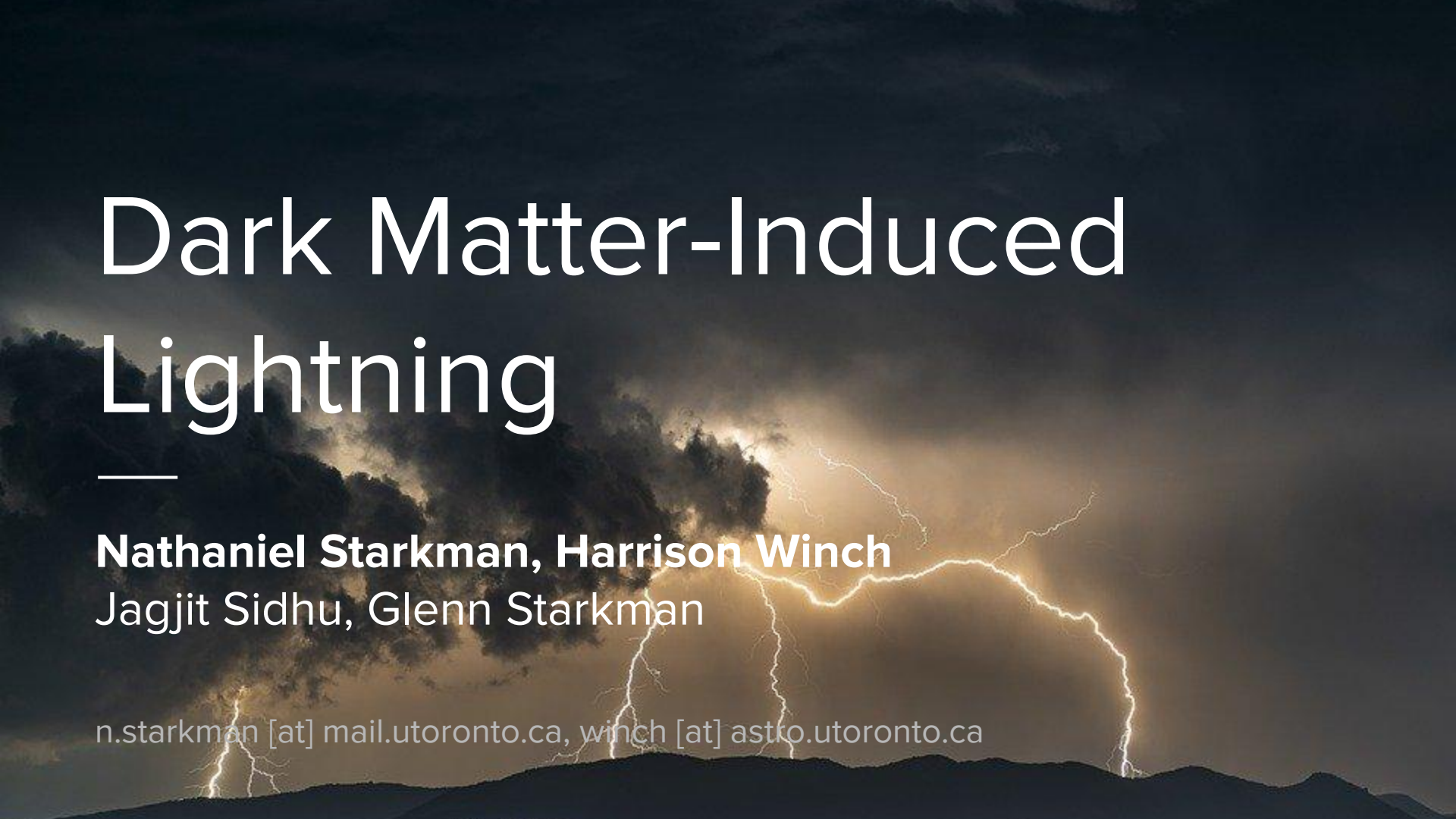

Dark Matter-Induced Lightning

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Straight Lightning as a Signature of Macroscopic Dark Matter

