# SPACE OBJECT CHARACTERIZATION STUDIES AND THE MAGDALENA RIDGE OBSERVATORY'S 2.4-METER TELESCOPE

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## 1. INTRODUCTION

The Magdalena Ridge Observatory's (MRO) fast-tracking 2.4-meter telescope is located at 10,612 feet atop the Magdalena Mountains in Central New Mexico, and is presently transitioning to an operational status. The MRO 2.4-meter is one of the largest telescopes in the world that has as its primary mission the physical characterization of small bodies (both natural and artificial) in the Solar System. The 2.4-meter's control system is designed to provide convenient and accurate non-sidereal tracking, and the telescope is capable of rapid movement (slew rates are up to 15 °/sec) making it an ideal instrument for non-resolved imaging of low-Earth orbit (LEO) space objects. The 2.4-meter telescope can accommodate a wide variety of instrument systems, and support the fabrication, integration, and operation of new instrumentation as well as the development of new and innovative techniques in space object identification studies.

Currently, we are investigating various methods to enhance and improve existing capabilities for unique discrimination of resident space objects. The temporal brightness variations (i.e., lightcurves) of unresolved targets such as artificial satellites can be used to develop a powerful tool for general characterization studies. Analysis of these temporal signatures permits the extraction of pertinent distinguishing features, and may also be an indicator for a change in general health status of a satellite. Payne [1] and Gregory [2] have demonstrated what can be obtained by adding multi-color information to traditional photometric intensity measurements for geosynchronous satellites. Our current focus is to introduce supplementary discriminators, including polarization data and simultaneously obtained spectral and temporal data. We will discuss new methods for incorporating such data, with a specific emphasis toward LEOs as our target objects. Our observing strategy will be to choose a statistically robust target set with know properties, obtain standard lightcurve intensity information, and then analyze the utility of adding the additional discerning information. Simultaneous data on satellites using geographically separated facilities should also prove beneficial. We will employ predictive modeling for assessing the usefulness of the obtained data for satellite classification and for the identification and interpretation of any anomalous signatures.

## 2. FACILITY DESCRIPTION

MRO's fast-tracking 2.4-meter telescope (Fig. 1) is one component of a dedicated $11 million facility operated by the New Mexico Institute of Mining and Technology (NMT), a small research and engineering university. First light for the observatory occurred on October 31, 2006, followed by months of additional telescope engineering, commissioning, and software development. Two primary drivers for this facility are the physical characterization of small solar system bodies [3] and supporting the nation's Space Situational Awareness (SSA) efforts by monitoring and characterizing resident space objects in close proximity to the Earth. In general, the 2.4-meter telescope can accommodate a wide variety of instrument systems, and support the fabrication, integration and operation of new instrumentation, as well as the development of new and innovative techniques in non-resolved characterization studies.

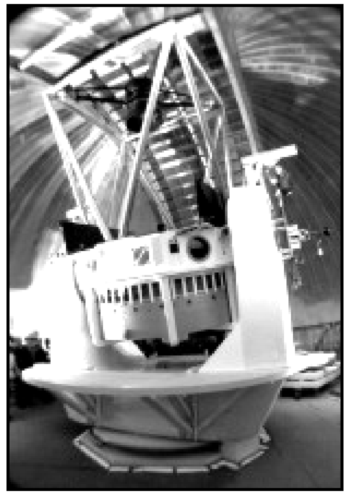

Fig.1. The Magdalena Ridge Observatory's 2.4-meter fast-tracking telescope. An instrument (an engineering CCD camera) is shown mounted to the right fork tine at the Nasmyth port. The telescope is capable of mounting 5 instruments (plus a Shack-Hartmann wavefront sensor) simultaneously, and initial implementation includes a 4Kx4K visible CCD camera, and a near-IR camera (for thermal studies).

The telescope is a modified Ritchey-Cretian design, with an overall focal ratio of f/8.9 and has an unvignetted field of view of 19 arcminutes. The intrinsic resolution of the optical system is defined by a full-width half-maximum (FWHM) of 0.2 arc-seconds for a point source. There are two Nasmyth ports (which can support larger and heavier instrumentation) and four bent Cassegrain ports, one of which permanently hosts a Shack-Hartmann wavefront sensor to facilitate automatic collimation and focusing. Therefore, the facility can simultaneously mount up to 5 instruments at any given time, streamlining the setup process for any given research project being hosted, and maximizing time on the night sky.

