Missouri Space Grant Consortium

2016 Associates Award Competition proposal

from

Drury University

Title:

An integrated system for the study of rotation states of large Low-Earth-Orbit orbital debris

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Summary of the proposed project: An integrated system for the study of rotation states of large Low-Earth-Orbit orbital debris

This project is designed to generate progress in scientific understanding of the rotational states of large orbiting anthropogenic debris objects, through comparison of telescopic observations (or "light curves") of these objects, with theoretical predictions. The predictions are constrained by the known shapes and assumed reflective properties of the objects, as well as by theoretical results from the equations of motion describing rotational dynamics. The proposed project involves the creation and initial testing of an integrated laboratory infrastructure and program designed to collect, analyze, and theoretically explain light curves acquired by observing large catalogued orbital debris objects in low earth orbit (LEO). The project will contribute to NASA's higher education educational outcome through the objectives of faculty and student support as described in Appendix A of the MOSGC program announcement, and will support the emphasis (described therein) of authentic hands-on student experiences in science and engineering disciplines. The proposed work will also support both the ARMD and SOMD mission directorates as described in Appendix B of the MOSGC program announcement, since knowledge of space debris dynamics is vital to safety of manned and unmanned missions in LEO, and this knowledge informs the SOMD regarding related safety issues. Specifically, the concept of Active Debris Removal (Liou, 2011) is under serious consideration by NASA, and knowledge of rotation states of the debris to be removed in this manner is critical to such an endeavor.

System design: The integrated system that we propose to create involves three major components, each of which can be only explained briefly here due to space constraints. The following are the components of the system:

The Drury University observatory (DUO)

The central component is a 14-inch Meade LX200 telescope, mounted on a Paramount MX+ robotic telescope system, made by Software Bisque Corporation. This assembly rests on a custom-made steel and cement pier assembly, and is housed within an 8' x 8' observatory shed with a remote-controlled roll-off roof. The telescope will eventually be controlled remotely from Drury University using TheSkyX Professional telescope control software (Software Bisque) and a suitable remote-access software such as Team Viewer. Custom software (see below) will allow tracking of large LEO debris objects as they pass over DUO, thus acquiring light curves which will be used in concert with other components described below, to constrain and understand rotation states of these objects.

Drury Optical Measurements Lab (DOML)

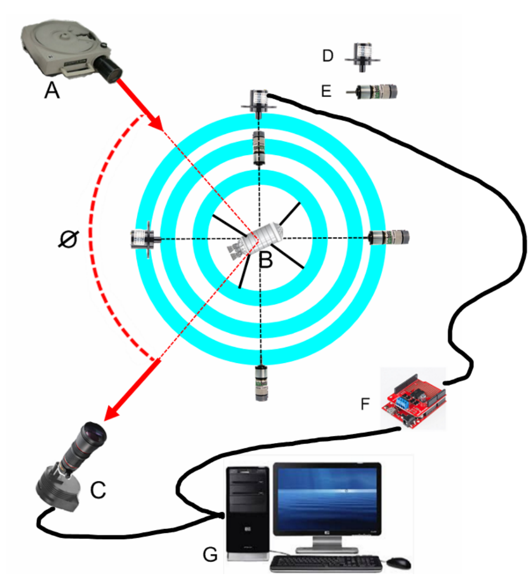

Figure 1: components of DOML:A) light source representing sun. B) 3D printed model of large LEO debris. (C)CCD camera with telephoto lens (representing telescope)(D)slip rings. (E) stepper motors, (F) arduino microcontroller, (G) controlling PC.

