Operations During Coarse Phasing of JWST

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JWST Communications

• Current baseline calls for DSN as communications element
  - Assumption of 8-hour continuous contact with a single ground station
  • 24-hour telemetry and real-time commanding (low data rate, S-band @ 2.3 GHz) available during commissioning using 26 m antennas (DSN 34 m antennas currently overbooked)
  • Up to 8 hours continuous contact available for high-rate science telemetry (assuming X-band @ 8.45 GHz) via DSN
    – 26 m antennas do not support X-band
  • Potential for upgrade to Ka-band (32 GHz) for high-rate science telemetry; would yield up to 2 hours continuous contact for science data download
JWST Communications

- JWST Level 2 Requirements (Revision B) related to communications during commissioning
  - 3.2.10.12.1.1 S-Band Communication
    - Until the completion of the commissioning of Observatory and Ground Segments shall be capable of 24 hour per day/seven day per week S-band forward and return link communications.
  - 3.2.10.12.1.2 X-Band Communication
    - Eight hour per day/seven day per week X-band return link communications shall be available for commencement of primary mirror phasing.
JWST Communications

- Due to current DSN hardware limitations, receipt of processed telemetry to S&OC may take between 8-24 hrs.
Primary operational blocks involved in co-phasing or coarse phasing JWST primary mirror (PM) segments using

Dispersed Fringe Sensing (DFS)

Dispersed Hartmann Sensing (DHS)
Purpose

Enable JWST WFSC WG to understand operations

(Enable SOC to understand basics of WFSC)

Identify operational differences between DFS and DHS
Commissioning Process
– Operational Performance Assumptions

1. Coarse Alignment
   - OTE - 0.5 arcsec 1-σ pointing
   - PM segments - <100 μm, 1 arcmin wing deployment
   - <100 μm ROC, 0.5 arcmin tilt, 100 μm piston
   - SM - <3 mm linear position, 5 arcmin tilt
   - <100 μm seg piston, <200 nm rms WFE
   - >150 μm seg piston, >250 nm rms WFE

2. Coarse Phasing/Fine Guiding
   - <1 μm rms WFE, <8 marcsec LOS jitter
   - >1 μm rms WFE range, <10 nm accuracy

3. Fine Phasing
   - <100 nm rms WFE setpoint
   - 150 nm rms WFE worst case decay

4. Wavefront Monitoring
   - >>150 nm rms WFE range, <10 nm measurement accuracy

Sensing requirements at each step determine interface parameters – FOV, etc.

From Atcheson (BATC)
Where does Coarse Phasing fit in JWST commissioning?

At end of Coarse Alignment
- < 100 micron segment piston
- < 200 nm RMS wavefront error (WFE)

At end of Coarse Phasing
- < 1 micron RMS WFE
- < 8 mas Line of Sight (LOS) jitter

From Atcheson (BATC)
What is DFS? (From Fang Shi, JPL)

Piston error between two segments

After coarse alignment the piston error between two segments is within the depth of focus. DFS piston capture range is limited by the effective dispersion of the grism. Therefore a good DFS design should enable DFS detect the piston error as large as the depth of focus.

The PSF Image of a pistoned wavefront at any particular $\lambda$ has a “dark band” in it with its position depend on the wavelength.

Without a grism all $\lambda$'s PSFs overlap and form a broad band PSF which is equivalent to two superimposed PSFs from each segment mirror – the information of the wavefront piston (i.e. “dark band”) is smeared out.

With grism each $\lambda$'s PSF separated – the continuous of “dark bands” form a DFS fringe.

Separation is in the dispersion direction.

DFS fringe is formed for a pair of segments with their PSF co-aligned (common tilts) separated from other segments, which are relegated to the PARKING LOT.

DFS fringe formed through a GRISM

The compensation of grating and prism of the grism forms no net deviation at central $\lambda$.

Dispersion perpendicular to base line between segment centers has the maximum of fringe contrast and no contrast when parallel to base line.

The drops of DFS fringe contrast as the dispersion deviate from the perpendicular position also strongly depend on the aperture sparseness formed by the segment.
DFS for 18-Hex Example: Segment Group

- Two-grism approach provides optimal visibility for all operations
  - 2 crossed dispersed grisms in NIRcam filter wheel (may have 1 in each of 2 channels)
  - 7 images
  - First phases segments into rows
  - Then phases rows to each other
  - Fine phasing between each “big move” to remove residual tilts
- Position the groups along a 45° line so that fringes from vertical and horizontal dispersion grism won’t collide
- The spots are (from lower left): PARKING LOT, Group #1, #2, #3 (middle), #4 and #5
- Spots are separated by 1 arcsec in x and y in the simulations

