Cloudy with a Chance of Dark Matter

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Preliminary

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and Joseph Bramante

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Queen's UNIVERSITY

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Canadian Astroparticle Physics Research Institute

Dissipative dark sectors

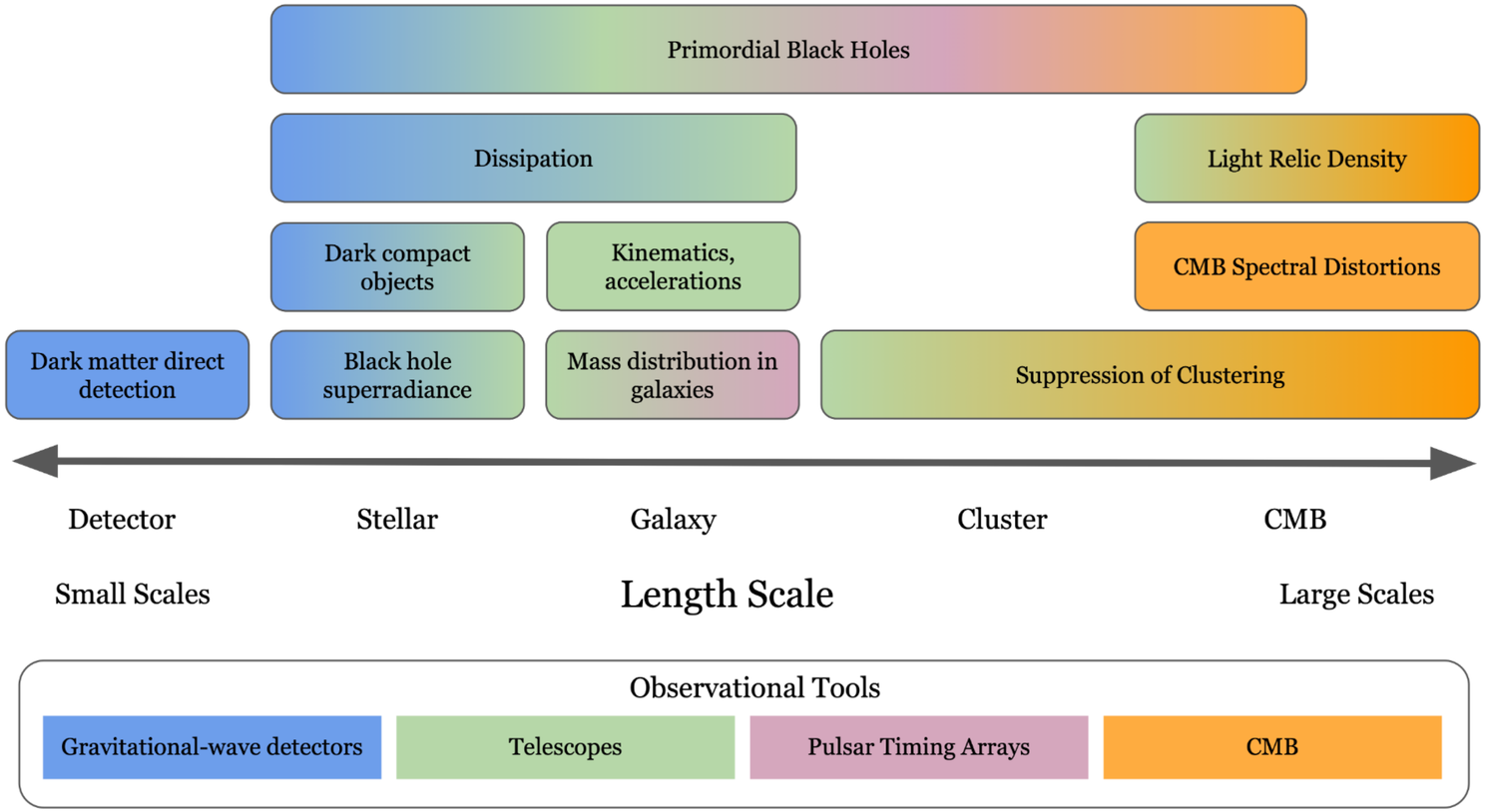


Figure from Snowmass 2021
White Paper (Brito et al. [2203.15954])

Dissipative dark sectors

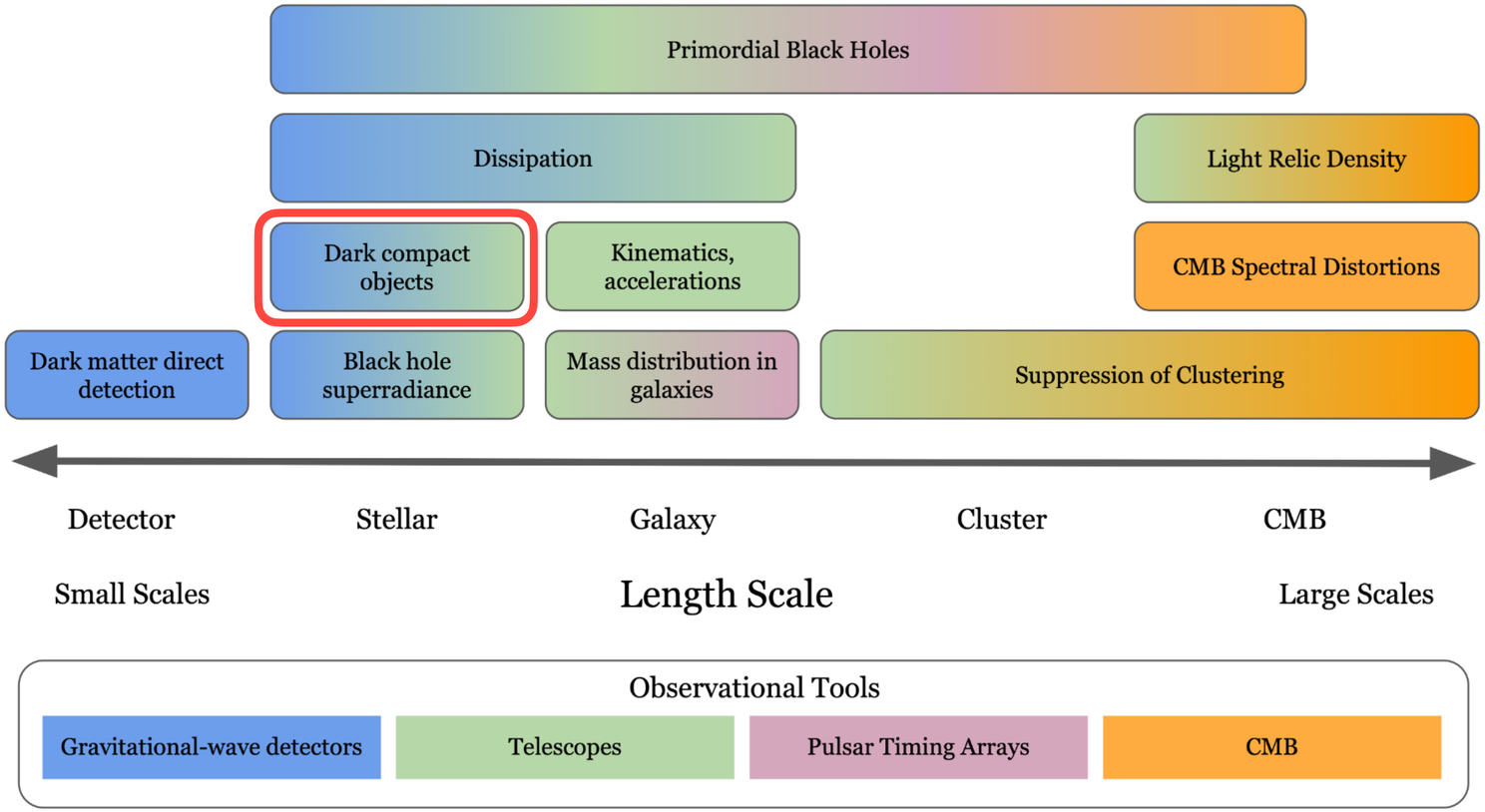


Figure from Snowmass 2021 White Paper (Brito et al. [2203.15954])

- Dark compact objects can form naturally in dissipative dark sectors

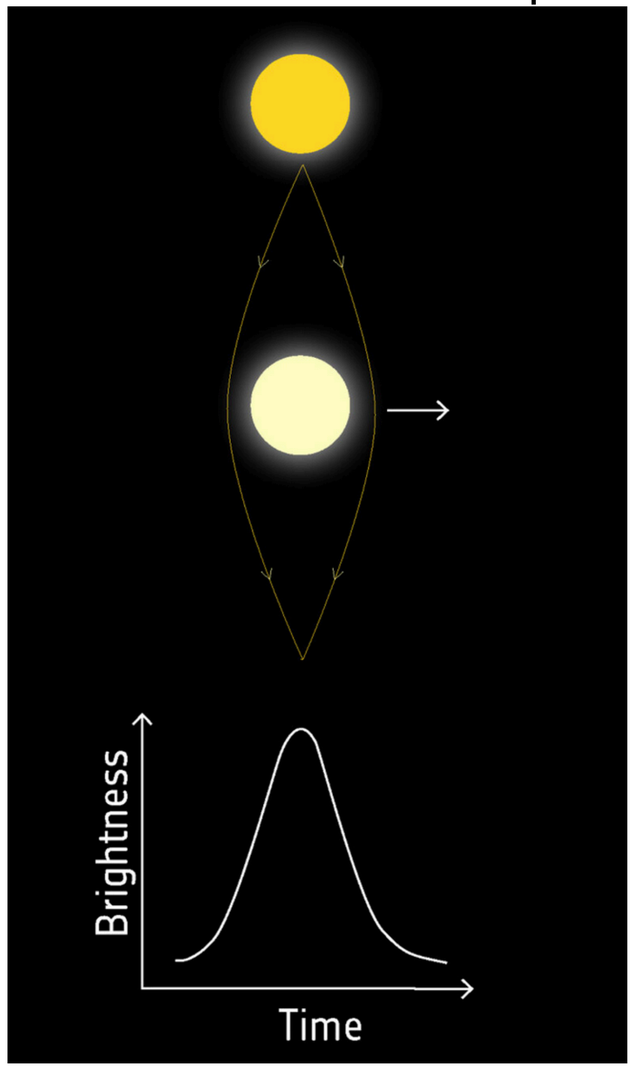
- Example list of dark substructures:

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]
Gurian, Liu, Jeong, Hosokawa, Hirano, Yoshida [2408.12940]
Roy, Shen, Barron, Lisanti, Curtin, Murray, Hopkins [2408.15317]
+many talks scattered throughout TeVPA 2024
+many more!

