Science with SOFIA

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Bernhard Schulz

Deputy Director

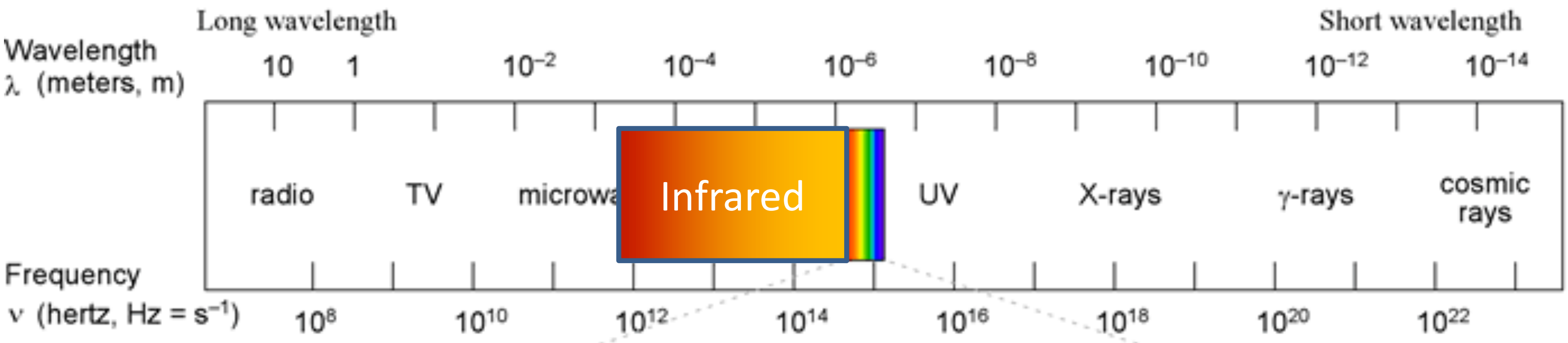
SOFIA Science Mission Operations, NASA Ames

Deutsches SOFIA Institut, Univ. Stuttgart

Overview

- Infrared and why do we care
- SOFIA the Stratospheric Observatory for Infrared Astronomy
- Science Examples
- Instrumentation and capabilities
- Observing with SOFIA
- Proposal Tools

Radiant Heat

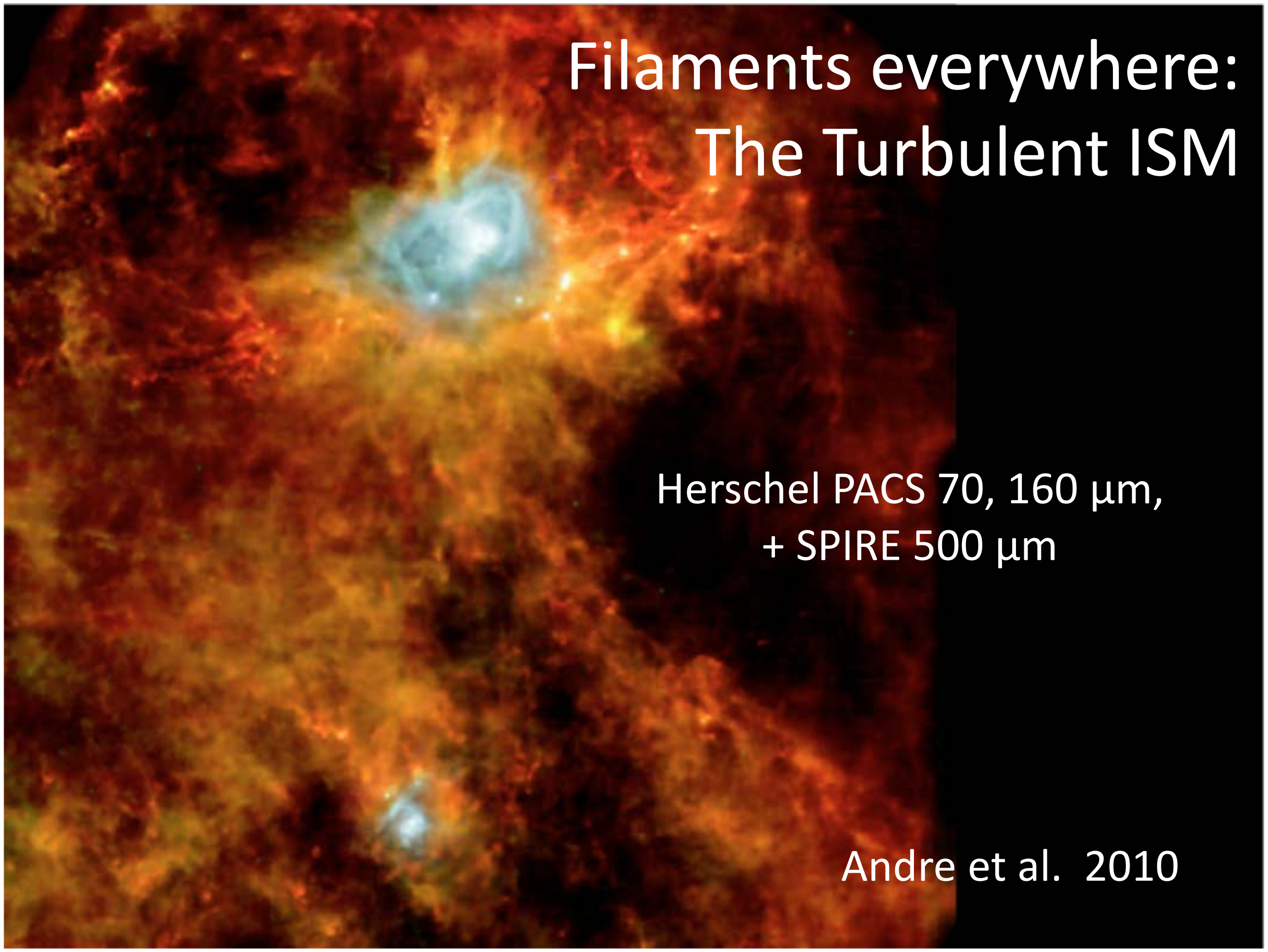


- “Heat Rays” had been described before year 1800 in the literature.
- It was known that this radiation can be reflected using mirrors.
- Herschel showed in 1800 “radiant heat” as part of the solar spectrum using thermometers.
- We now call the rays he observed, infrared light.

Why Infrared?

- In a nutshell:
  - Dust in space absorbs visible light but becomes transparent in the infrared.
  - Dust in space re-radiates absorbed energy in the infrared like a “gray body”, with the peak emission wavelength determined by its temperature.
  - Atoms and molecules in gas phase and as dust, sometimes ionized, provide a rich collection of unique diagnostics (many vibrational and rotational) in the Near-, Mid-, and Far-Infrared.
  - Aligned non-spherical dust grains can polarize continuum emission.
- Infrared broad band photometry/imaging:
  - Temperature / optical depth
  - Dust grain sizes / mass, etc.
- Infrared spectroscopy
  - Constituents of gas and dust, temperature, density
  - Molecular abundances and dust composition
  - Radial velocities of dust or gas components, etc.

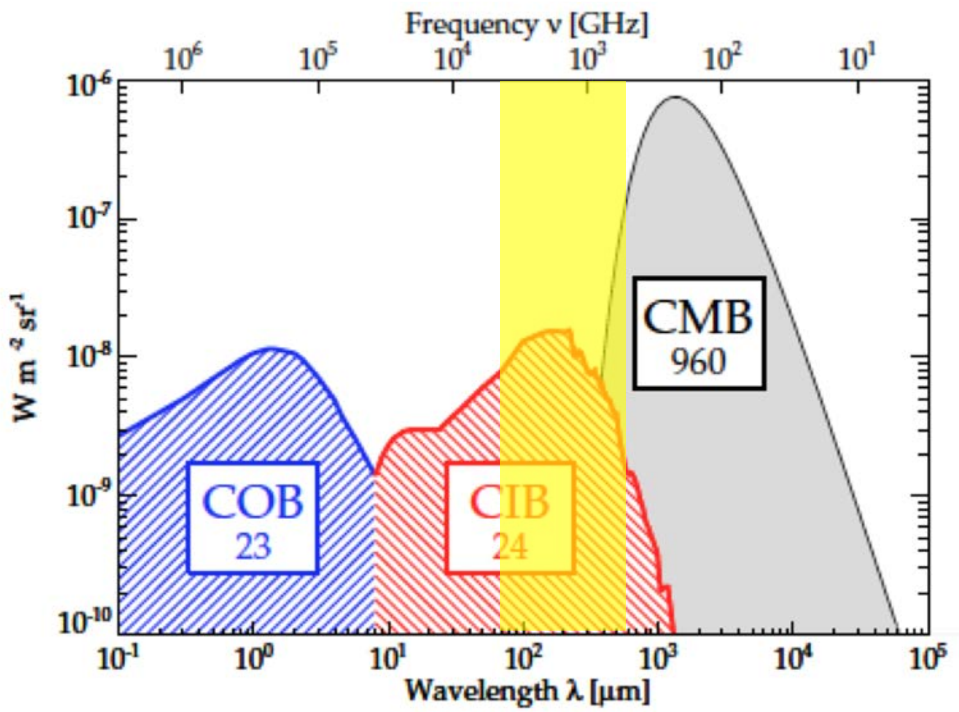
Star Formation



Fundamental questions

- Where do we come from?
- How did our solar system form?
- How are stars born?
- What regulates the collapse of the ISM?

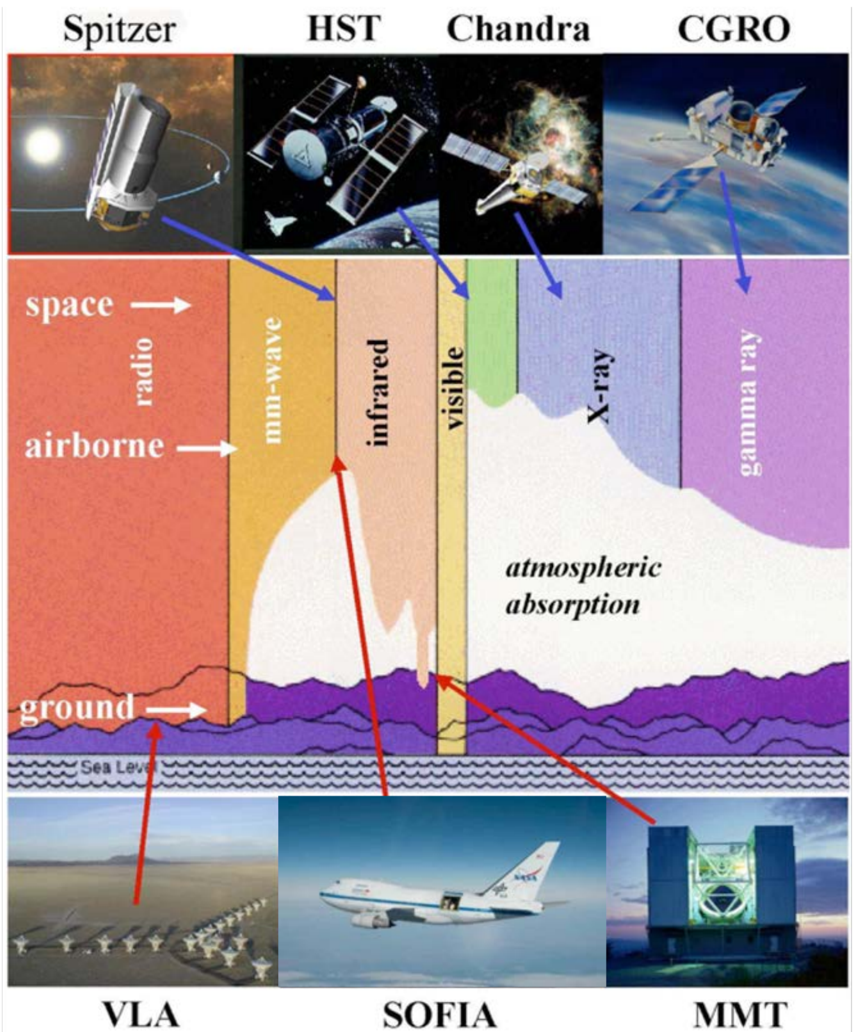
The Energy Budget of the Universe



CMB: Cosmic Microwave Background
COB: Cosmic Optical Background
CIB: Cosmic Infrared Background

- CMB originated short after the Big Bang when radiation and matter separated
- COB mainly from radiation of stars and black holes
- CIB from optical and UV radiation absorbed by dust and re-radiated in the infrared
- Since matter and light separated (CMB), half of the optical radiation emitted in the Universe was converted into infrared radiation

The Earth's Atmosphere



- Except for the useful function of supporting life, the Earth's atmosphere is very bad

…for astronomers

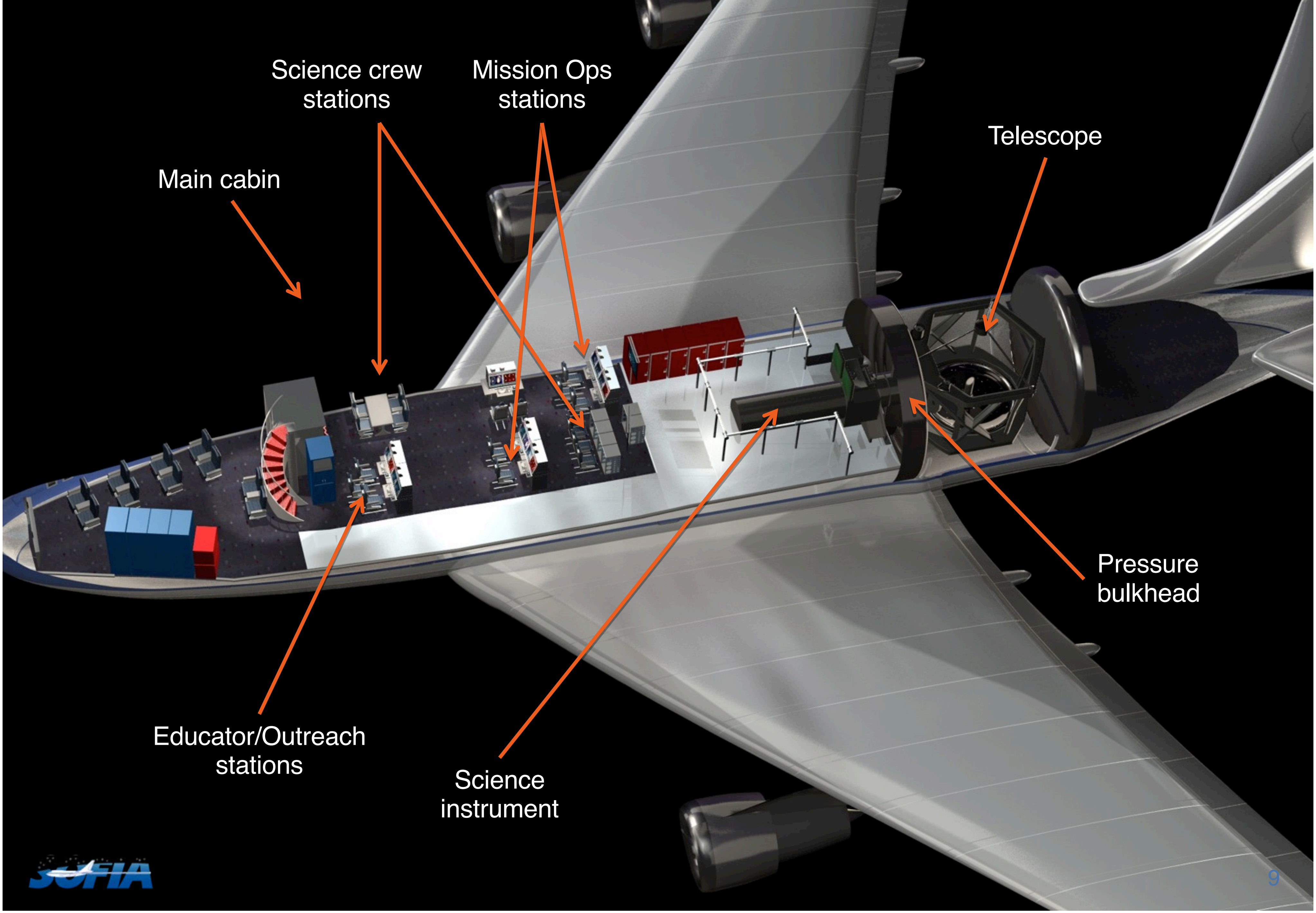
- Most of the electromagnetic spectrum is blocked from reaching the surface by water (H_2O) and other molecules (O_3, CO_2).

