Ground-based capabilities for general astrophysics and exoplanets science

Olivier Guyon

University of Arizona
Subaru Telescope, National Astronomical Observatory of Japan, National Institutes for Natural Sciences
Astrobiology Center, National Institutes for Natural Sciences
JAXA

HabEx meeting, Aug 3, 2016

HabEx Uniqueness

HabEx unique capabilities (not accessible from ground):

- Largest UV-Opt astronomical aperture in space
- Spectral coverage: UV not accessible from ground, continuous NIR coverage
- Angular resolution in UV .. and optical ?
- Ultra-high contrast
- High stability
  - → astrometry
  - → precision photometry, spectroscopy

Major ground facilities (Opt-NIR)

ELTs coming online in mid-2020s:

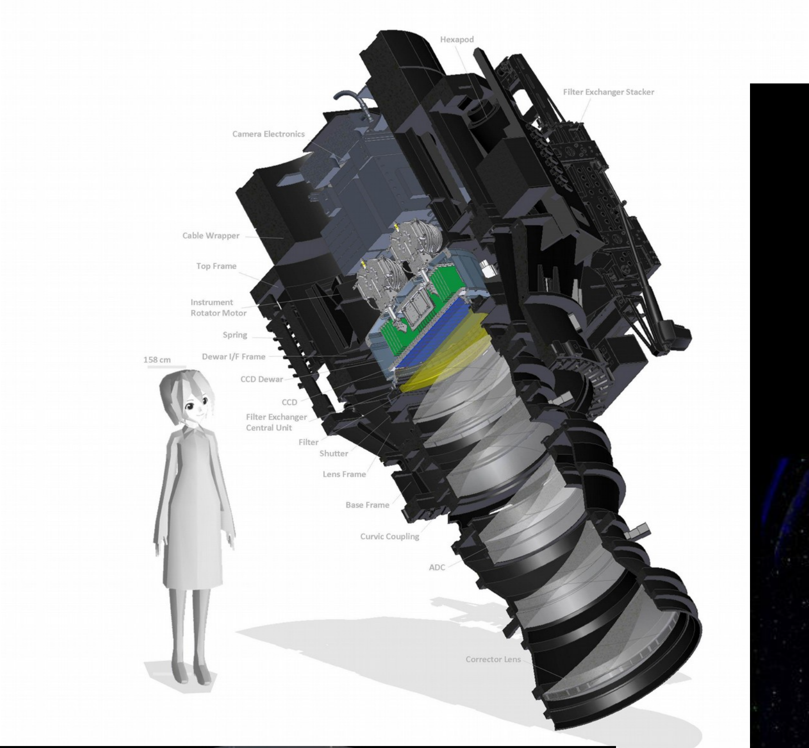
- E-ELT: 39m aperture, Chile
- TMT: 30m, Hawaii(?)
- GMT: 25m, Chile

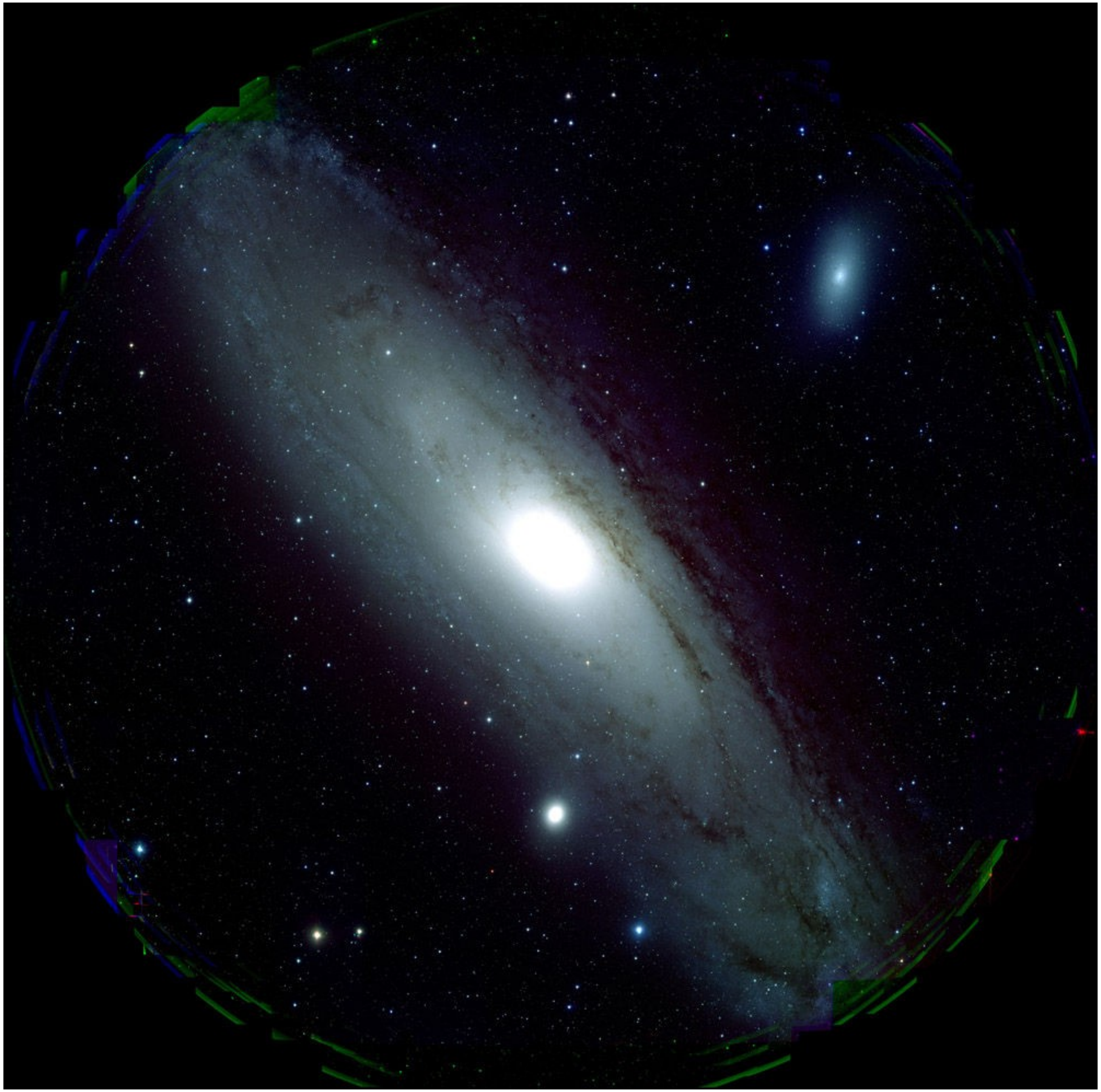
8-m class survey telescope/instruments:

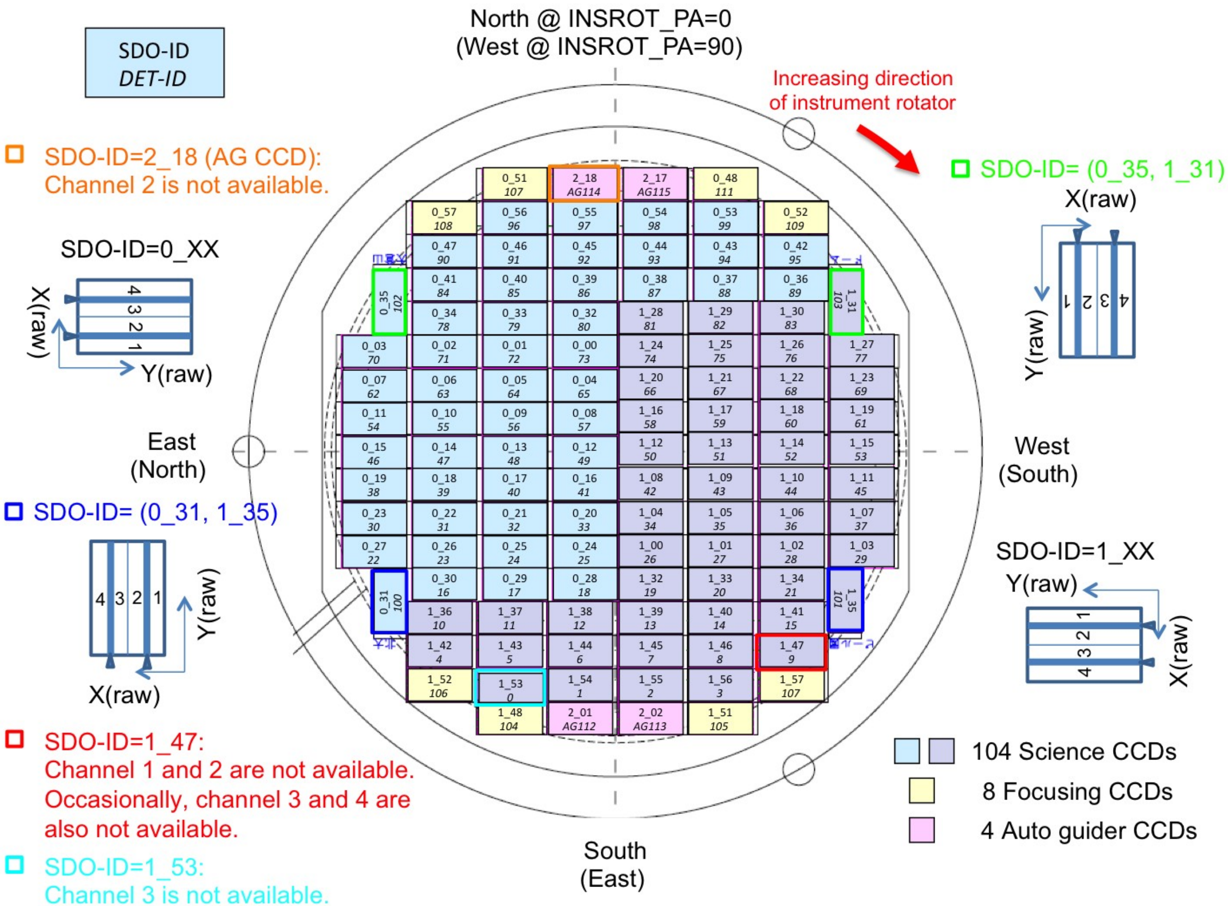
- Imaging: LSST
- Spectroscopy: Subaru-PFS

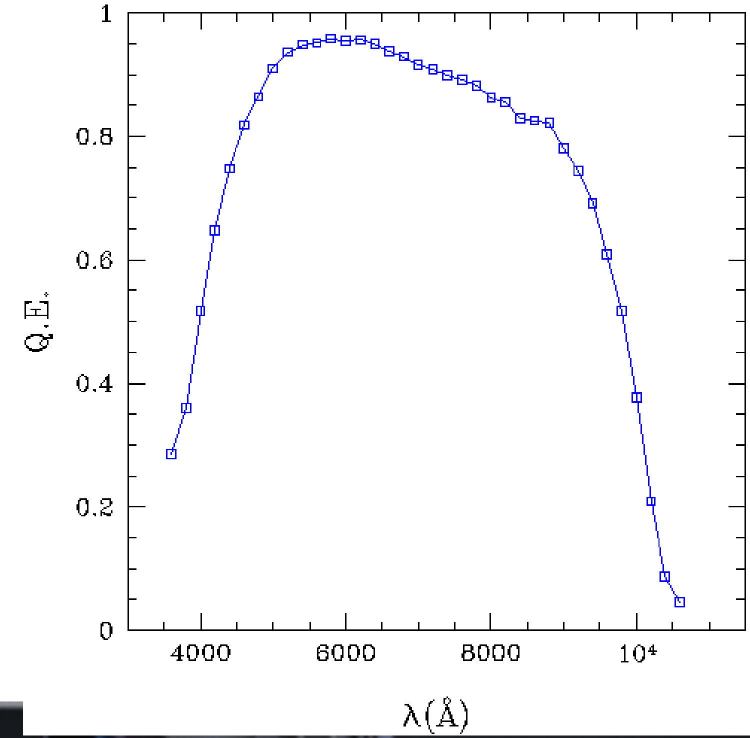
+ other dedicated survey facilities (LAMOST, PAN-STARRS PTF etc…)

