Future Spectroscopic Facility

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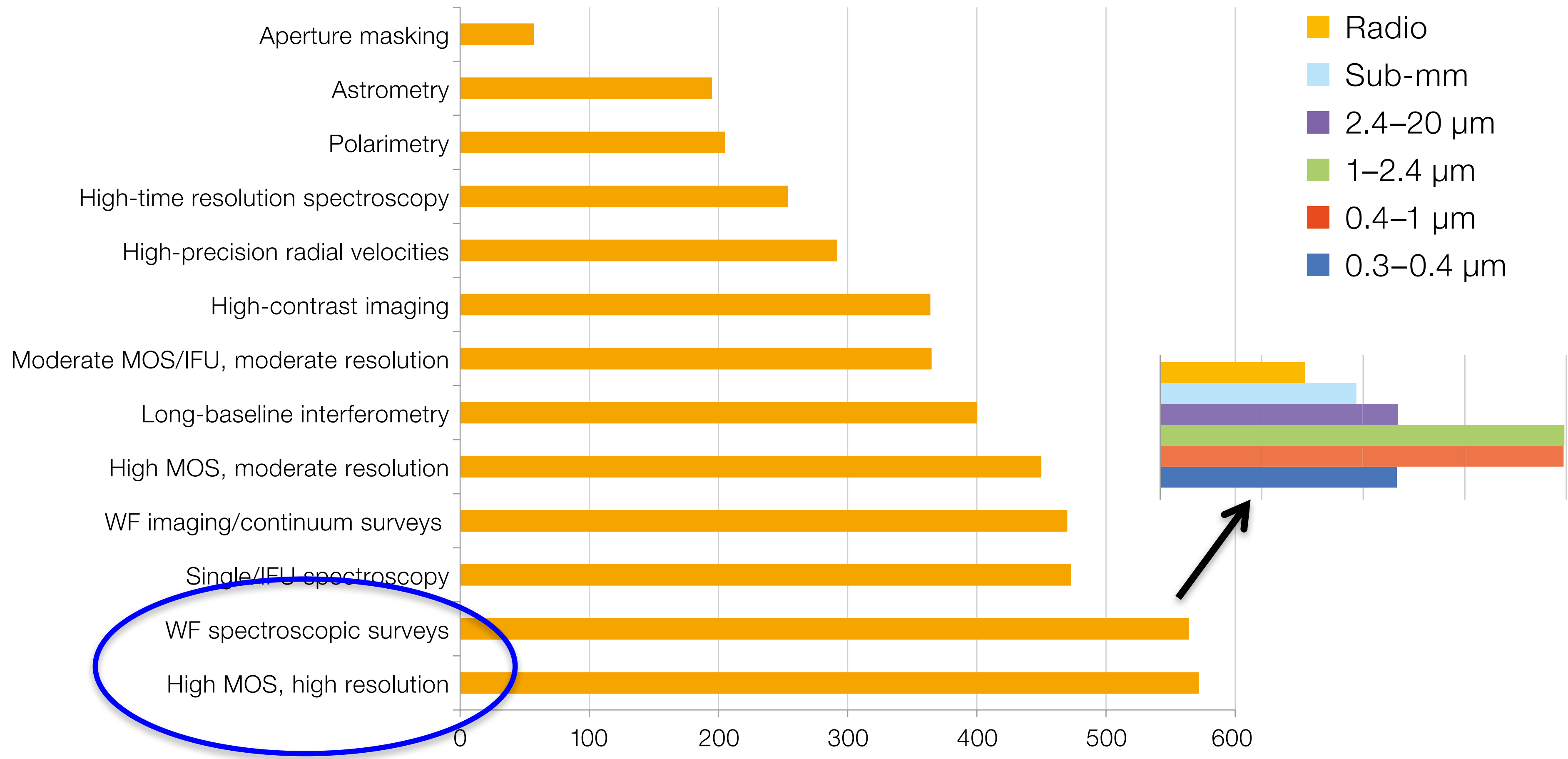
What

- A Study Concept – Not a Project
- Facility (Telescope & Instruments):
  - Telescope > 10M
  - Large Field of View
  - Large Multiplex
  - Dedicated
  - (In the Southern emisphere)

ESO Science Priorities - I

Q: What is most important capability for your research in 2020-2030?

1775 overall responses out of 9350 polled (20%)

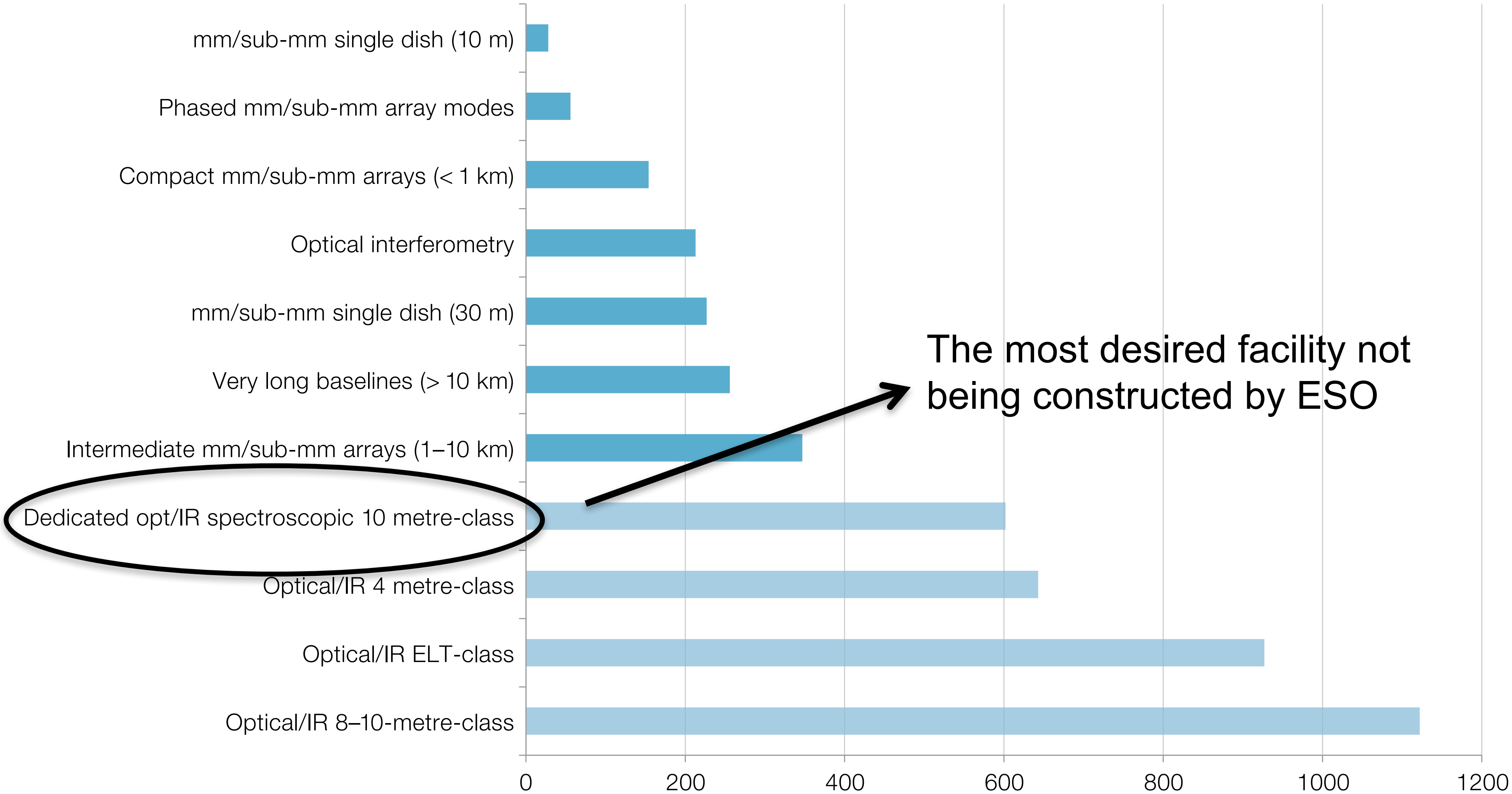


ESO Messenger #161 September 2015

ESO Science Priorities - II

Q: What facilities are most required for your research in 2020-2030?

