Final Review for the CEOI 5th & 6th Open Call Projects

Project Summaries

Review of the 5th Open Call Projects

10:10 High-Level System Integration of UK Receiver Technology for the STEAM-R & MWS Passive Microwave Instruments - Simon Rea, STFC RAL

The aim of this project is to further develop a novel high-resolution wideband spectrometer (WBS) and to undertake critical system-level design and breadboarding activities in preparation for full integration of a sideband-separating receiver with high-resolution spectrometer back-end into the MARSCHALS millimetre-wave airborne instrument.

A prototype of the novel FFT-based WBS was developed by STAR-Dundee Ltd using internal PV funding, which integrated FFT code developed by Astrium Ltd and the University of Dundee with support from ESA. The prototype WBS was successfully characterised with the MARSCHALS instrument with support from CEOI. UK sideband-separating mixer technology (SHIRM) was successfully prototyped with previous support from CEOI and a current project funded by the Centre has resulted in the first atmospheric measurements of a sideband-separating receiver from the Jungfraujoch Observatory.

The development of a second generation WBS is necessary to realise a unit which is fully compatible for future integration with MARSCHALS and which satisfies the operational requirements of passive mm-wave space-borne sensors. Deployment of the upgraded MARSCHALS instrument in a future measurement campaign will significantly strengthen the scientific and technical case for inclusion of sideband separating mixers on STEAM-R, the millimetre-wave instrument on the Earth Explorer 7 candidate mission PREMIER. Furthermore, development of the second generation WBS and its future deployment on MARSCHALS will firmly position the UK-developed high-resolution spectrometer solution for future space-borne sensors. Such a spectrometer is particularly relevant to the Microwave Sounder (MWS) within the scope of the Post-EUMETSAT Polar System (Post-EPS) mission.

10:40 System and Applications Study for a Future Geosynchronous Radar Mission

Stephen Hobbs, Cranfield University

All radar satellites so far have been in low Earth orbit (LEO). Images from these satellites are used for applications ranging from mapping forestry to measuring the movement of glaciers and even Earth's tectonic plates. Using LEO however means that we can't observe changes happening faster than about a week. Also, the atmosphere distorts images slightly and this complicates their use for very precise measurements.

An alternative to LEO is geosynchronous orbit (GEO). GEO is already used by weather satellites to take visible images using the Sun's illumination. Weather satellites produce frequent images over wide areas, but GEO has not been used so far for radar. Calculations and some initial experiments show that radar imaging from GEO is possible. This project's aims are to resolve some of the remaining technical problems, especially the processing needed to form good images, and to evaluate potential applications for GEO radar.

GEO radar could play a valuable role in monitoring natural hazards, weather and climate. One particular application would be to survey large areas for ground motion, e.g. landslide risk, subsidence and earthquakes. Another role may be measuring soil moisture: the frequent images mean that daily changes can be observed directly which will help early detection of drought or flood risks. GEO radar should also be much more responsive in cases of natural disasters: images will be available within hours whatever the weather, day and night.

A by-product of imaging from GEO will be maps of the Earth's atmosphere showing either humidity distribution or the state of the ionosphere. These data are valuable in themselves and will help with weather forecasting and climate studies. They may even help us to forecast space weather from the changes we will be able to detect in the ionosphere. Having measurements of the atmosphere as we image from GEO means that the atmosphere's effects can be removed, so GEO radar images could be used directly for precise measurements of changes at Earth's surface.

Although not yet demonstrated, the potential benefits of GEO radar justify this research which may lead to valuable new services from space.

10:55 Emulation and performance Study of an On-Board Level 1 Processor for Squinted SAR

Alex Wishart, Astrium Ltd

Astrium Limited and BAE Systems Advanced Technology Centre are developing a novel approach to real-time generation of Level 1 SAR products. The computationally intensive compression functions are formulated in algorithms designed for implementation in SRAM/Flash FPGA or ASIC hardware, suitable for satellite on-board processing. The approach is being tested through simulations using ERS-2 datasets as part of a 4th Call CEOI Seedcorn Study.

The aim of the present Seedcorn Study is to extend this technique to include azimuth focussing of squinted SAR systems such as the Wavemill oceanographic SAR concept. Wavemill uses forward and aft antennas nominally squinted at ±45o in azimuth to allow ocean currents to be sampled from orthogonal directions, allowing 2D surface currents to be mapped.

