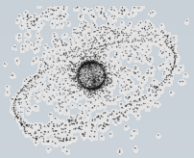
Long-term Evolution of High Area-to-Mass Ratio Objects in Different Orbital Regions

T. Schildknecht, A. Vananti, A. Hinze
Astronomical Institute, University of Bern, Switzerland

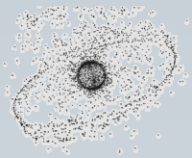
PEDAS1-0017-12

39th COSPAR Scientific Assembly, 14 - 22 July, 2012, Mysore, India



Outline

1. The AIUB/ESA HAMR Catalogue
2. Orbit Evolution in GEO & MEO
3. Summary



Catalogue of Small-Size Space Debris

- Build-up and maintenance of orbit catalogue of decimeter-sized debris in GEO/GTO/MEO
- Why?
  - Density/collision risk lower than in LEO
    BUT:
    No sinks → population constantly grows
  → Mitigation of debris is important
- Need to know nature and sources of debris

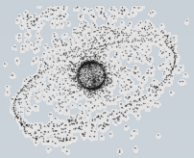
  Requires:
  - Orbit catalogue
  - Constant monitoring due to perturbations by non-gravitational forces

Sensors


1-m ESA Telescope
Tenerife


AIUBZimSMART


1-m ZIMLAT
Switzerland



High AMR GEO/GTO Catalogue

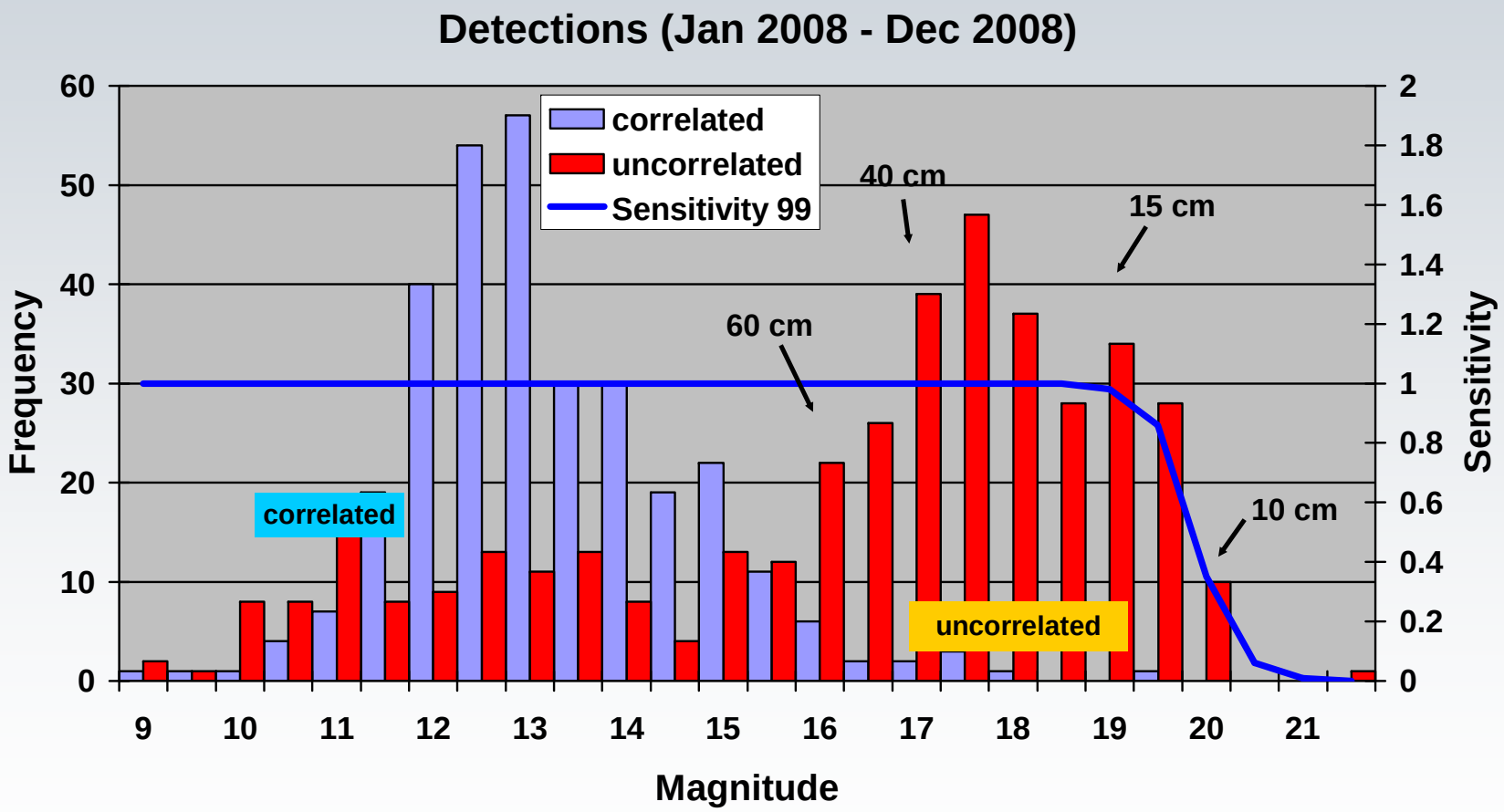
- Discover new objects: Obs. From Tenerife (OGS, AIUB)
- Secure orbits: obs. from OGS, Zimmerwald (AIUB)
- Maintain orbits: obs. from OGS, Zimmerwald, international partners, International Scientific Optical observation Network (ISON), ...
  - Daily orbit maintenance at AIUB and Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences (KIAM)

  → Orbit catalogue of high-altitude space debris

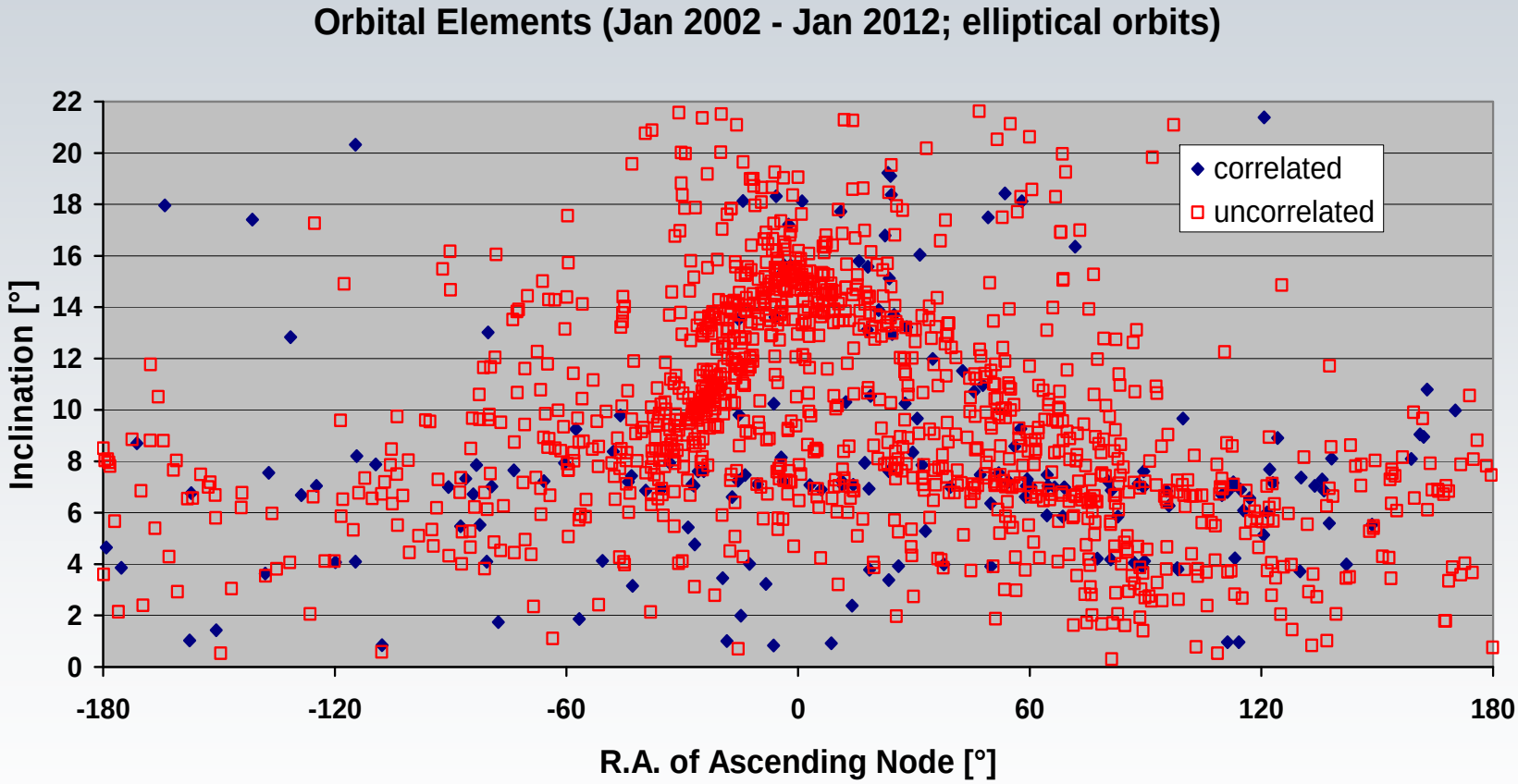
- Provide predictions:
  - To other partners (CNES, JAXA, NASA, Roscosmos...)
  - → to investigate physical properties of objects

