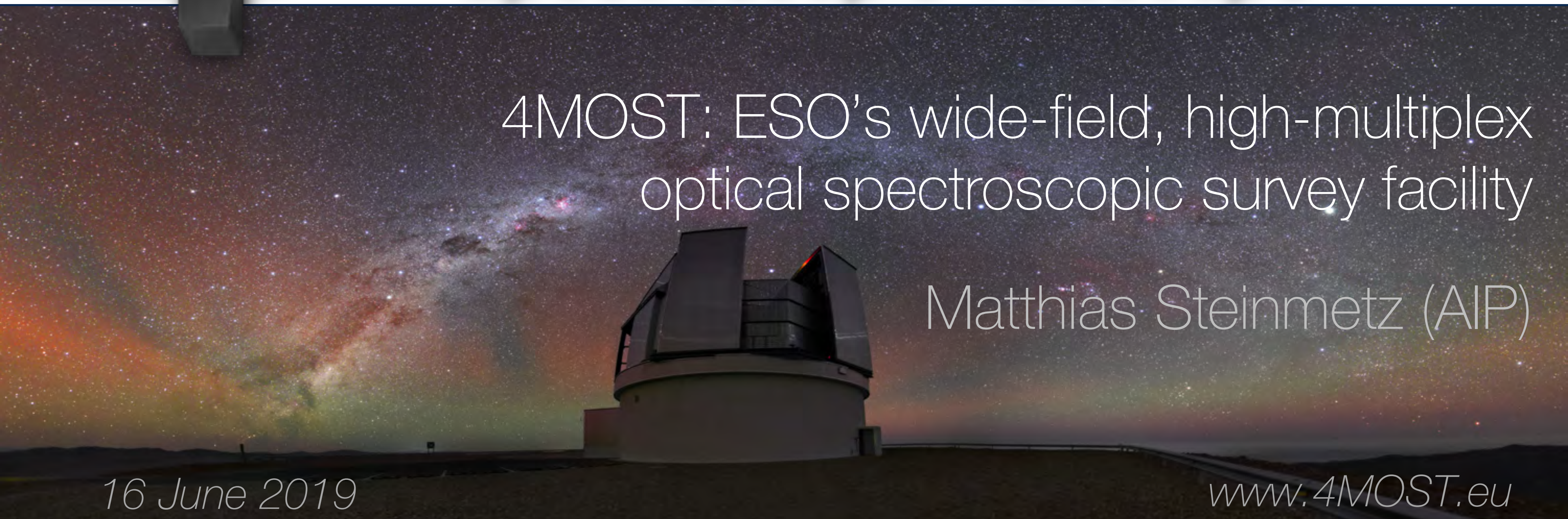
4MOST – 4m Multi-Object Spectroscopic Telescope



4MOST: ESO's wide-field, high-multiplex optical spectroscopic survey facility

Matthias Steinmetz (AIP)

16 June 2019

www.4MOST.eu

How I got involved in this …

- Chemical tagging (Freeman & Bland-Hawthorn 2002), substructure in velocity space (Helmi et al. 2000)
- Motivation: Astrometry mission DIVA (approved in 2001 as a mission in the German national space program DLR), on the US side: FAME
  - astrometry of some 40M stars, complete to V=10.5 (0.3 mas, 0.5 mas/a), but no RVs!
  - HIPPARCOS: Geneva Copenhagen Survey (2004): 11 years after end of mission
- Around 2002: about 50 000 stars in CDS with radial velocities, but 1 million galaxy redshifts!

A bit of RAVE history

GAIA Spectroscopy, Science and Technology
ASP Conference Series, Vol. 298, 2003
U. Munari ed.

RAVE: the RAdial Velocity Experiment

Matthias Steinmetz[1]

Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany

Abstract. RAVE[2] (RAdial Velocity Experiment) is an ambitious program to conduct an all-sky survey (complete to V=16 mag) to measure the radial velocities, metallicities and abundance ratios of 50 million stars using the 1.2 m UK Schmidt Telescope of the Anglo-Australian Observatory (AAO), together with a northern counterpart, over the period 2006 – 2010. The survey will represent a giant leap forward in our understanding of our own Milky Way galaxy, providing a vast stellar kinematic database three orders of magnitude larger than any other survey proposed for this coming decade. RAVE will offer the first truly representative inventory of stellar radial velocities for all major components of the Galaxy. The survey is made possible by recent technical innovations in multi-fiber spectroscopy, specifically the development of the 'Echidna' concept at the AAO for positioning fibers using piezo-electric ball/spines. A 1 m-class Schmidt telescope equipped with an Echidna fiber-optic positioner and suitable spectrograph would be able to obtain spectra for over 20 000 stars per clear night. Although the main survey cannot begin until 2006, a key component of the RAVE survey is a pilot program of 10^5 stars which may be carried out using the existing 6dF facility in unscheduled bright time over the period 2003–2005.

How I got involved in this …

- Chemical tagging (Freeman & Bland-Hawthorn 2002), substructure in velocity space (Helmi et al. 2000)
- Motivation: Astrometry mission DIVA (approved in 2001 as a mission in the German national space program DLR), on the US side: FAME
  - astrometry of some 40M stars, complete to V=10.5 (0.3 mas, 0.5 mas/a), but no RVs!
  - HIPPARCOS: Geneva Copenhagen Survey (2004): 11 years after end of mission
- Around 2002: about 50 000 stars in CDS with radial velocities, but 1 million galaxy redshifts!
- idea to have a 50 million object spectroscopic survey using an 2000 fibre Echidna-type positioner on the wide-field UK Schmidt Telescope (kickoff May 2002)
- target of opportunity: bright time of 6dF (6dFGRS in dark time) for proof of concept ⇨ RAVE

A bit of RAVE history

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over the period 2003–2005.

From RAVE to Gaia+

2003
RAVE starts

2004
SEGUE 1 starts
GCS results

CoRot
2006

SEGUE 2 & APOGEE 1 starts
2008

Kepler
2009

2010 ESO wide field survey call

2012
Gaia-ESO starts
LAMOST (4m)

K2
2014

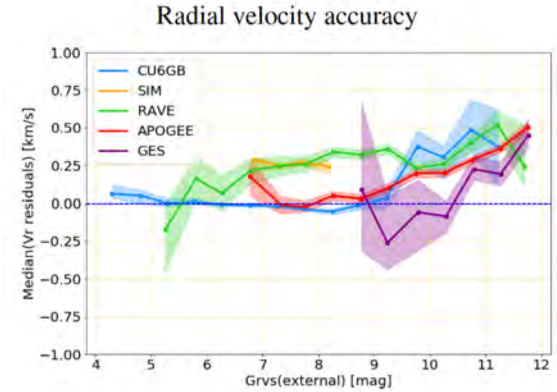
APOGEE 2 N/S
GALAH
starts (ongoing)
2014

