



Highlights from HST/NICMOS

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Abstract

The near-infrared camera and multi-object spectrometer (NICMOS) was installed in the Hubble Space Telescope in February 1997. After 22 months of operation the 110 kg supply of solid N₂, which cooled the NICMOS-3 HgCdTe detectors, was exhausted. The cryostat warmed up leaving the instrument in an electromechanically functional, but scientifically non-viable, passive state. Following a three year suspension of observations, an active cooling system featuring a reverse Brayton cycle micro-turbine was installed and integrated with NICMOS during HST servicing mission 3B. As a result the NICMOS detectors and cold optics have successfully been re-cooled to operationally effective temperatures and the science program has begun. We review the operating characteristics of the NICMOS instrument, its new cooling system, and its performance both in absolute terms and in comparison to its previous on-orbit incarnation. We discuss the scope and nature of the astronomical investigations that have been and are again enabled with NICMOS. Additionally, we present some of the first scientific results from programs executed with the re-cooled NICMOS.

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Prelude

“We recommend that the Reverse Brayton-Cycle Cryocooler of the NICMOS Cryocooler System (NCS) be installed on NICMOS on the SM3 servicing mission provided that a number of important concerns listed in Sections 6 and 7 are resolved to the satisfaction of the usual technical and flight-readiness reviews prior to flight. If the installation is successful and the astronomical findings continue to be of unsurpassed quality, a future review should determine whether routine operations should continue beyond SM4.” (Harwit, 1999).

1. Introduction

After a more than three year hiatus the near-infrared camera and multi-object spectrometer (NICMOS) has been returned to full operational status on the Hubble Space Telescope (HST). The three cameras in the NICMOS instrument provide near-infrared (NIR) im-

agery with spatial resolutions from $\sim 0.1''$ – $0.25''$ in spatially adjacent (but non-contiguous) wide and narrow fields-of-view. Working in space in the NIR (from 0.8–2.4 μm), NICMOS peers through dusty regions obscured at optical wavelengths that are otherwise compromised by the intrinsic brightness, wavelength-dependent opacity, and turbidity of the Earth’s atmosphere. The diversity of instrumental observing modes, including deep-imaging, wide-field imaging, coronagraphy, polarimetry and slitless (grism) spectrophotometry, have allowed NICMOS to address a wide range of astrophysical investigations from within our own solar system to the most distant reaches of the currently observable universe. Emissions from young objects embedded in optically opaque star and planet forming regions may be studied by NICMOS individually in our own galaxy and collectively in others. Light from the oldest observable galaxies is red-shifted from the rest-frame optical into the NICMOS pass bands.

Originally installed in February 1997, NICMOS was used heavily by astronomers in HST Cycle 7/7N. These capabilities ceased on January 4, 1999 when its supply of solid nitrogen cryogen, used to cool the instrument

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detectors and filters, was exhausted. During HST servicing mission 3B (March, 2002) a pathfinder “experiment” in space/cryogenic technology culminated in the subsequent re-cooling and resurrection of NICMOS. With the installation of a reverse Brayton-cycle micro-turbine cooler, heat-exchanger, and external radiator on HST, cryogenic Neon-gas circulating through the NICMOS cooling coils is now maintaining the NICMOS detectors and cold-optics at nearly optimum and highly stable temperatures. NICMOS is the first space cryogenic instrument to ever have been re-activated after cryogen depletion. The success of SM3B has literally moved space infrared (IR) astronomy out of the ice age.

2. Why augment HST with a near-infrared instrument?

NICMOS extends the Hubble Space Telescope’s UV/optical panchromatic vision into the NIR fulfilling a Level-1 requirement of the HST mission. With NIR light we penetrate regions obscured at visible and ultraviolet (UV) wavelengths. Dust, which is pervasive and prevalent in many forms throughout the universe, obscures many of the most interesting objects in optical/UV light and limits our ability to understand the dynamical, evolutionary, and energetic processes in many others. NIR light can penetrate this dust to reveal the birth places of planets, stars, and galaxies, as well as the centers of the most powerful galaxies in the universe.

We can also see further back into the ancient history of the universe with NIR light than in the visible and UV. With the global expansion of the universe, electromagnetic radiation is redshifted to longer wavelengths. The intrinsically more distant an object is, the greater the redshift, such that the most distant (currently) observable objects – those with the greatest redshifts – emit their light not in the optical/UV, but in the infrared. Distant quasars and galaxies provide, in the NIR, a look-back in time to the early epochs of the assemblies of large structures in the universe.

