HAWC  First Light Status and Science Potential

July 2001
HAWC

- Facility Instrument for SOFIA
- Diffraction-limited far-infrared camera
- 4 spectral bands covering far infrared spectrum (40-250 µm)
- 12 x 32 Pop-up Detector (PUD) array cooled to 0.2°K with adiabatic demagnetization refrigerator (ADR)
It’s the angular resolution, stupid.

Hard cutoff in MTF at angular frequency of $2R/\lambda$. 

$$\left[ \frac{2J_1(u)}{u} \right]^2$$
<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>Δλ/λ</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></td>
<td></td>
<td></td>
<td></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 H₂O, 40° elevation)</td>
<td>%</td>
<td>0.79</td>
<td>0.75</td>
<td>0.65</td>
<td>0.81</td>
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<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, AΩ=λ²)</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, AΩ=λ²)</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 can deliver diffraction-limited imaging in the spectral region completely obscured from the ground-- even if the initial pointing is only 2 arcsec rms.
**HAWC Status**

- **March 01: Passed CDR**
- **April 2001:** Re-structured HAWC development plan in accordance with revised SOFIA schedule
- **May 2001:** Submitted budget for FY 02-04 to USRA
- **June 2001**
  - Acceptance tests of ADR subsystem successfully completed
  - Documentation for incremental CADR for ADR subsystem submitted
  - Housekeeping subsystem hardware and software completed
  - All hardware components for pupil carousel mechanism delivered
  - Laboratory system for testing folded detector rows completed and checked out
  - Begin fabrication of array test cryostat
  - **Fabrication and testing completed for 3 JFET warm boards required for prototype array-- production proceeding on flight boards and spares**
- **July 2001**
  - Successfully completed folding detector rows for prototype (SHARC II) array
  - Successfully tested first two rows of folded detectors
Schedule

• As SOFIA’s facility far infrared camera, HAWC can deliver science results with unique value and impact during SOFIA’s first year of operation

• Revised development schedule will allow HAWC to fly by the end of FY 04:
  – FY 01
    • Complete prototype detector
    • Complete CADR for ADR subsystem
    • Fabricate test cryostat and prototype detector electronics
  – FY 02
    • Complete HAWC detector array
    • System tests of detector, optics, cryogenic suspension components, housekeeping electronics, ADR, instrument control software
    • System CADR
  – FY 03
    • Fabricate, assemble, and test flight system
  – FY 04
    • Burn-in testing of flight system
    • Completion of airworthiness certification
    • Initial flights
Impact of HAWC Data on Other Facilities and Instruments

- **SIRTF-- expected launch ~2002, expected lifetime ~5 years**
  - HAWC will provide data at three times the angular resolution of SIRTF in the far infrared and with comparable angular resolution to SIRTF data in the near and mid infrared
  - HAWC first-light data can be combined with SIRTF data (particularly legacy-program data) at shorter wavelengths to yield multi-wavelength “data cubes” at a self-consistent angular resolution of a few arcseconds. These data will have a large and immediate impact on a broad spectrum of astrophysical problems.

- **Herschel-- expected launch ~2007, expected lifetime ~3 years**
  - HAWC will explore the far-infrared universe accessible to Herschel
  - HAWC data will allow the observing program for Herschel to be optimized to make the best use of its limited operational lifetime

- **SOFIA-- initial science operations January 2005, lifetime ~20 years**
  - HAWC far infrared images will be needed to plan observations with and augment the data from SOFIA spectrometers (no other facility will have comparable resolution when SOFIA goes into operation)
HAWC Science Priorities (1)

- **Galactic Center**
  - HAWC will be the first far infrared instrument able to distinguish between radiation from the circumnuclear dust ring and dust clouds in the immediate environment of the nucleus itself.
  - What is the SED of the black hole itself?
  - Why is the black hole so quiet?
  - What is the distribution and temperature of dust near the nucleus?
  - How does the black hole affect its surrounding environment?
  - How does star formation in Galactic Center molecular clouds differ from star formation elsewhere?

- **Fragmentation and evolution of molecular clouds forming massive stars**
  - How do collapsing clouds fragment into Trapezium-type clusters?
  - What is the nature and role of accretion disks?
  - How do the protostars interact with their environment?
  - How do young OB stars interact with their environment?
  - What is the role of supernovae in regulating or terminating star-formation?

- **Protostellar, protoplanetary, and debris disks**
  - What are the SED’s of protostellar disks?
  - What is the spatial distribution and temperature of dust in debris disks around the nearest stars?
  - How do protostellar/debris disks evolve in time?

