BOOSTED DARK MATTER FROM THE SUN ENHANCED WITH SELF-INTERACTIONS

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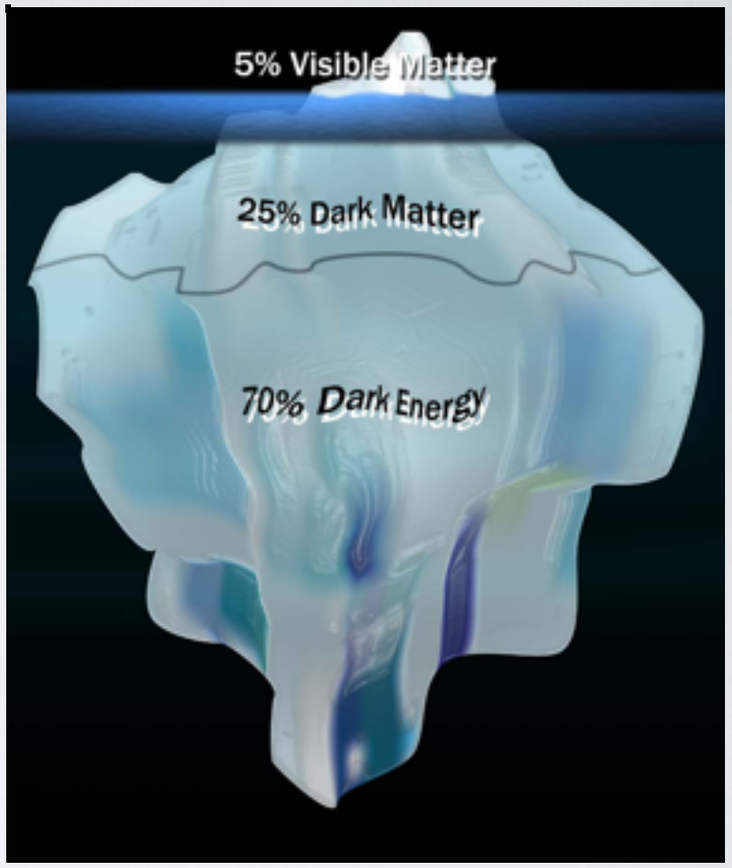
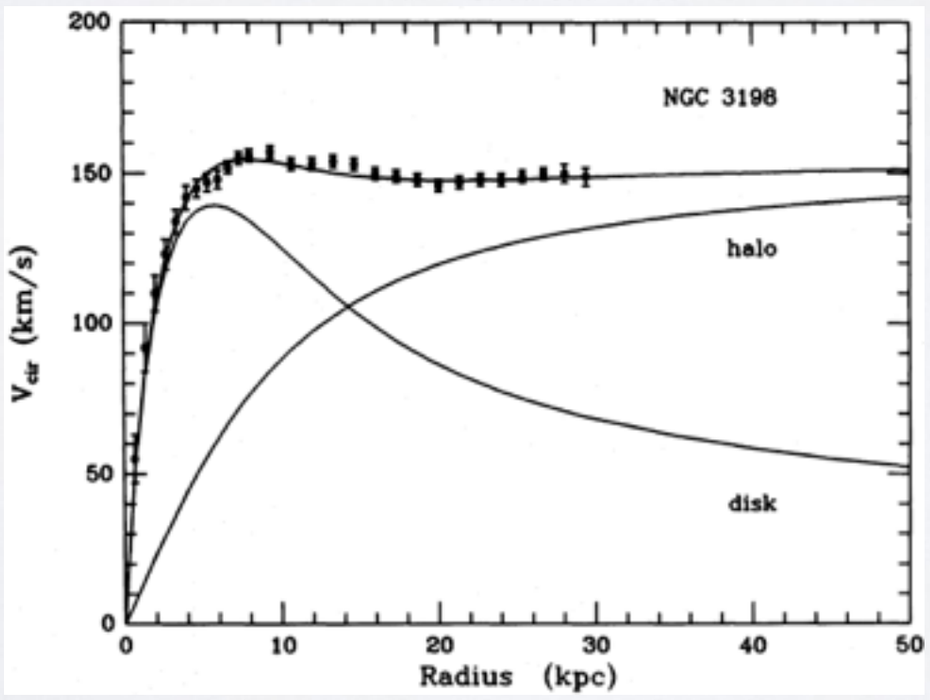
based on Phys. Lett. B 743(2015) 256-266 with K. Kong and JC Park

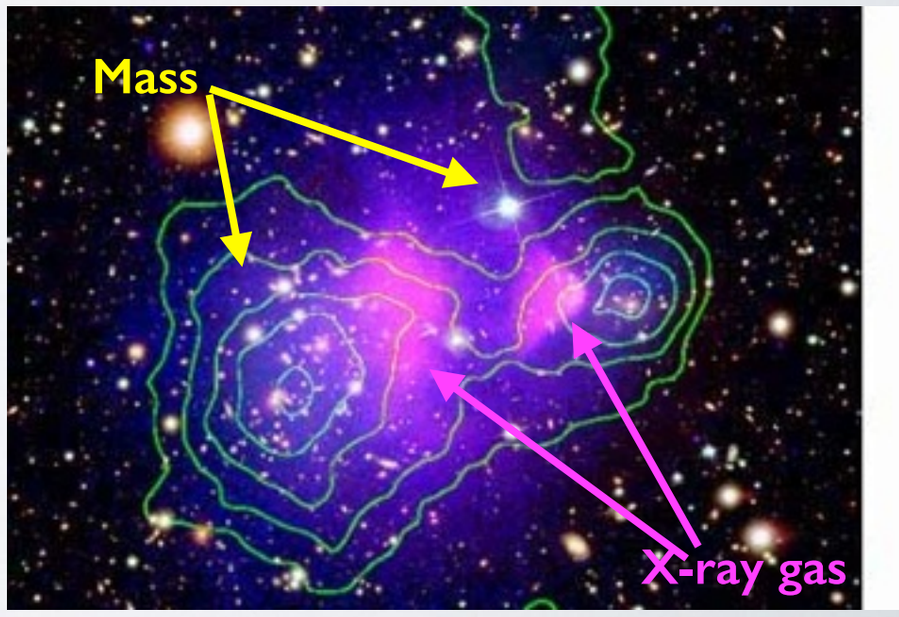
DARK MATTER

- Dark Matter comprises about 25% of our Universe.
- Astrophysical and Cosmological evidence:
  - ★ Galaxy rotation curves.
  - ★ Gravitational Lensing.
  - ★ Bullet cluster.
  - ★ Dynamics of structure formation.
  - ★ Velocity dispersion
  - ★ CMB Maps.
  - ★ . . .



