Telescopes Team (INS/TEL)
Overview and Highlights

Roeland van der Marel
(TIPS, November 21, 2013)
Overview

- **JWST**
  - OTE (I&T, WFS&C, PSF, SIAF)
  - ISIM (Coronagraphy, FGS, Pointing, I&T)
- **HST**
  - OTA (Focus, SIAF)
  - FGS
- **CMO**
  - OPTIIX
  - AFTA/WFIRST
- **Makidon Optics Lab**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>AFTA</td>
<td>Astrophysics Focused Telescope Assets</td>
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<td>CMO</td>
<td>Community Missions Office</td>
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<td>FGS</td>
<td>Fine Guidance Sensor</td>
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<td>HST</td>
<td>Hubble Space Telescope</td>
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<td>ISIM</td>
<td>Integrated Science Instrument Module</td>
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<td>I&amp;T</td>
<td>Integration &amp; Test</td>
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<td>JWST</td>
<td>James Webb Space Telescope</td>
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<td>OPTIIX</td>
<td>Optical Testbed &amp; Integration on ISS eXperiment</td>
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<td>OTA</td>
<td>Optical Telescope Assembly</td>
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<td>OTE</td>
<td>Optical Telescope Element</td>
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<td>PSF</td>
<td>Point Spread Function</td>
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<td>SIAF</td>
<td>Science Instrument Aperture File</td>
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<td>WFIRST</td>
<td>Wide Field InfraRed Survey Telescope</td>
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<td>WFS&amp;C</td>
<td>Wavefront Sensing &amp; Control</td>
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Staffing

- Rachel Anderson (0.2, RIAB) [Lab]
- Pierre Chayer [JWST/FGS]
- Colin Cox [HST/OTA, JWST/SIAF]
- Erin Elliott [JWST/OTE I&T, OPTIIX]
- George Hartig [JWST/ISIM+OTE I&T]
- Sherie Holfeltz (0.5, RIAB) [JWST/FGS]
- Charles Lajoie (1.0, RIAB) [JWST/WFS&C, JWST/Coronag, Lab]
- Matt Lallo [HST/OTA, JWST WFS&C, JWST/SIAF]
- Ed Nelan [JWST/FGS, HST/FGS]
- Marshall Perrin [JWST/WFS&C, JWST/PSF, OPTIIX, AFTA, Lab]
- Laurent Pueyo [JWST/WFS&C, JWST/Coronag, AFTA, Lab]
- Anand Sivaramakrishnan (0.1, NIRISS) [JWST/WFS&C, Lab]
- Remi Soummer [JWST/WFS&C, JWST/Coronag, AFTA, Lab]
- Roeland van der Marel [Lead]
JWST/OTE: Overview

18 Segments
Secondary
Tertiary
Fine Steering Mirror

132 DOF

25 m² area
WFE < 130 nm
ΔWFE < 57 nm in 2 weeks
T ~ 40 K
• Flight telescope + sunshield and spacecraft simulators.
• Most of the hardware will get down to 35 K.
• Assembly is suspended so that all components are connected vibrationally.
• Light sources at the Cassegrain focus of the primary/secondary pair.
• Some sources face “inward” to the tertiary and science instruments.
• 3 autocollimating flats return light from the “outward” sources.

Chamber A at Johnson Space Center. (Built for the Apollo missions.)

Center of curvature interferometer
Auto-collimating flats
Secondary
Suspension system rods
Primary mirror
ISIM (instrument package)

OTE Cryogenic Testing

Inward and outward test sources
Li N2 shrouds
He shrouds

Image: Chamber A at Johnson Space Center. (Built for the Apollo missions.)
Aligning & Commissioning JWST

- An extraordinarily complex process that will take several months
- From initial deployments of ~ mm accuracy to <130 nm RMS
- To be led by Ball Aerospace, in close partnership with STScI and GSFC
Coordinating WFS&C across the project

Wavefront Working Group
• Project-wide leadership & oversight for WFS&C, OTE commissioning, WSS development, commissioning simulations, & staff training

Wavefront Sensing System (WSS) development
• Software to sense & control the optics in flight
• Integrates Ball-provided algorithms components with the rest of the S&OC systems.
• Ongoing development, integration & test in partnership with OED SEB.

