Dark Matter and the primordial ^{7}Li anomaly

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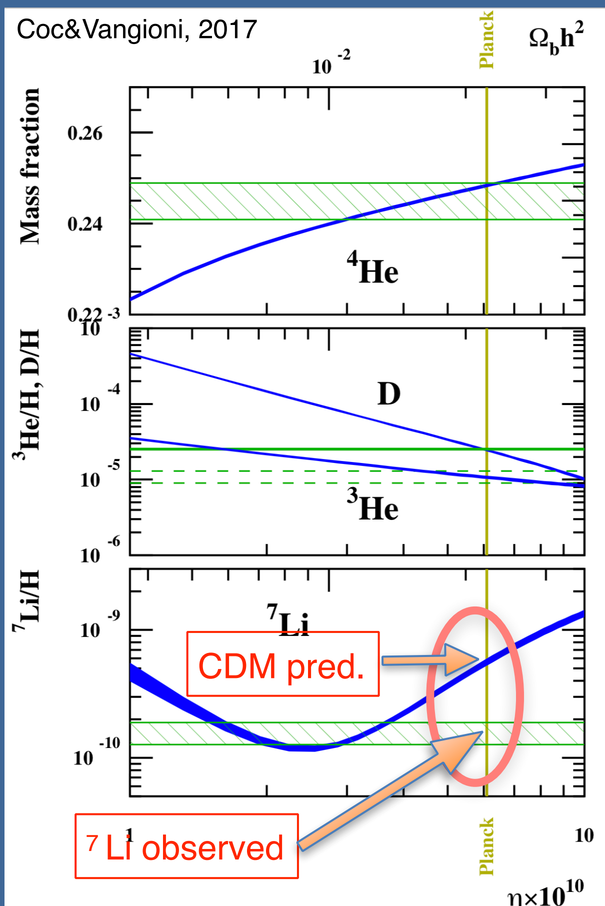
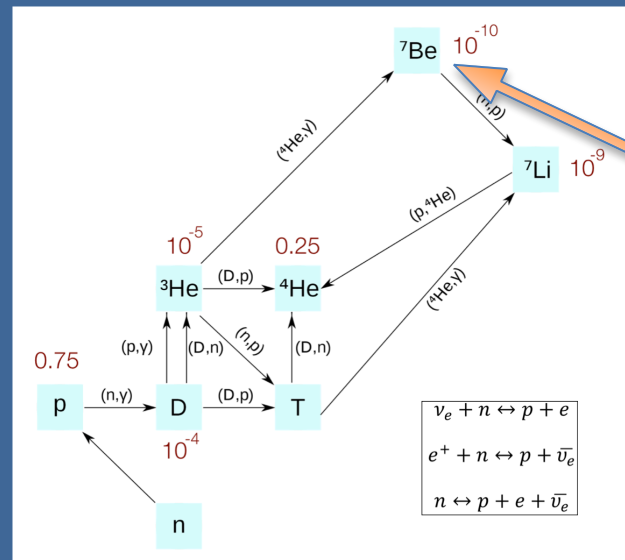
Hadronically Interacting DM may explain primordial ^{7}Li

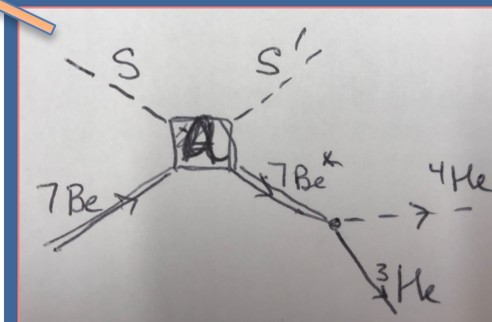
(GRF + R. Galvez, in preparation)