2018
Gaia-DR2

TESS

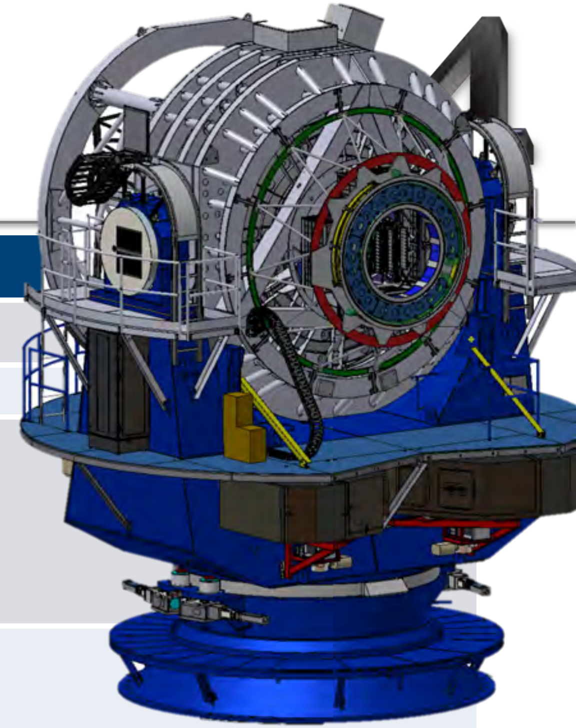
Gaia DR3
2020/2021

2020/2022-
MOONS,
4MOST, WEAVE,
SDSS-V



VISTA at Paranal Observatory, Chile

Instrument Specification



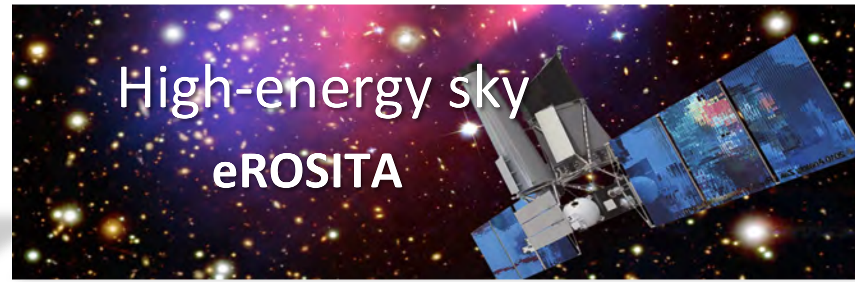
Specification	Design value
Field-of-View (hexagon)	~4.2 degree^2 (⌀>2.6°)
Multiplex fiber positioner	2436
Medium Resolution Spectrographs (2x) \# Fibres Passband Velocity accuracy	R~4000–7500 812 fibres (2x) 370-950 nm < 1 km/s
High Resolution Spectrograph (1x) \# Fibres Passband Velocity accuracy	R~20,000 812 fibres 392.6–435.5 nm, 516–573 nm, 610–679 nm < 1 km/s
# of fibers in Ø=2' circle	>3
Fibre diameter	⌀=1.45 arcsec
Area (first 5 year survey)	>2h x 18,000 deg^2
Number of science spectra (5 year)	~75 million of 20 min

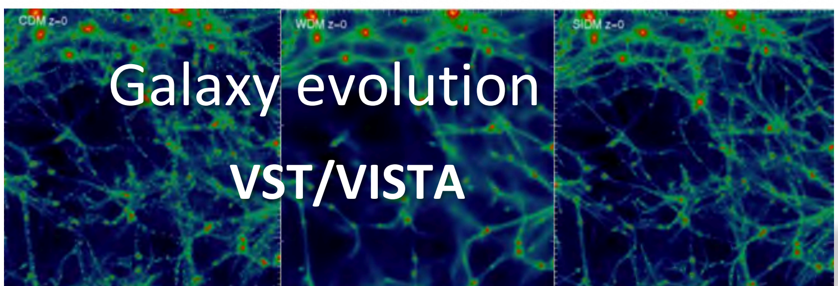
Wide-field, high-multiplex optical spectroscopic survey facility for ESO

- Status:
  - FDR completed, in construction phase, operations start end of 2022 (2-3 x 5 year)
  - GTO surveys: 70% in cycle 1, 20% in cycle 2 + 3
  - Call for Letter of Intent Q4/2019 for community surveys ⇒ call for proposals Q2/2020
- Science:
  - Cosmology, galaxy evolution, high-energy and **Galactic science**
  - Complement large-area space missions: Gaia, eRosita, Euclid, Plato
  - Complement groud-based surveys: VISTA, VST, DES, LSST, SKA, etc.
- Survey Facility:
  - Instrument, science operations, data products, science
  - Run all-sky 5 year *public surveys* in parallel with yearly data releases
  - Key surveys organized by consortium, add-on surveys from community through ESO
- Instrument specification:
  - High multiplex: 1600 fibres @R=5000 + 800 fibres @R=20,000 in parallel
  - Wavelength: LR: 370 - 950nm HR: 392 - 437 nm, 515 - 572 nm, 605 - 675 nm
  - 4.1m VISTA telescope of ESO, field of view: ∅ = 2.6°

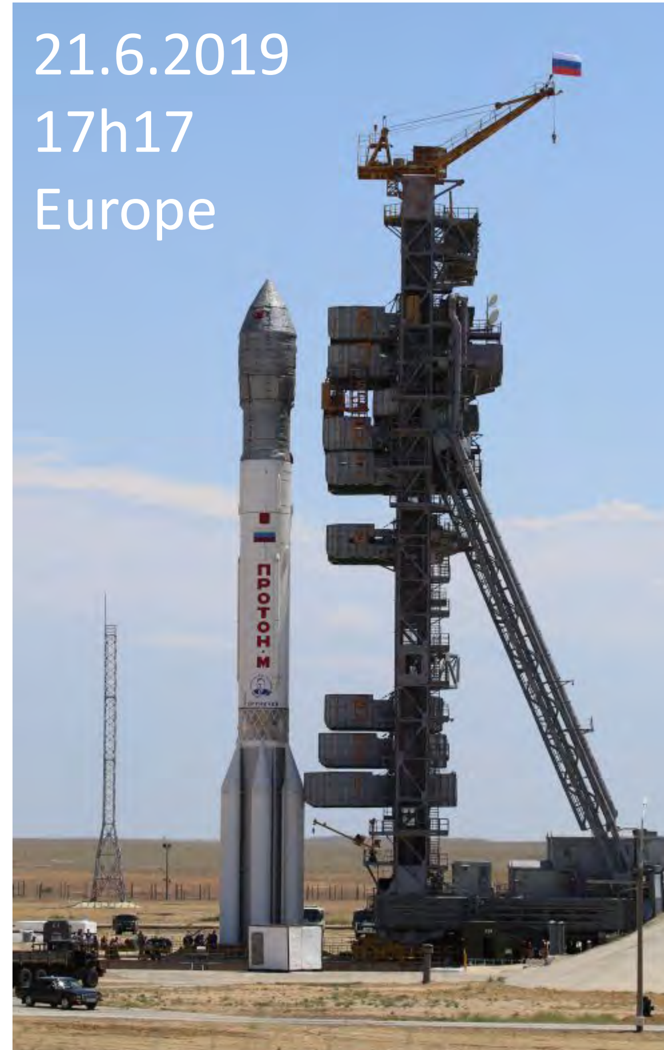
PI: R. de Jong (AIP)

Science Themes






19.12.2013


21.6.2019
17h17
Europe
ПРОТОН-М

Ten Consortium Surveys

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 Disk and Bulge LR Survey	Chiappini, Minchev, Starkenburg (AIP)
S4	Milky Way Disk and Bulge HR Survey	Bensby (LU), Bergemann (MPIA)
S5	Galaxy Clusters Survey	Finoguenov (MPE)
S6	AGN Survey	Merloni (MPE)
S7	Galaxy Evolution Survey (WAVES)	Driver (USW), Liske (HHU)
S8	Cosmology Redshift Survey	Richard (CRAL), Kneib (EPFL)
S9	Magellanic Clouds Survey	Cioni (AIP)
S10	Time-Domain Extragalactic Survey (TiDES)	Sullivan (Southampton)

March 2019 (No. 175)

Highlights include:

