Possible Dark Matter Signals from White Dwarfs

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Related Works

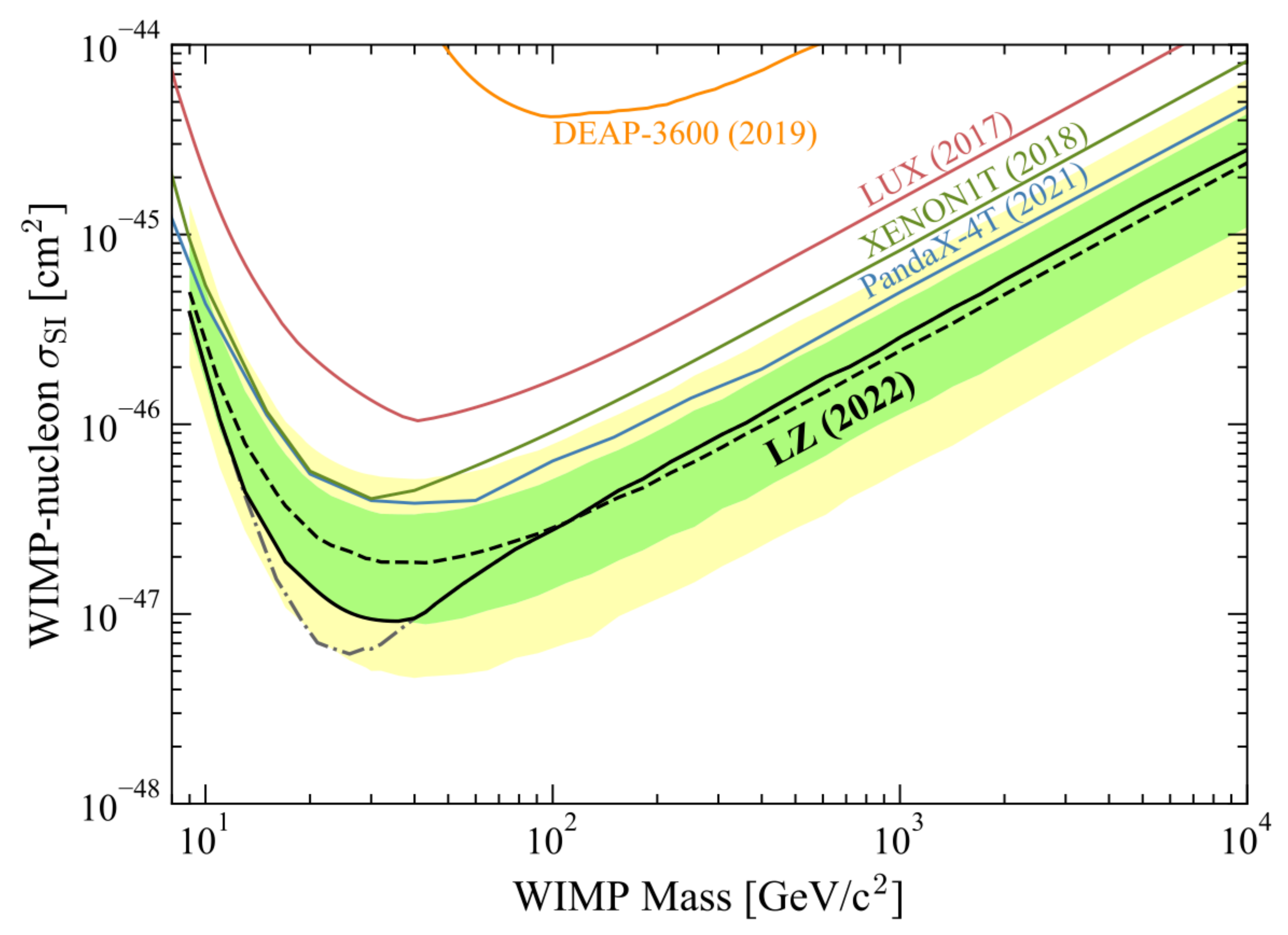
- Jia-Shu Niu, Hui-Fang Xue; **Possible Dark Matter Signals from White Dwarfs**, arXiv:2401.04931 [hep-ph].

Contents

- Motivation
- DM$\times$WD
- Results and Outlooks

Motivation

Constraints on DM-nucleon interactions (spin-independent)