ESA 2008 GEO/GTO Surveys

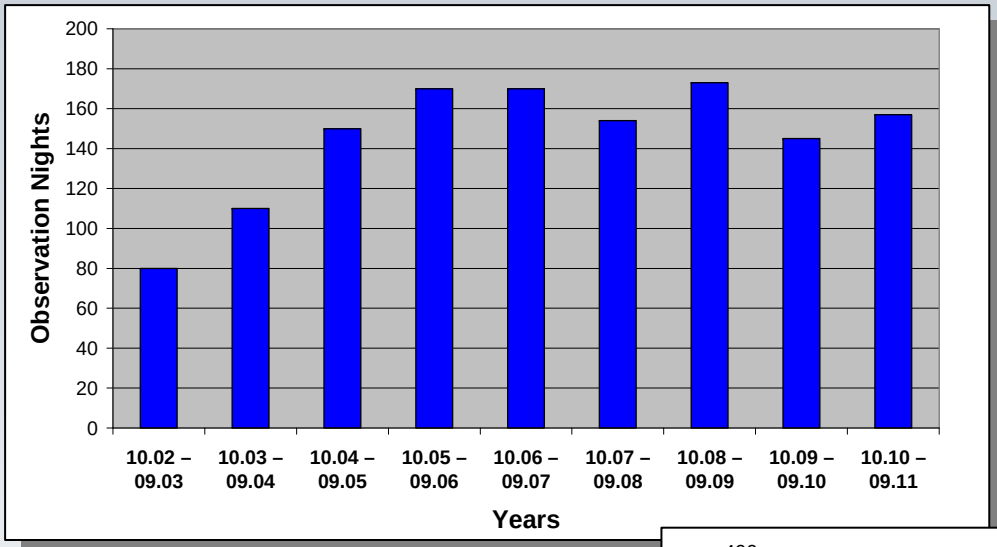
Continuous program, ~80 nights per year



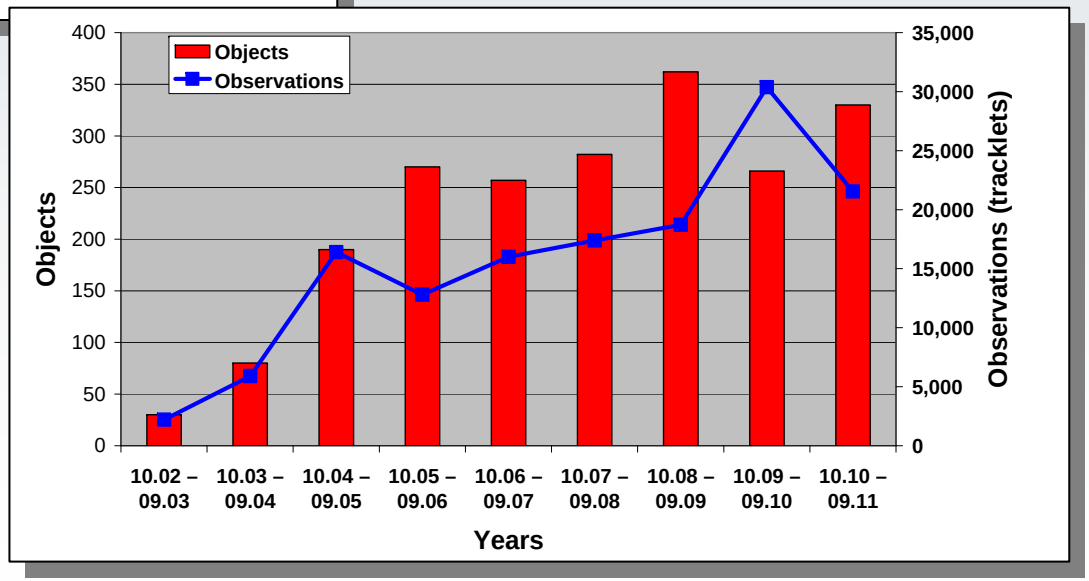
6-param. Orbits – *i* vs Ω



“Routine” ZIMLAT Support

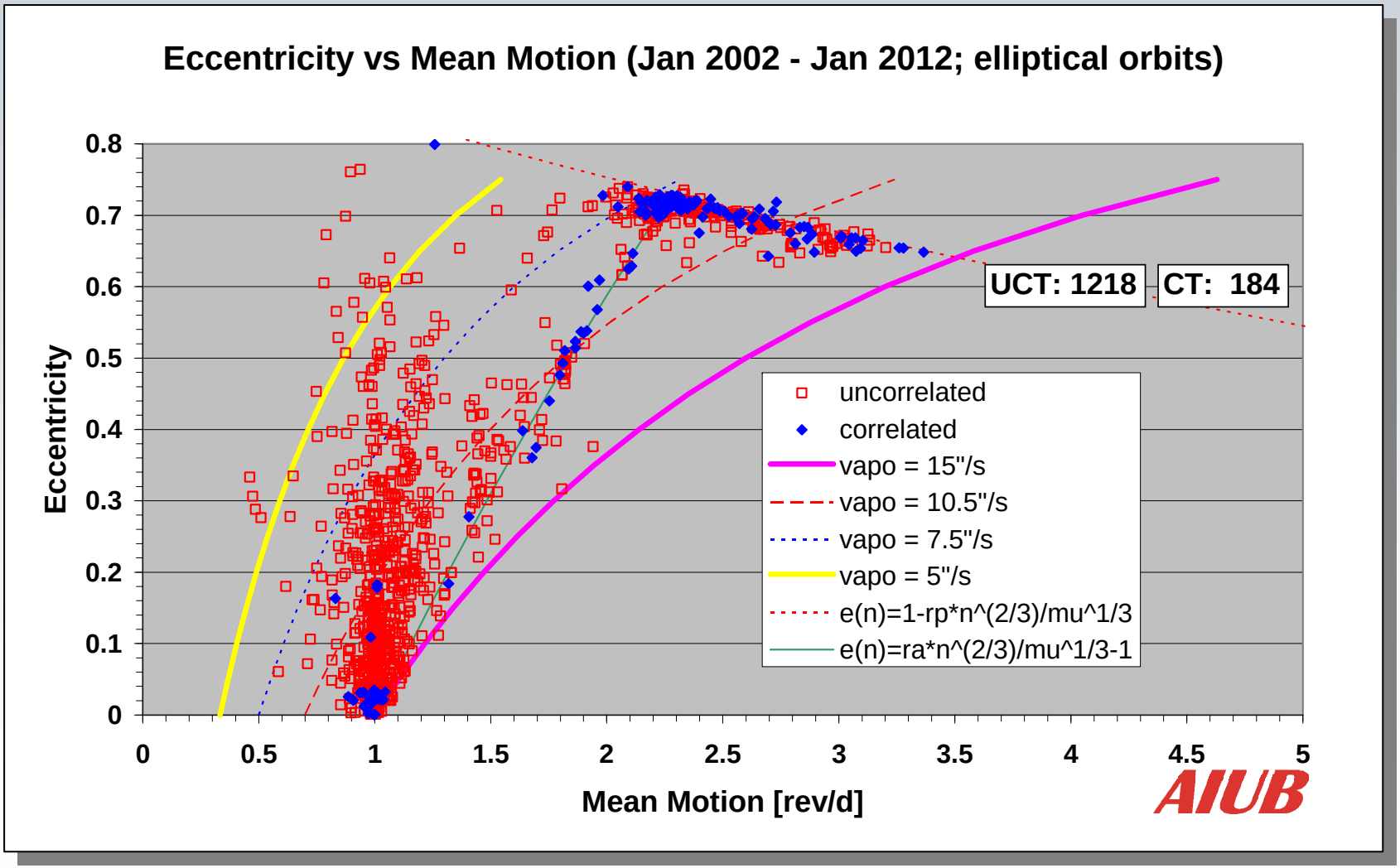


ZIMLAT
Observation Nights

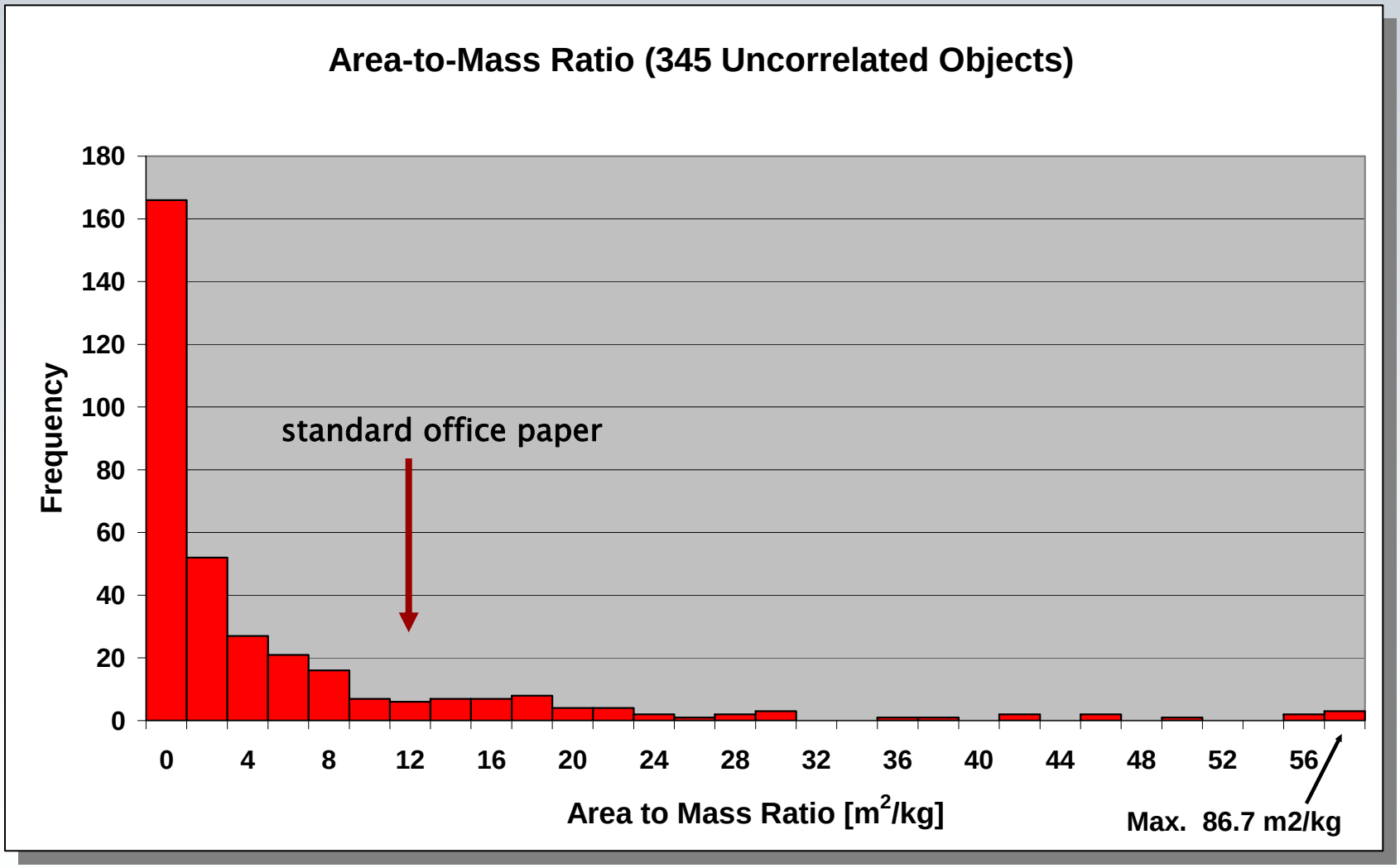


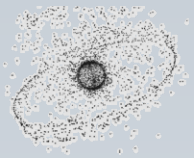
ZIMLAT
Observations / Objects

High AMR GEO/GTO Catalogue



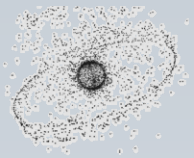
High AMR GEO/GTO Catalogue





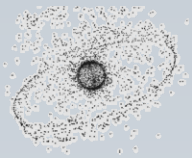
Outline

1. The AIUB/ESA HAMR Catalogue
2. Orbit Evolution in GEO & MEO
3. Summary



Methodology

- Assumption
  - There are sources of high AMR debris when objects are left in space for long time span (aging processes, breakup-events, ...)
- Question
  - What are the impacts for the concept of "graveyard" orbits
