Electric Double Layer is Secret Behind Revolutionary Space Thruster

Christine Charles and Rod Boswell

Researchers at the Plasma Research Laboratory have discovered a supersonic ion beam coming from an expanding plasma. This ion beam is accelerated by a current-free electric double layer. Double layers are of great interest in astrophysics (aurora, solar corona, extragalactic jets...) and rocket science (electric propulsion for low orbit satellites and for interplanetary spacecraft).

One of the most beautiful mysteries in the heavens is the aurora which is seen during winter months at latitudes about 20 degrees away from the poles. These "lights in the sky" are caused by the impact of electrons with energies of a few kV on the upper atmosphere which excite various lines of oxygen and nitrogen resulting in the splendid colours and draperies. These displays have been observed and recorded for over two millennia but it was only in the last half of the 20th century that some light was shone on the basic plasma physics underlying the acceleration of the electrons to these high energies. The tools used to obtain the results were polar orbiting (or highly eccentric) satellites which passed through the active auroral regions in only a few seconds. One needed luck to have the satellite there when there was an active aurora. Rocket flights have also provided immensely useful data but suffered the same problem of "when to launch".

Over the past 25 years, it has become accepted that the basic mechanism underlying most of the observable phenomena was the existence of a large electric double layer situated about one earth radius (about 6000 km) above the visible auroral regions. An electric double layer is a local region in a plasma

Above: Members of the plasma thruster team gathered round the prototype

Left: The aurora, seen here from the northern latitude of Fife, Scotland which can sustain a potential difference, much like a cliff of potential (like a riverwaterfall) that can energise charged particles falling through it. These double layers are rather exotic objects and are similar to collisionless shocks; they can only be described by resorting to non-linear physics. It is now recognised that they may play a major role in dissipation processes of solar flares. For example, some models of the current interruption mechanism leading to the production of solar flares invoke the existence of multiple weak double layers. Double layers are also thought to play a role in extragalactic radio emissions. In this case, particle beam driven wave instabilities on either side of gigantic double layer structures produce anomalous resistivity, maintaining a density cavity within which the double layer resides, creating optimal conditions for polarised radio emissions.

Electric double layers in plasmas have been studied experimentally, theoretically and by computer simulation. The majority of experiments reporting laboratory double layers generally fall into two types, current driven or current free double layers: the first involves creating two separate plasmas at different potentials and allowing them to interact in a central chamber joining the two sources with stable double layers being formed by careful manipulation of the external experimental parameters. It can also involve a current flow in cylindrical 'Q' machines or in DC discharges with an abrupt change in diameter. The second type involves a weakly magnetised system expanding away from a small source with the presence of a current free field aligned double layer. A few scientists have described experiments carried out in a pulsed system where the high potential in the upstream of the double layer was provided by the anode of the plasma source. However, for pressures above 5 x 10^{-5} Torr, no double layers were observed and above 4 x 10^{-4} Torr, no energetic ions were observed. Recently, in a research experiment called CHI KUNG, we have shown that a current free double layer can be generated in a plasma expansion in a magnetic field for pressures less than about 1 mTorr (Figure 1). A supersonic ion beam has been measured downstream of this double layer both for argon, hydrogen and oxygen discharges and to date there is no satisfactory theoretical analysis of this current-free double layer (Figure 2). The fascinating part is that the double layer is not triggered by forcing two plasmas (independantly generated by grids with separate potentials, much like a man-made dam) to interact, but self generates under certain parameters, much like the riverbed suddenly falling away to create a waterfall.

Apart from being an interesting phenomenon for space plasma physics, the ions accelerated by the double layer can be used for thrust in a space craft. Recently, there has been a renewed interest in plasma based thrusters for space applications and especially in non-gridded systems such as the Stationary Plasma Thruster or Hall effect thruster. This system uses a j x B type of plasma acceleration and was originally developed by the Russians: it is now being flown on spacecraft. Although no extraction grids are used, an electron source is still needed to properly neutralise the escaping ion beam.

A newly proposed system, magnetoplasma thrusters, uses plasma creation followed by perpendicular ion heating and adiabatic expansion to produce thrust (VASIMR at NASA). The ions need to be heated to some hundreds of eV perpendicular to the magnetic field and this is quite a challenge. The expansion of the plasma also provides up to 100 eV of energy from the electric field generated by the density gradient.

Our system presents a completely new phenomenon of a double layer in an expanding current free plasma to be used as the basis of a different genre of space plasma thrusters, the Helicon Double Layer Thruster (HDLT). We are currently building a prototype which will be tested at ESA (European Space Agency) in Europe. It is simple, has no moving parts, no electrodes and no need for a neutraliser. Both the research (CHI KUNG reactor) and development (HDLT prototype) efforts are being carried out in parallel by a team of scientists and Ph D students in collaboration with astrophysicists, rocket physicists, and plasma physicists around the world (USA, France, Norway, Sweden, Germany...).

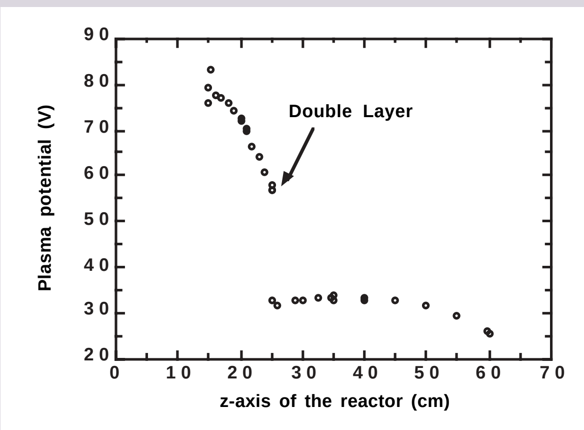

Figure.1: Potential drop at ~25 cm showing the double layer

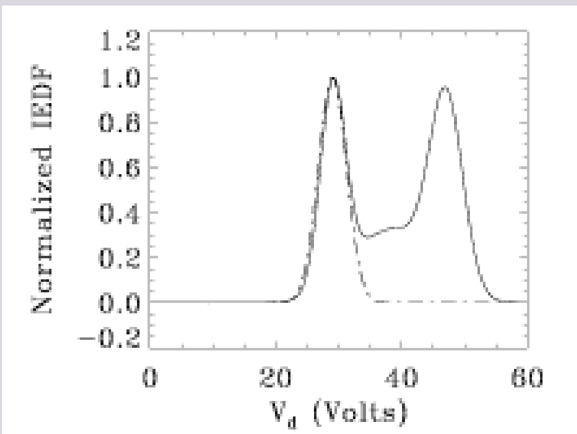

Figure. 2: Radial (facing the walls/dotted line) and axial (facing the double layer/solid line) Ion Energy Distribution Functions downstream of the double layer, showing the supersonic ion beam at high energy.