4MOST DOI: 10.18727/0722-6691/5117

4MOST: Project overview and information for the First Call for Proposals

Roelof S. de Jong^{1,a} Oscar Agertz² Alex Agudo Berbel³ James Aird⁴ David A. Alexander⁵ Anish Amarsi⁶ Friedrich Anders¹

Rene Andrae⁷ Behzad Ansarinejad⁵ Wolfgang Ansorge⁸ Pierre Antilogus⁹

Heiko Anwand-Heerwart 10

Anke Arentsen¹
Anna Arnadottir²
Martin Asplund⁶
Matt Auger⁴
Nicolas Azais^{1,11}
Dietrich Baade¹²
Gabriella Baker¹³
Sufyan Baker¹³
Eduardo Balbinot¹⁴
Ivan K. Baldry¹⁵
Manda Banerji⁴
Samuel Barden¹
Paul Barklem¹⁶

Eléonore Barthélémy-Mazot 17

Chiara Battistini 18 Svend Bauer 1 Cameron P. M. Bell 1 Olga Bellido-Tirado 1 Sabine Bellstedt 19 Vasily Belokurov 4 Thomas Bensby 2 Maria Bergemann 7

Joachim M. Bestenlehner²⁰

Richard Bielby⁵ Maciej Bilicki²¹ Chris Blake²²

Joss Bland-Hawthorn²³ Corrado Boeche²⁴ Wilfried Boland^{25,21} Thomas Boller³ Sebastien Bongard9 Angela Bongiorno²⁶ Piercarlo Bonifacio²⁷ Didier Boudon²⁸ David Brooks²⁹ Michael J. I. Brown³⁰ Rebecca Brown 13 Marcus Brüggen³¹ Joar Brynnel Jurek Brzeski 13 Thomas Buchert²⁸ Peter Buschkamp¹⁸ Elisabetta Caffau²⁷ Patrick Caillier²⁸ Jonathan Carrick³² Luca Casagrande⁶

Scott Case 13

Andrew Casey³⁰
Isabella Cesarini¹
Gabriele Cescutti³³
Diane Chapuis²⁸
Cristina Chiappini¹
Michael Childress³⁴
Norbert Christlieb¹⁸
Ross Church²
Maria-Rosa L. Cioni¹
Michelle Cluver²²
Matthew Colless⁶
Thomas Collett³⁵

Thomas Collett³⁵ Johan Comparat³ Andrew Cooper⁵ Warrick Couch^{36,22} Frederic Courbin³⁷ Scott Croom²³ Darren Croton²² Eric Daguisé²⁸ Gavin Dalton³⁸ Luke J. M. Davies 19 Tamara Davis³⁹ Patrick de Laverny⁴⁰ Alis Deason⁵ Frank Dionies¹ Karen Disseau²⁸ Peter Doel²⁹

Simon P. Driver¹⁹
Tom Dwelly³
Dominique Eckert³
Alastair Edge⁵
Bengt Edvardsson¹⁶
Dalal El Youssoufi¹

Daniel Döscher¹

Ahmed Elhaddad 18 Harry Enke 1 Ghazaleh Erfanianfar 3

Tony Farrell ¹³
Thomas Fechner ¹
Carmen Feiz ¹⁸
Sofia Feltzing ²
Ignacio Ferreras ²⁹
Dietrich Feuerstein ¹
Diane Feuillet ⁷
Alexis Finoguenov ^{3,41}
Dominic Ford ²
Sotiria Fotopoulou ⁵
Morgan Fouesneau ⁷
Carlos Frenk ⁵
Steffen Frey ¹
Wolfgang Gaessler ⁷
Stephan Geier ⁴²

Nicola Gentile Fusillo⁴³ Ortwin Gerhard³ Tommaso Giannantonio⁴ Domenico Giannone¹

Brad Gibson⁴⁴ Peter Gillingham¹³

Carlos González-Fernández⁴

Eduardo Gonzalez-Solares⁴

Stefan Gottloeber¹ Andrew Gould^{45,7} Eva K. Grebel²⁴ Alain Gueguen³ Guillaume Guiglion¹ Martin Haehnelt⁴ Thomas Hahn¹ Camilla J. Hansen^{7,46}

Camilla J. Hansen^{7,} Henrik Hartman² Katja Hauptner¹⁰ Keith Hawkins⁴ Dionne Haynes¹ Roger Haynes¹ Ulrike Heiter¹⁶ Amina Helmi¹⁴

Cesar Hernandez Aguayo⁵

Paul Hewett⁴
Samuel Hinton³⁹
David Hobbs²
Sebastian Hoenig³⁴
David Hofman¹⁷
Isobel Hook³²
Joshua Hopgood¹²
Andrew Hopkins¹³
Anna Hourihane⁴
Louise Howes²
Cullan Howlett¹⁹
Tristan Huet¹
Mike Irwin⁴
Olaf Iwert¹²

Pascale Jablonka³⁷
Thomas Jahn¹
Knud Jahnke⁷
Aurélien Jarno²⁸
Shoko Jin¹⁴
Paula Jofre⁴
Diana Johl¹
Damien Jones⁴⁷
Henrik Jönsson²
Carola Jordan⁷
Iva Karovicova¹⁸
Arman Khalatyan¹
Andreas Kelz¹
Robert Kennicutt⁴
David King⁴