- R.S. de Jong et al.: **4MOST: Project overview and information for the First Call for Proposals**
- G. Guiglion et al.: **4MOST Survey Strategy Plan**
- A. Helmi et al.: **4MOST Consortium Survey 1: The Milky Way Halo Low-Resolution Survey**
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- C. Chiappini et al.: **4MOST Consortium Survey 3: Milky Way Disc and Bulge Low-Resolution Survey (4MIDABLE-LR)**
- T. Bensby et al.: **4MOST Consortium Survey 4: Milky Way Disc and Bulge High-Resolution Survey (4MIDABLE-HR)**
- A. Finoguenov et al.: **4MOST Consortium Survey 5: eROSITA Galaxy Cluster Redshift Survey**
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25.6 MB PDF file

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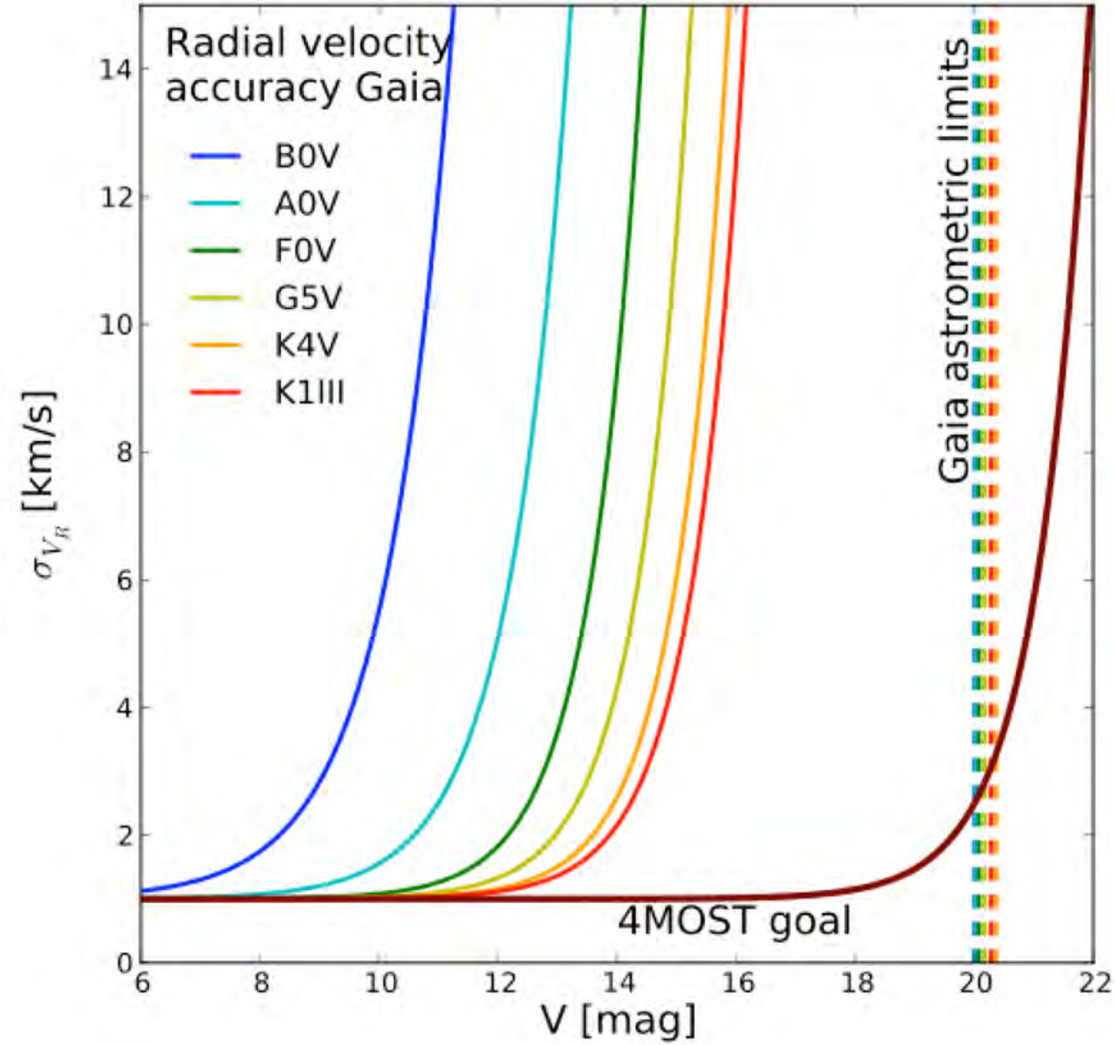

Radial velocity accuracy Gaia
B0V
A0V
F0V
G5V
K4V
K1III
Gaia astrometric limits
4MOST goal
σ_{V_R} [km/s]
V [mag]
0
2
4
6
8
10
12
14
6
8
10
12
14
16
18
20
22

4MOST Consortium Survey 1: The Milky Way Halo Low-Resolution Survey

Amina Helmi[1]
Mike Irwin[2]
Alis Deason[3]
Eduardo Balbinot[1]
Vasily Belokurov[2]
Joss Bland-Hawthorn[4]
Norbert Christlieb[5]
Maria-Rosa L. Cioni[6]
Sofia Feltzing[7]
Eva K. Grebel[8]
Georges Kordopatis[9]
Else Starkenburg[6]
Nicholas Walton[2]
C. Clare Worley[2]

- Characterizing Dark Matter halo of MW
- Constraining its nature
- Halo substructures – chemo-kinematic
- Metallicity distribution
- Constrains on yields first stars
- Characterisation of the stellar halo-thick disc interface from overlap with the 4MIDABLE-LR survey with the aim of jointly constraining the temporal assembly and evolution of the thick disc and inner halo

- $-10 < G + 5 \log10(\text{proper motion}) < 10$
- parallax $-2\sigma_{parallax} < 0.2$
- $0.55 < G{-}GRP < 0.8$ mag
- $15 < G < 20$ mag
- This leads to a sample of approximately 2 million objects
- $|b| > 20$ degrees.
- survey area: $-80 < Dec < +20$ degrees

4MOST Consortium Survey 2: The Milky Way Halo High-Resolution Survey

Norbert Christlieb[1]
Chiara Battistini[1]
Piercarlo Bonifacio[2]
Elisabetta Caffau[2]
Hans-Günter Ludwig[1]
Martin Asplund[3]
Paul Barklem[4]
Maria Bergemann[5]
Ross Church[6]
Sofia Feltzing[6]
Dominic Ford[6]
Eva K. Grebel[7]
Camilla Juul Hansen[5]
Amina Helmi[8]
Georges Kordopatis[9]
Mikhail Kovalev[5]
Andreas Korn[4]
Karin Lind[5]
Andreas Quirrenbach[1]
Jan Rybizki[5]
Ása Skúladóttir[5]
Else Starkenburg[10]

<table>
<tr><th>Criterion #</th><th>Bright survey</th><th>Faint survey</th><th>Deep survey</th></tr>
<tr><td>1</td><td colspan="2">$+20° \geq \mathrm{dec} \geq -80°$</td><td rowspan="2">Selected areas</td></tr>
<tr><td>2</td><td colspan="2">$|b| > 20°$</td></tr>
<tr><td>3</td><td colspan="3">[Fe/H] < -0.5</td></tr>
<tr><td>4</td><td>$12.0 \leq G \leq 14.5$</td><td>$14.5 < G \leq 15.5$</td><td>$15.5 < G \leq 17.0$</td></tr>
<tr><td>5</td><td colspan="3">$0.15 \leq (G_{BP}-G_{RP})_0 \leq 1.10$</td></tr>
<tr><td>6</td><td colspan="3">$(1.10 < (G_{BP}-G_{RP})_0 \leq 1.60)$ & $(M_G < 3.5)$</td></tr>
<tr><td>Total number of targets</td><td>1 150 000</td><td>800 000</td><td>26 000</td></tr>
<tr><td>Targets at [Fe/H] < -2.0</td><td>13 000</td><td>18 000</td><td>100</td></tr>
</table>

