SEARCH FOR GUT MAGNETIC MONOPOLES WITH THE MACRO EXPERIMENT AT GRAN SASSO

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1. INTRODUCTION

Gauge theories of unified interactions (GUT) predict MMs

$$SU(5) \xrightarrow[10^{-35}\,s]{10^{15}\,GeV} SU(3)\times[SU(2)_L \times U(1)_Y] \xrightarrow[10^{-10}\,s]{10^{2}\,GeV} SU(3)_C \times U(1)_{EM}$$

Lowest mass $m_M \sim m_x/G > 10^{16}$ GeV $\cong 0.02\ \mu g \rightarrow 10^{17}$ GeV

- M.M. as point defects (topological)
- M.M. produced at end of GUT ($t \sim 10^{-35}$ s)

$$e^+e^- \rightarrow M\overline{M} \quad , \quad q\overline{q} \rightarrow M\overline{M}$$

MM_{GUT} cannot be produced with accelerators

MMs follow "history" of Universe → slowed down, accelerated by galactic magnetic fields

Astrophysical limits → persistence of $B_{galactic}$

Parker bound $\Phi_P < 10^{-15} cm^{-2} s^{-1} sr^{-1}$

Extended bound $\Phi_E < (0.1 - 0.2)\Phi_P$

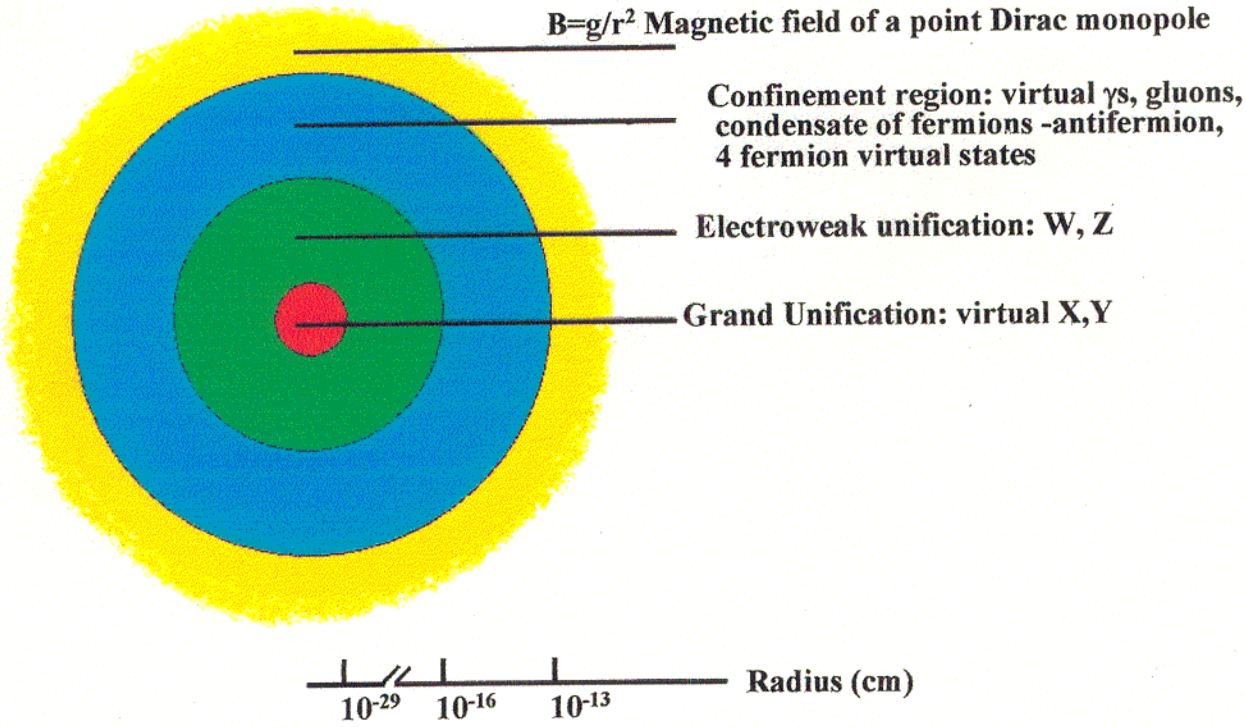
Search for MMs in the penetrating cosmic radiation

Direct searches

Catalysis of proton decay by MMs

PROPERTIES OF COSMIC GUT POLES

- MAGNETIC CHARGE $g = ng_D$ n = 1, 2, 3,...
  Several models predict n ⩾ 2, 3, $g_D = \frac{\hbar c}{2e} \simeq \frac{137}{2} e$
- MASS $m_M > m_x / \alpha \sim 10^{16} GeV \rightarrow 10^{17} GeV$
- SIZE EXTENDED OBJECT
  $r_{core} \sim 1/m_x \sim 10^{-29} cm$, $r_{EW} \sim 10^{-16} cm$
  $r_{confinem} \sim 1 fm$, $r > few\ fm \Rightarrow B = g/r^2$



- ELECTRIC CHARGE
  $\begin{cases} q = 0 & MM \\ q \neq 0 & Dyon \end{cases}$ $m_D > m_{MM}$
  Systems Mp, MAl^{27}, ... (Monopole-Dipole Interaction)
  (Mpe^-) like a "molecule"
- CATALYSIS OF PROTON DECAY
  $M + p \rightarrow M + e^+ + \pi^0$

