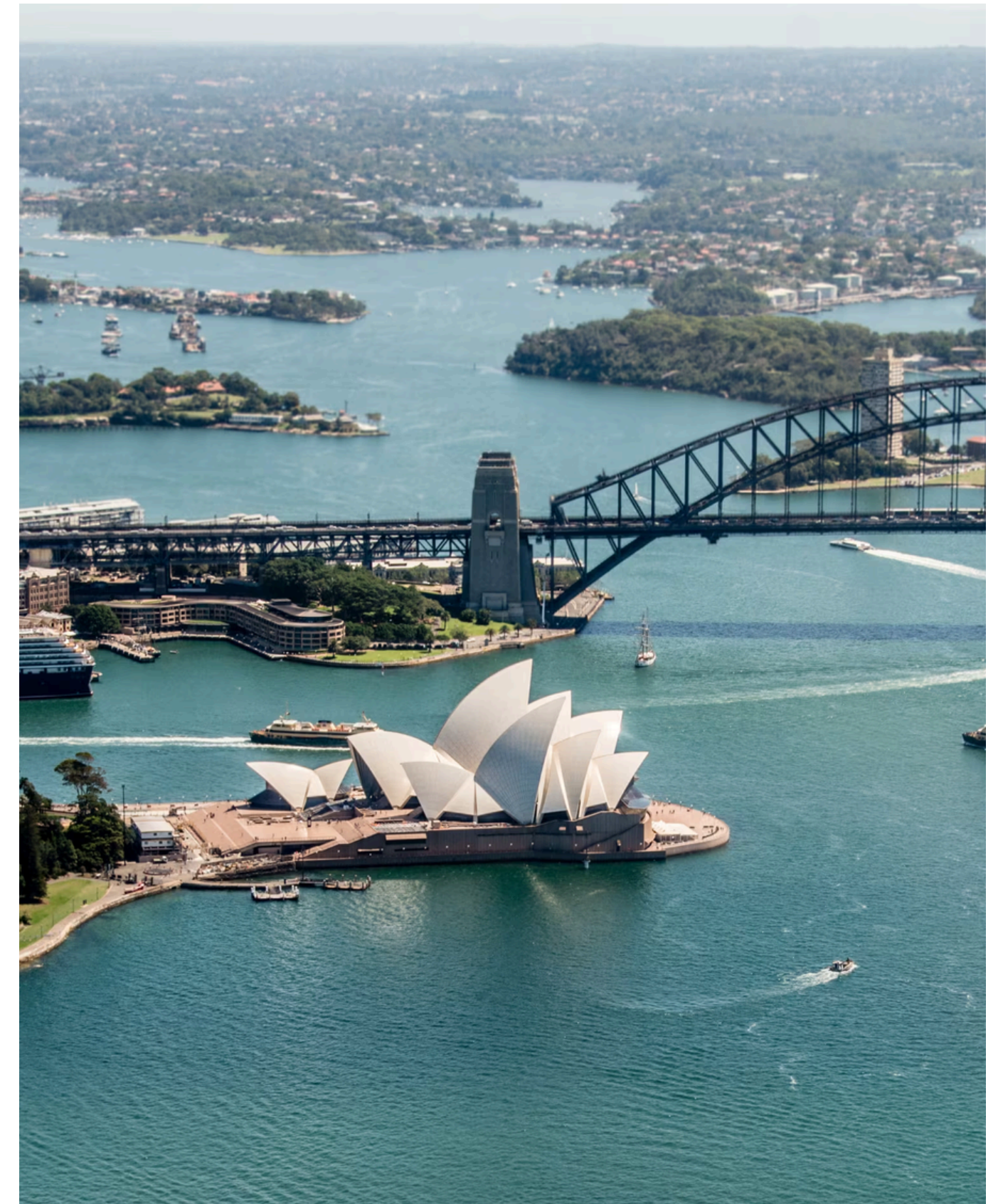


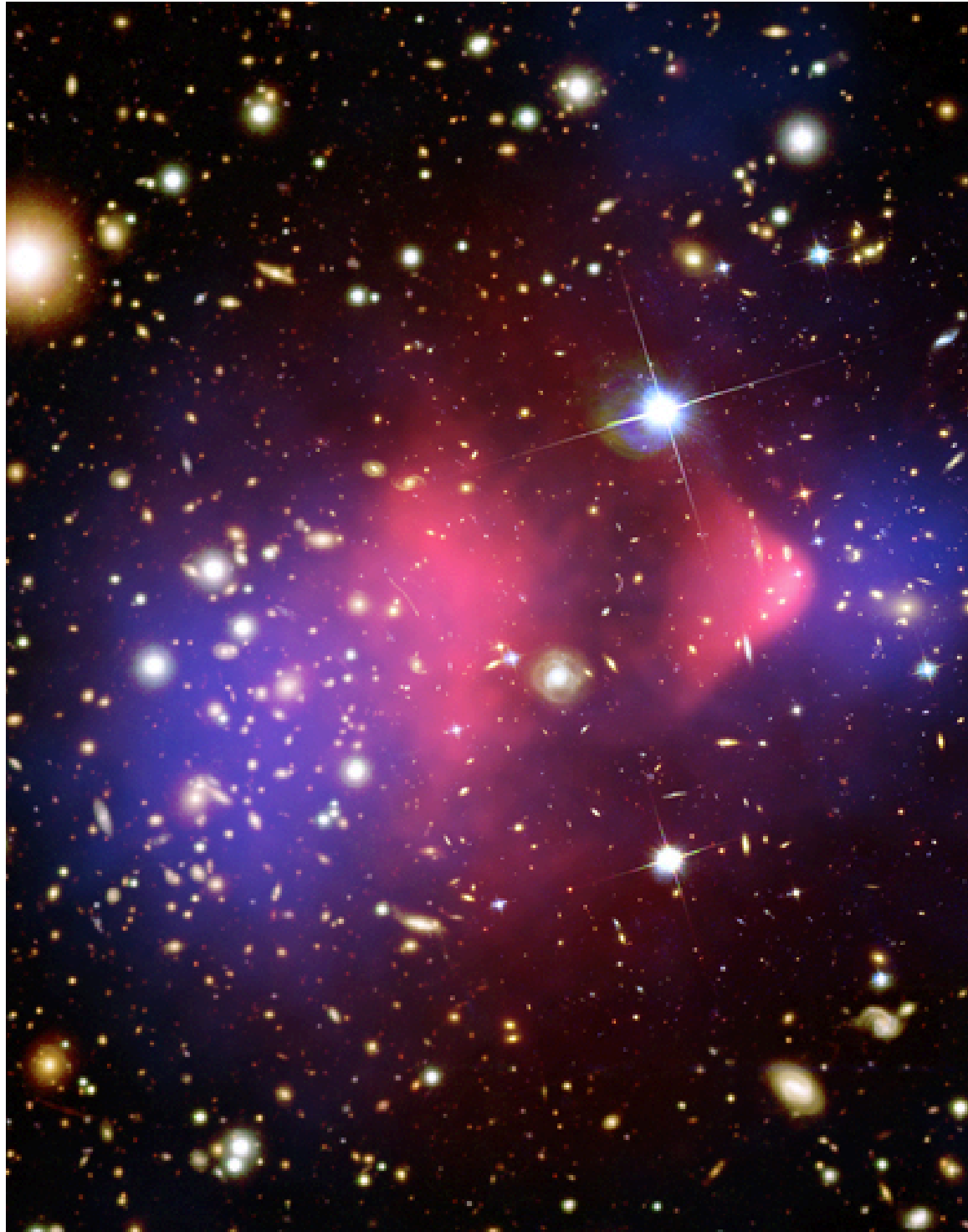
Giovani Dalla Valle Garcia and Juan Herrero-García
Based on: to appear soon arXiv: 2609.XXXXX

Self-Interactions Across Cosmic Scales
from
H E A V Y D A R K B A R Y O N S



XIX International Conference on Interconnections between **Particle Physics and Cosmology**
Sydney - September 1st, 2026





OUTLINE

Part I · Small Scales

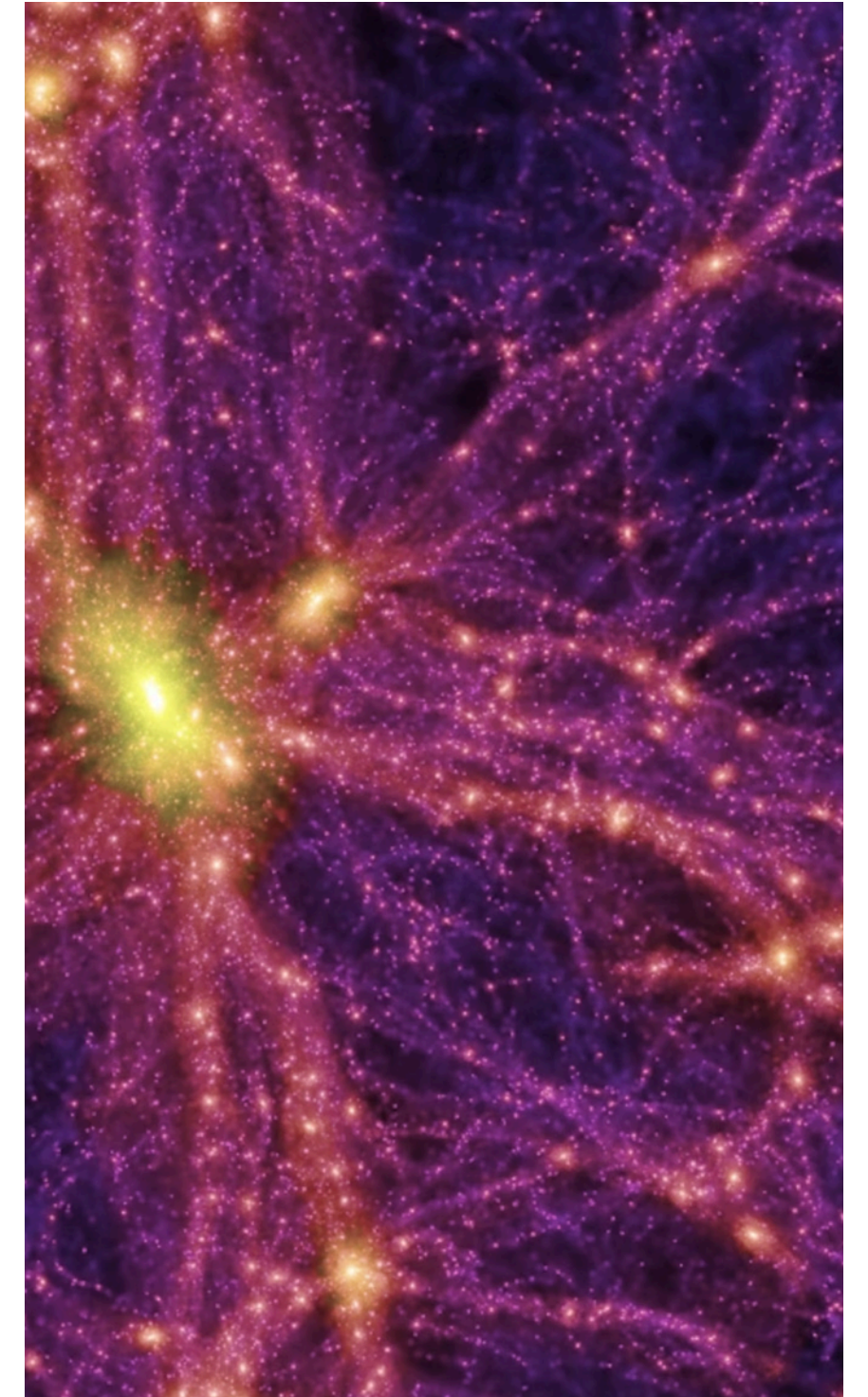
Problems and Self-Interacting Dark Matter as a solution

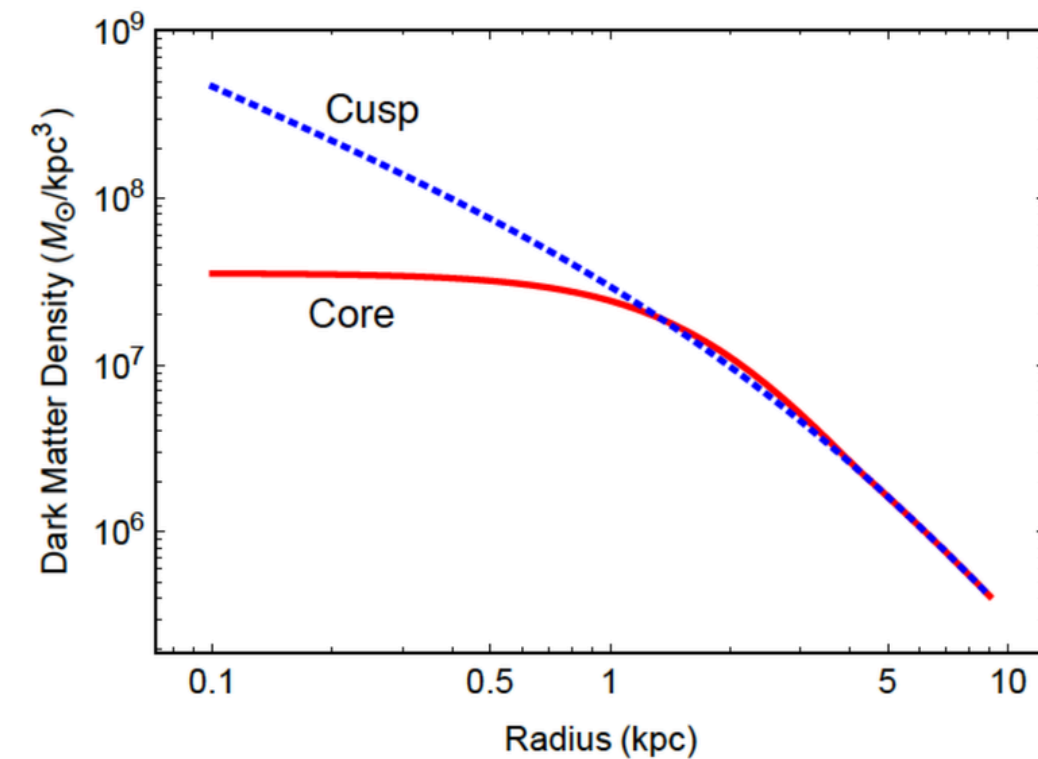
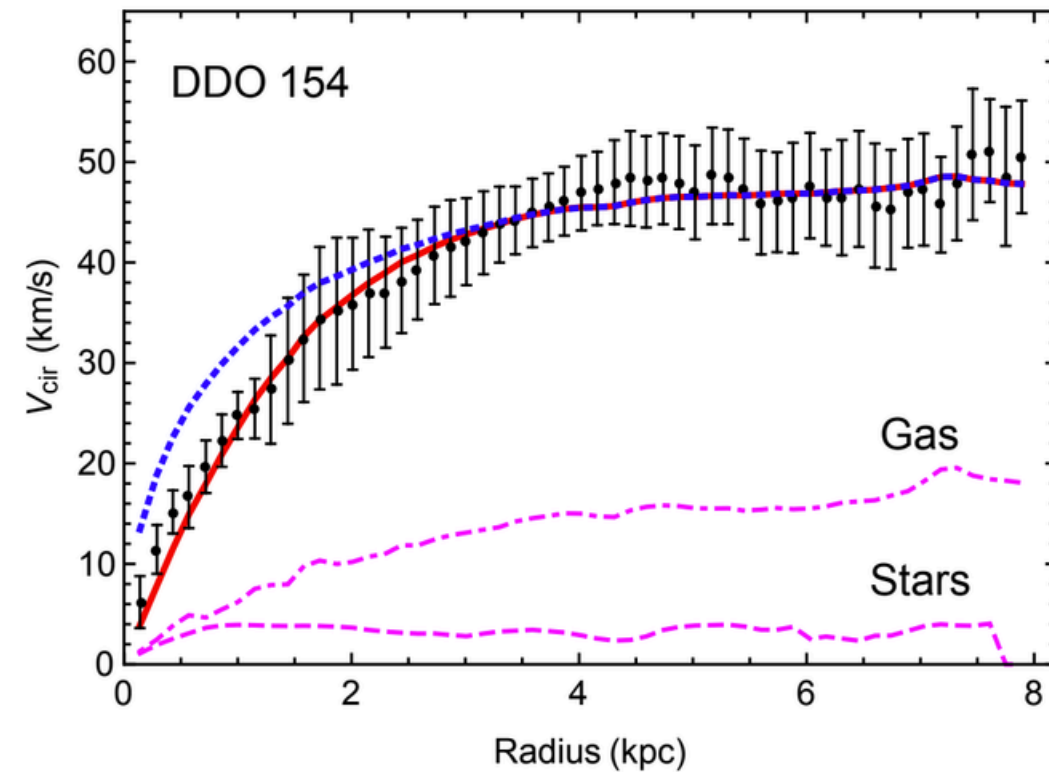
Part II · Confining Dark Sectors

Different dark matter candidates, heavy dark baryons and their interaction potential

Part III · Self-Interaction Cross Sections

Preferred parameter space (Asymmetric Dark Matter), velocity evolution, and comparison to data





S. Tulin and H. Yu in 1705.02358

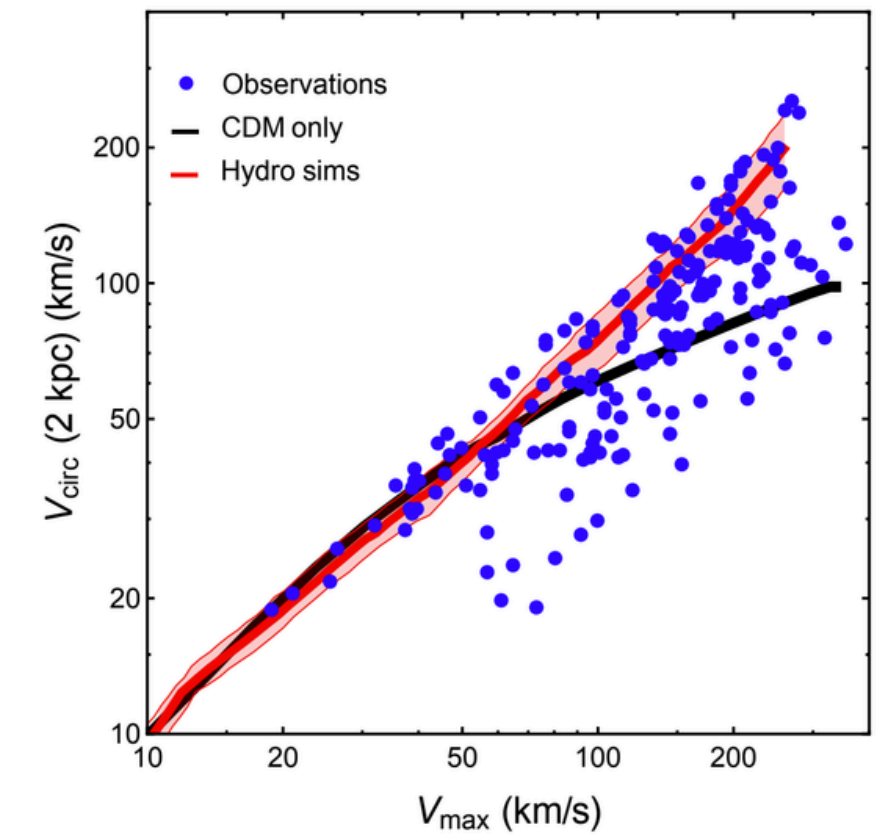
CRISIS ON SMALL SCALES

Λ CDM is an extremely successful model for $d \gtrsim \mathcal{O}(\text{Mpc})$. But:

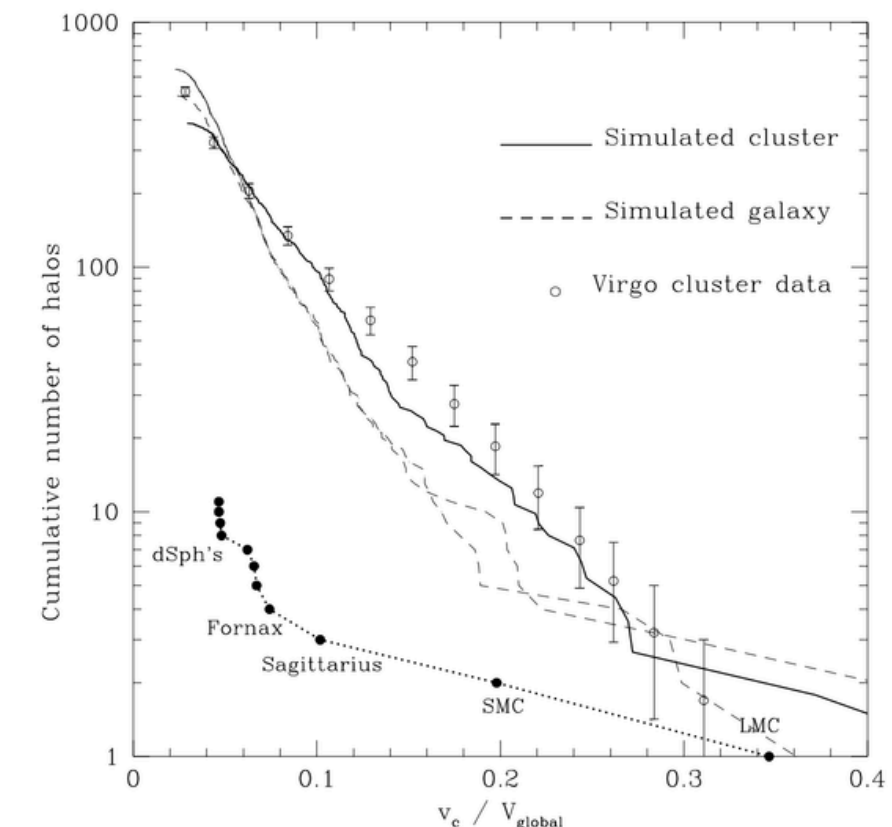
- Core-cusp problem
 - predic. $\rho_{\text{dm}} \propto r^{-1}$ vs $\rho_{\text{dm}}^{\text{obs}} \propto r^0$
- Diversity problem
 - large variations in density profiles
- "Missing satellites problem"
 - lack of a rich halo substructure
- Too-big-to-fail problem
 - largest substructures fail to form stars

Baryon feedback...

