## Advanced Imaging and Inverse Methods

The Advanced Imaging and Inverse Methods (AIIM) Group (J. Howard, A. Diallo, S. Padhi, G. Potter, I. Roy, J. Read and M. Gwynneth) led by Prof. Howard undertakes research into passive (optical) and active (laser-based) techniques for plasma diagnostics, and their associated inverse methods, with applications in industry and medicine. To complement this work, we also investigate issues relating to inverse methods and tomography whereby useful information can be extracted from line-of-sight integrated measurements by applying appropriate mathematical transformations.

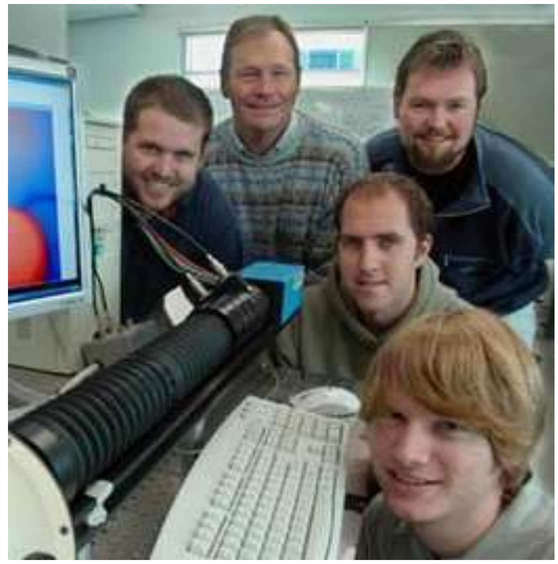


***Figure 13: AIIM Group: L-R Scott Collis, John Howard, David Oliver, Ben Powell and Michael Hush***

This year we were joined by postdoctoral fellows Dr Shantanu Padhi and Dr. Ahmed Diallo who commenced work on ISL and ARC funded activities in optical coherence imaging and microwave tomography respectively. Mr Jesse Read joined the group to undertake his honours thesis on studies of Alfvén activity in the H-1 Heliac. For personal reasons, Mr Greg Potter discontinued his MPhil work in this area during the year.

There have been a number of highlights for the group in 2008. With funding through the International Science Linkages program, we have obtained the first two dimensional images of the internal magnetic field inside a tokamak reactor. This has aroused considerable international interest, potentially leading to additional research contracts in coming years. Jesse Read obtained convincing data that identifies distinct branches of the Alfvén wave dispersion with rotational transform in H-1 and has confirmed the expected phase reversal between magnetic and density fluctuations either side of the mode resonance. Mr Read hopes to continue and subsequently publish this work through commencement of postgraduate studies in 2009. The contract work with JAEA on development of imaging filters for Thomson scattering was completed successfully in 2008 leading to publications and an invitation to present results at the Laser Aided Plasma Diagnostics (LAPD) Symposium in Italy in September 2009. In addition, during 2008 Prof Howard delivered invited presentations on work in coherence imaging at international conferences (Section V.1):

Prof Howard and Dr Diallo also attended and presented papers at the 17$^{th}$ topical conference on high temperature plasma diagnostics in Albuquerque in May. In the latter half of 2008, Prof Howard commenced preparation and planning for hosting at ANU of the 8th Japan-Australia Plasma Diagnostics Workshop during 2-5 February, 2009.

The group's research activities have been oriented around a number of projects

- Optical studies of Alfvén activity on the H-1 Heliac (MNRF funded, Read, Blackwell, Howard)

- Development of magnetic field imaging systems for the TEXTOR tokamak (ISL-funded activity, Diallo, Howard, Gwynneth) Application of imaging Fourier filters for Thomson scattering (JAEA funded, Howard, Gwynneth) Microwave imaging of human breast tissue (ARC funded, Padhi, Roy and Howard)

### Alfvén wave studies on the H-1 Heliac

By exploiting the advanced capabilities of the H-1 power supplies and control system, it is possible to ramp the current delivered to the helical control winding to perform dynamic scans of the magnetic configuration during a single discharge. This allows a large control-parameter space ($\kappa_h = I_h/I_{main}$) to be highly "compressed" and opens new possibilities for the study of H-1 plasma phenomena such as Alfvén-like activity observed in hydrogen discharges at 0.5 Tesla.