2.1. Penetrating the dusty murk

We demonstrate the dust-limiting views obtainable at UV/optical opaque wavelength as compared to the NIR by looking at two of the most well-known HST-observed fields, the Eagle Nebula and the Trapezium region of the Orion Nebula (Fig. 1). Optical/WFPC-2 images of the Eagle Nebula’s vast dust and gas clouds (dubbed the “Pillars of Creation”) by Hester et al. (1996) gave rise to an interpretation of a seething stellar nursery, but with most of the birthing process hidden from view by the obscuring dust. Peering through the dust with NICMOS we see a plethora of background stars, but very few are actually within the pillars, which are being ablated by photoionization from external very

hot stars. The NICMOS image reveals that except for isolated regions at the tips of the pillars, the era of active star formation within the Eagle Nebula has largely terminated (Thompson et al., 2002). The inverse, however, seems to be true in the optically thick region of the Orion Molecular Cloud’s Trapezium cluster. The optical image reveals young stellar objects with cocoons of enshrouding dust seen in silhouette against the ionizing radiation from the Nebula in the background (Bally et al., 2000), indicative of stellar/planetary systems in formation. NICMOS penetrated the dust and revealed a continuity of objects below the low-mass end of the stellar population with at least 50 young brown-dwarfs unseen in the optical, some of masses as low as 1% of the Sun (~10 times the mass of Jupiter and hence in the domain of giant planet masses). The formation of such a moderately large number of isolated low mass objects as seen by NICMOS was contraindicated by most theories of the initial mass function (Luhman et al., 2000).

2.2. Seeing deeper into the distant past

In 1995, before the NICMOS era, HST stared deeply, for 10 days, into an “empty” region of space devoid of any stars and bright galaxies (known as the “Hubble Deep Field” or HDF), resulting in what was at the time the deepest image of the early universe ever obtained (Williams et al., 1996). The WFPC-2 optical view, with integration times of ~40 h in each of four pass bands, revealed distant galaxies as faint as ~ magnitude 28. The four-color image left the impression of highly disorganized and fragmented structures (some referred to as “train-wrecks”) that very significantly modified the until-then prevailing thinking about early galaxy formation. NICMOS, in 1998, studied a selected portion of this same field (Thompson et al., 1999), finding ~44% more galaxies in the overlapping region than seen in the optical (with comparable integration times). The most distant (faintest) galaxies seen by NICMOS have NIR magnitudes of ~30 and ages of ~13 billion years (subject to the cosmology one adopts). Moreover, the lumpy “train-wrecked” appearance of the galaxies in the optical view (which imaged only their bright knots of star-birth) vanished in the NIR as the underlying disk structure, comprised of older (and redder) stars, invisible in the optical, emerged.

2.3. NICMOS observing modes

NICMOS opens up many other avenues of scientific investigation through its diversity of observing modes and capabilities (e.g., Fig. 2). In addition to deep imaging as in the HDF, and wide field imaging as in the Orion nebula, NICMOS enables discovery spaces through: Molecular and/or atomic line imaging in bands significantly affected by, or unavailable because of,

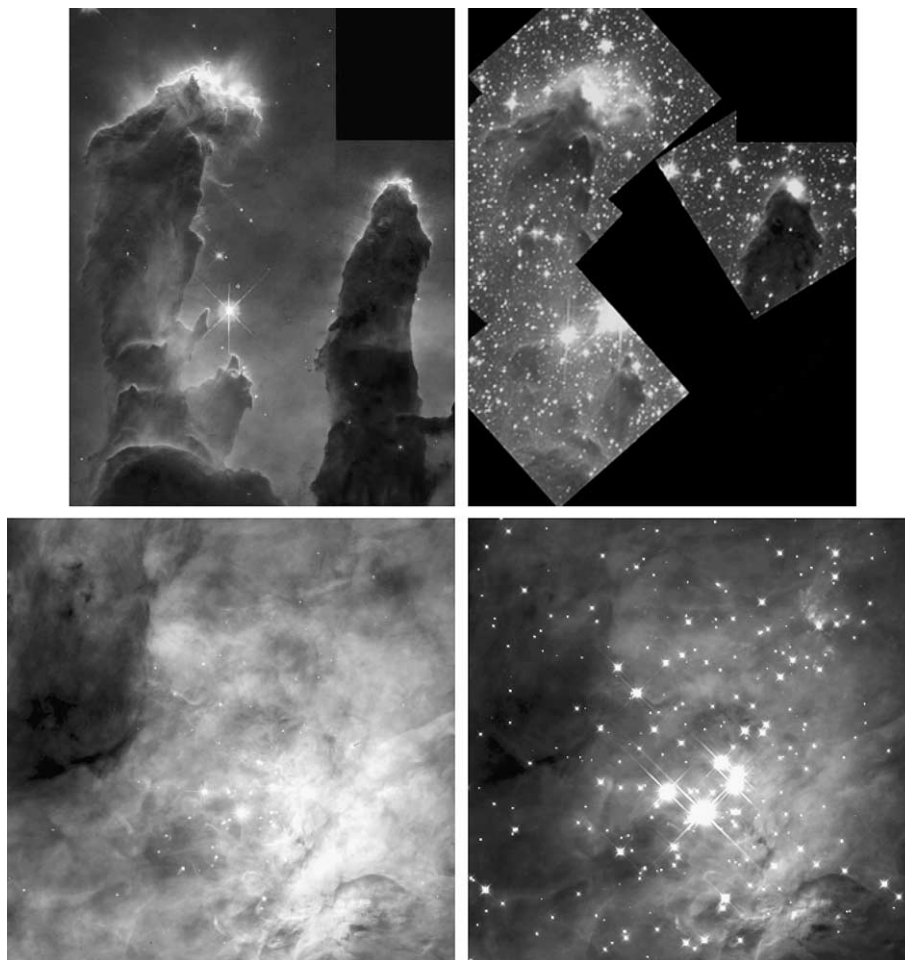


Fig. 1. Visible light (left) images of the Eagle (top) and Orion (bottom) Nebulae (trapezium region) obtained with HST/WFPC-2 compared to NIR (right) images of the same spatial regions taken with NICMOS.