4575 answers (avg. 3 per respondent)



A Highly Requested Facility

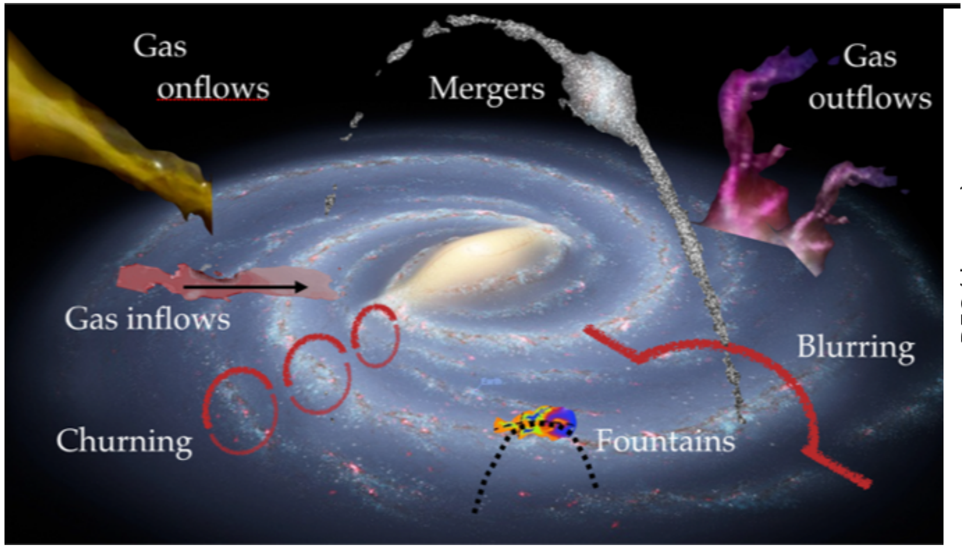
- Australian decadal plan 2016-2025
- NOAO: LSST best complement (Najita et al. 2016)
- French-Canadian MSE: Science cases & proposal
  (McConnachie et al. 2016)
- **ESO working group**… (R. Ellis, Chair , ESO)
  - Missing facility with highest demand from community survey

Ellis et al. 2017: 2017arXiv170101976E

Galactic Science

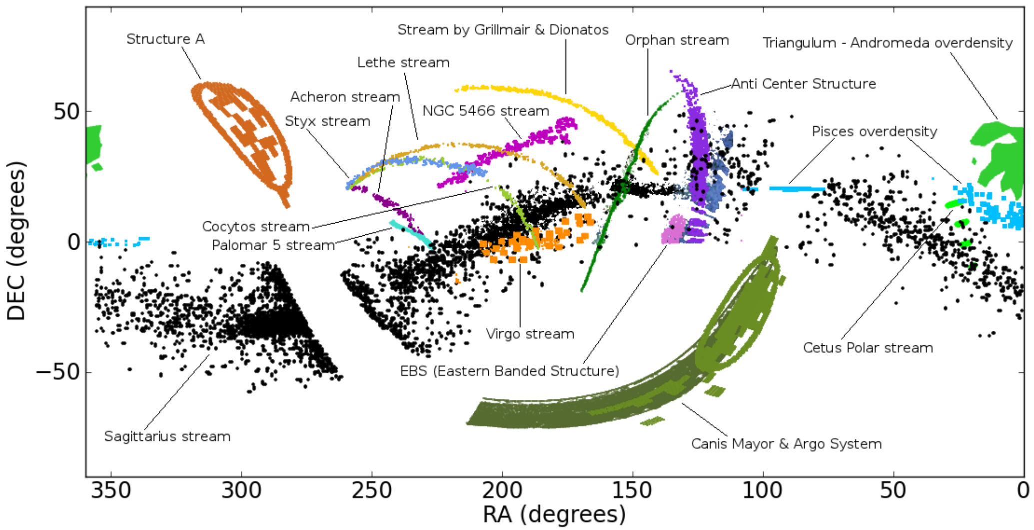
The Milky Way as a Model Organism

Stellar chemistry and kinematics as probes of physical processes for galaxy assembly



A. Recio-Blanco

Kinematics and ages of stars in Galactic streams as probe of the dark matter halo



P. Diez

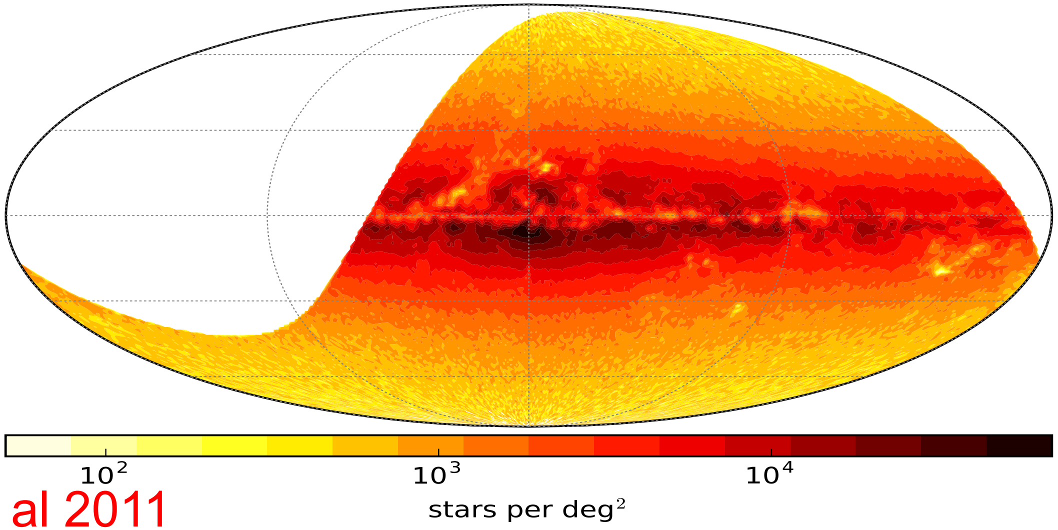
Ages, abundances & orbits of ~50-100 million stars throughout the Local Group

Four key answers

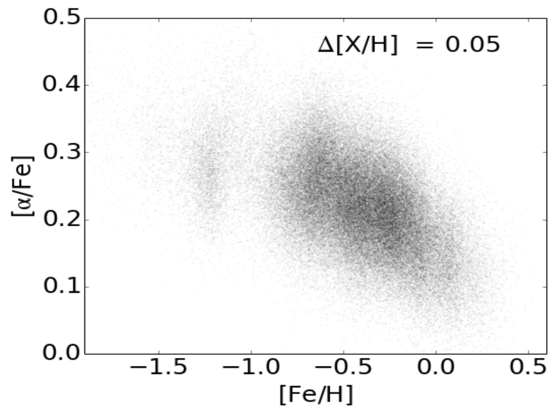
- Galactic gravitational potential and role of dark matter
  - 3D distribution of DM in Galaxy and its visible satellites
  - Evidence for low-mass dark halos (a key prediction of CDM)
- Assembly history of a prototypical large galaxy
  - Is this consistent with hierarchical cosmology?
  - `Chemical tagging' allows identification of widely-dispersed stars of common origin
- Stellar physics and origin of the chemical elements
  - Connecting nucleosynthetic yield with star formation history, gaseous inflow/outflows
  - Formation of heavy elements e.g. r-process
- Local group satellites as tests of low mass galaxy formation models
  - Connection to earliest sources in re-ionisation era