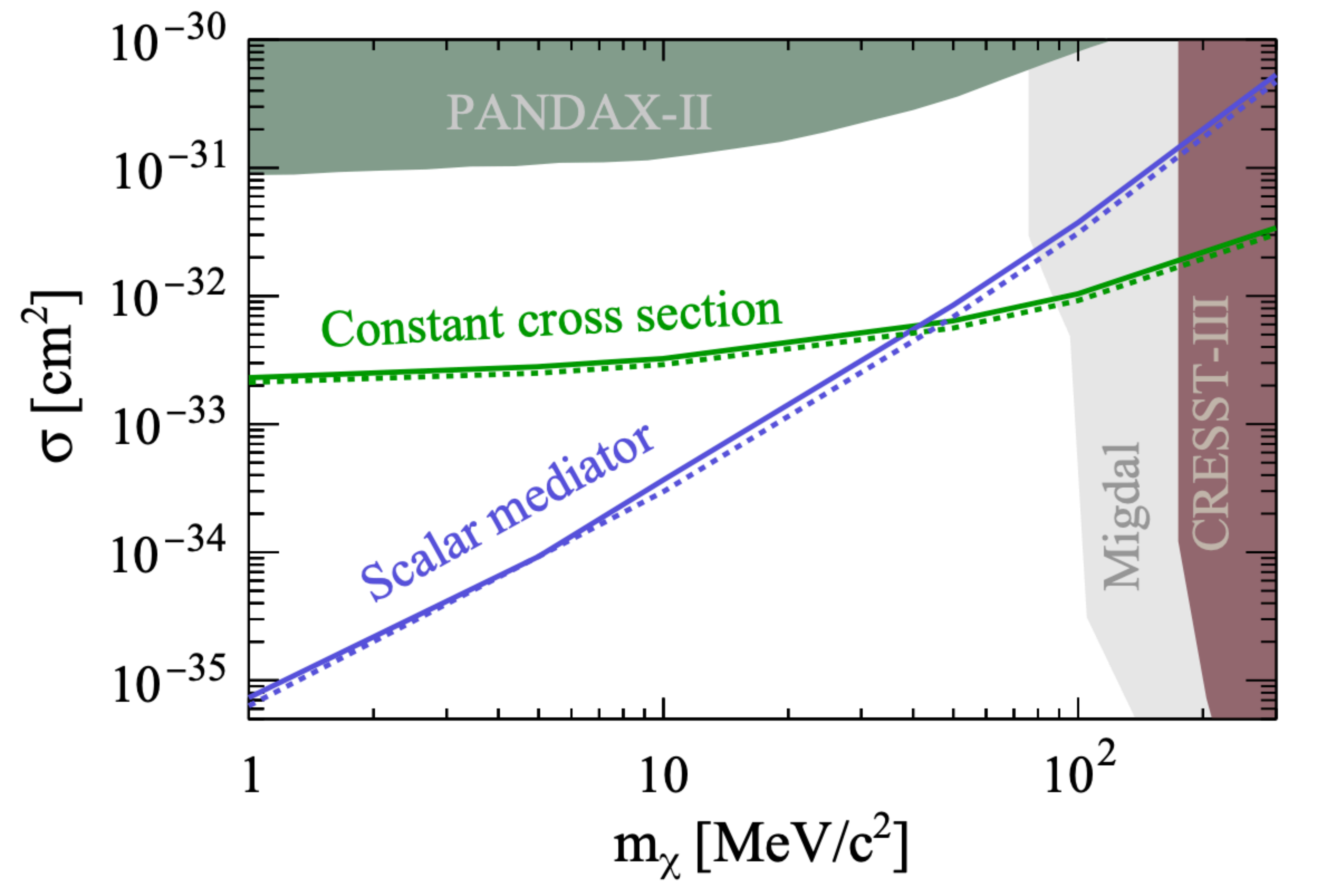


$\sigma_{\chi,n} \lesssim 9.2 \times 10^{-48}\ \mathrm{cm}^2$

for $m_\chi = 36\ \mathrm{GeV}/c^2$.

PRL 131, 041002 (2023).

Constraints on DM-nucleon interactions (constant cross-section model)

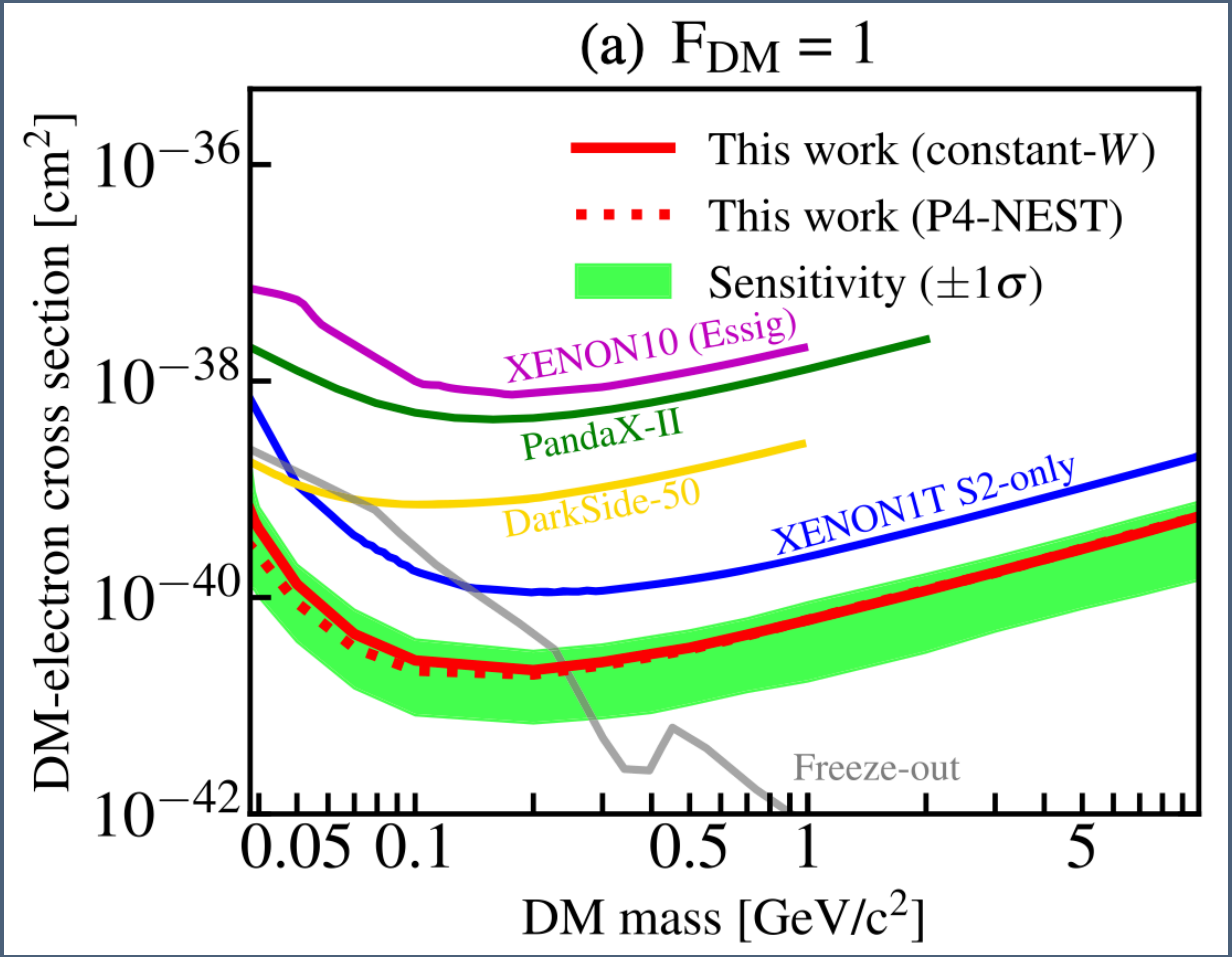


$\sigma_{\chi,n} \lesssim 10^{-33} - 10^{-32}\ \mathrm{cm}^2$

for $m_\chi = 1 - 300\ \mathrm{MeV}/c^2$.

PRL 130, 031802 (2023).

