Integration and Testing of a Cryogenic Receiver For the Exoplanet Climate Infrared Telescope (EXCITE)

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INTRODUCTION

The *EXoplanet Climate Infrared TElescope* (EXCITE) is a purpose-designed instrument which will obtain spectroscopic phase curves of hot Jupiters over entire orbital periods. EXCITE uses a moderate resolution spectrograph (50 = $\lambda/\Delta\lambda$) covering the 0.8–3.5 μm band. EXCITE will fly on a long duration balloon (LDB) at stratospheric altitudes of ~40 km.

EXCITE requires excellent photometric stability, which in turn drives the thermal and vibrational requirements of the instrument.

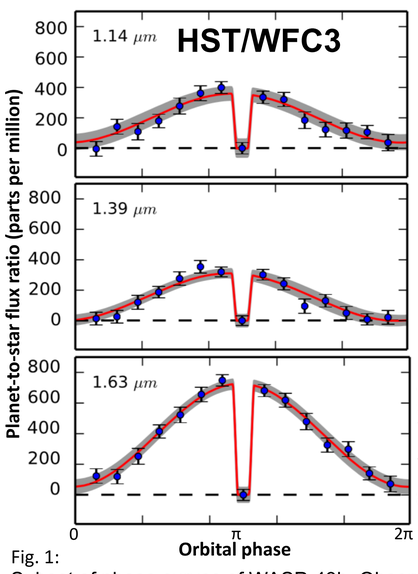

Fig. 1: Subset of phase curves of WASP-43b. Observations span 3 full orbital periods. *Stevenson et al. 2014*

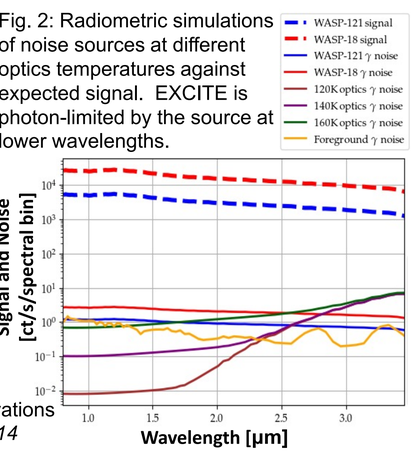

Fig. 2: Radiometric simulations of noise sources at different optics temperatures against expected signal. EXCITE is photon-limited by the source at lower wavelengths.

PAYLOAD

The EXCITE payload comprises a semi-custom Ritchey–Chrétien telescope with a 0.5 m primary mirror which interfaces with a receiver via a tip-tilt fine guidance system. These are housed in a gondola with three-dimensional pointing capability. This is a modification of the payload design used in the *Super-pressure Balloon-borne Imaging Telescope* (SuperBIT) experiment, which achieved sub-arcsecond pointing stability.

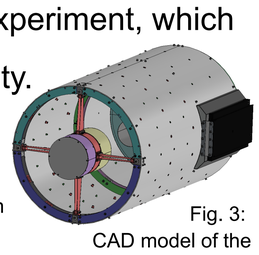

Fig. 3: CAD model of the telescope made by Officina Stellare.

Fig. 4: Image of EXCITE payload taken during the Ft Sumner, NM 2023 campaign. *(image credit K. Helson)*

- f/12 telescope
- The pointing system uses three nearly orthogonal axes: yaw, roll, and pitch.
- The gondola is constructed of 2.5 cm thick aluminum honeycomb.

CRYOGENIC RECEIVER

The EXCITE cryogenic receiver houses a focal plane array (Teledyne HAWAII-2RG), readout electronics (ACADIA* controller) and a diffraction-limited spectrometer. Active cooling is supplied by two linear pulse-tube cryocoolers (Thales LPT9310).