atmospheric telluric absorption (e.g., Paschen- α at 1.87 μm , a critical tracer of star formation in active galaxies); polarimetric imaging at high spatial resolution, and very low (<1%) instrumental polarization, which helps elucidate the nature of circumstellar and interstellar grains and their interactions with their environments; full-field low-spectral resolution ($R \sim 100$) grism (slitless) spectrophotometry at all wavelengths accessible to NICMOS; high dynamic range imaging which, when coupled with point-spread-function (PSF) subtracted coronagraphy yields per-pixel H-band background rejections in the unocculted wings of the PSF of an occulted point-target of 10^{-7} that of the flux density of the target (and $\sim 10^{-6}$ that of the peak pixel in the PSF core).

3. NICMOS – the instrument

3.1. Overview

NICMOS contains three independently re-imaged optical channels presenting different image scales and

field sizes to its NIR detectors over the wavelength regime from 0.8 to 2.4 μm . All three cameras carry 19 spectral elements, each with 16 wide, medium-band, and atomic/molecular line filters ($\sim 25\%$, 10%, and 1% pass bands), with a core set of “standard” photometric filters in each camera. Camera 1 provides high-resolution imagery, diffraction limited at and longward of 1 μm , over an $11'' \times 11''$ field-of-view. This $f/80$ camera is sampled by its focal plane detector with 0.043'' pixels. Camera 1 is equipped for polarimetric imaging at 0.8–1.1 μm with <1% instrumental polarization. Camera 2 provides a wider field ($19.3'' \times 19.4''$) at $f/45$, and is diffraction limited to a wavelength of 1.75 μm as sampled by 0.076'' wide pixels in its image plane. Camera 2 contains coronagraphic optics for high contrast imaging in the regions around point sources, optimized for H-band (1.6 μm) and shorter wavelengths. Instrumentally diffracted and scattered light in the wings of the PSF of coronagraphically occulted targets is reduced significantly when a bright object is placed in the 0.3 arc second radius coronagraphic occulting spot. Imaging polarimetry at wavelengths longer than in camera 1 (1.9–2.1 μm) is

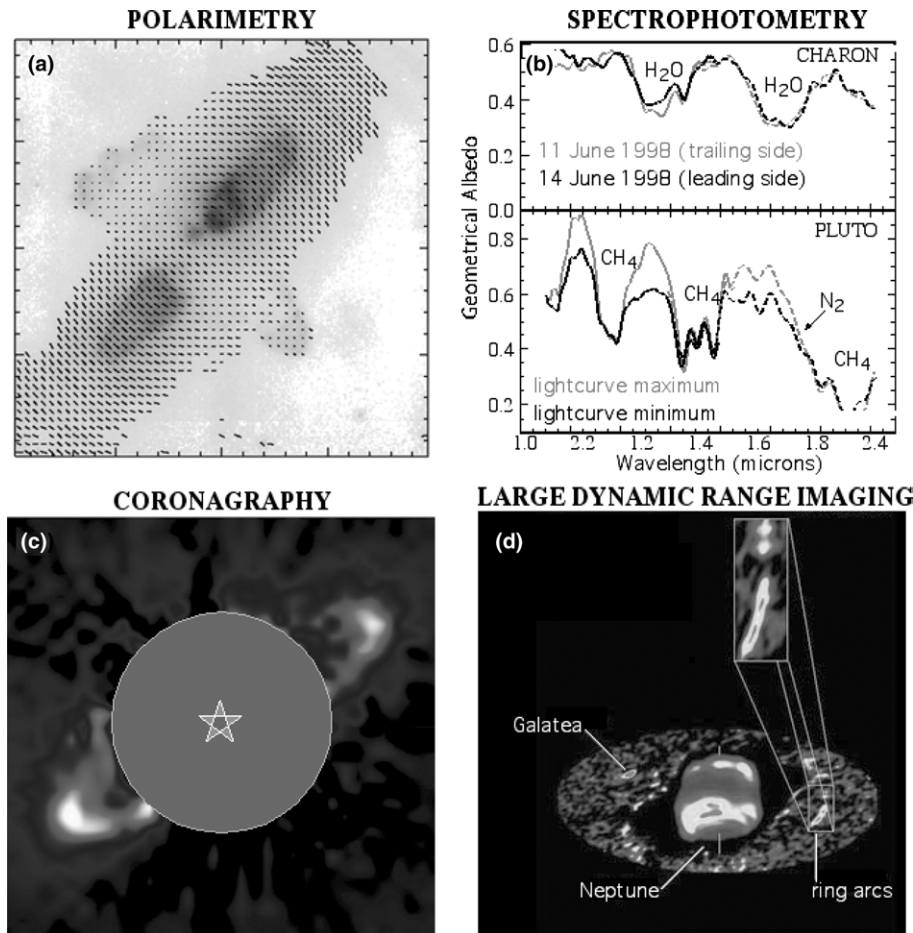


Fig. 2. Representative scientific investigations utilizing NICMOS. (a) Outflow properties associated with the death of a sun-like star, CRL 2688 (Hines et al., 2000). (b) Surface ice composition of Pluto and Charon (Dumas et al., 2001). (c) The dusty circumstellar debris ring about HR 4796A (Schneider et al., 1999). (d) Post-Voyager recovery of the Neptune ring-arcs (Dumas et al., 2001).

