

# Results of Optical Surveys for Space Debris in MEO

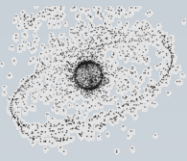
T. Schildknecht, A. Vananti, A. Hinze

*Astronomical Institute, University of Bern, Switzerland*

H. Krag, T Flohrer

*ESA / ESOC, Darmstadt, Germany*

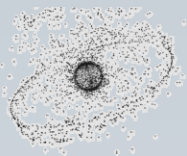
30th IADC Meeting, May 22 – 25, 2012,  
CSA, Montreal, Canada



# Outline

---

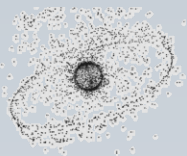
1. Survey for small-size debris in MEO (OGS)
2. Survey for large uncorrelated debris in MEO (ZimSMART)



# Introduction

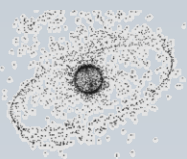
- **MEO Region**
  - orbital region of current and planned GNSS constellations, GPS, GLONASS, Beidou-2/COMPASS, GALILEO
  - becomes increasingly populated
  - **no published surveys for space debris**
- **Spatial Density**
  - **known population** < 250 objects → **very low density**
  - **no known breakup events**
- **But from experience in GEO ...**
  - GEO: 2 known and several suspected breakups  
→ 1–2 breakup events per 100 object in 25 years
  - additional sources: like aging s/c surfaces, etc.

**1 breakup → ~500 fragments > 10cm confined in single orbital plane**



# Introduction

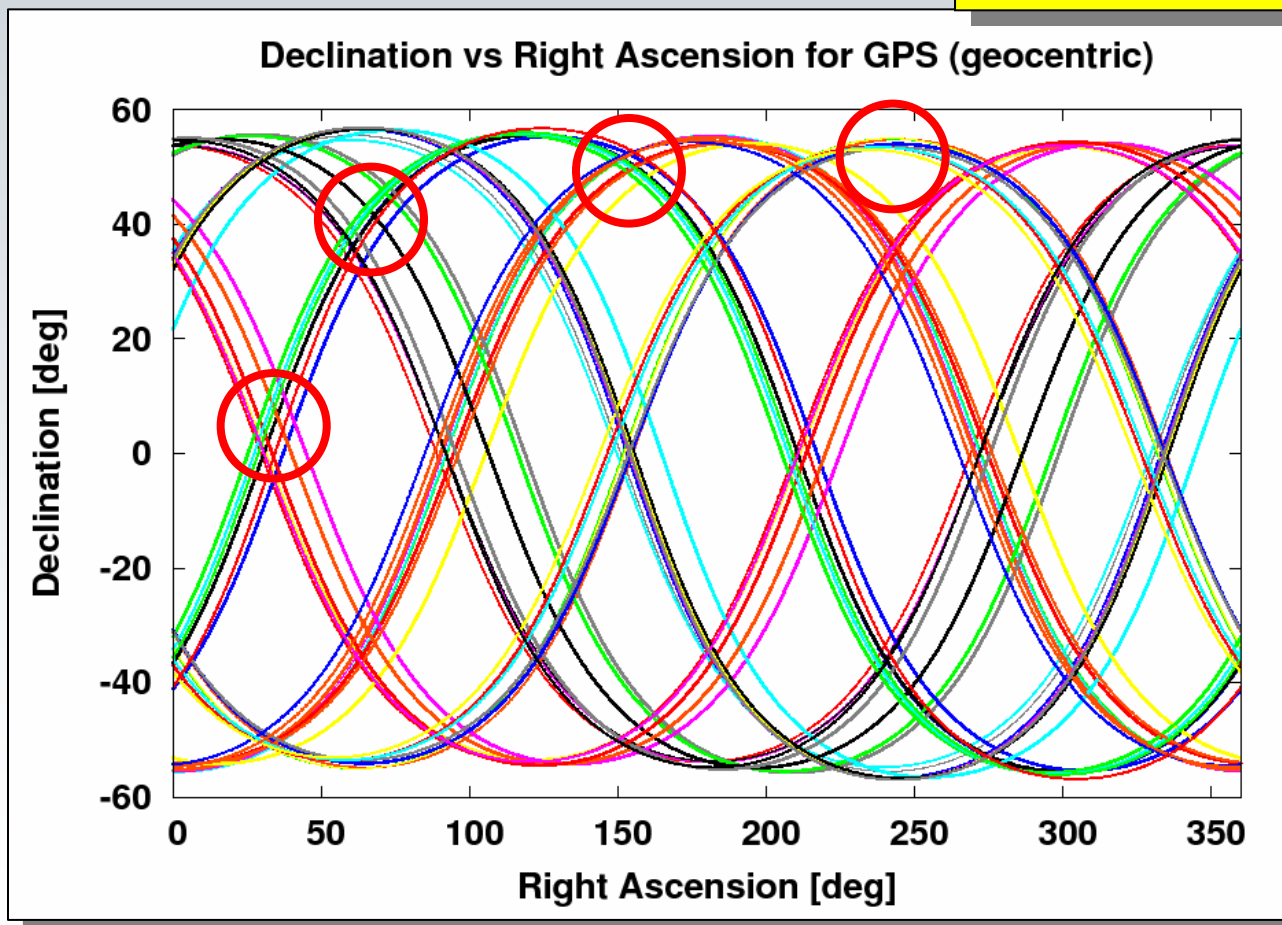
- Is there small-size debris in MEO?
- Approach
  - **statistical survey**
    - devise optimized survey strategies
    - optimize detection limit for faint objects
    - probe a (sub)population to collect statistical information
  - **generate synthetic breakup population**  
as baseline for
    - performance simulation of survey strategies
    - statistical analysis of observation results
  - **statistical analysis of survey results**
    - estimate probabilities for breakup events

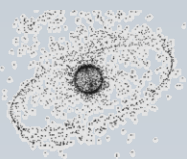


# MEO Observation Strategies

- Where to look?

GPS constellation

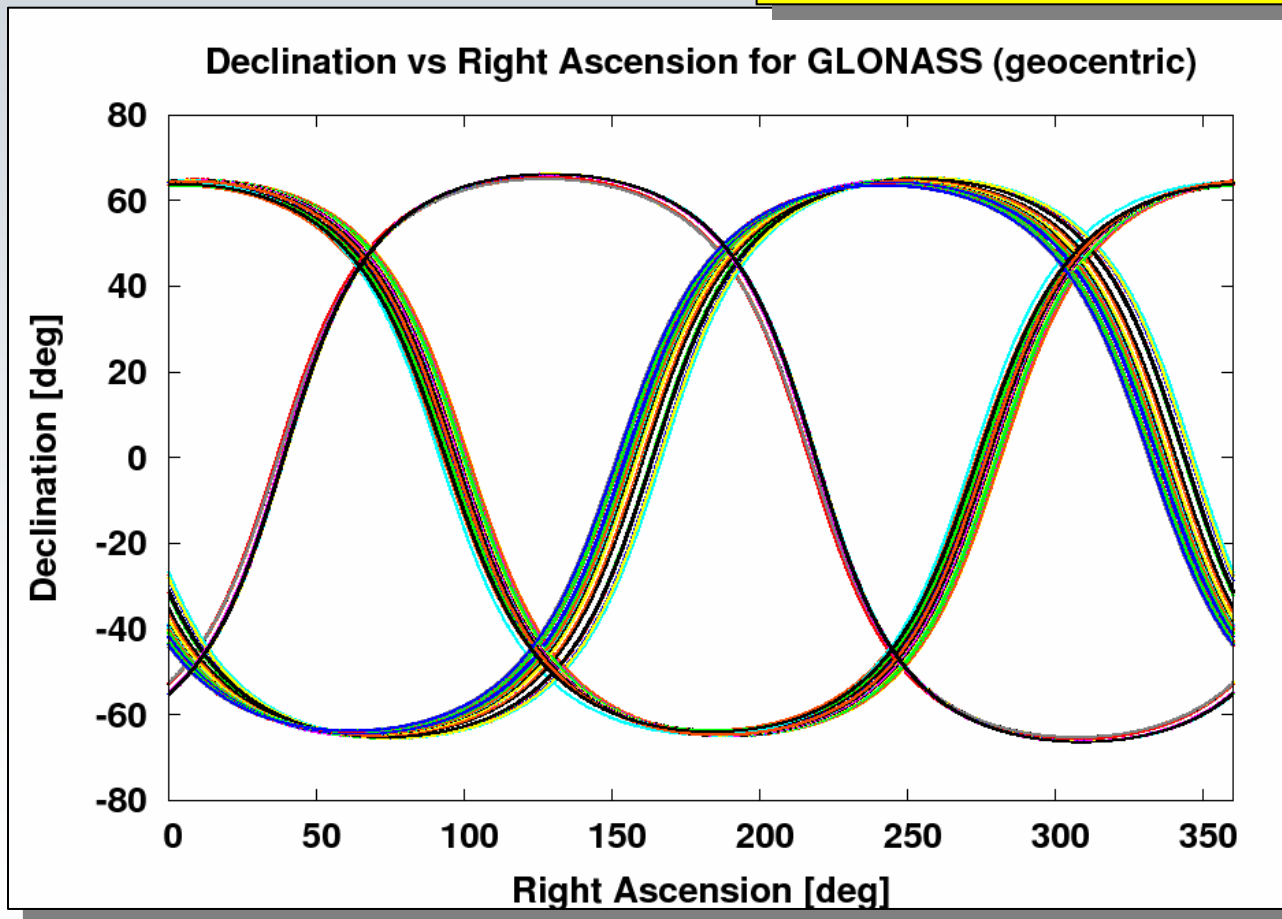


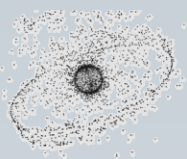


# MEO Observation Strategies

- Where to look?

