4MOST – 4m Multi-Object Spectroscopic Telescope

4MOST Cosmology Redshift Survey

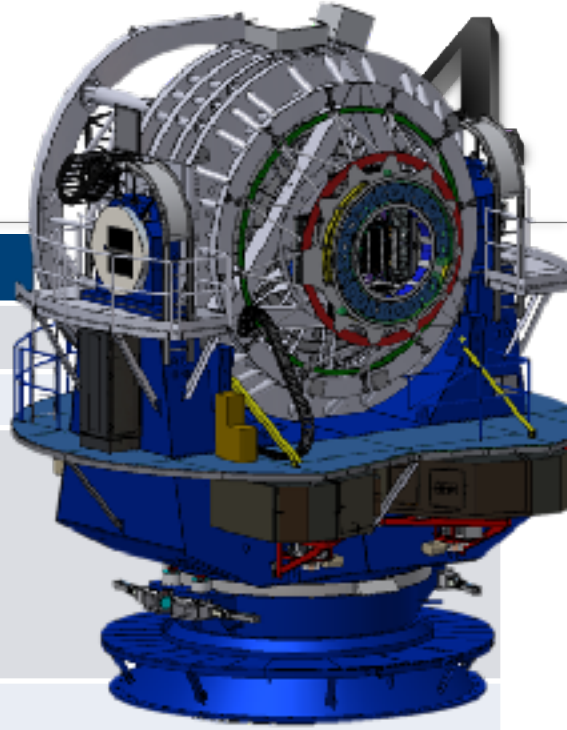
Johan Richard (CRAL)

Anand Raichoor, Chris Blake, Johan Comparat, Jean-Paul Kneib, Jenny Sorce, Tom Shanks, and the 4MOST Consortium

31st May 2018

www.4MOST.eu

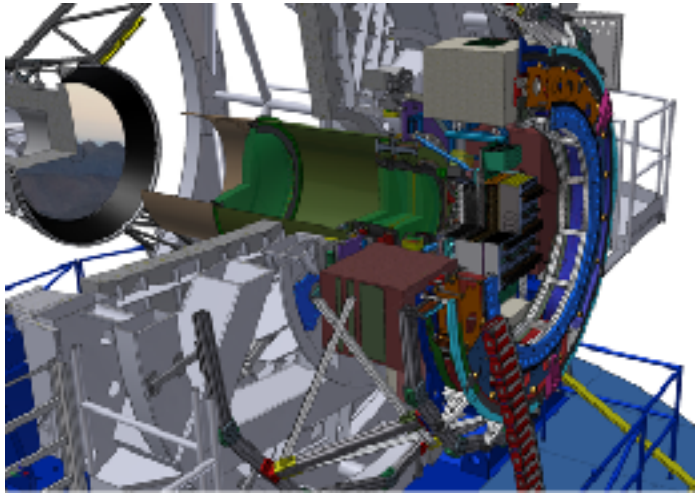
Instrument Specification

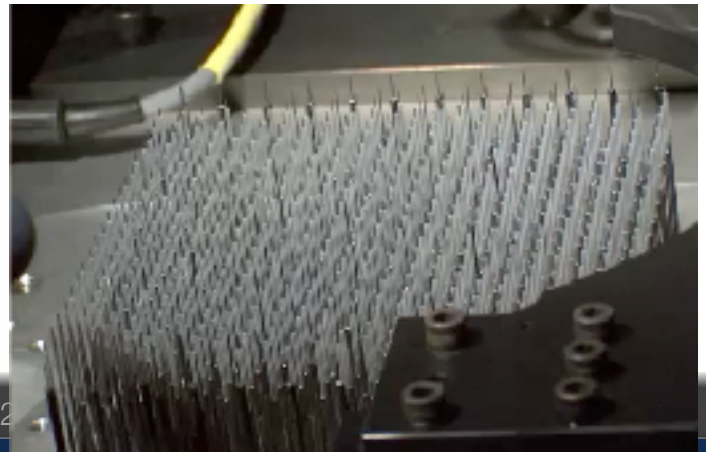


Specification	Design value
Field-of-View (hexagon)	~4.1 degree^2 (⌀>2.5˚)
Multiplex fiber positioner	2436
Medium Resolution Spectrographs (2x) # Fibres Passband Velocity accuracy	R~4000–7500 812 fibres (2x) 370-950 nm < 1 km/s
High Resolution Spectrograph (1x) # Fibres Passband Velocity accuracy	R~20,000 812 fibres 392.6-435.5, 516-573, 610-679 nm < 1 km/s
# of fibers in ⌀=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

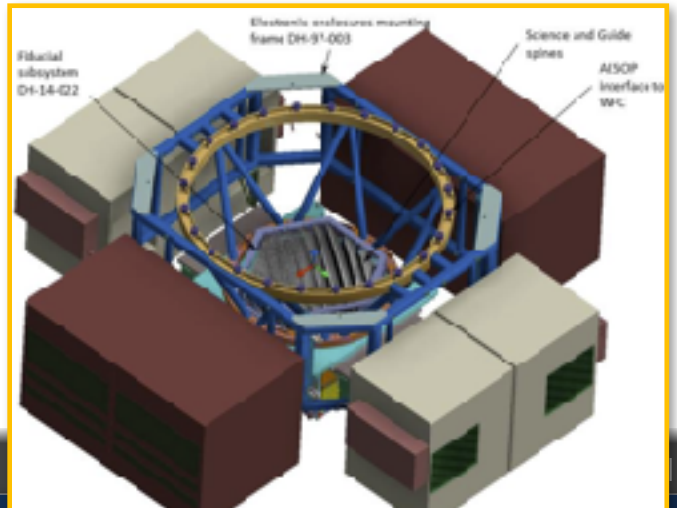
AESOP Fiber Positioner

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





64 spine prototype (AAO)



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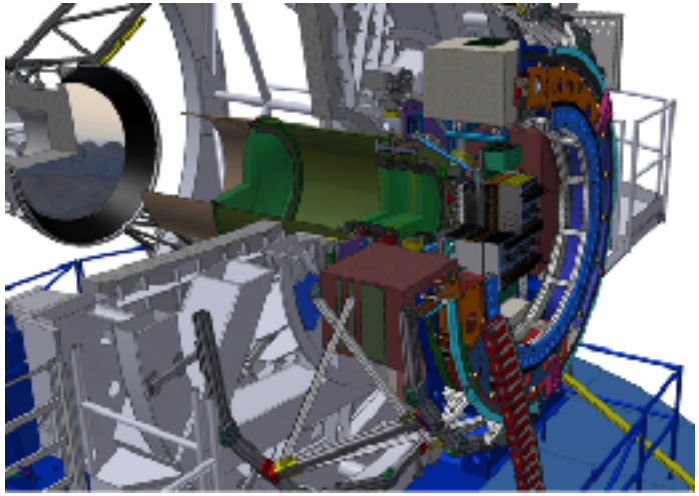

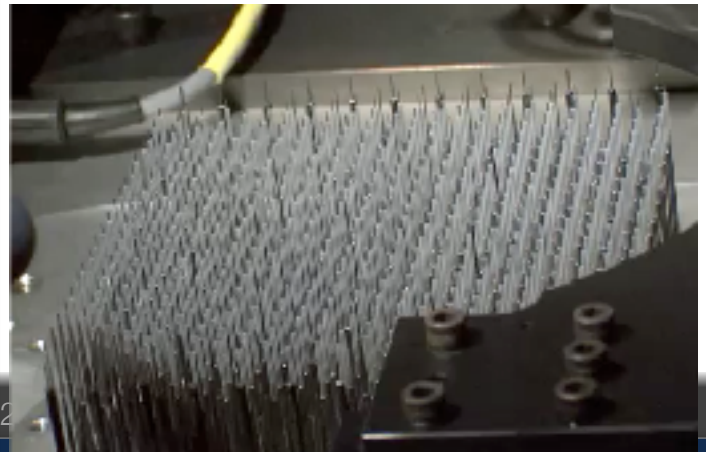

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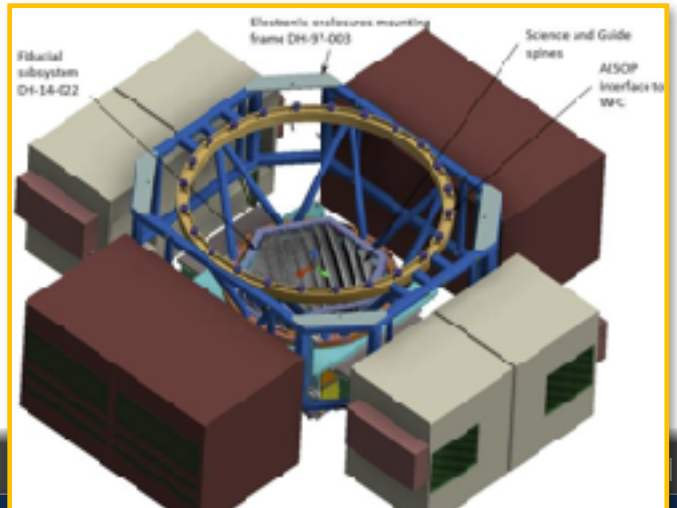

