Applied Astronomy: Optical Studies of Orbital Debris at Geosynchronous Orbit

Patrick Seitzer
Department of Astronomy
University of Michigan

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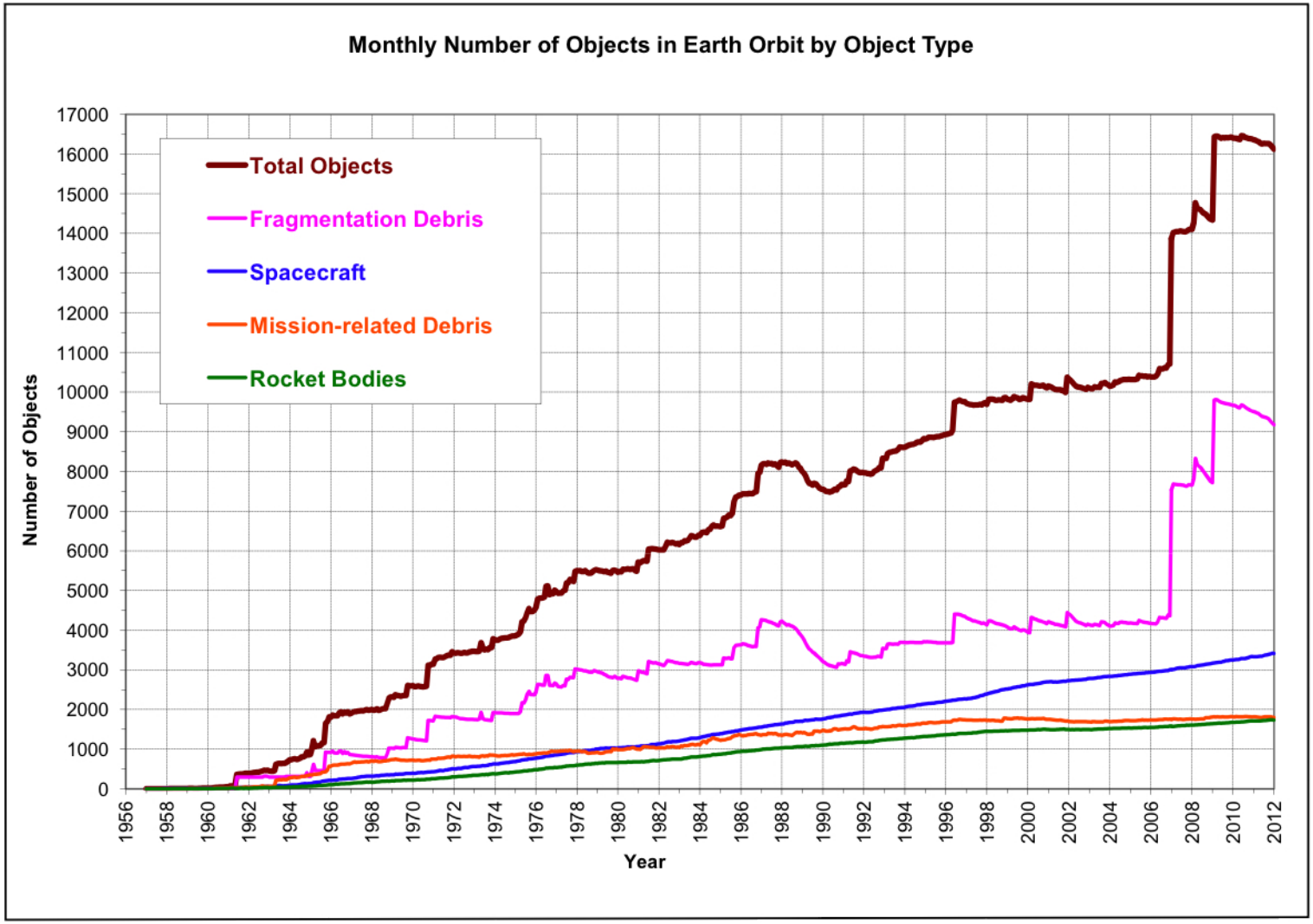
Today

- Intro to orbital/space debris – why do we care?
- Optical studies of orbital debris at GEO with UM's Curtis-Schmidt and Magellan telescopes

What is Orbital Debris?

- Spacecraft no longer active
- Rocket bodies
- Parts of spacecraft and rockets from fragmentation events.
- Junk – aperture covers, astronaut tool-kits, solid motor fuel, gloves, …..


Monthly Number of Objects in Earth Orbit by Object Type
Total Objects
Fragmentation Debris
Spacecraft
Mission-related Debris
Rocket Bodies
Number of Objects
Year
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000
17000
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
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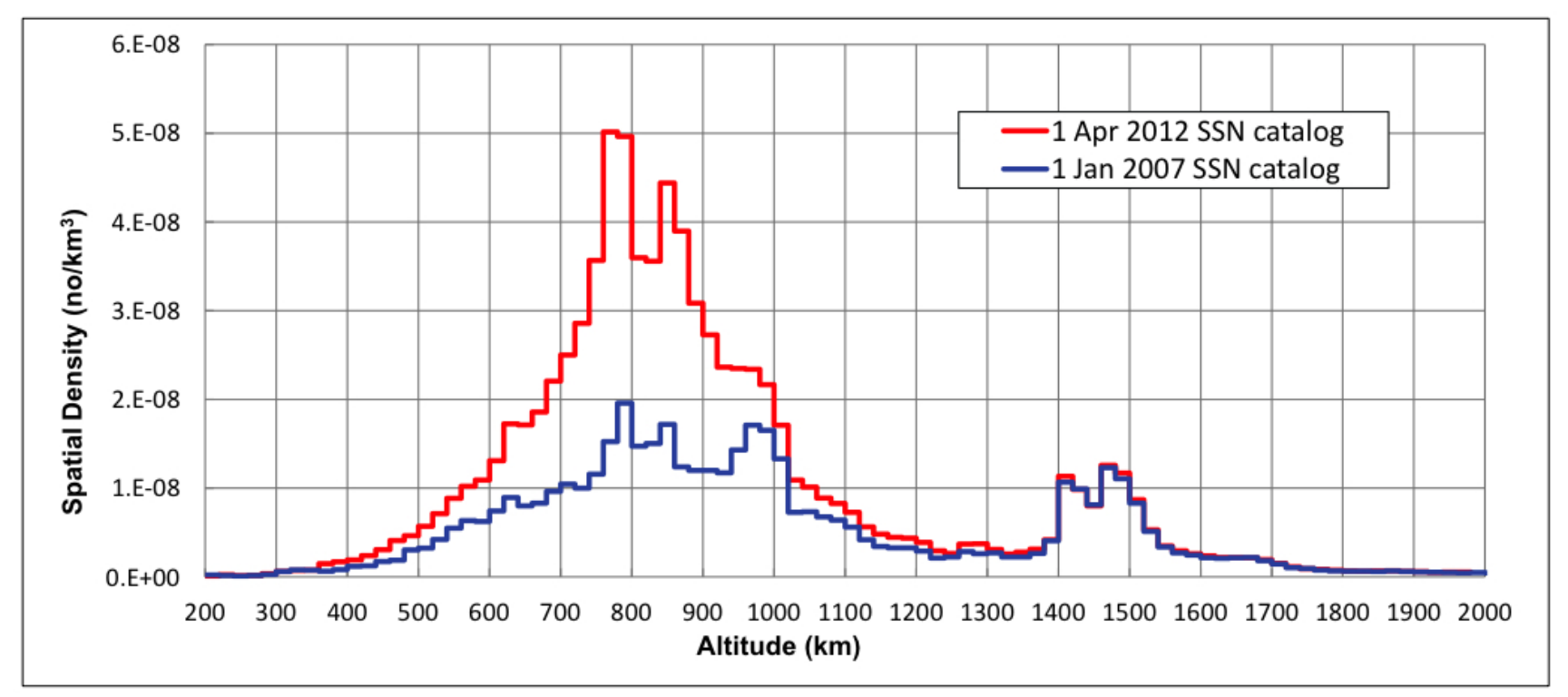
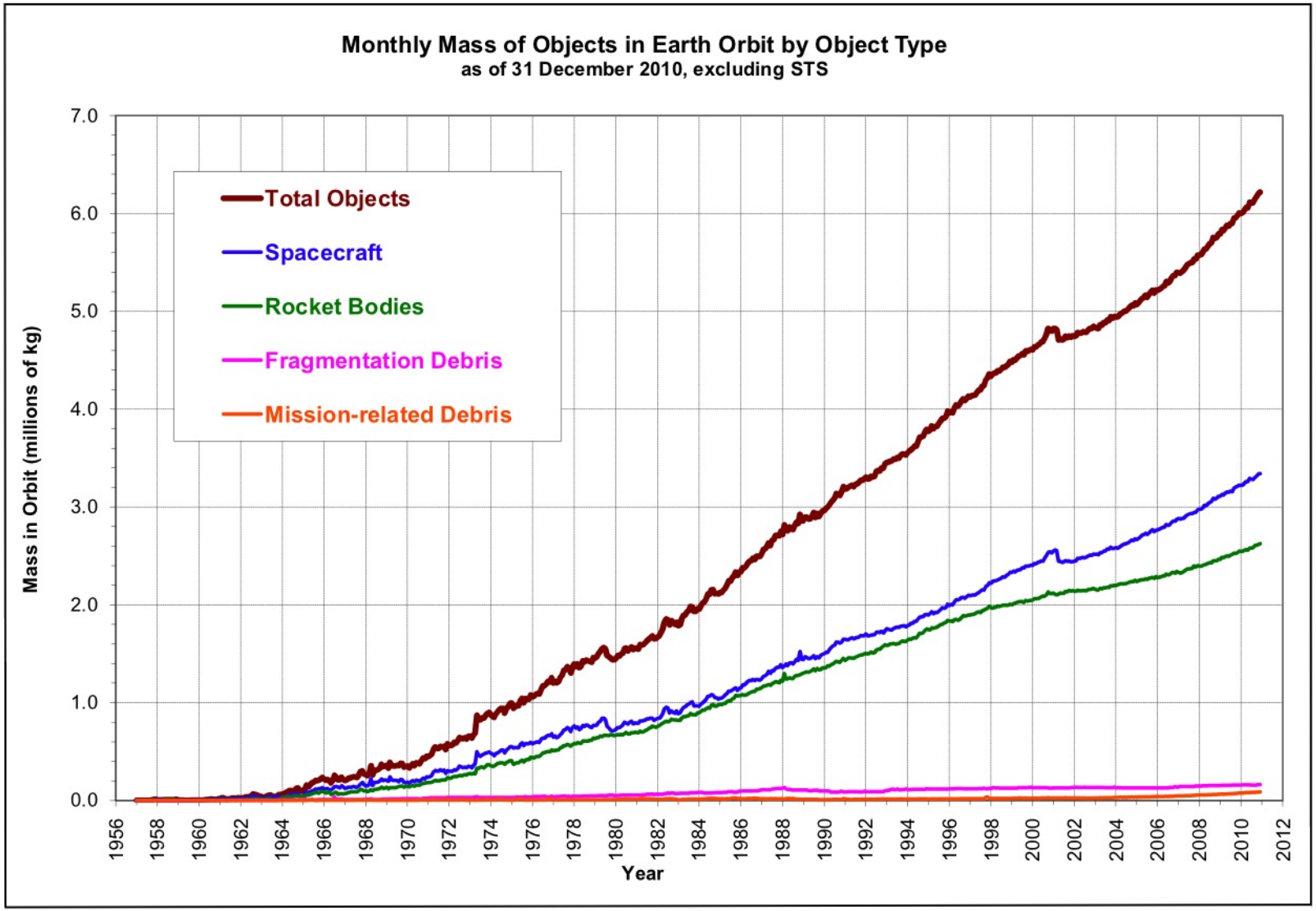
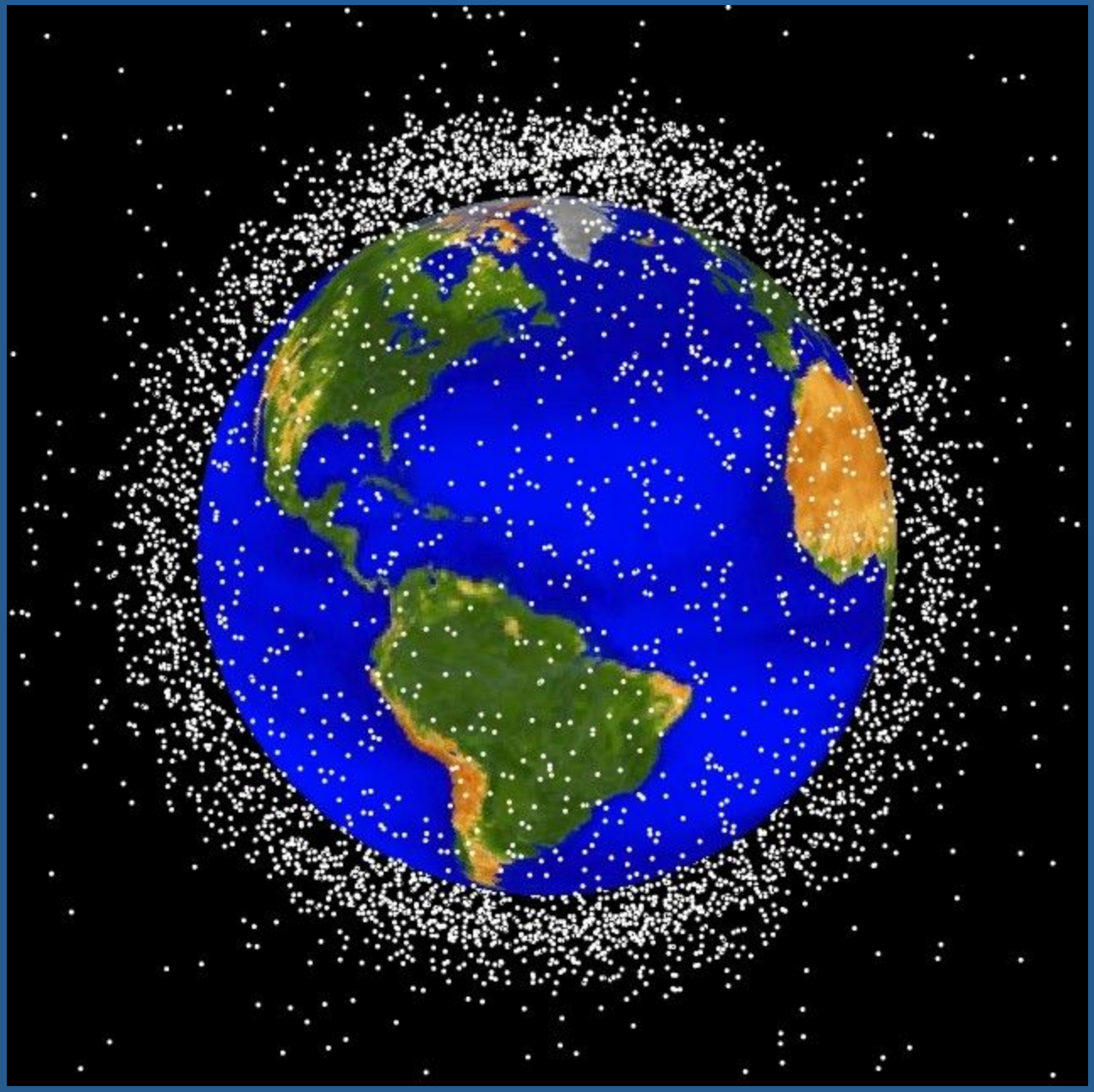
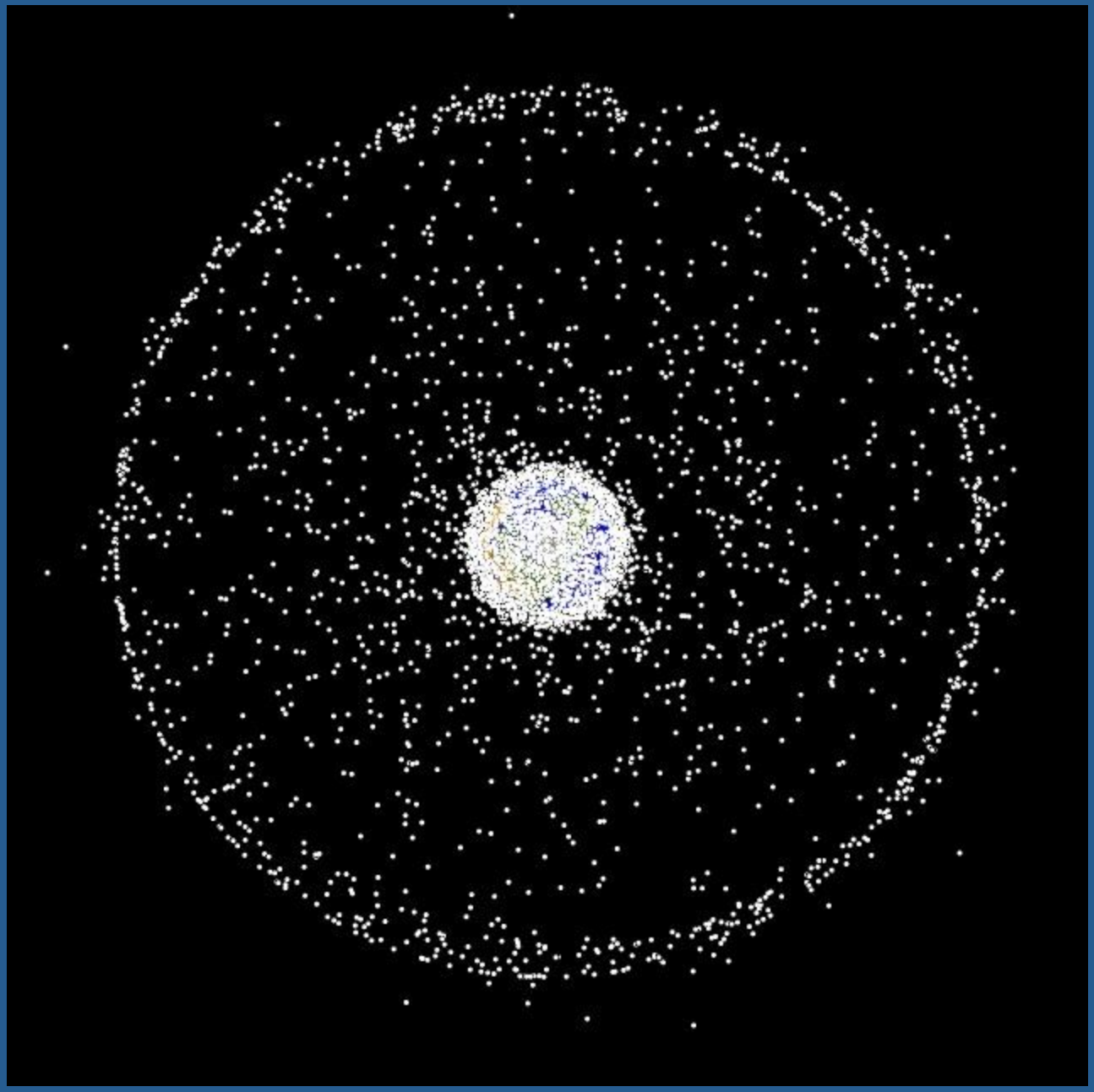
1998
2000
2002
2004
2006
2008
2010
2012

