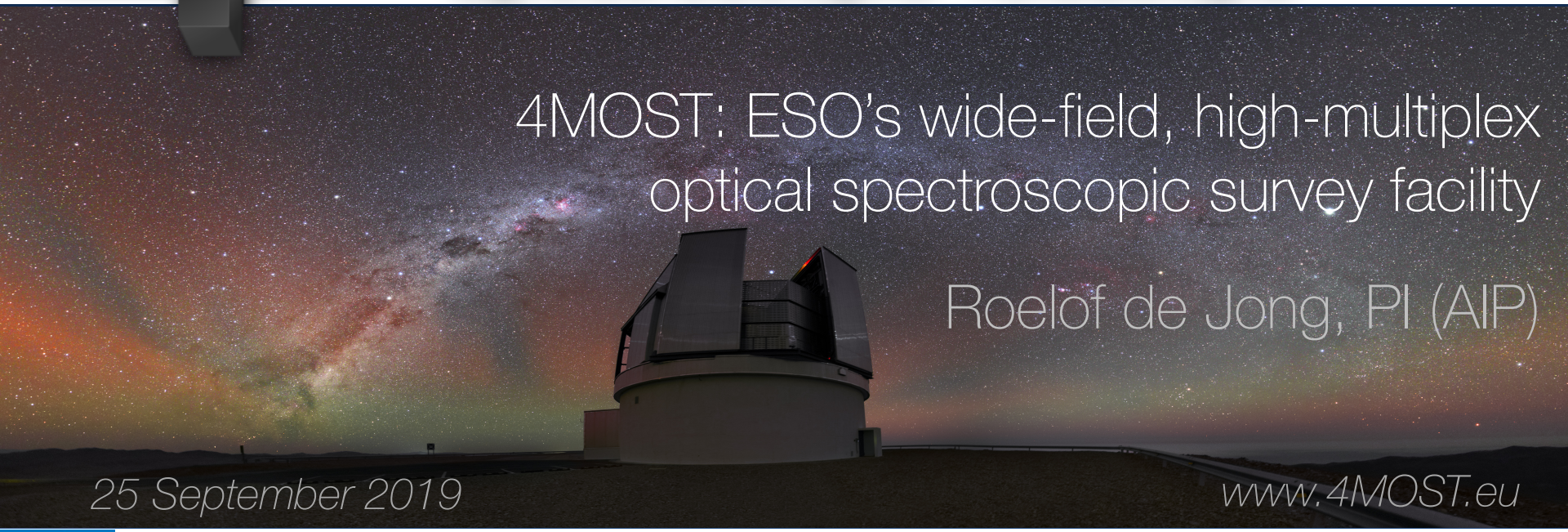
4MOST – 4m Multi-Object Spectroscopic Telescope



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

Roelof de Jong, PI (AIP)

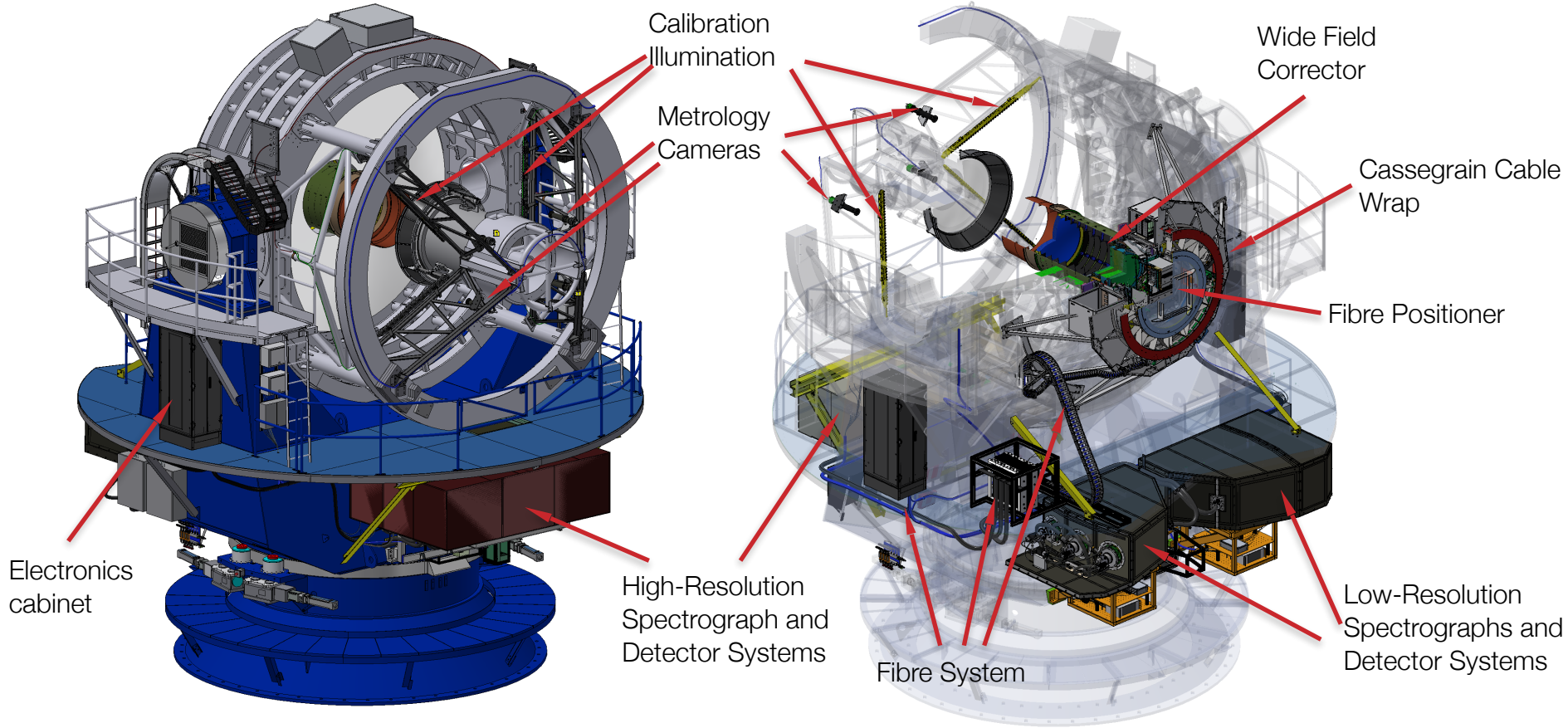
25 September 2019

www.4MOST.eu

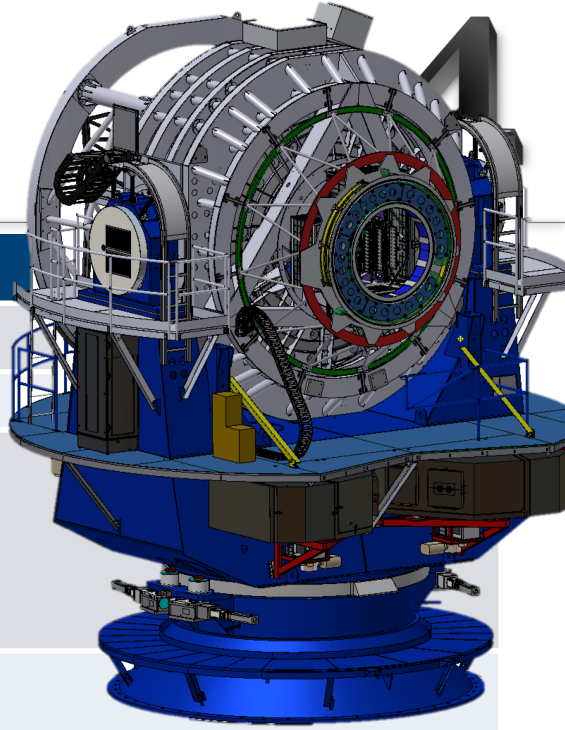
4MOST: Wide-field, high-multiplex optical spectroscopic survey facility for ESO

- Status:
  - ESO Council approved 4MOST in June 2015, ESO contract signed
  - FDR completed, 4MOST is in full construction and testing phase
  - Operations start on **VISTA** telescope late-2022 (at least 2x 5-year Surveys)
- Science:
  - Cosmology, galaxy evolution, high-energy, transients, and Galactic science
  - Complement large-area space missions: Gaia, eROSITA, Euclid, PLATO
  - Complement ground-based surveys: VISTA, VST, DES, LSST, SKA, etc.
- Survey facility:
  - Consortium delivers instrument, science operations, data products, science
  - Run all-sky 5 year public surveys in parallel, with yearly data releases
  - Key surveys organized by consortium in coordination with community
  - *Surveys solicited from Community through ESO peer-reviewed applications (Nov 2019!)*

4MOST on VISTA, Paranal



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 (goal < 0.5 km/s)
# of fibers in ⌀=2' circle	>3
Fibre diameter	⌀=1.42 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 Corrector and Atmospheric Dispersion Compensator (WFC/ADC)

