What is FIRST LIGHT?

End of the dark ages: first light and reionization

What are the first luminous objects?
What are the first galaxies?
How did black holes form and interact with their host galaxies?
When did re-ionization of the inter-galactic medium occur?
What caused the re-ionization?

... to identify the first luminous sources to form and to determine the ionization history of the early universe.

Hubble Ultra Deep Field
First Light: Observing Reionization Edge

Reionization started at about 600 M yrs after Big Bang. At 780 M yrs after BB the Universe was up to 50% Neutral. But, by 1 B years after BB is was as we see it today.  787 M yr Galaxy confirmed by Neutral Hydrogen method.

Neutral ‘fog’ was dissolved by very bright 1st Generation Stars (5000X younger & ~100X more massive than our sun).
Cosmic Web

Ripples in the early universe formed long filaments of hydrogen gas surrounded by ‘dark matter’.

Galaxies form at crossing points.

Most of universe’s matter is in these filaments and dark matter.

This one is 10B light years away.

A filament of the universe’s “cosmic web” is highlighted with parallel curved lines in this image, while a protogalaxy is outlined with an ellipse. The brightest spot (on the lower right side of the ellipse) is the quasar UM287. The other bright spot is a second quasar in the system. The image combines a visible light image with data from the Cosmic Web Imager.

CREDIT: Chris Martin/PCWI/Caltech
Charles Choi, Space.com, 5 Aug 2015.
Hubble Ultra Deep Field – Near Infrared

Near-Infrared image taken with new Wide-Field Camera 3 was acquired over 4 days with a 173,000 second exposure.

Hubble Ultra Deep Field – Near Infrared

47 Galaxies have been observed at 600 to 650 Myrs after BB.
What came first – Galaxies or Black Holes?
Each of these ancient 700 M yrs after BB galaxies has a black hole.
Only the most energetic x-rays are detected, indicating that the black-holes are inside very young galaxies with lots of gas.

Redshift
The further away an object is, the more its light is redshifted from the visible into the infrared.
Hubble Ultra Deep Field – Near Infrared

At 480 M yrs after big bang ($z \sim 10$) this one of oldest observed galaxy. Discovered using drop-out technique. (current oldest is 420 M yrs after BB, maybe only 200 M yrs)

Left image is visible light, and the next three in near-infrared filters. The galaxy suddenly pop up in the H filter, at a wavelength of 1.6 microns (a little over twice the wavelength the eye can detect). (Discover, Bad Astronomy, 26 Jan 2011)

JWST Summary

- **Mission Objective**
  - Study origin & evolution of galaxies, stars & planetary systems
  - Optimized for near infrared wavelength (0.6 –28 \( \mu m \))
  - 5 year Mission Life (10 year Goal)

- **Organization**
  - Mission Lead: Goddard Space Flight Center
  - International collaboration with ESA & CSA
  - Prime Contractor: Northrop Grumman Space Technology
  - Instruments:
    - Near Infrared Camera (NIRCam) – Univ. of Arizona
    - Near Infrared Spectrometer (NIRSpec) – ESA
    - Mid-Infrared Instrument (MIRI) – JPL/ESA
    - Fine Guidance Sensor (FGS) – CSA
  - Operations: Space Telescope Science Institute
Origins Theme’s Fundamental Questions

• How Did We Get Here?
• Where Are We Going?
• Are We Alone?

JWST Science Themes

- Big Bang
- First Light and Re-Ionization
- Galaxy Formation
- HH 30-16
- Star Formation
- Planetary Life
- Galaxy Evolution
Three Key Facts

There are 3 key facts about JWST that enables it to perform its Science Mission:

- It is a Space Telescope
- It is an Infrared Telescope
- It has a Large Aperture

Why go to Space

Atmospheric Transmission drives the need to go to space.

