

International Conference on Space Optics—ICSO 2014

La Caleta, Tenerife, Canary Islands

7–10 October 2014

Edited by Zoran Sodnik, Bruno Cugny, and Nikos Karafolas



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International Conference on Space Optics — ICSO 2014, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 10563, 105634I · © 2014 ESA and CNES
CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2304097

THE NIRSPEC ASSEMBLY INTEGRATION AND TEST STATUS

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ABSTRACT

The Near-Infrared Spectrograph (NIRSpec) is one of the four instruments on the James Webb Space Telescope (JWST) scheduled for launch in 2018. NIRSpec has been manufactured and tested by an European industrial consortium led by Airbus Defence and Space and delivered to the European Space Agency (ESA) and NASA in September 2013. Since then it has successfully been integrated into the JWST Integrated Science Instrument Module (ISIM) and is currently in ISIM Cryo-Vacuum Test#2. Since however two of its most important assemblies, the Focal Plane Assembly (FPA) and the Micro-Shutter Assembly (MSA) need to be replaced by new units we will present the status of the instrument, the status of its new flight assemblies in manufacturing and testing and give an outlook on the planned exchange activities and the following instrument re-verification.

Keywords: James Webb Space Telescope, JWST, Near-Infrared Spectrograph, NIRSpec

I. INTRODUCTION

NIRSpec, the Near-Infrared Spectrograph, is one of the four Science Instruments (SI) which will be flown on the James Webb Space Telescope (JWST) schedule for launch in 2018. The JWST is the follow-on mission to the Hubble Space Telescope (HST) and is developed to receive more information about the origins of the universe by observing infrared light from the first stars and galaxies.

A comprehensive description of the observatory and its main science goals is given by Gardner et al [1] and its current status is summarized at the SPIE Astronomical Telescopes and Instrumentation conference 2014 [2].

Fig. 1 shows the Optical Assembly (OA) of NIRSpec without its optical assembly cover mounted. Three electronic boxes, the Instrument Control Electronics (ICE), the Micro-Shutter Control Electronics (MCE) and the Focal Plane Control Electronics (FPE) complete the instrument. These electronic boxes will be mounted in the warm ISIM Electronics Compartment (IEC).

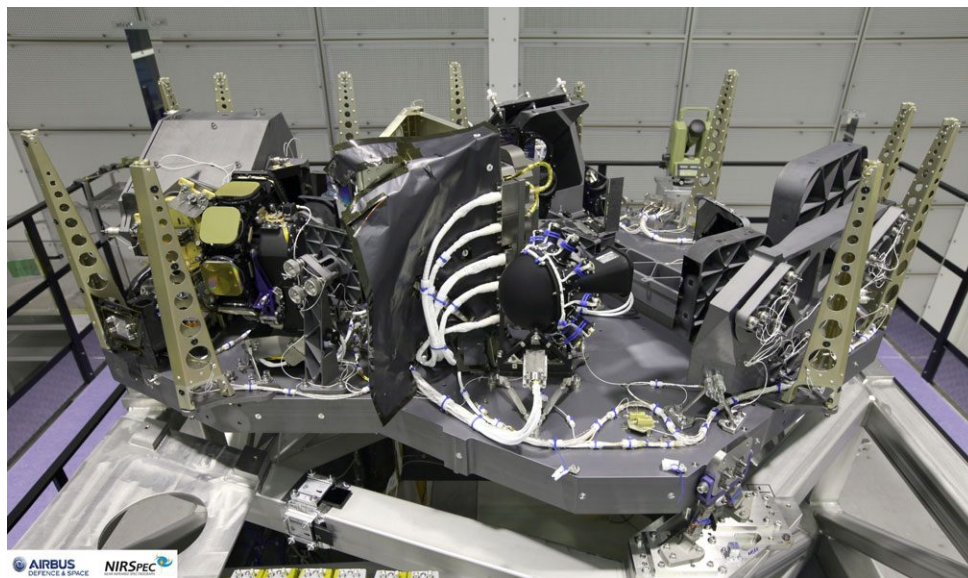


Fig. 1. The NIRSpec Instrument in the Airbus DS cleanroom prior to Instrument Cover integration

