Defence Research and Development Canada | Recherche et développement pour la défense Canada

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

Dark and Quiet Skies for Science and Society II

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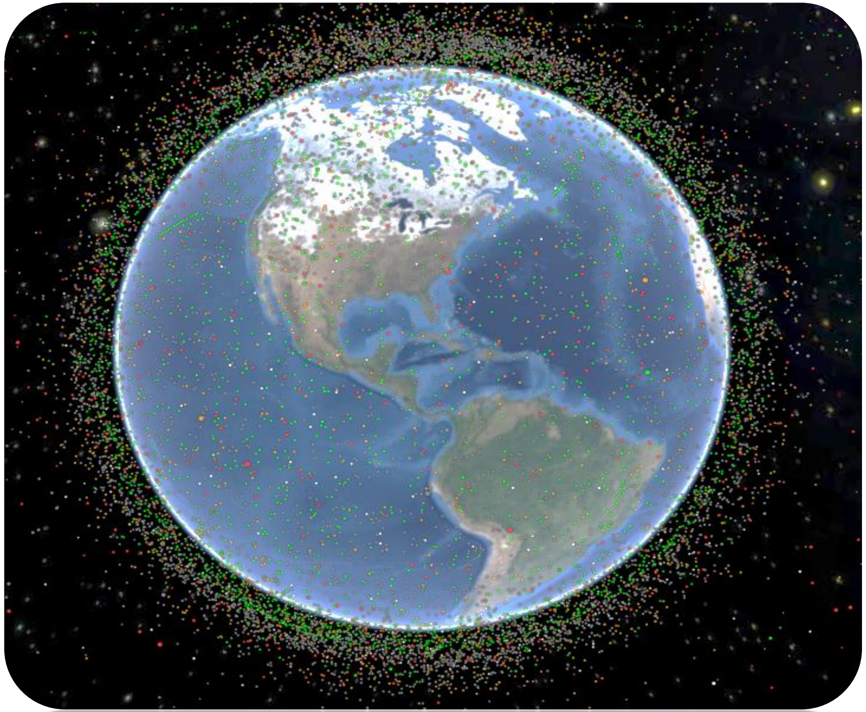
Canada

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***

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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* ~ 0.66), NEOSSat's photometric zeropoint uncertainty is approximately 0.25 magnitudes

