HAWC
(High Resolution Airborne Wideband Camera)
A Facility Camera for SOFIA

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- Peter Shirron (GSFC)
- Bob Silverberg (GSFC)
- George Voellmer (GSFC)
- Jesse Wirth (UC)

University of Chicago – primary responsibility
GSFC – detector array, ADR, acquisition software (IRC)

RIT – analysis software
Caltech – detector array
HAWC...

- Is a first generation facility far-infrared camera for SOFIA
- Will operate between 40 and 300μm - wavelengths inaccessible from the ground
- Is designed to provide high angular resolution – ~2.6 detectors per Airy disk at each wavelength
- Will have a 12x32 array of “pop-up” bolometers
Scientific Functional Requirements

- Image with high sensitivity at spatial frequencies unique to SOFIA
- Map luminosity, color temperature, and optical depth of large-grain component of interstellar dust
- Search efficiently for low-luminosity sources in the presence of bright extended emission
- Resolve multiple sources with separations near the resolution limit of SOFIA
- Observe bright Solar-System objects (science and calibration)
- Easily and accurately combine HAWC data with data from other instruments and facilities
- Rapidly produce calibrated images
Multiwavelength Capability

- Four passbands, chosen to match atmospheric bands.
- Each passband is observed separately.
- Time to change passbands is approximately 1 minute.
- Reimaging optics match to diffraction limit in each passband.
- ~2.6 pixels per FWHM of Airy disk.

Angular Resolution

Current HAWC pixel and array sizes.

Format: 12 x 32 pixel array

- 2.25" pixel:  
  - $\lambda$ 53 $\mu$m
  - FOV: 27" x 72"

- 3.5" pixel:  
  - $\lambda$ 88 $\mu$m
  - FOV: 42" x 112"

- 6.0" pixel:  
  - $\lambda$ 155 $\mu$m
  - FOV: 72" x 192"

- 8.0" pixel:  
  - $\lambda$ 215 $\mu$m
  - FOV: 96" x 256"
Passbands Match Atmospheric Transmission
Windows

Atmosphere transmission at 41,000 ft.,
40° elev., 7.3 μm zenith H₂O, 1 μm resolution

HAWC Filter Passbands

Windows
Available Field of View

SOFIA’s Field of View

HAWC’s current field of view at 215 µm

HAWC’s available field of view

256”
## Optical and Photometric Specifications

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Units</th>
<th>Band1</th>
<th>Band2</th>
<th>Band3</th>
<th>Band4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central wavelength</td>
<td>µm</td>
<td>53</td>
<td>88</td>
<td>155</td>
<td>215</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>$^{2} \lambda/\lambda$</td>
<td>0.10</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>Pixel size</td>
<td>arcsec</td>
<td>2.25</td>
<td>3.50</td>
<td>6.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Image diameter (FWHM)</td>
<td>arcsec</td>
<td>6</td>
<td>9</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>Detector array field size</td>
<td>arcsec</td>
<td>27x72</td>
<td>42x112</td>
<td>72x192</td>
<td>96x256</td>
</tr>
<tr>
<td>Detector array areal filling factor</td>
<td>%</td>
<td>&gt;95</td>
<td>&gt;95</td>
<td>&gt;95</td>
<td>&gt;95</td>
</tr>
<tr>
<td>Mean transmission (cold optics, including detector QE)</td>
<td>%</td>
<td>0.11</td>
<td>0.16</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>Mean transmission (warm optics plus vacuum window)</td>
<td>%</td>
<td>0.52</td>
<td>0.54</td>
<td>0.45</td>
<td>0.60</td>
</tr>
<tr>
<td>Mean transmission (atmosphere, 10µm of H$_{2}$O, 40° elevation)</td>
<td>%</td>
<td>0.79</td>
<td>0.75</td>
<td>0.65</td>
<td>0.81</td>
</tr>
<tr>
<td>Background power per pixel</td>
<td>nW</td>
<td>0.014</td>
<td>0.023</td>
<td>0.027</td>
<td>0.021</td>
</tr>
<tr>
<td>NEP (thermal background limit, one pixel)</td>
<td>fW (1 sec)</td>
<td>0.09</td>
<td>0.11</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Frequency range (for background-limited performance)</td>
<td>Hz</td>
<td>5-20</td>
<td>5-20</td>
<td>5-20</td>
<td>5-20</td>
</tr>
<tr>
<td>NEFD (1σ, chopped, background limit, extended source, A $\Omega=\lambda^{2}$)</td>
<td>Jy (1 sec)</td>
<td>0.75</td>
<td>0.72</td>
<td>0.69</td>
<td>0.43</td>
</tr>
<tr>
<td>NEFD (1σ, chopped, background limit, extended source, A $\Omega=\lambda^{2}$)</td>
<td>mJy (1 hr)</td>
<td>12.5</td>
<td>12.0</td>
<td>11.5</td>
<td>7.2</td>
</tr>
</tbody>
</table>
HAWC/ Sofia Science

HAWC will investigate the origins of galaxies, stars, planetary systems, interstellar dust and molecules.

- The **cool** universe
  - HAWC is particularly well suited for studying objects with temperatures between 15 K and 150 K.

- The **dusty** universe
  - Many dusty objects emit much or most of their energy in HAWC’s spectral band (40-300 μm).

- The **distant** universe
  - SOFIA’s angular resolution will allow HAWC to resolve distant submillimeter galaxies that emitted a significant fraction of the light in the universe.

