Commissioning of an advanced Gated Optical Imager (GOI) system to provide a new imaging capability for the Orion laser facility

by

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Abstract

We report on the design, build and commissioning of an advanced four-channel Gated Optical Imager (GOI) system to provide the Plasma Physics Technology Centre (PPTC) with a readily-accessible, cutting-edge capability for laser-plasma experiments – four-frame, ultra-fast (<100ps) 2D optical gating with enhanced spatial resolution (10 to 20 line pairs/mm). This step-change significantly enhances our capacity to deliver programmatic requirements and it is cost-effective as experimental data return is improved for all laser-target shots on the Orion laser facility. The new GOI system has been used to obtain the first four-channel data for a novel 2D Velocity Interferometer system for Any Reflector (VISAR) setup and for interferometric imaging of laser-target pre-plasma generation. The implications of these results for future experimental campaigns are discussed.

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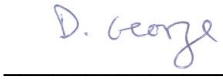
Reviewer:  Date: 30th September 2015

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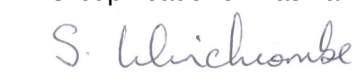
Authoriser:  Date: 1st October 2015

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1. CONTEXT

1.1. BACKGROUND

The Orion laser facility is designed to meet the requirements of AWE's technical programme and to support the UK's commitment to a science-based approach to stockpile stewardship. The facility commenced operations in April 2013, on behalf of the UK Ministry of Defence. Scientific data is now routinely recorded from high-energy density physics experiments centred on material properties, radiation science and plasma phenomena. These experiments are designed, conducted and analysed by the Plasma Physics Technology Centre (PPTC).

The commissioning of Orion target diagnostics is a vital part of being able to record experimental data both reliably and in the regime needed to support programmatic objectives. An ongoing programme of characterisation is undertaken on existing diagnostics, where, for example, calibrations may drift out over time or components need replacing. Additionally, new diagnostics and techniques are being developed to cover the capability gaps for future experimental campaigns. This report details a new diagnostic addition that is providing a cutting-edge capability for the PPTC.

1.2. PROGRAMMATIC REQUIREMENTS AND CAPABILITY

The first year of operations on the Orion laser facility provided a wealth of experimental data, from which it was identified that there was scope to progress diagnostic techniques and technology in line with the requirements of programmes within the Radiation Physics area of the Science, Engineering and Technology Directorate. In particular, validation of studies in Opacity, Warm Dense Matter, Spall-Strength and Equation-of-State all require combined ultra-fast 2D imaging (over gating times of 100ps) and multiple-frames (at least 4) in the optical regime with enhanced spatial resolution (10 to 20 line pairs/mm).

Following the first year of Orion operations this diagnostic capability was unavailable; multiple-framing in 1D had been carried out separately with streak camera systems and the Velocity Interferometer System for Any Reflector (VISAR) diagnostic (a laser and interferometer-based system capable of measuring the velocity profiles of rapidly moving objects), while a number of camera systems provided either time-integrated optical imaging or framing over gate times of > 2ns. There was no means of modifying existing diagnostic hardware and systems to provide the required capability. As a result, the optical diagnostics suite had to be upgraded in order to de-risk the delivery of programmatic requirements in Radiation Physics.

1.3. COLLABORATION AND OUTREACH

Since the new diagnostic capability could not be obtained in-house (see Section 2), there was an opportunity to work in collaboration on a new project. The collaboration involved Kentech Instruments, who specialise in the manufacture of high voltage fast pulse generator systems, X-ray streak cameras and gated detectors. In particular the company is respected and renowned for its

substantial experience in building fast cameras. They have also had key involvement in the build of the gated X-ray detectors currently used in Orion experiments.

In addition to supporting the core science mission at AWE, up to 15% of Orion time is available for access by the academic plasma physics community. The development of the new diagnostic capability was of significant relevance to academic access experiments, and the opportunity to field the new diagnostic in those experiments would enhance the potential for future Outreach activities.

2. NEW CAPABILITY DECISION

2.1. DIAGNOSTIC OPTIONS AVAILABLE

The options assessed to cover the capability gap highlighted in Section 1.2 are detailed in this section. These options considered existing diagnostic techniques and the ways in which a new diagnostic could be implemented.

2.1.1. OPTION 1: MULTIPLE 1D VISAR SYSTEMS

The VISAR system forms the core part of the Orion optical diagnostics suite. The VISAR system is comprised of a laser probe beam, interferometer bed, and a very high temporal resolution ($\leq$ 5ps) electro-optic streak camera. The system works by reflecting the probe beam off the moving target under investigation, then imaging this light through a wide-angled Michelson interferometer and onto the streak camera slit. The acceleration of the target is recorded as movement of an initially static interference fringe pattern on the streak camera. The accelerating target Doppler shifts the reflected light and the magnitude of the Doppler shift changes with the target's time varying acceleration. The time delay introduced in the interferometer causes light from two different defined times to interfere and as they have different Doppler shifts the fringe pattern then formed is shifted compared to that from the static target [1].

On the existing VISAR system, data is analysed as 1D streak camera lineouts. This enables (through measurement of interference fringe displacements over time) the determination of particle or shock velocity-time histories in energetic material states generated and driven by the Orion laser beams. However, shock and target velocities are only resolvable at points or fixed planes over the target.

Multiple 1D VISAR systems would yield insufficient information to create the full 2D velocity profile of a shock front, as information is still constrained to single planes. It is also expensive and space-inefficient to field 1D VISAR systems in multiple quantities. This option was therefore ruled out due to failing to meet the new capability requirement and not providing value for money.

2.1.2. OPTION 2: USE OF THE ‘ULTRA’ FRAMING CAMERA

An optical framing camera (the ‘ULTRA’) developed by Photek Ltd., has been fielded on Orion academic access experimental campaigns. The ULTRA camera system consists of optics to generate multiple optical images of the interaction under study, imaged onto a segmented intensifier. Each segment is gated separately by electronics to produce a frame from each image. The gated signals are then detected with a phosphor and read out using a fibre-optic coupled CCD camera. This approach has the advantage of being relatively compact and self contained. It is therefore fairly straightforward to align and configure the system.

The ULTRA camera has demonstrated high performance multiple-framing (8 frames) capability of 2D images in the optical regime. However the gating (of ≥ 2ns) and spatial resolution (~ 10 line pairs/mm) would not provide sufficient temporal or spatial resolution to satisfy the capability requirements for these particular plasma physics applications in future experimental campaigns. An upgrade to the ULTRA camera system had also been proposed (ULTRA2) to improve on the ULTRA gating time and number of frames. However the ULTRA2 would still have too long a gate time (≥ 250ps) and low a spatial resolution (10 line pairs/mm) to satisfy experimental requirements. This option was therefore ruled out as it did not meet the new capability requirement and a large upfront cost was needed for development of the full system.

2.1.3. OPTION 3: ADVANCED GATED OPTICAL IMAGER (GOI) SYSTEM

A Gated Optical Imager (GOI) system allows 2D optical imaging with defined exposure (gating) times. The system includes an intensifier head, control unit and trigger unit. The intensifier head consists of a microchannel plate (MCP) intensifier tube configured for the fast application of high voltage gate pulses to the photocathode with a high voltage supply for the tube bias voltages. The tube is biased off by means of a small positive potential applied to the photocathode with respect to the channel plate input. A short duration negative pulse is applied to the photocathode in order to switch the intensifier on. Once switched on, the photocathode converts the incident optical signal to electrons by photoelectric absorption. Electron pulses arriving at the MCP are amplified through secondary collisions with the MCP pore walls. The amplified pulses are then absorbed by a phosphor, which emits a visible signal that can be recorded by a suitably triggered camera. The control unit sets the gating mode, MCP biasing and delays for the intensifier head, while frame timings are set using the trigger unit. Multiple frames are captured using multiple intensifier heads and capture cameras. The system is similar to the ULTRA concept except each frame is captured on a separate MCP tube, rather than on a segment of a single larger multi-segmented tube. The image multiplying optics and capture camera systems have to be supplied and aligned separately. This approach would be appropriate for installation in the Orion facility.

Fast cameras based on the GOI gating scheme have been built for many years by Kentech Instruments Ltd. The latest GOI system from Kentech Instruments now allows <100ps, 2D optical frames to be captured with high timing precision. Kentech Instruments have conducted proof-of-principle testing on a novel magnetic field enhancement feature for an advanced GOI system, which improved spatial resolution by a factor of two or more (to > 10 line pairs/mm at fast gating speeds of ~ 100ps), quadrupling the number of picture elements captured. Furthermore, Kentech Instruments has prior experience of developing remote control interfaces in the software language (LabView) needed for Orion diagnostics. Remote control of the GOI system could be successfully integrated with the Orion control system. The GOI system also had the benefit of being modular; meaning that less up-front cost would be required to demonstrate the new capability requirement. This option was pursued since it would satisfy future programmatic requirements; it was feasible to incorporate on Orion and also represented best value for money.

