The Australian European Southern Observatory Positioner (AESOP)

C1. Statement addressing selection criteria

C1.1 Significance of research supported by the proposed research infrastructure

Executive Summary: The construction of the AESOP instrument, to be incorporated into the European Southern Observatory's VISTA telescope in Chile, will act as a 10-year buy-in to ESO's premier wide-field spectroscopic survey facility. This will enable Australian astronomers to lead a 2 million galaxy survey to address key questions related to: dark matter, galaxy formation, and the evolution of mass, energy and structure over half the age of the Universe. In addition, this proposal will secure full access for 8 Australian astronomers and their students and postdocs, to the design and scientific exploitation of all surveys to be conducted by VISTA over the next decade, including unprecedented studies of dark energy (i.e. the 'cosmological constant' Λ) and the Milky Way.

The European Southern Observatory (ESO) is the world's leading astronomical facility and is funded by an international government charter which now includes 15 member states. ESO operates three major observatories (Cerro Paranal, La Silla, and the Chajnantor plateau) in Chile involving a network of over 20 telescopes including the 4-metre class VISTA survey telescope (see Fig. 1). The Australian European Southern Positioner (AESOP) is a critical component of an approved $60 million upgrade which will convert the VISTA telescope from a dedicated near-IR imaging facility to what will be the world's leading wide-field spectroscopic facility (VISTA/4MOST).

This facility will be used to survey over 30 million (60 million) stars, galaxies and active-galactic nuclei over its first 5 (10) years of operations to address key questions related to dark energy, dark matter, and galaxy formation including the detailed mapping of the stellar populations of our own Galaxy and the comprehensive follow-up of a number of major ground and space based facilities (GAIA, eROSITA, Euclid, SkyMapper, ASKAP, SKA Phase I). In exchange for covering the labour-costs associated with AESOP, Australian-based astronomers have been invited to join the 4MOST Consortium for its first decade of operations as full members and to lead a study of 2 million galaxies (WAVES).

Figure 1: (*left*) a panoramic shot of the European Southern Observatories main site, Cerro Paranal, with the dedicated robotic VISTA survey telescope shown at the right-hand side. (*right*) a view of the VISTA telescope, a robotic 4-metre short-focal ratio telescope optimised for a wide-field of view. This telescope will be reconfigured and optimised for wide-field fibre-fed spectroscopy with the Australian European Southern Observatory Positioner as the critical fibre-positioning component of this upgrade. Images courtesy of ESO.

The Wide Area VISTA Extra-galactic Survey (WAVES)

The WAVES survey of $\sim$2 million galaxies to $r_{\rm AB} < 22$ mag will be one of the VISTA/4MOST flagship surveys, and if this LIEF bid is successful, will be led by Australian-based astronomers and open the the full Australian community. The current survey design consists of two interleaved studies (see Fig. 2): DEEP-WAVES optimised to study the evolution of mass and energy over a 6 billion year timeline, and WIDE-WAVES optimised to probe deep into dark matter halos to investigate the properties of dark matter.

• DEEP-WAVES will cover 100 sq. deg. to $r_{\rm AB} < 22$ mag and extend the power of galaxy population statistics out to $z \sim 1$. The ~ 1.2 m galaxies will allow for the detection of $\sim$50k dark matter haloes (to $10^{12}{\rm M}_{\odot}$), and 5k filaments, representing the largest group and filament catalogue ever constructed, and the first detailed study of galaxy evolution as a function of halo mass. The sample size would be 60 times the much lauded zCOSMOS-bright sample (60+ papers and 3,000+ citations).

• WIDE-WAVES will cover 750 sq. deg. to $r_{\rm AB} < 22$ mag with additional photo-z pre-selection ($z_{\rm photo} < 0.2$). This will target ~ 0.8 m galaxies and will uncover 85k dark matter halos, allowing a detailed study of the halo occupancy of 10^{11}–$10^{12}{\rm M}_{\odot}$ halos to a stellar mass limit of $10^7{\rm M}_{\odot}$, and providing a field dwarf galaxy sample to 5×10^6 Mpc^3 (see Fig. 3).

