SUNny gluonia as DM

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HET-BNL

Lattice 2016; 07/27/16

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[with Yue Zhang @ Caltech; arXiv:1602.00714=>PRD]

outline

- **Intro …….**
- **Key important characterstics**
- **Basic philos…..seek as simple a solution as possible which *naturally* accounts for them**
- **Viable candidate?**
- **Possible repercussions**
- **Future directions…..inc possible non-perturbative (lattice) studies**

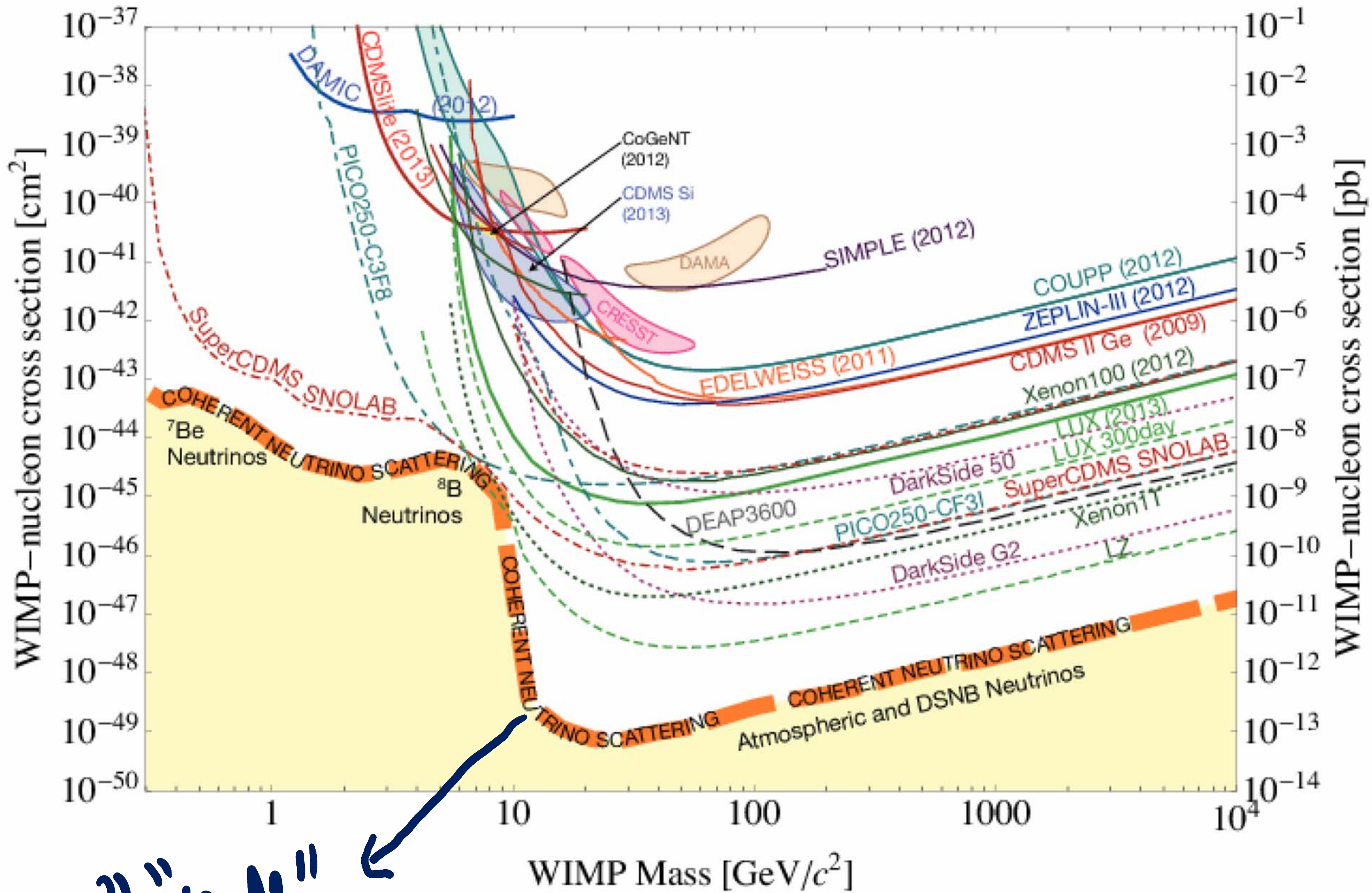
Introduction + motivation

- **Preponderance of DM over matter is sometimes (often) used as a rationale to suggest that the underlying explanation for DM may well require considerable complexity i.e. much more complicated than theories of matter**

- **Pursue different philosophy:**
- **Explore as simple a solution as possible and introduce complexity iff forced by experiments and observations**

Two Key characteristics

- **Proven to be exceedingly difficult for direct detection ……………….=> fig**
- **Remarkably, the only compelling evidence of DM that so far we have is gravitational !**
- **Seek simple natural explanation for these key features**



ν "wall"

[irreducible ν background]

SIMPLICITY IS OUR PRIORITY!

