Feasibility of an Imaging Motional Stark Effect Diagnostic for Edge Current Measurements on MAST-U

S. Gibson[1], A. Thorman[2], C. A. Michael[3], M. Carr[2], N. C. Hawkes[2], J. Howard[4] and R. M. Sharples[1]
sam.gibson@durham.ac.uk
1. Centre for Advanced Instrumentation, Department of Physics, Durham University, DH1 3LE
2. Culham Science Centre, Abingdon, Oxfordshire, OX14 3EB
3. University of California Los Angeles, Westwood, Los Angeles
4. Plasma Research Laboratory, Australian National University, Canberra, Australia

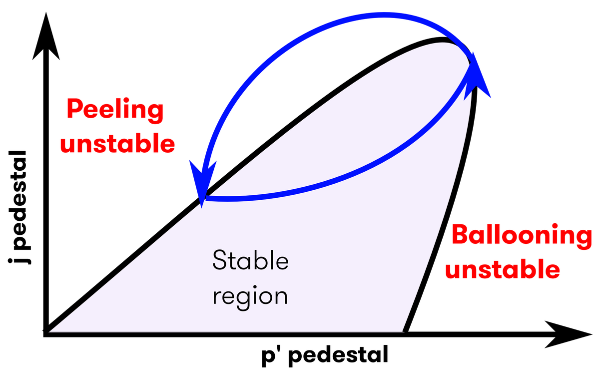
Durham University

An Imaging Motional Stark Effect (IMSE) diagnostic has been designed for MAST-U. Synthetic diagnostic images were forward modelled including realistic spectral broadening effects. The diagnostic would be capable of recovering edge current features with a width on the order of ~2cm. At a temporal resolution of 1ms, the polarisation angle profile can be measured with an uncertainty of σ=0.5°.

Motivation

Local measurement of the edge current density is necessary for:
- **Verification of neoclassical current models**
- **Improved Edge Localised Mode (ELM) stability analysis**

MSE diagnostics[1] measure magnetic pitch angle and constrain plasma equilibrium for safety factor q and current profiles[2].

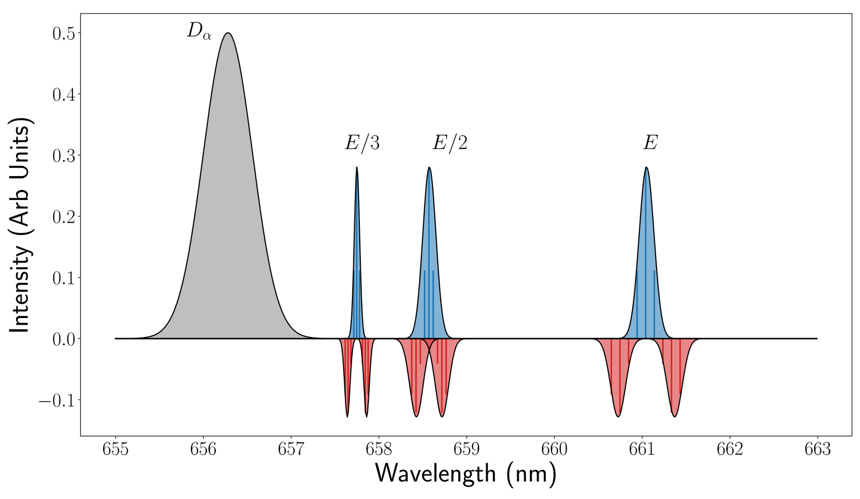


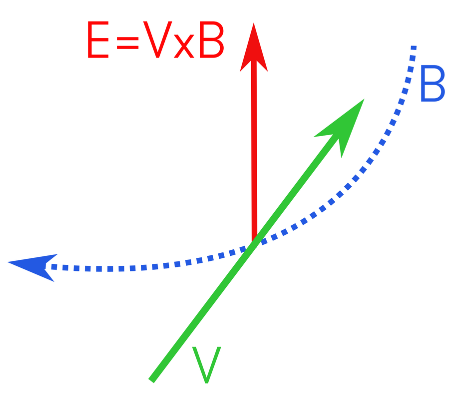
Understanding ELM stability requires accurate knowledge of both the pedestal pressure gradient and the edge current density.

