Dark Matter Particle in QCD

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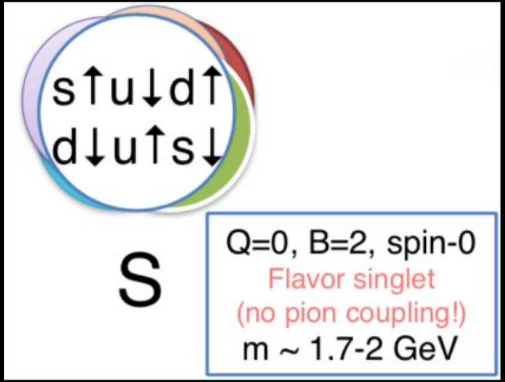
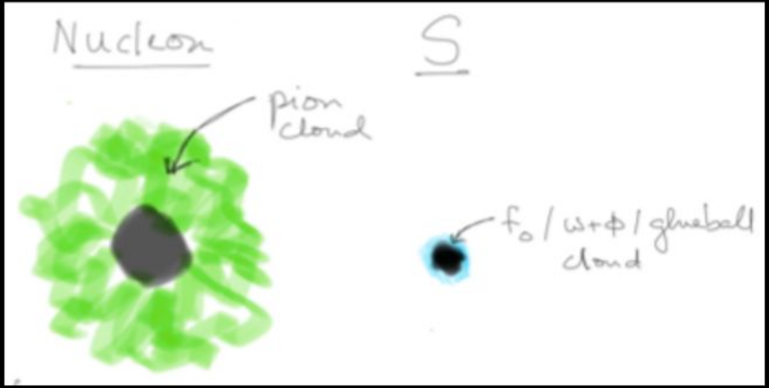
Based on
1805.03723 G. Farrar
20xx.xxxxx G. Farrar, ZW, X. Xu
20xx.xxxxx G. Farrar, ZW

Background review
Farrar, 1708.08951

uuddss sexaquark (*S*)



