James Webb Space Telescope (JWST)

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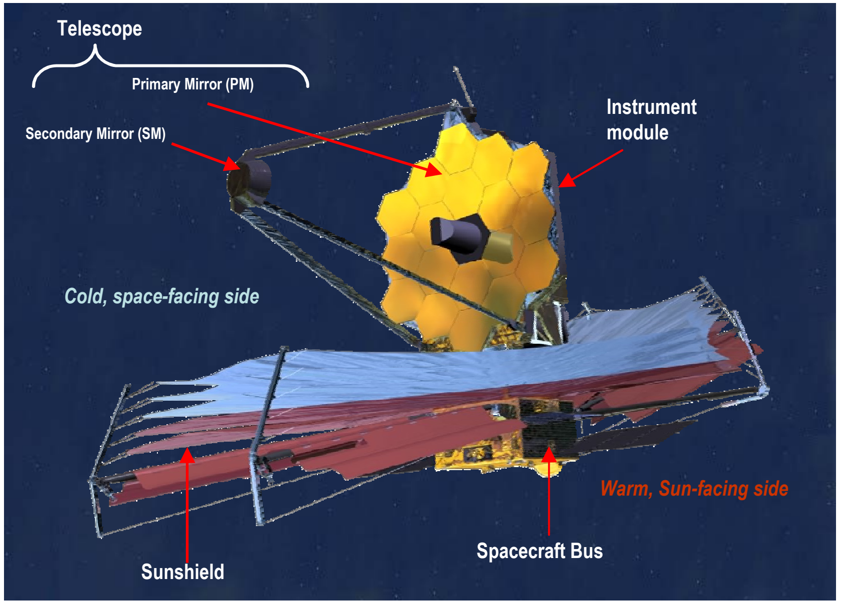
Project Status for the CAA

James Webb Space Telescope (JWST)

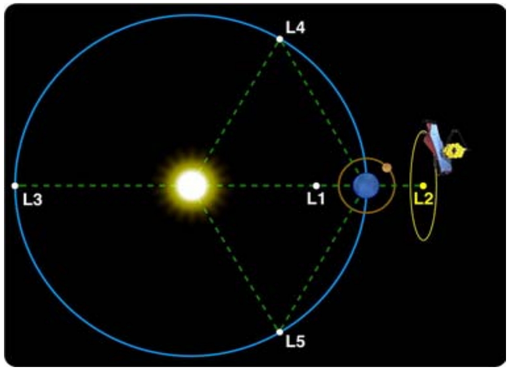
Mission Objective

- Study the origin and evolution of galaxies, stars and planetary systems - **facility like HST with thousands of users, almost weekly discoveries in NY Times**
  - *Optimized for infrared observations (0.6 – 28 μm)*



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 Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA
- Operations: Space Telescope Science Institute (STScI)



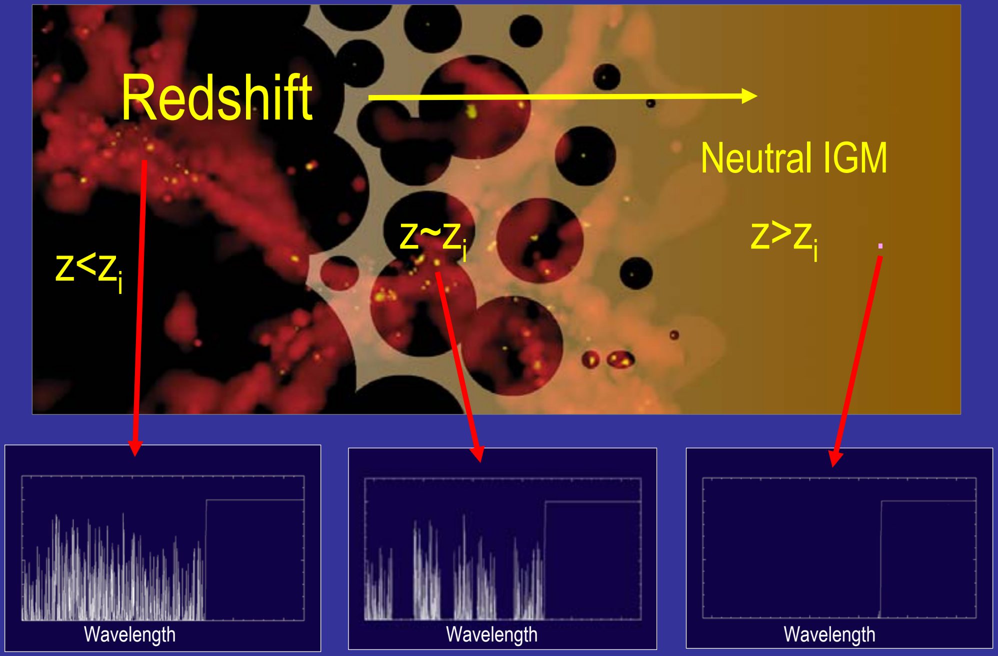
Description

- Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch NET June 2013 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov

