An Overview of the James Webb Space Telescope at STScI

Jerry Kriss
Building JWST ... an outline

- Science Goals for JWST
- How we get there:
  - The Observatory & Spacecraft (TRW, prime contractor)
  - The Science Instruments
  - NASA/ESA/CSA Collaboration
  - The Integrated Science Instrument Module (ISIM)
- Our role in JWST:
  - The Science & Operations Center (S&OC) at STScI
- What’s the Schedule?
S&OC Project Personnel

- Peter Stockman: Project Scientist, JWST Mission Head
- David Hunter: Project Manager, Dep. JWST Mission Head
- Judy Ashwell: Dep. PM for Resources
- Knox Long: Dep. Project Scientist
- John Isaacs: JWST System Engineer
- [Joe Pollizzi: Ground System Dev. Manager]

Key Teams:
- Science Instrument Team: Jerry Kriss
- Systems Team: Wayne Kinzel
- Flight Software Team: Vicki Balzano
- JWST Detector Characterization (IDTL): Don Figer

Peter Stockman, 9/24/02
The STScI Science Instrument Team

- Detector Scientist: Don Figer
- NIRCam Instrument Scientist: Stefano Casertano
- NIRSpec Instrument Scientist: Mike Regan
- MIRI Instrument Scientists: Bernie Rauscher & Margaret Meixner
- FGS Instrument Scientist: Ed Nelan
JWST Sees the First Stars and Galaxies

Time in Years

300,000
100 Million
1 Billion
5 Billion
12 Billion

Big Bang

COBE

JWST

HST

Ground-Based Observatories

Bernie Seery, 6/27/02
First Light:

- Characterize the space density and luminosity evolution of protogalaxy-sized objects from redshifts 15? to 6.
1. JWST Sees “First Light”

Depth: \( AB \sim 34 \) in \( 10^6 \) s

Redshifts: Lyman \( \alpha \) to \( z = 40 \) (?)
4000 Å to \( z = 10 \)

JWST will detect \( 1 \, M_\odot \, yr^{-1} \) for \( 10^6 \) yrs to \( z \geq 20 \) and \( 10^8 \, M_\odot \) at 1 Gyr to \( z \geq 10 \)
(conservatively assuming \( \Omega = 0.2 \))

ASWG: Simon Lilly
JWST Science: Four Major Themes

First Light:
- Characterize the space density and luminosity evolution of proto-galaxy-sized objects from redshifts 15? to 6.

Galaxy, AGN & ISM Evolution:
- Determine the structural and chemical evolution of galaxies, AGN, and inter-galactic gas and the interplay between them from redshifts 6 to 1.
2. Galaxy Assembly and Evolution

- How and from what were galaxies assembled?
- What is the history of star birth, heavy element production, and the enrichment of the intergalactic material?
- How were giant black holes created and what is their role in the universe?

John Mather, 4/17/01
JWST Science: Four Major Themes

- **First Light:**
  - Characterize the space density and luminosity evolution of proto-galaxy-sized objects from redshifts 15? to 6.

- **Galaxy, AGN & ISM Evolution:**
  - Determine the structural and chemical evolution of galaxies, AGN, and inter-galactic gas and the interplay between them from redshifts 6 to 1.

- **Star Formation:**
  - Establish the physical connection between the gas environment and the resulting star formation with the emphasis on the early dust-enshrouded period of star formation.
3. Star Formation

- By what process do pre-stellar cores collapse to form stars?
- What are the physical natures of the nascent stellar cores of the youngest protostars?
- How does matter accrete onto them?
- What organic matter is present in the circumstellar environments of protostars?
- Is there water, and where is it located?
JWST Science: Four Major Themes

- **First Light:**
  - Characterize the space density and luminosity evolution of proto-galaxy-sized objects from redshifts 15? to 6.

- **Galaxy, AGN & ISM Evolution:**
  - Determine the structural and chemical evolution of galaxies, AGN, and inter-galactic gas and the interplay between them from redshifts 6 to 1.

- **Star Formation:**
  - Establish the physical connection between the gas environment and the resulting star formation with the emphasis on the early dust-enshrouded period of star formation.

