

# SOFIA-ALMA Synergies

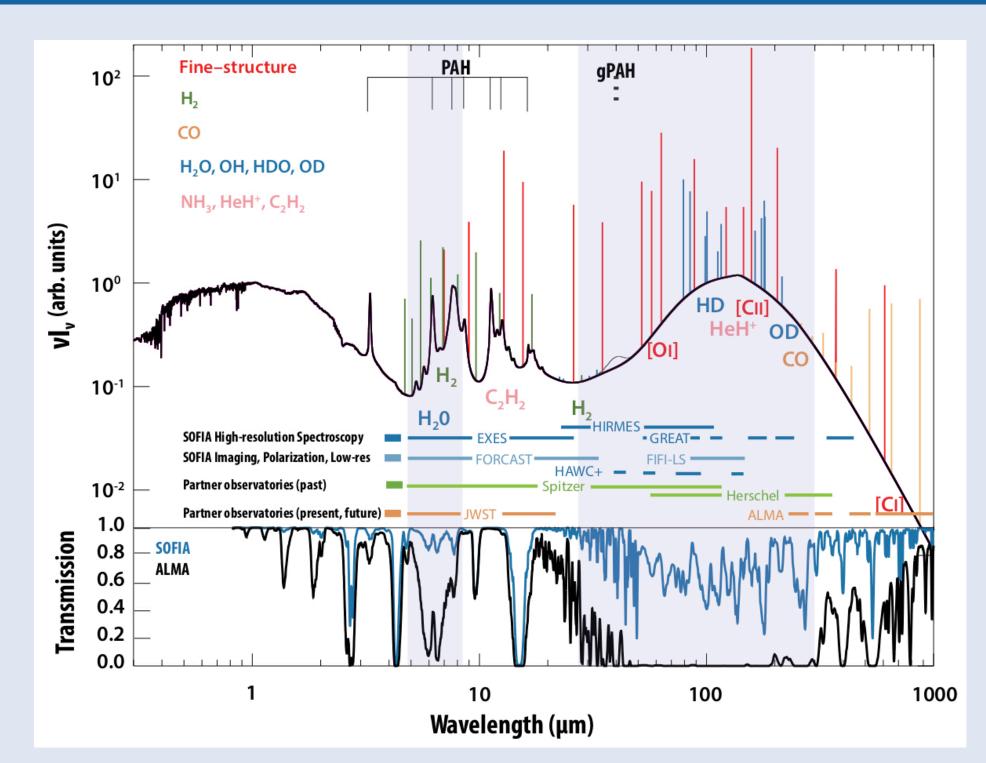
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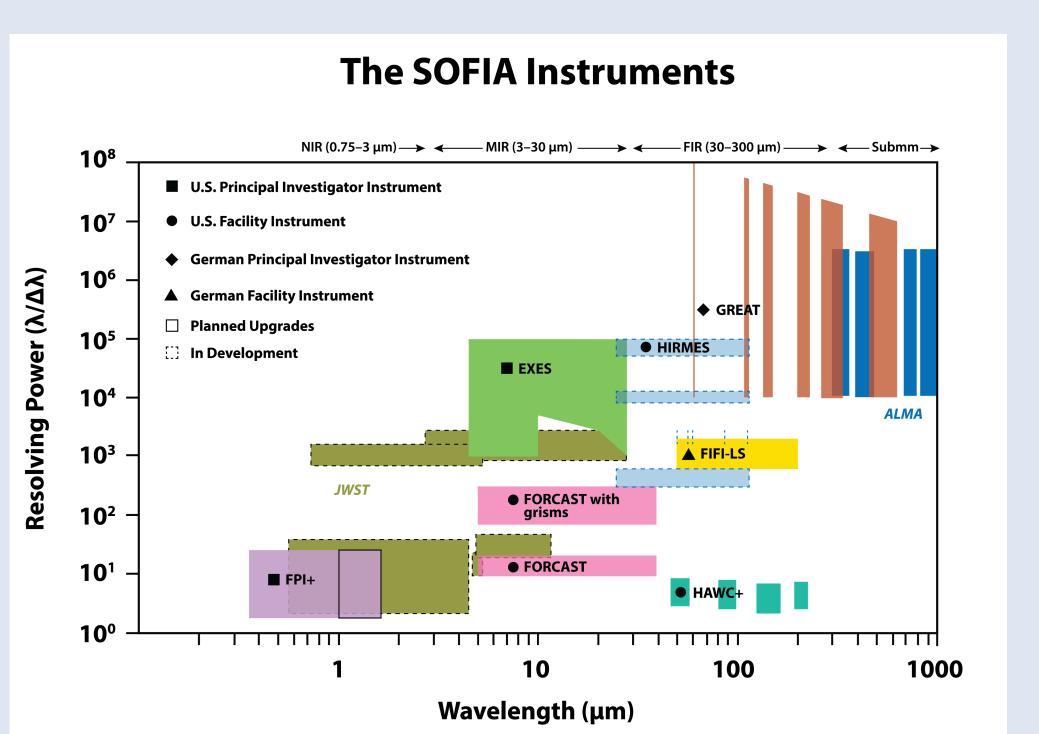
#### **The Far-Infrared**

