Q-ball Search Mini-review

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Supersymmetric Q-balls

MSSM predict the existence of Q-balls with baryon and lepton numbers.
Kusenko, PLB (1997)

Aggregates of squarks $\tilde{q}$, sleptons $\tilde{l}$ and Higgs fields.

Vacuum expectation values are aligned with some flat directions.

Baryonic Q-balls with a large baryon number B can be stable against decay into nucleons.

Form in the early universe and exist as dark matter.

Kusenko and Shaposhnikov, PLB (1998)

Formation Process

Two types: Kusenko et al., PRL (1998)

- Neutral Q-balls
  SENS (Supersymmetric Electrically Neutral Solitons)
- Charged Q-balls
  SECS (Supersymmetric Electrically Charged Solitons)

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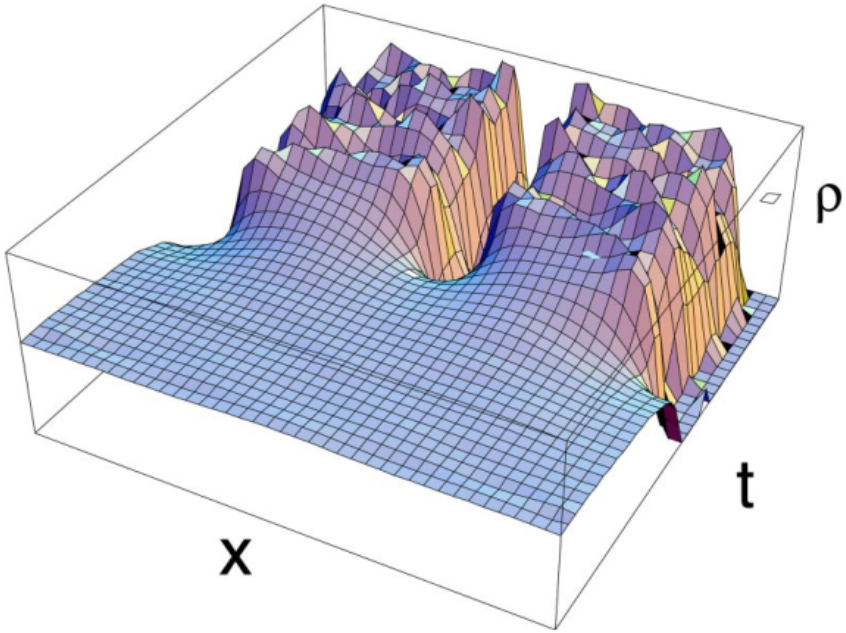
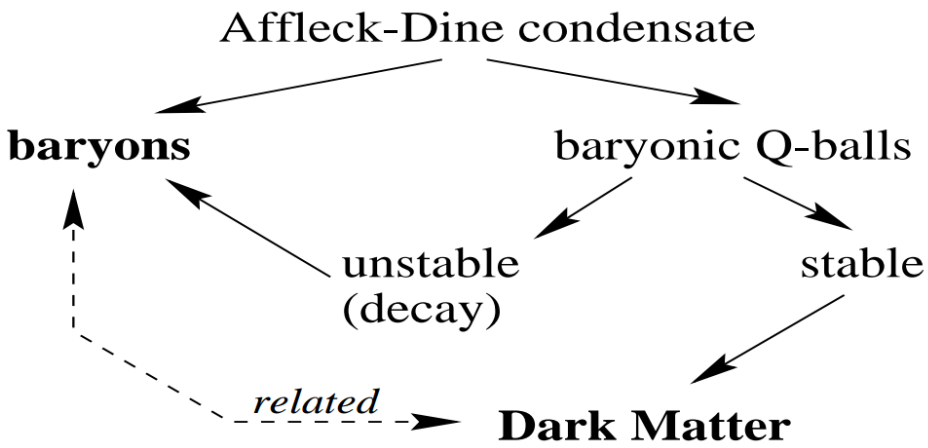
SENS can form at the end of inflation from the fragmentation of the Affleck-Dine (AD) condensate.





Dine and Kusenko, Rev.Mod.Phys. (2003)

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Baryon number $B \sim 10^{22} \div 10^{30}$.

