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CanX-7 deorbit summary

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CanX-7 mission rationale

- **In c.2010, DRDC recognized that the increasing use of small satellites poses a potential debris risk in low earth orbit due to**
  - Small satellites' relatively low area/mass ratios
    - Small size, dense structural arrangement makes them long-lived at high altitudes
  - At altitudes > 600 km, orbital lifetimes exceed the 25 year IADC / UN COPOUOS deorbit guidelines
  - Nanosatellites and microsatellite's inexpensive design make them attractive for new entrants into space operations

- **Deorbiting microsatellites – engineering challenges**
  - **Small satellites have limited capacity for propulsion meeting IADC deorbit guidelines**
  - Small size and power limit the deltaV available onboard
  - Classical propulsion systems require active attitude guidance and control
    - Nanosatellites cannot necessarily guarantee such bus functionality at the end of mission life.
  - Expense of propulsion systems may be disincentive for small scientific missions

- **University of Toronto's Space Flight Lab (SFL), with DRDC and Canadian government sponsorship, developed the CanX-7 technology demonstrator**
  - **Drag sail technology demonstration**
  - Uses a small portion of the nanosatellite volume
  - Inexpensive deorbit design with little/no impact on other payloads and subsystems
  - Effective for nano/micro satellites operating above 600 km altitude

Testing deorbit technologies is consistent with Canada's position to support the sustainability of space, for the benefit and in the interest of all

CanX-7 mission overview

- **Mission objectives**
  - ADS-B signal (aircraft) reception test
  - Test de-orbit drag sail
- **Mission Partners**
  - University of Toronto, Space Flight Laboratory
  - Royal Military College of Canada
- **CanX-7 details**
  - Launched: 26 September 2016
  - Cospar ID: 2016-059F
  - 3U Cubesat, 10 x 10 x 34 cm, 3.75 kg
  - 3 Watts power
  - Payloads:
    - L-band ADS-B receiver
    - 4 m² drag sail (4 segments)
  - Orbit: SSO 703 x 660 km @ 98° inclination

