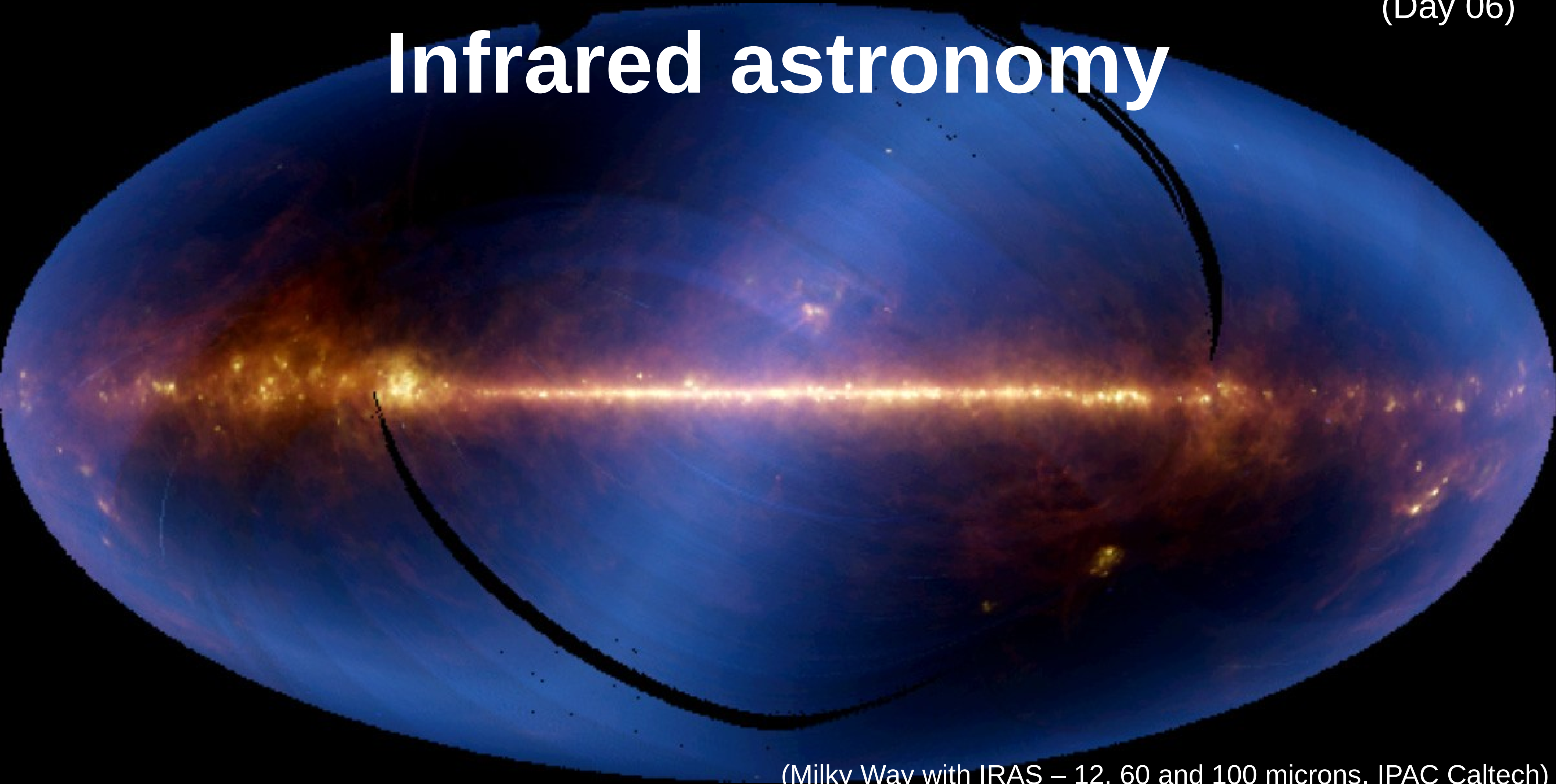
(Day 06)

Infrared astronomy



(Milky Way with IRAS – 12, 60 and 100 microns. IPAC Caltech)

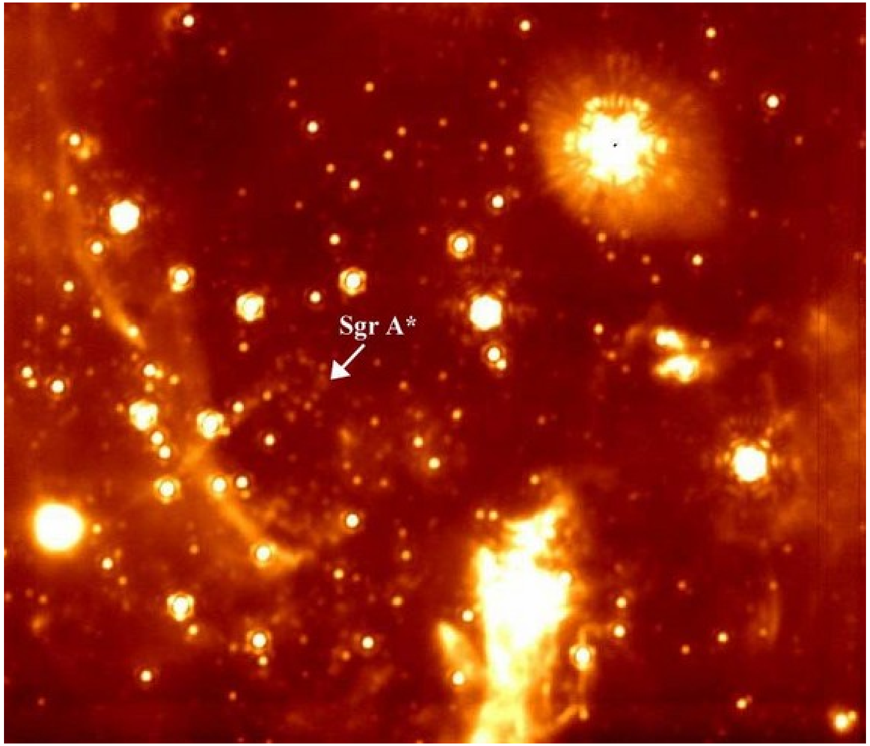
Today

(M16 with HST. Visible and near IR.
Credits: NASA, ESA, and G. Bacon)

1. Infrared astronomy
2. HAWK-I (near-IR imager)
3. CRIRES (near-IR spectrograph)
4. KMOS (near-IR IFU)
5. VISIR (mid-IR imager and spectrograph)
6. SOFIA
7. JWST

Why observe in the IR?

- To see through the dust (star forming regions, Galactic center, other “dusty” galaxies)
- To detect cool objects (M dwarfs, brown dwarfs, planets, exoplanets)
- To study the dust (dust disks in YSOs, ejected dust clouds in evolved giants, star forming regions, galactic disks)
- Redshifted objects (distant galaxies, Lyman alpha forest)
- And objects detected in the optical but with emission extending to the IR

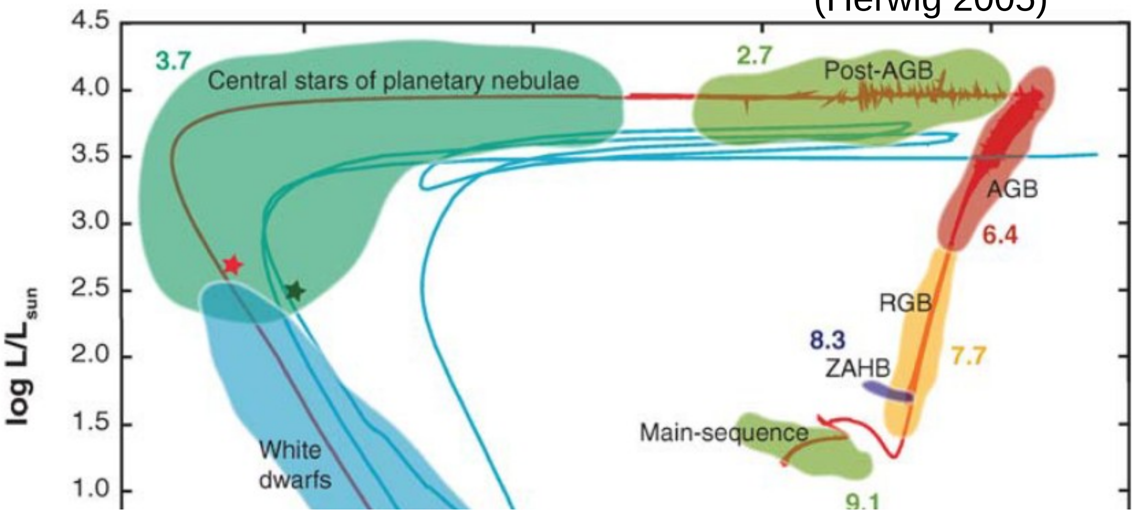


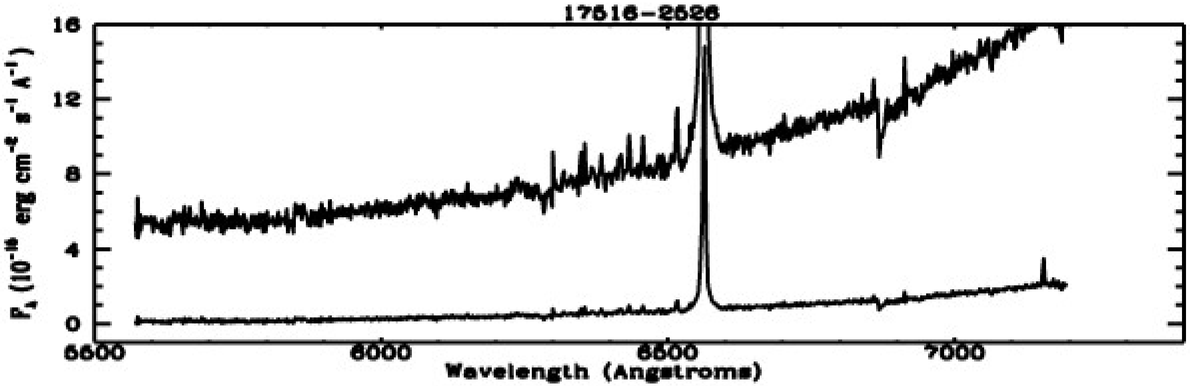
(Galactic Center at 4μm Credit: A. Ghez group; UCLA)

Let’s define a science case

- We looked at an overdensity of stars found by Gaia
- Confirmed with photometric observations as a cluster
- Spectroscopy gave a list of members
- One star in the field is an RV member and has Hα in emission
- Could be a post-AGB candidate
- We want to clarify its nature and search for a circumstellar dust shell
- Photometry and spectroscopy in the near- to mid-IR (V ~ 21 mag)

(Herwig 2005)





(Suarez et al. 2006)

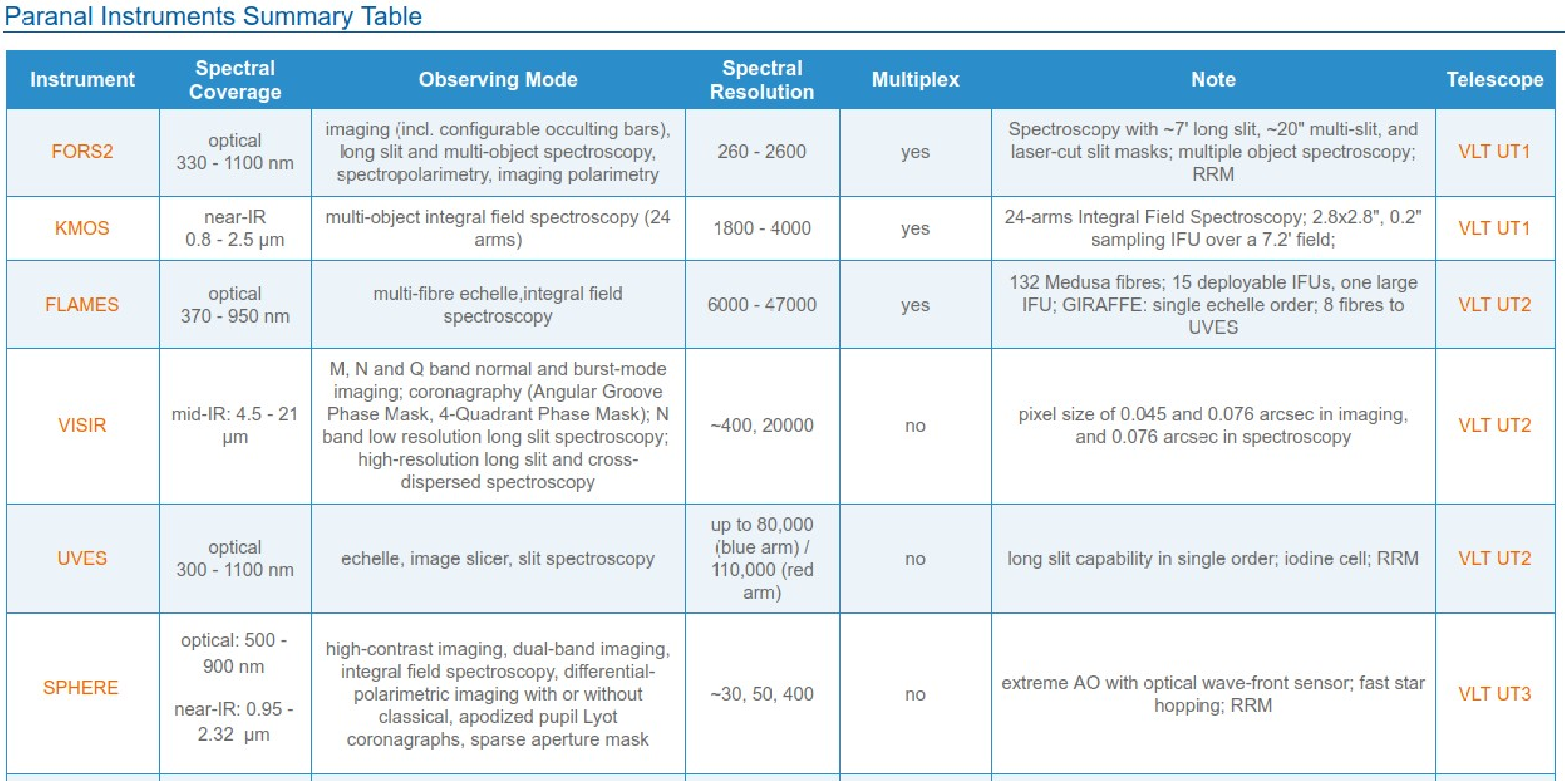
If you want to observe with the VLT, read the call for proposals

- Updated list of offered instruments
- Informs on recent policy changes
- and on future plans for the instruments
- Describes important definitions (proposal types, observing modes, OBs, ...)
- Several links for additional information
- Binding document if the proposal is approved
- **Reading is a must for 1st time users!**

ESO Call for Proposals – P109

Proposal Deadline: 23 September 2021, 12:00 noon CEST

Optical spectrographs @VLT



Paranal Instruments Summary Table

Instrument	Spectral Coverage	Observing Mode	Spectral Resolution	Multiplex	Note	Telescope
FORS2	optical 330 - 1100 nm	imaging (incl. configurable occulting bars), long slit and multi-object spectroscopy, spectropolarimetry, imaging polarimetry	260 - 2600	yes	Spectroscopy with ~7' long slit, ~20" multi-slit, and laser-cut slit masks; multiple object spectroscopy; RRM	VLT UT1
KMOS	near-IR 0.8 - 2.5 µm	multi-object integral field spectroscopy (24 arms)	1800 - 4000	yes	24-arms Integral Field Spectroscopy; 2.8x2.8", 0.2" sampling IFU over a 7.2' field;	VLT UT1
FLAMES	optical 370 - 950 nm	multi-fibre echelle,integral field spectroscopy	6000 - 47000	yes	132 Medusa fibres; 15 deployable IFUs, one large IFU; GIRAFFE: single echelle order; 8 fibres to UVES	VLT UT2
VISIR	mid-IR: 4.5 - 21 µm	M, N and Q band normal and burst-mode imaging; coronagraphy (Angular Groove Phase Mask, 4-Quadrant Phase Mask); N band low resolution long slit spectroscopy; high-resolution long slit and cross-dispersed spectroscopy	~400, 20000	no	pixel size of 0.045 and 0.076 arcsec in imaging, and 0.076 arcsec in spectroscopy	VLT UT2
UVES	optical 300 - 1100 nm	echelle, image slicer, slit spectroscopy	up to 80,000 (blue arm) / 110,000 (red arm)	no	long slit capability in single order; iodine cell; RRM	VLT UT2
SPHERE	optical: 500 - 900 nm near-IR: 0.95 - 2.32 µm	high-contrast imaging, dual-band imaging, integral field spectroscopy, differential-polarimetric imaging with or without classical, apodized pupil Lyot coronagraphs, sparse aperture mask	~30, 50, 400	no	extreme AO with optical wave-front sensor; fast star hopping; RRM	VLT UT3

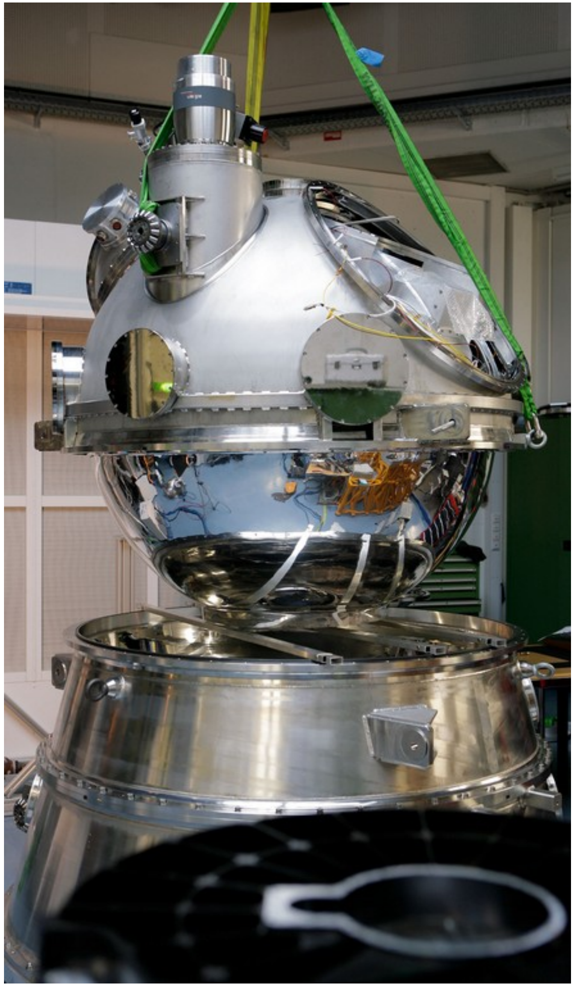
https://www.eso.org/sci/facilities/lpo/cfp/cfp109/instrument_summary.html

Optical spectrographs @VLT

X-SHOOTER	UV-optical-NIR 300 - 2500 nm	echelle, slit and integral field spectroscopy	~5000-17000	no	full spectral coverage with one pointing; slit + IFU; RRM	VLT UT3
CRIRES	near-IR 0.95-5.3 µm	echelle, slit spectroscopy, spectro-polarimetry	~40,000-80,000	no	AO assisted, 29 wavelength settings, 0.2"x10" and 0.4"x10" slits, gas cells for precision RV measurements, linear and circular polarimetry below 2500 nm.	VLT UT3
HAWK-I	near-IR 0.85-2.5 µm	broand and narrow band imaging, fast photometry	-	-	pixel size of 0.106"; field: 7.5'x7.5', subwindow readout capability; GLAO; RRM	VLT UT4
MUSE	optical 465 - 930 nm	integral field spectroscopy	1770 @ 480nm 3590 @ 930nm	no	IFU size on sky 60"x60" with spaxel size 0.2" (WFM) or 7.5"x7.5" with spaxel size 0.025" (NFM); GLAO, LTAO, no AO; RRM.	VLT UT4
ESPRESSO	optical 380 - 788 nm	fibre-fed échelle spectroscopy	140,000, 190,000, or 70,000 (median)	no	2 fibres (1 object, 1 sky or simultaneous reference); RV precision < 1 m/s (with the ultimate goal of reaching 10 cm/s); 1-UT and 4-UT modes	VLT UT1, VLT UT2, VLT UT3, or/and VLT UT4
GRAVITY	near-IR 2.05 - 2.45 µm	spectro-interferometry	R ~ 20, 500, & 4000	no	4 beam combiner - delivers spectrally dispersed visibilities, differential and closure phases	VLTI - ATs VLTI - UTs

https://www.eso.org/sci/facilities/lpo/cfp/cfp109/instrument_summary.html

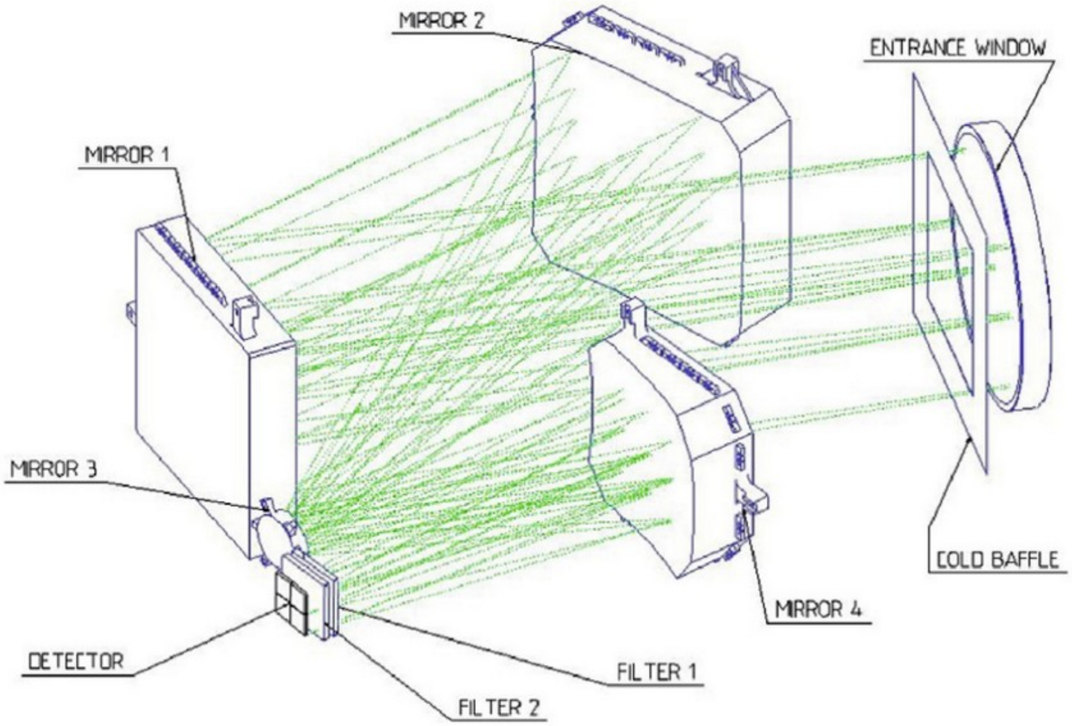
HAWK-I

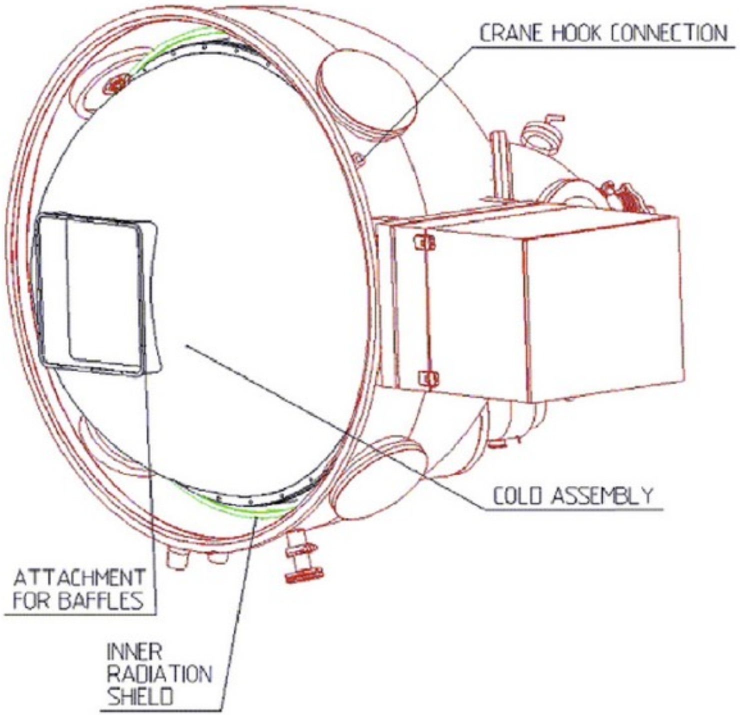

(Credit: ESO)