NEOSSat during mass properties testing - 2012

Key observing geometry from LEO

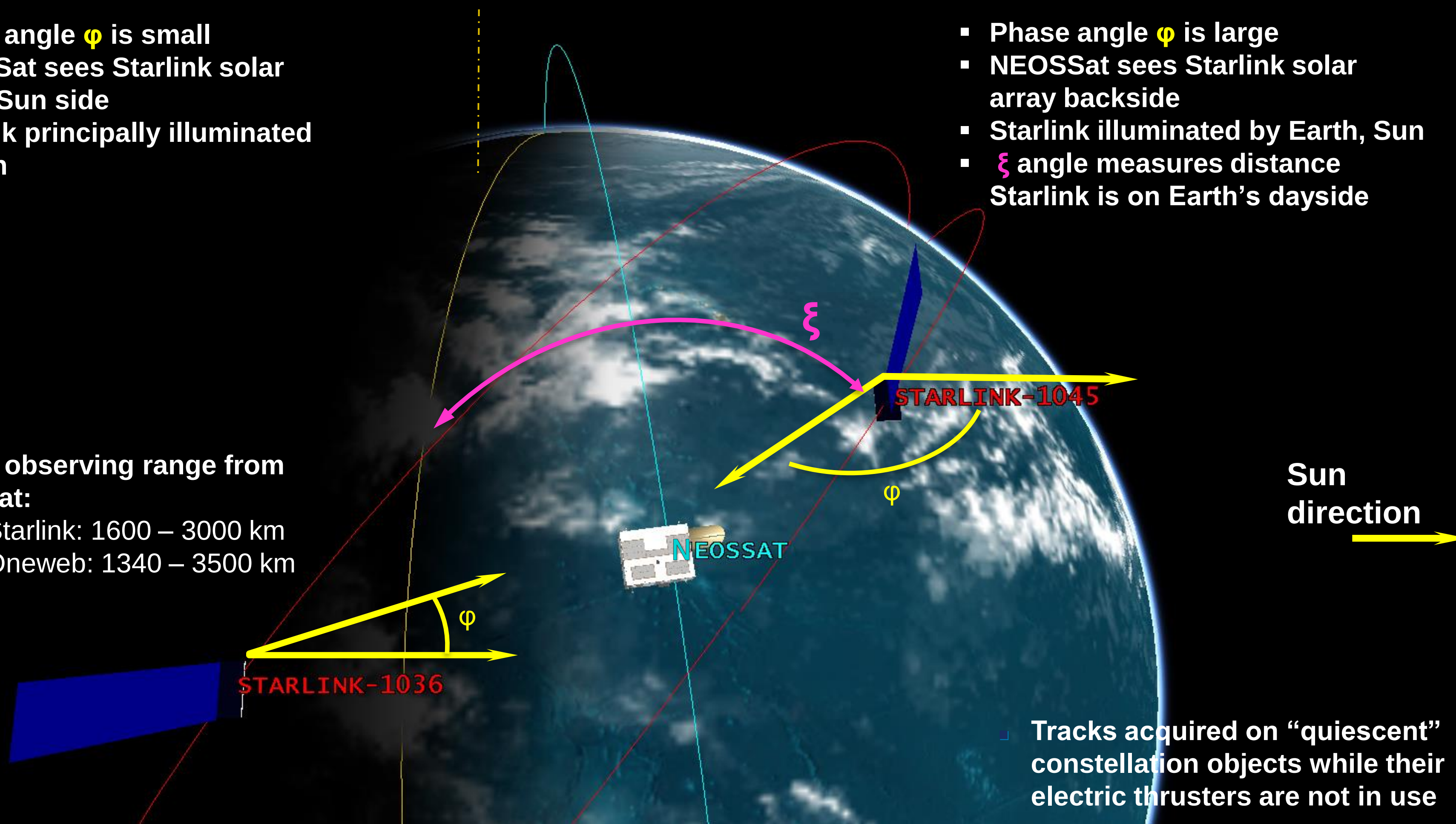
Earth's Nightside

- Phase angle φ is small
- NEOSSat sees Starlink solar panel Sun side
- Starlink principally illuminated by Sun

Earth's Terminator

Earth's Dayside

- Phase angle φ is large
- NEOSSat sees Starlink solar array backside
- Starlink illuminated by Earth, Sun
- ξ angle measures distance Starlink is on Earth's dayside

