New Delhi. The primary objective of this work was to establish a procedure to obtain reliable dates of potsherd and sediment samples from the archaeological sites of Digaru – Kolong River Valley. Samples have been collected from the test pits excavated at Bagibari village (26°11′24.23′′N latitudes and 92°3′33.18′′E longitudes), Marakdola village (26°4′3.52′′N latitudes and 91°53′33.92′′E longitudes), Shankargog village (26°7′12.92′′N latitude and 92°4′40.06′′E longitude) at Kamrup district and Silchang village (26°7′19.12′′N latitude and 92°21′1.90′′E longitude) at Morigaon district of Assam. The study aims to understand the time frame for the past settlement in the Digaru-Kolong river valley. Establishing a precise chronology of these sites will allow to put the artifacts into clear chronological context with respect to the appearance and disappearance of several vital phenomena.

Moreover, accurate site dating will also allow a more precise analysis of the environmental and climatic data available, allowing further reconstruction of Late Pleistocene environments during the Holocene in Northeast India. The pre-treatment of samples was done in the IUAC Graphitization laboratory as per the recommendations of the following paper [1]. This paper recommends the physical pre-treatment as removal of any visible contaminations and chemical pre-treatment using (Acid-Base-Acid) ABA protocol. Samples were measured at IUAC using the AMS facility. The outcome of the analysis is mentioned below.

Table 1: AMS dating of the Potsherd samples

Sl. No.	Sample Name	Sample ID	pMC value	Radiocarbon Age (BP)	Calibrated Age Range	Median Age
1.	BGIc8	IUACD#21C3660	89.823 ± 0.271	862 ± 24	1051 – 1249 C.E.	1186 C.E.
2.	BGIc9	IUACD#21C3661	86.750 ± 0.296	1141 ± 27	777 – 980 C.E.	913 C.E.
3.	MRKc16	IUACD#21C3662	89.050 ± 0.274	931 ± 24	1031 – 1159 C.E.	1098 C.E.
4.	SKGc3	IUACD#21C3663	90.574 ± 0.258	795 ± 22	1213 – 1273 C.E.	1242 C.E.
5.	SLGc6	IUACD#21C3664	94.189 ± 0.294	480 ± 25	1412 – 1449 C.E.	1432 C.E.

Table 2: AMS dating of the Sediment samples

Sl. No.	Sample Name	Sample ID	pMC value	Radiocarbon Age (BP)	Calibrated Age Range	Median Age
1.	BGIs3	IUACD#21C3665	80.306 ± 0.311	1761 ±31	170 – 382 C.E.	286 C.E
2.	BGIs4	IUACD#21C3666	79.868 ± 0.295	1805 ±29	130 – 323 C.E.	209 C.E
3.	SKGs1	IUACD#21C3667	91.735 ± 0.355	693 ±31	1264 – 1388 C.E.	1291 C.E.
4.	SLGs1	IUACD#21C3668	83.418 ± 0.285	1456 ±27	560 – 649 C.E	608 C.E.
5.	MRKs1	IUACD#21C3669	79.909 ± 0.257	1801 ±25	132 – 322 C.E	217 C.E.

The outcome or date of the archaeological records in this study indicates post-Neolithic or late Neolithic cultural patterns in the region. However, the lifestyle and cultural patterns of the contemporary communities are still similar to the Neolithic pattern.

REFERENCES

[1] Sharma, Rajveer, G.R. Umapathy, Pankaj Kumar, Sunil Ojha, Satinth Gargari, Rajan Joshi, Sundeep Chopra, Dinkar Kanjilal. 2018. 'AMS and upcoming geochronology facility at Inter University Accelerator Centre (IUAC), New Delhi, India.' Nuclear Inst. and Methods in Physics Research B. **438**. 124-130

5.5 ATOMIC AND MOLECULAR PHYSICS

5.5.1 X-ray energy shift and multiple ionisation in Bi due to 2-5 MeV Xe-ion impact.

C V Ahmad[1,2], R Gupta[1,2], K Chakraborty[1,2], D K Swami[3] and P Verma[2]

[1]Department of Physics, Kalindi College, East Patel Nagar, University of Delhi, New Delhi-110008.

[2]Department of Physics and Astrophysics, University of Delhi, New Delhi-110007.

[3]Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi-110067.

