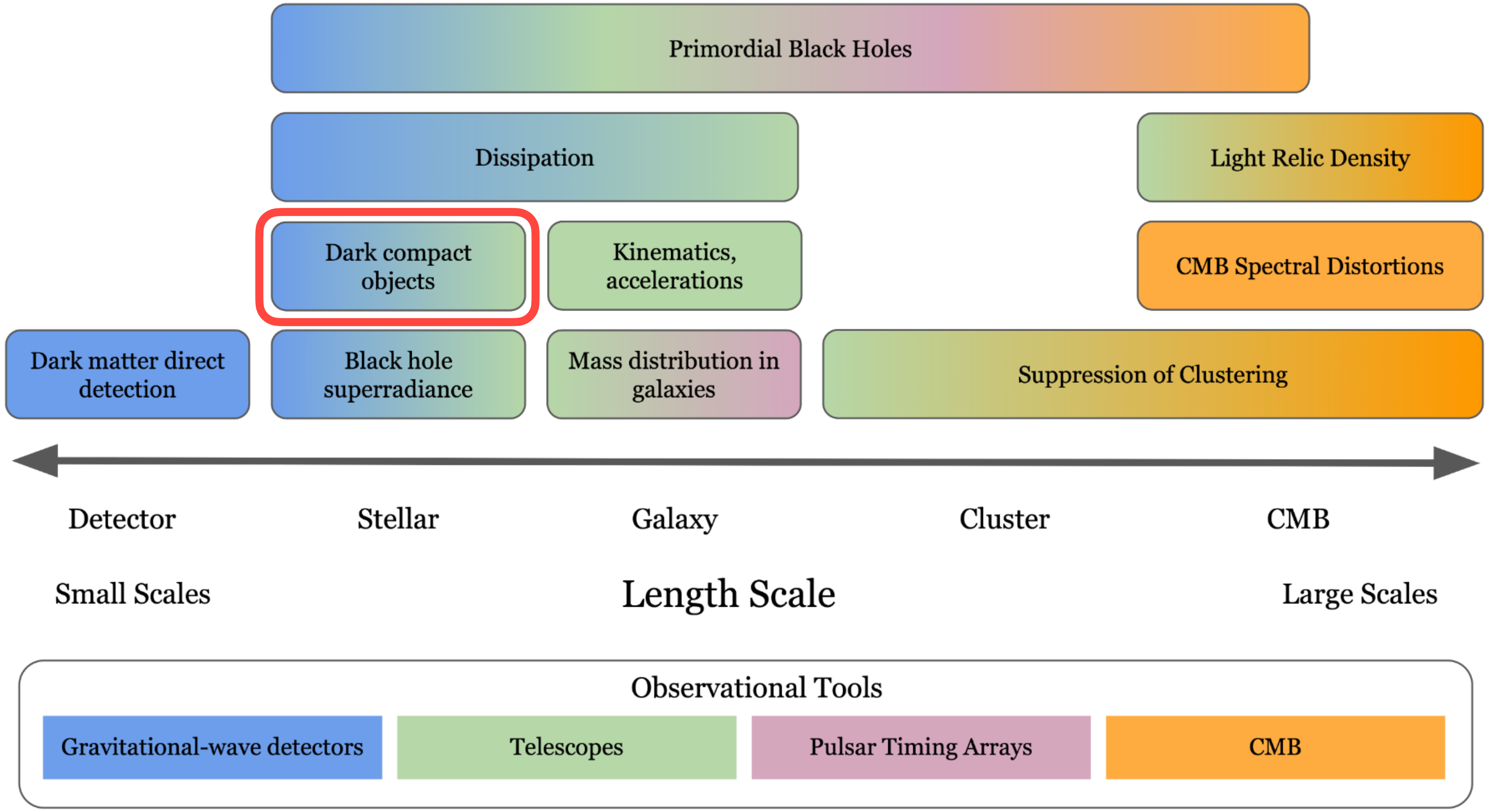


Figure from Snowmass 2021
White Paper (Brito et al. [2203.15954])

- Dark compact objects can form naturally in dissipative dark sectors

- Lots of recent work on dark substructures (e.g.):

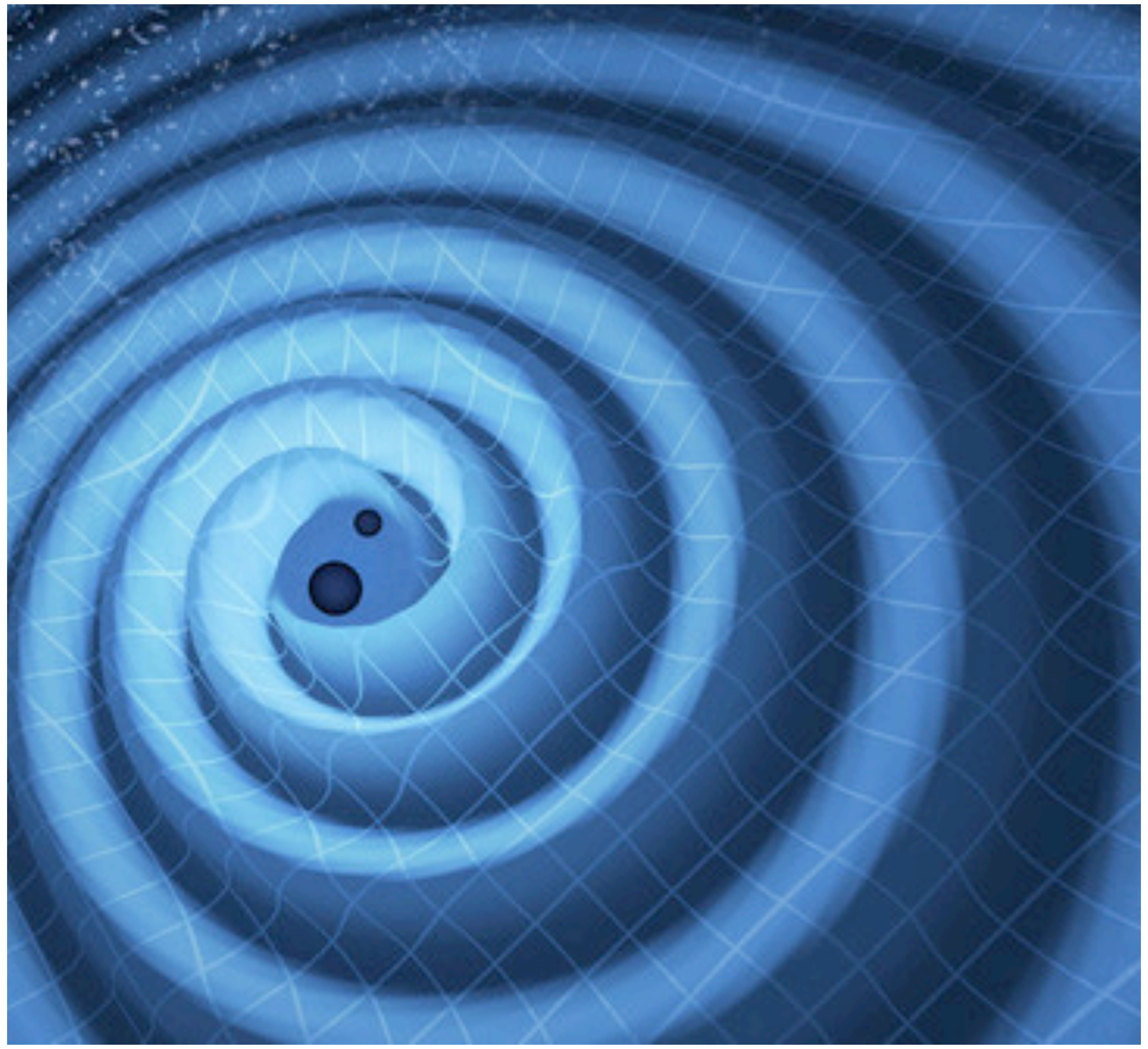
Buckley, DiFranco [1707.03829]
Ghalsasi, McQuinn [1712.04779]
Chang, Egana-Ugrinovic, Essig, Kouvaris [1812.07000]
Curtin, Setford [1909.04072]
Gurian, Ryan, Schon, Jeong, Shandera [2209.00064]
Roy, Shen, Lisanti, Curtin, Murray, Hopkins [2304.09878]
Flores, Lu, Kusenko [2308.09094]
Bramante, Diamond, **JLK** [2309.13148]
Gemmell, Roy, Shen, Curtin, Lisanti, Murray, Hopkins [2311.02148]
Bramante, Cappiello, Diamond, **JLK**, Liu, Vincent [2405.04575]
Roy, Shen, Barron, Lisanti, Curtin, Murray, Hopkins [2408.15317]

+many more!

How do we find them?

How do we find them?

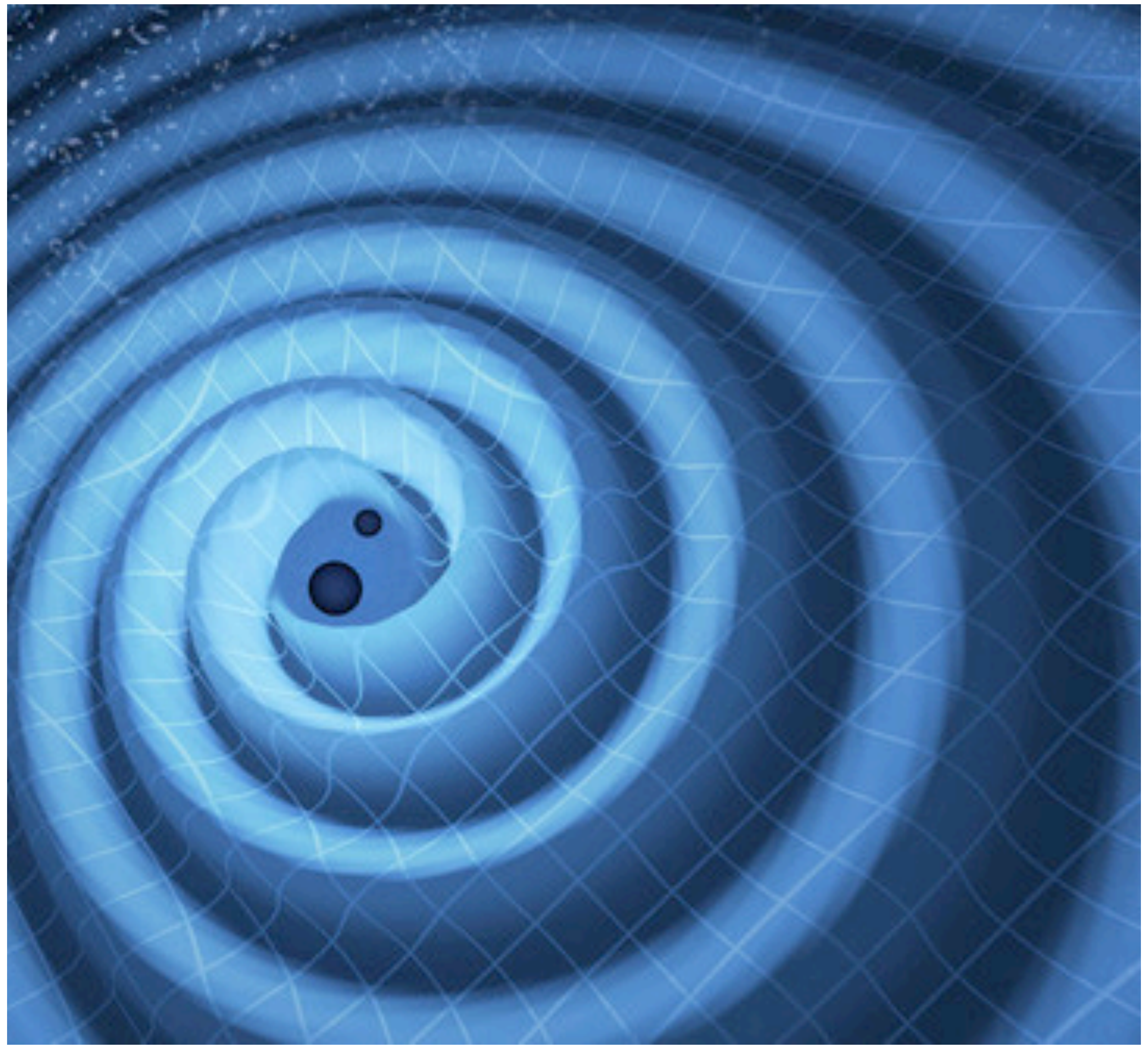
Credit: LIGO



Gravitational
waves

How do we find them?

Credit: LIGO



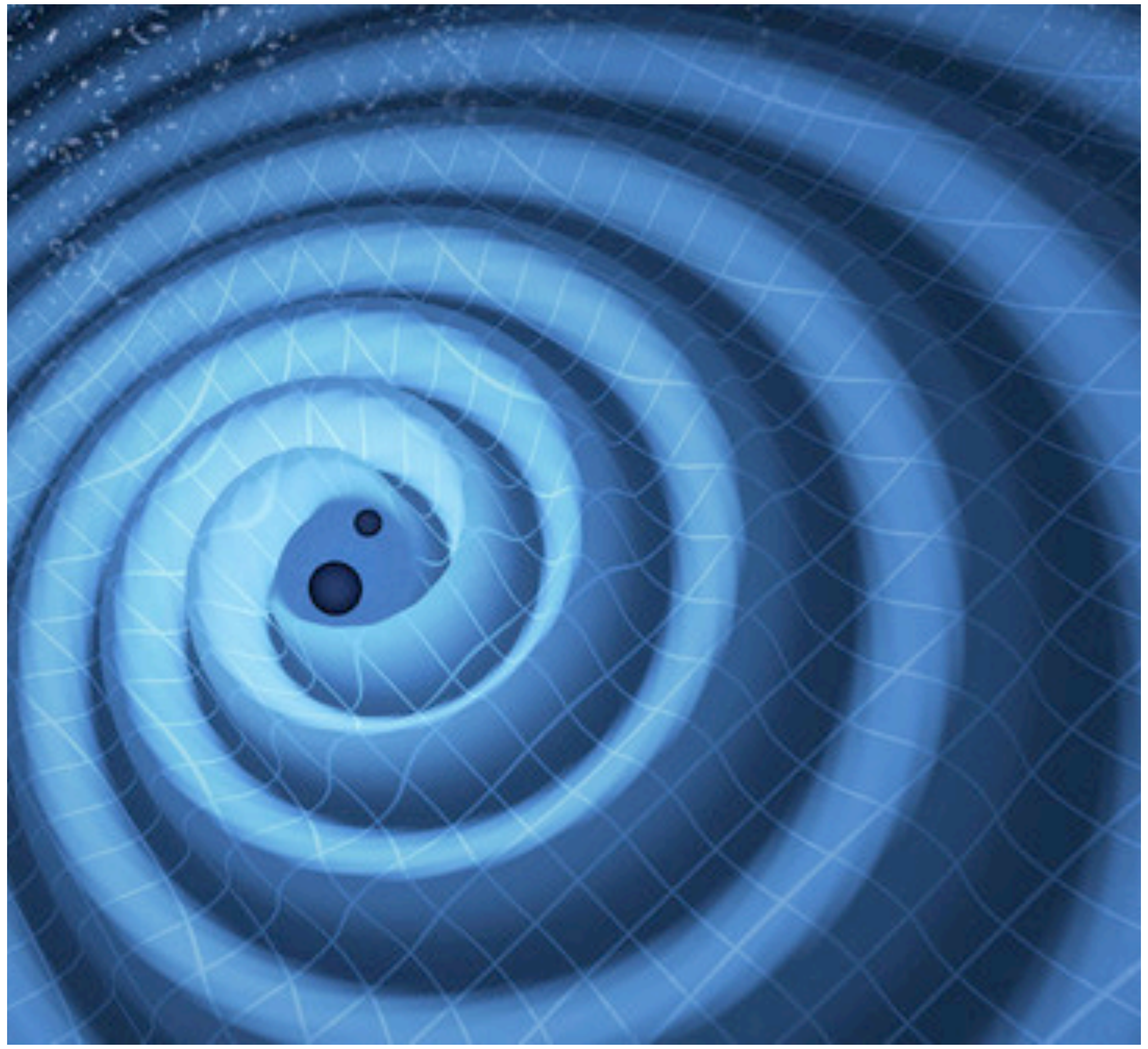
Gravitational waves

Credit: NASA

Microlensing

How do we find them?

