

# What is SOFIA's Role?



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# SOFIA's Evolving Role in the Last Decade

- Original proposed instruments: FORCAST, EXES, HAWC, GREAT, FIFI-LS
  - In 2011, only the original GREAT and FORCAST available for observations
- GO Cycle 1 observations began in 2013 – in addition to original two instruments, FLITECAM and HIPO (visible occultations)
- “New” instrument examples – HAWC added polarimetry, wavebands; GREAT added new frequencies, and moved to arrays; FORCAST and FLITECAM added gratings (including higher res. cross dispersed gratings for FORCAST) ; facility cryocooler was installed; FPI+; GREAT also upgraded LOs, back ends, mixers, cooling

**SCIENCE COMPLEXITY EVOLVED ALONG WITH THE INSTRUMENTS**

# SOFIA's Evolving Role in the Last Decade cont.

- Original instrument PIs were all former KAO IR instrumentalists.
  - First science papers from Cycle 1 - FORCAST camera from 5-40 microns of Orion and the GC circumnuclear ring; with the GREAT heterodyne spectrometer from 130-240 microns of protostellar infall, the interface of M17 with its SW molecular cloud, and CO observations of the GC circumnuclear ring, and a visible wavelength stellar occultation of Pluto
  - Some planetary nebula and nova observations as well.
- Now SOFIA science is conducted by a broader (not broad enough!) community of astronomers who depend on multi-wavelength observations to address specific science goals - many of the talks these past 3 days have illustrated the synergy with many space and ground-based observatories, at a range of wavelengths from X-Ray to Radio (even IceCube neutrinos!)

# Unique Capabilities Reiterated

- SOFIA is the currently the only game in town at wavelengths from 5-8  $\mu\text{m}$ , and 30-300  $\mu\text{m}$
- A warm telescope is the ideal platform for high resolving power spectrometers – like EXES (4.5 – 28.3  $\mu\text{m}$ ) and GREAT (heterodyne wavelengths from  $\sim 60$  – 600  $\mu\text{m}$  with the upGREAT LFA and HFA, and 4GREAT modules)
  - Near future cooled space telescopes, e.g. JWST, will be extremely sensitive, but with instrumentation with far lower resolving power, and a far more restrictive wavelength coverage and field of view
  - Gas kinematics in mid and far IR – unique capability
- HIRMES was conceived to fill an important gap for SOFIA – including a mode with high spectral resolution from 25-122  $\mu\text{m}$ , the upper band wavelength specifically designed to allow observation of HD line emission as a proxy for the dominant  $\text{H}_2$  component in protoplanetary disks

# Unique capabilities cont.

- HAWC+ Far IR imaging polarimetry of star forming regions complements ground-based 350 and 850  $\mu\text{m}$  polarimetry of cooler molecular clouds; bridges the small spatial scale ALMA submm and mm and larger spatial scale Planck polarimetry – unique SOFIA capability
  - Also polarimetry of the GC, M82 and other external galaxies, other extended galactic sources
- FIFI-LS spectral line images at modest resolving power (1000 – 2000) from 50 – 200  $\mu\text{m}$  also provide a currently unique capability
- FORCAST mid-IR spectral imaging remains in substantial demand by observers – even at wavelengths duplicating those of JWST, many objects are simply too bright for JWST.
- The substantial fields of view of SOFIA instruments favor surveys, and study of diffuse objects

**AS DETECTOR ARRAY FORMATS AND SENSITIVITY INCREASE, SOFIA INSTRUMENTS WILL CONTINUE TO CARVE OUT UNIQUE SPACE**

# HIRMES Cancellation

- HIRMES science considerations drove the recent SOFIA Flagship Review – provided a unique capability that the large protoplanetary disk community was standing behind
  - evolution of protoplanetary systems via measurements of water–vapor, water–ice, HD and neutral oxygen lines.
  - process of mass accretion leading to star and planet formation, outflows from massive protostars, D/H ratios in giant planets
- Complicated instrument – detector development slower than projected. Cost and schedule impacted.

**Many speakers made it clear that a HIRMES-like instrument is essential for their science – SPICA and OST are more than a decade away, and are not certain facilities, in any event.**

# How best to fulfill SOFIA's role in the future?

1. Clear from the last 3 days that HIRMES-like capability is required for a variety of scientific topics – **would increase the user base because of protoplanetary disk community among other interested communities**
  - Question: is the HD science case to measure disk masses for HIRMES sufficiently strong to indicate an instrument concentrating on just that line instead of the more complicated all purpose HIRMES? (Erick Young stated that a revived GREAT “M” channel is less sensitive).
  - Question: is there any advantage/disadvantage to building several new SOFIA instruments fulfilling the capability of some aspect of HIRMES rather than restarting HIRMES in 3 years or preferably less?

