Preparing for the James Webb Space Telescope

Jason Kalirai
(Project Scientist for JWST at STScI)
The James Webb Space Telescope
The JWST Instrument Suite

NIRCam

MIRI

NIRISS

NIRSpec
Space Based MOS

Mid IR IFUs

Near IR IFUs

Science Capabilities

Ultra Sensitive and High Resolution Imaging

Bright Object Modes

Single Object and Wide-Field Slitless Spectroscopy

Moving Target Support

NIR and MIR Coronagraphy
Multiplexed Spectroscopy in Crowded Environments

248,000 microshutters!

Human Hair 90 um Dia.
Multiplexed Spectroscopy in Crowded Environments
Multiplexed Spectroscopy in Crowded Environments

Targets in Operable Shutters

x Targets Outside Shutters
JWST Point Source Sensitivity
JWST is on schedule for its Oct 2018 LAUNCH!
A Better Snapshot of the Cycle 1 JWST Science Program

“Exploring the Universe with JWST”
Conference in ESTEC (Oct 12-16, 2015)
R. Ellis - z = 8 galaxy **spectra** w/ JWST

Hubble deep field imaging has contributed to demographics of early galaxies (#s, LFs, colors)

**JWST spectroscopy will address detailed astrophysics**
- nature of star formation: regular or burst-like (feedback)
- ionizing spectrum (stellar pops, role of AGN)
- escape fraction of Lyman limit photons
- chemical composition: O/H, C/O ratios (early nucleosynthesis)
- is there dust?
Tremendous progress in understanding $1 < z < 6$ galaxies, where 75% of the Universe’s stars formed.

**JWST’s resolution and sensitivity in the near IR will be a game changer, and answer these questions**
- How much hidden star-formation at $z > 3$?
- What are we missing? Red galaxies - dusty and/or old?
- Galaxy structures at $z > 3$? Where are the mergers? Where are metals and gas outflows at high $z$?
- Super massive black holes/AGNs at $z > 1$? What is the role of (dusty) AGN in galaxy assembly?
- What is the role of environment?
E. van Dischoeck - Embedded Phase of Star Formation w/ JWST
Spitzer, Herschel, WISE, and ground submm have built complete inventories of protostars out to a few kpc
JWST IFU spectroscopy will now characterize physics and chemistry on 10 - 1000 AU scales
- lots of IR diagnostics to use, each giving insights on the disk, accretion, shock, UV, high energy, etc.
- need modeling tools and lab data!
- JWST spatial resolution will resolve disks and envelopes.
- Physical structure of warm dust, geometry, earliest stages of massive star formation, variability, where
does matter enter disk, fragmentation, resolve accretion from outflow shocks, water transport from clouds.

A More Complete Snapshot of Cycle 1 Science
Space based IR observations have uncovered the substellar regime.

**JWST NIR and MIR imaging will measure complete stellar-planetary census in star forming regions**

- JWST will see free floating Jupiter mass objects in Orion
- thousands of circumstellar disks in a variety of environments and evolutionary states
- unbiased IMF over a complete mass distribution, and its variation with environment (e.g., spatial)
- spectra of 1-10 M\textsubscript{JUP} objects in clusters to help interpret spectra of young planets
A. Ferguson - Resolving Populations in the Local Volume w/ JWST

HST has been limited to direct measurements of the oldest stellar generations in the Local Group. JWST will measure the fossil record of different galaxy types in detail:

- wonderful opportunity to connect near-field and far-field approaches that study galaxy assembly
- infrared baseline provides high precision ages of dark matter dominated UFDs (suppression by reionization)
- diverse history of dwarfs and their cosmological significance
- spatially resolved star formation histories for different galaxy types in the Local Volume

Brown et al. (2014)
Great Observatories have played a tremendous role in studying the Solar System. JWST can track every object outside the orbit of Mars - atmospheric dynamics and chemistry of outer planets - spectroscopy of moons and rings to assess temporal variation (seasonal and time variable effects) - set the stage for future planetary missions to the outer Solar System - dedicated talks on KBOs, comets, Titan, occultations, asteroids
V. Meadows - Characterizing Potentially Habitable Planets w/ JWST

K2 and TESS are (will) yield prime targets for JWST follow up

**JWST provides our first opportunity to characterize habitable zone terrestrial planets**

- JWST may be able to detect O4 dimer at 1.06 and 1.27 microns (Earth like planet at 5 pc)
  - will require ppm sensitivity, long integrations, and favorable conditions (e.g., no haze).
- warm mini Neptunes will be straightforward for JWST (cloud and atmospheric composition)
- lots of exciting mid infrared exoplanet science also
Represents the Scientific Community and Advises the STScI Director