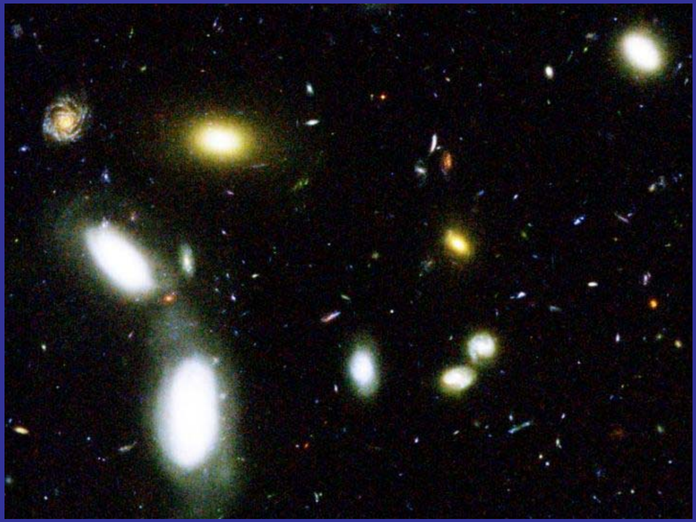
End of the dark ages: first light and reionization

- What are the first galaxies?
- When did reionization occur?



Lyman Forest Absorption | **Patchy Absorption** | **Black Gunn-Peterson trough**

Simulated JWST spectra showing the epoch of reionization



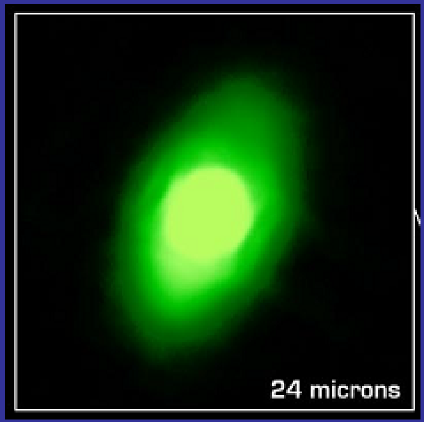
Galaxies in GOODS Field

The assembly of galaxies

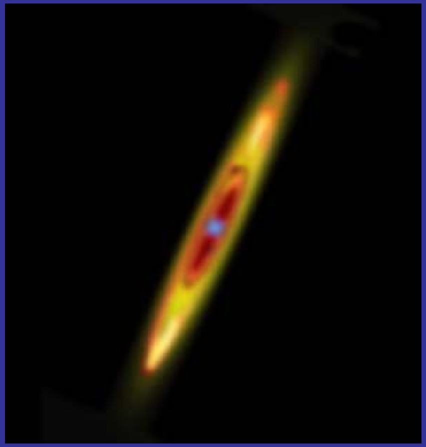
- Where and when did the Hubble Sequence form?
- How did the heavy elements form?

Birth of stars and protoplanetary systems

- How do clouds collapse?
- How does environment affect star formation?



