Las Cumbres Observatory 'Sinistro' astronomy imager captures first light

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The Sinistro Camera is mounted. The controller is at the bottom, the camera body above that, and the 21-slot filterwheel above that. Credit: LCOGT

Las Cumbres Observatory Global Telescope (LCOGT), with first lights at nine new 1-meter telescopes since April of 2012, achieved another critical milestone by capturing the first on-sky image with a production Sinistro camera. In development for over six years, the camera is arguably more important than the telescopes that will use them. "A telescope is really nothing more than a large camera lens," explained Joe Tufts, instrumentation scientist on the Sinistro project. "A large, precise, stable, and very expensive camera lens."

Sinistro is the primary science camera designed specifically for the LCOGT 1-meter telescope network. While numerous science cameras are available in a more or less off-the-shelf format, all make design choices which are not optimal for LCOGT science and operations. LCOGT opted for an in-house design to provide the fastest possible readout with a noise consistent with that of observable 1-meter astronomical sources, while at the same time allowing for extremely flexible configuration, and robust telemetry suitable for remote robotic operation.

This week, the first production Sinistro, vacuum-pumped to 1e-7 mbar, and cooled 100 ºC below freezing, snapped its first on sky images. Tufts said, "If any one thing had not gone right – if a near-perfect vacuum was not achieved, or complete cooling – the image would not have been possible. So those first images tell us a lot."

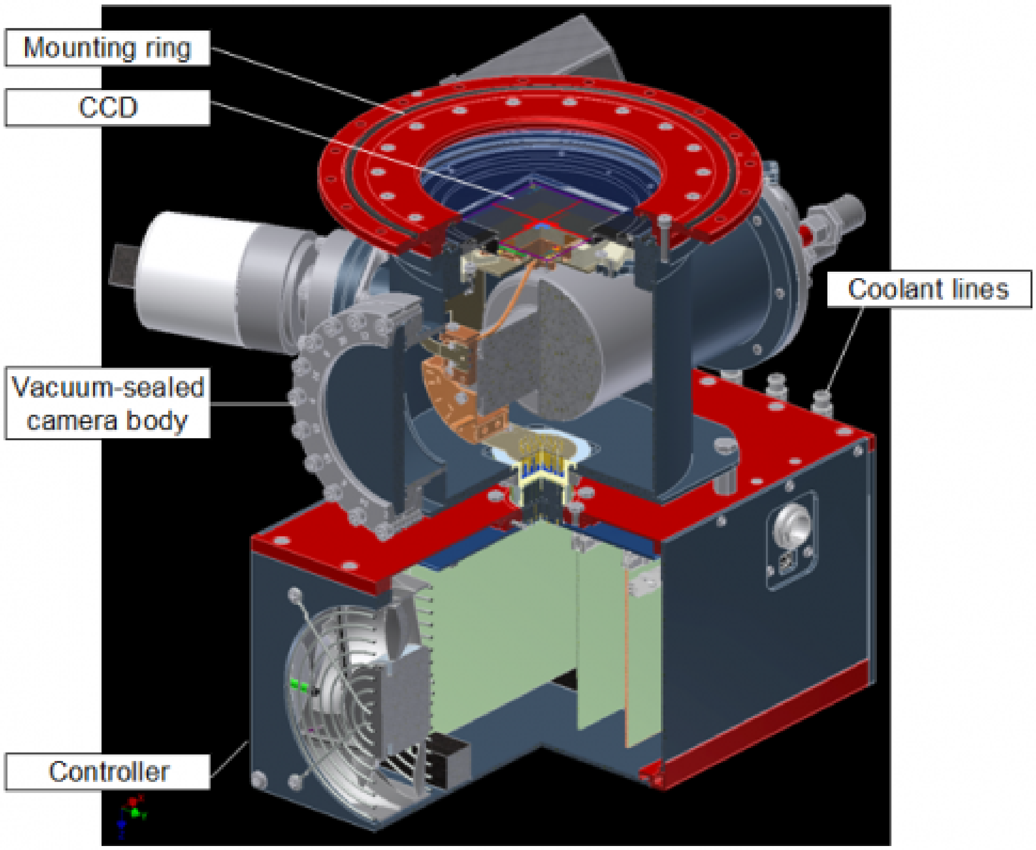
The camera was ultimately developed by a closely-integrated team of four divergently trained engineers at LCOGT. Tufts is an instrumentation scientist; Rich Lobdill, electrical engineer and designer; Ben Burleson, software engineer; and Annie Hjelstrom, mechanical engineer.

Sinistro, which means left-hand (three members of the team are left handed) in Italian, was loosely named after the villain in Joe's favorite childhood book, La Verità si Trova Spesso al Buio. Presently the Sinistro is achieving about 7 e- noise which is 40% of the noise of the current off-the-shelf production camera. This translates to a 0.4^2=0.16 times the minimum useful exposure time. Sinistro is also roughly a half magnitude (40%) more sensitive and the minimum exposure time to achieve a background (rather than read noise) limited exposure is about 9 times shorter than the current camera. "So," Tufts stated, "in one sense the camera is 9 times faster than the current one."