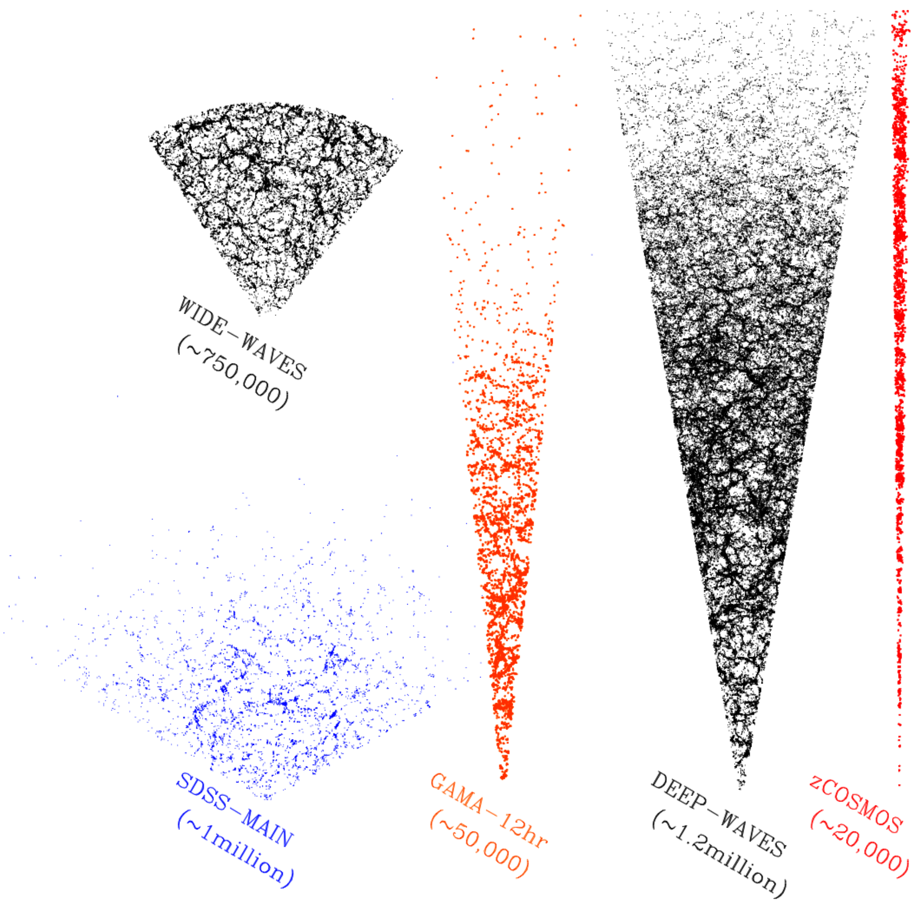

Figure 2: A comparison of cone plot sections (0.5deg thick) from various surveys as indicated. All cones are shown to the same scale with WIDE-WAVES extending to z=0.2 and DEEP-WAVES to z=1.0. The data for the WAVES surveys are simulated using the Theoretical Astrophysics Observatory, courtesy CI Croton.

Figure. 2 illustrates visually the order of magnitude improvement of WIDE and DEEP WAVES in terms of mapping the structure of the cosmic web over the currently leading spectroscopic surveys while Figure 3 shows the advance in terms of measuring the space-densities of galaxies to very low stellar mass values. This Australian-led survey, builds upon previous high-impact Australian studies (2dFGRS, CI Colless et al., 2001; WiggleZ, CI Drinkwater et al., 2010; 6dFGS, Jones et al., 2004, and GAMA, CI Driver et al., 2011) by more than an order of magnitude, and is optimised to build the largest statistical sample of low-mass satellite galaxies within a cosmologically representative volume. These Australian surveys have had exceptionally high impact, producing over 340 peer reviewed papers and over 30,000 citations to date.

The WAVES principal design driver is to test the consensus cold dark matter model by measuring: the galaxy stellar mass function to very low stellar masses (see Fig. 3; Baldry, CI Glazebrook & CI Driver 2008); the dark-matter halo-mass function (to $10^{11}{\rm M}_{\odot}$; Murray, CI Power & CI Robotham 2013); halo occupation statistics (to $10^4{\rm M}_{\odot}$; Berlind et al., 2003); and galaxy merger rates (CI Robotham et al., 2014), with the ultimate goal of constraining the mass and physical properties of the dark-matter particle, i.e., we will test Cold, Warm and Self-interacting dark matter models (CI Power 2013) along with alternative gravity models

(Carlesi et al., 2014).

This requires not only the construction of an extensive fully-sampled galaxy survey, such as WAVES, but also bespoke billion-particle numerical simulations and the careful comparison of these data against the observed distributions (e.g., Prada et al., 2012). These simulations are currently in development using the Pawsey supercomputing Centre and some preliminary examples of the broad halo distribution showing obvious quantifiable differences are shown in Fig. 4. In order to probe to the very faintest depths we will also apply a pioneering halo-refinement method. This method uses the 2 million galaxies to first define a detailed catalogue of dark matter halos (groups; CI Robotham et al., 2011) which in-turn can be combined with a high-fidelity photometric redshift catalogue (provided initially by VST and later by LSST), to identify the very faintest occupants of each dark-matter halo to depths of $5 \times 10^4 M_\odot$ (see Fig. 3).

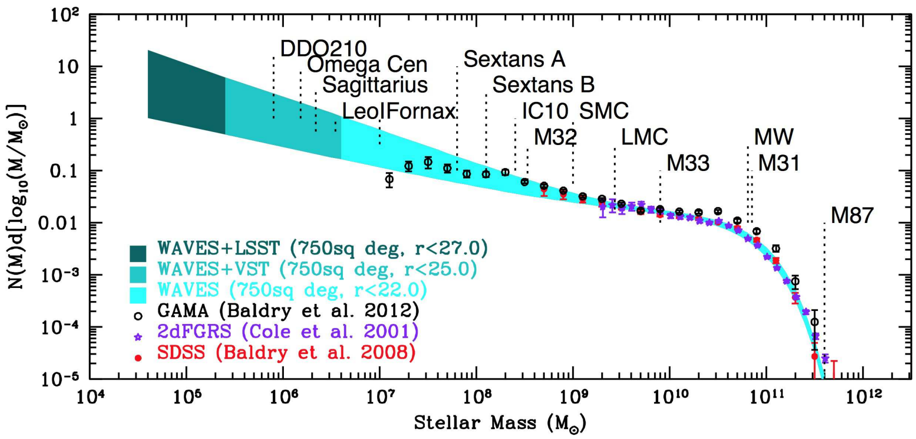

Figure 3: Our current understanding of the space-density of galaxies are shown as data points (as indicated) while the mass range probed by WAVES and its photometric extensions are indicated by the blue shaded regions. The locations of known galaxies from the Local Group are indicated.