- **H**igh **A**cuity **W**ide field **K**-band **I**mager (Kissler-Patig et al. 2008)
- Near-infrared cryogenic wide-field imager installed at the Nasmyth A focus of UT4

  (Instrument 120 K, detectors 80 K)
- Filters from 1.0 to 2.2 microns (Broad Band: *Y*, *J*, *H*, *Ks* + narrow band)
- FoV: 7.5’ x 7.5’
- Detectors: mosaic 4 Hawaii-2RG chips
- GRAAL AO module, to be used with the 4LGS system (Ground Layer Adaptive Optics)

HAWK-I



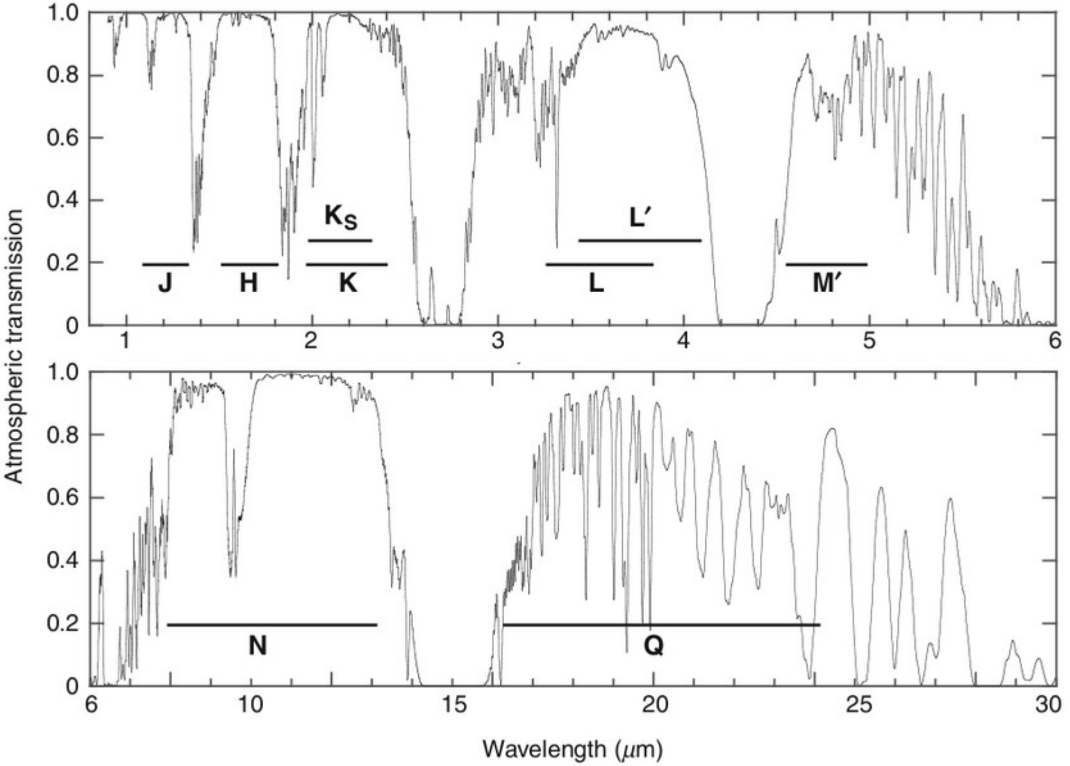


(Kissler-Patig et al. 2008)

IR-bands

1. Near-IR from 0.75-1.0 μm to 5μm;
2. Mid-IR from 5 μm to 25μm;
3. Far-IR from 25μm to 350μm.

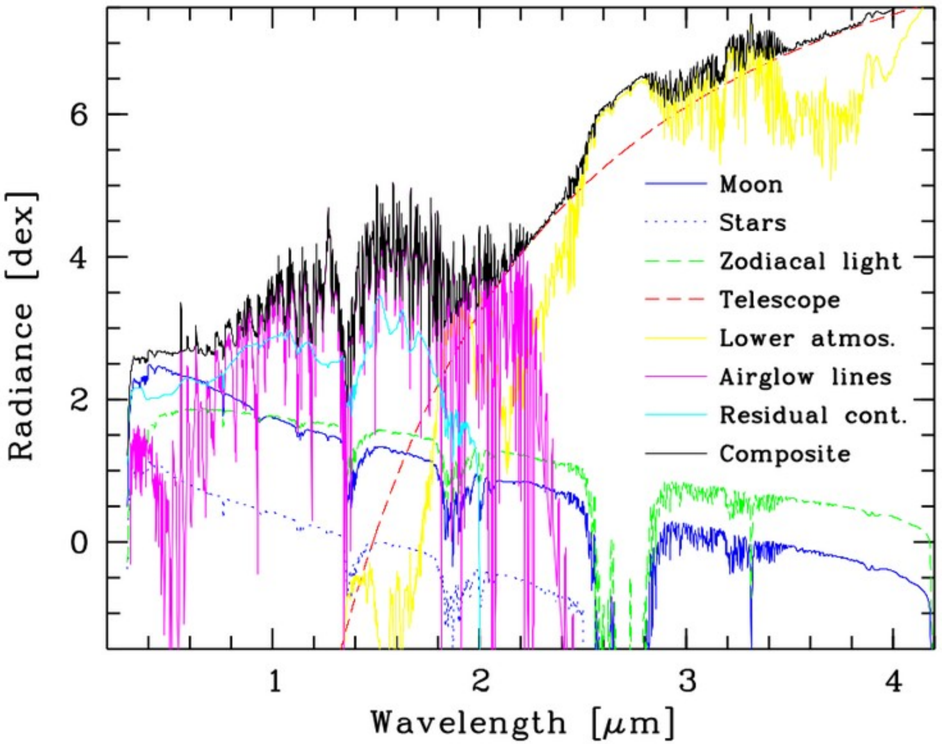
- The sky is different in the IR in comparison to the optical
- Extinction is dominated by lines (H_2O, sometimes saturated)
- Variations are strong (with λ). Variations also in short time scales
- Atmospheric extinction correction to airmass zero does not work



(Tokunaga et al. 2013)

Sky background

- Airglow lines (OH at 85-100 km)
- Thermal emission from the telescope and the atmosphere above 2.3 microns
- Scattered light from the Moon is just a minor source of background (no need to request dark or grey time)
- From space, zodiacal light is the main source of background



(Credit: ESO)

Sky background

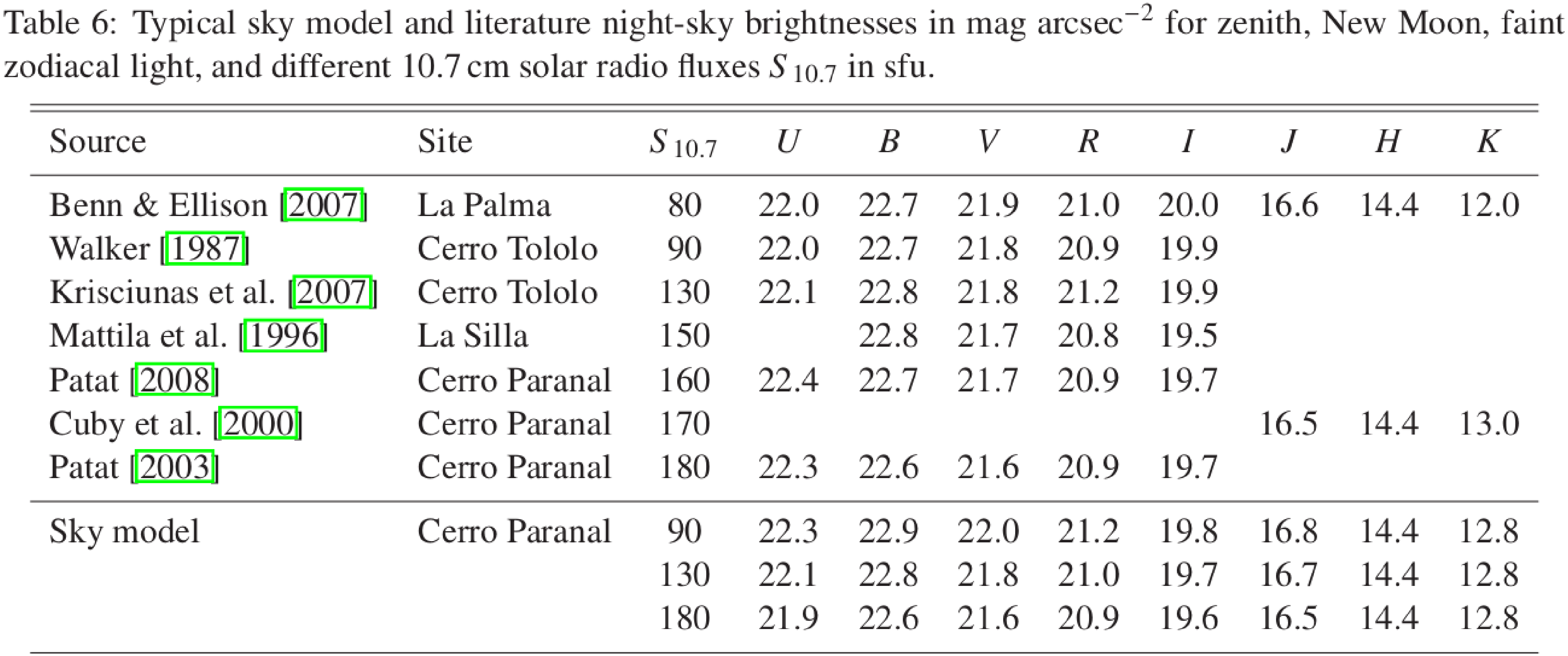


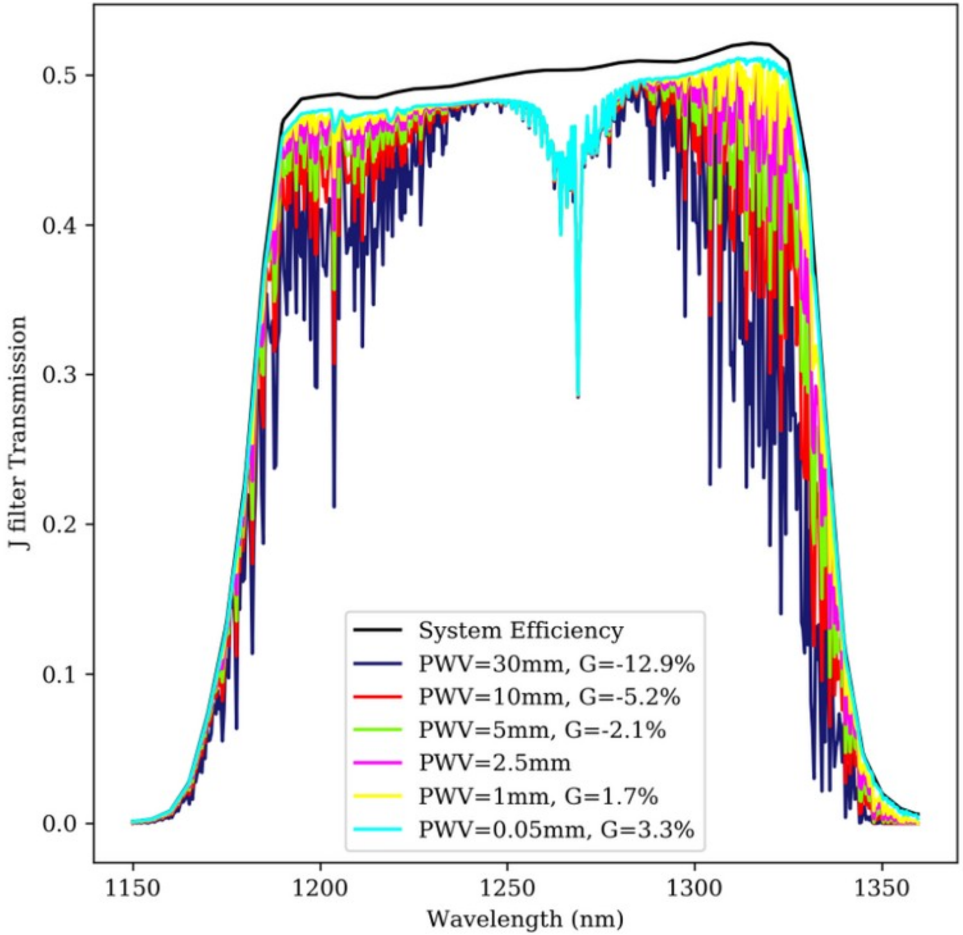
Table 6: Typical sky model and literature night-sky brightnesses in mag arcsec^{-2} for zenith, New Moon, faint zodiacal light, and different 10.7 cm solar radio fluxes $S_{10.7}$ in sfu.

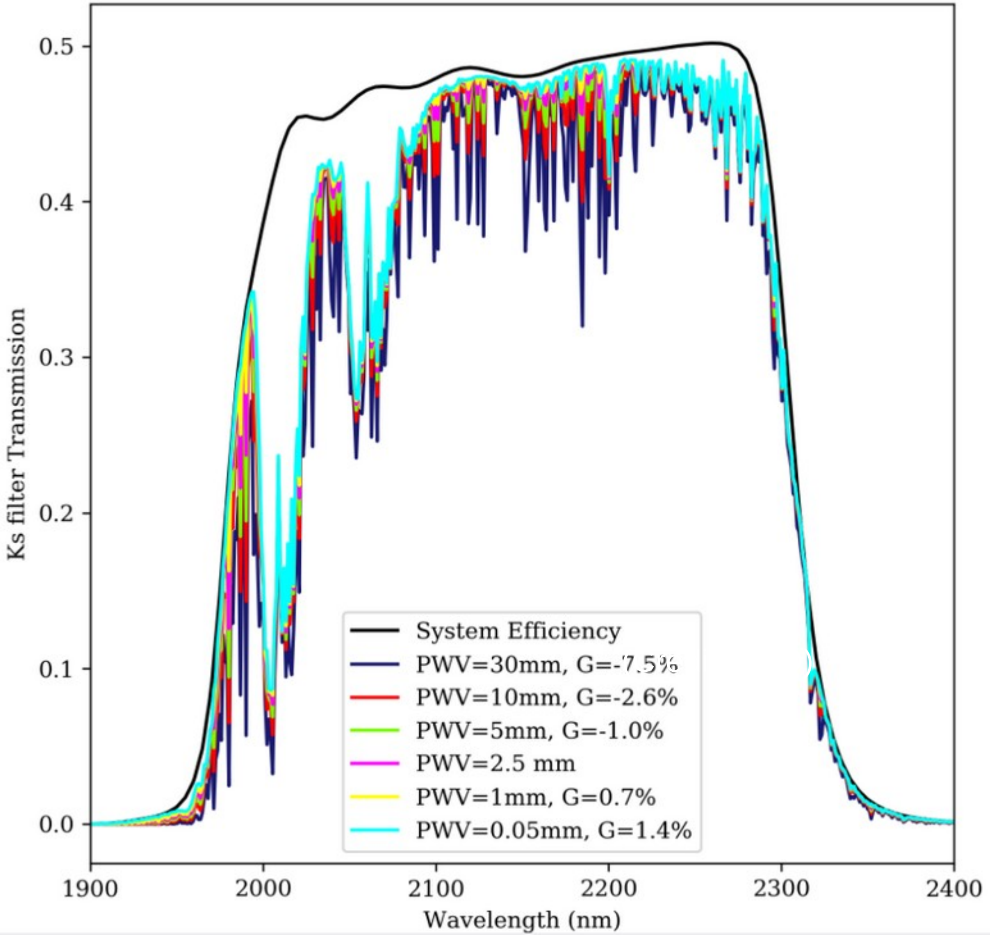
Source	Site	$S_{10.7}$	U	B	V	R	I	J	H	K
Benn & Ellison [2007]	La Palma	80	22.0	22.7	21.9	21.0	20.0	16.6	14.4	12.0
Walker [1987]	Cerro Tololo	90	22.0	22.7	21.8	20.9	19.9			
Krisciunas et al. [2007]	Cerro Tololo	130	22.1	22.8	21.8	21.2	19.9			
Mattila et al. [1996]	La Silla	150		22.8	21.7	20.8	19.5			
Patat [2008]	Cerro Paranal	160	22.4	22.7	21.7	20.9	19.7			
Cuby et al. [2000]	Cerro Paranal	170						16.5	14.4	13.0
Patat [2003]	Cerro Paranal	180	22.3	22.6	21.6	20.9	19.7			
Sky model	Cerro Paranal	90	22.3	22.9	22.0	21.2	19.8	16.8	14.4	12.8
		130	22.1	22.8	21.8	21.0	19.7	16.7	14.4	12.8
		180	21.9	22.6	21.6	20.9	19.6	16.5	14.4	12.8

(Credit: ESO)

Water vapour

(Credit: ESO)





Photometric standards

- Images of a 2MASS standard field are taken daily in the broad band filters

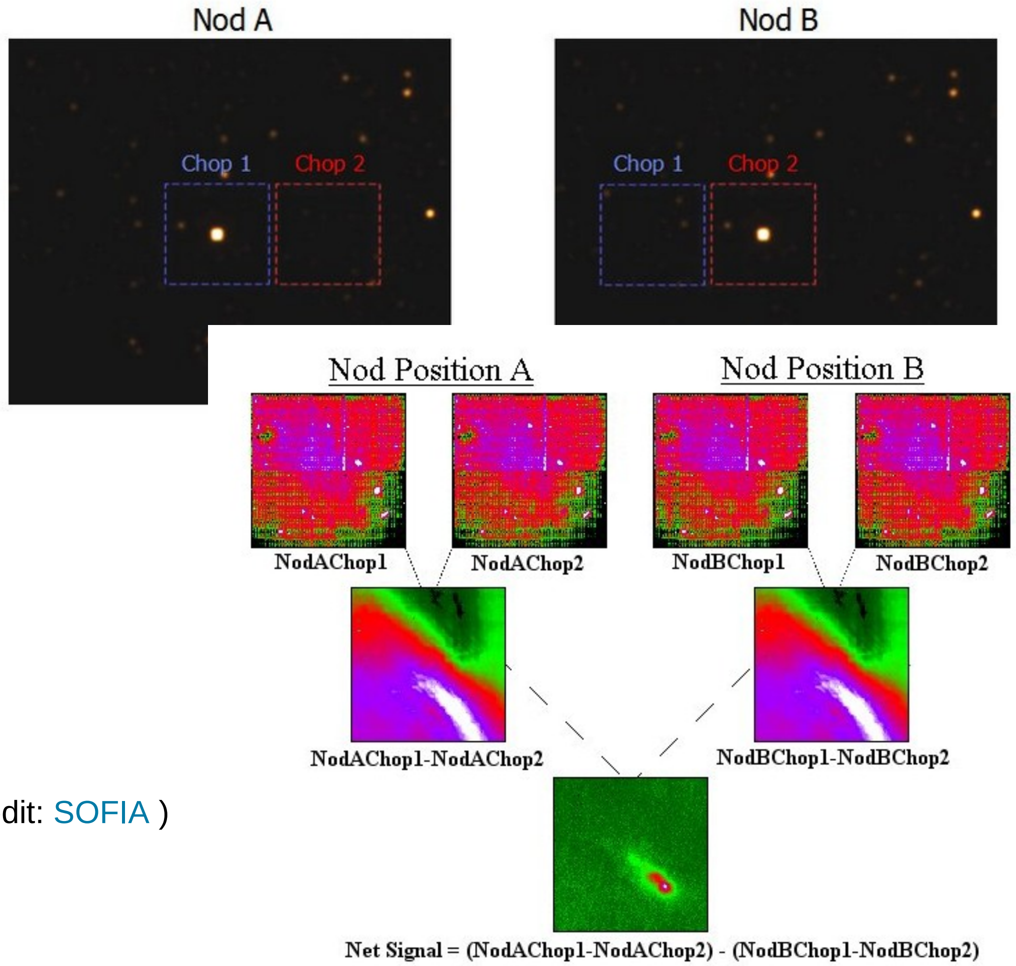
  (2MASS – all sky survey in J, H, Ks)

- If you need standards taken before or after the science, then time for calibrations has to be included
- Calibration at the 0.05-0.10 mag level, 2MASS stars in the field might be enough
- 2MASS calibration fields (link in the HAWK-I manual)

(Credit: 2MASS)

Chop and nod

- The sky is bright and variable
- Sky background correction is an important concern when planning to observe in the IR
- Chopping is done with the secondary mirror
- Jittering: add a small random offset on top of nod
- Nodding by moving the telescope
- To properly remove telescope thermal emission and any systematic trend/gradient on sky background



(Credit: SOFIA)

DIT and NDIT

- (**N**umber of) **D**etection **I**ntegration **T**ime
- Exposure times limited to where the response to the signal is linear
- For HAWK-I detectors, limit ~60 000 electrons
- Max DIT depends on the background level
- Choose your DIT accordingly

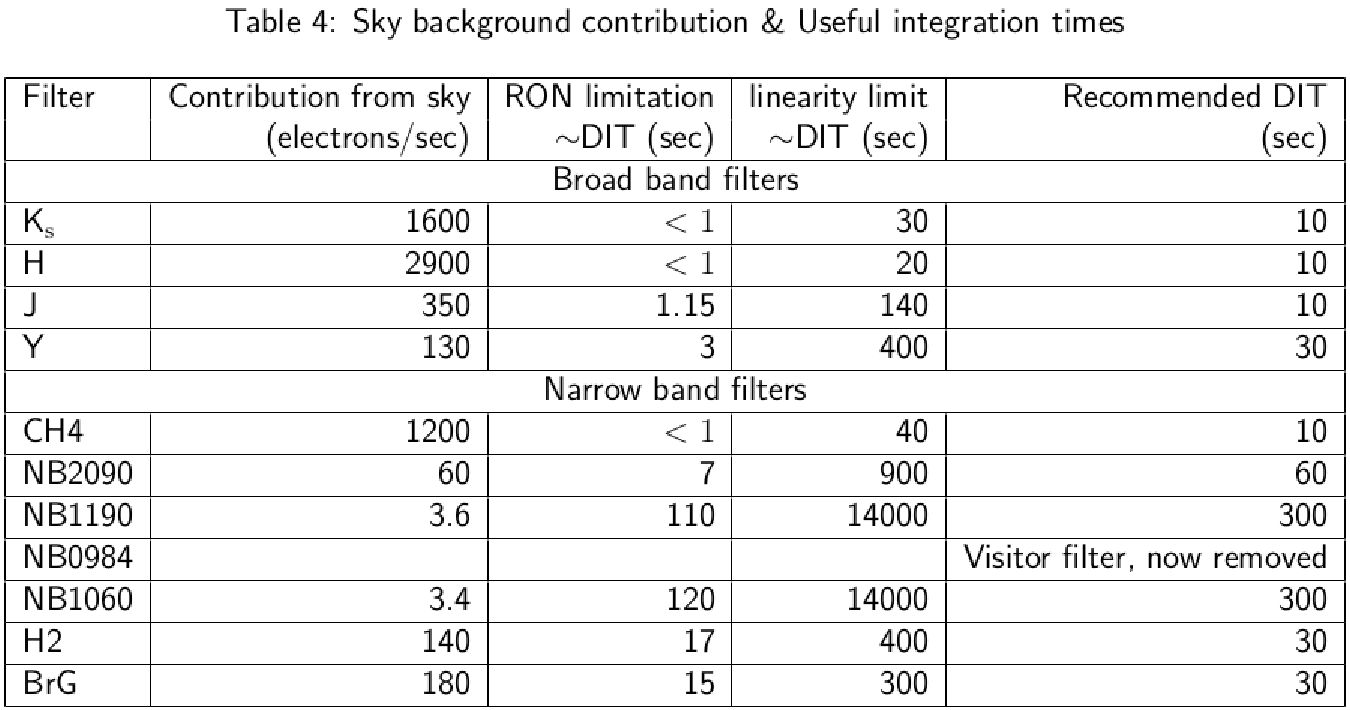


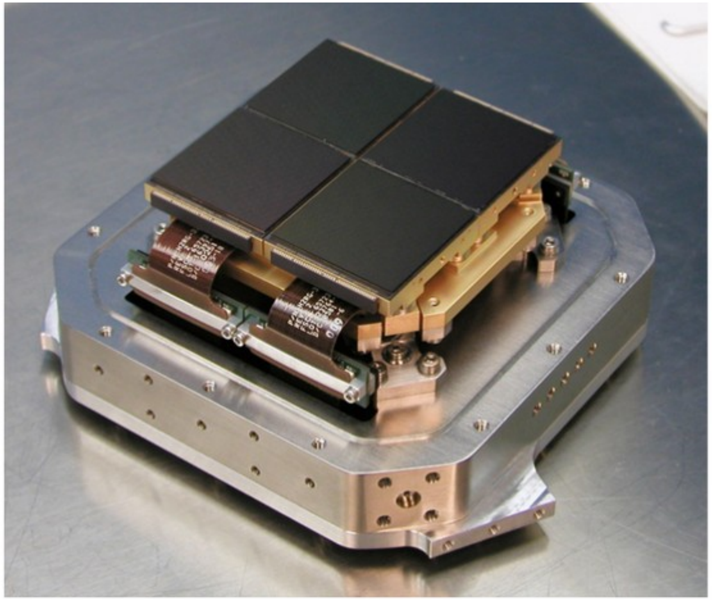
Table 4: Sky background contribution & Useful integration times

