The Keck Wide-Field Imager

The most powerful wide-field optical imager on Earth (or in space) for the foreseeable future

Helping Keck maintain leadership in the 30-class telescope era

KWFI
Keck Wide-Field Imager

Instrument and science team

KWFI Team: J. Cooke (Swinburne; PI), R. Dekany (Caltech/COO; Project Manager), R. Bertz (Caltech/COO; Deputy Project Manager), P. Gillingham (AAO+Macquarie; Lead Optical Engineer), M. Radovan (UCO; Lead Mechanical Engineer), R. Smith (Caltech/COO; Lead Detector Engineer), S. Krishnan (Swinburne/FoF; Lead FEX Engineer), R. Seikel (Swinburne/ADACS: Lead Software Engineer), G. Poole (Swinburne/ADACS), T. Travouillon (ANU/AITC), J. Fucik (Caltech/COO), H. Kaptan (Swinburne/FoF), C. Webster (Swinburne/FoF), A. Delacroix (Caltech/COO), J. Hurley (Swinburne/ADACS), S. Salaheen (Swinburne/ADACS), J. Cantos (Swinburne/ADACS), C. Steidel (Caltech), J. Brodie (Swinburne), M. Brown (Caltech), N. Suzuki (Kavli IPMU, UC Berkeley), B. T. Bolin (Caltech/IPAC), J. Burchett (UCSC/NMSU), M. Cowley (QUT/UQ), D. Fisher (Swinburne), R. Foley (UCSC), G. Foran (Swinburne), K. Glazebrook (Swinburne), G. Kacprzak (Swinburne), R. Margutti (UC Berkeley), B. Mobasher (UCR), A. Möller (Swinburne), J. Mould (Swinburne), A. Rest (STScI), J. Rhodes (JPL/Caltech), R. M. Rich (UCLA), L. Wang (TAMU), I. Wold (NASA/GSFC), J. Zhang (Swinburne)

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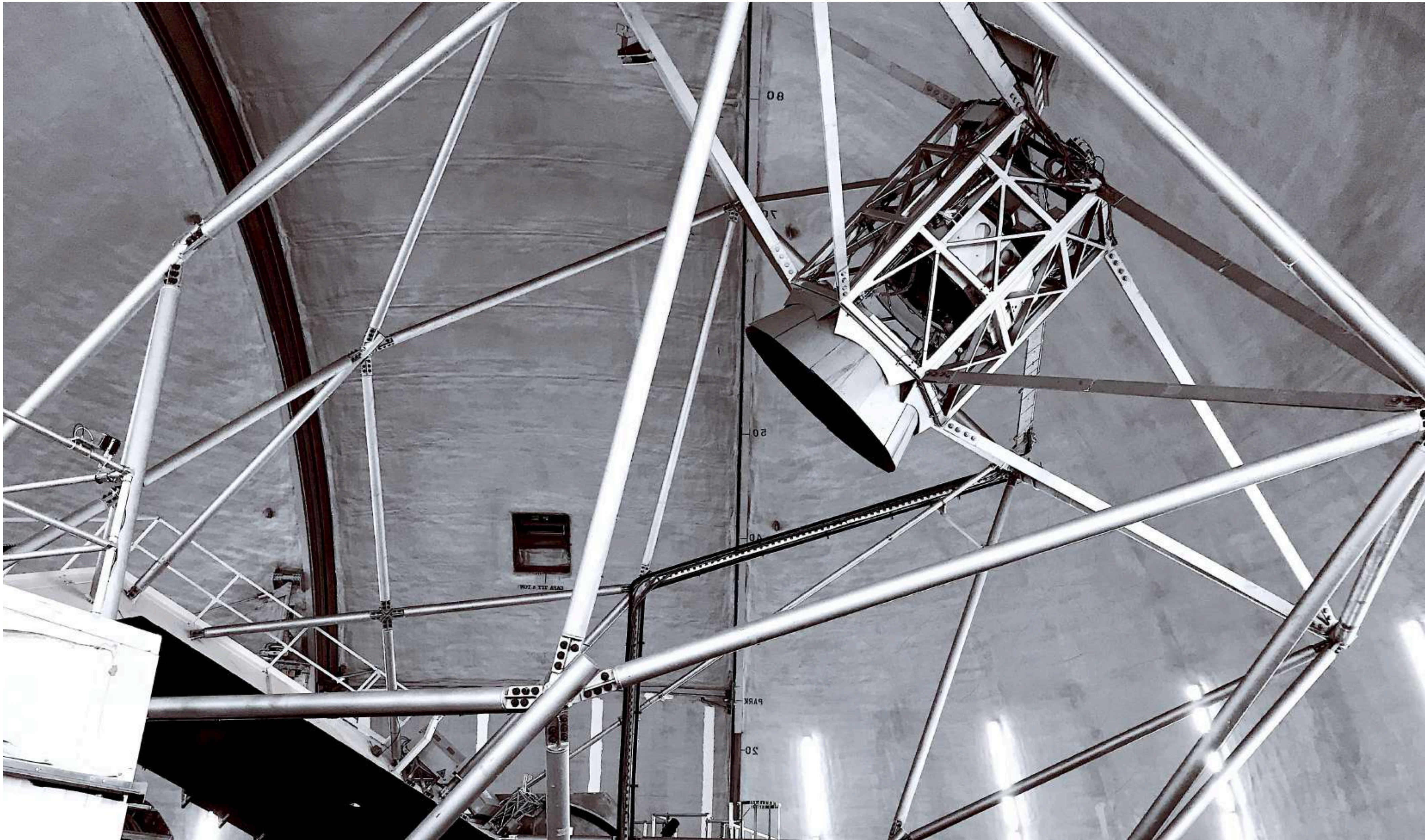
Prime focus wide-field optical imager

What is KWFI?

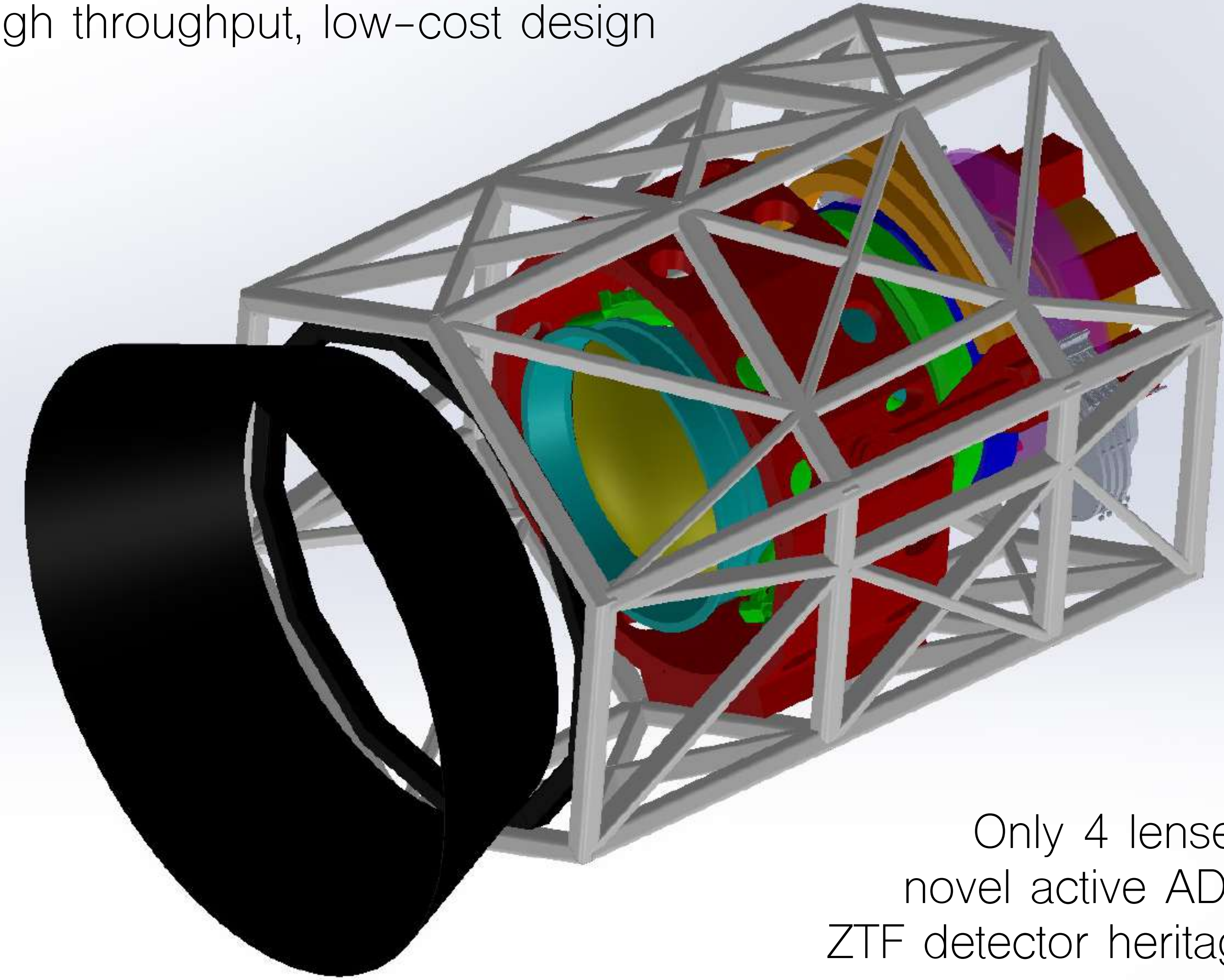
Prime focus wide-field optical imager



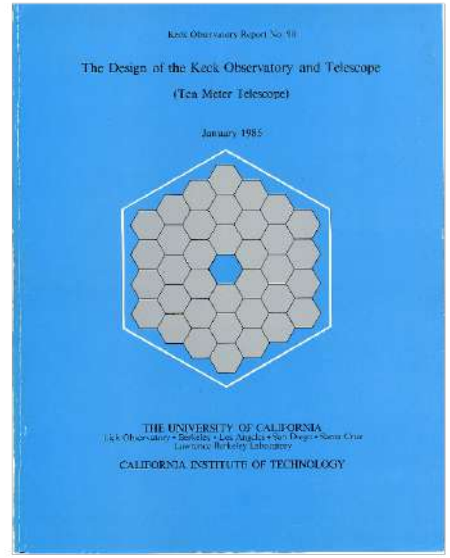
Keck was designed for a prime focus wide-field camera

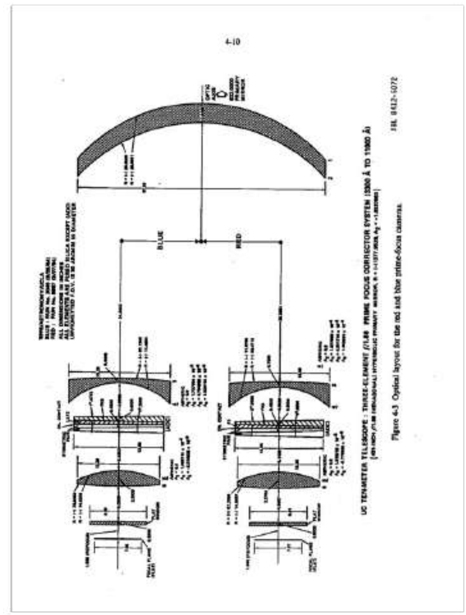
What is KWFI?

High throughput, low-cost design

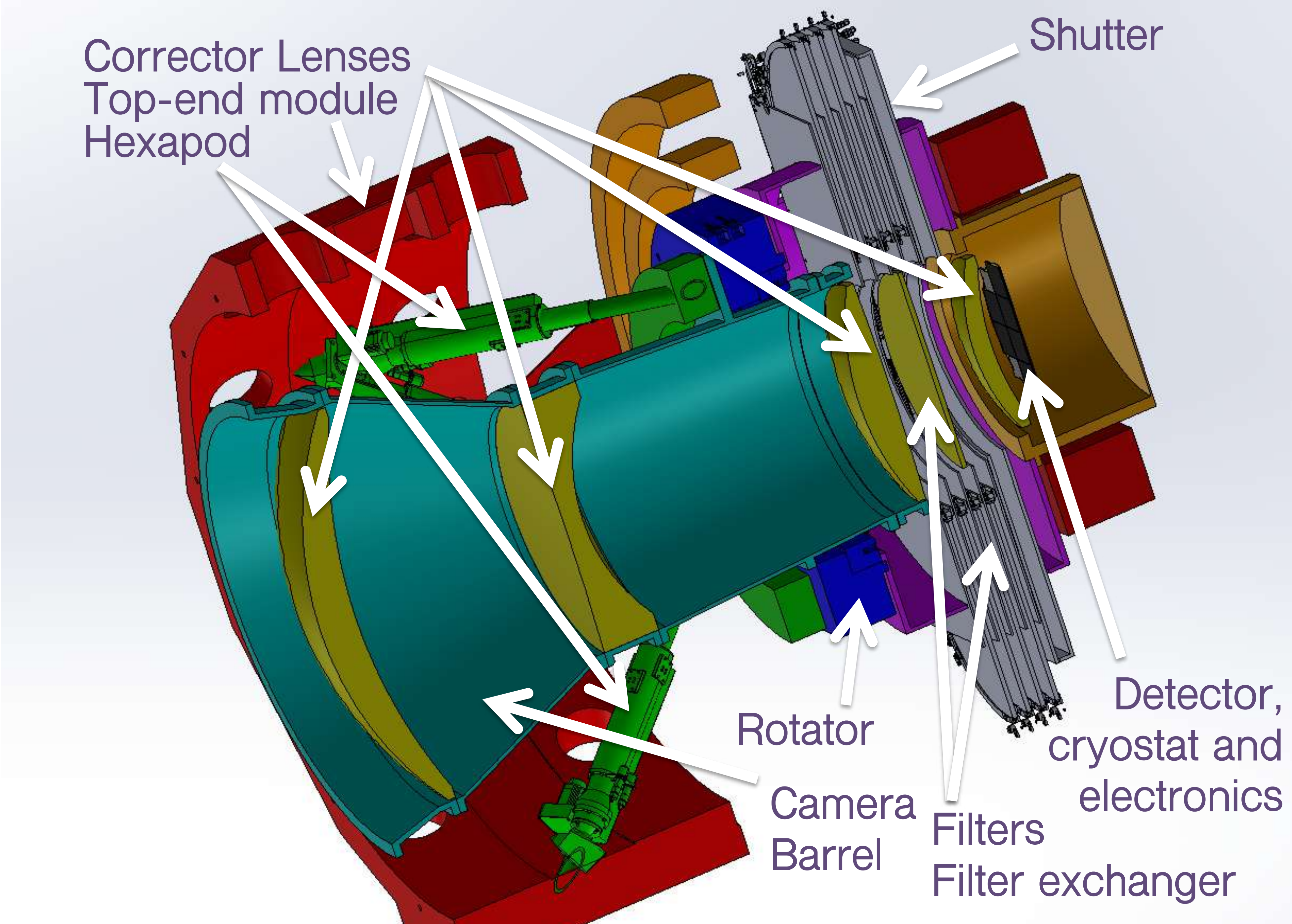


Only 4 lenses,
novel active ADC,
ZTF detector heritage



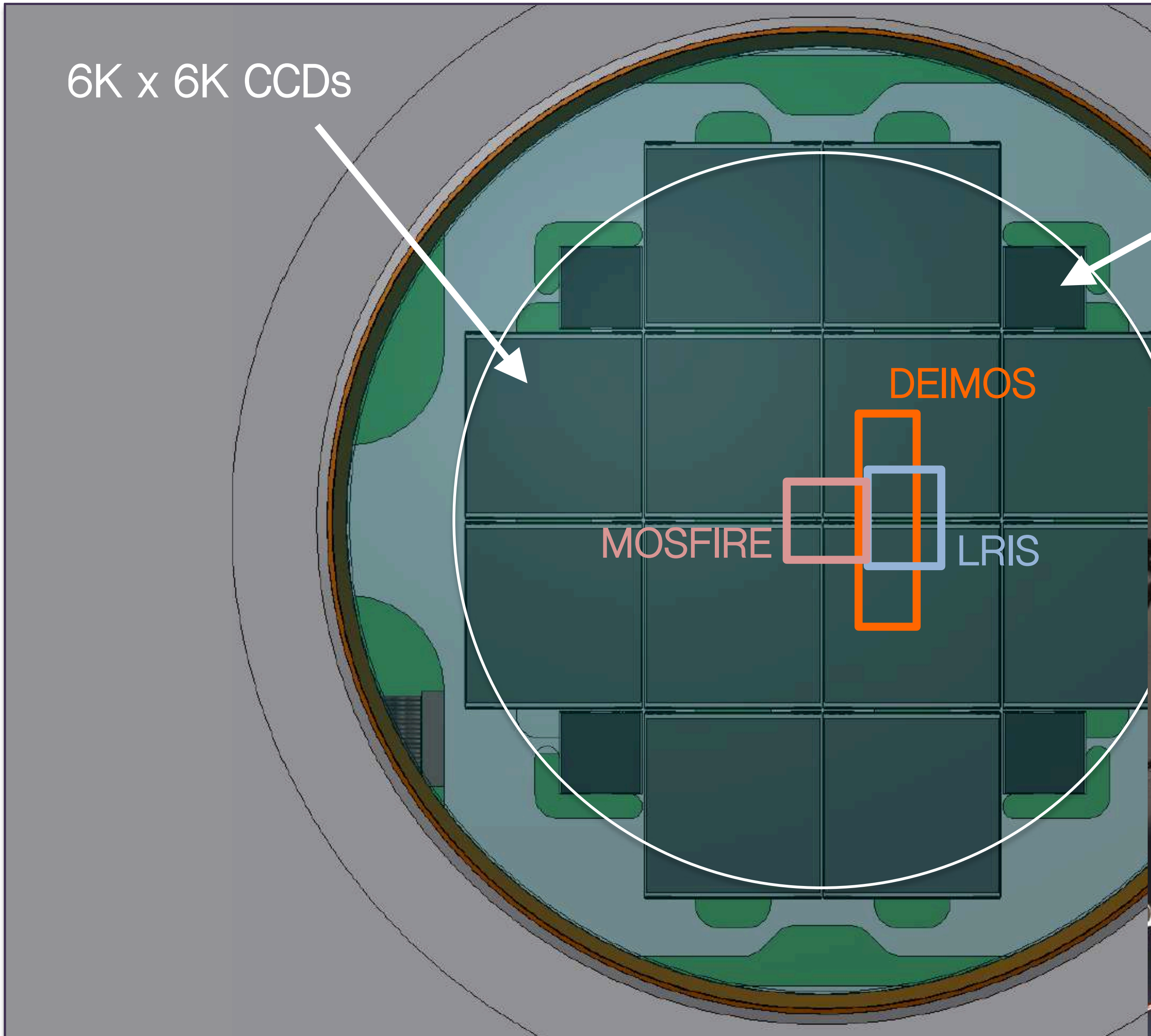


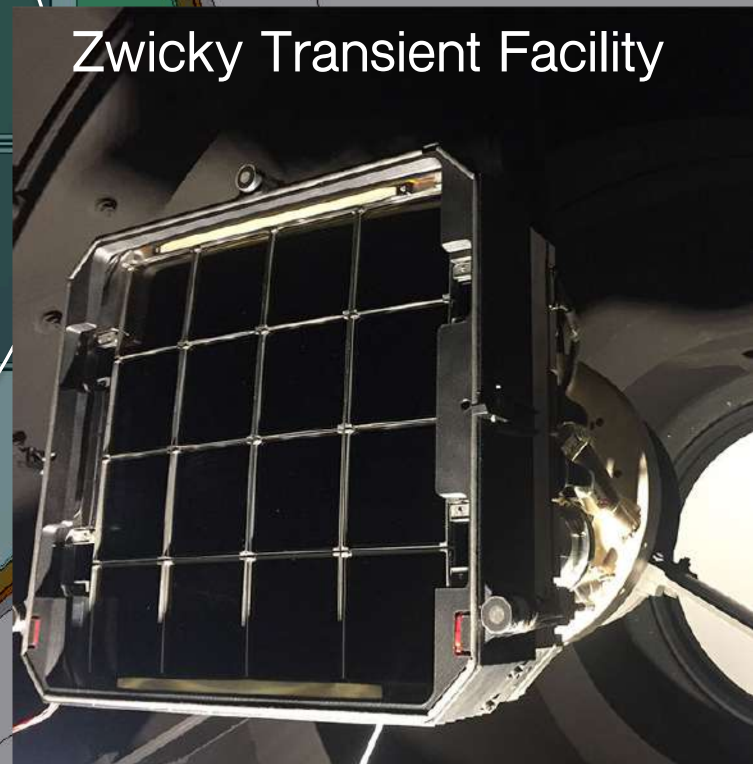
What is KWFI?