Credit: LIGO



Gravitational waves

Credit: NASA

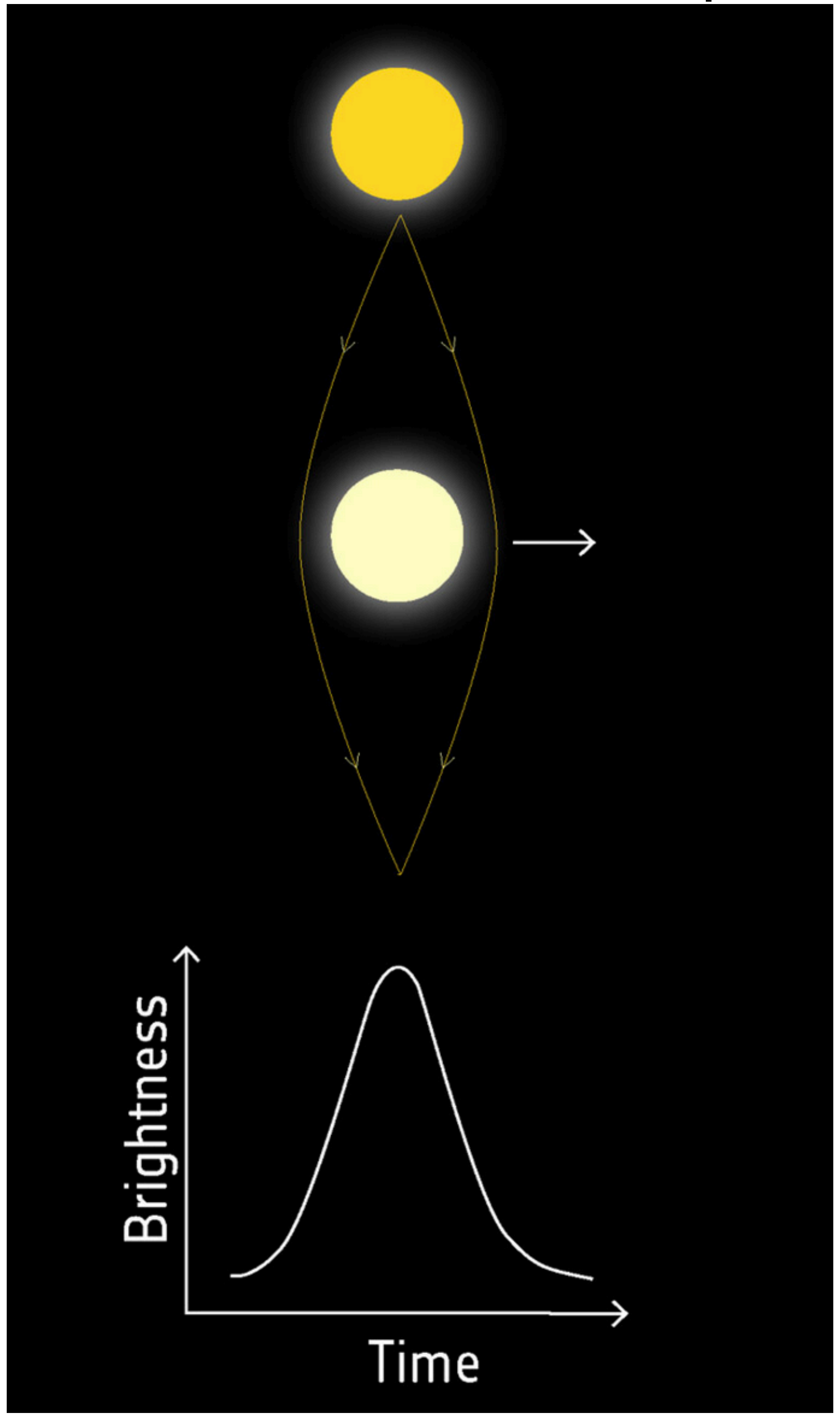
Microlensing

Credit: IKEA

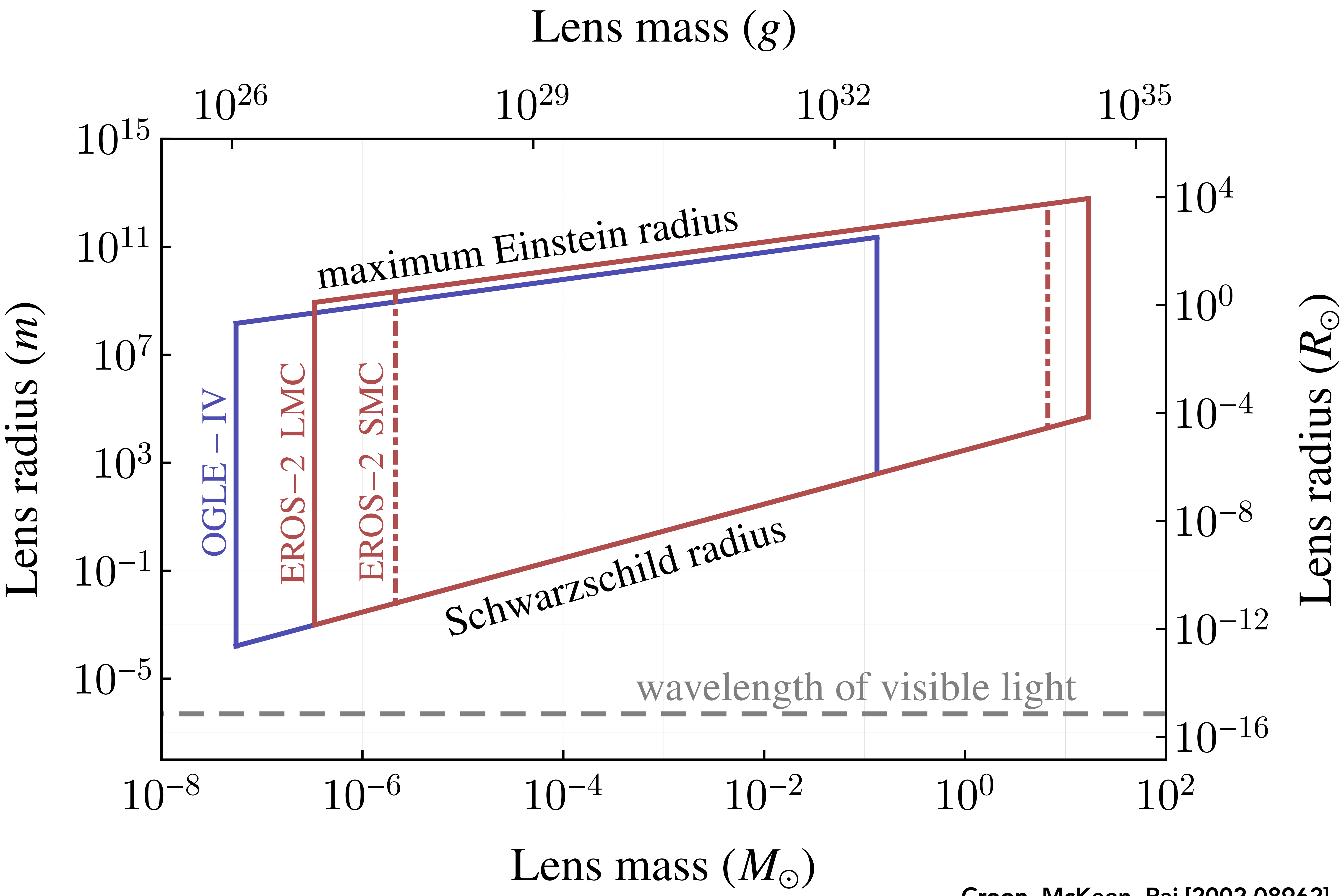
Lampshades?

Microlensing

- Looks for the amplification of starlight



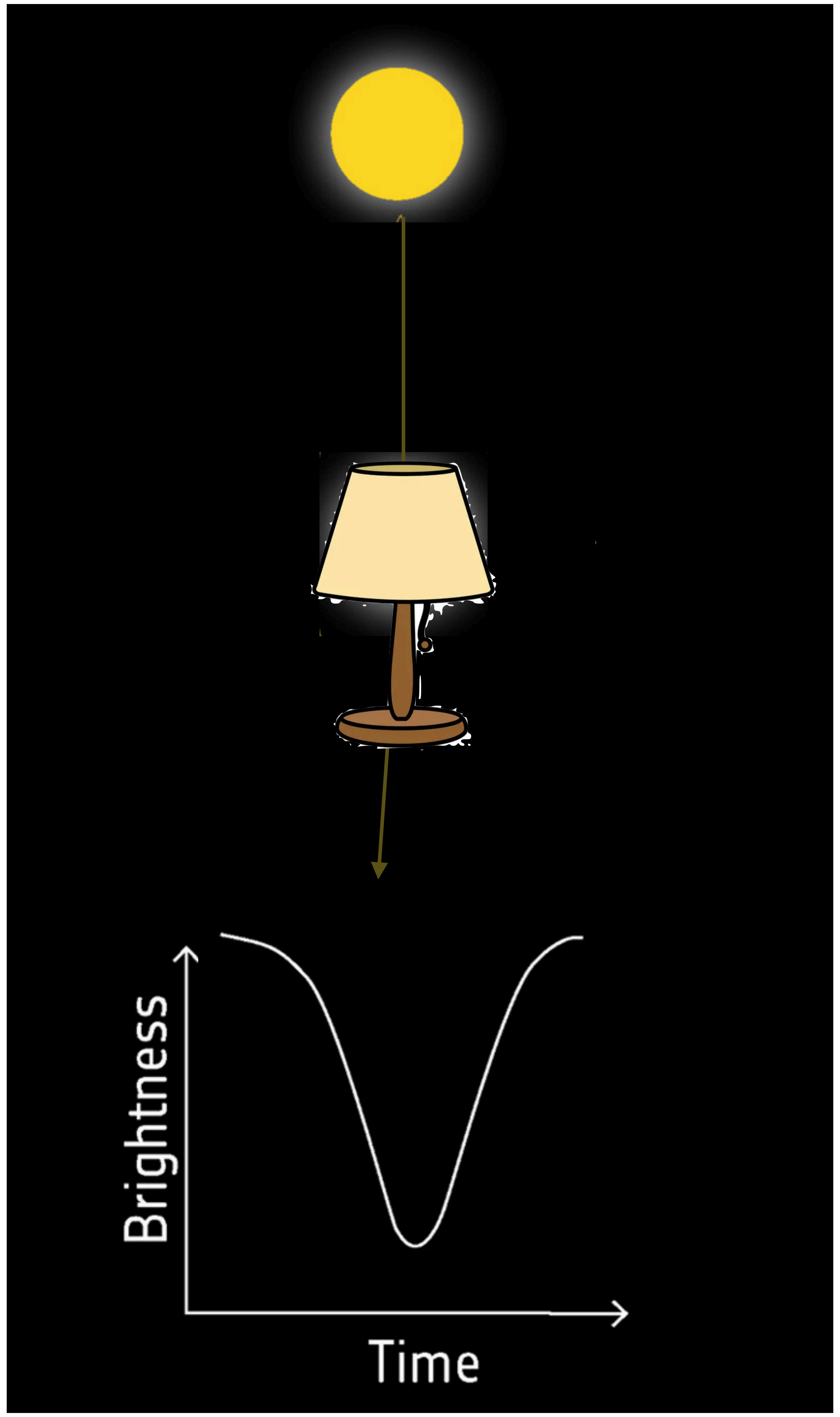
Credit: ESA



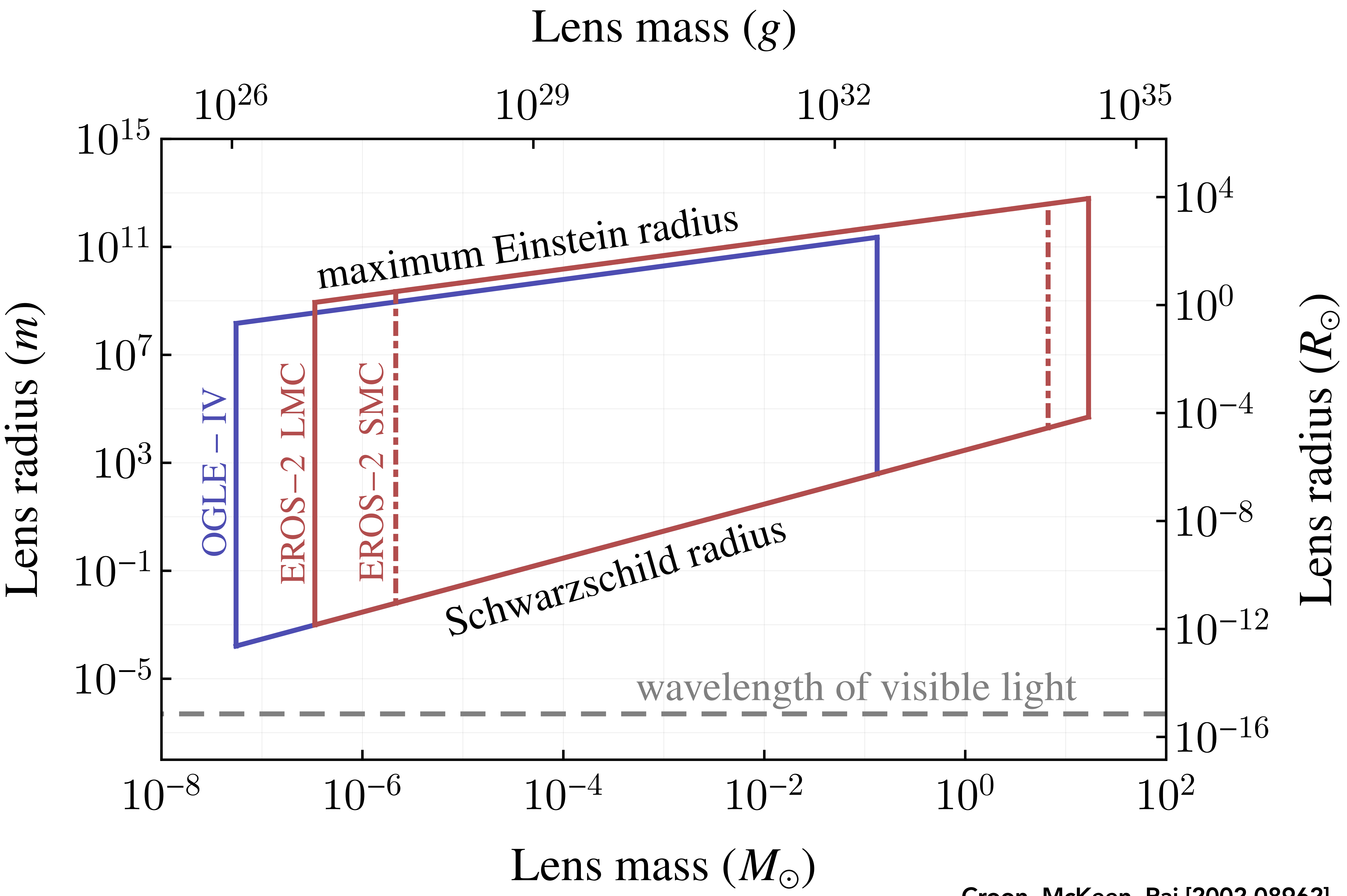
Croon, McKeen, Raj [2002.08962]

Lampshades/Clouds

- Looks for the *decrease* of starlight, but same data!