**GLONASS constellation**

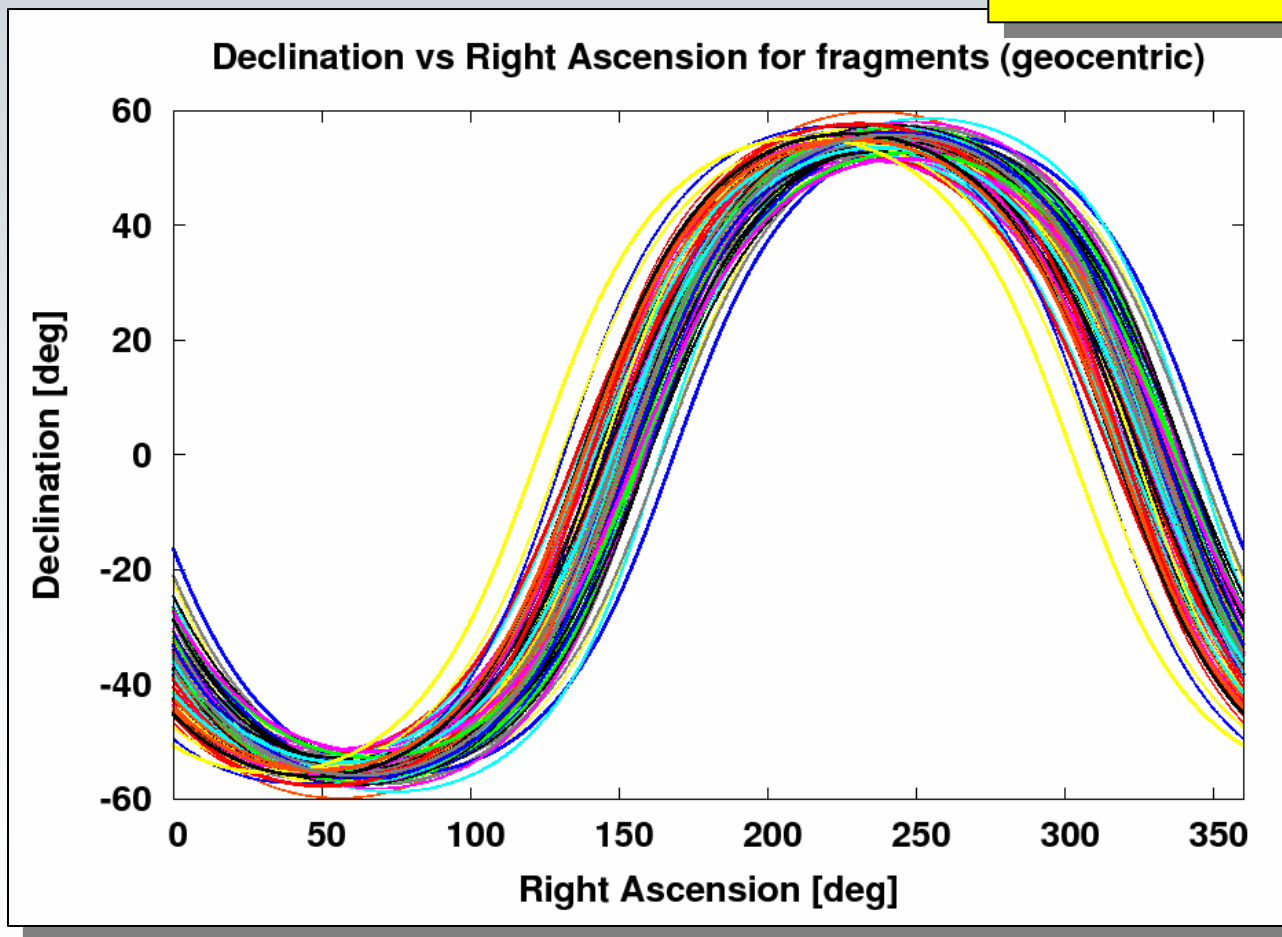


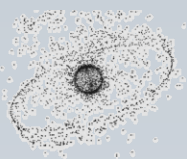


# MEO Observation Strategies

- Where to look?

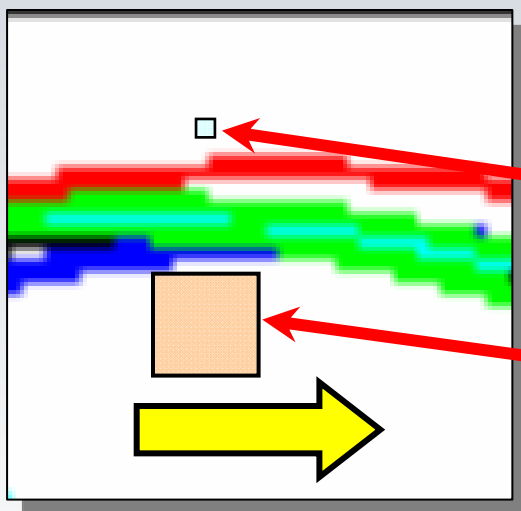
breakup event





# MEO Observation Strategies

- Culmination points



- GPS
- $20^\circ \times 20^\circ$
- culmination point
- velocity  $\sim 30''/s$

ESASDT FOV

ZimSMART FOV

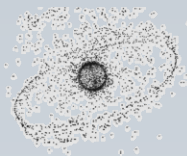




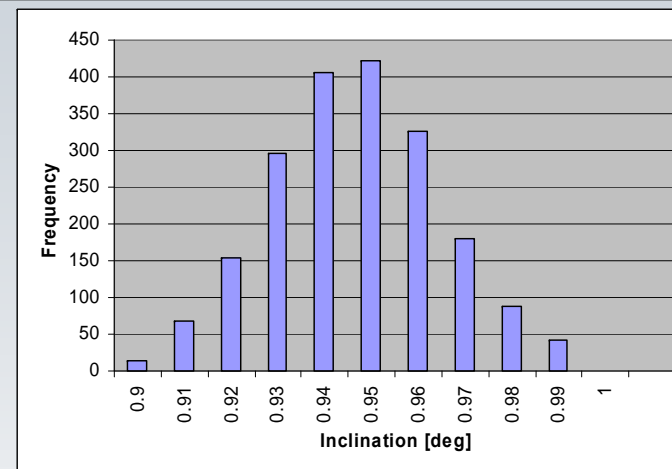
# Synthetic Population

- Generation of synthetic population
  - GPS Orbit (as an example)
  - explosion with isotropic velocity distribution (2000kg)
  - Monte Carlo runs:  
explosion at different anomalies
- fit normal distributions for orbital elements of explosion population (a, e, i, node)
- every TLE object may explode
- convolve with distribution of TLE population
- synthetic population (at  $t_0$ )
- convolve with increased dispersion of orbital elements after 15y (from orbit propagation)
- synthetic population (at  $t_0 + 15y$ )

