Russian Academy of Sciences
Keldysh Institute of Applied Mathematics

CHARACTERIZATION OF GEO AND HEO OBJECTS USING MULTI-YEAR STATISTICS ON BRIGHTNESS MEASUREMENTS

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61st IAC
Prague, 27 Sep - 1 Oct 2010

Research Goals

Understanding deterministic GEO object population distribution by various parameters

Verification of applicability of diffuse sphere model usage for statistical modeling of GEO, HEO and MEO objects brightness distribution

Checking consistency in observed brightness patterns for objects of the same design located on different orbits and having different observability conditions

Understanding approaches which can be used for brightness estimation in sensor tasking for survey and track modes

GEO region definition (KIAM database)

Inclination range – 0°…30°

Eccentricity ≤ 0.2

Period range – 1100…2060 min (corresponds to mean motion range approx. 0.7…1.3 rev/day)

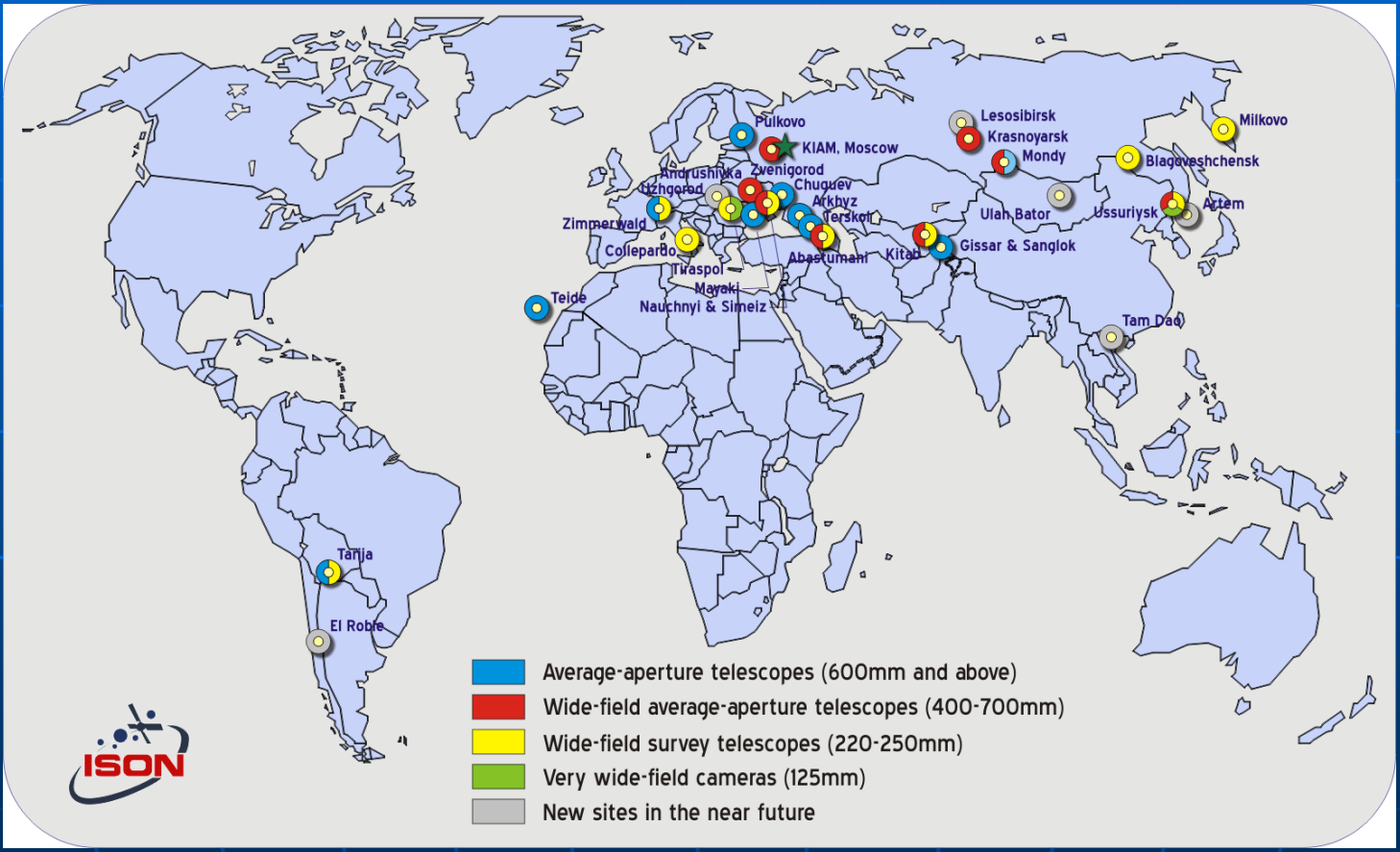
HEO orbit definition (KIAM database)

Inclination range – 0°…180°

Eccentricity > 0.2

Period > 200 min

I S O N
International Scientific Optical Network



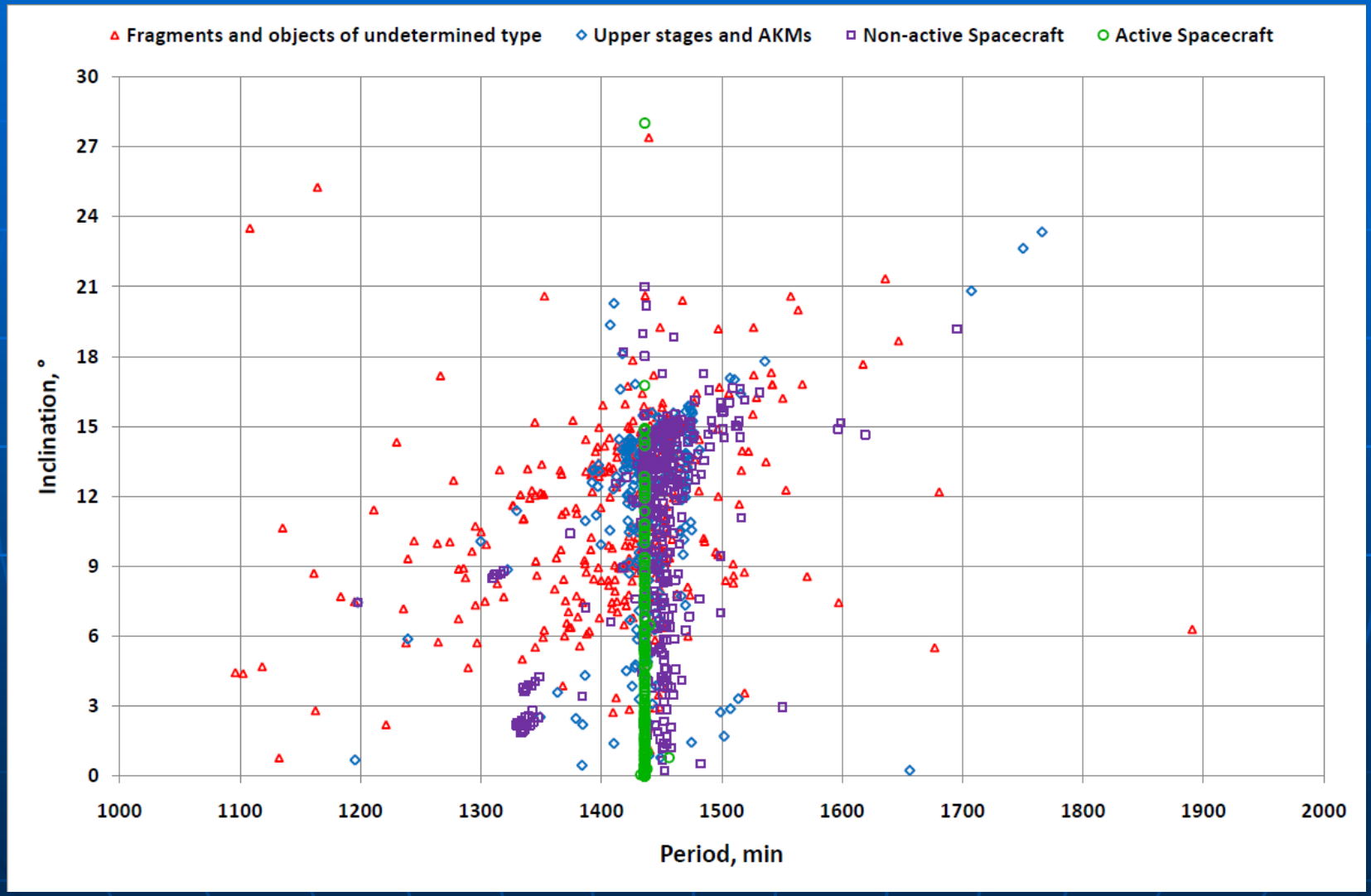
GEO Population Knowledge (KIAM database, Sep 1, 2010)

- Total – **1530** objects in GEO region with orbits maintained routinely, including
- *Spacecraft* – **909**
  407 under control, 502 non-functional
- *Upper stages and AKMs* – **256**
- *Fragments and objects of undetermined type* – **365**

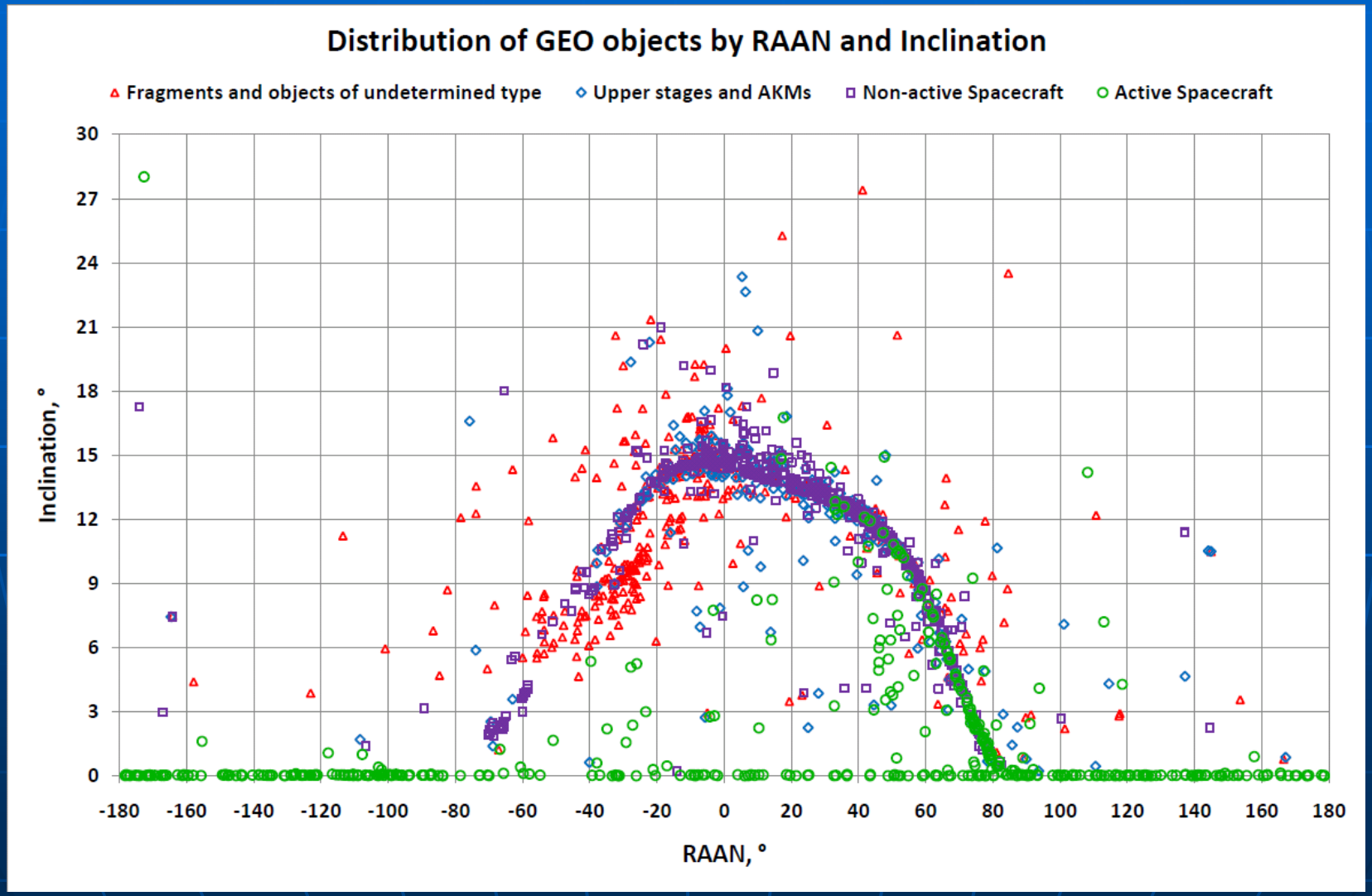
HEO and MEO Objects Measured (KIAM database, Sep 1, 2010)

- Total – **1699** objects on HEO and MEO with orbits updated occasionally or by tasking, including
- *Spacecraft* – **394**
- *Upper stages and AKMs* – **560**
- *Fragments and objects of undetermined type* – **744**