4 Lens Groups with 2 counter-rotating prisms

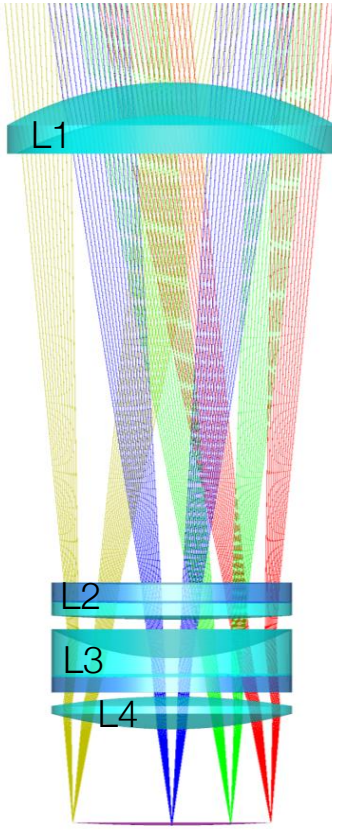
Field Ø = 2.6 degree

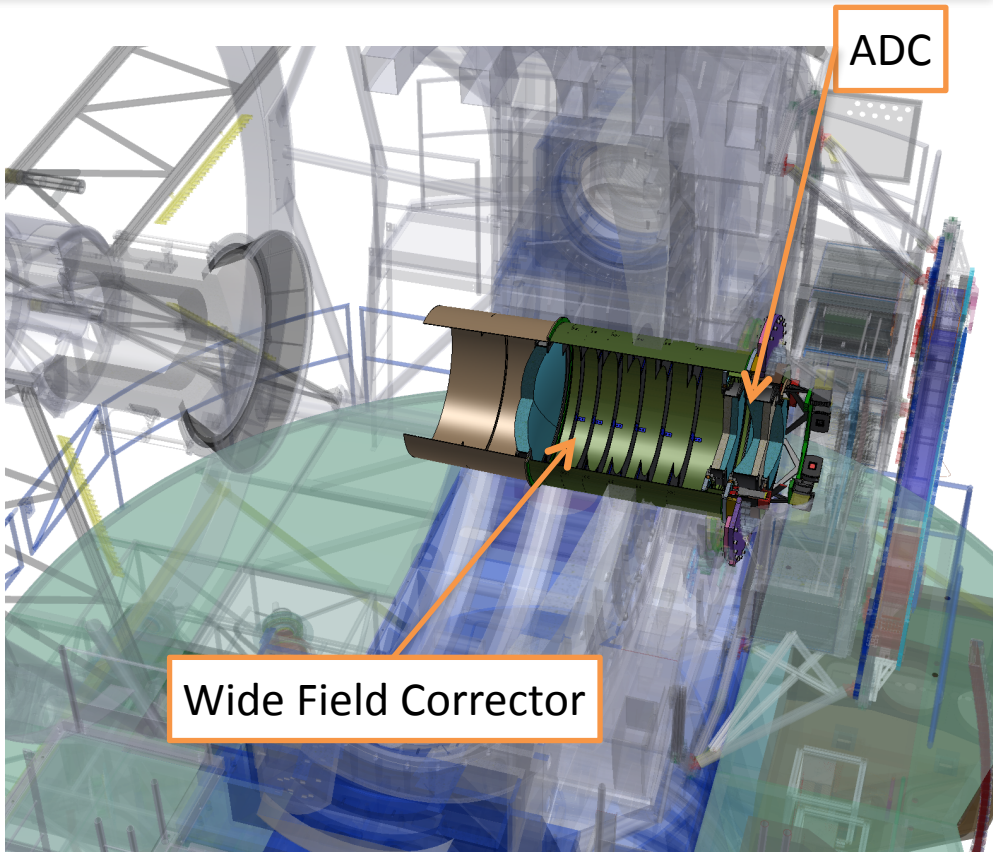
535 mm Focal Diameter
Largest lens ~950mm

ADC functions to ZD=55°

L1 – Fused Silica
L2 – L2A – LLF1; L2B – NBK7
L3 – L3A – NBK7; L3B – LLF1
L4 – NBK7

Design and construction AIP
Assembly and alignment UCL





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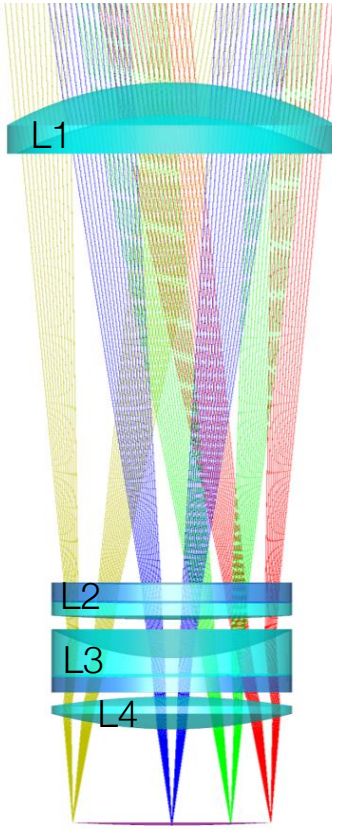
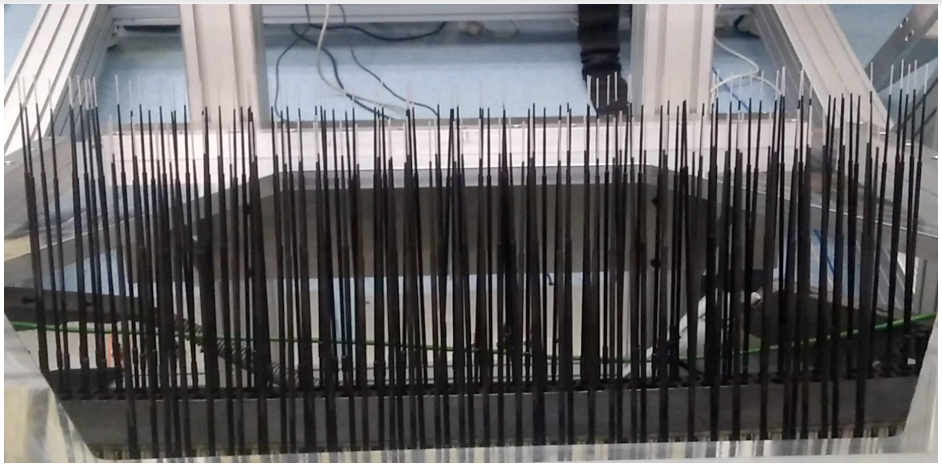


AESOP Fiber Positioner

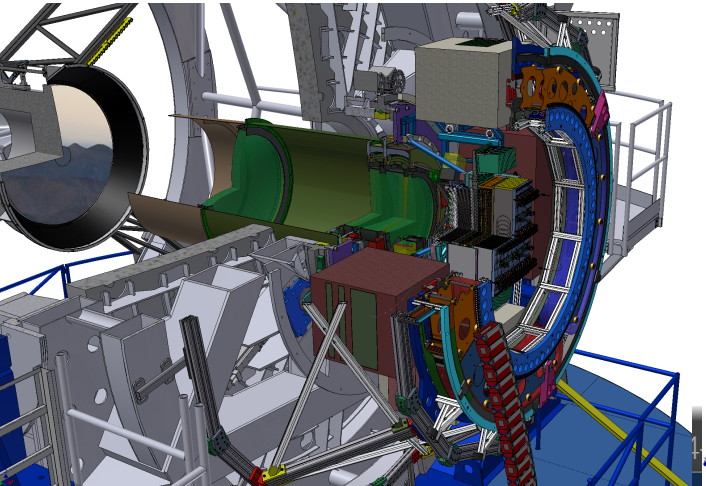
2436 Fiber Probes
- patrol diameter 2.4x pitch
  = 3.23 arcmin
- RMS accuracy < 10μm / 0.17″
- minimum separation ~20″
- reconfiguration time <2 min during CCD readout

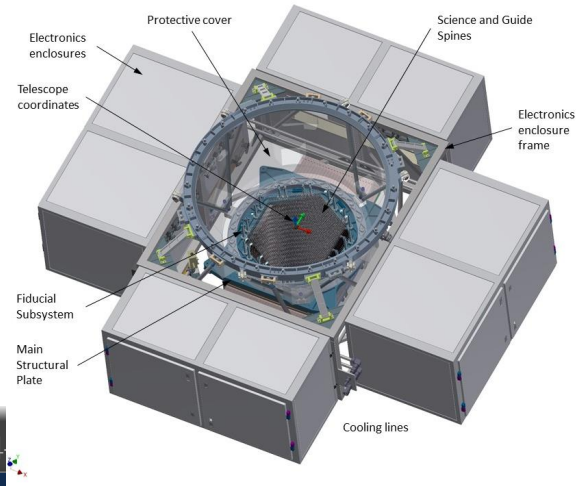
24 Fiducials

12 Guide Probes



Designed and built at AAO





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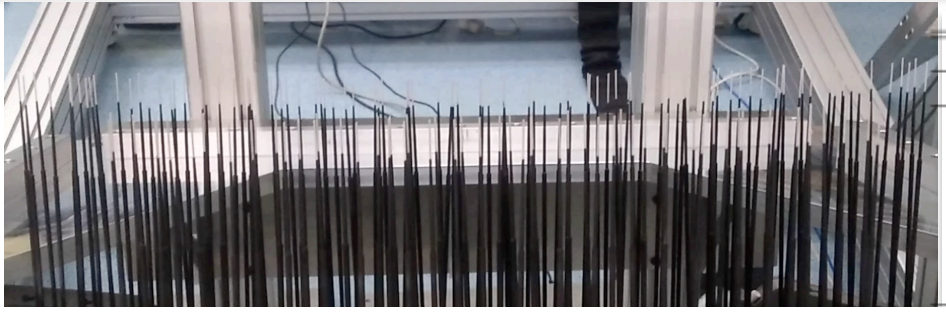
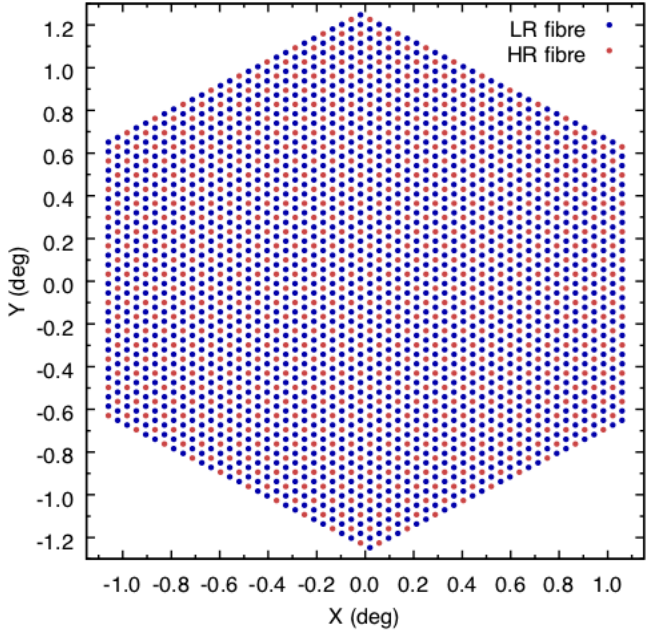
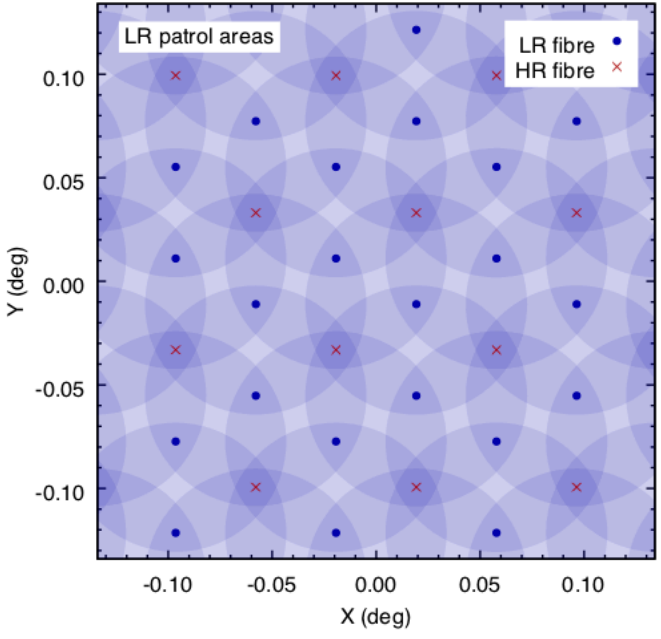
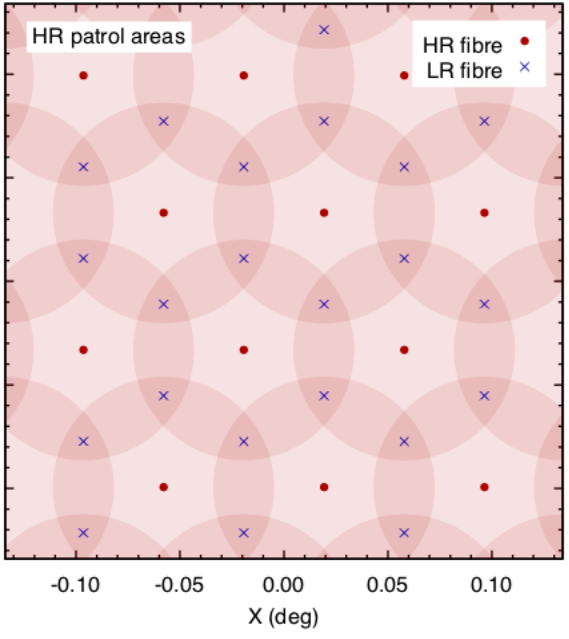


