Mechanical Design, Cryogenic Architecture, and Telescope Integration of the GRANCAIN Infrared Camera for the GTC.

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Abstract. GRANCAIN (GRAN CAmara INfrarroja) is the first-light cryogenic near-infrared (NIR) imager to be installed at the Nasmyth focus of the Gran Telescopio Canarias Adaptive Optics system (GTCAO). This paper presents the final mechanical architecture of the instrument, the cryogenic engineering solutions, and telescope integration. The instrument is housed in a 160-L aluminum 6061-T6 cryostat driven by a SHI CH-104 closed-cycle Gifford–McMahon (GM) cryocooler. To address the inherent mechanical noise of GM technology, a custom anti-vibration system was implemented to attenuate the vibrations transmitted to the main cold structure. This design effectively dampens mechanical noise while maintaining a highly efficient thermal link, ensuring optimal cooling power delivery to the detector. Consequently, the cryogenic system provides a stable 77 K environment for the detector assembly. The monolithic aluminum optical bench supports the 2:1 collimator–camera system, a cryogenic filter wheel, the cold stop, and a 4-Mpx HAWAII-2 PACE detector. The mechanical design uses athermalized, black-anodized 6061-T6 mounts that provide five degrees of freedom for precise alignment and compensate for thermal contraction during cooldown. A rigorous as-built verification plan—including CNC machining control, laser-tracker measurements, and cryogenic alignment tests—ensured compliance with the tolerance budget. Notably, first on-sky results confirm that the mechanical and thermal stability of the instrument meet the requirements to achieve near-diffraction-limited NIR imaging at the GTC.

1. Introduction

The pursuit of high spatial resolution in ground-based astronomy necessitates the use of large telescopes and AO systems [1],[2]. The GTC utilizes the GTCAO system to provide nearly diffraction -limited images [3],[4]. This system corrects atmospheric aberrations to enable precise scientific observations. GRANCAIN serves as the first-light imaging instrument for this facility, operating in the *J*, *H*, and *K* infrared bands. Cryogenic engineering is fundamental for NIR instrumentation to manage thermal background noise and detector performance [5]. Operating in the NIR spectrum requires eliminating excess thermal radiation from the instrument itself. Specifically, the detector must be cooled to reduce dark current to negligible levels. Achieving these conditions requires integrating the opto-mechanical train within a high-vacuum cryostat. GRANCAIN is integrated into the Nasmyth B platform of the GTC, positioned directly at the output focus of the GTCAO. This configuration places the camera behind the AO system's optical bench. A significant challenge in this setup is the mechanical vibration induced by the cryogenic cold head. Due to the camera is a high-resolution system, these vibrations can severely degrade image quality if not properly damped. The instrument must maintain extreme structural and thermal stability to preserve the point spread function (PSF) provided by the AO system. The following sections detail the mechanical and cryogenic strategies employed to meet these astronomical requirements at the GTC.

2. Project Baseline and Top-Level Requirements

The primary goal of GRANCAIN is to provide high-resolution sampling, particularly in the *K*-band, with a pixel scale of 11 mas [6]. The instrument covers a field of view (FoV) of 22 arcsec. Key scientific drivers include high-resolution imaging of TESS planet candidate host stars and the study of relativistic jets in blazars. It also aims to characterize the multiplicity of low-mass stars and perform deep-field imaging around quasars. To support these goals, the instrument must achieve a throughput greater than 70%. Background noise at the detector must be limited strictly by the sky. This requires a telecentric optical design with a cold stop to eliminate internal thermal radiation.

3. Optical Layout

The optical layout follows a collimator-camera configuration with a 2:1 magnification ratio. The system includes five commercial optical elements and a NIR detector (figure1).

- Cryostat Window: Plane–parallel CF63 infrared fused-silica lens with anti-reflective (AR) coating to maximize transmission and minimize reflections.
- Optics: The collimator and camera assemblies employ AR-coated ZnSe plano-convex lenses. Both mounted in athermalized mounts designed to preserve optical alignment and focus during cryogenic shrinkage through a tailored combination of materials with different thermal expansion coefficients and compensating geometries [7].
- Filter Wheels: Two independent wheels house six filters (three wide-band and three narrow-band). They are driven by Phytron cryogenic stepper motors.
- Cold Stop: A 6 mm mechanical pinhole positioned at the pupil plane suppresses thermal background radiation and reduces stray light contamination.
- Detector: 4-Mpx HAWAII-2 PACE (H2P) Teledyne array, optimized for the *K*-band.