David King⁴
Francisco Kitaura⁴⁸
Jochen Klar¹
Urs Klauser¹³
Jean-Paul Kneib³⁷
Andreas Koch²⁴
Sergey Koposov⁴
Georges Kordopatis⁴⁰
Andreas Korn¹⁶
Johan Kosmalski ^{12,28}
Rubina Kotak^{49,50}
Mikhail Kovalev⁷
Kathryn Kreckel⁷
Yevgen Kripak¹³

Mirko Krumpe¹ Koen Kuijken²¹ Andrea Kunder¹ Iryna Kushniruk² Man I Lam¹ Georg Lamer¹ Florence Laurent²⁸ Jon Lawrence 13 Michael Lehmitz⁷ Bertrand Lemasle²⁴ James Lewis⁴ Baojiu Li⁵ Chris Lidman^{36,6} Karin Lind¹⁶ Jochen Liske³¹ Jean-Louis Lizon 12 Jon Loveday⁵¹

Hans-Günter Ludwig 18 Richard M. McDermid 52

Kate Maguire⁴⁹ Vincenzo Mainieri¹² Slavko Mali¹³ Holger Mandel¹⁸ Kaisey Mandel⁴ Liz Mannering^{36,19} Sarah Martell⁵³

David Martinez Delgado²⁴

Gal Matijevic¹
Helen McGregor¹³
Richard McMahon⁴
Paul McMillan²
Olga Mena⁵⁴
Andrea Merloni³
Martin J. Meyer¹⁹
Christophe Michel¹⁷
Genoveva Micheva¹

Jean-Emmanuel Migniau²⁸

Ivan Minchev¹
Giacomo Monari¹
Rolf Muller¹³
David Murphy⁴
Daniel Muthukrishna⁴
Kirpal Nandra³
Ramon Navarro⁵⁵
Melissa Ness⁷
Vijay Nichani¹³
Robert Nichol³⁵
Harald Nicklas¹⁰
Florian Niederhofer¹
Peder Norberg⁵
Danail Obreschkow¹⁹

Seb Oliver⁵¹
Matt Owers⁵²
Naveen Pai¹³
Sergei Pankratow¹
David Parkinson³⁹
Jens Paschke¹
Robert Paterson¹³
Arlette Pecontal²⁸

lan Parry⁴
Dan Phillips¹
Annalisa Pillepich⁷
Laurent Pinard¹⁷
Jeff Pirard¹²
Nikolai Piskunov¹⁶
Volker Plank¹
Dennis Plüschke¹

Estelle Pons⁴
Paola Popesso⁵⁶
Chris Power¹⁹
Johan Pragt⁵⁵

Alexander Pramskiy 18

Dan Pryer⁵¹ Marco Quattri ¹²

Anna Barbara de Andrade Queiroz¹

Andreas Quirrenbach¹⁸ Swara Rahurkar¹ Anand Raichoor³⁷ Sofia Ramstedt¹⁶ Arne Rau³

Alejandra Recio-Blanco 40

Roland Reiss¹²
Florent Renaud²
Yves Revaz³⁷
Petra Rhode¹⁰
Johan Richard²⁸
Amon David Richter¹⁰
Hans-Walter Rix⁷
Aaron S. G. Robotham¹⁹
Ronald Roelfsema^{57,55}
Martino Romaniello¹²

David Rosario⁵ Florian Rothmaier¹⁸ Boudewijn Roukema^{58, 28}

Gregory Ruchti² Gero Rupprecht 12 Jan Rybizki⁷ Nils Ryde² Andre Saar¹ Elaine Sadler²³ Martin Sahlén¹⁶ Mara Salvato³ Benoit Sassolas 17 Will Saunders 13 Allar Saviauk1 Luca Sbordone⁵⁹ Thomas Schmidt¹ Olivier Schnurr 1,60 Ralf-Dieter Scholz¹ Axel Schwope¹ Walter Seifert 18 Tom Shanks⁵ Andrew Sheinis 36,61 Tihomir Sivov¹ Ása Skúladóttir7 Stephen Smartt⁴⁹

Scott Smedley 13

Greg Smith¹

Robert Smith⁵¹ Jenny Sorce^{28,1} Lee Spitler⁵² Else Starkenburg¹ Matthias Steinmetz¹

Ingo Stilz¹⁸
Jesper Storm¹
Mark Sullivan³⁴
William Sutherland⁶²
Elizabeth Swann³⁵
Amélie Tamone³⁷
Edward N. Taylor²²
Julien Teillon¹⁷
Elmo Tempel^{63,1}
Rik ter Horst⁵⁵
Wing-Fai Thi³
Eline Tolstoy¹⁴
Scott Trager¹⁴
Gregor Traven²

Pier-Emmanuel Tremblay⁴³

Laurence Tresse²⁸
Marica Valentini¹
Rien van de Weygaert¹⁴
Mario van den Ancker¹²
Jovan Veljanoski¹⁴
Sudharshan Venkatesan¹³

Lukas Wagner¹ Karl Wagner¹⁸ C. Jakob Walcher¹ Lew Waller¹³ Nicholas Walton⁴

Nicholas Walton⁴ Lingyu Wang^{57,14} Roland Winkler¹ Lutz Wisotzki¹ C. Clare Worley⁴ Gabor Worseck⁴² Maosheng Xiang⁷ Wenli Xu⁶⁴