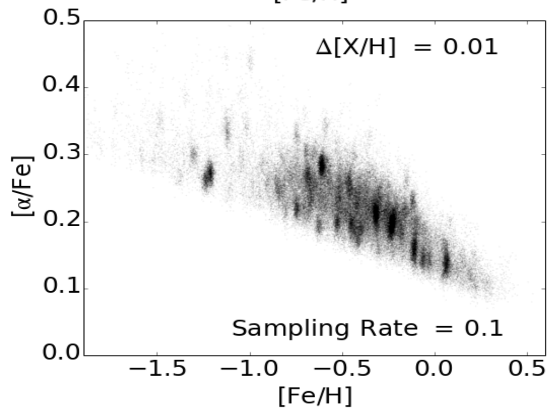
Illustrative Survey

R~20,000-40,000 spectra of 85M stars with m_V<17



Sharma et al 2011

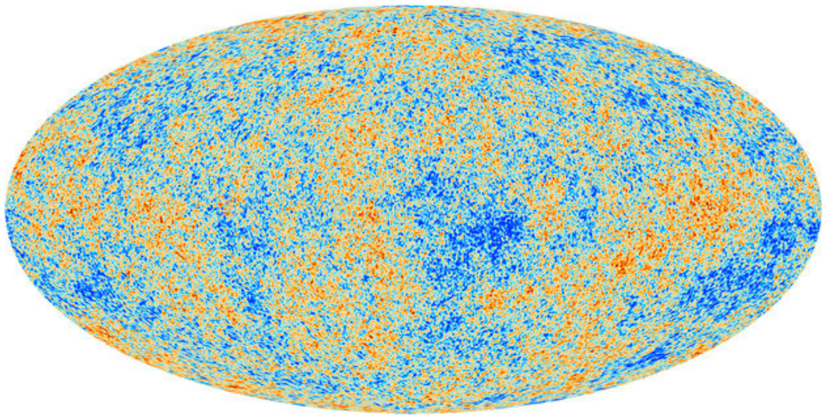




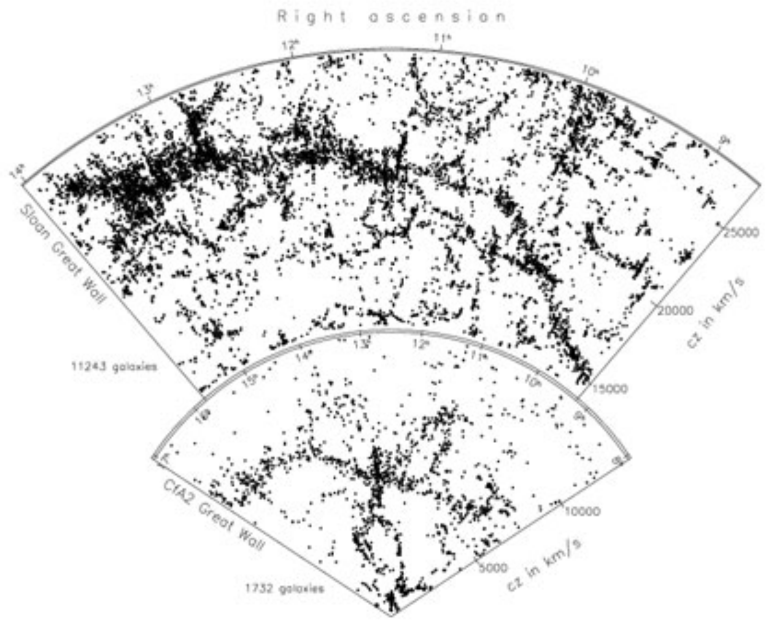
Ting et al 2016

- Stellar target densities at V~17 range from 600 to 10,000 deg^{-2} : a high multiplex requirement (N~5000)
- Kinematic data can be secured to fainter limits
- **Precise** abundances in 1-2 hours
- Such an ambitious survey would take ~5 years

Extragalactic Science



➜ ?



Planck CMB

SDSS z < 0.1

The major goal is to chart the evolving 3D structure of the cosmic web and link this to the assembly history and chemical enrichment of galaxies and their circumgalactic gas

But reaching beyond z~1 to the peak of SF activity is prohibitive with current facilities.

Illustrative Surveys

- Evolution of the Cosmic Web $1 < z < 4$
  - 6 × 1 Gpc^3 redshift bins each containing 10^6 galaxies
  - Magnitude limit ranges from i_{AB}~23.1 (z~1) to 25.8 (z~4)
  - Emission line redshifts requires 2–7 hrs
  - Lyα absorption tomography @ z~2.3-3 also requires 2-7 hrs
  - Concurrent R~1000 surveys would take 400 nights (3-5 yrs)
  - Commensurate with e.g. investment made by PFS
- Baryonic cycle via stellar/ISM studies @ z~2.5-4
  - Higher s/n~10 per Å and R~3000 for absorption lines
  - Targetting i_{AB}~24 requires 20-50 hrs
  - Diverting 5% of fibres in parallel with Cosmic Web survey yields 2 x 10^5 high quality spectra (100 × VANDELS)

LSST and Transient Science

What Response to LSST?

- LSST will transform searches for time-dependent phenomena, a major growth area in astrophysics
- Science themes include:
  - Classical SNe – astrophysics and cosmology
  - Rarer events – SNe Ib/c, SLSNe, GW events, kilonovae, gap transients, tidal disruption events…smoking guns !
  - AGN – reverberation mapping
- Distinguish between follow-up of rare *live events* and accumulated *transpired events* where host galaxy redshifts and local environment properties will be ascertained
- ~300000 SNe/Yr – 10-20 live events ~400 transpired/field...

Science Requirements (ESO WG)

- **Diameter > 10 m**
- **FOV = 5 deg^2** (~25 X VLT, or ~25 X full Moon)
- **N_{obj} = >5000 LR, ~5000 HR**
- R = 1000-3000 LR, 20-40000 HR
- Δλ = 360-1000 nm LR, 3(TBD) regions for HR
- IFU: FOV>3x3 arcmin, R~5000, Δλ =325 - 1000 Nm
- Non-science requirements (project)
  - Use same LR spectrograph for IFU and fibres
  - Use E-ELT components, located in ESO site
  - Enhancing by > 10 existing or planned facilities