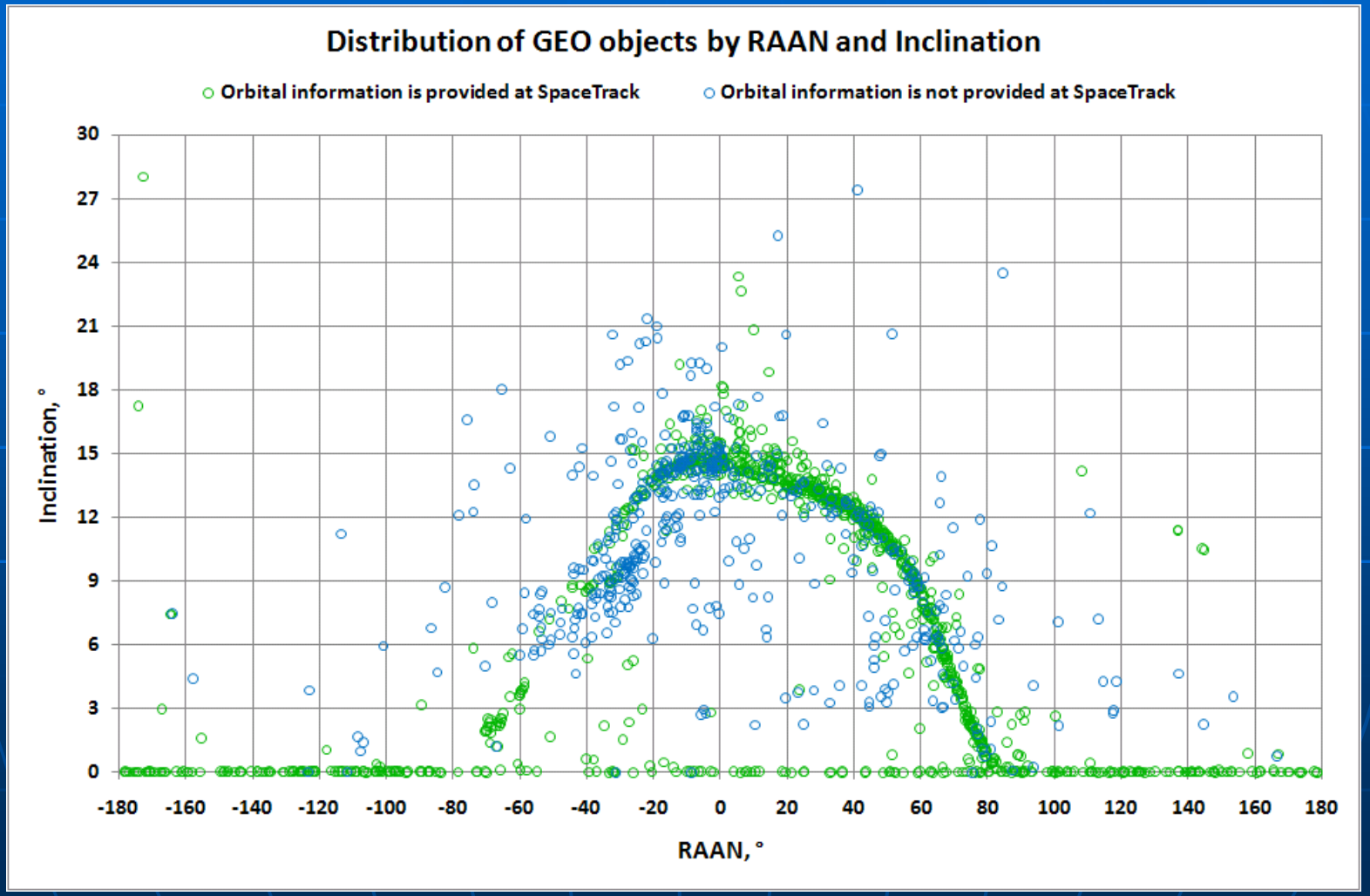
Distribution of 1530 GEO Objects by Period and Inclination



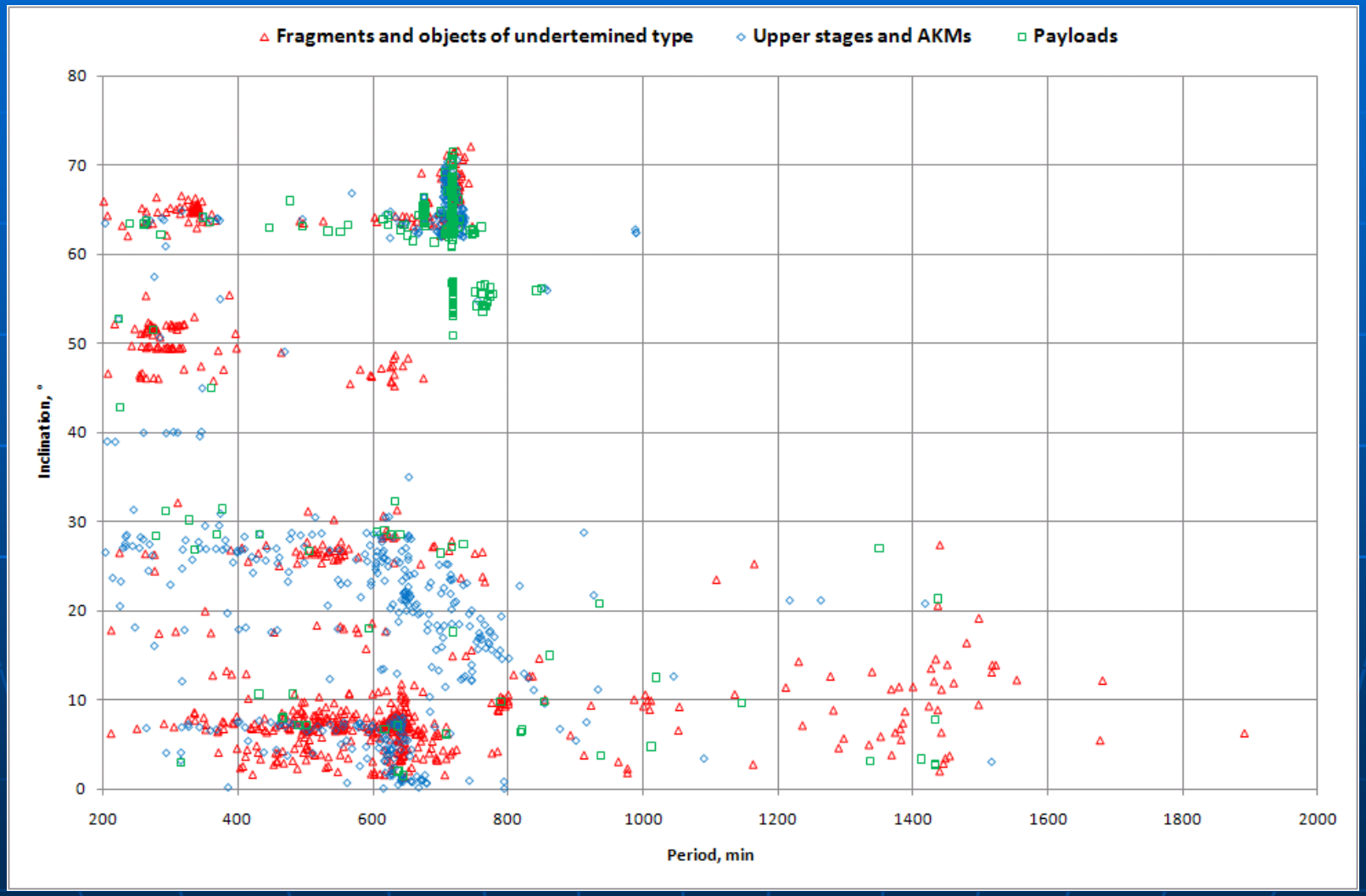
Distribution of 1530 GEO objects by RAAN and Inclination



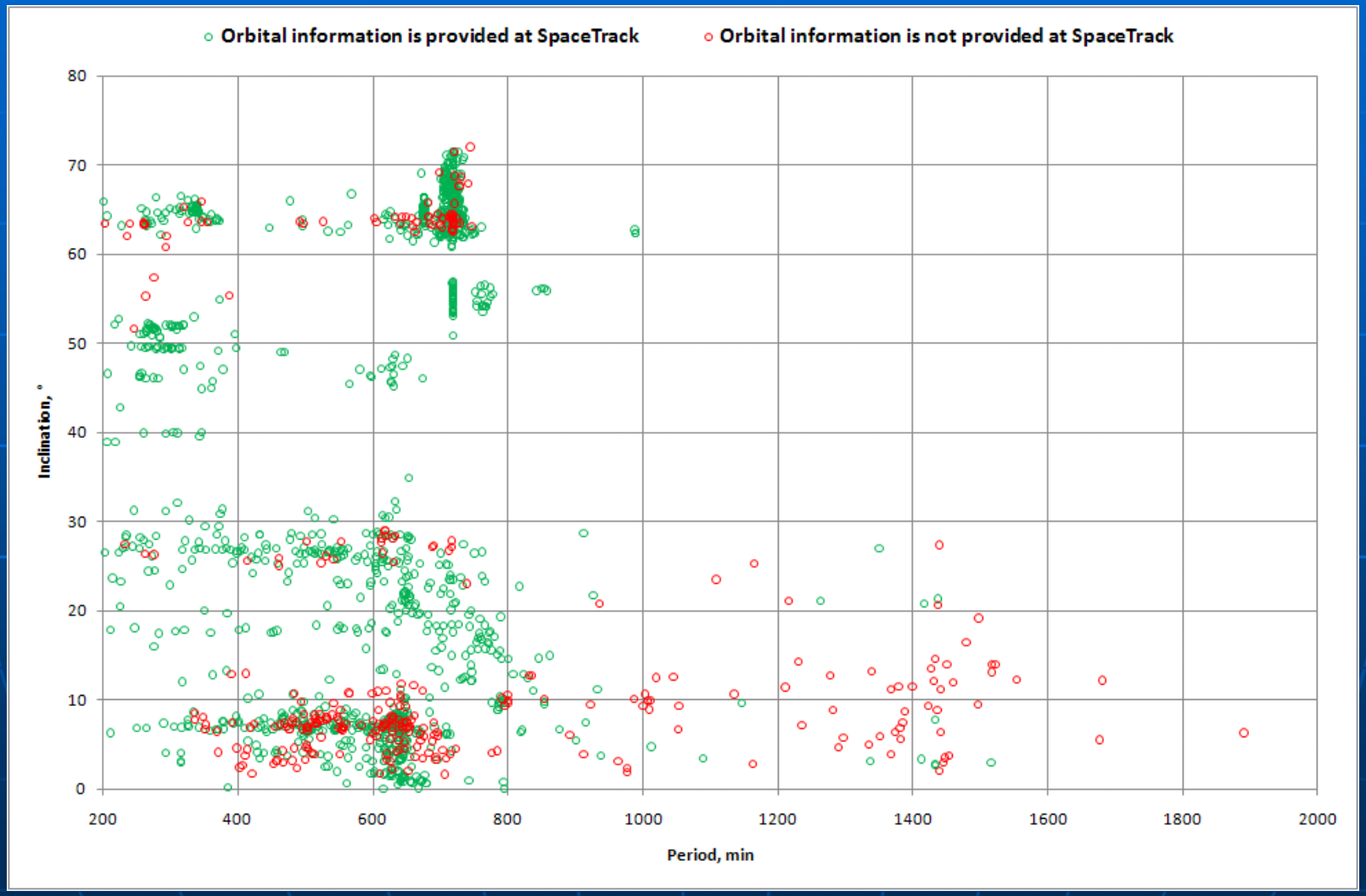
Distribution of 1530 GEO objects by RAAN and Inclination



Distribution of 1699 HEO and MEO objects by Period and Inclination



Distribution of 1699 HEO and MEO objects by Period and Inclination



“Brightness” – what is measured?

