Science with SOFIA

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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.
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

Filaments everywhere: The Turbulent ISM

Herschel PACS 70, 160 μm, + SPIRE 500 μm

Andre et al. 2010

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** 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

**Abbreviations:**
- CMB: Cosmic Microwave Background
- COB: Cosmic Optical Background
- CIB: Cosmic Infrared Background
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 (H₂O) and other molecules (O₃, CO₂).

- 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: 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 crew stations
- Mission Ops stations
- Main cabin
- Telescope
- Pressure bulkhead
- Educator/Outreach stations
- Science instrument
Science Flight On-Board of SOFIA

Telescope with GREAT

Instrument Team

Aurora Australis

Telescope Operators

Preliminary Data Reduction

Pilots posing with Aurora
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
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).

**SOFIA measures:**
- CO
- Dust
- Fine structure
- Hydrides
- HD
- NH₃
- PAHs
- Water

**To determine:**
- Age
- Composition
- Density
- Gas Dynamics
- Magnetic Fields
- Pressure
- Shocks
- Temperature
Science Examples
First Detection of Helium Hydride in Space

- 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

Güsten et al. 2019, Nature

GREAT = German Receiver for Astronomy at Terahertz Frequencies
SOFIA/HAWC+ Detection of a Gravitationally Lensed Starburst Galaxy at z= 1.03


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

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)
“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.
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/158 µm) 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
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.

Image from ESO/VLT

EXES Spectra (preliminary)
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.

Departure shot by New Horizons Mission to Pluto.

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

**FPI+** Focal Plane Imager Plus
- \( \lambda = 0.36–1.10 \, \mu m \)
- \( R = 0.9–29.0 \)
- Optical Camera, always running!

**HAWC+** High-resolution Airborne Wideband Camera Plus
- \( \lambda = 50–240 \, \mu m \)
- \( R = 2.3–8.8 \)
- Bolometer Camera & Polarimeter

**FORCAST** Faint Object Infrared Camera for the SOFIA Telescope
- \( \lambda = 5–40 \, \mu m \)
- \( R = 100–300 \)
- Grism Spectrometer

**FIFI-LS** Far Infrared Field-Imaging Line Spectrometer
- \( \lambda = 51–203 \, \mu m \)
- \( R = 600–2,000 \)
- Grating Spectrometer

**EXES** Echelon-Cross-Echelle Spectrometer
- \( \lambda = 4.5–28.3 \, \mu m \)
- \( R = 1,000–10^5 \)
- High Resolution Spectrometer

**GREAT** German Receiver for Astronomy at Terahertz Frequencies
- \( \lambda = 63–612 \, \mu m \)
- \( R = 10^6–10^8 \)
- Heterodyne Spectrometer
Science Instruments on SOFIA

Ground Based NIR/Optical
Two Spitzer Channels

Resolving Power ($\lambda/\Delta\lambda$)

Wavelength (µm)

NIR (0.75–3 µm) → MIR (3–30 µm) → FIR (30–300 µm) → Submm

FPI+
EXES
FORCAST grisms
FIFI-LS
GREAT
HAWC+
ALMA

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

SOFIA Workshop, 8-10 June 2020, DSI Universität Stuttgart
Science Instruments on SOFIA

Ground Based NIR/Optical
Two Spitzer Channels

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

Year


Wavelength (μm)

1000

100

10

ISO

Akari

Herschel

SOFIA

Spitzer

WISE

Warm Spitzer

Hubble/NICMOS

Hubble/WFC3

SPICA

ORIGINS
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.

* FPI+ in science mode is always available

No flights by guest observers during COVID-19
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 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_Fl_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
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**

**Maintenance / Upgrades #17 w/ 'C Check'**

<table>
<thead>
<tr>
<th>Cycle 6 Start</th>
<th>Cycle 6 End</th>
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**NZ**

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**Time**

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<tr>
<th>Aircraft Prep</th>
<th>Ferry O/F, J, F</th>
<th>Prep</th>
<th>Orient</th>
<th>8 Flights</th>
<th>LFA/HFA</th>
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**Media**

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**Tour**

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**Flights**

<p>| Cycle 6 J FORCAST |</p>
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**COSPAR Test**

<p>| Cycle 6 J FORCAST |</p>
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**Key**

