WEAVE –the next generation wide field spectroscopy facility for the WHT

Gavin Dalton & the WEAVE Team

RAL Space

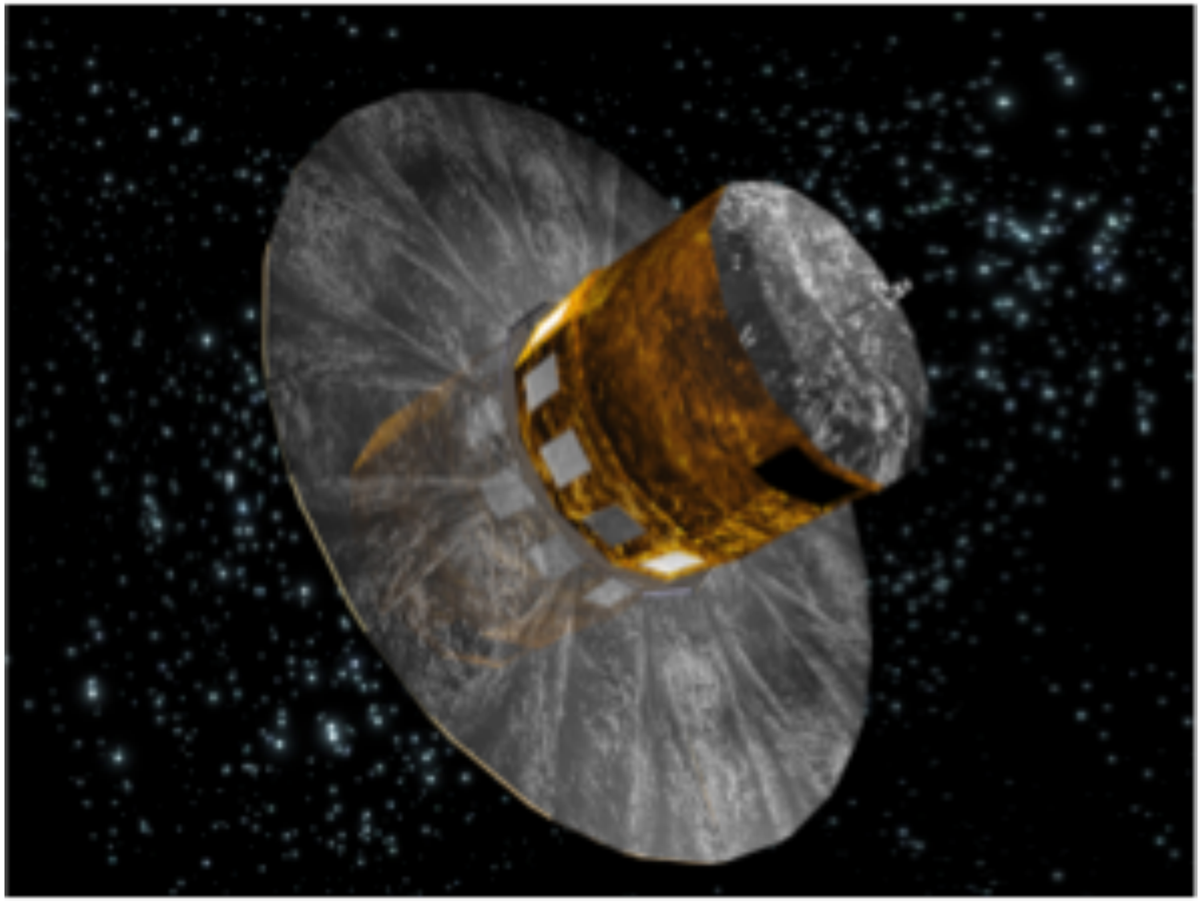
Overview

- Primary Motivation: Galactic science
- Derived specifications
- Overview of instrument design
- Opportunities for IFU science
- IFU key science goals
- IFU specfications
- WEAVE summary

Galactic archaeology surveys: exploiting Gaia's full potential

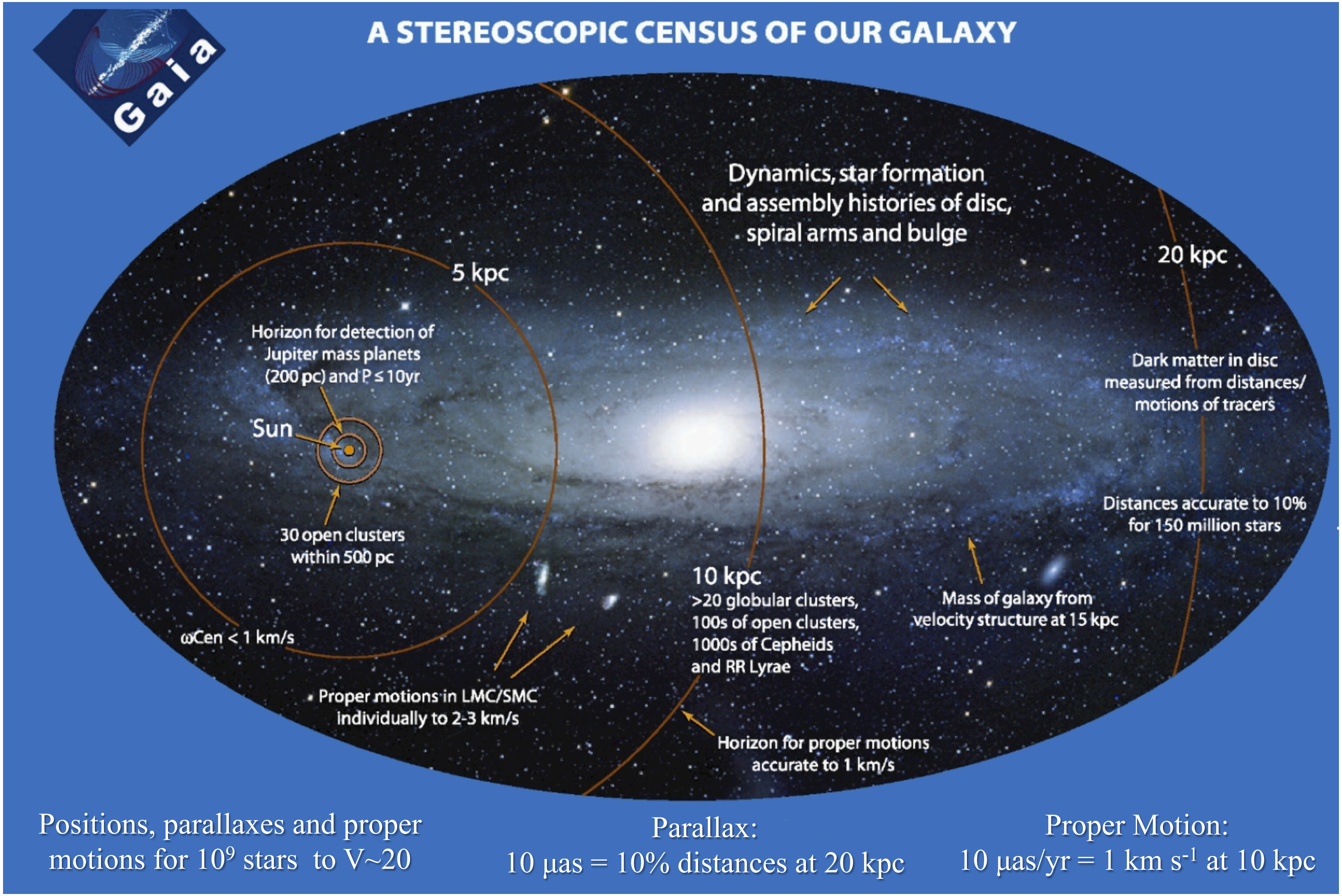
- Gaia: Astrometry at micro-arcsecond precision
  - The history of the Milky Way

Launches November 2013
5 year survey from L2…



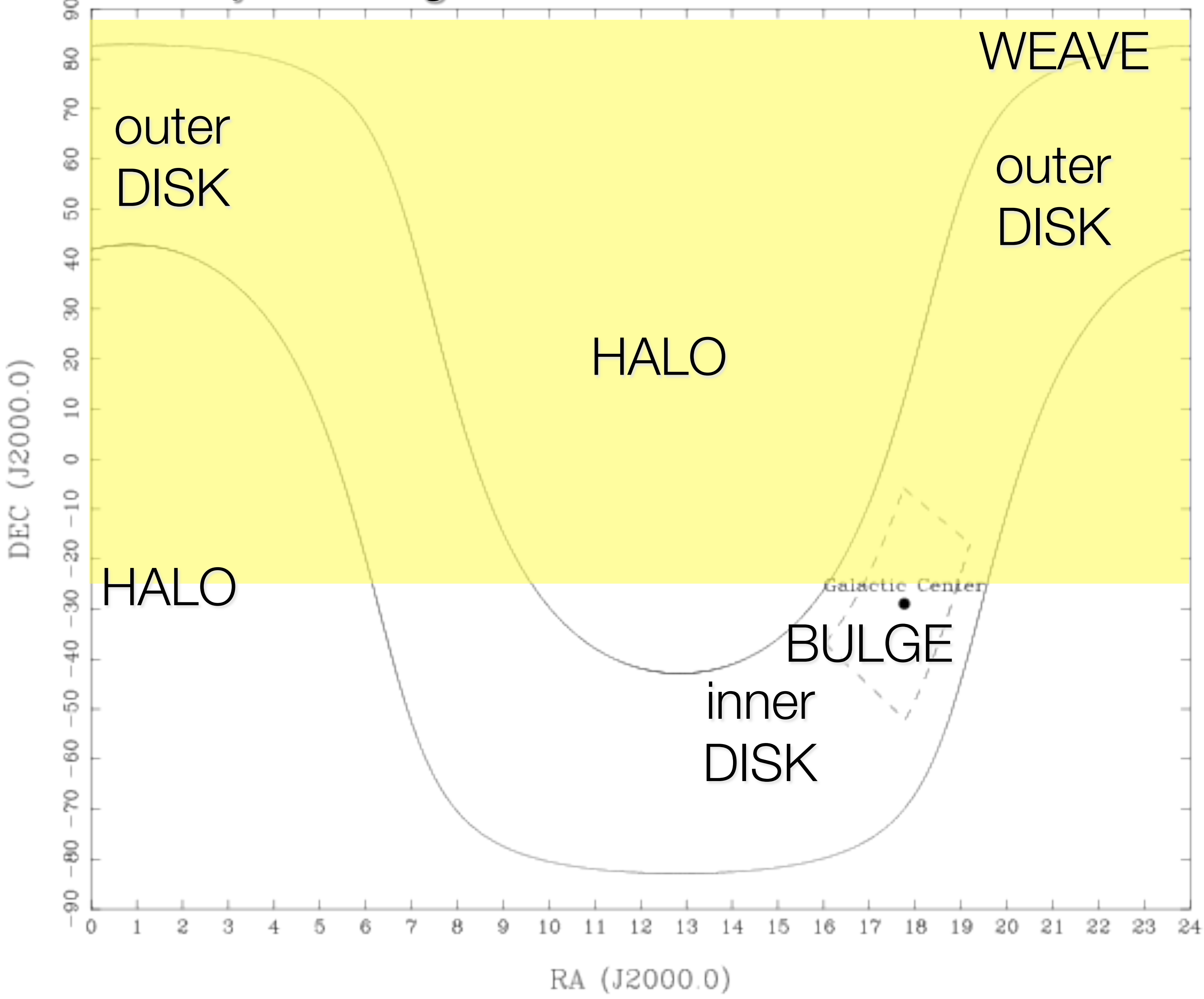
Galactic archaeology

- The Galactic halo
- Dynamics of the Galactic disks
- Chemical labeling
- Open clusters