David Yong⁶ Cheng Zhao³⁷ Jessica Zheng¹³ Florian Zscheyge¹ Daniel Zucker⁵²

- Leibniz-Institut für Astrophysik Potsdam (AIP), Germany
- ² Lund Observatory, Lund University, Sweden
- Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
- Institute of Astronomy, University of Cambridge, UK
- Department of Physics, Durham University, UK
- ⁶ Research School of Astronomy & Astrophysics, Australian National University, Canberra, Australia

- Max-Planck-Institut für Astronomie, Heidelberg, Germany
- ⁸ RAMS-CON, Assling, Germany
- ⁹ Laboratoire de physique nucléaire et de hautes énergies, Paris, France
- ¹⁰ Institut für Astrophysik, Georg-August Universität Göttingen, Germany
- ¹¹ IRIDESCENCE, Paris, France
- ¹² ESO
- ¹³ Australian Astronomical Optics Macquarie, Sydney, Australia
- ¹⁴ Kapteyn Instituut, Rijksuniversiteit Groningen, the Netherlands
- ¹⁵ Astrophysics Research Institute, Liverpool John Moores University, UK
- ¹⁶ Department of Physics and Astronomy, Uppsala universitet, Sweden
- ¹⁷ Laboratoire des Matériaux Avancés, Lyon, France
- ¹⁸ Zentrum für Astronomie der Universität Heidelberg/Landessternwarte, Germany
- ¹⁹ International Centre for Radio Astronomy Research/University of Western Australia, Perth, Australia
- ²⁰ Physics and Astronomy, University of Sheffield, UK
- ²¹ Sterrewacht Leiden, Universiteit Leiden, the Netherlands
- ²² Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Hawthorn, Australia
- ²³ Sydney Institute for Astronomy, University of Sydney, Australia
- ²⁴ Zentrum für Astronomie der Universität Heidelberg/Astronomisches Rechen-Institut, Germany
- ²⁵ Nederlandse Onderzoekschool Voor Astronomie (NOVA), Leiden, the Netherlands
- ²⁶ Osservatorio Astronomico di Roma, INAF, Italy
- ²⁷ GEPI, Observatoire de Paris, Université PSL, CNRS, France
- ²⁸ Centre de Recherche Astrophysique de Lyon, France
- ²⁹ Department of Physics and Astronomy, University College London, UK
- ³⁰ School of Physics and Astronomy, Monash University, Melbourne, Australia
- ³¹ Hamburger Sternwarte, Universität Hamburg, Germany
- ³² Physics Department, Lancaster University, UK
- ³³ Osservatorio Astronomico di Trieste, INAF, Italy
- ³⁴ School of Physics and Astronomy, University of Southampton, UK

- ³⁵ Institute of Cosmology and Gravitation, University of Portsmouth, UK
- ³⁶ Australian Astronomical Observatory, Sydney, Australia
- ³⁷ Laboratoire d'astrophysique, École Polytechnique Fédérale de Lausanne, Switzerland
- ³⁸ Department of Physics, University of Oxford, UK
- 39 School of Mathematics and Physics, University of Queensland, Brisbane, Australia
- ⁴⁰ Observatoire de la Côte d'Azur, Nice, France
- ⁴¹ University of Helsinki, Finland
- 42 Institut für Physik und Astronomie, Universität Potsdam, Germany
- ⁴³ Department of Physics, University of Warwick, UK
- ⁴⁴ E. A. Milne Centre for Astrophysics, University of Hull, UK
- ⁴⁵ Ohio State University, Columbus, USA
- ⁴⁶ Dark Cosmology Centre, Københavns Universitet, Denmark
- ⁴⁷ Prime Optics, Eumundi, Queensland, Australia
- ⁴⁸ Instituto de Astrofísica de Canarias, La Laguna, Tenerife, Spain
- ⁴⁹ School of Mathematics and Physics, Queen's University Belfast, UK
- ⁵⁰ University of Turku, Finland
- ⁵¹ University of Sussex, Brighton, UK
- ⁵² Department of Physics and Astronomy, Macquarie University, Sydney, Australia
- ⁵³ School of Physics, University of New South Wales, Sydney, Australia
- ⁵⁴ Instituto de Física Corpuscular, Universidad de Valencia, Spain
- ⁵⁵ Nederlandse Onderzoekschool Voor Astronomie (NOVA), Dwingeloo, the Netherlands
- ⁵⁶ Physics Department, Technische Universität München, Germany
- ⁵⁷ Netherlands Institute for Space Research (SRON), Groningen, the Netherlands
- ⁵⁸ Torun Centre for Astronomy (TCfA), Nicolaus Copernicus University, Poland
- ⁵⁹ Pontificia Universidad Católica de Chile, Santiago, Chile
- ⁶⁰ Cherenkov Telescope Array Observatory, Bologna, Italy
- ⁶¹ CFHT, Kamuela, Hawaii, USA
- ⁶² School of Physics and Astronomy, Queen Mary University of London, UK
- ⁶³ Tartu Observatory, University of Tartu, Estonia
- ⁶⁴ XU-OSE, Heidelberg, Germany

We introduce the 4-metre Multi-Object Spectroscopic Telescope (4MOST), a new high-multiplex, wide-field spectroscopic survey facility under development for the four-metre-class Visible and Infrared Survey Telescope for Astronomy (VISTA) at Paranal. Its key specifications are: a large field of view (FoV) of 4.2 square degrees and a high multiplex capability, with 1624 fibres feeding two low-resolution spectrographs ($R = \lambda/\Delta\lambda \sim 6500$), and 812 fibres transferring light to the high-resolution spectrograph (R ~ 20 000). After a description of the instrument and its expected performance, a short overview is given of its operational scheme and planned 4MOST Consortium science; these aspects are covered in more detail in other articles in this edition of The Messenger. Finally, the processes, schedules, and policies concerning the selection of ESO Community Surveys are presented, commencing with a singular opportunity to submit Letters of Intent for Public Surveys during the first five years of 4MOST operations.

