How CubeSats are Helping Address the Space Debris Problem: Results from the Polar Orbiting Passive Atmospheric Calibration Spheres

13th Annual Summer CubeSat Developers' Workshop

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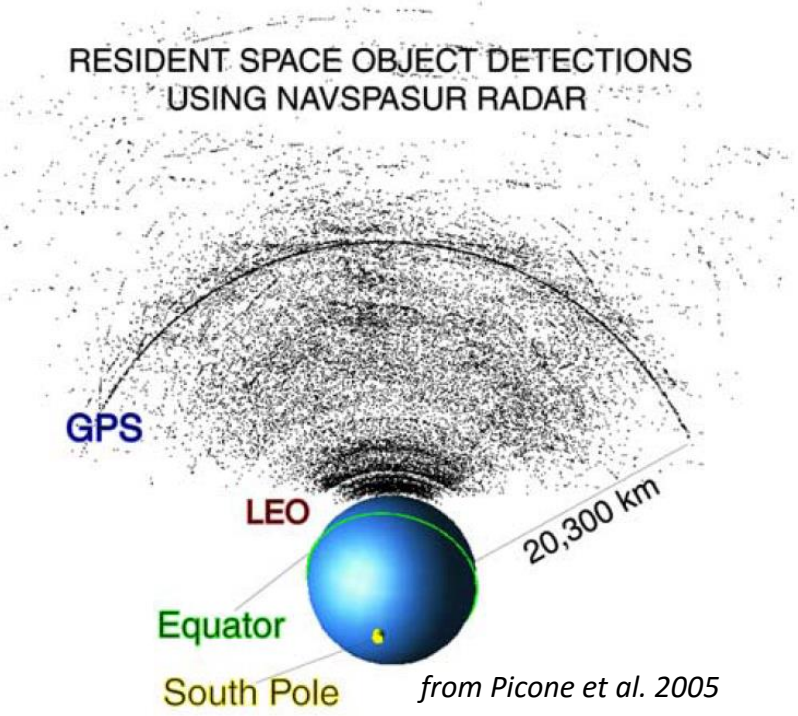
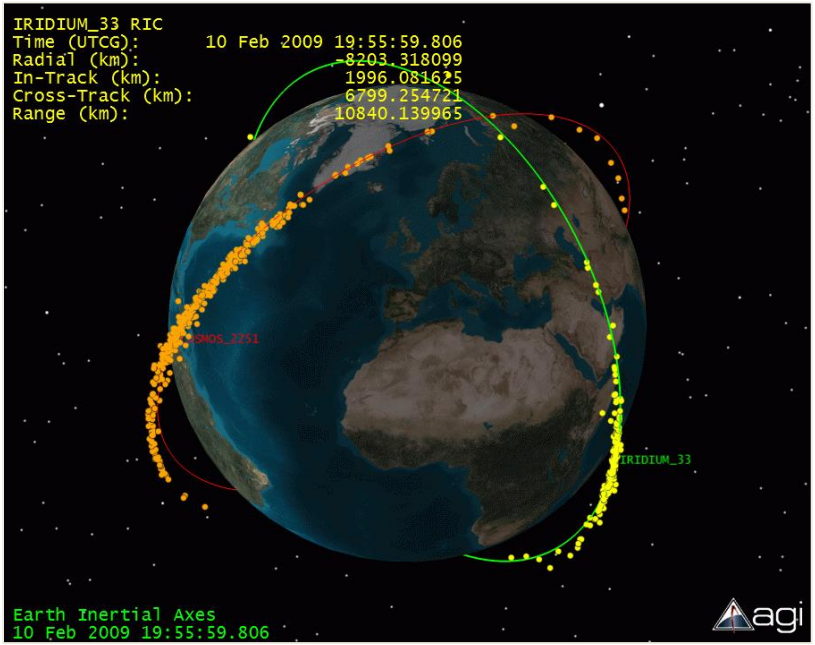
Marcin Pilinski – ASTRA LLC.

Gil Moore – Project POPACS

Space Debris and Satellite Drag



from Picone et al. 2005



Satellite drag errors degrade capability to:

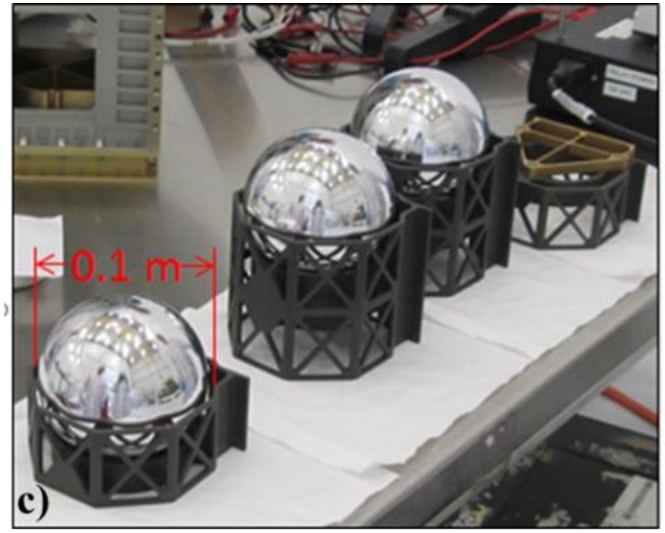
- Maintain accurate catalog of all space objects including debris
- Predict and avoid space collisions
- Predict satellite reentry time & location
- *Atmospheric calibration efforts were lacking atmospheric data at high latitudes*
- This is not small satellite problem vs. big satellite problem, it is an issue for all space assets

At the start of 2016

Total Number of CubeSats Launched 417	Total Number of Debris Generated by DMSP Satellites 346
Total Number of Debris Generated by Cosmos-Iridium 1296	Total Number of Debris Generated by Fengyun ASAT 3428

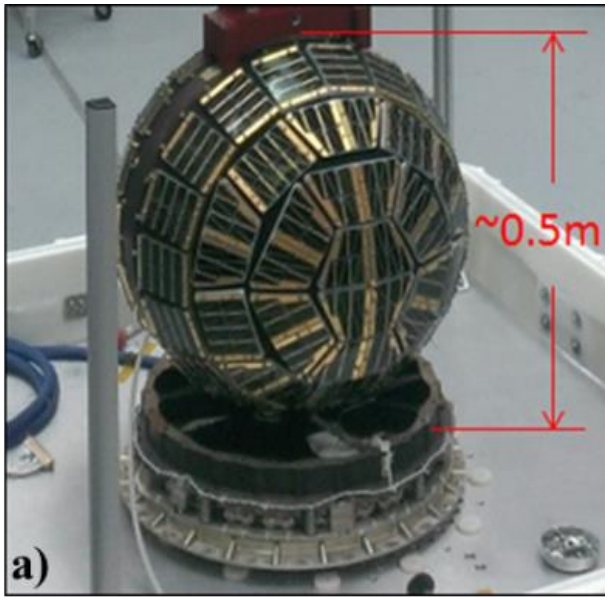
What is POPACS

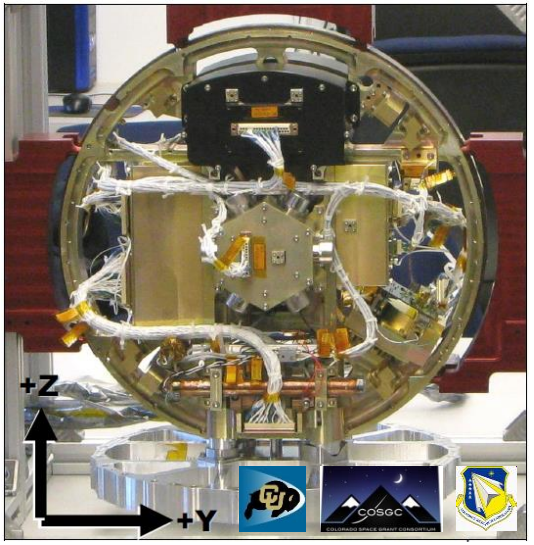
- Polar Orbiting Passive Atmospheric Calibration Spheres
- Launch 9/29/2013 into a high inclination elliptical orbit by Falcon 9
  - ~340 km perigee altitude
  - ~1510 km apogee altitude
  - ~0.08 eccentricity
  - 81.0 deg inclination
- Investigate thermospheric density variability
- Calibrate satellite drag models to improve orbits