Gaia RVS: no radial velocities for V>17; No abundance

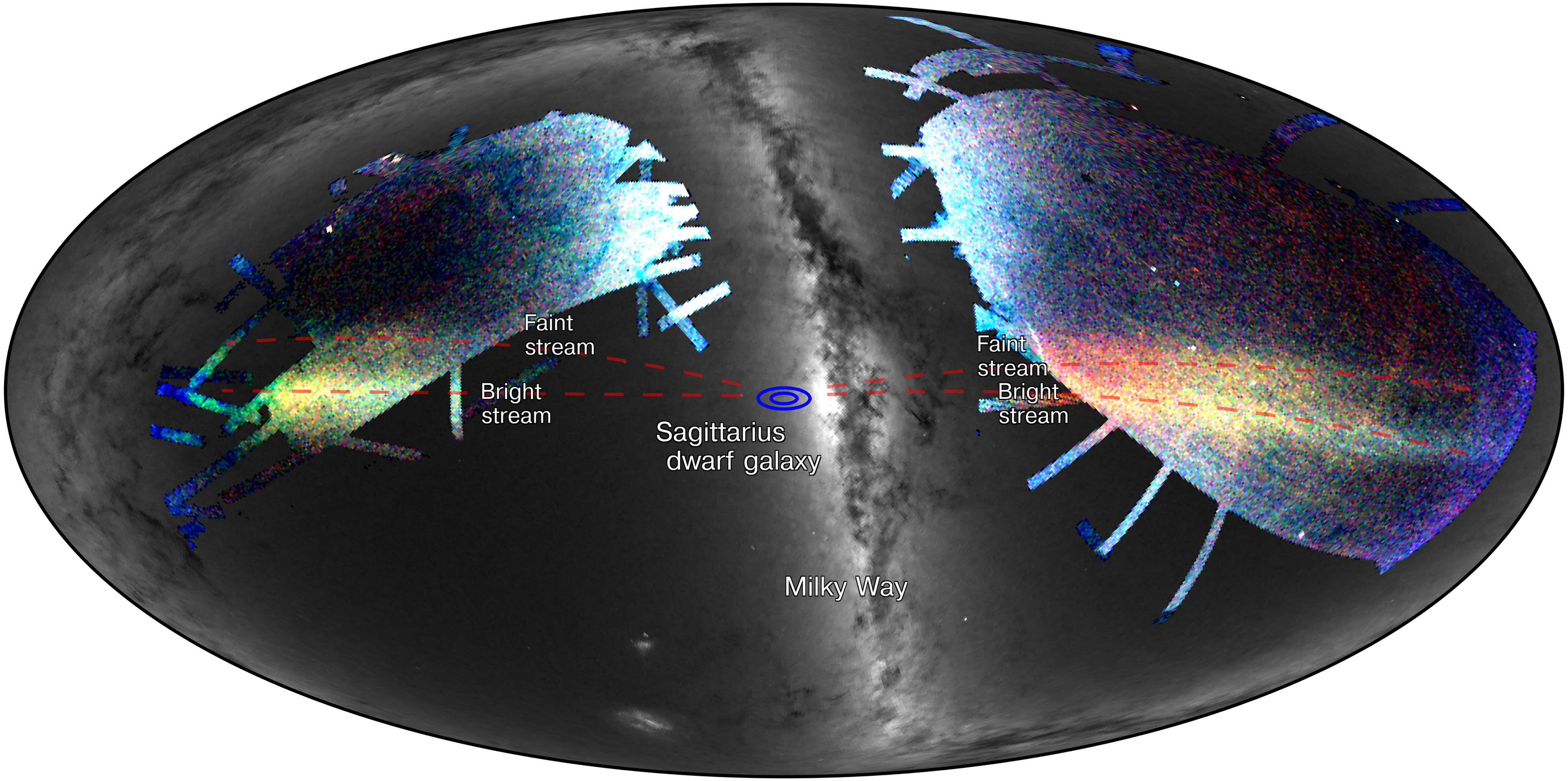
WEAVE sky coverage



Galactic archaeology: *How did our Galaxy form?*

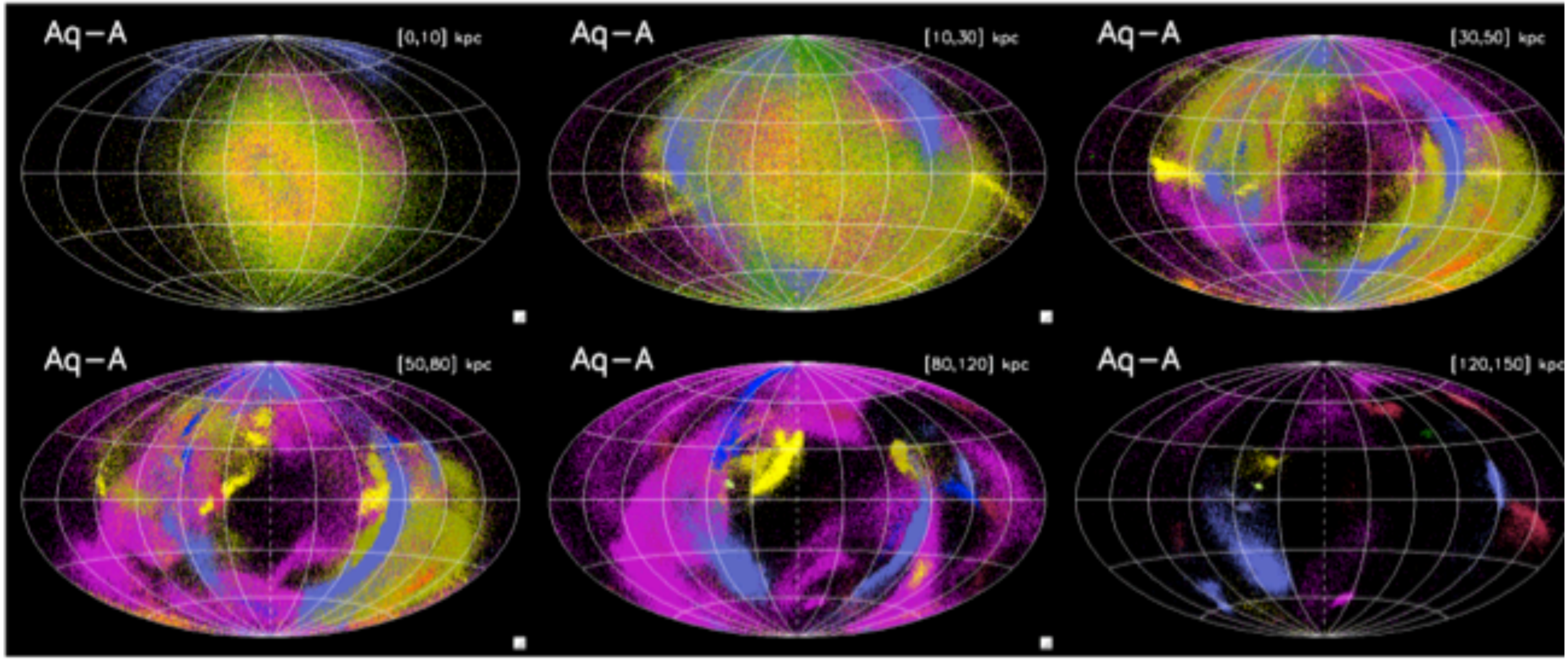
- ✧ The Galactic halo:
  - ✧ how was it formed? accreted or in-situ?
    - ⟹ V_r, [Fe/H], [α/Fe] to 10kpc
  - ✧ what is the total mass of the Milky Way?
    - ⟹ BHB/RGB stars beyond 80kpc
  - ✧ what is the shape of the Milky Way's gravitational potential?
    - ⟹ Stellar streams (50—100kpc)
  - ✧ how much substructure is there in the halo?
    - ⟹ 2 km s^{-1} velocities in streams
  - ✧ Where/what are the most metal-poor stars in the Milky Way?
    - ⟹ 10^5 candidate metal poor stars from SDSS

- The halo records the **formation history** of the MW
  - outer halo (>20 kpc): streams detected as overdensities easily in imaging surveys (long mixing timescales)
  - inner halo (10-20 kpc): merged components are well-mixed, need chemodynamics



Simulations of the Galactic halo

✧ CDM formation models predict that the halo is **highly structured** due to accretion events



Colours represent stars from different merger events…

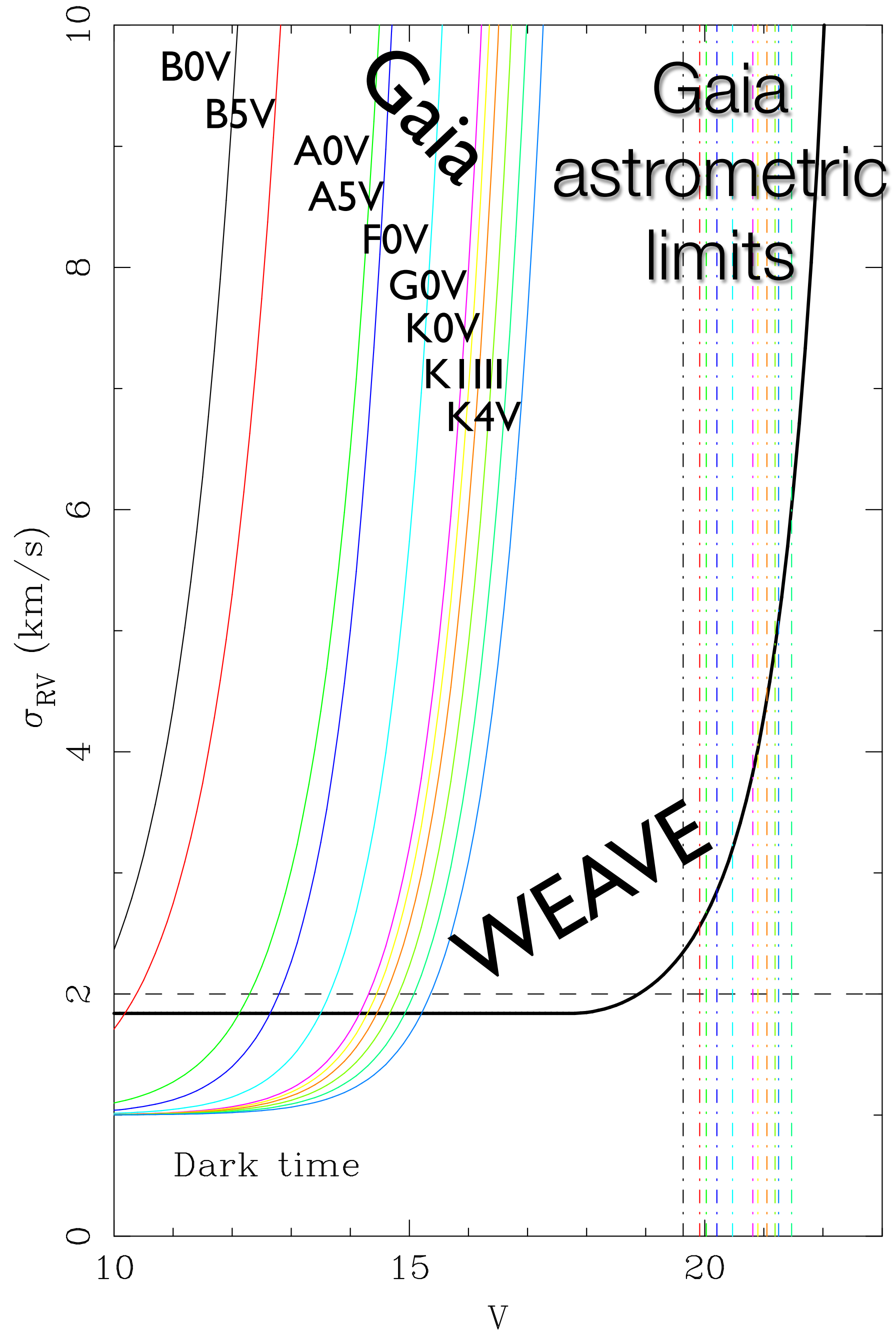
Galactic archaeology: *How did our Galaxy form?*

- ✧ The Galactic disk(s):
  - ✧ How many disks are there really? what are their relationships with the bulge, the halo, and each other
    ⟹ Full phase space information throughout the disk
  - ✧ Did they form through accretion or *in situ* processes?
    ⟹ Moving groups beyond the solar neighbourhood
  - ✧ How significant is radial migration?
    ⟹ Measure metallicity gradients in the disk

⟹ All require v_r<2 km s^{-1}, Abundances & stellar parameters

WEAVE at R=5000

- WEAVE will measure radial velocities to $\sigma(v_r)<2$ km/s at V=20 in 1hr of dark time (V=19 in bright time), *closely matching the Gaia photometric limits*
  - WEAVE will be able to determine the radial velocities of *any* of the ~10^9 Gaia stars that RVS won't!

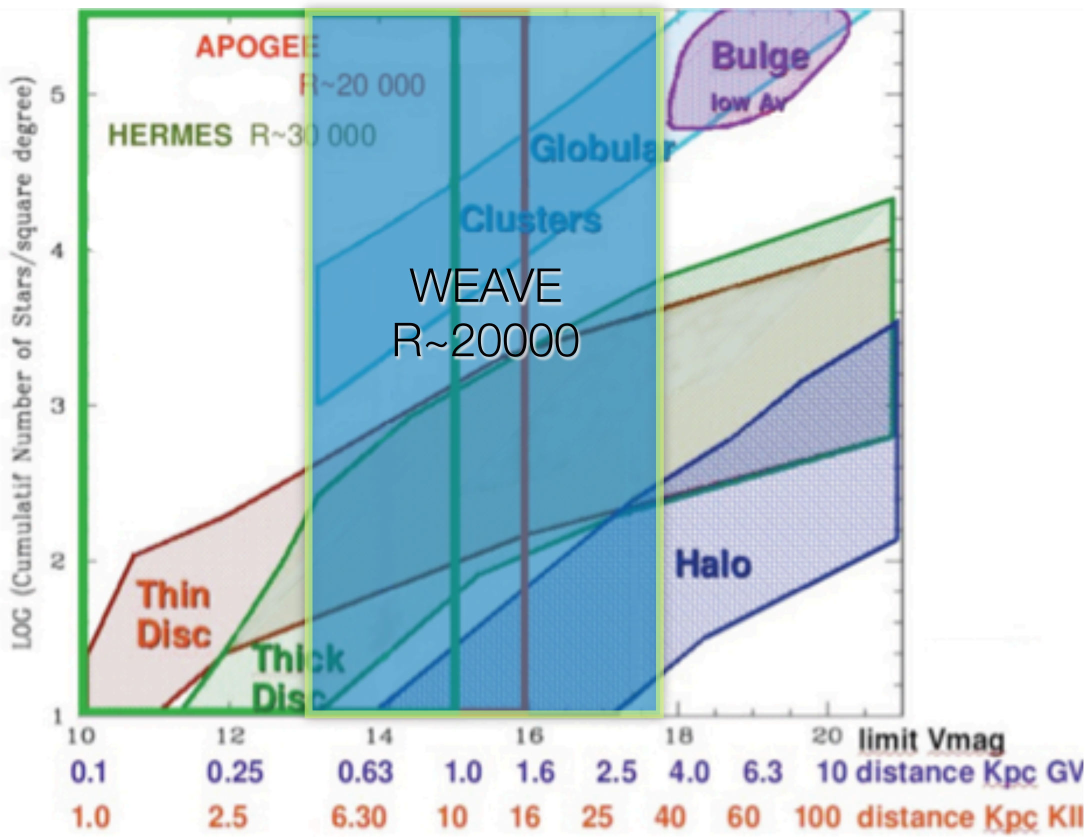


Galactic archaeology: *How did our Galaxy form?*

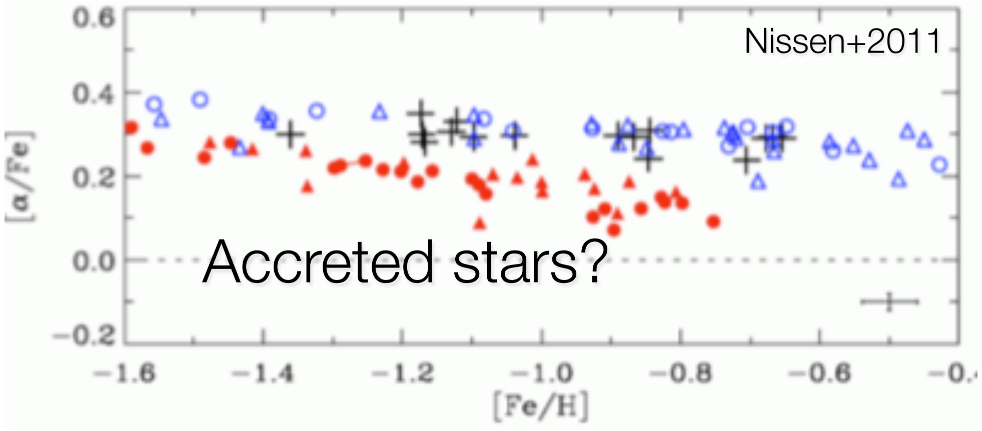
- Galactic Populations:
  - Assembly history of the disks
    ⇒ Abundances to <0.1dex to ~3kpc, chronometers [Ba/Eu]
  - Streams, groups and substructures?
    ⇒ High precision dynamics (< 1km s^{-1}) and abundances
  - Nucleosynthesis patterns in metal-poor stars
    ⇒ detailed abundance of Li, C, α -elements

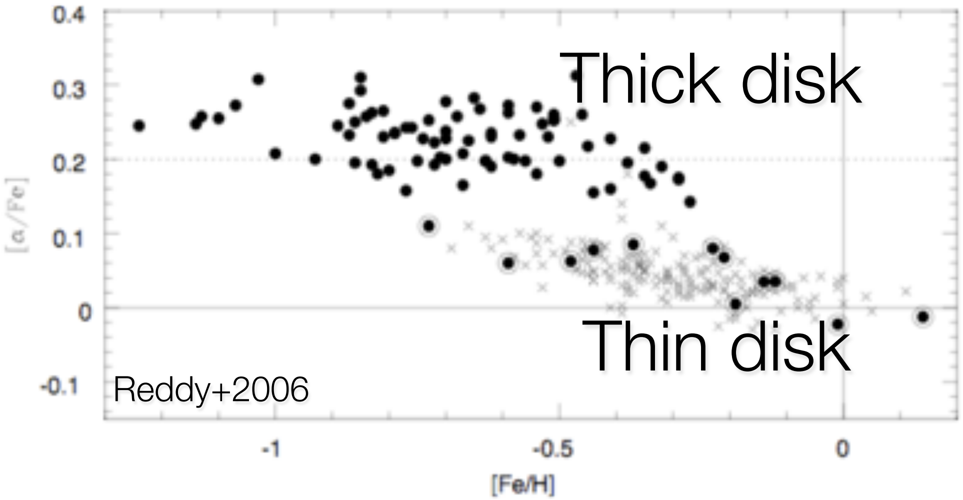
WEAVE at R=20000

- Abundances to ~0.1 dex accuracy will allow chemical labeling of stars
- WEAVE will reach V~17 in ~2 hours at S/N>60/resolution element at R=20000

