AFTA-WFIRST Coronagraph Instrument Status Report -- ExoPAG

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Outline

- Introduction
- Newly selected architecture description
- Status and next steps
- Summary
AFTA Coronagraph Instrument will:

- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

**Table:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandpass</td>
<td>430 – 980nm</td>
</tr>
<tr>
<td>Measured sequentially</td>
<td>in five ~10% bands</td>
</tr>
<tr>
<td>Inner working angle</td>
<td>100 – 250 mas</td>
</tr>
<tr>
<td>~3λ/D, driven by science</td>
<td></td>
</tr>
<tr>
<td>Outer working angle</td>
<td>0.75 – 1.8 arcsec</td>
</tr>
<tr>
<td>By 48X48 DM</td>
<td></td>
</tr>
<tr>
<td>Detection Limit Contrast</td>
<td>≤ 10⁻⁹ (After post processing)</td>
</tr>
<tr>
<td>Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extreme stability requirements</td>
<td></td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>~70</td>
</tr>
<tr>
<td>With IFS, R~70 across 600 – 980 nm</td>
<td></td>
</tr>
<tr>
<td>IFS Spatial Sampling</td>
<td>17mas</td>
</tr>
<tr>
<td>Nyquist for λ~430nm</td>
<td></td>
</tr>
</tbody>
</table>
Star light suppression optics

OTA (PM, SM) → TM, relay, FSM → DM #1, DM #2 → Relay, Occulting Masks & Filters → LOWFS → Drift control loop (<2Hz) → Jitter control loop (250Hz?)

High contrast loop during initialization → Coronagraph FPA

LOWFS FPA
IFS → IFS FPA

Telemetry → Post processing

1kX1K, Si low noise FPA; 150K, IWA 0.25/λ arcsec, OWA 2.5/λ arcsec, λ(0.43-0.98um)

2kX2k, Si low noise FPA; 150K, λ(0.6-0.98um), R~70, 17mas sampling

Optics
Control
Detector
Post processing on ground
Star light suppression -- Technical Approach

Six different concepts

Down select 12/15/2013
http://wfirst.gsfc.nasa.gov/

Primary Architecture (OMC)  Back-up Architecture (PIAACMC)

Visible Nuller Coronagraph: Phase-Occulting (Lyon, GSFC)
Visible Nuller Coronagraph: DaVinci (Shao, JPL)

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TTL-5 @ start of Phase A (10/2016)  TRL-6 @ PDR (10/2018)
Primary Architecture:
Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot

- SP and HL masks share very similar optical layouts
- Small increase in overall complexity compared with single mask implementation
Contrast simulations with AFTA pupil, aberrations and expected range of telescope pointing jitter

- OMC in its “SP mode” provides the simplest design, lowest risk, easiest technology maturation, most benign set of requirements on the spacecraft and “use-as-is” telescope. This translates to low cost/schedule risk and a design that has a high probability to pass thru the CATE process.

- In its “HL mode”, the OMC affords the potential for greater science, taking advantage of good thermal stability in GEO and low telescope jitter for most of the RAW speed

**Graphs:**

- **HLC Aberrated System, Post-EFC**
  - Contrast vs. 
  - \( \lambda/\lambda = 550\text{nm} \)
  - Lines represent:
    - No jitter
    - 0.2 mas
    - 0.8 mas
    - 1.6 mas
  - Legend:
    - No jitter, no aberrations, no EFC

- **Shaped Pupil, Post-EFC**
  - Insensitive to jitter
  - Lines represent:
    - 20%, 2-sided
    - 20%, 1-sided
    - 10%, 2-sided

Good balance of science yield and engineering risk
The results indicate telescope LOS jitter less than 1 mas over a wide range of wheel speeds, before LOWFS tip/tilt correction.