Credit: ESA



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Lampshades/Clouds

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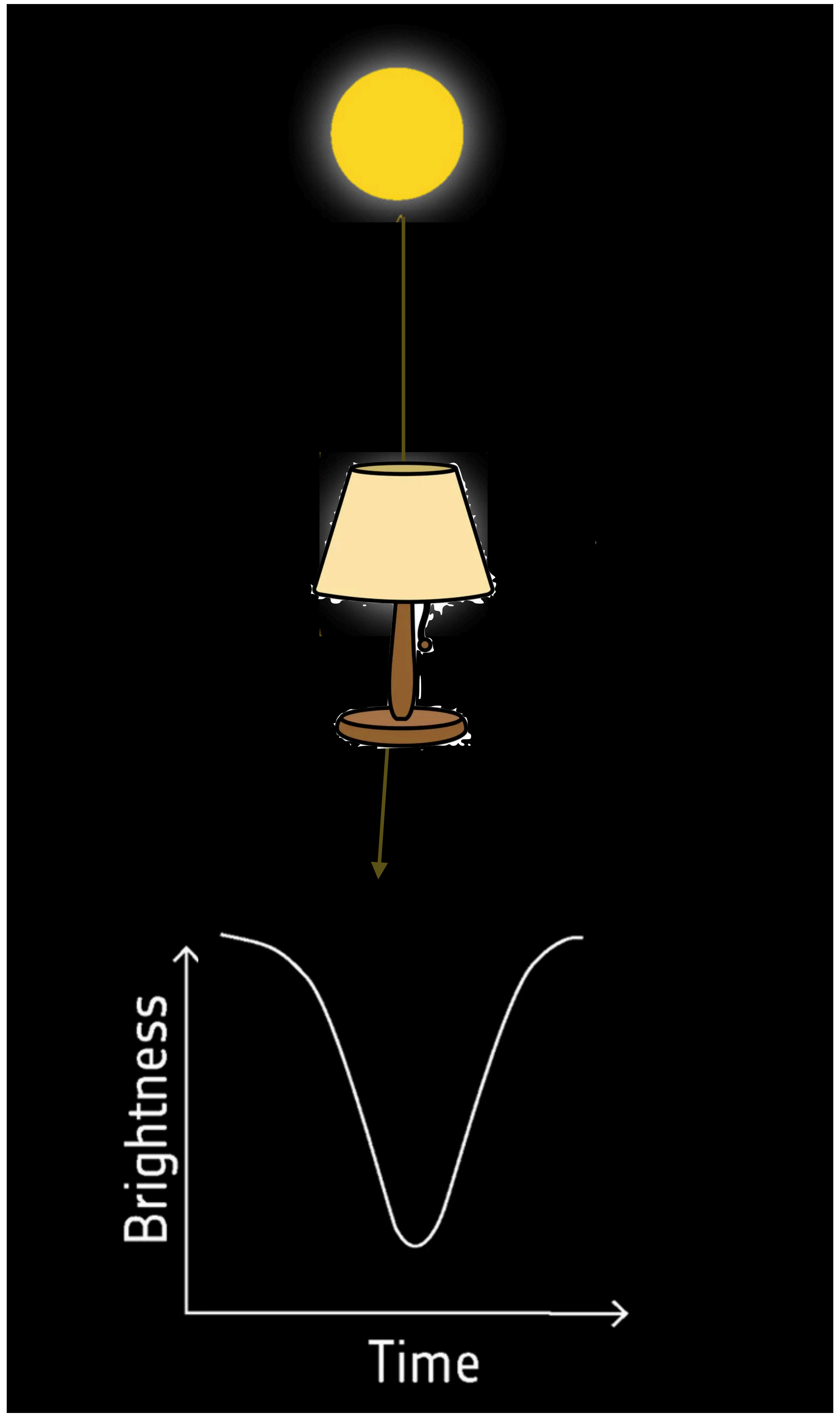
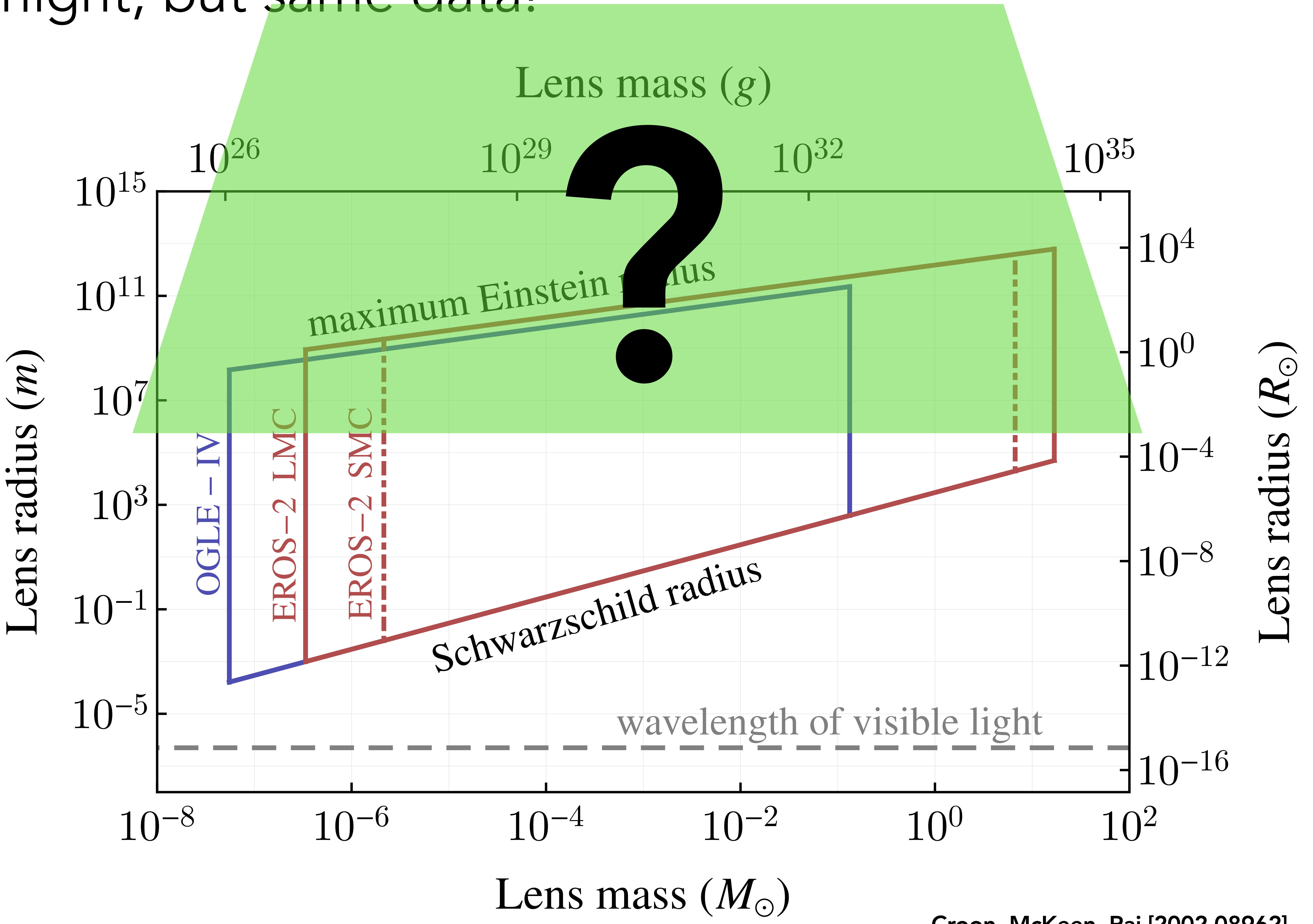


Credit: ESA



Croon, McKeen, Raj [2002.08962]

Dimming due to DM clouds

- Transmission (Bai, Lu, Orlofsky [2303.12129])

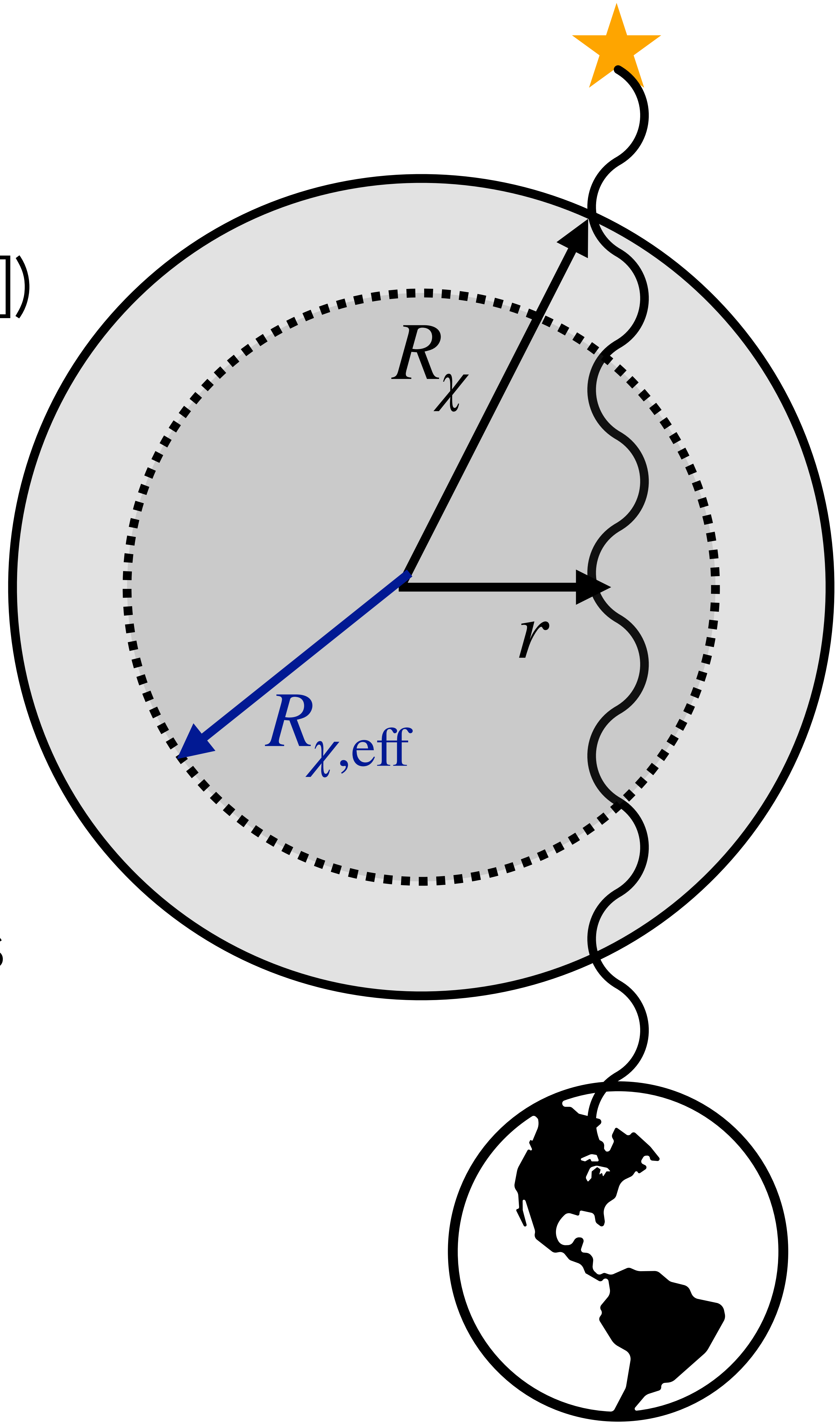
$$T(r) = \exp\left(-2\tau_0\sqrt{1-(r/R_\chi)^2}\right)$$