# How best to fulfill SOFIA's role in the future?

- More general question: Detector issues affect many SOFIA instruments, present and future (HIRMES).
- Need higher resolving power and larger format blue channel for FIFI-LS
- Need sensitive shorter wavelength capability for HAWC+. It has been suggested to use FORCAST Si:Sb BIB array if FORCAST decommissioned. (DRS was unable to replicate useful Si:Sb 40  $\mu\text{m}$  arrays). I personally would like an enhanced FORCAST to continue.
  - Mid-IR detector array capability needs substantial funding.
- SOFIA and NASA should sponsor a workshop of experts to evaluate realistic prognosis for mid-IR arrays for SOFIA (NASA funding for SOFIA detectors should be walled off from those for other scientific programs).

# How best to fulfill SOFIA's Role in the Future?

2. Combined velocity resolved observations and magnetic field observations of star formation regions – e.g. role of magnetic fields in star formation – does turbulence or outflows/inflows dominate? Need multi-wavelength polarimetry to untangle mechanisms for polarization.

- Scanning polarimetry and larger HAWC+ arrays to increase efficiency
- Shorter wave bands for HAWC+
- Always need increased sensitivity
- [CII] narrow band filter for HAWC+ polarimetry??
- Advantages/disadvantages of utilizing GREAT polarization capability?

3. Time domain proposals every 6 months, say, for time on FORCAST? variable sources (e.g. deeply embedded outbursts with HAWC+ and FORCAST). HAWC+ narrow band filters?

- Will Fischer's talk one of many talks depending on FORCAST availability. Should it be decommissioned or enhanced? Better and larger detector arrays (need development)? ; add grating capability?
- Important for studies of evolved stars, novae, supernovae as well as young protostellar outbursts

4. Need L-band capability again for TNOs; Q-band important; continue FORCAST

- L band from ground; Q band harder and easier to justify

5. EXES – is a PI instrument; Its use is governed by the availability of the PI team to support GOs.

- Question: What would be gained or lost by making EXES a facility instrument?
- Are larger format, more sensitive detector arrays required?

6. SOFIA diffraction limited at 30  $\mu\text{m}$ .

- Can we improve telescope jitter further to improve image quality at shorter wavelengths? Is it a needed investment?
- Magnitude of seeing vs. jitter at  $\lambda < 30 \mu\text{m}$ ? Possibility (need for) AO?

7. Where should first instrument development emphasis be placed? Moderate or high spectral resolving power? (Disk kinematic tomography demands high). Larger format, more sensitive arrays for instruments?

# Future Observing Strategies for SOFIA

- Tension between individual GO programs and large Legacy Teams exploiting multiple instruments on a specific science themes - Mike Werner, Spitzer Space Telescope Project Scientist suggested (and Betsy Mills emphasized today the need for diverse large teams). Mike's suggestion follows:
  - “In alternate years, the solicitation calls for Legacy Programs, which take up ~one-third of the time averaged over two years, and targeted science themes [not limited to a single instrument nor to a single science team], which also take up ~one-third of the time averaged over two years.”

**SOFIA NEEDS TO FURTHER EVOLVE TO A SCIENCE COMMUNITY FROM AN INFRARED COMMUNITY**

# Synergy with Other Observatories

- Talks have emphasized the multi-wavelength study of specific objects in order to tease out properties – too many different synergistic platforms to fully list
- Polarimetry – synergy with BISTRO project at the JCMT, as only one example; another example of ground-based submm facilities includes ALMA observations of protostars' complementary polarimetry at longer wavelengths; near IR polarimetry of dark clouds at many facilities.
- Complementarity with near future space missions – e.g. JWST, ARIEL and ground-based facilities – Rubin Observatory – as well as planned, but not yet certain space missions such as SPICA, OST, even NEOSM for example.
- Complementarity with balloon-borne instruments occasionally mentioned

# The Path Forward – Summary of Important Questions

- Instrument upgrades vs. new instruments?
  - John Bally - SOFIA detector and instrument development for future mid and far-IR space missions - is this more important than SOFIA science itself?
- Observing efficiencies – e.g scan+chop polarization mode HAWC+?
- HIRMES completed vs. new HIRMES-like instrument vs. HIRMES component modules ?
- Detectors, Detectors, Detectors – format, wavelength coverage, sensitivity
- Observing strategies?
- Archival research – how to make data more accessible to diverse teams?
- Encouraging larger community to be involved – how do we make them feel more welcome? How do we encourage younger investigators?
- Expand FIFI-LS blue channel FOV, higher resolving power (to attract extragalactic observers)
- Legacy vs. GO?
- More southern flights?