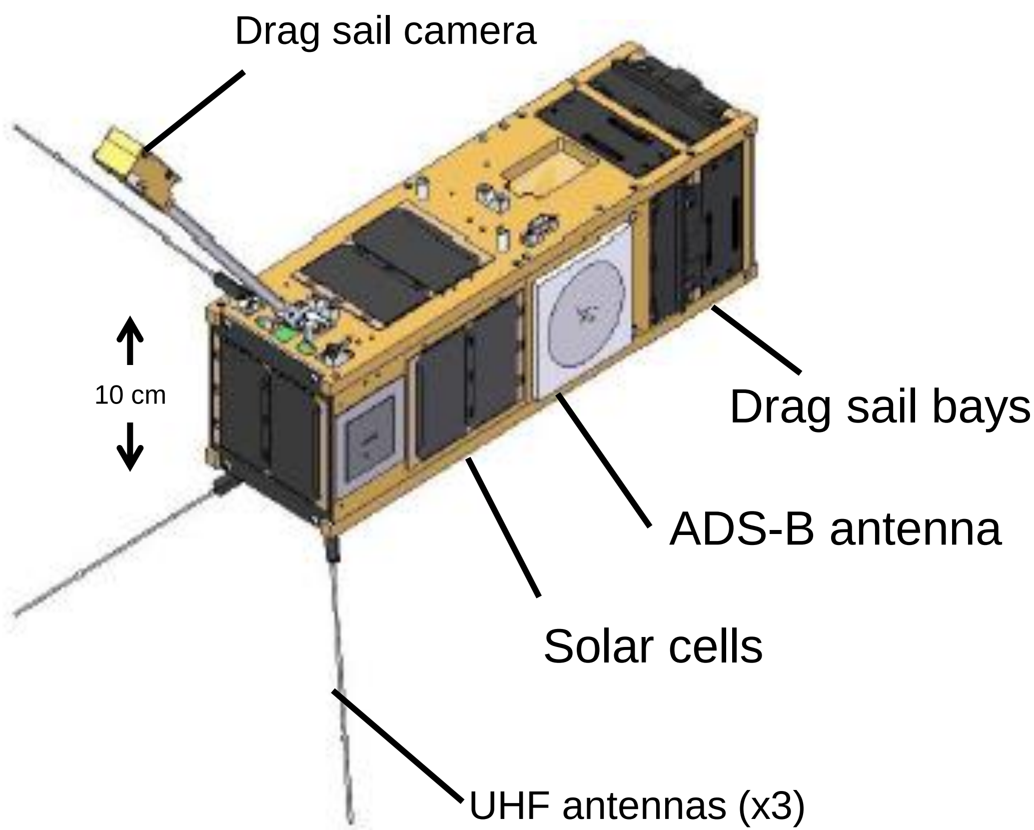
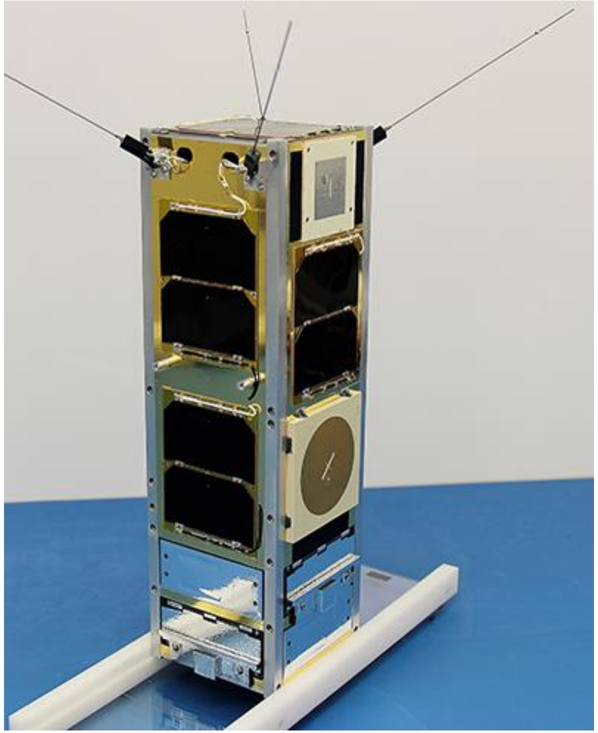


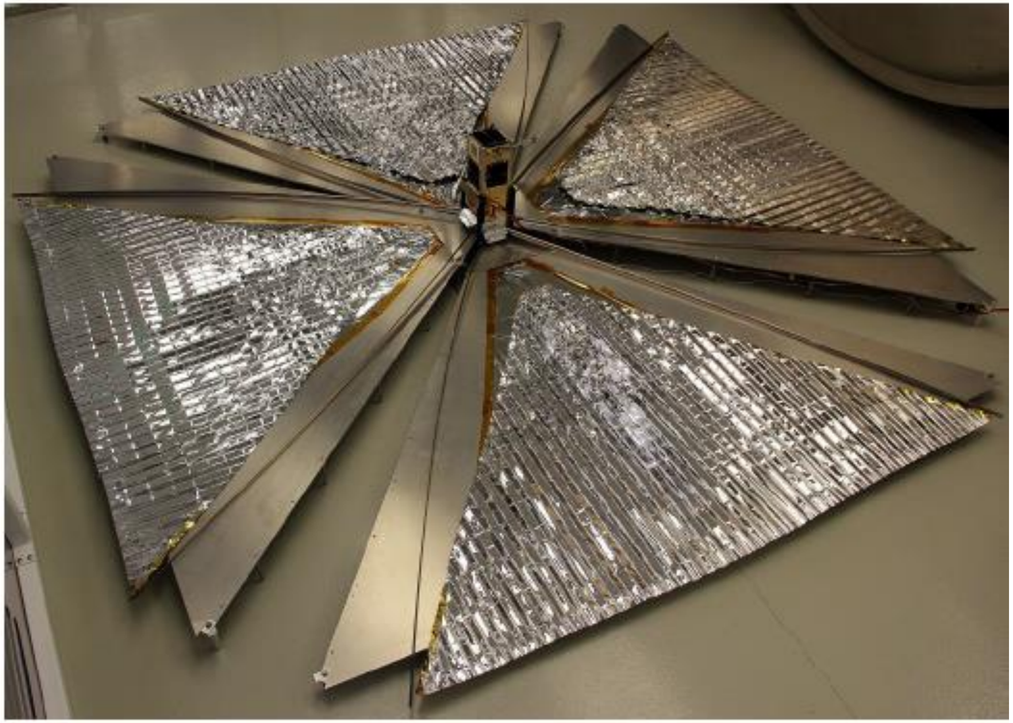
Image credit: University of Toronto, SFL