- Method
  - Propagate orbits of a sample of observed debris over a time interval of 50 years assuming different AMR values (0.02, 0.02, 1, 5, 15 m^2/kg).

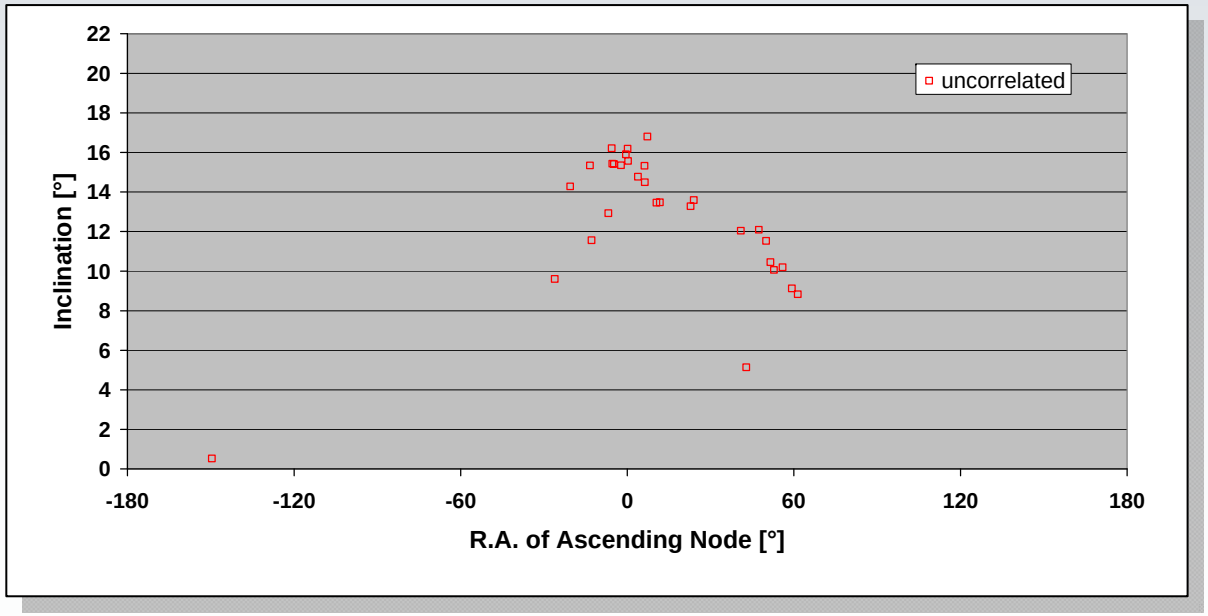


Propagator

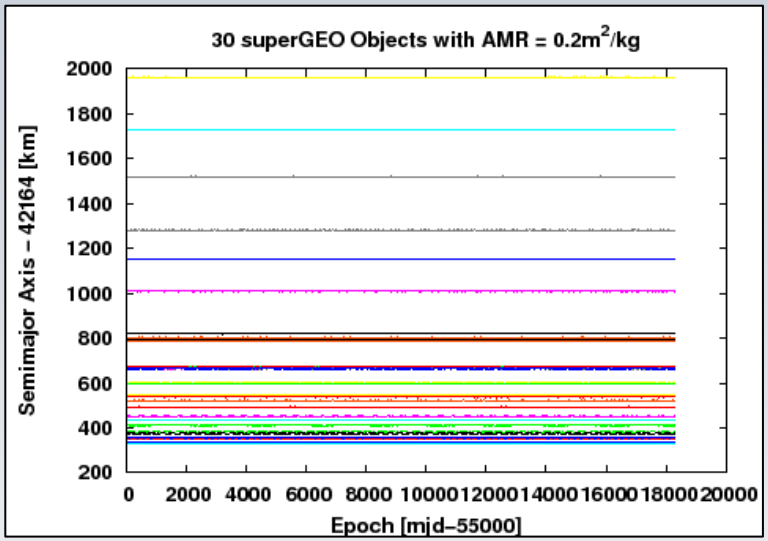
- CelMech SATORB Propagator
  - numerical integrator (variable step size)
  - 12 x 12 Earth gravity field
  - gravitational perturbations from
    - Sun
    - Moon
    - Earth tides
  - corrections due to general relativity
  - direct radiation pressure (Sun only)
  - eclipses (Earth, Moon)

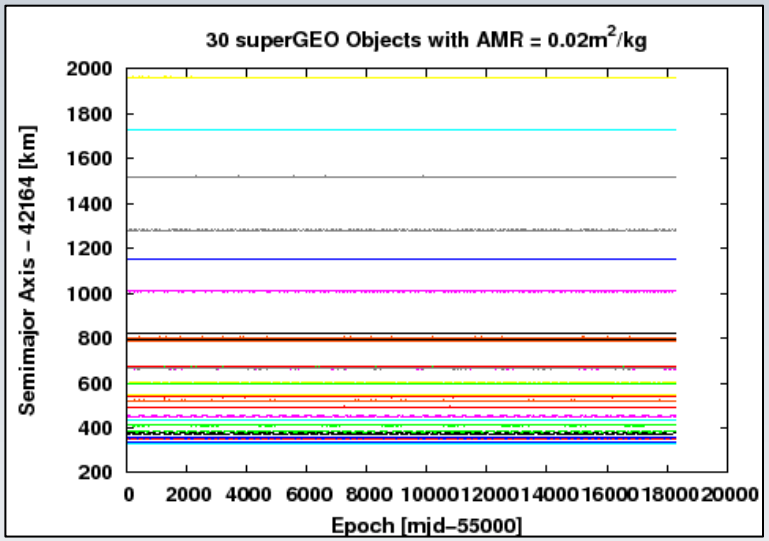
Sample of super-GEO Objects

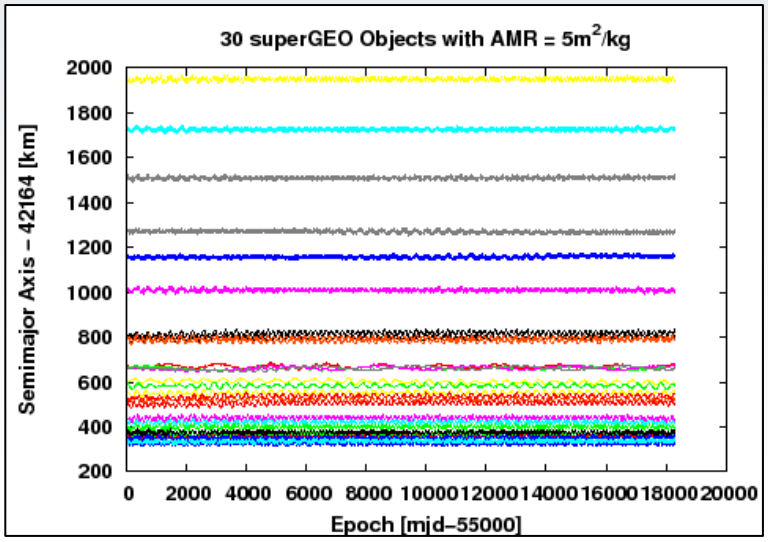
- Sample of 30 debris objects in super-GEO region
  - $a > 42464$km (>300km above GEO)
  - $e < 0.05$; then set to 0.001
  - $t_0 = 55000$mjd (2009-06-18)