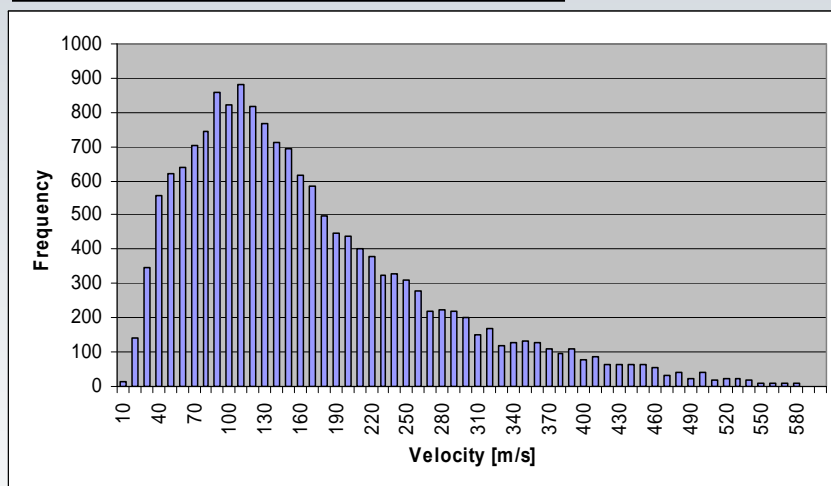
# Simulated Breakup



dispersion of  $i$  from explosion

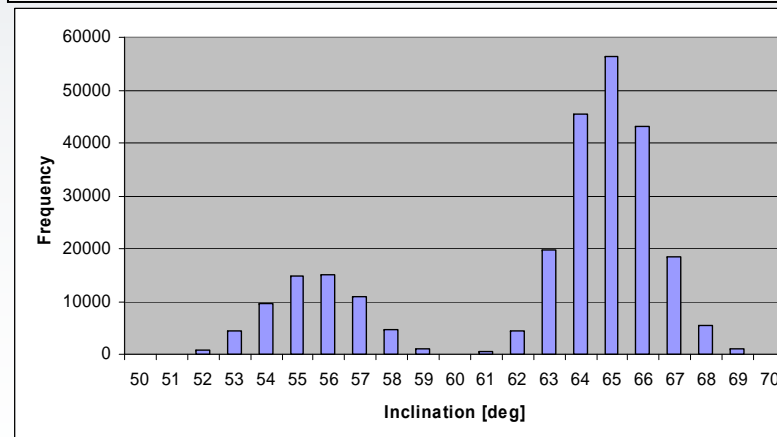


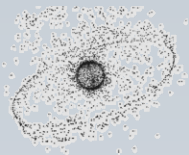
Distribution of the  $d\nu$



Maximal number of fragments at about 100 m/s

convolution with TLE population



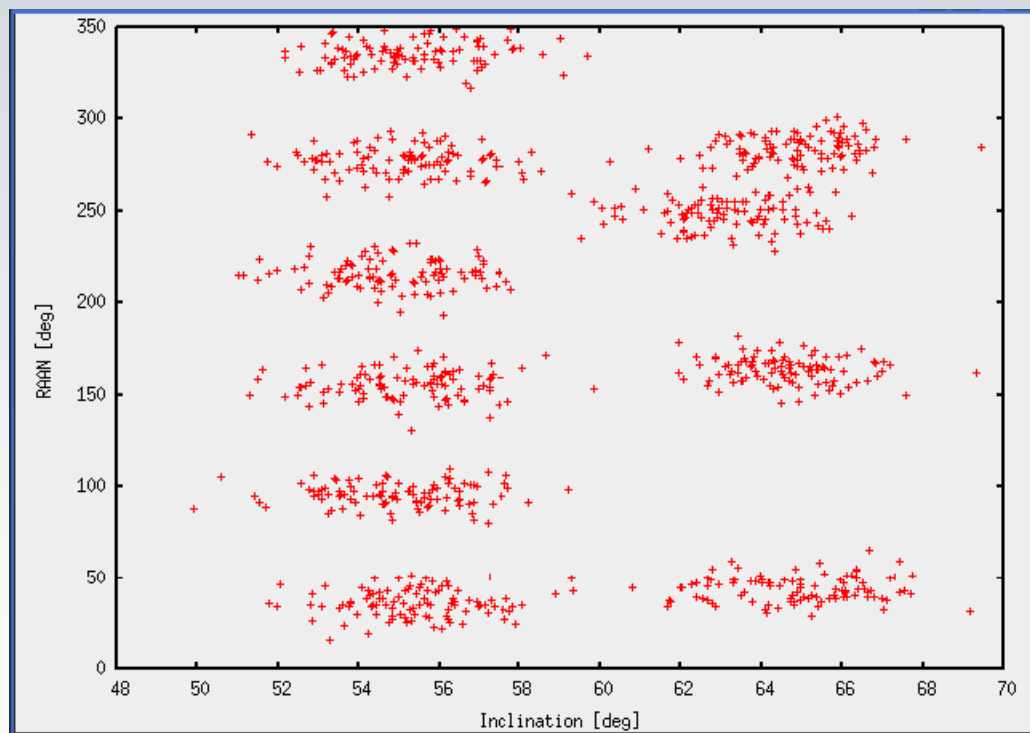


# Synthetic Population

## Convolution of explosion scenario and evolution dispersion

$$\sigma^2_{\text{tot}} = \sigma^2_{\text{expl}} + \sigma^2_{\text{evol}}$$

	$\sigma$ expl	$\sigma$ evol	$\sigma$ tot
<b>a [km]</b>	1220	$\approx 0$	<b>1220</b>
<b>e</b>	0.02	0.01	<b>0.022</b>
<b>i [°]</b>	1.5	0.5	<b>1.58</b>
<b>RAAN [°]</b>	5	5	<b>7</b>



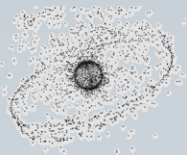


# MEO Surveys

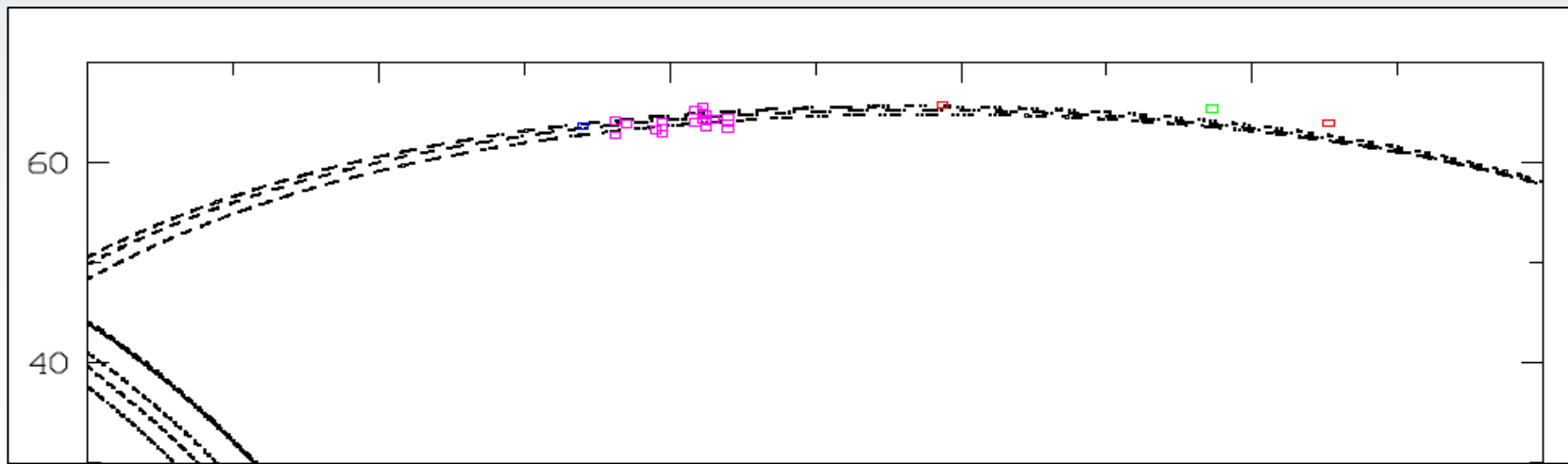
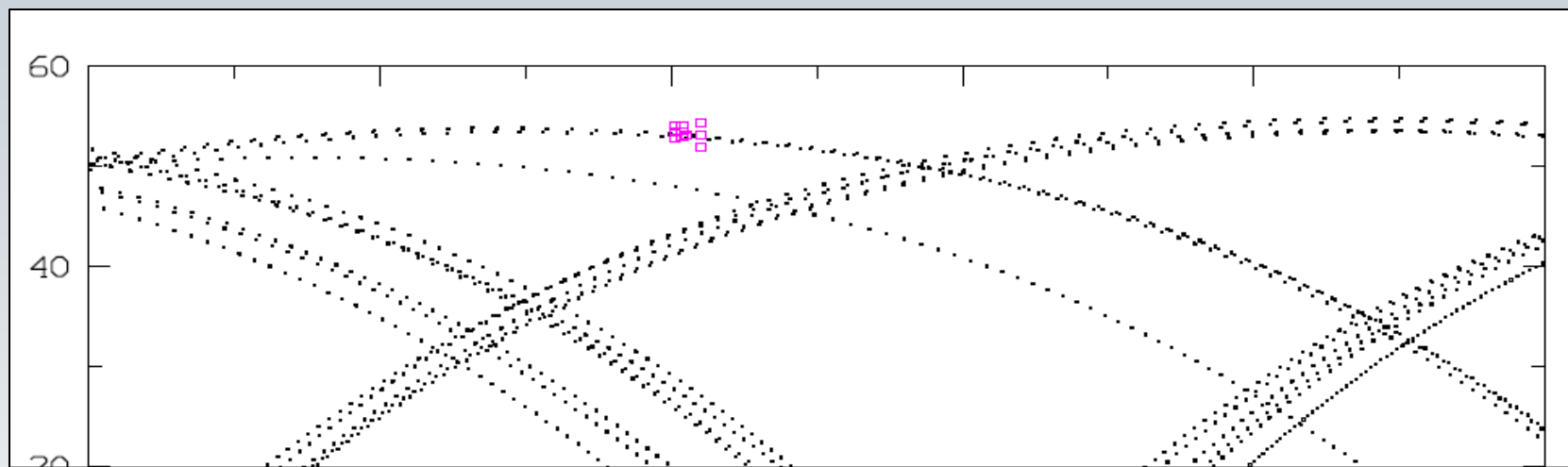
---

## January to November 2010

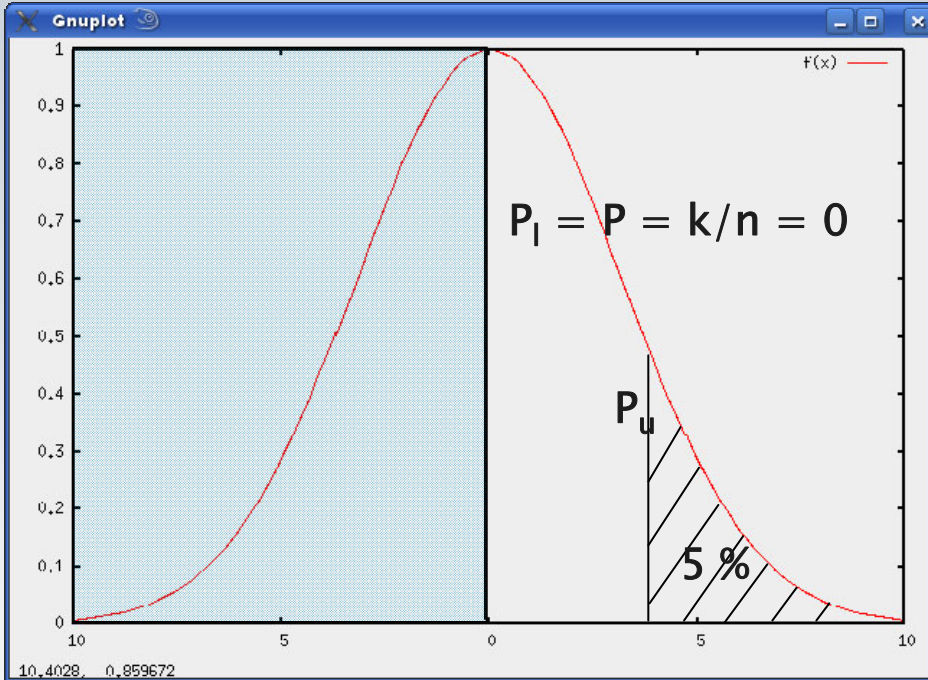
- 44 nights at OGS
- Different GPS and GLONASS orbital planes surveyed at the culmination and crossing points
- 284 Surveys series of 10 minutes
  - 62 in GPS orbital planes
  - 222 in GLONASS orbital planes
- All catalogue objects found (no “no-shows”)
- **NO uncorrelated object found during 3124 minutes (GEO/GTO surveys yield one uncorrelated object every 45 min)**



# Survey at the culmination



# Inferred Population



Binomial distribution:

$$p_k = \binom{n}{k} p^k (1-p)^{n-k}$$

$n$  = number of trials

$k$  = number of successes

$p = M/N$

$M$  = number of black balls

$N$  = total number of balls

Estimator:  $P = k/n$

Confidence interval  $[P_l, P_u]$  around  $P$ :

