Science Themes for SOFIA in the Extended Mission

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Science Strategy Update

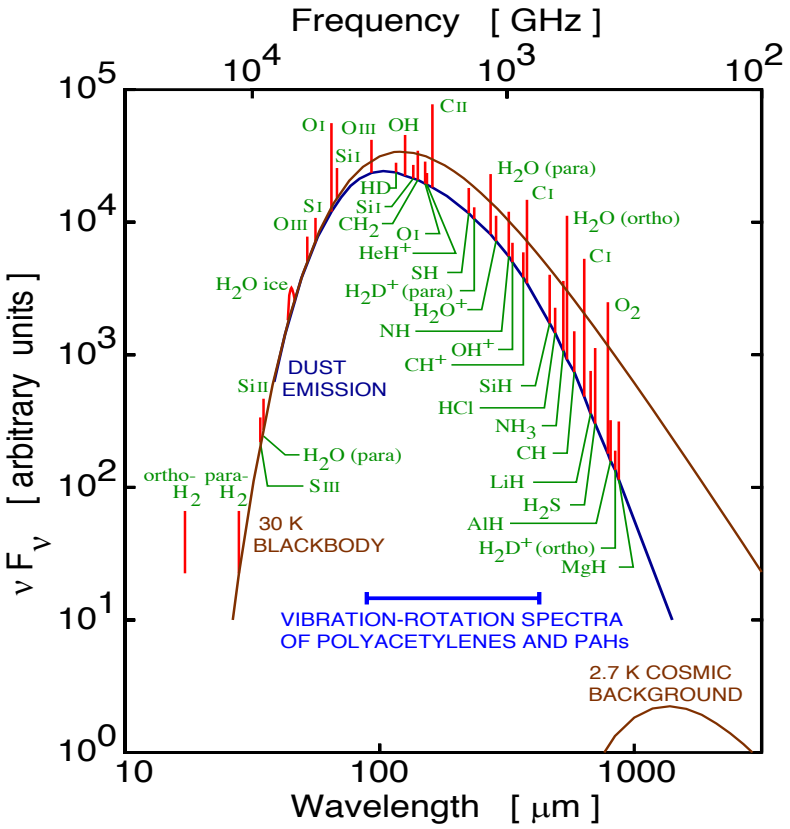
- Core science leadership team meeting regularly, focusing on Senior Review.
  - Proposal Manager (Bob Frey) is helping to focus preparation, proposal writing, and messaging
- Using external councils, particularly the SOFIA International Summit (SIS) which is made up on both US and German science representatives, to review strategy.
- Senior Review science themes in the extended mission feature in subsequent slides.
  - As the world's largest FIR observatory, SOFIA has already provided answers to important astrophysical questions in our universe and demonstrated far-IR technology advancements.
  - In preparation for the Senior Review we are defining how to transform the Observatory to meet future needs of the astronomical community.

How Did Dust Build the Universe?

After the Big Bang, dust appears simultaneously with the first galaxies. Since then, it has played a crucial role in heating/cooling, molecule formation, and dynamics of galactic gas.

SOFIA is the premier observatory to study dust in the wavelength regime of its maximum emission.

- How and where is dust formed in explosive events (novae/SNe)?
- How does dust survive in the initial/reverse shocks?
- How is dust formed in outflows of evolved stars?
- How does dust evolve in star-forming dense molecular cores? In proto-planetary disks?



Emission from a star forming region (~70K) with spectral lines imposed on the dust continuum.