Spitzer image

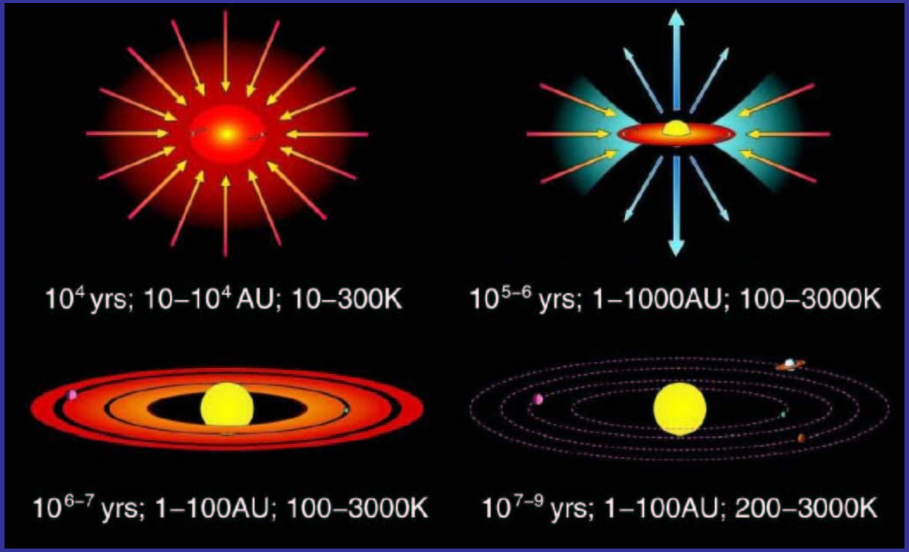


Simulated JWST image

Fomalhaut dust disk at 24 microns

Deeply embedded protostar

Circumstellar disk



Agglomeration & planetesimals

Mature planetary system

Shu et al theory of planetary system formation

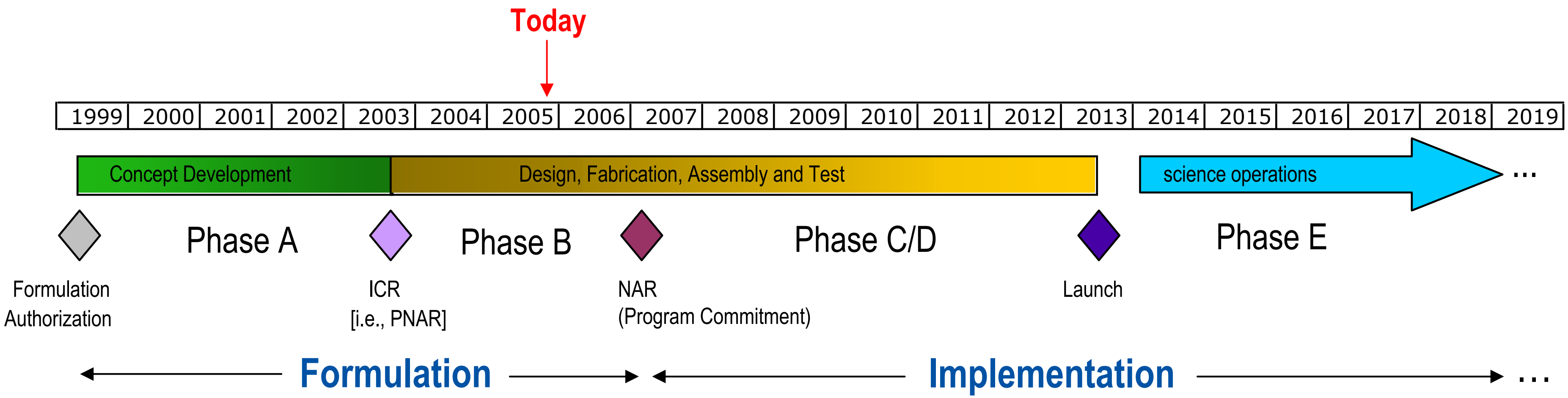
Planetary systems and the origins of life

- How do planets form?
- How are circumstellar disks like our Solar System?

Comparison with other systems

- **HST: 2.7 x diameter, same angular resolution, but at 2.7x longer wavelength**
- **HST NICMOS: 189 x FoV, 38 x better sensitivity at K band, 8x better at H band. K band survey 270,000 x faster**
- **Spitzer:**
  - 8 x Spitzer diameter
  - Diffraction limited at 2 microns vs. 6 microns
  - 8 to 24 x better angular resolution
  - Point source zodi limited photometry speed ratio (D^4) = 4096
  - 10 x lower dark current (few e/hour/pixel) than Spitzer detectors, supports spectroscopy at R ~ 1000 at high redshift
- **Ground:**
  - JWST and GSMT are complementary where capabilities overlap: HST:Keck diameter ratio ~ JWST:GSMT
  - Background ~1,000,000 x larger on ground at 5 microns
  - Multi-object spectroscopy factor of 100, comparable to ground instruments
- **For details, see SAT presentation by M. Mountain**

JWST Program



- **Early emphasis on vigorous technology development to retire risk**
  - ~20% of Phase A through D total invested so far
  - Pacing items (primary mirror, detectors) already in Phase C/D and flight production per agreement with HQ at the Initial Confirmation Review (ICR)

JWST Cost Update

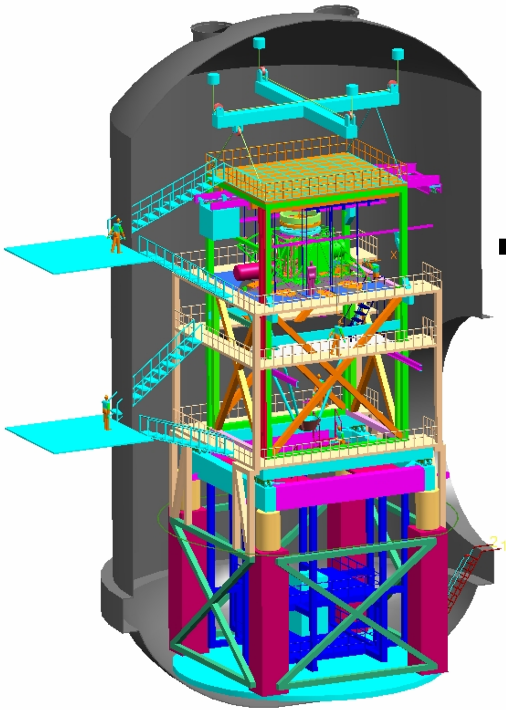
- **JWST total run out cost (concept through operations for 10 years) has grown 30% (from $3.5B to $4.5B) due to a number of factors:**
  - Delay in approval for ESA provided Ariane launch ($300M)
  - 10 month additional launch delay due to funding shortfalls ($250 M)
  - Requirement changes and other cost growth ($290 M)
  - Additional contingency added by HQ ($210 M)
- **Several actions taken to understand cost growth:**
  - JWST Project developed cost and risk reduction plan
  - Independent Review Teams chartered by NASA HQ over the Summer 2005
  - Agency Program Management Meeting in July 2005
  - Go forward plan presented to Administrator in early September 2005
- **Peak funding occurs in FY08, major wedge for new programs opens up**