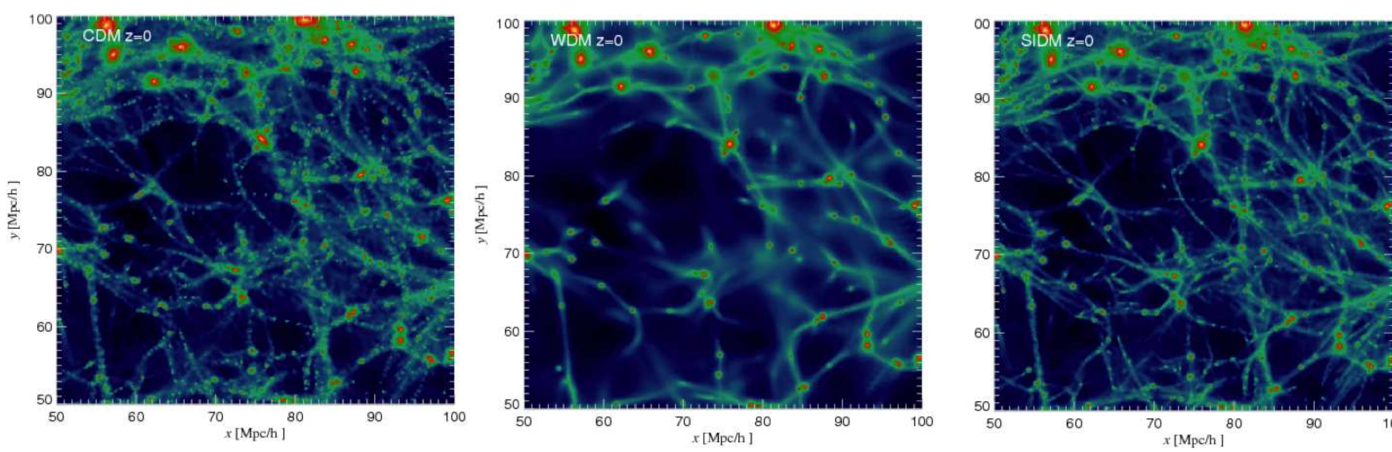

Figure 4: Three numerical simulations of the distribution of dark matter in Cold, Warm or Self-interacting Dark Matter (left to right). There are many ways in which these distributions appear different, all of which will be explored by WAVES, WAVES+VST and WAVES+LSST.

In brief our goals are:

(1) Establish the physical processes that shape the properties of the satellite galaxy populations: we will use state-of-the-art supercomputer simulations of Cold Dark Matter (CDM) and its alternatives, such as Warm Dark Matter (WDM) and Self-Interacting Dark Matter (SIDM), coupled to sophisticated galaxy formation models, to place stringent constraints on the physical processes that drive galaxy formation in low-mass haloes (principally star formation and feedback) and on the mass of the dark matter particle. Our focus will be on measuring the (i) the space-density of galaxies within dark matter halos (a key test of dark matter particle mass), (ii) the radial distribution of galaxies within dark matter halos, (halo occupation statistics), and (iii) and the frequency of dynamically bound galaxy pairs. This work will exploit Australian HPC facilities (e.g. the Pawsey Centre) in conjunction with data from ESO VST and the US LSST telescopes.

(2) Measure the evolution of the mass and energy budgets since half the age of the Universe: we will directly measure the baryon content (gas, stellar, dust and dark) and energy (photon) budgets via spectralenergy distribution modelling, for over 2 million galaxies allowing us to construct a detailed model of the growth of mass and structure and the energy processes associated with this evolution. This work will be done in conjunction with data from the Australian Square Kilometre Pathfinder and the Phase I of the Square Kilometre Array (led by CIs Meyer and Sadler).

(3) Identify the emergence and growth of structure on 1kpc-10Mpc since half the age of the Universe: we will quantify the frequency, properties, and emergence of filaments, superclusters, clusters, groups, spheroids, discs, bulges, and bars over a 6 billion year baseline. This work will be done in conjunction with the European Space Agency's Euclid facility scheduled for launch in 2022 which will provide the necessary $0.2''$ imaging to resolve galaxy structures. Access to Euclid for this purpose is approved as part of a Euclid Legacy Survey involving CI Driver.

(4) Enter the Dark Ages by finding the very first galaxies: we will robustly identify over 100,000 dark matter halos at intermediate distances. Those haloes with the densest mass distributions can then be used as *gravitational lenses* to amplify the light ($\times 20$) of the most distant background galaxies using NASA's James Webb Space Telescope, scheduled for launch in 2018. CI Driver is part of a JWST Team with guaranteed time for Dark Age studies using this technique.

