Macro Dark Matter

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Based on arXiv:1410.2236
(in collaboration with Glenn Starkman and Bryan Lynn)

Dark Matter: What is it?

- WIMPS? Axions? No detection yet
- Supersymmetry? Nothing (so far) from the LHC
- The “WIMP miracle” may not be so miraculous
- The standard paradigm is threatened
- Alternatives?

Dark matter in the Standard Model?

(Witten, 1984)

- Considered a (1st order) QCD phase transition in the early universe
- Different stable phases of nuclear matter may exist (hadronic vs. quark)
- Hadrons plausibly produced alongside nuclear objects of 10^9 to 10^{18} g

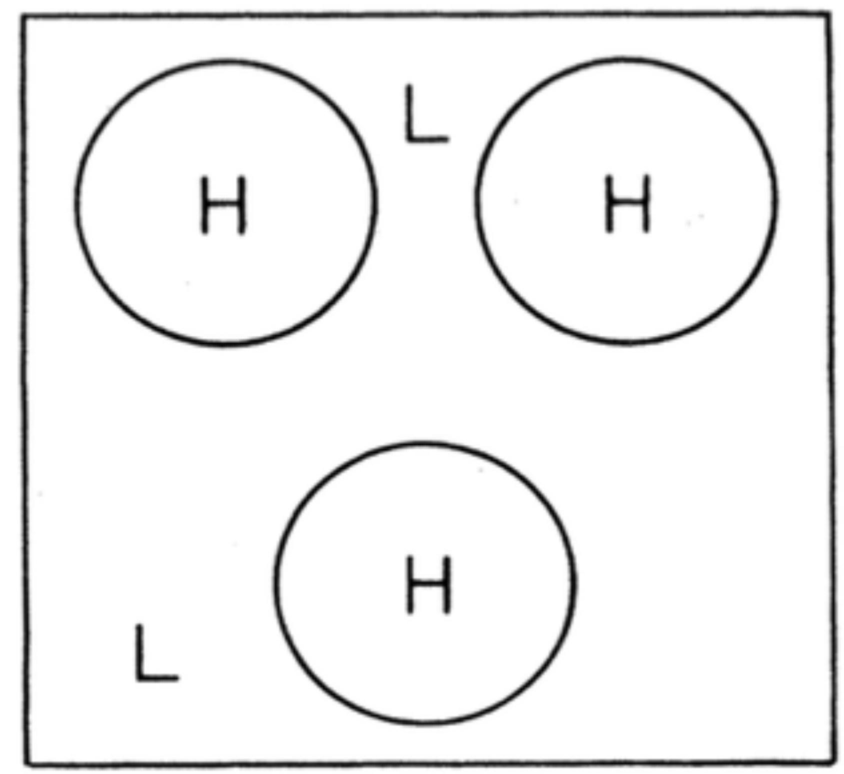
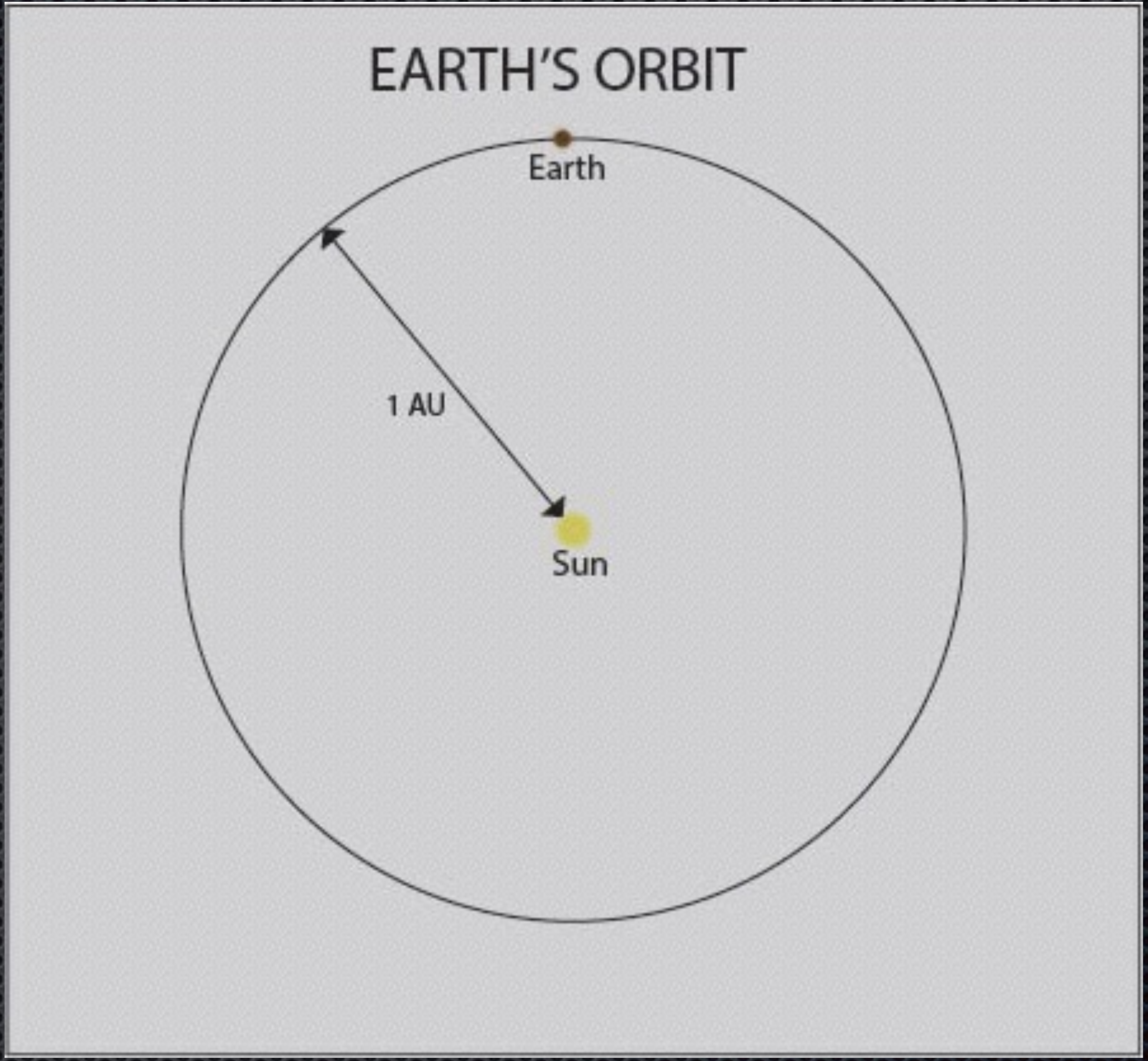