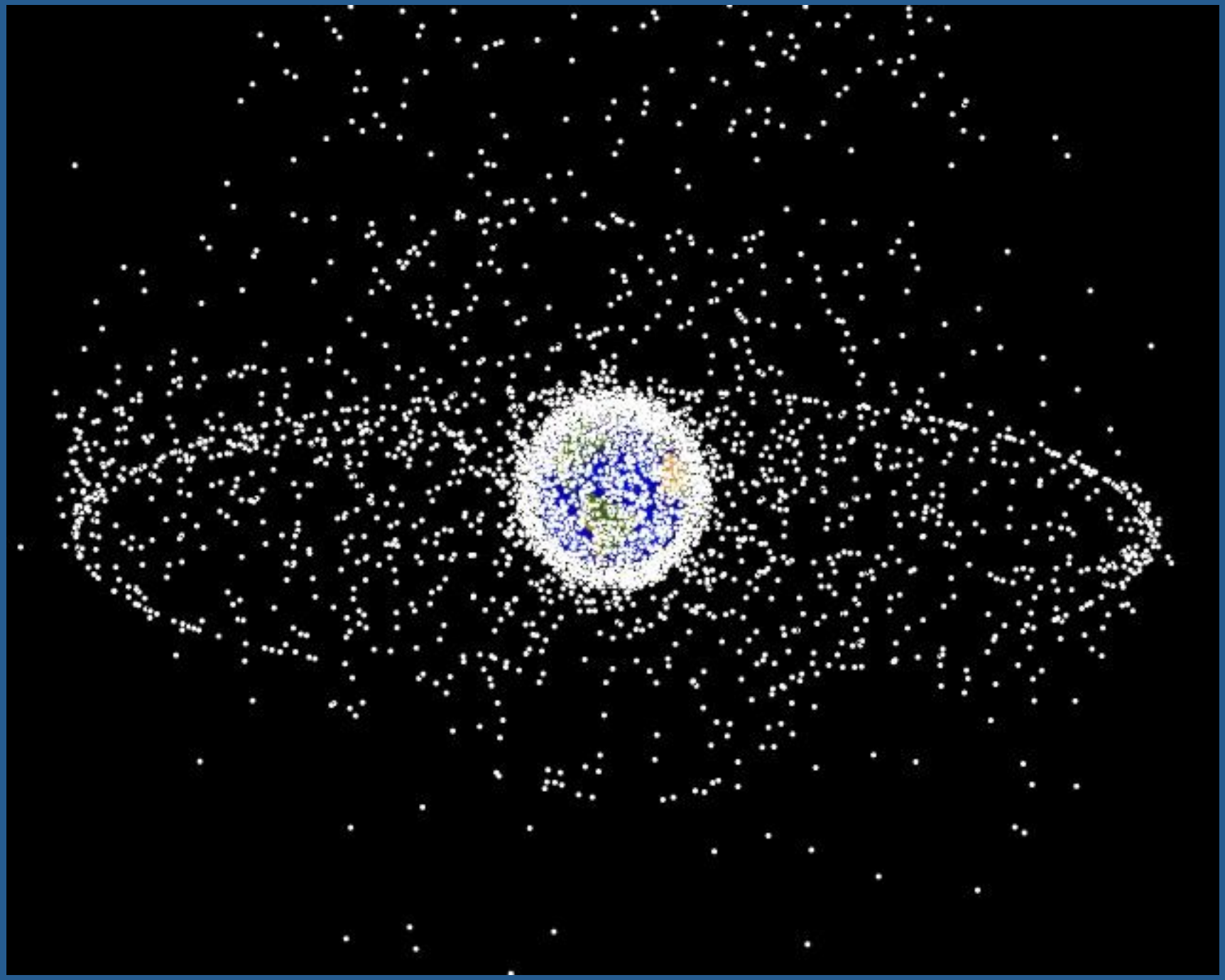

6.E-08
5.E-08
4.E-08
3.E-08
2.E-08
1.E-08
0.E+00
Spatial Density (no/km3)
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Altitude (km)
1 Apr 2012 SSN catalog
1 Jan 2007 SSN catalog



Monthly Mass of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.







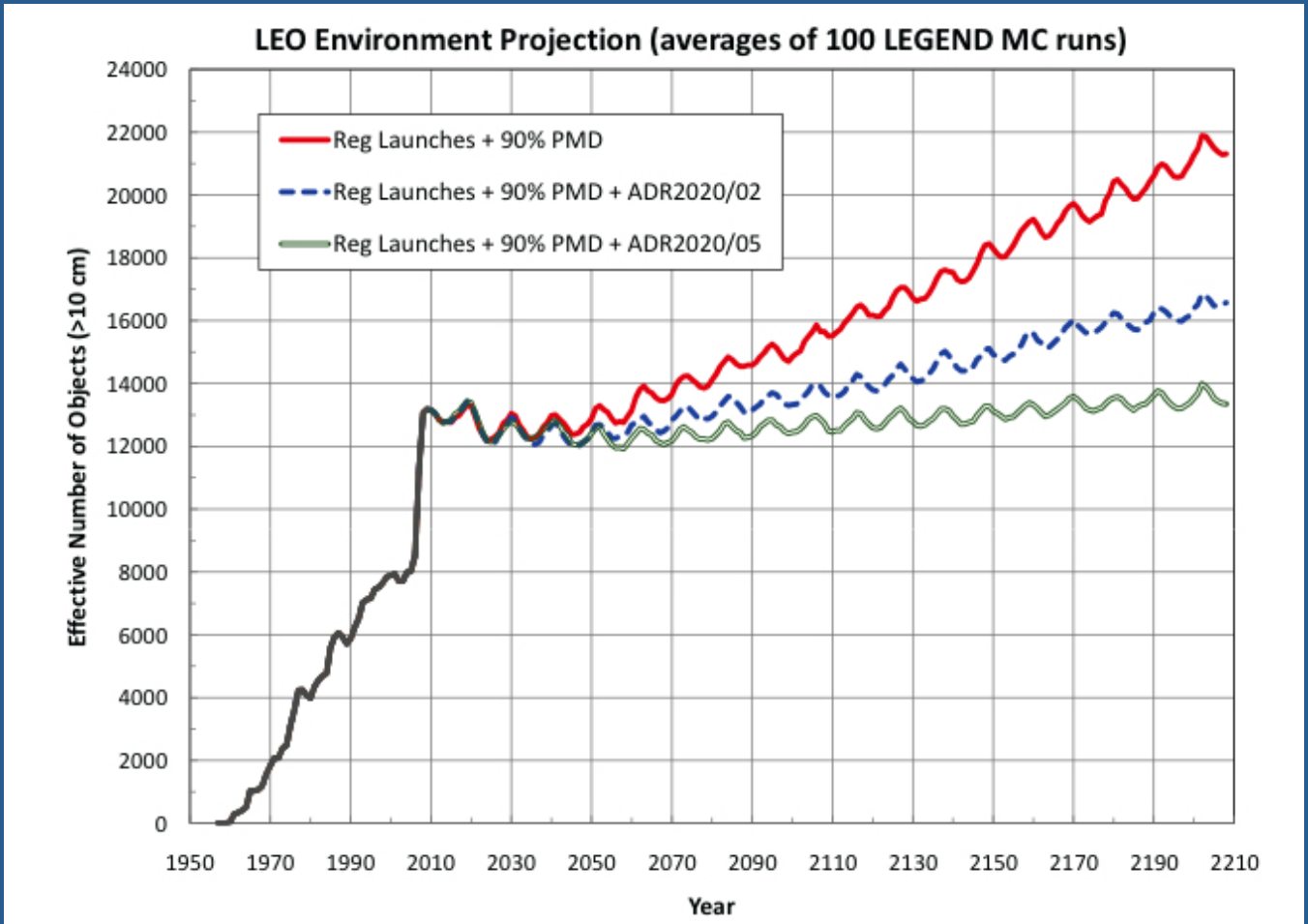
Mission Planning Essential

- Design of spacecraft to minimize debris generation during launch and operation.

- Post mission spacecraft disposal (PMD) – within 25 years of end of mission:
  - Disposal orbit, or
  - Complete destruction on re-entry into Earth's atmosphere – nothing reaches the ground – "Design to Demise"

Even if do nothing – worst is yet to come!

Models from J.C- Liou (NASA)



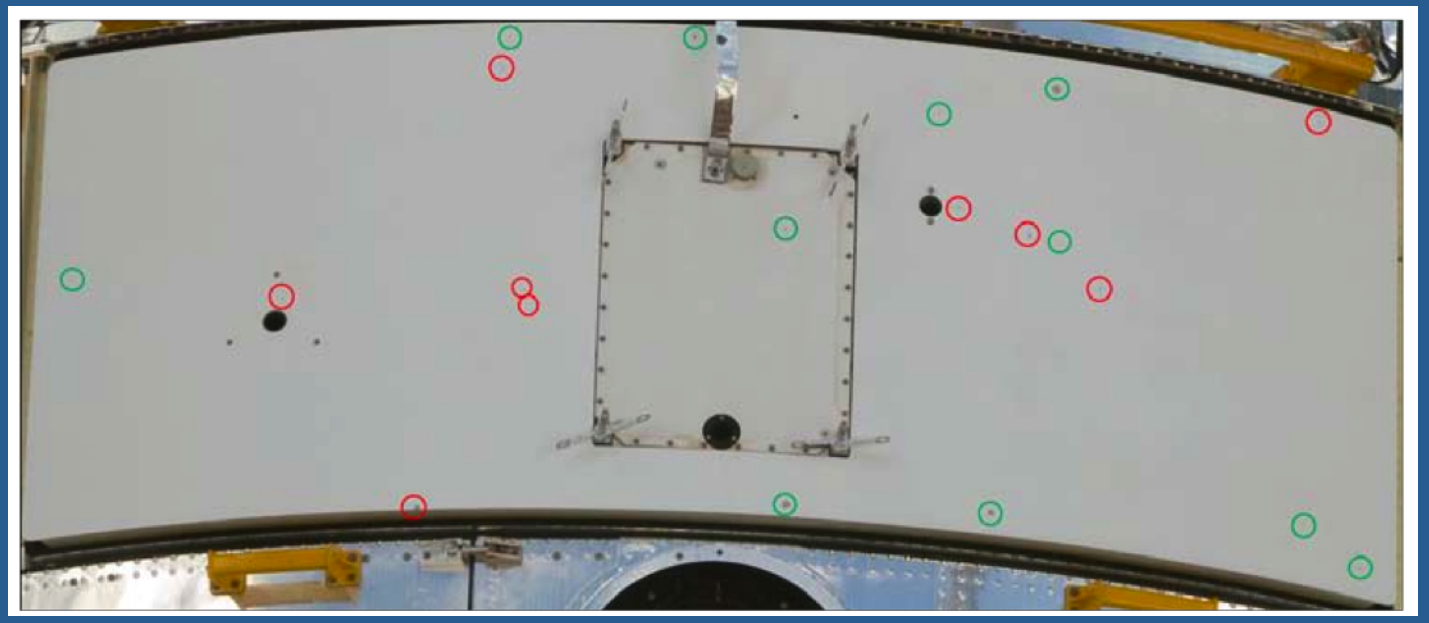
Kessler syndrome – N increases due to mutual collisions.


DON'T LET GO
SANDRA
BULLOCK
GEORGE
CLOONEY
GRAVITY
10.4.13

Why do we care ?

- Over 20 active astronomy missions in Low Earth Orbit (LEO – altitude less than 2000 km).
- Examples – HST, FERMI, GALEX, SWIFT, COROT
- More ready for launch and planned.
- Risk to these missions from debris.

impacts on spacecraft surface



2002

2009

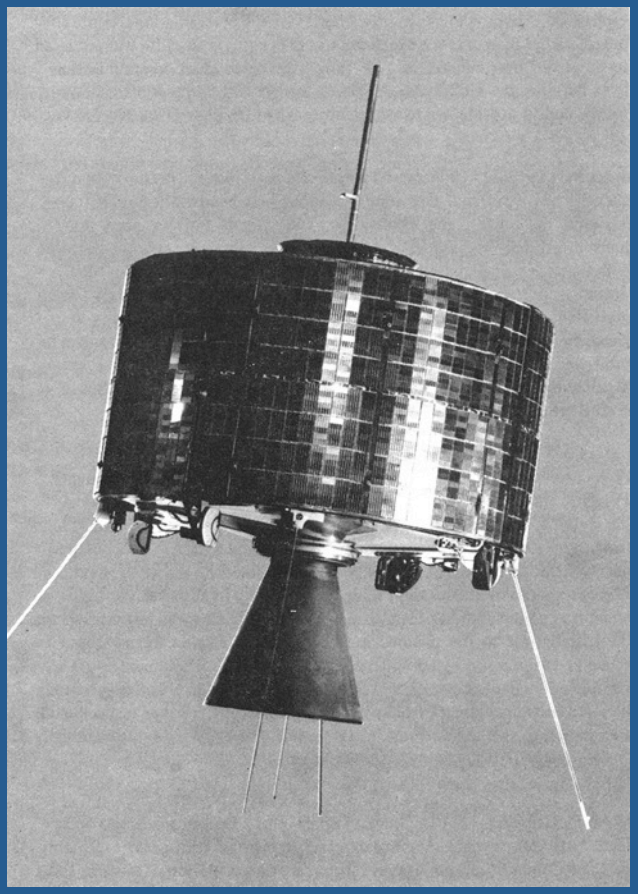

WFPC2 radiator
S125E007066

Optical Studies of Orbital Debris at Geosynchronous Orbit

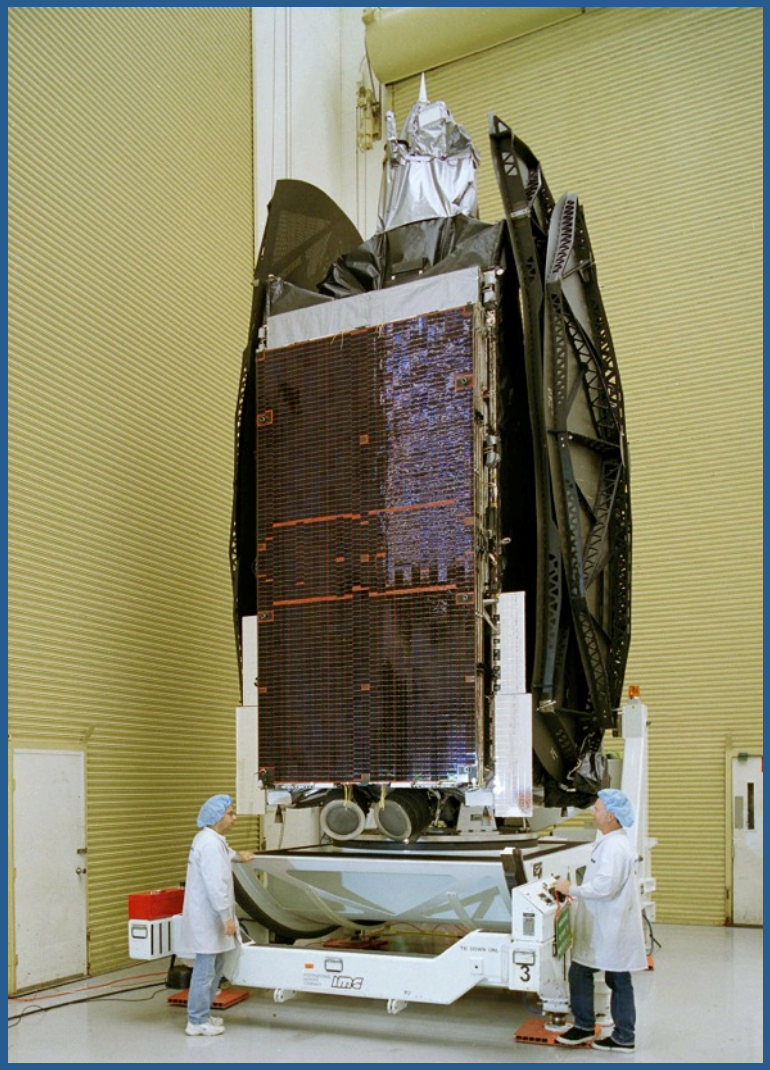
- Geosynchronous Earth orbit – GEO
  - Period = 23h56m = Earth's rotation period
  - Eccentricity = 0 ; Inclination = 0 degrees
- Over 250 active satellites in this regime – communications, weather, ??
- Most important single orbit there is.
- Study at optical rather than radar due to r^4 losses in radar.