11:10 High-frequency Doppler Radars for a Polar Precipitation Mission

University of Leicester lead, presentation by Peter Huggard, STFC RAL

Despite the well-recognized role played by clouds and precipitation in affecting our climate, gaps in the remote sensing observational capabilities of their vertically resolved microphysics significantly hamper progress in understanding the physical processes within them, whose parameterizations underpin numerical weather and climate models. Accurate measurement of solid precipitation remains particularly challenging and accurate large-scale estimations of the snowfall are not yet available. While the CloudSat mission has paved the way towards the use of millimetre wave radars (94 GHz) for monitoring snow and for providing vertically-resolved precipitating cloud microphysical measurements, it has become clear that multi-frequency radar observations are irreplaceable assets to overcome the snow microphysical deadlock, i.e. the dependence of the snow rate on the snow microphysical characteristics: particle habit, fall velocity and size distribution.

This study aims at better quantifying the information content coming from dual-frequency reflectivity ratio measurements and at identifying the optimal frequency pair for discriminating between snow habits and for narrowing down uncertainties in snow-rate estimates. Besides considering the 35-94 GHz pair, initially proposed for the EE8 Polar Precipitation Mission radar, higher frequencies (140 and 220 GHz) will be examined. Since the deployment of space-borne radars

at such high frequencies is challenging, the critical technology development requirements required for an EE9-like space-mission will be assessed. Specifically, a subsystem to component level study of the high power millimetre wave frequency multipliers required to drive the radar transmitter's output stage will be undertaken. The resulting design guidelines will accelerate eventual hardware development, and will provide an input to a technology development roadmap.

11:45 Advanced GRIN Lens Design for mm-wave Radiometer Systems

Graham Maxwell-Cox, Astrium Ltd

This seedcorn project investigates the design methodology for producing Gradient Index (GRIN) lenses for sub-mm wave applications in radiometers using metamaterials. This work follows on from the Metamaterial Matching Study (CEOI 4th call, 2011).

The observation that there are standing waves in a sub-mm-wave radiometer system, due to reflections between horn feeds and focusing lenses, leads to a need to produce better matched horn / lens combinations to reduce beam distortion and reduce RF losses. The use of GRIN lenses may be indicated, but requiring complex dielectric formats and structures that are not easily produced in the microwave region. In particular, the use of metamaterials for the lens body may be required with εr and μr varying in the lens volume. This project aims to identify suitable materials for space use, design and analysis methodologies to produce the correct metamaterial and the manufacturing requirements for a complete lens.

12:00 Pre-development of Critical Technology for Metop-SG MWS Instrument (166/183 diplexer)
Mike Winser, Astrium Ltd

Astrium Ltd, is undertaking development of a 165/183GHz waveguide diplexer, supported by STFC Rutherford Appleton Laboratory (RAL), and supplier Thomas Keating. The diplexer has the potential to greatly reduce the complexity of the Quasi-Optical Network (QON) for the MetOp-SG Microwave Sounder (MWS) instrument. The 165 GHz channel must be separated from the 183 GHz channels in order to allow these to use separate mm-wave receivers since it is not possible for a single receiver to cover the full bandwidth. The separation of the channels can, in principle, be performed quasi-optically using a dichroic beam splitter but the resultant QON would be complex. An alternative approach is to use a common QON path for both sets of channels and then perform the separation within a waveguide diplexer. The diplexer will consist of a Y-junction with suitable cavity waveguide filters in the 2 output arms. The main requirement will be to achieve low insertion loss (< 1 dB) between 164 – 167 GHz and between 175 – 191 GHz. Since the diameter of the waveguide will be ~1mm, manufacture of the diplexer will only be possible by electroforming. Three identical waveguide diplexers will be manufactured and tested to verify that both the required mechanical tolerances of <5μm and the insertion loss performance over the required 165 and 183 GHz MWS channels have been achieved. The development will not only enable the UK to prepare for the Phase B MWS instrument opportunity by addressing a key instrument technical issue not covered by the ESA Phase A and parallel technology development studies but also has potential application to other instruments operating in the 100 GHz to 200 GHz frequency range.

