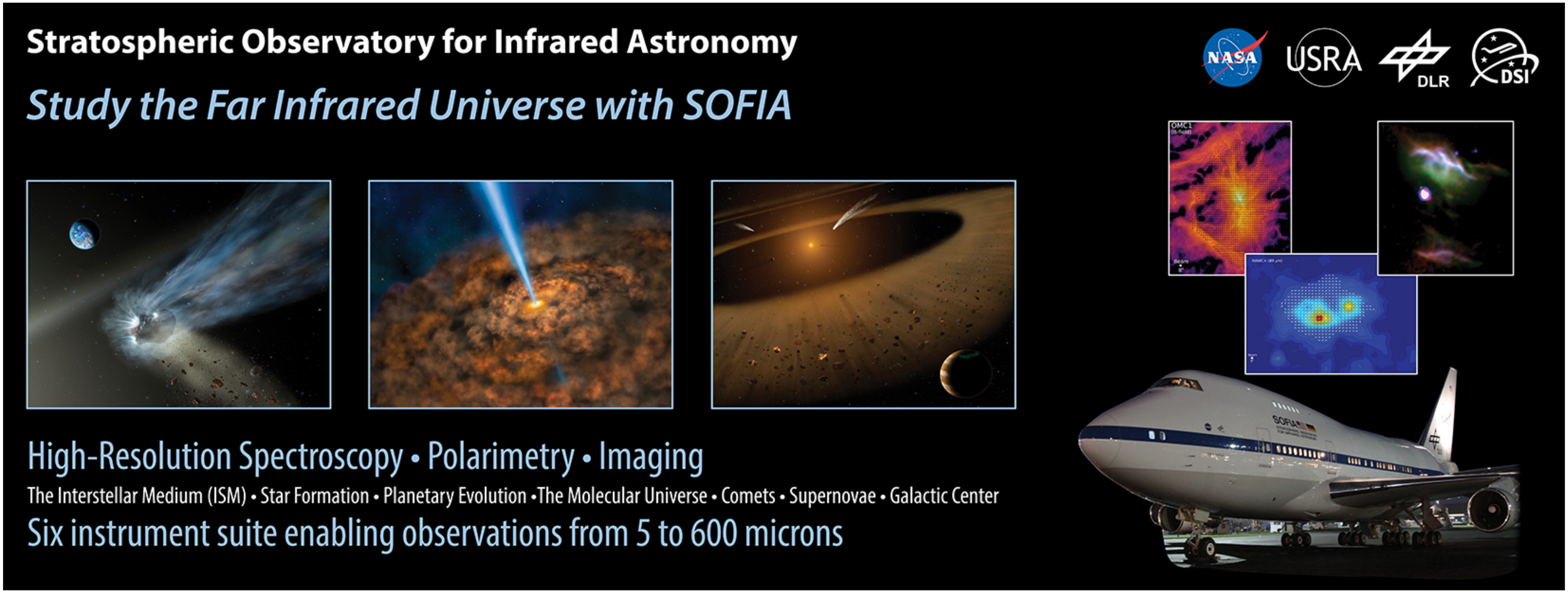
SOFIA Today and Tomorrow

Stratospheric Observatory For Infrared Astronomy



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Science Mission Operations Director

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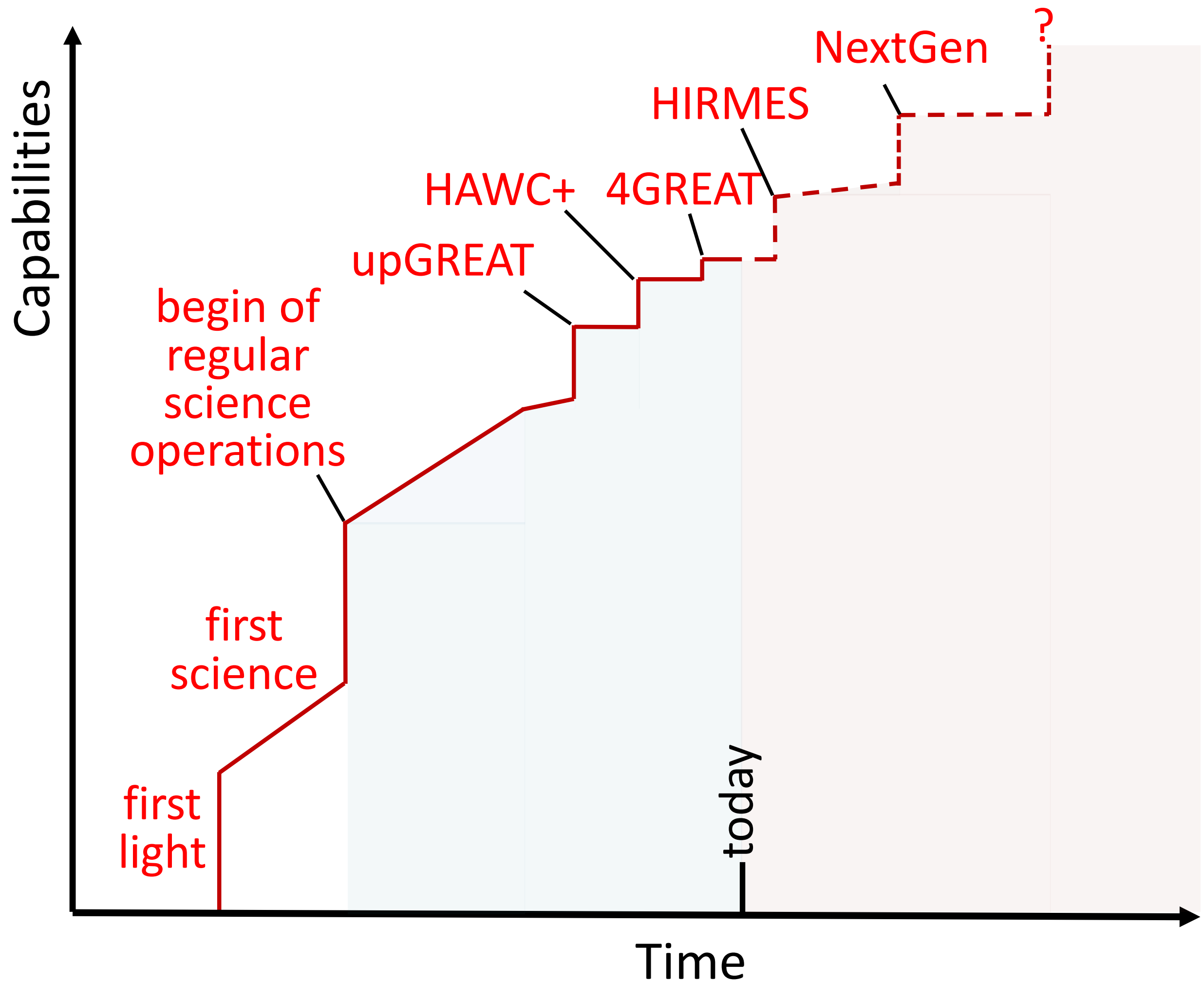
SOFIA Overview

