Scientific Capability of the James Webb Space Telescope and the Mid-InfraRed Instrument

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on behalf of
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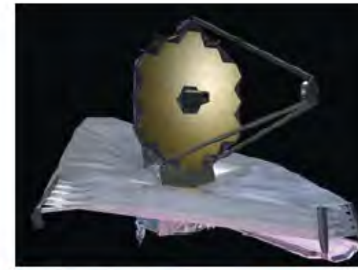
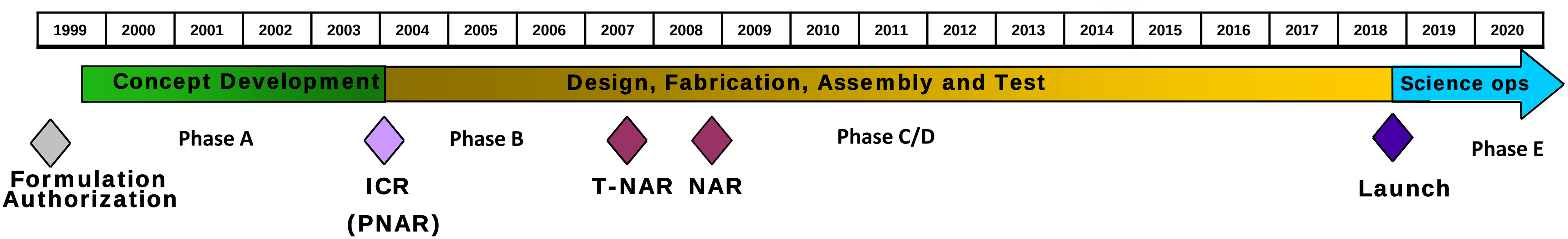
MIRI European PI

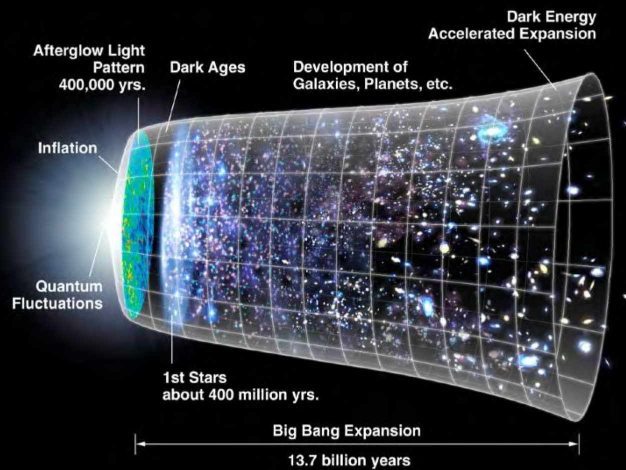
The Infrared Flagship mission JWST

- **JWST will be one of the "great observatories" of the next decade**
  - Often presented as the next step after the Hubble Space Telescope (HST)
- **Joint mission between NASA, ESA and CSA**
  - High-priority endeavor for the associated astrophysical communities
- **Setup similar to the HST one**
  - Over the duration of the mission, > 15% of the total JWST observing time goes to ESA Member states applicants
- **To be launched at the end of 2018 for a minimum mission duration of 5 years (10-year goal)**



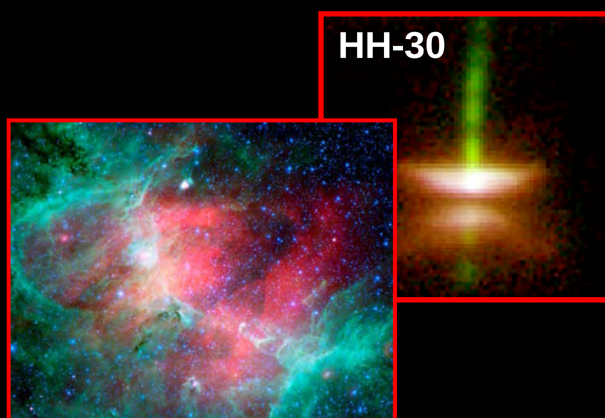


JWST Science Overview

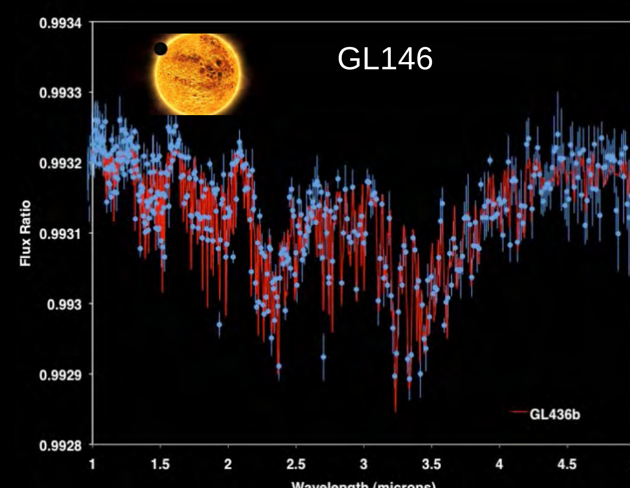


First Light and Re-Ionization

Assembly of Galaxies



Birth of stars and
proto-planetary systems



Planetary systems and the origin of life

JWST Design Drivers

- **Wavelength coverage spanning the optical to mid-infrared spectrum (0.6-28 microns)**
  - A cryogenic space telescope in orbit around the very stable Sun-Earth L2 environment with the right instruments
- **High sensitivity (10 nJy in 10,000s;10σ)**
  - A cooled 6.5-meter diameter primary mirror
- **Angular resolution similar to the HST one but in the near infrared (65 mas @ 2 μm)**
  - A 6.5-meter diameter primary mirror diffraction limited at around 2 microns
- **A low background level from the NIR to the MIR.**
  - A cryogenic space telescope in orbit around the very stable Sun-Earth L2 environment
- **Both imaging and spectroscopic capabilities.**
  - A suite of versatile and powerful instruments