van Albada et al 1985



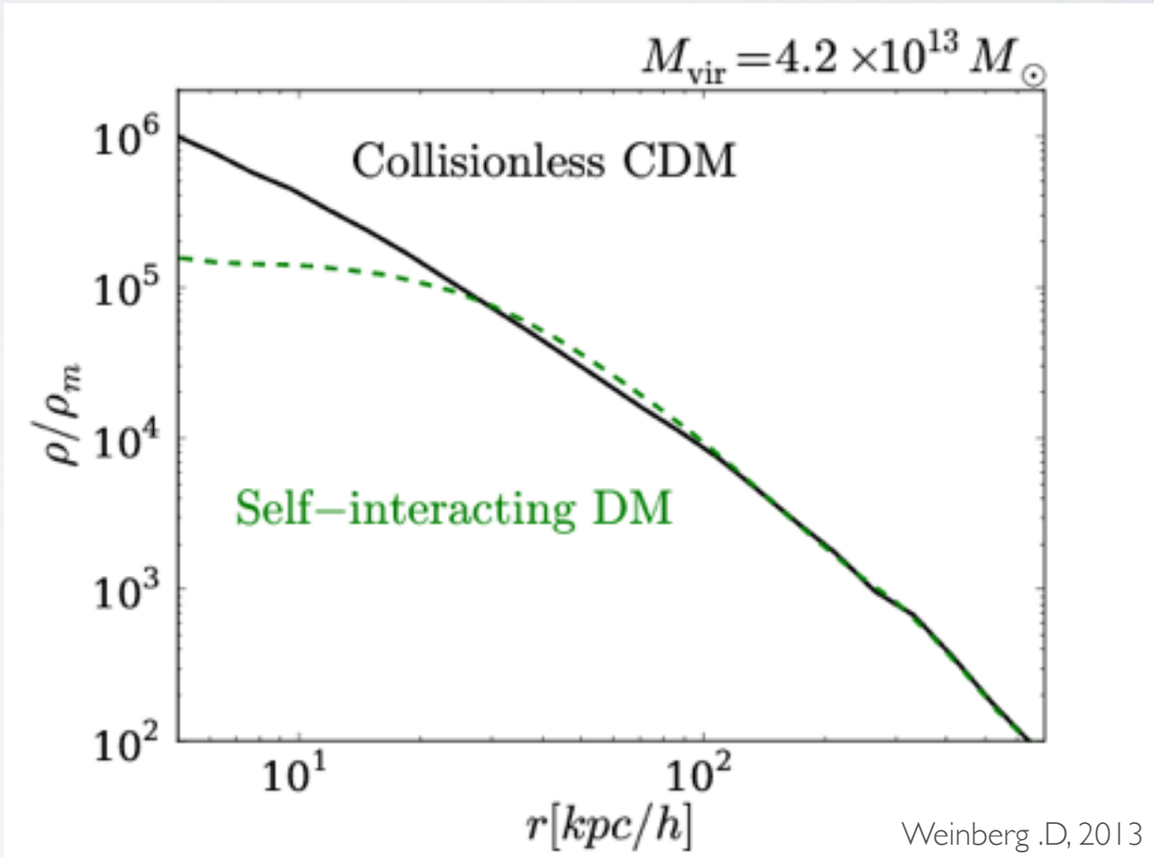


Clowe et al

- Nature of DM is unknown
- Compelling paradigm: CDM
- CDM simulations compare very well to observations at large scales.
- Few anomalies CDM cannot explain, especially at small scales:
  - ✳ Cusp-vs-cored problem.
  - ✳ Missing Satellites problem.
  - ✳ Too big to Fail problem.

Proposed Solutions

- Warm Dark Matter.
- Self Interacting Dark Matter.



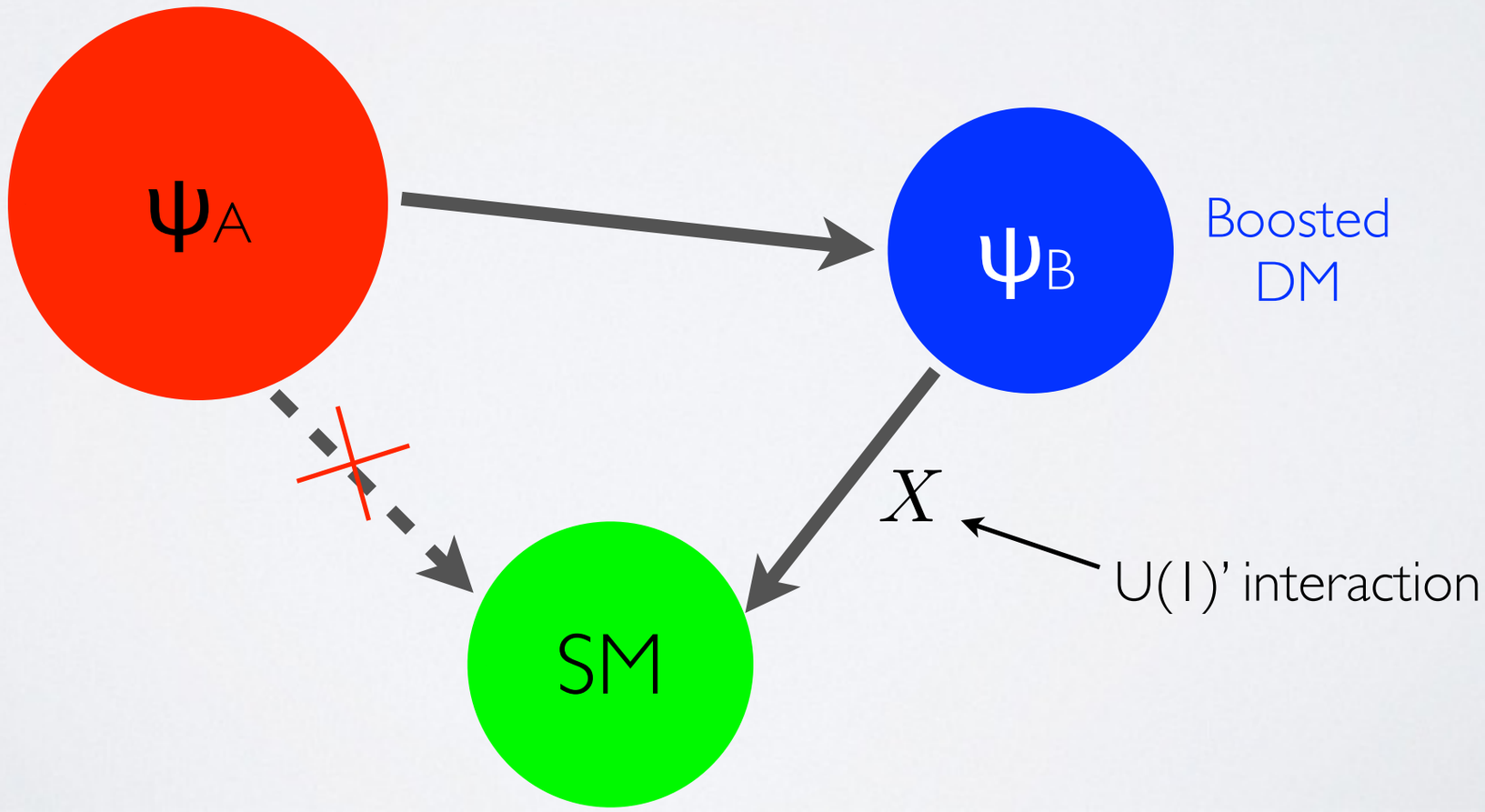
Weinberg .D, 2013

$0.1\,cm^2/g < \sigma_{\chi\chi}/M_\chi < 1.25\,cm^2/g$

BASIC SETUP

- Two species of DM: ψ_A and ψ_B with $M_A > M_B$. $(eg. U(1)' \otimes U(1)'')$
- ψ_A is dominant and has no direct coupling to SM.
- ψ_B is sub-dominant, direct coupling to SM.
- Existing relic ψ_B is small, freeze-out earlier.

