# Laboratory Investigation of Ion Induced Astrochemical Processes on Ices

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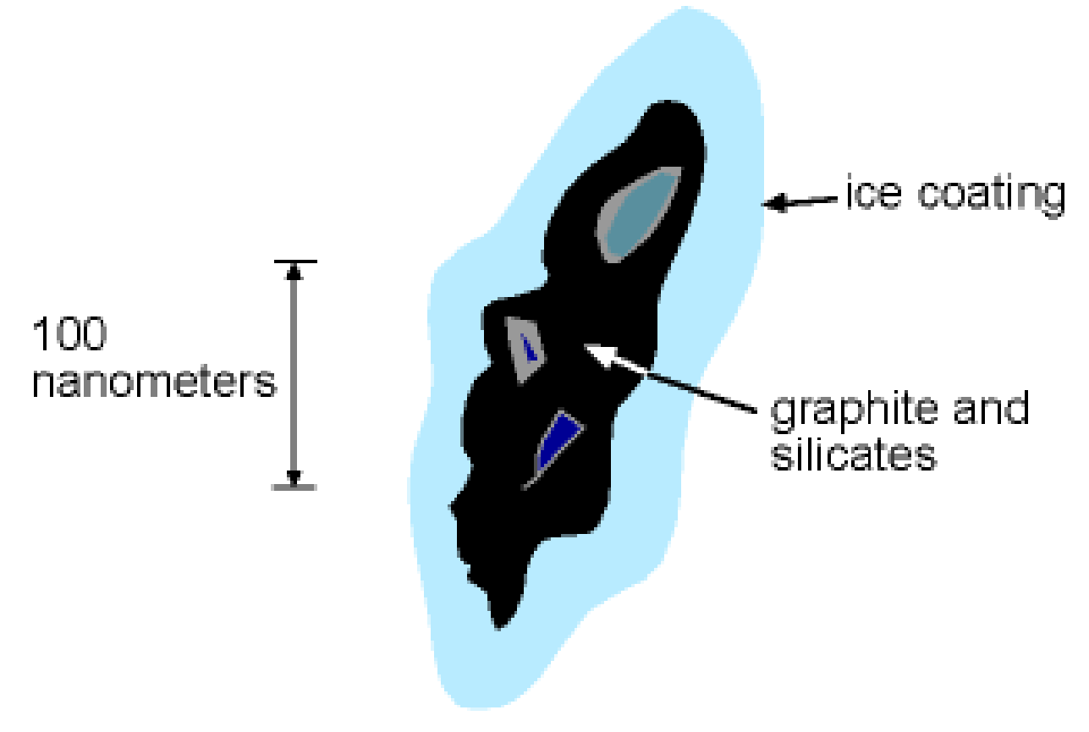
## Introduction

The space between the stars is not empty but filled with a very diffuse gas with extremely low densities and temperatures, which is a unique laboratory with conditions not normally encountered on Earth. A surprisingly large number of molecules have been observed in so-called interstellar clouds, but how are molecules formed? Why do their abundances differ from place to place? What does this tell us about the chemistry and physics of these regions?