• The AESOP system constitutes a 10 year buy-in to VISTA/4MOST allowing direct Australian leadership of a major spectroscopic campaign of 2 million galaxies designed to push the cold dark matter hypothesis to its limits, probe the lowest galaxy stellar masses ever studied outside the Local Group, and follow the evolution of energy, mass and structure over a 6 billion year baseline. •

Dark energy and Galactic Archaeology within the broader 4MOST collaboration

WAVES is one of 8 surveys which will be conducted with VISTA/4MOST within its first 5 years of operations. In providing the critical AESOP component to the 4MOST upgrade, a number of Australian-based astronomers (~ 8 and their students and postdocs) will be permitted to join the 4MOST Consortium. These astronomers, referred to as the 4MOST 8, will become full team members involved in the design, execution, and exploitation of all 8 surveys. These surveys are currently focused on follow-up of major space-based facilities (GAIA, eROSITA, and Euclid), and include a major study of cosmology (dark energy, growth of structure, and lensing), and a study of the formation of our Galaxy and the evolution of the Milky Way (Galactic Archaeology); two areas in which Australia has an extremely strong international profile through previous and ongoing surveys (2dFGRS, WiggleZ, 6dFGS, OzDES, RAVE, GALAH, SkyMapper). In addition the programmes to be conducted in the second 5 years, yet to be defined, are expected to involve significant follow-up of targets identified by the Australian Square Kilometre Array Pathfinder (ASKAP), MWA, JVLA, SkyMapper, and other wide-area survey facilities in which Australia is closely involved (e.g., LSST).

Measuring the physics of dark energy with VISTA/4MOST surveys: Over the past two decades the case for dark energy has become compelling, and a story in which Australian scientists have been very closely involved. Originally hinted at from K-band galaxy number-counts (Yoshii & Peterson 1995) and the ages of the oldest systems (Chaboyer et al., 1996), dark energy was brought into sharp focus by the discovery of the accelerating Universe via SN Type Ia (CI Schmidt et al., 1998), and a key prediction confirmed through the measurement of baryonic acoustic oscillations (CI Glazebrook & CI Blake 2003) from the Australian-led 2dFGRS (Cole et al., 2005), WiggleZ (CI Blake et al., 2011), and 6dFGS surveys (Beutler et al., 2011). However, *the physical nature of dark energy is not yet understood*, and leads to two compelling scenarioes each with far-reaching consequences:

- Einstein's theory of gravity, General Relativity, requires modification on large cosmic scales to produce an effective repulsive gravitational force.
- The Universe must be filled with a new form of energy which, unlike any known form of matter or energy, exerts a negative pressure.

Distinguishing between these two flavours cannot be achieved via a single simple experiment but requires the combination of observations of the rate of expansion of the Universe with time, and the rate at which structure grows. The VISTA/4MOST all-sky cosmological survey will perform leading measurements of both of these quantities, enabling direct tests of the physics of dark energy, at higher redshifts than previously possible. In fact VISTA/4MOST will contribute to the study of dark energy in three critical ways:

Baryonic Acoustic Oscillations (BAOs). This technique exploits a preferred separation of galaxies imprinted by sound wave propagation between the time of the Big Bang and recombination, resulting in an excess of galaxy pairs on 150Mpc scales that may be used as a standard ruler for measuring cosmic distances (e.g., CI Blake et al., 2011; Andrewson et al., 2014).

Peculiar motions of galaxies. As galaxies fall toward overdense regions as non-relativistic test particles, these motions produce correlated Doppler shifts in galaxy redshifts that create an overall clustering anisotropy as a function of the angle to the line-of-sight, known as redshift-space distortion (RSD).

Gravitational lensing. The patterns of weak gravitational lensing imprinted by the relativistic deflections of light rays from distant galaxies as they travel through the intervening large-scale structure. This signal may be measured using correlations in the apparent shapes of background galaxies in deep imaging surveys.

Velocities and lensing are complementary because *only their combination allows general deviations to the Einstein field equations to be constrained* (Zhang et al. 2007, Song et al. 2011) but require both exquisite deep imaging and extensive spectroscopic measurements. The most important deep imaging surveys, which allow the gravitational lensing component of this signal to be measured, cover the southern sky: including the Dark Energy Survey and the Large Synoptic Survey Telescope. However, the main existing spectroscopic surveys which can be used to constrain the galaxy velocities, such as BOSS, have been carried out by the Sloan Digital Sky Survey in the north. By performing a spectroscopic southern-sky survey overlapping with this lensing data, VISTA/4MOST will enable powerful tests of gravitational physics, in which Australian 4MOST consortium members can have full involvement.

• VISTA/4MOST will therefore make a key contribution to the study of dark energy, and is one of the key experiments in which Australian-based scientists can directly contribute through both their expertise and the provision of AESOP as our buy-in to 4MOST. •

Galactic Archaeology and the search for low-metallicity stars: VISTA/4MOST will also have a profound impact on Galactic archaeology, i.e. the study of the history of the Milky Way. Indeed, understanding the formation and evolution of galaxies is one of the biggest challenges in contemporary astrophysics and cosmology. While WAVES will illuminate the vast diversity of galaxies in the cosmos, other 4MOST surveys will enable unprecedented in-depth studies of our own Galaxy, at a level of detail not possible for any other galaxy. It will determine the properties, space velocities and chemical compositions of millions of stars in the Milky Way from which we will be able to piece together its full star formation and merger history, the evolutionary connection between all the major stellar populations, and the Galaxy's detailed dark matter potential, in addition to providing key tests of stellar astrophysics (e.g. Freeman & CI Bland-Hawthorn 2002).