$M \sim M_S B^p$, where $p < 1$ and M_S is a SUSY breaking scale.
Typically, $p = 3/4$ and $M \sim 10^{19} \div 10^{25}$ GeV.

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SENS may interact with nucleon, catalyze the nucleon decay leading to the emission of pions, and releasing about 1 GeV energy per collision.

During this process, SENS become SECS carrying positive charges.

Searching SENS through nucleon decay

SENS can be sought at nucleon decay experiments by searching for continuous emission of pions.

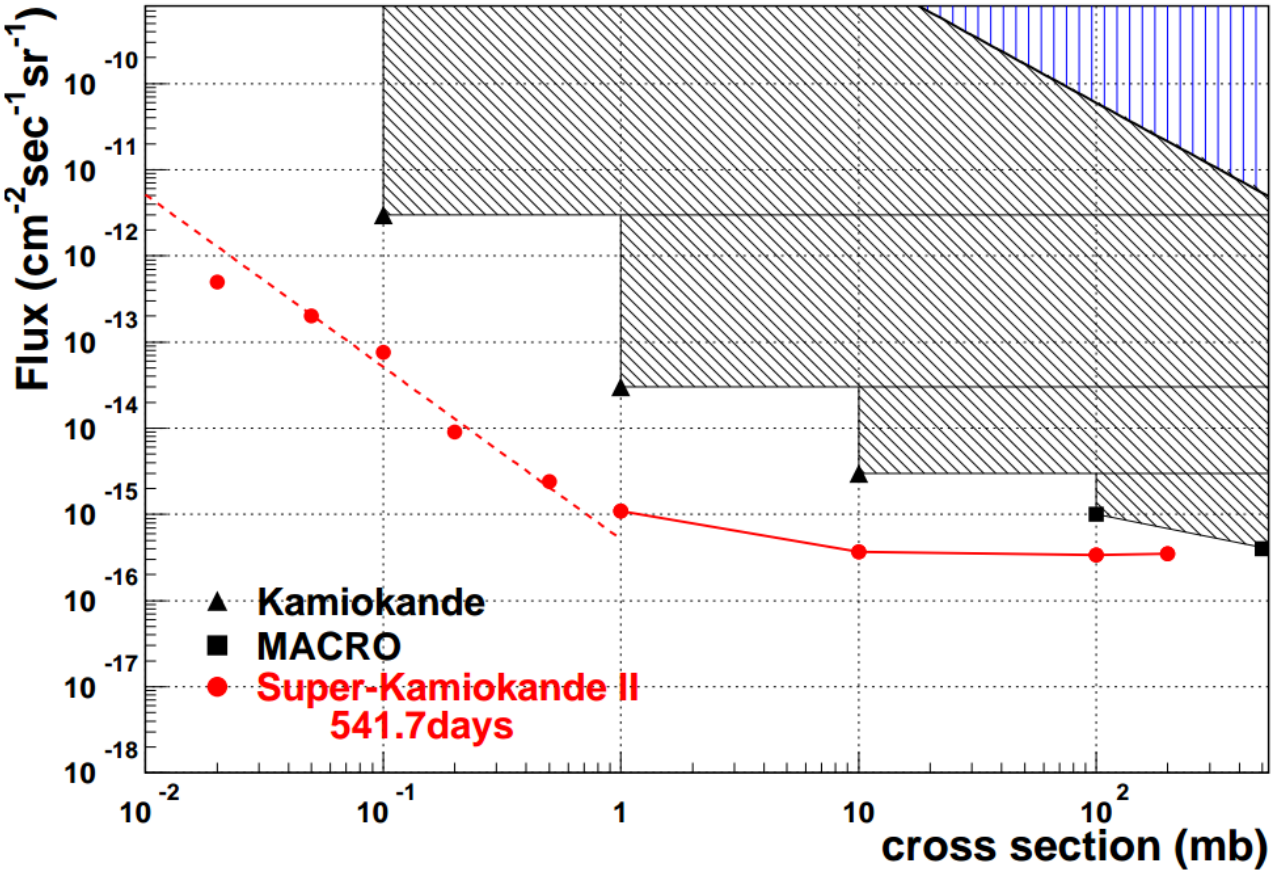
Cross section σ is roughly the geometrical size of the Q-ball $\sigma = \pi R_Q^2$, where R_Q is the radius of Q-ball.

