The James Webb Space Telescope and First Light: Project Update, What to Expect & How to Prepare.

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Talk at the ASU Origins Workshop: “Is Our Universe Necessary?”, ASU, Tempe, AZ, Sat Feb 1, 2014
Outline

• (1) Brief Update on the James Webb Space Telescope (JWST) Project

• (2) JWST and First Light: What Will it See & How to Prepare?

• (3) Charts to Answer what You Always Wanted to Ask but didn’t.

Workshop Question: Is Our Universe (incl. First Light!) necessary?

My Answer: To answer Q, need JWST + scientists, engineers, machinists, managers, politicians, lobbyists & lawyers $\Rightarrow$ Need Universe!

Sponsored by NASA/HST & JWST
A fully deployable 6.5 meter (25 m²) segmented IR telescope for imaging and spectroscopy at 0.6–28 $\mu$m wavelength, to be launched in Oct. 2018. Nested array of sun-shields to keep its ambient temperature at 40 K, allowing faint imaging ($AB=31.5$ mag $= 1$ nJy) and spectroscopy.
80% of launch mass designed and built as of Jan. 2014.
JWST instrument update: US (UofA, JPL), ESA, & CSA.

Instrument Overview

**Fine Guidance Sensor (FGS)**
- Ensures guide star availability with >95% probability at any point in the sky
- Includes Narrowband Imaging Tunable Filter
- Developed by Canadian Space Agency & COM DEV

**Mid-Infra-Red Instrument (MIRI)**
- Distinguishes first light objects; studies galaxy evolution; explores protostars & their environs
- Imaging and spectroscopy capability
- 5 to 27 microns
- Cooled to 7K by Cyro-cooler
- Combined European Consortium/JPL development

**Near Infra-Red Camera (NIRCam)**
- Detects first light galaxies and observes galaxy assembly sequence
- 0.6 to 5 microns
- Supports Wavefront Sensing & Control
- Developed by Univ. of AZ & LMATC

**Near Infra-Red Spectrograph (NIRSpec)**
- Measures redshift, metallicity, star formation rate in first light galaxies
- 0.6 to 5 microns
- Simultaneous spectra of >100 objects
- Developed by ESA & EADS with NASA/GSFC Detector & Microshutter Subsystems

All delivered: MIRI 05/12; FGS 07/12; NIRCam 07/13, NIRSpec 9/13!
Mirror Status

- 15 flight primary mirrors and the flight secondary mirror are at GSFC in storage
  - All spares were at GSFC in storage (SM spares, 3 PMSA spares)
    - 2 EDU mirrors sent back to Ball for gear motor rework
  - All flight gear motor refurbishment is complete
  - All flight mirrors will be at GSFC by end of year, needed in 2015

Jan 2014: All 18 flight mirrors now delivered to NASA GSFC (MD).
Backplane Support Frame, Center Section, & Wings

- Center Section is complete
- Wings and cryo cycling is complete
- BSF assembly is complete
- Integration of the BSF to Center Section Complete
  - Cryo Cycling at MSFC XRCF complete

Sunshield Template Membrane Work Completed

- All Template Layers Completed
- Preparing for flight article manufacturing
- First two Flight Manufacturing Readiness Reviews Completed
- Membrane pull out test complete

Flight sunshield to be completed & tested by 2015 at Northrop (CA).
841 orbits HUDF 13 filters (false-color): objects affect $\sim 45\%$ of pixels!!

(2) What to expect in Webb (UltraDeep) Fields re. First Light?
HUDF weighted log-log: $F_{\text{uv}}N_{\text{uv}}U_{\text{BVIzYJWH}}$, $AB \lesssim 31$ ($\gtrsim 2$ nJy).
HUDF WFC3 IR Galaxy Counts: What to expect in Webb (UltraDeep) Fields?


- Faint-end near-IR count-slope $\sim 0.12 \pm 0.02$ dex/mag $\iff$
- Faint-end LF-slope ($z_{med} \sim 1.6$) $\alpha \sim -1.4 \Rightarrow$ reach $M_{AB} \sim -14$ mag.
- WUDF (- - -) can see $AB \lesssim 32$ objects: $M_{AB} \sim -15$ (LMCs) at $z \sim 11$.
- Lensing will change the landscape for JWST observing strategies.
Evolution of Schechter LF: faint-end LF-slope $\alpha(z)$, $\Phi^*(z)$ & $M^*(z)$:

- For JWST $z \gtrsim 8$, expect $\alpha \lesssim -2.0$; $\Phi^* \lesssim 10^{-3} (\text{Mpc}^{-3})$ (Oesch+ 11).
- HUDF: Characteristic $M^*$ may drop below $-18$ or $-17.5$ mag at $z \gtrsim 10$.