2.2. PROGRAMME DRIVERS

Besides the need to satisfy the new capability requirement, a definitive breakdown of programmatic requirements was presented in the technical case to procure the advanced GOI system. These programmatic requirements are shown in Tables 1 – 3.

A modular approach was followed in order to develop the GOI system as an integrated part of the Orion optical diagnostics suite. The first step was to bid for a two-channel system on the basis of the programmatic requirements outlined in Tables 1 – 3. The two-channel system would then be installed, tested and used on an experimental campaign to demonstrate the new capability requirement. Following this demonstration, a case was made to bid for a further two channels to provide the minimum data set (of four channels) per laser shot needed to satisfy a programmatic requirement. This approach also had the advantage that the infrastructure needed for a working four-frame system would already be established in the two-frame system, thus reducing potential risks for full system operation.

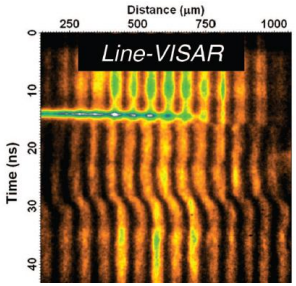
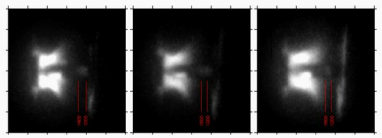
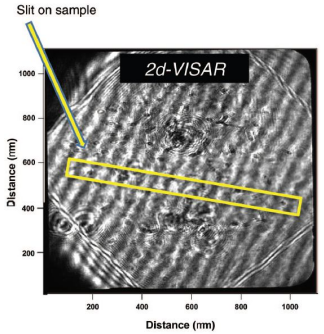
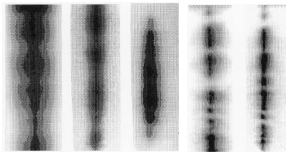
Radiation Physics programmes	Experimental requirement(s)	Fundamental diagnostic specifications	Currently achievable with Orion optical diagnostic suite?	Achievable with new GOI system?
Strength, Equation of State	Establish the uniformity and evolution of shock velocity profiles in 2D, including time-dependent structural phase transformations and deformations in materials. Evaluate the drive on targets leading to shock fronts and conduct multiple-frame imaging of the target reflectivity.	Velocity interferometer system for any reflector (VISAR) available in 2D to analyse full shock profile. Imaging without significant motion blurring; gating times need to be 100ps or less to avoid issues associated with fringe blurring. Capture minimum of 4 frames to show sufficient fringe displacement data over time.	The 1D VISAR system only allows target velocities to be resolved at points or fixed planes over the target.  *1D VISAR interferogram [2]* Optical framing camera ('ULTRA') developed by Photek, demonstrates multiple-framing capability of 2D images in the optical regime, but gating times are > 2ns, so images would be too blurred.  *ULTRA sequence of plasma flow with >2ns gating [3]* ✗	The latest GOI system developed by Kentech provides ultra-fast 2D optical imaging with up to 80ps gate times and multiple-framing.  *2D 'snapshot' VISAR [4]* The GOI system is modular and could easily be integrated into a new 2D VISAR system.  *Image sequence of z-pinch plasma with GOI system using 1ns gating [5]* ✓

Table 1. Need for advanced GOI system: Strength and Equation of State programmatic requirements after first year of Orion operations.

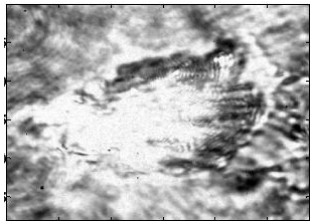
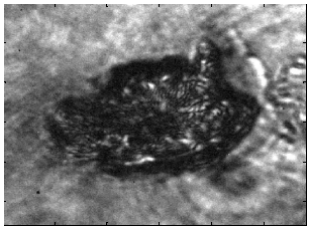
Radiation Physics programmes	Experimental requirement(s)	Fundamental diagnostic specifications	Currently achievable with Orion optical diagnostic suite?	Achievable with new GOI system?
Short-Pulse Interactions	Gate-out coherent self-emission from short-pulse beam harmonics. Progress the fidelity of measurements close to the target, and improve dynamic range of camera systems. Reduce uncertainty in measuring prepulse levels from short-pulse experiments.	Multiple-frame, ultra-fast (100ps gating minimum) 2D imaging. Suitable optical layout for each experimental requirement.	In the existing optical diagnostic suite, camera images become saturated and the point of interaction on the target is obscured by the effects of self-emission.  ***Shadowgraphic image of laser-irradiated glass target without optical gating of self-emission [5]*** There is no 2D imaging system fast enough to gate out coherent self-emission. ✗	The latest GOI system from Kentech instruments provides the underlying capability requirement.  ***Shadowgraphic image of laser-irradiated glass target with optical gating of self-emission [5]*** Flexibility to incorporate the GOI into the optical diagnostic suite with addition of simple optics to provide beam paths and light levels for each requirement. ✓

Table 2. Need for advanced GOI system: Short-pulse Interactions programmatic requirements after first year of Orion operations.

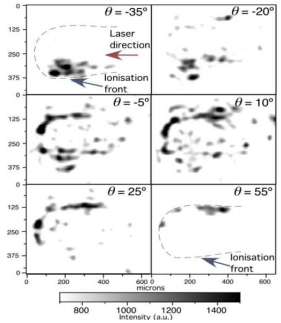
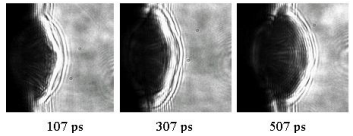
Radiation Physics programmes	Experimental requirement(s)	Fundamental diagnostic specifications	Currently achievable with Orion optical diagnostic suite?	Achievable with new GOI system?
Warm Dense Matter Opacity	Capture multi-frame pulse train from single short-pulse shot. Diagnose breakdown of the target surface prior to the arrival of the main pulse in short-pulse experiments, to understand the formation of shocks and flows from short-pulse interactions. Conduct measurements of charged particle number densities and evolution of the magnetic field variation at the target.	Etalon to generate a suitable pulse train that decays exponentially over time. Use of interferometry to measure charged particle densities. Polarisers to produce a pulse train with different planes of polarisation over short timescales (≈≤ 1ns). Schlieren polarimetry to map the magnetic field at the target. Gate individual pulses from the pulse train over timescales ≈ ≤ 100ps, and in multiple frames over a 2D area.	Pulse train could be generated with the addition of suitable optics. However no diagnostics can image the gated pulses. Limited analysis of pulse signals only possible, which would not provide sufficient information to understand formation of shocks, flows and electron / magnetic field dynamics in the vicinity of the target. ✗	The latest GOI system from Kentech instruments provides the underlying capability requirement. *(a)*  *(b)*  ***(a) Plasma polarimetry to determine magnetic field distribution [6] and (b) imaging of a plasma-target interface [7], of quality expected for new GOI system*** Each experimental requirement will require 4 frames. An 8-frame GOI system will allow simultaneous measurement of charged particle number densities and magnetic field dynamics. ✓

Table 3. Need for advanced GOI system: Warm Dense Matter and Opacity requirements after first year of Orion operations.

3. ADVANCED GATED OPTICAL IMAGER INSTALLATION

3.1. OVERVIEW OF HARDWARE

The GOI system is an optical diagnostic that provides a timed sequence of exposures through a set of four GOI heads (single-frame gated intensifiers). Gating on the intensifiers is typically 80ps – 250ps at set values of 80ps, 105ps, 130ps and 250ps (fast mode), however the system may also be operated with gating over 300ps – 5ns (medium mode), 10ns – 10µs (slow mode) and in DC mode for exposure tests.

The intensifier tubes for the GOI system are biased through a controller unit up to 6kV and with limited current and no access to HV connections. The controller unit is connected to mains power. High voltage pulses are used to trigger the GOI heads with very good timing stability (typically 3ps rms jitter). A trigger box is supplied with a single low voltage 30V trigger via the Orion timing system to provide these pulses. The GOI heads are controlled either locally (for setup, RS-232) or remotely (setup/shot operations, Ethernet) by commands to the GOI controller unit via a computer interface. An outline of the key hardware of the GOI system made by Kentech Instruments is shown in Figure 1.

The GOI heads each have an aperture of 18mm and contain an S20 cathode on a quartz input window. The wafer-type of the MCP design gives a large number of pixels across the full 18mm diameter cathodes. A P43 phosphor is used after the MCP and optical signals are guided into a lens-camera system. A lens-camera system is used for the rear end of the GOI system since a fibre-optic bundle would add significant complexity with the need to be contact-mated with phosphors and sensors of the Optical Image Capture System (OICS) cameras. Also, an old (but faulty gating) GOI system had already been tested using high quality photography lenses to image the phosphor in a similar setup and demonstrated that light levels and resolution were not a problem.