- the strong gravitational lens system **JVAS B1938+666 (perturber)**

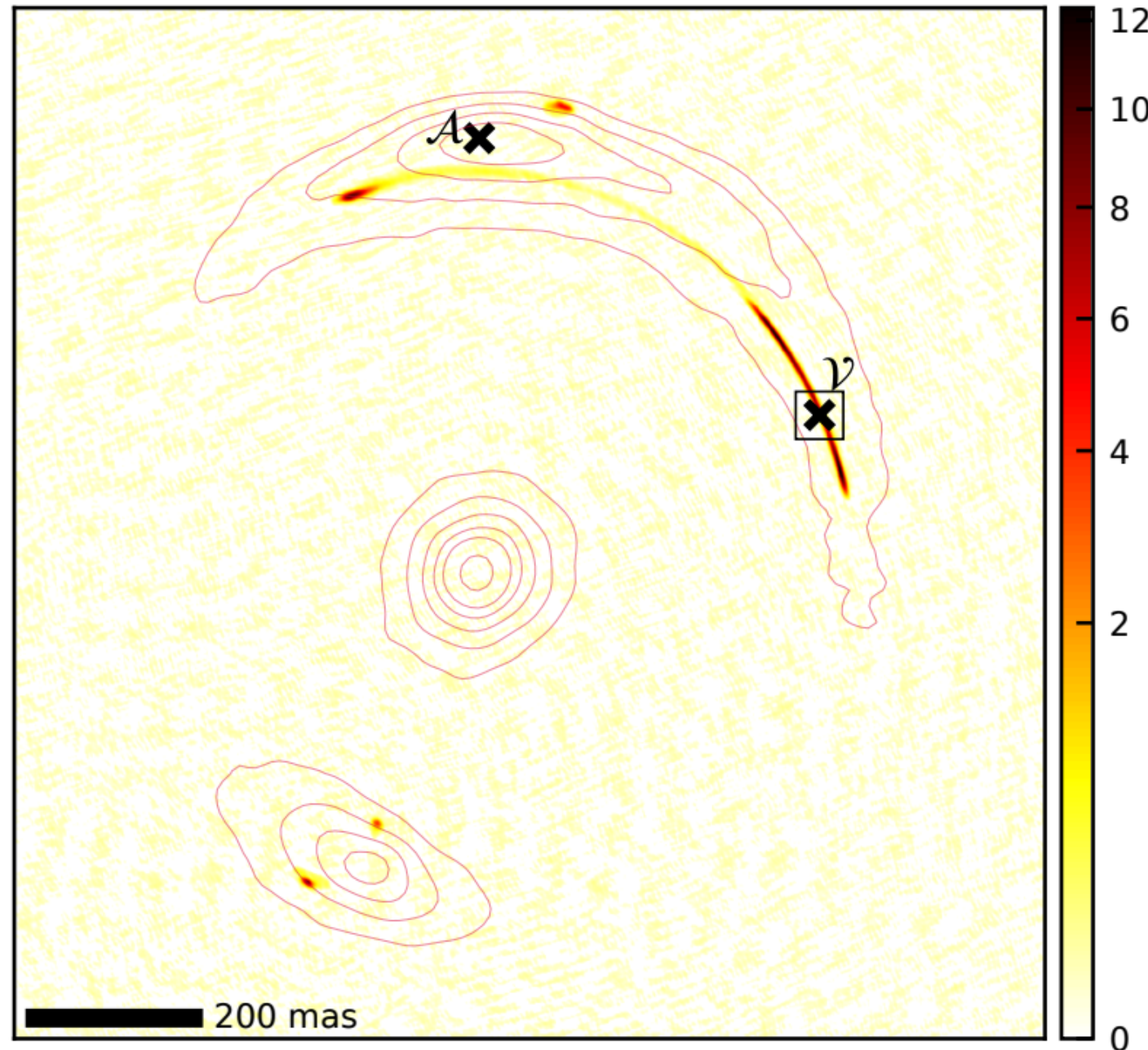


S. Tulin and H. Yu in 1705.02358



B. Moore et al. in 9907411

JVAS B1938+666



D. M. Powell *et al.* in 2510.07382

CRISIS ON SMALL SCALES

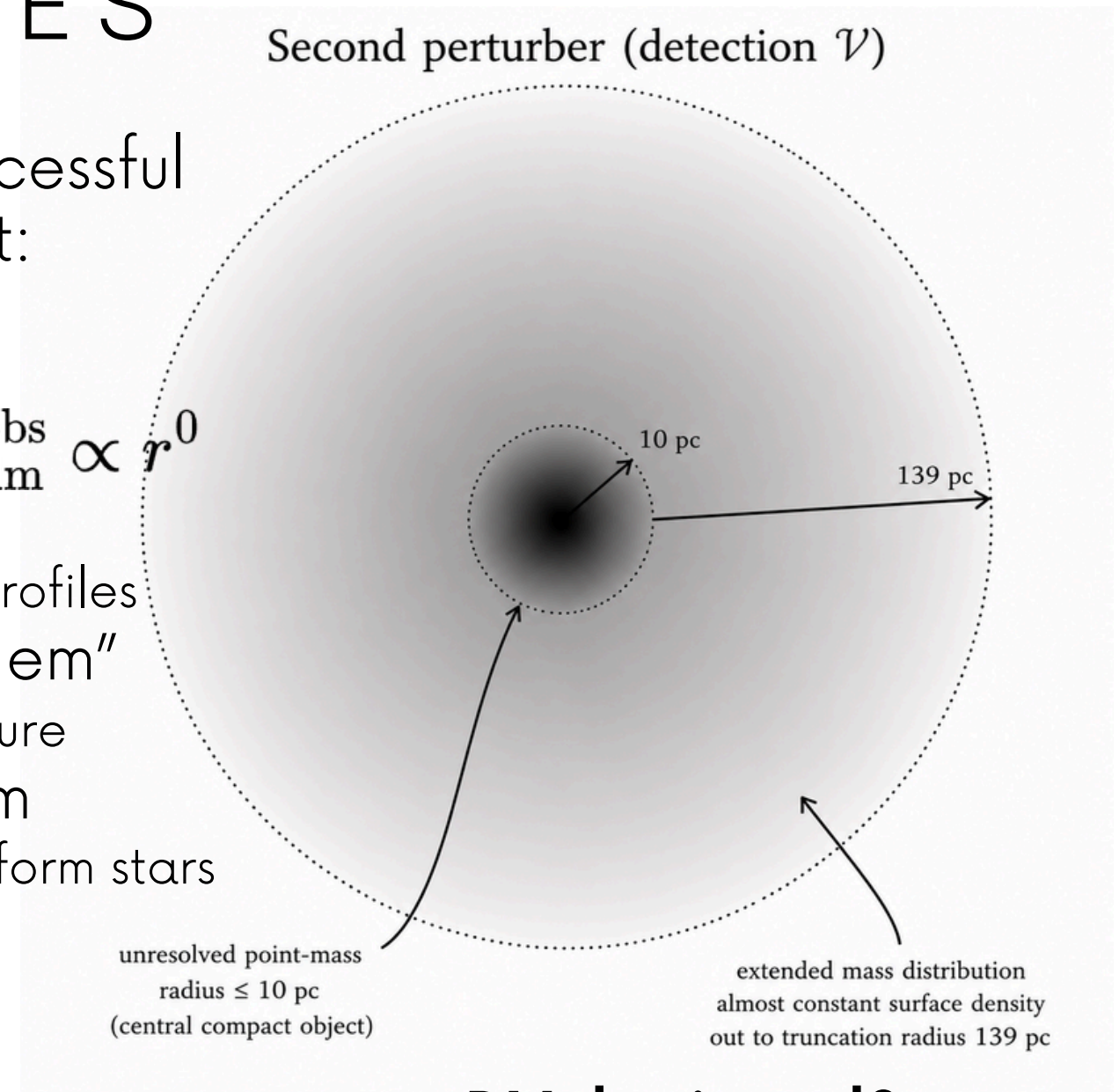
Λ CDM is an extremely successful model for $d \gtrsim \mathcal{O}(\text{Mpc})$. But:

- Core-cusp problem
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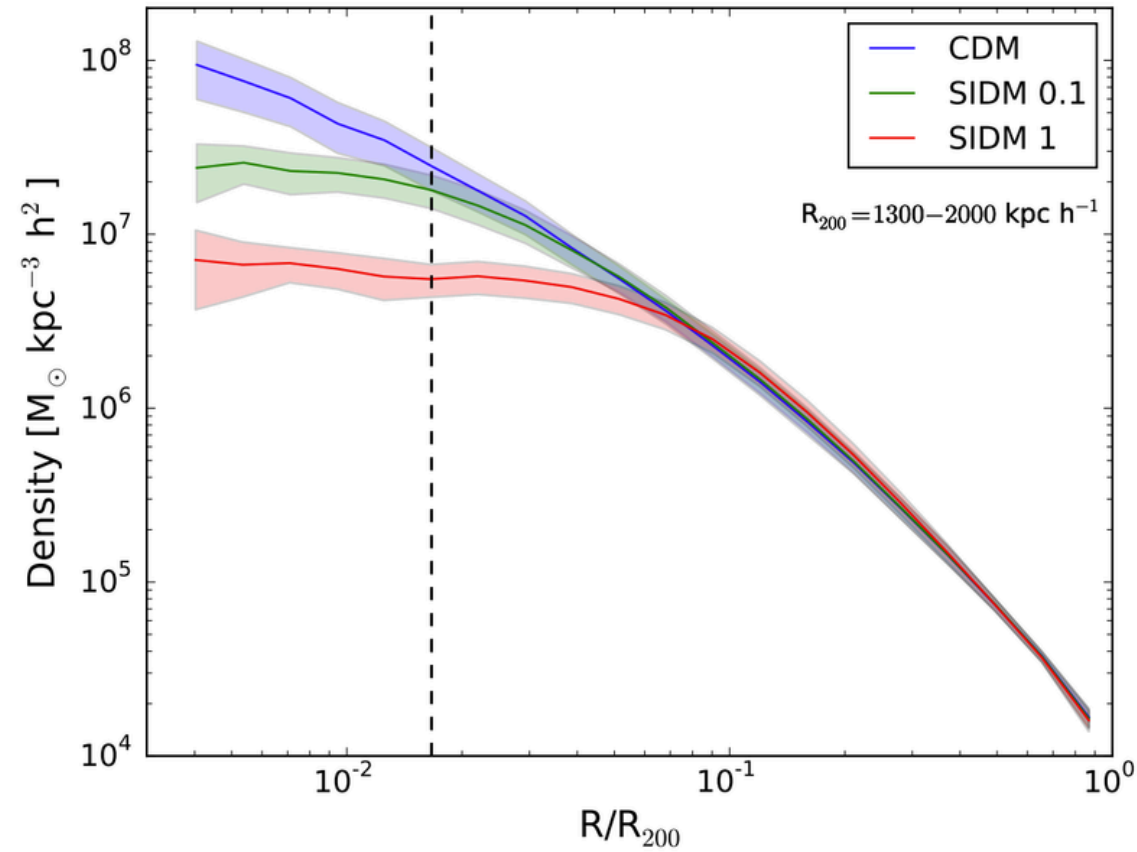
Baryon feedback...

- the strong gravitational lens system
JVAS B1938+666 (perturber)
 $> 5\sigma$

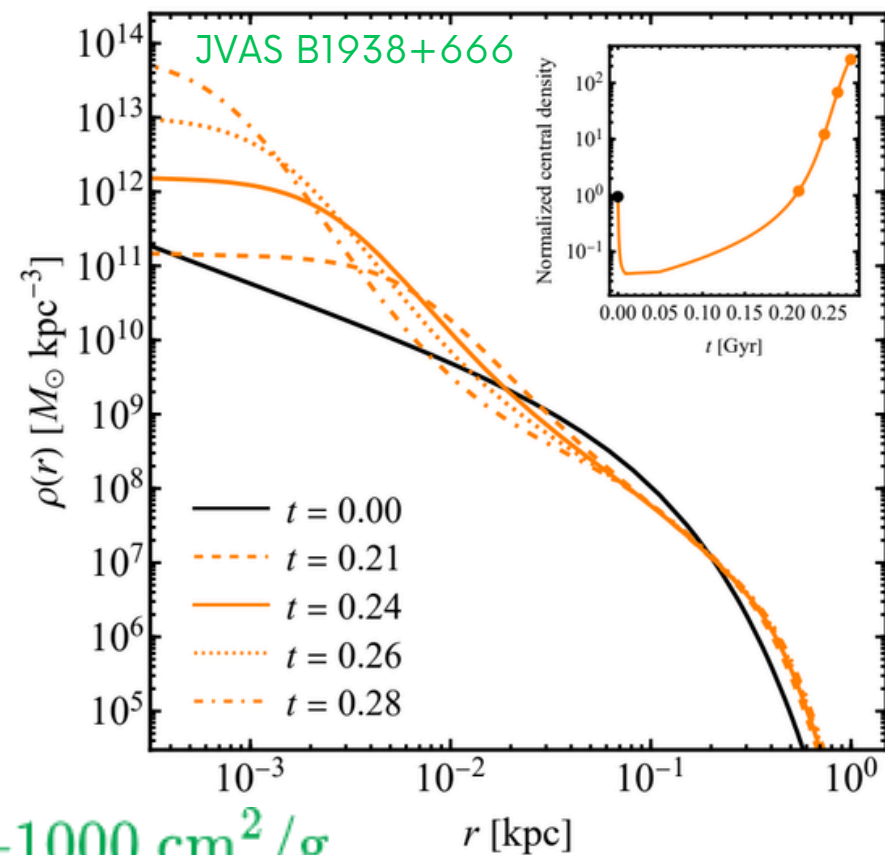
Best fit by S. Vegetti *et al.* in 2601.02466



DM dominated?



T. Brinckmann *et al.* in 1705.00623

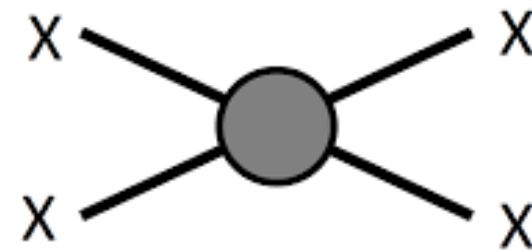


X. Zhang and H. Yu in 2606.12909

$\sigma/m \sim 100 - 1000 \text{ cm}^2/\text{g}$

SELF-INTERACTING DARK MATTER

Dark matter (DM) could interact with itself.



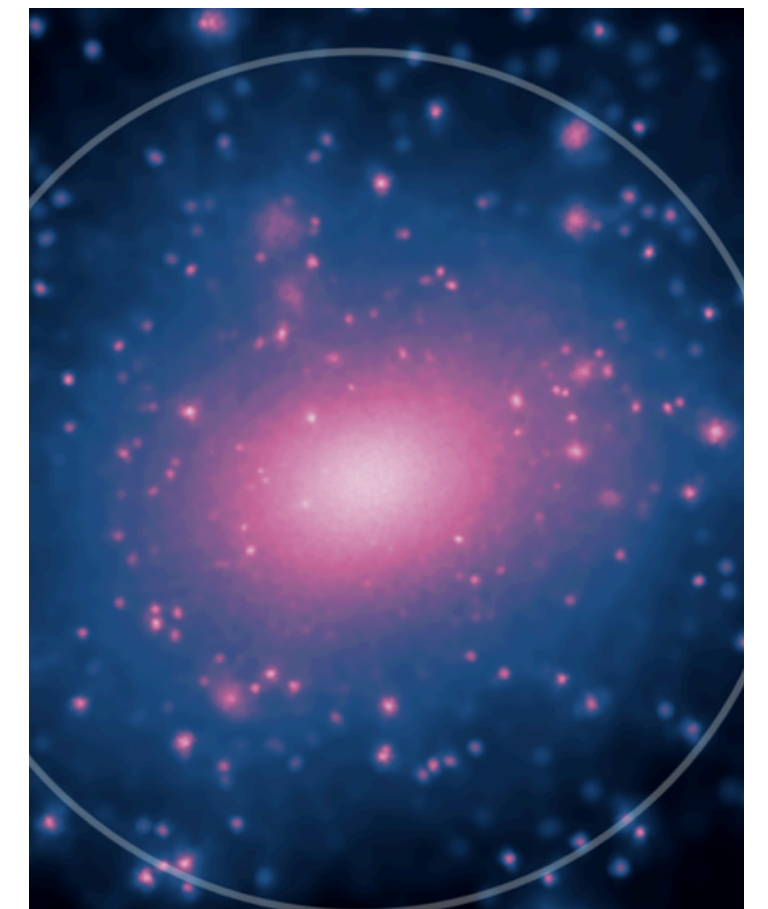
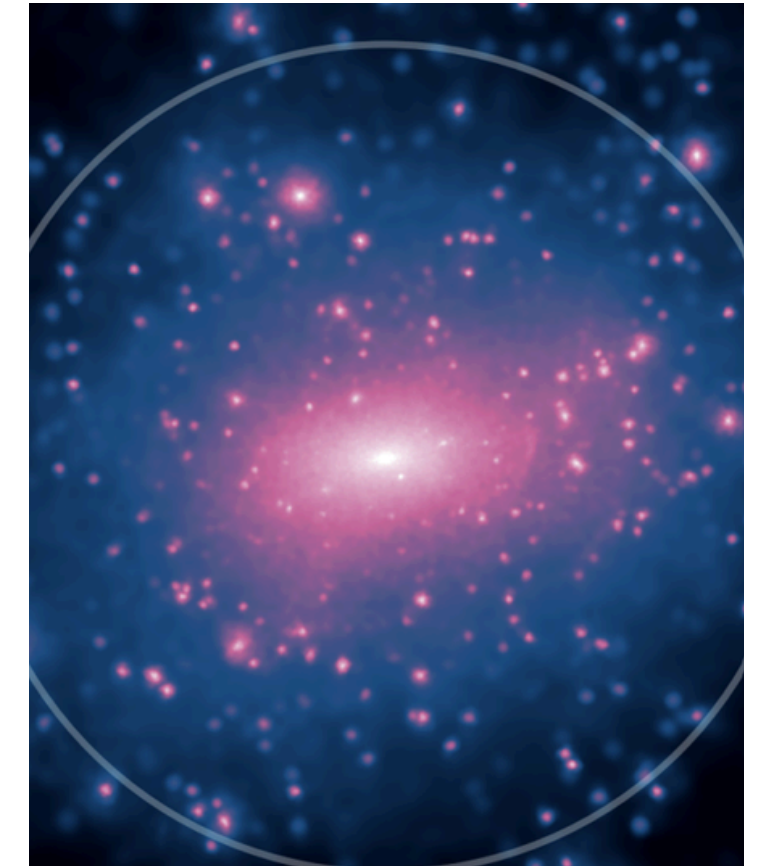
First sign of non-gravitational interactions of DM?!