NIRSpec is a multi-object spectrograph that is capable of simultaneously measuring the near infrared spectrum of up to 100 objects like stars or galaxies with low, medium and high spectral resolutions. The observations are performed in a 3 arcmin x 3 arcmin field of view over the wavelength range from 0.6 micrometer to 5.0 micrometer. It also features a set of slits and an aperture for high contrast spectroscopy of individual sources, as well as an integral-field unit (IFU) for 3D spectroscopy.

The instrument is one of the ESA contributions to JWST and is built by Airbus DS GmbH (former Astrium GmbH), a group of European Subcontractors and NASA which contributed the Micro-Shutter Subsystem (MSS) and the Detector Subsystem (DS).

II. OVERVIEW OF THE NIRSPEC INSTRUMENT

The architecture of the instrument is constituted by a baseplate on which the optical components are attached such, that after the light from the JWST telescope mirrors is coupled-in by the Coupling Mirrors (COM), the optical path is routed parallel to the baseplate. The functional assemblies of NIRSpec are shown in **Fig. 2** and were explained in detail by Bagnasco et al. [3].

The optical path (cf. **Fig. 3**) is mainly defined by 3 three-mirror anastigmats (TMAs), the fore optics TMA (FOR) - which provides a telecentric intermediate focal plane where the multi-object selection mechanism called Micro-Shutter Assembly (MSA) is located, the collimator TMA (COL) - which collimates the light onto the disperser carrying Grating Wheel Assembly (GWA) and the camera TMA (CAM) - which images the light onto the two 2k x 2k MCT detectors.

Further assemblies are the RMA which carries two plane mirrors for refocussing, a Filter Wheel Assembly (FWA) which carries filters for wavelength selection and an on-board calibration assembly (CAA) which provides several spectral line and flat-field illumination sources for in-orbit instrument calibrations.

In order to enable very long exposures of up to 10,000 seconds in the near infrared wavelength regime the instrument operates at -235°C (38K) and utilizes a highly a-thermal concept with all mirrors, the mirror mounts and the optical bench base plate all manufactured out of the silicon carbide ceramic BOOSTEC® SiC.

