# Mapping the Dark Matter Distribution in the Local Universe with The Asteroid Terrestrial-impact Last Alert System (ATLAS) and the University of Hawai‘i 2.2-m Robo-AO system

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## Preamble:

The following text was written in the context of a private foundation proposal and presents a specific example of the kind of project that could be undertaken with a dedicated follow-up facility being fed by all-sky transient surveys.

## Scientific context:

Cosmological studies by observational astronomers have revealed two unexpected and, as yet, unexplained features of the Universe: dark matter and dark energy. Dark energy causes the Universe to expand at an accelerating rate and dark matter is the dominant source of gravity. Normal matter such as stars and galaxies flow in response to the gravitational tug of dark matter clumps. This can be seen in the clumpy distribution of visible galaxies and their peculiar velocities with respect to the local expansion (i.e. velocity field). There have been recent claims that the velocity field in the "nearby" (1 billion light years) Universe is bigger than expected based on the standard cosmology of Gaussian inflation, dark energy, and cold dark matter. We will experimentally measure the 3-dimensional map of dark matter in the nearby Universe to an accuracy and precision over ten times better than previous attempts. This experiment has the potential to directly discover new properties of dark matter, and indirectly provide limits on the Gaussian nature of inflation and the properties of dark energy.

This responds directly to the NWNH Panel Reports key activities on dark matter: *“Improve astrophysical constraints on the local dark matter density and structure on subgalactic scales to test the paradigm of cold, collisionless, and stable dark matter and to look for evidence for alternative dark matter candidates.”*

## 1. What O/IR capabilities are you using, are you planning to use, and will you need through the LSST era?

We are planning to build a system that will enable us to precisely map the dark matter distribution in the local Universe by using “standard-candle” SNIa to measure the nearby velocity field, the same tool used to discover dark energy. Mapping the local velocity field to a billion light years requires: 1) detecting thousands of SNIa; and 2) characterizing each one to realize the full distance accuracy. 1) Starting in 2015, all new SNIa within a billion light years will be discovered by the fully operational facility ATLAS (Tonry, J., PASP 123, 58-73, 2011). 2) These SNIa only provide an accurate and precise measurement when the full light curve and the dust extinction have been measured and calibrated. This can be measured with a combination of the ATLAS images and a low-resolution spectrum over near infrared wavelengths. To obtain the necessary efficiency and observing time for a low-resolution infrared spectrum, we will build a low-resolution infrared spectrograph for the University of Hawaiʻi 2.2-m telescope on Maunakea where observing time is plentiful, and augment it with a Robo-AO (Baranec, C., et al. ApJ, 790, L8, 2014) high-efficiency robotic laser adaptive optics system. The Robo-AO system removes the blurring effects of our atmosphere, making images 5 to 20 times sharper, boosting the infrared point-source sensitivity against the sky background by a factor of 9. In essence, Robo-AO gives the UH 2.2-m the infrared sensitivity of a 6.3-m telescope without adaptive optics.

The majority of the nearby SNIa host galaxies have measured velocities. We will combine distance and velocity to extract the dark-matter-influenced peculiar velocity from the expected Hubble flow, which in turn lets us map the 3-dimensional structure of dark matter in the nearby Universe and tests cosmological theories.

**Impact:**

Although we have no idea what triggered the creation of the Universe, we have a very clear picture of how we think it has evolved. The Universe briefly inflated under the influence of one form of dark energy that has since disappeared, it cooled and clumped under the influence of dark matter, and it is now starting to slowly inflate again under the influence of a new type of dark energy. If this is correct, there should be remnant velocity deviations from the overall expansion, and the form and amplitude of these velocities can tell us about the nature of dark matter, dark energy, and the clumping process. Moreover, it is possible that the observed residual velocities will not agree with the consensus theory, which will force us to revise the theory and properties derived for these mysterious components of the universe. It is therefore imperative that we experimentally measure the structure of dark matter in the nearby Universe to answer these fundamental questions on its evolution.

**Additional science:**

ATLAS' prime mission is to identify asteroids that pass perilously near the Earth. The UH 2.2-m Robo-AO system will enable ATLAS to assess the potential hazard of each asteroid, which is proportional to its total mass. Mass is determined from reflectivity and density, both of which are very uncertain. For example, fewer than 10% of asteroids are composed of iron, but on impact, small iron asteroids are more dangerous than large low-density stony asteroids. Their reflectivities and densities can be distinguished using colors and spectra; but, they must be measured quickly and simultaneously because asteroids tumble. This can be done efficiently with the UH 2.2-m Robo-AO system and its low-resolution infrared spectrograph. With such data, the ATLAS discoveries can be quickly converted to mass and the real impact hazard assessed.

The UH 2.2-m Robo-AO facility will uniquely enable many new high-resolution surveys across all fields of astronomy. The prototype helped validate NASA's 3,000 Kepler exoplanet host candidates (Law, N., et al., ApJ, 791, 35, 2014, and in preparation) and our new system will do the same for the projected up to 30,000 planet host candidates discovered by NASA's 2017 TESS mission.