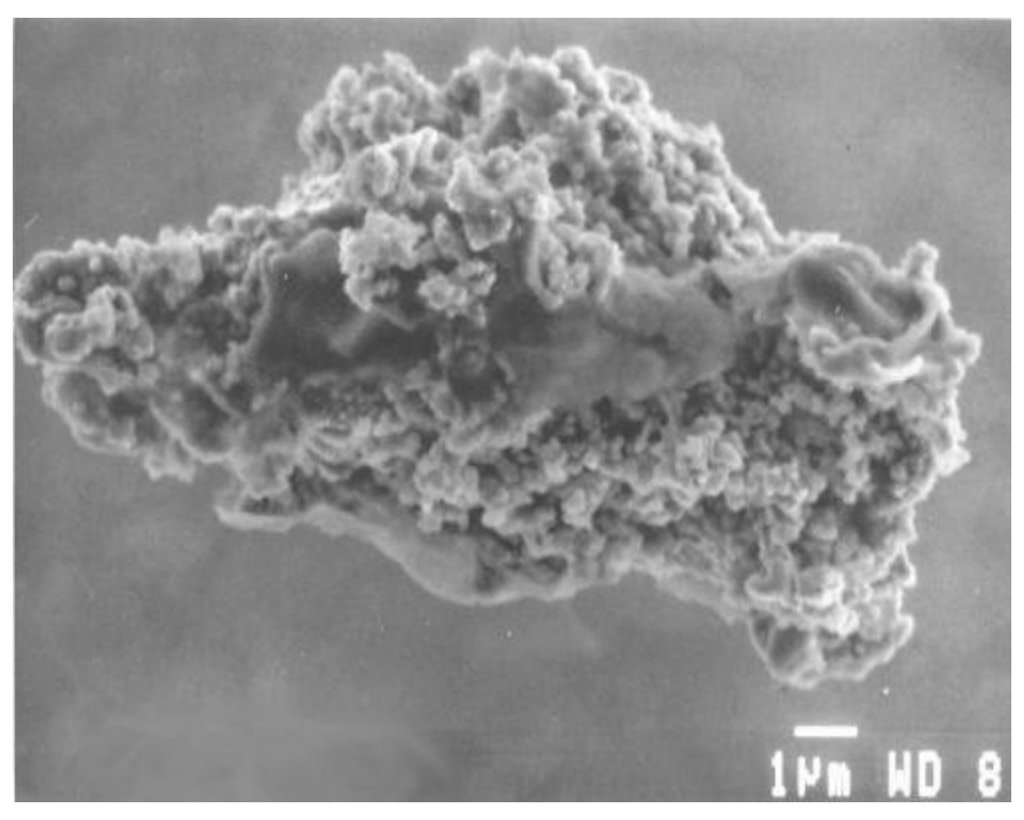
Dust grains are a very important component of the Inter Stellar Medium (ISM) and they are made of carbon, silicates and water ice which has frozen out around the carbonaceous or silicate core. The grains themselves are thought to be formed in the winds of evolved stars. Evolved stars have very low temperatures < 2000 K. It is believed that many complex molecules are formed on these grains. Ice covers these dust grains and as the icy material is exposed to stellar radiation, photons induce chemical reactions. The temperatures and the densities in the ISM are very low hence chemistry can occur which is different to that on Earth.



A typical dust grain (note the tiny scale!).