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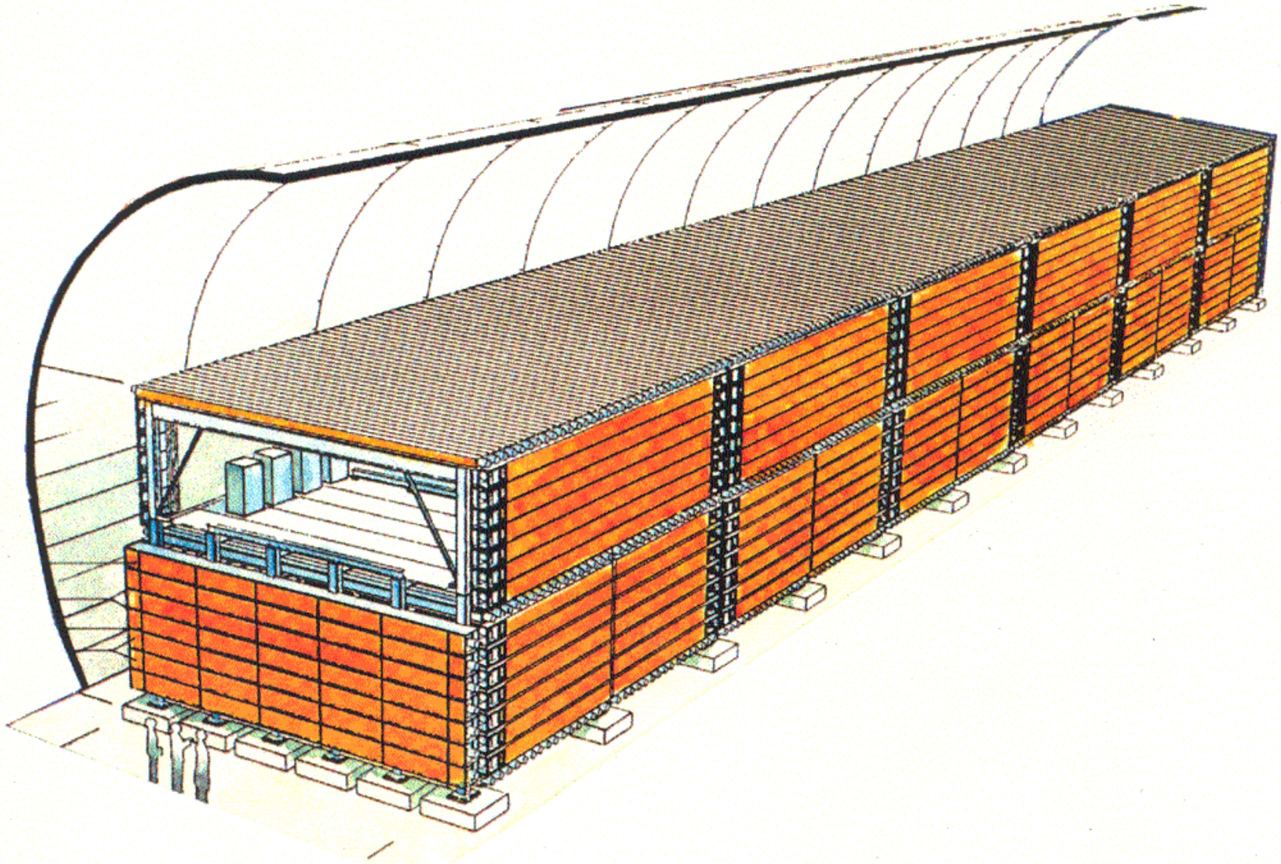
2. THE MACRO EXPERIMENT



- 76.6m × 12m × 9.3m
- Average rock overburden : 3700 hg/cm^2
  Reduction factor of downgoing μ : $\sim 10^6$
- Total acceptance : $S\Omega \simeq 10000$ m^2 sr
- Limited streamer tubes } ALSO REDUNDANT ELECTRONICS
- Scintillation counters ($m_{SCINT.} \sim 600$ t)
- Nuclear track detectors

