

## Artemis: a sub 10-fs XUV source for ultrafast time-resolved science

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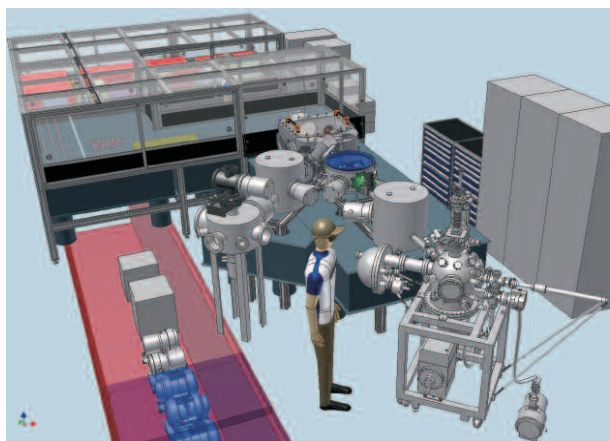
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### Introduction

Artemis is a multi-partner, multi-disciplinary project to develop a facility based on high repetition rate, few optical cycle tuneable laser sources – one of which will be used to produce ultra-fast XUV pulses through high harmonic generation. These synchronised sources will then be coupled to a number of beam-lines with end-stations for materials science and atomic and molecular physics and chemistry (figure 1). The aim is to combine frontier femtosecond optical and synchrotron technologies and enable new science in the emerging field of ultrafast X-rays.



**Figure 1.** View of the Artemis facility showing the laser (at the back, XUV beamlines and science stations (front right) and the underground services trench (front left).

### Laser beamlines

The Artemis facility will provide a variety of ultrafast, synchronised laser beamlines which can be configured flexibly either to generate XUV or as pump and probe pulses. The basis of the facility is a recently-commissioned 14 mJ, 30 fs, 1 kHz Ti:Sapphire CPA system operating at 780 nm. Part of the output energy is split and spectrally broadened in a gas-filled hollow fibre and recompressed using chirped mirrors to give sub-10 fs pulses. This technology was successfully implemented in Astra TA1, where 0.3 mJ, 10 fs pulses were routinely available. The

laser system is carrier-envelope phase controlled<sup>[1]</sup>, enabling us to provide few-cycle pulses with precisely defined optical electric fields. Factory tests of the carrier-envelope phase control showed that it could be reproducibly locked to 185 mrad for over 20 minutes.

Part of the 14 mJ, 30 fs output can also be used to drive a widely tuneable OPA system, providing 30-100 fs pulses from 1 to 20  $\mu\text{m}$ . IR pulse energies of up to 1.2 mJ at 1350 nm and 20  $\mu\text{J}$  at 4  $\mu\text{m}$  will be available.