ASIC for **Control **A**nd **D**igitization of **I**magers for **A**stronomy

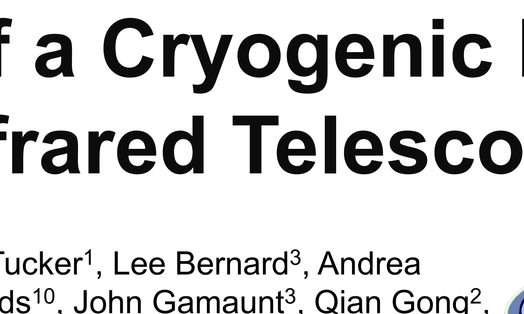

Fig. 5: Image of cryogenic receiver mounted to telescope assembly *(K. Helson)*

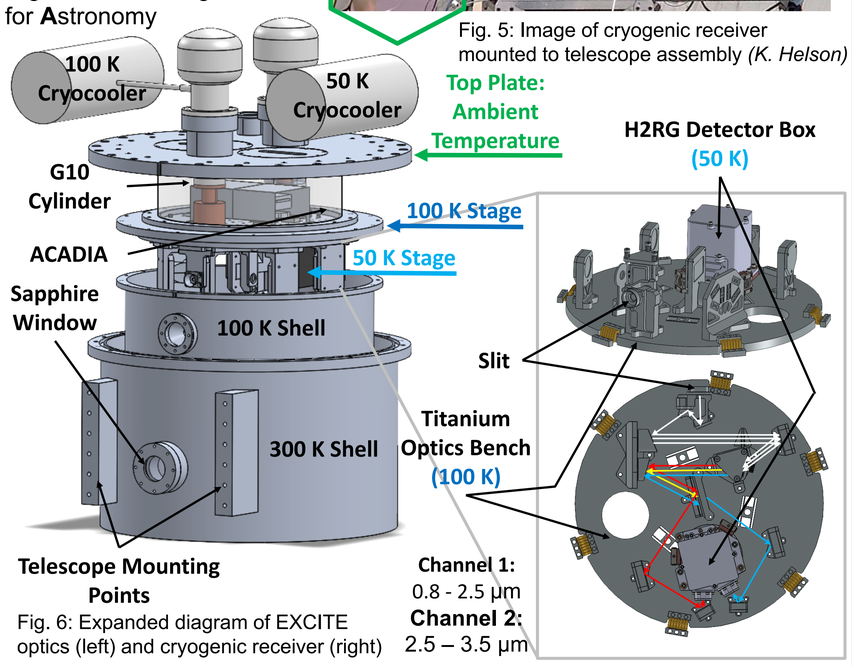

Fig. 6: Expanded diagram of EXCITE optics (left) and cryogenic receiver (right)

CRYOGENIC CONTROL ELECTRONICS

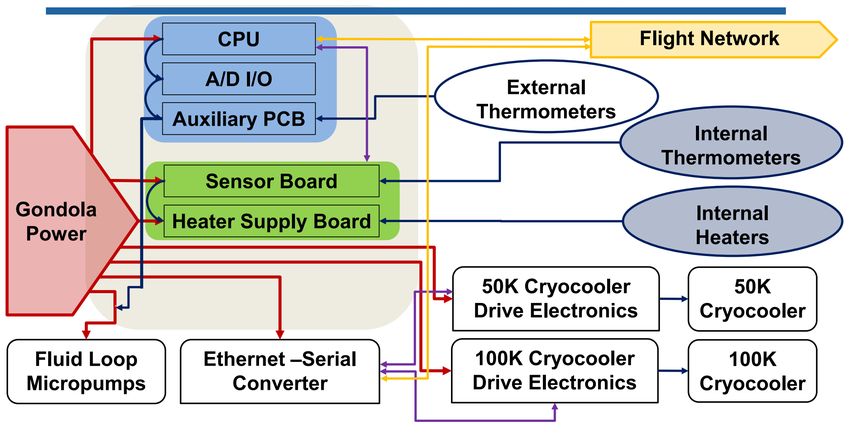

Fig. 7: Connection diagram of cryogenic control electronics

The Cryogenic Control Computer (CCC) consists of a PC-104 computer stack with auxiliary electronics which manage and monitor the performance of the cryogenic system. The CCC sends and receives commands and telemetry over the flight network to facilitate control of the receiver from the ground. The CCC interfaces with cryocooler drive electronics built by West Coast Solutions, which actively measure and reduce compressor vibrations based on accelerometer input.

Main CCC Program:

Build telemetry frame and send over the flight network

Ex:
lakeshore_serial → 'KTEMP? A\n'
'120.0' → CCC
ktemp_a=120.0 → telem_frame

- Check for commands received over flight network and process the input.

'cryo1_vac 0' → **CCC**
cryo1_serial → 'vmax 0.0\n'

- Perform other looped operations, such as ramping voltage and checking operational limits

if compressor1_temp > 50:
cryo1_serial → 'vmax 0.0\n'

wait time, then loop

THERMAL MANAGEMENT

The cryocoolers are designed to cool the spectrometer to ~100 K and detector to ~50 K. Each cryocooler is expected to dissipate ~75 W under normal operating conditions (skin temperature 20° C). Two redundant closed recirculating methanol fluid loops pass through the cryocooler heat sinks and radiate heat via two 1 m^2 sky-facing aluminum panels coated with silver Teflon tape.