Is it possible to measure edge currents accurately using MSE?

Motional Stark Effect

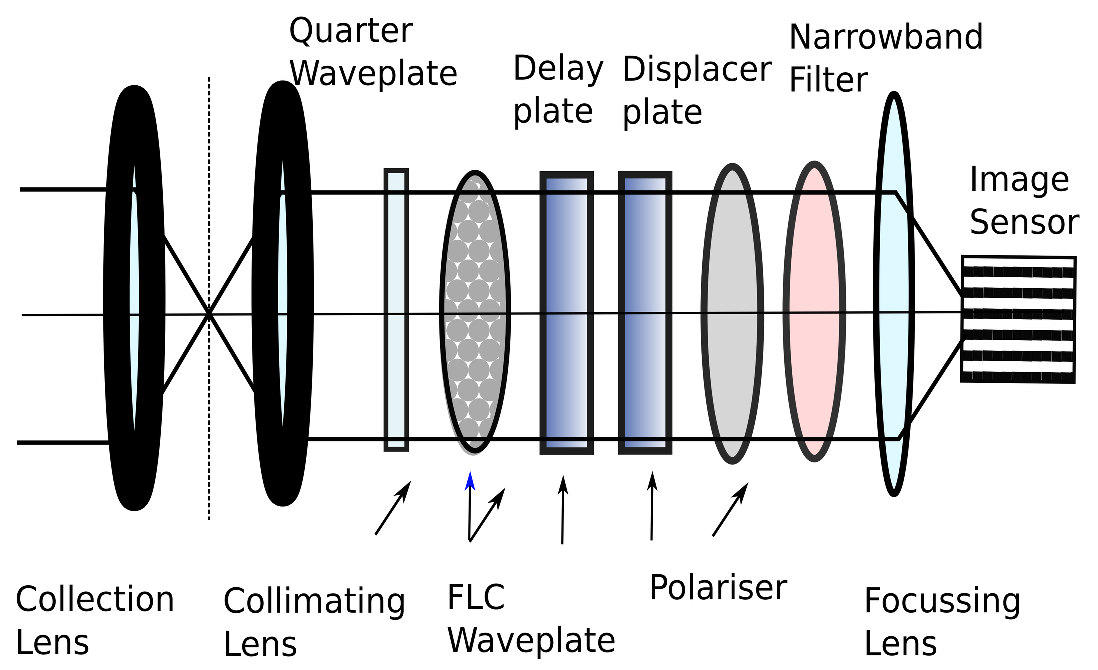
Neutral beam atoms move across B field, inducing E = V x B field. Doppler shifted emission is polarised with respect to E direction.





The IMSE Diagnostic

The IMSE diagnostic[3] is a **polarisation interferometer**, which captures **2D snapshot images** of neutral beam emission.



Polarisation information is **spatially encoded as an interferogram** in the image using birefringent waveplates.

Obtain 2D profiles (γ, Bz, jφ) ~200×200 measurements
Measures emission from entire MSE multiplet

Spectral Broadening

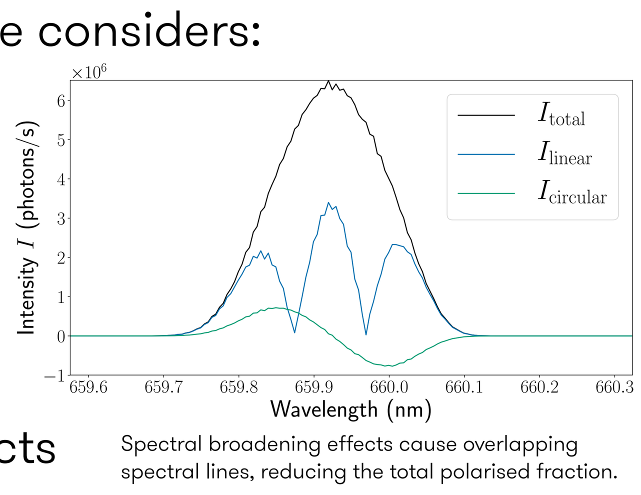
To what extent do spectral broadening effects impact the achievable resolution of edge current features?

