NIRCam and the James Webb Space Telescope (JWST)
What is JWST?

- Scientific successor to both the Hubble Space Telescope and the Spitzer Space Telescope
- A big technological leap by using a deployable primary mirror
- A cool telescope optimized for infrared use - sunshield and "L2 orbit" enable the cooling
Where the hell did it all come from?

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Arizona’s Role in JWST

- Arizona is home to one of the four instruments and plays a large role one of the others:
  - Arizona is the prime contractor to Goddard Space Flight Center for the Near Infrared Camera, the only all-U.S. instrument on JWST
  - **Prof. George Rieke** is the co-leader of the MIRI (Mid-Infrared Instrument) Science Team
- **Jonathan Lunine**, Planetary Sciences Department, is an “Interdisciplinary” Scientist; he represents astrobiology and the search for extra-solar planets
- **Rogier Windhorst** from ASU is an “Interdisciplinary” Scientist; he represents the search for the most distant galaxies
- So U of Az has three of seventeen members of the JWST Science Working Group and the state has 4 of 17 - never has there been such a geographic concentration for a NASA mission (and 2 more of the 17 are from LBT partner institutions!)
NIRCam Partners

- Science Team from Arizona, JPL, Rochester Institute of Technology, Canada, Hawaii, Switzerland
- Lockheed-Martin in Palo Alto, CA, is responsible for design and construction of the most of the instrument
- Arizona is procuring detectors from Rockwell Scientific in Camarillo, CA, and will deliver them to L-M after characterization
- Space Telescope Science Institute will operate NIRCam after launch
- Current contract value is ~$104M
Salient Facts

- 6.6 m (tip-tip) deployable primary mirror
  - 18 Be hexagons
  - 25 m² collecting area
- 0.6-28 μm wavelength range
- 5 year mission life (10 year goal)
- Passively cooled to ~30-40K
- Ariane 5 launch
  - Sun-Earth L2 Lissajous orbit
- 2088 W power, 6190 kg (wet)
- Uplink 0.25, 2, 16 kbps
- Downlink 0.2, 2, 16 kbps, 2,4,6,8 Mbps
- > 401 Gbit recorder

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<th>Formulation Phase (A/B)</th>
<th>Implementation Phase (C/D)</th>
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Launch Timeframe
Observatory Launch Configuration Concept in Ariane 5 with 5m Fairing

- Long Fairing 17m
- Upper stage (ESC-A)
- H155 Core stage (EPC)
- P230 Solid propellant booster (EAP)
- Vulcain engine
- Top View of Observatory stowed in 5m fairing

Total Height: 51.37m
Getting to L2 Orbit

- Launch
- ~1,500,000 km
- Trajectory correction maneuver 1 L + 15 hrs
- Sunshield deployment L + 2 days
- Observatory available for ISIM activities L + 70 days
- Observatory first light (ISIM at safe operating temp) L + 59 days
- Telescope deployment L + 4 days
- Main Engine Start 1 264 sec
- Main Engine Cut-Off 1 785 sec
- Main Engine Start 2 1694 sec
- Main Engine Cut-Off 2 2084 sec
- JWST separation 39 min
- L2 orbit achieved L + 109 days
- Initiate ISIM testing and certification L + 113 days
- ~37,400 km
- ~1,500,000 km
- L2
Integrated Science Instrument Module

Near Infra-Red Camera (NIRCam)
- Detects first light
- 0.6 to 5 microns
- UofAz/LMATC instrument (M. Rieke)

Near Infra-Red Spectrometer (NIRSpec)
- Studies galaxy formation, clusters, chemical abundances, star formation, and kinematics
- 0.6 to 5 microns
- Simultaneous spectra of >100 objects
- ESA provided (P. Jakobsen) with NASA Detectors (B. Rauscher) & Microshutter (H. Moseley)

Mid-Infra-Red Instrument (MIRI)
- 100x sensitivity over previous systems
- Imaging and spectroscopy capability
- 5 to 28 microns
- Cooled to 7K by Dewar
- Combined ESA/NASA contributions (G. Wright, G. Rieke, M. Ressler)

Fine Guidance Sensor (FGS)
- Ensures guide star availability with >95% probability at any point in the sky
- Includes Tunable filters (R~100)
- CSA provided (J. Hutchings)
JWST’s Science Themes

The First Light in the Universe:
Discovering the first galaxies, Reionization

Period of Galaxy Assembly:
Establishing the Hubble sequence, Growth of galaxy clusters

Birth of Stars and Protoplanetary Systems:
Physics of the IMF, Structure of pre-stellar cores, Emerging from the dust cocoon

Planetary Systems and the Origins of Life:
Disks from birth to maturity, Survey of KBOs, Planets around nearby stars
What is the Reionization Era?
A Schematic Outline of the Cosmic History

- The Big Bang
  The Universe filled with ionized gas
- The Universe becomes neutral and opaque
  The Dark Ages start

Galaxies and Quasars begin to form
The Reionization starts

The Cosmic Renaissance
The Dark Ages end

Reionization complete, the Universe becomes transparent again

Galaxies evolve

The Solar System forms

Today: Astronomers figure it all out!