CDM prediction for 7Li is 10σ above observation

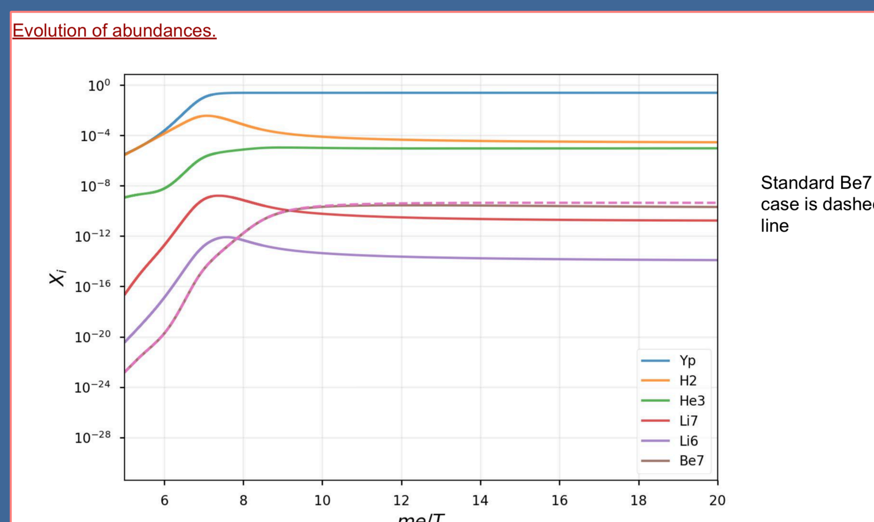




DM breaks up ^{7}Li & ^{7}Be, reducing predicted abundance



T< 80 keV⇒only loosely bound ^{7}Li & ^{7}Be are affected



KE threshold for breakup

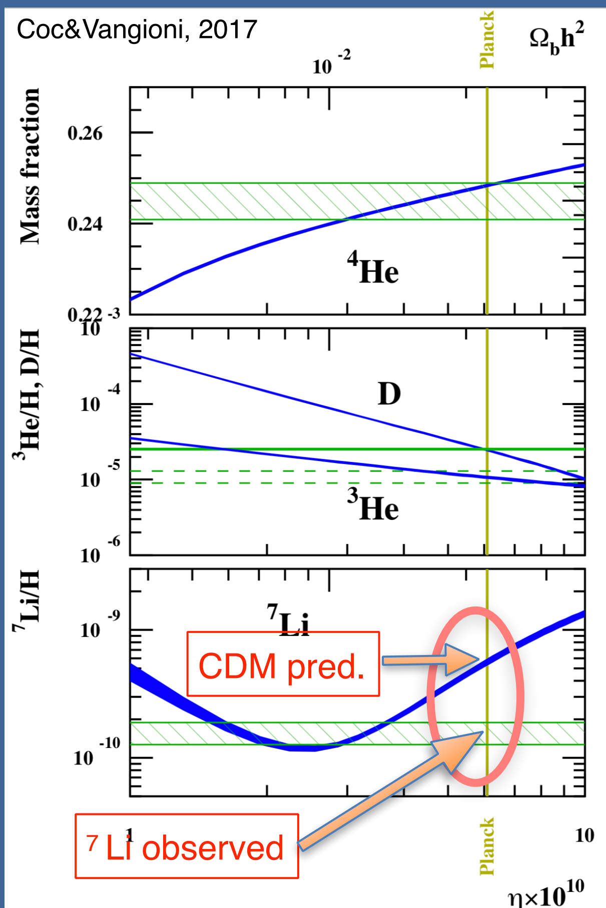
- ^{7}Be 1.58 MeV
- ^{7}Li 2.46 MeV
- ^{3}He 4.47 MeV
- ^{3}H 5.75 MeV
- ^{4}He 19.3 MeV
- [d, 2.2 MeV, replenished]

Is there a 7Li problem?

CDM prediction is secure (nuclear physics checked)

CDM prediction for 7Li
is 10σ above observation

Cyburt, Field, Olive 2008; PDG updates, …
Coc&Vangioni, 2017



Spite Plateau (1982; plot from Spordone+10)

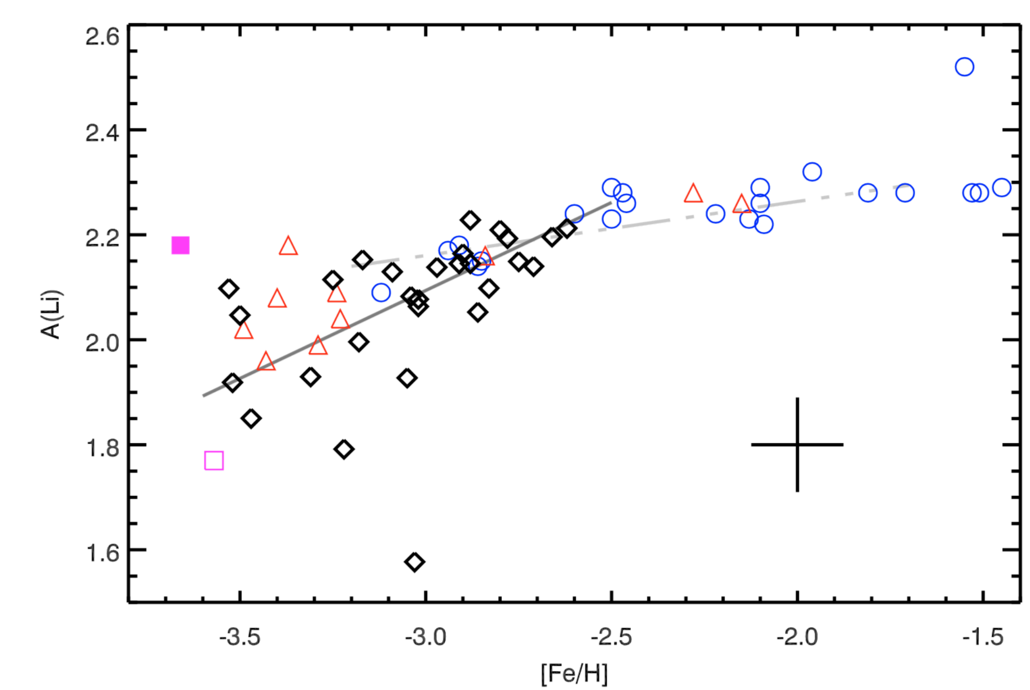


Fig. 15. A unified view of A(Li) vs. [Fe/H] from some studies for which a common temperature scale can be assumed. Blue circles, Asplund et al. (2006) data, red triangles, Aoki et al. (2009) data, magenta

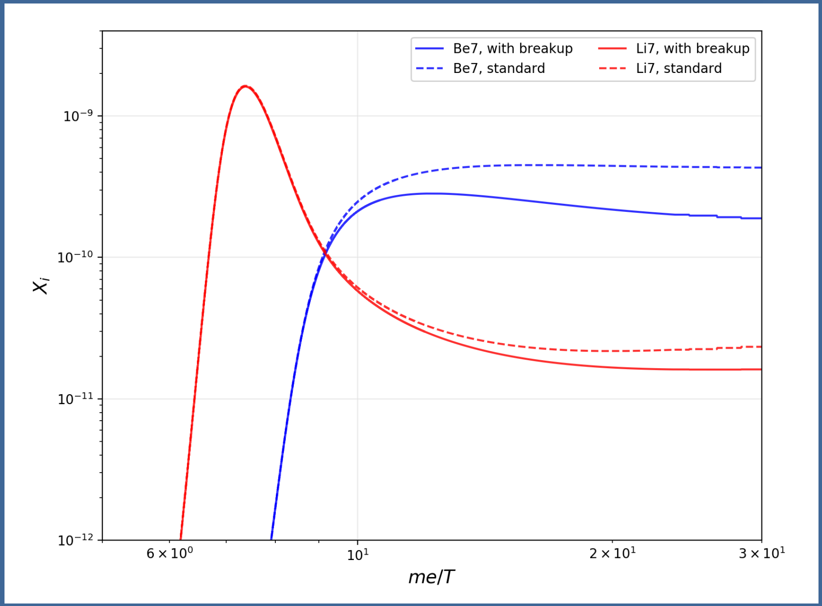
> 90% of ^{7}Li comes from ^{7}Be

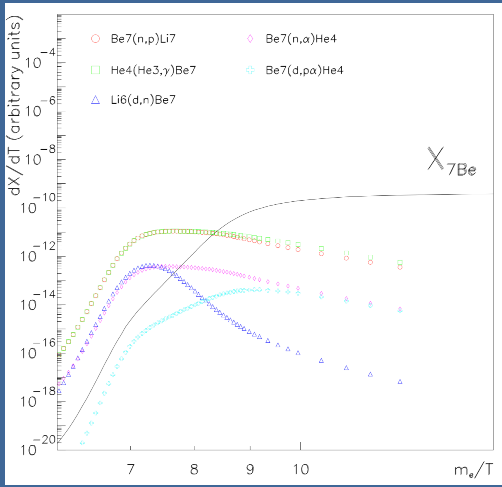
at recombination, $^7Be + e^- \rightarrow {}^7Li + \nu$