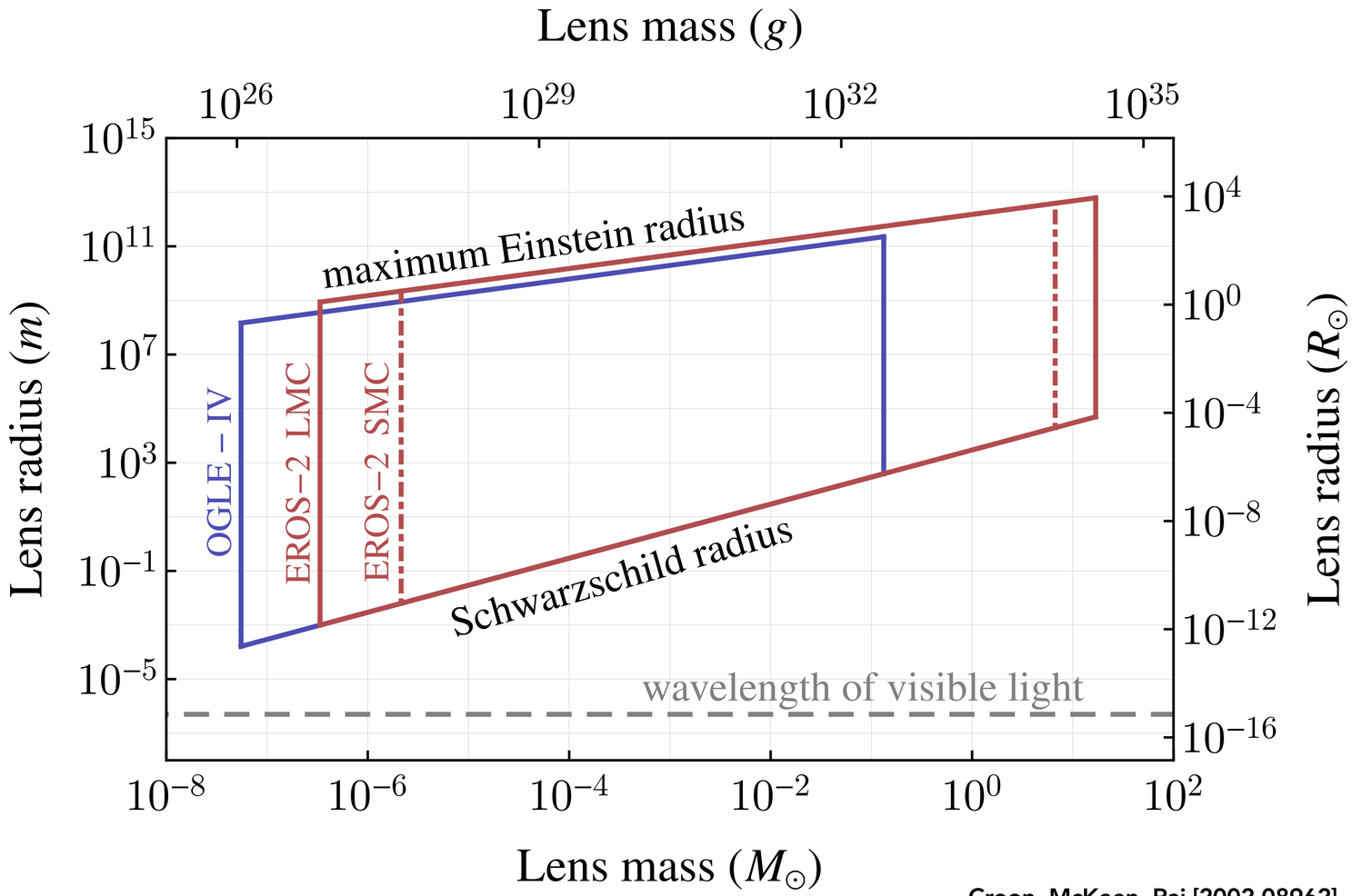
- How do we look for them?
  - Gravitational waves
  - Microlensing
  - **Lampshades?**

Microlensing

- Looks for the amplification of starlight



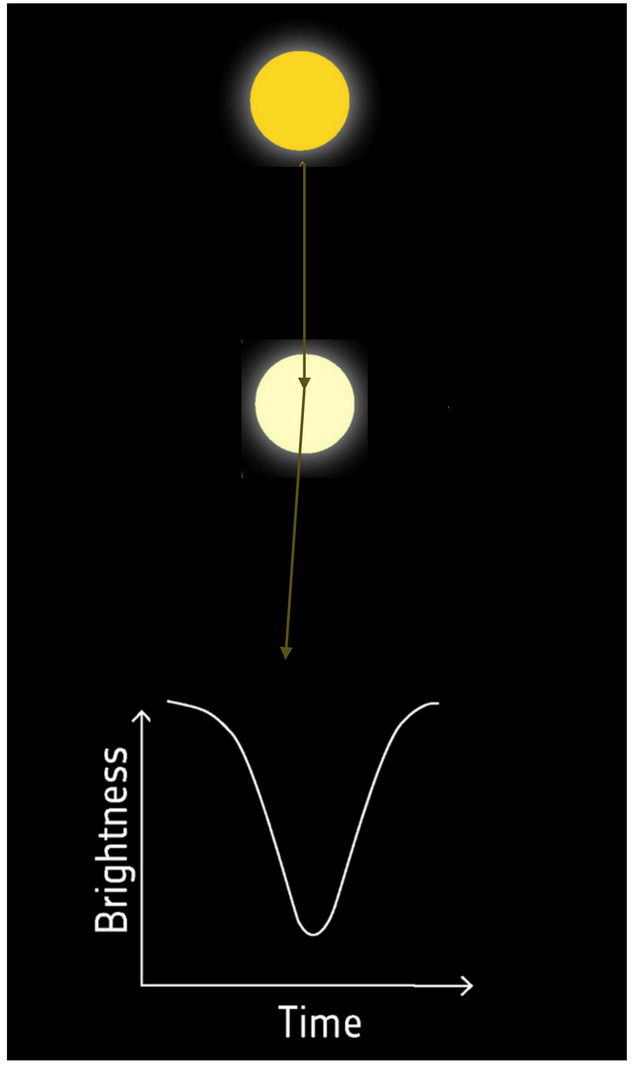
Credit: ESA



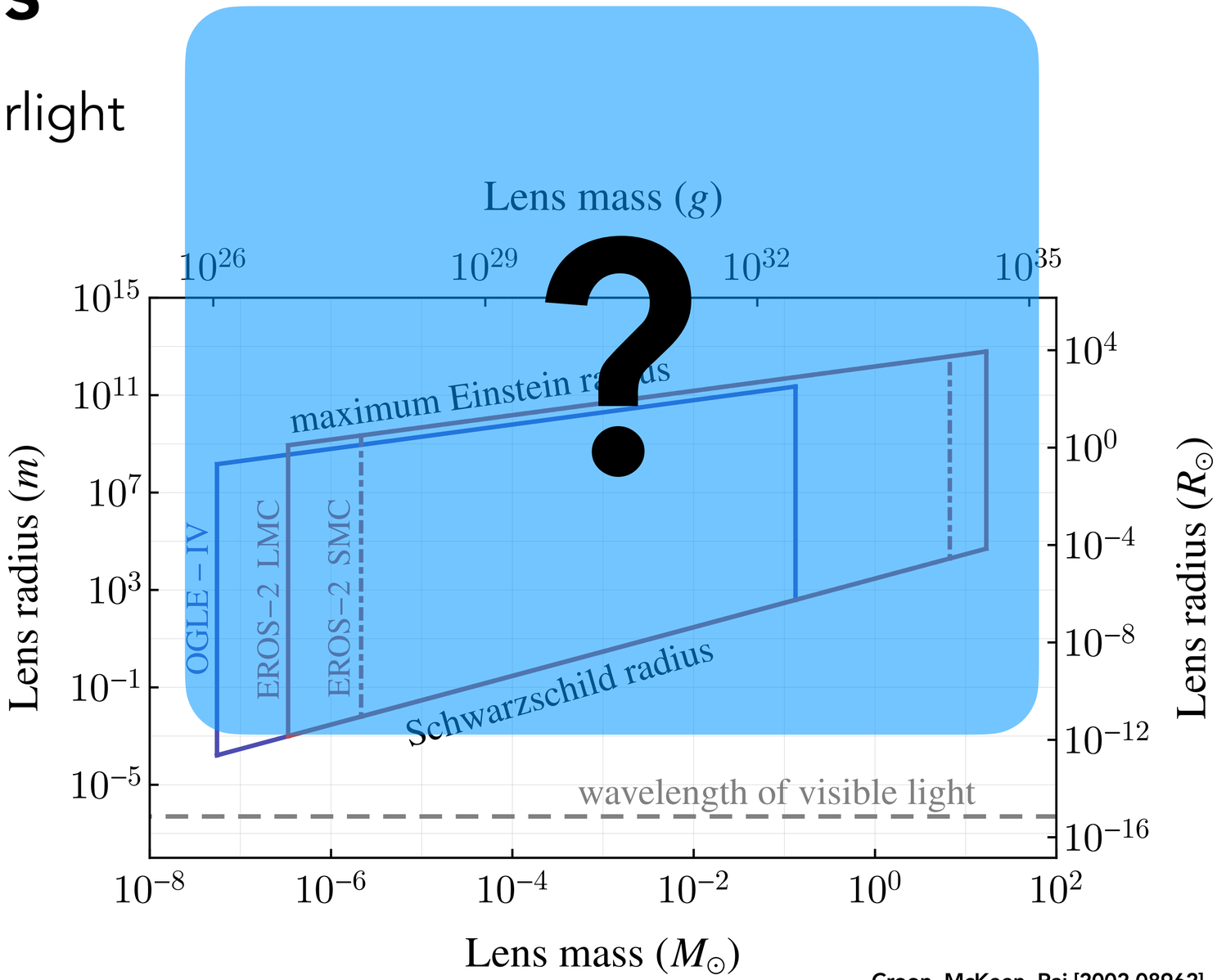
Croon, McKeen, Raj [2002.08962]

Lampshades/Clouds

- Looks for the *decrease* of starlight



Credit: ESA



Croon, McKeen, Raj [2002.08962]

