Recent Scientific Highlights from the Stratospheric Observatory for Infrared Astronomy (SOFIA)

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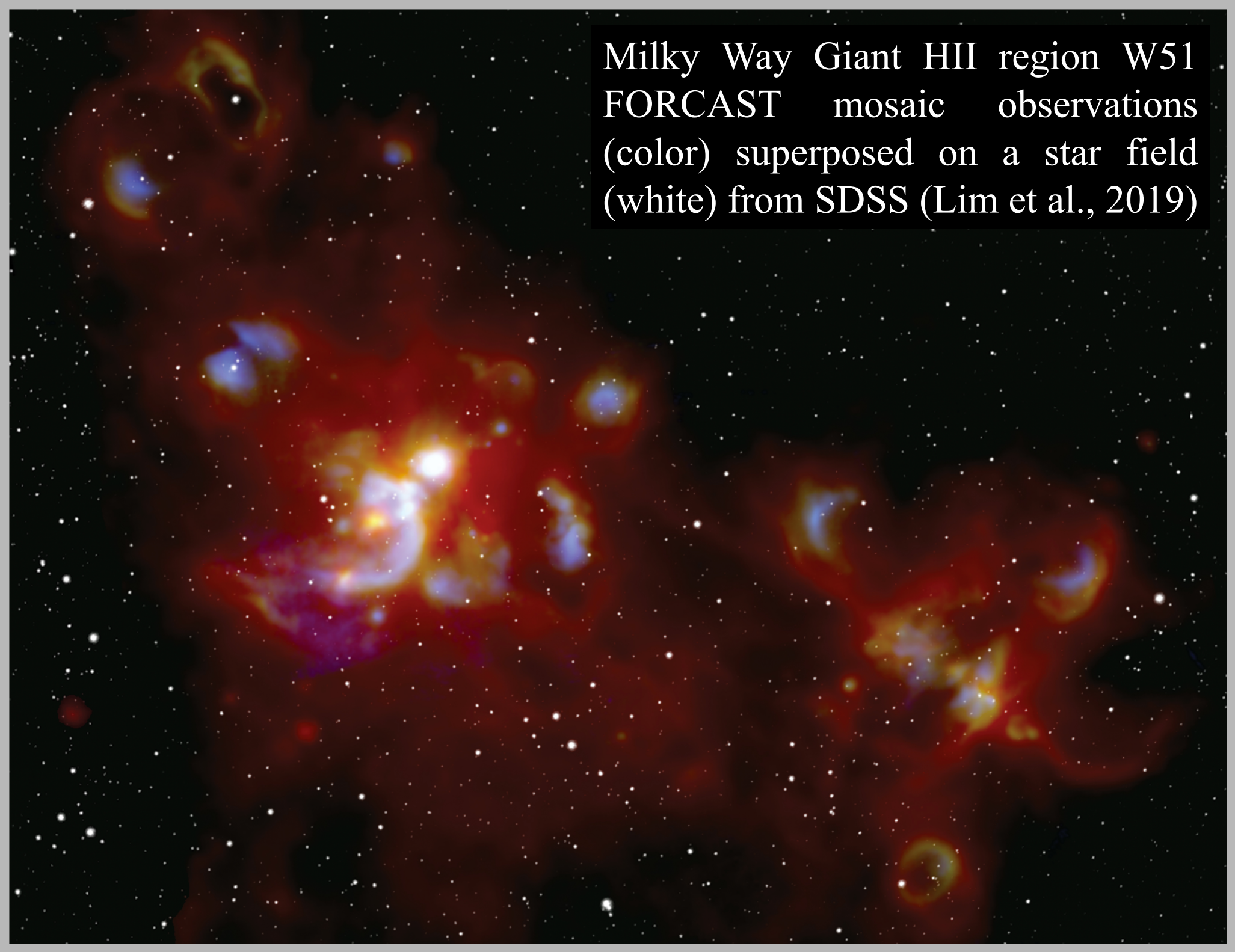
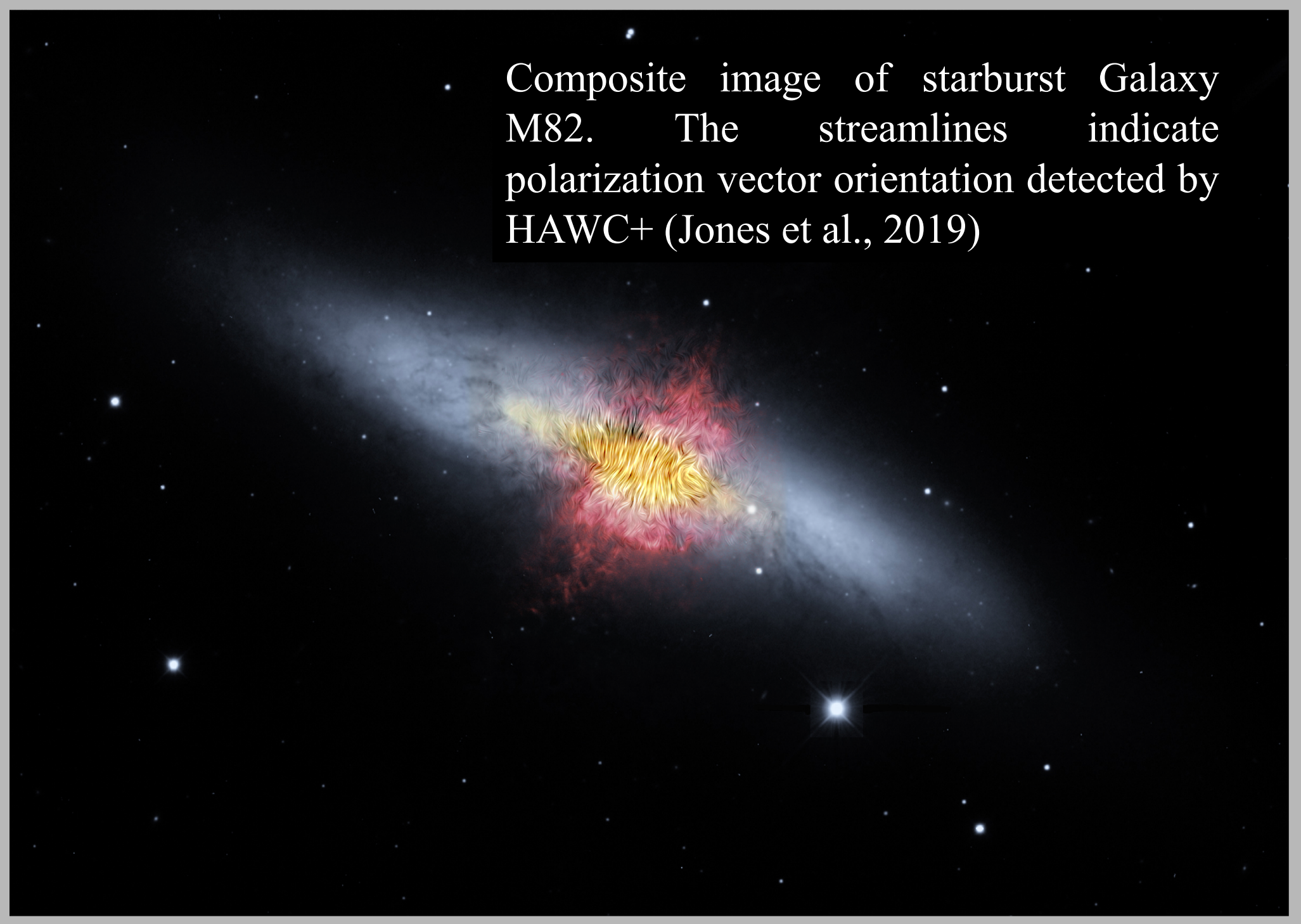
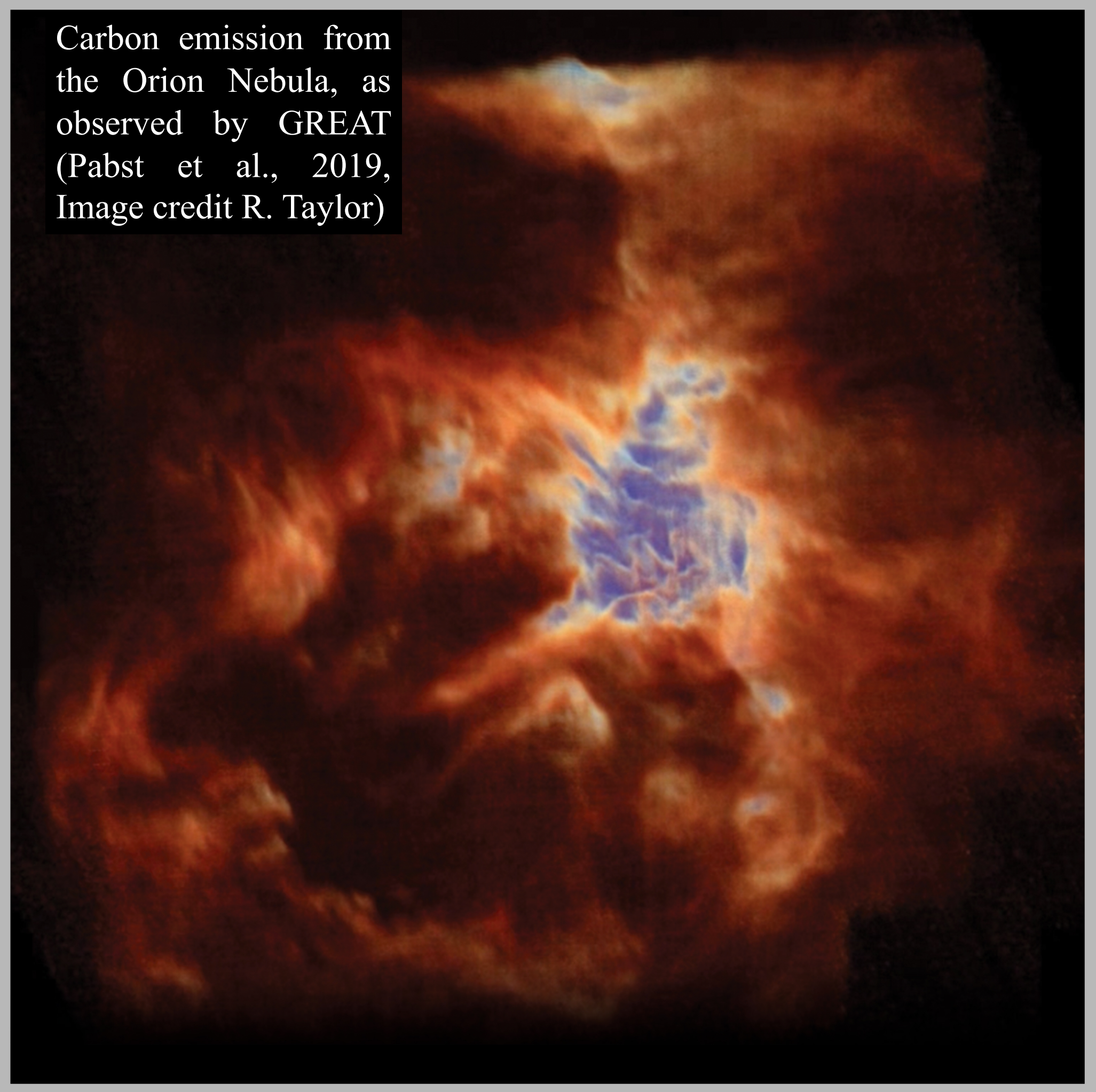


