4MOST — 4-metre Multi-Object Spectroscopic Telescope

Roelof de Jong[1]

[1] Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

Team members:
Svend Bauer[1], Gurvan Bazin[2], Ralf Bender[2], Hans Böhringer[3], Corrado Boeche[1], Thomas Boller[3], Angela Bongiorno[3], Piercarlo Bonifacio[4], Marcella Brusa[3], Vadim Burwitz[3], Elisabetta Caffau[5], Art Carlson[2], Cristina Chiappini[1], Norbert Christlieb[5], Mathieu Cohen[4], Gavin Dalton[6], Harry Enke[1], Carmen Feiz[5], Sofia Feltzing[7], Patrick François[4], Eva Grebel[5], Frank Grupp[2], Francois Hammer[4], Roger Haynes[1], Jochen Heidt[5], Amina Helmi[8], Achim Hess[2], Ulrich Hopp[3], Andreas Kelz[1], Andreas Korn[9], Mike Irwin[10], Pascal Jagourel[4], Dave King[10], Gabby Kroes[11], Georg Lamer[1], Florian Lang-Bardl[2], Richard McMahon[10], Baptiste Meneux[2], Shan Mignot[4], Ivan Minchev[1], Joe Mohr[2], Volker Müller[1], Bernard Muschielok[2], Kirpal Nandra[3], Ramon Navarro[11], Ian Parry[10], Johan Pragt[11], Andreas Quirrenbach[5], William Rambold[1], Martin Roth[1], Roberto Saglia[3], Paola Sartoretti[4], Olivier Schnurr[1], Axel Schwope[1], Matthias Steinmetz[1], Jesper Storm[1], Will Sutherland[12], Rikter Horst[11], David Terrett[6], Ian Tosh[6], Scott Trager[8], Lars Venema[11], Marija Vlajic[1], Jacob Walcher[1], Nicolas Walton[10], Mary Williams[1], Lutz Wisotzki[1]

[1] Leibniz-Institut für Astrophysik Potsdam, [2] Universitäts-Sternwarte Munchen, [3] Max-Planck-Institut für extraterrestrische Physik, Garching, [4] GEPI, Observatoire de Paris, [5] Zentrum für Astronomie der Universität Heidelberg, [6] Rutherford Appleton Laboratory, Didcot, [7] Lund Observatory, [8] Kapteyn Astronomical Institute, Groningen, [9] Department of Physics and Astronomy, Uppsala University, [10] Institute of Astronomy, Cambridge, [11] NOVA-ASTRON, the Netherlands, [12] Queen Mary College London.

4MOST (4-metre Multi-Object Spectroscopic Telescope) is a very large field (goal > 5 square degrees) multi-object spectrograph with up to 3000 fibres and spectral resolutions of 5000 and 20 000, proposed for the New Technology Telescope (NTT) or the VISTA survey telescope. The science cases covering Gaia follow-up for chemistry and kinematics of the Galaxy and redshift surveys of targets from the eROSITA X-ray mission are briefly outlined.

The 4MOST consortium aims to provide the ESO community with a fibre-fed spectroscopic survey facility on either VISTA or the NTT with a large enough field of view (FoV) to survey a large fraction of the southern sky in a few years, a multiplex and spectral resolution high enough to detect chemical and kinematic substructure in the stellar halo, bulge and thin and thick discs of the Milky Way, and enough wavelength coverage (> 1.5 octave) to secure velocities of extragalactic objects over a large range in redshift. Such an exceptional instrument enables many science goals, but our design is especially intended to complement two key all-sky, space-based observatories of prime European interest, Gaia and eROSITA. Such a facility has been identified as of critical importance in a number of recent European strategic documents (Bode et al., 2008; de Zeeuw & Molster, 2007; Drew et al., 2010; Turon et al., 2008) and forms the perfect complement to the many all-sky survey projects around the world.

