Hubble Science Briefing

NASA’s Next Flagship Observatory: The James Webb Space Telescope

September 6th, 2012
Jason Kalirai (STScI)
NASA’s Next Flagship Observatory
The James Webb Space Telescope

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Outline
1.) NASA’s Great Observatories
2.) The Top Astronomy Questions Today
3.) The James Webb Space Telescope
4.) JWST – Technology
5.) JWST – Science
The Great Observatories
The Great Observatories

**HST Discoveries**
1.) Dark energy and the expansion of the Universe
2.) Supermassive black holes
3.) The age of the Universe
4.) Gravitational lensing
5.) Dark matter
6.) Imaging and spectroscopy of exoplanets
7.) Sources of GRBs
8.) Ages of stellar pops beyond the Milky Way
9.) Precise Measurements of the Hubble Constant
10.) Intensities of Supernovae

....
The Hubble Space Telescope - Powers of 10

1,000,000 Observations

100,000 Citations received in past two years

10,000 Refereed papers

1,000 Number of proposals received each year

100 Graduate students supported each year

10 Redshift of most distant galaxy candidate

1 Nobel prize
The Hubble Space Telescope’s Longevity
A New Set of Scientific Challenges

Hubble and Spitzer have paved the way for a telescope that combines the best features of both.
New Frontiers of Astronomy

1.) Seek the first stars and galaxies that formed in the early Universe, and follow the ionization history
A New Set of Scientific Challenges

New Frontiers of Astronomy

2.) Determine how galaxies evolve from the early Universe to the present day (stars, gas, metals, dark matter)
A New Set of Scientific Challenges

New Frontiers of Astronomy

3.) Solve the mysteries of star formation and birth of protoplanetary systems
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New Frontiers of Astronomy

4.) Probe the chemical properties of solar systems (including our own) to constrain the building blocks of life
A New Set of Scientific Challenges

A “Wish List” for an Exoplanet Spectroscopy Platform

Dr. David Charbonneau (CfA/Harvard) Jan 2012 AAS Meeting (Austin, TX)

1.) Orbit that assures thermal stability and low background
2.) Orbit that assures long dwell times
3.) A stable PSF and excellent pointing
4.) Infrared sensitivity (planetary temperatures; molecules)
5.) Aperture sufficient to permit medium resolution spectroscopy
A New Set of Scientific Challenges

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These are obtained with a large aperture, cryogenic telescope placed at L2, with a detailed error budget and careful instrument characterization prior to launch.
**New Frontiers of Astronomy**

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2. Determine how galaxies evolve from the early Universe to the present day (stars, gas, metals, dark matter)
3. Solve the mysteries of star formation and birth of protoplanetary systems
4. Probe the chemical properties of solar systems (including our own) to constrain the building blocks of life

**Answering the Challenges**

- Requires 100 times the sensitivity of Hubble
- Requires 10 times the image sharpness of Hubble in the infrared
- Requires wavelength coverage out to 27 microns
The JWST Concept

**Answering the Challenges**

- A telescope with >100x more power than present Great Observatories
- Comparable in size to the largest ground-based telescopes, yet light weight (JWST is the size of a tennis court).
- Deployable in space
- Operates at cryogenic temperatures
- Launches out to 1 million miles
- Contains a new generation of complex instrumentation to ensure diverse modes of operation without servicing
The JWST Concept

**Technological Firsts to Achieve this Mission**

1.) Segmented Beryllium Primary Mirror  
2.) Composite Backplane Structure  
3.) Mirror Phasing and Control Software  
4.) Application Specific Integrated Circuit  
5.) Micro-Shutters  
6.) Sunshield Membranes  
7.) Mid-Infrared Detectors  
8.) Cryo-cooler for Mid-Infrared Instrument  
9.) Other “inventions” (e.g., Tinsley’s Shack-Hartmann technique for mirror surface measurement, SSHS)
The Largest Cryogenic Telescope ever Constructed