4MOST is being developed to address a broad range of pressing scientific questions in the fields of Galactic archaeology, high-energy astrophysics, galaxy evolution and cosmology. Its design allows tens of millions of spectra to be obtained via five-year surveys, even for targets distributed over a significant fraction of the sky. While many science cases can be addressed with 4MOST, its primary purpose is to provide the spectroscopic complements to large-area surveys coming from key European space missions like eROSITA and the ESA Gaia, Euclid and PLATO missions, as well as from ground-based facilities like VISTA, the VLT Survey Telescope (VST), the Dark Energy Survey (DES), the Large Synoptic Survey Telescope (LSST) and the Square Kilometre Array (SKA).

Multiple science cases must be carried out simultaneously in order to efficiently fill all the fibres in a high multiplex instrument like 4MOST. This necessitates effective coordination between different science teams. To enable this, the 4MOST Consortium will perform Public Surveys using 70% of the available fibrehours in the first five years of operation.

These Public Surveys are Guaranteed Time Observations (GTO) that the Consortium receives in return for building the facility and for supporting ESO in the operation of 4MOST. Public Surveys of the ESO and the Chilean host country communities will fill the other 30% of available fibre-hours in the first five years of operation. These surveys will be chosen by a one-time, competitive, peerreviewed selection process, similarly to other ESO Calls for Public Surveys. Here, a fibre-hour is defined as one hour of observing time, including overheads, with one fibre; hence 4MOST offers 2436 fibre-hours every hour that it is observing.

Following this overview, which contains information on instrument performance and on the procedures associated with the use of 4MOST by the community, this issue of The Messenger includes additional articles on the 4MOST science operations model, the survey plan of the 4MOST Consortium, and a description of the ten Public Surveys that the Consortium intends to carry out. Together these articles are intended to prepare the ESO community for the proposal process that will commence in the second half of 2019. The process will start with a one-off opportunity for the submission of Letters of Intent to apply for Public Surveys to be executed during the first five years of 4MOST operation.

Organisation

The 4MOST project is organised along three branches:

- Instrument responsible for the development, construction, and commissioning of the instrument hardware and associated software;
- Operations for the planning, data reduction, archiving, and publishing of the observations including the associated data-flow;
- Science the branch that develops
 the different Surveys and is responsible
 for science analysis and publication.
 The instrument and operations branches
 are mainly performed by the 4MOST
 Consortium and are jointly called the
 4MOST Facility.

Table 1. 4MOST key instrument specifications.

Instrument parameter	Design value	
Field of view (hexagon)	~4.2 square degrees (Ø = 2.6 degrees)	
Accessible sky (zenith angle < 55 degrees)	> 30 000 square degrees	
Expected on-target fibre-hours per year	LRS: > 3 200 000 h yr ⁻¹ , HRS > 1 600 000 h yr ⁻¹	
Multiplex fibre positioner	2436	
Low-Resolution Spectrographs LRS (× 2) Resolution Number of fibres Passband Velocity accuracy Mean sensitivity 6 × 20 min, mean seeing, new moon, S/N = 10 Å-1 (AB-magnitude)	< <i>R</i> > = 6500 812 fibres 3700–9500 Å <1 km s ⁻¹ 4000 Å: 20.2, 5000 Å: 20.4, 6000 Å: 20.4, 7000 Å: 20.2, 8000 Å: 20.2, 9000 Å: 19.8	
High-Resolution Spectrograph HRS (x 1) Resolution Number of fibres Passband Velocity accuracy Mean sensitivity 6 x 20 min, mean seeing, 80% moon, S/N = 100 Å ⁻¹ (AB-magnitude)	< <i>R</i> > = 20 000 812 fibres 3926–4355, 5160–5730, 6100–6790 Å < 1 km s ⁻¹ 4200 Å: 15.7, 5400 Å: 15.8, 6500 Å: 15.8	
Smallest target separation	15 arcseconds on any side	
# of fibres in random \emptyset = 2 arcminute circle	≥ 3	
Fibre diameter Ø = 1.45 arcseconds		

The instrument is under construction at a number of Consortium institutes, coordinated by the 4MOST Project Office located at the Leibniz-Institut für Astrophysik Potsdam (AIP). Once the subsystems are finished at the different institutes, they will all be transported to Potsdam and extensively tested there as a full system before being shipped to Paranal. At Paranal the 4MOST instrument will be installed, tested, and commissioned on the VISTA telescope.