$\Rightarrow$ Will have significant consequences for JWST survey strategy.
What do the 6 possible $z\approx 9$ and single $z\approx 10$ HUDF candidate mean? Integrate Schechter LFs with $\alpha(z)$, $\Phi^* (z)$ and $M^* (z)$: $\lesssim 45\%$ sky-coverage by $AB\lesssim 30$ objects (Koekemoer$^+$13). Cosmic Variance $\gtrsim 30\%$. For any $\alpha(z\gtrsim 9-10)$, implies $M^* (z\gtrsim 10) \gtrsim -17.5$ mag (fainter!), so plan:

- (1) [Left] Webb “Medium-Deep” Fields (WMDF) ($10 \times 4 \times 2$h RAW): Expect few $z\approx 10-12$ objects to $AB\lesssim 30$ mag, so plan lensing targets.

- (2) [Middle] Webb Deep Field (WDF) ($4 \times 25$h 7-filt NIRCam GTO): Expect 8–25 objects at $z\approx 10-12$ to $AB\lesssim 31$ mag.

- (3) [Right] Webb UltraDeep Field (WUDF) ($4 \times 150$h; NIRCam DD?): Expect 30–90 objects to $AB\lesssim 32$ mag, many more if lensing targets.
Schechter LF \((z \lesssim 6 \lesssim 20)\) with \(\alpha(z), \Phi^*(z), M^*(z)\) above and \(\mu = 0.70\).

Area/Sensitivity for: HUDF/XDF, 10 WMDFs, 2 WDFs, & 1 WUDF.

- Will need lensing targets for WMDF–WUDFF to see \(z \sim 14–16\) objects.
HST Frontier Field A2744: JWST needs lensing to see First Light at $z \gtrsim 10-15!$
What are the best lenses in 2018: Rich clusters or (compact) galaxy groups?

[Left] Redshift surveys: SDSS $z \lesssim 0.25$ (Yang$^+$ 2007), GAMA $z \lesssim 0.45$ (Robotham$^+$ 2011), and zCOSMOS $z \lesssim 1.0$ (Knobel$^+$ 2012).

- **GAMA**: 22,000 groups $z \lesssim 0.45$; 2400 with $N_{spec} \gtrsim 5$ (Robotham$^+$ 11).
- $\lesssim 10\%$ of GAMA groups compact for lensing (Konstantopoulos$^+$ 13).
- Large group sample to identify optimal lens-candidates for $z \gtrsim 6$ sources.

(2) Gravitational Lensing to see First Light population at $z \gtrsim 10$. \

![Graph showing redshift surveys and halo mass vs. lookback time.](image)
GAMA group mass versus concentration assuming NFW DM halo profiles. Contours = Nr of expected lensed sources ($\Delta z=1$; Barone-Nugent$^+$ 13).

- 10 WMDFs on best GAMA groups add $\sim 50–100 \ z \sim 6–15$ sources ($AB \lesssim 30$).
- Also get $\gtrsim 10 \times$ more ($\gtrsim 500$) lensed sources at $\sim 2–15$.

WUDFF if pointed at clusters adds $\sim 6 \times$ more ($\gtrsim 3000$) sources at $6 \lesssim z \lesssim 15$. 
Two fundamental limitations may determine ultimate JWST image depth:

1. **Cannot-see-the-forest-for-the-trees effect [Natural Confusion limit]**: Background objects blend into foreground because of their own diameter
   ⇒ Need multi-λ deblending algorithms.

2. **House-of-mirrors effect [“Gravitational Confusion”]**: Most First Light objects at $z \gtrsim 12–14$ may need to be found by cluster or group lensing.
   ⇒ Need multi-λ object finder that works on sloped backgrounds
   ⇒ If $M^*(z \gtrsim 10) \gtrsim -18$, need to use & model gravitational foreground.
Conclusions

- Project replan in 2010-2011. No technical showstoppers thus far.
- More than 80% of JWST H/W built or in fab, & meets/exceeds specs.

(2) JWST is designed to map the epochs of First Light, Reionization and Galaxy Assembly & SMBH-growth in detail. JWST will determine:
- Formation and evolution of the first star-clusters after 0.2 Gyr.
- How dwarf galaxies formed and reionized the Universe after 1 Gyr.
- JWST will need to use lensing to see First Light objects at z \( \gtrsim 12 \).