During his honours thesis, Jesse Read deployed multiple 16-channel imaging photomultiplier tube arrays at toroidally distinct locations in order to investigate the spatio-temporal structure of the eigenmodes and their dependence on rotational transform. The rotation direction of the mode was confirmed to be in the ion diamagnetic drift direction, while a phase reversal between the magnetic and light fluctuations across magnetic resonances at rational ratios of the toroidal and poloidal mode numbers, consistent with Alfvén-type modes, was observed. Figure 14 (a) shows the temporal development of the cross-power spectrum of light and magnetic fluctuation signals, while (b) shows contours of the cross-phase between magnetic and light intensity fluctuations for a 16-channel PMT camera viewing the full plasma poloidal cross-section. The phase flip occurs at positions $\kappa_h$=0.26, 0.42 and 0.57 in the figure, corresponding in turn to resonant helical plasma structures having toroidal and poloidal mode numbers n/m = 6/5, 5/4 and 4/3. This scan in $\kappa_h$ obtained during a single discharge of duration 100ms.

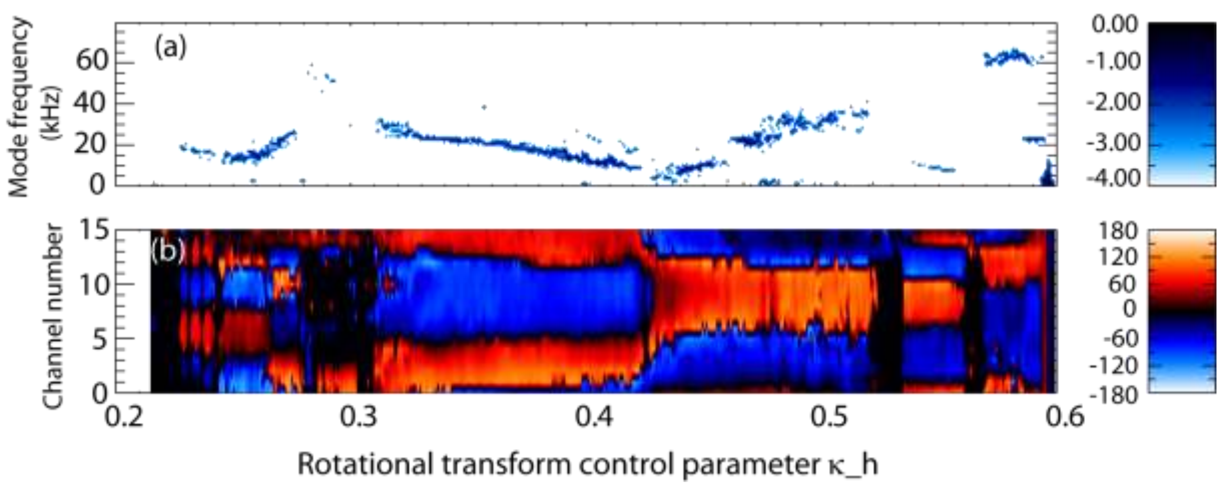



***Figure 14:** (a) Time-frequency plot of the log of the power spectrum of Alfvén fluctuations versus rotational transform control parameter $\kappa_h$ during a discharge in which the helical current is ramped between 0.2 and 0.6 times the magnitude of the primary toroidal current. Note the appearance of characteristic "whale-tail" branches. (b) colour contours of the cross-phase between magnetic and light intensity fluctuations for a 16-channel PMT camera viewing the full plasma poloidal cross-section. The flip of the relative fluctuation phase across major magnetic configuration resonances, as well as the maintenance of mode integrity across wide ranges of transform is apparent.*

### World's first internal magnetic field imaging system

We have invented, installed and operated the world's first 2-D plasma magnetic field imaging system. First results from the magnetic field imaging system installed on the TEXTOR tokamak in Germany were submitted for publication in Dec 2008. The work has already been recognized through an invitation to present a paper on "Imaging Motional Stark Effect Polarimetry", at the International Workshop on Active Beam Spectroscopy for control of the fusion plasma, Lorentz Center, The Netherlands, in March 2009.

