The Physics Teacher

Imaging artificial satellites: An observational challenge

D. A. Smith and D. C. Hill

Citation: The Physics Teacher **54**, 444 (2016); doi: 10.1119/1.4962790
View online: http://dx.doi.org/10.1119/1.4962790
View Table of Contents: http://scitation.aip.org/content/aapt/journal/tpt/54/7?ver=pdfcov
Published by the American Association of Physics Teachers

***Joe Heafner*, Column Editor,** Science Department
Catawba Valley Community College, Hickory, NC 28602; heafnerj@gmail.com

Imaging artificial satellites: An observational challenge

D. A. Smith and D. C. Hill, Guilford College, Greensboro, NC

According to the Union of Concerned Scientists, as of the beginning of 2016 there are 1381 active satellites orbiting the Earth,[1] and the United States' Space Surveillance Network tracks about 8000 manmade orbiting objects of baseball-size and larger.[2] NASA estimates debris larger than 1 cm to number more than half a million.[3] The largest ones can be seen by eye—unresolved dots of light that move across the sky in minutes. For most astrophotographers, satellites are annoying streaks that can ruin hours of work. However, capturing a resolved image of an artificial satellite can pose an interesting challenge for a student, and such a project can provide connections between objects in the sky and commercial and political activities here on Earth.

In this paper we describe a method by which one can use a computer-controlled telescope to image artificial Earth-orbiting satellites. The J. Donald Cline Observatory at Guilford College houses a 16-in f/8.4 RCOS telescope[4] on a Paramount ME[5] with an SBIG STF-8300M CCD camera. Control of the mount and camera[6] is carried out through software packages TheSky6[7] and MaximDL,[8] respectively. Although the procedure we share here is specific to this setup, the same steps can presumably be carried out in any equivalent telescope system.

The most interesting satellites are in low Earth orbit—below 2000 km. These objects can circle the Earth in just 90 minutes. The greatest challenge in observing artificial satellites is the fact that their high proper motion demands precise targeting and fast but even tracking, much faster than the usual 15°/hr one needs for tracking celestial targets. Satellites in higher orbit, like communications and geosynchronous satellites, are too far away (altitude of 35,800 km) to be resolved by a small ground-based telescope. Satellites are visible in the night sky when they reflect sunlight. The peak viewing times are therefore in the few hours after sunset and before sunrise. In the middle of the night, satellites fall in the shadow of the Earth and are too dark to see.

The first step toward imaging a satellite is to identify a target. The software TheSky6 provides a list of the "100 (or so) brightest satellites." Once this list is loaded, TheSky6 will display each satellite as a dot with a name superimposed on the map of the sky. The website http://www.heavens-above.com gives minute by minute pass information, including paths and estimated magnitudes. You will want to look for targets that are bright and high in the sky or are of particular interest to you because of their structure or origin. When you have identified the passes you want to image, you can compile the targets' orbital parameters to load into TheSky6.

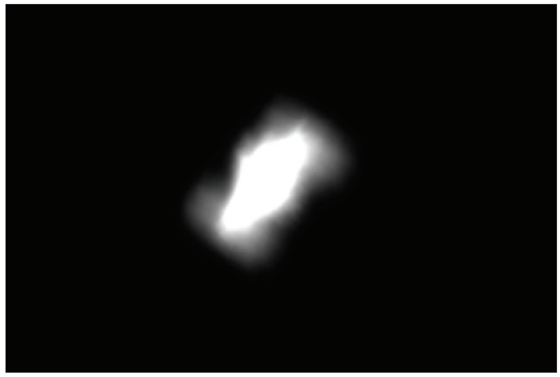

Fig. 1. Image of the International Space Station. Recorded on April 19, 2016, at 00:30 (UT) with 16-in RCOS telescope, 0.1-s exposure, through B filter at a distance of 430 km. The main body of the station is bright on the diagonal, and perpendicular solar panels are clearly evident on either side of the body. There is some evidence for structure in the center, consistent with the much closer image shown in Fig. 2.

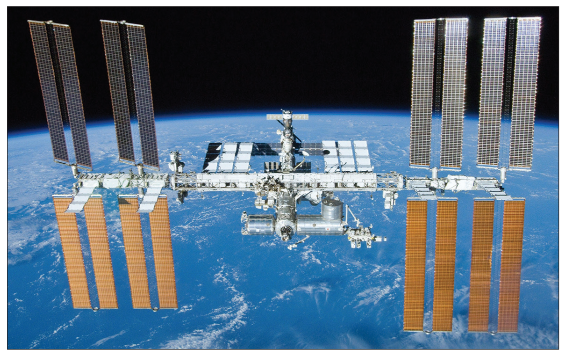

Fig. 2. Image of the ISS in orbit from the Space Shuttle Atlantis in May 2010 (public domain image, courtesy of Wikipedia).

Next you must convince the telescope to track this target. It is helpful to first slew the telescope to the general region where the satellite will become visible. TheSky6 has a "Track Satellite" option that shows the telescope's position and motion relative to the target. You can also click to gain offsets for tracking. We have used this approach to image many satellites of different national origins, but we share only two examples here.

