

Spherical Retroreflector with an Extremely Small Target Error: International Experiment in Space

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On board of the METEOR-3M (1) spacecraft launched on December 10, 2001, a novel-type laser retroreflector (RR) is installed. The spherical RR has the advantage of minimum target error introduced in ranging measurements.

After the METEOR-3M(1) launching, a problem arose with the Global positioning system equipment on board of the satellite, and to provide the necessary precision of orbit determination for the NASA SAGE-III equipment operation, it has been decided to use the international SLR network.

Based on measurement results obtained at the SLR-station near Moscow, estimations have been made of the spherical RR cross-section.

The main center responsible for precision orbit determination (POD) was MCC (Russia). POD was made also by Honeywell Technology solutions, Inc (HTSI). The MCC and HTSI results have practically equal accuracy, and are satisfactory for the SAGE-III mission purpose.

The obtained results may be a basis for development and engineering of a full-scale ball-lens RR-satellite providing an extremely small target error, which is important for geophysics, geodynamics, and some other scientific areas.

As already reported at the 11-th International Workshop on Laser Ranging, a novel-type retroreflector has been proposed, designed and built in the R&D Institute for Precision Instrument Engineering (IPIE, Moscow, Russia). It is based on the optical Luneberg lens concept (Figures 1, 2). The retroreflector is a multilayer glass sphere; it provides uniform reflection characteristics when viewed within a very wide range of angles, and can provide a cross-section sufficient for observations at low to medium orbit heights.

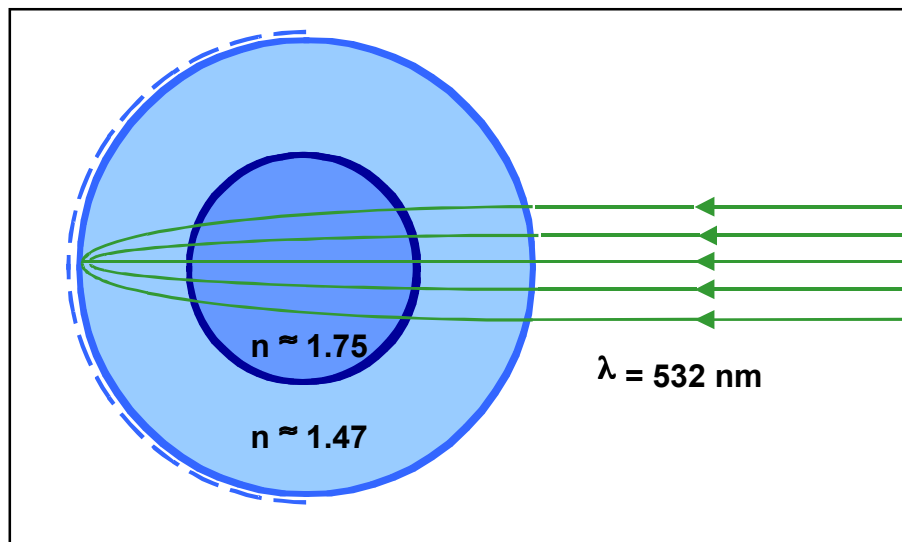


Figure 1. Spherical retroreflector optical layout

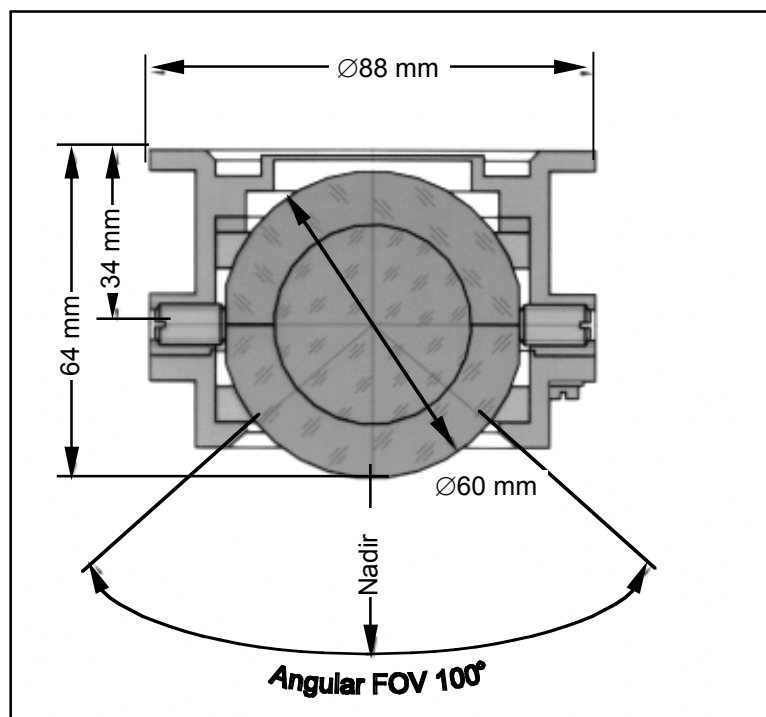


Figure 2. Spherical retroreflector in holder

If used as an autonomous passive target satellite, it can provide very low target errors (less than 0.1 mm). Practically, the target error of such a retroreflector depends primarily on the uncertainty of its operating temperature, causing a corresponding uncertainty of the optical path length inside the ball lens.

Such a retroreflector satellite will have also some other advantages (ideally spherical shape, simple rotation rate determination (if necessary), and minimum in-flight slowdown of rotation rate (as there are no conducting parts where currents interacting with the Earth magnetic field can be induced).

December 1, 2001, a prototype of such a retroreflector has been launched on board of the METEOR-3M(1) satellite into a circular orbit 1018.5 km high. Since then, it has been observed by many SLR-stations of the ILRS network (see Table 1) as well as by the new Russian SLR-station near Moscow (Table 2). Analysis shows absence of any signature, and an RMS error of about 3 mm for stations having high-resolution time-of-flight counters.

