**THE END OF AN ERA, THE BEGINNING OF A LEGACY: SOFIA 6 µm VIPER OBSERVATIONS.** C.I. Honniball[1], W.T. Reach[2], P.G. Lucey[3], A. Arredondo[2] and E.R. Malaret[4], [1]NASA Goddard Space Flight Center, Greenbelt, MD, USA (casey.i.honniball@nasa.gov), [2]Universities Space Research Association, Columbia, MD, USA, [3]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, Honolulu, HI, USA, [4]Applied Coherent Technology, Herndon, VA, USA

**Introduction:** The conclusion of the Stratospheric Observatory For Infrared Astronomy (SOFIA) brings the end of an era for infrared astronomy. SOFIA was a 2.5-meter telescope carried on a Boeing 747SP aircraft whose mission was to observe the far infrared universe. In the last few years SOFIA has made some important discoveries, one of which was the detection of molecular water ($H_2O$) on the sunlit surface of the Moon [1, 2]. Prior to this detection it was unknown if $H_2O$, hydroxyl (OH) or both are responsible for the hydration signal at 3 µm. The detection and subsequent characterization of $H_2O$ is of high interest to both the lunar and exploration communities.

The instrument used to observe the Moon and detect $H_2O$ is the Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST). The spectral range of FORCAST is 5 to 8 µm which has been termed the crossover region. This region is not only home to the 6 µm $H_2O$ feature but also to mineralogic features like olivine, pyroxene, and plagioclase [3]. This "crossover" region is new to lunar science but SOFIA's extensive observations of the Moon with FORCAST provide the only opportunity to study this spectral range currently.

While SOFIA will no longer be flying in our night skies, its discoveries about the lunar water cycle and minerology will continue for years to come. In this abstract we present all the lunar observations conducted by SOFIA. We also provide preliminary observations of the NASA Volatiles Investigating Polar Exploration Rover (VIPER) landing region that will be used to place VIPER hydration measurements into regional context.

**Observations:** At the time of writing this abstract SOFIA is still in operation conducting its final science flights in September 2022. At the end of the SOFIA mission, we will have observed the Moon on as many as 17 nights (planned nights in September can be lost to technical issues), and observations from 10 nights are currently in the SOFIA science archive. Some of observations conducted by SOFIA are spatially resolved maps of geologically important locations while others are spatially sparse maps that aim to study the behavior of $H_2O$ across the Moon. Table 1 provides the flight names, UTC date and the target observed. All the data are or will be available on SOFIA's science archive hosted in the Infrared Science Archive (IRSA) managed by the Infrared Processing & Analysis Center (IPAC).

The reduction of lunar FORCAST data is considered a special case and requires extra attention to correct for atmospheric absorption and an instrumental artifact. For further detail please refer to [1,2].

**Community resources:** Our team is currently working with Applied Coherent Technology to ingest SOFIA lunar observations into the Lunar Quickmap. Two products that will be available once calibrations are complete are the radiance and $H_2O$ abundance for each pixel observed with SOFIA. Along with that supporting information such as latitude, longitude, and the lunar time of day of each pixel will be available. We are still in the beginning stages of this process.

Table 1: SOFIA observations of the Moon.

| Flight Name | UTC Date | Target |
|---|---|---|
| Jadzia | Aug. 31, 2018 | Clavius |
| Octavia | Jun. 23, 2021 | Moretus |
| Oprah | Jun. 30, 2021 | Goldschmidt, EudoxusA, Theophilus, Bushing, Pentland, Clavius |
| Jessica | Feb. 17, 2022 | VIPER region |
| Jacob | Feb. 19, 2022 | Water behavior |
| Pepe | May 11, 2022 | Copernicus, Mare hydration anomaly, Water behavior |
| Pavel | May 12, 2022 | Gruithuisen domes, Aristarchus, Mersenius, Mare hydration anomaly, Water behavior |
| Pamela | May 13, 2022 | Water behavior |
| Pratik | May 17, 2022 | Gruithuisen domes, Aristarchus, Reiner Gamma, Mersenius, Water behavior |
| Phineus | May 18, 2022 | Proclus, Gruithuisen domes, Reiner Gamma, North pole, Water behavior |
| Pandora | May 19, 2022 | Gruithuisen domes, Water behavior |
| Volker* | Sept. 7, 2022 | North pole region |
| Vikram* | Sept. 8, 2022 | North pole region |
| Venture* | Sept. 9, 2022 | South pole region |
| Vivek* | Sept. 10, 2022 | Water behavior |
| Vivian* | Sept. 14 2022 | Apollo 11, 17, Goldschmidt, Theophilus, Humorum pyroclastic, Kepler |
| Vulcan* | Sept. 15, 2022 | Plato, Mairan domes, Sulpicius Gallus pyroclastic, Apollo 16, Theophilus, Tycho |
| Vasco* | Sept. 16, 2022 | Mare hydration anomaly, Mairan domes, Apollo 14, Sulpicius Gallus pyroclastic, Vaporum pyroclastic, Apollo 16, Airy swirl, Moretus |
| Virgil* | Sept. 17, 2022 | Apollo 14, Aristarchus, Sinus Aestuum pyroclastic, Rima Bode pyroclastic, Humorum Pyroclastic |

