MEGACONSTELLATION SATELLITES

Practical Ways Amateurs Can Help

By Brad Young

The December 2021 issue of the *Reflector* included an abridged version of an article by Dr. Paul Daniels, "The Mega Constellation Threat." The original article[1] contains additional relevant data.

Dr. Daniels and many others have been alerting us to the threat to scientific research since the Starlink and OneWeb constellations began launching. The astronomy community has also produced several papers on this issue, and the concern over several other low Earth orbit (LEO) projects in the works. The National Science Foundation's NOIRLab and the American Astronomical Society have convened two Satellite Constellations Conferences, producing reports on everything from best practices of brightness estimation to global policy development.[2] To their credit, SpaceX attended these and other conferences, and has been active in mitigation efforts including redesigning spacecraft, raising operational orbits, and working with concerned stakeholders. Anthony Mallama has written an article in *Sky & Telescope* regarding the effect on brightness resulting from these efforts.[3]

PREVIOUS STUDIES

There are many works available that describe the brightness of the Starlink and OneSat payloads, the effect of redesigned spacecraft (VisorSat, DarkSat) and orbit manipulation. Many of these are based on a reasonable sample size and present the data with appropriate caveats. The approximate 1,000 km magnitudes (defined in detail later in this article) derived by arguably the best methods are magnitude 6 for the original Starlink and magnitude 7 for OneWeb and the VisorSat Starlink.

Despite the progress made in quantifying the impact, there are lingering concerns to keep in mind:

1. Much data has been compiled with many measurements at one location, or few measurements at several locations.

2. In most cases, the data was gathered using imaging equipment at sites or by researchers who would be affected by any effect on sky darkness.

3. Satellite brightness is notoriously difficult to measure accurately and consistently, even with imaging equipment.

4. Most importantly, there are several new satellite and constellation designs and operators coming soon.

Items 1 and 2 are important only in that they provide weaknesses in reliability. However, this is easily managed by adding other sources of data and increasing the sample size. Item 3 is an inherent characteristic; there will always be errors. However, it is reasonable that the accuracy of predicted brightness will increase with more and better data.

Item 4 is the real conundrum. Putting aside current concerns, all the prediction models being built now will have to be modified once new assets are launched. Although some equipment parameters will be known, not all will, and this will stymie the operators in their design as well. As more models are flown (and there's no doubt the existing operators will modify their assets), it will become even more important to understand what is happening before the situation is more alarming. This will provide useful information for improved design, policy, and licensing.

HAVE WE LOST SCIENCE?

It is much harder to determine whether scientific data may be lost if we are not careful. The current approach by those upset with the spike in spacecraft numbers is a well-meaning, poorly funded mandate that is competing with a trillion-dollar industry. That industry is crucial infrastructure and is innovating internet access for all. Neither side of this issue is wrong; informed, rational decisions are needed.

Engineering decisions about mitigation and threat management rely on real data about several items, including the actual brightness of the satellites after achieving their stable, final orbits. There is opportunity for the amateur astronomy community to make valid, crowdsourced measurements to provide these crucial data to both effect change and influence policy and opinion. The issue is educating our observing community, so they can both contribute data and act as motivated and informed voices as citizen scientists.

MOVING FROM PROBLEM TO PRACTICALITY

The number of active amateur satellite observers who report data is small, and much of that is concentrated on deriving orbit details, called elements, via symbiotic work of observer reports and orbital analysts. There are some observers who report varying brightness such as flaring or flashing (tumbling) but this is an even more niche area.

As with astronomy in general, satellite spotting is not easy and requires time and effort to learn and do. On the bright side, expenses can be kept low; in fact, most of you already have all the necessary equipment. An overview of the process for estimating satellite brightness is given in the chart below, with blue items indicating preparatory or subsequent indoor activities, and orange representing real-time observing or imaging

STEPS IN MAKING OBSERVATIONS OF BRIGHTNESS

SELECT TARGET SATELLITES → GET PREDICTIONS FOR YOUR SITE → CHOOSE WELL-VISIBLE FOV OF PASS → CHOOSE COMPARISON STARS IN FOV →

OBSERVE COMP STARS WITH TARGET → RECORD POSITION (OPTIONAL) AND MAGNITUDE VS. COMP STARS → RECORD ANY SIGNIFICANT BRIGHTNESS VARIATION → REDUCE AND REPORT DATA activities. This simplistic view can be expanded as follows.

SELECT TARGET SATELLITES

There are thousands of Starlinks (global coverage is the key) so, given clear skies, this is not an issue but for one point. The Starlinks do not attain their final orbits and controlled orientations until up to a month after launch. They are wonderful to see in the early days after launch, but data taken at that stage quickly become obsolete. Consequently, until each object attains its final orbit, observational metric data are usually not useful.

GET PREDICTIONS FOR YOUR SITE

This also is usually not a problem, with several websites and apps available. At a minimum, you will need to know your location, expected time of observation, and your equipment's limiting magnitude. Remember, moving objects may appear dimmer visually, and imaging may not provide the usual gain on brightness you see with stationary objects.