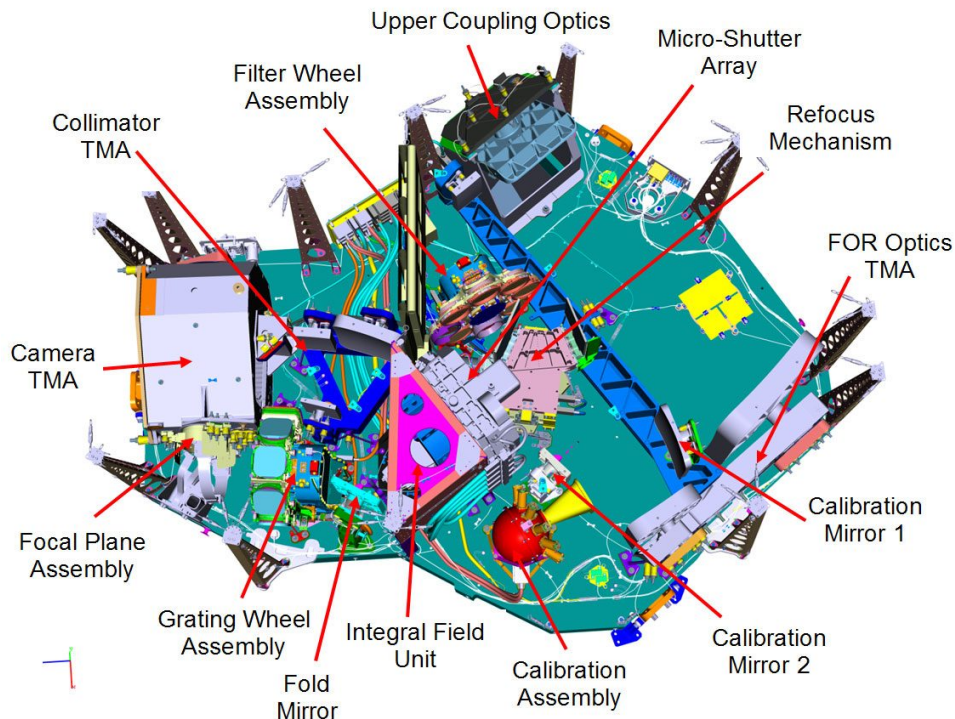


Fig. 2. The NIRSpec Optical Assembly with its main functional Assemblies (Instrument Cover removed)

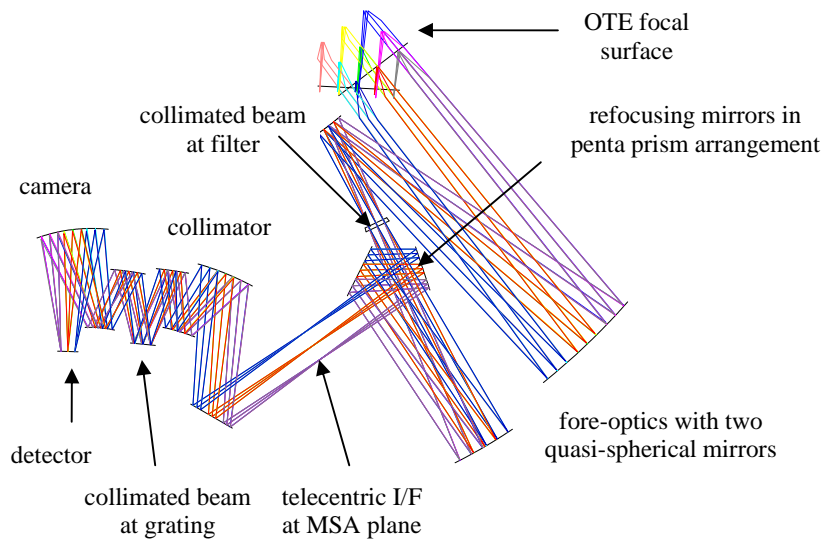


Fig. 3. NIRSpec Optical Path and Design Features

The instrument size is approximately 1900x1400x700 mm and it weighs about 196 kg with about 100 kg of SiC. The optical assembly is for straylight and thermal reasons protected by an externally aluminized and internally black coated Kapton Cover. The operation of the instrument is performed with three electronic boxes.

III. NIRSPEC ASSEMBLY-INTEGRATION-TEST (AIT) STATUS

A. Status of NIRSpec at Delivery to NASA

NIRSpec has been shipped to NASA in September 2013 after having passed successfully the verification and test campaign. The campaign included a cryo-vacuum verification and calibration test at qualification temperature which was followed by an acoustic noise test at acceptance level and a sine vibration test at protoflight level. After the sine vibration test a further cryo-vacuum verification test was performed in order to verify that the instrument performance did not degrade due to the mechanical tests.

During NIRSpec and other JWST Science Instrument tests it was found that the NIR detectors suffer from a gradually increasing number of hot pixels. This effect was found to be accelerated by higher temperatures. An extrapolation of the degradation lead to the conclusion that the performance of the detectors would, by the time of JWST launch, become unacceptable.

In order to determine the root cause of the degradation a NASA failure review board was established which traced the degradation back to a detector design flaw that allowed indium to interdiffuse with the gold contacts and migrate into the HgCdTe detector layer [4]. As a consequence of this, design improvements have been derived and new batches of detectors which do not suffer from this problem have been manufactured and the design improvements validated [4]. Based on the new design it was decided to manufacture new NIR detectors for all SIs which would then be integrated into a new FPA and after testing into the respective instruments.