available in camera 2 with similar low instrumental polarization as in camera 1. Camera 3 enables wide field imaging at “short” wavelengths ($<1.9 \mu\text{m}$), with a $52'' \times 52''$ field-of-view in its $f/17$ optical channel. Although spatially undersampled with the filters provided, camera 3 is well suited for deep imaging. Camera 3 also provides three gratings for slitless spectrophotometry, with spectral resolutions of ~ 100 , covering the full wavelength range of sensitivity of the NICMOS detectors. The fields-of-view of the three cameras are nearly adjacent on the sky, but not spatially contiguous. Simultaneous imaging with all three cameras is possible, but camera 3 (the “wide field” imager) is not confocal (an unrealized goal, but not a requirement for NICMOS) with cameras 1 and 2.

3.2. NICMOS detectors

NICMOS, the instrument, employs three NICMOS-3/PACE technology detectors, which were manufactured for space-qualified use by the Rockwell Electro-Optics Center under the direction of the

University of Arizona’s Steward Observatory. The three 256×256 pixel HgCdTe photodiode arrays (one at the re-imaged focal plane of each camera) are indium-bump bonded to a sapphire substrate and addressed through a silicon multiplexor. Each 128×128 pixel quadrant is read out through independent on-chip amplifiers (located at the four corners of the focal plane array), and sampled with 16-bit analog-to-digital converters. The NICMOS detectors can be read-out non-destructively while integrating from 0.2 to several thousand seconds, providing a sampling (data quantization) dynamic range of 22 stellar magnitudes in a single exposure. The per-pixel detector read-noise is typically ~ 22 electrons when read-out in this non-destructive “multiaccum” mode. A “bright object mode” supports per-pixel integrations as short as a millisecond. Dark currents are $\sim 0.1 e^{-1} s^{-1} \text{pixel}^{-1}$ with the arrays at a temperature of 61 K (where they were operated on-orbit from 1997–1998 with a solid nitrogen (SN_2) coolant) and $\sim 0.2\text{--}0.3 e^{-1} s^{-1} \text{pixel}^{-1}$ at 77 K (where they are currently being operated, cooled by recirculating cold Neon gas). The arrays exhibit wavelength-dependent detective quantum

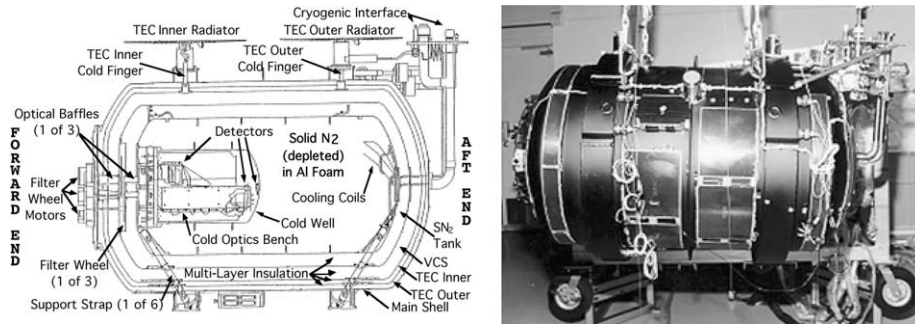


Fig. 3. Schematic representation (also see Malhorta et al., 2002) and post-fabrication photograph of the NICMOS dewar.

efficiencies (dQE) of $\sim 30\text{--}80\%$, with dQE increasing at longer wavelengths where the inter-pixel dispersion in dQE is greatly reduced. The devices reach hard saturation with well-depths of $\sim 200,000$ electrons, and respond with a very high degree of linearity to $\sim 75\%$ of full well depth.

3.3. NICMOS dewar and plumbing

The NICMOS detectors are mounted on a ridging Invar optical bench in a “cold well” inside of an evacuated dewar as shown in Fig. 3 (left). The dewar, containing a 98% porous aluminum foam outside of the cold well, was filled with 110 kg of liquid N_2 before launch and frozen by flowing liquid helium through a set of cooling-coils at its aft end. Fig. 3 (right) shows the as-built dewar before integration with the NICMOS optics and placement into the instrument enclosure. Light enters the dewar through three heavily baffled optical entrance ports passing through sapphire windows. The dewar cavity was sealed and periodically re-cooled on the ground, but vented on orbit to maintain the SN_2 below its triple-point and to permit the slowly sublimating nitrogen gas to cool the optical filters. Pre-launch, the predicted on-orbit lifetime of the SN_2 cryogen was ~ 4.5 years, based upon an anticipated on-orbit parasitic heat load of ~ 220 mW.