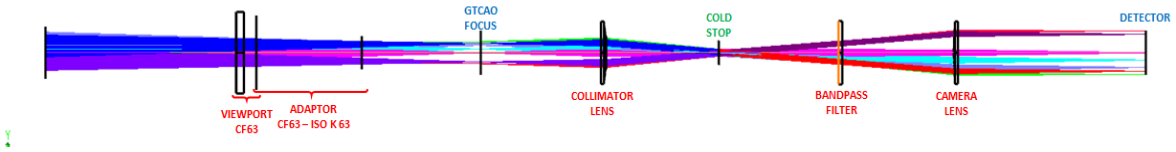

Figure 1. GRANCAIN optical layout showing the ray tracing path from the viewport to the detector [6].

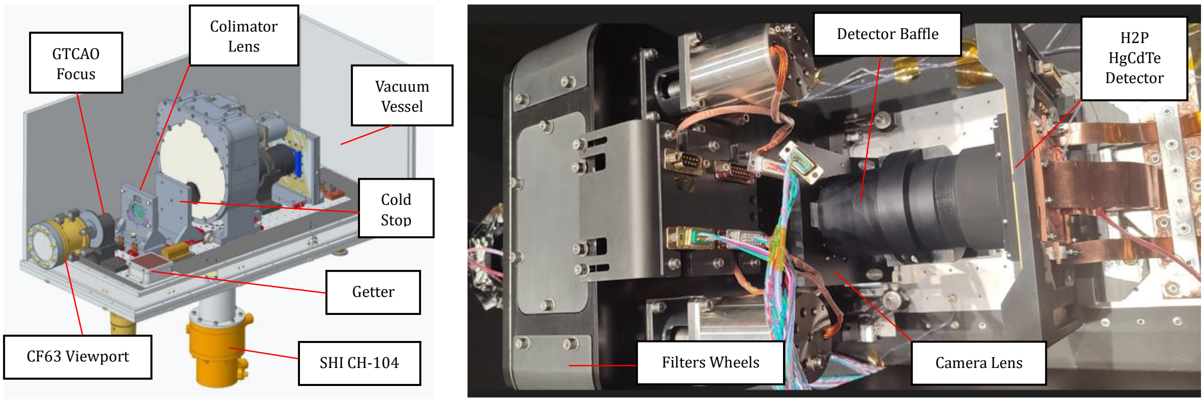

Figure 2. GRANCAIN CAD design vs. physical assembly. Left: 3D CAD model detailing the optomechanical integration in the cold plate within the aluminum vacuum vessel. Right: Top view of the as-built instrument inside the laboratory, showing the optical mounts, mechanisms, wiring harness, and thermal connections.

4. Cryogenic Structure

4.1. Cryostat and Vacuum Performance

The instrument is housed in a 140-liter rectangular cryostat (figure 2) fabricated from aluminum 6061-T6 manufactured in Infrared Labs Tucson, Arizona. The structure includes transverse reinforcement ribs to minimize cover deformation under ultra-vacuum conditions. The vacuum system, anchoring a HiCube 80 Pro turbo-molecular pump, is designed to reach 10^{-4} mbar within 12 hours. Preliminary tests confirmed a leakage rate of $2.81\cdot10^{-6}$ mbar l/s and outgassing rate of $1.12\cdot10^{-6}$ mbar l/s cm^2 at 2.52 hours for N_2.

4.2. Thermal Management and Cooling

Cooling is provided by a Sumitomo SHI CH-104 single-stage GM cryocooler with a capacity of 34W at 77 K. To reduce radiative heat loads, internal cryostat faces are polished. A radiation shield anchored to the cold plate, externally polished and coated internally with Aeroglaze Z306 black, dissipates approximately 30 W of heat power. The cold plate is thermally isolated from the vacuum vessel by four G10 legs. Thermal analysis and in-situ tests in the telescope confirm that the detector reaches 53 K. This provides a sufficient margin for the Lakeshore 336 system to maintain the 77 K set point via thermal resistors (one 10 Ω in the detector fanout and two 22 Ω in the cold plate). The temperature distribution across the cold plate shows a 14 K gradient from the cold-head anchor to the farthest optomechanical mount.