At dwarfs and galaxies:

$$\sigma/m \gtrsim 1 \text{ cm}^2/\text{g}$$

But at clusters:

$$\sigma/m \lesssim 1 \text{ cm}^2/\text{g}$$



T. Brinckmann *et al.* in 1705.00623

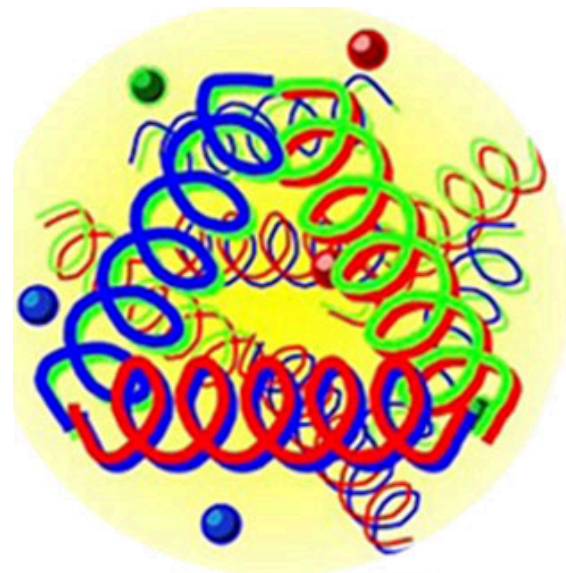
Giovani Dalla Valle Garcia

CONFINING DARK SECTORS

the minimal case

dark glueball DM

$$m_{\text{DG}} \sim \Lambda_d$$



glueball?

MULTIPLE MOTIVATIONS

- Hierarchy Problem
 - composite Higgs/technicolor
- Flavor Hierarchy Problem
 - warped extra dimensions(holography)
 - partial compositeness
- Strong CP Problem
 - high-quality QCD axions (composite axions)
- Dark-GUTs (baryon-DM coincidence)
- Rich and Varied Phenomenology

$SU(N)$

confining at Λ_d

- Small scale issues

$$\sigma_{\text{scat}}(v) \stackrel{!}{\simeq} \frac{4\pi}{\Lambda_d^2}$$

- **Instability!**

CONFINING DARK SECTORS

alternatives

add dark quarks:

- (multiple) light quarks
 - resonances: σ_{np} – deuteron
 - mostly focused on dark mesons
- heavy quarks $m_Q \gg \Lambda_d$?

only the lightest heavy quark is relevant

MULTIPLE MOTIVATIONS

- Hierarchy Problem
 - composite Higgs/technicolor
- Flavor Hierarchy Problem
 - warped extra dimensions(holography)
 - partial compositeness
- Strong CP Problem
 - high-quality QCD axions (composite axions)
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$SU(N)$
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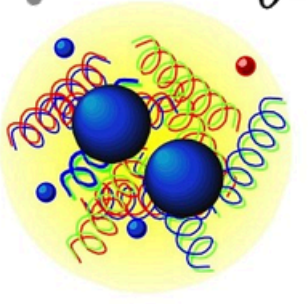
$\frac{\delta \frac{m_\pi}{\Lambda_d}}{\frac{m_\pi}{\Lambda_d}} \sim \frac{1}{50}$

$m_\pi \approx m_\eta$
 θ -term

$\pi_d, \eta, \dots$

meson

Instability!



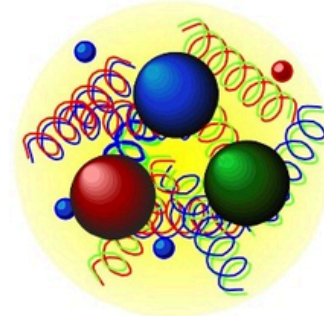
Only two relevant parameters:

$$N, \xi \equiv m_Q / \Lambda_d$$

Then,

$$\alpha_d(\mu_0) = \frac{2\pi}{\beta_d \log(\mu_0 / \Lambda_d)}$$

- At the baryon scale: $\mu_0 \sim v m_Q \approx a_B^{-1}$



baryon

stability: dark baryon number

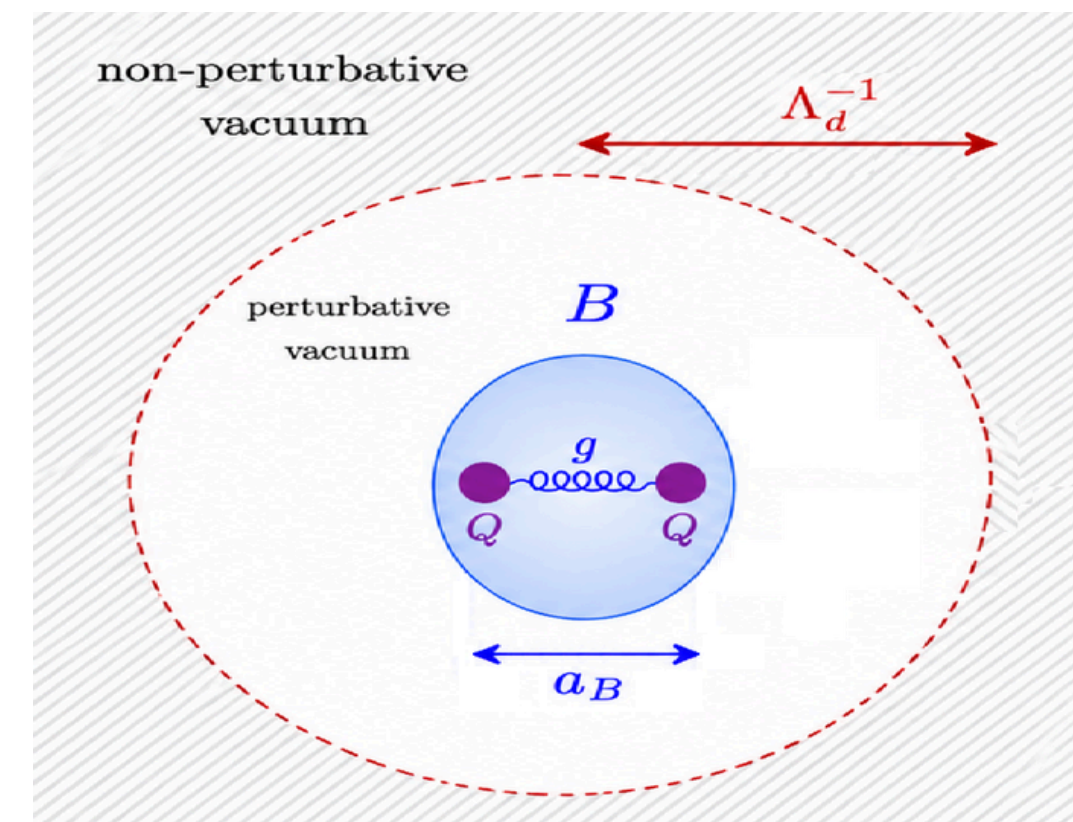
$$U(1)_B \leftrightarrow U(1)_{B'}$$

No ad-hoc symmetry!

- a Coulombic state: $a_B^{-1} \sim C_N \alpha_d m_Q \gg \Lambda_d$

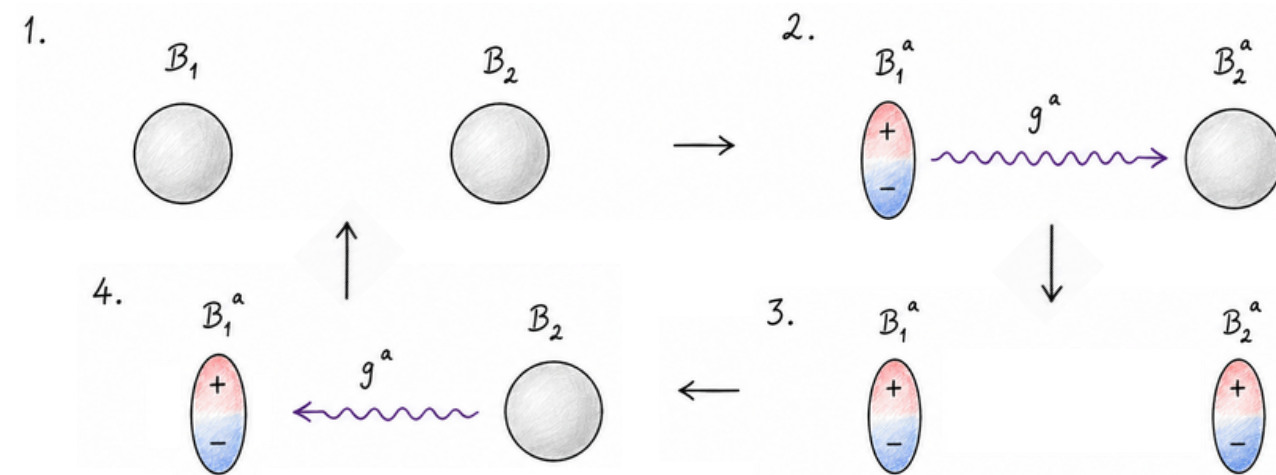
$$V_q(r_{ij}) = -\frac{C_N}{N-1} \frac{\alpha_d}{r_{ij}} + \cancel{\Lambda_d^2 r_{ij}}$$

HEAVY DARK BARYONS



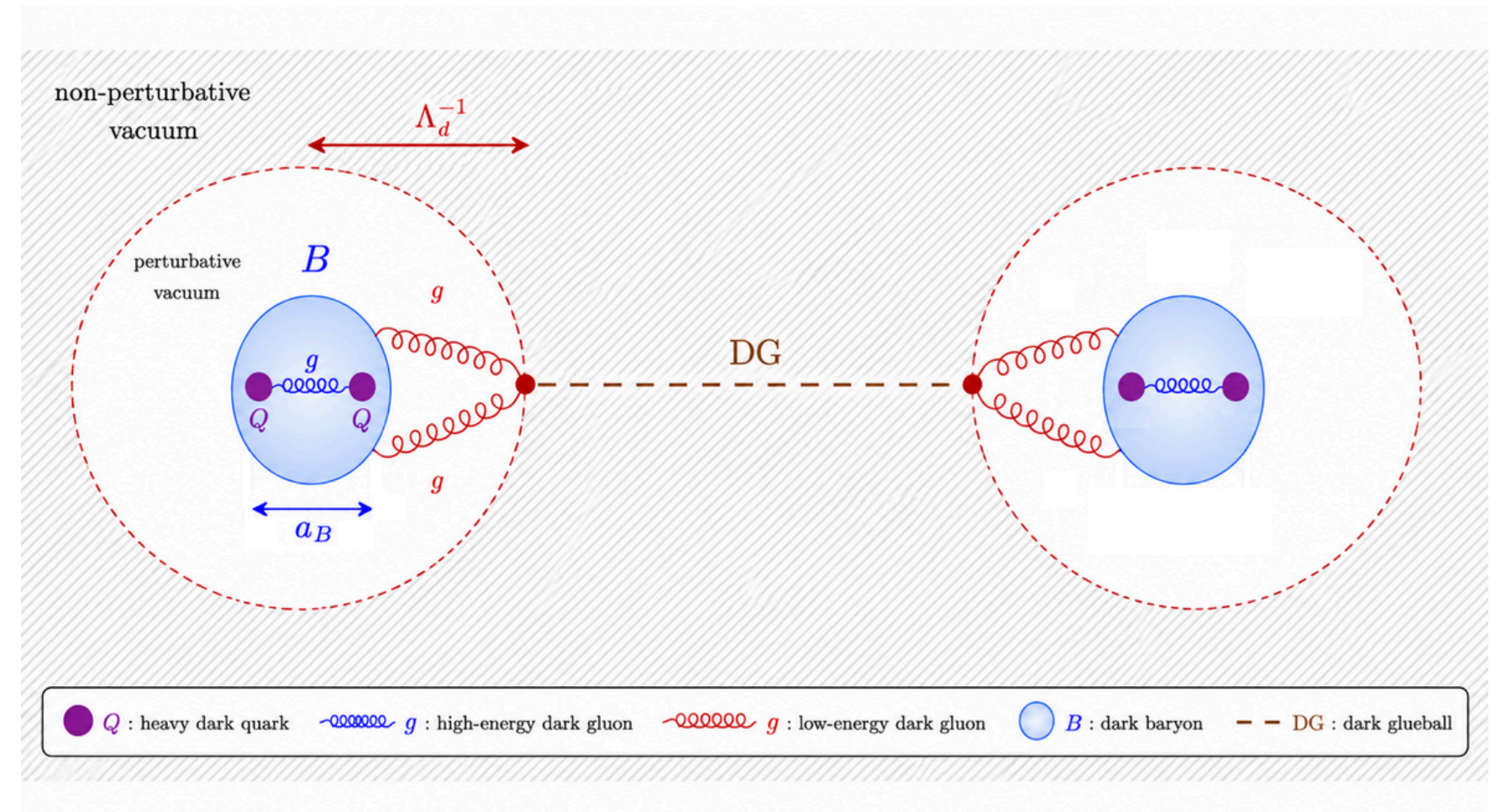
Interaction potential

- instantaneous dipole-induced dipole interaction



leads to Van der Waals forces:

$$V(r) \propto \alpha_B^2 \begin{cases} r^{-6}, & a_B \ll r \ll \epsilon_B^{-1}, \\ r^{-7}, & \epsilon_B^{-1} \ll r \ll \Lambda_d^{-1}, \\ e^{-m_{\text{DG}} r}/r, & r \gg \Lambda_d^{-1} \end{cases} \quad t_c \sim \epsilon_B^{-1}$$



Chromo-electric polarizability

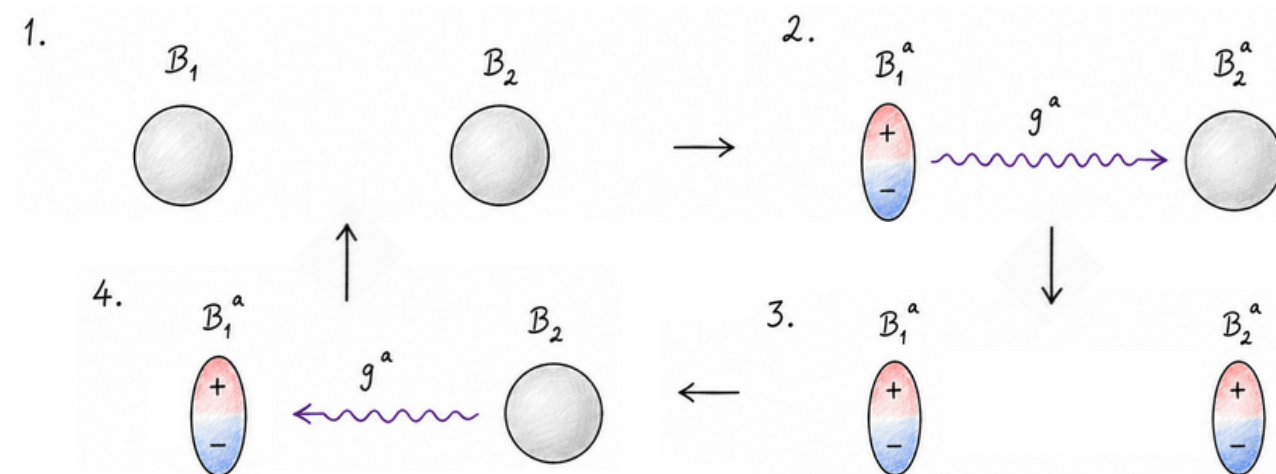
$$\alpha_B \equiv \frac{1}{N(N-1)} \frac{1}{3} \sum_{i < j}^N \langle \phi | r_{ij}^k \frac{1}{(H_a + \epsilon_B)} r_{ij}^k | \phi \rangle$$

Electric polarizability of the hydrogen

$$\alpha_P = 8\pi\alpha_{\text{em}} \sum_{k'} \frac{\langle 1S | z | k' \rangle \langle k' | z | 1S \rangle}{E_{k'} - E_{1S}}$$

Interaction potential

- instantaneous dipole-induced dipole interaction

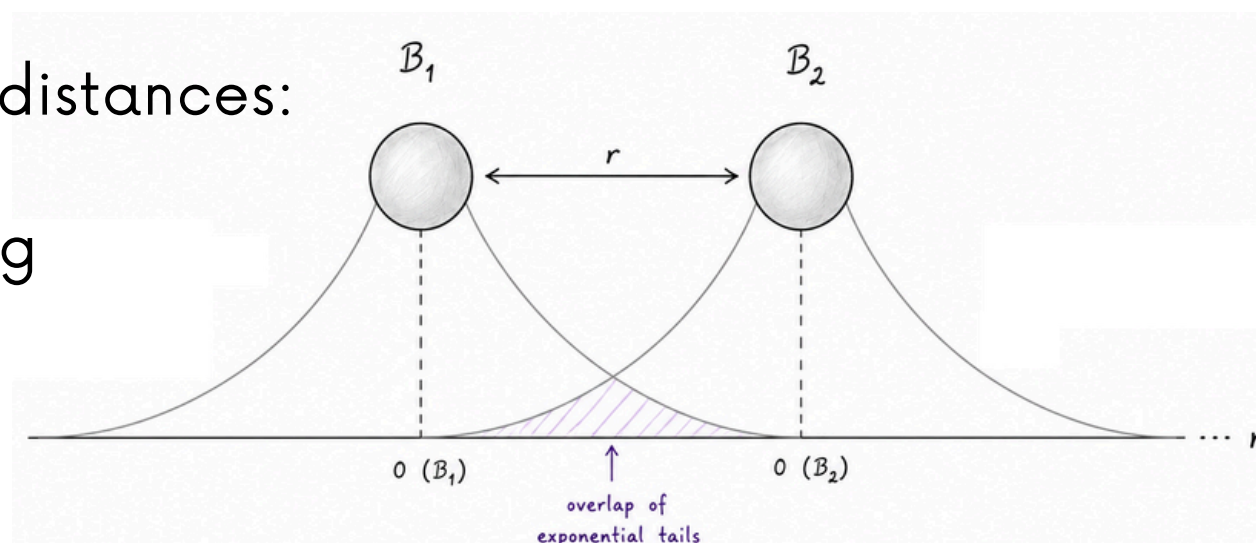


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$$V(r) \propto \alpha_B^2 \begin{cases} r^{-6}, & a_B \ll r \ll \epsilon_B^{-1}, \\ r^{-7}, & \epsilon_B^{-1} \ll r \ll \Lambda_d^{-1}, \\ e^{-m_{\text{DGR}} r}/r, & r \gg \Lambda_d^{-1} \end{cases} \quad t_c \sim \epsilon_B^{-1}$$

- at short distances:

Pauli-blocking



Baryon 1S overlap

$$S(x) = e^{-x} (1 + x + x/3)$$

Hydrogen-hydrogen (1311.6468)

$$\frac{V_t}{\epsilon_0} = \exp(c_0 - c_1 r - c_2 r^2) - D(r) \left(\frac{c_6}{r^6} + \frac{c_8}{r^8} + \frac{c_{10}}{r^{10}} \right)$$

$$D(r) = \exp(-(r_1/r - 1)^2)$$

We regularize our potential at small scales as

$$V_{\text{tot}}(r) = V_{\text{reg}}(r) + V_{\text{rep}}(r) \quad \text{with } V_{\text{rep}}(r) = c \epsilon_B e^{-r/a_B}$$