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Macroscopic dark matter (macros) is a broad class of alternative candidates to particle dark matter. These candidates would transfer energy to matter primarily through elastic scattering. A sufficiently large macro passing through the atmosphere would produce a straight channel of ionized plasma. If the cross-section of the macro is $\sigma_x \gtrsim 6 \times 10^{-9} cm^2$, then under atmospheric conditions conducive to lightning (eg. a thunderstorm) the plasma channel would be sufficient to seed a lightning strike with a single leader. This is entirely unlike ordinary bolt lightning in which a long sequence of hundreds or thousands of few-meter-long leaders are strung together. This macro-induced lightning would be extremely straight, and thus highly distinctive. Neither wind shear nor magnetohydrodynamic instabilities would markedly spoil its straightness. The only photographically documented case of a straight lightning bolt is probably not straight enough to have been macro-induced.

We estimate the region of macro parameter space that could be probed by a search for straight lightning from the number of thunderstorms happening on Earth at any time. We also estimate the parameter space that can be probed by carefully monitoring Jupiter, e.g. using the Hubble Space Telescope.

All code and data is available at `https://github.com/cwru-pat/macro_lightning`.

I. INTRODUCTION

Assuming General Relativity is the correct theory of gravity on all scales, there is considerable evidence for dark matter [1]. Macroscopic dark matter (macros) is a broad class of dark-matter candidates that represents an alternative to conventional particle dark matter with wide ranges of masses M_x and cross sections σ_x that could still provide all of the dark matter. Macros typically refer to a broad family of composite dark matter models arising from some early-universe phase transition, often composed of strange quark matter.

Of particular interest would be macros of approximately nuclear density satisfying

$$\sigma_x \approx 2 \times 10^{-10} \left(\frac{M_x}{g}\right)^{\frac{2}{3}} [\mathrm{cm}^2], \qquad (1)$$

as several models for macros describe potential candidates with approximately that density. The idea that macros could be formed entirely within the Standard Model was originally proposed by Witten [2] in the context of a first-order QCD phase transition. Subsequently [3, 4] described a more realistic model for Standard-Model macros as bound states of nucleons with significant strangeness. Nelson [5] studied the formation of nuggets of strange-baryon matter during a second QCD phase transition – from a kaon-condensate phase to the ordinary phase. Others have considered non-Standard-Model versions of such objects and their formation [6].

Some of us, working with colleagues, have recently explored which regions of macro parameter space remain unprobed [7–11]. A longstanding constraint comes from examination of a slab of ancient mica for tracks that would have been left by the passage of a macro moving at the typical speed of dark matter in the Galaxy. This was used to rule out macros of $M_x \leq 55\,\mathrm{g}$ for a wide range of cross sections (see [7, 12, 13]). Various microlensing experiments have constrained the dark-matter fraction for masses $M_x \geq 10^{23}\,\mathrm{g}$ [14–18]. Wilkinson *et al.* [19] utilized the full Boltzmann formalism to obtain constraints from macro-photon elastic scattering using the first year release of Planck data. More recently, the existence of massive white dwarfs was used to constrain a significant region of macro parameter space [20] (as revisited and extended by [11]). The region of parameter space for which macros produce injuries similar to a gunshot wound was recently constrained by historical analysis of a well-monitored segment of the population [9].

The parameter space for electrically charged macros, with the macro charge as an additional free parameter, was recently constrained [21] based on a variety of terrestrial, astrophysical and cosmological measurements. The parameter space for antimatter macros was constrained by [22] using arguments analogous to those cited above for macros.

More work has been done recently to identify addi-

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What is a “Macro”?

- ≝ Macroscopic dark matter
- Broad class of composite dark matter models
  - ex: strange quark nuggets
- Transfer energy to matter primarily through elastic scattering.