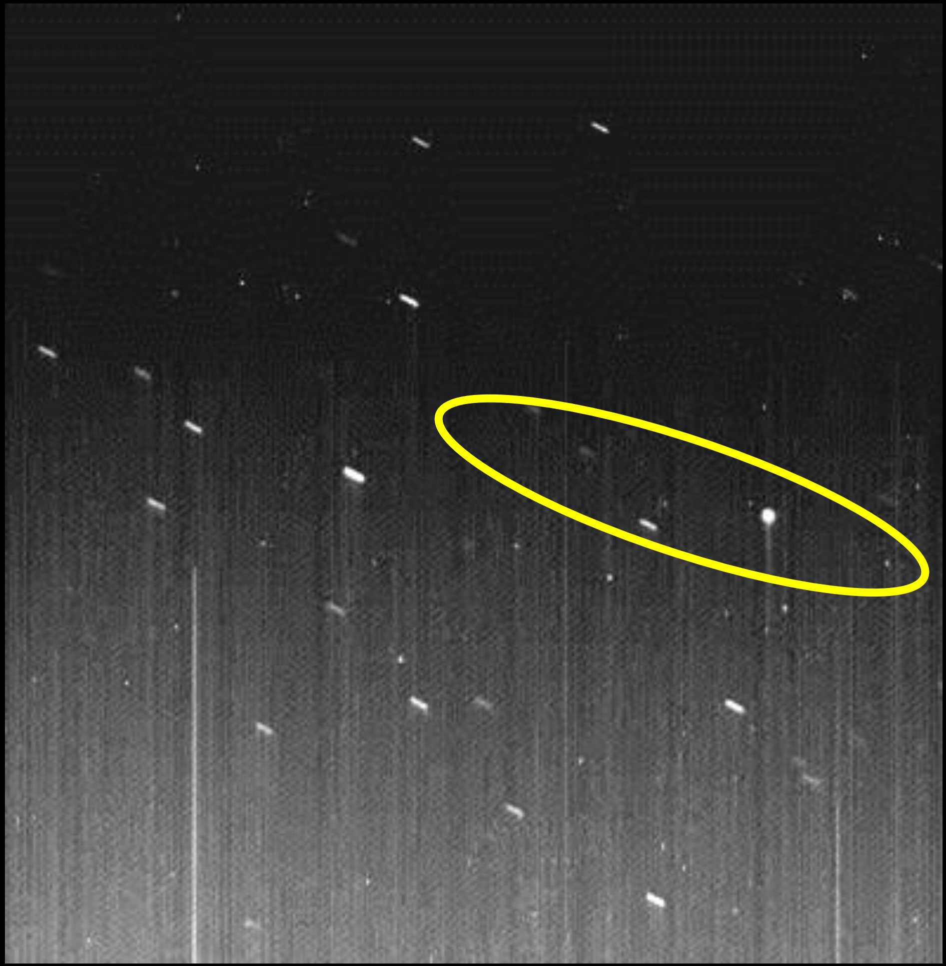


- Typical observing range from NEOSSat:
  - Starlink: 1600 – 3000 km
  - Oneweb: 1340 – 3500 km

- Tracks acquired on "quiescent" constellation objects while their electric thrusters are not in use

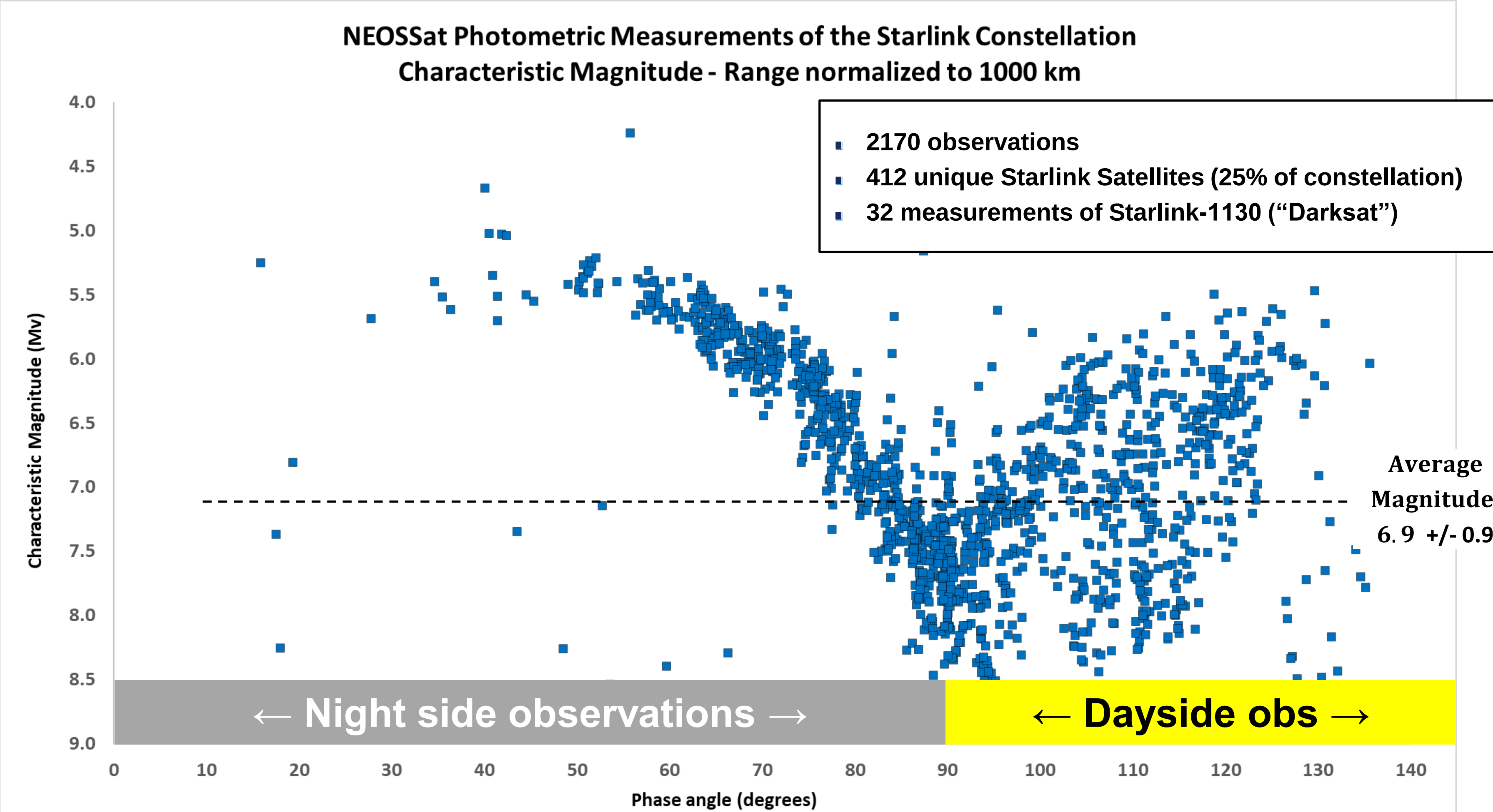
Starlink SSN ID: 44763 - Sample observations

