SOFIA – Capabilities & Context

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SOFIA

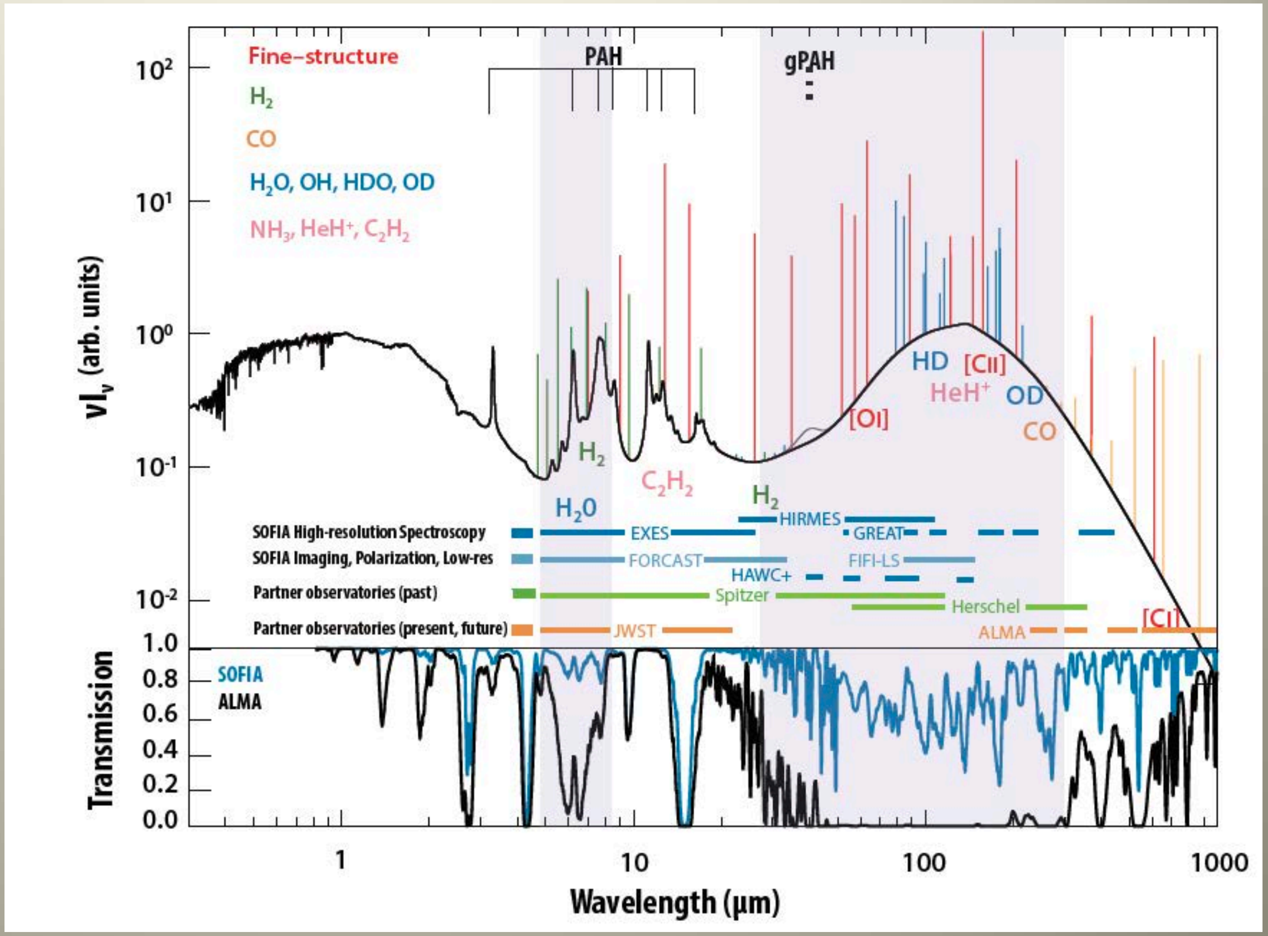
Stratospheric Observatory for Infrared Astronomy

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?