Agashe et al (arXiv: 1405.7370)



BASIC FEATURES

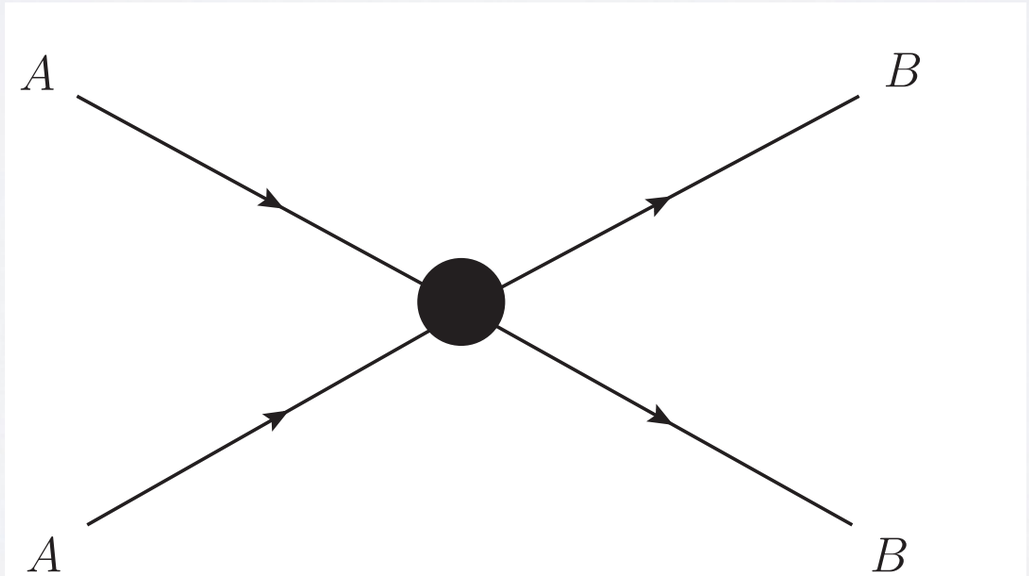
- Relic density of Ψ_A is set by annihilation into Ψ_B.

$$\psi_A \bar{\psi}_A \rightarrow \psi_B \bar{\psi}_B$$ Assisted Freeze-out Mechanism

- Annihilation products, Ψ_B are boosted with factor $\gamma = M_A/M_B$.

- 'Boosted Dark Matter'

- Indirect detection of Ψ_A through boosted Ψ_B.



- Detect boosted ψ_B through its interaction with SM.

$$\mathcal{L} \supset -\frac{1}{2} \sin\epsilon \, X_{\mu\nu} F^{\mu\nu}$$

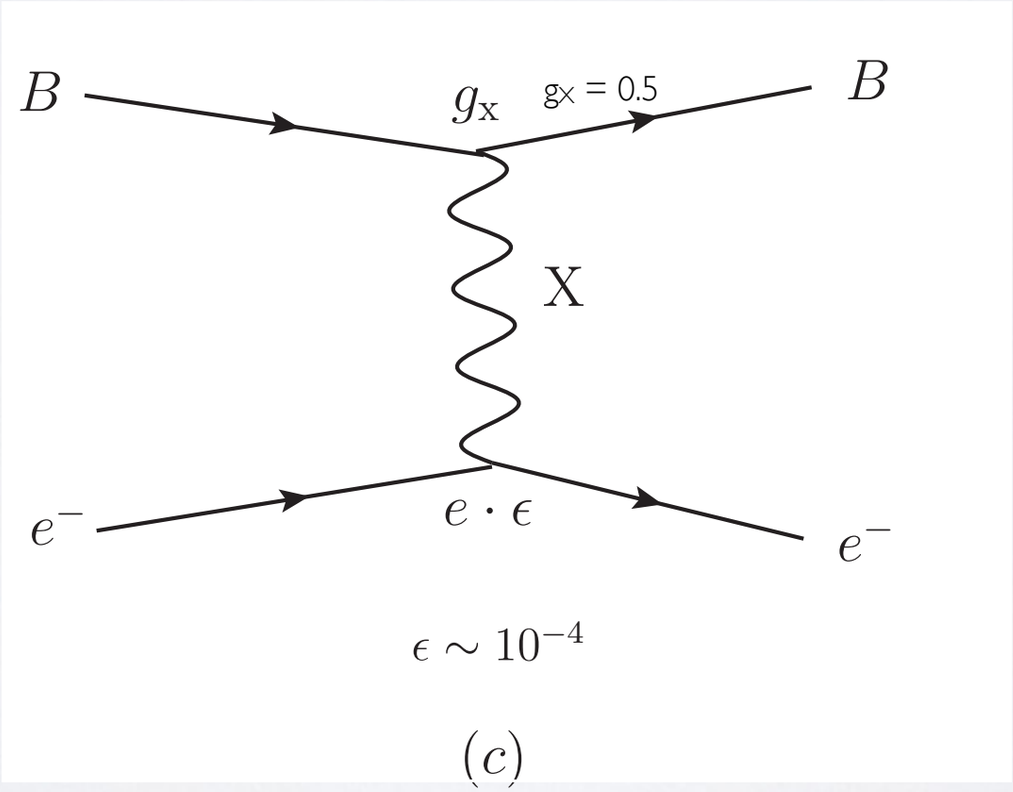
Interaction of photon with hidden Boson

- Via kinetic mixing of SM photon with hidden 'Dark' X.

- Direct detection of boosted ψ_B through SM.

- Indirect-direct detection of ψ_A.

Smoking Gun for Non-Minimal DM sector.



BOOSTED DM FROM THE SUN

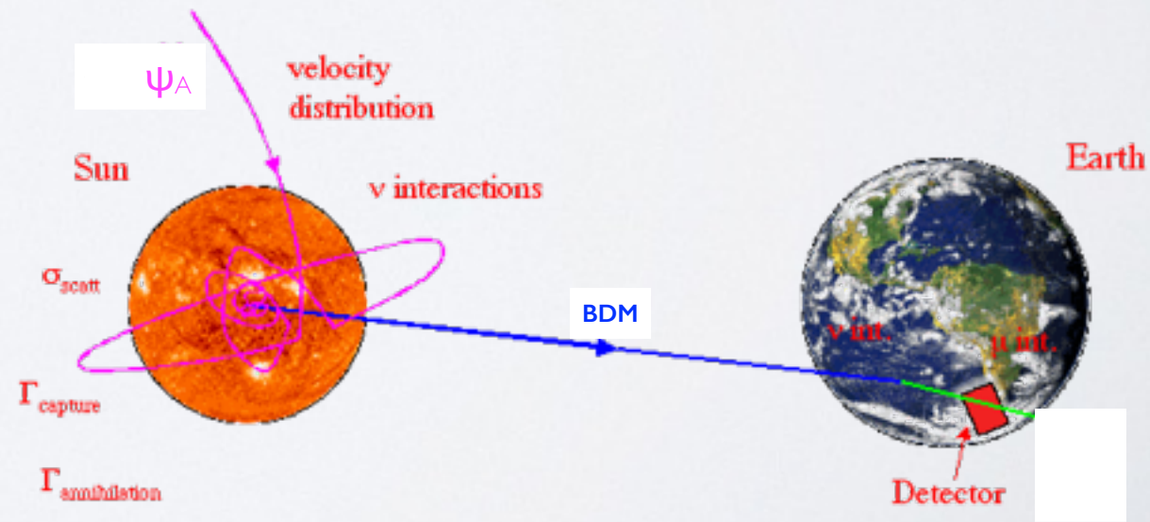
- Time evolution of number density of DM particles in sun is:

$$\frac{dN_\chi}{dt} = C_c + (C_s - C_e)N_\chi - (C_a + C_{se})N_\chi^2$$

Chen, Lee, Lin & Lin(2014)