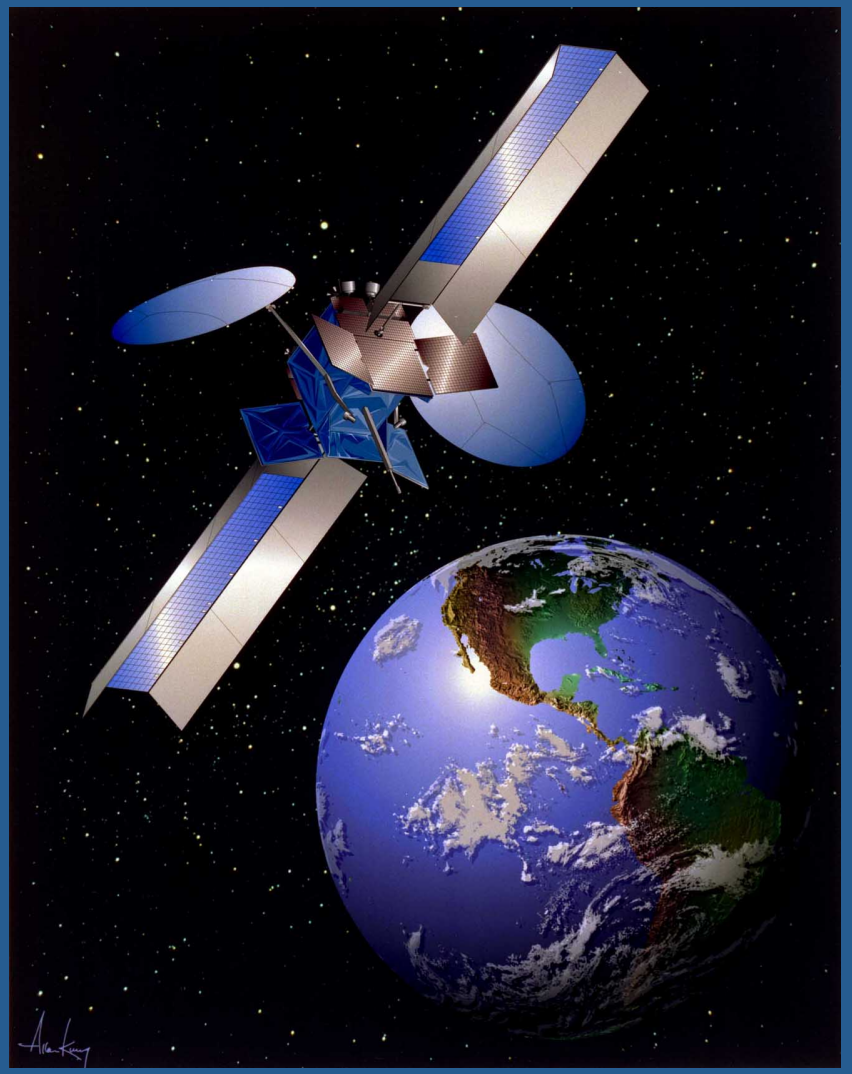
Syncom 1 – launched February 14, 1963

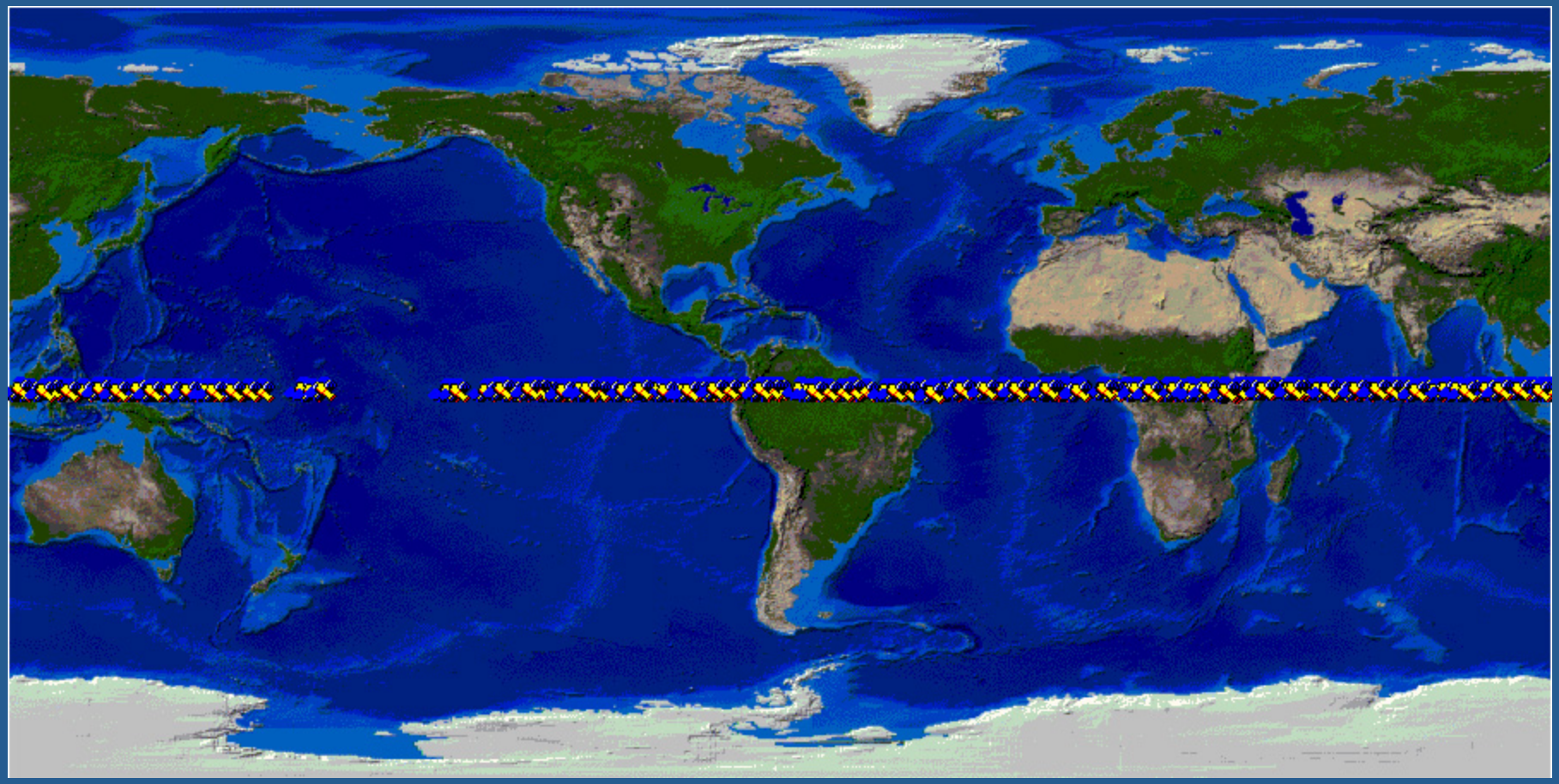
Failed on orbit insertion – 1st piece of GEO debris!

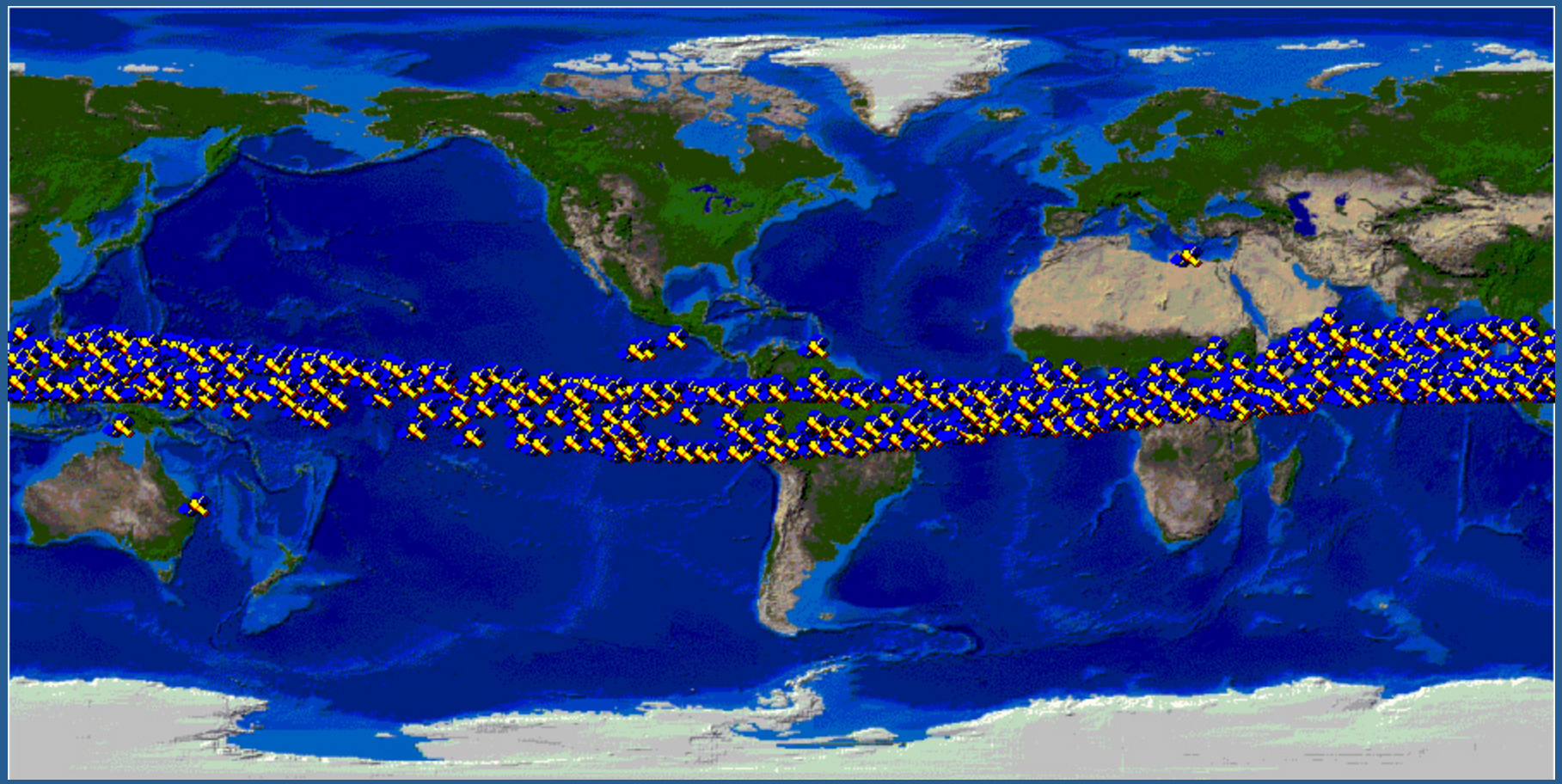


Example of recent GEO payload: XM-2 “Rock” satellite for direct broadcast radio





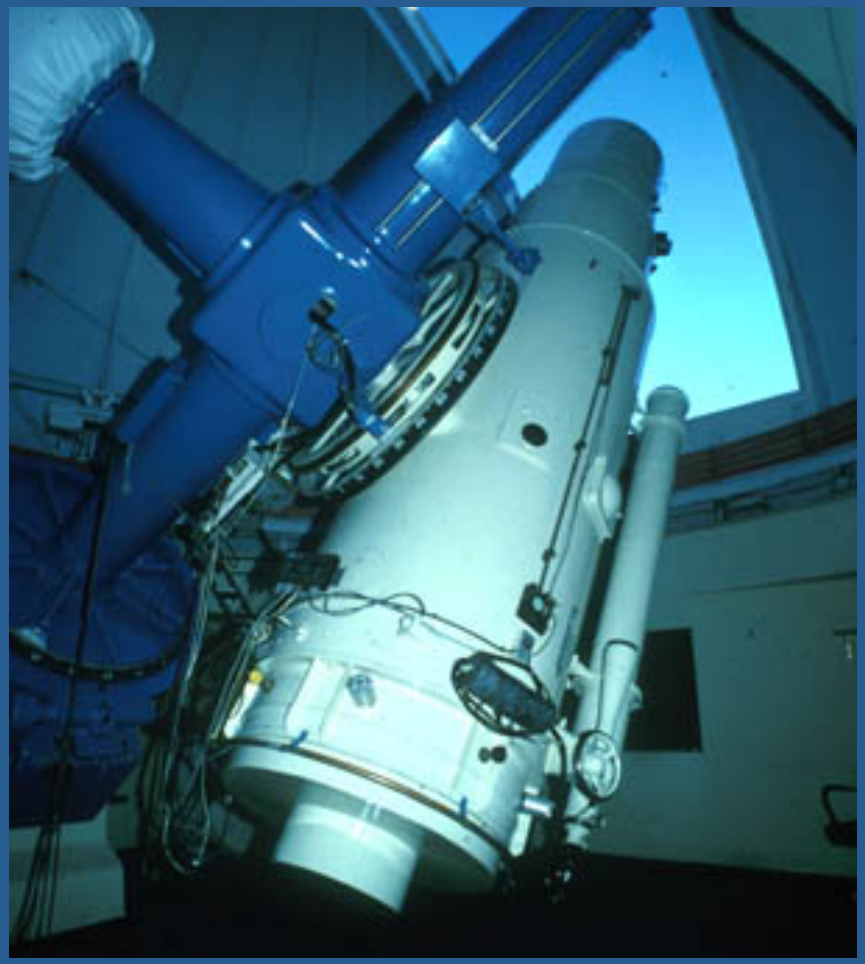




MODEST – **M**ichigan **O**rbital **DE**bris **S**urvey **T**elescope

the telescope formerly known as the Curtis-Schmidt

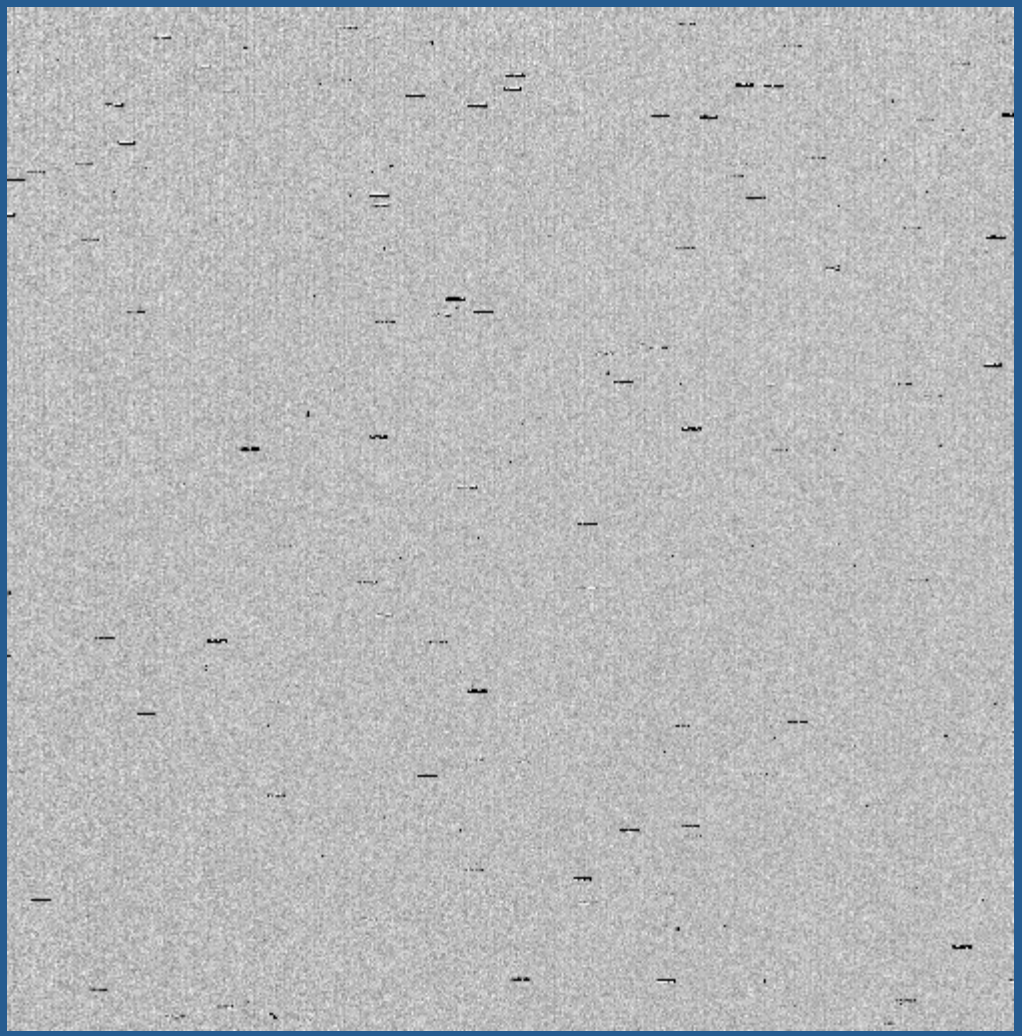
Cerro Tololo Inter-American Observatory, Chile



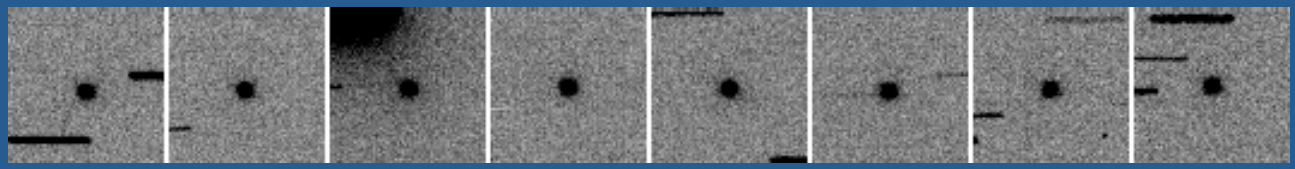
0.61-m Schmidt telescope
GEO debris survey began February 2001

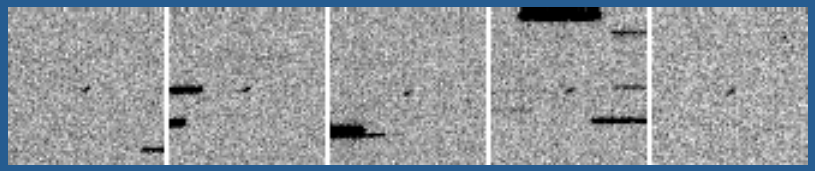
GEO Debris Survey

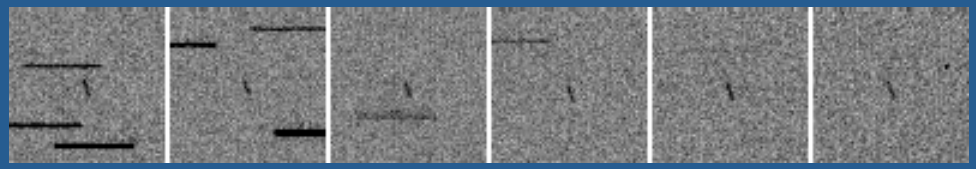
- Scanning CCD through a broad R filter (V+R).
- 5 second exposure every 37.9 seconds as track position of constant right ascension and declination all night long close to anti-solar point.
- Cover strip over 100 degrees long by 1.3 degrees high each night.
- Average of 8 detections of each GEO object as it crosses field of view in 5.2 minutes – allows determination of position, brightness, and angular motion.
- 4 detections required for real object, corresponds to S/N = 10 for each detection.