4MOST will perfectly complement the recently launched ESA GAIA space mission, which will map the Milky Way in exquisite detail by determining the distances and proper motions of a billion stars (Perryman et al. 2001). GAIA will also measure radial velocities but only of the brighter objects (accuracy $<$ 2km/s only for $V < 15$mag), leaving a crucial gap that 4MOST will fill by obtaining accurate velocities for 12 million stars down to $V = 20$mag in the disk, halo and bulge using the low-resolution ($R = 5000$) spectrographs. Together with GAIA, this will provide full 6D phase-space information for the stars, which will be tremendously powerful for unraveling the history of the Milky Way, especially as the 4MOST spectra will also enable determination of stellar metallicities and alpha-element abundances. This represents a factor of ten larger sample than any previous or current Galactic survey, like RAVE, SDSS or GALAH.

In addition, the high-resolution mode of 4MOST will be used to obtain spectra of 2 million Galactic stars at high-resolution ($R = 20000$) over the wavelength regions 395-457nm and 587-673nm, enabling a determination of the detailed stellar chemical compositions for ~ 15 elements, covering all the nucleosynthetic production channels with an accuracy of typically 0.1 dex. This will be a perfect complement to the GALAH survey, which is focused on $V < 14$mag disk stars. Together these will enable chemical tagging: identifying the stars born together in star-forming associations and thus the lost solar siblings (e.g. Mitschang, CI Zucker et al. 2014).

Of particular relevance for the Australian community, 4MOST will be an ideal instrument for discovering the lowest metallicity and the oldest stars in the Milky Way. From SkyMapper photometry (Keller, CI Schmidt, et al., 2007), we can identify candidates for these extremely rare metal-poor stars in the Galactic halo as well as the bulge but the stars must be spectroscopically vetted. Currently this is done one star at a time, which is very time-consuming, but with 4MOST this spectroscopic confirmation stage can be massively accelerated by piggy-backing on other surveys, yielding many tens of thousands of extremely metal-poor stars. Understanding the elusive first stars and how they shaped the Universe is a central pillar in astronomy, a field that Australia is leading (e.g. Keller, CI Asplund, CI Schmidt et al., 2014).

• Involvement in 4MOST over its first 10 years of operations will ensure that Australian's world-leading position in Galactic archaeology and the search for the first stars will continue into the next decade. •

C1.2 Need and use of the proposed research infrastructure

Australia has traditionally played a leading role in the study of galaxies (including the Milky Way) and cosmology through wide-field spectroscopy best exemplified by surveys such as the 2dFGRS, WiggleZ, 6dFGS, GAMA, RAVE and GALAH. This is primarily due to the wide-field of view available to the 4m Anglo-Australian Telescope (its 2 degree field was world leading until very recently), and the very strong fibre-positioning group at the Australian Astronomical Observatory. This collaboration, between technology and science, has allowed for major returns in terms of high-impact science results and in international procurement of fibre-placement technologies. Australian built fibre-positioners are deployed on the Japanese Subaru telescope (Echidna with FMOS), and the European Southern Observatories Very Large Telescope (OzPos within FLAMES). Furthermore the Australian-designed MANIFEST system has been selected as the only technology to proceed to design phase for the 30 million Giant Magellan Telescope and Australia has produced conceptual design studies (by invitation) for ESO's VISTA/4MOST facility (AESOP), and the USA (DESI/Mayall) facility. However while the technology has advanced significantly, Australian's national facility while currently competitive (See Fig. 5), will no longer be competitive with the new facilities under construction (Subaru/PFS, VISTA/4MOST, Mayall/DESI),

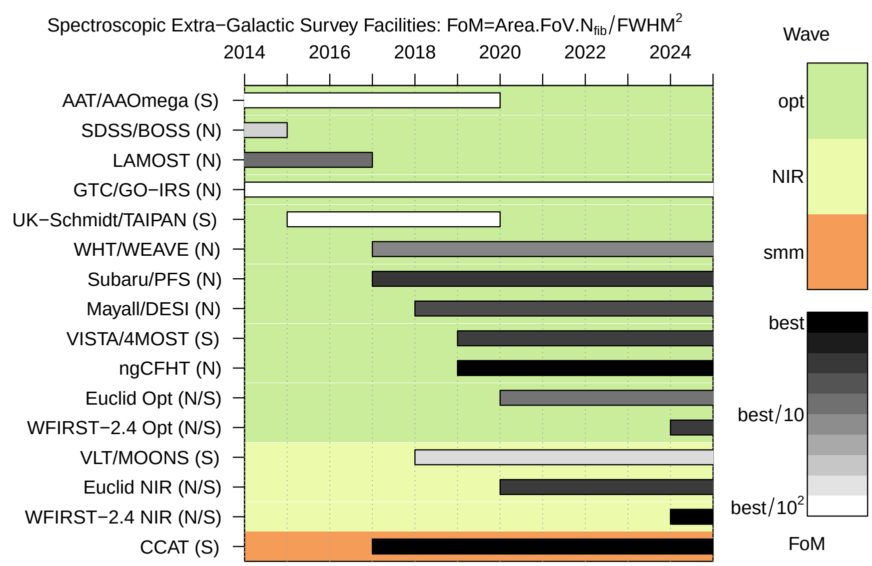

Figure 5: A graphic comparing wide-field spectroscopic facilities using a standard figure-of-merit (FoM). The greyscale of the bars relates to the FoM with black representing the best and white the worst on a logarithmic scale. While Australia has a fairly unique hold in this area the facilities under development, which rely on Australian built components, will soon out-compete Australia's capacity in this area.