*Planned flights at the time of this writing with two flights acting as backup.

**Recent results:** On February 17th, 2022 (UTC) we observed about a quarter of the lunar nearside surface south of -60˚ latitude with ~5 km spatial resolution. These observations covered the VIPER landing site region. After calibration and processing following procedures outlined in our upcoming paper [4] surface features are readily visible in the radiance data at 5.5 µm (Fig. 1 right). A water emission feature is observed in portions of this region and seen on the left of Fig. 1. To detect the 6 µm feature we ratio the target to a reference location ideally at higher temperatures. This means that the emission of $H_2O$ is always with respect to a reference site. In this case the reference was Mare Fecunditatis.

In this data set there is a gradual decreasing trend in $H_2O$ toward the south pole. During these observations some of the far side was visible to SOFIA including the Nobile landing site for VIPER roughly indicated by the red circle in Fig. 1. In this image we can see H2O features that correspond with high radiance areas but also $H_2O$ features that do not correlate with radiance. These observations are very preliminary and in-depth analysis needs to be completed.

**Upcoming investigation:** With observations of the VIPER landing site and its surrounding region we will investigate the abundance of $H_2O$ present in the region and place VIPER hydration measurements at 3 µm into regional context. The map in Fig.1 and others observed in September will allow us to estimate how much $H_2O$ is present in on surfaces with a 3 µm hydration band detected by VIPER's Near-Infrared Volatiles Spectrometer System (NIRVSS).

We have also mapped the same region with the NASA InfraRed Telescope Facility (IRTF) at 3 µm. Comparing IRTF and VIPER results will provide a means to ground truth remote sensing data and extend the VIPER results to a broader context.

**References:** [1] Honniball C. I. et al. (2020) Nat Ast, 10.1038/s41550-020-01222-x. [2] Honniball C. I. et al. (2022) GRL, 10.1029/2022gl097786. [3] Kremer, C. H. et al. (2020) GRL, 47. [4] Reach W. T. et al. (in prep) Sci. Adv.

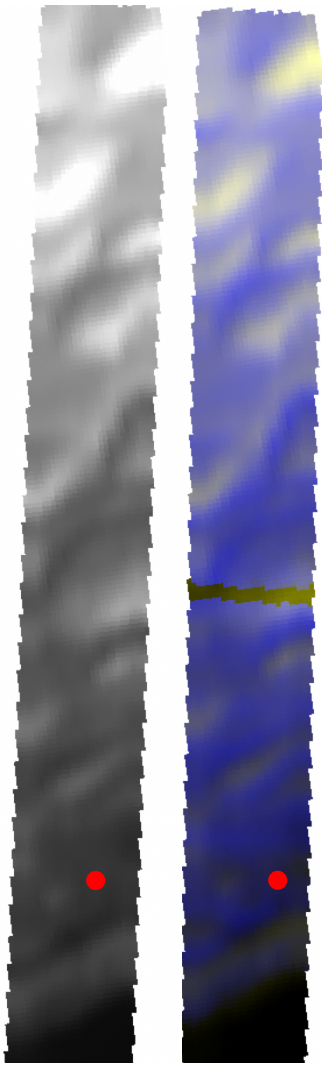

**Figure 1:** The left shows the radiance of the Nobile region while the right shows the $H_2O$ emission in blue on top of the radiance image. The red dot indicates roughly the location for VIPER.