- Exceptions:
  - long wavelength radio waves
  - Some Infrared wavelengths
  - Visible light
- Solutions:
  - Airplanes (good for instrument development, residual atmosphere)
  - Balloons (cheap, residual atmosphere, limited instrument retrieval)
  - Spacecraft (no atmosphere, most expensive, no instrument retrieval)

SOFIA Stratospheric Observatory for Infrared Astronomy

- SOFIA: Modified B747SP aircraft with a 2.7m telescope
- Joint Program between the US (80%) and Germany (20%)
- Unique FIR access (5 - 320 μm) for the astronomical community
- Flies up to 13.7 km (45,000 feet), above 99.9% of the water vapor in the atmosphere
- Suite of infrared imagers, spectrometers and polarimeters
- Operated by NASA, DLR, USRA, and DSI
- Regular science operations began in 2014 (Design lifetime 20 years)

SOFIA Interior Layout

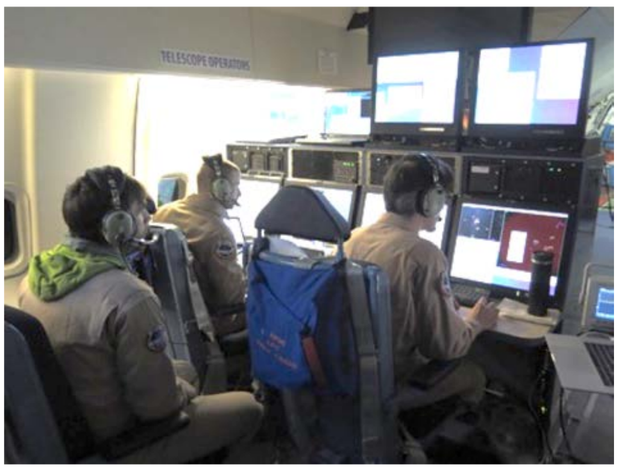


Science Flight On-Board of SOFIA

Telescope with GREAT

Instrument Team

Aurora Australis



Telescope Operators

Preliminary Data Reduction

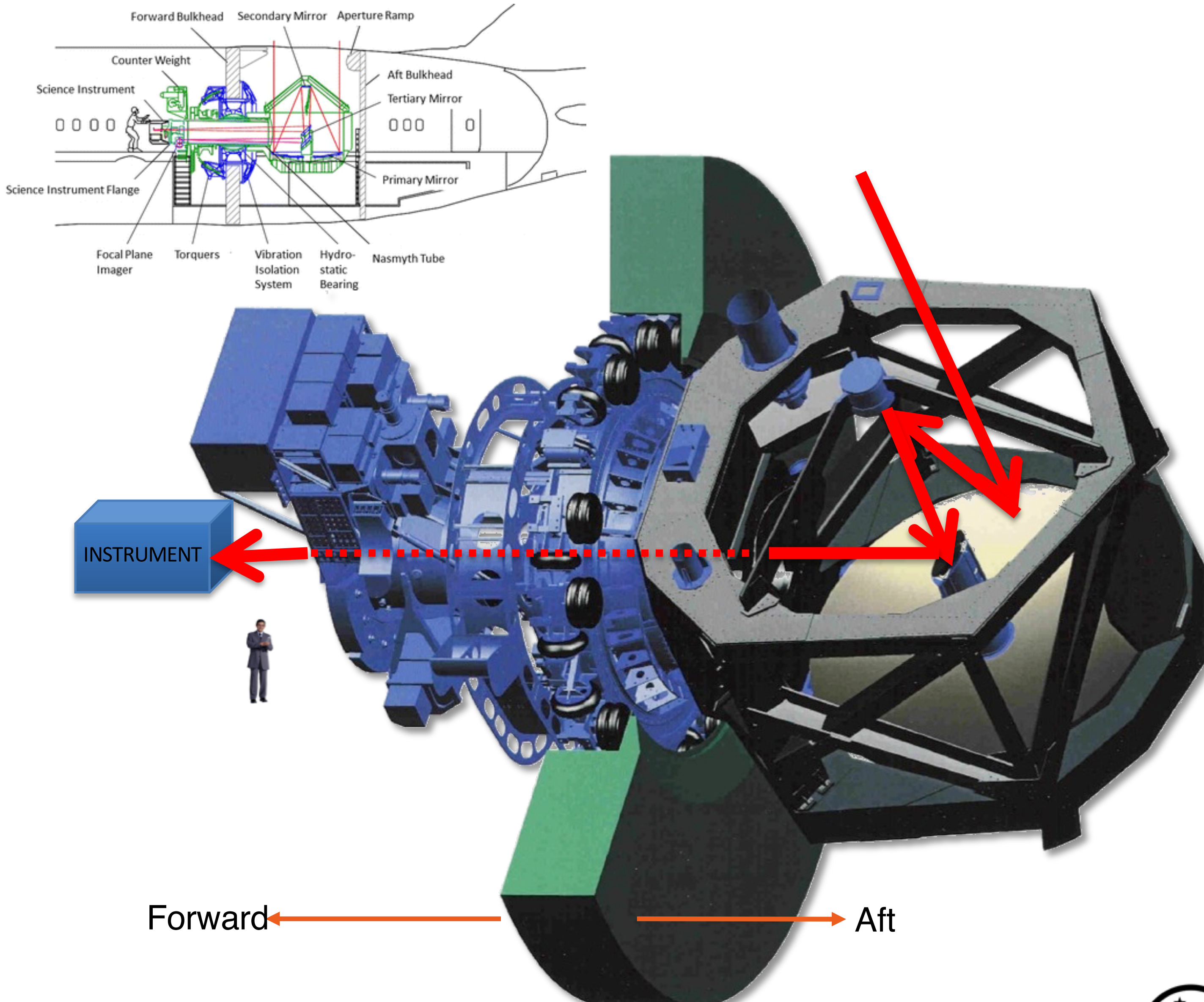
Pilots posing with Aurora

USRA

DSI

THE SOFIA TELESCOPE

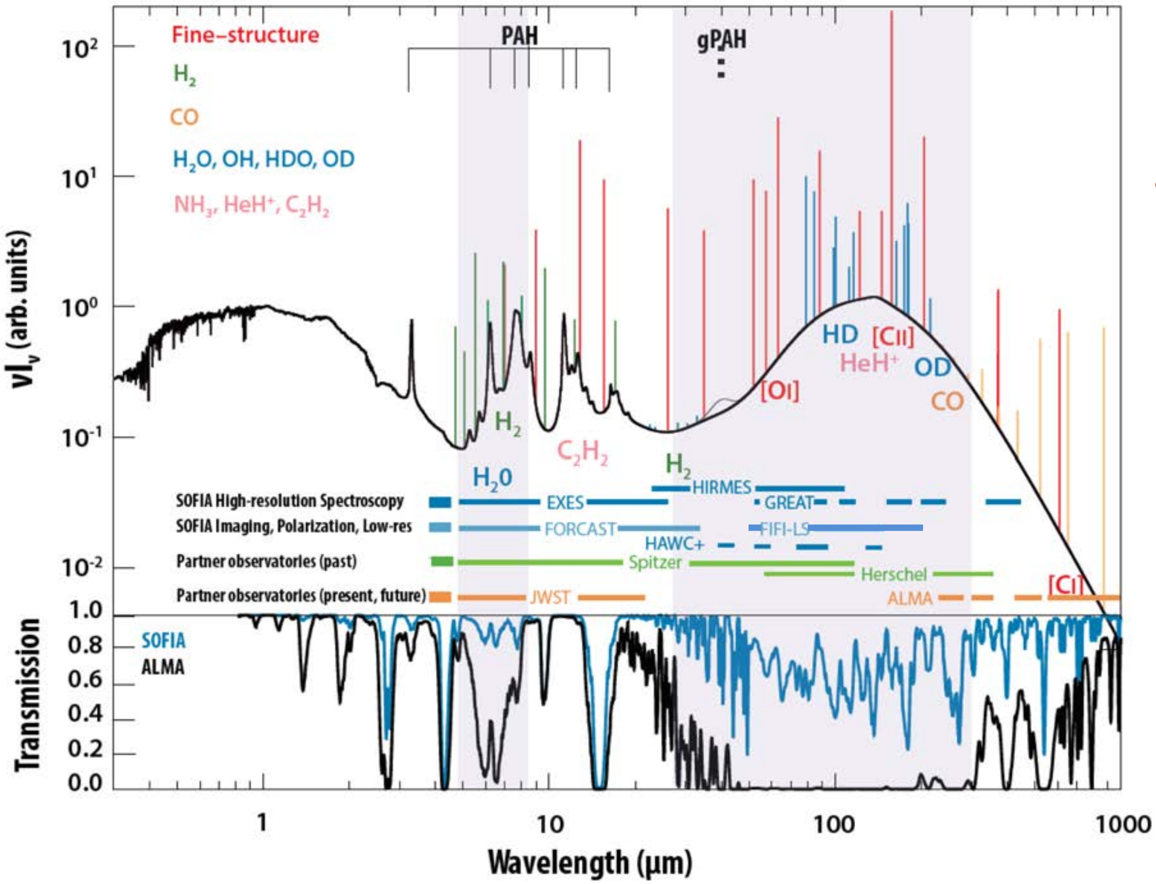
- The telescope is a major contribution from Germany
- 2.7 meter diameter mirror
  2.5m illuminated
- Wavelength: 0.3 to 1,600 microns
- Installed weight: 17 metric tons



The Hidden Infrared Universe

SOFIA measures:

- CO
- Dust
- Fine structure
- Hydrides
- HD
- NH_3
- PAHs
- Water



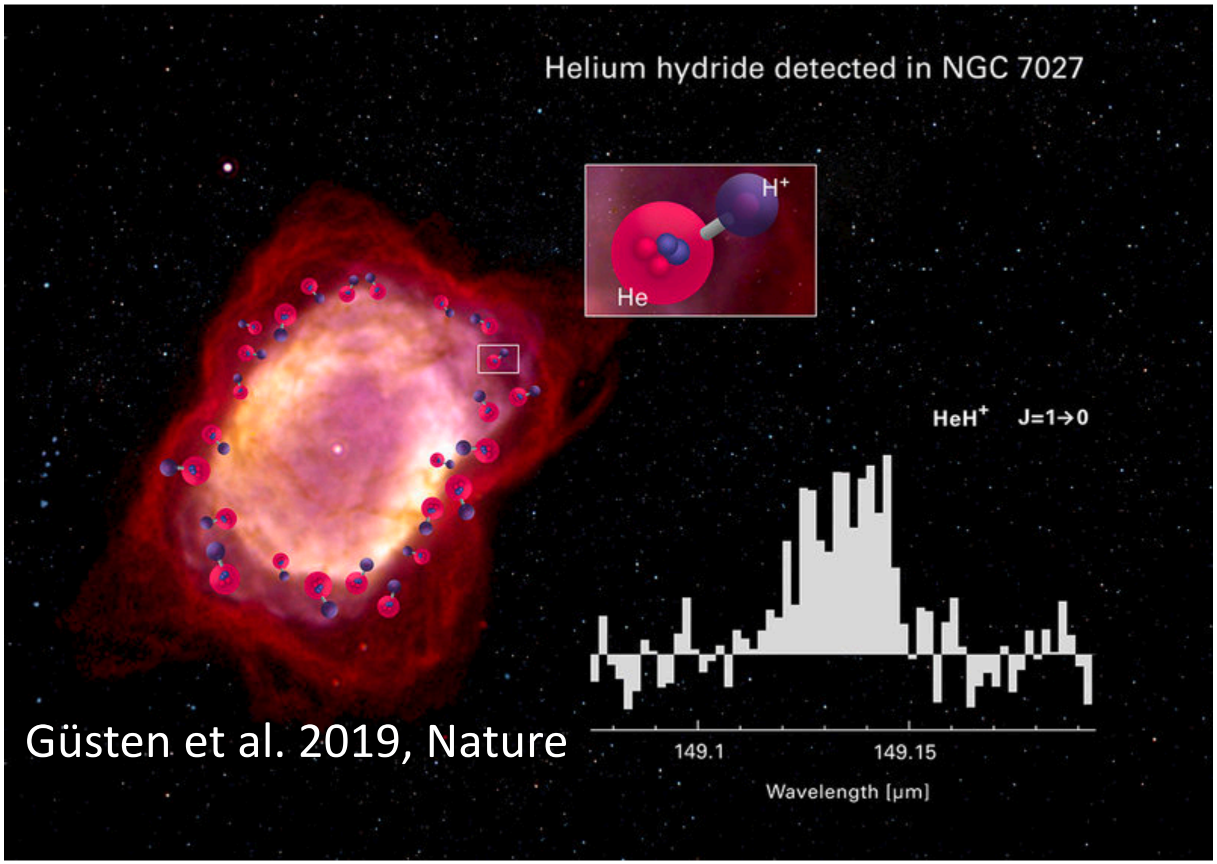
To determine:

- Age
- Composition
- Density
- Gas Dynamics
- Magnetic Fields
- Pressure
- Shocks
- Temperature

SOFIA provides community access to the mid- and far-infrared sky, impossible to observe from the ground or any current space-based telescopes; it fills the spectral gap between JWST's longest wavelength (28 μm) and ALMA's shortest wave-length (320 μm).

Science Examples

First Detection of Helium Hydride in Space

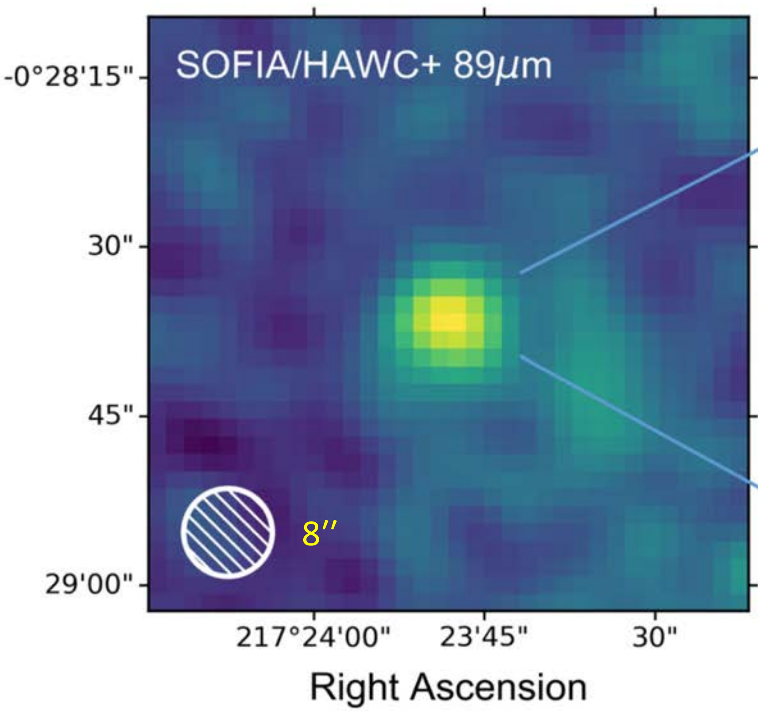


GREAT = German Receiver for Astronomy at Terahertz Frequencies

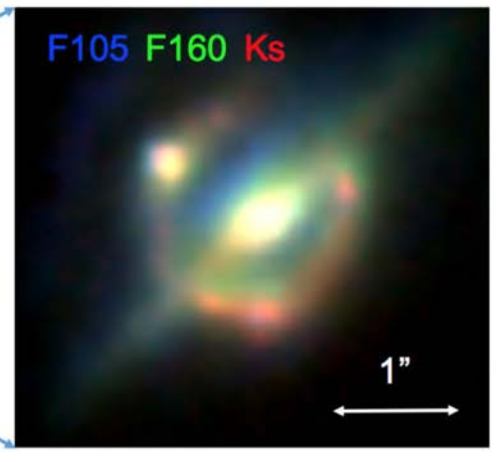
- HeH^+ First molecule of different atoms that formed after the Big Bang
- HeH^+ reacted then with neutral H providing pathway to H_2
- Conditions in planetary nebulae predicted to be right for its formation today
- Line at 2.01 THz observed with GREAT

HAWC+

SOFIA/HAWC+ Detection of a Gravitationally Lensed Starburst Galaxy at z= 1.03



SOFIA/HAWC+ 89µm detection of J1429-0028. The source is unresolved.



3-color image of the gravitationally lensed system using HST F105W (blue), F160W (green), and Keck Ks (red) imaging data (Timmons et al. 2015)

27-band spectral energy distribution (SED) modeling including the new SOFIA/HAWC+ data by **Ma, et al (2018).**

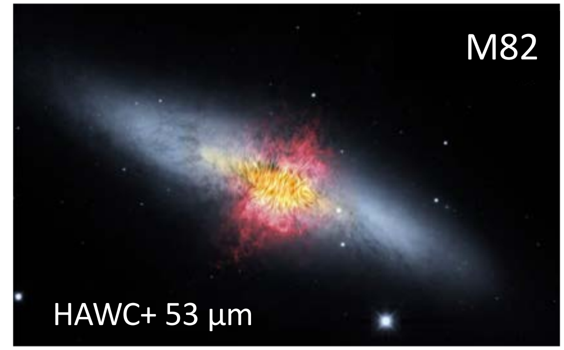
Constraints on the fractional AGN contribution to the total IR luminosity (in this case negligible).

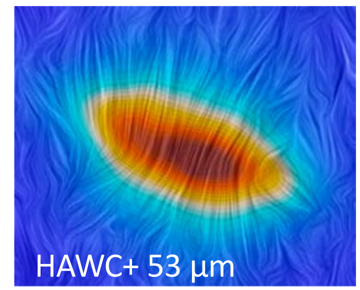
HAWC+

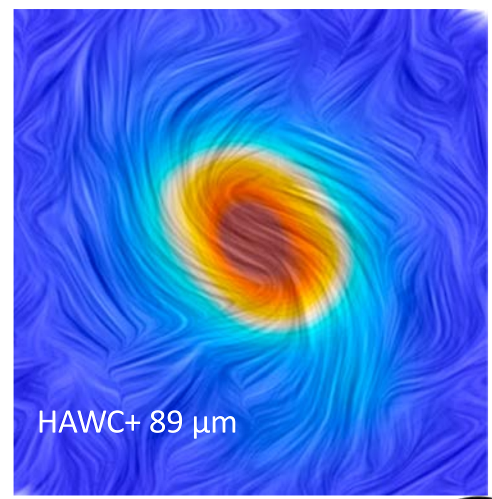
"SOFIA/HAWC+ Polarization in Galaxies: It's All About the Magnetic Fields", Lopez-Rodriguez 2018, AAS Press Release 123.07

M82 – Dust grain polarization aligned with starburst outflow.

NGC 1068 – Magnetic field is well ordered and traces spiral arms.



