On Detecting Strange Quark Matter with GLAST-LAT

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Introduction

Stable Strange Quark Matter

Strange Quark Matter (SQM) is a proposed state of nuclear matter made of roughly 1/3 of up, down and strange quarks which are bound in a hadronic bag of baryonic mass as small as A=2 and as large as stars (see for example [1])

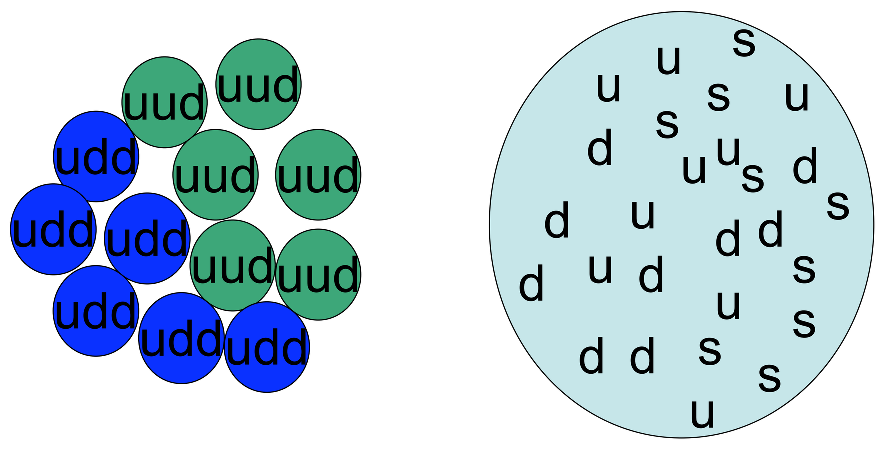
This type of matter can be stable or meta-stable in a wide range of strong interaction parameters and could form the true ground state of nuclear matter. The question of stability, however, can not be answered from first principles in QCD, thus must be settled experimentally by detecting SQM, small chunks of which are called strangelets.

Detecting stable SQM would have important implications by not only shedding new light on the understanding of strong interactions, but also for practical applications such as high Z material and clean energy sources [2].

In addition SQM, produced primordially in the Big Bang, might provide part of the Dark Matter.

Why does stable SQM not contradict common sense ?

Experimental evidence shows that nuclear matter consists of protons and neutrons and not some bag of up, down and strange quarks. So, how can SQM be the true ground state of nuclear matter ?
In order for SQM to be stable, a significant fraction of strange quarks needs to be present. Considering an iron nucleus (A=56) would require a simulataneous change of many u and d quarks into s-quarks via the weak interaction, a process with very low probability.



^{12}C: Z/A = 0.5

Strangelet: Z/A = 0.131

Experimental Signatures

The prime signature for a strangelet is its very low charge to mass ratio (Z/A), for example in the colour flavour locking scheme [3]:

$$Z \approx 0.3A^{2/3} \quad (1)$$

Meaning for a given velocity a strangelet has larger rigidity than normal nuclei (R = p/z). Measurements of the charge to mass ratio are possible with satellite-borne experiments such as PAMELA [4] or the future ISS experiment AMS [5]. Another possibility is searching for massive nuclei in lunar or earth soils with high precisions mass spectrometers (see reference in [2]).

In GLAST, we propose to indirectly search for strangelets by their characteristic interaction products (see below).

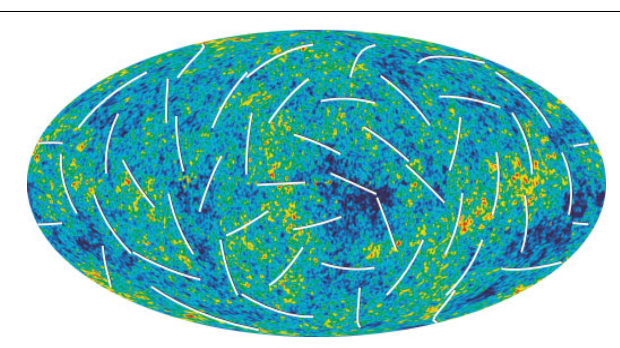
Potential Sources of stable SQM

Primordial Strange Quark Matter

In the first order phase transition from the Quark Gluon Plasma, stranglets migt have formed which than could contribute to the Dark Matter. The flux of these strangelets can be estimated to [7]:

$$\phi \approx 10^5 A^{-1} \rho_{24} v_{250} cm^{-2} s^{-1}\ sr^{-1} \quad (2)$$

Where $\rho = \rho_{24} 10^{-24}$g cm^{-3} and v = v_{250}250 km s^{-1}. ρ_{24} = 1 corresponds to approximately the dark matter density.