Corrector Lenses
Top-end module
Hexapod
Shutter
Rotator
Camera
Barrel
Filters
Filter exchanger
Detector,
cryostat and
electronics

1-degree diameter field of view

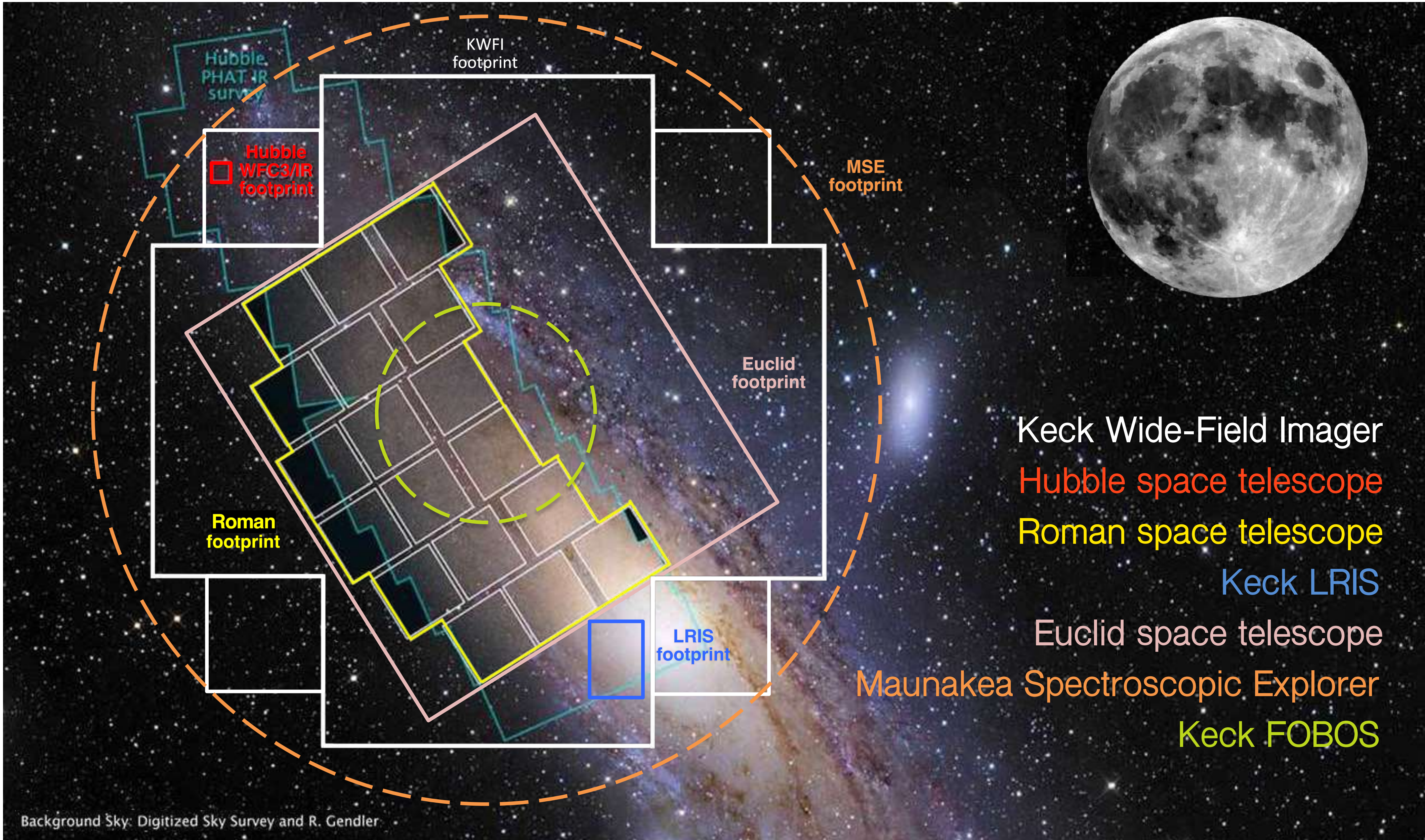
What is KWFI?





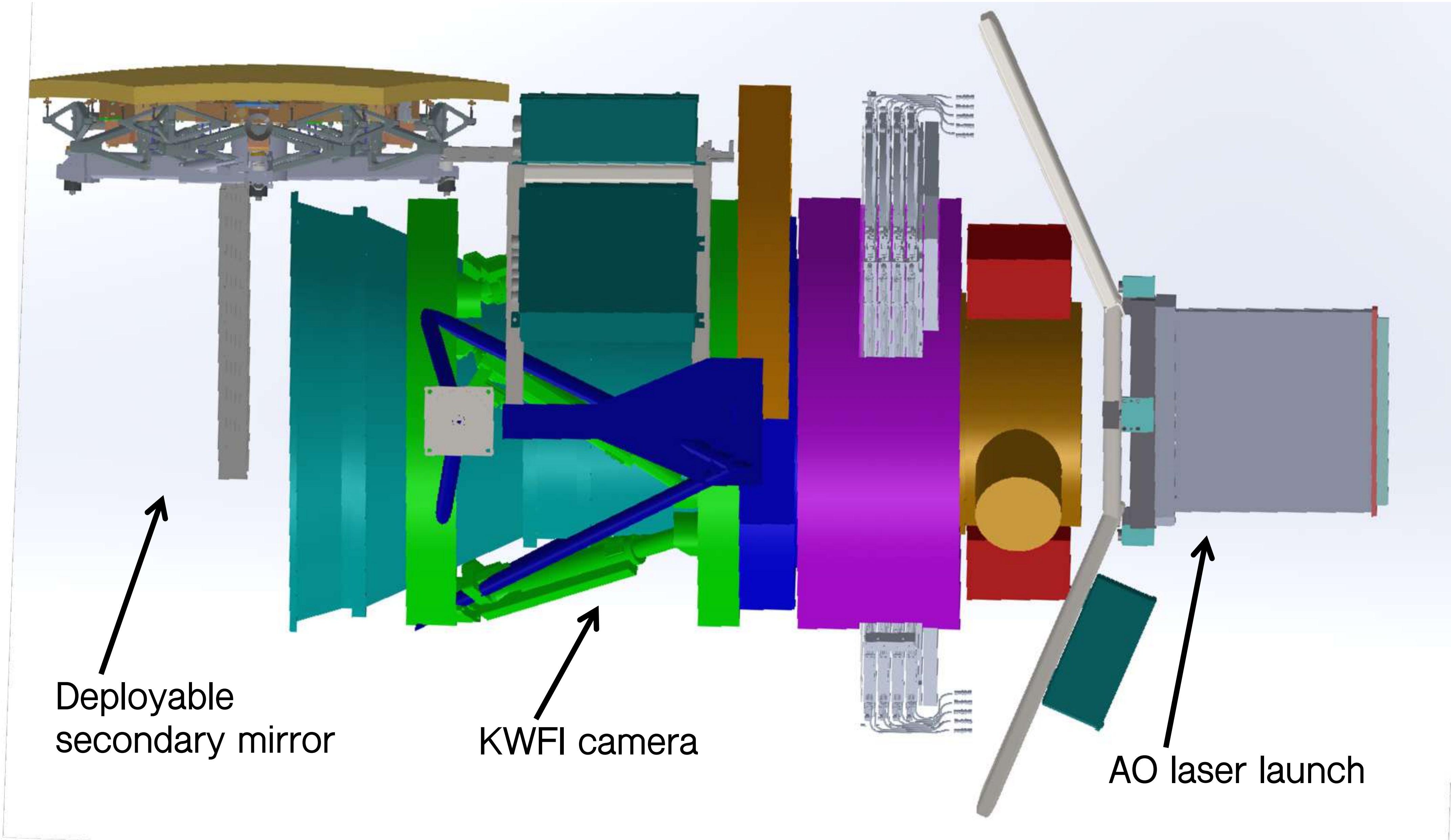
1-degree diameter field of view

What is KWFI?



Enabling new science and fast science

What is KWFI?



Landscape and Urgent Need

Why KWFI?

Wide-field imagers are **fundamental to astronomy** and underpin nearly all research areas, including all wavelengths (i.e., source detection, host galaxies, etc.).

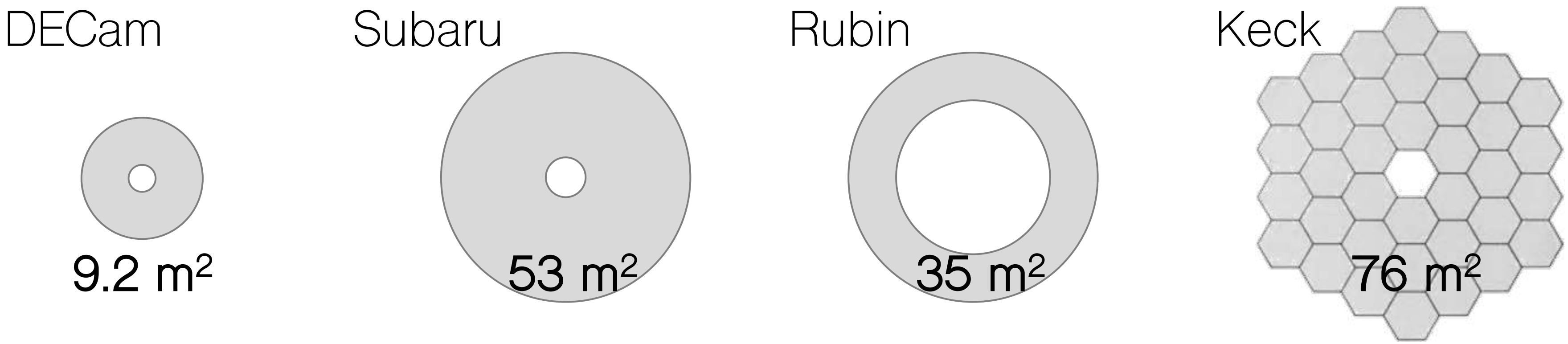
Wide-field imagers are **very high, or the highest, demand instruments** on their respective telescopes

KWFI will be a **facility instrument** for discovery and science essential to upcoming facilities and instruments, as well as unique science no other telescope can do, **not even 30m telescopes.**

Landscape now to 5 years and beyond:

Upcoming wide-field spectrographs **Keck FOBOS**, **Maunakea Spectroscopic Explorer** (MSE), and **Subaru Prime Focus Spectrograph** (PFS)**,** upcoming mega-facilities, including the **Square Kilometre Array** *(ASKAP, MeerKAT, MWA)*, **Cherenkov Telescope Array, KM3NeT,** the **TMT**, **GMT**, **E-ELT**, and **James Webb Space Telescope,** current gravitational wave detectors, i.e., **LIGO/Virgo/KAGRA/LIGO-India,** and next-generation gravitational wave detectors (**CE, ET, LISA**), the **Roman** and **Euclid** wide-field IR space telescopes, and others.

Existing and future wide-field images *(circa 2027)*



Current wide-field (> 0.5 deg) optical imagers on 4m+ class telescopes

CFHT Megacam
3.6m – 1 deg

CTIO DECam
4.0m – 2.2 deg

Subaru Hyper-SuprimeCam
8.2m – 1.5 deg

Future wide-field imagers on 4m+ class telescopes

Vera C. Rubin Observatory
6.5m – 3.5 deg

Why KWFI?

Existing and future wide-field imagers *(circa 2027)*

Current wide-field (> 0.5 deg) optical imagers on 4m+ class telescopes

CFHT Megacam
3.6m – 1 deg
[Maunakea Spectroscopic Explorer (MSE)]

CTIO DECam
4.0m – 2.2 deg
[Poor u-band sensitivity]

Subaru Hyper-SuprimeCam
8.2m – 1.5 deg
[No u-band, optics shared with Prime focus spectrograph (PFS)]

Future wide-field imagers on 4m+ class telescopes

Vera C. Rubin Observatory
6.5m – 3.5 deg
[Poor u-band, 10 yr survey, no individual programs, (~1-2%) ToO program(?)]

Keck Wide-Field Imager
10.0m – 1.0 deg
Superb u-band throughput
All Northern and 2/3rds Southern sky
ToO/multiplexing capable

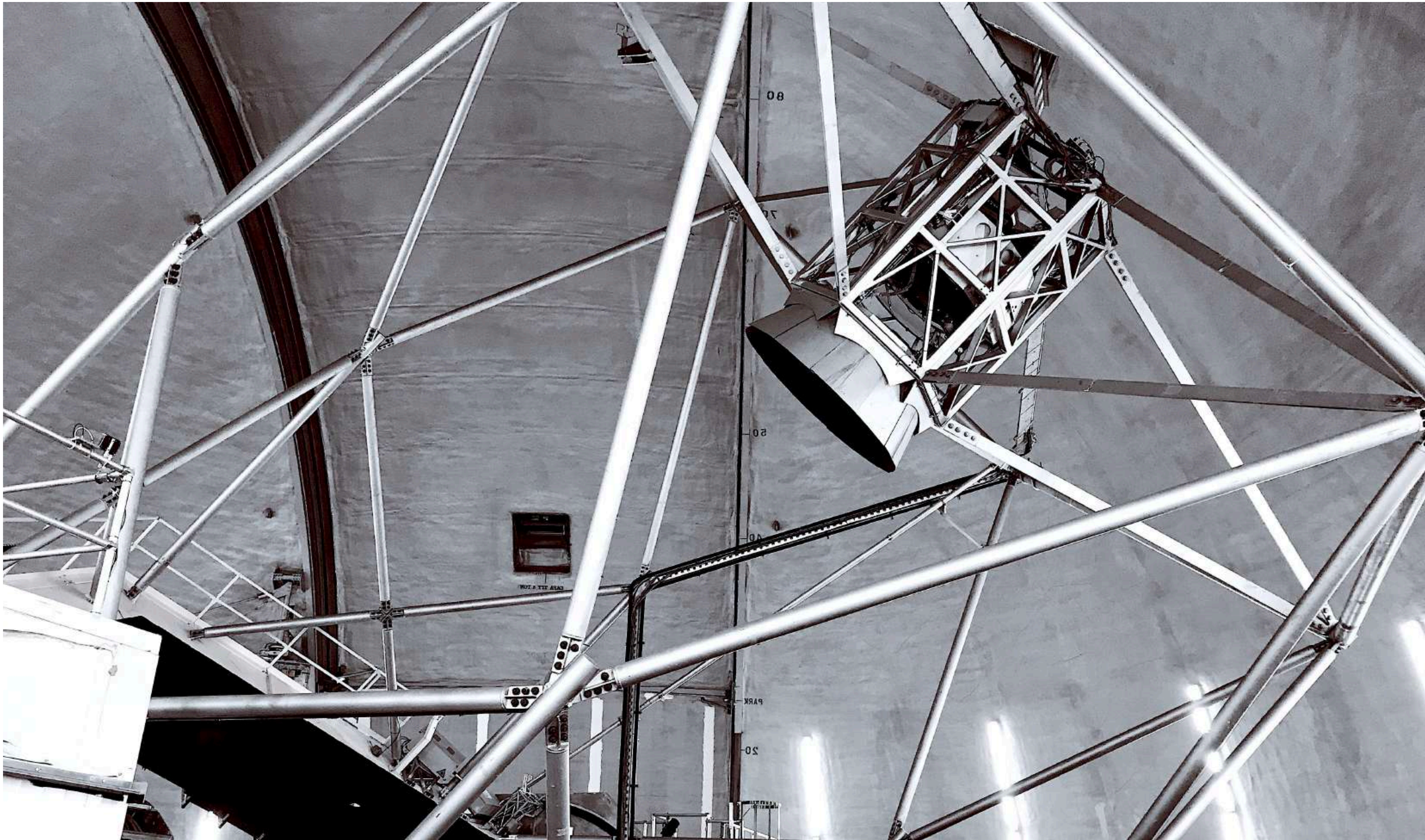
KWFI on Keck – maintaining leadership

Impact of wide-field imagers – *Plot shamelessly stolen from a talk by Hilton*
KWFI will help Keck maintain its leadership in the era of 30m-class telescopes

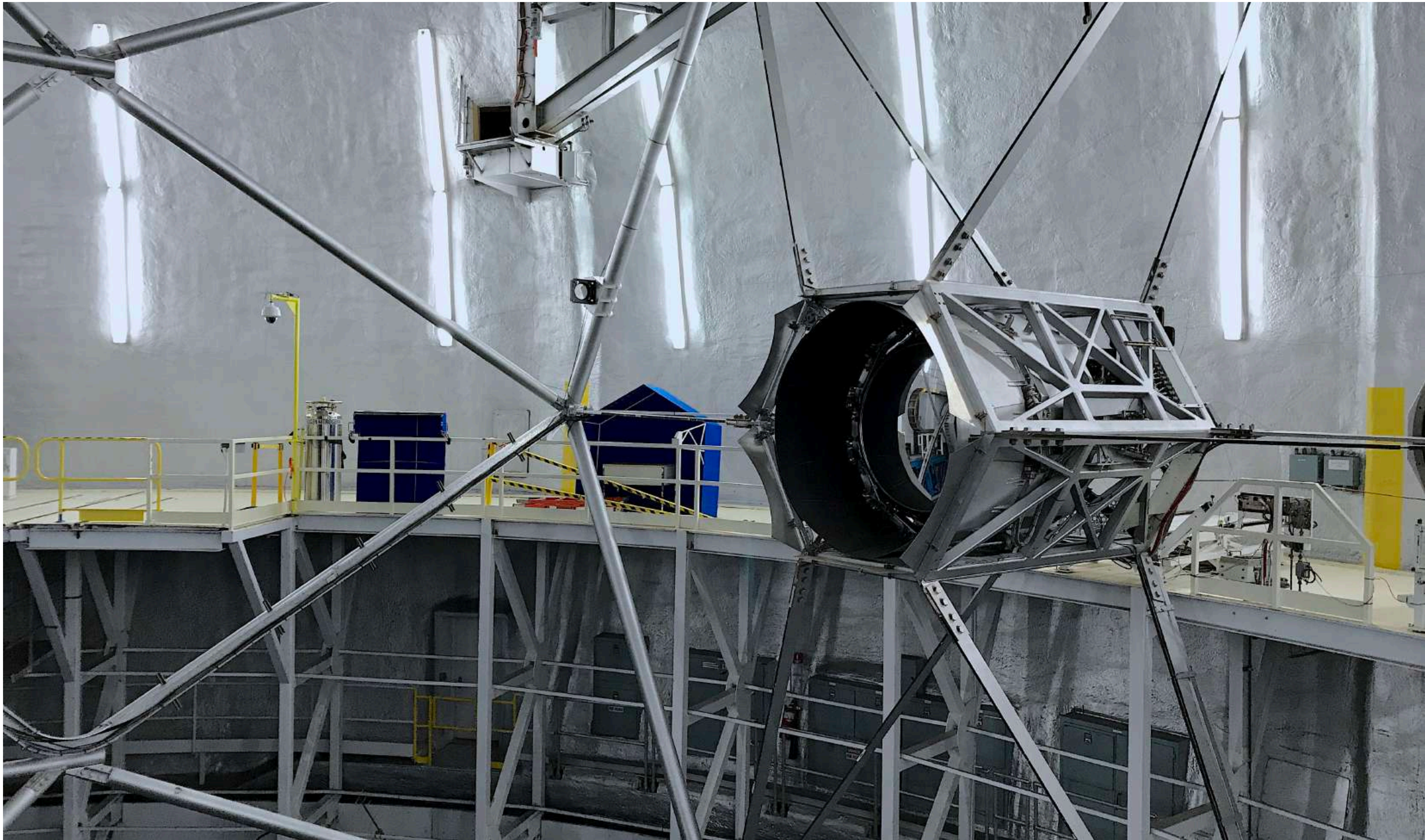
MIPP vs. Total Impact. Color shows sum of % Hip. Size shows sum of P/T. The marks are labeled by Telescope.