In order to enhance spatial resolution, a magnetic field is applied axially to the image intensifier. This limits transverse motion of the electrons emitted from the photocathode, associated with image blur, as compared to a standard GOI head. This is particularly applicable to the fastest gating speeds at which the intensifier is operated close to cut-off and the accelerating voltage is at a minimum. The magnetic field acts on the photoelectrons generated by the cathode. In these conditions the applied field can increase the spatial resolution by a factor of two or more, quadrupling the number of picture elements captured. The best spatial resolution is nominally 20 lines pairs/mm at the fastest gate time (80ps). The GOI head and controller units were calibrated by Kentech Instruments upon manufacture. A short-pulse laser of 40ps duration, 820nm wavelength was used as part of a semi-automated system to provide the gating profiles and relative signal levels. A camera set at a maximum repetition rate of 100Hz was used to capture light from the phosphor.

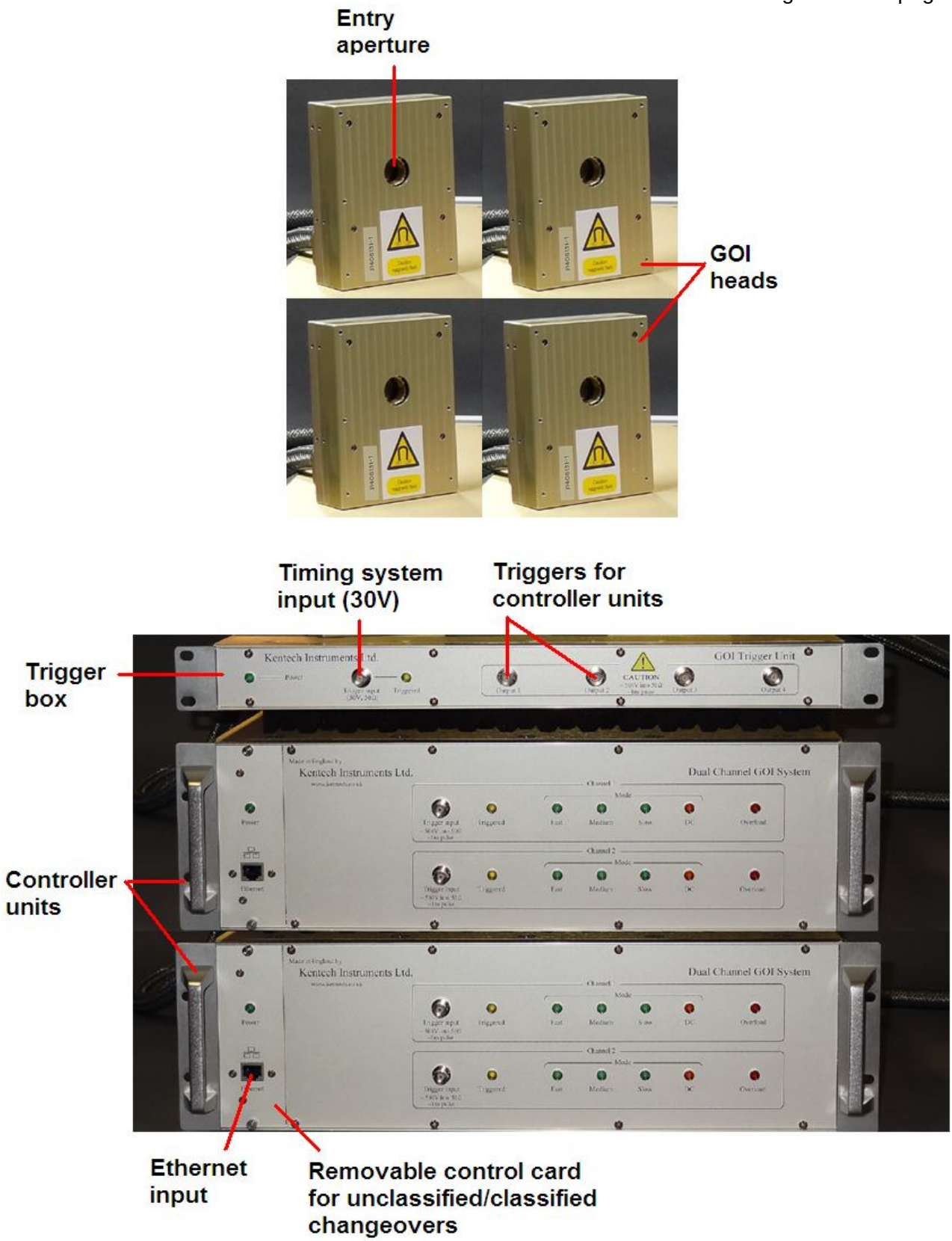


Figure 1 – Key components of the four-channel advanced GOI system made by Kentech Instruments: GOI heads, the trigger box and the dual channel controller units.

The following additional hardware (already available apart from the rack and some hardware at insignificant cost) was needed to complete the GOI system infrastructure:

- Lenses, beam splitting optics, relay optics and suitably triggered CCD cameras controlled with the OICS to record the phosphor output signals from the GOI heads.
- Computer with software to communicate with the GOI system controller units and Ethernet switch to allow control system communications with the computer.
- A rack to house all the electrical hardware, integrated with the Orion power distribution, timing system and target diagnostic control system.

The full installation of the GOI system in the Orion Target Hall is discussed in the following sections.

3.2. INITIAL TARGET HALL LAYOUT

The GOI system had to be integrated as an Orion target diagnostic, and the deciding factors for installation were available space, experimental requirements and the ability to assemble the necessary optics. In particular, initial experiments required a 2D VISAR application for studies in radiative shocks and their counter-streaming interaction, as well as material strength. The GOI system would provide 2D gated framing and operate in parallel with the existing VISAR system to provide a point of reference for the new measurements. As a result the GOI system had to be based adjacent to the VISAR setup on optical table 1 of the Orion Target Hall (optical tables 2/3). Optics was assembled to create additional light paths (GOI system frames) from the VISAR interferometry bed detailed in Section 2.1.1. Having determined the layout on the optical tables, the additional hardware specified in Section 3.1 could then be put into service.

As mentioned in Section 2.2, a modular approach was taken towards the development of a four-channel GOI system. The two-channel layout shown in Figure 2 was first used to establish the GOI system infrastructure. Macro-planar lenses (F number of 2, focal length 100mm made by Zeiss) are positioned 40cm behind the GOI heads and focus light pulses onto progressive scan CCD (JAI TM-2040 GE with a 1200 x 1600 array of 7.4μm pixels) OICS cameras. The difference in the path lengths from the primary image to the GOI heads was used to introduce a fixed, inter-frame delay. This scheme would be followed for the four-channel configuration of the system.

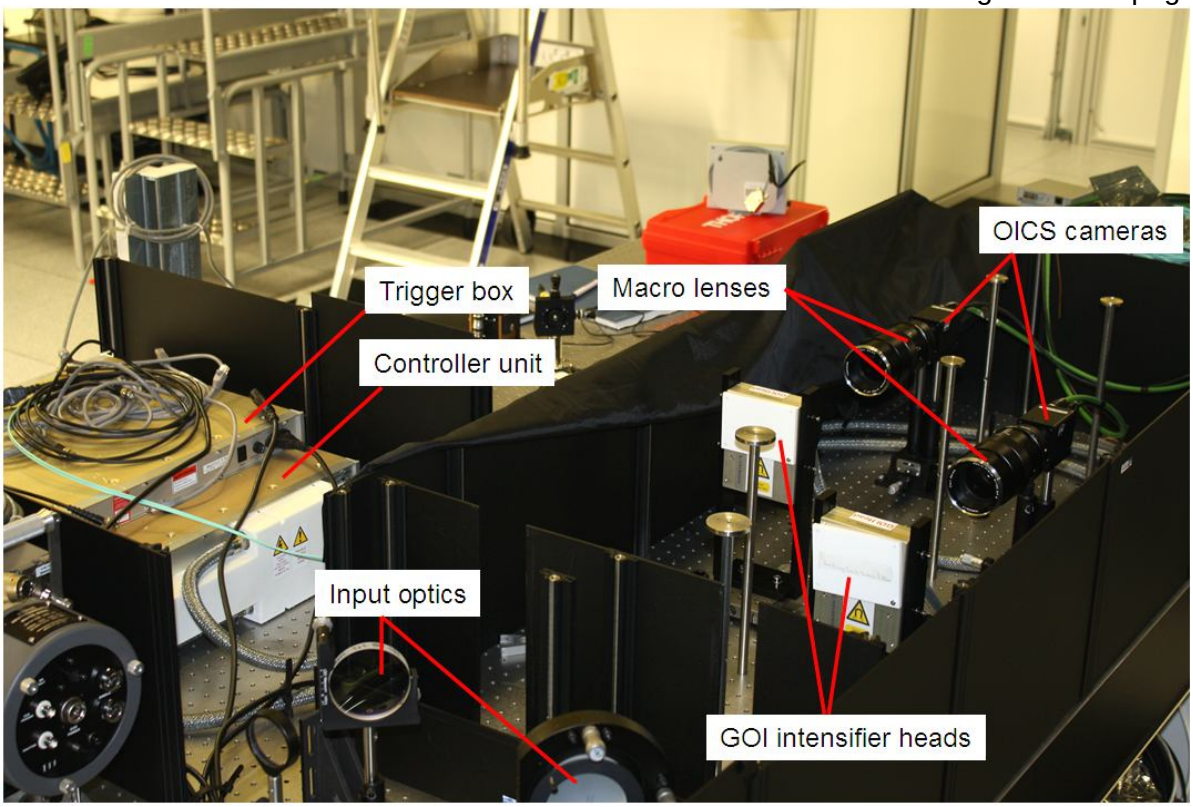


Figure 2 – Two-channel GOI system setup initially used on optical tables 2/3 of the Orion Target Hall to establish the GOI system infrastructure (Ethernet switch and computer not shown).

