

# OBSERVING STRATEGIES FOR FOCUSED ORBITAL DEBRIS SURVEYS USING THE MAGELLAN TELESCOPE

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## ABSTRACT

A breakup of the Titan 3C-17 Transtage rocket body was reported to have occurred on 4 June 2014 at 02:38 UT by the Space Surveillance Network (SSN). Five objects were associated with this breakup and this is the fourth breakup known for this class of object. There are likely many more objects associated with this event that are not within the SSN's ability to detect and have not been cataloged. Several months after the breakup, observing time was obtained on the Magellan Baade 6.5 meter telescope to be used for observations of geosynchronous (GEO) space debris targets. Using the NASA Standard Satellite Breakup Model, a simulated debris cloud of the recent Transtage breakup was produced and propagated forward in time. This provided right ascension, declination, and tracking rate predictions for where debris associated with this breakup may be more likely to be detectable during the Magellan observing run. Magellan observations were then optimized using the angles and tracking rates from the model predictions to focus the search for Transtage debris.

## 1. INTRODUCTION

The NASA Orbital Debris Program Office (ODPO) maintains and publishes environmental models from Low Earth Orbit (LEO) to GEO based on in-situ, radar, and optical measurement data. In order to characterize the orbital debris population in the GEO region, measurements are acquired using various ground-based telescopes focused on faint debris searches. Time on large telescopes dedicated to GEO observations is difficult to obtain so it is important to optimize the observations such that they are likely to detect objects of interest. We present a method that can be used to focus observations on the regions and rates at which debris from recent breakups is expected to be found towards both detecting more debris and testing the current breakup models.

### 1.1. Titan Transtage Breakups

Though there have been few breakups recorded at GEO, two of the breakups have involved Titan Transtage spacecraft. As a result, the Titan Transtage and associated debris have been studied by the ODPO for both material studies and small debris detection [1][2]. To date, there have been four known Titan breakups (see Tab. 1). The two in GEO have broken up due to unknown events but possible causes include unspent propellant or collisions with smaller debris fragments.

On 4 June 2014, a provisional breakup of a Titan 3C Transtage rocket body occurred. The specific object has the International Designator 1969-013B with the SSN number 03692. This breakup happened 45 years after the spacecraft's launch and presented a rare opportunity to attempt to characterize and compare a breakup at GEO to the current NASA breakup models.

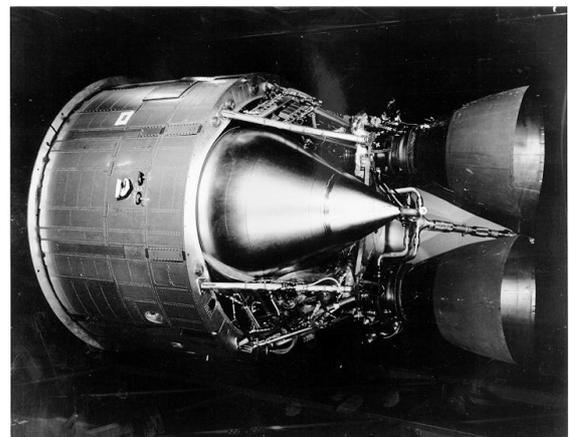


Figure 1. Titan 3C Transtage prior to launch

Table 1. Known Titan Transtage Breakups

Int Des	SSN Num	Breakup Date	Type
1969-013B	3692	4 June 2014	3C-17
1968-081E	3432	21 February 1992	3C-5
1965-108A	1863	21 December 1965	3C-8
1965-082DM	1822	15 October 1965	3C-4

## 2. MODELED TITAN TRANSTAGE DEBRIS

Over many years, NASA has developed the Standard Satellite Breakup Model to better understand the nature of how man-made objects breakup on orbit. The specifics of this model have been described in Liou, *et al.* 2002 [3]. Fundamentally, the model produces a population of debris objects with a distribution of mass and characteristic lengths, with the number of objects increasing roughly as a power law as the objects get smaller.