- **Sails stowed in –X bay of 3U nanosatellite bus**
- **ADS-B mission operated for 7 months.**

CanX-7 mission overview



CanX-7 drag sails stowed



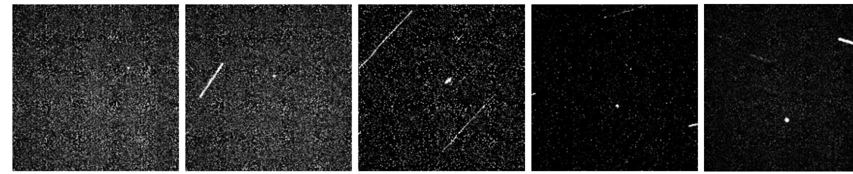
4 m^2 drag sail deployed

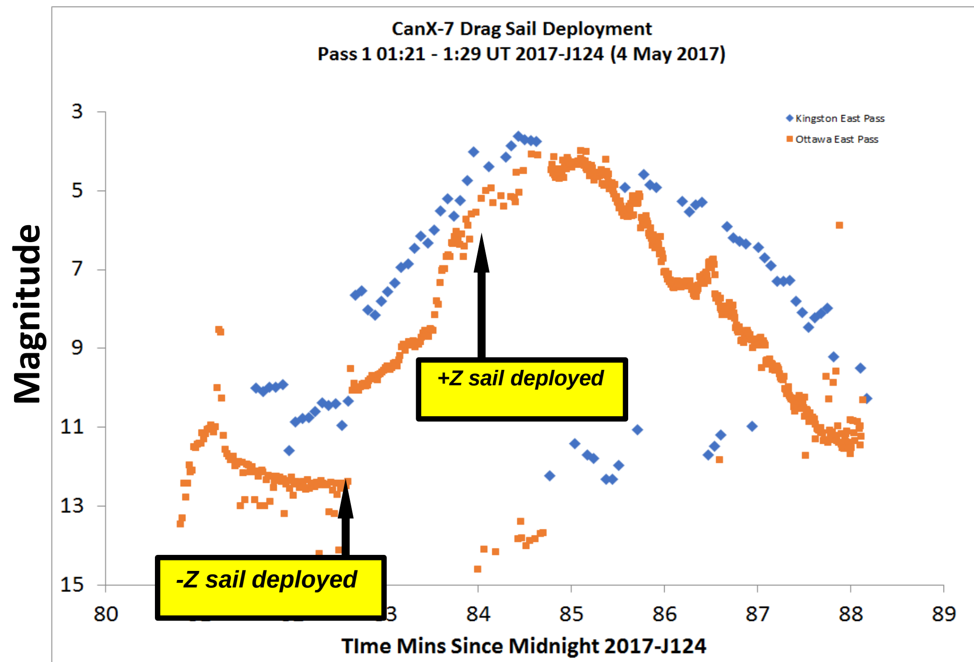
Image credit: University of Toronto, SFL

- **Sails comprised of 4 segments of aluminized polyimide deployed using burn wire, spring mechanism**
- **Sails actuated by ground command for CanX-7 testing**