Constraints on DM-electron interactions (F(q)=1)

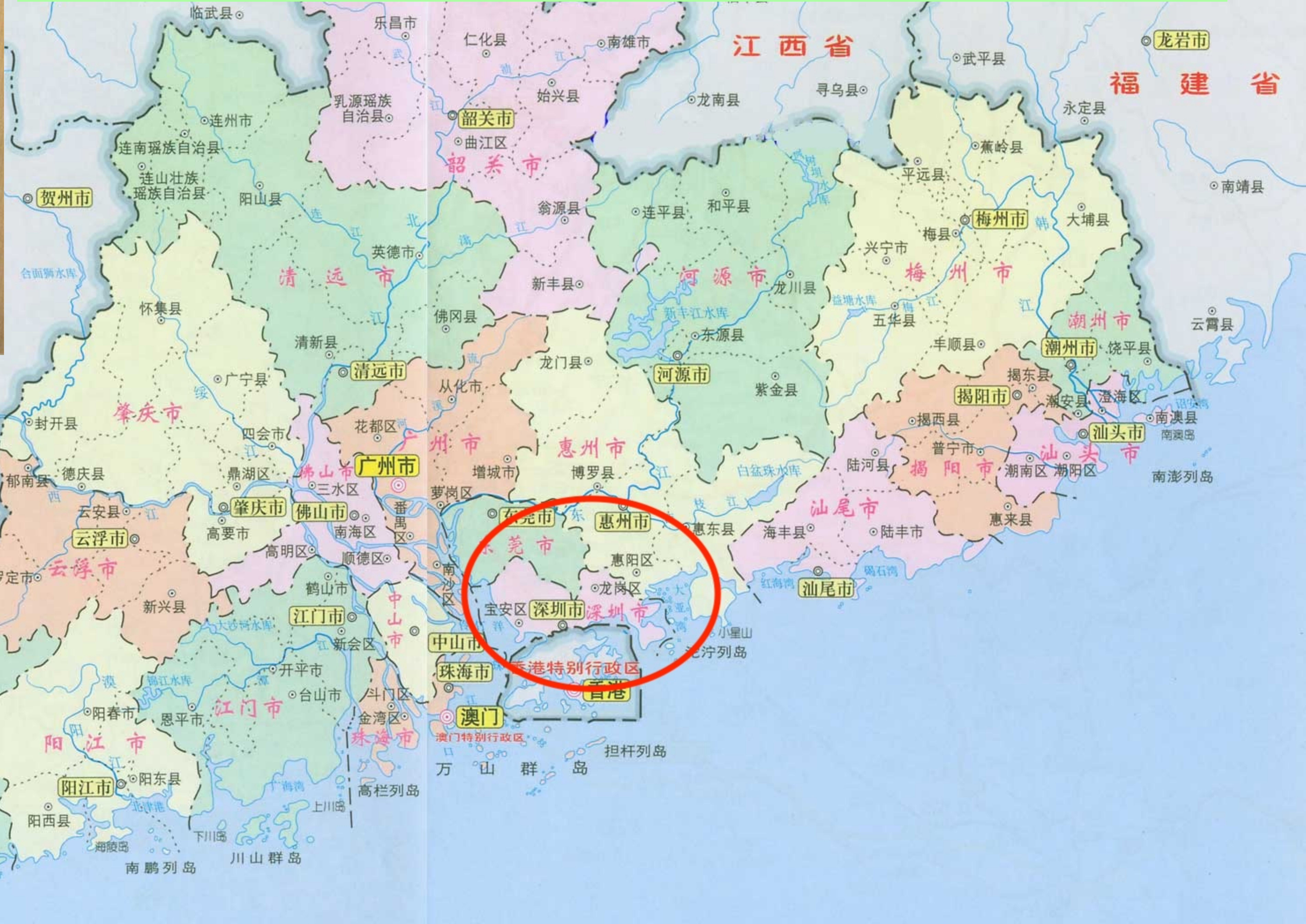


$\sigma_{\chi,e} \lesssim 2.1 \times 10^{-41}\ \mathrm{cm}^2$

for $m_\chi = 200\ \mathrm{MeV}/c^2$.

PRL 130, 261001 (2023).

一九七九年，那是一个春天，有一位老人在中国的南海边画了一个圈。。。



一九七九年，那是一个春天，有一位老人在中国的南海边画了一个圈。。。

在“南方”——画圈！

DM×WD

White Dwarfs (WDs)

- The final evolutionary state of over 97% stars in the Milky Way.
- Relative simple structure: an electron-degenerate core and an atmosphere envelope.
- No nuclear reaction in the core.
- The most electron-dense objects which we know today.

the most promising laboratories to measure the DM-electron interactions

For pulsating WDs,

- **the structure and evolutionary stage can be precisely determined by asteroseismology;**
- **the cooling evolution rates can be represented by the period variations of their pulsation modes, which can be detected by long-time photometric observations.**

When WD meets DM, then …

In our galaxy, the DM particles are inevitably streaming through these WDs, which will loose energy when they scatter with the constituents (nuclei and electrons) of the WDs. If the velocity of these DM particles (after speeding down) less than the escape velocity of a WD, they will be captured and bounded by the star.

These **captured** DM particles will then **accumulate**, **annihilate** in the WD, or **evaporate** from the WD.

The DM in a WD can be expressed as

$$\frac{\mathrm{d}N_\chi}{\mathrm{d}t} = C_* - E_* \cdot N_\chi - A_* \cdot N_\chi^2,$$

where C_* is the DM particle capture rate of the star, E_* is the DM particle evaporation rate of the star, and A_* is the DM particle annihilation rate of the star.

How to detect DM via WDs ...

For pulsating WDs, we have

$$\frac{\dot{P}}{P} \simeq -\frac{1}{2}\frac{\dot{T}_c}{T_c} - \frac{1}{3}\frac{\dot{M}_*}{M_*},$$

where T_c is the core temperature of the WD, and M_* is the mass of the WD.

The effects of DM related processes on a pulsating WD:

- **DM capture and accumulation** will decrease $\dot{P}$, in which processes the DM particles transfer kinetic energy to the star's constituents ($\dot{T}_c > 0$) and increase the mass in the star ($\dot{M}_* > 0$);

- **DM evaporation** will increase $\dot{P}$, in which process the star's constituents transfer kinetic energy to the DM particles ($\dot{T}_c < 0$) and decrease the mass in the star ($\dot{M}_* < 0$);

- **DM annihilation** will decrease $\dot{P}$, in which process the DM particles inject energy into the star ($\dot{T}_c > 0$).

