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In search of an affordable, robust, rotationally invariant model for radiation transport

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Motivation

Radiation transport is an important field of research with applications in:

- Nuclear-power generation
- Medical Imaging
- Cancer Treatment
- Agricultural Industry

We believe that the techniques developed for the construction of radiation modelling can be a stepping stone towards this relatively new and expanding field.

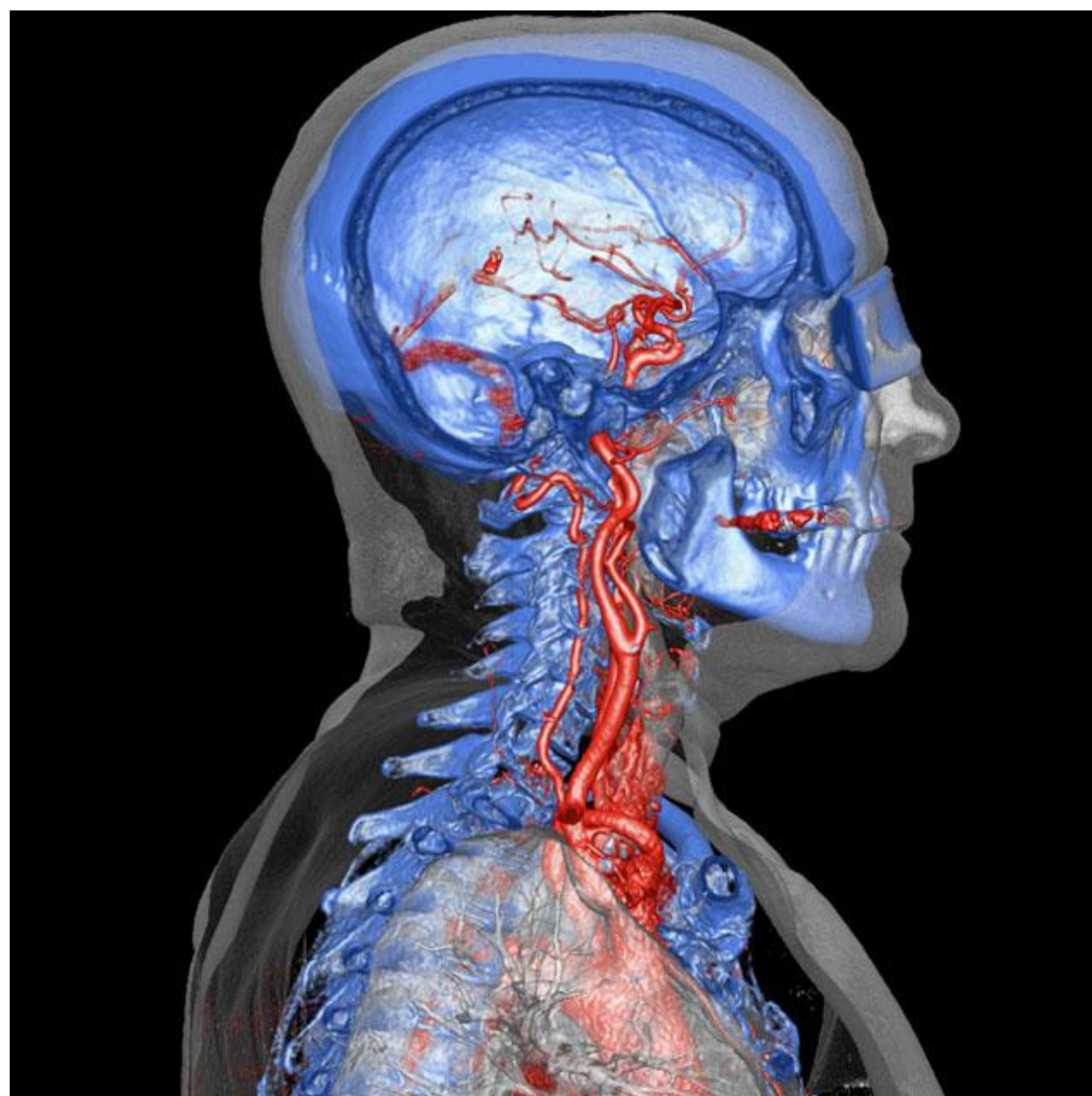


Figure 1. Modern CT scans provide very detailed images by using relatively low radiation doses, e.g. blood vessels, and internal organ [1].

Introduction

At this moment in time, modeling of general radiation transport is numerically challenging. Direct treatments of photon transport are too expensive, as the number of photons involved in typical situations is vast. All current models produce numerical artifacts in solutions. One common model (known as the discrete-ordinate method) only allows radiation to travel in predetermined directions. In this case, the solutions are dependent on the orientation of the original axes. Another method based on spherical-harmonic representations of the distribution function that characterizes photon velocities is rotationally invariant, but can produce non-physical solutions that predict negative photon density in some regions.

