Funded by the European Union

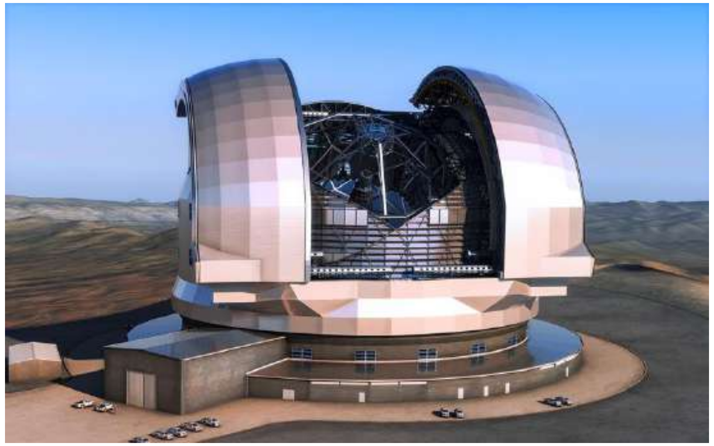
The Wide-field Spectroscopic Telescope

Matthias Steinmetz
Leibniz-Institut für Astrophysik Potsdam (AIP)
for the WST collaboration

Annual Meeting of the German Astronomical Society, 18 September 2025

Landscape in the 2030+

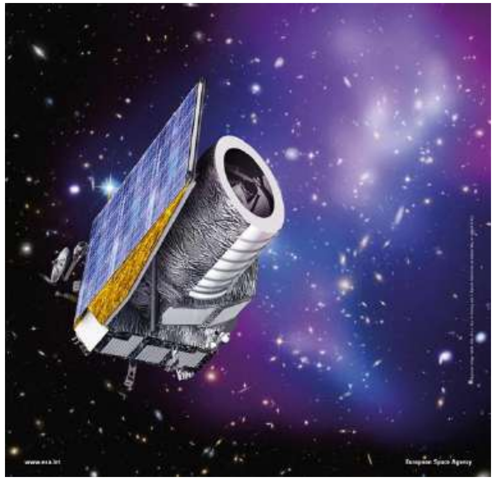
- Upcoming ground-based telescopes: ELT, LSST/VRO (Vis), SKAO (Radio), CTA (High Energy), ET (Grav. Wave)
- Present & Upcoming space telescopes: JWST (IR), Euclid (Vis/NIR), Roman Space Telescope (Vis/NIR), Athena (X-rays)
- They will detect and classify a huge number of objects.



ELT

Vera Rubin Observatory (VRO/LSST)

SKA



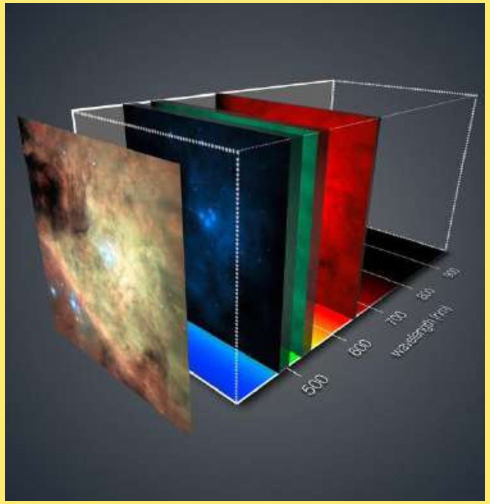
Euclid (ESA)

but to probe the physics of these objects, we need spectra

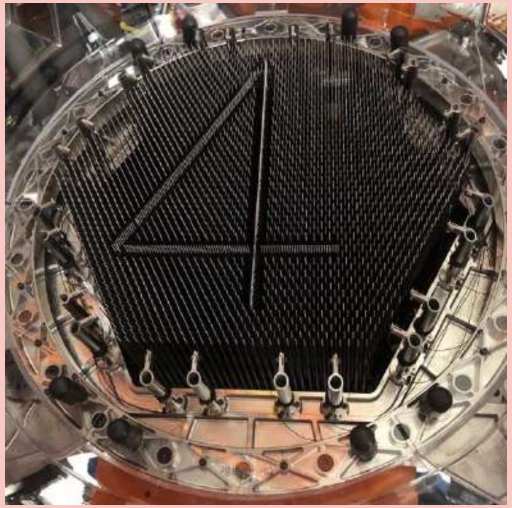
but to probe the physics of these objects, we need spectra!