Another finding of the NIRSpec environmental test campaign was that some of the 4 Micro-Shutter Arrays, that form the multi-object selection apertures of the Micro-Shutter Assembly (MSA) [5], were sensitive to Acoustic Noise. The impact of this was that, due to the acoustic noise loads, the amount of shutters that were stuck closed, i.e. shutters that cannot be opened but are permanently 'stuck closed', significantly increased. An effect of this was additionally a strong reduction in shutter-array closure contrast.

The Flight Model (FM) MSA is shown in **Fig. 4**.



Fig. 4. FM Micro-Shutter Assembly (Credit: NASA)

Due to the significant degradation and unclear expectable performance after higher level acoustic noise tests a NASA Failure Review Board was initiated. The performed investigations revealed that due to manufacturing tolerance add-up some quadrants had arrays which were susceptible for acoustic noise and others not. Since the amount of stuck shutter became critical for the NIRSpec Target Acquisition Mode it was decided to build a new Flight Spare (FS) MSA with slight design modifications implemented. In case the FS MSA performance would be better than the currently integrated FM then it would become the new FM MSA (FM2).

B. Integration of NIRSpec into ISIM and current Status

After its delivery NIRSpec has been prepared for the integration into the JWST Integrated Science Instrument Module (ISIM) which is a large CFRP structure carrying all 4 SIs. In March 2014 NIRSpec, which was the last instrument to be integrated, was finally mounted to ISIM (**Fig. 5**, left).

During the integration great care had to be taken to avoid contact of the ceramic instrument with any of the ISIM structures finally enabling all of the 3 NIRSpec Titanium Kinematic Mounts to engage with their pre-aligned counterparts on ISIM.

With all instruments integrated a successful ISIM System Functional Test has been performed in April 2014. Afterwards ISIM was moved to the Space Environment Simulation Chamber (**Fig. 5**, right) and prepared for its Cryo-Vacuum Test #2 which was started in mid of June 2014. At the time of writing this article the cryo test was running since about 1 month and thus the majority of the 3.5 months of test was still to be done.

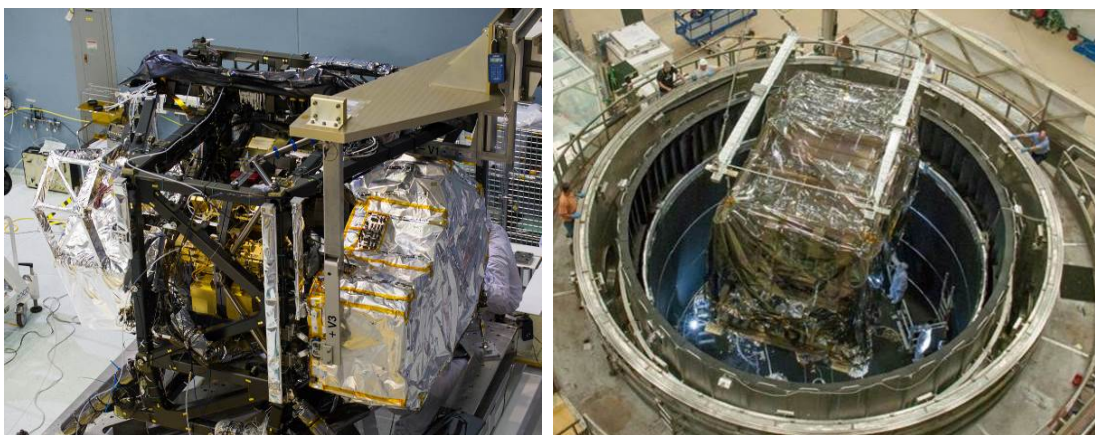


Fig. 5. NIRSpec integration to ISIM (left) and ISIM integration into the SES Chamber for CV#2 (right) (Credit: NASA)