A Long Lens

The LCOGT 1-meter network is designed for scintillation limited time domain astronomy. Scintillation refers to variations in the apparent brightness or position of a distant luminous objects viewed through a medium such as Earth's atmosphere. For Las Cumbres Observatory, this typically means variable light sources in the night sky and includes objects and events such as supernovae, gamma ray bursts, exoplanet microlensing, and near-earth objects.

These targets require precision photometry, typically of a single variable source. To extract this information despite a highly variable atmosphere typically requires real time comparison to nearby celestial objects of similar brightness. To this end, the Sinistro camera is designed to give the largest possible field while maintaining the atmospheric turbulence limited resolution of the telescope system. This translates to a 26.6 arcminute field of view with a resolution of 0.389 arcseconds per pixel. (Arcminutes are an angular measure equivalent to 1/60th of a degree. The angle covered by the diameter of the full moon as viewed from earth is about 30 arcminutes, while 0.389 arcseconds corresponds to a US dime viewed from about 6 miles away). The design optimizes the network as an excellent follow-up tool for larger field surveys like the existing Pan-STARRS and Sloan Digital Sky Survey (SDSS), and the proposed future Large Synoptic Survey Telescope (LSST).



This is a cut-away view of the Sinistro camera. Credit: LCOGT

Currently using a Fairchild Imaging 486 charge-coupled device (CCD), Sinistro is designed to work effectively with a variety of high resolution CCDs with a host of differing read-out modes. This allows the upgrade of CCDs in the future, or deployment on other telescopes with CCDs more closely optimized to the purposes of those telescopes.

Hard Body

The Sinistro camera consists of a stainless steel chamber that serves electrical, thermal, and mechanical functions. Built in a clean-room, the camera is fully sealed using metal gaskets prior to removal to the testing bench.

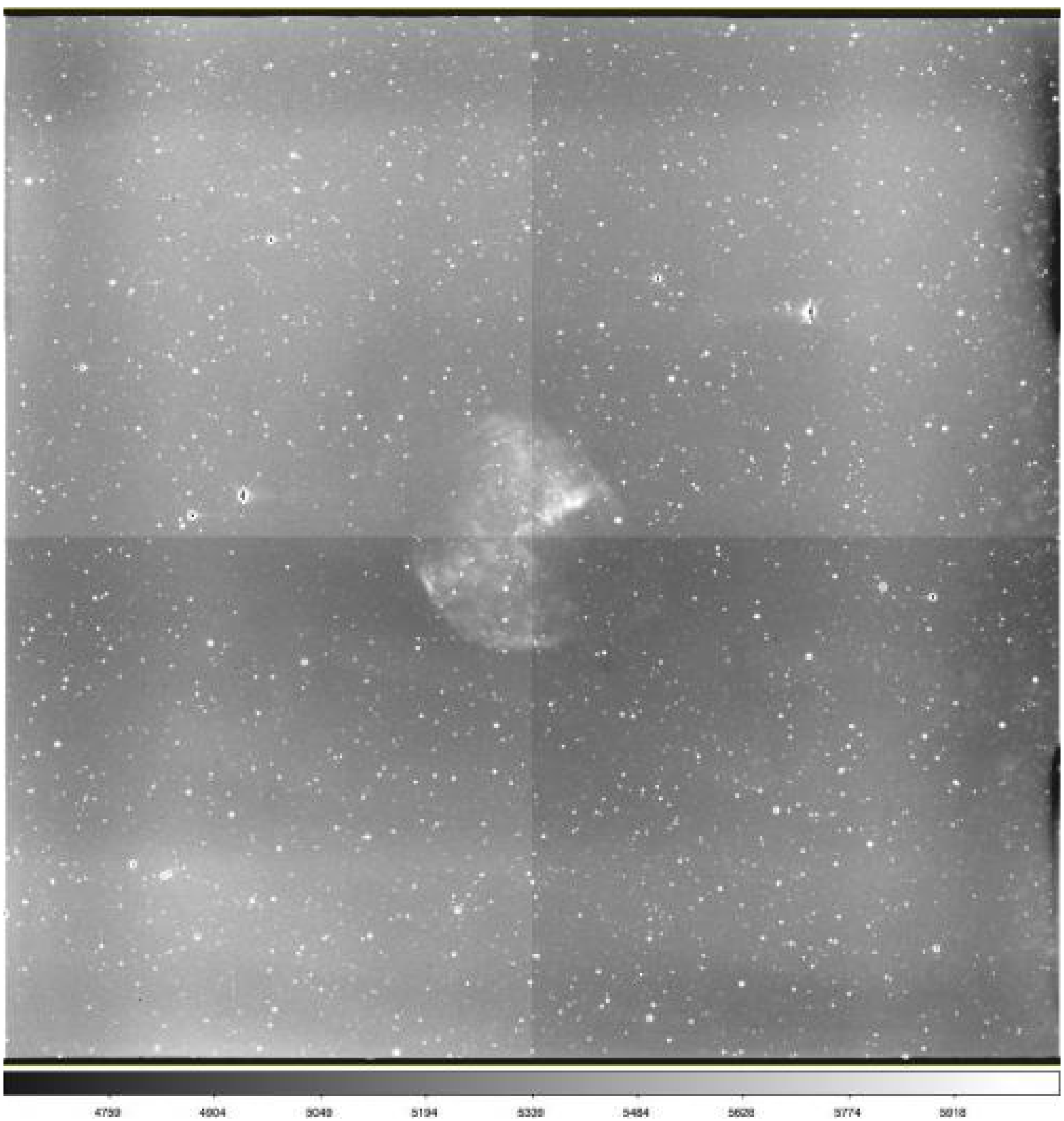
Tufts reported earlier in the week that, "After a week of scrubbing, washing, baking, and dust free assembly, Annie Hjelstrom gets a production Sinistro camera on the vacuum pump. Over a weekend the pressure drops inside the camera by a factor of 10,000,000 removing enough of the air to insulate the dry-ice cold CCD from the relative oven of the lab. By late Monday morning we can begin cooling the detector, and by the late afternoon achieve an operating temperature of -100.000 ºC."