(3) JWST will have a major impact on astrophysics this decade:
- IR sequel to HST after 2018: Training the next generation researchers.
- JWST will define the next frontier to explore: Dark Ages at z \( \gtrsim 15–20 \).
References and other sources of material shown:

- http://www.asu.edu/clas/hst/www/jwst/clickonHUDF/ [Clickable HUDF map]
- http://ircamera.as.arizona.edu/nircam/
- http://ircamera.as.arizona.edu/MIRI/
- http://www.stsci.edu/jwst/instruments/nirspec/
- http://www.stsci.edu/jwst/instruments/fgs

Any (space) mission is a balance between what science demands, what technology can do, and what budget & schedule allows ... (courtesy Prof. Richard Ellis).
Mega-Projects must learn how to build Coalition / fit into community ...
- JWST hardware made in 27 US States: \( \geq 80\% \) of launch-mass finished.

- Ariane V Launch & NIRSpec provided by ESA; & MIRI by ESA & JPL.

- JWST Fine Guider Sensor + NIRISS provided by Canadian Space Agency.

- JWST NIRCam made by UofA and Lockheed.
# Fiscal Year 2014 HQ Milestones

Assumes JWST is appropriated in FY2014 the full President’s budget request of new obligation authority (NOA).

<table>
<thead>
<tr>
<th>Month</th>
<th>Milestone</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Oct-13</td>
<td>1 Primary Mirror Backplane Support Structure Cryogenic Testing Readiness Review</td>
<td>Completed 9/10</td>
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<tr>
<td></td>
<td>2 Mirror Deployment Electronics Unit Manufacturing Readiness Review</td>
<td>Completed 10/8</td>
</tr>
<tr>
<td></td>
<td>3 Jet Propulsion Lab. (JPL) Cryogenic Test Chamber Readiness Review</td>
<td>Delayed: pulse tube, cooler shield issues</td>
</tr>
<tr>
<td></td>
<td>4 Johnson Space Center (JSC) Telescope and ISIM support structure fabrication complete</td>
<td>Completed 11/4</td>
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<tr>
<td>Dec-13</td>
<td>5 Spacecraft Critical Design Review Complete</td>
<td>Delayed to 1/14 [shutdown]</td>
</tr>
<tr>
<td></td>
<td>6 MIRI Cryocooler Flight Cold Head Assembly delivered to ISIM</td>
<td>Delayed 1/21/2014</td>
</tr>
<tr>
<td></td>
<td>7 JSC Clean Room ready to receive ground support equipment</td>
<td>Delayed to 1/14 [shutdown]</td>
</tr>
<tr>
<td></td>
<td>8 Complete ISIM cryogenic-vacuum risk reduction test</td>
<td>Concluded 11/13/2013, but not all tests completed because of shutdown</td>
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<tr>
<td>Jan-14</td>
<td>9 Delivery of last Primary Mirror Segment to GSFC</td>
<td>Completed 12/16</td>
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<td></td>
<td>10 Observatory Operations software scripts Build 3 Complete</td>
<td></td>
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<td></td>
<td>11 New detector focal plane arrays for NIRCam ready for integration into instrument</td>
<td>Completed 11/20</td>
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<tr>
<td>Feb-14</td>
<td>12 Secondary Mirror Mount delivery</td>
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<td></td>
<td>13 MIRI Cryocooler flight electronics delivered to JPL</td>
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<tr>
<td></td>
<td>14 Final Data Management Subsystem Design Review</td>
<td>Completed 11/22</td>
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<td></td>
<td>15 Flight NIRCam and NIRSpec ready for integration into ISIM</td>
<td>Delayed to 3/14 [shutdown]</td>
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<tr>
<td>Mar-14</td>
<td>16 Spacecraft Solar Array Manufacturing Readiness Review</td>
<td></td>
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<tr>
<td></td>
<td>17 JSC Chamber A Telescope ground support equipment test #1 design review</td>
<td></td>
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<tr>
<td>Apr-14</td>
<td>18 Telescope actuators electronics drive unit delivery</td>
<td></td>
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<td></td>
<td>19 Flight MIRI cryocooler assembly delivered to JPL</td>
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<tr>
<td></td>
<td>20 MIRI Cryocooler Flight Refrigerant Line Deployment Assembly delivered to integration and testing</td>
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<td></td>
<td>21 Sunshield Membrane Cover Assembly Manufacturing Readiness Review</td>
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<td></td>
<td>22 MIRI cryocooler Test Readiness Review</td>
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<tr>
<td>May-14</td>
<td>23 Updated Observatory Commissioning Plan (rev C) delivery</td>
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<td></td>
<td>24 Start acceptance testing of flight cryocooler assembly and associated electronics</td>
<td>Delayed to 6/14 [shutdown]</td>
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<td>Jun-14</td>
<td>25 Start cryo-vacuum test with fully integrated ISIM (“CV2”)</td>
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<td>26 Flight spare MIRI cryocooler assembly delivered to JPL</td>
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<td>27 JSC Chamber A bake-out and cryogenic proof testing complete</td>
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<td></td>
<td>28 Hardware ready for MIRI cryo cooler test #3: checkout complete</td>
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<td>Jul-14</td>
<td>29 Spacecraft Mid-Course Correction Thruster Final Assembly complete</td>
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<td>30 Proposal Planning Subsystem build 9 complete</td>
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<tr>
<td>Aug-14</td>
<td>31 Sunshield Mid-boom and Stem assembly Manufacturing Readiness Review</td>
<td></td>
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<tr>
<td></td>
<td>32 Spacecraft Flight Software Build 2.2 Test Readiness Review</td>
<td></td>
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<tr>
<td></td>
<td>33 NIRSpec and FGS/NIRISS new Focal Plane Arrays ready for integration</td>
<td>Delayed to 9/14 [shutdown]</td>
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<tr>
<td>Sep-14</td>
<td>34 JSC cryogenic test telescope and ISIM test ground support equipment integration complete</td>
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<tr>
<td></td>
<td>35 Complete cryo-vacuum test of fully integrated ISIM (“CV2”) complete</td>
<td>Delayed to 10/14 [shutdown]</td>
</tr>
<tr>
<td></td>
<td>36 NIRSpec new microshutters ready for integration</td>
<td>Delayed to 10/14 [shutdown]</td>
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Blue font denotes milestones accomplished ahead of schedule, orange font denotes milestones accomplished late.

