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3d Tomography of Hydrogen and Helium Plasma Produced in the Proto-Sphera Experiment

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Provide an Abstract

A typical approach to 3D image reconstruction is computed tomography, which reconstructs the sought image based on a set of slice projections, relying on the Fourier slice theorem in 2D. The solution to the problem of how to reconstruct a function from its projections dates back to the paper by Radon in 1917 [1]. A projection slice collects the integral of some measurable response quantity through a set of plane (slice) parallel rays illuminating the object of interest. A collection of parallel projections through an object onto lines at varying angles is called direct 2D Radon transform [2]. The Fourier slice theorem guarantees that the Fourier transform of the Radon transform at a given angle equals the values of one row of the 2D Fourier transform. Then, the image is obtained by calculating the 2D inverse Fourier transform of the Radon Transform. In this way, a 3D image is obtained assembling the image of each slice.

We propose an imaging technique based on the Fourier slice theorem in 3D, which relates a set of projections onto planes, that is a 3D Radon transform, to a 3D Fourier transform. In this way, a set of projections onto planes, defined as 2D Radon transform, is related to the 3D Fourier transform. After a suitable transformation of coordinates, by calculating the 3D inverse Fourier transform of projections, the 3D image of the scanned object is reconstructed [3].

The formulation developed is applied to the 3D reconstruction of distribution of light emission of magnetically confined plasma, employing data provided by ENEA (Italian National Agency for Technology, Energy and Sustainable Economic Development) Frascati, Italy. This data includes visible light emission by both Hydrogen and Helium plasma, recorded within the framework of the PROTOSPHERA experiment. This experiment displayed the appearance and sustainment of a plasma torus around an internal magnetized plasma centerpost (jet) by self-organisation; an entirely unexplored phenomenon to date. The remarkable ideal magneto-hydrodynamic stability of the PROTO-SPHERA plasma is extremely significant, and it is obtained in a simply connected geometry, inside a perfectly insulating, transparent vacuum vessel, and without the need of a nearby stabilizing conducting shell. The analysis carried out enabled observation of the physics of the formation of the plasma torus [4]. By using six pictures captured by cameras arranged in cylindrical symmetry during experiment as Radon transforms, a meaningful 3D reconstruction of the spatial distribution of plasma visible light emission in the PROTO-SPHERA experiment at different time instants is obtained. It was shown how the plasma torus grows in 5-8 ms from a kinked filament, due to the destabilization of the plasma centerpost. In addition, it was observed that the plasma torus rotates around the centerpost axis, in analogy with phenomena observed in Pulsar morphology.

[1] J. Radon. On the determination of functions from their integrals along certain manifolds. Ber. Verh, Sachs Akad Wiss., 69:262–277, 1917.
[2] C. Kak, M. Slaney. Principles of computerized tomographic imaging. Society for Industrial and Applied Mathematics; 2001.
[3] S. Naghinajad, A. Pau. 3D ultrasonic tomography for image reconstruction: an application to the plasma dynamics of PROTO-SPHERA." ECCOMAS YIC, Porto, June 19-21 2023.
[4] F. Alladio, P. Micozzi, L. Boncagni, A. Pau, S. Naghinajad, S. Macera, Y. Damizia, P. Buratti, F. Filippi, G. Galatola Teka, F. Giammanco, E. Giovannozzi, M. Iafrazi, A. Lampasi, P. Marsili. PROTO-SPHERA: a magnetic confinement experiment which emulates the jet +torus astrophysical plasmas." *Under review*

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