JWST Plan presented to Administrator, Sept. 2005

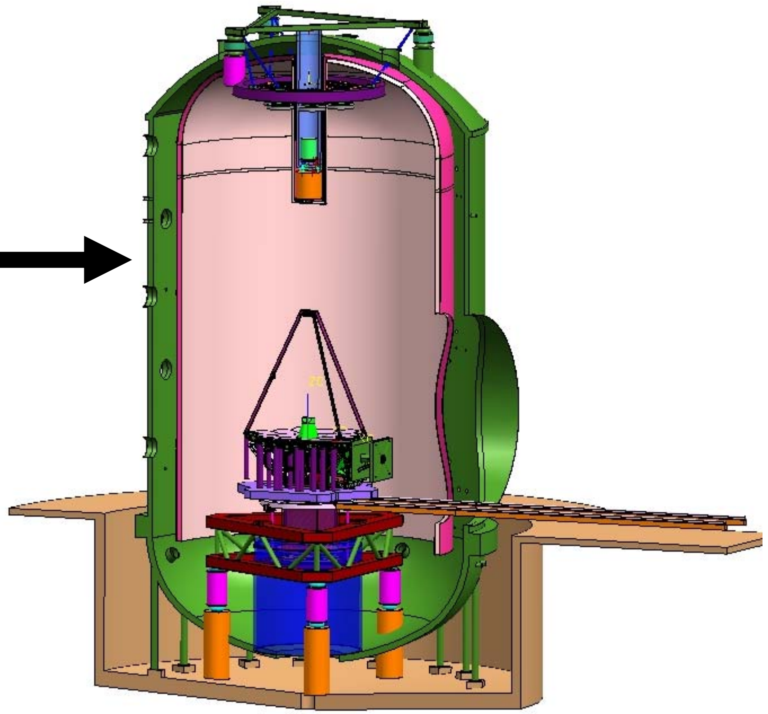
- Proposed new launch date of 2013
- Added contingency funds
- Removed a CSA instrument module to improve mass budget
- Improved test plan with feasible full-up test at JST ("cup-up")
- Relaxed performance requirements at < 1.7 microns (compare ground-based telescopes - see Matt Mountain report)
- Relaxed PSF stability requirements (more frequent adjustments)
- Deleted PSF circularity (anisotropy) requirement - was for cosmic shear studies
- Relaxed contamination requirement - potential sensitivity loss
- Transferred some ISIM electronics work from NGST to GSFC, negotiated lower NGST fee
- Will meet all Technical Readiness Level requirements by January 2007 (beginning of construction phase)

JSC "Cup Up" Testing Configuration Dramatically Simplifies Cryogenic Test Approach

Old "cup down" configuration used large metrology tower and test equipment inside cryo shrouds



New "cup up" configuration allows access to test equipment from top and bottom of chamber during cryo testing

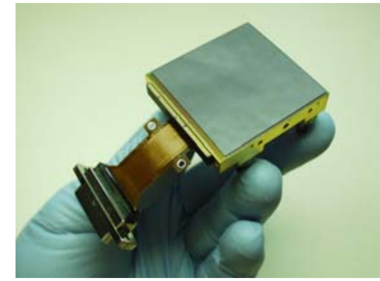


JSC size, accessibility, and large side door access make it well suited for this configuration

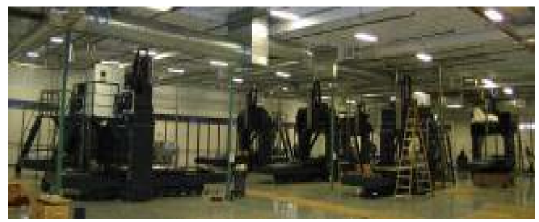
Long Lead Technology Development On Schedule