DOML consists of the experimental equipment shown in Figure 1. At the center is a system of three motorized gimbals; small models of catalogued LEO debris objects will be conceived in Autodesk Fusion 360, printed using a Taz5 3D printer, and hand-painted appropriately. They will then be suspended in the innermost ring with thin, dark colored wires. The three gimbal rings will be painted with flat black paint so as to reflect a minimal amount of light. A prototype of this device was recently constructed at Drury University. In its final form, a xenon arc lamp, simulating the sun, will be mounted on a rotatable arm, driven by a stepper motor and Arduino microcontroller so that the lamp can be moved by computer commands to chosen locations in a 360° angular range. A CCD camera with a telephoto lens and filter wheel assembly will be placed at a fixed location, from which the object suspended in the center can be imaged as it reflects light from the lamp. This arrangement will allow the simulation of realistic spectral data in the lab. The entire DOML apparatus will be surrounded by dark, flat black curtains and black ceiling. DOML will allow collection of simulated bidirectional reflectance distribution functions (BRDF' S) of the modeled debris objects which are to be suspended in the center. The data will be four dimensional, with three independent angles describing the orientation of the object relative to the laboratory coordinate system, and a fourth dimension entailed by the solar phase angle (simulated as the lamp-object-camera angle).

In the initial stages supported by the proposed grant, illumination of models will be effected using a simple collimated incandescent bulb housed in a 35mm slide projector, rather than with a (expensive) xenon arc lamp. Knowledge of the relative spectral irradiances of the sun (i.e. the bulb), together with the spectral transmissivities of the color filters used, will allow appropriate corrections to light curves in order to generate realistic variations of light curve data with wavelength.

Drury University Astrophysical Computational laboratory (DUAC)

The DUAC will consist of a dedicated cluster of computers, available due to the departure of a physics faculty member. This cluster will allow computations of the following to be performed efficiently in the Matlab computing environment:

1) Apparition geometries and timings: using NORAD-supplied two-line element sets (TLE's) publicly available over the Internet, software will be written (by the PI and research assistants) which will supply pointing instructions for selected cataloged LEO objects as they pass over DUO on any particular night. These instructions can be readily input into TheSkyX Professional software, thus controlling the telescope, and allowing the acquisition of light curves.

2) Rotational evolution of LEO objects: starting with simple free-precession states (cf. Ojakangas, 2013) near minimum-energy (maximum principal-axis rotation) states, sets of orientation trajectories covering ranges of plausible angular momentum and angular velocity orientations will be generated for each of the objects observed by DUO. Eventually, numerical evolution of the rotational states will include effects such as gravity gradient torques, internal friction effects, eddy-current torques caused by motion of metallic debris through the earth's magnetic field, and other relevant phenomena.

3) Synthetic light curves will be generated for each object using two methods:

a) An STL file of each chosen object will be created in Fusion 360. In addition to sending the model to the Taz5 printer, the file will be used to generate a point cloud (a set of 3D points describing the surface of the object). The point cloud will be used to create a triangular mesh of surface elements, which can be in turn input into existing Matlab code (written by Dr. Ojakangas) which can compute synthetic light curves given the object's TLE and the geographic location of DUO, for each particular apparition.

b) Plastic models of each object will be printed on the Taz5, and hand-painted appropriately using historical records for the object. Data obtained using DOML (described above) will then be combined with information on the approach geometry for a particular apparition to create synthetic light curves, for a range of likely rotation geometries.

Relationships between laboratory components

The components described above will ultimately be used together in the many paths shown schematically in Figure 2. Due to the required brevity of this proposal, these cannot not be described in more detail here.