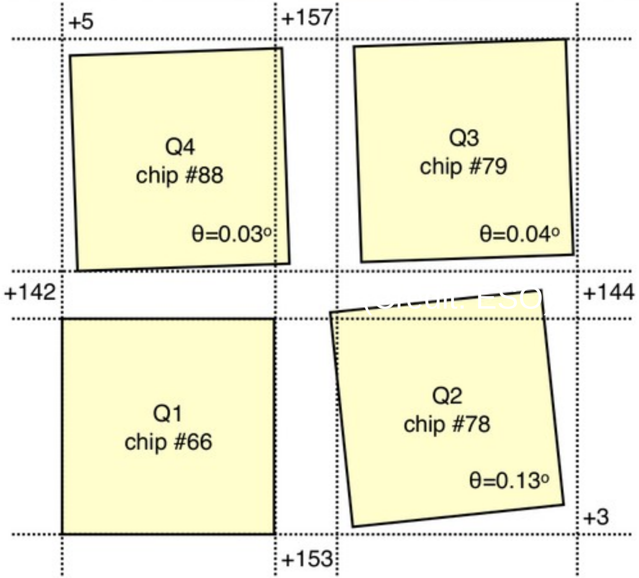
Filter	Contribution from sky (electrons/sec)	RON limitation ~DIT (sec)	linearity limit ~DIT (sec)	Recommended DIT (sec)
		Broad band filters		
K_s	1600	< 1	30	10
H	2900	< 1	20	10
J	350	1.15	140	10
Y	130	3	400	30
		Narrow band filters		
CH4	1200	< 1	40	10
NB2090	60	7	900	60
NB1190	3.6	110	14000	300
NB0984				Visitor filter, now removed
NB1060	3.4	120	14000	300
H2	140	17	400	30
BrG	180	15	300	30

(Credit: ESO)

HAWK-I detectors

- Mosaic of 4 2k×2k HgCdTe MBE arrays (molecular beam epitaxy)
- Intrinsic photoconductor
- Pixels of 0.106” on the sky
- Cut off at 2.5 microns (adjusting Cd fraction)
- Mind the gaps! (15 arcsec)
- The detector is read continuously in non-destructive mode every ~1.67s
- Saturated pixels are no longer read, but extrapolated

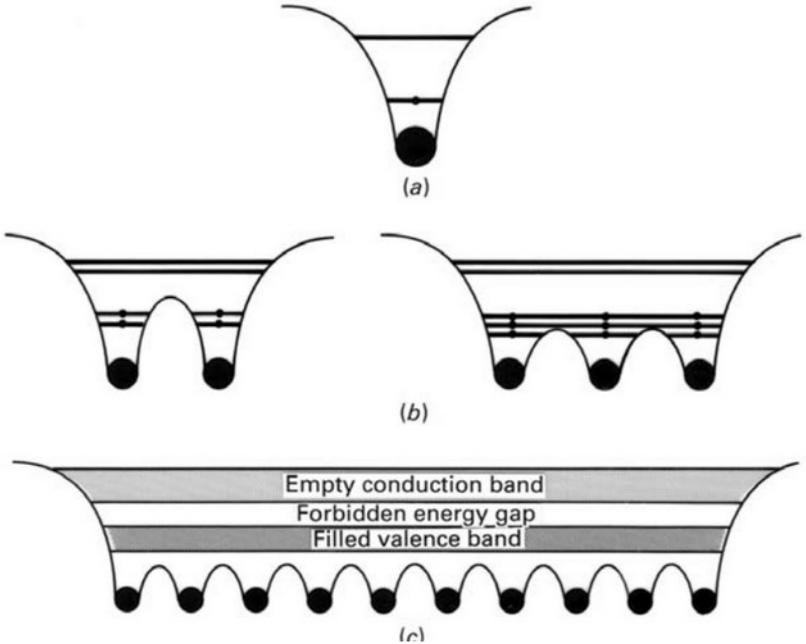




(Credit: ESO)

Photoconductor detectors

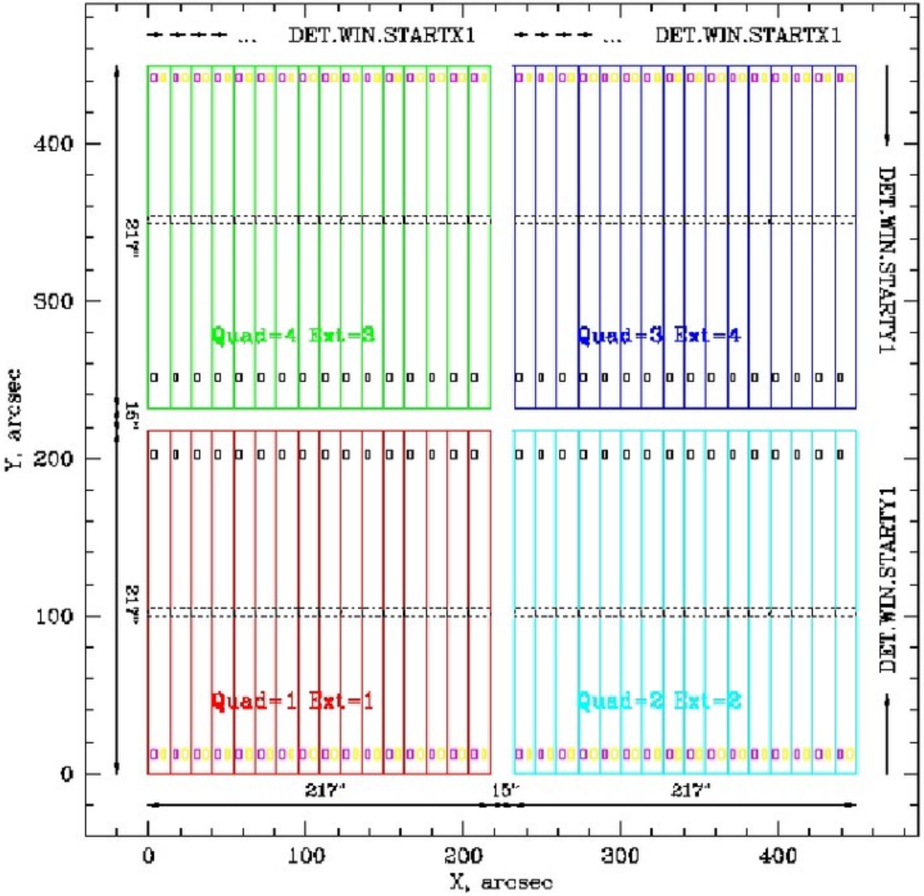
- When atoms come together to form a crystal, the outer electrons interact to bind the atoms
- The electrons are shared, the levels split
- With many atoms, a band is formed
- **Valence band**: inner filled energy levels
- **Conduction band:** higher energy levels where electrons are free to move under the influence of an electric force field
- **Bandgap**: minimum energy needed to promote electrons between valence and conduction band
- Extrinsic (or doped) semiconductors have impurity atoms to produce intermediate energy levels within the gap



(McLean 2008)

HAWK-I fast photometry mode

- Fast photometry high cadence and high-time resolution
- Minimum DIT: 0.01-0.1 sec
- Detector windowing (readout in 16 stripes of 128x2048 px)
- Windowing at the hardware level (only selected regions are read)
- There are limitations, see the manual

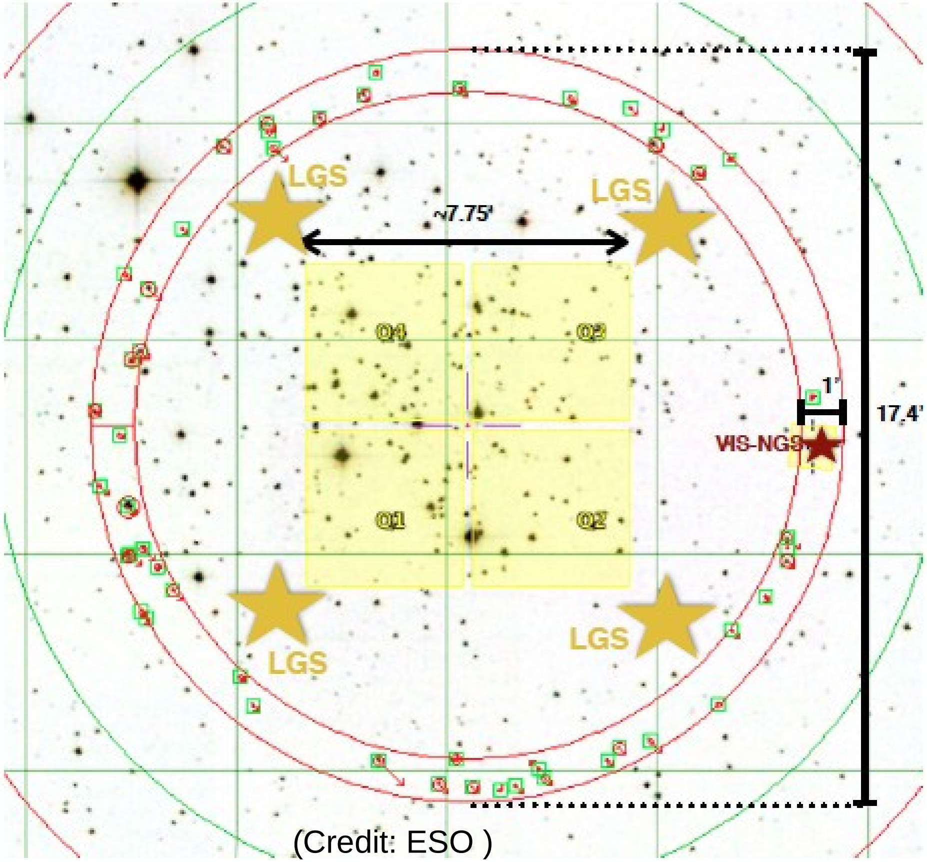


(Credit: ESO)

GRAAL

- GRAAL: adaptive optics module for use with HAWK-I
- Ground layer adaptive optics (GLAO)
- FoV 10.5’ x 10.5’
- 4 lasers pointed outside the science FoV
- GRAAL offers an improvement of about 40% on the K-band FWHM,
- Allows routine observations with 0.3” FWHM

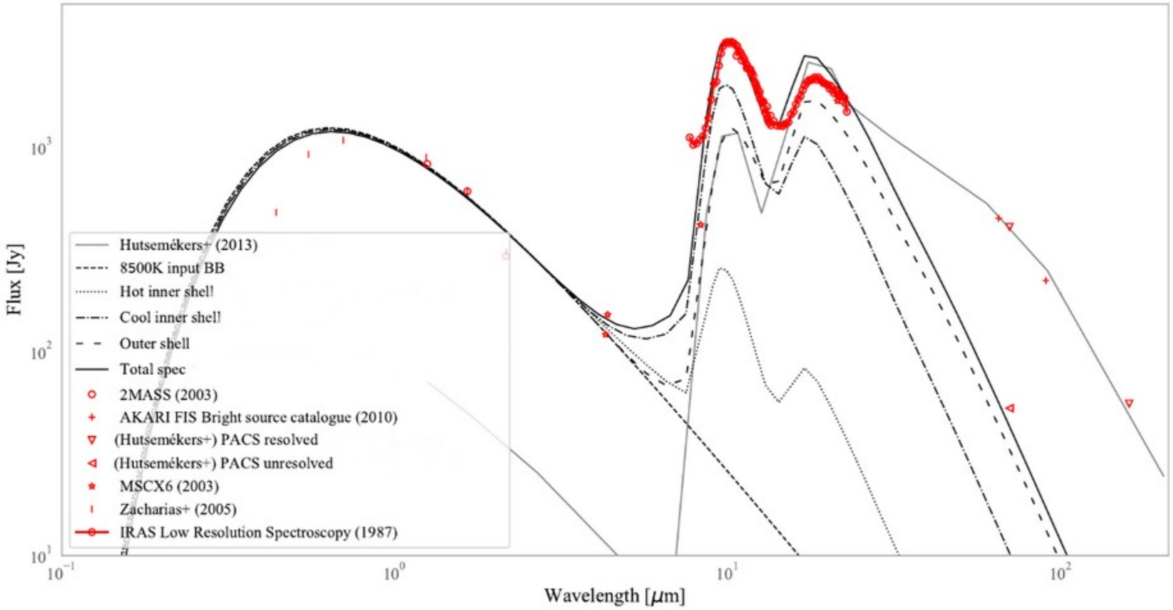
  (HAWK-I pixel has ~0.1”)



(Credit: ESO)

Strategy for our science case

- We do not know if there is extended structure to be detected
- HAWK-I + AO for the best FWHM
- Broad band J, H, K filters
- At the NIR likely only thermal emission from the central source
- But careful testing with the ETC needed
- Total exposure to have a good detection threshold (respecting recommended DITs)



(Koumpia et al. 2020)

Questions?

(Credit: Shutterstock)

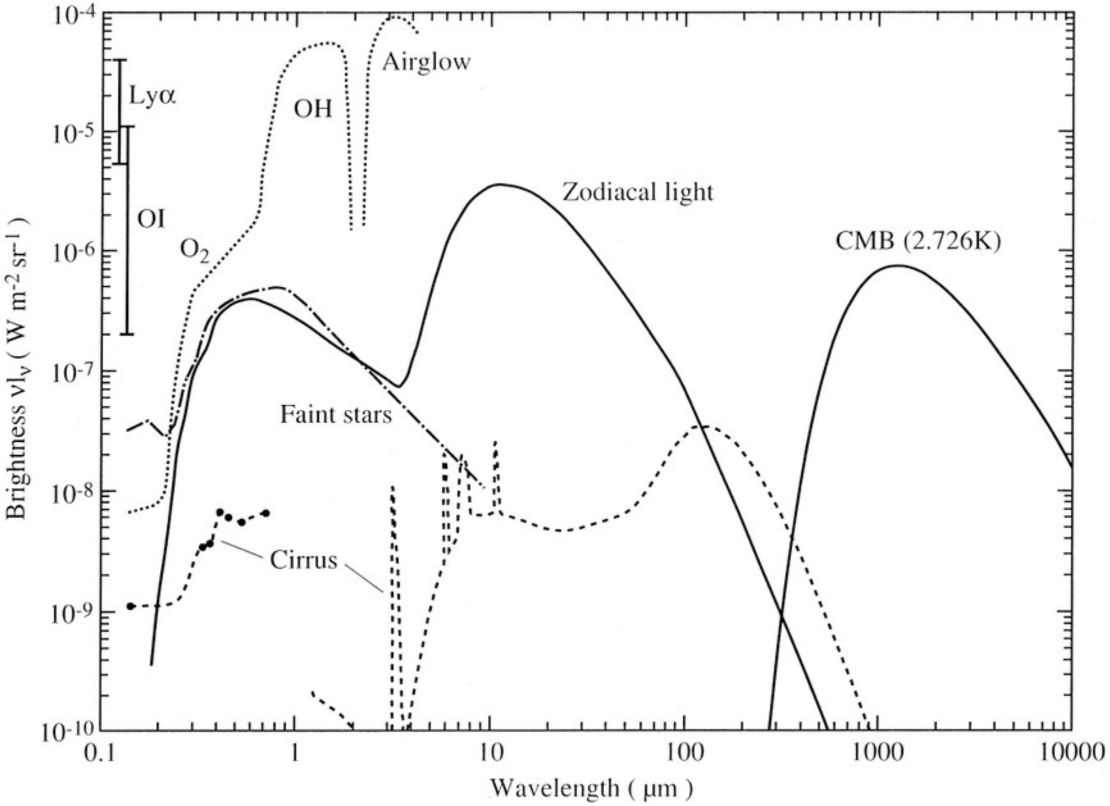
Let’s leave the ground towards space

Why from space?

- No seeing from Earth's atmosphere distortions
- No infrared emission from the atmosphere
- Only way to observe the entire infrared range without telluric absorption features

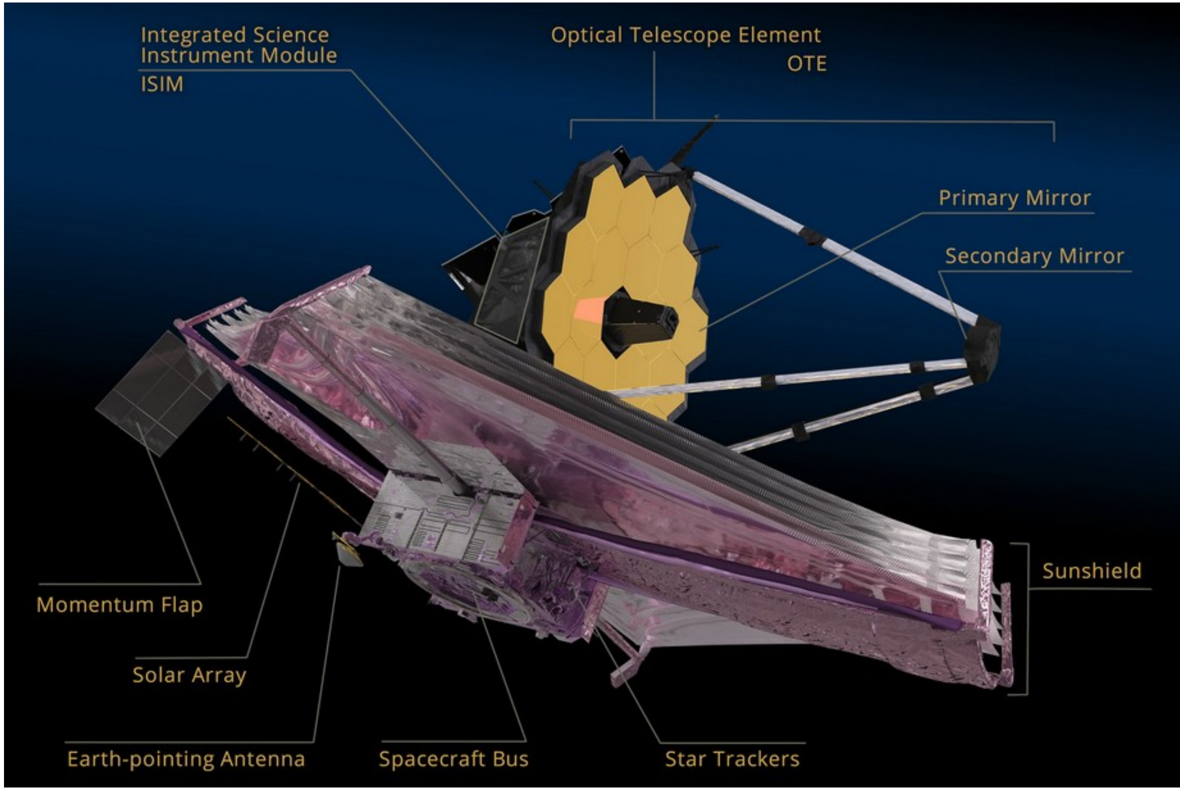
But,

- The whole telescope must be cooled to very low temperatures
- Costly if using cryogens (lifetime of the material and high-power consumption)
- Passive cooling with Sun/Earth shields (technological challenge)



JWST

- **J**ames **W**ebb **S**pace **T**elescope (Gardner et al. 2006)
- Jointly developed by NASA, ESA and Canadian Space Agency
- 6.5m diameter, 18 hexagonal segments (compare with 2.4m HST)
- To be launched on 22 December
- Mirrors of beryllium and coated in gold
- Visible to mid-infrared (0.6-28.3 microns)
- Orbit at L2 point
- Large solar shield to keep mirror and instruments < 50 K



(Credit: NASA)

JWST deployment sequence

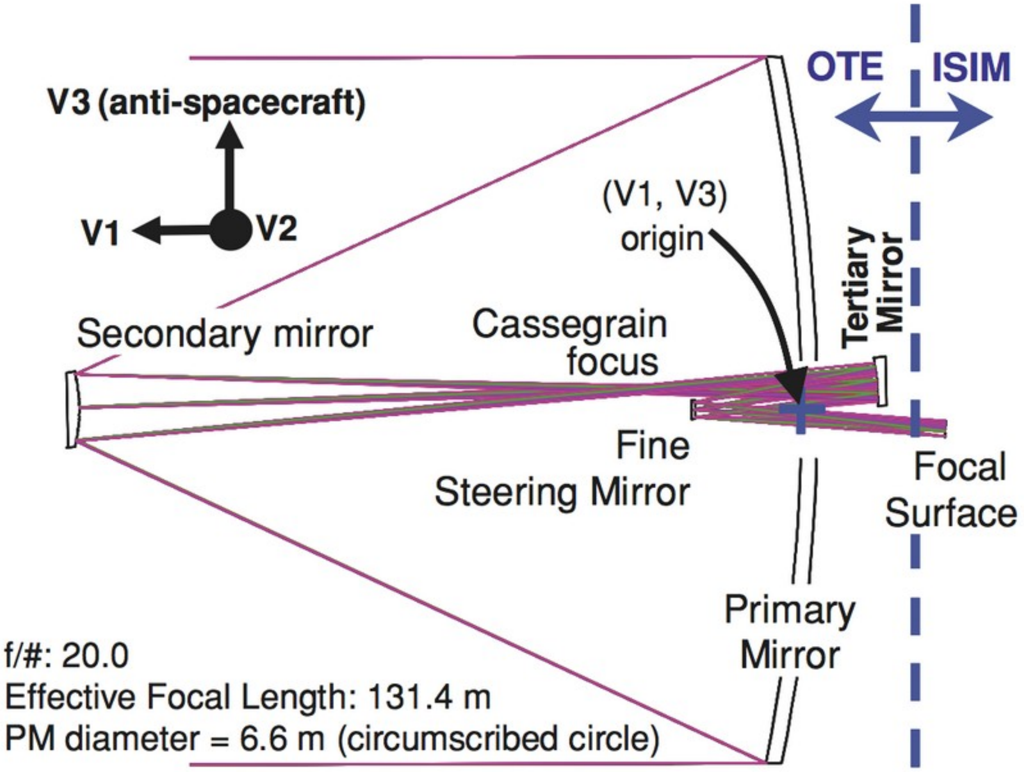
https://www.youtube.com/watch?v=RzGLKQ7_KZQ

NASA Webb YouTube Channel

https://www.youtube.com/c/NASAWebbTelescope

Optical layout

- Three mirrors OTE (Optical Telescope Element). Diffraction limited >2microns
- Focal length 131.4m, f-ratio f/20
- M1: 18x1.32m (6 actuators for spatial degrees of freedom + 1 for curvature)
- M2: circular, 0.74m diameter, slightly off-axis (with actuators)
- M3: fixed, concave, aspheric mirror, 0.73 × 0.52 m. Cancel aberrations and flattens the focal plane
- FSM: Fine Steering Mirror (flat mirror, stabilize image during observations, continuously adjusted in X- and Y-tilts)

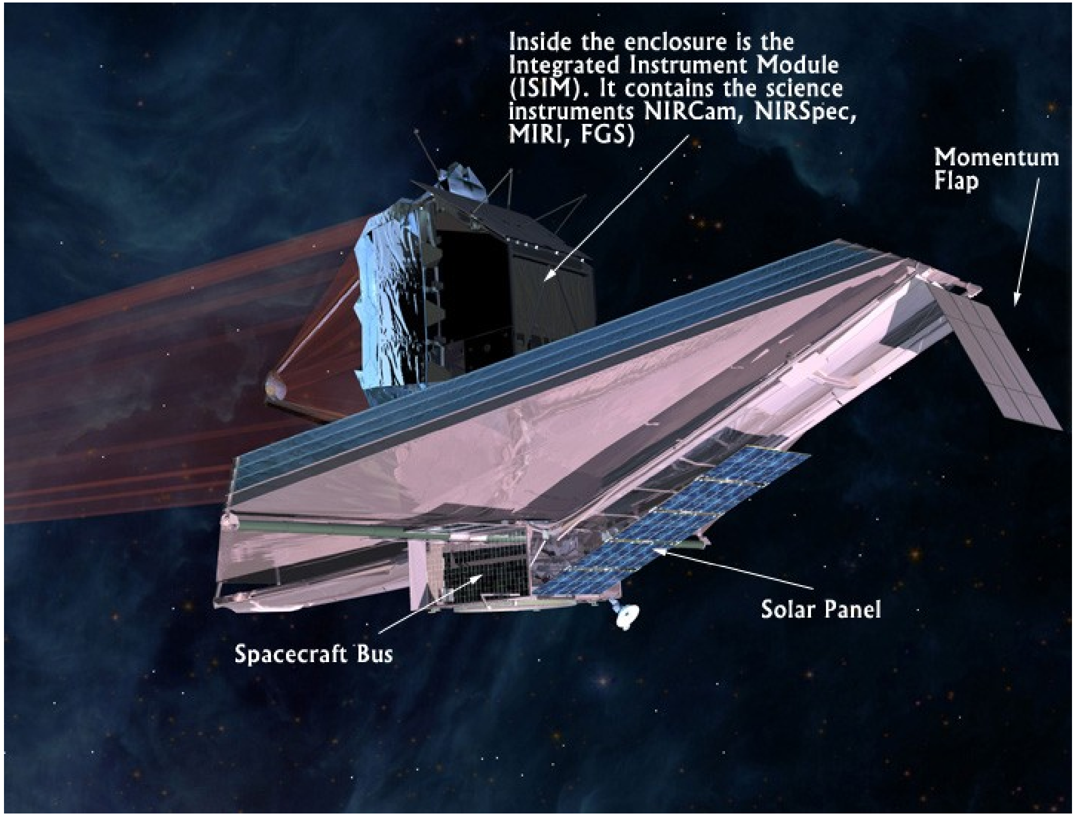


(Credit: NASA)