- All mirror facilities built
- All 18 primary mirror blanks made and 15 in machining
- EDU mirror segment in grinding stage; AMSD mirror was good enough (< 20 nm residuals when cold)
- Wavefront Control testbed (1/6 scale) complete
- Flight detectors are in fab cycle now: 2K HgCdTe, 1K Si:As
- ASICs CDR very soon
- Microshutter flight unit candidates manufactured
- Cryocooler selection in January 2006, based on 3 vendors from ACTDP program (also needed by Con-X, TPF-I)

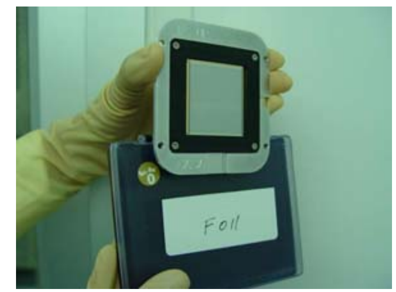
JWST PM Be Blanks



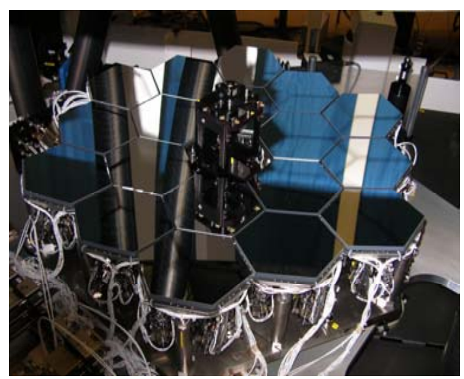
HgCdTe Flight Detector Candidate



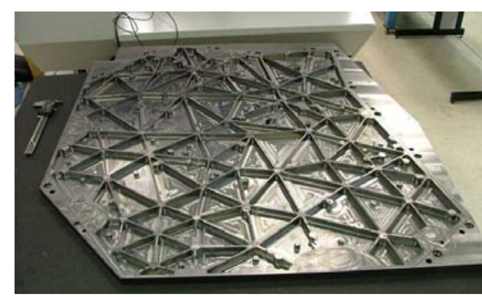
Tinsley JWST Facility



Flight Microshutter Candidate



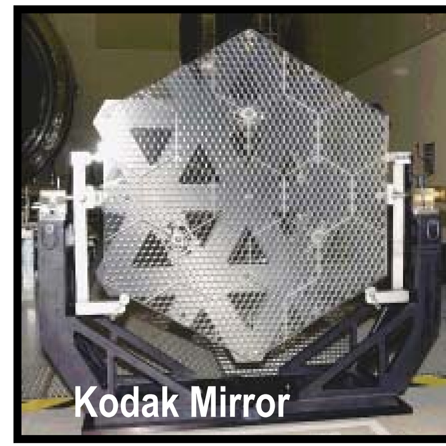
Ball Wavefront Control Testbed



NIRCam ETU Optical Bench

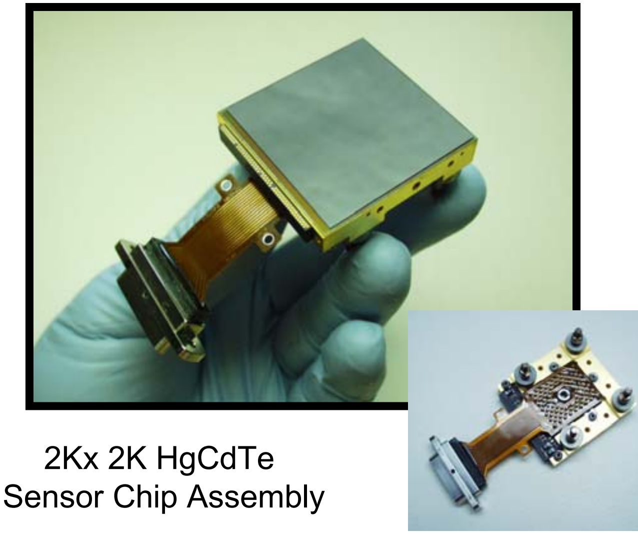
The JWST Advanced Mirror System Demonstrator (AMSD) was a multi-agency partnership

- **NASA, DOD, NRO form Large Lightweight Mirrors technology Partnership**
- **AMSD Phase I (study) 5/99**
  - 5 Contractors, 8 Mirror designs
- **AMSD Phase II (fab/Cryo test mirror) 5/00**
  - Down-selected to 3: Ball, Kodak (ITT) and Raytheon (Goodrich)
- **Completed cryo testing of Kodak and Ball Optic – 7/03**
- **AMSD also demonstrated cryogenic mirror actuators that met JWST specs (cryo and vibe tested)**
  - Actuators tested individually and as part of mirror system
- **Extensive use of AMSD data in selecting JWST Primary Optic technology – 8/03**
  - Demonstrated technical viability of proposed technology
  - Demonstrated programmatic viability
  - AMSD cost and schedule data used as BOE
  - Demonstrated cryogenic mirror actuators that met JWST specs (cryo and vibe tested)
  - Basis for Flight design (incorporated lessons learned in flight design)