- The **chemical** universe
  - HAWC will be an important tool for investigating the cool, large-grain component of the interstellar medium.
HAWC will observe a wide range of objects and processes

- Formation of stars in our galaxy
- Star formation in external galaxies
- Structure and evolution of proto-planetary and remnant disks
- Return of gas and dust from stars to the interstellar medium
- Composition and life-cycle of interstellar dust
- Interactions between young stars and their environments
- Conditions in regions surrounding active galactic nuclei
- Submillimeter emission spectrum of high-Z galaxies
Test Cryostat: Test Assembly
Spring 2002
Test Stand Load Test: or--
How I stopped worrying and learned to love the Cryostat

Yeeehaa...!!
Test Cryostat Suspension Load Test
714 lb.
Test Cryostat Suspension Load Test
747 lb.
# Test Cryostat Suspension Load Test

**HAWC Test Cryostat G10 Tab Test 7May2002**

### Reservoir Longitudinal Axis Vertical

<table>
<thead>
<tr>
<th>Add Load, lbs</th>
<th>Total Load, lbs</th>
<th>Dial Indicator, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>171</td>
<td>171</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>157</td>
<td>328</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>105</td>
<td>433</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>50</td>
<td>483</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>101</td>
<td>584</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>130</td>
<td>714</td>
<td>0.0005 0.0000 0.0023</td>
</tr>
<tr>
<td>-714</td>
<td>0</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Indicators A, B & C are spaced every 120 degrees adjacent to G10 tab locations. Indicator A is topmost. Indicators B & C are in the same horizontal plane.

### Reservoir Longitudinal Axis Horizontal

<table>
<thead>
<tr>
<th>Add Load, lbs</th>
<th>Total Load, lbs</th>
<th>Dial Indicator, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>34</td>
<td>0.0000 0.0000 0.0000</td>
</tr>
<tr>
<td>171</td>
<td>205</td>
<td>0.0020 0.0012 0.0007</td>
</tr>
<tr>
<td>87</td>
<td>292</td>
<td>0.0035 0.0020 0.0008</td>
</tr>
<tr>
<td>91</td>
<td>383</td>
<td>0.0050 0.0027 0.0014</td>
</tr>
<tr>
<td>105</td>
<td>488</td>
<td>0.0080 0.0034 0.0012</td>
</tr>
<tr>
<td>76</td>
<td>564</td>
<td>0.0110 0.0040 0.0020</td>
</tr>
<tr>
<td>105</td>
<td>669</td>
<td>0.0145 0.0050 0.0025</td>
</tr>
<tr>
<td>78</td>
<td>747</td>
<td>0.0170 0.0055 0.0030</td>
</tr>
<tr>
<td>-713</td>
<td>34</td>
<td>0.0008 0.0015</td>
</tr>
</tbody>
</table>
Adiabatic Demagnetization Refrigerator (GSFC)

Tests complete, delivered to UC April 02
64-channel Prototype Detector Electronics
Goddard’s Instrument Remote Control Software
(T. Ames)

- JAVA and XML
- Data stored in FITS format.
- Currently in use with SHARC II
Delivery of HAWC Prototype Detector
# HAWC Prototype Detector Array & Measured Characteristics

- About 85% yield overall.
- Red – dead in detector hardware
- Blue – dead elsewhere, or noisy
courtesy D. Dowell (Caltech)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R(T)</td>
<td>$920\ \Omega \cdot \exp[(39.2\ \text{K}/T)^{1/2}]$</td>
</tr>
<tr>
<td>R(0.5 K)</td>
<td>$6.4\ \text{M}\Omega$</td>
</tr>
<tr>
<td>G(T)</td>
<td>$1200\ \text{pW/K} \cdot T^{1.5}$</td>
</tr>
<tr>
<td>G(0.5 K)</td>
<td>$420\ \text{pW/K}$</td>
</tr>
<tr>
<td>NEP(electrical) (0.5 K)</td>
<td>$6 \times 10^{-17}\ \text{W Hz}^{-1/2}$</td>
</tr>
<tr>
<td>S</td>
<td>$4 \times 10^8\ \text{V/W}$ (dark)</td>
</tr>
<tr>
<td>NEP(electrical) (350 μm)</td>
<td>$3 \times 10^{-16}\ \text{W Hz}^{-1/2}$</td>
</tr>
<tr>
<td>S</td>
<td>$2 \times 10^7\ \text{V/W}$ (350 μm)</td>
</tr>
<tr>
<td>τ</td>
<td>~6 msec</td>
</tr>
<tr>
<td>C(0.5 K)</td>
<td>$4\ \text{pJ/K}$</td>
</tr>
</tbody>
</table>
Silicon Wafer Prior to Folding

- Doped silicon thermistors
Folding Apparatus

G. Voellmer
Completed Folded Row
Pixels After Folding
12 Stacked Rows
Observed SHARC II Sensitivity & Noise Spectrum

Measurements taken on CSO

Measurement made in lab
courtesy D. Dowell (Caltech)
Moon, Filtered

- “Background” with low spatial frequency removed
SHARC2 350 μm Results
January 2003

Antennae: NGC 4038–9

Palomar Sky Survey

SHARC II
350 μm

courtesy D. Dowell (Caltech)
SHARC2 350 µm Maps
January 2002

Horsehead Nebula

Palomar Sky Survey

SHARC II
350 µm

courtesy D. Dowell (Caltech)
Epsilon Eridani Debris Disk

- 30 mJy/beam peak intensity
- $F_\nu \sim \nu^{1.8}$ submillimeter spectrum, suggesting large particles

courtesy D. Dowell (Caltech)