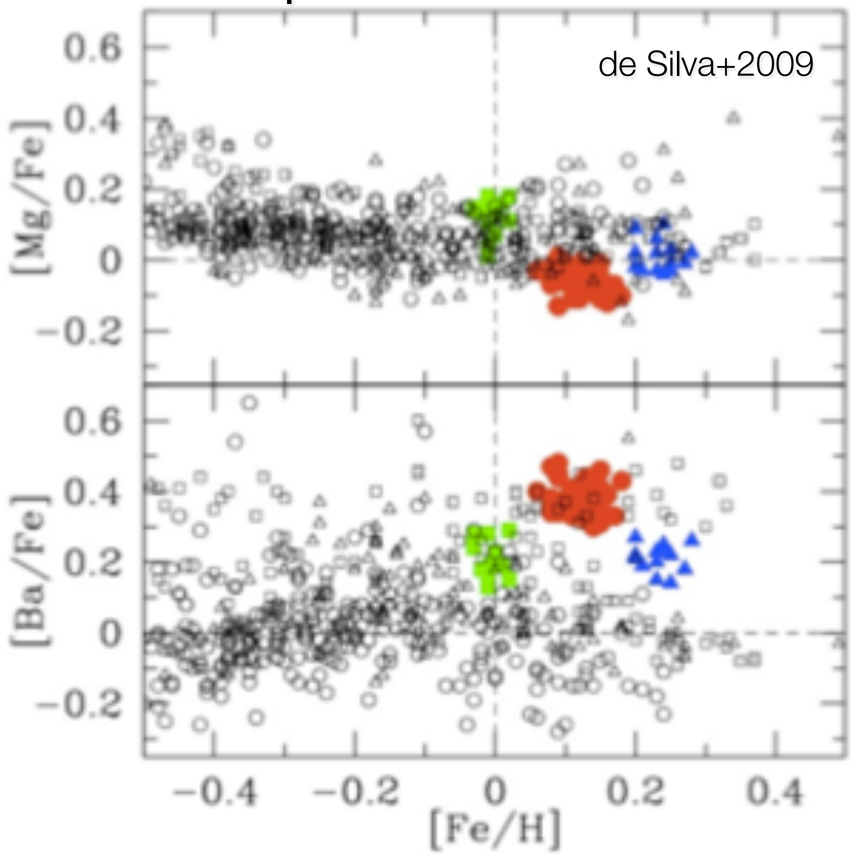


Chemical labeling: examples





3 open clusters



Open cluster goals

- Open clusters represent both a "ground truth" of our models of stellar evolution and a tracer population of star formation in the MW disk
  - Do all stars form in clusters? How do clusters evolve? How do they disperse their stars to the field? What is the impact of radial migration on this process?
  - Open clusters as tracers of MW disk star formation and chemical evolution
  - How good are our stellar evolution models?

GA Requirements

- Low Resolution Mode (R~5000)
  - Multiplex >~ 1000/2 degree FOV
  - Large simultaneous wavelength coverage
- High Resolution Mode (R~20000)
  - Multiplex >~500/2 degree FOV
  - Full coverage of element families for chemical labelling.

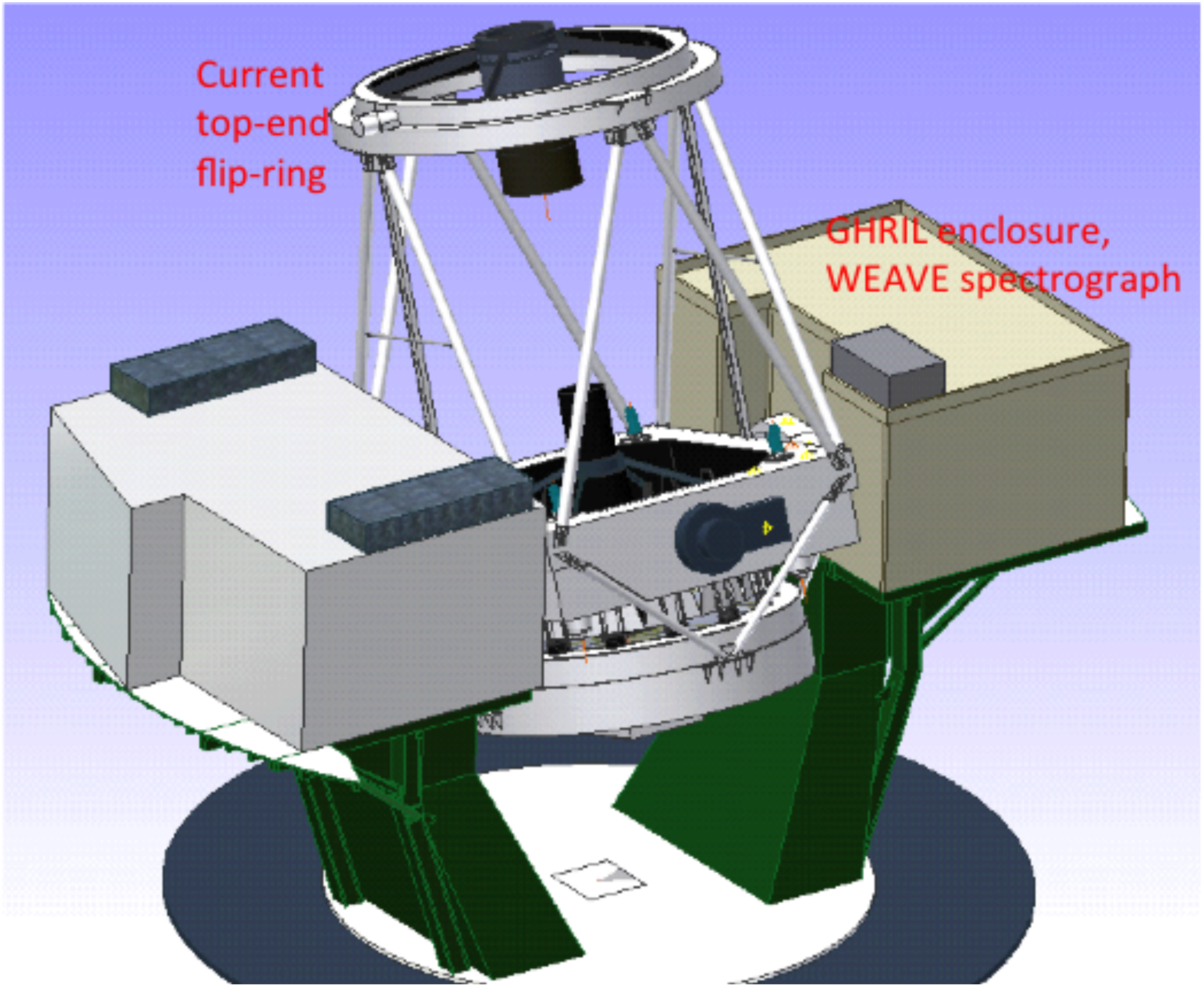
Key parameter summary…

Telescope, diameter	WHT, 4.2m
Field of view	2°
Number of fibers	1000
Fiber size	1.3”
Low-resolution mode resolution	4300–7200
Low-resolution mode wavelength coverage (Å)	3660–9840
High-resolution mode resolution	18560–21375
High-resolution mode wavelength coverage (Å)	4040–4650, (4730–5450) 5950–6850

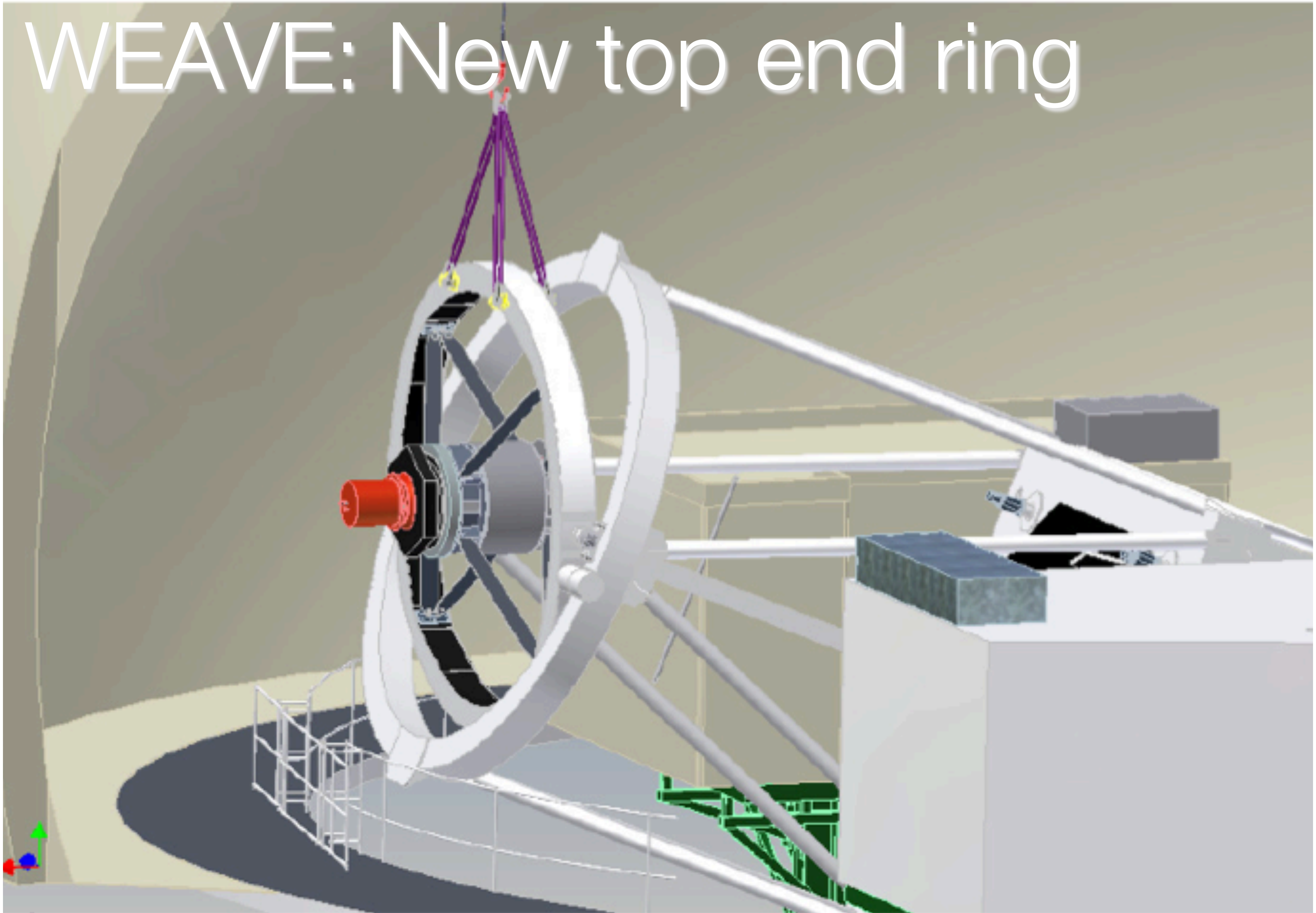
Galactic archaeology survey strategy

	log(N)	Area (deg^2)	R	Depth
Halo	6	1000	5000	V≤20
Disks	6.7	300	5000	V≤20
Chemical labeling	4.7 (disk) 5.7 (halo)	2000	20000	V≤17
Open clusters	4.7	150	20000	V≤17

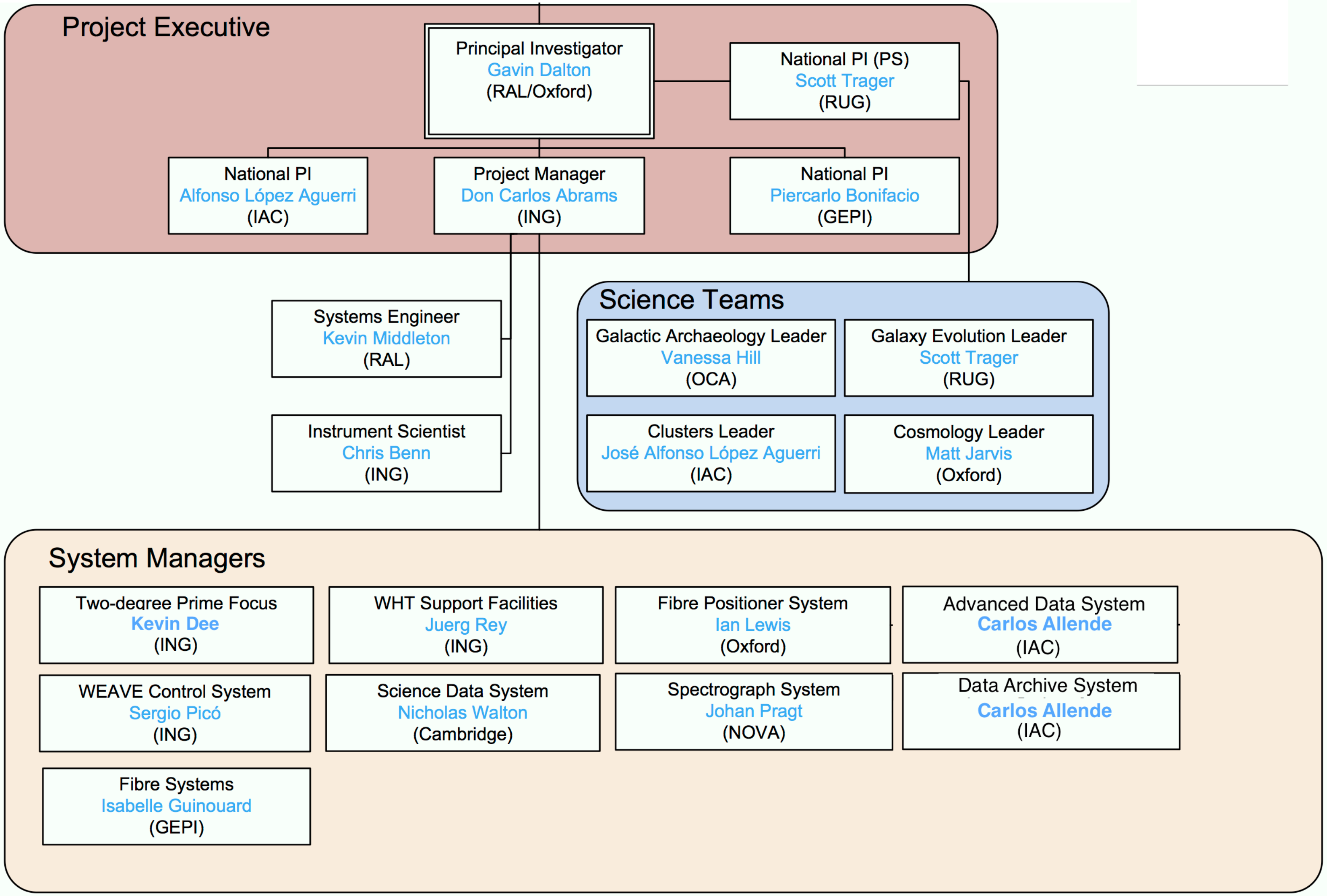
WEAVE: A new facility instrument for the WHT