Therefore, the proposal is to create a model based on an averaging of multiple discrete-ordinate treatments. The hope is that the results will not contain any regions of negative density and can approach rotational invariance. At first, the model is mathematically constructed using a technique known as "moment closure" and, afterwards, implemented in an existing large-scale computational code. The investigation of this type of model is performed through solution of canonical radiation-transport problems.

Methodology

The new model was constructed by taking the advantages that are present in two existing radiation models :

- The spherical harmonics method gives rotational symmetry.
- The discrete-ordinates method preserves the positivity of density.



Figure 2. The procedure used to create the new model.

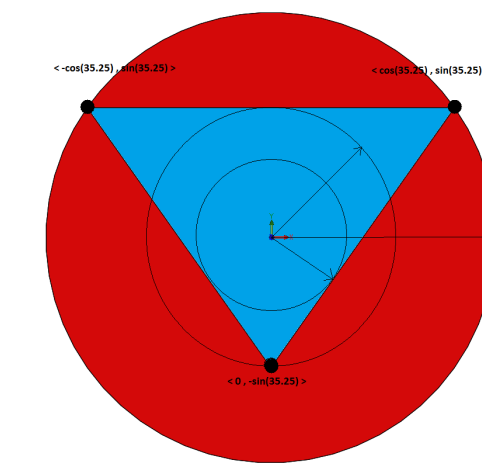


Figure 3. Tetrahedral Geometric Structure inside Sphere for New Model (view in XY plane).

