ION ACCELERATION FROM ULTRA THIN FOILS ON THE ASTRA GEMINI FACILITY

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OUTLINE

I Motivations

II Experimental Setup

III Experimental results and simulations

IV Summary
MOTIVATION

Understanding laser-driven ion acceleration mechanisms: i.e. TNSA, RPA (light sail, hole boring), BOA.

Ion Acceleration Applications:
- proton radiography (Cobble, 2002, J. Appl. Phys. 92, 1775.)
- production of warm dense matter (Koenig, 2005, Plasma Phys. Controlled Fusion 47, B441.)
- nuclear and particle physics (McKenna, P., et al., 2003a, Appl. Phys. Lett. 83, 2763.)

Investigation of biological response to high dose rate ion radiation

“Investigation and optimisation of emerging ion acceleration schemes, with a focus on processes based on the radiation pressure of an intense laser pulse, namely Light Sail, Hole Boring and shock acceleration; and assessment of the radiobiological effects of ultrafast ion energy deposition.”

PI: M. Borghesi, Queen’s University Belfast
**LASER DRIVEN-ION ACCELERATION**

**Target Normal Sheath Acceleration (TNSA)**

- Intensities above \(10^{19} \text{ W/cm}^2\)
- Electron acceleration to MeV energies
- Ponderomotive electron heating \(T_{\text{hot}} \sim (I\lambda^2)^{0.5}\)

Relatively thin foils allow electrons to reach the rear of the target and establish electrostatic sheath that generates a field \((10^{12} \text{ V/m})\) able to accelerate protons from contaminants.

**Radiation Pressure Acceleration (RPA)**

- Ions can be accelerated from target bulk by stronger field \((\sim 10^{14} \text{ V/m})\)
- Narrow band spectrum (whole foil acceleration)

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**USING CIRCULAR LASER POLARISATION:**

- No JxB acceleration
- No TNSA
- No target heating
- Quasi-static pressure drive
**EXPERIMENTAL SETUP**

**RUTHERFORD APPLETON LABORATORY**

**ASTRA GEMINI FACILITY**

### Set Up

- **Double Plasma Mirror**
- **WavePlate**
- **Off-axis Parabola**
- **Focusing Off-axis Parabola**
- **Collimating Off-axis Parabola**
- **Off-axis Parabola f/2**
- **Target**
- **λ/2 WavePlate**
- **λ/4 WavePlate**

### Thomson Parabola Spectrometer

- **Laser**
- **Target**
- **Magnet Dipole**
- **Electric Plates**
- **Detector**
- **Pinhole (~0.8 Tesla)**
- **~10kV**

### Stack of Radiochromic Film / CR-39

- **Laser**
- **Target**
- **RCF / CR-39 Stack**

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**GEMINI Laser**

- Pulse length ~ 40 fs
- Energy < 15 J
- Intensity ~ \(10^{21}-10^{22}\) W/cm²

**Experimental Conditions**

- Pulse length ~ 40-45 fs
- Energy ~ 13 J  \(\Rightarrow\) ~ 6.5 J on target
- PM ~ 50% and \(10^{12}\) contrast
- Intensity = \(2.7\times10^{20} \pm 25\%\) W/cm²
EXPERIMENTAL RESULTS: $C^{6+}$ ION SPECTRA

**LINEAR**

\[ dN/dE/d\theta \]

Ion Energy (MeV/u)

- 10nm
- 25nm
- 50nm
- 100nm

**CIRCULAR**

\[ dN/dE/d\theta \]

Ion Energy (MeV/u)

- 10nm
- 25nm
- 50nm
- 100nm

RAW DATA FROM IP

10nm Linear 10nm Circular

Increasing Energy

Zero point

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EAAC September 2015
EXPERIMENTAL RESULTS: PROTON SPECTRA

**LINEAR**

- Blue line: 10nm
- Red line: 25nm
- Green line: 50nm
- Purple line: 100nm

**CIRCULAR**

- Blue line: 10nm
- Red line: 25nm
- Green line: 50nm
- Purple line: 100nm

**RAW DATA FROM IP**

10nm Linear 10nm Circular

- Increasing Energy

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EAAC September 2015
• Very significant energies for CP at 10nm targets (35 MeV for protons and ~300 MeV for C$^{6+}$)
• Energies for CP higher for the thinnest targets: possibly RPA Light Sail dominates?
• 3D PIC simulations (A. Macchi, A. Sgattoni - Pisa University) reproduce the difference between CP and LP data with very good agreement
• 2D PIC simulations – good agreement with experiment
• LP irradiation leads to electron heating, target disassembly and transparency below 20nm C. CP pulses allow 20nm targets to stay opaque and to be driven by radiation pressure (A. Macchi, A. Sgattoni – Pisa University)
EXPERIMENT AND 3D SIMULATION – BEAM PROFILE

CARBON ION PROFILE USING CR-39

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<thead>
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<th>E&gt;10 MeV/u</th>
<th>CR-39</th>
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<td>CP</td>
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PROTON PROFILE USING RADIOCHROMATIC FILM

HDV2 LAYER 1 (10MeV)

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EBT2 LAYER 4 (20MeV)

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RCF/CR-39 STACK

6μm Al
500μm CR39
16 x HDV2
25 x EBT2

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CIRCULAR POLARISATION — BEAM STRUCTURE

Structured larger divergence beam; unstabilised radiation pressure drive

"Rayleigh Taylor" like instability

(a) Ion density distribution in the x-y plane


Snapshot at t = 30T showing the densities of Carbon ions (blue tones) and of protons (green tones).

A. Sgattoni et al., PRE 91, 013106 (2015)
Similar trends for Thomson Parabola Spectrometers at 4° and -9°
- Lower energies compared to preliminary experiment
- Shot to shot variation – unstable regime; target, laser, interaction is hard to reproduce
SUMMARY

We see higher energy proton and carbon ions for circular polarisation laser pulses compared to linear polarisation when using thin targets (<20nm).

3D simulations reproduce the cut-off energies for proton and carbon ions. 2D simulations generally underestimate the ion maximum energies, but the trend is well reproduced.

3D simulations also reproduce the beam profiles.
THANK YOU FOR YOUR ATTENTION