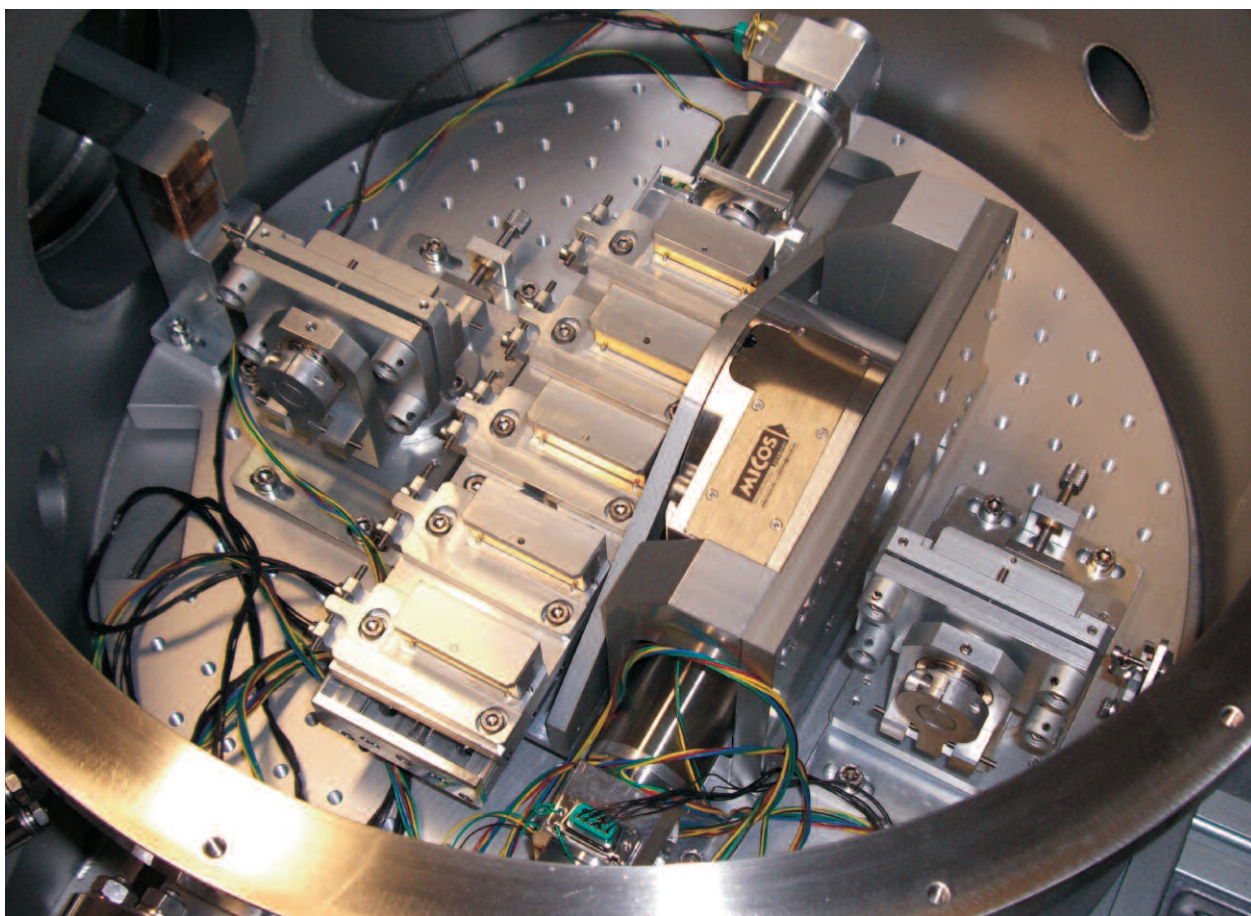
### XUV beamlines

XUV radiation in the wavelength range 10-100 nm (10-100 eV) will be produced through high harmonic generation (HHG) in a gas target. The resulting XUV radiation will have similar pulse-duration to the drive laser pulse, contain laser harmonics from 10eV to ~300eV and be synchronised to the drive laser pulse with sub-fs resolution. With conversion efficiencies up to  $10^{-6}$  at 30 eV, we estimate a photon flux of up to  $10^{11}$  photons  $\text{s}^{-1}$  per harmonic.

The XUV generated will be delivered to the interaction stations in two beamlines – one for broadband and one for monochromatised XUV pulses. Both of the beamlines will provide spectral filtering with a selection of thin metallic filters, focusing and recombination with pump or probe laser beams.

For experiments requiring wavelength and bandwidth selection, the harmonics will pass through a state of the art high resolution XUV monochromator for ultrashort pulses. This is being designed and built in collaboration with the LUXOR Laboratory of the Italian National Council of Research. The monochromator exploits the off-plane mounting of a plane grating and limits the time spread of the pulses, maintaining a good resolving power and high efficiency. The instrument is equipped with four interchangeable diffraction gratings to cover two spectral ranges with either high resolving power or short pulse duration, as shown in table 1.

The optical design is compact and is formed by three elements: two toroidal mirrors, one at the entrance to collimate the input radiation and one at the exit to focus it



**Figure 2.** The pulse-length preserving monochromator.

Grating 1	20-40 eV (62-31 nm)	10fs	$\lambda/\Delta\lambda$ 26@46 nm (27 eV)
Grating 2	100-35 eV (12-31 nm)	10fs	$\lambda/\Delta\lambda$ 23@20 nm (62 eV)
Grating 3	20-40 eV (62-31 nm)	56fs	$\lambda/\Delta\lambda$ 100@46 nm (27 eV)
Grating 4	100-35 eV (12-31 nm)	40fs	$\lambda/\Delta\lambda$ 70@20 nm (62 eV)

**Table 1.** Calculated performance of the monochromator for each of the four gratings.

on the exit slit, and one plane grating. The whole instrument can be mounted in a vacuum chamber of 50 cm diameter (figure 2). The monochromator has been tested with hollow cathode lamps to give the wavelength calibration. Measurements of the transmission efficiency through the complete monochromator with each of the four gratings show peak efficiencies of 20-30%. The four gratings, together with a gold mirror to enable a broadband XUV spectrum to be transmitted through the monochromator if required, are mounted on a translation stage to allow easy interchangeability.

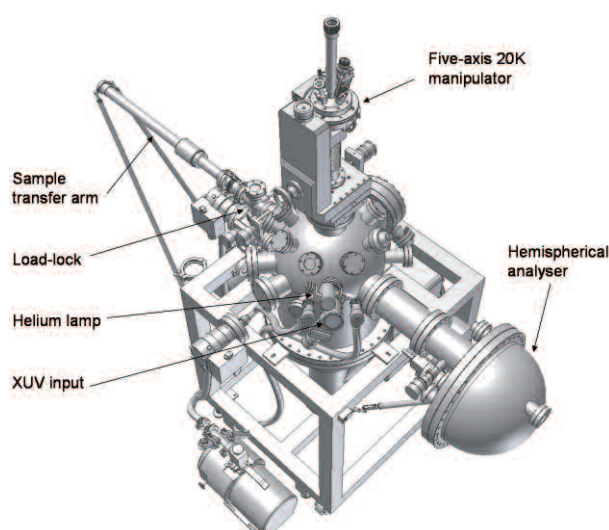
The output of the monochromator will be imaged onto the interaction region with 1:1 magnification using a gold, toroidal mirror at grazing incidence. In the broadband XUV beamline, a similar mirror images the high