The far-infrared spectral range provides a number of complementary diagnostics to the (sub-)mm wave observations possible with ALMA. For the foreseeable future SOFIA, together with balloon borne experiments, provide the only access to these tracers.

SOFIA provides unique access to the mid- to far-infrared range, mostly blocked by the atmosphere (*Right*). These wavelengths contain a large number of diagnostics of interstellar, circumstellar and galactic astronomy tracers, as well as the peak of the Planck curve for warm dust in the ISM and in disks.

We present a few examples of tracers and techniques where SOFIA and ALMA data provide synergies to enhance each other's capacities.



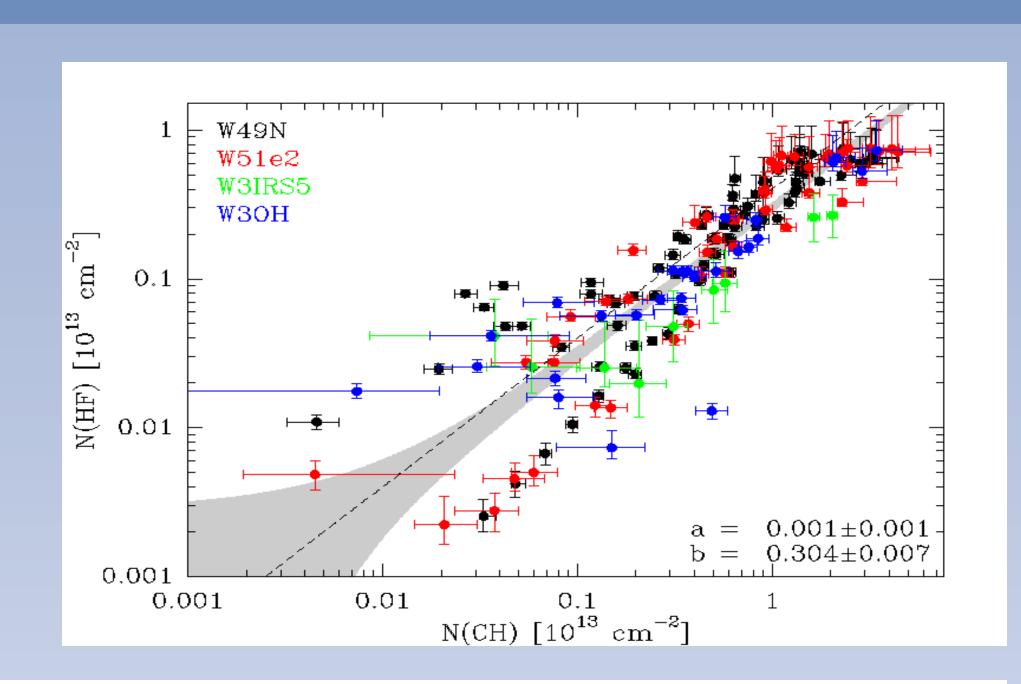


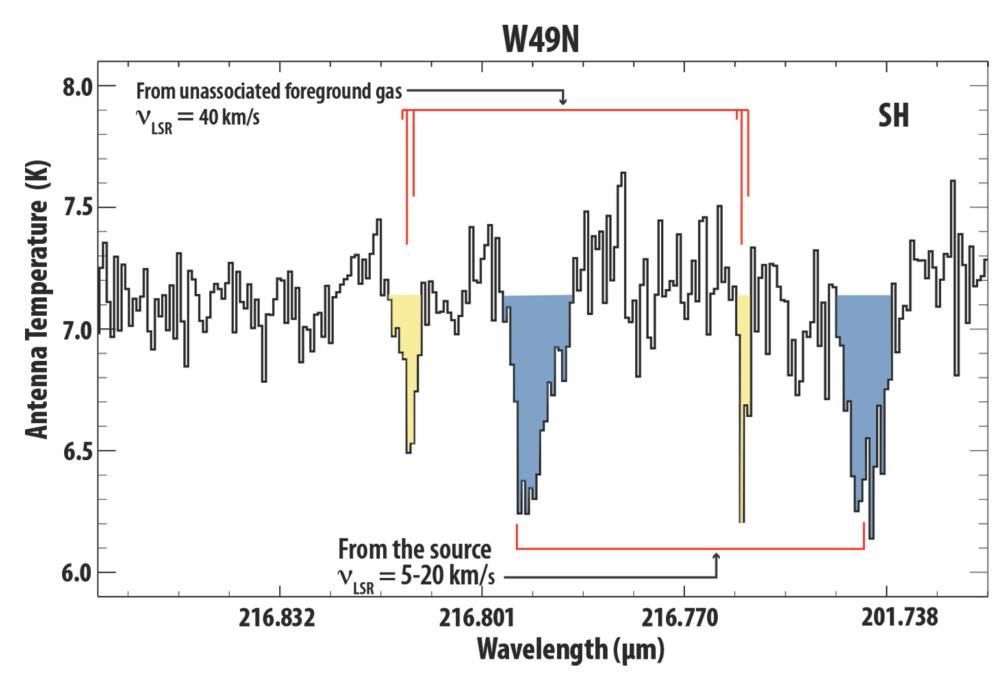
#### **Astro-Chemistry**

Because H<sub>2</sub> does not radiate efficiently in cold gas, proxy-tracers are needed to trace the total gas column. Since CO is known to freeze out onto grains in dark clouds, alternative proxies are needed. One such is the CH radical, whose optical lines are known to trace H<sub>2</sub> over many orders of magnitude in diffuse gas. (Top) The CH pure rotation transitions at  $v \sim 2.01$ THz available with SOFIA/ upGREAT reliably trace H<sub>2</sub> (HF is a known H<sub>2</sub> tracer, but prone to saturation effects) in dense, high column density gas. Wiesemeyer et al. (2018) have used SOFIA/ GREAT to show that in most situations CH reliably traces HF (and hence H<sub>3</sub>) also in

most dense, high column

density gas.