Infrared (mid and far/sub-mm) Telescopes (also uv, x-ray, and gamma-ray) cannot see through the Atmosphere.
Infrared Light

Why Infrared?
Why do we need Large Apertures?
Aperture = Sensitivity

Adapted from *Cosmic Discovery*, M. Harwit

Sensitivity Improvement over the Eye

<table>
<thead>
<tr>
<th>Year</th>
<th>Telescope</th>
<th>Aperture</th>
<th>f Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600</td>
<td>Galileo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1700</td>
<td>Huygens</td>
<td></td>
<td>Slow</td>
</tr>
<tr>
<td>1800</td>
<td>Short's</td>
<td>21.5&quot;</td>
<td>f 4.8</td>
</tr>
<tr>
<td>1900</td>
<td>Herschell</td>
<td>48&quot;</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Rosse</td>
<td>72&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Photographic & electronic detection
Telescopes alone
CCDs
HST
JWST

Sensitivity Matters

GOODS CDFS – 13 orbits
HUDF – 400 orbits
JWST will be more Sensitive than Hubble or Spitzer

**HUBBLE**
- 2.4-meter
- T ~ 270 K
- 123" x 136"
- $\lambda/D_{1.6\mu m} \approx 0.14$

**JWST**
- 6.5-meter
- T ~ 40 K
- 132" x 164"
- $\lambda/D_{2\mu m} \approx 0.06$
- 114" x 84"
- $\lambda/D_{20\mu m} \approx 0.64$

**SPITZER**
- 0.8-meter
- T ~ 5.5 K
- 312" x 312"
- $\lambda/D_{5.6\mu m} \approx 2.22$
- 324" x 324"
- $\lambda/D_{24\mu m} \approx 6.2$

**Wavelength Coverage**

**HST**
- 1 μm

**JWST**
- 10 μm
- 100 μm

**Spitzer**

How big is JWST?
How JWST Works

- JWST orbits the 2nd Lagrange Point (L2)
  - 239,000 miles (384,000km)
  - 930,000 miles (1.5 million km)

- JWST is folded and stowed for launch
- Observatory is deployed after launch

- Integrated Science Instrument Module (ISIM)
- Primary Mirror
- Secondary Mirror
- Solar Array
- Spacecraft Bus

Sun

Hot Side

Cold Side: ~40K

5 Layer Sunshield
JWST Science Instruments
enable imagery and spectroscopy over the 0.6 – 29 micron spectrum

JWST Requirements

Optical Telescope Element
25 sq meter Collecting Area
2 micrometer Diffraction Limit
< 50K (~35K) Operating Temp

Primary Mirror
6.6 meter diameter (tip to tip)
< 25 kg/m² Areal Density
< $6 M/m² Areal Cost
18 Hex Segments in 2 Rings
Drop Leaf Wing Deployment

Segments
1.315 meter Flat to Flat Diameter
< 20 nm rms Surface Figure Error

<table>
<thead>
<tr>
<th>Surface Figure Error</th>
<th>Low (0-5 cycles/aper)</th>
<th>CSF (5-35 cycles/aper)</th>
<th>Mid (35-65K cycles/aper)</th>
<th>Micro-roughness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 nm rms</td>
<td>18 nm rms</td>
<td>7 nm rms</td>
<td>&lt;4 nm rms</td>
</tr>
</tbody>
</table>
**Fun Fact – Mirror Surface Tolerance**

- **Human Hair**
  - Diameter is 100,000 nm (typical)

- **PMSA**
  - **PMSA Surface Figure Error**
    - < 20 nm (rms)

**Technology Development of Large Optical Systems**

- **MSFC is the JWST Primary Mirror Segment Technology Development Lead for JWST**
  - The 18 Primary Mirror segments

- **AMSD II – Be technology selected for JWST**
  - 6.5 M
Based on lessons learned, JWST invested early in mirror technology to address lower areal densities and cryogenic operations.

Advantages of Beryllium

Very High Specific Stiffness – Modulus/Mass Ratio

Saves Mass – Saves Money

High Conductivity & Below 100K, CTE is virtually zero.

Thermal Stability
Figure Change: 30-55K Operational Range

Beryllium

Surface Figure With Alignment Compensation

ULE Glass

Residual with 36 Zernikes Removed

Brush Wellman
Axsys Technologies
Batch #1 (Pathfinder) PM Segments

Batch #2 PM Segments

Fun Facts – Mirror Manufacturing

Before

After

Be Billet

250 kgs

Be dust which is recycled

Finished Mirror Segment

21 kgs

Over 90% of material is removed to make each mirror segment – want a little mirror with your Be dust?
Mirror Processing at Tinsley

Optical Testing Challenge

JWST

In-Process Optical Testing

Requirement Compliance Certification Verification & Validation

is probably the most difficult metrology job of our generation

But, the challenge has been met:

by the hard work of dozens of optical metrologists,

the development and qualification of multiple custom test setups, and

several new inventions, including 4D PhaseCam and Leica ADM.
Tinsley In-Process Metrology Tools