N_{fib}	LR fibers	HR fibres
	%	
1	–	39.8
2	7.2	46.1
3	50.9	14.1
4	33.0	–
5	3.6	–
6	5.3	–







Low Resolution Spectrograph (LRS)

3 arms spectrograph
3 CCDs 6k x 6k

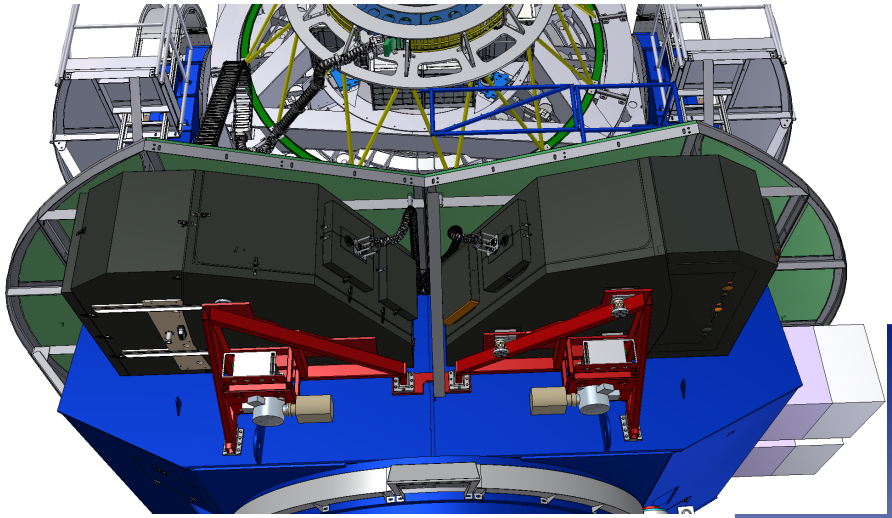
200 mm beam size

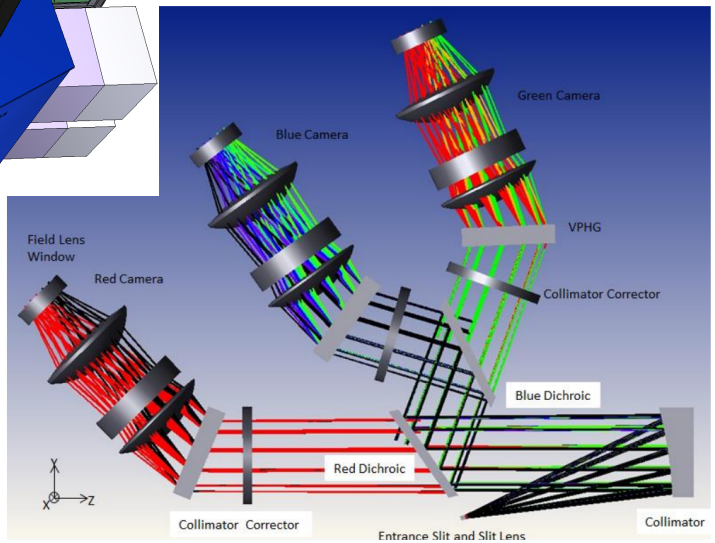
812 science fibres per spectrograph

2 mirrored spectrographs

Thermally stabilized

Design and build at CRAL in Lyon





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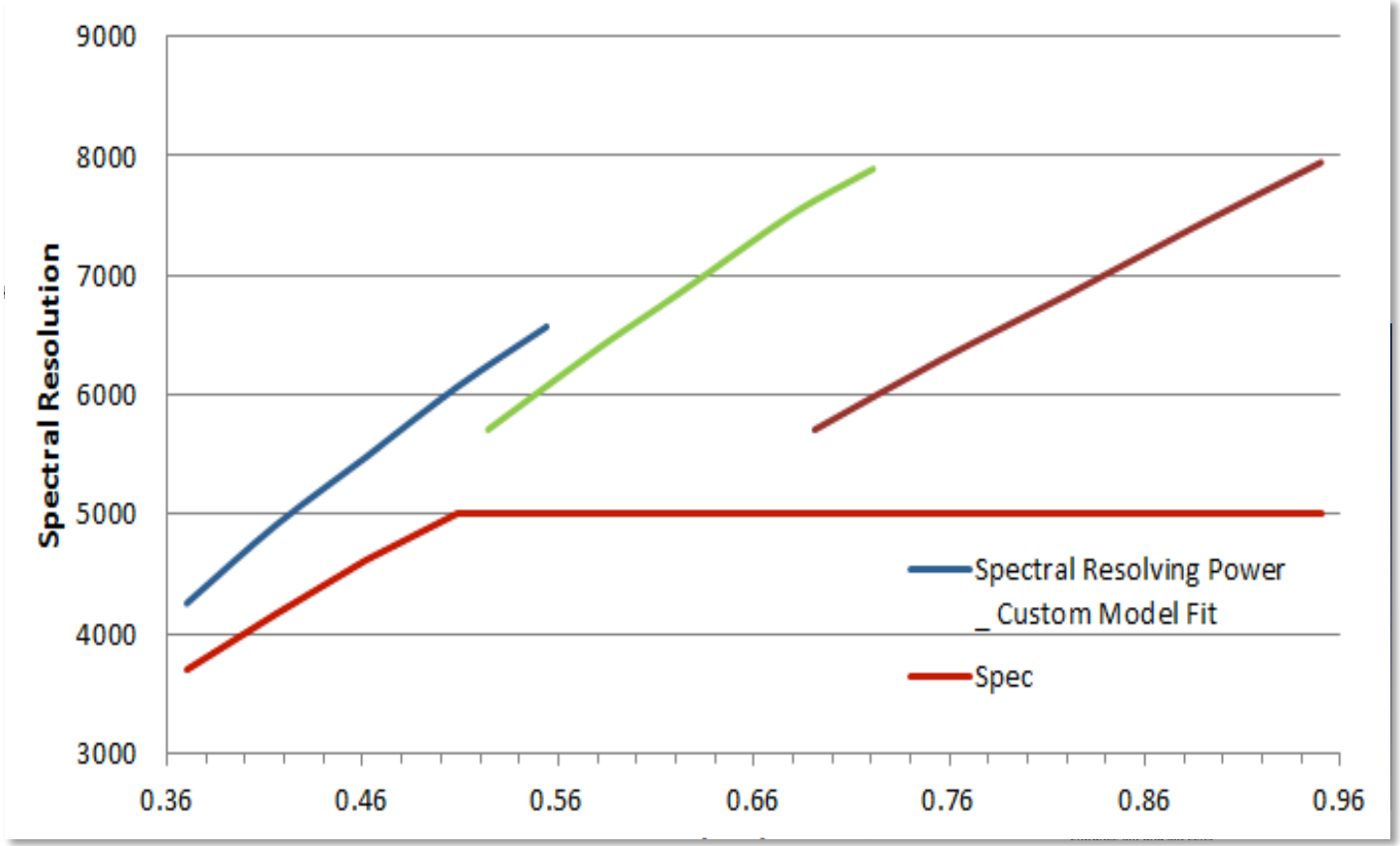


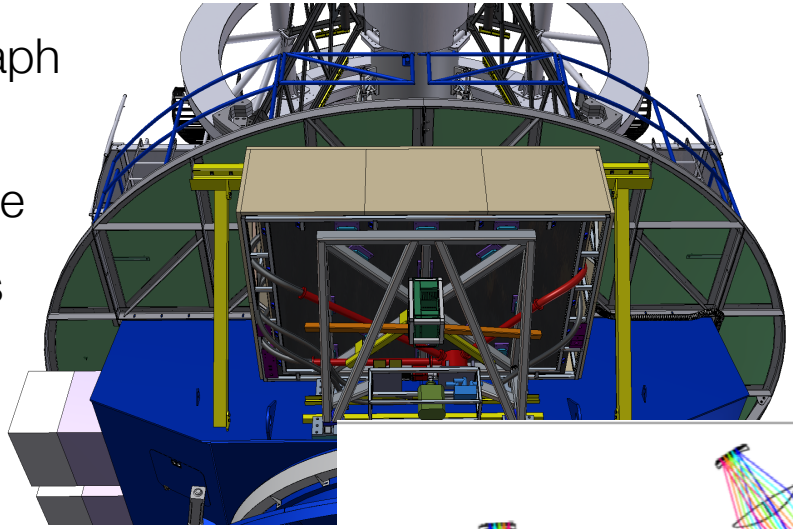
High Resolution Spectrograph (HRS)