- **S**: Weekend day
- **M**: US or German Holiday
- **T**: Instr. Commissioning Flight
- **F**: Baseline Observing Flight
- **W**: Ferry/Maint./Non-Sci Flight
- **R**: Educator on Flight
- **D**: Return to Base (RTB) Flight
- **I**: Work day
- **O**: Line Operations
- **C**: Contingency Instr. Comm. Flight
- **V**: Contingency Obs. Flight
- **F**: Ferry/Maint./Non-Sci Flight
- **M**: Media/VIP on Flight
- **N**: AFRC Regular Day Off
- **P**: Possible Maint/Up. Check Flt
- **D**: Deployment Observing Flights
- **S**: Short Flight
- **H**: Half Sci. & Half Ferry/Maint./Non-Sci Flt
- **T**: Educator on Flight
- **P**: MEDIA/VIP Flight
- **F**: Ferry/Maint./Non-Sci Flight
- **C**: Canceled Flight

**Observing Cycle: 6**

- Baseline Science Flights: 100 (TBD)
- Baseline RHs: 796 (TBD)
- Planned Obsv Prog Flights*: 98
- Estimated RHs*: 780

- "Year to date + Estimate"

Distributed: 9 May 2018

Slide Revision: 9 May 2018

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SOFIA Data Cycle System (DCS)

Welcome to the SOFIA Data Cycle System!

User Support
- About DCS
- Register With DCS
- DCS Help Resources

Proposal Development
- Download USPOT
- Search Proposals
- SOFIA Instrument Time Estimator
- ATRAN

Observation Planning
- Search Observing Plans
- Search AORs
- Search ObsBlocks/Legs
- Download Visibility Tool

Data Archive & Retrieval
- Search Science Archive
- Search Mission Data Archive
- Search Missions
- SOFIA Publications

The SOFIA Data Cycle System (DCS) provides tools and infrastructure for both General Investigators (Gis) and Science and Mission Operations (SMO) staff for:

- proposal preparation and submission
- observation and mission planning
- data archiving and distribution

All tools and resources are available using the links above.

To start using the DCS, please register and check out the documents in the DCS Help Resources area. In addition, most of the tools have embedded help pages and links.

Be sure to check the Message of the Day for recent news and updates regarding DCS status, including planned downtime for upgrades and maintenance.

https://dcs.arc.nasa.gov
Unified SOFIA Proposals and Observation Tool (USPOT)


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

https://dcs.arc.nasa.gov/proposalDevelopment/SITE/
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/
<table>
<thead>
<tr>
<th>Name</th>
<th>Principal Investigator</th>
<th>Description</th>
<th>Wavelength Range</th>
<th>Field of View Features</th>
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<tbody>
<tr>
<td><strong>FPI+</strong> (Focal Plane Imager Plus)</td>
<td>Jürgen Wolf, Universität Stuttgart, DSI</td>
<td>Visible light high speed camera Facility Instrument</td>
<td>0.36 – 1.10 μm R = 0.9 – 29.0</td>
<td>8.7’ x 8.7’ 1024x1024 CCD</td>
</tr>
<tr>
<td>FORCAST (Faint Object infraRed CAmera for the SOFIA Telescope)</td>
<td>Terry Herter, Cornell University</td>
<td>Mid-IR Camera &amp; Grism Imaging Spectrometer Facility Instrument</td>
<td>5 – 40 μm R = 100 – 300</td>
<td>3.2’ x 3.2’ 2x(256x256) Si:As, Si:Sb</td>
</tr>
<tr>
<td><strong>EXES</strong> (Echelon—Cross-Echelle Spectrograph)</td>
<td>Matthew Richter, UC Davis</td>
<td>Mid-IR High Resolution Echelle Spectrometer Facility Instrument</td>
<td>4.5 – 28.3 μm R = 1,000 – 10⁵</td>
<td>1” – 180” slit lengths 1024x1024 Si:As</td>
</tr>
<tr>
<td><strong>HAWC+</strong> (High-resolution Airborne Wideband Camera-Plus)</td>
<td>Charles Dowell, JPL, Caltech</td>
<td>Far-IR Bolometer Camera and Polarimeter Facility Instrument</td>
<td>53, 89, 154, 214 μm ~20% bands Δλ = 9 – 43 μm</td>
<td>from 1.4’ x 1.7’ (53 μm) to 4.8’ x 6.1’ (214 μm) 3x(32x40) bolometer</td>
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<tr>
<td><strong>FIFI-LS</strong> (Field Imaging Far-Infrared Line Spectrometer)</td>
<td>Alfred Krabbe, Universität Stuttgart, DSI</td>
<td>Far-IR Dual Channel Integral Field Grating Spectrometer Facility Instrument</td>
<td>51 – 120, 115 - 203 μm R = 600 – 2,000</td>
<td>30” x 30” (Blue) 60” x 60” (Red) 2x(16x25) Ge:Ga</td>
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<tr>
<td><strong>GREAT, upGREAT</strong> (German REceiver for Astronomy at Terahertz frequencies)</td>
<td>Rolf Güsten, MPI für Radioastronomie, Bonn</td>
<td>Far-IR Heterodyne, multi-pixel Spectrometer Facility Instrument</td>
<td>63 – 612 μm (0.49-4.74 THz 7 bands) R = 10⁶ – 10⁸</td>
<td>diffraction limited heterodyne receiver</td>
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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