- **NEOSSat collects 4-6 observations per track for < 4 minutes**

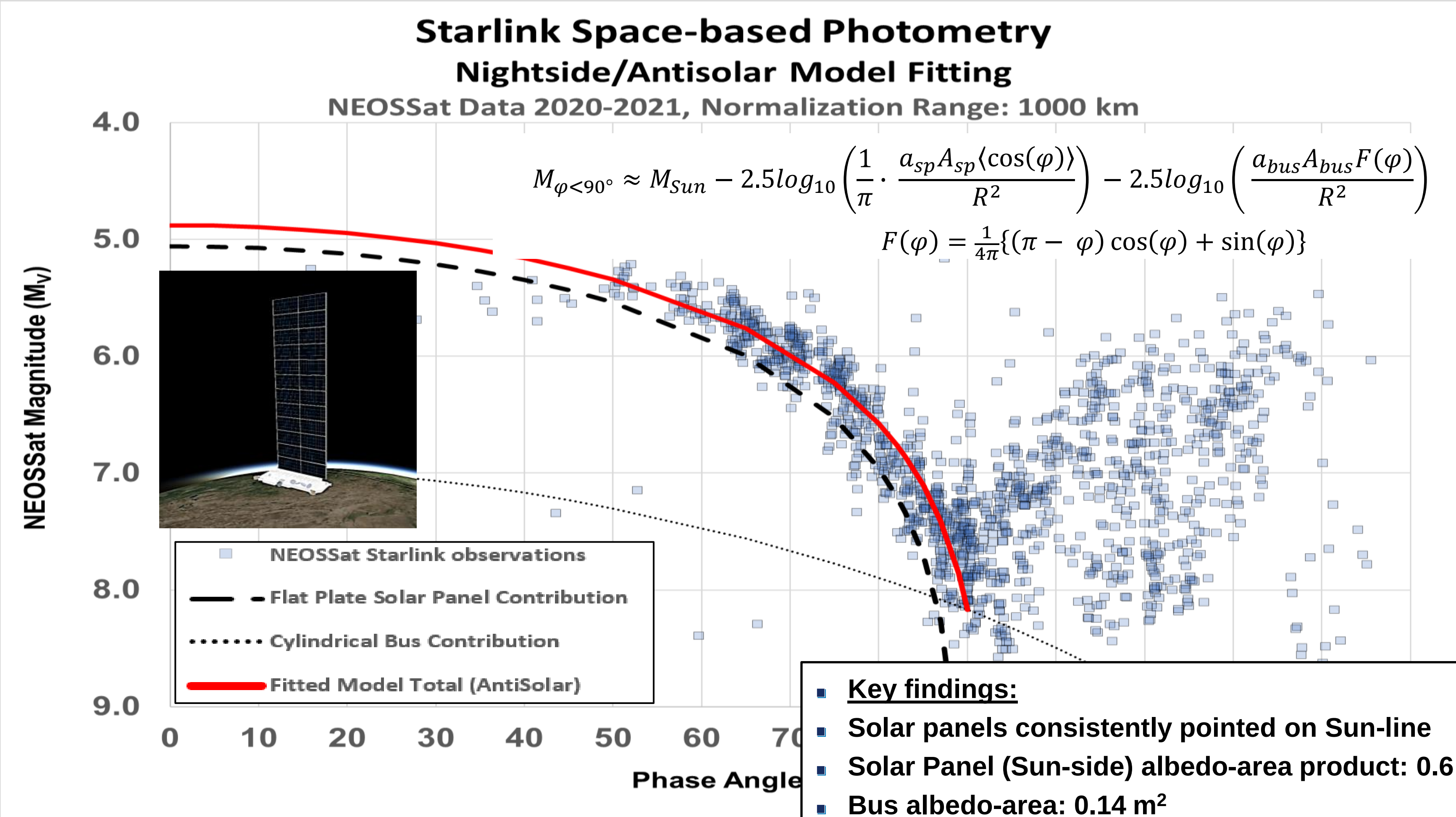


- **By “aggregating” tracks on different constellation members a light curve can be created**