Proposing and observing

- Science observations should start ~6 months after launch
- Cycle 1 observing programs have already been chosen
- Applications are open to all the community
- Date for Cycle 2 call for proposals?
- JWST has 4 instruments:

  1) Mid Infrared Instrument (MIRI),
  2) Near Infrared Camera (NIRCam),
  3) Near Infrared Spectrograph (NIRSpec),
  4) Near Infrared Imager and Slitless Spectrograph (NIRISS)



(Credit: NASA)

Focal plane

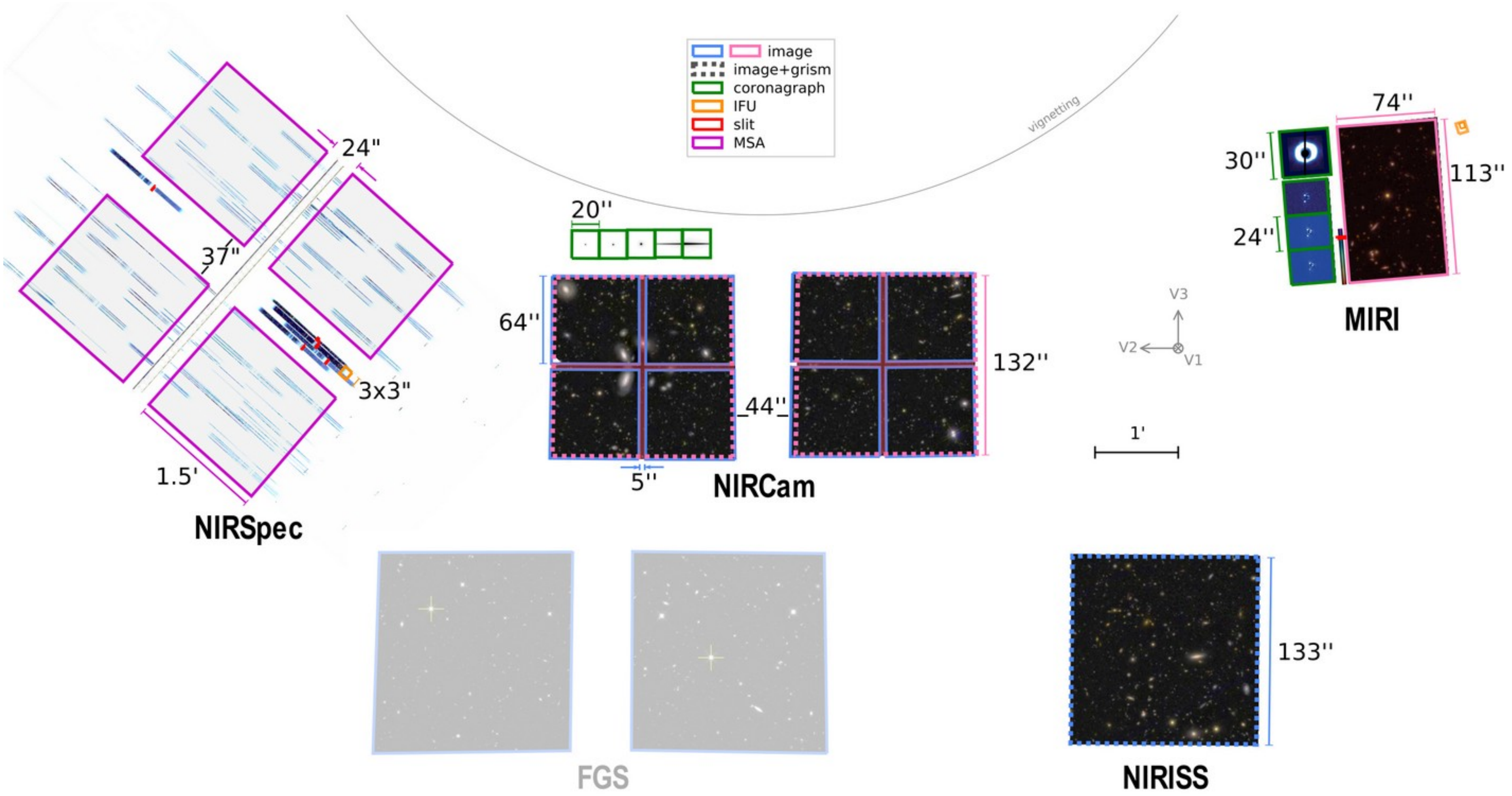
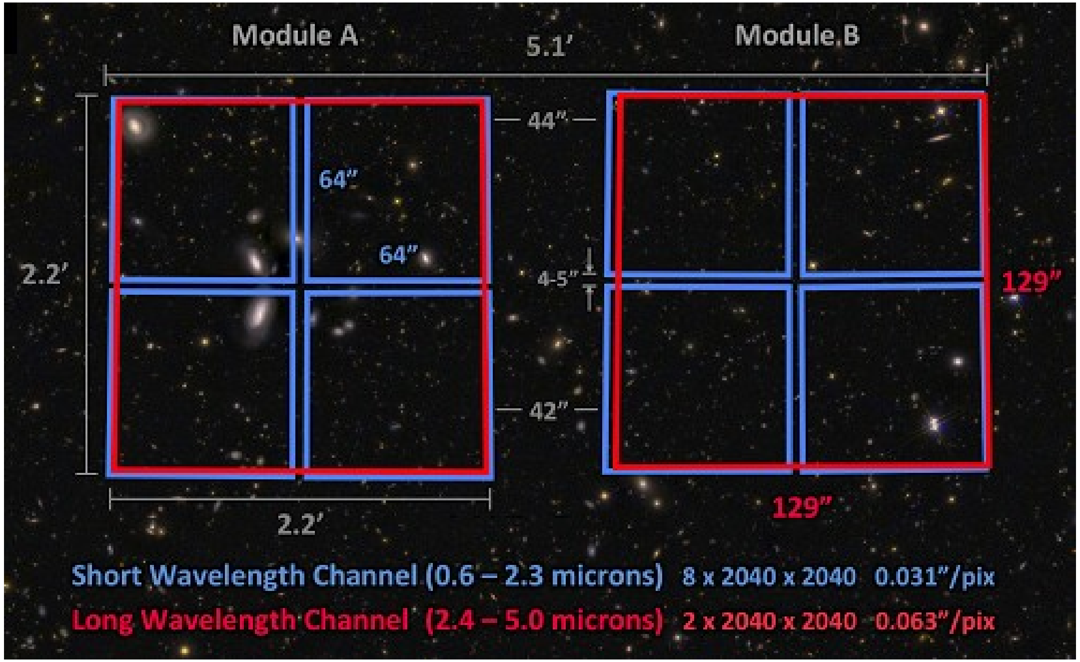


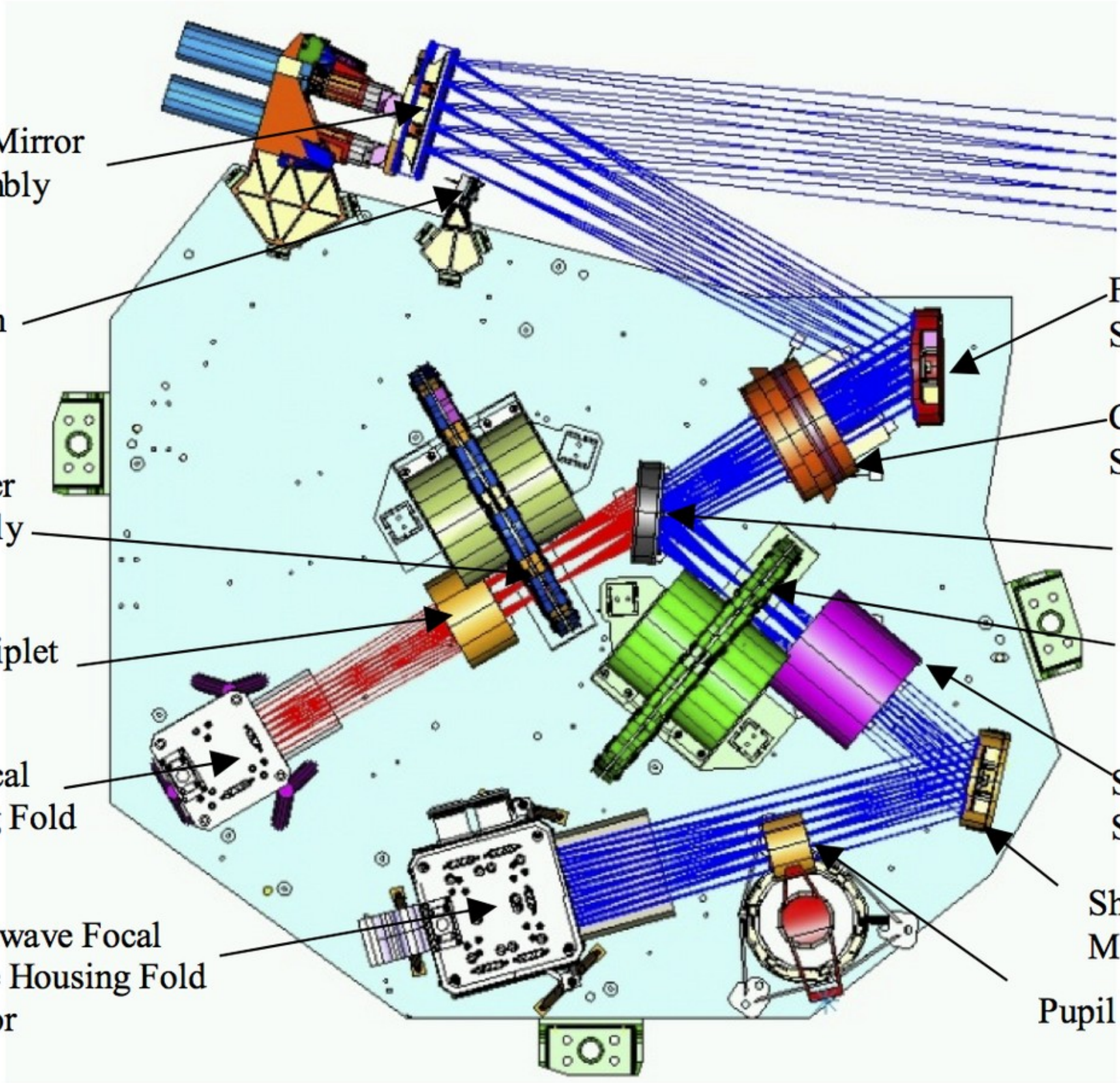
image
image+grism
coronagraph
IFU
slit
MSA
vignetting
24"
37"
3x3"
1.5'
NIRSpec
20''
64''
44''
132''
5''
NIRCam
74''
30''
113''
24''
MIRI
V3
V2
V1
1'
FGS
133''
NIRISS

Near Infrared Camera (NIRCam)

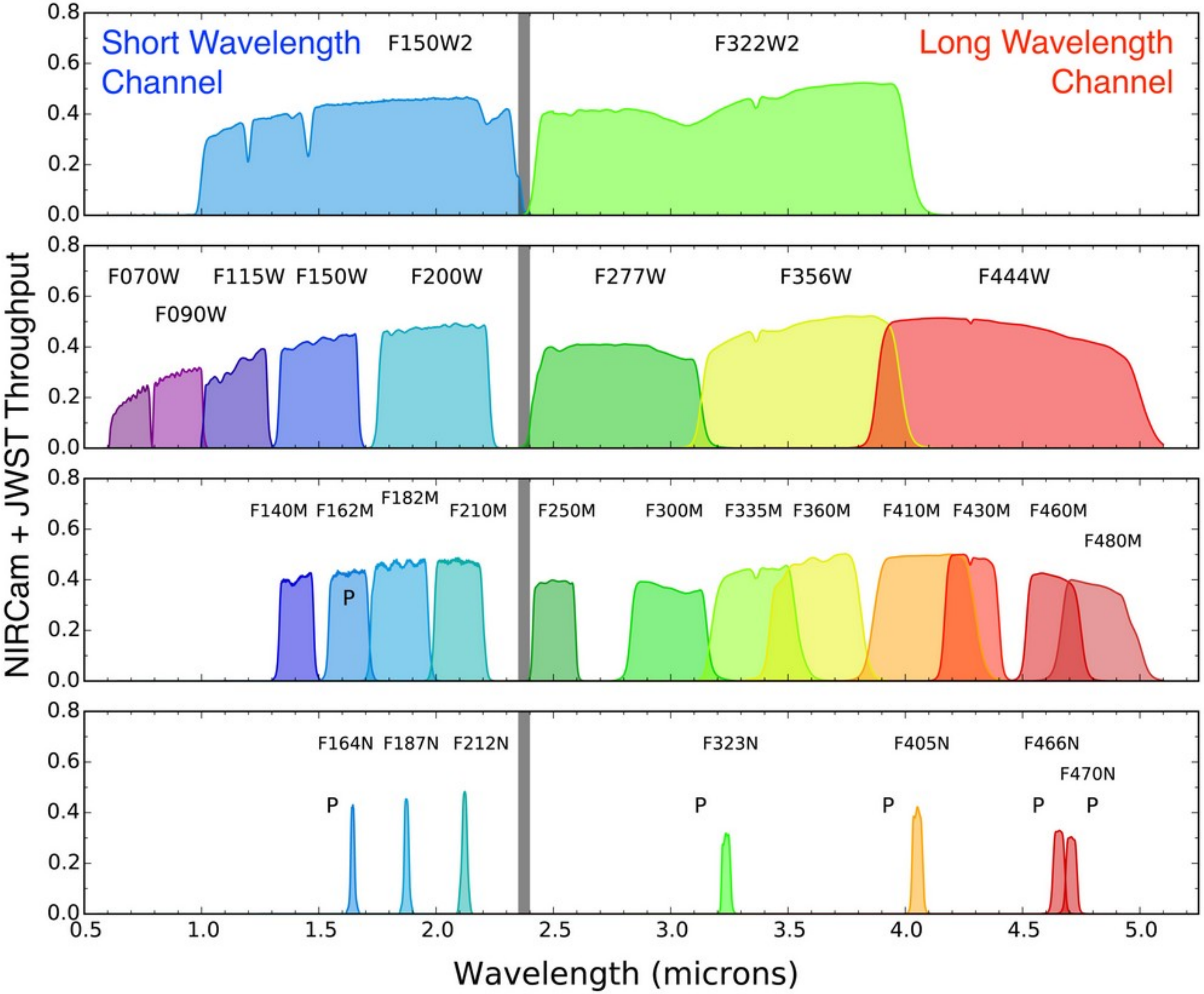
- Two nearly identical modules for redundancy and using the full field of view
- Two 2.2' × 2.2' fields separated by 44"
- Each module has a dichroic, for simultaneous short wavelength (0.6–2.3 μm) and a long wavelength (2.4–5.0 μm)
- 29 broad, medium, and narrow-band filters
- Coronographic imaging
- Wide-field slitless spectroscopy
- Time-series imaging
- Spectroscopic monitoring (grism time-series mode)
- 10 Teledyne HgCdTe detectors, 2k x 2k



(Credit: NASA)

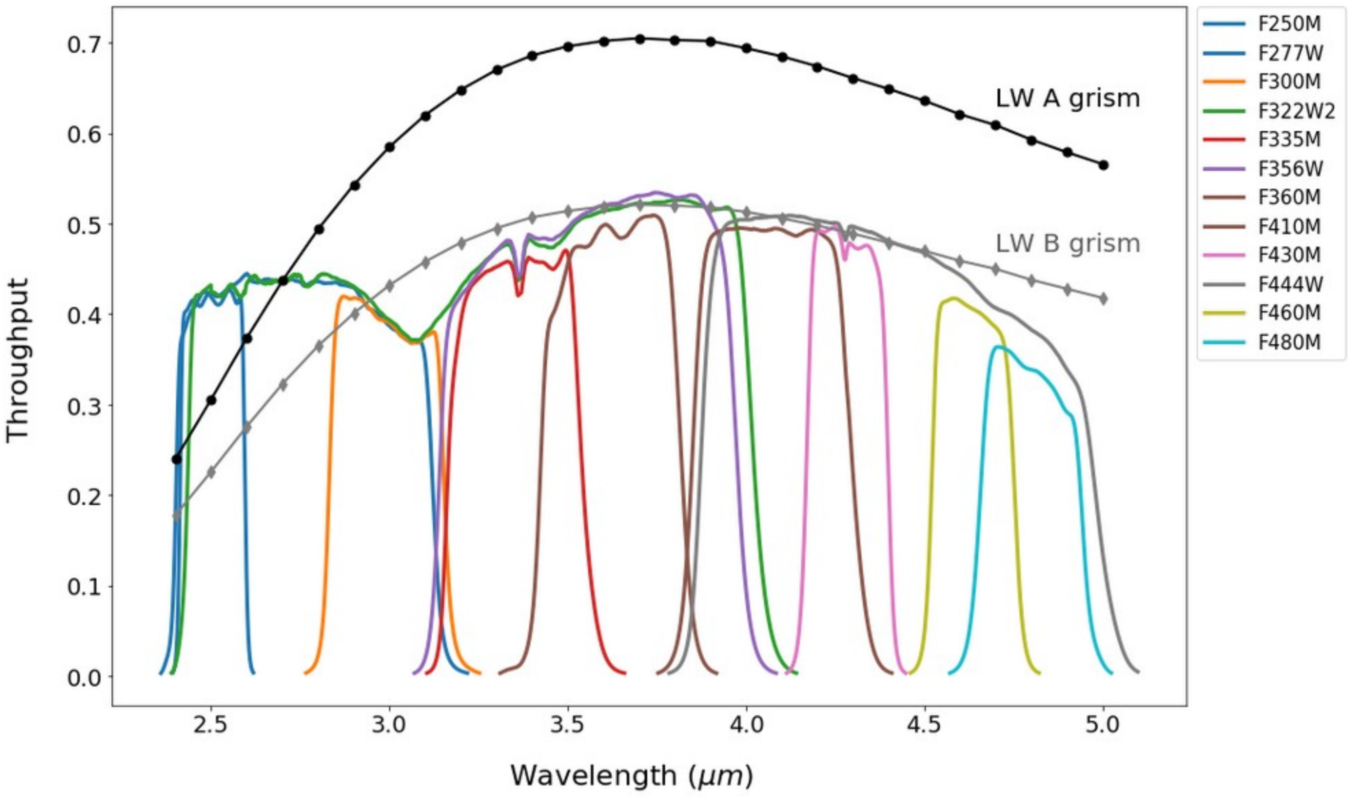

Pick-off Mirror Subassembly
Coronagraph Elements
First Fold Mirror Subassembly
Collimator Triplet Subassembly
Dichroic Beamsplitter
Longwave Filter Wheel Assembly Elements
Shortwave Filter Wheel Assembly Elements
Longwave Triplet Subassembly
Shortwave Triplet Subassembly
Longwave Focal Plane Housing Fold Mirror
Shortwave Fold Mirror
Shortwave Focal Plane Housing Fold Mirror
Pupil Imaging Lens

NIRCam Filters



NIRCam spectroscopy

- R~1600, with grisms, slitless spectroscopy at 2.4–5.0 µm
- Mostly, only 1st order spectra are visible but
- order sorting filters might be necessary
- Time-series mode: monitor single bright objects
- Time-series, reading part of the detector is possible

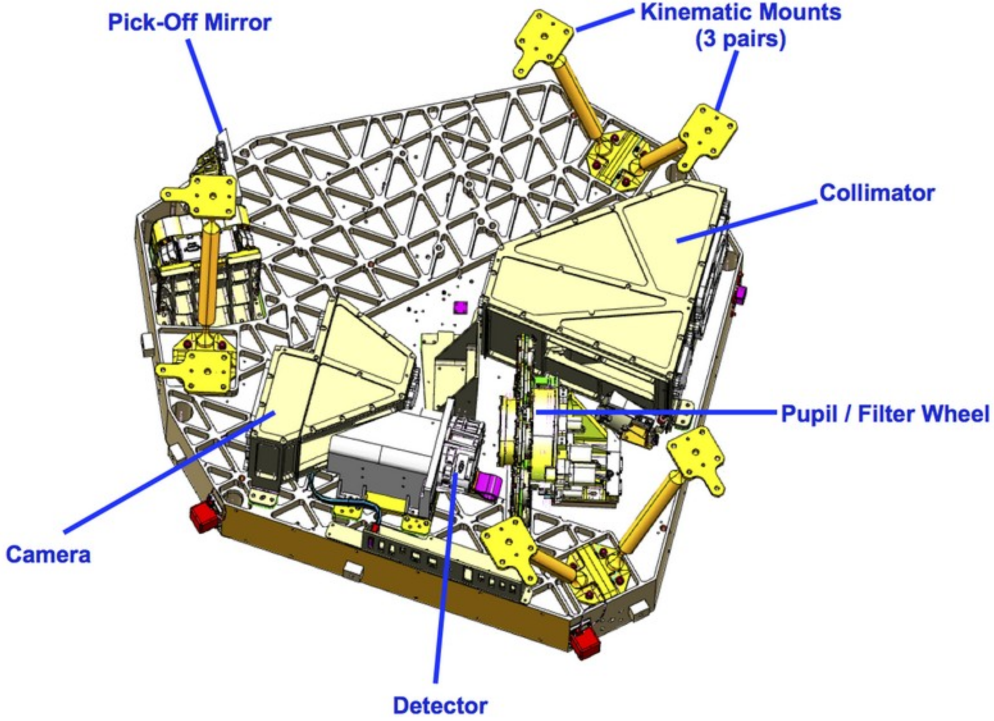


(Credit: NASA)

Near-Infrared Imager and Slitless Spectrograph (NIRISS)

- Wavelength range between 0.6 and 5.0 µm over a 2.2' x 2.2' FOV.