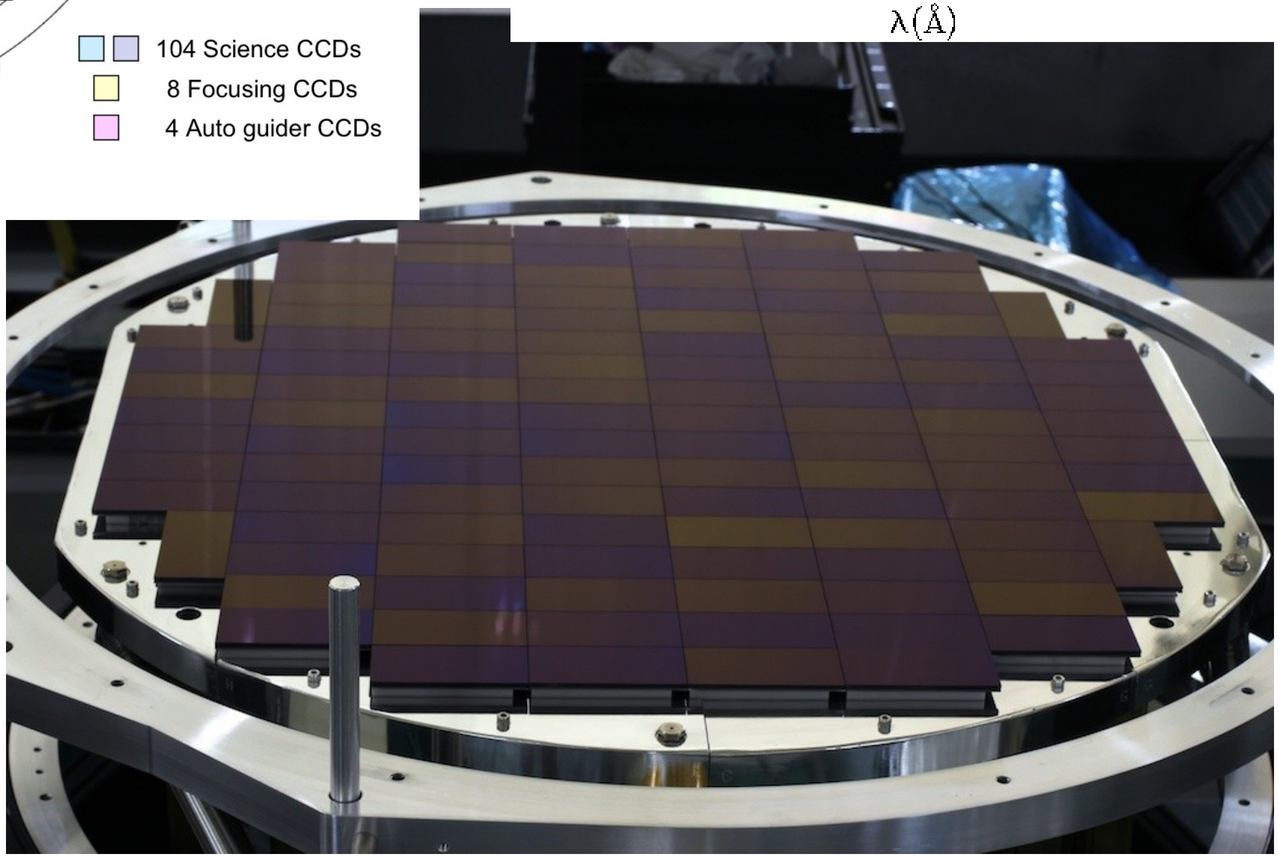
Wide FOV optical imaging: Subaru HSC





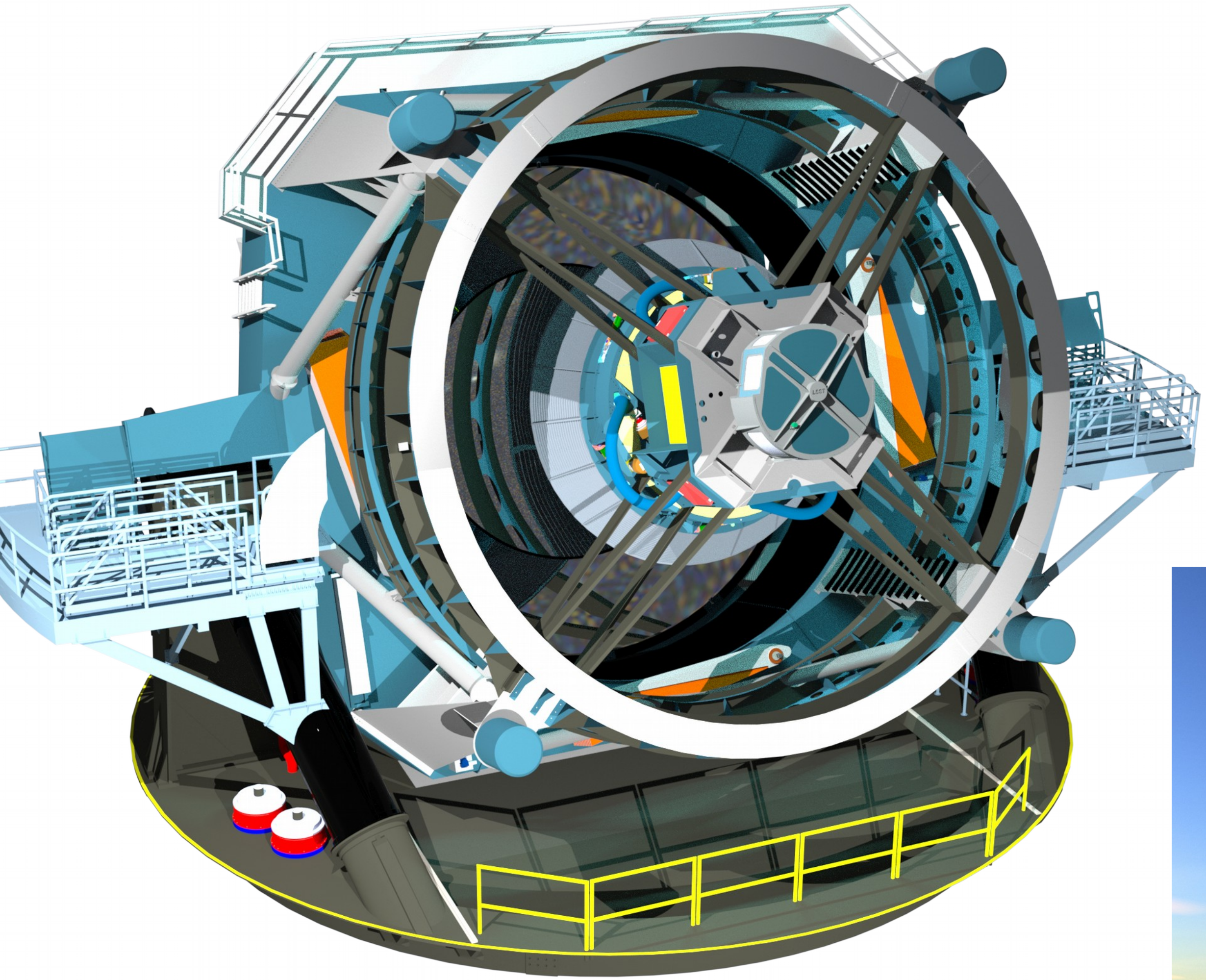


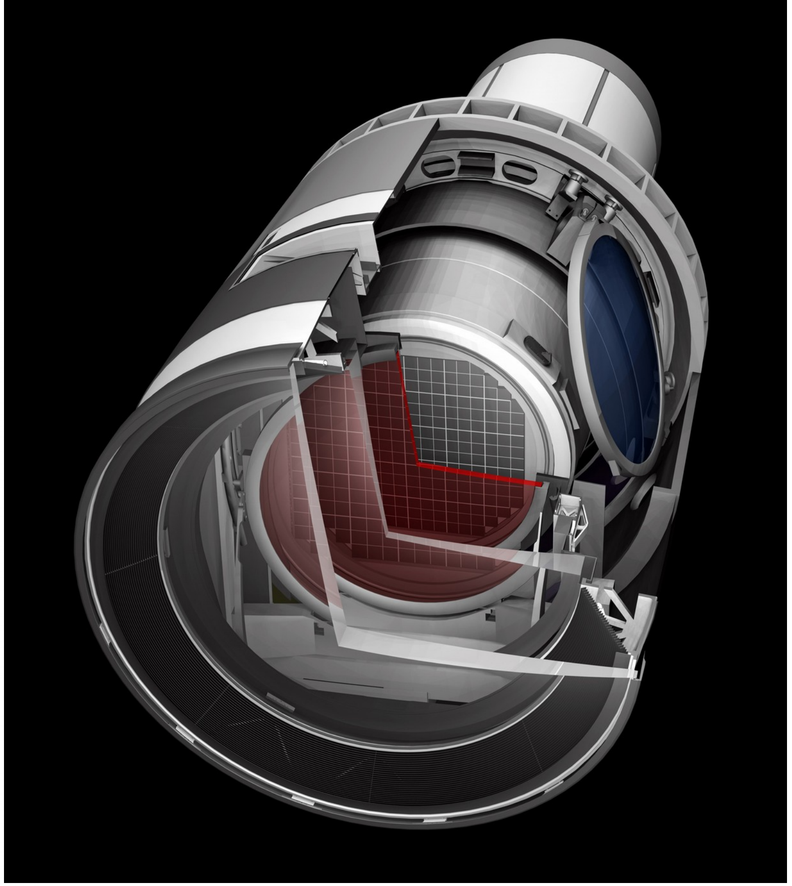




8m aperture, 1.5deg diam FOV
104 4kx2k CCDs

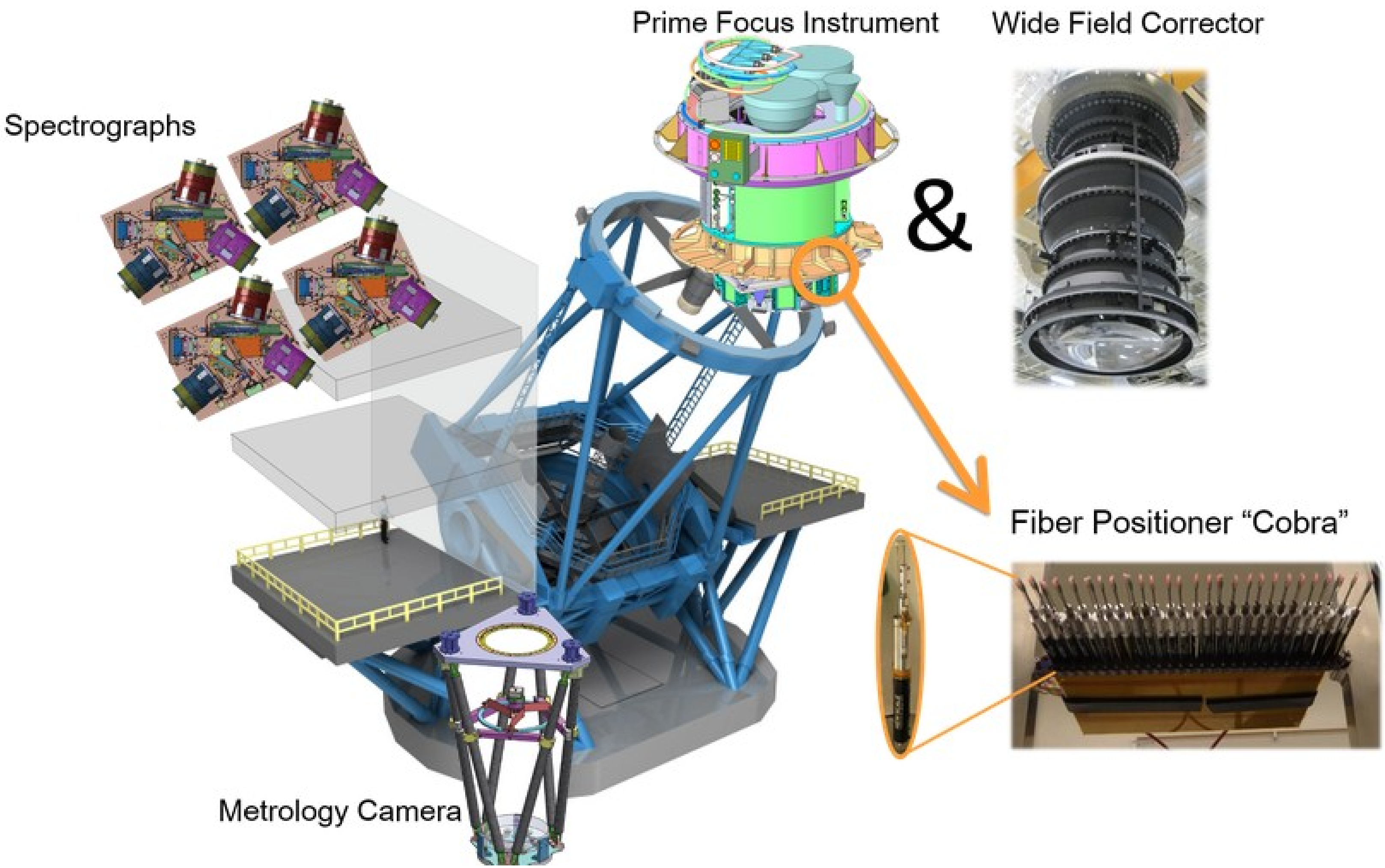
LSST





8m aperture, 3.5deg diam FOV
189 4kx4k CCDs

Subaru Prime Focus Spectrograph



2,400 fibers over 1.3 deg diam FOV
0.38 – 1.26 um

Increased image quality over moderate FOV in near-IR with GLAO

example: ULTIMATE-Subaru