- lower limit  $P_l$
- upper limit  $P_u$

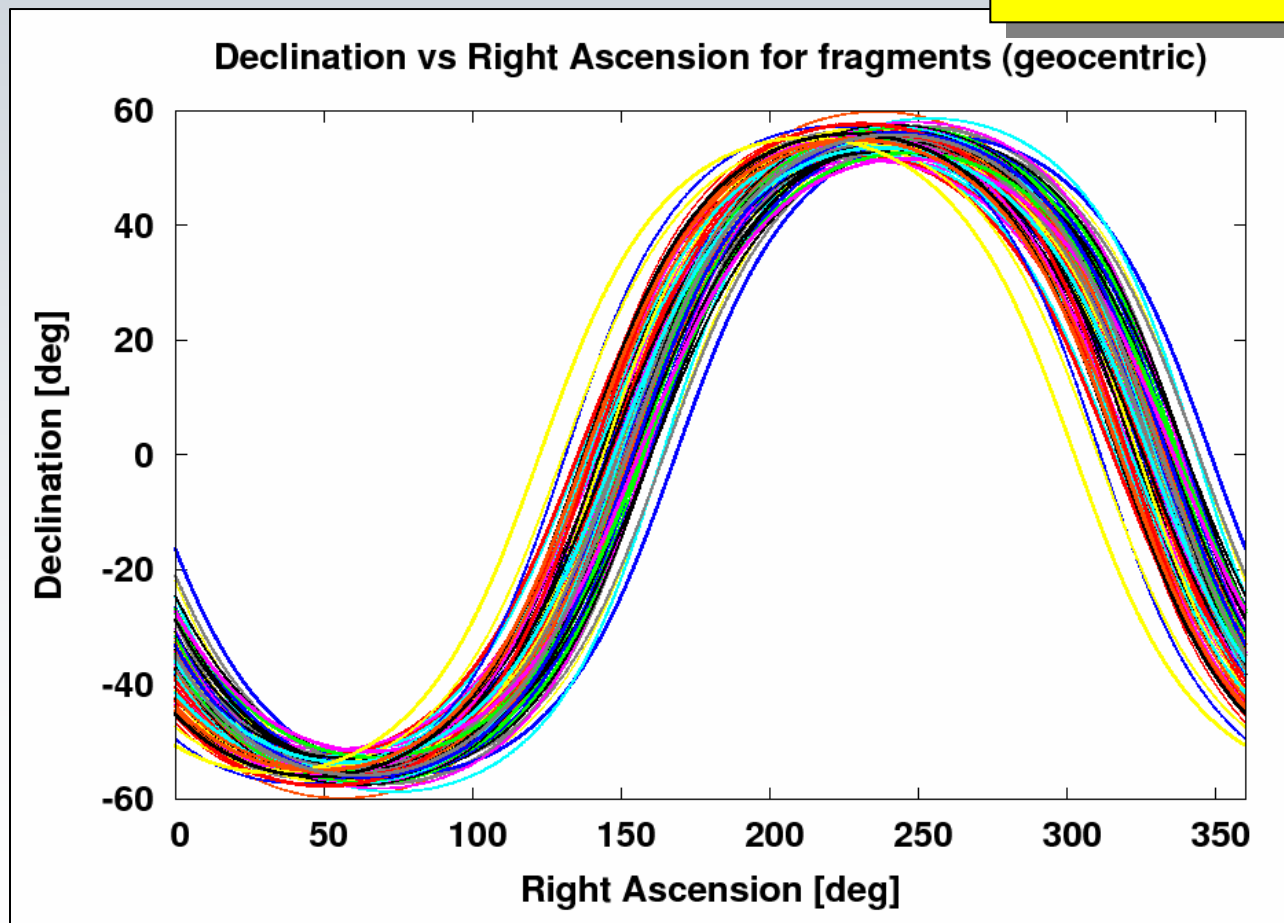
With  $k=0 \Rightarrow P_l = P = 0$

95% confidence:

$\Rightarrow P_u$  defines 5% area

# Breakup Population

breakup event



# Normalization Factors

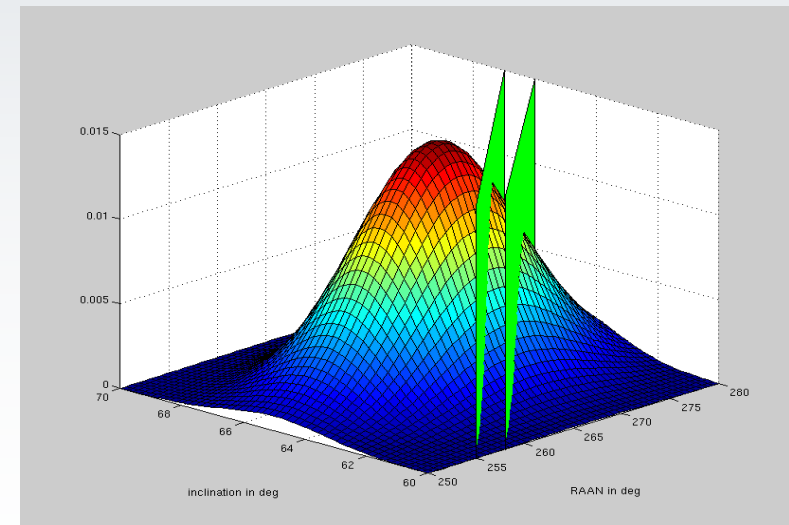
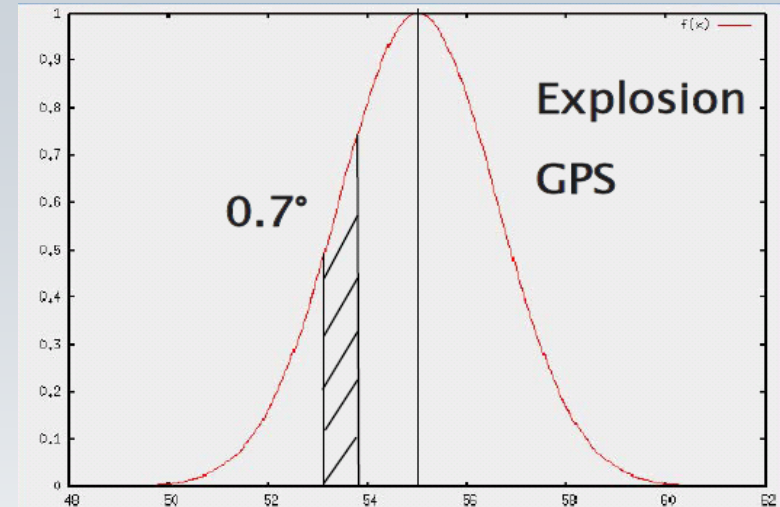
Assume breakup population in given orbital plane

Observation at the culmination:

- Fixed declination
- cover full explosion node range
- „2D“ – normalization factor

Observation outside culmination:

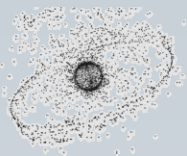
- Cover range of inclinations and nodes
- „3D“ – normalization factor



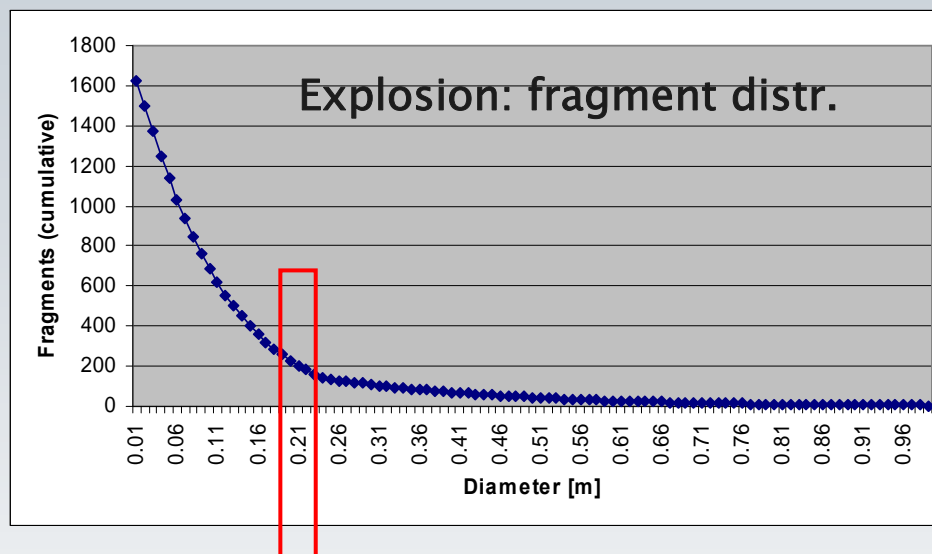


# Inferred Population

	GLONASS			GPS					
Group/plane	G1	G2	G3	N1	N2	N3	N4	N5	N6
RAAN	30	150	270	30	150	210	90	270	330
active	8	8	5	5	5	5	6	6	4
non-active	9	42	44	2	4	1	3	3	4
surveys [min]	704	748	1001	275	187	55	154	0	0
max. # of objects in plane (95% prob.)	38	20	6	73	308	140			



# Has an Explosion Occurred?



ESASDT limiting MEO object size  $\sim 20$  cm  $\rightarrow \sim 200$  objects

Max. number of objects in GPS planes:

GPS 1:  $\sim 73$

GPS 2:  $\sim 308$

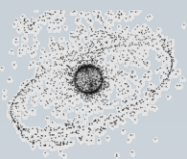
GPS 3:  $\sim 140$

Max. number of objects in GLONASS planes:

GLONASS 1:  $\sim 38$

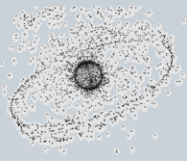
GLONASS 2:  $\sim 20$

GLONASS 3:  $\sim 6$



# Summary for small-size MEO Survey

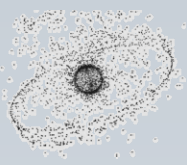
- First attempt to characterize small-size debris environment in MEO
  - conclusive results for 5 GNSS orbital planes
- MEO surveys for small-size debris in
  - 3 GPS planes
  - 3 GLONASS planes
  - no uncorrelated objects found in MEO after ~52h of surveys
- Statistical Analysis of MEO surveys
  - no evidence for breakup event (of large object) (95% confidence) in
    - 3 GLONASS orbital planes
    - 2 GPS orbital planes
    - 1 GPS plane with insufficient observations
- Start Survey of Molniya orbits (2012)



# Outline

---

1. Survey for small-size debris in MEO (OGS)
2. Survey for large uncorrelated debris in MEO (ZimSMART)

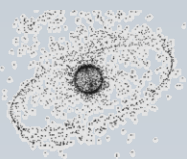


# ZimSMART MEO Surveys

## Comprehensive survey of MEO GNSS constellations (& Molniya)

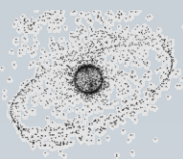
- Search for bright ( $\geq 14$ mag) uncorrelated objects
- Complete overage of orbital planes
  - along-track search w.r.t. reference object