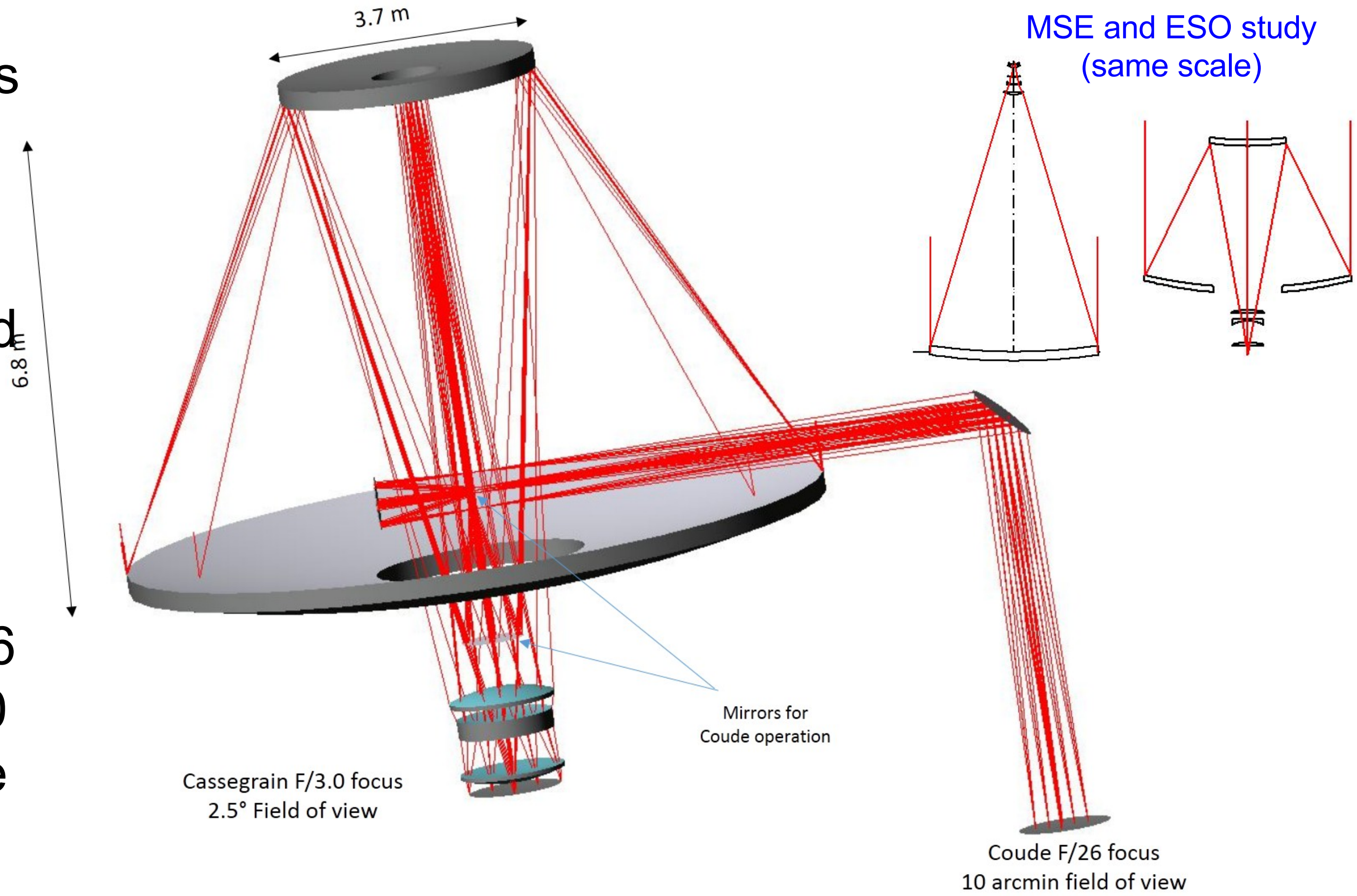
A Telescope Option

Is a 10-12m class telescope with a ~5 deg^2 FOV possible?

Cassegrain design is compact & flexible

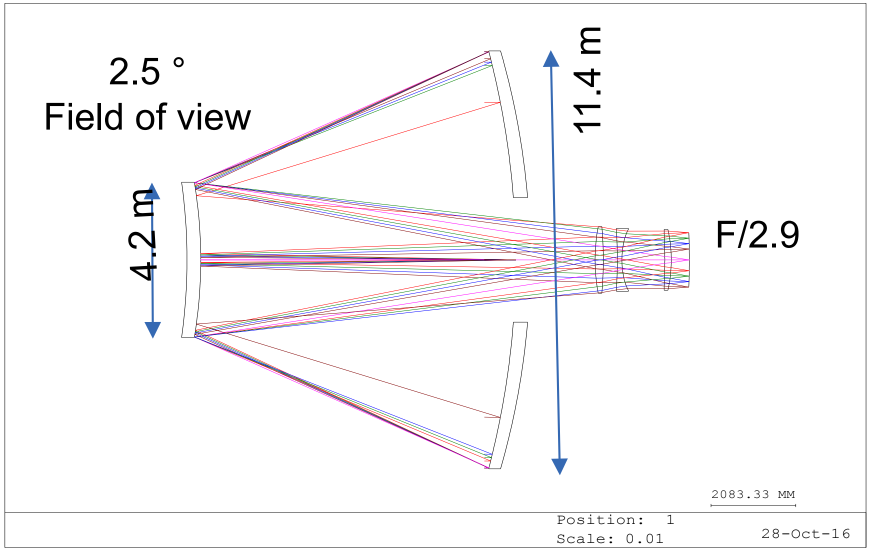
11.4m f/0.6 primary with a 5 deg^2 f/3 field ideal for fibres with good images from 360-1300nm.

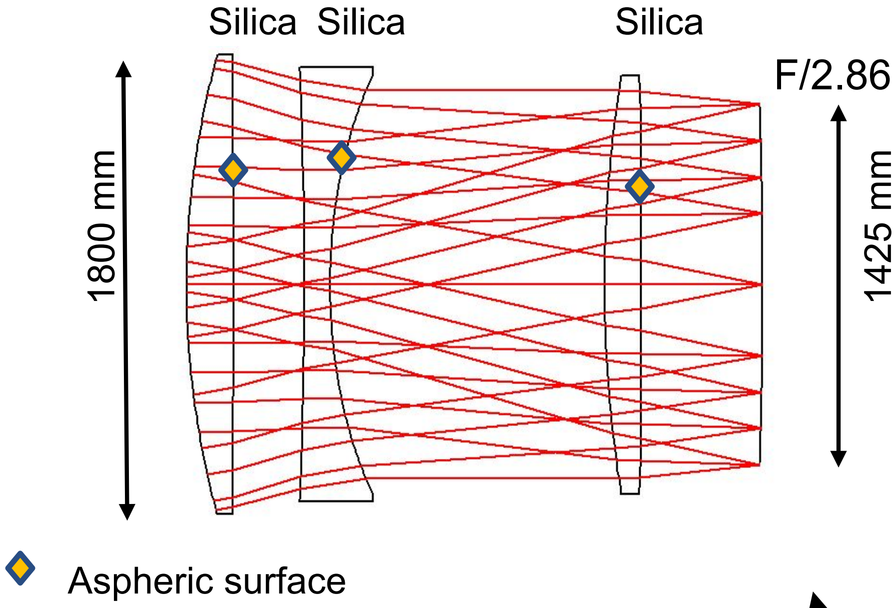
Gravity-invariant f/26 Coudé focus with 10 arcmin FOV suitable for a Super-IFU



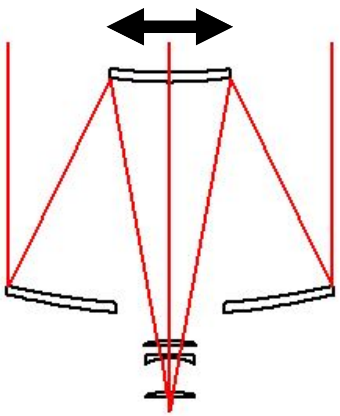
Pasquini et al SPIE 9906 arXiv 1606.06494