WFS&C Operations Working Group
• Refining ops concepts and detailed plans for OTE commissioning & maintenance.
• Feeds into OSS implementations and APT templates for WFS&C activities

Recent TEL Investigations
• WFS&C target star selection; Methods for initial boresight determination
• Predictive WFS&C control taking advantage of known pointing schedule
• Primary segment control algorithms with partially failed hexapods
• Cophasing segments with non-redundant tilts
WebbPSF provides simulated PSFs for all instruments based on telescope & instrument design and error budgets.

- Supports ETC development and coronagraphy planning
- Upcoming version 0.3 adds spectroscopy modes for NIRSpec, MIRI, & NIRISS
- Next step: compare to SI cryo test data
- Planned to evolve into on-orbit PSF tool (a la HST/TinyTim), with modern web interface. Will include temporal evolution of the OTE.

[Perrin]
SIAF in S&OC PRD contains SI geometry information (FOV, distortion, etc.) in focal plane

- Serves multiple system on-ground and on-board (APT, OSS, OPGS, VSS, DMS)
- Coordinated by SIAF Working Group

TEL delivered initial SIAF to OED/PRD earlier this year

- Data was examined and test-used by various systems
- Next improved delivery in 2014

SIAF fidelity will continue to evolve

- Optical models
- I&T cryo-vac calibrations
- On-orbit calibrations (observations of LMC astrometric reference field)
JWST/OTE: SIAF
OED/APS B’s SIAF visualization tool displaying part of initial SIAF delivery

[Lallo, Cox et al.]
JWST/ISIM: Coronagraphy

- Coronagraphy is key capability for JWST science
  - Exoplanets, Debris disks, AGN environments etc.
- Several coronagraphs on JWST (MIRI, NIRCam)
  - 4QPM, Lyot, band-limited wedges and sombreros
  - also non-redundant mask (NRM) on NIRISS

[Clampin et al.]
JWST/ISIM: Coronagraphy

- Planning Coordinated by Internal + External Coronagraph Working Groups

- Recent Activities
  - MIRI/FQPM coronagraphic target acquisition scenarios
    - Different slew accuracies (CDR estimates vs. Requirement)
    - minimize detector latencies
  - Small-grid dithers: improved performance w/post processing
  - Coronagraphic ops concept and templates (ongoing)
  - Coronagraphic ETC (ongoing)
JWST/ISIM: FGS

- Two imaging cameras with flight software (FSW) developed by CSA/ComDev

- Operational issues addressed by TEL/FGS
  - FGS operation studies with the JWST guide star catalog, GSC2
  - FGS Operations Concept Document
  - FGS Commissioning and Calibration Requirements and Plans

- FSW Performance testing
  - Use of GSFC Certification Lab to identify issues
  - Focus on simulation of realistic complexities: crowded fields, fields with compact galaxies, high background, cosmic rays, spacecraft pointing errors, drift, jitter, etc.
  - work with CSA/ComDev on rectification

- Support of cryo-vac testing of functionality
  - CV1RR generally successful
  - Hardware problem with communication loss
JWST/ISIM: Other Pointing Issues

• Line of Sight Working Group
  – Attitude Control System, pointing “transients”, etc.

• Moving Target Working Group
  – Added to the JWST baseline in 2007

• JWST Efficiency Working Group
  – Timing of guide star acquisitions, small Angle Maneuvers, etc.

• Many others ......
JWST/ISIM I&T: CV1-RR Test Config (GSFC SES Chamber)
OSIM serves as OTE surrogate for ISIM CV testing

Provides point sources and flat field illumination of SI’s
JWST/ISIM I&T Support

• **INS/TEL provided support**
  - OSIM development, testing and calibration process
  - ISIM CV test program development
  - NIRCam I&T process

• **CV1-RR optical outcomes**
  - OSIM performed nearly flawlessly through the test
  - Major goals accomplished, despite test truncation
    • SI alignment (boresight, pupil, focus) assessment
    • SI imaging performance (PSF, WFE) measurement
    • Limited stray light, flat field, detector characterization
HST/OTA: Focus Maintenance

- HST OTA shrinks as it dries over time
- INS/TEL monitors by monthly phase retrieval of calibration star images
- Linear shrinkage of the OTA since mid-2011 $\sim 2.6 \mu \text{ /yr}$
- Secondary mirror commanded outwards on $\sim$year timescales to maintain focus
- $3 \mu$ mirror move executed Tuesday Nov 12
HST/OTA: Focus Model

- HST also expands and contracts due to the dynamic heat loading in low-earth orbit ("breathing")
  - not actively corrected with mirror moves.