4. First light and first life

4.1. The ecstasy and the agony

Prior to launch, the NICMOS dewar suffered an unanticipated, but recognized, thermo-mechanical stress due to internal cryopumping of the SN_2 during required periods of active re-cooling of the un-vented dewar. A small (several millimeter) forward displacement of the cold optical bench was seen, and an internal refocusing mechanism (planned for use in on-orbit optical alignment) was replaced with unit accommodating a longer range of focal compliance. No other complications had been foreseen prior to launch.

NICMOS was installed in-orbit into the HST aft shroud and integrated with the telescope on 14 February 1997 during HST servicing mission 2 (STS-82). After successful in-bay aliveness and functional tests, a comprehensive on-orbit checkout program began even before the orbiter Discovery returned to the ground. On 4 March 1997 a historic “first light” image was obtained prior to the first iteration of the coarse adjustment of the NICMOS internal optical focus and alignment mechanisms. This image indicated that ascent to orbit had done very little in the way of degrading the excellent image quality that had been achieved from the ground optical alignment and calibration. On the same day, however, a thermal anomaly was seen in the near-real time engineering data and was watched closely. Within several hours it had become apparent that a heat-leak into the dewar, beyond the anticipated level of the parasitics, was evolving. This was rapidly identified an unintended contact across a vacuum gap in the optical baffle assembly at the forward end of the dewar.

4.2. The dewar “anomaly”

The “dewar anomaly”, a more rapid than expected expansion of the SN_2 , had pushed the cold well forward by a hydrostatic piston action of the ice “behind” it and a small, but highly consequential, point of contact was created between the inner and middle sections of the NICMOS vapor cooled shield. The result of that contact was a heat flow into the dewar at a rate twice what was expected, which raised the temperature of the ice, and the detectors, to ~ 61 K (from 58 K). This would prove of little consequence to the performance of the detectors, but would cause a reduction by a factor of more than two in the planned cryogenic lifetime. Additionally, the mechanical displacement of the optics bench in the cold well brought the camera 3 detector beyond the range of the instrument’s internal re-focusing mechanism. This thermo-mechanical excursion improved with time, and the camera 3 focus “relaxed” to the point where, except for the most critical science programs, images of acceptable quality

(~30% decrease in the peak intensity of the PSF) were being returned.

4.3. HST/NICMOS cycle 7

As the on-orbit check-out program progressed it was clear that NICMOS would live up to its promise of opening up new observational domains unreachable from the ground, and indeed behaved in every manner as anticipated from its ground calibration, though with reduced longevity. As the NICMOS science program ramped up, the response to the foreshortening of the NICMOS lifetime from 4.5 to 2 years was multi-faceted. The Space Telescope Science Institute (STScI) front-loaded the HST science program with predominantly NICMOS observations and accelerated the scheduling of programs designed for later epochs. A mid-cycle interim call for proposals was issued to take advantage of the availability of NICMOS before its premature demise. The HST Project accepted, at minimal risk, defocusing the HST secondary mirror with a physical move of ~60 μm to bring NICMOS camera 3 into best focus for two critical science campaigns which needed uncompromised performance in that camera. With these actions more than 97% of the science programs accepted for NICMOS were completed before the SN_2 cryogen was exhausted on 4 January 1999. After cryogen depletion NICMOS warmed up and, though it could take no useful scientific images, the instrument remained in a passively functional state.

5. Resurrection of NICMOS

5.1. A new lease on life

NICMOS had been designed as a limited-life mission. From the outset there was no plan to “refill/freeze” the cryostat after the SN_2 ice had been depleted (and indeed would have presented a significant challenge in the zero-g shuttle-bay environment). Nevertheless the NICMOS cryogenic interface was designed for astronaut accessibility to allow for unforeseen, future, contingencies. With the dewar empty, its thermal mass (with about 7 W of parasitic heat along the path through its long cooling lines to the detectors) suggested that an active cryogenic cooling system could be devised, within the power constraints of HST, to return NICMOS to service. Given the successes of the instrument in HST Cycle 7, a NASA-convened independent science review committee recommended the development of an active “flight cryocooler”, taken at-risk as a flight technology pathfinder experiment, to restore NICMOS to a cold operational state. This recommendation would ultimately lead to a dramatic technology demonstration (Cheng et al., 2002)

and a benchmark for “the end of the ice age” for space-based infrared astronomy.

5.2. Requirements and their fulfillment

To return NICMOS to a useful scientific condition the cooler would have to: (a) restore the detectors to a cold state at $< \approx 77$ K, (b) restore the spectral elements to < 160 K operation, (c) maintain thermal stability at the detector to better than ± 100 mK on orbit timescales, (d) maintain thermal stability at the filters to better than ± 5 K on multi-orbit timescales, (e) be vibrationally “quiet” so as not to degrade the ~4 milliarcsecond RMS jitter pointing authority to the HST line-of-site, provided by the spacecraft’s pointing control system, (f) maintain the thermal characteristics of the telescope’s aft shroud, so as not to affect the optical interface requirements of HSTs other instruments, and (g) provide all these capabilities within an operational power budget of ~350 W.