$m_{LOWER\ PART} \lesssim 5000$ t

3. DIRECT SEARCHES FOR GUT MONOPOLES

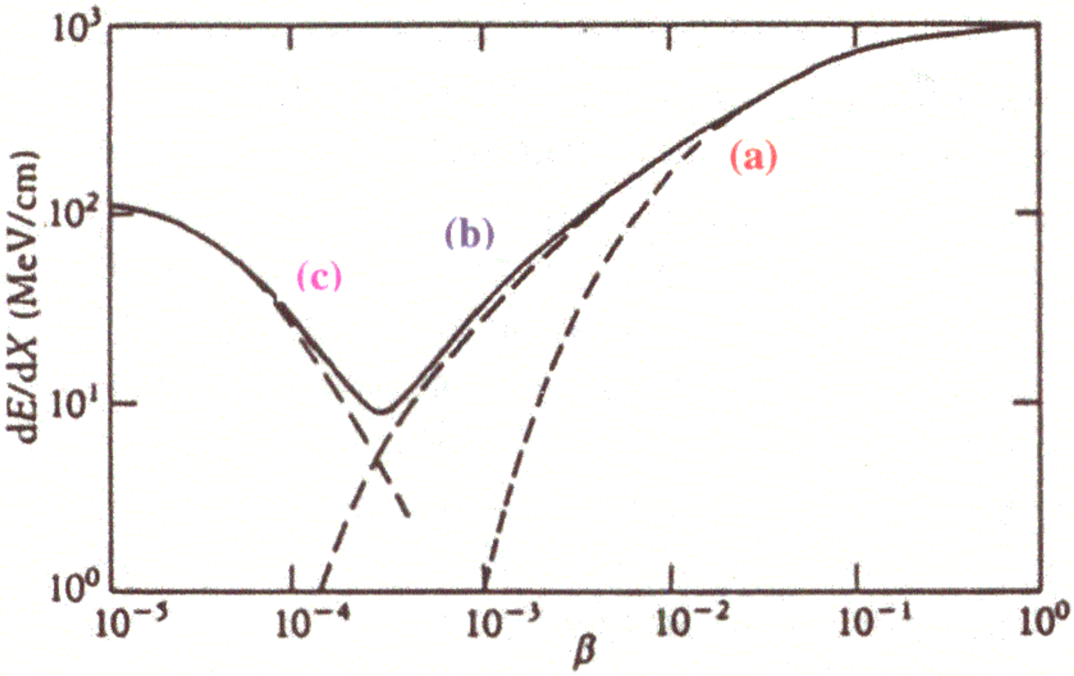
$\beta \gtrsim 10^{-2}$ (10^{-3}) — Ionization (Bethe-Bloch) (a)
$(Ze_{eq})^2 = (g\beta)^2$

$10^{-4} < \beta < 10^{-2}$ (1) — Excitation (b)
Medium (Z > 10) as Fermi gas

$10^{-4} < \beta < 10^{-3}$ — Drell effect in gas: $M\,He \rightarrow M\,He^*$
\+ Penning effect
$$He^* + CH_4 \rightarrow He + CH_4 + e^-$$

$10^{-5} < \beta < 10^{-4}$ — Elastic scattering (c)
(magnetic charge – atomic dipole moment interaction)

IN H_2



NUCLEAR TRACK DETECTORS (CR39) → R.E.L.

4. RESULTS OF MACRO M.M. DIRECT SEARCHES

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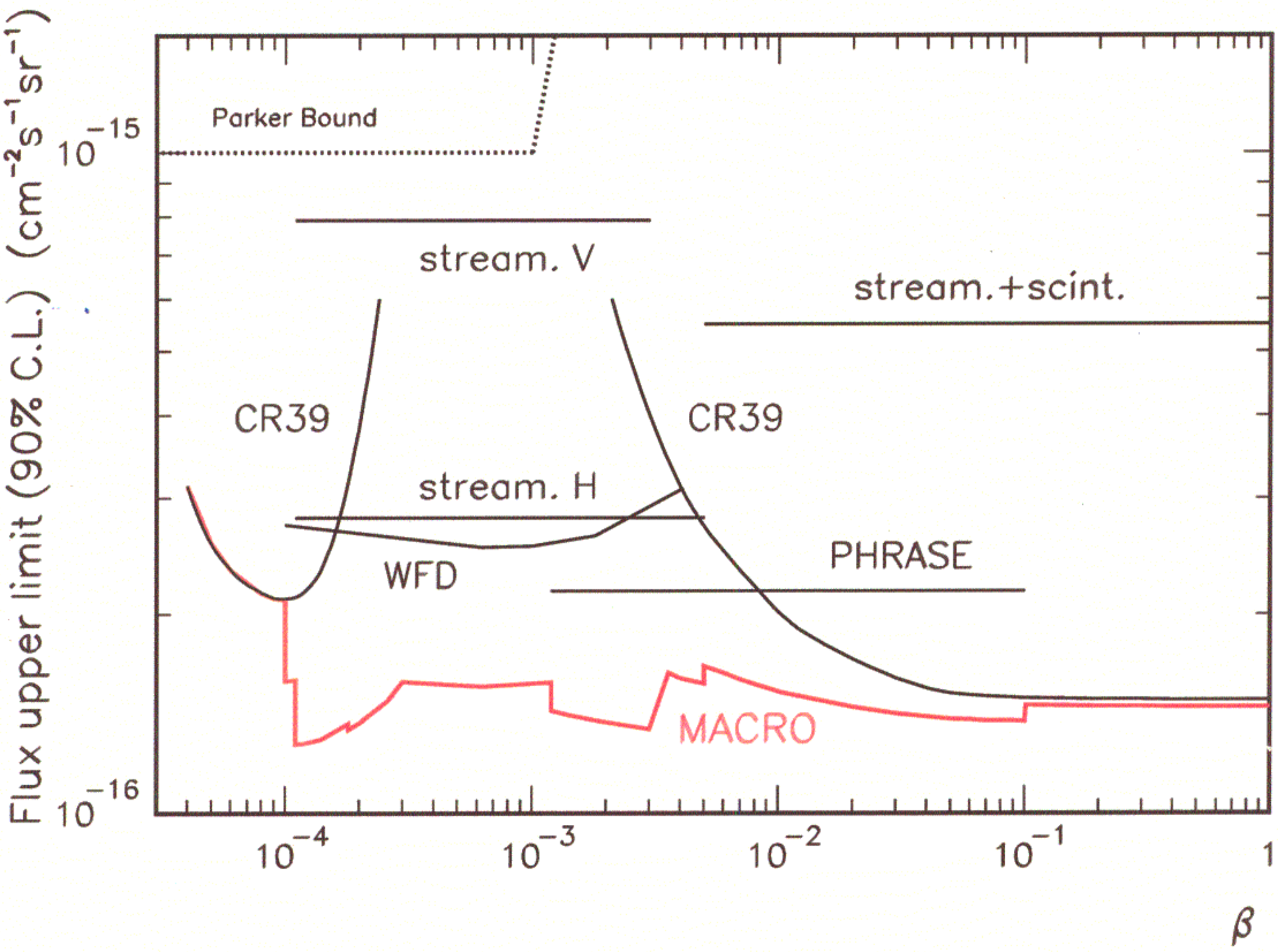
90% CL