- SOFIA is a modified B747SP aircraft with a 2.7m telescope
  - Operates in the optical–submm regime
  - Offers community unique FIR access (28 - 320 μm)
  - Joint Program between the US (80%) and Germany (20%)
- Operated by NASA, DLR, USRA, and DSI
- Regular science operations began in 2014
- Designed for 20 year lifetime (i.e. until 2034)
- Senior Reviews (2019, 2022, 2025, …) determine nature of continued operations

Capability Profile of SOFIA

With **SOFIA**, unlike for space missions…

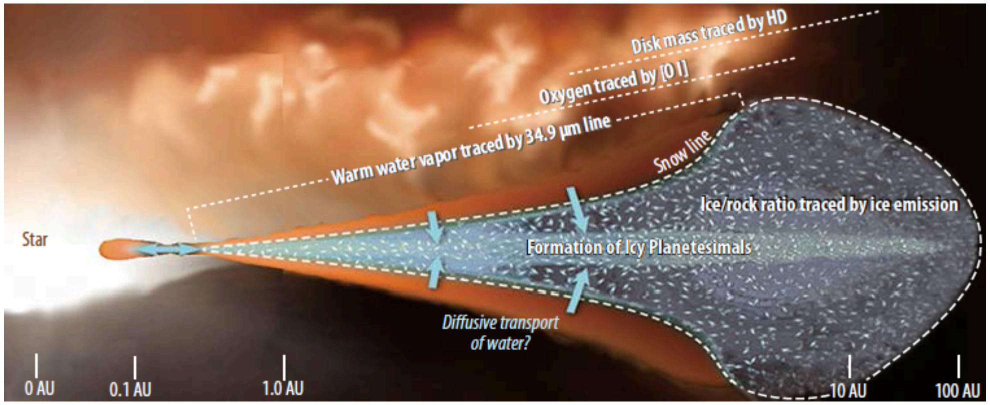
- Hardware repairs & upgrades are possible on a relatively short time scale
- New instruments can be added to address current relevant science questions
  - Ample power, mass, and computing capabilities support early versions of future space hardware

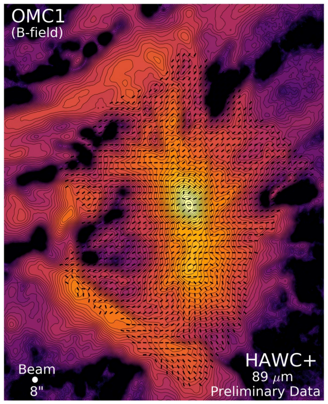


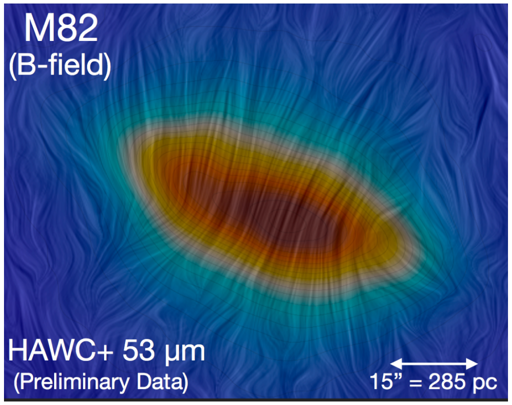
- **SOFIA Today** uniquely addresses relevant science questions as never before
- **SOFIA Tomorrow** will perform even more spectacularly as new capabilities are added

SOFIA Science Objectives Today & Tomorrow

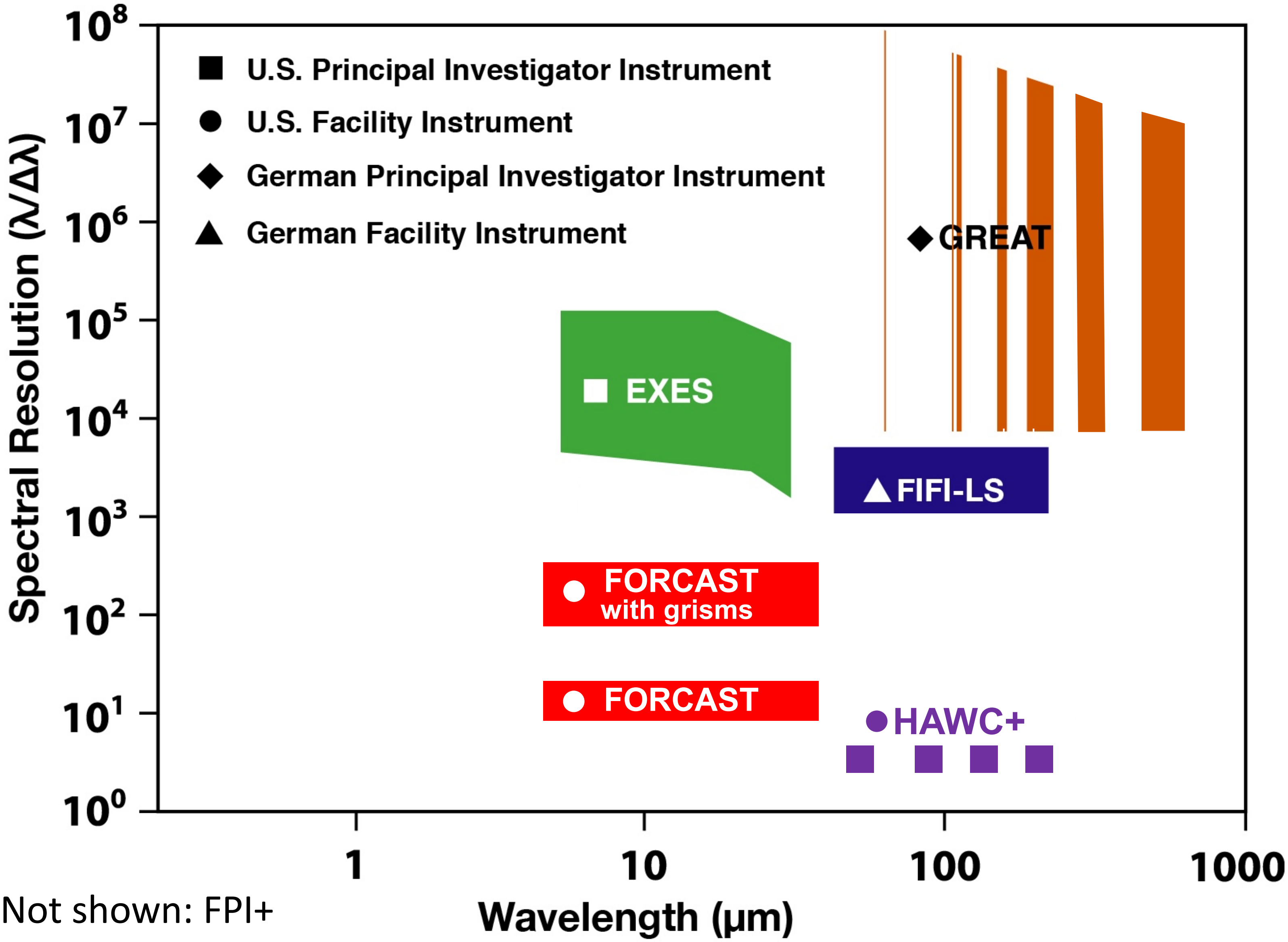
- **The Birth of Planets and Stars: Finally Charting the Infall**
- **The Path to Life: Water, Organics, and Dust through Cosmic Time**
- **Extreme and Hostile Environments: Unveiling Starbursts and AGNs**