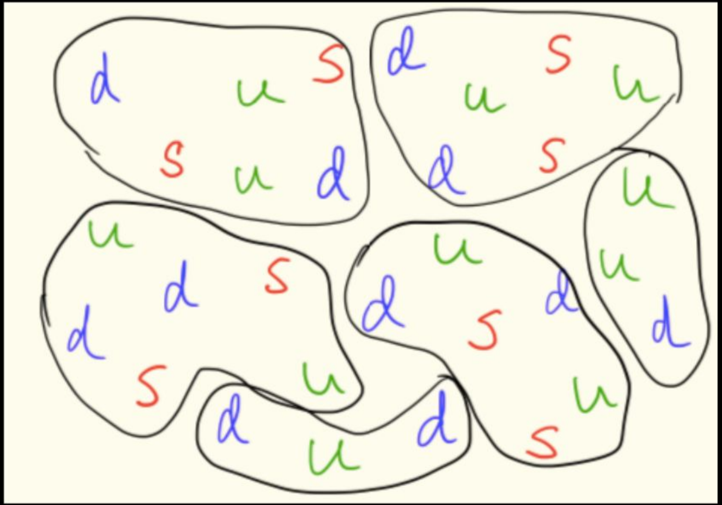


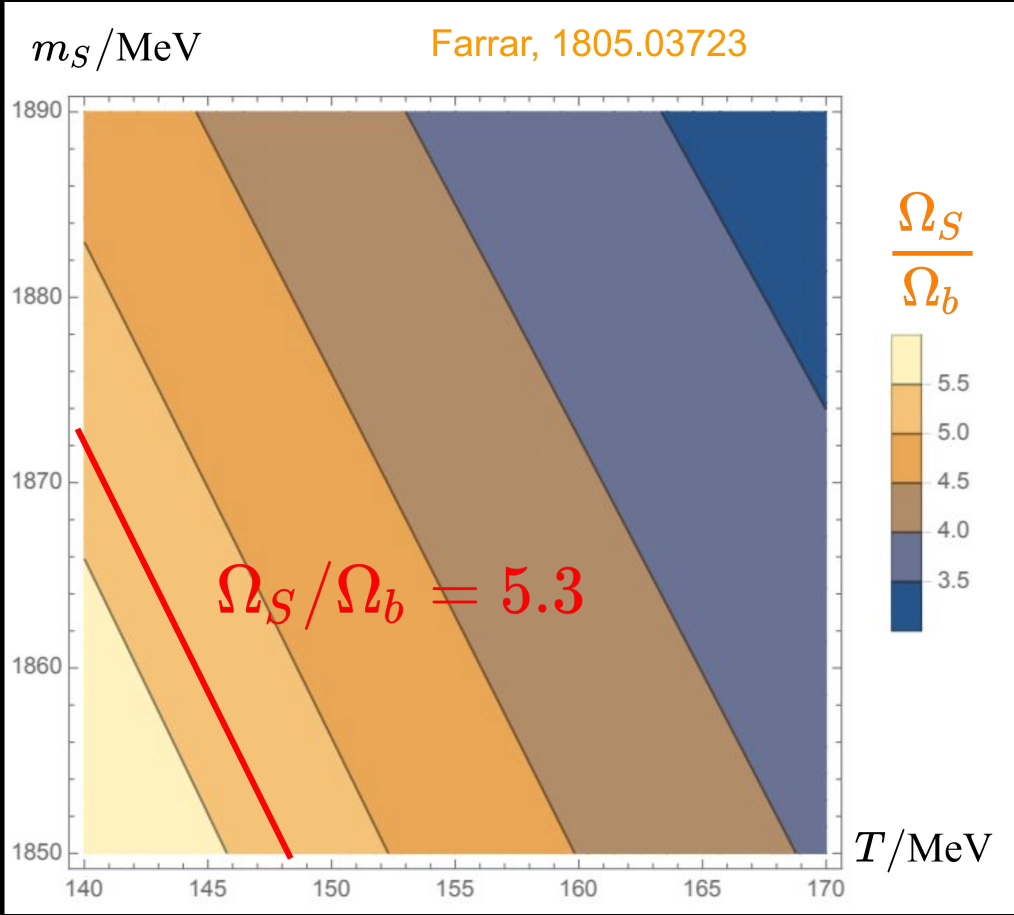
- Color-spin-flavor singlet: strong attraction between quarks
- Mass of *S* may be below 2 GeV
- Size of *S* may be much smaller than protons due to non-coupling to pions

$$r_{proton} = 0.87\ \mathbf{fm}$$

$$r_S = 0.1\text{-}0.3\ \mathbf{fm}$$

SDM abundance



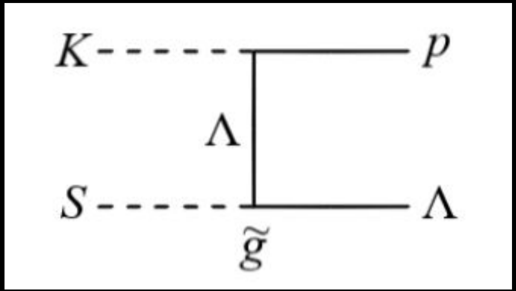


S forms at QGP-hadron transition (T = 140-170 MeV).
Abundance determined by stat mech, and quark masses.

Durability of *S*DM

Can the correct *S*DM abundance at QCD phase transition (T ~ 150 MeV) persist to later time? Questioned by Gross et al, 1803.10242
Kolb, Turner, 1809.06003