Star-birth clouds in m16

Cosmic ice sculptures;dust pillars in the Carina Nebula



The structure of a dust grain

starbridge.com.au

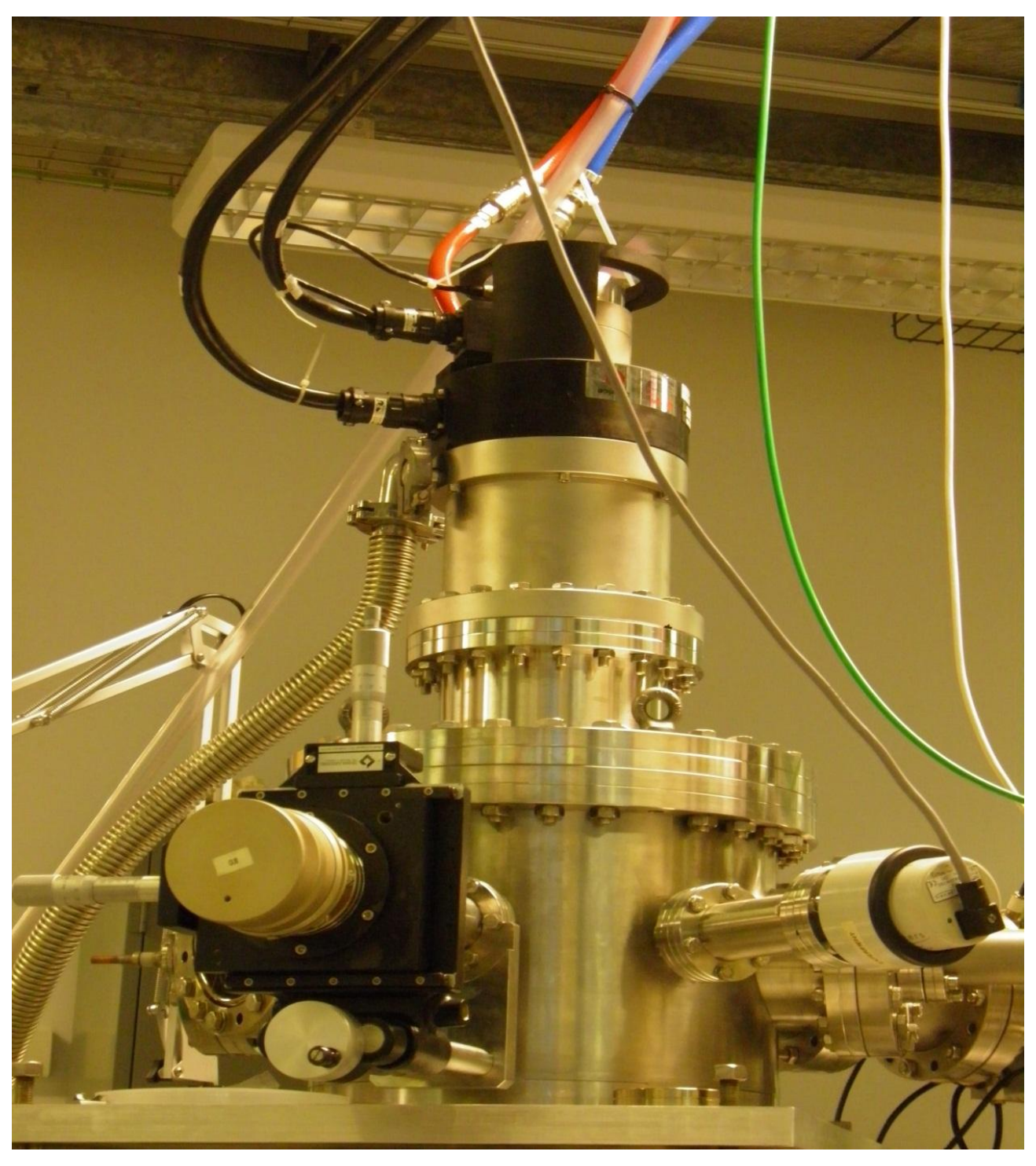
http://hubblesite.org

## Motivation

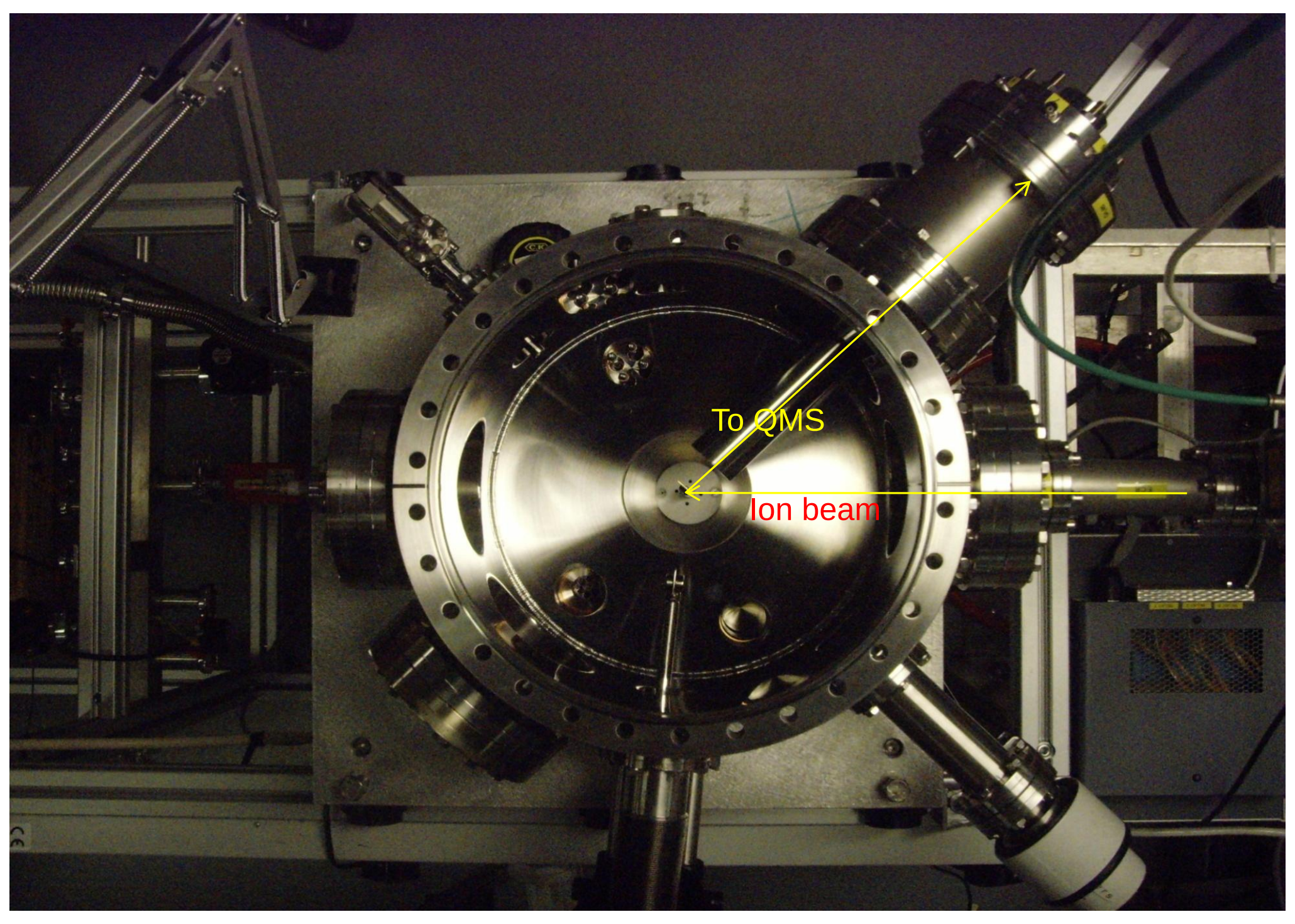
The most dominant ice species through the universe thought to be water ice and it has been well studied in the laboratory. Water ice has been detected in a large number of interstellar sources and a few circumstellar dust shells . Several studies have been carried out on water and other simple molecules in the ice phase. Interstellar laboratory ice analogues by McCoustra from Heriot-Watt University and Helen Fraser from University of Strathclyde, Nigel Mason from Open University, Milton Keynes, Wendy Brown from University College London, and Maria Elisabetta Palumbo from Osservatorio Astrfisico di Catania