Roberto Abraham (Toronto)
Neta Bahcall (Princeton)
Natalie Batalha (NASA Ames)
Stefi Baum (Manitoba)
Roger Brissenden (Chandra/SAO)
Hashima Hasan (NASA, ex-officio)
Tim Heckman (Johns Hopkins)
Garth Illingworth (Santa Cruz, Chair)
Malcolm Longair (Cavendish)
John Mather (NASA, ex-officio)
Mark McCaughrean (ESA, ex-officio)
Chris McKee (Berkeley)
Brad Peterson (Ohio State)
Alain Ouellet (CSA, ex-officio)
Joseph Rothenberg (JHR Consulting)
Eric Smith (NASA, ex-officio)
Lisa Storrie-Lombardi (Spitzer/Caltech)
Monica Tosi (Bologna)

http://www.stsci.edu/jwst/advisory-committee
JWST Advisory Committee Activities

JSTAC is chaired by Garth Illingworth (UC Santa Cruz)
JSTAC meets at STScI twice every year (last meeting May 2015)
See http://www.stsci.edu/jwst/advisory-committee for more information

Recently, JSTAC has been focussed on ways to maximize early science from JWST

2014-2015 JSTAC recommendations to the STScI Director

Mar 2014
Early Release Science

Mar 2014
Proprietary Time

Nov 2014
Proposal Selection, Observing Overheads, Duplication Policy

Jan 2015
Parallel Observations

May 2015
GO Funding Level
JWST Science Planning Timeline

Commissioning proposals

Commissioning (Oct 2018 - Apr 2019)

Apr 2019 - Cycle 1 science

GTO & GO

2016
2017
2018
2019
2020

Launch
Oct 2018

2016
2017
2018
2019
2020

2017
2018
2019
2020

2018
2019
2020

2016
2017
2018
2019
2020

Commissioning
proposals

Commissioning
(Oct 2018 - Apr 2019)

Apr 2019 - Cycle 1 science

GTO & GO

Draft (Jan 2016)
JWST Science Planning Timeline

- **2016**: Jan 2017 - GTO CP
- **2017**: Apr 2017 - GTO proposal deadline, Jun 2017 - GTO Cy1 observations finalized
- **2018**: April 2017, LAUNCH Oct 2018
- **2019**: Commissioning (Oct 2018 - Apr 2019), Apr 2019 - Cycle 1 science, GTO & GO
- **2020**
JWST Science Planning Timeline

- Commissioning proposals
- Nov 2017 GO CP
- Feb 2018 GO Cy1 deadline
- Apr 2019 - Cycle 1 science GTO & GO
- Apr 2019 - Cycle 1 science
- GTO & GO

Timeline:
- 2016
  - Jan 2017 - GTO CP
- 2017
  - Apr 2017 GTO proposal deadline
  - Jun 2017 - GTO Cy1 observations finalized
- 2018
  - LAUNCH Oct 2018

Draft (Jan 2016)
JWST Science Planning Timeline

The GO community will have very limited access to non-proprietary observations to aid preparations for Cycle 2 programs.
The Early Release Science Program (ERS)

The JSTAC has recommended an Early Release Science Program for JWST

June 2010

“..to obtain images and spectra that would be used to demonstrate key modes of the JWST instruments. The goal of this program is to enable the community to understand the performance of JWST prior to the submission of the first post-launch Cycle 2 proposals that will be submitted just months after the end of commissioning.”

“The JSTAC recommends that the First-Look data be released both in raw form and with any initial calibrations as soon as possible; the key aspect is speed.”

The JSTAC has reiterated its support for the ERS in recent meetings (e.g., see March 2014 letter)

Program Implementation

- STScI had an open dialogue about ERS concepts at recent meetings (e.g., Jan 2016 AAS meeting)
- Program will be supported by Director’s Discretionary time (assume ~15 modes x 20-25 hrs)
- Program will be shaped with significant involvement of the astronomical community
- Program will be selected to span key JWST observing modes, data analysis challenges, science areas
- Program will execute early in Cycle 1 and have no proprietary time
- ERS teams will be responsible for rapid delivery of science enabling products to MAST

The ERS program is a fantastic opportunity to become an expert on JWST

http://www.stsci.edu/jwst/science/ers

N. Reid’s ERS Presentation from the Jan 2016 AAS Meeting:

http://www.stsci.edu/jwst/doc-archive/presentations
Upcoming JWST Milestones for User Tools

2016
- ETC Engine Release (development)
- 227th AAS Conference

2017
- First User Documentation Release (incremental)
- ETC WebApp + Simulator Flight Release
- Early Release Science Program Deadline

2018
- Cycle 1 Deadline
- APT Flight Release
- Lots of science workshops and training sessions planned throughout
Coming Soon: Exploring the Universe with JWST II

September 24–27, 2007
Marriott Starr Pass, Tucson AZ

Science Organizing Committee:
Crystal Brogan, Dale Cruikshank, Ewine van Dishoeck, Alan Dressler (Chair), Richard Ellis, Rob Kennicutt, Rolf Kudritzki, Avi Loeb, John Mather, Yvonne Pendleton, Massimo Stiavelli (ex officio SWG liason), Peter Stockman (ex officio LOC liason), Leonardo Testi, Xander Tielens, Meg Urry, Jeff Valenti

Local Organizing Committee:
Jonathan Gardner, Matt Greenhouse, Heidi Hammel, John Mather, Neill Reid, Massimo Stiavelli, Peter Stockman, Harley Thronson

Image Credits:
ALMA (Courtesy NRAO/AUI and ESO), Herschel Spacecraft (ESA), TMT (Thirty-Meter Telescope Project), ELT (ESO).