SU(N)…simplest theory with non-trivial mass scale

$$\mathcal{L} = -\frac{1}{4} H^a_{\mu\nu} H^{a\,\mu\nu}$$

Parameters: N, Λ

Implicit: θ [later]

IN FACT THIS THEORY IS SO SIMPLE AND SO ELEGANT, IT SEEMS DIFFICULT TO BELIEVE THAT NATURE DOES NOT MAKE USE OF IT!

LOW LYING SPECTRUM

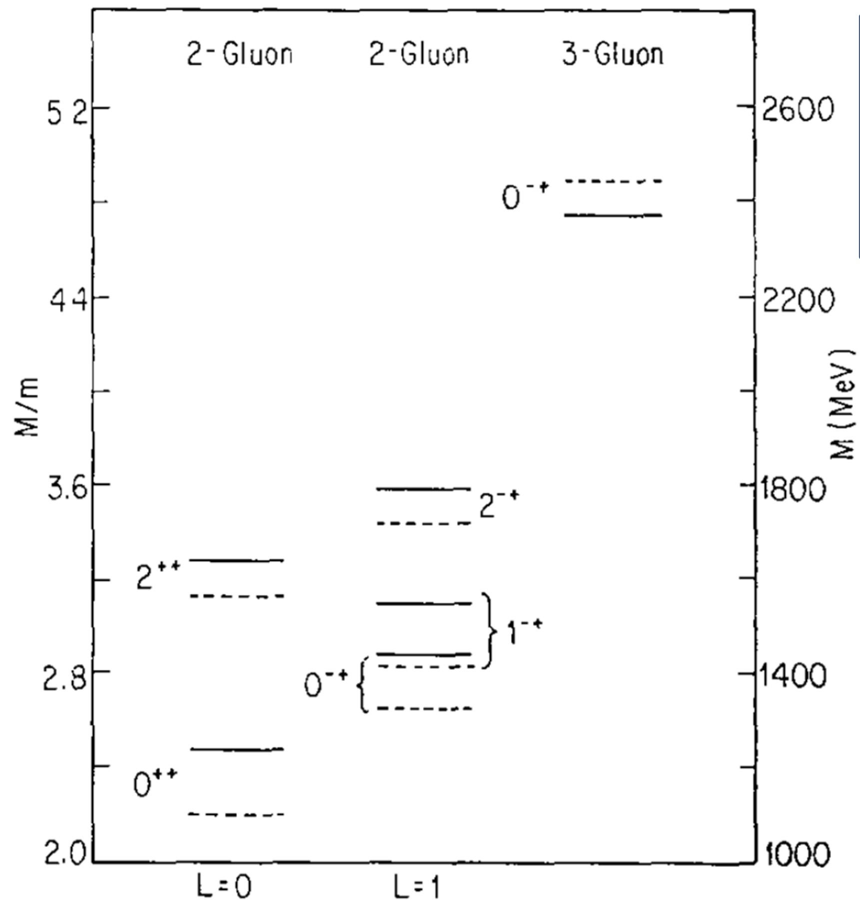
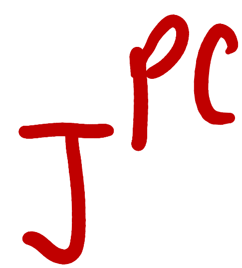
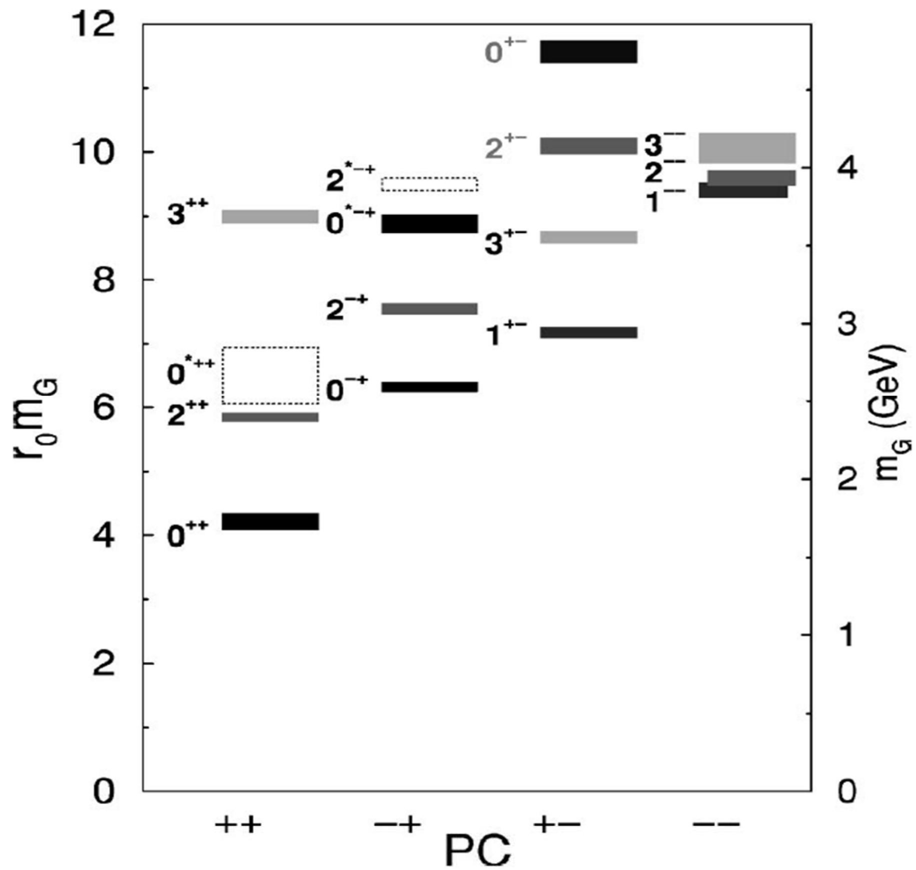