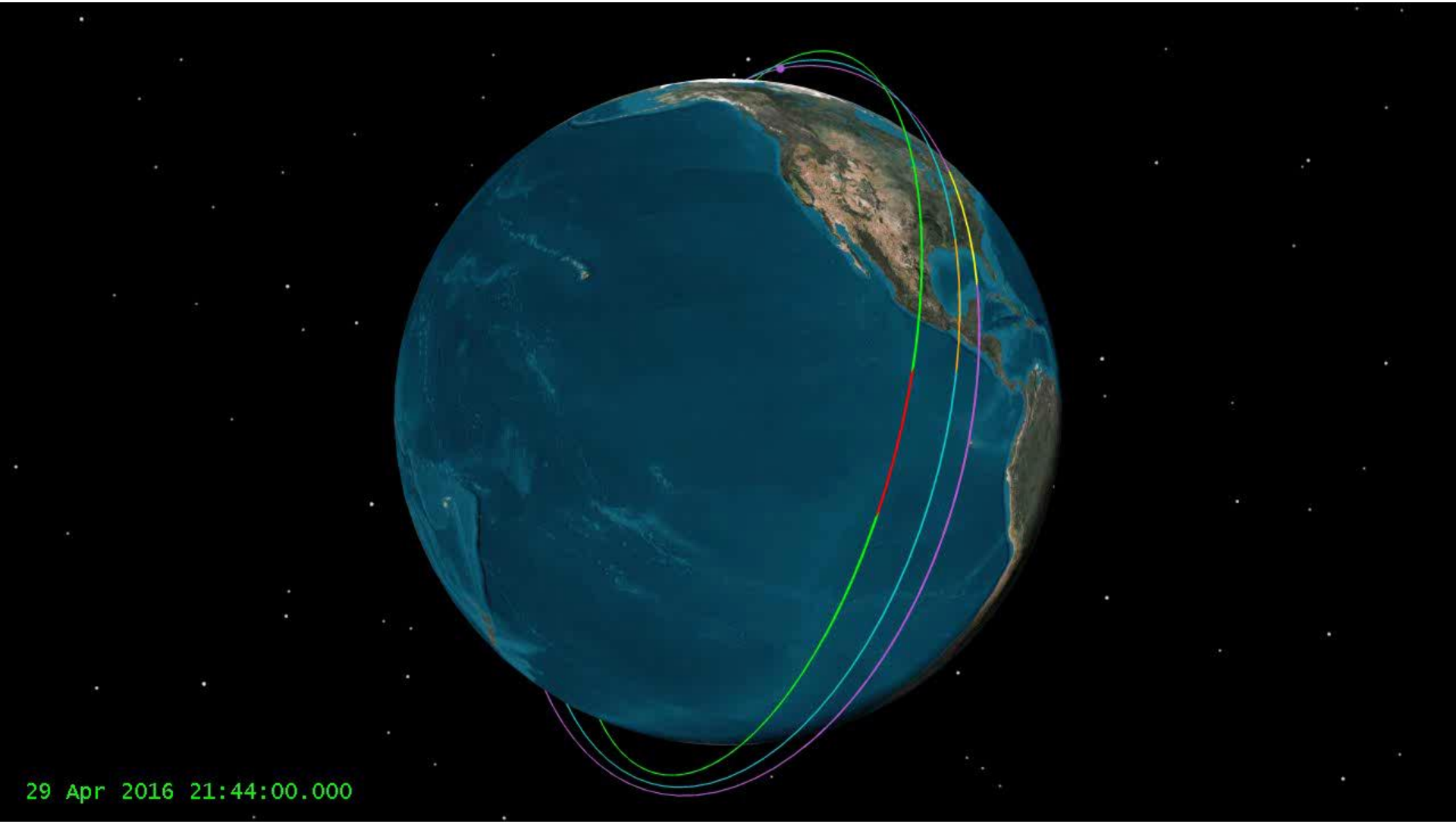
What is DANDE

- Drag and Atmospheric Neutral Density Explorer built by COSGC and CU, Boulder and funded by AFOSR and AFRL as part of the University Nanosat Program
- Launched into nearly identical orbit as POPACS
- Investigate thermospheric density variability
- Calibrate satellite drag models to improve orbits
- Test design of atmospheric instruments