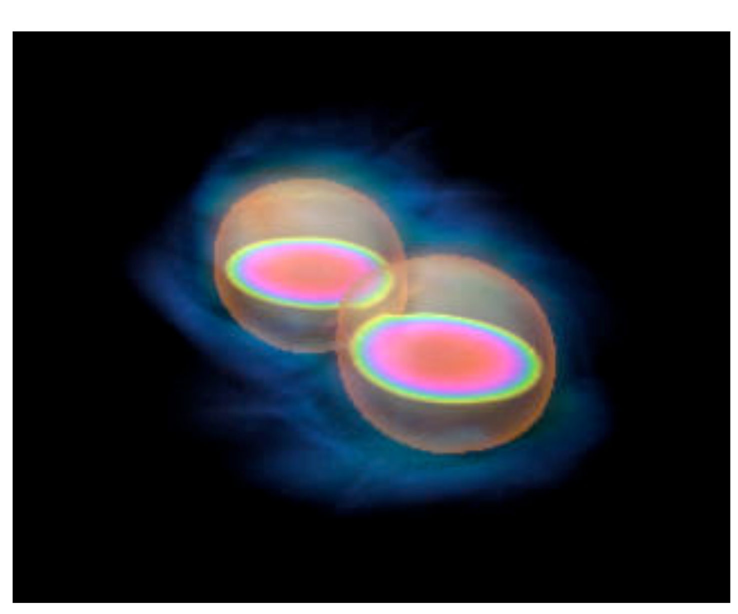


Courtesy: WMAP

Strange Star Collisions

If indeed SQM is stable, than it is very likely that what commonly is called neutron stars are in fact very large strangelets, called strange stars. In binary systems, these stars would undergo collision and thereby eject strangelets. It might be assumed that those strangelets accelerate and propagate similar to normal cosmic rays and together with the estimated rate of coalescence of neutron stars a flux can be estimated to, assuming colour flavour locking [8]:

$$\phi \approx 10^{-6} A^{-1.47}\ cm^{-2} s^{-1}\ sr^{-1} \quad (2)$$



Courtesy David Bock, NCSA

Signature in GLAST

The signature which we propose for the detection of strange quark matter in GLAST is the decay of the Λ^0 (uds) particle into protons and pions:

$$SQM + X \rightarrow n\Lambda \rightarrow p + \pi^-$$

Here X is the target material (in this case we consider the converter and silicon of the tracker) and n is the number of Λ^0 produced.

It is difficult to make general statements about how many Λ^0 will be produced. Under the approximation that a SQM of mass A has the quark content A(uds) and that the colour flavour locking condition holds we can make following prediction (for Z > 0):

$$n \approx 3.3 Z^{3/2}$$

Conclusions

The detection of stable strange quark matter would be a major achievement with implications for the knowledge of the strong interaction as well as potential practical applications. The GLAST-LAT has the potential to detect SQM or to set competitive limits. The prime signal would be events with large track multiplicity and many vertices. The major challenge for the search of SQM is the rejection of background mainly photons and protons.

