A sub-GeV dark matter model: $U(1)_{T3R}$ extension of SM

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WHY LOW MASS DARK MATTER MODEL

- Lack of evidence for WIMP miracle and recent interest in sub-GeV DM.

- DM with mass $\mathcal{O}(1-100)$ MeV evades tight constraints from the current direct detection experiments and can get right relic density.

- Why $m_{DM} \sim \mathcal{O}(1-100)$ MeV? DM arise from a new physics associated with the light flavor sectors.

- Connect the DM to the light flavor sector through a dark photon/Higgs interactions for right handed SM fermions.

- Can solve the Yukawa sector hierarchy problem in the light flavor sector.

MODEL

- Gauge symmetry : $SU(2)_L \times U(1)_Y \times U(1)_{T3R}$. The electric charge, $Q = T_{3L} + Y$.
- Anomalies cancel if we choose : one q_R^u, one q_R^d, one ℓ_R and one ν_R. need not be in same generation. Yukawa terms need ϕ insertion.
- ϕ gets VEV V :
  1. breaks $U(1)_{T3R}$ down to Z_2 parity.
  2. SM fermion masses is proportional to V.
  3. Only $\eta_{L,R}$ are odd under parity.
  4. we get physical bosons : ϕ' and A'.

field	q_{T3R}
q_R^u	-2
q_R^d	2
ℓ_R	2
ν_R	-2
η_L	1
η_R	-1
ϕ	-2

- η has both Majorna and Dirac mass term.
  1. we take $m_D << \lambda_M V$
  2. two physical states $\eta_{1,2}$ with $\Delta m = m_1 - m_2 = 2m_D$.
  3. $m_{1,2}$ scale with V.

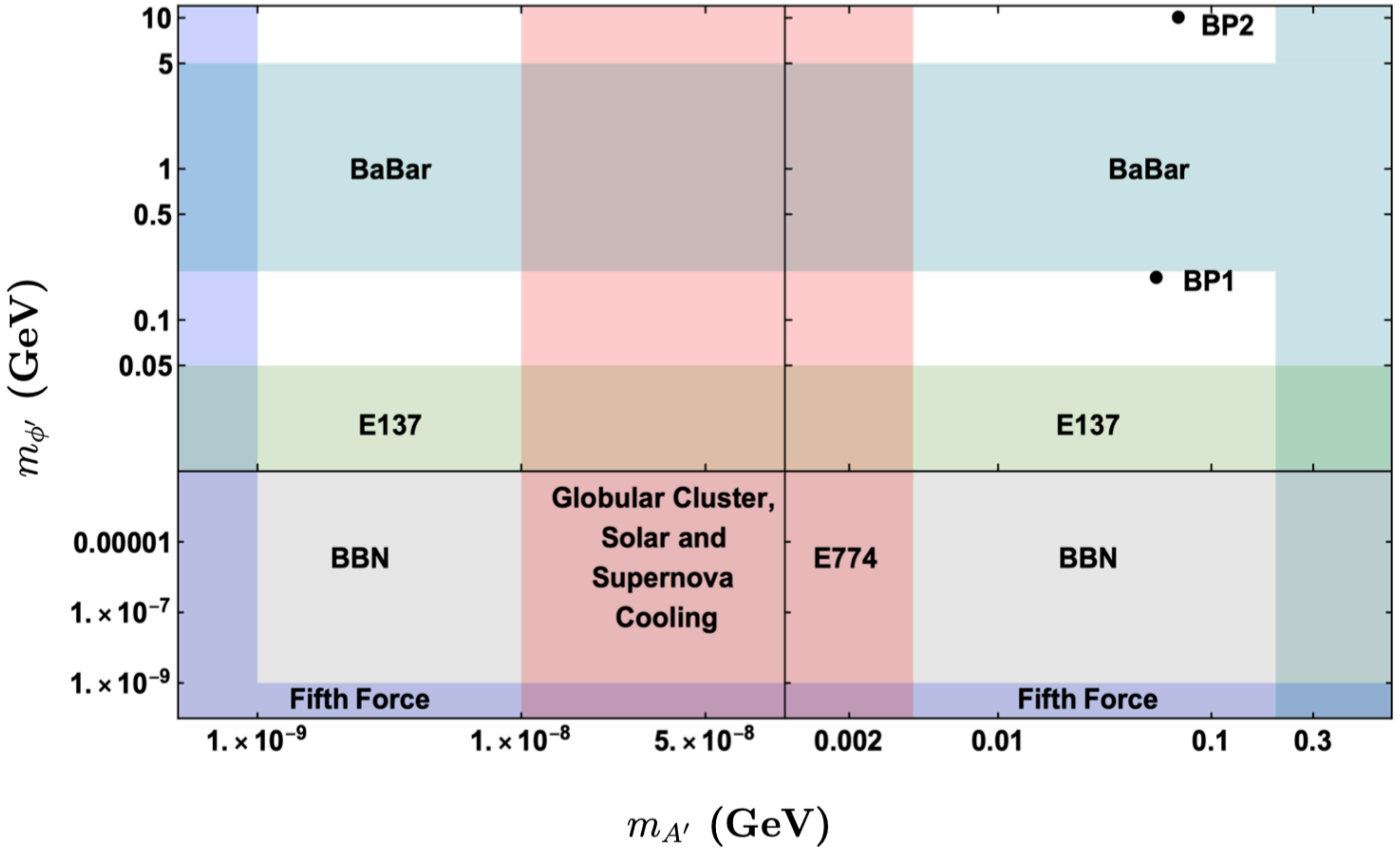
$$M_\eta = \begin{bmatrix} \lambda_M V & m_D \\ m_D & \lambda_M V \end{bmatrix}$$