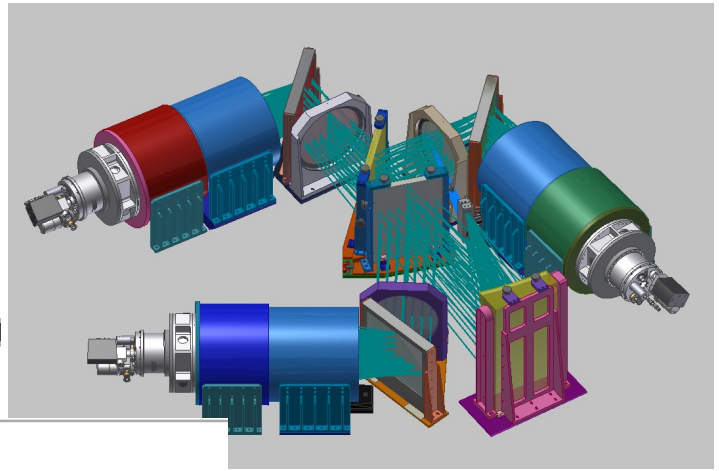
3 arms spectrograph
3 CCDs 6k x 6k

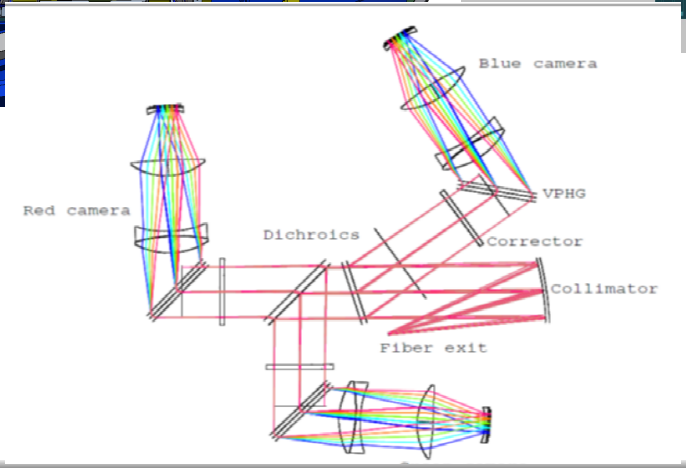
250 mm beam size

812 science fibres

1 spectrograph







Design and build at ZAH/LSW in Heidelberg

High Resolution Spectrograph (HRS)

3 arms spectrograph
3 CCDs 6k x 6k

250 mm beam size

812 science fibres

1 spectrograph

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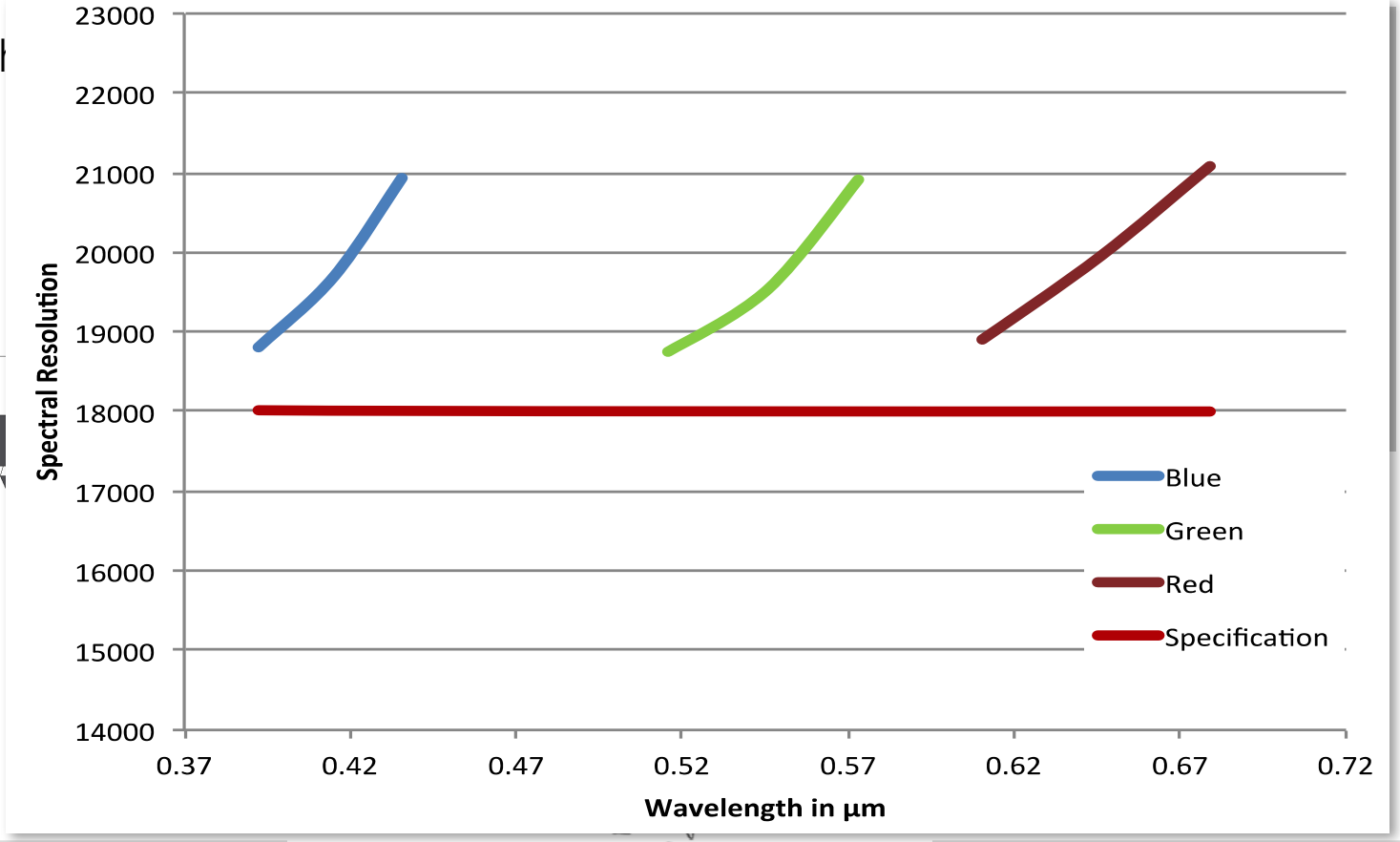
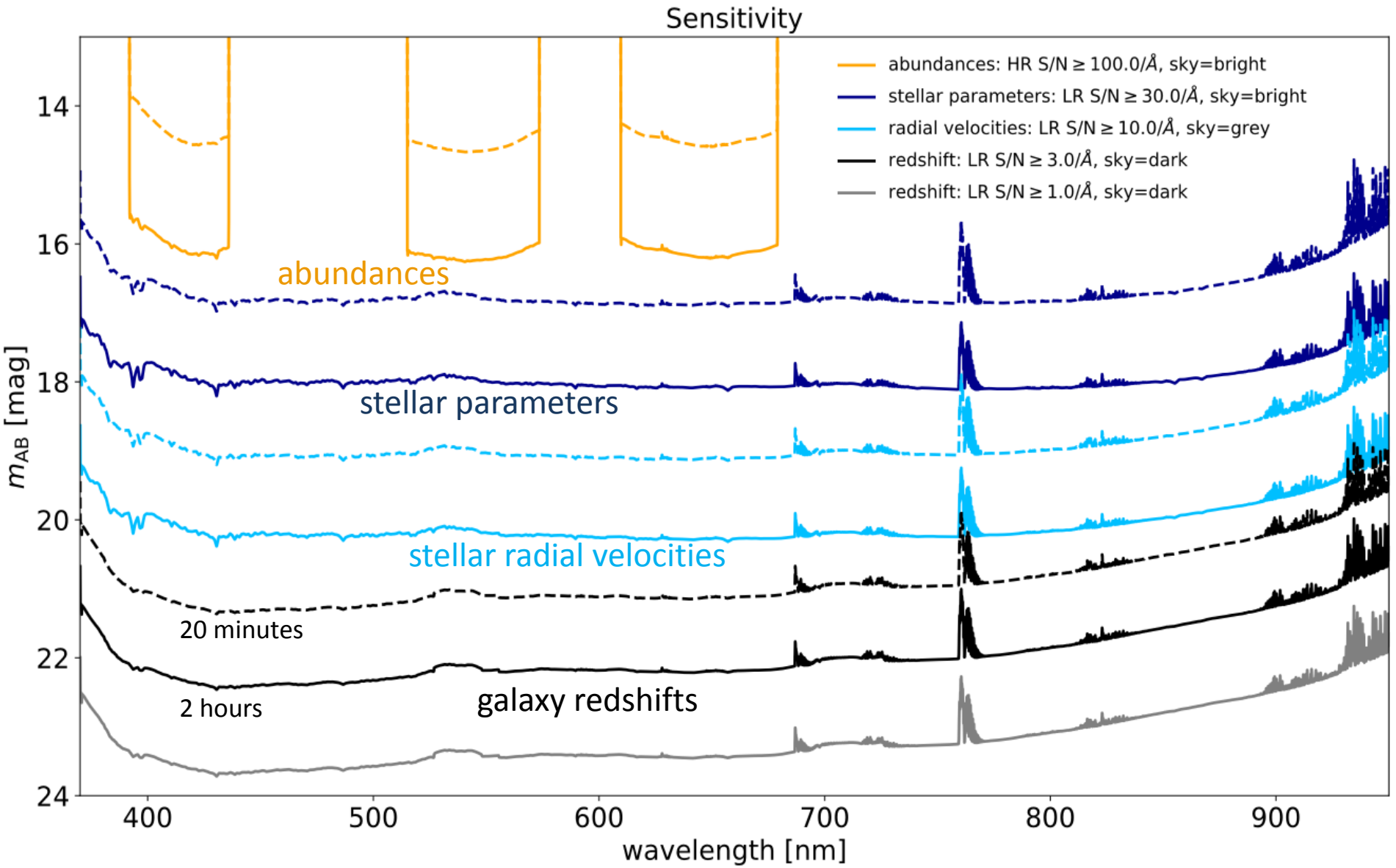
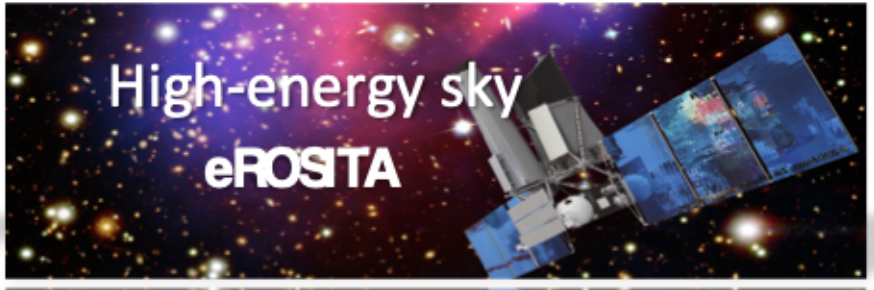
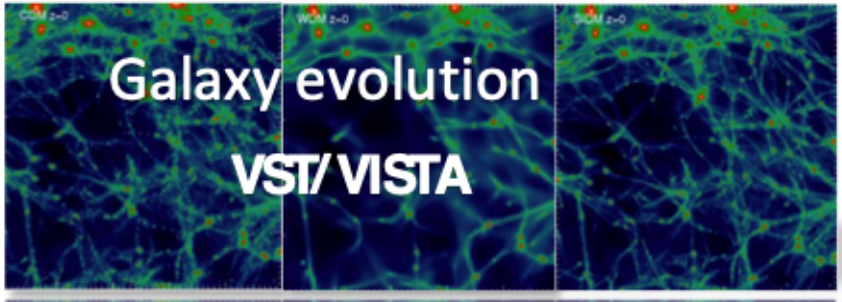
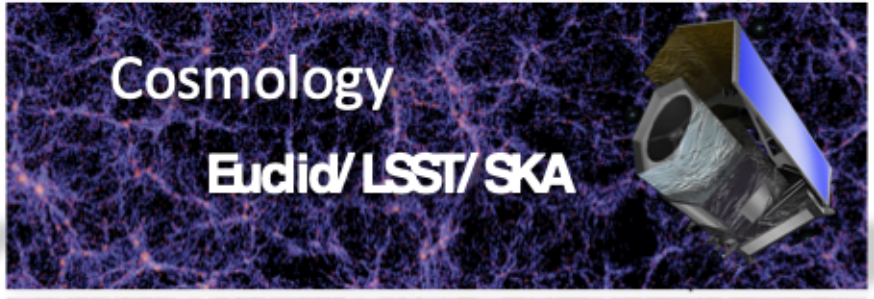