Breakup Rate from DM = $< n_{DM}\, \sigma_{bu}\, v >(T)$

- Sexaquark DM potentially works well
  - natural parameters
  - impending tension from direct detect?
- lighter DM ⇔ larger n_{DM}
  - same distribution of KE, higher v
  - easier to evade direct detection

$$\langle \sigma v \rangle = \sqrt{\frac{8}{\pi \mu_{ab}}} T^{-3/2} \int_0^\infty dE\, E\, \sigma(E)\, e^{-E/T}$$





for details on BBN, see Serpico+04

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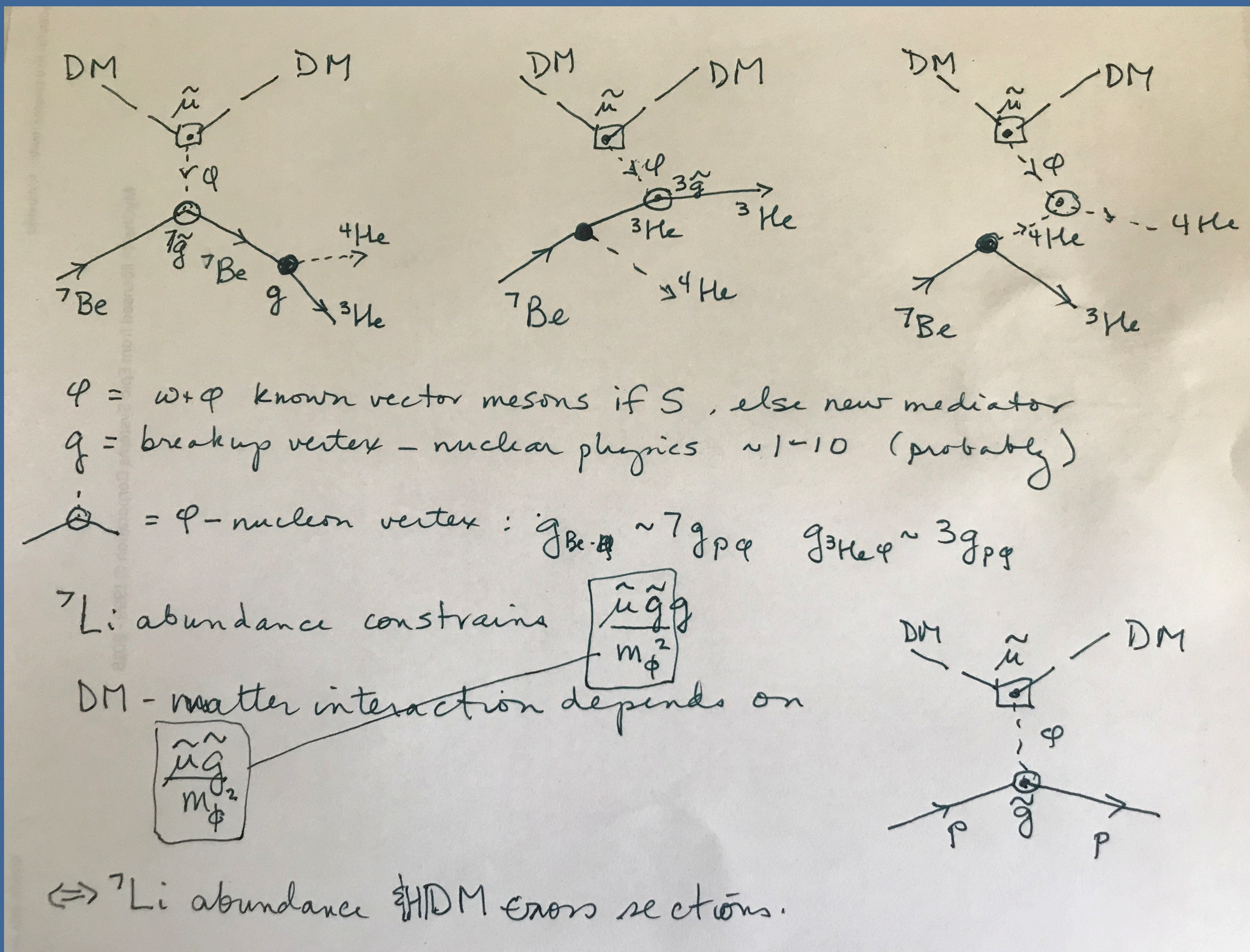
HIDM break up of ^{7}Li & ^{7}Be

(GRF + R. Galvez, in preparation)



Not so trivial to calculate σ_{bu}

- 3-body final state
- 4-parameter phase space integration
- poles near physical region
- first results encouraging

KE threshold for breakup =

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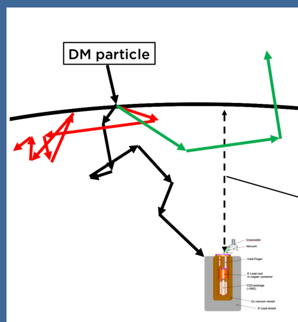
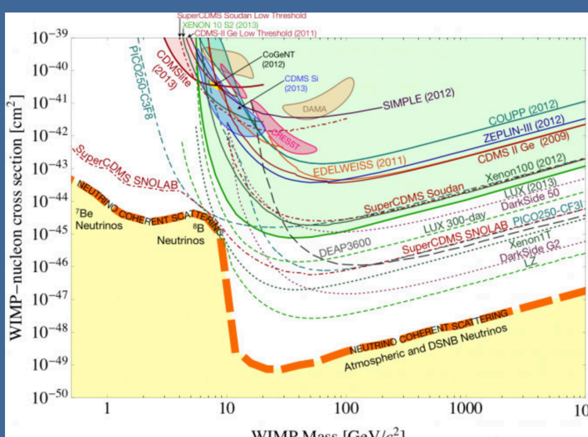
[d, 2.2 MeV, replenished]