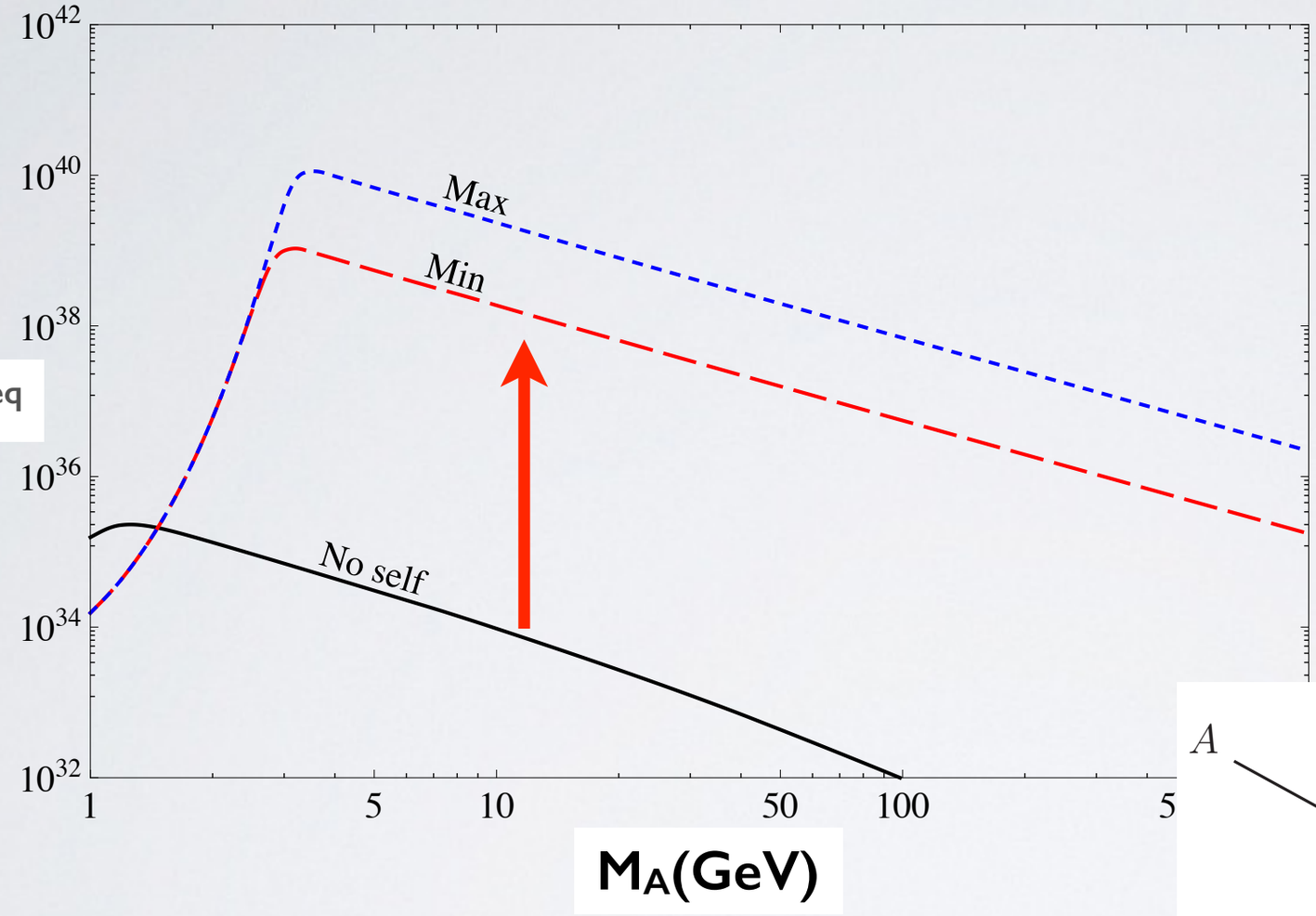
  - **Cc**: capture rate by nuclei inside Sun.
  - **Cs**: capture rate by DM already captured in Sun.
  - **Ce**: Evaporation rate due to DM-nuclei scattering.
  - **Cse**: evaporation rate due to DM-self interaction.
  - **Ca**: annihilation rate.

- Sun is point source.

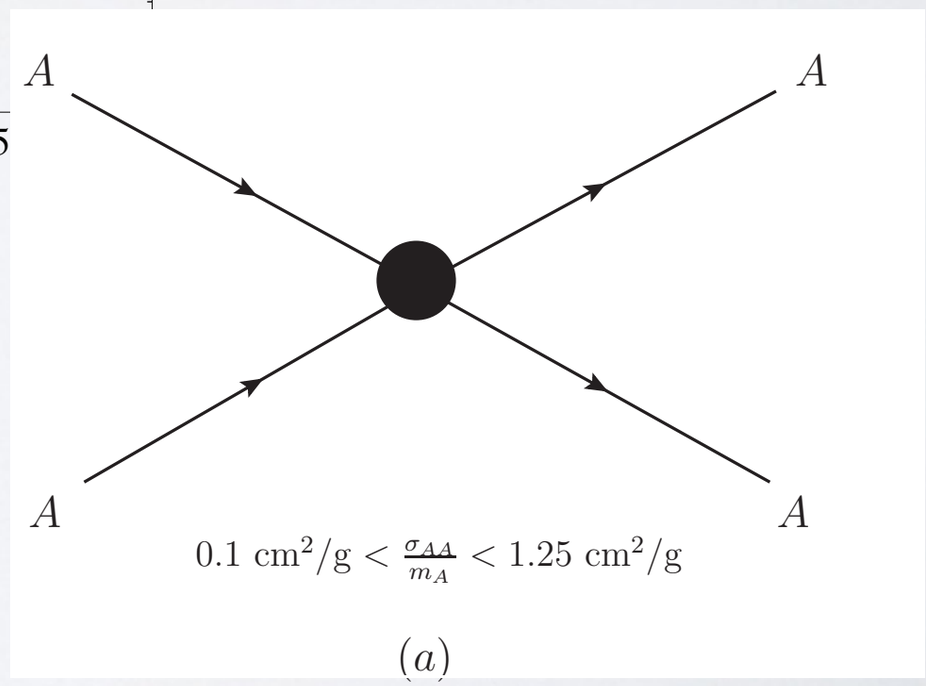


Berger et al (arXiv:1410.2246)

$$N_\chi(t) = \frac{C_c \, \tanh(t/\tau_{\rm eq})}{\tau_{\rm eq}^{-1} - (C_s - C_e)\tanh(t/\tau_{\rm eq})/2} \qquad \tau_{\rm eq} = \frac{1}{\sqrt{C_c(C_a + C_{se}) + (C_s - C_e)^2/4}} \,,$$



Importance of Self-Interaction



Flux of boosted DM particles

- Flux of boosted Ψ_B from the Sun:

$$\frac{d\Phi_B^{\rm Sun}}{dE_B} = \frac{\Gamma_A^{\psi_A}}{4\pi R_{\rm Sun}^2}\frac{dN_B}{dE_B}$$