How about the observed results?

ID	G117-B15A	R548	L19-2
Marks	DAV1	DAV2	DAV3
$P_{\rm obs}$ (s)	215.20	212.95	113.8
$P_{\rm the}$ (s)	215.215	213.401	113.41
$\dot{P}_{\rm obs}/P_{\rm obs}$ (s/s)	$(5.12 \pm 0.82) \times 10^{-15}$	$(3.3 \pm 1.1) \times 10^{-15}$	$(3.0 \pm 0.6) \times 10^{-15}$
$\dot{P}_{\rm the}/P_{\rm the}$ (s/s)	1.25×10^{-15}	1.08×10^{-15}	1.42×10^{-15}
$M_*/M_\odot$	0.593 ± 0.007	0.609 ± 0.012	0.705 ± 0.023
$\log(L_*/L_\odot)$	-2.497 ± 0.030	-2.594 ± 0.025	-2.622 ± 0.046
$\log(R_*/R_\odot)$	-1.882 ± 0.029	-1.904 ± 0.015	-1.945 ± 0.037
Distance* (pc)	57.37	32.71	20.87

$$\dot{P}_{\rm obs} > \dot{P}_{\rm the}$$

It can only be caused by **DM evaporation**.

Capture Vs. Evaporation in a equilibrium state

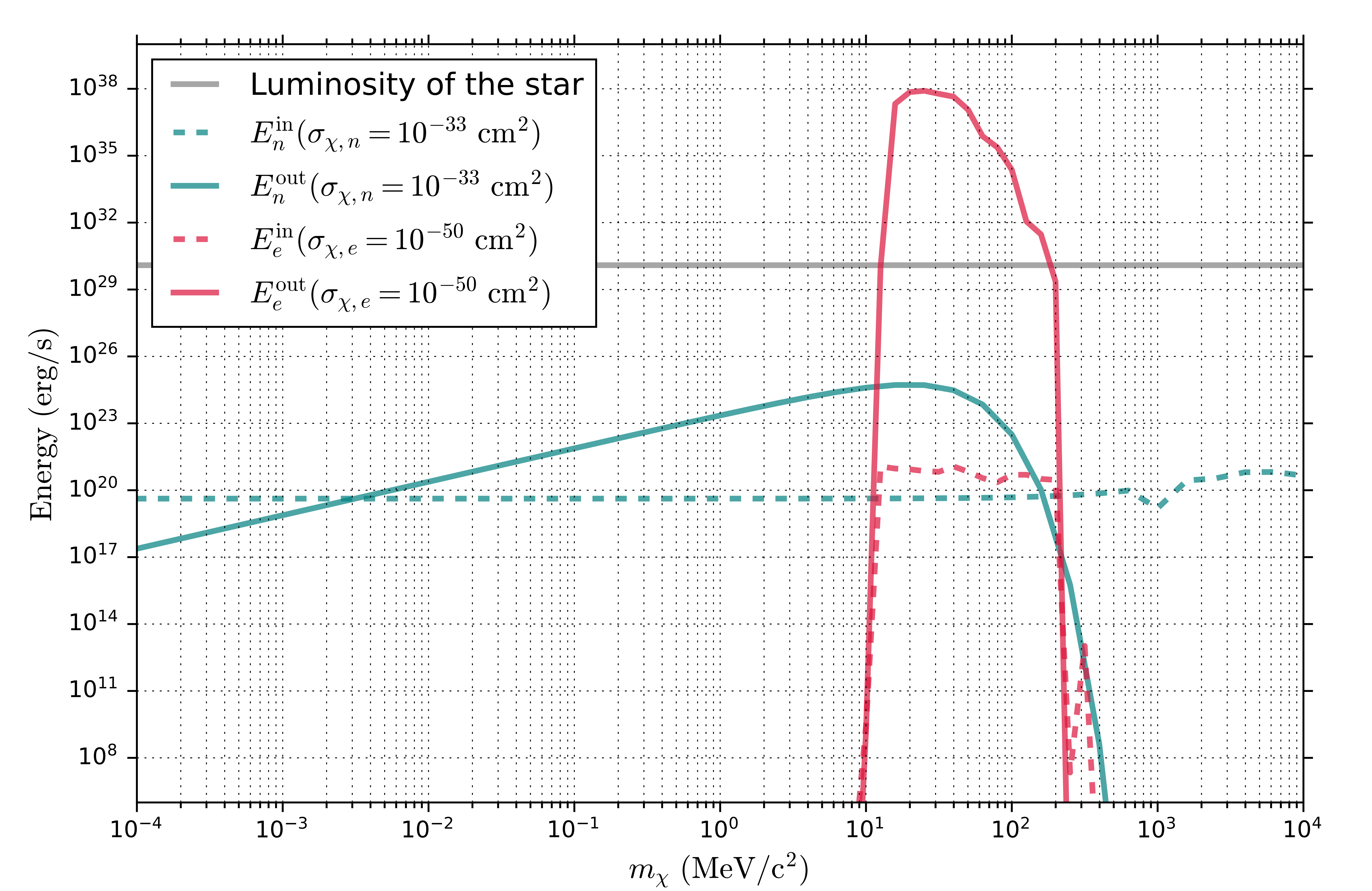
- $E^{\rm in}$: the capture process will transfer the energy of DM to the star;
- $E^{\rm out}$: the evaporation process will transfer the energy of star to the DM and then the external environment;
- $E^{\rm net} \equiv E^{\rm out} - E^{\rm in}$: the net energy a WD will lose or gain.

The observed results of DAVs demand

$$E^{\rm net} > 0,$$

which means the WDs should lose energy in the equilibrium state.