Fig. 3. Results of the numerical calculations. The scale on the left is in units of the gluon mass m; that on the right is in MeV, assuming m = 500 MeV. The solid lines refer to $s = 4m^2$ in the potential (6), and the dashed lines refer to a self-consistent determination of s.

Cornwall + AS PLB'83





MORNINGSTAR
+
PEARDON
PRD'99
Gluona Spectrum
SU(3) Pure gauge

FIG. 8. The mass spectrum of glueballs in the pure SU(3) gauge theory. The masses are given in terms of the hadronic scale r_0 along the left vertical axis and in terms of GeV along the right vertical axis (assuming $r_0^{-1} = 410$ MeV). The mass uncertainties indicated by the vertical extents of the boxes do *not* include the uncertainty in setting r_0. The locations of states whose interpretation requires further study are indicated by the dashed open boxes.

Low lying spectrum

- For QCD phenomenological models, [Cornwall+AS'80]

  as well as lattice calculations [Morningstar + Peardon'99] 0++ and 0-+ as lightest states with masses ~Λ_{QCD}
- For N>> 1, lightest gluonia masses go as

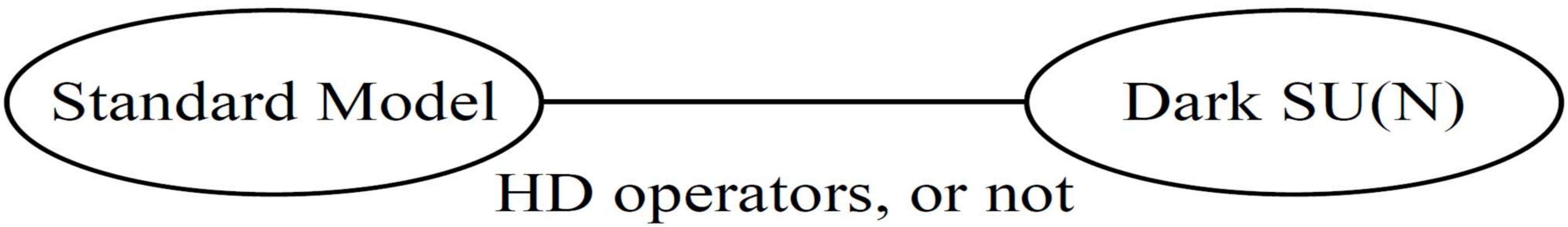
$$(\alpha + \beta/N^2)\Lambda$$

See : Lucini + Teper '01; Lucini, Rago + Rinaldi, '10

Interactions

- **Gravitational for sure…….decays to gravitons**

- **With SM ….unavoidable via higher dimensional operators**



- **No compelling reason to think nature cares whether DM interacts with our detectors or not**