Hjelstrom's design of the thermal controls was key. The design called for 0.5 W of control heat, and a base temperature of -120 ºC to keep the CCD safe from breakage. The fabricated and functioning Sinistro was expected to diverge to some extent from the design specifications, but after a long cooldown settled at 0.56 Watt and -119.85 ºC, which was functionally and technically perfect. In addition, the cold end of the thermal body achieved a base temperature of -197 deg C. "That's cold enough to liquify the air we breath," said Tufts, "and for the cryopump to remove another 90% of the remaining air."

Tufts explained, "there are over 1000 electronic components connected by a custom-built digital fabric consisting of 1000s of lines of hardware, microcontroller, and Windows code all doing exactly what they should do, exactly when they should do it, about 4 million times a second. And we did it on the first try."

Noise and Speed

Rich Lobdill who characterizes his role in designing the Sinistro control system as "why I wanted to come to Las Cumbres," was able to start with a very clean slate. The system requirements were low noise, high speed, and flexible configuration. The basics of such a system are the CCD itself which captures photons, a clock board that sequentially offloads the photo-electrons from the CCD, an analog board to digitize the electrons, a digital signal processor (DSP) that governs the parsing and sequencing of the clock and analog boards, and a modularly-configurable control board internally known as a Superfin that manages the system telemetry and control.



Sinistro’s raw, unprocessed first light image. Credit: LCOGT

Beyond this basic configuration, Lobdill remained intentionally naïve about how other photometric systems were designed, knowing that most suffered higher read noise that he was targeting because they used electronic switches during the read process. "I used linear processing which results in very little noise during readout." Lobdill was ultimately able to achieve his goal of reducing noise during high-speed readout to less than 10 electrons Root Mean Square per pixel (10e? RMS).

Ben Burleson's role has been translating the electrical design into functional drivers that control the camera/shutter and servo the temperature to within 0.5 mK. Burleson reflected that, "Working on Sinistro's software is an exciting challenge. We have to meet tight tolerances to produce what are literally amazing results. But it's worth it to witness what truly great engineering can accomplish."

The teams' overall target was to reduce readout, and all other system changeover times, to 4 seconds. To achieve the 4-second readout, the CCD is read by four parallel analog processors. In fact, the entire instrument system including the 21-slot filterwheel was optimized with three filter carousels and a photometric disk shutter to meet this specification. The goal is still elusive – optimal readout is currently firmware limited to 12 seconds – but with the camera functioning on-sky, the team can now focus more fully on performance.

The built in flexibility enables the standard square binning (2x2, 4x4), rectangular binning (2x4, 2x8, etc.), multiple selective regions of interest, and adjustable read-out speeds. The regions of interest option can speed camera function immensely by essentially skipping the readout and storage of all but the selected rectangular regions. Adjustable read-out allows an astronomer to request a slower readout which results in less noise, down to as low as 1 to 2e? RMS.

The system is also configurable to different CCDs and different CCD configurations. The system has been successfully configured and tested to run a mosaic of 2x2 4k x 4k x 10 um pixel detectors on the 1-meter telescopes. This provides a larger field of view for more accurate photometry and simultaneously a better resolution for the sites that permit it. It also enables the team to build an instrument for the 2-meter telescopes with essentially the same field of view as the 1-meter telescopes.

Deployment of the Sinistro cameras to the field is expected to begin this year. The first site will be either McDonald Observatory in Texas because it is relatively close to LCOGT headquarters, or the Cerro Tololo LCOGT node in Chile. There is one 1-meter deployed at McDonald, three at CTIO, thus Chile makes the best sense if three production Sinistro cameras are ready.

Provided by Las Cumbres Observatory Global Telescope

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