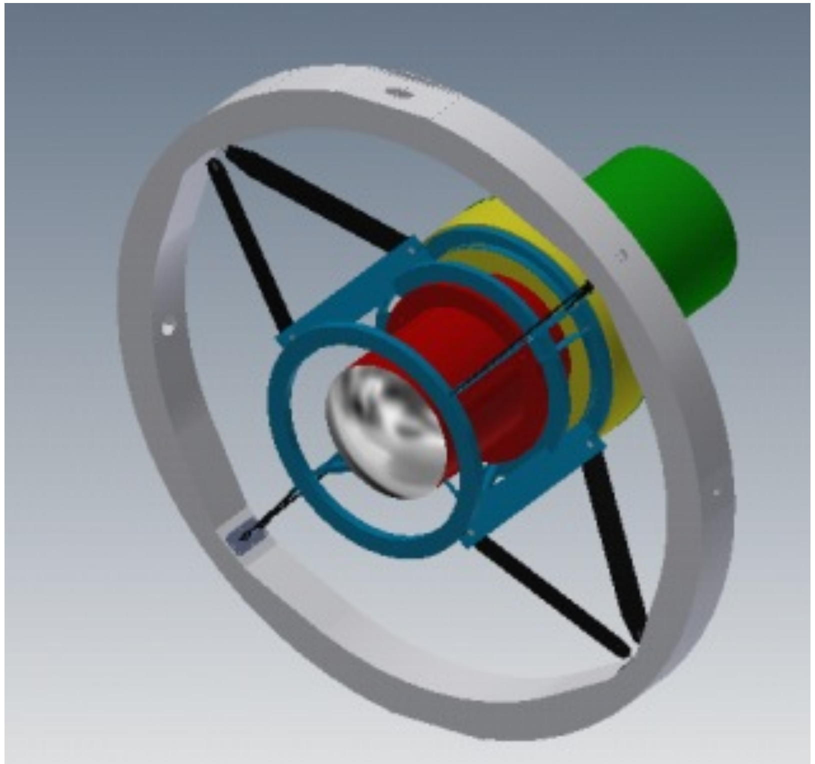
WEAVE: New top end ring



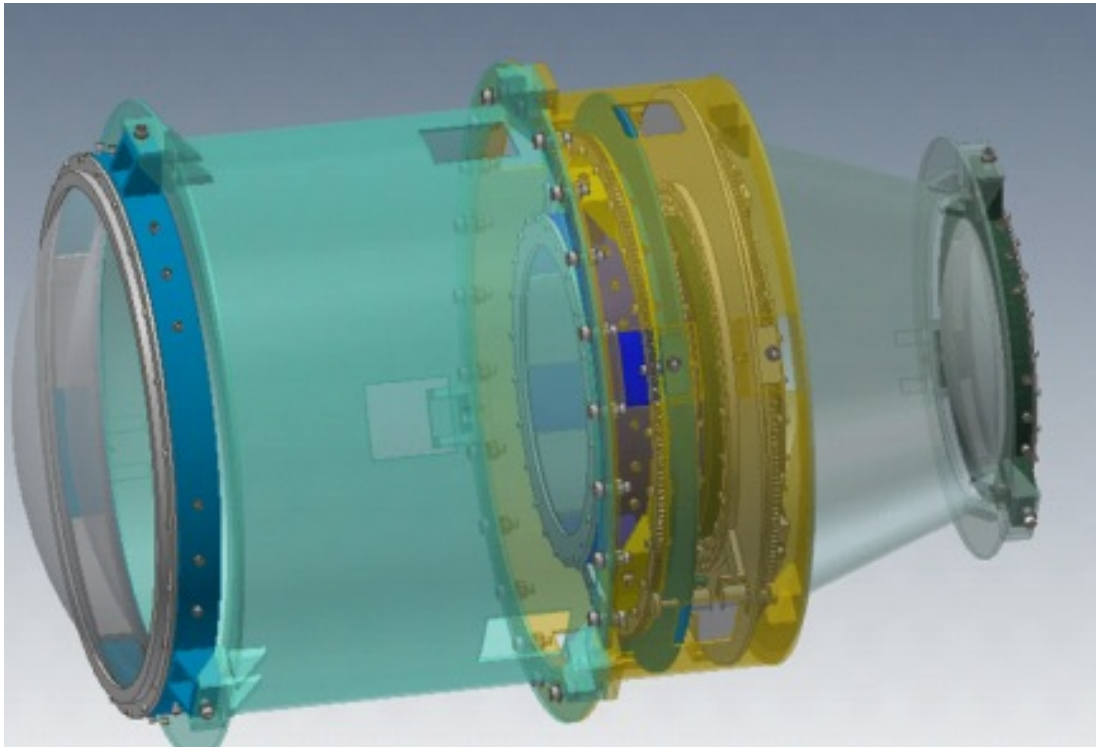
Project Structure



Prime Focus Corrector



New top-end ring, field corrector with atmospheric dispersion compensation and instrument rotator.



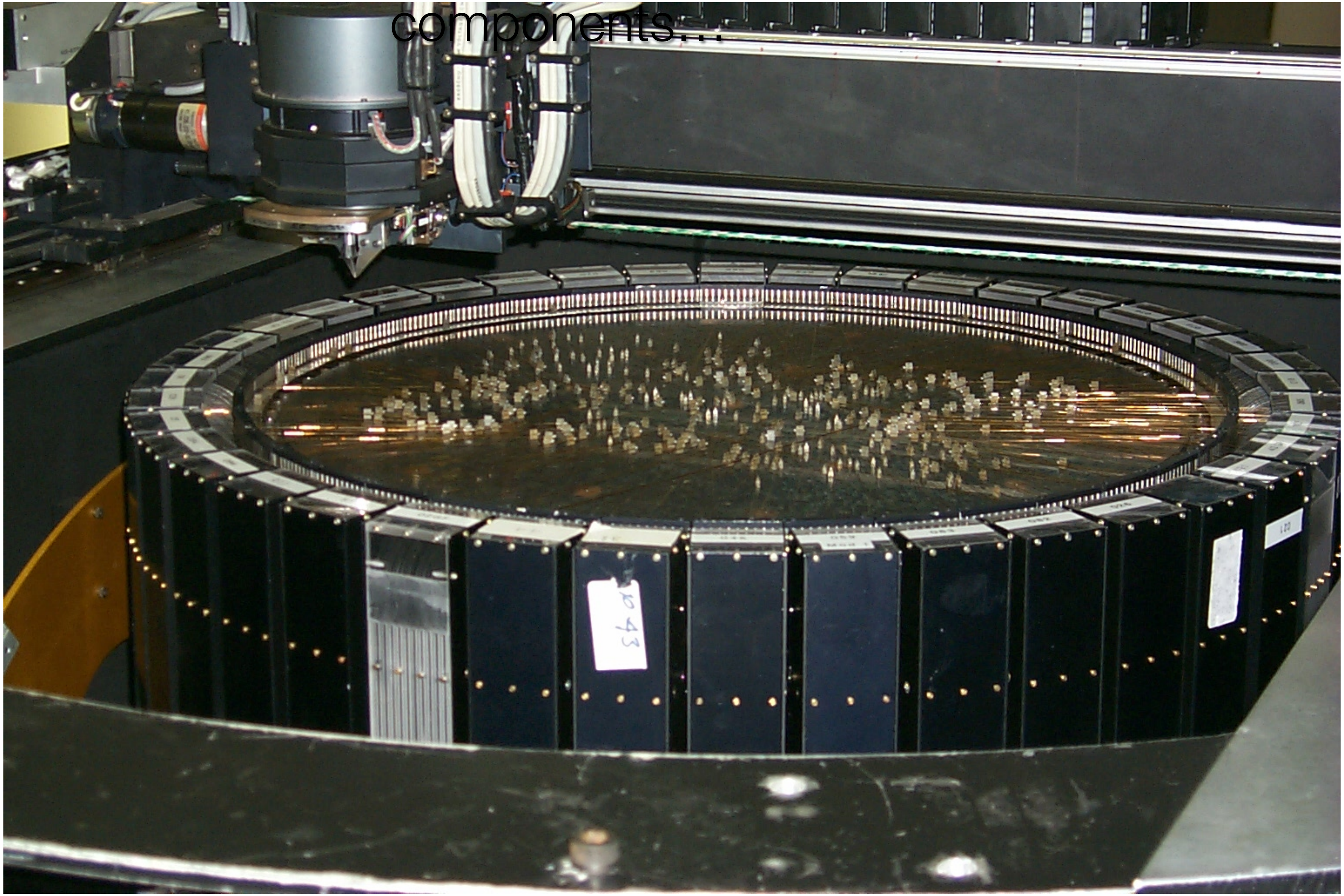
ING/NOVA design
Procurement through IAC

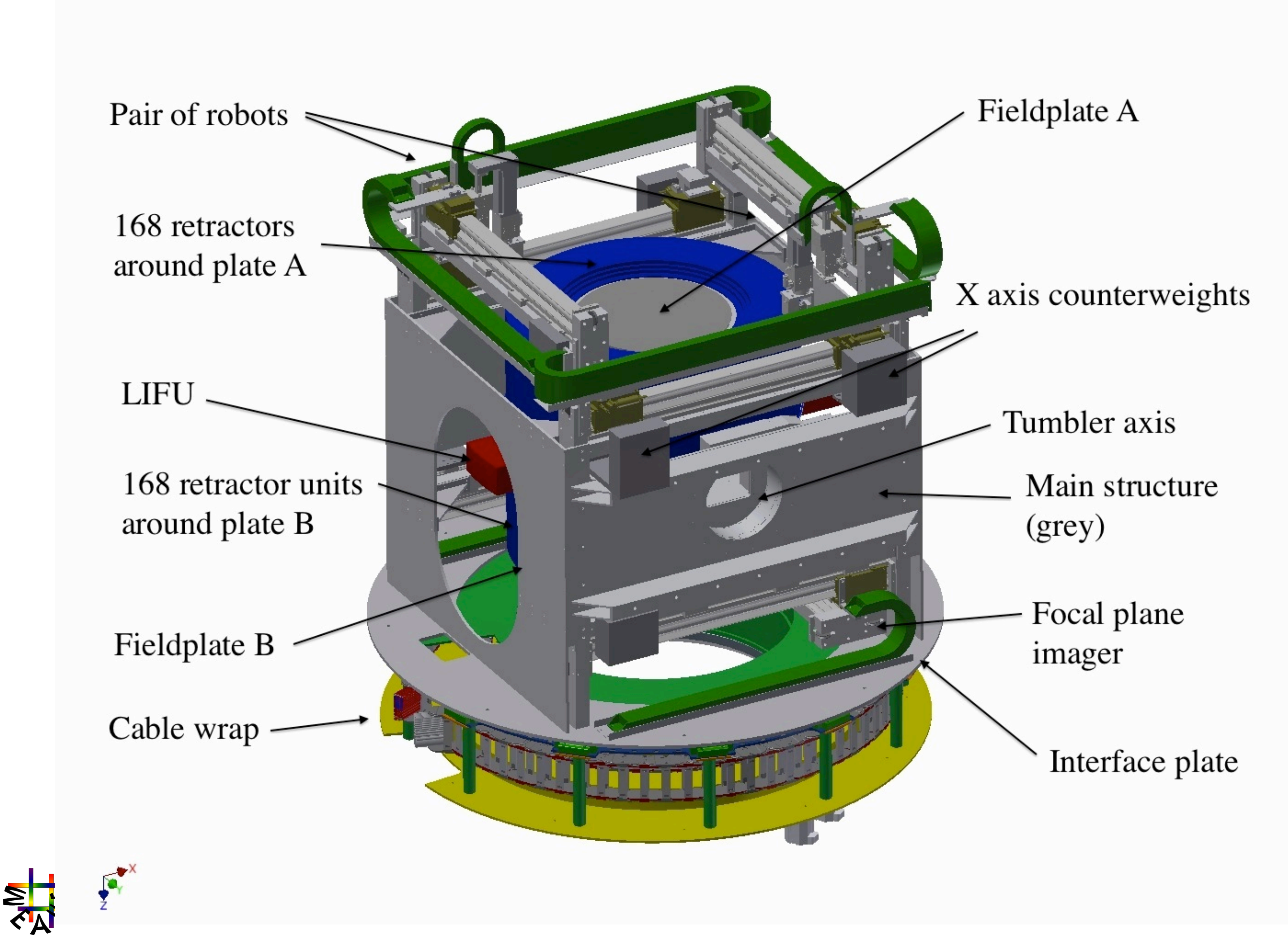
Fibre positioner

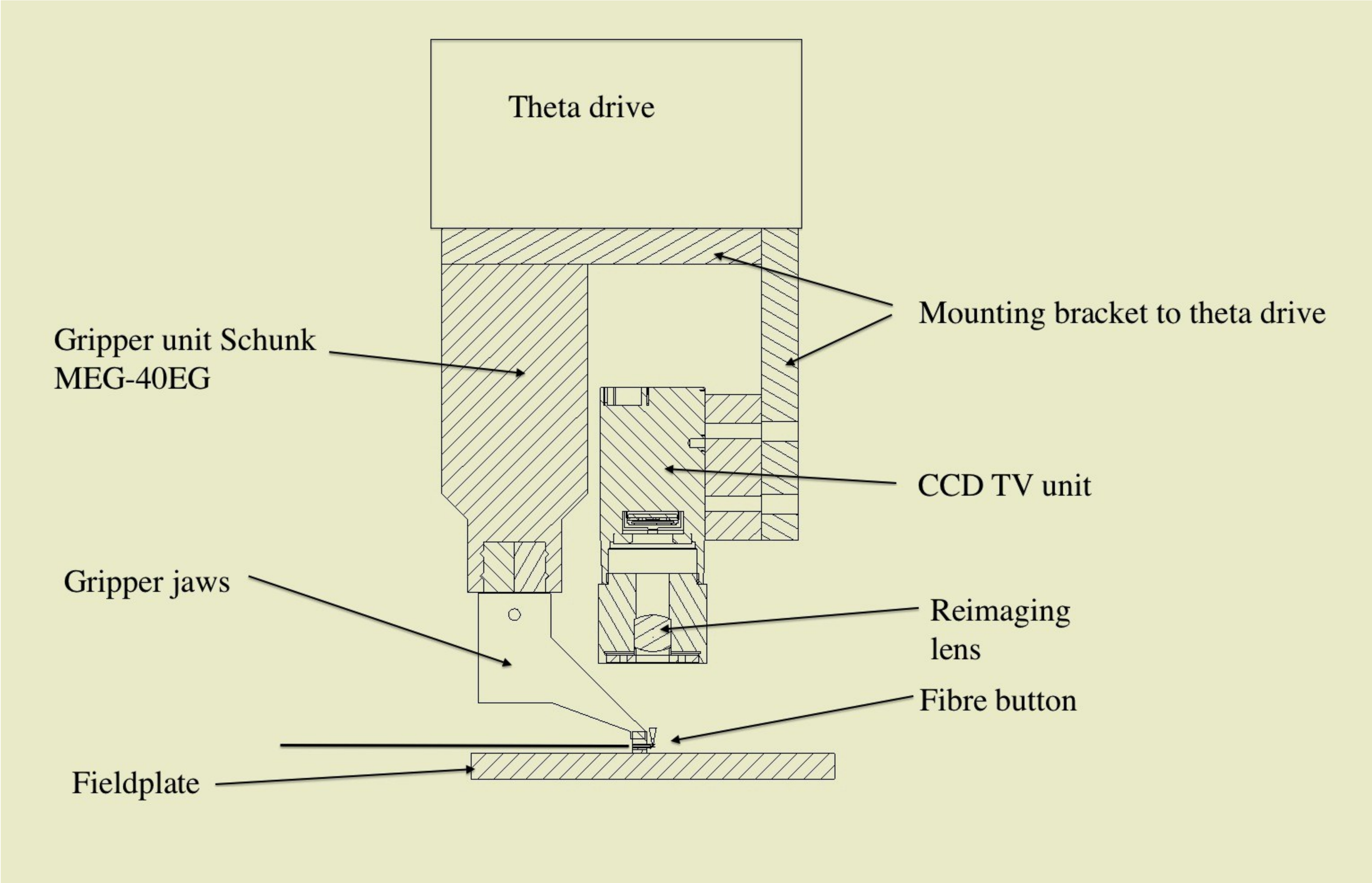
- Pick-and-place fiber positioner: COTS components
  - 2dF-like
  - tumbler with 2 field plates
  - 2 robots working in parallel
  - low-risk, low-cost
  - high flexibility

fiber wrap

Positioner concept similar to AF2/2dF, but all COTS components...