- **Planetary Systems and the Conditions for Life:**
  - Determine the basic physical and chemical properties of extrasolar planets and planetary systems in formation and determine their connection to Solar system bodies.
Vega Disk Detection

<table>
<thead>
<tr>
<th>λ (μm)</th>
<th>Flux* (μmJy)</th>
<th>Contrast (μm)</th>
<th>Star/Disk</th>
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<tbody>
<tr>
<td>11</td>
<td>2.4</td>
<td>1.5x10^7</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>400</td>
<td>2x10^4</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>1300</td>
<td>3x10^3</td>
<td></td>
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</table>

Reflected & emitted light detected with a simple coronagraph.

*per Airy disk

JWST resolution at 24μm = 5 AU at Vega, > 10 pixels across the inner hole
The Design Reference Mission (DRM)
(See http://www.jwst.nasa.gov/science/drm.html)

DRM Theme 1: Cosmology and the Structure of the Universe
- Mapping the Dark Matter Distribution at High Redshift with JWST
- Probing the Intergalactic Medium Out to the Reionization Epoch
- Measuring Cosmological Parameters with High-z Supernovae and the Evolution of the Cosmic Supernova Rate
- Observing the IR Transients of Gamma-Ray Bursts and Their Host Galaxies
- Microlensing in the Virgo Cluster and the Role of Baryonic Dark Matter in the Universe

DRM Theme 2: The Origin and Evolution of Galaxies
- Formation and Evolution of Galaxies I: The Deep Imaging Survey(s)
- Formation and Evolution of Galaxies II: The Deep Spectroscopic Survey(s)
- Formation and Evolution of Galaxies III: Cluster Galaxies
- Formation and Evolution of Galaxies IV: The relation Between Galaxy Evolution and AGN
- Formation and Evolution of Galaxies V: Obscured Star Formation at High Redshift

DRM Theme 3: The History of the Milky Way and Its Neighbors
- The Age of the Oldest Stars from the Faint End of the White Dwarf Luminosity Function in Globular Clusters
- A Complete Initial Mass Function for Old Stellar Populations
- The Ages and Chemistry of the Oldest Stellar Halo Populations
- A Spectroscopic Study of Cool Field Brown Dwarf Stars

DRM Theme 4: The Birth and Formation of Stars
- The Physics of Starformation: Understanding the Youngest Protostars

DRM Theme 5: The Origins and Evolution of Planetary Systems
- Evolution of Circumstellar Disks Around Young Stars: The Search for Gas and Remnant Dust
- Detection and Characterization of Jovian Planets & Brown Dwarf Companions in the Solar Neighborhood
- A Survey of the Trans-Neptunian Region
- Measuring the Physical Properties of Kuiper Belt Objects
- Explorations in Astrobiology: Evolution of Organic Matter from the ISM to Planetary Systems
JWST Observatory Basic Requirements

- **~ 6-m diameter, deployable primary mirror**
  - Provides needed sensitivity
  - Diffraction-limited at 2μm required resolution

- **0.6-28 μm wavelength range, near-infrared optimized**

- **Active Optics Reduces Mass and Cost**
  - Use of computers and lightweight adaptable structures to achieve overall stiffness and figure control of the optics

- **Deployable Structures**
  - Enables the use of less expensive, expendable launch vehicles with conventional fairings

- **L2 orbit**
  - Easy, direct access
  - Enables passive cooling to <50K
  - Provides high observing efficiency

- **5 year mission life (10 year goal)**

<table>
<thead>
<tr>
<th>Formulation Phase (A/B)</th>
<th>Implementation Phase (C/D)</th>
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<tbody>
<tr>
<td>FY99 00</td>
<td>01</td>
</tr>
<tr>
<td>Select Prime</td>
<td>SRR</td>
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</table>
NIRCam Requirements

- 4 x 4 arcmin FOV minimum field of view
- Diffraction-limited and critically sampled at 2.4 \( \mu m \)
  - \( \sim 0.03'' \) per pixel
- 1-5 \( \mu m \) coverage, with 0.6-5 \( \mu m \) as a goal
- Broad-band filters R\( \sim 3 \) covering the NIR and optical band. Narrow-band (R\( \sim 100 \)) spectroscopy can be done here, or with NIRSpec.
- Coronagraphic capability is a goal
NIRSpec Requirements