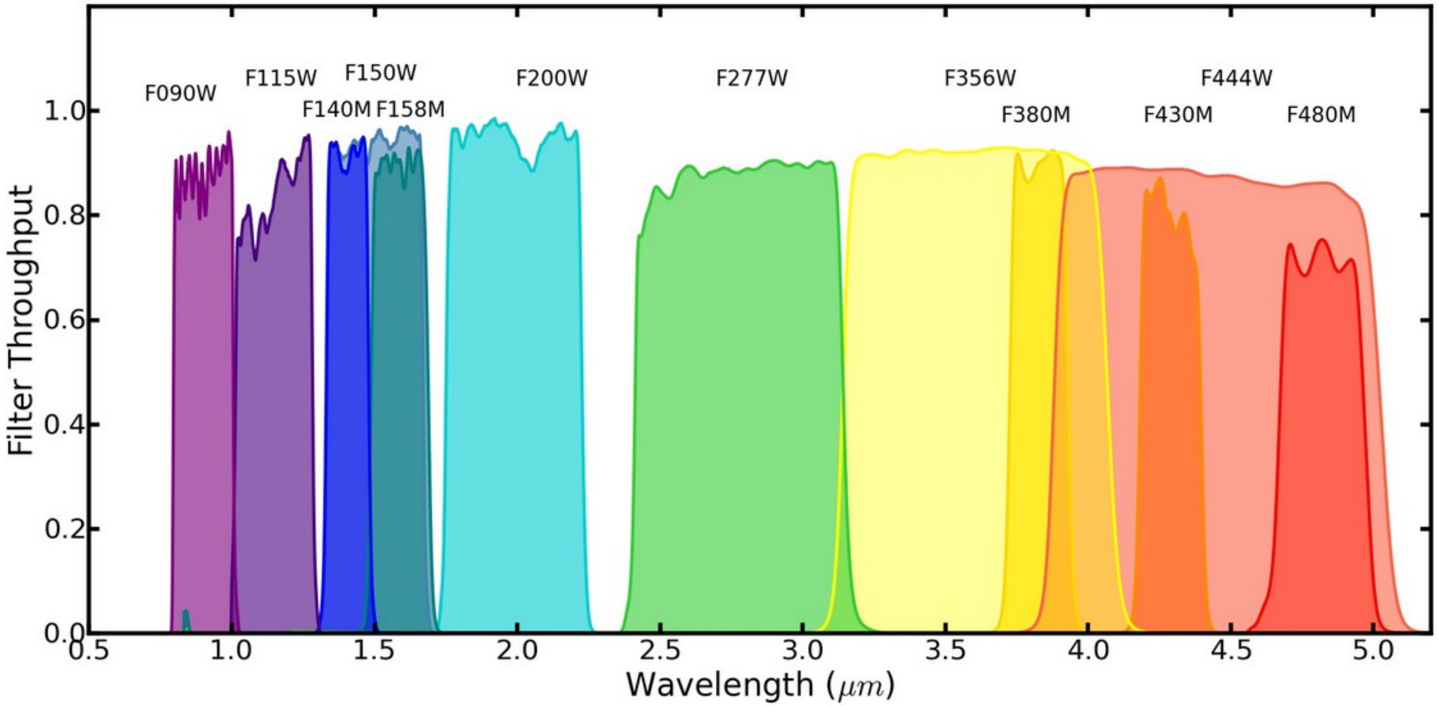
  1) Wide-field slitless spectroscopy (08-2.2 micron, R~150)
  2) Single-object slitless spectroscopy (0.6-2.8 microns, R~700)
  3) Aperture masking interferometry (2.8-4.8 microns)
  4) Imaging (0.8-5.0 microns)
- Single Teledyne HgCdTe detector, 2k x 2k,
- Read out non-destructively every 10.74s
- Windowing possible (64x64 px read out in 50.16ms)



(Credit: NASA)

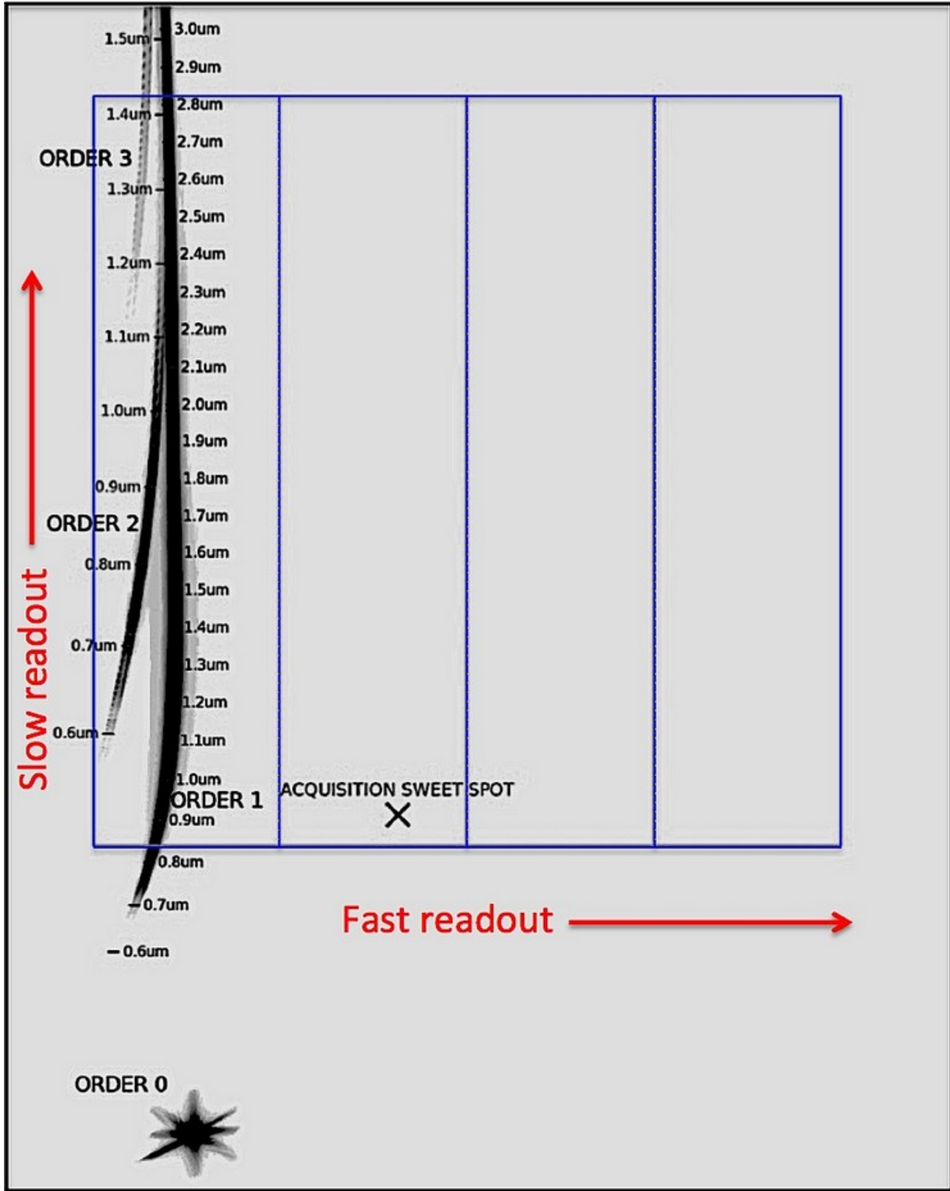
NIRISS Imaging

- Mostly for instrumental calibrations
- Or in parallel with NIRcam (cycle 1; for cycle 2 other modes in consideration)



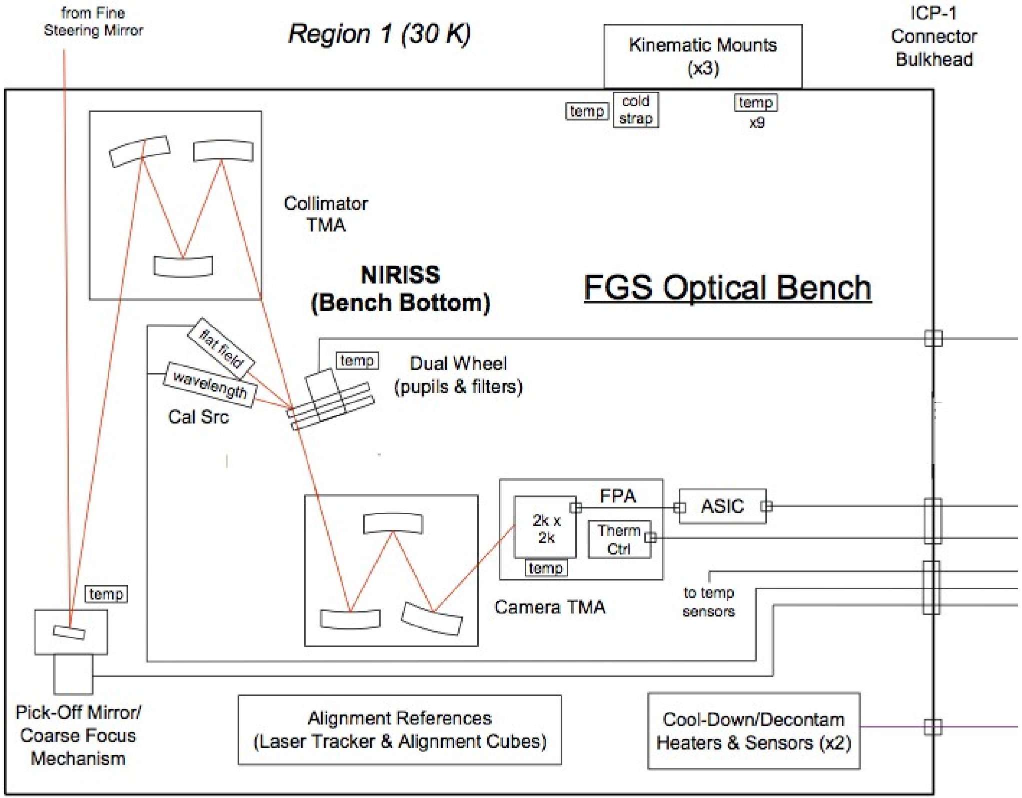
NIRISS SOSS mode

- Medium-resolution (R ~ 700) at 0.6-2.8 µm, in three cross-dispersed orders (third might be too weak)
- Time-series observation (TSO) with high-precision spectro-photometric stability.
- No dithering for stability
- Spectra of transiting exoplanet systems, around stars with J-band Vega magnitudes between 7 and 15.
- Nominal subarray readout (256x2048 px) or bright subarray (1st order only, 96x2048 px)

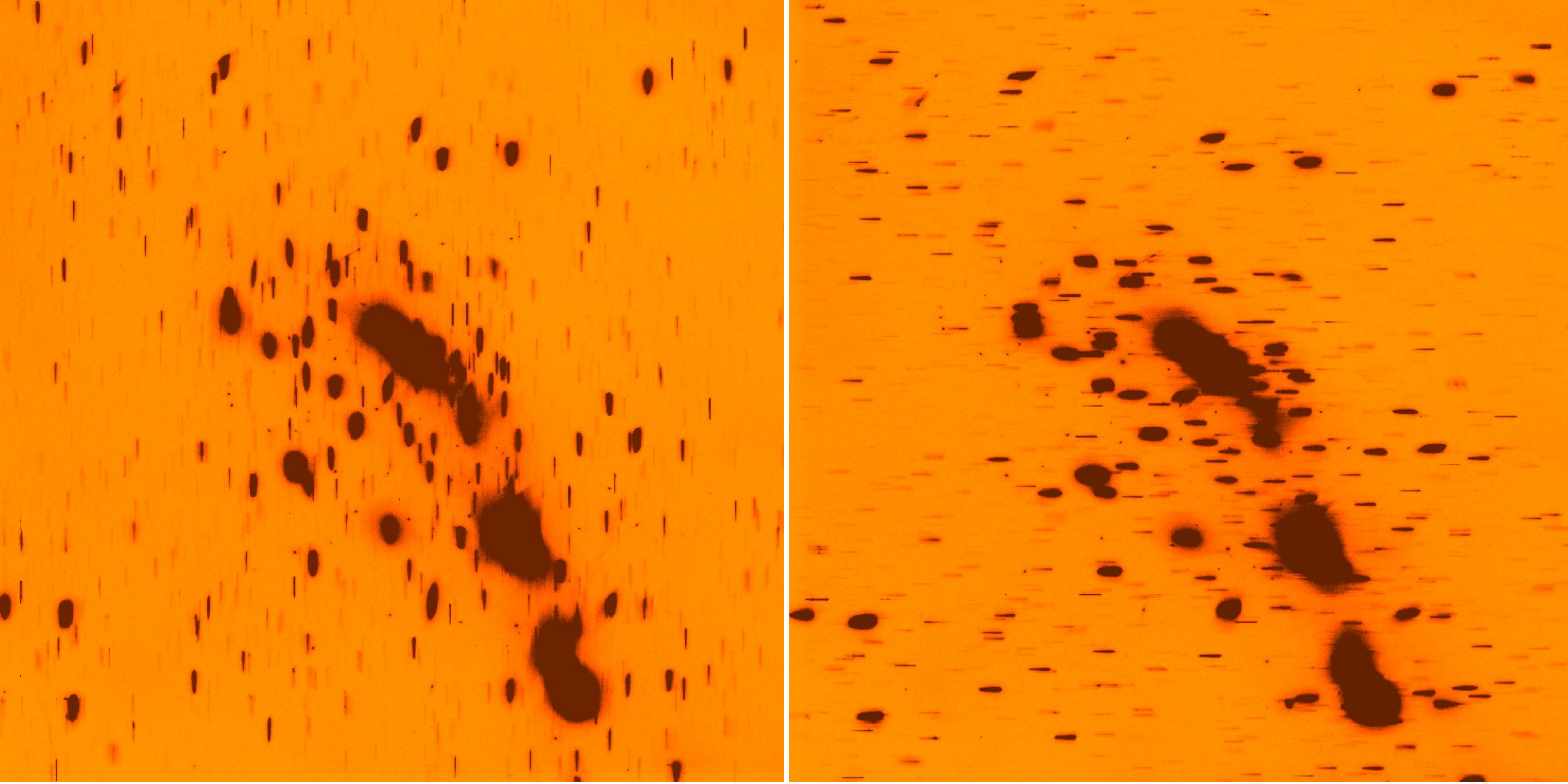


NIRISS WFSS mode

- Low-resolution (R ~ 150), between 0.8–2.2 µm, 2.2’ × 2.2’ FoV.
- Can be used very as a parallel observing mode with other instruments.
- Two grisms that disperse in perpendicular directions
- To help disentangle blended spectra in crowded fields
- Blocking filters (limit the wavelength coverage, reducing the blending)
- Dithering pattern recommended for improving sampling of the PSF



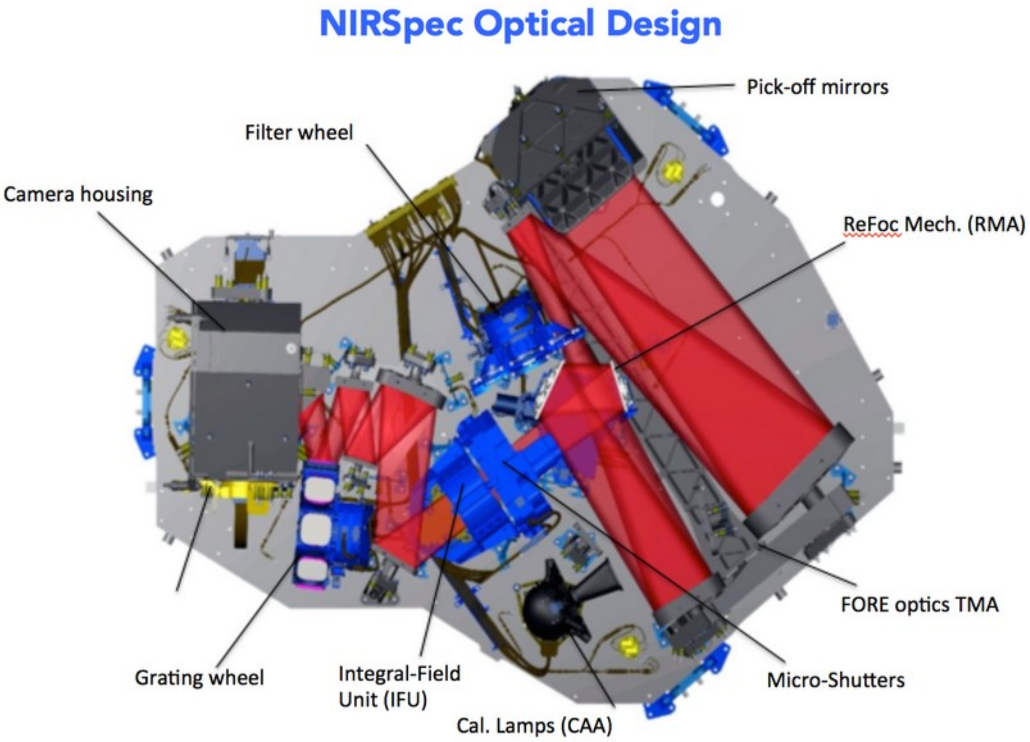
(Credit: NASA)



(Credit: NASA)

Near Infrared Spectrograph (NIRSpec)

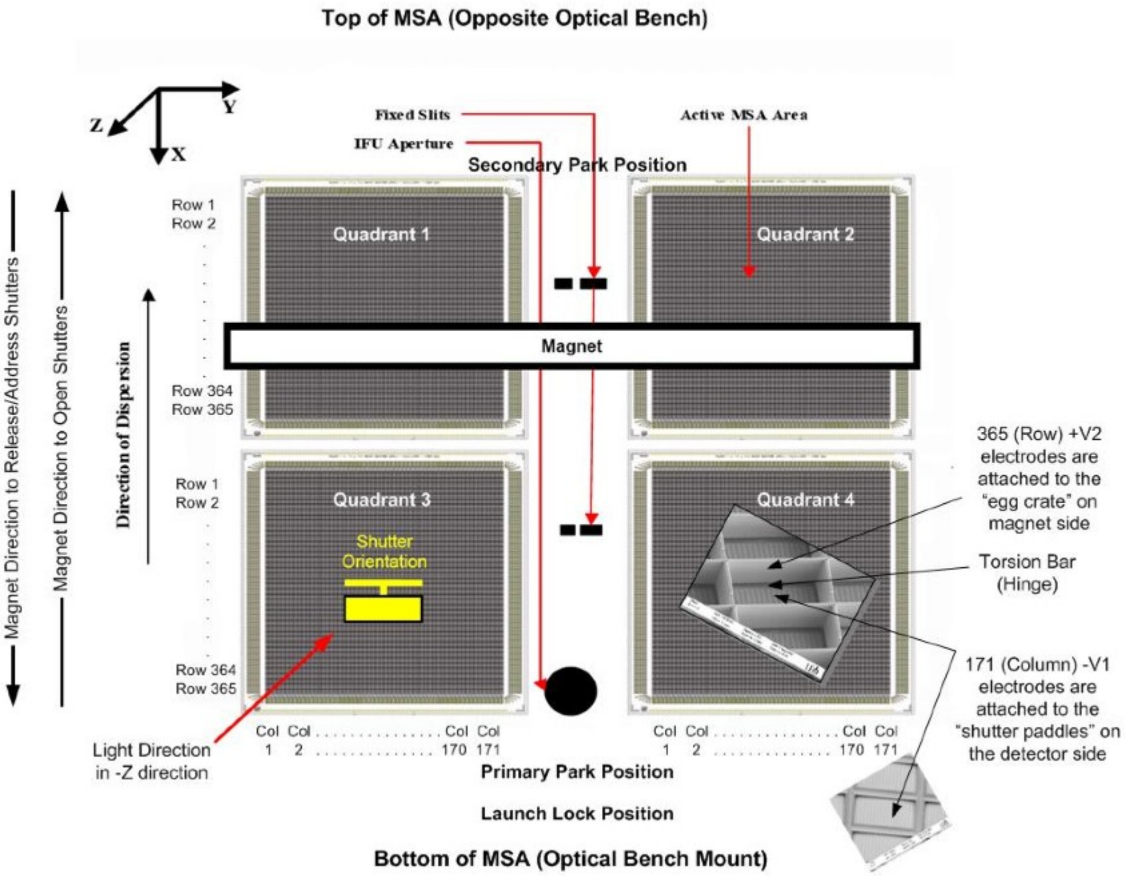
- Near-IR spectroscopy, 0.6–5.3 μm, 3.4 × 3.6 arcmin FoV
- R ~100, ~1000, and ~2700
  1) Multi-object spectroscopy (MOS) with the Micro-Shutter Assembly (MSA)
  2) Integral Field Unit (IFU) spectroscopy
  3) High-contrast single-object spectroscopy with the fixed slits
  4) Bright object time-series (BOTS) spectroscopy
- Two HgCdTe detectors, 2k x 2k, with 5.3 micron cut-off



(Credit: NASA)

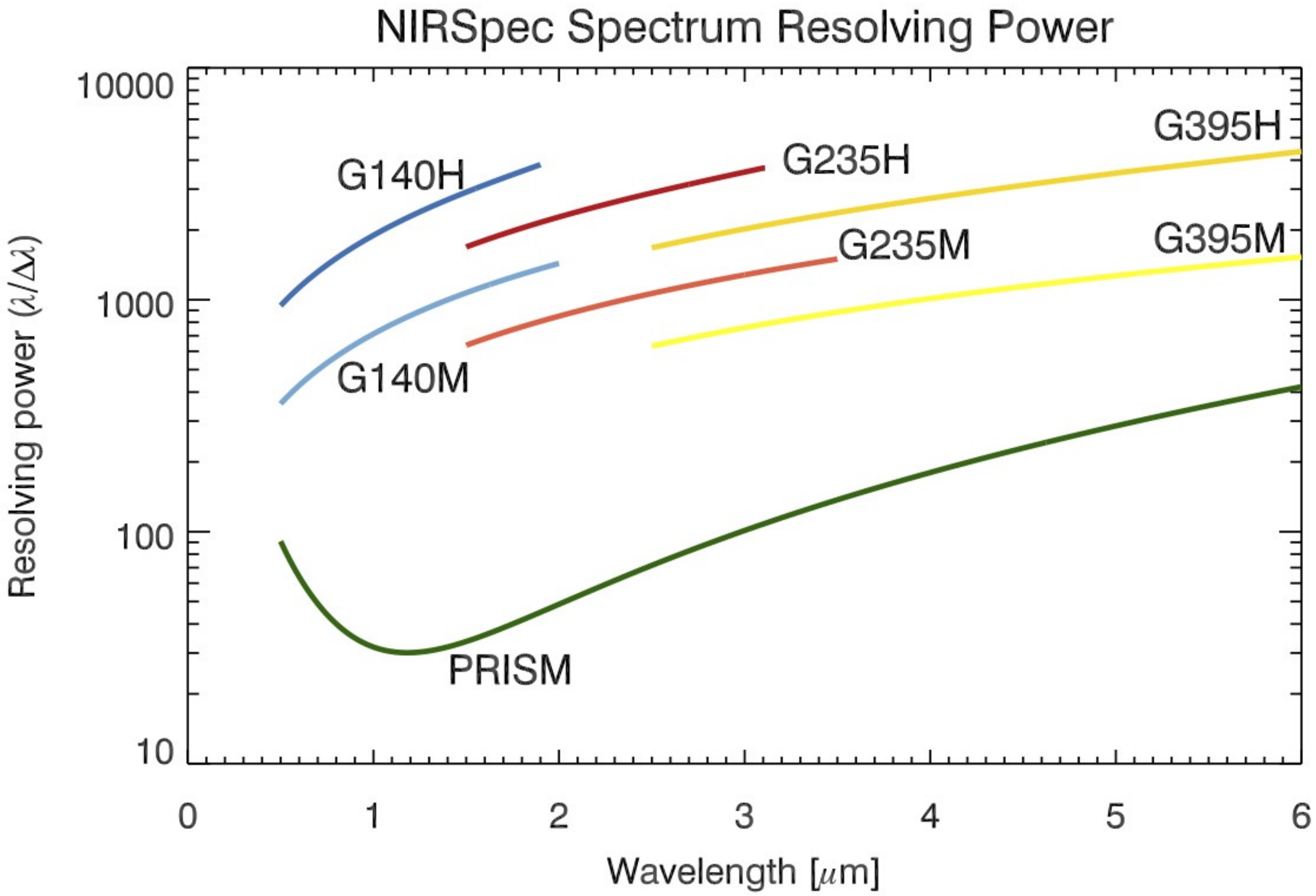
NIRSpec MOS with MSA

- ~250000 configurable micro shutters for slitlets in a MOS mask
- 4 quadrants with 365x 171 shutters
- Total area 3.6' × 3.4'. Gaps 23" (in the dispersion direction) and 37" (in the cross-dispersion direction)
- Each shutter has 0.20" × 0.46", with an ~0.07" separation
- Grating wheel: a low-resolution (R ~ 100) prism, three medium-resolution (R ~ 1000), three high-resolution (R ~ 2700) gratings



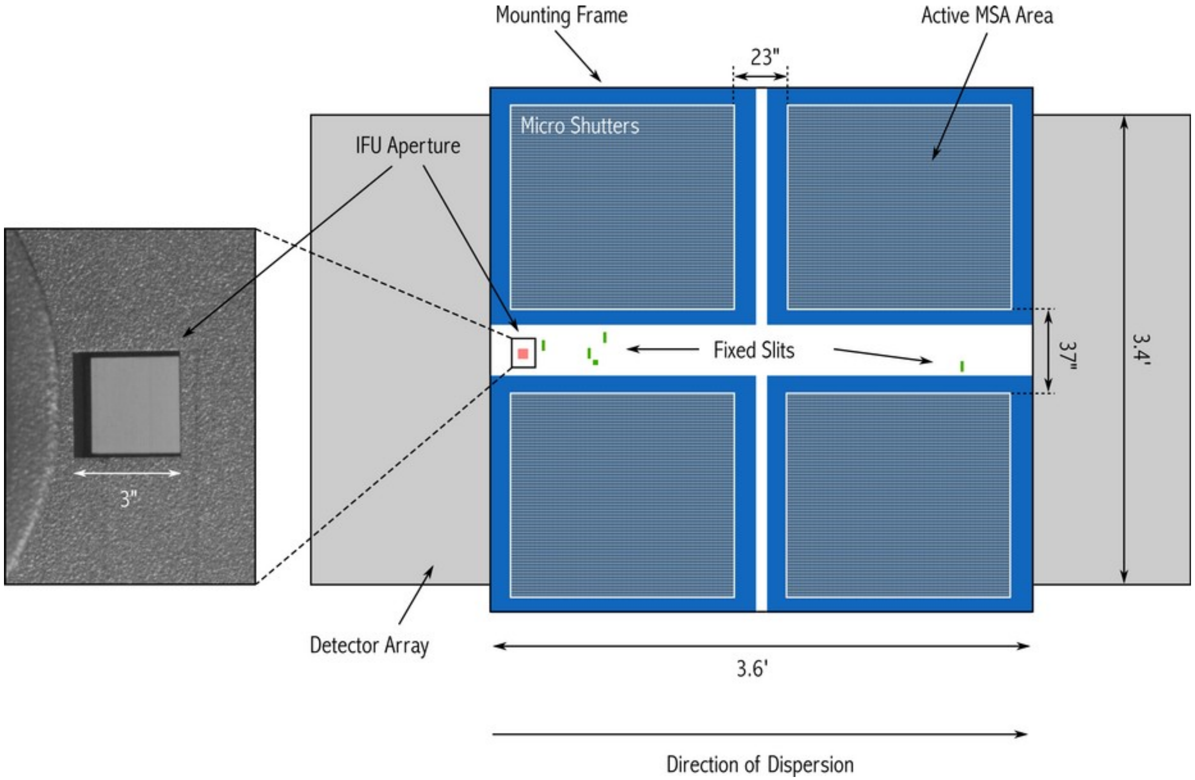
(Credit: NASA)