IV. FPA AND MSA STATUS

A. Status of the new FPA

At the end of July 2014 the new Focal Plane Assembly (S/N 106) was completely assembled (Fig. 6, left) vibration tested and had passed most of its characterization tests at its nominal cryo operational temperature ranging from 36.5K – 42.8K. The new detectors have been shown to meet or exceed the required performance specifications, and have a small and stable hot pixel population [6]. The expected delivery of the completely verified and characterized FPA is scheduled for September this year.

B. Status of the MSA Flight Spare

The Flight Spare MSA was completely assembled in May 2014 (Fig. 6, right, shows the MSA at intermediate assembly stage). After a first cold performance test at cryogenic temperatures the MSA went into the acoustic and vibration test campaign which it successfully passed. Afterwards it went into cryo testing which was still ongoing at the time of writing the article.

The data obtained so far shows that compared to the FM1 MSA the number of failed closed shutters is reduced by 2/3 and generally a far better average and median shutter contrast is achieved (Fig. 7). Therefore the FS MSA will become the new FM MSA (FM2).

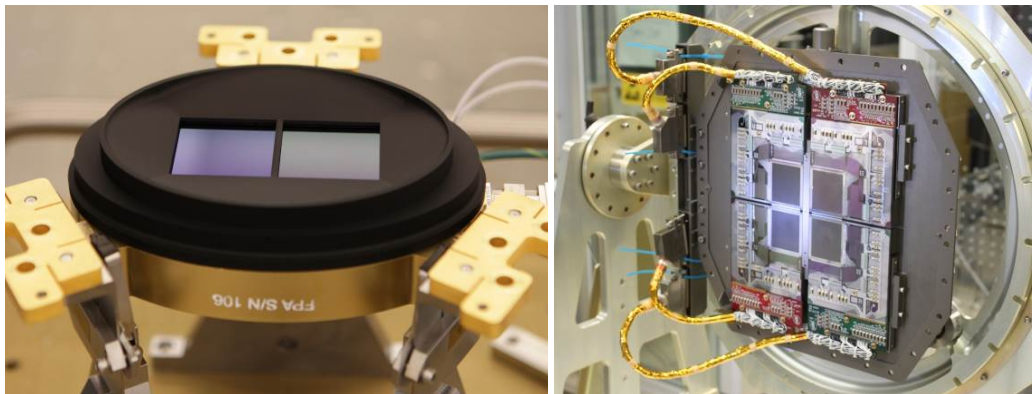


Fig. 6. The new NIRSpec FPA (S/N 106) completely assembled (left) and the FM2 MSA prior to integration of the MSA magnet arm mechanism and cover (Credit: NASA)

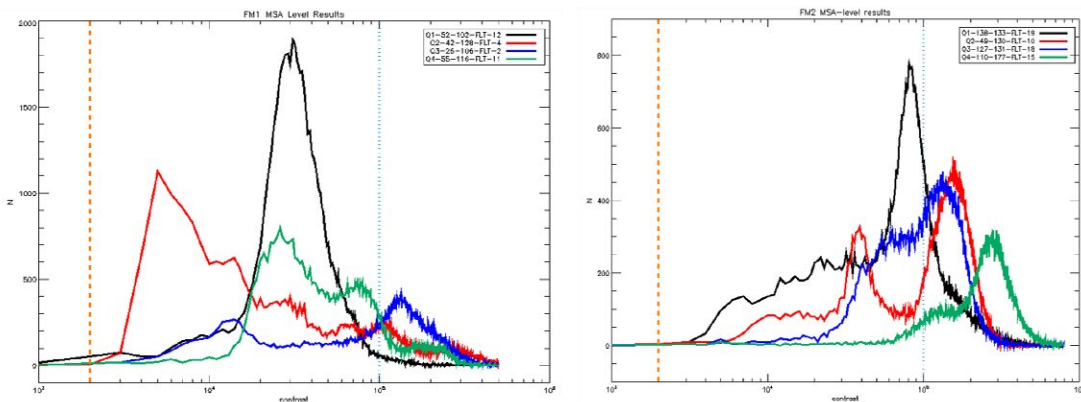


Fig. 7. FM1 (left) and FM2 (right) MSA shutter-quadrant contrast histograms. The new MSA shows generally much better contrast. (Credit: NASA)