Sensitivity
abundances: HR S/N ≥ 100.0/Å, sky=bright
stellar parameters: LR S/N ≥ 30.0/Å, sky=bright
radial velocities: LR S/N ≥ 10.0/Å, sky=grey
redshift: LR S/N ≥ 3.0/Å, sky=dark
redshift: LR S/N ≥ 1.0/Å, sky=dark
abundances
stellar parameters
stellar radial velocities
20 minutes
2 hours
galaxy redshifts
m_{AB} [mag]
14
16
18
20
22
24
400
500
600
700
800
900
wavelength [nm]

Science Themes



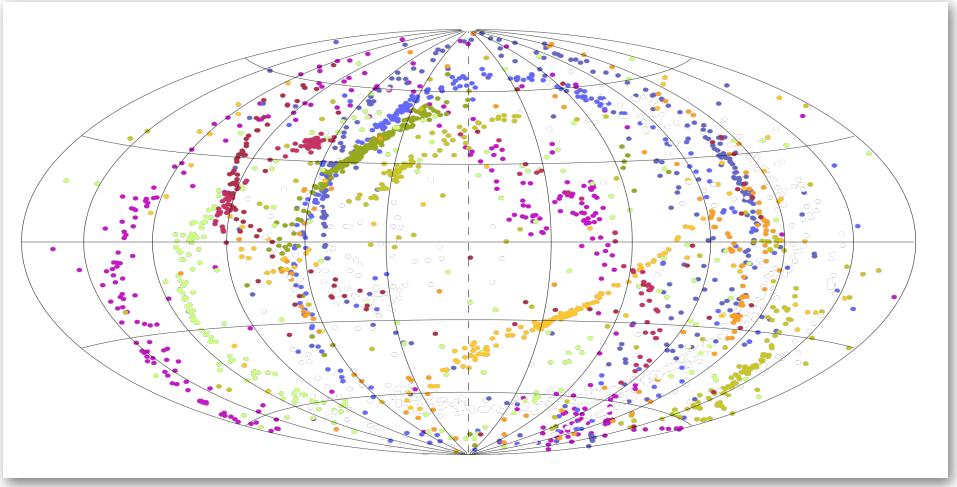


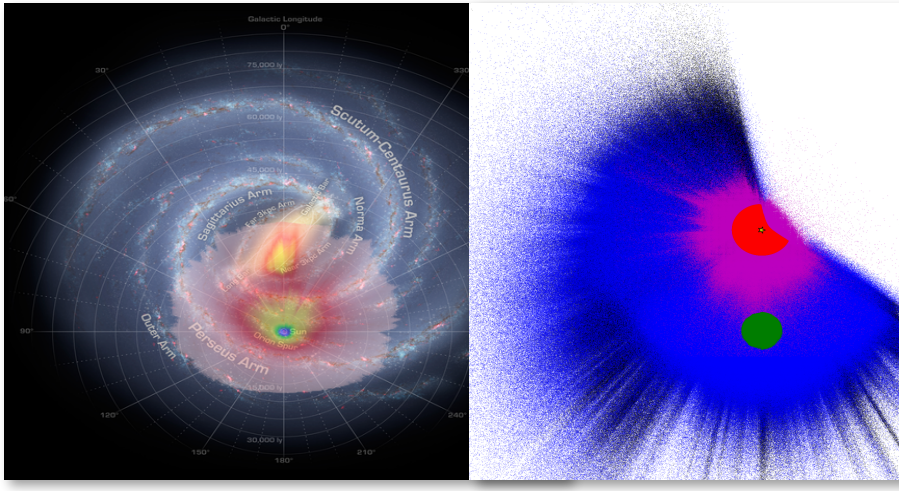


Ten Consortium Surveys

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	Comparat (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)

Galactic Archeology

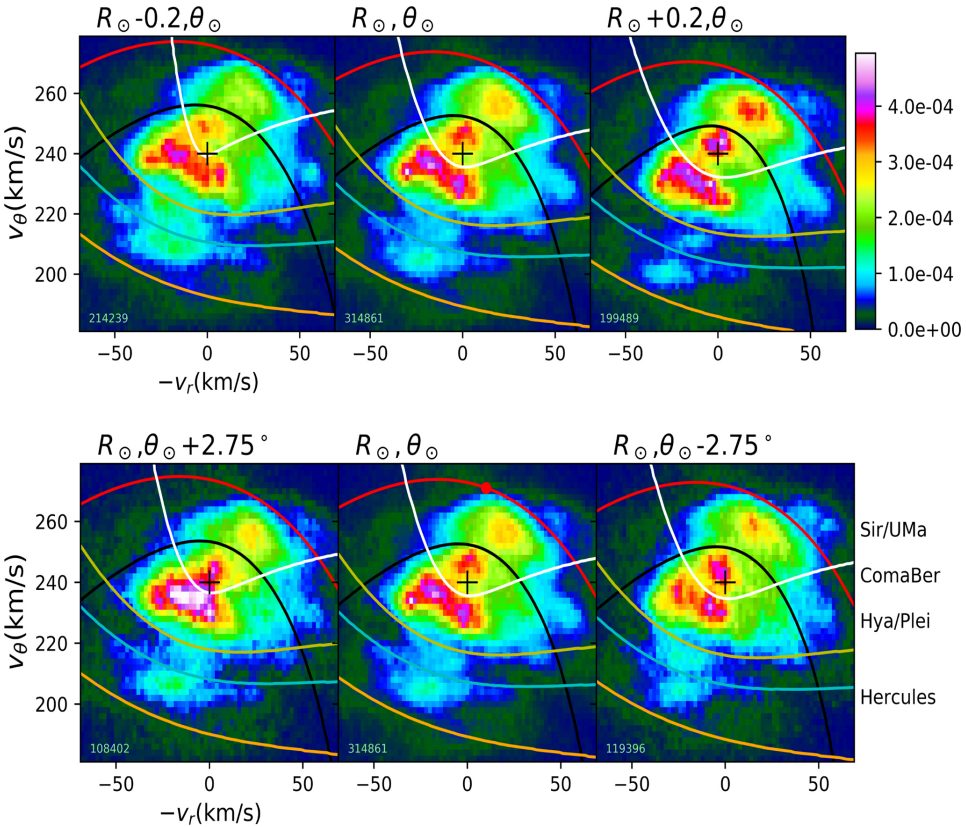




- Map the Dark Matter substructure of the Milky Way and Magellanic Clouds halos
- Chemo-dynamical substructure of the halo: Accreted versus in situ formation
- Importance of population migration

- Formation and dynamical evolution of the Milky Way disk and bulge components
- Constraints on the very first populations of stars (Pop III, IMF, rotation)
- Properties of exoplanet host stars

Milky way bar/spiral arms create moving groups in velocity distribution



- Gaia can do this to ~1kpc
- Gaia combined with 4MOST can do this to ~10 kpc, i.e. in almost half the Milky Way

Minchev et al. (2010)