MODEL

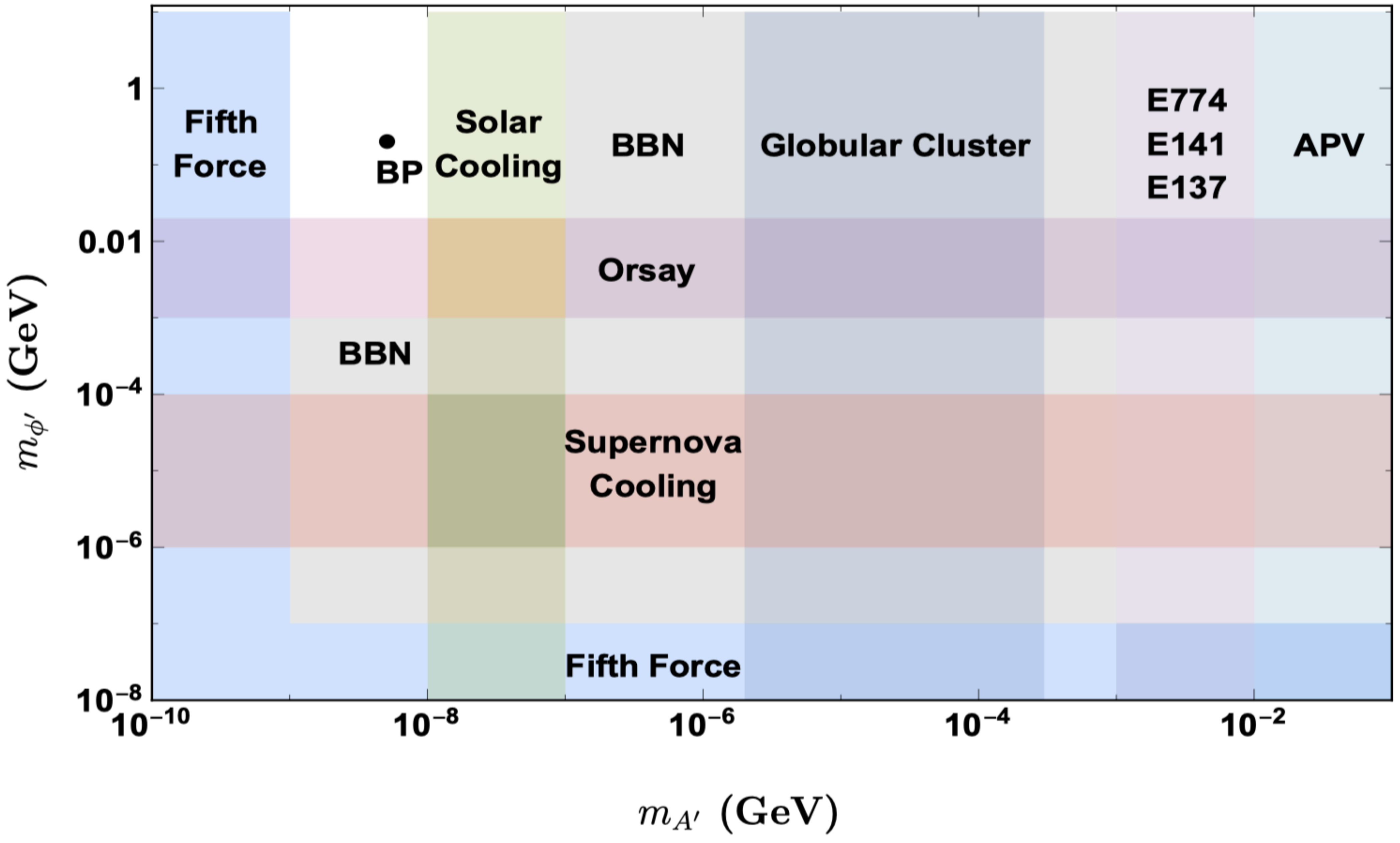
- If $V \sim \mathcal{O}(1-10)$ GeV, then SM fermions, $\eta_{1,2}$, ϕ' and A' are all sub-GeV.
- ϕ' coupling to $\eta_{1,2}$ is diagonal, while A' coupling is off-diagonal.
- New particles :
  1. A' (dark photon), ϕ' (dark Higgs) .
  2. sterile neutrino, ν_s (mostly ν_R)
  3. $\eta_{1,2}$ (Majorana fermion DM, comes from the mixing of $\eta_{L,R}$) .
- ϕ', A', ν_s are not stabilized by any symmetry. They will decay to SM particles.
- Two specific models with $V = 10$ GeV:
  1. • For $\ell = \mu$: $u_R, d_R, \mu_R, \nu_R, \eta_1, \eta_2, \phi', A'$.
  2. • For $\ell = e$: $u_R, d_R, e_R, \nu_R, \eta_1, \eta_2, \phi', A'$.