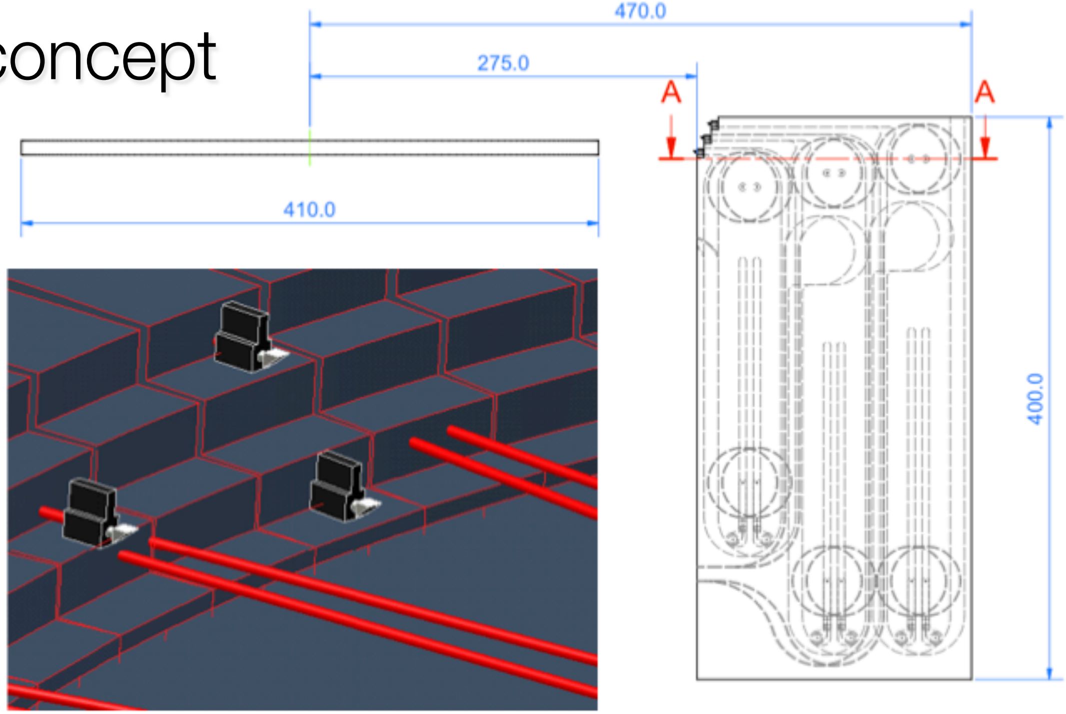



Pair of robots
Fieldplate A
168 retractors
around plate A
X axis counterweights
LIFU
Tumbler axis
168 retractor units
around plate B
Main structure
(grey)
Focal plane
imager
Fieldplate B
Cable wrap
Interface plate

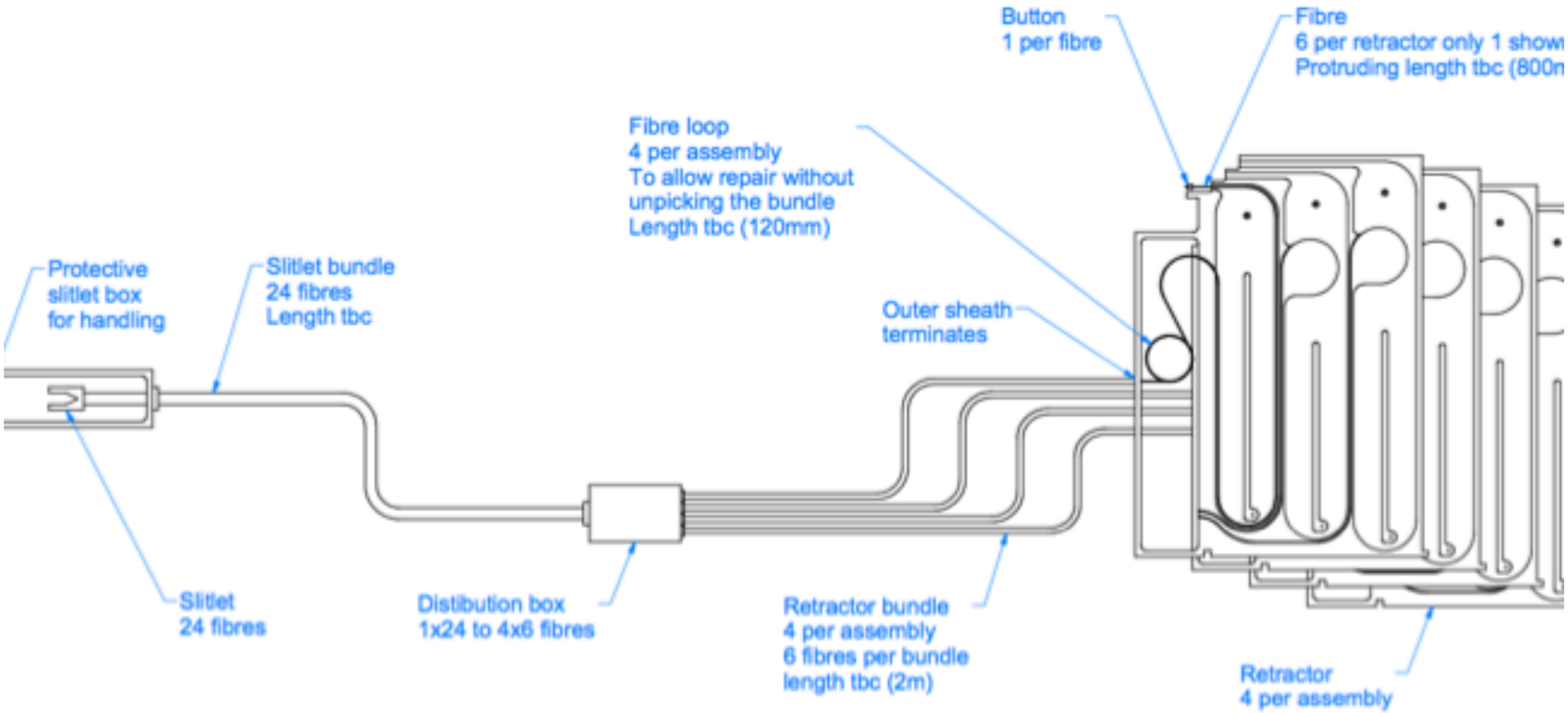

Theta drive
Mounting bracket to theta drive
Gripper unit Schunk MEG-40EG
CCD TV unit
Gripper jaws
Reimaging lens
Fibre button
Fieldplate

Fibre retractors

- Push park locations beyond useful field edge
- 1000 MOS buttons
- “Bull-ring” triple-parking concept

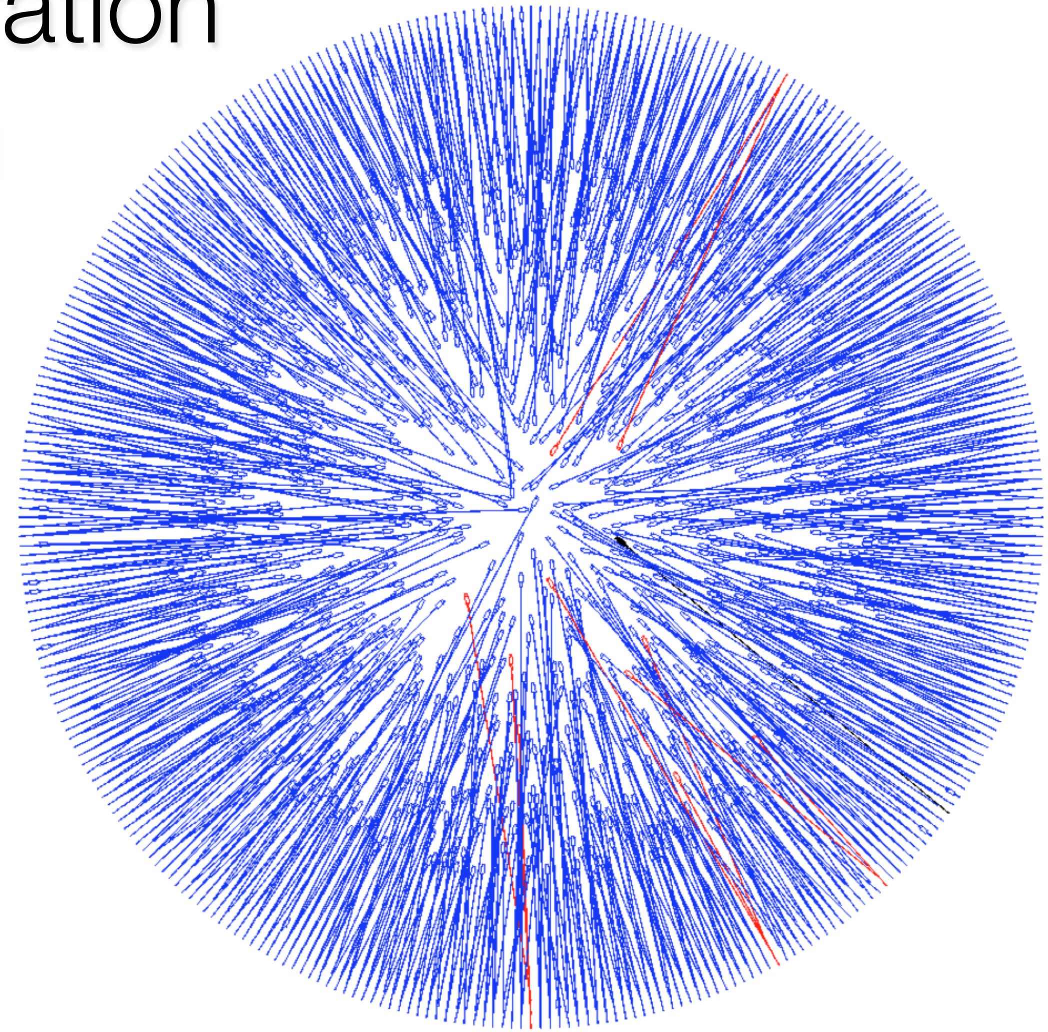


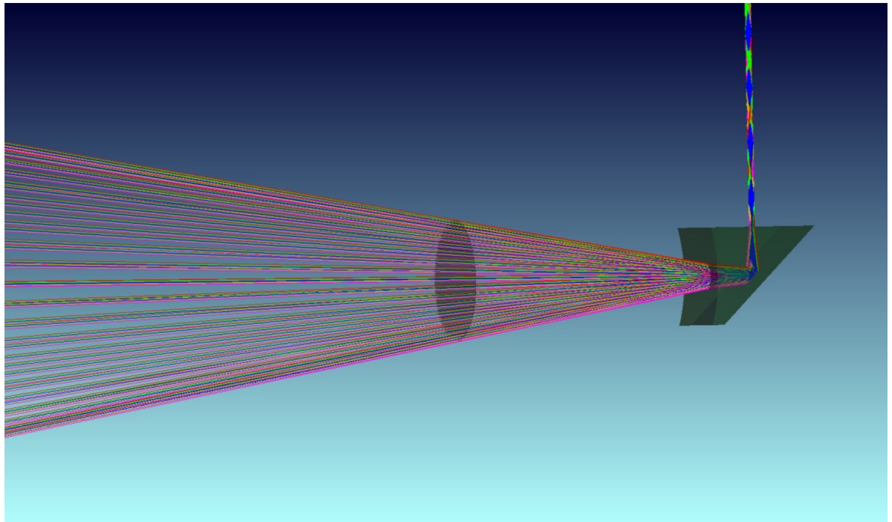
Fibre cables



MOS field configuration

- 97% of fibres allocated in test simulation (1.8x oversampled targets)
- ~8500 fibre crossings!
- ~1800 moves within ~55 minutes with two robots





8 AG fibres/field using 5” FOV coherent bundles

Dual-Beam Spectrograph Design

f/3.0 input, f/1.8 camera, 190mm beam diameter. 2x8kx3k e2V CCDs (CCD231-68) in each camera.