Energy loss rate is $-\frac{dE}{dx} = \sigma v^2 \rho$, where $v \sim 10^{-3} c$ is the virial velocity of cold dark matter, ρ is the density of the target matter.

Energy loss in the earth is negligible compared to the kinetic energy of Q-ball.

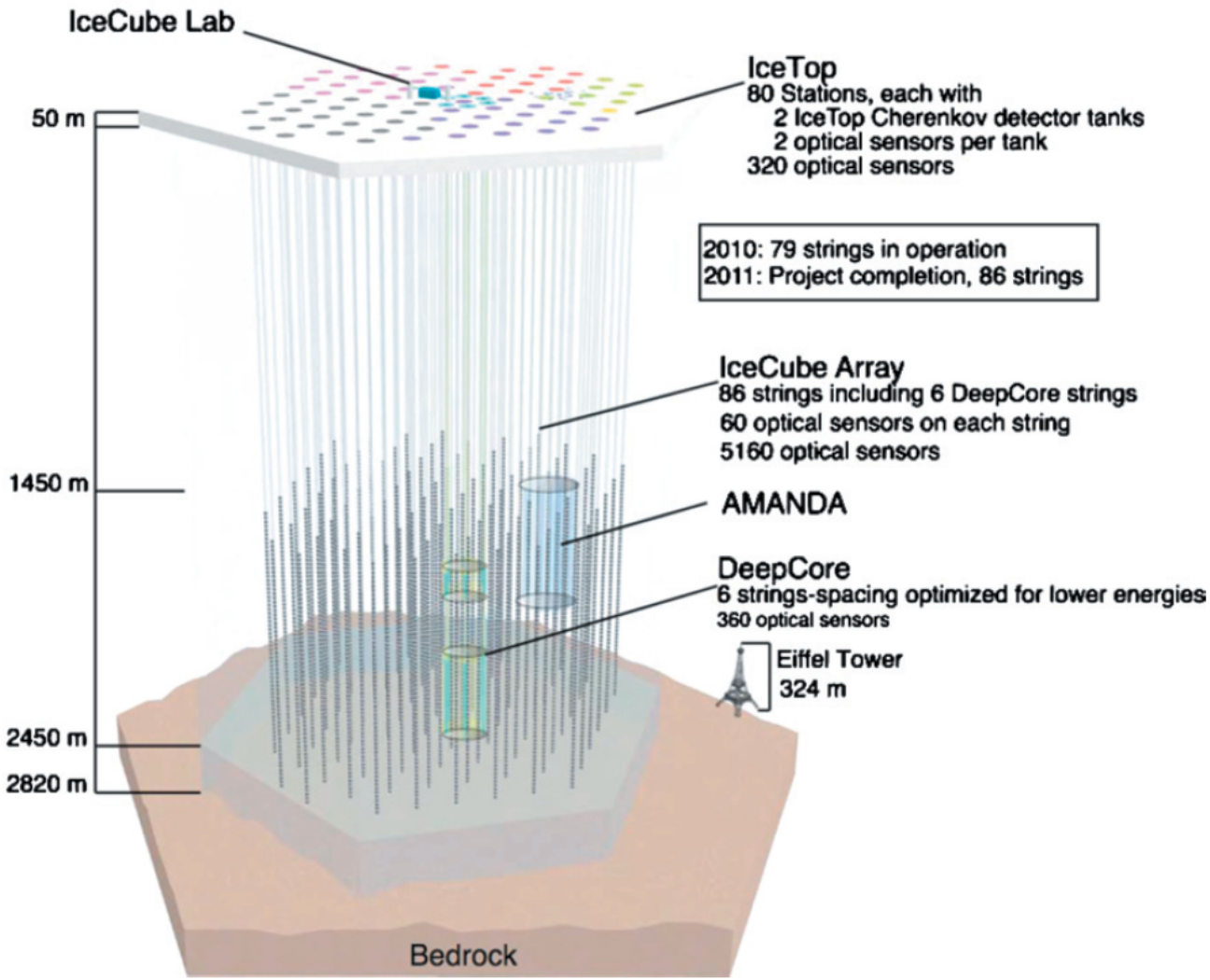
Super-Kamiokande

Super-Kamiokande is a cylindrical 50,000 ton water Cherenkov detector located 1000 m underground. The Super-Kamiokande Collaboration, PLB (2007)



IceCube

IceCube is a cubic-kilometer sized neutrino observatory constructed in the glacial ice at the South pole.