- Requires 100 times the sensitivity of Hubble
- Requires 10 times the image sharpness of Hubble in the infrared
- Requires wavelength coverage out to 27 microns
JWST Technology – A 6.5 m Segmented Mirror in Space

Ambient SFE

Cryogenic SFE at 40 K

Fine Steering Mirror

Tertiary Mirror

Secondary Mirror

Primary Mirror Segments
JWST Technology – A 6.5 m Segmented Mirror in Space
JWST Technology – A Tennis-Court Sized 5-Layer Sunshield
JWST Technology – A Complex Suite of Instruments

The Integrated Science Instrument Module Hosts 4 JWST Science Instruments

- The Near Infrared Camera – NIRCam
- The Near Infrared Spectrograph – NIRSpec
- The Mid Infrared Instrument – MIRI
- The Near Infrared Imager and Slitless Spectrograph – NIRISS

Not your Typical Telescope

- >40 imaging filters with fields of view larger than Hubble
- 8 different types of spectroscopic modes (wide field grism, single object, IFU, multiobject)
- 7 coronographs including non-redundant aperture masks for high-resolution imaging
NIRCam will be the workhorse imaging instrument of JWST
The Hubble UDF/IR (F105W, F125W, F160W)

Simulated JWST NIRCam
JWST Technology – NIRSpec

NIRCam will be the workhorse spectroscopic instrument of JWST
JWST Technology – NIRSpec Microshutter Array

Human Hair 90 um Dia.

Flight MSA

203 x 463 mas shutter pixel clear aperture, 267 x 528 mas pitch, 4 x 171 x 365 array

Human Hair 90 um Dia.
JWST Technology – NIRSpec Microshutter Array

The NIRSpec Microshutter Array superimposed on the center of Omega Cen

+ Targets in operable shutter
x Targets outside shutters
MIRI will be JWST’s most versatile instrument
JWST Technology – Integration and Testing
JWST Technology – Integration and Testing

Suspension system which holds the OTE support structure, CoCi, and ACFs.

Vibration isolation system for suspension system. Six minor intrusions thru the chamber.

Cryo-Position Metrology provided by photogrammetry with cameras mounted on windmills to provide conical scanning.

Suspension system which holds the OTE support structure, CoCi, and ACFs.

Test sources mounted on the AOS entrance. Inward sources sample the Tertiary Mirror. Outward sources make a pass and a half thru the OTE optics.
JWST: Finding Life-Bearing Planets

Searching for the Goldilocks Planet!
Determining Robust Physical Parameters

Doppler Method
Determine Planet Mass

Transit Method
Determine Planet Diameter

Calculate Planet Density and Infer Composition:
Gas giant (Jupiter), Ice giant (Neptune), or Rocky planet (Earth)
JWST: Finding Life-Bearing Planets

Transits Allow Studies of Atmospheres

Secondary Eclipse

See thermal radiation and reflected light from planet disappear and reappear

Transit

See radiation from star transmitted through the planet’s atmosphere
Transits Allow Studies of Atmospheres

Detection of:
- Atoms & Molecules
- Stratospheres
- Clouds
- Winds
What Would the Earth’s Spectrum Look Like?
- Every planet has a unique fingerprint, produced by its atmosphere.
- The Earth shows nitrogen, oxygen, carbon dioxide, and water vapor.
## JWST: Finding Life-Bearing Planets

**Progress in the Past Decade: Knowledge is Exploding**

<table>
<thead>
<tr>
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## JWST: Finding Life-Bearing Planets

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JWST: Finding Life-Bearing Planets

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<tr>
<td>2011</td>
<td>150 (but really 1300)</td>
<td>50</td>
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The Kepler Mission

Planetary candidates in 1st data release

- 1235 candidates
- 68 Earth-sized planets
- 54 candidates in habitable zone
- 5.4% of stars host Earth sized planetary candidate
- Kepler 22b announcement recently!
## JWST Transit Capabilities

