An update on Canadian Space-based photometric measurements on Satellite Constellations

Dark and Quiet Skies for Science and Society II

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Motivation and Objectives

- This research explores space-based measurements on Megaconstellation objects and investigates:
  - Challenges observing mega-constellation objects from LEO orbit and characterizes their photometric behaviour
  - Compares space-based photometric measurements of LEO mega-constellations (OneWeb, Flock) to Starlink
  - Also examines Starlink Darksat, Visorsat photometric behaviour
  - Contrast the photometric behavior of megaconstellation objects over phase angle as observed from space

- Space-based optical measurements adds complementary viewing geometry to ground-based campaigns to characterize space objects
NEOSSat space telescope

- **Near Earth Object Surveillance Satellite (NEOSSat)**
  - In orbit since 2013 (785 km Sun-sync orbit)
  - Visible light Maksutov telescope (15 cm, open filter)
  - Mission: Space Situational Awareness R&D, Astronomy
  - Operator: Canadian Space Agency / DRDC

- **NEOSSat originally developed for GEO object tracking**
  - LEO object tracking functionality enabled in 2016
  - NEOSSat uses “orbital node-crossing” technique to acquire LEO satellite tracks

- **NEOSSat Constellation observations Photometric Accuracy**
  - Landolt Stars used to estimate visible magnitude error
  - As LEO objects tend to be bright, instrument zeropoint uncertainty dominates our error estimate
  - Assuming space object spectra is similar to the Sun ($B-V \sim 0.66$), NEOSSat’s photometric zeropoint uncertainty is approximately 0.25 magnitudes
Key observing geometry from LEO

**Earth’s Nightside**
- Phase angle $\varphi$ is small
- NEOSSat sees Starlink solar panel Sun side
- Starlink principally illuminated by Sun

**Earth’s Terminator**

**Earth’s Dayside**
- Phase angle $\varphi$ is large
- NEOSSat sees Starlink solar array backside
- Starlink illuminated by Earth, Sun
- $\xi$ angle measures distance Starlink is on Earth’s dayside

**Typical observing range from NEOSSat:**
- Starlink: 1600 – 3000 km
- OneWeb: 1340 – 3500 km

- Tracks acquired on “quiescent” constellation objects while their electric thrusters are not in use
NEOSSat collects 4-6 observations per track for < 4 minutes

By “aggregating” tracks on different constellation members a light curve can be created
Starlink - Photometric Measurements (Range normalized)

- 2170 observations
- 412 unique Starlink Satellites (25% of constellation)
- 32 measurements of Starlink-1130 (“Darksat”)

Average Magnitude: 6.9 +/- 0.9
Starlink - Antisolar (Nightside) Model

Key findings:
- Solar panels consistently pointed on Sun-line
- Solar Panel (Sun-side) albedo-area product: 0.6 m²
- Bus albedo-area: 0.14 m²

Flat-plate solar array is a decent 1st order model for antisolar (nightside) photometric behaviour

\[ M_{\varphi<90^\circ} \approx M_{\text{Sun}} - 2.5 \log_{10} \left( \frac{1}{\pi} \cdot \frac{a_{sp} A_{sp} \cos(\varphi)}{R^2} \right) - 2.5 \log_{10} \left( \frac{a_{bus} A_{bus} F(\varphi)}{R^2} \right) \]

\[ F(\varphi) = \frac{1}{4\pi} \{(\pi - \varphi) \cos(\varphi) + \sin(\varphi)\} \]
Starlink - Dayside Model

Key findings:
- Solar Panel (space-side) albedo-area product: 10.5 m²
- Bus albedo-area: 0.14 m²

Backside of Starlink solar panel is ~18x more reflective than the Sun-facing side.
Starlink - “Darksat” and “Visorsat” Comparison

NEOSSat sees Starlink solar array from above

Ground based observer sees nadir bus face from below

Treatments apply to this portion, so behaviour is foreseeable

*Darksat* and *Visorsat* appear similar to other constellation members when viewed from space.
OneWeb – Photometric Measurements
1329 Observations, 81 unique satellites

General downward trend with phase angle
Slight increase for phase angle > 90°

More complex OneWeb satellite bus shape, unknown attitude, creates higher variability in its light curve.
Nanosatellites can be “as bright” as larger constellations depending on viewing geometry.
Key Findings

- **Space-based light curves obtained on LEO constellation objects using NEOSSat**
  - Observed objects during intervals when electric thrusting was inactive

- **Starlink Photometric measurements**
  - Starlink exhibits V-shaped light curve over phase angle (range normalized)
    - High variability over dayside explained by Earth illumination and albedo
  - Starlink main solar array consistently tracks Sun when viewed
  - Starlink averages $M_V$ 6.9 ± 0.9 (range normalized) when observed from space
  - Space-facing side of Starlink solar panel is ~18x more reflective than Sun-facing side
  - *Darksat* and *Visorsat* mimic other constellation members’ brightness when viewed from space

- **OneWeb**
  - Generally fades with phase angle, and tends to be fainter than Starlink by 2 mags, but highly variable
    - Believed to be due to complex bus shape
  - Averages $M_V$ 7.4 ± 0.8 (range normalized)
  - Some evidence that Onewebs brighten over dayside, but inconclusive due to variability

- **Flock**
  - Limited phase angle detections due to exposure time limitations
  - $M_V$ 9.4 ± 1.1 (range normalized)
  - Flock can comparably as bright as OneWeb under some circumstances
  - More observations required

- **References**