A 12m telescope with a 3 deg^2 field of view

A panoramic IFU „SuperMUSE“ with a 10 arcmin^2 FoV

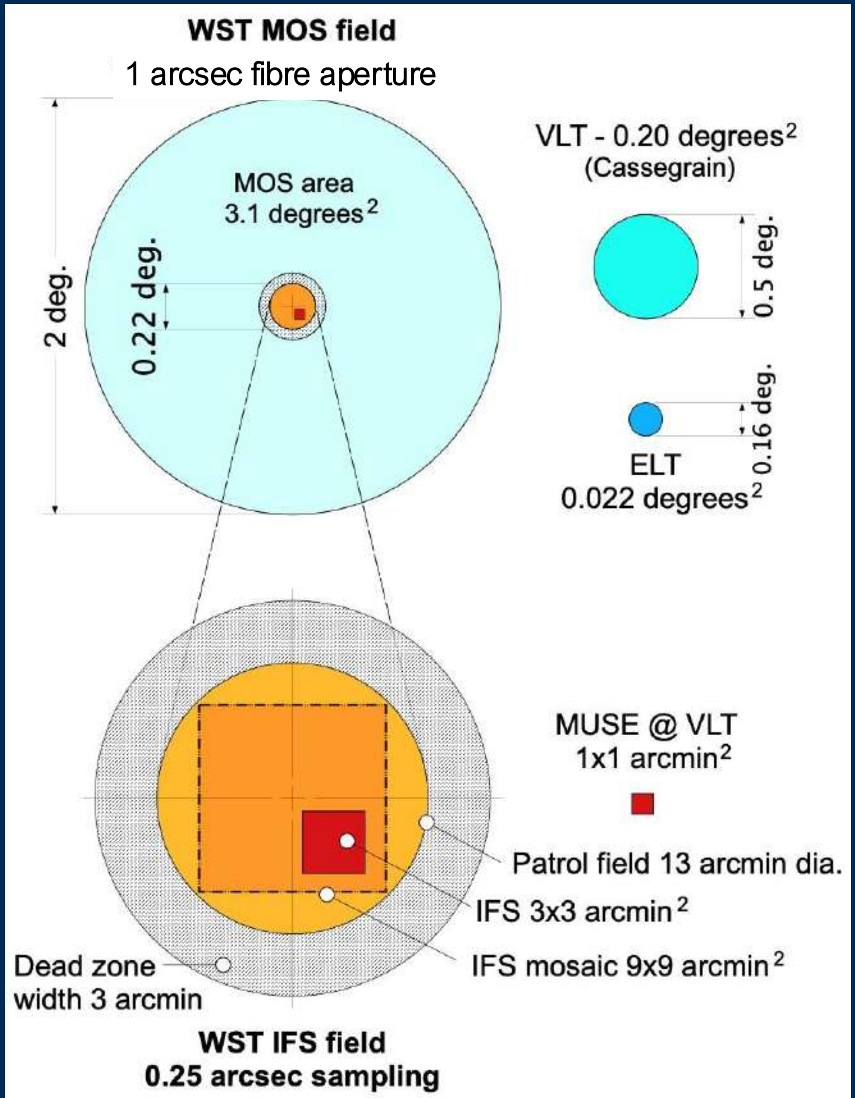


A high mulitplex multi-res MOS with fibre-level ToO capability

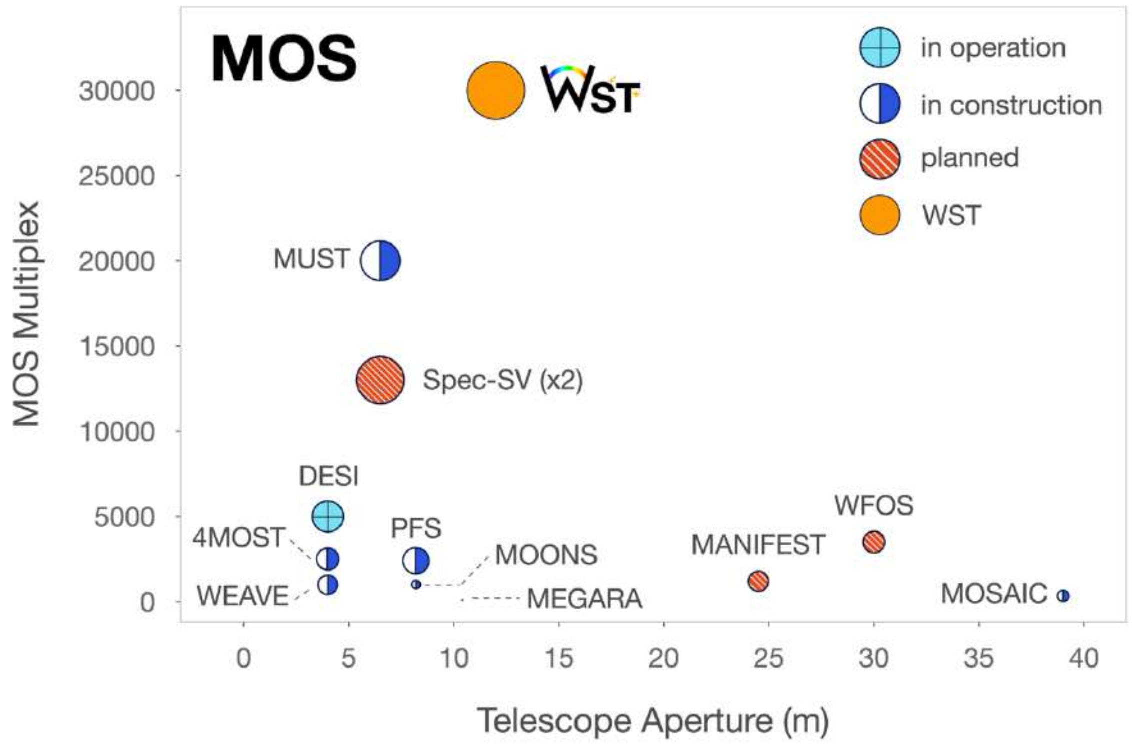


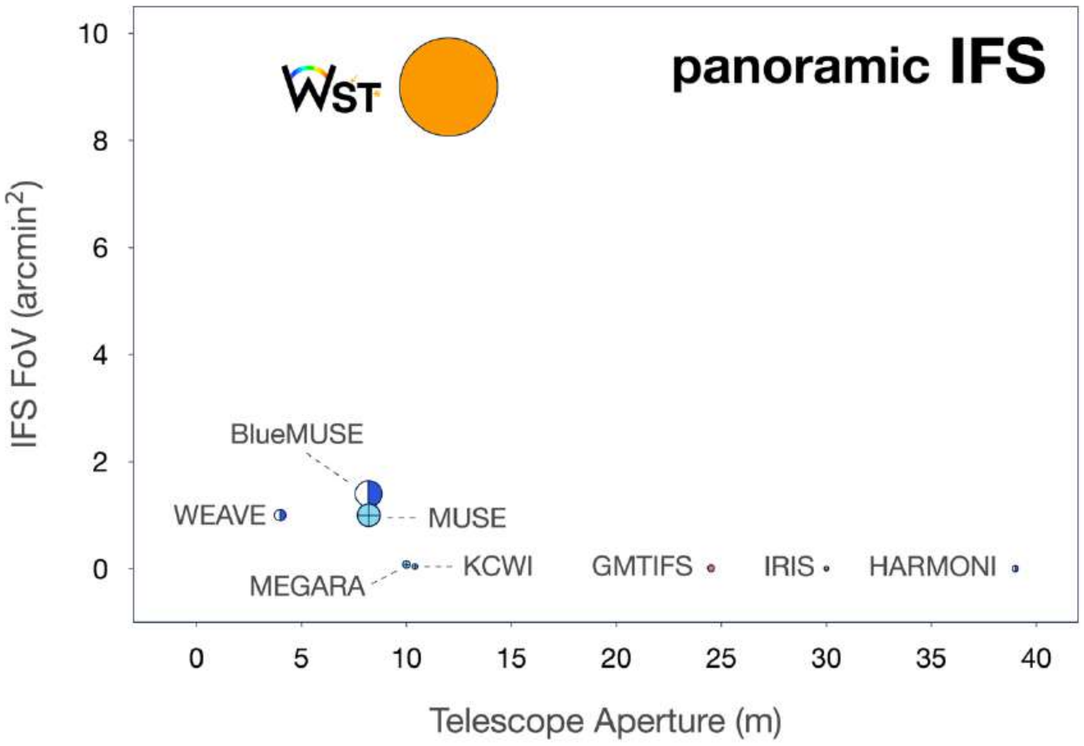
Top Level Requirements

Telescope Aperture	12 m, seeing limited
Telescope FoV	3.1 deg^2
Tel. Spec Range	0.35–1.6 μm
MOS LR Multiplex	30,000
MOS LR Resolution	3,000-4,000
MOS LR Spec Range	370–970 nm (simultaneous)
MOS HR Multiplex	2,000
MOS HR Resolution	40,000
MOS HR Spec Range	350–970 nm (3–4 regions)
IFS FoV	3×3 $arcmin^2$
IFS Resolution	3,500
IFS Spec Range	370–970 nm (simultaneous)
IFS Patrol Field	13 arcmin diameter
MOS & IFS parallel operations	
ToO implemented at telescope and fiber level	



Comparison with existing and planned facilities





Science Case

- Galactic
- Resolved Stellar Populations
- Extragalactic
- Cosmology
- Time Domain

The WST science white paper v1, Mainieri et al, 2024, astro-ph
194 pages, 214 authors https://arxiv.org/abs/2403.05398
v2 foreseen in 2027-2028

MOS-LR

MOS-HR

IFS

Gaia, Rubin/Roman, Euclid, SKAO, Einstein Telescope, ELT, …

Register to become a science team member:
www.wstelescope.com

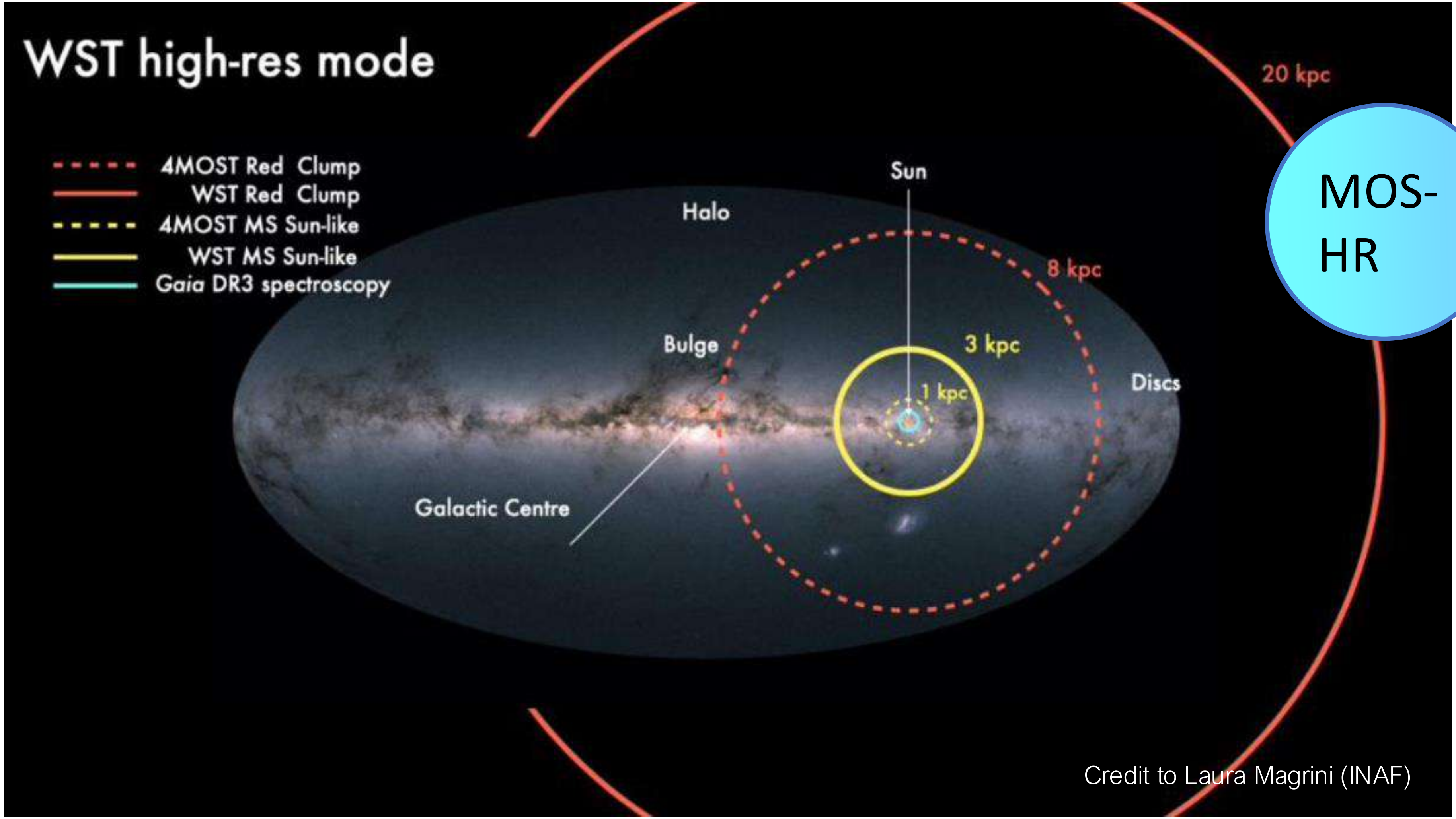
The formation history of the MW and its satellites

Galactic

Origins of elements

High spectral resolution survey of the whole sky

- full chemical information and RVs, up to G~16-17
- A few element abundances & RVs up to G~18-18.5
- at larger distances: metallicities & RVs + alphas



MOS-HR

Line detectability as a function of R

Galactic

Origins of elements

High spectral resolution survey of the whole sky

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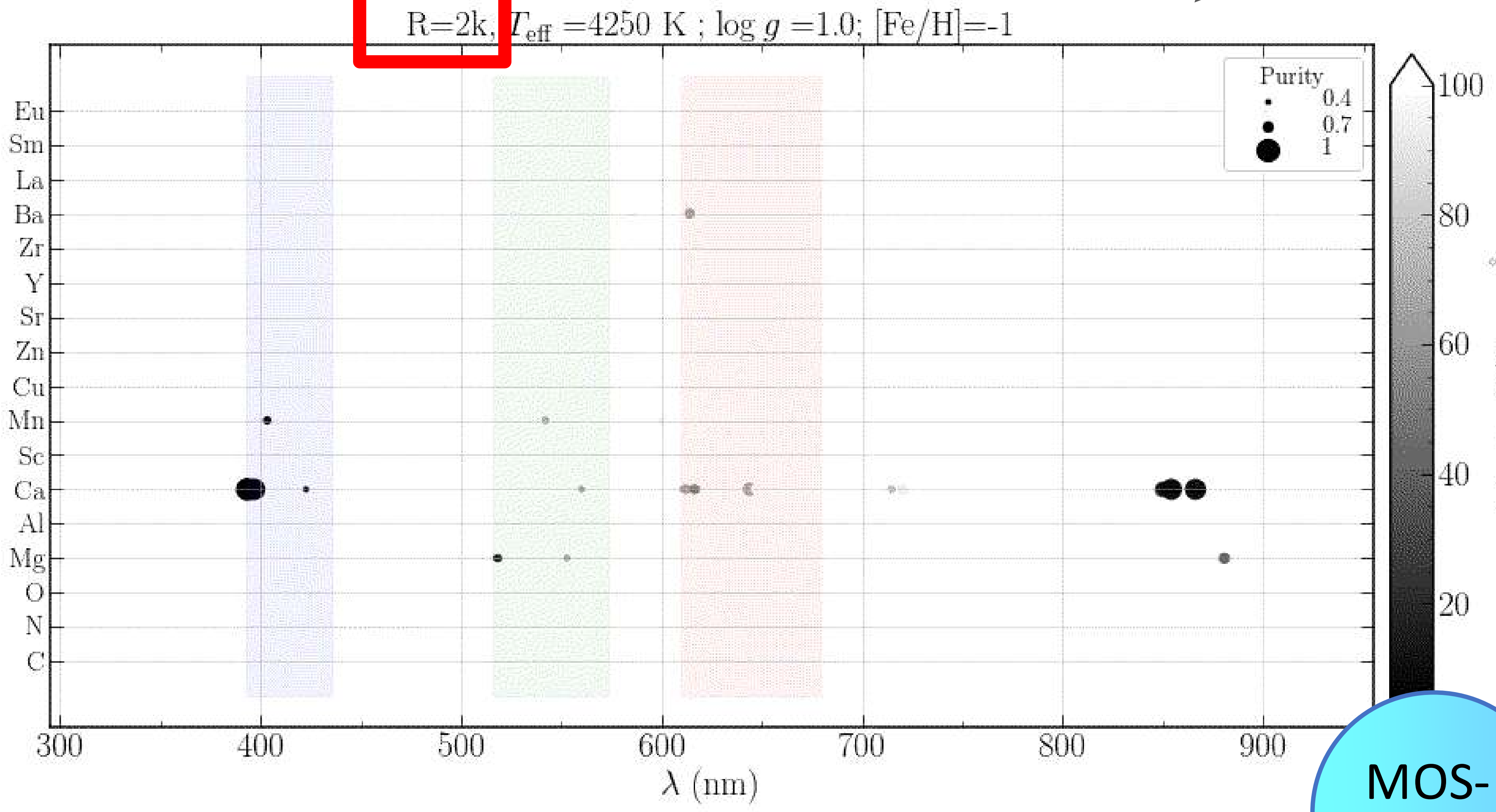
- at larger distances: metallicities & RVs + alphas