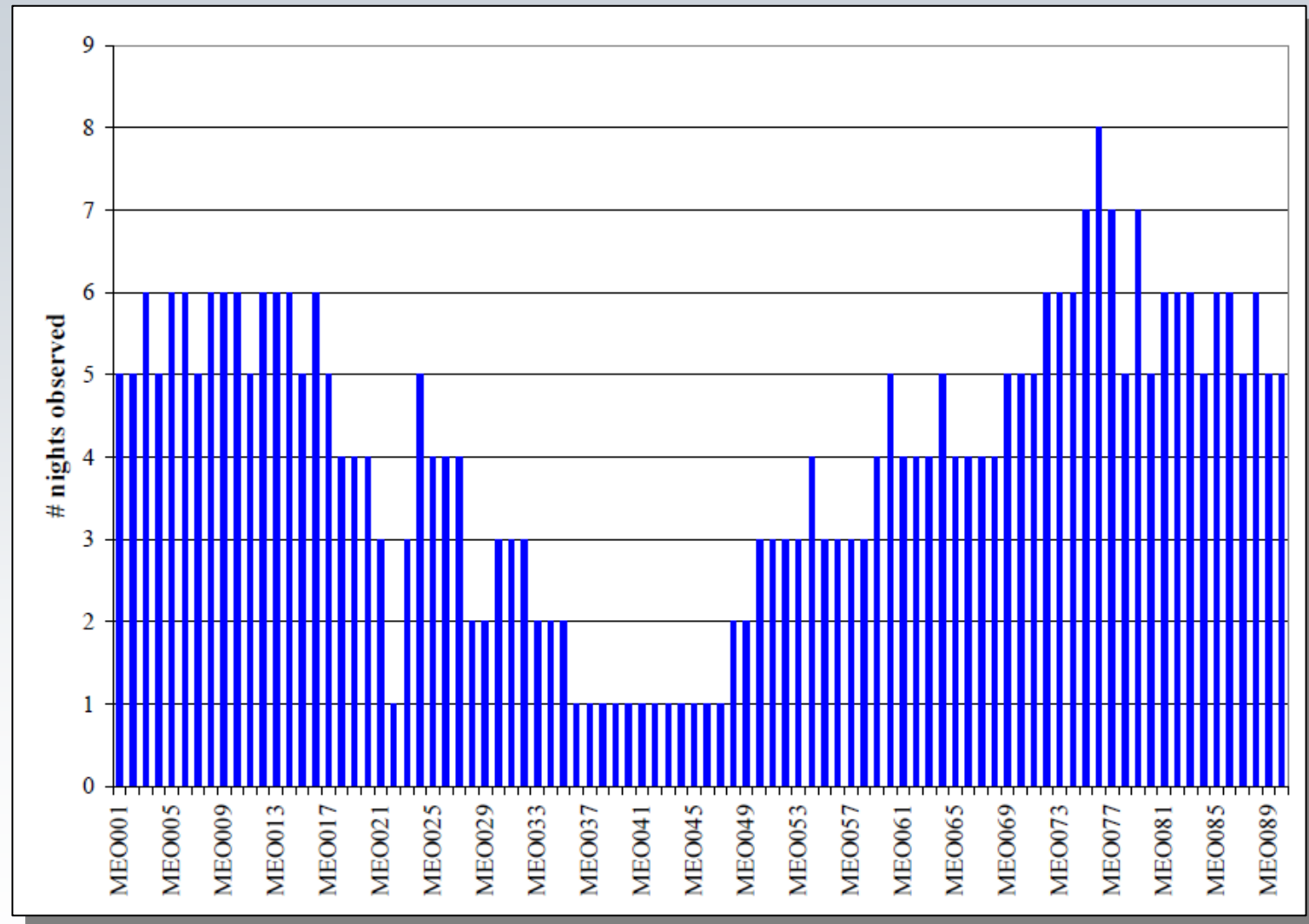


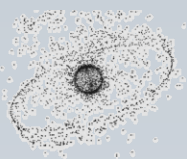
# ZimSMART MEO Surveys

Orbital plane	Reference object of that plane	Observation period	uncorrelated tracklets (all/MEO)
GIOVE-A	GIOVE-A (05051A)	18.4. – 9.5.2011	60 / 13
GLONASS 1	COSMOS 2471 (11009A)	5.7. – 8.8.2011	28 / 10
GLONASS 2	COSMOS 2471 (10041A)	16.5. – 4.7.2011	16 / 7
NAVSTAR GPS D	NAVSTAR 23 (91047A)	28.10. – 20.11.2011	37 / 6
NAVSTAR GPS E	NAVSTAR 22 (90103A)	8.9. – 11.10.2011	10 / 4
Molniya	MOLNIYA 1-93 (04005A)	15.10. – 22.10.2011	10 / 0
GLONASS 1	COSMOS 2442 (08046A)	9.8. – 2.9.2011	64 / 24

