WFIRST Payload Status
For SDT Meeting #5
November 20, 2014

D. Content
WFIRST Payload Systems Manager
David.Content@nasa.gov
Payload Update

Since July SDT, the Payload design has progressed to Cycle 5. Key changes:

• Solved potential problem with telescope optical bench (aft metering structure/AMS)
  • Tested load capability insufficient for WFIRST instrument complement
  • Instrument carrier now carries instrument and telescope loads at launch and holds instruments aligned to telescope

• Significant DRM progress across payload
  • Much more mature CGI concept
  • STOP analysis for Jan report will include all science modes (CGI, IFU, grism, wide field imaging)
  • Technology progress – 1st Detector milestone (2nd in December); 2 CGI milestones (3rd in December)
  • I&T planning significantly advanced
  • Risk reduction ramped up across both instruments
  • Pupil geometry – simpler pupil released (no ID ‘features’)
Optical Field Layout

- The Wide Field Instrument has two optical channels
  - A wide field imager and grism spectrometer
  - An integral field unit, used for supernova spectroscopy

- The coronagraph is a small field system in a separate field of view
  - Contains an imager and a integral field spectrometer viewing the same field
**WFIRST-AFTA Payload Block Diagram**

**Telescope**
- **282 K 2.4 m Telescope:**
  - T1: 2.4 m aperture
  - T2: 30% linear obscuration from baffle
  - 6 struts with realignment capability; outer barrel with recloseable doors

**Wide Field Science Channel**
- M3: Cold Pupil Mask
  - Temperature 170 K
  - Guiding performed using guiding functions contained in the 6x3 science SCAs
- Element Wheel: 8 positions (6 filters, GRS grism, blank)
  - Grism R = 550-800 (2 pixel)

**Wide Field Instrument**
- Prism Spectrograph: R = ~100 (2 pixel)

**Integral Field Unit Spectrograph Channel**
- Relay
- Slicer Assembly
- Prism Spectrograph

**Coronagraph Instrument**
- Relay
- COLIMATOR SUB-BENCH
- M3
- FSM
- 2 Fixed DMs
- Masks & Filters
- LOWFS
- Flip Mirror
- Imaging Detector
- IFS
- IFS SUB-BENCH
- CORONAGRAPH SUB-BENCH
- 1kx1k, Si low noise FPA; 150K; IWA 3λ/D, λ (430-980 nm)
  - OWA 20λ/D
- 1kx1k, Si low noise FPA; 150K; 600-980 nm bandpass; R~70, 17 masec sampling

**GRS = Galaxy Redshift Survey**
**SCA = Sensor Chip Assembly**
**DM = Deformable Mirror**
**FSM = Fast Steering Mirror**
**LOWFS = Low Order Wavefront Sensor**
**IFS = Integral Field Spectrograph**
**IWA = Inner Working Angle**
**OWA = Outer Working Angle**
WFIRST Payload I&T and Optical Verification
For SDT Meeting #5
November 20, 2014

L. Bartusek
WFIRST Payload Systems Engineer
Lisa.M.Bartusek@nasa.gov
Payload I&T Working Group

• The Payload I&T Working Group includes representatives from Mission and Payload, WFI, CGI, Telescope, Instrument Carrier covering disciplines including Systems, Structures, Optics, Thermal, I&T and Planning.

• The purpose of the Payload I&T activity is to...
  – Integrate the elements into the Payload. (The Spacecraft build occurs in parallel.)
  – Perform high fidelity end-to-end optical test for WFI
  – Perform optical interface test for the Coronagraph

• The Payload I&T and Optical verification concepts support the baseline Phase B/C/D schedule as described in the 2015 SDT Report. Milestone dates are as follows:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date w/o Reserve</th>
<th>Date w/Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery of Telescope</td>
<td>1/29/21</td>
<td>4/5/21</td>
</tr>
<tr>
<td>Delivery of CGI</td>
<td>2/13/22</td>
<td>5/22/22</td>
</tr>
<tr>
<td>Delivery of WFI</td>
<td>4/15/22</td>
<td>8/1/22</td>
</tr>
<tr>
<td>Delivery of Payload to Observatory I&amp;T</td>
<td>8/30/22</td>
<td>1/8/23</td>
</tr>
</tbody>
</table>
NOTES

1. WFI Optics Package includes Optical bench, IFU, Radiator and Cryocooler Electronics.
2. The CGI Tertiary sub-bench is treated as a separate assembly for early optical interface testing with the Telescope.
3. The CGI Optics Package, including the three sub-benches, the Radiator and Instrument Electronics, are delivered to Payload I&T as one assembly.
Optical Verification (1 of 2)