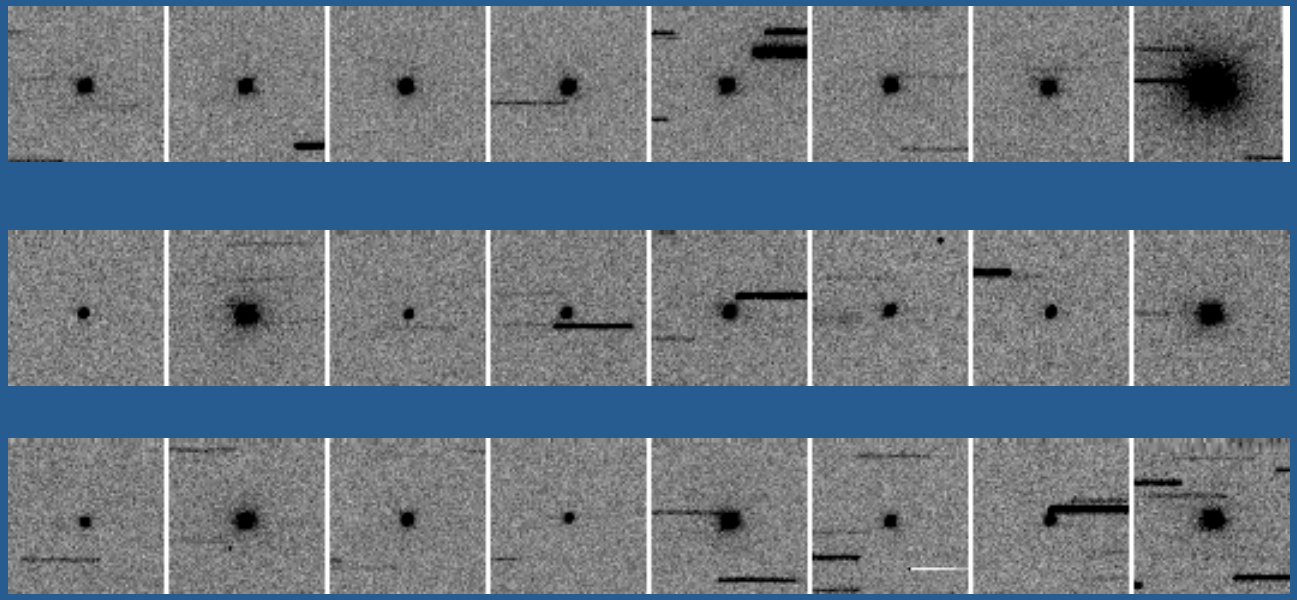
Examples of Detections

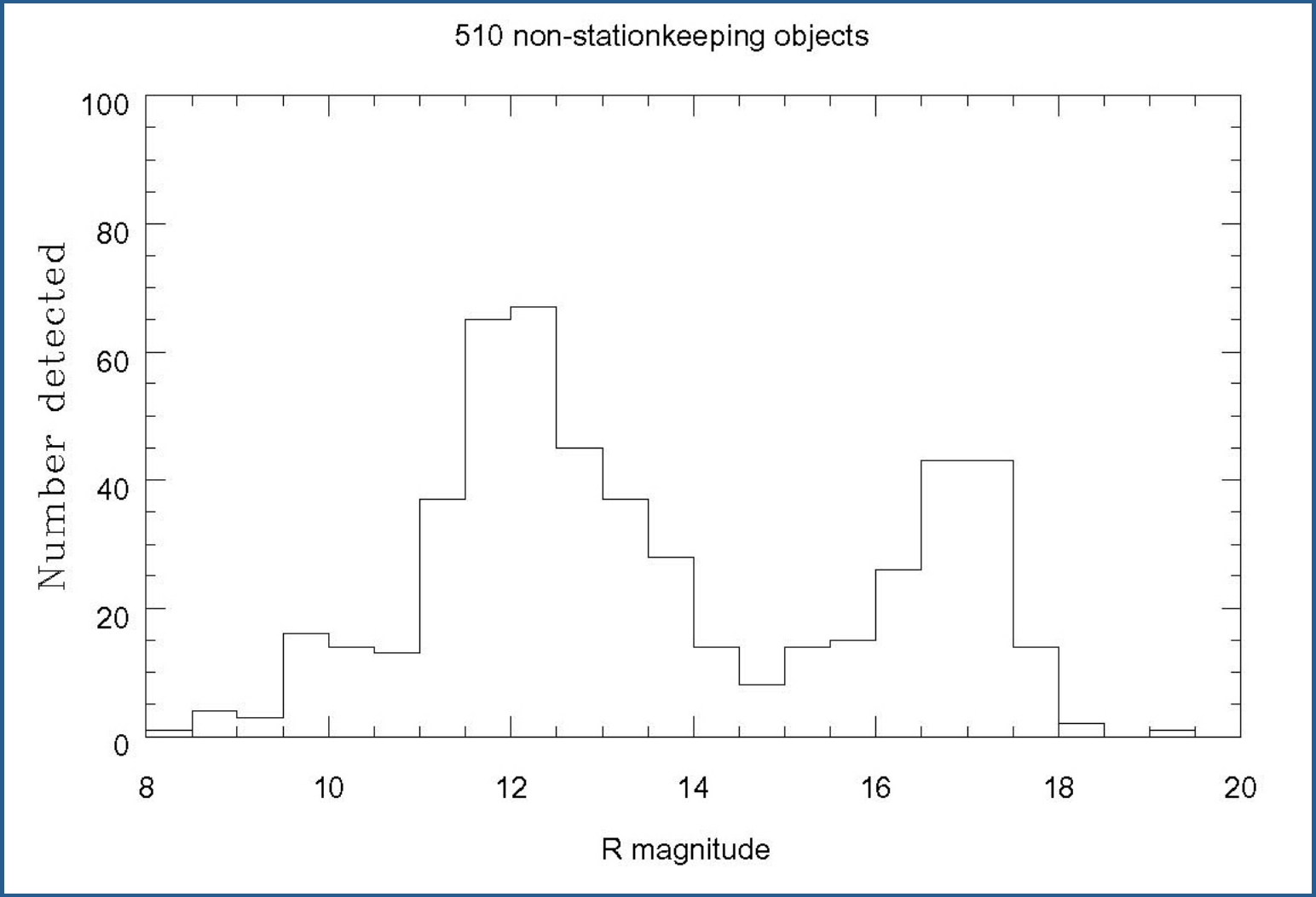




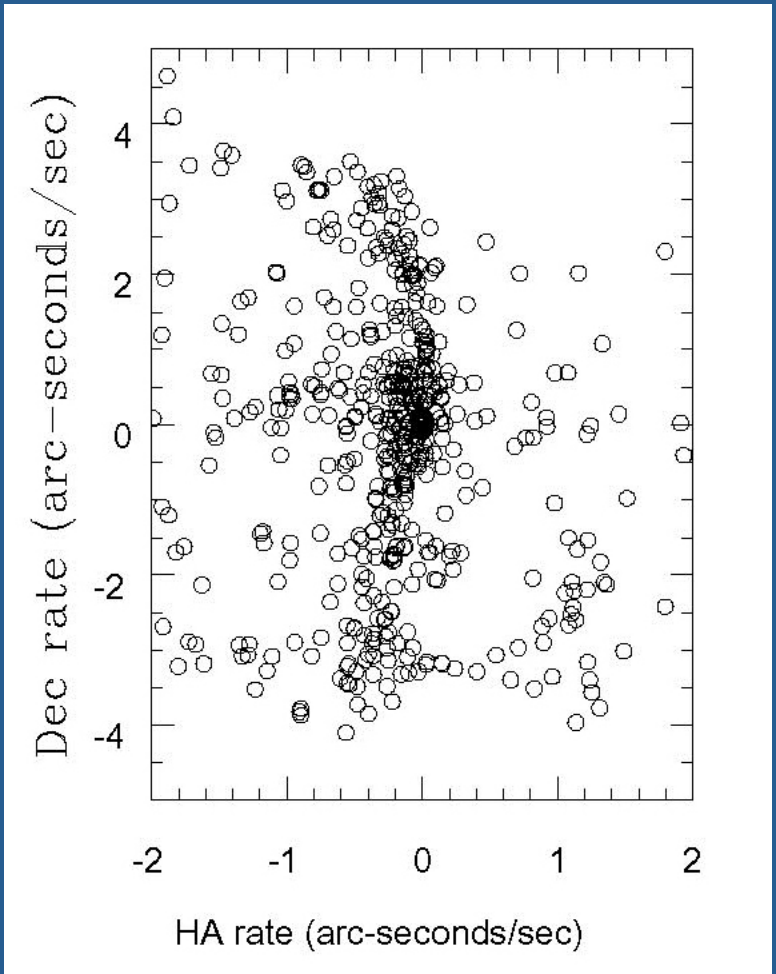


Debris Shape - Brightness Variations Common

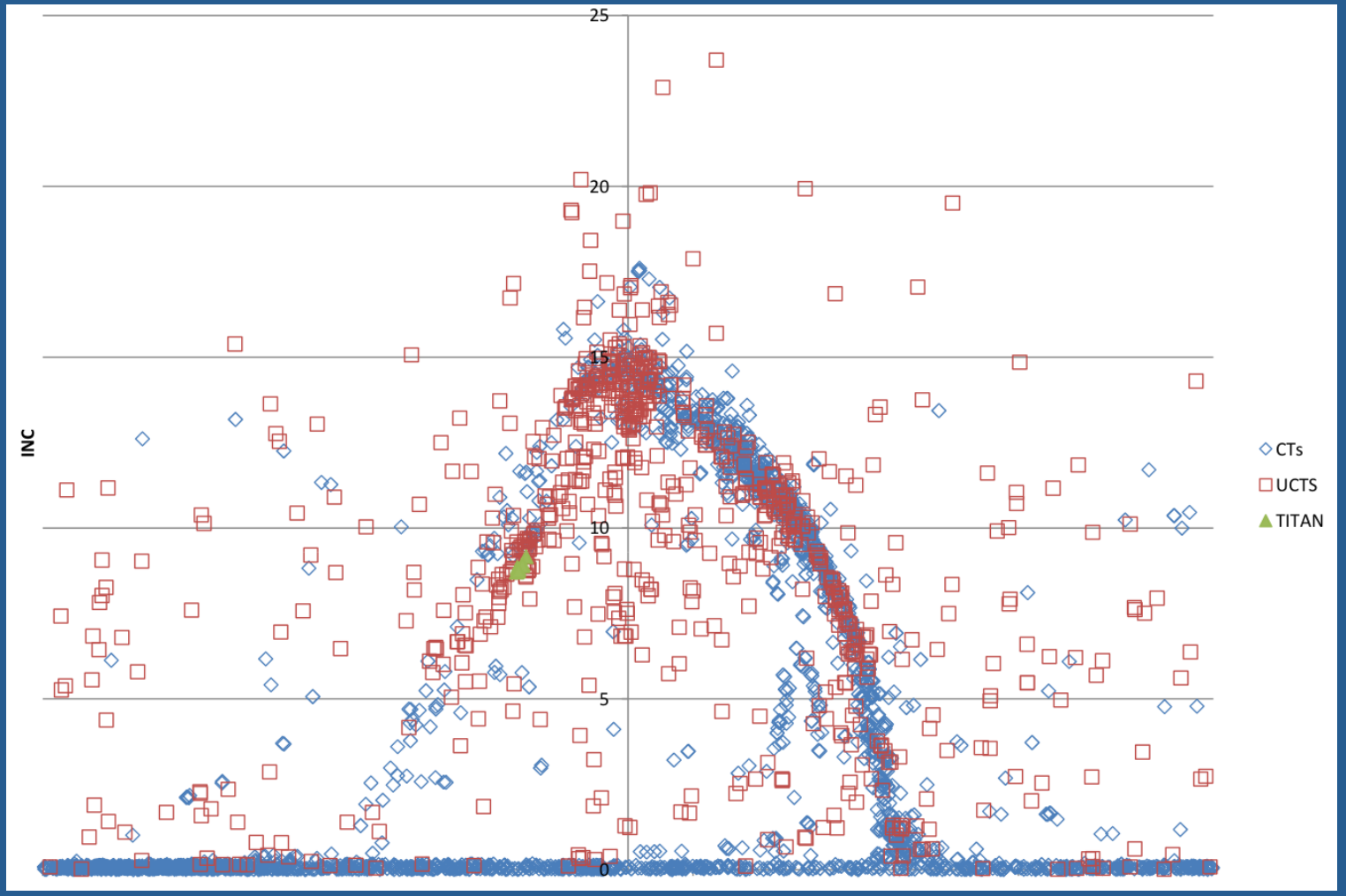



510 non-stationkeeping objects
Number detected
100
80
60
40
20
0
8
10
12
14
16
18
20
R magnitude

Observed Angular Rates

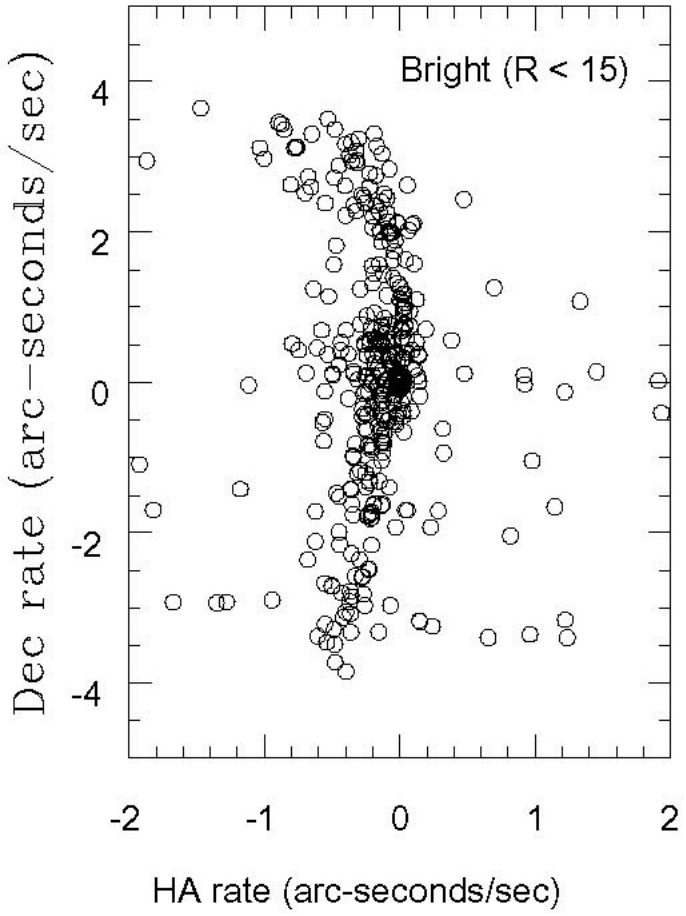


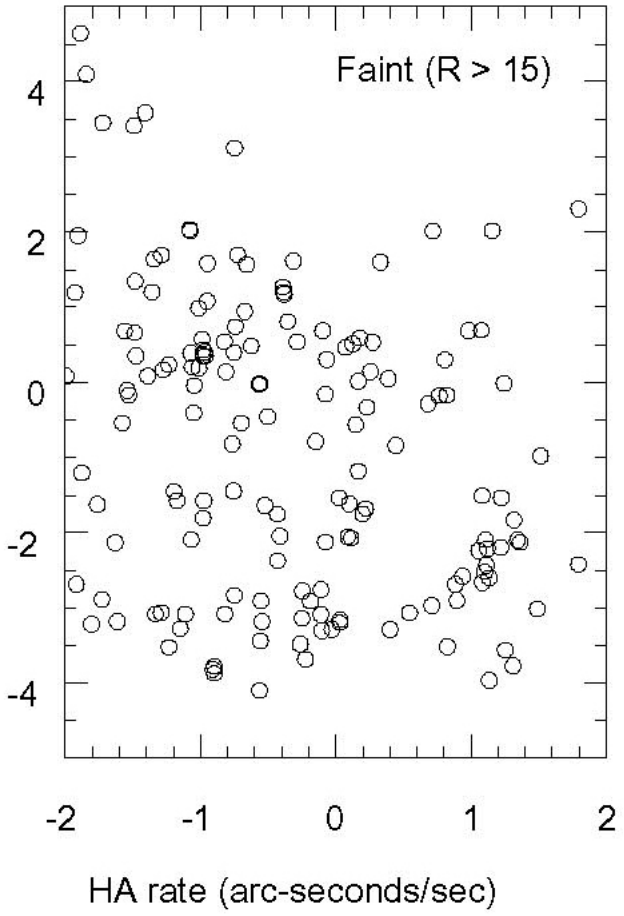
GEO: Right Ascension of Ascending Node vs Inclination