Prior to this work, motional Stark effect (MSE) diagnostic systems were restricted to expensive multiple discrete channel systems, each channel requiring dedicated sophisticated post detection electronics and data-acquisition. MSE systems measure the polarization orientation of components of the Stark-split and Doppler shifted Balmer-alpha emission from an injected high-energy hydrogen or deuterium neutral heating beam. Our imaging polarimetric system is essentially a complex birefringent filter that imposes spatial heterodyne carrier fringes in orthogonal directions on an image of the injected neutral beam formed on a CCD camera. Polarization and spectral information is encoded on the carrier fringes and a snapshot image of the beam can be demodulated for the polarization pitch angle. In turn, this allows the extraction of an image of the poloidal magnetic flux and hence the internal current distribution. This is a major step forward that could lead to significantly improved tokamak physics understanding and improved real-time control of tokamak devices.

The following figures and their captions illustrate aspects of the instrument and first results.

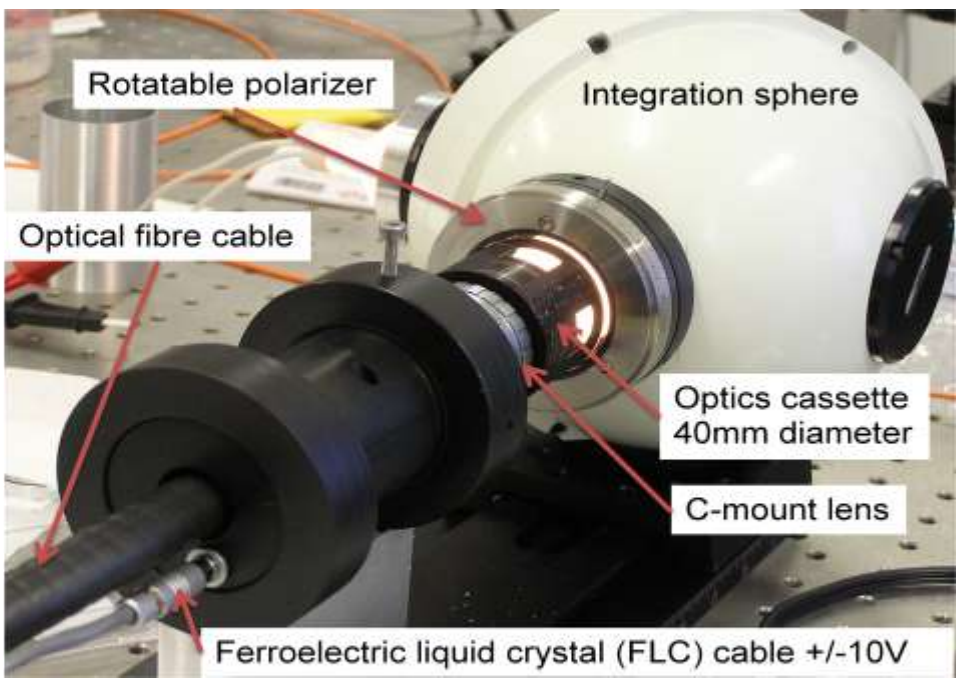



***Figure 15:** Photograph of the front-end optical cassette, c-mount lens and optical fibre cable installed for first internal current imaging experiments on the TEXTOR tokamak in Germany. The back end of the imaging optical fibre bundle is imaged by a fast CCD camera. In this photograph, the system is being calibrated using diffuse light from an integrating sphere.*

