What is the Magnetic Weak Gravity Conjecture for Axions?

Philipp Henkenjohann
University of Heidelberg

based on work with Arthur Hebecker & Lukas Witkowski [1701.06553]

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Motivation

Axions are inflaton candidates in models of large-field inflation. [Freese, Friemann, Olinto; 1990]

For these models to work one needs a super-Planckian axion decay constant f.
(See, however, [Kim, Nilles, Peloso; 2005 / Dimopoulos, Kachru, McGreevy, Wacker; 2008 / ...] for attempts to evade this requirement.)

The magnetic Weak Gravity Conjecture (WGC) for axions naively gives a strong constraint on f.

This talk is about the interpretation of the WGC. For recent attempts towards a 'derivation' see for example [Cottrell, Shiu, Soler; 2016 / Hebecker, Soler; 2017].

Electric Weak Gravity Conjecture

Question: Which consistent low energy effective field theories are also consistent with quantum gravity?

Part of the answer might be provided by the WGC: [Arkani-Hamed, Motl, Nicolis, Vafa; 2007]

Consider a U(1) gauge theory with charged particles (1-form theory):

$$S = \frac{1}{2g_e^2}\int F_2 \wedge \star F_2 + m\int_{\mathrm{WL}} \mathrm{d}l + q\int_{\mathrm{WL}} A_1 .$$

The electric WGC requires the existence of a particle with

$$m < q M_{\mathrm{P}} .$$

Magnetic Weak Gravity Conjecture

The magnetic WGC requires the minimally charged magnetic monopole to not be a black hole.

This is equivalent to the statement

$$\text{Schwarzschild radius} < \text{monopole radius}.$$

If we associate a cutoff Λ with the monopole radius, this implies

$$\frac{\Lambda}{M_{\mathrm{P}}} \lesssim g_{\mathrm{e}}.$$

In a weakly coupled theory ($g_{\mathrm{e}} < 1$) this implies an unexpected low cutoff!

Weak Gravity Conjecture for p-form theories

It is possible to generalize the WGC to theories with a p-form gauge potential in d space-time dimensions:

$$S = \frac{1}{2g_{\mathrm{e}}^2} \int F_{p+1} \wedge \star F_{p+1} + m \int_{\mathrm{WS}} \mathrm{d}V + q \int_{\mathrm{WS}} A_p .$$

The gauge potential A_p couples to a $(p-1)$-brane, which has a p-dimensional worldsheet (WS).

The magnetic object equivalent to the monopole is a $(d-p-3)$-brane.

According to the magnetic WGC this should not be a black brane:

$$\frac{\Lambda}{M_{\mathrm{P}}} \lesssim \left(g_{\mathrm{e}} M_{\mathrm{P}}^{d/2-p-1} \right)^{1/p} .$$

Magnetic Weak Gravity Conjecture for axions

For $p = 0$ the gauge potential A_0 is just a scalar and we obtain the action of an axion $\phi = A_0$ coupled to instantons.

By comparing with the kinetic term of an axion with decay constant f,

$$\frac{1}{2g_{\mathrm{e}}^2}\mathrm{d}\phi \wedge \star\mathrm{d}\phi = \frac{f^2}{2}\mathrm{d}\phi \wedge \star\mathrm{d}\phi,$$

we can identify $g_{\mathrm{e}} = 1/f$.

With this the WGC bound in 4 space-time dimensions reads

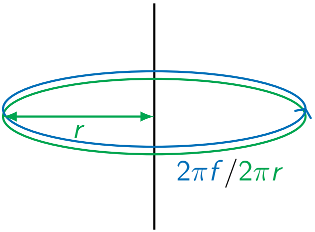
$$\frac{\Lambda}{M_{\mathrm{P}}} \lesssim \lim_{p\to 0}\left(\frac{M_{\mathrm{P}}}{f}\right)^{1/p},$$

which is zero for $f > M_{\mathrm{P}}$.

Axionic strings

The naive interpretation of a vanishing cutoff is that the theory with $f > M_{\rm P}$ is forbidden.

We want to check this naive conclusion by analyzing the object dual to instantons: An axionic string.



The axion winds around the string with periodicity $2\pi f$.

Hence, the (gradient) energy density is $\sim f^2/r^2$.

The tension of such a string diverges logarithmically (in flat space).

Axionic strings and gravitational backreaction

The static spacetime of an axionic string has a physical singularity in the center of the string and at a finite distance from the string! [Cohen, Kaplan; 1988]

One can get rid of these singularities by having a non-static spacetime. [Gregory; 1996 / Gregory, Santos; 2003]

This spacetime expands in the direction of the string but, however, this solution fails to be valid for $f \gtrsim M_P$.

For $f \gtrsim M_P$ the spacetime becomes highly non-static and expands in all directions. This is known as topological inflation and provides a (unconventional) UV-completion of the string.
[Linde; 1994 / Vilenkin; 1994]
Recent numerical work on this was done in [Dolan, Draper, Kozaczuk, Patel; 2017].

Interpretation of results

Now we have an interpretation problem. Although we have not found any black string solutions, we had to allow for non-static spacetimes in order to get a proper string solution (Note that this is true even for $f < M_{\mathrm{P}}$!). We are therefore essentially left with two options:

1) We do not accept a non-static object as a proper magnetic string required by the WGC. In this case $f \gtrsim M_{\mathrm{P}}$ is forbidden.
2) We do accept topological inflation as a proper magnetic string and hence, $f \gtrsim M_{\mathrm{P}}$ is allowed.

The meaning and relevance of non-static magnetic objects remains unclear...