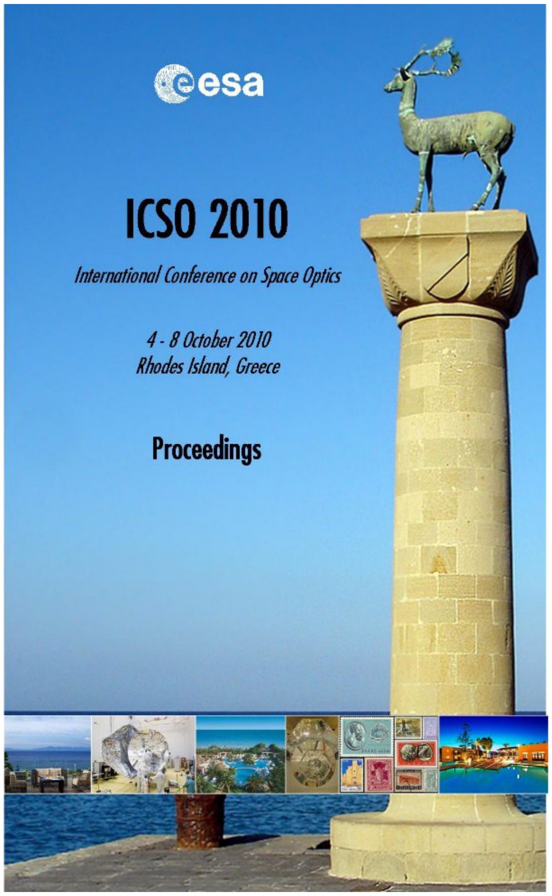
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

Edited by Errico Armandillo, Bruno Cugny,
and Nikos Karafolas



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International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny,
Nikos Karafolas, Proc. of SPIE Vol. 10565, 105652G · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2309104

USING CESIC FOR UV SPECTROGRAPHS FOR THE WSO/UV

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ABSTRACT

The World Space Observatory Ultraviolet (WSO/UV) is a multi-national project lead by the Russian Federal Space Agency (Roscosmos) with the objective of high performance observations in the ultraviolet range. The 1.7 m WSO/UV telescope feeds UV spectrometers and UV imagers. The UV spectrometers comprise two high resolution Echelle spectrographs for the 100 – 170 nm and 170 – 300 nm wavelength range and a long slit spectrograph for the 100 – 300 nm band. All three spectrometers represent individual instruments that are assembled and aligned separately. In order to save mass while maintaining high stiffness, the instruments are combined to a monoblock. Cesic has been selected to reduce CTE related distortions of the instruments.

In contrast to aluminium, the stable structure of Cesic is significantly less sensitive to thermal gradients. No further mechanism for focus correction with high functional, technical and operational complexity and dedicated System costs are necessary. Using Cesic also relaxes the thermal control requirements of ±5°C, which represents a considerable cost driver for the S/C design.

The WUVS instrument is currently studied in the context of a phase B2 study by Kayser-Threde GmbH including a Structural Thermal Model (STM) for verification of thermal and mechanical loads, stability due to thermal distortions and Cesic manufacturing feasibility.

INTRODUCTION

The World Space Observatory (WSO/UV) will provide future access to high-resolution far-UV spectroscopy.

WSO/UV is an international collaboration led by Russia (Roscosmos) to build a UV (102–310 nm) mission with capabilities which are presently and in the near and long-term future unavailable to the world-wide astronomical. community. The present mission design comprises a 1.7 m telescope. The main focal-plane instruments consist of an UV imager and 3xUV spectrographs summarized under the abbreviation WUVS (WSO/UV Spectrographs). The WUVS instrument consists of two high-resolution spectrographs (R ! 55 000), covering VUV range from 102–176 nm and the UV range from 174–310 nm range and a long-slit spectrograph (LSS, 1” × 75”, R ! 1000 – 2000) covering 102–310 nm.

The WUVS instrument is currently studied by the company Kayser-Threde in a phase B2 study till November 2010. Launch of WSO/UV is scheduled for launch in 2014.