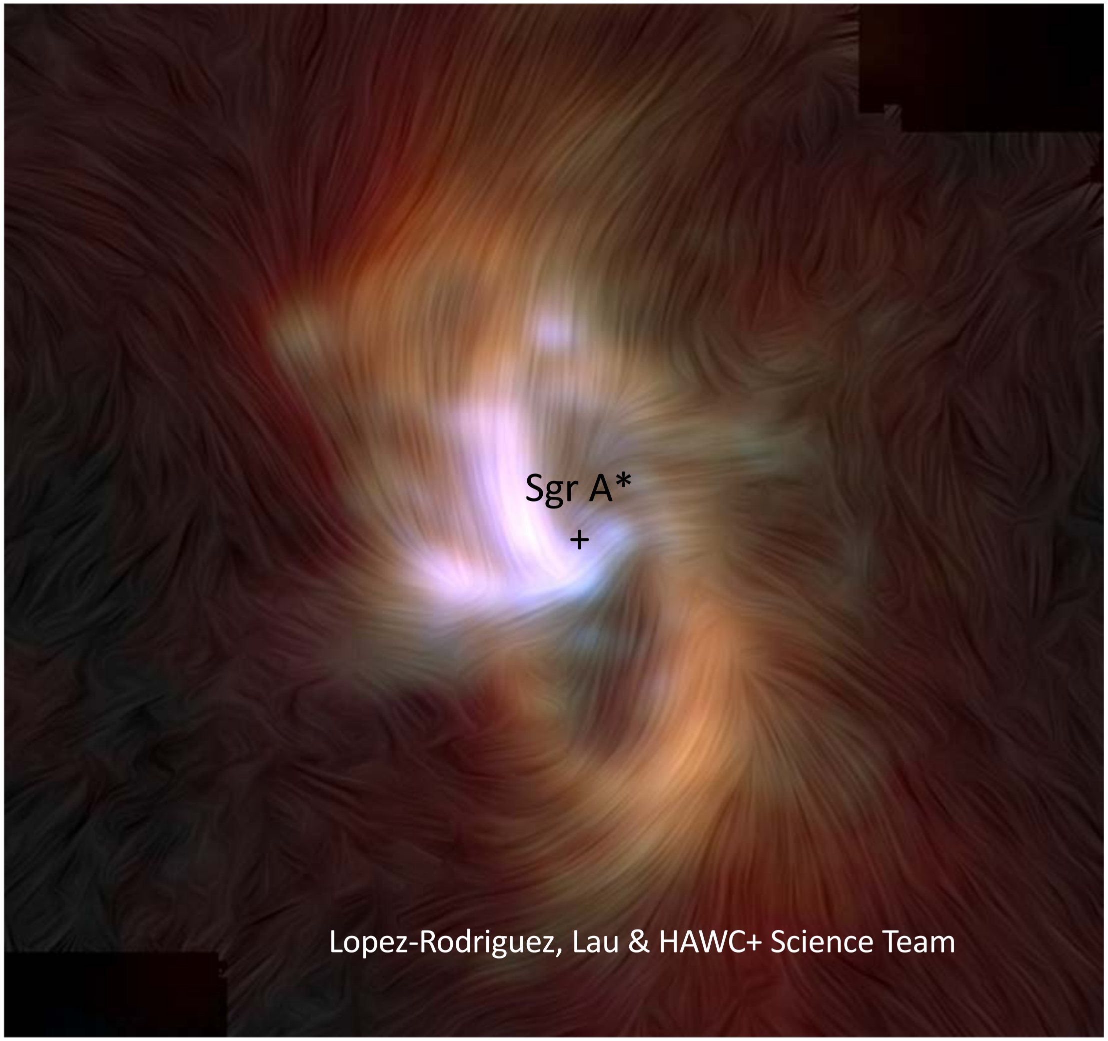




HAWC+

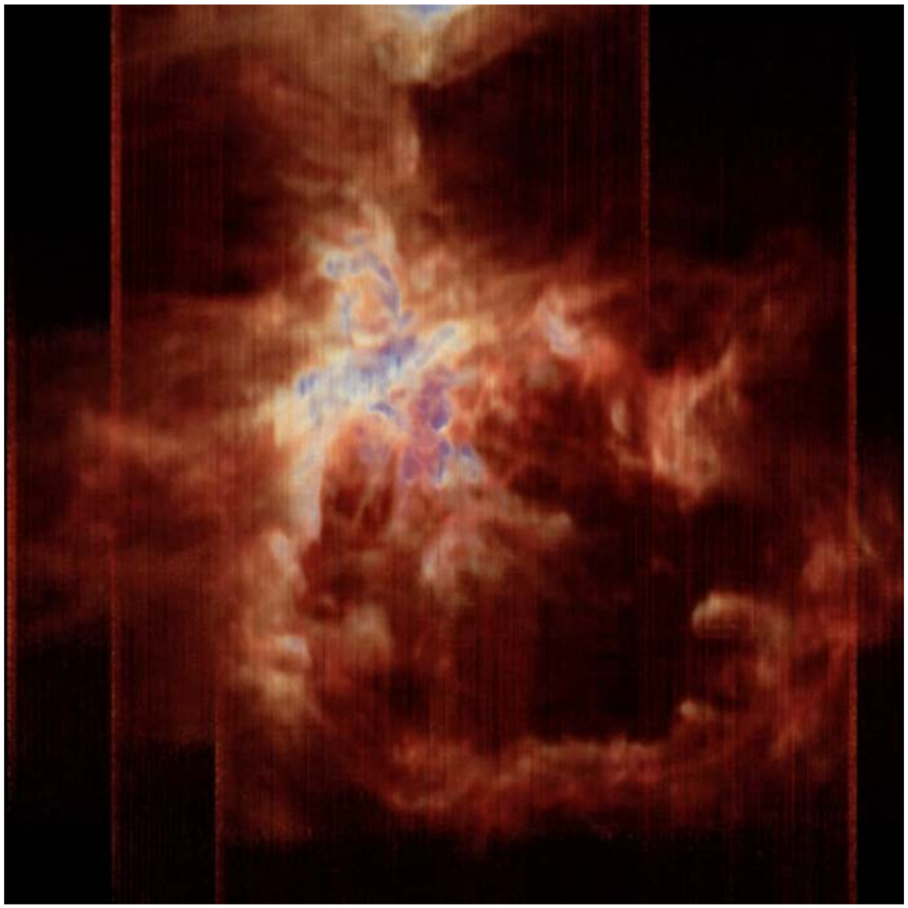
Magnetic Field at the Galactic Center

- SOFIA/HAWC+ polarimetry at 53µm traces magnetic field lines
- SOFIA/FORCAST reveals arcs of dusty material surrounding and possibly feeding the massive BH
- How strong would the magnetic field have to be to affect the galactic center dynamics?
- Does the magnetic field control or even quench the flow to the massive BH?



The Dragon in Orion

3D representation of [CII] velocity data

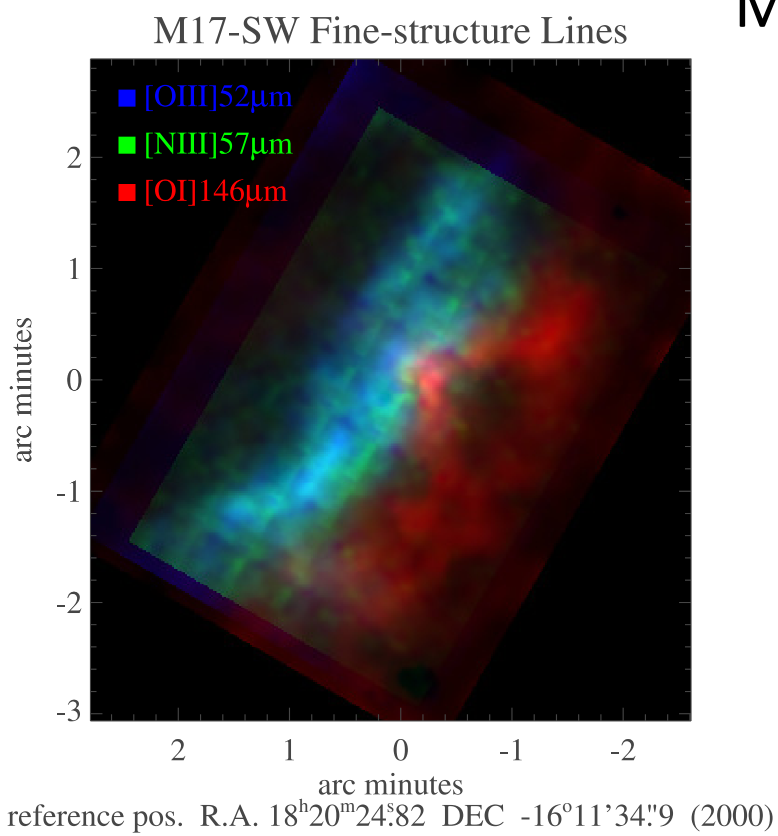


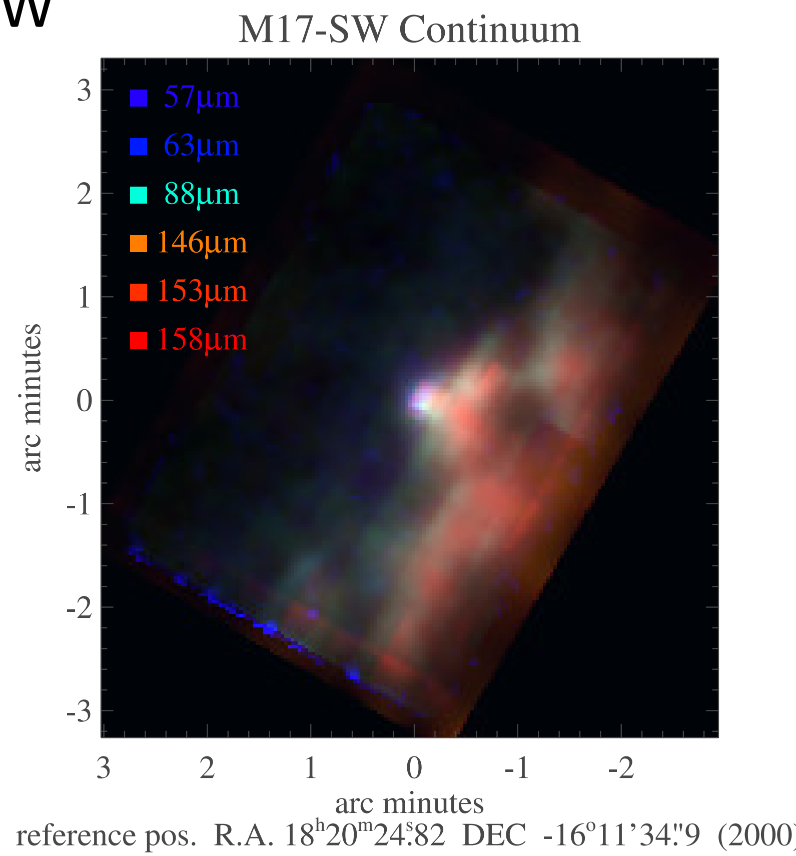
Pabst et al. (2019), Nature

- One square degree [CII] map (1.9 THz/158μm) of Orion SF-Region observed with upGREAT
- Measured in 40h where Herschel HIFI would have taken 2000h
- Interaction of massive stars with their environment regulates the evolution of star forming galaxies

FIFI-LS

M17-SW





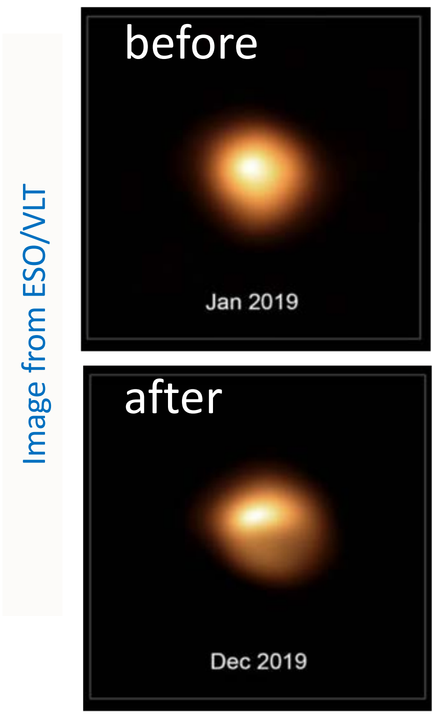
M17-SW is a well studied Photon-Dominated Region (PDR), the transition region from ionized to molecular gas.

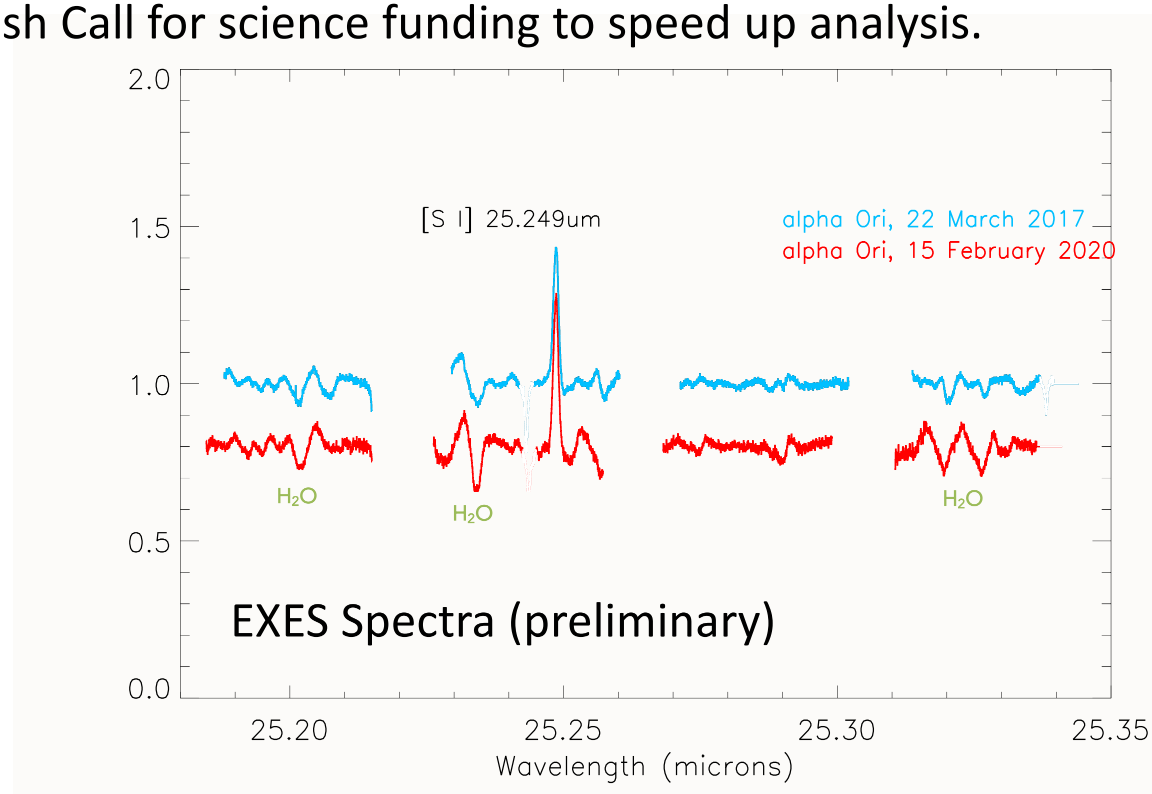
The lines from ionized and neutral species trace the different regimes. Also the color temperature of the continuum indicates the transition from a warmer to a colder phase.

Recent Dimming of Betelgeuse

Dimming of Betelgeuse: SOFIA investigates this Reg Supergiant

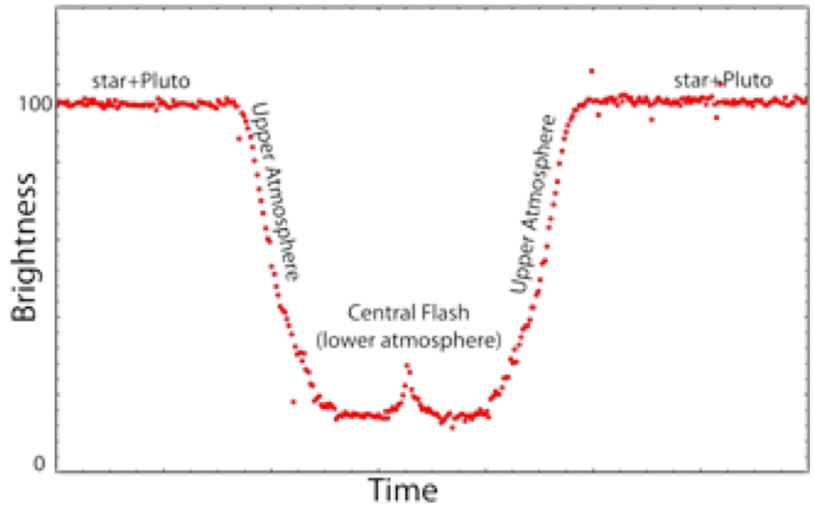
- SOFIA organized an observing campaign and managed to take data with 3 different instruments between February and March to provide key scientific data to the community for understanding/studying the changes in this red supergiant.
- EXES high resolution Mid-IR spectra are about to be published in a paper. FIFI-LS and GREAT spectral data are in the process of being analyzed.
- The Data becomes public once pipeline processing is complete.
- SOFIA has issued a Flash Call for science funding to speed up analysis.



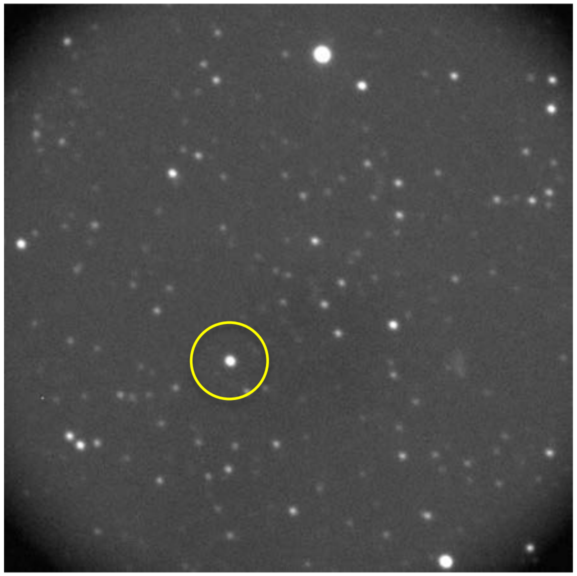


Pluto Occultation

- Occultation of 12-mag star by Pluto on 2015 June 29
- Simultaneous SOFIA observations with HIPO, FLITECAM, & Focal Plane Imager.
- Final ground-based shadow updates required course adjustments of 230 km
- Detection of strong "central flash" confirms accuracy of course corrections
- Comparison of multi-wavelength observations allowed detailed analysis of atmospheric profiles and aerosol content.



As observed by SOFIA, the central bright flash represents starlight refracted by the atmosphere of Pluto when the star was completely behind the planet.



Focal Plane Imager+ observation of Pluto occultation event on UT 2015-06-29 16:55. Video is approximately 4X real time.

Departure shot by New Horizons Mission to Pluto.

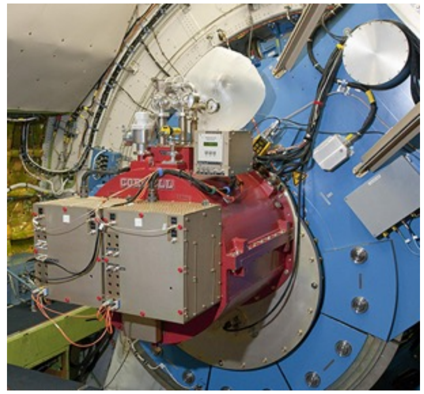
Instrumentation

The Scientific Instruments

FPI+ Focal Plane Imager Plus

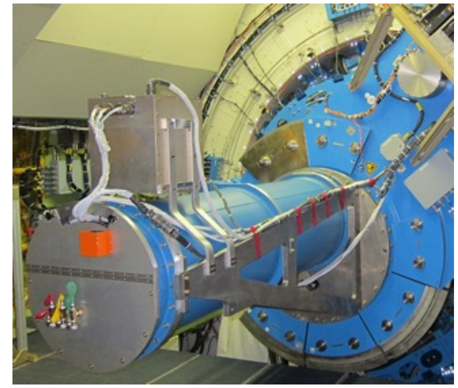
λ = 0.36–1.10 µm
R = 0.9–29.0
Optical Camera, always running!

