HIRMES: A Kilopixel Bolometer Array for Airborne Infrared Astronomy

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Abstract

The HIgh Resolution Mid-infrarEd Spectrometer (HIRMES) instrument will fly onboard the National Aeronautics and Space Administration's (NASA) airborne Stratospheric Observatory for Infrared Astronomy (SOFIA) in 2021. It will provide astronomers with a unique observing window (25 -122 μm) for exploring the evolution of protoplanetary disks into young solar systems. The instrument's focal plane comprises two independent arrays of transition-edge sensor (TES) bolometers: a low-light 8×16 array for high-resolution spectroscopy, and a higher saturation power 16×64 detector array for both spectroscopy and imaging. Both arrays feature special close spacing that provides nearly continuous coverage over one spatial axis.

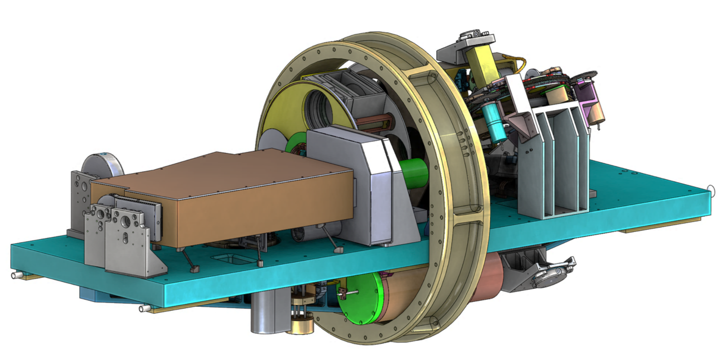
Though both pixels are designed around superconducting Mo/Au bilayers on suspended single-crystal silicon membranes, leg geometry and transition temperature have been tuned separately to suit the different optical loads. We have tested both types and expect photon-noise limited performance out of both. The unique environment of this instrument places demands on the size and weight of the detector package, as well as its mechanical and thermal properties. These constraints drove distinct solutions in readout architecture, mounting, and materials. We present detector characterization results and discuss the packaging of an airborne kilopixel array.

SOFIA and HIRMES

SOFIA is a customized Boeing 747SP outfitted with a 100 inch telescope. By flying at the tropopause, above almost all moisture in the atmosphere, it can view the infrared window otherwise only available to satellites.

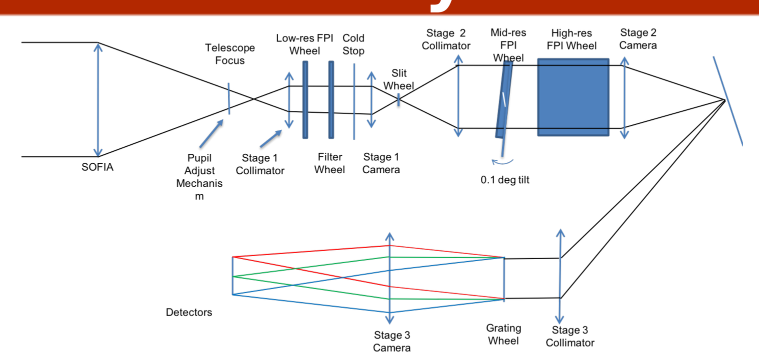
The telescope in flight.

HIRMES is a third generation upgrade to the observatory's suite of instruments. While designed as a general purpose imaging spectrometer, the flagship measurement will be mapping water and ice in protoplanetary disks. The high resolution modes of the instrument allow for the measurement of the velocities of oxygen and water lines, which provides significant information on spatial structure.

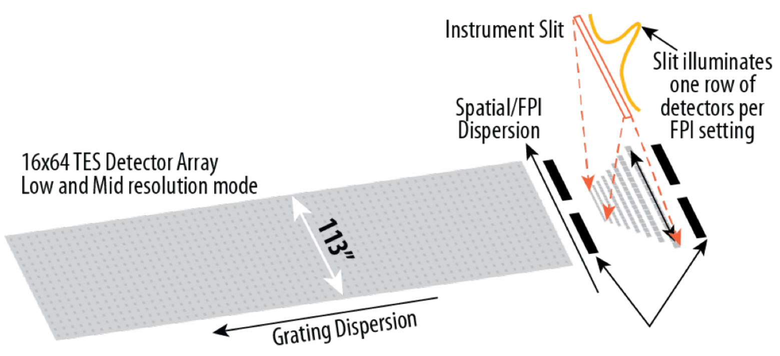


Drawing of the instrument interior. The entire optical bench (teal) is cooled to 4K. The focal plane (cooled to 70 mK) is housed inside the small magnetic shielding box at the center. The majority of the dewar space is occupied by optics.