The M X-Ray production cross-sections measured during heavy ion-atom collisions get enhanced due to multiple vacancies in higher shells, called as spectator vacancies. The increased number of spectator vacancies leads to less screening of the nuclear charge which results in increase of the binding energies of all energy levels [1-2].

Experimental observation of shift in the energies of the M-shell X-rays is a direct signature of multiple ionization in the M and higher shells [3].

The 75^0 beam line of Low Energy Ion beam facility (LEIBF) with its 10 GHz ion source was used to bombard low energy projectiles viz. 2-5 MeV Xe^{q+} ($10 \leq q \leq 14$) on Bi targets. Different target of Bi (thicknesses 120, 293 and, 431g/cm^2) were prepared in the target lab at IUAC [4]. These targets were mounted at the center of the vacuum chamber on a target ladder rotated at 45° with respect to the forward beam direction. The emitted X-rays were recorded by two silicon drift X-ray detectors (KETEK AXAS-A) mounted at 45° and 90° with respect to the incoming beam. The efficiency of these detectors was measured via bombarding thin film targets of Al and Ni by 350 keV H^+ ion along with calibrated radioactive of ^{55}Fe and ^{241}Am. The ion beam current was monitored through the combination of a collimator setup and a Faraday cup. The collimator setup is placed just before the target ladder at beam entrance port of the chamber, whereas the Faraday cup was placed 0^o with respect to the incoming beam behind the target ladder at the beam exit port of the chamber.

The scaled spectra of Bi (431g/cm^2) obtained due to impact of Xe-ion of energies 2-5 MeV is shown in **Figure 1**. The vertical lines on the energy axis are the theoretical standard X-ray energy lines of Bi [5]. Further analysis to implore the observed energy-shifts, intensity ratios and production cross-sections for this collision system is in progress and will be submitted for publication shortly.