Dimming due to DM clouds

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

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

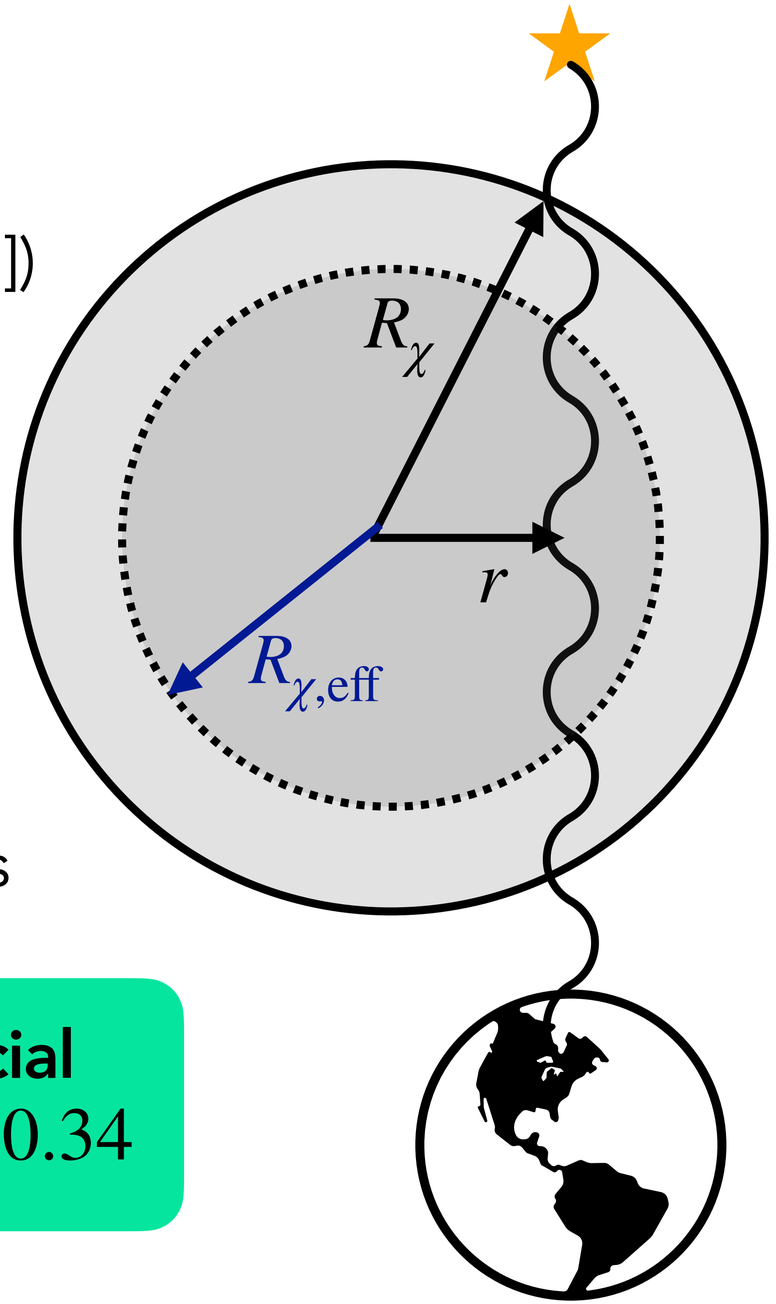
with characteristic optical depth

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

- Dimming threshold μ_0 gives effective radius of object

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

Fiducial
$\mu_0 = 0.34$




PREPARE TO GET SERVED
CLOUDY
with a chance of
DARK
MATTER
COLUMBIA PICTURES PRESENTS A SONY PICTURES ANIMATION FILM "CLOUDY WITH A CHANCE OF MEATBALLS" BILL HADER ANNA FARIS JAMES CAAN ANDY SAMBERG BRUCE CAMPBELL MR. T BOBBE J. THOMPSON
BENJAMIN BRATT NEIL PATRICK HARRIS AL ROKER LAUREN GRAHAM WILL FORTE
animation
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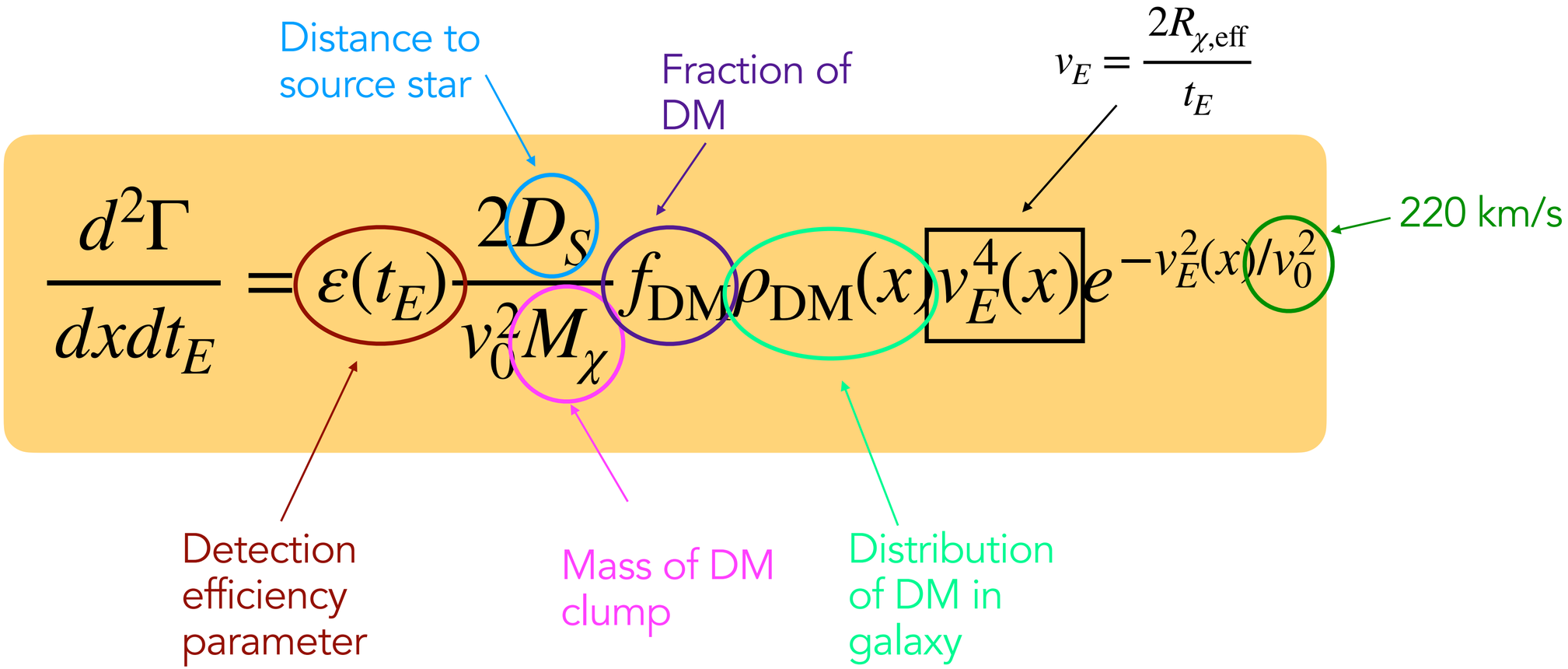
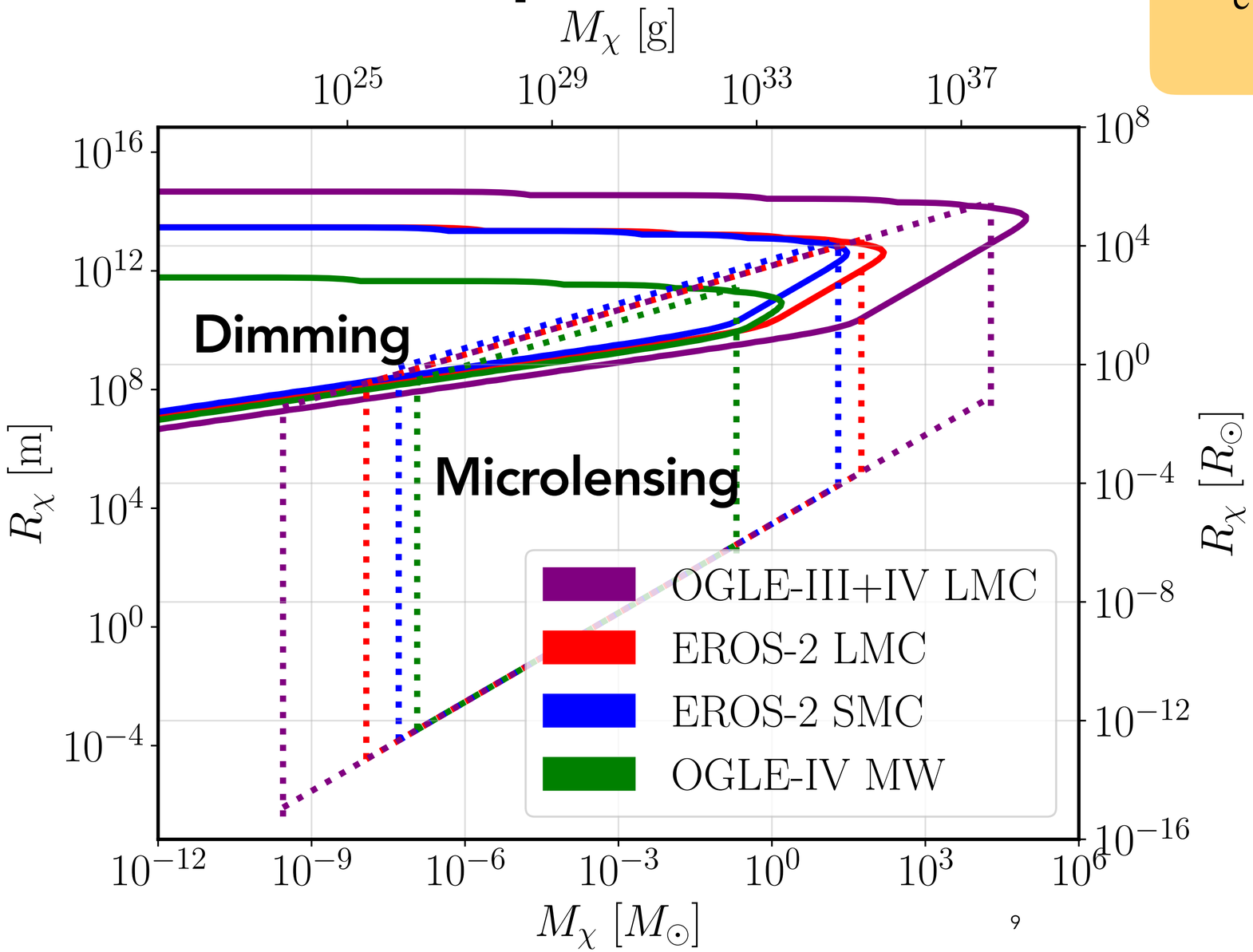
Event rate