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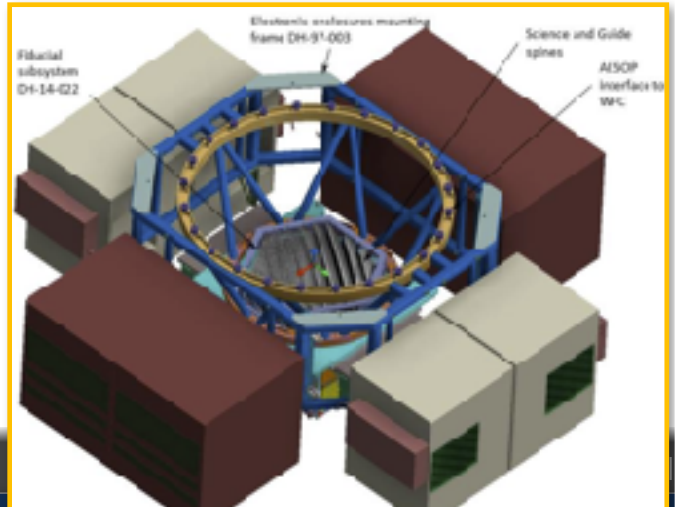

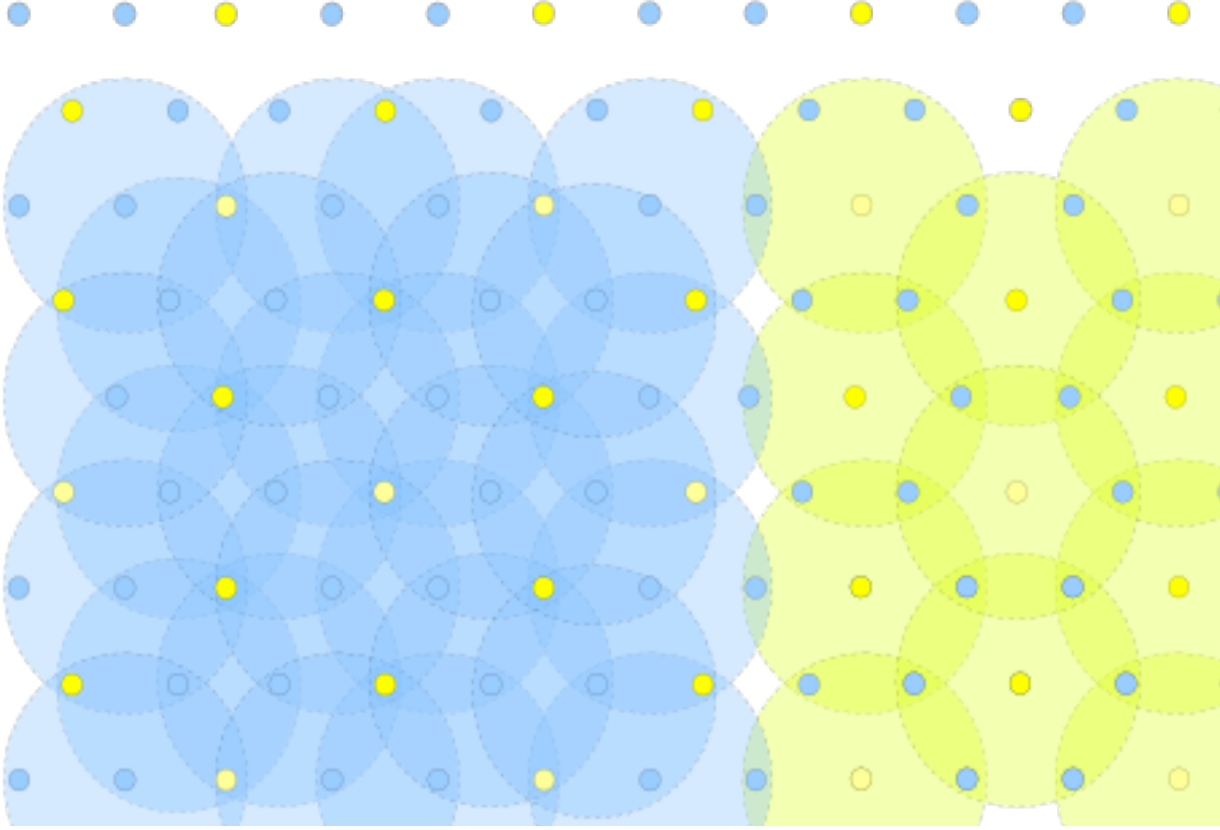

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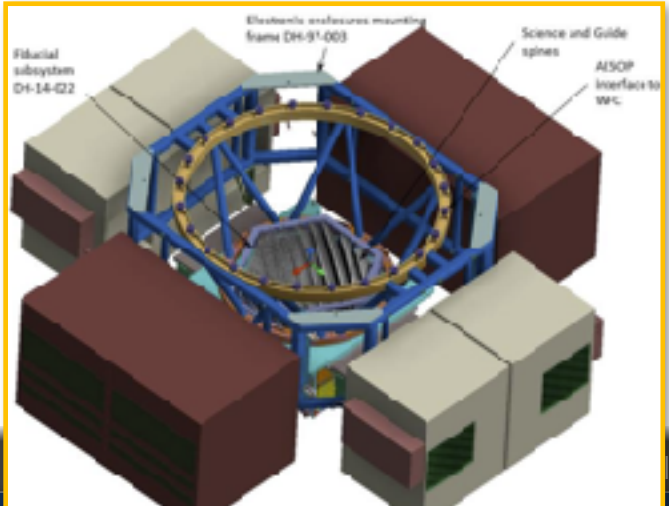

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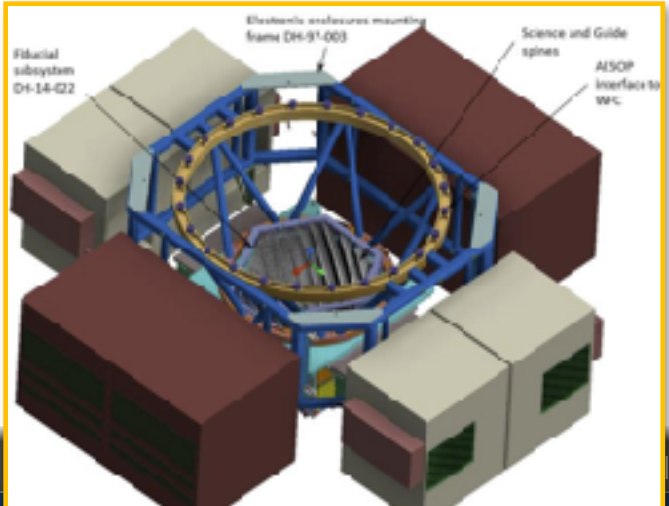

Science Themes

Science Themes

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

www.4MOST.eu

- Instrument specifications:
  - High multiplex: 1600 fibres to 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: ⌀=2.5° Status:
  - Contract signed with ESO, PDR and FDR-1 completed, *operations 2022* (≥2x 5 year)
- 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:
  - 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

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)	Nichol (Portsmouth)

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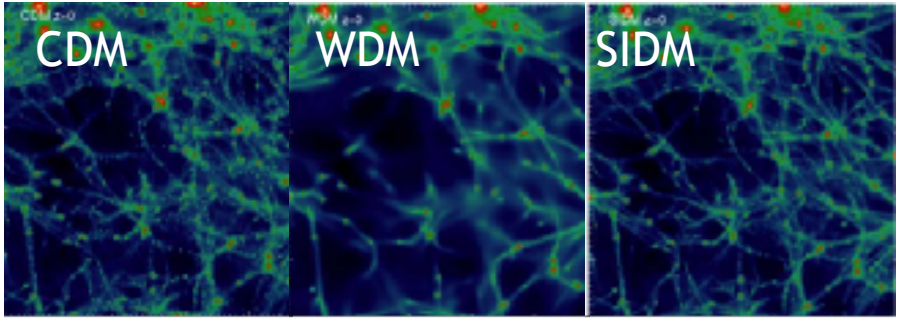
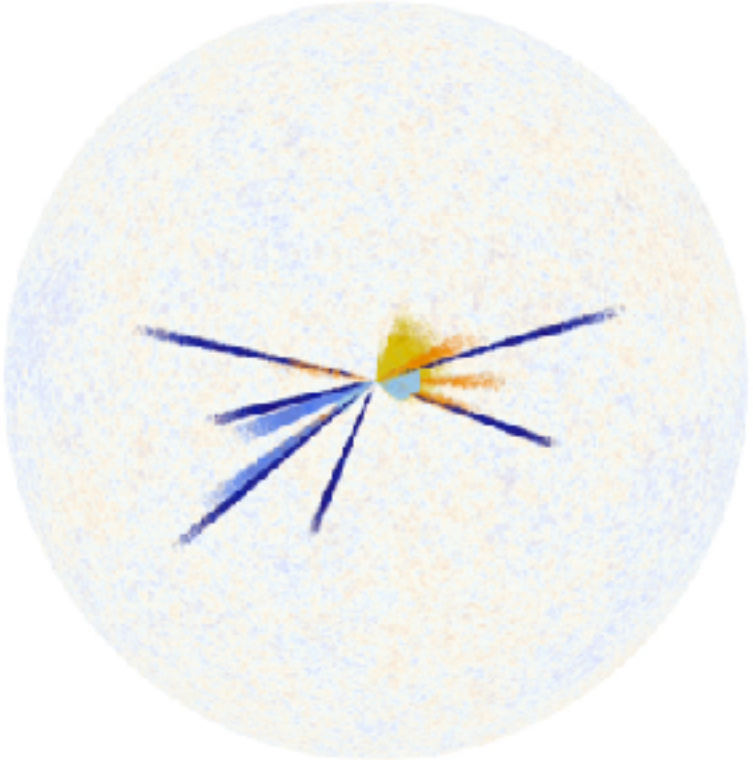
Galaxy and Dark Matter Evolution (WAVES)