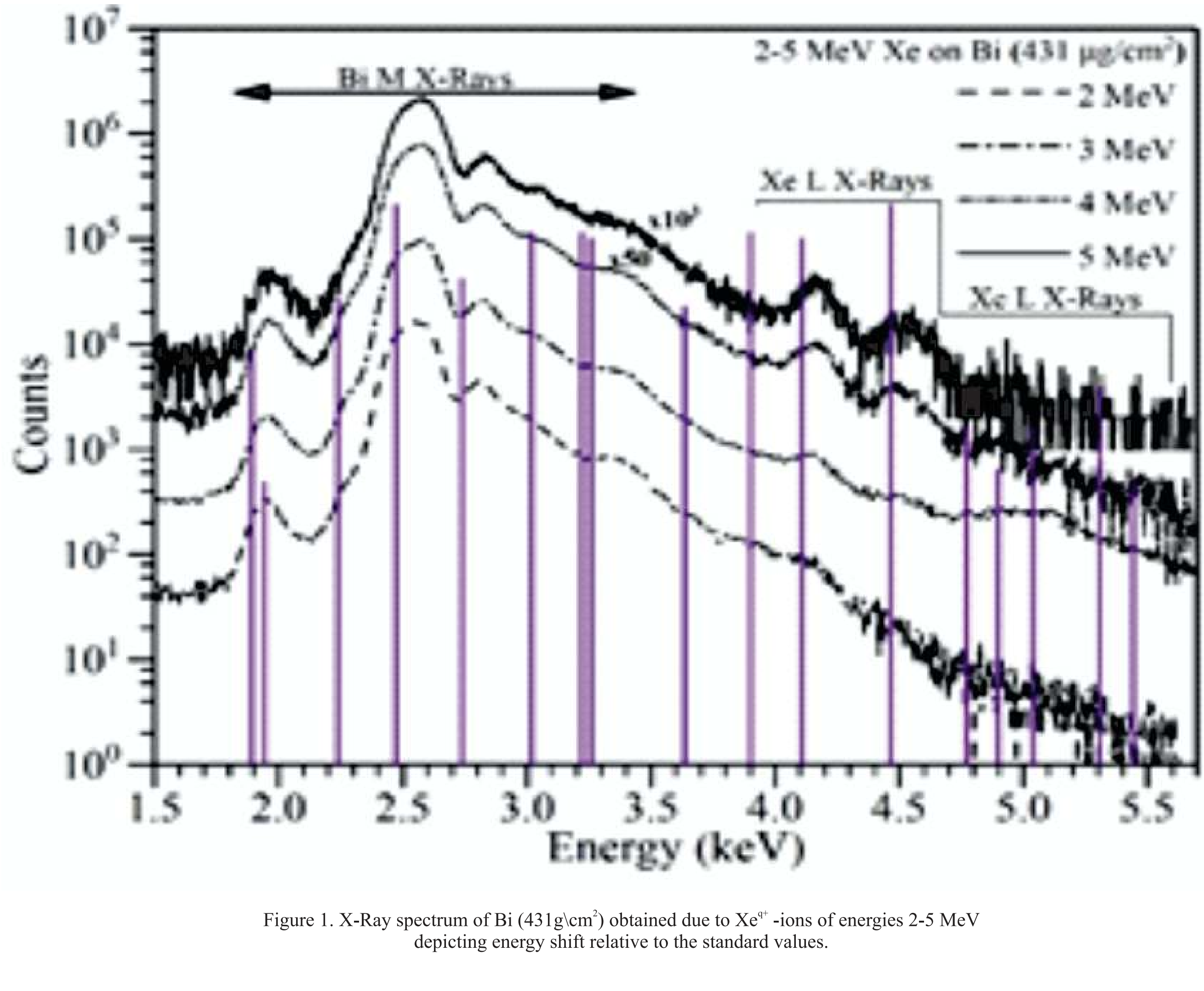

Figure 1. X-Ray spectrum of Bi (431g\cm^2) obtained due to Xe^{q+} -ions of energies 2-5 MeV depicting energy shift relative to the standard values.

REFERENCES:

[1] M. Czarnota *et al.* Phys. Rev. A **79,** 3, 032710 (1–14)(2009).

[2] P. Verma, *et al.*. J. Phys. Conf. Ser. **875(10), 092029,** 2011 *Phys. Scr.*, **T144**, **014032**. (2017)

[3] J. S. Braich *et al.* J. Phys. B: At. Mol. Opt. Phys. ***30,* 2359–2373** (1997).

[4] C. V. Ahmad *et al.*, Advanced Functional Materials and Devices. Springer, Singapore, 163-170(2022).

[5] J. A. Bearden *et al.*, Reviews of Modern Phys. **39(1),** 78(1967).

5.5.2 Exploring the influence of target atomic number (Z_2) on equilibrium mean charge state (q)

D.K. Swami[1] and R. K. Karn[2]

[1]Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi-110067, India.
[2]Kolhan University, Chaibasa, Jharkhand.

Charge changing processes of projectile ions with media particles, occurring in their penetration through gaseous, solid, and plasma targets, are of interest for solving fundamental problems in atomic and nuclear physics, plasma and accelerator physics, as well as for mastering many new applications [1-3]. The process is very complex due to a variety of physical phenomena including ionization, excitation, radiative decay, Auger decay, electron decay, radiative and non-radiative electron capture, etc. [4-6]. Several empirical formulae are proposed in order to replicate the value of mean charge states, such as Thomas-Fermi Model, Bohr Model, Betz Model, Nikolaev- Dmitriev Model, To-Drouin Model, Shima-Ishihara-Mikumo Model (S-I-M), Itoh Model, Schiwietz-Grande model (G-F-M), Ziegler-Biersack-Littmark Model (Z-B-L), Schiwietz Model, Fermi-gas-model (F-G-M) [7] have been developed based on the experimental results from electromagnetic measurements. Some of these models (Shima-Ishihara-Mikumo Model, Ziegler-Biersack-Littmark Model, Schiwietz Model, Schiwietz-Grande model, Fermi-gas-model) show a dependence of mean charge state on target materials and some models (Thomas-Fermi Model, Bohr Model, Betz Model, Nikolaev- Dmitriev Model, To-Drouin Model, Itoh Model) show no dependence of mean charge state on target materials. At present, there are a few computer programs ETACHA, GLOBAL, CHARGE, and BREIT for calculating the evolution of charge-state fractions as a function of the target thickness, when the ion beam passes through gaseous and solid media. Recently, a new version of the ETACHA program, called ETACHA4, has been developed [8], where the scope of the programme has been expanded to lower energies 0.05-30 MeV/u and also to heavier ions possessing up to 60 electrons.

In the present work, we have compared the empirical, semi empirical and theoretical (ETACHA4) model predictions for Z_2dependence of the equilibrium mean charge state (*q*) with experimental results[9].