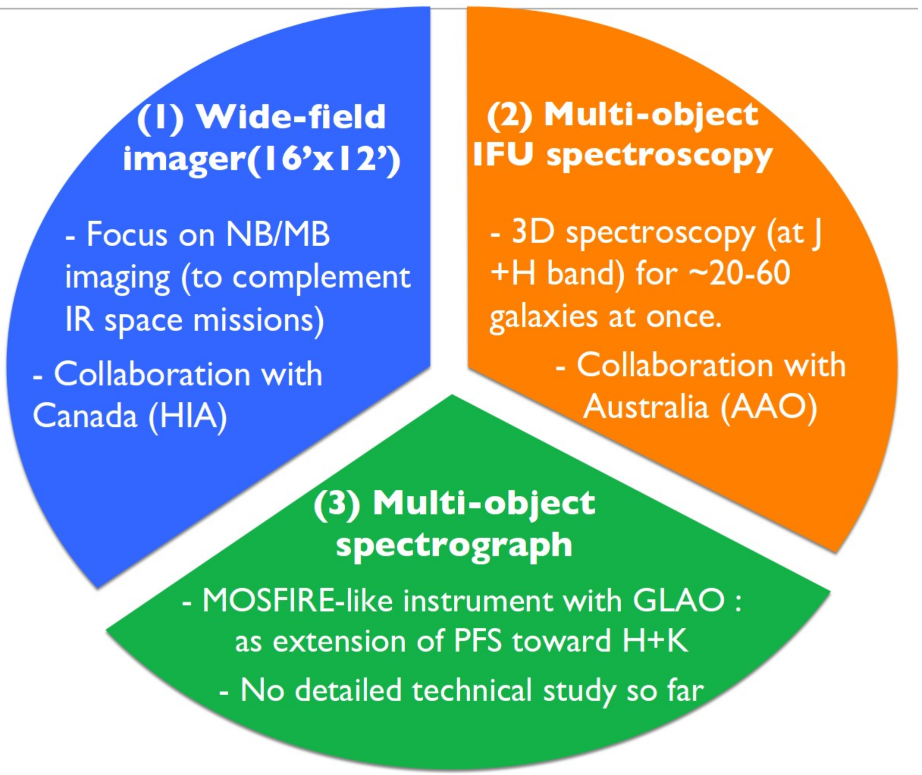
ULTIMATE key specifications: Ground-Layer AO

Field of View	15 arcmin
Focus	Cassegrain
Corrector	Adaptive secondary, 33 actuators across the diameter
Sky Coverage	Almost all sky

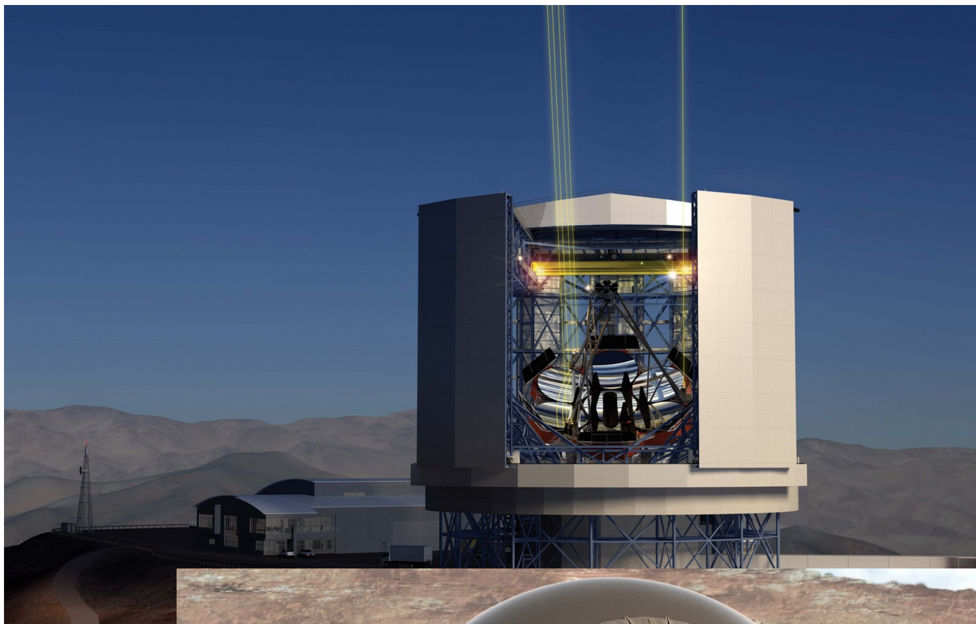
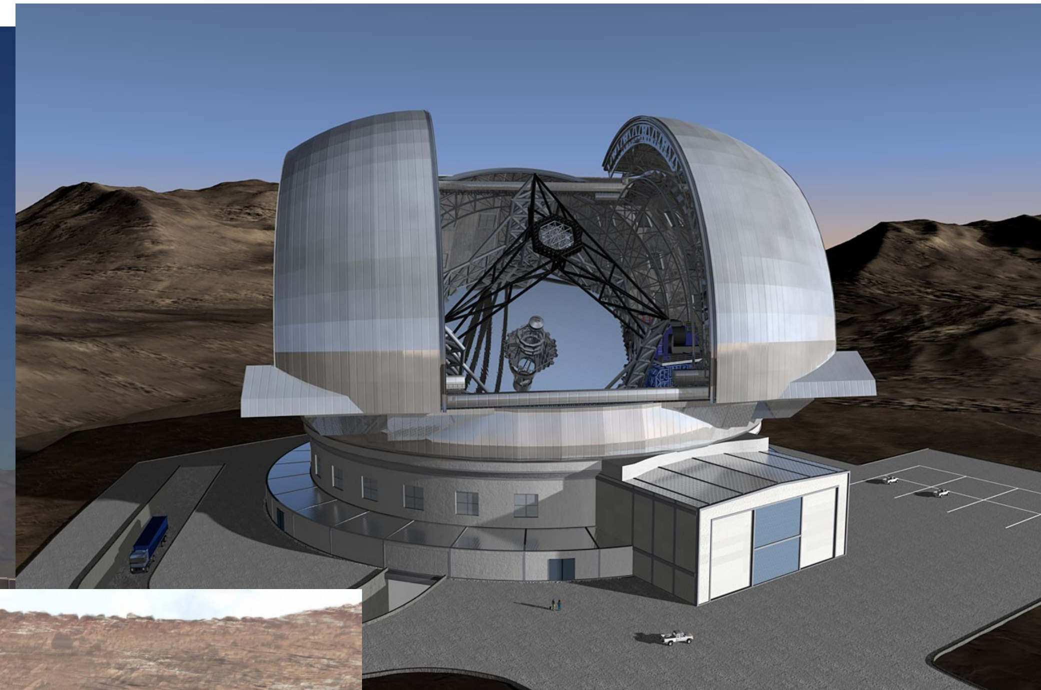
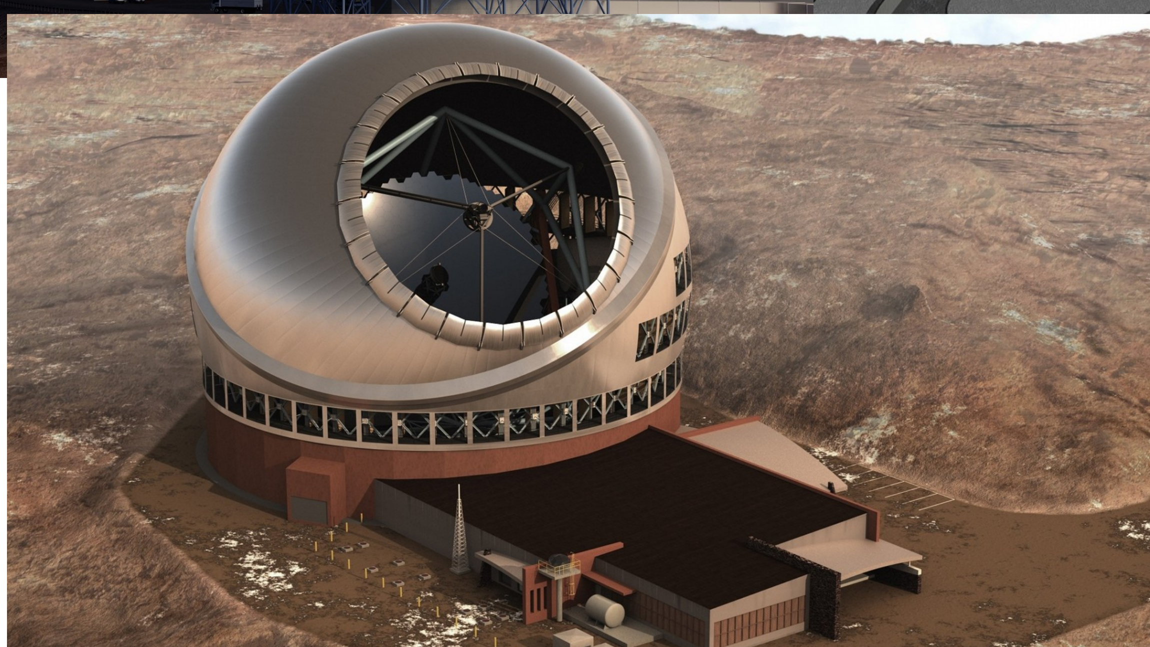
FWHMs at ‘Moderate’ condition

	GLAO	Natural
K-band	0.20”	0.44”
H-band	0.23”	0.49”
J-band	0.27”	0.51”
R-band	0.41”	0.65”