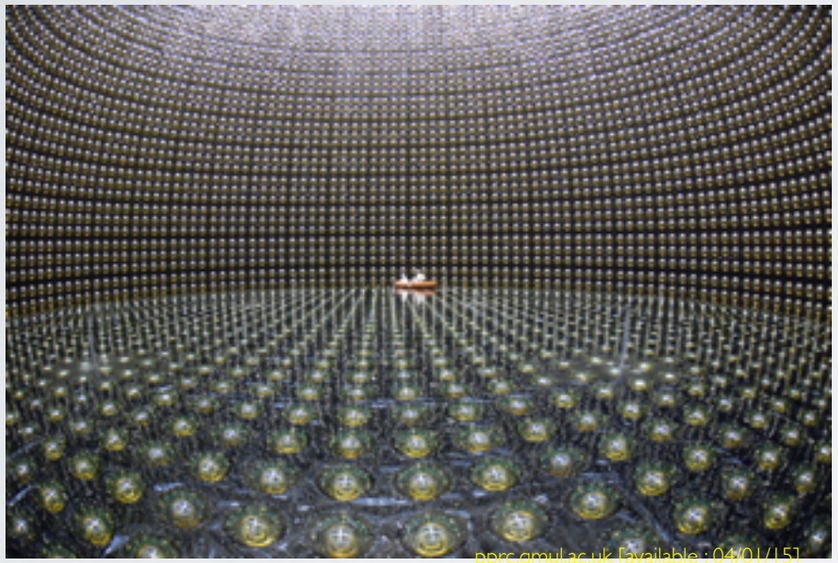
$$\Gamma_A^{\psi_A} = \frac{C_a}{2} N_{\psi_A}^2$$

$$\frac{dN_B}{dE_B} = 2\delta(E_B - m_A)$$

- Annihilation of Ψ_A produces 2 mono-energetic boosted Ψ_B's.
- Take into account other factors, e.g. energy loss of the Ψ_B particles during propagation through the sun.

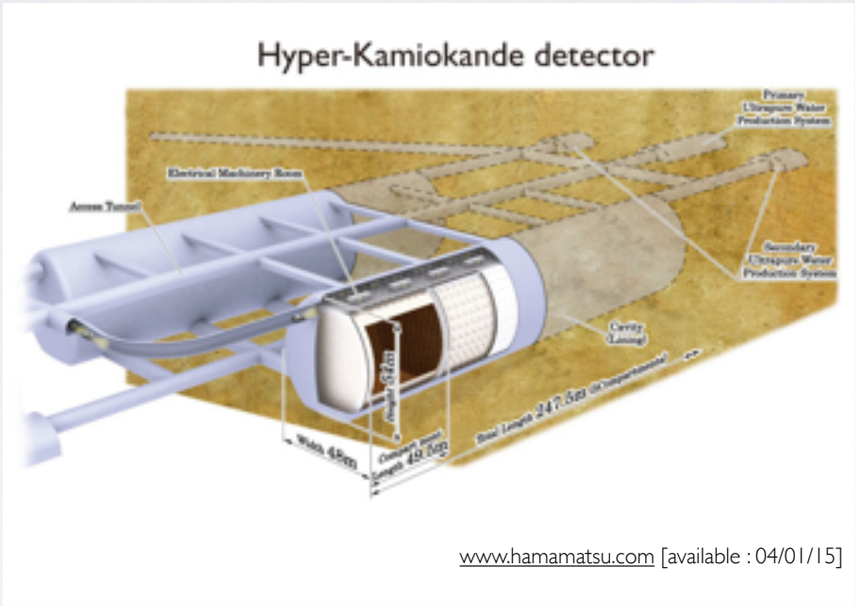
DETECTION OF BDM

- large volume neutrino detectors detect: $\nu_e n \rightarrow e^- p$



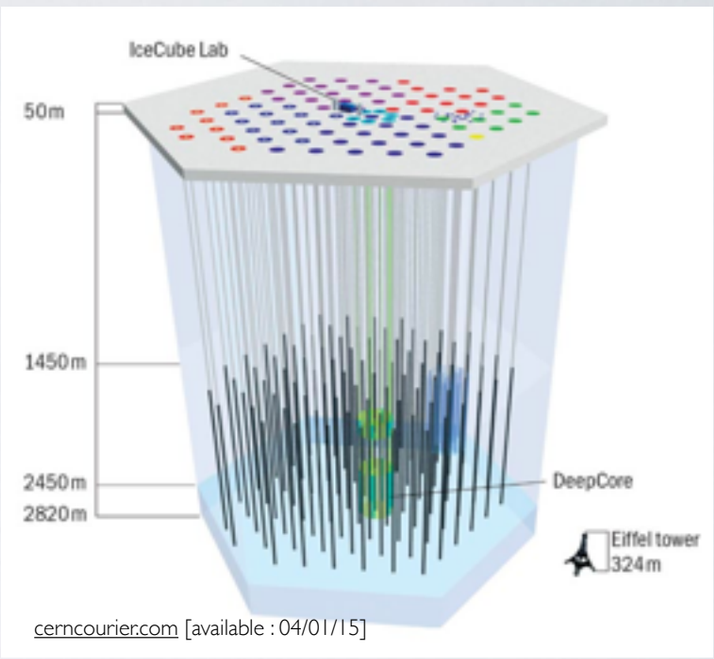
pprc.qmul.ac.uk [available : 04/01/15]

Super-K



www.hamamatsu.com [available : 04/01/15]

Hyper-K



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PINGU/Ice-Cube

- In same light BDM detected through $\psi_B e^- \rightarrow \psi_B e^-$
- Energetic electrons would produce Cherenkov light.
- BDM signal seen as single Cherenkov ring.

- Focus on Super-K, Hyper-K and PINGU.

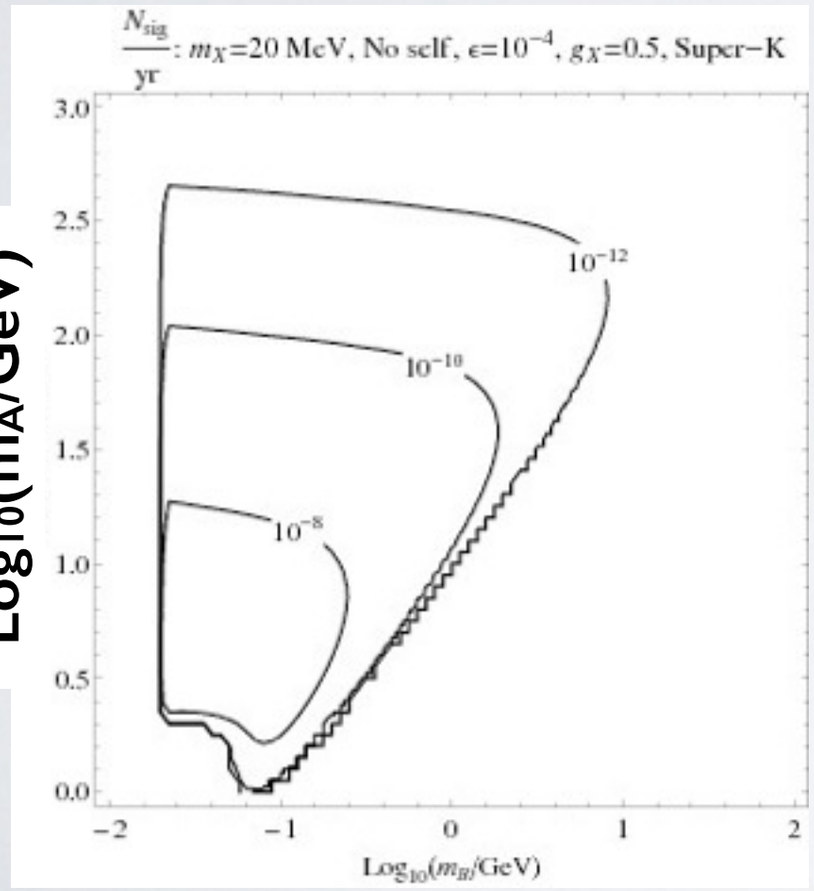
Experiment	Volume (MTon)	Ethres(GeV)	res(deg)
Super-K	0.0224	0.01	3
Hyper-K	0.56	0.01	3
PINGU	0.5	1	23
Ice-Cube	1000	100	30

- Angular resolution and energy threshold important for distinguishing Neutrino backgrounds.