Scientific Rationale for SOFIA

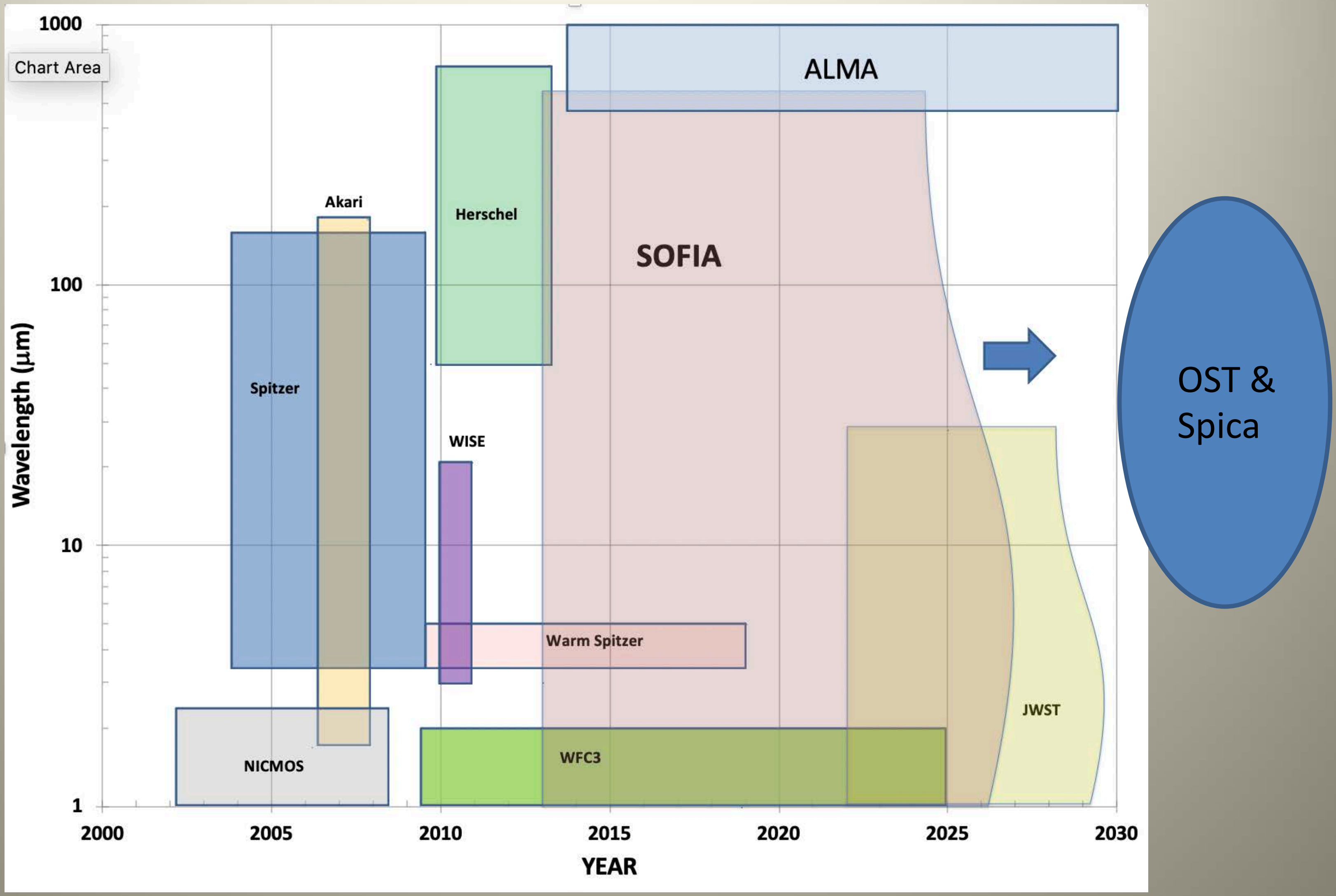
- The scientific rationale for SOFIA is that the Far IR is essential in understanding some of the key processes in the universe
- Most of the luminosity of star formation regions, external galaxies, and cooler objects in the universe is in far-IR and Sub-mm dust emission
- The most important emission 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.