V. OUTLOOK

Once the ISIM CV#2 is finished the SIs will be de-integrated from ISIM in order to swap out their degrading detectors and in case of NIRSpec additionally the MSA. The instrument de-integrations are scheduled for mid of December 2014. Directly thereafter the exchanges are planned to be conducted.

A. Detector Subsystem Exchange

For the Detector Subsystem the exchange means that the complete set of FPA, ASICs and instrument internal harness will be replaced (cf. Fig. 8). The Focal Plane Electronics (FPE) will be reused. The exchange of the ASIC assembly and the harness is a mechanical removal and integration only. The integration of the FPA requires however alignment activities. Since the infrared detectors cannot be operated at ambient temperature the alignment cannot be performed via optical stimuli. Therefore the alignment is purely based on reference coordinate metrology data.

The new FPA (S/N 106) will be integrated with a dedicated shim set which will be calculated from the NASA provided FPA metrology data and the metrology data of the Best Fit Plane (BFP) of the Camera detector focal plane.

For this the FPA 106 will first be mounted to an alignment jig and laterally pre-aligned (in the X/Y plane). Using this jig the FPA will then be installed on the Camera and the detector fine alignment (clocking) will be performed. In the case that the pre-alignment to the jig was not completely correct new metrology data will be measured to refine the pre-alignment. Fig. 9 shows the planned FPA exchange and alignment approach.

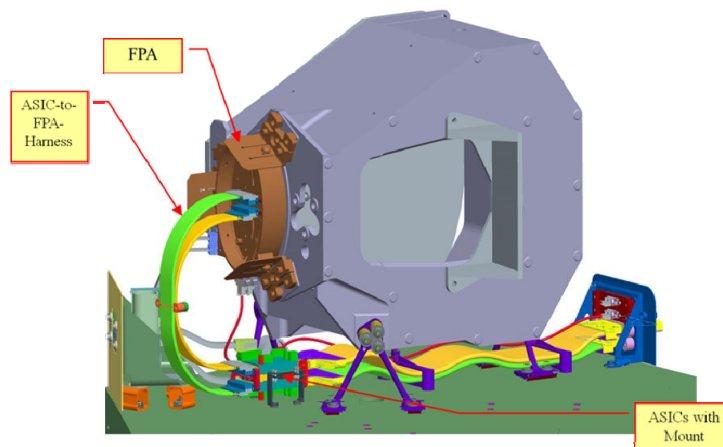


Fig. 8. Detector Subsystem hardware that is to be exchanged (Grey box represents SiC Camera housing)

