Orion Nebula Mosaic

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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)
Pop-up Detectors
Angular Frequency Response

Hard cutoff in MTF at angular frequency of $2R/\lambda$
# 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>∆λ/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>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 H₂O, 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, 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>
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</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.**
Relation of HAWC/SOFIA to Other Facilities and Instruments

- **SIRTF** -- 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 (e.g., legacy-program data) at shorter wavelengths to yield multi-wavelength “data cubes” at the best available angular resolution. These data will have a large and immediate impact on a broad variety of astrophysical problems.

- **Herschel** -- 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 SOFIA spectrometers (no other facility will have comparable resolution when SOFIA goes into operation)-- where should they look?
  - Line to continuum ratio is an important metric of conditions within emitting regions

- **LMT and ALMA**
  - LMT with bolometer camera will be a good match to SOFIA/HAWC
  - ALMA resolution will be much higher, field of view much smaller
SIRTF Legacy Proposals

- GLIMPSE: Galactic Legacy Infrared Mid-Plane Survey Extraordinaire
- GOODS: Great Observatories Deep Survey
- From Molecular Clouds to Planets
- SINGS: The SIRTF Nearby Galaxies Survey-- Physics of the Star-Forming ISM and Galaxy Evolution
- SWIRE: The SIRTF Wide-area Infrared Extragalactic Survey
What kinds of questions will HAWC address?

- Star formation
- Galaxy formation
- Planet formation
- Energy budget of galactic nuclei
  - Starbursts vs. AGNs
- Evolution of matter
  - Dust-- composition, creation, destruction
  - Physics of the interstellar medium
What will HAWC see, and what will it tell us?

• HAWC will see:
  – Predominantly light from large dust grains with temperatures of 15–150 K (but perhaps on occasion non-thermal emission from energetic particles)
  – The dust will in general be heated by stars or gravitational accretion
  – The dust emission will generally be optically thin

• Where will the light come from?
  – Predominantly from PDRs
    • Most of the light in the universe comes from PDRs
    • Much of what we know about PDRs we learned from the KAO

• HAWC images will tell us about the distribution of:
  – Luminosity
  – Temperature
  – Optical depth

• Ratios of large-grain dust emission to small-grain, PAH emission, or line emission are important diagnostics for composition and state of ISM
Angular Resolution

• Why is it important?
  – To reveal detail in complex extended sources
  – To separate closely space compact objects (stars, e.g., don’t generally form alone)
  – To distinguish compact objects against bright extended emission

• What are some important natural scales?
  – Circumstellar disks: ~ 100-1000 AU
  – Separation of brightest stars in young clusters: ~10 arcsec at distance of Orion
  – Separation of young clusters in molecular clouds: ~ 1 arcmin at Orion
  – Circum-nuclear zone in the Galaxy: radius ~200 pc
  – Circum-nucllar ring/cavity in the Galaxy: radius ~1 pc
  – Accretion disks around AGNs: ~ few light days
So-- where will we look and what might we expect to see?
45-250 µm map of Orion/OMC–1 made with 1–channel bolometer array on Lear Jet 30–cm telescope.

Orion is the “Rosetta stone” for high-mass star formation.

Protostar or HII region? BN, KL, or Nye-Allen?

More complicated-- one of first experimental studies of PDRs.
FIR Images of Orion/OMC–1 made with 60–channel bolometer array on KAO 90–cm telescope.

Much more detail in PDR emission.

Protostellar clusters isolated and distinguished from PDR.
Warm and Cold Dust in Orion/OMC–1

Vaillancourt (2001)
Stars, Dust, and Gas in Orion
Prestellar dense core
\( \sim 1,000,000 \) yr

Submillimeter Protostar
\(< 10,000 \) yr

Infrared Protostar
\( \sim 100,000 \) yr

T Tauri (CTTS)
\( \sim 1,000,000 \) yr

Evolved T Tauri (WTTS)
\( \sim 10,000,000 \) yr

Time
Debris Disks

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).

The disks are intrinsically far infrared objects.

ε Eridani

- **Observed properties**
  - Spectral type = K2V
  - Distance = 3.22 pc
  - Age ≤ 1 Gyr
  - IRAS detected excess FIR emission with half-power radius of 8-11 arcsec
  - 850 µm SCUBA/JCMT image shows ring of emission with radius of ~18 arcsec
- **Significance**
  - 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, emissivities, and sizes of the FIR and SMM emitting grains? (T_{60-100}=74K from IRAS data, equilibrium temperature at 18 arcsec radius ~ 30K ?)
    - What are the parent objects of the dust grains?
    - What do the observations tell us about the state and evolution of the associated planetary systems?
  - Need high angular resolution observations at 30-850 µm
Debris disk around ε Eridanae

Beam size

JCMT beam

850 µm

HAWC/SOFIA beam sizes

53 µm
88 µm
155 µm
215 µm

Size of Pluto’s orbit
The Galactic Center: a local laboratory for investigating AGNs and nuclear starbursts
Galactic Center in the FIR
Galactic Center SED

From Zylka et al. 1995
Nucleus of the Seyfert Galaxy
NGC 1068

Upper Panel: CO J=2-1 countours 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 resevoir of cloud material which feeds the accretion disk).
NGC 4038/39: Enhanced Star Formation in Colliding Galaxies

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 of star formation during the merger?
NGC 4038/39

850µm over 60µm

60µm over 850µm
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?
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 be ready 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 high “discovery potential” during the first years of SOFIA science operations
• HAWC far infrared images can be combined with SIRTF 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
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

• 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