It is clearly pointed out that experimental mean charge states [9] are not monotonically decreasing with the increase of target atomic number (Z_2), an oscillatory behaviour is observed in fig.1. The amplitude of the oscillation decreases with increase in projectile energy. The empirical formulae Z-B-L, G-F-M and Schiwietz model shows very weak dependence of mean charge state on Z_2 i.e. mean charge state of projectile ion does not change much due to increasing Z_2, there is not even a difference of 1 in (*q)* and also show monotonically decreasing with the increase Z_2. The S-I-M shows strong dependence of *q* on Z_2, but *q* monotonically increasing (not oscillatory behaviour) with Z_2. However, F-G-M shows oscillatory behaviour of *q* with Z_2, but in this model, *q* increases (not monotonically) with the increase of (Z_2) (opposite behaviour to experimental *q*) and F-G-M *q* overestimates experimental *q*. The difference between experimental *q* and F-G-M *q* is as much as 2-3. Theoretically, ETACHA4 does not show oscillatory behaviour of *q* with Z_2 and for intermediate Z_2, ETACHA4 *q* underestimates experimental *q* and the difference between experimental *q* and ETACHA4 *q* is as much as 4-5. Consequently, F-G-M or ETACHA4 may be used to estimate *q* inside the target. However, ETACHA4 can be used for a certain number of electrons in the projectile ion and thus difficulties arise in implementing it for heavier projectiles, whereas with F-G-M there is no such restrictions. Since, F-G-M *q* overestimates experimental *q* due to charge exchanging process at target exit surface i.e. electron capture from target exit surface to projectile ion. On the other hand, F-G-M shows oscillatory behaviour of *q* with Z2. Such agreement shows that F-G-M estimates *q* correctly inside the target and fermi velocity of target electrons and charge changing processes at exit surface of targets play important role.

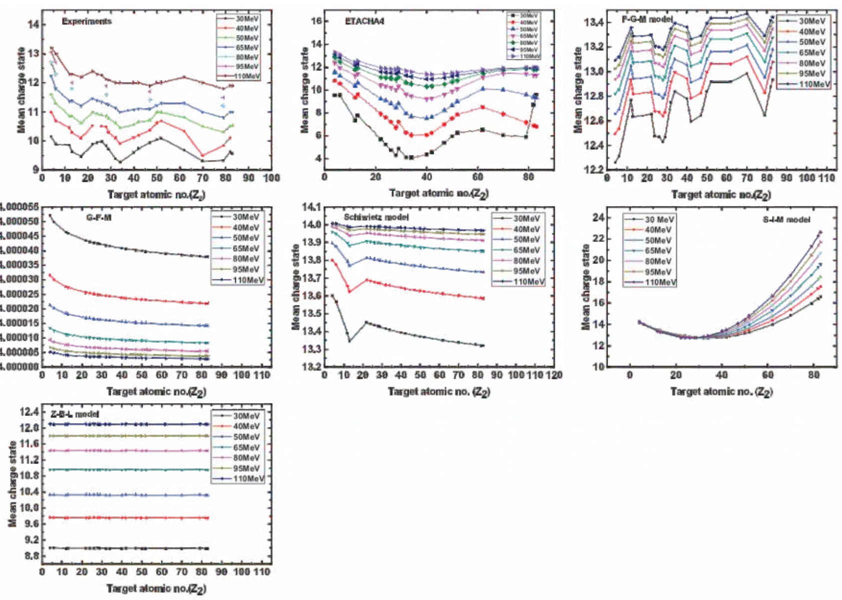

Fig.1. Comparison of experimental mean charge state[9] for various targets bombarded by ^{28}Si ions as a function of target atomic number with the emperical, semi-emperical[7] and ETACHA4[8] calculations.

REFERENCES:

[1] Betz H-D Rev. Mod. Phys. **44,** 465 (1972).
[2] Amaldi U. Kraft G Europhys, News **36,** 114 (2005).
[3] AQhlen S P Rev. Mod. Phys. **52,** 121 (1980).
[4] Allison *et al* Rev Mod Phys **25,** 779 (1953).
[5] Shima K. *et al* At. Data and Nucl. Data Tables **34,** 357(1986).
[6] Shima K. *et al* At. Data and Nucl. Data Tables **51,** 173 (1992).
[7] D.K. Swami *et al* Radi. Phys. And Chem. **153,** 120(2018).
[8] Lamour E. *et al* Phys. Rev. A **92,** 42703 (2015).
[9] Ishihara T. *et al* Nucl Inst. And Meth **204,** 235 (1982).