Detector Layout

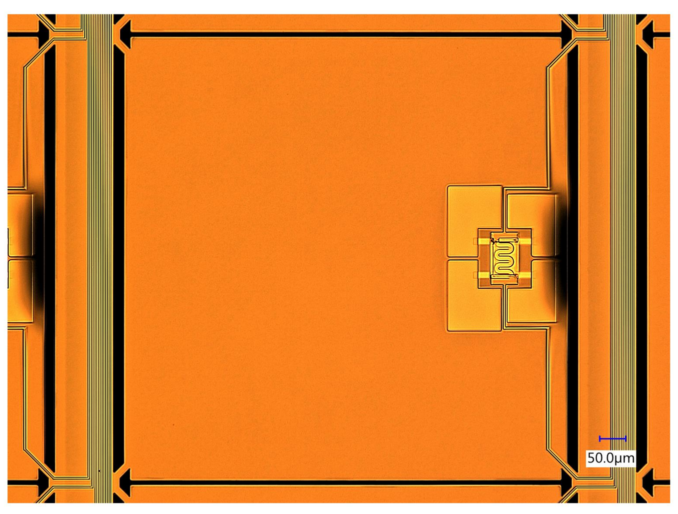


The instrument's flexibility comes from moveable optics that can select the resolving power. Gratings provide R of 600, while a Fabry-Pérot interferometer (FPI) provides an R of up to 100,000.



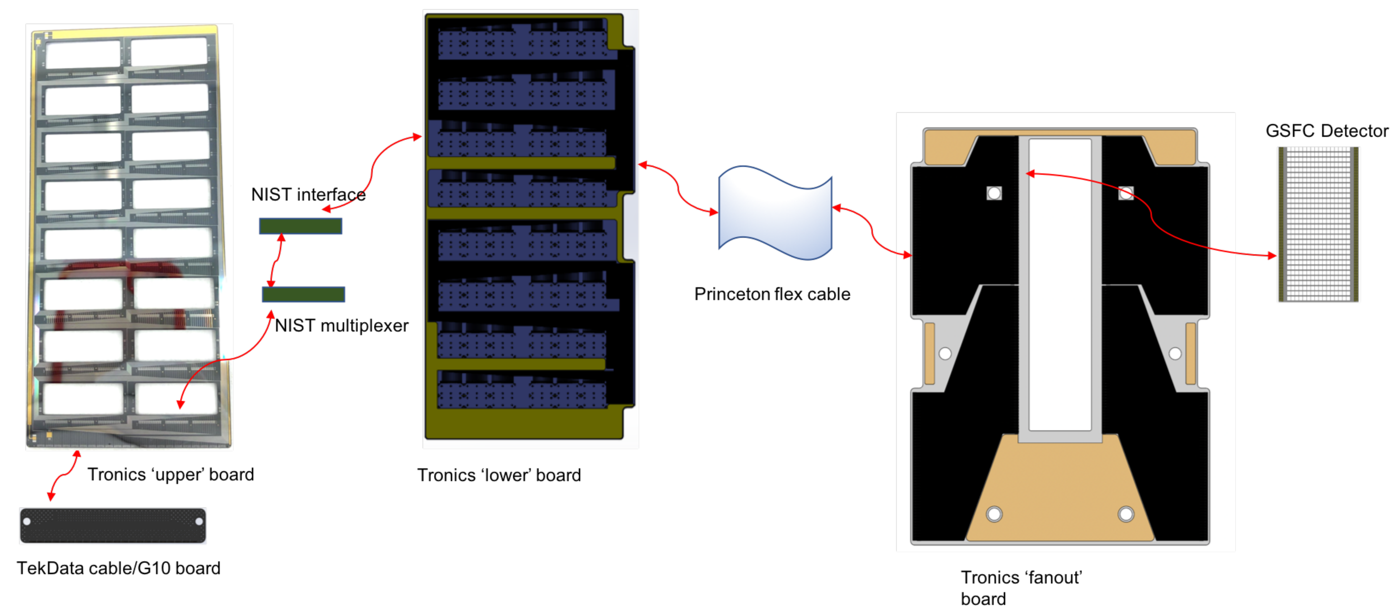
These separate dispersion modes are complemented by separately designed detector arrays.