Any object looks like a dot or like a trail on CCD-image

What is measured and called “brightness” depends of observation mode (survey, track)

Possibility to measure:
“single point” brightness (ends or middle of a trail),
integration time averaged for a “trail”,
integration time averaged for a “dot”

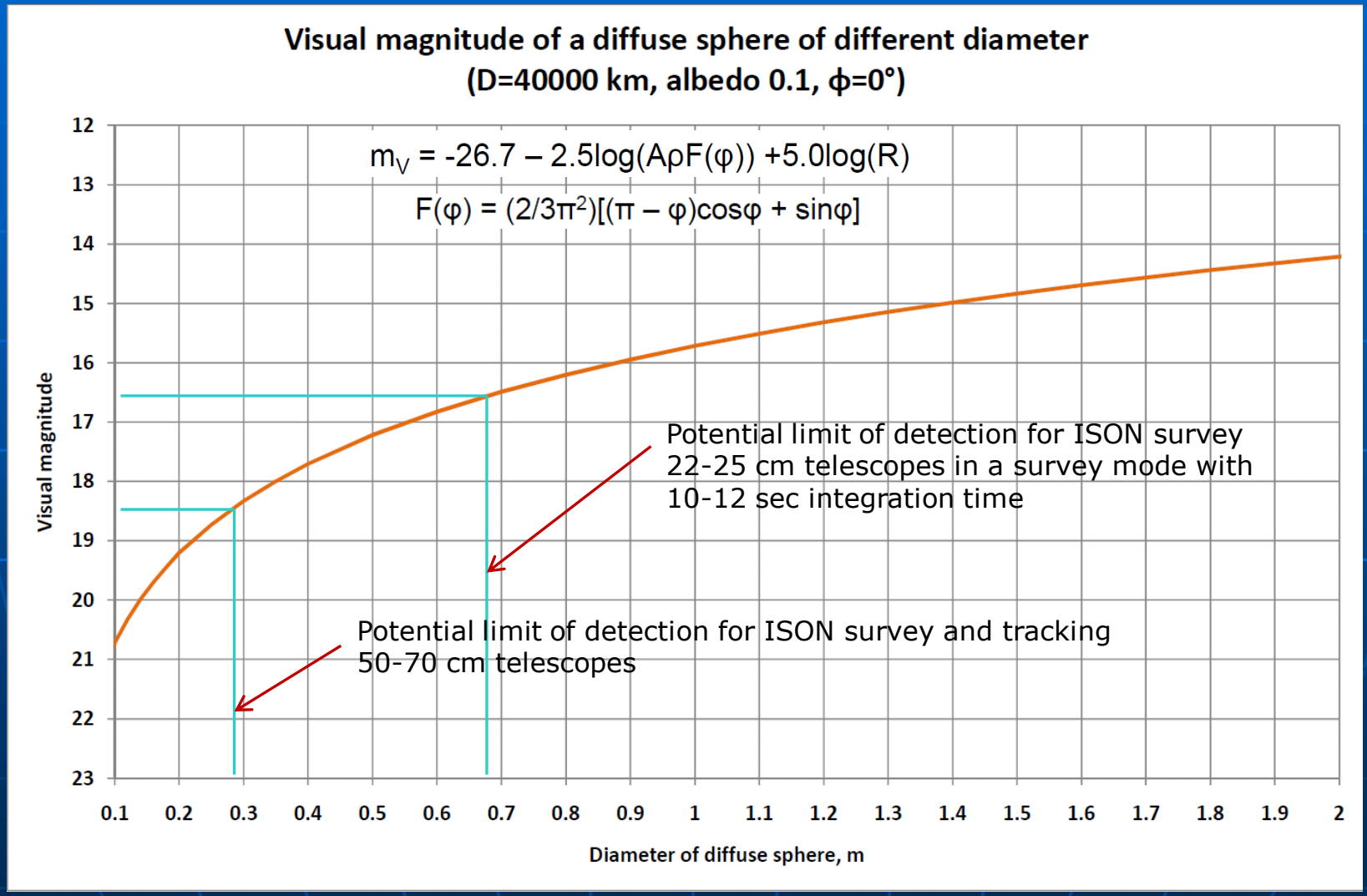
“Bright” and “Faint” Objects

“Bright” *– magnitude 16^m –16.2^m or brighter*

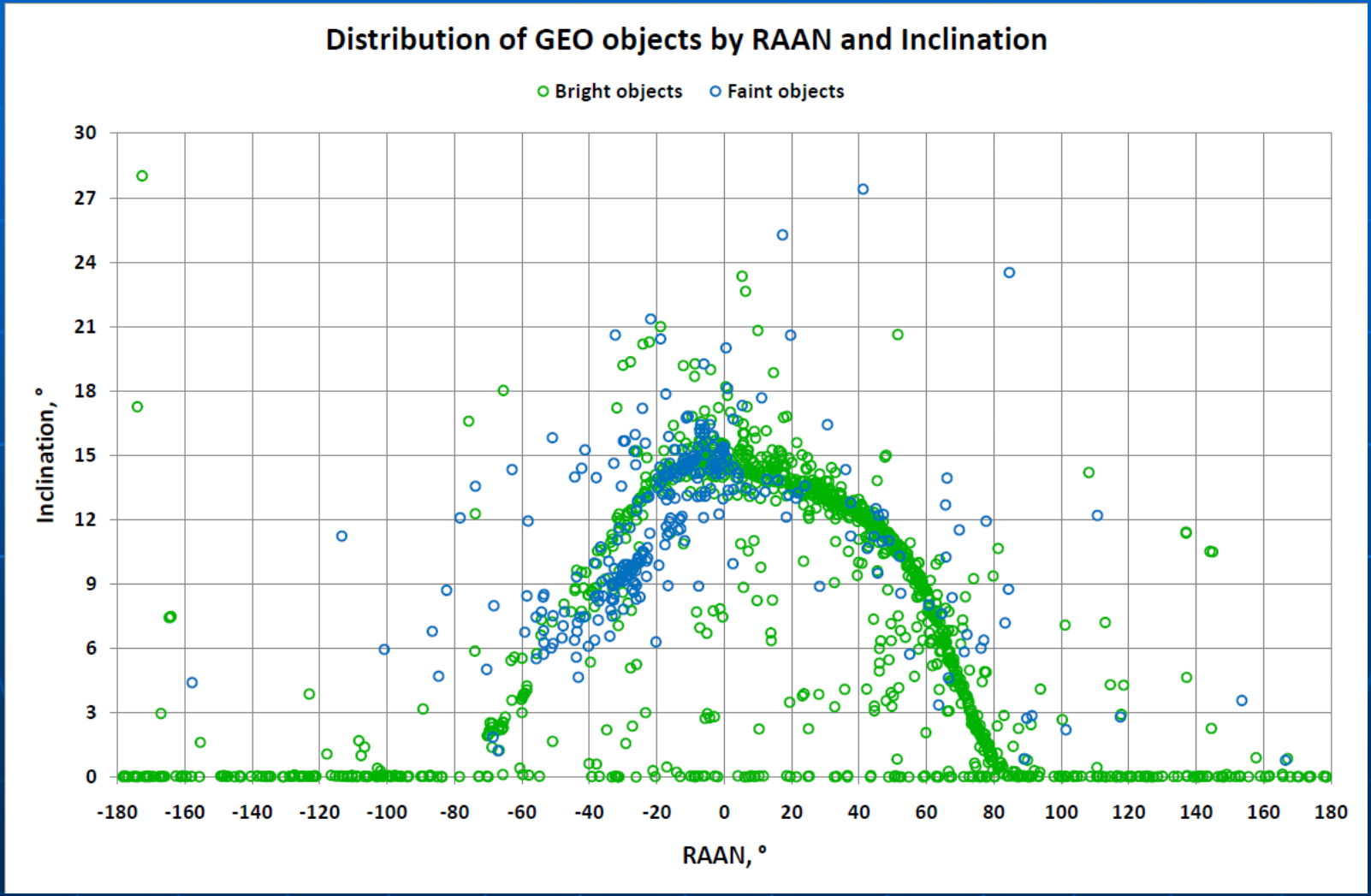
“Faint” *– magnitude fainter than 16.2^m*

- no filters
- phase angle range 0°-20°
- more than 80% of measured brightness values fall into one of two categories

Estimation of brightness of a diffuse sphere at GEO distance



Distribution of 1530 bright and faint GEO objects by RAAN and inclination



Characteristics of Objects Derived from Processing of Optical Measurements

- Orbital parameters
- AMR (mean, variations)
- Brightness pattern (mean, variations, proximity to diffuse sphere model)

Further correlation of AMR and brightness with an object of specific shape and mass can be studied mainly for bright known objects

Bright Objects

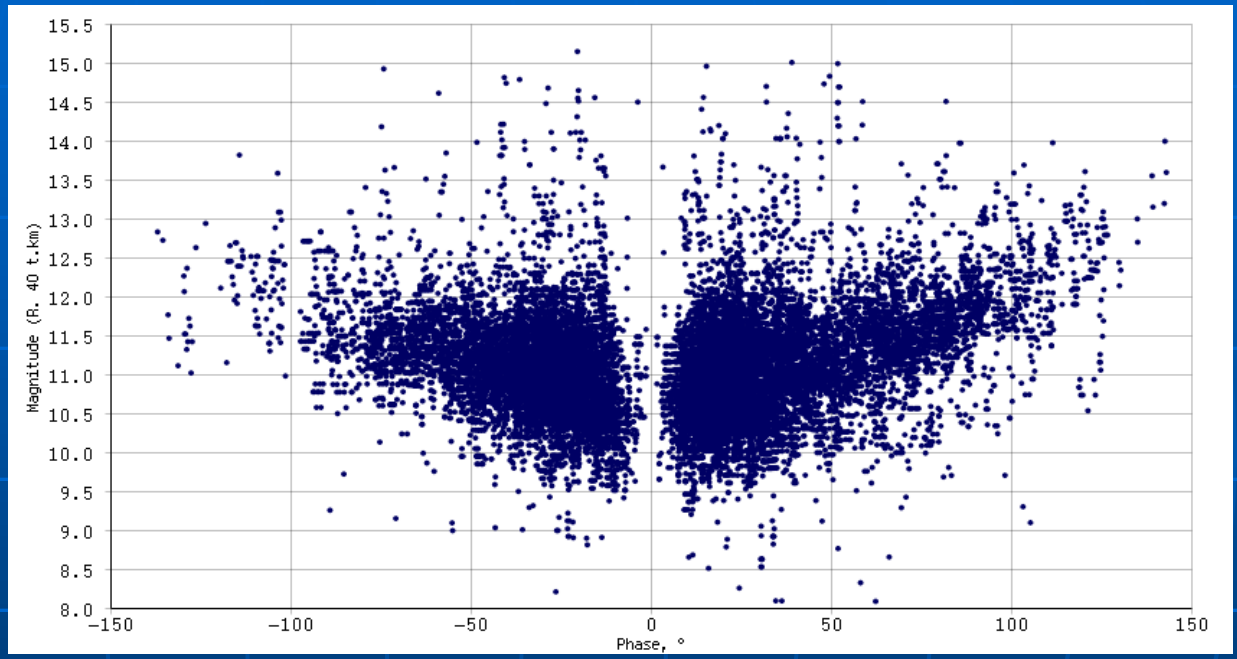
Spacecraft (designed on the base of more than 150 primary buses and their modifications), rocket bodies and AKMs (of more than 20 different types and modifications), large operational fragments and some of fragments of unknown type compose the group

Mainly very low AMR (<0.1 sq.m/kg) objects

Various brightness variation patterns

Brightness in many cases can not be modeled using diffuse sphere model

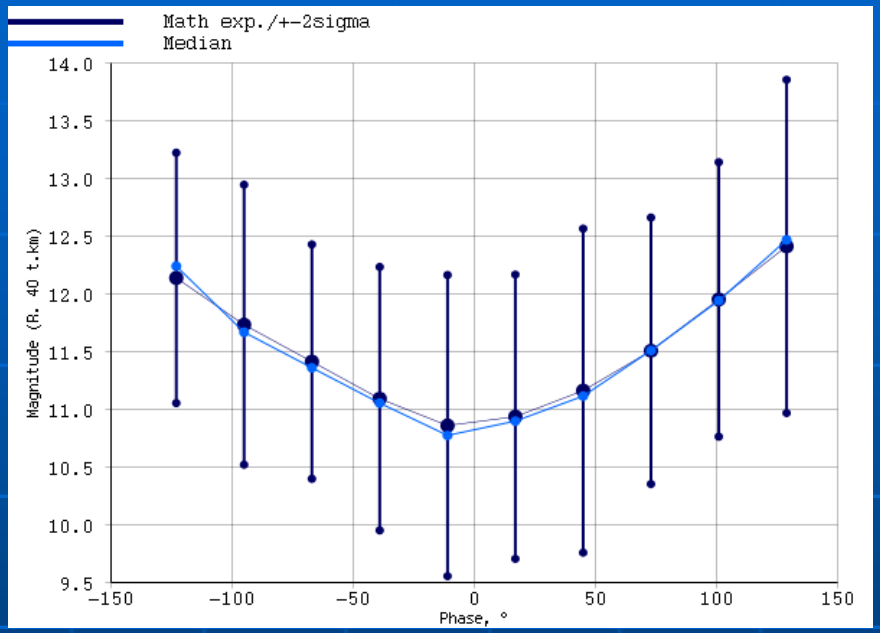
TITAN IV CENTAUR R/B

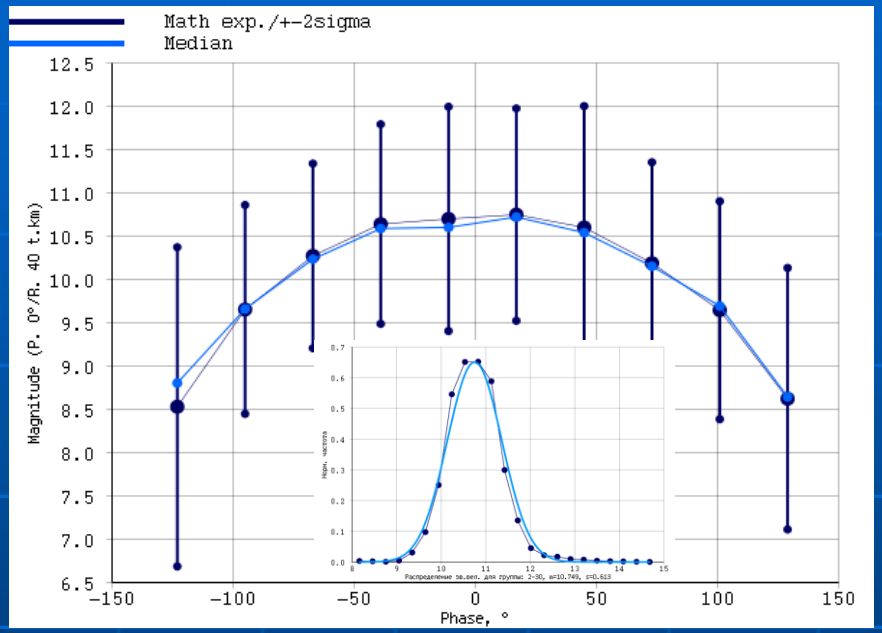


L=8.94 m
D=4.51 m

10 objects, 21623 measurements, 31 telescopes
Brightness corrected for range only (40000 km)