4MOST Consortium Survey 4: Milky Way Disc and Bulge High-Resolution Survey (4MIDABLE-HR)

Thomas Bensby[1]
Maria Bergemann[2]
Jan Rybizki[2]
Bertrand Lemasle[3]
Louise Howes[1]
Mikhail Kovalev[2]
Oscar Agertz[1]
Martin Asplund[4]
Paul Barklem[5]
Chiara Battistini[6]
Luca Casagrande[4]
Cristina Chiappini[7]
Ross Church[1]
Sofia Feltzing[1]
Dominic Ford[1]
Ortwin Gerhard[8]
Iryna Kushniruk[1]
Georges Kordopatis[9]
Karin Lind[2,5]
Ivan Minchev[7]
Paul McMillan[1]
Hans-Walter Rix[2]
Nils Ryde[1]
Gregor Traven[1]

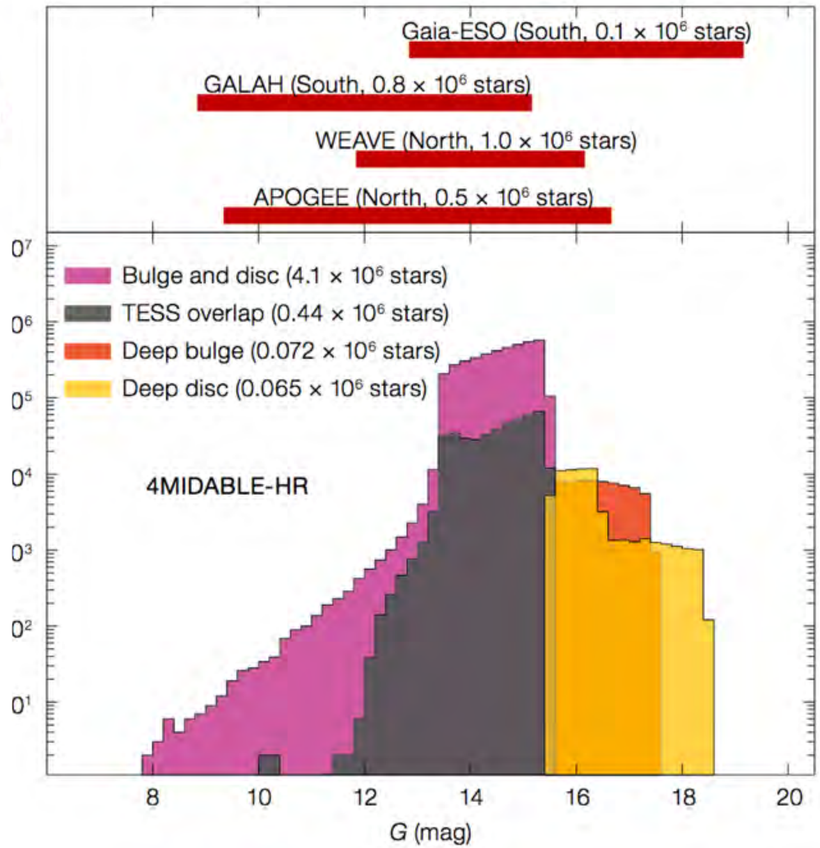


Figure 1. Magnitude distributions of our main bulge and disc sample and our two deep fields, one towards the bulge and one towards the 4MOST WAVES fields. The horizontal lines in the upper panel mark the magnitude ranges of selected high-resolution spectroscopic surveys, as indicated.

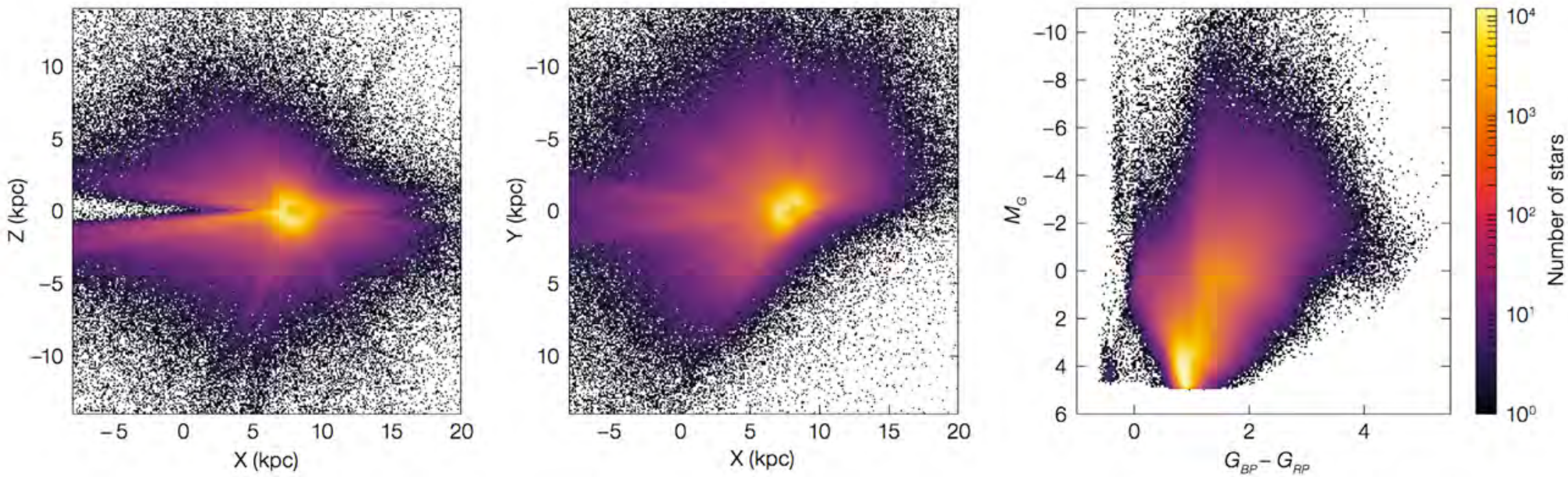
Deep Disk Field

Deep Bulge Field

Bulge Cepheid Field

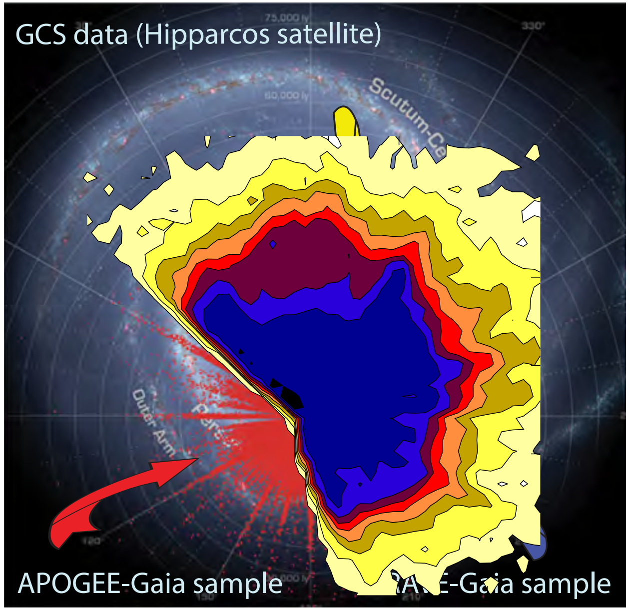
Simple Target Selection:

- G < 15.5 -> allows S/N = 100 per Å in 2 h
- M_G < 5 mag to avoid cool MS stars
- Gaia parallaxes to determine M_G
- – 80° < Dec < + 20°
- 21 M targets from the Gaia DR2
- Randomly reduced to ~ 4 M targets
- Goal: to observe **2.5 M stars**
- Disk deep (~ 65,000 stars) and Bulge Deep G < 17.5 (~ 72,000 stars)



4MOST Consortium Survey 3: Milky Way Disc and Bulge Low-Resolution Survey (4MIDABLE-LR)

Cristina Chiappini[1]
Ivan Minchev[1]
Else Starkenburg[1]
Friedrich Anders[2]
Nicola Gentile Fusillo[3]
Ortwin Gerhard[4]
Guillaume Guiglion[1]
Arman Khalatyan[1]
Georges Kordopatis[5]
Bertrand Lemasle[6]
Gal Matijevic[1]
Anna Barbara de Andrade Queiroz[1]
Axel Schwope[1]
Matthias Steinmetz[1]
Jesper Storm[1]
Gregor Traven[7]
Pier-Emmanuel Tremblay[3]
Marica Valentini[1]
Rene Andrae[8]
Anke Arentsen[1]
Martin Asplund[9]
Thomas Bensby[7]
Maria Bergemann[8]
Luca Casagrande[9]
Ross Church[7]
Gabriele Cescutti[10]
Sofia Feltzing[7]
Morgan Fouesneau[8]
Eva K. Grebel[6]
Mikhail Kovalev[8]
Paul McMillan[7]
Giacomo Monari[1]
Jan Rybizki[8]
Nils Ryde[7]
Hans-Walter Rix[8]
Nicholas Walton[11]
Maosheng Xiang[8]
Daniel Zucker[12]
and the 4MIDABLE-LR Team



Credit: Minchev

11 subsurveys

- Extended solar neighborhood
- Dynamical disk
- Faint dynamical disk
- Chemodynamical disk
- Bulge/inner Galaxy
- Very metal-poor stars
- White dwarfs
- Compact X-ray binaries
- Cepheids
- Asteroseismic targets
- Hot subdwarfs

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Call for LoI 2nd half 2019

System Integration Potsdam mid 2021

Acceptance Europe Feb 2022

Acceptance Chile Nov 2022

4MOST starts on VISTA 2022/2023 For 5 years

Schedule

Wide Field Corrector and Atmospheric Dispersion Compensator (WFC/ADC)

4 Lenses Groups with 2 counter-rotating prisms

Field Ø = 2.6 degree

535 mm Focal Diameter
Largest lens ~950mm

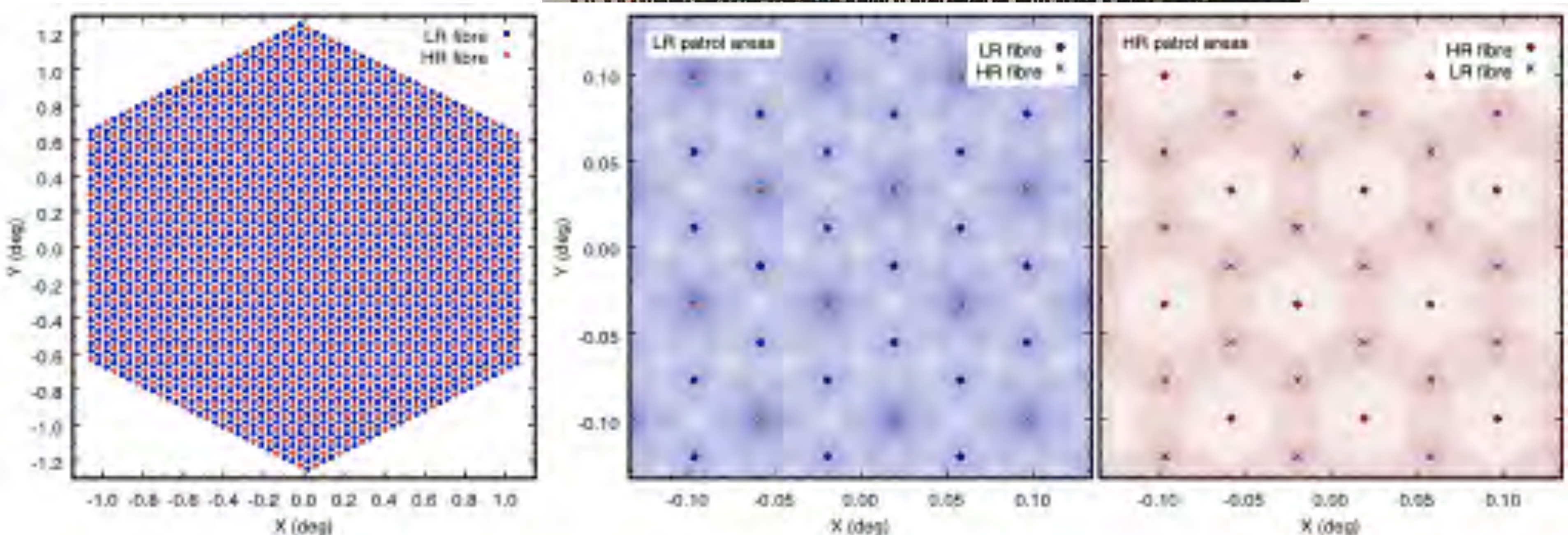
ADC functions to ZD=55°

Design AIP
Assembly and alignment UCL

AESOP Fiber Positioner

2436 Fiber Probes
-patrol diameter 2.4x pitch
-minimum separation ~20”
-reconfiguration time <2 min during CCD readout

N_{fib}	LR fibers %	HR fibres %
1	–	39.8
2	7.2	46.1
3	50.9	14.1
4	33.0	–
5	3.6	–
6	5.3	–



Low Resolution Spectrograph (LRS)