Milky Way Giant HII region W51 FORCAST mosaic observations (color) superposed on a star field (white) from SDSS (Lim et al., 2019)

Artist's impression of Supernovae 1987A Based on FORCAST dust continuum measurements (Matsuura et al., 2018)



Composite image of starburst Galaxy M82. The streamlines indicate polarization vector orientation detected by HAWC+ (Jones et al., 2019)



Carbon emission from the Orion Nebula, as observed by GREAT (Pabst et al., 2019, Image credit R. Taylor)

References

[1] HerreraCamus, R. et al. 2018a, ApJ, 861, 94

[2] Pineda et al., 2018, ApJL, 869, L30

[3] Busch, G. et al., 2018, ApJL, 866, L9

[4] Smirnova-Pinchukova, I. et al., 2019, arXiv:1905.10383 [5] Gordon. M. et al., 2018, arXiv:1811.03100

[6] Jones, T. et al., 2019, ApJL, 870, L9T

[7] De Buizer, J. M. et al., 2017, ApJ, 843, 27

[8] Liu, M., et al., 2019, ApJ, 874, 16

[9] Lim W. and De Buizer, J. M., 2019, ApJ, 873, 51

[10] Rangwala, N et al., 2018, ApJ, 856, 1

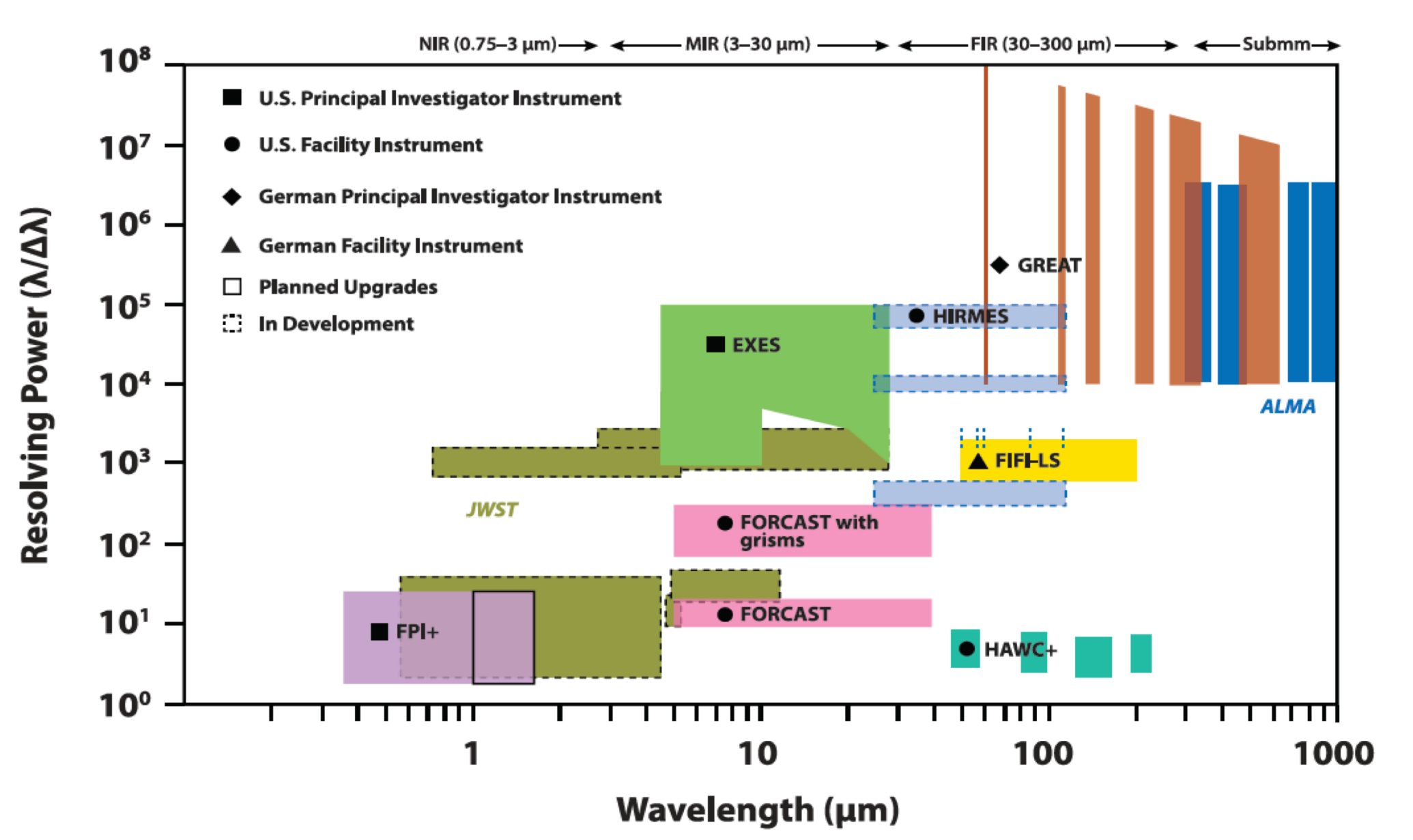
[11] Gusten et al., 2019, Nature, 568, 357–359