- Galaxy formation to dwarf satellite scale, halo occupation
- Evolution of mass & energy budget for z<1
- Growth of structure on 1kpc-10Mpc scales for z<1





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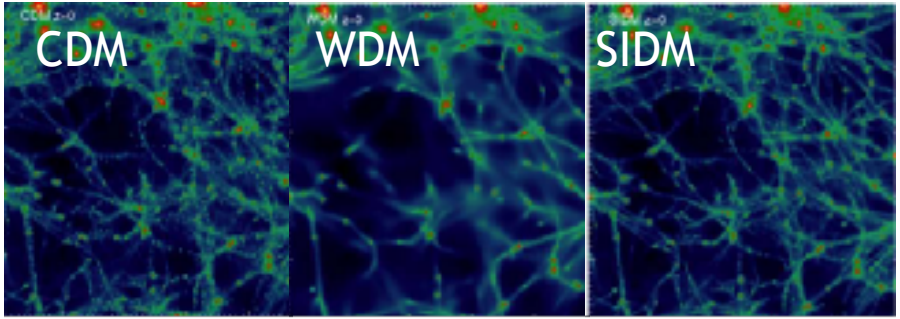

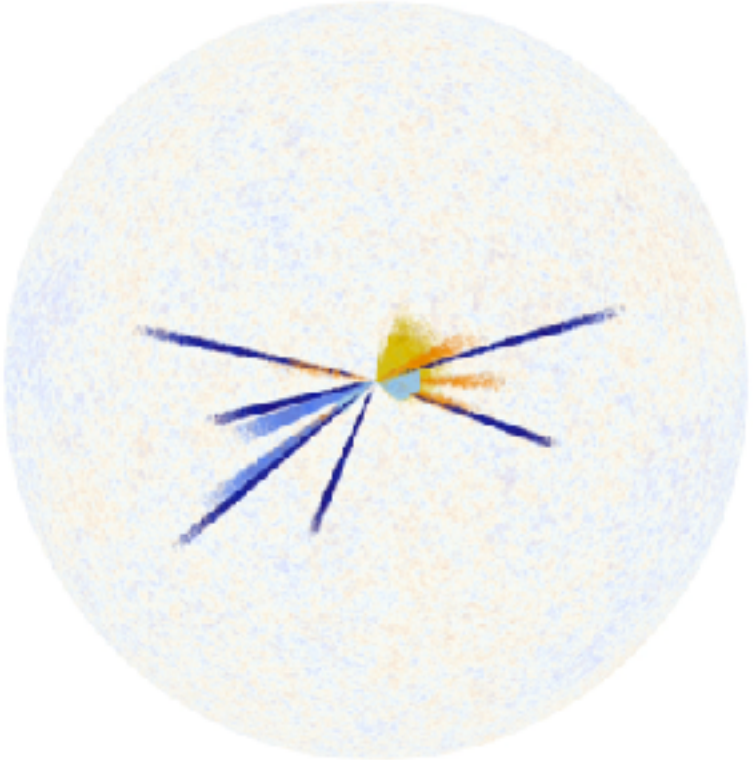

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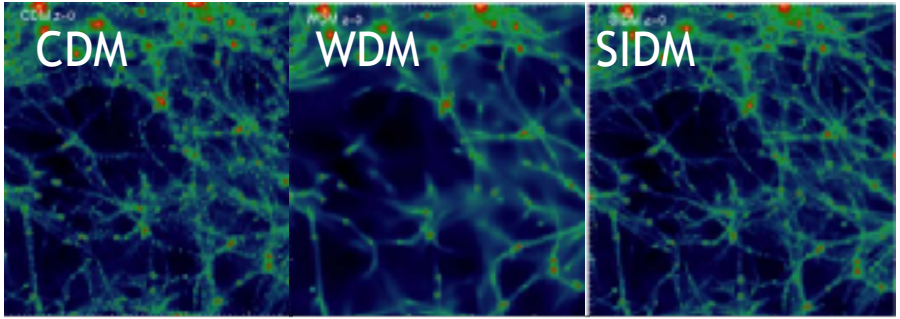
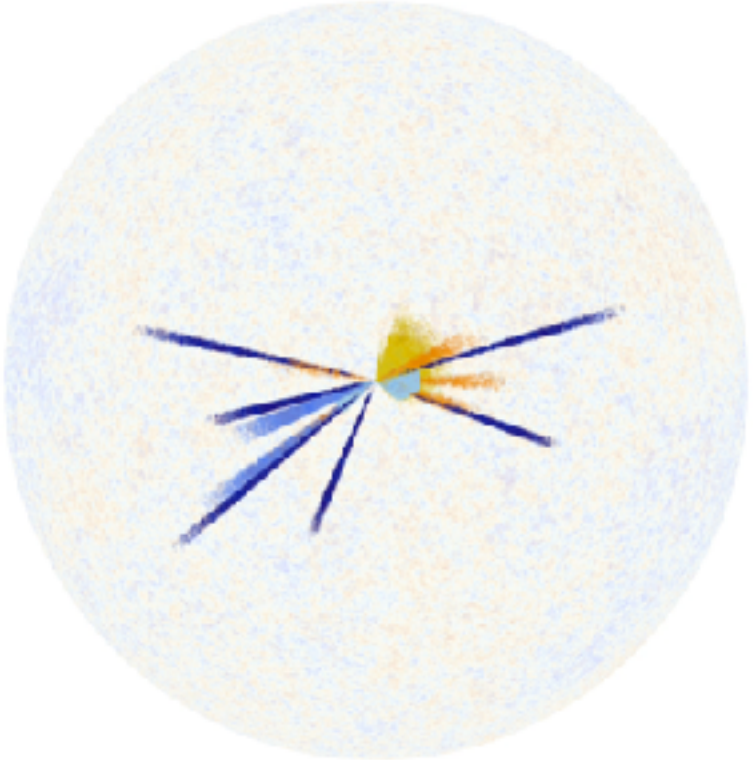
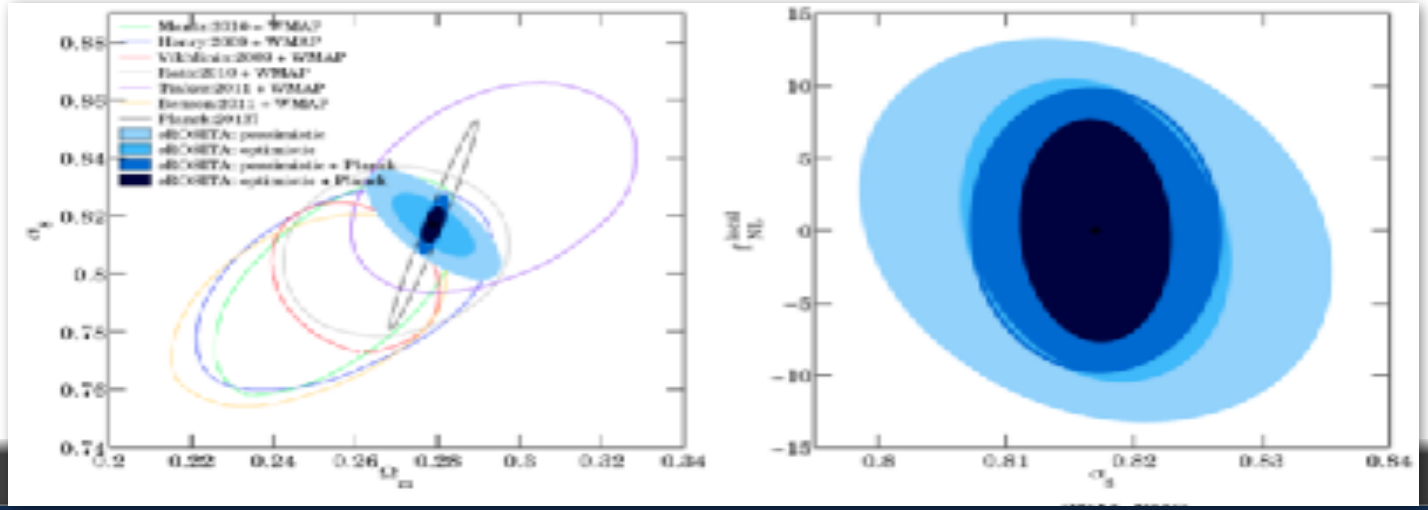