TITAN IV CENTAUR R/B



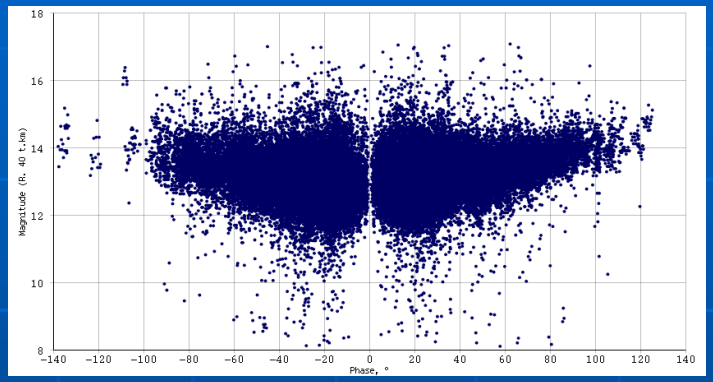


Correction for range,
No phase correction

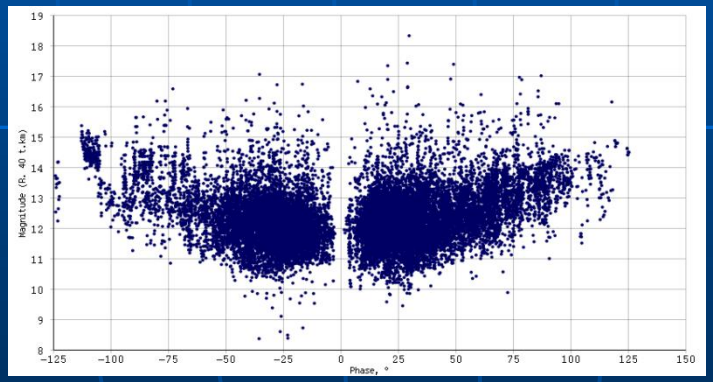
Diffuse sphere phase function applied

Brightness pattern is similar to the one for a diffuse sphere in a limited range of phase angles

BLOCK DM R/B

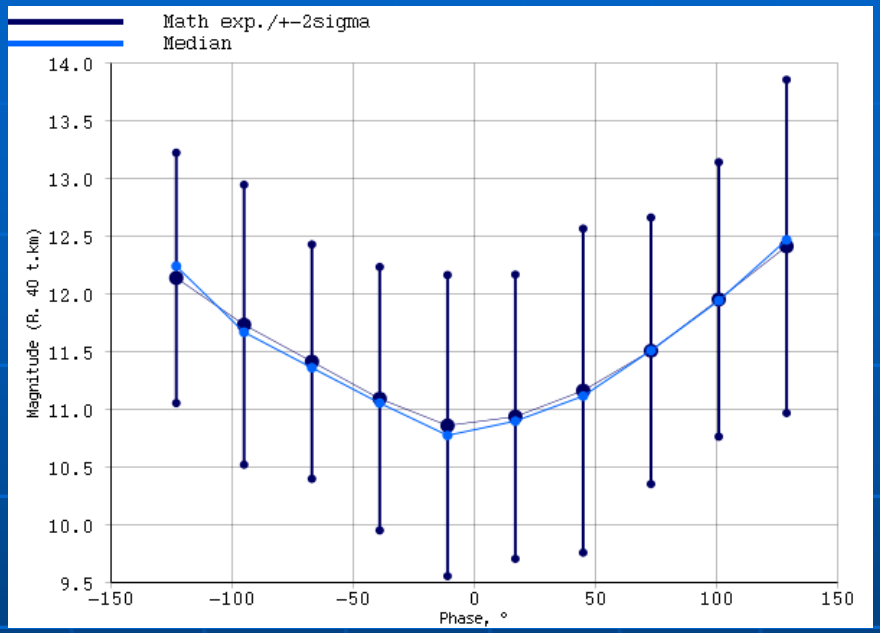


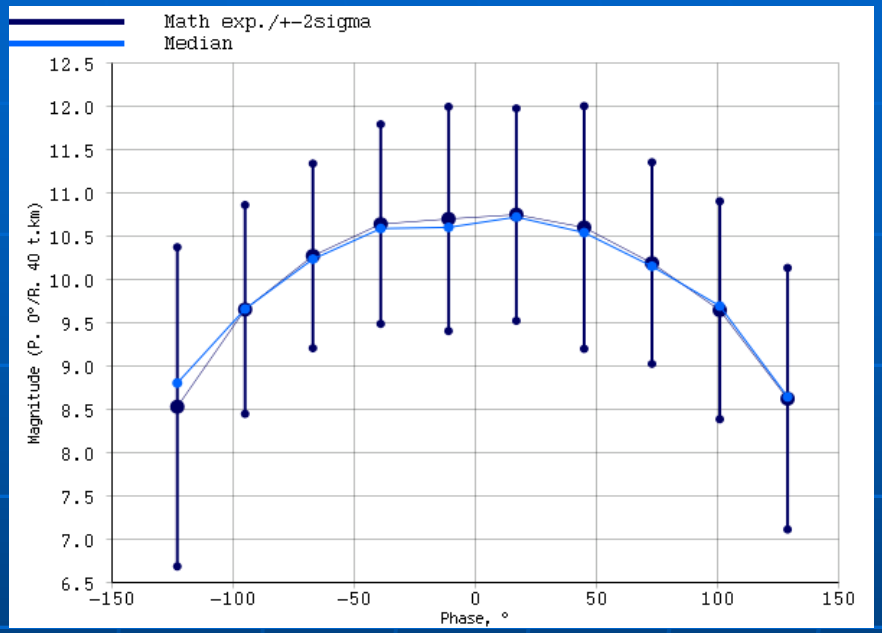
128 objects in GEO region,
152607 measurements,
30 telescopes. Brightness corrected for range only (40000 km)



86 objects on HEO and MEO orbits,
21735 measurements,
25 telescopes. Brightness corrected for range only (40000 km)

BLOCK DM R/B – GEO Launches



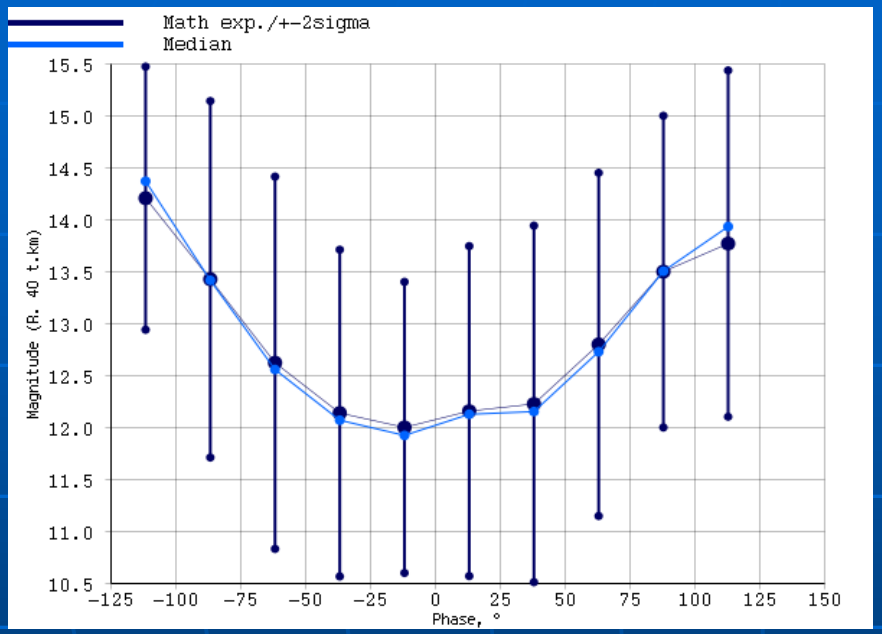


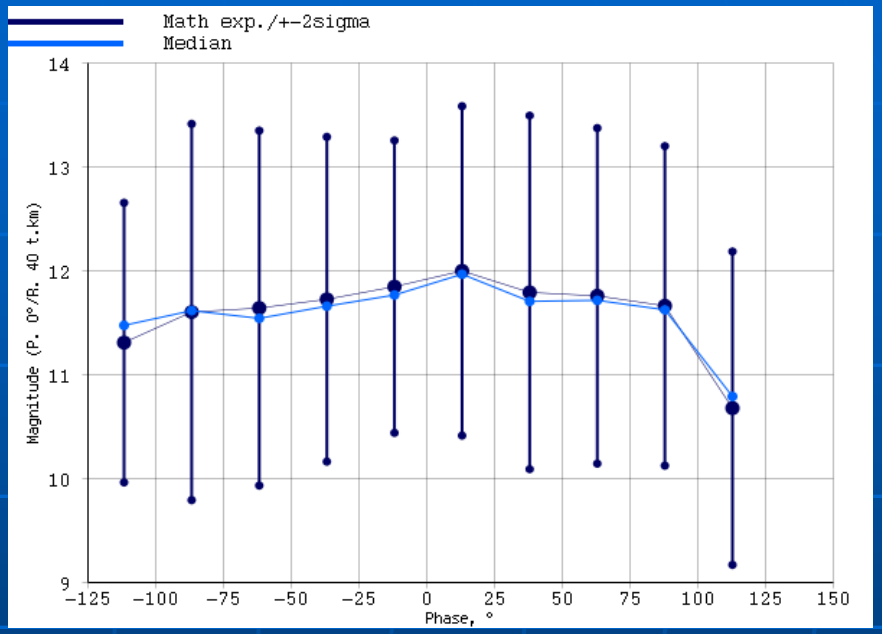
Correction for range,
No phase correction

Diffuse sphere phase function applied

Brightness pattern is similar to the one for a diffuse sphere in a narrow range of phase angles

BLOCK DM R/B – HEO&MEO Launches





Correction for range,
No phase correction

Diffuse sphere phase function applied

Brightness pattern is similar to the one for a diffuse sphere in more wide range of phase angles

BLOCK DM R/B – GEO and HEO&MEO Brightness Comparison

Range, deg of phase angle	Math. exp. GEO	RMS GEO	Math. exp. HEO	RMS HEO
50...75	13.50	0.48	12.80	0.83
25...50	13.30	0.48	12.23	0.86
0...25	13.09	0.46	12.16	0.79
-25...0	12.96	0.53	12.00	0.70
-50...-25	13.04	0.54	12.14	0.79
-75...-50	13.34	0.55	12.62	0.90

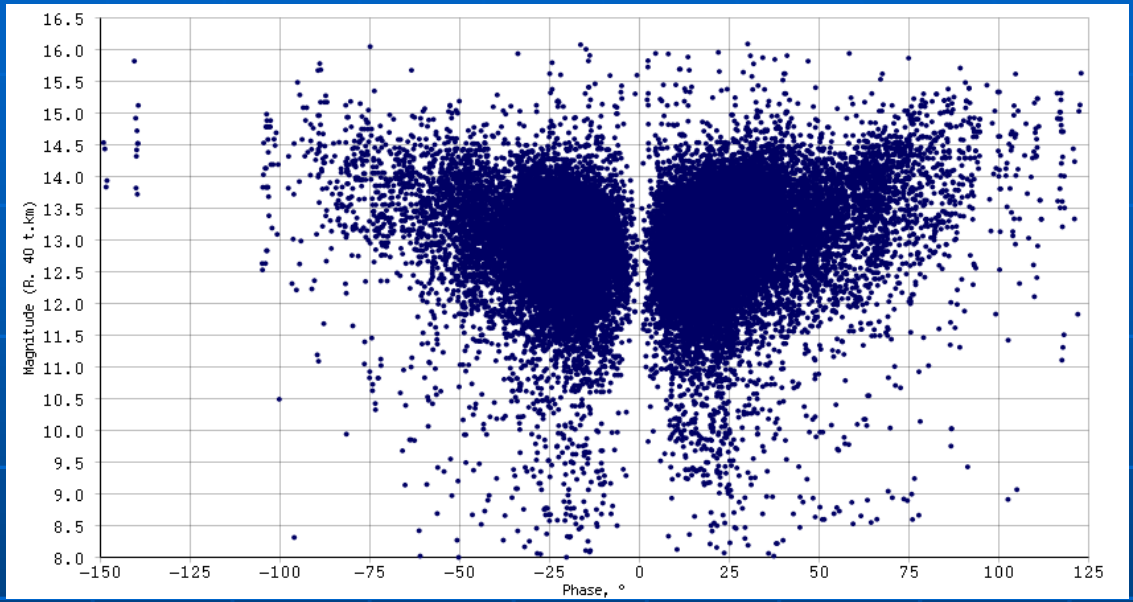
Block DM upper stages used for launches directly to GEO are of 0.7-1 magnitude order fainter than those ones launched to GTO or MEO