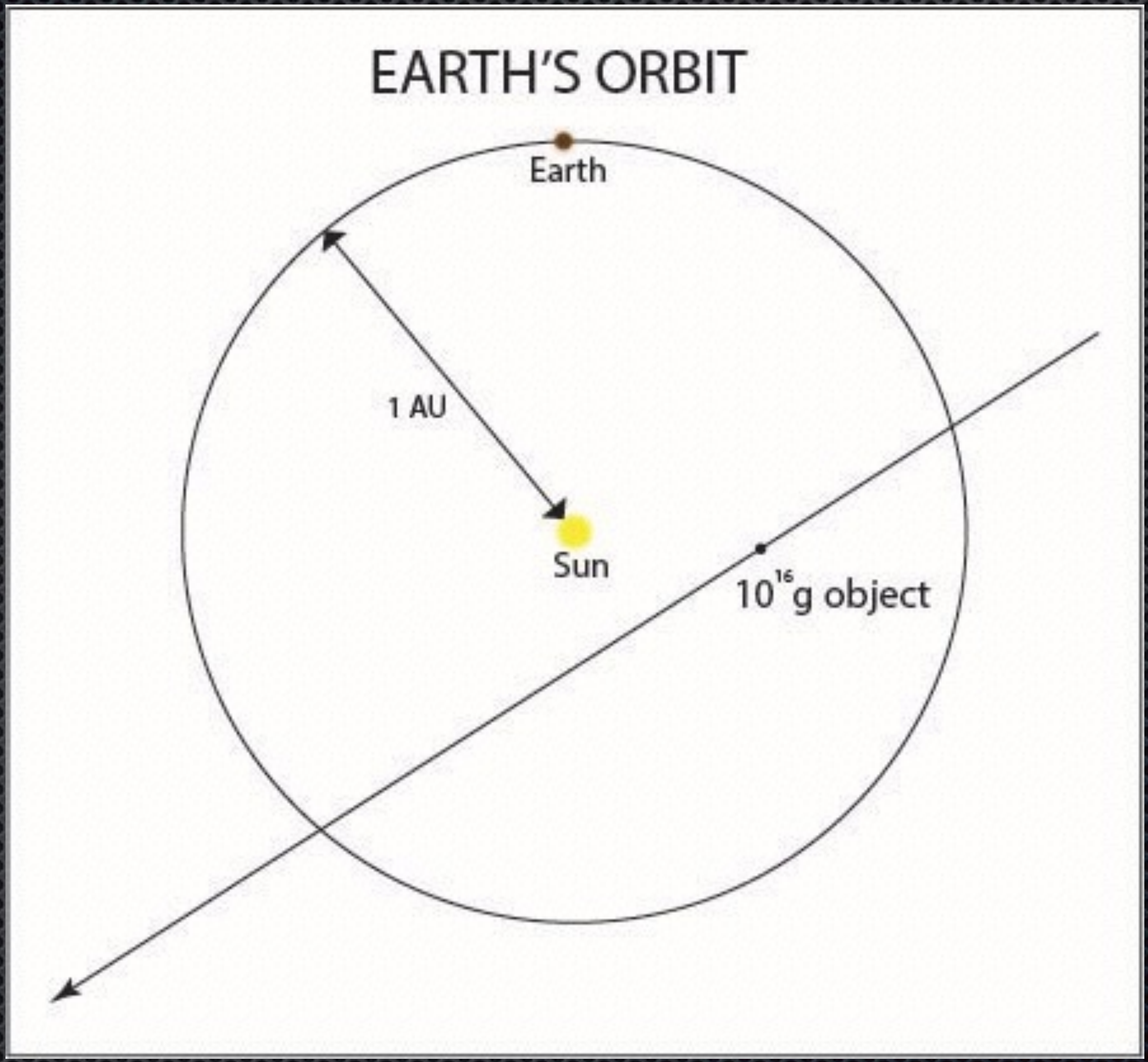
FIG. 3. Isolated shrinking bubbles of the high-temperature phase.

There should be 10^{16} g of dark matter within the Earth's orbital radius



Could this be the wrong picture?

There should be 10^{16} g of dark matter within the Earth's orbital radius



Could *this* be be the right picture?

How could this be?

- Interaction rates go as

$$\Gamma \sim n_X \sigma_X v \sim \frac{\sigma_X}{M_X} \rho_X v$$

or

$$\Gamma \sim n_X A_T v \sim \frac{1}{M_X} \rho_X A_T v$$

- Can make it small with small cross section or **big mass,** and therefore consistent with BBN, CMB, LSS, no Earth detection…
- We call $\frac{\sigma_X}{M_X}$ the “reduced cross section”

Some other macroscopic models

- In the **Standard Model**
  - Strange Baryon Matter (Lynn et al.,1990)
  - Baryonic Colour Superconductors (**+ *axion***) (Zhitnitsky, 2003)
  - Strange Chiral Liquid Drops (Lynn, 2010)
  - Other names: nuclearites, strangelets, quark nuggets, CCO’s, …
- Primordial Black Holes
- BSM Models, e.g. SUSY Q-balls, topological defect DM, …

What this work is about

- A systematic probe of “macroscopic” dark matter candidates that scatter classically (geometrically) with matter

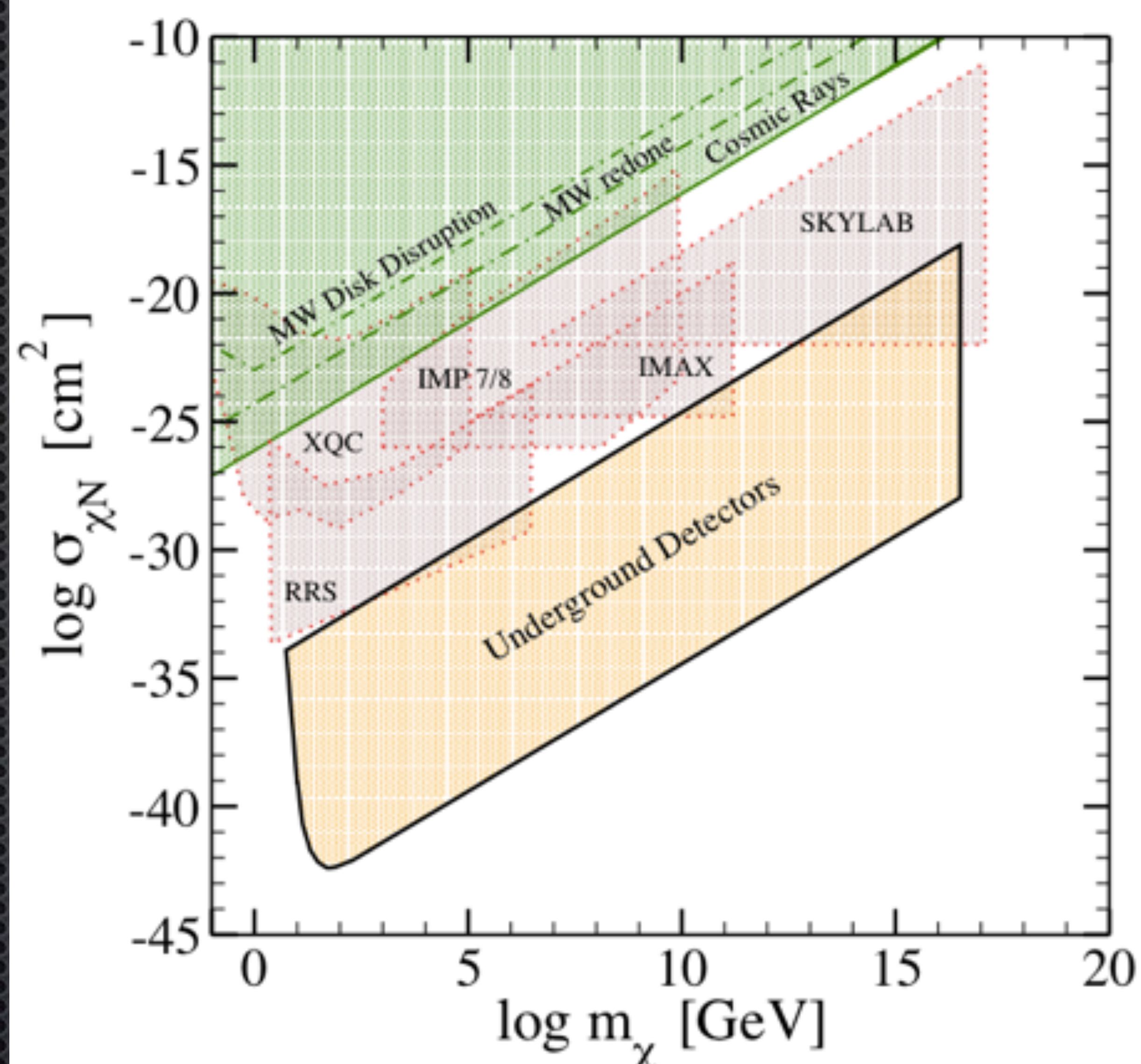
- We call this *macro dark matter* and the objects ***Macros***