precision of the measurement

MOS-HR

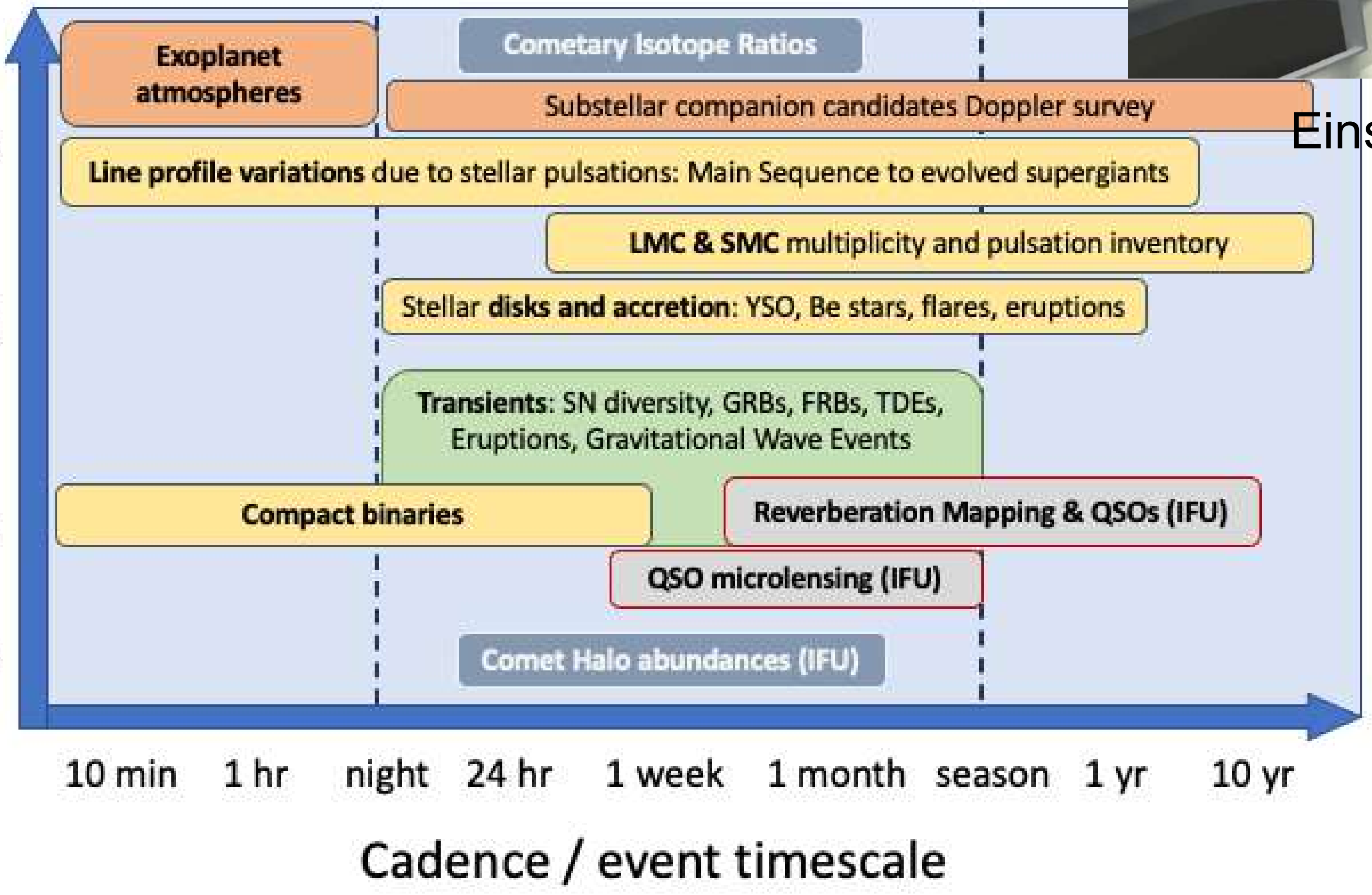
Time domain astrophysics

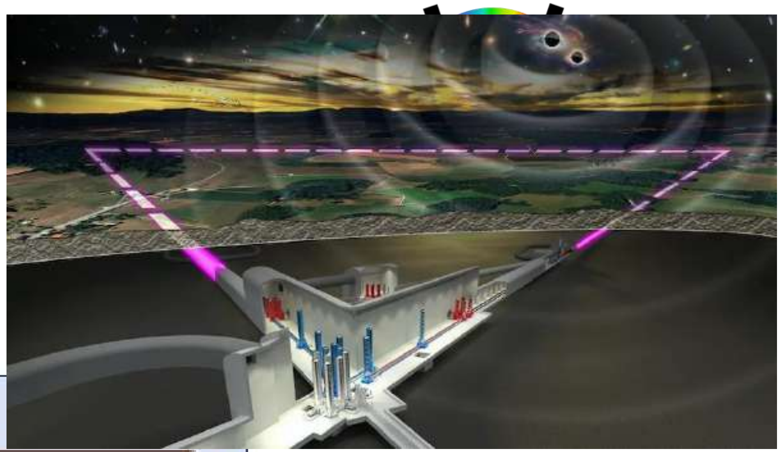
Time Domain

Gravitation Wave Events with EM signals (kilonovae)

- Cosmology: H_0
- Galaxy evolution: r-process element production
- Kilonova population studies: EOS of neutron stars, GR tests, …

Spectra required for identification & characterization
EM alerts (1000/sqdeg)





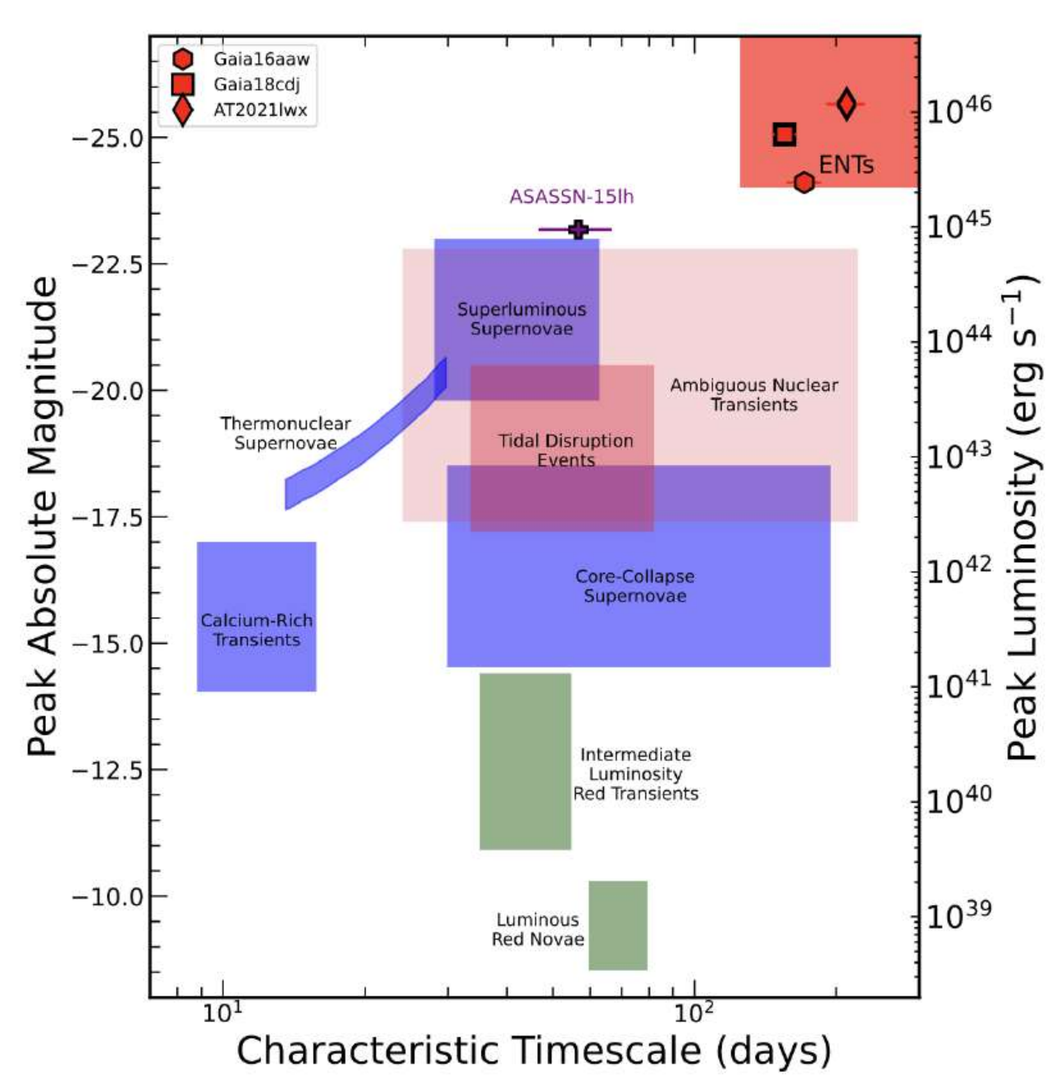
Einstein Telescope

Transients post Rubin/Roman era

In the 2040s Rubin will have discovered hundreds of thousands of transients

Build time-domain capabilities (e.g., Operational model, fast data processing) in WST to enable new science

- **Fiber-level ToO:** large scale follow-up of transients with WST will be key to get a full picture of their nature.
- **Spectroscopic variability:** WST will issue alerts enabling the detection of new classes of transients.

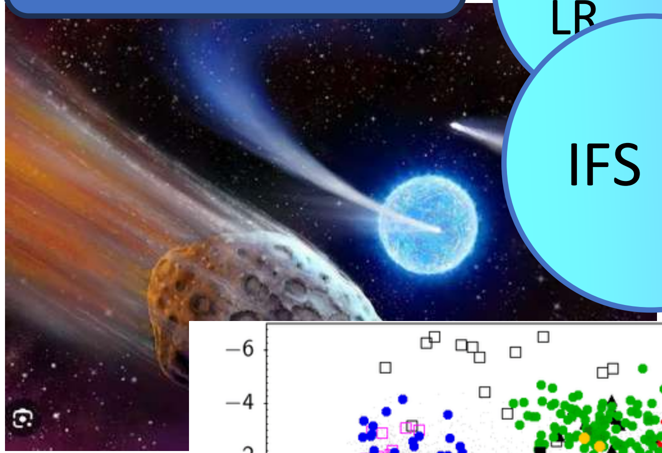


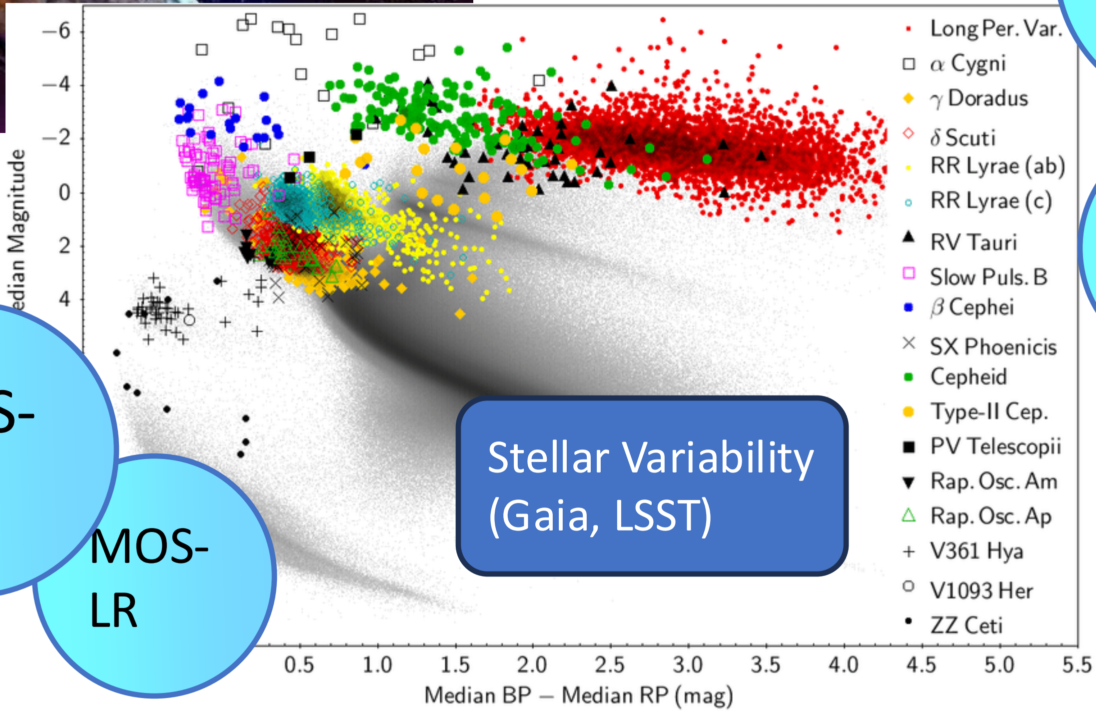
Time domain: Exciting science on all scales