The 2.4-meter's control system is designed to provide accurate non-sidereal tracking, allowing for longer exposure times to be utilized (extending the telescope's faintness limits), even for fast moving LEOs. Fig. 2 illustrates the telescope's ability to track on a 17th magnitude recently discovered near-Earth asteroid (2007 FK1) over a 300 second duration. LEO objects yields similarly excellent tracking precision. The telescope also has the capability to look 2° below the horizon for applications related to missile tracking.

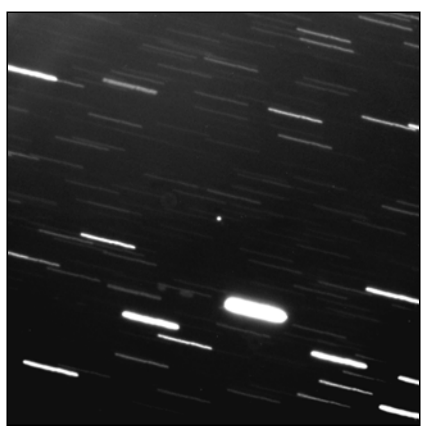

Fig. 2 Recently discovered near-Earth asteroid 2007 FK1 (center) is being tracked by the 2.4-meter telescope over a 300 second duration on May 27, 2007. The object's visual magnitude is ~17.1, and it is moving at a rate of 7 arcseconds per minute. Sub-arc-second point source profiles of the target asteroid were regularly obtained in this experiment. The camera used during this engineering test is an off-the-shelf 2Kx2K Apogee U-42 thermo-electrically cooled device.

## 3. CHARACTERIZATION OF RESIDENT SPACE OBJECTS

Our objective in using the fast-tracking 2.4-meter telescope is to augment existing space object identification (SOI) analysis techniques by focusing on the non-resolved imaging of objects in low-Earth orbit (LEOs). Our ultimate goal is to develop methods that will better refine estimates of an artificial object's position, orientation, shape, and general health status. Some of the techniques that we are utilizing include taking simultaneous data of satellites using geographically separated facilities, multi-color polarimetry to augment lightcurve observations, testing new sensors, and investigating the effects of space weather on resident space objects. Our approach includes both numerical modeling and actual data collection and interpretation.

To better interpret the observational data being collected, we employ a direct model which assumes that a lightcurve is a deterministic function of the target's physical parameters and the observer's viewing geometry. This model can provide a definitive result even for the most complex objects. Therefore, specific lightcurve signatures can be correlated with 3D shape peculiarities. The long term aim: construction of an entire atlas of known lightcurve signatures as a quick identification resource for resident space objects. For example, Fig. 3 depicts a lightcurve taken (using a 1.8m telescope) of mainbelt asteroid 3155 Lee. Finding the object shape or shape configuration that produces the observed features is an iterative process using our direct model, and we explore many hypotheses that have a high likelihood of producing the observed features. One attempt is illustrated in Fig. 4a, which shows the lightcurve generated by a dog-bone shape. It does not match the observed lightcurve well. We tried several other possibilities, and then switched to a two object system to attempt a match. The result using a binary pair, an ellipsoidal and a roughly spherical-shaped object, is shown in Fig. 4b. This simulation matches the actual data quite well. Another application of this model is detecting potentially hostile maneuvering micro-satellite companions to existing satellites. The lightcurves of objects in mutual orbits will display occultation and/or eclipse events, collectively referred to as 'mutual events', under favorable geometric circumstances. These signatures would be straightforwardly detected using the direct model.

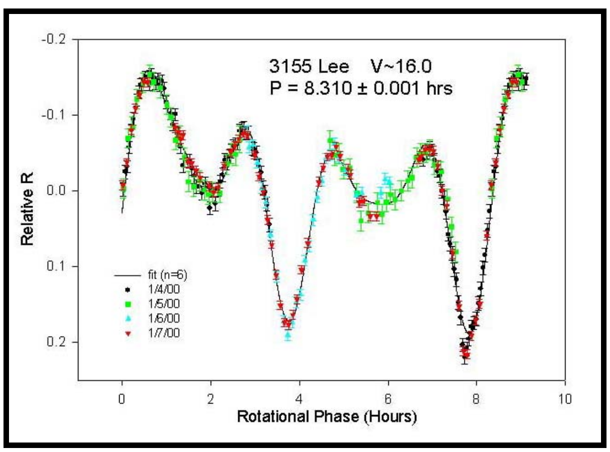


**Fig. 3:** Complex lightcurve of asteroid 3155 Lee taken using the 1.8m VATT telescope in Southeastern Arizona, prior to the MRO 2.4m telescope becoming operational.