3.3. PORTABLE RACK SETUP

As shown in Figure 2, all of the hardware was situated on top of the optical tables. In place of the hardware, a further two channels would be needed to provide the minimum credible data set from a laser shot to satisfy one of the programmatic requirements highlighted in Tables 1 – 3. As mentioned in Section 2.2, commissioning of a two-channel system was a prerequisite to procuring these additional channels, and the first GOI system imaging in the two-channel configuration is detailed in Section 5.

Following commissioning of the two-channel system shown in Figure 2, a portable rack was incorporated to house all the electrical hardware for the GOI system to enable installation of a four-channel system and this rack is shown in Figure 3. The rack used was a portable rack as the hardware needed to be located close to the GOI heads (due to a maximum 3m length of controller unit to GOI head cable) and the fixed racks in the Target Hall were too far away from the optical tables being used. Furthermore, the GOI system could be fielded on the VISAR optical table for future campaigns if desired. The portable rack is shown alongside the VISAR input optics in Figure 4.

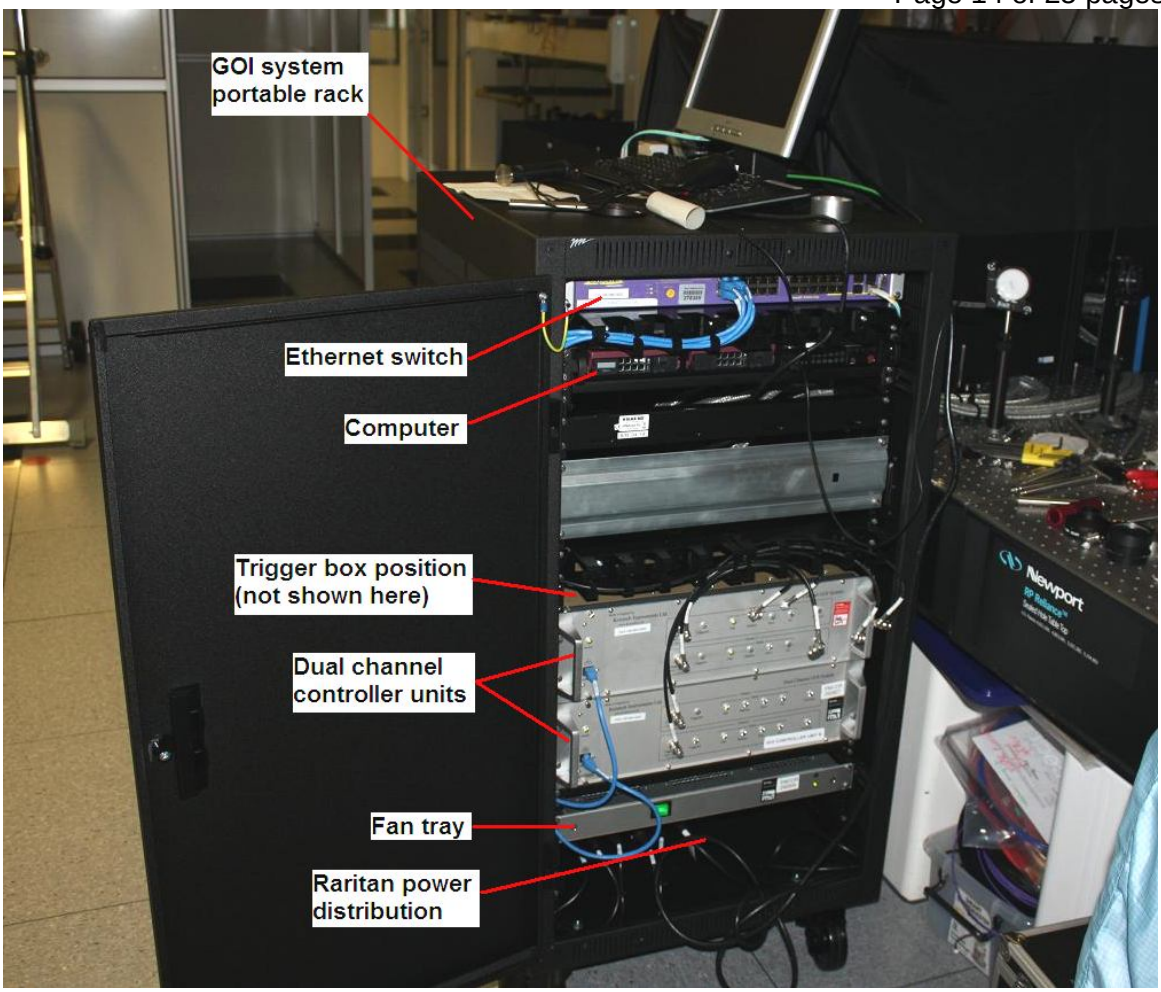


Figure 3 – Portable rack setup to house the GOI system electrical hardware.

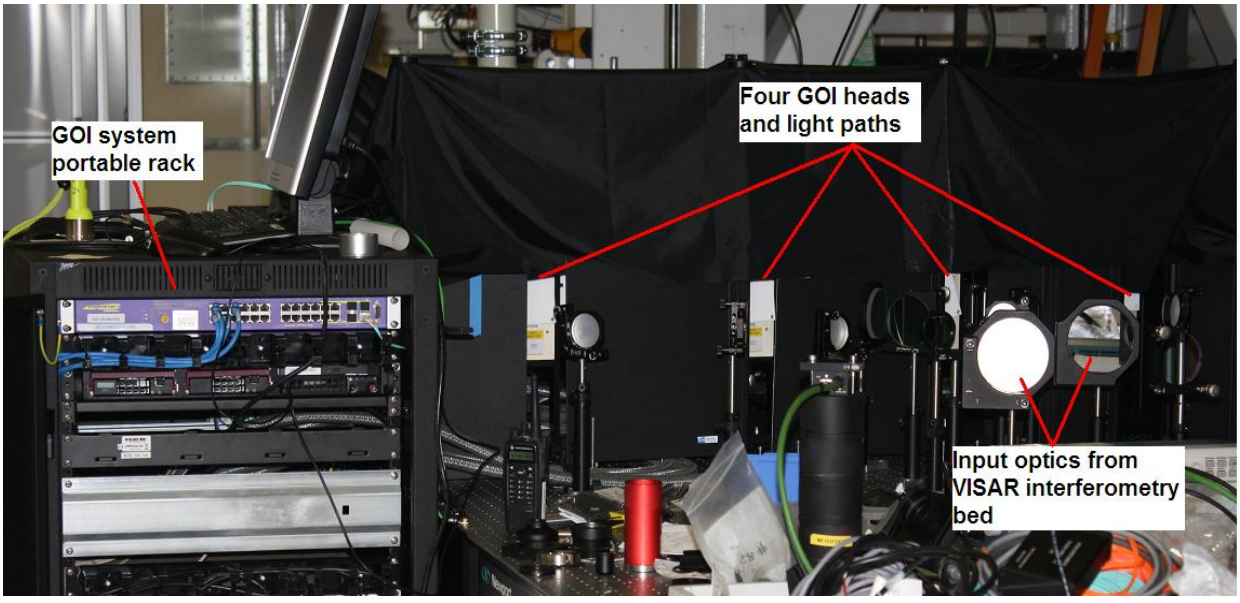


Figure 4 – GOI system portable rack and input optics for a four-channel GOI system.

3.4. ORION FACILITY CONSIDERATIONS

Beside the factors listed in Section 3.2 for installing the GOI system, the installation layout was rigorously reviewed to satisfy safety and security regulations at AWE. The most stringent measures were taken on electrical safety to ensure that the system design is in compliance with Company Safety Procedure (CSP) 3.2 and operations had been fully assessed by the Senior Authorised Person Electrical (SAP(E)). The portable rack provided a suitable method of containing high voltage equipment, while the optical table covers limit immediate access to the GOI heads. Hazards have been suitably labelled on the rack and around the optical tables. Detailed procedures are followed by experienced personnel to ensure safe system operation. A number of existing Orion diagnostics can only be used in certain configurations (e.g. those which are deployed in Ten-Inch Manipulators (TIMs), to be fielded closer to the target). However this system has the advantage of being available for use in any Orion experimental campaign. Furthermore the control cards shown in Figure 1 are removable, facilitating classified/unclassified changeovers (there is some flash memory stored on the card). This further demonstrates the new imaging capability is good value-for-money.