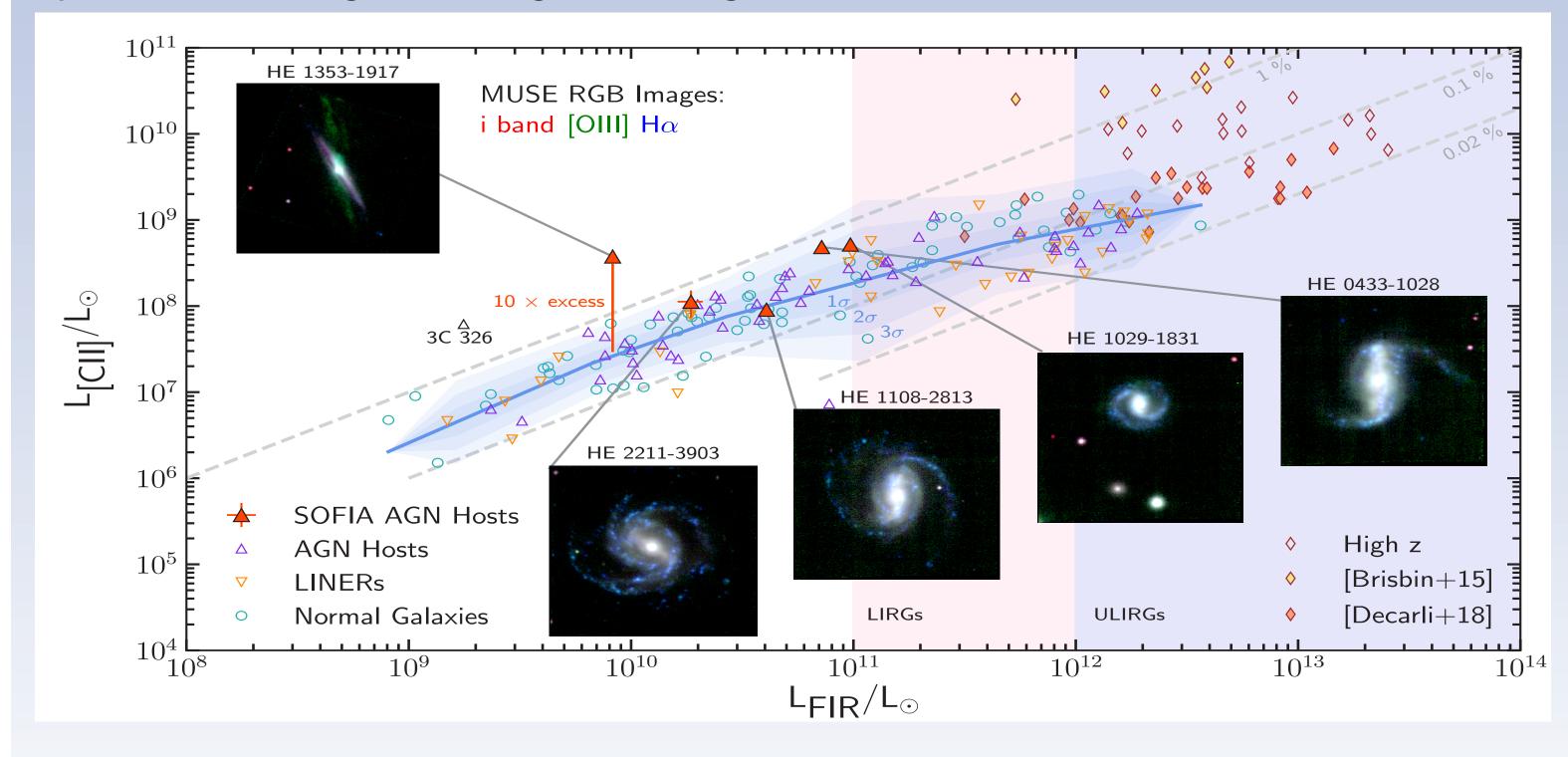




(*Bottom*) The discovery spectrum of SH, towards W49 is shown. (Neufeld et al. 2012; 2015) Chemical networks in the interstellar medium usually start with the simple hydrides that have their ground-state rotational lines in the far infrared, now accessible only with SOFIA.