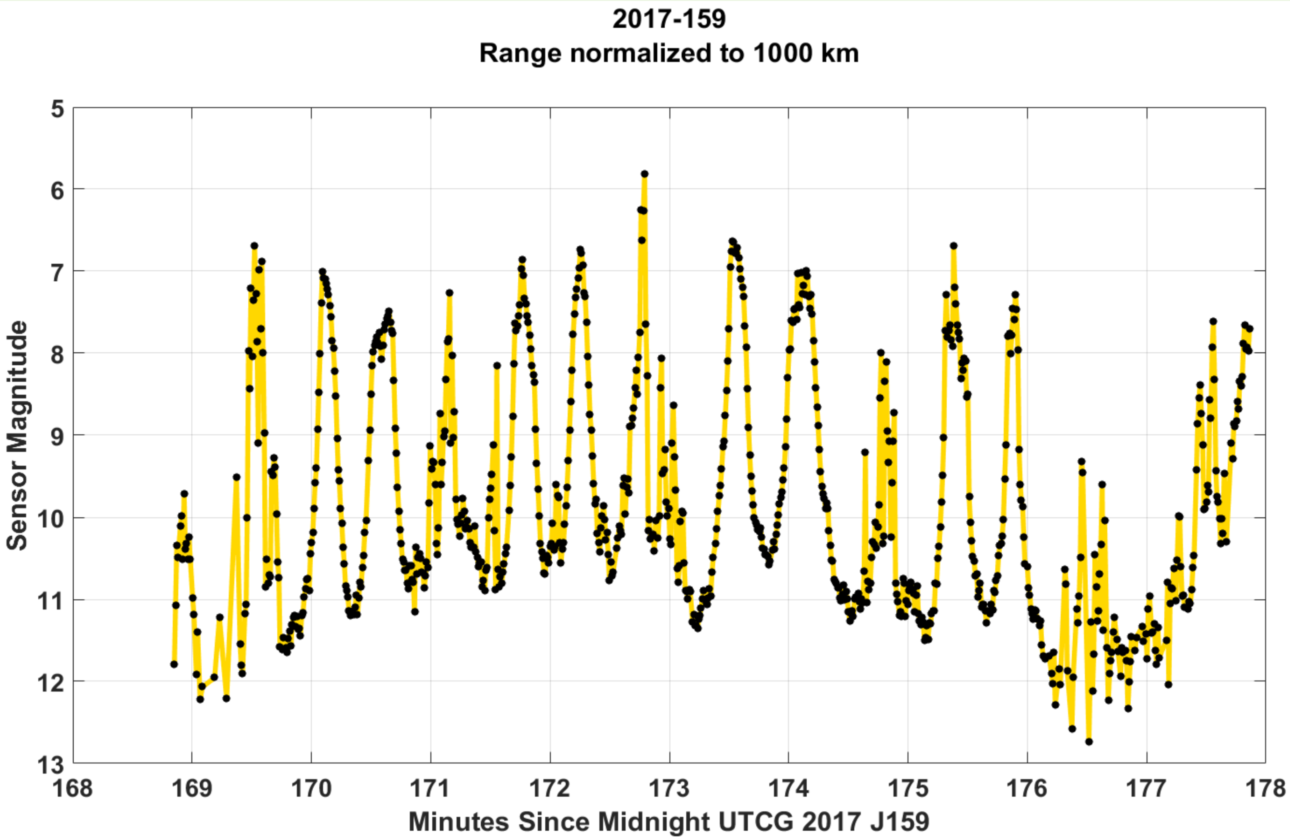
Drag sail deployment

- **After completion of the ADS-B mission, CanX-7 deployed drag sails on 4 May 2017**
- **Sail deployment measured by DRDC ground based optical telescopes**
  - Rare opportunity charactrerize a rapid shape, size change on a nanosatellite
  - Ground measurements assist in the validation of sail deployment if CanX-7 telemetry ‘ambiguous’
- **Sails deployed on 2 passes over eastern Canada**
- **Sails confirmed deployed using CanX-7 telemetry.**
- **Ground based imagery confirmed a photometric step change in brightness after first sail deployment.**
  - Others sails showed less dramatic change in brightness
- **CanX-7 temporarily naked-eye visible after 2nd sail deployment**