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



A heuristic plot



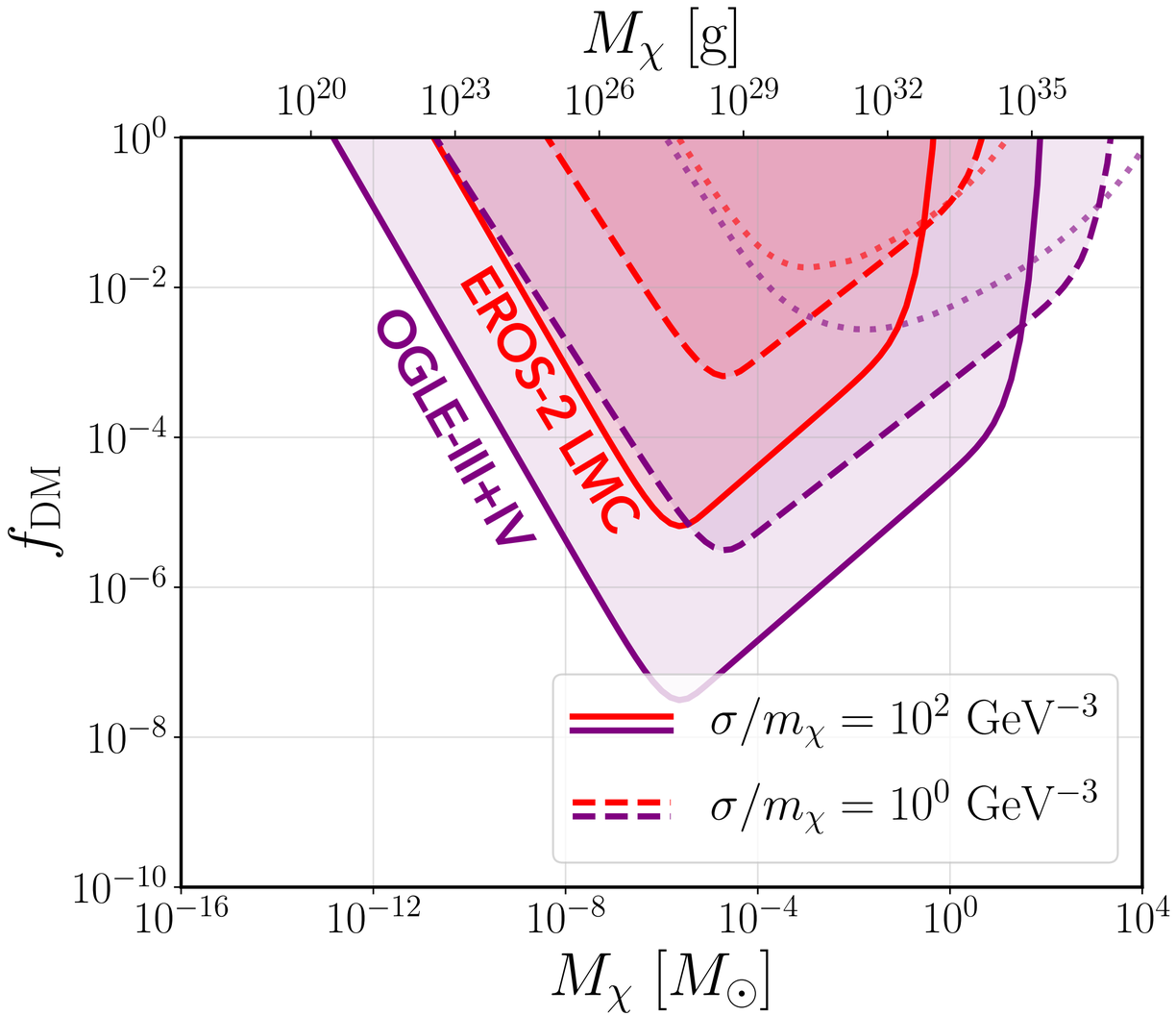
Number of events:

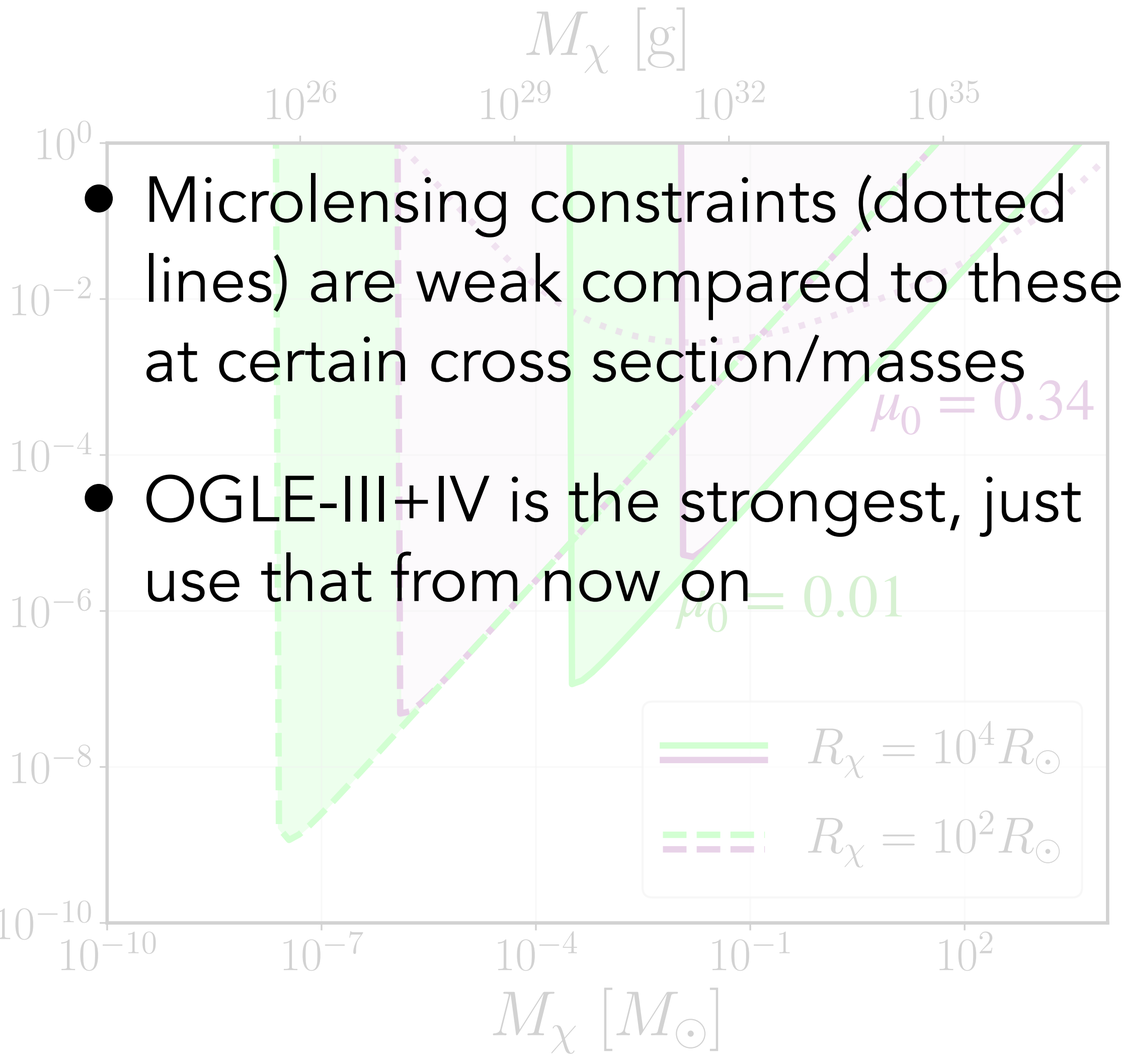
$$N_{\text{events}} = N_* T_{\text{obs}} \int_0^1 dx \int_{t_{E,\min}}^{t_{E,\max}} dt_E \frac{d^2\Gamma}{dx dt_E}$$

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]

DM fraction constraints (fixed τ_0)

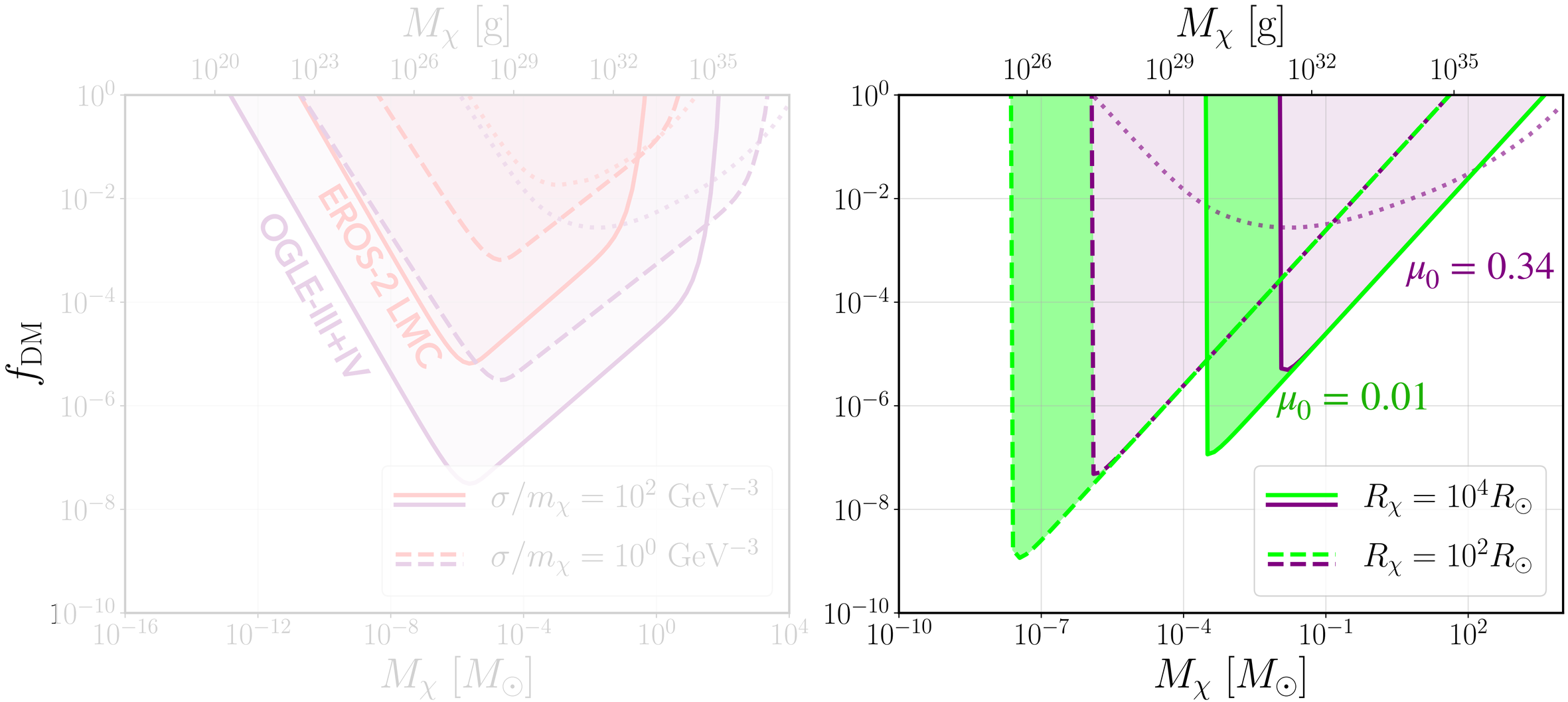
$$R_\chi = \sqrt{\frac{3}{4\pi}\frac{\sigma M_\chi}{m_\chi \tau_0}}$$