Results

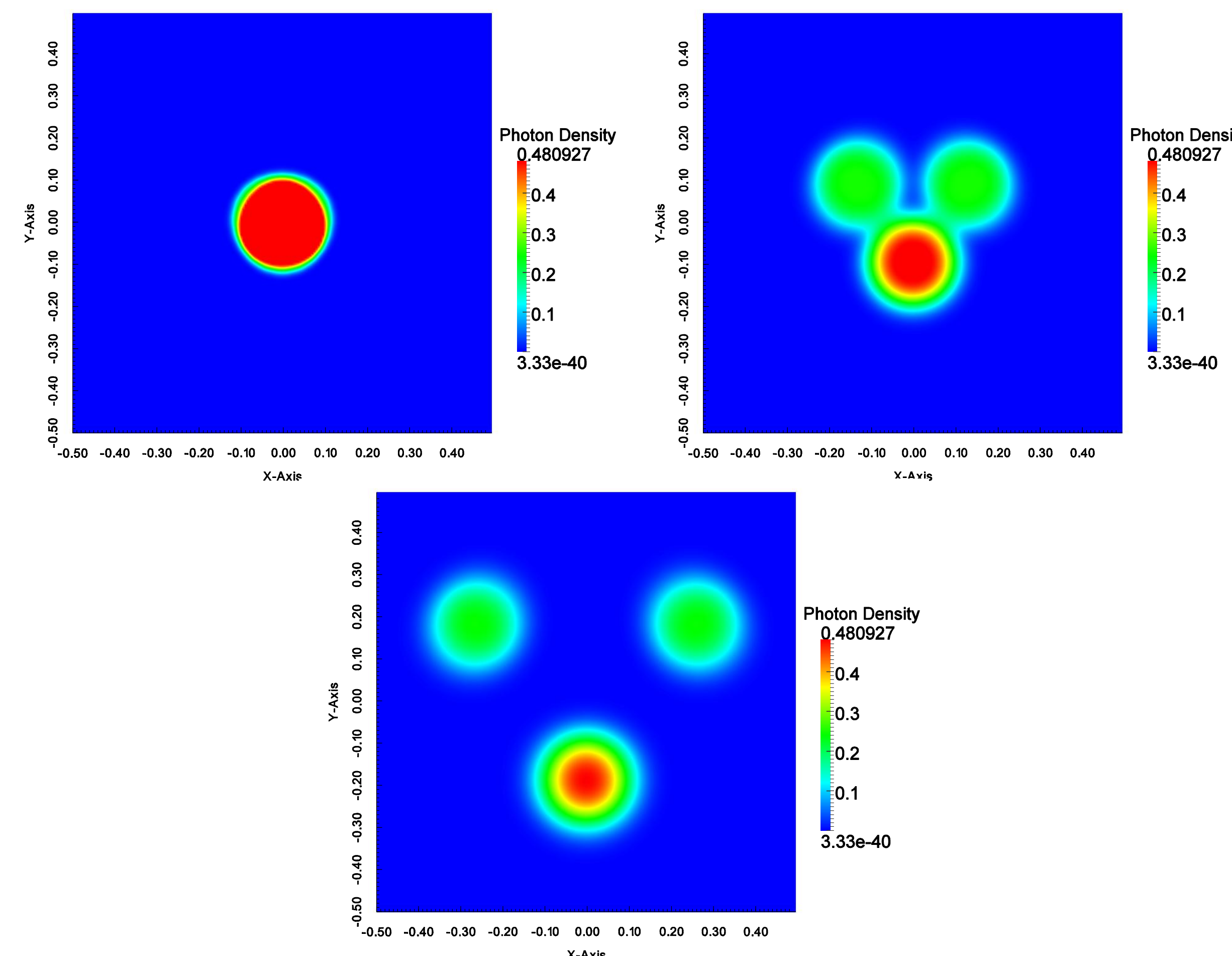


Figure 4. The Discrete Ordinates Radiation Model [S_N].

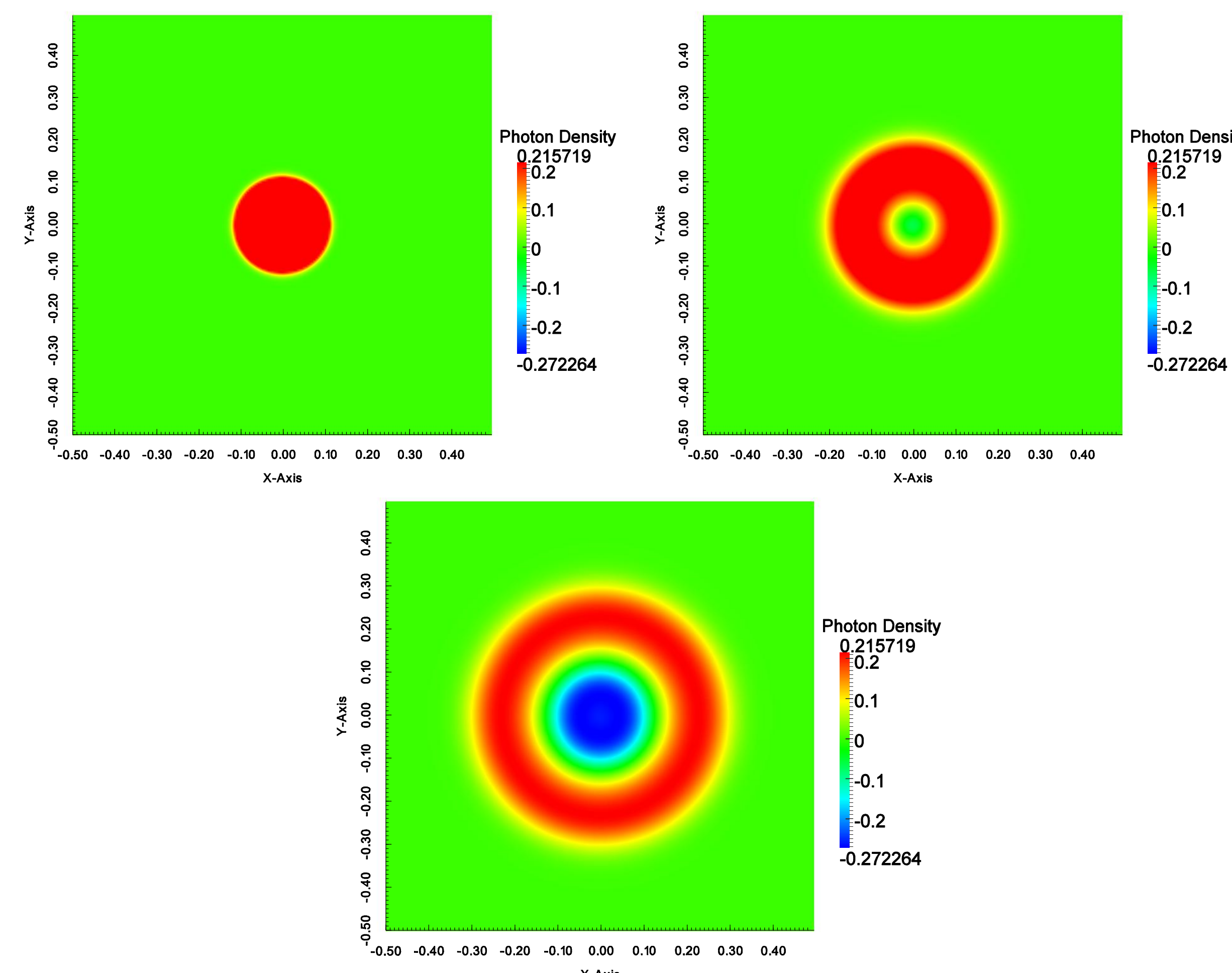


Figure 5. The Spherical Harmonics Radiation Model [P_N].