Solar system Comets & Exocomets

MOS-LR

IFS





MOS-HR

MOS-LR

Stellar Variability (Gaia, LSST)

Transient astronomy (stellar flares, SNe, TDEs, GRBs, etc.)

MOS-LR

MOS-HR

Compact objects (WDs, stellar-M BHs)

Gravitational Wave Source Characterization, Calibration sources

IFS

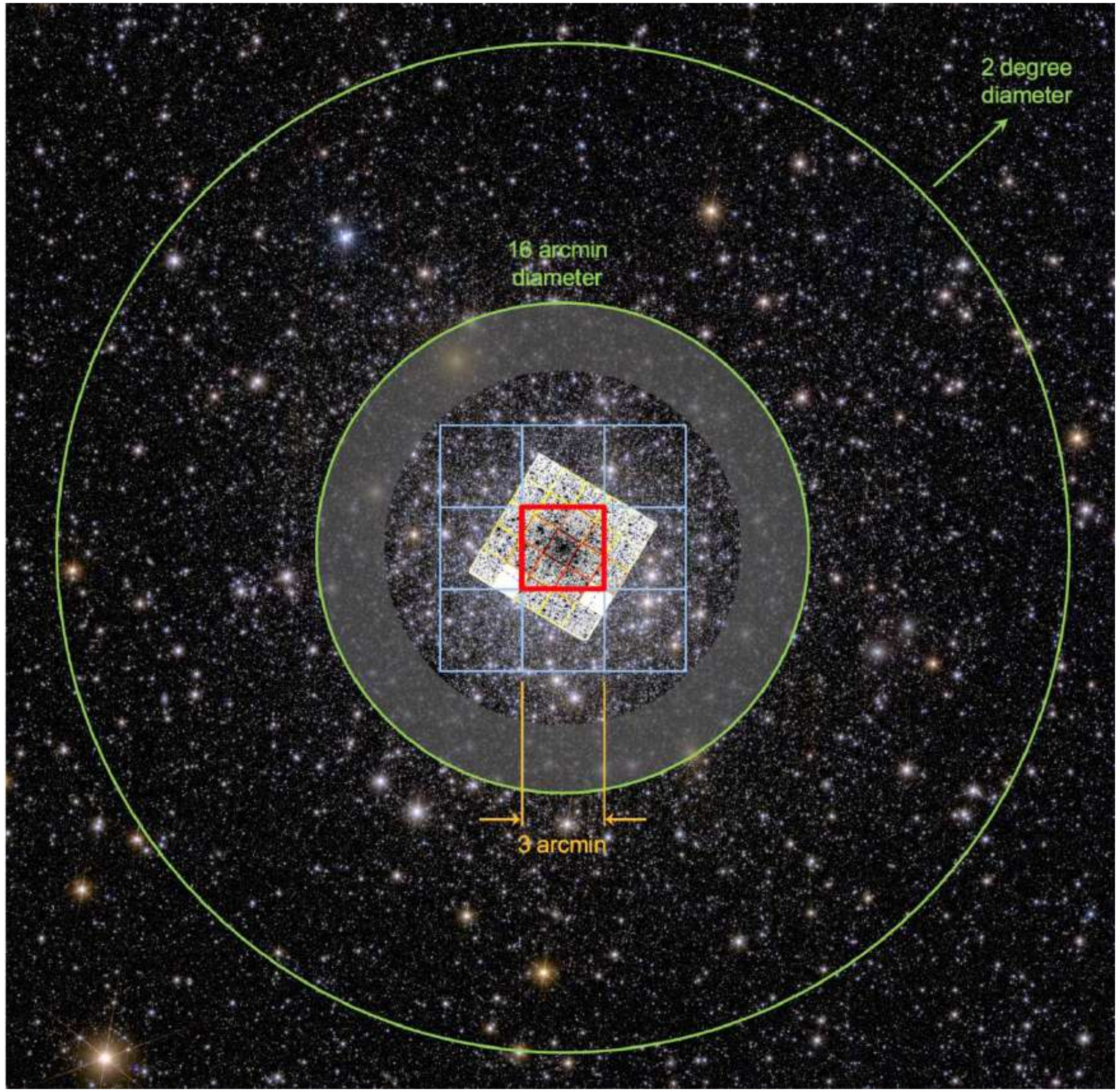
MOS-LR

Supermassive BHs (AGN, QSOs)

Stellar clusters and galaxies of the local group

Resolved Stellar Pop.

- **The population of massive stars in metal-poor galaxies**
- **The baryonic and dark matter halo properties of Local Group dwarf gals**
- **Extragalactic archeology & data mining of nearby galaxies**
- **The role of ultra-faint dwarfs in galaxy evolution**



IFS

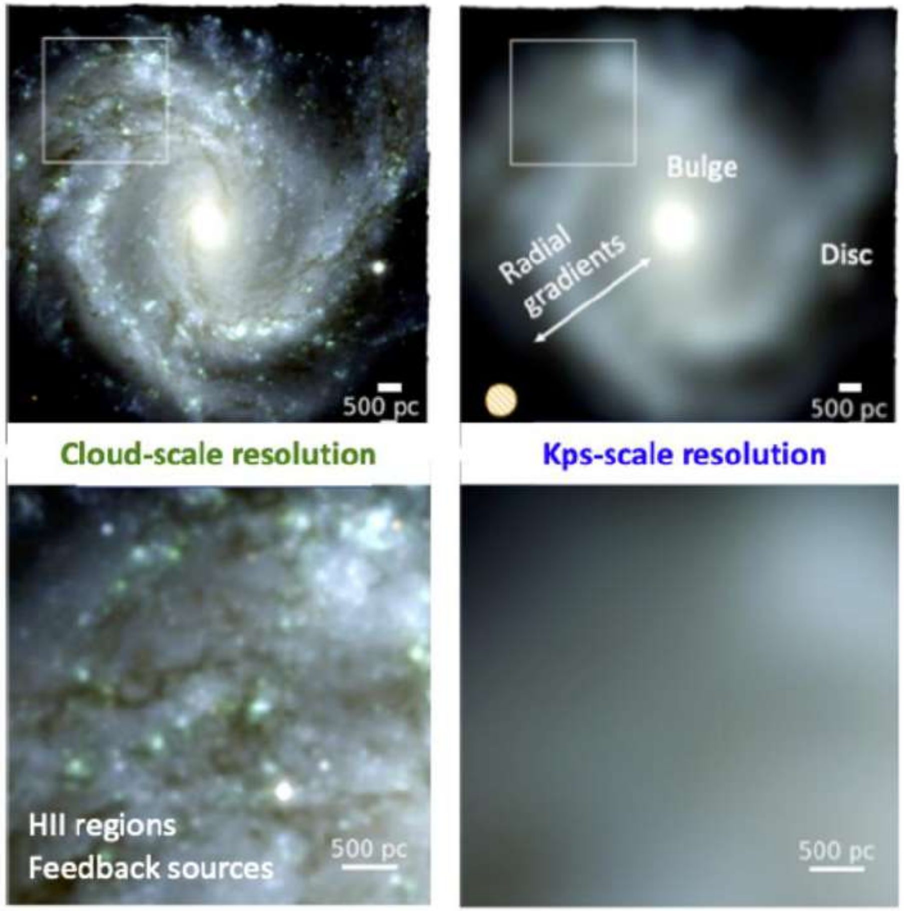
MOS-HR

A local volume galaxy IFS survey

Extragalactic

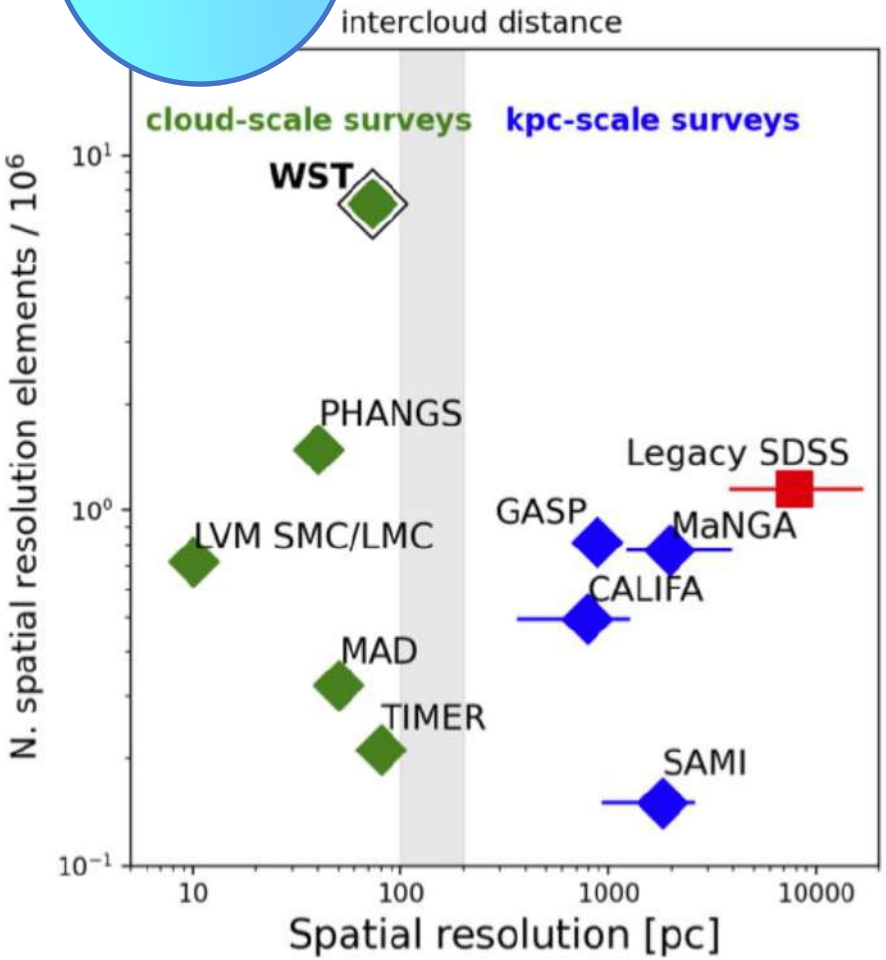
- The small-scale matter cycle
- Assembly history of galaxy components
- The galaxy-halo interface