harmonic source. As grazing incidence toroidal mirrors can introduce large amounts of coma, the spot-size of the XUV pulses will be measured by imaging the fluorescence induced by the XUV pulses on a crystal such as Cerium-doped YAG that fluoresces in the visible<sup>[2]</sup>. Recombination of the XUV pulses with a pump or probe laser beam can be achieved through several techniques. The XUV can be passed through a gold mirror with a small central hole, while reflecting the much larger laser beam off it. Alternatively, the laser beam can be transmitted through a thin silicon flat at Brewster's angle and XUV wavelengths >25 nm reflected.

The XUV radiation will be spectrally characterised using a flat-field spectrometer. This will detect radiation from 10 nm to 45 nm with a theoretical resolution of about 200. The detector consists of a 40 mm double stage MCP with a phosphor screen attached and a 14-bit camera. This instrument will also enable measurement of the carrier-envelope phase of the drive laser pulses<sup>[3]</sup>.

### The materials science station

The materials science station consists of a UHV ( $<2 \times 10^{10}$  mbar) chamber, a five-axis manipulator with helium 'cold finger' offering sample temperatures down to 20 K and a hemispherical analyser equipped with a 2-dimensional detector for energy- and angle-resolved photoemission experiments (figure 3).



**Figure 3. Schematic of the Materials Science Station.**

Monochromatic XUV pulses can be combined on the sample with 10 fs IR pulses and the broadly tuneable output from the OPA with variable time delay. The availability of short pulses and multiple wavelengths extends the station's capabilities by offering pump-probe techniques for time-resolved photoemission experiments to investigate coherent control and Fermi surface dynamics in complex oxides, non-adiabatic melting of charge order and Mott-gap dynamics as well as ultra-fast core-level photoemission.

The station consists of a spherical main chamber constructed from mu-metal, to reduce the effect of stray magnetic fields. Attached to the main chamber is a separate load-lock system which greatly increases sample turn-around time, reducing the down-time that is associated with vacuum pumping and bake-out. A magnetic transfer arm allows the sample to be easily transferred from the separate load-lock chamber to the sample manipulator. The high-resolution manipulator offers the opportunity for spatial and angular mapping of samples.

The chamber will include a LEED for characterisation of the surface. A helium discharge lamp will be available for off-line alignment of the analyser and calibration of the energy resolution. In the future, we hope to include provision for a wide-range of sample preparation techniques, such as an ion gun for sample cleaning and evaporators and sputterers.

### Atomic and molecular physics station

The atomic and molecular physics chamber will be designed for experiments on gas and cluster targets. This interaction station will permit experiments such as studies of the dynamics of aligned molecules, control of electron recollisions, tomographic imaging of 3D molecular orbitals, intramolecular Coulomb decay in clusters and dynamics of biological processes.

The interaction station will include a velocity-map imaging detector for ions and electrons. In velocity-map imaging,

the ions or electrons produced as a molecule or cluster ionised by the laser fragments are accelerated by a series of electrodes onto a two-dimensional detector. With careful design of the electrodes, ions (or electrons) with the same initial velocity but created in different parts of the interaction region arrive at the same point on the detector<sup>[4]</sup>. By applying an inversion algorithm to the resulting image, the original 3D velocity distribution of the particles can be recovered. Velocity-map imaging detectors also have the advantage that particles ejected at all emission angles can be collected, meaning that the full angular distribution can be measured without the need to rotate either the detector or the laser polarisation.

### Engineering

Building and engineering work to create a suitable laboratory infrastructure for the Artemis facility has been completed. Particular features of note have been the conversion of the 2 m deep trench under the lab into a service area and the creation of a system to isolate the beamline from potential sources of vibration. Laboratory space and services is also available for user groups to bring their own interactions stations.

The trench has been fitted out with lighting, power, cooling water, access stairs and forced ventilation to enable it to house the three chillers, two cryo-compressors and six scroll pumps required for the Artemis system. A crane has also been installed to both lift the trench covers which weigh over 500 kg each and get equipment in and out of the trench.

The vibration isolation system consists of a series of five rigidly joined 45 cm thick optical benches upon which the laser and optics are mounted. The benches are to a bespoke design, incorporating a dropped height to provide room for the vacuum chambers and holes through which a chamber support framework passes. The vacuum chambers are fixed to this framework which in turn is fixed to the ground, having no contact with the benches. The internal optics are attached to the optical benches and decoupled from the chamber in which they are housed by connection via edge welded bellows. This vibration isolation system should allow us to successfully deliver carrier-envelope phase locked pulses to the science stations.

### Project progress

The Artemis project is funded through a £1.5M Facility Development grant. The laser beamlines are now available for users and the first user experiment started in July 2008. XUV beamlines and science stations will come online in early 2009.

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