Milestones: How the Project reports its progress monthly to Congress.
Milestone Performance

- Since the September 2011 replan JWST reports high-level milestones monthly to numerous stakeholders

<table>
<thead>
<tr>
<th></th>
<th>Total Milestones</th>
<th>Total Milestones Completed</th>
<th>Number Completed Early</th>
<th>Number Completed Late</th>
<th>Deferred to Next Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY2011</td>
<td>21</td>
<td>21</td>
<td>6</td>
<td>3</td>
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<td>FY2012</td>
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<td>34</td>
<td>16</td>
<td>2</td>
<td>3</td>
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<td>FY2013</td>
<td>41</td>
<td>38</td>
<td>20</td>
<td>5</td>
<td>3</td>
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<tr>
<td>FY2014</td>
<td>36</td>
<td>7</td>
<td>5</td>
<td>10*</td>
<td>0</td>
</tr>
</tbody>
</table>

*Late milestones have been or are forecast to complete within the year. Shutdown related delayed milestones included in this tally

7 out of 10 FY14 milestones late by 1 month due to Government shutdown. None of these are on the critical path, so caused no launch delay.
When is a Mission Too Cheap?*

Implications of the WMAP year-9 & Planck13 results for JWST science:

The year-9 WMAP data provided better foreground removal (Komatsu\(^+\) 2011; Hinshaw\(^+\) 2012; but see: Planck XVI 2013.)

First Light & Reionization occurred between these extremes:

- (1) Instantaneous at \(z \approx 11.1 \pm 1.1\) (\(\tau = 0.089 \pm 0.013\)), or, more likely:
- (2) Inhomogeneous & drawn out: starting at \(z \gtrsim 20\), peaking at \(z \lesssim 11\), ending at \(z \approx 7\).

The implications for HST and JWST are:

- HST/ACS has covered \(z \lesssim 6\), and WFC3 is covering \(z \lesssim 7–9\).
- For First Light & Reionization, JWST will survey \(z \approx 8\) to \(z \approx 15–20\).

Question: If Planck-\(\tau\) ↓ \(\lesssim 0.08\) (TBD, Planck14), then how many reionizers will JWST see at \(z \approx 10–20\)?
[Left] GAMA groups with secure AAT redshifts for $R \lesssim 19.8$ AB-mag. Also show redshift probability and absolute magnitude ($M_r$) distributions.

[Right] Measured group redshift distribution for two GAMA groups.

- Will select our WMDF IDS targets on groups (+ some clusters).
Same as p. 15, but optimistic $M^*(z)$ drop: $\mu = 0.33$ (Oesch et al. 2013).

- If so, far more $9 \lesssim z \lesssim 12$ objects expected in XDF, even though $N(6 \lesssim z \lesssim 8)$ remains the same $\iff M^*(z \sim 11)$ fainter than $-17.5 \pm 0.5$ mag?
Same as pg. 15, but pessimistic $M^* (z)$ evolution parameter: $\mu = 1.0$.

- If so, JWST surveys would need lensing to see most $\gtrsim 11$ objects.
- Add $z \approx 6$ QSO host galaxy limits (or fluxes) by Mechtley$^+$ (2012, 2013).
B, I, J AB-mag vs. half-light radii $r_e$ from RC3 to HUDF limit are shown.

All surveys limited by by SB (+5 mag dash)

Deep surveys bounded also by object density.

Violet lines are gxy counts converted to to natural conf limits.

Natural confusion sets in for faintest surveys (AB$\gtrsim$25). Will update for JWST.