- **Molecular** - OH at 53 μm, 79 μm, 84 μm, 119 μm, and 163 μm, and H₂O at 58 μm, 66 μm, 75 μm, 101 μm, and 108 μm, NH₃ 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+, ¹³CH+

- **PAHs** - 6.2, 7.7, 8.6 and 11.2 μm and longer wavelengths

- **Water** H₂O - 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, NH₃, H₂O - 43 μm, 63 μm (crystalline), 47 μm (amorphous)

- **Organics/Nitriles** – C₂H₂, C₄H₂, C₃H₃+, C₃H₄, C₂N₂, CH₄, “haystack condensate” at 45.45 μm

- **Cations** – ortho-D₂H⁺ 203 μm (1.47 THz), para-H₂D⁺ 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


“... as much as 40% (3.8×10^{39} \text{ 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.
• ALMA is now using the [CII] line at 158 µm as 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.

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

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.
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).

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

Discover the context: Each day a different image or photograph of an interesting astronomical phenomenon is featured, along with a brief explanation written by a professional astronomer.

2019 February 27

Magnetic Orions

Image Credit & Copyright: NASA, SOFIA, D. Chini et al. & DLR, M. McCaughrean et al.

Explanation: Our magnetism affects 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 the infrared light. When one or both of the protostars of the Orion Nebula is aligned with the local magnetic field, the magnetic field becomes strong enough to arrest the collapsing molecular cloud. The magnetic field is the result of the collapse of the protostar and will create a magnetic field that affects the star's development and the formation of new stars in the vicinity. The Orion Nebula is a detailed map of one of the most exciting regions in the sky.

2019 March 11

The Central Magnetic Field of the Cigar Galaxy

Image Credit: NASA, SOFIA, E. Lopez-Rodriguez, NASA's Jet Propulsion Laboratory, J. Matthews et al.

Explanation: Are galaxies giant magnets? Yes, just like the magnetic field of galaxies are typically much weaker than on Earth. As an example, the HAWC+ instrument on the airborne SOFIA observatory has been successful in detecting the magnetic field in the galaxy. The HAWC+ observations of the Milky Way's central magnetic field are the first direct detections of magnetic fields in the galaxy. The magnetic field is thought to be the result of the collapse of the protostar and will create a magnetic field that affects the star's development and the formation of new stars in the vicinity. The observation of the magnetic field in the galaxy provides insights into the formation and evolution of galaxies.
D. Riechers/Cornell and colleagues detected $z=3.9$ galaxy/AGN APM08279+5255 ($\lambda_{\text{rest}}=11, 18 \& 31 \mu\text{m}$) 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).
• **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. $\lambda=10$-$13\,\mu$m), very strong motivation must be provided for using e.g. SOFIA/EXES instead of Gemini/TEXES

![ATRAN Input Parameters](https://atran.arc.nasa.gov/cgi-bin/atran/atran.cgi)

[O I] 3P1-3P2 63.183705 $\mu$m
SOFIA is diffraction limited above wavelengths of 25µm

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