MIRI

NIRSpec

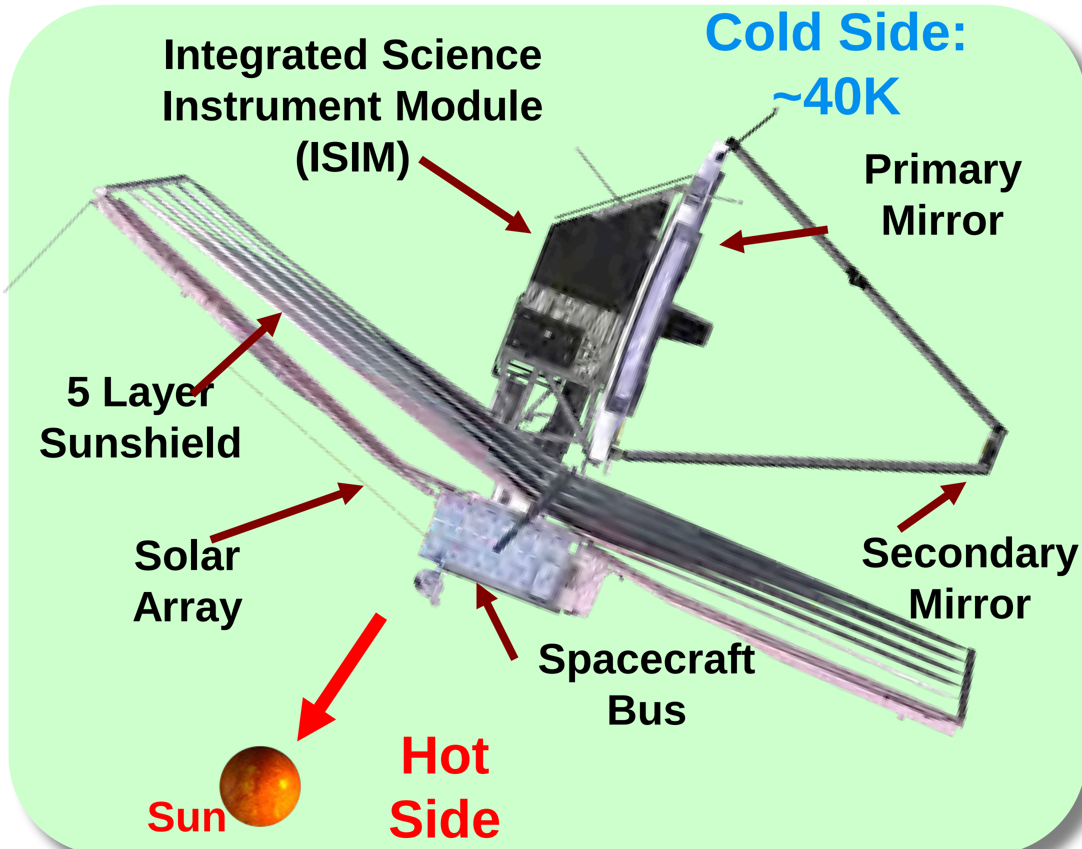
FGS/NIRISS

NIRCam

JWST

European Space Agency

JWST architecture

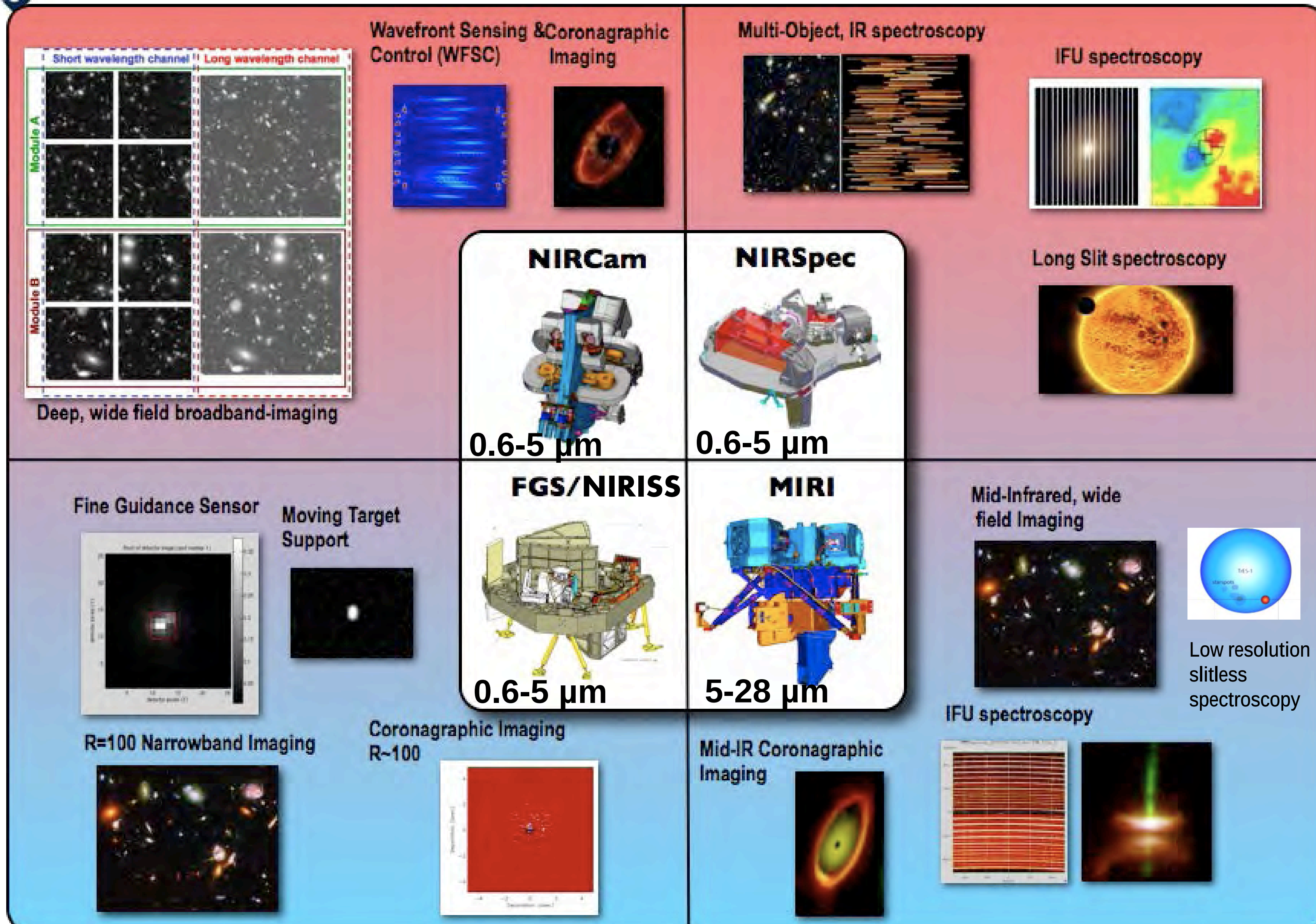


JWST is folded and stowed for launch

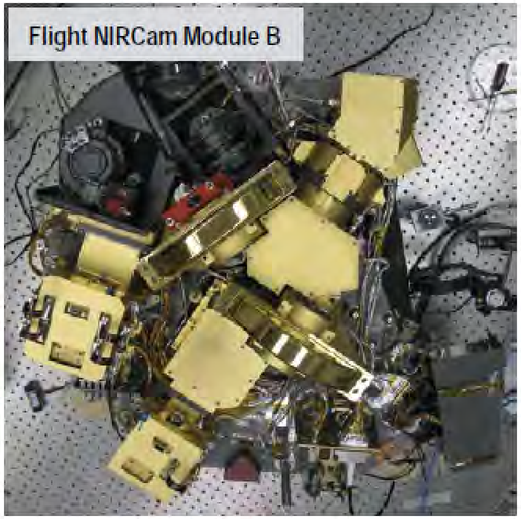
Observatory is deployed after launch

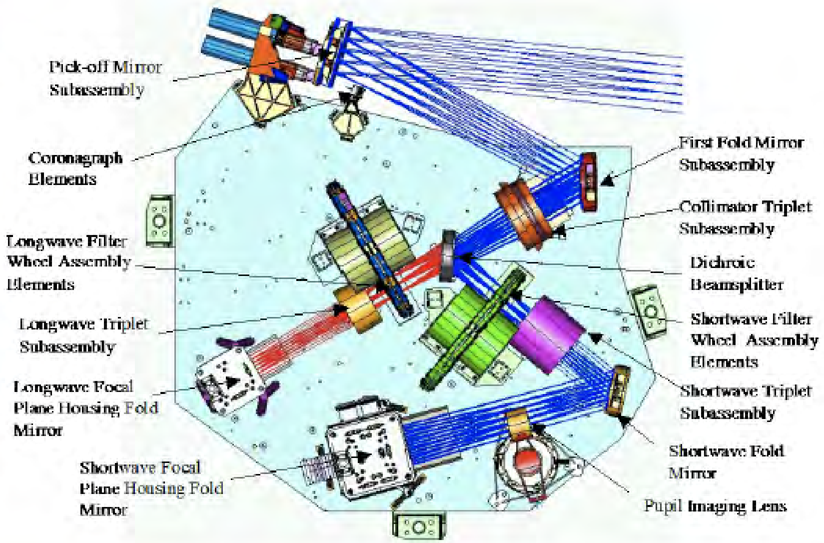
JWST Orbits the 2nd Lagrange Point (L2)

JWST will have 4 Science Instruments



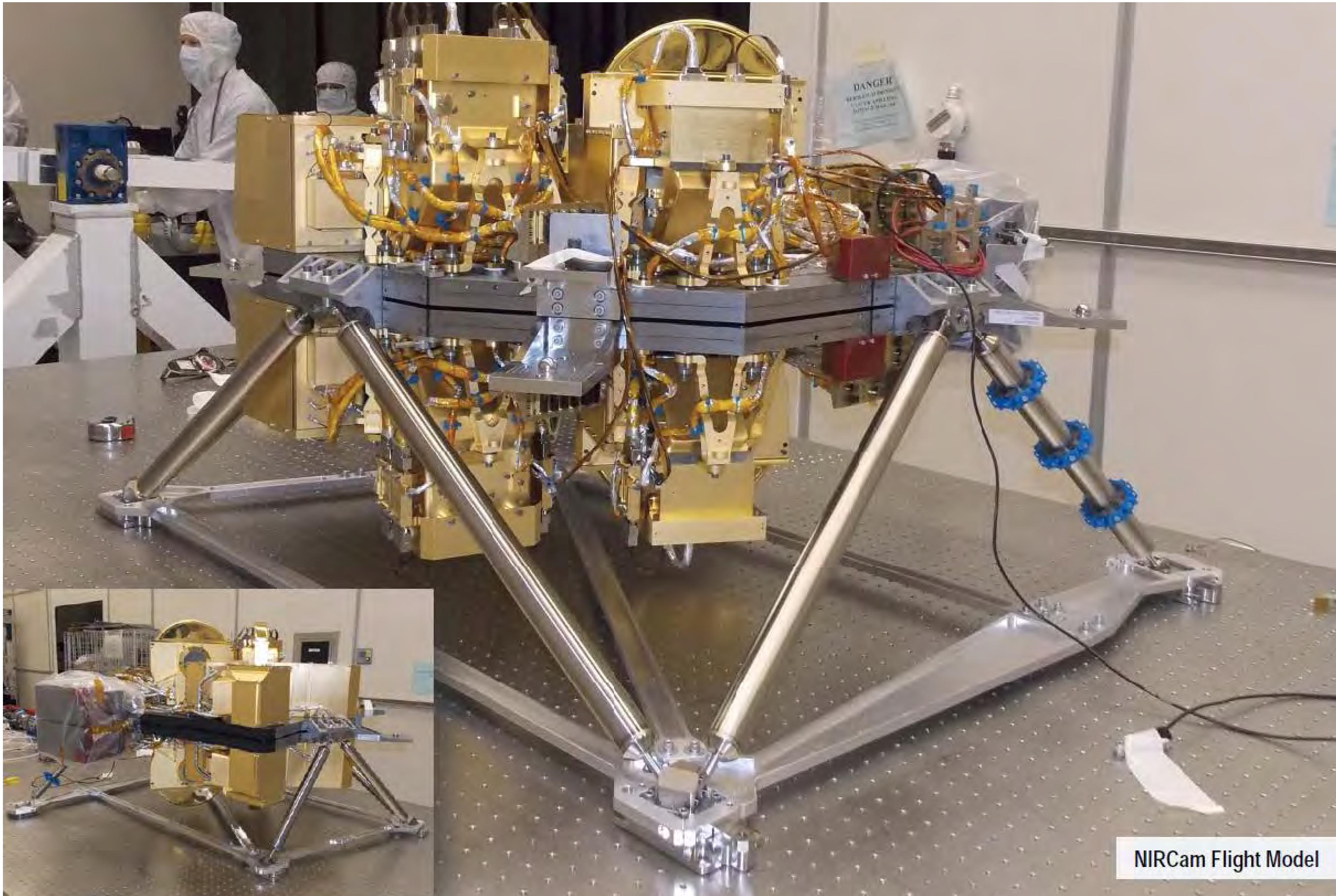
NIRCam will provide the deepest near-infrared images ever and will identify primeval galaxy targets for the NIRSpec