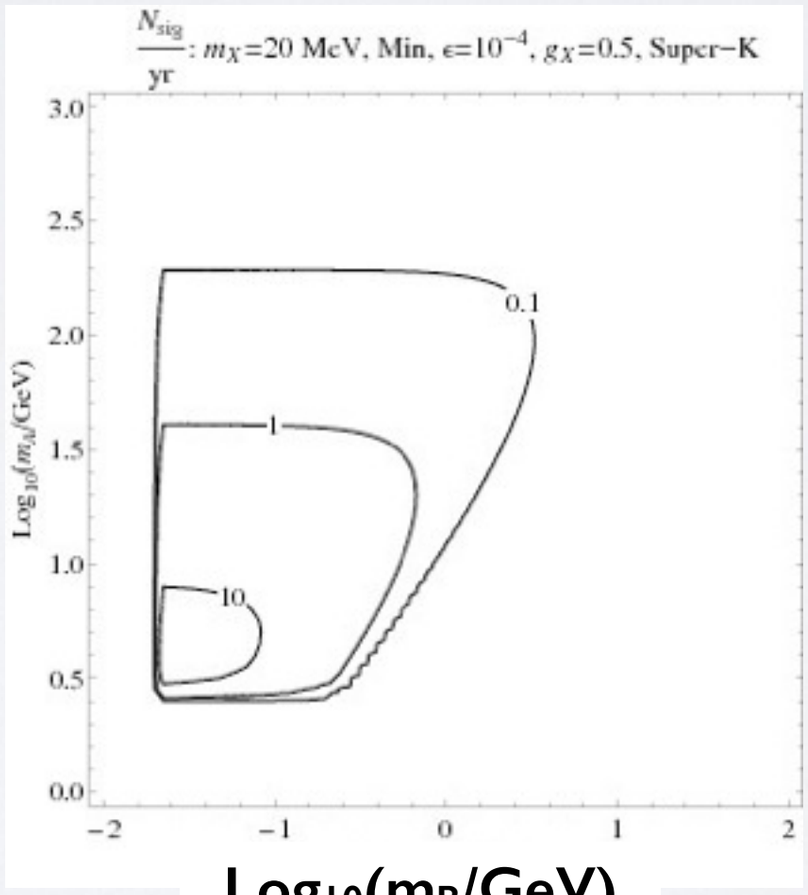
Signal Rates

$$N_{\rm sig} = \Delta T \, \frac{10 \, \rho_{\rm target} \, V_{\rm exp}}{m_{\rm H_2O}} \, \frac{2\Gamma_A^{\psi_A}}{4\pi R_{\rm Sun}^2} \int_{E_e^{\rm min}}^{E_e^{\rm max}} dE_e \, \frac{d\sigma_{Be^- \to Be^-}}{dE_e}$$

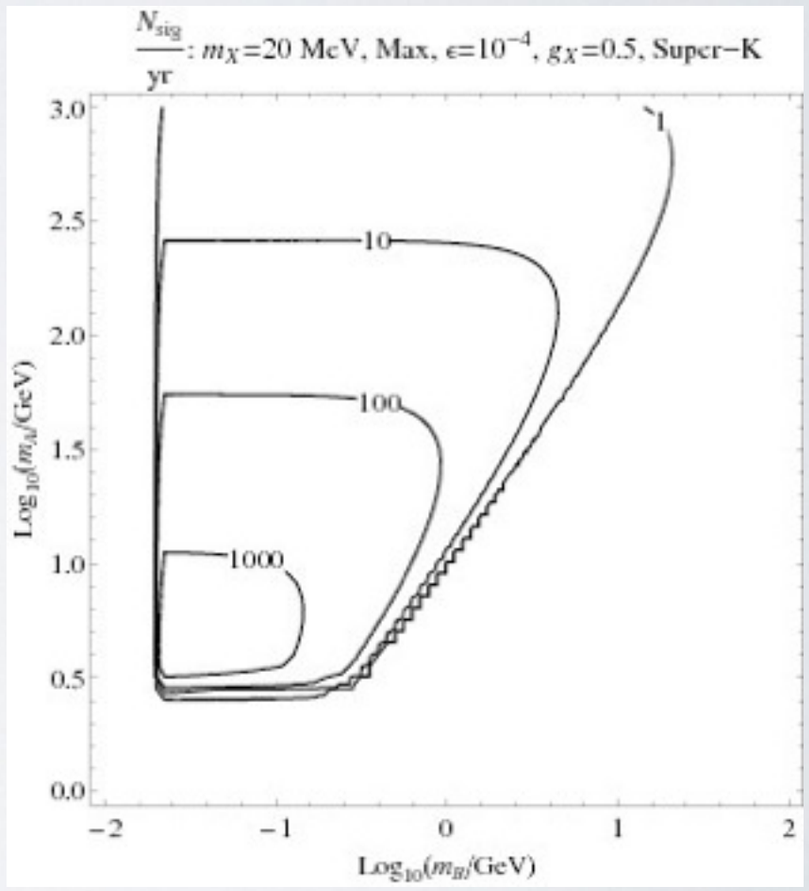
- For Super-K.