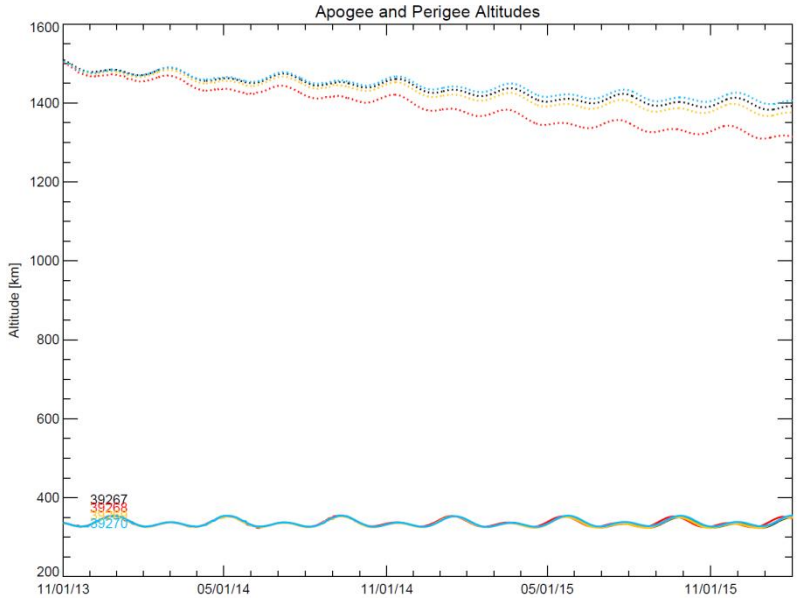


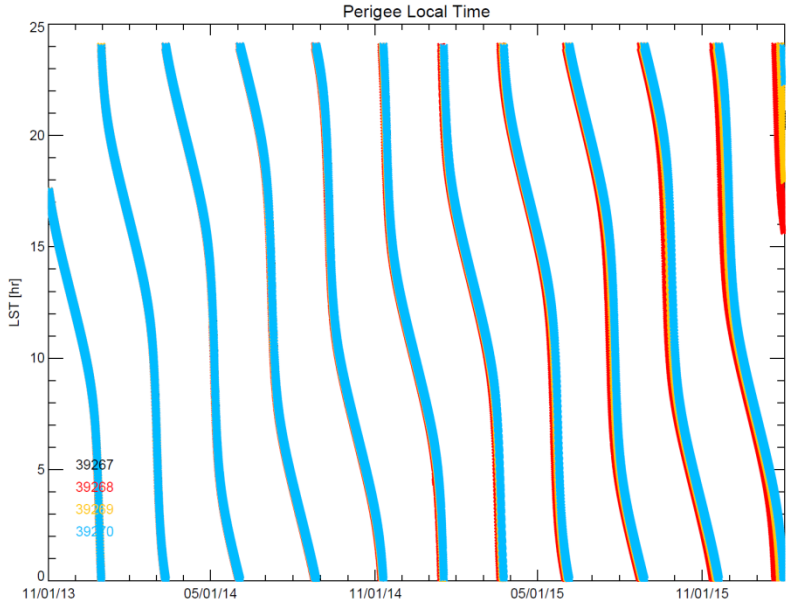
Orbit Evolution

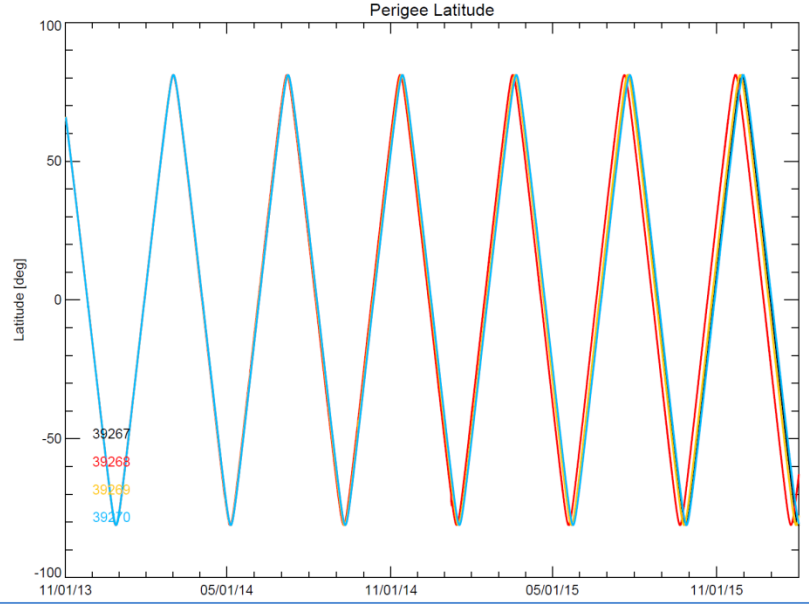


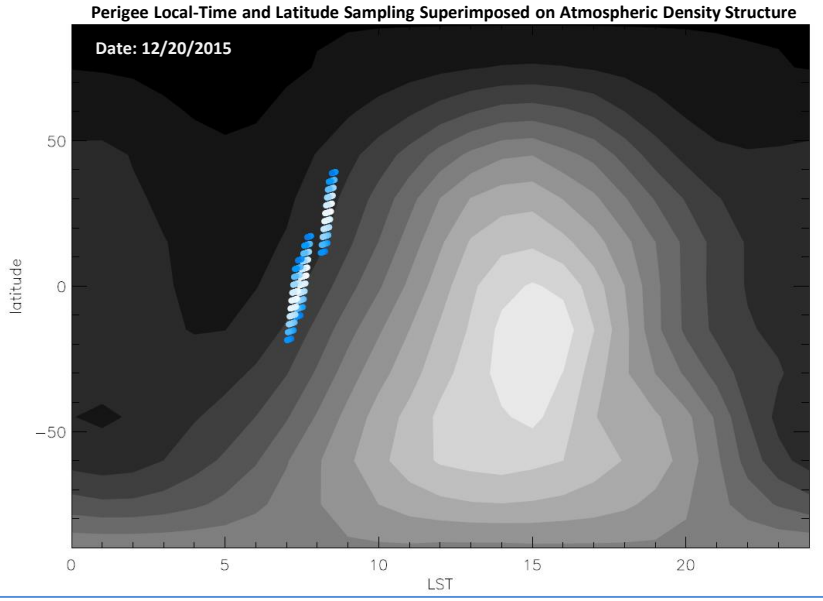
Numerical prediction of the orbital decay of the POPACS orbits three years after launch
image credit: Wes Bradley, Willowhill Precision.

Orbit Evolution

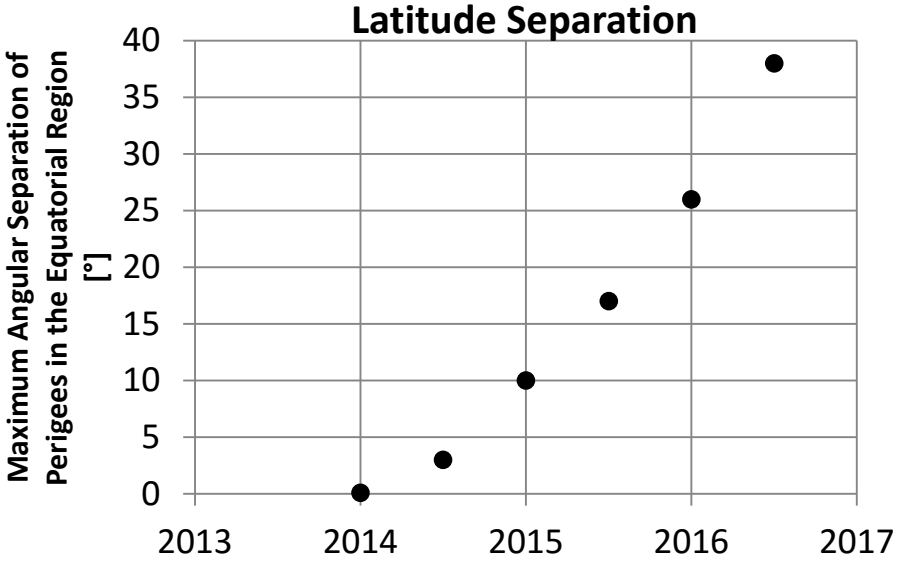


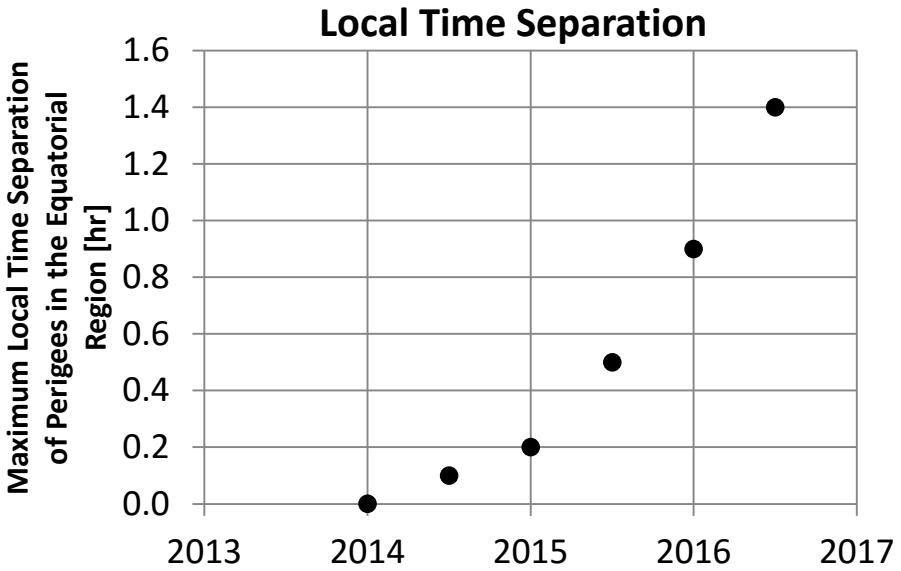


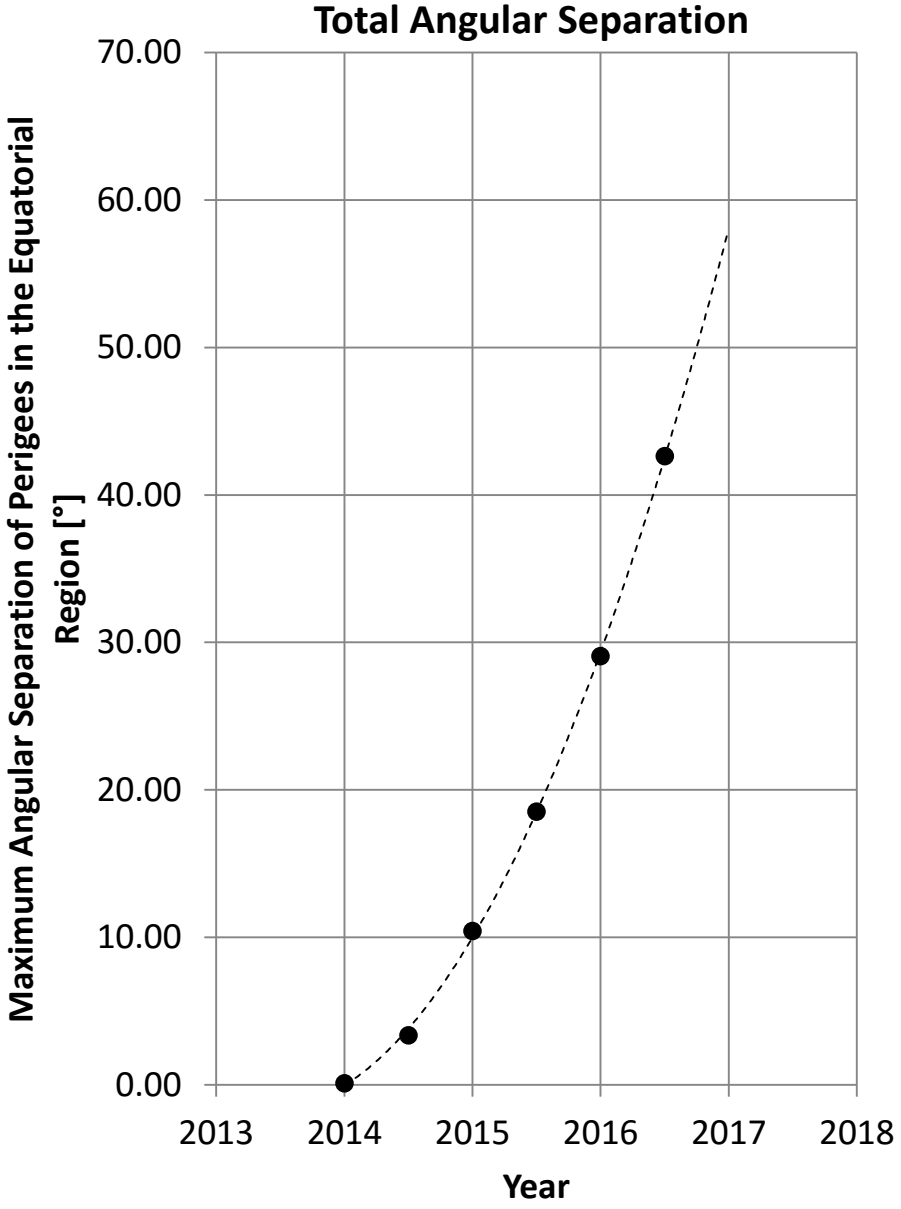




Geographic Coverage







Aerodynamic Properties (ballistic coefficients)

