

Ray Tracing

Introduction [±]

Ray tracing works started by Maeda and Kimura in Kyoto University in 1955 for whistler ray paths in the magnetosphere using a rather tedious graphical method, because electronic computers were not available then. Ray tracing technique using electronic computers was developed by J. Haselgrove in 1954. This technique was first used by Yabroff (1961) of Stanford Research Institute for whistler ray paths by using a digital computer, taking account of electrons in the magnetosphere, with the aim to check the above mentioned Maeda and Kimura's ray paths calculated by graphical method (1956).

Kimura(1966) at Stanford, developed a 3-D whistler ray tracing program based on Haselgrove technique taking account of the effect of three ions (protons, helium ions, and Oxygen ions), whose spatial distributions were followed by so-called diffusive equilibrium model(Angerami and thomas; 1964). The calculation by this new program results in several new findings, which enabled us to explain, for example, SP(subprotonospheric) whistlers observed by rockets and MR(magnetospherically reflected) whistlers.

This computer program has been used at Kyoto University, with a minor and major modification, since then, to interpret many whistler mode phenomema observed by Japanese satellites, Jikiken and Akebono. Later, these programs were extended to the HF frequencies and higher up to lower microwave, such as GPS frequencies.

I (I. Kimura) wrote such a historical account in the Radio Science Bulletin(Special issue for Haselgrove; 2008), to appreciate her original and invaluable theoretical works for the base of ray tracing using digital computer published by J. Haselgrove (1954). This technique has been used for ray tracing of various wave phenomena by space researchers in the world.

Dr. Owen Storey (whose famous PhD paper(1953) was the start of my research in this field, 55 years ago) gave a notice, in his private letter, to all authors who worked in the ray tracing in the past and wrote in the same issue (Bulletin No. 326 and 327; 2008) that there were many ray tracing works in the past and the results of calculations were published, but none of the software was open to the public. He advised us to start action to open software of the ray tracing. I agreed his recommendation, so that I have started the work of Open-software of our ray tracing programs, with the powerful cooperation of Dr. Yoshitaka Goto who had participated in the ray tracing work in Kyoto University, now affiliated in Kanazawa University. He checked again carefully the most important part of the ray tracing program, that is, Adams-Bashforth predictor method and -Moulton corrector method for the numerical integration of the differential equations for ray tracing, and he also kindly added description on those parts of the program.

We will introduce several basic programs mostly in Fortran Language, which may be rather out of date. However, the algorithms of the programs may be valuable to young scientists and this Fortran programs work still successfully on any PC by using Cygwin software and graphical software, such as Gnuplot. Some new programs developed by Y. Goto are written in the language C++. We hope that these Open- sources will be helpful to some researchers. Any comments and revision or modification of the programs and descriptions are welcome.

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First we would like to thank Dr. L. R. O. Storey for his advice to open our raytracing software to the public. We are also oblized to Dr. Danny Summers, now at Research Institute of Sustainable Humanosphere of Kyoto University, for his kind and careful reading of the draft to be used for this Open-software of Ray Tracing. We have to write the names of our colleagues for acknowledgments here ; A. Sawada, Y. Kasahara, A. Hikuma and K. Tsunehara, who developed most of sophisticated computer programs applied to determine the global electron density profile in the plasmasphere using the Akebono wave data (Omega signals). We, however, do not include the above program applied to analyze Omega data observed by Akebono satellite, since it is not adequate for introducing the fundamental ray tracing programs. Finally, we are oblized to Dr. Yoshiharu Omura of Kyoto University

for his continual encouragements for us to complete our works to open our ray tracing programs to the public, and for his efforts to publicize this open source.

March, 2010

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