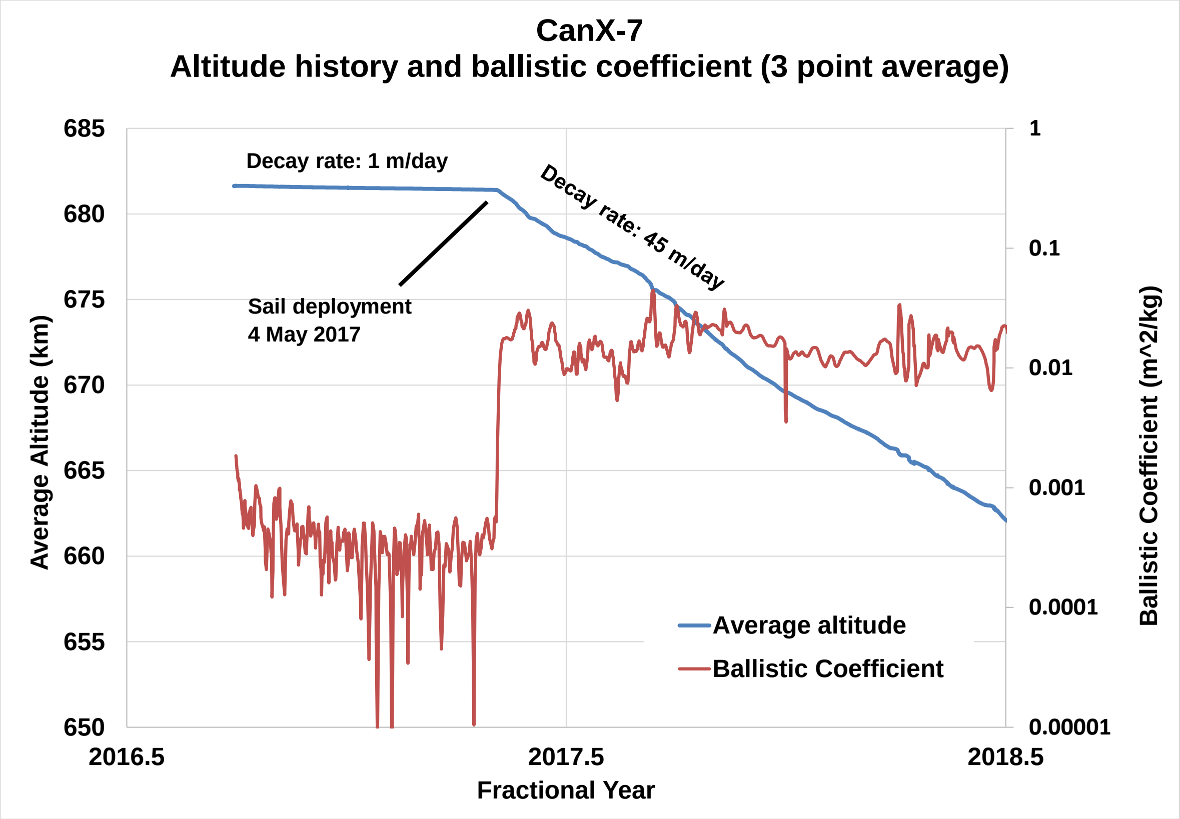
Post-deployment Photometry (2017-J159)



1 month after sail deployment – obvious rotation rate observed in CanX-7 light curve
Body rate of ~0.5-1.8 rpm inferred, and confirmed with SFL onboard telemetry.
Solar Radiation pressure causes pinwheeling effect due to drag sail torques
Manageble unless rotation rates exceeds 3-4 rpm (communications limit for CanX-7 radios). Addressable on other missions by onboard attitude despin command