4. CONTROL INTERFACE AND TESTING

4.1. OVERVIEW OF CONTROL INTERFACE

On Orion, target diagnostics are remotely controlled using the Target Data Acquisition System (TDAS). The interface for TDAS is a SCADA screen system and an OPC (Object linking and embedding for Process Control) server links the SCADA system with the LabView software that is needed to drive the GOI controller units. A number of OPC tags are used to set, activate and monitor the GOI controller unit variables. These variables include the modes mentioned in Section 3.1, the gate width for a mode, the voltage on the MCP and an electronic delay to the start of the frame (to aid synchronisation with the timing system triggers). Finally, the GOI system interface also includes status indicators for overloading (caused by saturation) and to show that a GOI head has triggered. The SCADA screen for the four-channel GOI system is shown in Figure 5.

Separate systems on Orion are used to control the triggering of the GOI heads and to view the visible signals output by the GOI head phosphor. These are the timing system, which is part of the Orion Central Control System (CCS) and the OICS imaging system highlighted in Section 3.1.

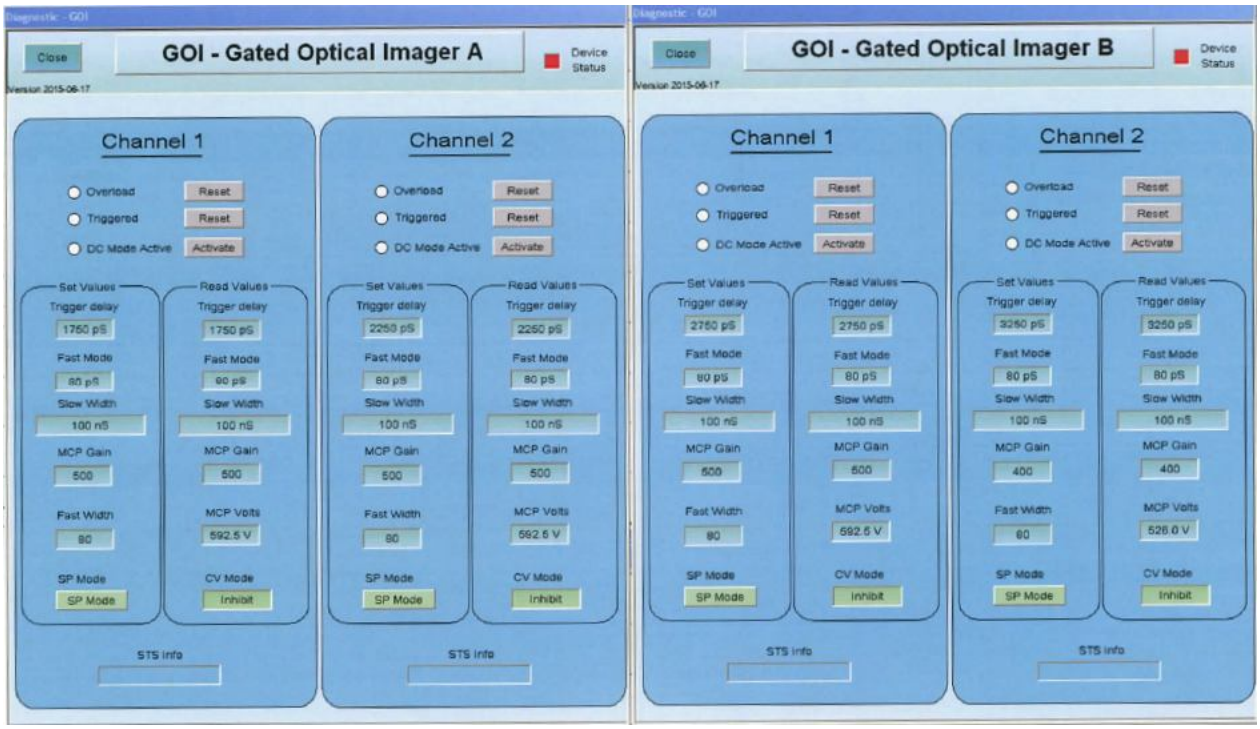


Figure 5 – SCADA screen interface for the four-channel GOI system. Each controller unit operates two of the GOI heads enabling the trigger delay, mode, gate width and MCP gain to be set.

4.2. PRE-EXPERIMENT TESTING

Following installation of the GOI system, preliminary tests were carried out in order to establish that the control interface was functional and that the GOI heads could be reliably triggered. The basic tests included mode setting on the controller unit once set on the control interface, and that status indicators on both the hardware and the interface were in agreement. An initial problem on using the system was that only one channel appeared to work on one of the controller units, but this was later found to be a network communication issue. Additionally, tests were conducted with the GOI head, macro lens and OICS camera combination. The gate width of the GOI heads was set to the maximum value first. A constant white light source was attenuated to a suitable level with ND (neutral density) filtering and used to illuminate a resolution test target in front of the GOI head. The gating mechanism of the GOI heads could then be checked and the gate width subsequently reduced.

A more challenging test was to set the correct trigger delay for each GOI head. This required the use of the Innolas laser system in the Target Hall to provide a sufficiently small pulse length. Initially, the only clues were the known delays introduced through the optical path lengths to each head, and known fiducial positions from streak cameras used in the VISAR setup. This was largely a process of trial and error, but as with the exposure test the GOI gate width was first set to the maximum value. Once an image was acquired on triggering, gate widths were reduced and smaller adjustments applied to the trigger delay. Some of this testing carried over into the first experimental campaign the GOI system was used on (material strength). After the trigger delays had been suitably set

for the minimum gate width (80ps) this needed synchronising with the laser shot trigger.

5. RESULTS

5.1. FIRST EXPERIMENT – TWO FRAMES

Two-frame data for a 2D VISAR application was first obtained in an academic access experiment on radiative shocks and their counter-streaming interaction. This was a laboratory astrophysics experiment in which the Orion long-pulse laser beams were used to drive counter-propagating radiative shocks in an enclosed gas-cell target. A schematic of the experimental design is shown in Figure 6. The optical diagnostics have a line-of-sight to one of the target viewing windows via TIM 44 of the target chamber. In order to probe the simultaneous optical self-emission of the interaction, the Innolas 2ω laser (532nm) was used as the probe beam source.

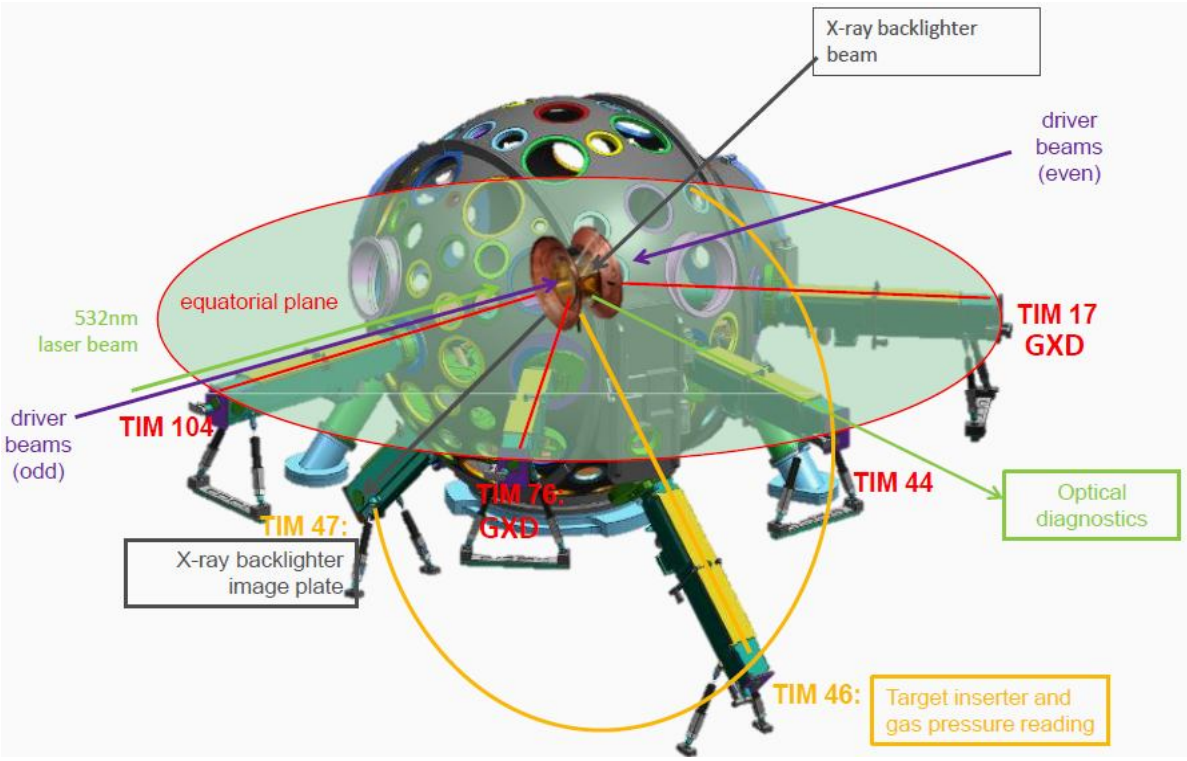


Figure 6 – Experimental design for the first two-frame GOI system images.