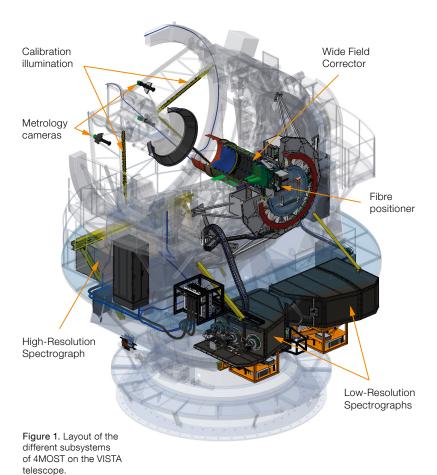
The operations branch is led by the Operations Development Group, consisting of the leads of the different subsystems and working groups involved in observation planning and data-flow. It also contains the 4MOST Helpdesk activities.

The science programme is organised into several surveys. The members of the survey teams are spread over all participating institutes and each team is led by one or more Survey Principal Investigators (Survey Pls). Coordination between all participating surveys is performed by the Science Coordination Board (SCB), consisting of all Survey Pls. The science branch is overseen by two Project Scientists, one for Galactic and one for extragalactic science, who have both a science guidance and a managerial role.

Instrument

The 4MOST instrument design was driven by the science requirements of its key Consortium Surveys. Within a 2-hour observation 4MOST has the sensitivity to obtain redshifts of r = 22.5 magnitudes (AB) galaxies and active galactic nuclei (AGN), radial velocities of any Gaia source (G < 20.5 magnitudes [Vega]), stellar parameters and selected key elemental abundances with accuracy better than 0.15 dex of G < 18-magnitude stars, and abundances of up to 15 elements of G < 15.5-magnitude stars. Furthermore, in a five-year survey 4MOST can cover > 17 000 square degrees at least twice and obtain spectra of more than 20 million sources with a resolution of R ~ 6500 and more than three million spectra with a resolution of $R \sim 20000$ for the typical science cases proposed. The main instrument parameters enabling these science requirements are summarised in Table 1.

Figure 1 provides an overview of the main instrument subsystems. A new Wide Field Corrector (WFC) equipped with an Atmospheric Dispersion Compensator (ADC) that provides corrections to a 55-degree zenith angle distance creates a focal surface with a 2.6-degree diameter. Two Acquisition and Guiding (A&G) cameras ensure correct pointing, while four



Wave Front Sensing (WFS) cameras steer the active optics system of the telescope.

The AESOP fibre positioning system based on the tilting spine principle can, within 2 minutes, simultaneously position all of the 2436 science fibres that are arranged in a hexagonally shaped grid at the focal surface. The accuracy of fibre positioning is expected to be better than 0.2 arcseconds thanks to a four-camera metrology system observing the fibre tips back-illuminated from the spectrograph. The tilting spine positioner has the advantage that each fibre has a large patrol area; each target in the science field of view can be reached by at least three fibres that go to one of the Low-Resolution Spectrographs (LRS) and one or two fibres that go to the High-Resolution Spectrograph (HRS). This ensures a high allocation efficiency of the fibres to targets, even when targets are clustered.

Each spectrograph accepts 812 science fibres and six simultaneous calibration

fibres attached to either end of the spectrograph entrance slit. The covered wavelength range and resolution of the LRS and HRS spectrographs are as listed in Table 1 and depicted in Figure 2. Each type of spectrograph has three channels in fixed configurations covering three wavelength bands, and is thermally invariant and insulated (HRS) or temperature controlled (LRS) for stability. Each channel is equipped with a 6 k × 6 k CCD detector with low read noise (< 2.3 electrons per read) and with high, broadband quantum efficiency. The spectra are sampled with about three pixels per resolution element.

A calibration system equipped with a continuum source, a Fabry-Perot etalon, and ThAr lamps can feed light through the telescope plus science fibres combination and also directly through the simultaneous calibration fibres into the spectrograph slit to ensure accurate wavelength calibration. This will ensure that we can typically reach better than

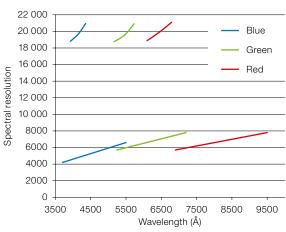


Figure 2. Spectral resolution in the three channels of the 4MOST High-Resolution (HRS, upper lines) and Low-Resolution Spectrographs (LRS; lower lines).

1 km s⁻¹ accuracy on stellar radial velocities. The expected sensitivity is depicted in Figure 3. The estimated observing overheads are currently conservatively estimated to be 3.5 minutes per repointing of the telescope and 4.4 minutes per science exposure for repositioning of the fibres, obtaining attached calibration frames, and performing detector readout. We aim to reduce these overhead numbers in the future by executing more exposure setup activities in parallel and by reducing the number of attached night-time calibration exposures once we have established the stability and calibration reproducibility of the full system.

Operations

The 4MOST operations scheme differs from other ESO instrument operations in that it allows many different science cases to be scheduled simultaneously during one observation. To accommodate the range of exposure times required for different targets, the same part of the sky will be observed with multiple exposures and visits. Objects that require longer exposures will be exposed several times until their stacked spectra reach the required signal-to-noise. 4MOST operations also differ from the standard ESO scheme in that the 4MOST Consortium plays a primary role in planning the observations (Phase 2) and in reducing, analysing and publishing the data (Phase 3).