Pixel Design

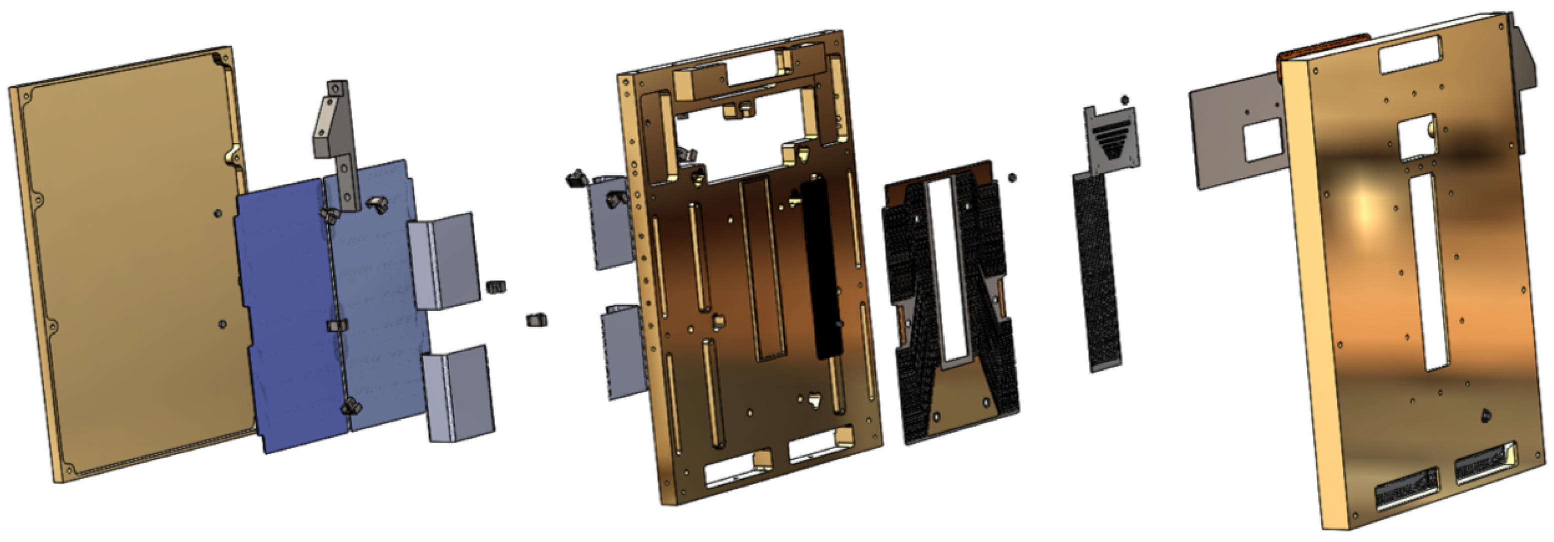


The fundamental design of both types of pixel is the same. They are Au/Mo TESs on intrinsic silicon membranes. Optimized for different light inputs, however, the Low-Res pixels use a 1.3 μm membrane and a T_c of 150 mK to achieve a saturation power of 20 pW at 70 mK, while the High-Res pixels use a 450nm thick membrane and a T_c of 100 mK for a saturation power of 0.15 pW at 70 mK. In this design they should both be photon noise limited for their respective signals.

