Non-Redundant Aperture Masking Interferometry (AMI) and Segment Phasing with JWST-NIRISS

~65 mas angular resolution imaging in F380M, F430M & F480M

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For
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1 - Binary Point Sources (exoplanets)

2 - Imaging (dusty tori in AGN)

3 - Fizeau Interferometric Cophasing of Segmented Mirrors

If your segments need alignment

FICSM
NIRISS (née TFI)

F430M PSF CLEAR

65 MAS PIXELS
Nyquist at 4 micron

NIRISS (née TFI)

F430M PSF NRM

WebbPSF Python module (Perrin)

Primary Beam
40 pixels
2.5"

Primary Beam
40 pixels
2.5"

[Image of diagrams and labels]
Simulation description

- Master PSF
  - OTE phase maps RevV
  - NRM mask G7S6SC
  - Polychromatic, using F430M filter profile
  - Created with oversampling of 11x11 compared to NIRISS pixels
    - Soummer, Pueyo, Sivaramakrishnan, Vanderbei OpEx 2007
- Pointing
  - Telescope **pointing error for acquisition and dithers**: 15 mas RMS
  - Telescope **pointing jitter while guiding**: 5 mas RMS
  - Simulated at 0.01 pixel precision using oversampled PSFs
Simulation description

• Detector
  – Pixel **flat field** error: 0.1%
  – Non-uniform **intra-pixel sensitivity**
     - 1 at pixel center, decreasing to 0.8 (+/- 0.05) at pixel corners
     - Gaussian profile, Gaussian distribution of corner relative QE
  – 21 e- **read noise** per CDS
  – Mean **dark** current of 0.012 e-/sec
  – Inter-pixel capacitive coupling included
  – Bad pixels included
JWST sim cf PHARO data

PHARO on Pal 200": Martinache, Bernat, Lloyd

JWST sim w/jitter
Bad pixels overlaid on PSF

- log display scale

Bad pixel fraction 1%

- Randomly distributed, 5/6\textsuperscript{th} of bad pixels are grouped in a “cross pattern” while 1/6\textsuperscript{th} are single pixels
- Bad pixels assumed completely unusable

Bad pixel fraction 5%
Simulation description

- Observation
  - \( L' = 7.5 \) mag star
  - 256x256 subarray \( (t_{\text{frame}} = 0.66 \text{ s}) \)
  - Read mode, TFIRAPID, \( N_{\text{frame}} = 1, N_{\text{group}} = 14 \)
    - Peak pixel kept at <70000 e- in last read
  - 9 dithers on a 3x3 grid with 4” step
    - Assumed that the central 7x7 pixel box at each dither position was free of bad pixels
  - 121 integrations at each dither position
  - 3 hour clock-time total on target
    - plus a similar sequence on a calibrator
  - 12 min exposure on each of target and calibrator
### Results – Detection Limits

- Magnitude loss in contrast compared with 0% bad pixels

<table>
<thead>
<tr>
<th></th>
<th>0.06”</th>
<th>0.08”</th>
<th>0.10”</th>
<th>0.20”</th>
<th>0.30”</th>
<th>0.40”</th>
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<tbody>
<tr>
<td>0%</td>
<td>0.00</td>
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<tr>
<td>0.5%</td>
<td>-0.09</td>
<td>-0.09</td>
<td>-0.09</td>
<td>-0.13</td>
<td>-0.20</td>
<td>-0.19</td>
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<tr>
<td>1%</td>
<td>-0.09</td>
<td>-0.10</td>
<td>-0.11</td>
<td>-0.17</td>
<td>-0.26</td>
<td>-0.23</td>
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<tr>
<td>2%</td>
<td>-0.33</td>
<td>-0.34</td>
<td>-0.35</td>
<td>-0.40</td>
<td>-0.51</td>
<td>-0.49</td>
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<tr>
<td>3%</td>
<td>-0.63</td>
<td>-0.63</td>
<td>-0.62</td>
<td>-0.65</td>
<td>-0.75</td>
<td>-0.74</td>
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<tr>
<td>4%</td>
<td>-0.82</td>
<td>-0.81</td>
<td>-0.80</td>
<td>-0.81</td>
<td>-0.91</td>
<td>-0.90</td>
</tr>
<tr>
<td>5%</td>
<td>-1.09</td>
<td>-1.06</td>
<td>-1.04</td>
<td>-1.03</td>
<td>-1.12</td>
<td>-1.13</td>
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\( V_{21} = V_{12} \exp\{-i\phi_{12}\} \)

\( V_{12} = V_{12} \exp\{i\phi_{12}\} \)
Good uv-coverage if you repeat an observation with~ 60 degrees rotation (2 months ± ~1 fortnight)
MIRIAD invert; clean; restore – using the normalized point source dirty map as clean’s beam
7.5 mag AGN, bar 22.5x fainter pixel-by-pixel 2.63s, 7.89s, 26.3s, and 73.6s exposure with noise
1, 3, 10, 28 images coadded without recentering to remove JWST jitter, SAM errors
Segment tilting – choose non-redundant patterns
(eg Monnier et al Keck segment tilting)
Recover segment piston (few nm) & tip-tilt (10mas)
Capture range – 150 micron pistons, 0.5 arcsec tilts (NIRCam)
Should work on NIRISS/NIRCam/MIRI
Enables NIRISS WFS (1 NRM + 1 Full Aperture PSF)
FICSM DATA
PRECOMPUTED LOOK-UP TABLES

Example: Three segments in a group

Cheetham Honours Thesis (Sydney), also as JWST-STScI Tech. Report
Cheetham, Tuthill, Sivaramakrishnan & Lloyd, in prep.
Sivaramakrishnan & Acton Operational details for JWST in JWST-STScI Tech. Report
**FICSM algorithm**

1. An image is taken, with a narrow bandwidth filter
2. The narrowband image is used in a tip/tilt fitting program, to measure tip/tilt
3. The mirrors are adjusted to remove the measured tip/tilt
4. Two images are taken, with broad bandwidth filters at different wavelengths
5. The new images are used in a piston fitting program, where independent measurements are performed on each
6. The piston measurements are compared. If they do not agree, the difference between them and the wavelength difference are used to recover the correct piston
7. The mirrors are adjusted to remove the measured piston
8. The method is repeated once, to remove residual errors.
Binary Point Sources (exoplanets)

IMAGING (dusty tori in AGN)

Fizeau Interferometric Cophasing of Segmented Mirrors

*If your segments need alignment*

FICSM