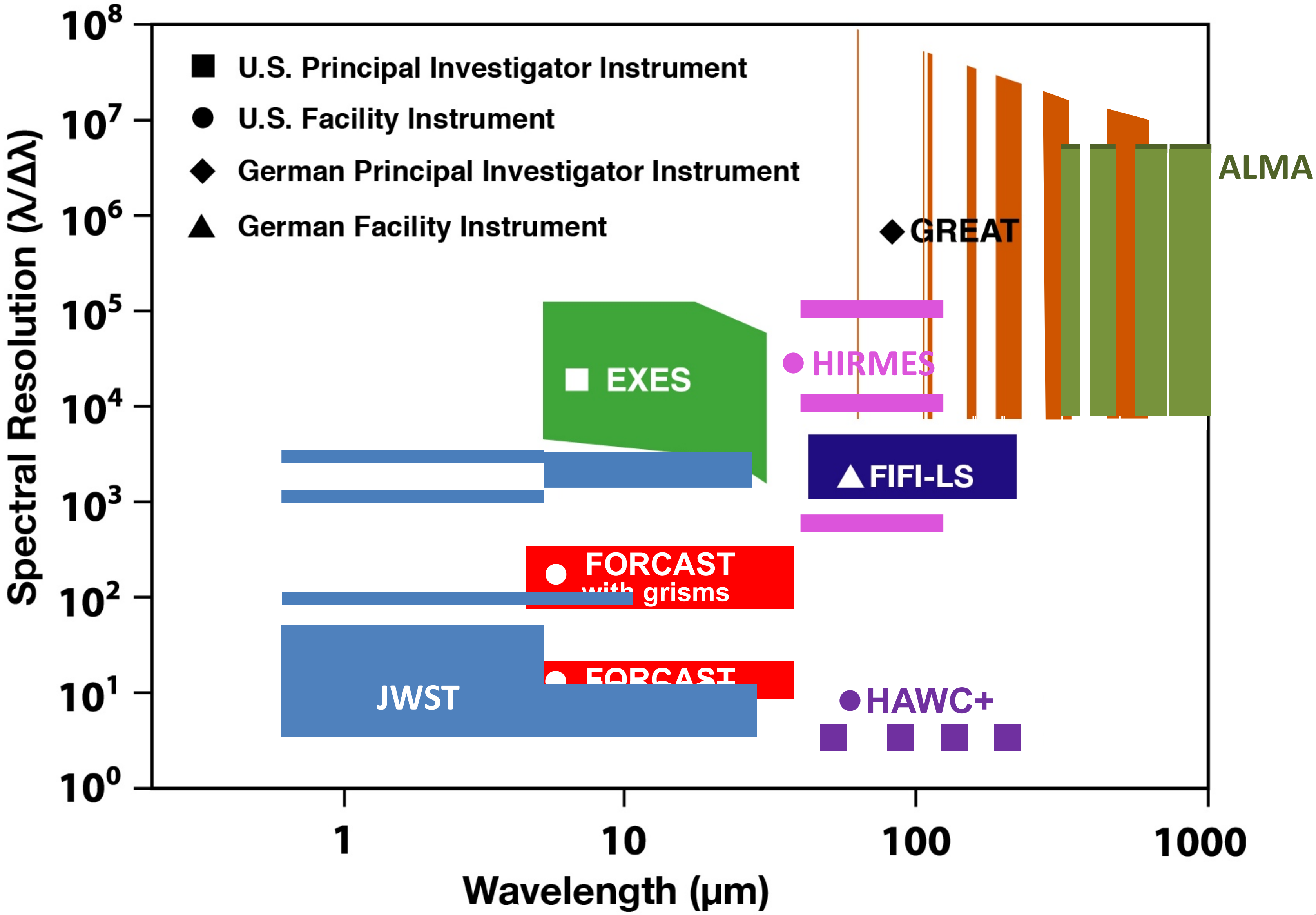


Science Instruments on SOFIA



Not shown: FPI+

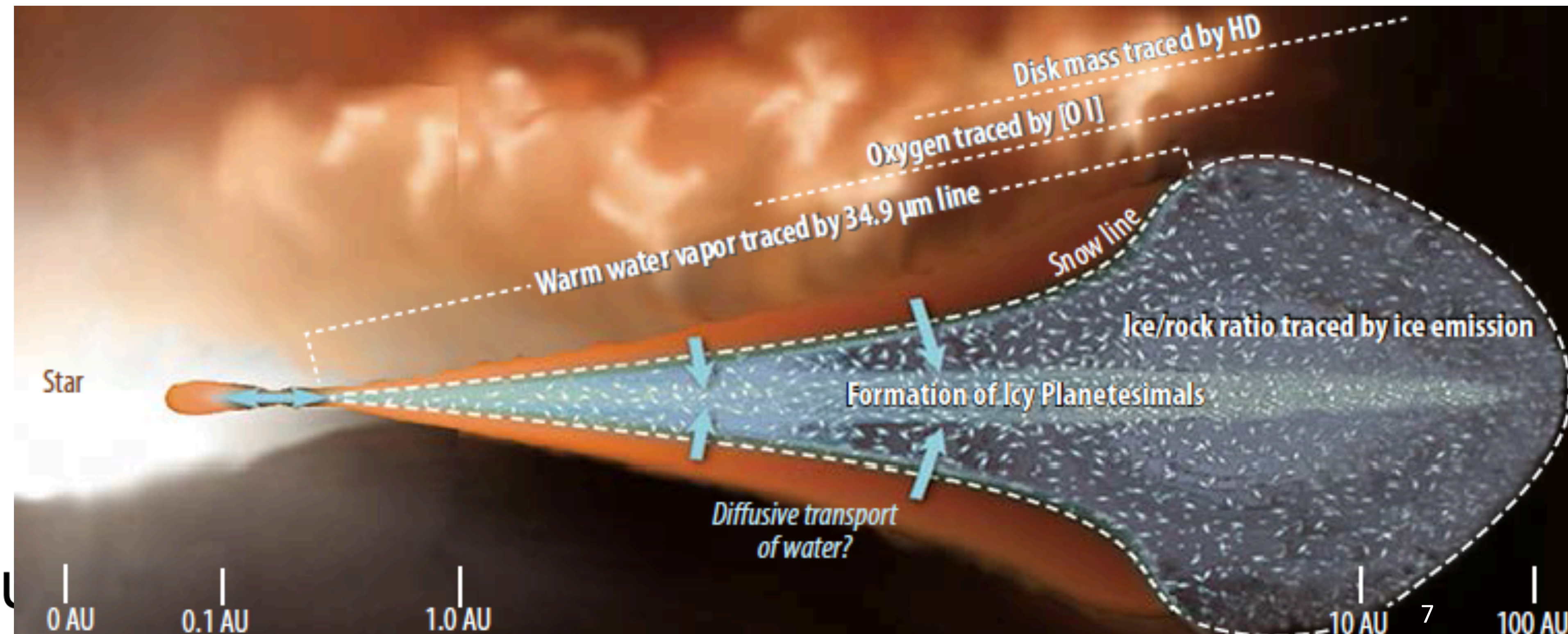
Science Instruments on SOFIA



HIRMES

(HIgh Resolution Mid-infrarEd Spectrometer)

- Spectroscopy with R=600 to R=100,000: 25µm – 122µm
- Spectral imaging capabilities for a few selected emission
  - HD (112µm): How does the disk mass evolve during planetary formation?
  - What is the distribution of oxygen, H_2O-ice and H_2O-vapor in different phases of planet formation?
  - What are the kinematics of oxygen and H_2O-vapor in protoplanetary disks ?
- 100's of disks within 500 pc are within HIRMES' grasp
- SOFIA to provide quantitative answers, arbitrate competing theories