- Basic parameters: mass, cross section, charge, and some model-specific (e.g. elastic vs. inelastic scattering)

$$M_{\rm X},\ \sigma_{\rm X} = \pi R_{\rm X}^2,\ V(R_{\rm X})$$

Strongly-interacting dark matter

- Starkman, et al. (1990), Mcguire and Steinhardt (2000), Erickcek, et al. (2007), Mack et al. (2007)
- More or less constrained up to ~ 10^{17} GeV
- Will extend the search to about 10 solar masses (~ 10^{58} GeV)



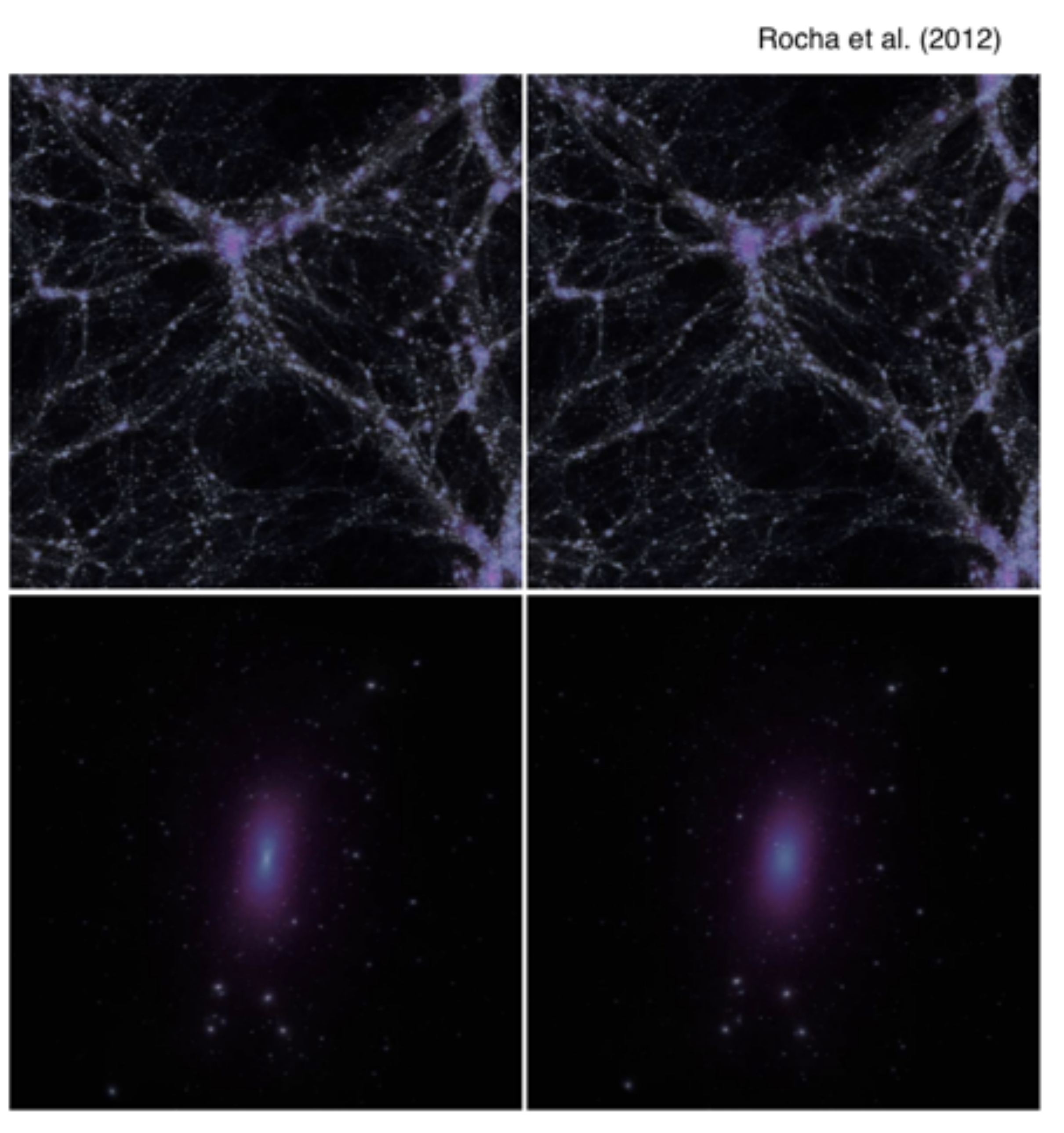
Mack, et al. (2007)

Effects on Large Scale Structure
(Self-interacting dark matter)

- Spergel and Steinhardt (2000) (cusp-core issue)
- Simulations vs. obs: e.g., Davé et al. (2000), Randall et al. (2007), Rocha et al. (2012)

$$\sigma_{\rm xx}/M_{\rm x} \lesssim 1 \ \ {\rm cm}^2/{\rm g}$$

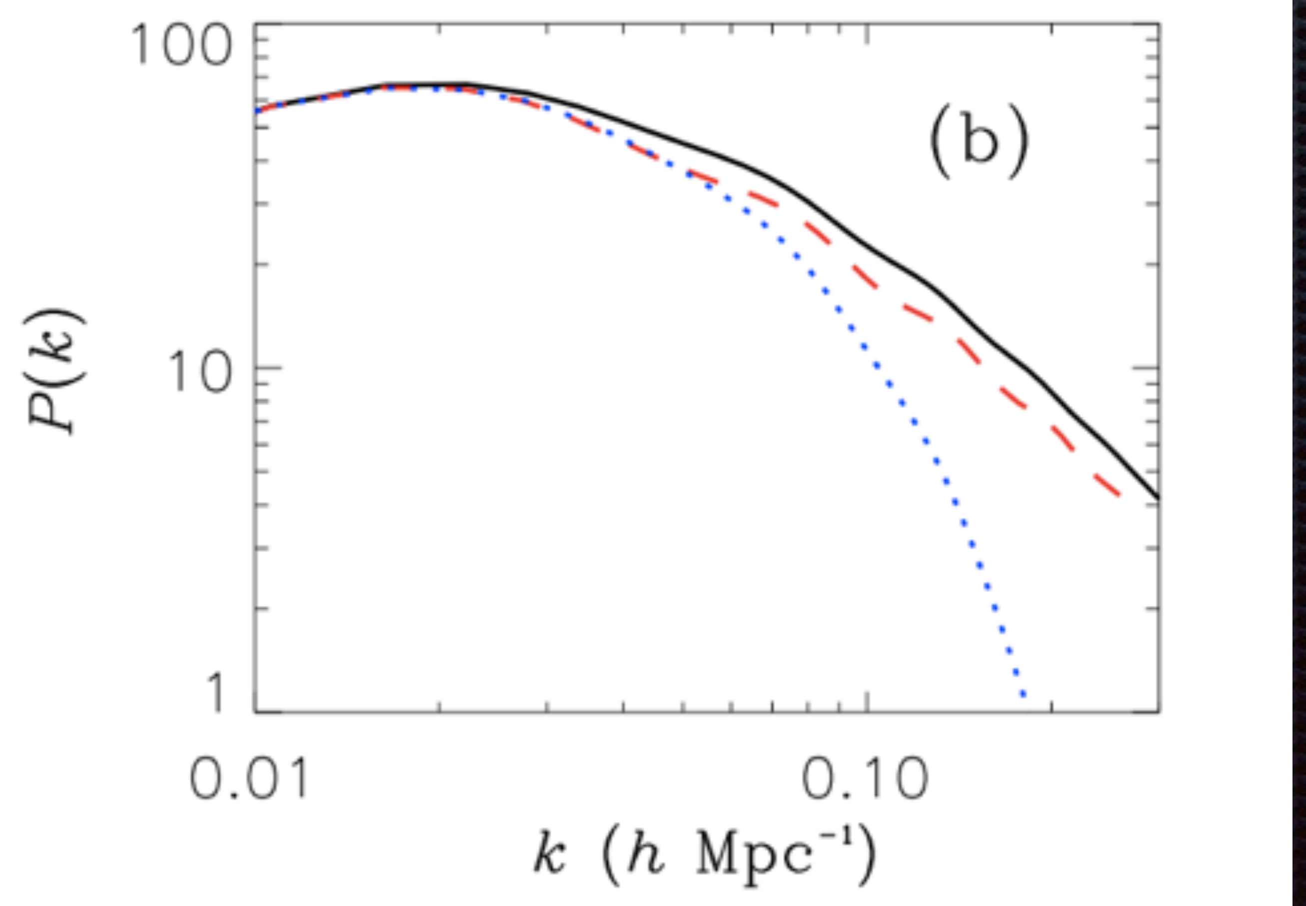
$$\Rightarrow \sigma_{\rm x}/M_{\rm x} \lesssim 0.25 \ \ {\rm cm}^2/{\rm g}$$