Readout Chain and Packaging

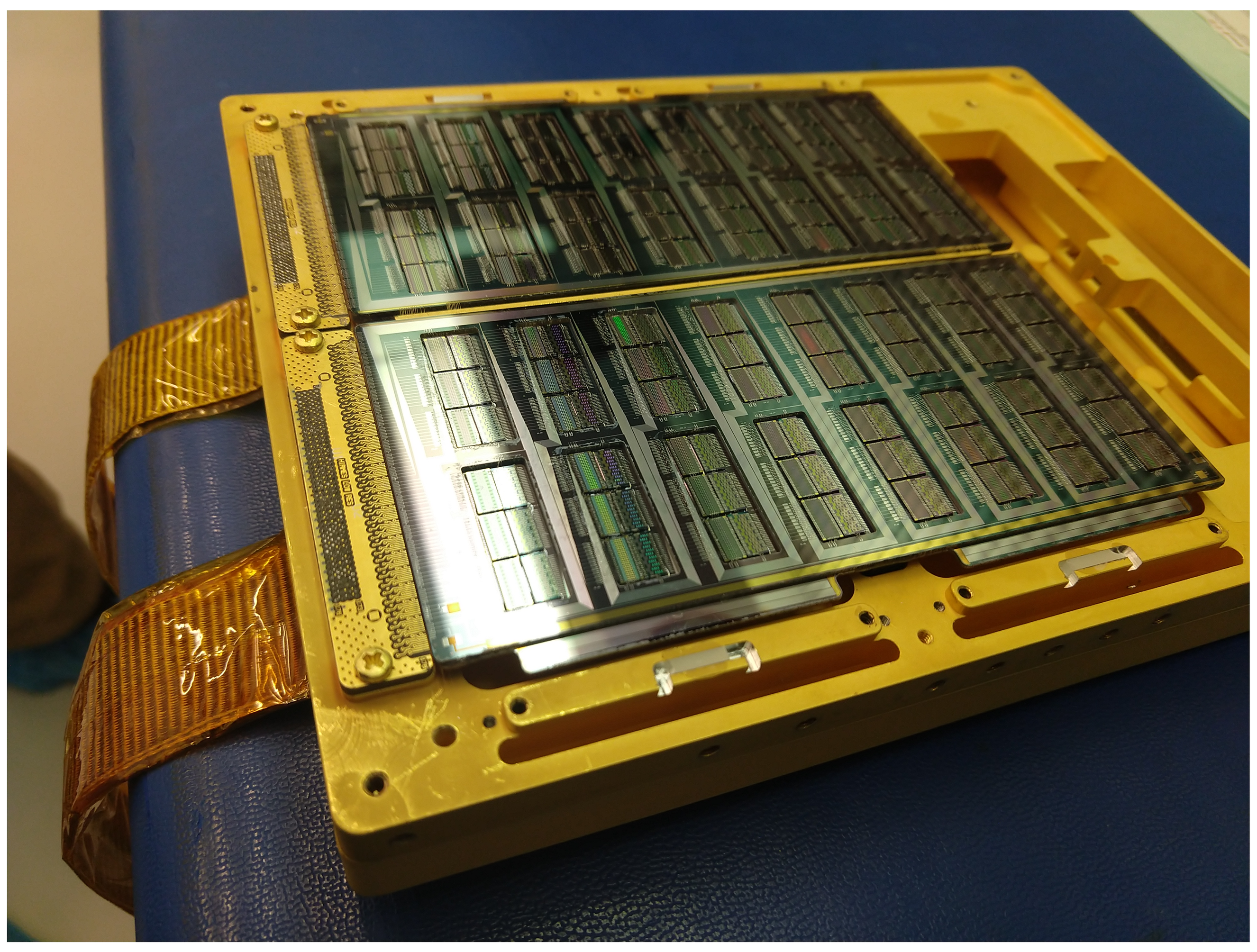


The readout architecture for the low resolution array is a proven 32x32 TDM scheme. However, fitting the components thereof into a reasonably sized package requires special considerations. Signal is routed to the backside of the package by flexible connectors with aluminum traces. On the backside, the multiplexing and interface chips are mounted in a two layer stack of silicon boards with aluminum traces. The upper of these two boards has holes to accommodate the chips and the step down bonds to the lower board.