Metrology tools provide feedback at every manufacturing stage:

- Rough Grinding: CMM
- Fine Grinding/Rough Polishing: Scanning Shack-Hartmann
- Final Polishing/Figuring/CNF: Interferometry

PMSA Interferometer Test Stations included:

- 2 Center of Curvature CGH Optical Test Stations (OTS1 and OTS2)
- Auto-Collimation Test Station

Data was validated by comparing overlap between tools

Independent cross check tests were performed at Tinsley and between Tinsley, Ball and XRCF.

Leitz CMM

Provided Low-Order Figure and Radius of Curvature Control

Over course of program, software and process improvements dramatically reduced cycle time and increased data density
Wavefront Sciences Scanning Shack-Hartmann

SSHS provided bridge-data between grind and polish, used until PMSA surface was within capture range of interferometry.

SSHS provide mid-spatial frequency control: 222 mm to 2 mm

Large dynamic range (0 – 4.6 mr surface slope)

When not used, convergence rate was degraded.

Comparison to CMM (222 - 2 mm spatial periods)

8/1/2006 data

Smooth grind

SSHS
4.7 µm PV, 0.64 µm RMS

CMM
4.8 µm PV, 0.65 µm RMS

Point-to-Point Subtraction: SSHS - CMM = 0.27 µm RMS
Full Aperture Optical Test Station (OTS)

Center of Curvature Null Test (Prescription, Radius & Figure)
- PMSAs measured in 6 rotational positions to back-out gravity
- ADM – measures spacing between CGH and segment
- CGH – generates aberrated wavefront
- Quad cells – mounted to segments measure displacement of spots projected through CGH to determine parent vertex location

Results are cross-checked between 2 test stations.
Test Reproducibility
(OTS-1 Test #1 vs. Test #2) VC6GA294-VC6HA270

Power
(Radius Delta: 0.02 mm)

Astigmatism:
4.4 nm RMS

Mid Frequency:
4.3 nm RMS

High Frequency:
3.9 nm RMS

Total Surface Delta:
PV: 373 nm
RMS: 7.6 nm

Auto-Collimation Test

Auto-Collimation Test provides independent cross-check of CGH Center of Curvature Test

Verifies:
Radius of Curvature
Conic Constant
Off-Axis Distance
Clocking

Note: is not a full-aperture figure verification test
Tinsley Laboratory – Final Shipment

Primary Mirror Segment Assembly at BATC
Ball Optical Test Station (BOTS)

Tinsley ambient metrology results are ‘cross-checked’ at BATC

BOTS measurements:
- Measure Configuration 1 to 2 deformation
- Measure Configuration 2 to 3 deformation
- Create a Gravity Backout file for use at XRCF
- Measure Vibration Testing Deformation
- Measure Vacuum Bakeout Deformation
- Measure Configuration 2 mirrors for BATC to Tinsley Data Correlation

Initially, BOTS and TOTS Radius did not agree. Discrepancy was determined to be caused by bulk temperature difference. Agreement is now at 10 nm rms level.
PMSA Flight Mirror Testing at MSFC XRCF

Cryogenic Performance Specifications are Certified at XRCF

Cryo-Vacuum Chamber is 7 m dia x 23 m long

Primary Mirror Cryogenic Tests
XRCF Cryo Test

Flight Mirrors in XRCF
Mirror Fabrication Status
ALL DONE & DELIVERED

Gold Coated Mirror Assemblies


Spare Mirrors

Flight Mirrors

SURFACE FIGURE ERROR
Total PM Composite: 23.2 nm RMS
PM Requirement: 25.0 nm RMS

Mirrors ≥ 98% at 2 µm
Primary Mirror Backplane

Pathfinder backplane (central section) is complete for test procedure verification at JSC
Flight Backplane under construction

Pathfinder Testing
Flight Backplane Testing

Observatory level testing occurs at JSC Chamber A

Verification Test Activities in JSC Chamber A
- Cryo Position Metrology
- Primary Mirror Stability Test
- Focus Sweep Test (inward facing sources)

Crosscheck Tests in JSC Chamber A
- Pupil Alignment Test
- Rogue Path Test
- Pass-and-a-Half Test
- Primary Mirror WFE Test
- End-to-End WFSC Demonstration

Chamber A:
- 37m tall, 20m diameter, 12m door
- LN2 shroud and GHe panels
JWST Launched on Ariane 5 Heavy

JWST folded and stowed for launch in 5 m dia x 17 m tall fairing

Launch from Kourou Launch Center (French Guiana) to L2

JWST vs. HST - orbit

JWST will operate at the 2nd Lagrange Point (L2) which is 1.5 Million km away from the earth.