5.5.3 Significance of the high charge state of projectile ions inside the target and its role in electron capture leading to target-ionization phenomena

Soumya Chatterjee[1], Prashant Sharma[2], Shashank Singh[3], Mumtaz Oswal[4], Sunil Kumar[5], C. C. Montanari[6], **D. Mitra[1]**, and T. Nandi[7]

[1]*Department of Physics, University of Kalyani, Kalyani, Nadia 741235, West Bengal, India*
[2]*Department of Particle and Astrophysics, Weizmann Institute of Science, Rehovot 76100, Israel*
[3]*Department of Physics, Panjab University, Chandigarh 160014, India*
[4]*Department of Physics, Dev Samaj College for Women, Sector 45 B, Chandigarh 160014, India*
[5]*Govt. Degree College, Banjar, Kullu, Himachal Pradesh 175123, India*
[6]*Instituto de Astronomía y Física del Espacio, CONICET and Universidad de Buenos Aires, Buenos Aires, Argentina*
[7]*Inter-University Accelerator Centre, Aruna Asaf Ali Marg, Near Vasant Kunj, New Delhi 110067, India*

The K shell ionization of different targets (Cu, Zn, and Ge) induced by 3 to 5 MeV/u Si projectile ions have been studied using the *Pelletron accelerator facility at IUAC*. We observed that the measured ionization cross-sections differ at least a factor of two from the theoretical direct ionization cross-sections. This underestimation is attributed to the charge-exchange from target K-shell to projectile K- and L-shells. Ionization due to the electron capture from the target K-shell to the K- and L-shell of the projectile ions have been considered to resolve this difference. Such observation can only be possible if the projectile ions attain up to H- and He-like charge states. In this regard, projectile charge state inside the target is extremely essential. Corresponding projectile charge state fractions are evaluated from the Lorentzian charge state distribution, where mean charge state is calculated using Fermi gas model [1] and width from the Novikov and Teplova approach [2]. The bare and H-like projectile ions inside the targets have been utilized to calculate the K-K capture contribution using the prescription by Lapicki and Losonsky [3]. Considering the contribution of ionization due to the K-K + K-L electron capture along with the direct coulomb ionization, theoretical predictions matched well with the measured cross-sections. Furthermore, we have validated this methodology with available data for Si ion on Ti target. Such results may be useful in many solid target-based applications. The work has been published in **PHYSICAL REVIEW A 104, 022810 (2021)**

REFERENCES:

[1] Werner Brandt, Roman Laubert, Manuel Mourinot and Arthur Schwarzschild, Phys. Rev. Lett. **30**, 358(1973)
[2] N.V. Novikov, Ya. A. Teplova Phys. Lett. A **378**, 1286(2014)
[3] Grzegorz Lapicki and William Losonsky, Phys. Rev. A **15**, 896(1977)
[4] M. Msimanga, C. Pineda-Vargas, and M. Madhuku, Nucl. Instrum. Methods Phys. Res., Sect. B **380**, 90 (2016).

5.5.4 Experimental observation of sequential pathway in three body breakup of acetylene

Jatin Yadav[1,a], C.P. Safvan[2], Pragya Bhatt[2], Pooja Kumari[1], Aditya Kumar[2], Jyoti Rajput[1,b]

[1]*Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India*
[2]*Inter-University Accelerator Center, Aruna Asaf Ali Marg, New Delhi 110067, India*
[a]*jatinyadav222@gmail.com*, [b]*jrajput.du@gmail.com*

The three body fragmentation of a molecular ion can takes place through two mechanisms. One is concerted which is a single step process and other mechanism is sequential which takes place in two or more steps. These two mechanisms are illustrated below for the three body breakup of triply charged acetylene :

Concerted mechanism: $[C_2H_2]^{3+} \rightarrow H^+ + C^+ + CH^+$ (1)

Sequential mechanism: **Step 1 :** $[C_2H_2]^{3+} \rightarrow H^+ + [C_2H]^{2+}$ (2)