12:15 The Design of an Innovative Ice Cloud Imager for the Global Measurement of Cirrus Cloud Dave Summers, SEA

Radiative transfer in the atmosphere is a key climate driver. Radiative transfer in clear air is reasonably well understood – leading to such actions as the global control through UN Treaty of chemicals with major atmospheric effects, such as chlorine-based solvents. Much less well understood is the effect of clouds; low altitude clouds will be studied in detail by the EarthCARE mission, but high altitude cirrus remains a problem. There is anecdotal evidence that the frequency of high altitude cirrus may have been increasing since the development of the jet engine, but systematic global measurements remain for the future. The UK-provided SCR on Nimbus 5 made cirrus measurements during 1973 with 50µm and 130µm channels; a great deal was learned but this did not become an operational system.

More recently, it has been concluded that the preferred approach is to make measurements around the same frequencies, but approached from the microwave side; 300µm corresponds to 1THz, and submm radiometer technology is now becoming available at frequencies in the high 100s of GHz.

The ICI instrument was planned to fly on MetOp 2G, but even though its scientific desirability is not in question, its selection is now in doubt for financial reasons. The UK Met Office is known to have led the arguments for the provision of this data set.

In the activity described here it is proposed to study means of providing such cirrus cloud measurements at the lowest possible cost. We propose to compare the submm technology approach with the infrared approach in order to identify the lowest cost instrument which would provide useful data. This will lead to a high value-for-money solution and will enable the disruptive technology developed in the UK to be deployed in a timely manner.

12:30 Assessment of a New Low Weight Mirror Fabrication Technique for Future EO Space Systems - Peter MacKay, Gooch & Housego

The aim of the project is to investigate alternate methods of reducing the weight of mirrors for space applications while retaining the required stability of surface form. Two alternate means of joining Zerodur® components without epoxy will be investigated and the optimum will be chosen for use in the second half of the project. Epoxy is to be avoided because of potential outgassing issues. The optimum bonding method will be selected and used in two different designs of fabricated lightweighted 150mm diameter planar mirrors. In the first lower risk method the mirror blank will be lightweighted using traditional pocketing techniques. However to increase the stability, a planar back plate will then be bonded to the ribs using the technique selected in the first section of the project. The second method building up the support webbing from individual components will also be investigated, offering the potential for lower mirror blank fabrication costs, but at significantly higher risk.

13:30 The Ultra-Compact Air Quality Mapper (UCAM) to Measure Nitrogen Dioxide in the Urban Environment - Roland Leigh, University of Leicester

Air quality continues to be a global challenge, with increasing urbanization and improved understanding of the impact of poor air quality on human health. The Ultra-Compact air quality mapper (UCAM) is a novel instrument concept to measure nitrogen dioxide in the urban environment, thus providing vital information on emission sources and downwind exposure. In this project the University of Leicester with Surrey Satellite Technology Ltd. will produce an instrument concept and outline design, suitable for a launch opportunity with very constrained volume, mass and cost budgets.

13:45 Hollow Waveguide Laser Heterodyne Radiometer – A Fully Integrated, Miniaturised and Ruggedized Instrument - Damien Weidmann, STFC RAL

This project addresses the design, manufacture and demonstration of a fully integrated, miniaturised Quantum Cascade Laser Heterodyne Radiometer for Earth observation. It represents the combination of highly successful work on laser heterodyne radiometry with novel hollow waveguide optical integration techniques. The work will culminate in demonstrating the integration, ruggedisation and miniaturisation of a laboratory bench based system which originally had a footprint of 75 x 75 cm and will be reduced to something that can be held in the palm of the hand, e.g. ~10 x 10 cm. Commensurate reductions in mass and optical robustness will also be achieved. These will be coupled with significant improvements in heterodyne mixing efficiency leading to a fundamental advance in laser heterodyne radiometer instruments for Earth observation applications and beyond.

The scope of the project encompasses the design, realization, demonstration, and assessment of a fully integrated system comprising both active (quantum cascade laser, optical detector) and passive (polarizer and beam splitter/combiner) components. The components will be integrated into alignment features in a common ceramic substrate which also incorporates a hollow waveguide mixing circuit. In this manner the aim will be to design, build and assess the very first fully integrated, miniaturised and ruggedized, laser heterodyne radiometer. The proposed work represents a critical step towards the development of an in-orbit demonstrator instrument.