Starlink - Photometric Measurements (Range normalized)



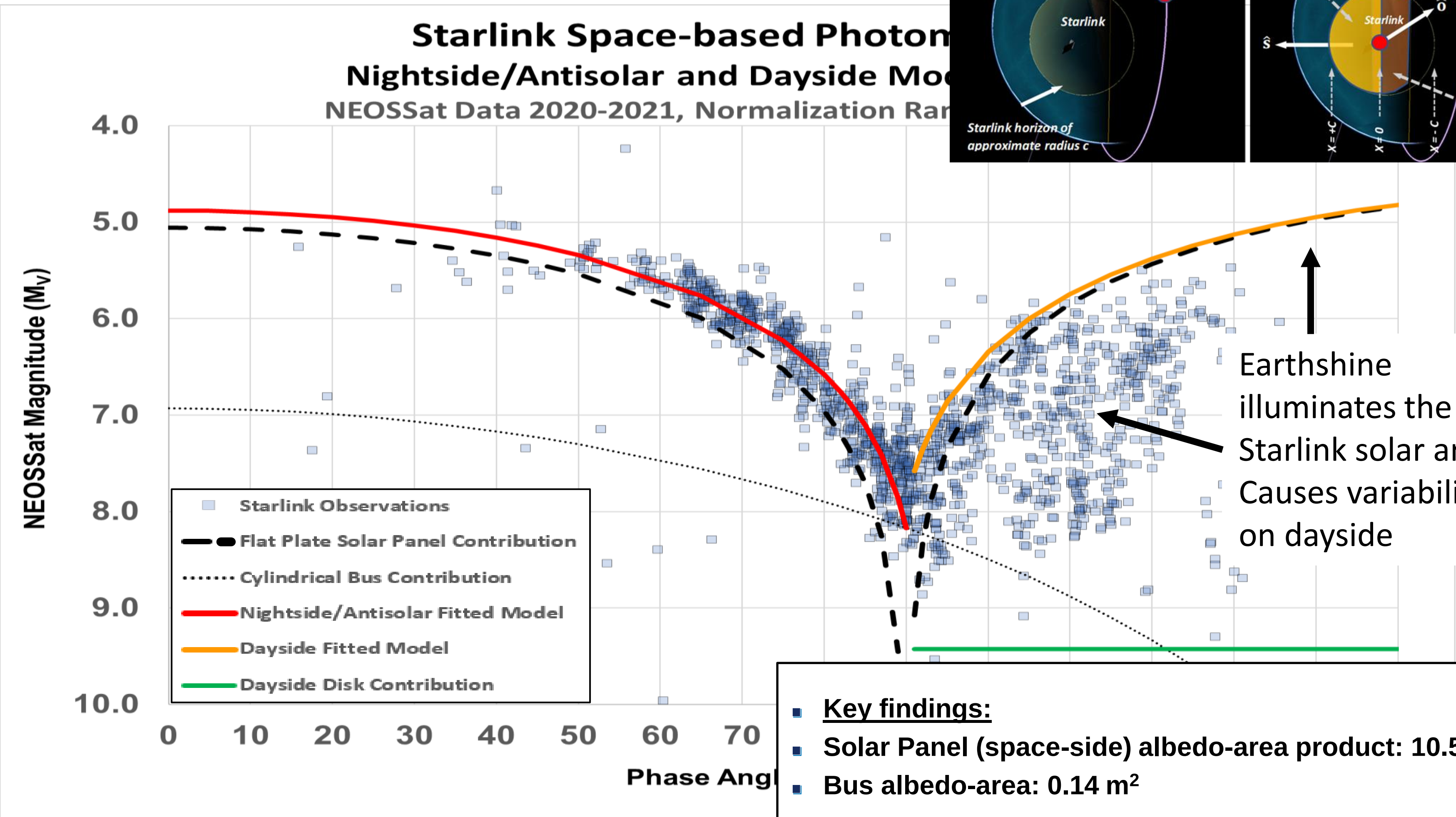
Starlink - Antisolar (Nightside) Model



- **Key findings:**
- **Solar panels consistently pointed on Sun-line**
- **Solar Panel (Sun-side) albedo-area product: 0.6 m^2**
- **Bus albedo-area: 0.14 m^2**