These arguments overlooked dissociation amplitude $\tilde{g}$ is small



Requirement $H > n_K\langle\sigma v\rangle$ **at T ~ 150 MeV**

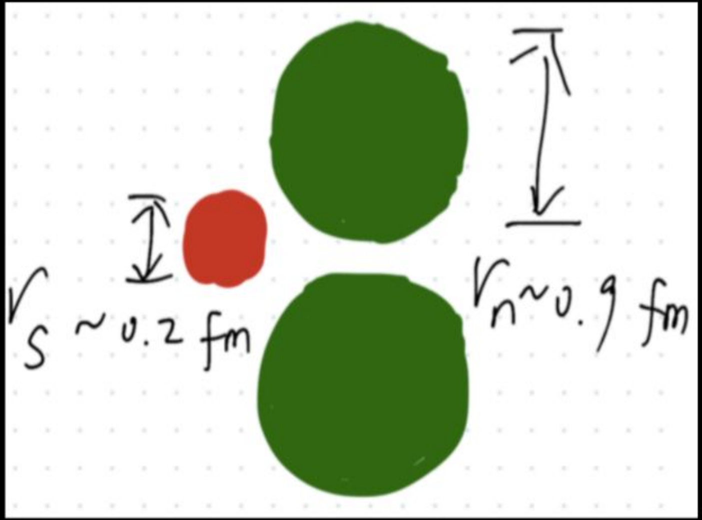
$$\tilde{g} \lesssim 2\times10^{-6}$$

In this talk, I address the feasibility of a small $\tilde{g}$.
Theoretical calculation & experimental constraints

Theory of $\tilde{g}$

$\tilde{g}$ is the dissociation amplitude of *S* into two baryons (e.g. $\Lambda\Lambda$)

$$\tilde{g} = \langle BB' | H_{\rm QCD} | S \rangle$$



Two contributions

I. Tunneling suppression from short-distance BB' repulsion
II. Spatial redistribution of six quarks in *S* to BB'

Two parameters

I. S radius $r_S = 0.1\text{-}0.3$ fm
II. Hardcore radius of baryons $r_c = 0.3\text{-}0.5$ fm

$$\tilde{g} = (0.05\text{-}10^{-4}) \times \left(\frac{r_S}{r_B}\right)^{10\text{-}18}$$

$$= 10^{-4}\text{-}10^{-18}$$

BB' hardcore repulsion ignored by Gross et al, 1803.10242
McDermott et al, 1809.06765