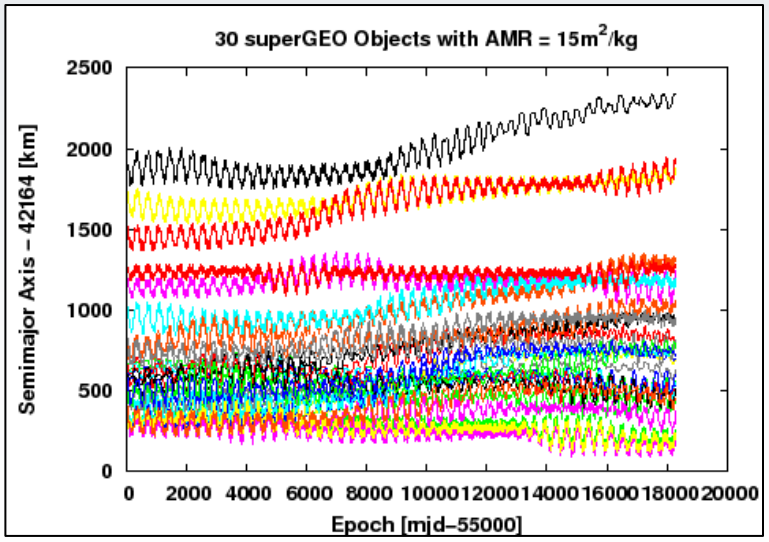


Evolution of Semimajor Axis

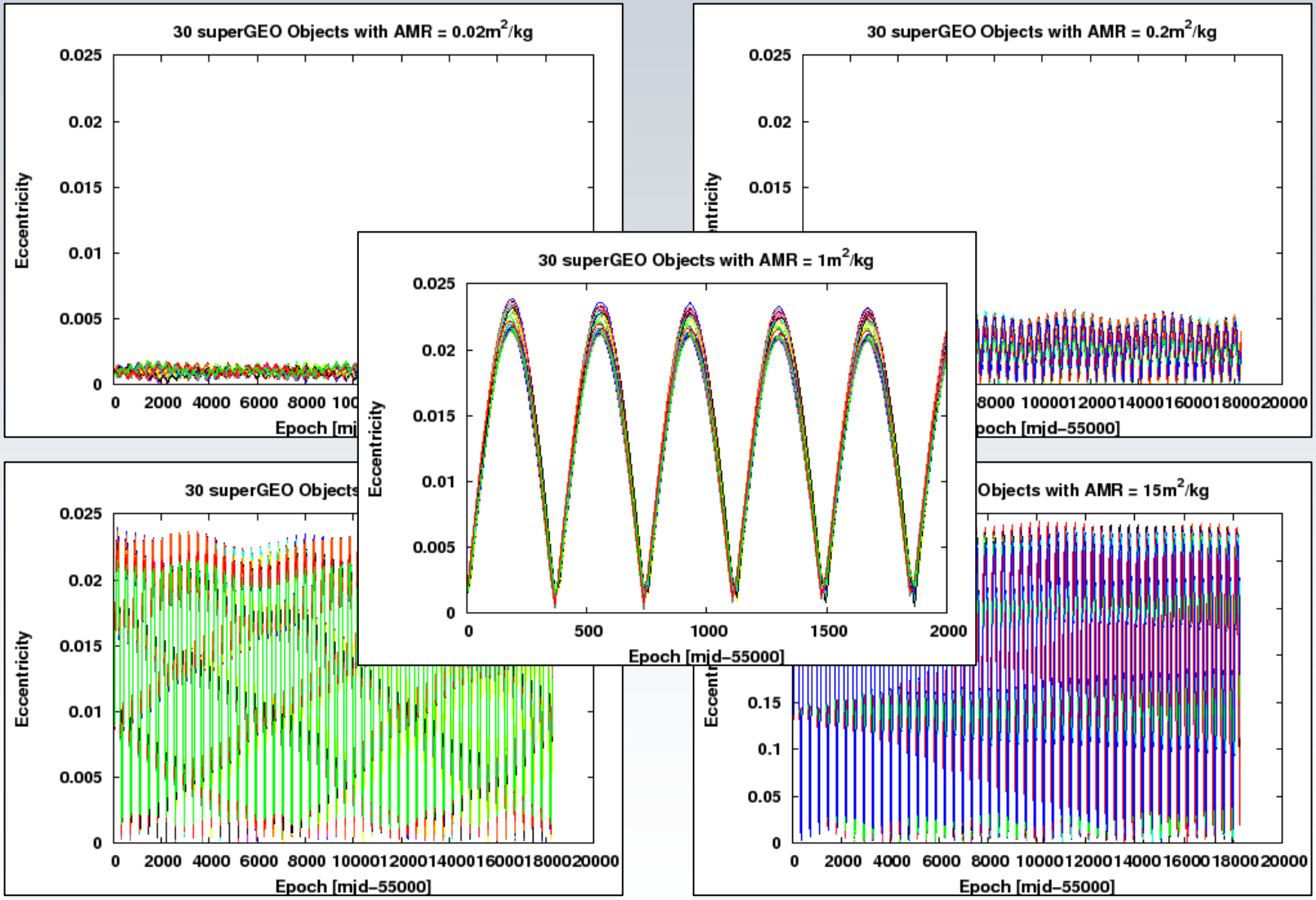




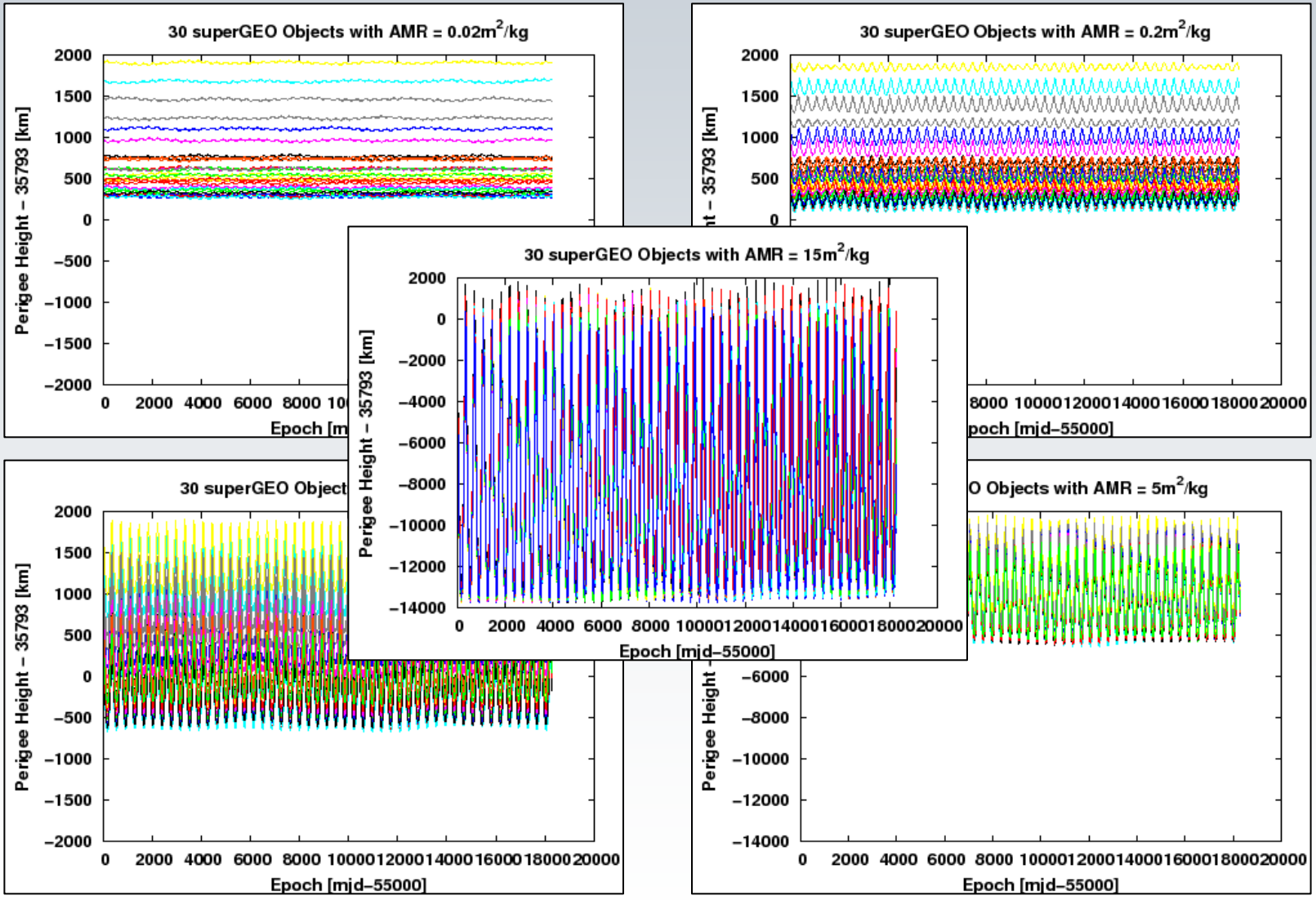




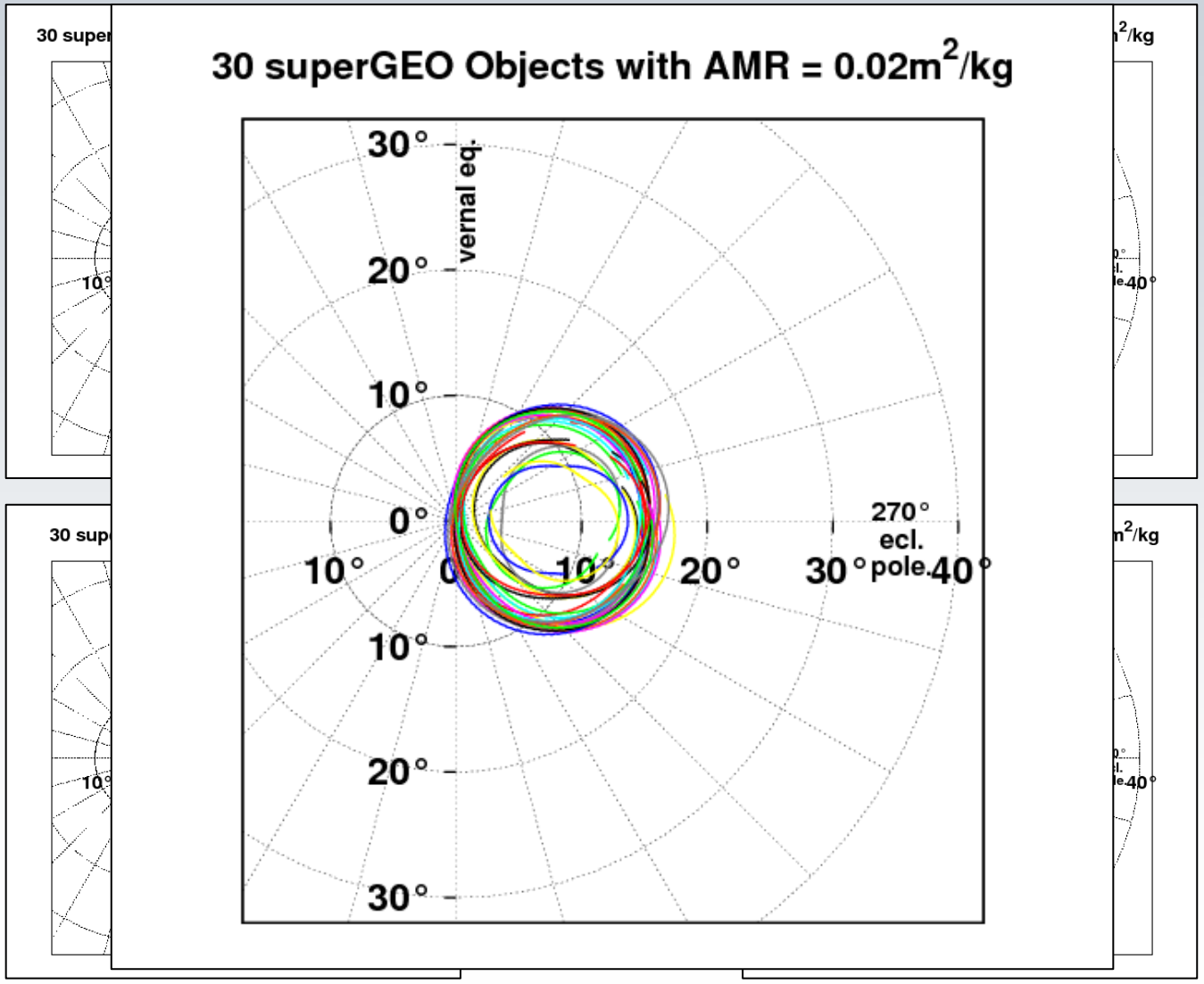
Evolution of Eccentricity

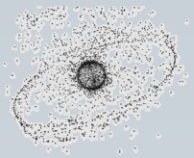


Evolution of Perigee Height



Evolution of Orbital Plane

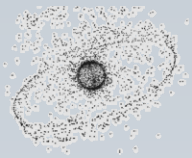




GEO Graveyard

- Objects in GEO graveyard orbits (>300km above GEO) will cross GEO altitude if AMR>0.2m²/kg
  - will also cross 0° GEO region for particular inclination/argument of perigee combinations
  - orbital plane and argument of perigee are both changing over time