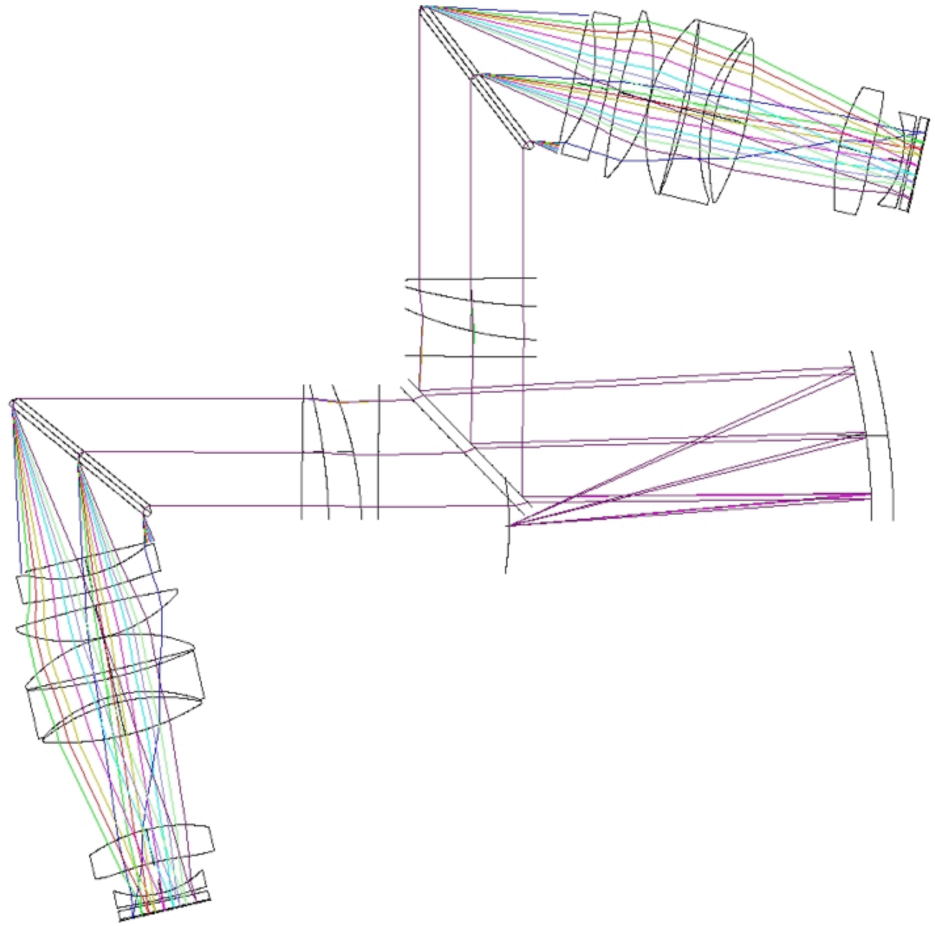
Slit curved to give uniform spectral coverage for all fibres in low-res

7-lens cameras (3 aspheres)

16k spectral pixels, R=5000 over 370—1000nm in one shot

Camera lenses are F2, LLF1, N-FK51A, and LAK9

Some vignetting allowed in high res



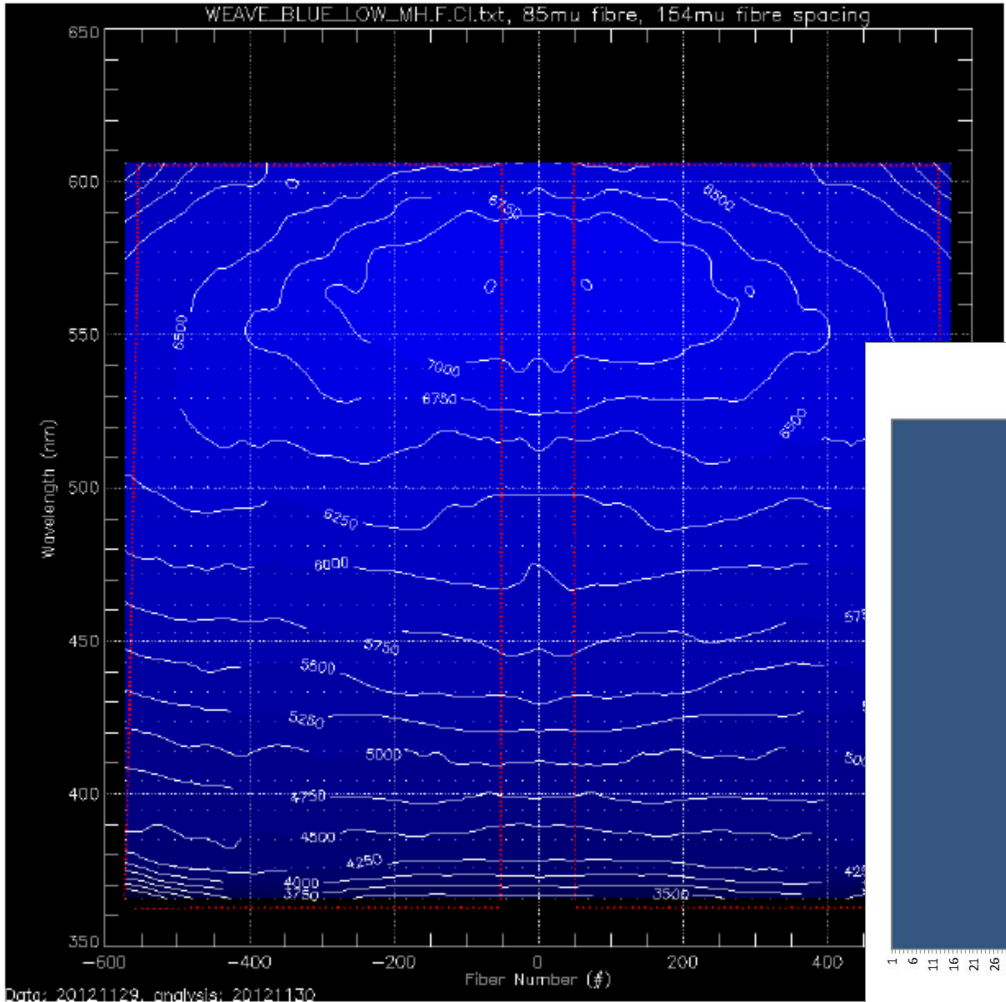
Optical design

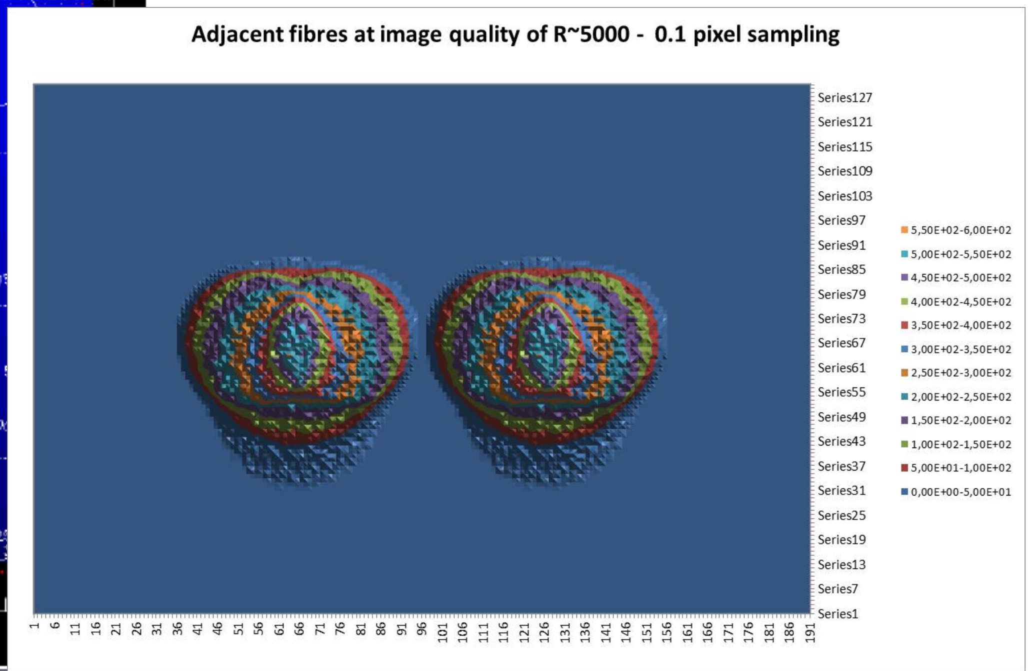
Resolution maps produced across detector, including spectrograph image quality and detector sampling

Verfied by two different calculation methods

Example: blue low res.

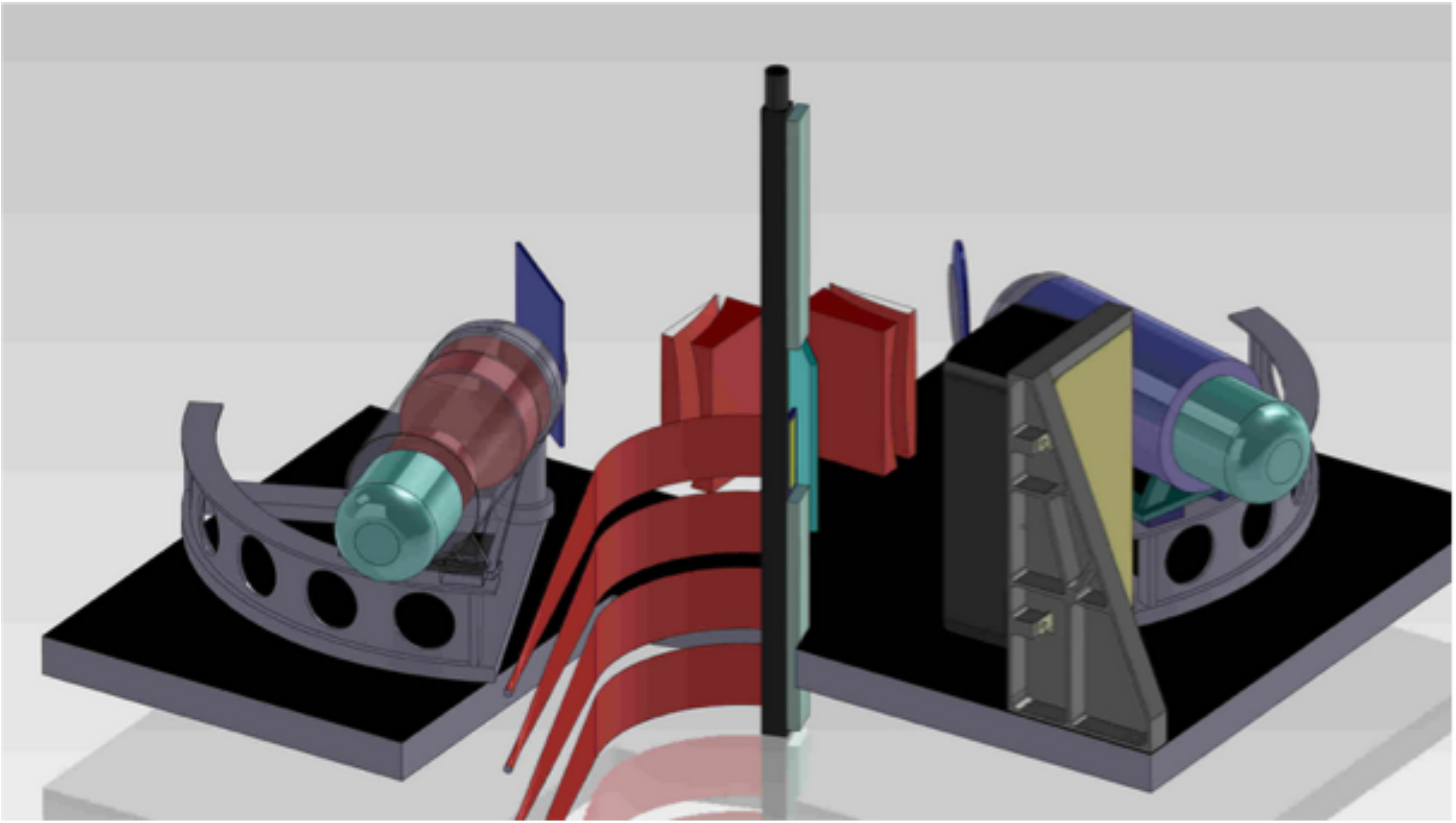
R calculated as lambda/dlambda with gaussian fit to spectrograph PSF



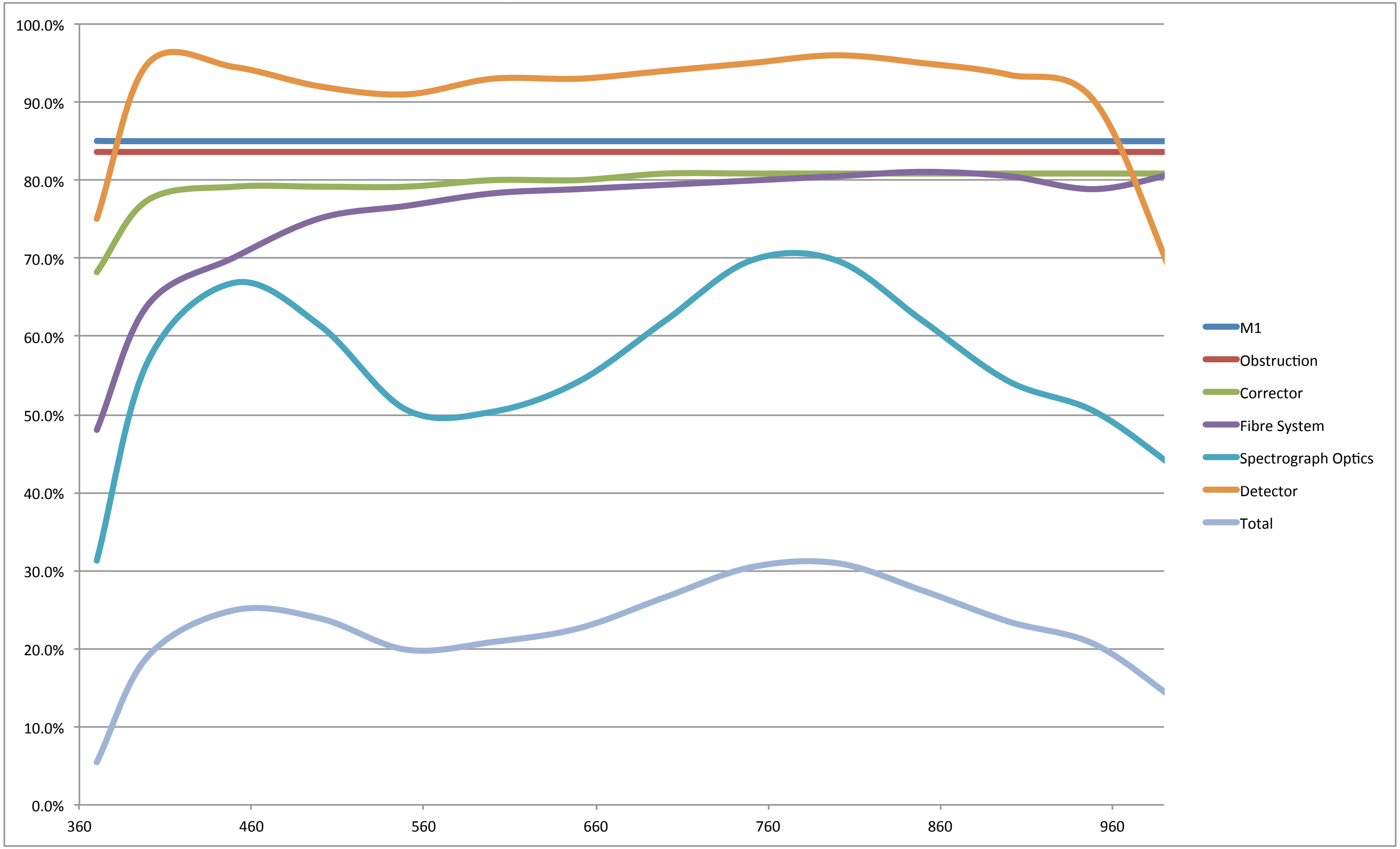


Spectrograph Mechanics

Grating exchange, slit exchange, shutters and camera motion achieved by pneumatic drives to kinematic positions – repeatable motions