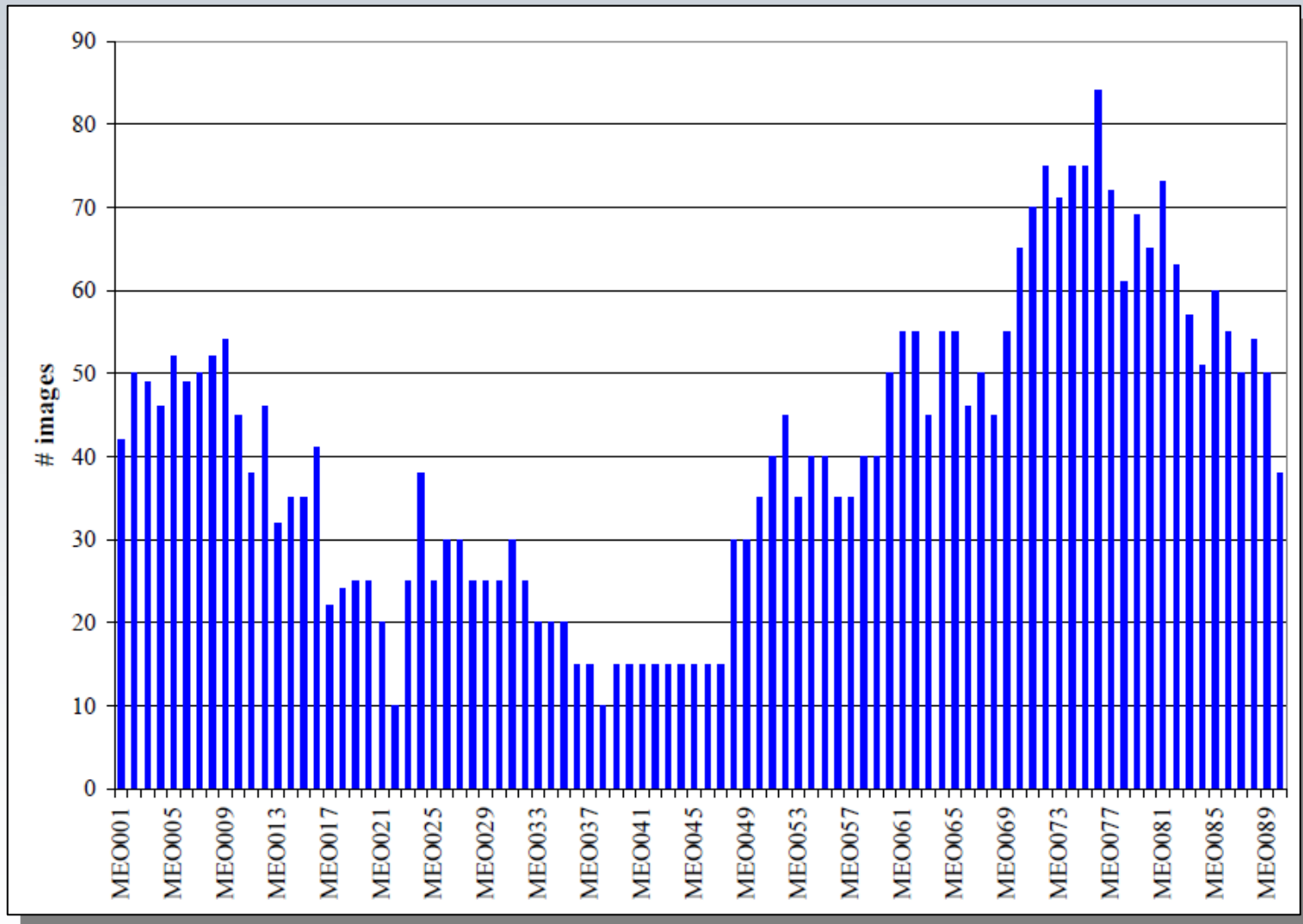


# Example Coverage of GLONASS 1 Plane

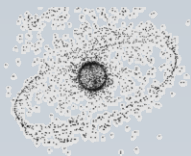




# Example Coverage of GLONASS 1 Plane

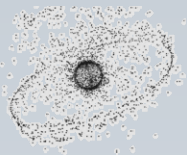




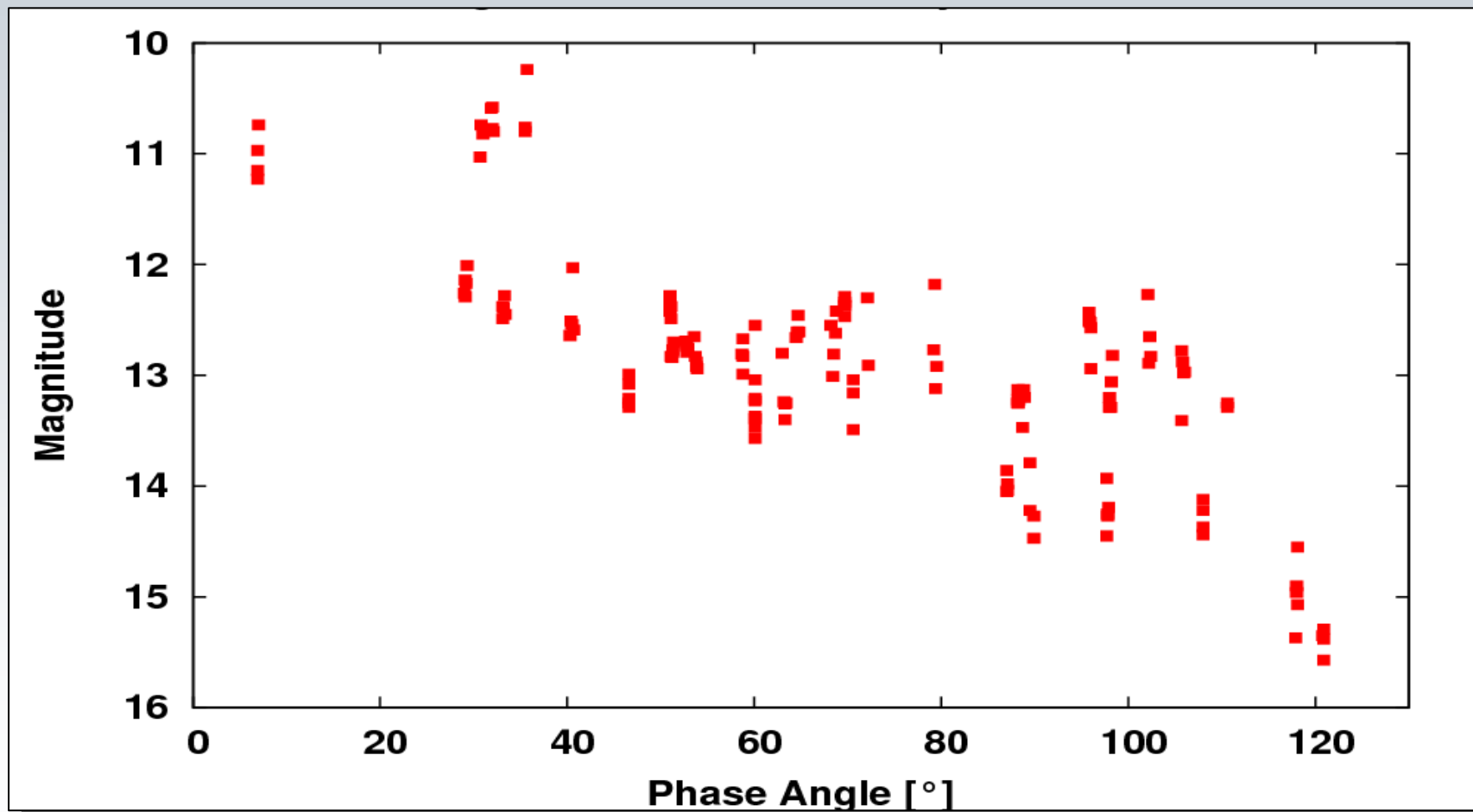


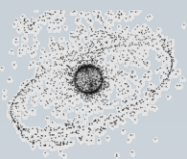
# Uncorrelated Object

- Discovery of uncorrelated, large object (Z11317A)
- Object observed over period of 50 days (still followed up)
- Compare characteristics with known objects
  - Mag vs phase angle (phase function)
  - evolution of AMR