## Experiment

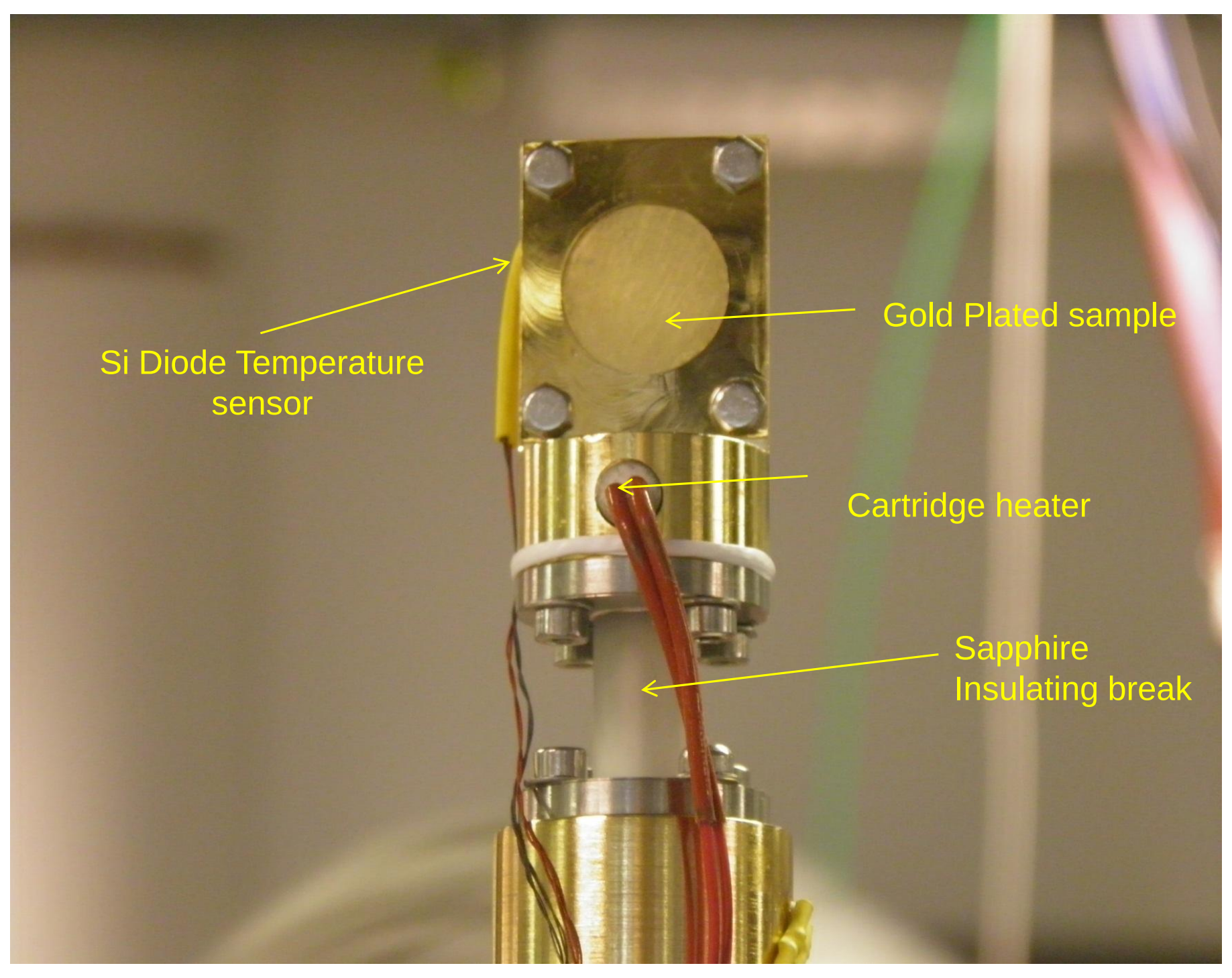
The experiment with ices at QUB will be different from any work done this far because a new experimental apparatus is being developed to investigate interactions of singly and multiply charged ions with analogues of astrophysical ice. The experimental set up consists of an ECR ion source, an ion accelerator, a UHV target chamber and QMS for analysis.