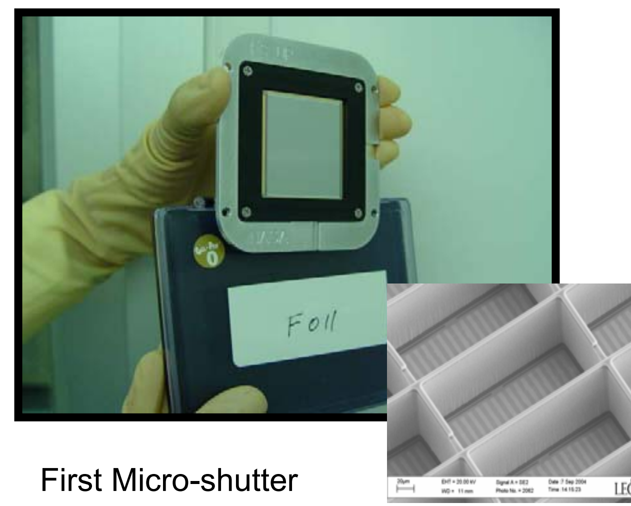
Early ISIM technology investments have paid off

- **Infrared Detector Technologies:**
  - HgCdTe Detectors used for NIRCam, NIRSpec, and FGS
  - JWST significantly advances the state-of-the-art from the HST/NICMOS 256x256 arrays:
    - Grew detector format by 64X to 2048x2048 pixels
    - Doubled wavelength coverage, pushing long-wave cut-off from 2.5 microns to 5.0 microns
    - Lowered dark current by 10X
  - MIRI SiAs Detectors 1024x1024, sixteen times Spitzer/IRAC



2Kx 2K HgCdTe
Sensor Chip Assembly

- **Micro-Electronic-Mechanical Systems (MEMS):**
  - NIRSpec uses a MEMS device to define its viewing aperture
    - "Micro-shutters" essentially invented for JWST
    - Technology brought from TRL1 to 5 in three years



First Micro-shutter
Array Flight
Candidate

Recent Primary Mirror Progress

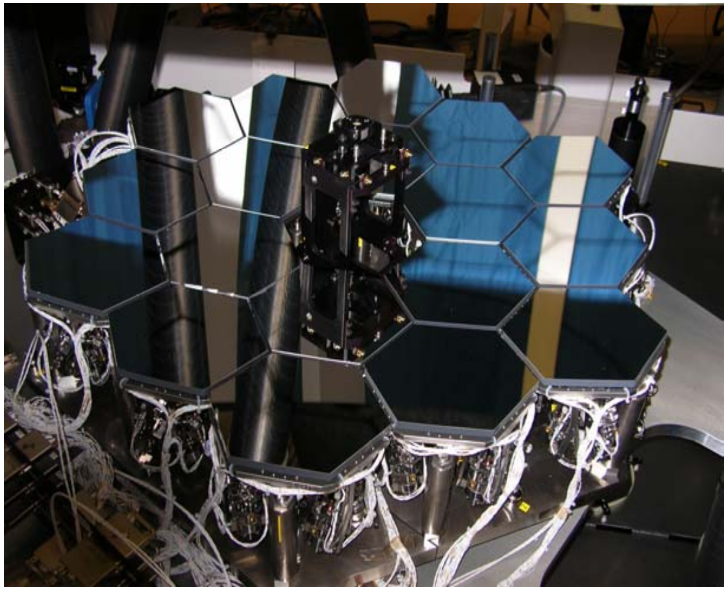
Flight Primary Mirror Fabrication has begun!
- All 18 Be blanks completed and shipped
- Started Machining on 15 of 18 Blanks

- **Significant progress in JWST Mirror Manufacturing Facilities**
  - Completed Mirror Machining Center at Axsys
  - Figuring and Polishing Facility nearing completion at Tinsley
  - Primary Mirror Segments Cryogenic Testing Facility Upgrades 95% complete at MSFC
- **Utilized AMSD to significantly reduce risk**
  - Stress characterization
  - Grinding process improvements
- **Fabrication of JWST Primary Mirror Segment Engineering Development Unit underway**
  - Completed Machining at Axsys
  - Started Figuring at Tinsley

Wavefront Sensing and Control (WFSC) Current Status

- **Ball Aerospace is on schedule in developing a 1/6th scale test bed for proving algorithms to fine phase the telescope with all degrees of freedom**
  - All 18 mirror assemblies are on the test bed and working
  - Test bed will be fully operational by December 2005
- **Based on models demonstrated on the earlier test beds, complete end to end simulations have been run successfully of WFSC**
- **Demonstration of TRL 6 on the Ball test bed in 2006**
  - Provides final validation of simulations

