Sexaquark Mass in the Cooper Triples Formalism

Biplab Mahato

@ Kraków

December 13, 2025

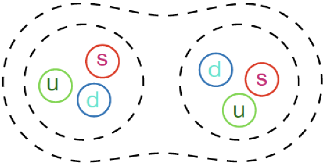
Motivation

- Sexaquark has been hypothesised to be a deeply bound, compact six-quark bound state of (uuddss).
- It has been proposed as a candidate for dark matter. (**Farrar (2018)**)
- Numerous work including its effect on the softening of equation of state for neutron stars. (**Shahrbaf et. al. (2022)**).
- Experimental signal is yet to be observed. Dores-Farrar-Kornakov[1] proposed antiproton-nucleus system $\bar{p} - {}^{3}\mathrm{He}$'s annihilation as a probe.
- There has been a significant debate on its mass.
- I will introduce a model inspired from condensed matter physics to describe the mass.

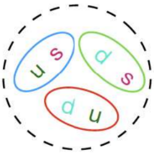
[1] Eur. Phys. J. C (2023) 83:1149

Sexaquark

- It is different from Dihyperon.
- It is proposed to be neutral, flavor singlet scalar particle with spin 0^+.
- If the sexaquark binding energy deep enough then the decay can happen via doubly weak process granting it a lifetime greater than the age of the universe. Which makes it a very good candidate for dark matter.



H-dibaryon ($\Lambda\Lambda$ molecule)



Sexaquark (3-diquark state)

Sexaquark Mass

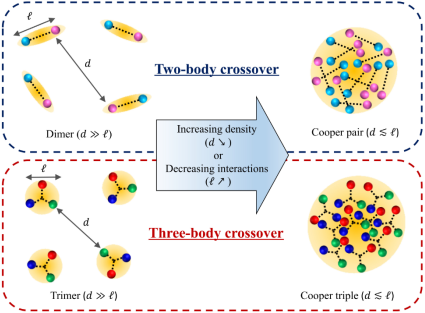
- Theoretical estimation of Sexaquark mass has a very broad range.
- MIT bag model with $SU(3)_f$ predicts 1760MeV.
- From QCD sum rules in $SU(3)_f$ 1878MeV and 2190MeV otherwise.
- Three diquark state with chromomagnetic and electric interaction $M_S = 1883$MeV. (**Buccella PoS**)

Bounds

- 1200MeV sexaquark can thermally repoduce the desired cosmological dark matter abundances.
- Nuclear stability restricts smaller sexaquark masses. $M_S \geq 1860 MeV$.
- Masses below 1878MeV allows for stability against faster decay.
- So the interested region is the narrow region of mass between 1860 and 1878MeV.

Cooper Triples

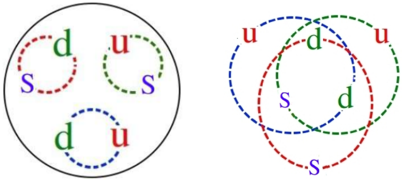
- Cooper Triples are extension of the Cooper pairs in condensed matter physics.
- Three particles near the Fermi surface interact with each other with the three body forces.
- It also undergoes Superconducting to Bose-Einstein condensate(BCS-BEC) transistion, which has been mapped to hadron-quark crossover in the paper (**Tajima et. al. (2023)**).



(**Photo: Tajima et al. (2023)**)

Cooper Triples

- The same method can be extended to include diquarks instead of quarks, creating sexaquark.
- Blaschke et. al. has used this framework in the context of quark deconfinement in compact stars.