Decays to gravitons

m = mass of lightest (i.e. 0++ onia)

$$\Gamma_\phi \sim m^5/M_{pl}^4 \sim \tau_U^{-1}\,(m/10^7\,\mathrm{GeV})^5$$

where $\tau_U = 10^{17}$ sec is the age of the universe

[Jim. Analysn]

immediate consequences

- **The mentioned interactions likely *naturally* account for:**

- **Why it has been so difficult to detect DM in "direct detection experiments"**

- **SUN-onia will of course have gravitational Interactions [more later]**

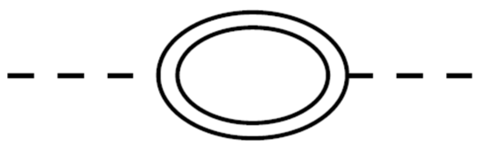
OUR FOCUS WILL BE ON THE LIGHTEST 0++ ONIA; MORE RECENTLY FORESTELL ET AL IN 1605.08048 HAVE EXTENDED CONSIDERATIONS TO OTHER ONIA

Interactions of dark [SUN] gluonia

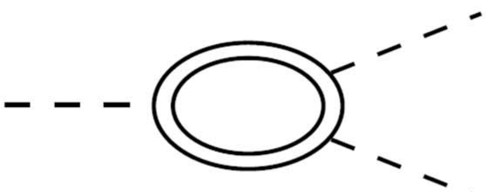
- Scalar potential:

$$V(\phi) = \frac{1}{2}m^2\phi^2 + \frac{1}{3!}\lambda_3\phi^3 + \frac{1}{4!}\lambda_4\phi^4 + \frac{1}{5!}\lambda_5\phi^5 + \cdots$$

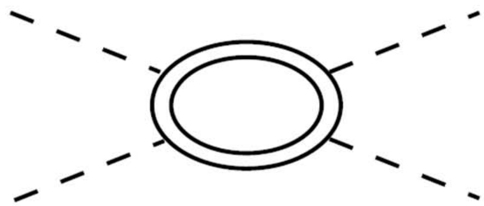
Power counting in the large N limit



$\phi \sim \sqrt{N}$



$\lambda_3 \sim \frac{m}{N}$



$\lambda_4 \sim \frac{1}{N^2}$

Constraints due structure formation I

- **2 to 2 elastic scattering of gluonia:**

  $\sigma \sim 1/m^2N^2$

- **For this DM to address the ``core/cusp problem''* of dwarf galaxies:**

$$0.1\,\mathrm{cm}^2/\mathrm{gram} < \sigma_{2\to 2}/m < 10\,\mathrm{cm}^2/\mathrm{gram}$$

$$m \sim 0.1\,\mathrm{GeV} \cdot N^{-4/3}$$

*See e.g. W. Blok 0910.3538

II

- **Interactions also allow 3=>2 inelastic annihilation**

  3=>2 reaction rate, Γ (3=>2) ~ $(n_\phi)^2$ σ (3=>2) with

  σ (3=>2) ~$1/m^5N^2$

- **The 3=>2 process tends to make ϕ relativistic & warmer until there gets to be balance with the reverse 2=>3 rate**
- **The final DM relic density is given by value of n_ϕ at the decoupling of the 3=>2 annihilation**