Table 1

Number of METEOR-3M(1) passes observed by stations of the International Laser Tracking Network till September 21, 2002

Station Name	Station No.	Number of passes
NASA stations		
Greenbelt (MOB-7)	7105	13
Haleakala	7510	6
Hartebeesthoek	7501	14
McDonald	7080	4
Monument Peak	7110	52
Yarragadee	7090	60
Total		149
Other stations		
Beijing	7249	1
Changchun	7237	16
Grasse	7835	15
Graz	7839	31
Herstmonceux	7840	51
Matera (MLRO)	7941	2
Mount Stromlo	7849	2
Potsdam	7836	5
Riga	1884	2
Riyadh	7832	29
San Fernando	7824	28
Shanghai	7837	6
Simosato	7838	4
Wetzell	8834	1
Total		193
Grand Total		342

Table 2***Number of METEOR-3M(1) passes observed by the new Russian SLR station near Moscow***

Month 2002	Number of passes
January	
February	1
March	6
April	10
May	16
June	13
July	12
August	9
September	3
Total	70

Precision orbit determination (POD) has been provided by the Mission Control Center (MCC, Russia) as well as by Honeywell Technology Solutions, Inc (HTSI, USA). The same POD accuracy has been achieved in both organizations.

The POD results are used for support of the SAGE-III mission (NASA, USA); the corresponding instrument operates successfully on board of the METEOR-3M(1) satellite. The SAGE-III POD requirement is to provide an error in the METEOR-3M(1) position prediction no more than 500 m along the orbit.

Figure 3 shows the results of orbit determination and prediction, based on SLR and RF measurements. As a base (zero line), the orbit computed from SLR network data during September 20, 2002 to September 26, 2002 has been used. The plots show deviations from the basic solution for various particular solutions. The red line shows deviations of an orbit obtained September 23, 2002, using a standard procedure of RF measurements processing; the blue line shows the result of a week-long prediction obtained from the standard solution for September 16, 2002, from RF measurements. The black line shows orbit deviations obtained from SLR measurements (regular operation of the MCC-M Laser Center using data from September 18, 2002 to September 23, 2002).

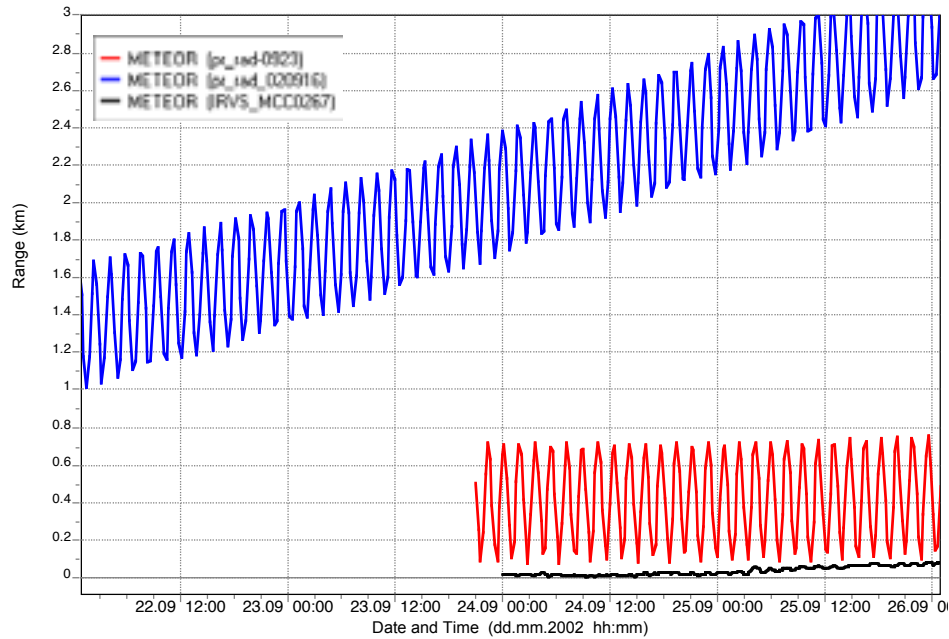


Figure 3. Orbit deviations for solutions based on SLR and RF measurement data

The MCC provides daily POD data based on SLR, and IRVS distribution for stations. The maximum prediction error along the orbit is less than 100 m, with mean values 20...30 m along the orbit and <10 m in directions normal to the orbit.

Using the signal strength estimations from observations of the near-Moscow station, calculations have been made of the retroreflector cross-section. From comparative measurements made during observations of METEOR-3M(1), LAGEOS-1, LAGEOS-2, ETALON-1, and ETALON-2 in similar conditions (visibility and elevation), it was found that the cross-section of the 60-mm-diameter prototype retroreflector is about 10,000 square meters.

Based on the currently obtained results we now propose to design, build, and launch an autonomous satellite-retroreflector of this type, having the following parameters.

Ball lens external diameter	214 mm
Satellite mass	14.5 kg
Retroreflector cross-section	>100,000 sq. m.
Target error	<0,1 mm

If properly designed, the satellite will provide a cross-section substantially higher than 100,000 square meters, and will be accessible for precise ranging at orbit heights up to 2000 km by most of the currently operating SLR-stations.

If high-reflectance coating will be deposited on half of the external spherical surface, the rotating satellite will be seen in reflected sunlight at a distance of 2000 km as a twinkling star of 11-th star magnitude.

The required orbit parameters of such a satellite should be determined in accordance with the mission goals. The development, manufacturing, and organization of launching may be accomplished by the Institute of Precision Instrument Engineering (IPIE).