The fully integrated instrument will be tested in the laboratory using blackbody sources and absorption spectroscopy to establish noise equivalent spectral radiance figures and compare them with ideal ones.

14:00 The Application of a New Bolometer Processing Technique to Fire Measurement & Monitoring from Space - Mark Chang, SSTL

Fires are important indicators for understanding the carbon cycle and for monitoring and forecasting atmospheric composition. Global biomass burning is the second largest source of trace gases and the largest source of fine carbon particles in the troposphere, and a key parameter for models is the emission rates of smoke from fires. The detection and measurement of fires from space has been demonstrated using a variety of instruments including the NOAA AVHRR, MODIS and Bird HSRS infrared (IR) payloads. These measurements are achieved using spectral bands in the visible, middle-IR (3-5 µm) and long-wave IR (8-14 µm) to distinguish the signature of fires from those of clouds and sun glint. To date the technology solution has dictated the use of expensive cooled detectors. The proposed programme will explore new processing techniques and the performance of new broadband uncooled detectors to assess the feasibility of achieving adequate performance at much lower cost.

14:15 Concept Studies for a Methane Emission Imager - a Small Satellite Payload for Greenhouse Gas Monitoring - Hartmut Boesch, University of Leicester

We define a novel concept for measuring atmospheric concentrations of the important greenhouse gas methane (CH4) based on the use of discrete shortwave infrared spectral bands. We will use the CH4 proxy retrieval method to infer atmospheric concentrations, which has proven heritage with SCIAMACHY and most recently successfully employed by Leicester University for GOSAT. Such an instrument concept offers significant advantages over existing systems in terms of size and superior spatial resolution, providing a realistic option for a small satellite payload and a possible greenhouse gas demonstration on the SSTL TechDemoSat platform.

14:30 TRUTHS – A Mission to Provide Observational Climate Data to Enable the Unequivocal Detection of Climate Change - Paul Green, National Physical Laboratory

The establishment of an observational climate benchmark data set of sufficient accuracy to enable the unequivocal detection of climate change with the ability to constrain and test climate forecast models on a decadal time scale is one of the key challenges laid down by the international climate science community. The UK led TRUTHS (Traceable Radiometry Underpinning Terrestrial- and Helio-Studies) and its US sister, CLARREO (Climate Absolute Reflectance and Refractivity Observatory) are mission concepts proposed to address this exacting issue.

Although not selected in the recent ESA EE8 call, TRUTHS received a strong recommendation of support and encouragement that an early implementation should be explored as part of a wider international collaborative effort. In support of that goal this project will look towards optimising the mission's scientific objectives and consequential observational requirements to facilitate future more detailed mission design studies.

The study will be limited to climate benchmarks involving measurements of solar radiation incident upon and/or reflected from the Earth. However, it will consider a range of potential options for achieving these, ranging from: incremental improvements of existing or planned sensors; the payload requirements/options for a dedicated self-contained mission; upgrade of performance of other sensors by reference calibration against a "high accuracy satellite" or some combination of these approaches.

The Draft mission requirements document resulting from this study will be developed to ensure that the required high SI traceable accuracy can be achieved and demonstrated whilst also considering the relative complexity and risk of implementation through contrast with anticipatable performance capabilities through knowledge and experience of existing instrumentation and methods.

Review of the Instruments and Missions 6th Open Call Projects

15:00 POLYDOROS – A W-Band Doppler Radar to Characterize Clouds, Precipitation Microphysics and Horizontal Winds - STFC RAL lead, presented by Neil Humpage, Uni of Leicester

Wide swath scanning W-band Doppler radar systems have the potential of characterizing the three dimensional structure not only of clouds and precipitation microphysics but also of horizontal winds. Their unprecedented view of clouds and precipitation systems can provide unique observations for data assimilation and for modelling studies, with a great potential in the improvement of numerical weather prediction and in the forecasting of extreme weather events like hurricanes, typhoons and severe weather. A W-band conically scanning radar concept with Doppler estimates based on the polarization diversity pulse-pair technique has been established in previous ESA studies. We propose to study the benefit of adding pulse compression to the radar design both to reduce the cross-talk between the H and V returns and to increase the overall signal-to-noise ratio, with expected improvements both in detection and in Doppler estimates accuracy. A trade-off study will be performed by coupling sophisticated end-to-end radar Doppler simulators with pulse compression signal processing. Configuration parameters (e.g. chirp length, chirp bandwidth, pulse-pair distance) will be changed over a wide range of values in order to determine the configuration that optimizes coverage and/or accuracy for Doppler velocity estimates and that reduces the impact of the blind layer, of aliasing and of range side-lobes contamination. This study will enable a critical refinement for a W-band conically scanning Doppler radar concept to be proposed for the upcoming Earth Explorer 9 call.