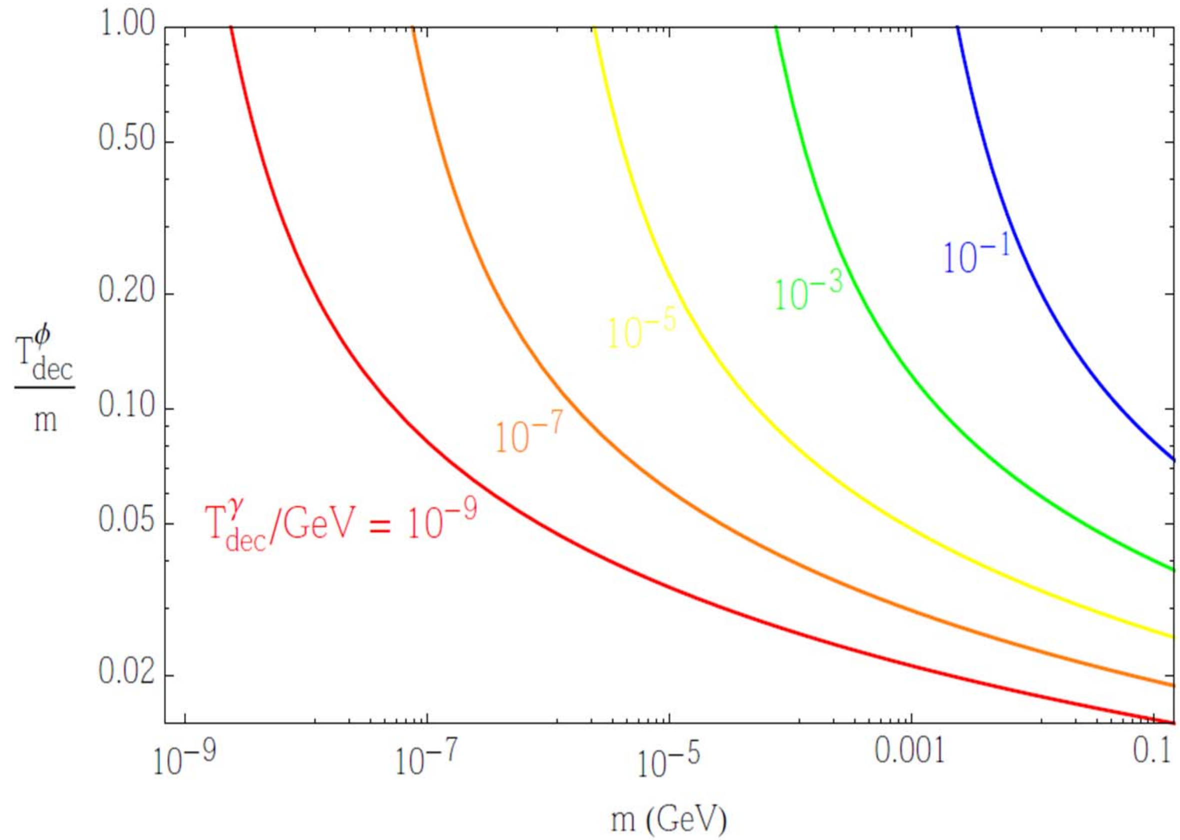
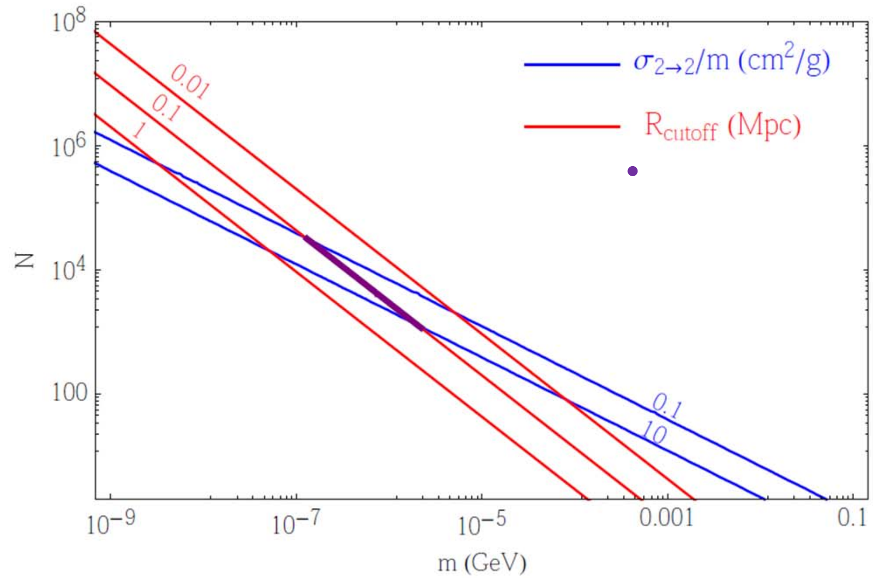


FIG. 2. Ratio of temperature T_ϕ to the mass m of ϕ particles at the decoupling of $3 \to 2$ annihilation that could give the correct dark matter relic density. The curves correspond to different photon temperatures (T^{γ}_{dec}) at this epoch. Roughly, T_ϕ is only one order of magnitude below the mass, and the ϕ particles remain heated before the decoupling.