- 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

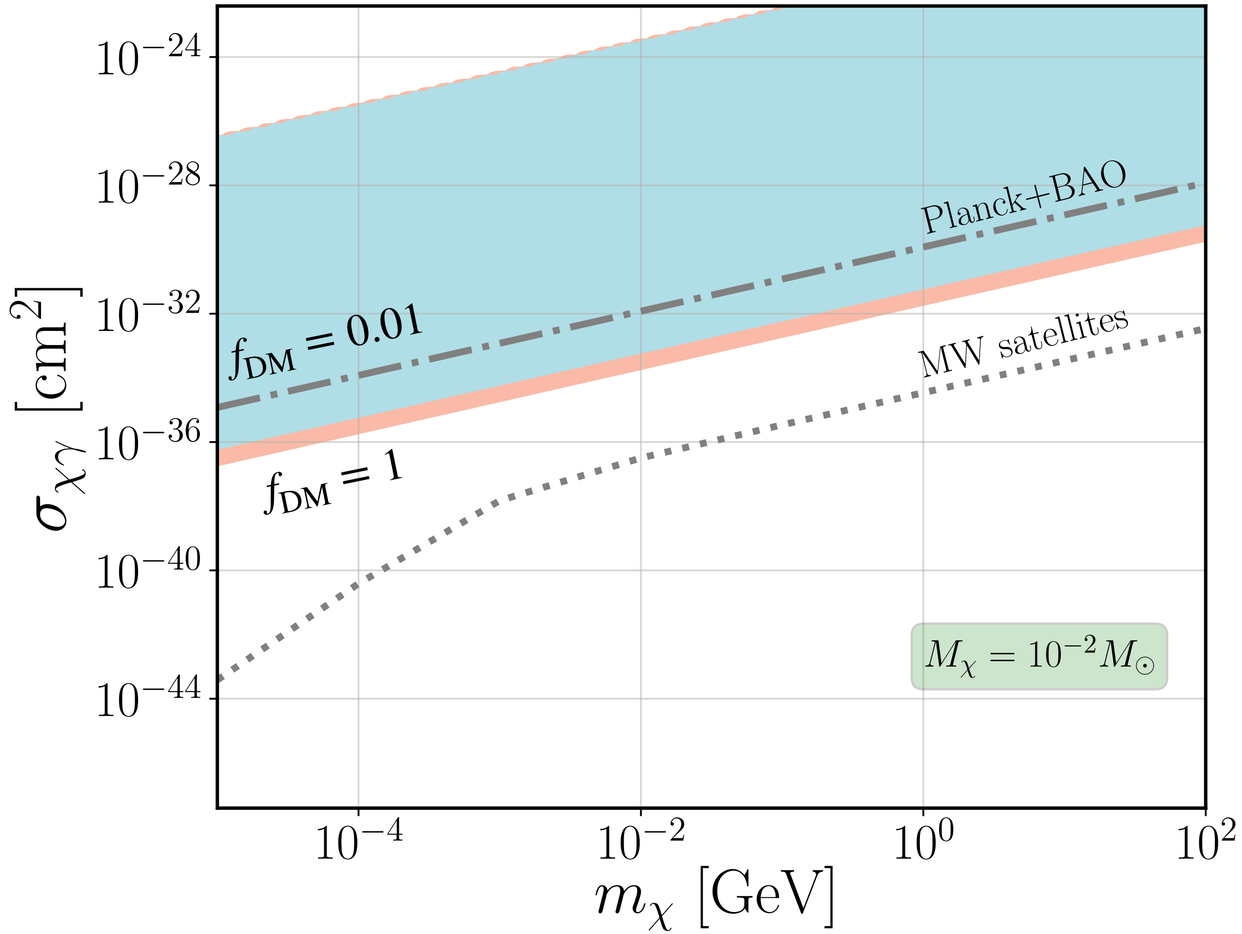
DM fraction constraints (fixed R_χ)

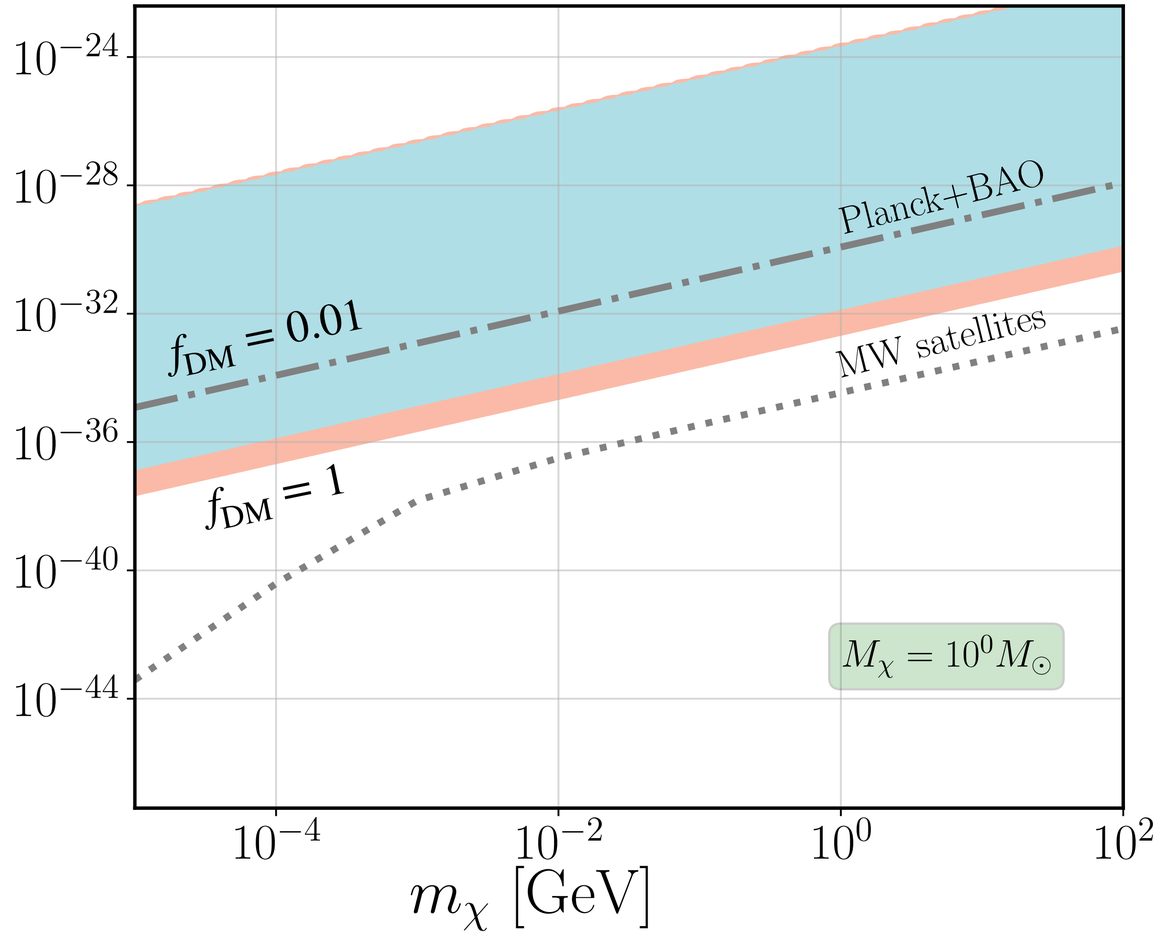


Microscopic properties

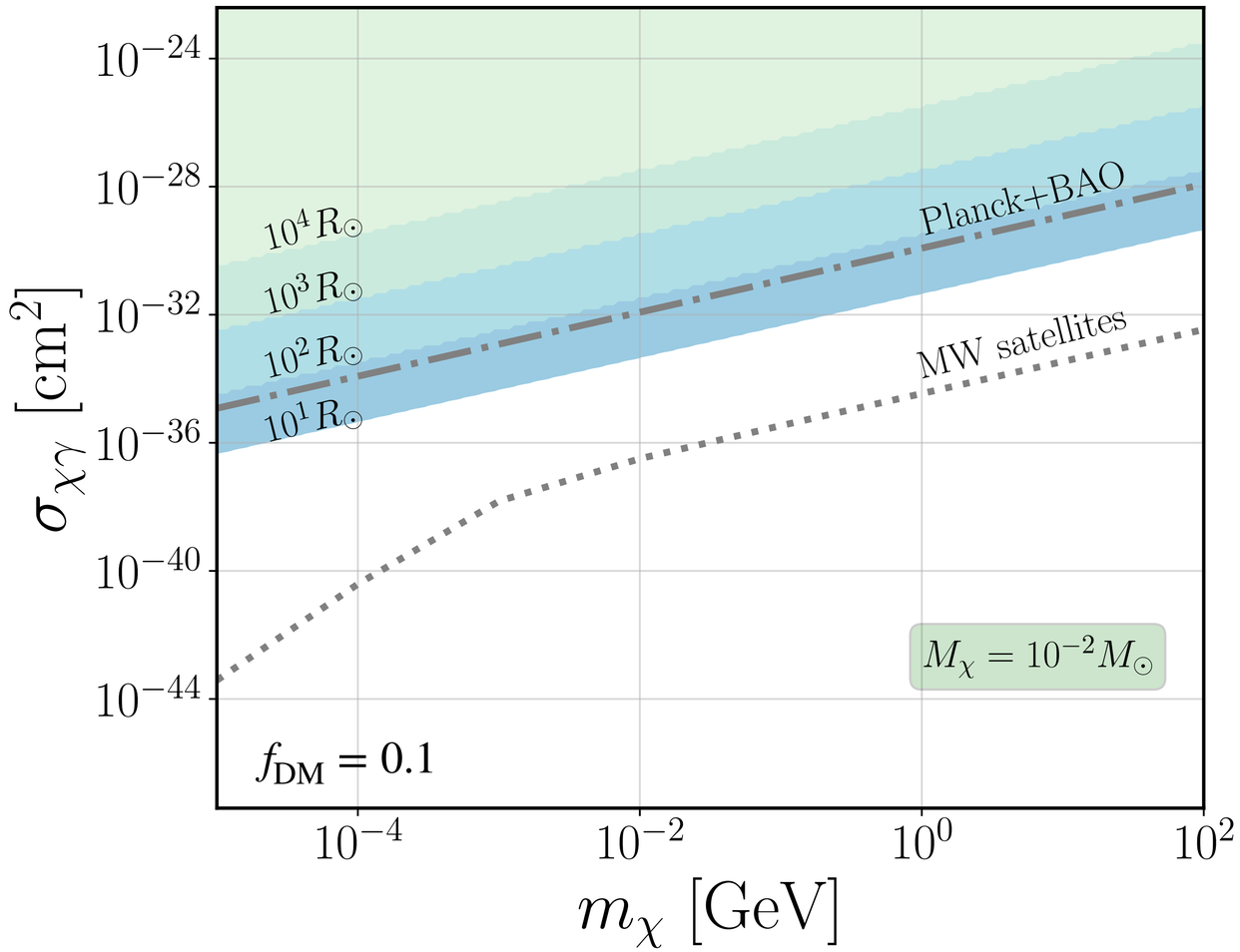
- We have seen how to constrain macroscopic properties such as clump masses, sizes, what about microscopic properties?
- Consider two different types:
  - DM-SM photon elastic scattering cross section and mass
  - Effective charge and mass of millicharged dark matter