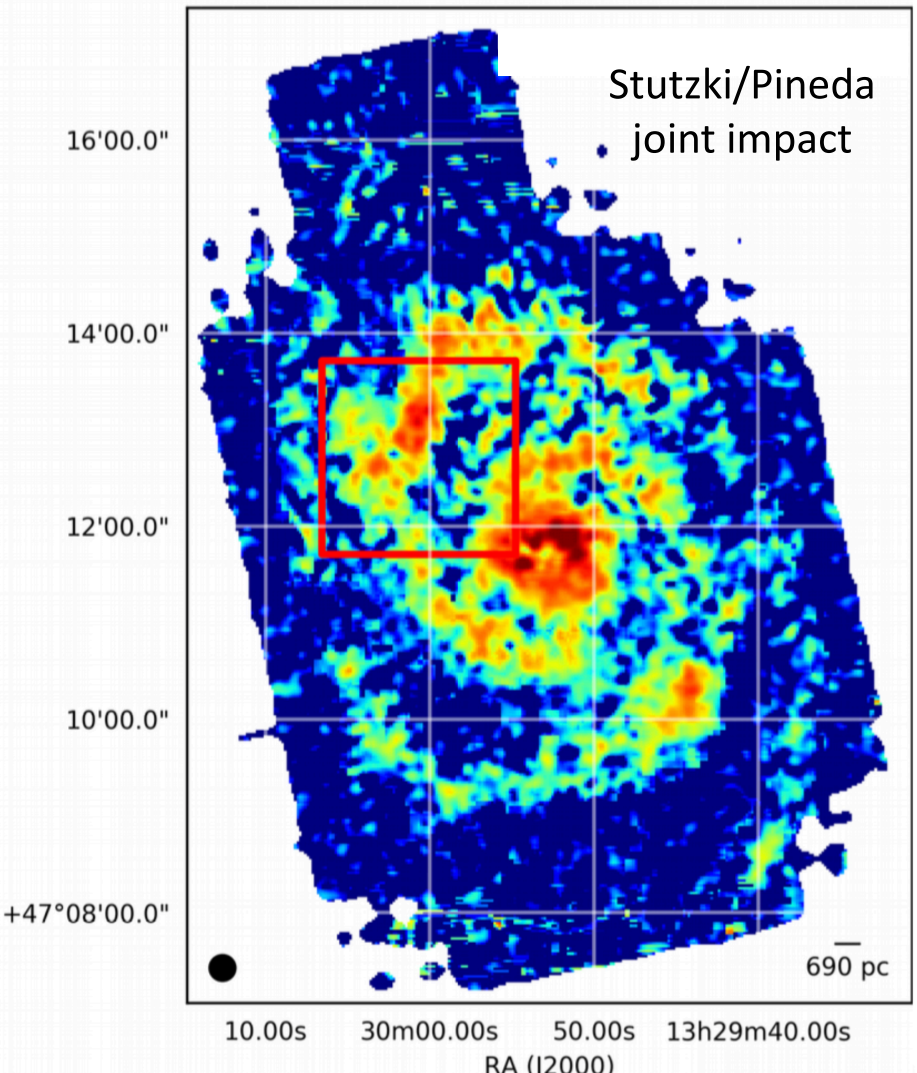


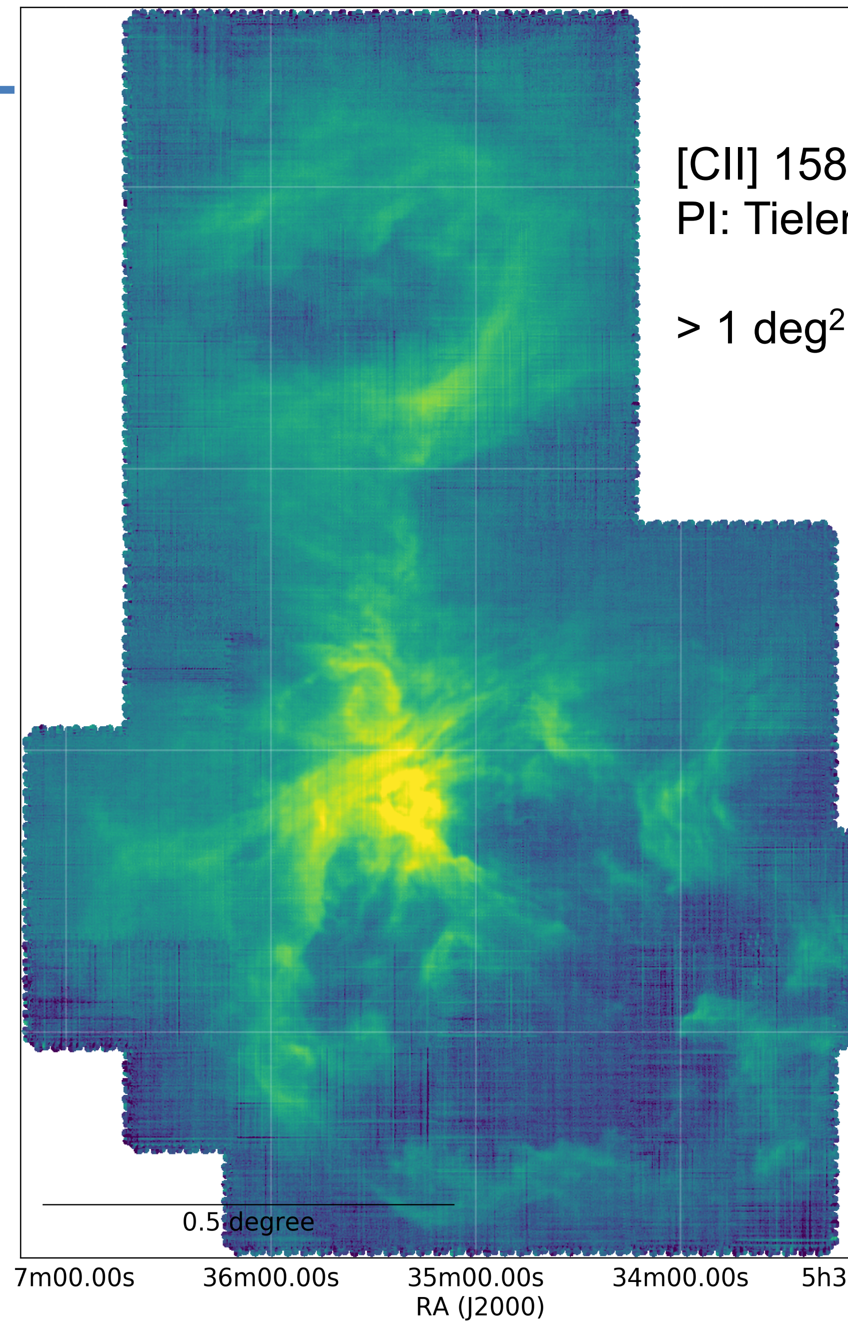
Recent SOFIA Science Highlights

- upGREAT: [C II] mapping (50x faster than Herschel)
  - 1/3 of HIFI's time spent on Band 7 (>10% of total Herschel time)
  - SOFIA-upGREAT LFA has already surpassed Herschel's [C II] coverage
  - Simultaneous 7-pixel mapping of [O I] 63 & 145μm and [CII] 158μm possible