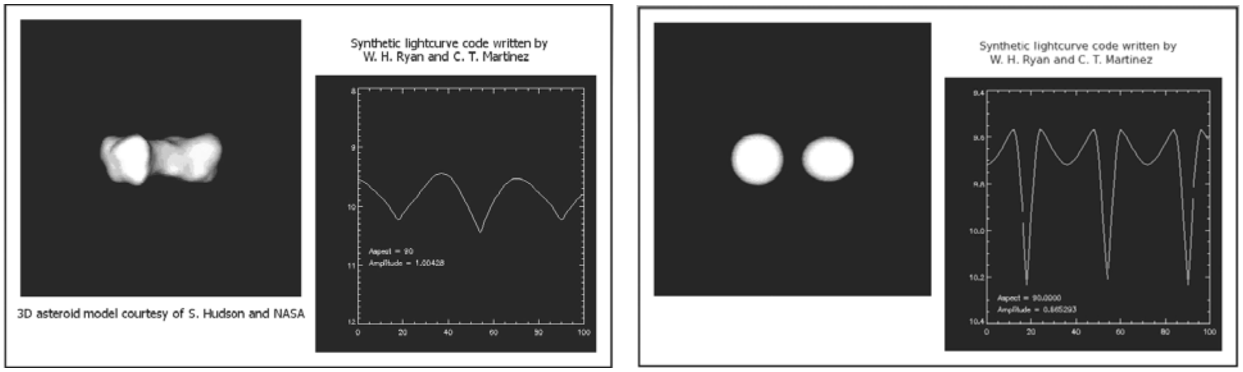


**Fig. 4 a,b:** Direct model simulation a) using a complex shape b) using two simple objects.

Further analysis along these lines continues in order to investigate how successfully this direct model can generate look-up tables for actual satellite identification. To better establish the foundation for this work, we have selected a set of known objects (primarily LEOs) for assessment and development. Since our goal is to improve current capabilities, we will thoroughly investigate ways in which these objects can be characterized.

## *Microlens Sensor*

One of the new characterization techniques that we are in the process of testing combines both temporal and spatial information. *Solid State Scientific Corporation* has developed a unique spectral imaging sensor prototype that simultaneously images sixteen color bands at video rates.  This The spectral imager operates in the visible to near-infrared (VIS/NIR), has a 9º field of view, and uses a 512 x 512 staring camera to capture one 128x128x16 spectral data cube during each camera integration time.  All 16 images will be acquired with no time latency in spatial or spectral acquisition.  The sensor system represents a fully-integrated, easily-portable sensor that measures, displays, stores, and analyzes spectral data cubes.  Development of this sensor represents a unique opportunity in hyperspectral sensing and imaging.

The new sensor combines staring imaging technology with the state-of-the-art in micro-lens fabrication technology to produce a new spectral imager.  The ability of the new sensor to rapidly acquire spectral data cubes provides an unprecedented opportunity to investigate algorithms for dynamic event classification based on temporal-spectral signatures.  In addition, the small physical size of the sensor demonstrates the possibility of portable hyperspectral imaging. This type of spectral-temporal characterization may prove beneficial for more instantaneous and less ambiguous satellite identification.

The first test run using the microlens sensor is scheduled for September 2007. The object dataset focuses on LEO objects brighter than $5^{th}$ visual magnitude, and absolute calibration is also being done. Sensor development and prototype testing can be conveniently and inexpensively accomplished at the MRO facility.

## *Polarization Studies*

Another technique with the capability to expand general SOI analysis is the incorporation of polarization effects. Polarimetry enhances the amplitude of an object's light curve, and provides a significantly more sensitive method to measure information on a satellite's surface.  One of the goals of our research study is to experimentally ascertain the utility of polarimetry for identifying changes in resident space objects, particularly for those objects that can not be imaged with sufficient spatial resolution to be adequately identified with the hyperspectral and image enhancement techniques currently in use. Polarization information has the potential to improve discrimination between objects based on their angularity, electrical conductivity, and surface roughness, which can provide a valuable complement to their hyperspectral and temperature signatures.