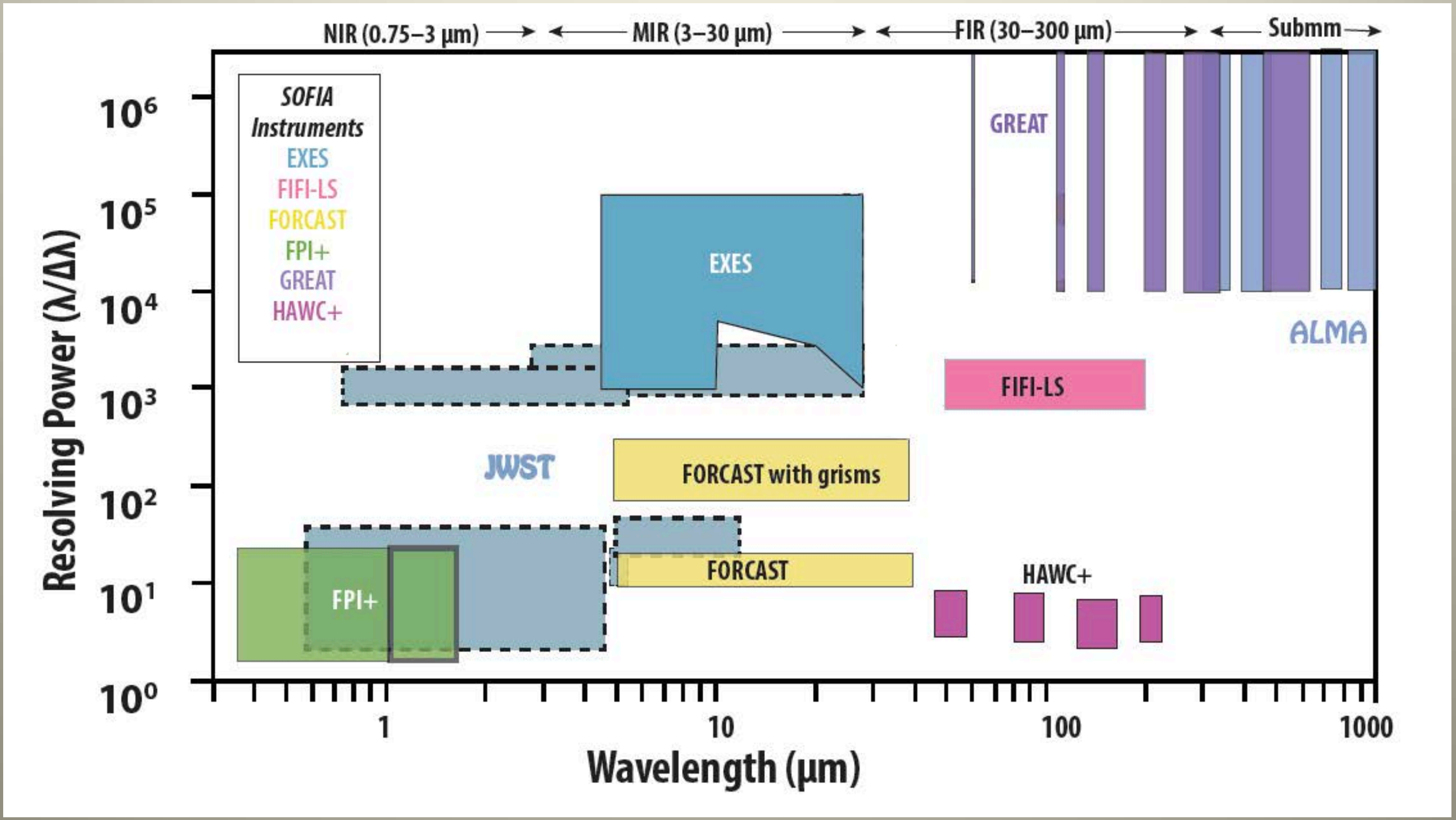
IR Mission Coverage



SOFIA Instrument Complement

Instrument	Description	Coverage
FPI+ (Focal Plane Imager Plus)	Visible light high speed camera	0.360 – 1.1 µm
EXES (Echelon-Cross- Echelle Spectrograph)	High Resolution (R > 10^5) Echelle Spectrometer	5 – 28 µm
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 magnitude more impactful than the competition

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  - SOFIA provides unique, but specialized, capabilities