- HAWC+: Orion Magnetic Fields
- HAWC+: Active Galaxies: NGC 1068 and M82 polarization
- HAWC+: Detection of z=3.9 lensed galaxy APM08279

M51: [C II] mapping with upGREAT

ORION: [C II] w/ upGREAT





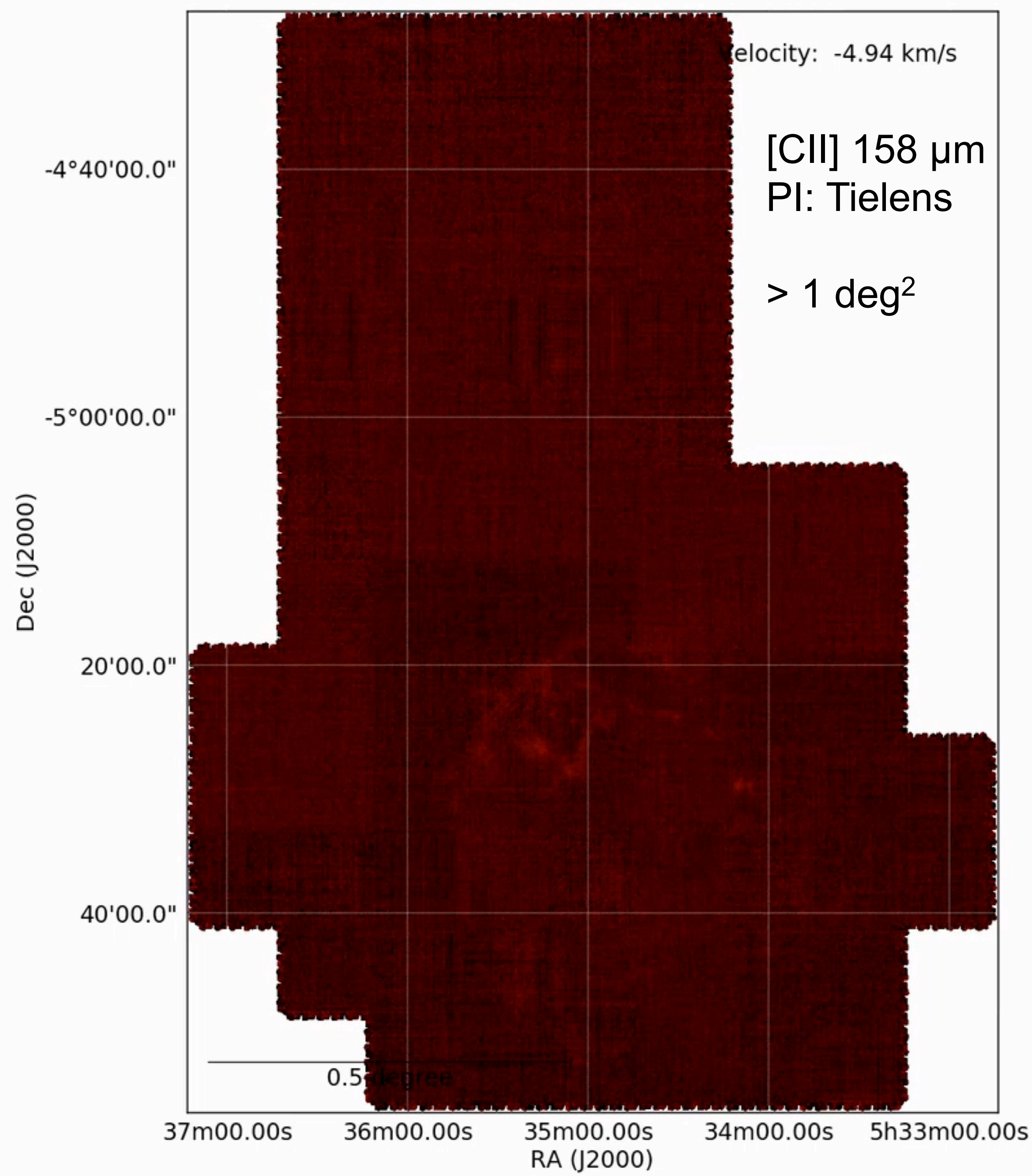
[CII] 158 μm
PI: Tielens

> 1 deg^2

[CII] 158μm is primary coolant of ISM gas, comprising ~1% of the Milky Way's total energy output