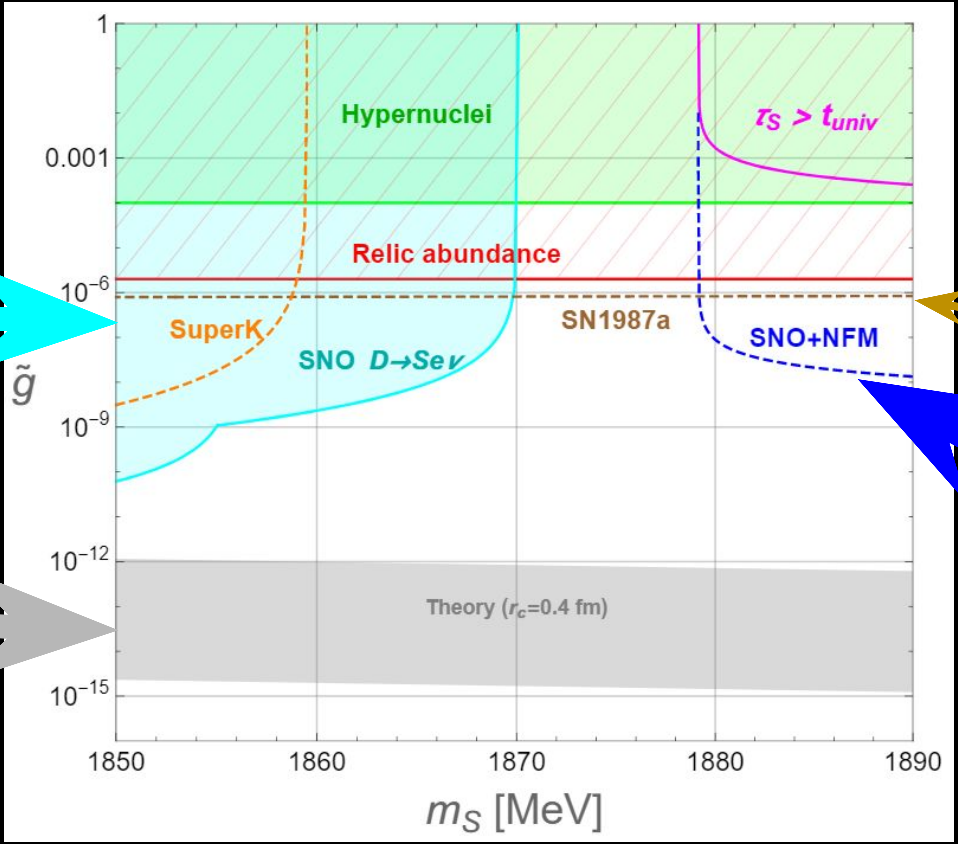
They got very large $\tilde{g}$

Farrar, Zaharijas, 0308137
Farrar, ZW, to appear
Farrar, ZW, Xu, to appear

Prediction and constraints on $\tilde{g}$

Deuteron stability

Theory value



SN1987a cooling

S stability

Farrar, ZW, to appear
Farrar, ZW, Xu, to appear

Prediction and constraints on $\tilde{g}$

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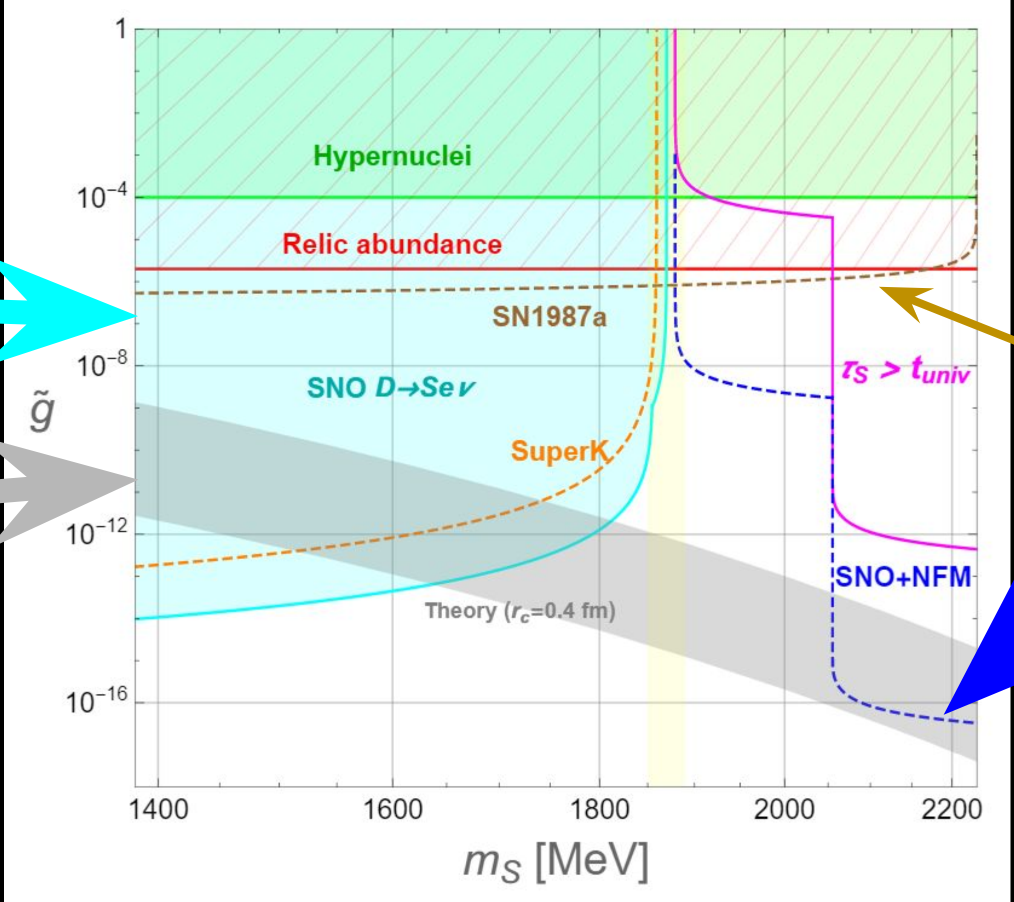


SN1987a cooling

S stability

Farrar, ZW, to appear
Farrar, ZW, Xu, to appear

Sudbury Neutrino Detector (SNO)