- Highest fidelity optical verification for WFI occurs at Payload level. Four simultaneous test setups are considered:
  - Primary Mirror Center of Curvature test to track largest error source separately
  - WFI Half Pass test to replicate Instrument-level results and track WFI alignment separately
  - Payload ETE test uses focus-diversity wavefront sensing methodology to verify WFI+Telescope WFE under flight-like conditions
    - Mirror sag is characterized in lower assembly level tests.
    - Preliminary analysis by A.Jurling shows this method works for unknown aberration in the range of interest
  - CGI ETE test to check Coronagraph alignment to Telescope and verify CGI+Telescope WFE at one wavelength
- Combination allows separation of changes from baseline to Telescope and WFI

Error Budget Levels for the Telescope + two Instruments, including CGI active correction
- WFI + Telescope = 90 nm-rms
- CGI + Telescope = 14 nm-rms

Surface Figure 1g Distortion Maps
Gravity sag of PM dominates

From WFIRST_Integrated_Model_Cycle3-STOPv2b_Gravity140430.pptx
Optical Verification (2 of 2)

- CGI is verified in a piecewise approach
  - The flight tertiary sub-bench is delivered to Exelis for interface testing with the flight FOA.
  - At CGI level, Coronagraph performance is verified using a sub-scale optical telescope assembly simulator.
  - The CGI ETE test at Payload level uses a null diffractor to correct the WFI FPA source beam and direct the corrected beam into the Coronagraph using the auto-collimating flat.
- Permits WFE verification at one wavelength within CGI+Telescope allocation
Integrated Modeling (IM) Summary:  
Cycle 4 Results  
Cycle 5 Status

Carl Blaurock, Cliff Jackson, and the IM Team  
141118
Major Cycle-4 IM Products

- **Optical Paths Modeled:**
  - Telescope/WFI (in Widefield Imaging Mode, or WIM, config),
  - Telescope/WFI (in Widefield Spectroscopy Mode, or WSM, config)
  - Telescope/CGI

- **STOP Results:**
  - WFI WFE/PSF_ellipticity/LOS Stability for WFI Worst Slew
  - CGI WFE/LOS Stability for CGI Priority Slew

- **Jitter Results:**
  - WFI and CGI WFE/LOS Stability Assessed for RWA, Cooler, and HGA Inputs
Analysis Assumptions

- **Structural/Thermal/Optical Performance (STOP)**
  - Cooldown Assumptions:
    - WFI prelaunch offsets correct 78% of cooldown alignment shifts to meet error budget ... no prelaunch figure corrections needed; T2/F2 refocused once after cooldown
    - CGI cooldown-subtracted only (perfect alignment on-orbit); same T2 refocus as WFI
  - Slew Cases:
    - WFI Worst Slew: Hot (max Earth WFI optical bench radiator (OBR) input) to Cold (min OBR input), w/worst pitch & roll Δ; hourly STOP 6 hours before/18 hours after slew
    - CGI Priority Slew: dark hole to target star slew; hourly STOP for 24 hrs after slew
  - Model Uncertainty Factor (MUF): 2.0x

- **Jitter**
  - D-strut isolators between SC bus and payload
  - Reaction wheels: four Honeywell HR-14s with wheel isolators
  - High Gain Antenna: tracking rates, with passive damping and micro-stepping
  - Cryo-cooler: flow noise dominated, applied to compressor and WFI and IFU FPA heat exchangers
  - MUF of 2.5x - 5.86x (cooler disturbance includes 10.0x MUF)
## WFI Widefield Imaging Mode (WIM) Cyc-4 IM Results Overview

<table>
<thead>
<tr>
<th>Metric</th>
<th>Discipline</th>
<th>Source</th>
<th>Predict</th>
<th>Requirement</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFE</td>
<td>STOP</td>
<td>Cooldown</td>
<td>36.2 nm</td>
<td>~36.2 nm RMS</td>
<td>By design</td>
</tr>
<tr>
<td>WFE Stability</td>
<td>STOP</td>
<td>WFI Slew</td>
<td>0.063 nm / 184 sec</td>
<td>0.707 nm RMS / 184 sec</td>
<td>11.2x</td>
</tr>
<tr>
<td></td>
<td>Jitter</td>
<td>RWA</td>
<td>0.219 nm</td>
<td></td>
<td>2.4x</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HGA</td>
<td>0.192 nm</td>
<td>0.29 nm (RSS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooler</td>
<td>0.004 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS Stability</td>
<td>STOP</td>
<td>WFI Slew</td>
<td>1.8 masec</td>
<td>14 masec RMS</td>
<td>7.8x</td>
</tr>
<tr>
<td></td>
<td>Jitter</td>
<td>RWA</td>
<td>5.9 masec</td>
<td></td>
<td>2.1x</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HGA</td>
<td>3.3 masec</td>
<td>6.7 masec (RSS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooler</td>
<td>0.128 masec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipticity</td>
<td>STOP</td>
<td>WFI Slew</td>
<td>1.97e-4 / 184 sec</td>
<td>4.7e-4 / 184 sec</td>
<td>2.4x</td>
</tr>
<tr>
<td>Stability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1) 18 SCAs considered in WFI STOP performance assessment; one central FPA field point for WFI Jitter assessment; 2) STOP LOS stability per Observatory ACS estimate; 3) Jitter results from rigid body mirror motions, but STOP results include mirror motions/deformations; 4) Cooldown per budget allocation of 36.2 nm out of ~90 nm total WFE \ldots achieved w/78% correction of cooldown shifts.
# CGI IM Results Overview