  - precession of orbital planes not significantly changed for AMR<5m²/kg
- Consistent with IADC deorbit guideline:
  $\Delta H_{min} = 235 + 1000*cr*AMR$ [km]

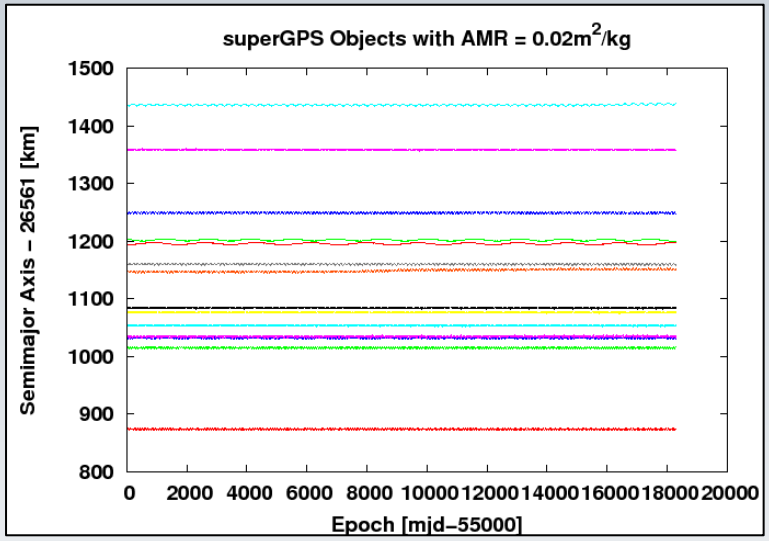
  → 435km for AMR=0.2m²/kg

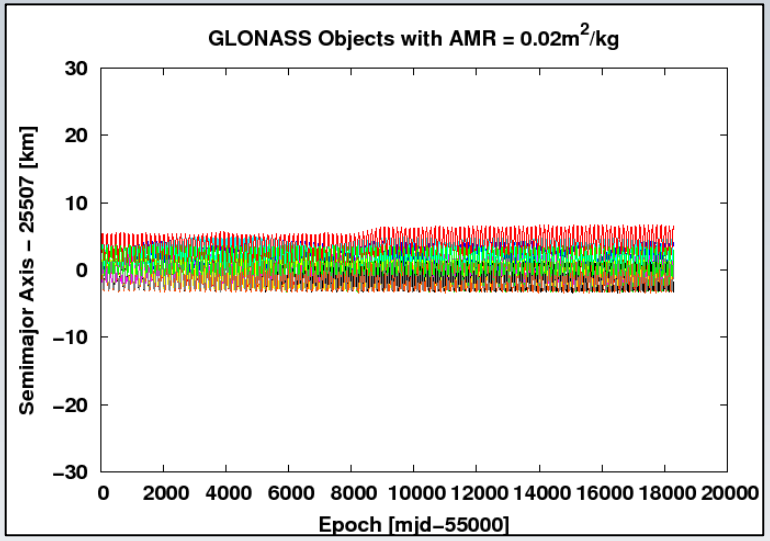


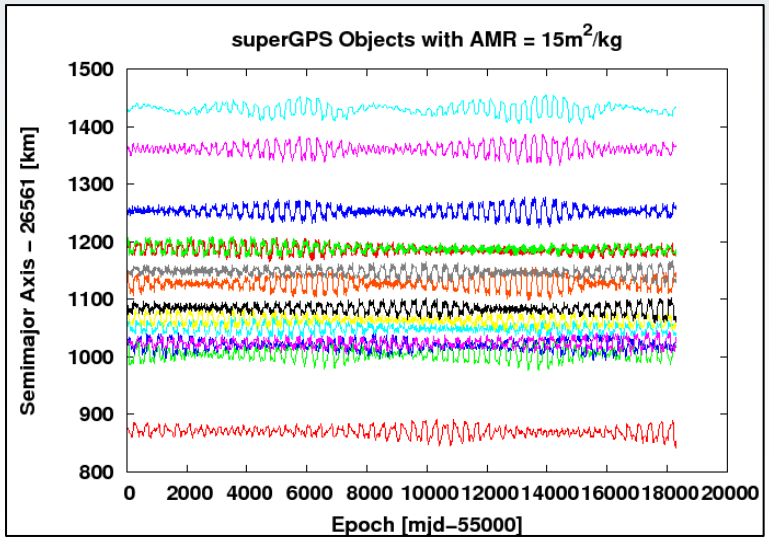
Sample of super-GPS/GLONASS Objects

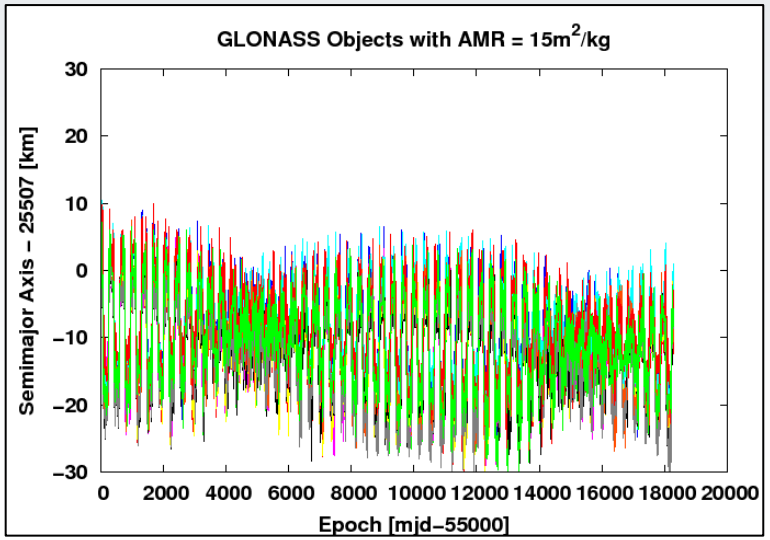
- Sample of super-GPS objects (14)
  - $a > 27400$km (>900km above GPS)
  - all orbital elements at actual values
  - $t_0 = 55000$mjd (2009-06-18)
- Sample of GLONASS objects in plane G2 (11)
  - $a \approx 25508$km
  - all orbital elements at actual values
  - $t_0 = 55000$mjd (2009-06-18)