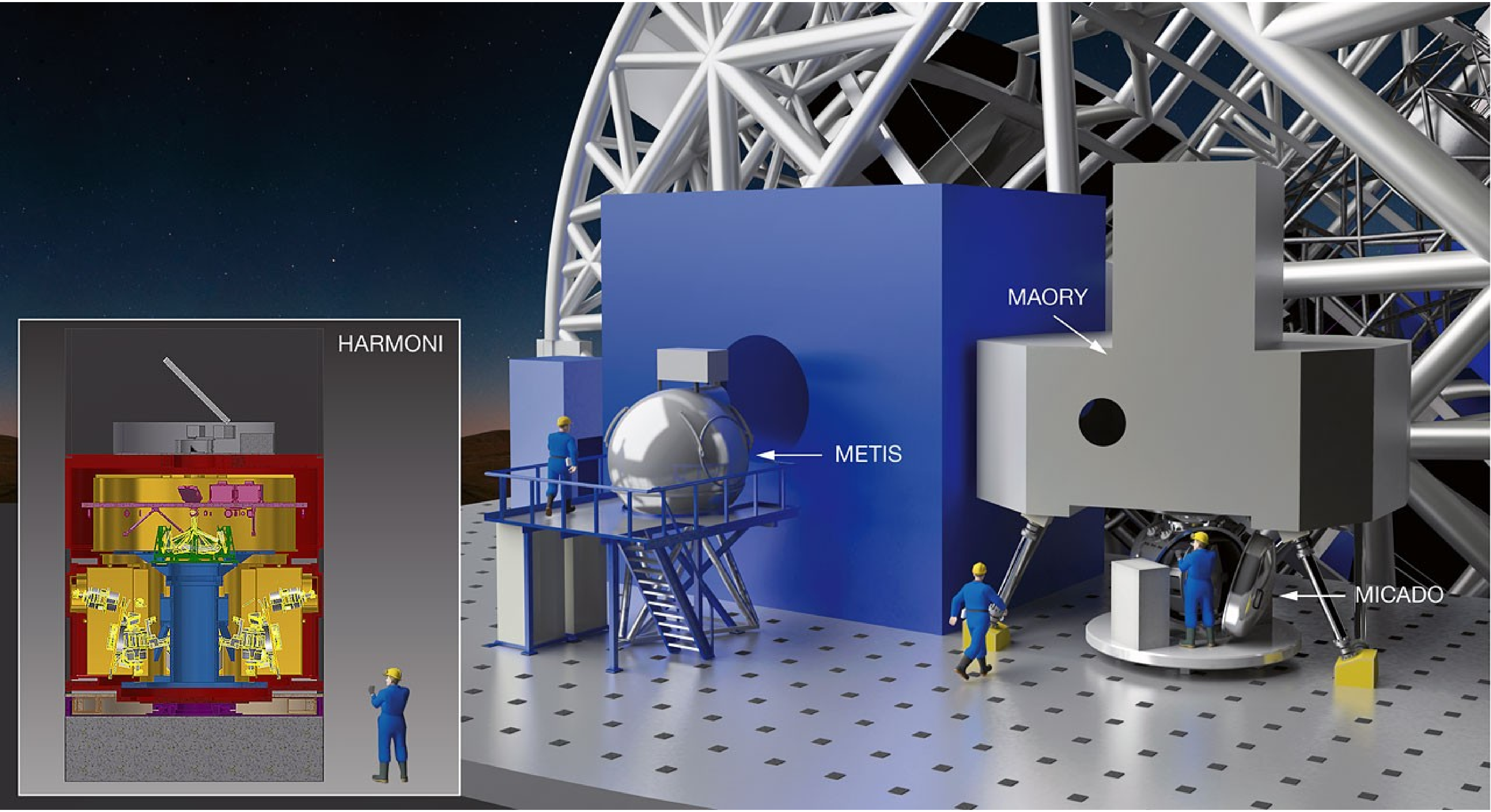
ULTIMATE-Subaru Instruments



ELTs

E-ELT first light instruments



E-ELT – First Light instruments

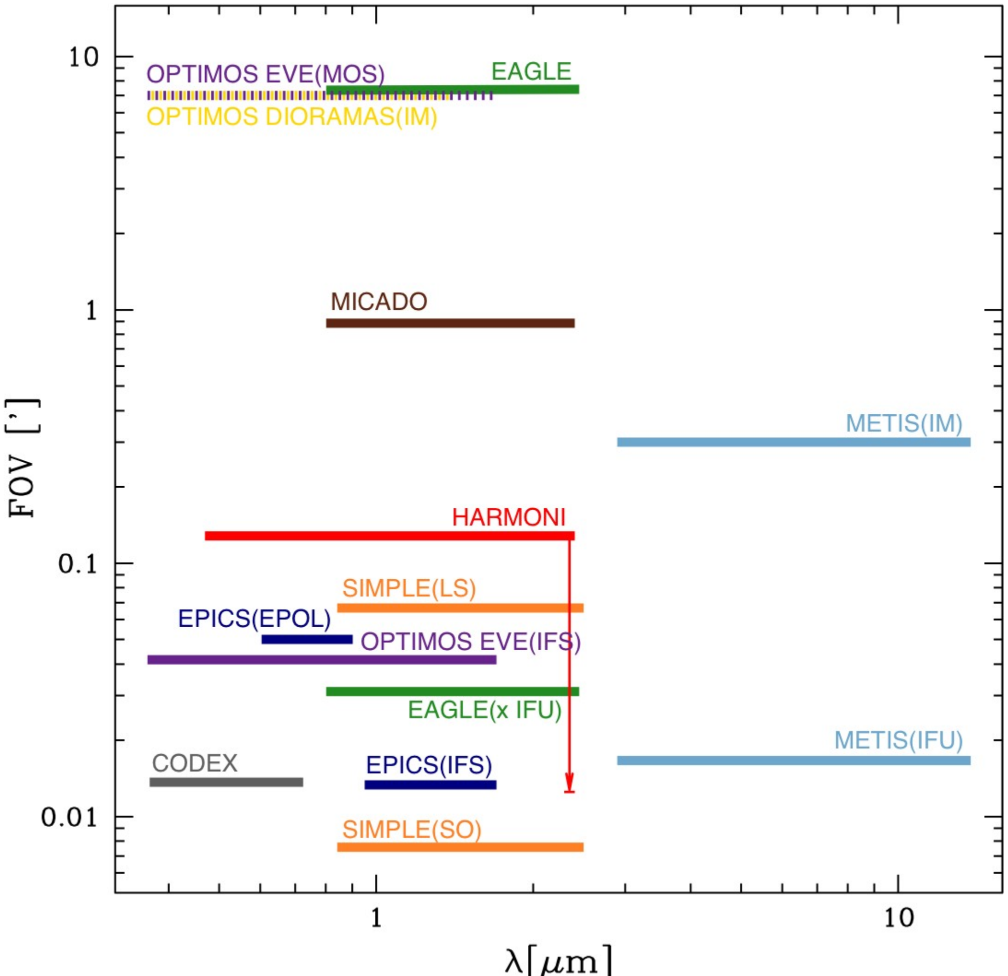
MAORY + MICADO
(Multi-conjugate Adaptive Optics RelaY for the E-ELT)
(Multi-AO Imaging Camera for Deep Observations)
0.8 – 2.4 um
diffraction-limited imaging (6 – 12 mas)
R=8000 spectroscopy

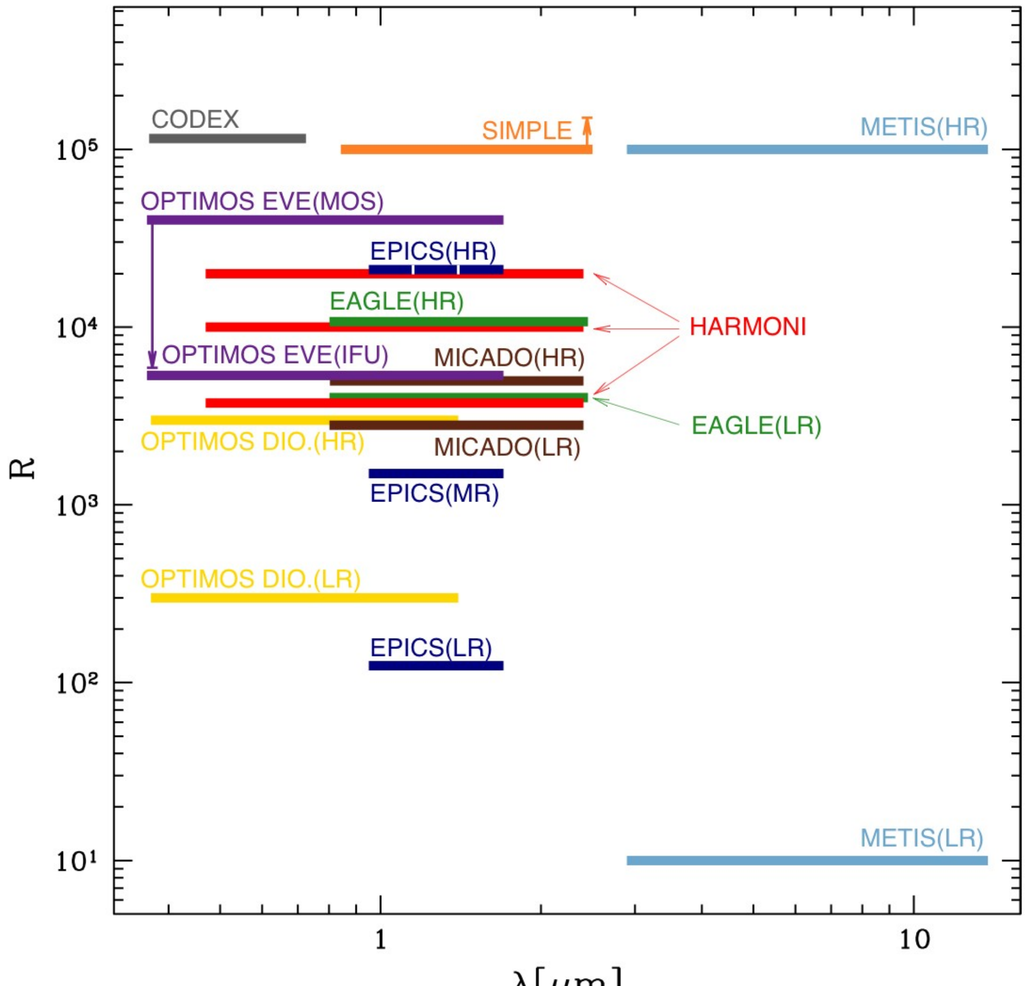
HARMONI
(High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph)
0.47 – 2.45 um
IFS
R = 3000 – 20,000 spectroscopy

METIS
10um imaging and spectroscopy
high contrast imaging

E-ELT instruments

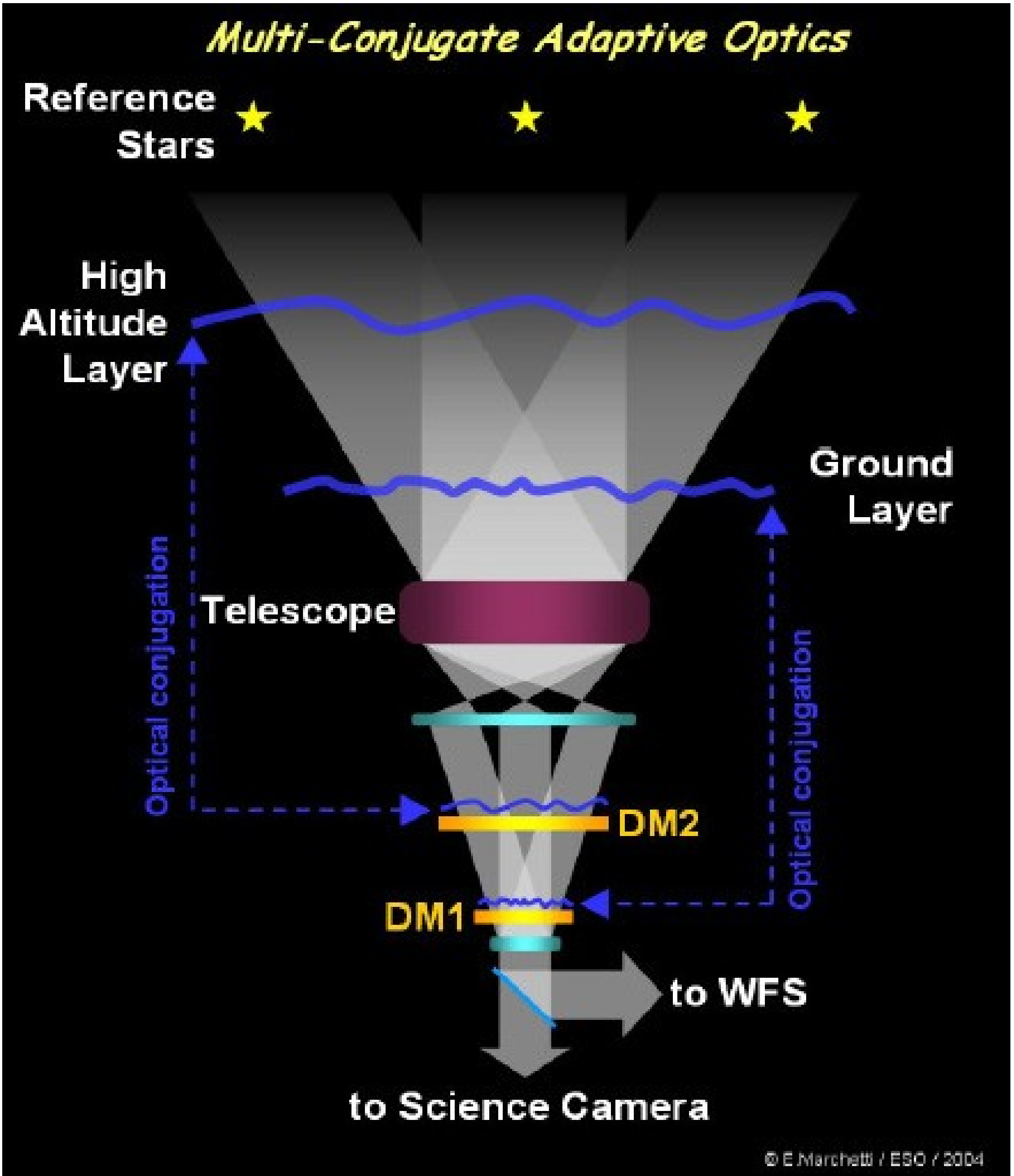
Exoplanet science:
CODEX (precision RV), METIS (10um imaging) and EPICS/PCS (direct imaging, NIR)





Multi-Conjugate Adaptive Optics (MCAO)