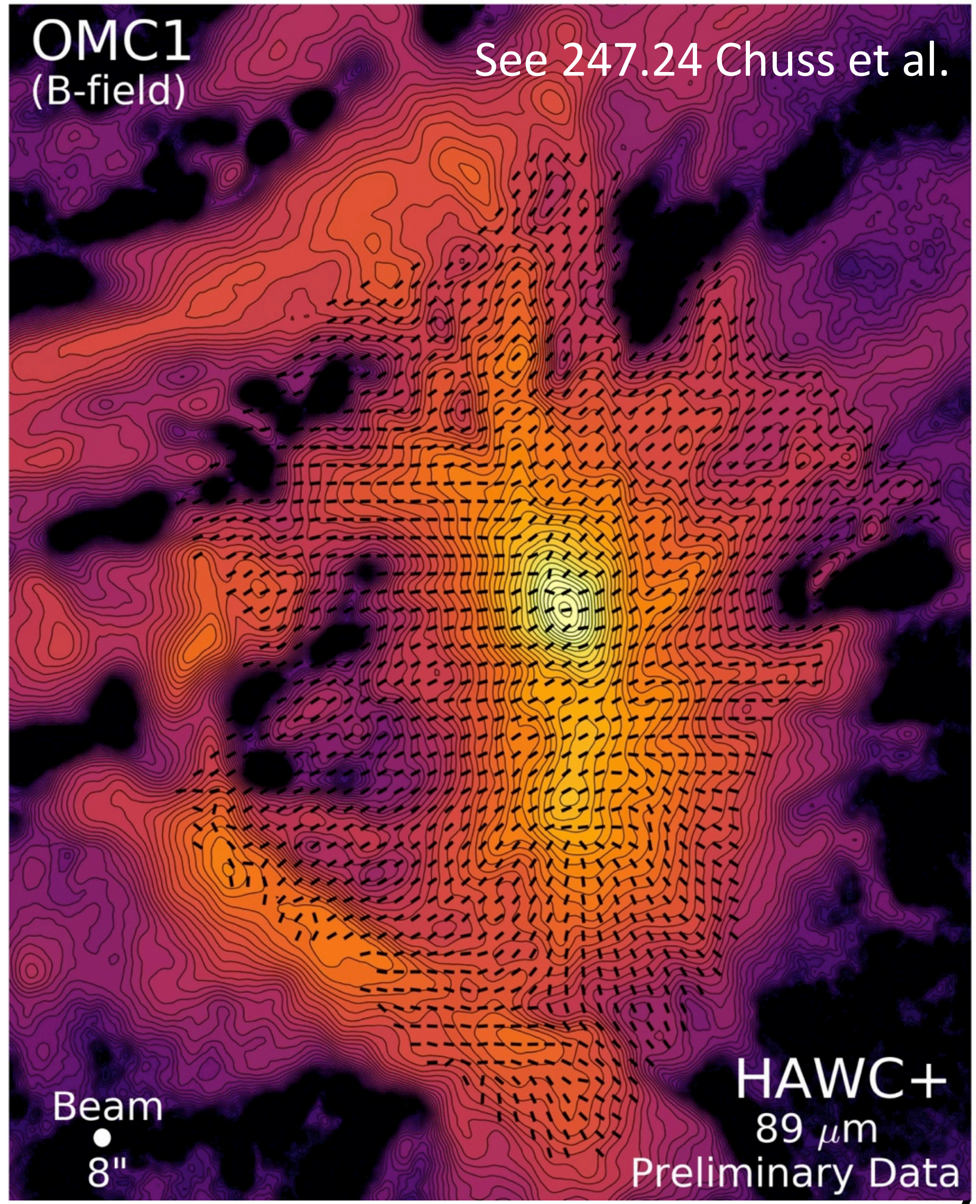
ORION: The C+ Movie

- ALMA is now using the C+ line at 158 μm as a star formation rate indicator for z>5. Is this line a good star formation rate indicator?
- How does C+ relate to the CO-dark gas in a real environment?
- What are the bubble kinematics and energetics?
- Tielens (PI) Program to map ~1 square degree (~40 hours)
  - ~2.5 million individual C+ emission spectra @ sub-km/s resolution
  - Herschel-HIFI would have required 2000 hours for this project (approx. 7% of the Herschel mission)