4.3. Vibration Mitigation and Anti-Vibration System

The GM cold-head (CH) induces harmonic vibrations at 2 Hz with displacement amplitudes of 12μm. These vibrations are perpendicular to the optical Z-axis, which is the most sensitive configuration [8], [9]. To mitigate this, a custom anti-vibration system was developed. It consists of aluminum and stainless-steel bellows to anchor the CH to the cryostat and an "octopus" system with flexible Oxygen-Free High Conductivity (OFHC) copper thermal links to mitigate vibrations to the cold structure (figure 3). This system reduces the vibration amplitude reaching the optical bench by a factor of 3. Laboratory tests verified that the vibration displacement of the spot on the detector is approximately 5 μm, which is lower to the pixel size of the detector [10]. The natural frequencies of the cold plate (first mode at 50.13 Hz) are far from the 2 Hz excitation frequency, preventing resonance.

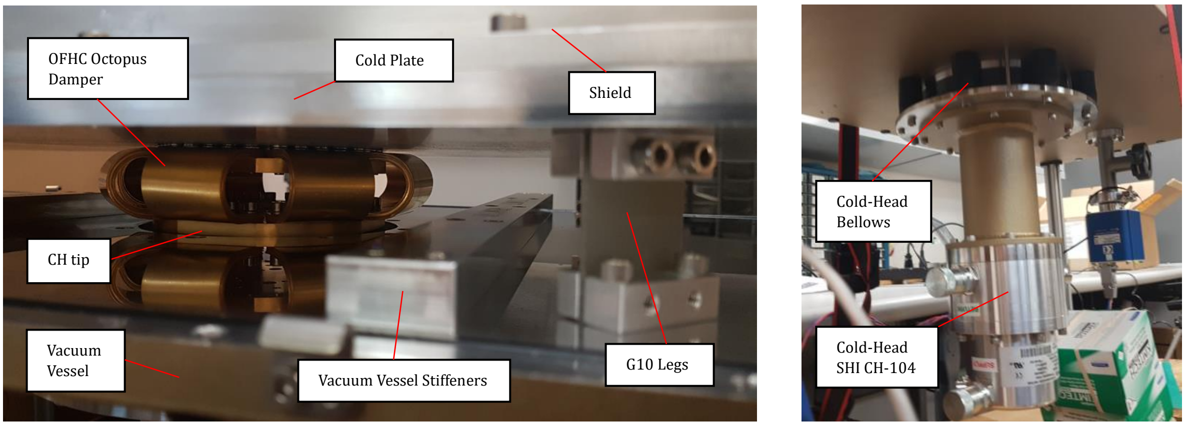

Figure 3. Left: "Octopus" system with flexible OFHC copper links to isolate the cold plate from the tip vibrations of the CH. Right: External bellows designed to isolate the vacuum vessel from the CH vibrations.