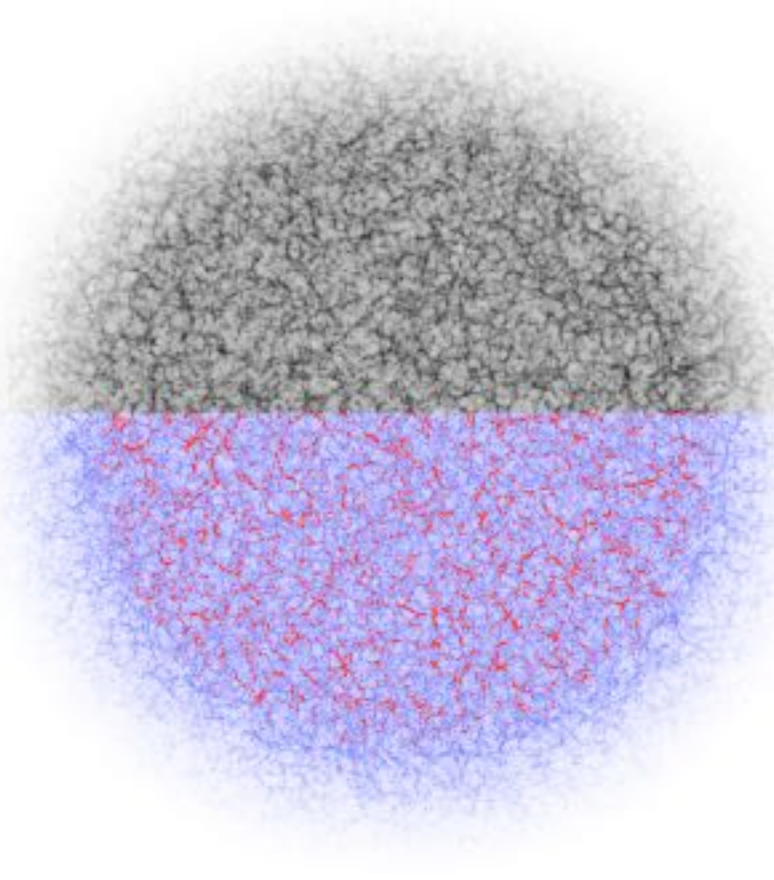
eROSITA complement

- German - Russian X-ray mission, Launch March 2018
- 8x all sky survey, 0.5 –10 keV
- *Dark Matter and Energy, growth of structure*
- Strong cosmology constraints from Galaxy Cluster evolution
- AGN evolution and Galaxy-Black Hole co-evolution
- Active galactic compact objects to constrain stellar evolutionary channels



Cosmology

- *Dark Energy* and *General Relativity* constraints by measuring cosmic expansion history and growth of structure:
  - **Weak Lensing**: Photo-z calibrations and characterize the foreground
  - **Galaxy Clusters**: Redshifts and velocity dispersions of Galaxy Clusters
  - **BAO and RSD**: LRGs, ELGs, AGN, Lyα forest
- Concentrate on redshifts z<~1 and z>2.4 to complement Euclid

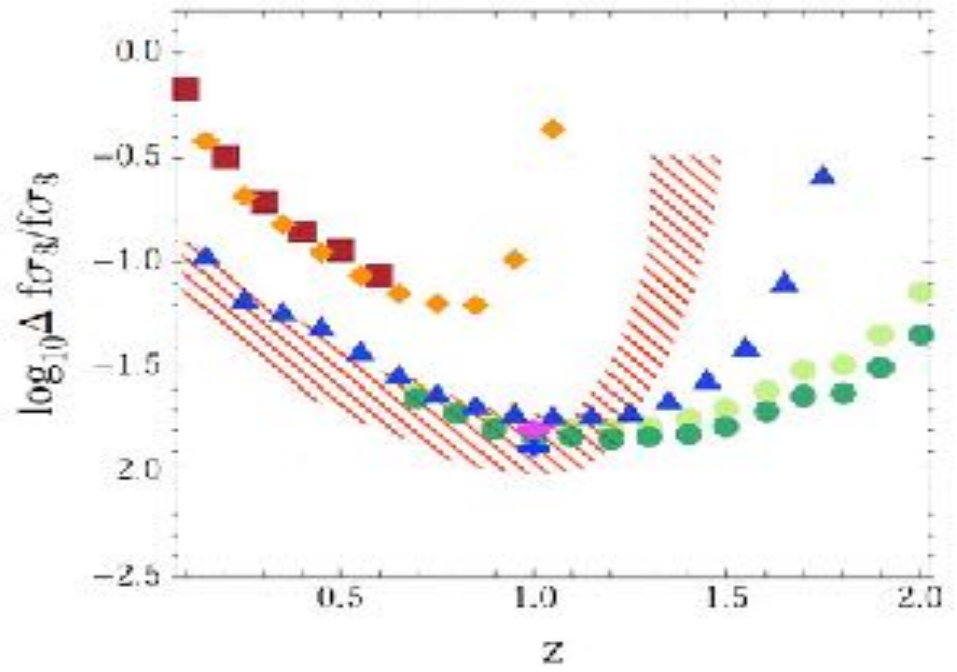


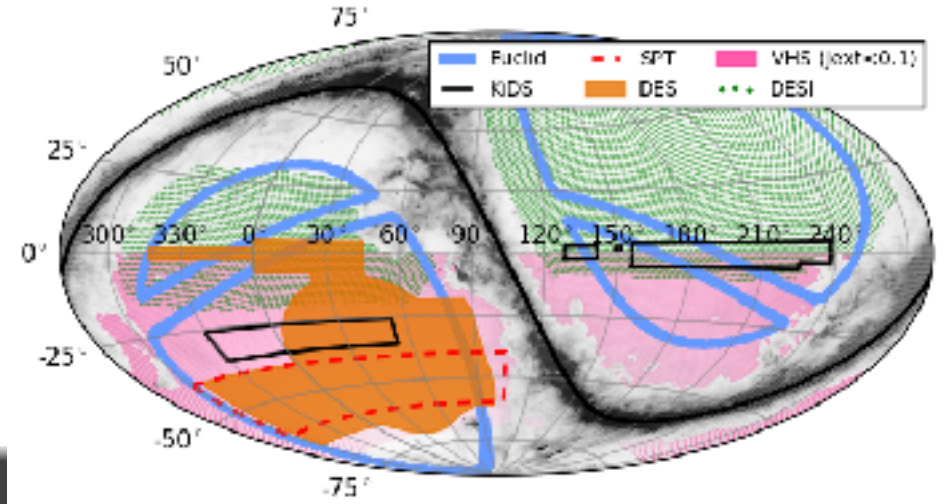
Cosmology Survey : strategy

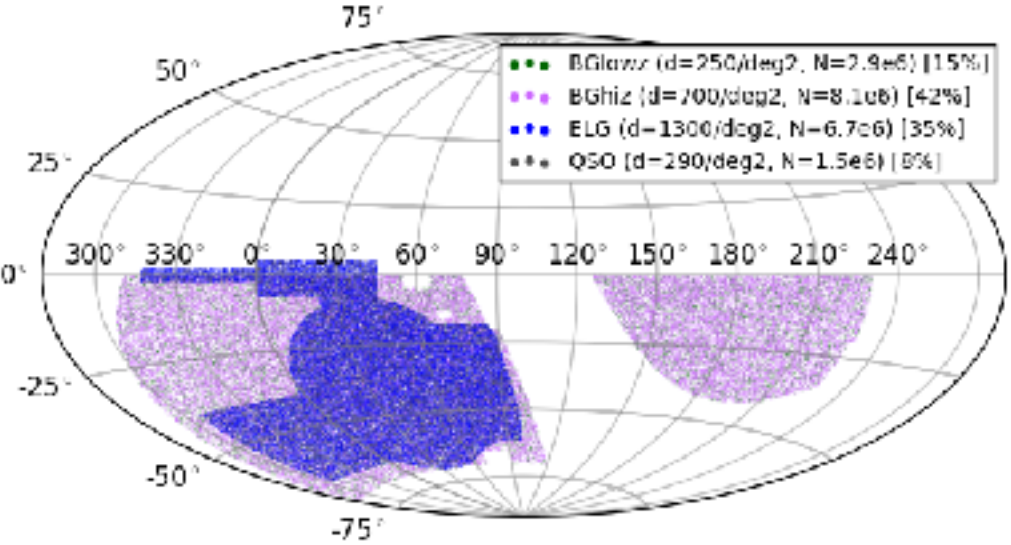
- Hard to be competitive with DESI for BAO measurements in terms of number of targets and timeline of the survey.
- Strengths: synergies with southern facilities:
  - cross-correlation with weak-lensing (DES, LSST)
  - synergies with radio surveys
  - synergies with CMB surveys
- DECAM provides the best quality of imaging to select targets, until we have access to LSST.