For this breakup, 9510 objects as small as 1cm were generated with their range of masses and characteristic lengths plotted in Fig. 2. These objects were created

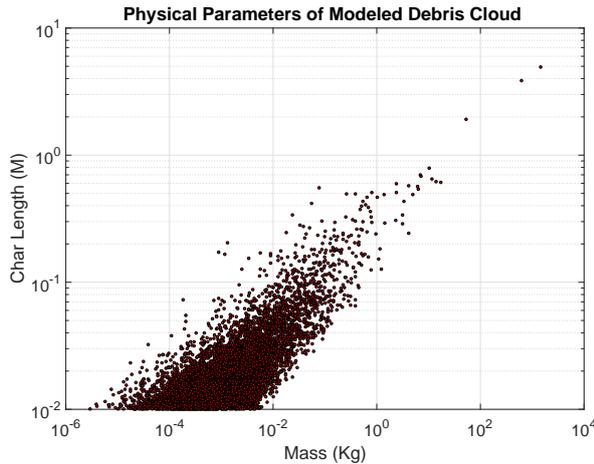


Figure 2. The Characteristic Length vs the Mass of the objects produced using the NASA Breakup Model. These objects were propagated forward from the location and time of the 4 June breakup and used to predict locations and tracking rates of possible associated debris over Las Campanas Observatory. Objects as small as 1cm were modeled but likely beyond the detection limit of the Baade telescope.

with orbital properties consistent with the location and epoch of the 4 June breakup and propagated forward to the dates of the planned Magellan observations from Las Campanas, Chile. Two-line element sets of the simulated debris were then created for each object and their ground-based observational parameters were calculated for every

30 seconds over a 2 day period as seen from the Magellan telescopes. These parameters included Right Ascension (RA), Declination (Dec), RA rate, Dec rate, range, and longitudinal solar phase angle.

The density of the number of objects in a region of RA/Dec space during the observing period was calculated over the observable sky, effectively providing an estimate of the probability of detection of associated Titan Transtage debris for each RA and Dec. The density value and corresponding RA and Dec were plotted as a surface plot like one in Fig. 3. The background stars were also plotted to determine locations of high stellar density. These regions need to be avoided, if possible, to limit false detections and photometric contamination of the man-made objects within the field of view.

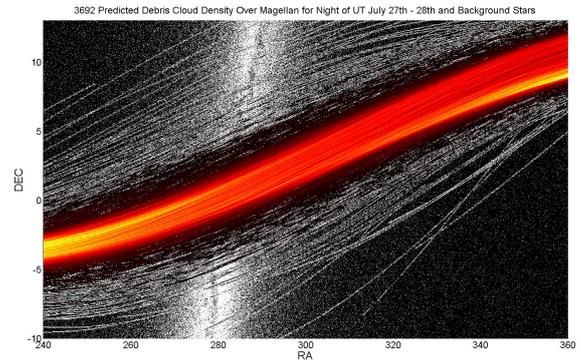


Figure 3. A density plot showing the path of the modeled debris objects in RA and Dec space over Las Campanas Observatory on the nights of 27-28 July 2014. The regions of sky that are red to orange in color have more of the modeled objects passing through that location than the darker regions. Background stars are also plotted and used for reference to minimize stellar contamination during the object detection process.

Plotting the debris cloud in this way provided a location in the sky where, according to the models used, detections of debris associated with the 4 June breakup were likely. The RA and Dec to be observed were chosen by determining the location of the densest region of the modeled debris cloud nearest the anti-solar point, not in the plane of the Milky Way.

In addition to knowing where to point, the rate at which the debris objects are moving in RA/Dec space is also necessary to both increase the detected signal and more easily distinguish the Titan Transtage breakup objects from other debris that may be detected. In a similar way to Fig. 3, the modeled debris objects' RA rate, Dec rate, and population density were plotted as a surface plot (see Fig. 4 and 5).

The peak RA/Dec rates associated with this method gives global, all-sky tracking rates for which you can expect to find associated debris. However, once a region of sky

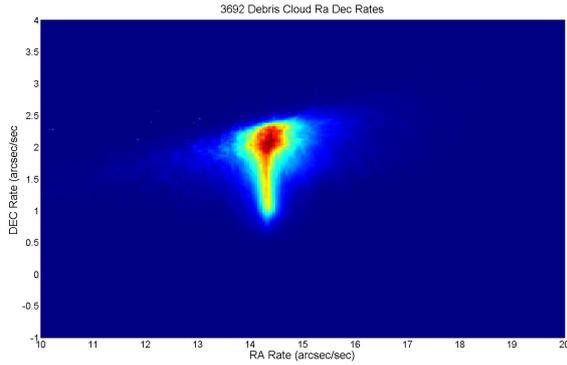


Figure 4. Density plot showing the distribution of the RA and Dec rates of the propagated modeled debris objects during the night of observations over Las Campanas Observatory. The peak values represent the tracking rates necessary for most objects to appear near-circular on the focal plane, thus minimizing the noise inherent in detections that are smeared across many pixels. Objects detected moving at these rates are theorized to be more likely associated with the breakup cloud rather than background debris.