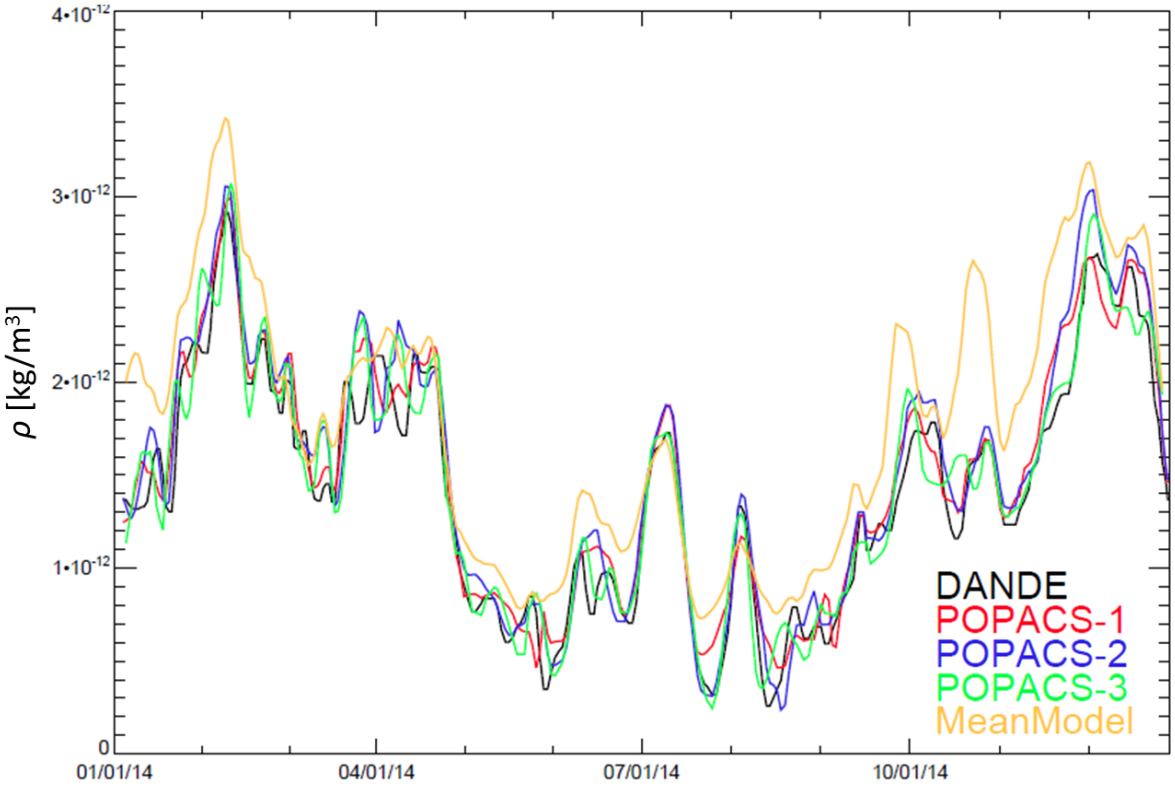
Satellite	A (m^2) [min, median, max]	C_D [min, median, max]	M (kg)	C_DA (m^2) [min, median, mode[a], max]
DANDE-LAB	[0.180, 0.219, 0.243]	[2.205, 2.281, 2.364]	46.495 ± 0.115	[0.420, 0.496, 0.529, 0.549]
DANDE	[0.172, 0.175, 0.177]	[2.260, 2.287, 2.319]	37.168 ± 0.131	[0.394, 0.400, 0.400, 0.404]
POPACS-1	0.00784 ± 0.00001[b]	2.287	0.999 ± 0.000†	0.01794 ± 0.00003†
POPACS-2	0.00780 ± 0.00006[b]	2.287	1.498 ± 0.000[b]	0.01784 ± 0.00014[b]
POPACS-3	0.00783 ± 0.00004[b]	2.287	2.005 ± 0.000[b]	0.01790 ± 0.00008[b]

[a]Mode computed assuming the satellite is randomly tumbling
[b]Based on preflight measurement uncertainties