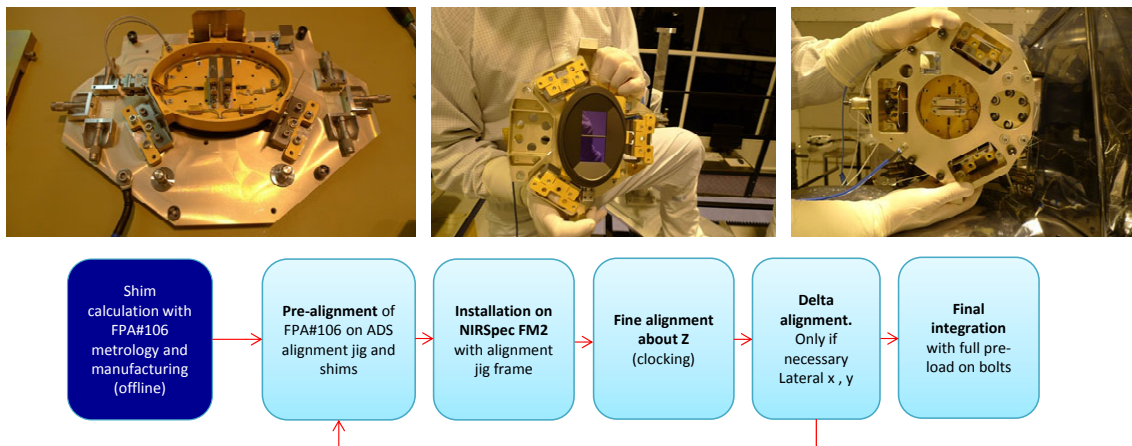


Fig. 9. FPA exchange and alignment approach

B. MSA Exchange

In the case of the MSS (Micro-Shutter Subsystem) only the MSA will be exchanged. The corresponding harness and the Micro-shutter Control Electronics (MCE) will be reused.

The integration of the FM2 MSA requires great care as it weighs close to 10kg and needs to be lowered by a crane to a central position of the instrument which is very close to several other sensitive assemblies.

The MSA is mounted to the MSA/IFU bracket (see Fig. 10). This bracket carries also the Integral Field Unit (IFU) which is aligned to the residual NIRSpec optical train and whose position cannot easily be changed anymore. For illumination of the IFU the MSA part which separates the four shutter quadrants, the so called cruciform, has a 1.4mm x 1.4mm square opening (see Fig. 10, right). As part of the MSA alignment this aperture needs to be co-aligned in X,Y and rotation to the slightly smaller IFU entrance aperture leaving ~ 100-150µm for alignment accuracy in X and Y direction.

The MSA alignment to the bracket is ensured by two pins which have a tolerance of about +/-40µm but do not allow for larger lateral alignments. In order to avoid any additional delta alignment effort, NASA had to replicate the previous FM MSA metrology data to the FM2 MSA. This was performed very successfully and with the achieved residual pin offset of ~10µm in X and ~17µm in Y the new MSA can be integrated to the MSA/IFU bracket merely relying on the already implemented alignment pins. Thereafter the alignment will be checked with Laser Tracker and Theodolites. Fig. 11 shows the MSA exchange and alignment approach.

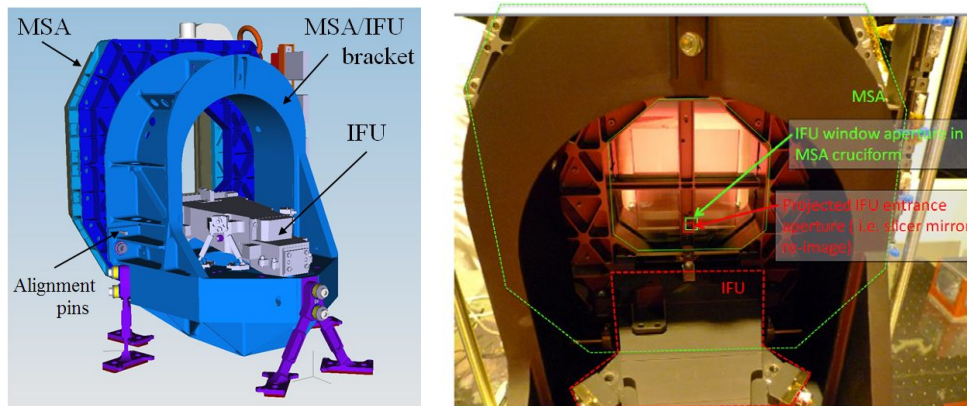


Fig. 10. CAD view of MSA and IFU mounted on the bracket (left) and location of the IFU aperture on the MSA Cruciform (right)