15:10 Wavemill – A Mission to Provide Wide Swath, High Resolution, High Precision Maps of Ocean Topography and Surface Currents - Benjamin Dobke, Astrium Ltd

Ocean currents have a significant impact on the transfer of energy and moisture between the ocean and atmosphere. There is a strong scientific need to resolve mesoscale features such as eddies, fronts and filaments to help improve operational ocean models and the understanding of oceanic mixing. For the near-shore region maps of ocean surface currents are of key importance for scientists and policy makers dealing with a variety of fields including meteorology, ocean commerce, disaster management and mitigation.

Ocean circulation monitoring on a global scale is already possible with radar altimeters (e.g. from the Jason-1/2 satellites). However, the correct modelling of ocean flows and circulation requires significantly improved spatial and temporal resolution to avoid effects such as aliasing due to the periodicity of tidal signals. Furthermore, measurements derived from conventional altimeters provide poor coverage due to their small swaths (typically a few km) and will give ambiguous signal returns close to land.

The Wavemill concept is a novel wide-swath hybrid interferometric SAR instrument which addresses the mesoscale sampling issues. It offers the ability of generating wide swath, high resolution, high precision maps of ocean topography and surface currents in the open-ocean and coastal zone using a single spacecraft. It will utilise both along (ATI) and across track (XTI) interferometry to measure ocean current velocity and surface height in the sub-15km region, within multiple 100km wide instantaneous swaths. This capability gives Wavemill the unique ability to separate surface currents from the underlying geostrophic currents, a relationship of key interest to not only the scientific community, but also the commercial, governmental, and civilian sectors. These objectives are directly aligned with key NERC marine science objectives and the scientific challenges to understand and quantify variability in ocean dynamics and circulation as set out in ESA's Living Planet Programme.

The Wavemill mission is a rapidly maturing concept with strong UK academic and industrial involvement including the possibility of a UK science lead. It is a candidate for ESA's Earth Explorer 9 core mission series with a nominal launch expected around 2020. The purpose of this CEOI funded study will be to develop the concept further both at an instrument and system level to ensure a mature concept is available to be submitted into the next ESA Earth Explorer call, improving the prospect of mission selection.

15:20 An Assessment of the Thermal IR Laser Heterodyne Radiometer for monitoring atmospheric trace gases - Damien Weidmann, STFC RAL

Improved understanding, modelling, and predicting of climate & pollution underpins the importance of monitoring trace gases from space. Major advances for both process understanding and monitoring applications require increased resolution on contemporary and planned future satellite missions (vertical, spatial and temporal) in order to bridge the gap in scales from satellite to surface networks.

LHR is identified to offer a solution through compact new technology, whose development is being pioneered in UK (CEOI, STFC, NERC). Developing to higher TRL would position UK to capitalize on its early worldwide lead in this technology and position for deployment on novel airborne platforms (UAVs, HAPs or Cubesats) in preparation for future flight opportunities.

This proposal is to perform a critical assessment of relevant applications and observing requirements to identify the priorities to drive design specifications of an LHR for initial field deployment. This will entail: a review of requirements for proposed future missions to sound atmospheric composition from space, identification of primary driver species and wavelength ranges which best exploit LHR capabilities, radiative transfer calculations to quantify benefit of LHR spectral resolution vs established techniques and establish sensitivities, and an initial assessment of spatial and temporal resolution achievable for different viewing geometries.

The study will reach conclusions and make recommendations concerning prioritisation of target species and application and next steps on instrument development and airborne deployment to demonstrate capabilities.