or in the design phase (ngCFHT/MSE). To remain scientifically competitive it is vital Australian scientists are involved not just in the construction of these facilities but also their scientific exploitation. Fig. 5 shows the planned facilities capable of wide-field spectroscopy currently under design or development. While the Australian AAOmega and Taipan facilities have the advantage of being unique for the next few years, they will soon be overrun by those facilities under development (black bars extending over the latter half of the coming decade). Of the facilities listed in Fig. 5 by far the most attractive for Australian astronomers is VISTA/4MOST because of its location in Chile opening up the Southern Hemisphere (indicated by the (S) in the figure labels) where key Australian imaging (SkyMapper) and radio wavelength surveys are being conducted (ASKAP/EMU, ASKAP/WALLABY and ASKAP/DINGO), and where the future SKA Surveys will be conducted. A unique opportunity has arisen for Australia to join the 4MOST facility by covering the construction labour costs of the AESOP positioner, estimated to be \$3.1m.

C1.3 Nature of the alliance and commitment between organisations named on proposal

The lead, eligible and partner organisations listed here commit to the construction of the AESOP positioner by covering the Australian labour-costs estimated at \$3.1m (20FTEs over a 4 year period). The hardware costs will be covered by the external 4MOST collaboration led by the Leibniz Institut für Astrophysik Potsdam (AIP), Germany. Following construction the AESOP positioner will be delivered to ESO for integration into the 4MOST re-fit of the European Southern Observatories VISTA telescope, estimated at \$60 million.

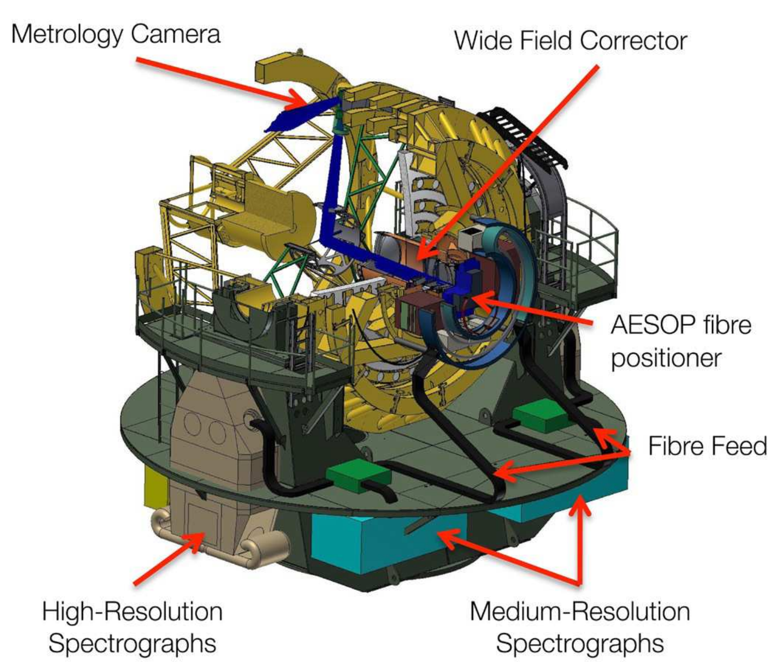

Figure 6: A schematic of ESOs VISTA telescope and the 4MOST re-fit including AESOP

The 4MOST facility including: AESOP (i.e., a replacement wide-field corrector top-end for the VISTA telescope, and 5 European built spectrographs, Fig. 6), constitutes the most expensive and intricate instrument ever built by ESO, with the AESOP fibre placement element a critical component of the whole instrument. The massively multiplexed fibre positioning of AESOP is possible through its pioneering Echidna mechanism (see Fig. 7). The AAO is also involved in a number of other aspects of the full design including the replacement wide-field corrector top-end and spectroscope designs.

AESOP, as envisaged by the innovative AAO design, contains and manipulates 2400 spines each encasing a fibre-optic cable. The spines can be automatically aligned to match the distribution of targets on the sky within 2–5 mins thereby allowing for the simultaneous measurement of 2400 spectra within a single 20min integration (with fainter objects requiring multiple 20min integrations). The 2400 fibres are then fed down into the VISTA telescope housing assembly where the light is diffracted and imaged within a series of spectrographs. The pioneering Echidna spine technology is not just a concept

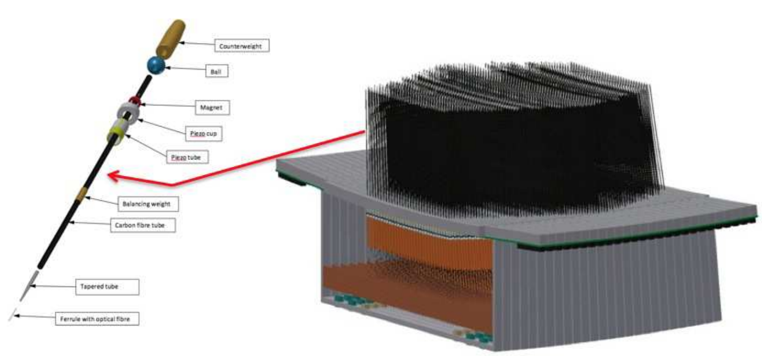

Figure 7: A schematic showing the AESOP Echidna layout (*right*) and a zoom in on an individual Echidna spine (*left*).

but a proven design, demonstrated through the construction of a similar, although smaller scale, Echidna positioner integrated into the FMOS instrument on the Japanese owned 8m Subaru Telescope in Hawaii. The device has been extremely reliable in operation at Hawaii, only a single spine out of 414 has failed over the last 7 years of operation. This corresponds to a failure rate of less than 0.05% per year. In the words of Dr Naoyuki Tamura, Principal FMOS Scientist "Echidna has been working really well".