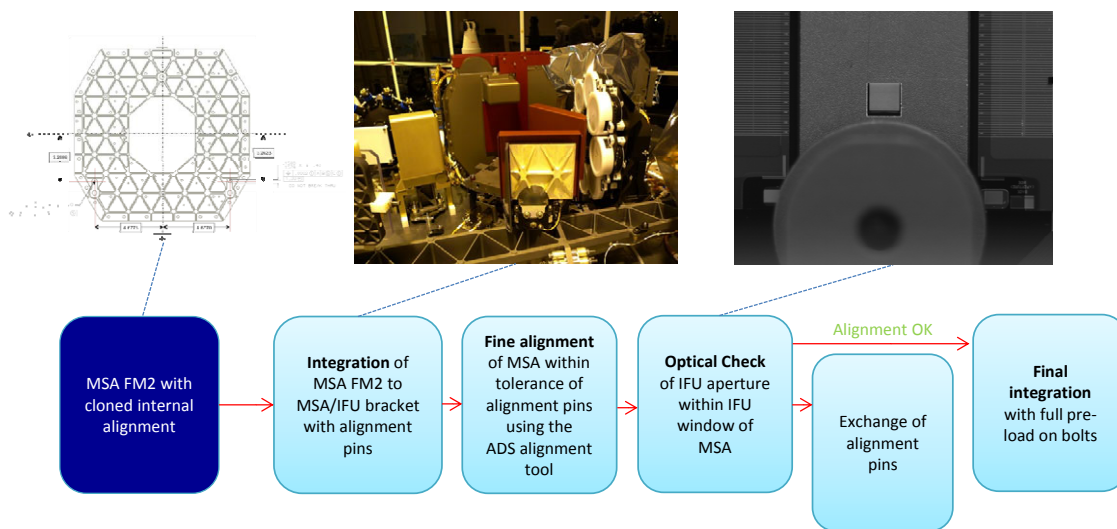


Fig. 11. MSA exchange and alignment approach

As a fallback solution, in case a delta alignment becomes necessary, a special alignment tool is manufactured and alignment pins with smaller diameter will be used to ensure that the necessary alignment range is available. The final check of the correct alignment will be performed using the correlation of the IFU aperture and the IFU window on the MSA cruciform. The IFU will be back illuminated such that the MSA window shift versus the IFU aperture can be observed through the instrument front optics (FOR and COM optics).

C. NIRSpec re-integration to ISIM and succeeding environmental ISIM Tests

Once the FPA, ASICs, FPA harness and the MSA are mechanically exchanged, harness safe-to-mates will be performed and after the electrical integration MSS and DS Short Functional Tests to re-verify the functionality. Thereafter the NIRSpec cover will be reinstalled. The total exchange activity is scheduled to last 28 working days.

As soon as all Science Instrument assembly exchange activities are done, the instruments will be re-integrated in reverse order into ISIM. This, according to the current planning, is scheduled to occur in the Feb. 2015 timeframe. Once that is completed ISIM will be vibration and acoustic noise tested which will serve also as SI workmanship acceptance test. In May/June 2015 ISIM will undergo EMI / EMC Testing which will be followed by the ISIM Cryo-Vacuum Test#3 (CV#3). During the cryo test the final performance verification and calibration of NIRSpec will be performed. This will primarily concern verification of the DS and MSS. After the CV#3 ISIM will be delivered to OTIS (Dec. 2015).

VI. SUMMARY

Following the delivery to ISIM, NIRSpec has been integrated to ISIM and is currently (Aug. 2014) in cryo-vacuum test #2. After the test it will be de-integrated from ISIM to exchange its non-flight worthy Focal Plane Assembly and its degraded Micro-Shutter Assembly with new improved FM builds. The exchange is planned such that a minimum of alignment steps are necessary. The instrument re-verification will occur on ISIM level tests which are scheduled to be finished by end of 2015.

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