Science drivers

The Gaia satellite will provide distances from parallaxes and space kinematics from proper motions for more than one billion Milky Way stars down to m_V ~ 20 mag. Gaia will also provide radial velocities and astrophysical characterisation for about 150 million stars, but its sensitivity is limited to m_V ~ 12–16 mag, strongly dependent on stellar spectral type, because its spectrograph only covers the Ca II-triplet region at 847–874 nm. Figure 1 shows how, by covering the full optical wavelength region, the 4MOST instrument complements Gaia where it lacks spectroscopic capabilities, so that full 6D-space coordinate information can be obtained and objects throughout the Milky Way chemically characterised. Large-area surveys of faint Galactic stellar objects will enable us to elucidate the formation history of the Milky Way.

Models of hierarchical galaxy formation predict large amounts of dynamical substructure in the Milky Way halo that 4MOST can detect through measuring red giant branch (RGB) stars (see Figure 2). Furthermore, we will determine the three-dimensional Galactic potential and its substructure, discern the dynamical structure of the Milky Way disc and measure the influence of its bar and spiral arms, measure the Galactic assembly history through chemo-dynamical substructure and abundance pattern labelling, and find thousands of extremely metal-poor stars to constrain early galaxy formation and the nature of the first stellar generations in the Universe.

eROSITA (extended ROentgen Survey with an Imaging Telescope Array, Predehl et al., 2010) will perform all-sky X-ray surveys in the years 2013 to 2017 to a limiting depth that is a factor 30 deeper than the ROSAT all-sky survey, and with broader energy coverage, better spectral resolution and better spatial resolution (see Figure 3). We will use 4MOST to survey the > 50 000 southern X-ray galaxy clusters that will be discovered by eROSITA, measuring 3–30 galaxies in each cluster. These galaxy cluster measurements determine the evolution of galaxy populations in clusters, yield the cluster mass evolution, and provide highly competitive constraints on dark energy evolution. 4MOST enables us to determine the nature of > 1 million active galactic nuclei (AGNs), thus constraining the cosmic evolution of active galaxies to z = 5. With 4MOST we will characterise several hundreds of thousands of dynamo- and accretion-powered Galactic X-ray emitters, thereby uncovering the active Milky Way and constraining evolutionary channels of stellar populations.

Other science cases that are fully feasible with 4MOST, but that will not drive the design, include the dynamic structure and content of nearby galaxies, follow-up of extragalactic radio and infrared surveys, and constraining dark energy properties through baryon acoustic oscillation (BAO) measurements.

Instrument specification

The 4MOST facility consists of a wide-field corrector with atmospheric dispersion corrector, acquisition, guiding and wavefront sensing systems, a fibre-positioning system, and a fibre train feeding the light to an R > 20 000 spectrograph and several R ~ 5000 spectrographs. The baseline and goal instrument specifications can be found in Table 1. We have preliminary wide-field corrector designs yielding 7 square degree FoV on the VISTA 4.1-metre telescope and 3 square degree FoV on the 3.58-metre NTT. We will study two fibre positioner designs, one based on a variation of