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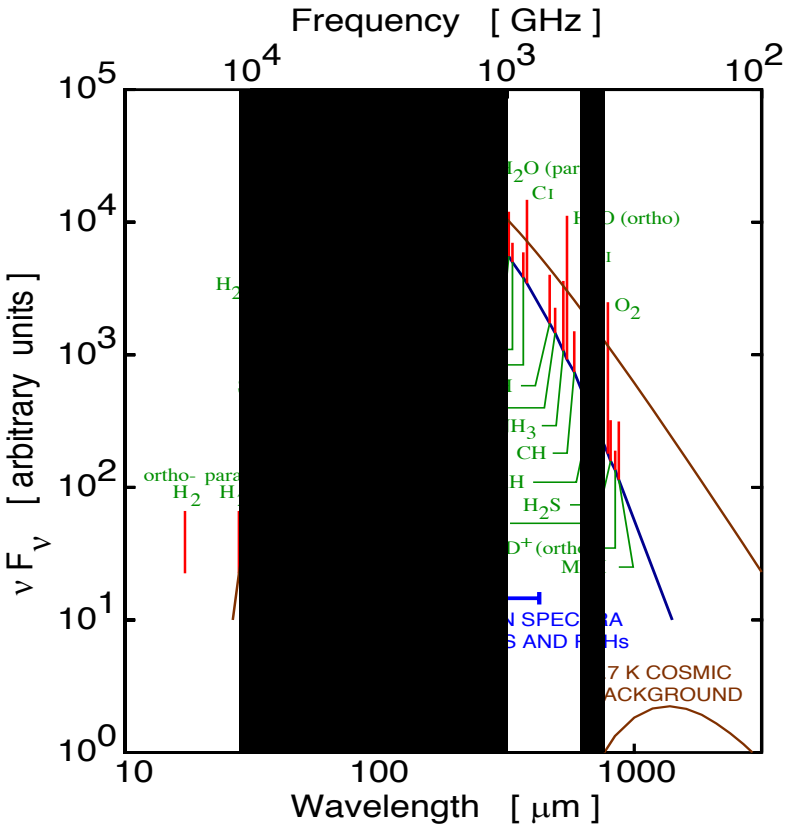

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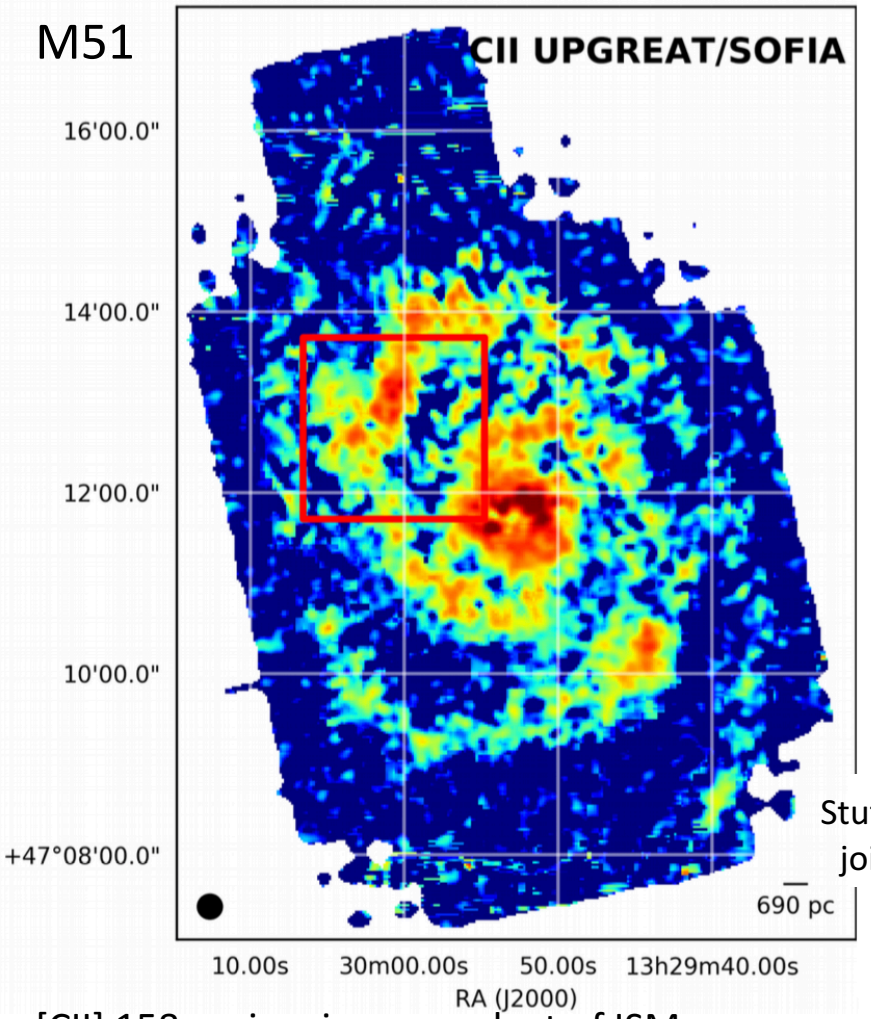
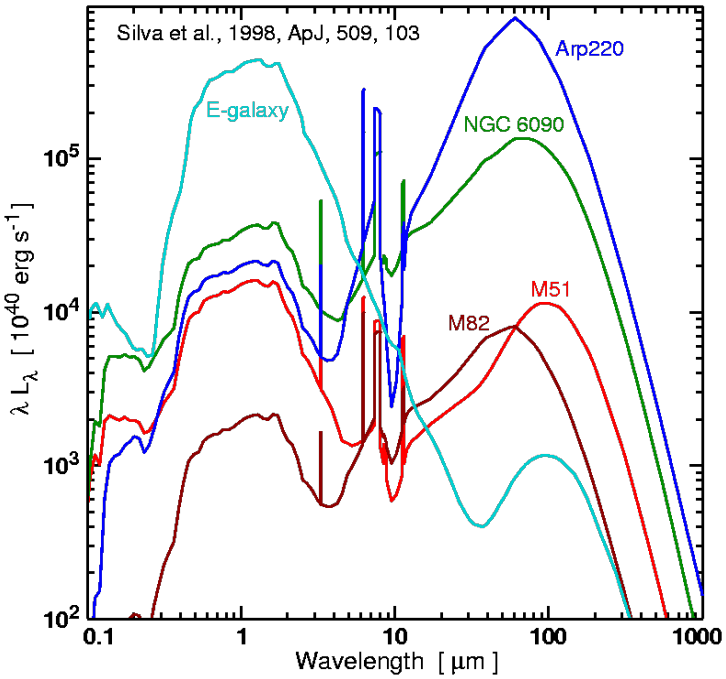
FIR-Emission from Star-forming Galaxies