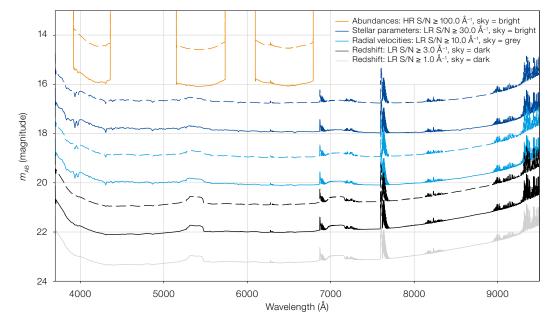


Figure 3. The expected 4MOST pointsource sensitivities for the signal-tonoise levels and lunar conditions indicated in the legend. The solid lines are for a total exposure time of 120 minutes, whereas the dashed lines are the limits for 20-minute exposures. The approximate conversion to signal-to-noise per pixel is obtained by dividing the HRS values by 3.3 and the LRS values by 1.7. For clarity, sky emission lines are removed - this mostly affects results redward of 7000 Å. Mean (not median) seeing conditions, airmass values, fibre quality and positioning errors, etc., are used, in order to ensure that this plot is representative for an entire 4MOST survey, not just for the optimal conditions. Typical science cases for obtaining detailed elemental abundances of stars (orange), stellar parameters and some elemental abundances (dark blue), stellar radial velocities (light blue), and galaxy and AGN redshifts (black: 90% complete, grey: 50% complete) are shown.

These Consortium activities are closely monitored by ESO to ensure uniform progress and data quality for all surveys. The details of 4MOST operations are described in the accompanying article in this edition of The Messenger (Walcher et al., p. 12).

Science

The 4MOST science programme formulated by the Consortium has been organised into the ten surveys listed in Table 2. There are five surveys centred on stellar objects to perform Galactic archaeology of different components of the Milky Way and the Magellanic Clouds, with the goal of understanding their current structure and their assembly history. There are four surveys of extragalactic objects aiming to characterise cosmological parameters, the nature of dark energy and dark matter, and the formation history of galaxies and black holes. Finally, there is a survey dedicated to time domain discoveries, mainly in synergy with the LSST facility where supernova transients and guasar luminosity variations will be complemented with spectroscopic observations.

For most of these surveys, millions of spectra will be obtained, having a huge legacy value for the community and creating an enormous potential for serendipitous discoveries. Being the only facil-

ity in the south with such a large field of view and multiplex capability creates numerous unique opportunities for 4MOST. Of special interest are synergies with new southern hemisphere facilities under construction such as LSST, SKA, and ESO's ELT. The southern sky is of particular interest for Galactic archaeology, with good access to the Milky Way bulge and the Magellanic Clouds. For this science, the R ~ 20 000 of the HRS enables accurate abundance measurements of many elements; the $R\sim6500$ LRS spectra also have higher spectral resolution and better sampling of the spectral resolution elements than similar highmultiplex, wide-field facilities, thereby allowing better stellar elemental abundance determinations. 4MOST provides an unprecedentedly large volume coverage of all Galactic components, thereby expanding on the legacy of the ESA Gaia mission.

This Messenger edition contains sufficiently detailed descriptions of the Consortium Surveys and the overall observing strategy (Guiglion et al., p. 17) to enable the ESO community to develop complementary surveys using the roughly 4.8/2.4 million LRS/HRS fibrehours available to them in the first 5-year survey. The process of integrating community observing programmes into the 4MOST survey programme is described in the next section.

Community programmes

In designing the 4MOST operations system, the aim has been to follow normal ESO operations as much as possible. This means that 4MOST follows the ESO Public Surveys sequence of programme selection (Phase 1), observation preparation (Phase 2), programme execution at the telescope, and finally data reduction, analysis, and publication (Phase 3). However, 4MOST, being a survey facility running typically many science programmes simultaneously in each observation, has required some modifications to the normal process, as described below.

As highlighted earlier, 4MOST Surveys have a duration of five years. This ensures that large projects can be accomplished with carefully crafted completeness goals and well understood selection functions. New programmes will be selected and started only once every five years and, after a short run-in period, the observing strategy will stay as stable as possible during each five-year survey programme. All surveys on 4MOST will be Public Surveys, which means that the raw data will be published immediately in the ESO archive and that the science teams of the surveys have an obligation to release higher-level data products that have legacy value for the community.

Table 2. 4MOST Consortium Surveys and their Principal Investigators.

No	Survey Name	Survey (Co-)PI
S1	Milky Way Halo LR Survey	Irwin (IoA), Helmi (RuG)
S2	Milky Way Halo HR Survey	Christlieb (ZAH)
S3	Milky Way Disc and Bulge LR Survey (4MIDABLE LR)	Chiappini, Minchev, Starkenburg (AIP)
S4	Milky Way Disc and Bulge HR Survey (4MIDABLE HR)	Bensby (Lund), Bergemann (MPIA)
S5	Galaxy Clusters Survey	Finoguenov (MPE)
S6	AGN Survey	Merloni (MPE)
S7	Galaxy Evolution Survey (WAVES)	Driver (UWA), Liske (UHH)
S8	Cosmology Redshift Survey	Richard (CRAL), Kneib (EPFL)
S9	Magellanic Clouds Survey (1001MC)	Cioni (AIP)
S10	Time-Domain Extragalactic Survey (TiDES)	Sullivan (Southampton)

The community can propose for one of two types of Survey programmes with 4MOST.