MSESIM[4] forward modelling code considers:

Doppler Broadening
- NBI velocity, divergence, width

Geometric Broadening
- Collection solid angle, observation volume

Spherical tokamak challenges
- Low B field, field curvature effects

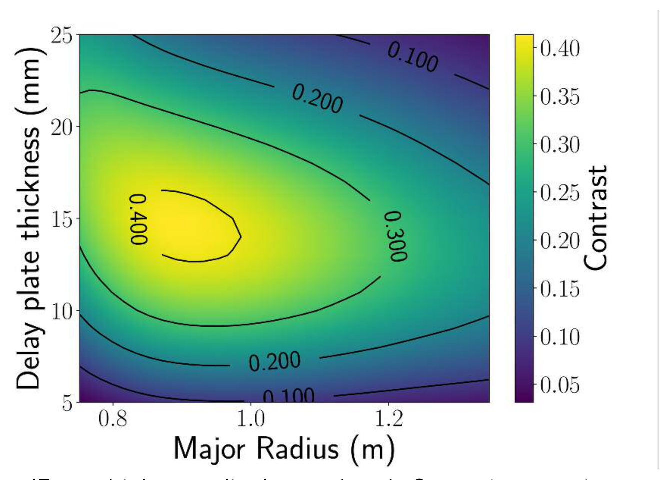


Spectral broadening effects cause overlapping spectral lines, reducing the total polarised fraction.

Diagnostic Design

Waveplates

Choose L to maximse fringe contrast.



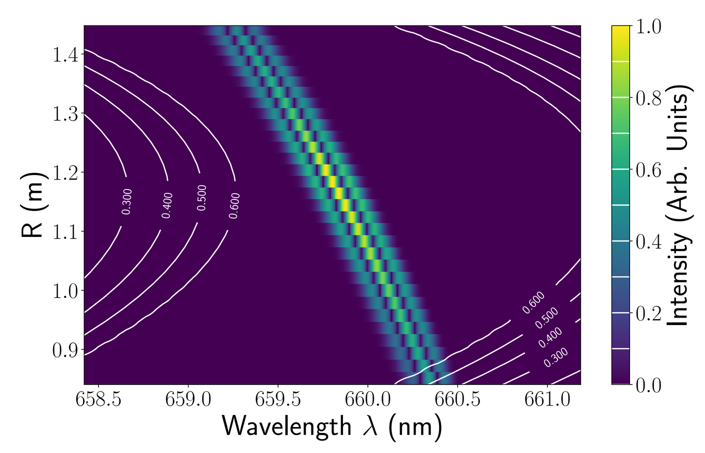
Delay plate 15mm thickness, displacer plate L=3mm gives maximum contrast of 40% in core, 20% at the plasma edge.

Fringe curvature arises from **thick waveplates**.
Field widen delay plate with halfwave plate.

Non ideal crystal effects introduce higher order phase effects in birefringent crystals. The half wave plate acts to flip the ordinary and extraordinary rays to effectively cancel out the fringe curvature effect.

Bandpass Filter

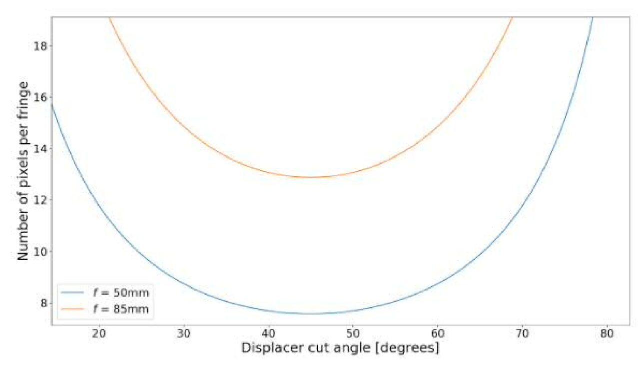
Choose CWL to capture only full energy beam component and tilt filter ~2° to track doppler shift across field of view.