Corrector with Innovative ADC

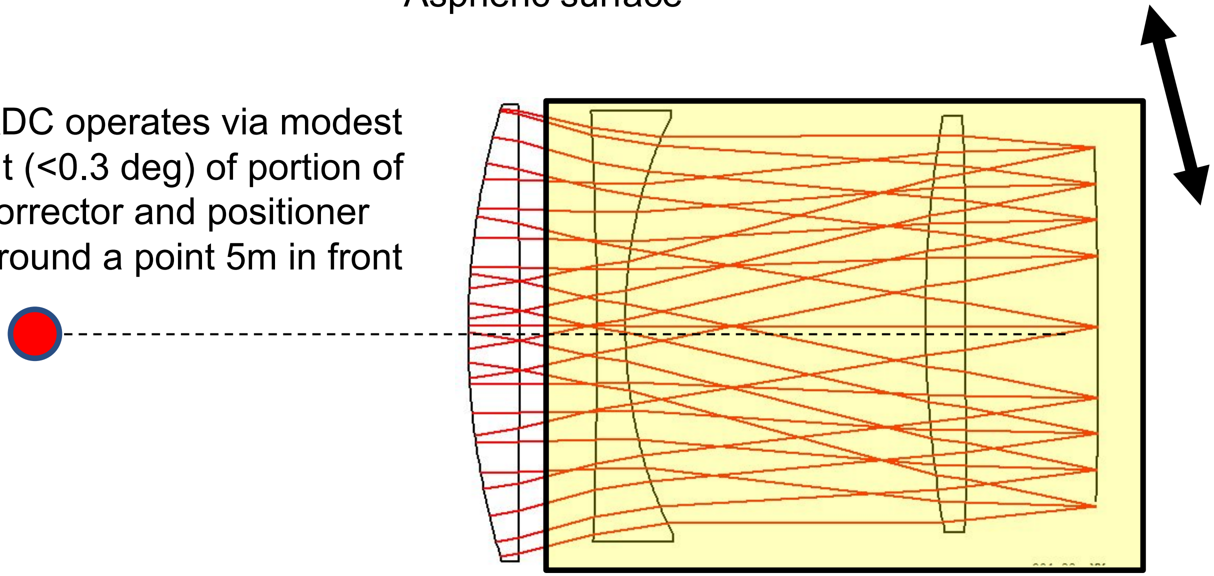




M2 translation to compensate coma



ADC operates via modest tilt (<0.3 deg) of portion of corrector and positioner around a point 5m in front

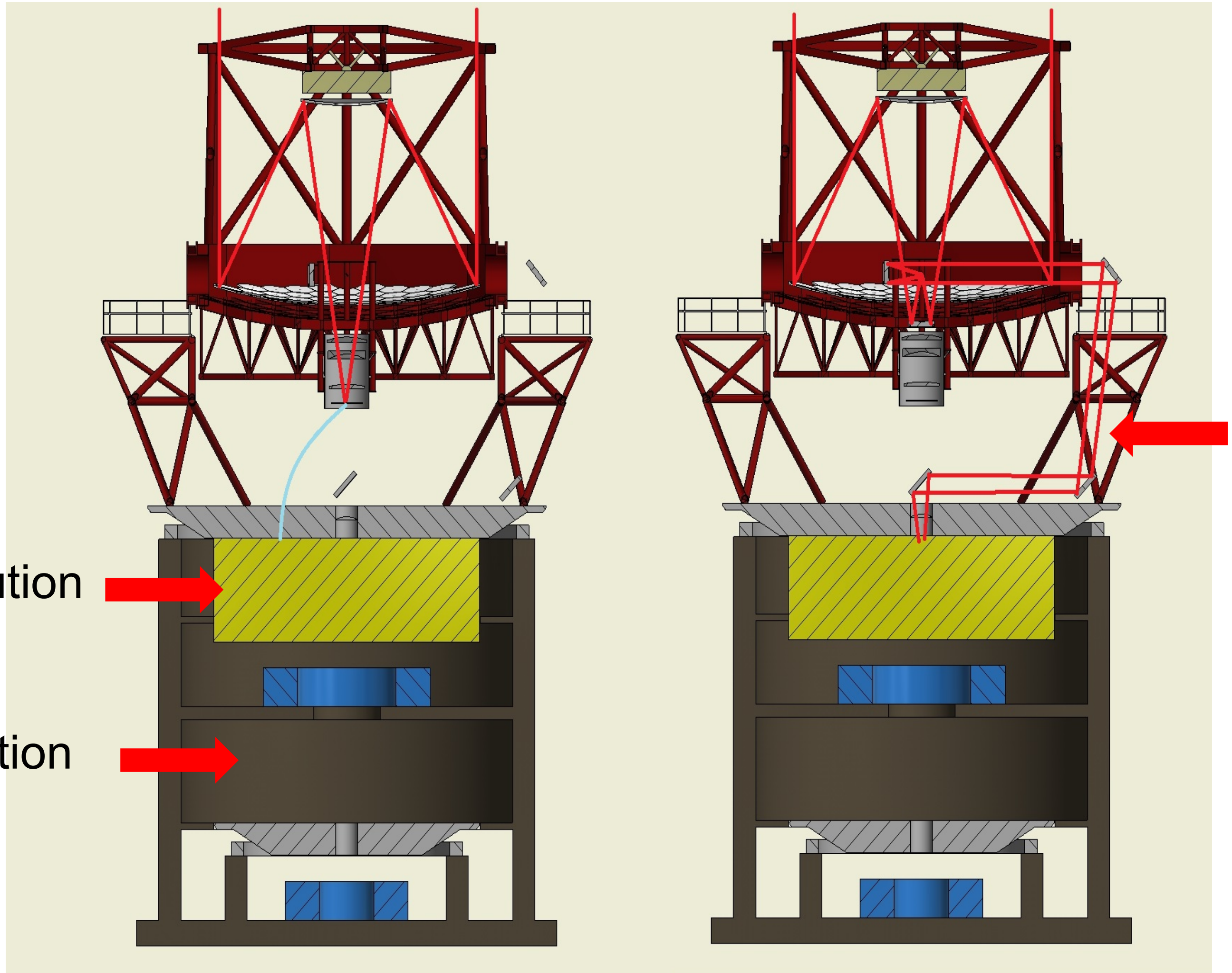


Concept Telescope

Can accommodate all spectrographs and Coudé focus in a compact enclosure

High Resolution

Low Resolution



Coudé train
10 arcmin FOV
(Super-MUSE)

Concept Fibre Positioner

- Positioner for DESI: 10.4 mm pitch ➔ >**14500 objects** (5000 for DESI to be produced by 2017)
- MOONS-type positioner allows **each point** to be reached by 3 buttons ➔ can be reached by 2 L-Res and 1 H-Res if 10K L-Res and 5K H-Res (2:1)

From Kneib 2017: size refers to Motor sizes, pitch is larger

A Ω product (m^2 deg^2)

	Telescope Diameter	Central Obstr.	Aperture²	Ω (deg^2)	Product
ESO VLT (VIMOS)	8.0	0.97	48.75	0.043	2.08
ESO VLT (FLAMES)	8.0	0.97	48.75	0.136	6.63
ESO VISTA (4MOST)	3.7	0.89	9.57	4.00	38.3
ESO VLT (MOONS)	8.0	0.97	48.75	0.136	6.63
WEAVE	4.2	0.88	12.2	3.14	38.3
SUBARU (PFS)	8.0	0.97	48.75	1.33	64.7
MAYALL (DESI)	3.8	0.85		8.00	77

	Telescope Diameter	Central Obstr.	Aperture²	Ω (deg^2)	Product
LSST (imaging only)	8.2	0.63	33.27	9.62	320
MSE	11.2	0.97	96.0	1.50	144
ESO CONCEPT STUDY	11.2	0.86	84.6	4.91	**415**