3 arms spectrograph
3 CCDs 6k x 6k

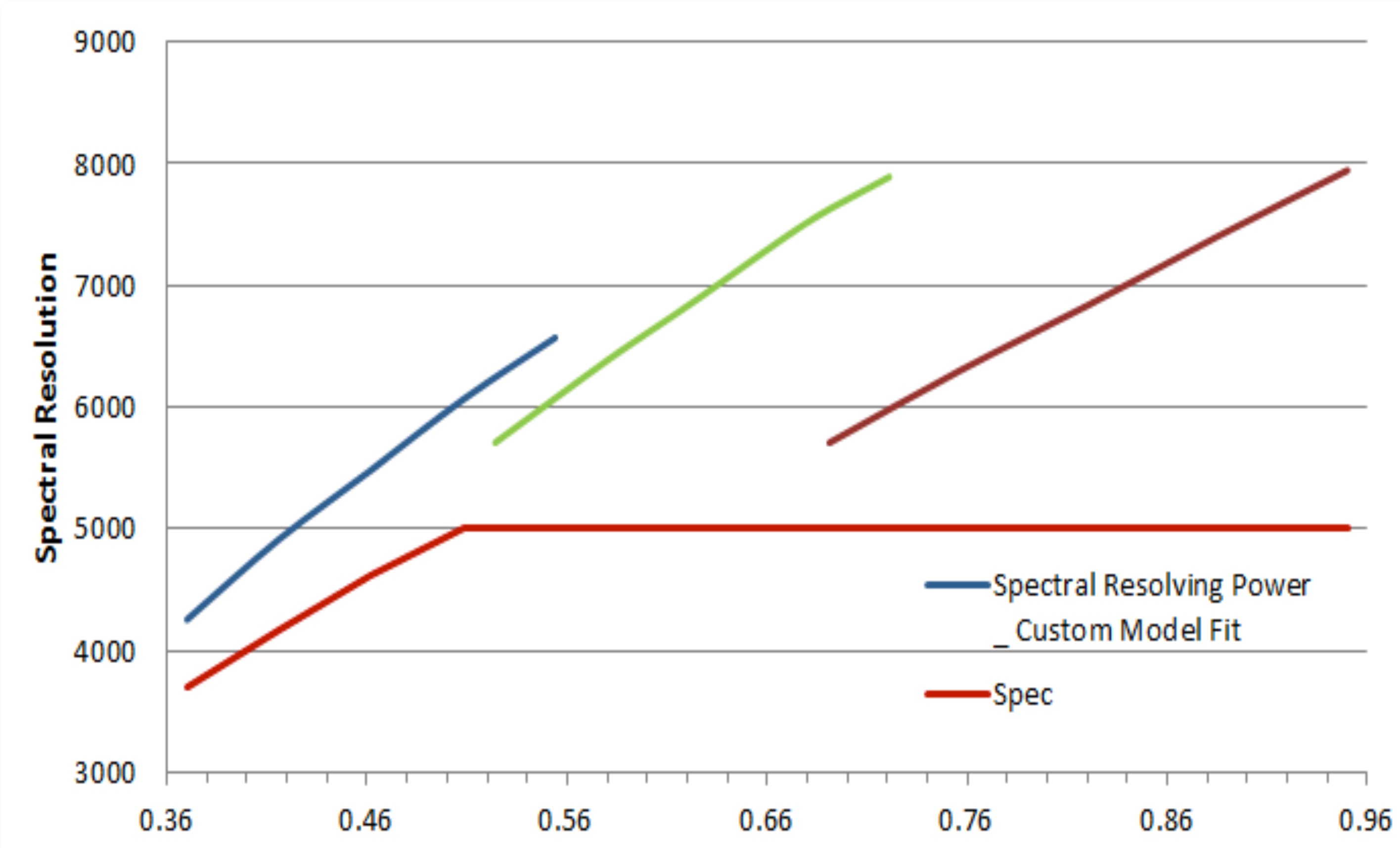
200 mm beam size

812 science fibers per spectrograph

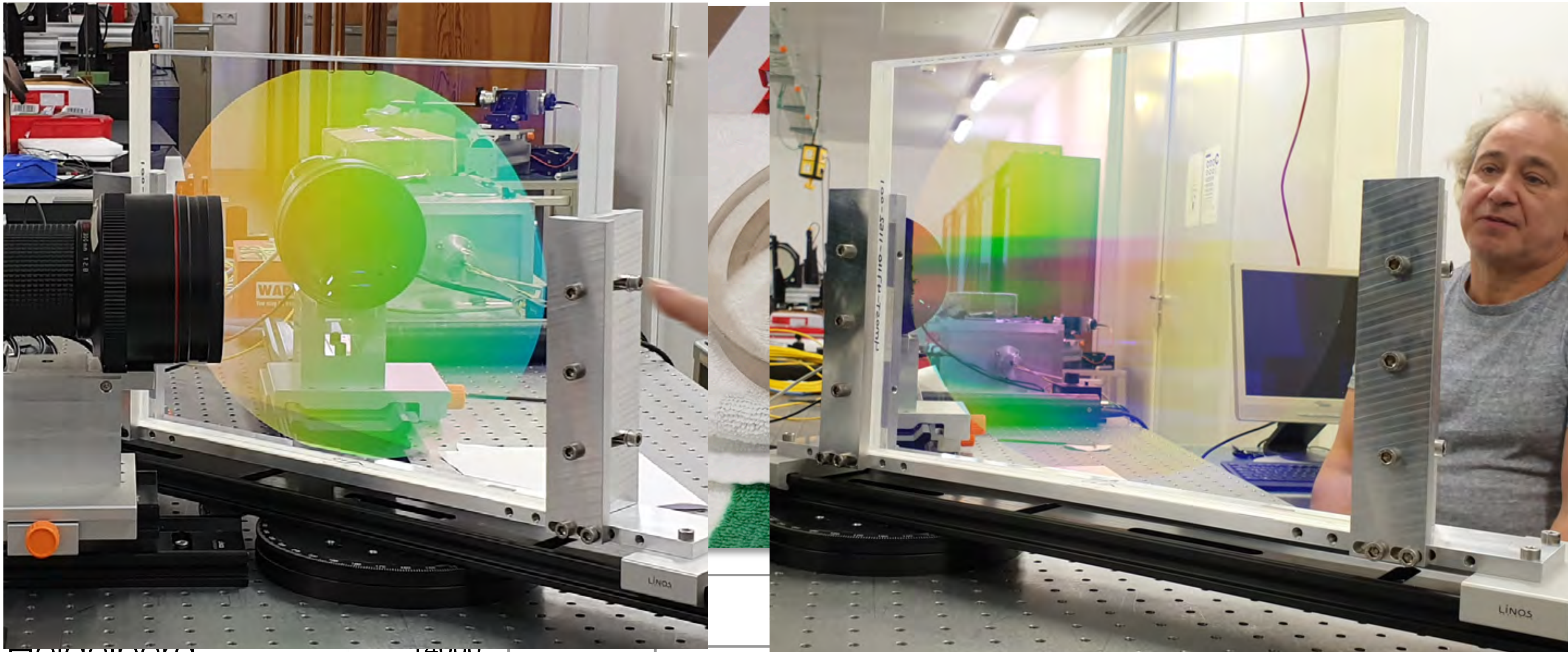
2 mirrored spectrographs

Thermally stabilized

Design and build at CRAL in Lyon.



High Resolution Spectrograph (HRS)



Heidelberg.