[12] Lis et al., 2019, A&A, 625, L5

[13] Encrenaz et al., 2016, A&A, 586

Telescope and Instruments

Access to the mid- and far-IR domain requires observations to be performed from above most of the opaque terrestrial atmosphere. The SOFIA telescope, onboard a modified 747 SP aircraft, flies at up to 45,000 feet. It consists of a parabolic 2.7 m primary and hyperbolic secondary in a bent Cassegrain configuration.

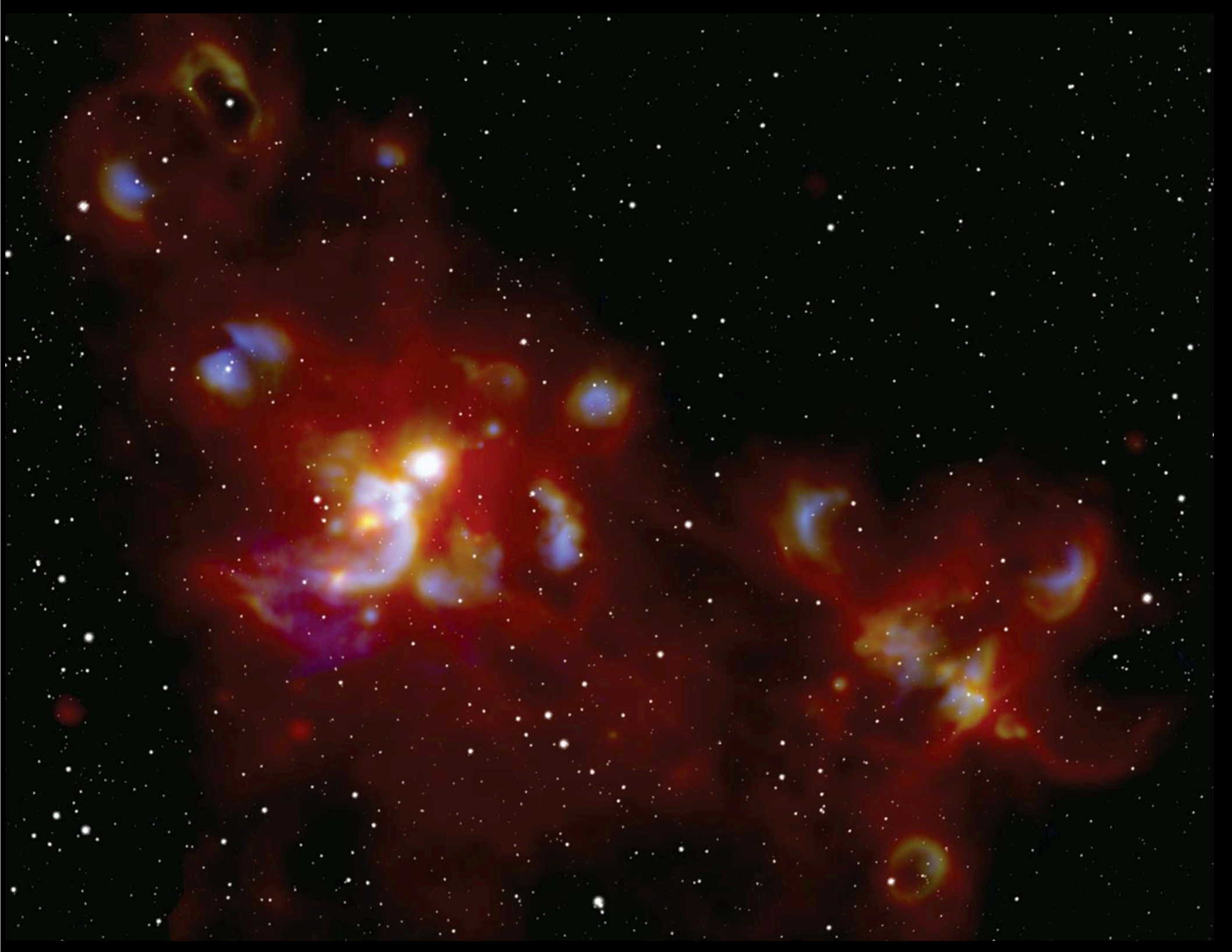


Currently five infrared instruments can be used on SOFIA, observing between 4 - 600 µm and spanning a wide range of spectral resolutions up to R=106. SOFIA's instruments offer fast mapping modes, allowing for better mapping sensitivities than past infrared spacecrafts. The instrument suite is designed to complement at best capabilities from current and future facilities, in particular JWST and ALMA. The HIRMES instrument (22-122 µm) is currently in development.

SOFIA flights depart in general from SOFIA's home base in Palmdale, CA. In addition, SOFIA is deployed annually to New Zealand to observe the Southern Sky.