The 4MOST collaboration will accept delivery of AESOP as a buy-in to the 4MOST survey programme and in return will guarantee the leadership of the 2 million galaxy WAVES redshift survey as outlined in Section C1 along with full membership for 8 senior Australian-based research leaders (the '4MOST 8' and their postdocs/students) to all 4MOST surveys; these roles would be allocated based on the institutional contributions and maximising the science return to Australia. The 8 Australian members will have the same rights within the 4MOST consortium as a full ESO member including the opportunity to be fully involved in the the design, and planning phase which is currently underway and why engagement now is critical.

C1.4 Investigators

The 25 investigators named on the proposal includes senior figures from the extra-galactic, cosmology and Galactic Archaeology communities with tremendous combined experience in leading, designing, implementing and exploiting wide area spectroscopic surveys (2dFGRS, 2QZ, 6dFGS, GALAH, GAMA, MGC, HIPASS, RAVE, SAMI, SkyMapper, TAIPAN, WiggleZ, OzDES) as attested by numerous awards, prizes (e.g., Nobel, Gruber, RAS), papers (collectively over 2000), citations (collectively over 100,000), fellowships (1 WA Premier's Fellow, 2 Laureate Fellows, 1 QEII, 5 Future Fellows, and 1 Super Science Fellow) and appointments to senior posts within the community (3 Directors, 3 Fellows of the Australian Academy, and 3National Committee of Astronomy representatives). The expertise of the team is very much valued and sought after by the 4MOST collaboration (see supporting letter from 4MOST PI, Dr Roelof de Jong, section A8.3) and one would expect that the selected 4MOST 8 will have a significant influence not only over WAVES but over most of the other 4MOST surveys as well.

The team also includes the Director (W. Couch), Head of Science (A. Hopkins), Head of Instrumentation (A. Sheinis), and Head of National Facilities (C. Lidman) of the Australian Astronomical Observatory who are directly responsible for ensuring AESOP is delivered on time and to spec. They have a superb track record in producing high quality fibre-positioning instruments to international observatories and the timely construction and deployment of AESOP will further strengthen this reputation.

C2. Research infrastructure arrangements

All requested LIEF funding including the cash contributions from the lead institute, the eligible institutes, partner organisation, and the in-kind contribution from the partner organisation will be used to cover the labour costs associated with building the AESOP positioner at the Australian Astronomical Observatory, i.e., all requested funds are to be spent on Australian-based FTEs related to the mechanical, electrical and software engineering aspects of constructing AESOP ($3.1m). The hardware ($2 million) will be funded by the 4MOST Consortium, a group of 11 European Universities and ESO, led by the Leibniz Institut für Astrophysik Potsdam in Germany. AESOP will be delivered to the European Southern Observatory in return for Australia leading a 2 million redshift galaxy-evolution survey (WAVES), *AND* full access for 8 senior members of the Australian Astronomical community and their associated Research Associates and Graduate students. The 4MOST 8 will be selected initially (i.e., for the initial design phase and first few years of operation) from the team specified in section C3 based on their institutional contributions. However it is expected that the 4MOST 8 will evolve over the period of membership as best serves the national interest. During the periods of membership the 4MOST 8 will be eligible to be fully engaged in any of the 4MOST Consortium's survey programmes. For the first 5 years these projects include follow-up of 15 million stars selected from GAIA and SkyMapper for Galactic Archaeology studies, follow-up of the Russian/German eROSITA X-ray telescope, and a major cosmology survey of 12 million galaxies. Australian involvement will continue for the duration of the 4MOST Consortium (expected to be a minimum of 10 years). This arrangement is an unprecedented opportunity for direct Australian engagement in a major European Southern Observatory. As AESOP will be delivered to the European Southern Observatory there will be no legacy financial liability nor operation costs, these will be borne by ESO alone. A letter of support from the 4MOST Principal Investigator is attached as part of Section A8.3 summarising the current understanding which will be formalised following the LIEF outcome and the confirmed award of the 4MOST contract to the AAO to construct AESOP.