Speakers:
Tom Abel, Mike Barlow, Mark Dickinson, Carsten Dominik, Xiaohui Fan, Steve Furlanetto, Zoltan Haiman, Tim Heckman, David Jewitt, Avi Loeb, Mark Marley, Mike Meyer, Sara Seager, Alice Shapley, Max Tegmark, Alexander Tielens, Jean Turner, Ewine van Dishoeck

Sept 2007 (Tucson)
Jun 2011 (STScI)
Oct 2015 (ESTEC)

October 24-28th, 2016
Montreal, Canada
#JWST
A Breakthrough in Photon and Diffraction Limited Science

**Photon Limited Science**

Hubble pixels are 0.04-0.05” at <1 micron and 0.13” at > 1 micron
Spitzer pixels are 1.2” at < 8 micron and 2.55” at 24 micron

--- Hubble does not achieve Nyquist sampling of the diffraction limit
--- Spitzer only achieves Nyquist sampling at > 24 microns

**Diffraction Limited Science**

JWST achieves Nyquist sampling of the diffraction limit at 2, 4, and 7+ microns
JWST Commissioning Phase (6 months)

**Phase I - Commission the Spacecraft (30 days)**
- Launch and mid-course corrections
- Deployment of solar arrays, sunshield, mirrors
- Subsystem check outs
- NIR instrument cooldown modifications

**Phase II - Commissioning the Telescope (90 days)**
- Fine phasing of Optical Telescope Element (OTE) with NIRCam & FGS
- NIR instruments are activated and checked out
- MIRI cooldown via the cryocooler
- All science instruments used to align and optimize OTE

**Phase III - Commissioning the Science (60 days)**
- Each instrument is independently focused, calibrated, and characterized
- Science instruments participate in observatory level tests (thermal slew, stray light, mechanism disturbance, moving target)
- Begin ERO, ERS, Cycle 1 science and calibration programs asap

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<th>Oct 2018</th>
<th>April 2019</th>
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[Diagram showing timeline from Oct 2018 to April 2019]
Near Infrared Camera (NIRCam)

NIRCam Capabilities

2 channel imager from $\lambda = 0.6$ to $5.0$ microns, get $\lambda < 2.5$ & $\lambda > 2.5$ micron simultaneously
Nyquist sampling of diffraction limit at 2 microns (0.032”/pixel) and 4 microns (0.065”/pixel)
2.2’ x 4.4’ field of view
Short and long wavelength coronagrapy
Slitless spectroscopy for $\lambda = 2.4 – 5.0$ micron

Built by Univ. of Arizona and Lockheed-Martin
Near Infrared Spectroscopy (NIRSpec)

NIRSpec Capabilities

Near Infrared wavelength coverage of $\lambda = 0.6$ to 5.0 microns
Three different spectral resolutions of $R = 100$, 1000, and 2700
Modes: Single Slit Spectroscopy (slits with 0.4” x 3.8”, 0.2” x 3.3”, 1.6” x 1.6”)
    Integral Field Unit (3.0” x 3.0”)
    Multi Object Spectroscopy (3.4’ x 3.4’ with 250,000 - 0.2” x 0.5” microshutters)

Built by ESA and Airbus
Mid Infrared Instrument (MIRI)

MIRI Capabilities
High resolution imager with sensitivity from $\lambda = 5$ to 28 microns, 10 broad-band filters
$\lambda = 5.0$ to 28.3 microns with 0.11” pixels
1.23’ x 1.88’ field of view
Coronagraphy at 10.65, 11.4, 15.5, and 23 microns (24” to 30” field of view)
Integral Field Unit with $R = 2200$ to 3500, at 4 wavelengths (image slices 0.18” to 0.64”)
Single Slit Spectroscopy from 5.0 to ~14 microns in 0.6 x 5.5” slit ($R \sim 100$ at 7.5 microns)

Built by ESA and JPL
Near Infrared Imager and Slitless Spectrograph

NIRISS Capabilities

Imaging - $\lambda = 0.9$ to 5.0 microns over a 2.2' x 2.2' field of view with 0.065” pixels

Wide Field Slitless Spectroscopy - $\lambda = 1.0$ to 2.5 microns at $R \sim 150$

Single Object Slitless Spectroscopy - $\lambda = 0.6$ to 2.5 microns at $R \sim 700$

Aperture Mask Interferometry - $\lambda = 3.8$ to 4.8 microns, enabled by non-redundant mask

Built by CSA and COMDEV
JWST Primer

Description
Deployable infrared telescope with a 6.5 meter segmented adjustable primary mirror
Cryogenic temperature telescope and instruments optimized for IR performance
Launch in Oct 2018 on an ESA Ariane 5 rocket to Sun-Earth L2 point (1 million miles)
10-year science mission goal

Organization
Mission lead: NASA’s Goddard Space Flight Center
International collaborators: European and Canadian Space Agencies (ESA and CSA)
Prime Contractor: Northrop Grumman Aerospace Systems
Flight and Science Operations Center: Space Telescope Science Institute