CONSTRAINTS

- Main Constraints:
  1. e^+e^-colliders: BaBar
  2. Electron beam dump expts.: $A', \phi' \to e^+e^-$.
  3. Astrophysical: Supernova and solar cooling, Globular cluster.
  4. Fifth force, APV, BBN.



- $\ell = \mu$ **model :**



- $\ell = e$ **model :**

- We take V ~ 10 GeV and small neutrino mixing angle.
- Three benchmark points which we will see get the relic density right also.
- $g-2:$ ϕ' (positive) and A' (negative) in one-loop can be fine-tuned against each other or heavy new physics.

DIRECT DETECTION

- Two channels:
  1. ϕ' mediated : SI, elastic, isospin-invariant.
  2. A' mediated : SI, inelastic and isospin-violating (opposite coupling to u and d).

- Current constraints for low mass DM:

  1. CRESST III : $\sigma_{SI} \sim 10^{-35}$ cm² for $m \sim 200$ MeV.
  2. XENON1T : $\sigma_{SI} \sim 10^{-29} - 10^{-30}$ cm² for $m \sim \mathcal{O}(1 - 100)$ MeV .
  3. CDEX-1B: $\sigma_{SI} \sim 10^{-32} - 10^{-34}$ cm² for $m \sim (50 - 180)$ MeV.
  4. DM-electron scattering : XENON10, SuperCDMS and SENSEI : $\sigma_{SI} \leq 10^{-38}$ cm² for $m \sim \mathcal{O}(1 - 100)$ MeV .

- Our benchmark models satisfy all the constraints.