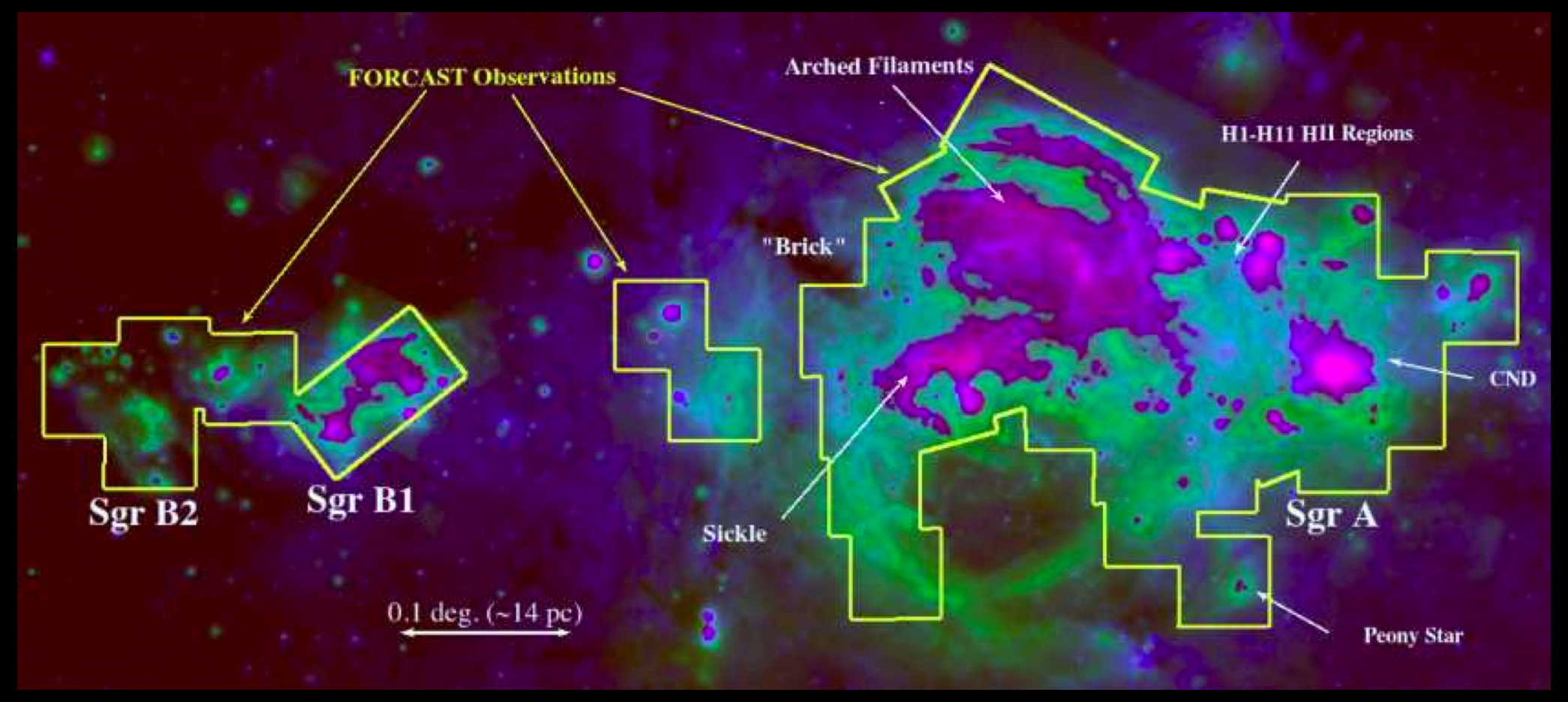
Young Stellar Objects' Characterization

SOFIA's midinfrared imager, FORCAST, is ideally suited to study massive young stellar objects (YSOs) as several ongoing studies demonstrate.



Lim et al., 2019: imaging survey of Milky Way Giant H II region W51 (FORCAST)

The SOFIA Massive (SOMA) star formation survey [7,8] characterizes massive YSOs by measuring the midinfrared (MIR) fluxes of these massive YSO. The MIR is a crucial wavelength regime as it captures the rise of the spectral energy distribution (SED) towards its peak encoding information on the amount and location of hot dust near the forming stars. The FORCAST image of W51A [9] above demonstrates these capabilities.

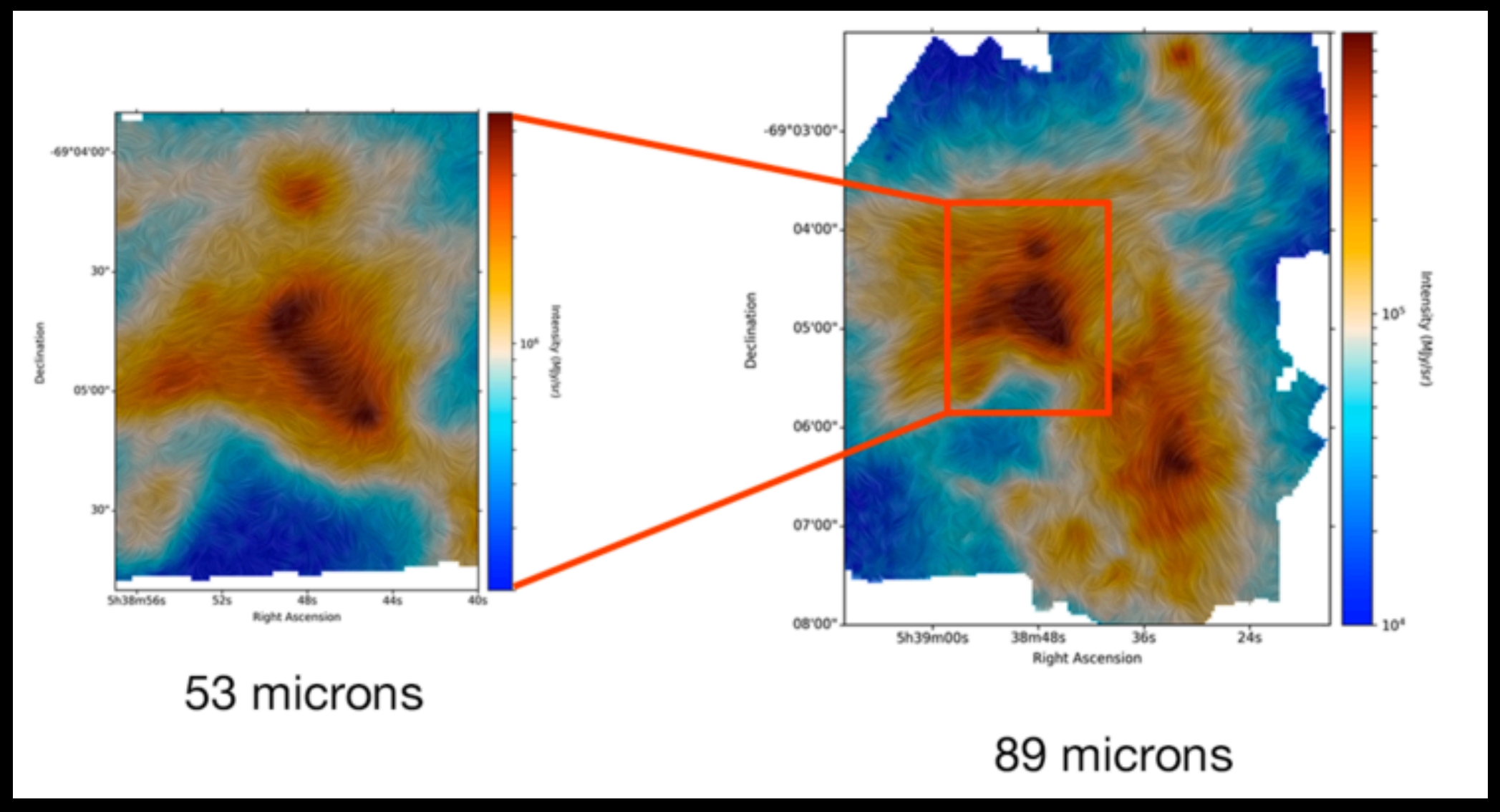


Galactic center survey targeted by the FORCAST legacy program led by M. Hankins (Caltech).

The study of massive star formation with FORCAST is ongoing with the SOFIA legacy program "Constraining Recent Star Formation in the Galactic Center" by PI Matthew Hankins, Caltech. Under this program, FORCAST will map large parts of the inner galaxy and will greatly aid in the creation of a census of massive young stellar objects in the region. The data, which will become public immediately, will help constraining the star formation rate in the Galactic Center and improve star formation models for this region.