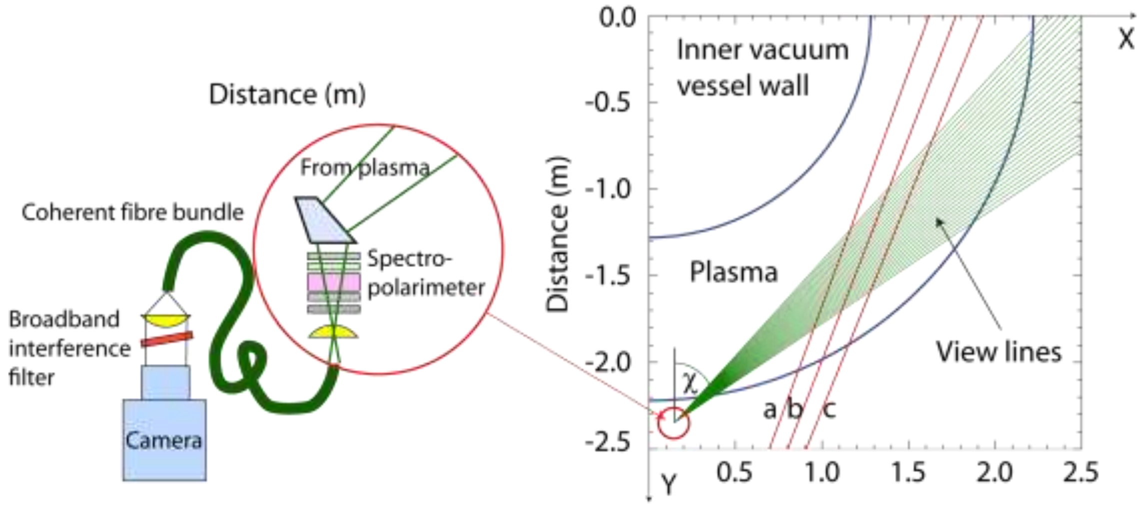



*Figure 16: The TEXTOR system geometry. The neutral beam spans the region designated by the lines labelled `a', `b' and `c'. The green lines represent the span of the camera lines of span. A coherent fibre bundle transports the image to a broadband interference filter and CCD camera.*

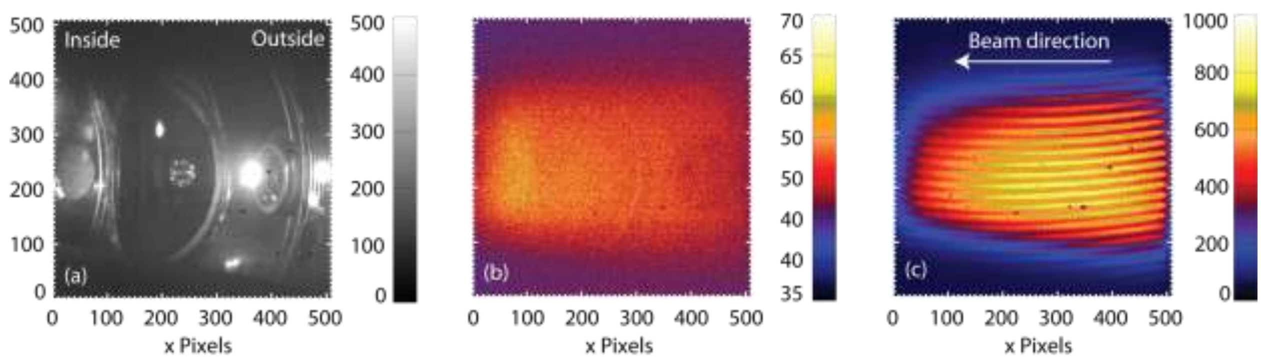



*Figure 17: Left: The camera view of the internally illuminated TEXTOR vacuum vessel. Centre: continuum plasma emission near 662nm (no beam) and Right: The image when the neutral beam is activated. Visible interference fringes indicate that the light is polarized. The phase of the carrier fringes conveys the polarization angle of the MSE multiplet from which can be deduced the internal current distribution.*