As shown by Figure 7 the speckle content was too high, with poor fringe visibility, and this was attributed to setup issues for the experiment (e.g. pointing, focusing). The results were also limited as the plasma quickly became opaque and there were a number of triggering issues with the GOI hardware (which turned out to be a fault with the streak camera trigger, later replaced). Nevertheless the data indicated the GOI system could perform <100ps, 2D optical gating, resolve the counter-streaming shock structure and the imaging issues would be addressed in a later campaign.

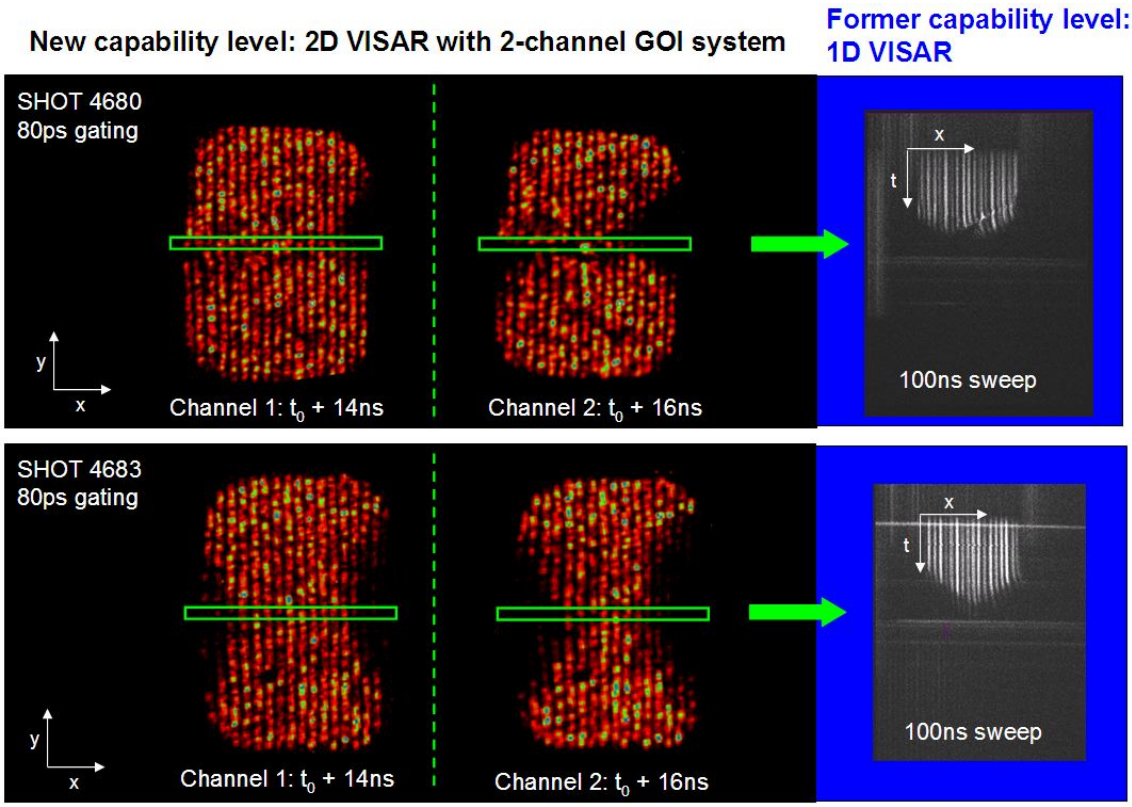


Figure 7 – Initial results with a two-channel, 80ps-gated GOI system showing frames 14ns and 16ns after the laser shot. The former capability level utilising 1D VISAR is also shown for comparison.

5.2. 2D VELOCITY INTERFEROMETER FOR ANY REFLECTOR (VISAR) DATA

The GOI system was next used once two further channels had been built and the four-channel system installed as detailed in Section 3.3. Essentially the experimental design was as shown in Figure 6, but with some metrology modifications to the targets and improvements to the laser and optics setup. Four-channel, 2D VISAR data obtained with the GOI system is shown in Figure 8, while higher-quality data resolving the gas-fill pipe of the target (although recorded on just two of the channels) is shown in Figure 9. The effective spatial resolution of the system was also assessed using one of the images in Figure 9. A lineout through one of the sets of fringes is shown in Figure 10. The minimum resolvable fringe separation highlighted is approximately 10 camera pixels, or 74μm, which translates to 13.5 line pairs/mm. This is in good agreement with both the performance specification for the GOI head and the spatial resolution criterion of > 10 line pairs/mm set out in Section 1.2.

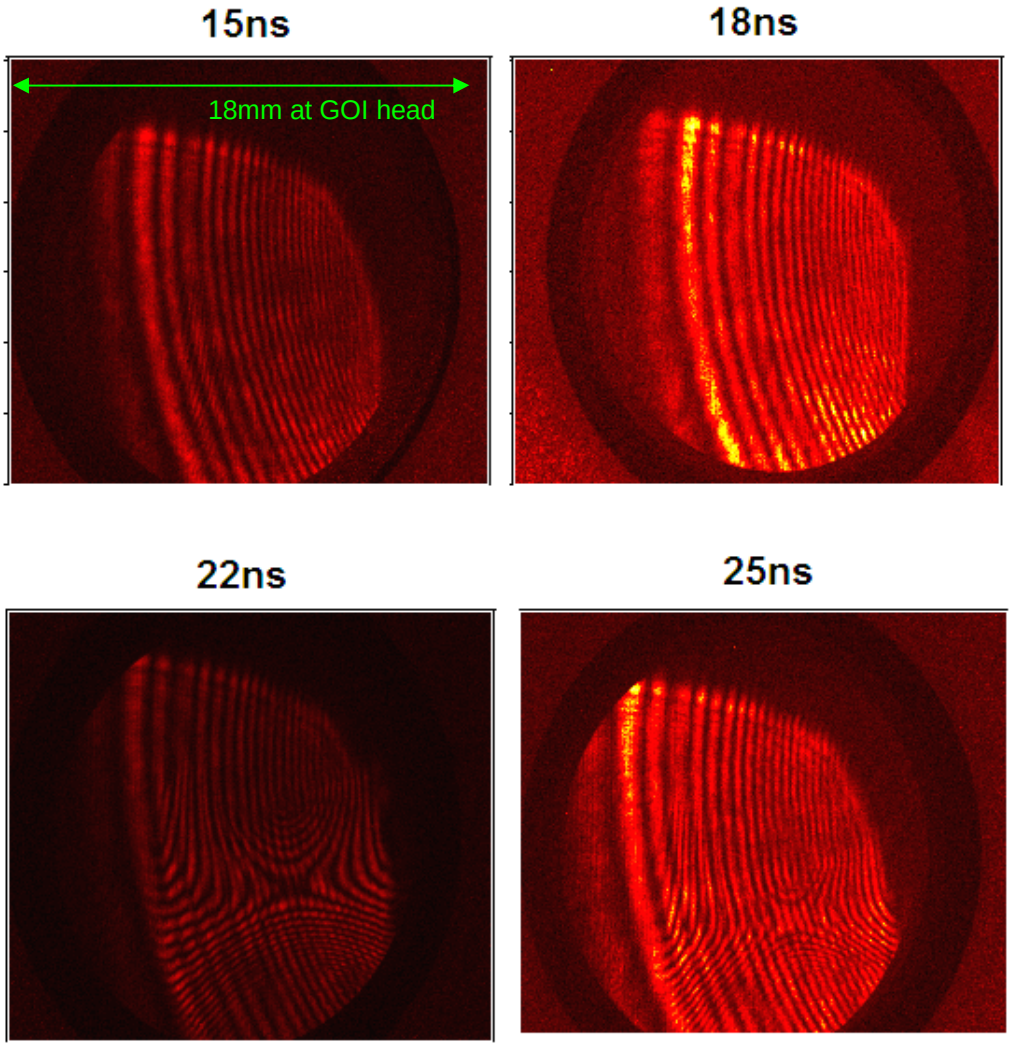


Figure 8 – Shot 5037: Full set of images from a four-channel, 80ps-gated GOI system showing frames 15ns, 18ns, 22ns and 25ns after the laser shot.