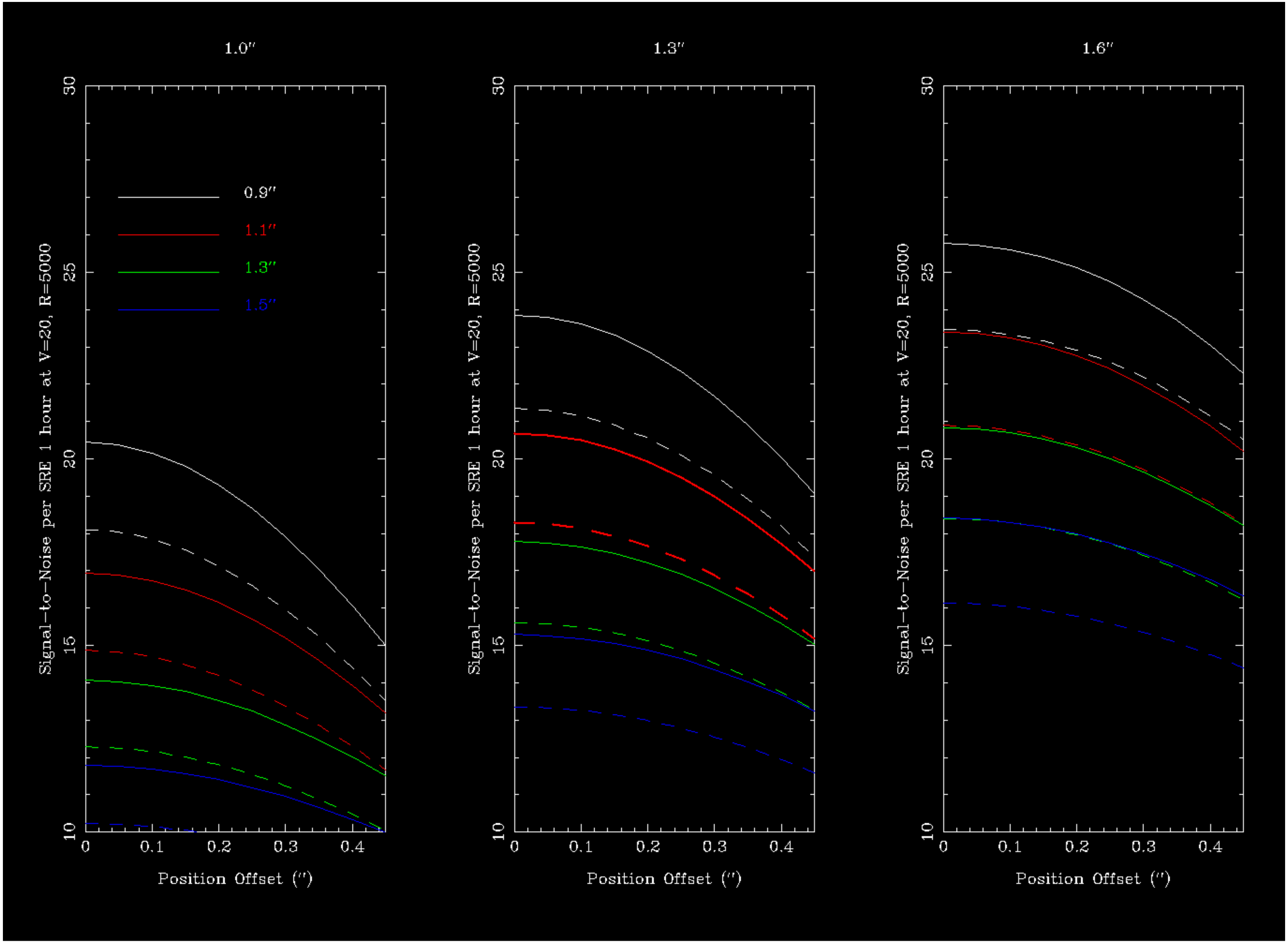


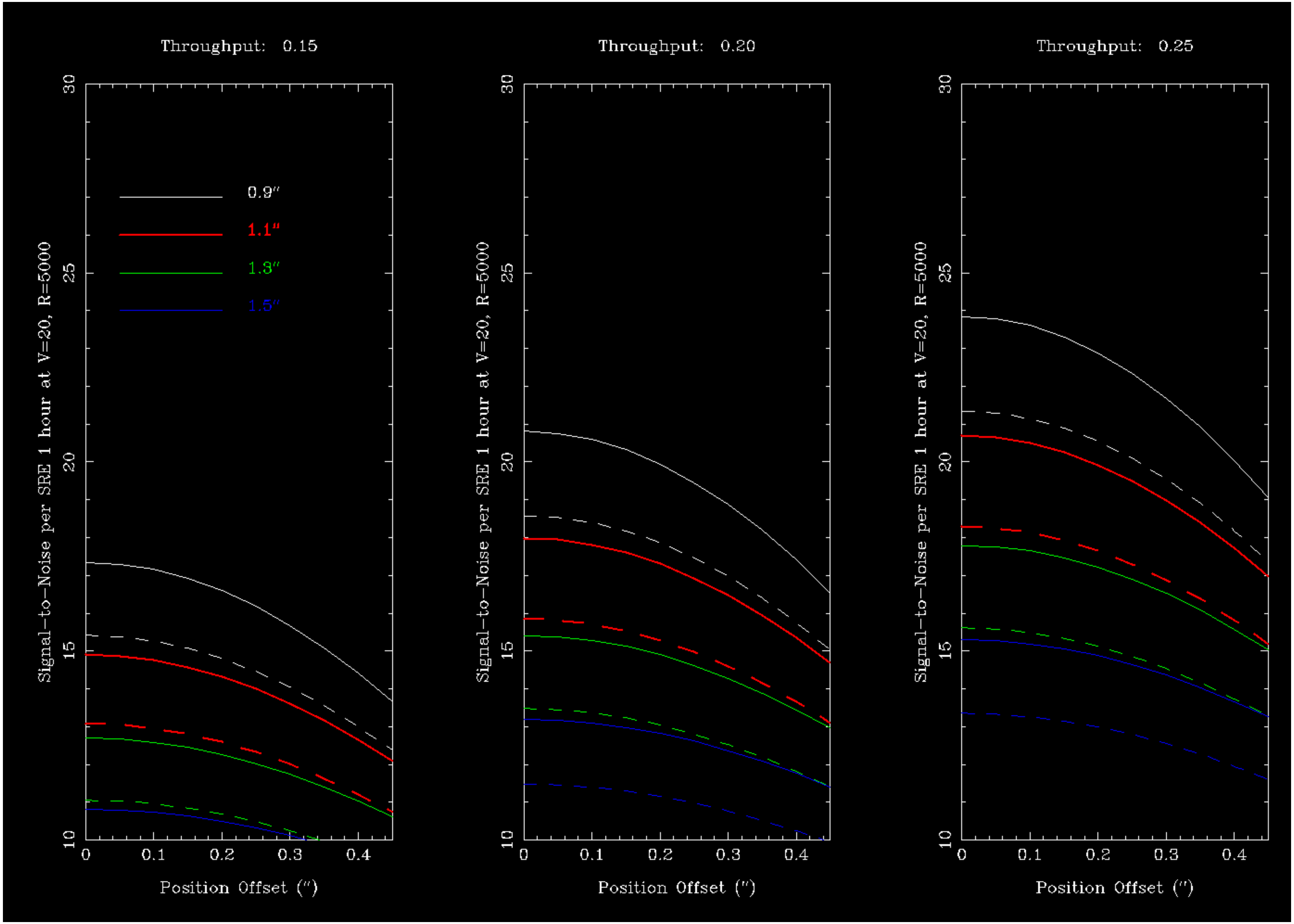
WEAVE throughput



Wavelength (nm)

More photons/object than VLT FLAMES, with 10x


1.0″
1.3″
1.6″
0.9″
1.1″
1.3″
1.5″
Signal-to-Noise per SRE 1 hour at V=20, R=5000
Position Offset (″)
10
15
20
25
30
0
0.1
0.2
0.3
0.4



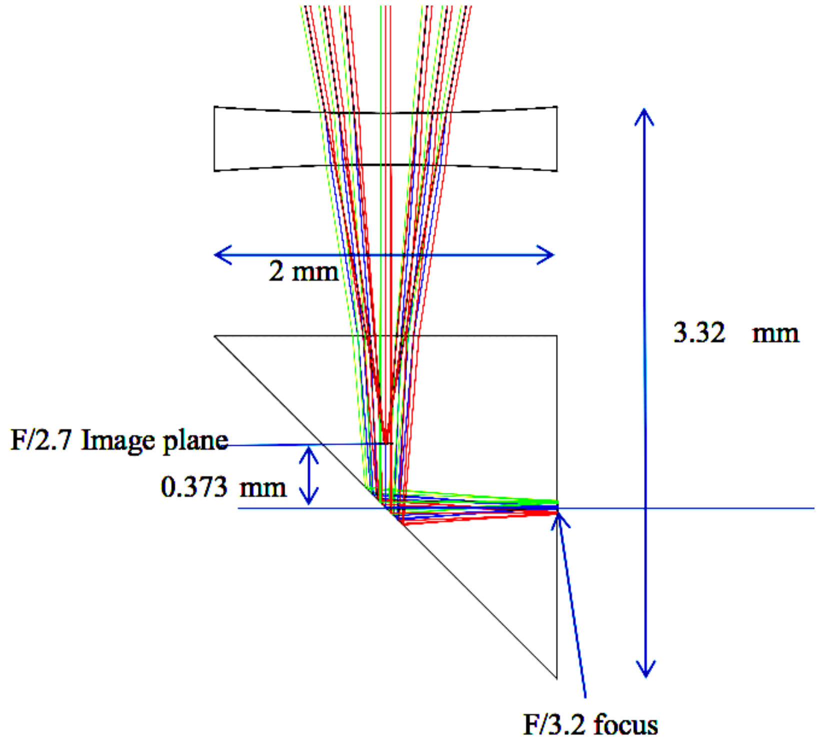
Throughput: 0.15
Throughput: 0.20
Throughput: 0.25
Signal-to-Noise per SRE 1 hour at V=20, R=5000
Position Offset (″)
0.9″
1.1″
1.3″
1.5″

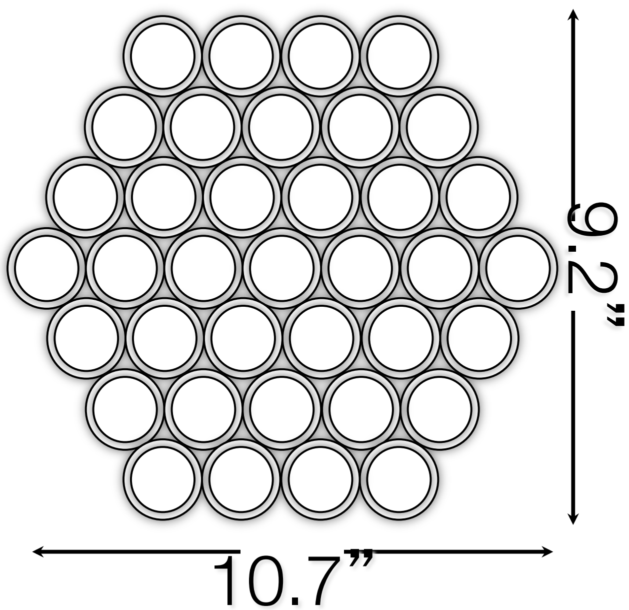
IFU Opportunities

- Spectrograph with full coverage and large slit length
  - Slit exchange is built-in to the design
- Pick and Place positioner provides easy route to deployable mini IFUs
- Tumbler 90° position provides obvious location for a separate monolithic IFU

Mini IFU concept

- 20 miniIFUs on one field plate, ~9”x9”, 1.3” pitch
- Small enough to be handled by the gripper