#### [C II] as a Tracer of Extragalactic Star Formation

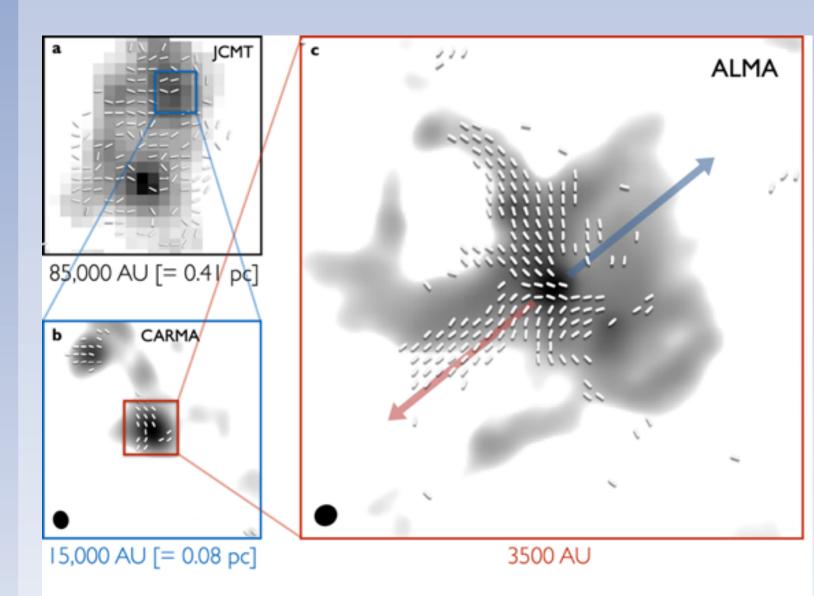
The [C II] at 158mm is often assumed to be a reliable tracer of star formation, also in the early universe. However, local universe observations with SOFIA (Appleton et al., 2018; Smirnova-Pinchukova et al. 2019) show that in some cases AGN activity can cause significant additional [C II] luminosity in the host galaxies. This figure (*below*) shows the line luminosity as a function of FIR luminosity for several classes of high-distance galaxies, overlaid with the Smirnova-Pinchukova et al sample (red triangles). Normal star-forming and starburst galaxies are shown in green circles AGN host galaxies in purple triangles, LINER galaxies in orange upside-down triangles, and high-redshift galaxies in brown diamonds.

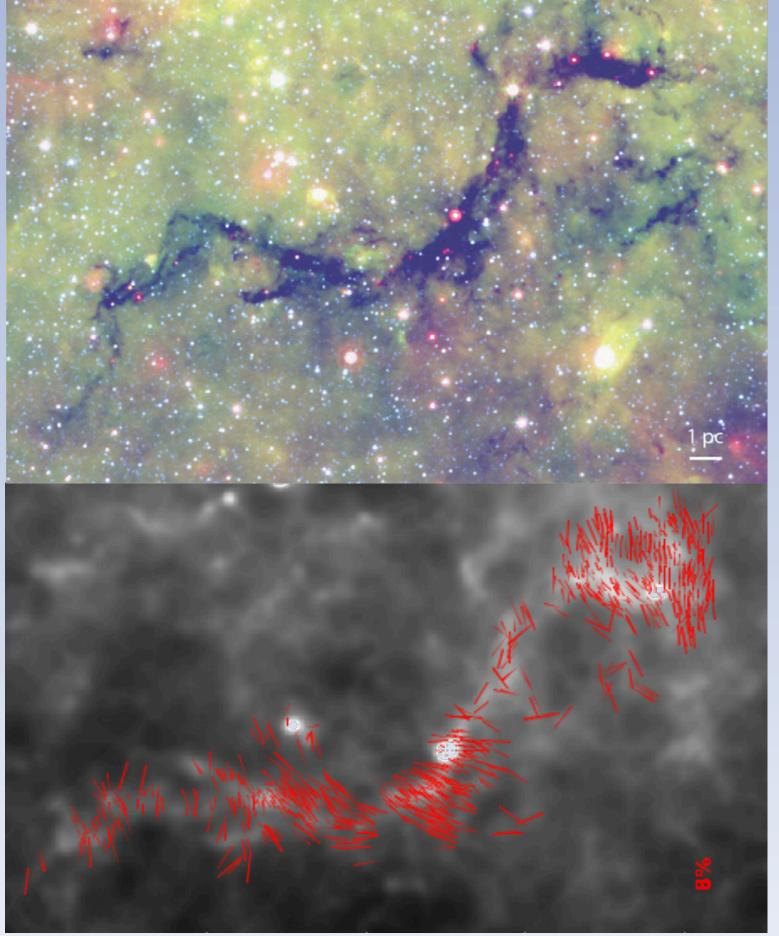


The blue line is the mean of the low-redshift galaxies distribution, and the blue-shaded areas correspond to 1, 2, and 3 sigma. Pink and purple shades represent LIRG LFIR  $> 10^{12}$  regimes.