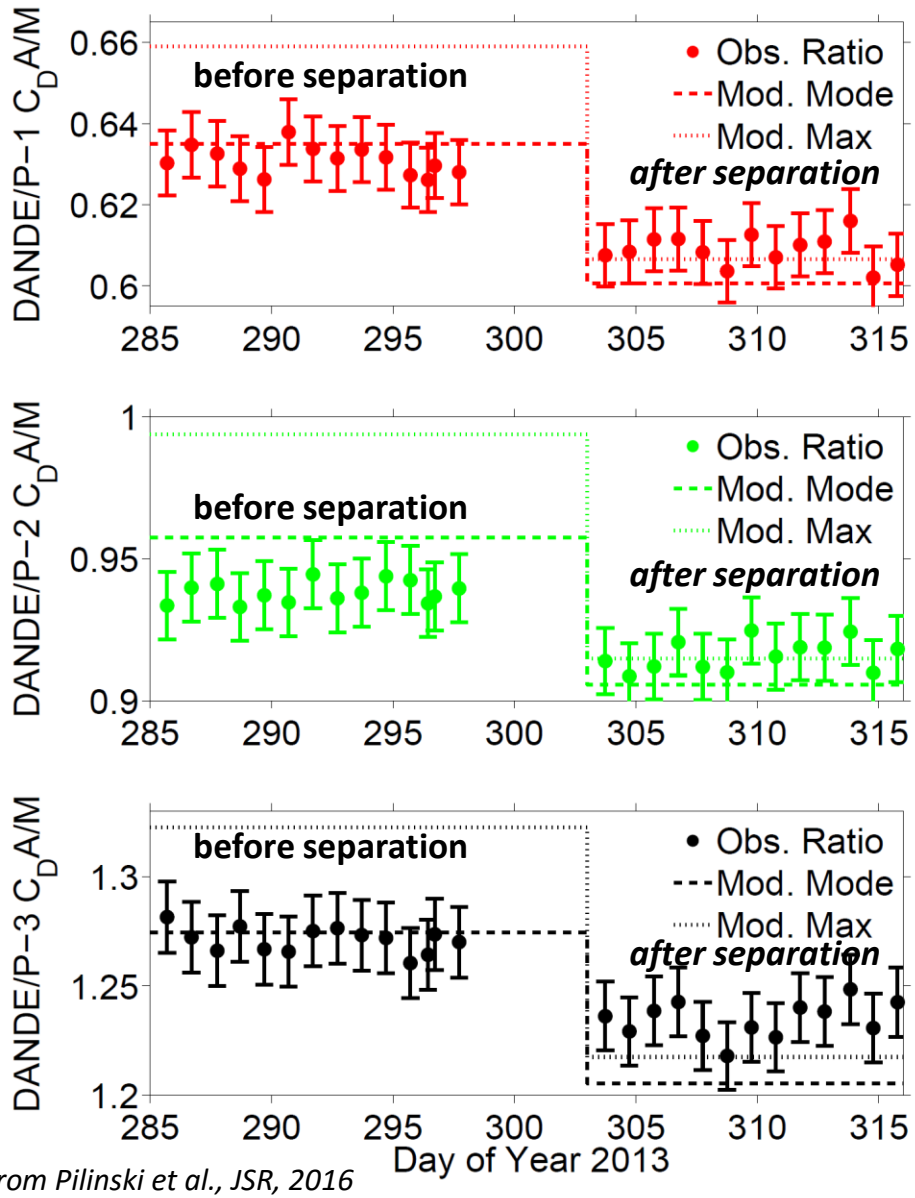
from Pilinski et al., JSR, 2016

accurate ballistic coefficients…

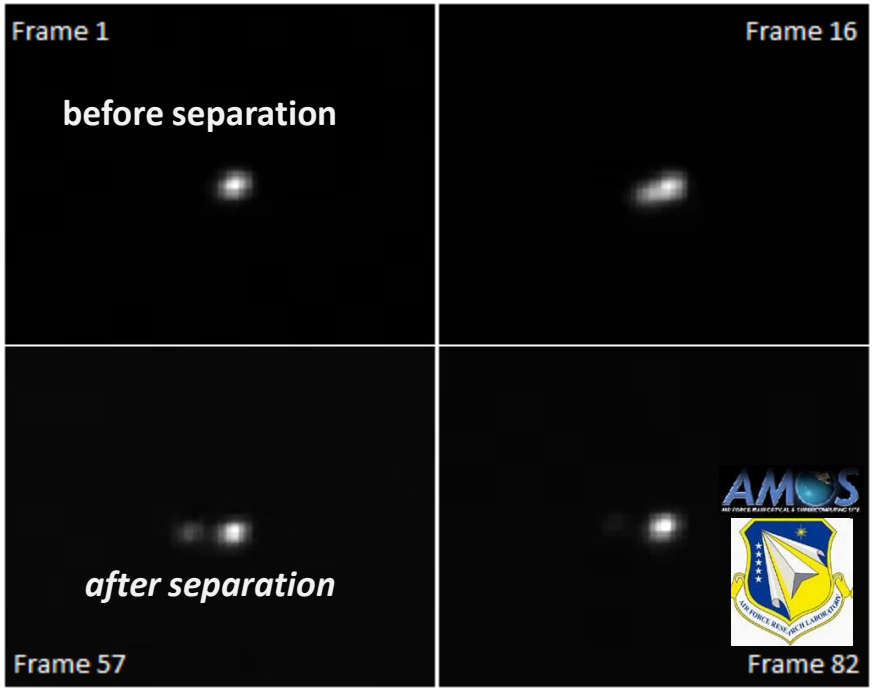
…lead to accurate atmospheric density measurements

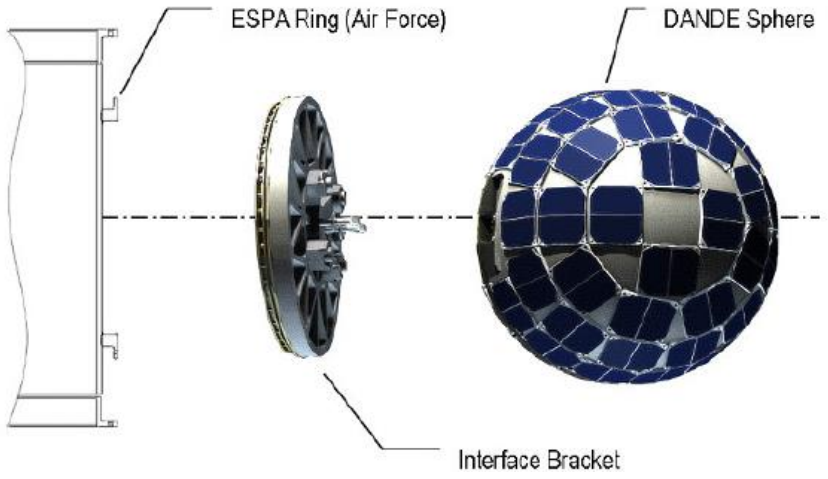


Aerodynamic Analysis, DANDE Separation

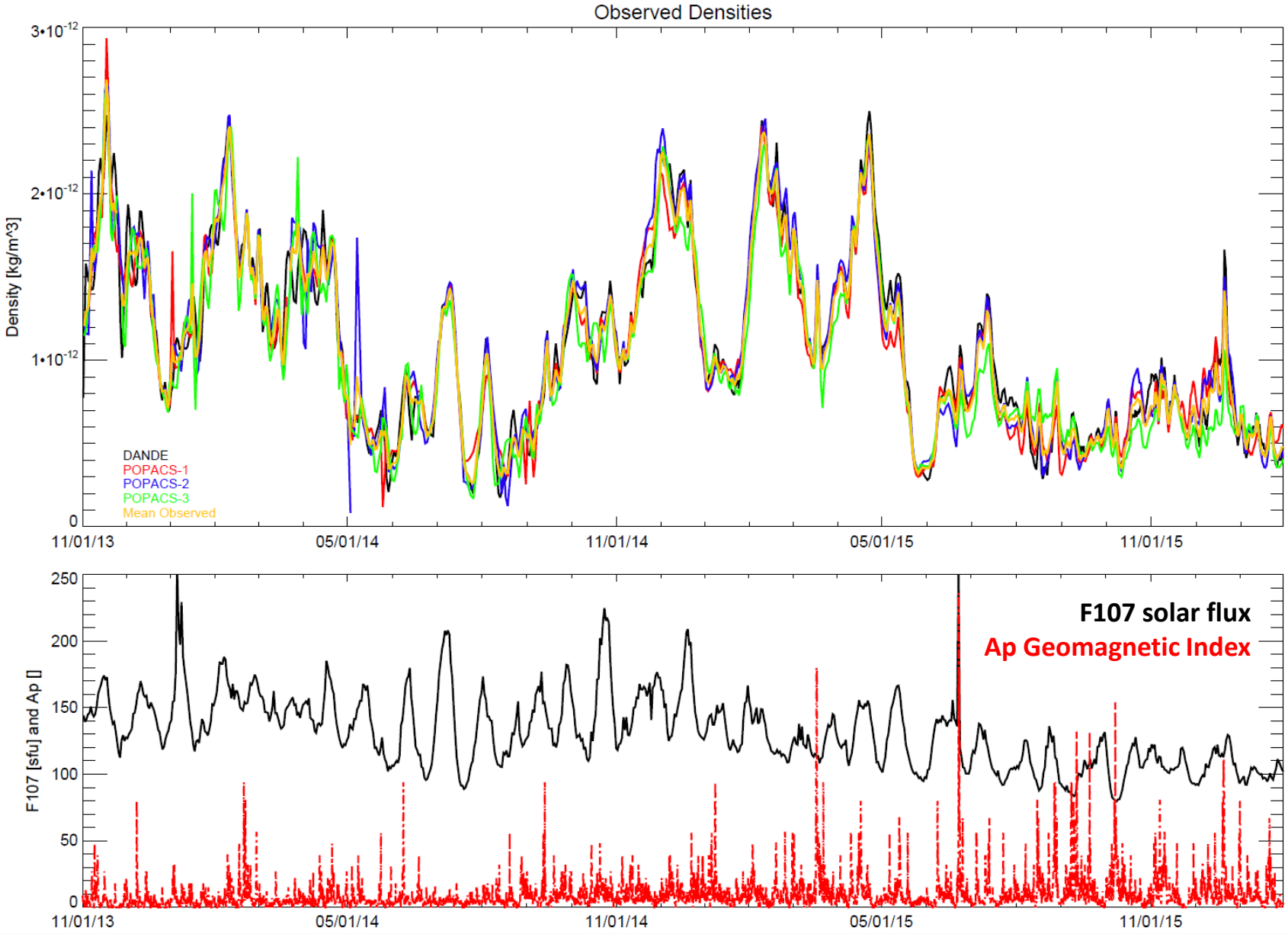


from Pilinski et al., JSR, 2016



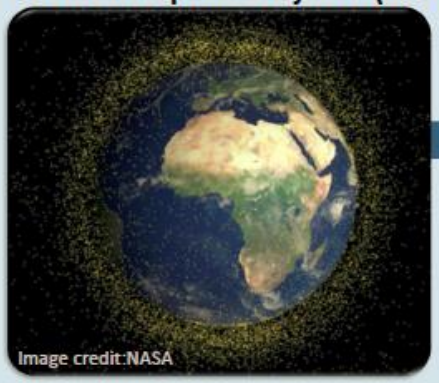


Atmospheric Measurements



Atmospheric Assimilation for Improved Conjunction Analysis

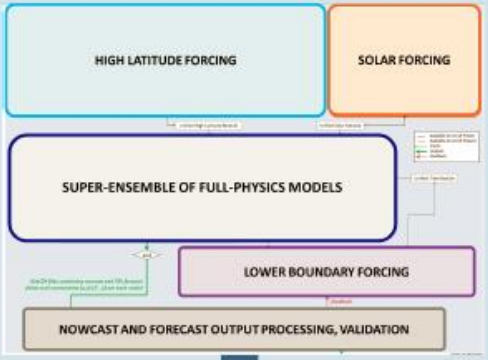
Resident Space Objects (LEO)



satellite drag and density observations

- ***Orbit observations***
- *GPS*
- *Accelerometers*
- *O/N_2*
- *Mass Spectrometer*