For SI + WARM

$10^{-4} \le m \le 10^{-2}$ MeV

0.1 KeV   10 KeV

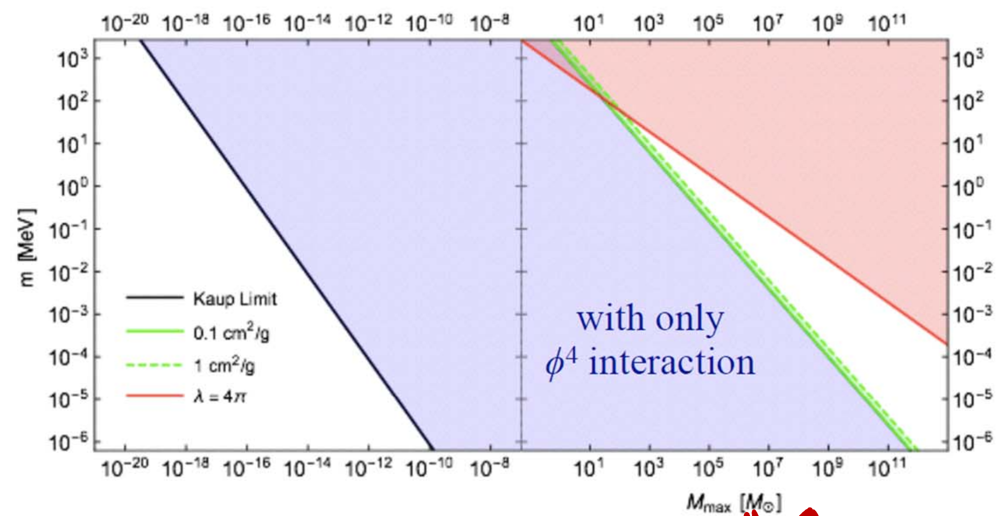
$10^5 \le N \le 10^3$

FIG. 1. The parameter space of m versus N where the lightest hidden glueball could be a self-interacting and/or warm DMC. The two blue curves correspond to constant values of DM self interaction cross section, $\sigma_{2\to2}/m = 0.1, 10\,\text{cm}^2/\text{gram}$, respectively. Self-interacting DM lives between the blue curves. The red curves correspond to constant values of damping scale in the power spectrum, $R_{\text{cutoff}} = 0.01, 0.1, 1\,\text{Mpc}$, respectively. Warm DM lives along the middle red curve. The glueball dark matter can be both self-interacting and warm at the intersection of the two regions (thick purple curve).

More Gravitational Effects

Gravitation: BEC of dark glueball yields macroscopic dark stars.

Repulsive interaction ($\lambda_4 > 0$) could leads to lensing effects.



SI+W DMC ⇒ $10^6 \to 10^8 \odot$!

Further work in progress to explore more general potentials.

Eby, Kouvaris, Nielsen, Wijewardhana (1511.04474)

BEC of scalars with only ϕ^4 Repulsive interaction

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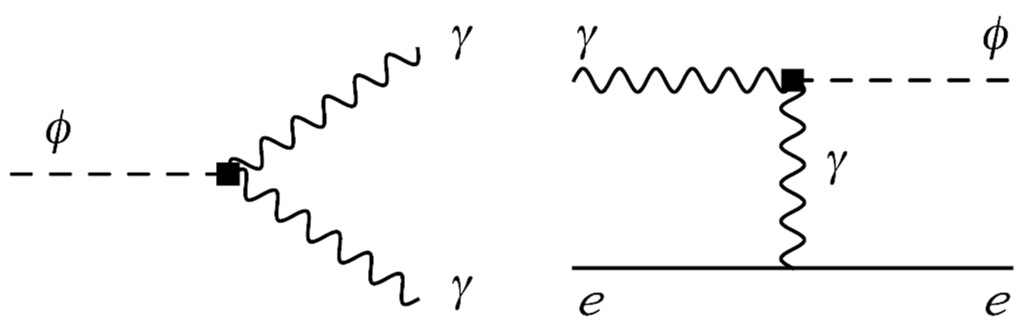
Interactions with the SM via HDO

$$\mathcal{L}_{int} = (1/M^n) H_{\mu\nu} H^{\mu\nu} \mathcal{O}_{SM}$$

interactions with photons as an example

$$\mathcal{L}_{int} = \frac{1}{M^4} H_{\mu\nu} H^{\mu\nu} (F_{\alpha\beta} F^{\alpha\beta}) \rightarrow \frac{N m^3}{M^4} \phi F_{\alpha\beta} F^{\alpha\beta}$$