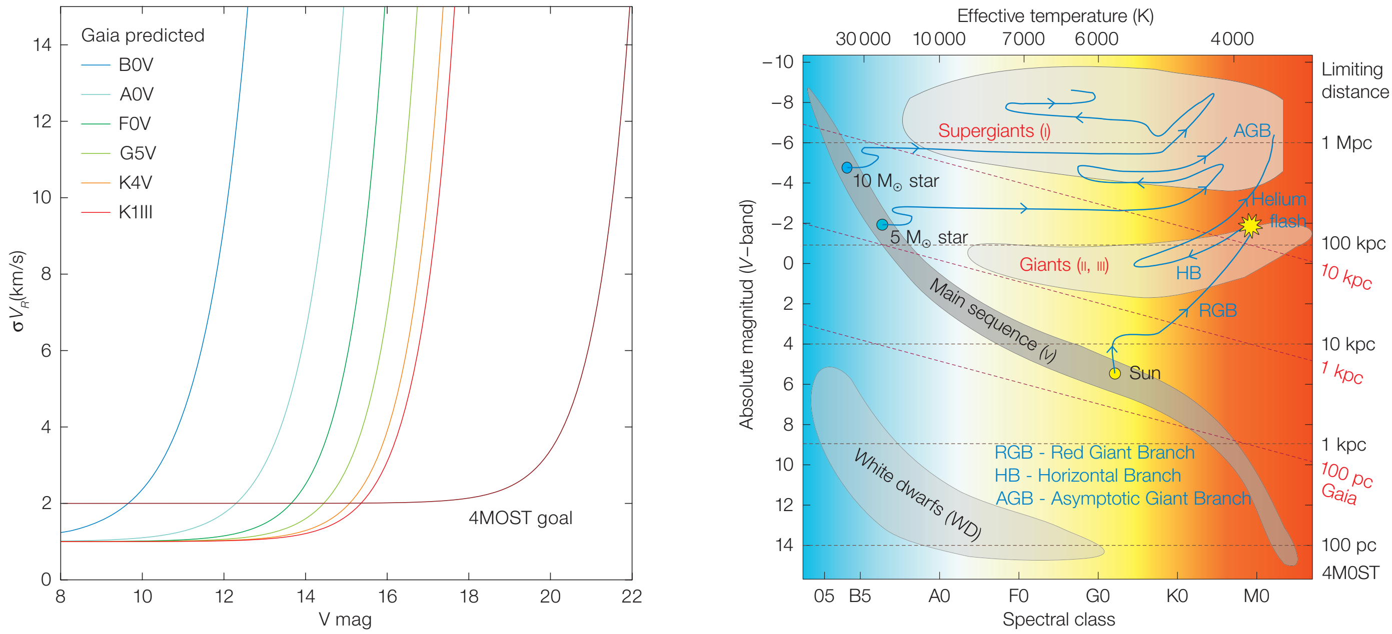

Figure 1. Left: The 4MOST goal for radial velocity accuracy compared to the Gaia end of mission accuracy as function of stellar apparent magnitude. Our aim is to match the spectroscopic magnitude limits of 4MOST to the astrometric limits of Gaia, thereby enabling 6D-phase space studies to Gaia's limits. Right. Limiting distances for radial velocity measurements with Gaia (maroon diagonal) and 4MOST (black horizontal) overlaid on a Hertzsprung–Russell diagram. 4MOST can measure Sun-like stars to nearly the centre of the Milky Way, RGB stars to 100 kpc, and massive stars throughout the Local Group, substantially expanding on Gaia's spectroscopic view. Distance limits for the 4MOST high resolution spectroscopy are about four times smaller.

the Echidna design as developed by the Australian Astronomical Observatory (AAO) for FMOS (Akiyama et al., 2008) and another one based on the positioner design of the Guoshoujing (formerly LAMOST) Telescope (Hu et al., 2004).

Efficient full-sky surveying requires at least 1500 targets to be observed simultaneously, but our goal is to provide a multiplex of > 3000 to create a unique, world-class facility. Most fibres will lead to spectrographs with spectral resolution of $R \sim 5000$ covering the full optical wavelength range, but about 10% of the fibres will permanently go to a spectrograph with resolution of $R > 20000$. The facility will be complemented with a full array of software to enable target selection, scheduling, data reduction and analysis, and an archive. During the conceptual design phase we will perform a number of trade-off studies to find the

