SOFIA – JWST Synergies
Tom Greene (NASA Ames)
SOFIA International Summit
14 November 2017

Getting the Big Picture of Cosmic Origins
Technical and Mission Information

- 6.5-m, 25 m² primary, T ~ 40 K
- 0.6 – 28 µm imaging & spectroscopy
- Faint target optimized
- > 8000 hours / year
- Launch in 2019, 5 – 10+ years operations

- 2.5-m, 4.5 m² primary, T ~ 220 K
- ~0.35 – ~250 µm imaging & spectroscopy
- Bright target optimized
- < 1000 hours / year
- Operational now, extended mission 2019+?

11/14/17
James Webb Space Telescope (JWST)

- 6.5-m primary mirror; 25 m²
- 18 segments, T~40K, zodi-limited to 10 μm
- Instruments:
  - NIRCam: $\lambda = 0.7 - 5$ μm imager and slitless spec.
  - NIRSpec: $\lambda = 0.6 - 5$ μm wide-field, slit, and IFU spec.
  - MIRI: $\lambda = 5 - 28$ μm imager, slit, slitless, IFU spec
  - NIRISS/FGS: $\lambda = 0.6 - 5$ μm imager, slitless spec
- 2019 launch
  - GO Cycle 1 due 6 Apr 2018
  - 5 yr req life, >10 yr goal
JWST Science Instruments
How are they synergistic or complementary?

<table>
<thead>
<tr>
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<th>SOFIA</th>
<th>JWST</th>
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<tbody>
<tr>
<td>Wavelength range</td>
<td>Wide: 0.3 – 250+ μm</td>
<td>Subset of SOFIA</td>
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<tr>
<td>Dynamic range</td>
<td>Bright objects &gt; 10 Jy OK</td>
<td>Bright objects saturated</td>
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<tr>
<td>SI Fields of View</td>
<td>HAWC+ &gt; ~10 arcmin^2</td>
<td>&lt; 10 arcmin^2 per SI</td>
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<tr>
<td>Mapping efficiency</td>
<td>High</td>
<td>Low or moderate</td>
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- SOFIA and JWST will likely not observe the same objects in the same way.
- Joint programs could exploit complementary capabilities to tackle large-scale problems.
  - e.g., energy transfer and balance across large spatial and thermal scales at high visual extinction.
    (stars → jets → clouds, or AGN → jets → galaxies)
Multiple Observatories are needed to understand global processes.
Example 1: Gas and shocks in protostellar jets
(Jochen Eisloeffel)

• How is energy transferred from accretion disks to the jets of young stars?
• How does this feed back into the molecular clouds where stars form (large energy & size scales)
• Requires observations of molecular lines and continuum emission on many size and energy scales
Example 1: HH46 and jet / outflow (B. Nisini)

JWST and SOFIA data probe and inventory the gas over a range of excitations: from hot to warm.
Example 1: Gas and shocks in protostellar jets
(Jochen Eisloeffel)

• What gas is flowing in jets?
  – JWST samples faint (high Av) high excitation
    • Fe forbidden lines give $T_e$, $n$, $A_v$
    • Warm $H_2$ rotation & ro-vibration in jets and $H_2O$ in shocks
    • 2 x 2 / 3 x 3 NIRSpec and MIRI MRS IFU maps (~10” x 10”) are sensitive to S/N > 30 on 5E-5 erg/s/pixel lines in ~900 s each position
  – SOFIA samples low excitation
    • 63 and 145 μm [OI] measure mass flux of warm flows
    • 1 hr GREAT to $10^{-18}$ W m$^{-2}$ arcsec$^{-2}$, i.e. 4x10-17 W m$^{-2}$ pixel$^{-1}$

• Modest and comparable integration times on each observatory allow census of numerous objects
Example 2: Star formation in the LMC (Margaret Meixner)

- How does star formation occur in low metallicity environments, and how does it differ from the Milky Way?
  - LMC N79 Super Star Cluster and its high mass YSO H72.97-69.39 are good targets

- JWST will observe the young stellar population
  - Luminosities, timescales, circumstellar material (PAHs)

- ALMA will study the molecular gas

- SOFIA will study shock-excited gas
  - 63 μm [OI]
  - PDR in 158 μm [CII] and high-J CO
Large Magellanic Cloud: N79

*Investigating super-star cluster formation at low metallicity*

Ochsendorf et al. (2017 Nat Astr)
Star formation in LMC-N79

Rival to 30 Dor in Lum, but more Av

B. Ochsendorf, H. Zinnecker, ... Meixner+ 2017 Nature Astronomy
NIRCam
MIRI

Most luminous MYSO
(> 2 x 10^6 L_{sun})

Comprehensive study of
Most luminous YSO:
- ALMA CO, HCN, HCO+
- Magellan-FIRE spectra
- Herschel HERITAGE photometry
- Spitzer-SAGE photometry
- SAGE-Spec spectra
- near-IR photometry
- SOFIA spectroscopy:
  - High J CO
  - [CII] 158 μm
  - [OI] 63 μm

Nayak et al. in prep.

M. Meixner JWST GTO program (~ 8 hrs):

MIRI imaging 3 fields:
F770W, F1000W, F1130W,
F1500, F1800W, F255W

NIRCam imaging 4 fields:
F150W/F356W, F200W/F444W,
F115W/F300M
Summary & further thoughts

• Yes, there are ways that SOFIA and JWST observations can work together to address science questions

• Most fruitful applications may be in attacking ‘big picture’ problems that require an inventory of lines or objects across a wide range of wavelengths and dynamic ranges
  – 2 Cosmic Origins examples presented here

• The community will likely come up with more innovative and interesting programs
  – A multi-observatory call of some sort may yield good proposals
    • May want to consider a workshop first to generate interest & define call

• Consider legacy-like datasets for extended SOFIA mission?