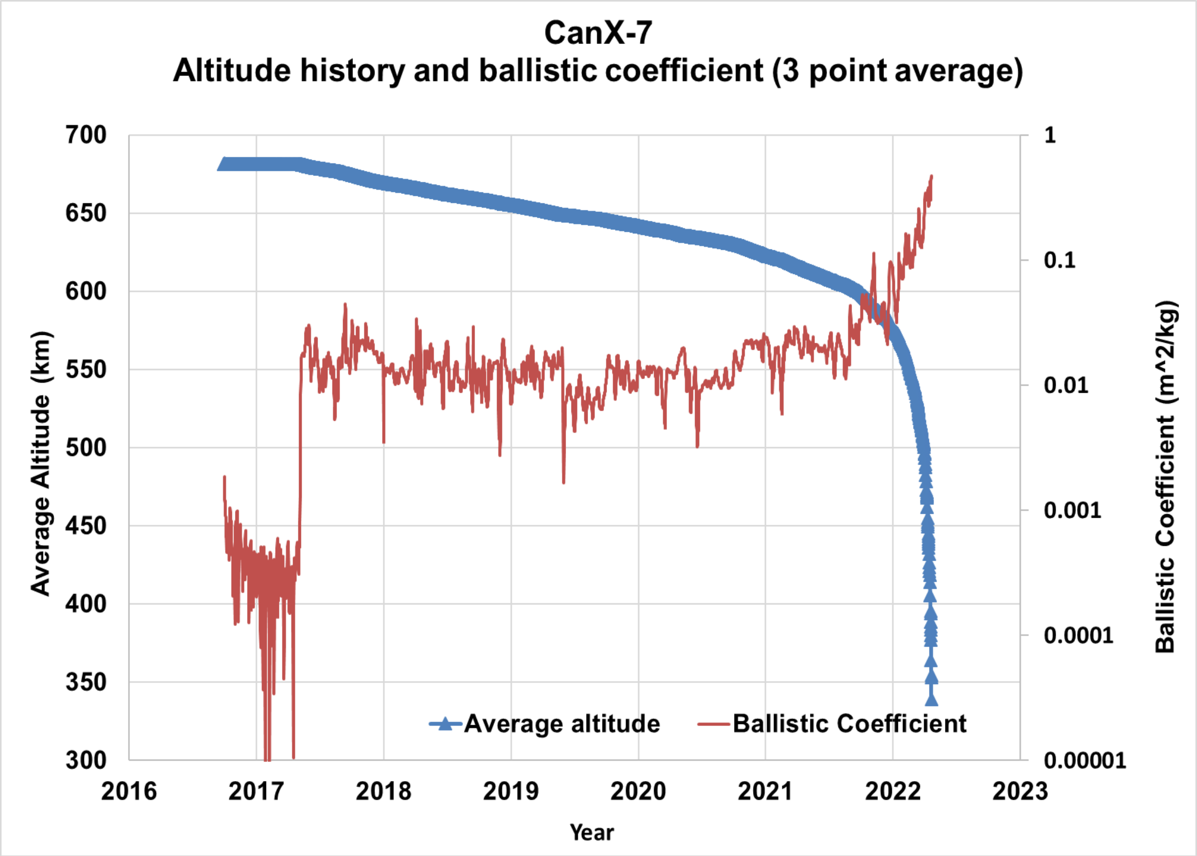
CanX-7 orbit changes after sail deployment

- **CanX-7's orbit after sail deployment showed clear change of altitude decay rate**
  - Prior to deployment, CanX-7 altitude decay rate was ~1 meter/day
  - Post-sail deployment, the altitude decay rate increased to ~45 meter/day
- **CanX-7's inverse ballistic coefficient showed a 100x increase**
  - Consistent with drag sail increasing the nanosatellite's cross sectional area
  - Evidenced in TLE orbital data



CanX-7 orbital decay

- **Altitude decay was steady until average altitude fell below 625 km**
  - Sharp knee in altitude decay rate at the start of 2022
- **Prior to re-entry, the ballistic coefficient, inferred from orbital data, <u>increased</u> from ~0.01 to > 0.5 m^2/kg**
- **What caused the increase in ballistic coefficient prior to re-entry?**