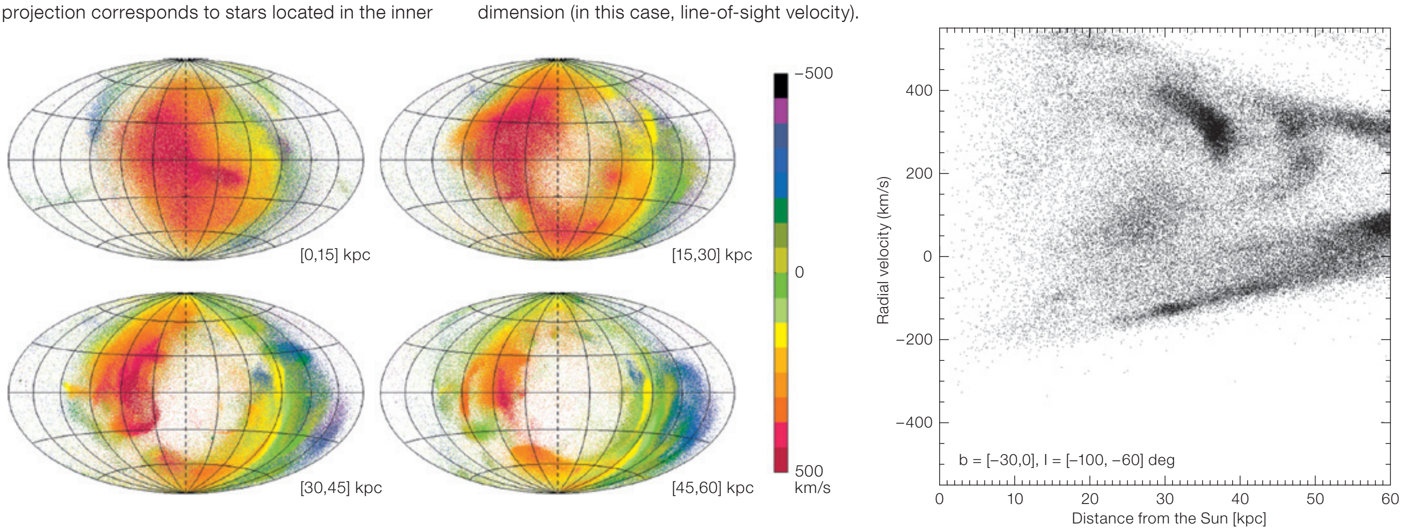

Figure 2. Spatial and radial velocity substructure distribution of RGB stars on the sky for a stellar halo formed in the Aquarius project cosmological simulations (Cooper et al., 2010; Helmi et al., 2011). The projection corresponds to stars located in the inner halo in four distance bins (left) and in one direction on the sky (right) and clearly demonstrates the large amount of substructure that becomes apparent, consequent on the opening of a new phase-space dimension (in this case, line-of-sight velocity).

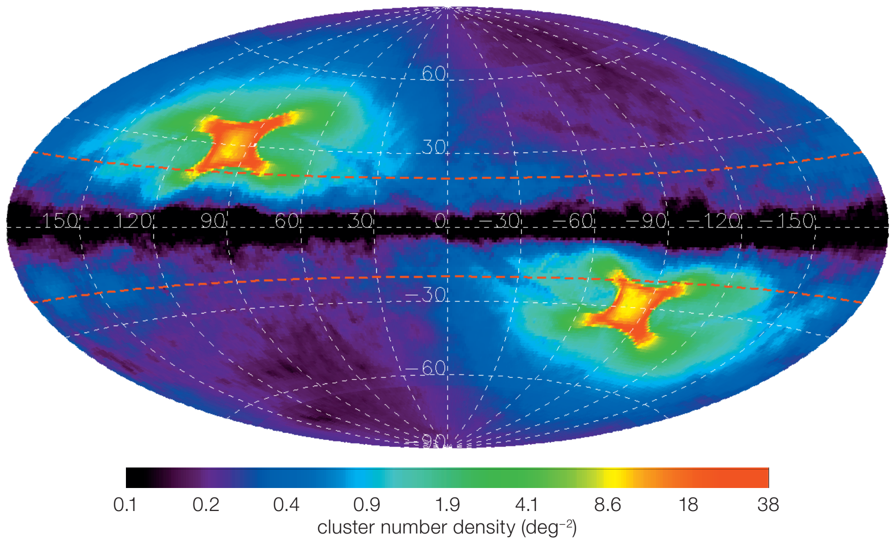

Figure 3. All-sky map (in Aitoff projection) of the predicted number density of eROSITA galaxy cluster detections (from Mühlegger, 2010). 4MOST enables efficient follow-up of the ~70 000 clusters detected in the southern hemisphere and provides dynamical mass estimates for a large fraction of them by measuring radial velocities of 5–30 galaxies in each cluster.

optimal designs for both the VISTA and the NTT telescopes, with ESO then making the final telescope selection about halfway through the study.