CHOOSE WELL THE VISIBLE FIELD OF VIEW (FOV) OF PASS

Now things become more challenging. Many apps will give you an expected brightness, culmination point (where it is highest in sky), or a sky chart for the pass. However, satellites do not always match the predictions, especially in brightness (hence the whole point of this effort). You will also need to consider the following:

1. How will I find this FOV?
2. Are there comparison stars nearby I can use to estimate magnitude?
3. Is the sky dark enough?
4. Is this the right part of the pass? See phase angle discussion below.

CHOOSE COMPARISON STARS IN THE FOV

This is very similar to the process used for variable stars, except the target is moving. You must also use the same spectral basis for magnitude. Do not use defocus or large dithering with imaging techniques, as the satellite may be rendered unseen or the trail poorly integrated.

OBSERVE COMPARISON STARS WITH TARGET

This is the first outdoor activity, and the most important of all. Imaging or visually observing the object, as it passes the field stars selected, is crucial.

ESTIMATE AND RECORD MAGNITUDE AND NOTE ANY SIGNIFICANT BRIGHTNESS VARIATION

Very rarely, a Starlink or other target may show flaring (brightening and dimming over several seconds) or flashing behavior. Although these should not be used for determining standard magnitude, they are still important to report, as such behavior also needs to be tracked.

REDUCE AND REPORT DATA

After the observing or imaging is complete, there are several paths to a final, useful report.

- Visual observers that have the comparison star magnitudes are ready to reduce their findings.
- Imagers will need to do the same, using software to process the image to determine the same data.
- Using either the prediction or the actual time and position, the range and phase angle must be determined. This is the distance from object to observer and the Sun-object-observer angle. Both are available using predictions only, but the best data will come when the actual position and time are measured.

AN EXAMPLE

The following is far from a procedure, but will act as a guide. On December 20, 2021, I observed several Starlinks from my home, using 8×40 binoculars and the stopwatch on my Android phone, set using WWV by phone. Following steps outlined above:

Selecting targets

(NORAD catalog number, satellite name):

48571	STARLINK-2221
48583	STARLINK-2237
48595	STARLINK-2252
48556	STARLINK-2151
48604	STARLINK-2757

Getting predictions

(STARLINK-2757 will be used as a single example): *Heavens-above.com* gives the prediction shown at the bottom of the page, with the object passing between Taurus and Aries:

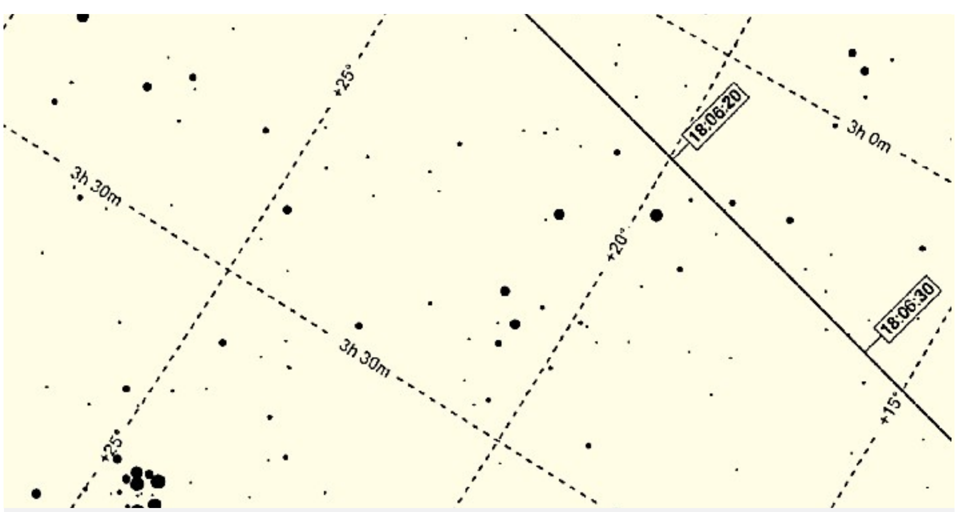
I chose to observe and record when the spacecraft was predicted to pass between the comparison stars Epsilon Arietis (magnitude 4.63) and Delta Arietis (4.35). I found an apparent magnitude of 4.4, equivalent to Delta Arietis. It was steady in brightness and passed at a time of 00:06:20 UT, which means it was on time.

Using another prediction app, I found the following:

Range (miles) = 436
Phase Angle = 62.9°

Note that phase angle for satellites is defined as 0 degrees at exactly opposite the sun – this may be unusual if you are used to observing minor planets, etc.