WUVS INSTRUMENT

The basic setup of the VUV and UV spectrographs is quite similar. Light collected by the telescope is focused in the entrance slit. After the entrance slit the light is collimated and then spectrally dispersed via the Echelle grating. After the Echelle grating, the spectra are spatially separated by a cross disperser and then focussed on a Micro Channel Plate (MCP) detector. Between focussing mirror and MCP detector the signal dynamic is adapted by grey filters. The general setup of the WUVS optics system is exemplarily illustrated with the UV optics in the following figure.

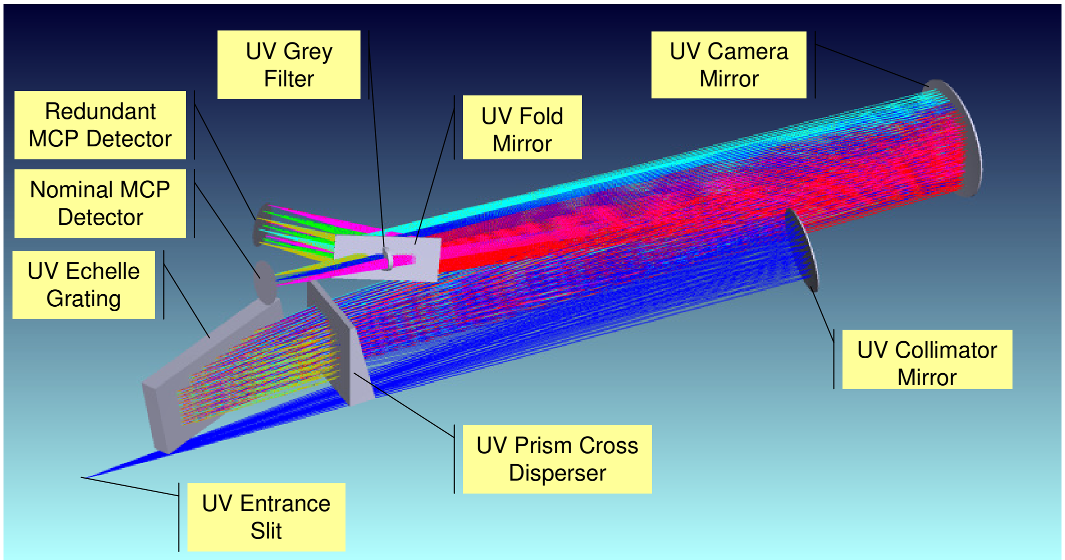

Fig. 1: Optical Design of UV instrument

In order to reduce mass, all instruments are accommodated by a single spectrograph structure. The main instrument requirements are illustrated in the following table.

Table 1: Main Instrument Requirements

Parameter	**Baseline Requirements**
Wavelength coverage • UV Spectrograph • VUV Spectrograph • LSS Spectrograph	 174 - 310 nm 102 - 176 nm 102 – 310 nm
Spectral Resolution • UV Spectrograph • VUV Spectrograph • LSS Spectrograph	 > 55.000 (at mid wavelength) > 55.000 (at mid wavelength) > 1000 (at mid wavelength)
Minimum sensitivity • SNR= 10 in 10 h • SNR= 100 in 10 h	All values in [mag] VUV :16; UV : 18 UV, LSS :tbd VUV :11; UV : 13 UV, LSS :tbd
MCPDetector size	∅52 mm, 30 mm (main dispersion), 40 mm (cross dispersion)
Count rate	up to 300.000 s-1 (detected)
Mass budget	< 184 kg

To reach the required optical performance a high position accuracy (decenter ≤ 5 µm, tilt ≤ 1 arcsec) is required. The high stability requirements in conjunction with the large temperature range and thermal gradient demand for a high performance structure with low CTE.

The usage of standard material such as Aluminium with its large CTE would require complex compensation mechanism, either by structural design or by focussing mechanism. The mass requirements will be difficult to achieve. In the following the design drivers of the WUVS instrument are listed:

- Low CTE related thermal distortions (derived from optical tolerances)
- High stiffness to maintain high position precision
- High temperature range (+/- 5°C) and large thermal gradient
- Low mass (< 184 kg)
- Avoidance of focussing mechanism to compensate CTE related distortion

Due to the challenging design drivers the material Cesic (provided by the company ECM) has been selected for the design of the spectrograph structure.