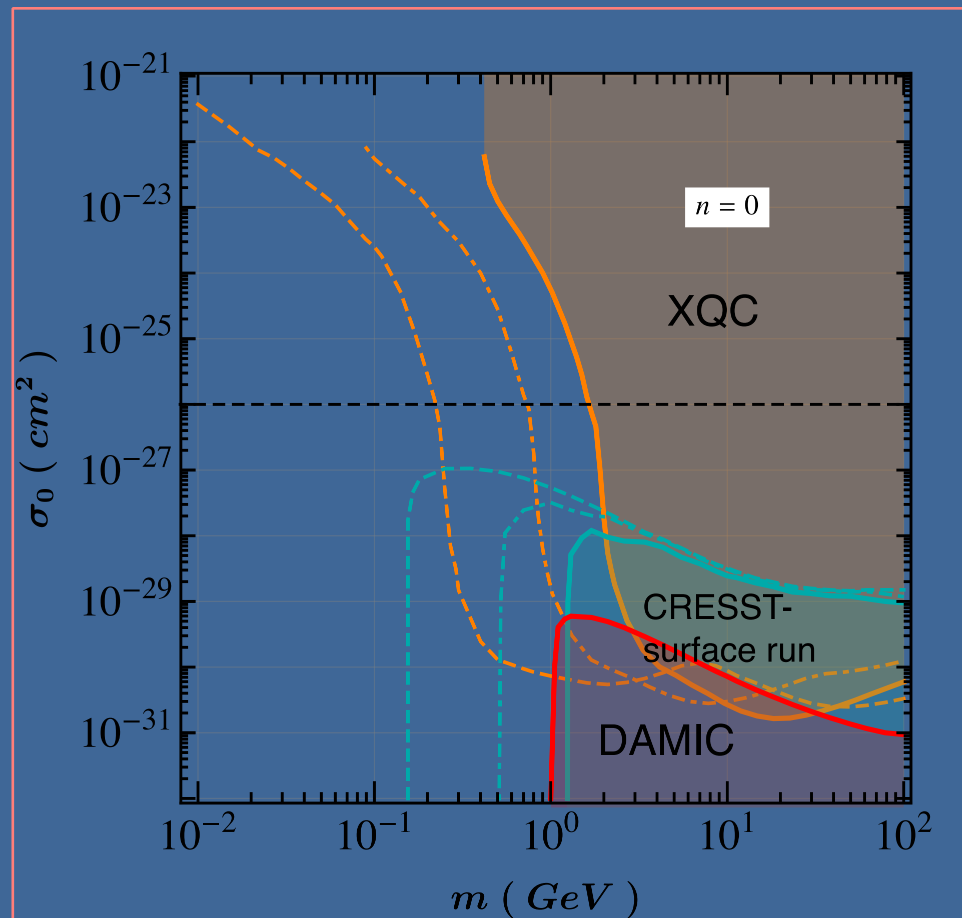
Direct Detection Limits on Hadronically Interacting Dark Matter

Shielded detectors are not sensitive for large σ_{DM-N} and $m_{DM} \lesssim$ GeV (energy loss)