1020 galaxies at D<25 Mpc (1200 IFS pointings)



Credits: Belfiore Emsellem

IFS



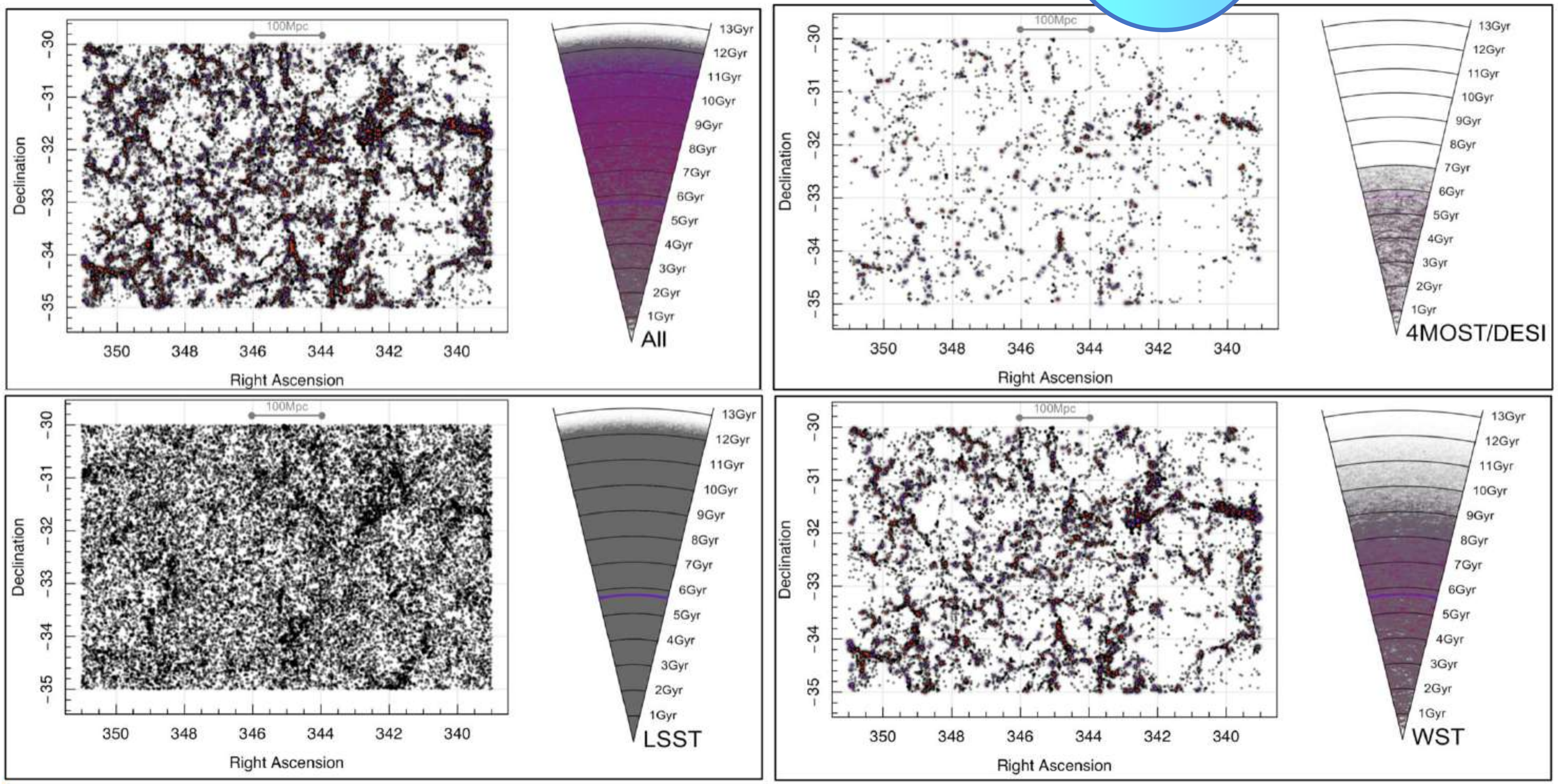
Reconstructing dark matter distribution

MOS-LR

Extragalactic

Reconstructing the dark matter 3D distribution with unprecedented fidelity up to z=1.6

A complete Z=24 mag survey over ~50 sq.degrees containing a total of 2.3 million galaxies and 130k groups & pairs (with no photo-z cut).



Simulation of the reconstructed DM distribution at z=0.6 from LSST, 4MOST/DESI and WST

Courtesy Simon Driver

MOS & IFS synergy: MOS driven survey
Galaxy assembly: gas, stars and DM

MOS-LR

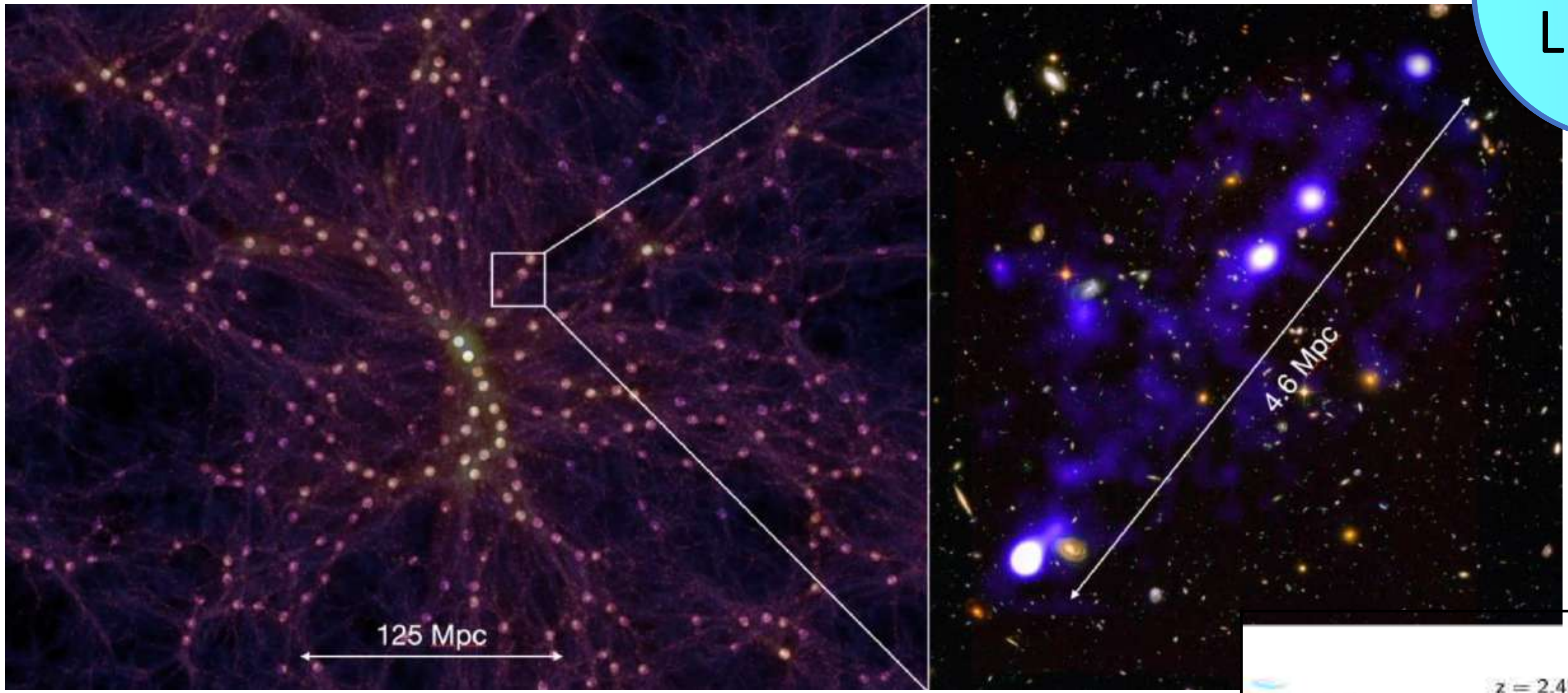
IFS

Extragalactic

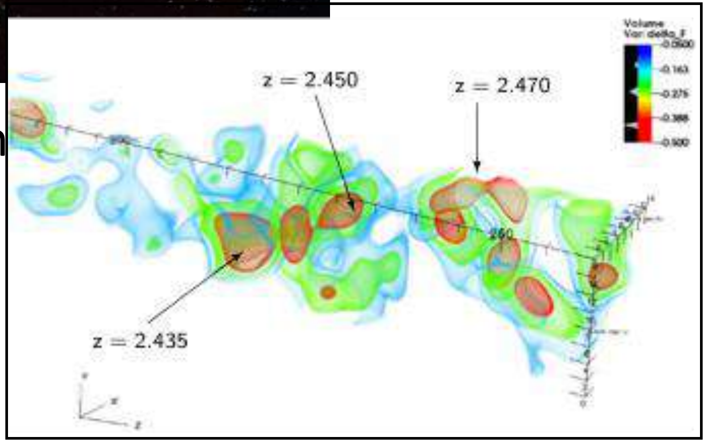
The cosmic web and its evolution at the time of the peak of star formation

Reconstruction of the evolving 3D density distribution with SDSS-like fidelity from spectra of 6 million 1<z<4 galaxies – a legacy survey

Specifically for z~2.3-3, the topology of the dark matter over large volumes from Lyman α forest seen in absorption line spectra of background galaxies



MOS: IGM tomography in absorption and 3D distribution of galaxies
IFS: z=2-7 LAEs, small scale clustering, resolved CGM & IGM emission in Lyα