- 1) Participating Surveys from the ESO community will join the Consortium Surveys in a common observing programme, where they share the available fibres in each observing block and are "charged" fibre-hours only for their fraction of fibres used. They also share the time spent on any duplicate targets in common between surveys, get full access to all data from the Consortium and participating community programmes, and are invited to collaborate in the higher-level data analysis and publication efforts.
- 2) Non-Participating Surveys get their own (half) nights on the telescope and will be "charged" fibre-hours for the full 2436 fibres during that time regardless of whether they can all be filled. These surveys will receive calibrated and extracted spectra from the Consortium data management system, but will not have access to any data other than their own and they will be responsible for delivering higherlevel data products to the ESO archive on their own. While many aspects are the same for Participating and Non-Participating Surveys, critical differences during the various execution phases of the Surveys are highlighted below.

Phase 1

4MOST Phase 1 will begin with a Call for Letters of Intent. Each Letter of Intent is expected to set out: the science goals of the proposed survey; a description of its scope (for example, the number of targets and their distribution on the sky, the targets' luminosity range, the approxi-

mate number of fibre-hours needed); an initial list of Survey team members and their roles (i.e., a simple management plan); and whether the proposal is for a Participating or Non-Participating Survey. To estimate the feasibility and scope of the observations an Exposure Time Calculator (ETC) will be provided through an ESO web interface for single targets, and through an ETC tool from the 4MOST Consortium for many targets at once. After a peer review of the Letters of Intent that will be managed by ESO, a number of teams will be invited to respond to the 4MOST Call for Proposals, at which time ESO may suggest that some of the community proposals merge with other community or Consortium proposals.

At this stage a more detailed science case will be required as well as a full (mock) target catalogue with template spectra, spectral success criteria, and a total survey goal encapsulated by a figure of merit. A web-based version of the 4MOST Facility Simulator (4FS) will be provided, allowing proposers to check the feasibility of their proposed survey. 4FS will provide an estimate of the number of successfully observed targets in a five-year survey when run either standalone (Non-Participating proposals) or in conjunction with the Consortium Surveys (Participating proposals) and the required number of fibre-hours. Clearly, proposals that are well matched to the overall observing strategy of 4MOST as described in the 4MOST Survey Plan article in this edition (for example, surveys with sparsely distributed targets or with looser completeness requirements) have a higher chance of being successfully executed in the amount of time available.

After selection of all Consortium and Community Surveys through ESO's peer review process for Public Surveys proposals, the selected programmes will be invited to submit survey management plans, approval of which by the ESO Director General is mandatory before the final acceptance of a Public Survey. The survey management plan will contain a detailed list of science data products and timeline for their release. For Consortium and Participating Community Surveys a single, joint survey management plan will be delivered. For Non-Participating Community Surveys, each Survey PI will be responsible for the delivery of a survey management plan.

Phase 2

After selection, the members of the Participating Community Surveys will join the Consortium Surveys to form the joint Science Team. The Community Survey Pls will become members of the Science Coordination Board and it is expected that the Community Surveys will provide staff effort to the different 4MOST working groups, most notably those on survey strategy, selection functions, quality assurance, and, if they so wish, higherlevel pipelines. The target catalogues of the Community Surveys will be merged with those of the Consortium and through an iterative process a joint survey plan will be developed to observe all targets. Once the final observing strategy has been agreed upon, only small changes in strategy will be allowed during the operations phase without approval by the SCB and/or ESO. The 4MOST Operations Group provided by the Consortium will create all Observing Blocks running on 4MOST.

Non-Participating Surveys will not join the Science Team, but will be provided with software to create and submit their own Observing Blocks which will be scheduled on their assigned (half) nights. Any significant changes from the original Non-Participating Survey plan will have to be approved by ESO.

Phase 3

As with ESO's Public Survey policies, 4MOST Survey programmes have data delivery obligations to ESO and its community. All 4MOST raw data will become available as soon as they have been ingested into the ESO archive at the end of each night. The raw data will be processed by the Consortium Data Management System to remove instrumental effects and create one-dimensional, fluxand wavelength-calibrated Level 1 (L1) spectra. The L1 data will be released yearly through the ESO archive. For Participating Surveys, dedicated classification, stellar and extragalactic pipelines run by Consortium working groups will produce Level 2 (L2) data products like object type likelihoods, stellar parameters, elemental abundances and redshifts, etc. These products will be released through the ESO archive on a schedule to be agreed upon with ESO before the start of the observations. All L1 and L2 products will also be released through the 4MOST World Archive operated by the Consortium, which will also contain matched catalogues from other facilities and added value catalogues with data processed beyond the standard pipelines. While the Consortium will take care of uploading the L1 and L2 products to the ESO archive for the joint Science Team, Non-Participating Surveys will have to produce and upload their own L2 products to ESO.

Policies

Given the joint use of the available fibres and the corresponding mixed nature of the data products, members of the Consortium Surveys and Participating Community Surveys, i.e., members of the joint Science Team, have to abide by a number of policies to ensure fair use of data and a fair return on investment. Community Survey membership will be limited to those on the original proposal plus up to 15 additional members added at a later stage if a certain capability or expertise is needed that is not available within the Science Team. Participating Community Survey targets may overlap by a maximum of 20% with Consortium targets, but will share the required "cost" in exposure time for the overlap, allowing both surveys to do more in their allotted amount of fibre-hours. All data products are shared among all Science Team members. However, all science exploitation shall take place in projects announced to the whole Science Team and restrictions regarding this exploitation may be applied when a new project overlaps significantly with an existing PhD project or with the core science of a Survey that the project proposer is not a member of. Full details of these Science Team policies as approved by ESO will be released alongside a Code of Conduct when the Call for Letters of Intent is published. By submitting a Participating Survey programme the proposers implicitly agree to comply with these policies.