BREEZE-M R/B – GEO and HEO&MEO Brightness Comparison

Range, deg of phase angle	Math. exp. GEO	RMS GEO	Math. exp. HEO	RMS HEO
45...70	12.81	0.48	12.82	0.75
20...45	12.52	0.55	12.42	0.74
0...20	12.38	0.54	12.45	0.60
-20...0	12.15	0.49	12.34	0.60
-45...-20	12.26	0.48	12.26	0.67
-70...-45	12.64	0.49	12.56	0.68

Breeze-M upper stages used for launches directly to GEO have demonstrating the same brightness as those ones launched to GTO or MEO

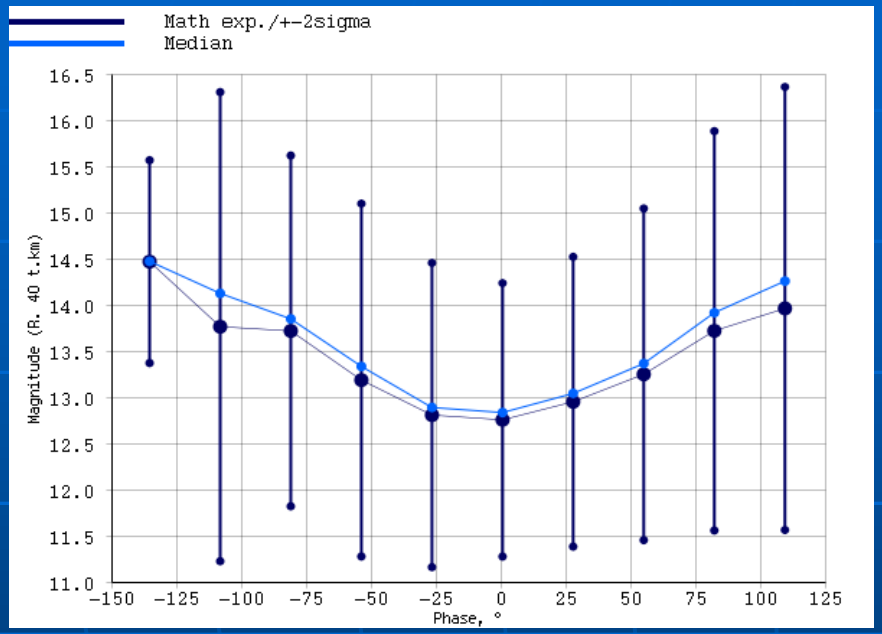
Spacecraft of GORIZONT Type (Not Operational)

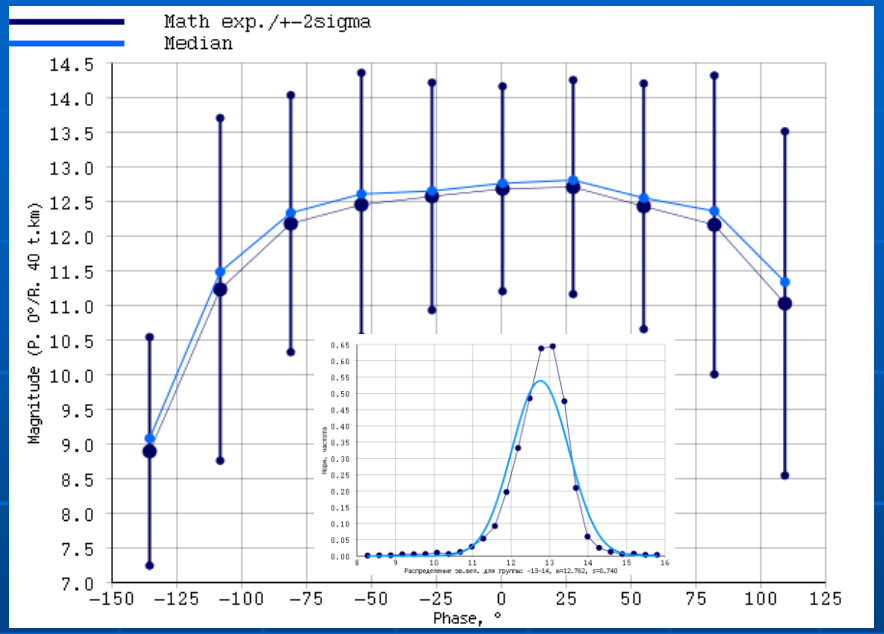


26 objects, 35364 measurements, 26 telescopes

Brightness corrected for range only (40000 km)

GORIZONT SPACECRAFT (Not Operational)





Corrected for range, no phase correction

Diffuse sphere phase function applied

Looks like a diffuse sphere in a wide range of phase angles!!!

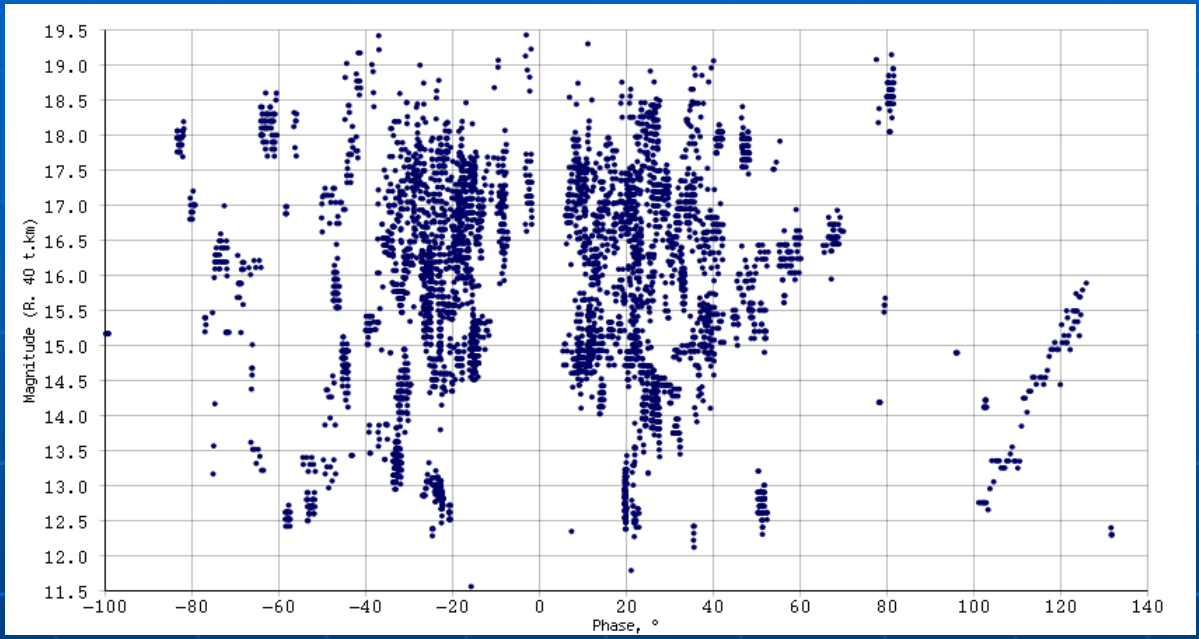
AMR for Bright Objects

For the absolute majority of bright objects AMR do not exceed 0.1 sq.m/kg

There are a few unique exceptions. The most interesting are

90052 AMR=0.6 sq.m/kg
90054 AMR=1.7 sq.m/kg
90121 AMR=21 sq.m/kg

Object 90052
AMR=0.6 sq.m/kg

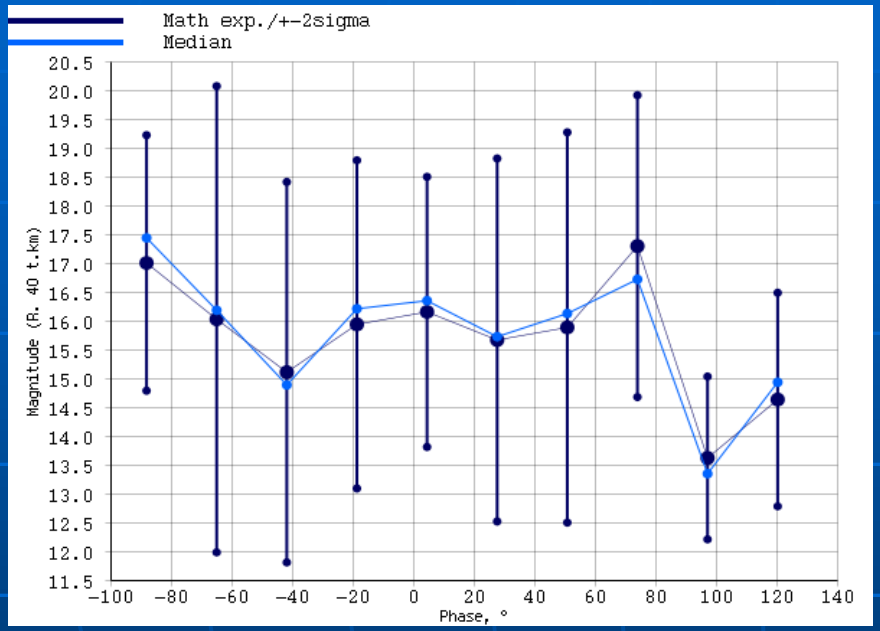


4946 measurements, 18 telescopes

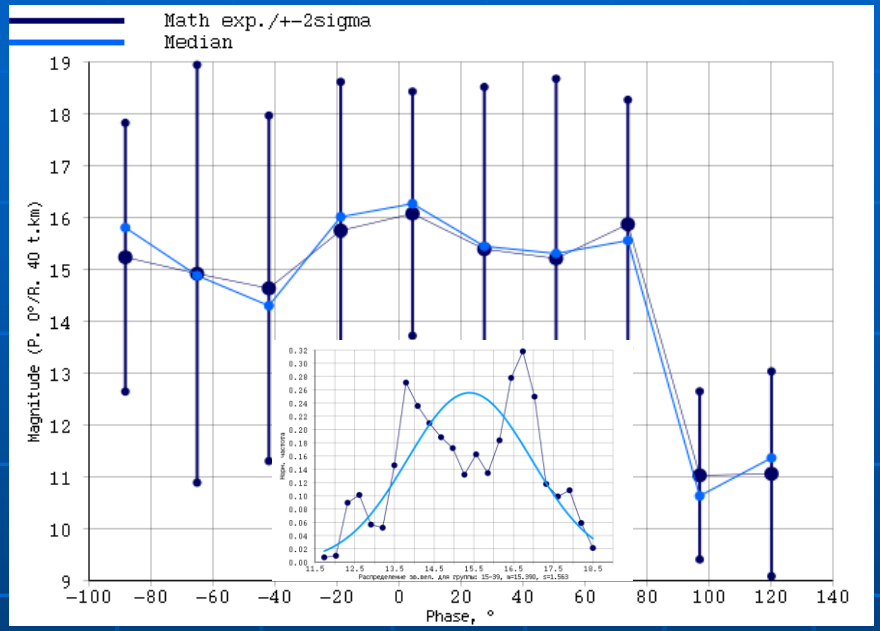
Brightness corrected for range only (40000 km)

Brightness variations – up to 7.5 mag!!!