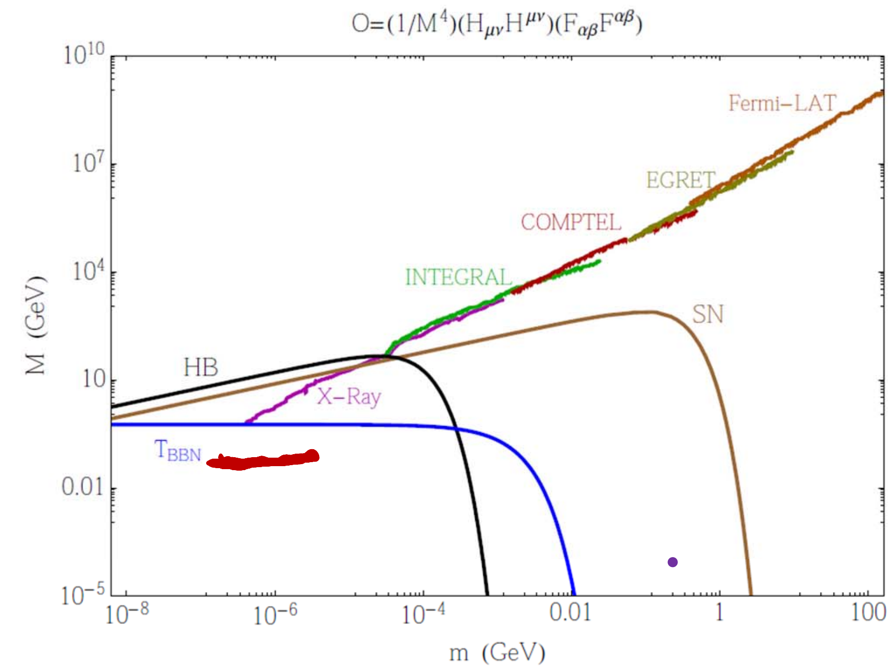


FIG. 3. Lower bounds on the cutoff scale M. Cosmic ray photon observations constrains glueball dark matter decay into photons, and from right to left, the curves correspond to constraints from Fermi-LAT, EGRET, COMPTEL, INTEGRAL, X-ray. The black (brown) solid curve is the lower bound on M from the energy loss argument of HB (SN). The blue curve represents the requirement that the hidden sector is not thermalized with the SM sector below the BBN temperature.

~ KeV < m_ϕ < MeV , M ~ EW Scale ~ 100 GeV

Implications of $\theta H\widetilde{H}$

- This can generate an effective interaction with the SM

$$\theta\,(1/M^4)(H\widetilde{H})(G\widetilde{G})$$

=> $$\theta_{\rm QCD} G\widetilde{G}$$

$$\theta_{\rm QCD} \sim (m/M)^4\theta$$

$< 10^{-3}$ automatically satisfied

Using nedm bound of 10 -26 em => $\theta_{\rm QCD} \lesssim 10^{-13}$.

Theta SUN ~ O(1) cannot be ruled out !
Possibly interesting implications

Key issues for non-perturbative studies

- Potential for s s scattering, attractive or repulsive?
- pp…..?

Repulsion

- Key to BEC into Dark SUN-onia stars[DSS]
- DSS could lead to gravitational lensing
- DSS gives rise to possibly different pattern of gravitational waves [under study]

FOR QCD SOME STUDIES

Glueball-glueball scattering in a constituent gluon model

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Abstract. In this work we use a mapping technique to derive in the context of a constituent gluon model an effective Hamiltonian that involves explicit gluon degrees of freedom. We study glueballs with two gluons using the Fock-Tani formalism. In the present work we consider two possibilities for 0^{++}: (*i*) as a pure $s\bar{s}$ and calculate, in the context of a quark interchange picture, the cross-section; (*ii*) as a glueball where a new calculation for this cross-section is made, in the context of the constituent gluon model, with gluon interchange.