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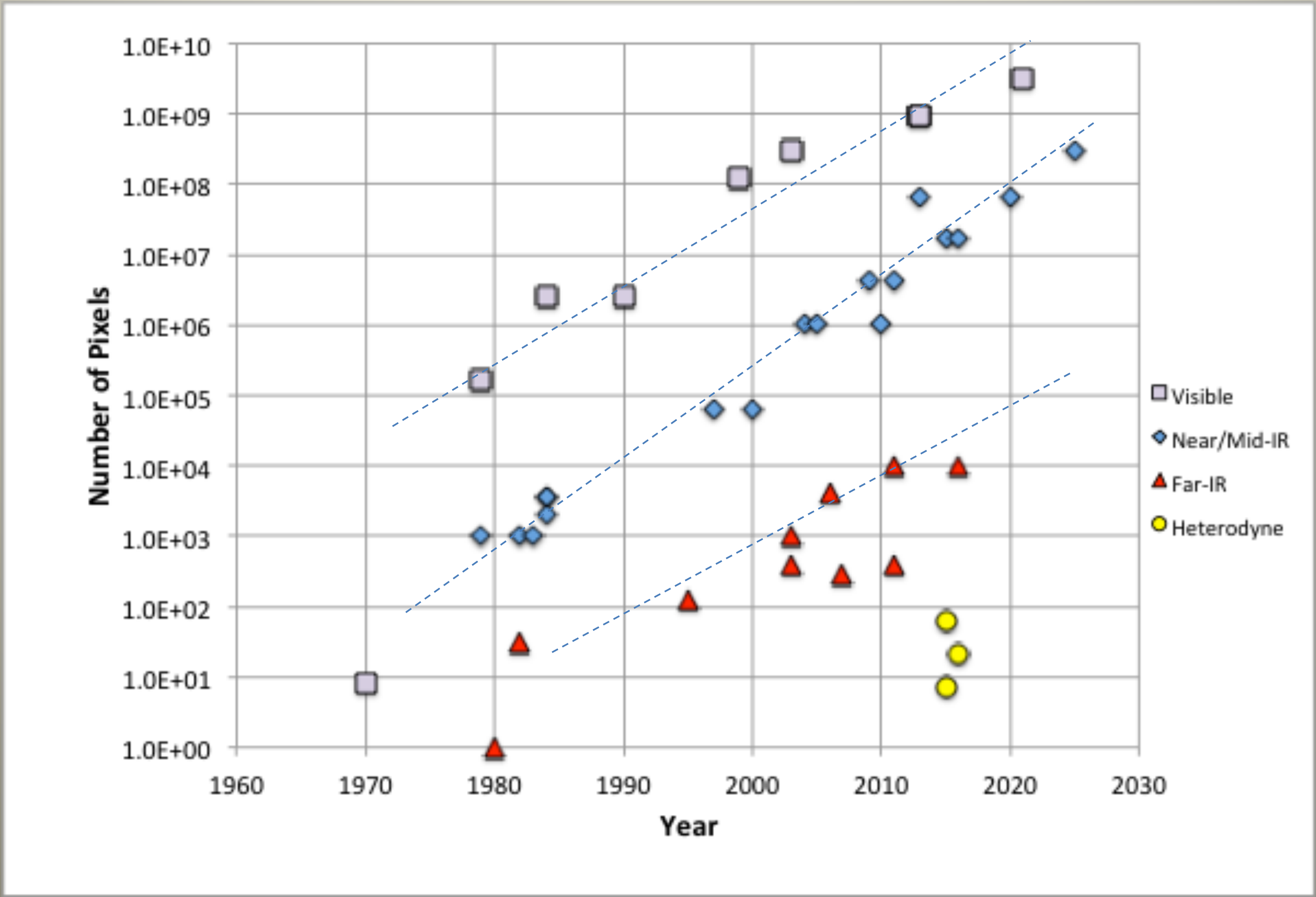
- SOFIA has the capability to carry diverse, large instruments
  - SOFIA provides unique, but specialized, capabilities
- SOFIA instrument development can take advantage of the latest advancements in technology