Why KWFI?

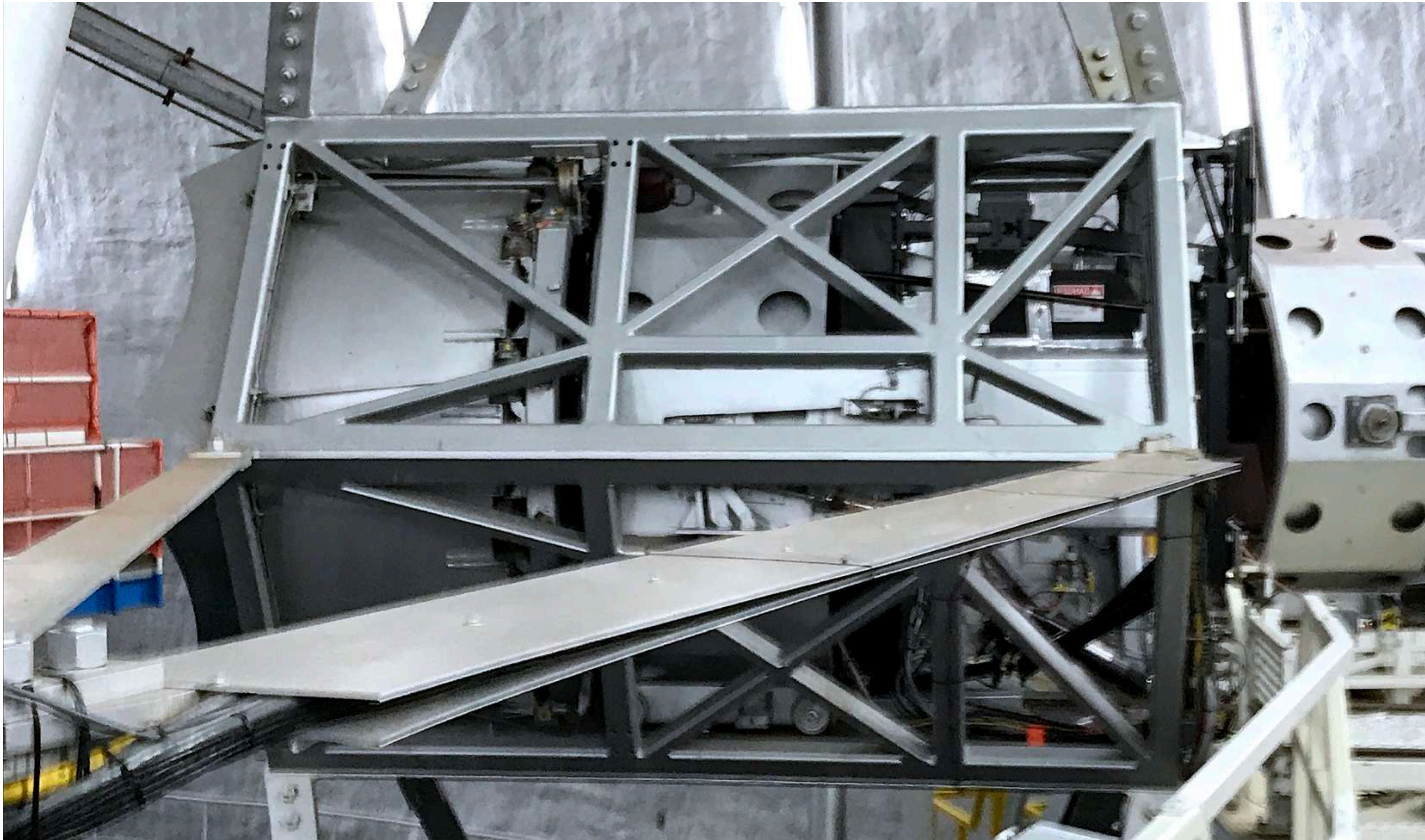
Modular design – no top-end restructuring



Modular design – no top-end restructuring

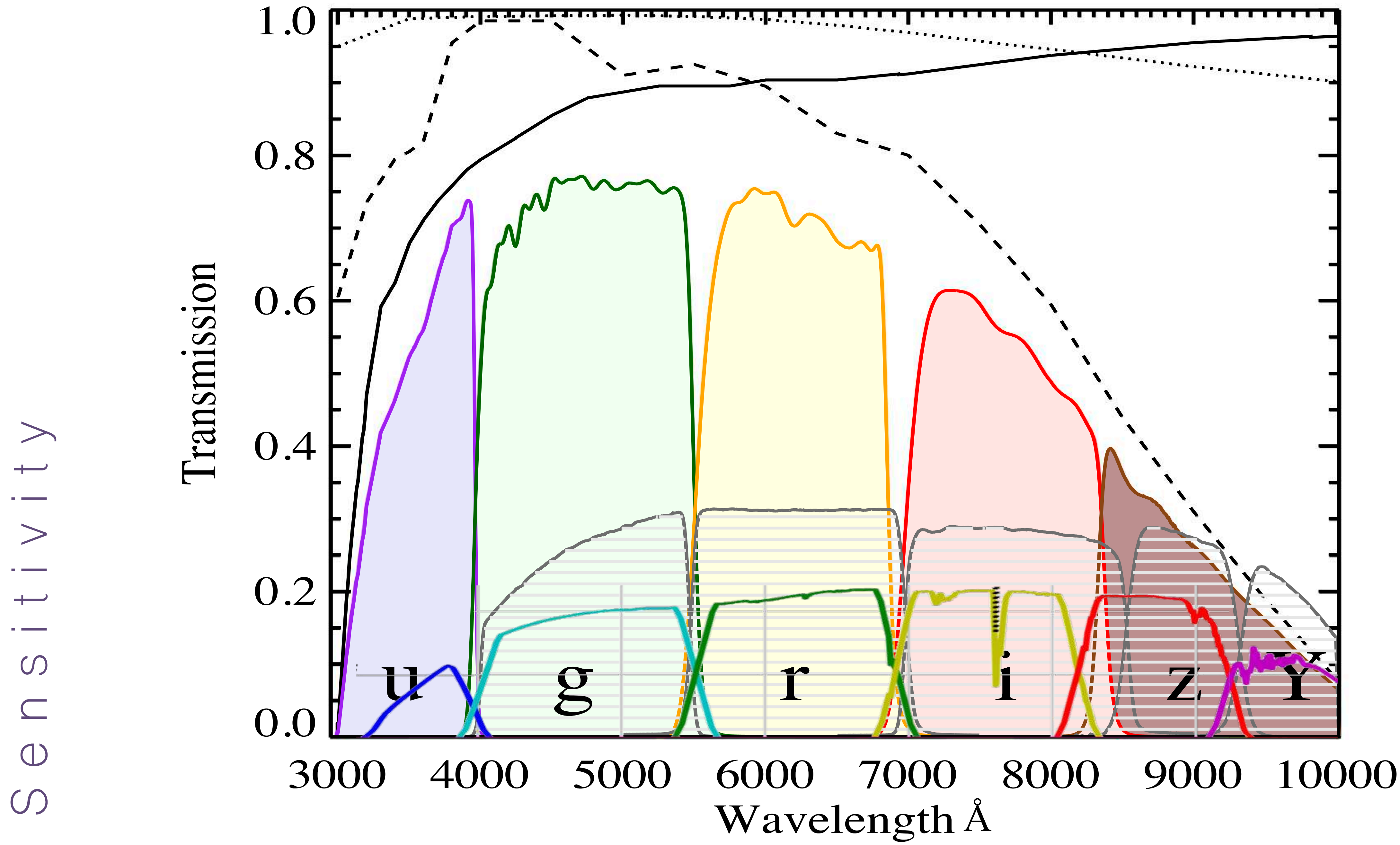


Modular design – no top-end restructuring



Modular design – no top-end restructuring

4145 m – Unparalleled UV transmission


Sensitivity
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
u
g
r
i
z
Y
3000
4000
5000
6000
7000
8000
9000
10000
Wavelength Å

Groundbreaking depths, unparalleled UV sensitivity

Sensitivity

- We need to start thinking in terms of m ~ 29 and 30 *(~10-4 nano-Jy)*
- 0.145" per pixel resolution, < 15 s readout
- 5 Sloan broadband filters, room for 3 user filters, < 15 s filter change
- Extremely deep u-band, sensitive to the near-UV
- Same night instrument multiplexing with deployable secondary
- Real-time data reduction pipeline and analysis

Time	u	g	r	i	z
5 min	26.7	27.0	26.3	25.4	24.3
30 min	27.7	28.0	27.3	26.4	25.3
2 hr	28.4	28.8	28.0	27.1	26.0
20 hr	29.7	30.0	29.3	28.4	27.3

5 sigma depths, 0.8" FWHM seeing, 3 days from New Moon

For comparison, HSC Ultra-Deep survey: no u g = 28.4 r = 28.0 i = 27.7 z = 27.1

Groundbreaking depths, unp

- We need to start thinking in terr
- 0.145" per pixel resolution, < 1
- 5 Sloan broadband filters, roon
- Extremely deep u-band, sensit
- Same night instrument multiple
- Real-time data reduction pipeli

Throughput:

- 5-sigma point source depth: Single exposure and idealized for stationary sources after 10 years, **LSST** — **KWFI**
  - u : 23.9, 26.1 — 2 min
  - g : 25.0, 27.4 — 10 min
  - r : 24.7, 27.5 — 45 min
  - i : 24.0 , 26.8 — 70 min
  - z : 23.3, 26.1 — 150 min

Sensitivity

Time	u	g			
5 min	26.7	27.0			
30 min	27.7	28.0	27.3	26.4	25.3
2 hr	28.4	28.8	28.0	27.1	26.0
20 hr	29.7	30.0	29.3	28.4	27.3

5 sigma depths, 0.8" FWHM seeing, 3 days from New Moon

For comparison, HSC Ultra-Deep survey: no u g = 28.4 r = 28.0 i = 27.7 z = 27.1

Science only possible with KWFI

Science

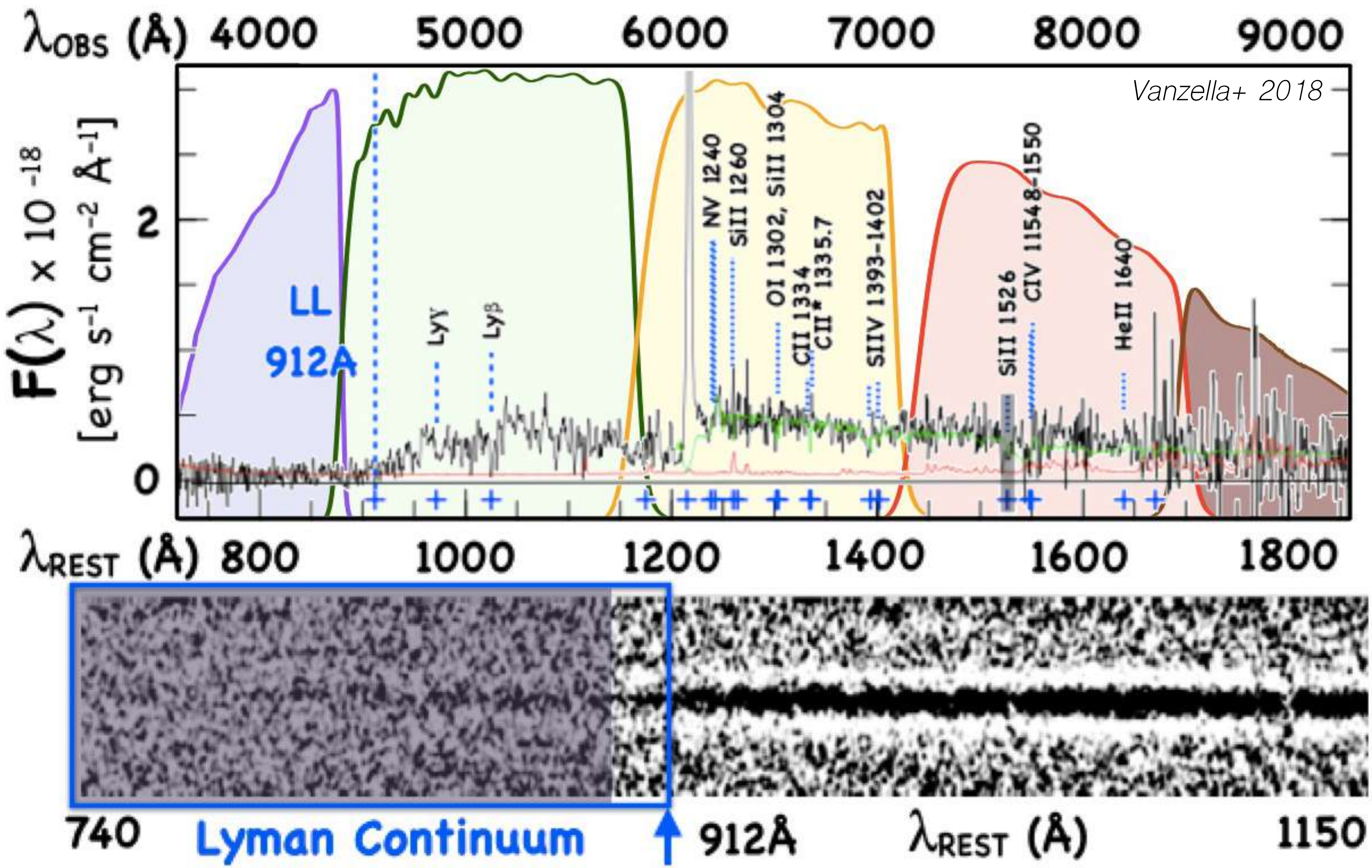
- Reionization: Lyman continuum from z ~ 3-4 galaxies
  Can only be done at z ~ 3-4, Lyman continuum is in the u-band (needs m ~ 28-30 in u-band)
- 5-detector and next-gen gravitational wave follow up *(CE, ET, LISA)*
  Current BNS and NSBH require 4-8m, future events farther/fainter but more localised
- Rare and faint (m ~ 28-30) targets for JSWT and 30m aperture telescopes
  Lensed galaxies, rare sources, high-z galaxies and massive galaxy clusters
- Wide-field IR space missions Roman & Euclid that are missing 3000-5500A coverage
  Need very deep (m ~ 28-29) optical wide-field imaging for weak-lensing, phot-zs, etc.
- Upcoming wide-field spectrographs, e.g., MSE *(1.2 deg) Australia is invested*
  High density spectroscopic targets, faint-end populations, mixed populations
- Extragalactic FRB counterparts and fast transient physics *(fast m > 27, ~50 nJy, CMOS msec)*
- z ~ 2-4 supernovae, PISNe, and the first stars *(characterise FUV for z ~ 7 - 20)*
- CGM and Lya, MgII, OVI emission at z ~ 2-4 *(wide, very deep blue narrowband)*
- Large-scale structure, galaxy populations, luminosity function faint end slope, etc..
- Globular cluster efficient selection and metallicity beyond Local Group
- Milky Way, Local Group stellar population selection, low metallicity stars
- Ultra compact, ultra diffuse, low surface brightness galaxy selection
- Faint/diffuse solar system objects, NEOs, TNOs, KBOs, comet outgassing, etc.

