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3-D Structure of Pulsed Volume Radiator

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We view a volume radiator as a two-dimensional projection. Determination of the full 3-D structure of the radiator may take a 3-D reconstruction based on many such 2-D views. CAT or MRI scans are such examples.[1] When the volume radiator evolves rapidly as in the case of a laser-produced plasma (LPP) plume, it is not practical to rely on a very large number of 2-D projections. Further complications arise when the radiator exhibits significant self absorption of its own emissions. We present a new robust 3-D reconstruction method, applicable to transient radiators of arbitrary shape and of non-uniform profiles in temperature and density.

The approach is built on two mutually orthogonal side-view luminosity streaks for the duration of the radiator's lifetime and a front-view snapshot, taken at an early moment. No symmetry assumptions are invoked. Two power-law scaling relations are invoked, however, each with a scaling constant and a scaling exponent, in order to link the local pressure and temperature to the specific emission intensity of a local differential volume element.

Of central interest is arbitrarily structured plasma with significant self absorption. We have selected for our investigation a LPP plume confined in a dense neutral gas. This is because the plume evolves into an irregular volume radiator, providing a useful test platform. The interface between the neutral gas and the LPP plume can become Rayleigh-Taylor unstable when the mass density disparity between the two media reaches a threshold condition at higher neutral gas densities. The consequences are irregular growths of the plume over time with the attendant loss of shot-to-shot reproducibility and the development of local electric fields due to resultant charge separation within the plasma plume.

We present a new algorithm as a general method for reconstruction of the 3-D structure of an arbitrary LPP plume, the structure being given in terms of the local specific emission intensity of each individual plasma element. Our development has addressed the reconstruction in stages of increasing complexity: a) axisymmetric LPP plumes with self-absorption;[2] b) asymmetric but non-self absorbing LPP plumes;[3] and c) non-axisymmetric self-absorbing LPP plumes.[4,5] We focus our attention on a Rayleigh-Taylor unstable LPP plume from an aluminum target in dense argon.

The method can accommodate the open physics issue of the breakdown of the classical scaling of Debye length with plasma density in the high-density regime. The breakdown affects the self absorption and ionization potential lowering, which in turn modifies the detected 2-D view of the plasma at a given time.

To begin, the scaling constants and the scaling exponents are first selected, and a plasma structure is proposed in terms of specific emission intensity. The 3-D reconstruction proceeds self consistently by evaluating the luminosity in the respective directions of the two streaks at a given time according to the proposed specific intensity profile. Error signals are computed between the calculated and the measured luminosity. The corrections to the specific intensity are determined with the front-view snapshot providing the weighting function for allocation of the luminosity error into the specific intensity corrections along each given side-view line of sight.

Specifically, the local plasma pressure and temperature are first obtained using the scaling relations. Noting that the particle collision times are of the order of 10 fs while the volume radiator evolves in time scales of 1 ns, the equilibrium distribution of electrons and ions are found by solving thirteen simultaneous Saha equations self consistently. A new shielding length is calculated, which gives the estimates for ionization potential lowerings[5] and plasma absorption.[5,6] The process is repeated with a revised specific intensity profile until the luminosity errors are minimized. The weighting function is updated by the optimal specific intensity profile in order to launch the structure reconstruction for the next time step, together with the luminosity data from the two streaks.

The scaling constants and scaling exponents are calibrated by requiring that the full plasma structure produces the measured global lower dimensional properties of the volume radiator: the total mass, energy and plasma attenuation coefficients for a laser beam traversing the plasma at two different wavelengths.

References

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