15:30 Using a THz Limb Sounder to Monitor Important Chemical Species in the Mesosphere and Lower Thermosphere - SSTL lead, presentation by Bruce Swinyard, STFC RAL

This project aims to assess the requirements and feasibility of providing a low cost space mission to observe terahertz frequency (THz) atomic and molecular transitions to trace and monitor important chemical species in the Mesosphere (55 - 90 km) and lower thermosphere (90 - 120 km), a region known as the MLT. Observations show that the mesosphere is cooling an order of magnitude faster than the troposphere is warming in response to increased greenhouse gas concentrations and stratospheric ozone depletion. It therefore provides a highly geared indicator of global climate change. Given its importance, it is surprising that the chemistry of the MLT has not been well studied to date by space based platforms. Part of the reason is that the best probes of the important chemical species (atomic O, OH, H2O, NO etc) lie in the THz for the MLT and the technology for observing them has been seen as expensive to deploy in comparison to other wavebands. Recent technical advances in heterodyne receivers, especially in the area of Quantum Cascade Lasers (QCLs) as local oscillators, planar Schottky mixers and digital signal processing, mean that payload resource demands (mass power and volume) are being significantly reduced and are evolving towards compliance with smaller spaceborne missions. This opens the possibility of using SSTL type low cost space platforms to deploy a multiple band THz system using UK developed technology for the receivers.

The study will identify the key THz transitions required to model and interpret the chemistry in the MLT. To do this we will run sophisticated atmospheric and retrieval models to assess line strengths and the impact of detection noise on scientific return. This work will provide the critical requirements on the payload and mission. We will link these to a review of currently available and future developments of THz receiver technology which will be fed into the payload and mission design tasks. Our initial assessment is that all of the technology required for this ground breaking mission resides in UK industry, universities and institutions. In short, the technology of Schottky diode mixers (RAL Space) and low mass local oscillators (QCLs - Leeds) plus fast digital wide band spectrometers (Astrium/Dundee) make this project feasible on low cost platforms (SSTL). The key points for the present study are to perform a scientific trade-off between various transitions in the 1 to 5 THz band, to assess the technical feasibility of building receivers to detect these lines and to undertake a mission level study to look at the feasibility of utilising a low cost SSTL platform. By demonstrating that such a mission is feasible we will be well placed to bid for a full mission study funded either directly through UKSA or through a proposal for an ESA Earth Explorer mission of opportunity.

15:40 Frequency Selective Surface Filters – Providing Accurate Numerical Predictions of Beam Propagation and Reflection - Raymond Dickie, Queens University Belfast

The purpose of this project is to develop a new numerical model for finite Frequency Selective Surfaces (FSS) which will provide extremely accurate numerical predictions of beam propagation and reflection, when the filter is illuminated by a Gaussian beam. The model development will be carried out on the 24 GHz channel of the MetOp-SG Microwave Sounder (MWS) for an FSS that has recently been fabricated and tested. The project develops a capability not covered in earlier phases or other studies and will demonstrate for the first time results for finite FSS with a scaled Gaussian beam illumination. Given that this better reflects the Quasi-Optical Instrument (QOI) environment, more precise numerical predictions will be obtained. Finite FSS modelling requires significantly more computer resources than previous approaches but these are now becoming more accessible due to the availability of hardware accelerated GPU computing.

15:50 Flying the ComPAQS Air Quality Instrument as an Airborne Demonstrator to Map NO2 Over Leicester at High Resolution - James Lawrence/Roland Leigh, Univ. of Leicester

The CompAQS project, developed initially under CEOI funding and now supported by funding from NERC through the CityScan project, has demonstrated a key UK competence in remote sensing of Air Quality using visible spectroscopy. A CompAQS payload concept was developed for the TechDemoSat(1) flight opportunity, with a number of future possibilities for flight including EE-X, TechDemoSat-n, or a Bi-Lateral mission. Air Quality concerns remain high in scientific, economic and policy agendas with recent studies suggesting a European cost of poor air quality at €165bn p.a. There is increasing awareness of health and quality-of-life impacts of exposure to poor air quality, with health costs in the UK alone estimated at £15bn p.a. Furthermore, with increasingly high-resolution greenhouse gas missions such as CarbonSat being proposed, the use of NO2 as a short-lived tracer of combustion-related emissions could be a new use for a small-profile NO2 mapper, such as CompAQS.

This project takes the current CompAQS spectrometer, which has been tested as part of the CityScan ground-based network, and provides two flight demonstration opportunities. These flights will map NO2 over Leicester at 20 x 20 m resolution, and demonstrate key CompAQS concepts of source identification and exposure mapping.