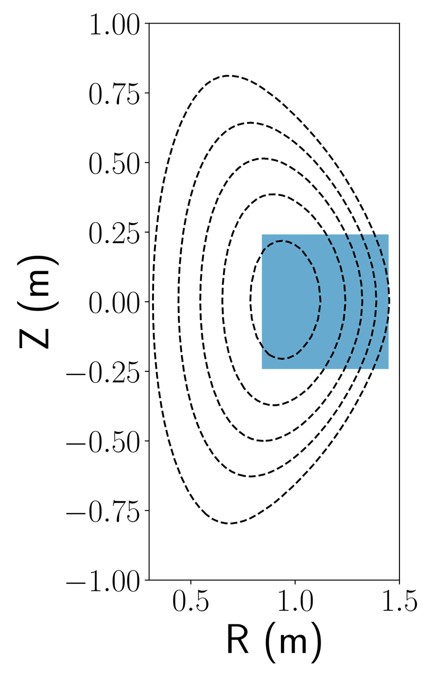


CWL 660nm, FWHM 3nm

Lenses

Camera lens focal length determines image fringe frequency. Require at least 10 pixels per fringe for acceptable resolution.

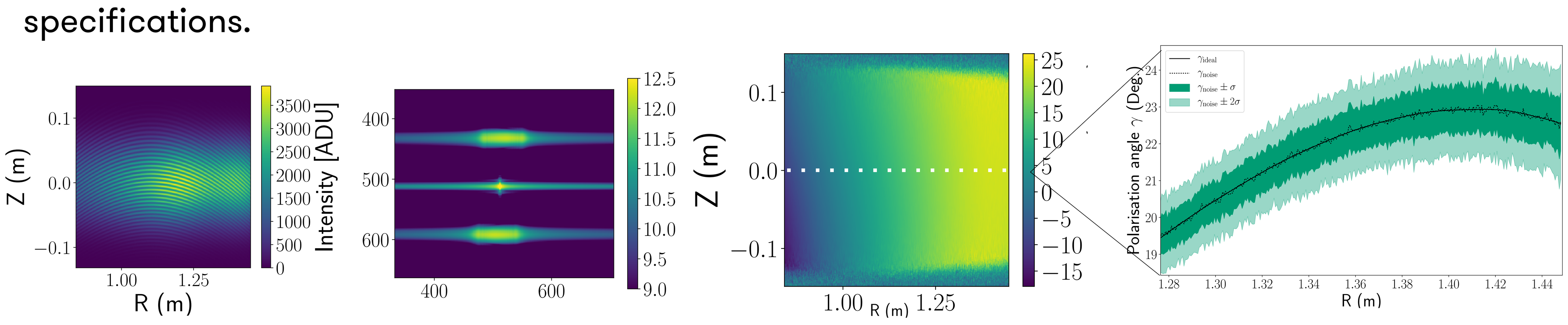




Collection lens f=85mm
f/1.8 provides good field of view.
Crystal size increases vignetting
Diameter 40mm
AR Coating 650-670nm

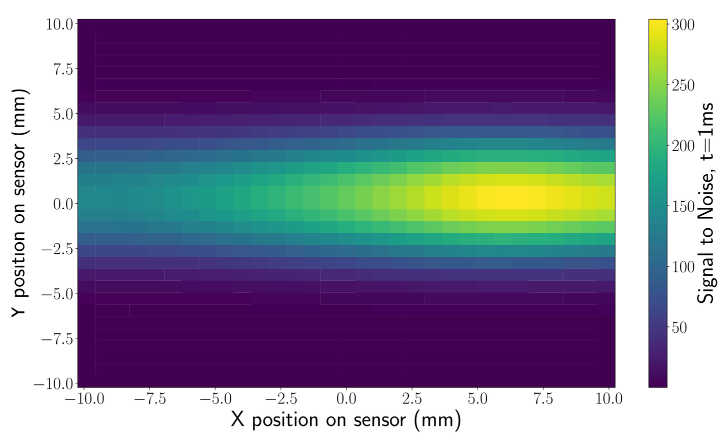
Modelled Performance

Forward modelled noisy images were generated to retrieve the polarisation angle uncertainty in a typical MAST scenario, when **considering shot, read and dark noise** according to the camera specifications.