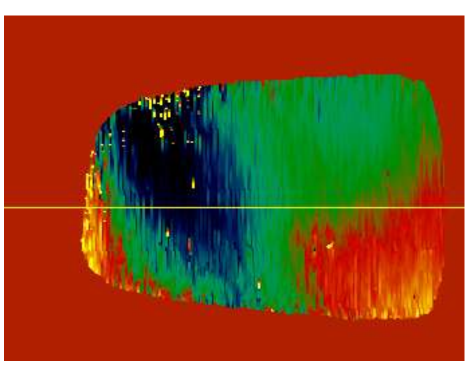
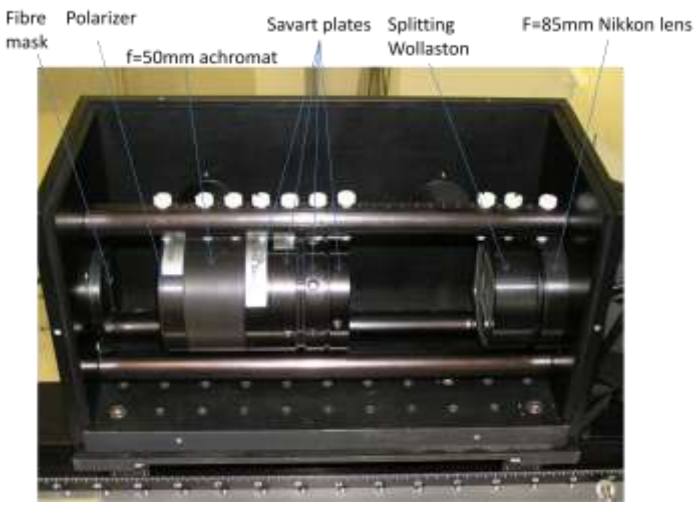


*Figure 18: Typical demodulated polarization tilt angle image. The observed spatial variation in pitch angle conforms well to expectations based on simple models of the internal current distribution.*

## Thomson scattering system for JAEA

This year saw the completion of a contract with the Japanese Atomic Energy Agency to develop and deploy a compact coherence imaging system for Thomson scattering measurements on their premier fusion device, the JT-60U tokamak at the Naka Fusion Research Establishment, Japan. Successful trials of a simple dual channel system were performed on the TPE-RX reversed field pinch in Japan in March 2007 and reported at the 13th International Symposium on Laser-Aided Plasma Diagnostics in Takayama, Japan, September 2007. A photograph of the final JAEA instrument and associated calibration images are shown in Figure 19. Results from this work will be presented at the LAPD meeting in Italy in 2009.



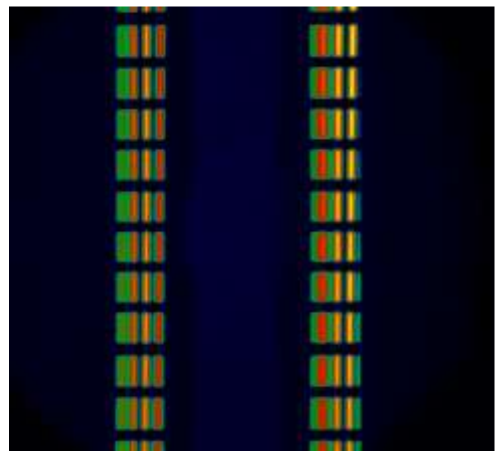



***Figure 19: Left: Photograph of the imaging interferometer shipped to JAEA. Right: calibration images of white light source fringes for a vertical array of input optical fibre channels. Left and right hand image pairs are in antiphase.***

## Coherence imaging for space-borne applications

There has been significant interest from Canadian aerospace company COM DEV in developing CI systems for atmospheric wind speed measurements. Dr. Andrew Bell, a Program Scientist with COM DEV, has approached Prof. Howard regarding construction of a prototype Doppler interferometer system for an interplanetary space mission to measure planetary wind speeds. Dr. Bell has seed money from COM DEV and plans to visit Australia in 2009 to propose funding options and explore R&D opportunities.

Coherence imaging systems have been successfully applied to processing plasma (Section IV) and in Industry (Section VII).