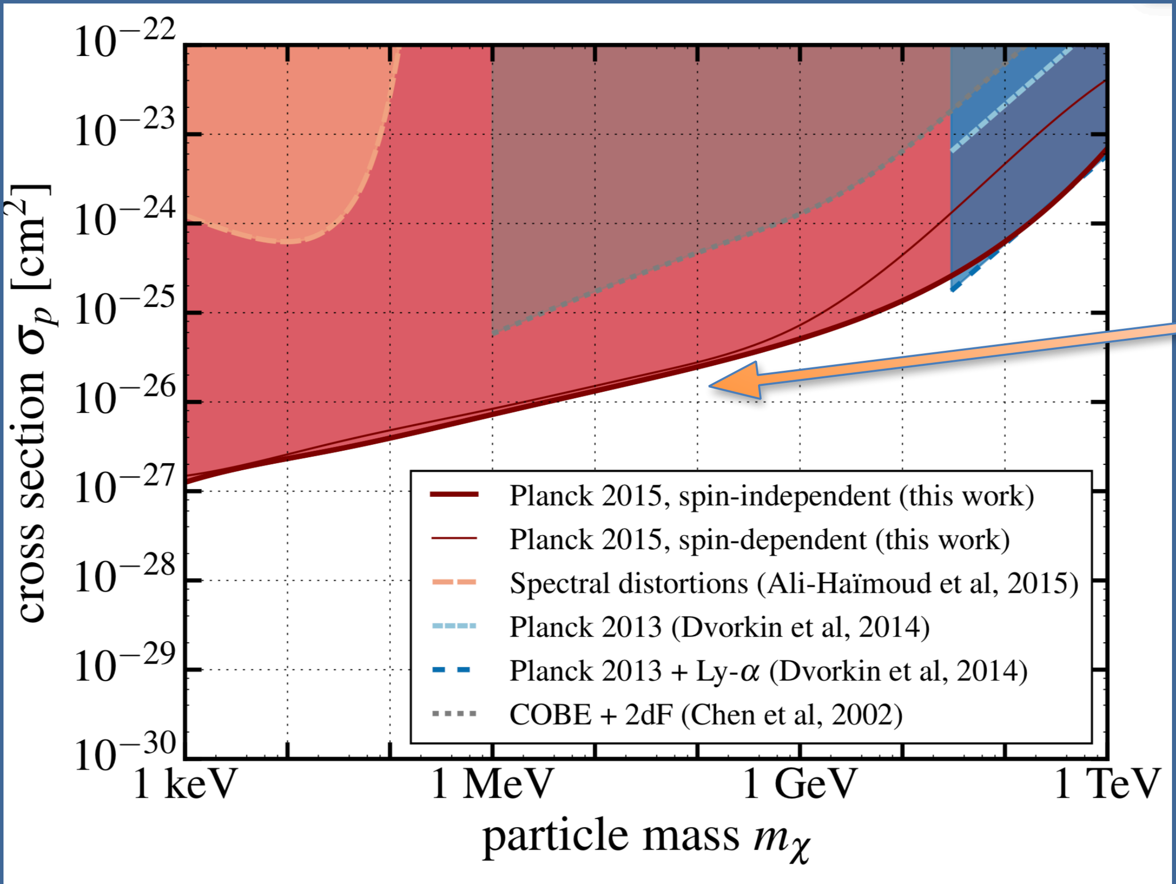
Familiar WIMP limits DO NOT APPLY





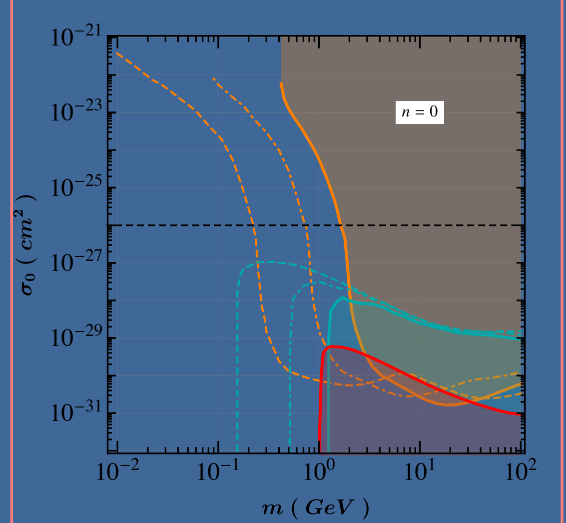
direct detection limits for HIDM   Mahdawi-GRF 2018

MeV-GeV: cosmology



Glucevic-Boddy 2017

Hadronic-level cross sections are allowed…



direct detection limits for HIDM
Mahdawi-GRF 2018

Hadronically interacting Dark Matter can form atmosphere around Earth ➜ *new constraints for 0.5-5 GeV*

D. Neufeld, GRF, C. McKee 2018

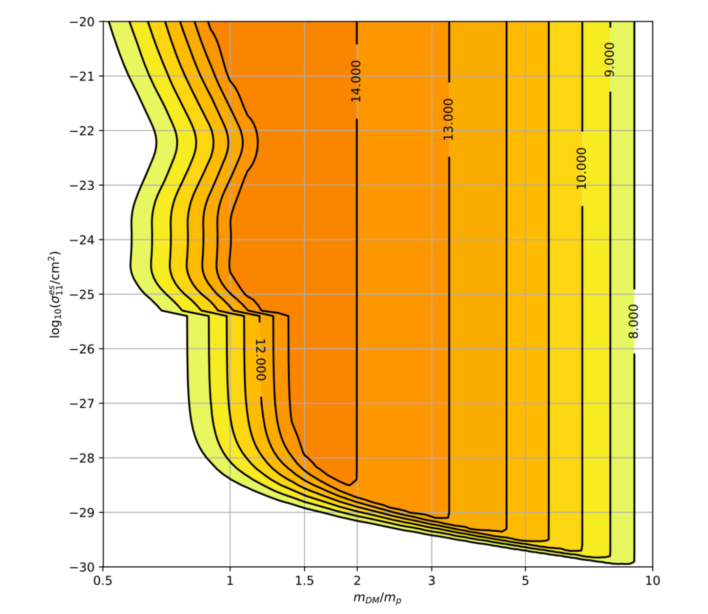


Fig. 6.— Number density of HIDM at the Earth's surface, $n_{\rm DM}(R_\oplus)$, in the $\mathrm{m_{DM}} - \sigma_{11}^{\rm es}$ plane. Contours are labeled by $\log_{10}(n_{\rm DM}/{\rm cm^{-3}})$.

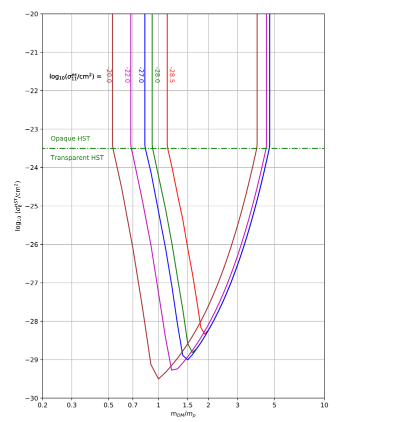


Fig. 9.— Upper limits on $\sigma_8^{\rm sc}$, implied by 0.8 km yr^{-1} orbital decay rate for a satellite at an altitude of 600 km. Results are shown for three values of $\sigma_{11}^{\rm es}$ for which the LSS lies in the crust ($10^{-28.5}$, 10^{-28}, and $10^{-27}\,{\rm cm^2}$), and two values for which the LSS lies in the atmosphere (10^{-22} and $10^{-20}\,{\rm cm^2}$). The curves are labeled with $\log_{10}(\sigma_{11}^{\rm es})$.

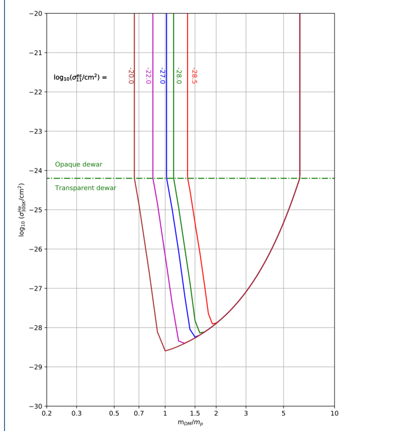


Fig. 10.— Upper limits on $\sigma_{300\,{\rm K}}^{\rm He}$ implied by a LHe vaporization rate of $\leq 0.5\%$ per day, for LHe exposed to 300 K thermal HIDM. Results are shown for several values of $\sigma_{11}^{\rm es}$. The curves are labeled with $\log_{10}(\sigma_{11}^{\rm es})$.