Surveys with 4MOST

To reach maximum impact, we propose to use 4MOST continuously for a five-year Public Survey delivering ≥ 7 million (goal 25 million) spectra over 10 000–20 000 square degrees, which is an order of magnitude larger than the Sloan Digital Sky Survey (SDSS) spectroscopic survey at > 2.5 times the spectral resolution. The targets selected for this Public Survey could be determined through a combination of open calls to the ESO astronomical community and the consortium guaranteed time observations (GTO), with all surveys running in parallel. Observing objects from many survey catalogues simultaneously at each pointing enables surveys that require tens of thousands objects spread sparsely over the sky. Such surveys have too few targets to use all 4MOST fibres in one pointing, but are too large to be performed in standard observing modes with existing facilities.

The consortium will make all data, including high-level science products, available to the general public in yearly increments through a high-quality database system.

European astronomers have currently no access to a 4MOST-like facility, and frankly, such an instrument does not exist worldwide. Only the HERMES instrument currently under construction for the AAO in combination with the planned, but not yet funded, BigBOSS or SuMIRe prime focus instruments (for the 4-metre Kitt Peak and 8-metre Subaru telescopes respectively) would provide similar capabilities as those proposed for 4MOST. However, even if these instruments were successfully constructed, European astronomers would not have direct access to them. For many science cases where spectral samples of more than a few 100 objects are required, 4MOST will outperform existing instrumentation on 8-metre-class telescopes like FLAMES and VIMOS. Running in permanent Public Survey mode, it will take observations for many science programmes simultaneously, enabled by its huge grasp in multiplex, field of view and wavelength coverage. The reduced photon-gathering power of a 4-metre-class telescope is thus easily compensated by the larger field of view and the increased time available per target. Therefore, if 4MOST is realised, the ESO community gains a facility that can be described as an 8-metre-class instrument on a 4-metre telescope.

References

Akiyama, M. et al. 2008, SPIE, 7018, 94
Bode, M., Cruz, M. & Molster, F. 2008, *The ASTRONET Infrastructure Roadmap*
Cooper, A. P. et al. 2010, MNRAS, 406, 744
de Zeeuw, P. & Molster, F. 2007, *A Science Vision for European Astronomy* (ASTRONET)
Drew, J. et al. 2010, *Report by the European telescope strategic review committee on Europe's 2–4m telescopes over the decade to 2020* (ASTRONET)
Helmi, A. et al. 2011, ApJL, 733, L7
Hu, H. et al. 2004, SPIE, 5492, 574
Mühlegger, M. 2010, Ph.D. thesis, Technische Universität München
Predehl, P. et al. 2010, SPIE, 7732, 23
Turon, C. et al. 2008, *Report by the ESA-ESO Working Group on Galactic populations, chemistry and dynamics*, ST-ECF, ESO

Specification	Baseline	Goal
Field of view	3 degree^2	> 5 degree^2
Multiplex fibre positioner	1500	> 3000
Spectrographs – blue arm		
resolution @ 500 nm	R ~ 3000	R ~ 5000
passband	420–650 nm	370–650 nm
Spectrographs – red arm		
resolution @ 850 nm	R ~ 5000	R ~ 7500
passband	650–900 nm	650–1000 nm
HR spectrograph (10–20 % of all fibres)		
resolution		R > 20 000,
passbands		390–450 & 585–675 nm
Number of fibres in 2′ circle	> 3	> 7
Reconfigure time	< 8 min	< 4 min
Area (5-year survey)	10 000 deg^2	2 × ~ 20 000 deg^2
Objects (5-year survey)	6 × 10^6	> 20 × 10^6
Start operations		end 2017

Table 1. Baseline and goal instrument specification.