Evolution of Semimajor Axis

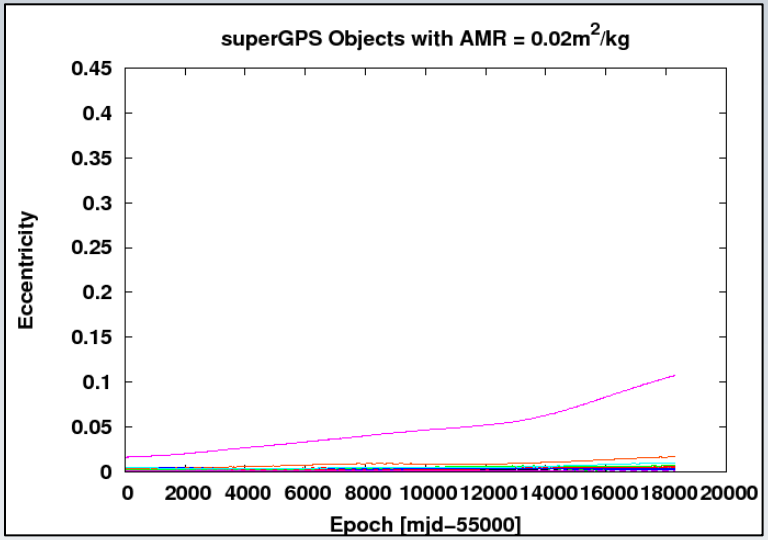


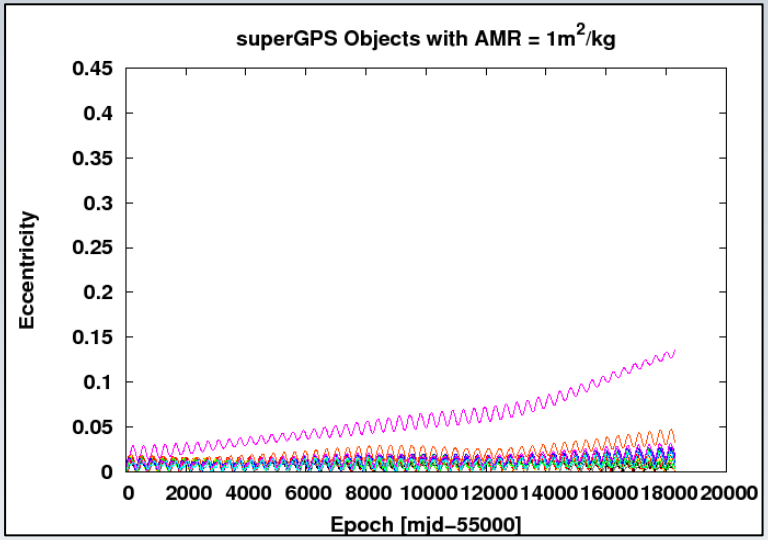


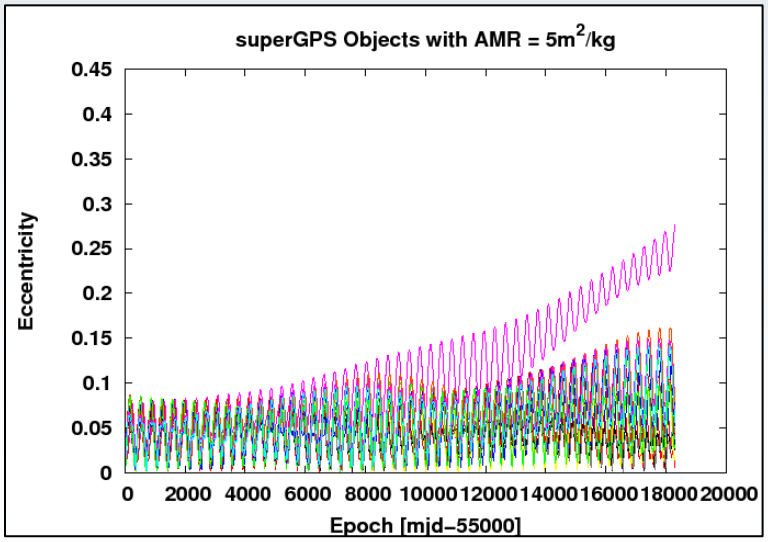


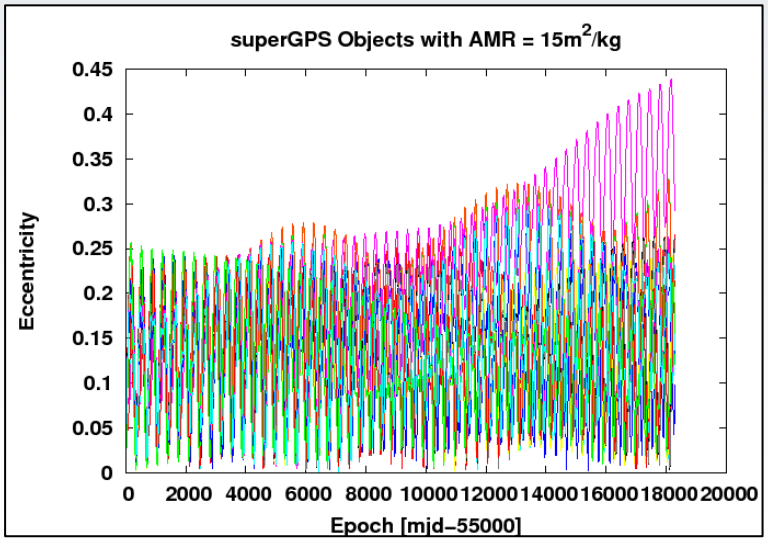


Evolution of Eccentricity (GPS)

