Near-Earth asteroids have attracted an increasing level of interest in recent years for a variety of reasons, from scientific curiosity to future exploration to concerns about potential impactors. NASA has made it a major goal to find and characterize the near-Earth asteroid (NEA) population. My research focuses on the characterization aspect. I work with radar and infrared observations of asteroids, in order to find out as much as possible about the asteroids' physical properties, and to explore the limitations that the data impose on what it is possible for us to know. There are many thousands of asteroids that are Earth's close neighbors in space, but only a handful have been explored in detail. I am working to increase our level of knowledge.

One of the best ways to study near-Earth asteroids is with radar observations, in which a powerful series of coherent radio waves is transmitted toward an asteroid, and the echoes that reflect off the asteroid are received some time later. Careful analysis of echoes received over the course of an asteroid's rotation makes it possible to determine the asteroid's size, shape, and spin state, often with great accuracy. For instance, measurements of the distance can be made with an accuracy of 7.5 meters, for an asteroid that may be millions of kilometers away.

Since 2010, NASA has greatly increased its level of funding for the planetary radar program at Arecibo Observatory, which has the world's largest and most sensitive radio and radar telescope. This has led to correspondingly large increases in the total number of asteroids studied and the number of high-quality detections for which it is feasible to determine physical properties in detail.

Observations of asteroids at infrared wavelengths reveal the relative strengths of reflected sunlight and their intrinsic thermal emission at infrared wavelengths due to their temperature. Thermal modeling based on the asteroid's shape from radar observations, combined with optical and infrared measurements, can provide information on its optical albedo, thermal inertia, and other properties. Conceptually, a thermal model provides a mathematical formulation of how the temperature of a region on the asteroid depends on the past and present level of incoming solar radiation. The simplest thermal models assume that any sunlight absorbed by the surface is immediately re-radiated into space, but more sophisticated (and realistic) models account for vertical conduction of heat, and mutual heating of regions of the surface that face each other. For any single infrared observation, there are typically a large number of thermal models that provide a good fit (e.g., a line across the parameter space), but given several observations from different viewing geometries, one can find a unique solution.

Radar and infrared observations of asteroids are often done separately from each other, with no attempt at coordination. Some asteroids for which there are radar-based shape models have not been observed systematically (or at all) in the infrared. On the other hand, since there are many more asteroids that have been observed in the infrared than by radar, reliable shape models are only available for a few. This will remain true for the foreseeable future, since there are far more facilities for infrared observations than for radar observations.

With no information on most asteroids' shapes, a common assumption is to suppose that the asteroid is spherical and to determine the size and thermal properties of a sphere that would match the infrared observations. However, applying these spherical thermal models to non-spherical asteroids leads to large errors in the derived properties.

As an example, consider near-Earth asteroid (8567) 1996 HW1, which radar
observations showed to be an elongated contact binary. In certain viewing geometries, HW1's flux density at infrared wavelengths varies by a factor of about three as it rotates, mainly because of its projected area changing. If one assumed that HW1 was a sphere and calculated the diameter of the sphere that would be needed to give the observed infrared flux density, I showed that one would find variations of ±30% (a maximum-to-minimum range of about 1.8) from HW1’s actual volumetric mean diameter, depending on the rotation phase at which it happened to be observed. This would make its volume (and its mass) uncertain by a factor of about six. Spherical thermal models often must be used, when only limited optical and infrared observations are available, but the resultant errors can be large. These could have major implications for future exploration – or, in the case of objects that may impact Earth, deflection efforts. Accurate information about an asteroid's size and other physical properties is necessary for the proper planning of any mitigation program.

For several years, my collaborators and I have been observing near-Earth asteroids with the Arecibo radar system, and in the infrared, with the NASA InfraRed Telescope Facility on Mauna Kea. We have observed dozens of asteroids. For the asteroids we target, this puts us in a position to get as much information as is possible from remote sensing. The only way to find out more about an asteroid is through an expensive spacecraft flyby.

My projects fall into two general categories. The first is studying specific individual asteroids for which there are radar and infrared observations. From the radar observations, sometimes combined with lightcurve observations, I can determine an asteroid's, size, shape, and rotation state. Then, using the infrared observations, I can determine the asteroid's albedo, thermal inertia, and other thermal properties (such as the roughness of its surface, normally parameterized as the fraction covered by hemispherical craters). In practice, this means running many thermal models, where the asteroid's thermal properties are set to a wide range of plausible values, and seeing which model spectra best match the data. Over the past year, I have streamlined that process by writing scripts to run suites of thermal models and process their results.

No two asteroids are identical, and each asteroid presents its own unique challenges when doing data analysis. The first asteroid that I studied in detail was (137032) 1998 UO1. There are lightcurves of 1998 UO1 from five apparitions, but the radar observations did not have very high resolution. Thus, the data for UO1 had quantity but not quality. I showed that UO1 is nearly ellipsoidal, with a maximum diameter of about 1.2 kilometers. Somewhat surprisingly, UO1 does not have a detectable satellite, despite having a similar size and rotation period (2.9 hours) to other asteroids that do have satellites. In the near future, I will do similar analyses of other near-Earth asteroids – most likely (170502) 2003 WM7 and (85989) 1999 JD6. 1999 JD6 is particularly interesting and relevant to my interests, since different infrared observations of it have given discrepant estimates of its size. And with the high pace of asteroid observations, I (along with any future students) can count on having many other asteroids to study in the more distant future.

The second class of projects involve more general studies of the asteroid population. I am currently studying how the shape affects the infrared spectrum for some non-spherical asteroids with high-quality shape models. While it has been known for decades that an asteroid's thermal emission must depend on its shape, having a number of good asteroid shape models (mostly from radar observations) is a more recent development. Part of this project was my analysis of thermal emission from 1996 HW1, as discussed above. I am comparing the thermal parameters that one would derive from spherical thermal models to the
properties that one finds when the true shape is known. I will then investigate the effects of temperature-dependent thermal properties on infrared spectra. After that, there are many other subtle effects that may measurably affect infrared spectra, such as variations in surface properties and signatures of binary events; I plan to explore those effects.

The two classes of projects support each other. Many individual asteroids must be studied in detail before one can make reliable statements about the detailed properties of the population as a whole. In turn, the results of the general studies guide the choice of future targets and provide direction for the analysis of the data. While we will never know every detail about every asteroid, we can certainly build upon our current level of knowledge, and I look forward to continuing my part in that effort.