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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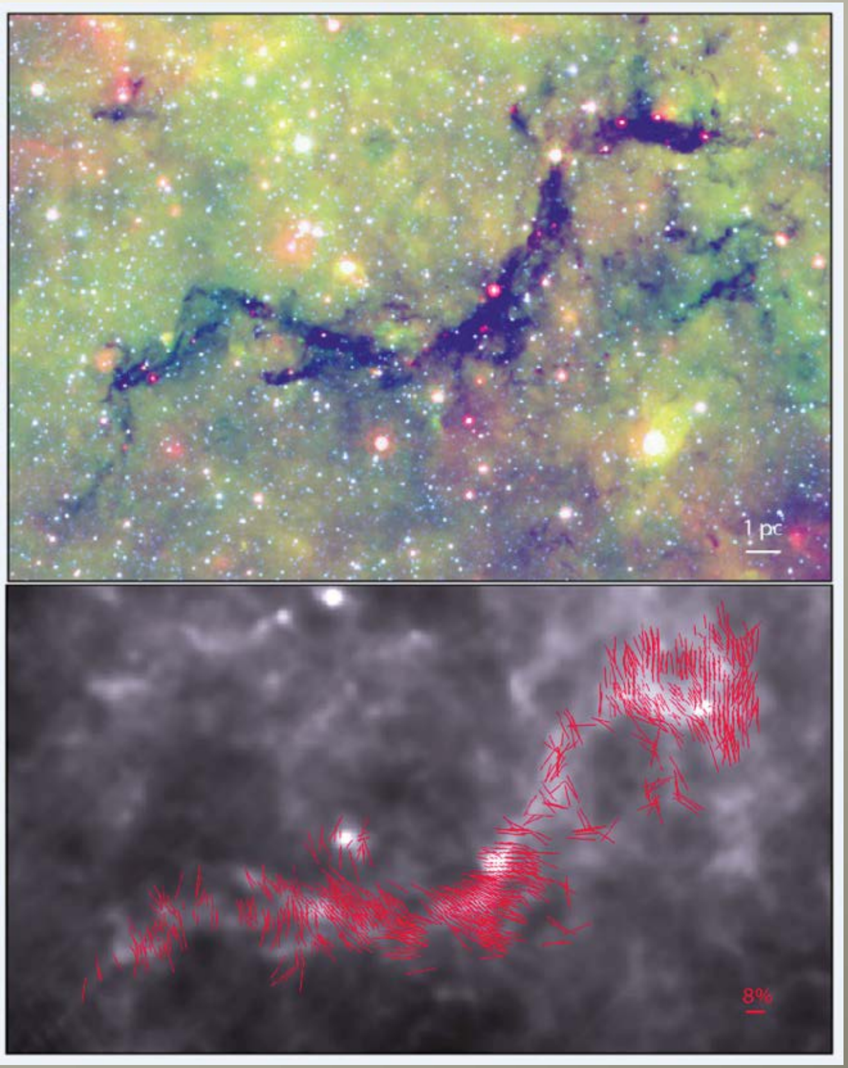
  - SOFIA Opportunity
    - Galactic Center Region

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?