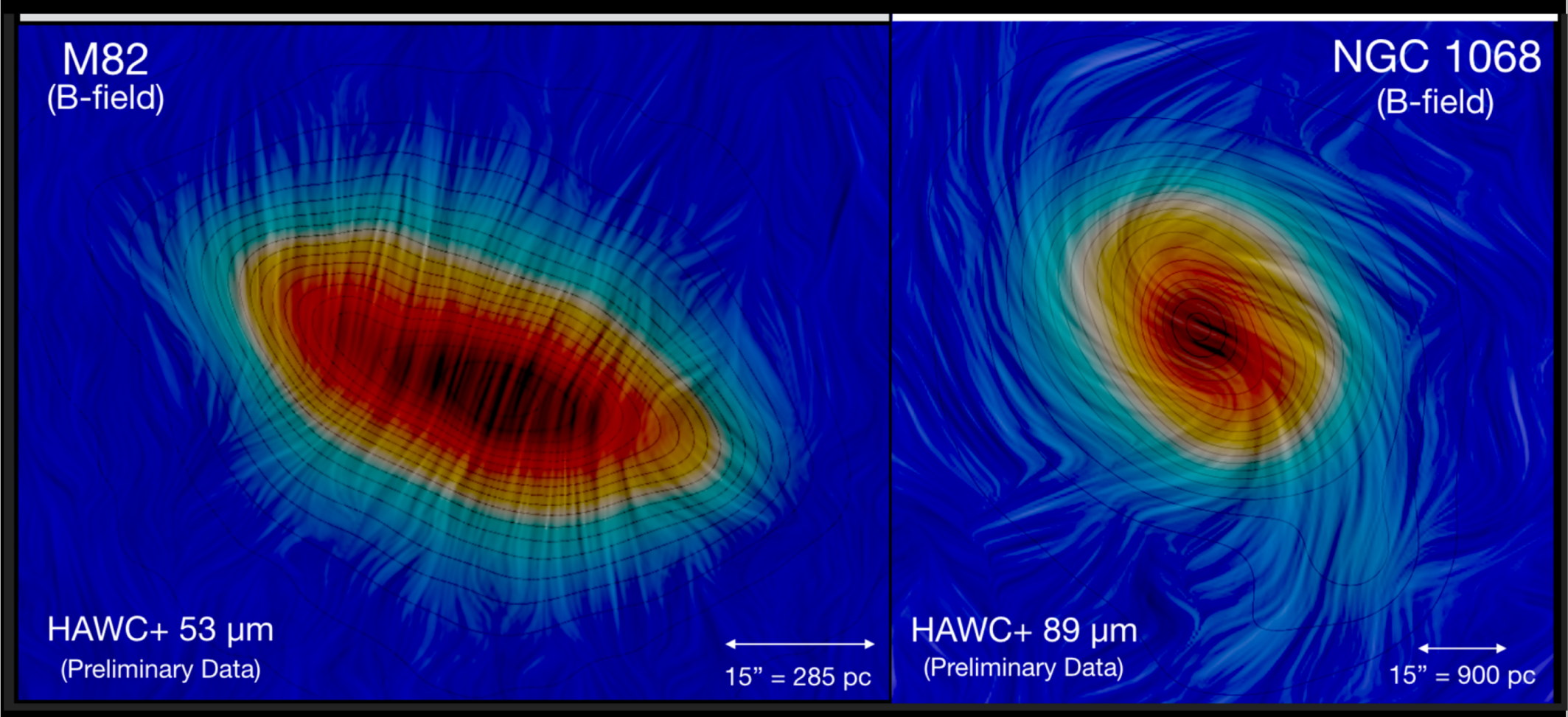
Tracing Magnetic Fields in Star-Forming Regions

Thermal continuum emission from dust grains can display polarization direction patterns if grains are aligned by a magnetic field. Polarization mapping is hence a technique of choice to retrace he morphology magnetic fields and evaluate their role in star formation and galactic evolution.



Gordon et al., 2018: IR emission and polarization field in the 30 Doradus nebula, an HII region in the LMC.

The polarization mode on the HAWC+ instrument onboard SOFIA (50240 microns) is perfectly suited to polarization mapping studies on galactic scales, capturing emission from cold dust (10-100 K).

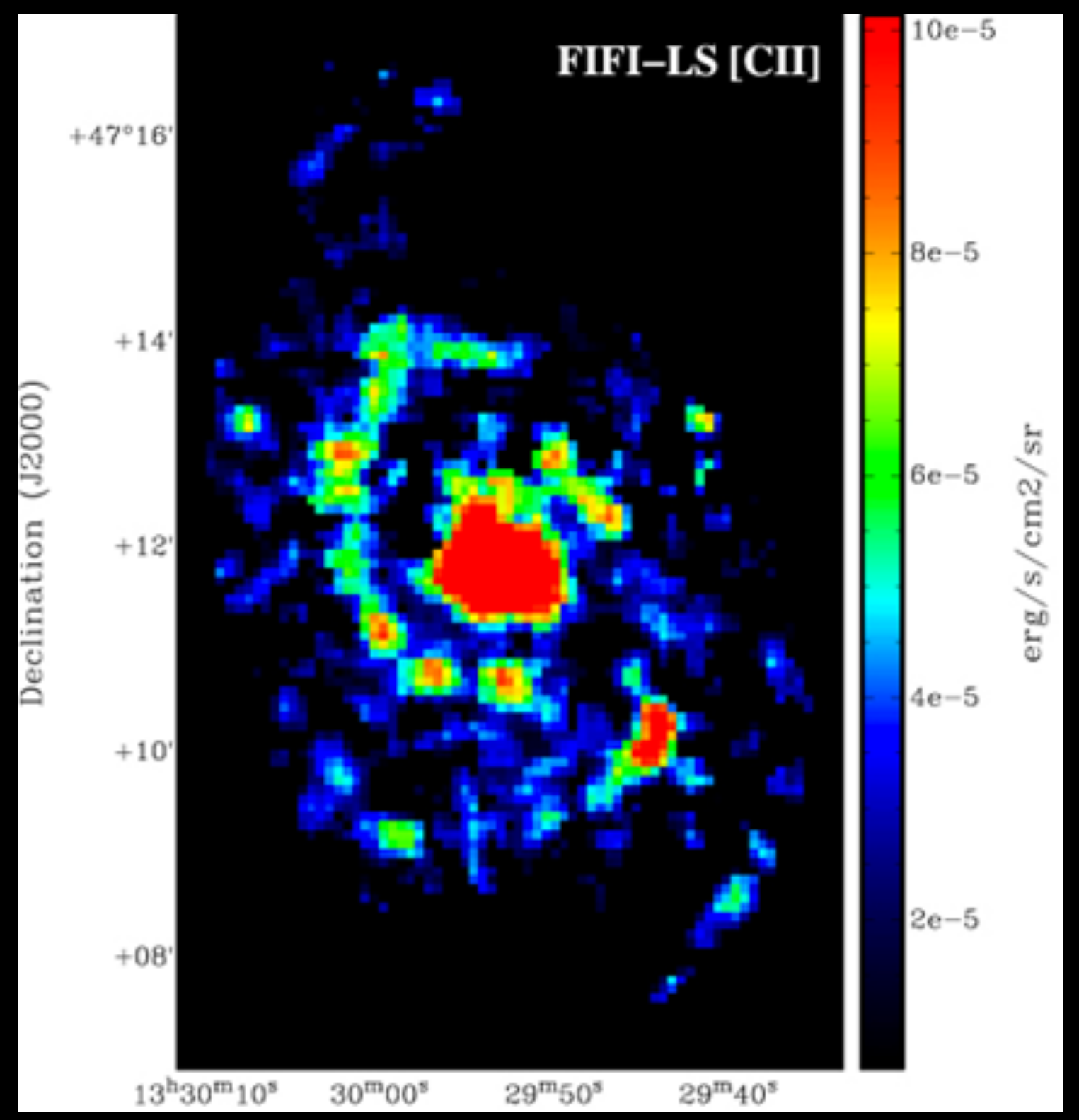


Jones et al., 2019: IR emission and polarization field in active galaxies M82 and NGC1068

In addition to high resolution mapping of galactic star formation regions [e.g., 5], mapping of nearby galaxies can also be performed [e.g., 6], Polarization mapping of starburst galaxy M82 revealed that the magnetic field is dragged by the strong bipolar galactic wind.