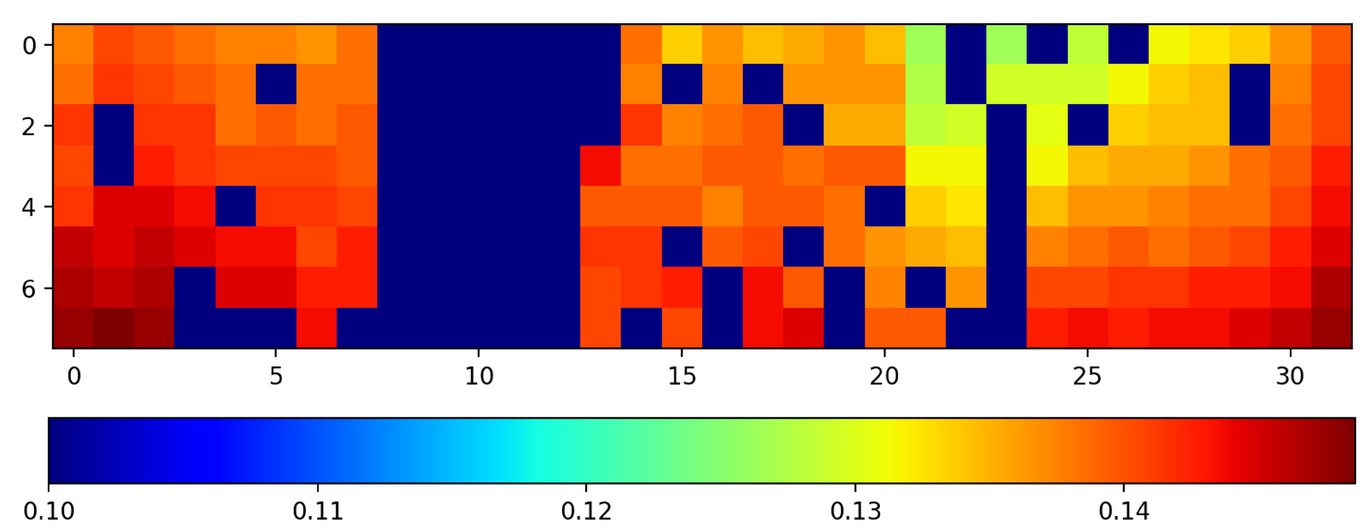
An exploded view of the two-sided packaging. All the silicon readout boards mount by titanium flexures to the central magnesium chassis.

Engineering Tests



The backside multiplexing for the kilopixel low resolution array. There should be about 7692 wirebonds visible in this photo. As with any other TDM system, a broken wirebond, or open trace in the top layer, results in the loss of 32 pixels.

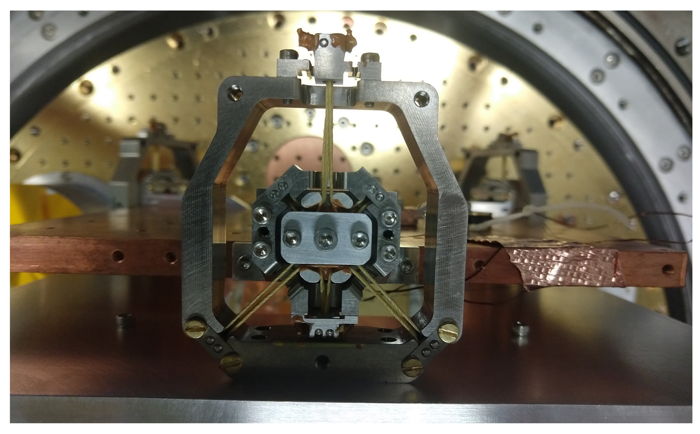
We have fully built one quarter of the low -resolution array. Despite the challenges of the fanout boards and wiring, only one column was lost in its entirety. Yield was roughly 80 percent.