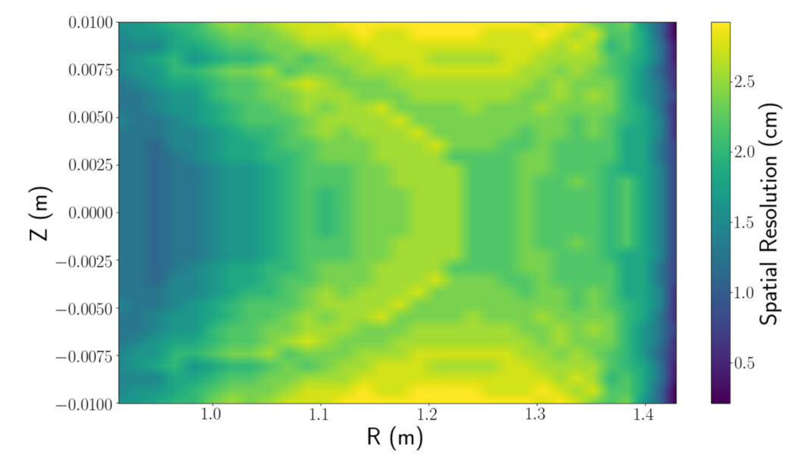


Modelled Image **FFT** **Demodulated 2D polarisation angle** **Midplane polarisation angle**

Generated forward modelled image. The power spectrum showing the carrier frequency and some broadband noise frequency from image digitization. Resulting 2D polarisation angle profile. Comparison of 1D radial profile to noise free profile, including 2σ envelope.



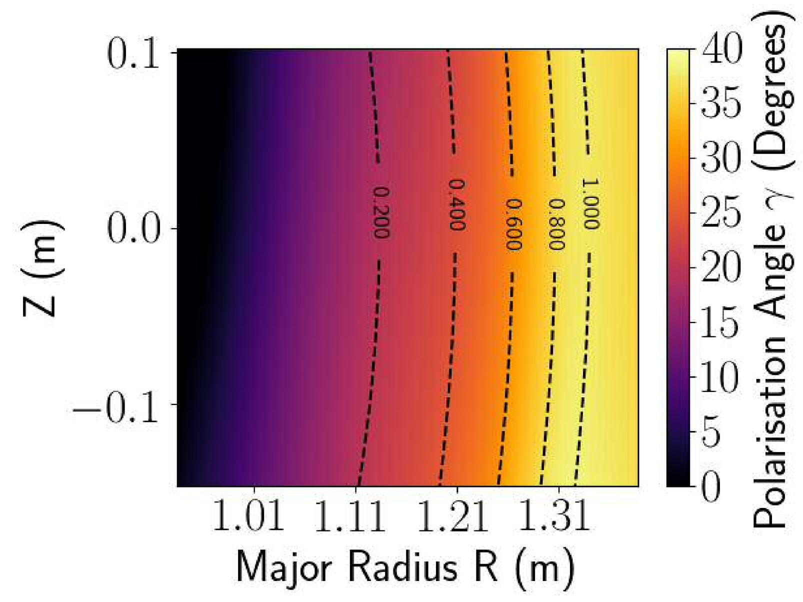
Signal to noise ratio across the modelled image, using the specifications of a Photron SA-4 camera. 1024×1024 pixel CMOS sensor, read noise 41.2±0.52 e- dark noise 3.55±0.02e-, QE ~ 42% at 660nm.



Spatial resolution across the modelled image, average dR = 2cm spatial resolution when considering finite beam effects.

Edge Current Scenario

Using a high power MAST-U plasma scenario, an increase in the polarisation angle of 3 degrees is observed over the pedestal region, indicative of edge bootstrap current.



Broadening effects limit the maximum spatial resolution of these features to 2cm.

Outlook:

To what extent can we resolve bootstrap current vs radial electric field?
Determine performance in other MAST-U scenarios
Determine improvement in equilibrium reconstruction using IMSE as a constraint

[1] F. M. Levinton, Phys. Rev. Lett., 63(19), (1989)
[2] M. F. M. De Bock et. al, Plasma Phys. Control. Fusion, 54(2), (2012)
[3] J. Howard, Plasma Phys. Control. Fusion, 50(12), (2008)
[4] M. F. M. De Bock, et. al, Rev. Sci. Instrum, 79, 10F524 (2008)

FUSION CDT — EPSRC Centre for Doctoral Training in the Science and Technology of Fusion Energy
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