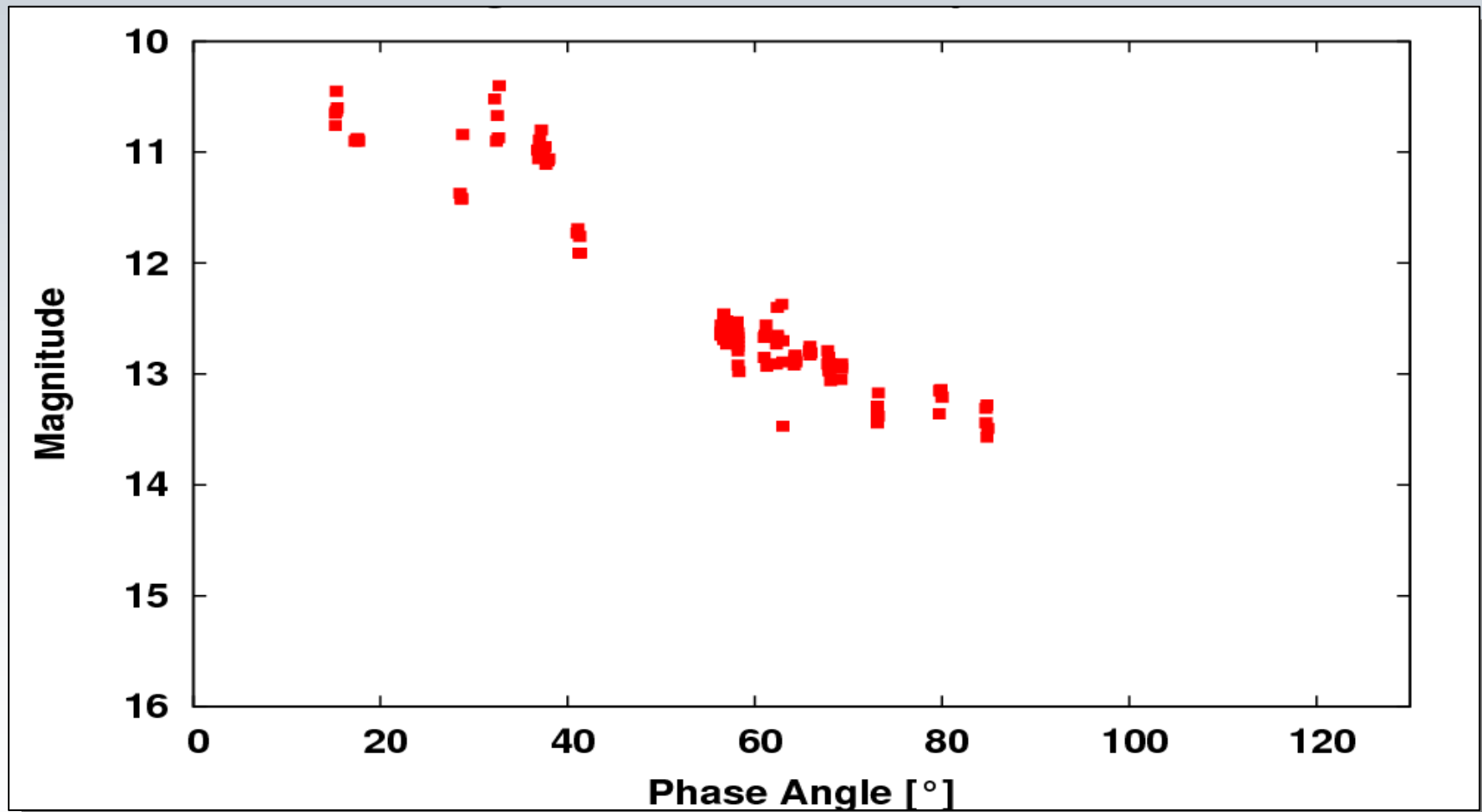


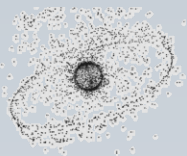
# Phase Function Z11317A



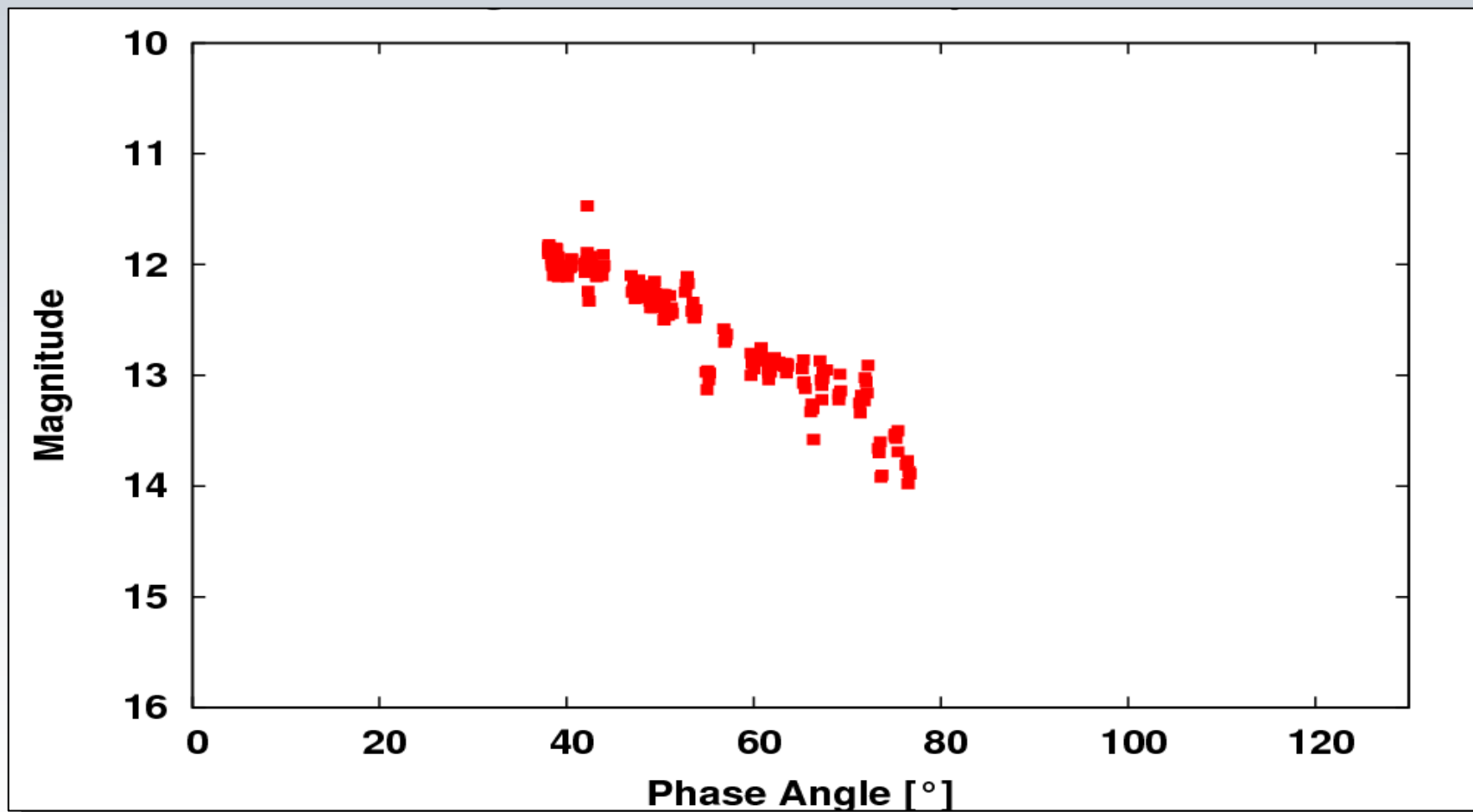


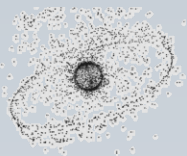
# Phase Function Controlled GNSS



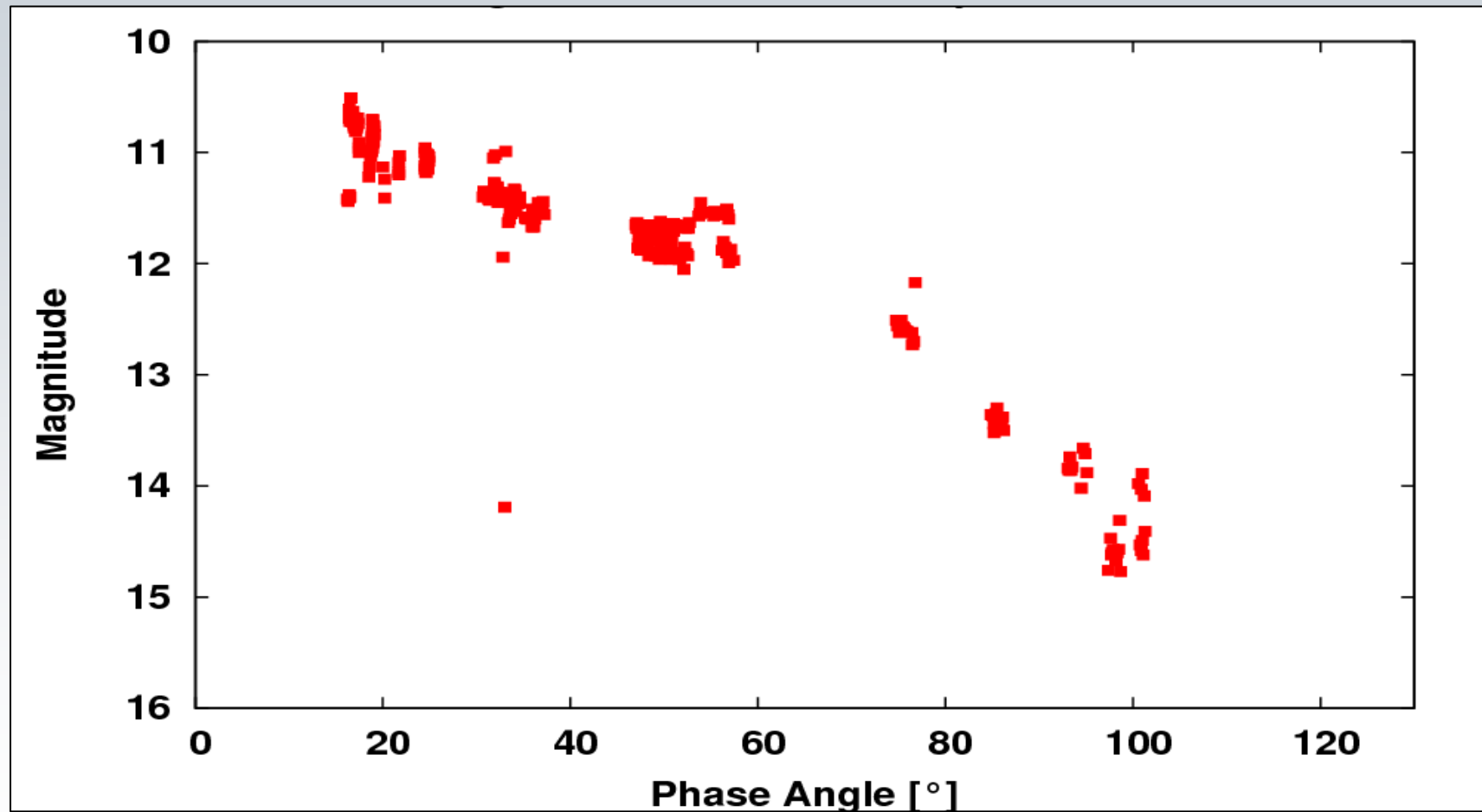


# Phase Function Controlled GNSS

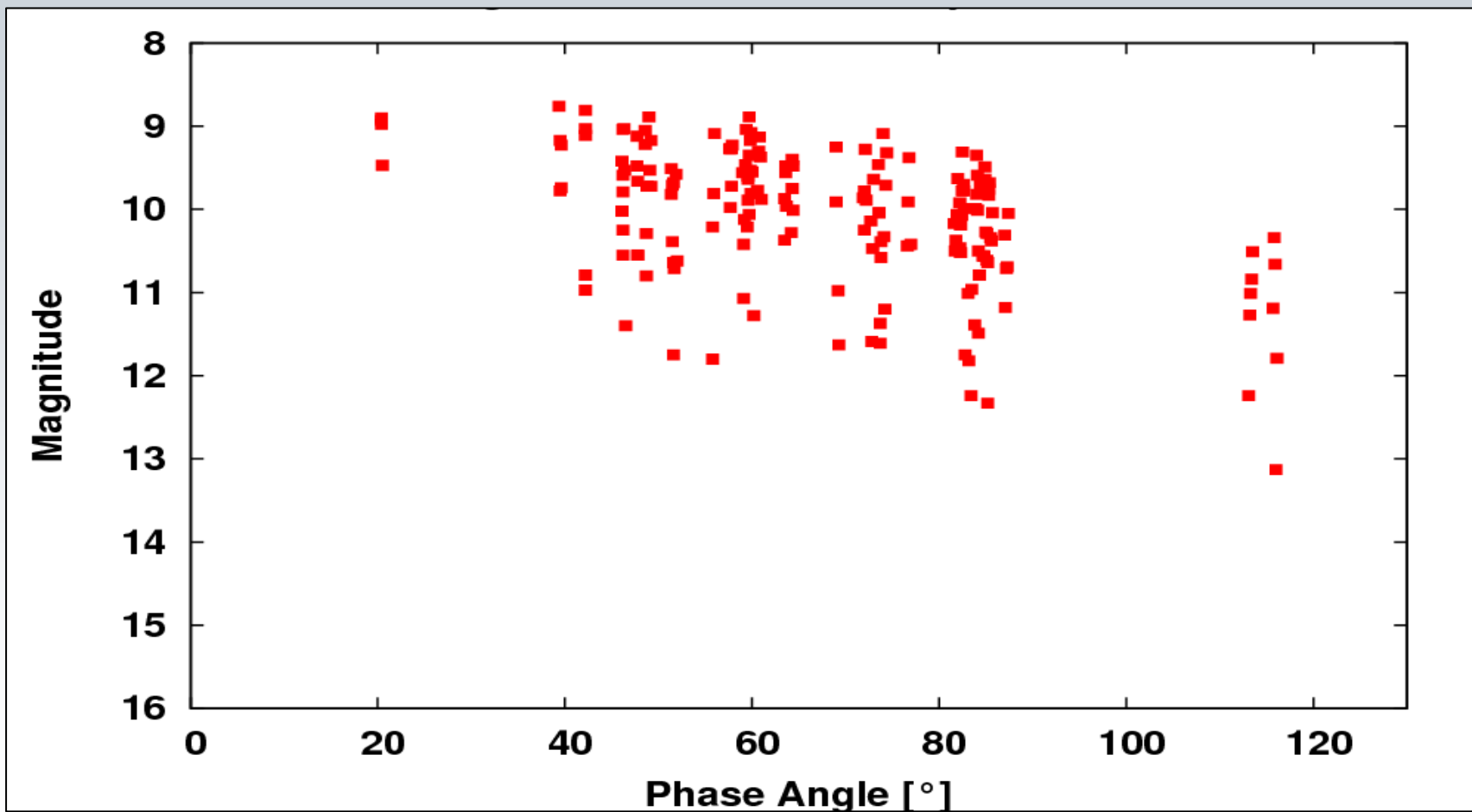


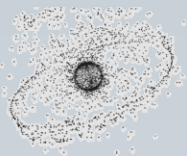


# Phase Function Controlled GNSS

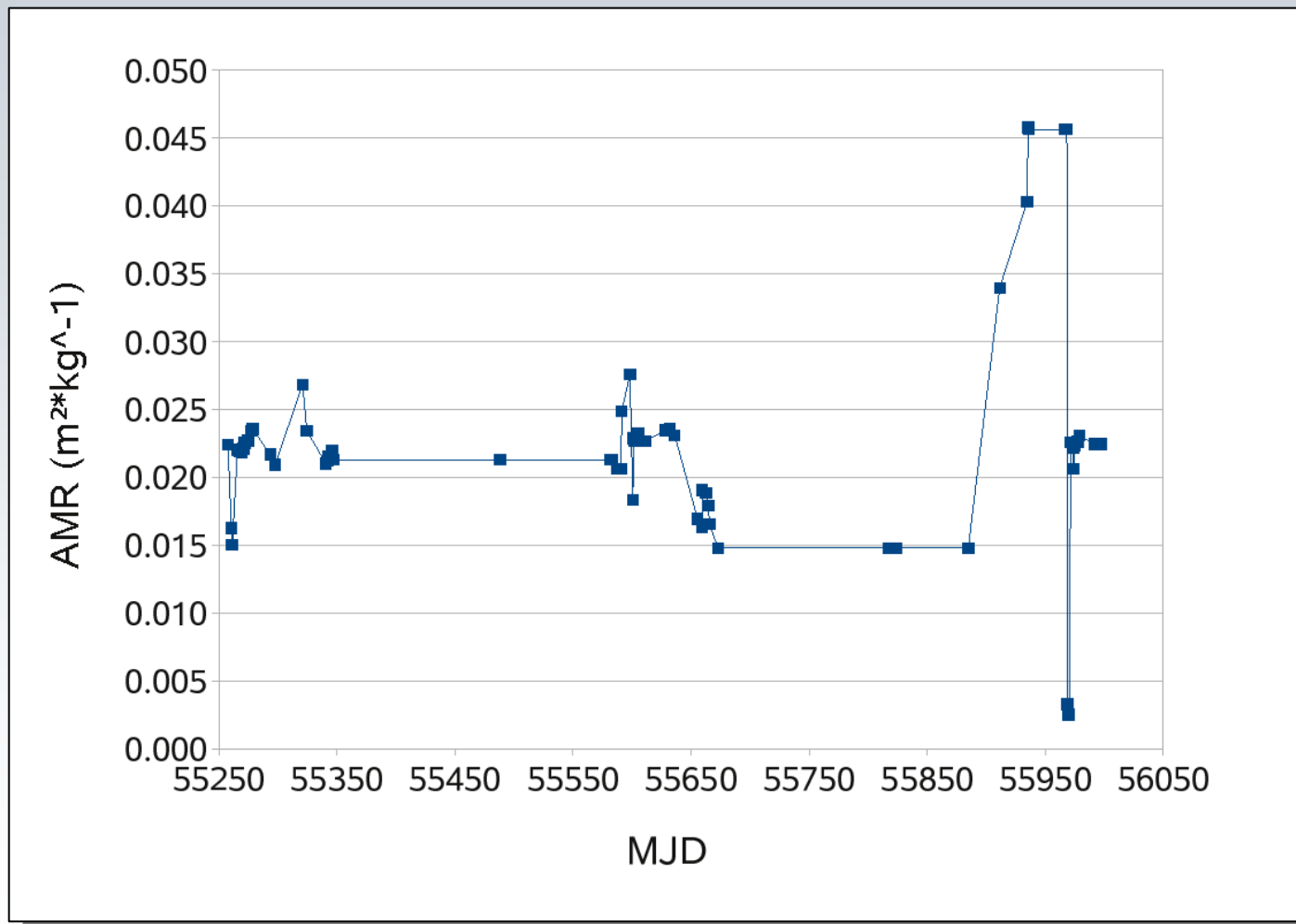


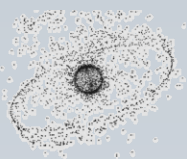
# Phase Function of R/B



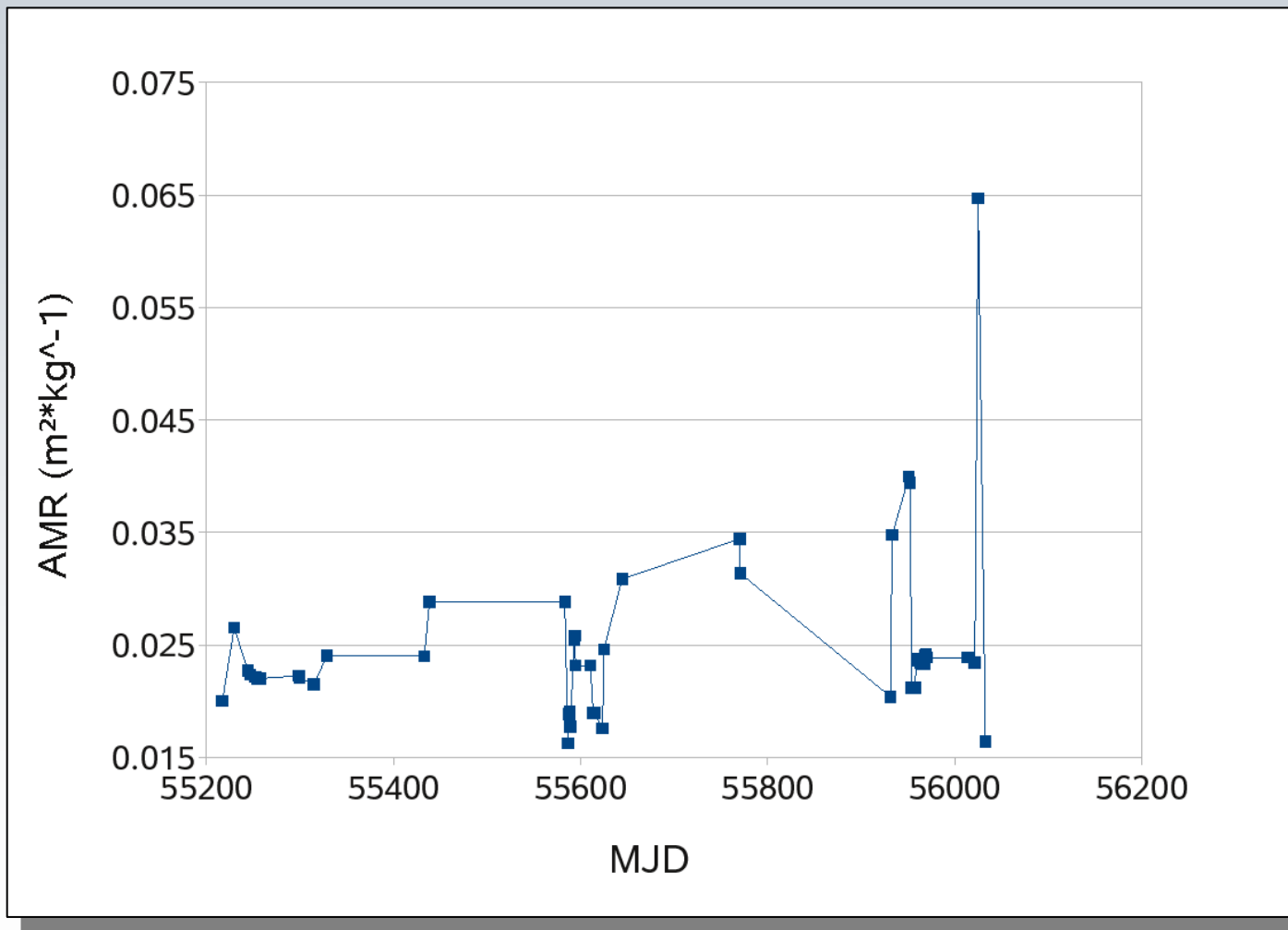


# AMR Variation Controlled GPS 03005A

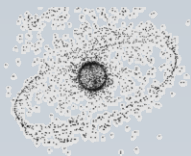