RAAN

Two Populations at GEO



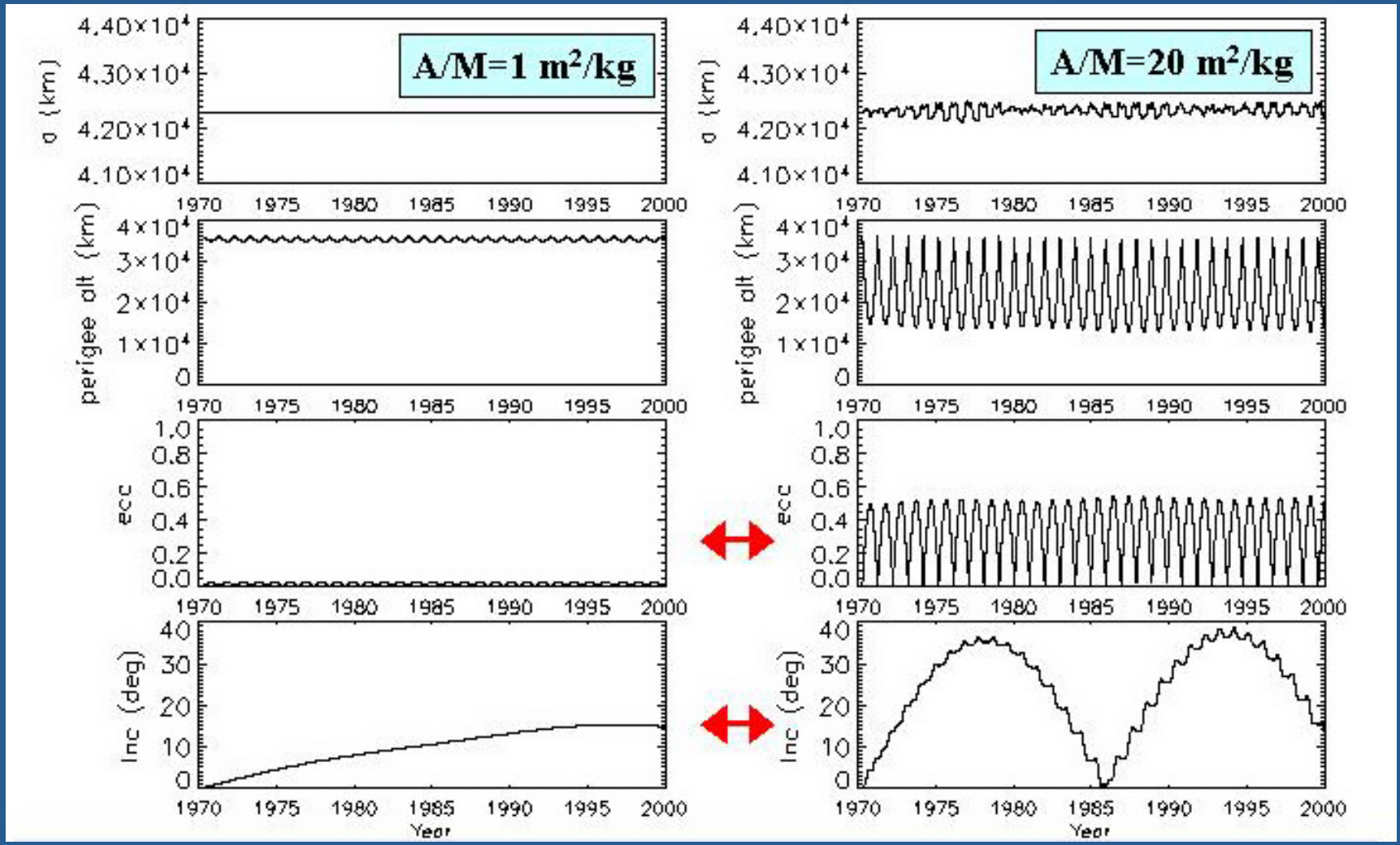


High Area-to-Mass Ratio Material (A/M)

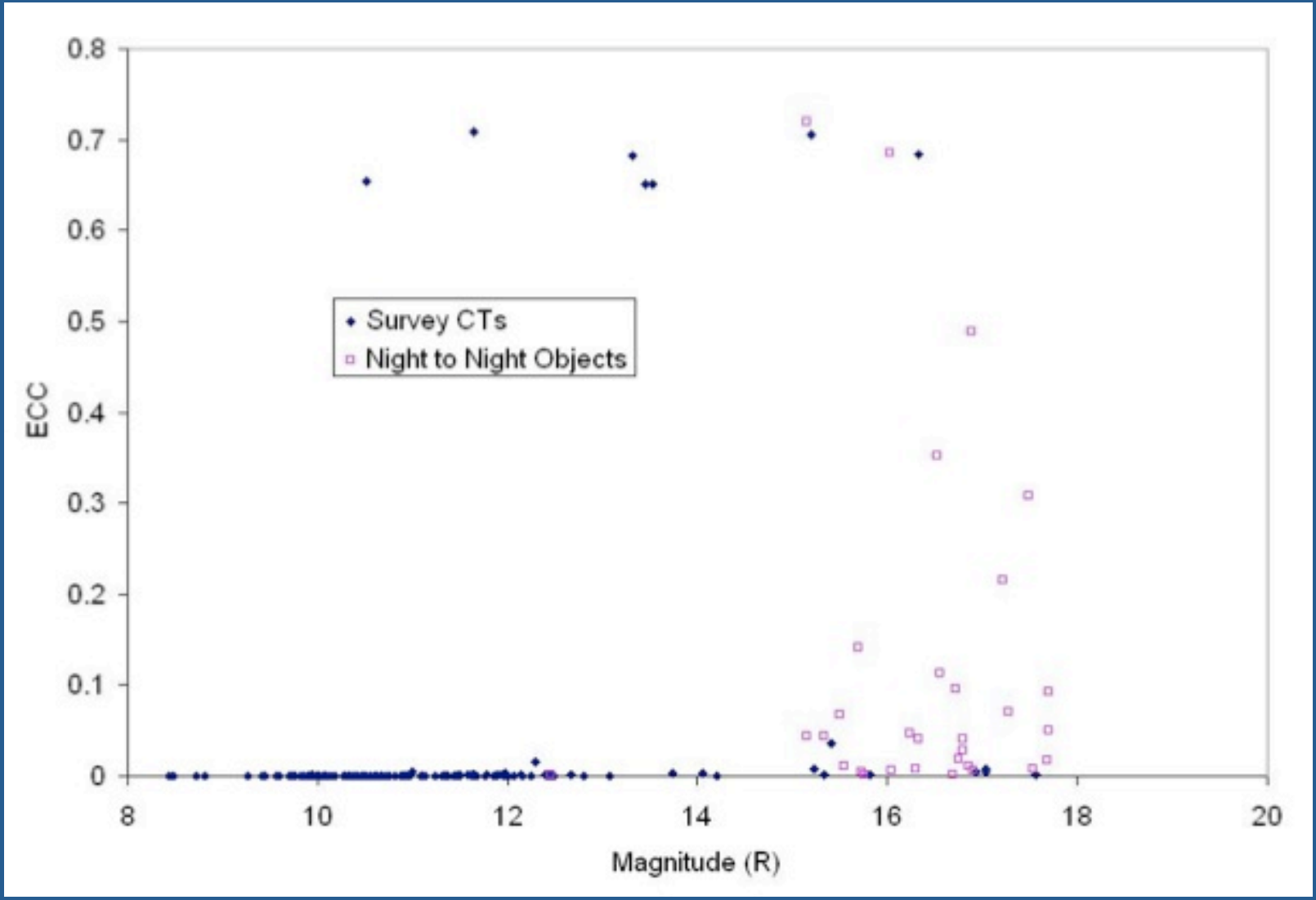
- Consider sheets of
  - Aluminum foil
  - Spacecraft insulation blankets (MLI)
  - Highly reflective, not very massive.
  - Orbits significantly perturbed by solar radiation pressure.
  - See models by Liou & Weaver (2005)

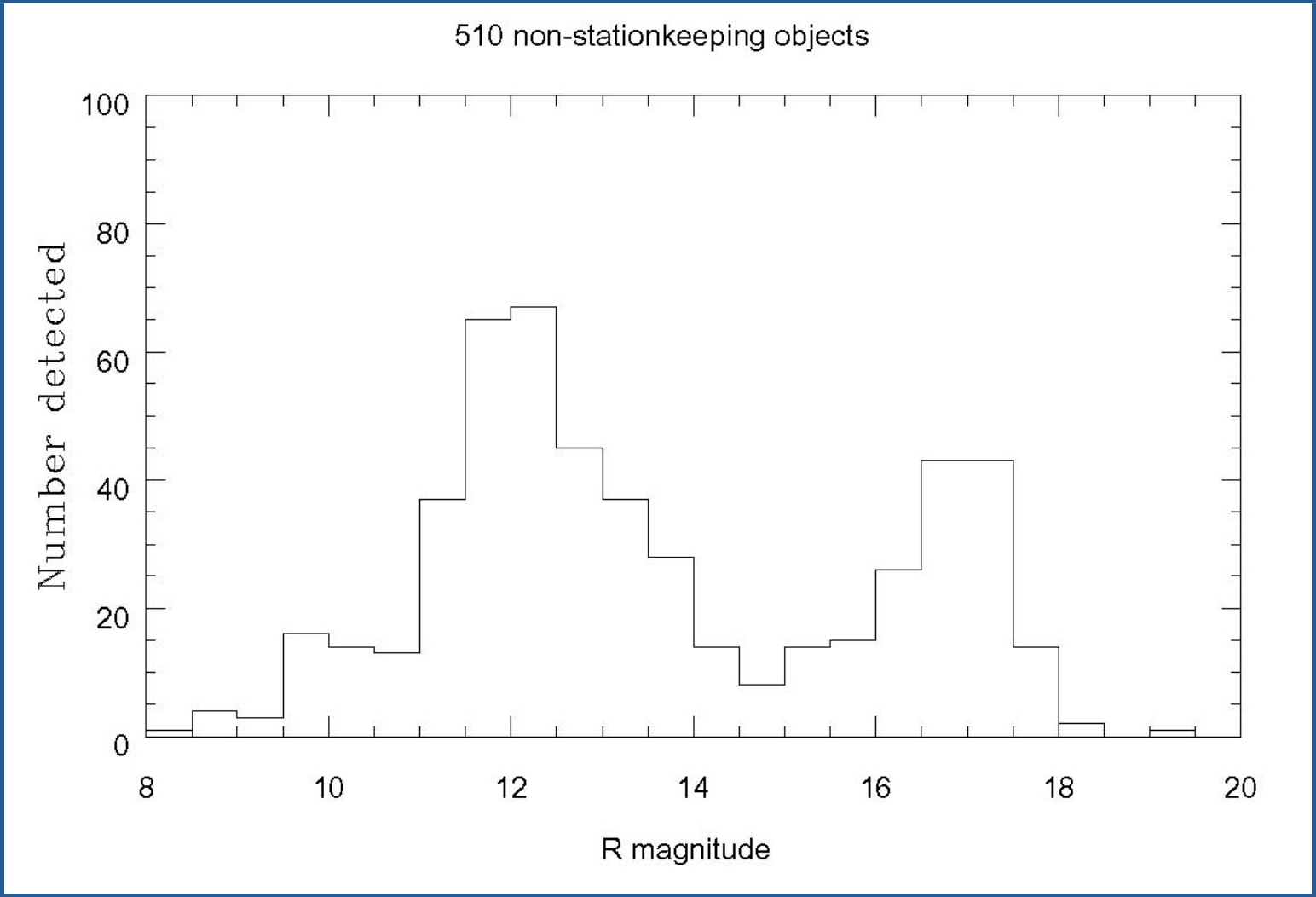
  - ‘Dark matter’ debris (ball bearings) have low A/M; dominant perturbations from gravitational effects.

Liou & Weaver (2005) models



Magnitude vs Eccentricity

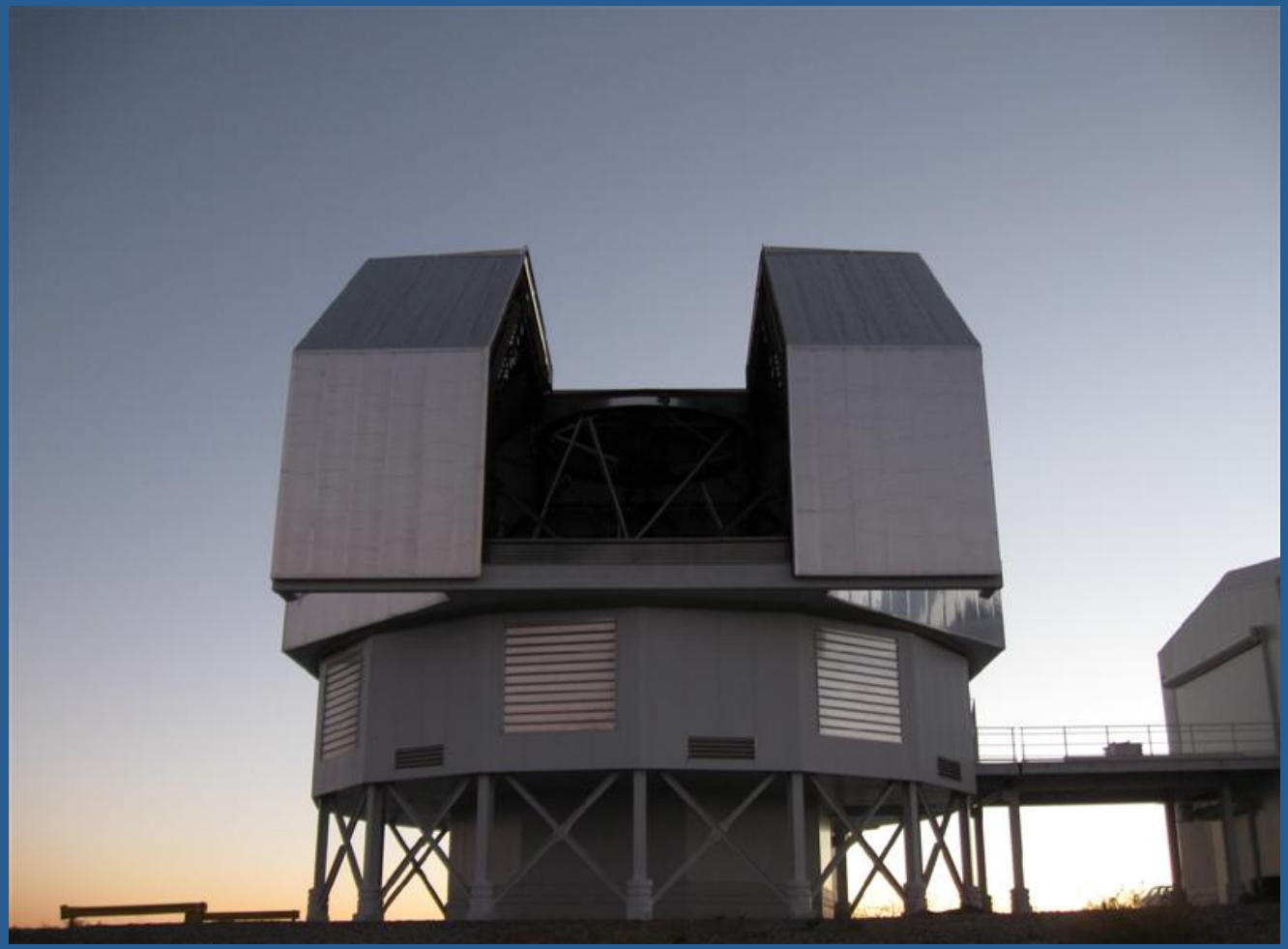



510 non-stationkeeping objects
Number detected
100
80
60
40
20
0
8
10
12
14
16
18
20
R magnitude

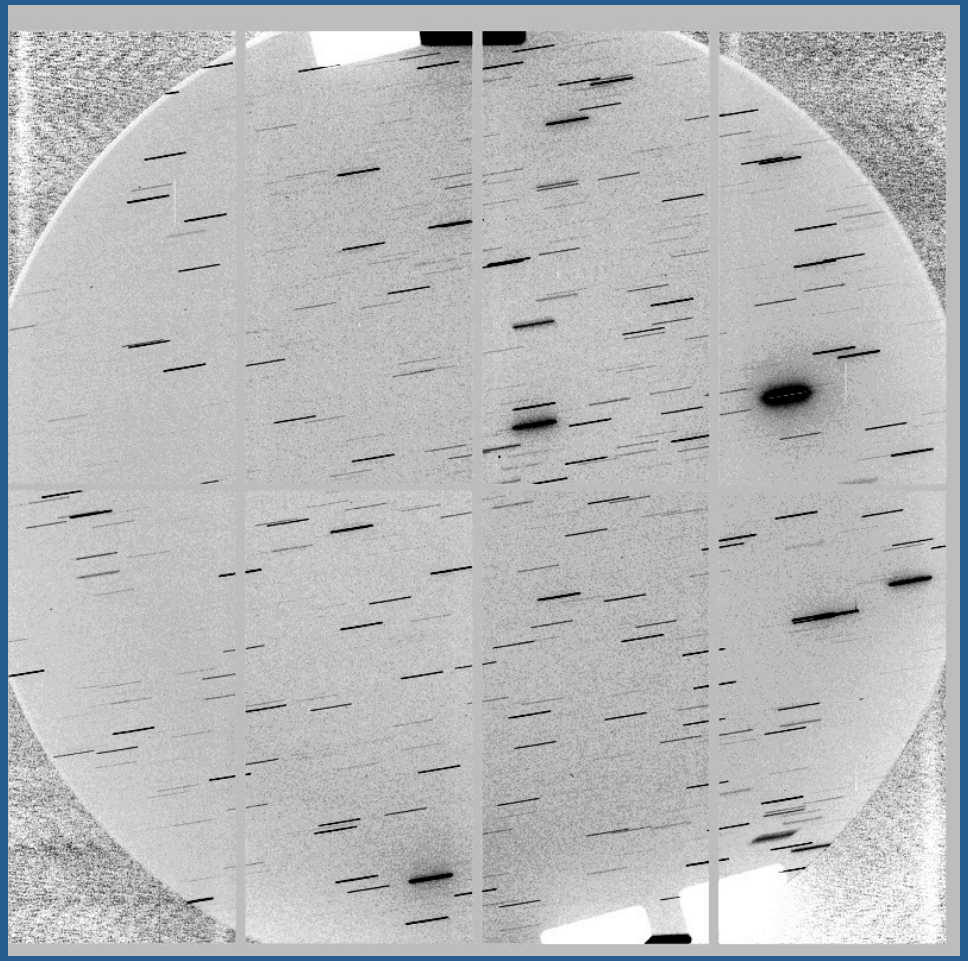
What is the distribution of faint debris?