$g = g_D$



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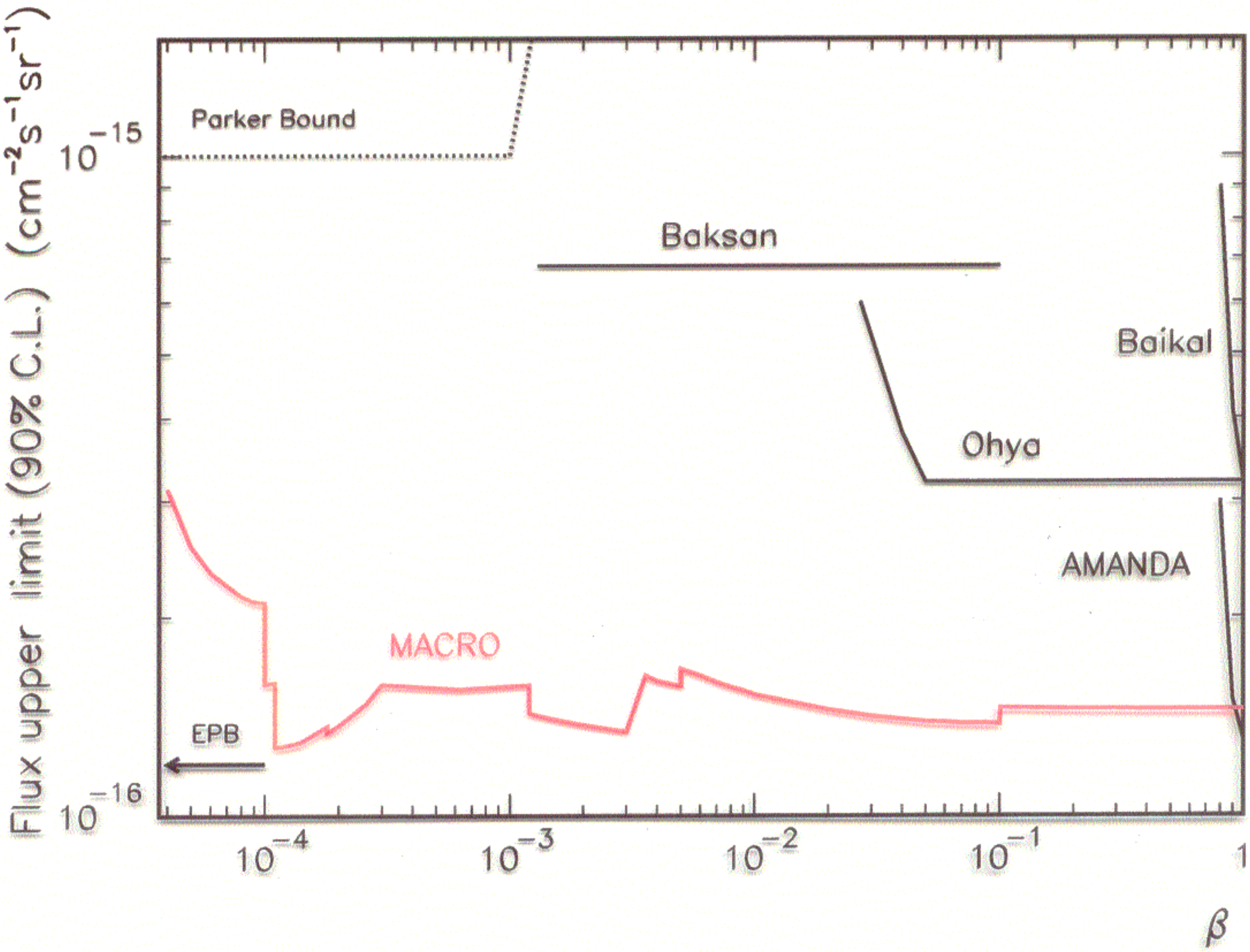
90% C.L. LIMITS