Reionisation and the first stars

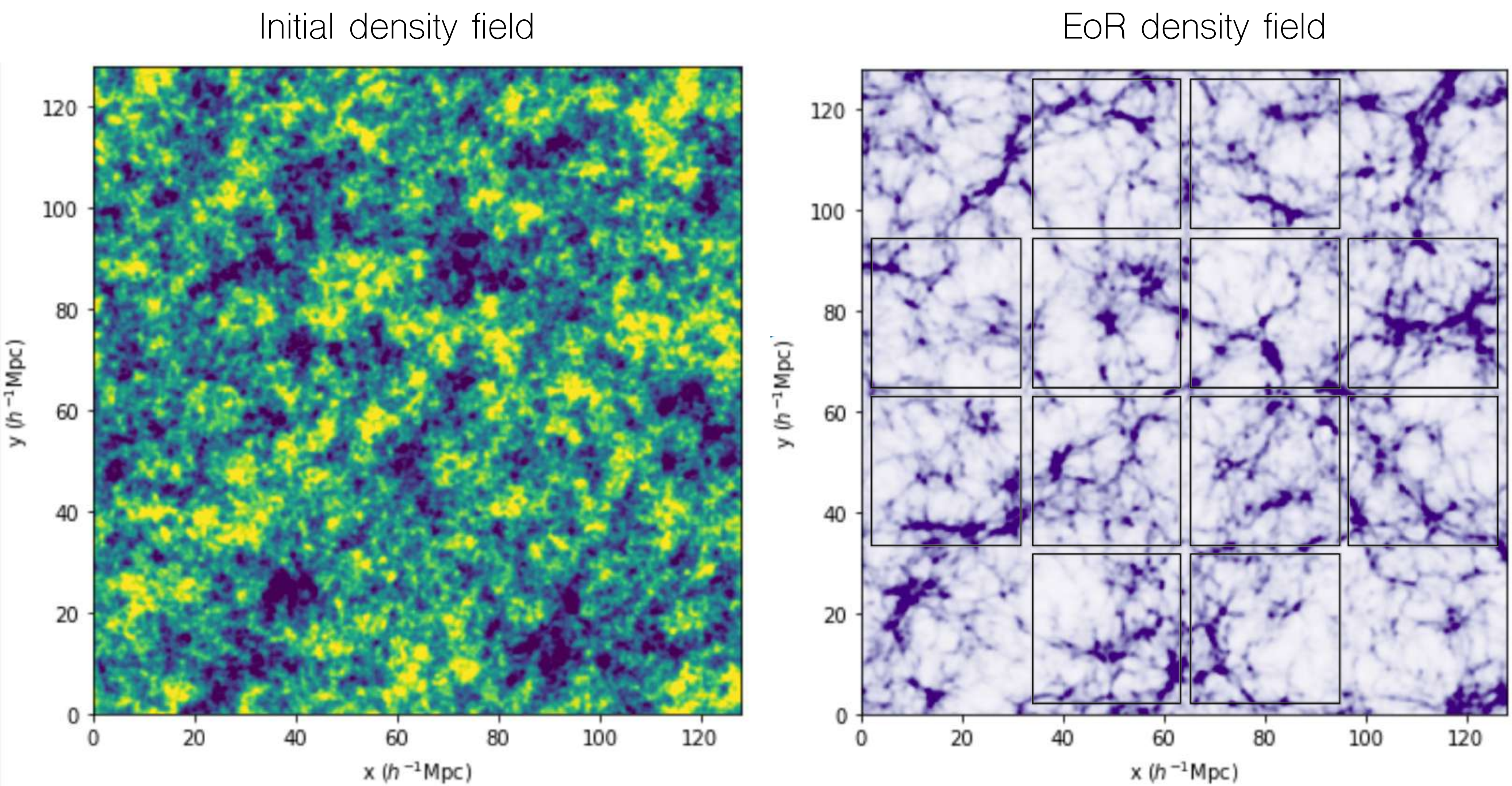
ASTRO 3D

Science

Reionisation and the first stars

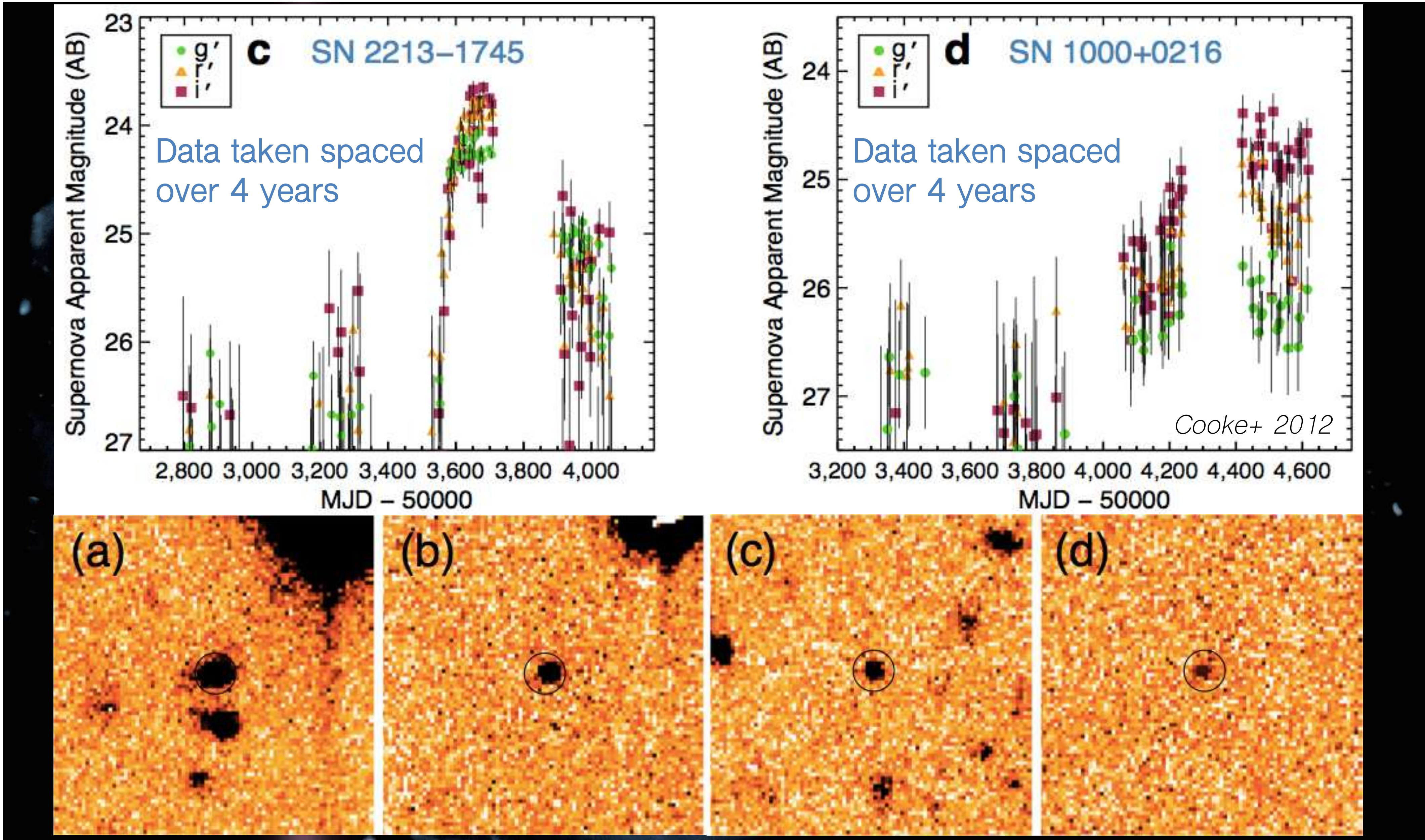


Reionisation and the first stars



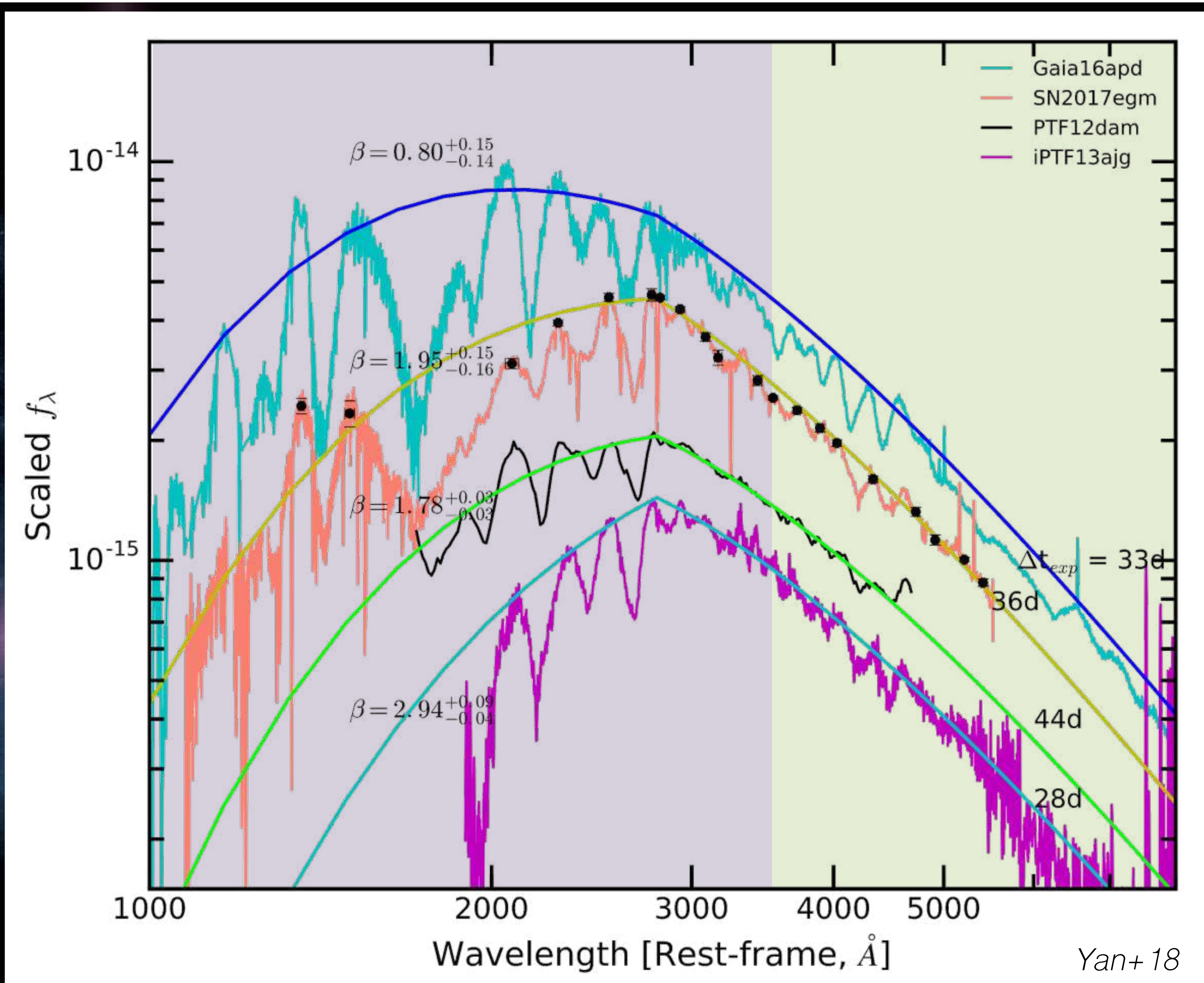
Science

Reionisation and the first stars



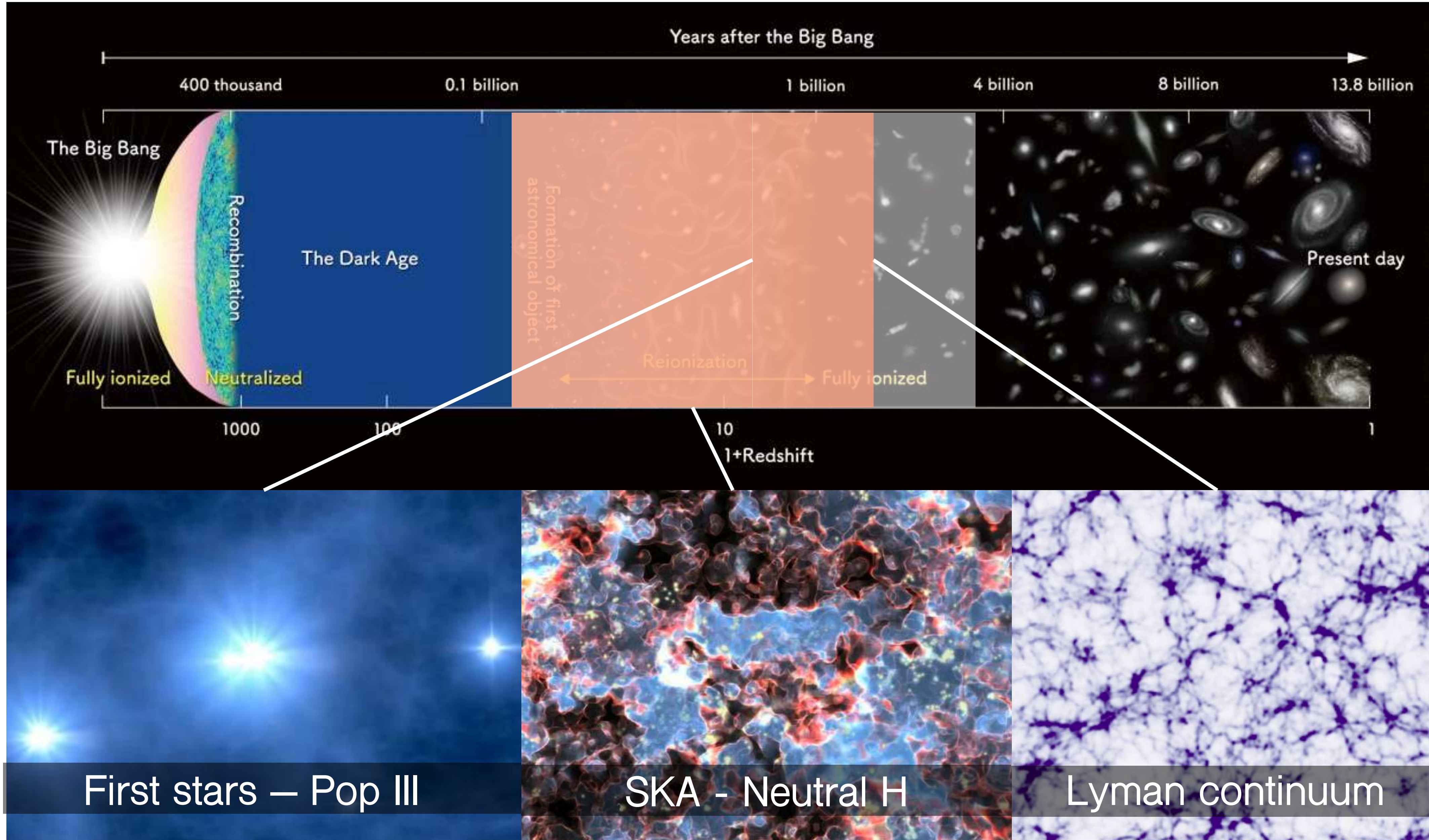
Science

Reionisation and the first stars



Science

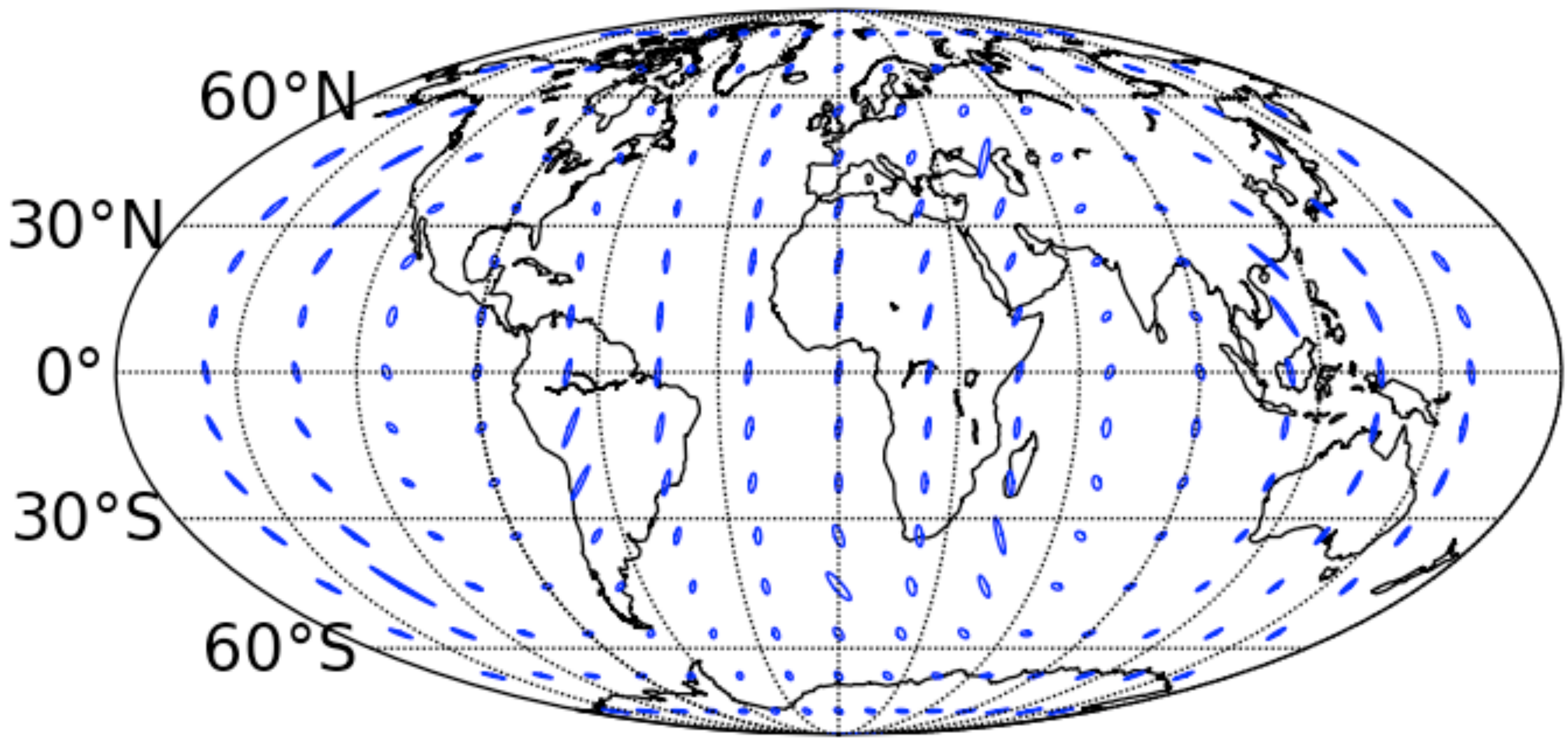
Reionisation and the first stars



Science

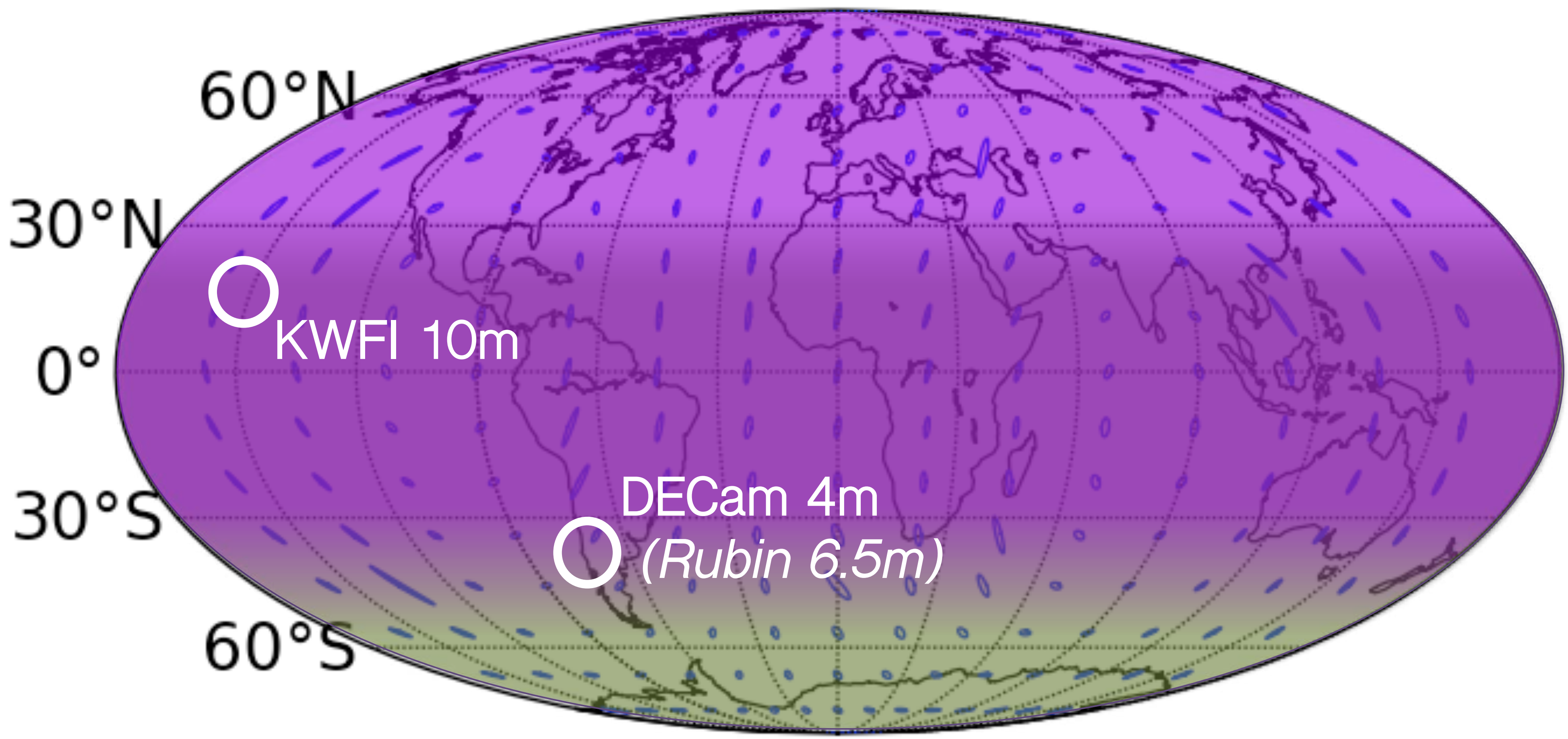
Gravitational waves – *location, location, location*