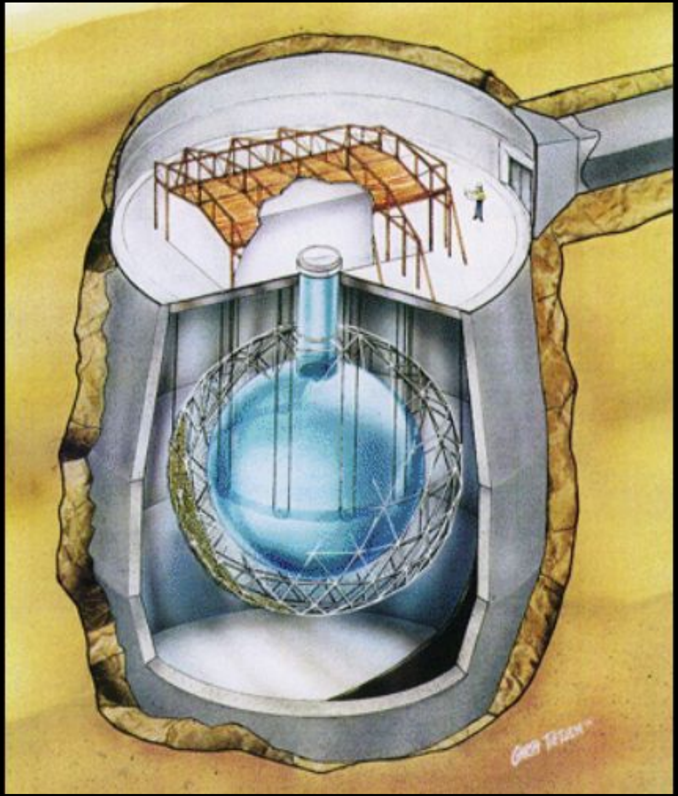
SNO has recorded *e* and *n* events produced by solar neutrinos.

$$\nu_e + \mathrm{D} \to 2p + \boxed{e^-}$$

$$\nu + \mathrm{D} \to \boxed{n} + p + \nu$$

(detection equally sensitive to e^+)

We use the data released by SNO to constrain $\tilde{g}$.