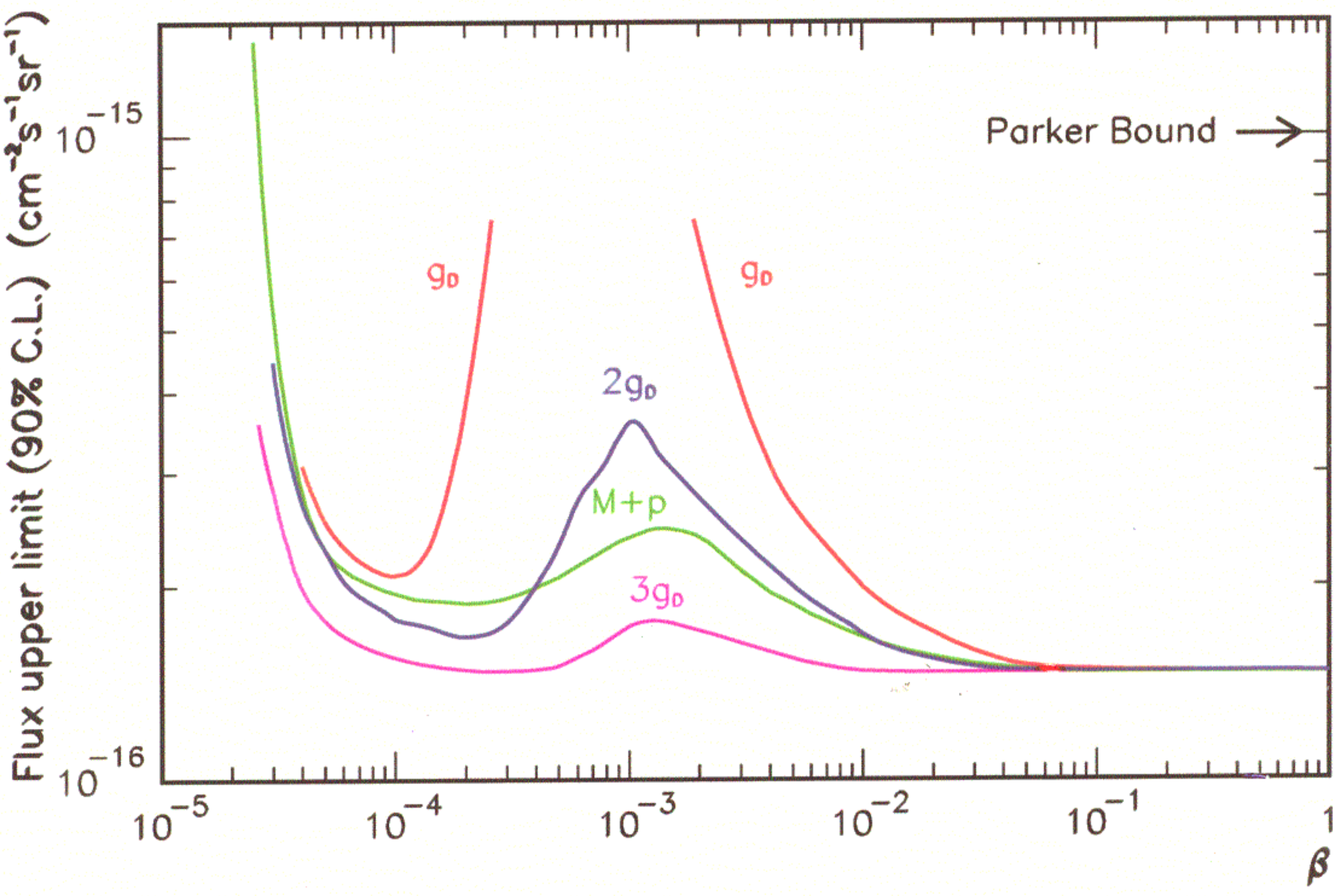
FOR G.U.T. MAGNETIC MONOPOLES

$\sigma_{CATALYSIS} < 1$ mb



MACRO

MM SEARCHES WITH NUCLEAR TRACK DETECTORS (CR39)



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5. MM CATALYSIS OF PROTON DECAY

$M + p \rightarrow M + e^+ + \pi^0$

GUT-MM − p INTERACTION MAY VIOLATE BARYON AND LEPTON NUMBER CONSERVATION

IF $\sigma_{\Delta B \neq 0} \sim \sigma_{CORE} \sim 10^{-56}\ cm^2$ NEGLIGIBLE

IF $\sigma_{\Delta B \neq 0} \sim \sigma_{STRONG}$ ⇒ COULD SEE A SERIES STRING OF p DECAYS ALONG MM TRAJECTORY

(RYBAKOV-CALLAN EFFECT)

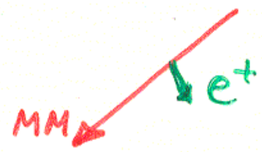
$\sigma_{\Delta B \neq 0} \sim \sigma_0/\beta$ OR $\sim \sigma_0/\beta^2$

p-DECAY DETECTORS

IMB, KAMIOKANDE } H_2O CHERENKOVS $\phi < 1\text{-}3\ 10^{-15}\ cm^{-2}s^{-1}sr^{-1}$ $10^{-5} < \beta < 10^{-1}$, $5 \cdot 10^{-5} < \beta < 10^{-3}$