## **Magnetic Fields in warm and Extended Regions**

The "Snake" Infrared Dark Cloud. (*Right*) Spitzer 4.5, 8 and 24 mm image in blue, green, and red, respectively. This IRDC appears dark against the Galactic background emission. Red sources are young, embedded protostars.

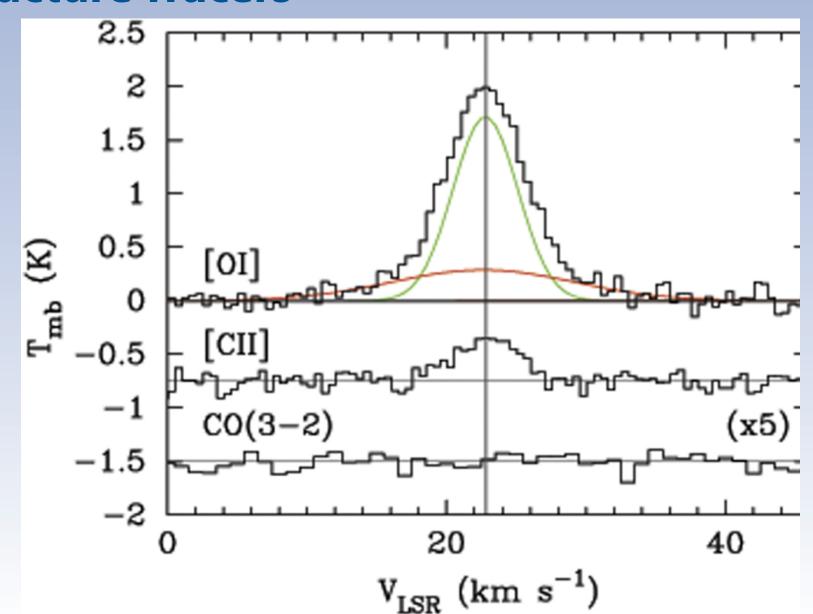




(*Above, left*) Herschel 250 mm image with magnetic field directions from SOFIA/HAWC+ polarization vectors superposed (red lines). The magnetic fields are more often perpendicular than parallel to the filament (Stephens et al., in prep.). Combining such "large-scale" structure of the warm dust with high-resolution ALMA observations (Hull et al. (2017) constrains the structure and importance of magnetic fields in star formation.

### **Spectrally Resolved Lines as Structure Tracers**

Spectrally resolved far-infrared lines provide complementary information about dust disks. Here, the [O I], and [C II] spectra toward the BHD 50138 are shown. Whereas previous interferometric observations gave strong evidence for a hot gas and dust disk in Keplerian rotation, our observations are the first to provide unambiguous evidence for a large warm disk around the star. (Sandellet al., 2018))



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## **Solar System Abundances**

The D/H ratio in cometary water as a function of the active fraction of the comet. The symbol color coding is given on the right side of the plot, and the dynamical class (Oort-Cloud, OC, or short-period Jupiter-Family, JF, comets) indicated. The blue horizontal line corresponds to the terrestrial D/H value. The dasheddotted line shows the expected D/H assuming two sources of water: D-rich (3.5×terrestrial) from the

nucleus and D-poor (terrestrial). Comets with an active fraction equal to 0.08 are assumed to release only D-rich water.

The surface mineralogy of other minor Solar System objects can also be probed by midinfrared spectroscopy (e.g. Vernazza et al., 2017).