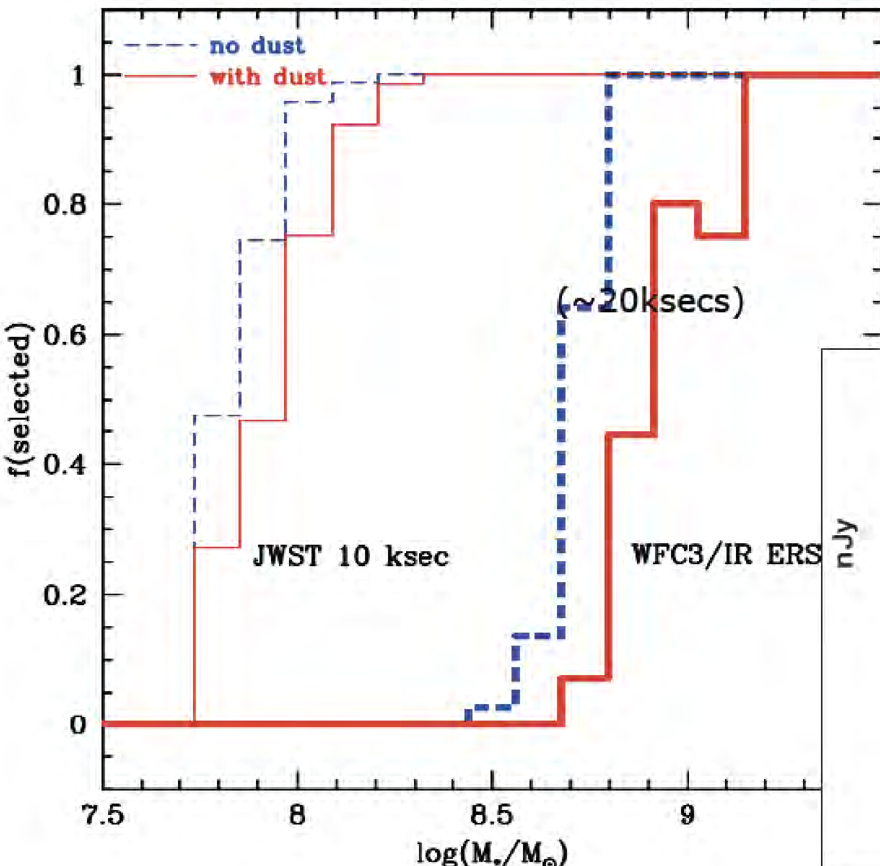
- Developed by the University of Arizona with Lockheed Martin ATC
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 4, 10, 100 (filters + grism), coronagraph
  - Field of view: 2.2 x 4.4 arc minutes
  - Angular resolution (1 pixel): 32 mas < 2.3 microns, 65 mas > 2.4 microns
  - Detector type: HgCdTe, 2048 x 2048 pixel format, 10 detectors, 40 K passive cooling
  - Refractive optics, Beryllium structure
- Supports telescope wavefront sensing

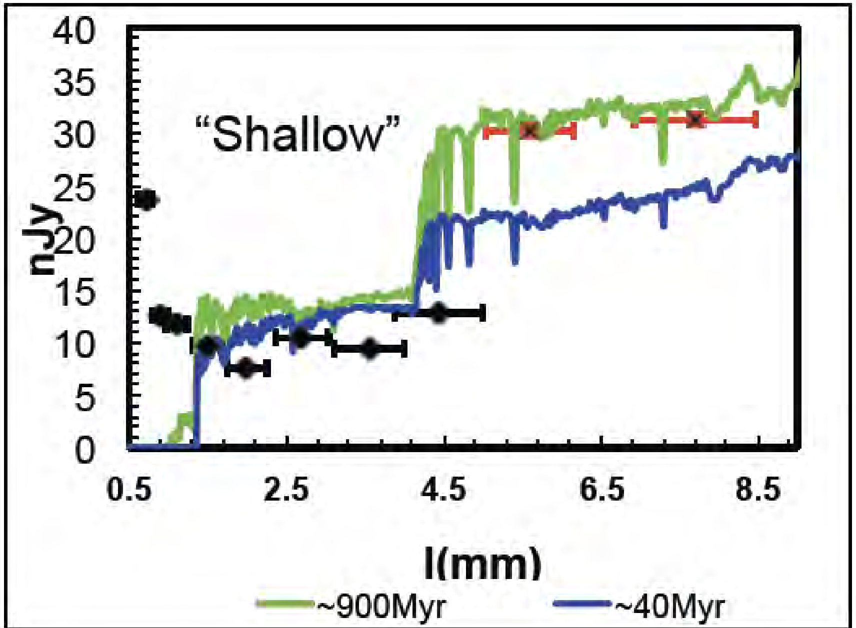
NIRCAM delivered into GSFC in July 2013

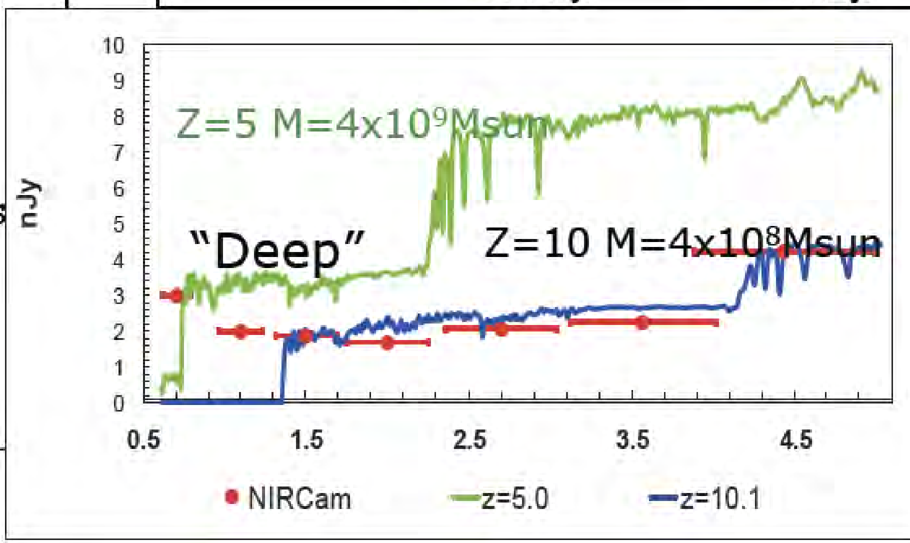


NIRCAM sensitivity

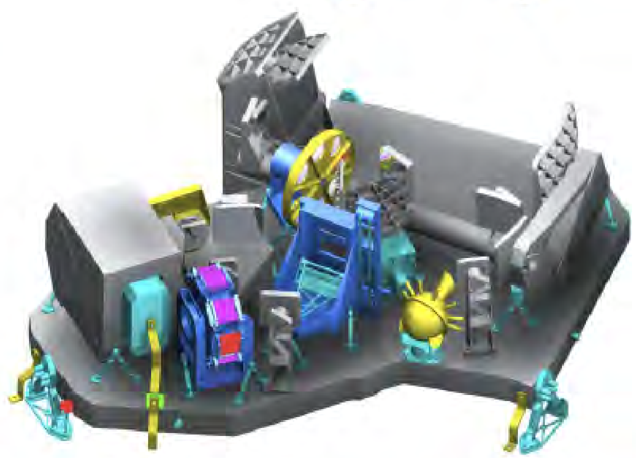
NIRCam will have the sensitivity to find z~10 galaxies and low mass galaxies at lower redshifts.

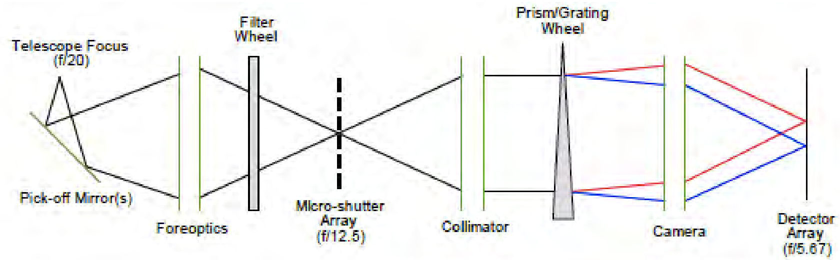


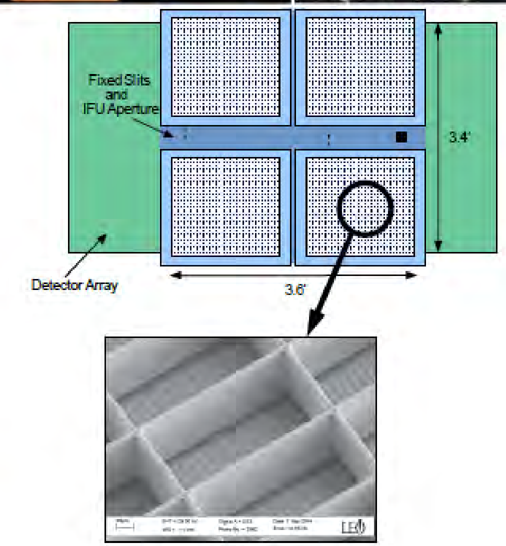




The NIRSpec will acquire near-infrared spectra of up to 100 objects in a single exposure







- Developed by the European Space Technology Center (ESTEC) with Astrium and Goddard Space Flight Center
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 100, 1000, 3000
  - Field of view: 3.4 x 3.4 arc minutes
    - Aperture control:
      - Programmable micro-shutters, 250,000 pixels
      - Fixed long slits & transit spectroscopy aperture
      - Image slicer (IFU) 3x3 arc sec
  - Detector type: HgCdTe, 2048 x 2048 format, 2 detectors, 37 K passive cooling
  - Reflective optics, Silicon Carbide structure and optics

NIRSpec spectroscopic modes

JWST/NIRSpec

MOS

Multi-object spectroscopy with 0.2"-wide mini-slits.

- 9 square arcmin. field of view
- Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure.
- Medium spectral resolution (500 to 1300), grating-based mode covering the 0.7-5.0 range

IFU

IFU spectroscopy with a 0.1" sampling.

(IFU made of 30 slices for a total of 900 "spaxels")

- 3"x3" field of view
- Low spectral resolution (30 to 300), prism-based mode covering the 0.6-5.0 micron range in one exposure.
- Medium (500 to 1300) and high (1400-3600) spectral reso-lution modes, covering the 0.7-5.0 range in 4 exposures.
- IFU and MOS cannot be used at the same time.

SLIT

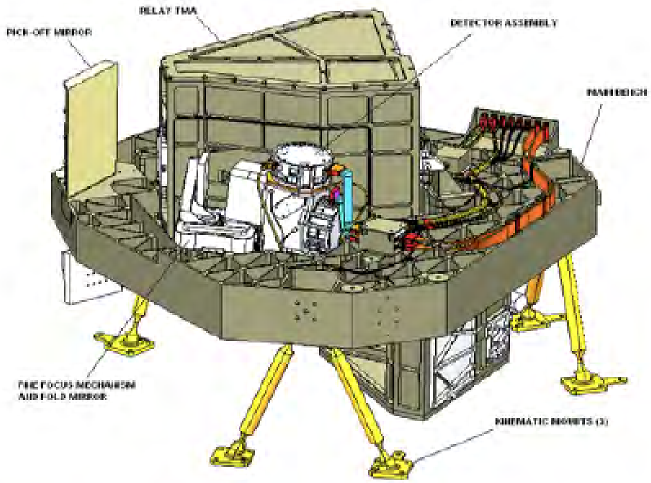
High-contrast slit spectroscopy.