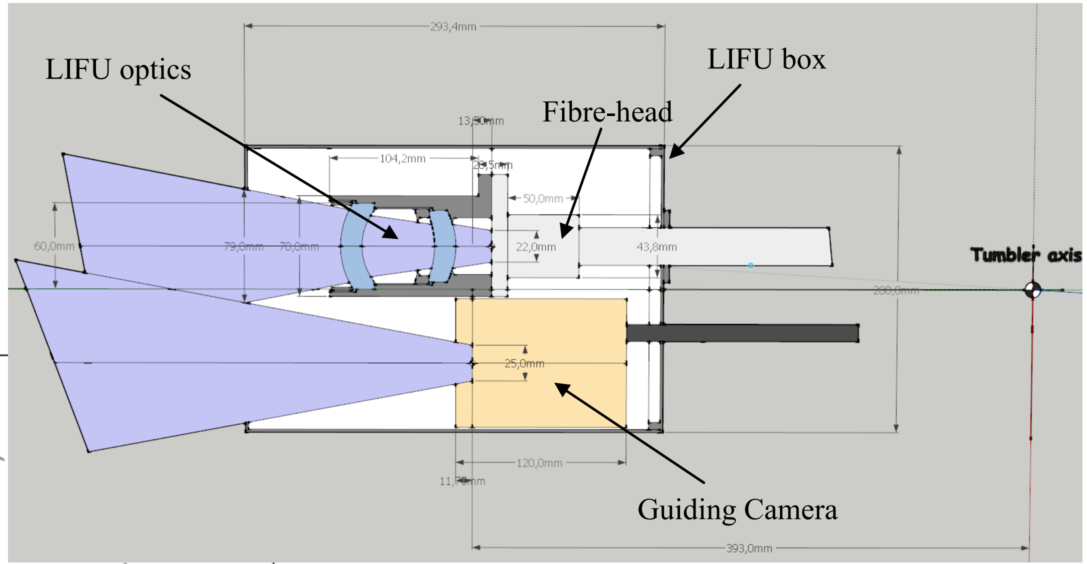


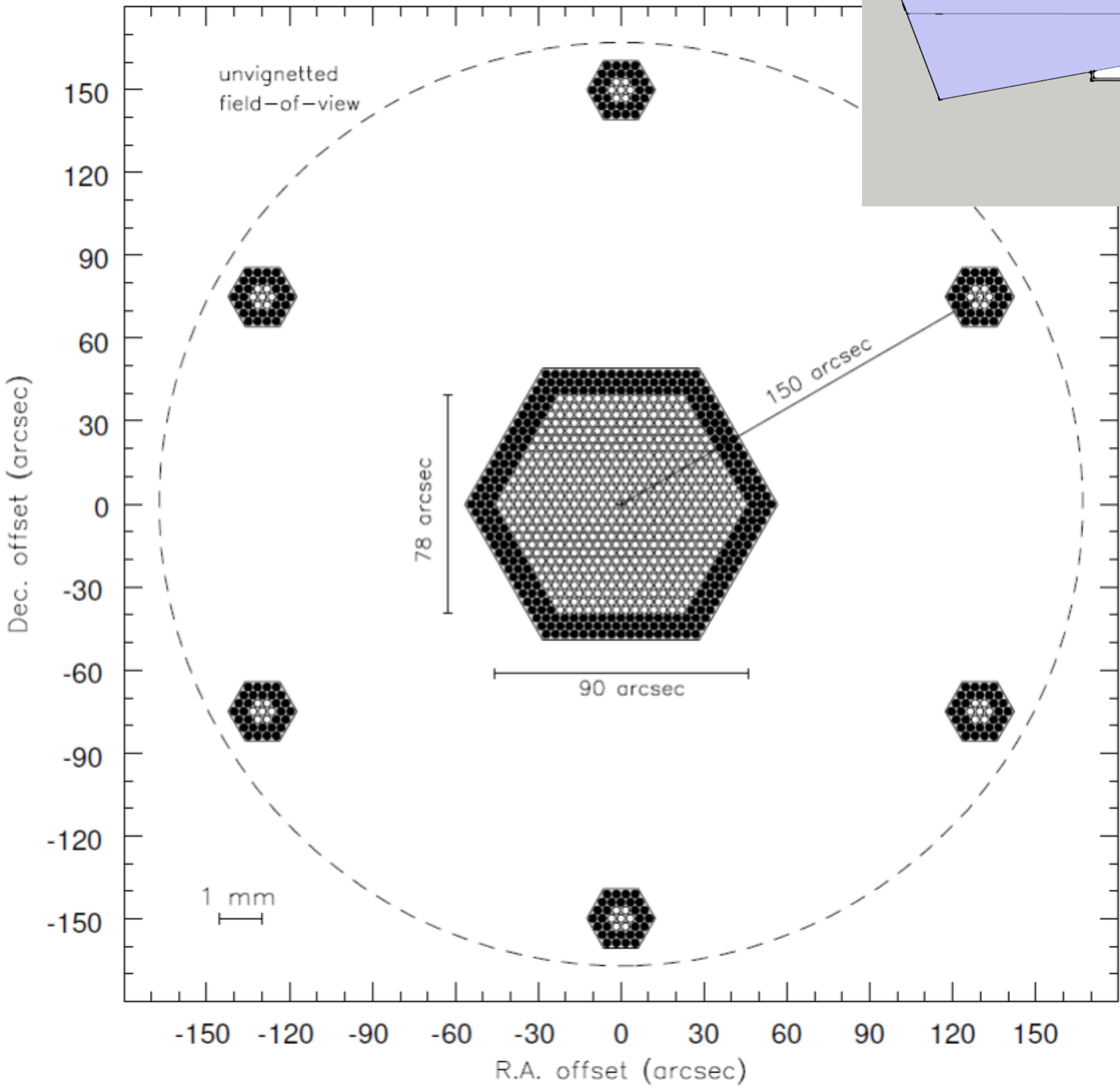


37 fibres/mIFU -> 24 units possible within slit length

1 mIFU replaces 3 MOS fibres, so 2 mIFUs/retractor

LIFU





- Large IFU with ~547 fibres ~90” x ~60”, 2.6” pitch
- Dedicate AG unit for repeatability
- Offset sky bundles

Galaxy Evolution Science: WEAVE-LOFAR

- LOFAR is the world's largest low-frequency radio telescope array
- The LOFAR Surveys KSP will deliver ~10^7 continuum targets over ~10^4 deg^2 at 30, 60, 120, 200 MHz
- These will be *strongly* biased towards emission-line galaxies, especially *star-forming galaxies*

- Galaxy evolution science is *multiwavelength* science!
- Our goal here is to understand
  - the evolution of
    - *dwarf* galaxies
    - the *kinematics* of galaxies
    - the population of *radio-emitting* galaxies
  - the impact of large-scale environment on these evolutionary pathways
  - and the distribution of dark matter in present-day galaxies

WEAVE-Clusters

- What is the effect of environment on galaxy evolution?
  - as a function of mass: what is the impact on the scaling relations, kinematics, and stellar populations of dwarf galaxies?
  - as a function of local environment: what happens to galaxies in the infall regions of clusters?
  - as a function of lookback time: how do the kinematics and stellar populations of cluster galaxies evolve?

WEAVE-Clusters

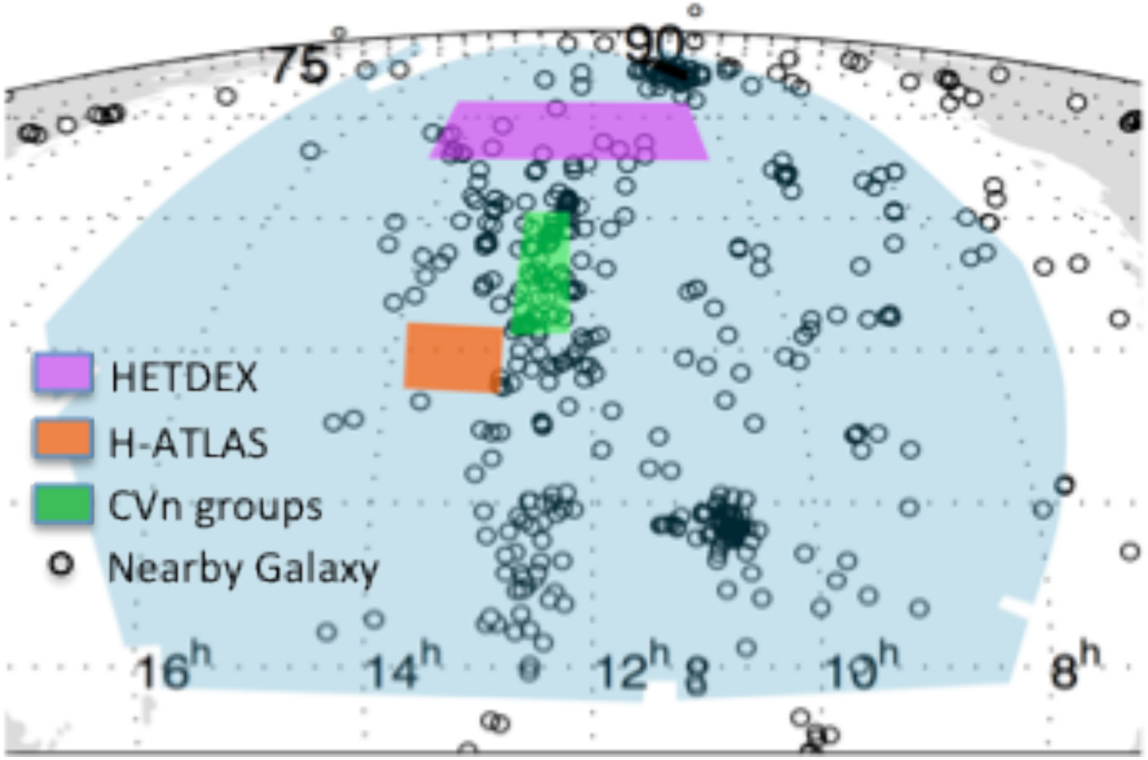
- **Layer 1**: Tracing the evolution of dwarf galaxies in clusters
  - >10^4 cluster dwarfs at R=5000 down to M_r<-16 with MOS mode + 10^3 cluster dwarfs with **mIFUs** to derive *spatially-resolved properties*
- **Layer 2**: The infall regime
  - 10^4 galaxies in 10 large superstructures at z~0.1–0.2 at R=5000 to R<21 in **MOS** mode
- **Layer 3**: The evolution of cluster galaxies at z<0.5
  - 25 cluster cores with **LIFU** mode

Galaxy Evolution Science: WEAVE-Apertif

- Apertif is the world's first working focal-plane array, capable of full Westerbork resolution (~15") over a single, full 8 deg^2 pointing in the frequency range 1000–1750 MHz with nearly the sensitivity of the present "single-pixel" WSRT front-ends

WEAVE-Apertif

- The APERTIF Medium-Deep Survey will survey 10^4 galaxies at $0.1<z<0.4$ over 500 deg^2 in the 21cm line of HI, while the shallow all-sky survey will survey 10^4 galaxies at $z<0.1$
  - *spatially-resolved* kinematics of the neutral gas and stellar pop^{n}s



WEAVE-Apertif

- **Tier 1**: 10^4 galaxies, half over 10^4 deg^2, half over 500 deg^2 with **mIFU** at R=5000 to probe star-formation quenching and the fueling of the blue cloud
- **Tier 2**: 50 LSB galaxies with **LIFU** at R=10000 to determine masses of their dark and luminous matter using disk kinematics
- **Tier 3**: 10 nearby disk galaxies with **LIFU** to determine the impact of secular evolution on their gas and stars

Should be complementary to MaNGA…

WEAVE-LOFAR

- WEAVE can obtain redshifts for ~10^7 emission-line galaxies detected by LOFAR at z<1.3 (OII) and z>2.3 (Lyα)
  - Radio continuum fluxes + redshifts = unbiased star-formation rates over large range of cosmic time!
  - Spectra will often give metallicities and even stellar velocity dispersions: chemical evolution and stellar masses
  - Black hole accretion mechanism can be determined for radio AGN: evolution of BH accretion rate and stellar-BH co-evolution

WEAVE-LOFAR

- A properly-selected sample of ~$5x10^6$ galaxies over 10^4 deg^2 is critical for effective follow-up of LOFAR
  - select by radio power and, when possible, by optical color
- Depths to V~21 are required (but S/N requirements not strict)

Additional Galaxy evolution science cases

- Extragalactic star clusters
- Dwarf galaxies in the local cosmological volume
- Stellar populations at intermediate redshifts
- Ultra-deep spectroscopy

Key parameter summary…

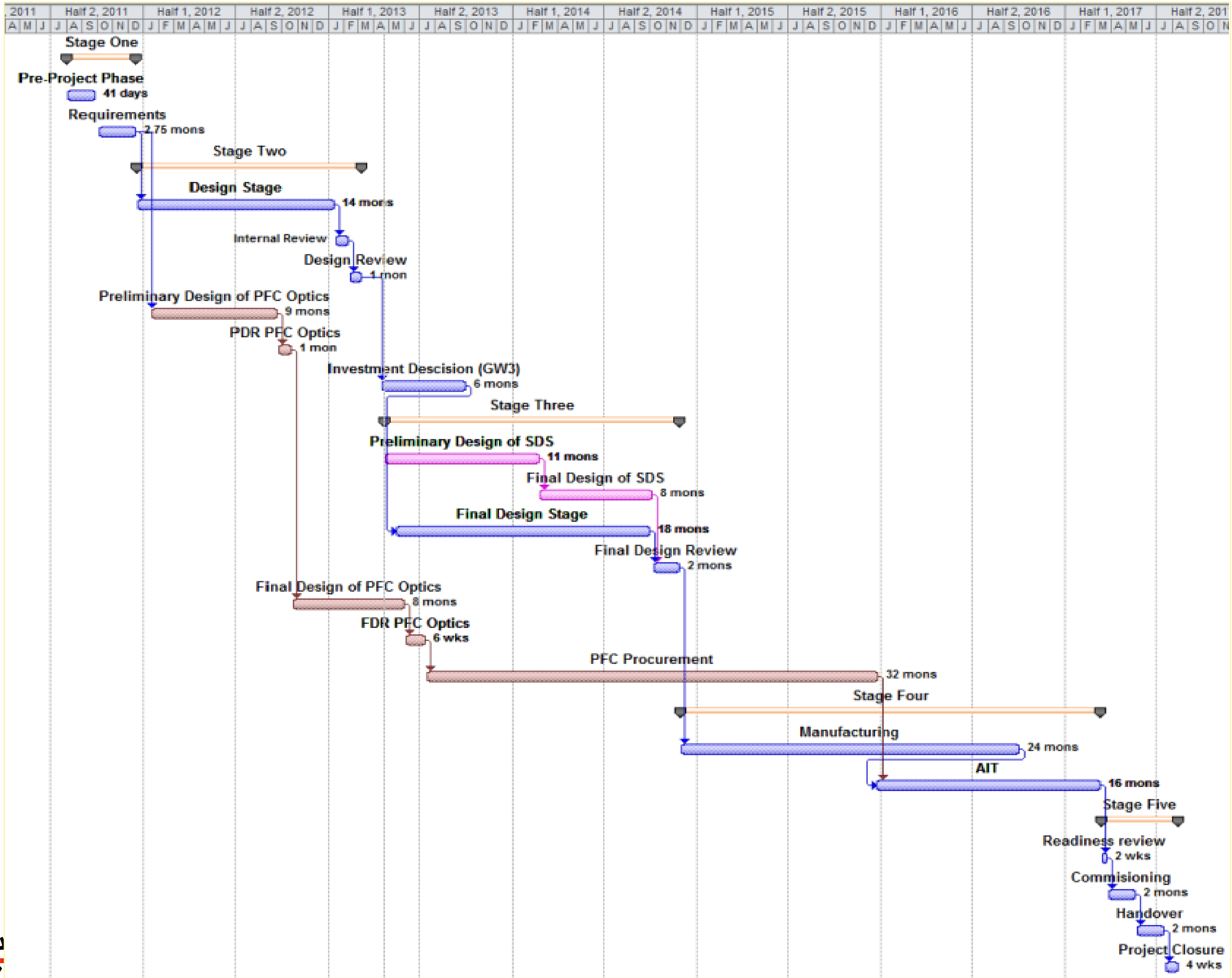
Telescope, diameter	WHT, 4.2m
Field of view	2º
Number of fibers	1000
Fiber size	1.3”
Number of small IFUs, size	~20, 9”x12” (1.3” spaxels)
LIFU size	~1.5’x1’ (2.6” spaxels)
Low-resolution mode resolution	4300–7200
Low-resolution mode wavelength coverage (Å)	3660–9840
High-resolution mode resolution	18560–21375
High-resolution mode wavelength coverage (Å)	4040–4650, 4730–5450 5950–6850

Nominal survey parameters

Survey	Mode	No. Objects	Area (deg^2)	Nights
GA halo LR	MOS/R=5000	10^6	6500	215
GA halo HR	MOS/R=20000	$5x10^4$	2500	115
GA disk LR	MOS/R=5000	$5x10^6$	2000	90
GA disk HR	MOS/R=20000	$5x10^5$	2000	715
Clusters L1	MOS/R=5000	$3x10^4$	150	25
Clusters L1	mIFU/R=5000	10^3	150	50
Clusters L2	MOS/R=5000	10^4	30	10
Clusters L3	LIFU/R=5000	150	0.08	75
LOFAR	MOS/R=5000	$4x10^6$	10000	575
Apertif-mIFU	mIFU/R=5000	10^4	1000	290
Apertif-LIFU	LIFU/R=20000	60	0.025	60

N.B. Reduction in total time from the fact that the LOFAR and Halo surveys overlap…

La Palma weather is dependable… 7.5 hours/night every night is the average… makes survey planning easy!



Half 2, 2011
Half 1, 2012
Half 2, 2012
Half 1, 2013
Half 2, 2013
Half 1, 2014
Half 2, 2014
Half 1, 2015
Half 2, 2015
Half 1, 2016
Half 2, 2016
Half 1, 2017
Stage One
Pre-Project Phase
41 days
Requirements
2.75 mons
Stage Two
Design Stage
14 mons
Internal Review
Design Review
1 mon
Preliminary Design of PFC Optics
9 mons
PDR PFC Optics
1 mon
Investment Descision (GW3)
6 mons
Stage Three
Preliminary Design of SDS
11 mons
Final Design of SDS
8 mons
Final Design Stage
18 mons
Final Design Review
2 mons
Final Design of PFC Optics
8 mons
FDR PFC Optics
6 wks
PFC Procurement
32 mons
Stage Four
Manufacturing
24 mons
AIT
16 mons
Stage Five
Readiness review
2 wks
Commisioning
2 mons
Handover
2 mons
Project Closure
4 wks