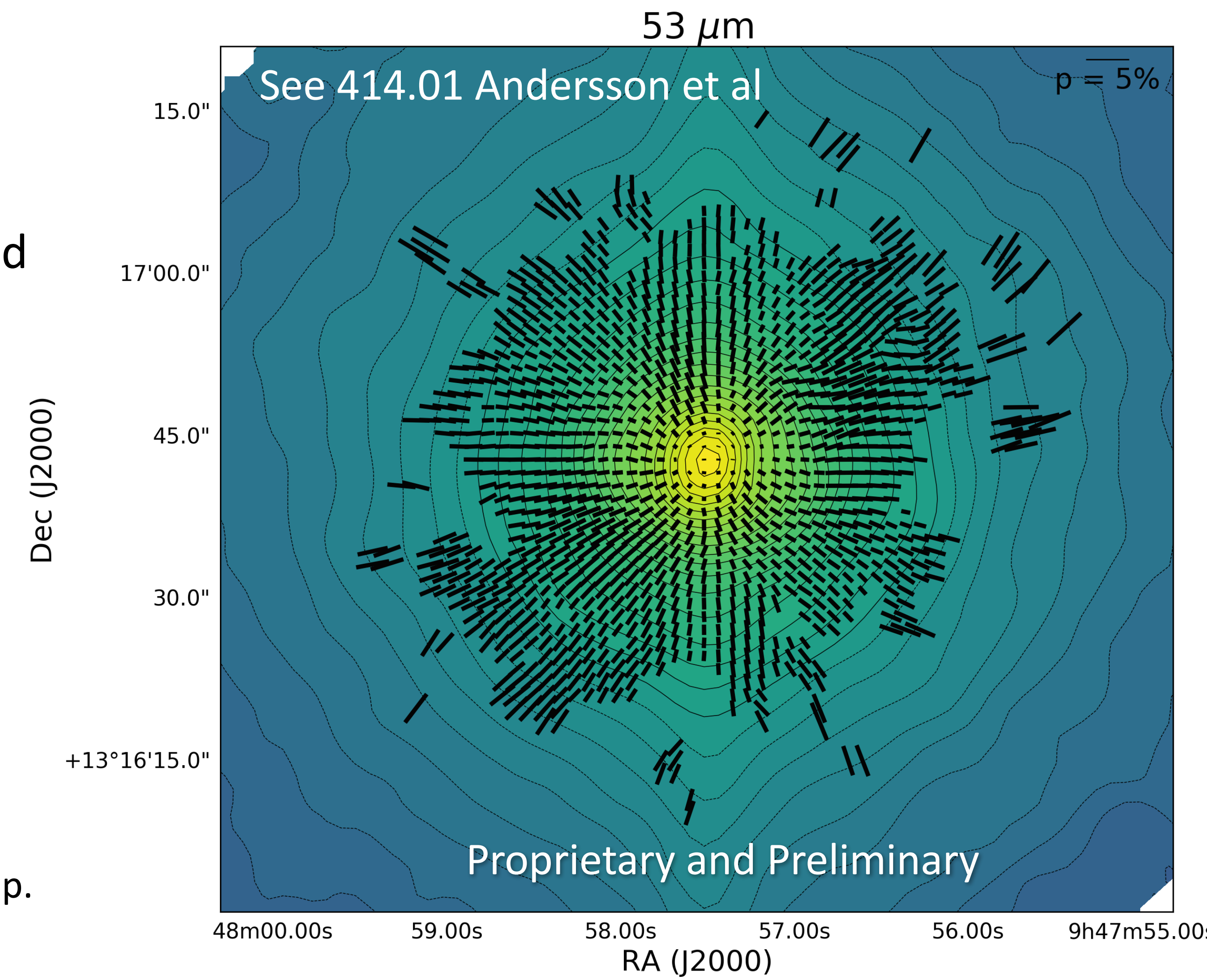
HAWC+: Orion Magnetic Fields

- HAWC+ adds the capability of observing polarization in the Far-IR
- Far-IR polarization of thermal radiation is due to emission of aligned dust grains, whereas Near-IR polarization has component of scattered light.
- Different wavelengths probe different regions (emission-weighted polarization)
- Far-IR generally gives the orientation of magnetic fields (exception: IRC+10216)



Understanding the microphysics of ISM polarization

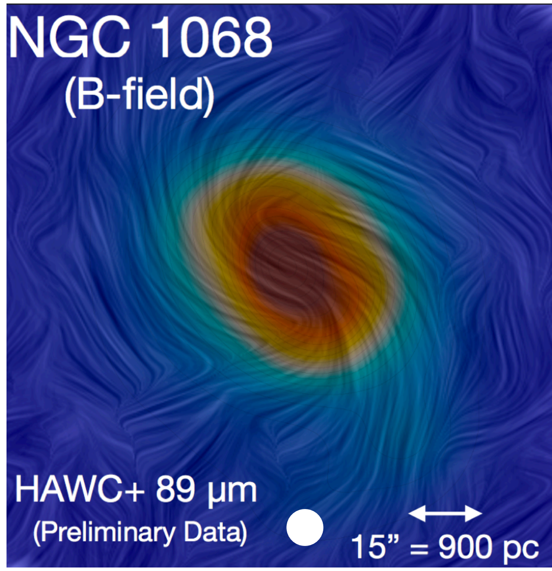
- The mass-losing carbon-rich AGB star IRC+10216 shows a radial temperature and polarization pattern consistent with radiation alignment torque (RAT) theory rather than via magnetic fields.

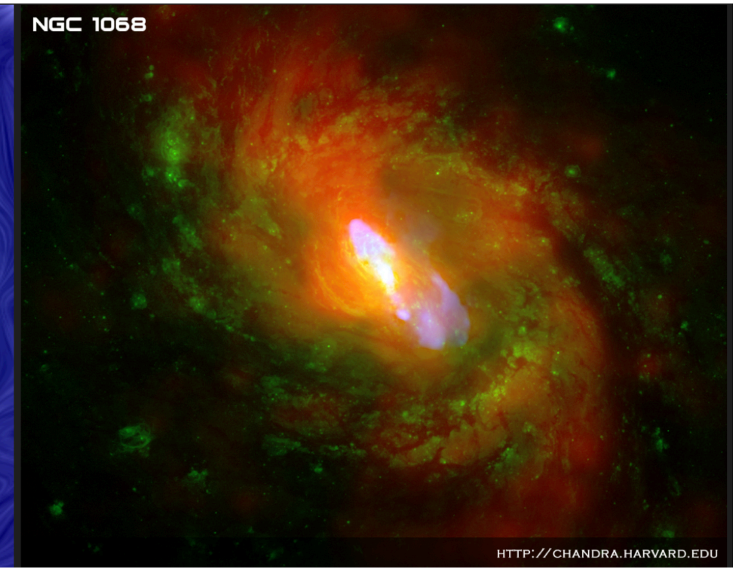


Andersson et al. 2018, in prep.

HAWC+ Observations of Active Galaxies

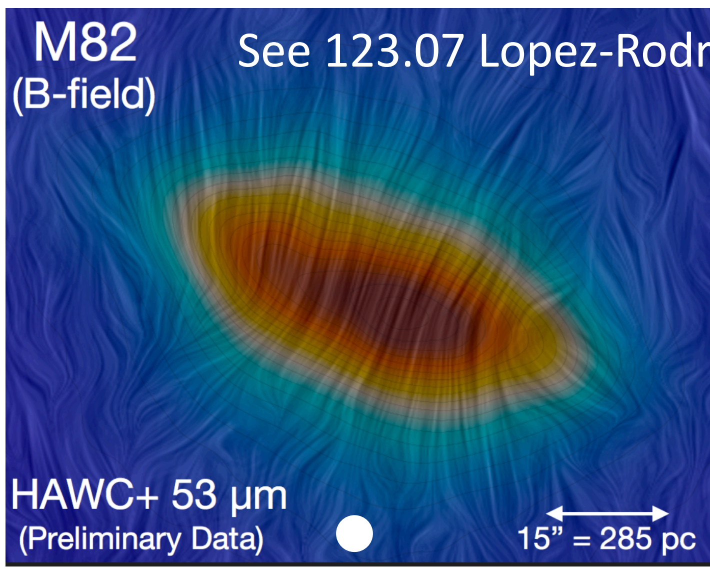
Active Galactic Nuclei
- Magnetic arms due to polarized emission from aligned dust grains
- Spiral magnetic fields





Starburst Galaxy
- Dusty galactic outflows driven by star formation
- Polar magnetic fields