Dusty galaxies emit mostly in the Far-IR. These wavelengths probe their star formation properties and evolution



Stutzki/Pineda joint impact

1/2 of energy emitted since the Big Bang is in the Far-IR/submm

Far-IR flux measures star formation activity and/or AGN activity

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

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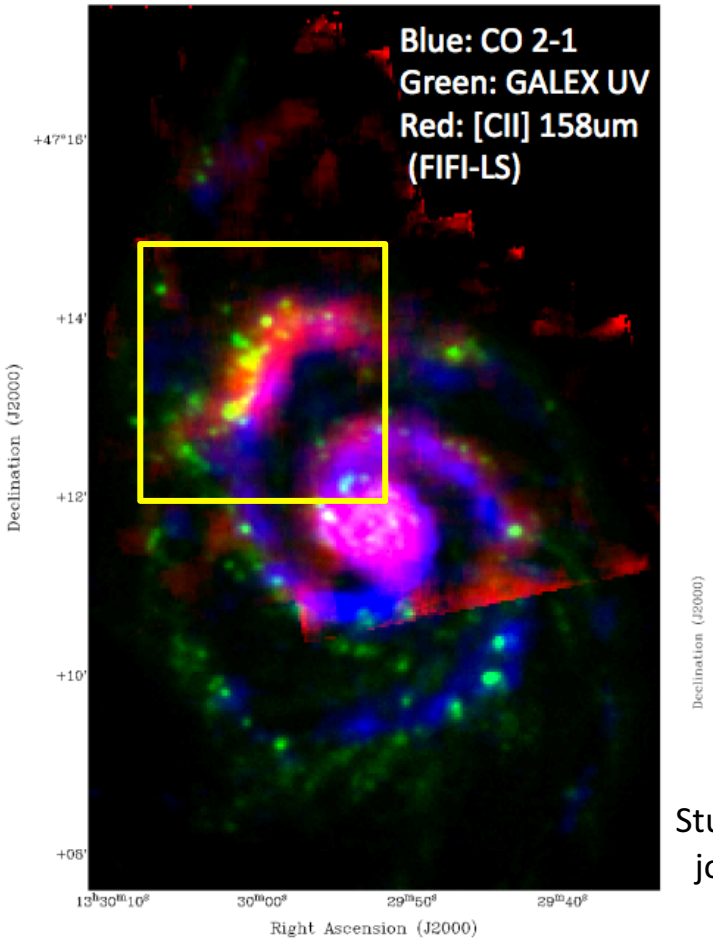