MOS & IFS synergy: IFS driven survey of Massive Clusters

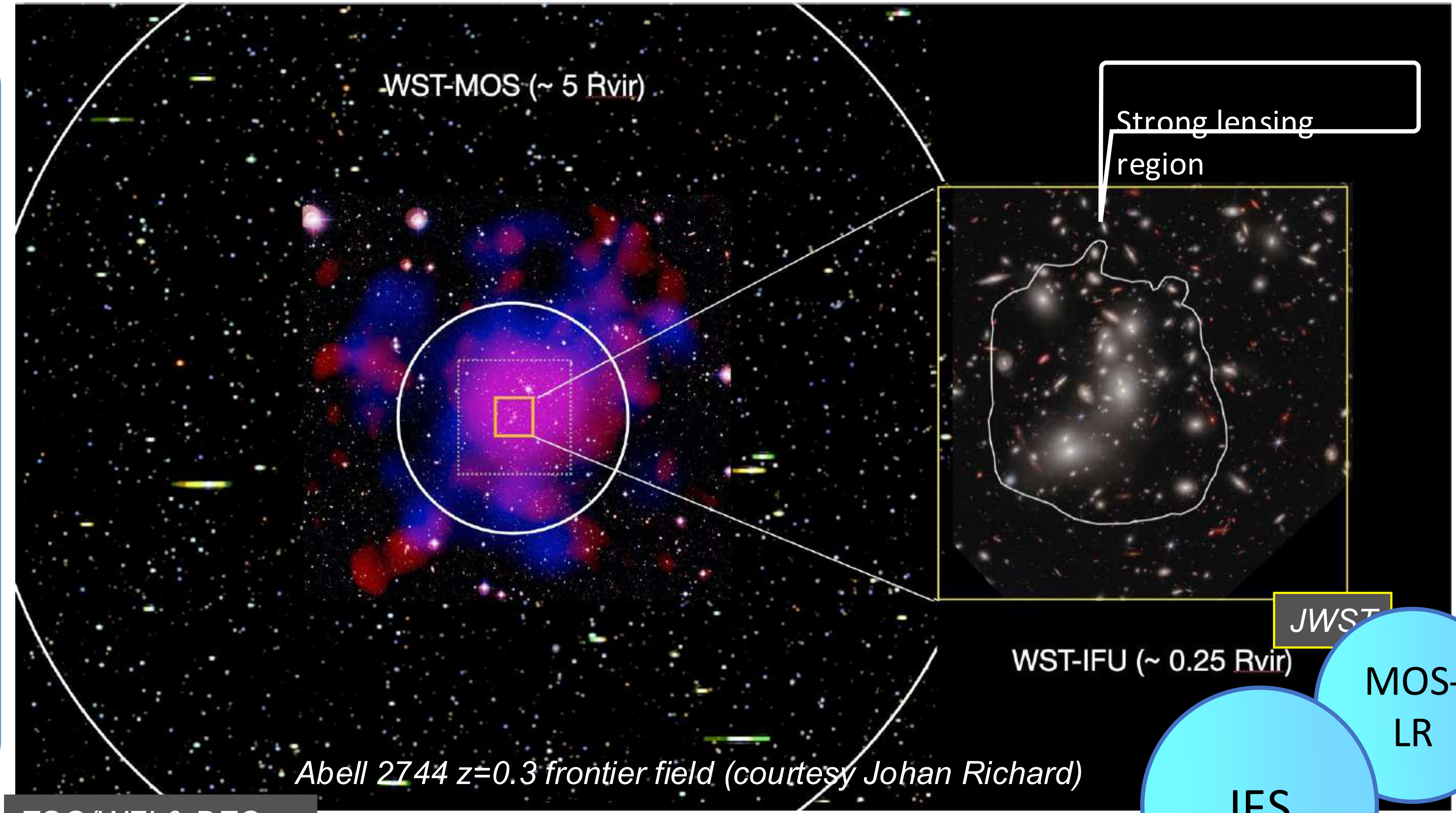
Cosmology

Massive Clusters

A comprehensive view of the massive clusters in the Universe – measure their mass (using X-ray, lensing, dynamics), how they grow with time, and how they connect to LSS of background galaxies

Targets: 2500 massive clusters @z=0.1-1, from SZ survey eROSITA, Athena (X-rays) Euclid (WL) galaxies selected from LSST photometry

X-Rays emission (XMM) *Large scale filamentary structure (Weak lensing Jausac et al 2016*



Abell 2744 z=0.3 frontier field (courtesy Johan Richard)

ESO/WFI & DECam

MOS-LR

IFS

Stage V Cosmology surveys: Extending current studies to higher z and larger statistics

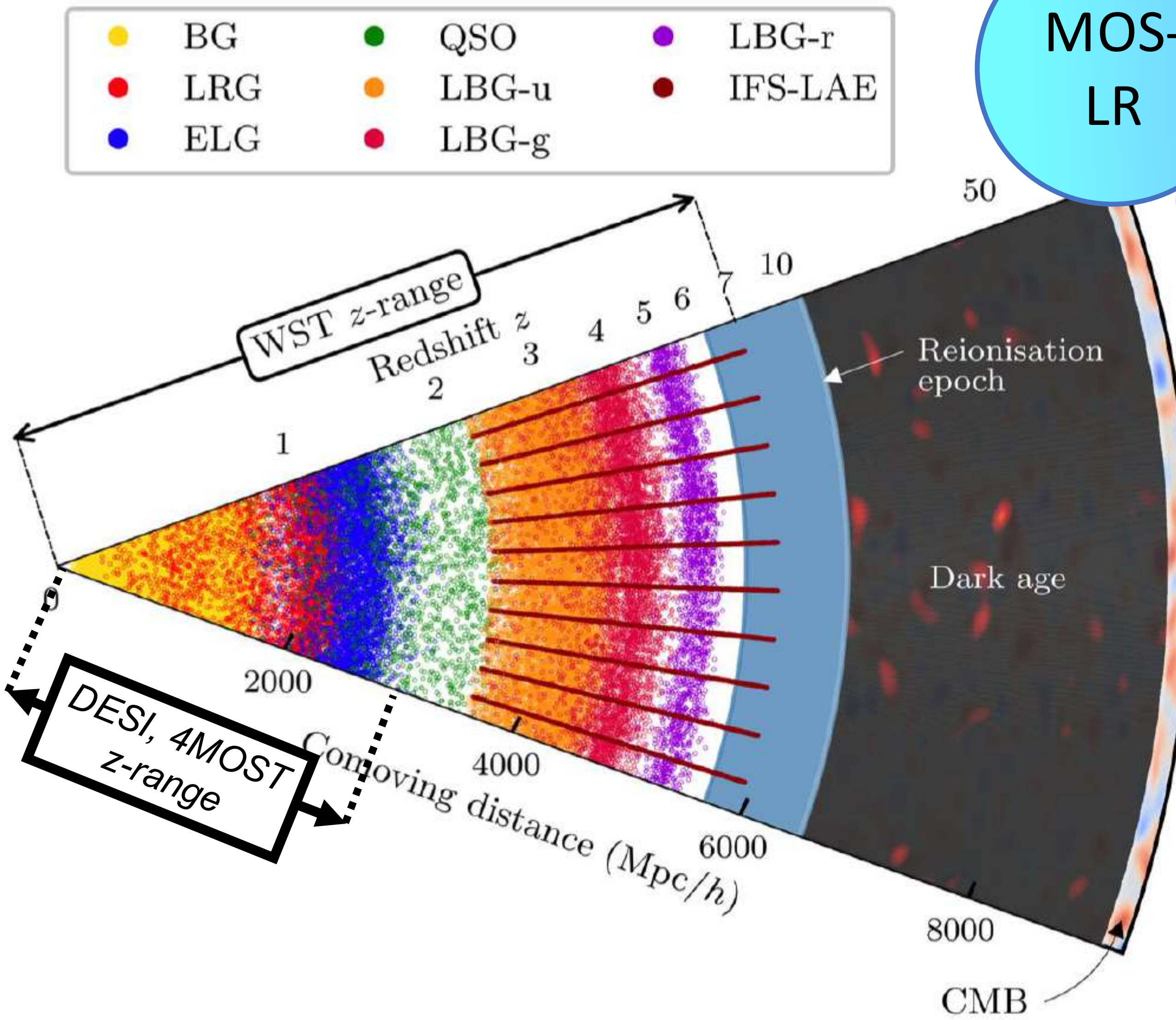
MOS-LR

IFS

Cosmology

200 millions galaxies over 18,000 deg^2 in 7 years

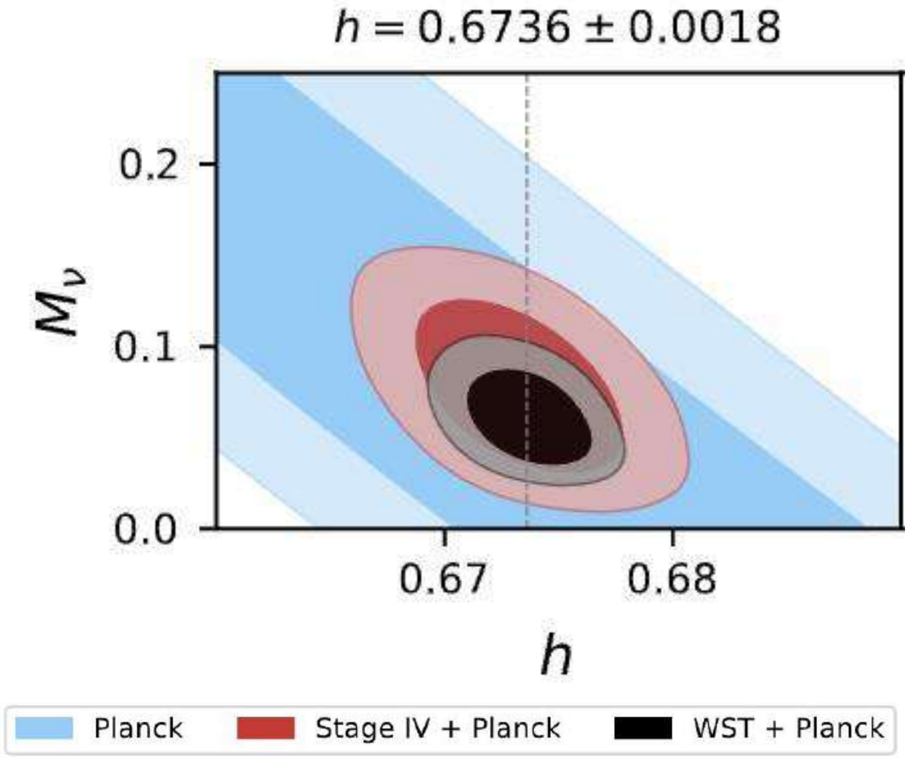
- BAO parameters
- Growth rate of structures
- Primordial non-Gaussianities
- Constrain on neutrino mass
- Constrain on dark energy