Born-Mayer-type potential

large N finds also an exp in 1102.2197

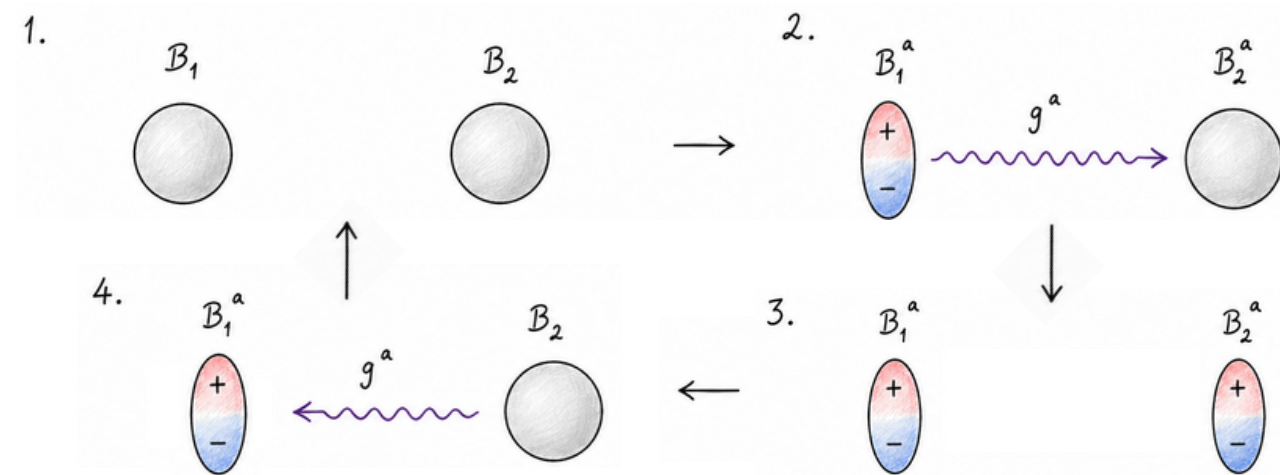
$$c \text{ and } r_{\text{in}} \equiv a_B x_{\text{in}}$$

Hydrogen-hydrogen (1311.6468)

$$c \approx 1 \text{ averaging } c \approx 3/4 \text{ and } x_{\text{in}} \sim 5-10$$

Interaction potential

- instantaneous dipole-induced dipole interaction



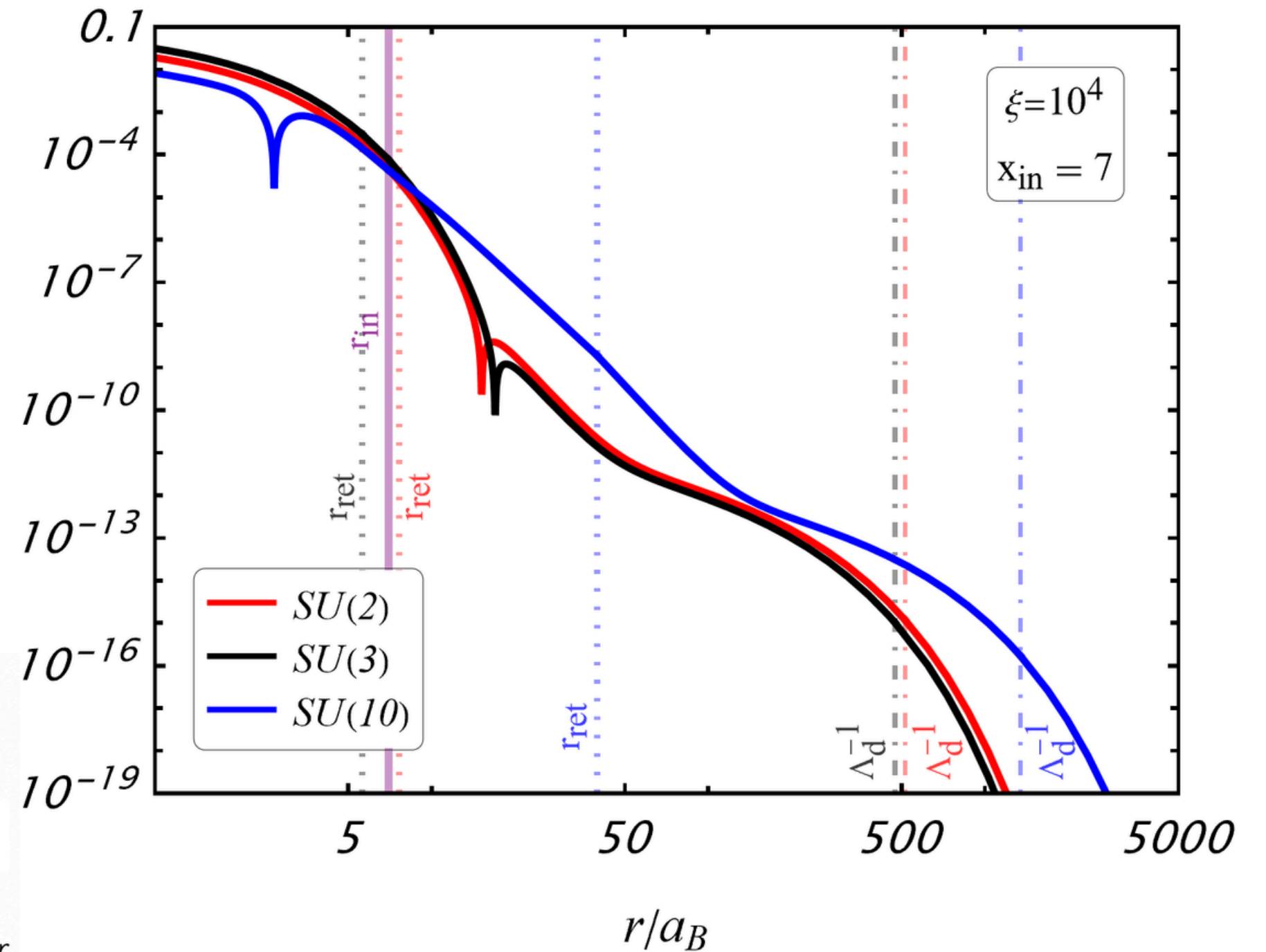
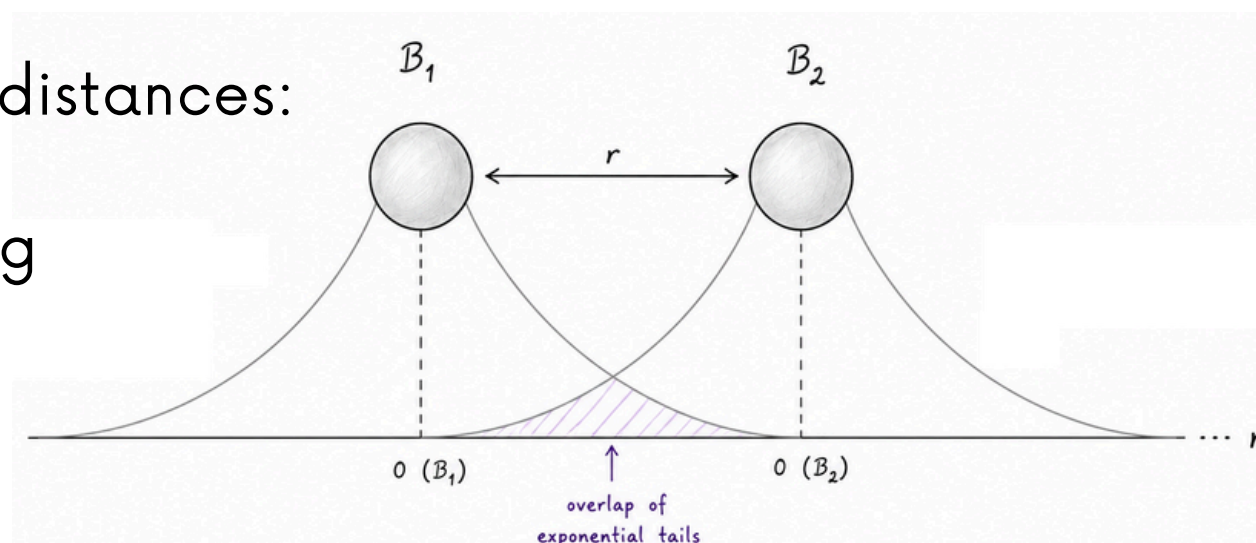
leads to Van der Waals forces:

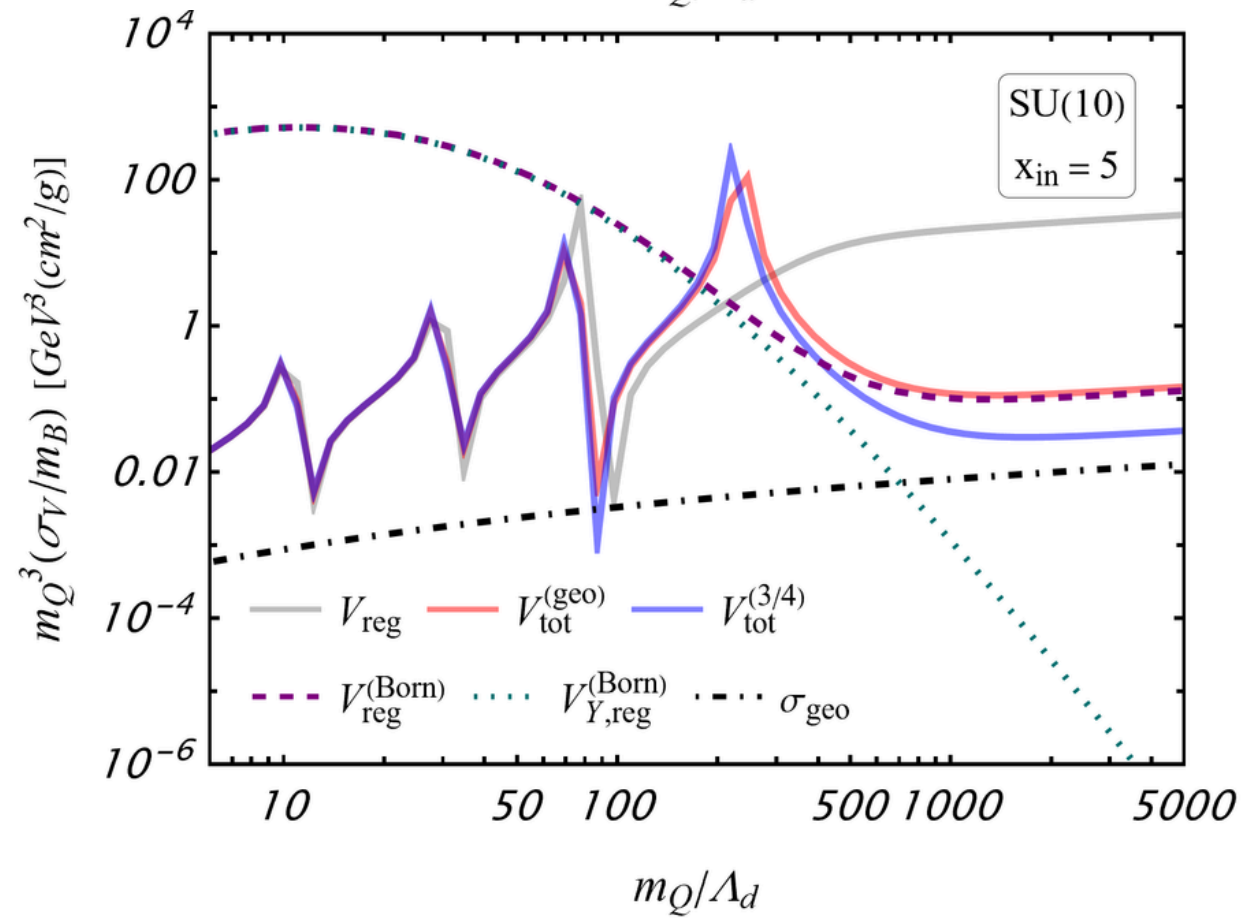
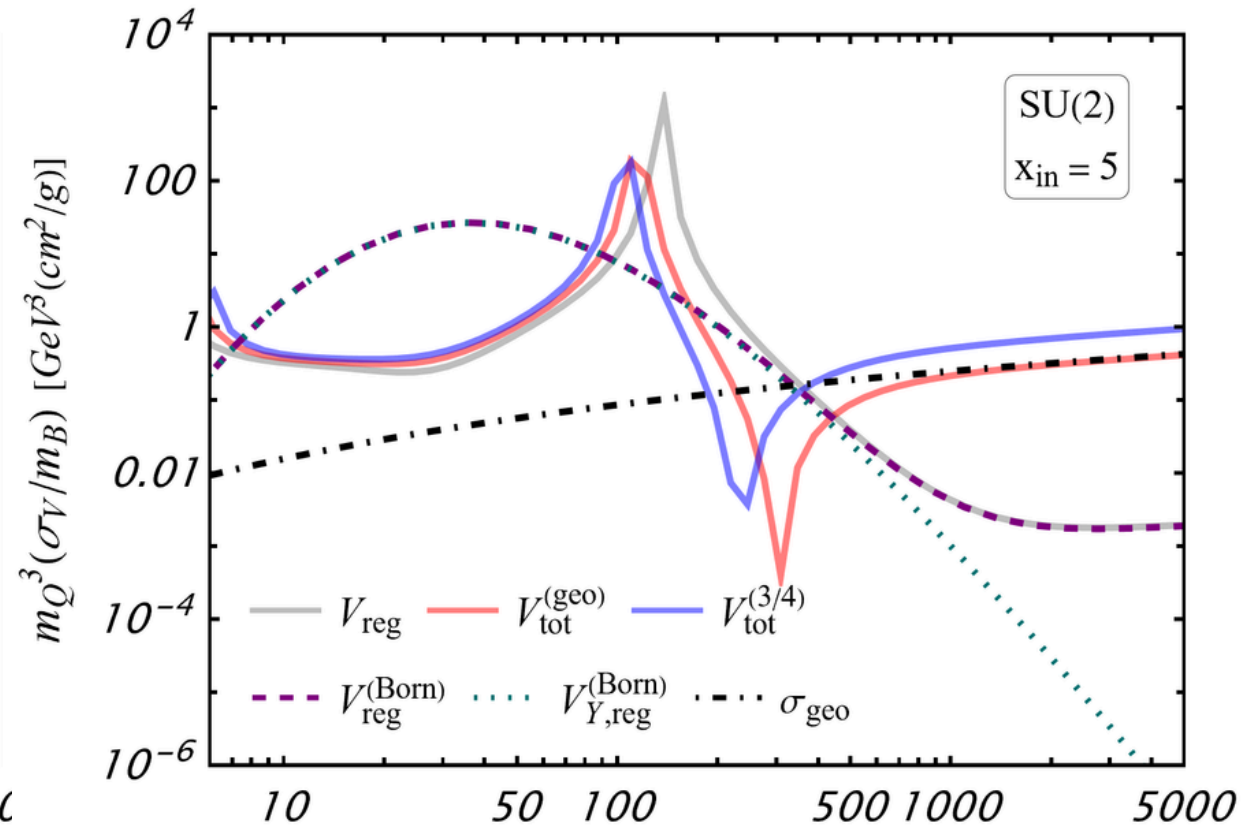
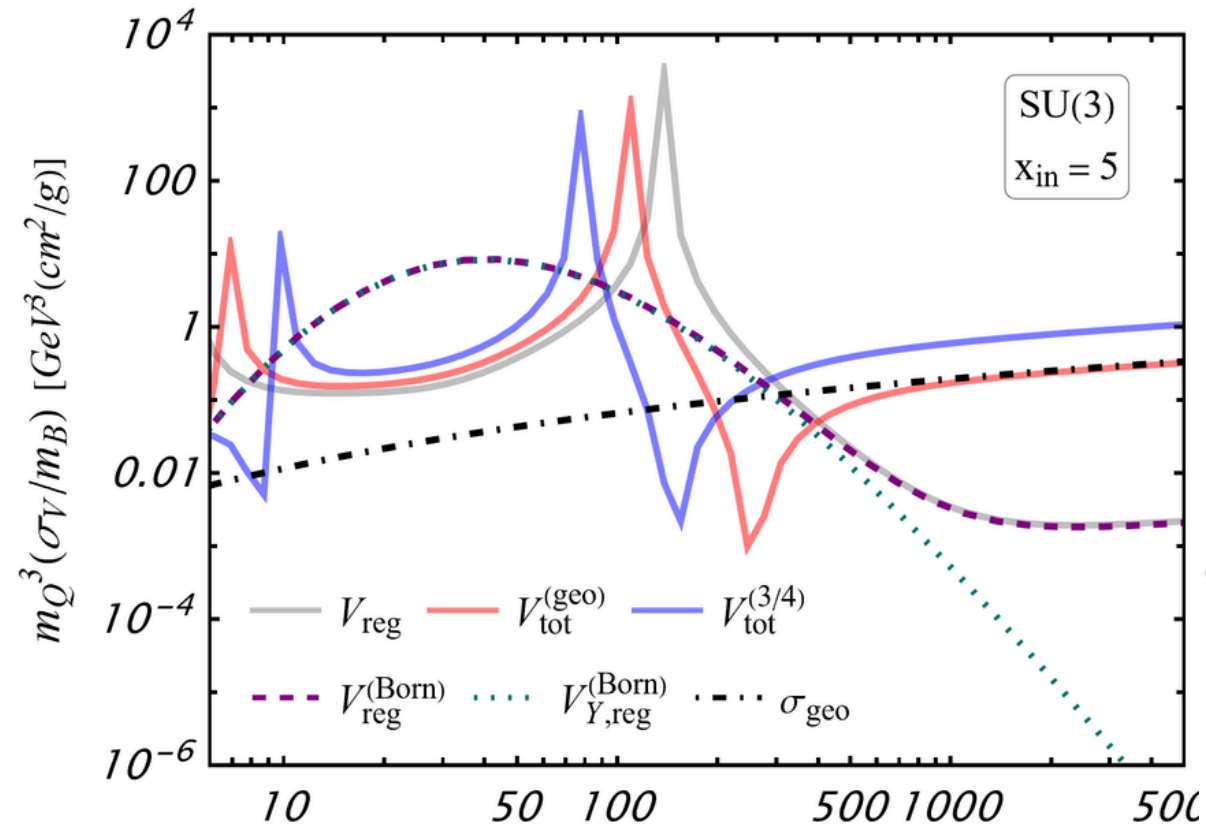
$$V(r) \propto \alpha_B^2 \begin{cases} r^{-6}, & a_B \ll r \ll \epsilon_B^{-1}, \\ r^{-7}, & \epsilon_B^{-1} \ll r \ll \Lambda_d^{-1}, \\ e^{-m_{DG}r}/r, & r \gg \Lambda_d^{-1} \end{cases} \quad t_c \sim \epsilon_B^{-1}$$

$|a_B V_{tot}|$

- at short distances:

Pauli-blocking





CROSS SECTIONS

$$\sigma_V = \int d\Omega \sin^2 \theta \frac{d\sigma}{d\Omega}, \theta \neq 0, \pi$$

METHODS

- Partial Waves (Baron spin $S_B = N/2$)

$$\sigma_V = w_{\text{even}} \sigma_V^{\text{even}} + w_{\text{odd}} \sigma_V^{\text{odd}}$$

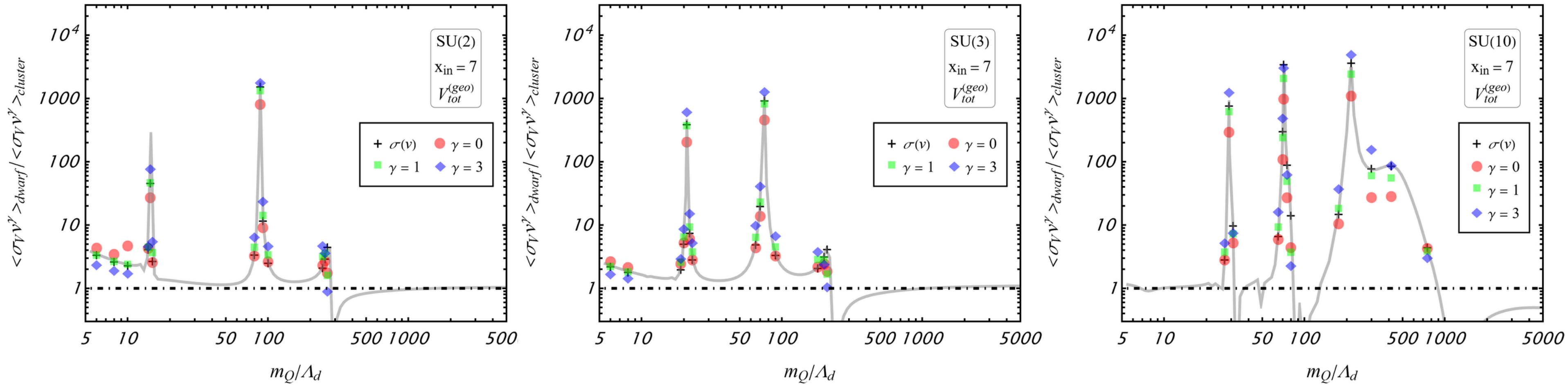
$$\sigma_V^{\text{even}} = \frac{8\pi}{k^2} \sum_{\ell \text{ even}} \frac{(\ell+1)(\ell+2)}{2\ell+3} \sin^2(\delta_{\ell+2} - \delta_\ell)$$

$$\sigma_V^{\text{odd}} = \frac{8\pi}{k^2} \sum_{\ell \text{ odd}} \frac{(\ell+1)(\ell+2)}{2\ell+3} \sin^2(\delta_{\ell+2} - \delta_\ell)$$