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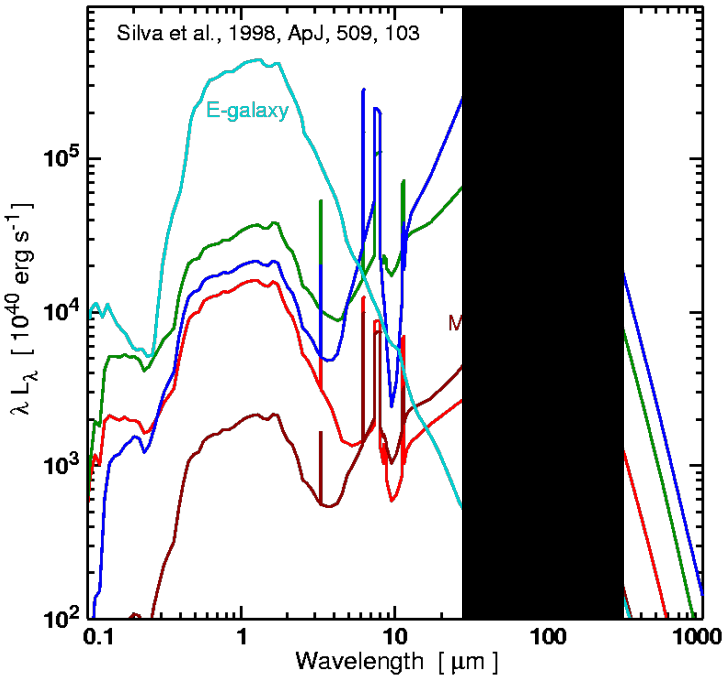

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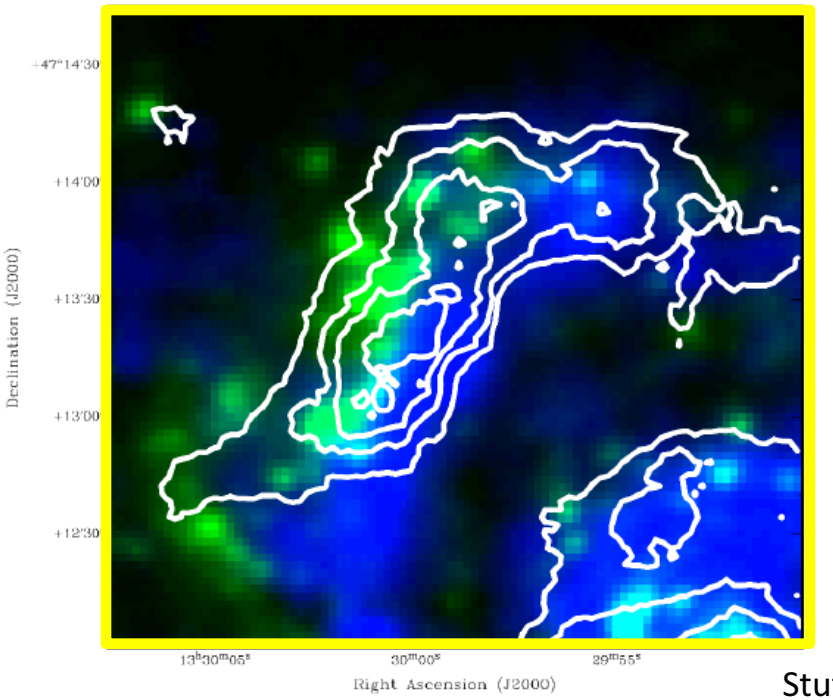

