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EXOTIC IMAGING: IR focal-plane arrays enable imaging that is out of this world

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The HAWAII-2RG infrared focal-plane arrays are incorporated in some of the largest ground-based observatories in the world, and are bound for space too.

JAMES W. BELETIC

Infrared astronomy has advanced rapidly since the first two-dimensional IR-imaging arrays were produced in the 1980s. From the modest 32 × 32-pixel arrays that provided a breakthrough 20 years ago, the size of IR arrays has increased to the 2048 × 2048-pixel arrays that are now the standard in IR astronomy. Infrared arrays have greatly expanded the exploration capability of telescopes because infrared can see through the gas and dust in star-forming regions (see Fig. 1). Infrared wavelengths are also required for studying distant galaxies for which the expanding universe has shifted visible light into the IR spectrum.

FIGURE 1. The Orion Nebula was imaged with the WIRCam (Wide Field Infrared Camera) of the 3.6 m Canada-France-Hawaii Telescope in Hawaii. WIRCam is based on a 4096 × 4096-pixel mosaic of four H2RG short-wave (1 to 2.5 μm) sensors (inset). Most of the red stars in this image were first observed with the advent of IR cameras. (Courtesy of Canada-France-Hawaii Telescope)

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The HAWAII-2RG is Teledyne's most advanced IR-imaging array for astronomical instrumentation and is widely used in the newest generation of instruments for ground-based and space-based observatories (see Fig. 2). The HAWAII-2RG (H2RG) is a 2048 × 2048-pixel array based on 18 μm pixel pitch that provides high quantum efficiency (QE greater than 80%) and very low noise (less than six electrons), which enables astronomers to detect and study the faint light from the most distant galaxies.

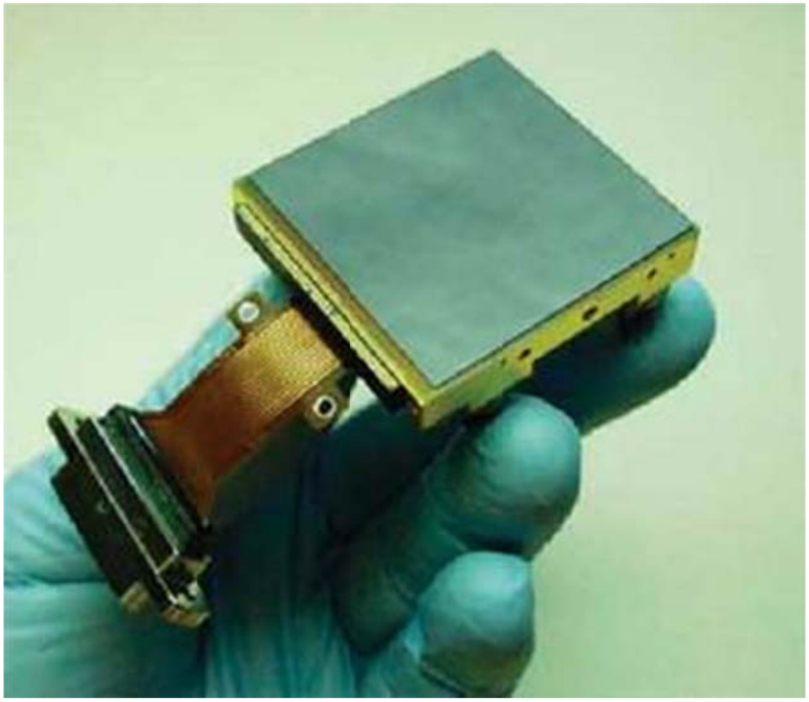

FIGURE 2. The HAWAII-2RG (H2RG) is a 2048 × 2048-pixel imaging array. (Courtesy of Teledyne Imaging Sensors)
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Fifteen H2RG IR arrays (63 million pixels) will fly in the James Webb Space Telescope (JWST; seewww.laserfocusworld.com/articles/277182), and the H2RG is in use or planned for instrumentation at nearly every major ground-based observatory. Many instruments will use a mosaic of four H2RG arrays to provide a 4096 × 4096-pixel focal-plane array (see Fig. 1 inset). The H2RG is the most prominent member of the evolving HAWAII family of IR imaging arrays produced by Teledyne Imaging Sensors for astronomy. The HAWAII acronym stands for mercury cadmium telluride (HgCdTe) Astronomical Wide Area Infrared Imager, and other members of the HAWAII family are the H1, H1R, H1RG, and H2. For these arrays, the H stands for HAWAII, the number 1 or 2 denotes 1024 × 1024 or 2048 × 2048 pixels, R denotes reference pixels, and G denotes guide-window capability.

Many H1 and H2 arrays are in use at ground-based observatories (see Fig. 3). The H1R flew on the Deep Impact asteroid intercept mission and is integral to the Wide Field Camera 3 (WFC3) being installed in the Hubble Space Telescope in 2008. In addition, two mid-wave IR (sensitive to 5.2 μm) H1RG arrays will be flown in the Wide-field Infrared Survey Explorer (WISE) to launch in 2009 for an all-sky 3.5-to-23 μm IR survey.