<table>
<thead>
<tr>
<th>Application</th>
<th>Planet Type</th>
<th>Res.</th>
<th>JWST Scientific Investigations</th>
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<tbody>
<tr>
<td>Transit Light Curves</td>
<td>Gas Giants</td>
<td>5</td>
<td>- Planet prop. w/ RVs (mass, radius) → physical structure</td>
</tr>
<tr>
<td></td>
<td>Intermediate Mass</td>
<td>5</td>
<td></td>
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<td></td>
<td>Super Earths</td>
<td>5</td>
<td></td>
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<tr>
<td></td>
<td>Terrestrial Planets</td>
<td>5</td>
<td>- Detection of terrestrial transits</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Transit timing: detection of unseen planets</td>
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<tr>
<td>Phase Light Curves</td>
<td>Gas Giants</td>
<td>5</td>
<td>- Day to night emission mapping</td>
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<td>Hot Neptunes</td>
<td>5</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Dynamical models of atmospheres</td>
</tr>
<tr>
<td>Transmission</td>
<td>Gas Giants</td>
<td>3000</td>
<td>- Spectral line diagnostics</td>
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<tr>
<td>Spectroscopy</td>
<td>Intermediate Mass</td>
<td>100-500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Super Earths</td>
<td>&lt;100</td>
<td>- Atmospheric composition measurements (C, CO₂, CH₄)</td>
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<td></td>
<td></td>
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<td>- Follow up of survey detections</td>
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JWST: Finding Life-Bearing Planets

A Simulated JWST/NIRSpec Observation
- Hydrogen-Rich Super Earth (1.4 R_{Earth}, 5 M_{Earth})

M. Clampin – Model by E. Kempton
JWST will Study the First Galaxies

Why measure galaxies in the Universe’s first billion years?
  • Seeds of today’s galaxies started growing.
  • Dark matter halos of massive galaxies first formed.
  • Significant metals first formed.
  • When the Universe was reionized.

JWST will resolve ambiguities from Hubble and Spitzer in interpreting high redshift galaxies.
A candidate $z \sim 10$ galaxy; Bouwens et al. (2011)
Hints from Hubble that a big change is occurring 400 – 600 Myr after the Big Bang.

JWST will provide a robust picture of the number of galaxies and their properties.

May need help from gravitational lensing (do homework now).

How do we know if we’ve found the first galaxies? See R. Ellis’ talk at the “Frontier Science Opportunities with JWST” meeting.
Properties

- Thought to be very massive (25 – 500 Msun)
- Form in isolation
- $T_{\text{surface}} \approx 100,000$ K
- Luminous sources of ionizing photons
- 2-3 Myr lifetimes

D. Whalen’s talk at the “Frontier Science Opportunities with JWST” meeting

New simulated light curves show late time rise over > 100 days.

Infrared energy diffuses out through dense ejecta of PI SNe... can be measured with JWST to $z > 10$ and maybe 15 with strong lensing in this model.

Ground based follow up with 30-m telescopes will help distinguish progenitors.
JWST and Dark Energy

1.) JWST is the only telescope that can measure type Ia SNe out to $z = 3.5$

2.) JWST will characterize Cepheids in further galaxies
   • Calibrate more type Ia SNe
   • Simpler in the IR, less scatter

3.) $H_0$ to 1%, ties down ties local expansion rate.

4.) Planck CMB gives distance scale at $z = 1000$.
   $\longrightarrow$ Two measurements provide an over constrained problem. Take one of the measurements, vary the cosmological model (i.e., $w$) to match the other.
Keep up to Speed with JWST


JWST Exposure Time Calculator – http://jwstetc.stsci.edu/etc/

JWST PSF Tool – http://www.stsci.edu/jwst/software/webbpsf.html

JWST Email For Community Input – jwst_input@stsci.edu

JWST Facebook Page For Astronomers – “JWST Observer”

JWST Twitter – @auraJWST


JWST flickr – http://www.flickr.com/photos/nasawebbtelescope/