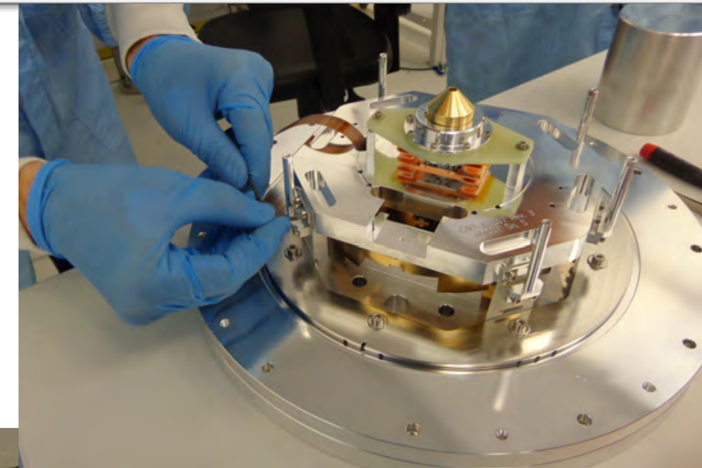
14000

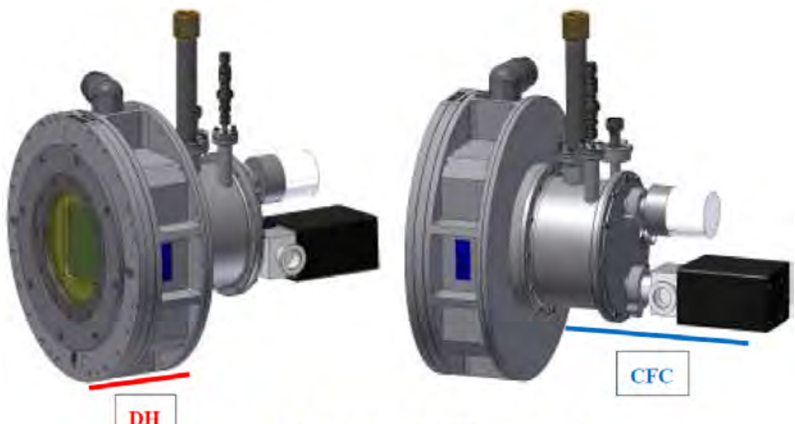
0.37 0.42 0.47 0.52 0.57 0.62 0.67 0.72

Wavelength in µm

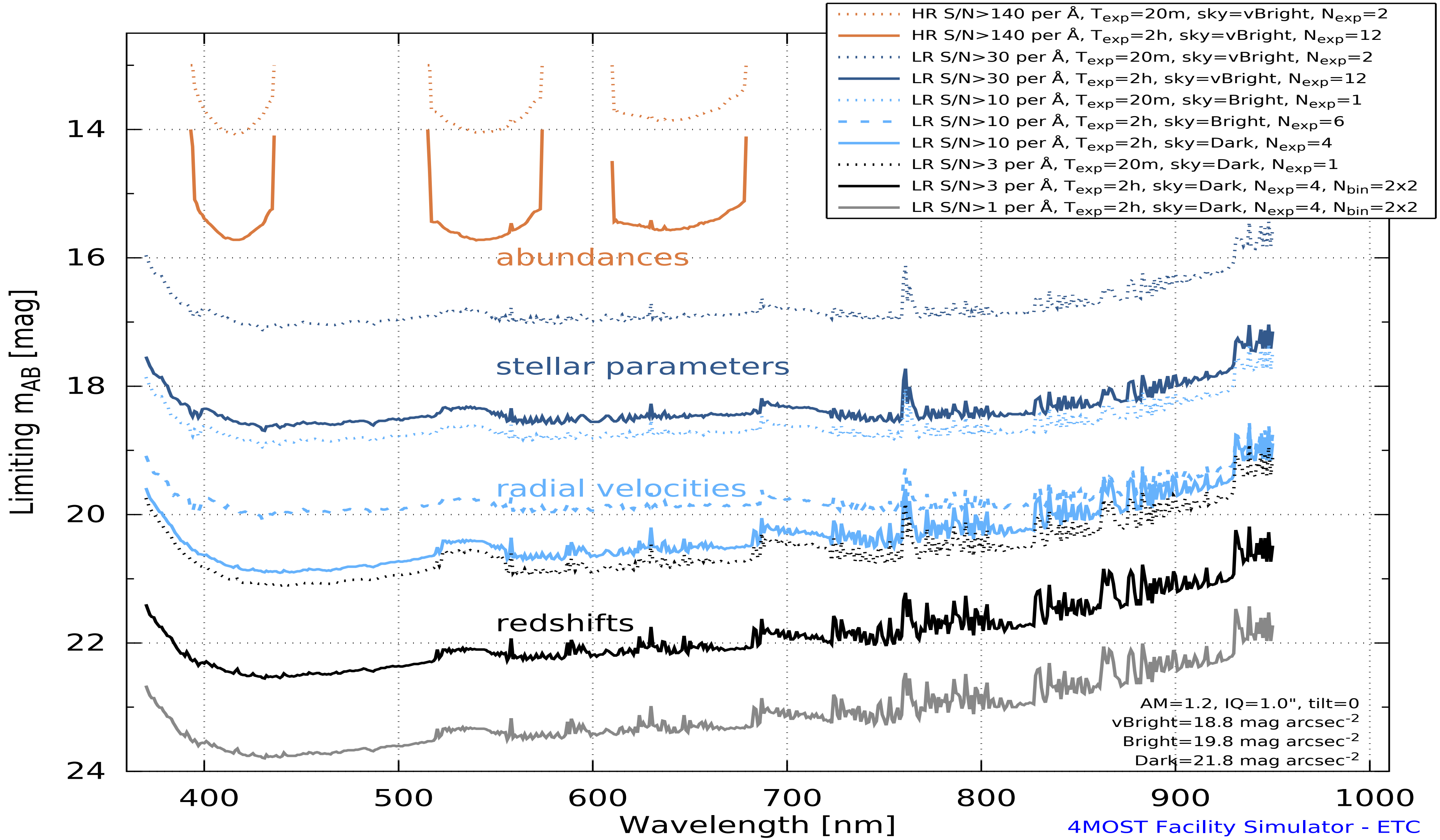
4MOST Detectors

- 9 identical detectors
  (plus spares and engineering devices)
- E2V 6kx6k – Deep Depletion – Broad Band Coating
- Detector head based on ESPRESSO design
- Cooling and controls identical to MUSE design
- All to ESO standards





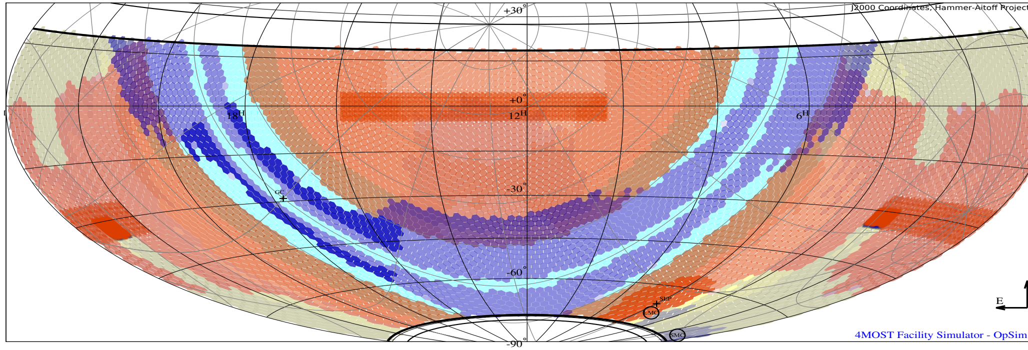
Design and build at ESO in Garching.