HST in Low Earth Orbit, ~500 km up. Imaging affected by proximity to Earth
JWST Science Theme #1

End of the dark ages: first light and reionization

What are the first luminous objects?
What are the first galaxies?
How did black holes form and interact with their host galaxies?
When did re-ionization of the inter-galactic medium occur?
What caused the re-ionization?

... to identify the first luminous sources to form and to determine the ionization history of the early universe.

Hubble Ultra Deep Field
When and how did reionization occur?

Re-ionization happened at $z > 6$ or $< 1$ B yrs after Big Bang. WMAP says maybe twice?

Probably galaxies, maybe quasar contribution

Key Enabling Design Requirments:
- Deep near-infrared imaging survey (1nJy)
- Near-IR multi-object spectroscopy
- Mid-IR photometry and spectroscopy

JWST Observations:
- Spectra of the most distant quasars
- Spectra of faint galaxies

JWST Science Theme #2:

The assembly of galaxies

How did the heavy elements form?
How is the chemical evolution of the universe related to galaxy evolution?
What powers emission from galaxy nuclei?

When did the Hubble Sequence form?
What role did galaxy collisions play in their evolution?
Can we test hierarchical formation and global scaling relations?
What is relation between Evolution of Galaxies & Growth/Development of Black Holes in their nuclei?

... to determine how galaxies and the dark matter, gas, stars, metals, morphological structures, and active nuclei within them evolved from the epoch of reionization to the present day.
Distant Galaxies are “Train Wrecks”

Merging Galaxies = Merging Black Holes

Combined Chandra & Hubble data shows two black holes (one 30M & one 1M solar mass) orbiting each other – separated by 490 light-years. At 160 million light-years, these are the closest super massive black holes to Earth.

Theory says when galaxies collide there should be major disruption and new star formation.

This galaxy has regular spiral shape and the core is mostly old stars.

These two galaxies merged with minor perturbations.

Galaxy NGC3393 includes two active black holes
X-ray: NASA/CXC/SAO/G.Fabbiano et al; Optical: NASA/STScI

Charles Q. Choi, SPACE.com, 31 August 2011
JWST Science Theme #3:

Birth of stars and protoplanetary systems

How do molecular clouds collapse?
How does environment affect star-formation?
What is the mass distribution of low-mass stars?
What do debris disks reveal about the evolution of terrestrial planets?

... to unravel the birth and early evolution of stars, from infall on to dust-enshrouded protostars, to the genesis of planetary systems.

David Hardy

Spitzer has Found “The Mountains Of Creation”

L. Allen, CfA [GTO]
The Mountains Tell Their Tale
Interstellar erosion & star formation propagate through the cloud

Young (Solar Mass) Stars are Shown in This Panel
Really Young Stars are Shown in This Panel


Stellar Shockwave

Shockwave created by Zeta Ophiuchi which is moving towards the left at about 24 kilometres per second.

STARSTUFF IMAGE by Stuart Gary, ABC Science, 20 July 2015
Star Formation in Dust/Gas Cloud

Herschel discovered 700 newly-forming stars condensing along filaments of dust in a never before penetrated dark cloud at the heart of Eagle Nebula. Two areas glowing brightest in icy blue light are regions where large newborn stars are causing hydrogen gas to shine.

SPACE.com 16 December 2009

Orion Nebula Protoplanetary Discs

Hubble has discovered 42 protoplanetary discs in the Orion Nebula

Credit: NASA/ESA and L. Ricci (ESO)
All of Life’s Ingredients Found in Orion Nebula

Herschel Telescope has measured spectra for all the ingredients for life as we know them in the Orion Nebula.

(Methanol is a particularly important molecule)

Wired.com Mar 2010

---

JWST Science Theme #4:

Planetary systems and the origins of life

How do planets form?
How are circumstellar disks like our Solar System?
How are habitable zones established?