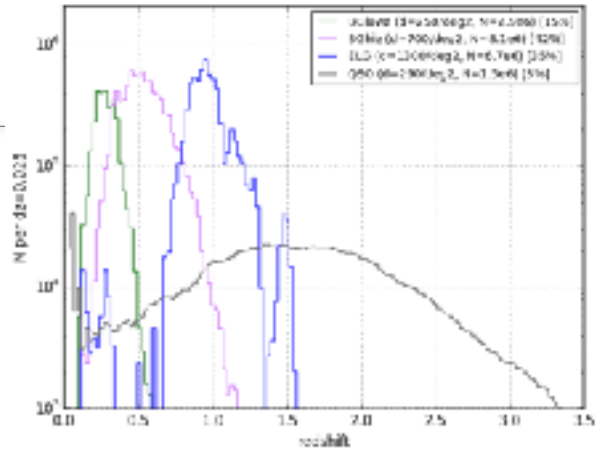
Cosmology Survey

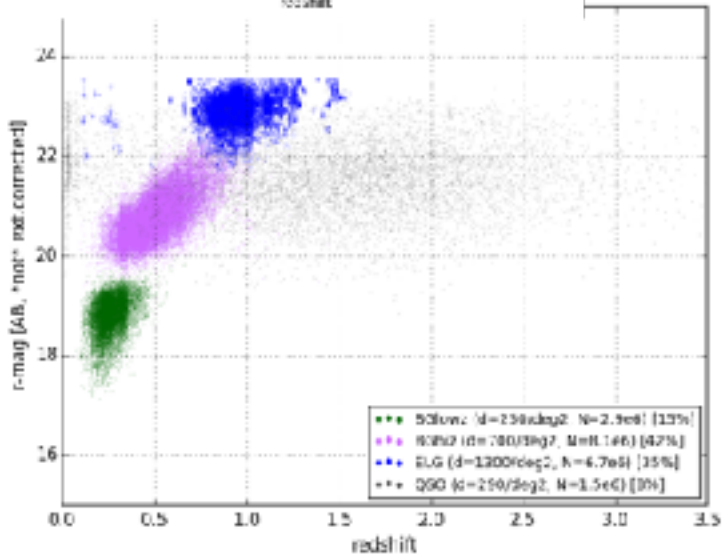
- Wide Field Low-Z survey: (0.1<z<0.8)
  - Up to 10M bright galaxies (J<20)
  - 15,000 degree^2
- BAO and Lensing Survey: (0.7<z<1.1)
  - Up to 6M targets
  - 6,000 deg^2 area covered by DES+KIDS
- Quasar Redshift Survey: (0.9<z<3.()
  - 15,000 degree^2
  - Variability selection from DES and PANSTARRS plus WISE photometry











target	imaging	redshift range	density
BGlowz	VHS+WISE	0.05<z<0.4	250/deg2
BGhiz	VHS+WISE	0.4<z<0.8	700/deg2
ELG	DES	0.7<z1.1	1300/deg2
QSO	DES+WISE	0.9<z<3.5	190/deg2

Why combination of lensing and RSD?

- Sensitive to theories of gravity in complementary ways
- General perturbations to FRW metric:

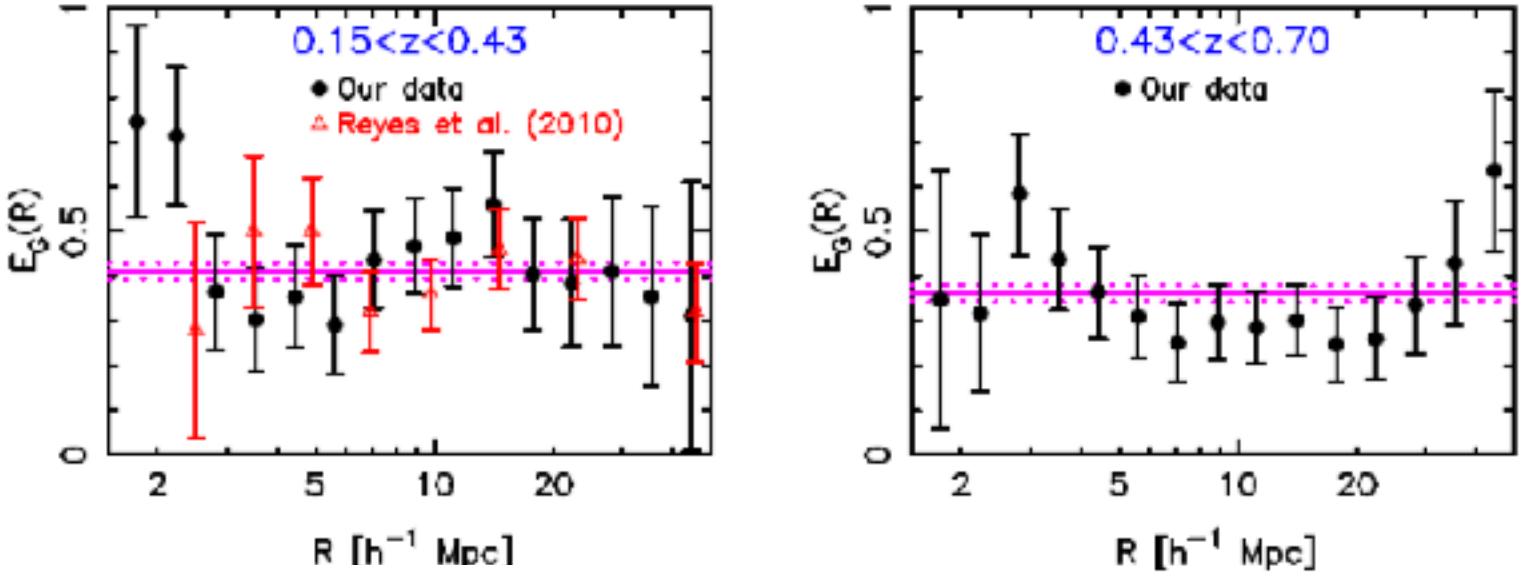
$$ds^2 = [1+2\psi(x,t)]\,dt^2 - a^2(t)\,[1-2\phi(x,t)]\,dx^2$$

- (ψ, ϕ) are metric gravitational potentials, identical in General Relativity but can differ in general theories
- Relativistic particles (e.g. light rays for lensing) collect equal contributions and are sensitive to $(\psi + \phi)$
- Non-relativistic particles (e.g. galaxies infalling into clusters) experience the Newtonian potential ψ

(courtesy: Chris Blake)

RCSLenS/CFHTLenS vs BOSS/WiggleZ cross-correlation

RCSLenS: Testing gravitational physics through the cross-correlation of weak lensing and large-scale structure



$$E_G(R) = \frac{1}{\beta}\frac{\Upsilon_{gm}(R, R_0)}{\Upsilon_{gg}(R, R_0)} = \Omega_m / f$$

(courtesy: Chris Blake)

Blake et al. 2016

Photometric redshift calibration

- Photometric redshift errors are one of the leading systematics for weak lensing tomography
- Mean and width of redshift distributions in each photo-z bin must be known to accuracy ~ 10^{-3}
- Method (1) : spectroscopic training set [issues : sample variance, incompleteness of training set, outliers]
- Method (2) : photo-z/spec-z cross-correlations [issues : degeneracies with galaxy bias, cosmic magnification]
- Currently unsolved problem for current and future lensing surveys (DES, LSST, Euclid)

(courtesy: Chris Blake)

Combination of lensing and spec-z surveys

- Improvement of cosmological measurements through addition of galaxy-galaxy lensing

e.g. determines bias of lens sample which improves RSD measurements of lenses, especially when using multiple-tracer techniques (e.g. Cai & Bernstein 2012)

- Spec-z survey allows definition of lens samples (e.g. groups, galaxy types) enabling a range of studies

- Understanding, calibration and risk mitigation of systematic errors (photo-z errors including outliers, intrinsic alignments, cosmic shear)

(courtesy: Chris Blake)

QSO survey

z < 2.2 quasar tracers (130 deg^{-2})

- QSO lensing (overlap with DES and LSST) - estimates of lensing convergence.
- Study of QSO clustering environment
- Quasar Hubble diagram (non-linear Lx - Luv relation, Risaliti & Lusso 2015)
- 1% error on BAO scale
- 40% overlap with the 4MOST AGN e-Rosita survey

z > 2.2 quasar tracers (~ 60 deg^{-2})