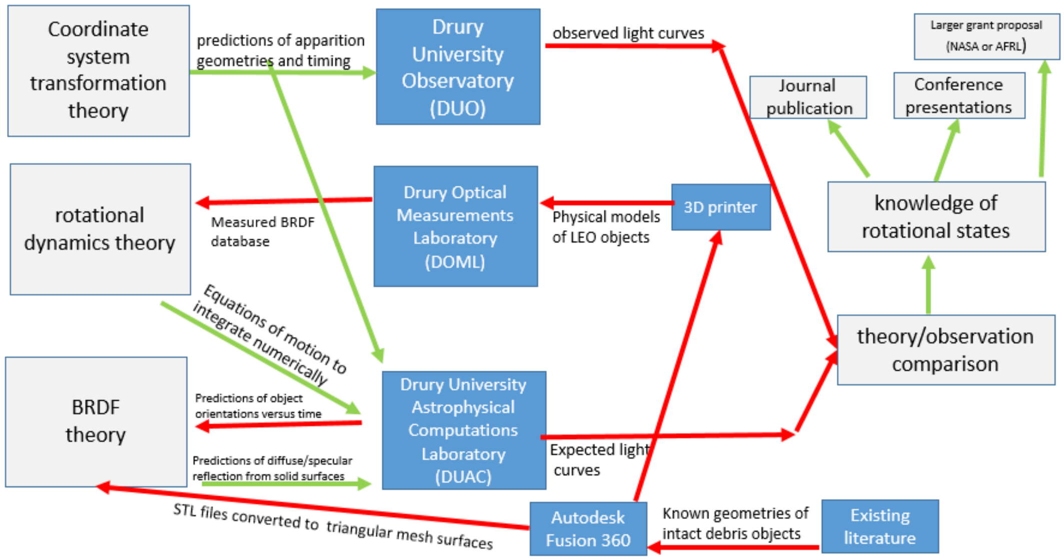

Figure 2: relationships between components of program infrastructure and activities.

Anticipated activities, metrics, and outcomes of the requested grant:

- Creation of STL model of at least 2 common intact large LEO debris of known geometries.
- Creation and appropriate painting of 3D printed models of the above-mentioned debris objects.
- Construction of the DOML in basement of Trustee Science Center at Drury University, including:
  - 3D printing and assembly of new gimbal system using stepper motors (prototype uses PID control and DC motors), slip rings, Arduinos.
  - Creation of code that will allow automated collection of data for a suspended model
  - Software written to allow automated storage of data for a given model object. Storage array will be a quaternion-based equal-area database at each of a range of solar phase angles values.
- Actual telescopic observations of at least 2 orbital debris objects will be made with DUO. These observations will be compared with predictions generated using DUAC, and the degree to which predictions of actual rotational behaviors can be determined from the observational data will be assessed using forward modeling.
- 3 students will present preliminary results: at the annual MOSGC meeting and Drury's Research Experience in Natural Sciences (RENS) Symposium
- PI will present research at 1 appropriate conference
- 1 paper will be submitted to an appropriate journal (e.g. the Journal of Spacecraft and Rockets) describing the project
- 2 students will pursue advanced STEM field degrees after project is completed

In addition to attainment of the above explicit goals, it is anticipated that this proposed program will generate enthusiasm and interest that will draw more students to STEM fields.

Number of project participants:
It is anticipated that one faculty advisor (Dr. Gregory Ojakangas) and three research assistants will be directly involved in this project, and that at least one of the RAs (33%) will be female. Although collaboration and shared duties will be encouraged, one of the RAs will be in charge of 3D printing and painting of models, one will be in charge of programming and one will be in charge of observations using DUO.

References:

Liou, J.-C. (2011) An active debris removal parametric study for LEO environment remediation, Advances in Space Research 47 (2011) 1865–1876.

Ojakangas, G. W. and Cowardin, H., "Probable Rotation States for Rocket-Bodies in Low-Earth Orbit", The 2013 AMOS Technical Conference Proceedings, Kihei, HI, 2013

Budget Narrative:

NASA funding for 9 week PI summer salary $13,131
($56,900/9 month contract)*(12 months/52 weeks) = $1,459/week

Drury Cost Share for 16% payroll burden $2,101
(taxes, worker's compensation, retirement match)
($13,131)*(16%)

NASA funding for consumable supplies $350

Drury Cost Share for consumable supplies $850

Drury Cost Share for CCD Camera $2,000
CCD camera is needed to acquire data with the 14" telescope-- our old CCD cameras are not supported by telescope control software.

Drury Cost Share for Observatory Pier $500
This welded steel pier fits between cement pier and Paramount MX+ telescope mount: $300 for materials, $200 for installation

Drury Cost Share for Faculty travel $1,500
Travel to space surveillance conference, possibly AMOS (http://amostech.com/) conference on Maui, where P.I. has given talks twice before, COSPAR (http://cospar2016.tubitak.gov.tr/en/) or other.

Drury Cost Share for Student travel $1,000
Student accompaniment to AMOS or other conference (see above)