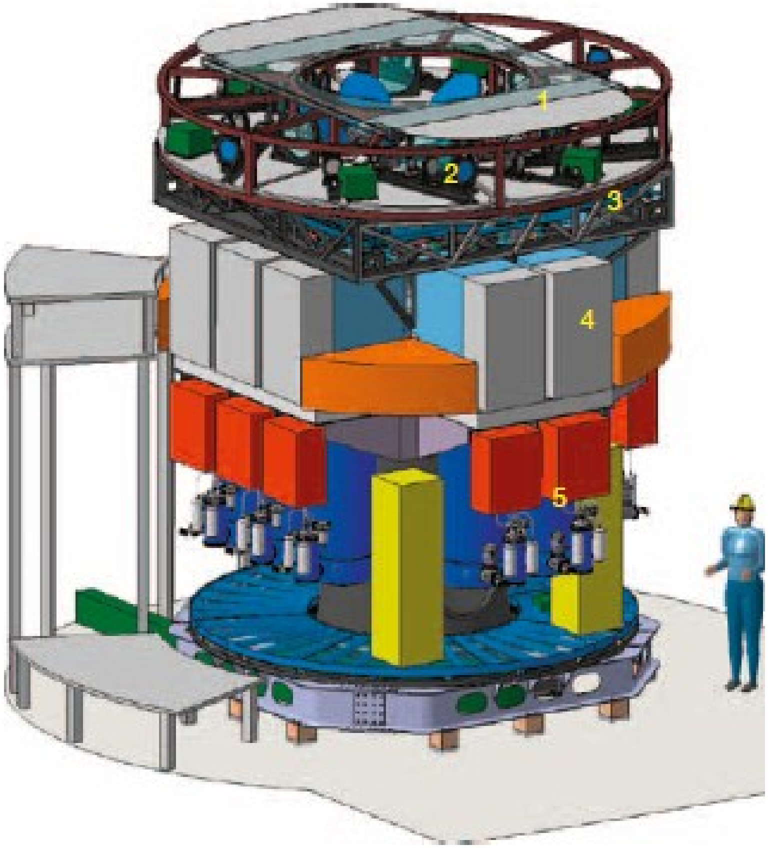
Concept: Use several DMs conjugated at different altitudes to perform correction over a wide fielf of view



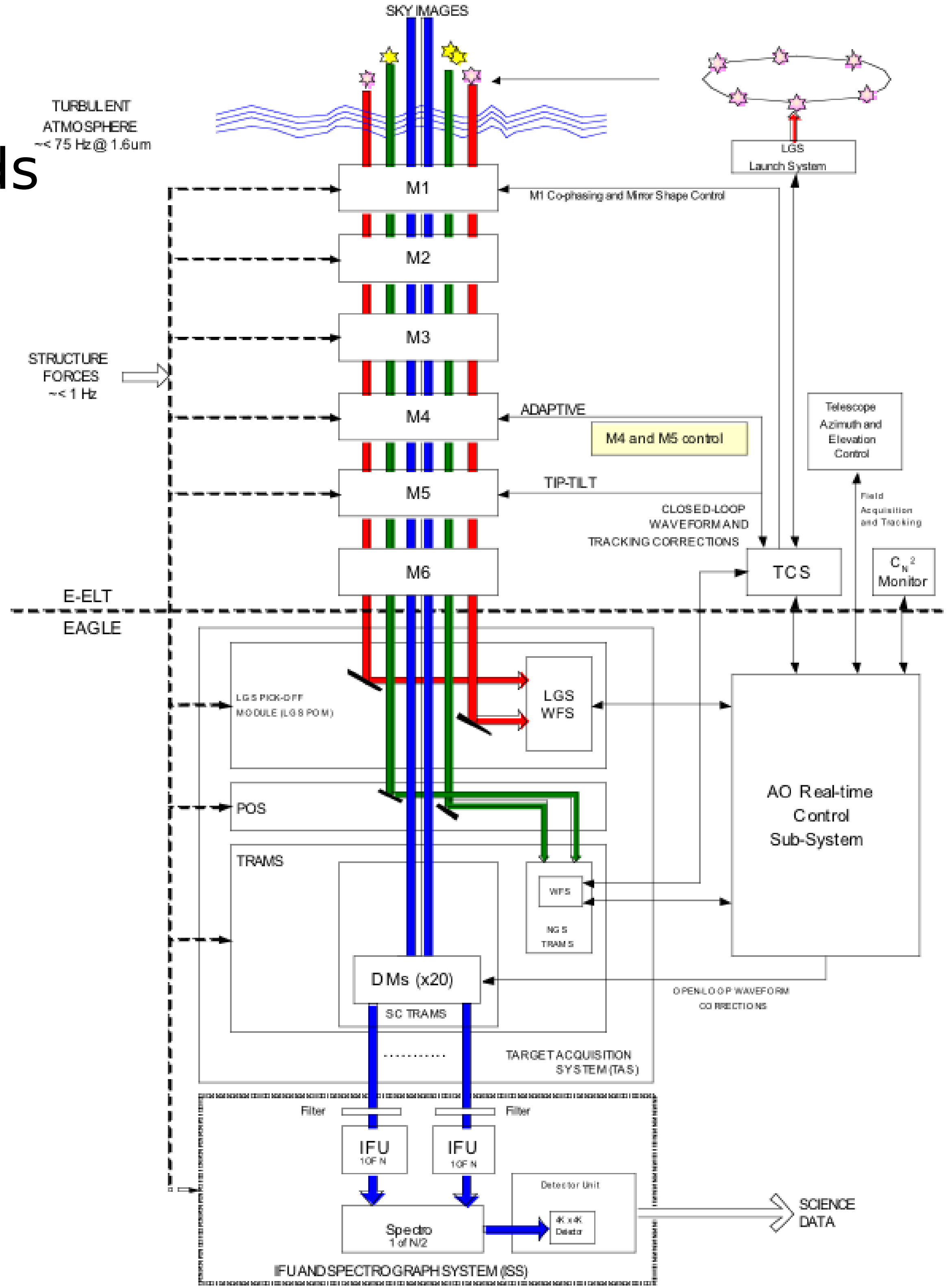
Gemini South MCAO system

EAGLE
(ESO E-ELT project)

MCAO system with 20 fields
0.8-2.45 um



1 Shutter
2 Laser Guide Star Sensing System
3 Pick-off System (Focal Plane)
4 Target Reimaging and Magnification System (including Deformable Mirror)
5 Integral Field Unit and Spectrograph System



TMT instruments

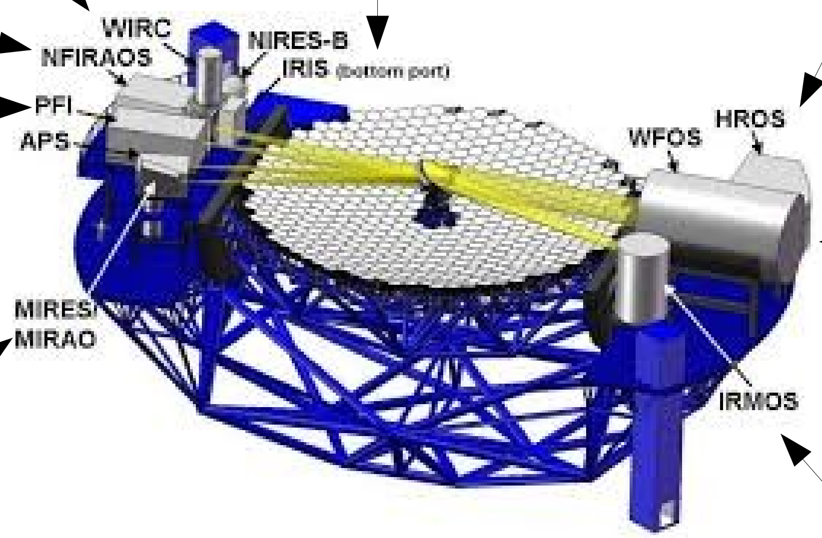
High resolution spectro
R=50,0000
0.31-1.1 um
(Seeing limited)

Wide FOV imager
NIR, 30”

Near-IR imaging (0.83-2.4um)
+ IFU, R=4000-10000

AO system
+ IRMS multi-slit spectro

high contrast
imaging

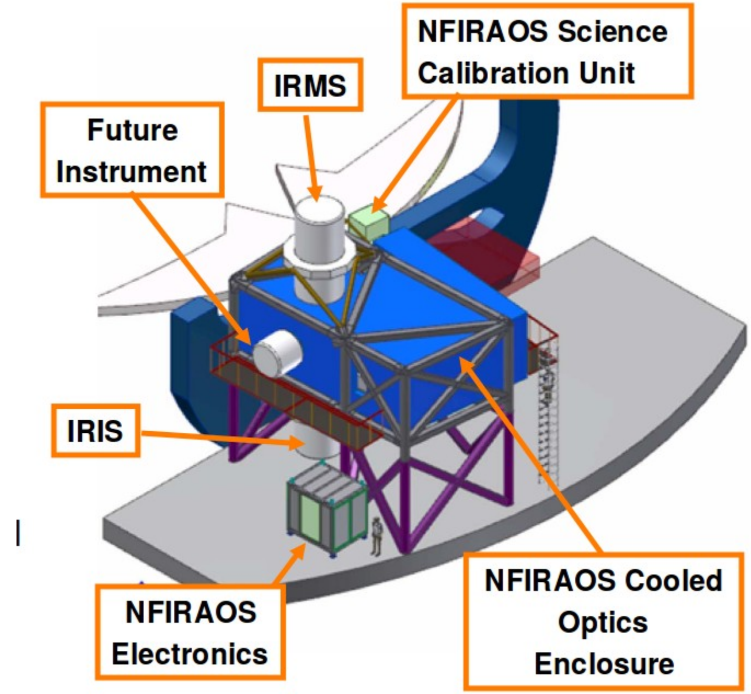


Visible light MOS
40 sq ' FOV
R=1000-8000
0.31-1.1 um
(Seeing limited)

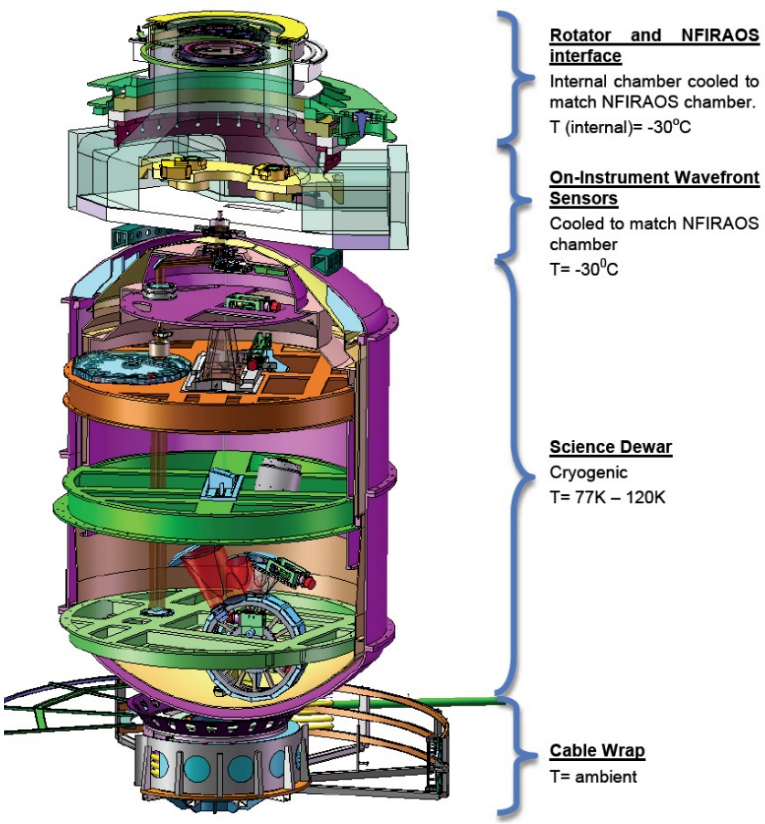
High res spectro
mid-IR
R=100,000
4.5” slit length
10” imaging FOV