5-detectors in 2027+ will localise events to 9-30 deg^2



Gravitational waves — *sky coverage*

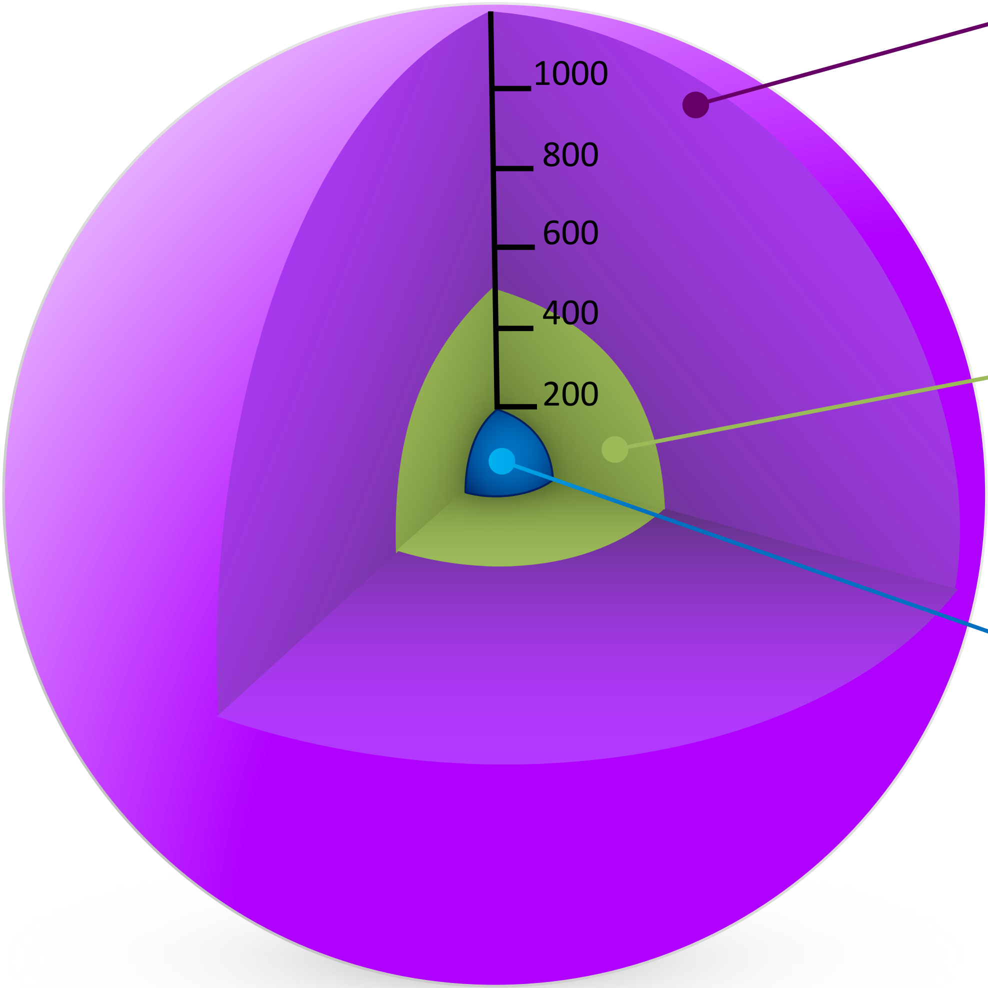
Only KWFI can reach > 90% of kilonovae



2/3rds Southern Hemisphere and all Northern Hemisphere

Science

Gravitational waves — *volume, volume, volume*



Approximate range for GW170817-like events

KWFI — 10m

KWFI will get 100s of times more volume than 1m-class telescope searches. Can get the blue rise of kilonovae, faint NS-BH events and BNS events fainter than GW170817.

DECam — 4m

Can reach some current events, but fewer events out to the distances reached in upcoming runs. Reach for NS-BH events is ~200 Mpc.

1m-class telescopes

Can get GW170817-like events to ~200 Mpc and the expected ~1.5 mag fainter peak NS-BH events to ~80 Mpc.

Science

Very high-energy gamma-ray and particle sources

Science

Fast radio bursts

Science

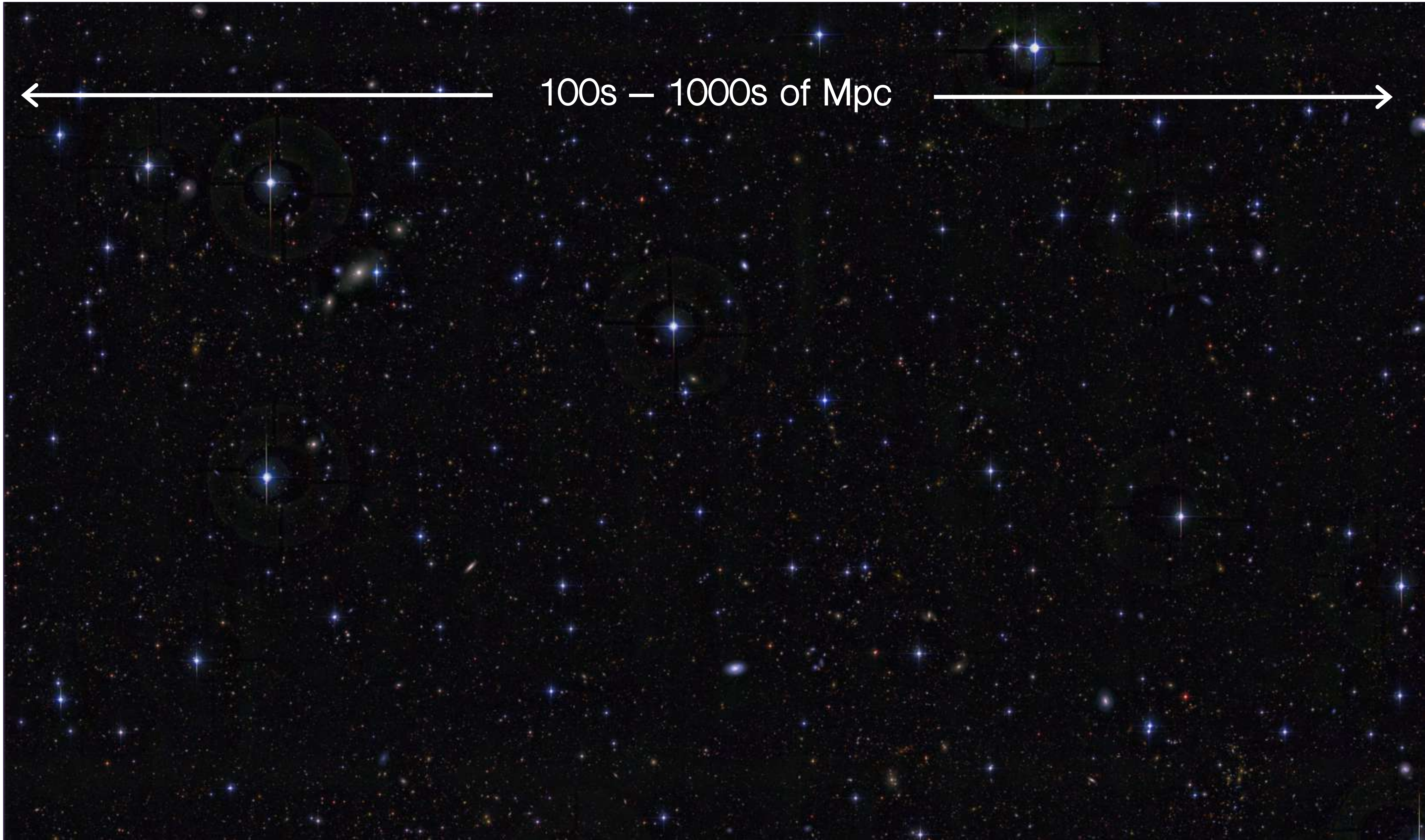
Transients

- Detection and localisation of transients *(GRBs, FRBs, particle sources, GW sources, etc.)*
    - Rapid-response
    - Very faint sources, ultra-long GRBs, etc.
    - Near-real-time data processing and analysis
    - Rapid multiplexing for spectroscopy, IFU spectroscopy, IR imaging, etc.

- Non-ToO transient searches
    - Kilonova searches beyond the LIGO/Virgo horizon
    - Deep UV/optical follow up for faint counterparts and high-z sources
    - Early Universe searches (e.g., CCSNe, SLSNe)

- Coordinated transient searches
    - Faint counterparts to fast events, CMOS (millisecond sampling)
    - Multi-wavelength information on fast events before they fade
    - Off-axis GRB searches
    - Supernova shock-breakout searches
    - Type Ia supernova ejecta collisions with companion stars
    - Stellar mergers
    - Tidal disruption events, etc.

Large-scale structure

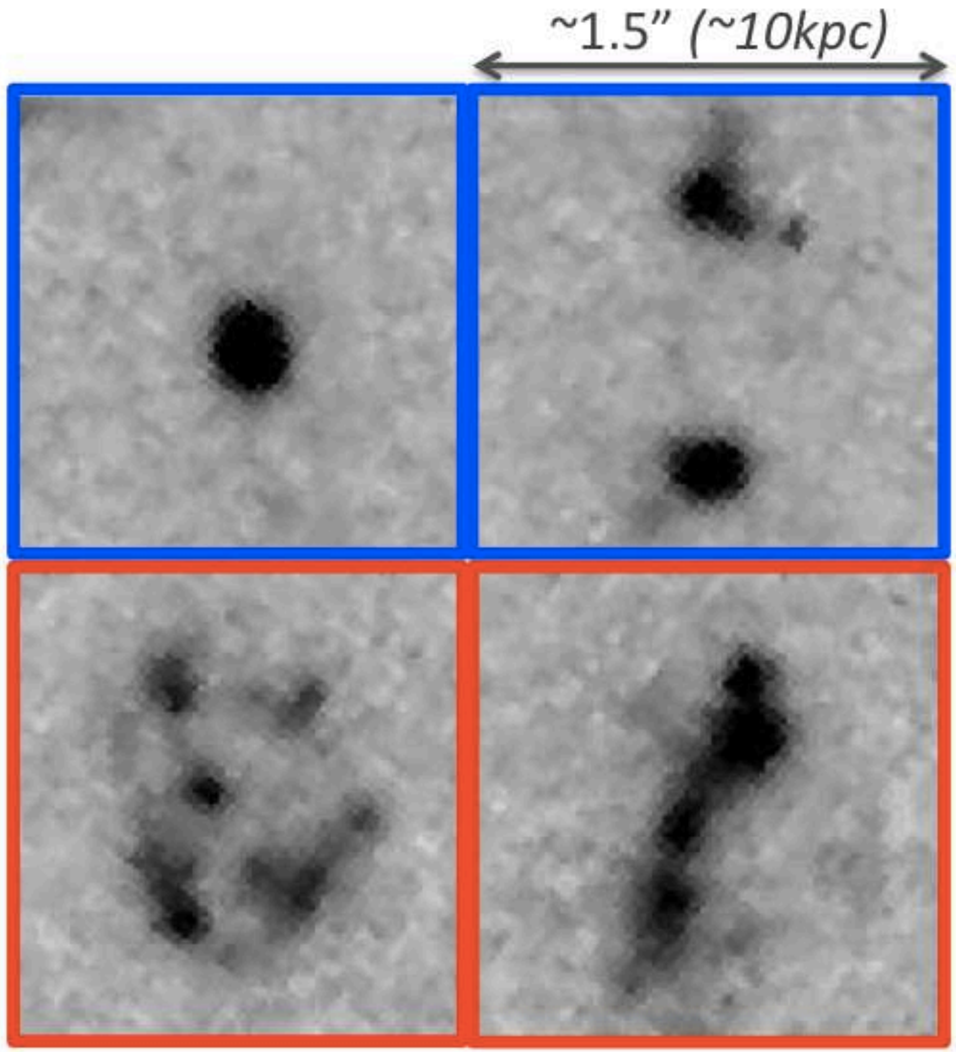


Science

Lyman break galaxies – *the power of broadband*

Properties from broadband photometry

- Morphology
- Kinematics
- Net Lya EW
- ISM line strengths
- Halo mass
- Large-scale environment
- Interactions
- Outflows
- Dust/age
- Star formation rates