with characteristic optical depth

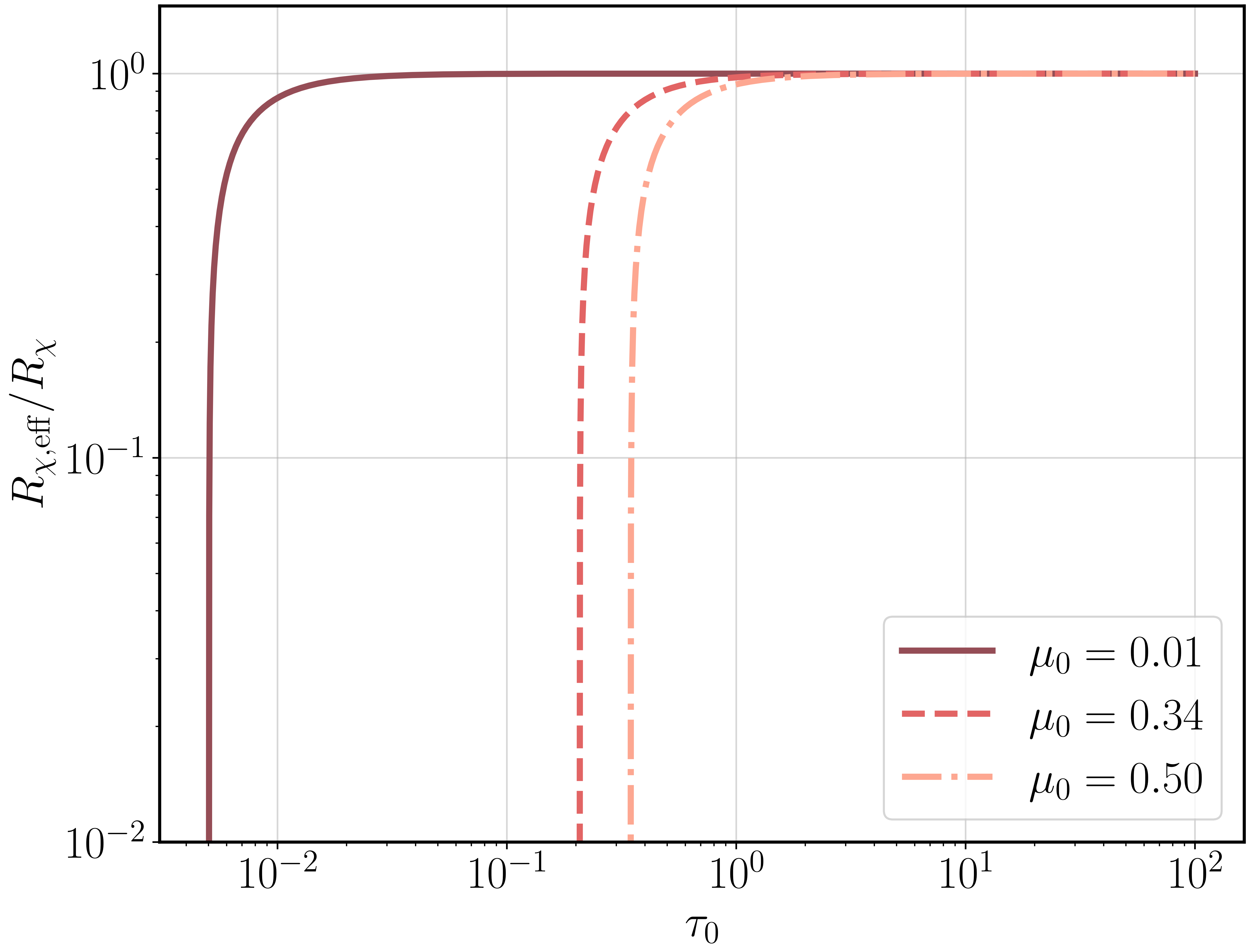
$$\tau_0 \equiv R_\chi n_\chi \sigma$$

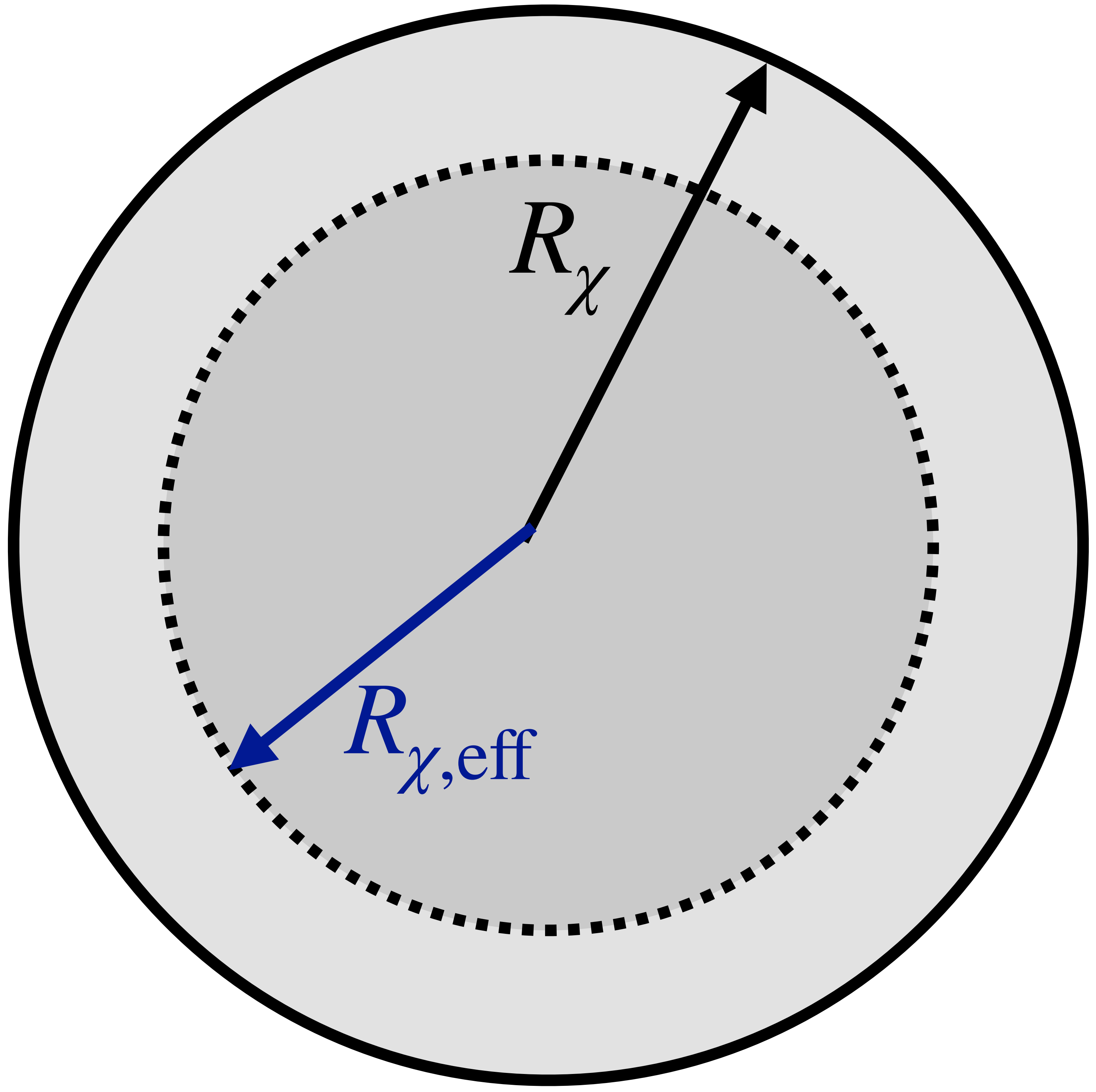
- Dimming threshold μ_0 gives effective radius of object

$$R_{\chi,\mathrm{eff}} = R_\chi\sqrt{1-\frac{1}{4\tau_0^2}[\ln(1-\mu_0)]^2}$$



Effective radius





$$R_{\chi,\mathrm{eff}} = R_\chi \sqrt{1 - \frac{1}{4\tau_0^2}[\ln(1-\mu_0)]^2}$$

Fiducial
$\mu_0 = 0.34$

$\tau_0 = 1$

Differential event rate

- Can find expected number of dimming events from lampshades with mass M_χ

$$\frac{d^2\Gamma}{dx\,dt_E} = \epsilon(t_E)\frac{2D_S}{v_0^2 M_\chi} f_{\rm DM}\,\rho_{\rm DM}(x)\,v_E^4(x)\,e^{-v_E^2(x)/v_0^2}$$

$$v_E = \frac{2R_{\chi,\rm eff}}{t_E}$$

Distance to source star

Fraction of DM

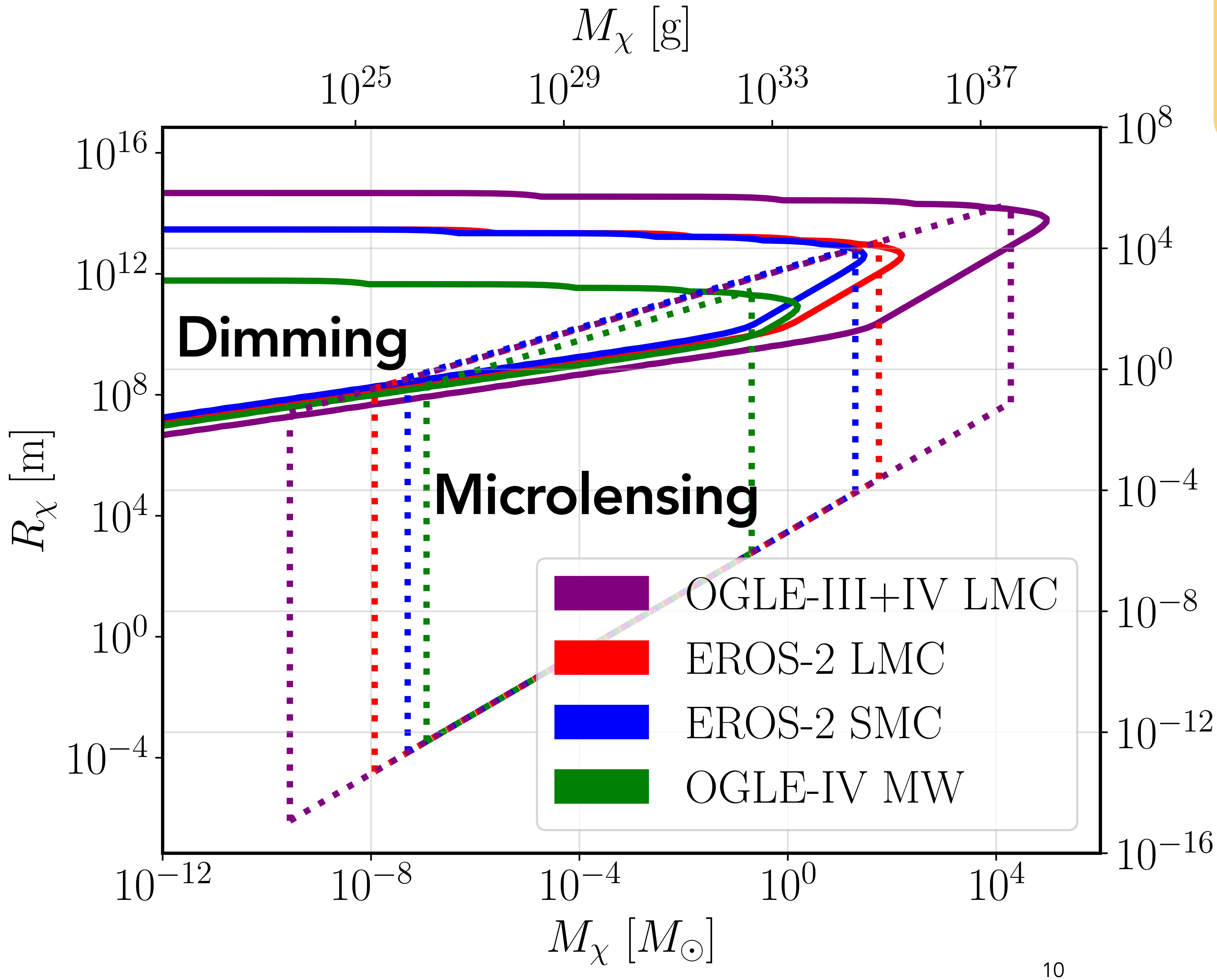
220 km/s

Detection efficiency parameter

Mass of DM clump

Distribution of DM in galaxy

A heuristic plot

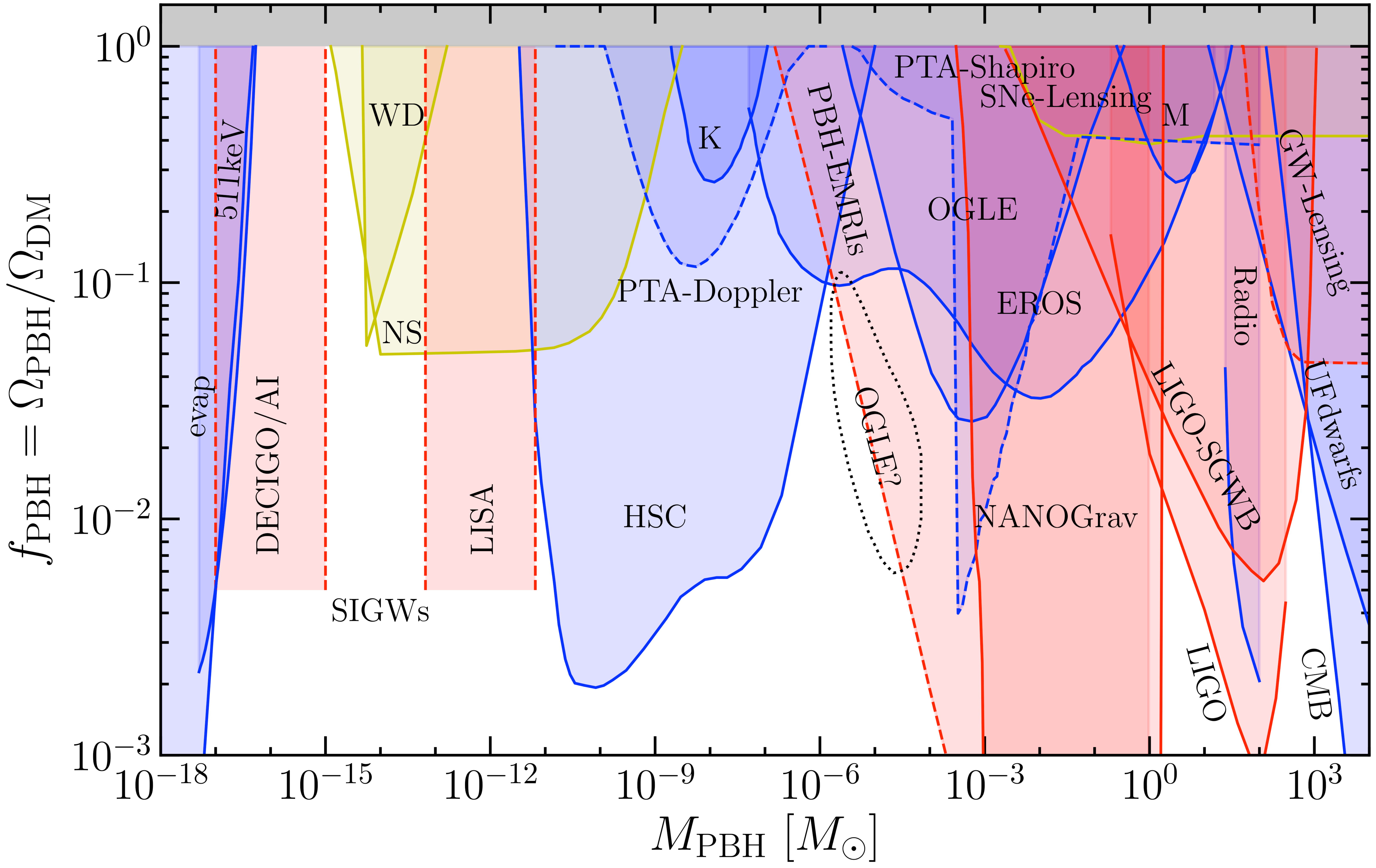


Number of events:

$$N_{\rm events} = N_* T_{\rm obs} \int_0^1 dx \int_{t_{E,\rm min}}^{t_{E,\rm max}} dt_E \frac{d^2\Gamma}{dx dt_E}$$