<table>
<thead>
<tr>
<th>Metric</th>
<th>Discipline</th>
<th>Source</th>
<th>Predict</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFE Stability</td>
<td>STOP</td>
<td>CGI Slew</td>
<td>0.3 nm / hr</td>
</tr>
<tr>
<td></td>
<td>Jitter</td>
<td>RWA</td>
<td>0.230 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HGA</td>
<td>0.183 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooler</td>
<td>0.004 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.294 nm (RSS)</td>
</tr>
<tr>
<td>LOS Stability</td>
<td>Jitter</td>
<td>RWA</td>
<td>5.86 masec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HGA</td>
<td>4.42 masec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooler</td>
<td>0.127 masec</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.34 masec (RSS)</td>
</tr>
</tbody>
</table>

Notes: 1) Optical performance assessed at CGI first focus; 2) Jitter predicts from rigid body mirror motions only; 3) STOP predicts include T1/T2 mirror motions/deformations, but only rigid body motions of CGI internal mirrors; 4) Margins not assessed as requirements are in formulation.
Cycle 5 Status

• Updates
  – Telescope/IFU optical path modeled and added
  – Correlated FOA model included
  – CGI OS1 slew identified as CGI priority slew case

• STOP/Jitter models are proceeding for mid-December analysis complete date
  – SC, WFI, CGI, Telescope optical/thermal/structural models largely complete
  – Preparing to integrate Observatory model and perform pipe-cleaner runs

• MUFs updated
  – STOP: credit for ISIM measured material properties database
  – Jitter: credit for RW, stepper motor model test validation
WFIRST Wide Field Instrument Status

D.Content for A. Whipple

arthur.l.whipple@nasa.gov
WFI technical update

- WFI design update
  - Cycle5 design cycle completed
    - Primary Objectives:
      - Incorporate optimized carrier load path
      - Structural/thermal/optical integration and Integrated Modeling analysis of CGI and IFU
    - Major Changes:
      - Structure and latches refined to take advantage of new truss structure Instrument Carrier
      - Added IFU mechanical packaging (including focus mechanism and connection to cryocooler)
  - Cycle5 analysis and design
    - v. 5.0.6 WFIRST-AFTA Cycle 5 Wide Field Channel optical model delivered
    - Wave Front Error budget in 3rd revision
    - Stress and thermal analysis updates in-work
  - Cycle5 Integrated modeling underway
    - New: Instrument Carrier, WFI IFU, CGI
Cycle 5 IFU Changes

- Spectrograph simplified and improved
  - Reduced from 6 mirrors to 2
  - Anamorphic Asphere Focus Mirror
  - Same imaging performance
  - Prism has flatter R-curve

- Dual slicer takes advantage of unused relay field and unused detector pixels for photometric redshift calibration spectroscopy

IFU layout 71 x 41 x 13 cm
Grism Risk Reduction Effort

- First visible-blazed grating *test pieces* characterized
  - Desire peak efficiency of 90% or more at 630nm
  - Test grating samples demonstrated 90-94% at 630 nm
  - Continue to work with multiple vendors on the gratings to be applied to prototype prisms
  - Working with NIST to investigate their emerging ability to provide high efficiency diffractive surfaces

- Mount design completed and mechanical parts in fabrication

Grism mechanical design and mounting ring in fabrication

Grism layout and procured substrates

Grism samples
Element Wheel and F2 Actuated Mirror Mount

Risk Reduction Efforts

- Mechanical parts complete
- Composite parts in fabrication
- Motors and sensors are in-hand and working in lab to develop controller

Element Wheel composite parts in fabrication

Electro-mechanical lab bench
M3 Risk Reduction Effort

- Industry Request for Information yielded considerable interest in writing
- Responses under study for applicability to WFI and implications for development plans and schedule
Bandpass Filter Coating Risk Reduction Effort