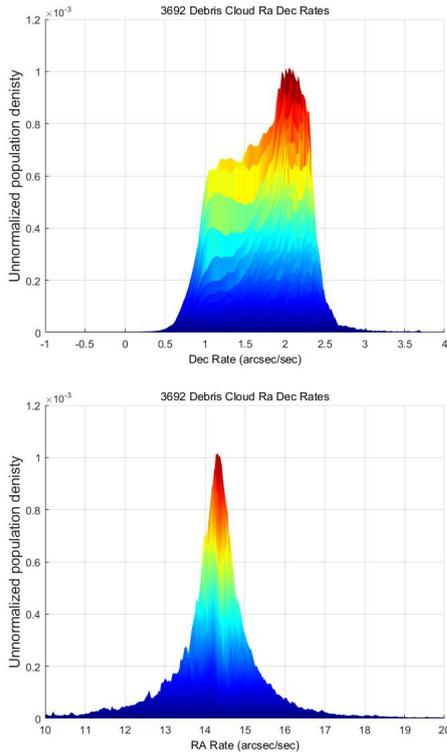


Figure 5. Same as Fig. 4 but with the RA/Dec rate components separated for clarity. The individual peaks show the most common RA/Dec rates expected for the Titan Transtage debris during the observing period.

is chosen (using the information in Fig. 3), the tracking rates need to be tailored for this particular patch of sky.

To better illustrate this, Figure 6 shows another plot similar to Figure 3 but with the observations occurring during October 2014. In a situation such as this, the Earth's shadow prevents sunlight from being reflected off of debris directly near the anti-solar point so it is useful to observe two regions around the shadow: one region that rises earlier in the night, switching to the later RA region shortly after the first crosses the meridian. This helps maximize the amount of light reflected back towards the observer and the time the telescope surveys regions at lower airmasses. For the two regions shown in Figure 6, the Dec tracking rates vary from roughly 0.6 arcsec/sec to -0.3 arcsec/sec. Because of this, tracking rates are calculated separately for each region.

The method above was developed for and used to help guide the observations discussed in the following section.

### 3. OBSERVATIONS

Through a collaboration with the University of Michigan, telescope time was obtained on the Magellan Baade 6.5 meter for two half nights shared with another project. The Inamori Magellan Areal Camera and Spectrograph (IMACS) f/2 instrument was used which provided a 0.5-degree diameter field-of-view across eight SITE 2Kx4K 15-micron charge coupled devices (CCD). Five second images were taken using the broad R filter which provided a passband from 4800 to 7800nm. The time obtained was spread across two nights on 27-28 July 2015. Conditions were clear and near-photometric for observations taken on 26 July with seeing on average less than 0.8 arcsecond Full Width Half Maximum (FWHM).

Twenty sequences of 16 images were taken at the expected tracking rate and at the RA and Dec associated with the maximum likelihood of a high density of Titan debris population discussed above. Two images were taken while sidereally tracking to establish focus then 16 were taken at the predicted tracking rate. The preliminary results of these observations are discussed in Seitzer, *et al.* [4].

### 4. CONCLUSIONS AND FUTURE APPLICATIONS

This work describes a method to optimize detection of debris clouds using ground-based, telescopic surveys. Using the NASA Standard Satellite Breakup Model, we produce a propagated modeled debris cloud as tracer to predict where and at what rate debris is likely to be detected, based on the existing models. Comparisons between observations and models are on-going and will be presented at a later date but this work presents the method used in the hopes others may potentially