CESIC MATERIAL

Cesic material is a ceramic matrix composite that is characterized by high stiffness and mechanical strength, high thermal conductivity, low CTE, and quick, relatively inexpensive manufacturing times. These characteristics make Cesic an ideal material at reasonable cost for high-precision space optical and structural applications.

The material possess the following mechanical properties:

- Very broad operating temperature range from 4 K (cryogenic) to 1670 K (high energy applications)
- Low specific density (2.97 g/cm³)
- High stiffness (up to 350 GPa) and bending strength (320 MPa)
- Low coefficient of thermal expansion: 2,3 x 10^{-6} K^{-1} @ RT
- High thermal conductivity: ~ 125 W/mK

DESIGN SPECTROGRAPH STRUCTURE

The spectrograph structure basically of three monolithic Cesic elements

- Outer frame structure
- Main plate
- Frame work

Next figure illustrates the assembled spectrograph structure. The main part of the envelope is occupied by the outer frame structure. The main function of the outer frame structure is to provide a stable accommodation of the upper optical elements (collimator and camera mirrors) of the three instruments and instrument cover. The optical elements itself are mounted on a framework which is fixed via a 4-point screw connection to the on the upper part of the outer frame structure.

The required stiffness of the outer frame structure is realized by a combination of panels and struts. Sufficient accessibility for integration and alignment of the optical elements is given. The access areas will be sealed with foil for straylight protection and uniform thermal radiation.

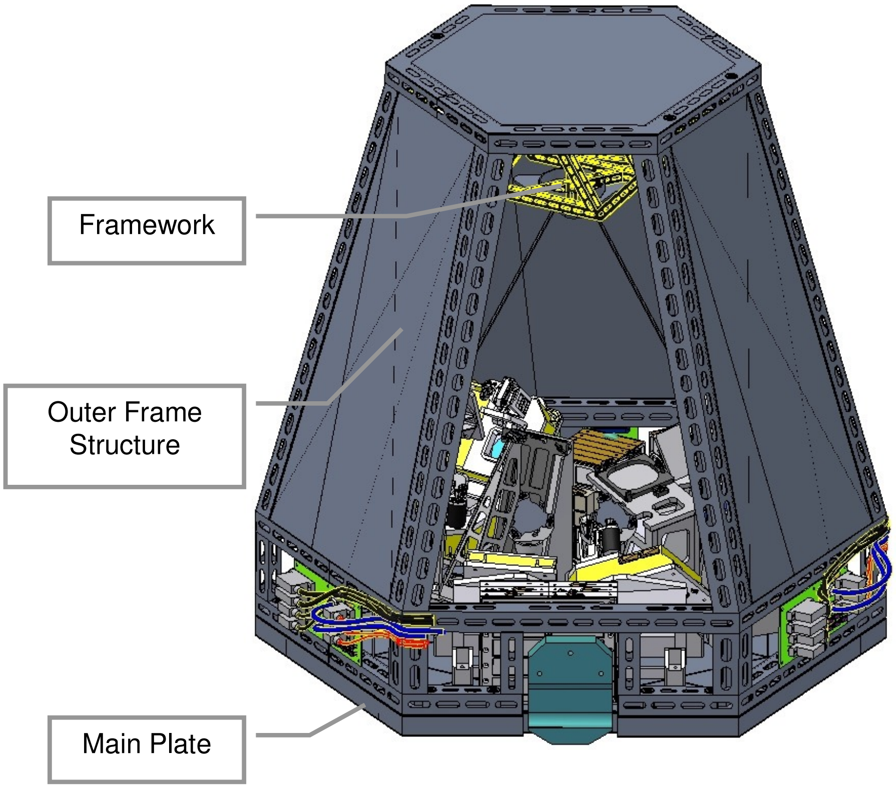

Fig. 2: Assembled spectrograph structure

The main plate accommodates most of the optical elements and detector units. It consists of a monolithic Cesic sandwich structure composed of triangles. All optical elements are accommodated either by a framework in the upper part of the instrument or on the main plate.

