James Webb Space Telescope (JWST) and Star Formation

Zermatt ISM meeting
September 24, 2010
Tom Greene (NASA Ames)
& many other JWST scientists

Spitzer Serpens A image courtesy of NASA/JPL-Caltech/L. Cieza (UT)
JWST in a nutshell

- 6.5-m primary mirror; 18 segments
- $\lambda < 1 - 28 \ \mu m$
- Instruments:
  - NIRCam
  - NIRSpec
  - MIRI (cam + spec)
  - FGS w/TF
- $\geq 2014$ launch
  - Ariane V to L2
  - 5 yr req life
  - 10 yr goal
  - No cryogens
JWST Instruments: NIRCam (NASA)

- Images over 0.7 – 5 μm Nyquist sampled at 2 & 4 μm
  - Broad, medium, and narrow bands
  - R ~ 1700 slitless spectra 3 – 5 μm (series filter)
  - Coronagraphic imaging
- 2 identical modules, each with short and long wavelength dichroics: 2 x 2' x 2' FOV
- M. Rieke (U Arizona) is PI
- Filters and other information: http://ircamera.as.arizona.edu/nircam/
FGS: Fine Guidance Sensor (CSA)

- 2 NIRCam-sized (2.3' x 2.3' adjacent FOVs)
  - $\lambda = 2\mu m$ critical sampling
  - $\lambda = 0.8 - 4.8 \mu m$ wide band guider imaging
- R=100 imaging with tunable filter (TFI) for science
  - $\lambda = 1.5 - 2.6 \mu m$ and $3.1 - 5 \mu m$ operation
- Non-redundant mask for moderate contrast, high spatial resolution science imaging
- J. Hutchings (FGS) and R. Doyon (TFI) are PIs
NIRSpec (ESA): 1 – 5 µm spectra

- Multi-object spectrograph
  - 3.4' x 3.4' FOV
  - Mosaic of microshutter arrays (250,000 shutters, each 200 x 460 mas)
- Also has fixed slits and IFU
- R=100 (1 setting) and R=2700 (3 settings) spectroscopy with coarse (100 mas) spatial sampling for single or multiple objects
- R~100 prism covers 0.7 – 5µm
- P. Jakobsen science team lead
MIRI: Mid-infrared instrument (EC/NASA)

- MIRI has an imager, $F \sim 100$ spectrograph, and $R=3000$ IFU spectrometer (G. Wright PI; G. Rieke science lead)
## Instrument Properties

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Channel/Mode</th>
<th>Wavelength (microns)</th>
<th>Typical Spectral Resolution ($\lambda/\Delta \lambda$)</th>
<th>FOV</th>
<th>Angular Resolution (arc sec)</th>
<th>Number of Sensor Chip Arrays</th>
<th>Mega Pixels</th>
<th>Detector Type / Format</th>
<th>Detector Temp (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIRCam</td>
<td>Shortwave</td>
<td>0.6 - 2.3</td>
<td>4,10,100</td>
<td>2.2 x 2.2 each of 2 modules</td>
<td>0.032 / pixel</td>
<td>8</td>
<td>34</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Longwave</td>
<td>2.4 - 5.0</td>
<td>4,10,100</td>
<td>2.2 x 2.2 each of 2 modules</td>
<td>0.065 / pixel</td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
<tr>
<td>NIRSpec</td>
<td>Multi-Object Spec</td>
<td>1.0 - 5.0</td>
<td>1000</td>
<td>203 x 463 mas clear shutter aperture, 267 x 528 mas pitch, 4 x 171 x 365 shutter array format, 9.7 sq arcmin multi-object targetable solid angle</td>
<td>see FOV</td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>37</td>
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<tr>
<td></td>
<td>Long Slits (5)</td>
<td>1.0 - 5.0</td>
<td>100, 1000, 2700</td>
<td>200 x 3500 mas x 3, 400 x 4000 mas, 100 x 2000 mas</td>
<td>see FOV</td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>37</td>
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<tr>
<td></td>
<td>IFU</td>
<td>0.7 - 5.0</td>
<td>2700</td>
<td>3 x 3 arc-sec</td>
<td>0.10 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
</tr>
<tr>
<td>MIRI</td>
<td>Imager</td>
<td>5 - 27</td>
<td>4-6</td>
<td>1.9 x 1.4</td>
<td>0.11 / pixel</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Low Res Slit</td>
<td>5 - 11</td>
<td>100</td>
<td>5&quot; x 0.6&quot;</td>
<td>see FOV</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Med Res IFU</td>
<td>4.87 - 7.76</td>
<td>3000</td>
<td>3.7&quot; x 3.7&quot;</td>
<td>0.16 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td></td>
<td></td>
<td>7.45 - 11.87</td>
<td>3000</td>
<td>4.7&quot; x 4.5&quot;</td>
<td>0.28 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td></td>
<td></td>
<td>11.47 - 18.24</td>
<td>3000</td>
<td>6.2&quot; x 6.1&quot;</td>
<td>0.39 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td></td>
<td></td>
<td>17.54 - 26.82</td>
<td>2250</td>
<td>7.1&quot; x 7.7&quot;</td>
<td>0.65 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td>FGS-TF</td>
<td></td>
<td>1.6 - 2.5, 3.2 - 4.9</td>
<td>100</td>
<td>2.2 x 2.2</td>
<td>0.065 / pixel</td>
<td>1</td>
<td>4</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
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<tr>
<td>FGS-Guider</td>
<td></td>
<td>0.8 - 5.0</td>
<td>0.7</td>
<td>2.3 x 2.3 each of 2 modules</td>
<td>0.068 / pixel</td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
</tbody>
</table>