Effects on Large Scale Structure
(Dark matter-baryon interactions)

- Boehm et al. (2001, 2002, 2004)
- Chen et al. (2002)
- Dvorkin et al. (2014)

$$\sigma_{\mathrm{X}}/M_{\mathrm{X}} \leq 3.3 \times 10^{-3}\ \mathrm{cm}^2/\mathrm{g}$$



Chen, et al. (2002)

Ancient Mica

- Old samples of mica buried deep (~km) underground
- Chemical etching reveals lattice defects
- Makes for a good exotic particle detector
- Rules out certain DM

$$\lesssim 55\,\mathrm{g}$$

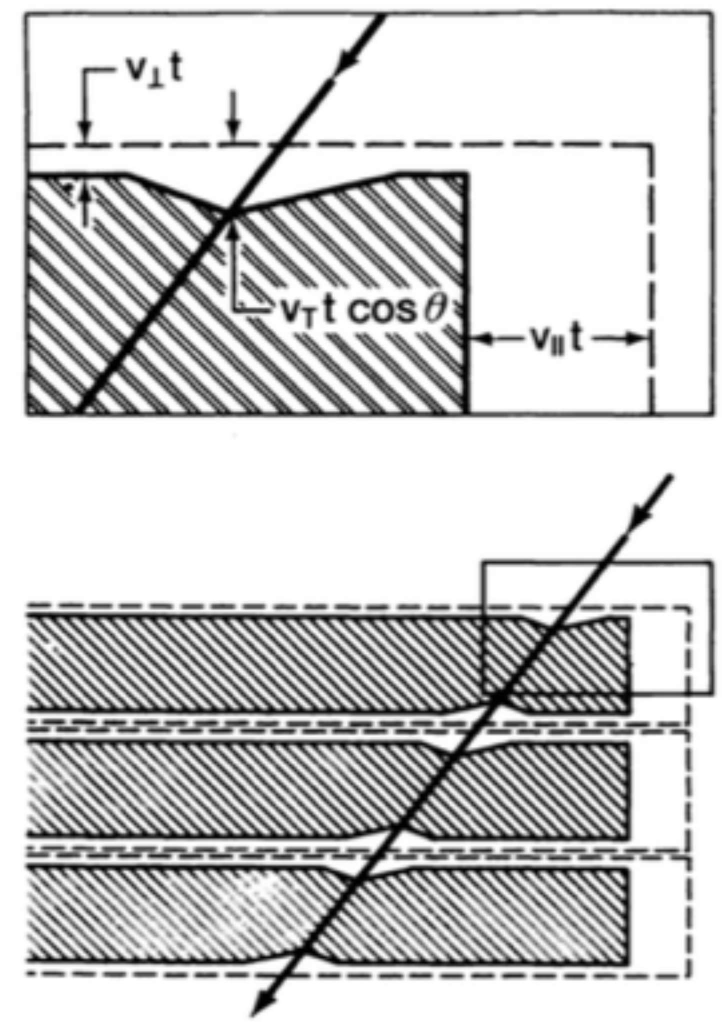
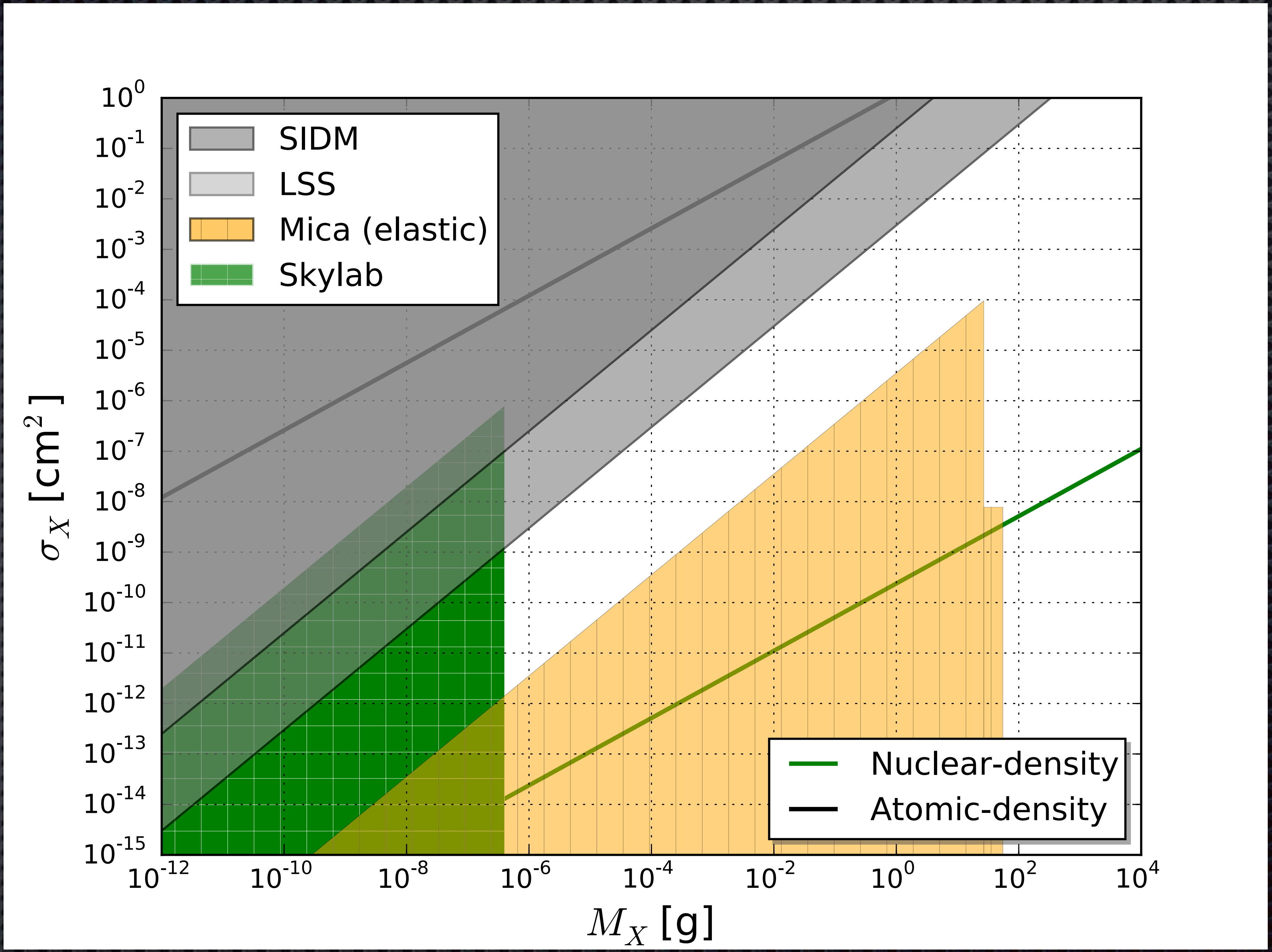