MACRO: DEDICATED SEARCH USING STREAMER TUBES

LOOK FOR { SLOW MM TRACK, FAST e^+ TRACK



{ SPACE TRACK
TIME TRACK { DIGITAL, ANALOG
2 TRIGGERS

DEDICATED MONTE CARLO

ONLY DECAYS INSIDE APPARATUS

$\phi < 3 \cdot 10^{-16}\ cm^{-2}s^{-1}sr^{-1}$ $10^{-4} \lesssim \beta \lesssim 5 \cdot 10^{-3}$

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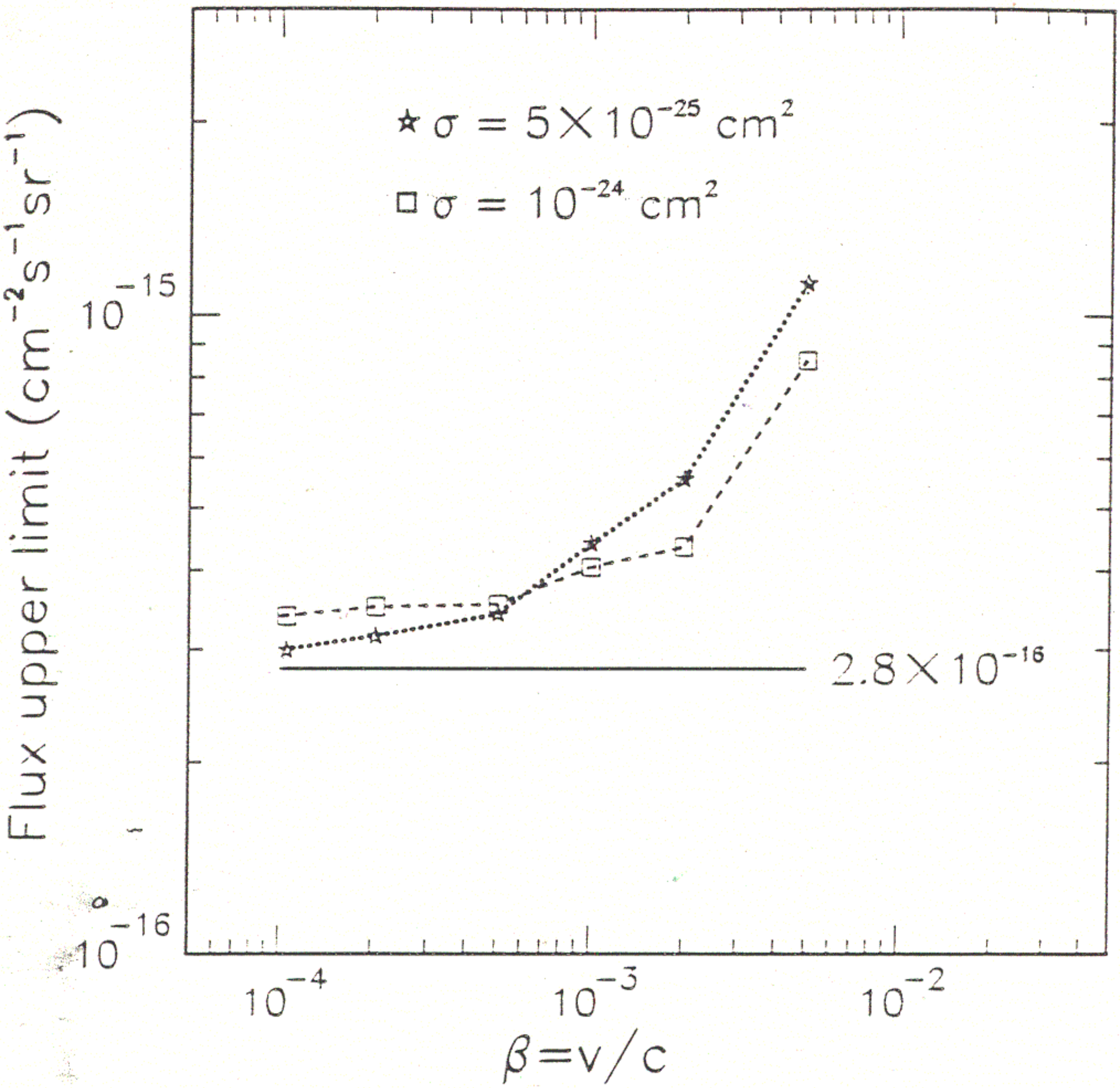
MACRO

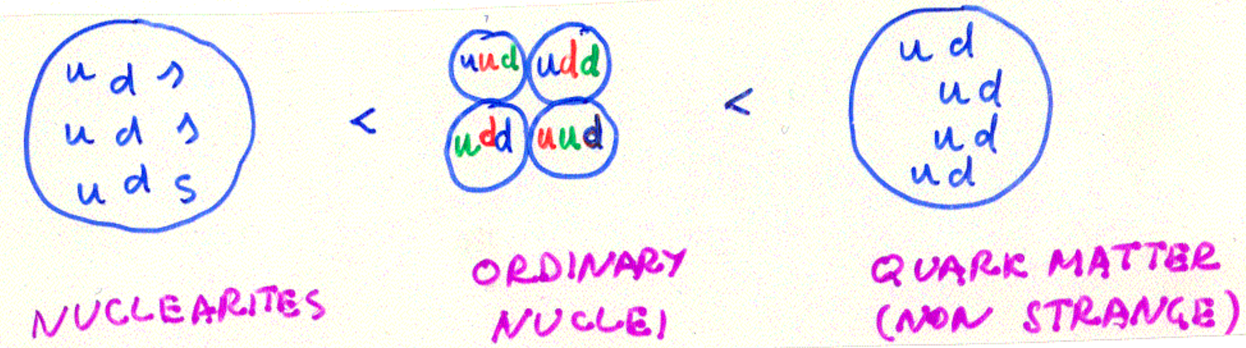
CATALYSIS OF p DECAY

90% CL



6. STRANGE QUARK MATTER (NUCLEARITES)

Conglomerates of uds quarks
could be stable for any A (few < A < 10^{57})