Probing fundamental physics

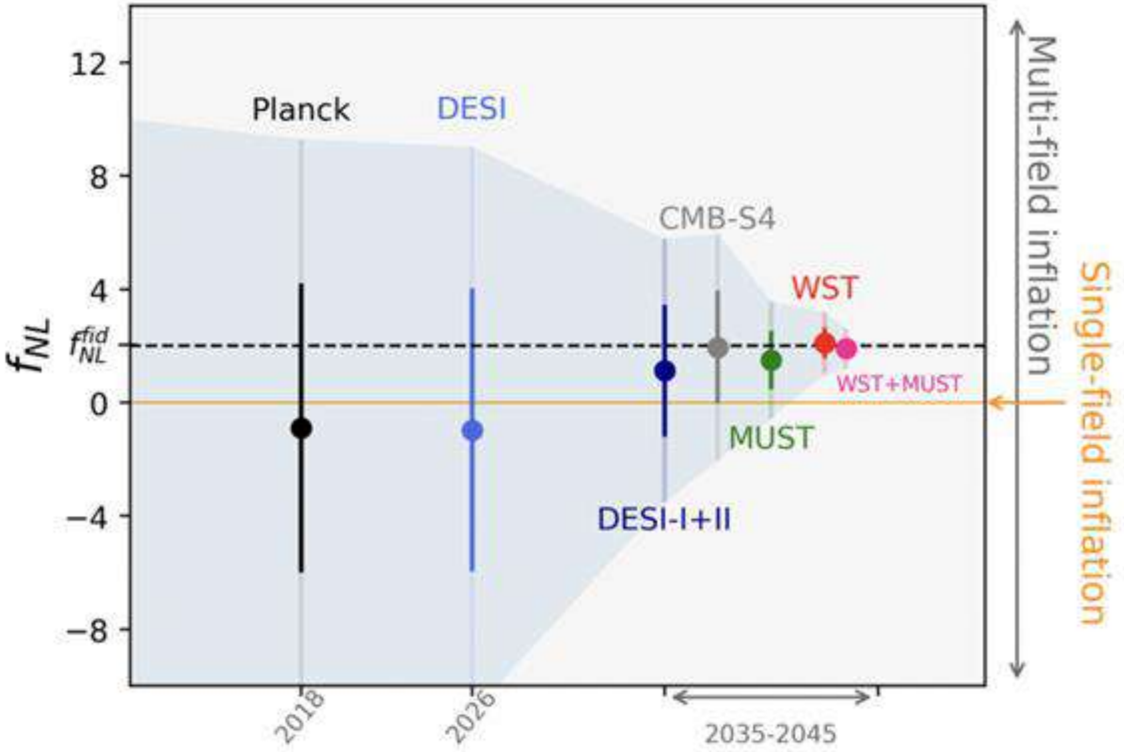
Neutrinos mass

In the most conservative case (M_ν=0.06 eV) WST could provide a 3.5σ evidence of non-null neutrino masses



Primordial non-Gaussianities

WST will be able to distinguish for the first time between single-field and multi-field inflationary models



In the first 5 years of operation, WST will provide:

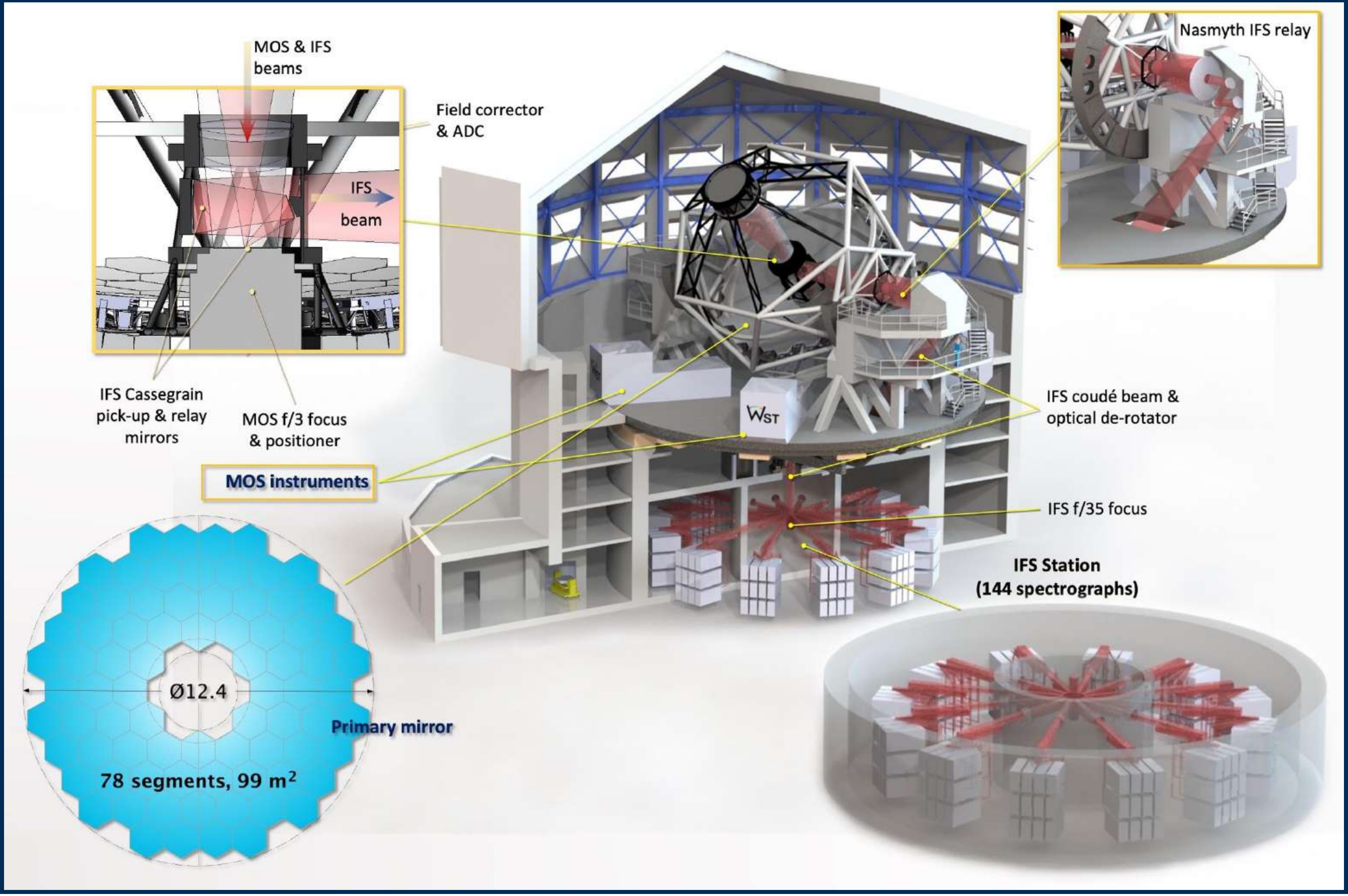
- MOS LR
  - **300 million** galaxies (to AB 24.5) over **14,000 deg^2**
  - **25 million** stars (to AB 23.0) over the **entire galaxy and local group**
- MOS HR
  - **2 million** stars (to AB 17.0) over most of the galaxy
- IFS
  - **4 billion** spectra over 30 deg^2 in diverse environments (low-density fields, galaxy and stars clusters, galactic fields …)
    - *example: 17 million of LAEs (z=2-7), AB~29, inc. 700,000 with z>5*

Discovery Power

- *Be careful making predictions, in particular those about the future.* K. Valentin.
  - e.g. no extra-solar planet in the VLT science case, Renzini & Leibundgut, 1997
  - e.g. no mention of CGM in emission in high-z galaxies in MUSE science case, Bacon et al, 2001
- Parallel IFS blind survey accompanying MOS ⇒ huge discovery space

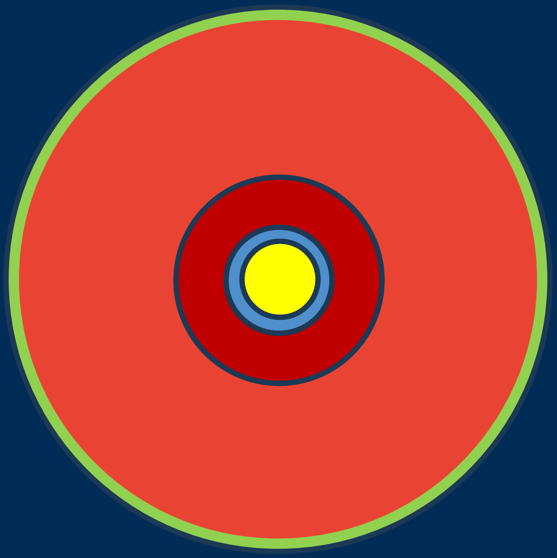
Upgrade Plan

- An IR (1-1.6 µm) extension of the MOS-LR
- A MOS mini-IFUs
- A GLAO for the IFS
- …..

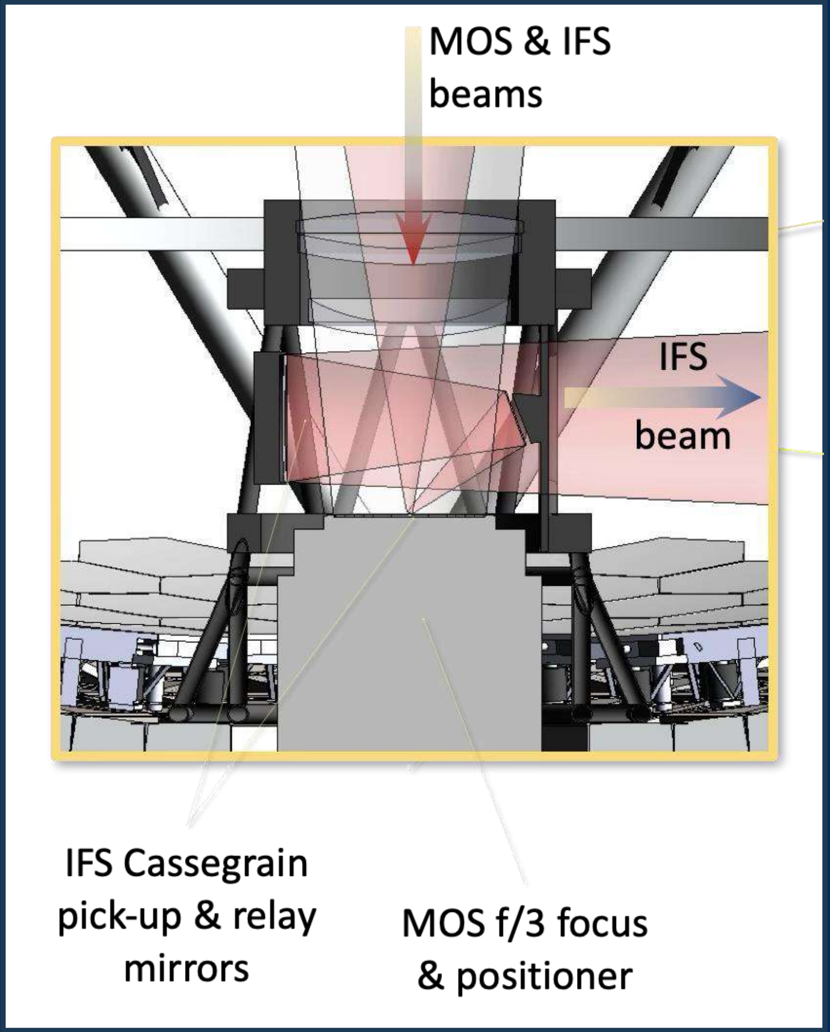


MOS & IFS
beams
Field corrector
& ADC
IFS
beam
IFS Cassegrain
pick-up & relay
mirrors
MOS f/3 focus
& positioner
MOS instruments
Nasmyth IFS relay
IFS coudé beam &
optical de-rotator
IFS f/35 focus
IFS Station
(144 spectrographs)
Ø12.4
Primary mirror
78 segments, 99 m²

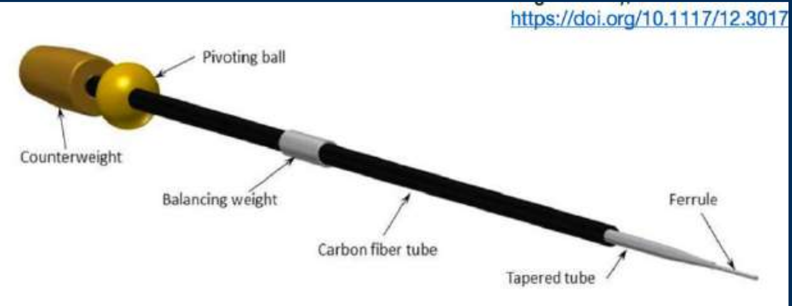
Innovation - Telescope



Facility	Etendue AΩ ($m^2.deg^2$)
WST/MOS	351
Rubin/LSST	319
Subaru/HSC	50
ELT/MOSAI C	13
VLT/MOONS	7