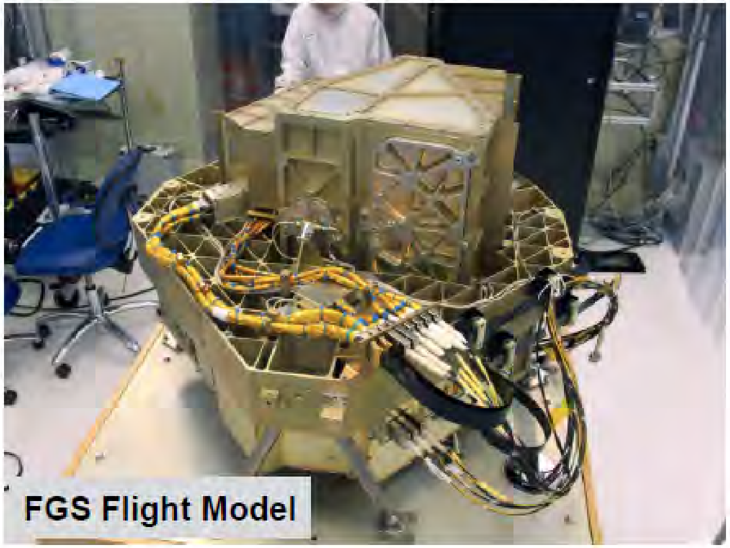
(including with a 1.6"x1.6" square aperture for extra-solar planet transit observation)

- 5 slits available
All spectral resolution modes available.
- SLIT can be used simultaneously to IFU or MOS.

NIRSpec delivered to GSFC in September 2013

FGS-Guider & –NIRISS: Telescope pointing control imagery & slitless spectroscopy for Ly-α surveys and exoplanet transits



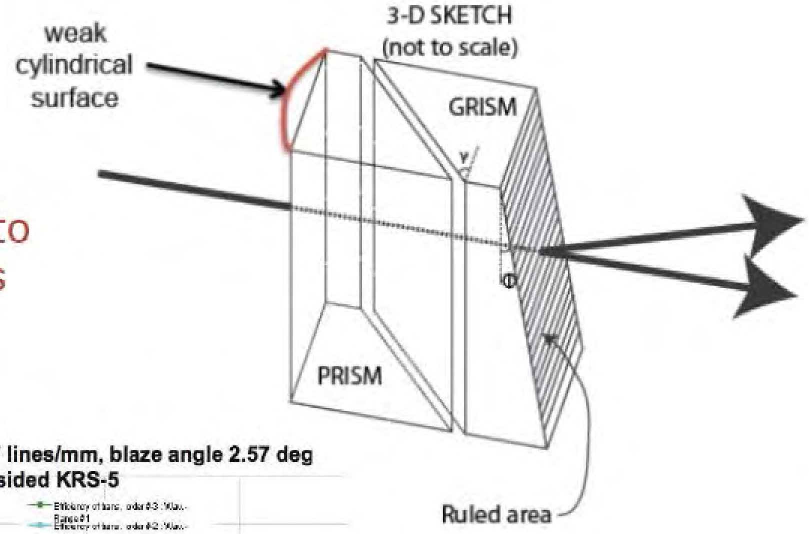


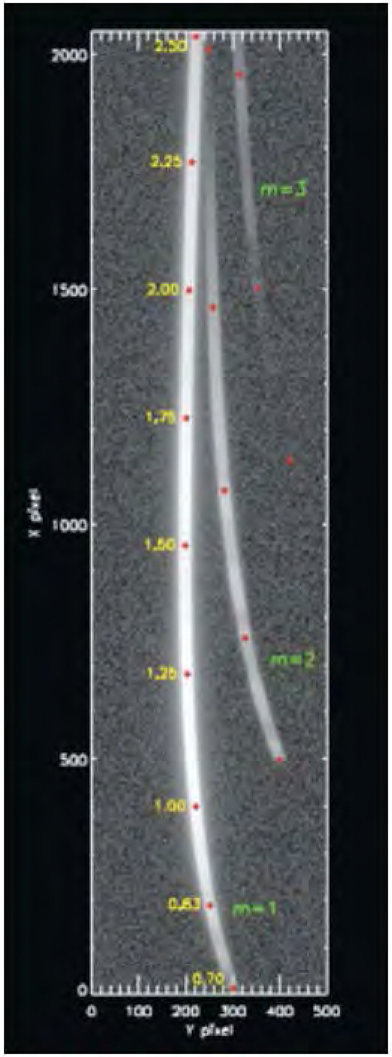
- Developed by the Canadian Space Agency with ComDev
  - Broad-band guider (0.6 – 5 microns)
  - Field of view: 2.3 x 2.3 arc minutes
  - Science imagery:
    - Slitless spectroscopic imagery (grism)
      - R ~ 150, 0.8 – 2.25 microns optimized for Ly alpha galaxy surveys
      - R ~ 700, 0.7 – 2.5 microns optimized for exoplanet transit spectroscopy
    - Sparse aperture interferometric imaging (7 aperture NRM) 3.8, 4.3, and 4.8 microns
  - Angular resolution (1 pixel): 68 mas
  - Detector type: HgCdTe, 2048 x 2048 pixel format, 3 detectors
  - Reflective optics, Aluminum structure and optics

FGS delivered to GSFC in July 2012

Slitless spectroscopy

Weak lens defocuses along spatial direction to allow more pixels to sample spectrum



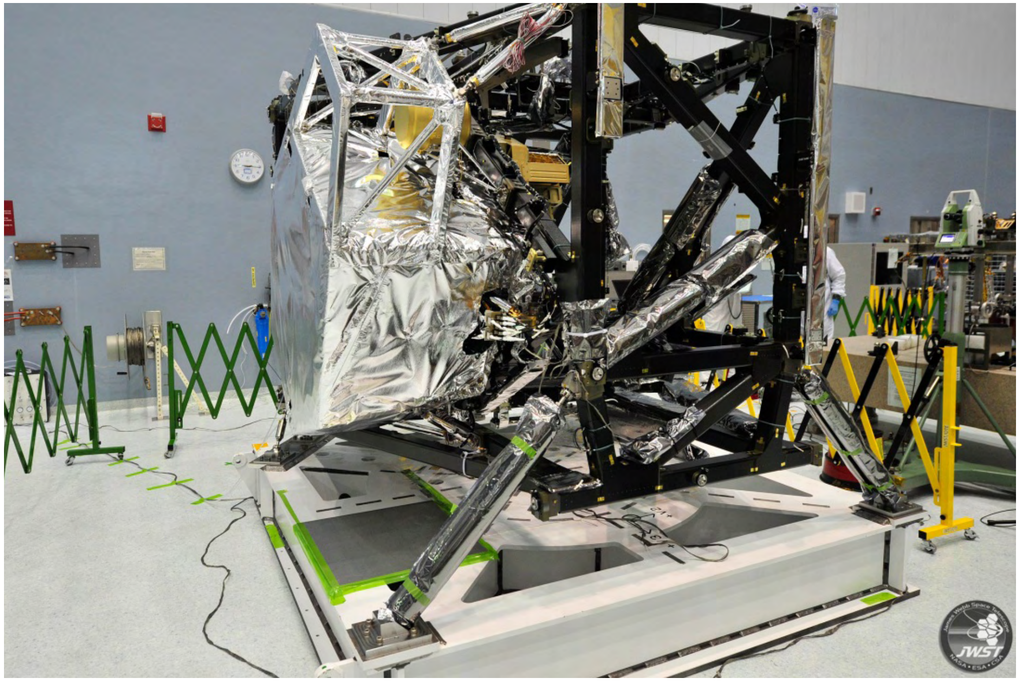


- **Specially designed for exoplanet transit spectroscopy.**

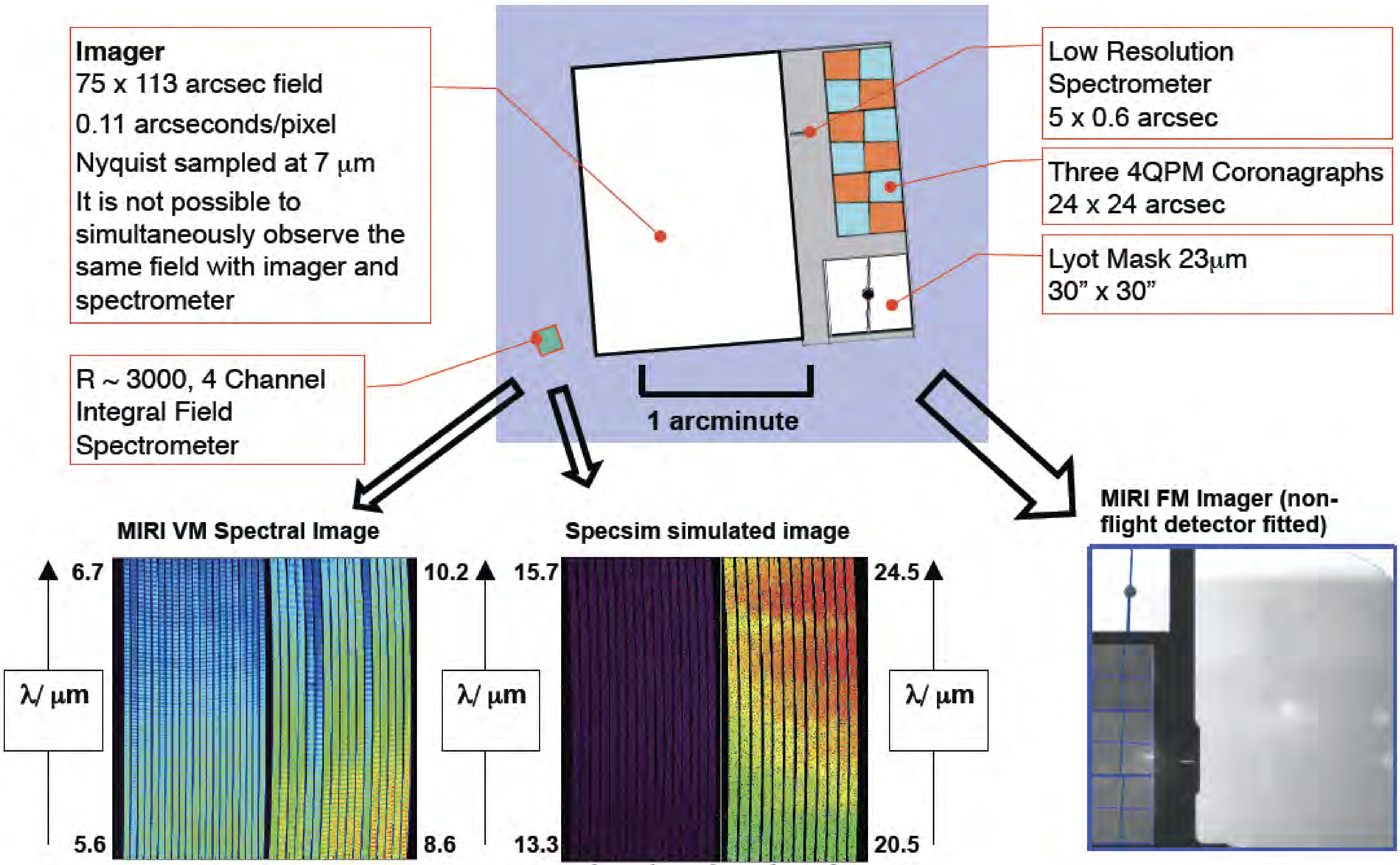
The MIRI instrument will characterize circumstellar debris disks, extra-solar planets, and the evolutionary state of high-z galaxies