Survey	Source	Number of stars [millions]	Observing Time [days]	Time range [days]
EROS-2	LMC SMC	5.49 0.86	2500	[1,1000]
OGLE-IV	MW	48.8	1826	[0.1,300]
OGLE-III+IV	LMC	78.7	7300	[1,7300]

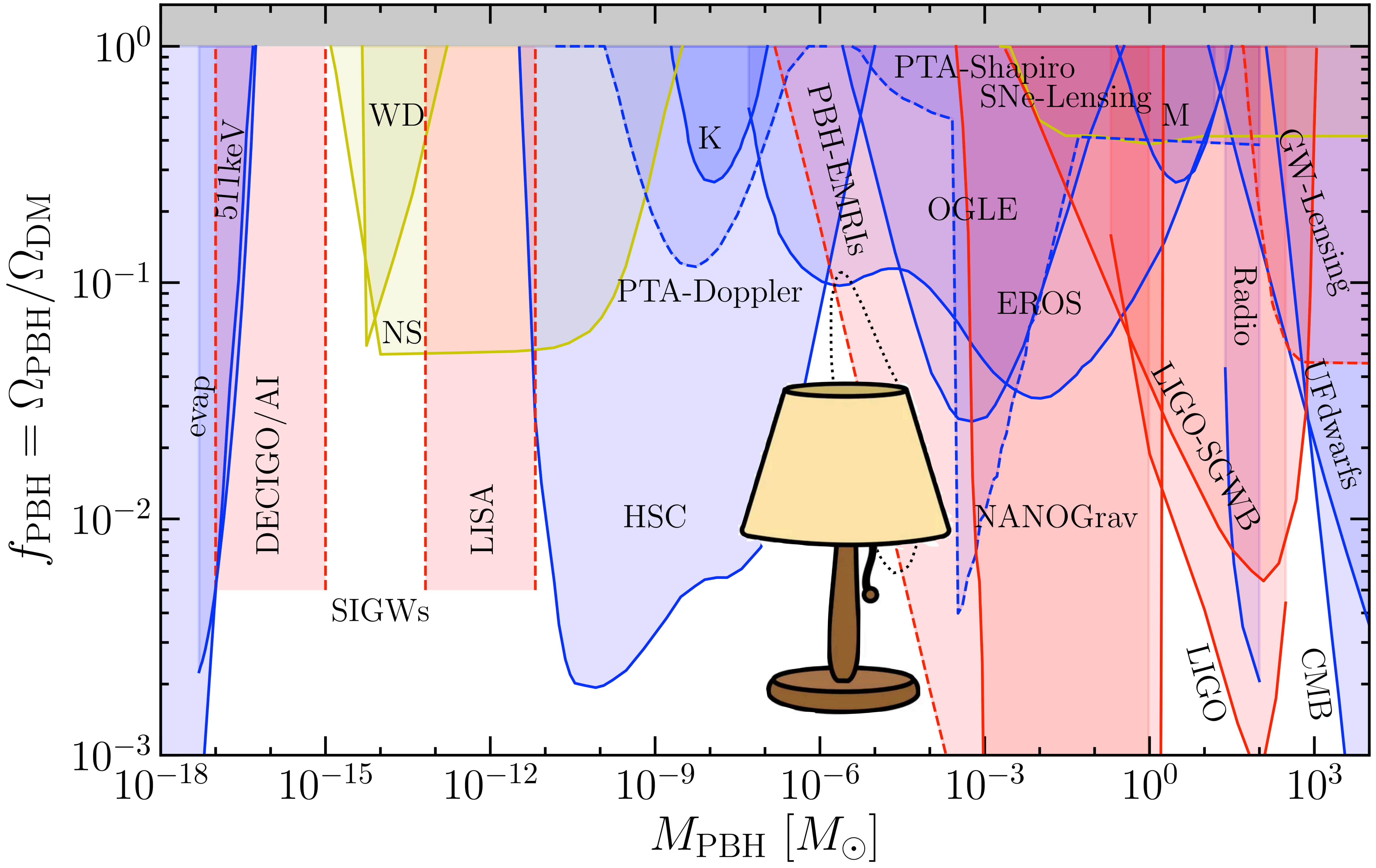
Macroscopic properties



Gravitational waves

Microlensing

Macroscopic properties



Gravitational waves

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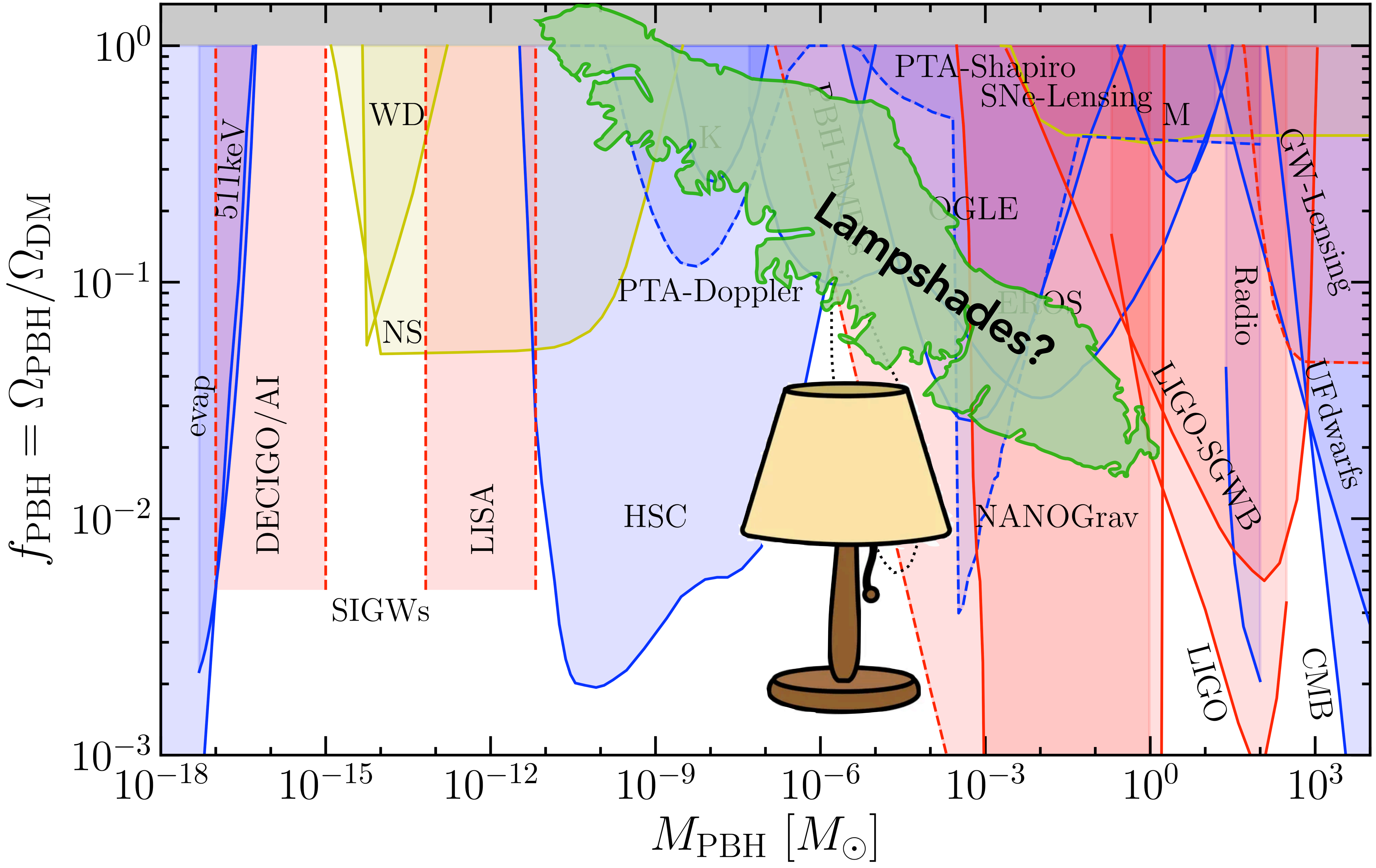
Lampshades?

Macroscopic properties



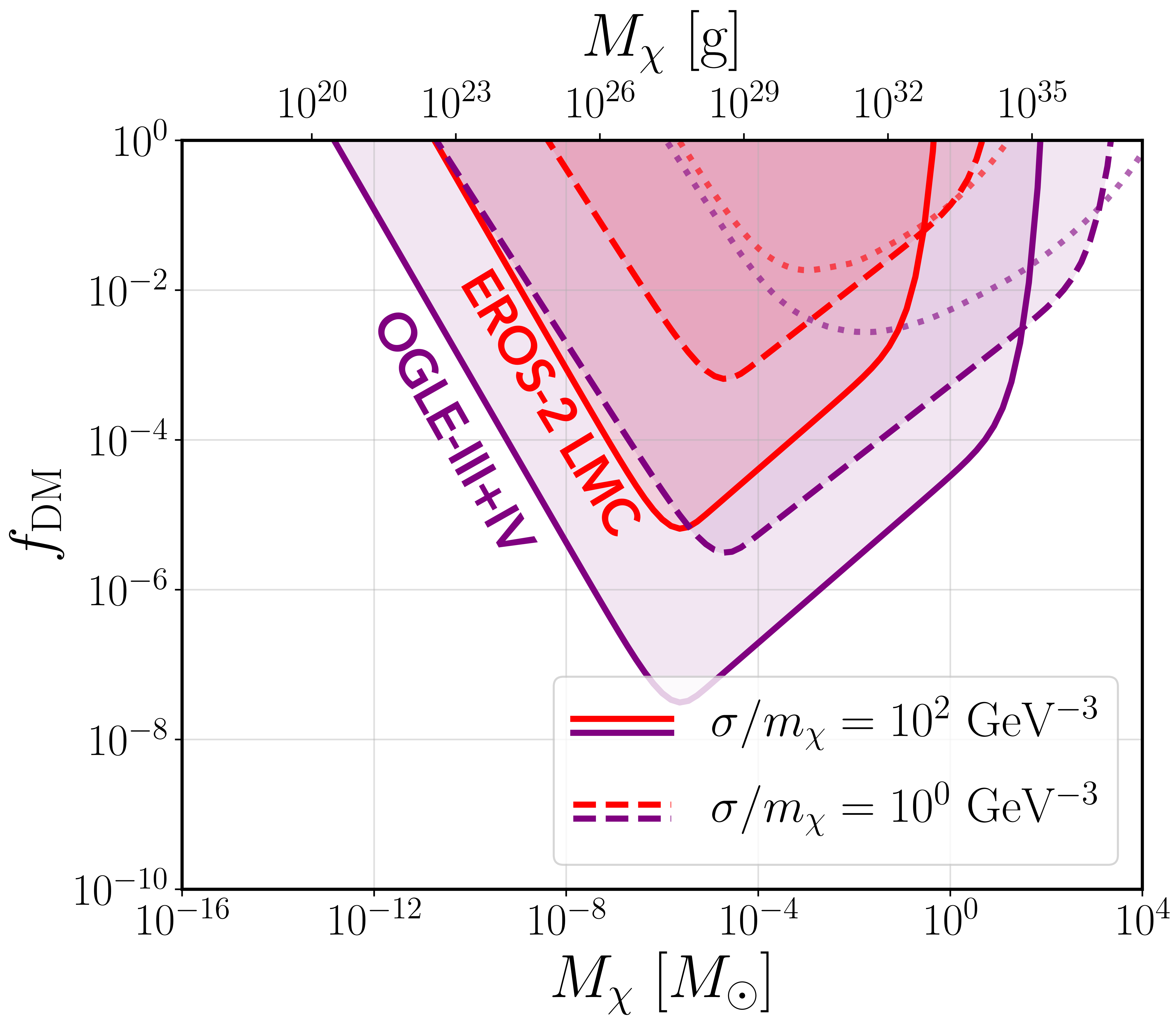
Gravitational waves

Microlensing

Lampshades?

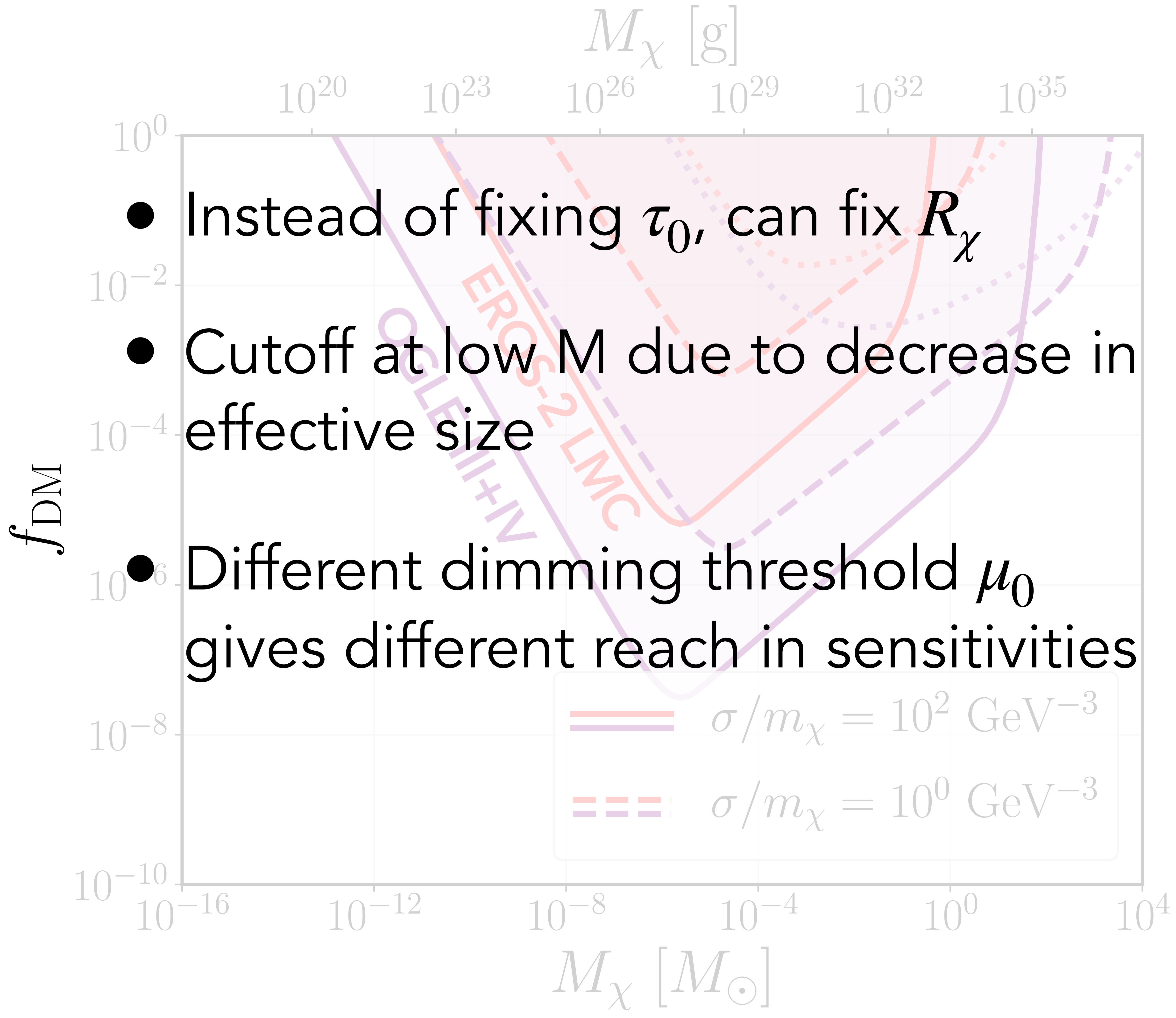
DM fraction constraints (fixed τ_0)