- Does debris distribution continue to increase with fainter optical brightness?
- In particular, what is distribution fainter than R = 20 (roughly 10 cm in diameter).
- Requires large telescope and excellent image quality.
- Goal: reach the faintest limiting magnitude possible from the ground.

Imaging with Baade telescope – March 2011



Magellan data example: SSN 33513

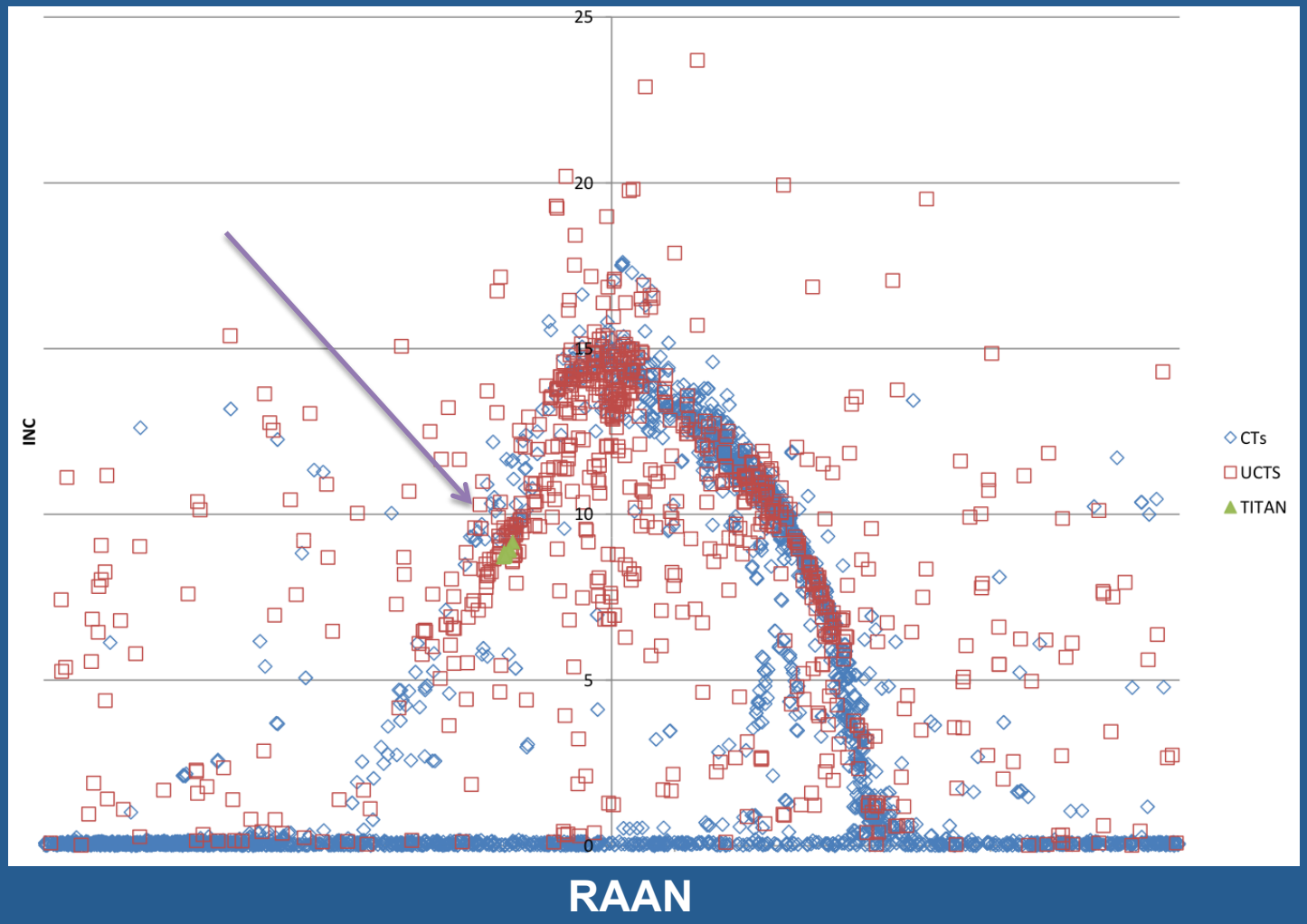


Magellan Target: Titan debris 1968-081

- Fragmentation of Titan 3C Transtage at GEO – occurred 21 Feb 1992.
  - *NASA History of On-Orbit Satellite Fragmentations (14th Edition, 2008)*
- 8 debris objects plus Titan 3C Transtage in catalog.
- All clustered in RAAN-INC space.
- Objective of this run – is there optically faint debris on circular orbits associated with this fragmentation?
- Observed two Titan debris fragments: 25001 and 33513.
- Observed 'pseudo objects' with same orbit as 25001 and 33513, but different mean anomalies – typical offset step 15 degrees.
  - 30 x 5 second exposures while tracking at pseudo object rate.
  - 30 x 5 second exposures with telescope tracking off.

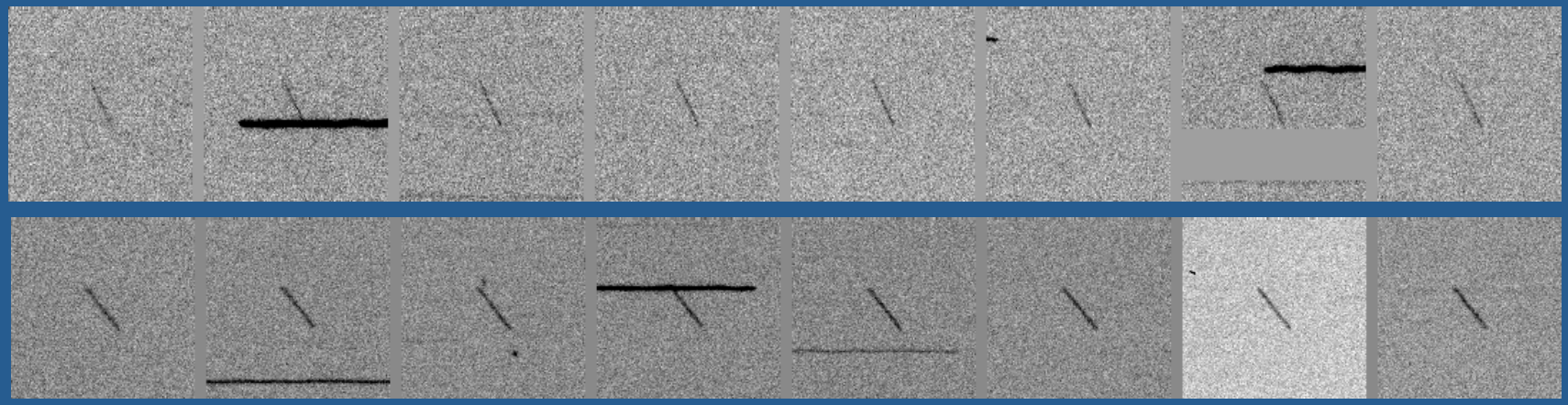
MODEST 2007-2009: RAAN vs Inclination

assuming circular orbits



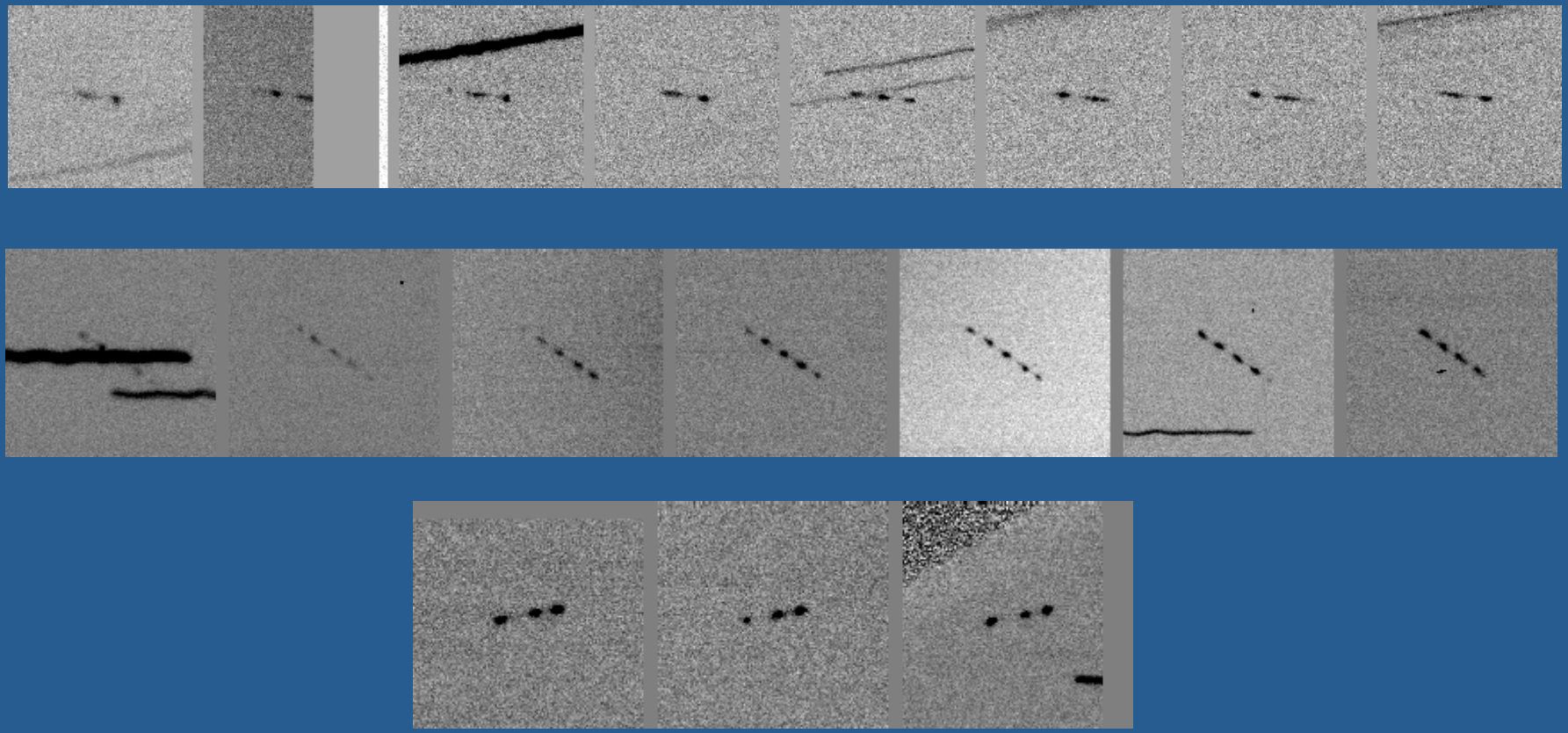
Examples of Detections

- Postage stamp size 51.6x51.6 arc-seconds.
- 5 second exposures.
- 3 classifications:
  - Streaks
  - Glints
  - Intermediate



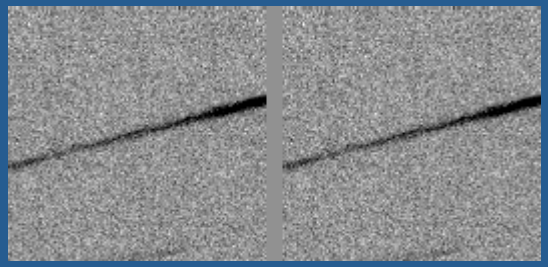
Glints

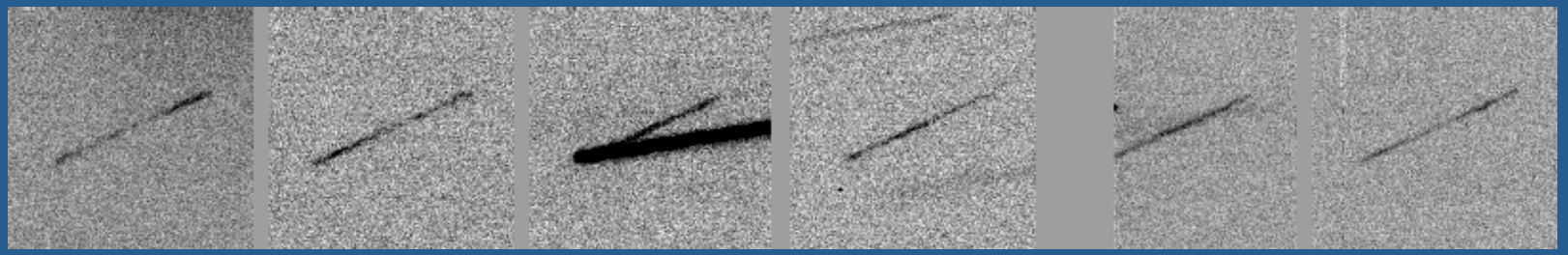
- Glint brightness ranges from R = 19.8 to detection limit (R > 21.0).

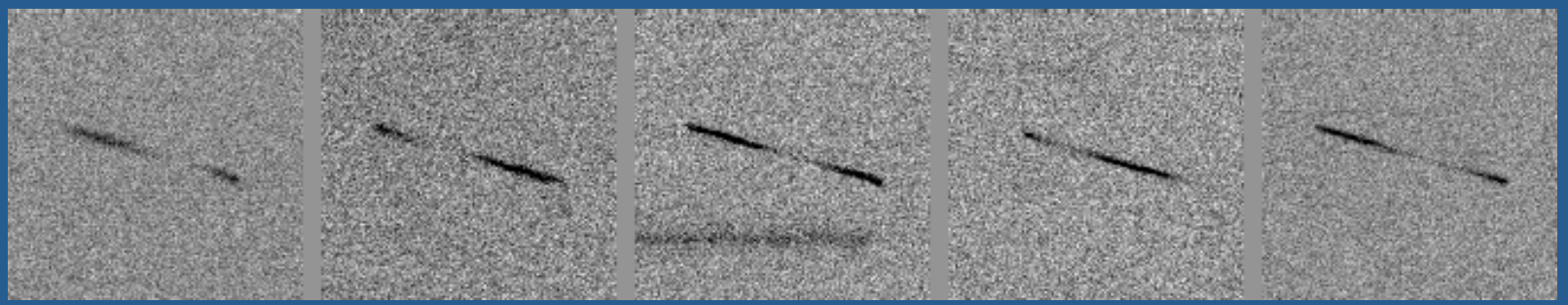


Intermediate Cases

- Streak not uniform – slow tumblers?







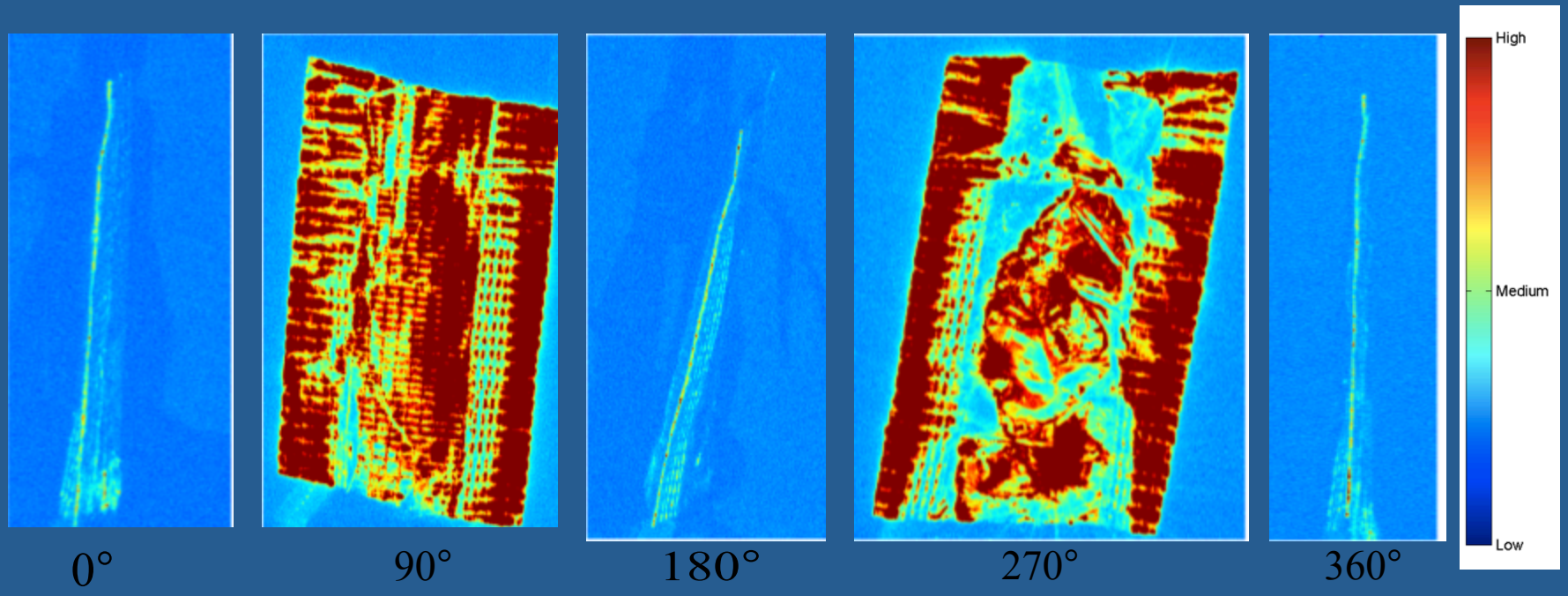
Preliminary Imaging Results

- 19 objects detected in 6 hours of observing with 0.5-deg diameter field (0.2 sq deg) at one RAAN-INC pair.
- Probably 12 have rates consistent with circular orbits at GEO.
- Detection rate for optically faint GEO objects: 10 per hour per sq deg.
- This is 10x rate of detection on 0.6-m MODEST: 1 per hour per sq deg.
- Suggestion of very large population of faint debris?
- Follow-up with Blanco/Decam? 90 minutes of DD time in full moon obtained to test this. More time sought.