- Developed by a consortium of 10 European countries and NASA/JPL
  - Operating wavelength: 5 - 29 microns
  - Spectral resolution: 5, 100, 2000
  - Broad-band imagery: 1.9 x 1.4 arc minutes FOV
  - Coronagraphic imagery
  - Spectroscopy:
    - R100 long slit spectroscopy 5 x 0.2 arc sec
    - R2000 spectroscopy 3.5 x 3.5 and 7 x 7 arc sec FOV integral field units
  - Detector type: Si:As, 1024 x 1024 pixel format, 3 detectors, 7 K cryo-cooler
  - Reflective optics, Aluminum structure and optics

MIRI 1st instrument delivered to NASA in May 2012

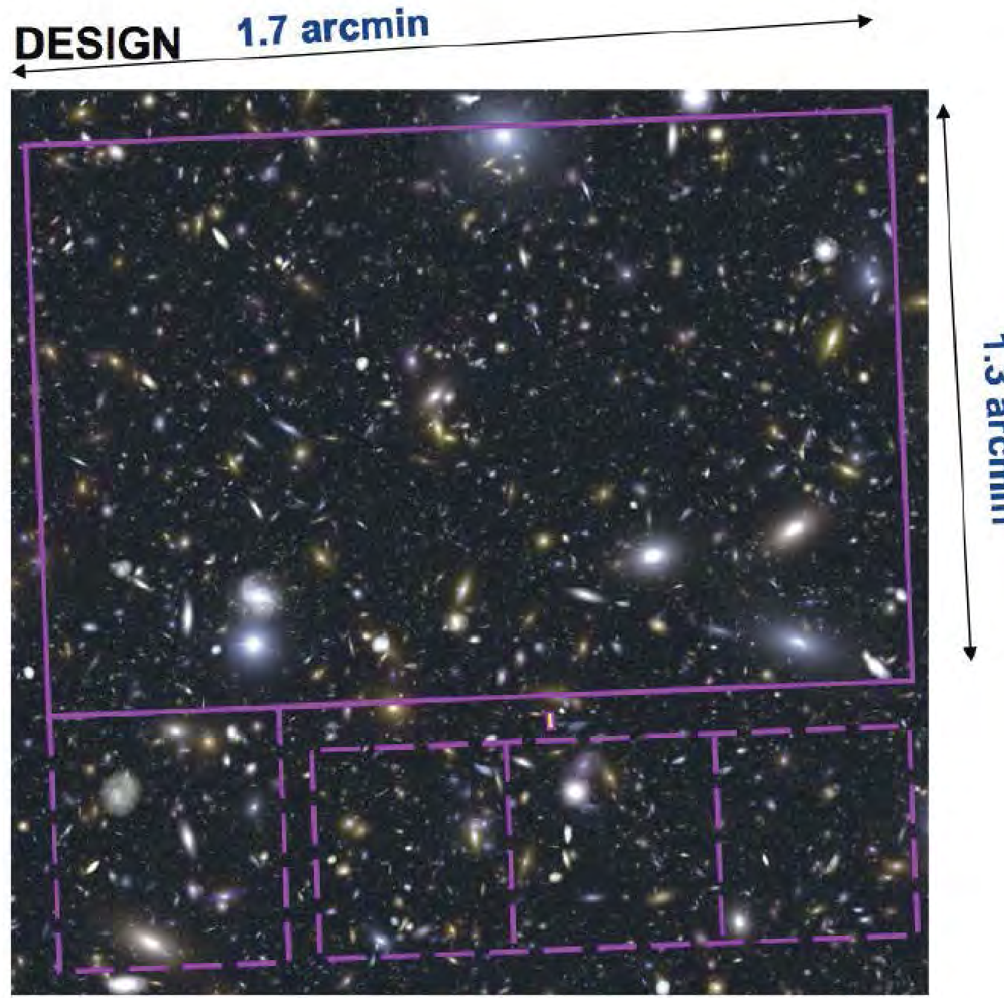


Focal Plane: The best 1kx1k Si:As detectors (with Spitzer heritage) ever produced provided by JPL.



MIRI Capabilites - Imager

- **Sampling of 0.11 arcsec / pixel**
- **Diffraction limited λ > 5.6 μm**
- **Additional capabilities:**
  - Coronagraphy
  - Single object R ~100 spectroscopy.



Simulated NIR JWST field (Myungshin Im 1998)

The mass assembly of galaxies

- Detection of bright high redshift sources (lensed or not-lensed, QSOs..)

➔ Imaging deep fields.

- Mass and morphology of the older stellar population.

➔ Deep images in the 6-8 micron domain provide direct measurement of the rest-frame red/near-IR light of z=6-10 galaxies.

- Role of starbursts and AGNs in galaxy evolution

MIRI IFU spectroscopy

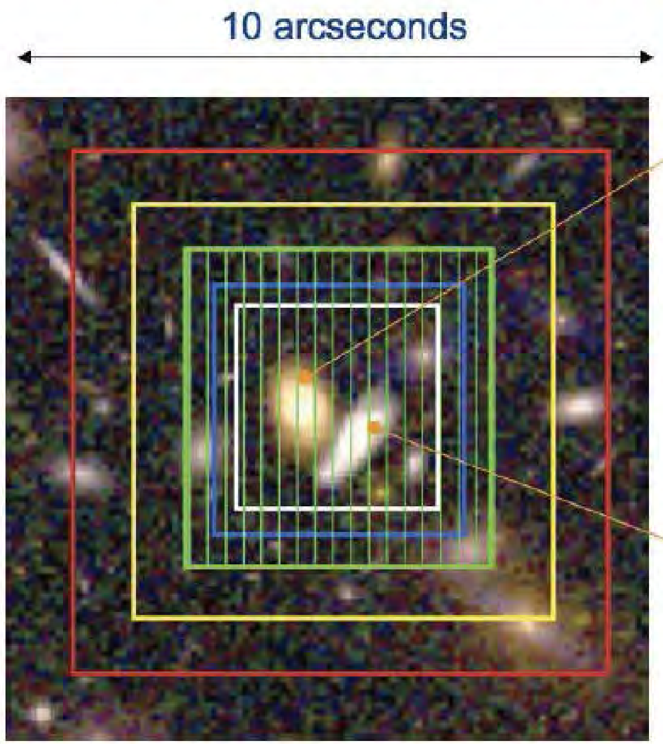
- **Medium resolution IFU spectroscopy**

Channel 1
(4.9 - 7.7 μm)

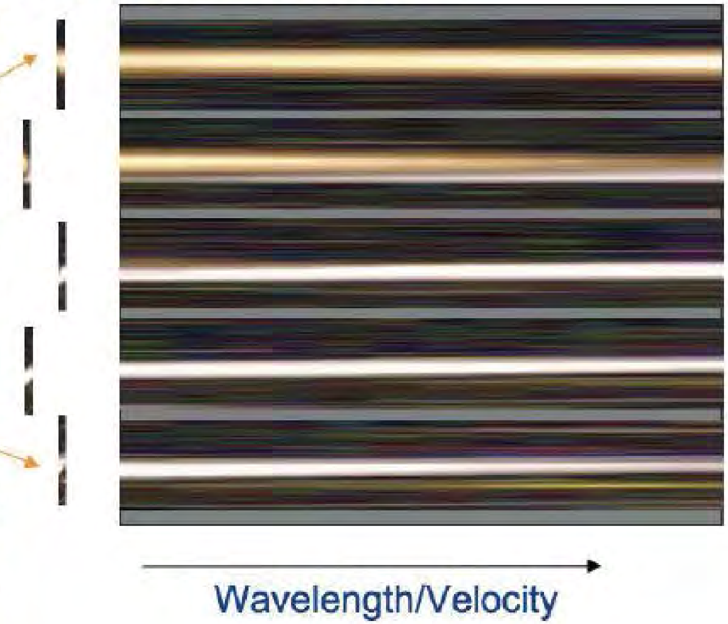
Channel 2
(7.4 - 11.8 μm)

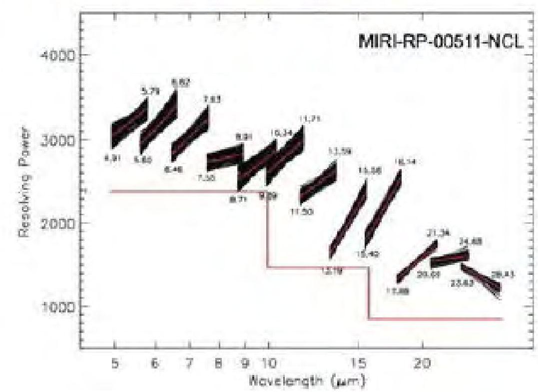
Channel 3
(11.4 - 18.2 μm)

Channel 4
(17.5 - 28.8 μm)



Each channel's field of view is sliced, dispersed and detected.