- Born Approximation $q = 2k \sin \frac{\theta}{2}$

$$\frac{d\sigma}{d\Omega} \simeq \frac{4m^2}{q^2} \left| \int dr' r' V(r') \sin(qr') \right|^2$$

Velocity behavior



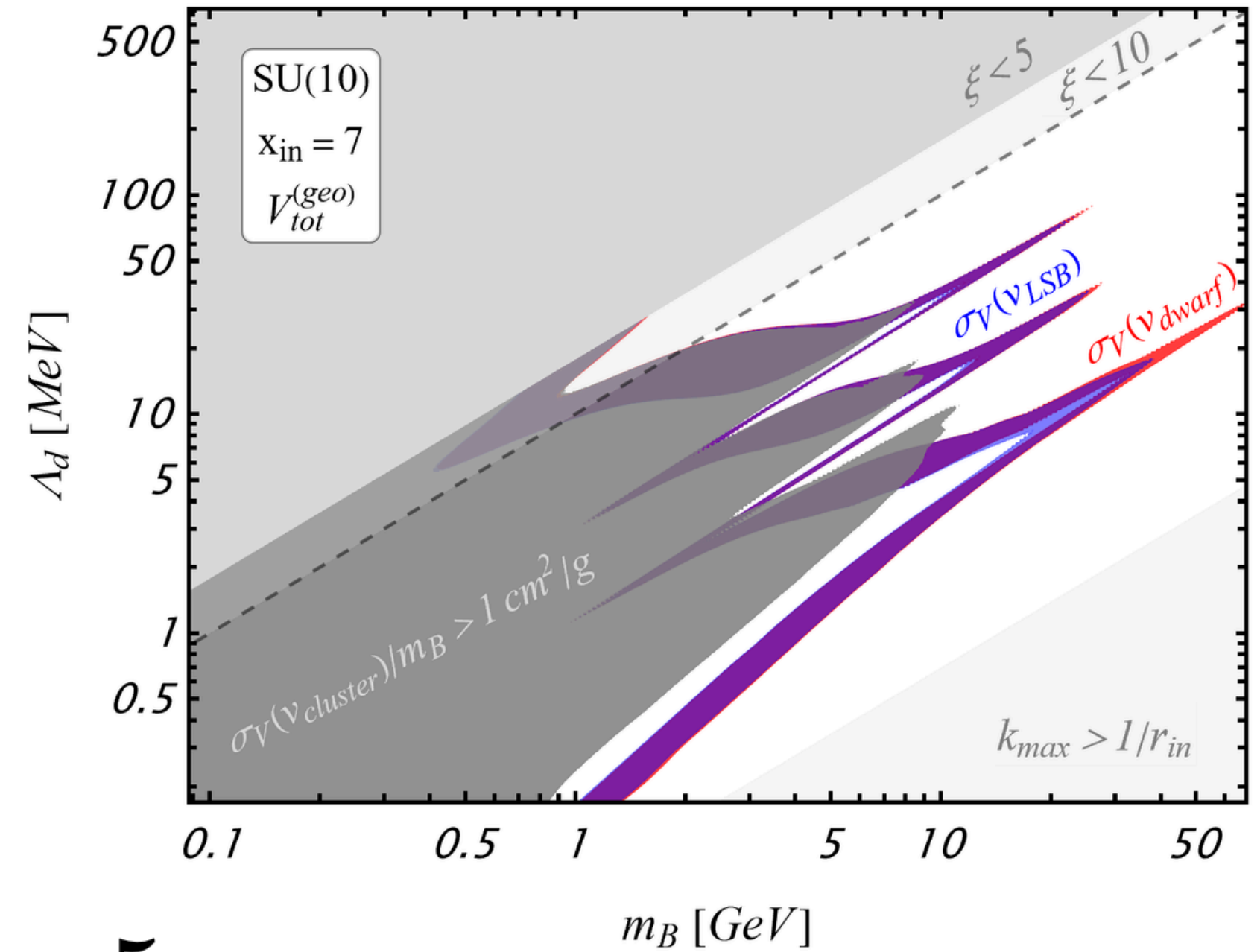
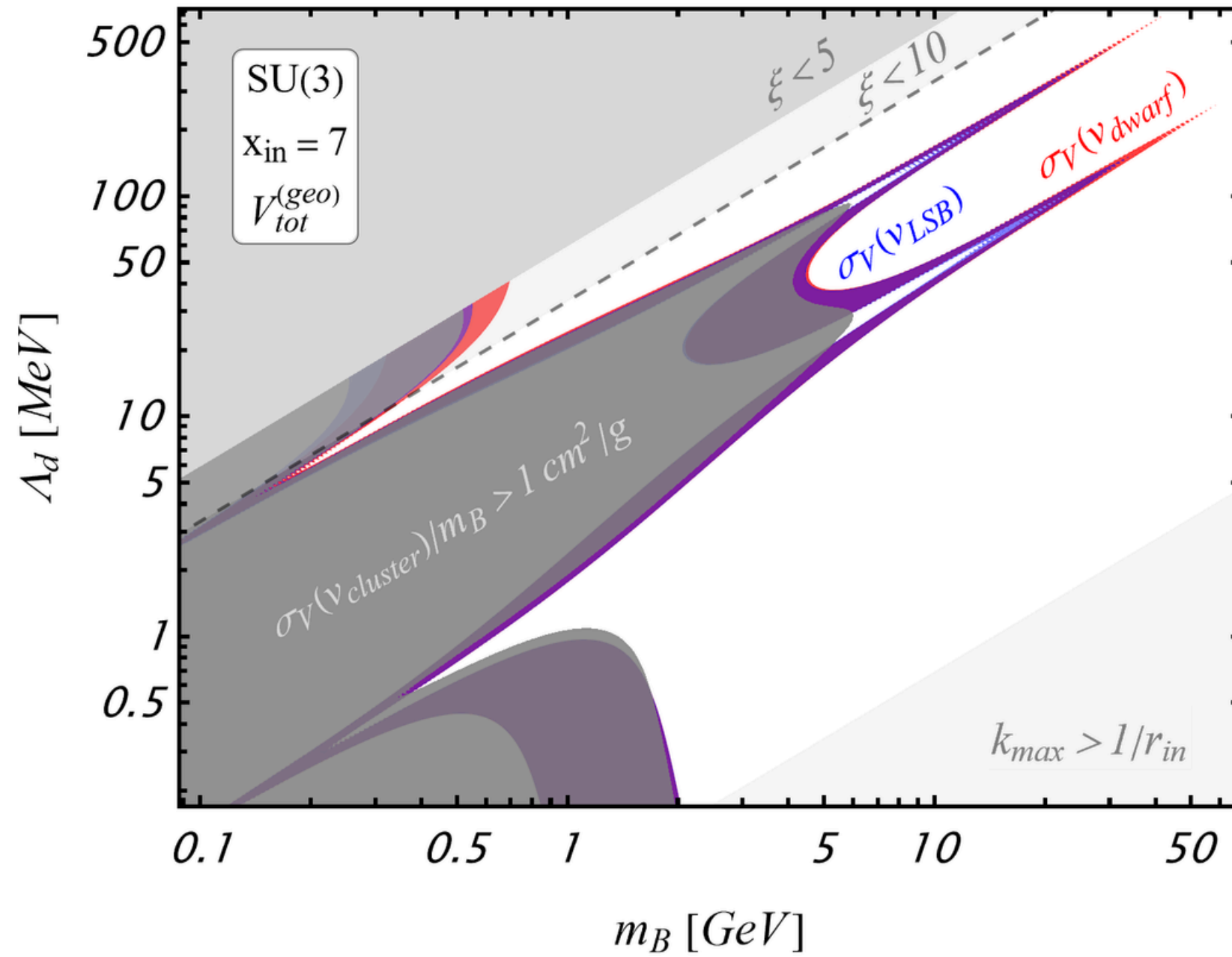
$$\bar{\sigma}_V = \frac{\langle \sigma_V v^\gamma \rangle}{\langle v^\gamma \rangle} = \frac{\int_0^\infty dv f_{\text{rel}}(v) v^\gamma \sigma_V(v)}{\int_0^\infty dv f_{\text{rel}}(v) v^\gamma}$$

$$\xi \lesssim 10^3$$

$$\alpha_B^{(2,3)} / a_B^3 \ll \alpha_B^{(10)} / a_B^3$$

PREFERRED PARAMETER SPACE

$$\sigma(\sim 30\text{--}150 \text{ km/s})/m \sim 1\text{--}10 \text{ cm}^2/\text{g}$$



$$m_B \sim 5m_p$$

$$\Lambda_d \sim (0.01 - 3) \Lambda_{\text{QCD}}$$

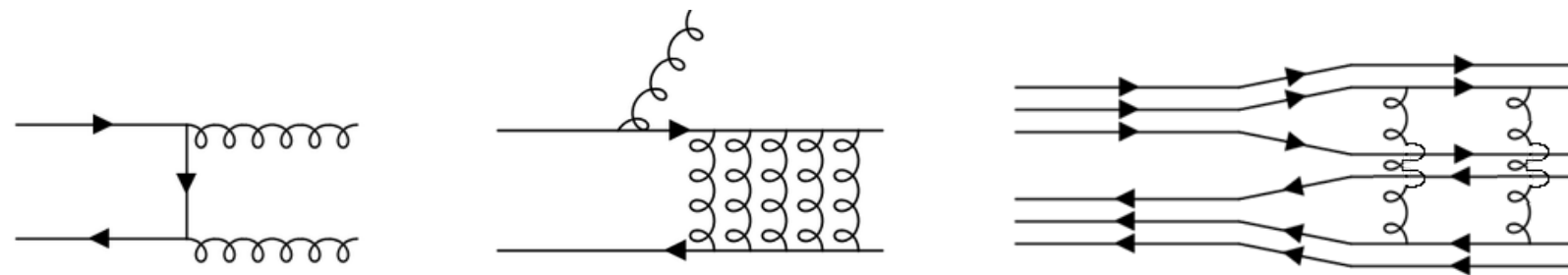
ASYMMETRIC DARK MATTER (ADM)

$$\begin{array}{l} m_B \sim 5m_p \\ \Lambda_d \sim (0.01 - 3) \Lambda_{\text{QCD}} \end{array} \implies \eta_{\text{DM}} \sim \eta_{\text{SM}}$$

Moreover, the abundance of the **symmetric** part is

$$\frac{\Omega_B h^2}{0.12} \lesssim 10^{-10} \left(\frac{m_B}{\text{GeV}} \right)^2 \xi \frac{T_d}{T_{\text{SM}}} \Big|_{T_d \simeq \Lambda_d}$$

$$\implies \boxed{\Omega_B h^2 \ll 0.12}_{\text{symmetric}}$$



Too much dark glueballs:

$$\frac{\Omega_{\text{DG}} h^2}{0.12} \simeq 10^6 \frac{\Lambda_d}{100 \text{ MeV}} \left(\frac{T_d}{T_{\text{SM}}} \right)^3 \Big|_{T_d \simeq \Lambda_d}$$

$$\implies \boxed{T_d \lesssim 10^{-2} T_{\text{SM}}} \text{ or portal}$$

● previously

$$V(r) = -\frac{\alpha_d}{r} e^{-\Lambda_d r} \text{ with } \alpha_d = 1$$

• leading to WIMPs

$$m_B \sim \text{TeV and } \Lambda_d \sim (0.1 - 1) \text{ MeV}$$

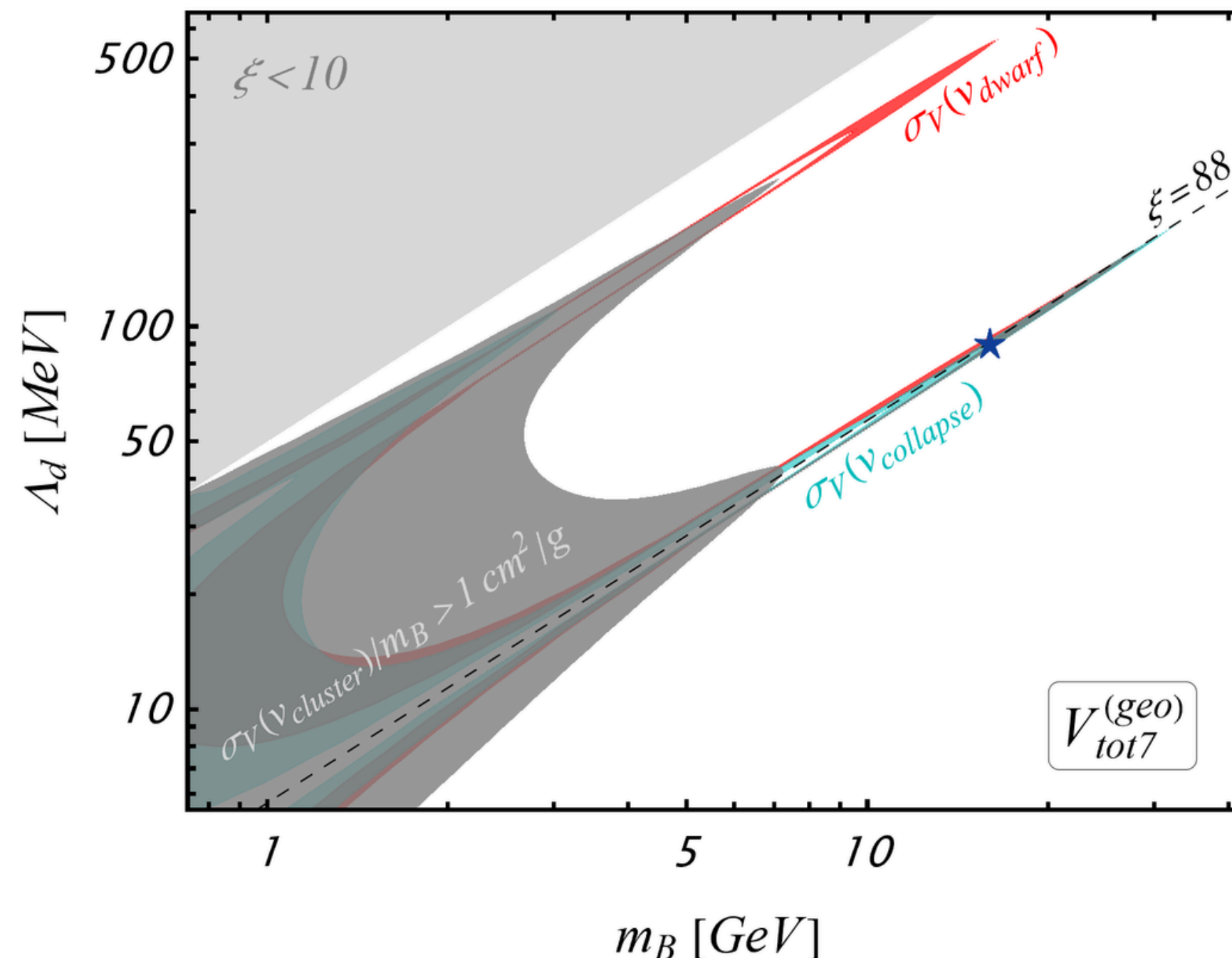
K. K. Boddy in 1402.3629 15

Gravothermal Core Collapse

A possible **explanation** for the second perturber of the JVAS B1938+666 system:

$$\sigma(\sim 5 \text{ km/s})/m \sim 100\text{--}1000 \text{ cm}^2/\text{g}$$

SU(2) :