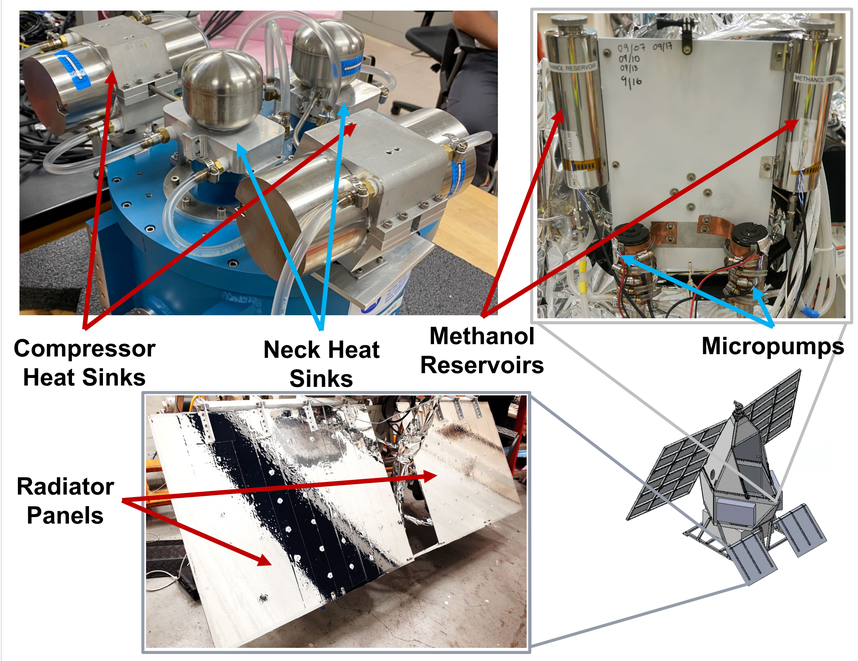

Fig. 8: Images of components of thermal management system: cryocooler compressors and bulbs with heat sinks (top left), methanol reservoirs and micropumps (top right), and radiator panels (bottom left). Position of pumps and panels on gondola indicated at bottom right. (*Image credits K. Helson and T. Rehm)*

VIBRATION MANAGEMENT

During the EXCITE 2023 field campaign in Ft Sumner, NM the active vibration control system was integrated and refined alongside on-sky pointing tests. The drive electronics were able to reduce vibrations in the fundamental and third harmonics by a factor of five, and in the second harmonic by a factor of ten. We will quantify this system and its effects on pointing stability during our upcoming **2024 North American test flight.**

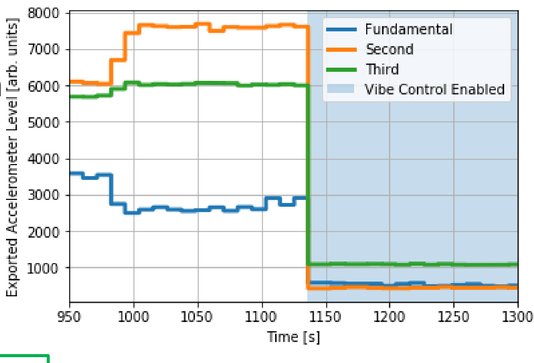

Fig. 9: Representative plot of cryocooler accelerometer data before and after active vibration control was enabled in the field. Vibrations significantly reduced in all three measured harmonics.

Operational Milestones:

- ✓ Cryocooler compressor pistons can be temporarily locked during termination
- ✓ Heat effectively dissipated by fluid loop in lab and thermal vacuum chamber
- ✓ Science requirements for internal temperature met under various conditions
- ✓ Vibration reduction measures meet instrument requirements and are flight ready

REFERENCES

Nagler, Peter C., et al. "Observing exoplanets in the near-infrared from a high altitude balloon platform." *Journal of Astronomical Instrumentation* 8, 1950011 (2019)

Romualdez, L. Javier, et al. "Robust diffraction-limited near-infrared-to-near-ultraviolet wide-field imaging from stratospheric balloon-borne platforms—Super-pressure Balloon-borne Imaging Telescope performance." *Rev. Sci. Instrum.* 92, 019901 (2021)

Stevenson, K. B., et al. "Thermal structure of an exoplanet atmosphere from phase-resolved emission spectroscopy." *Science*, *346*(6211), 838-841 (2014)

Tucker, Gregory S., et al. "The Exoplanet Climate Infrared TElescope (EXCITE)." *Ground-based and Airborne Instrumentation for Astronomy VII*. International Society for Optics and Photonics, 10702, 107025G (2018)