Step 2 : $[C_2H]^{2+} \rightarrow C^+ + CH^+$ (3)

The final detected set of fragment ions are same in both the fragmentation mechanisms, so it becomes difficult to separate the events arising from two different mechanisms. To address this issue, the three-body coincident data on the dissociation channel $[C_2H_2]^{3+} \rightarrow H^+ + C^+ + CH^+$ is analysed using the method of native frames [1, 2] to check for the possibility of sequential breakup having the two steps shown in equations 2 and 3. In this method, the first step of the breakup is analysed in the centre-of-mass frame of $[C_2H_2]^{3+}$ and the second step is analysed in the centre-of-mass frame of $[C_2H]^{2+}$(figure 1(A)) . The KER (kinetic energy release, which is the sum of kinetic energy of the fragments) distribution for the first step and the second step is determined independently and the angular correlation between the fragments generated in the two steps is established. The result of this analysis is shown in figure 1(B) which is a distribution of KER associated with the second step of the sequential breakup, referred as KER_2 , and the angle (θ) between the direction of the first two-body breakup and second breakup in their respective centre-of-mass frames. For an intermediate molecular ion formed in the first step, $[C_2H]^{2+}$, if the lifetime of the populated electronic state is much larger than its rotational period, the angular correlation between the two steps is lost. Thus we expect to get a uniform distribution parallel to the θ-axis. As seen in figure 1(B), the uniform vertical distribution is evidence of such a long lived state of $[C_2H]^{2+}$ and indicates the presence of a sequential breakup [3].

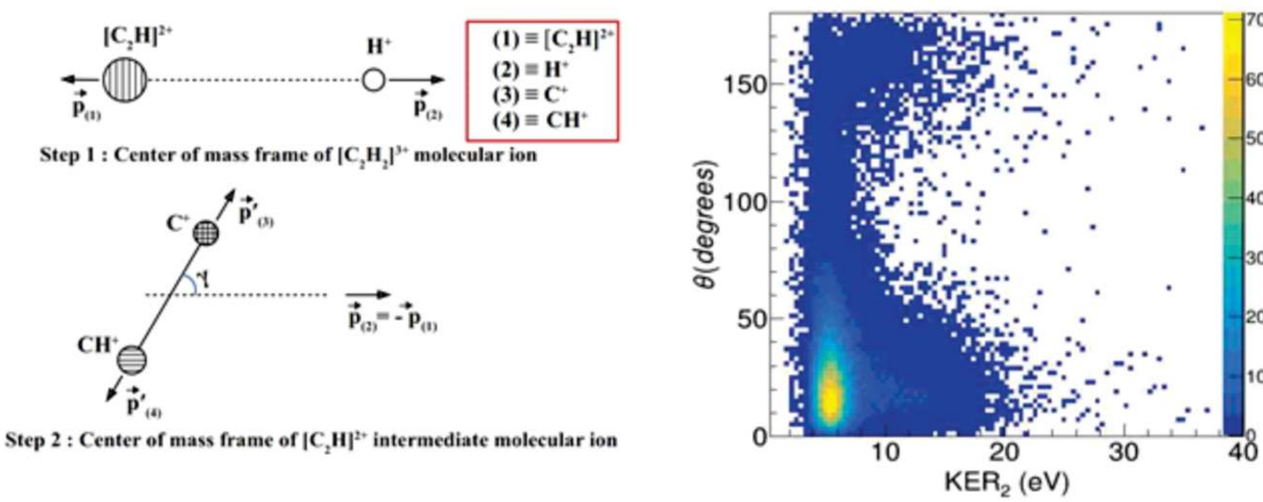

Figure : (A) A schematic of the *native frames approach* for the sequential breakup of $[C_2H_2]^{3+}$ via $[C_2H]^{2+}$. The unprimed and primed vectors represent centre-of-mass frame of $[C_2H_2]^{3+}$ and $[C_2H]^{2+}$ respectively. (B) A distribution of θ - KER_2 assuming sequential breakup via $[C_2H]^{2+}$. (See text for more details)

REFERENCES:

[1] J. Rajput *et. al.* Phys. Rev. Lett. **120**, 103001(2018).

[2] Herendra Kumar *et. al.* J. Chem. Phys. **148**, 064302(2018).

[3] Jatin Yadav *et. al.* J. Chem. Phys. (accepted for publication)