For Non-Participating Surveys there may be at most a 30% overlap in targets with other Surveys and they will not share exposure time with other Surveys. This means that any duplicate targets in Non-Participating Surveys will be observed twice as there is no means to coordinate the effort with other Surveys. Non-Participating Surveys are free to devise their own membership, data access, and publication policies.

Further information

ESO and the 4MOST Consortium are jointly organising the "Preparing for 4MOST" workshop, which will take place at ESO Garching on 6–8 May 2019. The purpose of this workshop is to transfer knowledge from the 4MOST Consortium to the broader ESO community, and hence to prepare the community for the exciting scientific opportunity to use 4MOST. This will assist potential community Pls to successfully respond to the Call, and will foster scientific collabora-

Table 3. 4MOST Consortium institutes and their main roles in the Project.

Institute	Instrument responsibility	Science lead responsibility	
Leibniz-Institut für Astrophysik Potsdam (AIP)	Management and system engineering, telescope interface (including WFC), metrology, fibre system, instrument control software, System AIV and commissioning	Milky Way Disc and Bulge LR Survey, Cosmology Redshift Survey, Magellanic Clouds Survey	
Australian Astronomical Optics - Macquarie (AAO)	Fibre positioner	Galaxy Evolution Survey	
Centre de Recherche Astrophysique de Lyon (CRAL)	Low-Resolution spectrographs	Cosmology Redshift Survey	
European Southern Observatory (ESO)	Detectors system		
Institute of Astronomy, Cambridge (IoA)	Data management system	Milky Way Halo LR Survey	
Max-Planck-Institut für Astronomie (MPIA)	Instrument control system hardware	Milky Way Disc and Bulge HR Survey	
Max-Planck-Institut für extraterrestrische Physik (MPE)	Science operations system	Galaxy Clusters Survey, AGN Survey	
Zentrum für Astronomie der Universität Heidelberg (ZAH)	High-Resolution spectrograph, Instrument control system software	Milky Way Halo HR Survey	
NOVA/ASTRON Dwingeloo	Calibration system		
Rijksuniversiteit Groningen (RuG)		Milky Way Halo LR Survey	
Lund University (Lund) Uppsala universitet (UU)		— Milky Way Disc and Bulge HR Survey	
			Universität Hamburg (UHH)
University of Western Australia (UWA)		— Galaxy Evolution Survey	
École polytechnique fédérale de Lausanne (EPFL)		Cosmology Redshift Survey	

tions between the community and the 4MOST Consortium. Members of the community who are considering applying for a 4MOST Public Survey are strongly encouraged to attend this meeting in order to obtain detailed information, and to have the opportunity to ask questions, exchange ideas, and build collaborations.

The latest information about 4MOST and its planned surveys is available on its website¹. Information can also be obtained through the 4MOST helpdesk, which can be reached through ESO's User Support Department², the 4MOST web site, or by mailing the project directly³.

Schedule

The 4MOST Project moved into full construction after passing Final Design Review-1 in May 2018. Major milestones in further development and construction are the release of the Call for Letters of Intent in the second half of 2019 which will have a submission deadline about

2 months later, completion of the system integration in Potsdam in July 2021, passing the full system test including operations rehearsals for the Preliminary Acceptance Europe by February 2022, and the installation and commissioning of the facility at VISTA for Provisional Acceptance Chile in November 2022, after which the first five year survey will start.

Consortium and Minor Participants Institutes

The 4MOST Consortium institutes and their main roles in the project are listed in Table 3. The following Minor Participant institutes are also contributing to the development of 4MOST: Durham University, University of Sussex, University College London, Institute for Astrophysics Göttingen (IAG), University of Warwick, University of Hull, Universität Potsdam, Laboratoire d'Etudes des Galaxies, Etoiles, Physique et Instrumentation (GEPI), IN2P3/Laboratoire des Matériaux Avancés (L.M.A.); and for the TiDES Sur-

vey: Lancaster University, Queen's University Belfast, University of Portsmouth, and University of Southampton.

Acknowledgements

Financial support for 4MOST from the Knut and Alice Wallenberg's Foundation, the German Federal Ministry of Education and Research (BMBF) via Verbundforschungs grants 05A14BA2, 05A17BA3 and 05A17VH4, and from the German Research Foundation (DFG) via Sonderforschungsbereich SFB 881 "The Milky Way System" is gratefully acknowledged.

References

Guiglion, G. et al. 2019, The Messenger, 175, 17 Walcher, C. J. et al. 2019, The Messenger, 175, 12

Links

- ¹ The 4MOST website: www.4most.eu
- ² ESO's User Support Helpdesk: usd-help@eso.org
- ³ 4MOST project mailing address: help@4most.eu

Notes

 $^{\rm a}$ Roelof de Jong is the 4MOST Principal Investigator.



The full moon sets behind VISTA near Paranal.