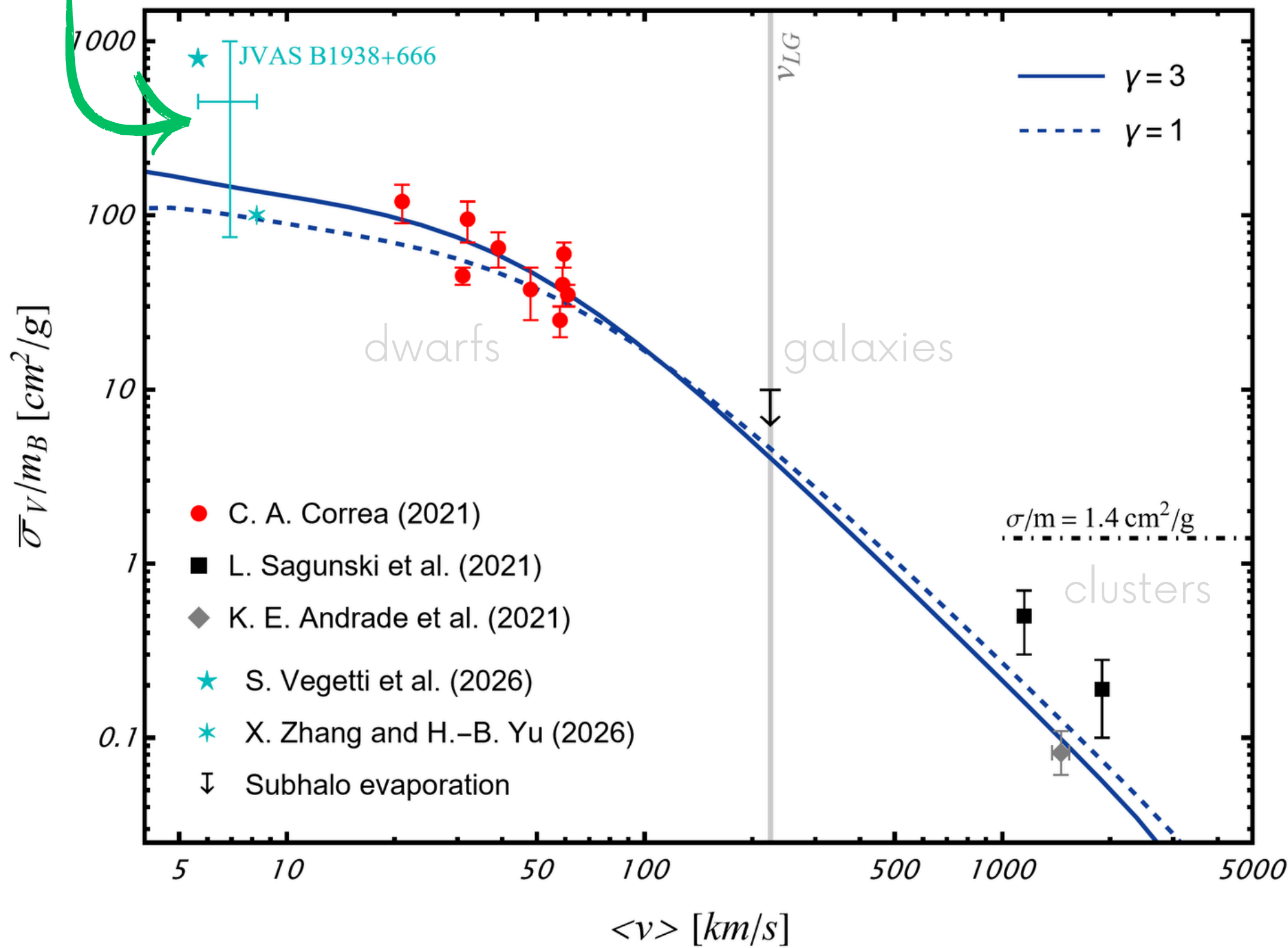


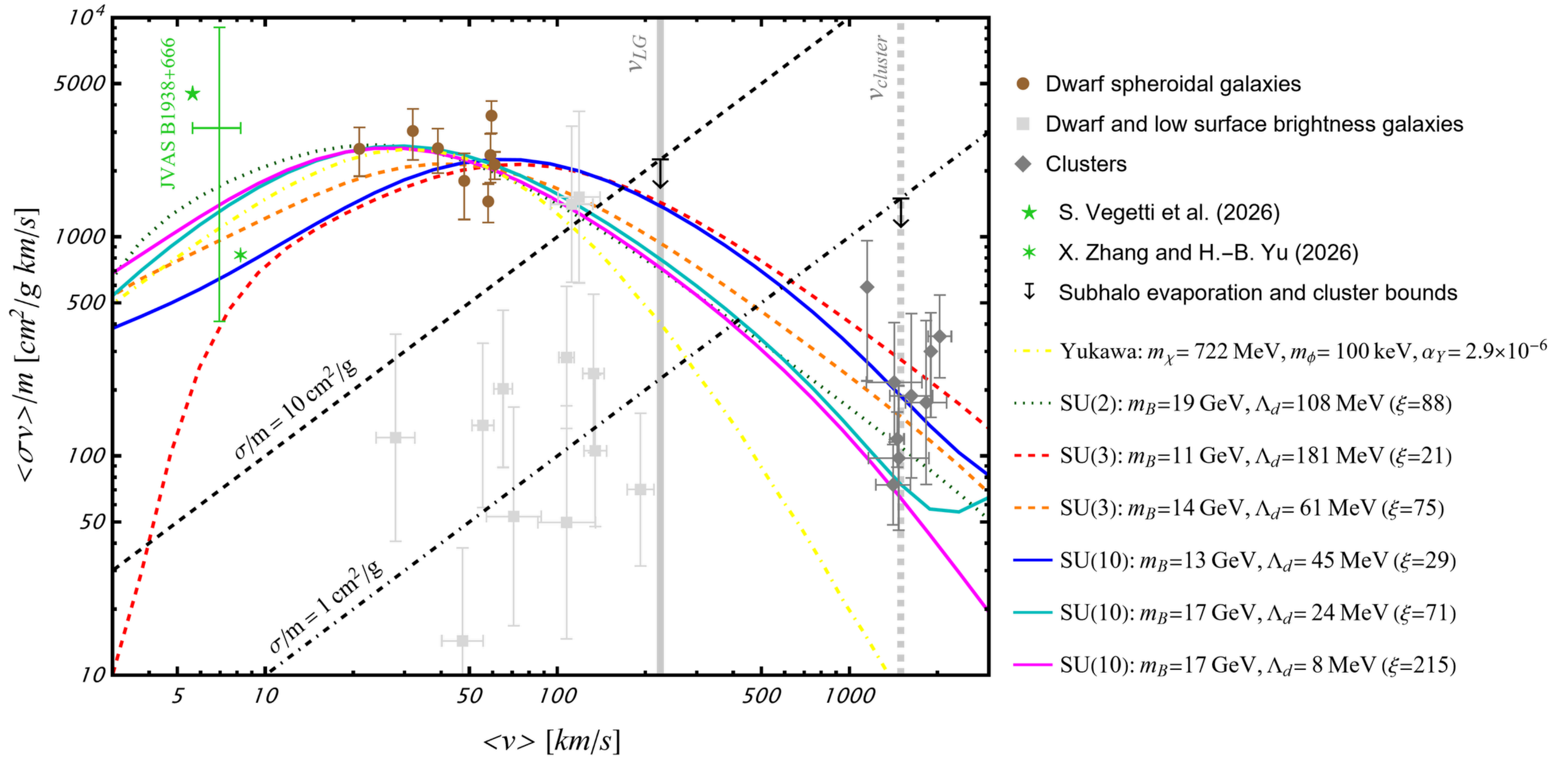
A more recent analysis:
 $\sigma(\sim 30 \text{ km/s})/m \sim 50 \text{ cm}^2/\text{g}$
(anti-correlation between the central
DM densities and their orbital
pericenter distance)

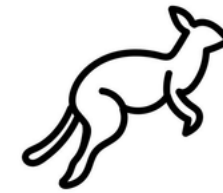
JVAS B1938+666 SYSTEM(PERTURBER)

$m_B = 16 \text{ GeV} , \Lambda_d = 90 \text{ MeV}$

SU(2) :



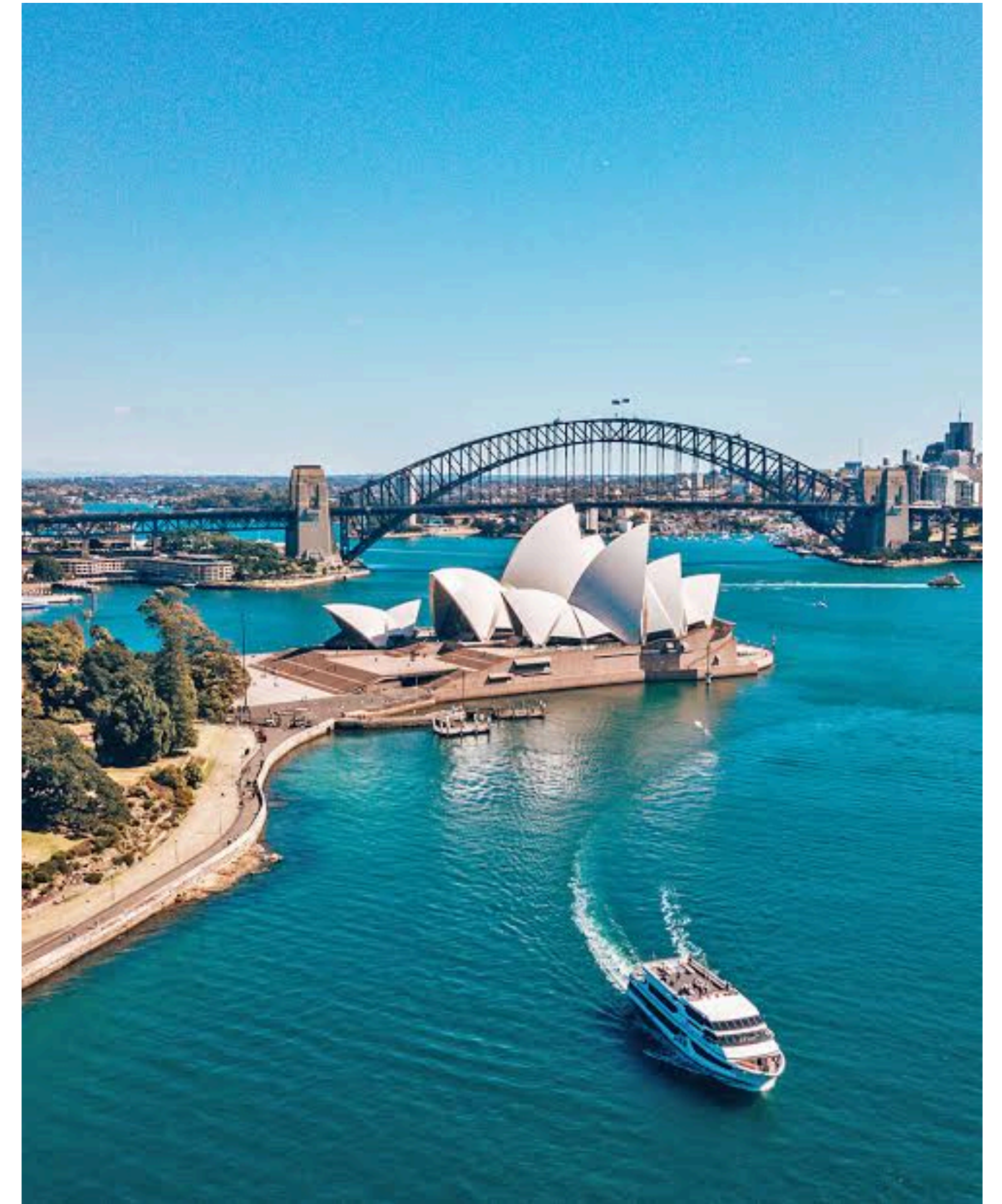




CONCLUSIONS

- Heavy dark baryons present a **rich velocity evolution**
- A possible solution to small scale problems
 - and a natural **Asymmetric Dark Matter** model
- It could **explain** the recently discovered
 - 2nd perturber of the **JVAS B1938+666** system

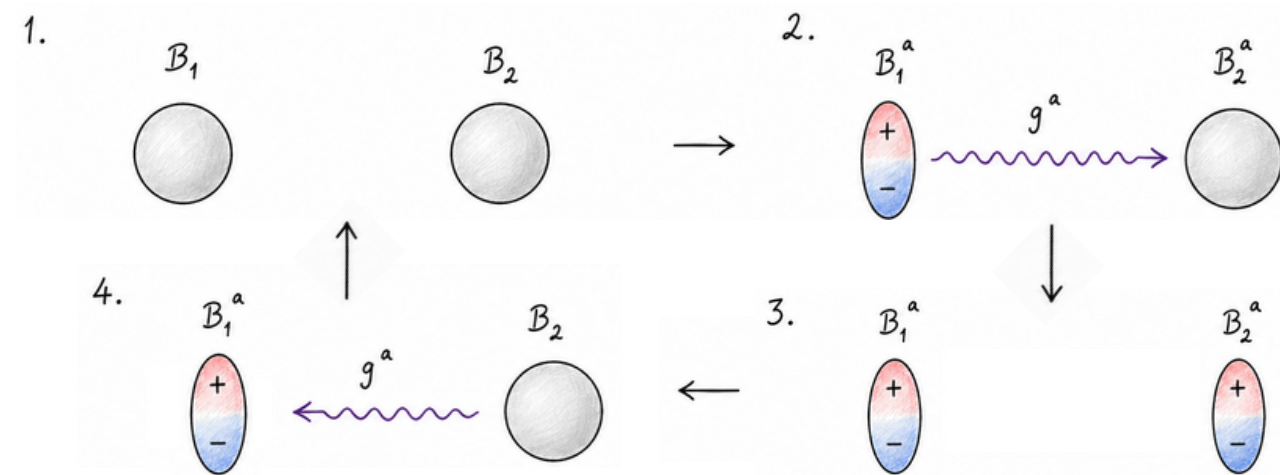
THANK YOU! QUESTIONS?



B A C K U P S L I D E S

Interaction potential

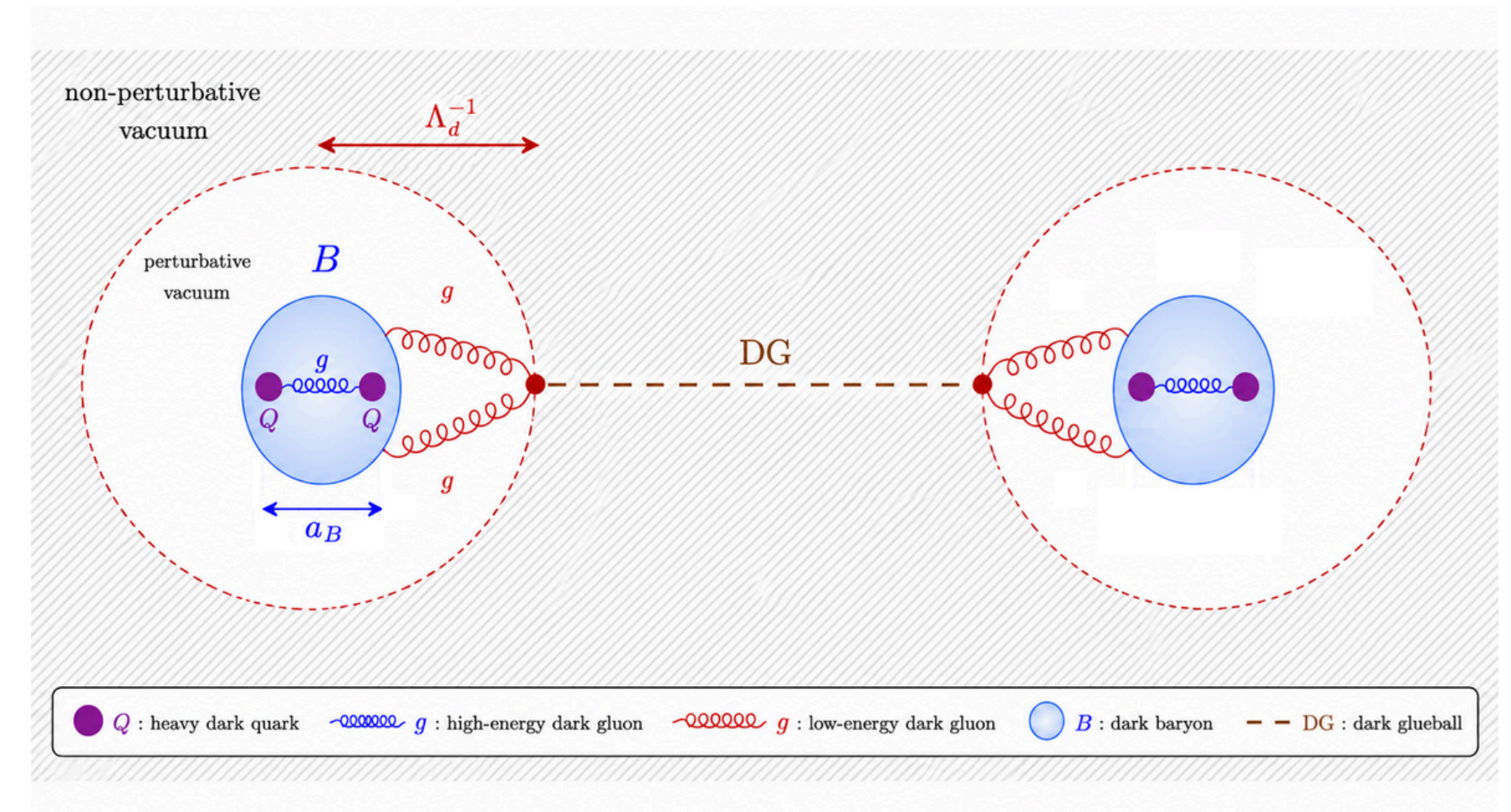
- instantaneous dipole-induced dipole interaction



leads to Van der Waals forces:

$$V(r) \propto \alpha_B^2 \begin{cases} r^{-6}, & a_B \ll r \ll \epsilon_B^{-1}, \\ r^{-7}, & \epsilon_B^{-1} \ll r \ll \Lambda_d^{-1}, \\ e^{-m_{\text{DG}} r}/r, & r \gg \Lambda_d^{-1} \end{cases} \quad t_c \sim \epsilon_B^{-1}$$

$$\begin{aligned} g^2 \mathbf{E}^{a2} &= \frac{g^2}{2} (\mathbf{E}^{a2} - \mathbf{B}^{a2}) + \frac{g^2}{2} (\mathbf{E}^{a2} + \mathbf{B}^{a2}) \\ &= -\frac{1}{4} g^2 G_{\alpha\beta}^a G^{a\alpha\beta} + g^2 (-G_{0\alpha}^a G^{a0\alpha} + \frac{1}{4} g_{00} G_{\alpha\beta}^a G^{a\alpha\beta}) = \frac{8\pi^2}{b} \theta_\mu^\mu + g^2 \theta_{00}^{(G)} \end{aligned}$$