FORCAST Faint Object Infrared Camera for the SOFIA Telescope



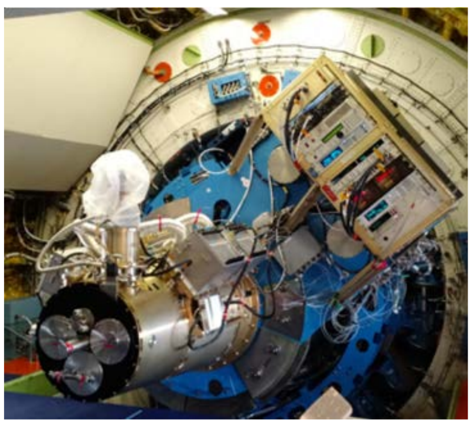
λ = 5–40 µm
R = 100–300
Grism Spectrometer

EXES Echelon-Cross-Echelle Spectrometer



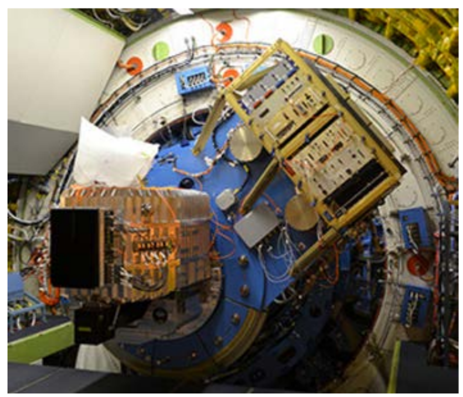
λ = 4.5–28.3 µm
R = 1,000–10^5
High Resolution Spectrometer

HAWC+ High-resolution Airborne Wideband Camera Plus



λ = 50–240 µm
R = 2.3–8.8
Bolometer Camera & Polarimeter

FIFI-LS Far Infrared Field-Imaging Line Spectrometer



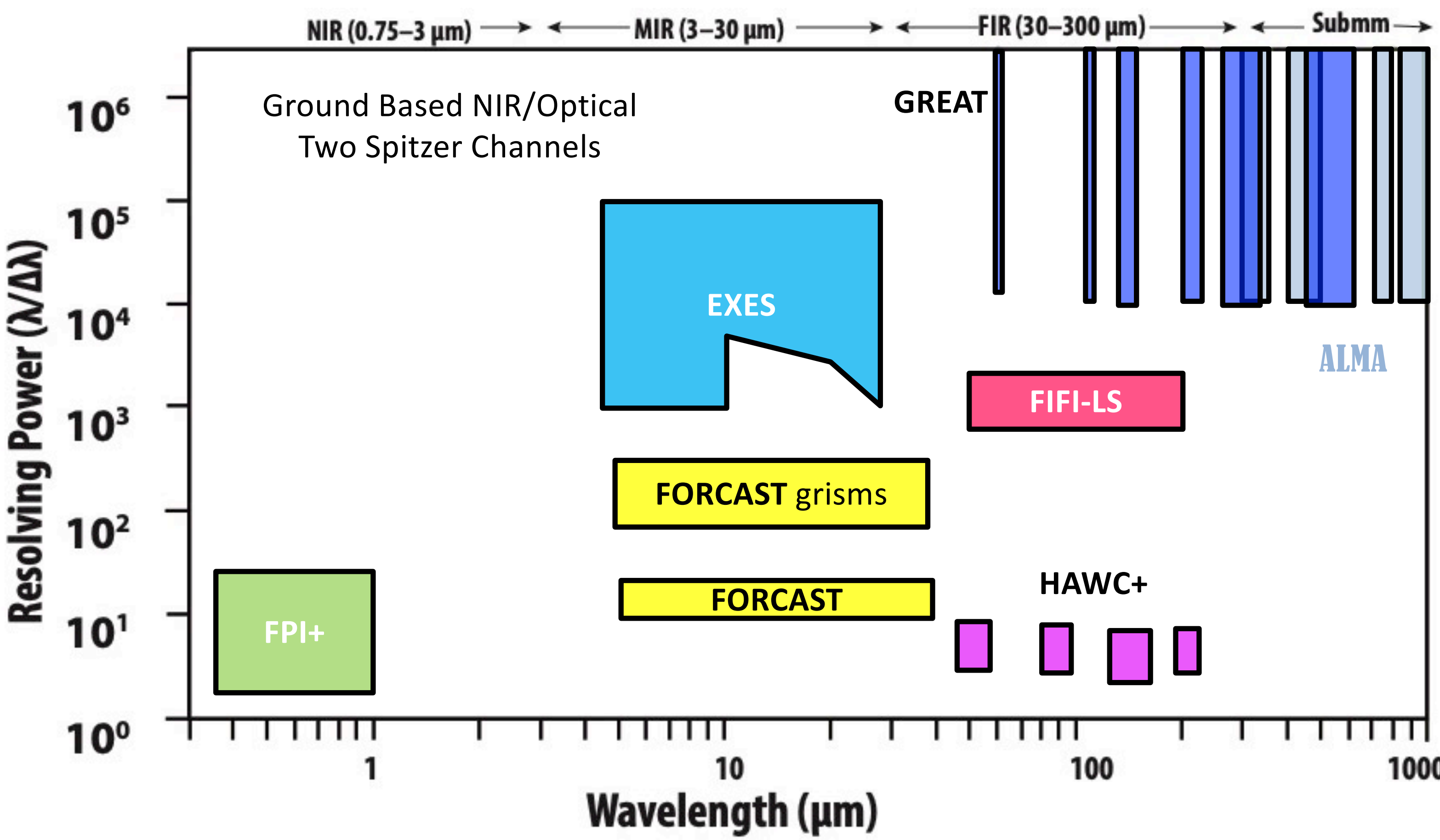
λ = 51–203 µm
R = 600–2,000
Grating Spectrometer

GREAT German Receiver for Astronomy at Terahertz Frequencies

λ = 63–612 µm
R = 10^6–10^8
Heterodyne Spectrometer

Science Instruments on SOFIA

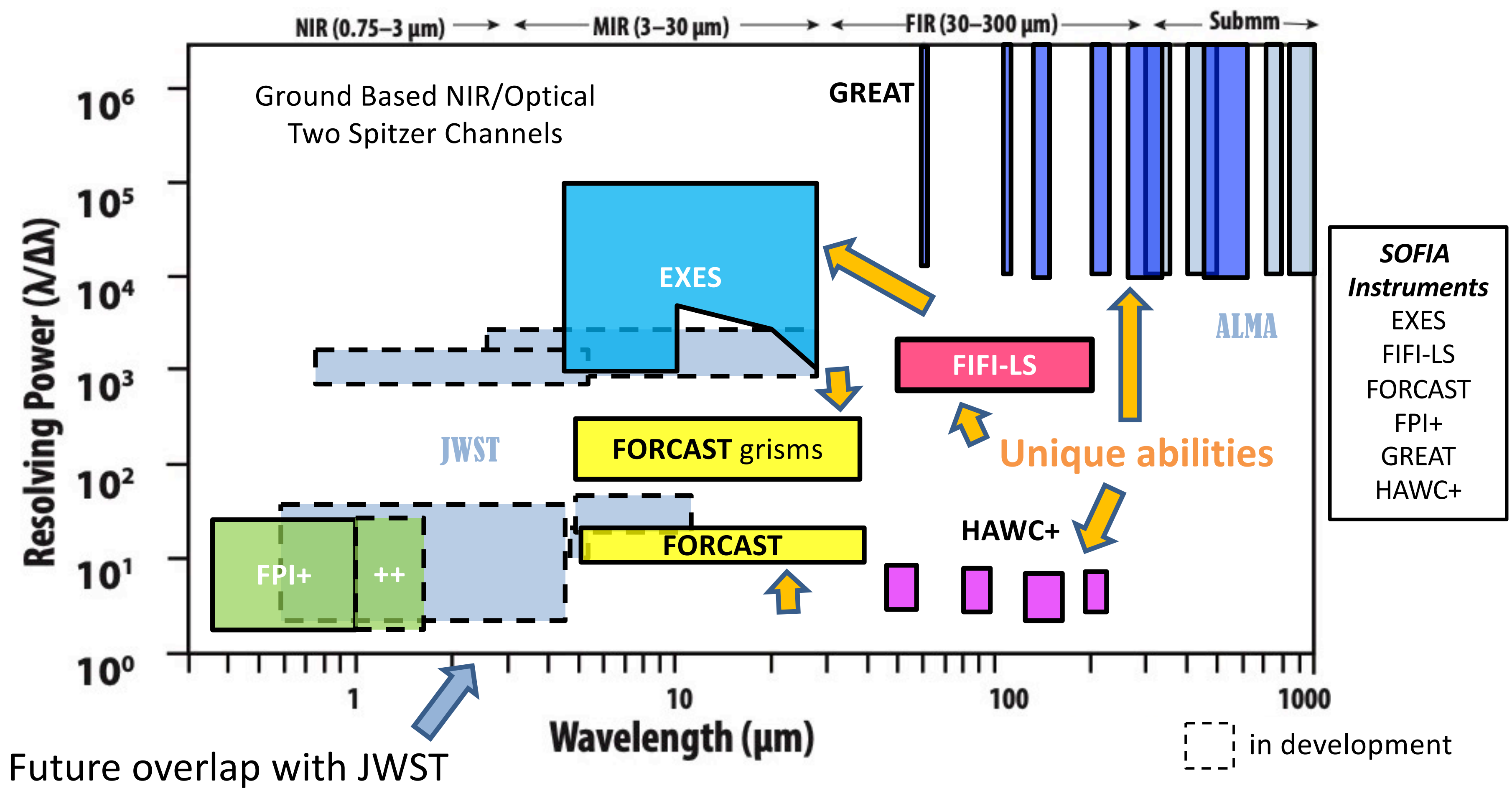
synergy with ALMA



SOFIA Instruments
EXES
FIFI-LS
FORCAST
FPI+
GREAT
HAWC+

ALMA Atacama Large Millimetre Array (Chile)

Science Instruments on SOFIA



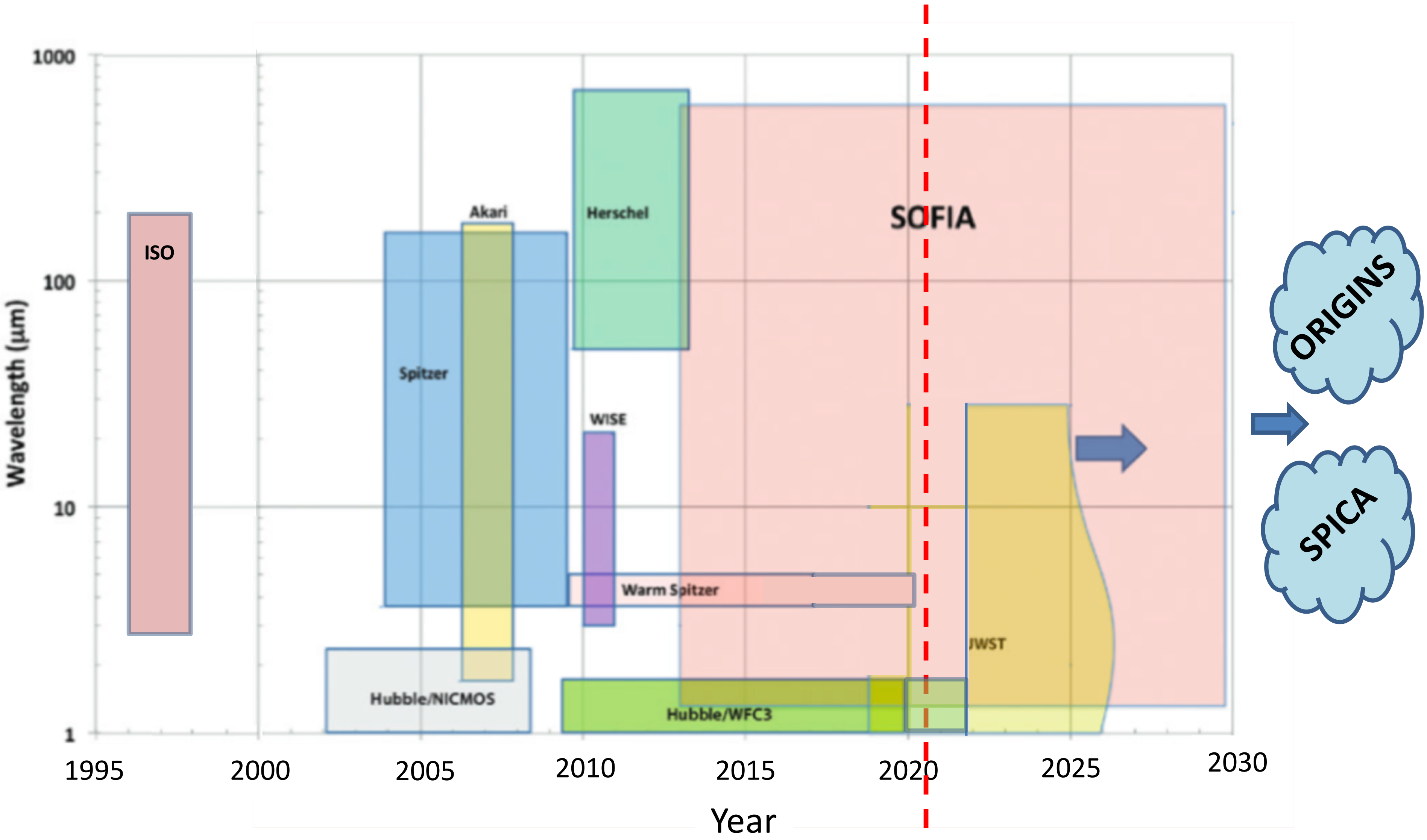
ALMA Atacama Large Millimetre Array (Chile)

JWST James Webb Space Telescope (in development)

SOFIA Is Unique

- Access to Mid- and Far-Infrared
  - No satellite mission beyond 28µm within the next decade
  - Unlike many balloon experiments the instruments are returned safely
  - Flexible and comprehensive instrument suite
- Fast turn-around for new instruments
  - State of the art technology (allowable to have “problems”)
  - Instrument access in flight
  - Broken instruments can be repaired and flown again
- Inertial platform
  - Fast mapping
  - Small Sun-avoidance angle (40˚ sun above horizon, ~25˚ sun below horizon)
    - Venus, comets, ToOs (novae, SN etc.)
- World-wide access
  - Northern and Southern hemisphere
  - Occultations
- Long baseline temporal studies
  - Designed for 20 year life time

Mid-/Far-IR Observatories in Time



Observing with SOFIA

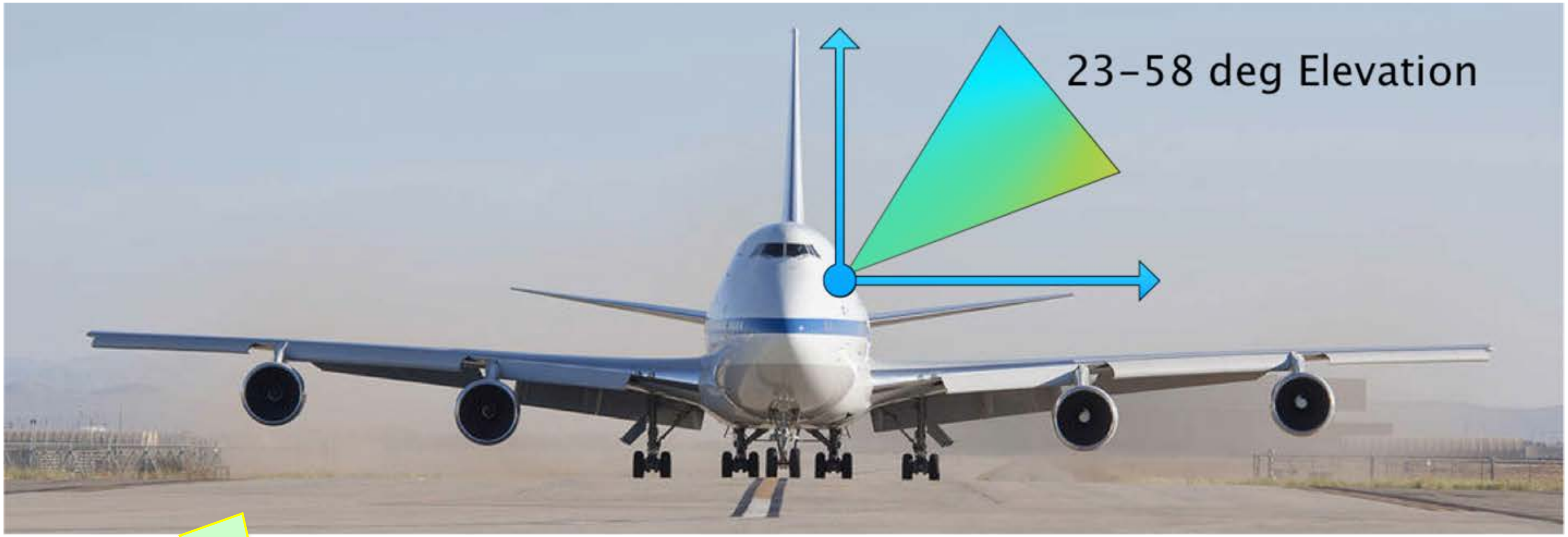
Proposing and Observing with SOFIA

- Annual proposal call
  - Call for Proposals beginning of July, Proposal Deadline beginning of September
  - Cycle Start end of April of the following year
- Two phase proposal process (much like HST):
  - Phase 1: Science justification and Technical feasibility
  - Phase 2: Detailed observation definition (After selection)
- Only one* instrument on the plane at the time:
  - Flight Series (2-3 weeks) planned after proposal selection
  - Some constraints of timing sensitive observations
  - ToOs are welcome but need to be clear on instrument/timing requirements
- Queue/Service mode observations
  - Guest Observers (GOs) are welcome to fly, but not required
  - Limited real-time modifications allowed
  - Participation can provide a better understanding of data
- Data are pipeline processed by the Science Center (/PI teams)
  - However, SOFIA is still inside of the atmosphere, so residual effects are unavoidable and need to be understood by the user.