... to determine the physical and chemical properties of planetary systems including our own, and to investigate the potential for the origins of life in those systems.

Robert Hurt
Planetary Formation Questions and 2 Models

- How do planets and brown dwarfs form?
- How common are giant planets and what is their distribution of orbits?
- How do giant planets affect the formation of terrestrial planets?
- What comparisons, direct or indirect, can be made between our Solar System and circumstellar disks (forming solar systems) and remnant disks?
- What is the source of water and organics for planets in habitable zones?
- How are systems cleared of small bodies?
- What are the planetary evolutionary pathways by which habitability is established or lost?
- Does our solar system harbor evidence for steps on these pathways?

**TWO PLANET FORMATION SCENARIOS**

**Accretion model**
- Central star
- Dust disk
- Orbits dust grains accrete into "planetesimals" through gravitational forces.
- Planetesimals grow, moving in near-coplanar orbits, to form "planetary embryos."
- Gas-giant planets accrete gas envelopes before disk gas disappears.
- Gas-giant planets scatter or accrete remaining planetesimals and embryos.

**Gas-collapse model**
- A protoplanetary disk of gas and dust forms around a young star.
- Gravitational disk instabilities form a clump of gas that becomes a self-gravitating planet.
- Dust grains coagulate and sediment to the center of the protoplanet, forming a core.
- The planet sweeps out a wide gap as it continues to feed on gas in the disk.

History of Known (current) NEO Population

- **2006**
  - **Earth Crossing**
  - **Outside Earth's Orbit**

**Known**
- 340,000 minor planets
- ~4500 NEOs
- ~850 Potentially Hazardous Objects (PHOs)

Landis, "Piloted Flight to a Near-Earth Object", AIAA Conference 19 Sep 07
The central star of the Helix Nebula, a hot, luminous White Dwarf, shows an infrared excess attributable to a disk in a planetary system which survived the star’s chaotic evolution.

Dust disks are durable and omnipresent.

Planetary System Formation effects Dust

‘Kinks’ in the debris disk around Beta Pictoris was caused by the formation and subsequent migration of a Jupiter-sized planet called Beta Pictoris b.

The planet orbiting Beta Pictoris has caused a kink in the debris disk surrounding the star, as seen in this false-color image from the Hubble Space Telescope. CREDIT: Sally Heap (GSFC/NASA)/Al Schultz (CSC/STScI, and NASA)

Nola Taylor Redd, SPACE.com; 08 December 2011
Spiral Arms Hint At The Presence Of Planets

Disk of gas and dust around a sun-like star has spiral-arm-like structures. These features may provide clues to the presence of embedded but as-yet-unseen planets.

Near Infrared image from Subaru Telescope shows disk surrounding SAO 206462, a star located about 456 light-years away in the constellation Lupus. Astronomers estimate that the system is only about 9 million years old. The gas-rich disk spans some 14 billion miles, which is more than twice the size of Pluto's orbit in our own solar system.

Photonics Online 20 Oct 2011

Direct Imaging of Planet Formation

ALMA is mm/sub-mm 15-km baseline array telescope producing a 35 mas resolution image. (10 m telescope at 500 nm has 10 mas)

HL Tau is 1 million year old ‘sun-like’ start 450 light-years from Earth in constellation Taurus.

Concentric rings separated by gaps suggest planet formation.

HL Tau is hidden in visible light behind a massive envelope of dust and gas. ALMA wavelength sees through dust.

ALMA image of the young star HL Tau and its protoplanetary disk. This best image ever of planet formation reveals multiple rings and gaps that herald the presence of emerging planets as they sweep their orbits clear of dust and gas.

Credit: ALMA (NRAO/ESO/NAOJ); C. Brogan, B. Saxton (NRAO/AUI/NSF)
HR 8799 Planet (b)

HR 8799 Planet (b) has water, methane and carbon monoxide in its atmosphere.

HR 8799 is 129 light-years from earth and 1.5X the size of our sun in the constellation Pegasus.

Planet (b) is 7X mass of Jupiter

Transit Method Finds Planets

Kepler (launched in 2009) searched for planets by staring at 165,000 stars looking for dips in their light caused when a planet crosses in front of the star.