arXiv 0407114

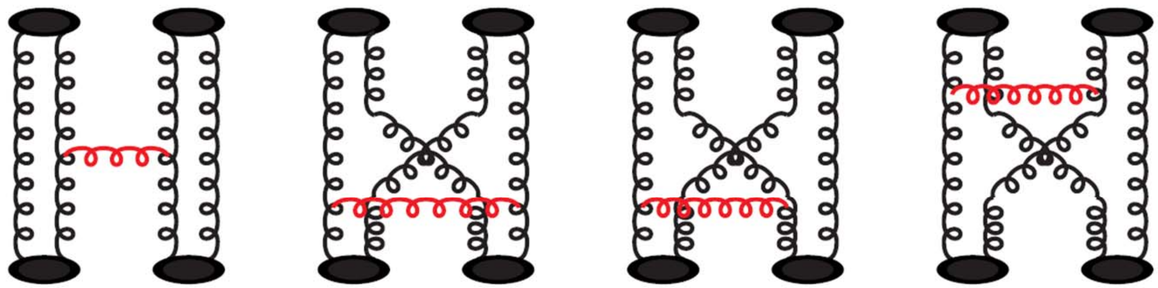
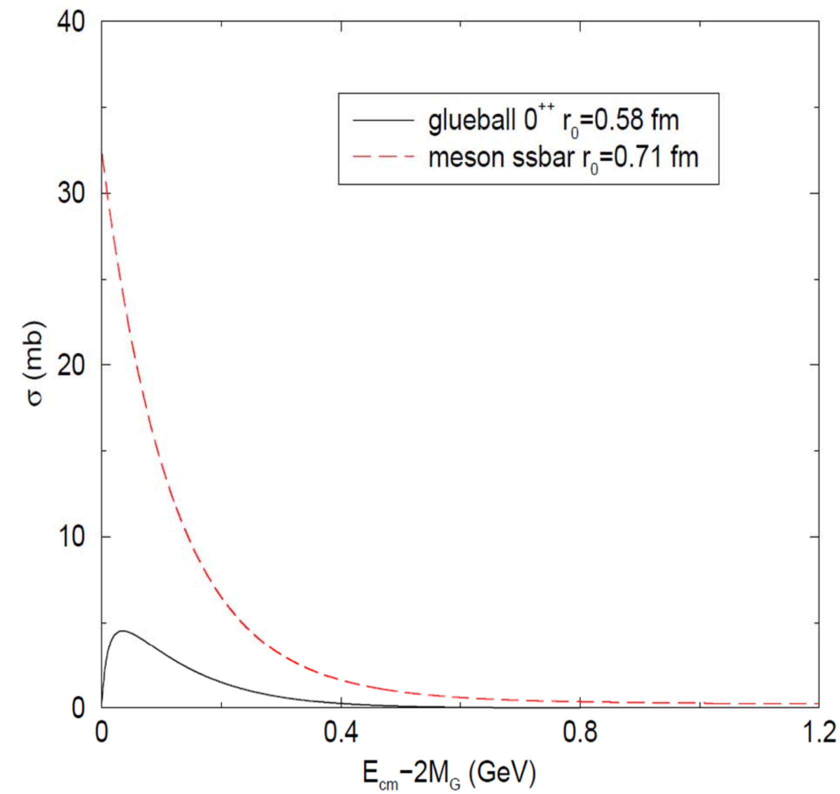


FIGURE 1. Diagrams representing the scattering amplitude h_{fi} for glueball-glueball interaction wi constituent gluon interchange.

1 gluon exch pot. model... rather naive?



0++ possibly repulsive?

FIGURE 2. Cross-section comparison for 0^{++} with the following parameters $\beta = 0.1$, $\lambda = 1.8$, $k = 0.21$, gluon mass $m = 0.6$ GeV. The $s\bar{s}$ quark model parameters: $m_q = 0.55$ GeV, $\alpha_s = 0.6$.

A well known study in QCD is ππ scattering

- In fact this is part of the RBC-UKQCD major project, K=> ππ and Ɛ' and in particular for Ɛ'

scattering phases of ππ are very important.

See [CU] thesis of Qi Liu [2012] and Daiqiang Zhang [2015] and in progress

- See also E. Shabalin, arXiv:1511.00498 who uses ChiPT.
- Scattering length for I=2 is + → repulsive
- And for I=0 is - → attractive

Summary & Outlook

- **SUN pure gauge theory provides a strikingly simple and viable DMC…[It'd be a bit surprising if nature does not make use of the simplicity of this theory]**
- **It provides a (technically) *natural* explanation for the only compelling evidence, i.e. gravitational, that we have so far**
- **It also *naturally* explains why direct detections so far have been giving null results**
- **Non-perturbative studies of this fascinating theory are called for, esp $\emptyset\emptyset \Rightarrow \emptyset\emptyset$ ….is it attractive or repulsive for low lying gluonia?**
- **Exciting possibility of BEC and gigantic Dark SUN "stars" of 10^6 to 10^8 X solar masses leading to the possibility of enhanced lensing effects!**

XTRAS

This paper gives an overview of the attempts to determine the distribution of dark matter in low surface brightness disk and gas-rich dwarf galaxies, both through observations and computer simulations. Observations seem to indicate an approximately constant dark matter density in the inner parts of galaxies, while cosmological computer simulations indicate a steep power-law-like behaviour. This difference has become known as the "core/cusp problem", and remains one of the unsolved problems in small-scale cosmology.

See e.g WJG De Blok

arXiv: 0910.3538