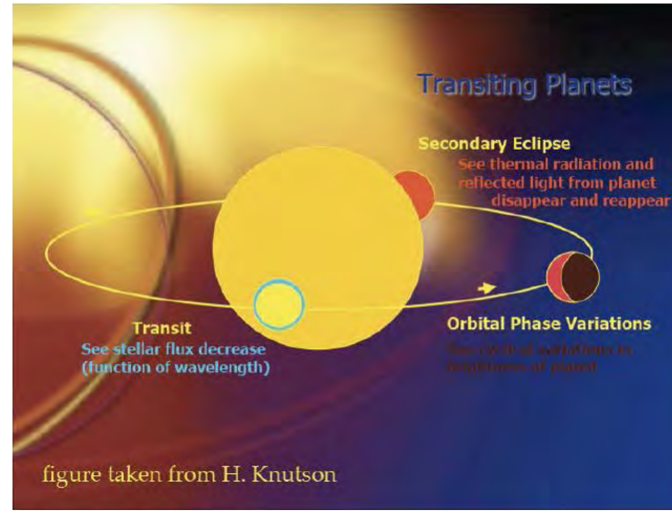
Science Capabilites

Exo-planet characterisation

- Study of the spectrum of exoplanets in the mid-infrared domain.

➔ Transit spectroscopy (not planet hunting).

- Direct imaging (e.g. beta-Pictoris) Coronagraphy



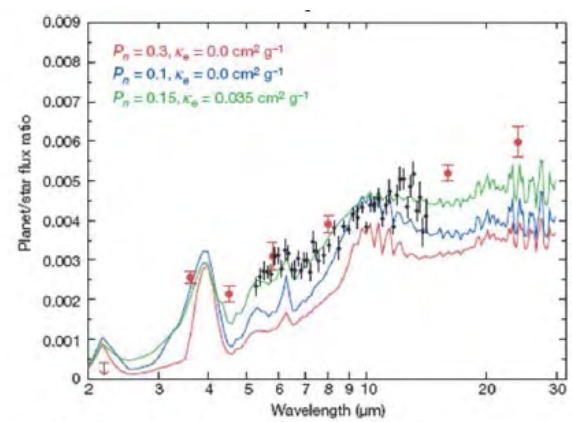
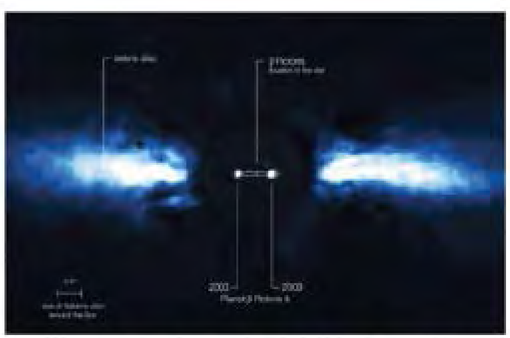


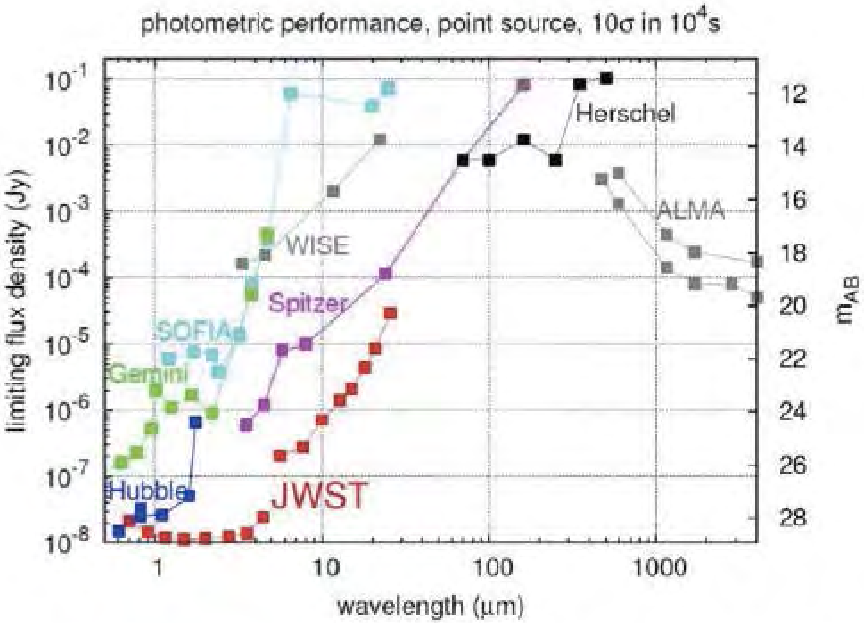
Figure 3 **Comparison of spectral observations with broadband photometry and theoretical models of the dayside atmosphere of HD 189733b.** The black points show the mean planet/star flux ratios for six second-order spectra (5–8 μm) and four first-order spectra (7.5–14 μm). The data have been binned by a factor of four after light-curve fitting (corresponding to two IRS resolution elements), and the plotted uncertainties reflect the standard error in the mean in each wavelength bin. The filled red circles show broadband measurements from ref. 5 at 3.6, 4.5, 5.8, 8.0, 16 and 24 μm (error bars on this data, s.e.). The upper limit at 2.2 μm is derived from Keck spectroscopy[16]. The red, blue and green traces are atmospheric model predictions for three values of a dayside–nightside heat redistribution parameter, P_n, and two values of the extra upper-atmosphere opacity, κ_e. The model predictions have not been scaled in any way.

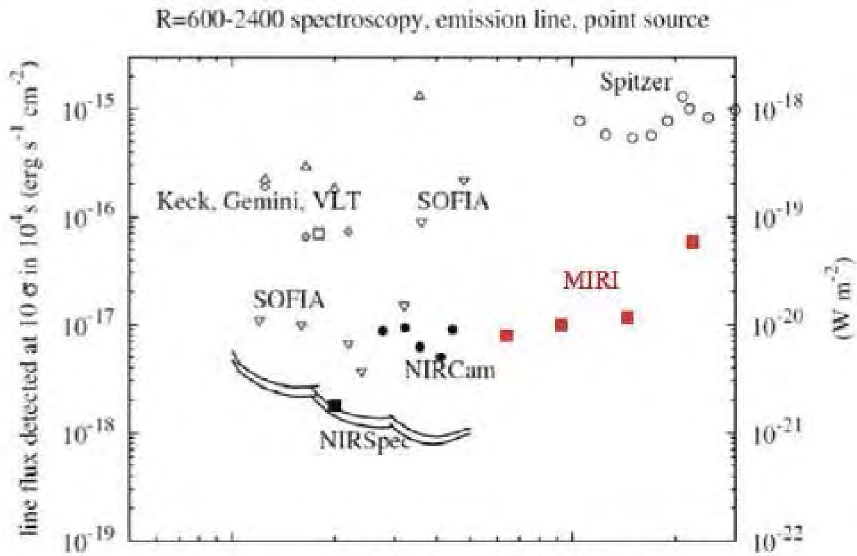
From Grillmair et al., Nature 2008.

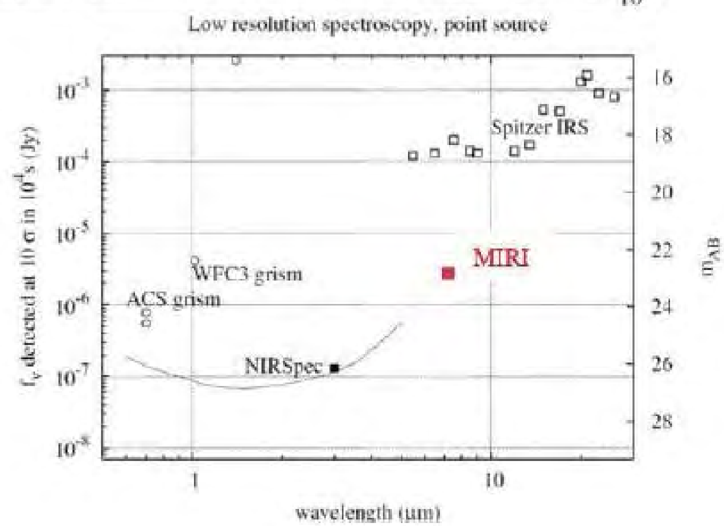


Combination of two images taken in 2003 and 2009 with the NACO (ESO-VLT) coronagraph, showing the movement of an exoplanet around the β-Pic star (Lagrange et al. 2010).