“First Light Machine”

- Original rationale for JWST is the discovery of the first light-emitting objects
- Discovery of reionization sources is the same or very closely related goal
- How do we know if we’ve found a first light object?
Galaxy Assembly: Merger History

- Diffraction Limit for JWST at 2μm is 0.06” ==> adequate for resolving galaxy scale lengths, morphologies
Birth of Stars and Protoplanetary Systems

JWST’s sensitivity in the 3-10μm range enables new probes of the star formation process:

• Density profiles in collapsing clouds
• Variation of IMF with metallicity and environment
• Circumstellar disk physics including jet dynamics
Molecular Cloud Profiles

- Measure stars through clouds -- light attenuation profiles give density profiles
- Provides much higher angular resolution than sub-mm or mm data (can get 1-2″ resolution = ~100 AU)

Azimuthally averaged extinction profile which gives the density profile.

Images and plot from Alves et al. 2001
NIRCam Design Details

Light beam from telescope
More Design Details

1. Pick-Off Mirror Assembly
2. Coronagraph
3. First Fold Mirror
4. Collimator Lens Group
5. Dichroic Beamsplitter
6. Long Wave Filter Wheel Assembly
7. Long Wave Camera Lens Group
8. Long Wave Focal Plane Housing
9. Short Wave Filter Wheel Assembly
10. Short Wave Camera Lens Group
11. Short Wave Fold Mirror
12. Pupil Imaging Lens
13. Short Wave Focal Plane Housing
NIRCam as a Wavefront Sensor

- NIRCam will provide imagery during first alignment of telescope for ground analysis
  - used for initial capture of primary mirror segments and coarse alignment (simple imaging mode)
  - used for coarse phasing (uses Dispersed Hartmann Sensor [DHS])
  - used for fine phasing (focus diverse phase retrieval uses weak lenses in the pupil wheel)
- NIRCam will be used throughout the mission to keep the primary mirror aligned
  - routine wavefront sensing uses the same technique as the fine phasing step above
- NIRCam includes a pupil imaging lens to ensure pupil and DHS alignment and to provide pupil characteristics
Short Wavelength Detector Assembly

Mask shields shiny regions and detector edges

Mosaic Plate matches thermal expansion of modules and locates them precisely with pins and pads.

Thermal standoffs isolate detectors from instrument for active thermal control

Hybrid Detector Modules aligned to meet position requirements

Flex Cables thermally isolate detectors from instrument

FPA Baseplate is foundation of build-up, and is critical interface to instrument

Optical Cube Assembly provides metrology reference for integration
NIRCam Education and Public Outreach

- Team emphasis: Girl Scouts of the USA
  - Train adult leaders of our local Sahuaro Council
    - Develop new materials to combat illiteracy
  - Train leaders from all 317 US Councils
  - Support troops within Sahuaro Council

- Curriculum development
  - Personalized activities and experiments
    - relate JWST to human eye
  - Cosmology concepts & activities
  - Revising “Sky Search” badge materials

- Leveraging
  - Funding sources, collaborations, etc.

- New Mt. Lemmon Science Center
  - New 2.4m telescope for “research-based science education”
  - Associated science education center

Girl Scout leaders at first JWST+NIRCam Astronomy Camp April '03
NIRSpec Requirements

A multi-object dispersive spectrograph (MOS) for 1-5 µm, with R~1000, with pixels matched to the sizes of high redshift galaxies (~0.1''), and covering a 3’x3’ field or larger, and capable of observing > 100 objects simultaneously. Ideally, the spectral resolution would be selectable and would extend down to R ~ 100.

