German/European Instrumentation Effort

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Workshop 26-28 Jul 2021
• 231 registered participants;
• 3 days @ ~4.5h per day
• 56 Presenters
• **Main Themes**: ISM, PDRs, shocks, star formation, astrochemistry
• 1/3 of presentations extragalactic
  – High resolution spectroscopy MIR and FIR

An example from the talk by Maytraiyee Tiwari

![Average spectra](image)

- RCW 49, Tiwari et al.
- Average spectra over the entire observed mapped region
- $^{12}\text{CO} \times 1.5$
- $^{13}\text{CO} \times 4$

![Energetics and Morphology](image)

- KE of shell = $2 \times 10^{50}$ ergs.
- ME from winds = $6 \times 10^{55}$ ergs.
- Plasma’s thermal energy = $2.4 \times 10^{50}$ ergs
- The shell is broken open in the west and the plasma is venting out.
- Shell’s expansion must be driven by momentum.
Science Requirements

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  - Trade spectral resolution for sensitivity

An example from the talk by Melanie Chevance

30Dor: SOFIA/FIFI-LS data

Chevance et al. 2020b
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  - High resolution spectroscopy MIR and FIR
  - Trade spectral resolution for sensitivity
  - Polarimetry in FIR
  - MIR/FIR broadband photometry
  - Specific lines
  - Time sampling
- **Specific requests:**
  - Fine structure lines, HD, CO ladder, oxygen compounds
  - large scale mapping of [NII] 122\(\mu\)m / 205\(\mu\)m
  - 350\(\mu\)m filter
  - NIR capabilities for occultation obs

<table>
<thead>
<tr>
<th>Session</th>
<th>Talks</th>
<th>Posters</th>
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<tbody>
<tr>
<td>Solar System</td>
<td>5</td>
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<tr>
<td>Star &amp; Planet Formation</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Interstellar Medium</td>
<td>15</td>
<td>8</td>
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<tr>
<td>Late Stellar Evolution</td>
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<tr>
<td>Nearby Galaxies</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>High-Redshift Galaxies</td>
<td>3</td>
<td>4</td>
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</tbody>
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**Instrumental Requirements**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Count</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Spectrometer</td>
<td>46</td>
<td>73%</td>
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<tr>
<td>Photometer</td>
<td>15</td>
<td>24%</td>
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<tr>
<td>Heterodyne</td>
<td>32</td>
<td>51%</td>
</tr>
<tr>
<td>R=5000 FIFI</td>
<td>13</td>
<td>21%</td>
</tr>
<tr>
<td>FIFI-LS</td>
<td>19</td>
<td>30%</td>
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<tr>
<td>EXES</td>
<td>4</td>
<td>6%</td>
</tr>
<tr>
<td>FIR camera</td>
<td>12</td>
<td>19%</td>
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<tr>
<td>MIR camera</td>
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<td>3%</td>
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<tr>
<td>NIR camera</td>
<td>3</td>
<td>5%</td>
</tr>
<tr>
<td>Pol.</td>
<td>7</td>
<td>11%</td>
</tr>
<tr>
<td>Time sampling balloon</td>
<td>5</td>
<td>8%</td>
</tr>
<tr>
<td>Time sampling balloon</td>
<td>6</td>
<td>10%</td>
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<tr>
<td>single pointing maps</td>
<td>21</td>
<td>33%</td>
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<tr>
<td>maps</td>
<td>37</td>
<td>59%</td>
</tr>
<tr>
<td>Total Science Cases</td>
<td>63</td>
<td>100%</td>
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</tbody>
</table>

Version: 14-Oct-2021
Second Workshop

Workshop 17-19 Nov 2021

• 156 registered participants;
• 3 days @ ~4.5h per day
• 31 Presenters

• Main Themes:
  – Airborne platforms
  – Heterodyne devices/systems
  – Direct detection devices/systems
  – Instruments and funding
Heterodyne Technology