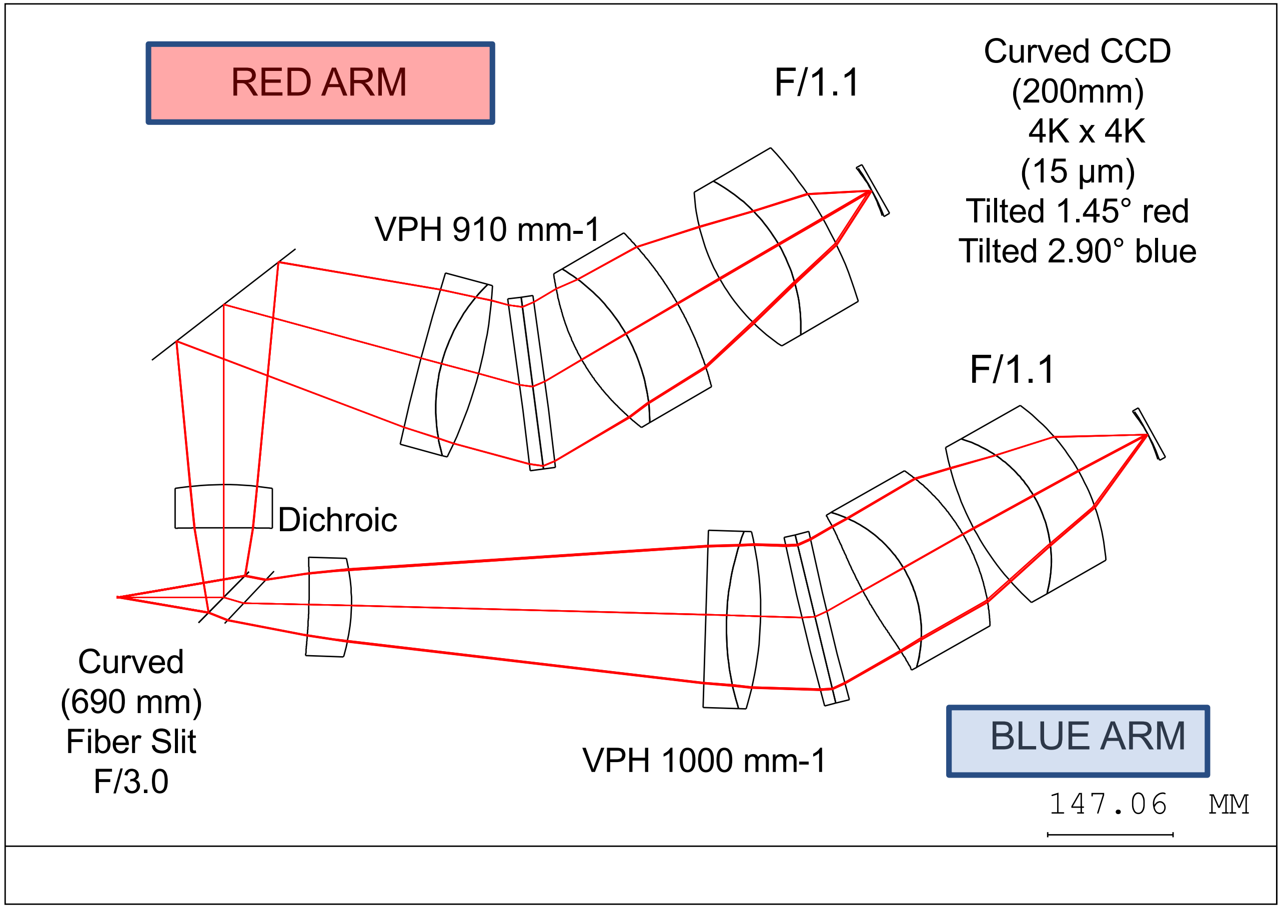
Spectroscopic Surveys Power

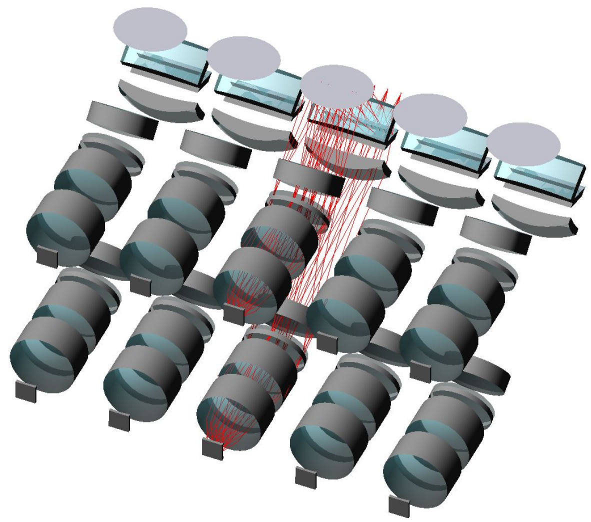
Telescope	Area (m^2)	Ω (deg^2)	N_{obj}	$A x \Omega x N_{obj}$
AAT/2df	11.95	3.14	392	14700
WHT/Weave	12.2	3.14	1000	38300
VISTA/4MOST	9.6	4.00	2400	92160
Mayall/DESI	12.	8.0	5000	480000
VLT/MOONS	48.8	0.14	1000	6832
Subaru/PFS	48.8	1.3	2400	152256
CFHT/MSE	96	1.5	4200	604800
SpecTel	85	4.9	**15000**	**6247500**

Enhancing by a factor 10 the presently planned facilities
+Fully dedicated!

Concept Low-Res Spectrographs

Two-arm spectrograph design accommodating 650 fibers at R~2600
f/3.0 collimator with dichroic splitting λλ380-690nm and 680-1000nm
f/1.1 camera feeding curved 4K CCDs