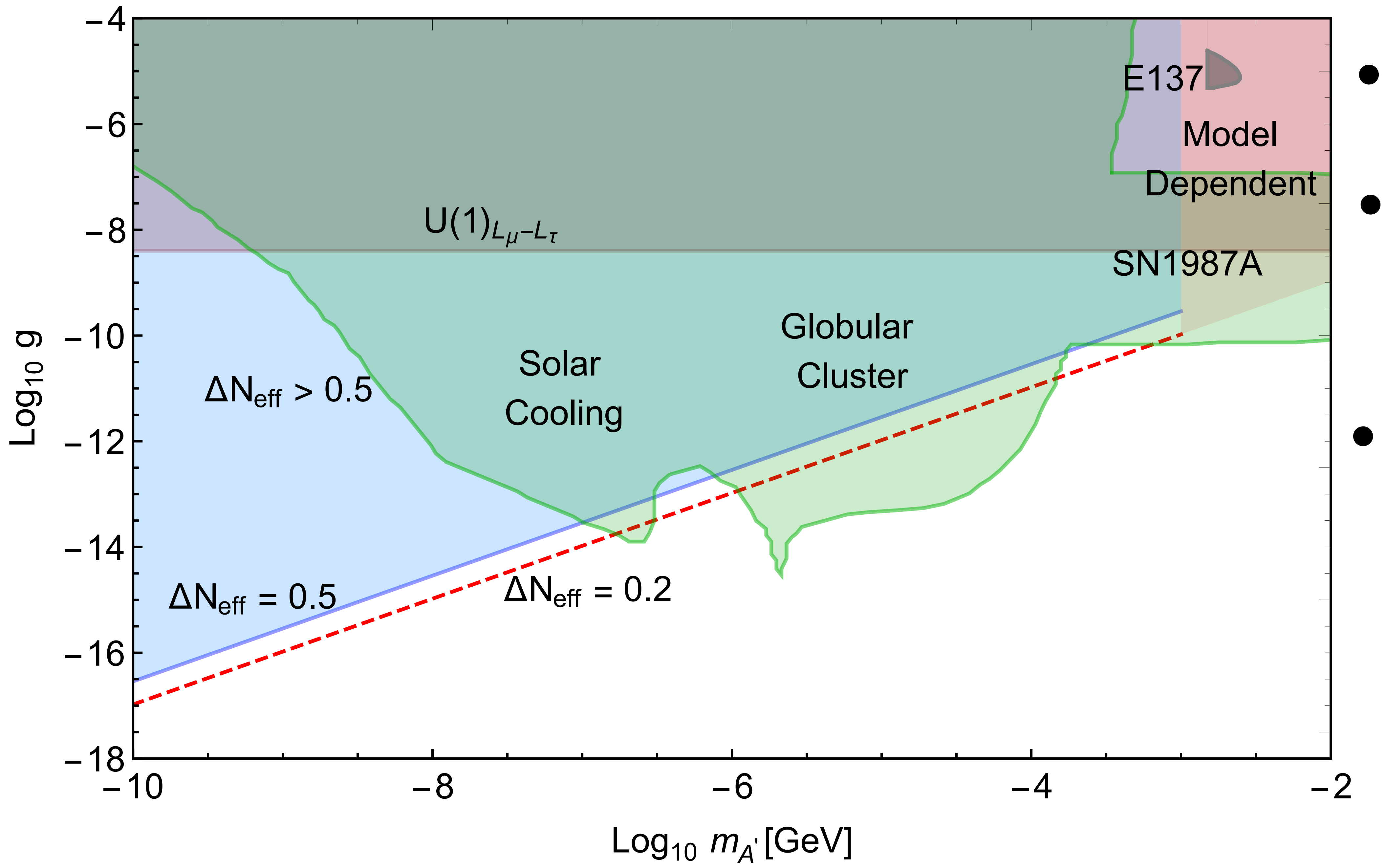
RELIC DENSITY

- We try to get the thermal relic abundance from the (co-)annihilation to SM particles or dark sector particles.
- The dominant two body final states are :
  $\bar{\ell}\ell, \bar{\nu}\nu, \pi\pi, \pi^0(\phi', A', \gamma)$ and the purely dark sector channels $A'A', \phi'\phi'$ and $\phi'A'$.
- Three benchmark models :