Typical SIS Receiver Architecture

- Sky
- Telescope Optics
- Beam Splitter
- Feedhorn
- RF Antenna
- Mixer
- 300 K Electronics and Readout
- LO
- 4 K Stage
- LNA

Herschel HIFI

Balanced Mixer fort CHAI

Balanced Mixer at 1.9 THz

460 GHz

SuperCam 64 Pixel (Guest on APEX)
Heterodyne Technology

- Highest spectral resolution ($R \approx 10^6$)
- Well understood technology

- Feedhorns
- Mixer:
  - $v > 1$ THz: HEB (Hot electron bolometers)
  - $v < 1$ THz: SIS (Superconductor-Insulator-Superconductor)
  - IF Bandwidth $< 5$ GHz, with new materials $\approx 9$ GHz possible

- Local Oscillator (LO):
  - $v < 2$ THz: Frequency multiplied types
  - $v > 2$ THz: Quantum cascade lasers (QCL)

- Backend Spectrometer
  - Much electronics that requires power
- 100 Pixels challenging
- Challenges:
  - Micromachining and handling
  - Miniaturization
  - LO coupling and power
  - Mixer cooling
  - Low power spectrometer electronics (CMOS?)

- Modular approach? 35 pixels?
- Single frequency exchangeable front end
Direct Detection Technology

MKIDs

Integral Field Unit (IFU)

TES Detectors

Cold Electron Bolometers

Si Polarimetric Bolometers
Direct Detection Technology

- large pixel counts
- No quantum noise penalty
- Maximum $R \sim 10^5$

Kinetic Inductance Detectors (KIDs)
- Lumped element KIDs (CNRS Grenoble)
  - NEP $\sim 10^{-19}$ W/√Hz
- Antenna Coupled KIDs (SRON, TU-Delft)
- Integrated Field Unit (IFU) (TU-Delft)
  - Spectrally resolved pixels with KIDs
  - 350 μm spectral mapping at $R \sim 10$ (“filter”) or $R = 100$-2000?
- FIFI+LS Upgrade (Illinois, DSI, JPL, UdEC, USRA)
  - Use JPL Starfire KID development
  - Increase spaxels to 9x7 and FOV by 1.75
  - Extend range to 42μm and 206μm

Transition Edge Detectors (TES)
- Wide range all IR/submm, very adaptable
- TES application for security scanner (Leibnitz Inst.)

Semiconductor Bolometers
- Silicon Polarimetric Detector Arrays (CEA, MPE)
  - On chip polarimetry
  - Add spectroscopy with Etalon, Fabry-Perot Scanner, Moving Backshort

Cold Electron Bolometers
- Multichroic receivers with Cold-Electron Bolometers (Chalmers, Nizni Novgorod TU...)
- Wide wavelength range and very small detector element
- Self cooling
Airborne Platforms

- **SOFIA** (NASA, DLR)
  - Airplane 2.7m telescope, ~150 flights per year to the stratosphere 4 flights/week @ 10h
  - Crewed mission
  - Fully functional observatory with 20 year operational lifetime
  - Payload mass <600kg, <6500 Watts (instrument only)
  - LHe cryocoolers

- **COPILOT** (CNES, IRAp, IAS, CEA, Cardiff, Rome)
  - Balloon missions, 1 m telescope
  - Wide field broad band photometry of C+

- **Blast Observatory** (NASA and Italian space agency)
  - Balloon mission, 1.8 m Gregorian telescope
  - 175 µm 250 µm, 350 µm MKIDs (~8000 det), 30 days, ~500 W power by solar cells (up to 1980W)
  - Payload 1225kg (includes telescope)

- **ASTHROS** (NASA-JPL)
  - Balloon mission, 2.5m telescope, 2 year cadence
  - [NII] 122µm (2.675 THz) and 205µm (1.461 THz), 4 pixels, 4K cryocooler, 20 days
  - 15 days around Antarctica
  - Payload 2700 kg, 900kg, 450kg (balloon type)
  - 900 W of power