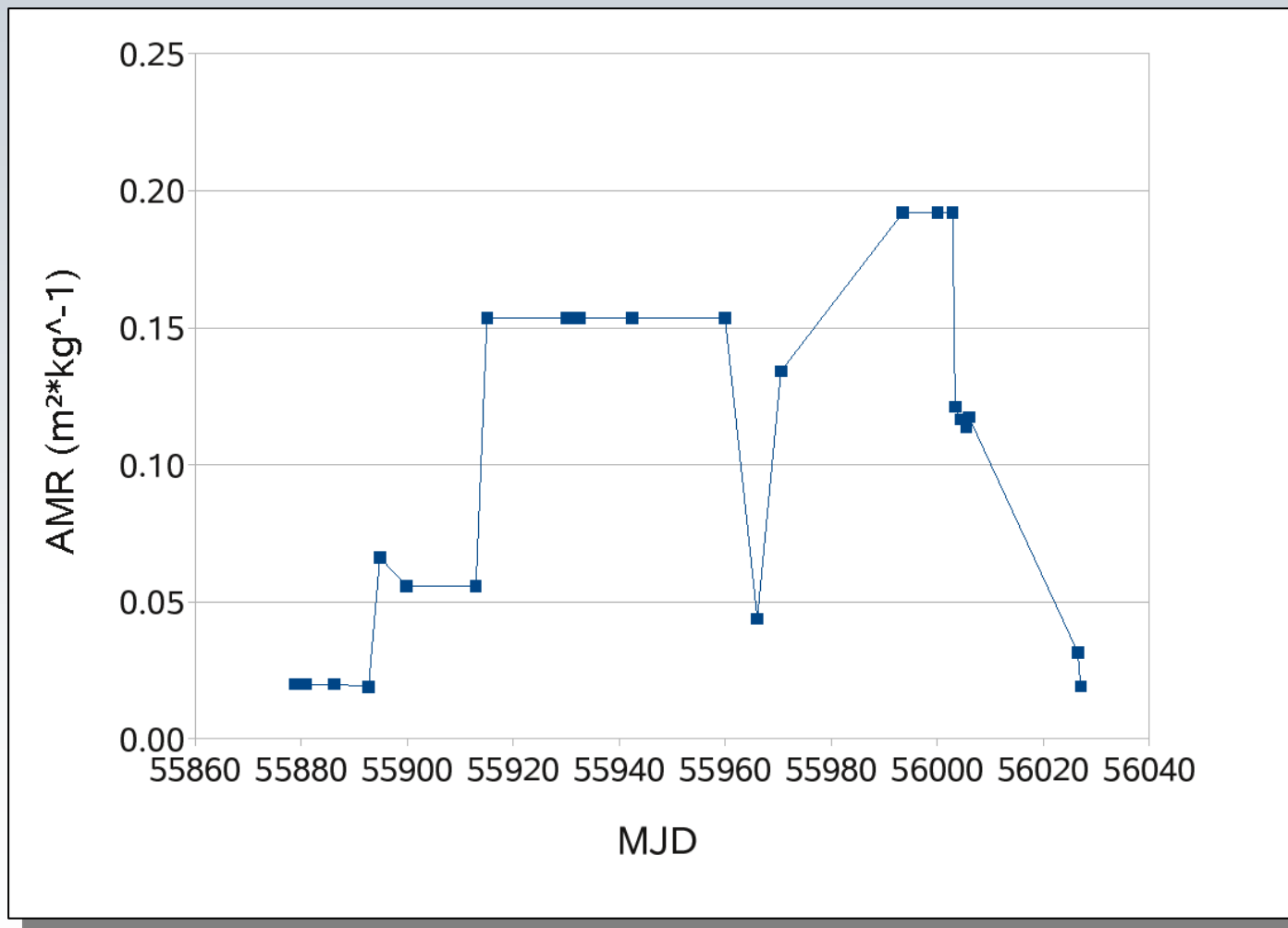
# AMR Variation Controlled GPS 03010A

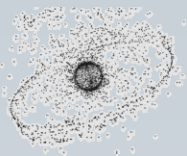






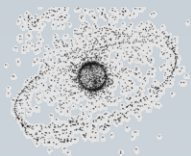
# AMR Variation Z11317A





# Summary MEO Bright Object Survey

- Uncorrelated tracklets of objects in GNSS MEO orbits found ( $\text{mag} \geq 14$ )
- Large uncorrelated object in GNSS orbit plane
- Work in progress:
  - investigate characteristics of uncorrelated object (light curves, etc.)
  - derive statistical results
    - probabilities for uncorrelated objects in each GNSS plane
  - Continue survey of Molniya orbits



# Acknowledgments

---

- Great thanks to our observers at the OGS and Zimmerwald!