MIRI Sensitivity

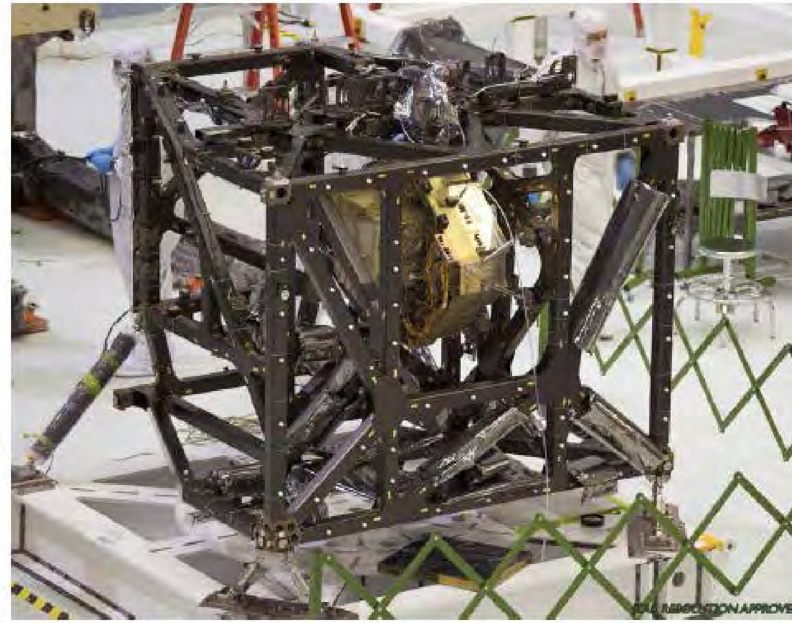


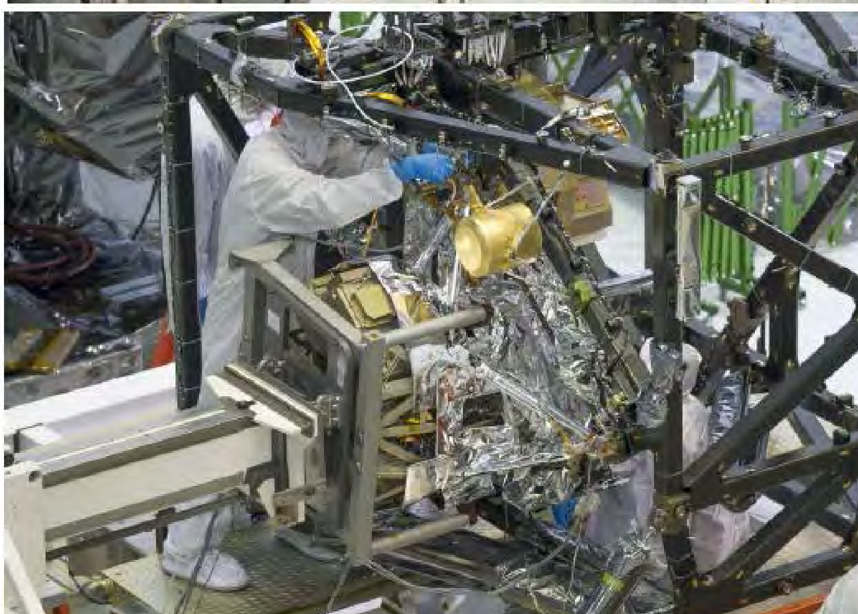




- **MIRI provides a huge increase in observational capabilities compared to current and future facilities**
  - Orders of magnitude in sensitivity & resolution
  - many of the most important results likely to be unexpected discoveries.”

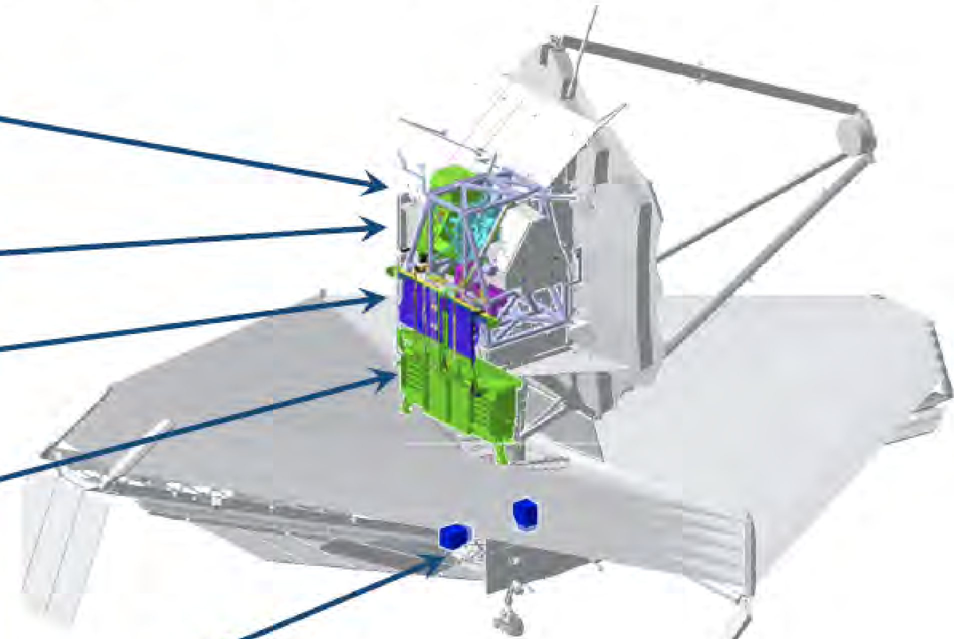
Integration of FGS, NIRISS, and MIRI instruments with the ISIM structure completed; NIRCAM and NIRSpec following currently





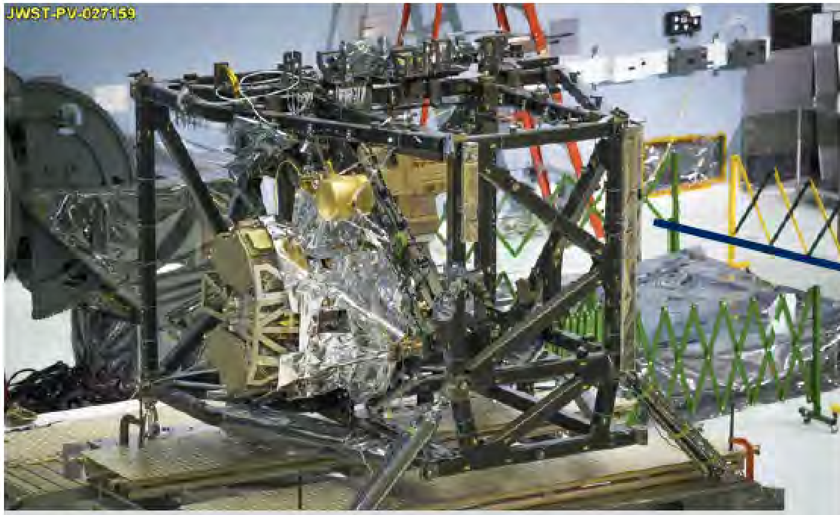
The Integrated Science Instrument Module (ISIM) is the Science instrument payload of the JWST

- ISIM is one of three elements that together make up the JWST space vehicle
  - Approximately 1.4 metric tons, ~20% of JWST by mass
  - Completed its Critical Design Review during 2009 and is currently in integration and test
- The ISIM system consists of:
  - Four science instruments
    - Complete - MIRI, FGS NIRCam, NIRSpec
  - Nine instrument support systems:
    - Complete - Optical metering structure system
    - Complete - Electrical Harness System
    - Complete - Harness Radiator System
    - Complete - ISIM electronics compartment
    - Complete - ISIM Remote Services Unit
    - Complete - Cryogenic Thermal Control System
    - Complete - Command and Data Handling System
    - Flight Software System
    - Operations Scripts System

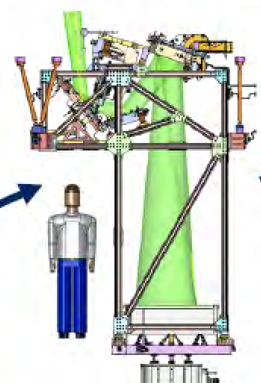


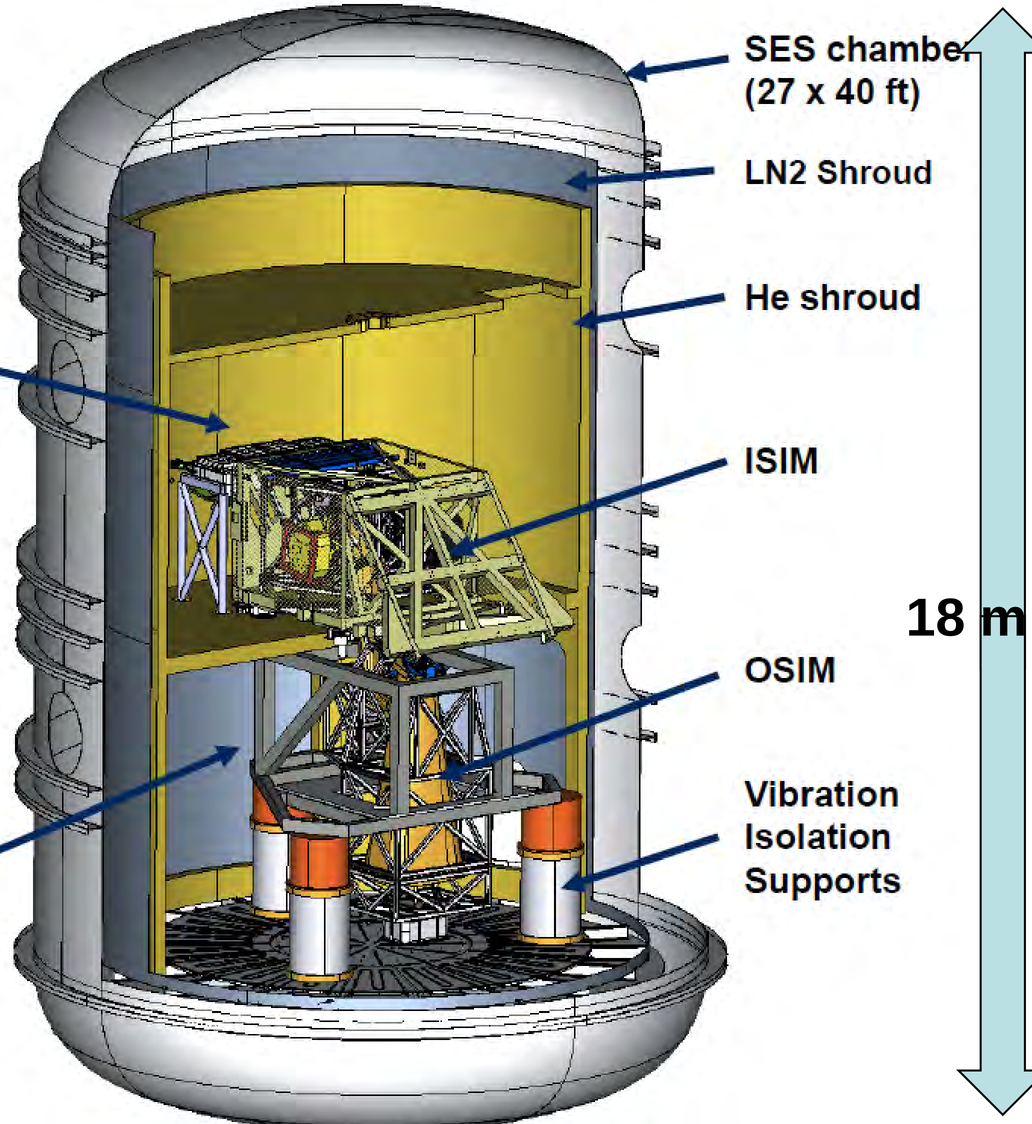
ISIM will be tested at ~ 35 K in the GSFC SES chamber Using a cryogenic telescope simulator (OSIM)