- **Sunrise Mission** (MPS Göttingen)
  - 1 m telescope, UV and visible
  - Altitudes are 35km-43km
  - Durations are 5-6 days arctic, <43 days antarctic
Airborne Platforms as Observatories

- Airplane and balloons have each their individual strengths
- **SOFIA**
  - Regular observations 4 days a week
  - Safe landings
  - Good calibration
    - Long instrument lifetime
  - Observatory operation serves many communities
  - Accommodating power and mass limits
  - Moveable observatory
    - “Rapid” response within reason is possible
  - Overflight restrictions only minor problem

- **Balloons**
  - Higher altitude
  - Long observing time, especially with high pressure balloons
  - Relatively cheap
  - Safe landing considered biggest issue
    - Gondola protection for payload
  - Probability for total loss high
  - Overflight restrictions an issue in the north
  - Very different schedule considerations
    - Typically plan for 1 flight, next one ~2 years later
    - Waiting for the right weather conditions
  - Stringent mass and power limitations
    - Long duration balloons less lift
  - Good for focused longer duration missions
• Terahertz Mapper
  – Relatively clear idea how it will look
  – Specific frequencies important (science feedback needed)

• 100 Pixels considered a challenge
  – Needs simple reproducible design
  – Multiple suggestions of building modular and upgradeable
    • (GREAT example)
  – LOs for >1 THz will be QCLs that are harder to tune
  – Exchangeable front ends for single frequency

• Expertise is still there. Funding needed.
Direct Detection Instrument Ideas

- FIFI+LS: FIFI-LS Upgrade to more pixels and better detectors
  - Est. cost is ~$4M ($2.5M is for detectors), ~2.5 years (1.5 years downtime)
- HIRMES-2: Solve detector issues, reduce complexity and finish
- HIRMES pHD: HD specialized spectrometer based on HIRMES
  - Could be modular approach to HIRMES-2
- Near-infrared channel for SOFIA's Focal Plane Imager FPI+
  - NIR channel ~$350k, new M3 ~$940k
- B-BOP derivative for Co-PILOT (or SOFIA)
- 350 μm Spectral Mapper based on IFU technology

- Many options: Loop back with science needed
Airborne Platforms

• Balloons are great for focused high altitude missions
  – It is still a long way to a regular observatory operation
  – Main obstacles are
    • Considerable risk during landing
    • Strong weather dependence of launch

• New airborne observatories need safe landing and mobility
  – Study steerable glider landing and propulsion systems
  – Study by Keck Institute of airships reaching 65000 ft.
  – Considering development time, this would be a good SOFIA successor

• SOFIA is a working and well performing observatory
  – There are still 11 years of the 20 year operational lifetime left
  – New instrumentation can be built but needs project stability
Conclusion

- European technology is there to substantially upgrade SOFIA abilities and science.
- Another iteration with scientists is needed
- Any European funding will require project stability for the projected development time, i.e. >= 5 years
- Balloons are good for specific tasks but are not the Far-IR observatory solution for the next 10-15 years due to lack of safe landing capability and strong weather dependence

Keep SOFIA flying!

Stopping now is like stopping Herschel after 2 years!

Agree on a remaining lifetime and provide stability
- Spend a moderate budget per year on upgrades
- Start preparing for a successor now
Backups
Sensitivity Limits Direct Detection vs. Coherent Detection

Talk by Baselmans
High resolution spectroscopy using direct detectors

On needs a folded mechanism to beat the long path length differences:

- disambiguation distance: $\Delta d = \frac{1}{2} \lambda \cdot R$, $R = \frac{\lambda}{\delta \lambda}$
- Resonant cavities, such as VIPA's, are more compact

Bourdarot, G. Et al., (2018). Experimental test of a 40 cm-long R=100 000 spectrometer for exoplanet characterisation. https://doi.org/10.1117/12.2311696