$$R_\chi = \sqrt{\frac{3}{4\pi}\frac{\sigma M_\chi}{m_\chi \tau_0}}$$

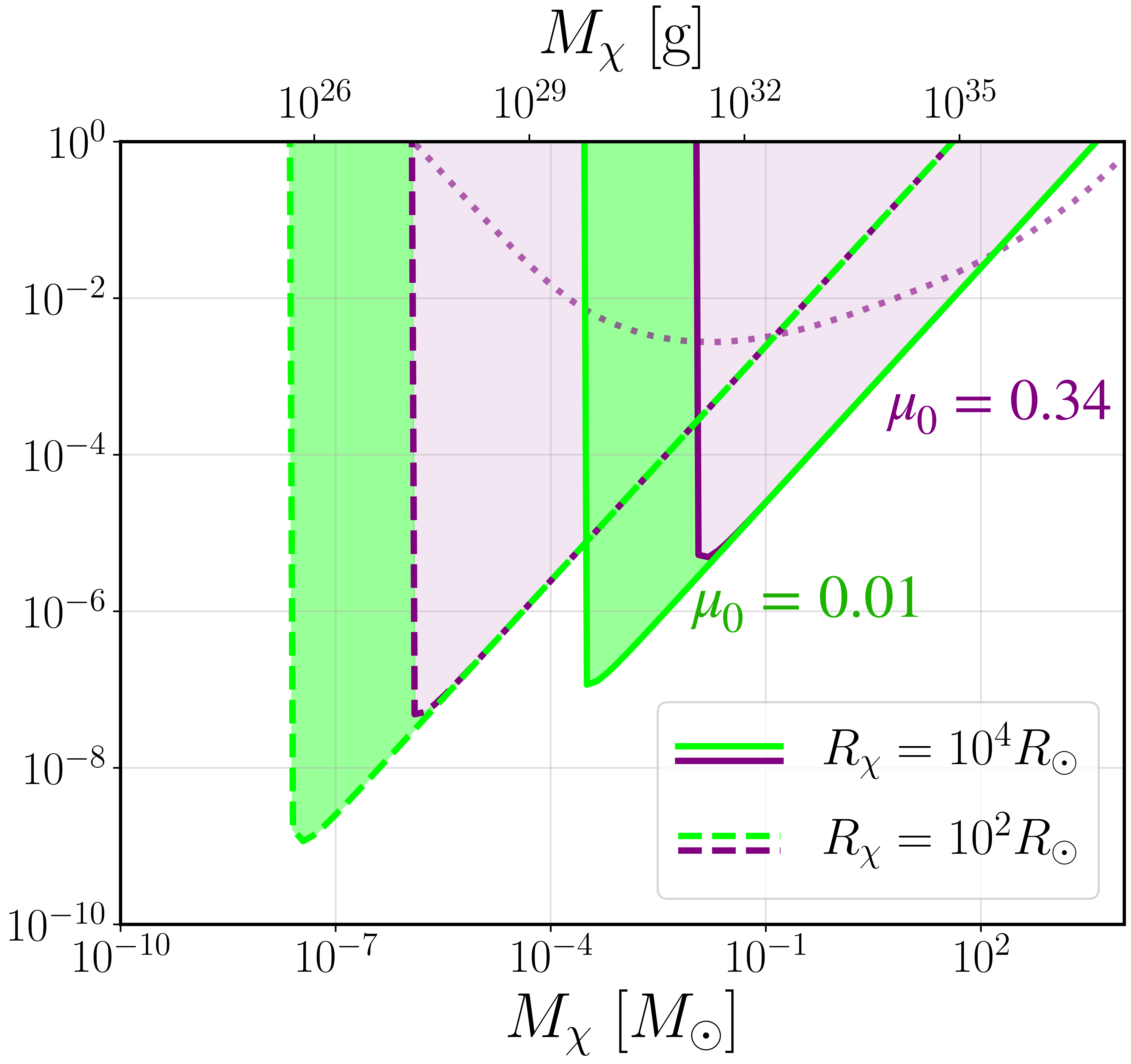


- Null observations can set limits of DM fraction
- Microlensing constraints (dotted lines) are weak compared to these at certain cross section/masses
- OGLE-III+IV is the strongest, just use that from now on

DM fraction constraints (fixed R_χ)



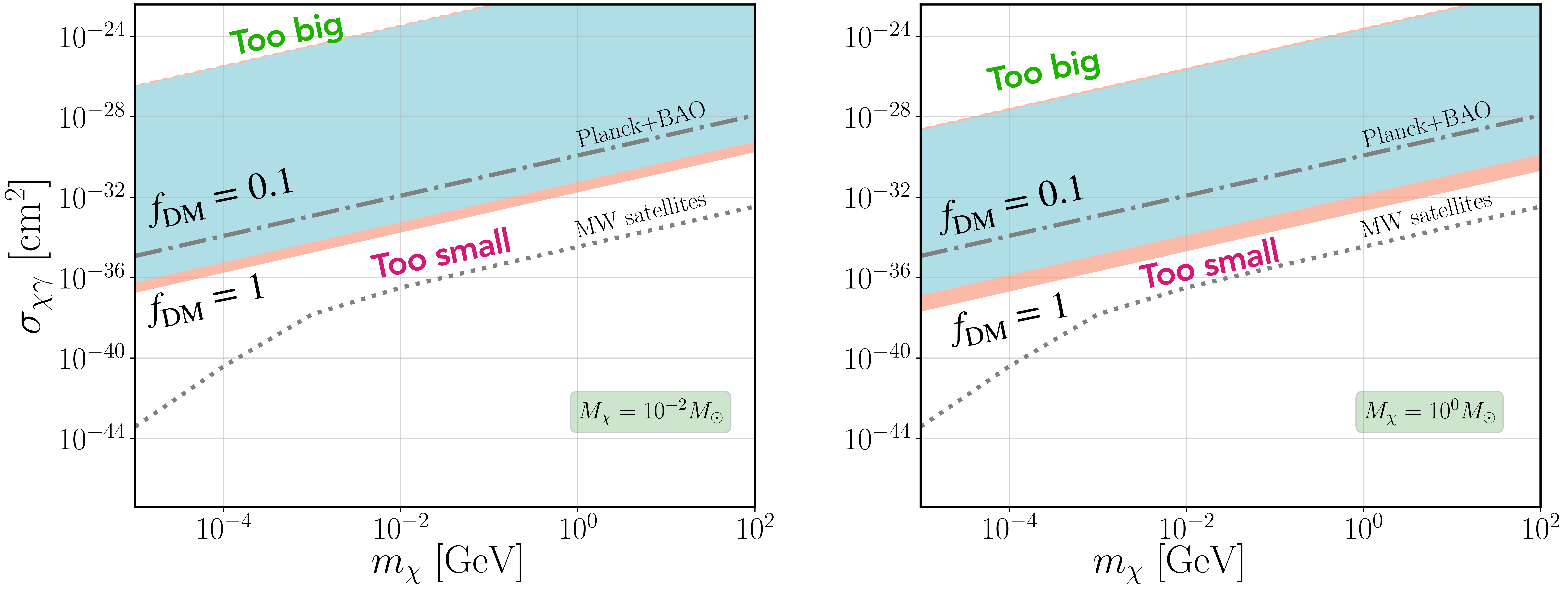
- Instead of fixing τ_0, can fix R_χ
- Cutoff at low M due to decrease in effective size
- Different dimming threshold μ_0 gives different reach in sensitivities



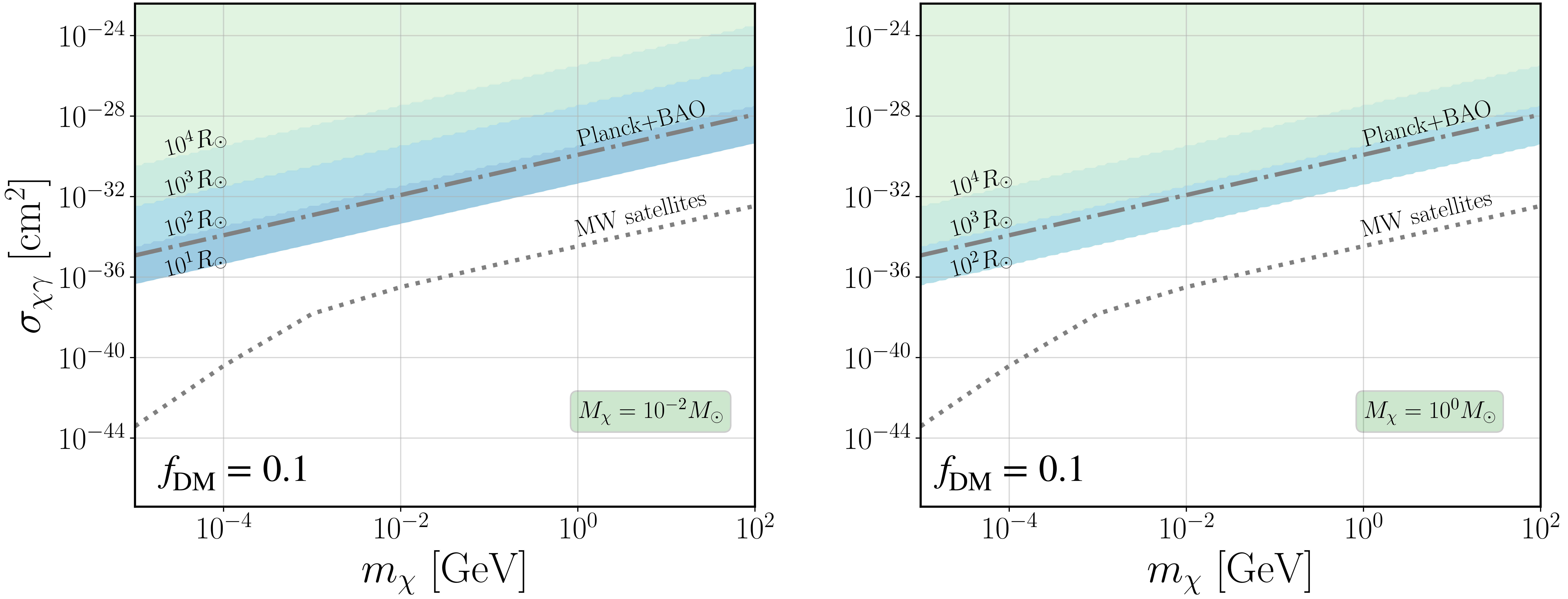
Microscopic properties

- We have seen how to constrain macroscopic properties such as clump masses, sizes, what about microscopic properties?
- Advantage of DM-photon interaction
- Consider two different types:
  - DM-SM photon elastic scattering cross section and mass
  - Effective charge and mass of millicharged dark matter

