Enhanced ion acceleration using high contrast laser pulses on the Astra laser system.

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Outline

• Astra and Astra Gemini
• Laser pulse contrast diagnostic
• Astra TA2 Experiment Results
• Ultra-fast ion diagnostics
• Astra LIBRA Experiment
The Astra Laser – TA2

Wavelength: 800nm
Energy: 0.7J
Pulse length: 40 fs
Power: 15 TW
Intensity: $5 \times 10^{19}$ W/cm²

Contrast: $10^6$-$10^8$
Astra Gemini – TA3

Services area

Laser Area 3

Single beam
15 Joulles
beam
50fs pulses
1 shot /min
$10^{10}$ to $10^{13}$
variable contrast
Real laser pulses

Thin target foil will ablate, expand and deform before main pulse hits it = failure
Plasma mirror switching

Effect of laser contrast

275 mJ @ $10^{10}$ contrast using plasma mirror

Mora fit (130 fs acc time)

275 mJ @ $5 \times 10^7$

225 mJ @ $10^6$

McKenna 2002

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Target normal view of ion beam
Experimental Geometry

- Plasma mirror
- Equivalent focal plane monitor
- Ion spectrometer (back 0°)
- Ion spectrometer (back 8°)
- Ion spectrometer (laser forward)
- Optical transition radiation
- Ion spectrometer (front 0°)
- Reflected energy calorimeter and imaging KeV X-ray camera
- Beam "footprint" and optical gated imager
- Target Equivalent focal plane monitor
- Plasma mirror
- Footprint imager
- 0°, 8°
- Scintillator
- Filter
- Electron Spectrometer
- B = 1KG, 0.02-2 MeV

Science & Technology Facilities Council
High-repetition rate Ion spectrometer

BC422Q calibration

Counts per MeV

Proton Energy (MeV)

0 0.2 0.4 0.6 0.8

0 5 10 15 20 25 30

Imaging lens and laser rejection filter onto EMCCD camera

Protons from main slit

Protons from 2nd pinhole

Carbon ions

Flash Al overcoated scintillator

E-field plates wedged to give enhanced dispersion for applied voltage ~ 2.5KV

B-field magnets

Thin foil target

Laser Beam 0.3 J 40 fs

Dual entrance slit 1000:1 throughput

Absoulte in situ cross calibration

Scintillator

CR39

Ions

Paper in preparation

$y_p \propto \frac{ZB}{\sqrt{mK}} \quad y_e \propto \frac{ZE}{K}$

$\frac{m}{dt^2} = ZeE + Zev \times B$
Optimum focus set-up?

\[ E_{\text{max}} = 2ZT_{\text{hot}} \left[ \log(\omega_p \tau_{\text{ef}}) + \sqrt{1 + (\omega_p \tau_{\text{ef}})^2} \right]^2 \]

Good fit for spot focus work

Target Rear 0° – Defocus Scan - Al 6μm

2 MeV
Best focus
-50μm
-100μm
-150μm
-200μm
-250μm
-300μm
-350μm

0.2 MeV

(160507)
Defocus scan – Al 6 μm

Spectrometer shows peak emission at defocus

Footprint shows peak emission at highest intensity

Thermal distribution
Defocus – Al 50 nm

Order of magnitude greater flux

Integrated spectra on-axis (a.u.)

Integrated footprint signal (a.u.)

Defocus (microns)

Spot size (microns)
Target Rear – Defocus Scan thin foil

Note – reproducible non thermal ion emission

Axial Spectra

Beam footprint

Best focus

Axial emission strongest when defocused

Beam strongest when focused

Al 50nm, 35fs @ 10^{10} contrast

Significant difference between beam and axial emission

-ve moves target towards parabola
Low contrast 50 nm targets?

Target normal rear spectrometer

Off normal rear spectrometer

Target normal front spectrometer
Specular reflectivity in TA2

![Graph showing specular reflectivity versus intensity (Wcm-2) with two categories: No plasma mirrors (blue diamonds) and Plasma mirrors (red squares). The x-axis represents intensity (Wcm-2), and the y-axis represents specular reflectivity. The plot includes error bars indicating variability.](image-url)
Gemini Plasma Mirror System

Requirements of the system:

• Occupies minimum volume in the interaction chamber

• Enables ready use of 0, 1 or 2 plasma mirrors as required while retaining all diagnostic alignment

• Fully motorised for use under vacuum

• Takes maximum number of shots between optic changes and allows quick and easy optic changes
Gemini Plasma Mirror System

Double/single plasma mirror set-up:

By-pass set-up:
Gemini Plasma Mirror System

- 60 Shots per plasma mirror change
- This can be increased to 100 with the current system.
Gemini Plasma Mirror System

• Double plasma mirror set-up gives 48% energy throughput: about 69% from each plasma mirror

• Installed near and far field cameras to monitor the beam quality out of the system

• Consistent quality far field images indicate good focusability
• Scaling laws at higher intensity regime.

• New acceleration mechanisms predicted • Ultra high contrast – 10

For preliminary results, see Marco Borghesi's Talk on Tuesday
Footprint monitor

- 2 scintillators emitting at 2 wavelengths are used in pairs
- Upto 6 energy bins with flexible configuration

- Signal is split at the CCD camera so that 2 proton energies can be measured using one optical line

Target

Scintillator pair

Reflective pellicle

Debris pellicle

Stack 1 light output

Stack 2 light output

Stack 3 light output

Gated CCDs
Open view

Proton source
Low contrast data

20um Al 13.0J
+50um Focus
5-8 MeV energy bin
20° FWHM

20um Al – 11.4J
Tight focus
5-8 MeV energy bin
15° FWHM
High contrast data

500nm Al 12.1J
Tight focus
5-8 MeV energy bin
7° FWHM

50nm Al – 12.3J
Tight focus
5-8 MeV energy bin
6° FWHM
RCF comparison

- 10μm Au
- 13.0 J
- 15° FWHM

- 10μm Au
- 13.5 J
- 17° FWHM
Summary

• Low intensity “cold-electron” drive
  • Defocus may offer beam manipulation options- (low X-rays)
  • Option to recover flux for low contrast systems.
  • Non-thermal distribution observed. Simulations and Analysis ongoing

• High contrast enables thin “ideal” targets
  • Specular reflectivity monitors contrast online
  • Observed reflectivity drop off with preserved reflected quality

• LIBRA Gemini Experiment
  • Development of new flexible high-repetition systems: target insertion, plasma mirrors, ion spectrometers.
  • Extended the study to $10^{21}$ W/cm2 on Astra Gemini
    - See Marco Borghesi’s Talk for more details.