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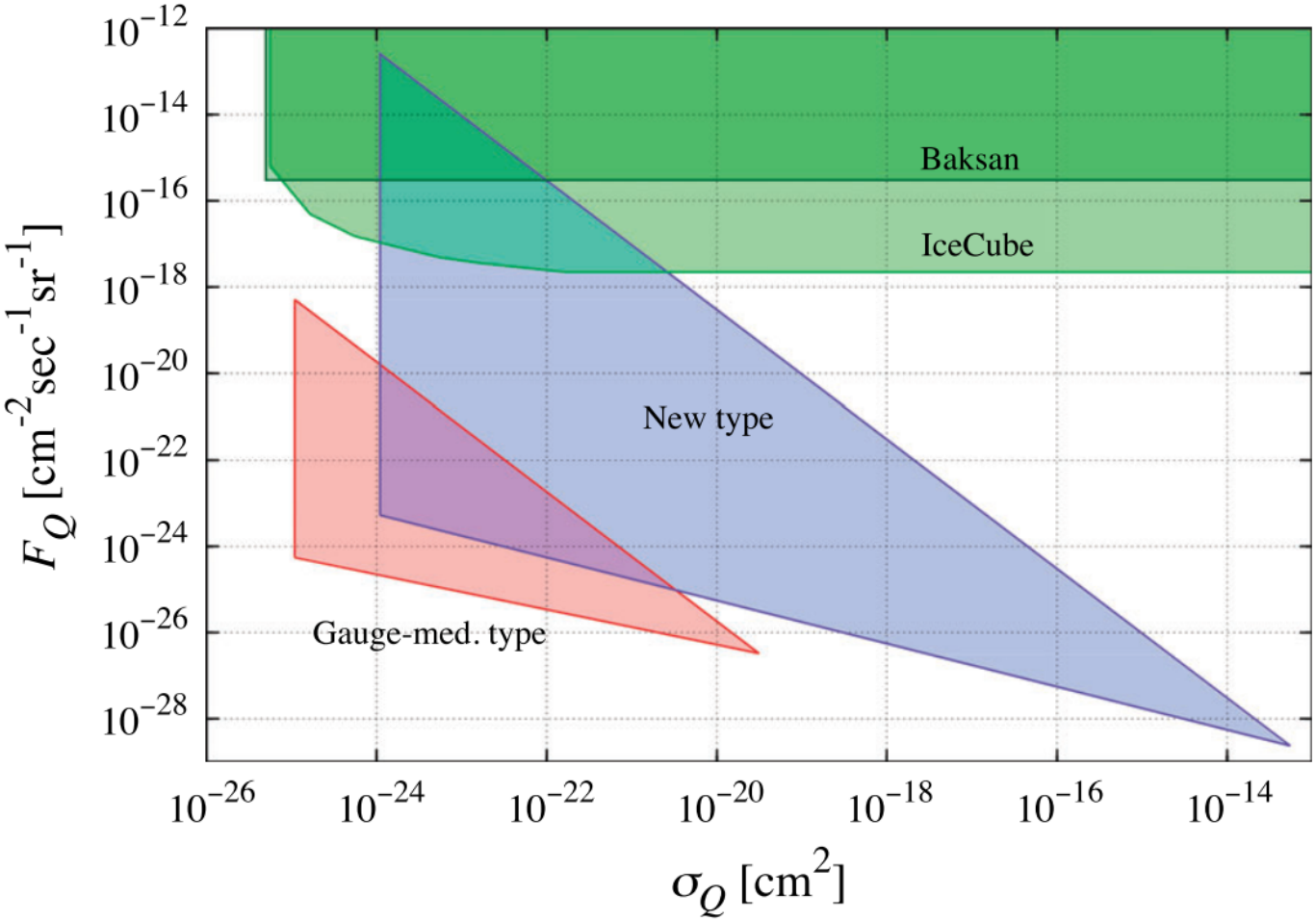


Searching SECS through High Ionization

The high ionization property of SECS makes it possible to search SECS in cosmic rays.

The size of the SECS is smaller than its surrounding electron cloud.