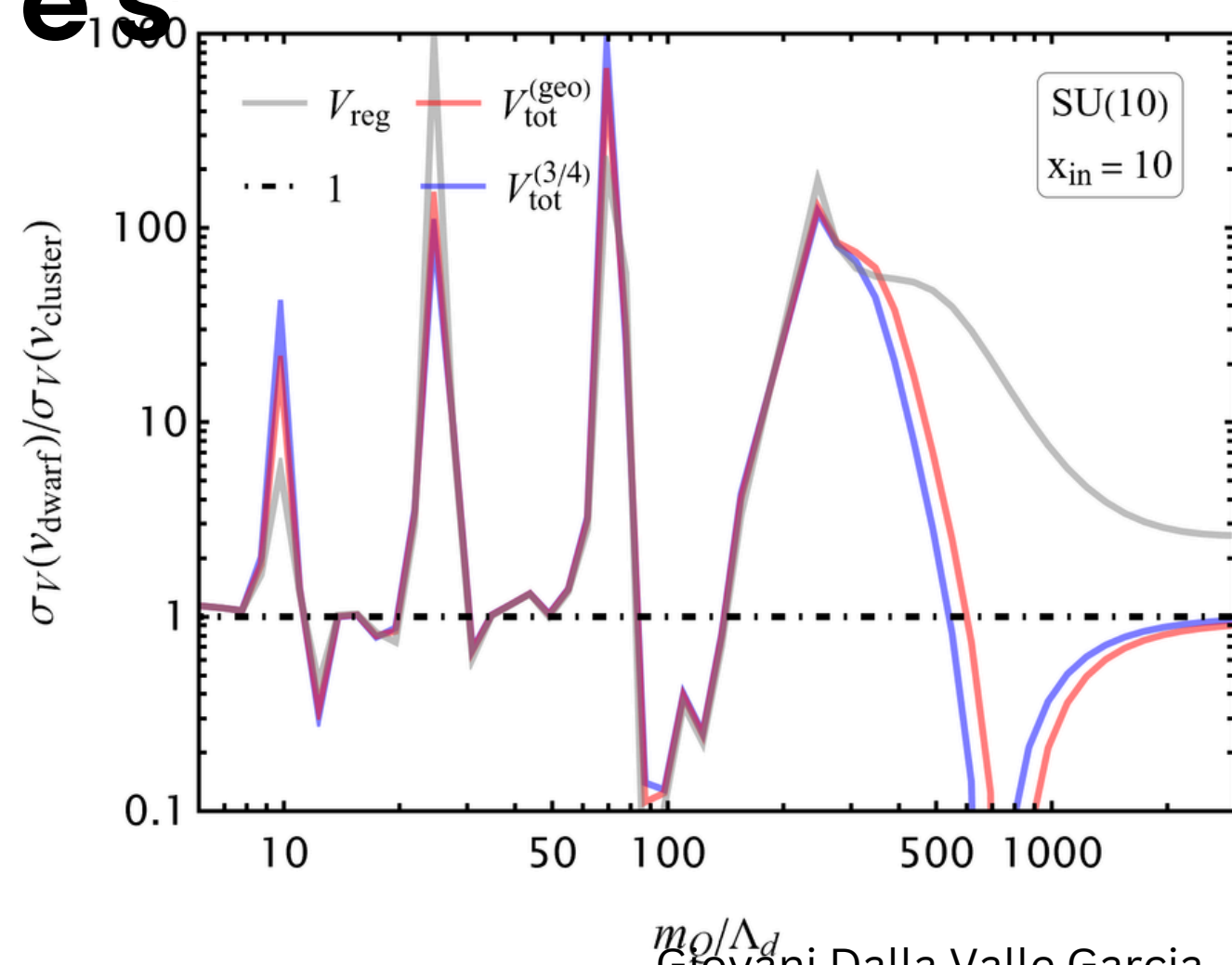
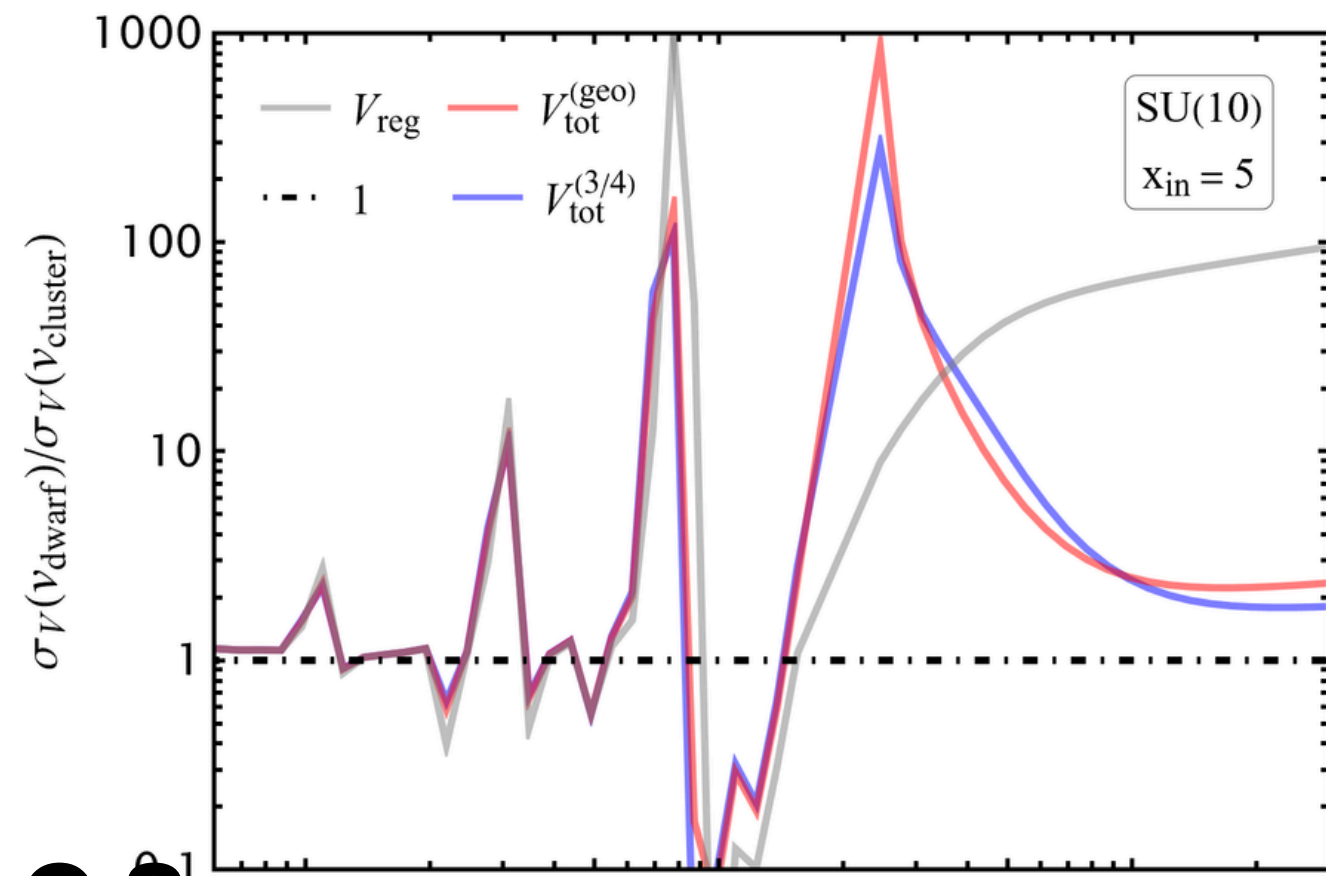
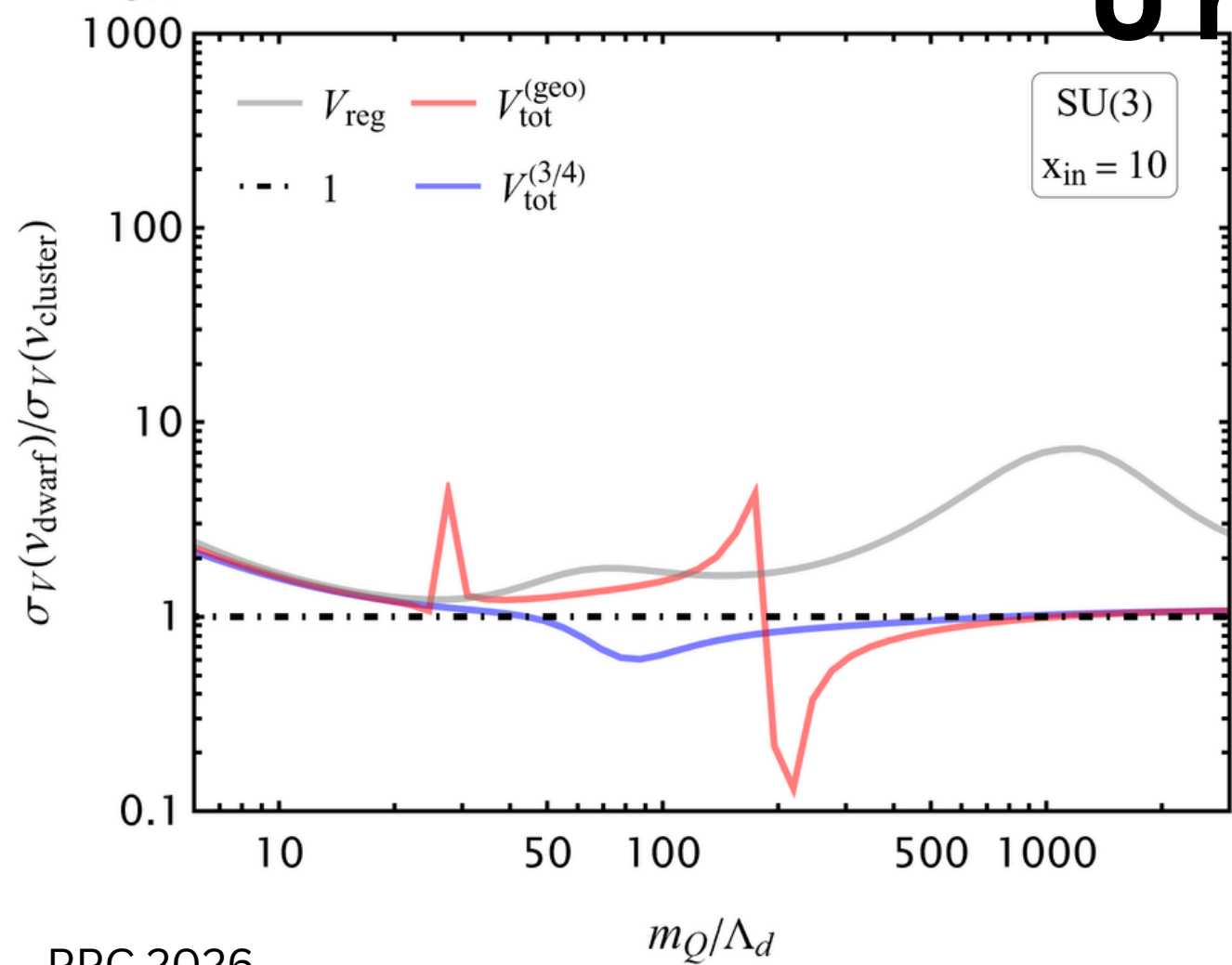
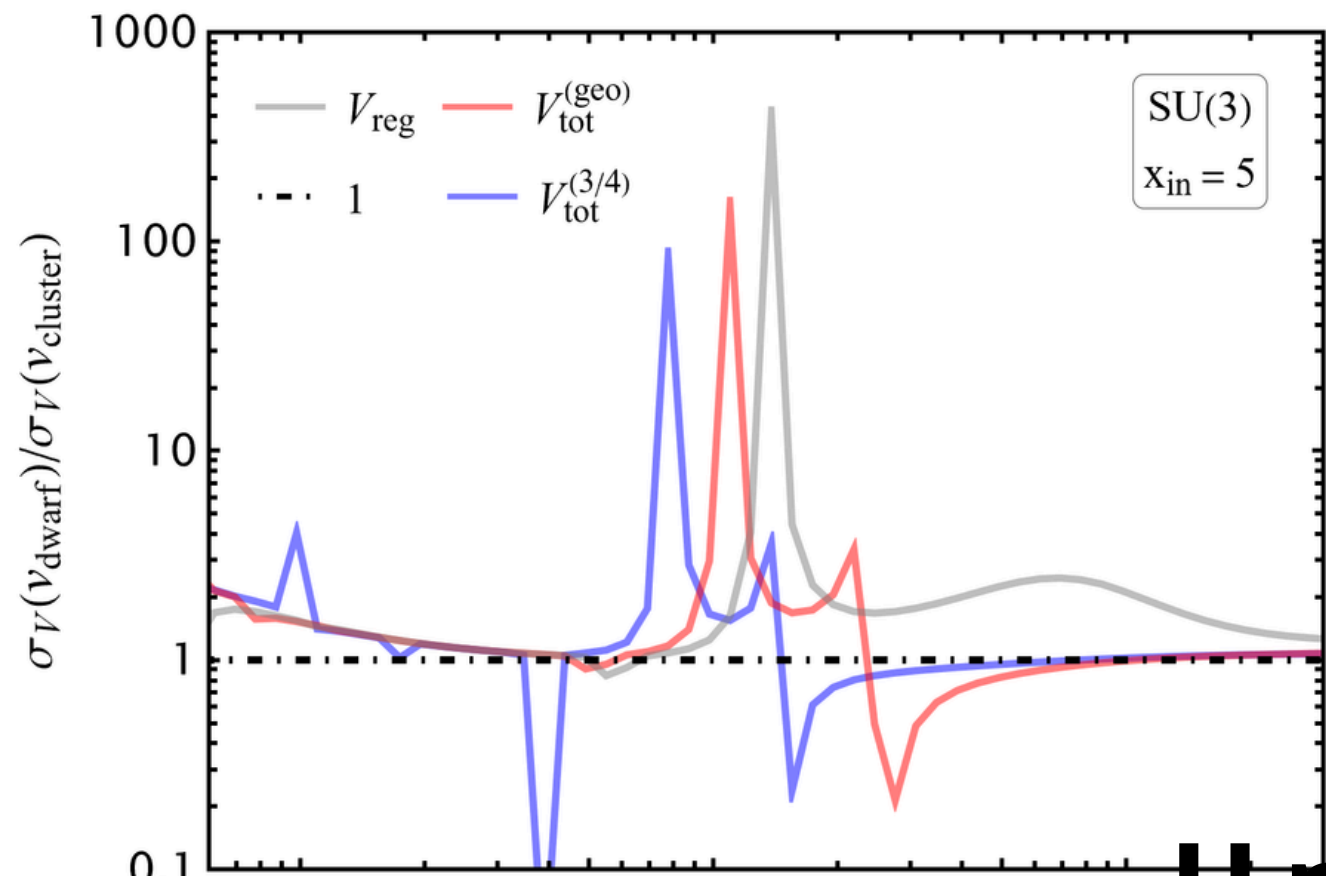


$$r \gg t_c \sim \epsilon_B^{-1}$$

$$V(r) = -\alpha_B^2 \left(\frac{4\pi^2}{b} \right)^2 \int dm_\sigma^2 \rho_\theta(m_\sigma^2) \frac{e^{-m_\sigma r}}{4\pi r}$$

Non-perturbative effects can now be computed via the spectral density

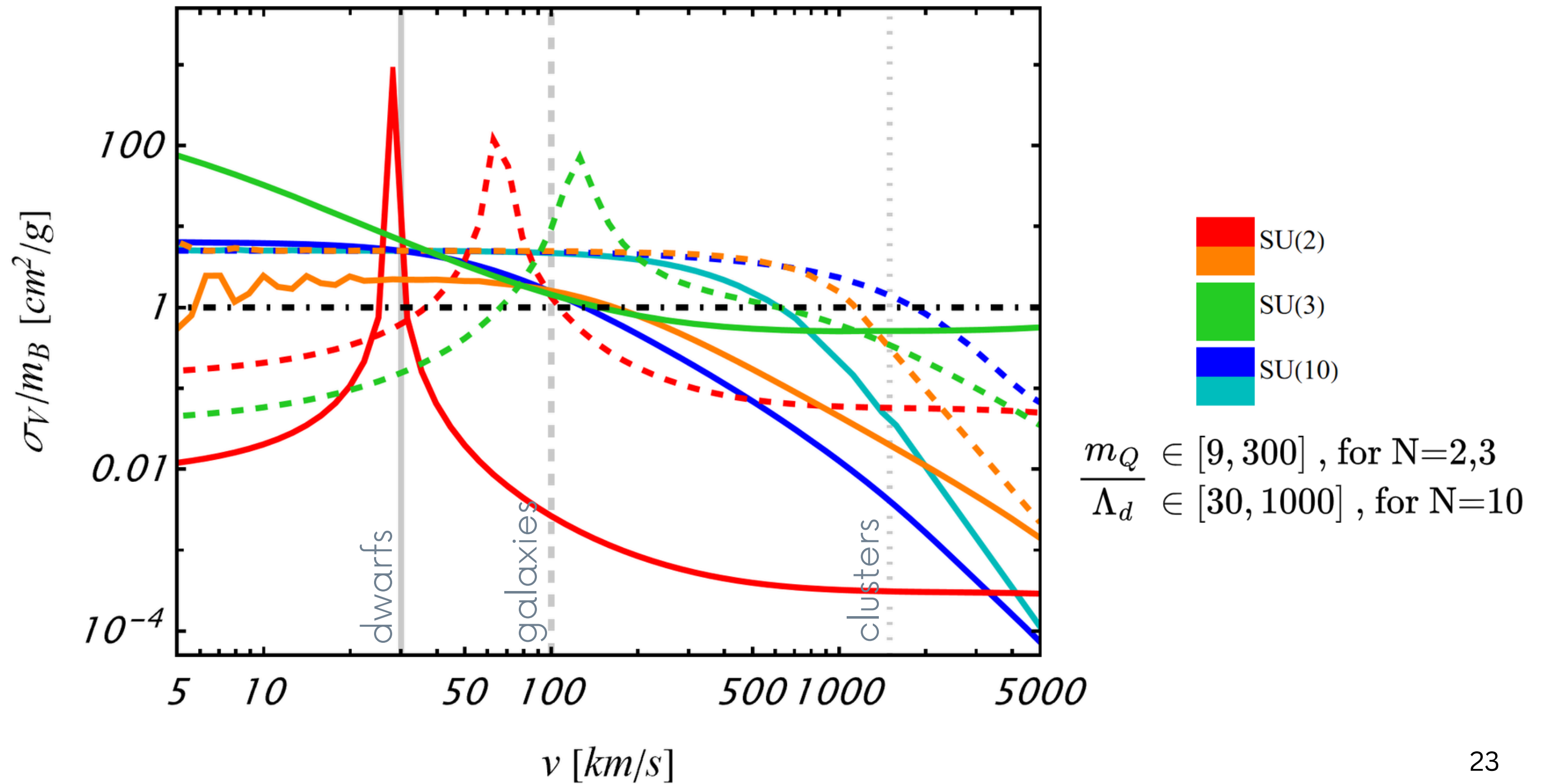
$$\rho_\theta(m_\sigma^2) \simeq 4 \left(\frac{N}{3} \right)^2 m_{\text{DG}}^6 \delta(m_\sigma^2 - m_{\text{DG}}^2)$$