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

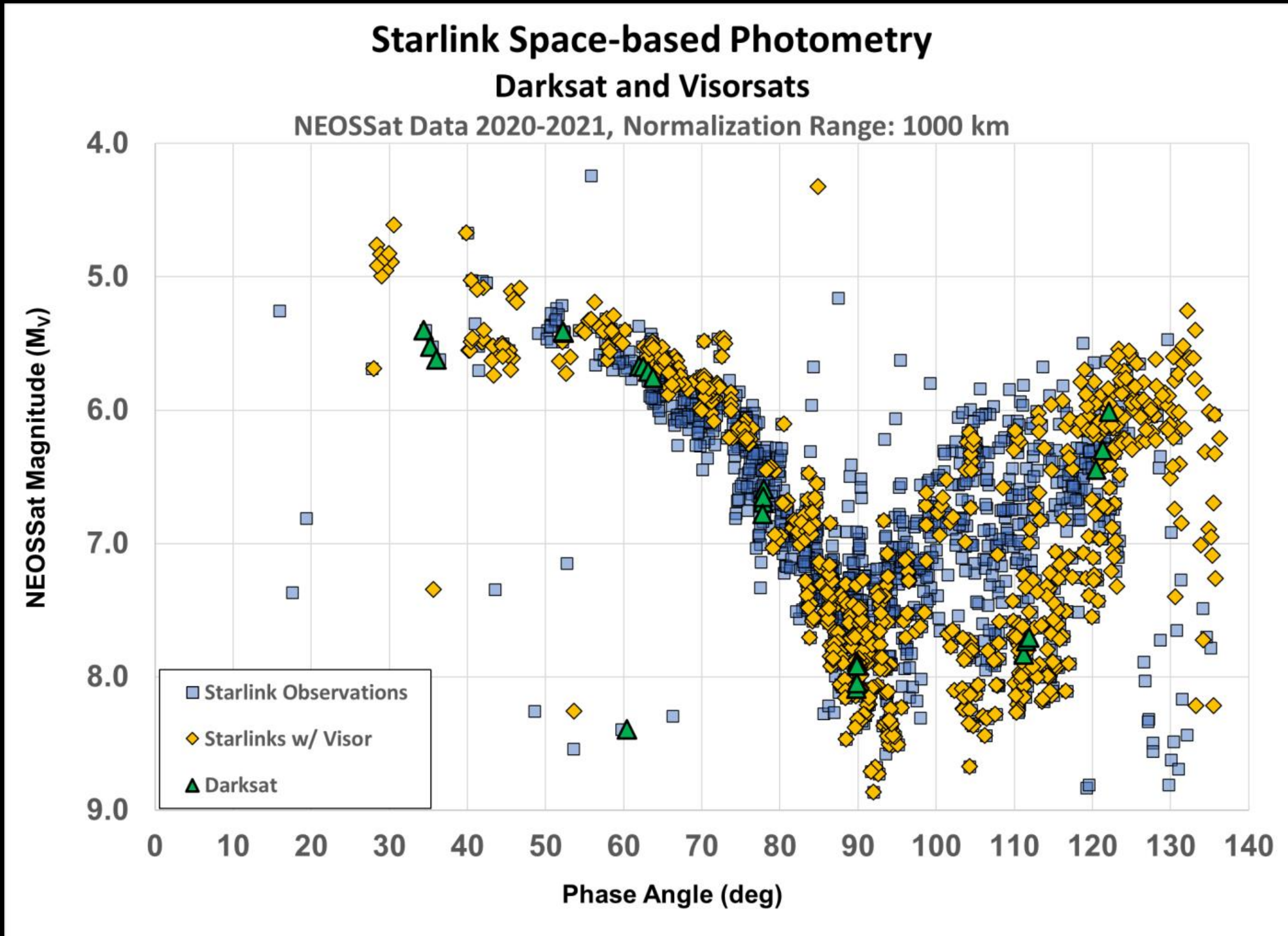
Starlink - Dayside Model

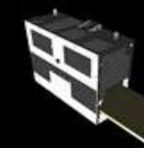


- <u>**Key findings:**</u>
- **Solar Panel (space-side) albedo-area product: 10.5 m²**
- **Bus albedo-area: 0.14 m²**