The cross section of collision with matter is much larger than the one of SENS.

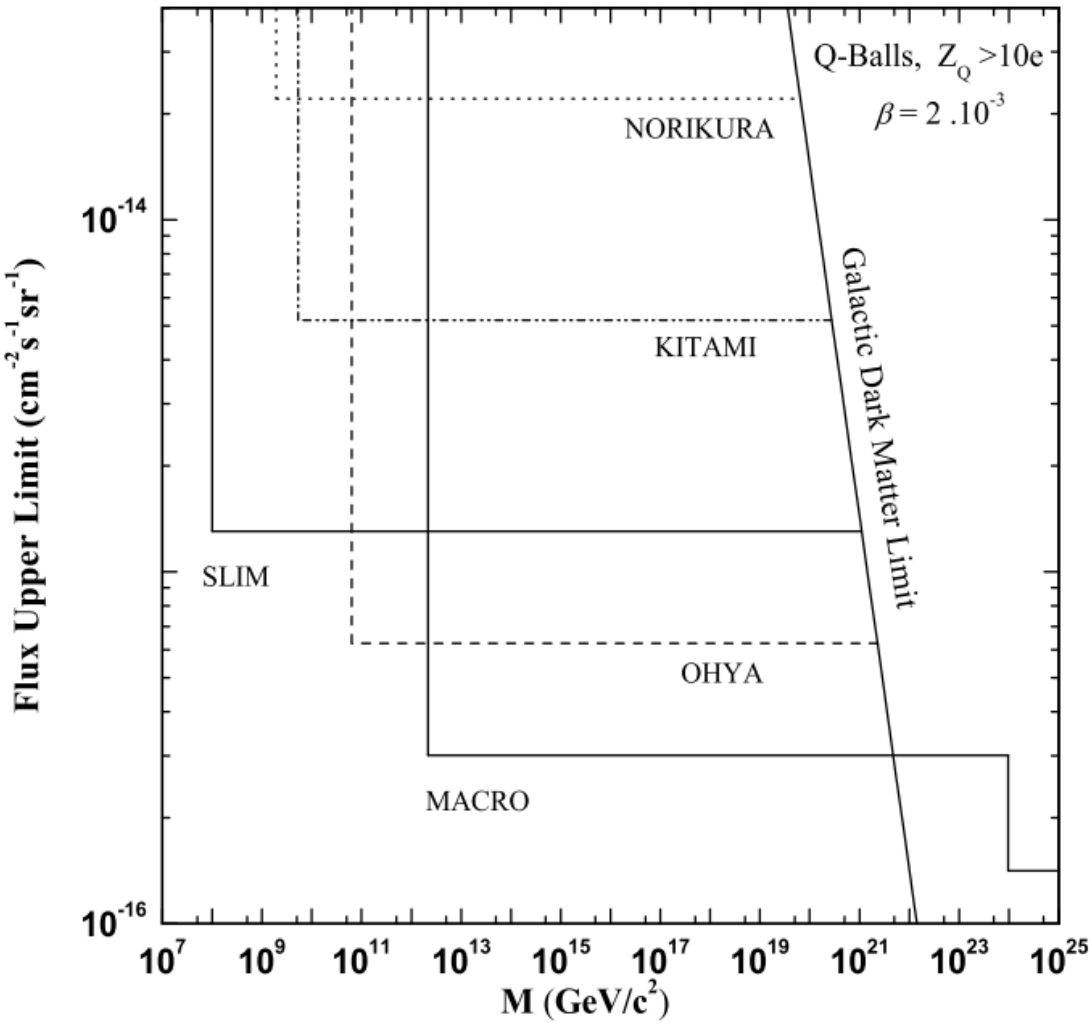
The energy loss of SECS comes from two parts, interaction with electrons and interaction with nuclei $\frac{dE}{dx} = \left(\frac{dE}{dx}\right)_{\text{electons}} + \left(\frac{dE}{dx}\right)_{\text{nuclei}}$.