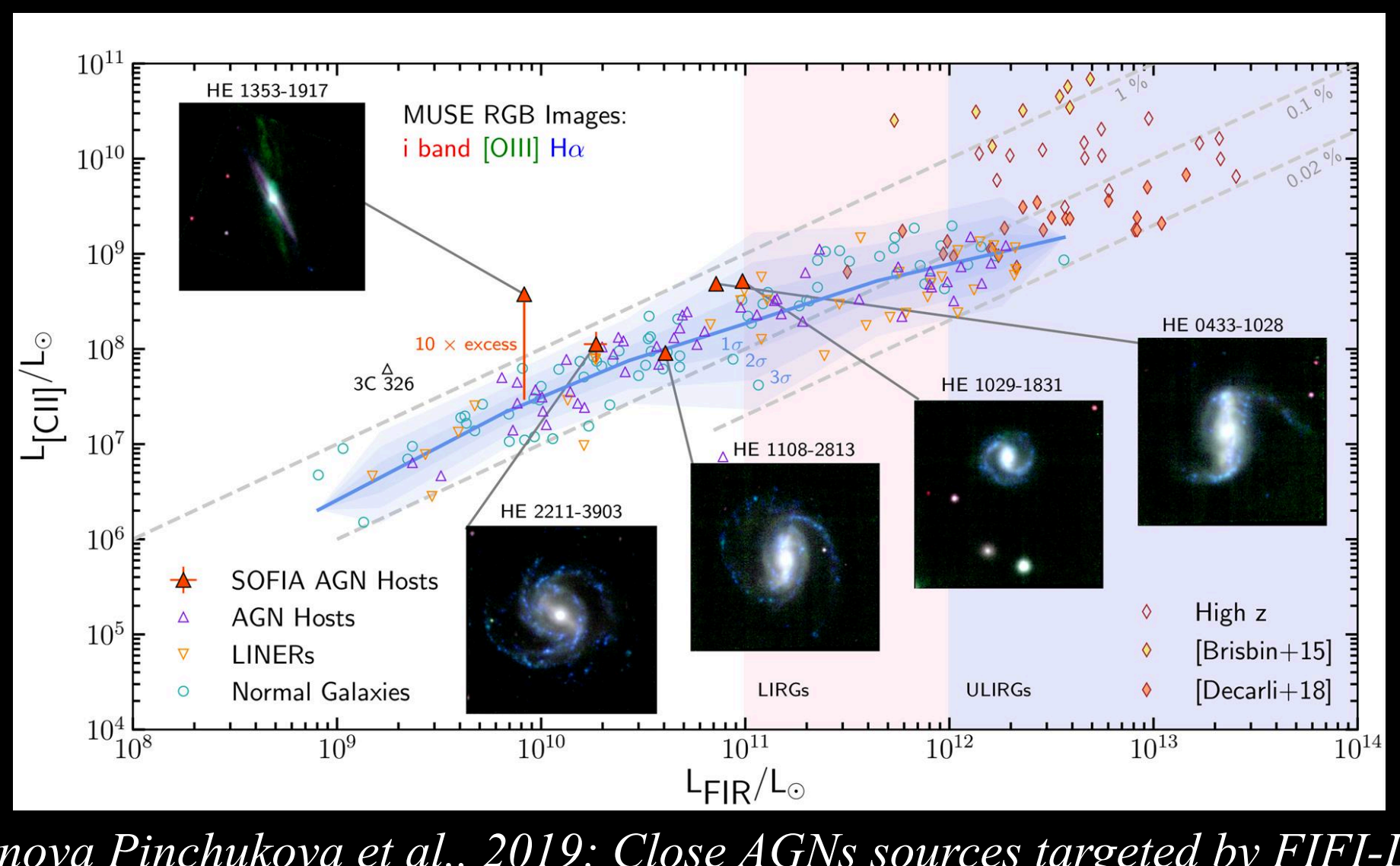
[CII] Emission: Calibrating the Distant Universe

[CII] lines are some of the strongest cooling lines for the interstellar medium (ISM) over a wide range of conditions. Several authors have shown a correlation between [CII] lines and other star formation tracers [1]. These relations show a large scatter exactly because the [CII] emission can arise from very different phases of the ISM.



Pineda et al., 2018: M51 map at 158 µm (FIFI-LS)

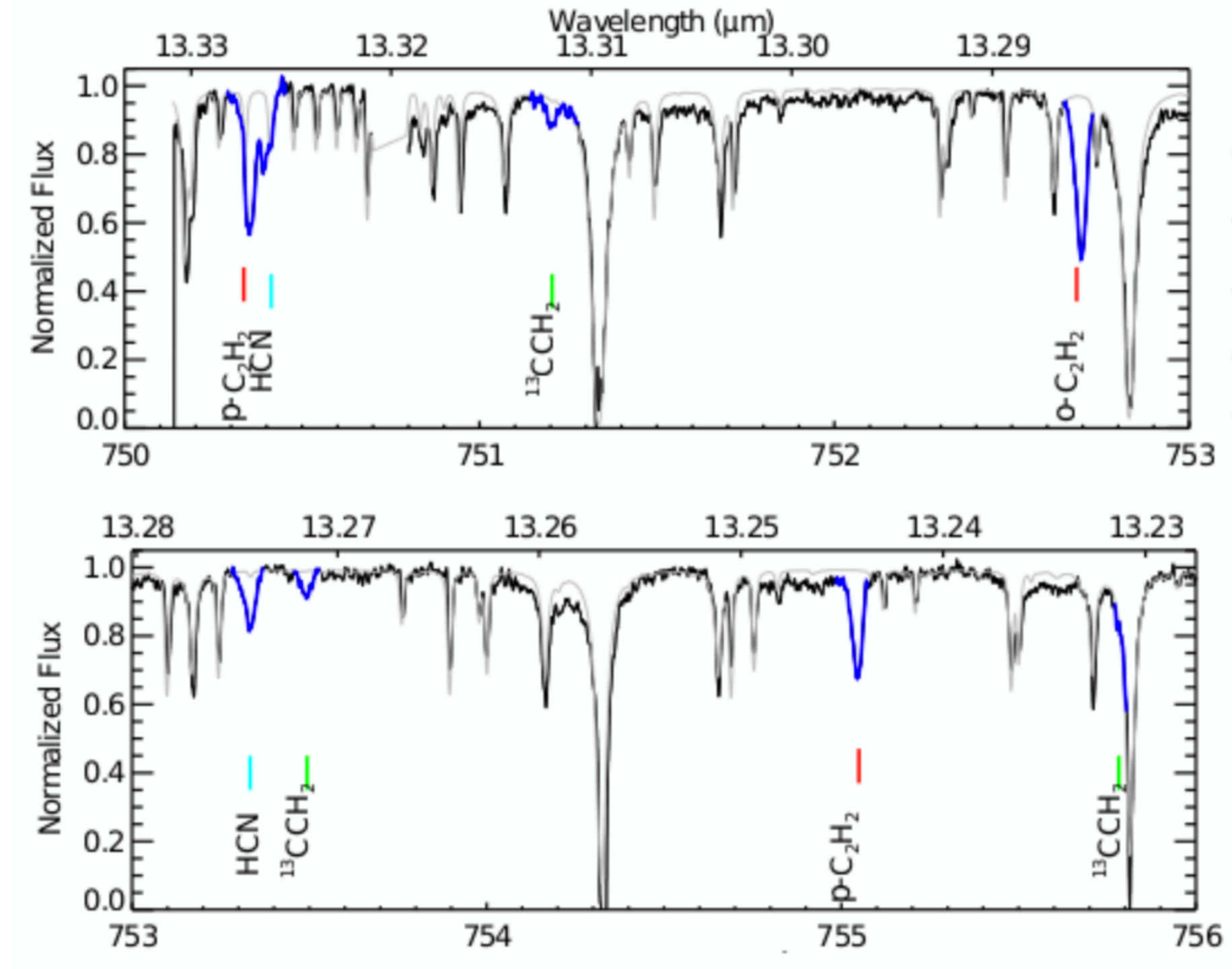
GREAT and FIFILS on SOFIA can both observe [CII] lines in the local universe and help understand the different contributions to the [CII] emission of a galaxy by spatially and spectrally (when using GREAT) resolving the [CII] emission of nearby galaxies. M51 including the companion was fully mapped with FIFILS and GREAT to study the [CII] emission from the different regimes in the spiral galaxy like the center, spiral arm, and interarm regions [2]. Further away, FIFILS observed the [CII] emission from five galaxies with an AGN to study the effect of the AGNs and star formation on the [CII] emission [3,4].