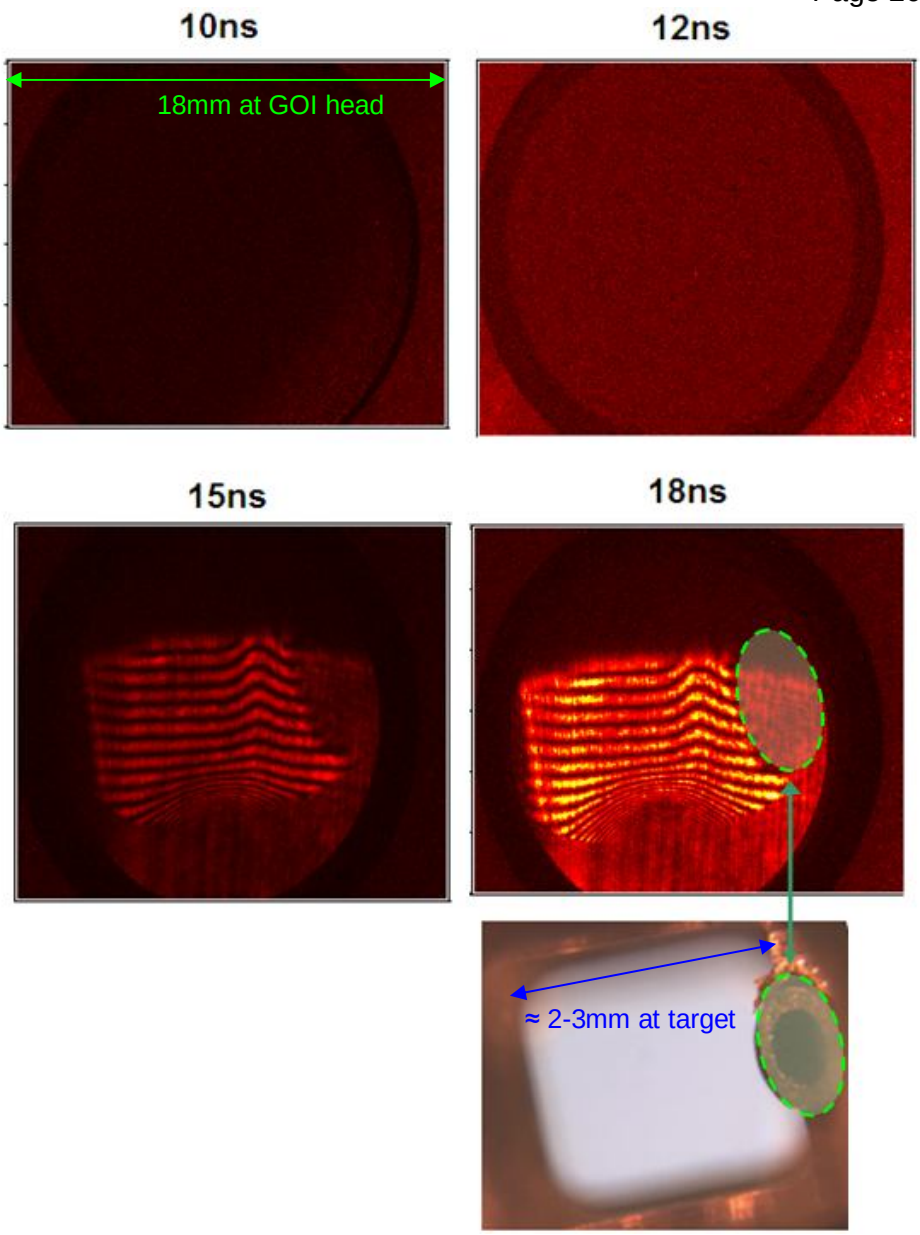


Figure 9 – Shot 5038: Two images captured on a four-channel, 80ps-gated GOI system showing frames 15ns and 18ns after the laser shot with a shock from the gas-fill pipe from the viewing window of the target resolved (circled in green).

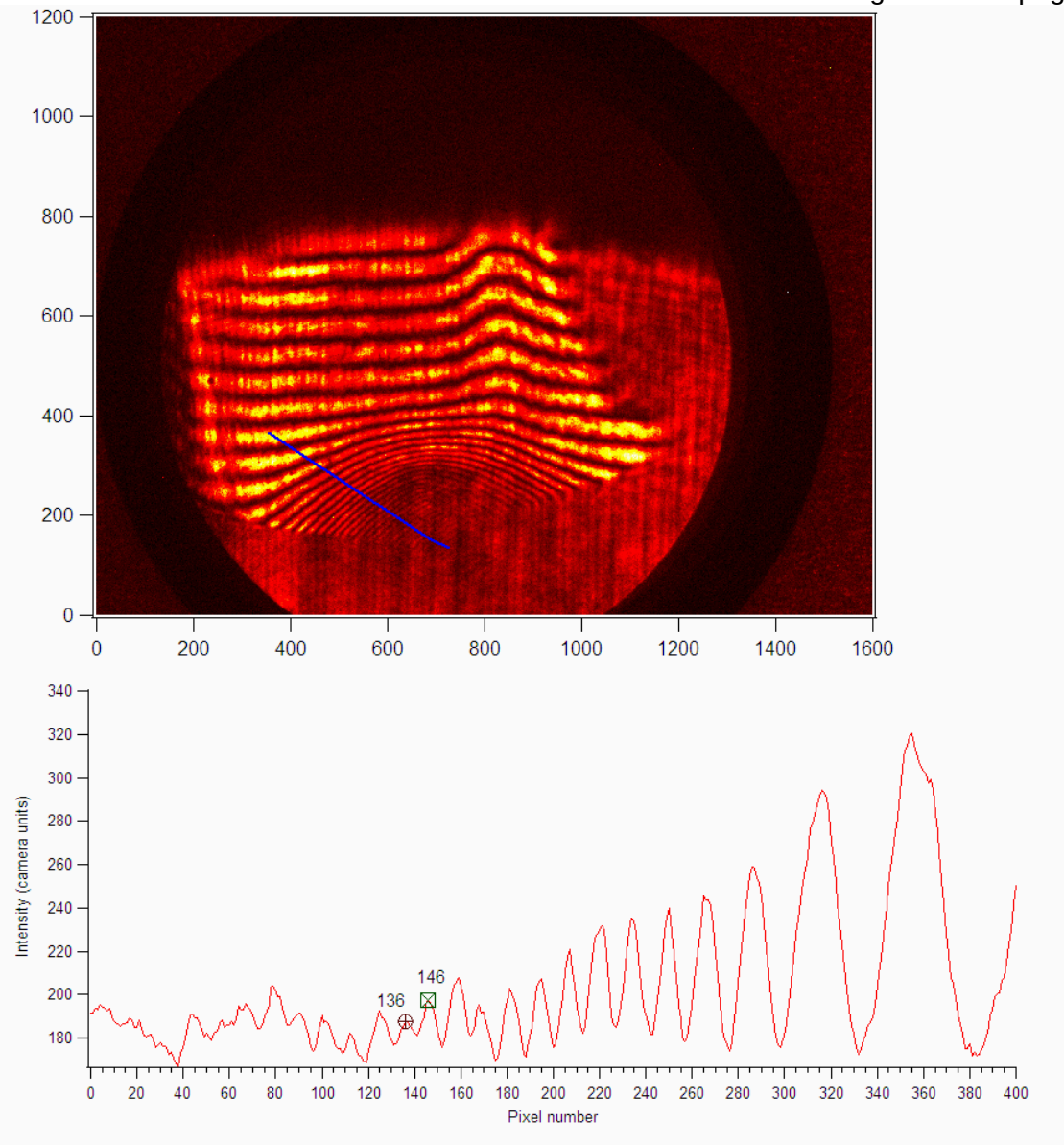


Figure 10 – Assessment of the effective spatial resolution of the advanced GOI system, using lineout through a gated fringe image in Figure 9.

5.3. ADDITIONAL INTERFEROMETRY DATA

The GOI system is also being used at the time of writing on further Orion campaigns (Short Pulse Capability development or S-CAP) to image preplasma, generated by using a single long pulse beam to ablate the front surface of a plastic (CH) foil. The aim of this part of the experiment was to improve the link between radiation-hydrodynamic modelling and generated pre-plasma conditions (a later phase was to direct the short-pulse beam into the pre-plasma to demonstrate 'channel boring'). The Innolas 2ω laser was again used as a probe beam for the laser-target interaction, although with the probe beam transiting the target rather than reflecting off it. A schematic of the experimental design is shown in Figure 11. The GOI system input was again routed through TIM 44.

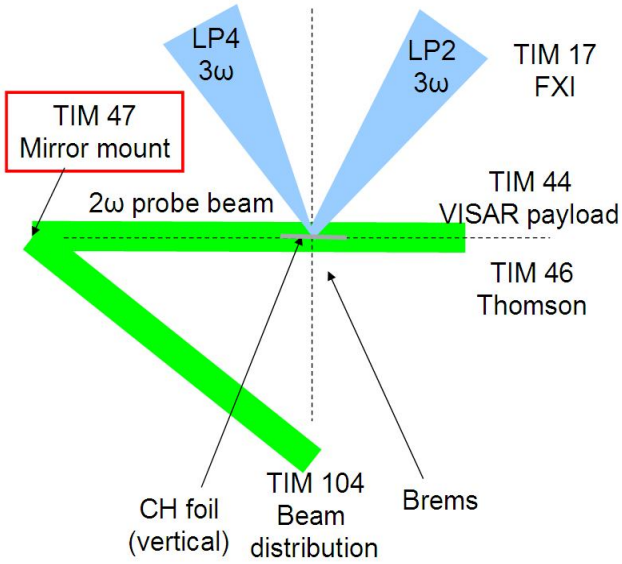


Figure 11 – Experimental design for use of the 2ω probe beam during S-CAP1.