Module of 5 such spectrographs would accommodate 3250 fibres

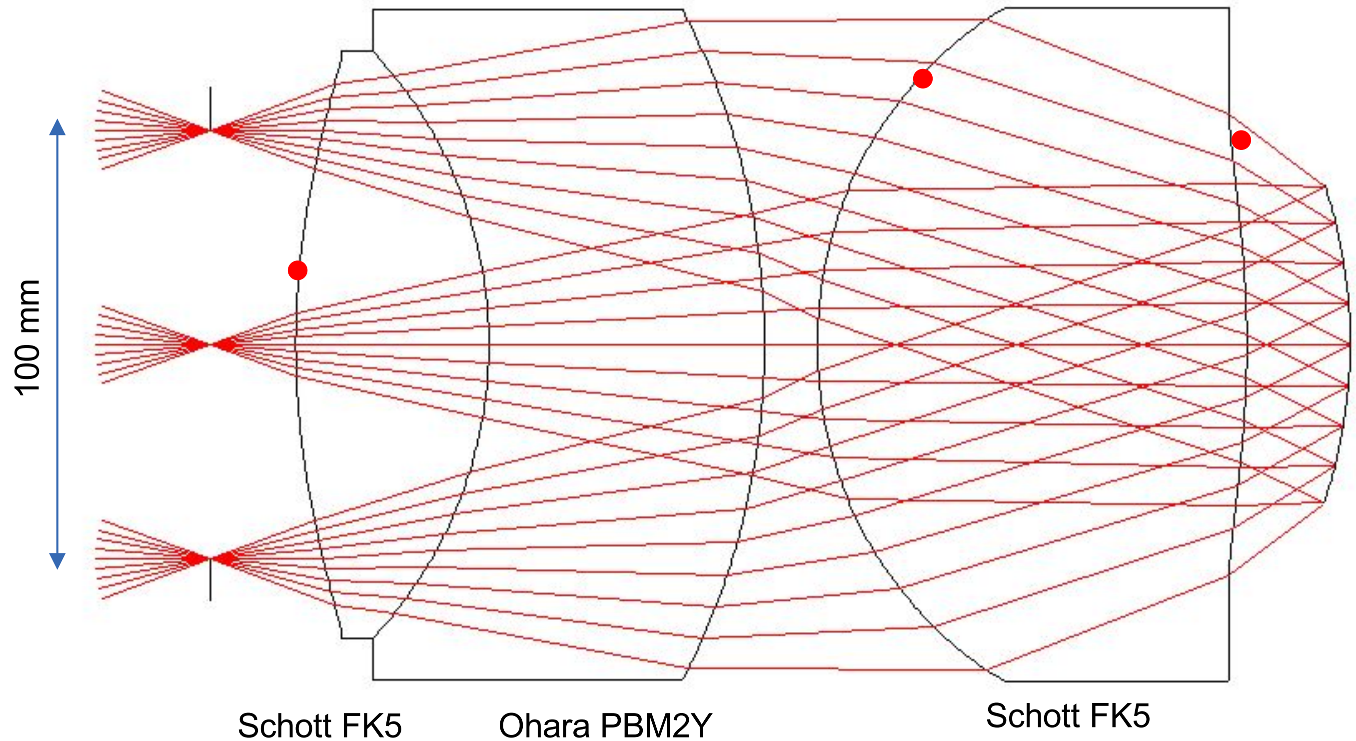
Fast Cameras,Curved Detectors

Scale : 0.3 arc sec / pixels on 11.4 m telescope ~65 MUSE spectrographs for 3X3 arcmin

FAST CAMERAS are a MUST

- For matching pixel
- To reduce number of spectrographs

F/N	1.1
Focal Length	110 mm
Pupil	100 mm
Field of view (ϕ)	76 mm
Wavelengths	450 - 900



40°Field of view

Concept High Res. Spectrograph

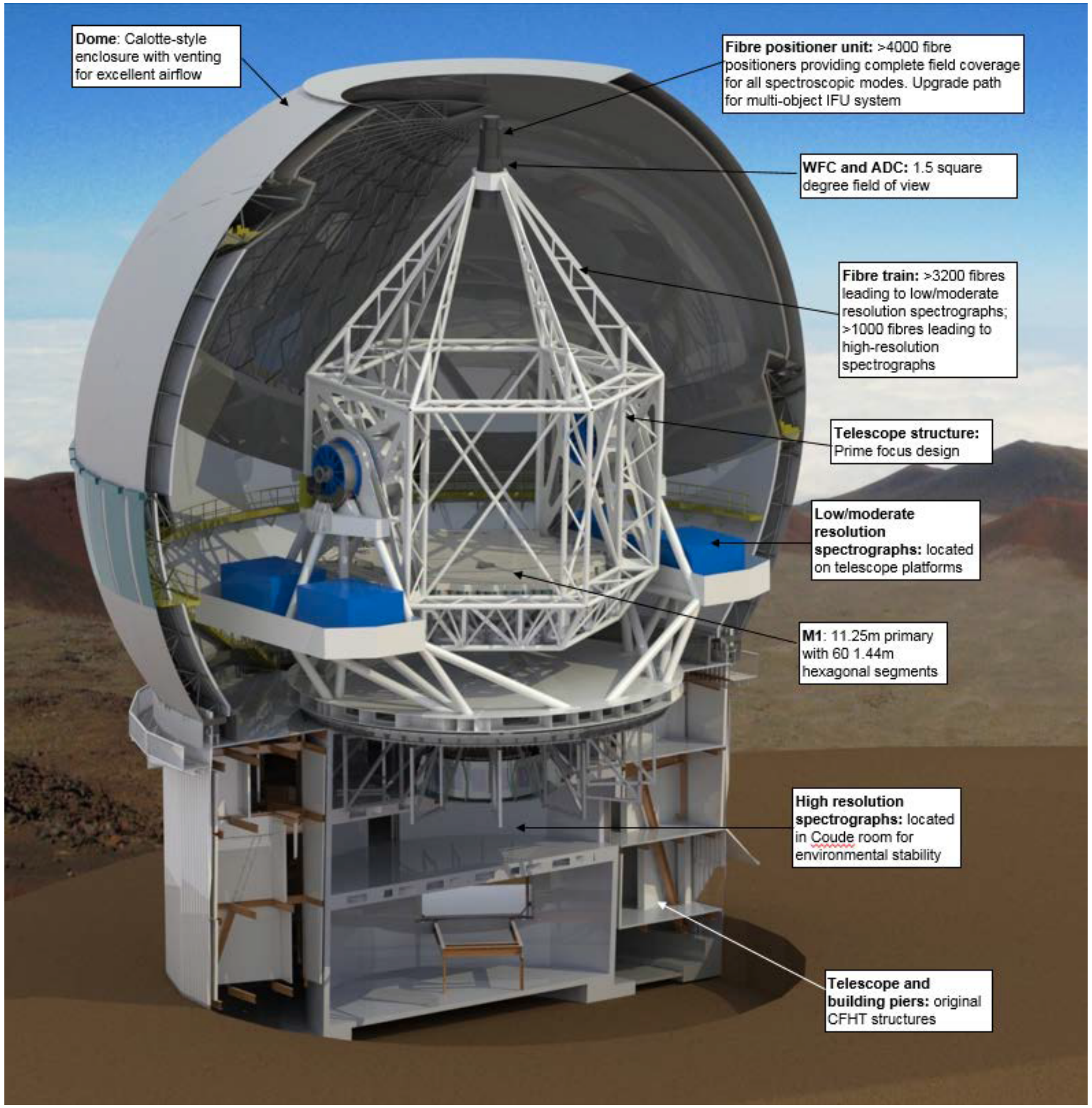
- ~3-5000 Objects at R>20000 for a 11.4m and 3 spectral ranges (Blue-NIR)
  - Very challenging
  - Trade-off between $N_{spectro}$ and Pupil size to be done..
  - Size, production, costs to be studied
  - Careful analysis of the Requirements (second step in science cases) required

Gratings and trade offs..

- Low-Res Spectrographs: (20 cm size)
  - ~20 (65 for IFU) 1000 l/mm , θ=15.5 deg, λ_c = 535 nm
  - ~20 (65 for IFU) 910 l/mm , θ=22.2 deg, λ_c = 810 nm
- High-Res Spectrographs: 2000, 2400, 3300 l/mm, (3 ranges, Hα to Ca II K), θ=44.1 deg
  - Three slices ($N_{spectro}$~18): 54 (18 each), 19*26 cm
  - Two slices ($N_{spectro}$~12): 36 (12 each), 28*39 cm
  - No slices ($N_{spectro}$~5):   15 (5 each), 56*77 cm

Maua Kea Spectroscopic Telescope (MSE)

- Project in Phase A from CHFT corporation+partners



Phase A Review end 2017
Phase B will follow
Construction starting on ~2022
(deconstruction 3.6m CHFT)