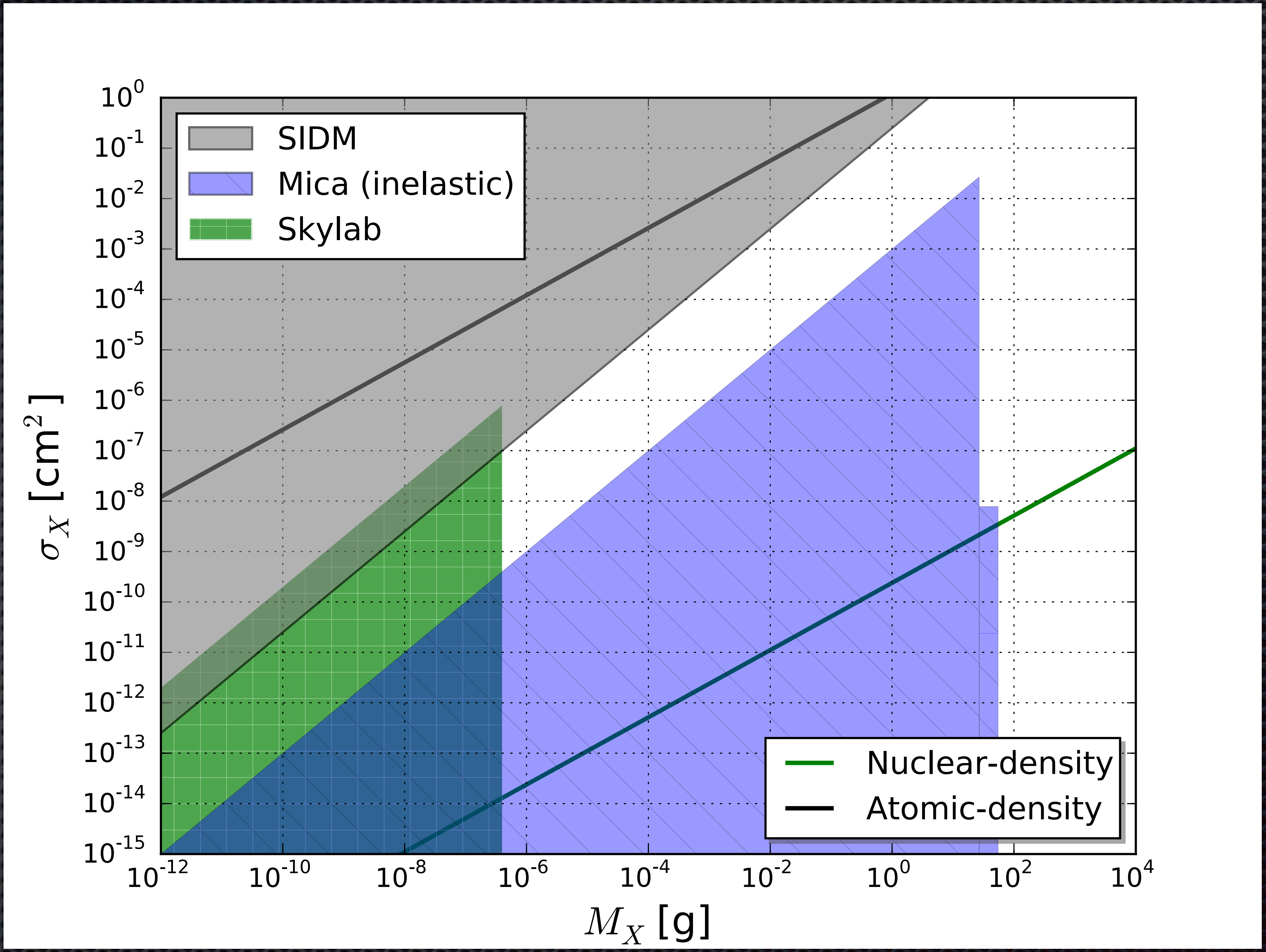
FIG. 2. Geometry of collinear etch pits along the trajectory of a hypothetical monopole-nucleus bound state in three sheets of mica that had been cleaved, etched, and superimposed for scanning.

Price and Salamon (1986)