SLIM and MACRO

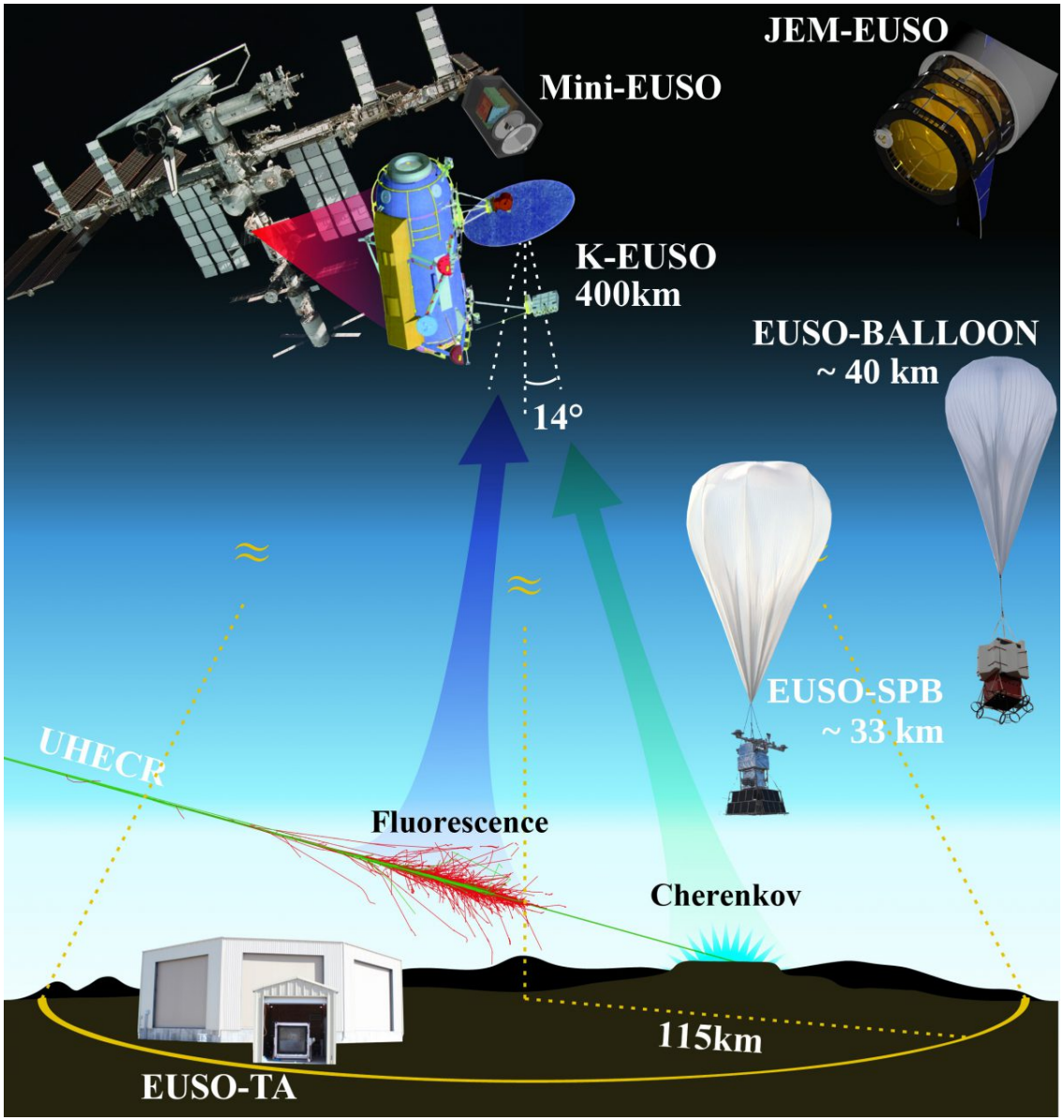
SLIM is a 427 m^2 array of Nuclear Track Detectors (NTDs) at high altitude (5230 m a.s.l.).

Cecchini et al., EPJC (2008)

MACRO is an underground experiment. It has three subdetectors: liquid scintillation counters, limited streamer tubes and nuclear track detectors.



JEM-EUSO



JEM-EUSO is a space mission devoted to the investigation of cosmic rays and neutrinos of extreme energy. Its super-wide-field telescope will look down from space onto the night sky to detect UV photons emitted from air showers in the Earth's atmosphere.