Elastic scattering cross section at fixed τ_0

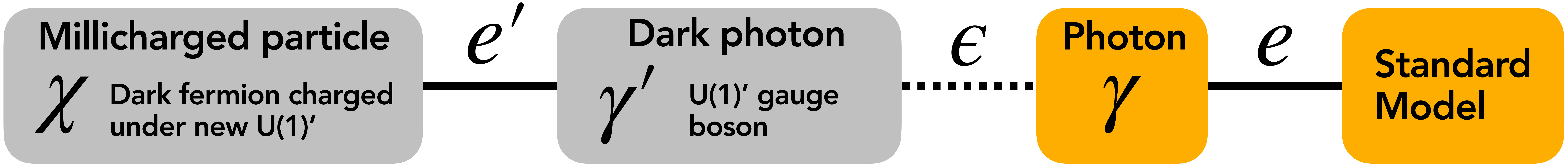


Elastic scattering cross section at fixed R_χ

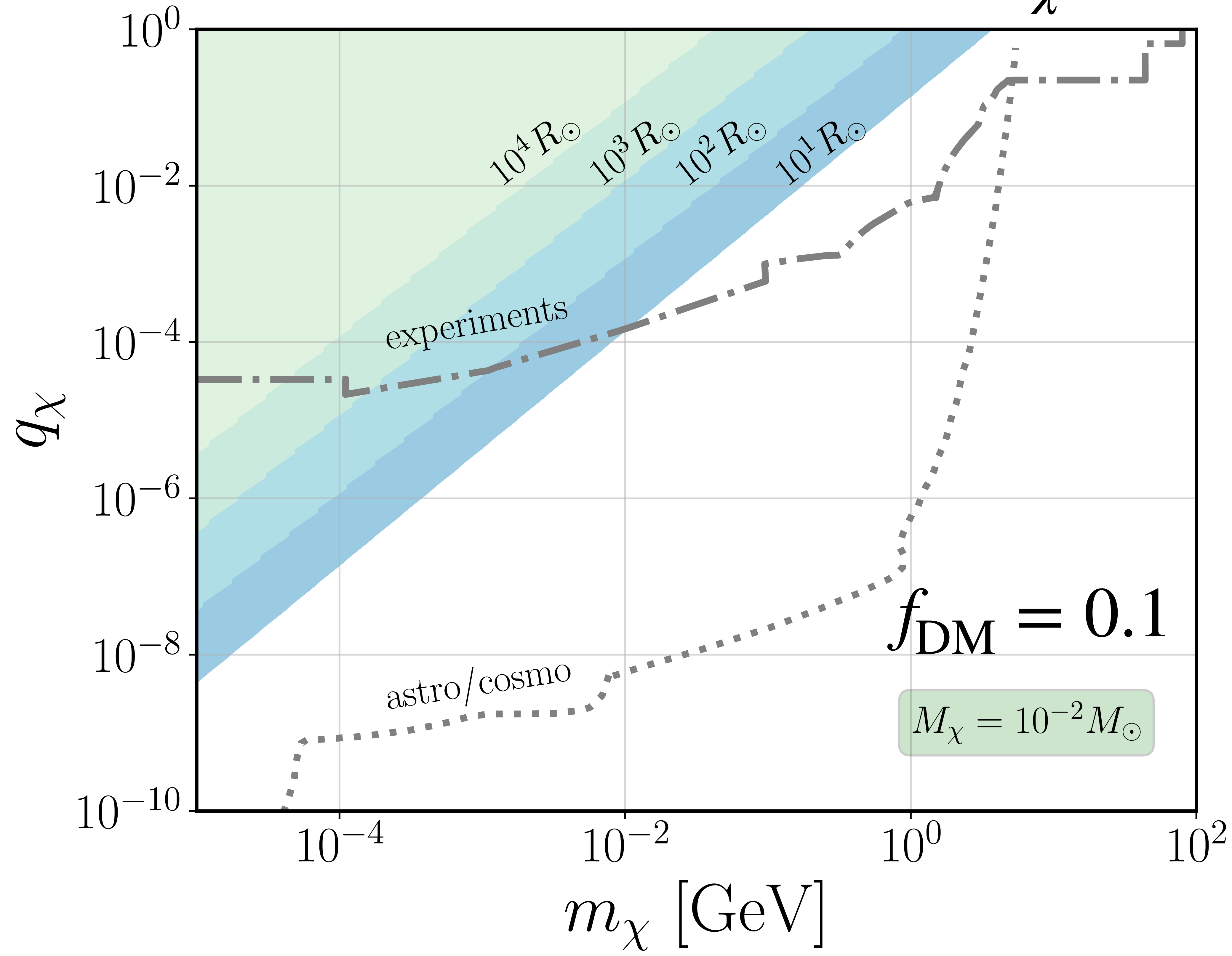


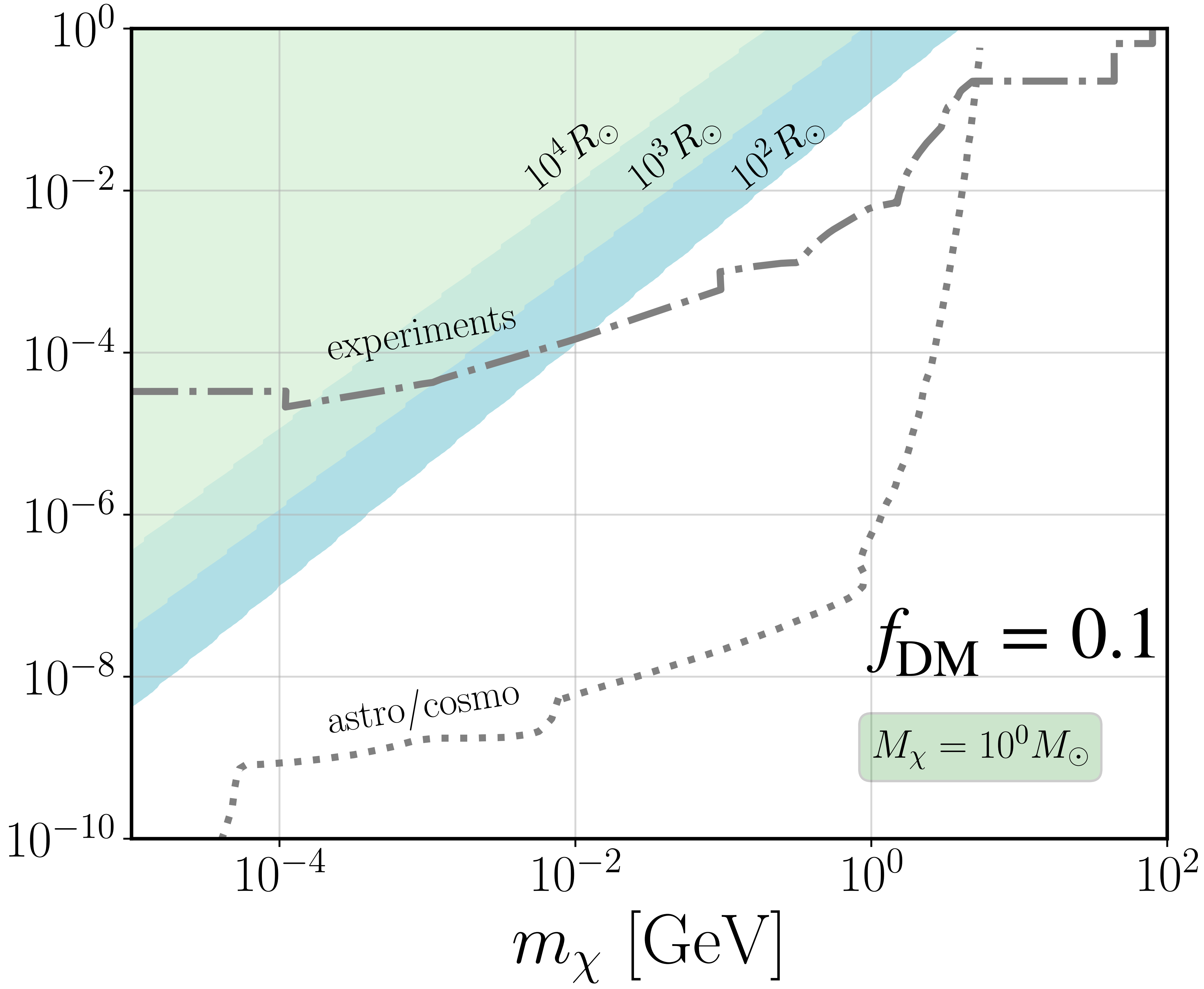
Millicharged Dark Matter

$$\mathscr{L} \supset \frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$



- χ gets an effective millicharge $q_\chi = \epsilon e'/e$





Millicharged Dark Matter

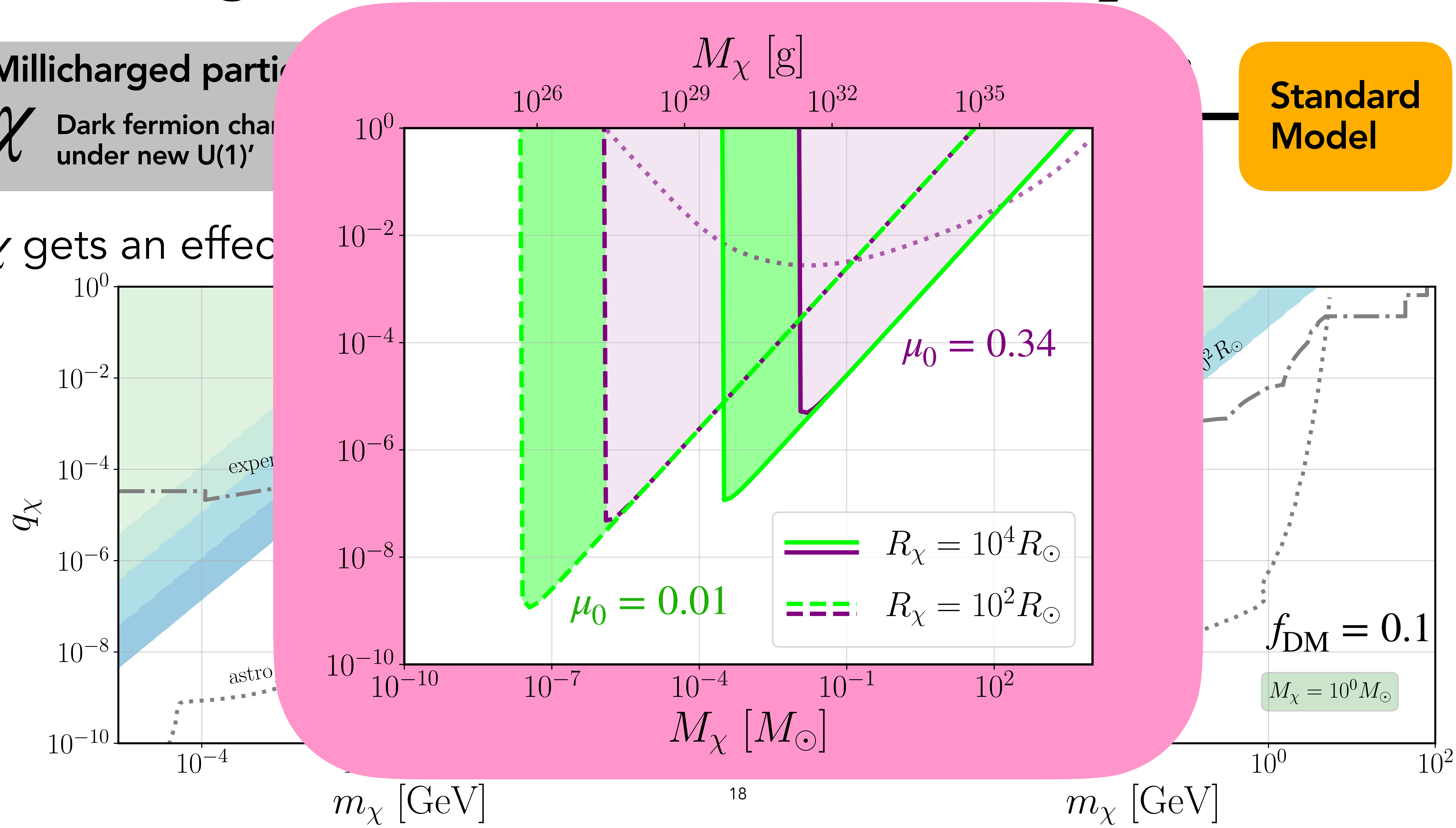
$$\mathscr{L} \supset \frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$