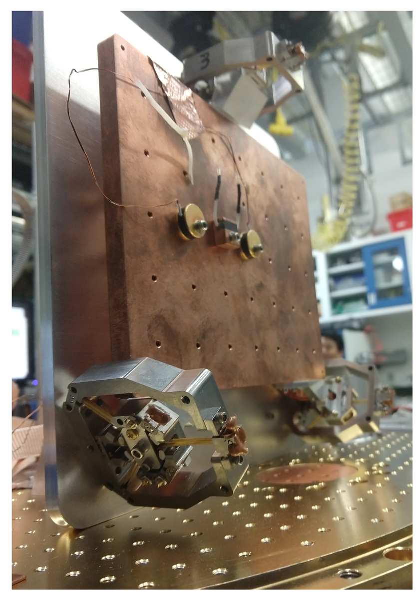
Map shows missing pixels and a power gradient towards the corners of the frame.

Thermal Suspension

Another special requirement for this instrument is that the package not be susceptible to vibrational heating from the thrum of the jet engines. To ensure that any vibrational mode is above that frequency, the box is suspended by three structures of tense kevlar, and the box itself is made of magnesium, which keeps it very light.

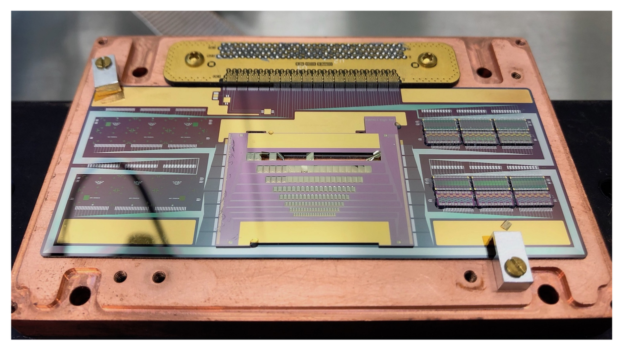


The kevlar suspension structure is only 2" in diameter, but incorporates an intercept stage. We have done preliminary tests with a dummy cold plate in place of the array and estimate the parasitic load on the cold stage to be about 30 nW when the cold stage is at 80 mK

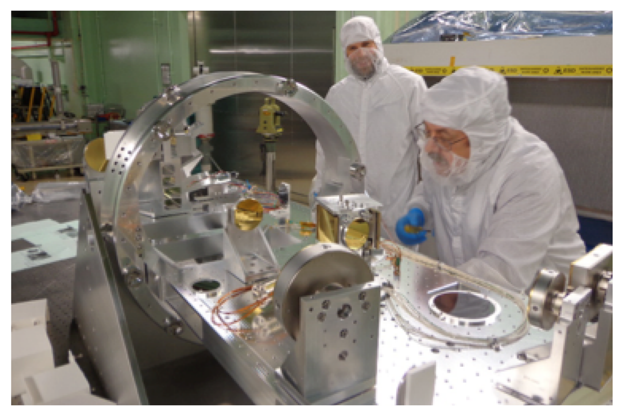


Next Steps

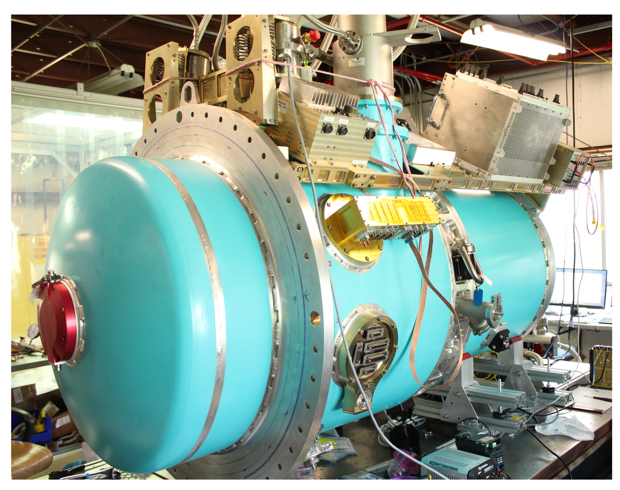
HIRMES is an ambitious project. The next steps for the focal plane are a full build up and integration, along with plenty of cryogenic testing along the way.



The high resolution array has been tested separately, but is yet to be integrated into the larger focal plane package.



The cryostat and optical bench are also under construction. They should be ready for integration with the focal plane together this winter.



Watch a video from NASA outreach about the HIRMES instrument on youtube.

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