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

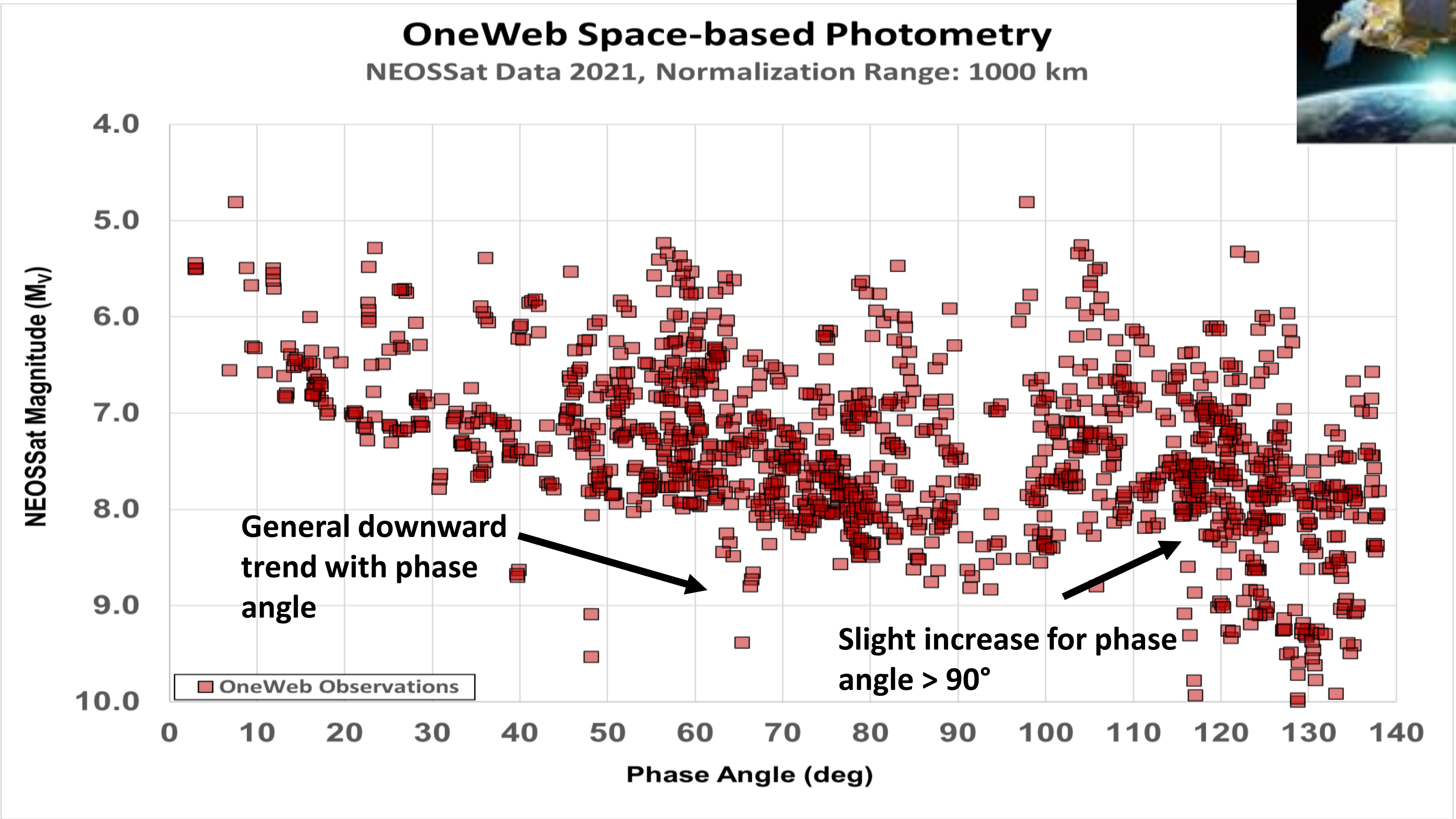
Ground based observer sees nadir bus face from below

Treatments apply to this portion, so behaviour is foreseeable

Darksat **and** ***Visorsat*** **appear similar to other constellation members when viewed from space**