Dragster Architecture



orbital analysis

Dragster

conjunction analysis

Super-Ensemble Approach

Image credit: TerraMetrics, Google

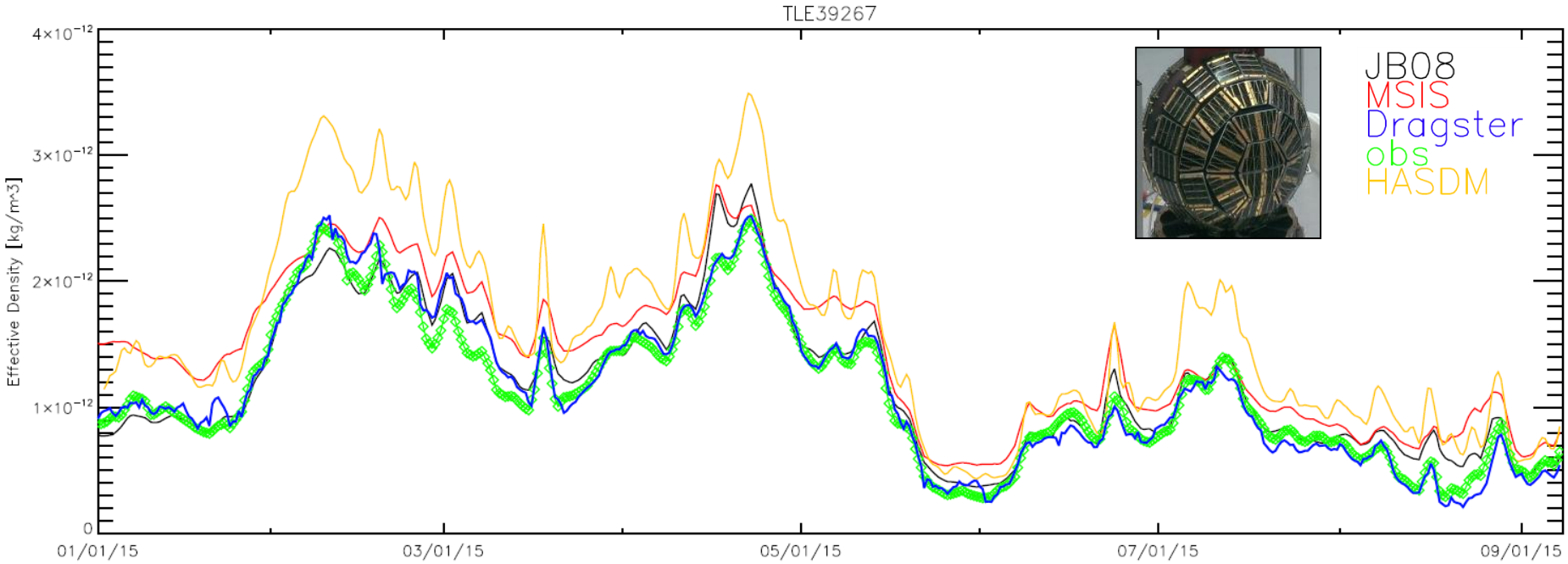
Output information feeds into existing orbit prediction and determination tools

Results

- Improved satellite orbit nowcast and 72h forecast
  - Improvements over HASDM and JB08
  - Up to three-fold improvement during storms and solar minimum
- Densities, winds, and composition outputs
- Covers altitudes from 30 km to 1500 km
- Improved performance during geomagnetic storms

Atmospheric Assimilation for Improved Conjunction Analysis

Satellite	Perigee Altitude [km]	MSIS Standard Deviation	JB08 Standard Deviation	HASDM Standard Deviation (no POPACS)	Dragster Standard Deviation (with POPACS)
DANDE (39267)	338	29.3%	17.3%	18.8%	10.9%



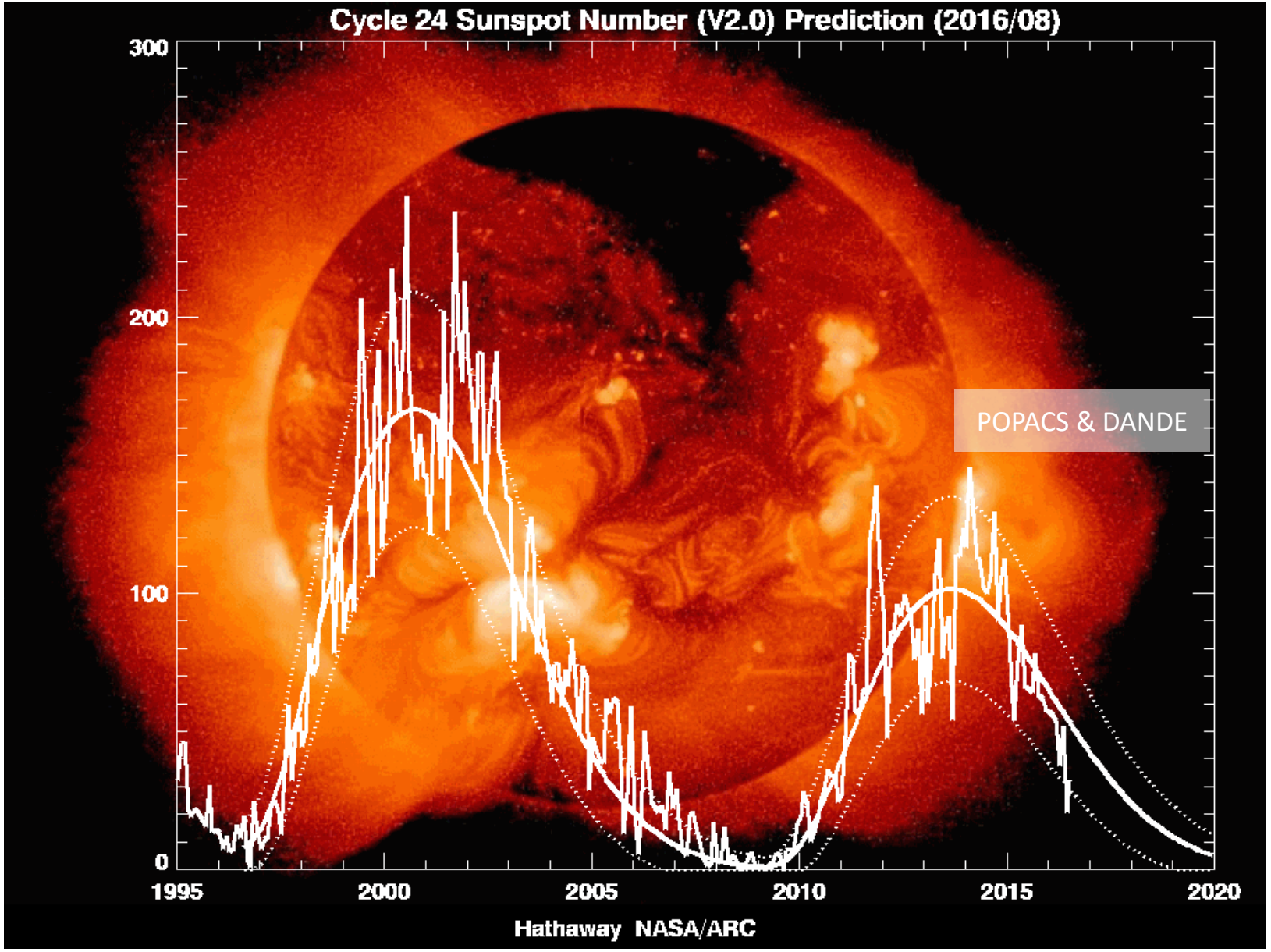
- Dragster model (blue) assimilates data from a number of objects including POPACS
- The DANDE satellite was used as a validation object to check on the assimilation results
- Proximity of POPACS to DANDE as well as their excellent aerodynamic characterization greatly improves the results over the other models