- 3 x 3 arcmin FOV
- 1-5 µm coverage
- R~1000 and R~100
- >100 sources simultaneously
- Configurable slit width/length
- MEMS array preferred
MIRI Requirements

- Imaging
  - $\lambda=5-27 \, \mu m$ wavelength range
  - Diffraction limited imaging with 0.1" pixels
  - ~1.7' field of view
  - Able to image sources as bright as 4 mJy at $\lambda=10\, \mu m$
  - $\geq 12$ bandpass filters
  - Low resolution spectrograph (R~100; $\lambda=5-10 \, \mu m$) for single, compact sources
  - Simple coronagraph

- Spectroscopy
  - $\lambda=5-27 \, \mu m$ wavelength range, goal to reach $\lambda=28.3 \, \mu m$
  - Integral field spectroscopy with $\geq 2$" field of view, goal =3" or more
  - R~1000-3000 from $\lambda=5-27 \, \mu m$
NASA-ESA Collaboration
(Peter Jakobsen, ESA Proj. Sci.)

“Partnership Concept” covers:
- HST after 2001
- European participation in JWST
- HST after 2001
- European participation in JWST

JWST collaboration on ‘HST model’
- Instrumentation, spacecraft hardware, operations
- Open competitive observing programme
- Guarantee of 15% or more of observing time
- F-mission level of commitment (~200Mg)

ESA participation approved by ESA SPC
- November 2000
- Reconfirmed May 2002

Aiming for Final Approval in February 2003
ESA’s Contribution to JWST

- NIR multi-object spectrometer (NIRSpec)
  - Stand-alone instrument or
  - Optics module & part of shared ISIM services

- Mid-Infrared Instrument (MIRI) Optics Module
  - Significant (~50%) collaboration with NASA and CSA
  - Special contributions from ESA member states

- Depending on JWST technical specifications:
  - Spacecraft Service Module (SSM) or
  - SSM subsystems & optical processing of telescope mirrors

- Science operations support for the first 2 years
  - Level comparable to that provided for HST
The CSA Contribution to JWST

- The Fine Guidance Sensors
  - Two modules with ~4’x2’ fields of view, 60 mas/pixel
  - Total value of ~$50M

- Contributions to NIRCam development:
  - All filter wheels (mechanisms & filters)
  - Two tuneable filter modules

- NIRCam Science Team Members
ISIM is the Payload of JWST

Instruments
- NIRCam
- NIRSpec
- MIR

Shared Subsystems
- Detector Electronics
- Flight Data System H/W & S/W
- Power and Harness
- Shared system GSE for prime and each SI
- NIR Thermal Control (radiator, etc.)

Matt Greenhouse, 9/24/02
ISIM Cryogenic Portion

Matt Greenhouse, 9/24/02
JWST Team Relationships

Observatory Prime

- Optical Telescope Element (OTE)
- Sunshield Prime
- Observatory I&T Prime
- Spacecraft Prime

Integrated Science Instrument Module (ISIM) NASA

- Fine Guidance Sensor (FGS) CSA
  - MIRI NASA/ESA
  - NIRCam U of AZ/CSA
  - NIRSpect ESA

Ground Segment STScI

- Science and Operations Center (S&OC) STScI
- Communications Element NASA
  - Wave Front Sensing And Control (WFS&C) Executive NASA

Launch Segment NASA

Prime

Optical Telescope Element (OTE)

LEGEND

GFE Prime

Matt Greenhouse, 9/24/02
ISIM Roles and Responsibilities

Flight Systems:
- Structure
- Thermal Control
- IC&DH Electronics
- Detector Electronics
- IC&DH Software

& Associated GSE

Development of Enabling Technologies

LEGEND:
- NASA
- Industry - Prime
- ESA
- CSA
- STScI
- University/Other Government

Matt Greenhouse, 9/24/02
Leverages off existing HST software and hardware systems to reduce costs and maintain a high quality customer interface.

Streamlined operations flow dramatically reduces cost and complexity.

Peter Stockman, 9/24/02
Leveraging off HST Systems

The NGST S&OC is Built Upon a Strong Foundation

Critical S&OC Capabilities

Peter Stockman, 9/24/02
STScI S&OC Roles

- Lead Scientific Community Outreach
- Conduct the science mission from solicitation to grants
- Support NASA and development partners
- Develop Planning and Scheduling System
- Develop Pipeline data reduction & data archive support
- Lead Education and Public Outreach
- Develop Flight Operations System

1 As per RFP and on-going discussions with NASA

Hornig NAS Report

HST Exp.