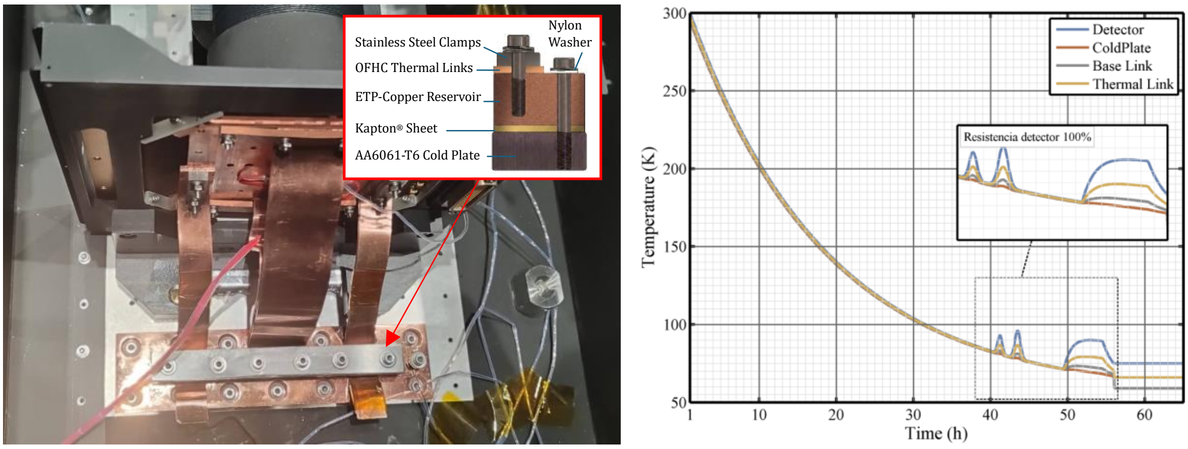

Figure 4. Left: Close-up of the detector integration with the thermal links and the copper reservoir highlighting the electrical isolation for the detector mount using a Kapton® sheet. Right: Cooldown process profile monitoring the detector, cold plate, base reservoir, and thermal links, illustrating the thermal response during testing including the detector heater activation spikes and steady-state thermal resistance control.

4.4. Detector Interface and Electrical Isolation

The detector mount is a critical interface. It is mechanically connected to the cold plate structure through high-conductivity thermal links to ensure rapid cooling. To eliminate parasitic ground currents and electrical noise in the sensitive H2P array, a 0.06 mm thin Kapton® sheet is placed between the cold structure and the detector mount through a copper reservoir (figure 4). This provides essential electrical insulation while maintaining the required thermal stability for image precision and to ensure the survival of the detector against sudden thermal fluctuations.

5. Telescope Integration, On-Sky Performance and Observations

GRANCAIN was integrated into the GTC Nasmyth B platform in June 2025. The instrument is anchored to the platform truss rails via a multi-bar support structure (figure 5). This structure is completely decoupled from the telescope rotator, as the GTCAO system uses its own optical K-mirror derotator. Alignment at the telescope utilizes a kinematic mount with three Spherolinder elements to adjust tip-tilt-plane precisely. The entrance focus of GRANCAIN is aligned to coincide with the exit focus of the GTCAO. Final alignment verification at the telescope involved using the GTCAO calibration source to confirm diffraction-limited performance on the detector.

Initial on-sky science verification has successfully demonstrated the mechanical and thermal stability of the GRANCAIN architecture. The instrument maintains its cryogenic set point within 0.1 K during long exposures, ensuring stable dark current levels. Point-source observations in the K-band confirm that the anti-vibration system effectively preserves the Strehl Ratio provided by the GTCAO, with no significant jitter observed in the resulting images. The telescope is currently in the primary mirror co-phasing phase, utilizing GRANCAIN for imaging and optical quality assessment. Figure 6 shows an on-sky image captured during the AO commissioning phase, aimed at enhancing the telescope's optical performance.