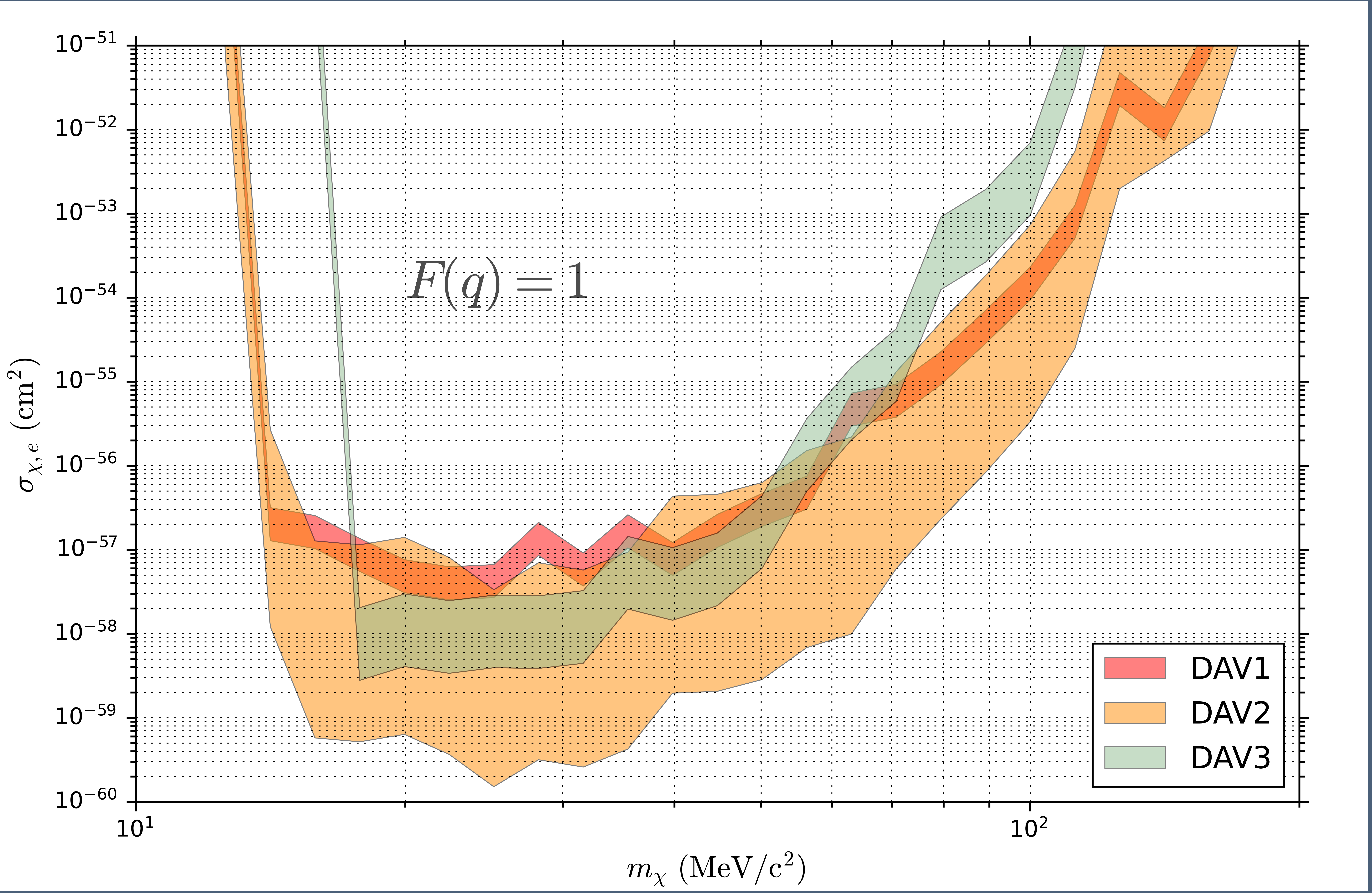
DAV1 as an Example



We will only consider the interaction between DM particles and electrons in the rest of this work.

Results and Outlooks

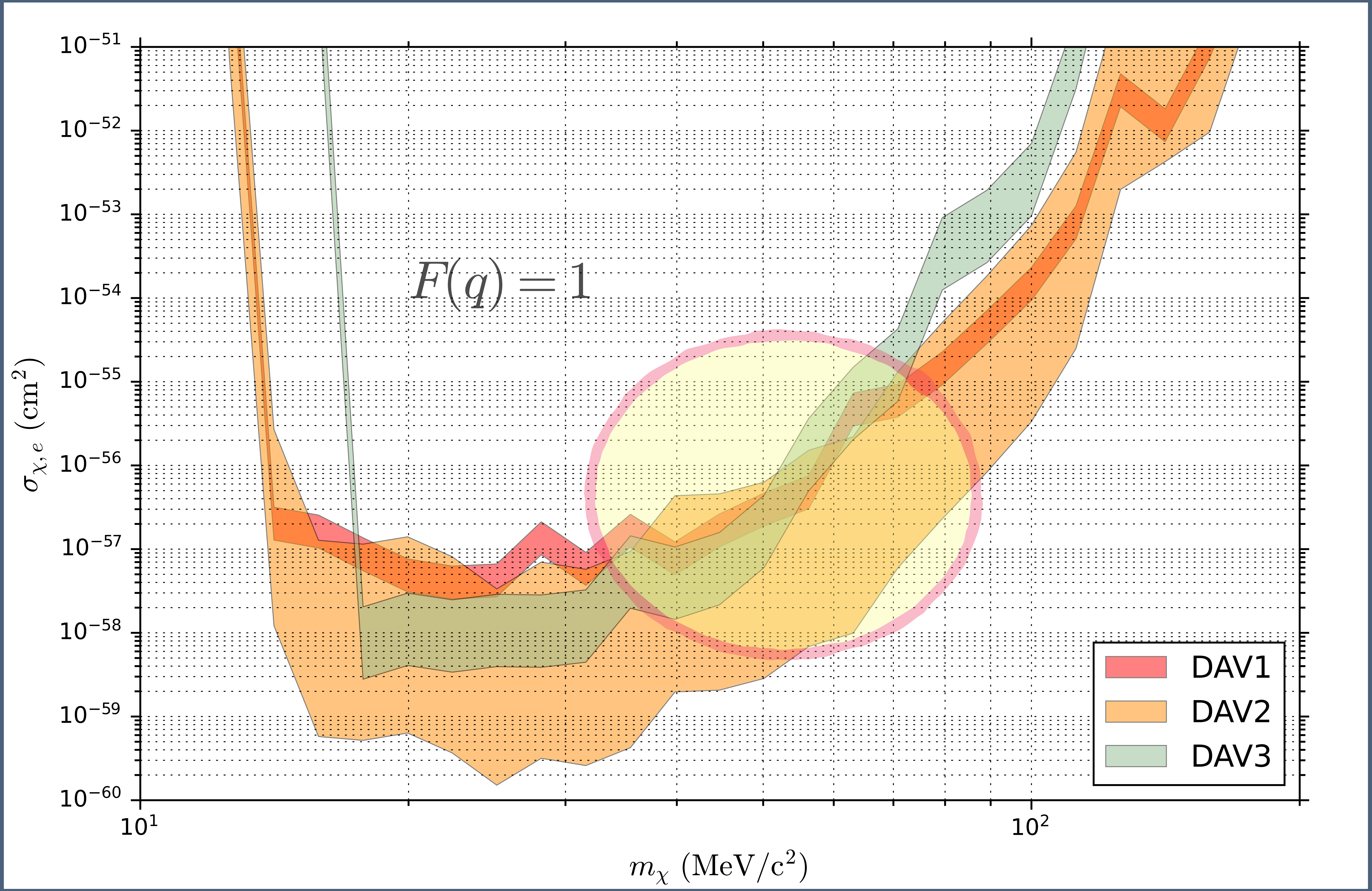
Allowed DM Parameter Region by 3 WDs ($F(q) = 1$)



