SOFIA – Capabilities & Context

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Stratospheric Observatory for Infrared Astronomy
Questions to Consider

• What are the key strengths of SOFIA?
• What are the key limitations of SOFIA?
• How does SOFIA fit in with past and future facilities?
• Given these considerations, what would be the best approach for new instrumentation?
The scientific rationale for SOFIA is that the Far IR is essential in understanding some of the key processes in the universe.

Most of the luminosity of star formation regions, external galaxies, and cooler objects in the universe is in far-IR and Sub-mm dust emission.

The most important emission lines responsible for the energy balance of the Interstellar Medium are in the far-infrared.
Principal SOFIA Legacies

• Physics of the Interstellar Medium
  – Energy Balance in Clouds
  – Lifecycle of the Interstellar Medium

• Star Formation
  – Physics of star forming filaments
  – Star Formation in Nearby Galaxies

• Solar System
  – High resolution spectroscopy of planets
  – High resolution spectroscopy of comets
  – Atmospheres of Trans-Neptunian Objects

• Far-Infrared Community
  – SOFIA provides the only general access to the Far-Infrared for the foreseeable future
  – The science on SOFIA is defined by the ideas of the community.
IR Mission Coverage
### SOFIA Instrument Complement

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FPI+</strong> (Focal Plane Imager Plus)</td>
<td>Visible light high speed camera</td>
<td>0.360 – 1.1 μm</td>
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<tr>
<td><strong>EXES (Echelon-Cross- Echelle Spectrograph)</strong></td>
<td>High Resolution (R &gt; 10^5) Echelle Spectrometer</td>
<td>5 – 28 μm</td>
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| **FORCAST (Faint Object infraRed CAmera for the SOFIA Telescope)** | Mid-IR Dual Channel Imaging Grism Spectroscopy | 5 – 25 μm  
                                              |                                                  | 25 – 40 μm                 |
| **FIFI-LS (Field Imaging Far-Infrared Line Spectrometer)** | Dual Channel Integral Field Grating Spectrometer | 42 – 110 μm  
                                              |                                                  | 100 – 210 μm               |
| **GREAT, upGREAT (German REceiver for Astronomy at Terahertz frequencies)** | High resolution (R>10^6) heterodyne spectrometer; multi-pixel spectrometer | 1.25 – 1.52 THz  
                                              |                                                  | 1.81 – 1.91 THz  
                                              |                                                  | 4.74 THz                    |
| **HAWC+ (High-resolution Airborne Wideband Camera-Plus)** | Far-Infrared camera and polarimeter              | Five ~20% bands at 53, 63, 89, 154, & 214 μm. |
SOFIA Spectroscopy in Context
Key Differences Between
SOFIA and Space Telescopes

• SOFIA is a warm telescope
  – Compared to a cold space telescope, the background from the
telescope is very high, limiting photometric sensitivity

• The number of hours per year provided by SOFIA will always be limited
  – A best, we can expect only an annual on-sky efficiency of ~10%
  – Consequently, the number of potential investigators is limited
  – By standard NASA metrics, each observation needs to be an order of
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  – SOFIA provides unique, but specialized, capabilities
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• SOFIA has the capability to carry diverse, large instruments
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• SOFIA instrument development can take advantage of the latest advancements in technology
Growth in Astronomical Sensors
Where NOT to Put All Those Pixels

• Large Format Imaging Arrays Unless They Support Unique Capabilities
  – Spitzer and Herschel have conducted photometric surveys that surpass anything possible with SOFIA
    • Nearby Star Formation Regions
      – C2D, Gould Belt Survey – Spitzer
      – HOPS, HGBS - Herschel
    • Galactic Structure
      – MIPSGAL, GLIMPSE, GLIMPSEII, GLIMPSE-3D – Spitzer
      – Hi-GAL - Herschel
    • LMC, SMC
      – SAGE – Spitzer
      – HERITAGE - Herschel
  • Local Group
    – SINGS – Spitzer
    – KINGFISH – Herschel
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    • Galactic Center Region
  • Local Group
    – SINGS – Spitzer
    – KINGFISH – Herschel
Key Science Questions in the SOFIA Domain

• What is the global energy balance in galaxies and how can this knowledge be applied to more distant systems?
  – Key heating and cooling lines in the Interstellar Medium

• What is the role of magnetic fields in star formation?
  – Measure B in a variety of environments

• How does feedback from massive star formation work?
  – Dynamical studies of star forming regions

• What determines the configuration of planetary systems?
  – Protoplanetary disk masses and evolution

• What is the chemical evolution of the Solar System?
Where Would I Put Instrumentation Resources?

• Focus on SOFIA-Unique Capabilities
  – High-resolution spectroscopy
  – Polarimetry
  – Occultations
  – Time variable phenomena

[I. Stephens et al., in prep.].
Example of a Successful Instrument Program - upGREAT

• GREAT - German Receiver for Astronomy at Terahertz Frequencies
  – Instrument Developed at Max Planck Institute for Radio Astronomy, Bonn
  – Rolf Güsten, PI
  – Heterodyne Spectrometers @ 1.3, 1.5, 1.9 THz, and ~ 2.5, 2.7 THz

• Steady improvements
  – Addition of high frequency band at 4.7 THz
  – upGREAT: 7+7-pixel array receivers at 157 \(\mu\)m, [C II]
  – upGREAT: 7-pixel array at 63 \(\mu\)m, [O I]
  – Cryocoolers
  – 4GREAT: four co-aligned pixels at 491-635 GHz, 890-1092 GHz, 1240-1525 GHz, and 2490-2590 GHz
• Upgrade GREAT spectrometer from 1 pixel to 7+7 pixels to map [C II]
upGREAT

- GREAT Science Highlights
  - Detection of oxygen on Mars
  - Detection of interstellar mercapto (SH)
  - Detection of HeH+ in the planetary nebula NGC 7027
  - [C II] map of Orion star formation region
    - Map accomplished in 13 flights or ~43 hours. Herschel would have required 80x more time.

Pabst et al. 2020, ArXiv 2005.03917
Why Was GREAT Great?

• GREAT had a strong Principal Investigator in Rolf Geusten
• GREAT was a German instrument
  – Steady funding from DLR and MPI
  – Insulated from many NASA constraints
    • Reviews except at acceptance
• Instrument was modular
  – Key interfaces with SOFIA were stable
  – Changes and improvements were made inside a known envelope
    • New arrays and channels were installed in existing Dewars
Impediments to Progress in Instrumentation

• Unsteady support for SOFIA from NASA
  – Lack of SOFIA-related technology support
  – Mishandled new-instrument calls

• Cost of instruments
  – Complexity of airworthiness process
    • Need to focus on real safety drivers
  – Adoption of many spaceflight standards
    • Should be able to take advantage of ability to repair problems and re-fly

• Time Needed to Develop Instruments
  – A more rapid development paradigm needs to be developed
  – Simpler, more focused instrumentation
  – Reuse of available engineering
HIRMES Dewar as a Standard Cryostat?