Kepler has found over 1000 ‘confirmed’ planets and over 4000 potential planets.
Nearly All Stars have Planets

Our galaxy has 100B stars of which 17B are like ours, so our galaxy could have 17B Earth size planets. But only a few will be in Habitable Zone. Also, need a moon.

Nancy Atkinson; Universe Today; January 7, 2013

Habitable Zone

Life requires water. Liquid water can only exist in the ‘Goldilocks’ Zone. The hotter the star, the further away the zone.

'Billions of stars' in the Milky Way may have planets that contain alien life, Ellie Zolfagharifard, Dailymail.com. 18 March 2015
> 100 Habitable Zone Planet Candidates
> > 24 smaller than 2 Earth Radii

All Stars may have 1 to 3 HZ Planets

Titius-Bode law (used to predict Uranus) states that ratio between the orbital period of the first and second planet is the same as the ratio between the second and the third planet and so on.

Thus, if you know how long it takes for some planets to orbit a star, you can calculate how long it takes for others to orbit and can calculate their position in the planetary system.

Blue dots show planets measured by Kepler in 151 systems.

Red boxes predicted ‘missing’ 228 planets
Average of 1 to 3 HZ planets per star.

‘Billions of stars’ in the Milky Way may have planets that contain alien life, Ellie Zolfagharifard, Dailymail.com, 18 March 2015
Kepler 452b

23 July 2015 NASA announced the confirmed discover of an Earth ‘cousin’ orbiting a star in the ‘habitable zone’. Planet is 60% larger than Earth with a 385 day orbit. Its Star is 1400 light years from Earth in the constellation Cygnus. Estimated age of the planet is 6B years compared to our own 4B years.

The size and scale of Kepler-452 system is compared to the solar system. Kepler-186 is a miniature solar system that would fit entirely inside the orbit of Mercury. (Credit:NASA/JPL-CalTech/R. Hurt)

How are habitable zones established?

Source of Earth’s H\textsubscript{2}O and organics is not known
Comets? Asteroids?

History of clearing the disk of gas and small bodies
Role of giant planets?

JWST Observations:
Comets, Kuiper Belt Objects
Icy moons in outer solar system
Where does the water come from?

Spitzer Spectrum Shows Water Vapor Falling onto Protoplanetary Disk

Search for Habitable Planets

atmosphere

habitatibility

interior

surface

Sara Seager (2006)
Search for Life

What is life?

What does life do?

Life Metabolizes

All Earth life uses chemical energy generated from redox reactions

Life takes advantage of these spontaneous reactions that are kinetically inhibited

Diversity of metabolisms rivals diversity of exoplanets

Sara Seager (2006)
Bio Markers

Spectroscopic Indicators of Life

Absorption Lines

- CO2
- Ozone
- Water
- “Red” Edge

Earth Through Time

Kasting Sci. Am. 2004
See Kaltenegger et al. 2006
Earth from the Moon

Seager
Beyond JWST

Heavy Lift Launch Vehicle enables even larger telescopes
8-m UV/Optical Telescope or
24-m Far-IR Telescope

Direct Imaging

Giant Space Telescopes will be able to directly image Planetary Systems using either internal coronagraphs or external star shades.

Simulated image for a 12-m telescope, a 100-m star shade, and 1 day exposure.
5/20/2016

Marc Postman, "ATLAST", Barcelona, 2009

R=100 ATLAST Spectrum of 1 Earth-mass Terrestrial Exoplanet at 10 pc

Exposure: 51 ksec on 8-m
4.3 ksec on 16-m

Reflectance \propto (Planet Mass)^{2/3}

5 Earth-mass: 8.5 ksec on 8-m

Bkgd: 3 zodi

O\textsubscript{2} (A)

H\textsubscript{2}O

H\textsubscript{2}O

H\textsubscript{2}O

H\textsubscript{2}O

SNR=10 @ 790 nm

Marc Postman, "ATLAST", Barcelona, 2009

Detecting Photometric Variability in Exoplanets

Marc Postman, "ATLAST", Barcelona, 2009
JWST – the First Light Machine

With its 6X larger collecting aperture, JWST will see back in time further than Hubble and explore the Universe’s first light.

Countdown to Launch

JWST is

making excellent technical progress

will be ready for launch late 2018

will be the dominant astronomical facility for a decade undertaking a broad range of scientific investigations
1000s of Scientists and Engineers in USA and around the world are working to make JWST.