- Except at wheel speed ~10 and 26 rps

Numerous opportunities exist for further jitter optimization:

- operational constraints,
- momentum management strategies,
- structural redesign,
- LOWFS design optimization

“Model uncertainty factor (MUF)” consistent with flight projects (MUF=2.5 for f<20Hz, and MUF=6 for f>40Hz, linear in between)
• Recent STOP model results indicate very stable telescope wavefront during operation
  – Dominant term is focus, \(~2\text{nm}\) over 24 hrs
  – Other low-order WFE \(<20\text{pm}\) over 24 hrs
Instrument Layout within the Allocated Envelope

From OTA

(1) Main OMC Bench

(1) (2)

(2) Detector Bench

Allocated envelope

Enough space for PIAA bench

Flipper mirror

Imaging FPA

IFS

(1) Main OMC Bench

Fold

FSM

TM

DM1

DM2

Lyot Mask Changer

Occulting Mask Changer

Pupil Mask Changer

Instrument Elex
**Functional Modularized Instrument**

- **Tertiary Module**: Functional Testing
- **DM Module**: Functional Testing
- **Coronag Module**: Functional Testing
- **IFS Module**: Functional Testing
- **Imager Module**: Functional Testing
- **Elex Module**: Functional Testing
- **PIAA** (optional): Functional Testing

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**Modularized Instrument:**

- Simple interface (collimated beam)
- Flexible early EDU risk mitigation
- Shorter flight I&T duration
- Ease of international participation

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**Modularized example (SIM ABC)**
Active Optics

**Fine Steering Mirror (FSM)**
- To correct telescope line-of-sight (wavefront tip/tilt) error
- Low risk with rich flight heritage

**Deformable Mirror (DM)**
- To correct telescope & instrument optical WFE (static and drift)
- Low risk with good heritage:
  - Flight PMN actuators, driver electronics
  - HCIT contrast demonstration to $10^{-10}$
  - Assembly passed random vibe test (2012)

Low risk for flight implementation
Coronagraph Masks

Reflective shaped pupil masks
• Black Si on Al mirror coating demonstrated at JPL/MDL and Caltech/KNI

Transmissive hybrid Lyot mask
• Profiled Ni layer (amplitude) overcoated with profiled MgF2 layer (phase) at JPL Trauger’s lab
• Linear mask fabricated and demonstrated $10^{-10}$ in HCIT for unobscured pupil

Both masks have credible plan for FY14 delivery to HCIT
System-Level Testbed Demonstration
Phase 1: Static Wavefront

Possible Path to Closing Gap

Demonstrate static wavefront performance in fully-assembled coronagraph vacuum testbed with simulated AFTA-WFIRST telescope pupil.

Key Demonstration Objectives
- Coronagraph masks/apodizers for AFTA-WFIRST obscured pupil
- Two-DM configuration
- Wavefront control algorithms developed
- Static wavefront performance:
  - $1 \times 10^{-8}$ contrast
  - $2\% \rightarrow 10\%$ BW (in 500-600 nm window)
System-Level Testbed Demonstration Phase 2: Dynamic Wavefront

Possible Path to Closing Gap

Demonstrate dynamic wavefront performance in fully-assembled coronagraph vacuum testbed with simulated AFTA-WFIRST telescope pupil in a dynamic env’t.

Key Demonstration Objectives (TRL 5)
- Dynamic OTA simulator
- DM/FSM integrated assembly
- LOWFS/C and algorithms developed
- Dynamic wavefront performance:
  - 1e-8 raw contrast
  - 1e-9 detection contrast
  - 2% → 10% BW (central wavelength of 550 nm)
  - IFS (R~70 TBD) separately
- Planet simulation and extraction
Negotiation with instrument scientist underway
Next Steps

• Technology Maturation:
  – Submit technology maturation plan to HQ with milestones FY14-FY16 (TRL-5 demonstration by 10/2016)

• AFTA-WFIRST DRM:
  – SDT interim report 4/2014
  – SDT final report 1/2015
  – CATE 2/2015

• Wider community participation
  – ACIST
  – International partnership
Summary

• Exciting coronagraph technology maturation for a generic telescope (such as AFTA)
  – Benefit future exo-Earth imaging missions using a generic telescope (such as ATLAST)
• AFTA-WFIRST Occulting Mask Coronagraph offers balanced science returns and engineering risks
• Strong interest from community and international partners, modularized instrument design offers simple interface and flexible contributions
Acknowledgement

- Contributions from team members from JPL, GSFC, Princeton, Univ of Arizona, Ames, LLNL, STScI, Caltech