These goals were realized with the NICMOS Cooling System (NCS), adopting a reverse Brayton cycle cryogenic cooler to circulate chilled Neon gas through the NICMOS cooling lines originally used to flow liquid helium to freeze the liquid N_2 into a solid cryogen (see Fig. 4). Heat is transferred from NICMOS instrument through a series of heat exchangers in the NCS and dissipated to space by a large external radiator coupled to NCS by capillary pumped loop lines. The NCS contains three micro-turbines manufactured by Creare, Inc. Active cooling is performed within a sealed “compressor loop” with one fast turbine (running at 432,000 rpm) compressing the gas and a slower (186,000 rpm) “turboalternator” at the opposite end of the loop expanding it. A third 72,500 rpm turbine in a circulator loop, coupled to the turboalternator through a heat exchanger internal to NCS, circulates cold Neon gas into and out of NICMOS (65 K in, 81 K out) through flexible cooling lines. These flex lines were connected to NICMOS through astronaut-servicable bayonet mounts on the instrument’s Cryogenic interface panel. The STS-109 crew integrated the cooling system with HST and NICMOS on 8 March 2002 during servicing mission 3B. After a few false-starts, a protracted cool-down lasting about 750 h, and initial experiments with the NCS thermal control law, the NICMOS cooling system has continued to function in a flawless fashion meeting all of the intended goals, and has fully re-enabled NIR observations with NICMOS on HST.

5.3. Second first light and the dawning of a new age for space infrared astronomy

NICMOS was recommissioned as a “new” HST science instrument. Stellar images were first obtained with the re-cooled NICMOS on 24 April 2002 in cameras 1 and

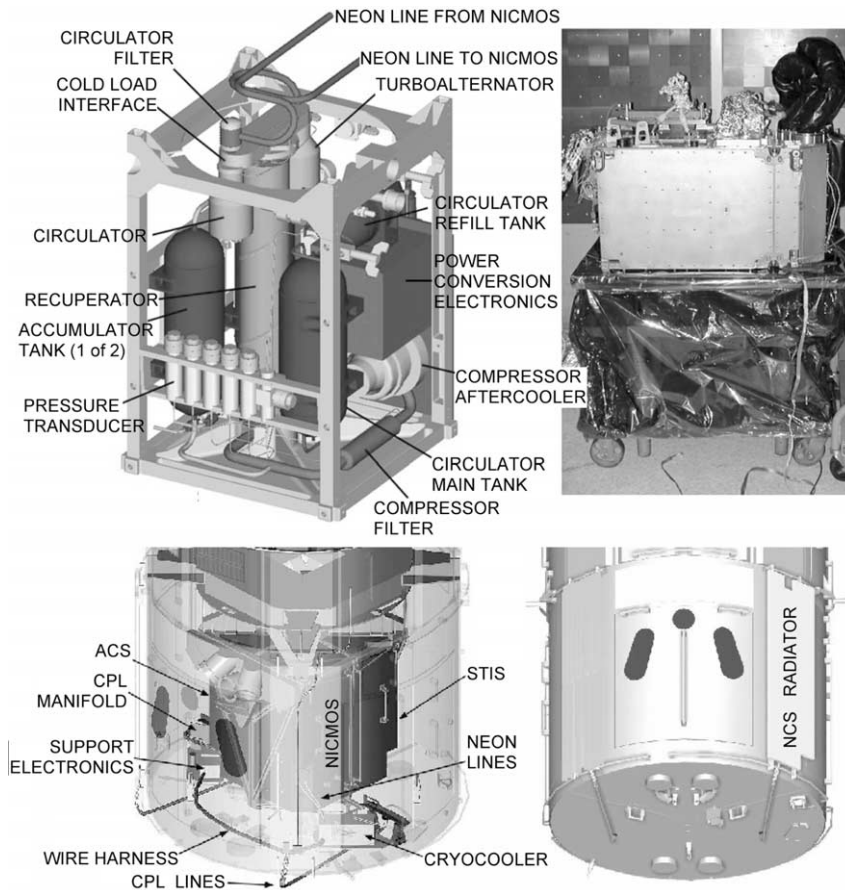


Fig. 4. Top: Schematic representation (left) and post-fabrication photograph (right) of the NICMOS Cryocooler. Bottom: Location of NCS + NICMOS system components with respect to the HST aft shroud.

2, and shortly thereafter in camera 3. The warm-up and cool-down of the NICMOS dewar left the optical system no worse for wear. The “first light” images were near-perfect from the outset, and clearly well within the range of adjustment to remove very small amounts of coma (which were subsequently nulled out). Camera 3 remained marginally defocused, but is actually closer to the extreme position of its focal compliance than at the end of the cycle 7 mission. Indeed, early science and calibration images taken with camera 3 indicate only a very marginal improvement would be realized by an HST secondary mirror move, and likely the gain would no longer outweigh the risk.