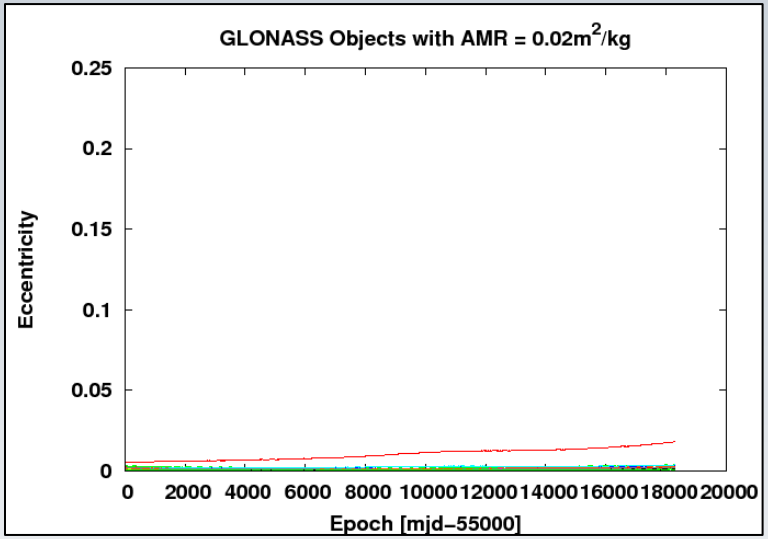


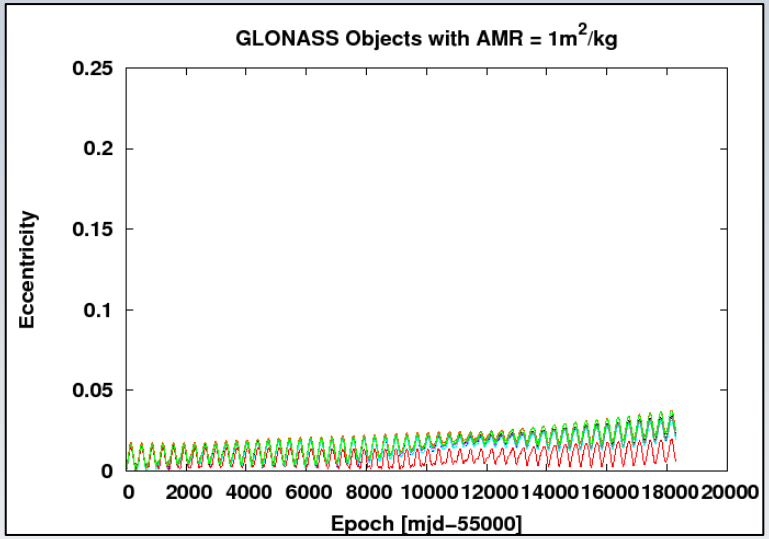


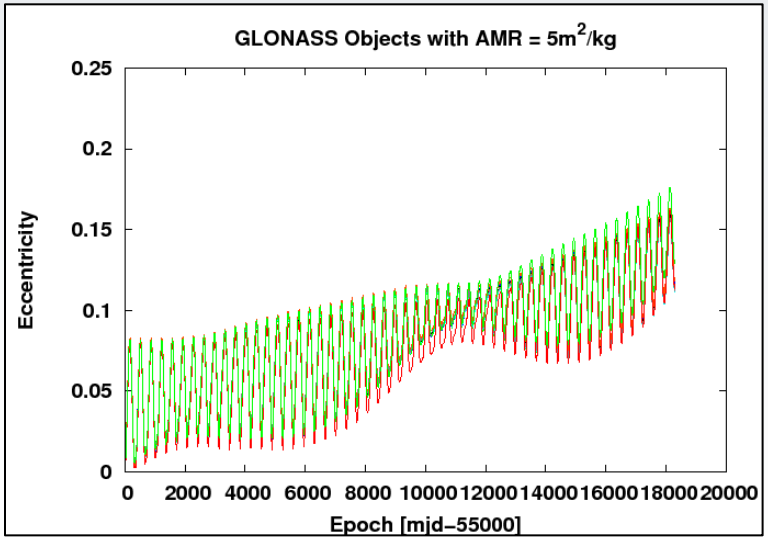


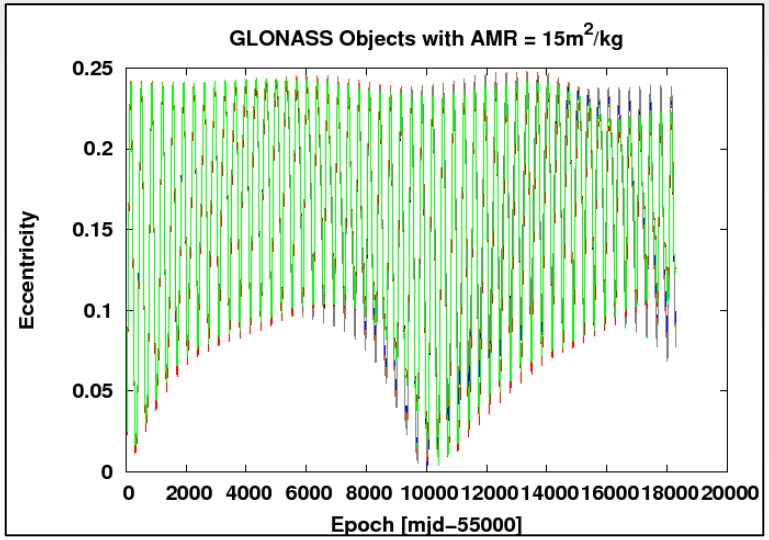


Evolution of Eccentricity (GLONASS)

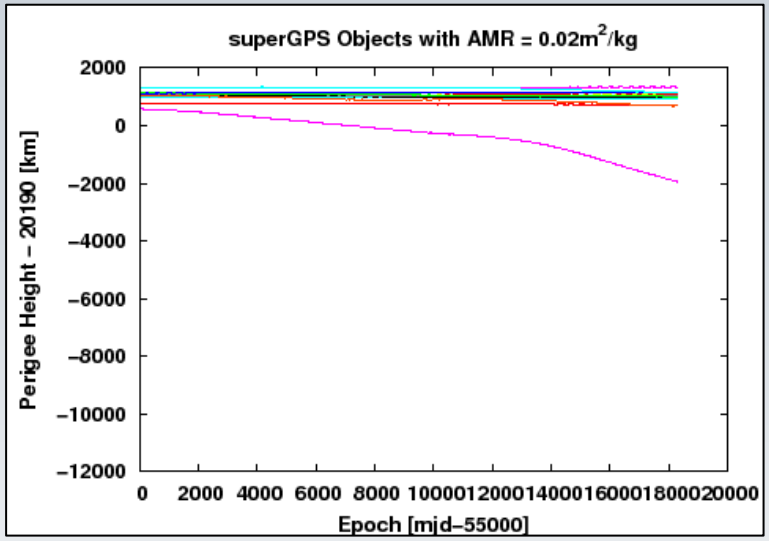


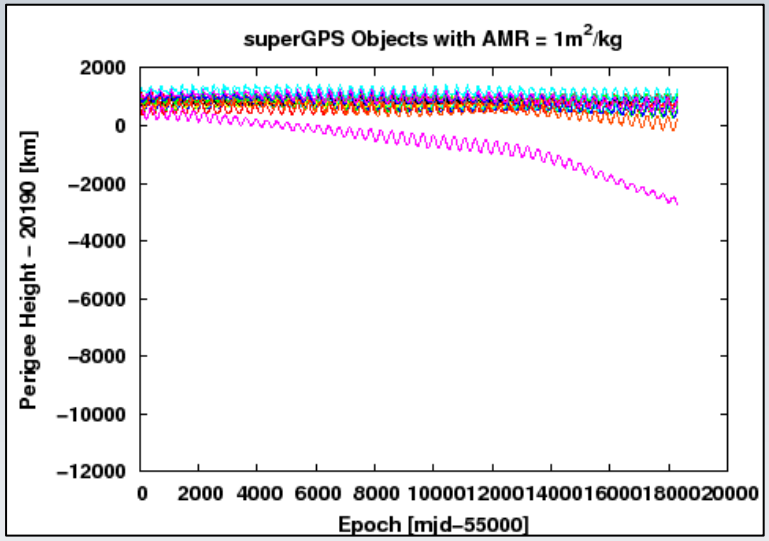


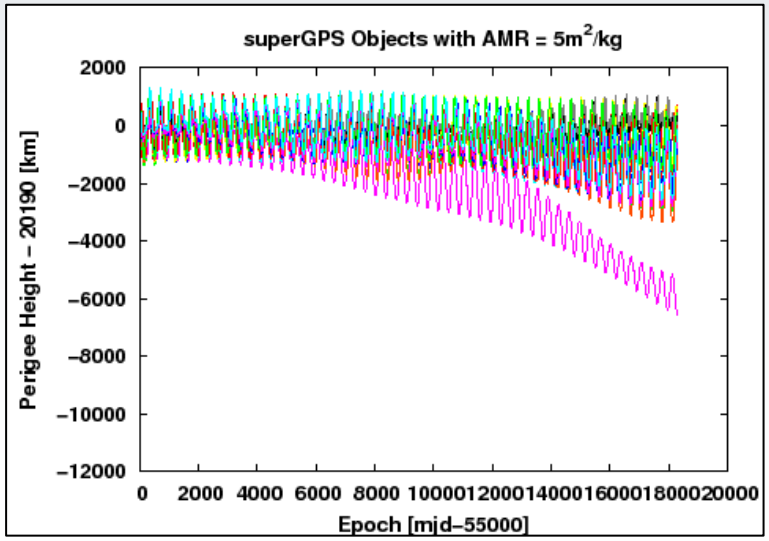


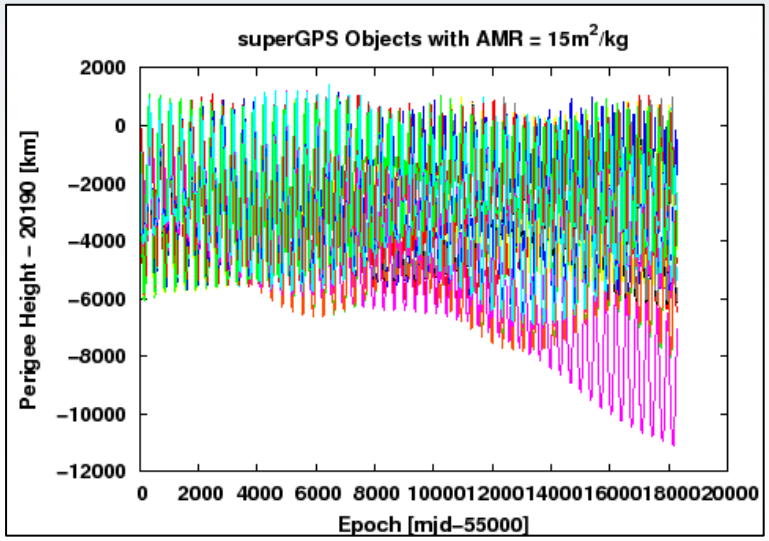


Evolution of Perigee Height (GPS)