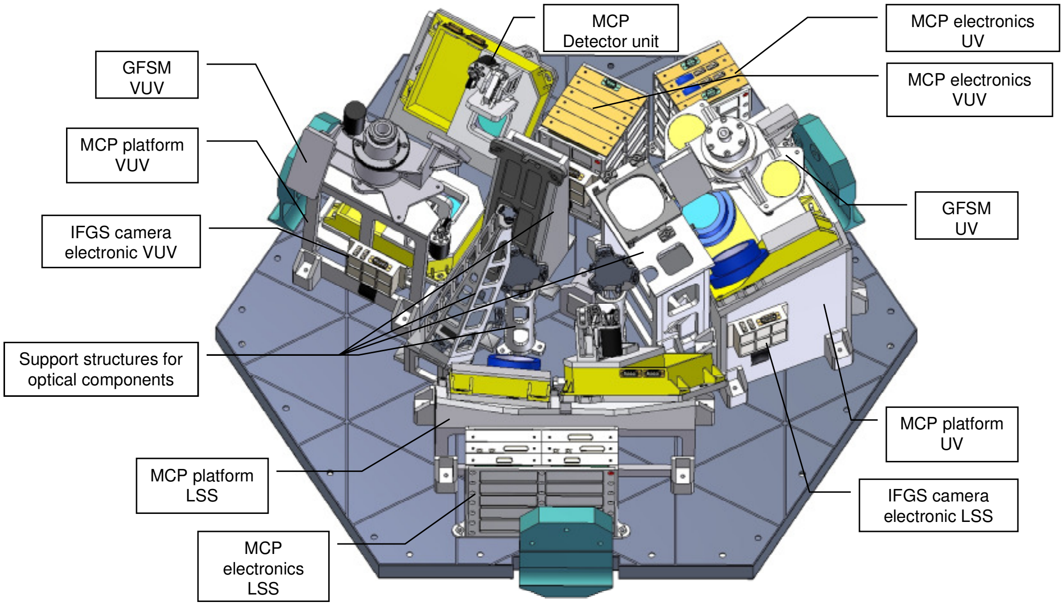

Fig. 3: Assembled main plate

The framework consists of a single monolithic Cesic element, which will be assembled from a set of single strut elements. The single struts will be machined and glue-assembled as green bodies and than infiltrated to a monolithic Cesic structure.

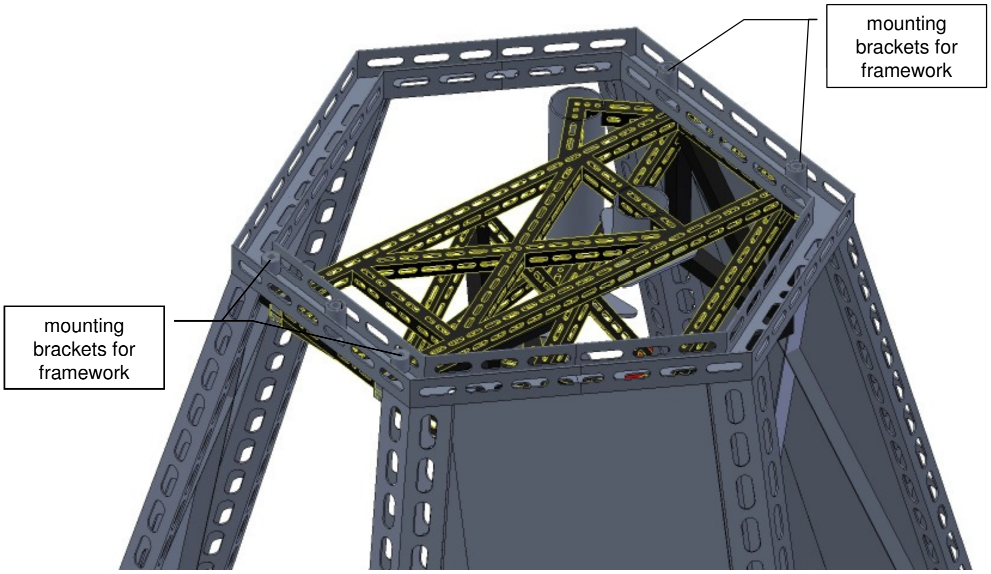

Fig. 4: Optical elements accommodated on the framework

The advantages of Cesic such as high mechanical stiffness, compression loads and low CTE are related with a high tensile stress sensitivity. This feature has to be compensated by a proper structural and interface design. After infiltration any machining of the Cesic material is limited to eroding and grinding. The Cesic conform design has therefore to consider interface requirements such as high accuracy in combination with machining and accessibility requirements. The tensile stress sensitivity has also an impact on the joining technique of Cesic with other materials. Huge differences of CTE's shall be avoided.