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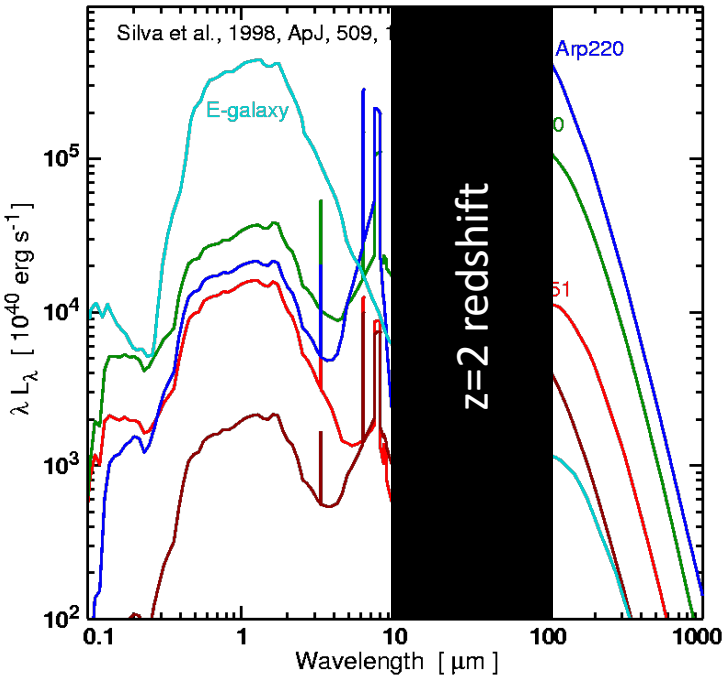

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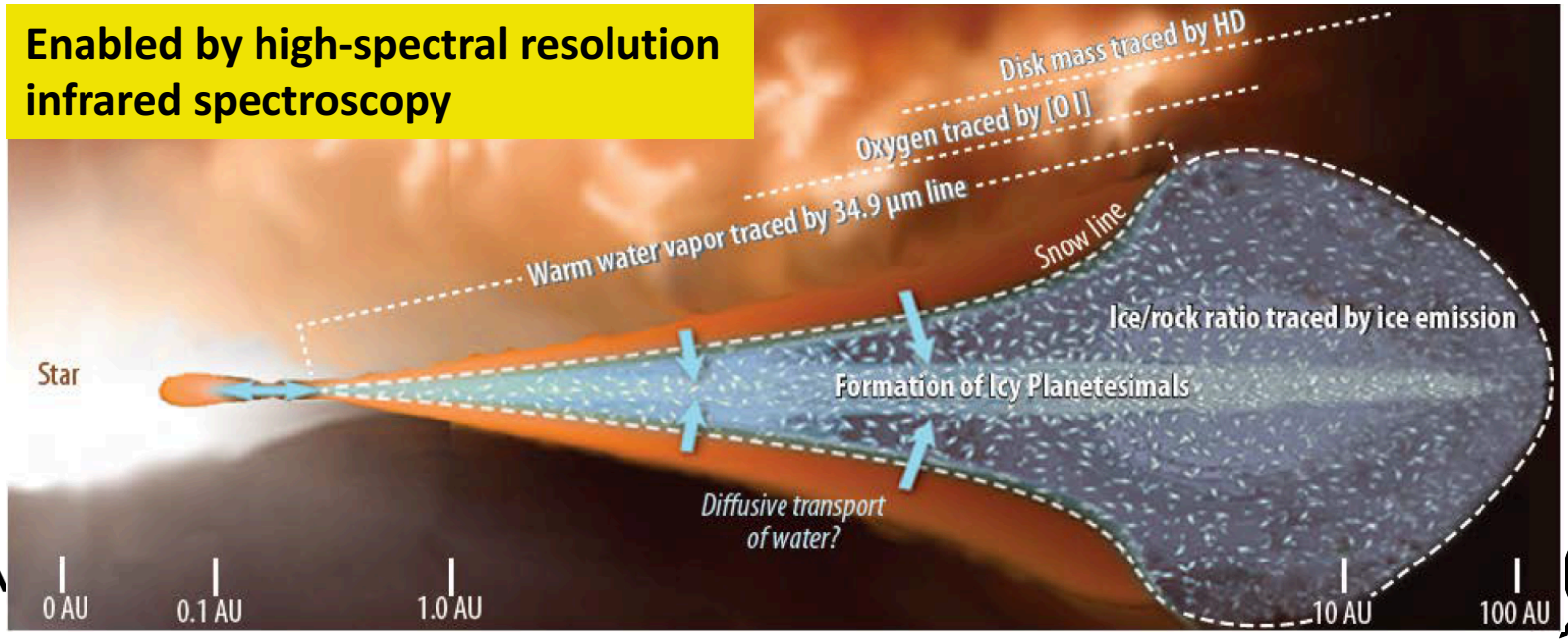
How do we trace water from protoplanetary disks to habitable zones?