Reflection Spectroscopy

- Goal – visible light (4000 – 8000 Angstrom) spectroscopy of GEO objects for comparison with laboratory spectra of surfaces of actual spacecraft materials.
- What are the possible surfaces seen at GEO?
- Simultaneous wavelength coverage – important if attitude of object changing.
- Using imaging spectrographs on Magellan 6.5-m telescopes. Large telescopes in excellent seeing – short exposure times. Important if irregularly shaped object tumbling and prevent contamination by star streaks.

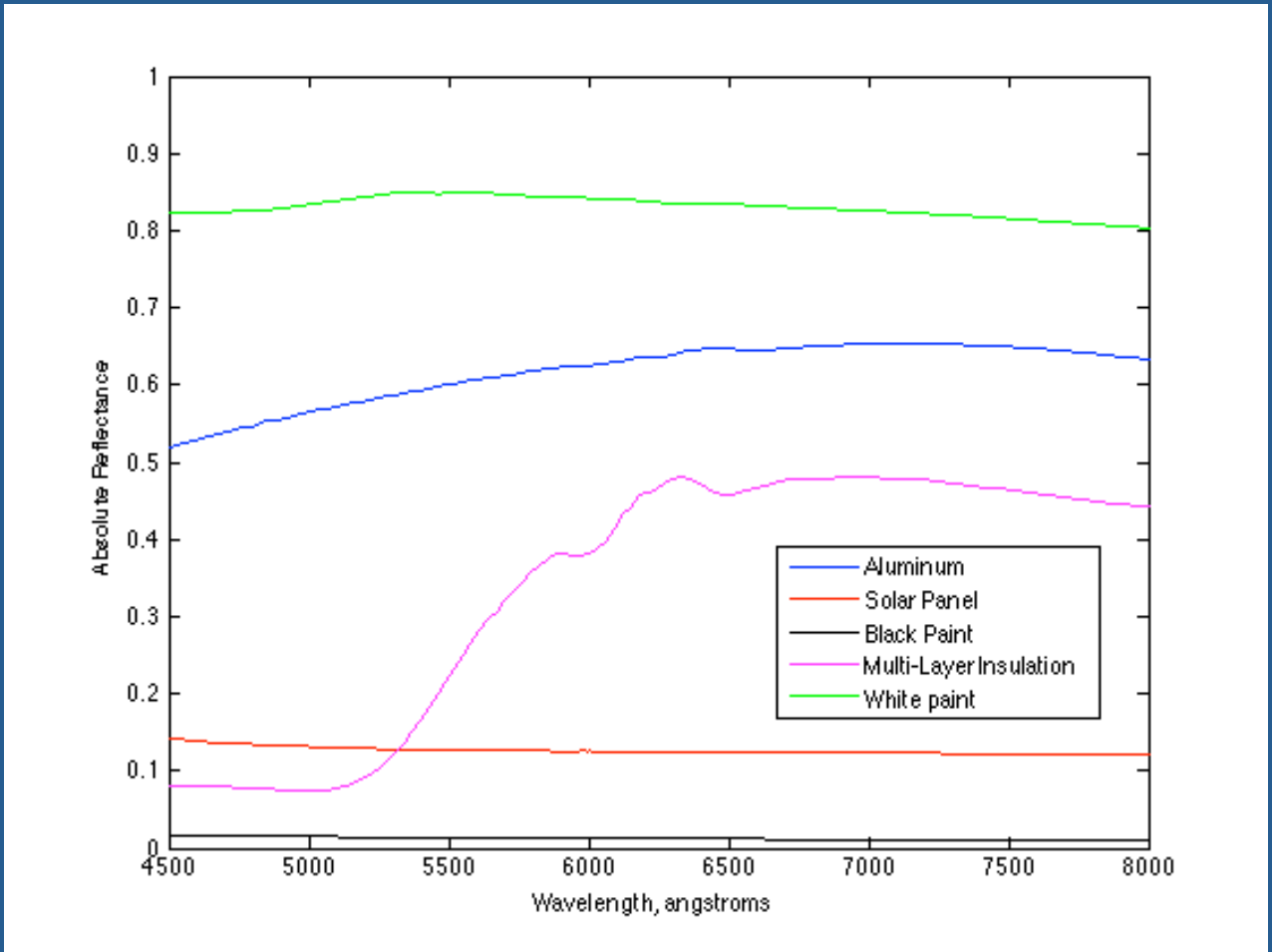
Example of MLI – Lab measurement



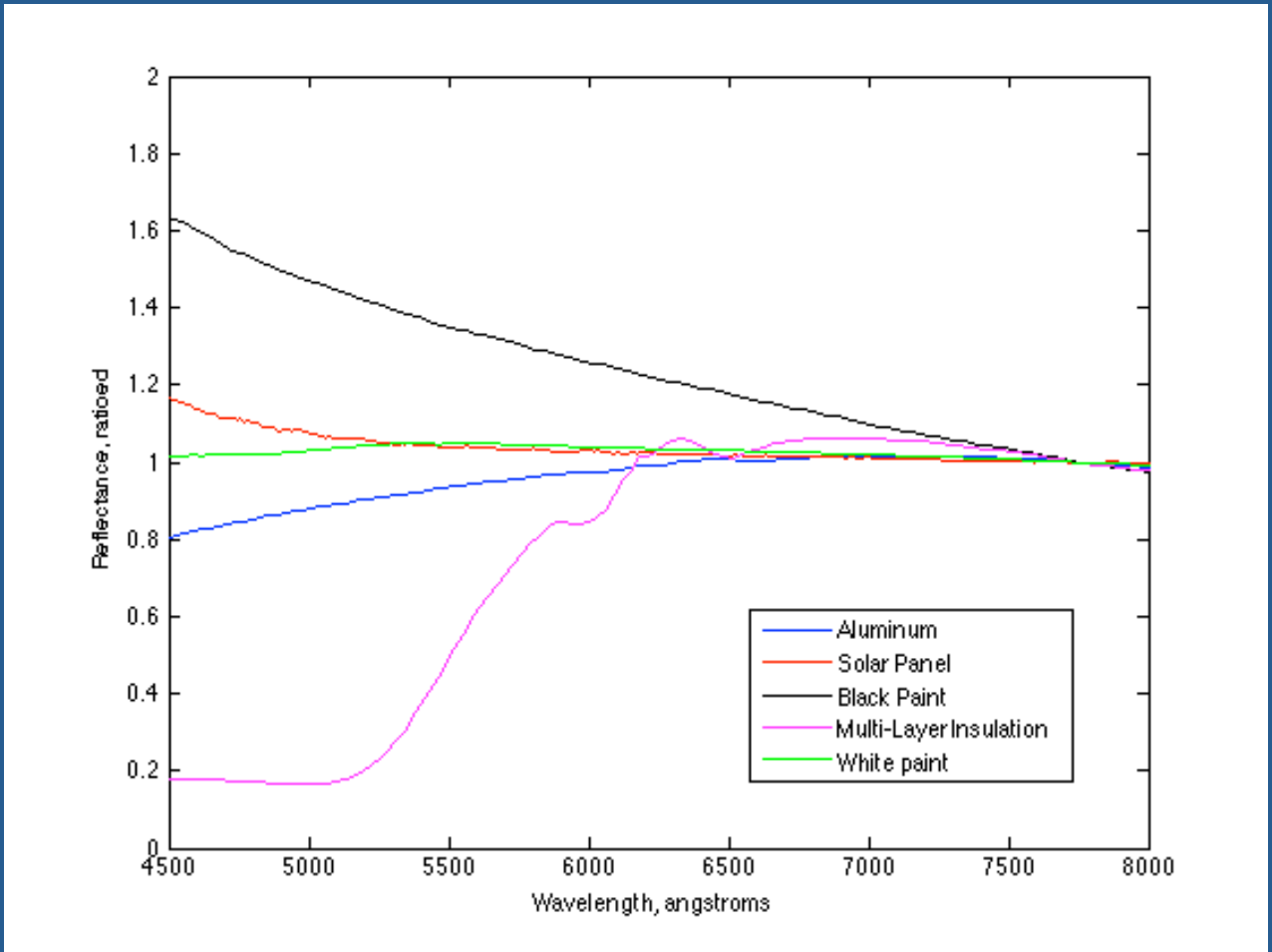
- 0º: partial view of spacecraft-facing and space-facing
- 90º: normal reflection to spacecraft-facing Kapton
- 180º: partial view of spacecraft-facing and space-facing
- 270º: normal reflection from space-facing Kapton
- 360º: theoretically should be exactly the same as 0º

Work of Heather Cowardin at NASA JSC

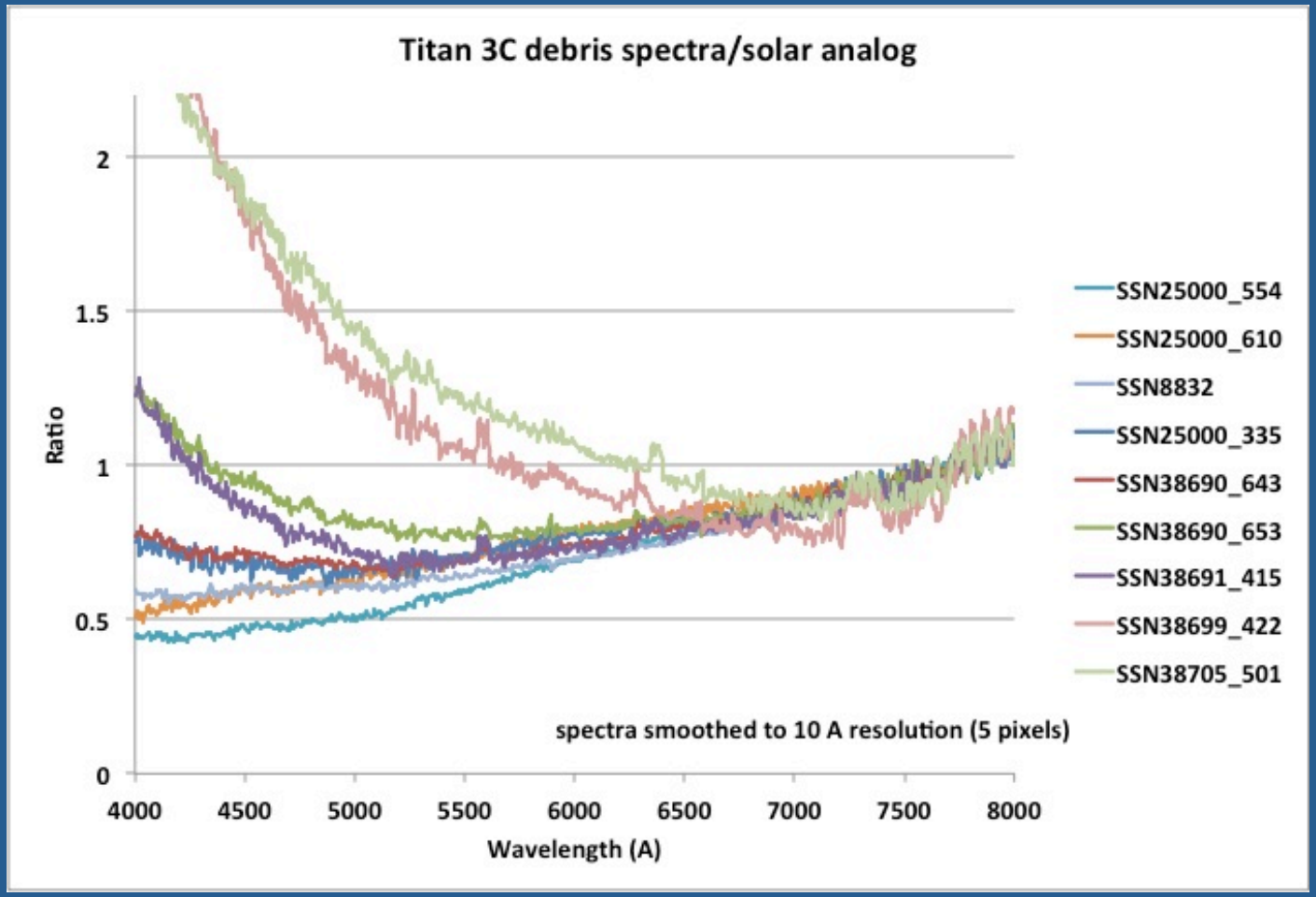
Laboratory Measurements



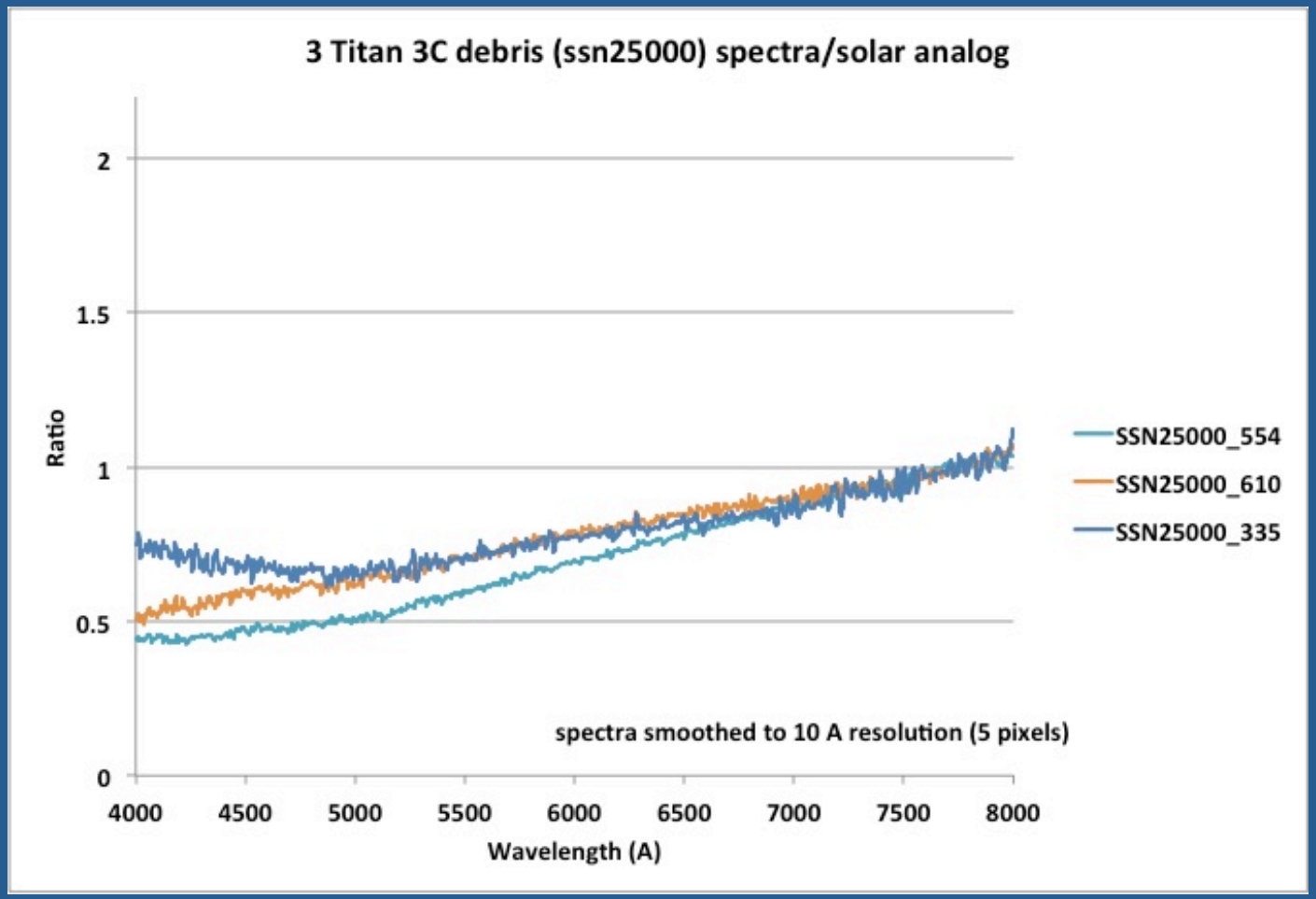
Laboratory Measurements normalized to 7500-8000 Angstroms