First of 3 SES test cycles of the flight ISIM begins during August 2013



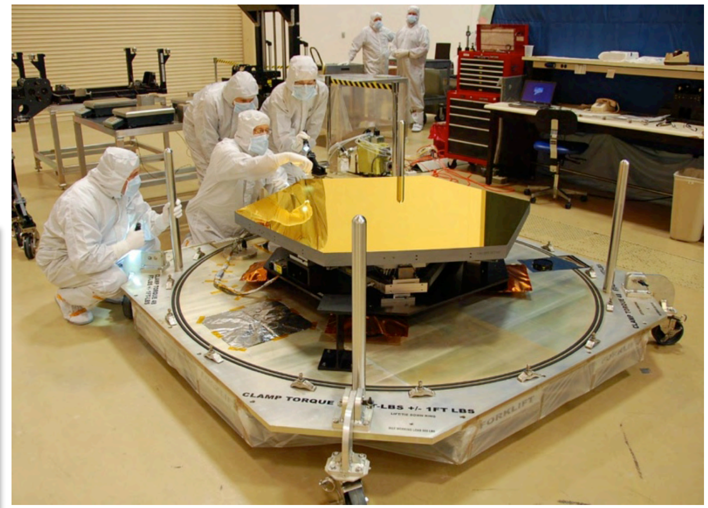
MIRI and FGS integrated with the flight ISIM structure

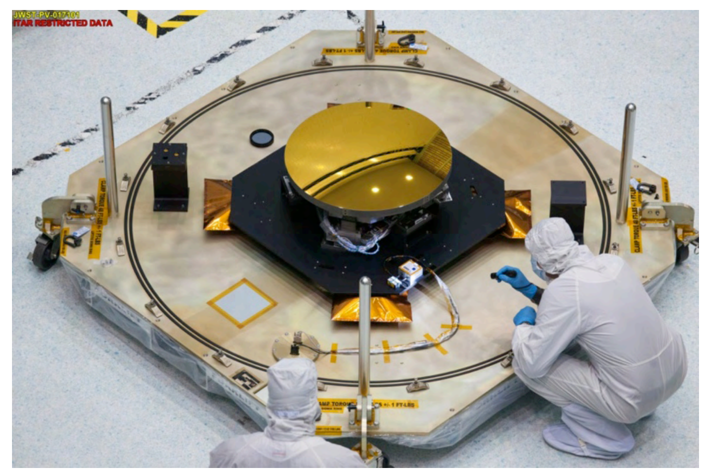




Telescope Mirror Status

- **All Optics are complete !**
- **Refurbishment of gear motors of all flight primary mirrors segment assemblies have been completed.**

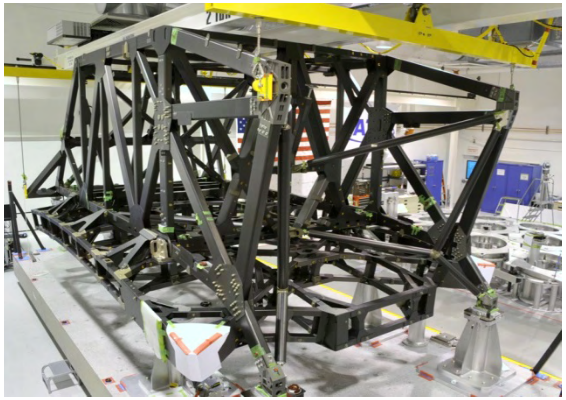


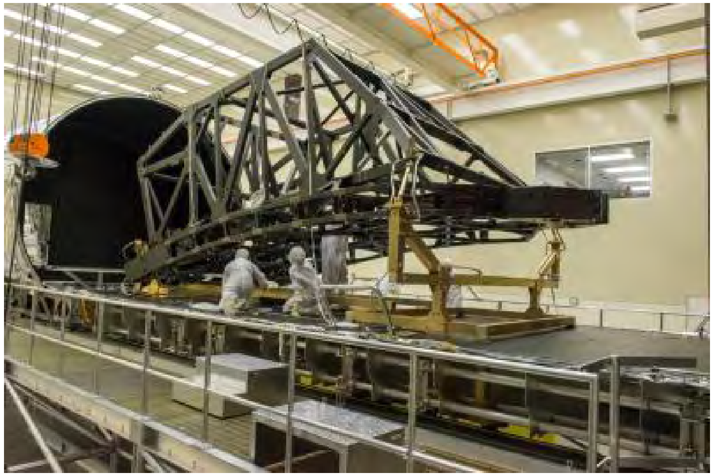


Backplane – Backplane Support Frame and Center Section

- **Center Section is complete**
- **BSF assembly is complete**
- **Integration of the BSF to Center Section complete**
- **Cryo set testing complete.**

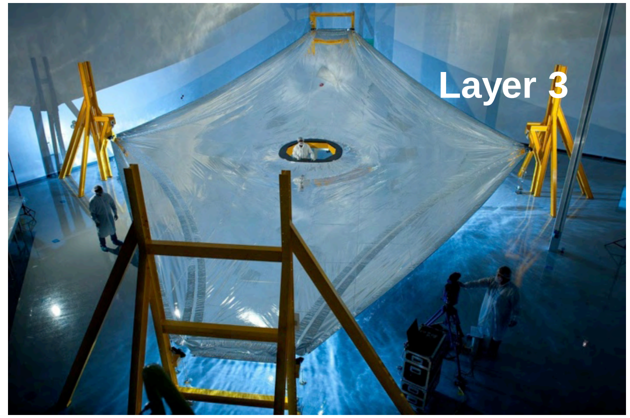
C5 Aircraft Offload at LAX



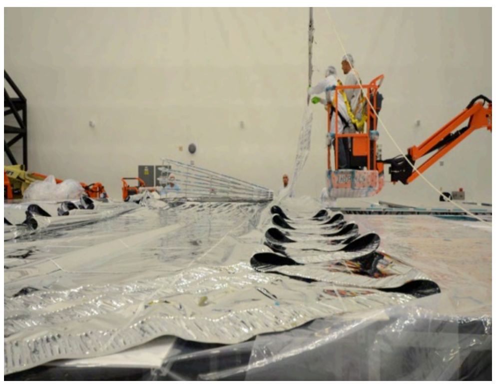


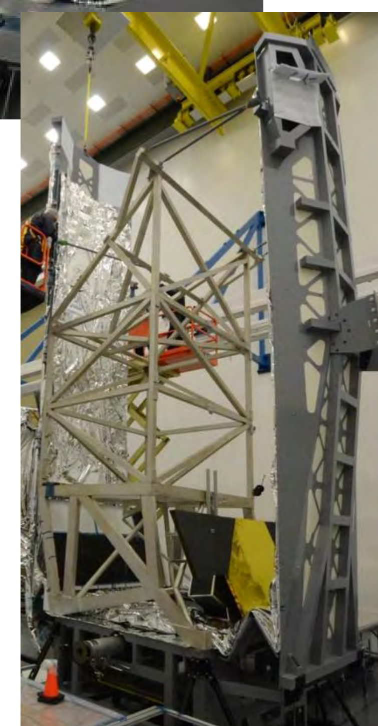
Sunshield progress

- All Template Layers Completed
- Preparing for flight article manufacturing
- First two Flight Manufacturing Readiness Reviews Completed

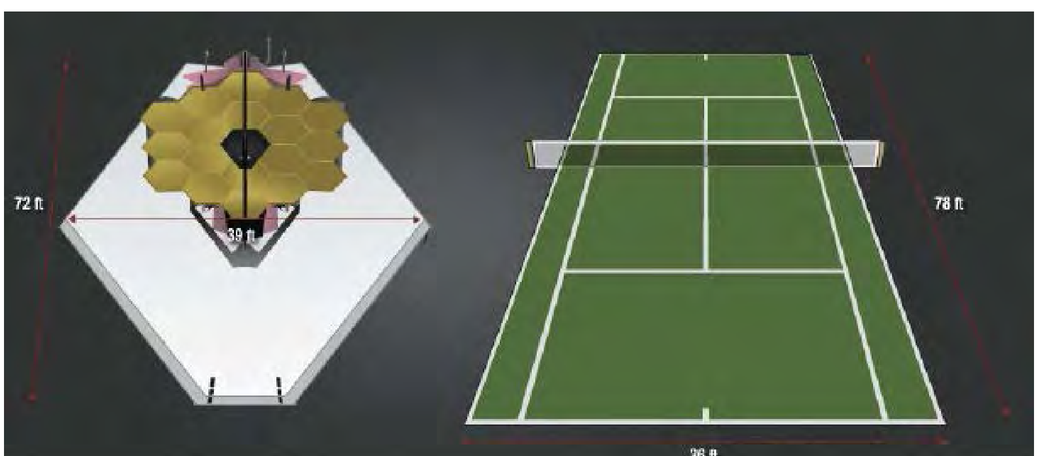


Stringing Operations





Template Layers 3-5



OTIS Test GSE Architecture

Almost 35-meter high!

This is becoming really huge...

OTIS-level testing...

European Space Agency

Status & Conclusion

- **Once at L2 JWST will be a versatile and powerful facility serving the needs of near- and mid-infrared astronomy with both high sensitivity and sub-arcsecond resolution**
- **setting the scene for FIRI at shorter IR wavelength**

- **Project executes according to “LRD 2018 re-plan” from 2011.**
  - All milestones are being met with few exceptions
  - System schedule contingency remains untouched
  - NASA project team shows high determination to remain ON schedule JWST funding for 2014 according to “LRD 2018 re-plan”.

- **Refurbishment of actuators for all Primary Mirror Segment assemblies completed.**

- **Manufacturing of telescope structure completed.**

- **ISIM completed first Cryo test!**

- **All flight instruments delivered!**
  - NIRcam delivered with flight detectors installed
  - NIRSpec delivered with non flight detectors and non flight micro shutter assembly