Conclusions

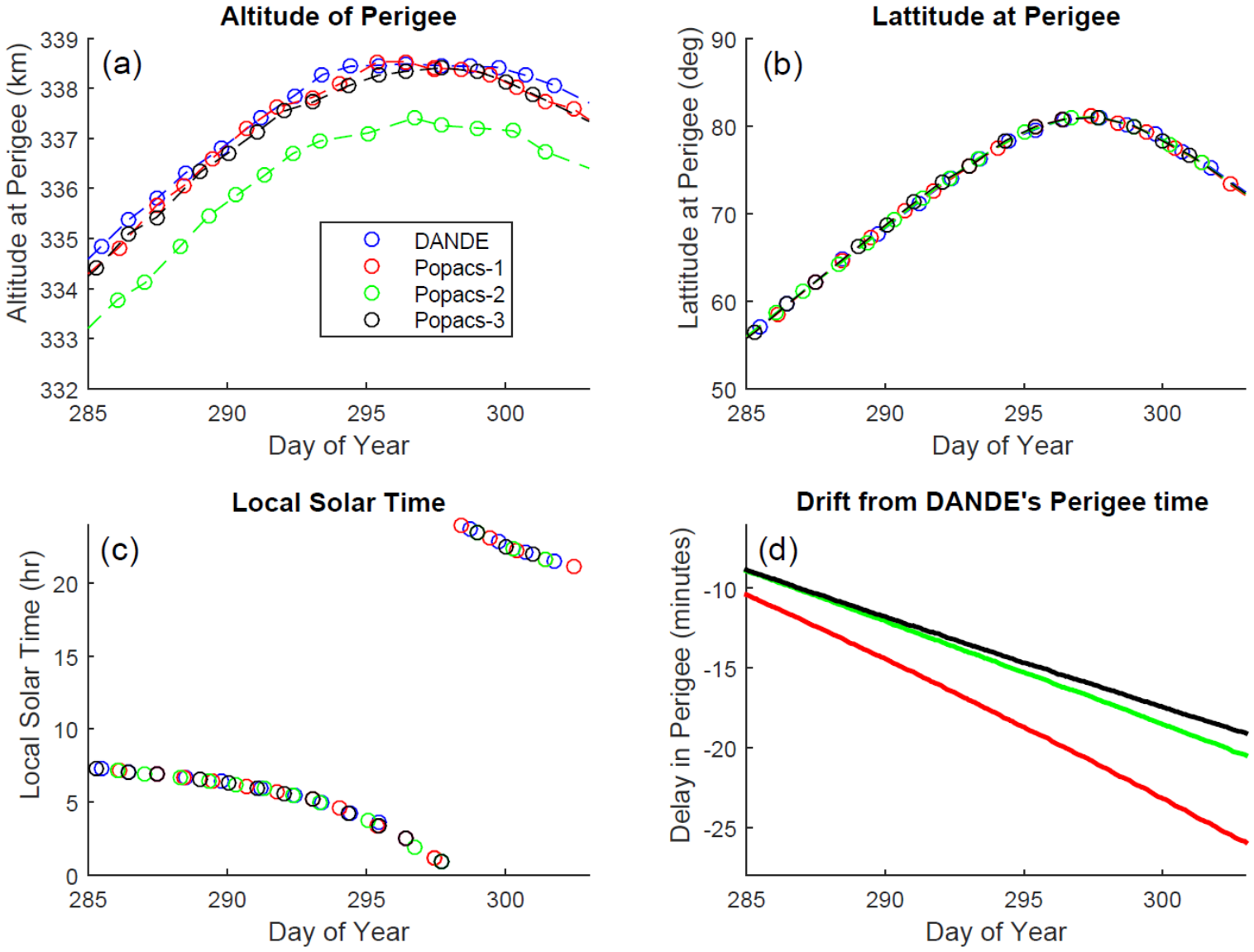
- CubeSats can be used as atmospheric calibration objects to improve orbit determination and tracking for the whole space community
- More POPACS-like spheres would be great but documenting the orientations, mass, and size of other CubeSats can still make them useful for atmospheric calibration
- The initial proximity of the POPACS satellites presents opportunities for studying spatial variability of the atmosphere at various scales