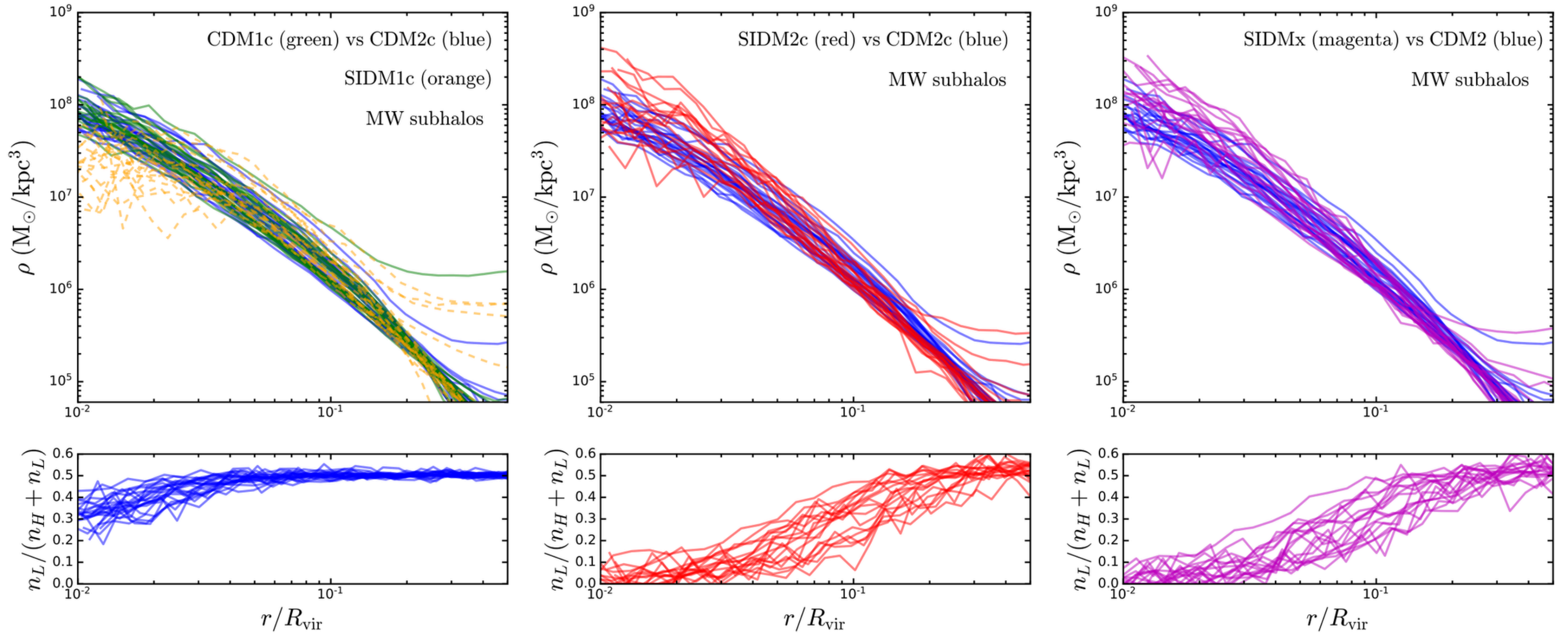
Uncertainties

$\xi \gtrsim 10^3$

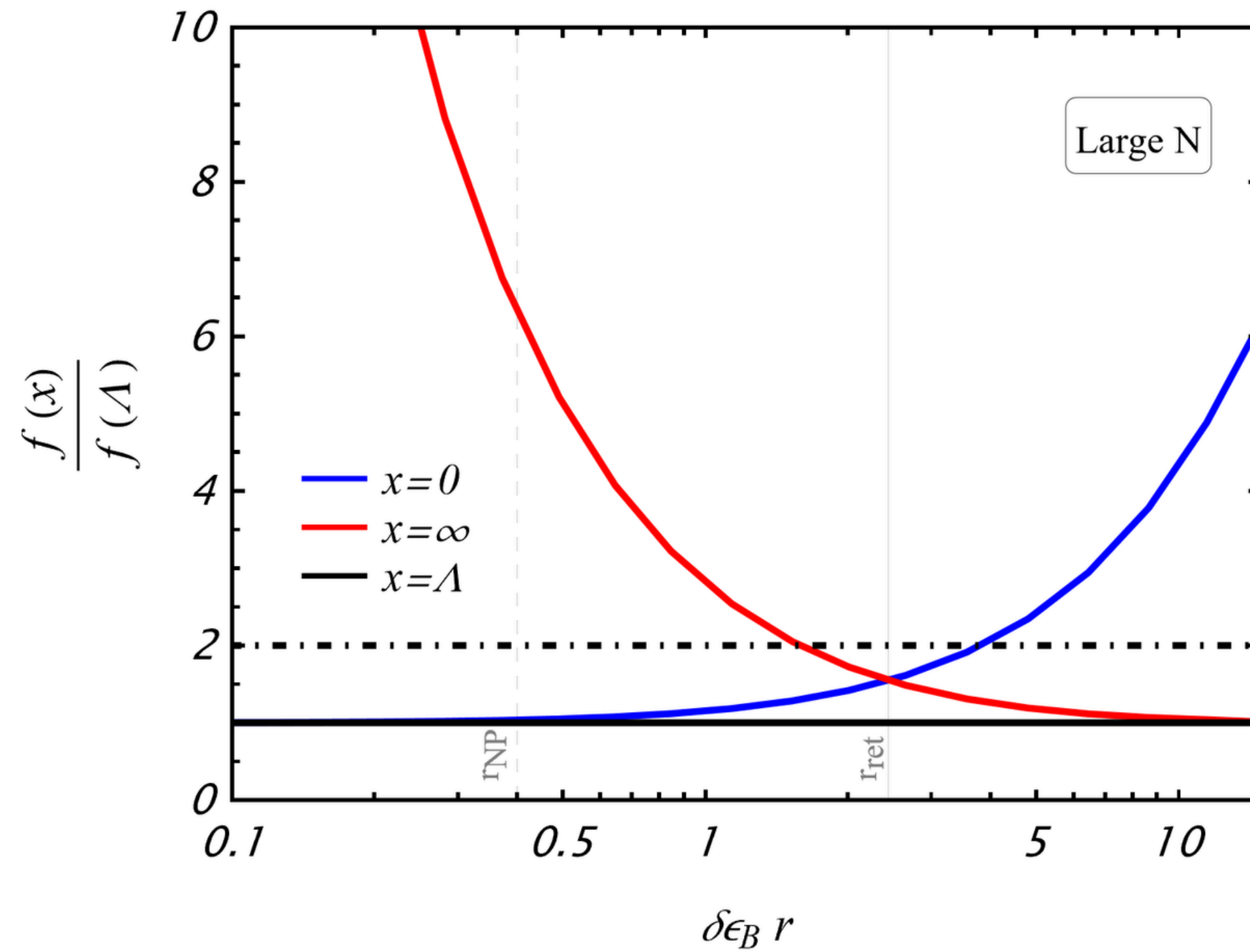
Velocity evolution



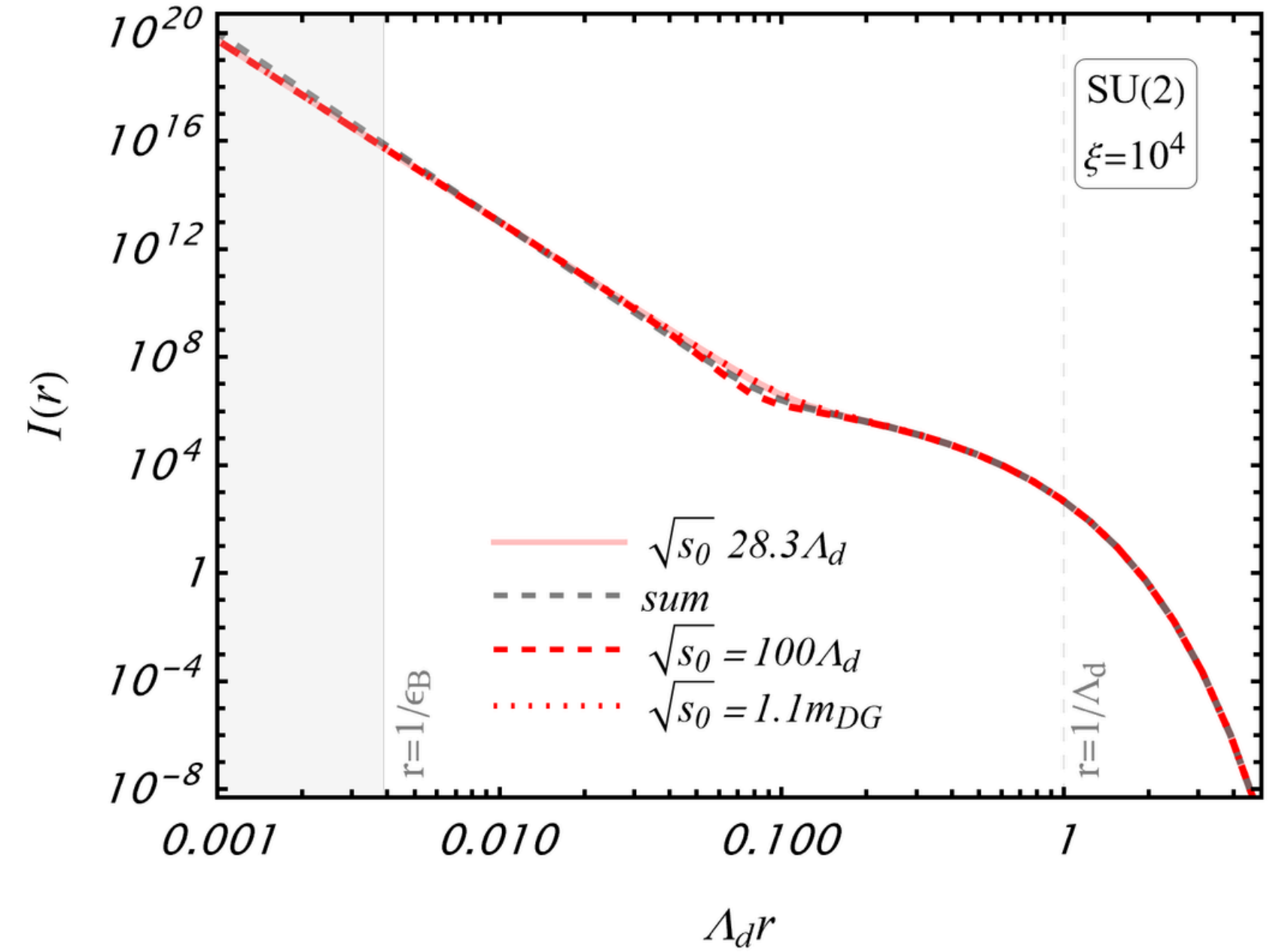
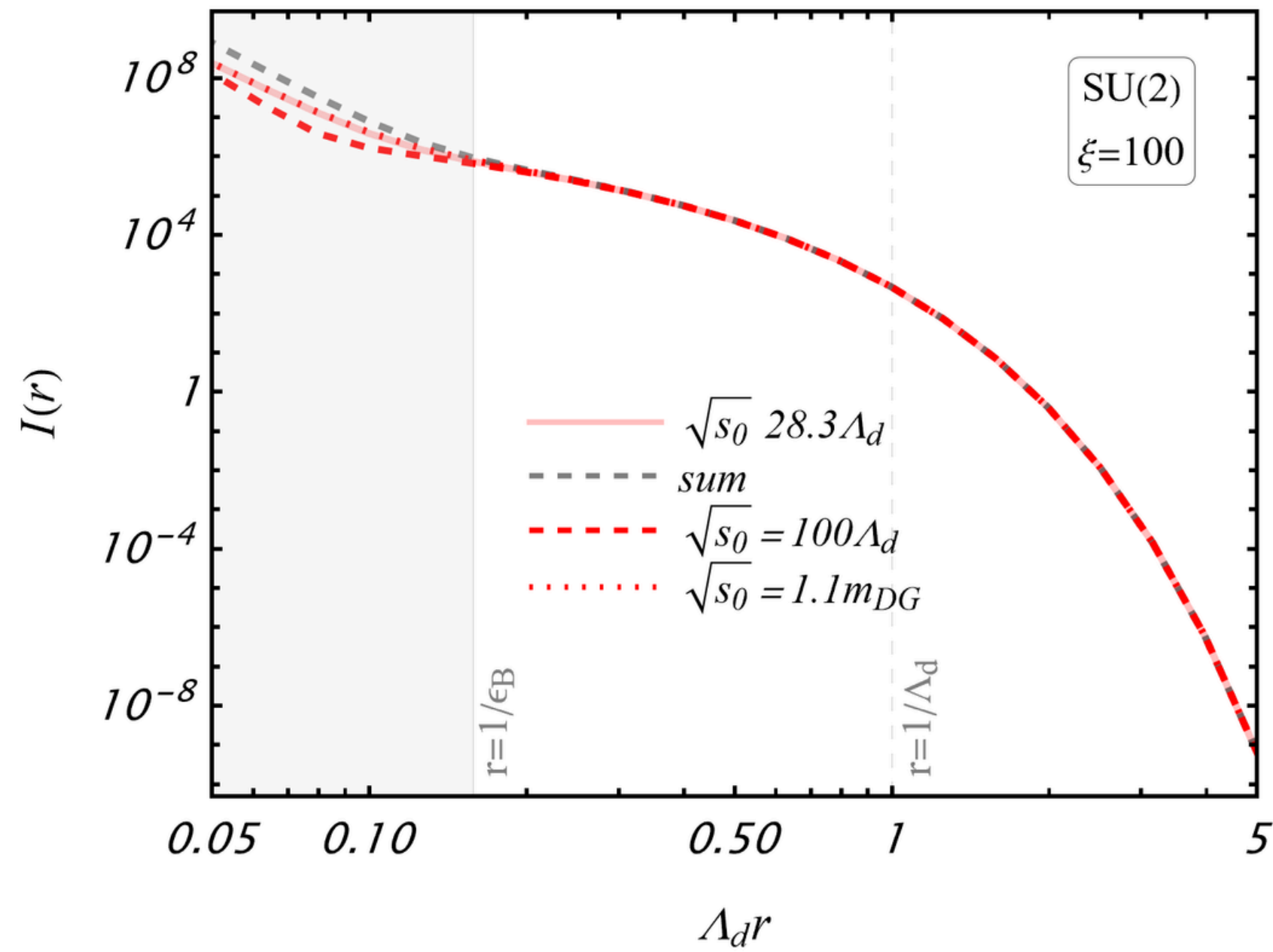
Diversity in 2-component SIDM via mass segregation



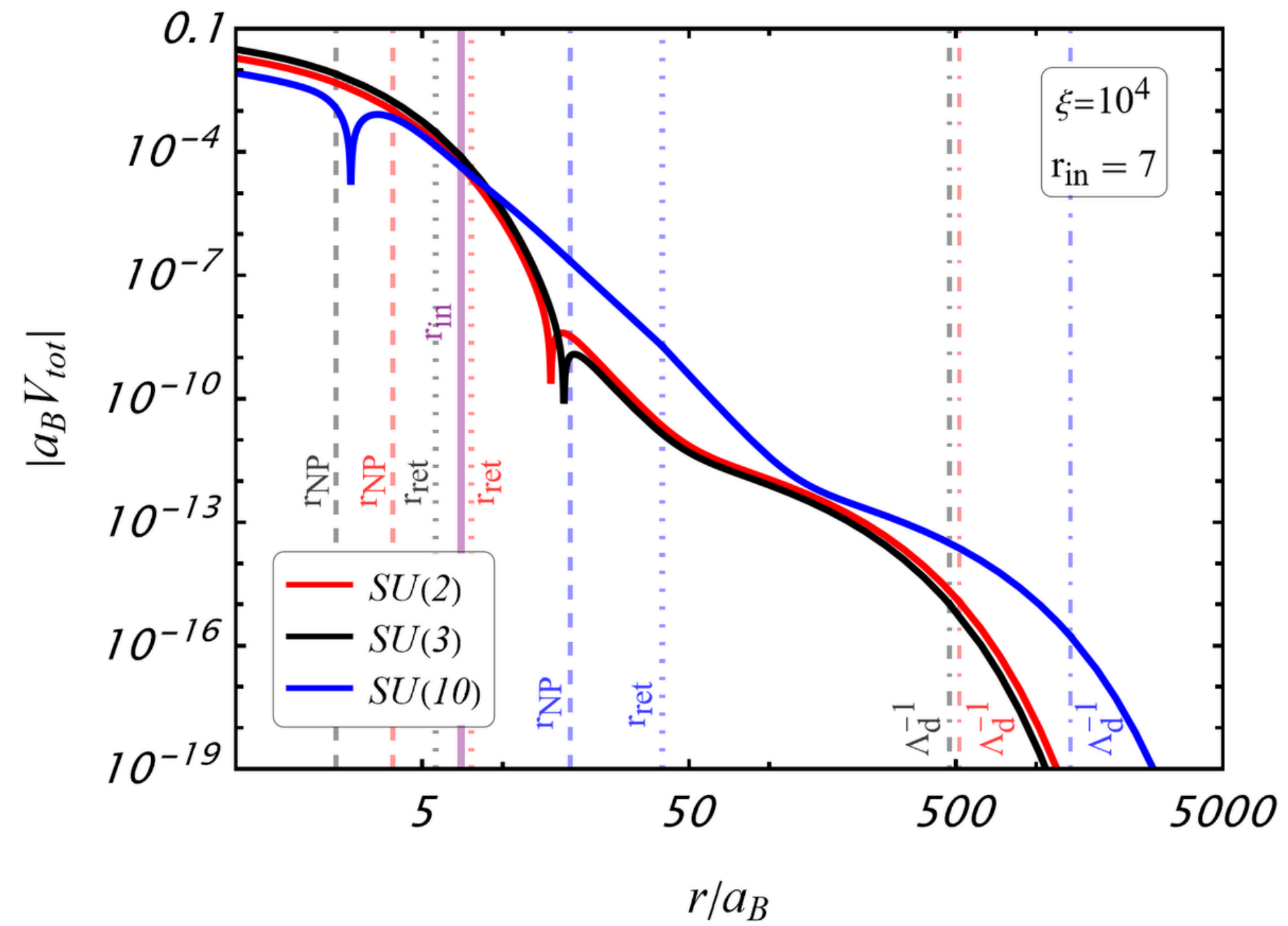
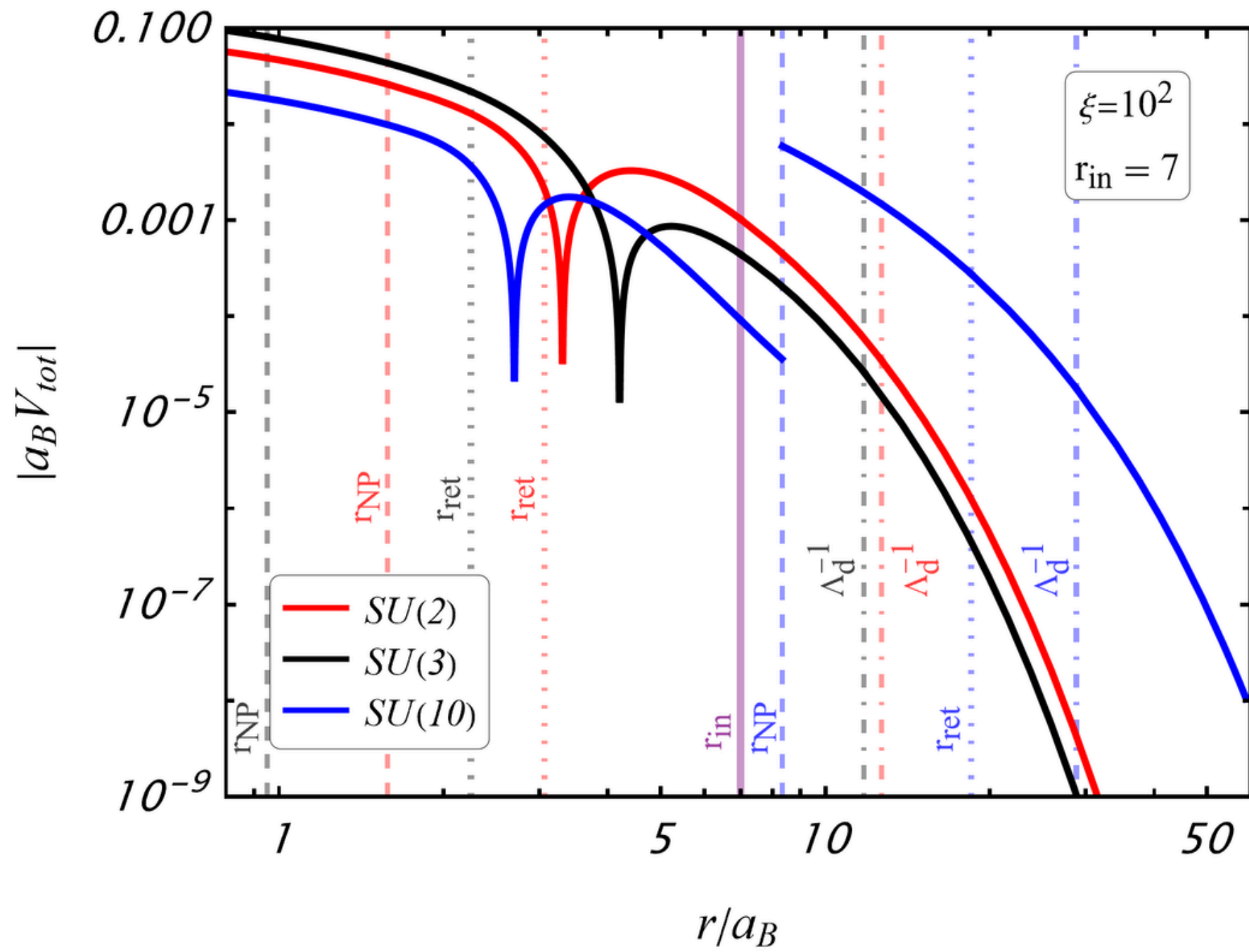
V6 to V7 transition



Sum of potentials



Non-perturbative effects



Re-annihilation(s)

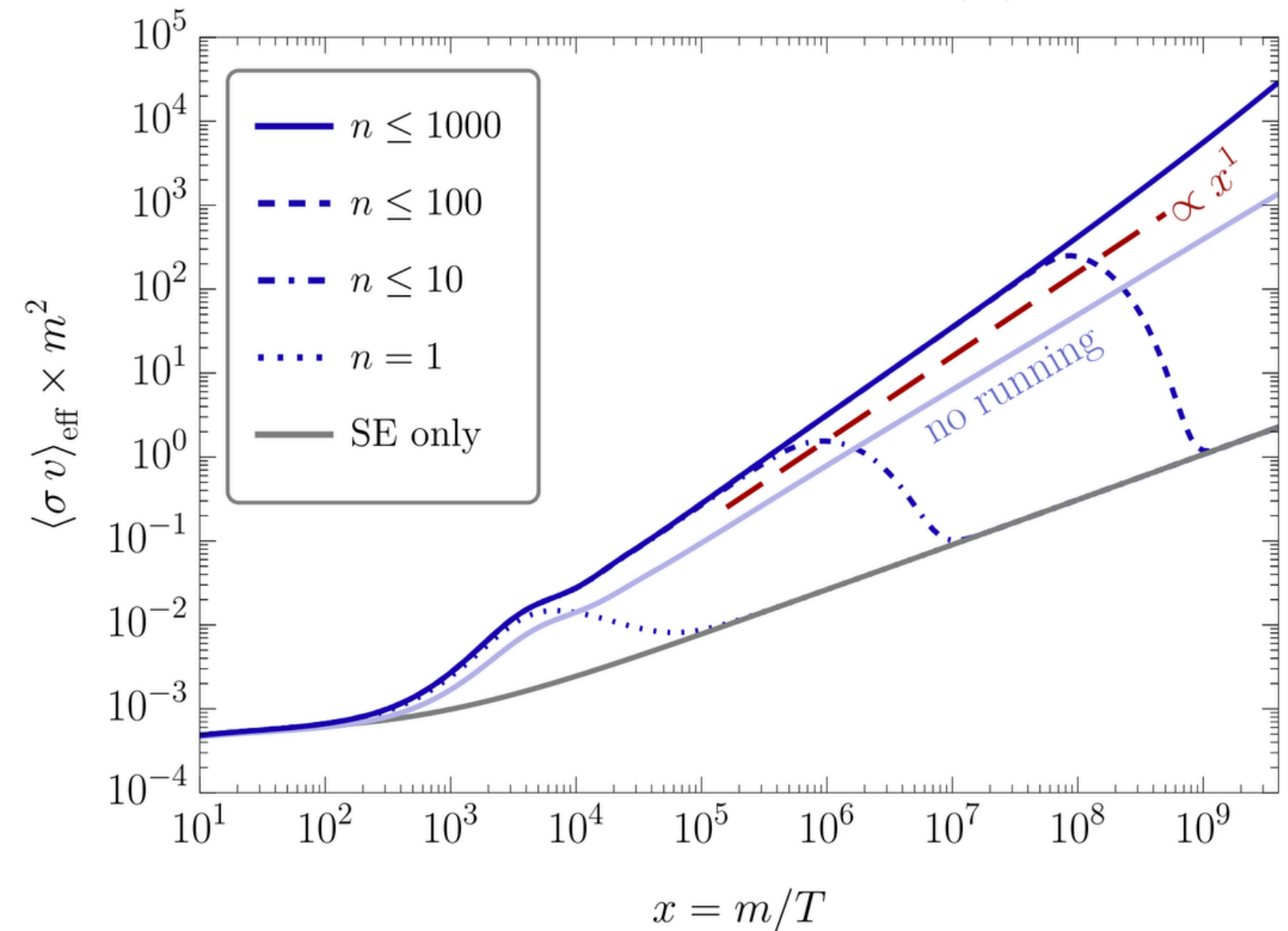
at low velocities

- Bound state formation

$$\langle \sigma v \rangle_{\text{eff}} = \langle \sigma v \rangle_{\text{ann}} + \sum_{n,l} \langle \sigma v \rangle_{nl} R_{nl}$$

T. Binder *et al.* in 2308.01336

Dark QCD effective cross section, $\alpha(m) = 0.025$



Re-annihilation(s)

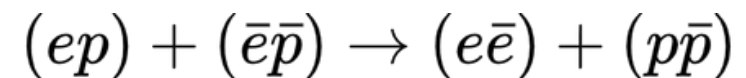
at low velocities

- **Bound state formation**

$$\langle \sigma v \rangle_{\text{eff}} = \langle \sigma v \rangle_{\text{ann}} + \sum_{n,l} \langle \sigma v \rangle_{nl} R_{nl}$$

- **Baryon annihilation**

analogous to hydrogen/anti-hydrogen annihilation



$$\sigma_{B\bar{B}} v \sim \frac{1}{\alpha_d} \frac{\pi}{m_Q^2} \gg \sigma_{Q\bar{Q}} v \sim \frac{\pi \alpha_d}{m_Q^2}$$

A. Mitridate *et al.* in 1707.05380