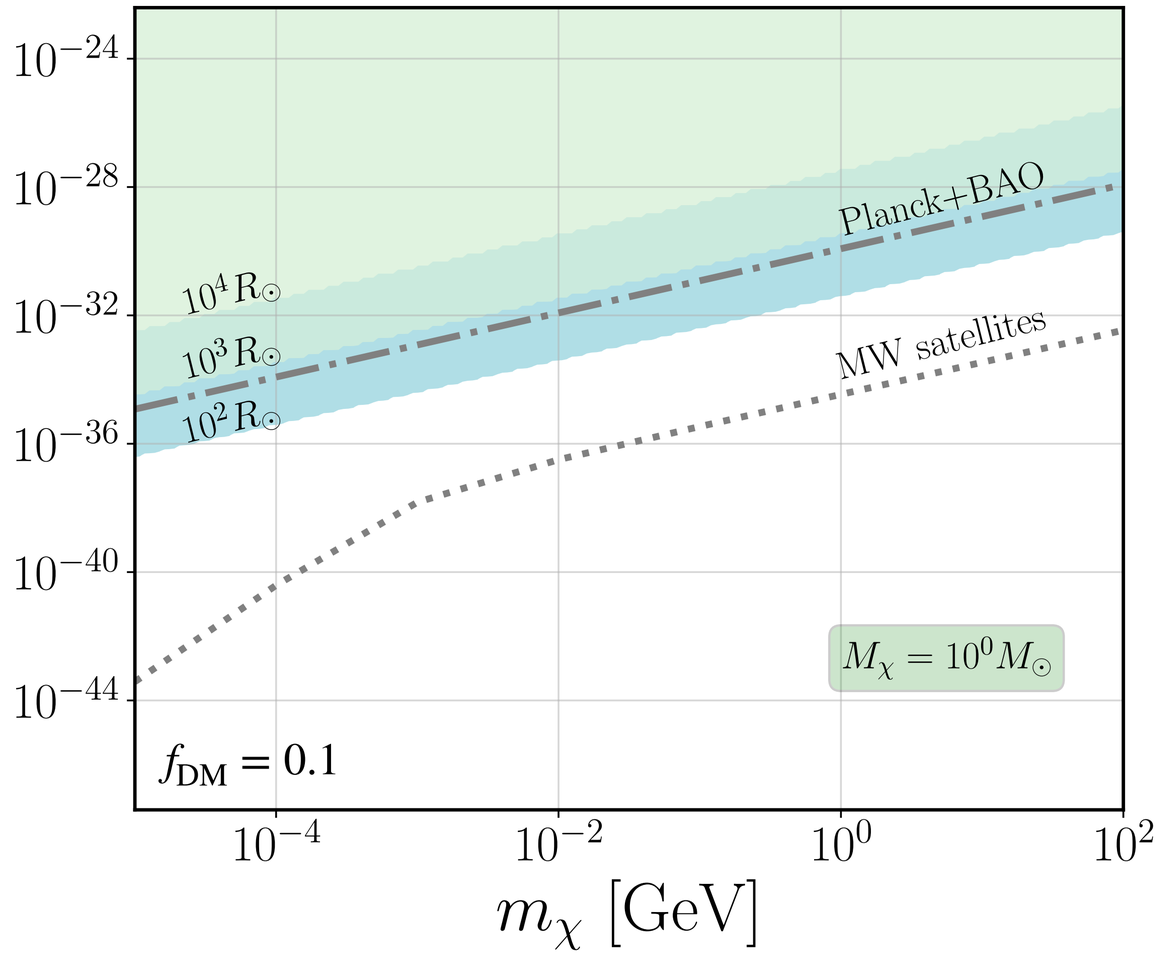
Elastic scattering cross section at fixed τ_0





Elastic scattering cross section at fixed R_χ





Millicharged Dark Matter

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

Millicharged particle
χ Dark fermion charged under new U(1)'

e'