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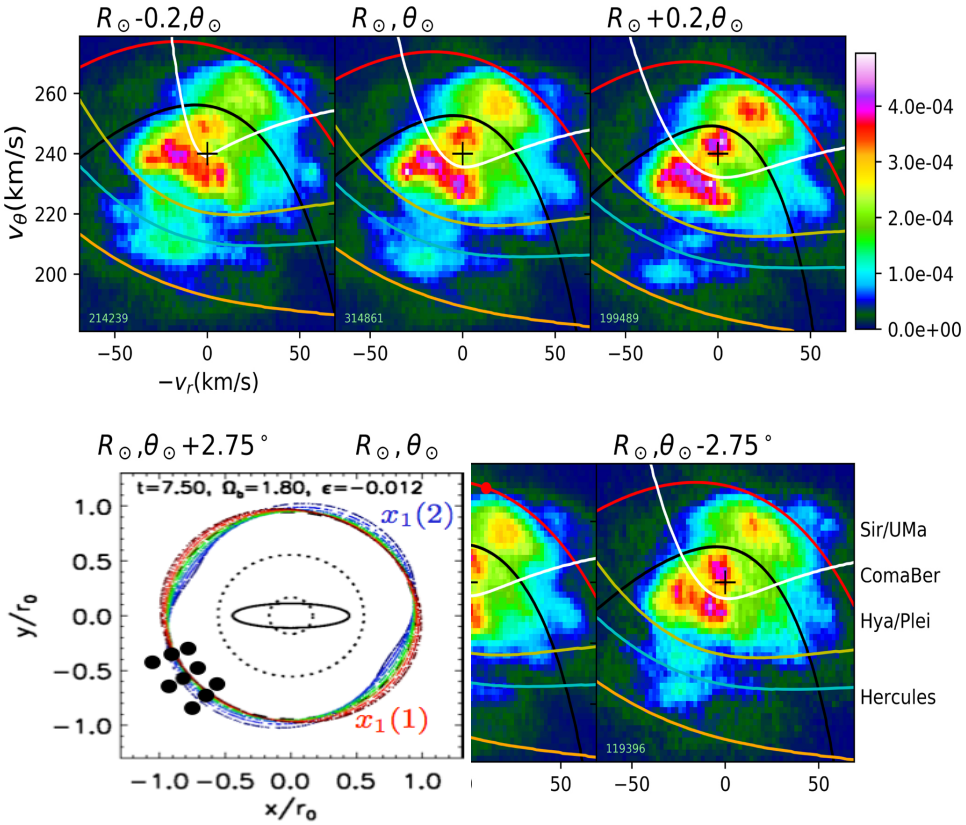

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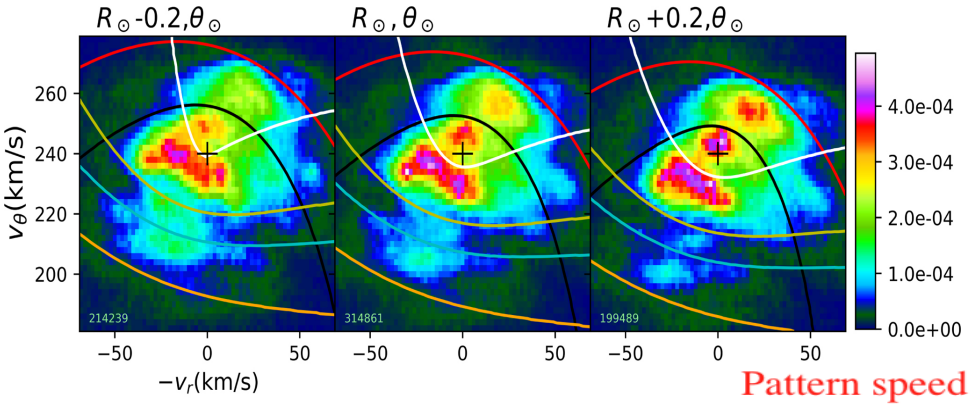

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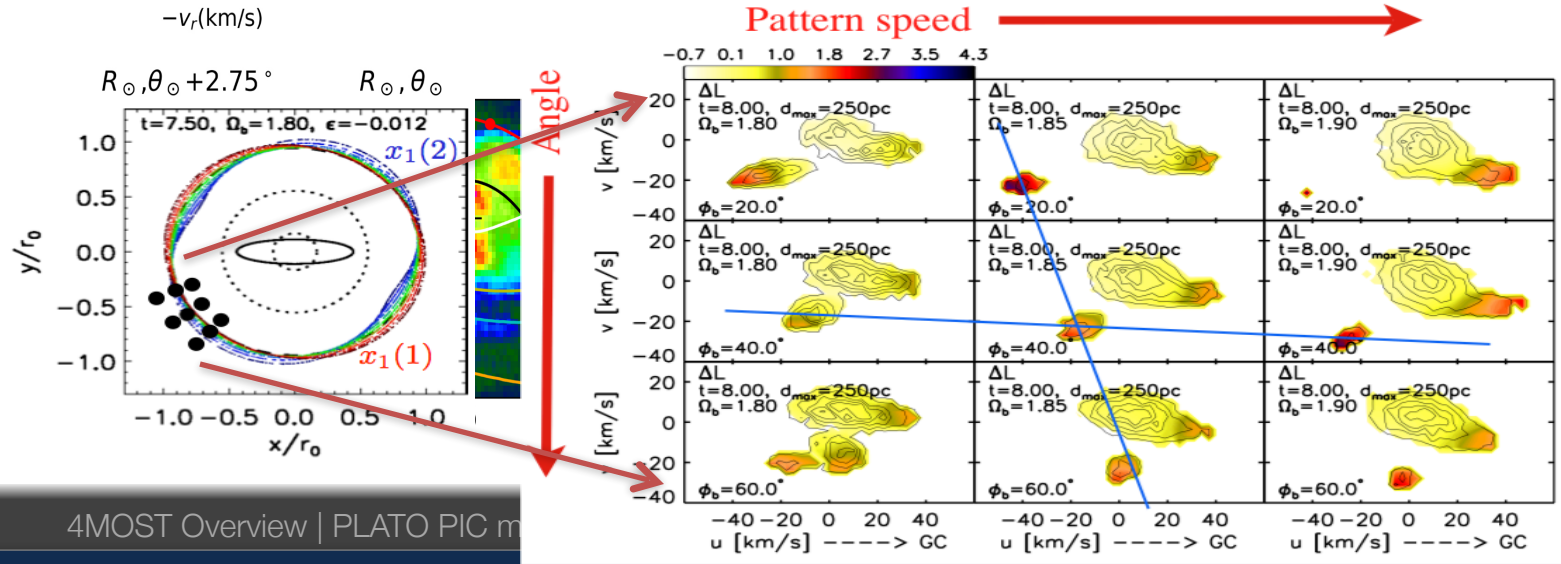
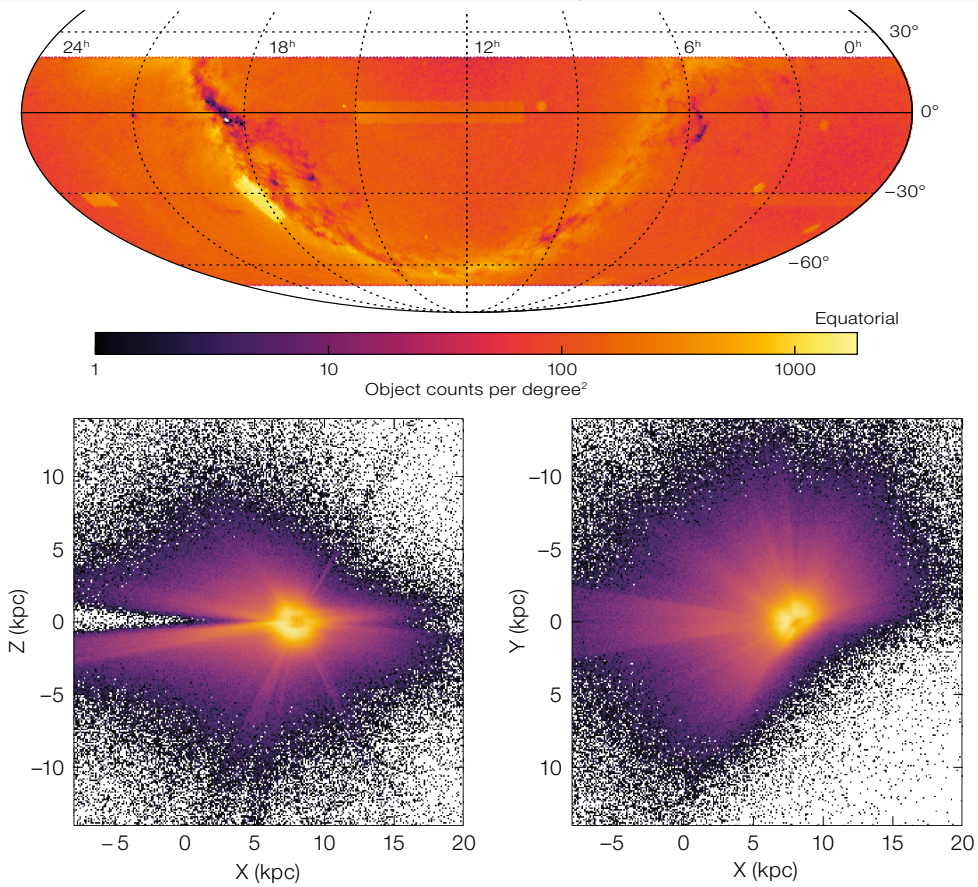
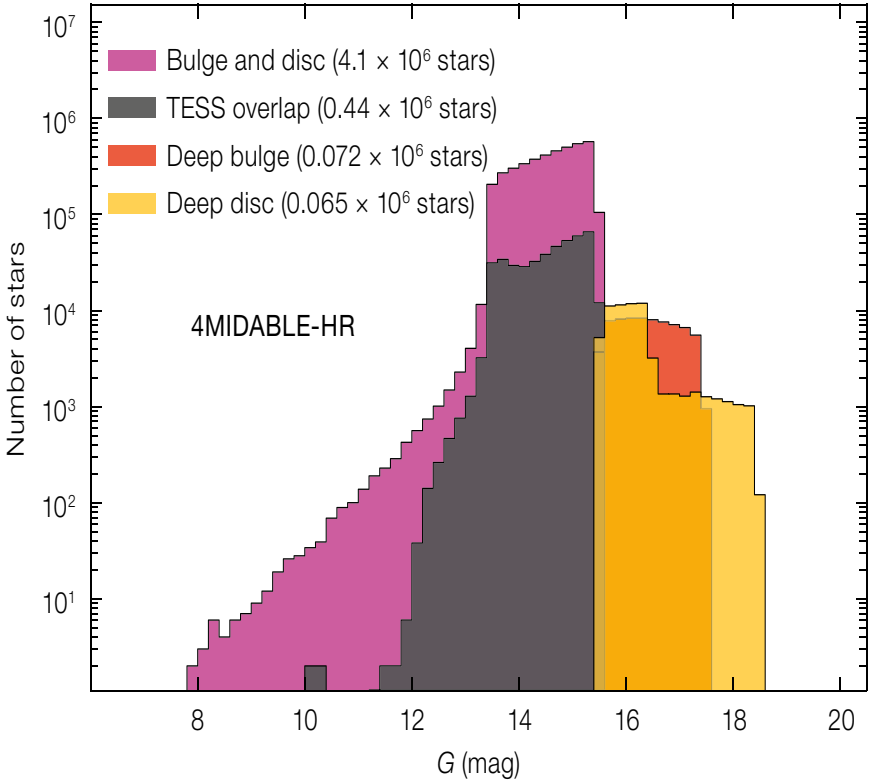
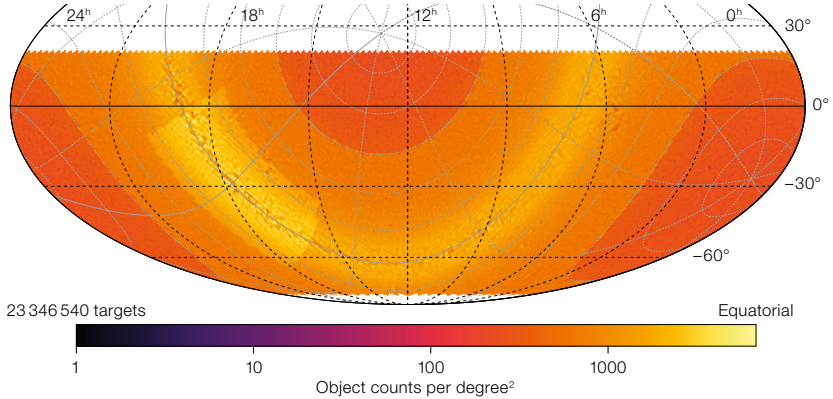