- SOFIA with HIRMES will address fundamental questions about the evolution of planetary systems.
  - How does the disk mass evolve during planetary formation with HD (112μm)?
  - 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

Enabled by high-spectral resolution infrared spectroscopy



What is going on in extreme environments?

SOFIA addresses key outstanding questions in galaxy formation…

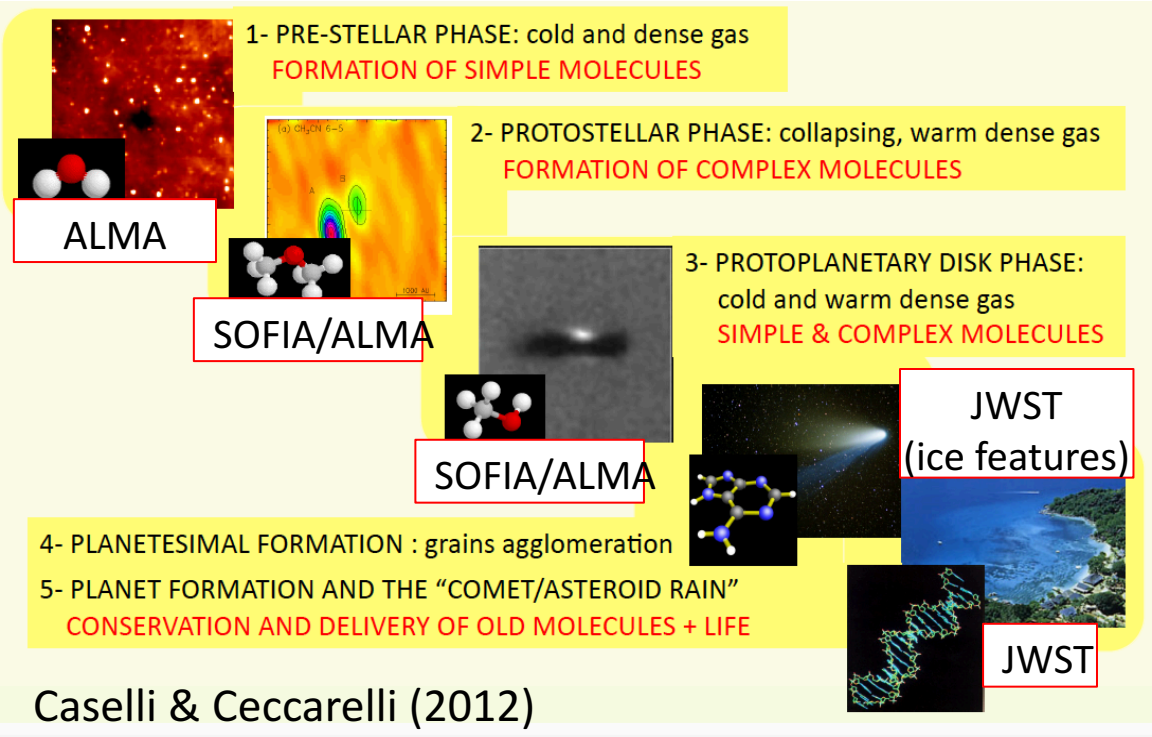
- What is the local truth of processes going on at z=2?
  - Galactic Center and parts of LMC/SMC as templates for starburst and ULIRGs
  - Galactic Center provides a high-pressure, high-density environment typical of galaxy mergers.
- How does material find its way into super-massive black holes? (dynamics, magnetic fields)
- What are the feedback effects on massive SF and SMBH on their immediate environments?

Enabled by high-spectral resolution mid-far/infrared spectroscopy and polarimetry

MIR FORCAST, X-rays and star show the CircumNuclear Ring of the Galaxy

How do atoms and simple molecules lead to life?

- SOFIA and ALMA together probe all phases of star formation: interstellar, prestellar, protostellar, proto-planetary disks, to planetary atmospheres in our solar system as templates for exoplanets.
  - How do we get the complex molecules from interstellar material transported to planetary systems?
  - What were the primordial sources of organic matter, and where does organic synthesis continue today?