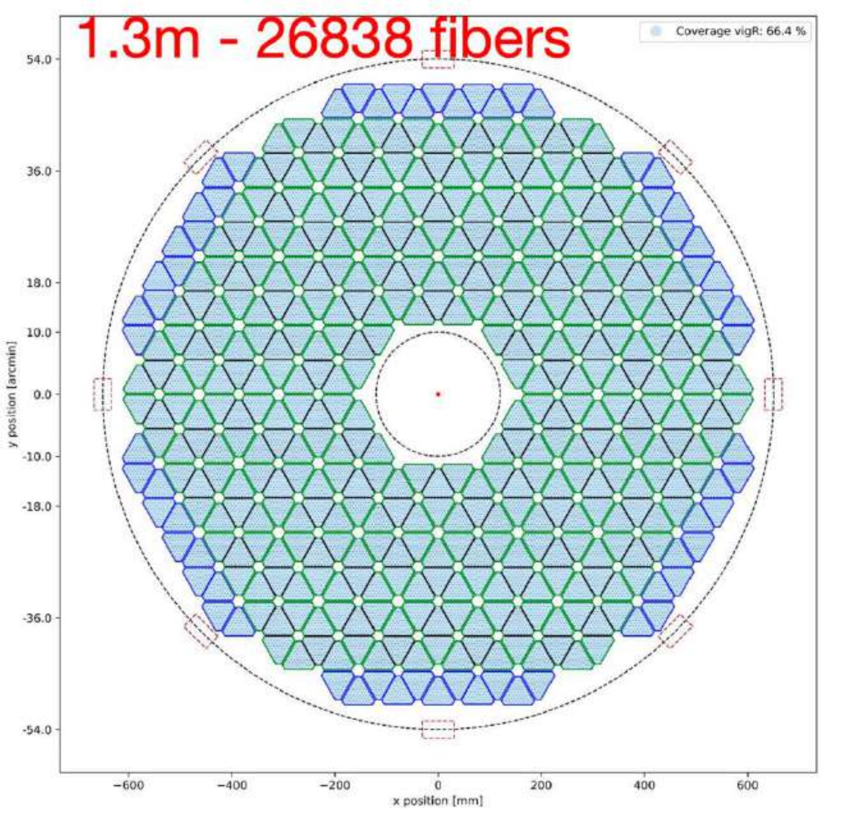


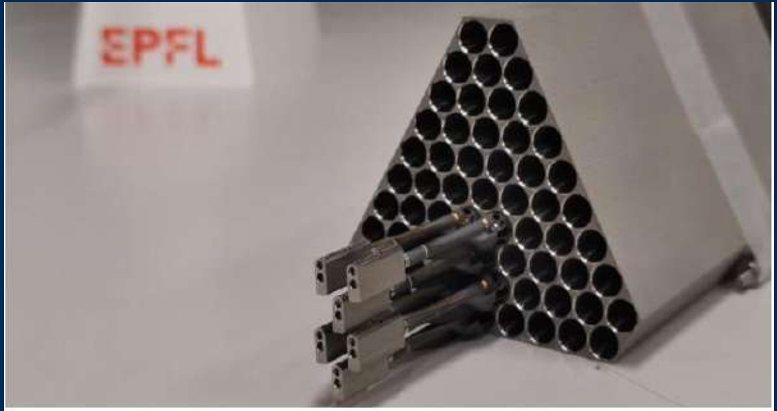
Innovation – MOS positioners



Tilting spines (Echidna, 4MOST)

FLEX design (AIP)



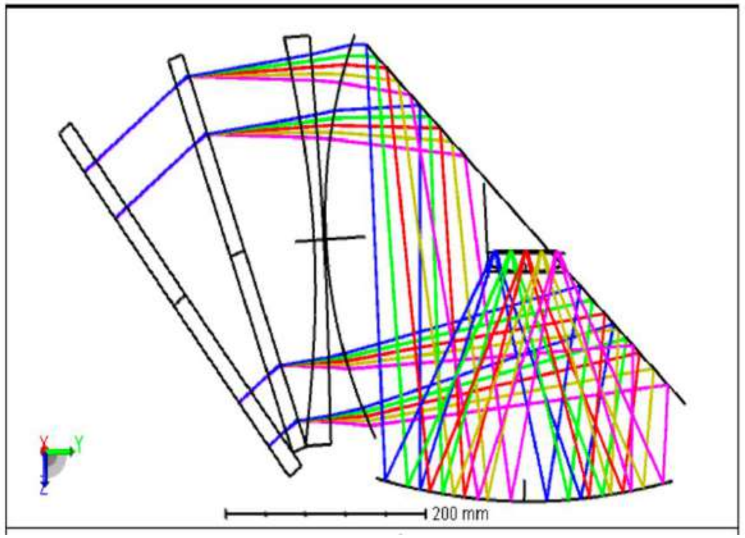


Theta-Phi positioners modules (EPFL)

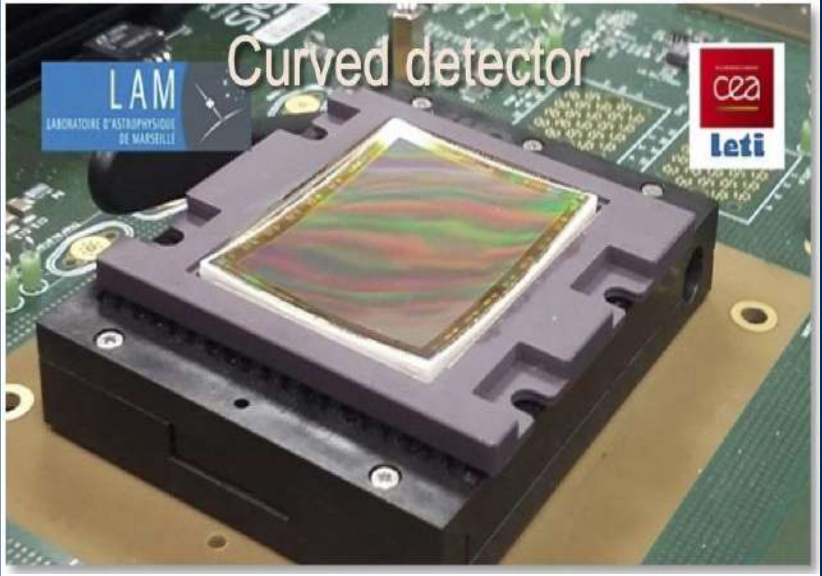
R-theta flexible positioner (UKATC)

Innovation - Spectrographs

- IFS : ~144 spectrographs, 2 channels, ~288 x 6k detectors
- MOS-LR: ~60 spectrographs, 3 channels, ~180 x 6k detectors
- MOS-HR: ~3 spectrographs, 3 channels, ~9 x 9k detectors

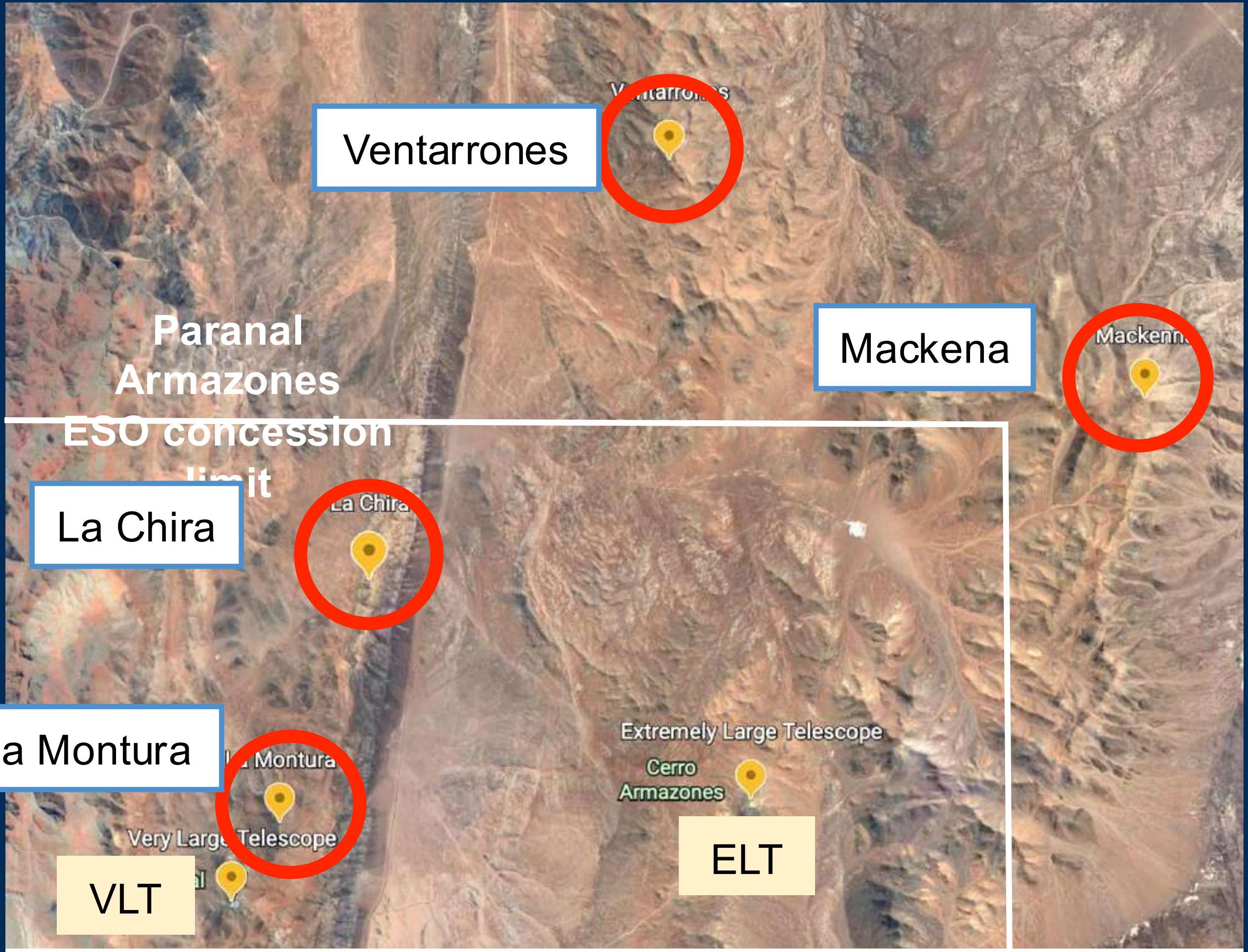


Folded solid schmidt spectrograph design f/0.75 (Sauders W)



Curved CMOS (LAM)

Potential sites in ESO areas



Potential sites in and around Paranal-Armazones ESO area
Angel Otarola (ESO)

Paranal solar plant - 9 MW (Filippi et al, 2022)

1700 t of CO_2 equivalent

Thank you

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Register now at wstelescope.com