Multiple IFUs
0.8-2.5 um
3” FOV per IFU
MOAO-fed

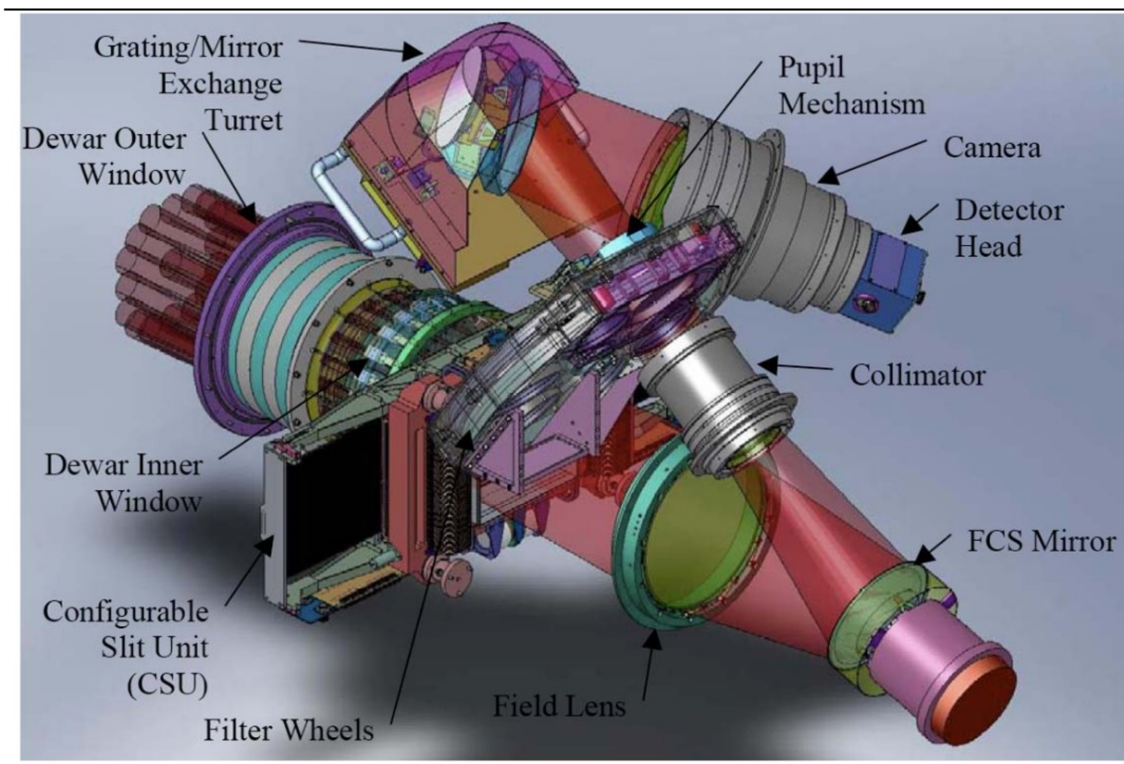
AO-fed TMT instruments (First light)



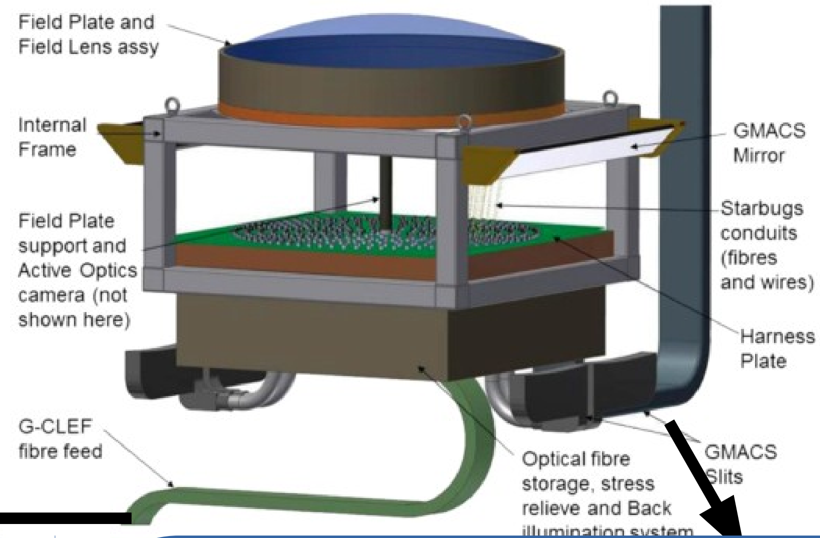
IRIS

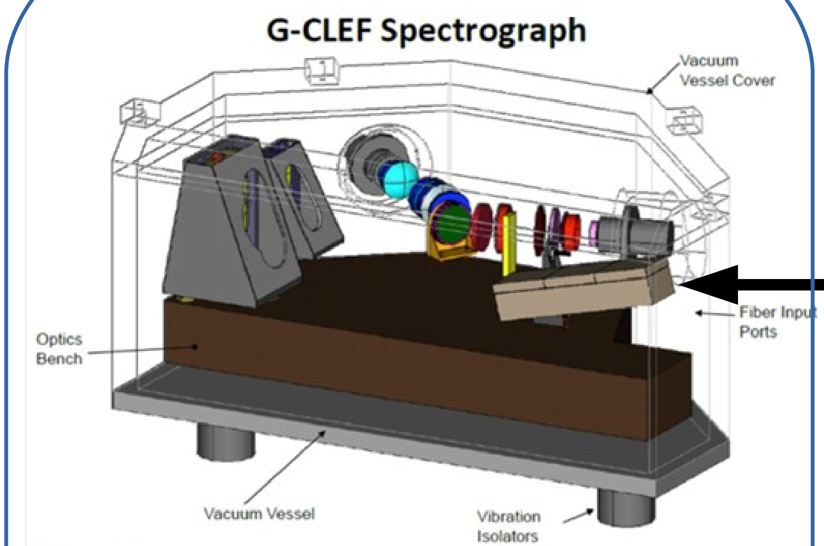


IRMS



GMT instruments: Optical spectroscopy





0.35 – 0.95 um
R: 19,000 – 108,000

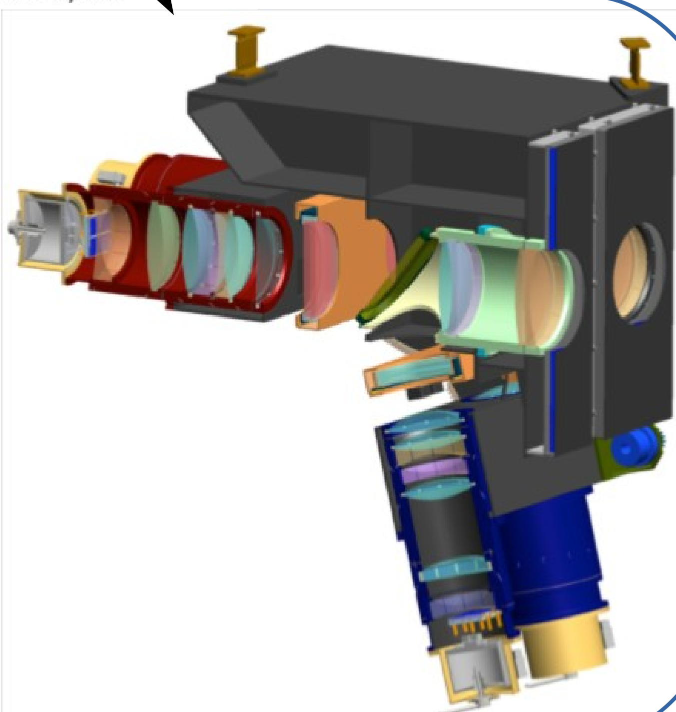
Exoplanets: precision radial velocity, transit spectroscopy
Stellar physics
Galaxies, cosmology

GMACS

0.35 – 0.95 um
R = 1,000 – 6,000

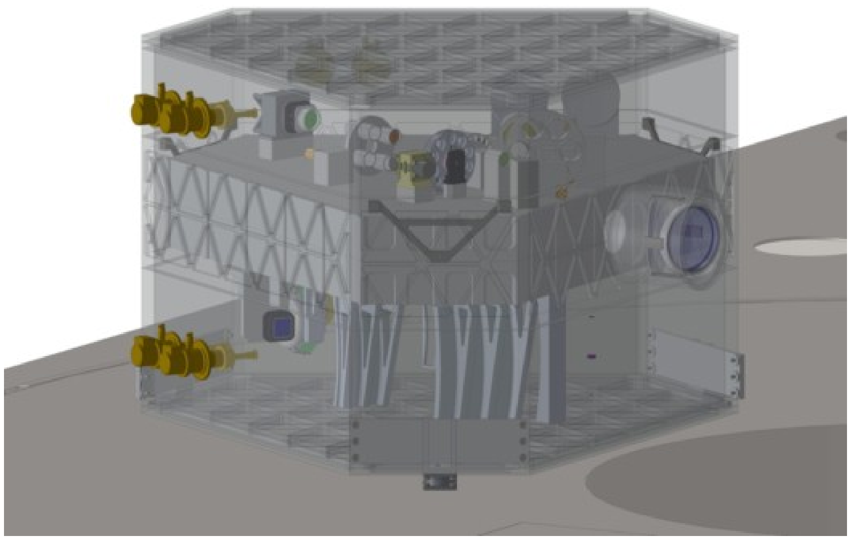
Multi-objects
(100s of spectra)

Galaxies, cosmology



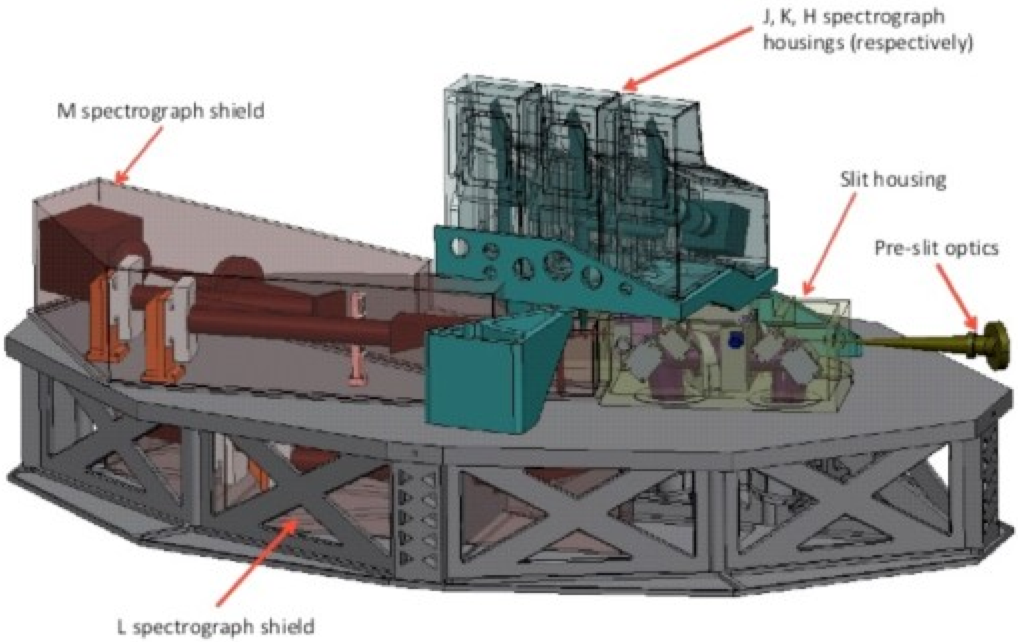
GMT instruments: NIR spectroscopy

Near-IR IFU and Adaptive Optics Imager – GMTIFS



0.9 – 2.5um IFU
R = 5,000 to 10,000
FOV: 20”x20” (imager), 0.3”x0.6”, 2.2”x4.5” (IFU)
5mas – 50mas resolution