$$\rho_N = M_N / V_N \cong 3.5 \times 10^{14} g \quad cm^{-2} \qquad (\rho_{nuclei} \cong 10^{14} gcm^{-3})$$

Could be part of the galactic dark matter and have v ~ 10^{-3}c

A passing nuclearite would leave a signal similar to that of a MM in scintillators and nuclear track detectors

MACRO limits ($\beta = 10^{-3}$)

$$\begin{cases} m_N > 0.1g & \Phi < 1.2 \times 10^{-16} cm^{-2} s^{-1} sr^{-1} \\ 10^{-11} < m_N < 0.1g & \phi < 2.4 cm^{-2} s^{-1} sr^{-1} \end{cases}$$

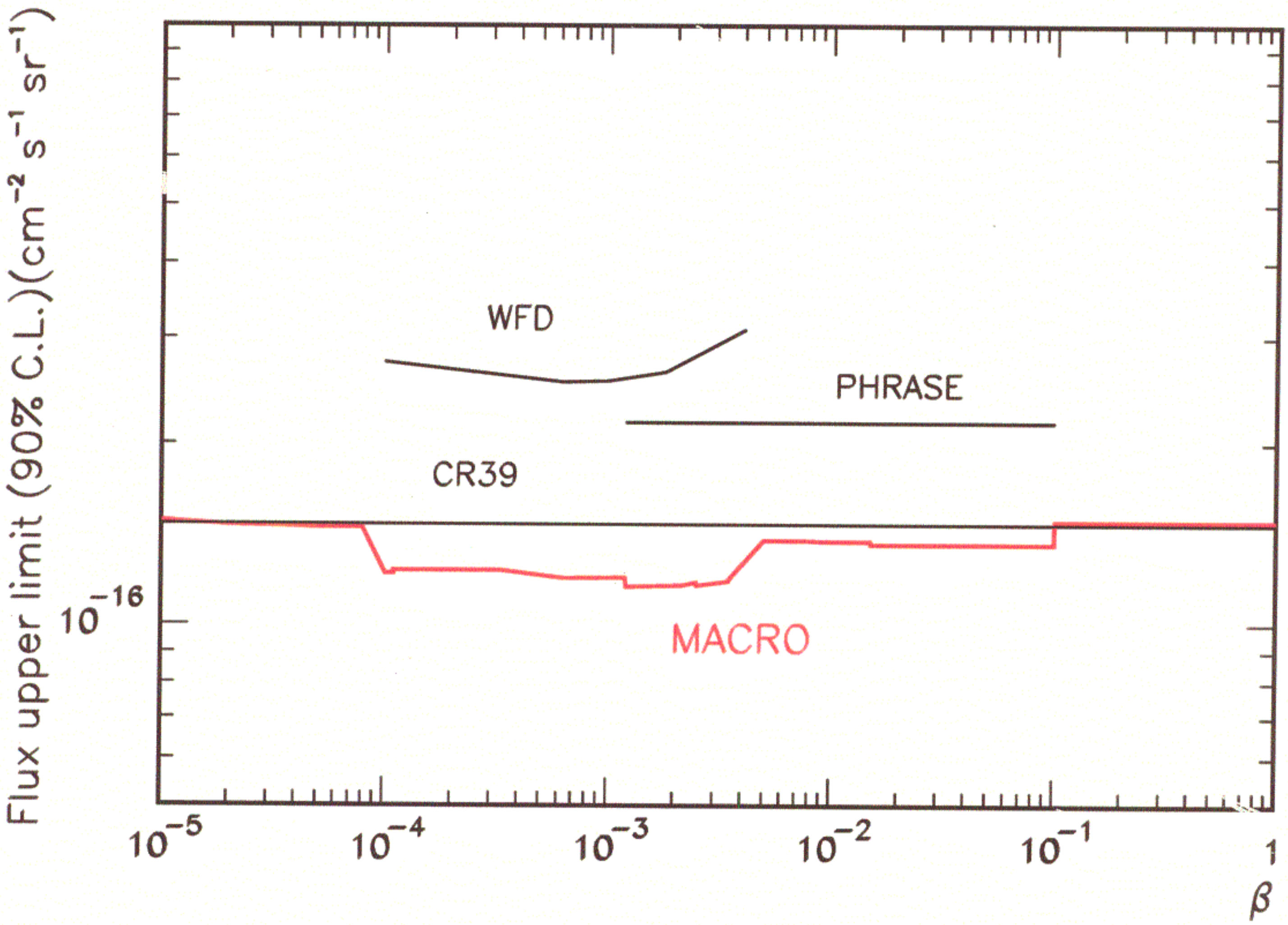
Supersymmetric Q-Balls

Coherent states of q, l and Higgs fields
Solitons with a large baryon number

Supersymmetric electrically charged solitons (SECS) should essentially behave in detectors as nuclearites