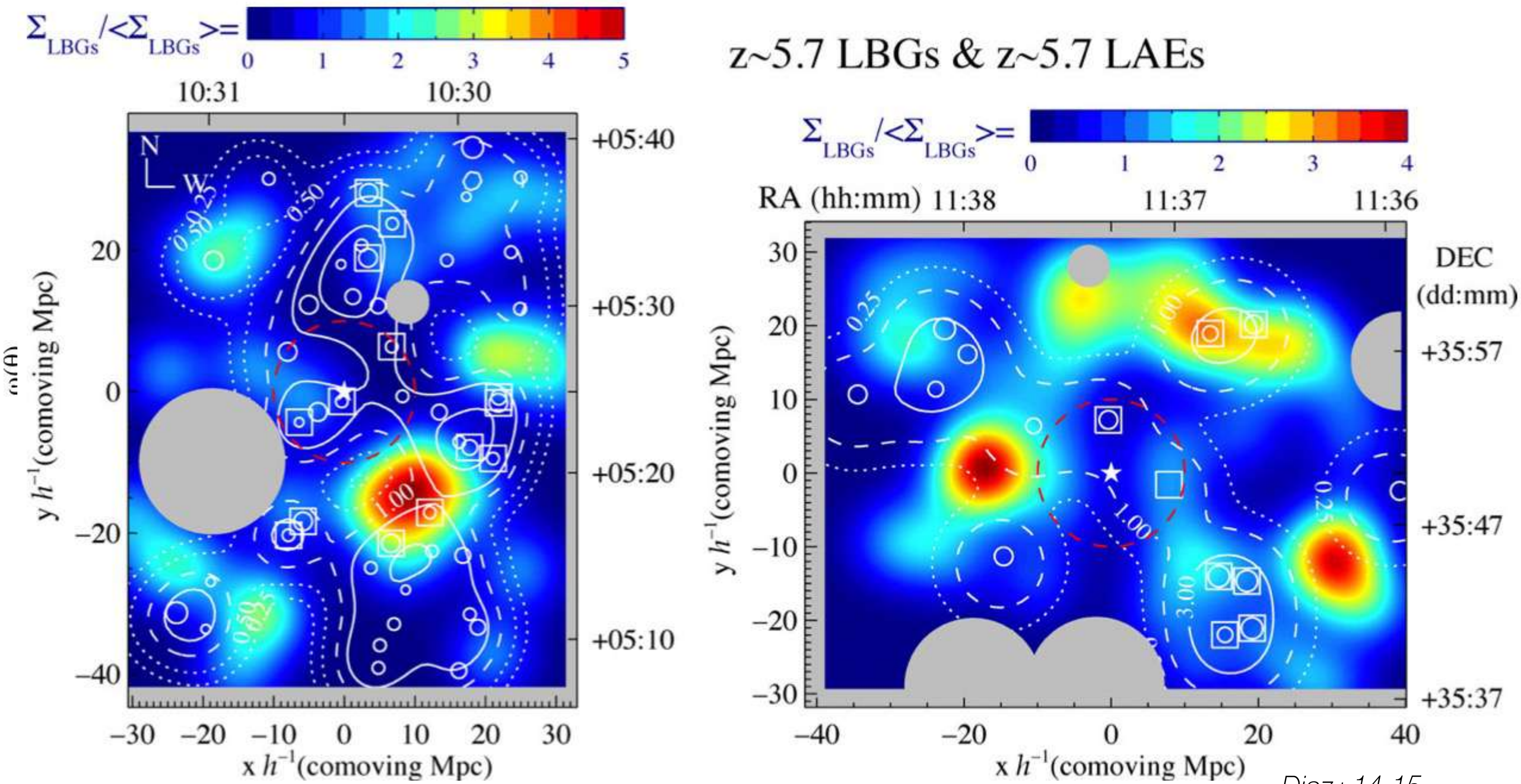


aLBG —— eLBG ——

Shapley+03; Law+ 07,12a,12b; Cooke+ 09,10,13; Foran+ 21a, 21b

Science

Large-scale structure – *environment, MDR*



Diaz+ 14, 15

KWFI depth → LBG/LAE/DLA interface

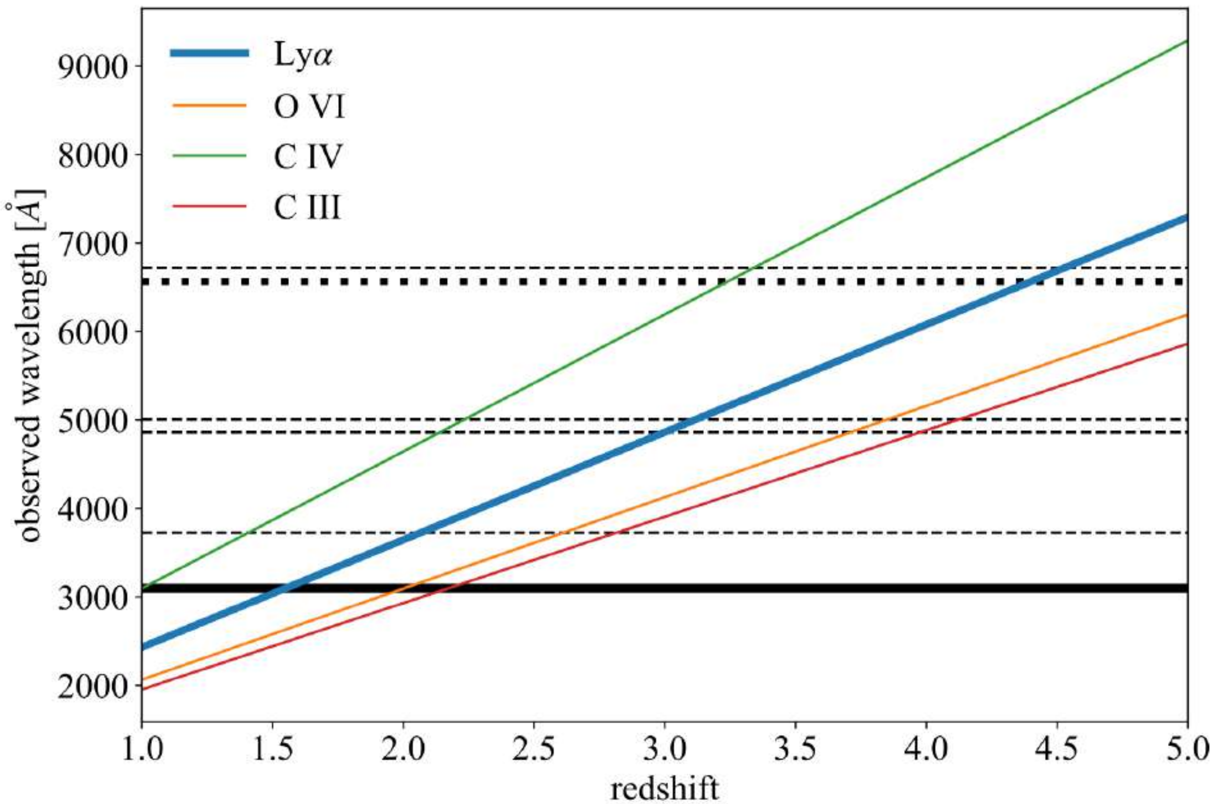
Unique capability for z ~ 1.5 - 2 LAEs

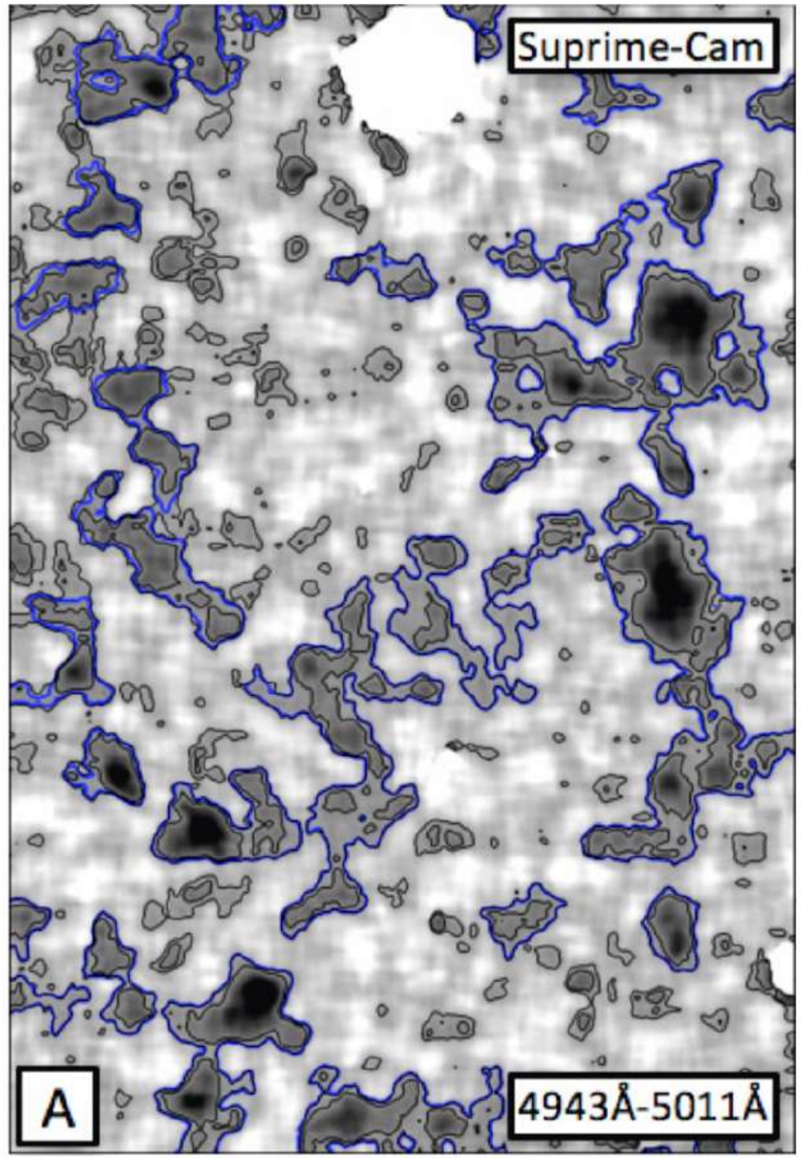
Science

Circumgalactic medium emission

Narrowband to directly image and map faint CGM emission with ~few kpc resolution

Lya at z ~ 1.5-3, MgII at z ~ 0.1-1 (radio accessible), OVI at z ~ 2-3.5
All are inaccessible with any other instrument



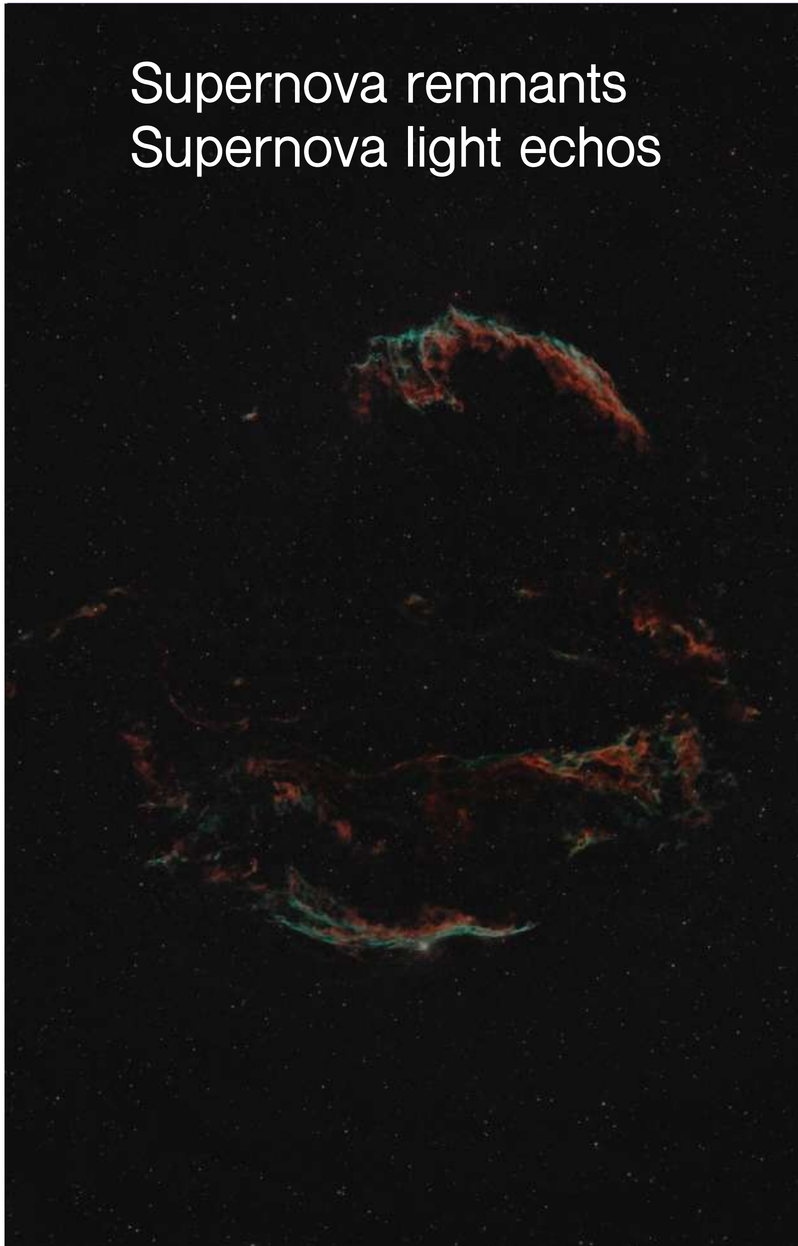


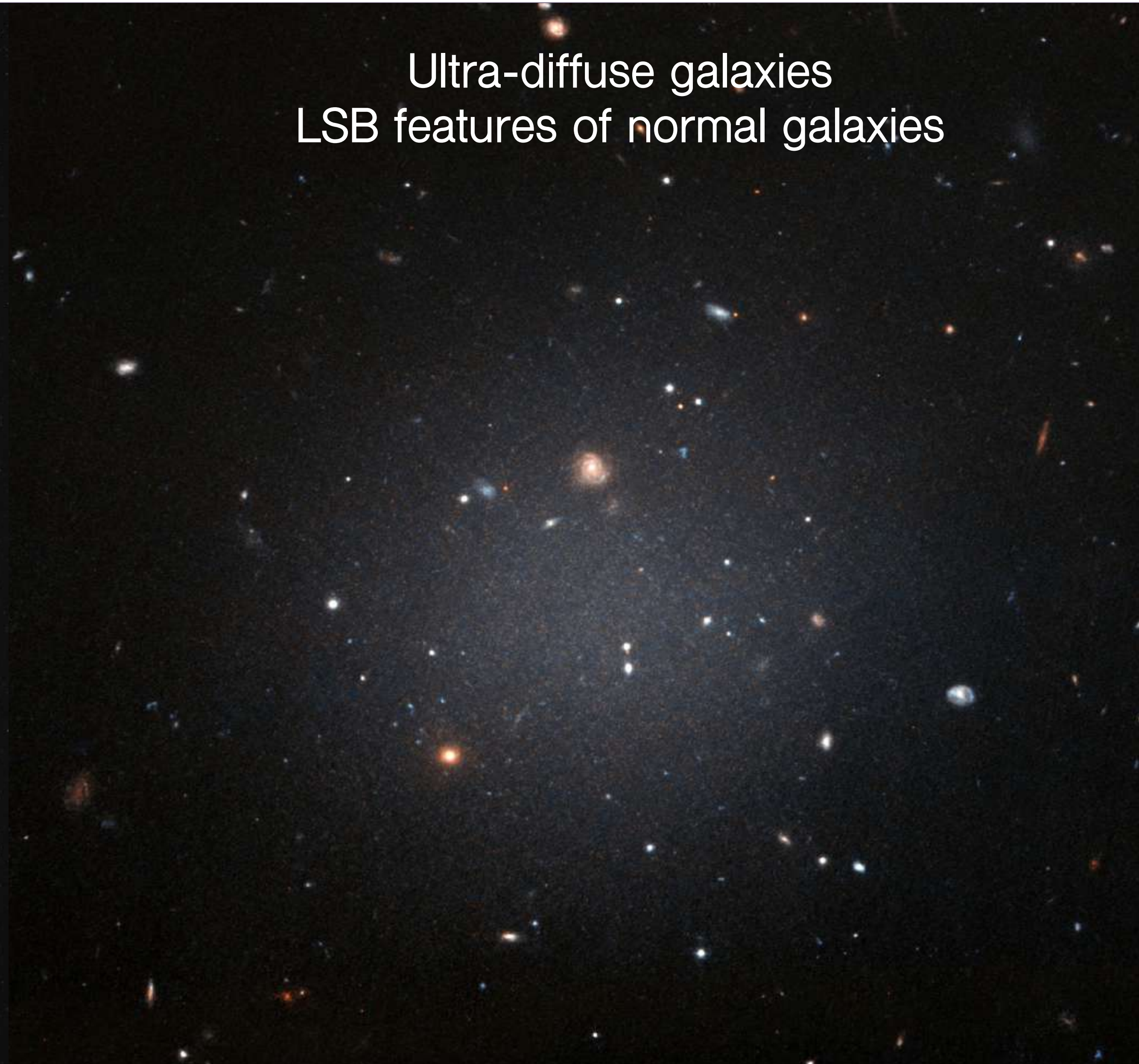
Umehata+19

Science

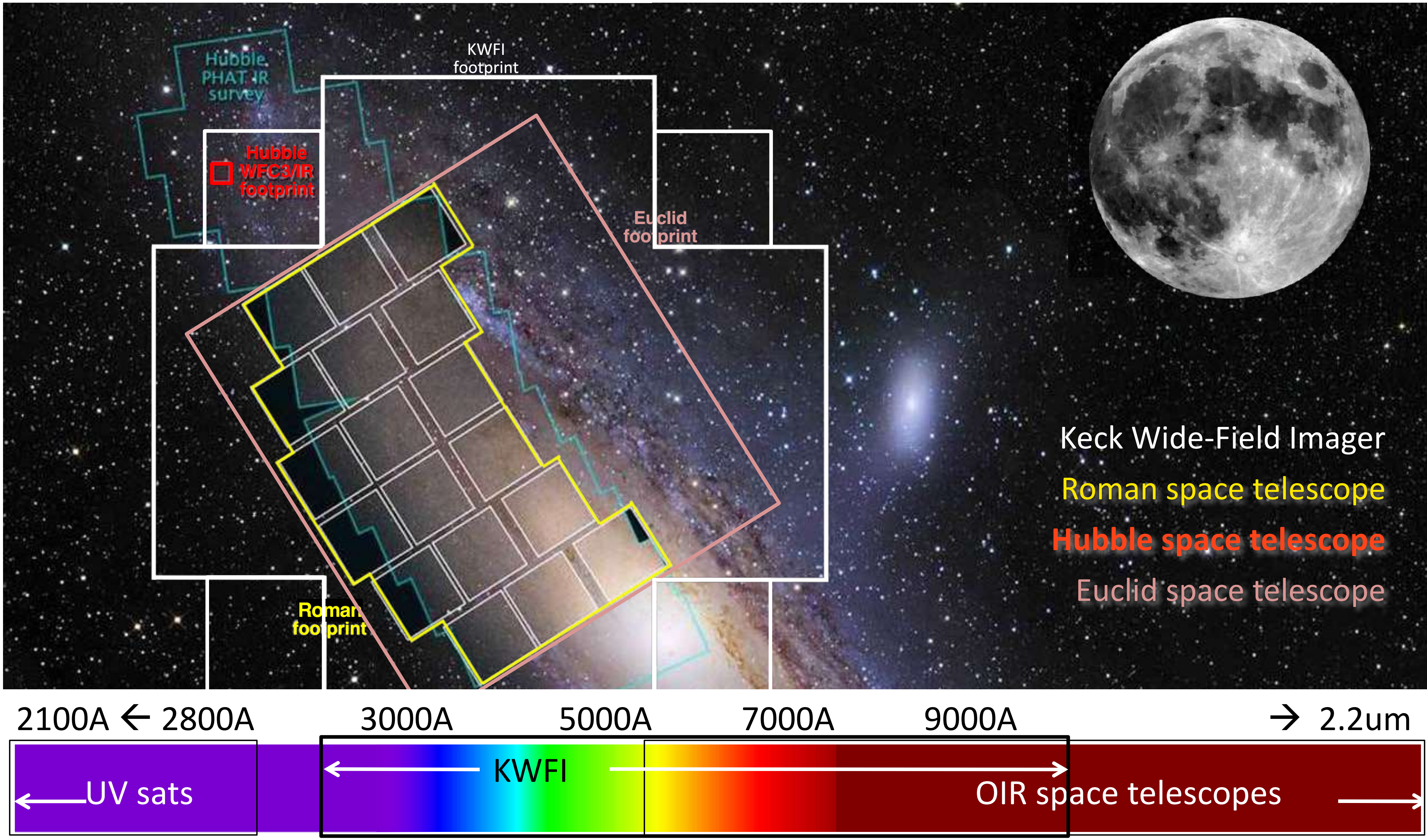
Low-surface brightness

Science



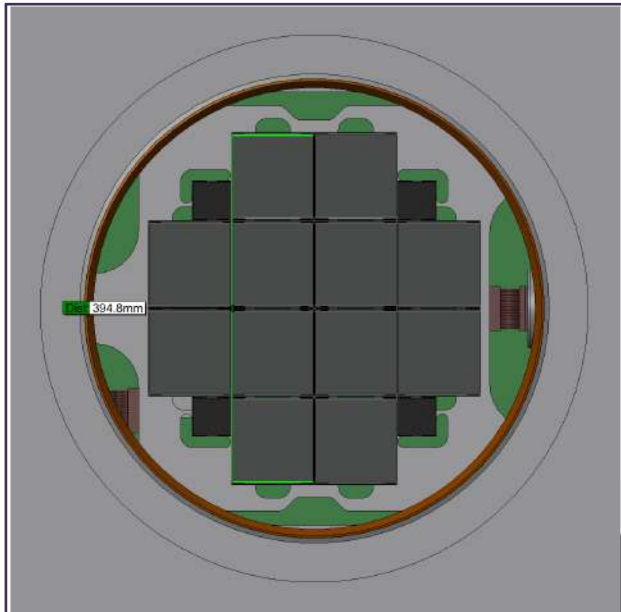


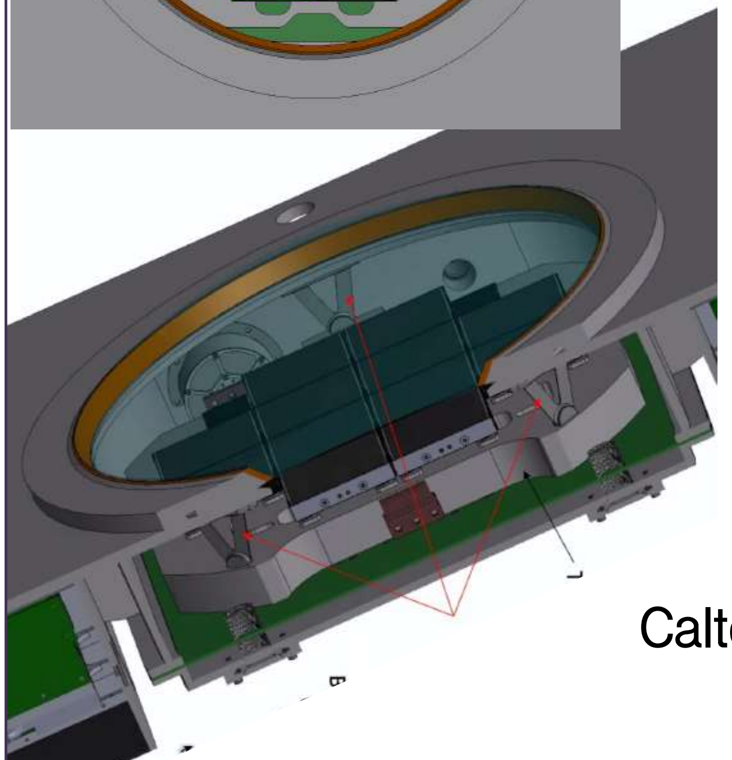
Wide-field space missions – BAO, dark matter/energy



Science

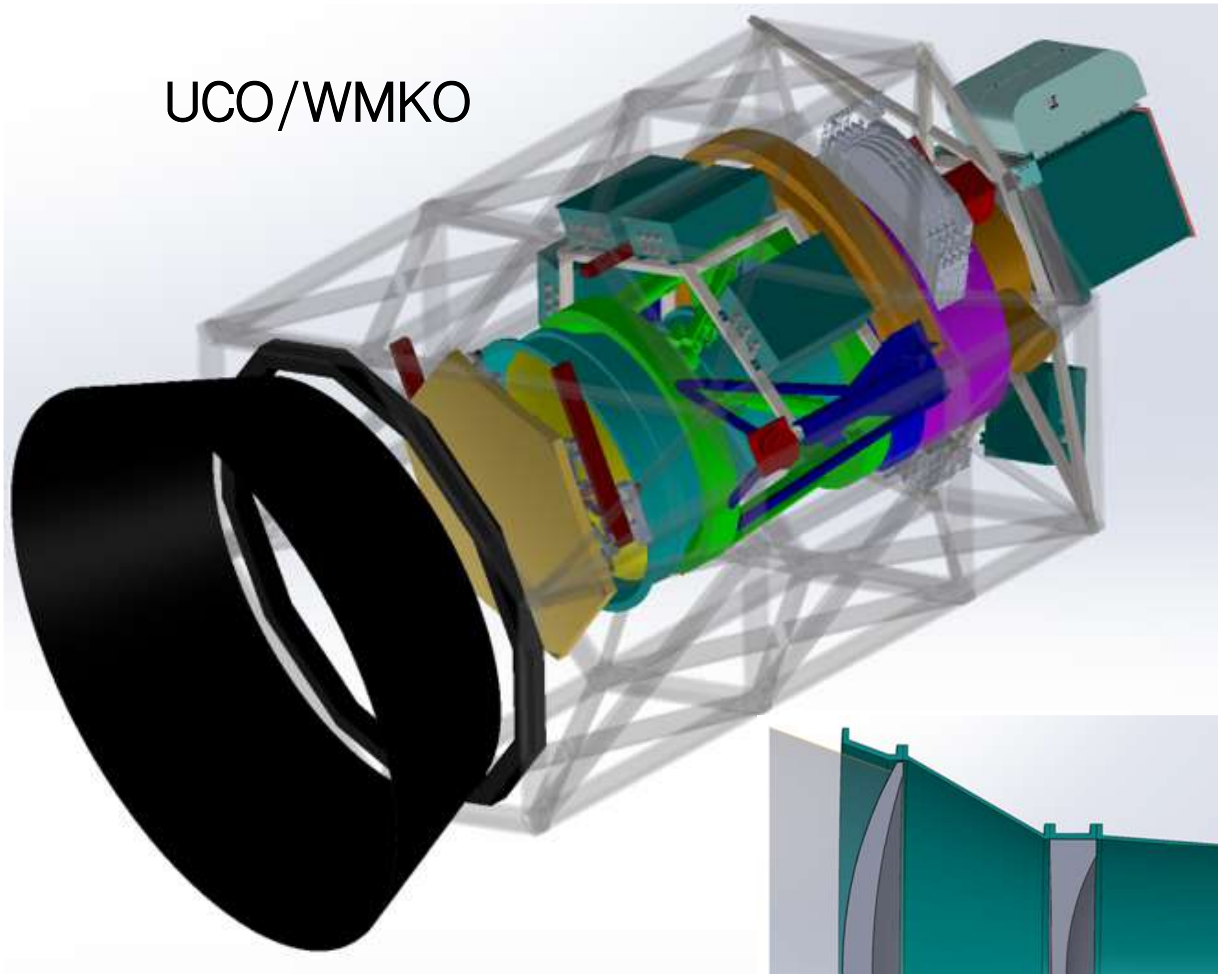
Work to date – *US partner contributions*