See 123.07 Lopez-Rodriguez et al



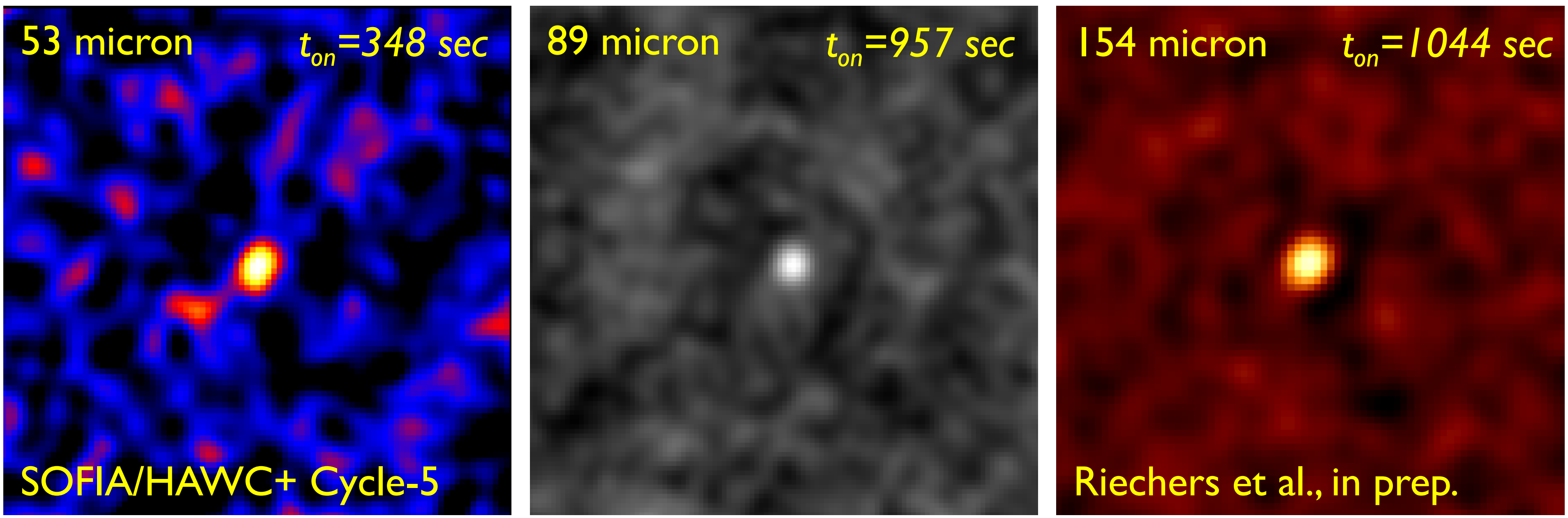
E. Lopez-Rodriguez & HAWC+ Science Team

SOFIA Detects z=3.9 Galaxy with HAWC+

Riechers et al. have used HAWC+ (PI : Dowell) to detect the z=3.9 lensed galaxy APM08279 in the continuum at λ=53, 89, & 154µm. Light from this galaxy was emitted 1.6 Gyr after Big Bang

These measurements at rest wavelengths λ_{rest}=11, 18, & 31µm will be used to separate AGN vs. starburst contributions to the IR luminosity of this early universe galaxy.

Using Lissajous scanning and image reconstruction, a SNR ~10:1 at all 3 wave-lengths was obtained in less than 40 min.



Team: D. Riechers (PI), C.D. Dowell, J. Staguhn, T.K.D. Leung, A. Kovacs (ID: 05_0165)

See related poster: 257.15 Brown et al. on a z=1.03 lensed starburst

SOFIA empowers early-career talent

https://sofia.usra.edu/science/publications/phd-theses

DLR

Author	Year	Title
Fuller, Lindsay	2017	Observing cool dust in active galactic nuclei on the SOFIA telescope
McAdam, Maggie	2017	Water in the early solar system: Mid-infrared studies of aqueous alteration on asteroids
Logsdon, Sarah	2017	FLITECAM/SOFIA Commissioning and Early Science and A Study of Late-T Dwarf Color Outliers with NIRSPEC/Keck
Büchel, Denis	2017	Hot Electron Bolometer Mixers for THz Arrays
Pfüller, Enrico	2016	Fast EMCCD Cameras for the Optical Characterization of the SOFIA Observatory and its Telescope Subsystems
Wiedemann, Manuel	2016	Improving the Sensitivity of the SOFIA Target Acquisition and Tracking Cameras
Glück, Christian	2016	A Study of the Distribution of Carbon in the nearby Universe
Kaswekar, Prashat	2016	Integrated motion measurement of three-dimensional lightweight structures
Colditz, Sebastian	2016	FIFI-LS – A Field-Imaging Far-Infrared Line Spectrometer for SOFIA: Completion of the Instrument, Laboratory and In-flight Calibration and Characterization
Shenoy, Dinesh	2016	A Study of Hypergiant Mass Loss in the Near-To-Mid Infrared: VY CMa, IRC +10420, mu Cep and rho Cas
Selig, Stefan	2016	Superconductor Insulator Superconductor Mixer Devices with Gold Energy Relaxation Layers
Guan, Xin	2015	Atmospheric calibration for sub-millimeter radio astronomy
Lau, Ryan	2014	Probing the Extreme Environment of the Galactic Center with Observations from SOFIA/FORCAST
Ricken, Oliver	2011	Setup, characterization and commissioning of the 1.4 THz channel of the heterodyne receiver GREAT
Angerhausen, Daniel	2010	Spectroscopic characterization of extrasolar planets from ground-, space- and airborne-based observatories
Smith, Erin	2008	Investigation of PAHs in Planetary Nebulae using FLITECAM
Wagner-Gentner, Armin	2007	SOFIA GREAT 1.9THz Heterodynereceiver, astigmatic optics, low loss THz windows
Munoz, Pedro	2007	Waveguide Heterodyne Mixers at THz-Frequencies - Superconducting Hot Electron Bolometers on 2-micron Si3N4 Membranes for GREAT and CONDOR
Philipp, Martin	2007	Development and construction of a BWO-based 1.9 THz Local oscillators for the heterodyne receiver
Bedorf, Sven	2005	Development of Ultrathin Niobium Nitride and Niobium Titanium Nitride Films for THz Hot-Electron Bolometers
Villanueva, Geronimo	2004	The High Resolution Spectrometer for SOFIA-GREAT: Instrumentation, Atmospheric Modeling and Observations
Mainzer, Amy	2003	Searching for Young Low Mass Objects Using FLITECAM

Concluding Remarks

- SOFIA provides the astronomical community's **only** access to the Far-IR today and in the near future.
- SOFIA Today produces top-tier science essential for understanding many complex phenomena closely aligned with NASA "Cosmic Origins" goals
- SOFIA Tomorrow will produce even more spectacular science, whetting the community's appetite for a future Far Infrared space mission

Visit SOFIA's Town Hall Meeting

- Come to SOFIA's Town Hall meeting on Thursday 7:30-8:30pm at Potomac D
  - Food provided
  - Learn about new instrument call in ROSES
  - Learn what's new in Cycle 7
  - Learn about new data analysis tools
  - Learn about new funding opportunities
  - Help shape SOFIA's future with ***your*** input
- And whenever you can, drop by the SOFIA booth

SOFIA presentations at AAS   white = PhD thesis

- **Santos** (rho Oph)
- **Simpson** (SgrB1 FIFI)
- **Rangwala** (hot core)
- **Kraemer** (star dust)
- **Tarantino** (NGC6946)
- **Michail** (HAWC instrument)
- **Lopez-Rodriguez** (AGN)
- **A. Brown** (lensed gal)
- **Sandell** (disks OI)
- **Fadda** (FIFI tool)
- **Hankins** (gal cen)
- **Gordon** (supergiants)
- **E. Cox** (disks pol)

- **Omelian** (R Aqr)
- **Chuss** (OMC1 pol)
- **Nayak** (LMC starform)
- **Andersson** (10216 pol)
- **Becklin** (Award talk)
- **MacLean** (Award talk)
- **Woodward** (comet)
- **Klein** (PDRs)
- **Towner** (protoclusters)
- **Dinerstein** (PN)

- **SOFIA Town Hall**
- **SOFIA Booth**

http://sofia.usra.edu