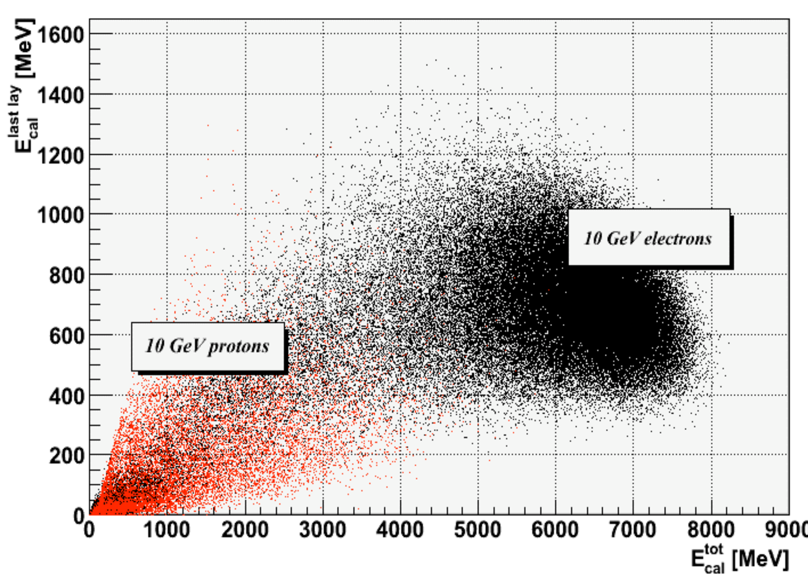
Backgrounds

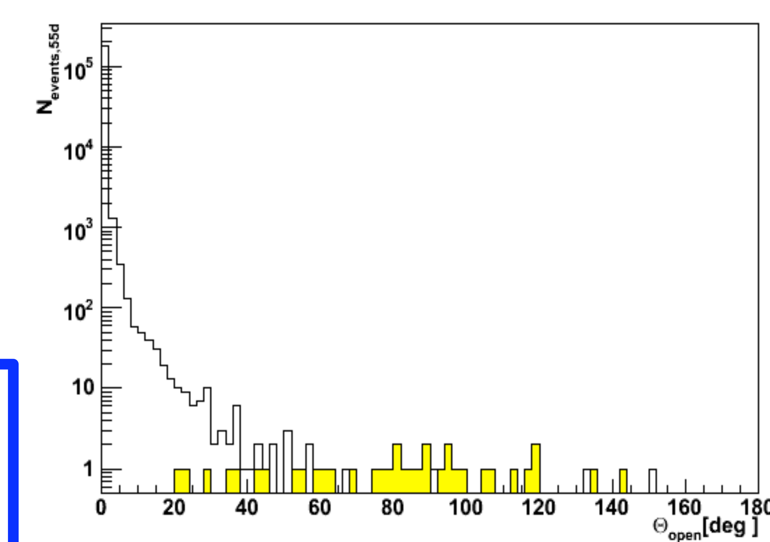
Photons and leptons

Contrary to e$^+$e$^-$ pairs, the pπ^- will give hadronic signal in the calorimeter. There are many possible ways of separating hadronic from electromagnetic signal. For illustration, we show the correlation between the energy deposited in the last layer of the calorimeter and the energy deposited in whole calorimeter as one possible discrminant (uppermost plot on the right)

Also the tracker gives handles to separate the Λ^0. The opening angle of the Λ^0 decay vertex can be calculated from kinematics and is on average signficantly larger than the opening angle from an e$^+$e$^-$ -vertex.

The middle plot on the right shows the opening-angle distribution for the complete DC2 set of detected photons (55 days) together with the expected number of SQM events. Following [8] for this figure we assumed a flux as given in equation (3) which depends on energy as $E^{-2.2}$. The energy distribution of the Λ^0 is taken to be exponentially decreasing. Furthermore, we postulated that all Λ^0 are tagged and the resolution of the opening angle determination is 30 %.





Hadrons

For hadrons the expected background will be depending on the charge Z.

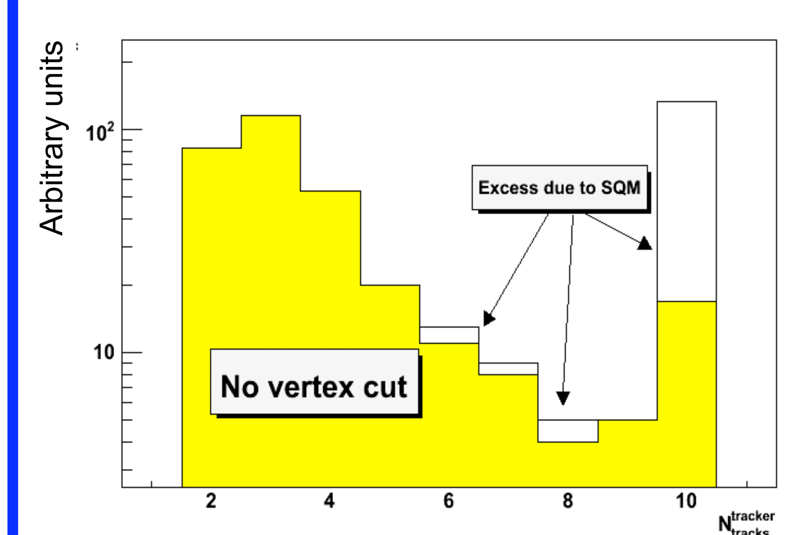
Strangelets with **Z=0** might produce a hadronic signal in the calorimeter with the only possible background being neutrons or inefficiency of the Anti-Coincidence Detector (which is on the level of 0.0003). The presence of neutral SQM seems quite unlikely, though stable solutions exist.

Strangelets with **Z=1.**

Keeping strangelets with Z=1 means that the ACD can not be used for rejection of protons. Assuming colour flavour locking those strangelets typically would produce 3 vertices from lambda decay which will be an efficient way to distinguish them from protons.