- To aid in understanding this effect on science, INS/TEL has developed, refined, and made available to the community a model that describes focus changes as a function of measured temperatures
  
  http://www.stsci.edu/hst/observatory/focus
HST/OTA: SIAF

- HST has a SIAF database, like JWST

- INS/TEL performs semi-annual “SI-FGS Alignment” observations of an astrometric cluster
  - Drifts of instrument positions in focal plane are generally small (≈0.1 arcsec)
  - SIAF entries are updated as necessary
SI Movement since SM4

ACS WFC1/WFC2 Average

WFC3 UVIS1/UVIS2 Average

STIS OV50

COS Moves
HST/FGS

- Three interferometers used for guiding and astrometry
- Dec 2012: extensive calibration program using existing M35 astrometric catalog, with bootstrapping into catalog of guide stars
- Re-calibrated the optical field angle distortion (OFAD) for FGS2r2 and FGS3 (last FGS3 calibration was 1999!)
  - FGS distortion residuals ~5 mas (was ~200 mas)
- Re-calibrated FGS-FGS alignments across all three FGSs
  - FGS-FGS alignment residuals ~50 mas (FGS2r2 was ~700 mas)
Residuals observed-predicted guide star pair separations

before recalibration:

- Median 0.32 arcsec

- RMS 0.36 arcsec

after recalibration:

- Median 0.13 arcsec

- RMS 0.31 arcsec
CMO/OPTIIX

- Optical Prototype Telescope Integration on the ISS eXperiment
- STScI partnered with JPL, GSFC & JSC in a design study for *assembling in space* a 1.5 m segmented telescope.
  - TEL involvement: WFS&C, operations, science case, outreach
- Pathfinder for ATLAST and potential testbed for new instruments
  - Hybrid nanolaminate mirrors, laser metrology truss, on-orbit robotic assembly of segments, WFS&C to reach diffraction limit in visible light, H4RG detectors...
- Successful PDR in Sep ‘12, currently suspended pending funding
CMO/AFTA

- **WFIRST**: Wide-Field Infra-Red Survey Telescope (#1 decadal survey recommendation)
- **AFTA**: 2.4m mirror(s) donated to NASA
- **AFTA/WFIRST**: includes coronagraph study option
  - Several TEL members involved with AFTA coronagraph working group for the selection of one particular design
  - Goal: fast process for mission start (phase A) early FY17

- **CMO/TEL involvement at several levels**
  - Advanced wavefront control / beam shaping [Pueyo talk]
  - Post-processing algorithms (PSF subtractions)
  - Funding options under negotiation
Russell B. Makidon Optics Laboratory

- Lab inaugurated May 2013
  - 3 Clean rooms, 4 optics tables, electronics room, office space
Russell B. Makidon Optics Laboratory

- Four experiments under development
- Functional: JWST testbed

Research:
- High-Contrast Imager for Complex Aperture Telescopes (HICAT) (Soummer et al.)
- NRM testbed (Sivarmakrishnan et al.)
- Zodiacal dust Polarimetry (Hines et al.)
• JWST
  • OTE I&T: Elliott, Hartig
  • OTE/WFS&C: Lallo, Perrin, Soummer, Lajoie, Sivaramakrishnan
• PSF: Perrin
• SIAF: Lallo, Cox
• Coronagr.: Soummer, Lajoie, Pueyo, Perrin
• FGS/Pointing: Nelan, Chayer, Holfeltz
• ISIM I&T: Hartig

• HST
  • OTA: Cox, Lallo
  • FGS: Nelan

• CMO
  • OPTIIX: Elliott, Perrin
  • AFTA/WFIRST: Pueyo, Perrin, Soummer

• Makidon Optics Lab
  • Soummer, R. Anderson, Perrin, Lajoie, Pueyo, Sivaramakrishnan