C3. Role of personnel

CI Driver, WAVES: UWA Winthrop Research Professor and PI of the GAMA and MGC surveys with expertise in survey design and galaxy formation and evolution. Driver will be the WAVES Principal Investigator (PI) within the 4MOST Consortium and is also closely involved with JWST and Euclid Legacy campaigns ensuring coordinated observations across these facilities.
CI Robotham, WAVES: UWA Fellow studying galaxy groups, galaxies and dark matter. Robotham is a key member of the GAMA management group and will become the WAVES Project Scientist. He will design the dark matter experiments to be carried out with WAVES.
CI Power, WAVES: UWA Research Professor heading the ICRAR numerical simulations group currently exploring Cold, Warm and Self-Interacting Dark Matter models. Power will lead the numerical simulation work supporting WAVES.
CI Meyer, WAVES: UWA Associate Professor and PI of the ASKAP/DINGO survey and a core member of the SKA Phase I Design Reference Team. Meyer is an expert in HI detection and stacking, and will ensure coordination between WAVES and ASKAP and SKA Phase I operations.
PI Couch, WAVES: Director of the Australian Astronomical Observatory and a leading expert on galaxy clusters and the processes which affect galaxy evolution within cluster environments. Couch is ultimately responsible for the timely delivery of AESOP to 4MOST.
PI Hopkins, WAVES: Head of Science at the Australian Astronomical Observatory, co-PI of the GAMA survey and PI of the upcoming TAIPAN survey, Hopkins leads the GAMA spectroscopic processing team at the Australian Astronomical Observatory, and will continue this role for WAVES.
PI Sheinis, WAVES: Head of Instrumentation at the Australian Astronomical Observatory. Sheinis and his team run the world's leading laboratory on fibre-positioning technologies and produced the initial design study for AESOP. Sheinis and his team will build, test, deliver, and commission the AESOP positioner for 4MOST.
PI Lidman, Transients: Head of National Facilities Support at the Australian Astronomical Observatory and PI of the OzDES survey, which has been awarded 100 nights of time on the AAT to study dark energy. Jointly awarded the Gruber Prize in Cosmology.
PI Brough, WAVES: Research Astronomer at the Australian Astronomical Observatory. Brough has significant experience in large spectroscopic campaigns and will play a key role in the exploitation of WAVES for galaxy evolution science.
CI Colless, WAVES/Cosmology: Director of the Research School of Astronomy and Astrophysics at the Australian National Observatory. PI of the 2dFGRS and co-PI of the WiggleZ Colless will lead research in areas of cosmology and contribute to the oversight of the WAVES and 4MOST teams.
CI Asplund, Gal. Arch.: Australian Laureate Fellow and leading Galactic archaeologist and stellar astrophysicist. A leading member of the GALAH survey and also overseeing the SkyMapper search for the first stars. Asplund will be closely involved in the 4MOST Galactic Archaeology surveys.
CI Schmidt, Cosmology/Gal. Arch.: Nobel Prize winner in Physics for the discovery of the accelerating expansion of the Universe. Cosmologist and Stellar Astrophysicist specialising in Supernova. PI of the SkyMapper facility which will provide critical input data for the dark energy and Galactic archaeology 4MOST surveys.
CI Glazebrook, Cosmology: Director of Swinburne's Centre for Astrophysics and Supercomputing. Leading cosmologist and one of the PIs of the WiggleZ Dark Energy Survey and ISI High citation Laureate. Glazebrook

will play a leading role in the design of the cosmology survey.
CI Blake, Cosmology: Faculty member at Swinburne and an expert on testing the cosmological model using the large-scale structure of galaxies. Blake is a PIs of the WiggleZ Dark Energy Survey producing key analysis constraining dark energy models. Blake will provide input into the design of the 4MOST dark energy survey.
CI Croton, WAVES: Faculty member at Swinburne and head of the Theoretical Astrophysics Observatory which provides a unique online interface to advanced semi-analytic simulations. Croton will provide expert advice on the best methods for comparing observational and numerical data to constrain galaxy formation.
CI Drinkwater, WAVES: Professor and principal investigator of the WiggleZ Dark Energy Survey which placed stringent constraints on the equation-of-state of dark energy. The discoverer of a new class of dwarf galaxy called Ultra Compact Dwarfs, he will play a leading role in the study of low luminosity galaxies.
CI Davis, WAVES/Cosmology: Associate Professor and leading cosmologist heavily involved in the WiggleZ Dark Energy survey. Will play a leading role in cosmology science undertaken on 4MOST.
CI Parkinson, Cosmology: Future Fellow and leading cosmologist specialising in alternative gravity theories and the prospects for testing them. Will play a leading role in cosmology science undertaken on 4MOST.
CI Croom, WAVES: Professor and PI of the SAMI survey allocated 200 nights on the Anglo Australian Telescope to investigate spatially dependent star-formation. Previously project scientist for the 2QZ survey.
CI Bland-Hawthorn, WAVES/Gal. Arch.: Professor and expert in chemical evolution, Galactic outflows, galaxy dynamics and Galactic Archaeology. A key member of the 2dFGRS, GAMA and GALAH surveys.
CI Sadler, WAVES: Professor, leading radio astronomer and principal investigator of the ASKAP-FLASH project, an all-sky HI absorption survey.
CI McDermid, WAVES: Faculty member of Macquarie University. An integral team member of the high impact ATLAS3D survey. McDermid will play a key role in the study of resolved galaxies within WAVES.
CI Spitler, WAVES: Faculty member at Macquarie University, Spitler is the Science Coordinator for the TAIPAN survey and cluster working group Team Leader for the OzDES survey. Spitler will focus on using WAVES to constrain the evolution of galaxies.
CI Zucker, Gal. Arch.: Future Fellow at Macquarie University. He has extensive expertise in the field of Galactic Archaeology and leading the early science exploitation of GALAH. He will play an important role in designing and exploring the 4MOST stellar surveys.
CI Jackson, WAVES: Premier's Fellow at Curtin responsible for overseeing CIRA's interests in the MWA and SKA. Previously a core member of the 2dFGRS team providing database capabilities.
CI Brown, WAVES: Head of Astronomy at Monash University and an expert in clustering analysis including, in particular, Halo Occupation statistics. Will play a key role in the detailed survey design of WAVES.
CI Webster, WAVES: Head of Astrophysics at the University of Melbourne and leader of the HIPASS survey with expertise in gravitational lensing. Will play a key role in the cosmology science.

C4. References

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