NIRSpec MOS with MSA



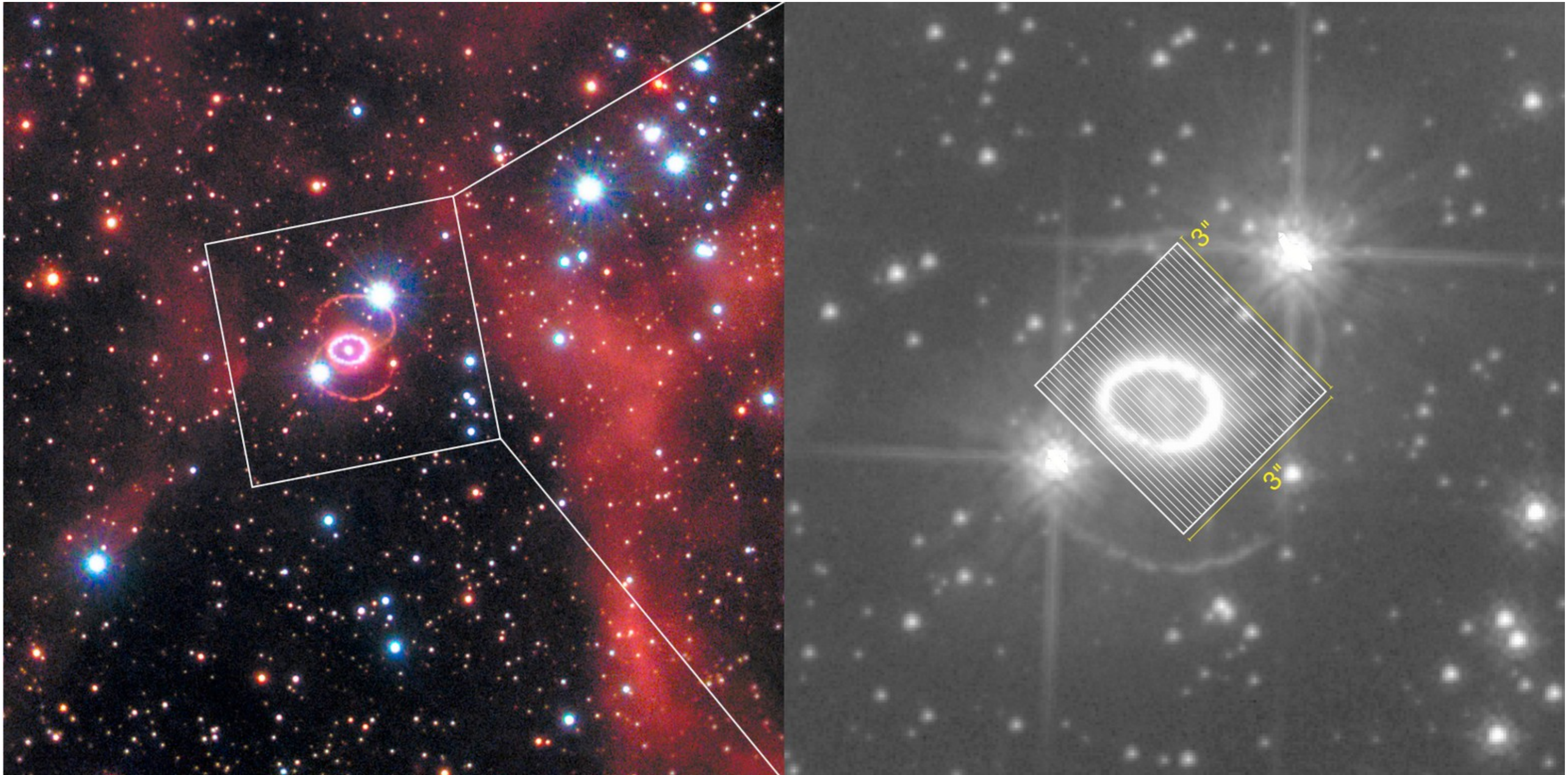
NIRSpec IFU spectroscopy

- Spectroscopy over a 3"x3" FoV with spatial resolution of 0.1"x0.1".
- 30 image slicers (0.1”x3”) and 30 pixels in the “spatial” direction
- Can use any of the gratings or prism
- MSA shutters should be closed for IFU observations, but might be stuck open…
- Dithering can help mitigate any contamination
- No subarray reading possible



(Credit: NASA)

NIRSpec IFU spectroscopy



NIRSpec Slit spectroscopy

- 5 fixed slits (FSs) for single-object spectroscopy
- All slits are open and taking spectra when this mode is used
- All dispersers and filters can be used in this mode
- Read out can be done of the whole detector, of a subarray with all slits, or of the subarray of a single slit
- Dithering recommended to improve sampling

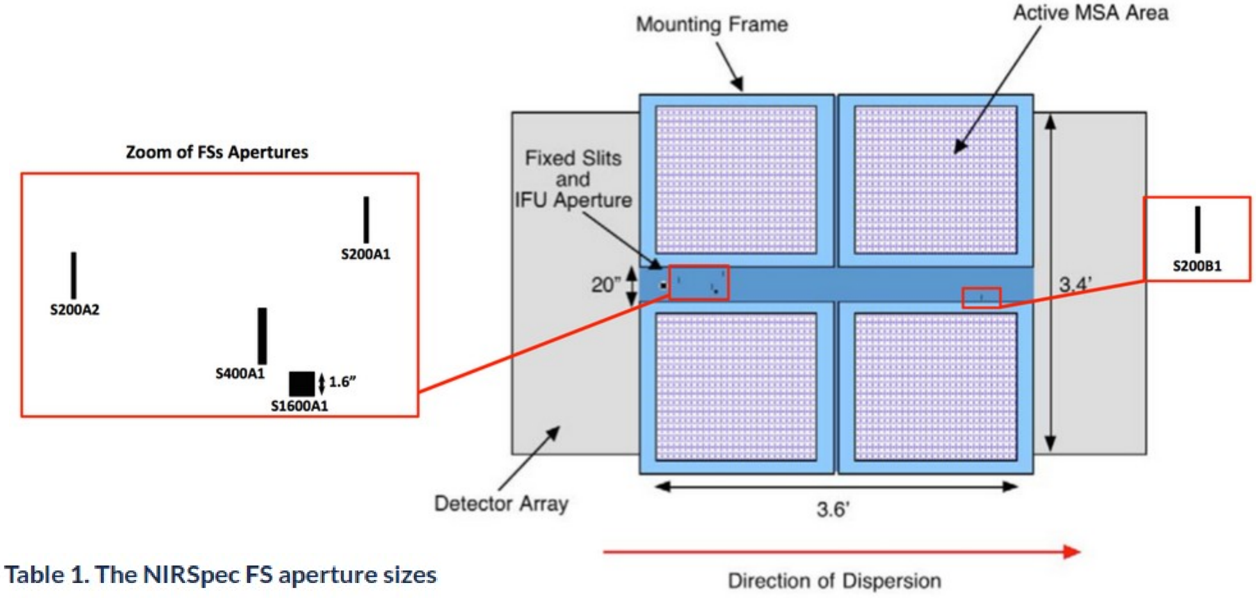
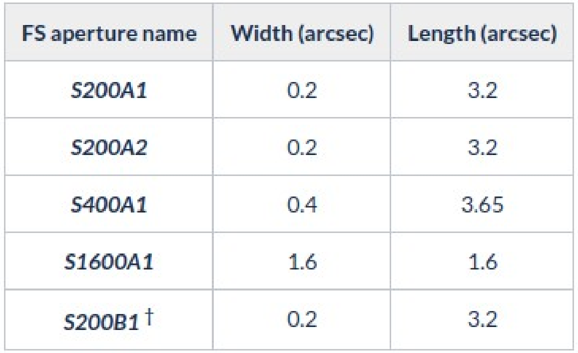


Table 1. The NIRSpec FS aperture sizes

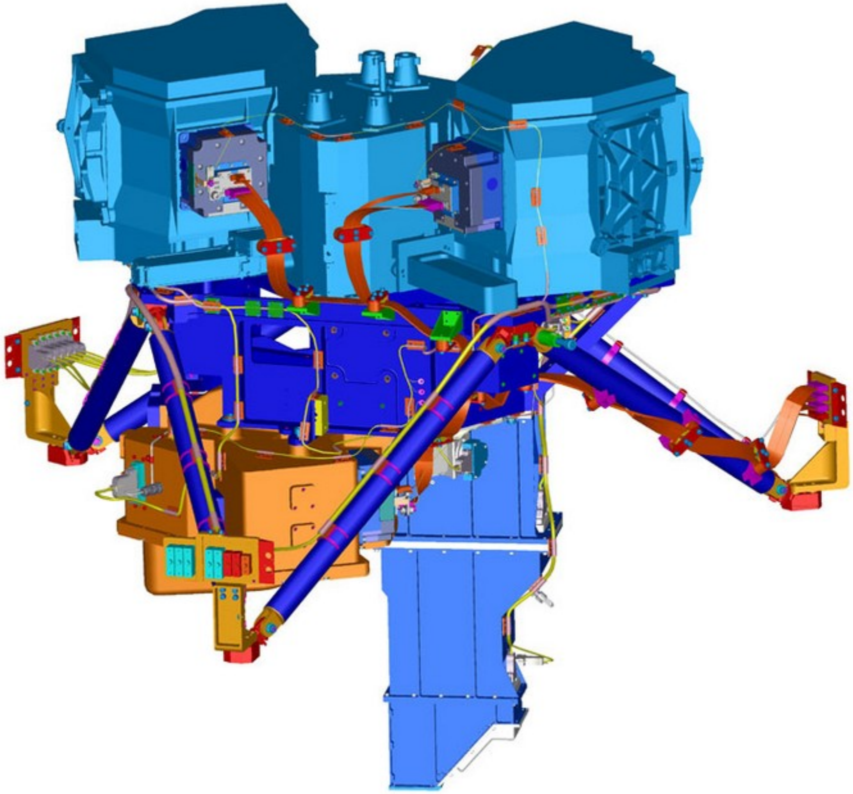


FS aperture name	Width (arcsec)	Length (arcsec)
S200A1	0.2	3.2
S200A2	0.2	3.2
S400A1	0.4	3.65
S1600A1	1.6	1.6
S200B1 †	0.2	3.2

(Credit: NASA)

Mid-Infrared Instrument (MIRI)

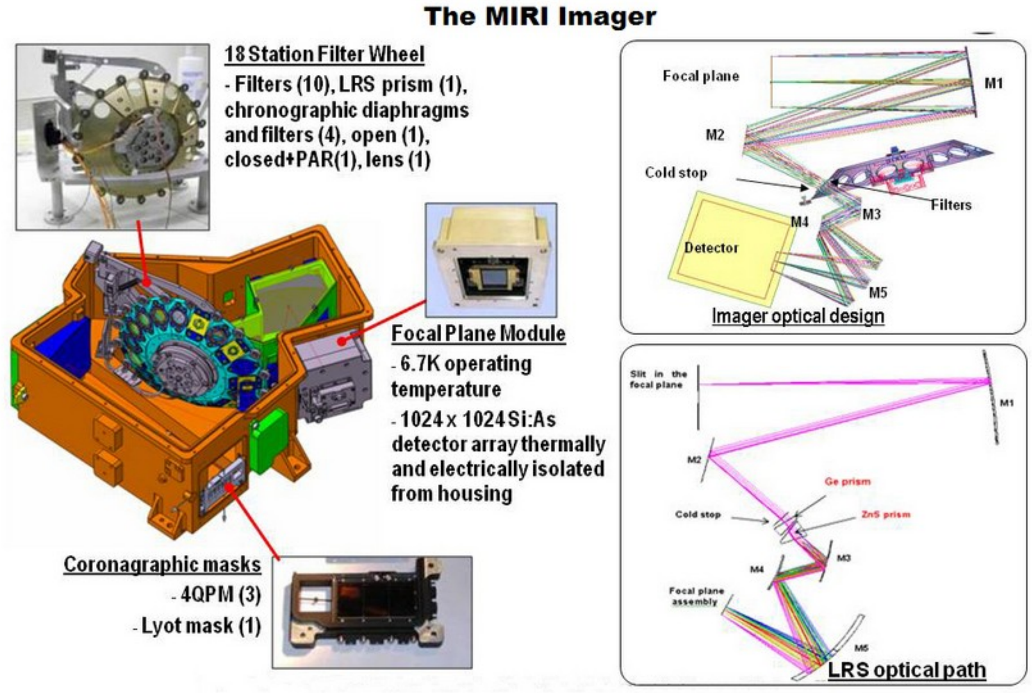
- Imaging and spectroscopic observing modes from 4.9 to 28.8 μm:
  1) Imaging
  2) Low-resolution slit and slitless spectroscopy
  3) Medium-resolution IFU spectroscopy
  4) Coronagraphy
- Three arsenic-doped silicon (Si:Ar) IBC arrays, with 1k x 1k px
- Actively cooled to 7 K by a cryocooler
- Can be used for parallel observations



(Credit: NASA)

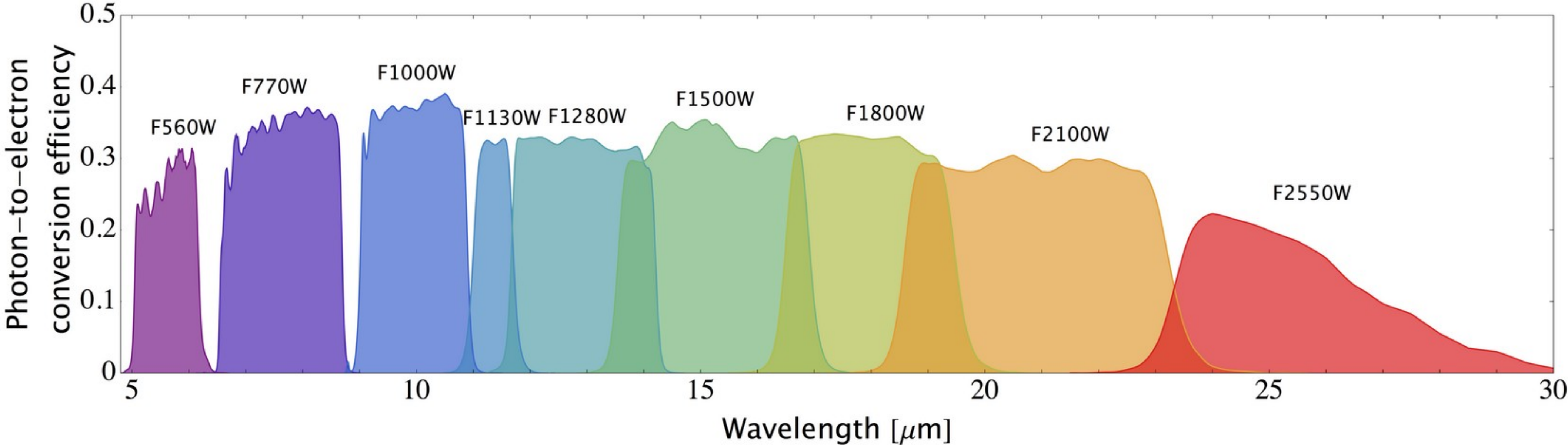
MIRI Imaging

- From 5.6 to 25.5 microns, FoV 74" x 113", plate scale of 0.11 "/pixel
- 9 filters, 8 broad band, one narrower (PAH emission)
- 5 small pre-defined set of subarrays for imaging bright sources, without saturating the detector
- 0.085 to 2.775 s of readout



(Credit: NASA)

MIRI Imaging

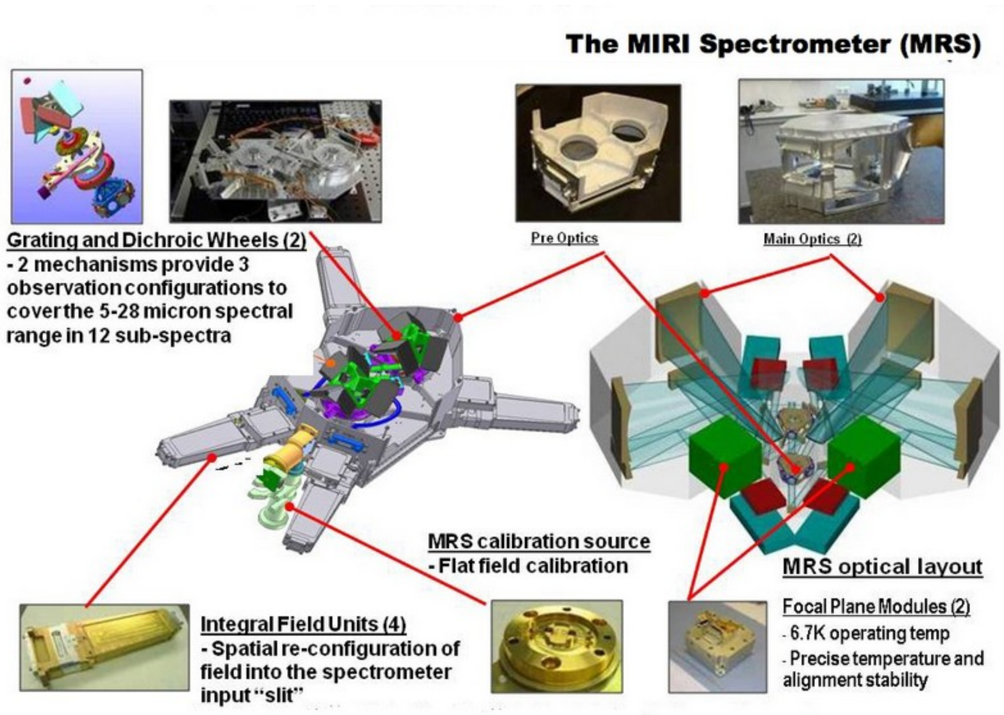


(Credit: NASA)

MIRI Spectroscopy

- Slit and slitless spectroscopy from 5 to 12 microns
- Slit is 4.7" long and 0.51" wide
- R~ 40 at 5 µm to R~160 at 10 µm, with a double prims
- Part of the MIRI imager

- MIRI medium-resolution spectrometer (MRS): 4.9-28.3 µm, FoV 6.9"x7.9"
- 4 IFUs for wavelength coverage, with different FoV
- Field divided in slices



The MIRI Spectrometer (MRS)

Grating and Dichroic Wheels (2)
- 2 mechanisms provide 3 observation configurations to cover the 5-28 micron spectral range in 12 sub-spectra

MRS calibration source
- Flat field calibration

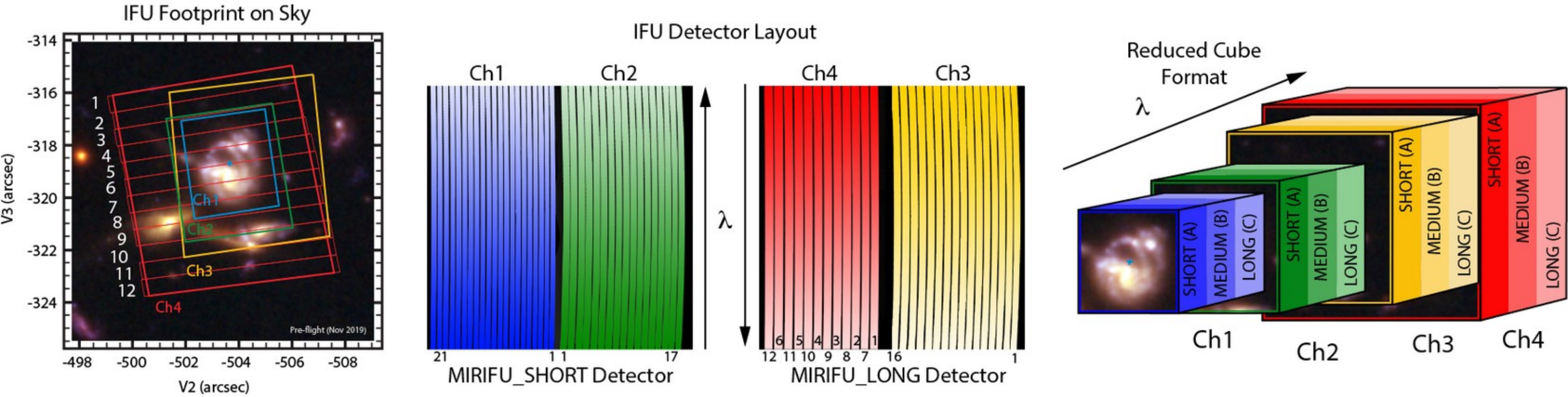
MRS optical layout

Integral Field Units (4)
- Spatial re-configuration of field into the spectrometer input "slit"

Focal Plane Modules (2)
- 6.7K operating temp
- Precise temperature and alignment stability

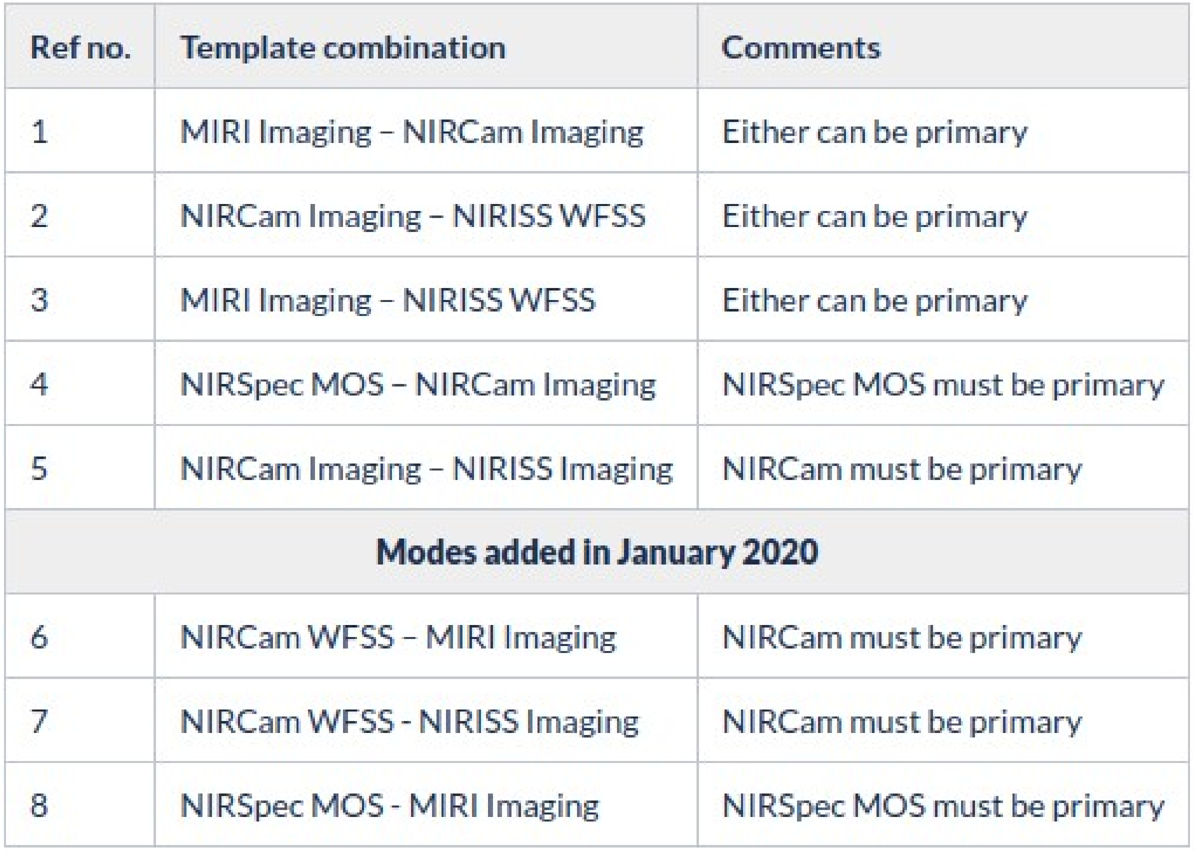
(Credit: NASA)