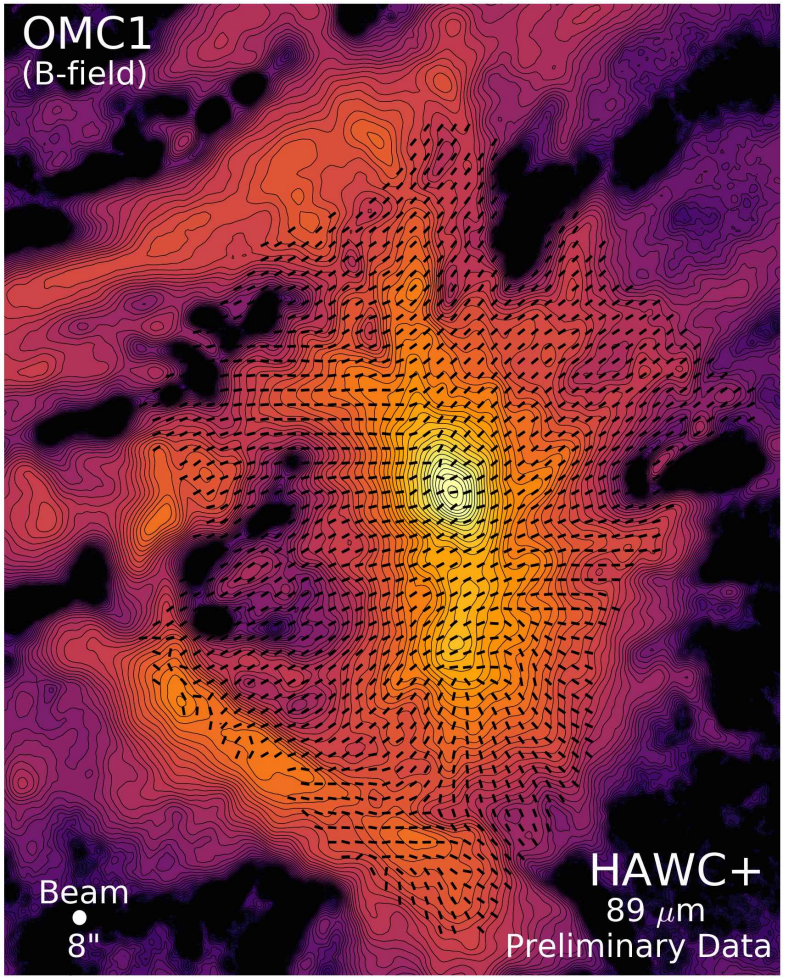
Caselli & Ceccarelli (2012)

"We have the opportunity with ALMA and SOFIA to study fundamentals of chemistry under conditions we cannot create here on Earth" – Astro2010, On the Threshold, p. 76

What is the Role of Magnetic Fields for Galaxy Formation & Evolution?

We are missing important physics in galaxy formation and evolution (in particular: magnetic field & cosmic ray information)

- Additional quantitative information for galaxy models is needed
  - What is the structure of magnetic fields at various spatial scales? (PLANCK+SOFIA+ALMA can address this)
- There is one mechanism to get polarization in the FIR: Aligned dust grains
  - Alignment due to magnetic fields
  - Alignment also possible by radiation on grains drifting through gas