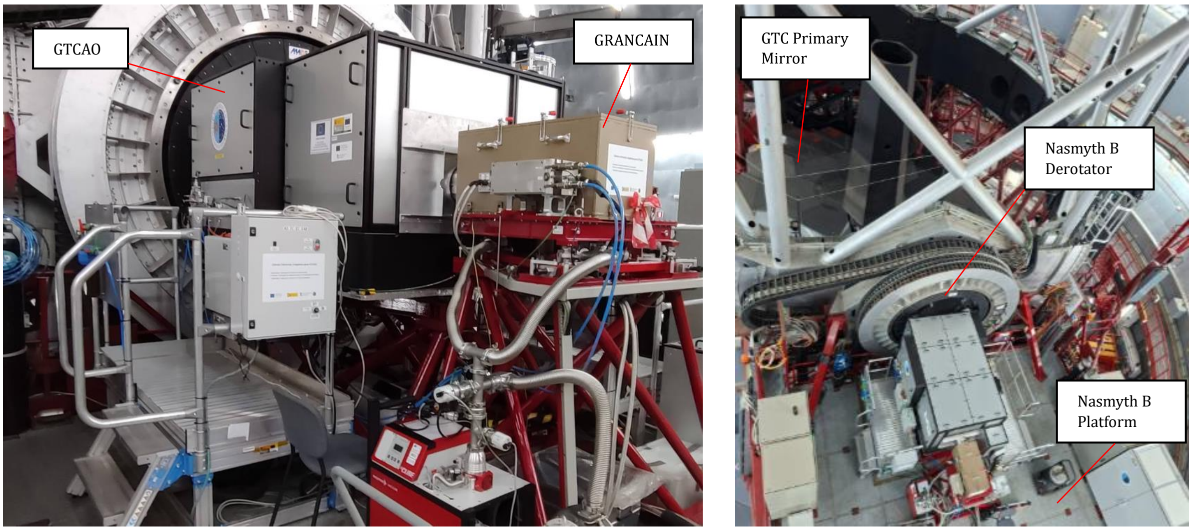

Figure 5. Integration of GRANCAIN at the GTCAO output focus, installed on the Nasmyth B platform of GTC.

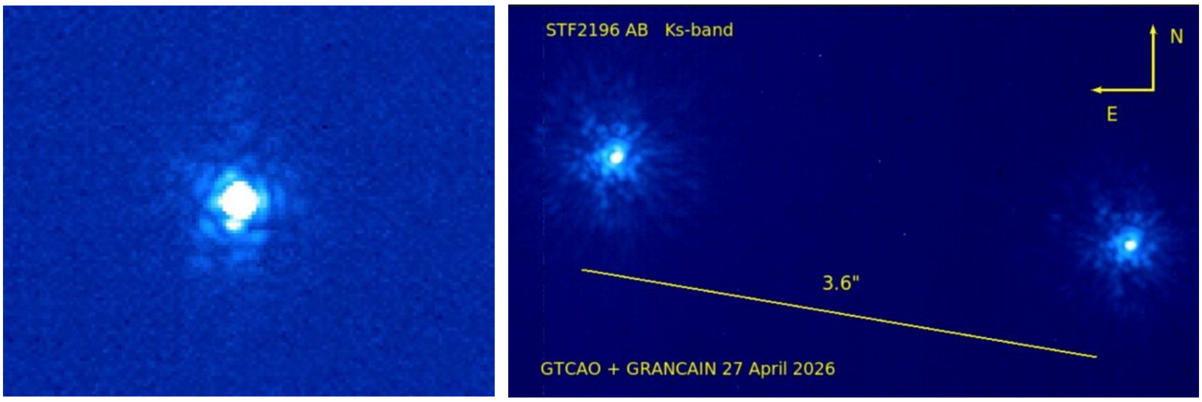

Figure 6. Left: Diffraction limited Image obtained with GRANCAIN in the Ks-band using the calibration source of GTCAO on 5 November 2025. The image has a Strehl Ratio (SR) of 0.91 and a Full Width Half Maximum (FWHM) is of 4.4 pix. Right: GRANCAIN first light image of the binary STF2196 in the Ks-band on April 27, 2026. The core near the diffraction limit and the first Airy ring can be seen in the central part of both stars.

The measured FWHM of 4.4 pixels, which is close to the expected theoretical value, confirms that the anti-vibration system effectively preserves image stability and core resolution at the diffraction limit.

7. Conclusions

The mechanical and cryogenic design of GRANCAIN has successfully met the rigorous requirements for first-light NIR imaging at the GTC. While GM closed-cycle systems inherently introduce more severe harmonic vibrations than Pulse Tube cryocoolers, they offer a significantly simpler and more robust operational architecture. Laboratory and on-sky performance demonstrated that these critical disturbances can be thoroughly mitigated with a proper anti-vibration design; in this case, the implementation of a custom "bellow-octopus" system reduced mechanical displacements to a level comparable to more complex cooling alternatives, achieving the necessary 60–77 K environment without compromising the high-resolution image quality provided by the AO. Furthermore, the integration of thermal masses acting as reservoirs ensures excellent thermal stability, effectively dampening transient temperature fluctuations during operations. By minimizing background radiation and dark current through robust vacuum and thermal engineering, GRANCAIN provides the GTC with a highly sensitive tool to capture infrared images at the diffraction limit. Currently, the instrument is actively deployed at the telescope, playing a fundamental role in the fine co-phasing of the GTC segmented primary mirror and serving as the primary benchmark for the performance evaluation of the GTCAO system.

Acknowledgments

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