Examples

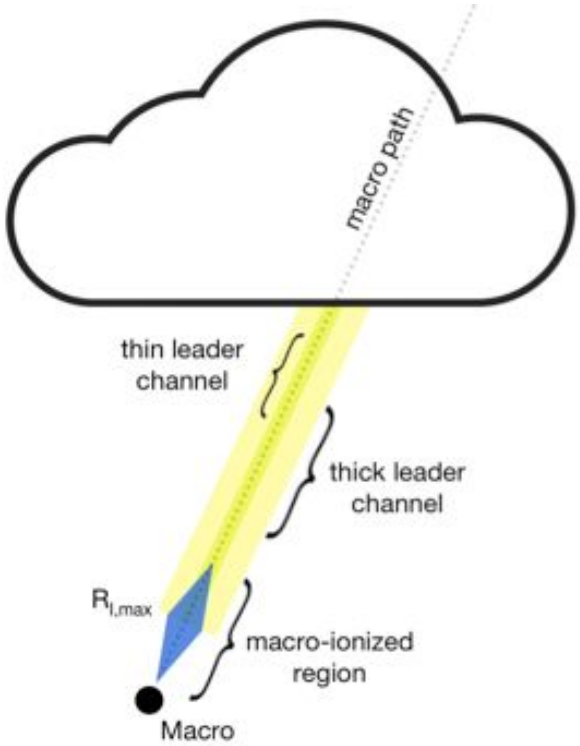
- E. Witten, Physical Review D 30, 272 (1984).
- B. W. Lynn, A. E. Nelson, and N. Tetradis, Nuclear Physics B 345 (1990).
- B. W. Lynn (2010), arXiv:1005.2124.
- A. E. Nelson, Physical Letters B240, 179 (1990).
- A. R. Zhitnitsky, Journal of Cosmology and Astroparticle Physics 2003, 010 (2003).
- D. M. Jacobs, G. D. Starkman, and B. W. Lynn, MNRAS (2014), 10.1093/mnras/stv774, arXiv:1410.2236.
- D. M. Jacobs, A. Weltman, and G. D. Starkman, Physical Review D 91, 115023 (2015).
- J. S. Sidhu, R. Scherrer, and G. Starkman, Physics Letters B 803, 135300 (2020).
- P. B. Price, Physical Review D 38, 3813 (1988).
- A. De Rujula and S. L. Glashow, Nature 312, 734 (1984).
- C. Alcock et al., The Astrophysical Journal 550, L169 (2001).

& and many more

Formation

- Macro forms plasma trail
- Lightning “leader” locks in trail
- Luminous lightning back-propagates along trail.

Prediction: macro-induced lightning would be extremely straight, and thus highly distinctive.