$$40\ \mathrm{MeV}/c^2 \lesssim m_\chi \lesssim 70\ \mathrm{MeV}/c^2$$

$$10^{-57}\ \mathrm{cm}^2 \lesssim \sigma_{\chi,e} \lesssim 10^{-55}\ \mathrm{cm}^2$$

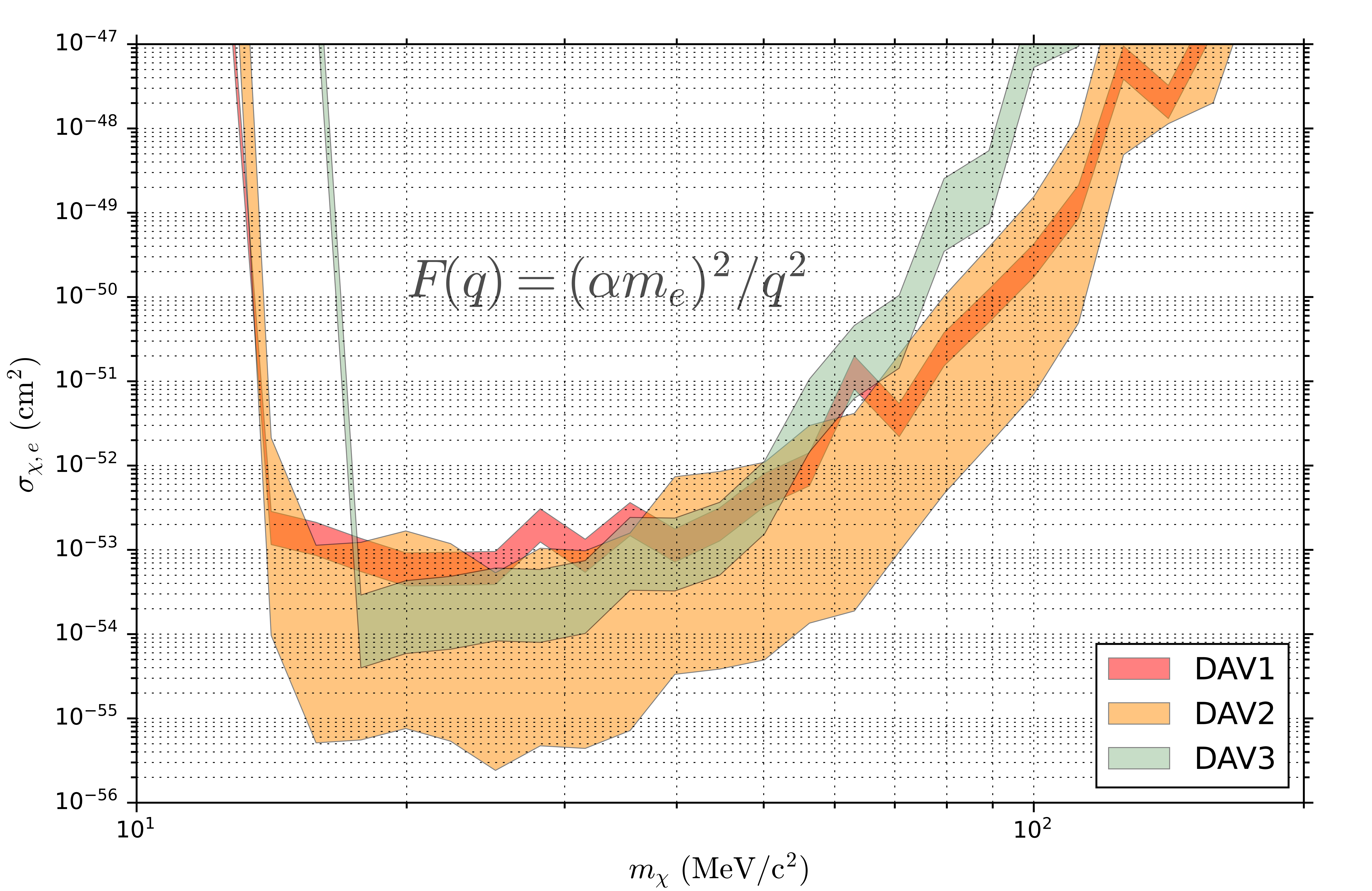
Allowed DM Parameter Region by 3 WDs ($F(q) = 1$)



$$40 \text{ MeV}/c^2 \lesssim m_\chi \lesssim 70 \text{ MeV}/c^2$$

$$10^{-57} \text{ cm}^2 \lesssim \sigma_{\chi,e} \lesssim 10^{-55} \text{ cm}^2$$