Courtesy of K. Szeto, MSE

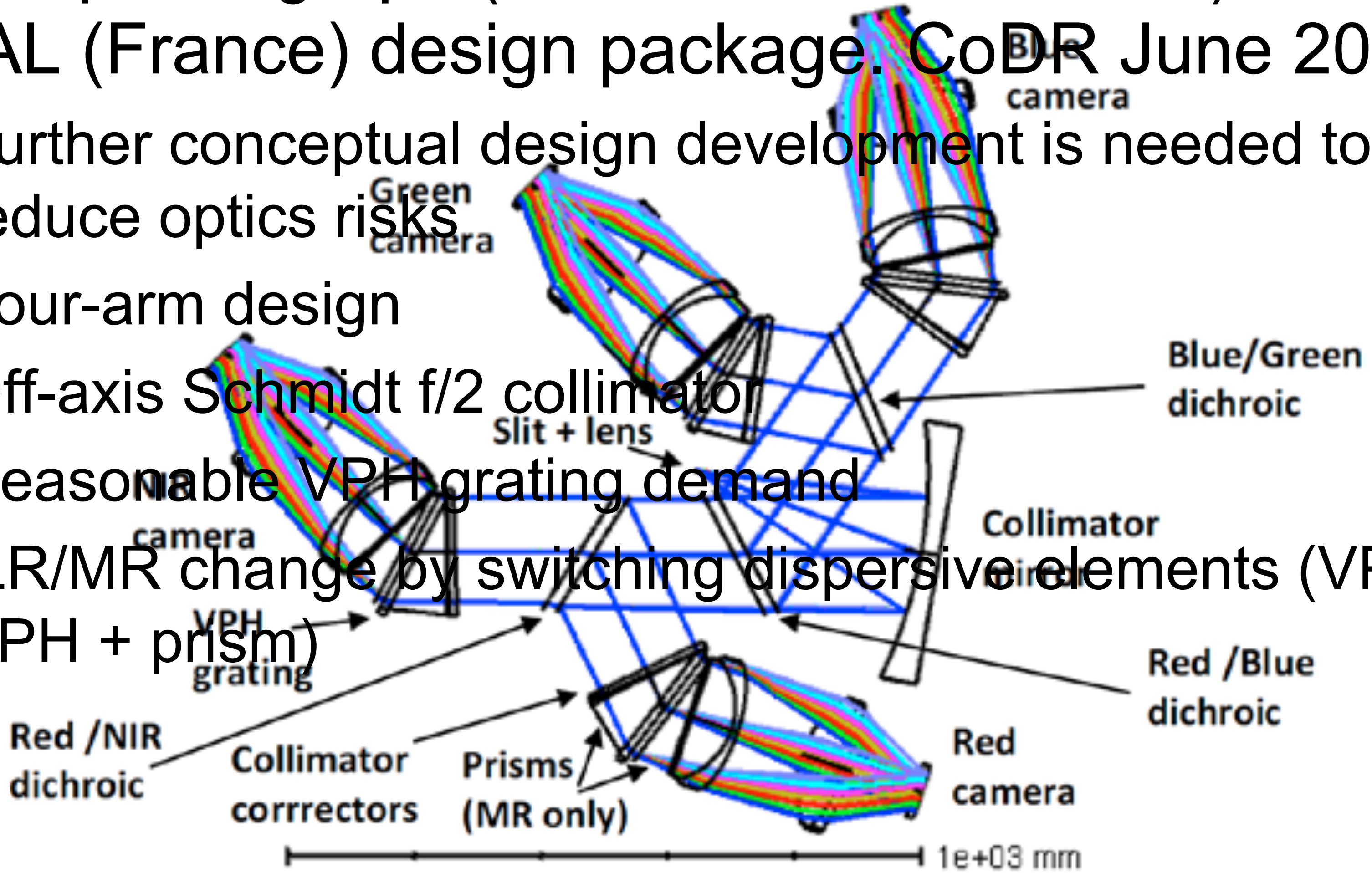
MSE Requirements

Top level baseline requirements

Primary Mirror Aperture	11.25 m, 60 x 1.44 m segments
Effective Diameter	10 m, based on collecting area
Field of View (FOV)	1.5 deg^2 (hexagonal)
Wavelength Range	0.36 to 1.8 um
Number of Fibers	>3,200 (low + moderate resolution) >1000 (high resolution)
Spectral Resolution	Low - R2,500/3,000 (0.36-0.95/0.95-1.8 um) Moderate - R6,000 (0.36-0.95 um) High - R40K/20K (0.36-0.6/0.6-0.95 um)

MSE Low-res Spectrographs(*6)

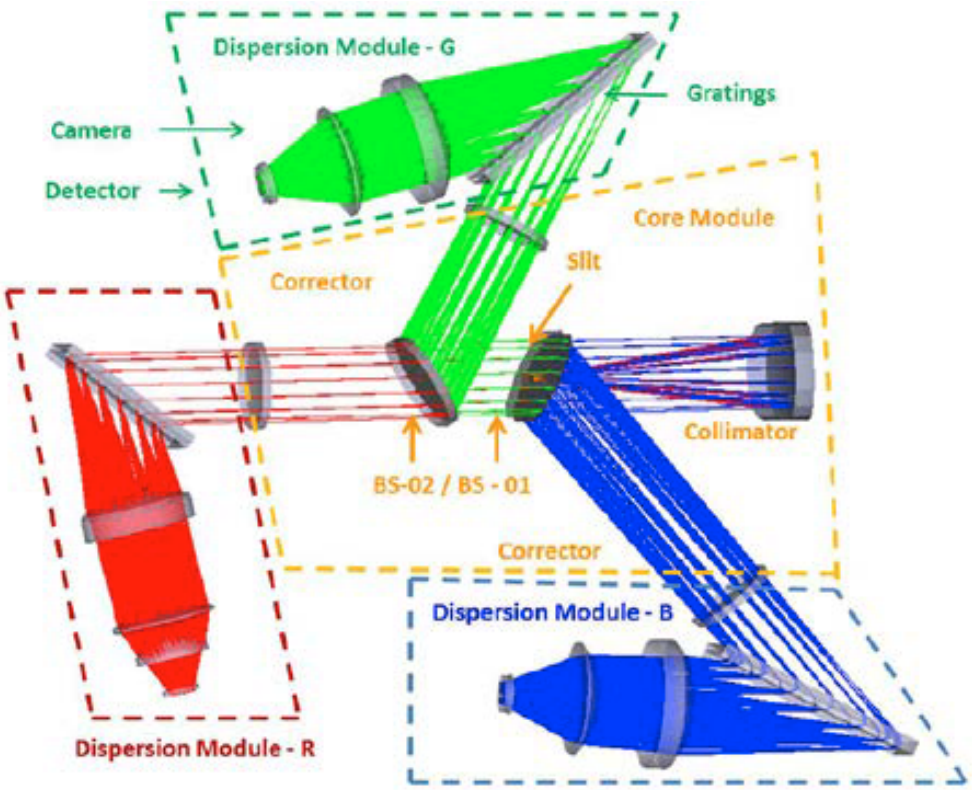
- LMR spectrograph (R=2500; 6000, ϕ1.0”*) is a CRAL (France) design package. CoDR June 2017
  - Further conceptual design development is needed to reduce optics risks
  - Four-arm design
  - Off-axis Schmidt f/2 collimator
  - Reasonable VPH grating demand
  - LR/MR change by switching dispersive elements (VPH or VPH + prism)



MSE High Res Spectrograph (*2)

- HR spectrograph (R=40K/20K, ϕ0.8”) NIAOT (China) design package. CoDR in April, 2017
  - ➢ Optically challenging requires large mosaic VPH gratings

Review recommended to pursue alternate optical designs for the collimator and dispersion elements to reduce risks.



Summary

- Should this be the next Facility? **YES**
  - Scientifically unique & transformational
  - Technically feasible
  - Tremendous Synergies with other facilities, especially ELT, LSST
  - Huge legacy, versatile..
- International Collaboration
- One million spectra/week !