With these first light images NICMOS became the first cryogenically cooled space IR instrument to be returned to service after the exhaustion of its pre-launch loaded coolant. NICMOS is now also the first space IR astronomical instrument to be actively cooled by refrigerative recirculation. As a technology demonstrator the NCS has paved the way for future space instrumentation, breaking the paradigm of reliance on passive, and massive, stores of on-board cryogenics with limited lifetimes. As an augmentation to NICMOS, the NCS system while highly successful is highly inefficient.

NCS consumes ~ 380 W of available spacecraft power to deliver ~ 7 W of cooling power, and more than 90% of that is parasitically dissipated before reaching the NICMOS detectors. Because NICMOS was designed for passive cooling with a solid cryogen, the detectors are not thermally isolated from the mass of the dewar itself. Significantly less power would be required for an active cooling system based upon the NCS heritage if the overall system were designed to cool only those elements that require cooling.

6. Early science results beyond the end of the ice age

The NCS has maintained the NICMOS detectors at $\sim 77.15 \pm 0.05$ K for the past six months. The higher (than cycle 7) operating temperature has resulted, as expected, in greater quantum efficiencies for the HgCdTe arrays (particularly at short wavelength) and with much less inter-pixel dispersion in their responsivity. The detector dark currents have increased with temperature (to $\sim 0.2\text{--}0.3$ $e^- s^{-1}$ pixel $^{-1}$), but not significantly enough to adversely affect science, as this degradation is more than offset by the significant gains

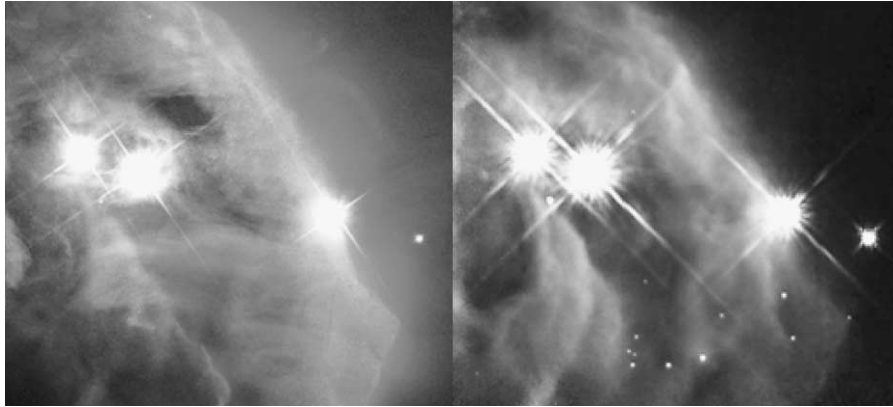


Fig. 5. The Cone Nebula. Left: ACS (visible light) image. Right: NICMOS (NIR) image.

in quantum efficiency. All in all, NICMOS has been performing in many respects “better than new” at its current, highly stable, operating temperature and only marginally defocused camera 3.

6.1. *Demonstration science*

Several targets of scientific interest were observed before the completion of the post-SM3B on-orbit re-verification program to assess the scientific potential of the re-cooled NICMOS (NICMOS Group and Science Team, 2002). The resulting publicly available data, taken under the Early Release Observation (ERO) program, unequivocally demonstrate the re-enabling of NICMOS science. In parallel, the servicing mission observatory verification program was completed in September 2002 enabling all selected science programs for HST cycle 11 to be scheduled on the telescope. We briefly discuss three of these ERO programs that were designed not only to demonstrate re-enabling of NICMOS science, but also to illustrate the import of the

complementary nature of the suite of HSTs imaging instruments and the benefits to analysis and interpretation of multi-wavelength observations.

The “Cone Nebula”, (NGC 2264, Fig. 5), was an ERO science target at visible wavelengths for HSTs new Advanced Camera for Surveys (ACS). This star-forming cloud is an environment with many similarities to the Eagle nebula (Fig. 1, top). The dense dust of the nebula obscures its interior at optical wavelengths, and belies the true nature of the region that is probed by NICMOS in the NIR. The cloud has been “sculpted” by ionizing UV radiation from nearby hot stars giving it its “craggy” appearance while releasing gas into the surrounding region (as seen by ACS). Stars revealed in the NICMOS near-IR image may be embedded in the cloud, or background objects. Images at longer wavelengths accessible to NICMOS are needed to determine their true origin and how they may influence, or be influenced by, the environment of the Cone Nebula.