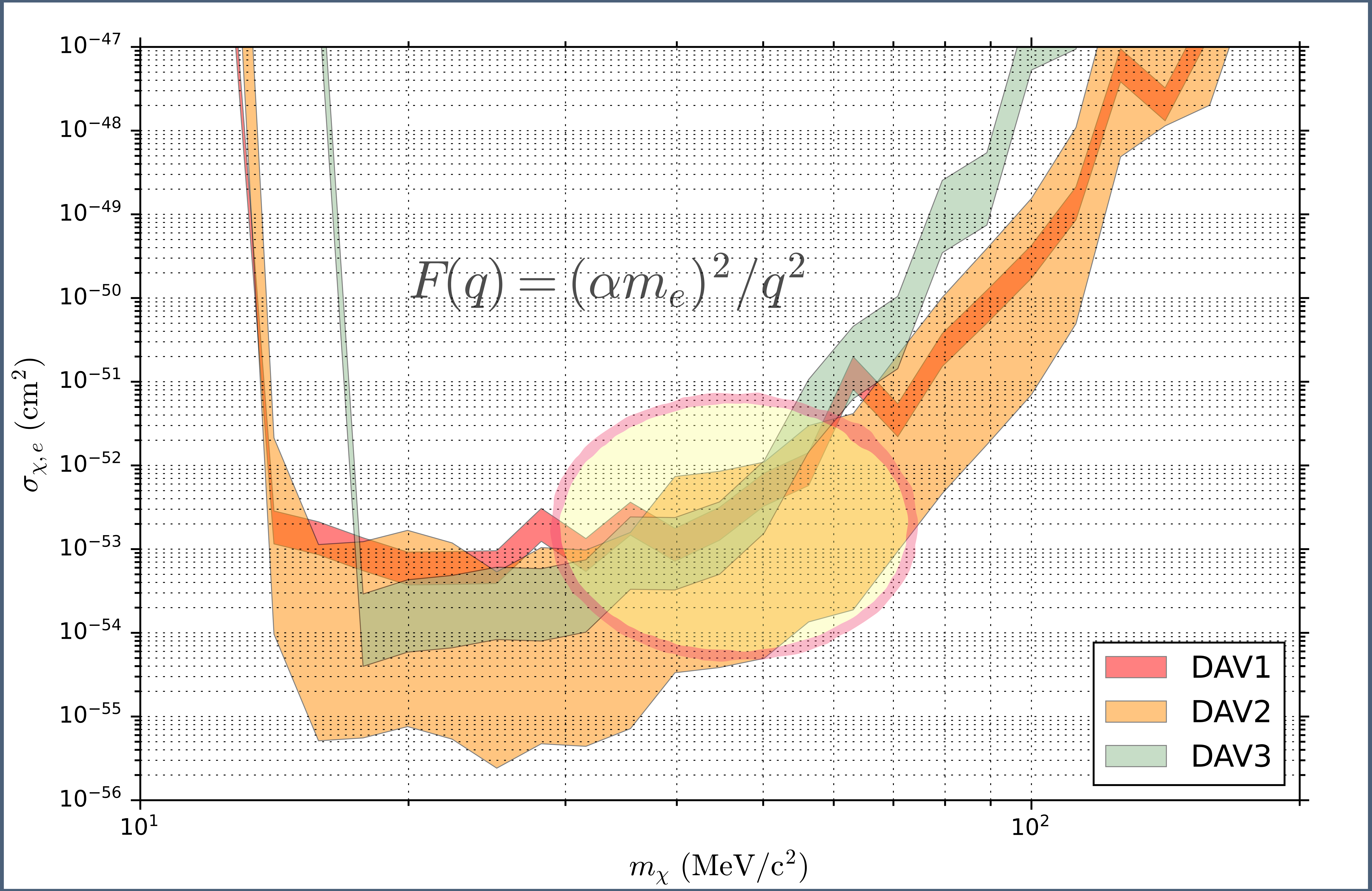
Allowed DM Parameter Region by 3 WDs ($F(q) = (\alpha m_e)^2/q^2$)



$$30 \text{ MeV}/c^2 \lesssim m_\chi \lesssim 60 \text{ MeV}/c^2$$

$$10^{-53} \text{ cm}^2 \lesssim \sigma_{\chi,e} \lesssim 10^{-51} \text{ cm}^2$$

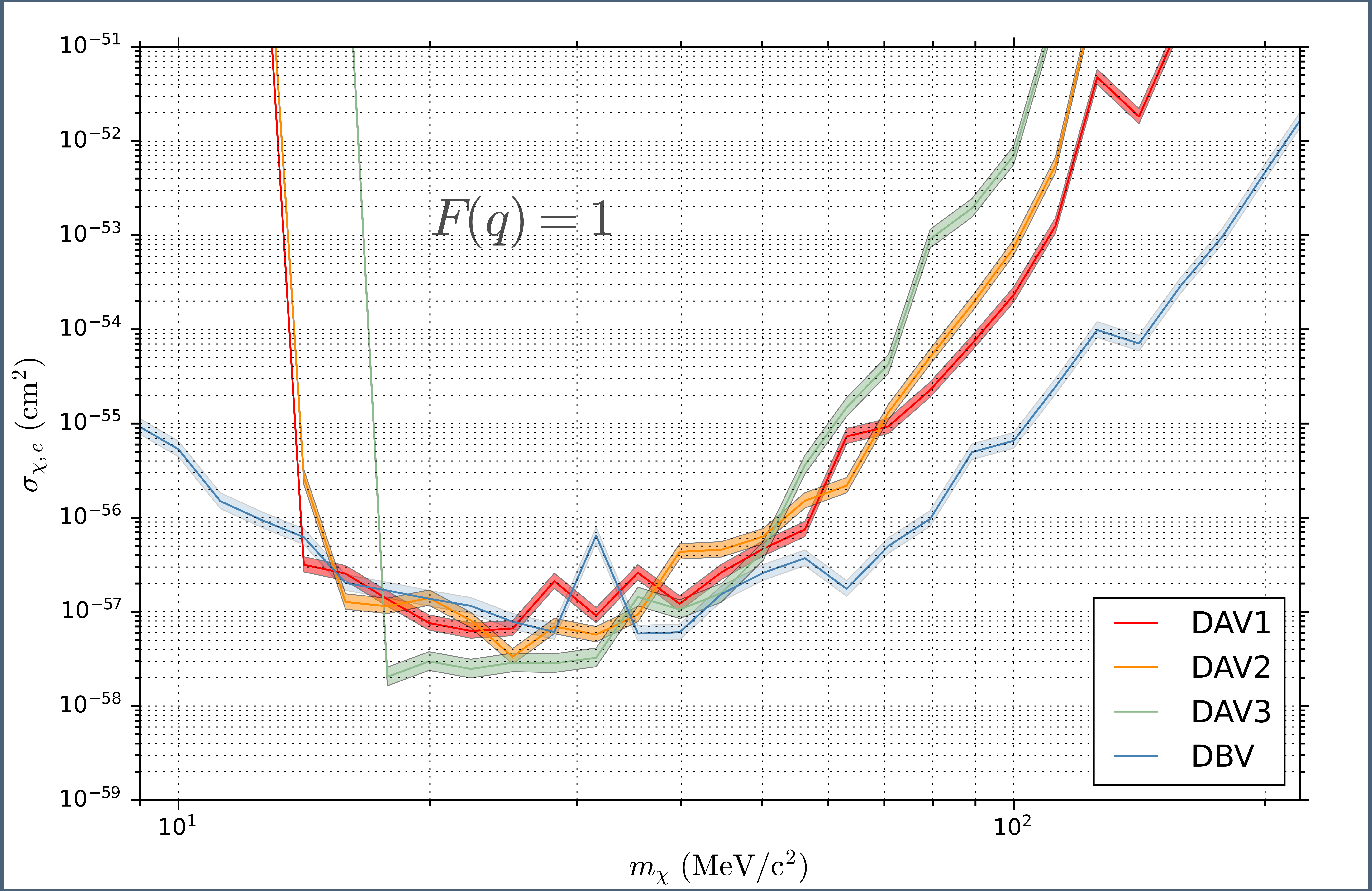
Allowed DM Parameter Region by 3 WDs ($F(q) = (\alpha m_e)^2/q^2$)