- Purchase Orders placed with multiple vendors to provide samples of W149, Z087, and Grism-AR coatings
- Assess risk, performance, and suitability for flight vendor
- 25 mm, 110, and 20 mm diameter substrates are being coated for spectral, wavefront, and radiation testing respectively
Wide Field Instrument Detector Development Update

D. Content (for the detector development team)

November 20, 2014
Summary

- Recent progress is very encouraging:
  - 8/6: 1\textsuperscript{st} detector technology milestone review (passed)
  - September: All testing completed for three lots of (banded array) development H4RGs – details below
  - October: 1\textsuperscript{st} full array lot (PV2a) started growth
  - Current: 1\textsuperscript{st} fully array lot done growth, started processing
    - 12/1: Detector TAC review of Milestone 2 (PV3 banded array)
  - Spring 2015: Initial deliveries to DCL of first SCAs from full array lot
  - Infrastructure development for rapid testing and characterization is proceeding
    - Cold metrology gantry (FPA flatness metrology at room temp or cold)
    - Cryostat nearing completion for testing 4 H4RGs in parallel
<table>
<thead>
<tr>
<th>MS #</th>
<th>Milestone</th>
<th>Milestone Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>√</strong> Produce, test, and analyze 2 <em>candidate passivation techniques</em> (PV1 and PV2) in <strong>banded arrays</strong> to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.</td>
<td>7/31/14</td>
</tr>
<tr>
<td>2</td>
<td>Produce, test, and analyze 1 <em>additional candidate passivation technique</em> (PV3) in <strong>banded arrays</strong> to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.</td>
<td>12/30/14</td>
</tr>
<tr>
<td>3</td>
<td>Produce, test, and analyze <em>full arrays with operability &gt; 95%</em> and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, QE greater than 60% (over the bandpass of the WFI channel), inter-pixel capacitance ≤3% in nearest-neighbor pixels at nominal operating temperature.</td>
<td>9/15/15</td>
</tr>
<tr>
<td>4</td>
<td>Produce, test, and analyze final selected recipe in <em>full arrays demonstrating a yield of &gt; 20% with operability &gt; 95%</em> and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, QE greater than 60% (over the bandpass of the WFI channel), inter-pixel capacitance ≤3% in nearest-neighbor pixels, persistence less than 0.1% of full well illumination after 150 sec at nominal operating temperature.</td>
<td>9/15/16</td>
</tr>
<tr>
<td>5</td>
<td>Complete environmental testing (vibration, radiation, thermal cycling) of one SCA sample part, as per NASA test standards.</td>
<td>12/1/16</td>
</tr>
</tbody>
</table>
The Band 1 pixel design exhibits the best performance across the 8 SCAs tested in the DCL and exceeds the milestone requirements by a significant margin.

- Other bands (3, 4) also show good performance; preliminary recommendation of band 1 folds in yield considerations as well as performance
- PV3 showing significant improvement in persistence (roughly 3x better than PV1/2)

<table>
<thead>
<tr>
<th>MS #</th>
<th>Milestone</th>
<th>Milestone Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Produce, test, and analyze 2 candidate passivation techniques (PV1 and PV2) in banded arrays to document baseline performance, inter-pixel capacitance, and shall meet the following derived requirements: dark current less than 0.1 e-/pixel/sec, CDS noise less than 20 e-, and QE greater than 60% (over the bandpass of the WFI channel) at nominal operating temperature.</td>
<td>7/31/14</td>
</tr>
</tbody>
</table>

### Milestone 2 Performance Requirements Have Been Met

<table>
<thead>
<tr>
<th>Milestone Requirement</th>
<th>PV1/2 Band 1 Average</th>
<th>PV3 Band 1 Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Dark Current (e-/pix/sec)</td>
<td>&lt;0.1</td>
<td>0.0023</td>
</tr>
<tr>
<td>Median CDS Noise (e- rms)</td>
<td>&lt;20</td>
<td>12</td>
</tr>
<tr>
<td>Median QE (%)</td>
<td>&gt;60</td>
<td>95%</td>
</tr>
</tbody>
</table>
H4RG-10 Development Upcoming Work

• Early in FY15, 2nd Full Array Lot will be started
  – Will confirm that the selected recipe(s) scale to the entire array
    and provide better full array uniformity and yield information.
  – Analysis will be complete by late CY15.
• The final pre-flight lot will be the Yield Demonstration Lot.
  – Anticipated start by early FY16.
  – A single flight candidate recipe will be used.
  – These detectors are expected to be of fairly high quality, and
    will be using during instrument development as engineering
    devices, for qualification testing, and for detailed performance
    characterization. Thus, detectors for flight instrument build-up
    will be available quite early.
  – Completion of the Yield Demonstration Lot is planned to be late
    in FY16, after which the flight build can be started.