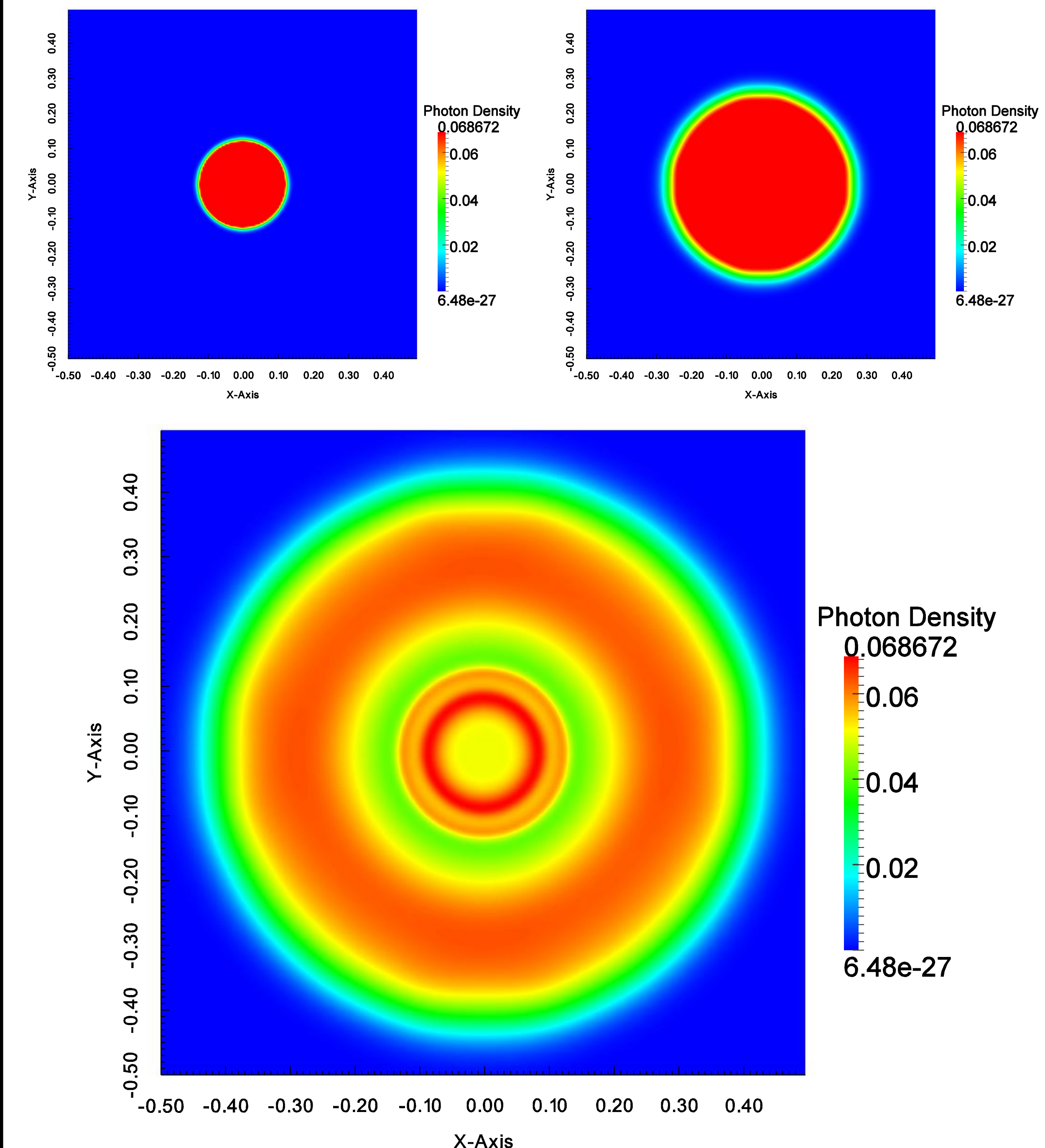


Figure 6. The Newly Created Radiation Model.

Conclusions

The created model show results which doesn't contain any region of negative density and approaches rotational invariance. Indeed, this proof of concept is promising for future studies in the field of radiation transport. The actual model can be studied more in-depth and the enhancement of the photon density field can be achieved by increasing the moments. Thus, in this case, the challenge consists in creating more complex geometries. However, it is expected that under very high moments the geometrical shape consists of the sphere itself. In that way, it can potentially produce an exact solution for the photons density behavior in space and time.

References

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2. C. Kristopher Garrett & Cory D. Hauck (2013) A Comparison of Moment Closures for Linear Kinetic Transport Equations: The Line Source Benchmark, *Transport Theory and Statistical Physics*, 42:6-7, 203-235, DOI: 10.1080/00411450.2014.910226
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