Tilt test segment pairs (cyan & magenta) away from PARKING LOT
DFS observing block
7 or more iterations with perfect actuators

- Acquire star in star tracker
  point one segment w/star to FGS and guide?
- Place grisms in two filter wheels over two detectors
  Place appropriate filters over grisms if needed
- Move N segment pairs out of PARKING LOT to separate on-chip locations
- Expose and read detector out
- Command segment tilts to re-arrange segment pairs
  Moves segments between in PARKING LOT and to be measured positions
- Expose and read detector out
- Repeat till all required segment pairs have been observed
- Data downlink as per science observation
  (presumably no other science observations being carried out at this stage)
DFS strength/risks (abbreviated)

• Strengths
  – Well-studied to date (Keck, lab)
  – 7 iterations with two grisms, perfect actuators
    • 18-hex pupil
  – Pupil sizing, alignment tolerances not an issue

• Risks
  – Number of iterations with imperfect actuators
  – Non-monotonic image quality during process
  – Big segment moves
  – Redundancy needs to be clearly understood
Dispersed Hartmann Overview

- Dispersed Hartmann Sensor is an enhancement to the laboratory and field proven Dispersed Fringe Sensor for measuring relative piston errors between separate apertures
- Operates on the principle of producing simultaneous dispersed fringe spectra from a family of segment configurations
- Overall implementation implies a balance between process duration and configuration accuracy

From Atcheson (BATC)
What is DHS?

Place a PRISM over the edge between two adjacent segments
  prism tilts the resulting spot away from ‘on-axis’ location on detector

When sent through GRISM the spot is smeared out in $\lambda$
  same as a DFS fringe

On a different pair of segments use a different tilt prism
  this spot does not overlap the first spot
  a second DFS-like fringe is created

Measure relative piston between all pairs of adjacent segments
  using a single exposure
Simulation code allows user to specify:

- Center wavelength
- Width of light spectrum
- Number of discrete wavelengths in the simulation
- Percent full well in the images
- Read noise
- Dark current
- Magnitude of star (affects noise due to dark current)
- Dispersion in X and Y directions
- Image sampling parameters

Assume pupil is 35 mm dia.
General conclusions

• Provided fringe contrast does not disappear, the DHS is generally insensitive to
  • Segment tip/tilt errors
  • Mask registration errors

• Capture range of Fine Phasing operation is large for tilt errors (~1.5 microns rms). The Coarse Alignment operations will meet or exceed the required capture range. Unobservables modes within capture range
Dispersed Hartmann Sensor Provides Streamlined Path to FGS Activation

1. Coarse Alignment
2. Coarse Phasing/Fine Guiding
3. Fine Phasing
4. Wavefront Monitoring

Grism placement accuracy leads to requirements on NIRCam pupil image – spatial, spectral, temporal

From Atcheson (BATC)

SIMPLE OPS (SOC comment)
From Atcheson (BATC)

DHS observing sequence
1 sensing, 1 check observation

- Establish segment image positions
- Calibrate segment image translation movements
- Calibrate sensor/fringe combination
- Move segment images to common location
- Initiate low grade FGS
  - Image diameter up to ~10X fully phased condition
  - Desired FGS performance 1 pixel (1-sigma) gaussian blur over pixel integration period (up to 100 sec)
- Move DHS component into WFS path
- Collect fringe information
- Download imagery to ground processing site
- Determine segment piston movements
- Upload actuator movements to correct piston errors
- Adjust all segments
- Capture coarse phased image
- Download and evaluate
DHS Strengths & Weaknesses

• DHS Strengths
  – Single image collection of all required information for PM segment piston adjustments simplifies commissioning operations
  – Separate, simultaneous observations allows continuous, uninterrupted FGS operation
  – Ground I&T imagery essentially identical to flight imagery
  – Monotonically improved PSF
  – Measurement does not disturb PSF

• DHS Weaknesses
  – Incomplete sampling of PM subapertures produces non-orthogonal relationship between piston and segment-level aberrations (notably tilt)
  – Pupil alignment requirement
  – Two separate image operations required during ground I&T
Ops point of view

• DFS is ‘well-understood’
  – Sensitivity to actuation error needs to be addressed
    • One day latency affects time to completion (risk)
  – Math of unsensed modes c.f. capture range
    • MGS works to mitigate tilt risk
  – Redundancy needs to be studied or reported on
  – FGS use needs working out
  – Repetition disturbs PSF (risk)

• DHS needs to be studied (potential benefits are significant)
  – Ground verification needs to be addressed
  – Pupil alignment needs to be addressed
  – Math of unsensed modes c.f. capture range
    • Does MGS work for DHS tilt risk too?
  – Redundancy needs to be studied or reported on