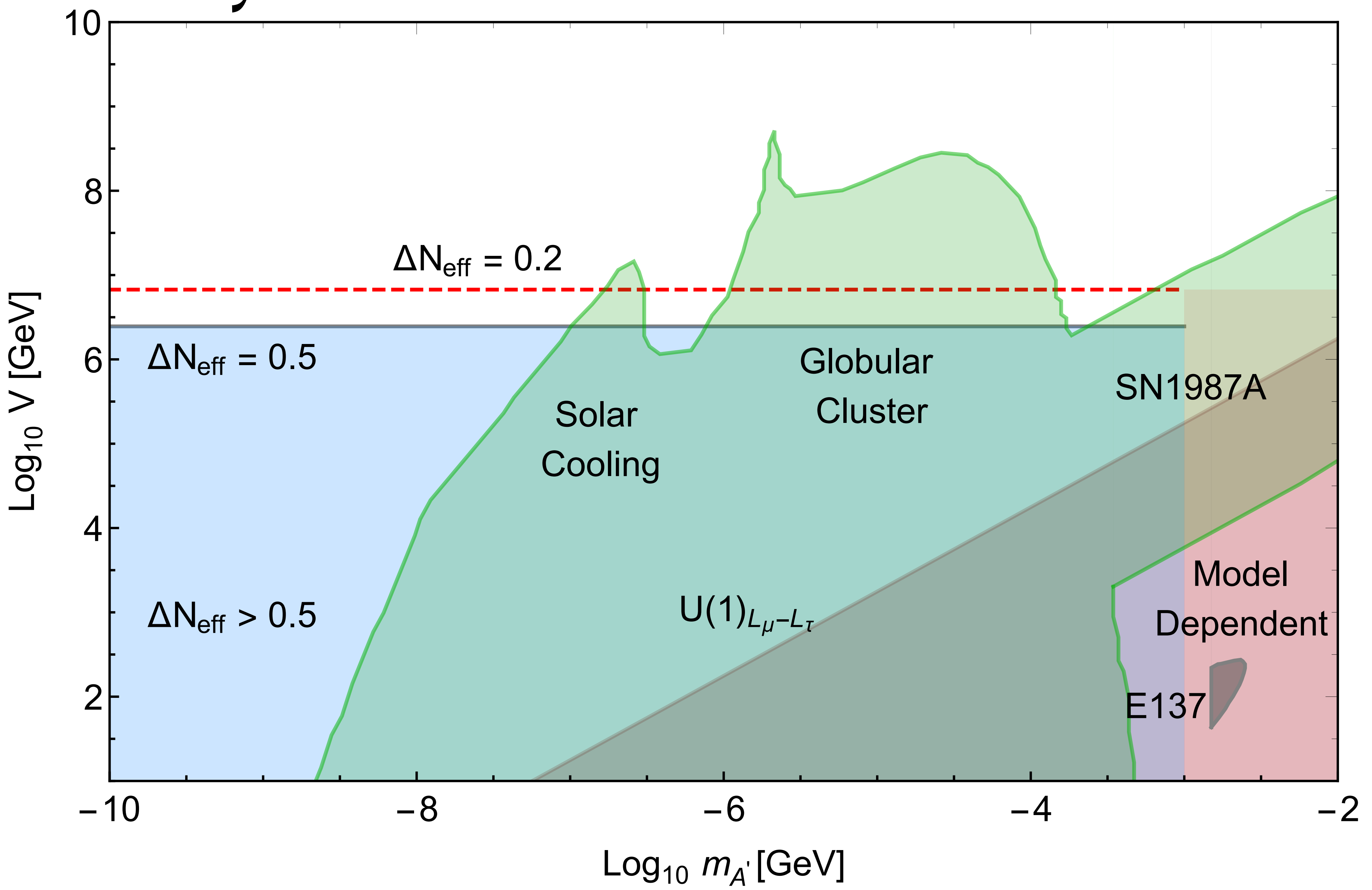
	$m_{A'}$ (MeV)	$m_{\phi'}$ (MeV)	m_η (MeV)	m_{ν_s}(MeV)	$m_{\nu D}$(MeV)	$\langle\sigma v\rangle$ (cm^3/sec)	$\sigma_{\rm SI}^{scalar}$(pb)	$\sigma_{\rm SI}^{vector}$(pb)
muon case	55	200	100	10	10^{-3}	3×10^{-26}	0.51	6.50
	70	10^4	50	10^{16}	10^4	3×10^{-26}	5.67×10^{-9}	1.80
electron case	5×10^{-6}	200	100	10	10^{-3}	3×10^{-26}	0.51	6.50

- The first and third becnhmark gets relic density via ϕ' resonance (p – wave supressed).
- The second benchmark gets the relic density from co-annihilation via A'.

CONTRIBUTION TO ΔN_{eff} FROM A'



- We studied for $\ell = \mu$ model : $\mu\bar{\mu} \to \gamma A'$.
- The constraints are much more severe than $U(1)_{L_\mu - L_\tau}$ because A' couples to chiral fermions.
- No matter how weak the coupling, the Goldstone mode (longitudinal polarization) does not decouple and equilibrates in the early universe.



- Even extremely light and weakly coupled A' of $U(1)_{T3R}$ is ruled out, unless the symmetry breaking scale is $\geq 10^7$ GeV.
- H_0 tension can be resolved for $\Delta N_{eff} \simeq 0.2$ by choosing V appropriately for $m_{A'} \leq 1$ MeV.
- For $1 \leq m_{A'} \leq 10$ MeV, this can be done by choosing neutrino mass matrix appropriately.

CONCLUSIONS

- The experiments are now focusing on sub-GeV dark matter.
- We present a sub-GeV DM model with $m_{DM} \sim \mathcal{O}(1-100)$ MeV natuarlly connected to the light flavor sector of SM and gives correct thermal relic density.
- Can solve the Yukawa sector hierarchy problem.
- Low mass mediator $\leq \mathcal{O}(10)$ GeV, consistent with the current experiments and can be probed in the future experiments.