No self-interaction

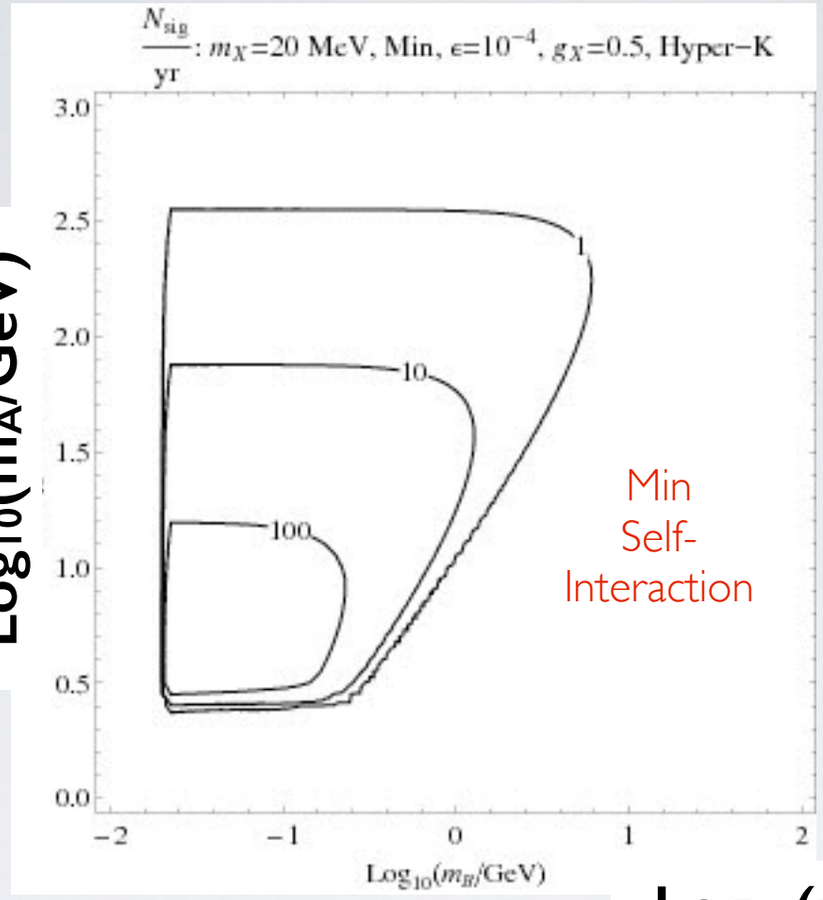


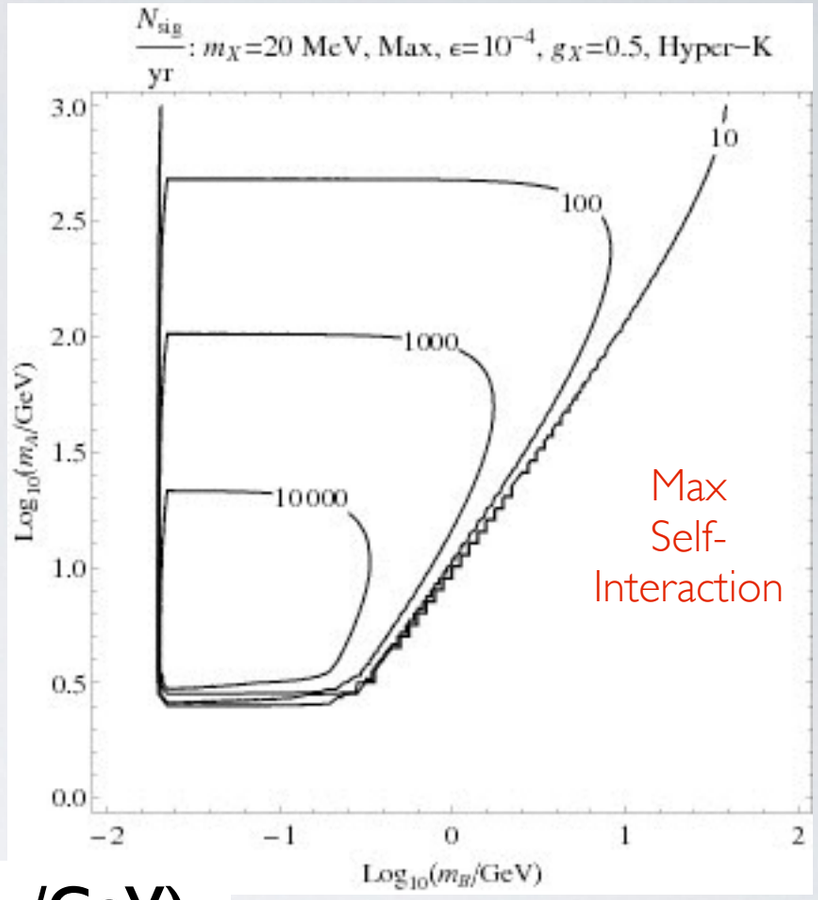
Min self-interaction



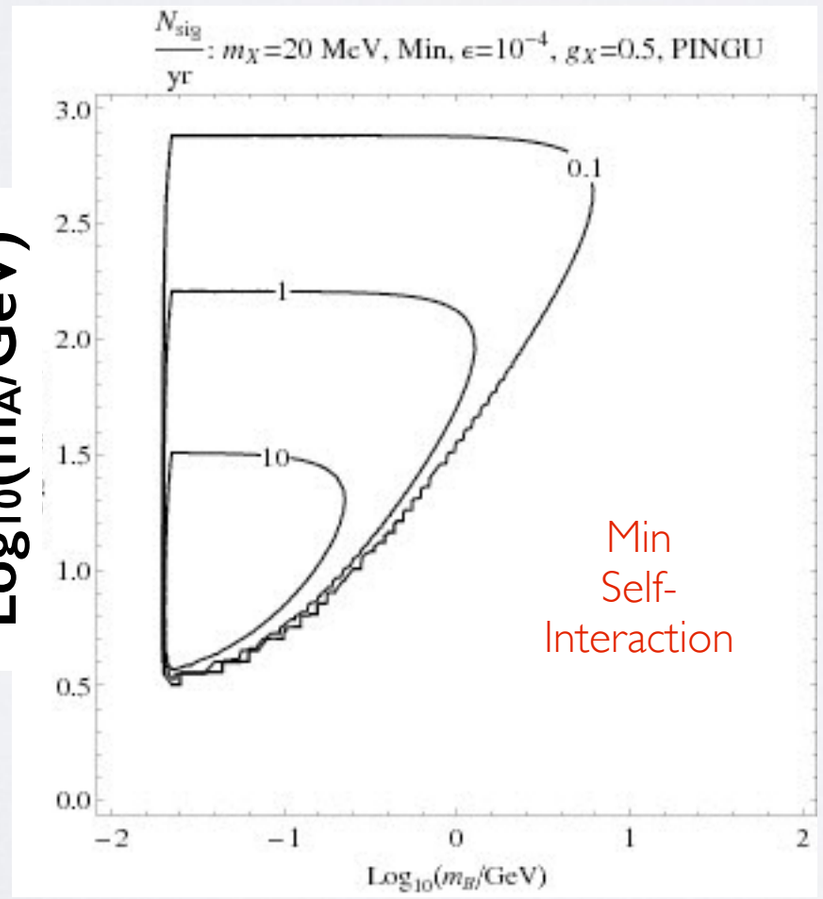
Max self-interaction

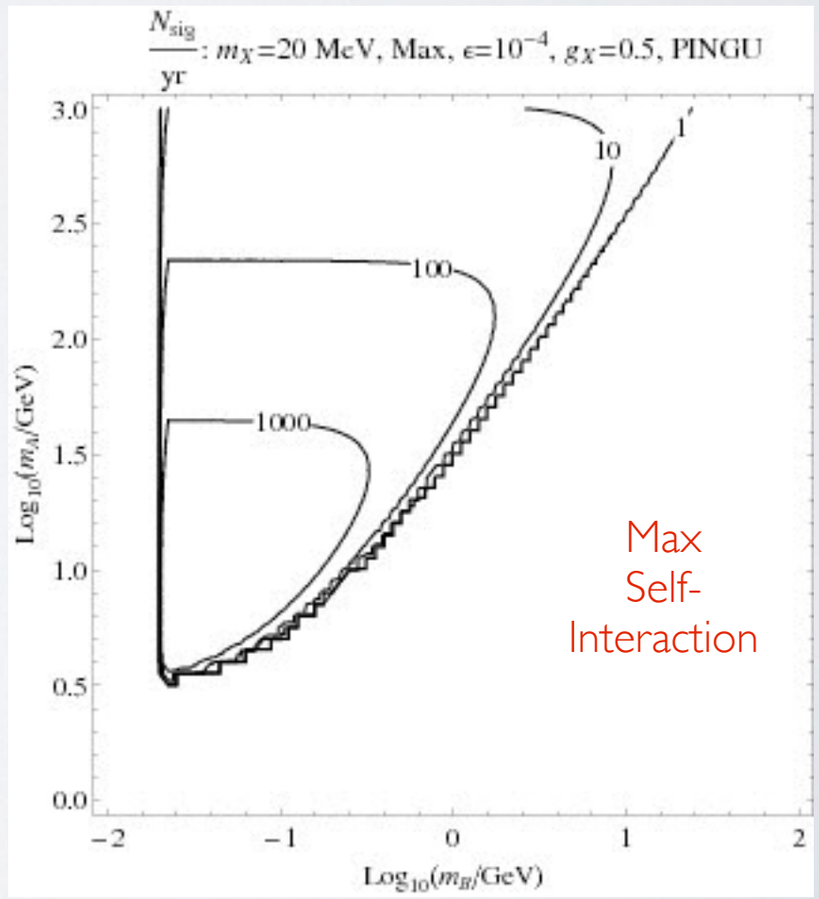
- For Hyper-K





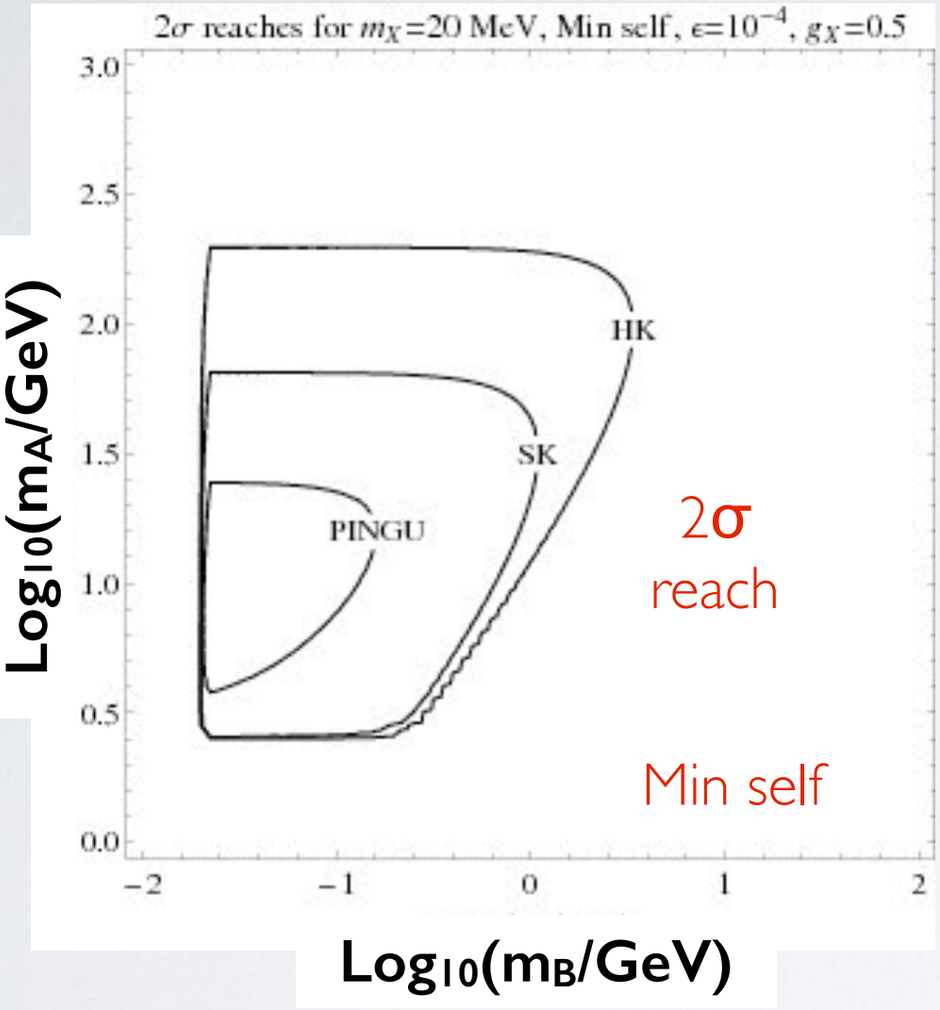
- For PINGU

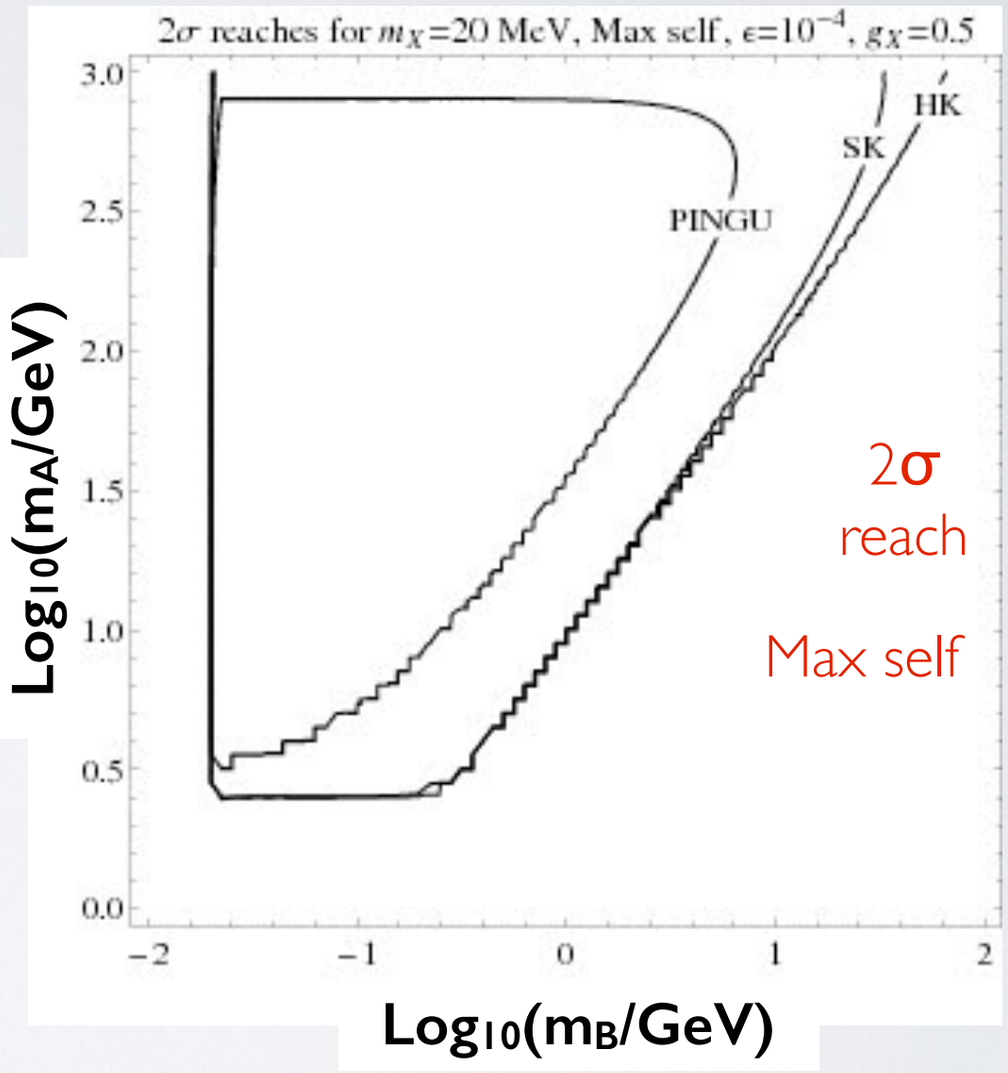




Experimental Reach

- 2σ sensitivity for 10 years of Data.





- Left Edge: $m_B > m_x$, Top Edge: number density n_{DM}
- Right Edge: $E_{max} > E_{min}$ Bottom Edge: Evaporation i.e. drop in N_A^{eq}

CONCLUSIONS & FUTURE WORK

- Self-interacting multi-component DM provides insight into several unanswered cosmological questions.
- Self interaction is helps enhance flux of Boosted DM.
- Hyper-K is so far the best prospect for boosted DM detection, it has large volume, lower threshold and low angular resolution.
- Consider Ice-Cube/PINGU:
  - Effective volume $V_{eff}(E)$.
  - Angular res $\theta_{res}(E)$.
- Proper modeling of energy loss inside Sun.
- Improve Boosted DM signal.

THANK YOU