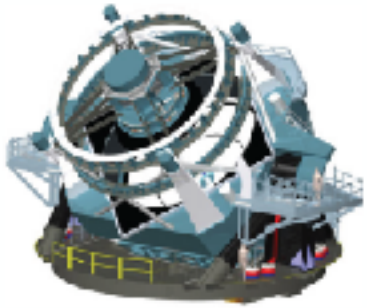
- Small scale Lyman-alpha forest clustering (higher resolution in the blue compared to DESI)
- Potential to reach fainter / higher redshift quasars.
- BAO and RSD analyses

(courtesy: Tom Shanks)

TiDES the Time Domain Extragalactic Survey

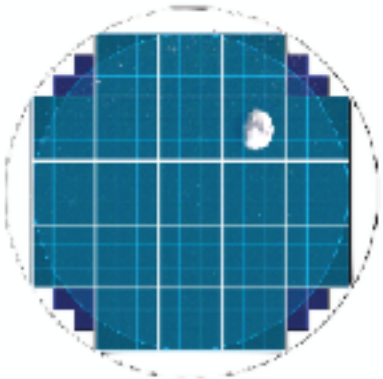
I. The transient and variable universe in the 2020s

- **LSST = Large Synoptic Survey telescope:**
  - 8.4m telescope, full southern sky every few nights
  - ugrizy band images
  - variability & transient discovery machine



- Classification & physical interpretation requires **spectroscopic follow-up**

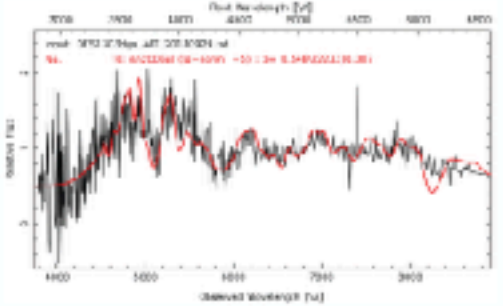
- **4MOST well matched to LSST** in terms of:
  - sensitivity
  - location
  - field of view



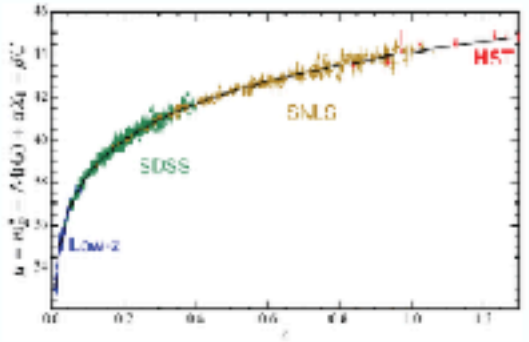
(courtesy: Bob Nichol)

II. Science goals for TiDES

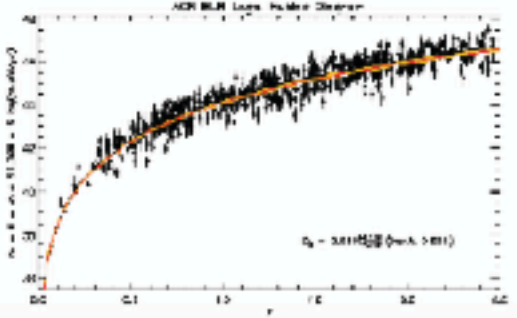
- **TiDES-Live Transients**
  - rapid (3-4 day) spectroscopic follow-up of LSST transient discoveries
  - plugging into the LSST data stream



- **TiDES-Supernovae cosmology**
  - spectroscopic classification of supernovae & host galaxies (training samples for photometric classification with LSST; see Yuan+15)
  - Hubble diagram for type Ia and type II supernovae



- **TiDES-AGN reverberation**
  - spectroscopic monitoring of AGN from LSST
  - black hole masses & Hubble diagram to z~2.5



(courtesy: Bob Nichol)

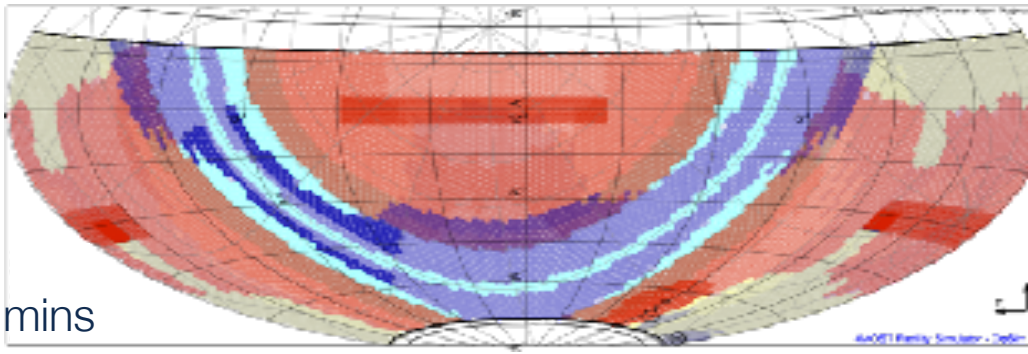
III. Survey Strategy

- **Guiding principles**
  - Select targets from LSST (live transients, supernovae, and AGN)
  - For live transients: most interesting ones have priority for TiDES
- **Target selection**
  - AGN: selected from LSST variability, initial spectra (see AGN survey)
  - SNe: selected from LSST, other transient surveys, not time critical
  - Live Transients: selection from LSST live data stream, TiDES pre-classification
- **Operations & scheduling**
  - *SNe and AGN:*
    - mostly repeat fields (e.g. LSST deep fields) + SNe hosts distributed over entire sky
    - no frequent target list update
  - *Live Transients:*
    - can be anywhere in the extragalactic
    - target list update every ~3 days, priority based on next fields observed

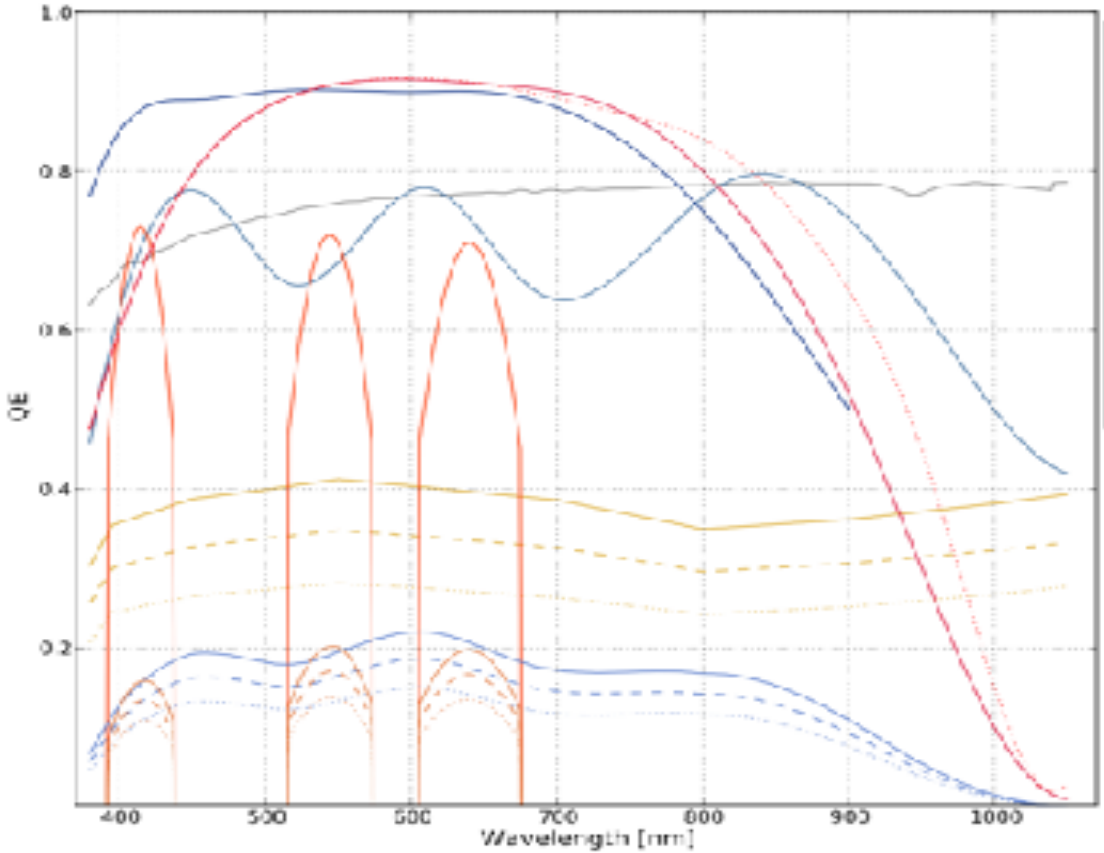
(courtesy: Bob Nichol)