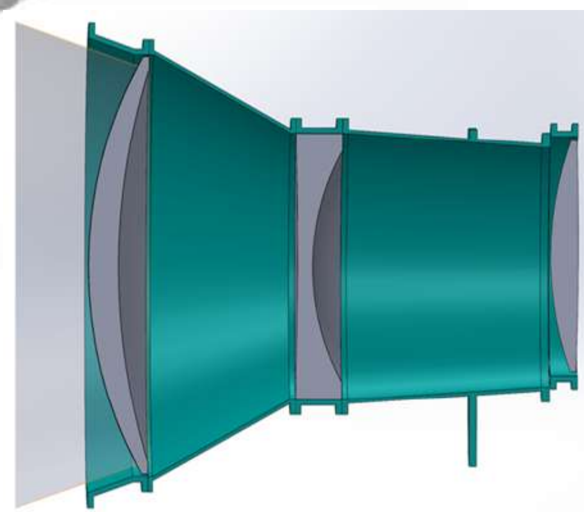


Caltech

UCO/WMKO



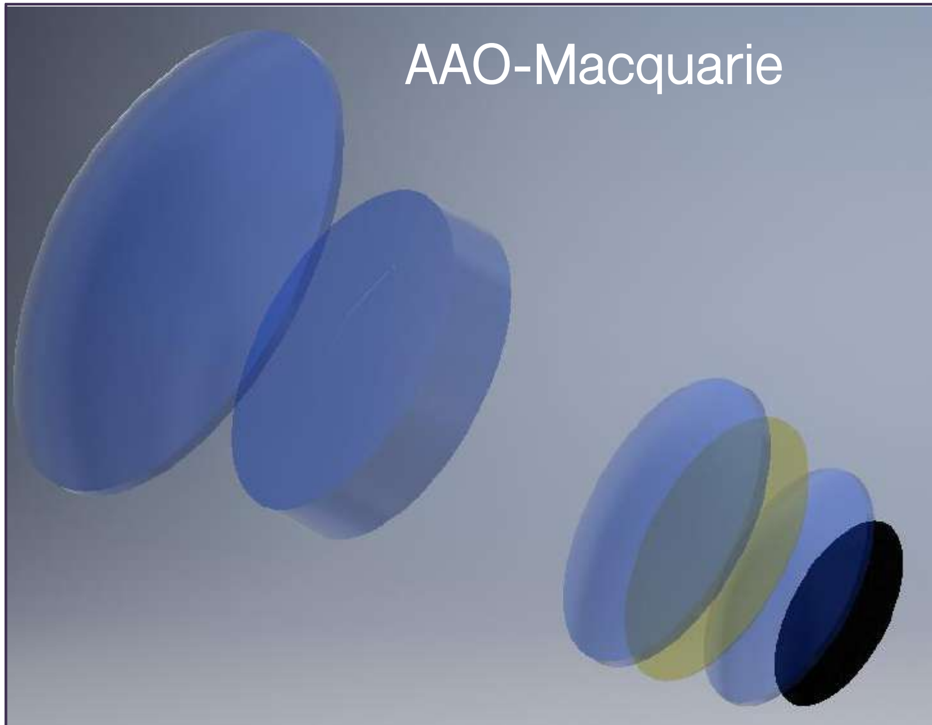
UCO

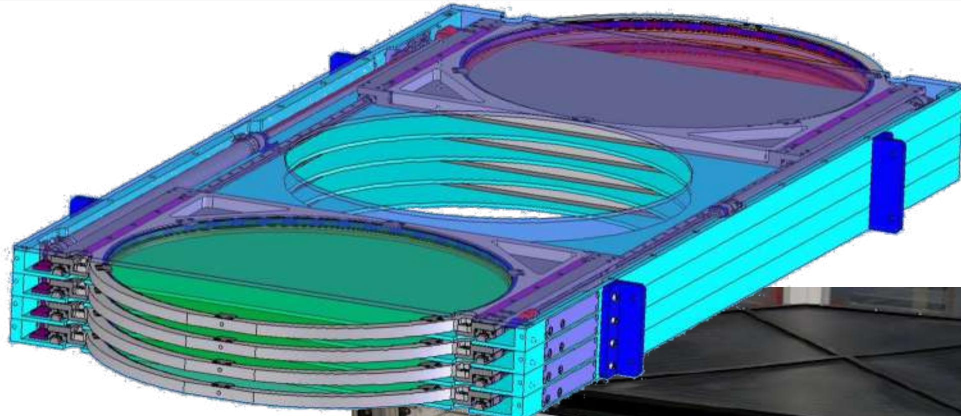


Status

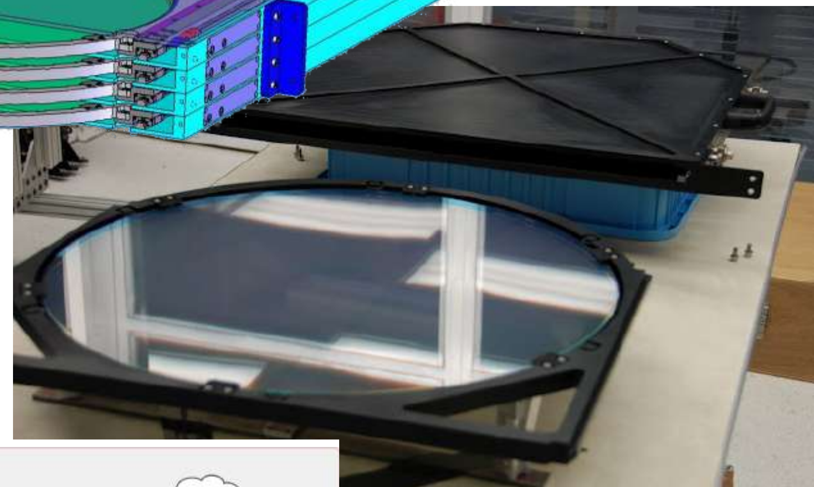
Work to date – *AU partner contributions*

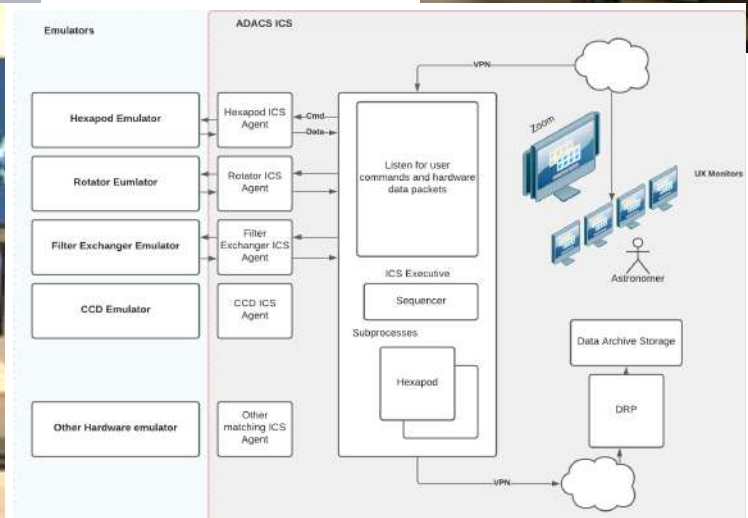
Status





Swinburne Factory of the Future

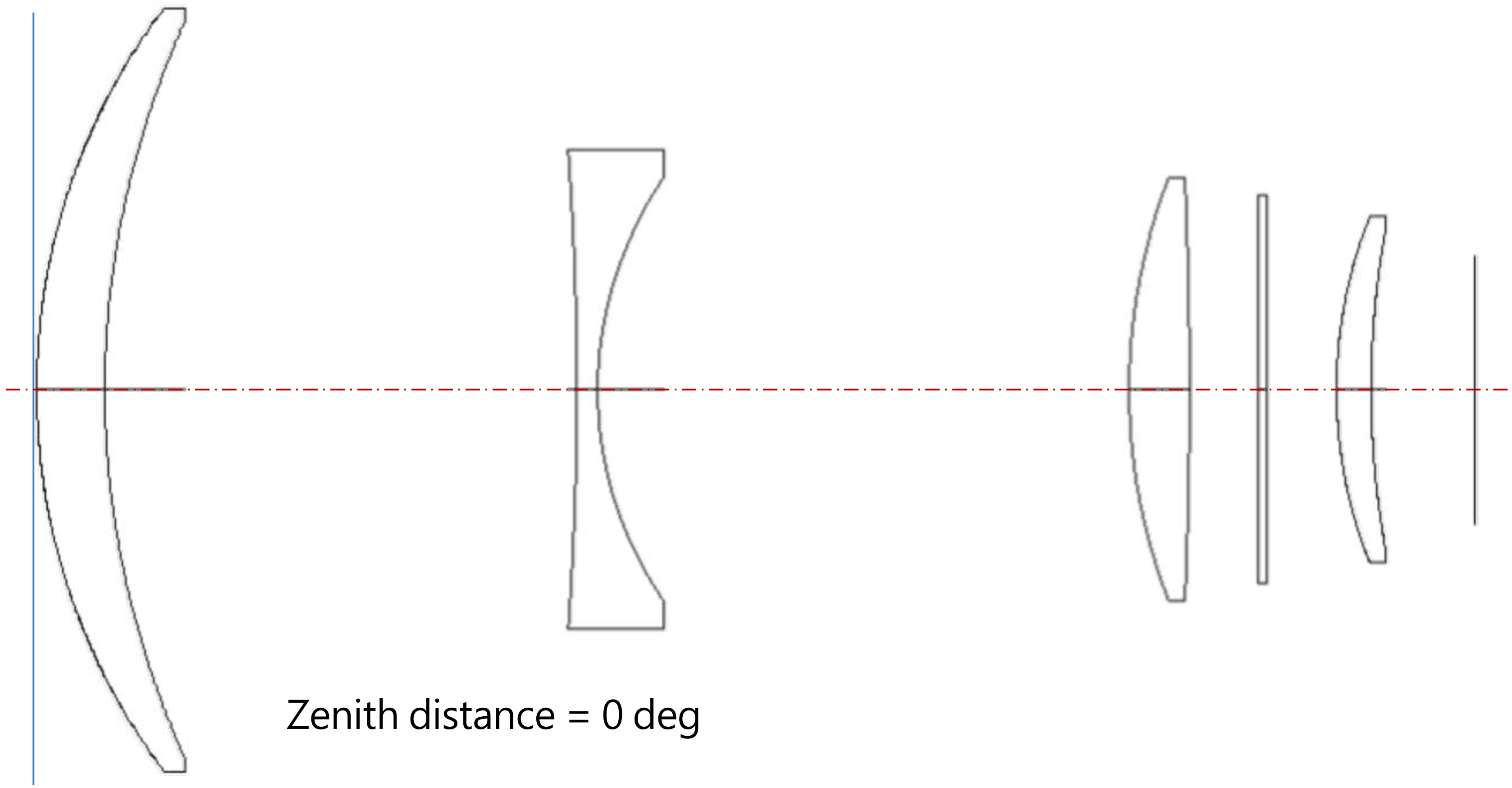




Swinburne ADACS

Work to date – *partner contributions*

ANU, AAO, and UCO

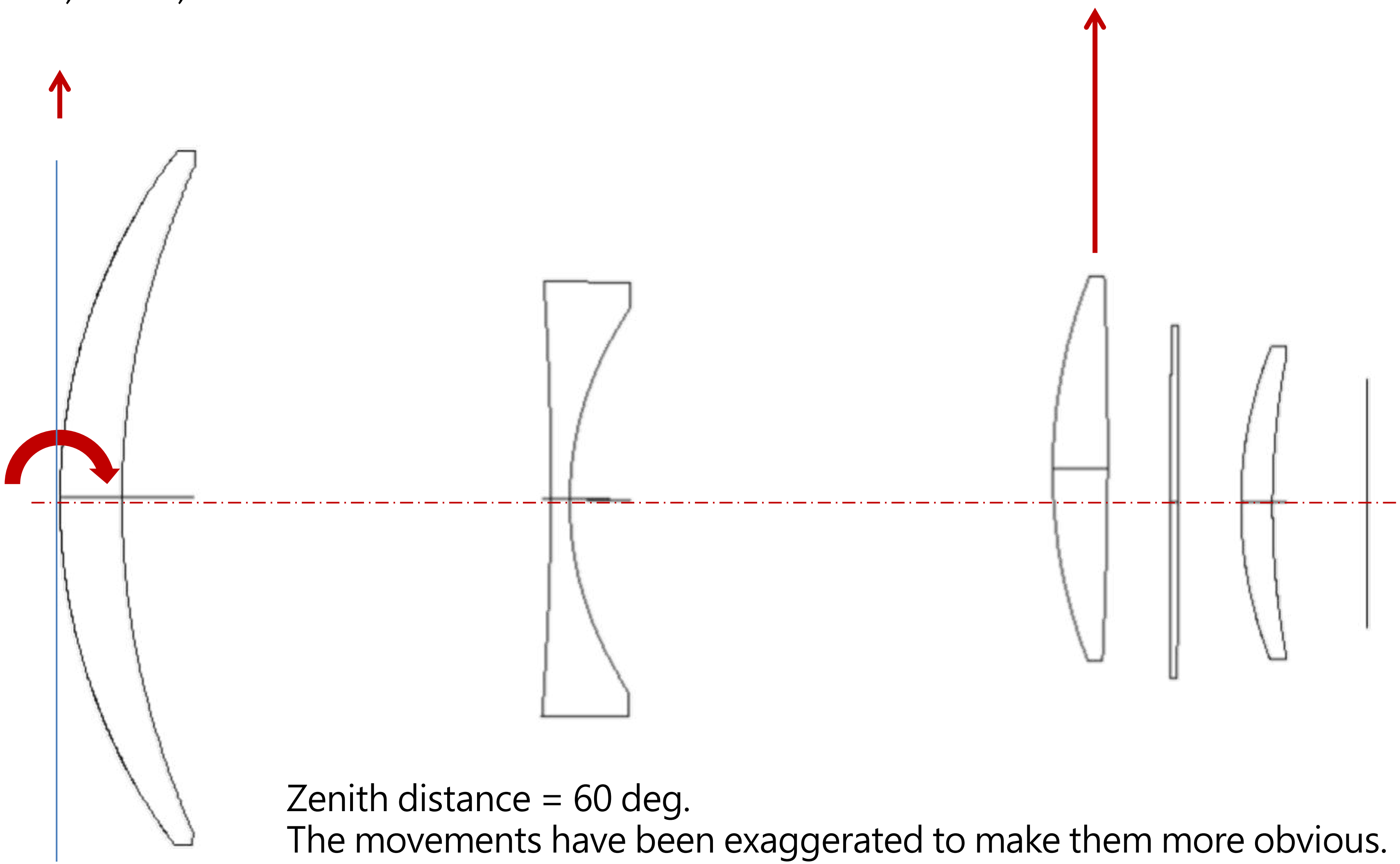


Zenith distance = 0 deg

Work to date – *partner contributions*

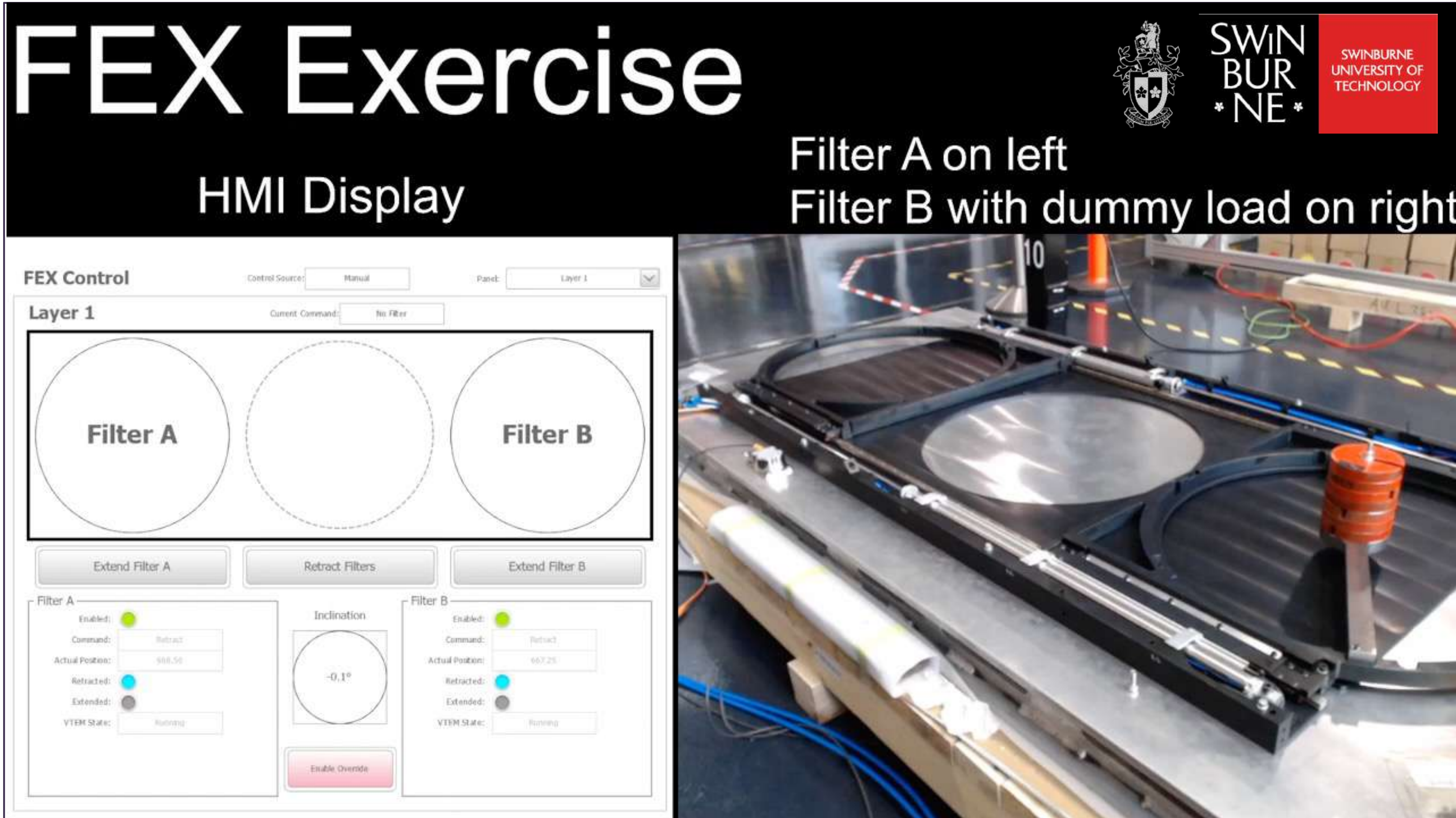
Status

ANU, AAO, and UCO



Zenith distance = 60 deg.
The movements have been exaggerated to make them more obvious.

