T.H.O.R.I.U.M. Nonsteady Radiation and Conductive Heat Transfer Analysis of the Large Space Telescopes Radiation Shields

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Some advanced astrophysical space telescopes such as JWST, CALISTO and Millimetron will operate with deeply cooled deployable mirrors with temperature 4K – 50K. The mirrors will be cooled down via radiation transfer by using system of radiation shields (or sunshields) – the layers of metalized polymer film. By the reason of temperature differences between sun oriented and shadow sides of such shields, their thermooptical and thermophysical properties vary thru shields layers. Moreover, these properties will vary during orbital cooling procedure. The significant role in cooling is also play shield's thermooptical characteristics, such as their wavelength dependency. In addition, non-Plank emission spectrum and shields surface imperfections should be taken into account.

The precise thermal analysis of space observatory in described assumptions is a complicated problem. An analytical analysis of radiation heat transfer can be done only for simple shapes of a radiation shield, but for real ones is applicable a numerical analysis only. The simplest method of complex surface representation in heat transfer analysis consists in division of such surface into discrete elements with constant temperature. The ratio of a single element heat radiation which is received by somebody element to full emitted radiation of this element is called a view factor. The view factors are formed into a matrix. Size of computer memory needed to store the matrix is a second-degree function of an element number. For example, model with 1000 elements will require 7.629 Mb of RAM to store, 10000 - 762.939 Mb and 100000 – **74.506 Gb** (!). Such a large matrix is difficult to store and operate on modern personal computers. Additional difficulties appear when the refraction of the radiation is taken into account. In this case, the matrix F can be nonsymmetrical and highly efficient compression methods are difficult to apply to it. It is needed to recalculate the matrix F after each time step to consider temperature dependency of the thermooptical properties. These factors force us to abandon direct calculation and subsequent storage of the matrix and to solve the problem by the Monte Carlo method. This method is realized by emitting photon bundles with a random wavelength in a random direction and tracing bundle trajectory until it absorption or exit outside the model.

We suppose that described problems with matrix F can be overcome by performing random test on an each step of time integration instead of whole matrix calculation and storing before integration process. The acceleration of random tests can be obtained by using the analogy between radiation heat transfer and computer graphics. The analogy is based on the similar tasks to solve. Both the radiation heat transfer analysis and computer graphics are required to define mutual visibility of each element by all remain elements. It is needed for bundle-element intersection detection. The computer graphics have got fast hardware realized algorithms for this purpose. This allows us to use them for acceleration of bundle-element intersection detection and therefore for speed up of the Monte-Carlo method realization.

The parallel distributed calculations may be utilized for the analysis of large scale model. Superposition principle allows us to do it. The full radiation flux absorbed by selected element on each time step is a simple sum of radiation fluxes emitted by all elements in the model and absorbed in selected element. It means that propagation of radiation heat flow from each element can be calculated independently. In parallel computing it results in reduced data transfer rate between computational devices. As we do not use matrix F, only vector of element's temperatures should be transferred to computational devices, instead of temperature vector and matrix F in traditional case.

The most suitable scheme for distributed computing is client–server architecture. The clients compute the radiation fluxes on the model elements; the server produces the input data for each time step and processes the computational results of the clients.

The described principles of analysis where implemented in a software which was developed by author. This software is T.H.O.R.I.U.M., Thermooptic Radiation Iteration Universal Module.

The code was released for Windows PC with GNU General Public License. T.H.O.R.I.U.M. allows to take into consideration:

- radiation mirror and diffuse reflection, transmission and absorption;
- material thermooptical properties temperature, time, wavelength and wave line dependence;
- material thermophysical properties temperature and time dependence;
- implicit definition of emission spectrum;
- moving of radiation sources.

T.H.O.R.I.U.M. features:

- open source;
- compatibility with MSC.NASTRAN bdf input files;
- graphical user interface;
- GPU-accelerated analysis;
- ability to use distributed computing in order to accelerate analysis.

The developed software was used for thermal analysis of Russian-led large space telescope Millimetron and Russian GLXP team Selenokhod moon rover.

The T.H.O.R.I.U.M. is available on http://sourceforge.net/projects/thorium.