STRUCTURAL AND THERMAL ANALYSIS

The mechanical design has been analysed by thermal and structural analysis. The following environmental conditions are applicable:

Acceleration and vibration loads

- Quasi static: 10 g along the Xs/c longitudinal axis, 5 g along each transversal axes Ys/c and Zs/c.
- Dynamic loads: random loads of 7 grms, 20 to 2000 Hz

Thermal Environment:

- Operational: The instrument shall operate in the temperature range of 20°C ±5°C
- Worst case: max. temperature gradient of spectrograph structure 10K (+15°C - +25°C) between opposite sides of the spectrograph structure

The ESATAN-TMS Workbench has been used to set up a geometrical model (GMM) for the calculation of radiative exchange factors and a thermal mathematical model (TMM) for the analysis of temperature distribution. Internal heat dissipating components are the MCP detectors (1W), the MCP electronic boxes (12W) as well as the 3x external Fine Guidance Systems with a total of 30. All thermal flows are coupled into the main plate of the spectrograph structure. Heat exchange is mostly performed via radiation to the thermal protective cover (TPC). Therefore all surfaces shall be painted black with an emissivity > 0.9. Radiative heat exchange to the optical bench is suppressed by means of MLI.

The thermal model has been used to determine the required interface temperatures of the optical bench and TPC (17 °C +/- 2K) as well as temperature distribution for worst case scenarios (10 K temperature difference) for thermal distortion.

The structural model has been modelled with FEMAP and calculated with NASTRAN. The main elements outer frame, main plate, and framework are all lightweighted. The lightweighting is performed by reducing the wall thickness of the elements while keeping their cross section area. The internal mounting elements are modelled based on a preliminary design (not lightweighted, not optimized). All optical elements are modelled as mass elements.

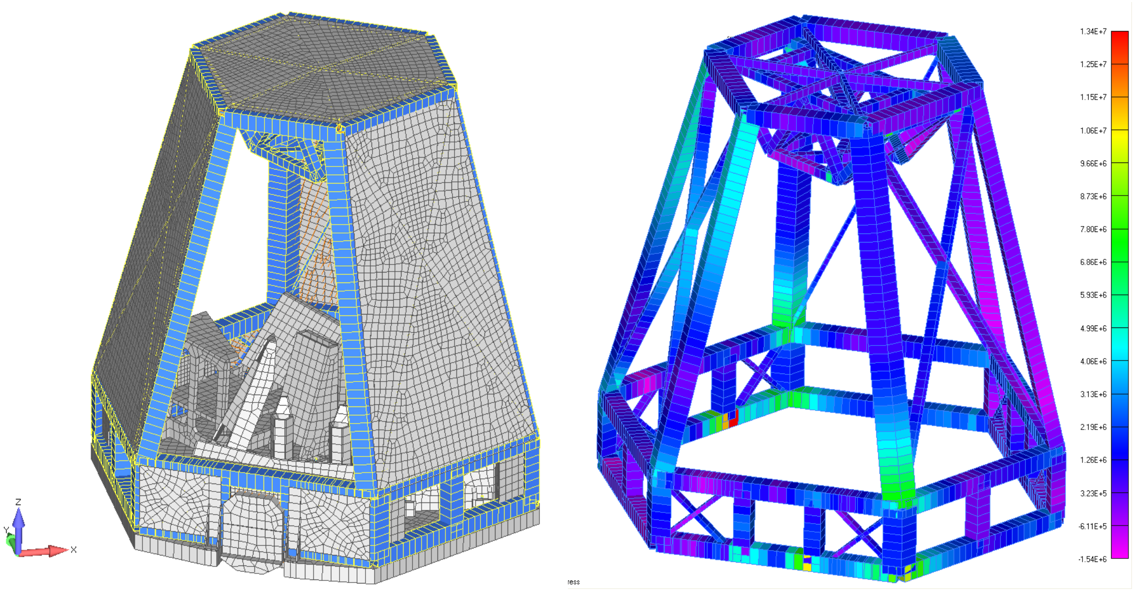

Fig. 5: Structural model (FEMAP/NASTRAN)

The structural analysis revealed the following results:

- Maximum tensile stress of Cesic® beams due to quasi-static loads is 13.4 MPa. With a material strength of 88 MPa this in a factor of safety of 6.5.
- Dynamic loads lead to stresses which are four times higher. The remaining factor of safety is 1.5.