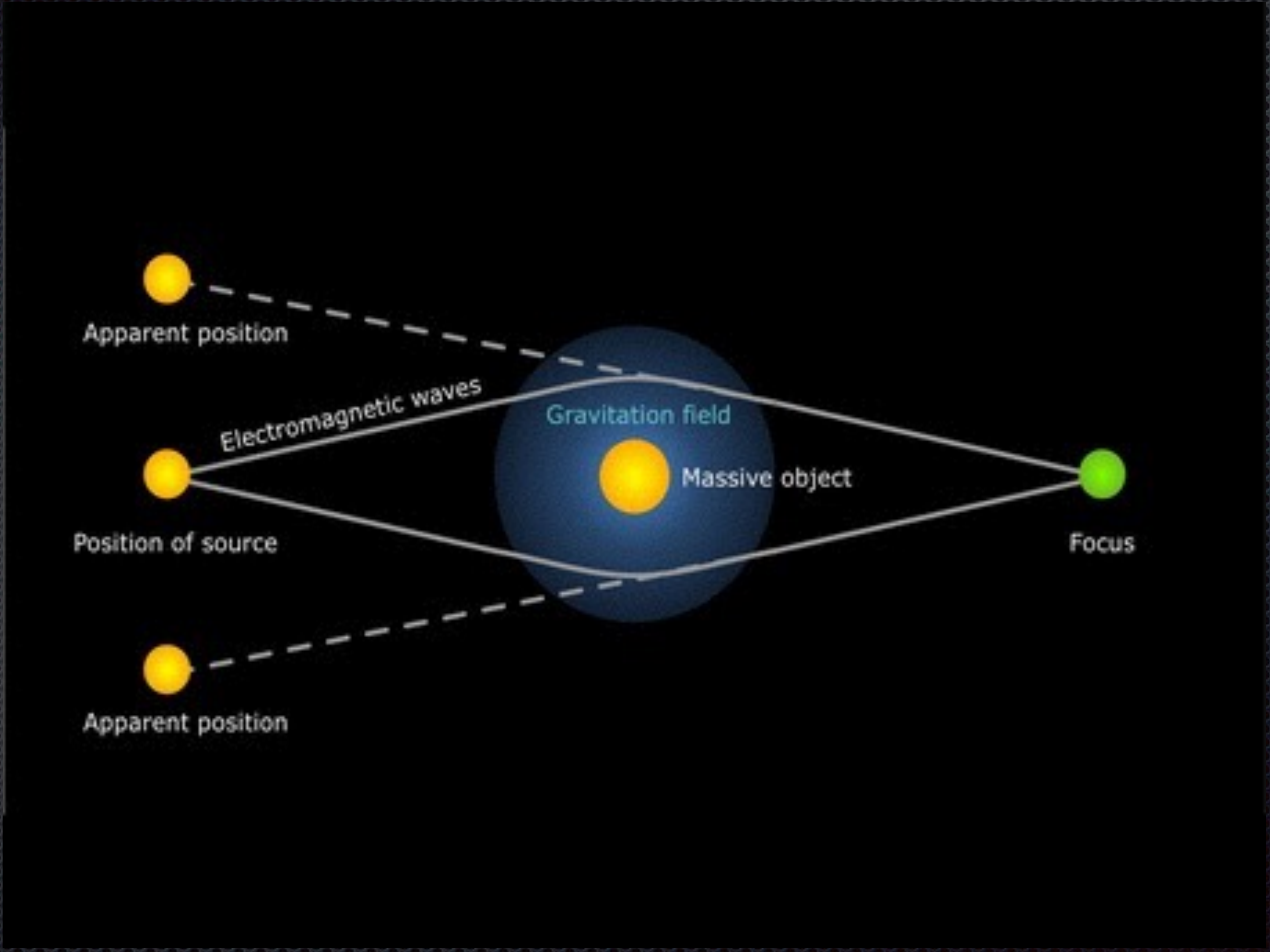
Elastically-scattering Macros



*In*elastically-scattering Macros

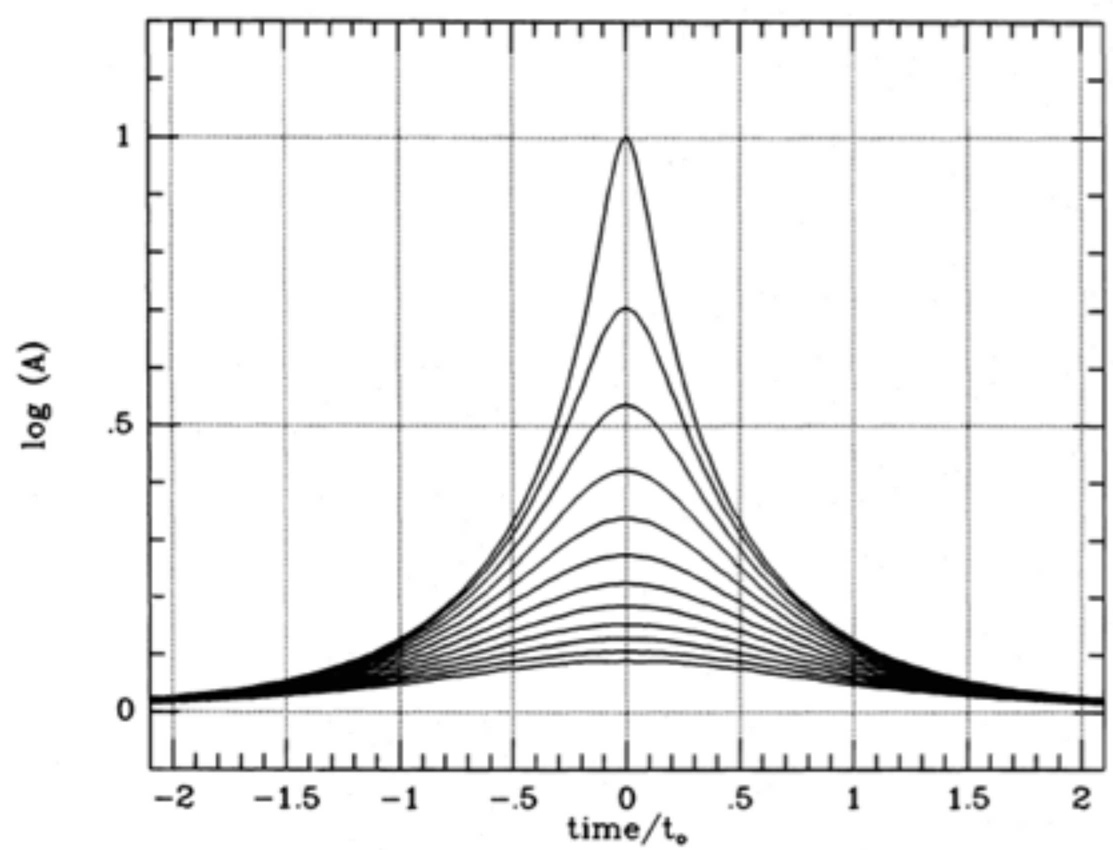


Gravitational Lensing

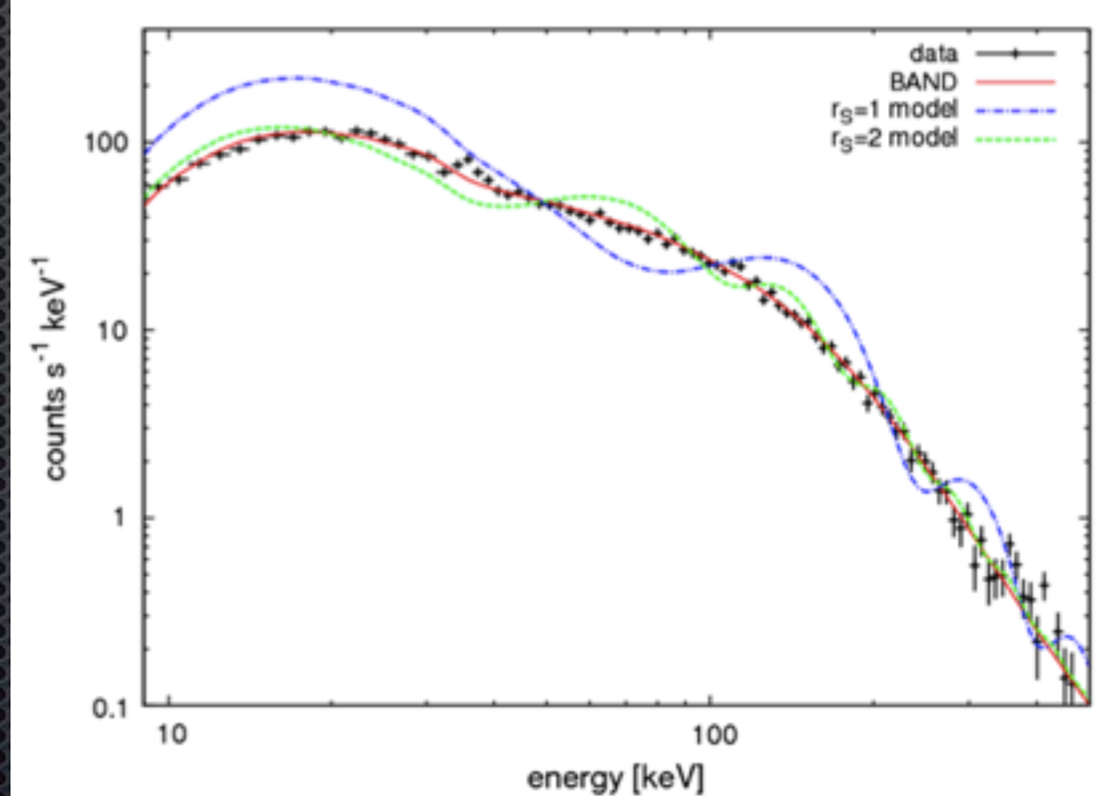


Gravitational Lensing

- Microlensing of stars in e.g. LMC (Paczynski, 1986)
- Femto-lensing of e.g. GRB's (Gould, 1992)



Paczynski (1986)