Dark photon
γ' U(1)' gauge boson

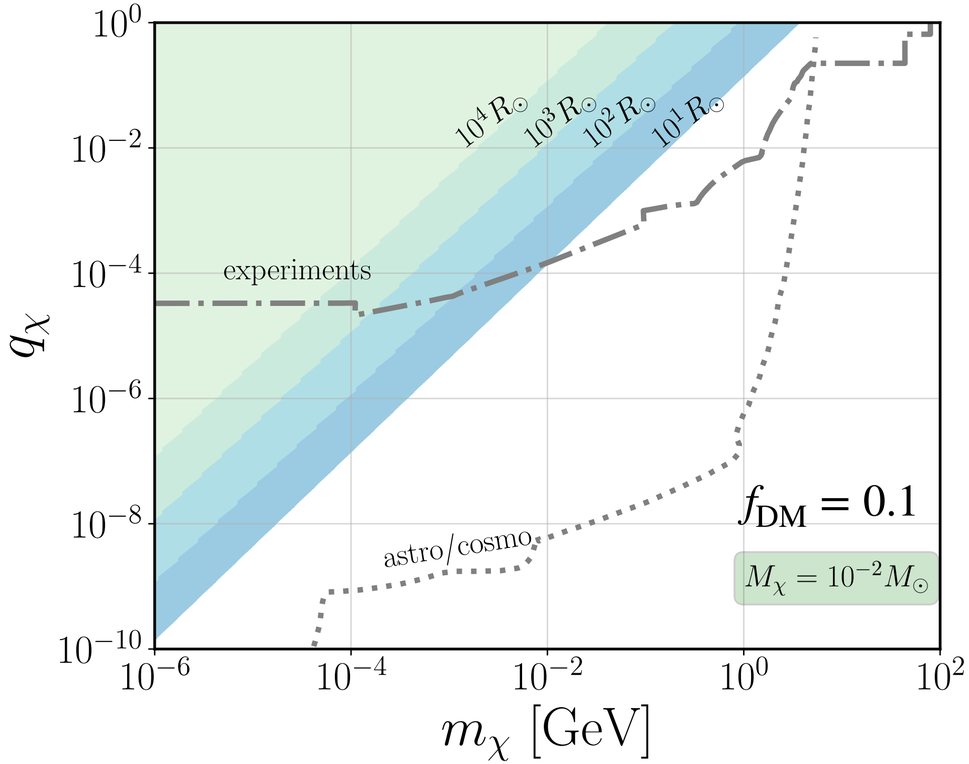
ϵ

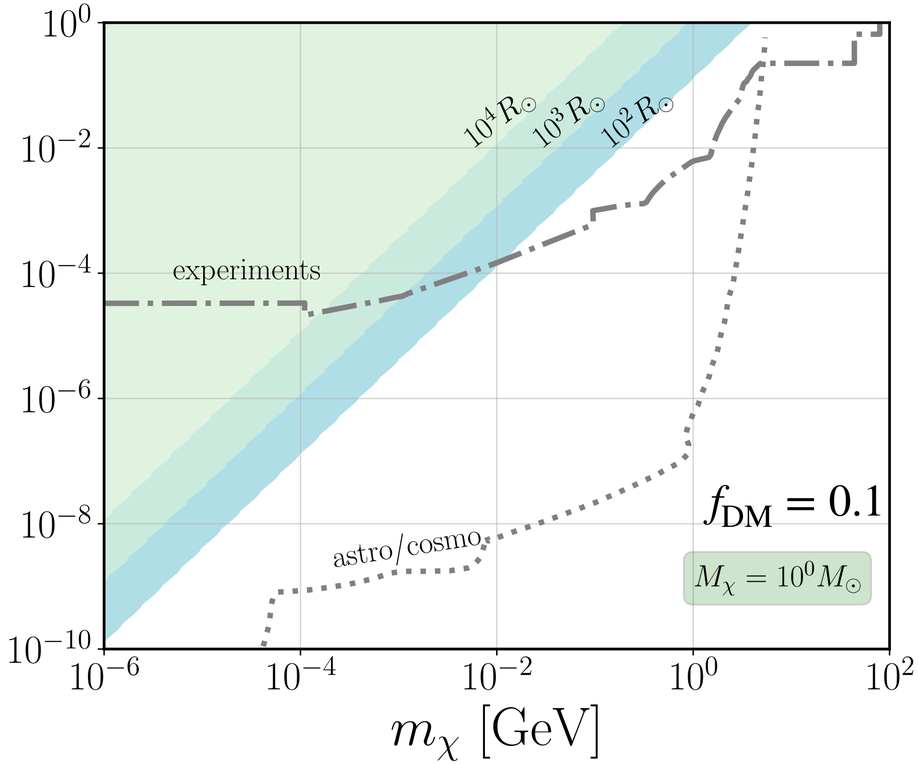
Photon
γ

e

Standard Model

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

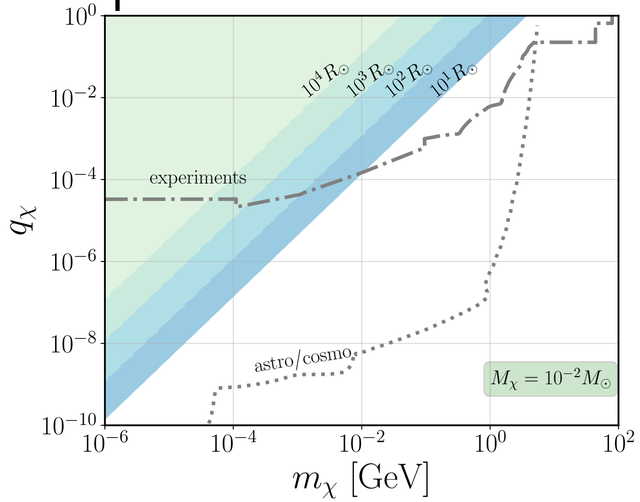




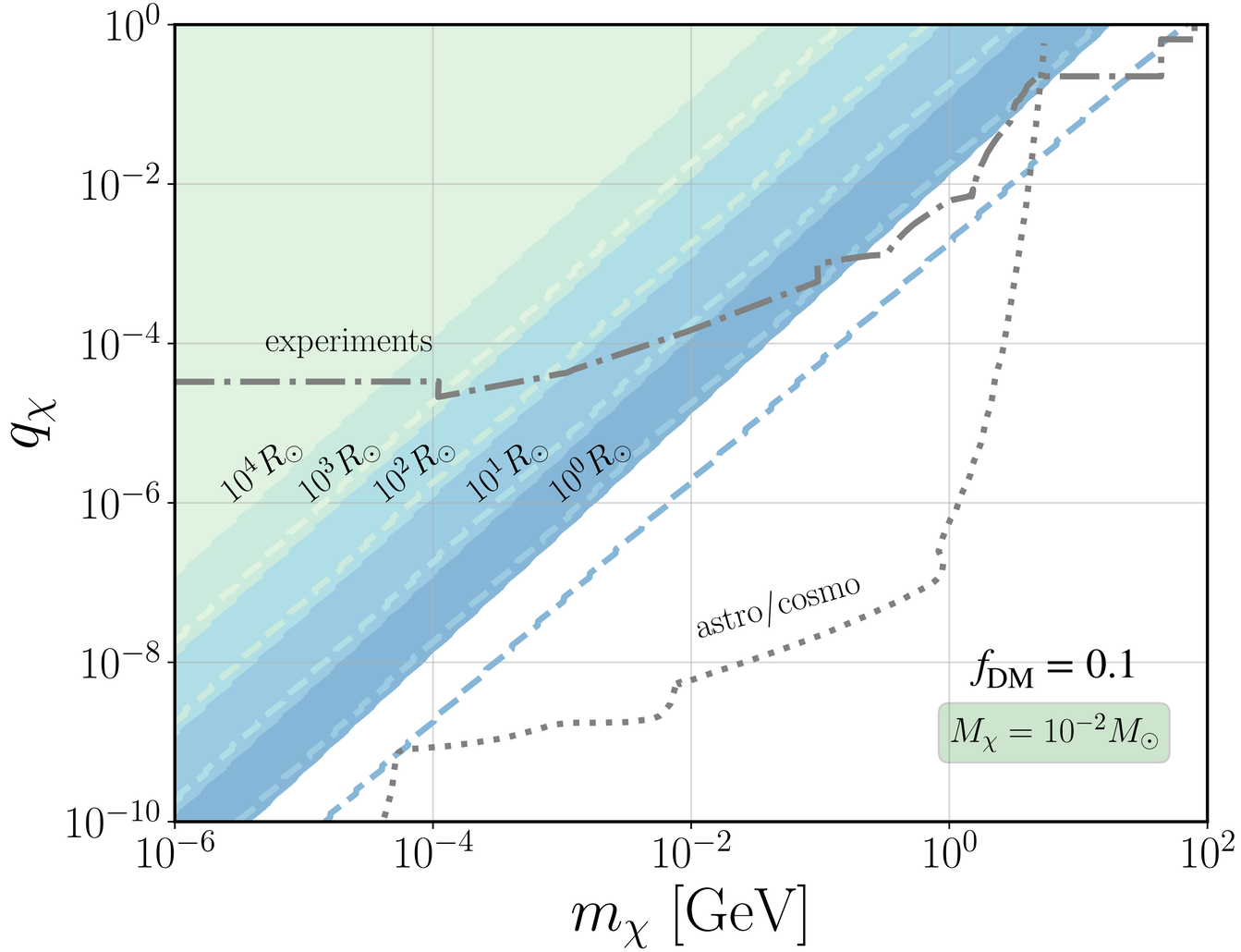
Can we do better?

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

Before:



After:



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
- If starlight looks cloudy, could be dark matter…

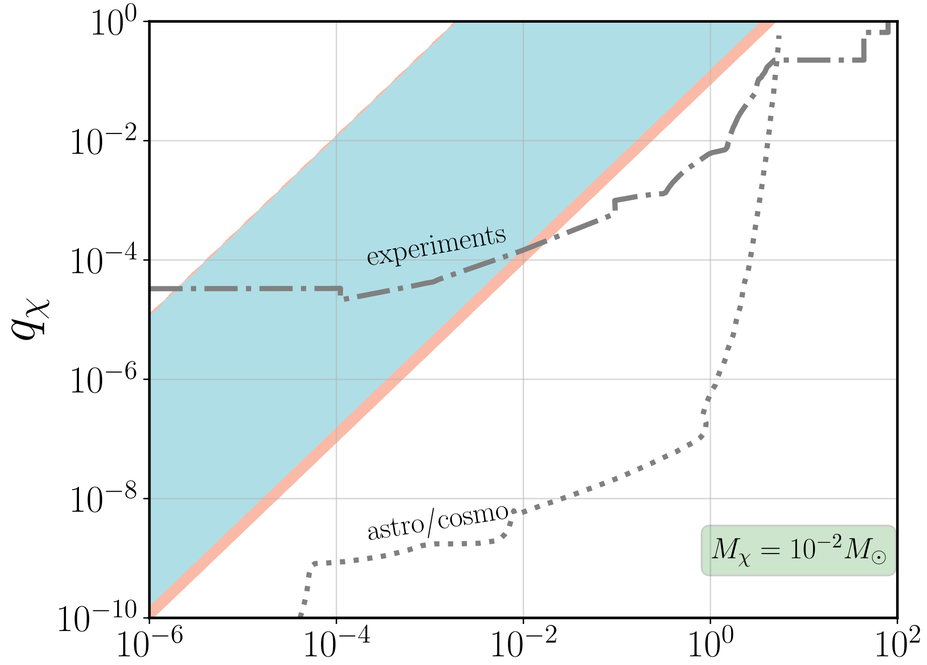
Future Studies

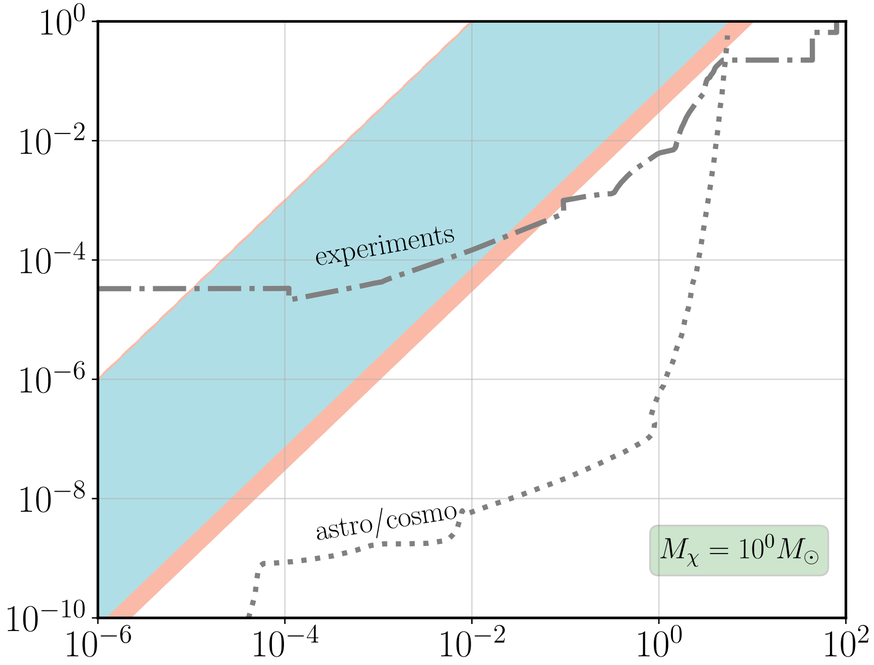
- What about resolvable sources? i.e. Subaru/HST, Roman, etc.
- Go through light curves for candidate events
- Foreground analysis of expected astrophysical events

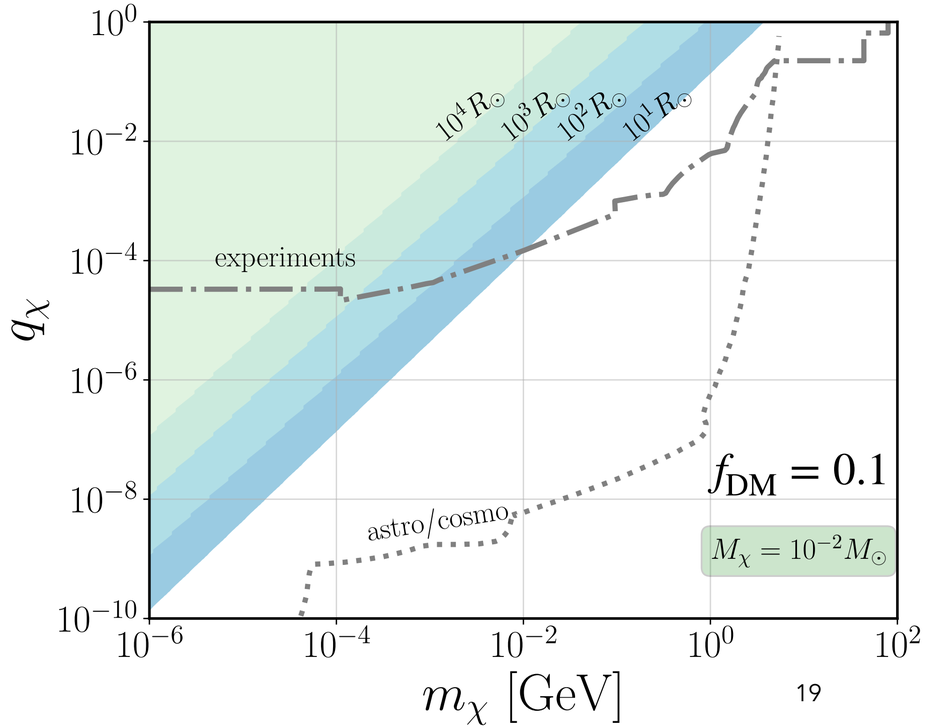
Thank you!