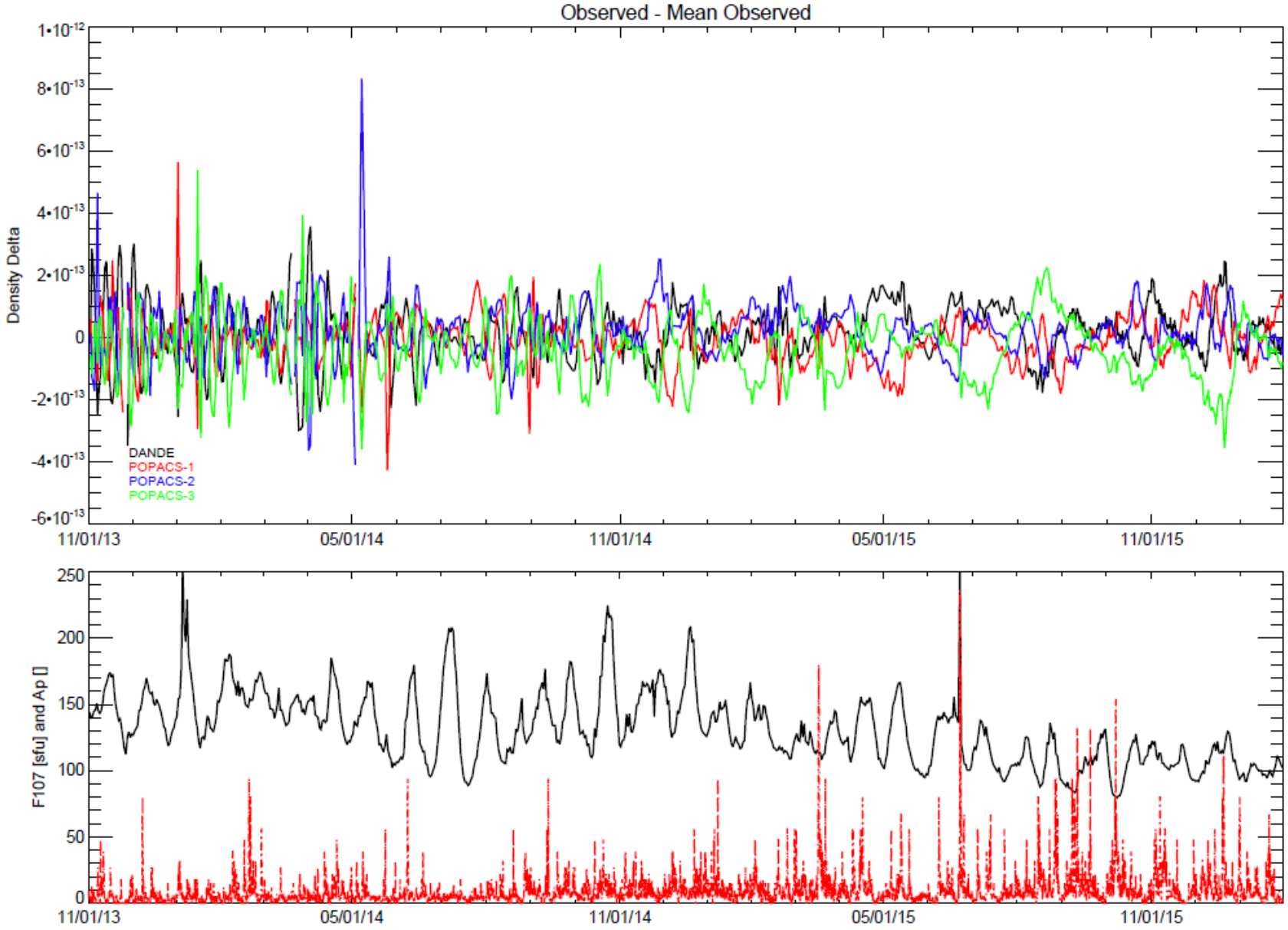
Backup Slides

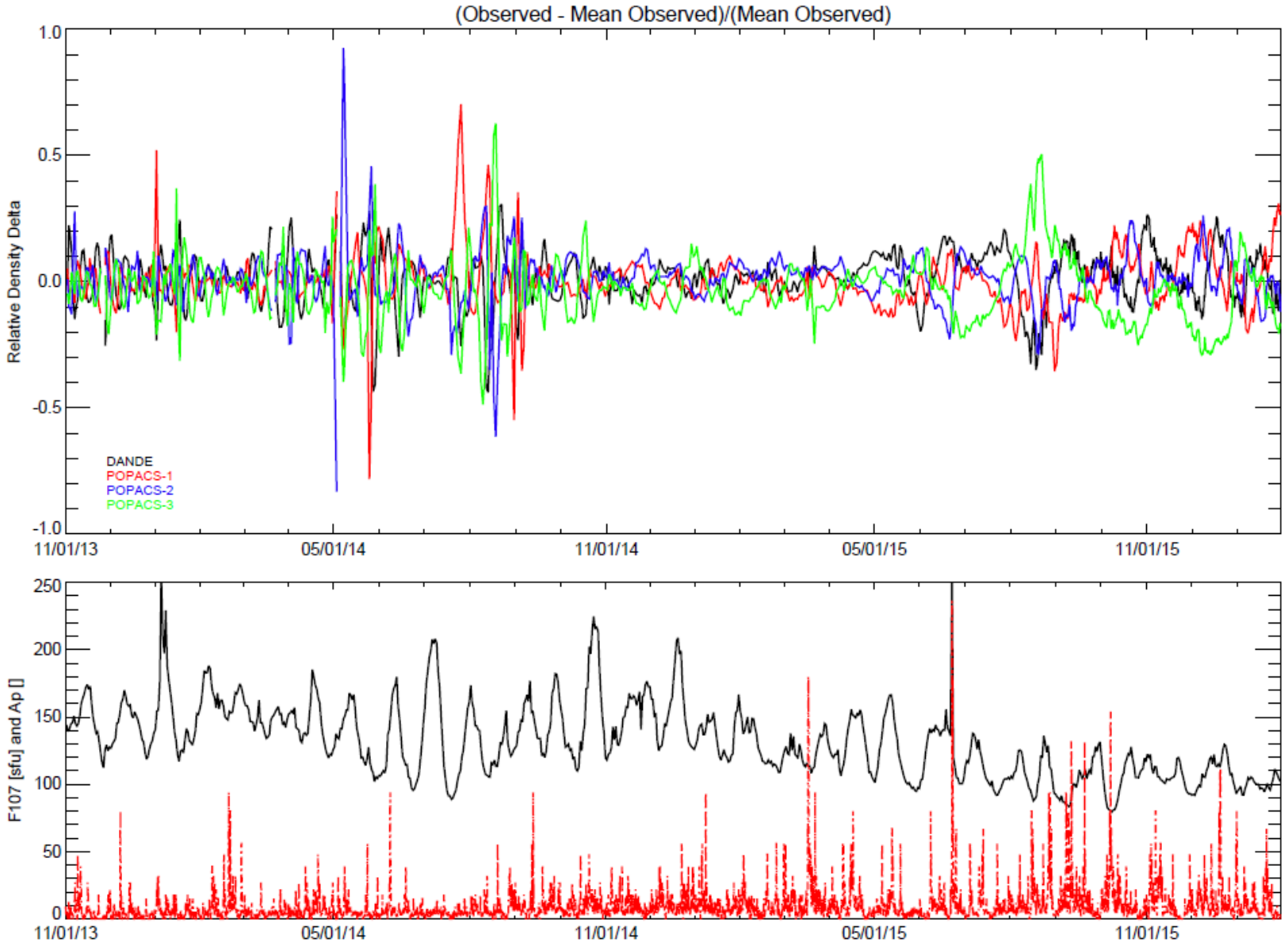
Solar Conditions



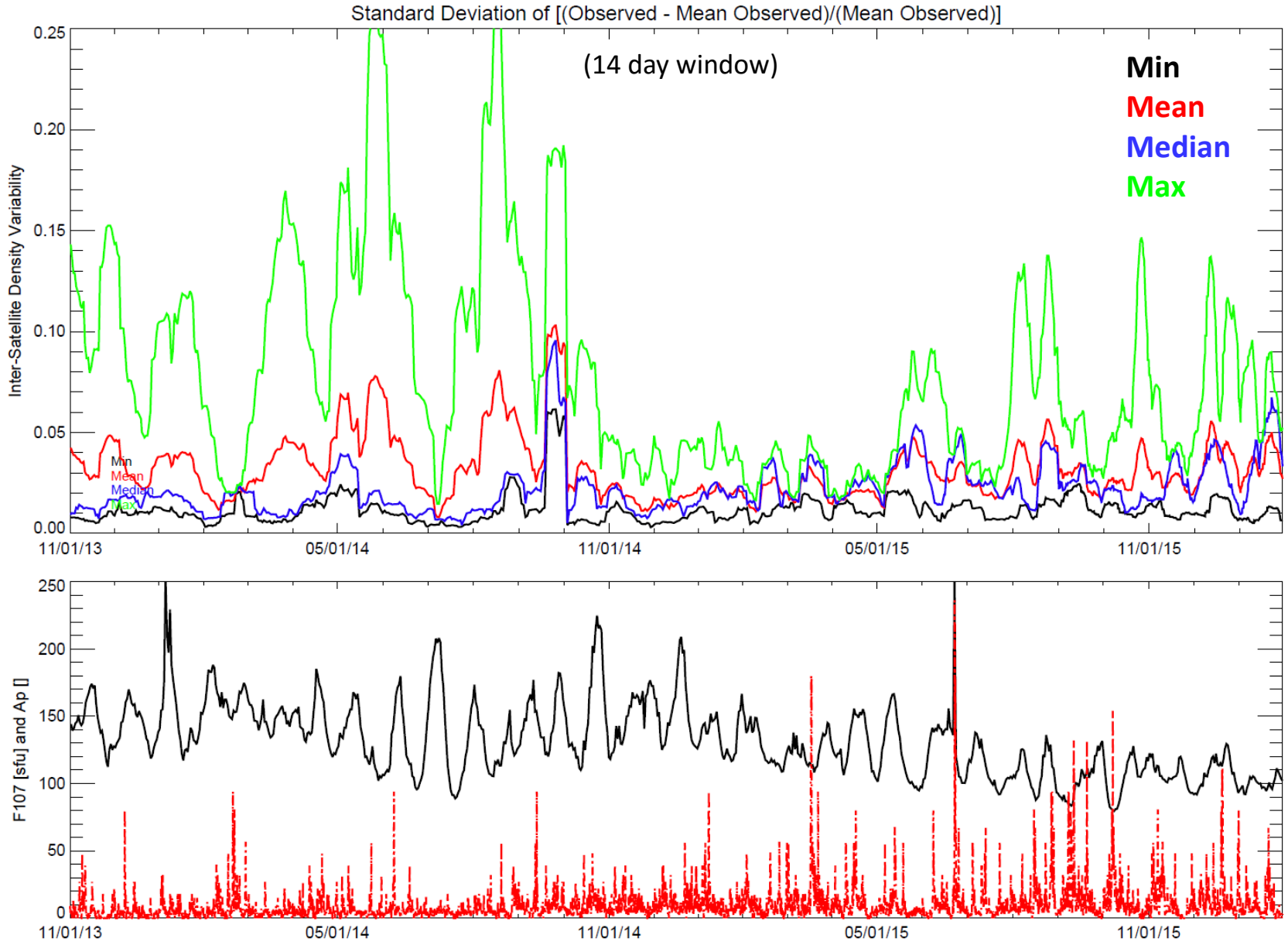
Initial Orbit Evolution




Observed - Mean Observed
Density Delta
1•10-12
8•10-13
6•10-13
4•10-13
2•10-13
0
-2•10-13
-4•10-13
-6•10-13
DANDE
POPACS-1
POPACS-2
POPACS-3
11/01/13
05/01/14
11/01/14
05/01/15
11/01/15
F107 [sfu] and Ap []
250
200
150
100
50
0
11/01/13
05/01/14
11/01/14
05/01/15
11/01/15


(Observed - Mean Observed)/(Mean Observed)
Relative Density Delta
1.0
0.5
0.0
-0.5
-1.0
DANDE
POPACS-1
POPACS-2
POPACS-3
11/01/13
05/01/14
11/01/14
05/01/15
11/01/15
F107 [sfu] and Ap []
250
200
150
100
50
0
11/01/13
05/01/14
11/01/14
05/01/15
11/01/15

Spatial Variability in the Atmosphere



Spatial Variability in the Atmosphere