- **Evolution of matter in the early universe**
  - What kinds of galaxies contribute to the far infrared background?
  - What kinds of processes are most important during galaxy formation?
  - What is the relative importance, energetically, of starbursts and AGN’s?
HAWC Science Priorities (2)

• **Powering mechanisms of ultra-luminous IR galaxies**
  - HAWC will have angular resolution to match ISO and SIRTF resolution at mid-IR wavelengths. This will allow a full spectrum of dust emission from different starburst regions covering the spectral regions dominated by PAHs (fluorescent emission from macromolecules), VSGs (very small grains emitting by non-equilibrium thermal emission), and large grains (which are in thermal equilibrium with the local interstellar radiation field). This combination will give a rich set of diagnostic tools for investigating the composition, radiation environment, and evolutionary state of the starbursts.
  - How do galaxy collisions trigger starbursts and how do the starbursts evolve? Example: NGC 4038/39
  - How does star formation in interacting systems differ from that in isolated galaxies?

• **Active galactic nuclei and circumnuclear starbursts**
  - What is the far infrared SED of an AGN?
  - How are AGN’s and circumnuclear starbursts related?
  - Examples: NGC 1068, NGC 1275, NGC 5128, NGC 4151, M82, NGC 253

• **Star formation in low-metallicity environments**
  - How do clusters of massive stars form and evolve in the Large Magellanic Cloud?
  - How does this differ from evolution of massive star clusters in our galaxy?

• **Star formation in spiral disks**
  - What are the luminosities and temperatures of starbursts in spiral arms, and how are they related to position with respect to spiral density waves?

• **Distribution and temperature of dust in protostellar cores**

• **Distribution and temperature of dust in outflows around old stars**
SEDs of Debris Disks

Spectral energy distributions of debris disks that were resolved by IRAS at 60 µm.

The curves are the sum of a hot blackbody fit to the stellar photosphere and a cold blackbody fit to the IRAS 25 and 60 µm flux densities (after subtraction of the photospheric flux).

• **Observed properties**
  – Spectral type= K2V
  – Distance= 3.22 pc
  – Age \( \leq 1 \) Gyr
  – IRAS detected excess FIR emission with half-power radius of 8-11 arcsec
  – 850 \( \mu \)m SCUBA/JCMT image shows ring of emission with radius of 18 arcsec

• **Significance**
  – May be a young analog of the solar system
    • Age near the end of the era of planet formation?
  – SMM ring radius similar to radius of Kuiper Belt

• **Questions**
  – Far infrared and submillimeter fluxes have different spatial distributions.
    • What are the temperatures and emissivities of the FIR and SMM emitting grains?
    • \( T_{60-100} = 74 \)K from IRAS data, equilibrium temperature at 18 arcsec radius \( \sim 30 \)K?
    • Need high angular resolution observations at 30-400 \( \mu \)m
Debris disk around ε Eridanae

Beam size

53 µm
88 µm
155 µm
215 µm

JCMT beam

850 µm

HAWC/SOFIA beam sizes

Pluto’s orbit
The Galactic Center is a local laboratory for investigating AGNs and nuclear starbursts.
Galactic Center in the FIR
From Zylka et al. 1995
Nucleus of the Seyfert Galaxy
NGC 1068

Upper Panel: CO J=2-1 contours superposed on H$_2$ 1-0 S1 emission

Lower Panel: CO J=2-1 emission (red) and OIII emission (green)

UV flux from an accretion disk around a massive black hole interacts with surrounding interstellar matter (the reservoir of cloud material which feeds the accretion disk).
HST image shows many luminous young clusters.

But-- the most luminous and the youngest are obscured by dust.

Where are the youngest star forming regions? What are their ages? What is the history star formation during the merger?

215 $\mu$m  155 $\mu$m  88 $\mu$m  53 $\mu$m
NGC 4038/39

850 µm over 60 µm

60 µm over 850 µm

215 µm  155 µm  88 µm  53 µm
Over half the light in the universe was emitted at far infrared wavelengths.
What is the History of Energy Production in the Universe?

The star formation rate was much higher in the past.

What kinds of objects and processes dominated at each epoch?

What is the relative importance of stars and AGNs?
Confusion-Limited Images of the FIRB
(based on simulations by Blain 1999)

Deep images at far infrared wavelengths will be limited by confusion.

HAWC and SOFIA complement SIRTF and ground-based SMM telescopes, providing a first look at the FIRB at a self-consistent angular resolution of ~15-20 arcsec.
Why HAWC needs to fly at first light

• HAWC can deliver diffraction-limited imaging, even if SOFIA does not initially meet its design requirements for pointing and image size
• HAWC will have unparalleled angular resolution at wavelengths inaccessible from the ground-- HAWC images will give the best “discovery potential” during the first year of SOFIA science operations
• HAWC far infrared images can be combined with SIRTF legacy data at shorter wavelengths to yield science results with large and immediate impact on a wide range of astrophysical problems
• Many “first light” targets will be “class prototype” objects-- the nearest and brightest of their kind-- which can be done effectively even at reduced sensitivity
• HAWC images will be needed to plan efficient observing programs for SOFIA spectrometers and for Herschel
• Conclusion: HAWC must be ready to deliver high-quality science observations during SOFIA’s first year of operation