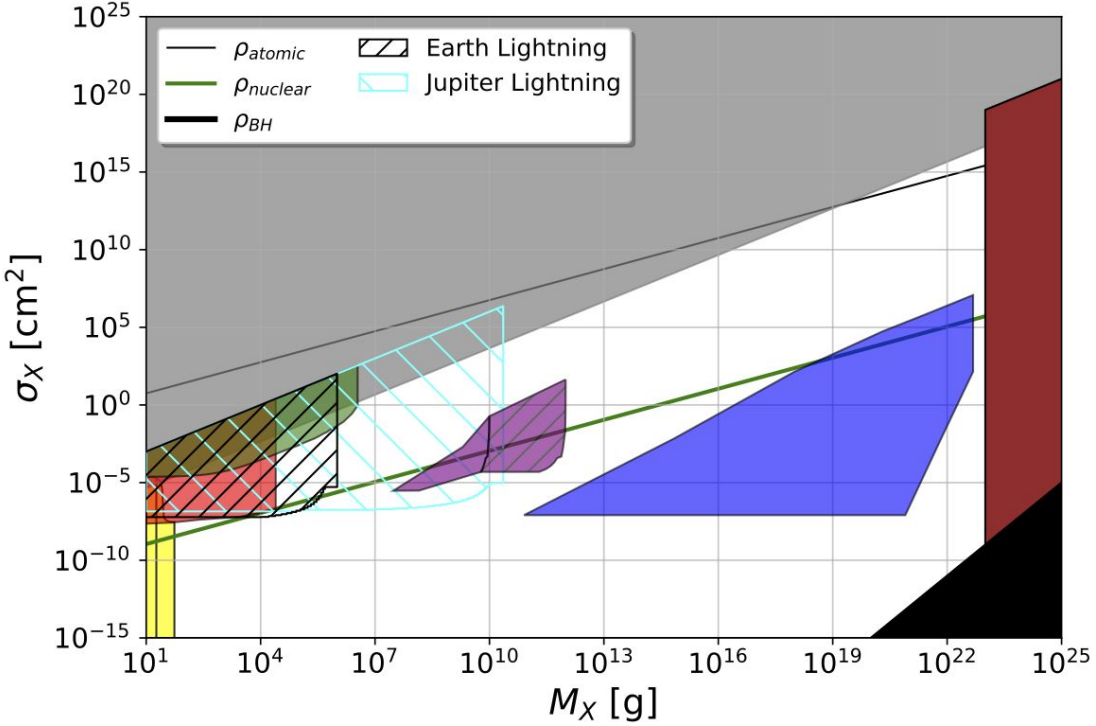
Straightest-Observed Lightning

Probably NOT straight enough.

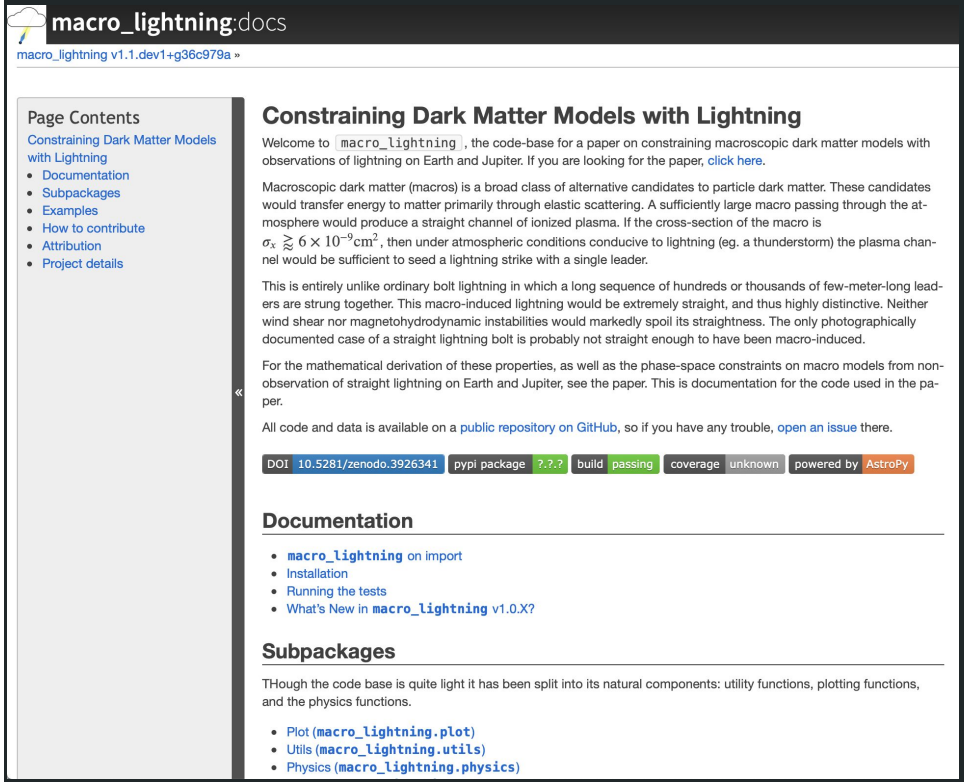
https://earthsky.org/todays-image/rare-straight-lightning-over-zimbabwe

Constraints

- Non-observation of distinctive, abnormally straight lightning
- Probe unconstrained parameter space
- Also, Jupiter.



Open-Source



https://macro-lightning.readthedocs.io/en/v1.0/