Capel et al., Advances in Space Research (2018)

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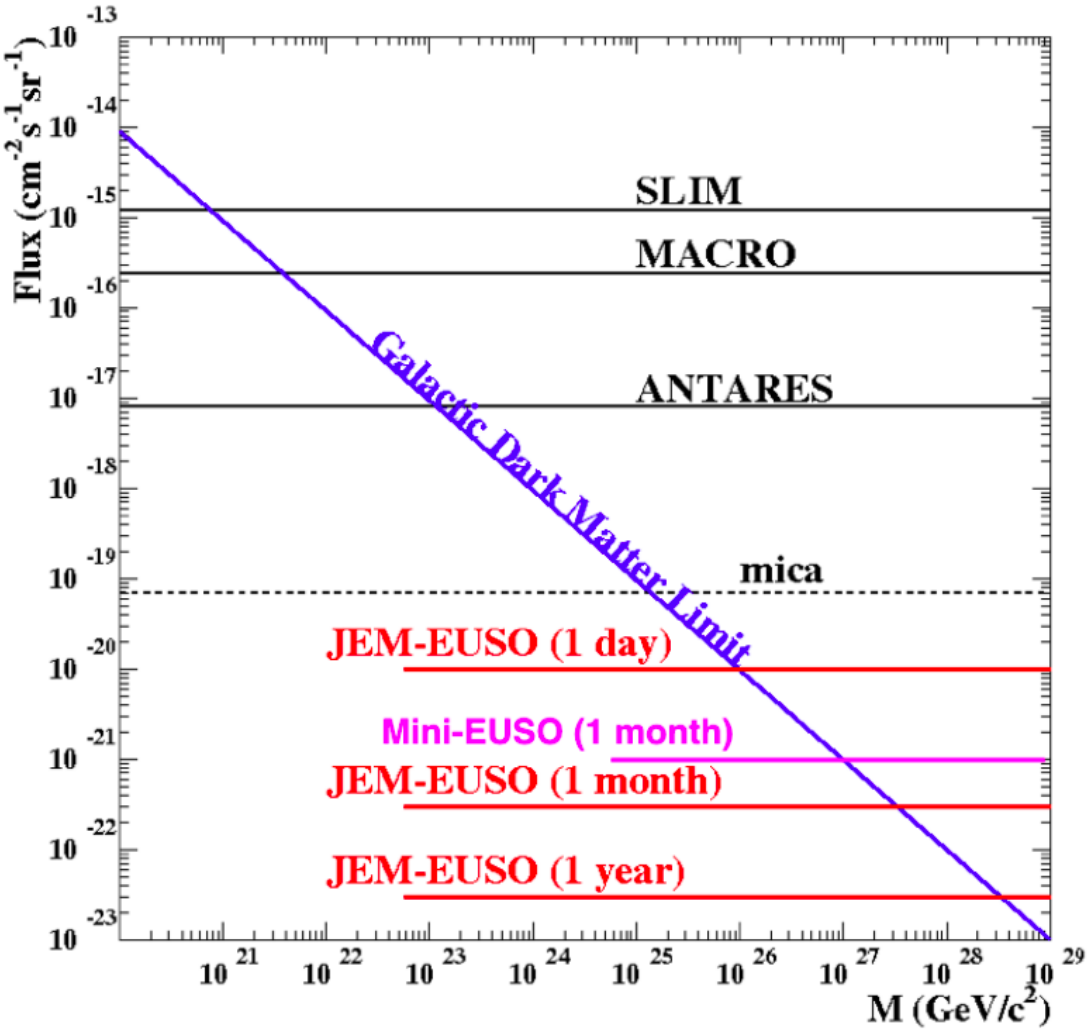

JEM-EUSO is a space mission devoted to the investigation of cosmic rays and neutrinos of extreme energy leading by Japan. Its super-wide-field telescope will look down from space onto the night sky to detect UV photons emitted from air showers in the Earth's atmosphere.

Capel et al., Advances in Space Research (2018)

Summary and Outlook

- Stable supersymmetric Q-balls can be dark matter candidates and play an important role in the evolution of universe.
- SENS can be searched by nucleon decay.
  SECS, which are converted from SENS, can be searched by high ionization.
- The parameter region of Q-balls has not been fully excluded.
- Some experiments (IceCube, JEM-EUSO etc.) have great sensitivity to detect Q-balls, if they exist, in the near future.

Thank you!