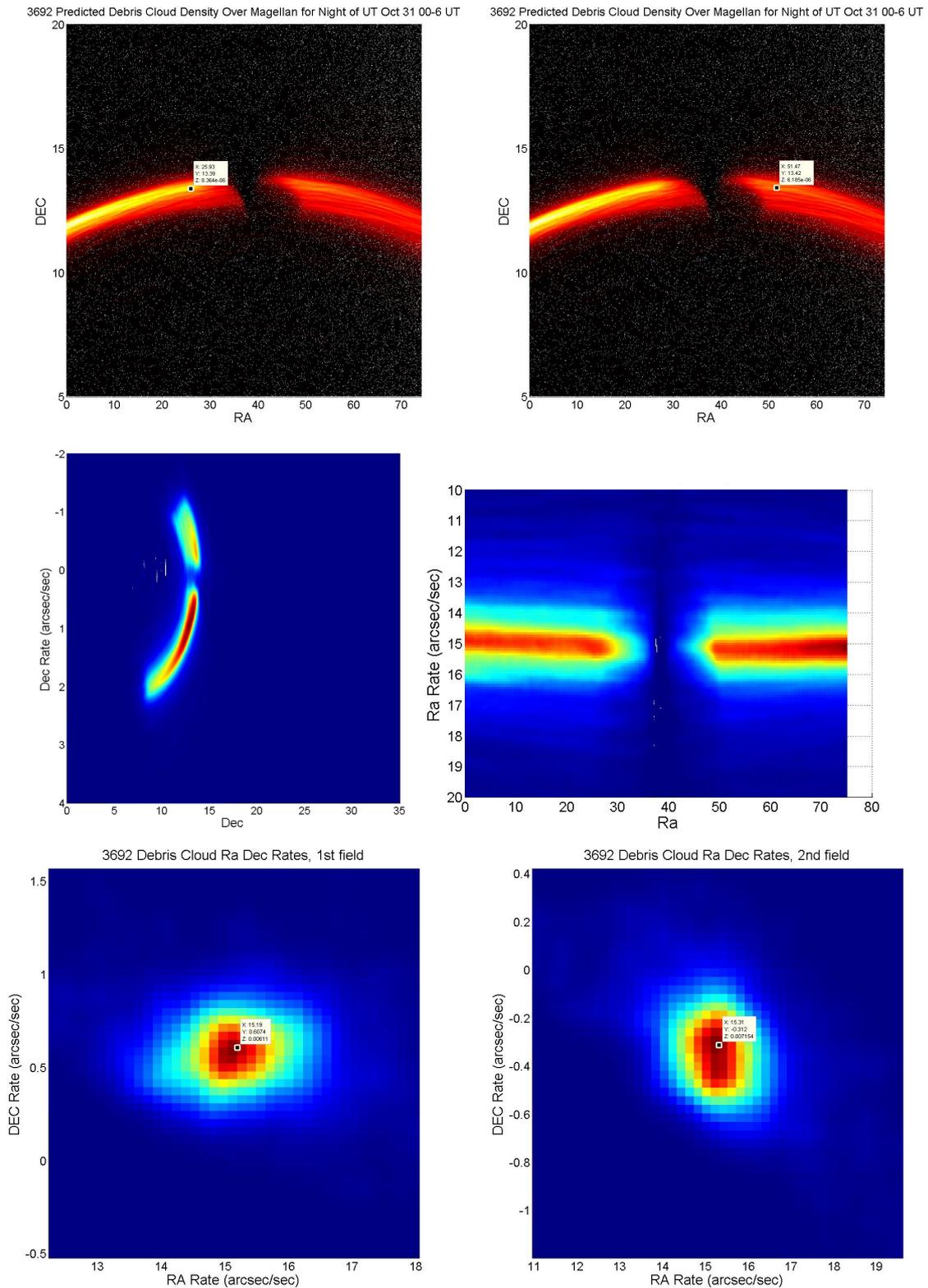


Figure 6. The same debris cloud as in Fig. 3 but propagated forward to an observing period centered on 31 October 2014. During these observations, the Earth's shadow prevents any objects at the anti-solar point from reflecting sunlight (illustrated in the top 4 figures as blank regions). The RA and Dec rates vary between the two regions so it is necessary to calculate the tracking rates for each individual region. The optimized RA and Dec tracking rates for the two regions are displayed in the bottom most figures.

use it for their own observations. The ODPO plans on using this and other methods to respond quickly and efficiently to future breakups using the NASA/AFRL Eugene Stansbury-Meter Class Autonomous Telescope and other NASA assets.

## ACKNOWLEDGEMENTS

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