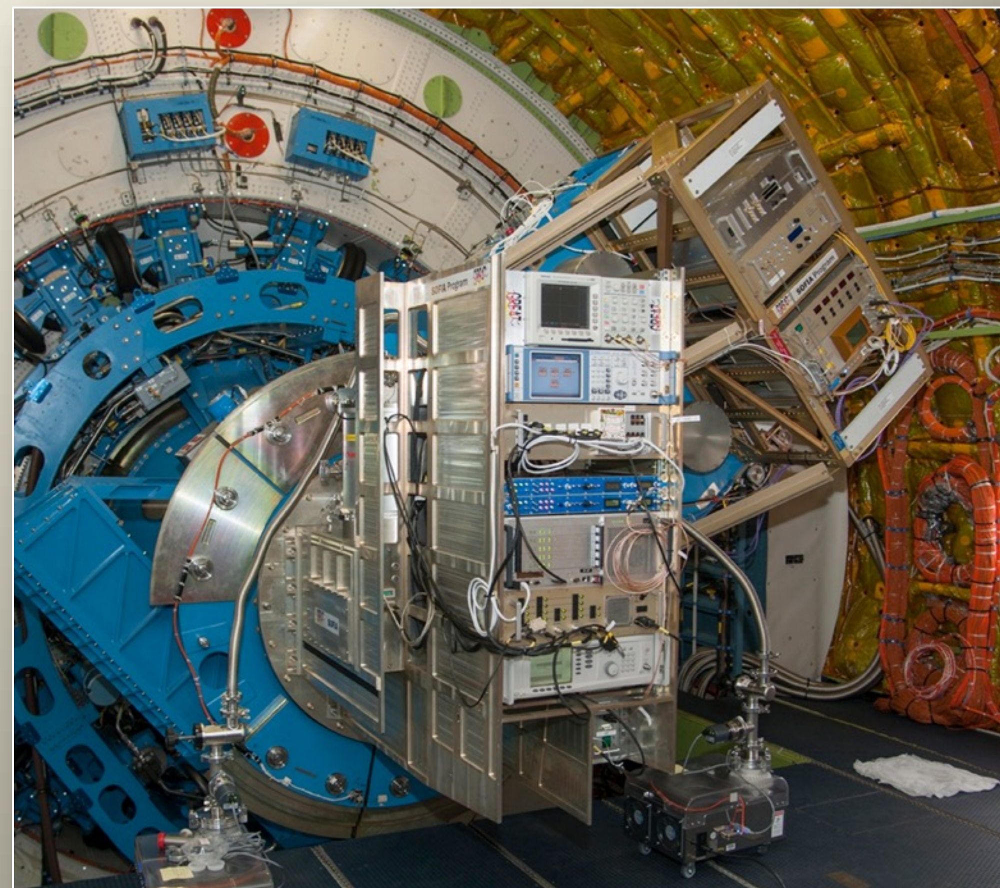
- Focus on SOFIA-Unique Capabilities
  - High-resolution spectroscopy
  - Polarimetry
  - Occultations
  - Time variable phenomena



[I. Stephens et al., in prep.].

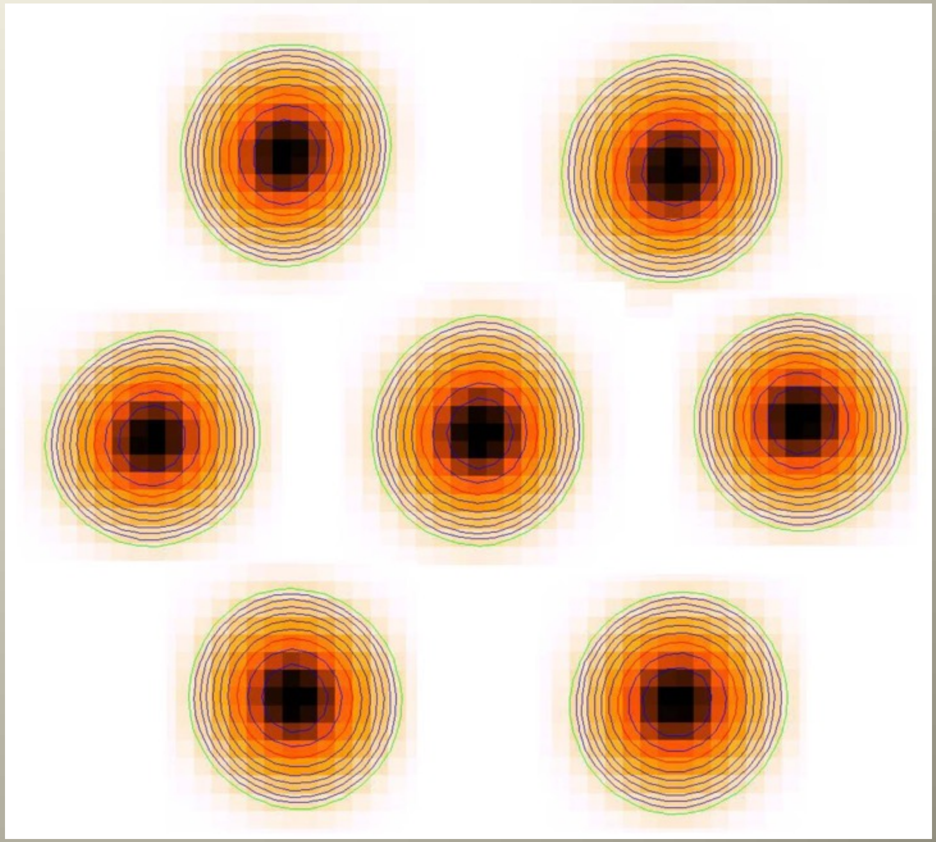
Example of a Successful Instrument Program - upGREAT