FIGURE 3. This composite of three images was taken using J, H, and K filters with Teledyne's HAWAII-1 short-wave IR detector array (1 to 2.5 μm) in the ISAAC instrument of the Very Large Telescope (VLT) in Chile. The pillars in the infrared view of the Eagle Nebula are less prominent than in visible-light images because near-IR light penetrates the thinner parts of the gas and dust clouds. (Courtesy of European Southern Observatory)

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Hybrid arrays

The HAWAII imaging sensors are hybrid complementary-metal-oxide-semiconductor (CMOS) arrays that combine the light-sensing capability of an IR detector material with the low noise and high functionality provided by a CMOS integrated circuit (see Fig. 4). The CMOS circuit is fabricated in the same silicon foundries that produce computer chips, but special amplifiers are required to sense the very small packets of photo charge produced by faint astronomical sources.

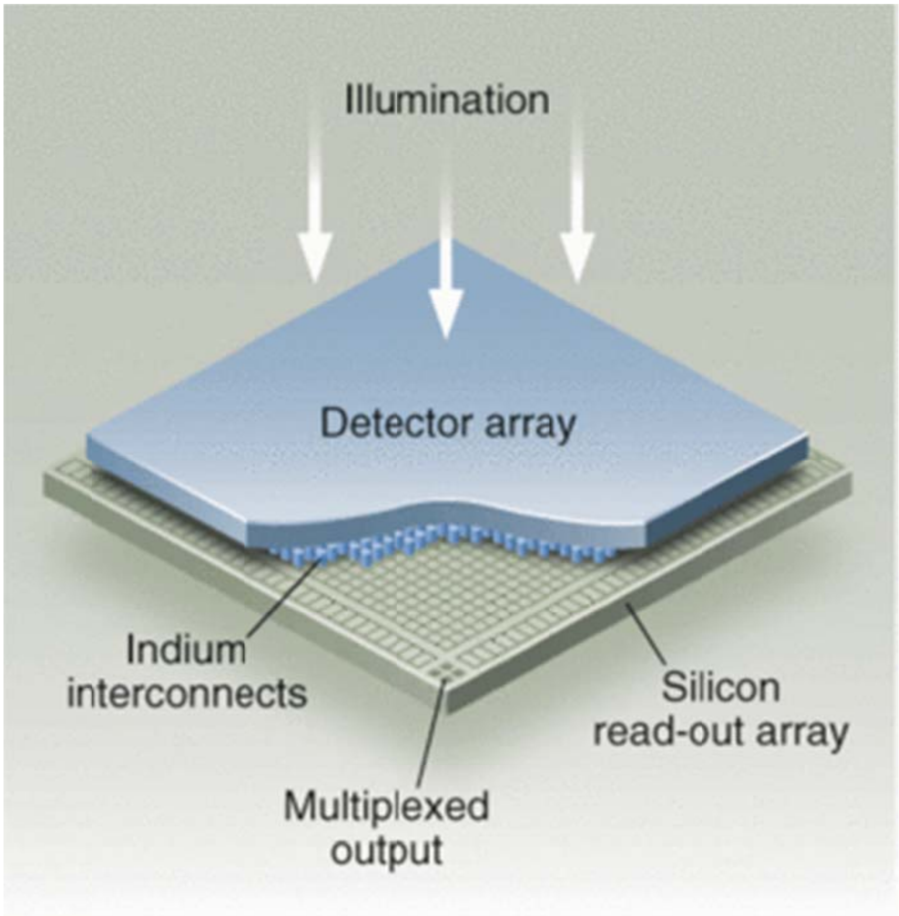

FIGURE 4. A hybrid CMOS detector array converts the illumination into photo charge that is collected into individual pixels within the detector layer. The photo charge is conducted to an amplifier in each pixel of the silicon read-out array by an indium interconnect. For the H2RG, there are more than 4 million indium "bumps." A sensitive amplifier within each pixel of the H2RG read-out array converts the electrical charge to a voltage signal that is output through the "multiplexer." The H2RG has 32 outputs for transmitting the amplified signal off-chip; the entire image can be read out of 1, 4, or 32 outputs. (Courtesy of Ian McLean, University of California, Los Angeles)

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For the IR detector material, Teledyne uses a layer of HgCdTe, slowly and precisely grown one atomic layer at a time, using molecular-beam epitaxy. A unique feature of HgCdTe is that, by varying the ratio of mercury to cadmium, we can optimize the bandgap and therefore the wavelength sensitivity of the detector layer for the scientific mission. Teledyne produces HgCdTe arrays with wavelength cutoffs for near-IR (1.7 to 2.5 μm), mid-wave (5 μm), long-wave (8 to 10 μm), and very long wave (up to 18 μm). The hybrid CMOS architecture produces

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