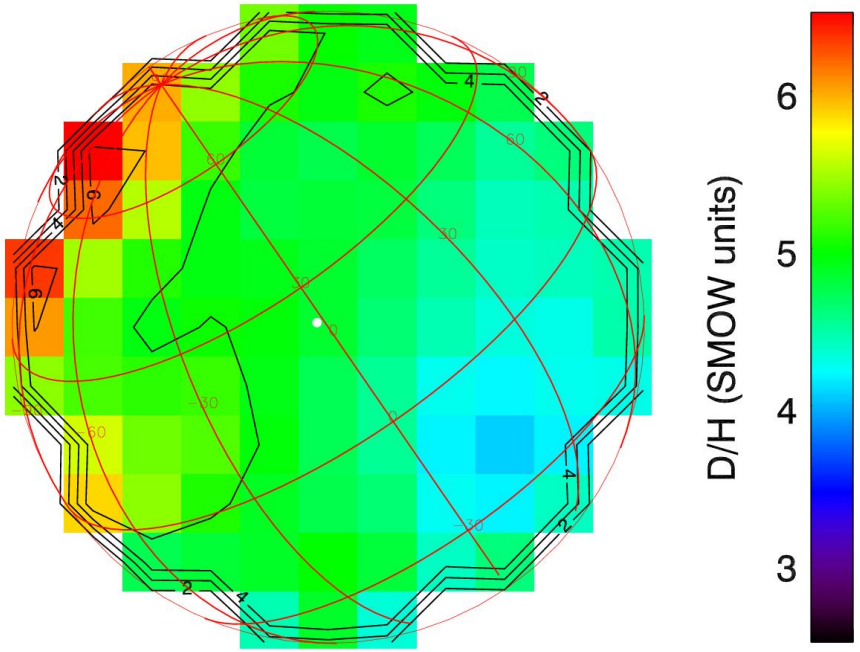


SOFIA/HAWC+/2017

How Does the Solar System Serve as Laboratory to understand Extrasolar Planetary Systems?

- Allow refinement of models of the outer planets including the atmospheric structure, composition, winds (dynamics), and cloud formation
- Prebiotic molecules on Titan? Enceladus? Europa?
- Time dependence of methane on Mars?

Measurement of D/H Ratio on Mars with EXES



Deuterium/ Hydrogen ratio expressed as factor of Vienna Standard Mean Ocean Water abundance. Observed enrichment of Mars is a factor of 4 to 5 times Earth abundance.

This science is enabled because…

- SOFIA is the world's only observatory in the far-infrared wavelengths (28-320μm).
  - Its unique capabilities (e.g. high resolution spectroscopy, polarization) are necessary for quantitative answers to key science questions.
  - Through the development of new instruments, new science themes can be quickly addressed.
  - Monitoring of time dependent phenomena requires coverage over many time scales
- SOFIA is an outstanding on-sky laboratory for development of future space-based instruments
  - Ample power, weight, and computing facilities as well as personnel on board allow lower TRL instruments to be designed, built, flown, debugged, used, and perfected before adapting and qualifying for space.
  - Example: HIRMES-type bolometer arrays will likely be on the Origins Space Telescope.

This science is enabled because…

- SOFIA maintains a working far-infrared community in preparation for a future space mission in the 2030s.
  - Need to maintain experts in dust physics, far-infrared spectroscopy and heating/cooling of gas and dust.
  - Far-infrared detectors are not commercially available: SOFIA provides the funding and focus required to keep technologists advancing this field.

Implementing Next Steps Today

- We need to improve publication statistics
  - Important science results are sitting in the computers of PIs
  - We will begin a program of calling PIs and asking what the SOFIA Science Center can do to help (carrot + stick?)
- We need to improve efficiencies of operations
- During Cycle 6 and extending into Cycle 7, we want to start a new program: 'SOFIA Key Project'
  - In addition to the regular GO program, "we" will define a set of innovative investigations with high impact science: Who is "we"?
  - Establish and fund focus science teams in the community
  - No proprietary period
  - Flexible operation model

Airborne astronomy cost efficiencies

- As we further defined SOFIA science and its implementation, we are investigating how to offer this science at lowest cost.
- Concept of Ops shall be “right-sized” for the science in the extended phase.
  - Current capabilities that are not required in the extended mission will not be supported.
  - AFRC Deputy Director of Operations is responsible to lead efforts to find cost reductions.
    - Streamline operational procedures & inspection requirements
    - Improve science instrument airworthiness requirements and process
    - Combining roles & responsibilities to maximize staffing efficiencies without compromising safety.

SOFIA Science Future

- SOFIA with HIRMES, plus JWST & ALMA, will address fundamental questions about the evolution of planetary systems.
- SOFIA continues to reveal the underlying physical processes and structure of the ISM, star formation and what drives galactic outflows.
- SOFIA provides local truth necessary for galaxy formation & evolution models.
- SOFIA, plus ALMA, powerfully studies the fundamentals of chemistry under conditions we cannot create here on Earth.