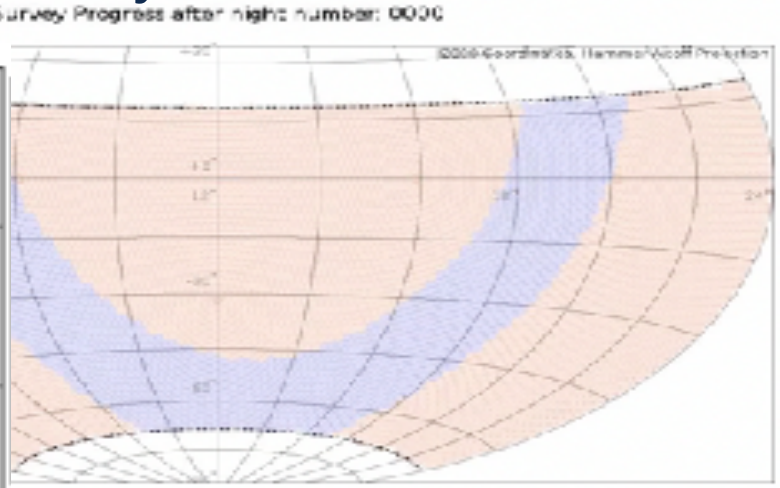
4MOST Operations

- 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 assignment, survey strategy and verify total survey quality





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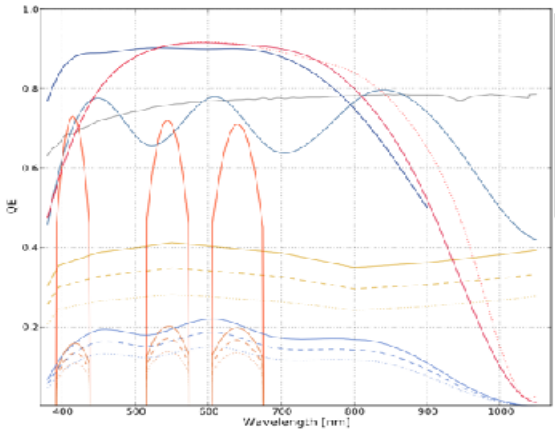

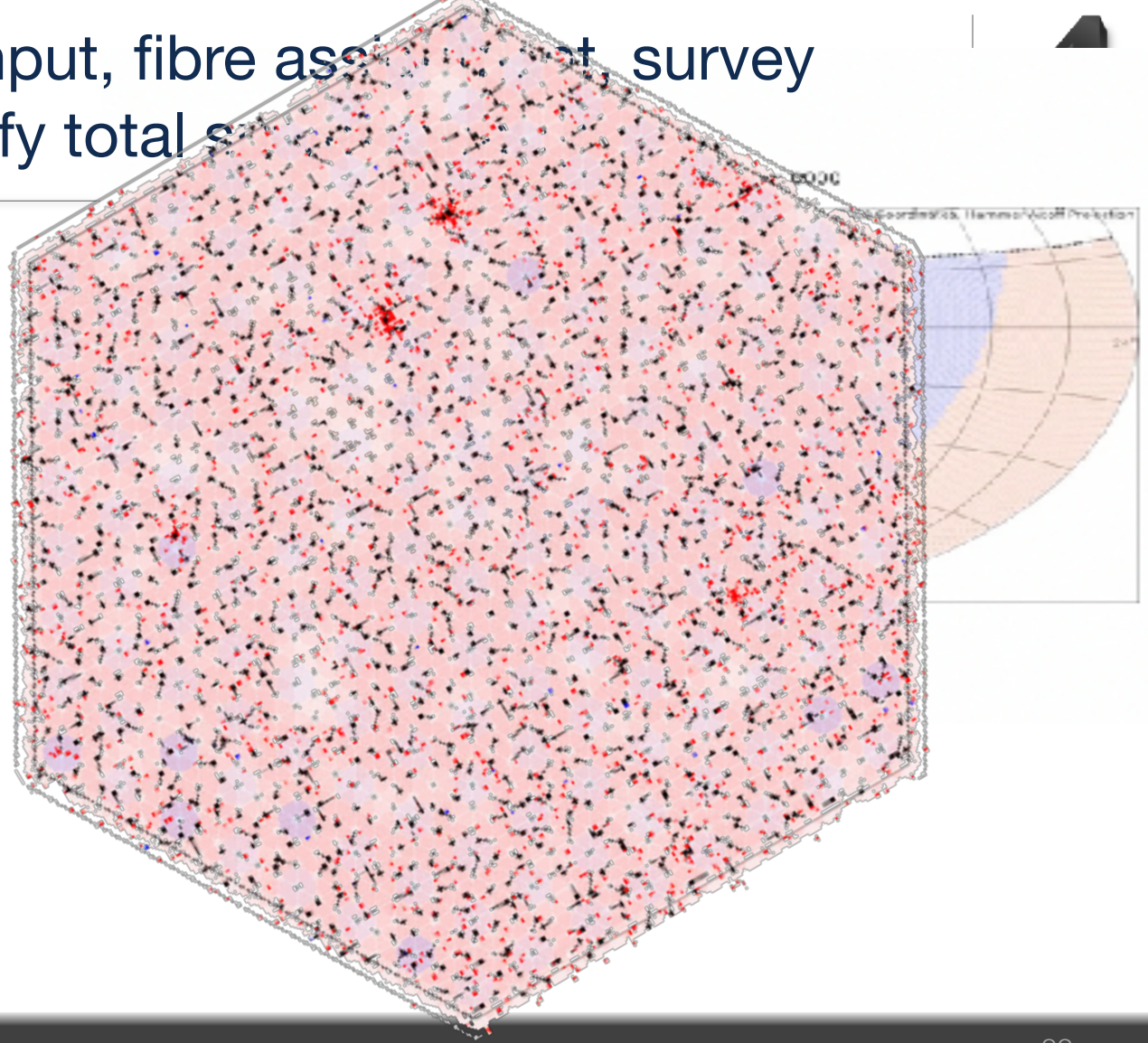

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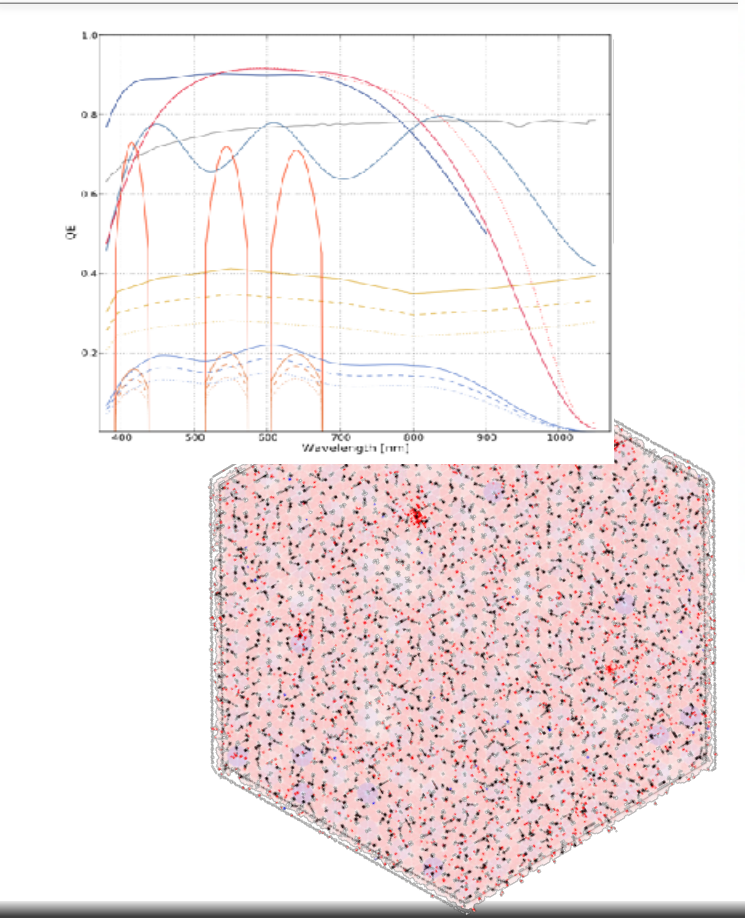