CanX-7 orbital decay

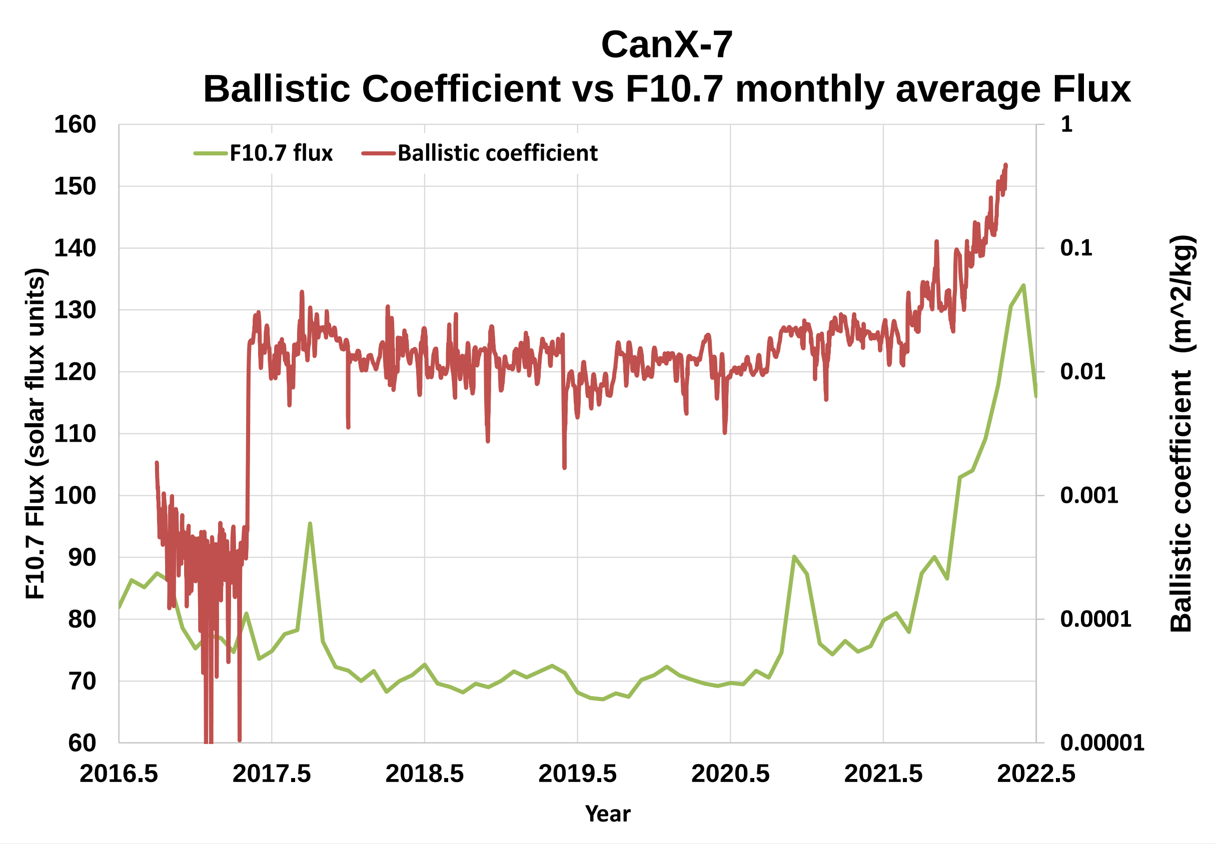
Two possible mechanisms for late change in inverse ballistic coefficient

1) Increasing solar flux from the Sun, as measured in the monthly average F10.7 wavelength showed increasing solar activity at start of solar cycle 25