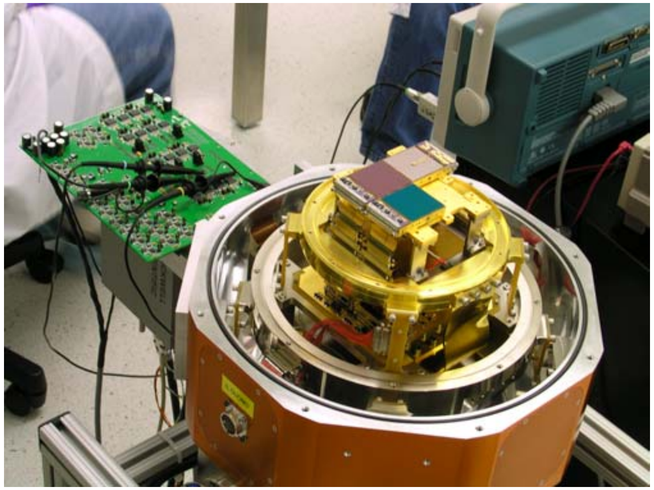
Ball WFSC Testbed



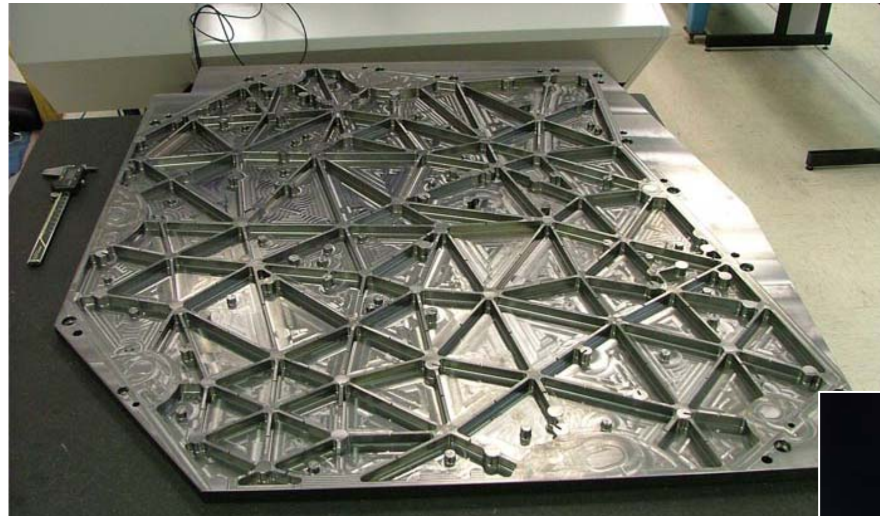
The ISIM system design, including science instruments, is mature

- **Majority of ISIM Subsystems and Instruments are through PDR**
  - NIRCam, MIRI, & FGS instruments completed PDR
  - NIRSpec PDR scheduled for Jan 06
  - ISIM Structure & ICDH Subsystems completed PDR
  - Thermal Subsystem PDR to occur Feb 06
  - Command and Data Handling Software is already complete and deployed to Instrument teams
- **Significant progress made on prototype and development models**
  - MIRI Structural/Thermal model has completed cryo testing
  - Prototype MIRI & NIRCam detector electronics built & tested
  - FGS filter wheel & tunable filter etalon mechanisms built
  - Demo-unit NIRSpec SiC bench and optics tested at cryo
  - ICDH development unit card set has been integrated & tested
- **Long lead ETU and Flight Hardware is in Production**
  - NIRCam ETU optical bench, lenses, and filters
  - Flight mid-infrared and near-infrared detectors
  - Flight NIRSpec microshutter arrays