The GOI system was used to capture the state of the foil and preplasma generated before and after the laser shot and the 2D interferometry results are shown in Figure 12. Short-pulse data was not recorded as the short-pulse laser beams were not available at the time. The three frames acquired had 80ps gating and were set apart by 500ps and 1ns intervals.

5.4. DISCUSSION

Considerable improvement in the 2D VISAR and interferometry imaging quality was made over three campaigns to commission the four-channel GOI system. A comparison of Figure 7 with Figures 8, 9 and 12 reveals reduced fringe speckles and much-improved fringe uniformity. Fine fringe shift details and fringe patterns are evident in Figures 9 and 12, which will satisfy the 2D VISAR and interferometry requirements for minimal fringe blurring and sufficient fringe displacement highlighted in Table 1. In particular the interferometry reveals previously unobserved dynamics following the laser-target interaction (shock at gas-fill pipe, live pre-plasma generation), which will be a significant method of verifying or constraining radiation-hydrodynamic model simulations. The effective spatial resolution of the system (13.5 line pairs/mm, shown in Figure 10 and also evident from Figure 12) is in good agreement with both the performance specification for the GOI head and the spatial resolution criterion of > 10 line pairs/mm set out in Section 1.2. Unfortunately there is insufficient data to conduct a more detailed shock analysis of the 2D VISAR data acquired at the time, due to unforeseen issues with the pulsed power operations during the campaign.

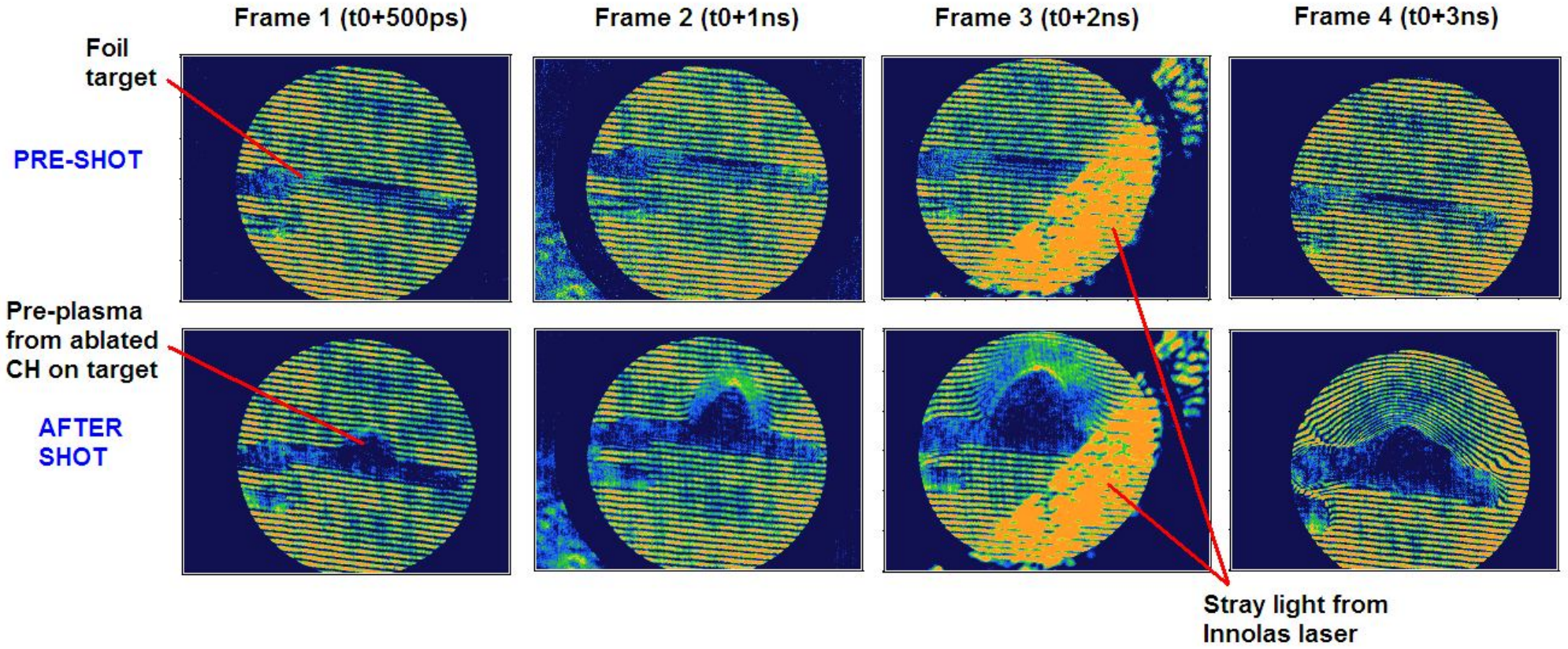


Figure 12 – Shot 5225: Interferometry traces of preplasma produced from a long pulse laser shot on a plastic foil target, captured on all four GOI channels (80ps exposures) with inter-frame times of 500ps and 1ns. PRE-SHOT shows static images from each GOI head; AFTER SHOT shows pre-plasma blow-off up to 3ns after long-pulse laser shot.

6. CONCLUSIONS

A definitive set of forthcoming programmatic requirements within the PPTC was identified and the criteria for satisfying these requirements have been evaluated in terms of available diagnostic techniques and technology at the Orion laser facility. The outcome of this review highlighted a key capability gap within the target diagnostics suite, this being the ability to perform multiple-frame, ultra-fast (<100ps) 2D optical gating of laser-plasma experiments with enhanced spatial resolution (up to 20 line pairs/mm). A number of options were considered, taking account of existing diagnostic techniques and the ways in which a new diagnostic could be implemented. This assessment showed that there was a business need to procure an advanced GOI system on the basis of the diagnostic fully satisfying the identified future programmatic requirements, being feasible to incorporate on Orion and representing best value for money.

A modular approach was taken towards development of a four-channel GOI system, which would provide the minimum credible data set to satisfy a programmatic requirement. The first step was to design, build and procure a two-channel GOI system to demonstrate the step-change in capability. The installation of this system also established the necessary infrastructure to run a four-channel GOI system. The two-channel GOI system was then commissioned in a novel 2D VISAR setup on an academic access experiment and successfully demonstrated to provide 80ps, 2D optical gating whilst resolving the structure of counter-streaming radiative shocks. Imaging issues were evident (speckle, fringe density) although this was largely attributed to the issues with the experimental setup (e.g. pointing, focusing). Following the demonstration, a case was presented in order to procure the remaining two channels of the GOI system.

A portable rack setup was designed and built to accommodate the four-channel GOI system. The four-channel system was commissioned on a similar campaign to the two-channel one, although there were some changes to target metrology. Significant improvement in the 2D VISAR imaging was obtained compared to the two-channel GOI system. In particular the finer fringe details needed to provide quantitative shock data can be seen (the effective spatial resolution is > 10 line pairs/mm) and the imaging is relatively speckle-free. More data is required to undertake a comprehensive shock analysis from the four-channel system, which could not be obtained at the time of writing due to issues with pulsed power operations on Orion.

The GOI system was also used in an interferometry-based setup on a campaign (S-CAP) to investigate short-pulse interactions, in order to address further programmatic requirements highlighted in Table 2. Multiple-frame, 80ps gating of pre-plasma generated from an ablated CH foil was recorded with inter-frame timing of 500ps and 1ns. This demonstrates an improved fidelity of measurements close to the laser-target, and as with the previous 2D VISAR experiment, an effective spatial resolution of > 10 line pairs/mm was evident. Once the inter-frame timing has been optimised this will allow simulations of radiation-hydrodynamic codes to be benchmarked.

Upcoming campaigns utilising the GOI system include an extension of the 2D VISAR experiments that have been detailed in this report. An extensive quantitative analysis of the results from these campaigns will be used to measure shock velocity profiles over the target. Additionally, short-pulse data (which could not be acquired in the S-CAP campaign due to short-pulse beamline unavailability) will be obtained from further S-CAP campaigns

to reduce uncertainty in prepulse measurements. A further objective will be to image 'channel boring' in preplasma created by a short pulse laser. The GOI will also be used in future Warm Dense Matter and Opacity investigations.

In summary, investment in the new GOI system has significantly enhanced our capacity to deliver programmatic requirements and it is cost-effective as experimental data return is improved for all laser shots on Orion. The PPTC now has a readily-accessible, cutting-edge capability also applicable to a large number of new experimental proposals. There is a desire to increase the four-channel GOI system to an eight-channel one, which could cover multiple programmatic requirements in an experiment, such as those detailed in Table 3. This will again need a robust case for investment, and such a system would be a unique asset on an international level.

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