No flights by guest observers during COVID-19

* FPI+ in science mode is always available

Telescope Observing Limits



"Azimuth" Range
+/- 3 Degrees

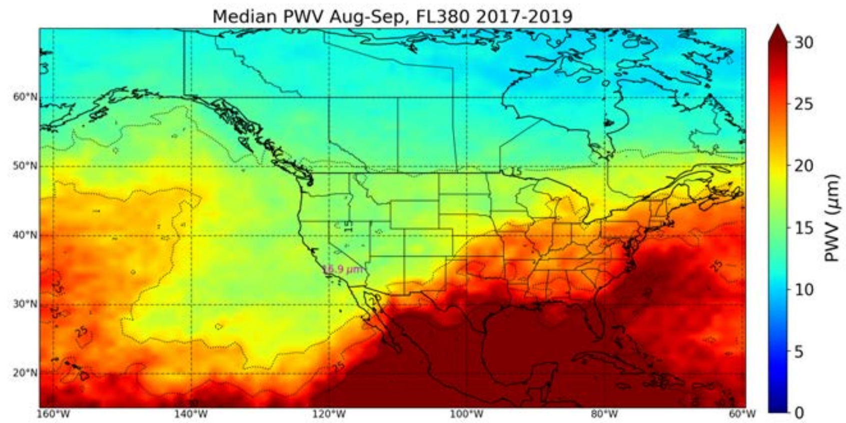
Slewing in "Az" is accomplished by turning the plane!

Many other boundary conditions

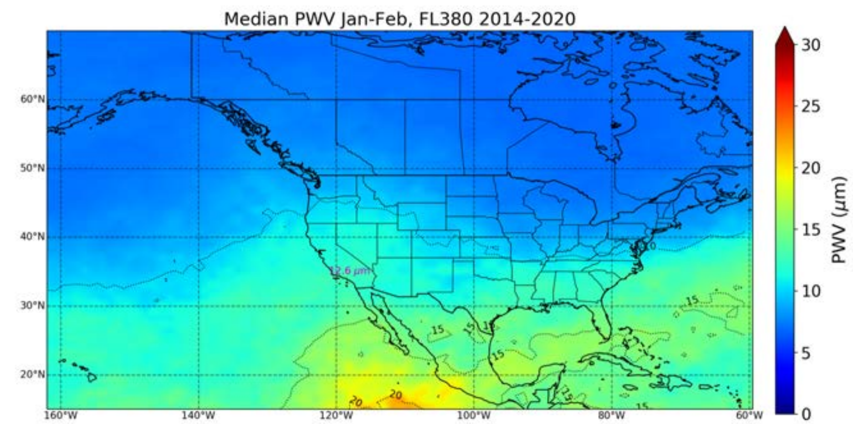
SOFIA Scheduling Constraints

- Telescope elevation limited to 23 - 60 degrees
- Flights must:
  - Be <10h (8h) total duration (crew work-day requirement)
  - Return to the originating airport
    - (nominally Palmdale, for New Zealand deployment Christchurch)
    - “For every hour flying North, we have to fly South for an hour”
  - Avoid “Special Use Areas”, Mexico, and other areas
- Minimize the impact of residual water vapor
  - Start at 39,000ft, climb to 41,000 and 43,000 as the plane lightens
  - Tropopause climbs steeply towards equator
- Optimize the science in the flight
  - SOFIA (FIR) targets tend to be clumped in the inner Galaxy and a few SF regions
  - Trade-off (often) between maximizing average priority and observing efficiency

Water Vapor at Altitude Over the Year

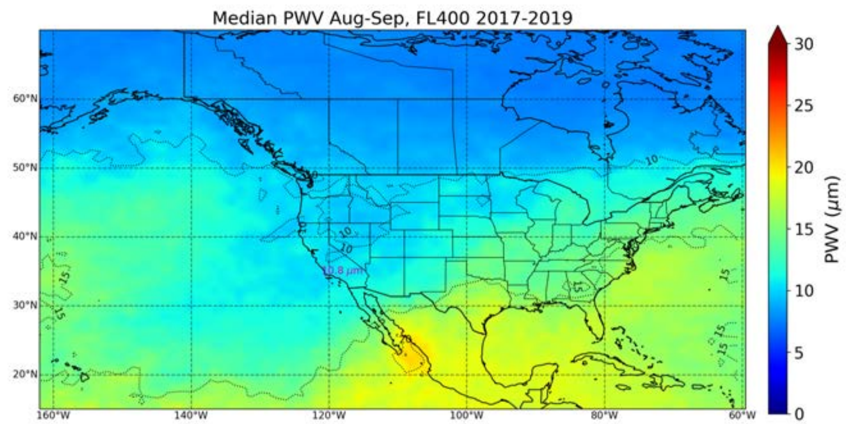


38,000 ft

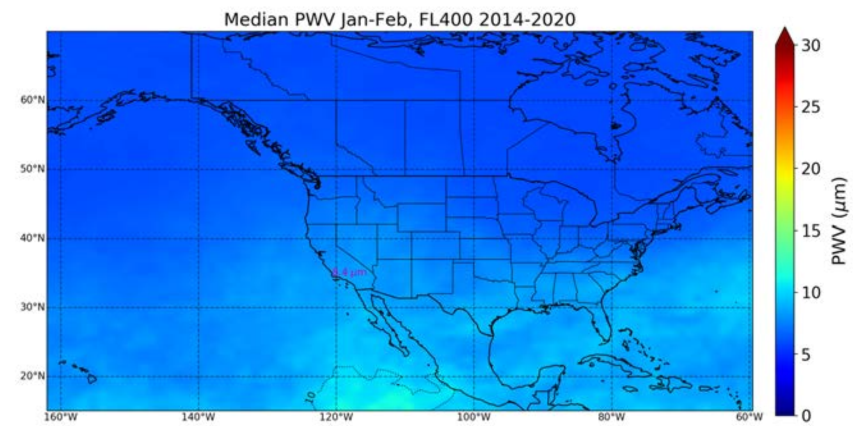


Northern Summer

Northern Winter

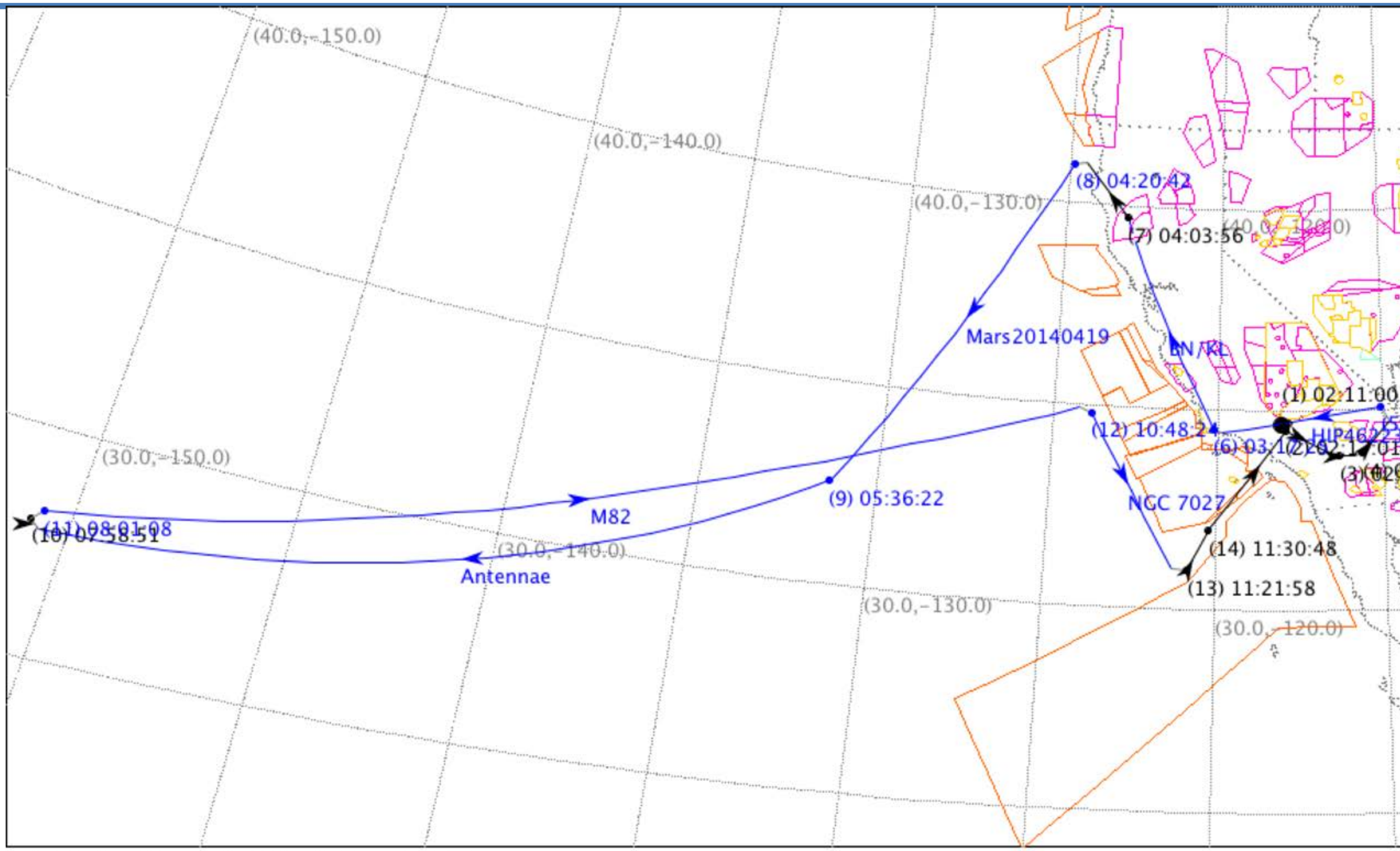


40,000 ft



Water Vapor content decreases with altitude and is less in winter.
During the northern summer with less favorable water vapor conditions in the north, SOFIA observes from New Zealand and schedules aircraft maintenance work.

Typical SOFIA Flight



Flight Plan Name: File: 201404_FI_02_WX12.fp
Flight ID: 2014/04/19
Est. Takeoff Time: 2014-Apr-19 02:11 UTC
Est. Landing Time: 2014-Apr-19 12:05 UTC
Flight Duration: 09:54
Weather Forecast : 1200 Fri Apr 18 2014 - 0000 Mon Apr 21 2014 UTC
Saved: 2014-Apr-18 13:57 UTC User: kbower

SOFIA Scheduling

- Once proposal selection is finalized, agree on high-level schedule of instrument campaigns, maintenance, and deployments
- The location and length of the Flight Series are matched to the target pool
- Flight plans are sensitive to exact dates (field rotations, LOS rewinds, SUAs…)
  - Most efficient baseline flight plan determined by software from millions of options
- About 10 weeks before the start of a series, final flight planning starts
- Flight plans set ~6 weeks before first flight
  - Posted to SOFIA web site
  - GO invitations sent out (nominally 2 GO seats /flight)

Cycle 6 Daily Overview – Page 1 of 2

Working Schedule as of 9-May-2018
- May use for operations planning
- Approval of the schedule by the Program Management Board forthcoming

SOFIA Stratospheric Observatory for Infrared Astronomy

Maintenance / Upgrades #15 w/ 'C Check' — Eng Run (10) · FCF (11) · Ferry (12)

S	S	M	T	W	T	F	S	S	M	H	W	T	F	S	S	M	T	W	H	F	S
21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12

May -- 2018

Cycle 6 Start · Europa · NZ Time

SI Install · OC#6 E EXES · OC#6 G GREAT LFA/HFA · OC#6 H (NZ) GREAT · Media

SI Install | Eng LO | 2 Flights | SI Rem | SI Install | 2 Flights LFA/HFA | Aircraft Prep | Ferry CHC - 2 flts | Prep | Orient | 8 Flights LFA/HFA | Post | Down | Prep | Swap

S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	H	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

May -- 2018 · June -- 2018

Tour · Tour · Tour · Tour · Tour · Tour · Titan

OC#6 H (NZ) GREAT · Code O Safety Day · OC#6 I (NZ) HAWC+ · FPI+ · 2 flts

Down | Prep | 8 Flights 4G/HFA | Post | Down | Prep | SI Rem. | Down | SI Install | 8 Flights | Post | Down | Prep | Prep | Titan | Prep | FerryPMD

S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	H	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

June -- 2018 · July -- 2018

COSPAR Tour

OC#6 I (NZ) HAWC+ · MD Inst. · Maintenance / Upgrades #17 · OC#6 J FORCAST

Tour | Crew Rest | SI Rem. | Eng LO | CR | Eng LO | Chk Flt | MD Rem | SI Install | SI Install | 10 Flights

S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

July -- 2018 · August -- 2018

OC#6 J FORCAST · SI Install · OC#6 K HAWC+

SI Rem. | SI Install | LO (H) | 10 Flights

S	M	T	W	T	F	S	S	H	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

August -- 2018 · September -- 2018

San Francisco Fleet Week

Code O Safety Day · OC#6 K HAWC+ · OC#6 L EXES

SI Rem. | SI Install | SI Install | 8 Flights | SI Rem. | SI Install | SI Install

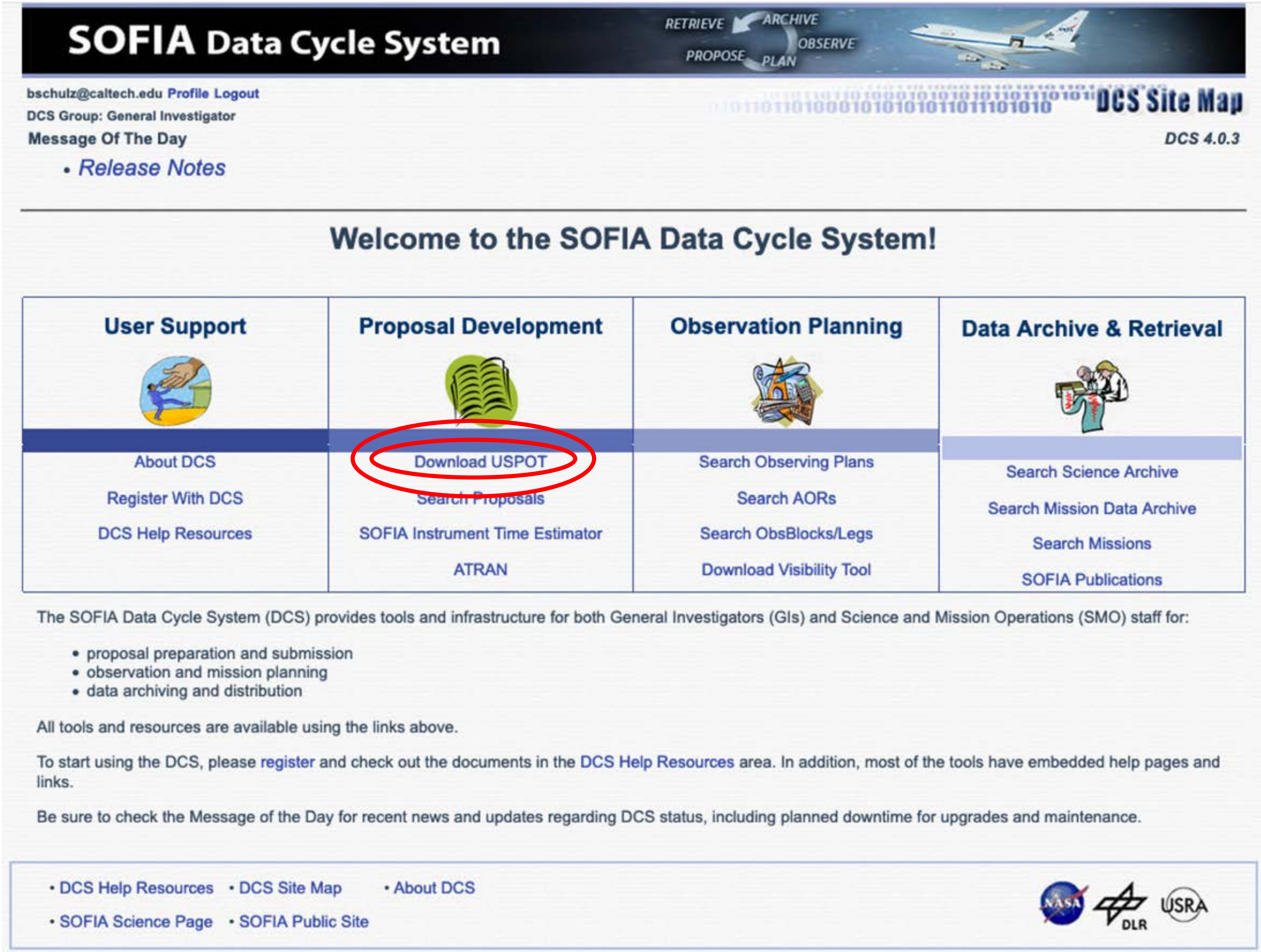
S	M	T	W	T	F	S	S	H	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3

October -- 2018 · November -- 2018

Key Observing Cycle: 6 Baseline Science Flights: 100 (TBD) Baseline RHs: 796 (TBD) Planned Obsv Prog Flights*: 98 Estimated RHs*: 780 (*Year to date + Estimate)

S / 7	**Weekend day**	(black text with no fill)
H / 4	**US or German Holiday**	(day of week box H or GH w/ red fill)
F / 6	**Instr. Commissioning Flight**	(bold white text, purple fill, bold border)
F / 6	**Baseline Observing Flight**	(bold white text, blue fill, bold border)
F / 6	**Ferry/Maint./Non-Sci Flight**	(bold white text, green fill, bold border)
F / 6	**Educator on Flight**	(white star on day of week)
F / 6	**Return to Base (RTB) Flight**	(single slash through day and date)
F / 6	**Work day**	(black text w/ day box grey fill)
F / 6	**Line Operations**	(bold border)
F / 6	**Contingency Instr. Comm. Flight**	(day box with purple fill)
F / 6	**Contingency Obser. Flight**	(day box with blue fill)
F / 6	**Contingency Ferry/Maint./Non-Sci Flt**	(day box with green fill)
F / 6	**Media/VIP on Flight**	(yellow star on date)
F / 6	**Canceled Flight**	(x through day and date)
F / 6	**AFRC Regular Day Off**	(day and date shown in red)
F / 6	**Possible Maint/Up. Check Flt**	(day and date box filled with lt. green)
F / 6	**Deployment Observing Flights**	(bold white text, light blue fill, bold border)
S / 28	**Short Flight**	(colored fill only lower half, bold bdr.)
S / 13	**Half Sci. & Half Ferry/Maint./Non-Sci**	(two colored fill)
F / 6	**Cont./Alternate Flight**	(blue/orange fill, bold border)
F / 6	**Deploy P1 Cont/ P2 Alt Flight**	(lt. blue/ lt. orange fill, bold border)