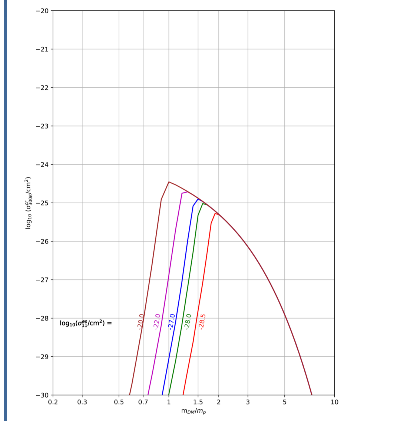


Fig. 12.— Lower limits on $\sigma_{300\,{\rm K}}^{\prime {\rm cr}}$, obtained from the requirement $k_{\rm DM}$
$4.3 \times 10^5\,{\rm erg\,s^{-1}\,cm^{-1}\,K^{-1}}$. Results are shown for several values of $\sigma_{11}^{\rm es}$. The curves a
labeled with $\log_{10}(\sigma_{11}^{\rm es}/{\rm cm^2})$. The allowed region is *above* the curves.

- Limits strongest for DM masses 1-3 GeV cross sections > 10^{-29} cm^2
- Using them to constrain models is underway (GRF+Xingchen Xu)

Interpreting limits on dark Matter with Hadronic Interactions

(GRF + Xingchen Xu, in preparation)

$$V(r) = \frac{\alpha}{r}\, e^{-r\, m_\phi}$$

m_ϕ = 1 GeV (flavor-singlet **ω-φ** combo), sourced by p or A

- v/c (DM) ~ 10^{-3} 10^3 km/s (galaxy clusters) down to 1 km/s (atm & z = 17)
    - must solve Schroedinger Eqn. **Born approximation generically fails badly**
    - cross section depends only on combos $a = \frac{v}{2\alpha}$ and $b = \frac{2\alpha\mu}{m_\phi}$

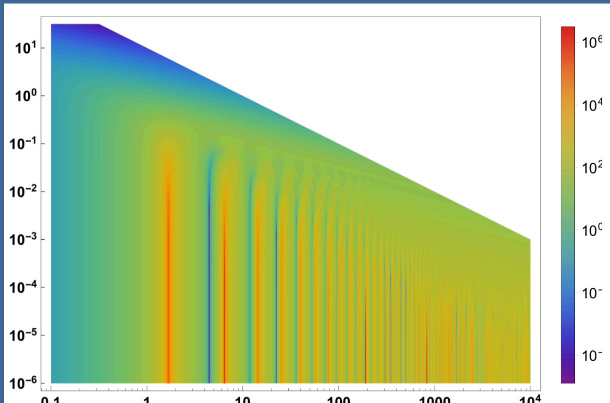


FIG. 1: $\sigma\, m_\phi^2$ as a function of $a = \frac{v}{2\alpha}$ and $b = \frac{2\alpha\mu}{m_\phi}$.

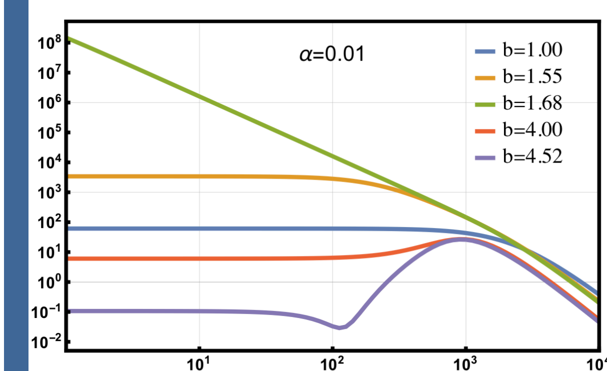


FIG. 4: $\sigma\, m_\phi^2$ versus v in km/s, for 5 values of $b = \frac{2\alpha\mu}{m_\phi}$.

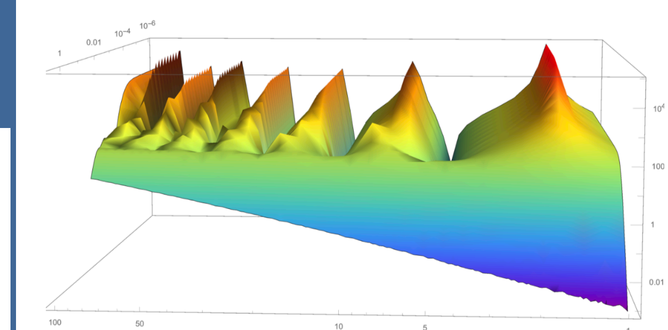


FIG. 2: 3D plot of $\sigma\, m_\phi^2$ in the a, b plane; b increases to the left and a decreases toward the back.