MSA=micro shutter array
MIRI: Mid-infrared Instrument

- 100x sensitivity over previous systems
- Imaging and spectroscopy capability; imager includes coronagraphs
- 5 to 27 microns
- Cooled to 7K by Dewar
- Combined ESA/NASA contributions (G. Wright, G. Rieke, M. Ressler):
  - European consortium to provide the optical bench
  - U.S. (JPL) to provide detectors, electronics, dewar
Summary

- When launched in 2011, JWST will give us unequaled sensitivity
- NIRCam Science Team will receive 900 hrs of observing time!
Summary of JWST’s Capabilities

- 25 m$^2$ collecting area using a segmented primary with 6.6-m tip-to-tip diameter
- L2 orbit enables passive cooling to $\sim$45K for primary mirror, $\sim$35K for instruments
- Four instruments:
  - NIRCam, 0.6-5 µm
  - NIRSpec, 0.6-5 µm, R$\sim$100-3000 and multi-object
  - MIRI, 5-28 µm, camera + R$\sim$2500 IFUs
  - FGS + TF, 1.2-4.8 µm R$\sim$100
Project is moving!

- Primary mirror segments and detectors are already in production
- Instruments are prototyping optics, mounts, electronics, mechanisms

Be mirror blank
Development mirror segment

Full size model at NGST
Prototype detector array - 7 electrons read noise in 1000 secs!

Concept Development
Design, Fabrication, Assembly and Test


mission formulation authorized
confirmation for mission implementation
science operations
launch

www.JWST.nasa.gov
NIRCam Design Features

- NIRCam images the 0.6 to 5 µm range using refractive optics
  - Dichroic used to split range into short (0.6-2.3 µm) and long (2.4-5 µm) sections
  - Nyquist sampling at 2 and 4 µm
  - 2.2 arc min x 4.4 arc min total field of view seen in two colors (40 MPixels)
  - Coronagraphic capability for both short and long wavelengths

- NIRCam is the wavefront sensor
  - Must be fully redundant
  - Dual filter/pupil wheels to accommodate WFS hardware
  - 3-dof pickoff mirror for pupil alignment Pupil imaging lens (PIL) to check optical alignment

- NIRCam includes self-calibration features
  - point-source emitters to check internal alignment after launch
  - pinhole flat field projectors for obtaining flats immediately after launch for use in initial mirror alignment
  - dark position for detector calibration

- Operates at 35K at L2
Complete instrument is comprised of two of these benches.
Each module has two spectral wave bands (0.6 microns to 2.3 microns and 2.4 microns to 5 microns)

- The majority of NIRCam exposure time will be used for deep survey observations using ~7 wide band filters
- Survey efficiency is increased by taking observations of the same fields in long wave and short wave bands simultaneously

- Short wavelength pixel scale is 0.032″/pix; long is 0.064″/pix
High Sensitivity is Paramount

- NIRCam sensitivity is crucial for detecting “first light” objects
- At 3-5µm, NIRCam can detect objects 100x fainter than Spitzer opening up new survey possibilities

The z=10 galaxy has a mass of $4 \times 10^8 M_{\text{Sun}}$ while the mass of the z=5 galaxy is $4 \times 10^9 M_{\text{Sun}}$.

Above assumes 50,000 sec/filter with 2x time on longest wavelength.
SMART Sources for Verification

This sketch uses “Option B” while “Option A” is now preferred.

Both inward and outward facing sources available at several field points. Mostly open to permit viewing of pupil wheel sources.

Solid plate with a grid of holes - now prefer Option A because of ability to view outward facing sources located on the pupil wheel.

Cartoon of light sources illustrating bi-directionality

This sketch uses “Option B” while “Option A” is now preferred.
‘L’ Shape Design- SMART

- The smart tool is L shape to maximize the unobstructed area
- 4 pts outward at 0.623, 2, 4 microns (TBR).
- Convex surfaces on outward side for reflective reference surface.
- 4 pts inward (broad band sources using tungsten)
- All point apertures = 50microns
- Installed on each module for characterization at ambient align, Cold Alignment, CPT1, CPT2, NOTES, WFS&C.
- Does not obstruct testing with the coronagraph

Edge along side the coronagraph may block the coronagraph view.
Team which built MIPS flight arrays will be re-assembled including QA/CM to be provided by Cindy Davidson (currently working at Raytheon in Tucson)

Design being done by Erick Young

Drafting help from Steward CAD Group

Thermal and Structural analysis to be performed by ATC

Parts Flow:

- Rockwell produces hybrids
- Arizona delivers SCA mounts+flex cables
- Rockwell attaches SCAs and characterizes them
- Rockwell delivers SCAs to Arizona
- Arizona mounts SCAs into FPAs
- Arizona verifies surface flatness at cyro and FPA performance
- Arizona ships FPA to ATC
- ATC vibes FPA
- At ATC, Arizona confirms performance after vibe and delivers FPA to ATC

Design retains current instrument and SCA interfaces while incorporating better isolation between SCAs.