IR Echelle Spectrograph – GMTNIRS

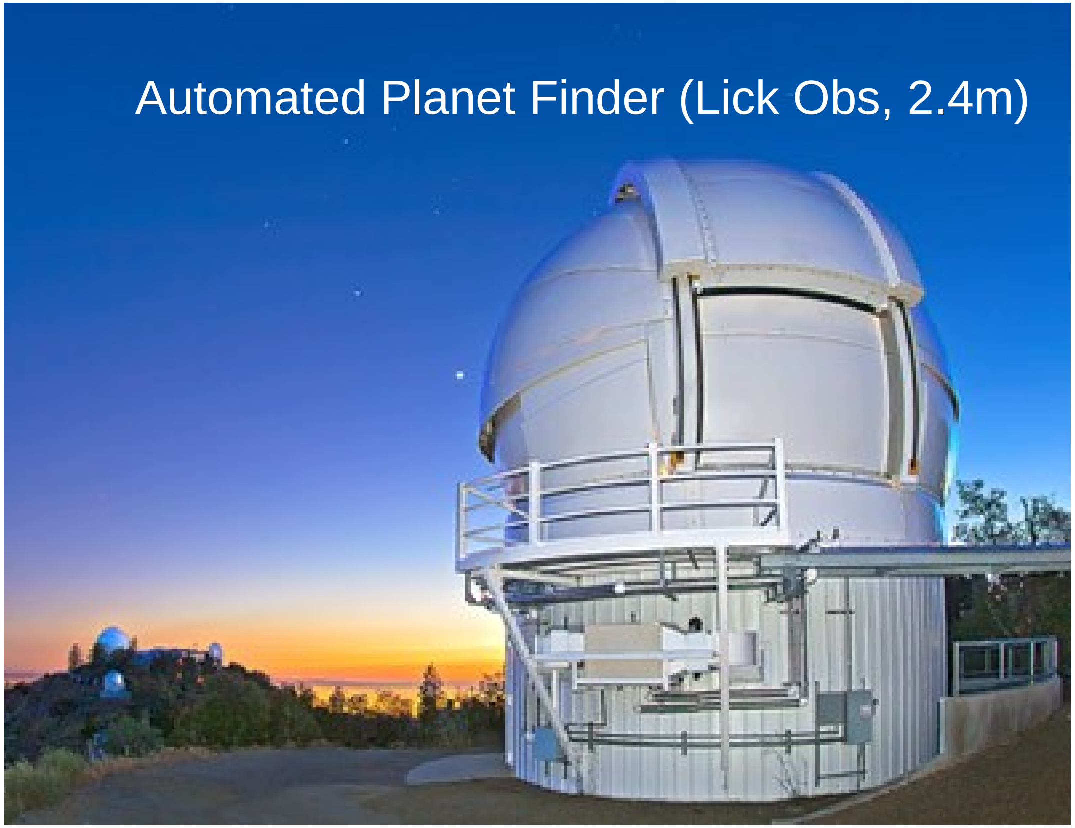


1.1 – 5.3um
R = 50,000 to 75,000

Exoplanet capabilities - RV

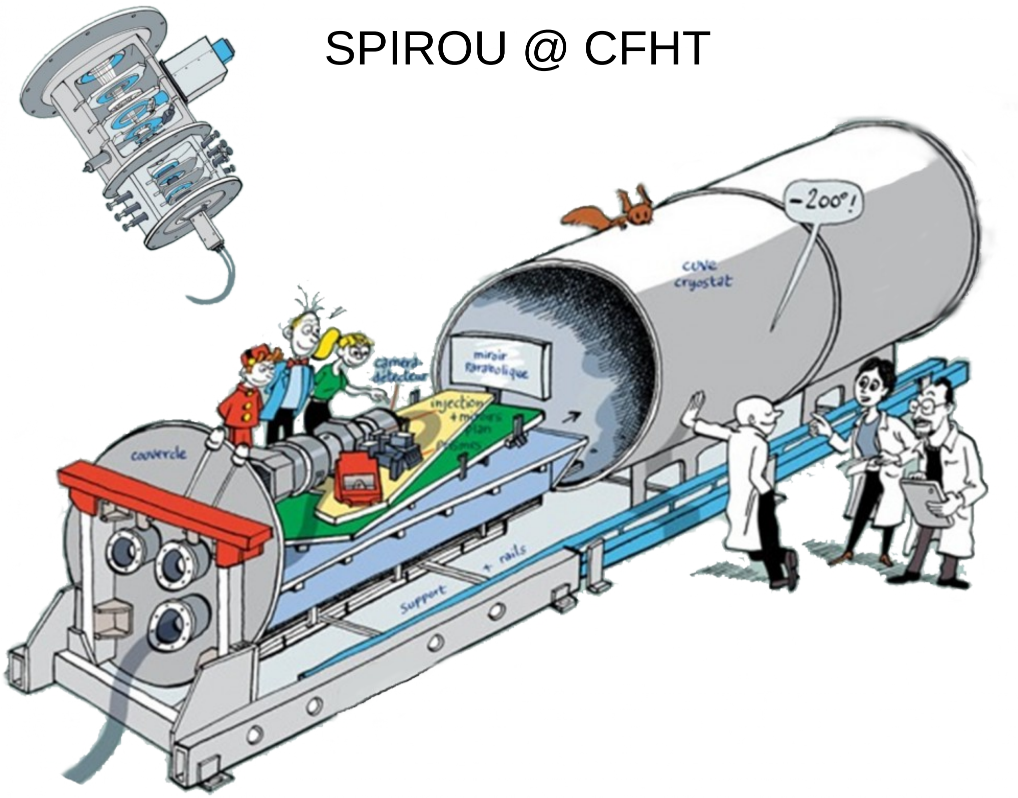
Optical RV is making steady progress and will reveal lower mass planets
Mix of high precision instruments on largest telescopes (for example CODEX on E-ELT), and dedicated robotic RV facilities

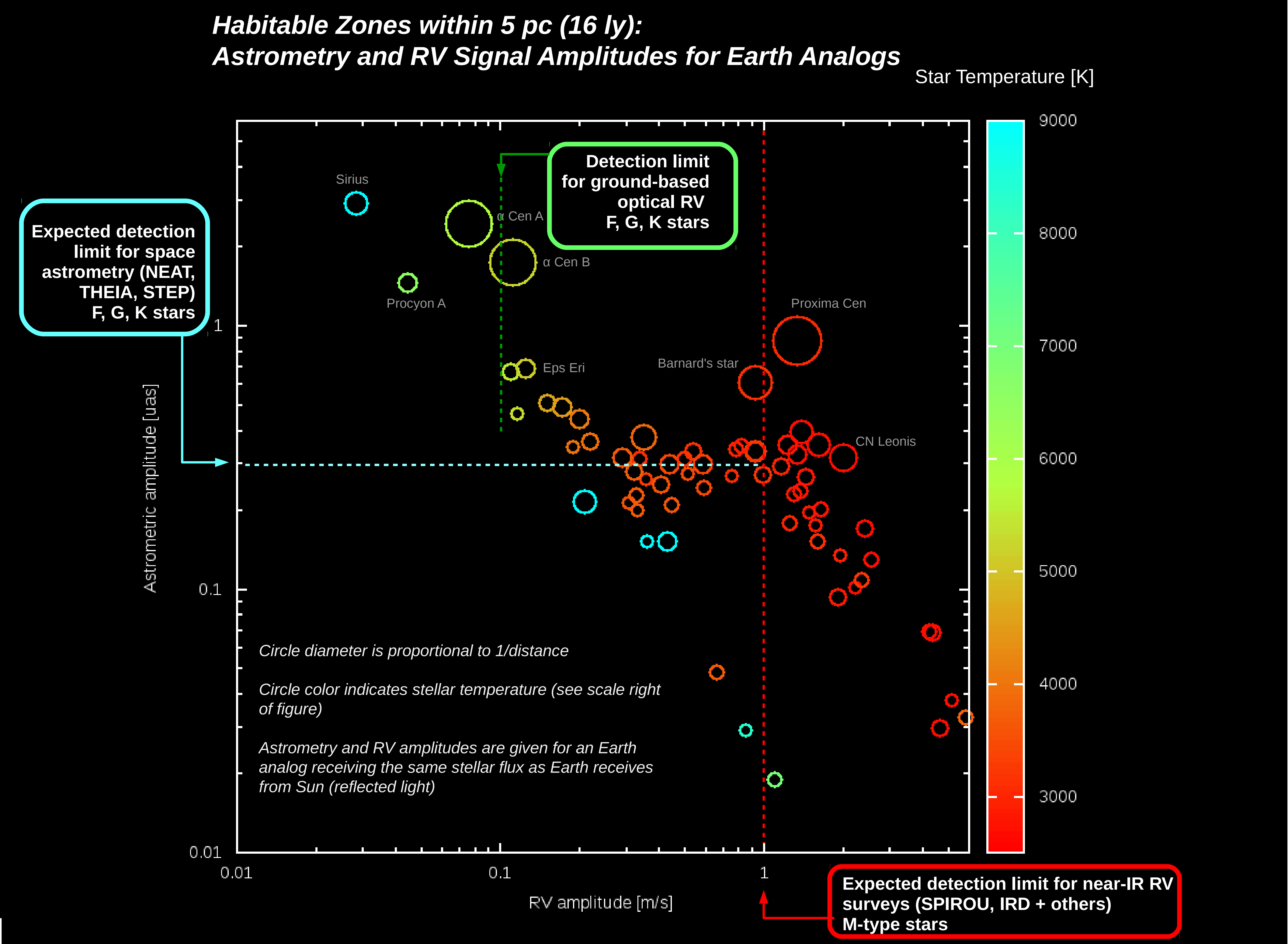
Near-IR RV will identify habitable planets around nearby M-type stars. First instruments being deployed **NOW**



Automated Planet Finder (Lick Obs, 2.4m)

SPIROU @ CFHT




Habitable Zones within 5 pc (16 ly):
Astrometry and RV Signal Amplitudes for Earth Analogs
Star Temperature [K]
9000
8000
7000
6000
5000
4000
3000
Expected detection limit for space astrometry (NEAT, THEIA, STEP) F, G, K stars
Detection limit for ground-based optical RV F, G, K stars
Expected detection limit for near-IR RV surveys (SPIROU, IRD + others) M-type stars
Sirius
α Cen A
α Cen B
Procyon A
Eps Eri
Barnard's star
Proxima Cen
CN Leonis
Astrometric amplitude [uas]
RV amplitude [m/s]
1
0.1
0.01
0.01
0.1
1
Circle diameter is proportional to 1/distance
Circle color indicates stellar temperature (see scale right of figure)
Astrometry and RV amplitudes are given for an Earth analog receiving the same stellar flux as Earth receives from Sun (reflected light)

Exoplanet capabilities – Direct imaging

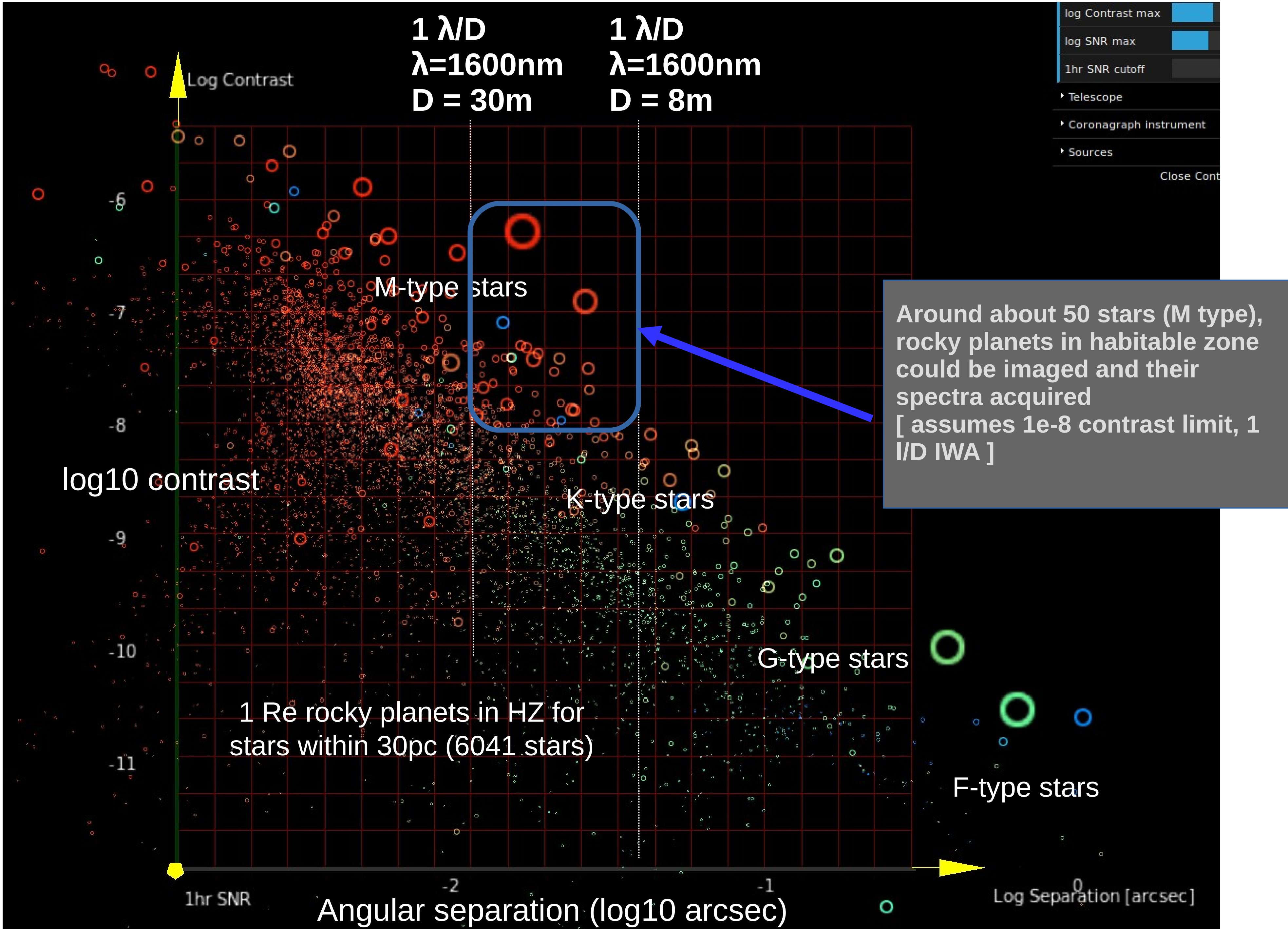
10um imaging: METIS @ E-ELT
→ thermal emission from Earth-size planets & larger around nearby stars