$30\ \mathrm{MeV}/c^2 \lesssim m_\chi \lesssim 60\ \mathrm{MeV}/c^2$

$10^{-53}\ \mathrm{cm}^2 \lesssim \sigma_{\chi,e} \lesssim 10^{-51}\ \mathrm{cm}^2$

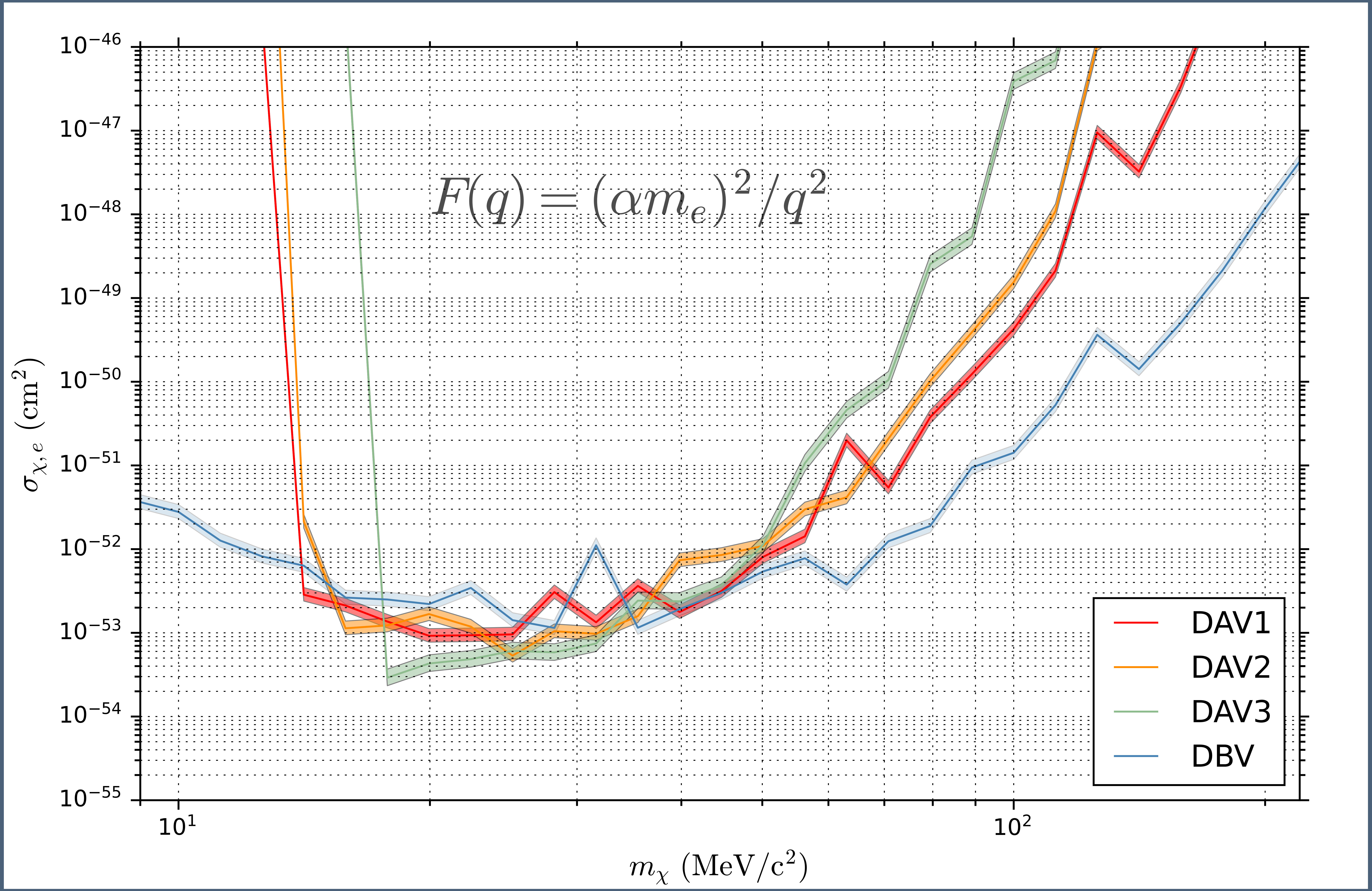
Exclusive Region by 4 WDs ($F(q) = 1$)



$$20\ \mathrm{MeV}/c^2 \lesssim m_\chi \lesssim 30\ \mathrm{MeV}/c^2$$

$$\sigma_{\chi,e} \lesssim 2 \times 10^{-58}\ \mathrm{cm}^2$$

Exclusive Region by 4 WDs ($F(q) = (\alpha m_e)^2/q^2$)



$$20 \text{ MeV}/c^2 \lesssim m_\chi \lesssim 30 \text{ MeV}/c^2$$

$$\sigma_{\chi,e} \lesssim 10^{-53} \text{ cm}^2$$

Outlooks

- more observations on more DAVs;
- more novel scenarios to perform cross checks;
- more theoretical hints related to the results.

Thank you for your Attention!

Thank you for your Attention!

Welcome to prove (**Nobel Prize**) or disprove (**PRLs**) it.