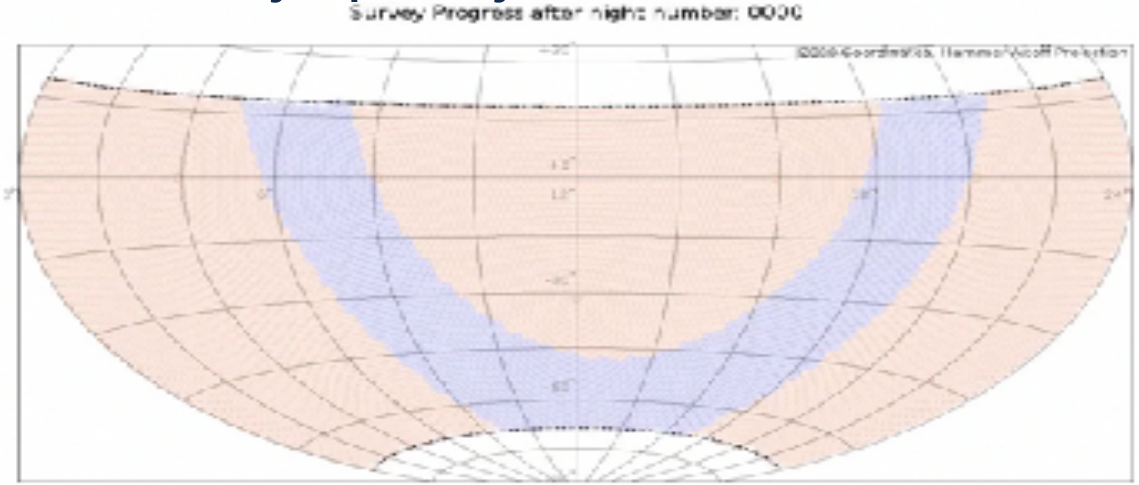

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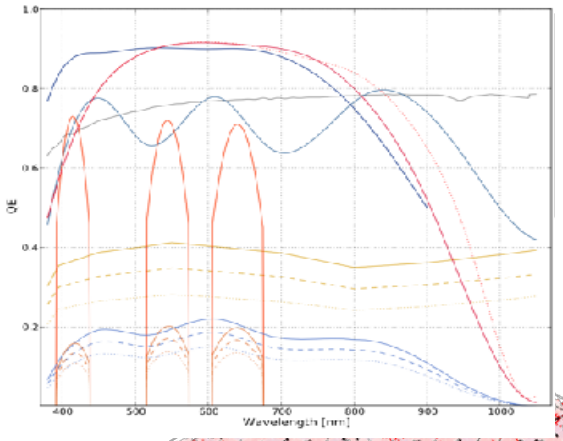
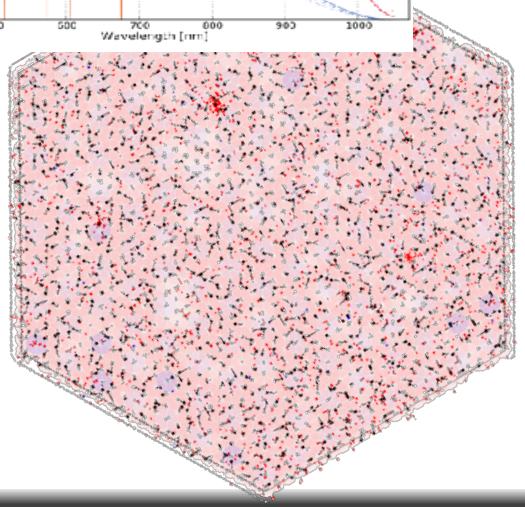
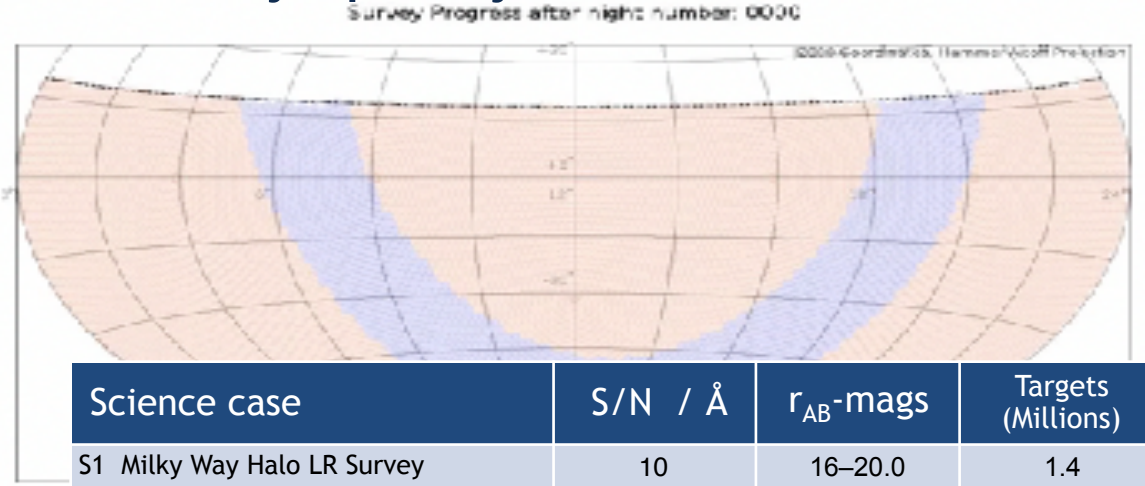
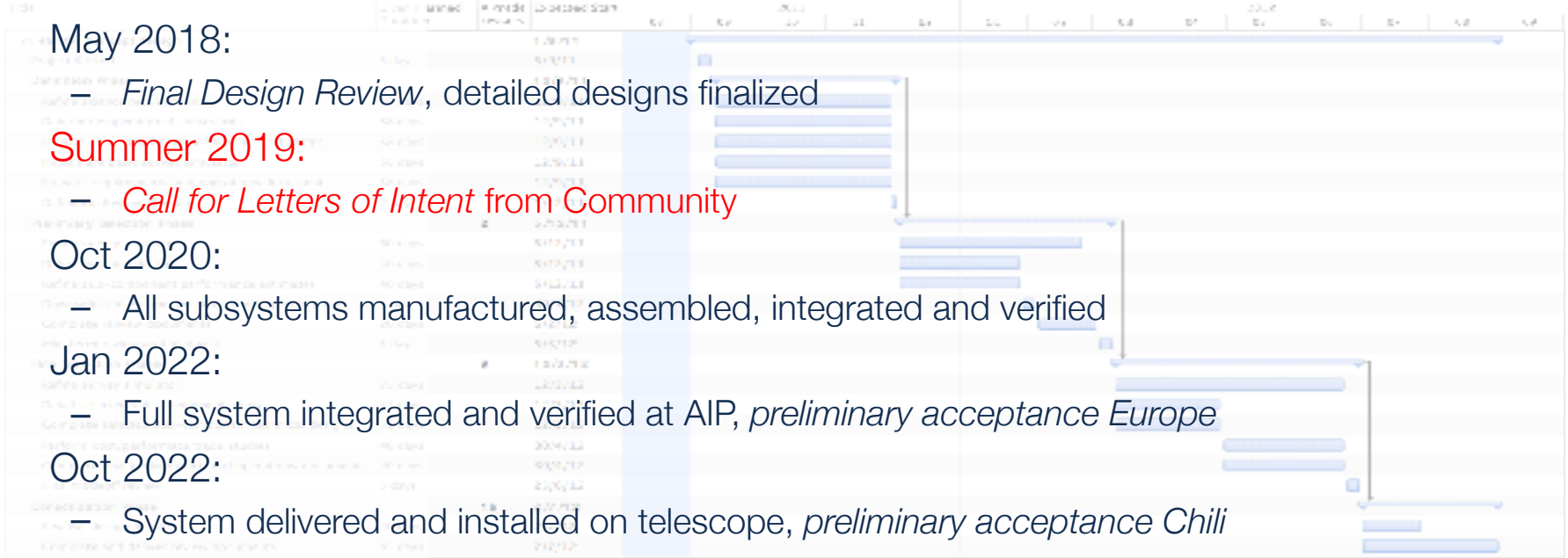






Science case	S/N / Å	r_{AB}-mags	Targets (Millions)
S1 Milky Way Halo LR Survey	10	16–20.0	1.4
S2 Milky Way Halo HR Survey	140	12–15.5	0.6
S3 Milky Way Disk and Bulge LR Survey	10–30	14–18.5	10.7
S4 Milky Way Disk and Bulge HR Survey	140	14–15.5	2.0
S5 Galaxy Clusters Survey	4	18–22.0	0.8
S6 AGN Survey	4	18–22.0	0.5
S7 Galaxy Evolution Survey (WAVES)	4	18–22.5	1.4
S8 Cosmology Redshift Survey	4	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



- May 2018:
  - *Final Design Review*, detailed designs finalized
- Summer 2019:
  - *Call for Letters of Intent* from Community
- Oct 2020:
  - All subsystems manufactured, assembled, integrated and verified
- Jan 2022:
  - Full system integrated and verified at AIP, *preliminary acceptance Europe*
- Oct 2022:
  - System delivered and installed on telescope, *preliminary acceptance Chili*

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

Community Proposals

- Call for Letters of Intent followed, for selected applicants, by Call for Proposals in 2019
- Fibre-hour share 30%, all surveys ESO Public Surveys
- Participating Surveys:
  - Become equal partner in Science Team with Consortium Surveys
  - Share survey strategy, 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
- Non-participating Surveys:
  - Receive own observing nights
  - Prepare own OBs, receive only L1 data products
  - Have no access to Consortium and Community Participating Survey data
  - Target duplication policy TBD

Thanks!


http://2018.sf2a.eu
July 4th: session on large spectroscopic surveys for cosmology
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SF2A 2018
Bordeaux 3-6 juillet 2018
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