Object 90052
AMR=0.6 sq.m/kg



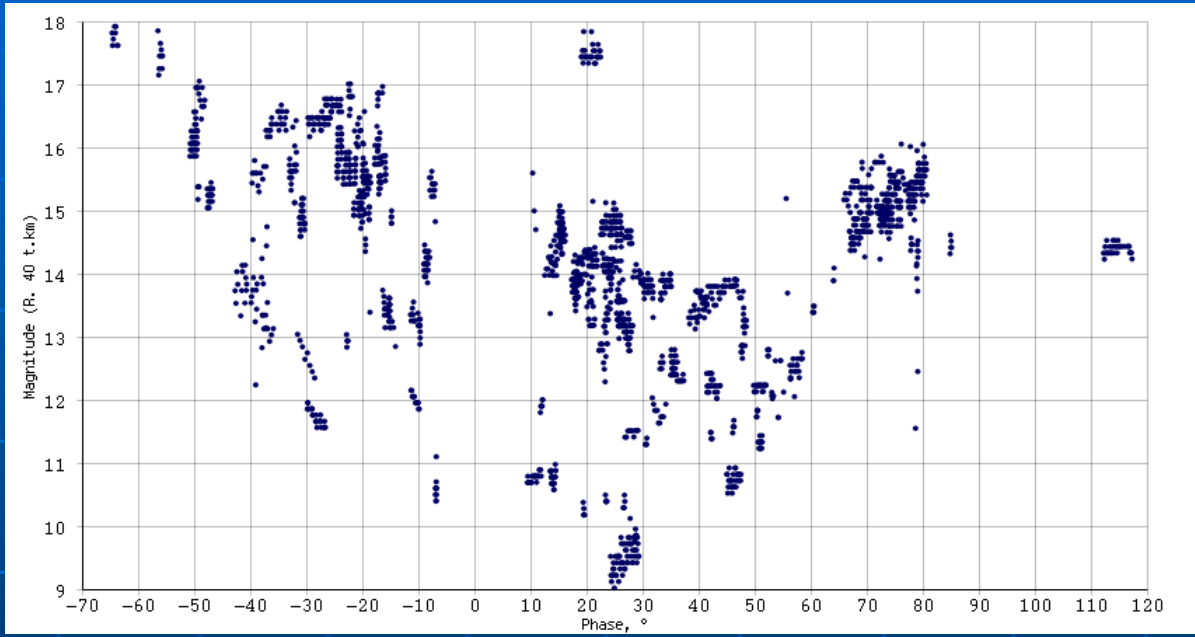
No phase correction



Diffuse sphere phase function applied

Model of diffuse sphere for brightness estimation is not applicable

Object 90054
AMR=1.7 sq.m/kg

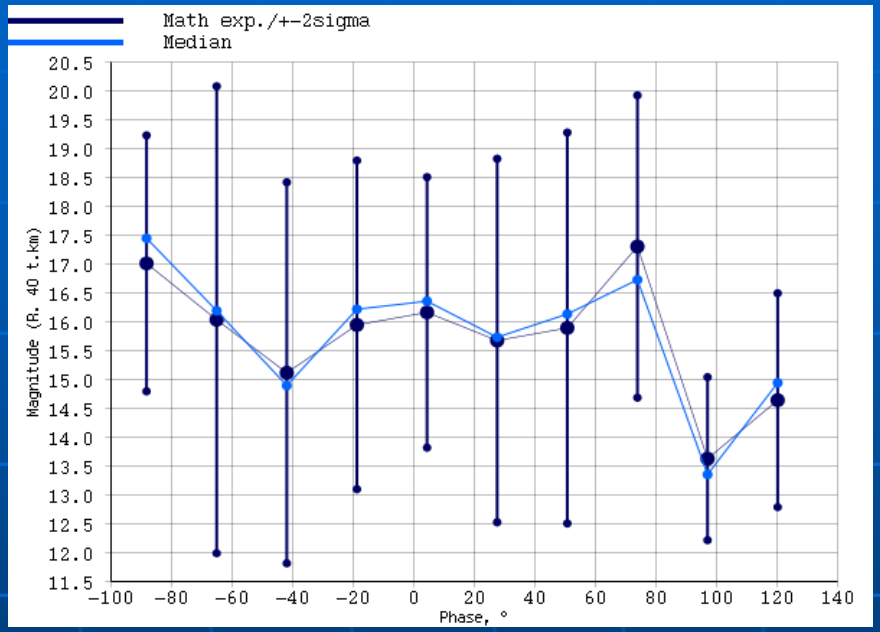


2039 measurements, 14 telescopes

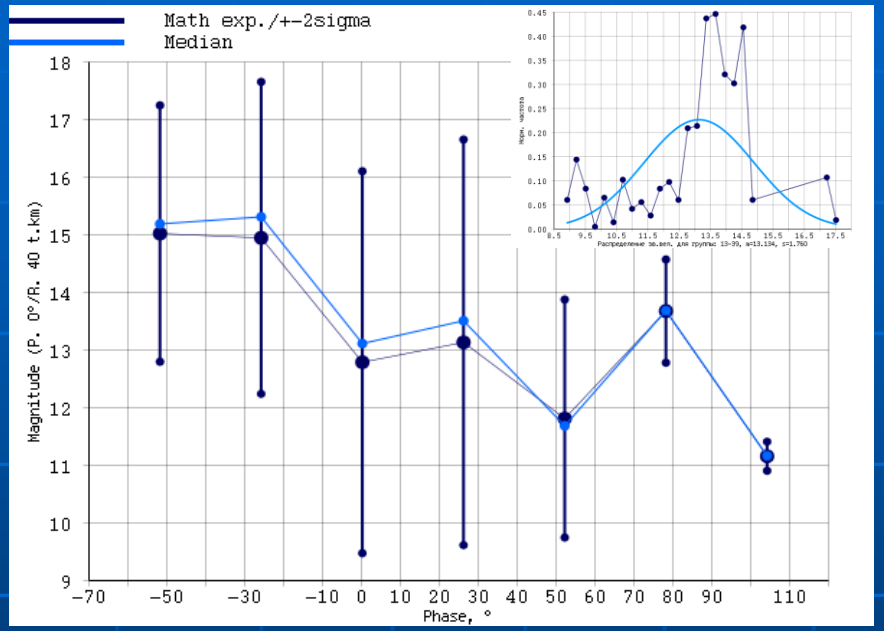
Brightness corrected for range only (40000 km)

Brightness variations – up to 9 magnitudes with observed 9^{th}-10^{th} mag!!!

Object 90054
AMR=1.7 sq.m/kg



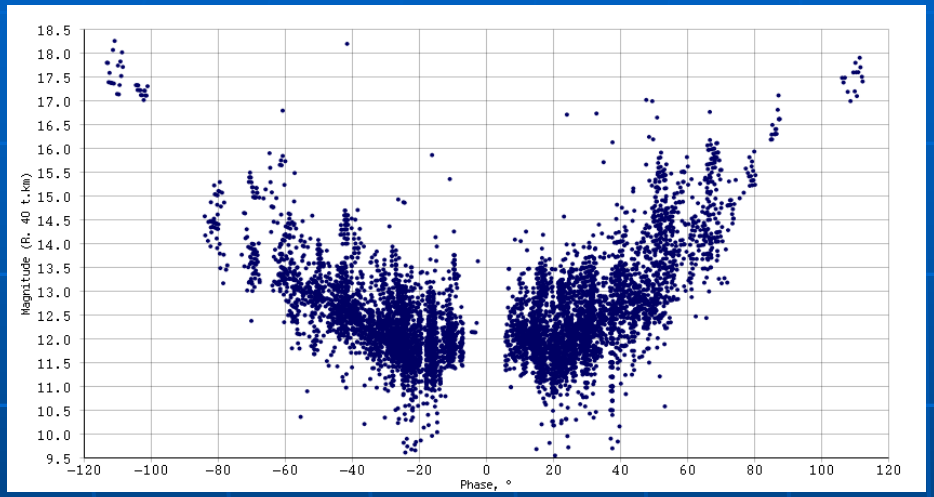
No phase correction



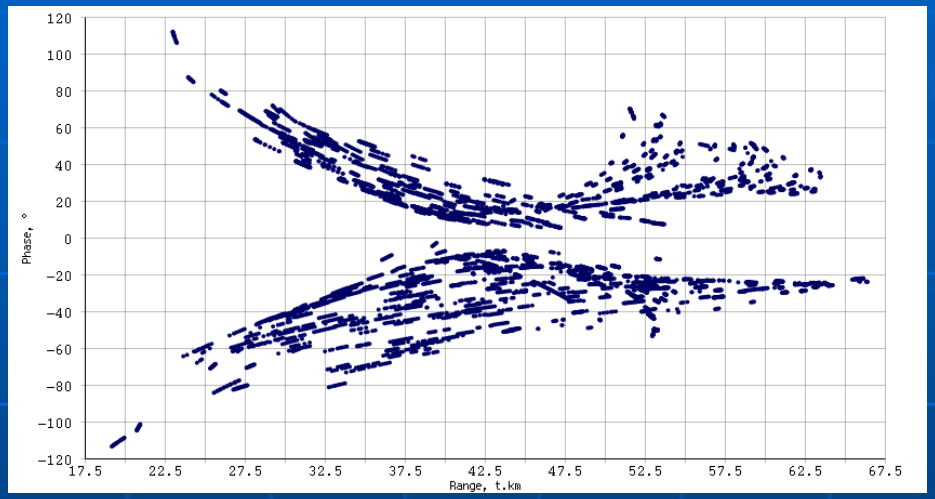
Diffuse sphere phase function applied

Model of diffuse sphere for brightness estimation is not applicable

Object 90121
AMR=21 sq.m/kg



Magnitude vs. Phase angle



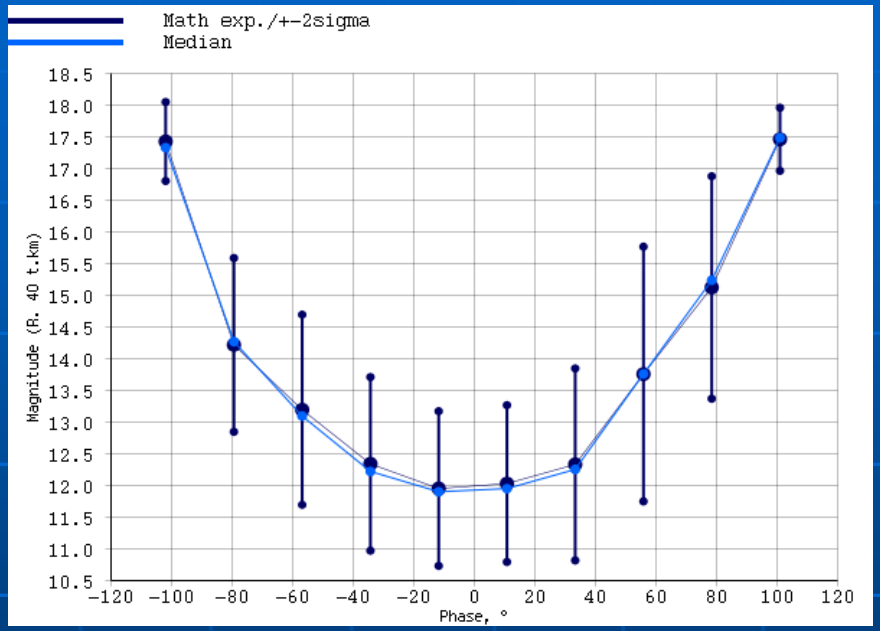
Phase angle vs. Range

8337 measurements, 22 telescopes

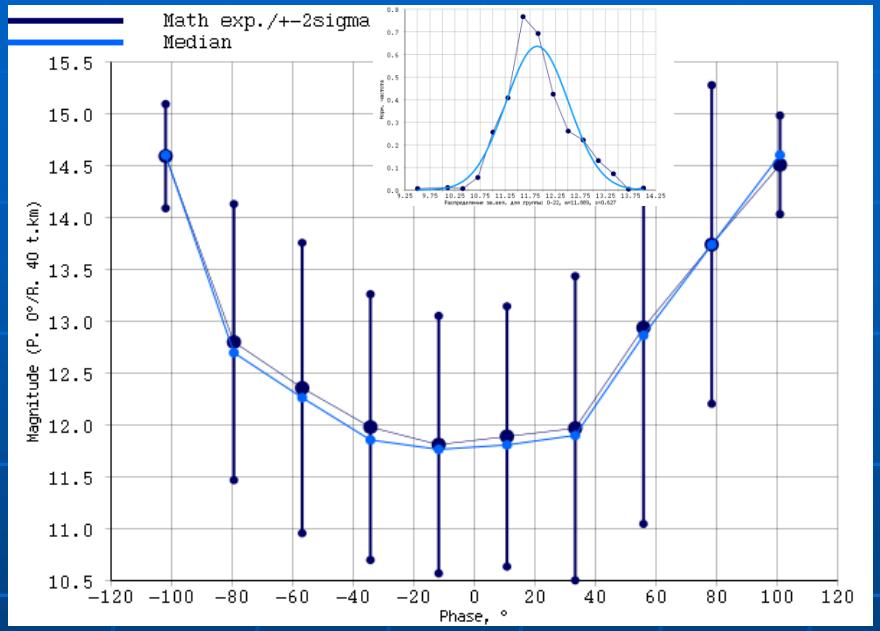
Brightness corrected for range only (40000 km)

Very bright and very high AMR

Object 90121
AMR=21 sq.m/kg



No phase correction



Diffuse sphere phase function applied

Model of diffuse sphere for brightness estimation is applicable only in a narrow range of phase angles