With respect to actual data collection, our strategy is to ascertain what can be accomplished with traditional photometry, and then explore the enhancements derived from including polarization data as a distinguishing feature in SOI. Modeling will also be performed, both as a predictive forward indicator of what we think the data acquired will look like, and as a post-processing tool to build a more robust vision of the resident space object under study.

### *Simultaneous Observations*

Another complementary function of the MRO 2.4-meter telescope for this SOI research initiative is the ability for it to provide a mechanism for obtaining simultaneous data on a resident space object. A simultaneous observation of an artificial target from multiple sites (having differing viewing geometries) is a powerful resource for providing enhanced characterization information with better constrained solutions. Databases would initially include photometry, but could be expanded to later incorporate spectro-photometry and polarization at significant phase angle variations. This data can then be used to better constrain satellite shapes, spin rates, and orientation. If feasible, it would be beneficial to have an existing telescope system take an adaptive optics image of one of our database objects at the same time unresolved lightcurve data is being acquired. This allows the actual image to be used as ground truth for increased fidelity and to refine our space object identification approaches.

Simultaneous observations can be obtained on various LEO, MEO, and GEO object types as a function of time as our investigation progresses. The difficulty of low altitude simultaneous observations is the balance between conditions being dark enough for observations from a distant site while still being visible (but not eclipsed) from MRO. This situation is visualized in the 3D-graphic shown in Fig. 5 using the Air Force's Maui-based space surveillance system and MRO as the test sites. For higher-altitude observations, the solar phase angle is not very different, but both facilities can do the observations in a nearly simultaneous "hand-off" fashion, lengthening the period over which observations of a single object are obtained. This is particularly valuable for the accurate measurement of objects with slow rotation rates.

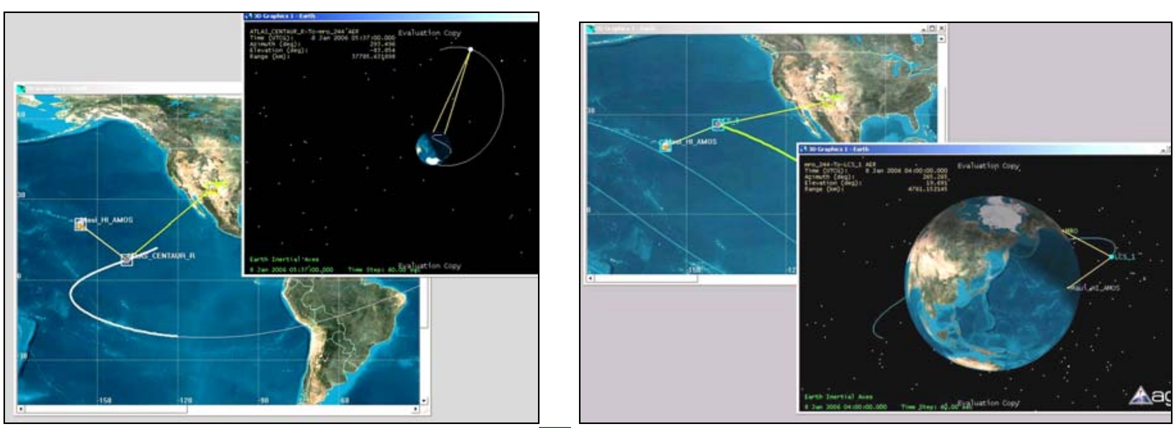

**Fig. 5:** Graphic display (using the software package STK) of the MRO and MSSS telescopes simultaneous observation a) of an Atlas Centaur and b) of a low-Earth orbit object.

## 5. CONCLUSIONS

All of these methods combined lead to a more fully defined effort into space object identification. The strength of our approach lies in combining and investigating not one, but several techniques for better real-time characterization studies. Our analysis is just beginning, but we expect that over the next three years we will acquire a large data base of observations on primarily low-Earth orbit objects, capitalizing on the fast-tracking capabilities of the MRO 2.4-meter telescope facility. A strong asset of the facility is the ability to quickly and easily respond to targets of opportunity. Further, new techniques and prototype instrumentation can be tested and refined efficiently and at modest costs.

# 6. REFERENCES

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