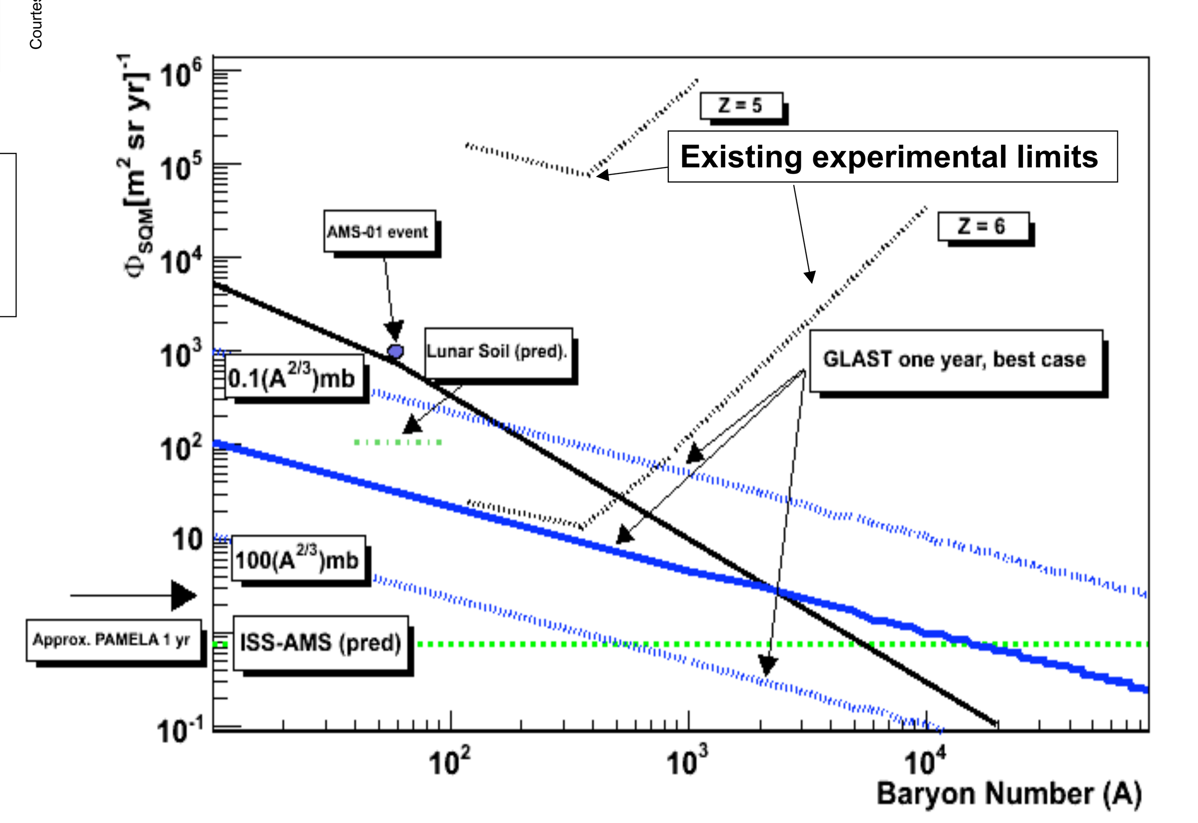
For strangelets with **Z >=2** there are several potential handles to be employed for discrimination. Protons can be rejected using the ACD signal which would reduce the background to a large extent by only keeping heavier nuclei.

Additional rejection can be gained by considering the vertex. SQM with Z>=2 would produce several vertices from Λ^0 decay, whereas protons would typically produce only 1 -2 vertices.



However, the present tracker vertexing is not designed to find multiple vertices. A simpler discrimination can be done using the number of tracks detected in the tracker. The lowermost plot on the right shows the number of tracks found in the tracker for protons (yellow shaded area) and the excess caused by SQM (no shading). In this plot we assumed a ratio of protons/SQM of 10^5 and an efficiency of ACD rejection of Z=1 tracks of 0.9997. Furthermore we assume colour flavour locking and a flux of SQM which is proportional to $Z^{-0.6}$ [8]. Under this assumptions GLAST could detect a clear signal of events with >10 tracks.

GLAST sensitivity



Right: Best case estimate of the LAT sensitivity to SQM for one year exposure (blue solid and dotted lines)

Here we optimistically assume that we have 100 % efficiency for tagging Λ^0 produced by SQM particles in the tracker and that our result will be no events seen with no remaining background.

This result depends on the cross-section, which we assume to be of the order of the strong interaction and from simple geometrical considerations:

$$\sigma \propto r^2 \propto A^{\frac{2}{3}}$$

Also included in this figure is the expected sensitivity of the AMS experiments (which might be flying on the International Space Station (ISS-AMS) [5], the expected limit from a search for SQM in lunar soil [5] and already obtained limits from Earth samples using high precision mass spectroscopy [8]. We also show one candidate for a Z=2 strangelet detected by AMS-01 [9]

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Acknowledgements: The authors would like to thank Jes Madsen for useful discussions.