Faint Objects

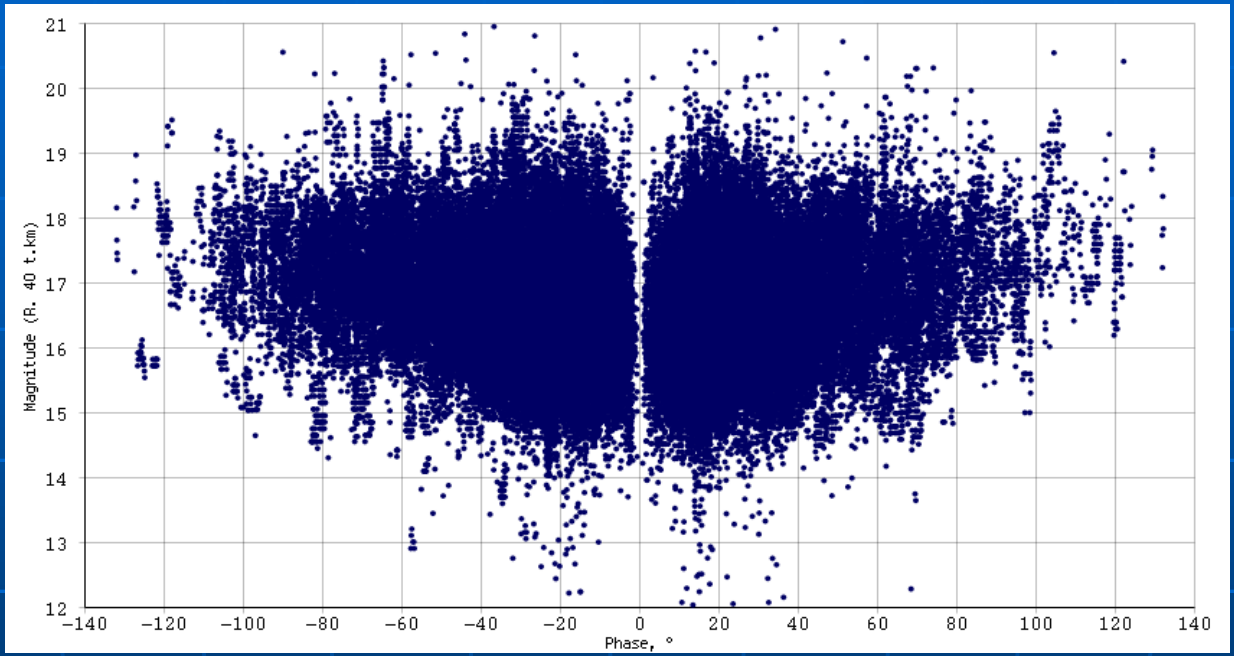
Only fragments and objects of undetermined type compose the group

Mainly high AMR (>0.9 sq.m/kg) objects

Various brightness variation patterns

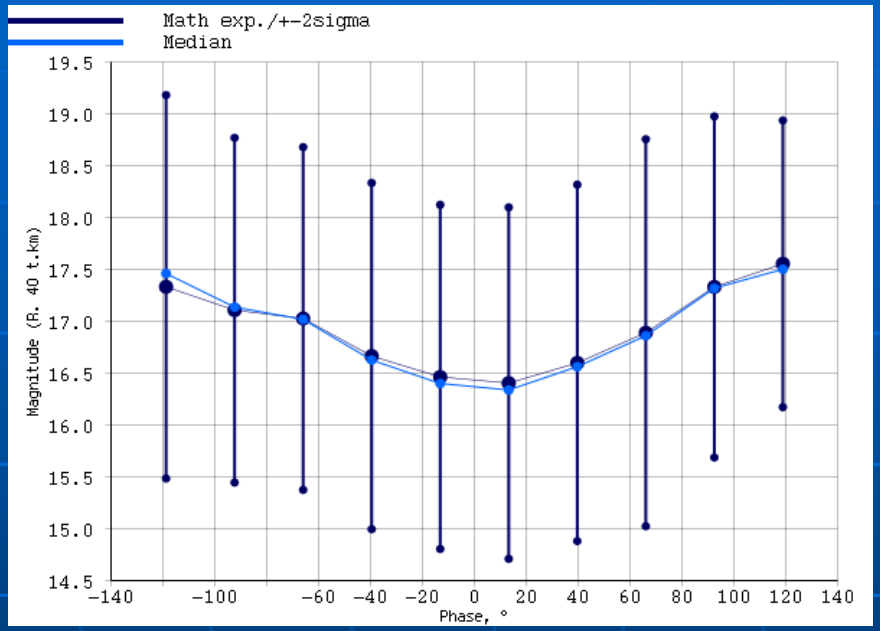
Brightness in most cases can not be modeled using diffuse sphere model

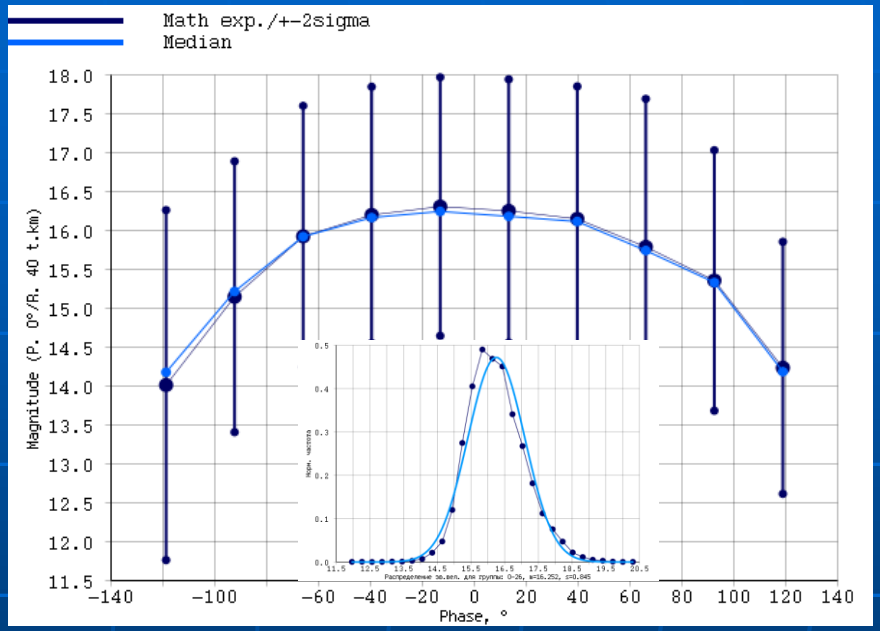
Faint Objects
AMR<0.9 sq.m/kg, 16^m < Mag < 17.5^m



80 objects, 122826 measurements, 23 telescopes
Brightness corrected for range only (40000 km)

Faint Objects
AMR<0.9 sq.m/kg, 16^m < Mag < 17.5^m



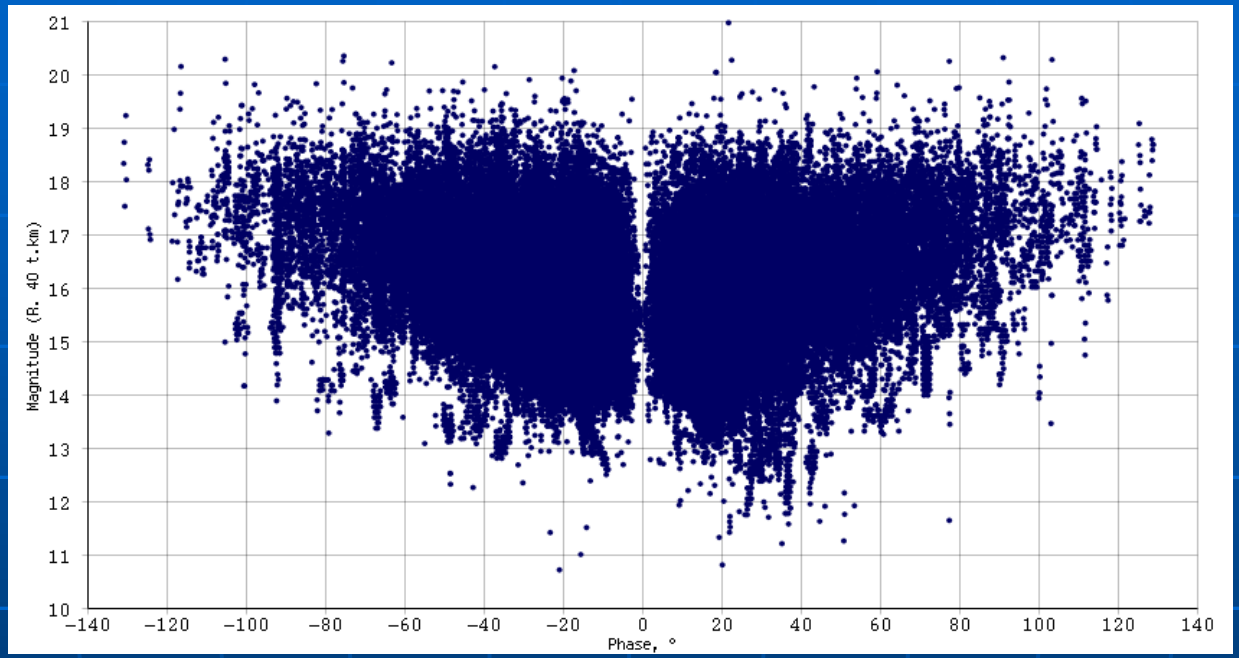


No phase correction

Diffuse sphere phase function applied

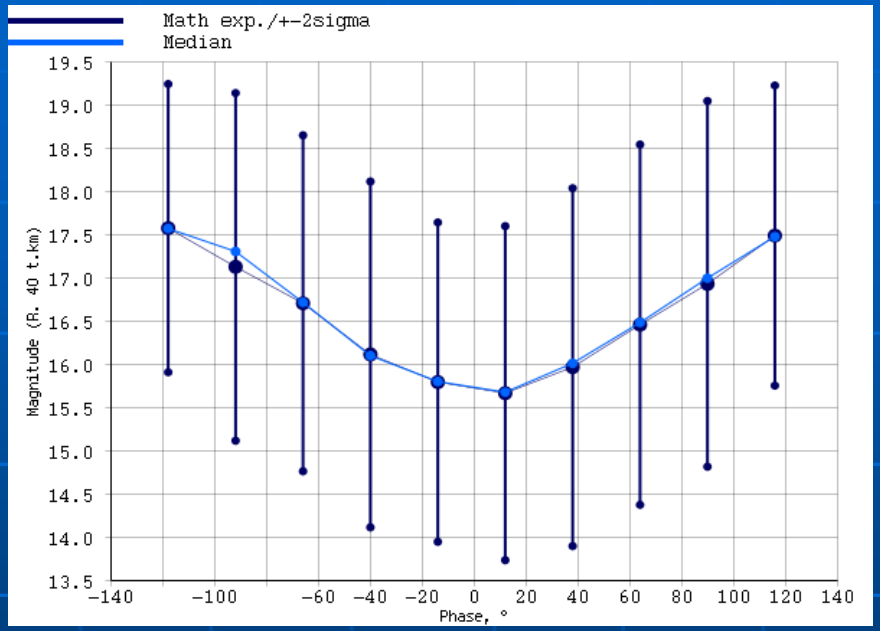
Model of diffuse sphere for brightness seems applicable in a certain range of phase angles

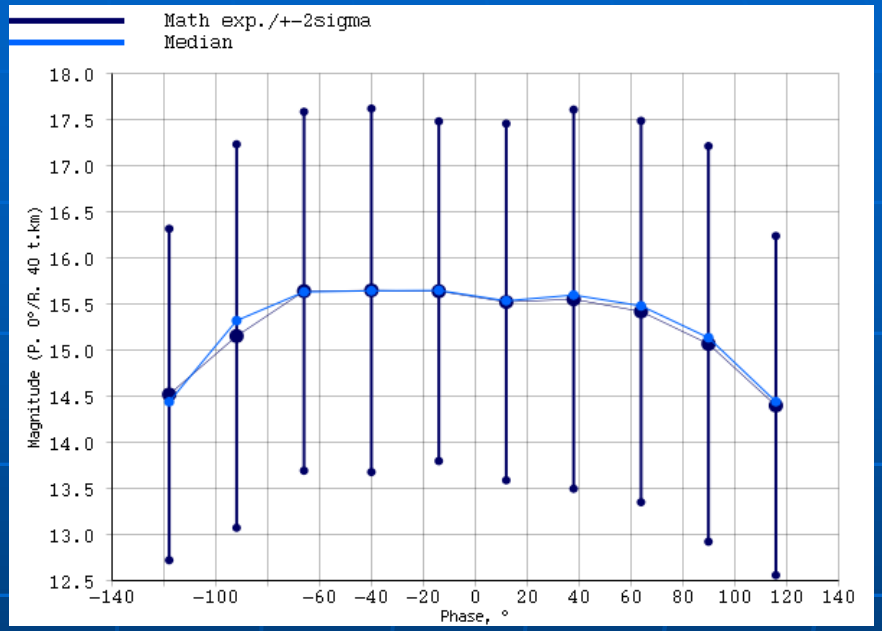
Faint Objects
AMR>=0.9 sq.m/kg, 16^m < Mag < 17.5^m



112 objects, 144545 measurements, 32 telescopes
Brightness corrected for range only (40000 km)