Millicharged parti

χ Dark fermion char
under new U(1)′

Standard Model

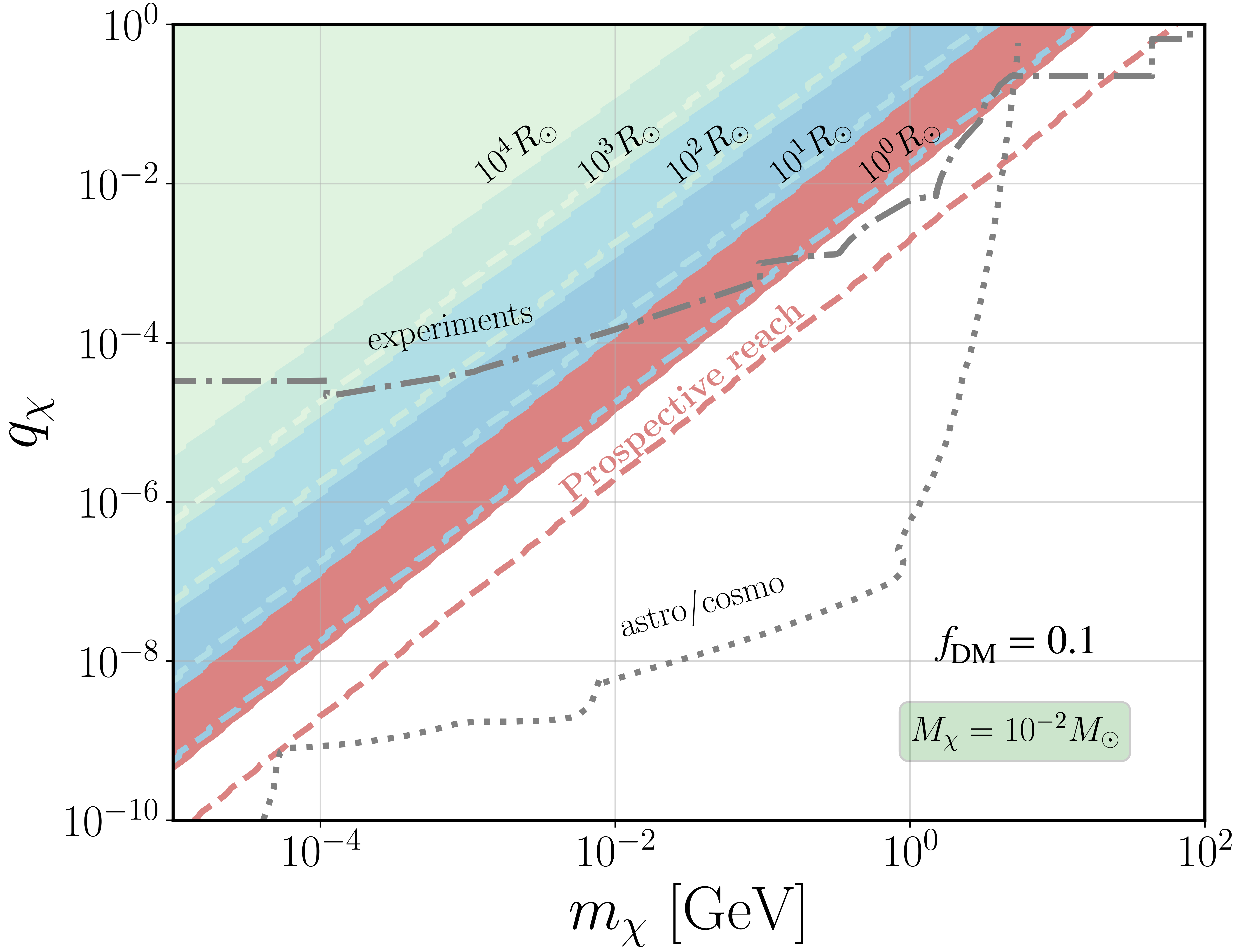
- χ gets an effec



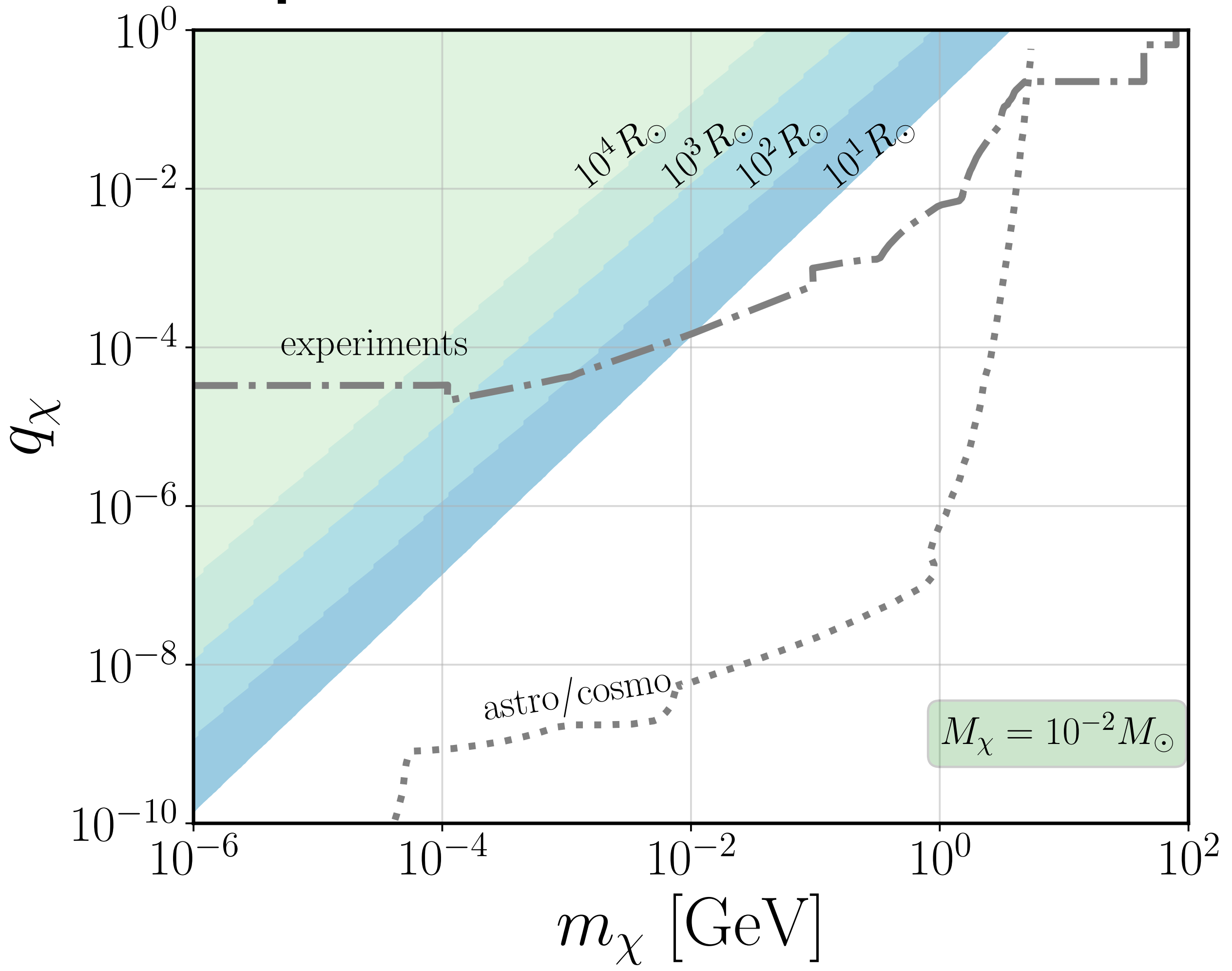
Can we do better?

- What if we could consider lower event times? (solid)
- Dimming threshold before was 34%, but what if we decrease it to 1%? (dashed)
- Both of these combined -> start getting competitive bounds

After:



Before:



Conclusions

- If dark sector predicts compact objects, can constrain macroscopic (astrophysical) properties
- Can give complementary bounds on microscopic (particle) properties
- Microlensing surveys can be used to search for dimming effects (✨**for free**✨) from DarkCOs
- If starlight looks cloudy, could be dark matter…

Future Studies

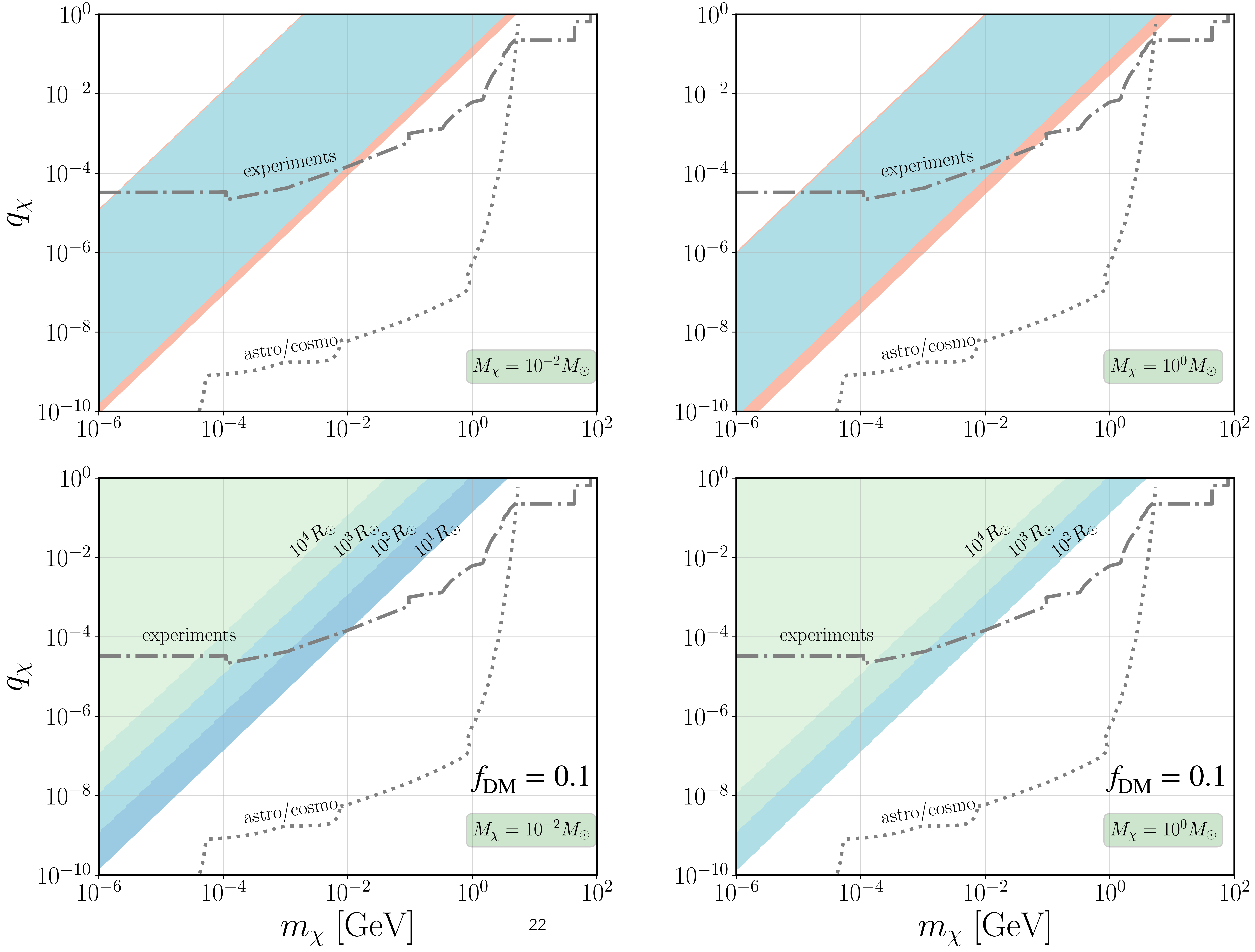
- What about resolvable sources? i.e. Subaru/HST, Roman, etc.
- Go through light curves for candidate events
- Foreground analysis of expected astrophysical events

Thank you!

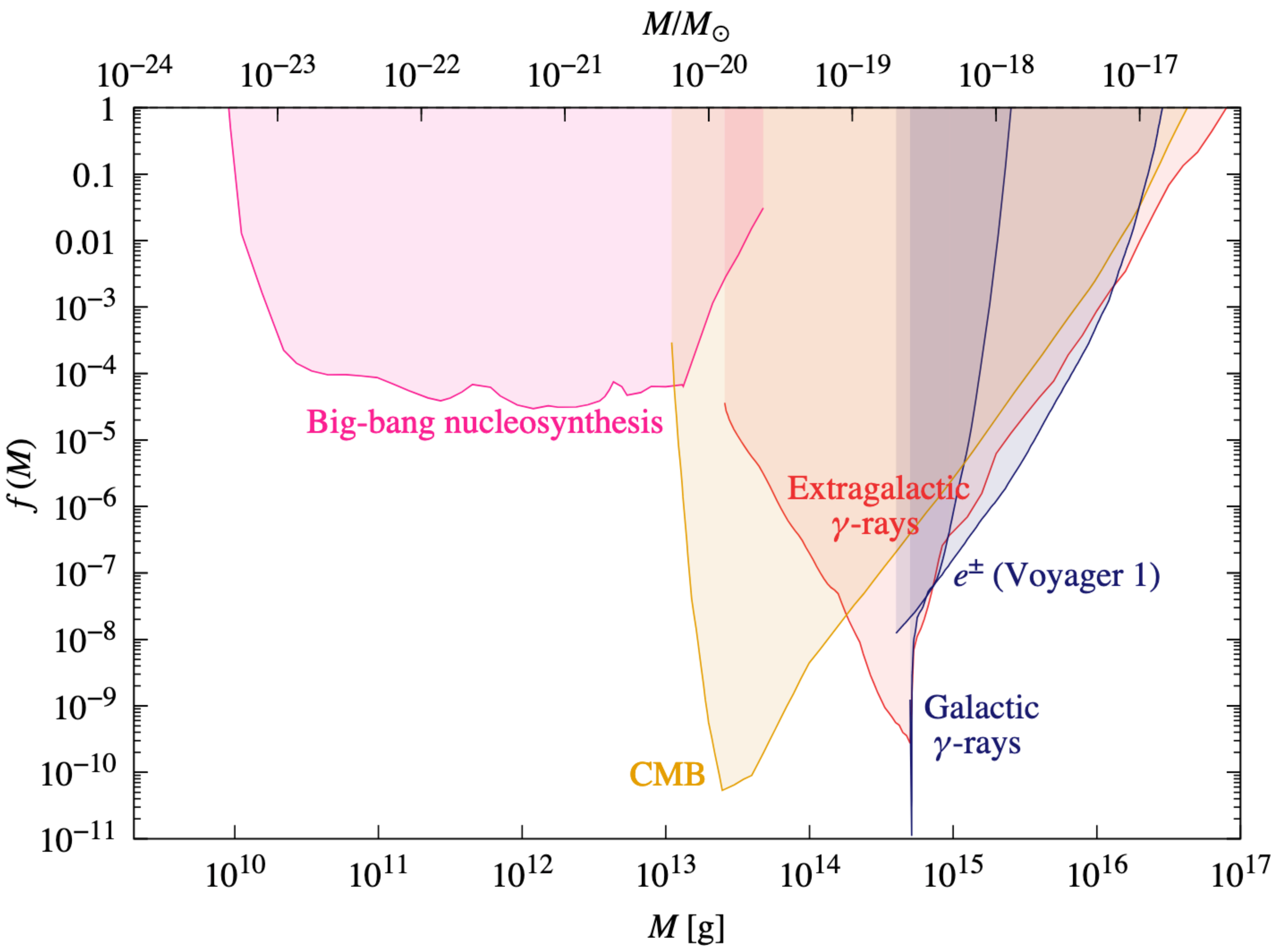
2409.08322

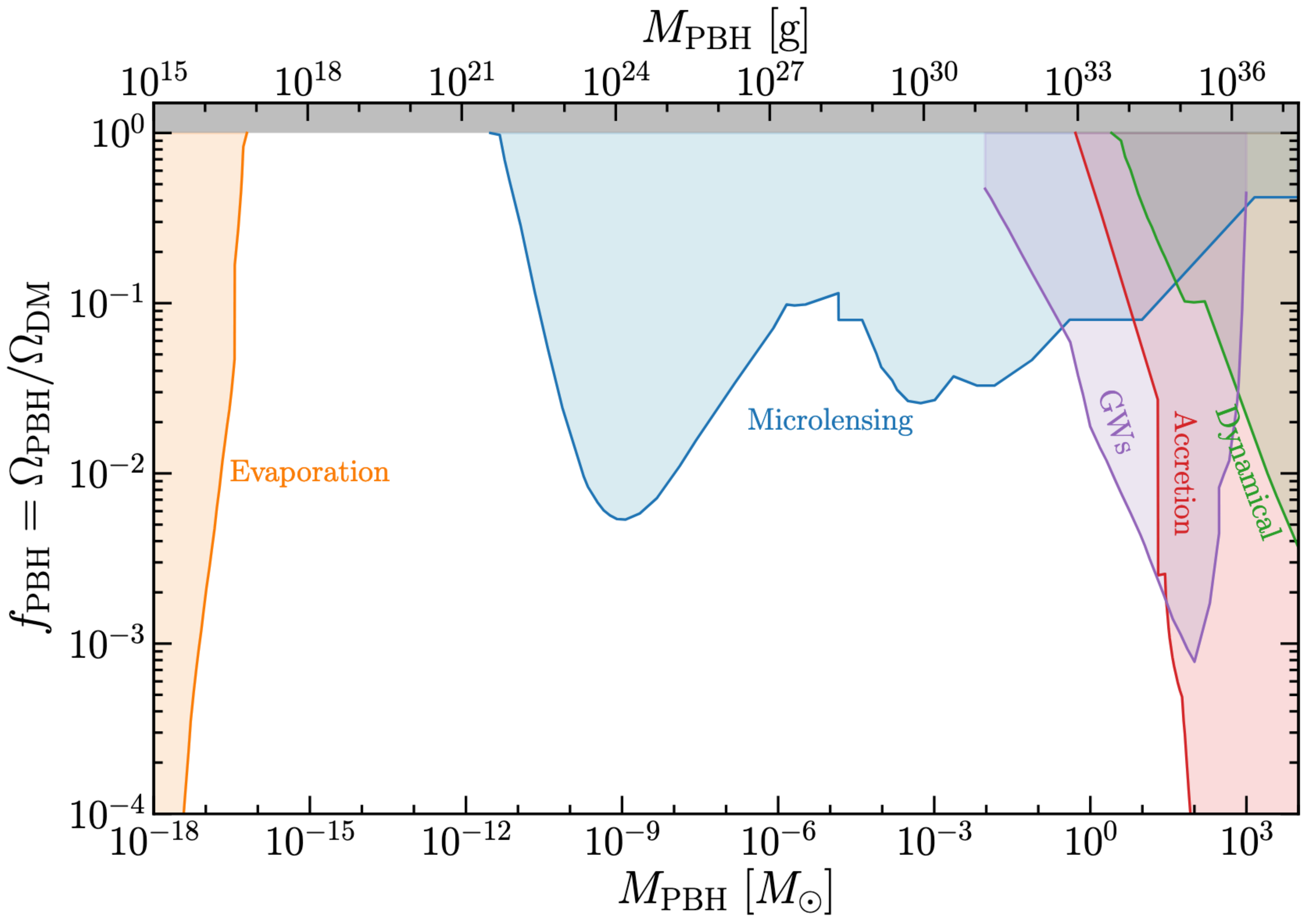
Supplemental Slides

MCPs


experiments
astro/cosmo
$M_\chi = 10^{-2} M_\odot$
$M_\chi = 10^{0} M_\odot$
$10^4\,R_\odot$
$10^3\,R_\odot$
$10^2\,R_\odot$
$10^1\,R_\odot$
$f_{\rm DM} = 0.1$
q_χ
m_χ [GeV]

PBH & MACHO Constraints





Figures from
Carr et al. 2021,
Green and Kavanagh 2020