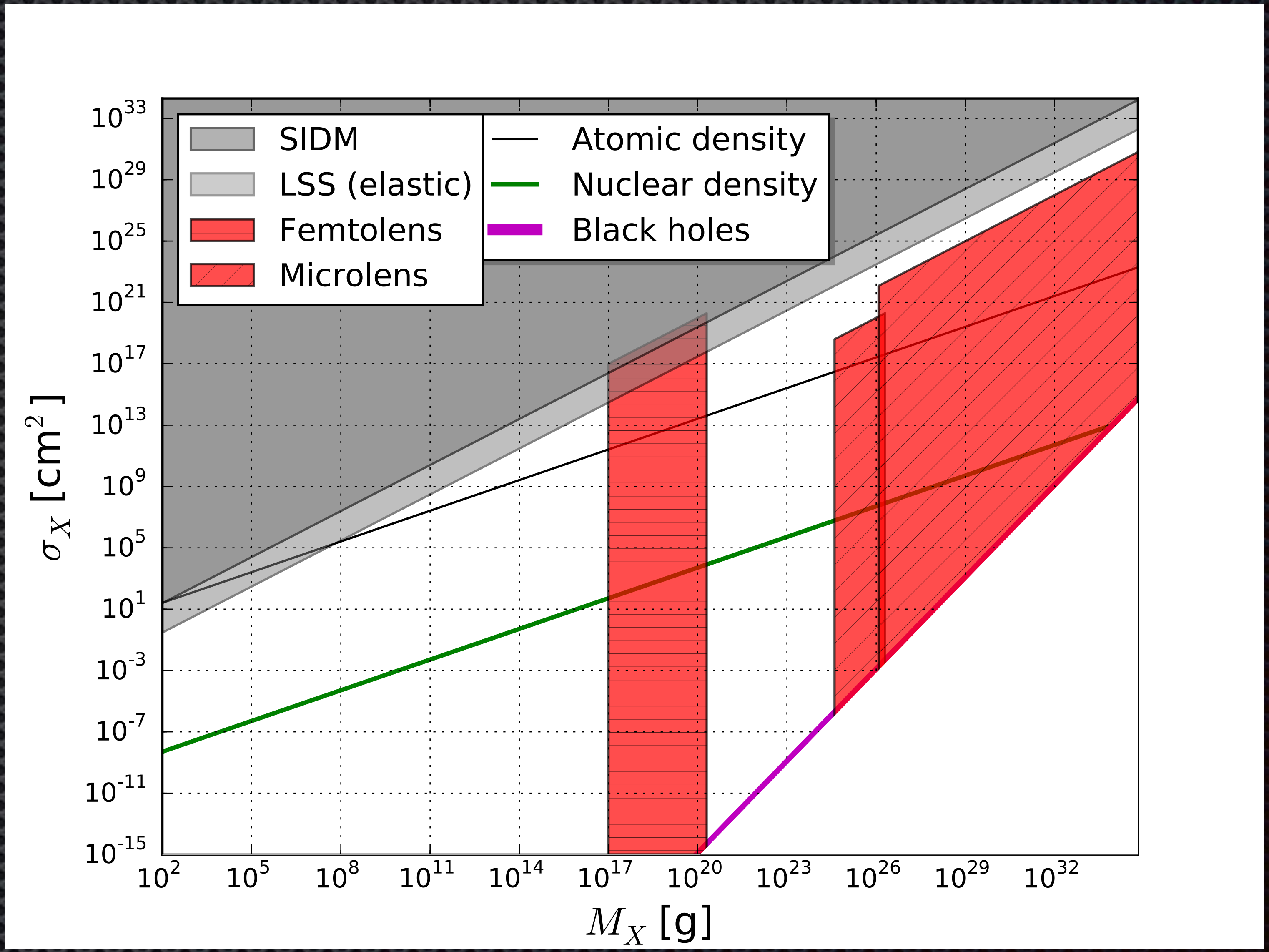


Barnacka et al. (2012)

Lensing constraints

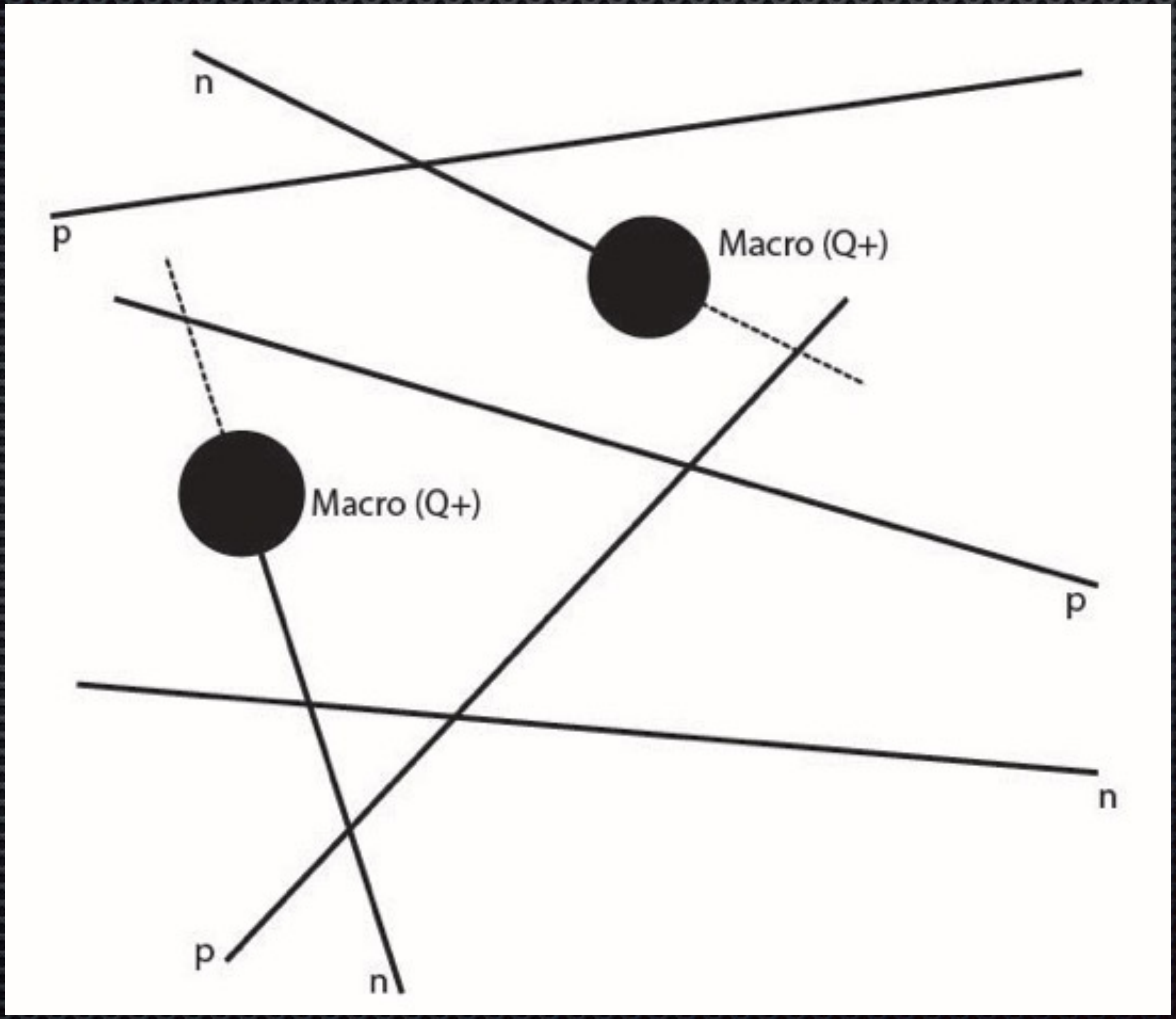
<u>Femtolensing</u>
Marani et al. (1998),
Barnacka et al. (2012)

<u>Microlensing</u>
Allsman, et al. (2000),
Tisserand, et al.(2006)
Griest et al. (2013)