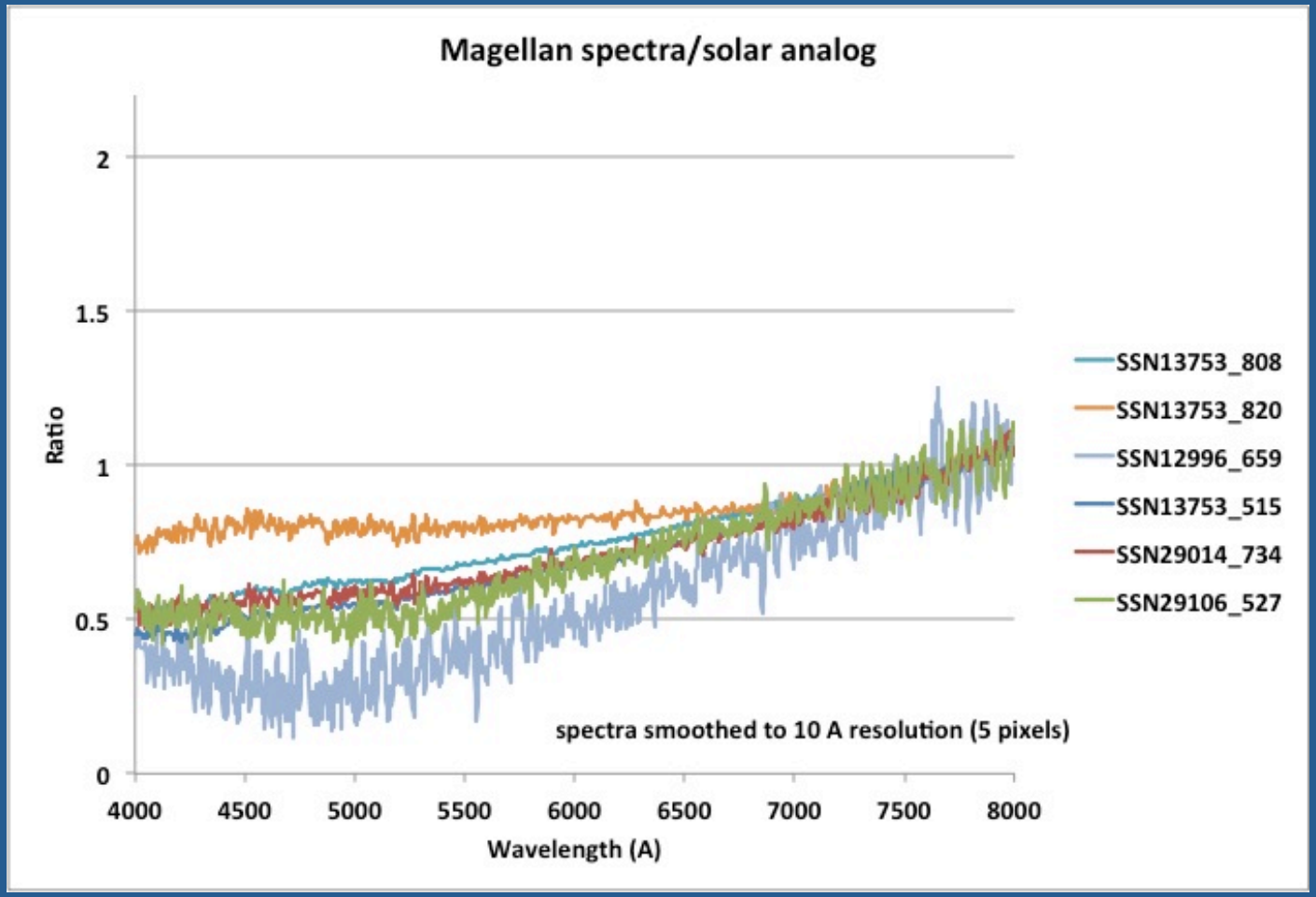
Titan Transtage Debris Observations



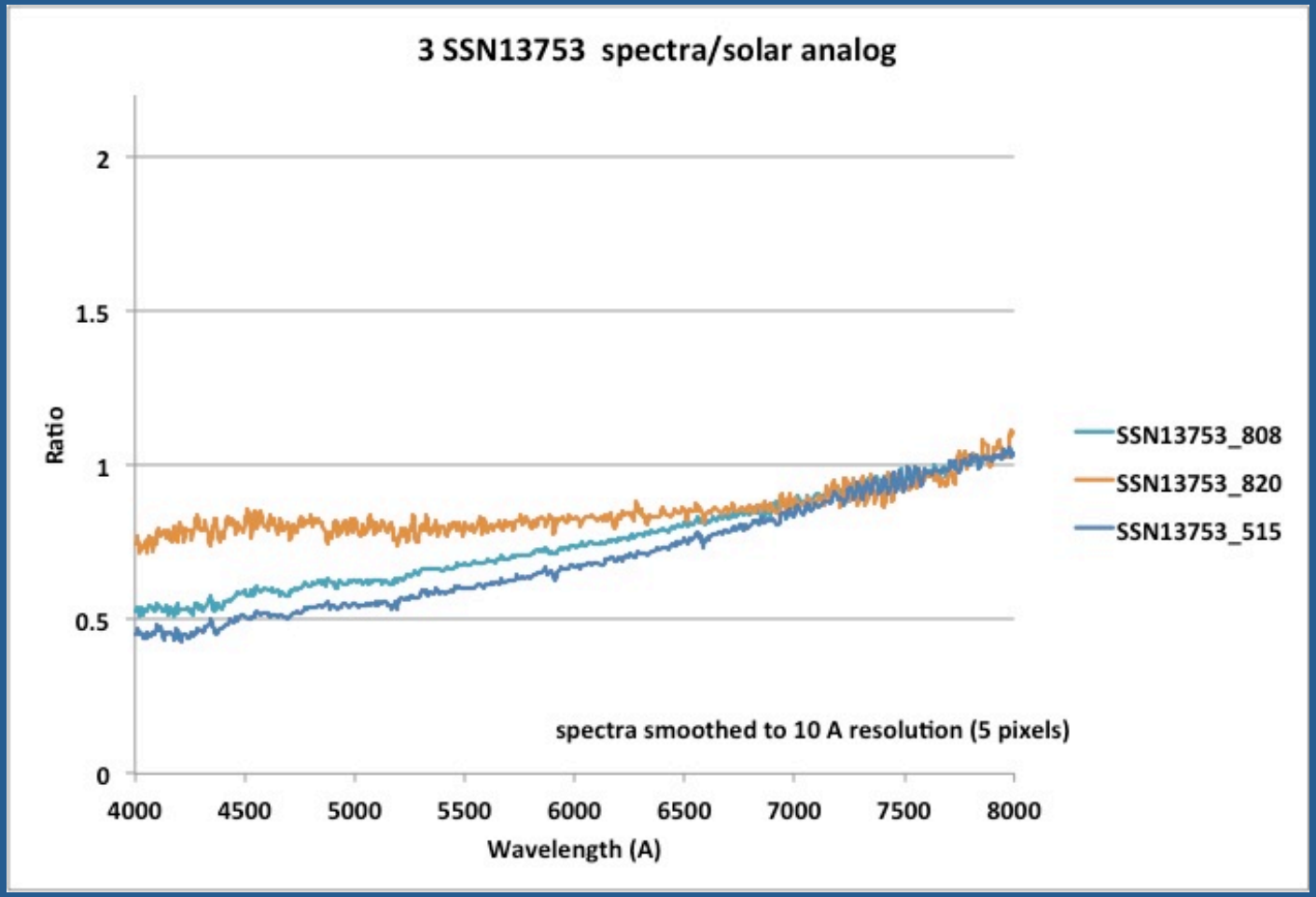
SSN 25000 Repeat Observations



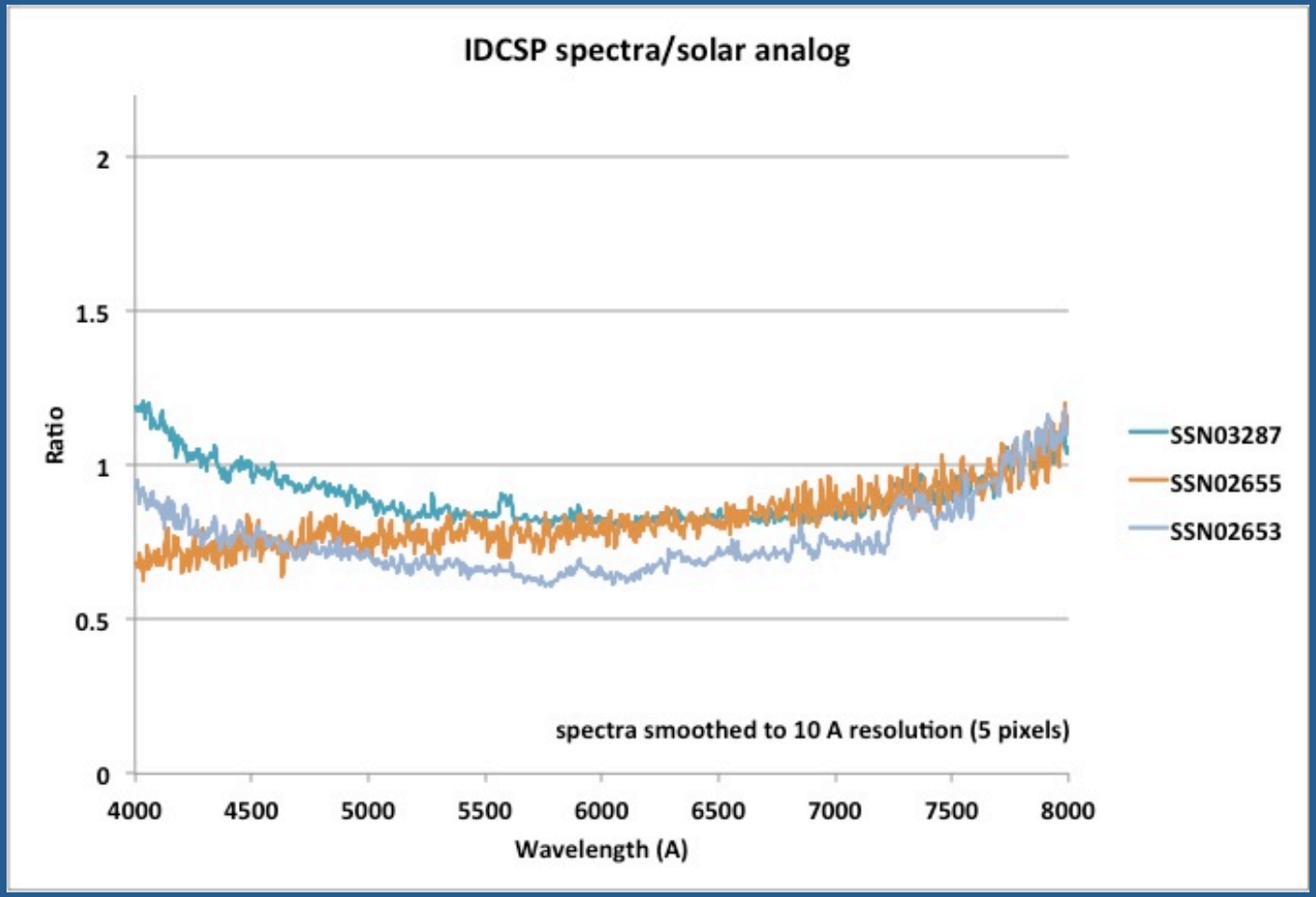
Other Objects



SSN 13753 Repeat Observations

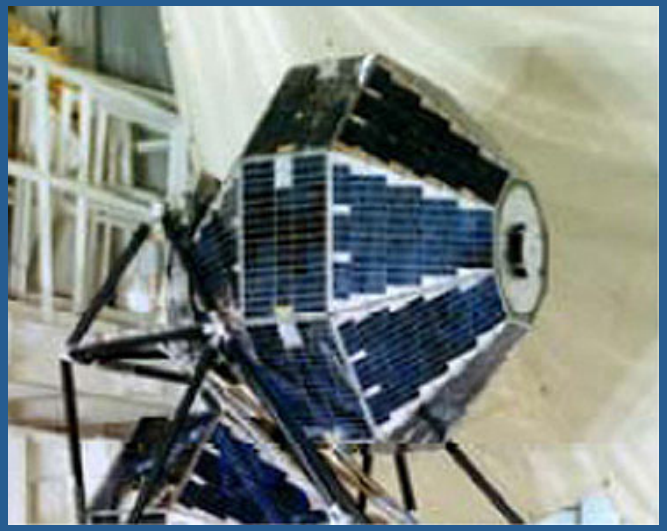


IDCSP Observations



Objects of known launch characteristics

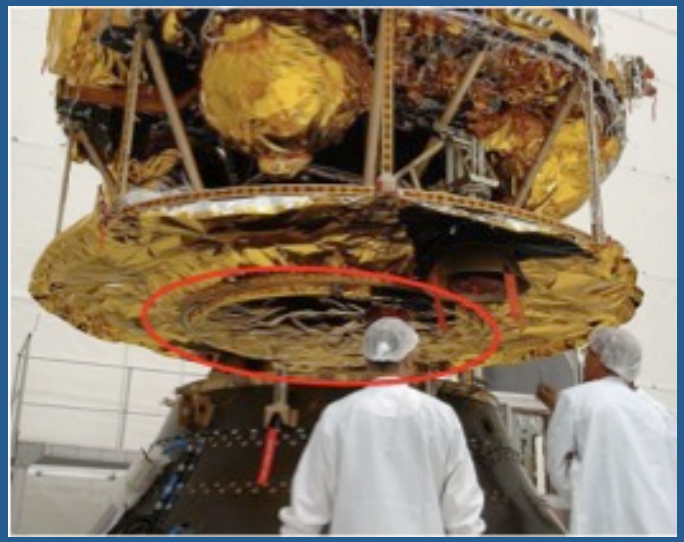
02655 IDCSP 15 1967-003H



USAF

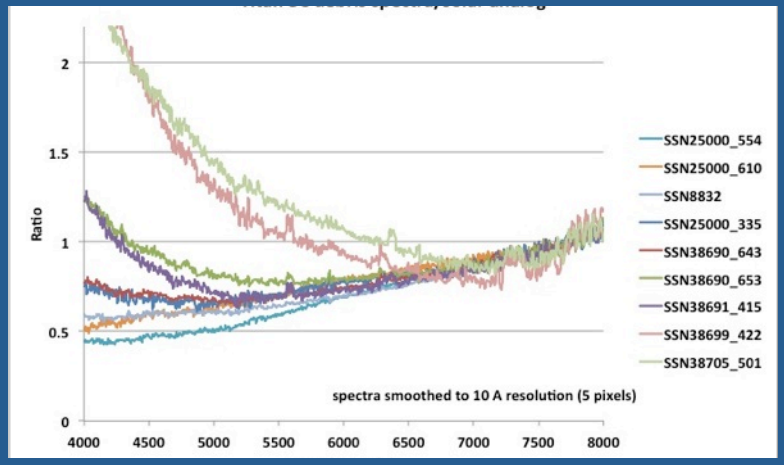
Initial Defense Communications Satellite Program
26 sided polygons of solar cells, 86 cm diameter.

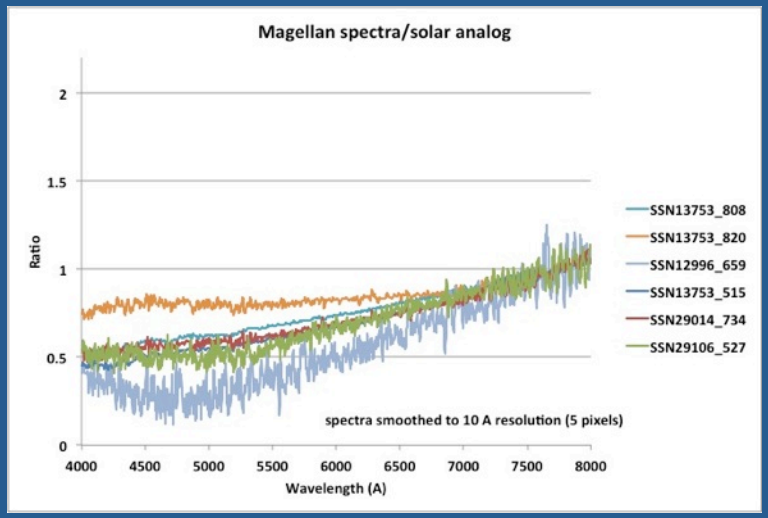
29106 MSG 2 Cooler cover 2005-049E



1.9 meter^2 area
Source: Jah and Kelecy IAC 2010

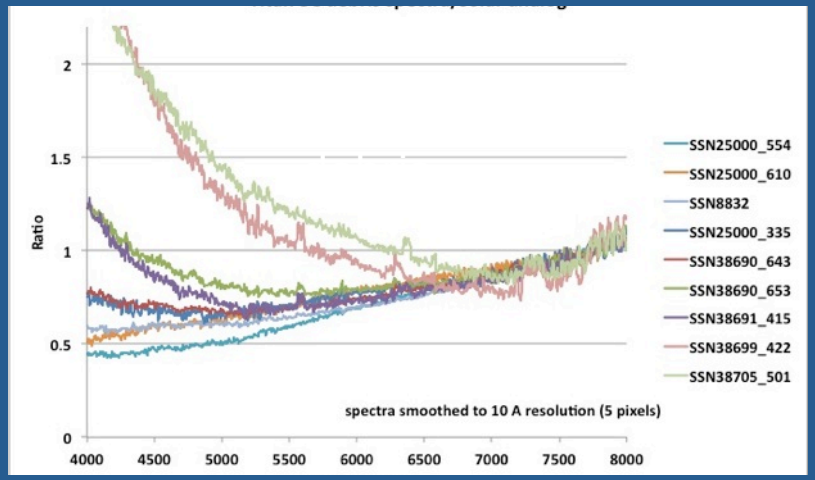
Interpretation of Observations

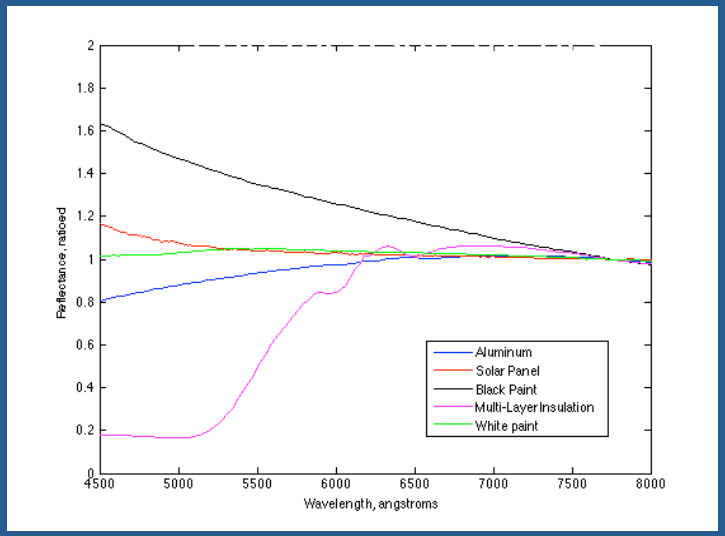




- Wide variety of spectral type: one common type shows constant slope from blue to red.
- IDCSP satellites have flattest response.
- 12996 EKRAN 2 DEB has greatest slope.
- 2 pieces of EKRAN 2 DEB (12996 and 29014 have different slopes.
- Titan 1968-081 debris – large variety of spectral types.
- With exception of flat response objects (IDCSPs), no obviously good fit to any laboratory measurements.

Conclusions





- **Mystery - most of observed spectra do not compare well with laboratory measurements. Why?**
  - Complex Surfaces.
  - Materials not in lab database.
  - Debris could be rapidly tumbling (faster than 30 second exposure time). Multiple surfaces presented to observer.
  - Incident angle differences?
  - Space weathering?
  - Errors in observing and/or reduction?
  - ????

Future

- GEO debris population –
  - What is the optically faint debris population: R > 20
  - How does it compare with LEO population?
  - How is it a function of age and orbital parameters?

- DEcam very powerful tool for probing this population.
  - 20x field of view of Magellan/IMACS.

More information

NASA's Orbital Debris Program Office

www.orbitaldebris.jsc.nasa.gov