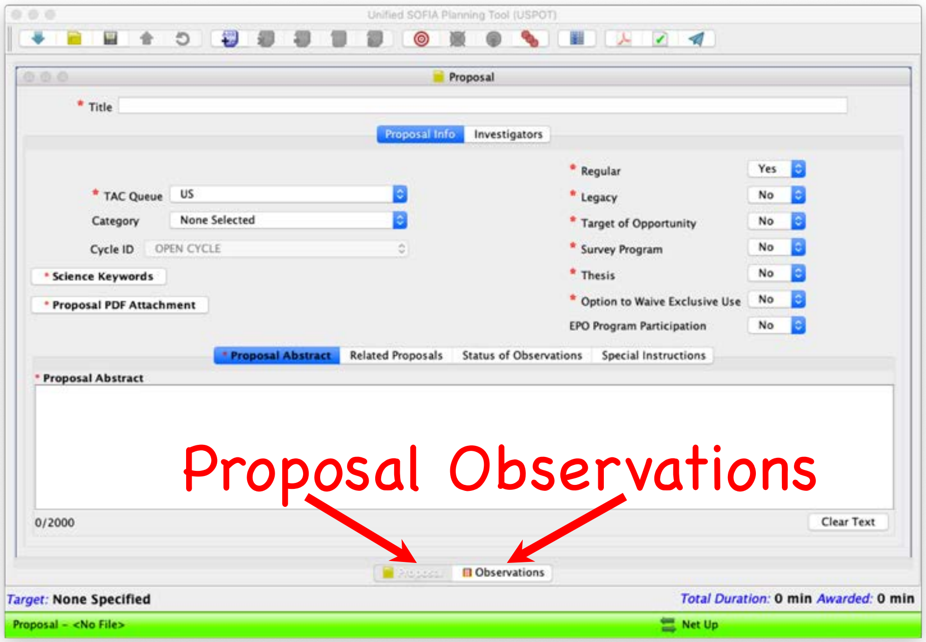
SOFIA Data Cycle System (DCS)



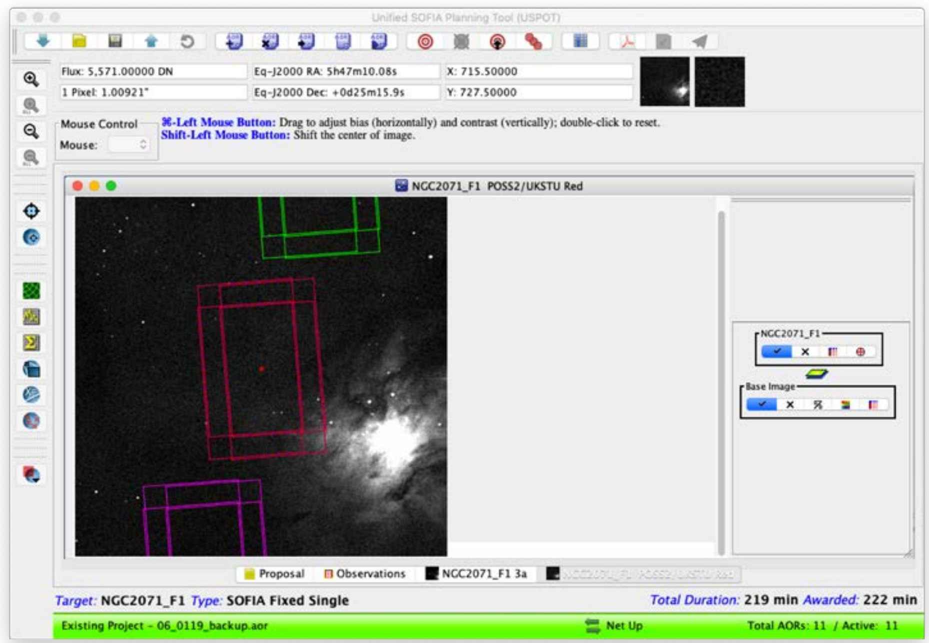
https://dcs.arc.nasa.gov

Unified SOFIA Proposals and Observation Tool (USPOT)

https://www.sofia.usra.edu/science/proposing-and-observing/uspot-manual

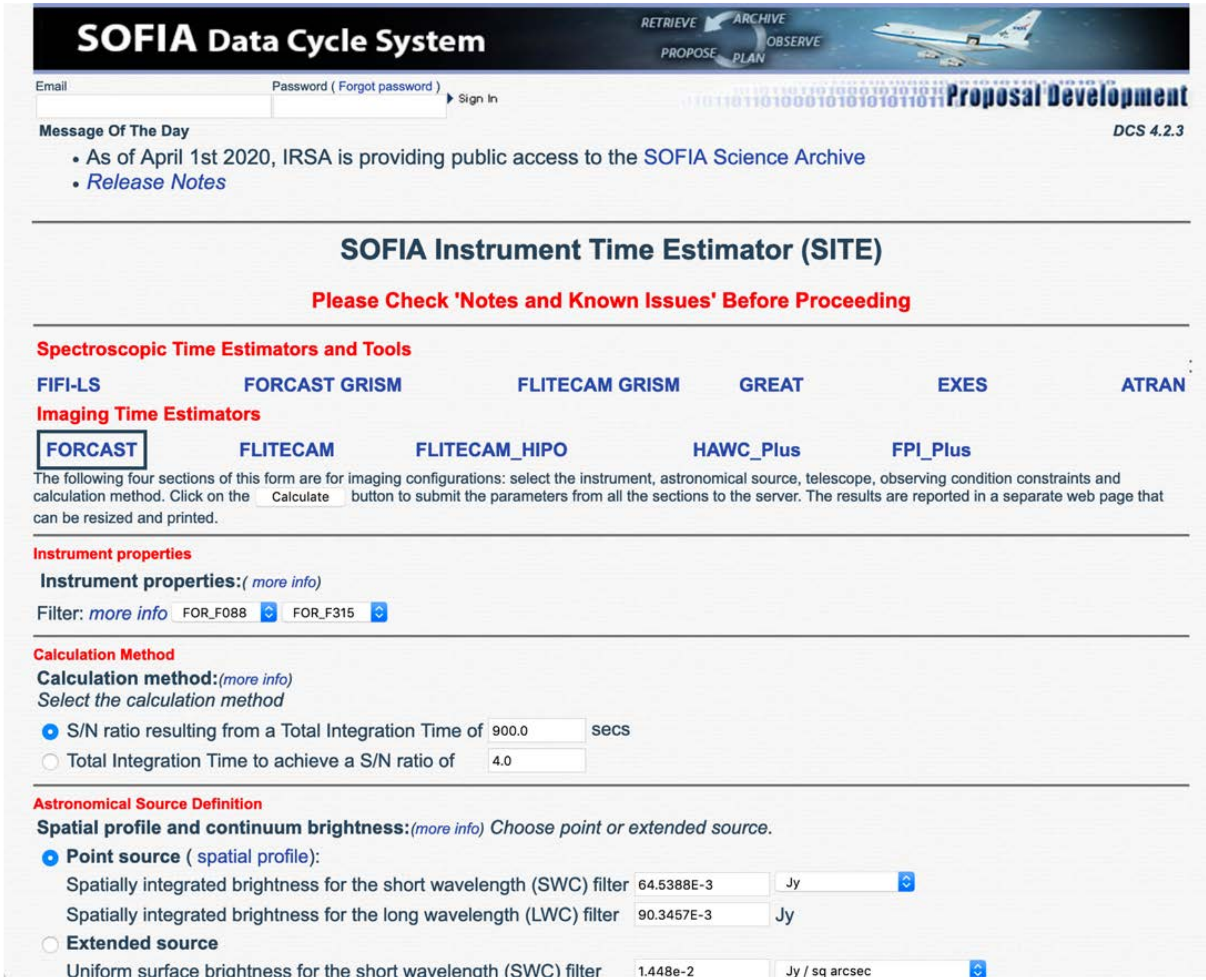


- Aid to prepare proposals including observations.
- Feeds proposal details into SOFIA DCS for planning.



Exposure Time Estimation

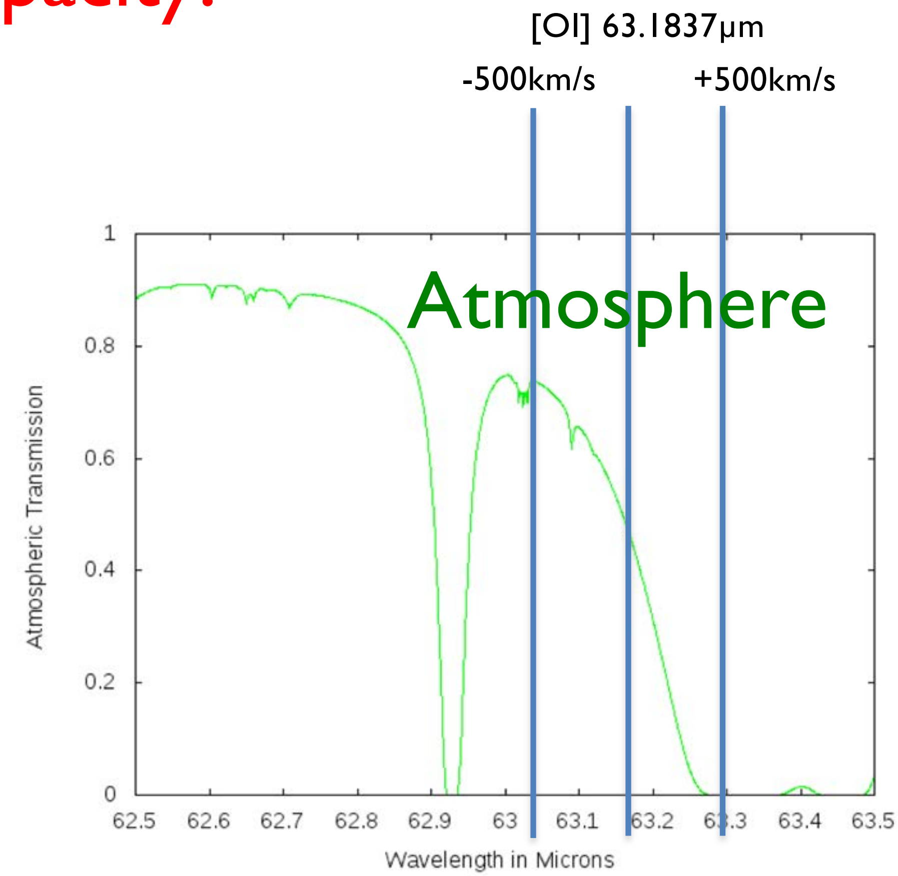
https://dcs.arc.nasa.gov/proposalDevelopment/SITE/



Exposure Time Estimation

Be aware of atmospheric opacity!

- For spectroscopic observations, it is critical to check the atmosphere's transmission at the **observing** wavelength.
- For EXES, FIFI-LS, and GREAT the variation of earth's velocity may be important. Included in Time estimators.



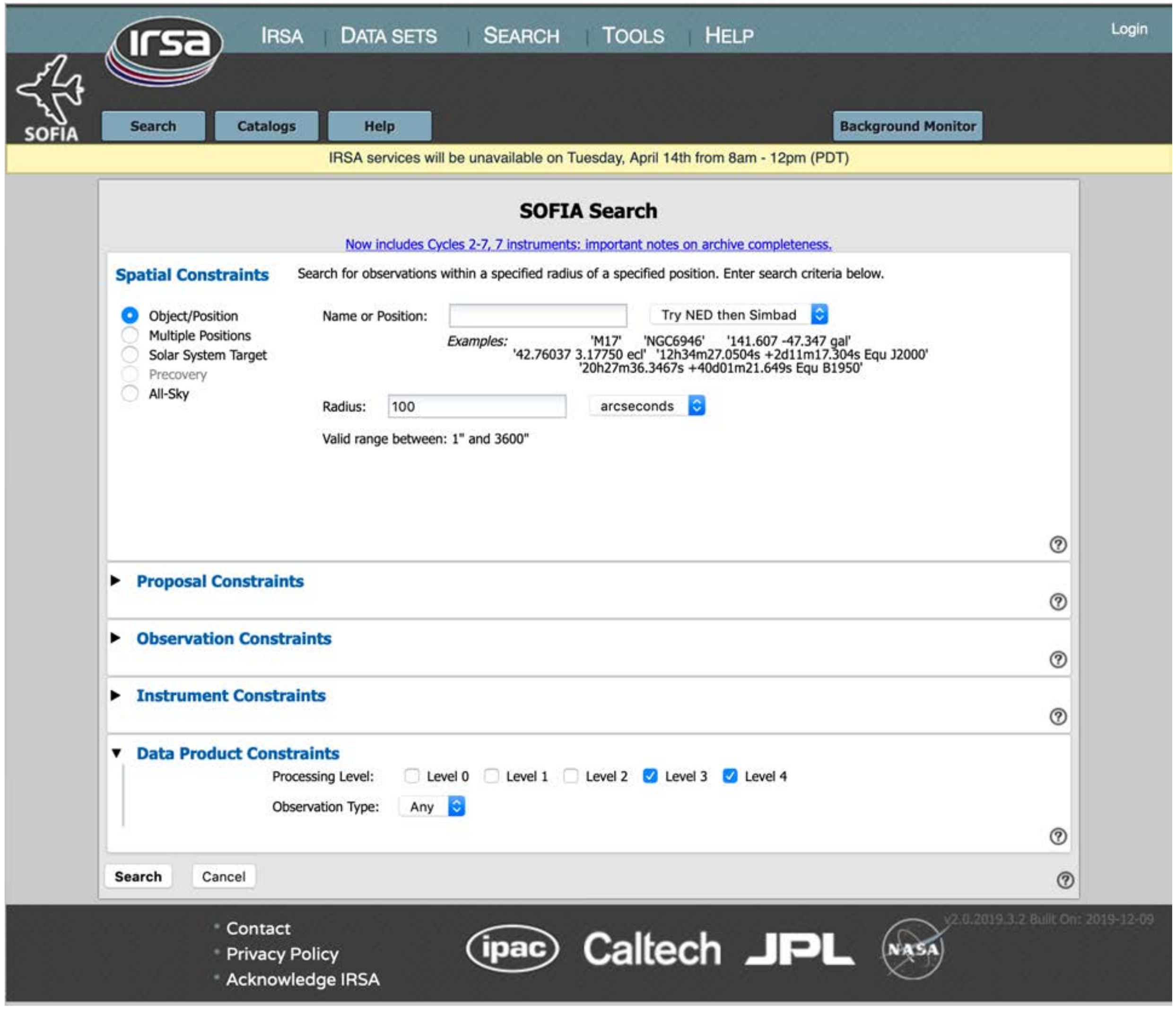
https://dcs.arc.nasa.gov/proposalDevelopment/SITE/

Data Available in IRSA

Currently Available

Cycles 2-7
7 Instruments

Archival Research!



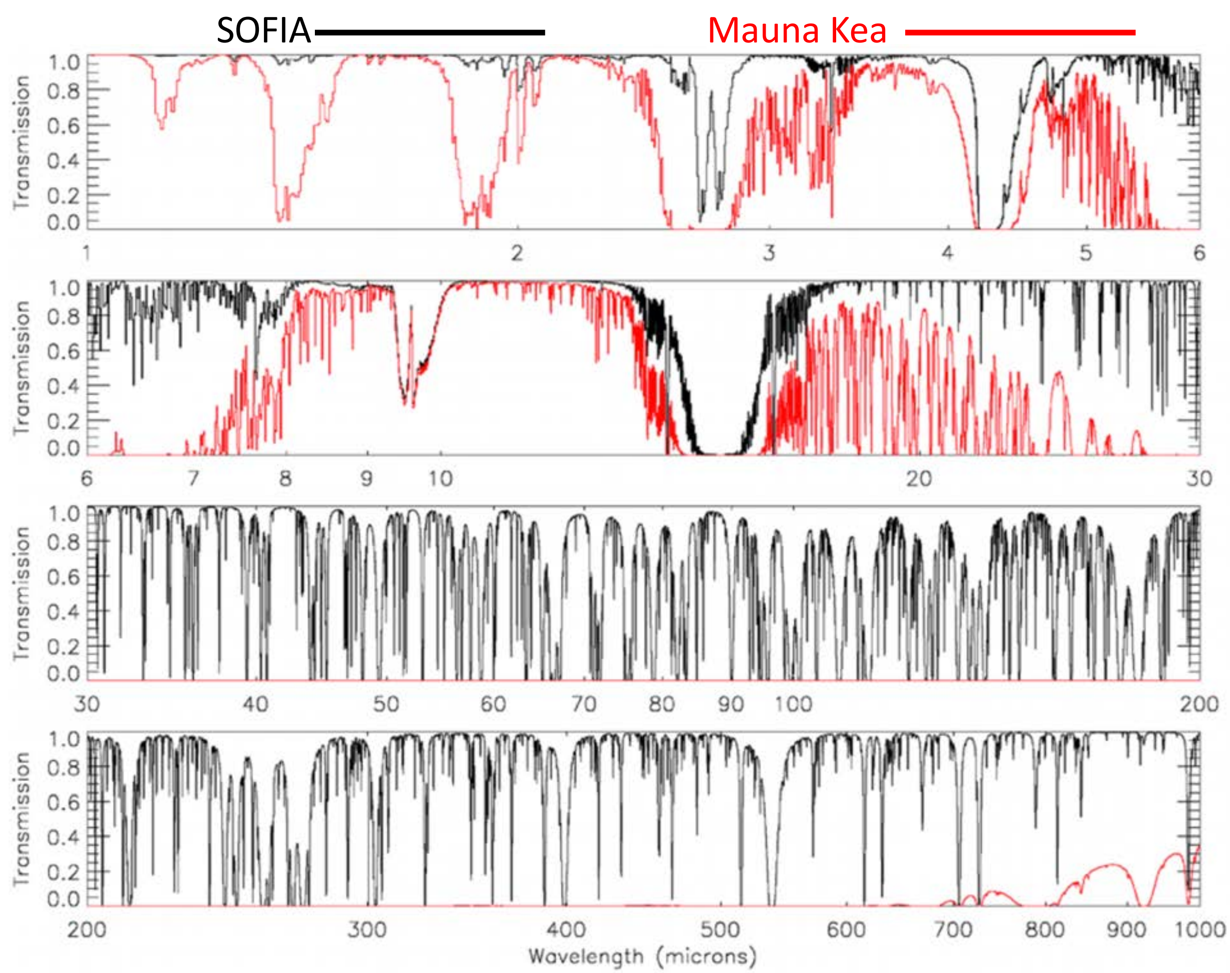
https://irsa.ipac.caltech.edu/applications/sofia/

Science Instruments

Name	Principal Investigator	Description	Wavelength Range Resolving Power R=λ/Δλ	Field of View Features
FPI+ (Focal Plane Imager Plus)	Jürgen Wolf, Universität Stuttgart, DSI	Visible light high speed camera *Facility Instrument*	**0.36 – 1.10 µm** R = 0.9 – 29.0	8.7' x 8.7' 1024x1024 CCD
FORCAST (Faint Object infraRed CAmera for the SOFIA Telescope)	Terry Herter, Cornell University	Mid-IR Camera & Grism Imaging Spectrometer *Facility Instrument*	**5 – 40 µm** R = 100 – 300	3.2' x 3.2' 2x(256x256) Si:As, Si:Sb
EXES (Echelon—Cross-Echelle Spectrograph)	Matthew Richter, UC Davis	Mid-IR High Resolution Echelle Spectrometer *PI Instrument*	**4.5 – 28.3 µm** R = 1,000 – 10^5	1" – 180" slit lengths 1024x1024 Si:As
HAWC+ (High-resolution Airborne Wideband Camera-Plus)	Charles Dowell, JPL, Caltech	Far-IR Bolometer Camera and Polarimeter *Facility Instrument*	**53, 89, 154, 214 µm** **~20% bands** Δλ = 9 – 43 µm	from 1.4' x 1.7' (53 µm) to 4.8' x 6.1' (214 µm) 3x(32x40) bolometer
FIFI-LS (Field Imaging Far-Infrared Line Spectrometer)	Alfred Krabbe, Universität Stuttgart, DSI	Far-IR Dual Channel Integral Field Grating Spectrometer *Facility Instrument*	**51 – 120, 115 - 203 µm** R = 600 – 2,000	30" x 30" (Blue) 60" x 60" (Red) 2x(16x25) Ge:Ga
GREAT, upGREAT (German REceiver for Astronomy at Terahertz frequencies)	Rolf Güsten, MPI für Radioastronomie, Bonn	Far-IR Heterodyne, multi-pixel Spectrometer *PI Instrument*	**63 – 612 µm** **(0.49-4.74 THz 7 bands)** R = 10^6 – 10^8	diffraction limited heterodyne receiver

Atmospheric Transparency

- The infrared is a key part of the spectrum for studying young stars, galaxies, planets, and the interstellar medium.
- The Earth's atmosphere is opaque to large parts of the infrared wavelength range. Water vapor absorbs much of this radiation.
- Stratosphere is a place with much less water vapor.