Smirnova Pinchukova et al., 2019: Close AGNs sources targeted by FIFI-LS are shown in insets.

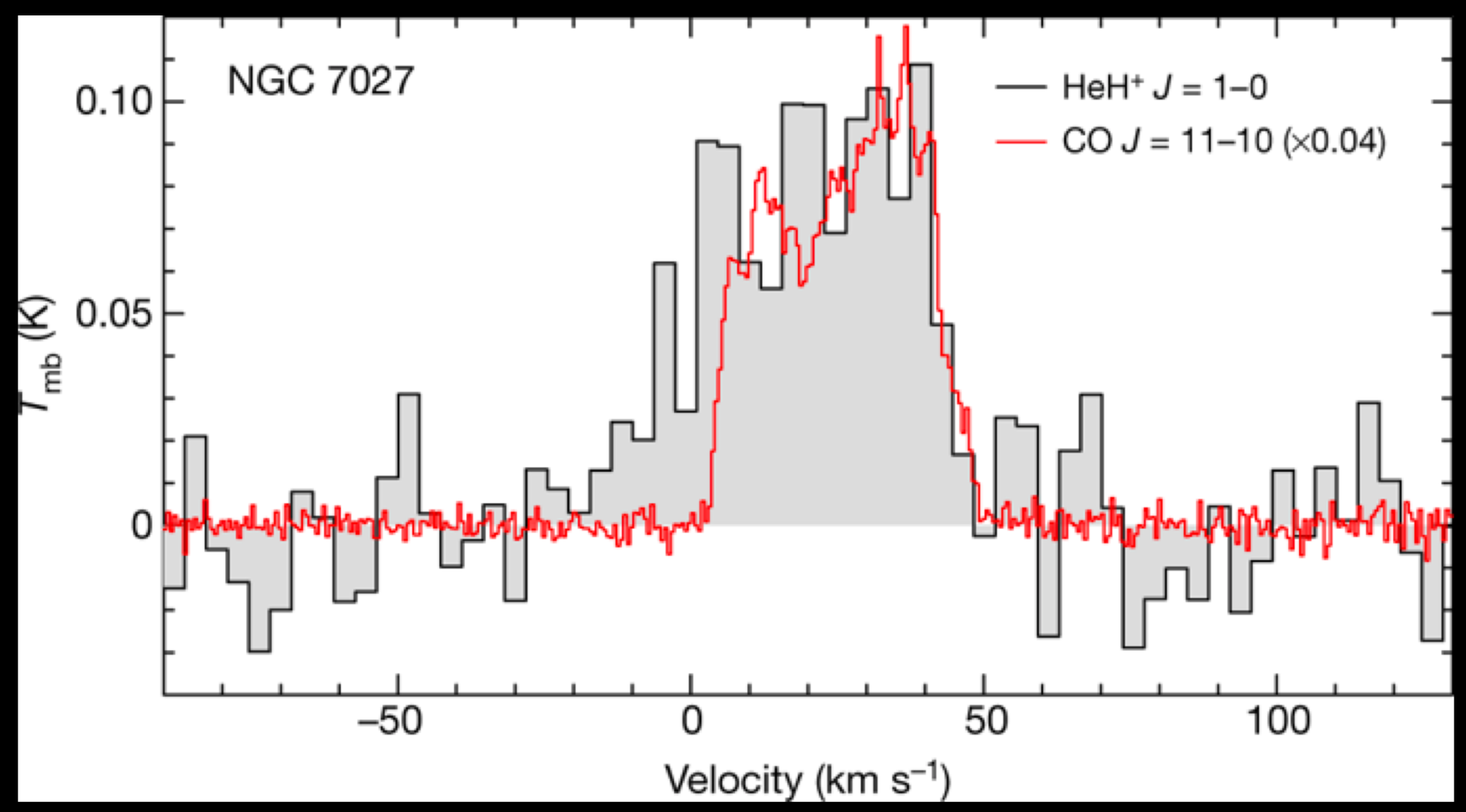
Molecular Inventory: Protostars to Comets

The wavelength range covered by SOFIA allows one to detect a variety of molecules in gas phase such as water (including many isotopes), simple and complex organics (CO, CO$_2$, CH$_4$, C$_2$H$_2$), and light hydrides (OH$^+$, SH, OD).