MACRO

NUCLEARITE SEARCHES



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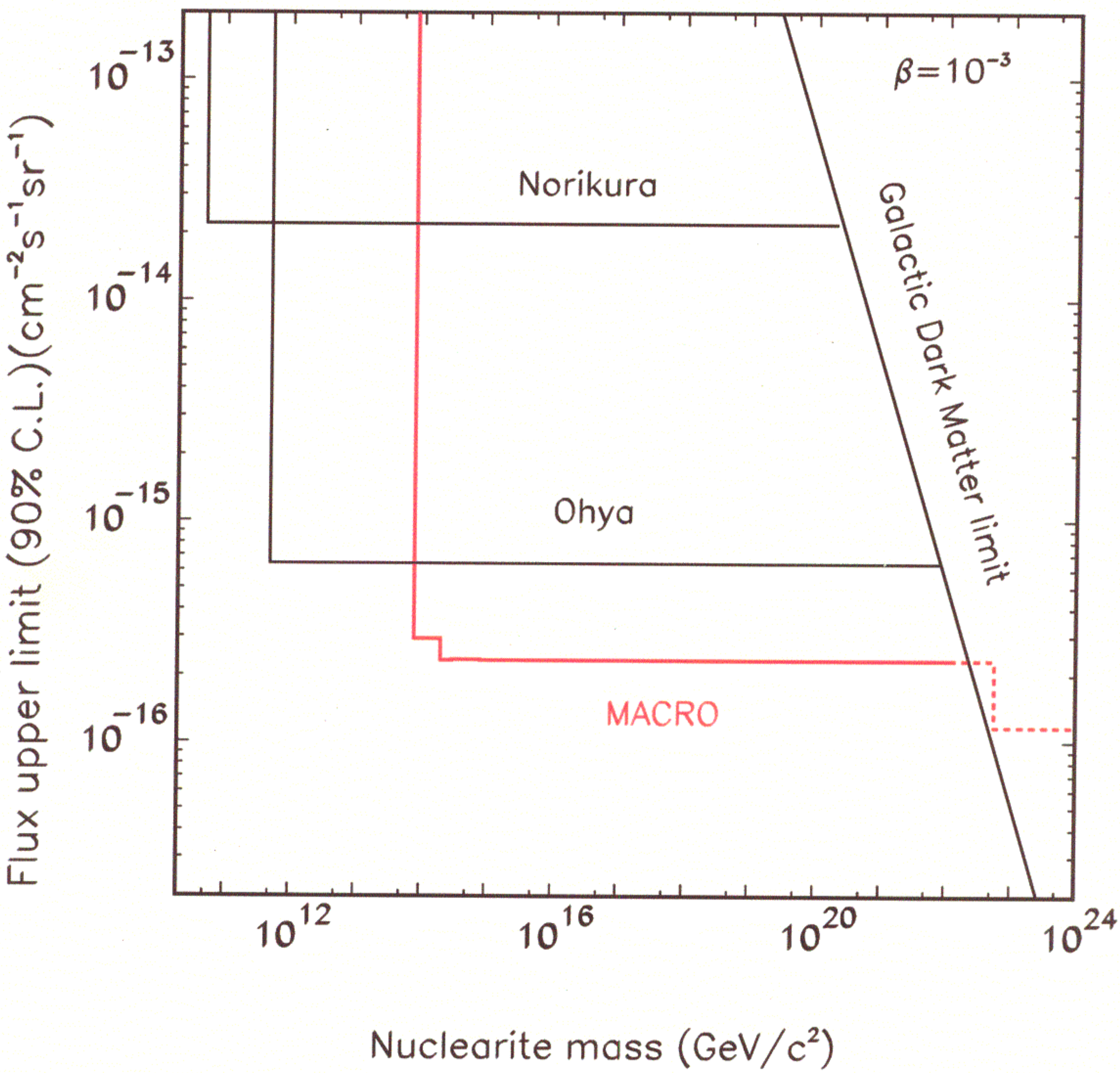
NUCLEARITES



7. CONCLUSIONS

MACRO Direct Flux limits for an isotropic flux of GUT MMs in the cosmic radiation:

$$\Phi_{MM} \lesssim 1.4 \times 10^{-16}\ cm^{-2} s^{-1} sr^{-1}$$ 90% C.L.

$$3 \times 10^{-5} < \beta < 1$$

For the future it is difficult to do better:

need new detectors with much larger surfaces

Catalysis of proton decay by MMs

$$\Phi_{MMCat} < (3-8) \times 10^{-16}\ cm^{-2} s^{-1} sr^{-2}$$

$$10^{-4} < \beta < 5 \times 10^{-3}$$ $\sigma_{CAT} \sim 5 \cdot 10^{-25}\ cm^2$

Nuclearites

$$\Phi_N < (\sout{1.4-2}\ 1.2-1.4) \times 10^{-16}\ cm^{-2} s^{-1} sr^{-2}$$

$$10^{-5} < \beta < 1$$