Filter exchanger (FEX) first layer of four

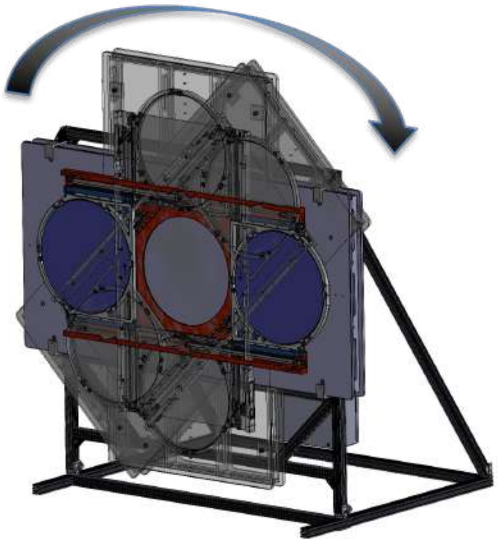


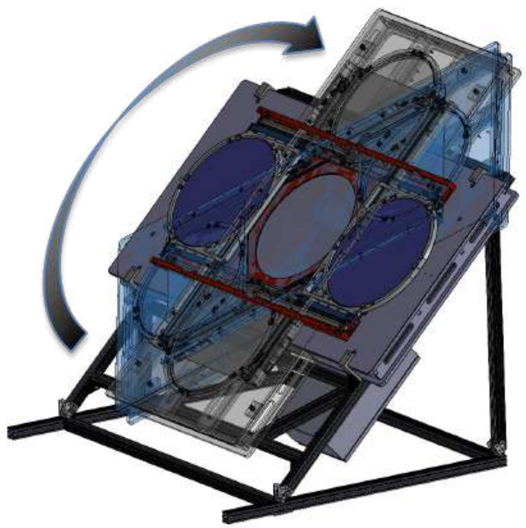
Filter exchanger next steps

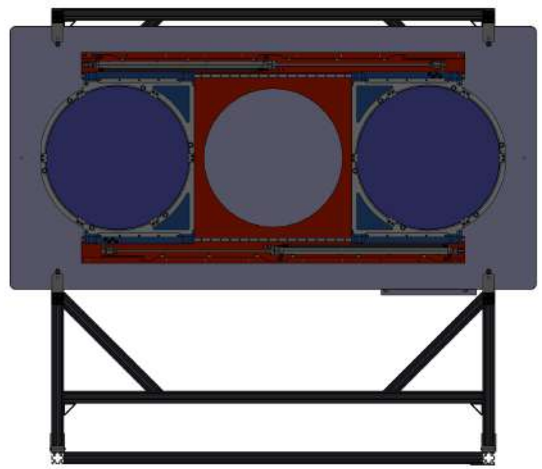
Late-2022 testing goals:

1. Validate the pneumatic control system performance at dome temperature and pressure at elevation
2. Swinburne team smart sensors and digital twin applications
3. Progress development of the deployable secondary mirror system

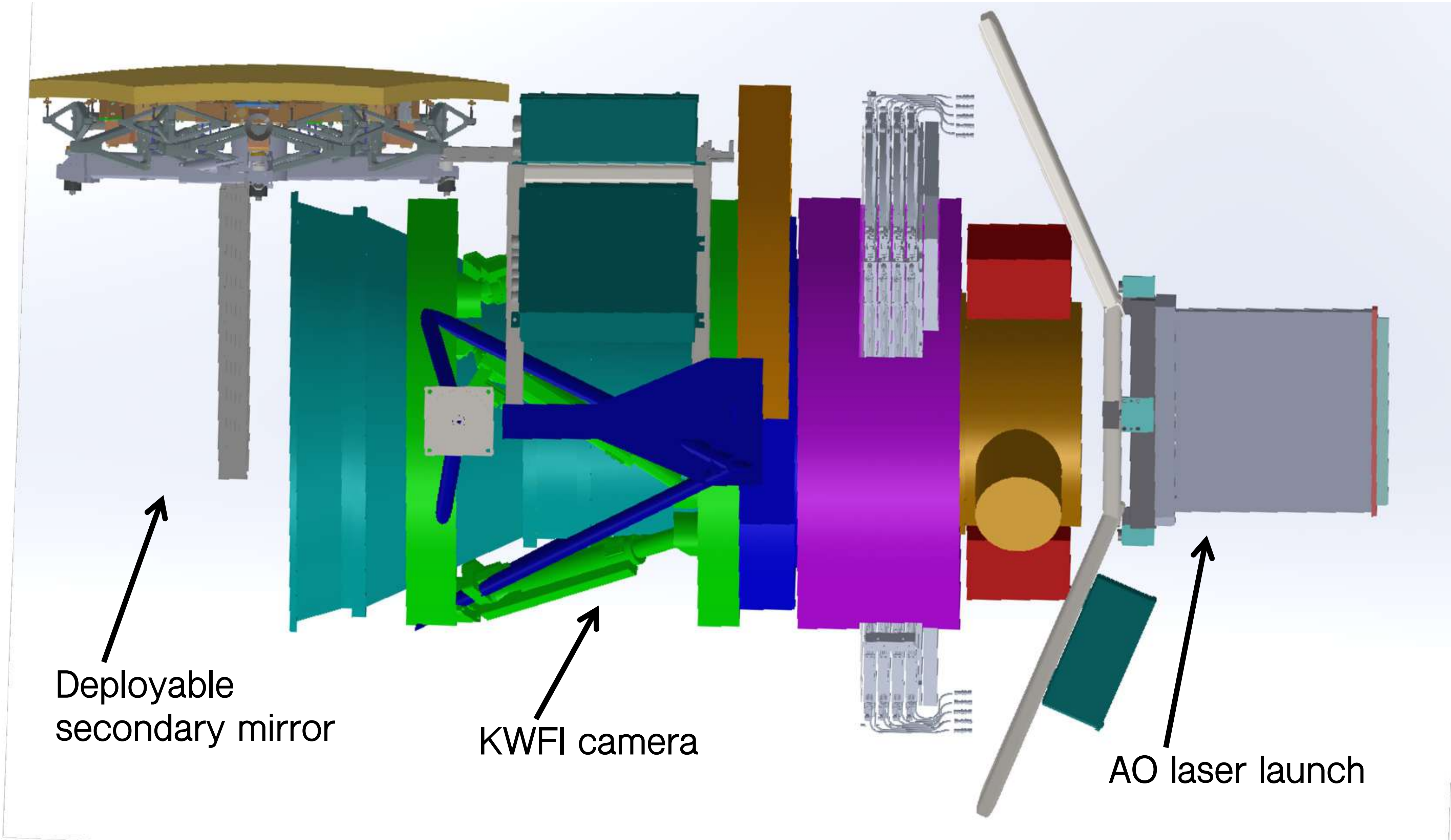
Testing location







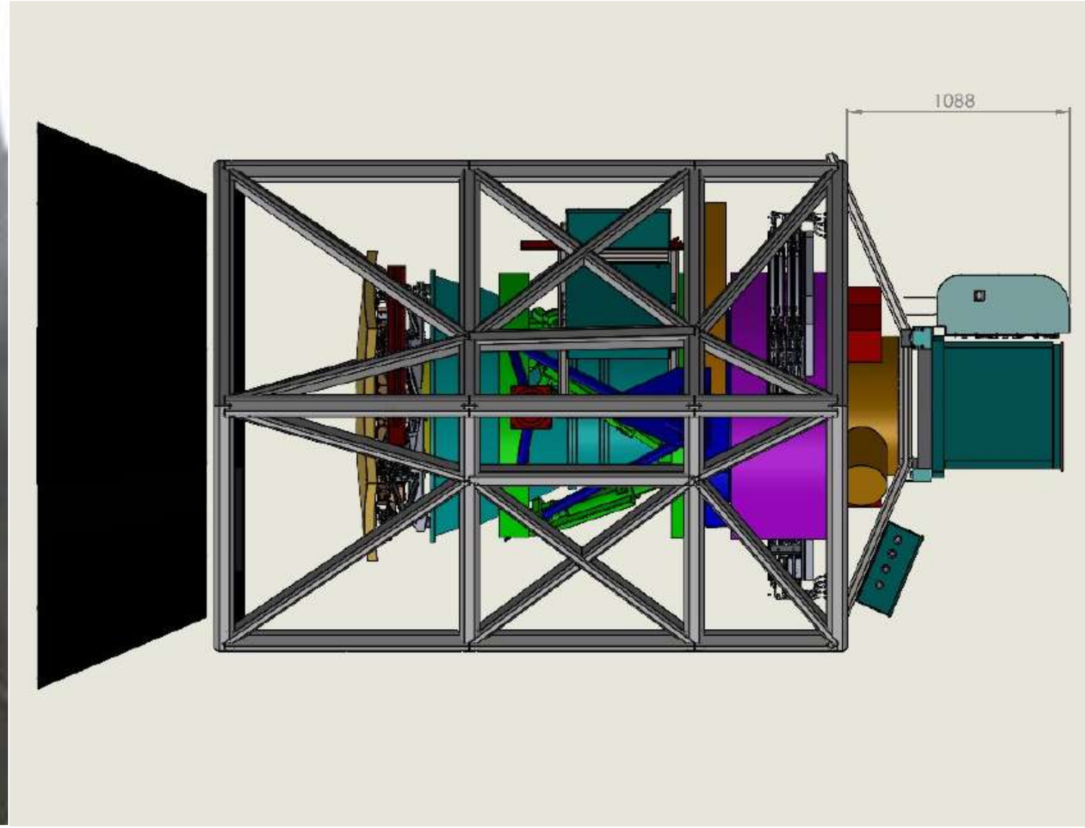
Deployable secondary and laser launch



Laser launch

Current Adaptive Optics laser launch is mounted to the roll-away module

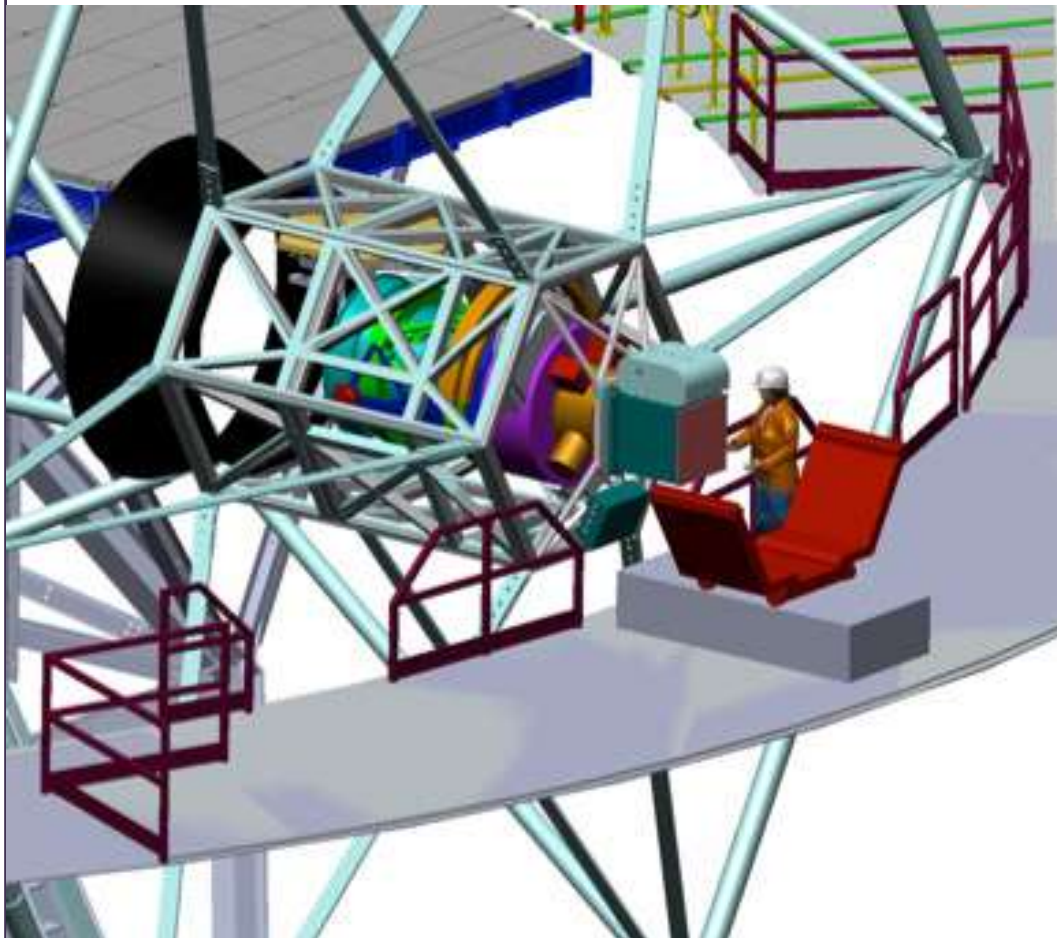
One solution for permanent KWFI installation is to mount the laser launch to the cage

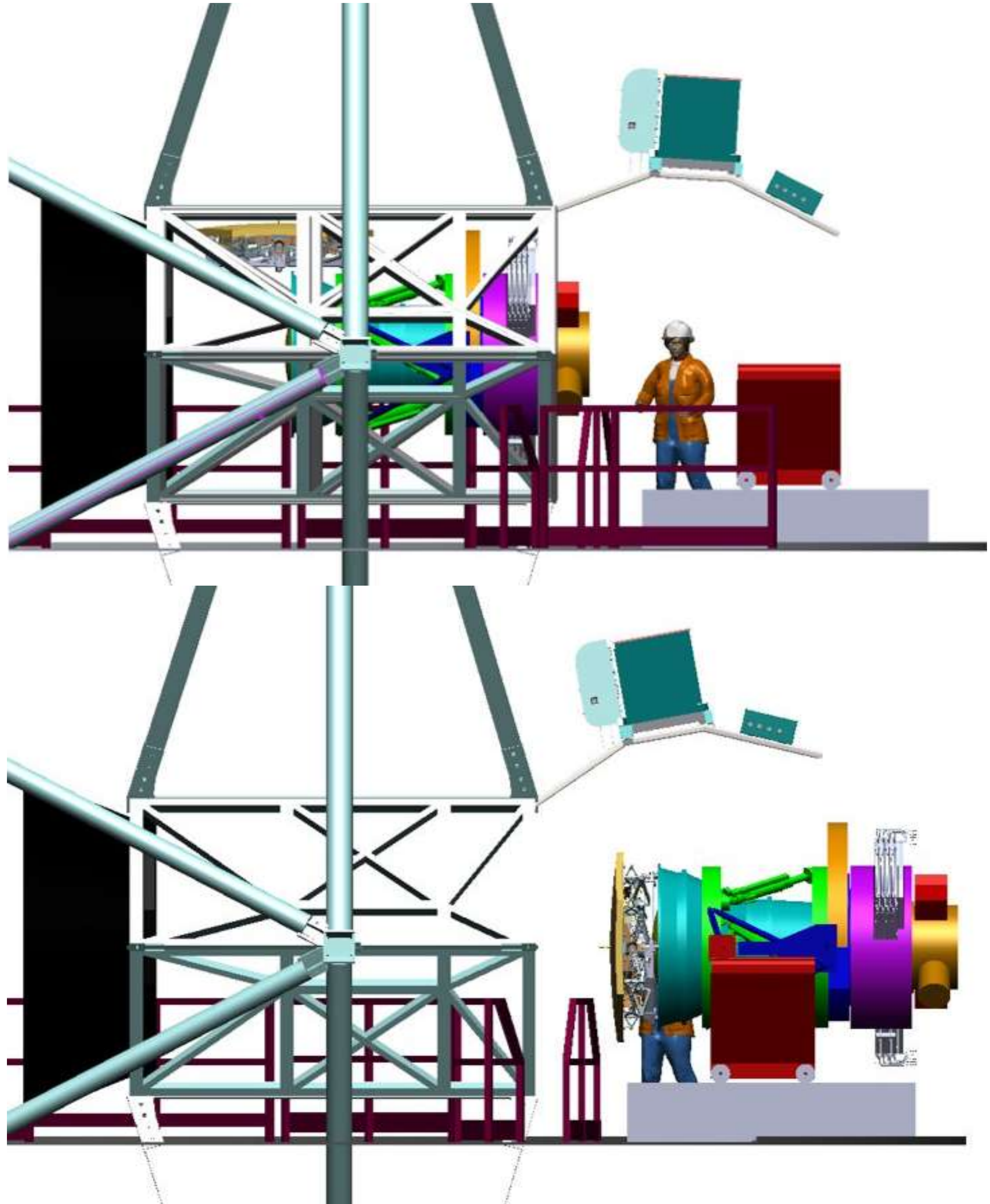


Installation and maintenance

The installation module may be changed to an installation cart to provide more space for the mirror and to remove excess weight.

The laser package "swing-away" design





Funding

Australian Government
Australian Research Council

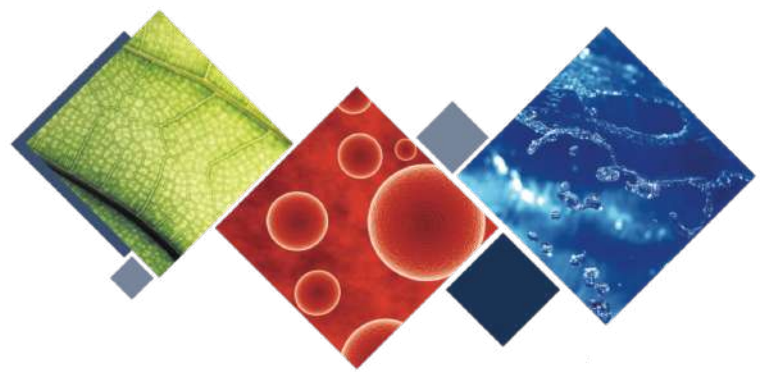
KWFI is strongly supported by Keck, UC, Caltech and Australian universities

A mature project
- Feasibility study, workshop, and mature conceptual design SSC funded
- Passed a rigorous proposal readiness review (PRR) assessed by experts from Rubin, DECam and DESI

Australian Research Council (ARC)
Linkage, Infrastructure, Equipment, and Facilities (LIEF) grant submitted
- Covers large optics (long lead items), industry 4.0 applications, and other components focusing on Australian expertise

Preparing a Proposal Development (PD) grant

Plan to propose for NSF in 2023
- Detector and other main components



Status

Timeline

KWFI
Keck Wide-Field Imager

The most powerful wide-field UV/optical camera on Earth or in space for the foreseeable future

- Can do science that cannot be done elsewhere, not even on 30m telescopes
- Extreme 3000-10000A depths over a wide field to enable new science, solve long-standing problems, and make high-impact discoveries
- Rapid Target of Opportunity capability, multiplexing modes
- Complements upcoming space missions and large-aperture facilities

Simplified timeline

Design, funding & development	Major funding & reviews	Construction and testing	First light
2019-2021	2022-2023	2023-2026	2027

Strong support by Keck and all communities
Successful funding to date

K W F I