Figures 1 and 2 show images of the International Space Station. Figure 1 is a 0.1-s image recorded through our 16-in telescope, while Fig. 2 shows the space station modules and solar panels from a closer perspective. You can see the body of the station as the bright diagonal in Fig. 1, with the perpendicular panels on either end. Figure 3 shows three 0.1-s images of the Chinese space station Tiangong-1 from the night of April 20, 2016, stitched together into a single figure. Figure 4 shows an artist's conception of the satellite, according to the Chinese Manned Space Engineering (CMSE) program.[9] This image is much less like our own than the ISS examples.

Fig. 3. Three images of Tiangong-1, recorded April 20, 2016, at 09:28 (UT) with a 16-in RCOS telescope, 0.1-s exposure, B filter. It is unlikely that these images are accurately depicting structure. The satellite shown in Fig. 4 is smaller than our resolution at this distance of 695 km, and therefore it is more likely the telescope mount jittered during exposure. Images like these can teach students not to take their images at face value, but to consider what can happen during the process of data acquisition.

Fig. 4. Artist's rendering of Chinese space station Tiangong-1. Tiangong-1 is 10.4 m in length and 3.3 m in diameter (image courtesy of CMSE).

One of the quantitative measurements that can be performed with these observations is to measure the linear size of the satellite. The reciprocal of the focal length of a telescope (3420 mm in our case) gives the conversion factor between linear size on the image (which one can derive from the size of the pixels) and the angular size of the object.[10] The Heavens Above website also gives a distance to the satellite at the time of an observation, so one can estimate the linear size of the satellite.

Our three images of the International Space Station from April 19, 2016, including the example in Fig. 1, imply a length across the body of the station of 101±3 m, 78±2 m, and 48±2 m, indicating that the station was probably rotating away from face on over the course of our few minutes of observations. The International Space Station is understood to be the largest artificial object in Earth orbit. Our largest size estimate is consistent to within three sigma with the 109 m published length of the ISS.[11]

The case of Tiangong-1 is more confusing. We imaged Tiangong-1 42 times over a four-minute interval starting April 20, 2016, at 09:26:28 (UT). Our Tiangong-1 images were taken with the same exposure time as our ISS images, and passes occurred with comparable tracking rates. In 39 of the 42 images, the satellite was an unresolved dot of size < 30 m. However, the structure displayed in Fig. 3 is closer to 100 m long (±3 m). According to public documents, Tiangong-1 should be, at the time of our observations in April 2016, a single cylinder of length 10.4 m and diameter 3.4 m.[12] This size is smaller than our resolution, and we should not expect to see any structure. However, the Chinese station appears in our images to have a crosspiece (see Fig. 3, in contrast to Fig. 4). The station was officially shut down in March of 2016,[13] and should not have any additional structure.

Our size calculations would indicate that the object in Fig. 3 is comparable in size to the ISS. It seems unlikely that the Chinese would successfully deploy a space structure that rivaled the largest manmade structure in orbit without announcing it. The three images included in Fig. 3 are not periodically spaced through the 42 images from the flyover, so it is not possible that we are catching one side of a rotating object that is unresolved from other angles. Furthermore, it's hard to imagine how a structure that is resolved to look like a "T" from one angle could be small enough in cross section from any angle to be unresolved. It is more likely that our images of Tiangong-1 are not truly spatially resolved (apparent structure is probably due to mount jitter during exposure) than that the Chinese government is being less than candid about their space activities.[14] This analysis shows how imaging artificial satellites can encourage a student both to consider carefully the sources of error in their images as well as to study international news.

Imaging artificial satellites with a moderate-sized terrestrial telescope is a modest technical challenge for astronomy students. Although satellites are usually an irritant for celestial observers, images of satellites can be used to illustrate the application of plate scale conversion calculations on objects of comprehensible size, which may be easier for students to grasp than trying to measure the diameter of a spiral galaxy. Furthermore, analysis of the morphology of the objects in the images can empower students to learn about the international politics of space: to connect the "up there" and the "down here."

References

1. http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database .
2. http://www.au.af.mil/au/awc/awcgate/usspc-fs/space.htm .
3. http://orbitaldebris.jsc.nasa.gov/faqs.html .
4. http://rcopticalsystems.com/telescopes/16tube.html .
5. http://www.bisque.com/sc/pages/Paramount-ME.aspx .
6. https://www.sbig.com/products/cameras/stf-series/stf/stf-8300m/.
7. http://www.bisque.com/sc/pages/thesky6family.aspx .
8. http://www.cyanogen.com/maxim_main.php .
9. http://en.cmse.gov.cn/list.php?catid=55 .
10. See, e.g., http://www.vikdhillon.staff.shef.ac.uk/teaching/phy217/telescopes/phy217_tel_principles.html for an explanation of this calculation.
11. http://www.nasa.gov/mission_pages/station/overview/.
12. P. Coue, "Tiangong-1, the first manned spacelab of China," *J. Brit. Interplanet. Soc.* **67**, 404-411 (2014).
13. http://en.cmse.gov.cn/show.php?contentid=1474 .
14. But while this article was in press, this very question was discussed in the news! See, e.g. http://www.space.com/33140-china-tiangong-1-space-lab-falling-to-earth.html and http://mashable.com/2016/07/13/tiangong-1-china-space-station-breakup .