4MOST Galactic Input Catalogues HRS

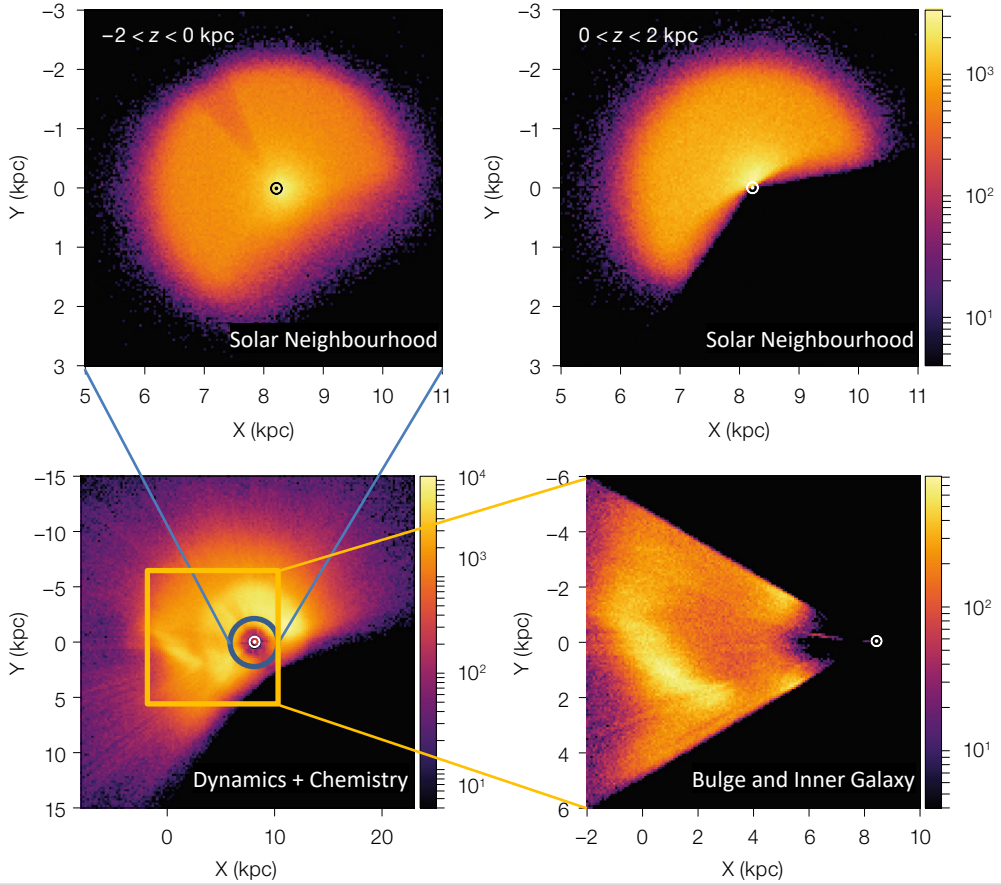




4MOST Galactic Input Catalogues LRS



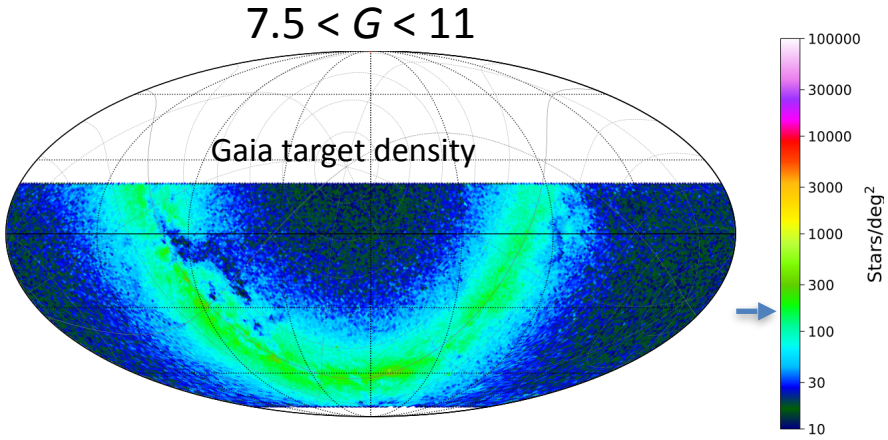
Sub-survey	Magnitude range	N_{goal}
Extended Solar Neighborhood	14.0 < G < 16.5	4.5×10^6
Dynamical Disk, |b| < 30	14.0 < G < 18.0	4.5×10^6
Faint Dynamical Disk, |b| < 15	18.0 < G < 19.0	2.8×10^5
Chemodynamical Disk, |b| < 30	14.0 < G < 18.0	2.5×10^6
Bulge and Inner Galaxy (BIG) |l| < 30, |b| < 20	16.0 < G < 17.0	1.0×10^6

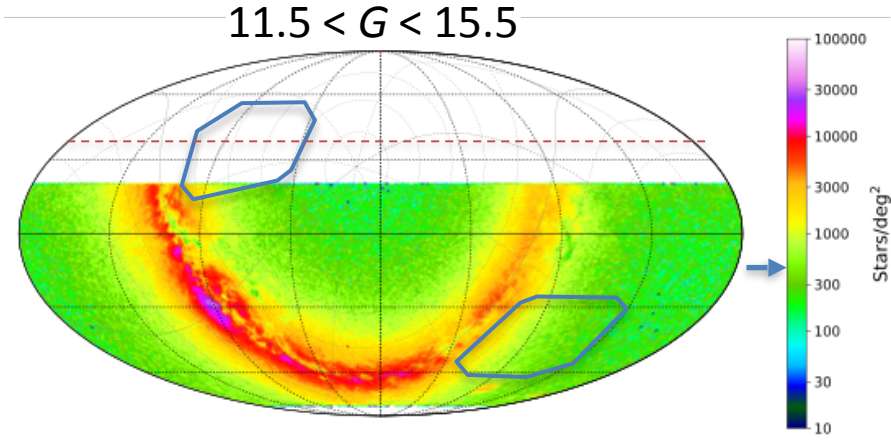


Poor observing conditions programme

- In 20 minutes:
  - HRS saturates at ~11.0 mag
  - LRS saturates at ~13.5 mag
- Example of poor conditions are:
  - Seeing >~1.5” (200 h/yr)
  - Cirrus (~50 h/yr?)
  - Twilight (150 h/yr)
  - Full moon in MW (100 h/yr)

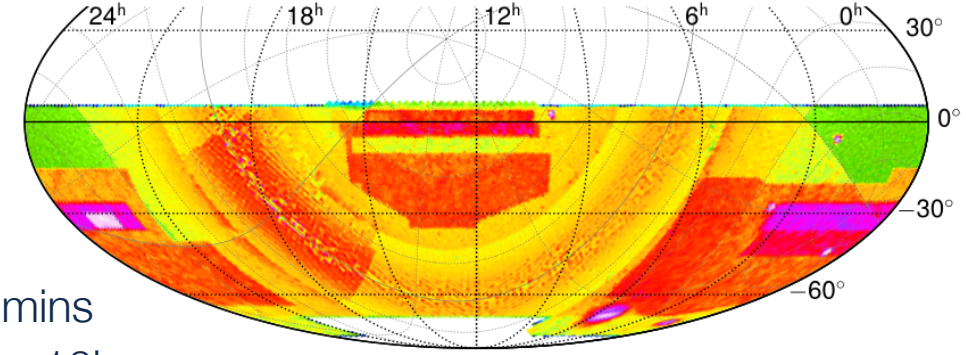
  } 500 h/yr
- All sky, quick (~2 min exposures) survey of almost all bright stars with -80° < DEC < 35° and
  - HRS: 5 < G < 11.5 mag
  - LRS: 11 < G < ~13.5 mag
- Conservative 7 fields/h, 3500 fields/yr, all sky < 2yrs
  - PLATO SPF field in ~2 months
  - Opportunities to repeat areas/targets
  - Are there fainter targets of interest to repeat?