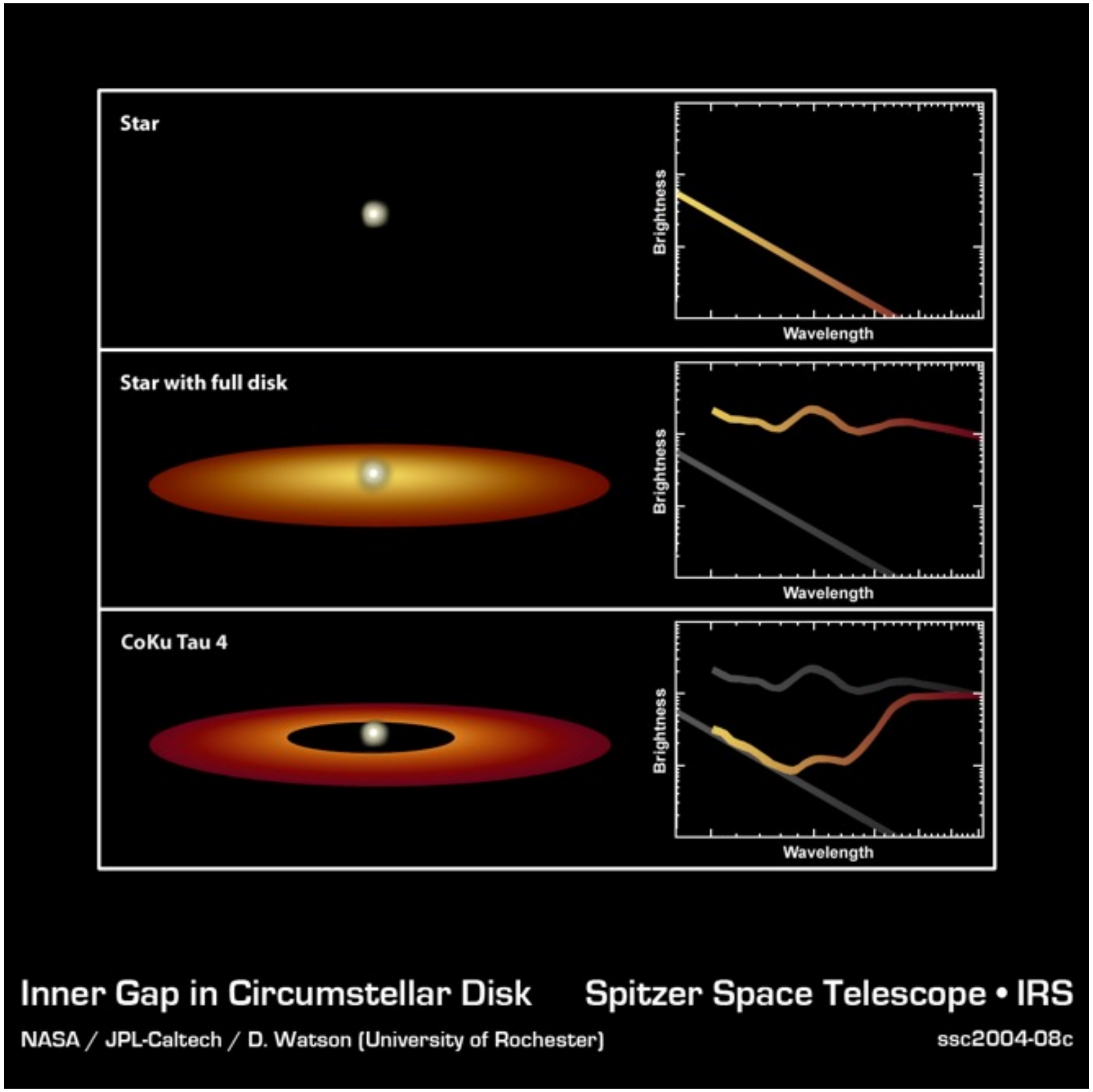


Species Accessible to SOFIA

Within many environments: Interstellar Medium, Diffuse Clouds, Molecular Clouds, Proto-stellar Disks, Debris Disks, Planetary Atmospheres, Comets

- Ionized Gas - [SI] 25.25 μm; [FeII] 25.99,35.35 μm, [SIII] 33.48 μm, [SiII] 34.81 μm; [Ne III] 36.0 μm, O [III] 52 μm, [N III] 57 μm, [O I] 63.18 μm (4.75 THz), [O III] 88.35 μm, [N II] 122 μm, [O I] 145 μm, and [C II] 158 μm; high-rotational CO
- Molecular - OH at 53 μm, 79 μm, 84 μm, 119 μm, and 163 μm, and H_2O at 58 μm, 66 μm, 75 μm, 101 μm, and 108 μm, NH_3 166 μm (1.8 THz)
- Hydrides – CH 149 μm (1.46 THz), SH 217 μm (1.38 THz), OD 119 μm (2.51 THz), (1.391 THz), HCl, HF (1.23 THz), ArH+, $^{13}CH+$
- PAHs - 6.2, 7.7, 8.6 and 11.2 μm and longer wavelengths
- Water H_2O - 6.1, 8.91, 34.9, 58, 66, 75, 101, 108 μm, … 231 μm …
- Deuterated Hydrogen HD – 28.5 μm, 56.2 um, 112 μm (2.674 THz)
- Ices – Hydrocarbon, NH_3, H_2O - 43 μm, 63 μm (crystalline), 47 μm (amorphous)
- Organics/Nitriles – C_2H_2, C_4H_2, C_3H_3+, C_3H_4, C_2N_2, CH_4, "haystack condensate" at 45.45 μm
- Cations – ortho-D_2H^+ 203 μm (1.47 THz), para-H_2D^+ 219 μm (1.37 THz)
- …

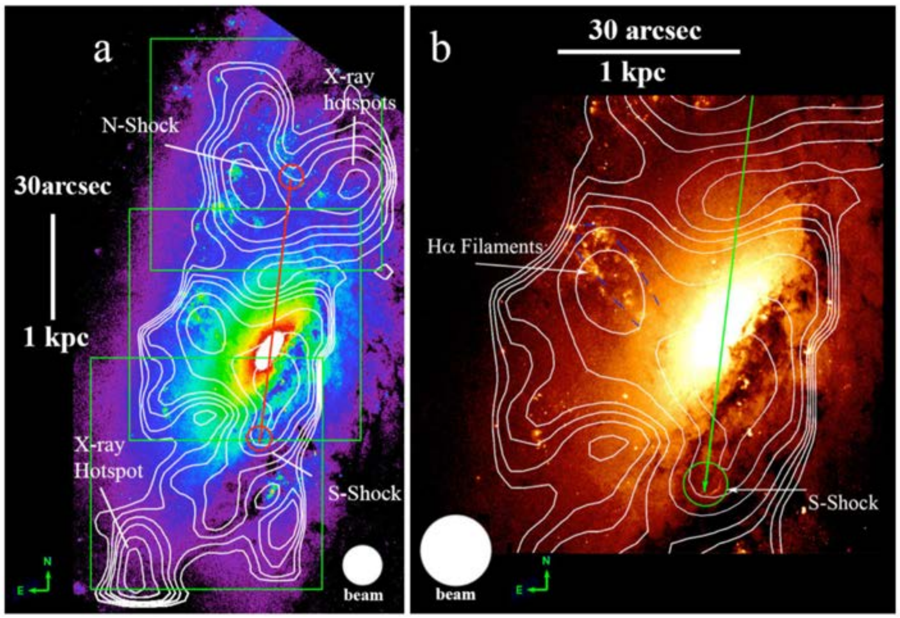
Protoplanetary Disks



- Dust disk emits IR radiation.
- Dust Temperature increases with proximity to star.
- Wavelength tells distance to star.
- Gap in IR-spectrum corresponds to gap in disk.
- Possible location of new forming planet “sweeping” up material.

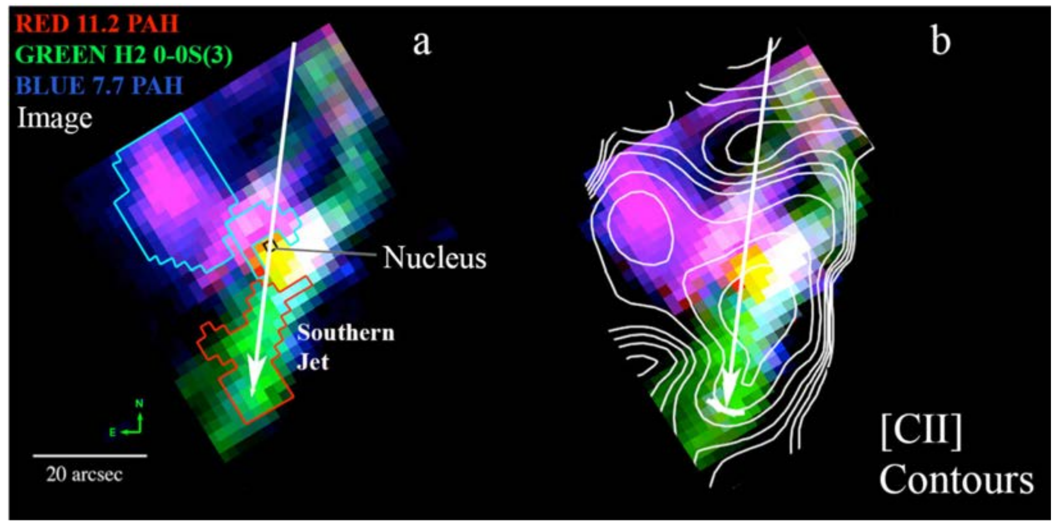
Jet-related Excitation of the [C II] Emission in the Active Galaxy NGC 4258 with SOFIA/FIFI-LS

Appleton, et al. (2018, ApJ, 869, 61)



(a) Contours of [C II] emission superimposed on false-color HST F657N WFC3 image over inner 3 kpc of NGC 4258
(b) Zoom-in on the [C II] emission (WFC3 image different color table)

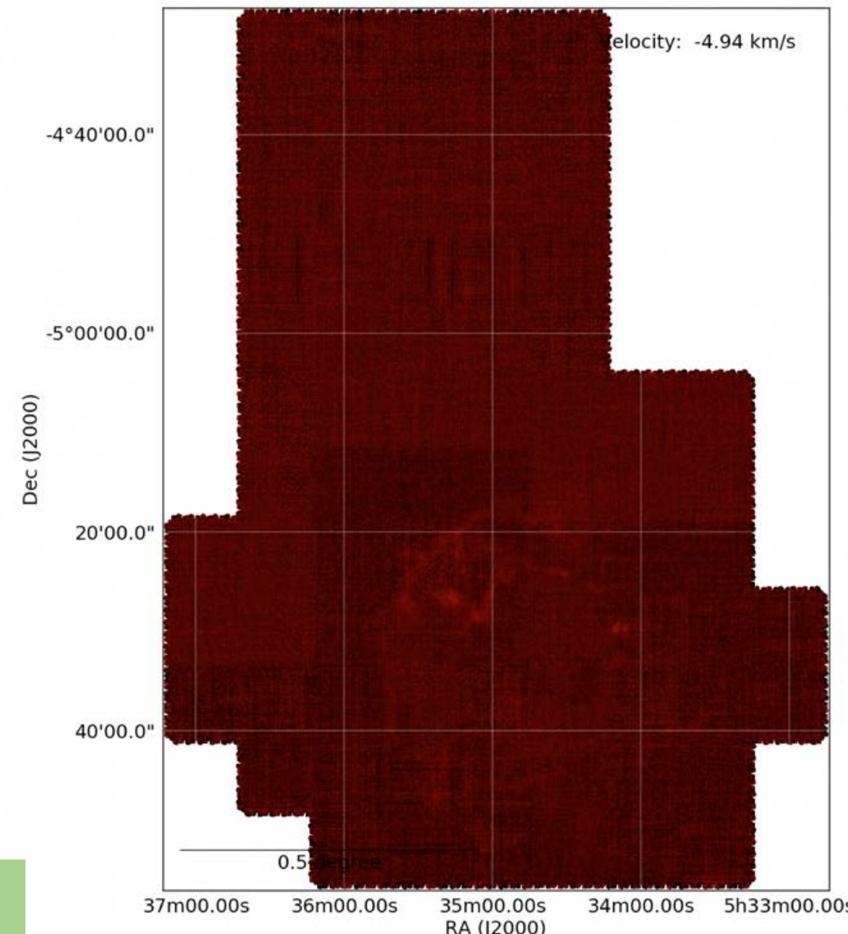
"… as much as 40% (3.8×10^{39} erg s^{-1}) of the total [C II] luminosity from the inner 5 kpc of NGC 4258 arises in shocks and turbulence […], the rest being consistent with [C II] excitation associated with star formation.



a) Spitzer IRS image of H2 0-0 S(3) 9.7µm (green) , PAH 11.2µm (red), and PAH 7.7µm (blue). PAH dominated (blue border) H2 line emission (green border).
b) Same with SOFIA [C II] contours superimposed.

Mapping Orion in [CII]

- ALMA is now using the [CII] line at 158 μm a a star formation rate indicator for z>5. Is this line a good star formation rate indicator?
- Goal of this study (Tielens et al. in prep) was to further examine the use of the [CII line as a tracer of star formation rate, measure the amount of molecular cloud mass not measured by CO ("CO-dark" gas), and semi-empirically determine the photo-electric heating efficiency over a wide range in incident UV fields.



40 Hrs SOFIA

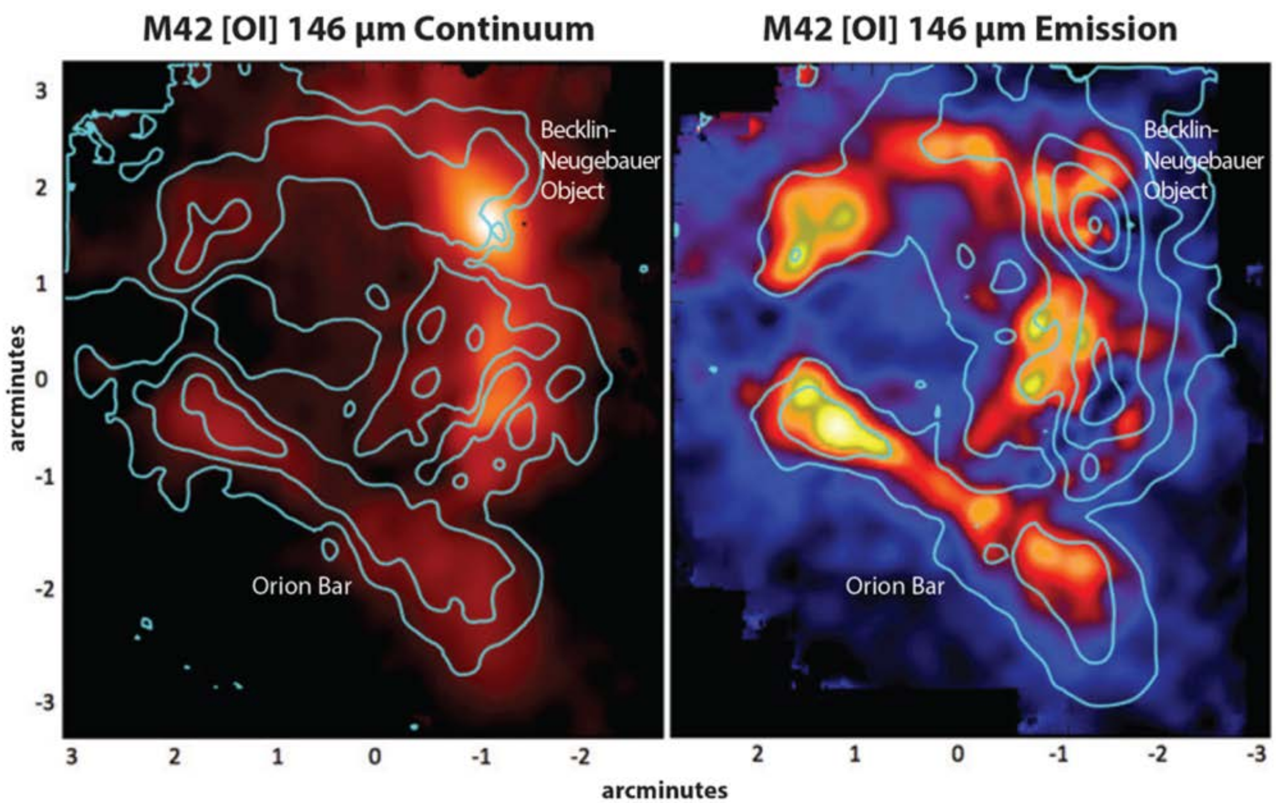
Herschel-HIFI would have needed 2000 hours for this project (approx. 7% of the Herschel mission)

FIFI-LS

"FIFI-LS *Mapping of M42 at 146 µm*", L. Looney, et al. In prep

Left: The far infrared continuum is shown, which peaks at the Becklin-Neugebauer object but also clearly shows the Orion Bar and a similar structure to the north-east.