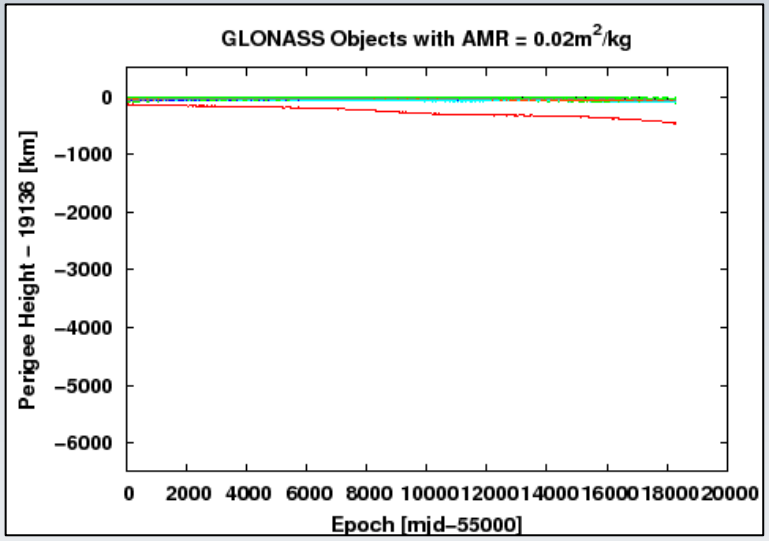


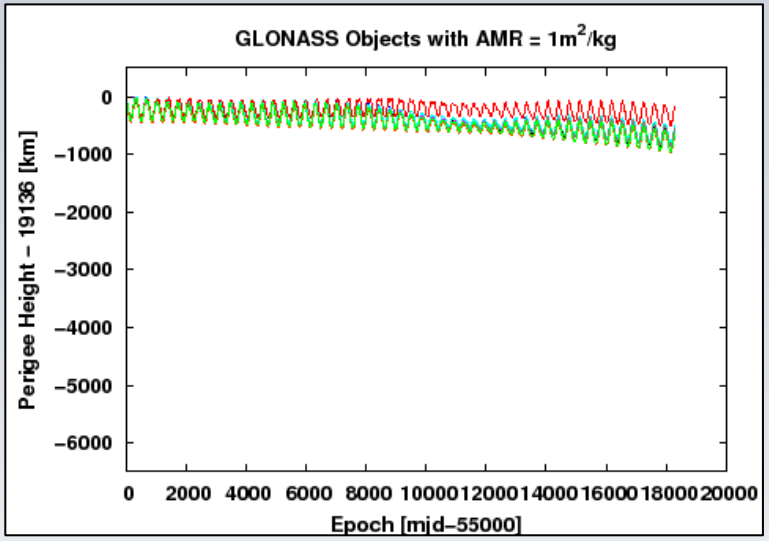


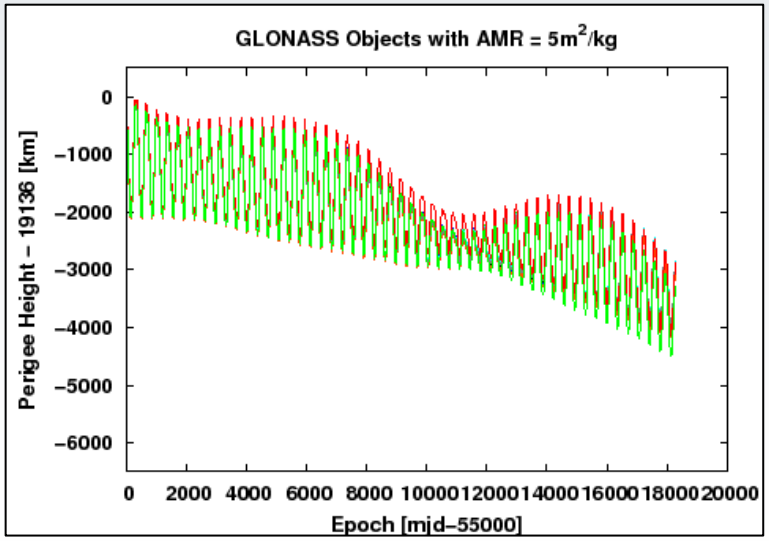


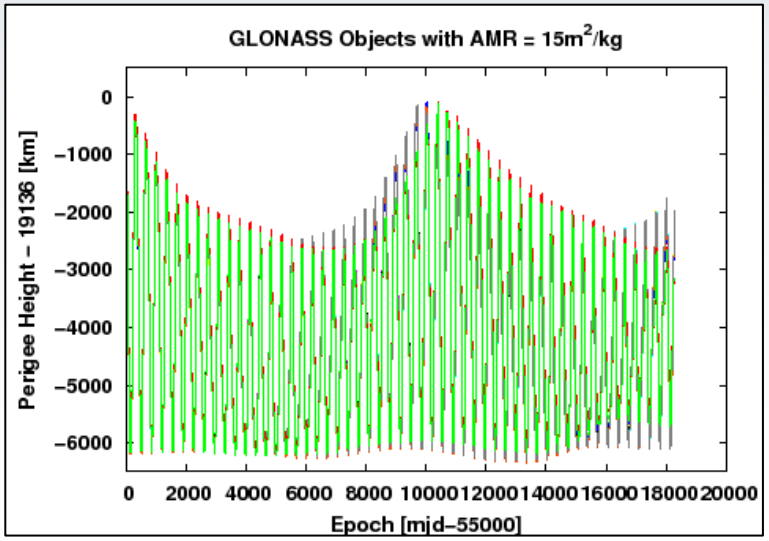


Evolution of Perigee Height (GLONASS)

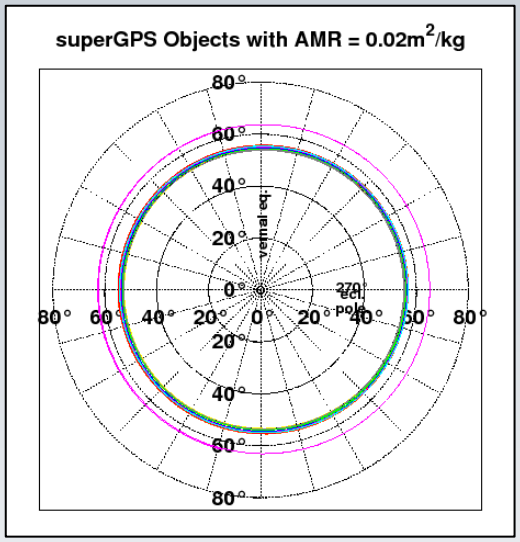


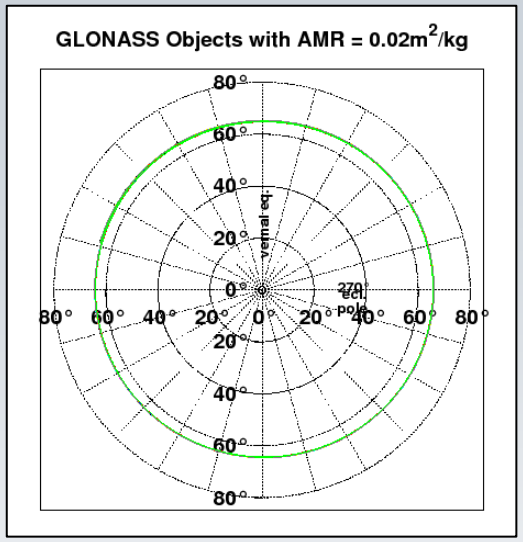


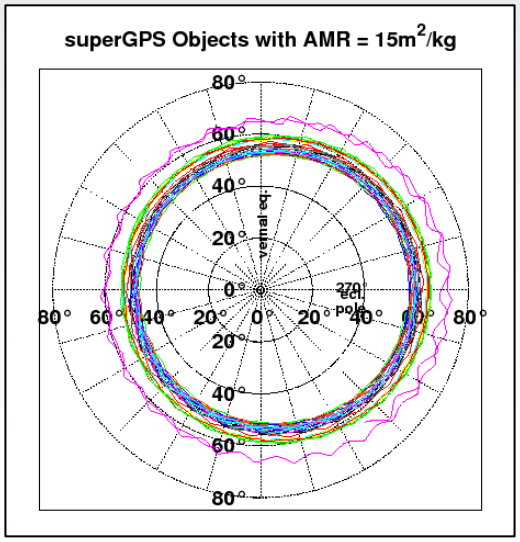


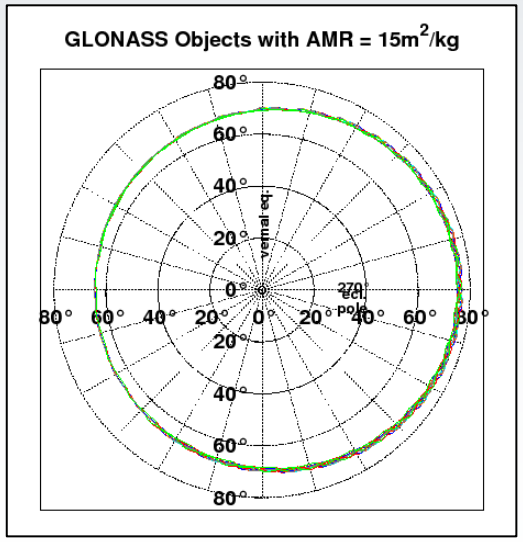


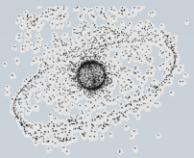
Evolution of Orbital Plane







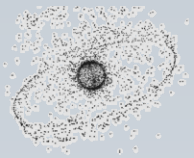




GPS/GLONASS Orbits

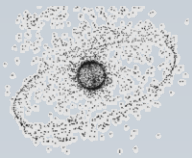
- Strong gravitational perturbations of GPS orbits due to 2:1 mean motion resonance
  - eccentricity
  - inclination, precession of orbital plane
- Objects in GPS graveyard orbits (>900km above GPS) will cross GPS altitude if
  - AMR $\gtrsim$ m²/kg

  OR
  - $e(t_0) \gtrsim 0.01$
- Perigee height of GLONASS orbits will change by >1000km if
  - AMR $\gtrsim$ 1m²/kg



Conclusions

- Catalogue of high AMR GEO/GTO objects
  - significant debris population with high AMR found in GEO and GTO region
  - orbits maintained by sharing the data in a network of observatories (KIAM, ISON)
- GEO/MEO graveyards
  - sources of high AMR debris to be expected when objects are left in space for long time span (aging processes, breakup-events, ...)
  - objects in GEO graveyard (300km above GEO) will cross GEO altitude if AMR>0.2m²/kg
  - perigee height of objects in GPS/GLONASS orbits will change for >1000km if AMR≳1m²/kg
  - long-term evolution of GPS orbits dominated by gravitational resonance effects for $e(t_0) \gg 0.01$



Acknowledgments

- Great thanks to our staff and observers at the OGS and Zimmerwald observatories!
- Support in the form observations to maintain the orbits is provided by the Keldysh Institute of Applied Mathematics (KIAM) in the framework of the ISON collaboration (AIUB-KIAM collaboration).