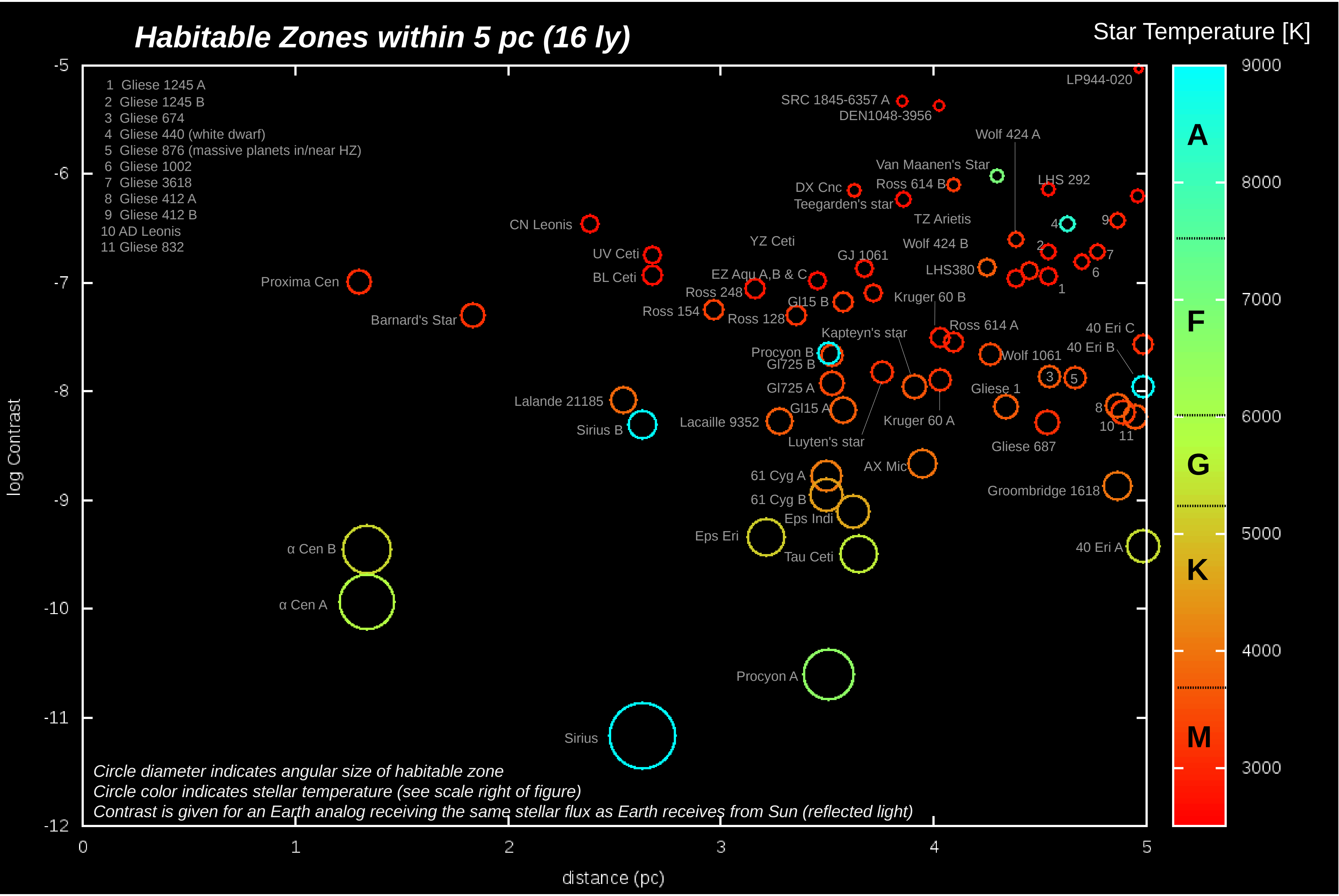
Near-IR / visible Extreme-AO:

8m telescopes: spectroscopy of self-luminous planets (young Jupiters)
.. and possibly reflected light imaging of nearby large planets

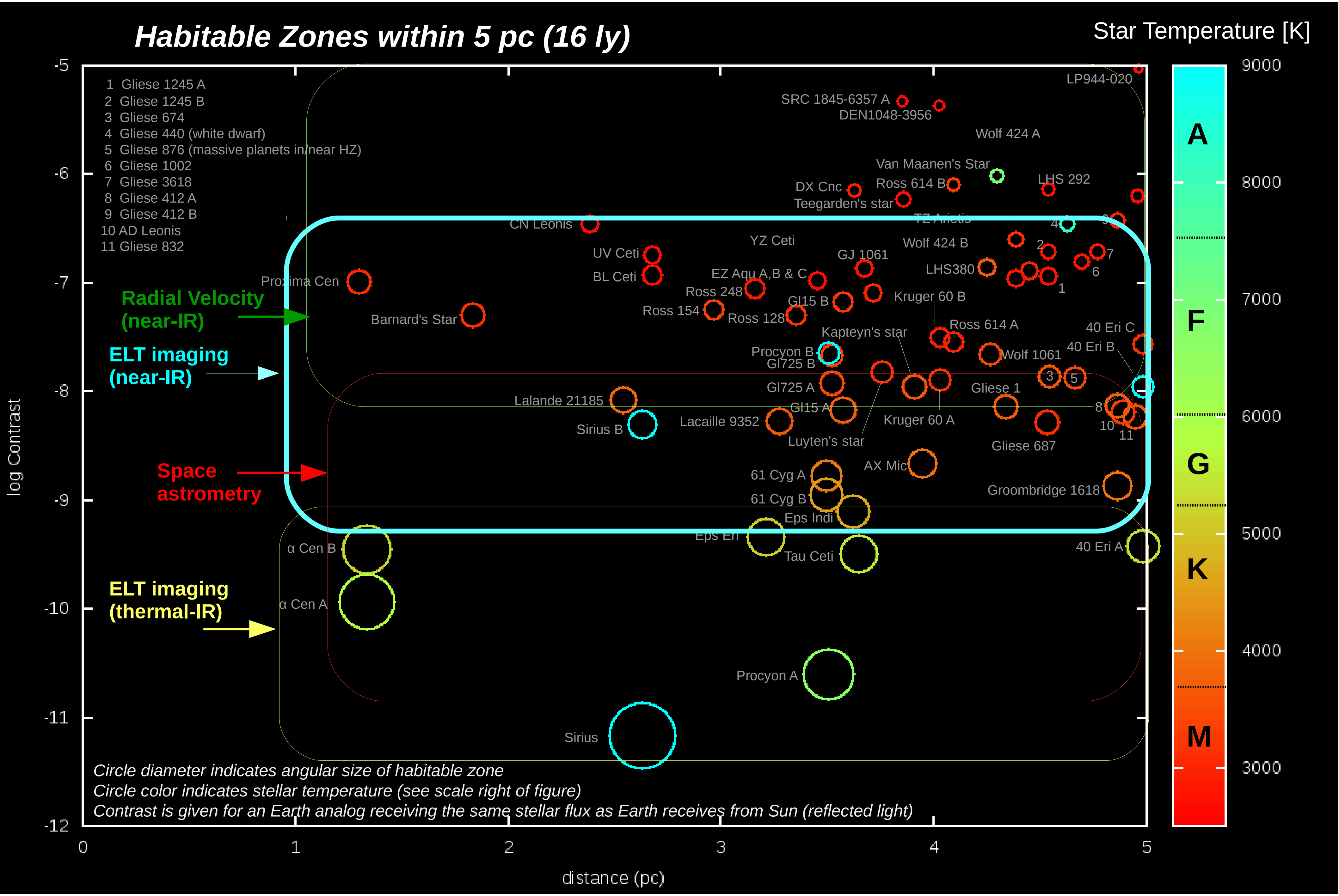
ELTs: detailed characterization of giant planets
Reflected light imaging and spectroscopy of Earths around M (& K?) type stars

Spectroscopic characterization of Earth-sized planets with ELTs





Habitable Zones within 5 pc (16 ly)
Star Temperature [K]
1 Gliese 1245 A
2 Gliese 1245 B
3 Gliese 674
4 Gliese 440 (white dwarf)
5 Gliese 876 (massive planets in/near HZ)
6 Gliese 1002
7 Gliese 3618
8 Gliese 412 A
9 Gliese 412 B
10 AD Leonis
11 Gliese 832
LP944-020
SRC 1845-6357 A
DEN1048-3956
Wolf 424 A
Van Maanen's Star
LHS 292
DX Cnc
Ross 614 B
Teegarden's star
TZ Arietis
CN Leonis
YZ Ceti
Wolf 424 B
UV Ceti
GJ 1061
LHS380
BL Ceti
EZ Aqu A,B & C
Proxima Cen
Ross 248
Gl15 B
Kruger 60 B
Ross 154
Ross 128
Barnard's Star
Ross 614 A
Kapteyn's star
40 Eri C
Procyon B
40 Eri B
Gl725 B
Wolf 1061
Gl725 A
Gliese 1
Lalande 21185
Gl15 A
Lacaille 9352
Kruger 60 A
Sirius B
Luyten's star
Gliese 687
AX Mic
61 Cyg A
Groombridge 1618
61 Cyg B
Eps Indi
Eps Eri
α Cen B
Tau Ceti
40 Eri A
α Cen A
Procyon A
Sirius
Circle diameter indicates angular size of habitable zone
Circle color indicates stellar temperature (see scale right of figure)
Contrast is given for an Earth analog receiving the same stellar flux as Earth receives from Sun (reflected light)
log Contrast
distance (pc)
A
F
G
K
M


Habitable Zones within 5 pc (16 ly)
Star Temperature [K]
1 Gliese 1245 A
2 Gliese 1245 B
3 Gliese 674
4 Gliese 440 (white dwarf)
5 Gliese 876 (massive planets in/near HZ)
6 Gliese 1002
7 Gliese 3618
8 Gliese 412 A
9 Gliese 412 B
10 AD Leonis
11 Gliese 832
Radial Velocity (near-IR)
ELT imaging (near-IR)
Space astrometry
ELT imaging (thermal-IR)
log Contrast
distance (pc)
Proxima Cen
Barnard's Star
CN Leonis
UV Ceti
BL Ceti
Ross 154
Ross 248
Ross 128
EZ Aqu A,B & C
YZ Ceti
GJ 1061
Gl15 B
Gl15 A
Gl725 A
Gl725 B
Procyon B
Kapteyn's star
Luyten's star
Kruger 60 A
Kruger 60 B
Lalande 21185
Sirius B
Lacaille 9352
61 Cyg A
61 Cyg B
Eps Indi
Eps Eri
Tau Ceti
AX Mic
Groombridge 1618
Gliese 687
Gliese 1
Wolf 1061
Ross 614 A
Ross 614 B
LHS380
Wolf 424 A
Wolf 424 B
Van Maanen's Star
DX Cnc
Teegarden's star
TZ Arietis
LHS 292
SRC 1845-6357 A
DEN1048-3956
LP944-020
40 Eri A
40 Eri B
40 Eri C
α Cen A
α Cen B
Procyon A
Sirius
A
F
G
K
M
9000
8000
7000
6000
5000
4000
3000
Circle diameter indicates angular size of habitable zone
Circle color indicates stellar temperature (see scale right of figure)
Contrast is given for an Earth analog receiving the same stellar flux as Earth receives from Sun (reflected light)

Summary

Ground-based telescopes will provide excellent visible light wide field imaging and MOS in visible and near-IR
Low resolution spectroscopy (IFS) and high resolution (R~100,000)

Adaptive optics will provide diffraction limited imaging anywhere in the sky at near-IR, and around bright sources (m~12 and brighter) in visible light

AO may provide nearly full sky coverage diffraction limited images in visible light (see Keck visible AO development plans)

Exoplanets:

RV (especially nearIR) will identify habitable planets

Spectroscopic characterization with direct imaging: Giant planets with 8m telescopes, Earth-like planets with ELTs

Nearest M (&K)-type stars provide opportunities for direct imaging + RV/astrometry