Right: Additionally, the [OI] line emission traces the photon-dominated regions around the Trapezium stars where the star's UV radiation irradiates the surrounding molecular cloud.

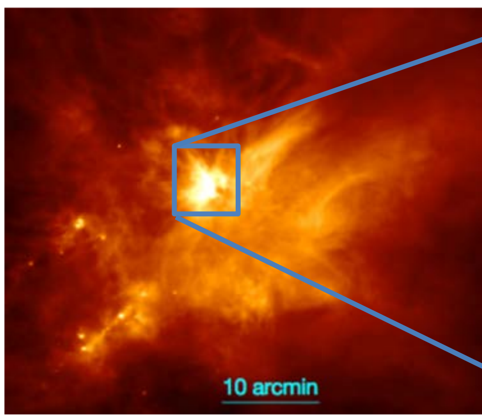


HAWC+

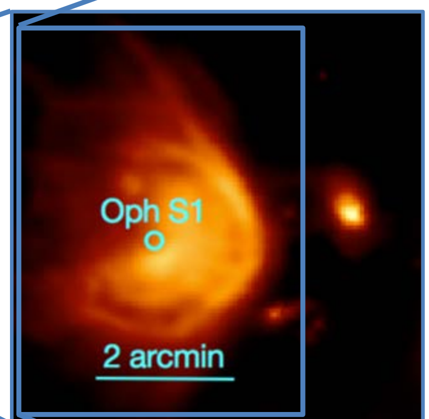
Examined the interstellar polarization spectrum using HAWC+ observations at 89 and 155 μm of the Rho Oph star forming region.

Changes in grain alignment from diffuse to dense regions is consistent with Radiative Alignment Theory (RAT).

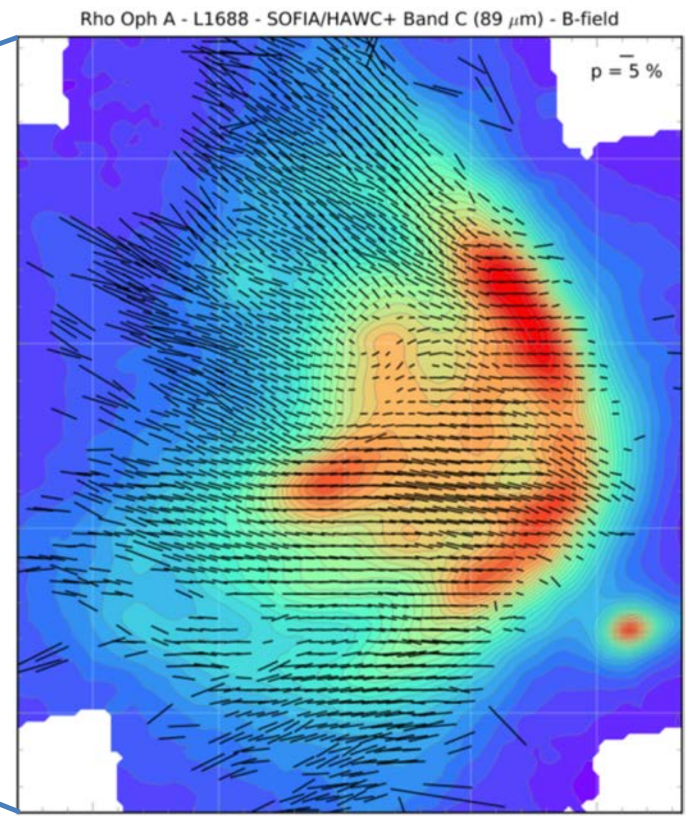
HAWC+ Observations of Rho Oph A – Santos et al., 2018, AAS Press Release 130.04



Herschel/PACS 160 μm map of L1688



Herschel/PACS 70 μm map of Rho Oph A



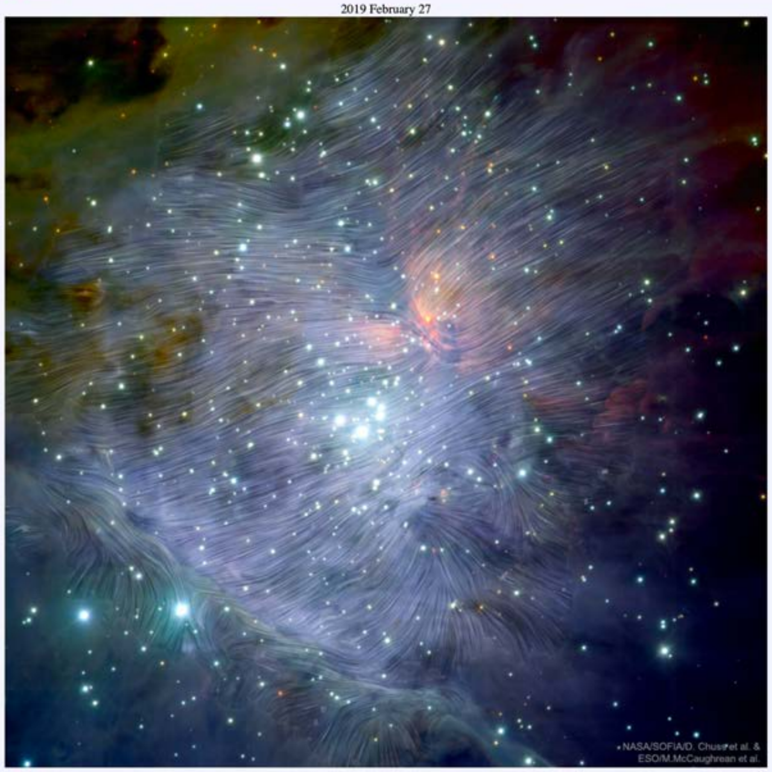
Additional tests of RAT theory, presented by Andersson et al., demonstrates radial alignment of grains around IRC +10216 (AAS Press Release 414.04).

Astronomy Picture of the Day

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2019 February 27



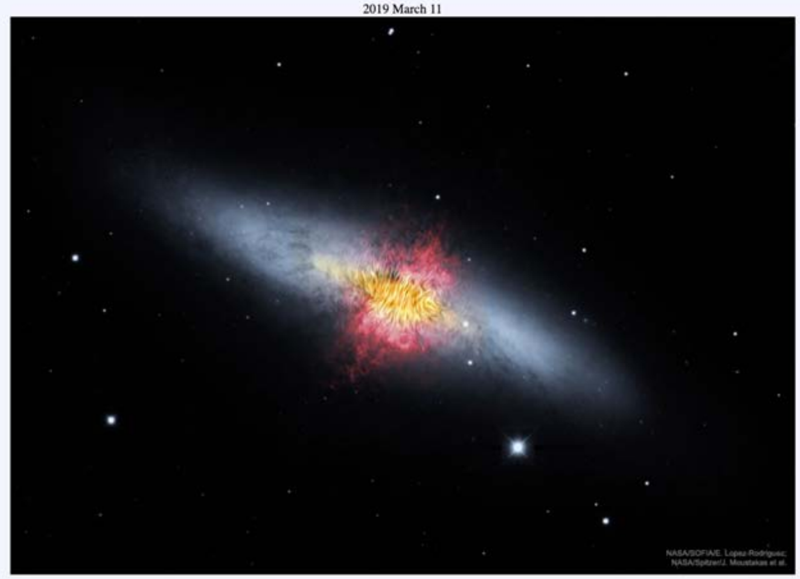
Magnetic Orion
Image Credit & Copyright: NASA, SOFIA, D. Chuss et al. & ESO, M. McCaughrean et al.

Explanation: Can magnetism affect how stars form? Recent analysis of Orion data from the HAWC+ instrument on the airborne SOFIA observatory indicate that, at times, it can. HAWC+ is able to measure the polarization of far-infrared light which can reveal the alignment of dust grains by expansive ambient magnetic fields. In the featured image, these magnetic fields are shown as curvy lines superposed on an infrared image of the Orion Nebula taken by a Very Large Telescope in Chile. Orion's Kleinmann-Low Nebula is visible slightly to the upper right of the image center, while bright stars of the Trapezium cluster are visible just to the lower left of center. The Orion Nebula at about 1300 light years distant is the nearest major star formation region to the Sun.

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

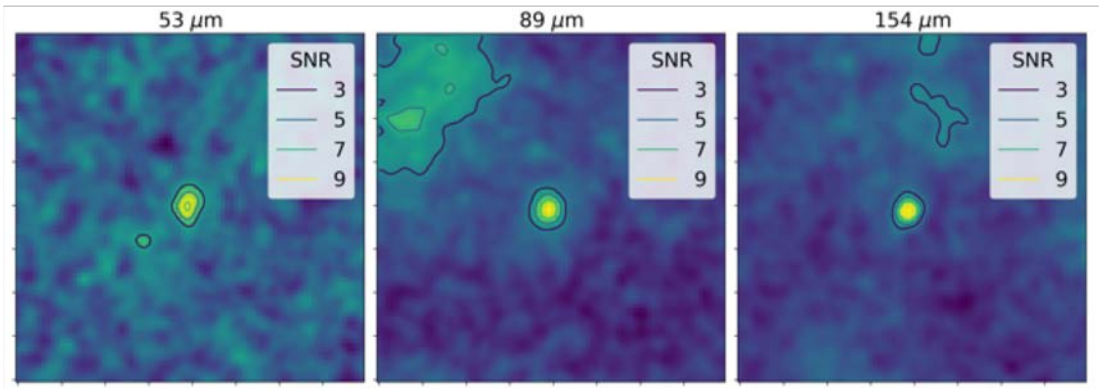
2019 March 11



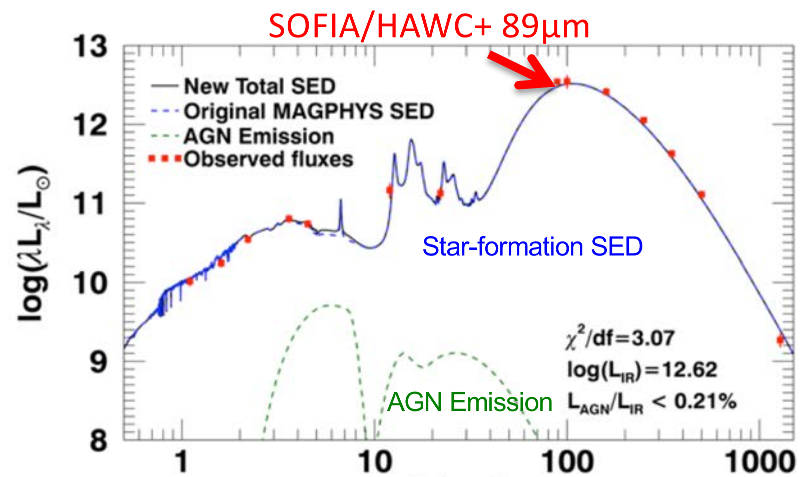
The Central Magnetic Field of the Cigar Galaxy
Image Credit: NASA, SOFIA, E. Lopez-Rodriguez; NASA, Spitzer, J. Moustakas et al.

Explanation: Are galaxies giant magnets? Yes, but the magnetic fields in galaxies are typically much weaker than on Earth's surface, as well as more complex and harder to measure. Recently, though, the HAWC+ instrument onboard the airborne (747) SOFIA observatory has been successful in detailing distant magnetic fields by observing the polarized infrared light emitted by elongated dust grains rotating in alignment with the local magnetic field. HAWC+ observations of M82, the Cigar galaxy, show that the central magnetic field is perpendicular to the disk and parallel to the strong supergalactic wind. This observation bolsters the hypothesis that M82's central magnetic field helps its wind transport the mass of millions of stars out from the central star-burst region. The featured image shows magnetic field lines superposed on top of an optical light (gray) and hydrogen gas (red) image from Kitt Peak National Observatory, further combined with infrared images (yellow) from SOFIA and the Spitzer Space Telescope. The Cigar Galaxy is about 12 million light years distant and visible with binoculars towards the constellation of the Great Bear.

Hyperluminous IR Galaxies: What powers them?



Data taken on October 2017 (OC5N)



Data taken on May 2017 (OC5E)

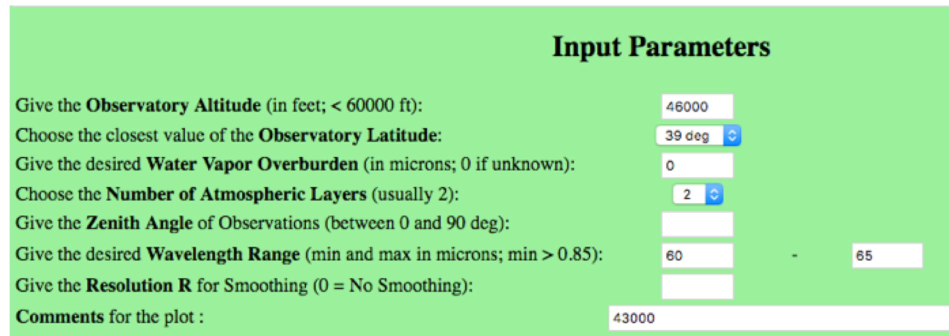
D. Riechers/Cornell and colleagues detected z=3.9 galaxy/AGN APM08279+5255 (λ_{rest}=11, 18 & 31 μm) with SOFIA HAWC+. Spectral Energy Distribution at shorter wavelengths that ALMA cannot access, measures hotter dust at these redshifts, to identify and characterize AGN in bright but dusty galaxies at high redshift.

A. Cooray/UC Irvine and colleagues measured the z=1.03 galaxy HATLASJ1429-0028 demonstrating SOFIA's HAWC+ capabilities. Another ~50 HATLAS galaxies missing FIR photometry still to be observed (Ma et al 2018).

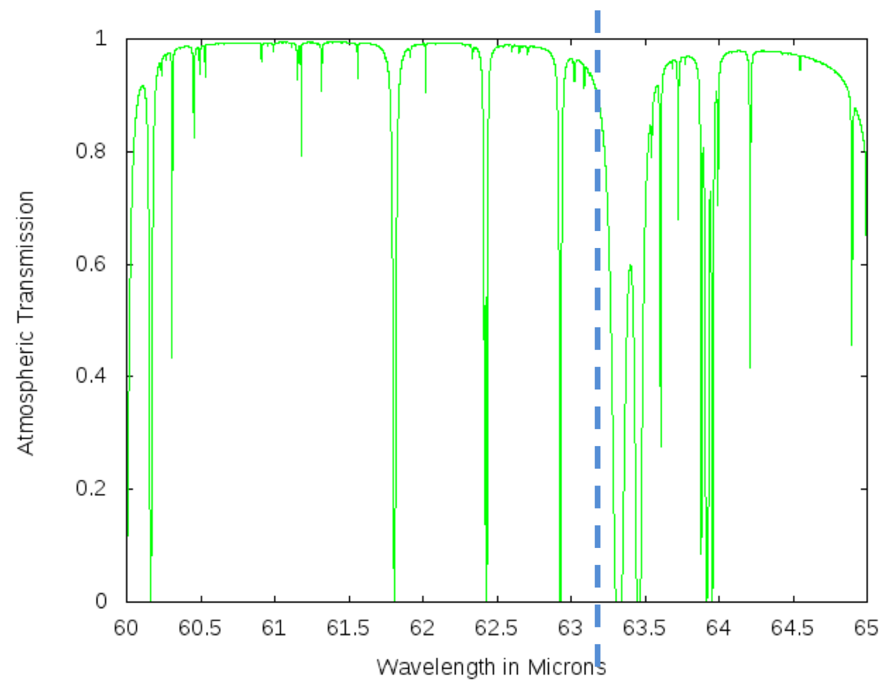
ATRAN

https://atran.arc.nasa.gov/cgi-bin/atran/atran.cgi

- **Atmospheric Transmission**
- atmospheric transmission as a function of wavelength
- On-line tool ATRAN developed and kindly provided to the SOFIA program by Steve Lord.
- ATRAN is ***necessary*** for planning SOFIA high-resolution spectroscopic observations.
- Also for medium resolution spectroscopy – e.g. FIFI-LS observations of [O I], the Doppler shift of atmospheric lines can have significant impacts on the sensitivity
- For spectral regions accessible from the ground (e.g. λ=10-13μm), very strong motivation must be provided for using e.g. SOFIA/EXES instead of Gemini/TEXES


Input Parameters

Give the **Observatory Altitude** (in feet; < 60000 ft): 46000
Choose the closest value of the **Observatory Latitude**: 39 deg
Give the desired **Water Vapor Overburden** (in microns; 0 if unknown): 0
Choose the **Number of Atmospheric Layers** (usually 2): 2
Give the **Zenith Angle** of Observations (between 0 and 90 deg):
Give the desired **Wavelength Range** (min and max in microns; min > 0.85): 60 - 65
Give the **Resolution R** for Smoothing (0 = No Smoothing):
Comments for the plot : 43000



[O I] 3P1-3P2 63.183705 µm

Spatial Resolution

SOFIA is diffraction limited above wavelengths of 25μm

	pointing jitter ["]	1.3	
	diameter [m]	2.5	
		SOFIA 2.5m	Other Missions
	Wavel. [micron]	**FWHM ["]**	**FWHM [“]**
SOFIA FORCAST	19.7	2.4	
MSX	21.0	2.5	12.0
Spitzer MIPS	24.0	2.7	6.0
SOFIA FORCAST	37.0	3.9	
Herschel PACS	**70.0**	**7.2**	**5.6**
Herschel PACS	**160.0**	**16.2**	**10.7**