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Universality of neutral atom acceleration in intense laser plasmas

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Intense laser produced plasmas are very well know for generation of high electron temperature plasma at high densities [1]. Plasma temperatures from tens of keV to a few MeV are routinely generated with intensities achievable even in university scale lasers. Even a few mJ lasers are sufficient to ionize inert gas atoms like Ar to charge states as large as 14+[2]. High energy electrons move out first from the plasma region and set up acceleration fields that easily tend to be as large as TeV/m even for modest laser fields [3]. Ion acceleration followed by high energy electron emission is thus an important aspect of studies in intense laser plasmas.

One seldom talks about charge transfer reactions or electron-ion recombination reactions in such hot dense plasma experiments. This is because when the electron temperature is very high, the possibility for an ion to capture an electron is low. So charge particle acceleration and getting a low emittance high energy electron/ions is of importance. Can such hot dense plasmas be a source of high energy atoms? Can we tweak the plasma generation conditions to convert most of the high energy ions to high energy neutral atoms? Can we modify the compact ion acceleration schemes to compact negative ion acceleration methods?

We posed these questions to wide range of plasma experiments. We found that indeed charge reduction of high energy ions to be reduced to high energy neutrals is universal in nearly all the plasma experiments. Irrespective of the conditions of the target, laser energy or laser pulse contrast etc, in every case, neutral atom formation is quite prominent. With nano-clusters as a target, charge transfer reactions can be tweaked to push neutralisaiton to a near 100%[4]. So, nearly all the high energy ions can be converted to neutral atoms with out any loss of kinetic energy. The low emittance high energy ion source thus becomes a low emittance high energy neutral atoms source, where even modest 10^{16} Wcm-2 lasers can generate atoms upto an MeV energy. Unraveling the physics of these experiments, show that Rydberg excitation of the atomic system surrounding the laser forms the efficient route to neutralization [5].

We followed the quest of looking for schemes to optimize neutral atom formation even with solid target experiments[6,7]. As in any conventional solid target experiments, a Thomson parabola spectrometer shows a very bright central spots that could be mistaken as light emission from the laser plasma. A methodical analysis of the central spot shows that the dominant signal there is actually high energy atoms and not light or x-rays[7]. Neutral atom formation can be made as large as 80% for low energy ions. Even with high contrast pulses (10^{-9}) of 10^{19} Wcm^{-2} on a plain solid target, proton neutralization can be as large as 60-80% for the low energy protons [8]. Electron ion recombination in the plasma plume close to the solid target would suggest much smaller fraction than what is seen experimentally. Why we see such a larger fraction of neutralization is an interesting puzzle to solve and it gives insight into the laser plasma evolution[9]. The electron-ion recombination rate is large enough to even generate H- ions even with the conventional solid targets and high intensity pulse.

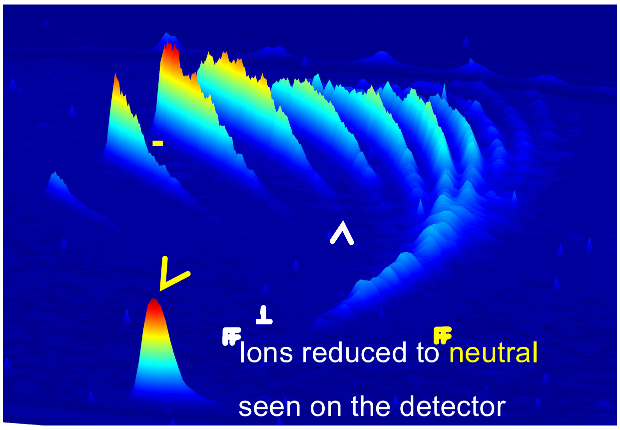

Figure: A Thomson Parabola spectrometer image with the ions and the central spot that may be mistaken for scattered light or x-rays, is in fact dominated by neutral atom signal and atom yield can be as large as the 80% of the ion signal.

In this talk, I will summarize the answer to all these unconventional observations and experiments that pave way to turn intense laser produced plasmas as a source of low emittance high brightness high energy neutral atoms.

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