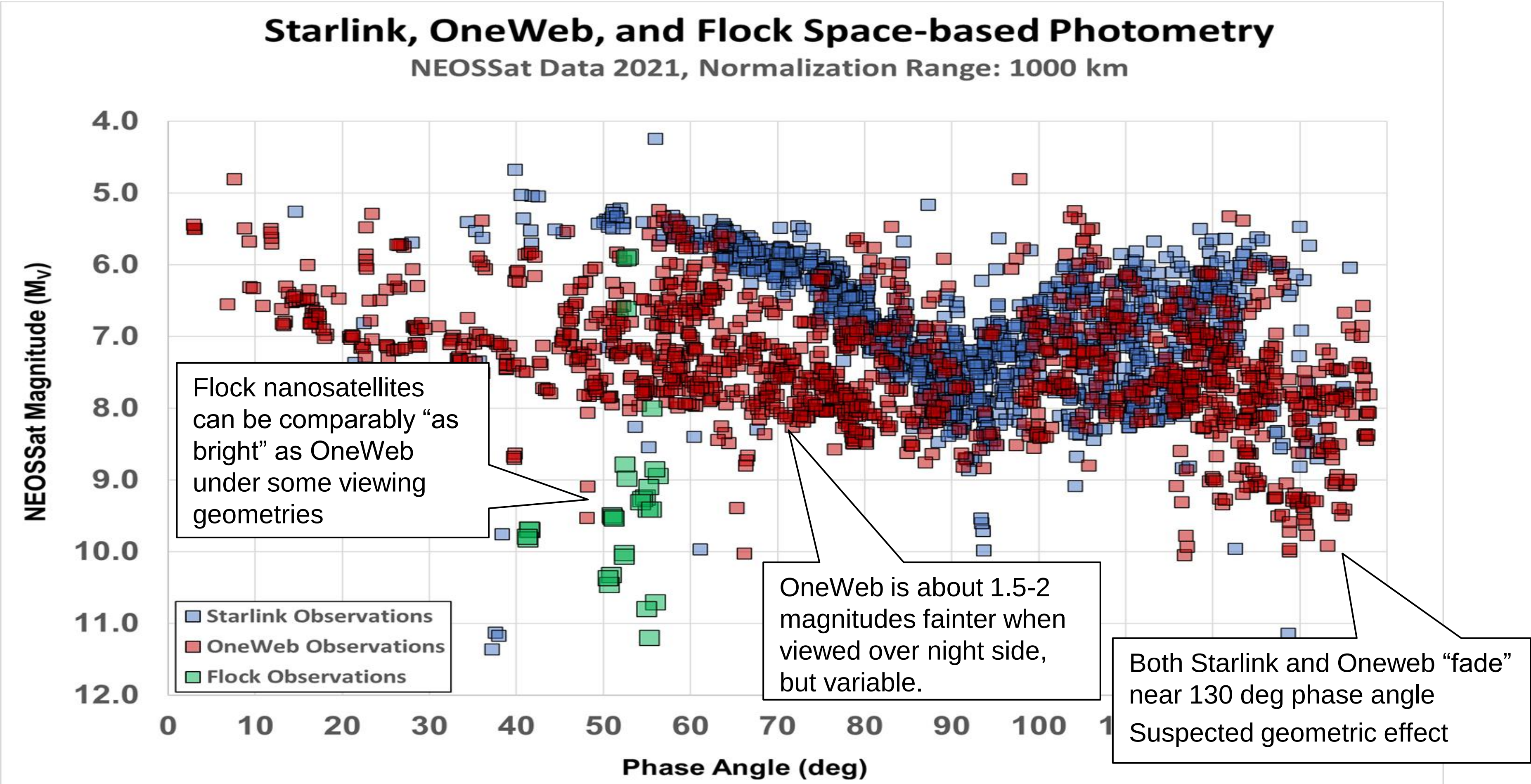
OneWeb – Photometric Measurements

1329 Observations, 81 unique satellites



More complex OneWeb satellite bus shape, unknown attitude, creates higher variability in its light curve.

Constellation comparison



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**

- **Johnson, C., Scott, R.L, Thorsteinson, S.E., "Space-based Photometric Observations of the SpaceX Starlink Constellation Satellites – Preliminary Findings", ASTRO 2020 Virtual Conference, 12 Nov 2020 https://casi.ca/resources/Documents/ASTRO/2020/NEOSSat_Observations_Starlink-CASI_Astro_2020.pdf**
- **Johnson, C., Scott, R.L, Thorsteinson, S.E., "Comparing Photometric Behaviour of LEO Constellations to SpaceX Starlink using a Space-based Optical Sensor", AMOS Conference 2021, September 2021**