NIRCam Hardware

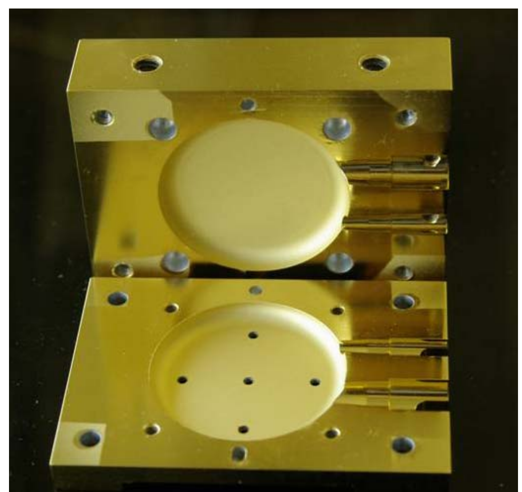


Eng Model 2Kx2K HgCdTe Detectors



ETU Optical Bench

Prototype Pickoff Mirror



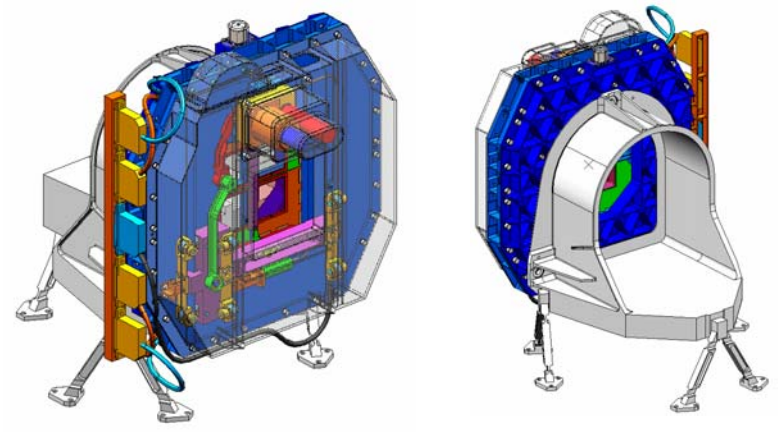
Prototype Calibration Cavity

Prototype Lens Triplet

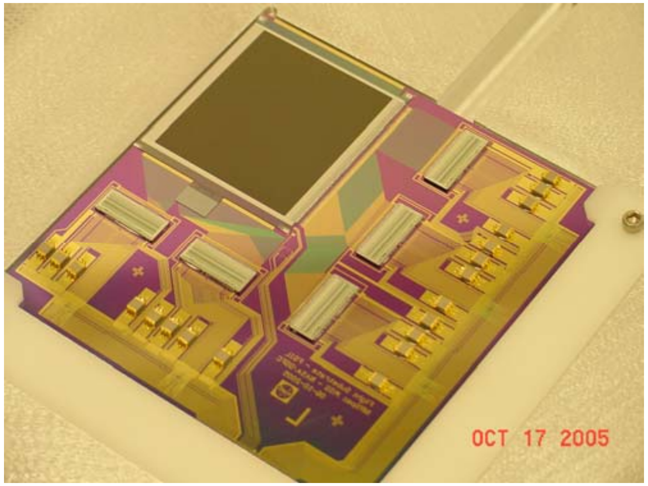
JWST NIRSpec Micro Shutter Subsystem

PI: S. Harvey Moseley - GSFC

The Micro Shutter Array (MSA) is a silicon-based field-selectable programmable aperture mask for the JWST Near-IR Spectrograph (NIRSpec) allowing numerous source combinations to be observed



Microshutter Assembly



First fully assembled substrate

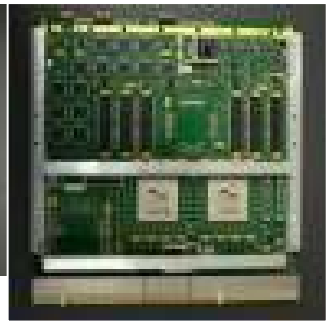
Current Status

- Currently producing 365 X 171 arrays
- Initial model components are being procured and tested.
- MSS Team is preparing for a summer 2006 TRL 6 Demo for the arrays

ISIM Subsystem Hardware

ICDH Development Unit Card Set

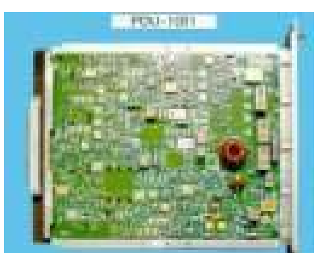
Bus Interface Card



Focal Plane Processor

Computer

Housekeeping



Power Distribution

Structure Plug Joint Test Samples

Composite Tube

Structure Saddle Joint Test Sample

This is the right budget

- JWST invested heavily in technology development before choosing contractors or design, unlike HST
- All contractors (except for cryocooler - January 2006 selection) are in place
- All international agreements are in place and their contractors are working to our schedules
- All ITAR agreements and extensions are on schedule
- All long-lead technology items are on schedule for the development confirmation review, January 2007
- Facilities for flight mirrors completed and working to spec
- Test items have met requirements for all major technologies: mirrors, detectors, microshutters, coolers, wavefront sensing and control
- Mass budget meets required margin (after deleting an instrument module)
- Schedule has required contingency (1 month/year)
- Cost plan has required contingency allocation
- Cost plan was validated by independent team from Langley & their independent consultants
- Technical risk was reduced by relaxing scientific requirements selectively
- Test plan was dramatically simplified and improved

Conclusions

- JWST will be a paradigm-shifting new capability for astronomy that will be a worthy successor to HST and maintain US leadership for the next decade
- JWST is meeting all its technology milestones, flight hardware is being built, and the mission is on track for a June 2013 launch date
- Recent budget growth has been analyzed and the underlying causes understood; there is no reason to believe there is a systemic problem
- Budget stability is required to enable launch in 2013