MIRI Spectroscopy



(Credit: NASA)

Parallel Observations



Ref no.	Template combination	Comments
1	MIRI Imaging – NIRCam Imaging	Either can be primary
2	NIRCam Imaging – NIRISS WFSS	Either can be primary
3	MIRI Imaging – NIRISS WFSS	Either can be primary
4	NIRSpec MOS – NIRCam Imaging	NIRSpec MOS must be primary
5	NIRCam Imaging – NIRISS Imaging	NIRCam must be primary
Modes added in January 2020		
6	NIRCam WFSS – MIRI Imaging	NIRCam must be primary
7	NIRCam WFSS - NIRISS Imaging	NIRCam must be primary
8	NIRSpec MOS - MIRI Imaging	NIRSpec MOS must be primary

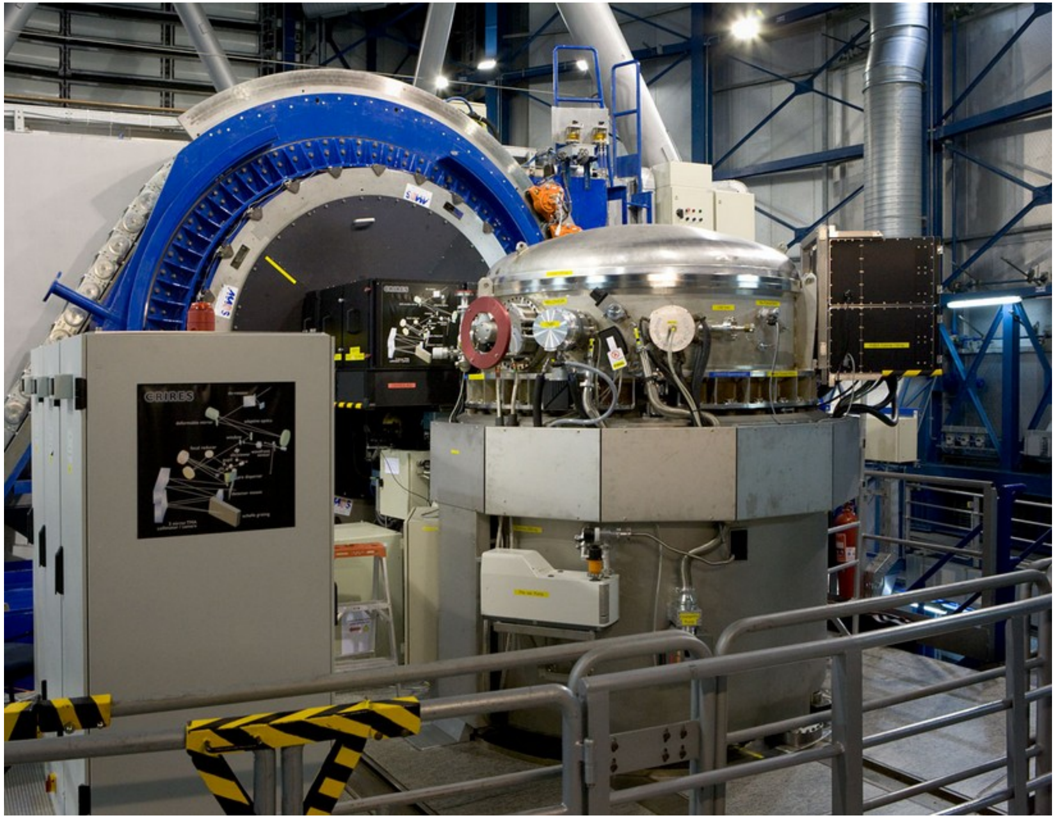
(Credit: NASA)

Questions?

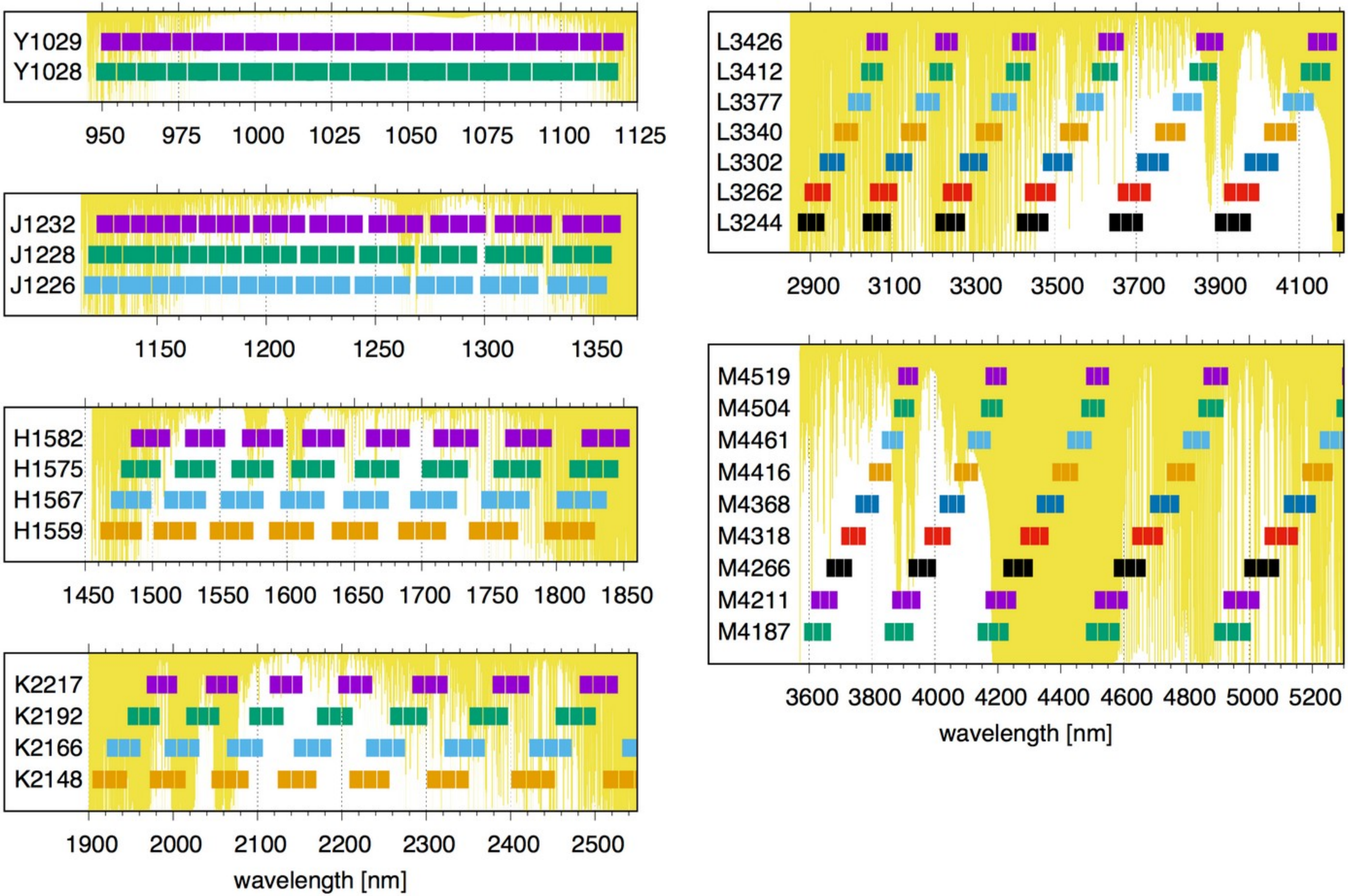
(Credit: Shutterstock)

CRIRES+

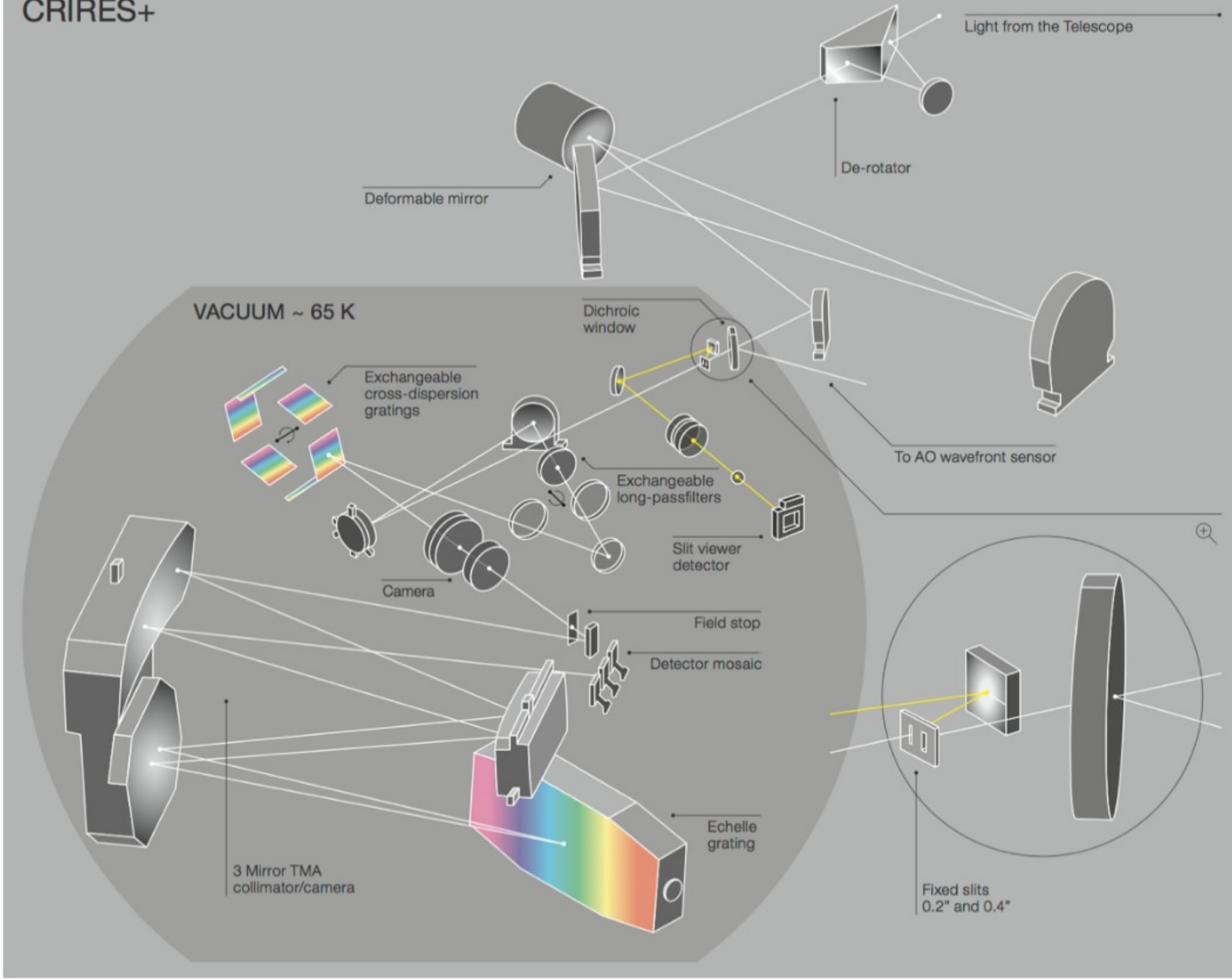
- Cryogenic high-resolution infrared echelle spectrograph (Dorn et al. 2014)
- Upgraded to be cross-dispersed and with a mosaic of three 2048x2048 HgCdTe detectors
- 0.95-5.3 microns (six gratings for the Y, J, K, H, L, M bands)
- R ~ 40 000 or 80 000 (slits 0.4” or 0.2”)
- MACAO AO system (with NGS, recommended airmass < 1.4)
- Polarimetry possible



(Credit: ESO)

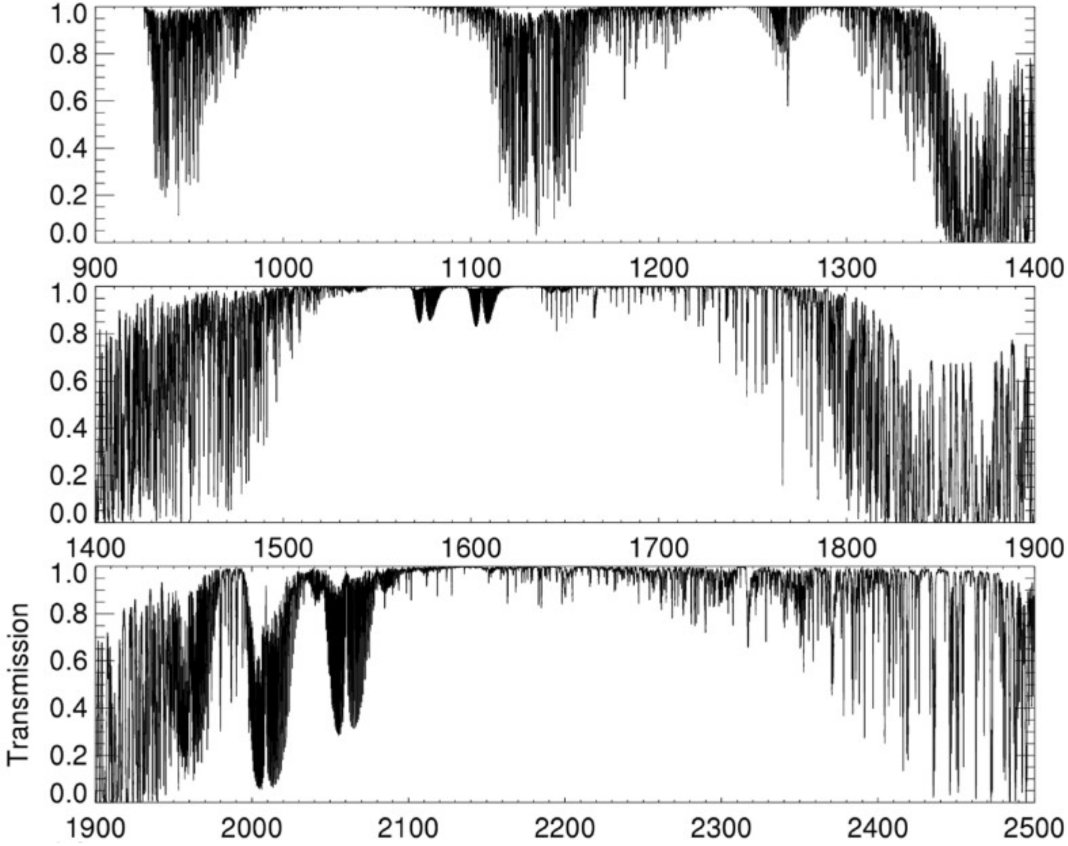

Y1029
Y1028
950
975
1000
1025
1050
1075
1100
1125
J1232
J1228
J1226
1150
1200
1250
1300
1350
H1582
H1575
H1567
H1559
1450
1500
1550
1600
1650
1700
1750
1800
1850
K2217
K2192
K2166
K2148
1900
2000
2100
2200
2300
2400
2500
wavelength [nm]
L3426
L3412
L3377
L3340
L3302
L3262
L3244
2900
3100
3300
3500
3700
3900
4100
M4519
M4504
M4461
M4416
M4368
M4318
M4266
M4211
M4187
3600
3800
4000
4200
4400
4600
4800
5000
5200
wavelength [nm]

CRIRES+


Light from the Telescope
De-rotator
Deformable mirror
VACUUM ~ 65 K
Dichroic window
Exchangeable cross-dispersion gratings
To AO wavefront sensor
Exchangeable long-passfilters
Slit viewer detector
Camera
Field stop
Detector mosaic
Echelle grating
3 Mirror TMA collimator/camera
Fixed slits 0.2" and 0.4"

CRIRES+

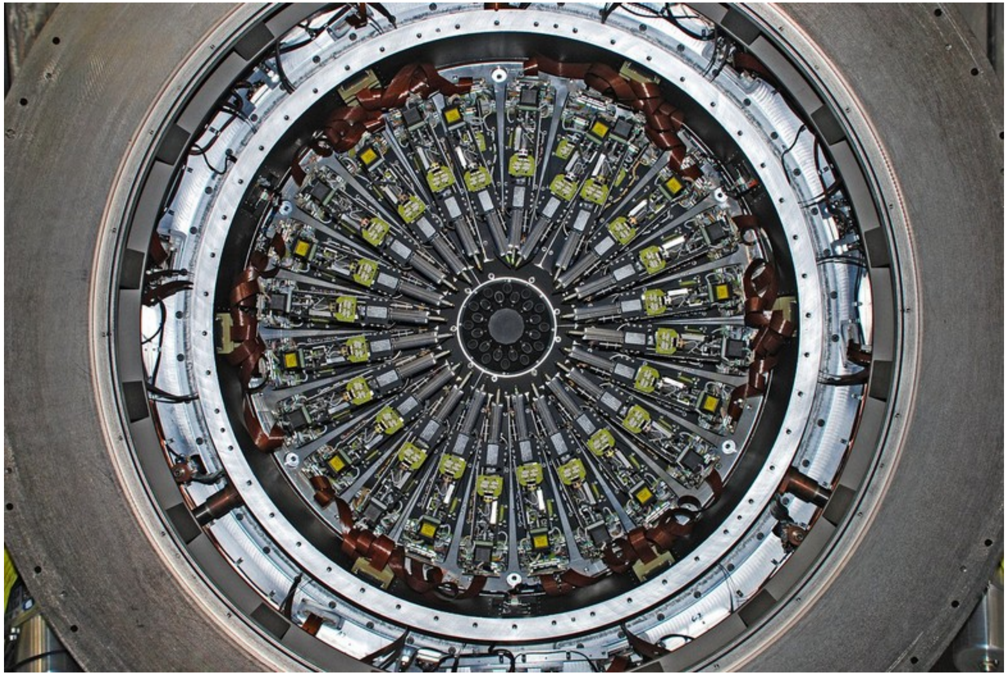
- Check where your lines of interest are located with respect to telluric lines
- YJH bands (<2000 nm), PWV < 5mm requires justification
- K band (2000-2500 nm), PWV = 2-4mm
- L and M-band (>2500 nm), PWV must be < 2.5 mm
- Telluric and/or spectrophotometric standards have to be requested
- Dark nights not necessary
- Photometric conditions for flux calibration



(Credit: ESO)

KMOS

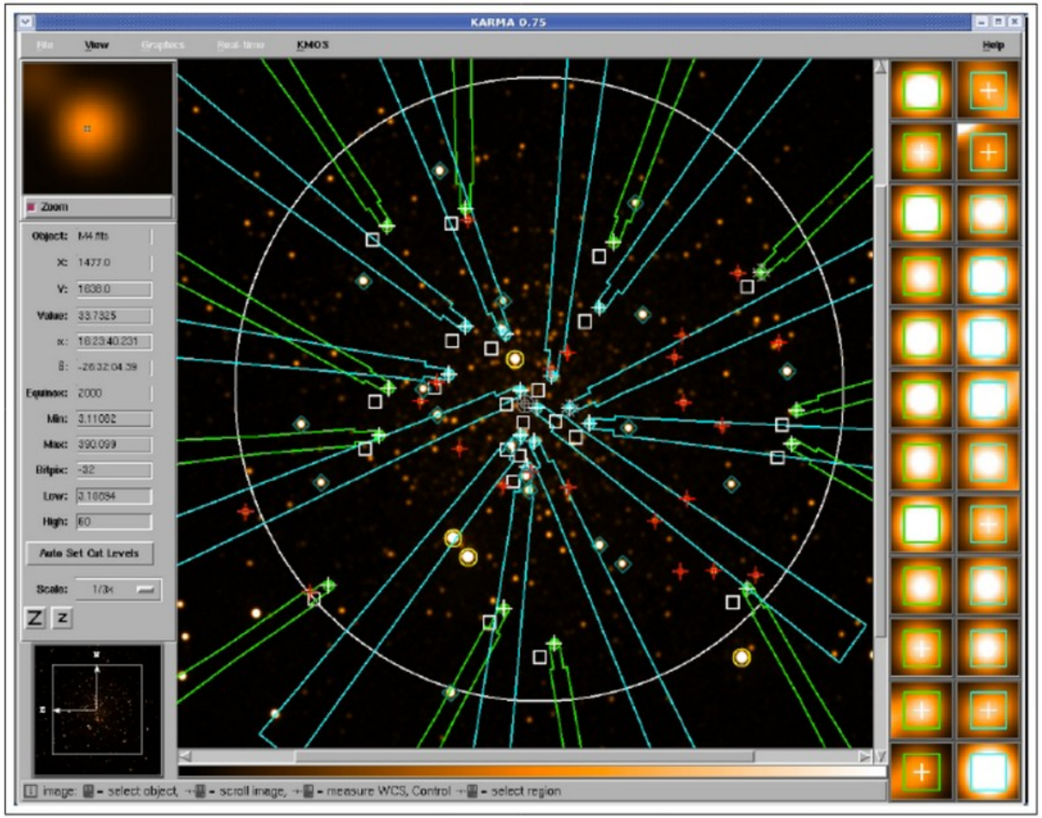
- **K**-band **M**ulti **O**bject **S**pectrograph (Sharples et al. 2013)
- 24 arms that patrol a 7.2’ diameter FoV
- Each arm has an image slicer dividing the field into 14 slices
- The slice is dispersed with 14 spatial pixels
- Each IFU has 2.8” x 2.8” (each pixel 0.2” x 0.2”)
- 0.8 to 2.5 microns (R = 3400, 3600, 4000, 4200, 2000 for IZ, YJ, H, K, HK bands)
- Minimum separation of ~6 arcsec
- Three HgCdTe 2kx2k detectors



(Credit: ESO)

KMOS

- DITs and NDIT must be selected using the ETC for max 2500 electrons/DIT/pixel, even for 0.4” seeing
- Recommended DIT for bright sources: 2.47s, 3s, 4s, 5s, 10s, 15s, 20s, 30s, 60s or 100s.
- For fainter sources: 1 NDIT x DIT = 300s, 400s, 480s, 600s, 900s, 1200s.
- Sky subtraction by nodding (see manual)
- Telluric standards taken within 2 hours of science, airmass difference of 0.2 (if not enough, need time for observations)



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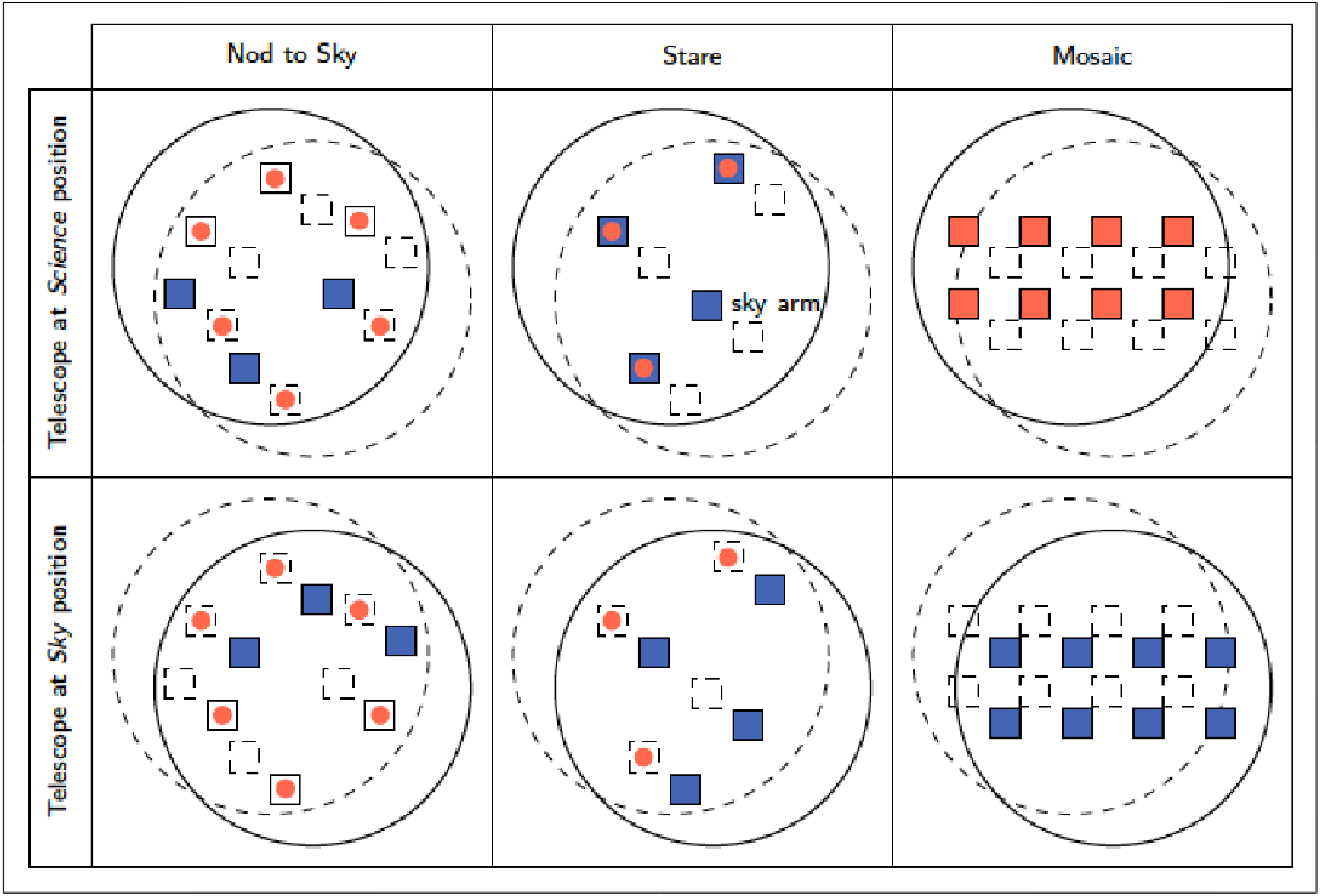
X: 1477.0
Y: 1638.0
Value: 33.7325
α: 18:23:40.231
δ: -26:32:04.39
Equinox: 2000
Min: 3.11082
Max: 390.099
Bitpix: -32
Low: 3.10694
High: 60
Scale: 1/3x