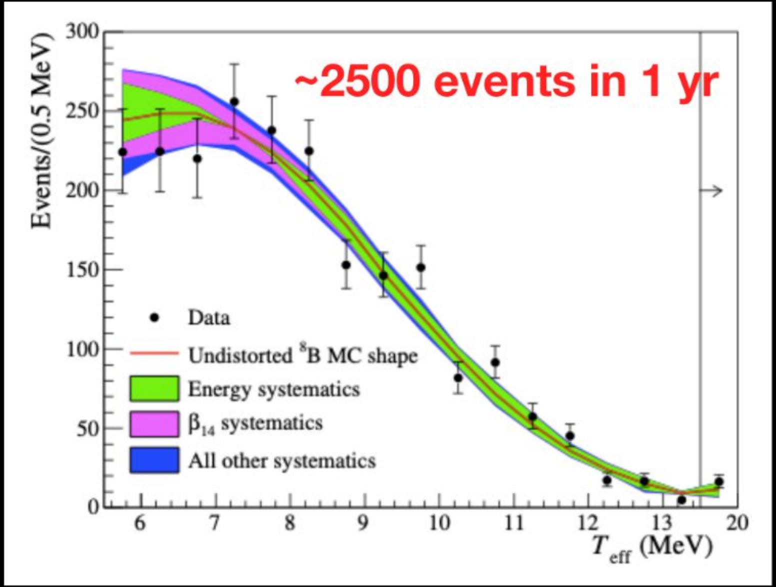


SNO, 1602.02469

Deuteron stability from SNO

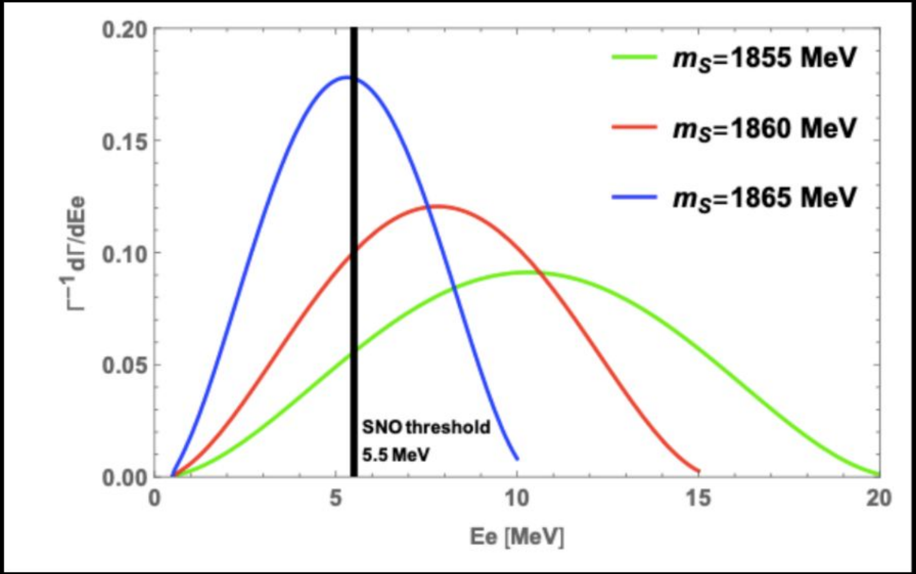
If *S* lighter than deuteron, D can decay to $S + e^+ + \nu$

SNO contains 10^6 kg $\mathrm{D_2O}$



Observed *e* spectrum SNO, 1602.02469

$$\frac{d\Gamma}{dE_e} = \frac{\tilde{g}^2 G_F^4 p_q^6 \sin^4\theta_c \cos^2\theta_c}{120\pi^3 m_D m_S}\sqrt{E_e^2 - m_e^2}\,E_e(m_D - m_S - E_e)^2$$



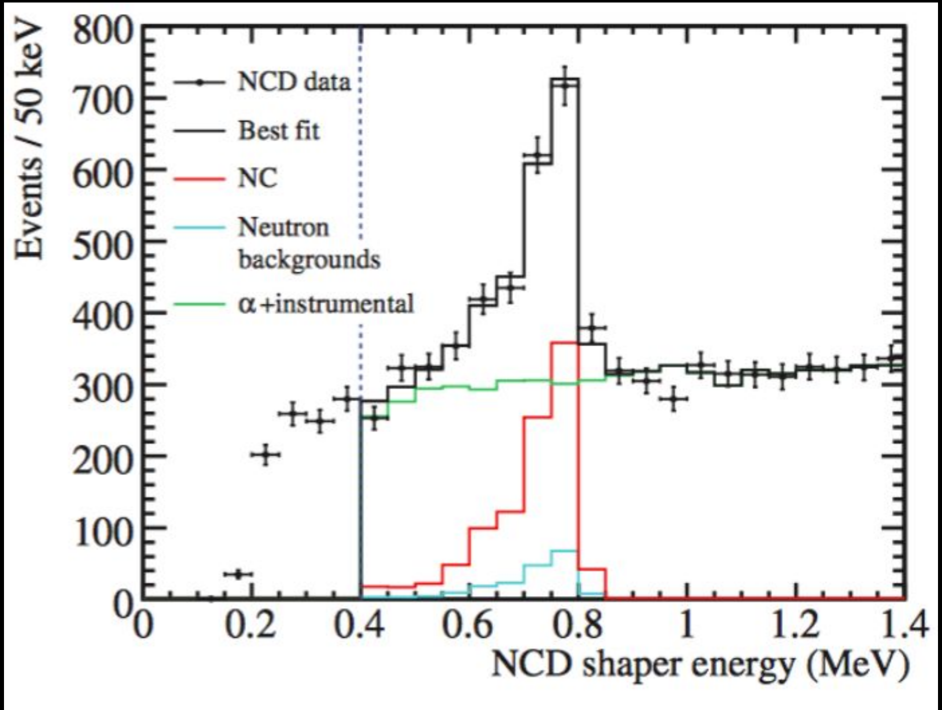
Expected *e* spectrum from D decay

$$\tau_D \geq 10^{32}\ \mathrm{yr}$$

Farrar, ZW, to appear

S stability from SNO

If *S* heavier than two neutrons, *S* can decay to *nn*



Observed *n* spectrum SNO, 1602.02469

We derive limit on *S* -> *nn* lifetime from SNO:

