Kalb-Ramond Dark Matter
IPP Early Career Theory Report

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Background

The Kalb-Ramond (KR) field is an antisymmetric tensor that arises naturally in string theory, but has received little attention in the context of cosmology. The Kalb-Ramond field shares features with two popular dark matter candidates: axions and dark photons–both of which have active experimental and observational efforts underway. In order to confirm a signal from either an axion or dark photon, one would first need to rule out Kalb-Ramond. With the support of the IPP Early Career Theory Fellowship, I worked with Edward Kolb at University of Chicago, where we made the first steps towards distinguishing Kalb-Ramond dark matter from its alternatives. Namely, we looked at the interacting theory, and considered its production in the early universe. Kalb-Ramond may be produced non-thermally through several possible production mechanisms (mentioned below). Looking at production is the first step towards understanding Kalb-Ramond as a dark matter candidate, and could have potentially profound implications for two very active areas of experimental research.

Contributions

During the fellowship, I contributed in the following ways:

- Enumerated the possible non-thermal production mechanisms for KR dark matter.
  - Gravitational particle production
  - Freeze-in
  - Misalignment
  - Tachyonic instability

  - Cosmic string decay

- Showed that KR and dark photons are dual in their non-minimal couplings with gravity (up to dimension 4 operators, in conformally flat spacetimes).

- Further developed the free quantum field theory for the KR field. This includes the canonical mode expansion and an explicit construction of the polarization states.

- Enumerated possible KR-Standard Model interactions (from an effective field theory perspective), in analogy to axion/dark photon couplings. These include

  - A Higgs interaction $\mathcal{L}_{int} \supset \phi^2 B_{\mu\nu} B^{\mu\nu}$
  - A dipole interaction $\mathcal{L}_{int} \supset -ig_1 B_{\mu\nu} \bar{e} \sigma^{\mu\nu} e$
  - Coupling to an axial current $\mathcal{L}_{int} \supset -g_2 \tilde{H}_\mu j_5^\mu$

  where B is the Kalb-Ramond field and H its field-strength.

- Derived the Feynman rules for the above interactions, and computed tree-level processes and cross-sections.

- Wrote Python code to compute the thermally averaged cross-section and calculate the relic abundance numerically.

In-Progress and Future Work

This is an ongoing project. It remains to compare abundances of KR with dark photon and axion constraints for comparable masses and couplings. Understanding the production of KR in the early universe is the first step towards distinguishing it from its doppelgangers. In future work, we will explore in more depth the implications of these interactions for direct detection experiments. Kalb-Ramond has pseudo-scalar and pseudo-vector interactions, and we believe parity considerations could be very important to disentangling the apparent dualities. We will also explore the possibility of correlated axion-dark photon signals in detectors, which could be a smoking gun signal of Kalb-Ramond dark matter.