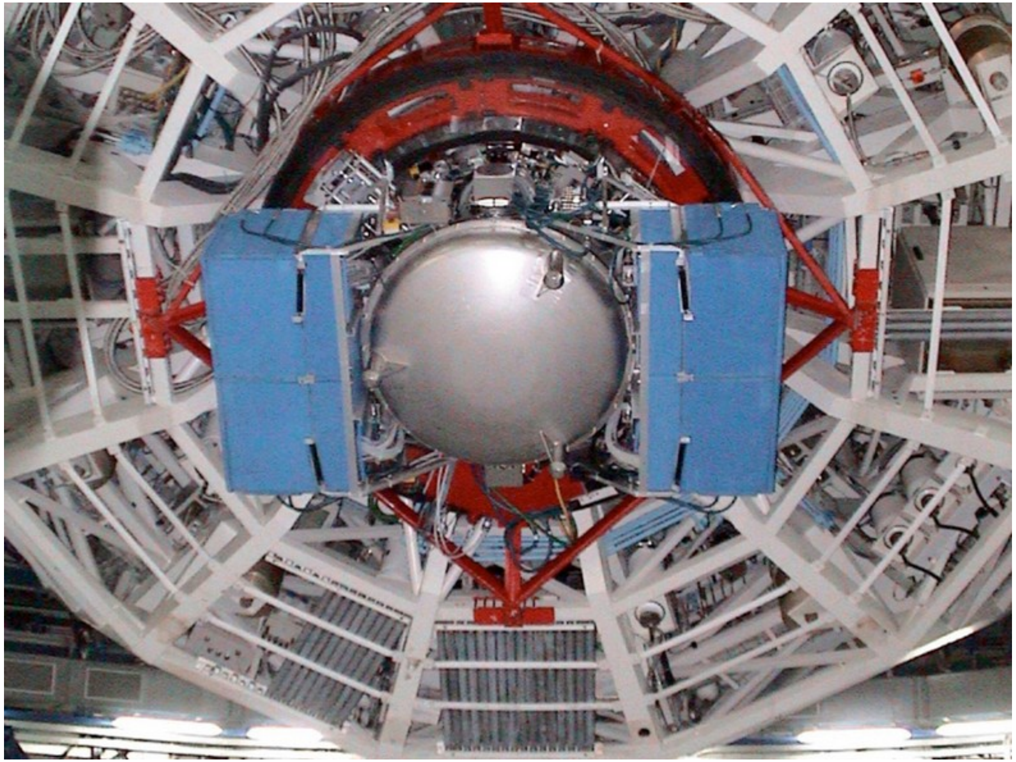
image: - select object, - scroll image, - measure WCS, Control - select region

(Credit: ESO)

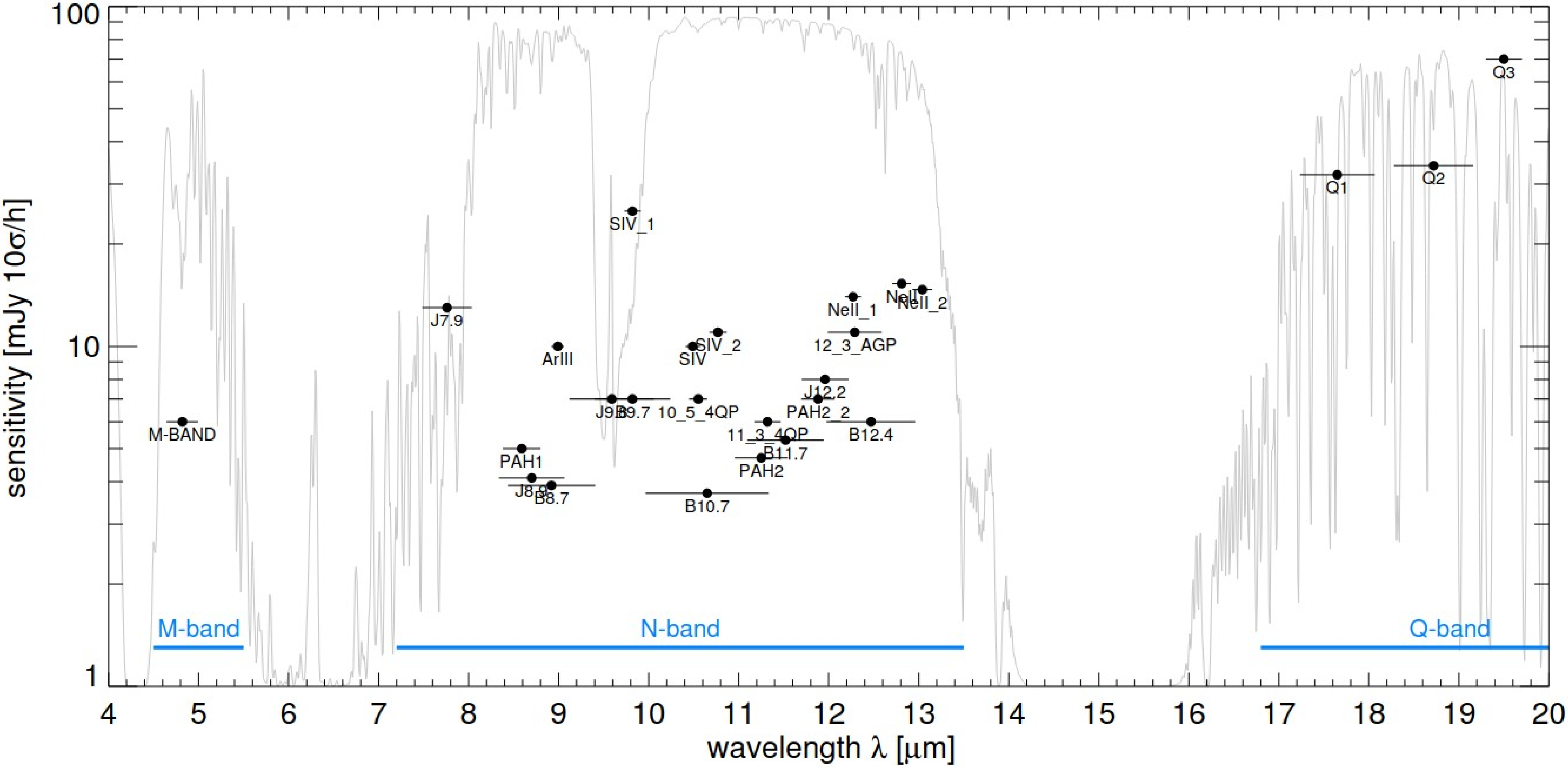

Nod to Sky
Stare
Mosaic
Telescope at Science position
Telescope at Sky position
sky arm

VISIR

- **V**LT **I**mager and **S**pectrometer for mid **I**nfra**R**ed (Lagage et al. 2004)
- Diffraction-limited imaging: M-band at 5µm, N-band between 8 to 13µm, and the Q band between 17 and 20µm
- FoV 38”x38” or 60”x60” (several filters)
- Low-resolution (R ~ 300, 8-13 microns)
- High-resolution (R ~ 15000) with order sorting filters or cross dispersed
- 1k x 1k Raytheon Aquarius IBC detector (Si:As)
- DITs few milli-seconds broad-band imaging, 2s high-resolution spectroscopy



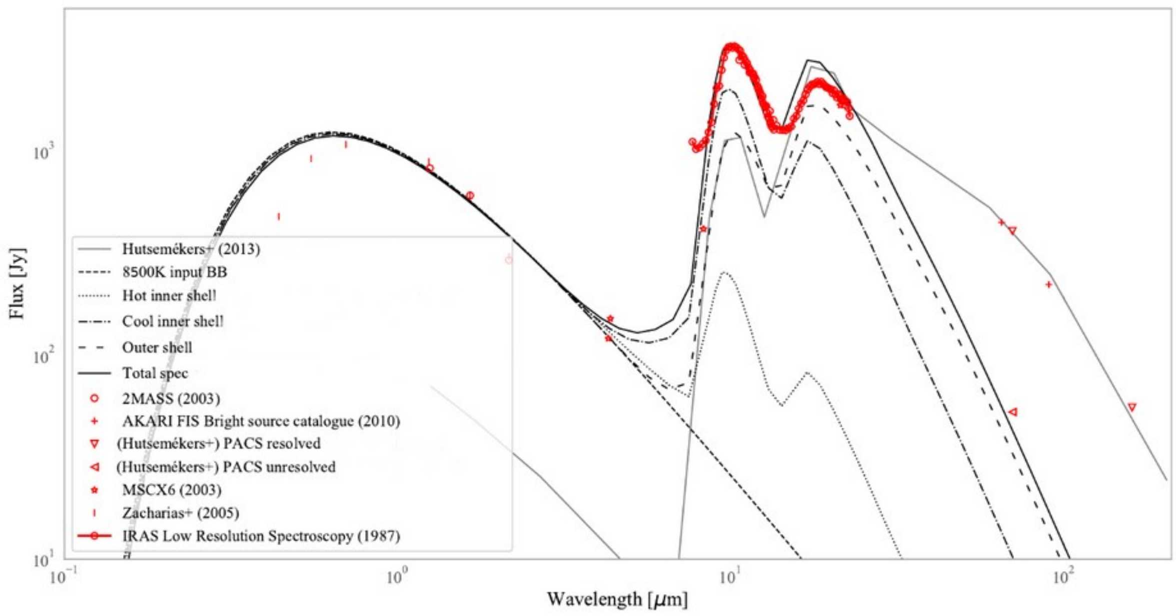
(Credit: ESO)


sensitivity [mJy 10σ/h]
wavelength λ [μm]
100
10
1
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
M-BAND
J7.9
ArIII
SIV_1
SIV
SIV_2
NeII_1
NeII
NeII_2
12_3_AGP
J12.2
PAH2_2
J9.8
B9.7
10_5_4QP
11_3_4QP
B11.7
B12.4
PAH1
PAH2
J8.9
B8.7
B10.7
Q1
Q2
Q3
M-band
N-band
Q-band

(Credit: ESO)

Strategy for our science case

- Imaging with HAWK-I and VISIR in broad band filters from the NIR to MIR
- Spectroscopy could wait the imaging results (did we find an extended source?)
- If not, we do not need IFU
- Neither the resolution of CRIRES
- Spectroscopy with VISIR (in the MIR) and maybe X-Shooter (in the NIR)
- Visitor or service?
- Strategy depends if this is a point or extended source



(Koumpia et al. 2020)

Questions?

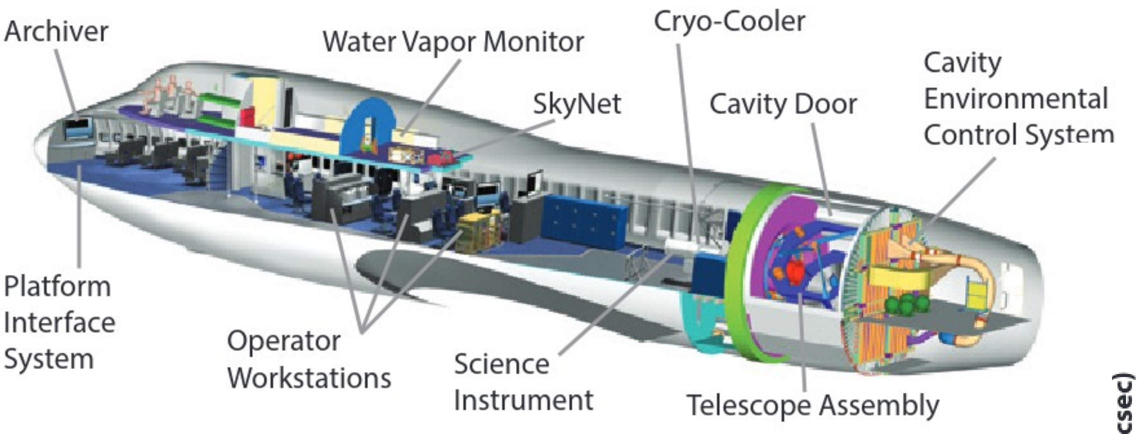
(Credit: Shutterstock)

SOFIA

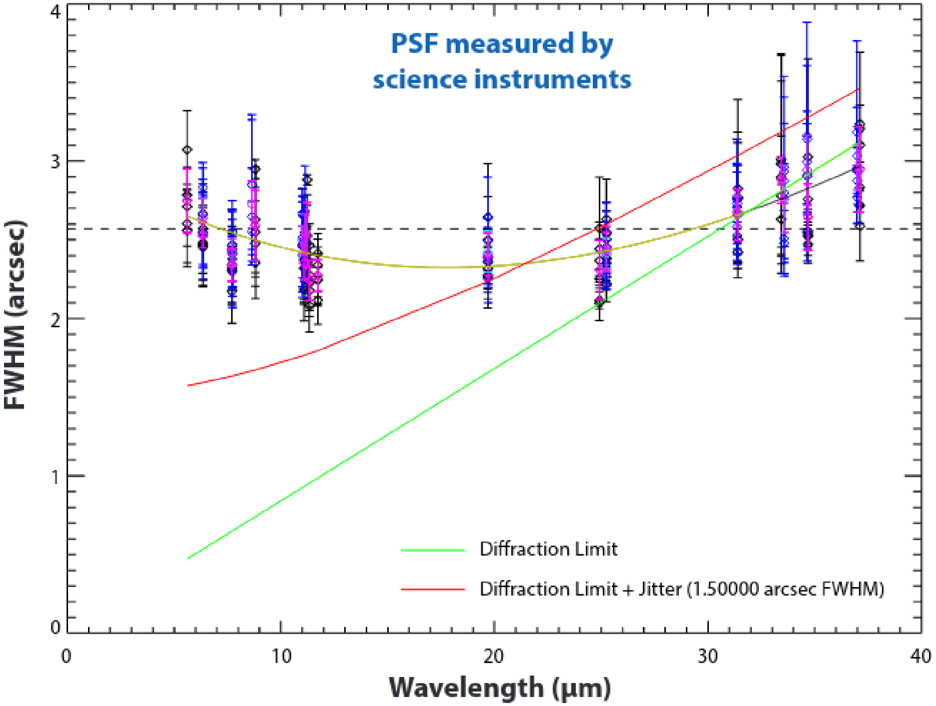
- **S**tratospheric **O**bservatory for **I**nfrared **A**stronomy (SOFIA)
- 2.7m Cassegrain telescope aboard Boeing 747SP aircraft
- Flies at 11-13.5 km of altitude
- NASA and DLR (German Space Agency)
- Non-US based scientists can apply to the 80% US time (20% for German affiliated scientists)
- Imaging and spectroscopy 0.3-1600 μm (optical to the sub-mm)
- 4 facility instruments + 2 PI instruments

(Credit: NASA)

SOFIA

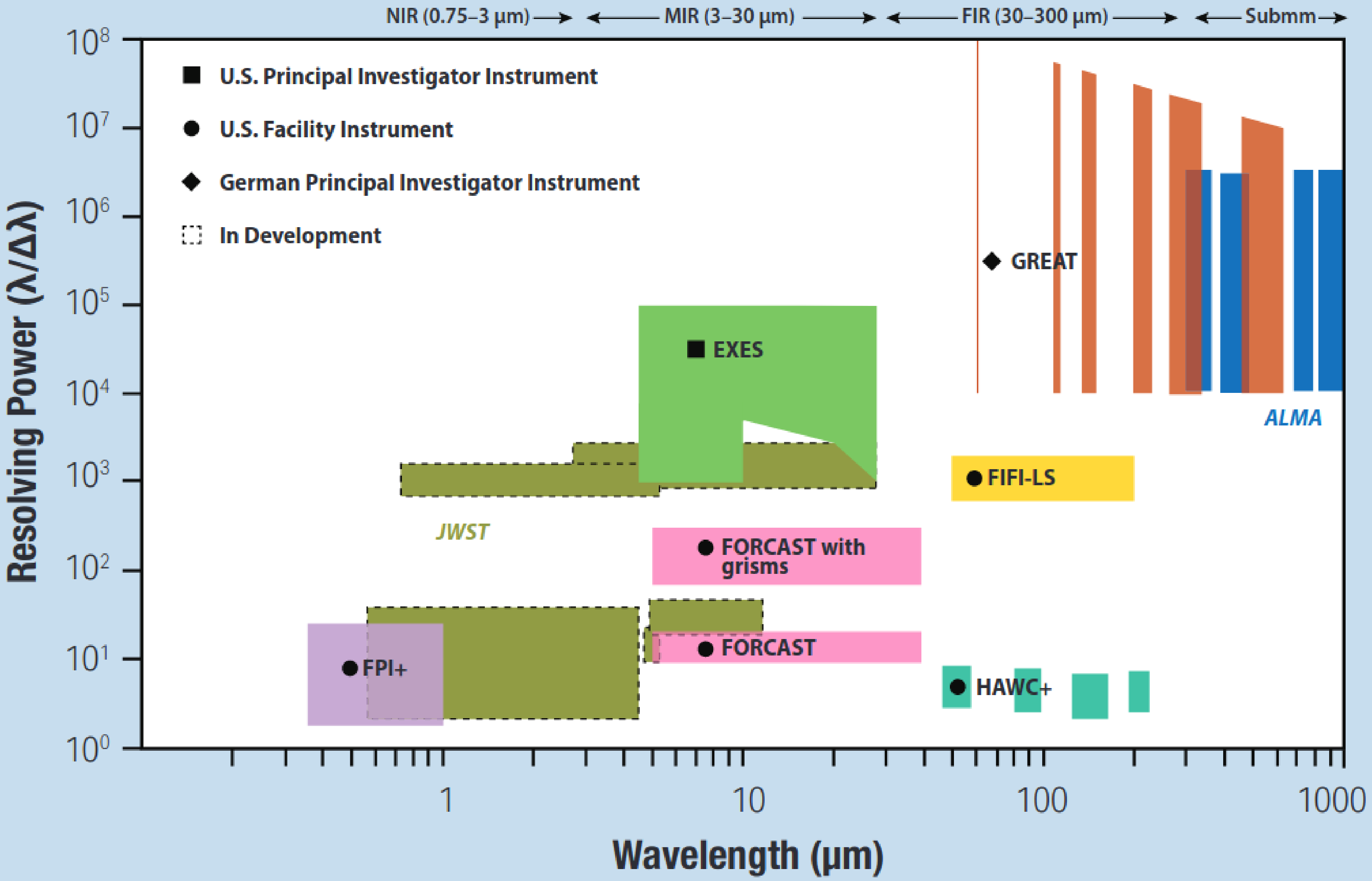


- Diffraction, jitter, optical aberrations, and defocus degrade image in the optical
- Turbulence and cavity seeing
- Uncertainty in the astrometric position is about 0.2 arcsec



(Credit: NASA)

The SOFIA Instruments

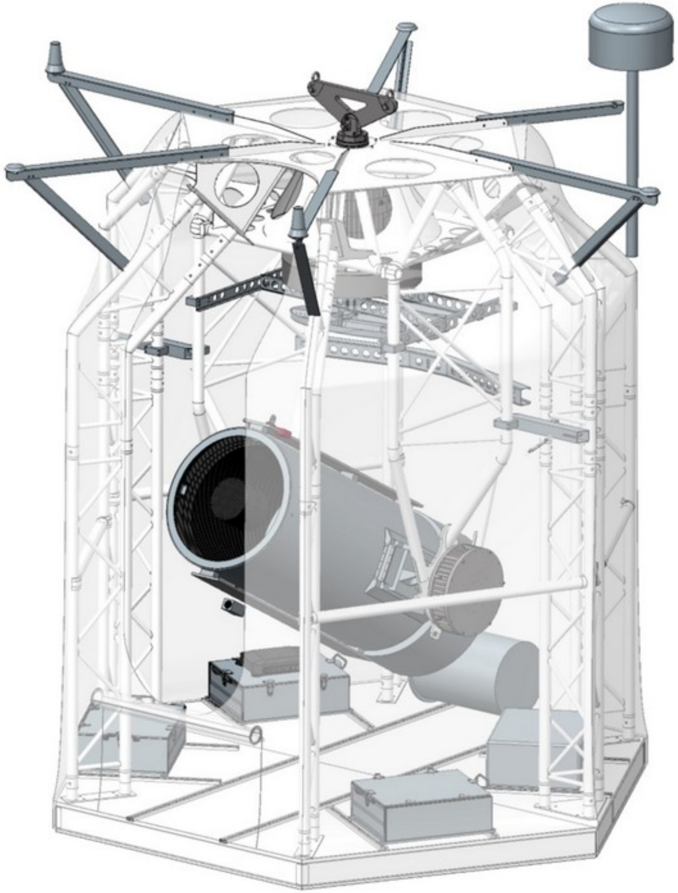


Name	Principal Investigator	Description	Wavelength Range Resolving Power $R=\lambda/\Delta\lambda$	Field of View Features
EXES	Matthew Richter, UC Davis	Mid-IR Echelle Spectrometer Facility Instrument	4.5 – 28.3 µm $R = 1{,}000 – 10^5$	1″ – 180″ slit lengths 1024x1024 Si:As
FIFI-LS	Alfred Krabbe, DSI	Far-IR Imaging Grating Spectrometer Facility Instrument	51 – 200 µm R = 600 – 2,000	30″ x 30″ (Blue) 60″ x 60″ (Red) 2x(16x25) Ge:Ga
FORCAST	Terry Herter, Cornell University	Mid-IR Camera & Grism Spectrometer Facility Instrument	5 – 40 µm R = 100 – 300	3.2′ x 3.2′ 2x(256x256) Si:As, Si:Sb
GREAT	Jürgen Stutzki, University of Cologne	Far-IR Heterodyne Spectrometer PI Instrument	63 – 612 µm $R = 10^6 – 10^8$	diffraction limited heterodyne receiver
HAWC+	Charles Dowell, JPL	Far-IR Bolometer Camera & Polarimeter Facility Instrument	50 – 240 µm $\Delta\lambda = 9 – 43$ µm	from 1.4′ x 1.7′ (53 µm) to 4.8′ x 6.1′ (214 µm) 3x(32x40) bolometer
FPI+	Jürgen Wolf, DSI	Focal Plane Imager Facility Instrument	0.36 – 1.10 µm R = 0.9 – 29.0	8.7′ x 8.7′ 1024x1024 CCD

(Credit: NASA)

European Stratospheric Balloon Observatory

- On-going prototype design study (Maier et al. 2021)
- At 30 to 40 km altitude, above 99% of Earth’s atmospheric mass
- 0.5-m prototype telescope for UV and visible light observations
- Service provider for wide community
- Next-generation FIR telescope are being studied
- 5-m-class far infrared flight system is estimated in a 15 year timeframe.



(Credit: ESBO)

Questions?

(Credit: Shutterstock)

REFERENCES

- Dorn et al. 2014 (The Messenger, 156, 7)
- Gardner et al. 2006 (SSRv, 123, 485)
- Herwig 2005 (ARA&A, 43, 435)
- Kissler-Patig et al. (A&A, 2008, 491, 941)
- Koumpia et al. 2020 (A&A, 635, A183)
- Lagage et al. 2004 (The Messenger, 117, 12)
- Maier et al. 2021 (arXiv:2111.11068)
- Sharples et al. 2013 (The Messenger, 151, 21)
- Suarez et al. 2006 (A&A, 458, 173)
- Tokunaga et al. 2013 (Infrared Astronomy Fundamentals)