$$\tau_{S\to nn} \geq 10^{19}\ \mathrm{yr}$$

Theoretical $S\to nn$ decay rate

$$\Gamma = \frac{\tilde{g}^2 G_F^4\, p_q^8\, \sin^4\theta_c \cos^4\theta_c\, m_S}{640\pi}\left(1 - \frac{4m_n^2}{m_S^2}\right)^{3/2}$$

Farrar, ZW, to appear

Supernova cooling

Processes like $\Lambda\Lambda \to S\gamma$ can accelerate the cooling of SN1987a.

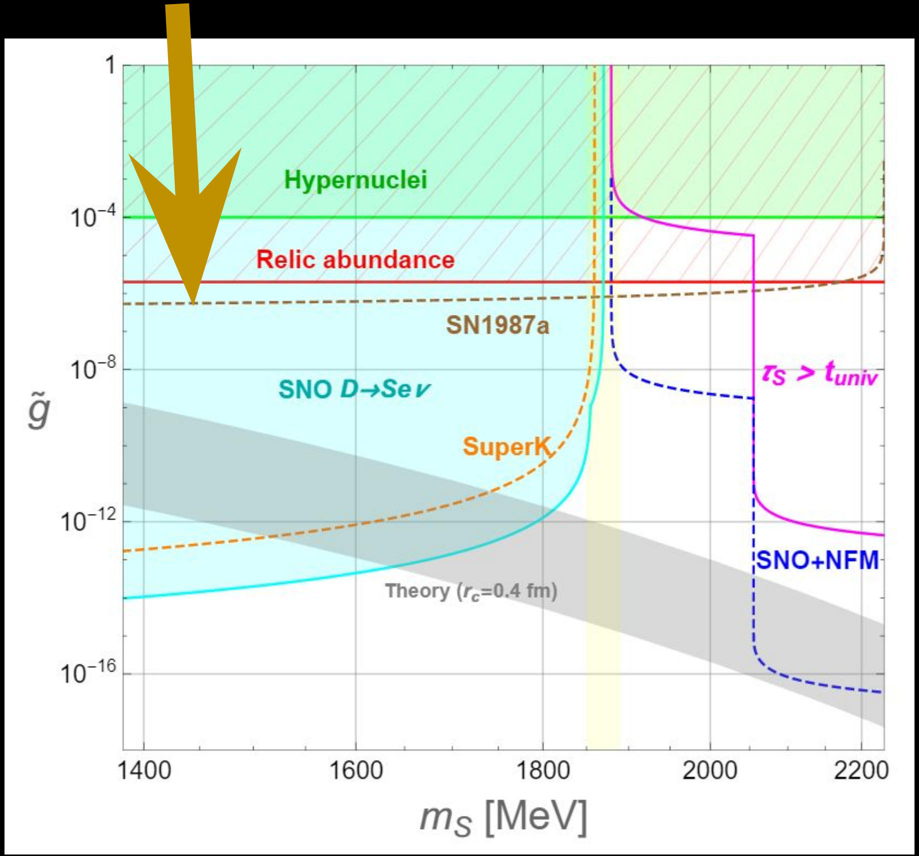
McDermott, Reddy, Sen, 1809.06765

Constrained by observed cooling time ~ 10 s. Not problematic with our prediction of $\tilde{g}$. (Contrary to the conclusion of McDermott et al)

(However, the 10 s cooling time has been put into debate. So this bound may not exist.)

Bar, Blum, D'Amico, 1907.05020

See Blum's talk in session J03



Summary

Derived constraints on $\tilde{g}$ from durability of *S*DM, and SNO data.

Compatible with theory values.

For direct detection constraints on *S*DM, see Xingchen Xu's talk in session Q10.

Thank you!