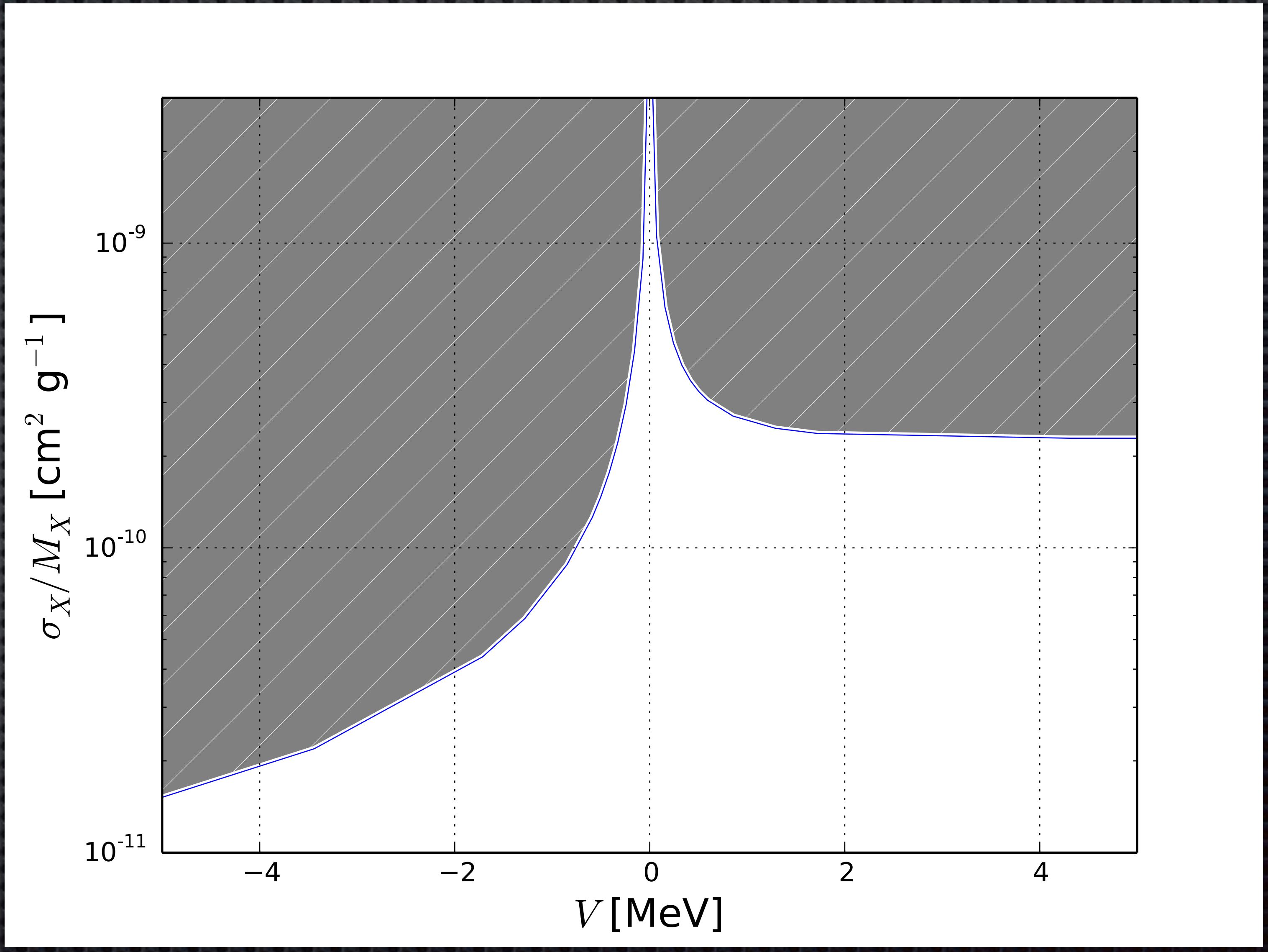
Model-*dependent* constraints

- Macros could absorb nucleons during primordial nucleosynthesis



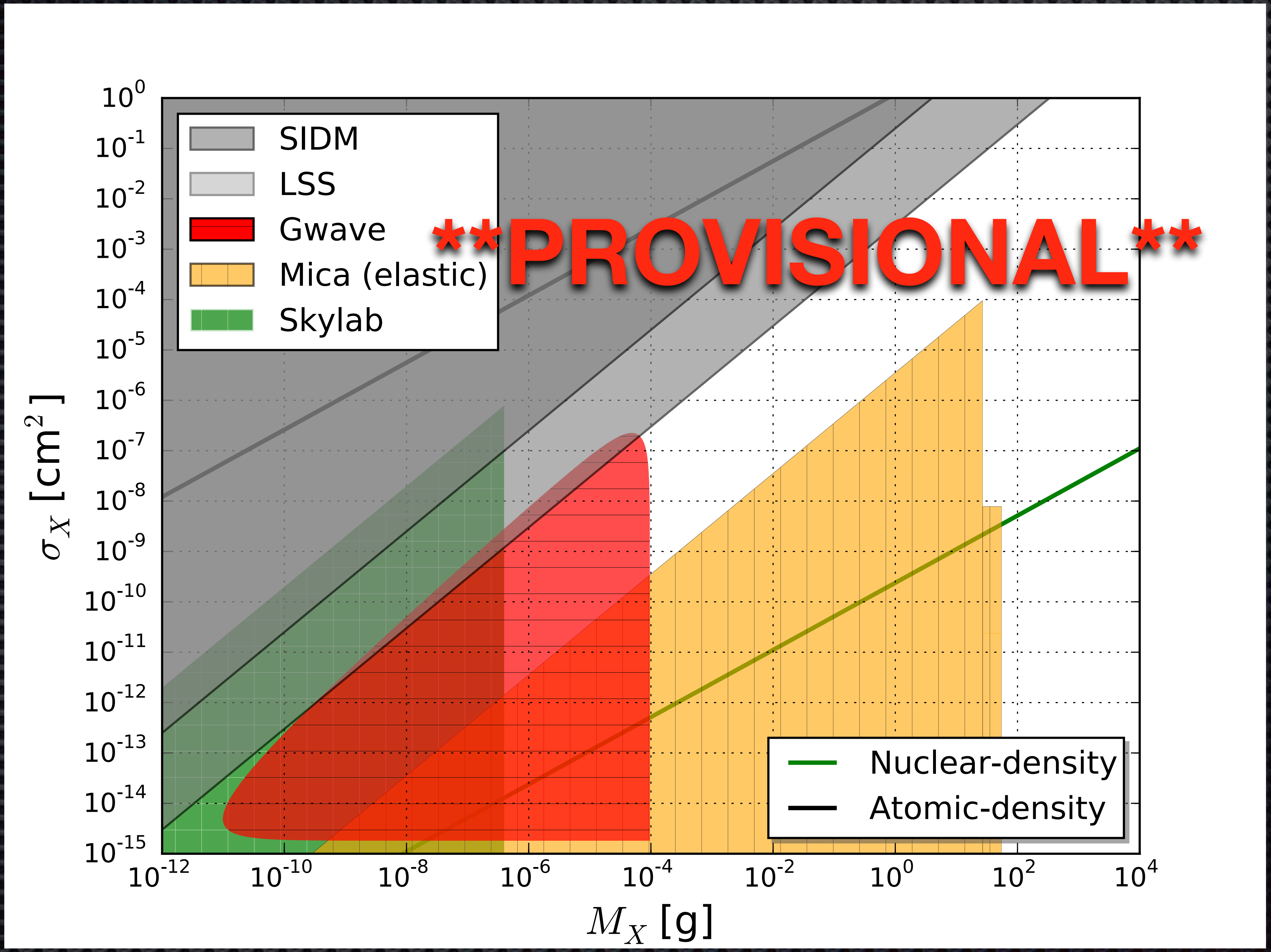
Model-*dependent* constraints

- Macros could absorb nucleons during primordial nucleosynthesis
- Helium mass fraction $X_4^{\rm obs} \simeq 0.25 \pm 0.01$ (Aver, et al. 2013)



Resonant-bar Gravitational Wave Detectors

DMJ, Starkman, Weltman (in prep)



Conclusions

- Dark matter doesn't have to interact weakly if it's very massive. It could still arise from the Standard Model.
- Even if it is beyond-the-SM in nature, there are large regions of parameter space for what the dark matter could be so we need to improve the constraints.
- Existing data and new probes (including astrophysical) will be required, and work is on-going.

Thank you!