- 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 μm, [C II]
  - upGREAT: 7-pixel array at 63 μm, [O I]
  - Cryocoolers
  - 4GREAT: four co-aligned pixels at 491-635 GHz, 890-1092 GHz, 1240-1525 GHz, and 2490-2590 GHz



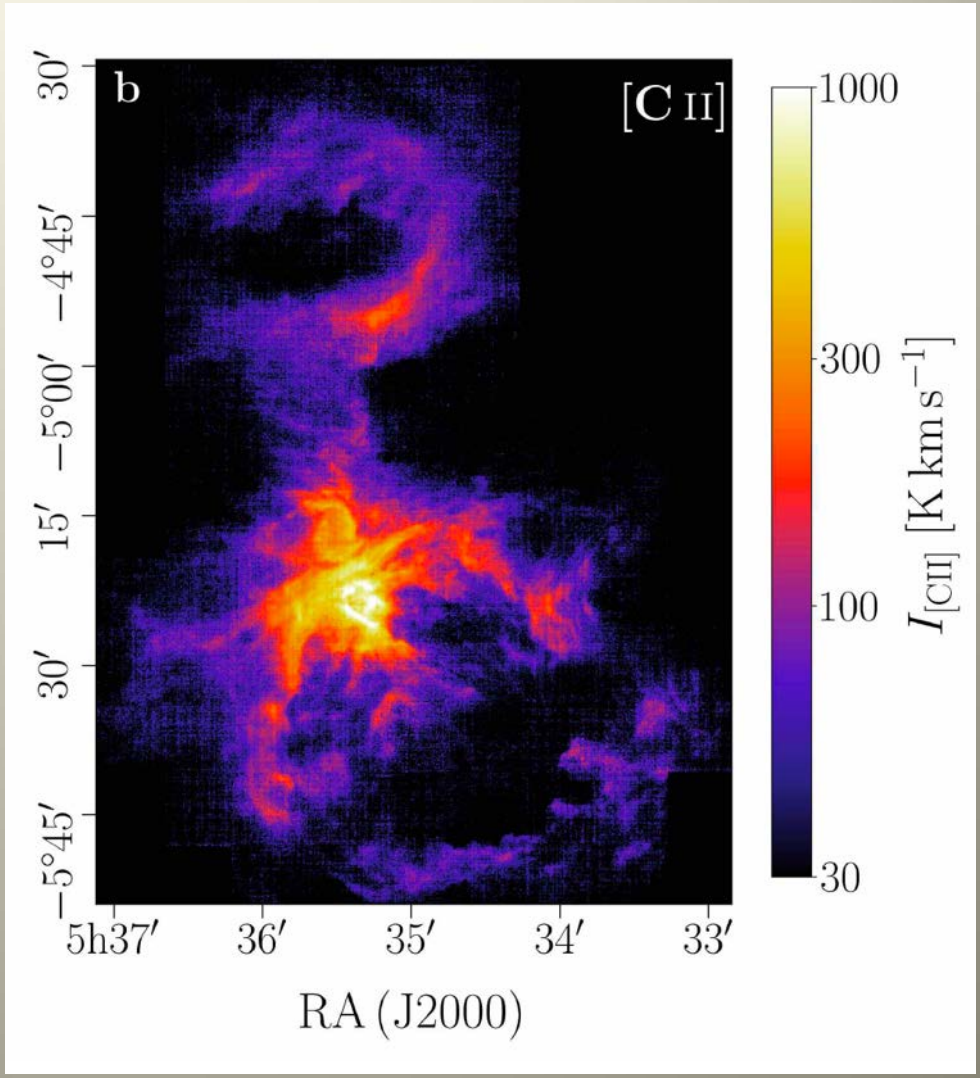
upGREAT

- 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?