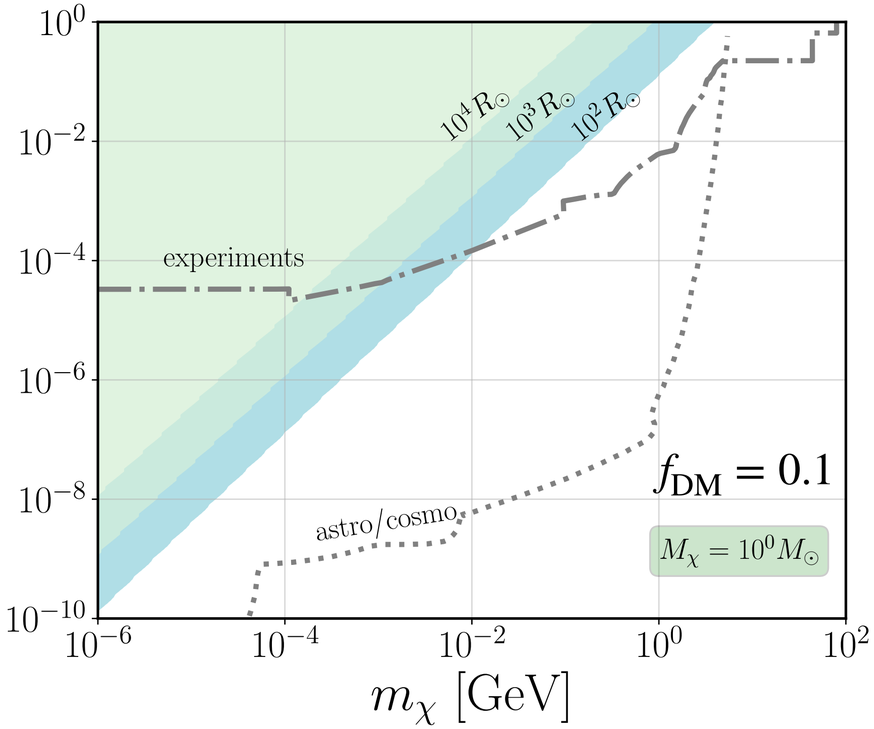
Supplemental Slides

MCPs


experiments
astro/cosmo
$M_\chi = 10^{-2} M_\odot$
q_χ


experiments
astro/cosmo
$M_\chi = 10^{0} M_\odot$


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


$10^4 R_\odot$
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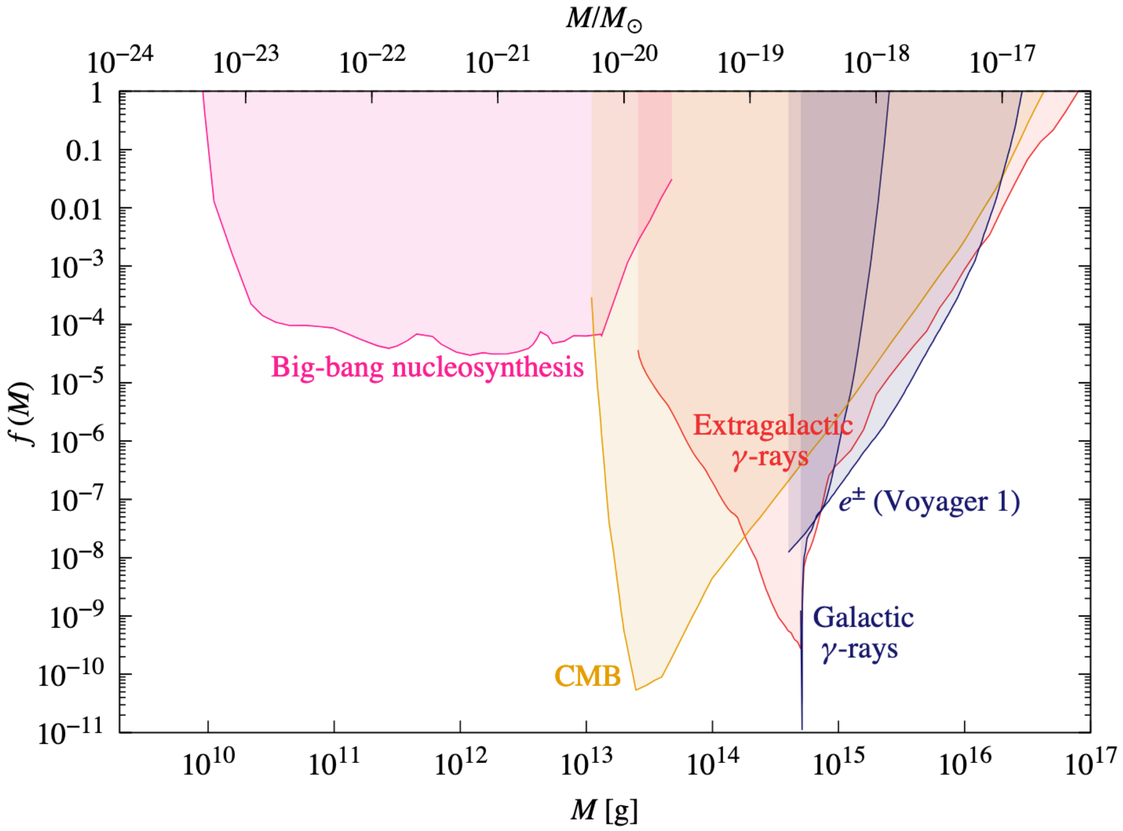
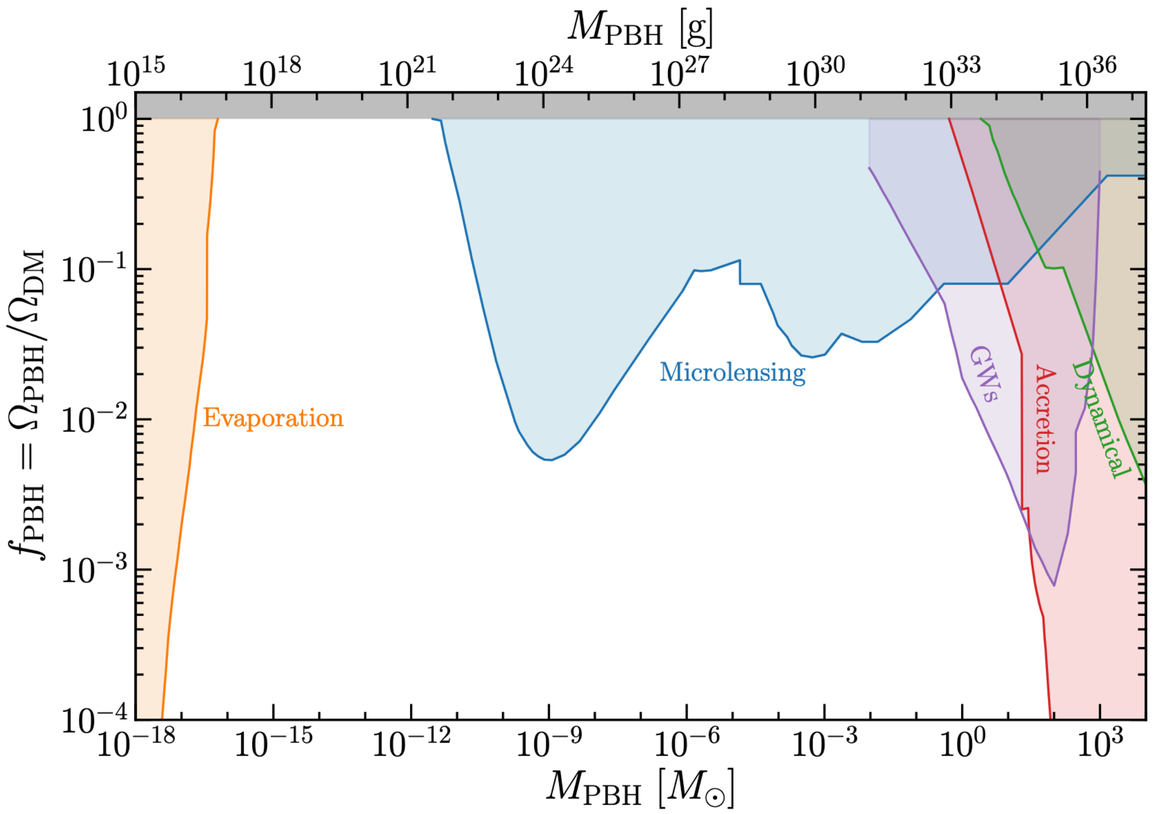
m_χ [GeV]

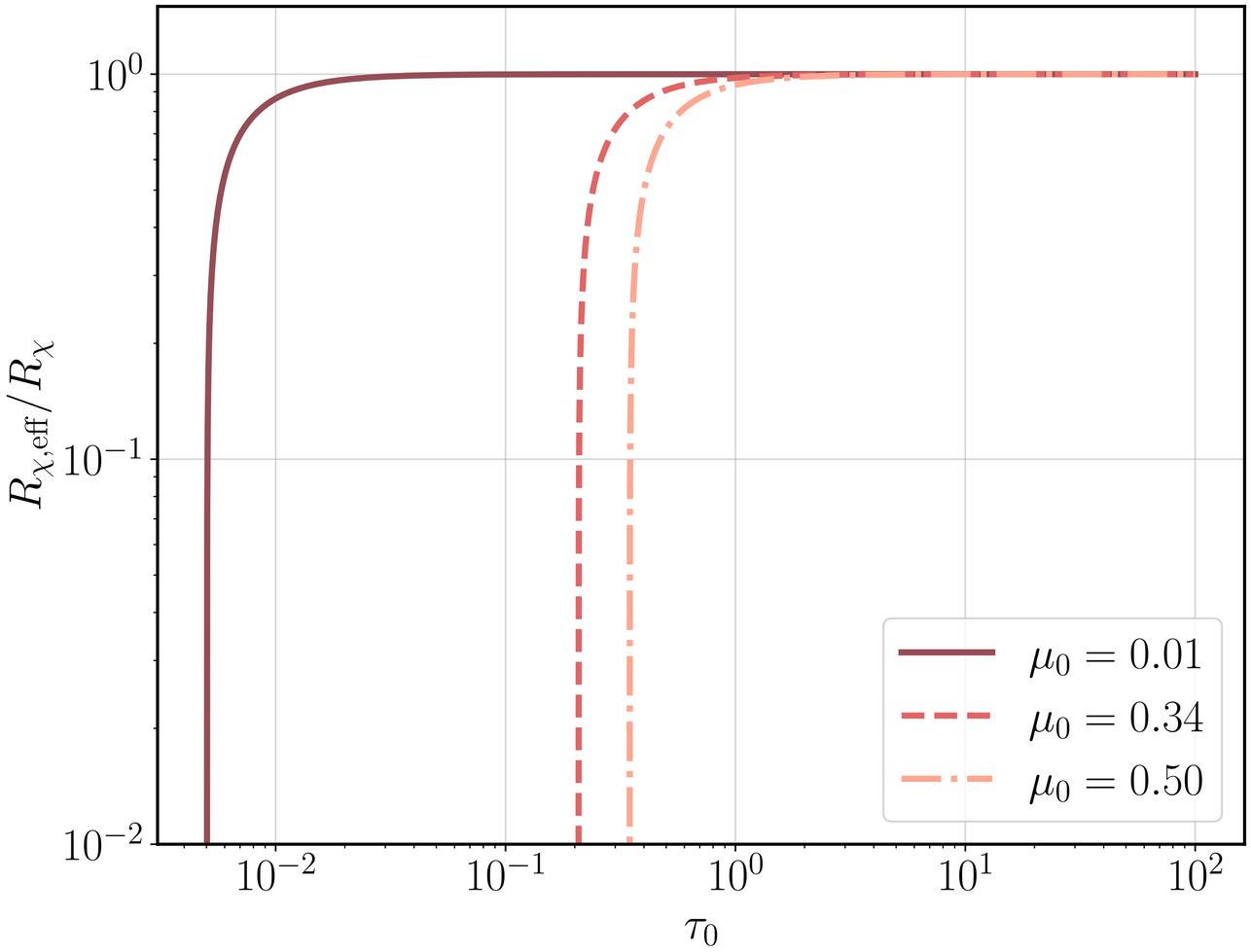
PBH & MACHO Constraints





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

Effective radius



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