The results of the thermal and structural analysis have been correlated with the optical design for an end-to-end optical performance assessment. 1-G release as well as worst case thermal loads have been considered. The required optical performance > 50.000 spectral resolution could be achieved.

VERIFICATION

A Structural Thermal Model (STM) design has been derived from the FM design to verify the structural and thermal performance of the design concept in representative environmental tests. In order to keep costs in the budget range while achieving a high level of representativeness only the VUV instrument will be built end-to-end completely in Cesic. For the other instrument subassemblies such as optical mounts, detector platforms and support structures will be realized as dummies. The STM shall be subjected to vibration and thermal loads test campaigns.

An additional objective of the STM is the verification of the thermal stability of the design concept wrt to the stringent optical performance requirements. A laser beam in combination with a dummy optic which consists of planar mirrors will model the optical beam. Any deformations of the Cesic structure, imposed by thermal loads, will have the same error effects in terms of distortion and de-alignment on the laser beam as on the real optical beam.

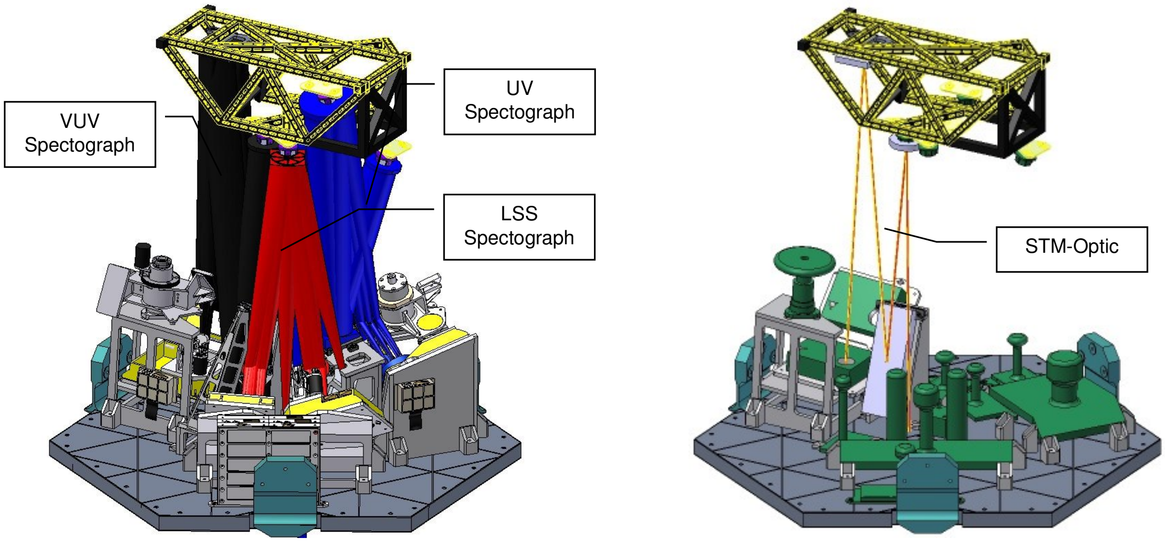

Fig. 6: Design of the Structural-Thermal-Model (STM) which shall simulate the thermal and structural properties of the WUVS instrument

CONCLUSION

Cesic material offers a wide range of benefits for the design of high performance optical instruments. The material properties require a specific design approach. The WUVS spectrograph structure is an all-Cesic design, which represents a new challenge/step for this kind of material. So far Cesic elements have been used in space applications on component and subsystem level. The positive results from design and analysis will be verified by the STM tests. The all-Cesic design approach has the potential to qualify for most challenging optical instrument designs in the near term future.

ACKNOWLEDGEMENTS

The Phase B2 of the WUVS instrument was performed under a contract from Lavochkin Association, Moscow. The authors would like to acknowledge INASAN (Moscow), IAAT (Tübingen) and ECM (Moosinning) for its co-operation.

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