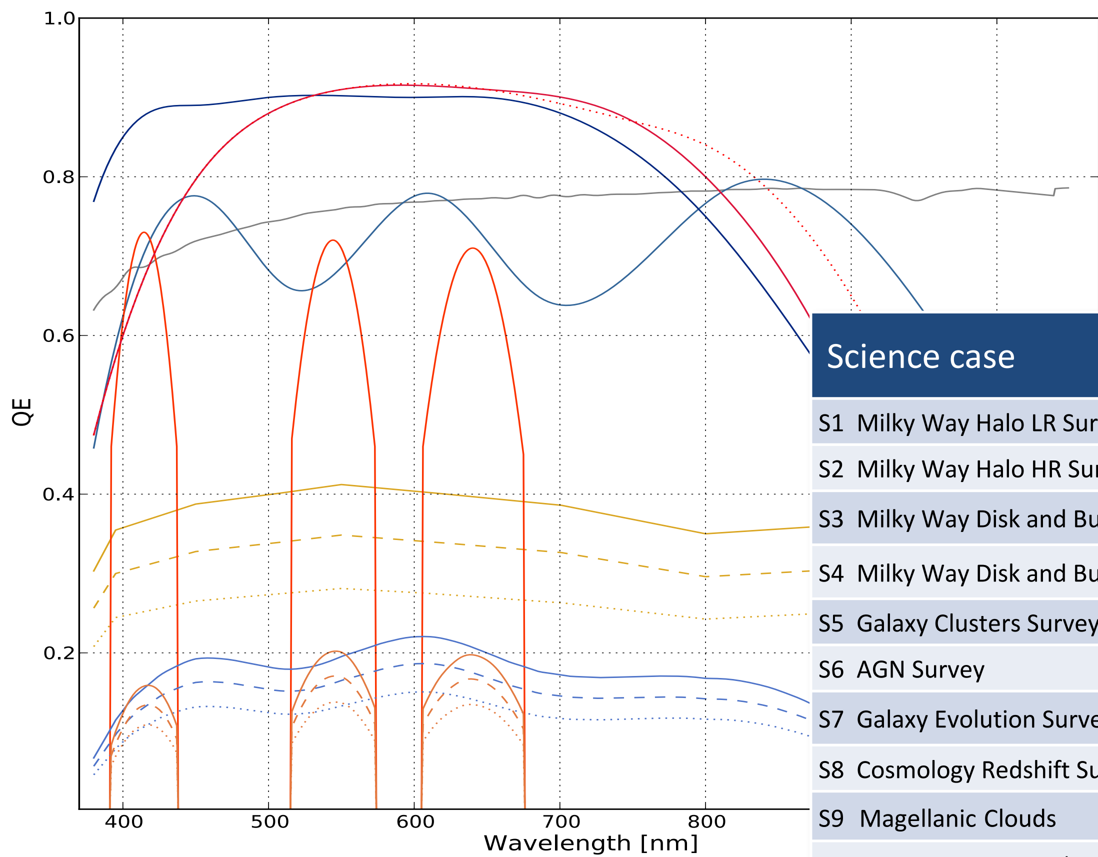
HR S/N>140 per Å, T_{exp}=20m, sky=vBright, N_{exp}=2
HR S/N>140 per Å, T_{exp}=2h, sky=vBright, N_{exp}=12
LR S/N>30 per Å, T_{exp}=20m, sky=vBright, N_{exp}=2
LR S/N>30 per Å, T_{exp}=2h, sky=vBright, N_{exp}=12
LR S/N>10 per Å, T_{exp}=20m, sky=Bright, N_{exp}=1
LR S/N>10 per Å, T_{exp}=2h, sky=Bright, N_{exp}=6
LR S/N>10 per Å, T_{exp}=2h, sky=Dark, N_{exp}=4
LR S/N>3 per Å, T_{exp}=20m, sky=Dark, N_{exp}=1
LR S/N>3 per Å, T_{exp}=2h, sky=Dark, N_{exp}=4, N_{bin}=2x2
LR S/N>1 per Å, T_{exp}=2h, sky=Dark, N_{exp}=4, N_{bin}=2x2
abundances
stellar parameters
radial velocities
redshifts
Limiting m_{AB} [mag]
14
16
18
20
22
24
400
500
600
700
800
900
1000
Wavelength [nm]
AM=1.2, IQ=1.0", tilt=0
vBright=18.8 mag arcsec^{-2}
Bright=19.8 mag arcsec^{-2}
Dark=21.8 mag arcsec^{-2}
4MOST Facility Simulator - ETC

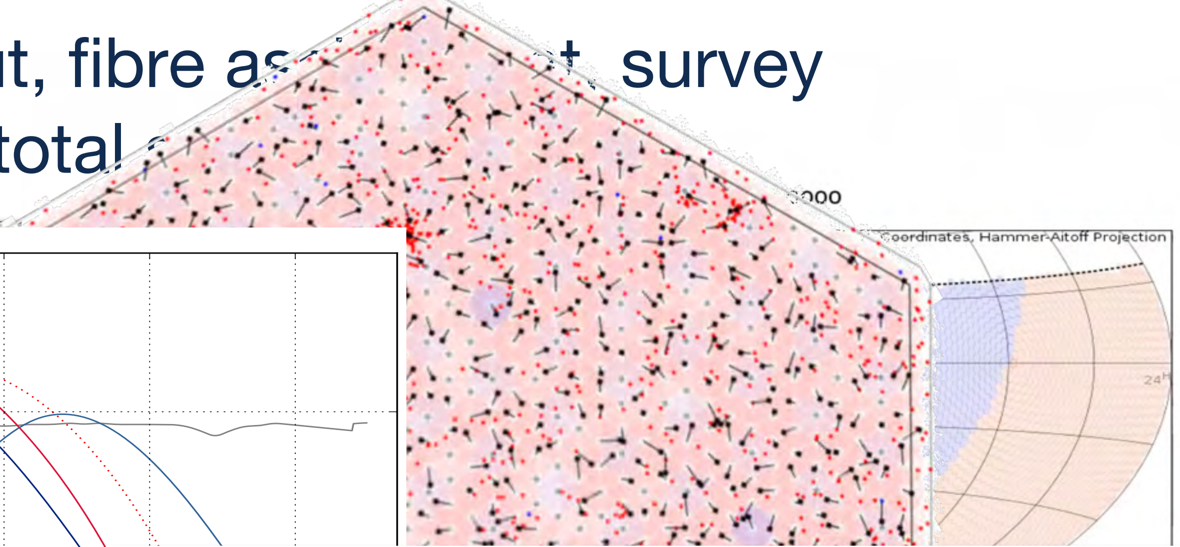
4MOST Operations

- Unique operations model for MOS instruments suitable *for most* science cases
- 4MOST program defined by *Public Surveys* of 5 years
- Surveys will be defined by ***Consortium*** and ***Community***
- All Surveys will run ***in parallel***
  - Surveys share fibres per exposure for increased efficiency
- ***Consortium Key Surveys*** will define observing strategy
  - Millions of targets all sky
  - Fill all fibres
- ***Add-on Surveys*** for smaller surveys
  - Small fraction fibers all sky or
  - dedicated small areas
  - 10^3 to 10^6 targets
- Several passes of sky with 2, 10, 20, 30 mins
- Wedding-cake distribution for total time 1h to 10h



Simulate throughput, fibre as... survey strategy and verify total ...





Science case	SNR/Å	r_{AB}-mags	Targets (Millions)
S1 Milky Way Halo LR Survey	10	16–20.0	1.4
S2 Milky Way Halo HR Survey	140	12–15.5	0.6
S3 Milky Way Disk and Bulge LR Survey	10–30	14–18.5	10.7
S4 Milky Way Disk and Bulge HR Survey	140	14–15.5	2.0
S5 Galaxy Clusters Survey	4	18–22.0	0.8
S6 AGN Survey	4	18–22.0	0.5
S7 Galaxy Evolution Survey (WAVES)	4	18–22.5	1.4
S8 Cosmology Redshift Survey	1	20–22.5	10.4
S9 Magellanic Clouds	10–30	16-20.0	0.3
S10 Transients Survey (TiDES)	4	18–22.5	0.3
Total			**>27**

Schedule and Milestones

- March 2019:
  - *Final Design Review-2*, detailed designs finalized
  - *Call for Proposals Readiness Review*, ready for Phase I community proposal selection
- Fall 2019:
  - *Call for Letters of Intent* from Community
- Jan 2021:
  - All subsystems manufactured, assembled, integrated and verified
- Feb 2022:
  - Full system integrated and verified at AIP, *preliminary acceptance Europe*
- Oct 2022:
  - System delivered, installed and commissioned on telescope, *preliminary acceptance Chile*
- Nov 2022 – Oct 2027:
  - First science survey of 4MOST, 30% of targets available for Community Surveys

4MOST

AIP

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University of Portsmouth

UNIVERSITY OF CAMBRIDGE

Durham University

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ESO

Durham University

Southampton

Lancaster University

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l'Observatoire GEP

IN2P3

UCL

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UNIVERSITY OF SUSSEX

WARWICK

AAO

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