Standard magnitude for a satellite is comparable to that of a star, except that both distance and phase angle are used. Many analysts use the 1,000 km magnitude as standard, determined at a range of 1,000 km and a phase angle of 0° (fully lit). The example calculation is based on a simplifying but important assumption, that the satellite has a perfectly spherical Lambertian surface. One way to describe this is a diffuse reflective sur-



Heavens-above.com's *prediction of the path of Starlink-2757 for the time of the author's observation*

DERIVED STANDARD MAGNITUDES OF EXAMPLE STARLINKS

NORAD ID	Name	Range R (km)	Phase Angle φ (degrees)	Apparent Magnitude M_a	Standard (1000km) Magnitude M_{1000}
48571	STARLINK-2221	782	39	4.4	5.9
48583	STARLINK-2237	1011	45	5.1	6.0
48595	STARLINK-2252	881	49	5.5	6.7
48556	STARLINK-2151	806	55	5.1	6.4
48604	STARLINK-2757	702	63	4.5	5.9

Based on: $M_{1000} = M_a + 15 - 5 \times \log(R) + 2.5 \times \log[\sin(\varphi) - (\pi - \varphi) \times \cos(\varphi)]$ (see ref. 4)

face. Of course, neither of these things apply for the megaconstellation satellites, and the art is to determine, from reported apparent magnitudes, the correction factor that models the actual reflectivity of the surface over a range of phase angles.

A FIRST STEP — THE EOSOC

The Astronomical League has an Earth Orbiting Satellite Observing Club, with instructions and activities that may help you take the first step. Doing a few of the observations could inspire you to complete that program, and/or report Starlink magnitudes. After this initial step, you may find satellites to be a nice addition to your hobby.

TOWARDS A REAL SOLUTION

Megaconstellations are a real concern to the public, amateurs, and astronomical researchers. Currently, there are groups working on this problem, and hopefully they will be able to provide a more effective way of gathering data. Perhaps you would like to contribute as a citizen scientist, monitoring and reporting data on the megaconstellations. If so, please contact me and I will try to point you to resources or just have a conversation with you about how you can become involved.

As amateur astronomers, we should be highly motivated to effect change in this critical area that may impact not only our hobby, but the serious study of the universe. ✶

Brad Young is a member of the Astronomy Club of Tulsa and an AL Platinum Observer. You can contact him at allenb_young@yahoo.com

References:

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2. " Satcon2 Working Group Reports," *zenodo.org/record/5608820#.YcUSaVIME2w*, accessed Dec. 23, 2021.

3. "Starlink Satellites Are Fainter Now – But Still Visible," *skyandtelescope.org/astronomy-news/starlink-satellites-fainter-but-still-visible/*, accessed Dec. 23, 2021.

4. *satobs.org/seesat/Apr-2001/0313.html*, accessed Dec. 31, 2021.

AMATEUR OBSERVATION OF THE SOLAR CORONA OUTSIDE OF A SOLAR ECLIPSE

By George Hripcsak and Klaus Hartkorn

SAFETY FIRST

AMATEURS ATTEMPTING SOLAR VIEWING OR IMAGING WITH HOMEMADE EQUIPMENT MUST EXERCISE EXTREME CAUTION TO MAKE SURE NO STRAY UNFILTERED SUNLIGHT REACHES THEIR EYES.

Amateur observations of the solar corona outside of a solar eclipse have been an elusive goal. Amateurs view and image solar prominences all the time with modern equipment. However, prominences are about 100 times brighter than the corona and benefit from the fact that they emit their light in narrow bands of wavelengths like hydrogen alpha (656.3 nanometers), combined with the fact that the Sun's overwhelmingly bright photosphere (the visible surface of the Sun) is blocked in those same wavelengths.

During a total solar eclipse, the corona is revealed to be a beautiful collection of white streamers several times the Sun's diameter. Author George Hripcsak first saw the corona during the 1998 total solar eclipse. He had seen photographs of the corona, which used to show little more than a diffuse glow. On his way to the viewing site, he saw a hand-painted beach towel for sale, and it showed the solar corona as a fanciful collection of pearly white streamers emanated from the eclipsed Sun. After seeing the eclipse, he realized that that beach towel was the only image he had ever seen that captured the beauty of the solar corona, and he wished he could see it again.

Seeing the corona outside of an eclipse is another story. The corona has several components. The E-corona is nearest to the photosphere and is due to emission of light in several lines such as Fe XIV (530.3 nm), although unlike the prominences, the photosphere's light at that wavelength is unblocked. The K-corona is due to photospheric light reflected off electrons above the photosphere and is polarized. The F-corona is due to photospheric light reflected off dust that reaches even further from the photosphere. Despite making up only one percent of the total light of the corona, the E-corona is the most feasible for amateurs because it emits light in narrow bands, which allows for the use of narrowband filters to reduce the effect of stray atmospheric light.

The main challenge to seeing the corona, which is almost as bright as a full moon, is the million-times-brighter photospheric light right next to it, due to light that is scattered both within the atmosphere and within the telescope. The general approach to viewing the corona, developed by Bernard Lyot in the 1930s, is to build an instrument that produces an artificial eclipse, handle all the stray light that is induced, and view from a high mountain to reduce atmospheric scattering.