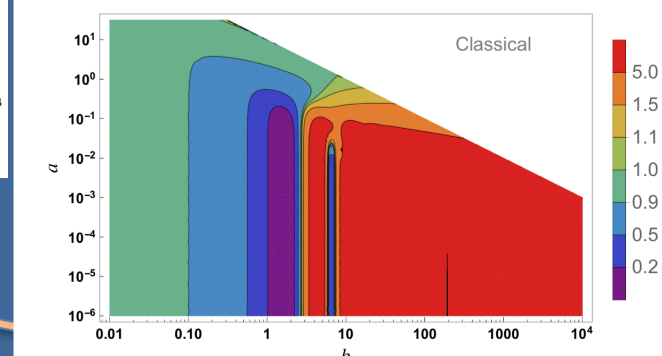
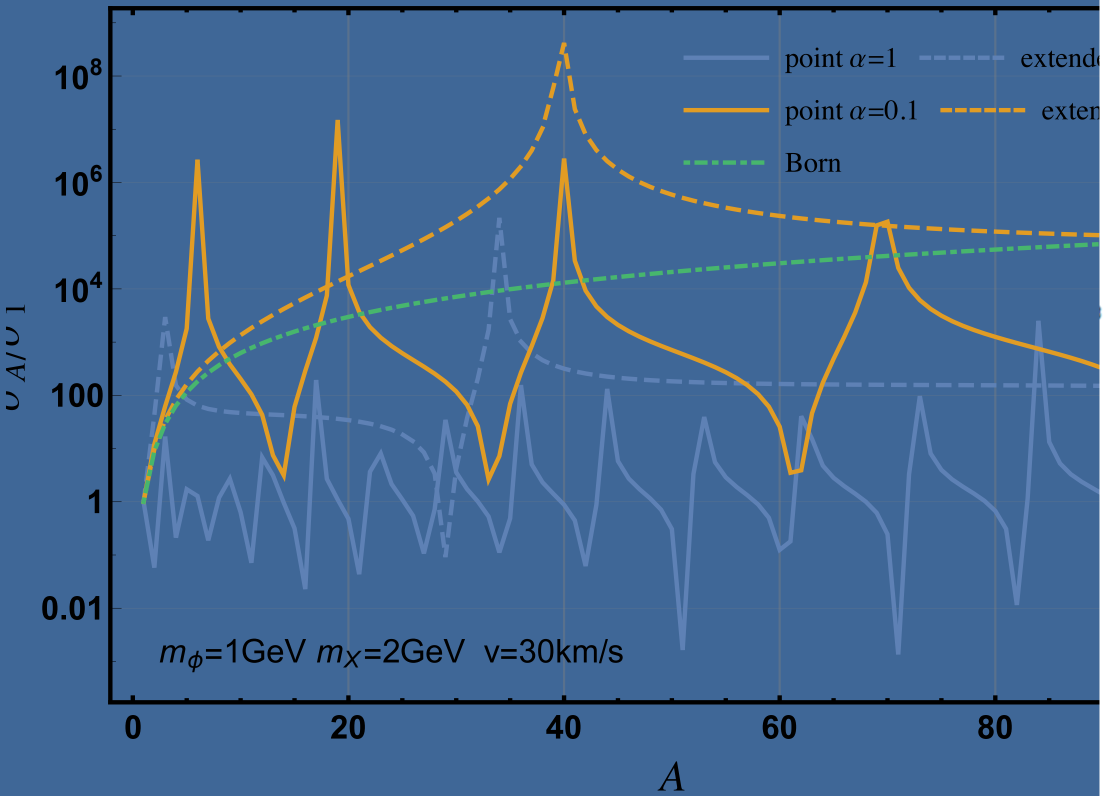


FIG. 3: Ratio of Born Approximation and Schroedinger Equation

Plenty of Room for HIDM, for now…

(GRF + Xingchen Xu, to appear shortly)

Caution: A-depedence very sensitive to nuclear form factor. Born approximation often misleading, by orders of magnitude.



Allowed regions of coupling from XQC (best Direct Detection)

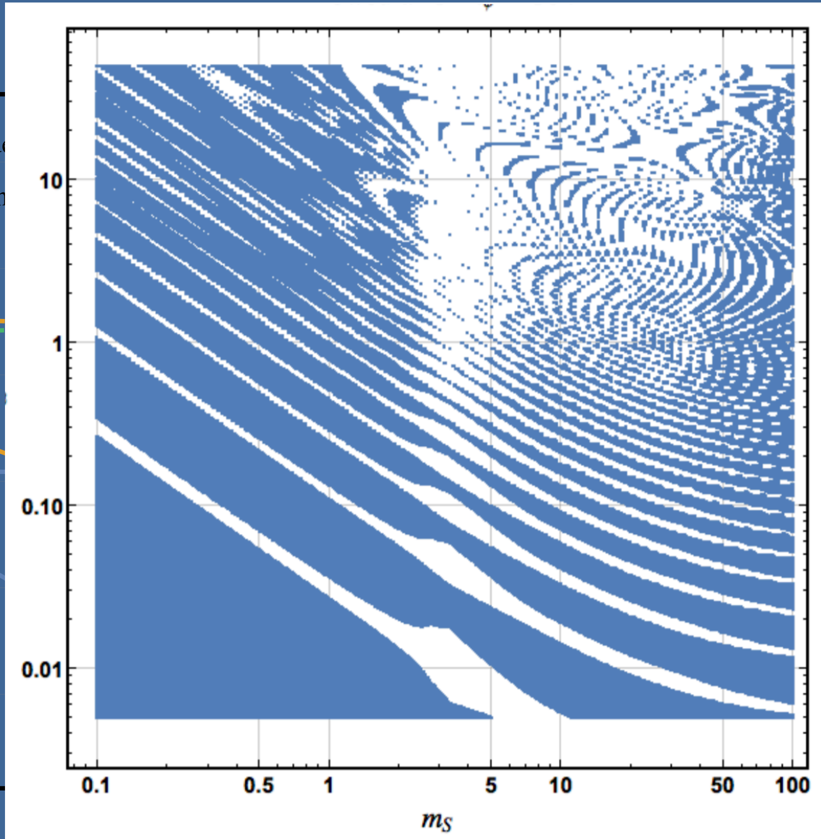


FIG. 7: Allowed regions (blue) in the coupling-DM mass plane α (vertical axis) and m_{DM} in GeV (horizontal axis) from XQC using

Alternatives to ^{7}Be breakup by HIDM

- New Physics
  - η (baryon-photon ratio) was larger at BBN than at recombination* due to late entropy injection; must happen before $z = 10^7$ to avoid constraints from spectral distortion.
    *(when measured by CMB)
  - Time-varying α to decrease binding energy of D during BBN
    - Dmitriev, Flambaum,Webb 2004
    - Coc, Nunes, K. Olive, Uzan, Vangione 2007

    but doesn't actually work => too-big D/H
  - Supra-thermal hadrons from DM decay (but ruins D&4He)
- Systematic problem with 7Li abundance measurements?