(Photo: Blaschke et al. arxiv:2202.05061)

Cooper Triples

- We solve the in-medium 3-particle T matrix with contact interaction.

$$T_3(\Omega) = \frac{V_3}{1 - V_3 \Sigma_3(\Omega)}$$

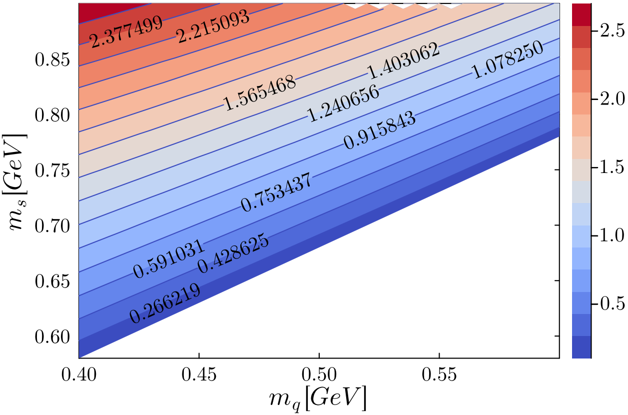
$$\Sigma(\Omega) = \sum_{\vec{k},\vec{q}} \frac{(1 - f_{\vec{k}})(1 - f_{\vec{q}})(1 - f_{\vec{k}+\vec{q}}) + f_{\vec{k}} f_{\vec{q}} f_{\vec{k}+\vec{q}}}{\Omega + 3\mu - \varepsilon_{\vec{k}} - \varepsilon_{\vec{q}} - \varepsilon_{\vec{k}+\vec{q}}}$$

where $f_{\vec{k}} = -\eta / \left(\exp\left[\beta(\varepsilon_{\vec{k}} - \mu) \right] - \eta \right)$ where $\eta = \pm 1$ negative(positive) for Fermions(Bosons) as constituent particles.

Sexaquark Mass Prediction

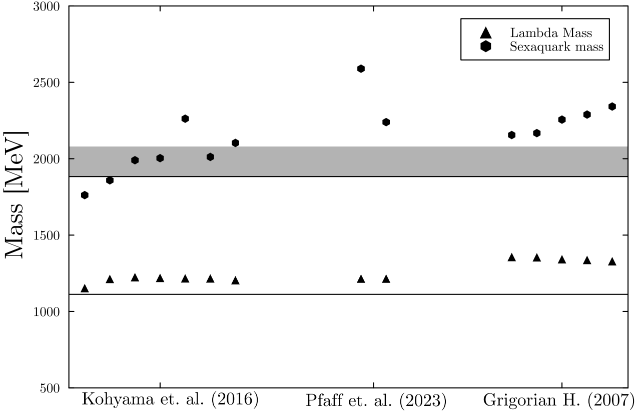
- We have two unknowns the constant coupling V_3 and a regularization cutoff(Λ) for the integrals.
- We treat Nucleon and Lambda baryon as Cooper triples of quarks and use their physical masses to fix the above parameters.
- The same parameters are used to calculate the sexaquark masses while treating it as a Cooper triples of three diquarks.
- Color confinement requires the diquarks inside sexaquarks to have same colors as quarks inside baryons. Since the coupling V_3 (assumed to be flavor agnostic), which is a proxy for gluonic interaction depends solely on color charges, one can use the same coupling for quarks and diquarks.

Sexaquark Mass Prediction



- We don't fix the quark masses and calculate sexaquark mass as a function of them. Diquark masses are taken to their thresold values.

Sexaquark Mass Prediction



- We take quark and diquark masses from chiral effective models parameters from various sources.

Medium Dependence

- Medium dependence of sexaquark requires input of the quark's medium dependence. Here we use 3 flavor NJL model for that.
- Sexaquark undergoes Mott dissociation at finite temperature, where stable bound sexaquark becomes unstable state with decay widths.

Conclusions

- Sexaquark is an interesting candidate to explore both theoretically and experimentally.
- We present an approach where we treat sexaquark as Cooper Triples.
- The simplistic model can reproduce mass of sexaquark consistent with the relevant bounds.
- In medium, either in high temperature or densities it undergoes Mott transition.
- In future it would be interesting to see more in medium effects such as Borromean state where the consituent diquarks becomes unbound while the sexaquarks remains bound.
- A more bootom-up approach using cluster decomposition is warrented.

Thank You!!