Faint Objects
AMR>=0.9 sq.m/kg, 16^m < Mag < 17.5^m



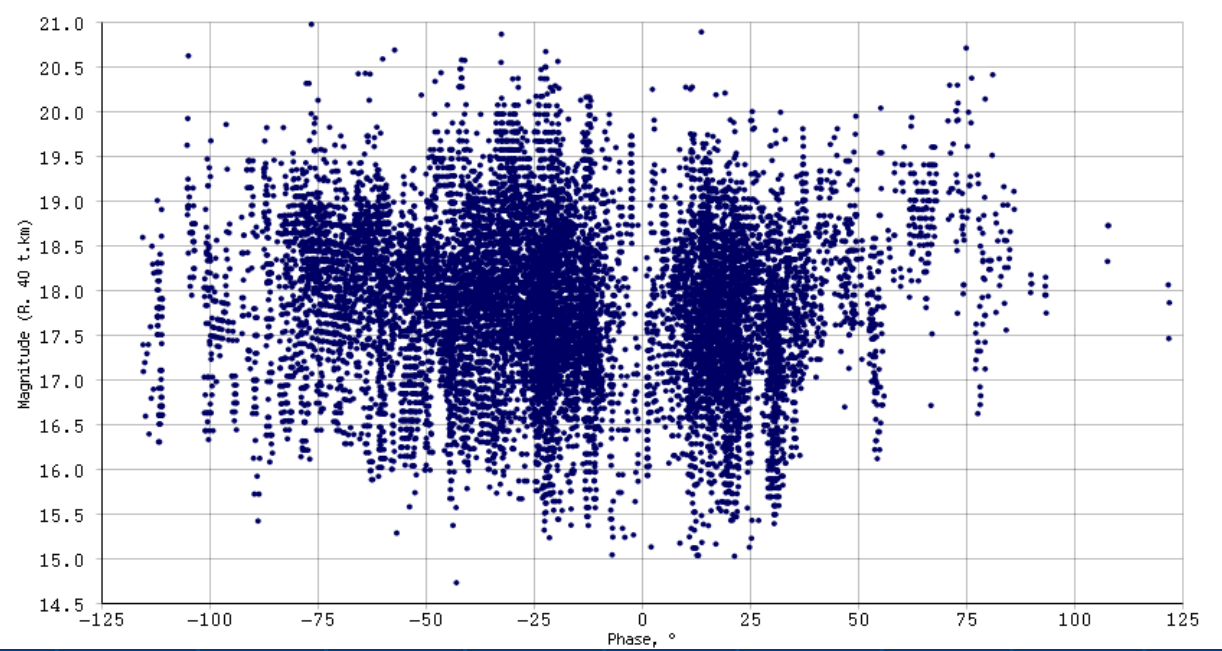


No phase correction

Diffuse sphere phase function applied

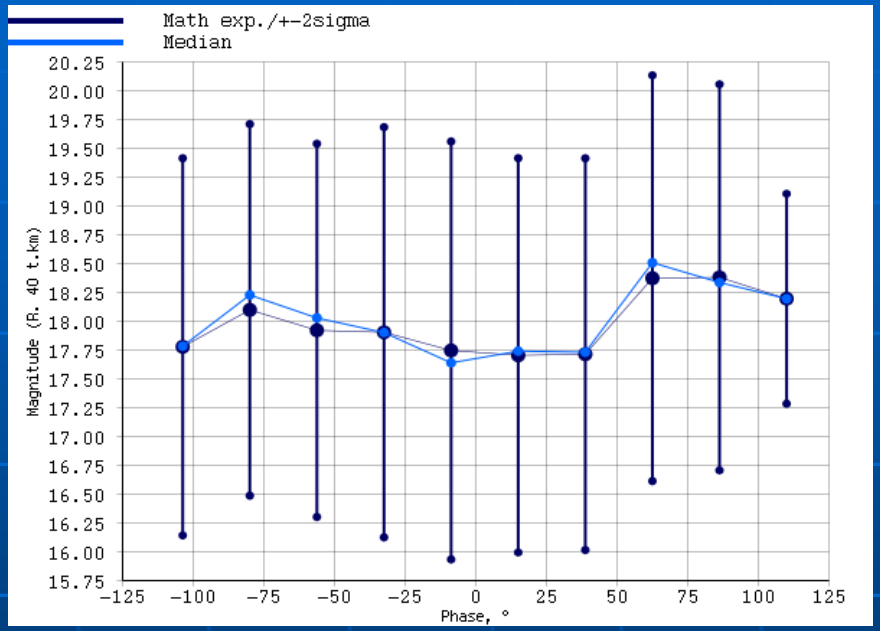
Model of diffuse sphere for brightness seems applicable in a certain range of phase angles

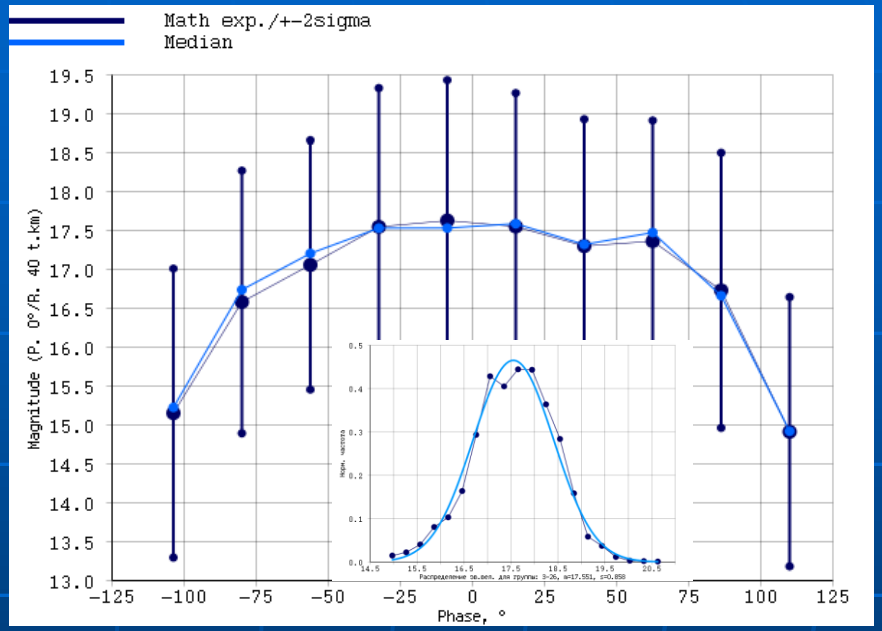
Faintest Objects
AMR<0.9 sq.m/kg, Magnitude > 17.5^{m}



21 object, 14684 measurements, 17 telescopes
Brightness corrected for range only (40000 km)

Faintest Objects
AMR<0.9 sq.m/kg, Magnitude > 17.5^{m}



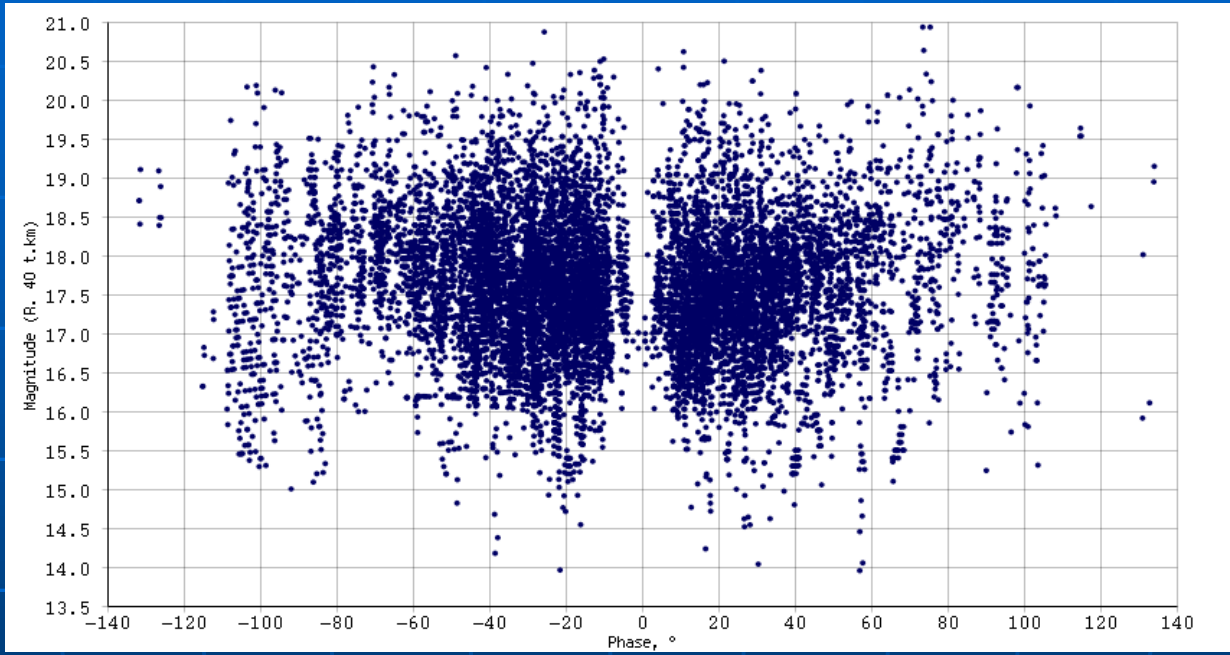


No phase correction

Diffuse sphere phase function applied

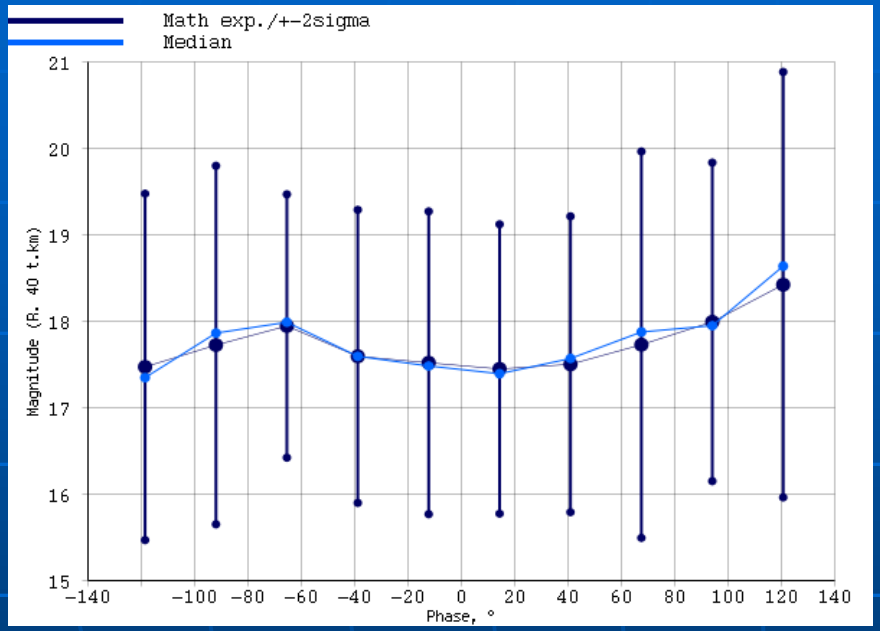
Model of diffuse sphere for brightness seems applicable in a wide range of phase angles

Faintest Objects
AMR>=0.9 sq.m/kg, Magnitude > 17.5^{m}

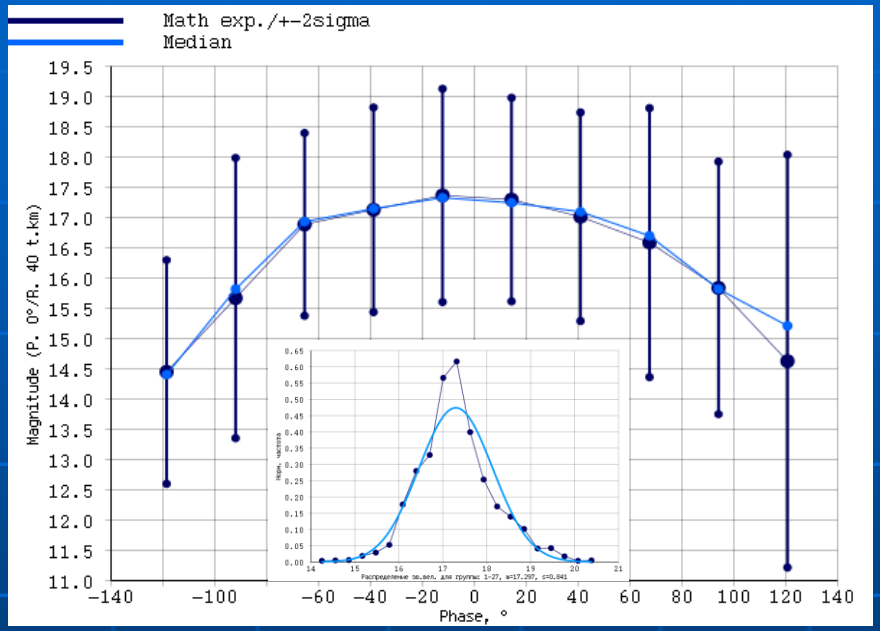


49 objects, 12473 measurements, 16 telescopes
Brightness corrected for range only (40000 km)

Faintest Objects
AMR>=0.9 sq.m/kg, Magnitude > 17.5^{m}



No phase correction



Diffuse sphere phase function applied

Difference with lower AMR faintest objects is minimal

Conclusions

- ISON network collects on a routine basis astrometric and brightness measurements for more than 1500 objects in GEO region
- Accumulated measurements can be used for statistical characterization of GEO population
- It is revealed that the model of diffuse sphere reflection is not applicable in many cases both for bright and faint GEO objects
- Distribution of measured brightness values within defined phase angle bins is very close to the normal (Gaussian) for majority of bright and faint GEO objects
- There are unique objects (presumably fragments) having unusual properties in terms of AMR and brightness. They should be studied individually

Acknowledgements

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