Summary

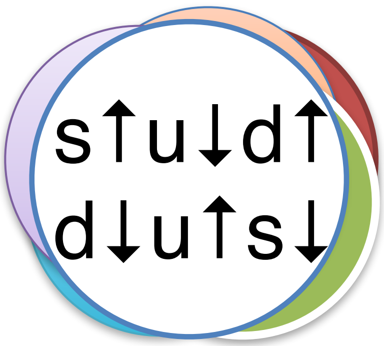
- ^{7}Li and BBN may become a smoking gun for HIDM in the MeV-few GeV mass range.
  - Factor-4 reduction relative to CDM prediction may be due to DM breakup (need mass ~ MeV-few GeV)
  - In-principle testable by looking for (reduced) ν_e *line* from
    $^7Be + e^- \rightarrow {}^7Li + \nu_e$ (Khatri-Sunyaev 2010)
- Requirements on Dark Matter to fix 7Li:
  - mDM >~ MeV, from BBN limit on relativistic species
  - σ_{bu} / m_{DM} ~ hadronic
  - Not too heavy (<~10 GeV)
    - heavy -> need higher cross section σ ~ 1/DM density
    - heavy -> <v> smaller (<v> ~ $1/\sqrt{m}$)

Backup Slides

Sexaquark Dark Matter

Glennys Farrar, NYU

6-quark, Q=0, B=2
Spin-0, scalar
Flavor singlet



S

Uniquely among hadrons, Fermi statistics is compatible with being symmetric in space and totally antisymmetric (singlet) in:

color
flavor **(Most-Attractive Channel)^3**
spin

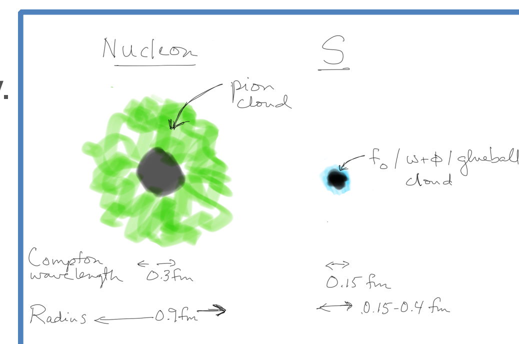
Hypothesis: S is *stable and spatially compact*
M_S <~ 2 m_p

This is compatible with all experiments and theory. *GRF 1708.08951*

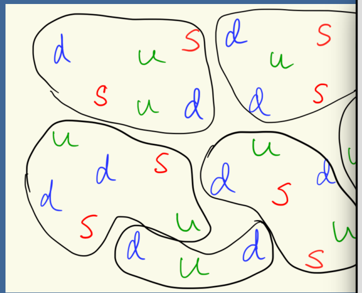
Eludes detection in accelerators because:

- neutrons are similar and 10^6 x more abundant
- small wfn overlap => hard to produce or destroy.

OK with direct detection expts *Mahdawi+GF1804.03073*

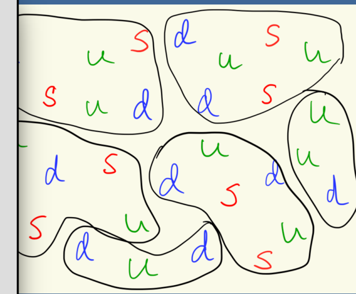


Same quark content as H-dibaryon* (Jaffe 1977), but different physics:
not a loosely bound di-Λ! *mass ~ 2150 MeV in bag model — decays in 10^{-10} s



DM to baryon ratio

using *stat mech, quark masses & temperature* of QCD transition



Prediction is correct AND accurate to ~20%, for entire range of M_S and T_{QCD}

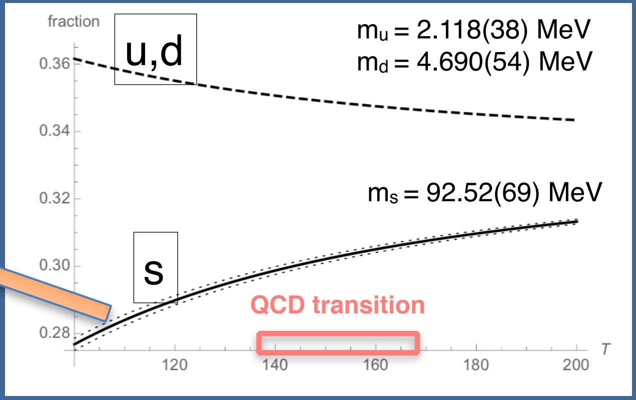
GRF, hep-ph:1805.03723

$m_S/(2m_p)$

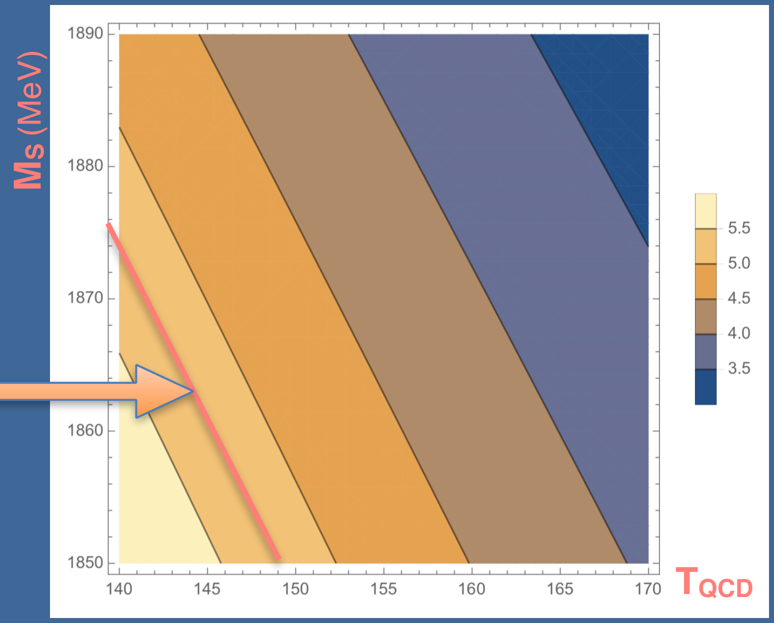
$$\boxed{\frac{\Omega_{DM}}{\Omega_b} = \frac{y_b\,\kappa_s\,3f_s}{1-\kappa_s\,3f_s}}$$

$$\kappa_s(m_S,T) = \frac{1}{1+(r_{\Lambda,\Lambda}+r_{\Lambda,\Sigma}+2r_{\Sigma,\Sigma}+2r_{N,\Xi})}$$

$$r_{1,2} \equiv \exp[-(m_1+m_2-m_S)/T]$$



Ω_{DM} / $\Omega_{b\ obs}$ = 5.3 ± 0.1



Prediction also applies to strange quark nuggets & PBH…
if sexaquark, places limit on breakup cross section.