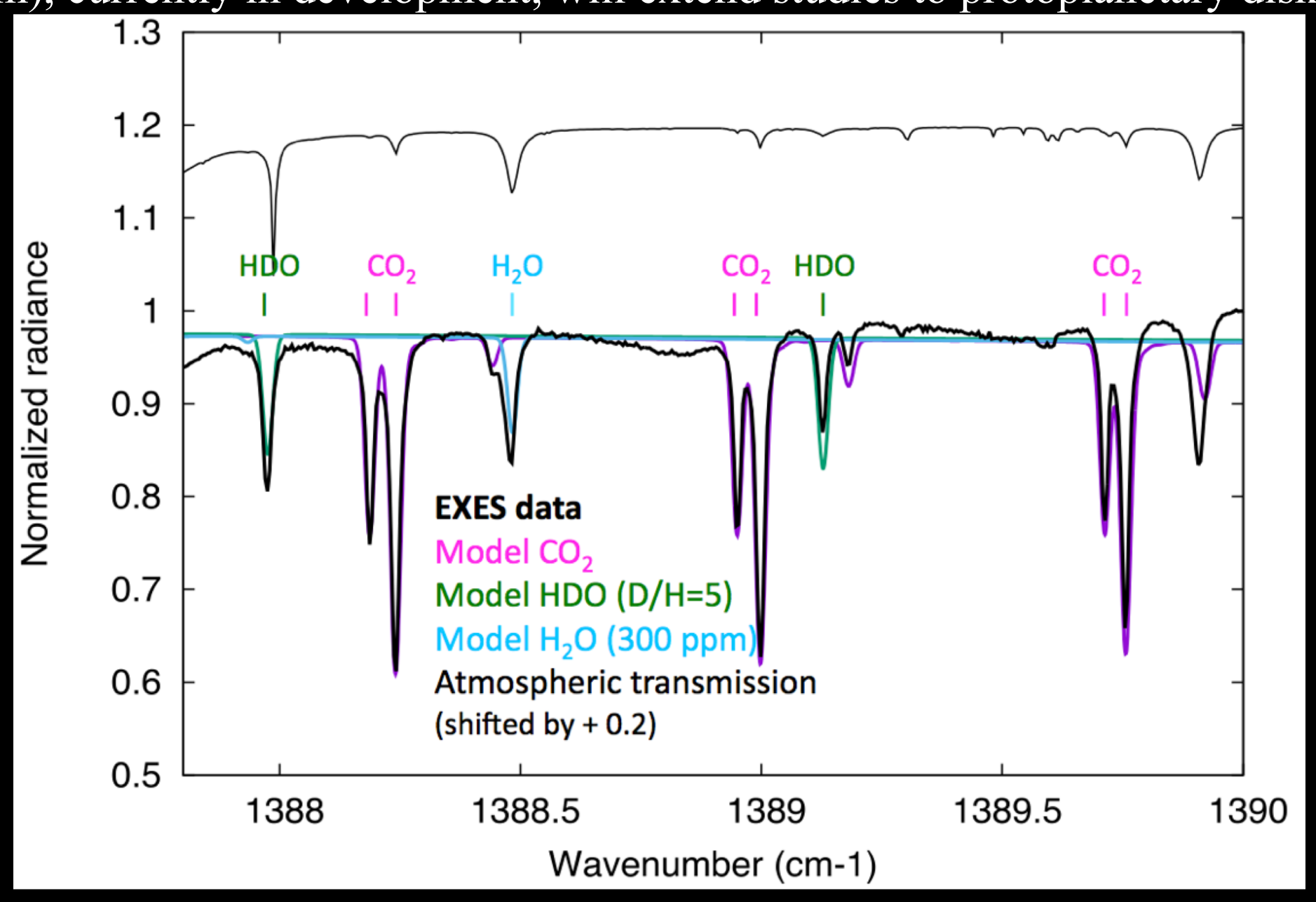
Rangwala et al., 2019 (EXES): Orion Hot Core

SOFIA hence enables unique molecular compositional studies which are essential to constrain:
- the chemical pathways from simple molecules to prebiotic species
- the reservoirs and release mechanisms of water (e.g., grain evaporation) in protostars and planetary systems



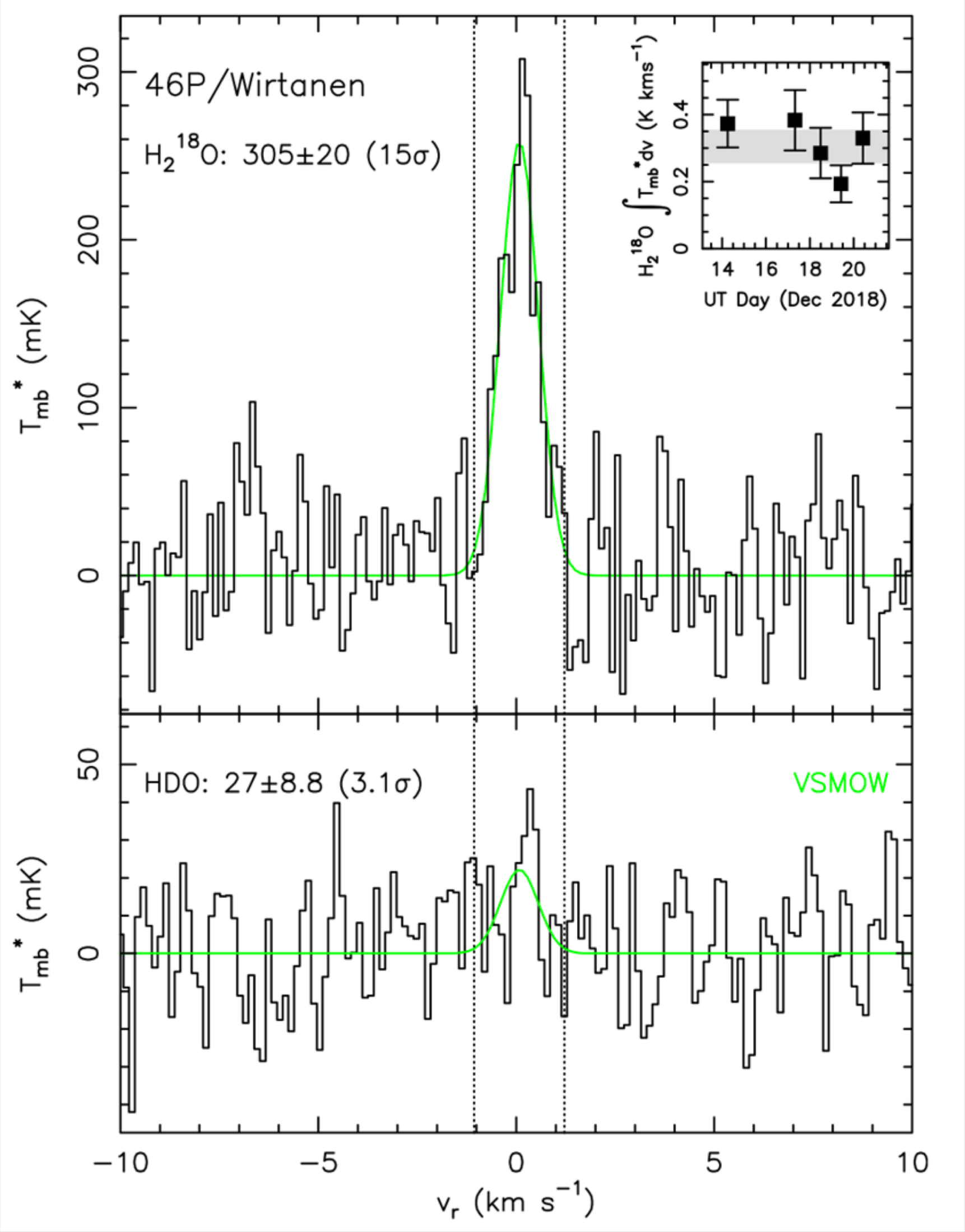
Gusten et al., 2019 (GREAT): First HeH$^+$ detection in a planetary nebulae

Targeted sources include warm regions such as hot cores in protostars [e.g., 10], planetary nebulae [11] as well colder regions such as cometary comae [12] and planetary atmospheres [13]. The new instrument HIRMES (25-122 µm), currently in development, will extend studies to protoplanetary disks.



Encrenaz et al., 2016 (EXES): Mars' atmosphere

The lines of interest are molecular rovibrational and rotational transitions, which can be resolved using high spectral resolution instruments EXES and GREAT.



Lis et al., 2019 – (GREAT): Comet Wirtanen