QUB UHV target chamber



view of the UHV target chamber from above



The temperature controlled sample holder on cold-head

## Apparatus

Ions are extracted ions from a ECR ion source. Large numbers of positively charged ions are produced within the plasma as the electrons are accelerated using 10 Ghz microwave radiation giving rise to electron impact ionization within the plasma. In ECR sources, the electrons are confined by a magnetic bottle produced by powerful NdFeB magnets. Extracted ions are focused with electrostatic lenses and pass through a 90 degree bending magnets for mass selection.

The ion accelerator is coupled to the UHV target chamber. The chamber consists of a cold-head with a sample holder where ices are deposited and a quadrupole mass spectrometer (Hiden HAL IV IDP model QMS) is used to register the neutral species formed. This QMS is capable of detecting positive ions, negative ions and neutral molecules. The cold-head is capable of achieving temperatures of ~ 10 K and below.

## Preliminary experiment

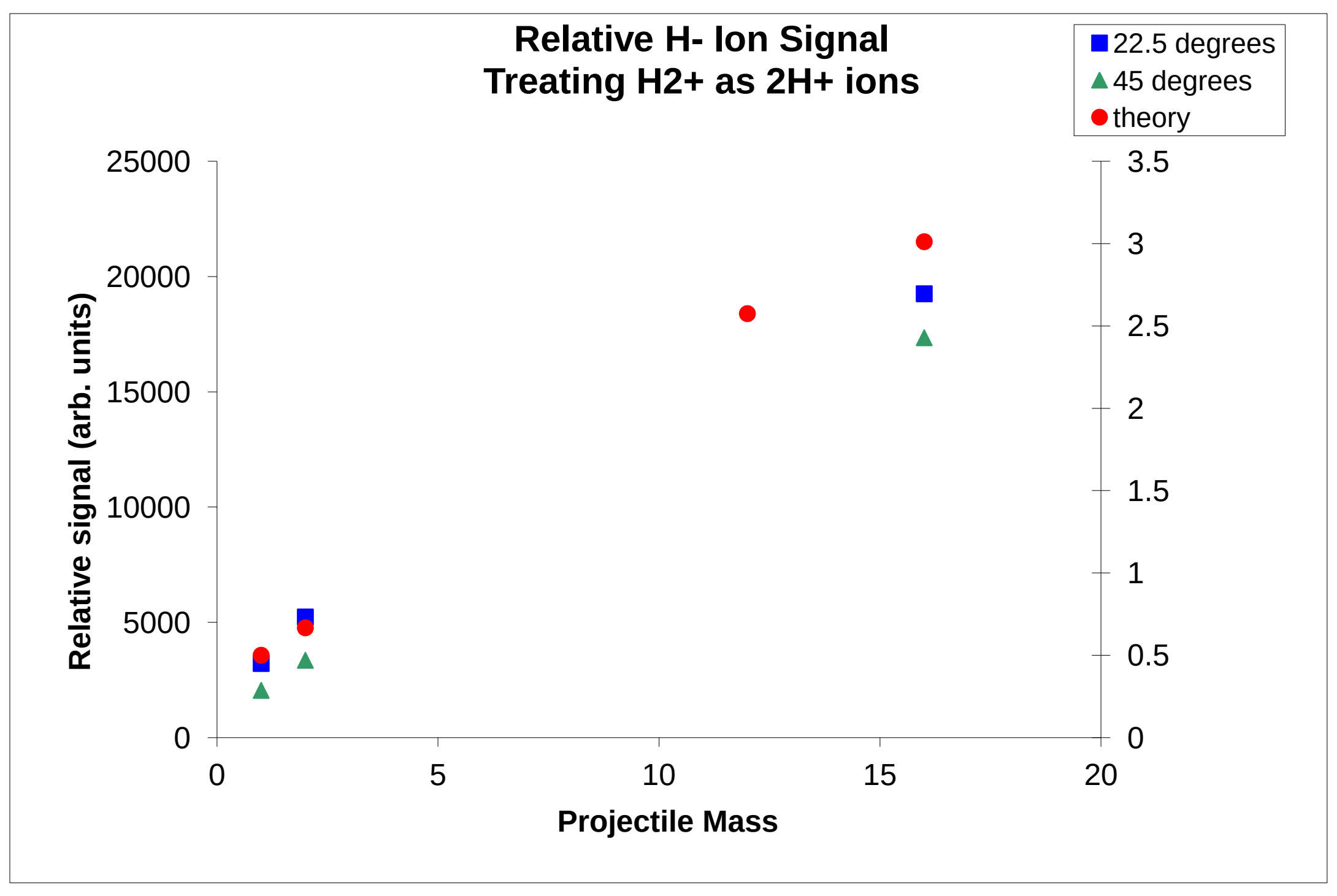
Prior to installation with the cold finger, experiments have been performed to investigate ion irradiation of a titanium surface. In an experiment on low energy dissociative electron attachment of $H_2$ at the Open University unusual $H^-$ signals were observed. It was speculated that at electron energies over the ionization energy of $H_2$ some $H_2^+$ ions were hitting the titanium repeller plate of the mass spectrometer and releasing $H^-$ ions.

Beams of $H_2^+$ , $D_2^+$ , $C^+$ and $O^+$ from a 10 Ghz permanent magnet ECR ion source were directed onto a Ti surface at 22.5 deg and 45 deg with respect to the normal of the target surface. The quadrupole mass spectrometer was positioned with its entrance 30mm the impact point of the ion bean on the target. Negative ions from the suraface were directed into the quadrupole by applying a negative bias of 27V to the target.

The $H^-$ ions observed in this experiment were produced by sputtering, they were not fromed directly from atoms in the primary ion beam. The $H^-$ yield observed is well modelled by a simple theoretical sputtering equation except in the case of the anomalous $C^+$ data. It may be that any $H^-$ formed directly from $H_2^+$ had too much kinetic energy to be detected in the quadruopole mass spectrometer.

$$S = 3.56\alpha \frac{Z_i Z_t}{\left(Z_i^{2/3} + Z_t^{2/3}\right)} \frac{m_i}{(m_i + m_t)} \frac{S_n(E)}{U_o} \frac{1}{cos\Theta}$$

*$H^-$ sputtering yields shown for $H_2^+$, $D_2^+$ and $O^+$. The $C^+$ signal is anomalous, possibly due to errors and a low ion beam current. Only a theoretical data point is shown for $C^+$.*



## Theory

Assuming that $H_2^+$ and $D_2^+$ ions can be treated as two $H^+$ and two $D^+$ ions the expression below for sputtering yield (for projectile ions above 1 keV energy) predicts the theoretical results shown below. The key factors in this equation are the masses of the sputtering ion, $m_i$, and the ejected ion, $m_t$, their atomic numbers, $Z_i$ and $Z_t$, the effective energy of the sputtering ion, $S_n(E)$, which we approximate as the ion energy.

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