New

Peter Stockman, 9/24/02
Conduct the Science Mission

- **S&OC Roles similar to those for HST**
  - Prepare and distribute Proposal Solicitation
  - Hold international Time Allocation Committee
  - Director allocates time
  - Support for proposal preparation and observation planning
  - Planning/Scheduling/Flight Ops/Calibration/Archive
  - **GO Grants**
  - Support for Public Release

- **Staffing size comparable to SIRTF’s Sci. Center**

Peter Stockman, 9/24/02
Mission-Level Science/Eng Support

- Science studies
- Mission level requirements and architecture
- Science Systems Engineering
- Design Reference Mission analysis and maintenance
  - DRM programs
  - JWST Mission Simulator
  - Exposure time calculators

Peter Stockman, 9/24/02
Support for ISIM & SI Teams

- **S&OC will provide:**
  - ~ 1 astronomer per instrument to ISIM dev and for SI-S&OC interface.
  - ~ 1 flight software person per instrument

- **S&OC will work with teams on:**
  - Early design for operability
  - Flight software review (activity descriptions)
  - Co-development of keywords, archive rqmts. Etc.
  - Co-development of calibration plan & algorithms
  - Co-analysis of I&T and commissioning data
  - Lead of calibration analysis

Peter Stockman, 9/24/02
Support of Observatory Development

- Science liaison with Observatory and OTE developers.
- Flight software (activity description) support
- On-site support during observatory end-to-end testing
  - Transitioning operations procedures from I&T to flight
  - Console operators to test ground system compatibility
- S&OC Interface to Wave front sensing and control efforts:
  - At Prime, JPL, GSFC
  - Focus on WFS&C operations system

Peter Stockman, 9/24/02
Development of Flight Operations System

- S&OC responsible for development of the Flight Operations System (the system that monitors telemetry and sends commands to the spacecraft).

- Plan is to utilize/augment the command and telemetry I&T system being developed by NASA.
  - Add interfaces to ground stations and data archives
  - Integrate with PRD and scheduling system

- End-to-End I&T with Observatory

- S&OC responsible for Project Reference Database development and tools
  - Will provide tools to the Flight h/w & s/w developers to access/update the PRD

Peter Stockman, 9/24/02
Planning & Scheduling

The S&OC will utilize new HST GUI Astronomers Planning Tools for proposal preparations and observation planning.

- Will utilize “target tuner” type displays (like SEA and APT)
- Will provide exposure time/ S/N estimators
- Goal: One step proposing and planning

Week to week/yearly planning done with Spike or simpler scheduling tool

Unique JWST validation tool will check that Observation Plans are valid (syntax, key constraints and restrictions)

Development to commence in ’06 -ready for GTO submissions.

Peter Stockman, 9/24/02
Pipeline data reduction & Data archive

- S&OC will use Multi-mission Archive at Space Telescope (MAST) capabilities:
  - OPUS to run all archive processes such as On-the-Fly pipeline processing (all data stored uncalibrated).
  - S&OC to develop pipeline scripts based on calibration requirements and algorithms. Pipelines to work at frame and mosaic level.

- MAST will evolve over next 6 years to use new storage media (probably spinning disks) and improved interfaces.

Peter Stockman, 9/24/02
**Perform Flight Operations**

- **Support launch and commissioning**
  - Operate JWST, develop proposals and observing schedules, participate in anomaly resolution

- **Conduct flight operations**
  - Communications, commanding, monitoring, performance analysis, mission scheduling, attitude determination, anomaly resolution.

Peter Stockman, 9/24/02
Education and Public Outreach

- STScI will support NASA in public releases during development

- STScI will lead EPO activities around and after launch:
  - Support and coordinate public releases from GTOs/GOs
  - Coordinate development of Early Release Observations
  - Educational material from JWST science

- STScI will lead the development of an Integrated JWST Education and Outreach Plan to document and coordinate the efforts and activities of the STScI, all major contractors and international partners. (2006-2008 timeframe)

- Maintain Public Website for JWST

Peter Stockman, 9/24/02
JWST Top Level Observatory Schedule