NGC 4013 is an edge on galaxy that was imaged at high spatial resolution, and at multiple wavelengths, by

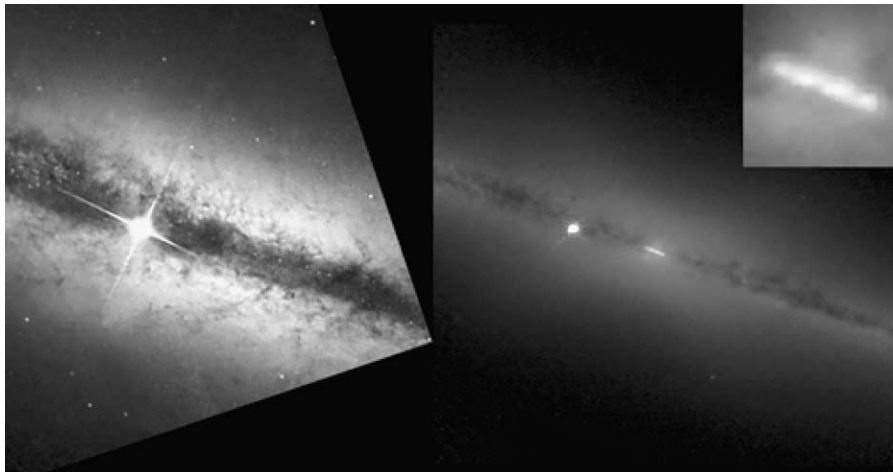


Fig. 6. NGC 4013. Left: WFPC-2 (visible light) image. Right: NICMOS Paschen- α image (circumnuclear region shown in detail at upper right).

HST's Wide-Field and Planetary Camera 2 (Fig. 6, left). In the optical, the galaxy exhibits a dense edge-on band of gas and dust, about 150 pc wide, which obscures the galactic nucleus. NICMOS reveals a 220 pc wide circumnuclear “ring”, seen edge-on in Fig. 6 (right), typical of star-forming rings in active disk galaxies, and is traced in hydrogen emission at $1.87 \mu\text{m}$ (a wavelength inaccessible to ground-based telescopes).

IRAS 19297-0406 is an ultra-luminous IR galaxy, which has now been observed panchromatically with ACS and NICMOS. The IR emission indicates IRAS 19297-0406 is ~ 100 times as luminous as our own Milky Way galaxy, and is creating about 200 times as many stars per year. Together, the multi-wavelength imaging program implicates a collision of four galaxies, generating a huge amount of IR luminous dust in a massive eruption of star formation. This merger is likely the progenitor of a massive elliptical galaxy.

6.2. Early “general observer” science results

The HST cycle 11 observing program with NICMOS had just begun, and few results have yet been reported, though some early start programs are indicative of what the return of NICMOS will likely bring. We present two examples from some of the earliest programs re-enabled soon after the cool-down of NICMOS.

The SIRTf-Selected Nearby Galaxy Survey (R. Kennicutt, U. Arizona) is a Paschen- α and H-band imaging survey measuring the extinction in the star forming regions of selected galaxies and is obtaining robust extinction-corrected maps of the star formation rate (SFR). Paschen- α is a key tracer of active star formation. These data, obtainable only with NICMOS, provide reliable, extinction-free measurements of SFRs and will extend the SFR-vs.-gas density relation to surface densities at least 30 times higher than using (optical) H- α based SFR measures and will bridge the gap between “normal” and IR-luminous starburst galaxies. This NICMOS imaging program is being carried out as a precursor to an extensive galaxy survey program to be undertaken as a SIRTf Legacy science program (the SINGS survey).

The Deceleration Test from $z = 1.2$ – 1.6 Type Ia Supernovae (A. Reiss, STScI). Type Ia supernovae provide the only direct evidence for an accelerating universe, suspected from those observed with redshifts $z \sim 0.5$, which are ~ 0.25 magnitudes fainter than they would be in a universe without acceleration. A powerful and straightforward way to confirm or reject this hypothesis is to look for cosmic deceleration in galaxies at redshifts > 1 , which would be a clear signature of a hybrid dark-matter and dark-energy universe. The first results from this program were reported with NICMOS follow-up imagery of a SNe Ia with $z = 1.06$ detected in a high galactic latitude deep field imaged earlier by the ACS

(Tsvetanov et al., 2002), which may implicate cosmic deceleration.

7. The future of NCS + NICMOS

During HST cycle 11, 968 imaging orbits and 245 spectrophotometric orbits of NICMOS data will be acquired. Time allocations for future investigations will be in the hands of to-be-convened time allocation committees. Technically, NCS + NICMOS could continue operating indefinitely. With the ice age over, NICMOS has no cryogenic consumables. There have been no indications of “leaks” in the Neon circulation loop and the system has ample supply of reserve gas (if needed) for future operations. Available spacecraft power may become an issue. The next generation of HST instruments, WFC3 and the Cosmic Origins Spectrograph, are both power-hungry instruments. When installed, currently as planned for the first quarter of 2005, NICMOS may have to be operated in a power-sharing or “campaign” mode with the new instruments, and parallel observing opportunities may also be curtailed. Beyond that the only “consumable” is money as HST is conceived to enter an era of “cheap operations” to await its eventual mission termination.

Note added in proof

As of 5 May 2004, with only one very short service interruption of no long term consequence or scientific impact to the continuing NICMOS programs, the NCS continues to function flawlessly and NICMOS continues to deliver uncompromising results as HST enters into its thirtieth observing cycle. We foresee a continuance of the unique capabilities offered by the NICMOS/NCS system well into the future, threatened only the eventual degradation of HST pointing authority with a likely “two-gyro” pointing control mode and possible early mission termination due to the recently announced cancellation of HST servicing mission 4 by NASA.

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