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
- *Key Surveys* set observing strategy
  - Millions of targets all sky
  - Fill all fibres
- *Add-on Surveys* for smaller surveys
  - Small fraction fibres all sky or
  - dedicated areas
  - 10^3 to 10^6 targets
- Several passes of sky with exposures 2–30 mins
- Wedding-cake distribution for total time 1h to 10h



Community Proposals

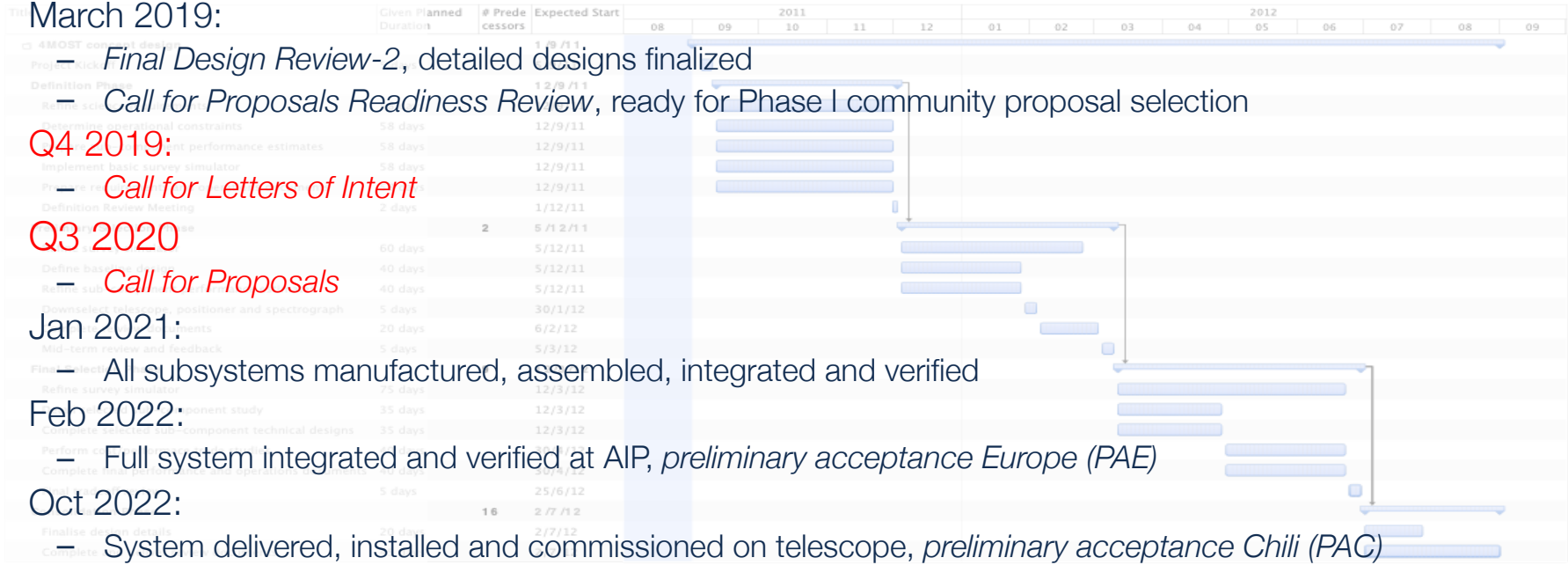
- Call for Letters of Intent issued Nov/Dec 2019, deadline Jan/Feb 2020
- For selected applicants, followed by Call for Proposals in Q3 2020
- Fibre-hour share 30%, all surveys ESO Public Surveys
- Available time: LRS: ~4M Fibre Hours, HRS: ~2M Fibre Hours

- Participating Surveys:
  - Become equal partner in Science Team with Consortium Surveys
  - Share survey strategy, Observation Blocks (OBs), L1 data products, selection function analysis, and optionally L2 data reduction pipelines
  - Can use all Consortium data (and vice versa), but core science protected
  - Time request only for the fibres actually used, not for all fibres in the instrument
- Non-participating Surveys:
  - Receive own observing nights
  - Prepare own OBs
  - Receive only L1 data products, no L2 data products
  - Have no access to Consortium and Community Participating Survey data
  - No more than 30% target duplication with other surveys (will be observed twice)
  - Will be “charged” full 2436 HRS+LRS fibres for time used, even if fibres are not all filled

Policies: data and publication rights

- Data releases:
  - L0 (raw data): public immediately
  - L1 (extracted, calibrated spectra): yearly
  - L2 (derived products): negotiated by each Survey with ESO
    - RV, Teff, log g, [Fe/H], abundances of ~15 elements (**α**, r-, s-process)
    - DR1 expected late 2025
- All data of all Surveys are accessible to all ST members
- Publications are limited to approved Projects. Consortium Projects may be rejected if overlapping with Community Survey Core Science and vice versa (SDSS-like policy). Also PhD Projects extra protected

Schedule and Milestones



- March 2019:
  - *Final Design Review-2*, detailed designs finalized
  - *Call for Proposals Readiness Review*, ready for Phase I community proposal selection
- Q4 2019:
  - *Call for Letters of Intent*
- Q3 2020
  - *Call for Proposals*
- Jan 2021:
  - All subsystems manufactured, assembled, integrated and verified
- Feb 2022:
  - Full system integrated and verified at AIP, *preliminary acceptance Europe (PAE)*
- Oct 2022:
  - System delivered, installed and commissioned on telescope, *preliminary acceptance Chili (PAC)*

- Nov 2022 – Oct 2027:
  - First science survey of 4MOST, 30% of targets available for Community Surveys

More information

- 4MOST Issue of ESO's The Messenger (no. 175)
- www.4most.eu
- help@4most.eu

4MOST – PLATO synergy

- Poor conditions programme PLATO overlap (also for STEP pointings):
  - all stars G < ~11.5 with HRS
  - most stars G =11.5–13.5 with LRS
- HRS main surveys overlap for G > 11.5 currently ~25%
- Repeats (only for bright sample!), RV and spectral variation
- Asteroseismology information would be key to derive ages for 4MOST stars and tremendously improve 4MOST (and hence PLATO) calibrations
- Including RGB stars in the PIC would enormously increase the usefulness of PLATO for 4MOST Galactic Archaeology
- STEP fields would increase the overlap with 4MOST by factor of 7!
- Happy to discuss optimal Community Proposal strategy
- Timescale/data access
  - Data Consortium Internal available end-2023, but Data Release-1 is end-2025
- Need for MoU?

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

www.4MOST.eu

- Status:
  - FDR completed, in construction phase, *operations start end-2022* (≥2x 5 year)
  - Call for Letter of Intent Nov/Dec 2019 ⟹ Call for Proposals Q3 2020
- Science:
  - *Cosmology, galaxy evolution, high-energy and Galactic* science
  - Complement large area space missions: Gaia, eROSITA, Euclid, PLATO
  - Complement ground-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 specifications:
  - High multiplex: 1600 fibres @ R~5000 + 800 fibres @ R~20,000 in parallel
  - Wavelength: LR: 370-950 nm HR: 392-437 & 515-572 & 605-675 nm
  - Large field-of-view on VISTA, 4m-class telescope: ⌀=2.6°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Science Requirements

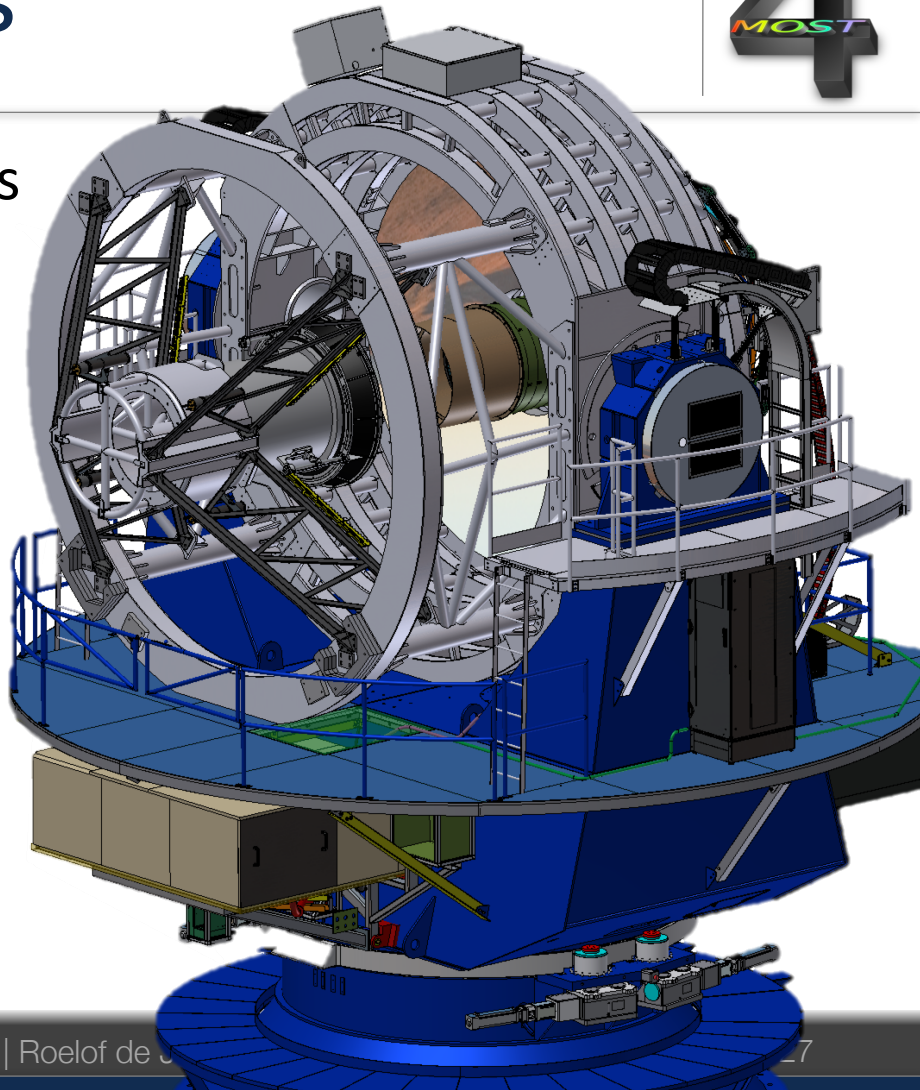
- 4MOST shall be able to obtain:
  - *Redshifts* of AGN and galaxies (also in clusters)
    - R~5000 spectra of 22 r-mag targets with S/N=5/Å with >3 targets in ⌀=2'
  - *Radial velocities* of ≤1 km/s accuracy and

  Stellar parameters of <0.15 dex accuracy of any Gaia star
    - R~5000 spectra of 20 r-mag stars with S/N=10 per Ångström
  - *Abundances* of up to 15 chemical elements
    - R~20000 spectra of 16 V-mag stars with S/N=140 per Ångström
- In a 5 year survey 4MOST shall obtain:
  - *15 (goal 30) million targets* at R~5000
  - *1.0 (goal 3.0) million targets* at R~20,000
  - *16,000 (goal 23,000) degree*^{2} area on the sky at least two times

4MOST Components

To deliver the performance objectives of 4MOST, the facility requires:

1. WFC/ADC/Baffles (AIP)
2. Fibre Positioner (AAO)
3. Metrology System (AIP)
4. Fiber Feed (AIP)
5. Low Resolution Spectrograph (CRAL)
6. High Resolution Spectrograph (LSW)
7. Detectors/Cryostats (ESO)
8. ACQ/Guiding and WFS (AIP)
9. Calibration System (NOVA)
10. Facility Control (MPIA & LSW)
11. Data Management (IoA + AIP)



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