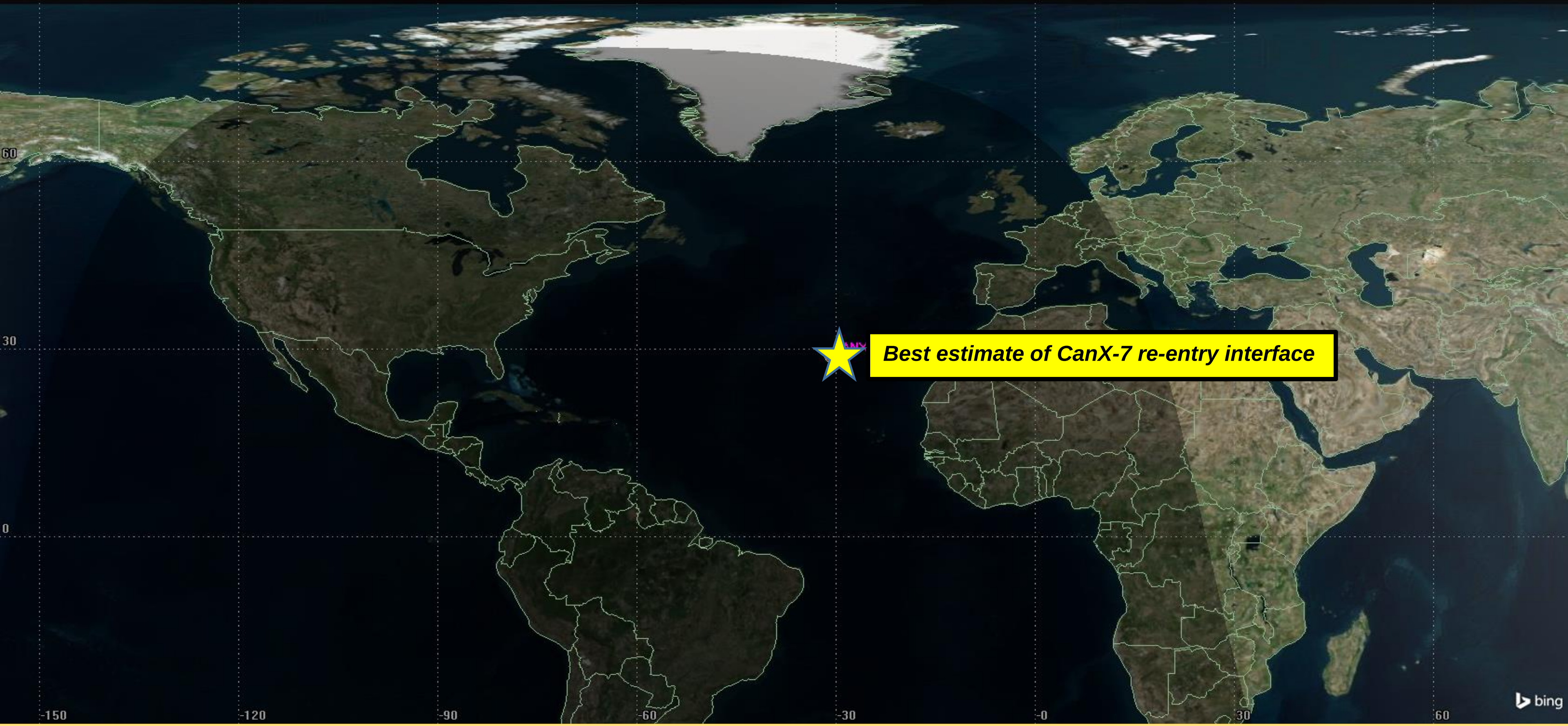
- Increasing solar UV increases neutral density at higher altitudes
- Ballistic coefficient is inferred from two-line orbital elements "lumps" ambient density into its estimation model

2) Shuttlecock effect

- As CanX-7 lowers its altitude, the increased atmospheric density causes the drag sails to 'shuttlecock'. This increases the cross sectional area of CanX-7 consistently per orbit vs a slow tumble of drag sail at higher altitudes



CanX-7 re-entry interface (best estimate)



- Best estimate of re-entry location provided by Canadian Space Operations Centre at 29.0°N, 329.5°E at 21 April 2022 04:16 UTC.
- West of Africa over Atlantic ocean

Key findings and Summary

- **CanX-7 re-entered on 21 April 2022**
  - Estimated location of re-entry interface: 29.0°N, 329.5°E
  - No re-entry prediction warning issued by the 18^{th} Space Control Squadron due to CanX-7's small size

- **First Canadian satellite "commanded" deorbit from LEO above 600 km using a passive deorbit technique**
  - Deorbited within 5 years of ADS-B mission completion
  - Drag sails prevented CanX-7 from staying on orbit for another 178 years posing a risk to other space objects

- **Drag sail effective for nano/microsatellite sized satellites**
  - Strong altitude decay rate observed (~45 m/day after sail deployment)
  - Photometric measurements showed evidence of rotational motion due to solar radiation pressure torques.
    - Rotational motion not expected to be an issue for a decommissioned mission
  - Start of solar cycle 25 increased ambient exospheric density which deorbited the nanosatellite somewhat earlier than expected. Combination of shuttlecock effect and ambient density increased late-stage rate of reentry
    - Could be used as a scheduling consideration for other small satellite missions for Space Traffic Management purposes to help ensure objects are removed from LEO in a timely manner

- **References:**

  - Scott,R.L., Thorsteinson, S.E., Bedard, D., Cotton, B., Zee, R, "Canadian Ground based optical observations of the CanX-7 drag sail deployment", CASI ASTRO 2018, Quebec, QC, 2018.