Table courtesy of Matt Greenhouse, JWST ISIM Project Scientist

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### Estimated Sensitivities

<table>
<thead>
<tr>
<th>Wavelength (microns)</th>
<th>Instrument/Mode</th>
<th>Bandwidth (l/DL)</th>
<th>SNR</th>
<th>Maximum Wall Clock Time (s)</th>
<th>Continuum Flux Density (nJy)</th>
<th>Continuum Flux Density (10^{-33} W m^{-2} Hz^{-1})</th>
<th>Unresolved Line Flux (10^{-21} W m^{-2})</th>
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</thead>
<tbody>
<tr>
<td>1.1</td>
<td>NIRCam</td>
<td>4</td>
<td>10</td>
<td>10,000</td>
<td>TBD</td>
<td>TBD</td>
<td>NA</td>
</tr>
<tr>
<td>2</td>
<td>NIRCam</td>
<td>4</td>
<td>10</td>
<td>10,000</td>
<td>10.40</td>
<td>0.10</td>
<td>NA</td>
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<tr>
<td>3.5</td>
<td>FGS-TF</td>
<td>100</td>
<td>10</td>
<td>10,000</td>
<td>126.00</td>
<td>1.26</td>
<td>NA</td>
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<td>3</td>
<td>NIRSpec/Low Res</td>
<td>100</td>
<td>10</td>
<td>10,000</td>
<td>120.00</td>
<td>1.20</td>
<td>NA</td>
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<td>2</td>
<td>NIRSpec/Med Res</td>
<td>NA</td>
<td>10</td>
<td>100,000</td>
<td>NA</td>
<td>NA</td>
<td>1</td>
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<tr>
<td>10</td>
<td>MIRI/ Broadband</td>
<td>5</td>
<td>10</td>
<td>10,000</td>
<td>700.00</td>
<td>7.00</td>
<td>NA</td>
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<tr>
<td>21</td>
<td>MIRI/Broadband</td>
<td>4.2</td>
<td>10</td>
<td>10,000</td>
<td>8700.00</td>
<td>87.00</td>
<td>NA</td>
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<tr>
<td>9.9</td>
<td>MIRI/Spectrometer</td>
<td>NA</td>
<td>10</td>
<td>10,000</td>
<td>NA</td>
<td>NA</td>
<td>10</td>
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<tr>
<td>22.5</td>
<td>MIRI/Spectrometer</td>
<td>NA</td>
<td>10</td>
<td>10,000</td>
<td>NA</td>
<td>NA</td>
<td>560</td>
</tr>
</tbody>
</table>

- MIRI R=3000 IFU is currently estimated to have point source sensitivity Fnu ~ 500 nJy @ S/N = 10 in 1E4 s in wide 10 µm filter
- Please take all values as estimates only: better values should be provided by June 2011
Status

- All instrument engineering models built, flight models to be delivered in 2011
Birth of stars and protoplanetary systems

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

David Hardy
How do proto-stellar clouds collapse?

- Stars form in small regions collapsing gravitationally within larger molecular clouds.
- We can see through thick, dusty clouds in the infrared.
- Protostars begin to shine within the clouds, revealing temperature and density structure.
- Observations consist of near- and mid-IR images that are used to create extinction maps via color and number information of background stars.

Barnard 68 in infrared light
Emission vs. Extinction maps

- High JWST sensitivity allows much deeper penetration and much finer sampling than ground-based extinction mapping:

Herschel Column Density of Aquila

2MASS extinction map of Aquila

Könyves et al. 2010

Könyves et al. 2010 / Bontemps et al. 2010
How do planets form?

- Giant planets could be signpost of process that creates Earth-like planets
- Solar System primordial disk is now in small planets, moons, asteroids and comets

- Observations:
  - Coronagraphic imaging of very young exosolar planets
  - Compare spectra of comets and circumstellar disks
How are circumstellar disks like our Solar System?

Here is an illustration of what MIRI might find within the very young core in Ophiuchus, VLA 1623.
JWST and Herschel: nearby dark clouds

- Herschel PACS & SPIRE find the most embedded objects
- JWST will observe those protostars in detail:
  - Both NIRCam fields shown
  - TFI line imaging
  - NIRSpec MOS R=3000 spectra
  - MIRI images and IFU spectroscopy

Serpens Herschel SPIRE 350 µm image & protostars (green) Bontemps et al. 2010
JWST and Herschel: LMC

Sewiło et al. (2010): SPIRE, PACS, and Spitzer MIPS. Herschel objects in red boxes

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Bendo et al. (2010) PACS M81
- Dual NIRCam fields shown
- Can map star formation in a few pointings

Klaas et al. (2010) PACS Antennae
- Single NIRCam / TFI field shown
- MIRI field inset
Other JWST Star Formation/ISM thoughts:

- Probe structure of protostellar envelopes with deep mid-IR imaging
- Chemistry of circumstellar envelopes with mid-IR spectra
- Probe “bottom end” of the initial mass function with multi-object spectroscopy of young clusters
- Images and spectra of jets in high and low mass star formation regions to study cessation of infall and entrainment of outflows
- Multi-epoch images to search for jet & stellar variability and investigate dynamical motions
- Tunable filter imaging of H2, PAH, HI Br, and other line emission