New VLT/NACO Images of Titan

As a complement to the NASA/ESA Cassini/Huygens mission, new VLT/NACO images have been obtained of the atmosphere and surface of Titan, the largest moon in the Saturnian system.

(Based on ESO press photos 08a-c/04 and ESO Press Release 09/04)

TITAN, THE LARGEST MOON OF Saturn was discovered by Dutch astronomer Christian Huygens in 1655 and certainly deserves its name. With a diameter of no less than 5,150 km, it is larger than Mercury and twice as large as Pluto. It is unique in having a hazy atmosphere of nitrogen, methane and oily hydrocarbons. Although it was explored in some detail by the NASA Voyager missions, many aspects of the atmosphere and surface still remain unknown. Thus, the existence of seasonal or diurnal phenomena, the presence of clouds, the surface composition and topography are still under debate. There have even been speculations that some kind of primitive life (now possibly extinct) may be found on Titan.

Titan is the main target of the NASA/ESA Cassini/Huygens mission, launched in 1997 and scheduled to arrive at Saturn on July 1, 2004. The ESA Huygens probe is designed to enter the atmosphere of Titan in early 2005, and to descend by parachute to the surface.

Ground-based observations are essential to optimize the return of this space mission, because they will complement the information gained from space and add confidence to the interpretation of the data. Hence, the advent of the adaptive optics system NAOS-CONICA (NACO) in combination with the VLT now offers a unique opportunity to study the resolved disc of Titan with high sensitivity and increased spatial resolution, and two research teams have recently reported their results on Titan.

Images of Titan

A team of French astronomers [1] used the NACO state-of-the-art adaptive optics system on the fourth 8.2-m VLT unit telescope (Yepun) in November 2002 and 2003, to map the surface of Titan by means of near-infrared images and to search for changes in the dense atmosphere. These extraordinary images have a nominal resolution of 1/30th arcsec and show details of the order of 200 km on the surface of Titan. To provide the best possible views, the raw data from the instrument were subjected to deconvolution (image sharpening).

Images of Titan (figs. 1–3) were obtained through 9 narrow-band filters, sampling near-infrared wavelengths with large

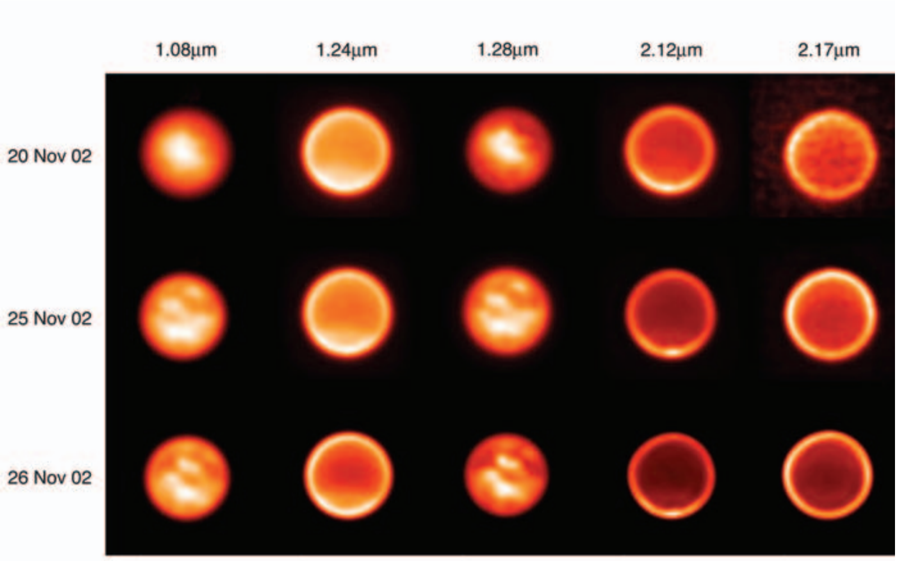


Figure 1 shows Titan (apparent visual magnitude 8.05, apparent diameter 0.87 arcsec) as observed with the NAOS/CONICA instrument at VLT Yepun on November 20, 25 and 26, 2002, between 6.00 UT and 9.00 UT. The median seeing values were 1.1 arcsec and 1.5 arcsec respectively for the 20th and 25th. Deconvoluted ("sharpened") images of Titan are shown through 5 different narrow-band filters - they allow to probe in some detail structures at different altitudes and on the surface. Depending on the filter, the integration time varies from 10 to 100 seconds. While Titan showed its leading hemisphere (i.e. the one observed when Titan moves towards us) on Nov. 20, the trailing side (i.e the one we see when Titan moves away from us in its course around Saturn) - which displays less bright surface features - was observed on the last two dates.

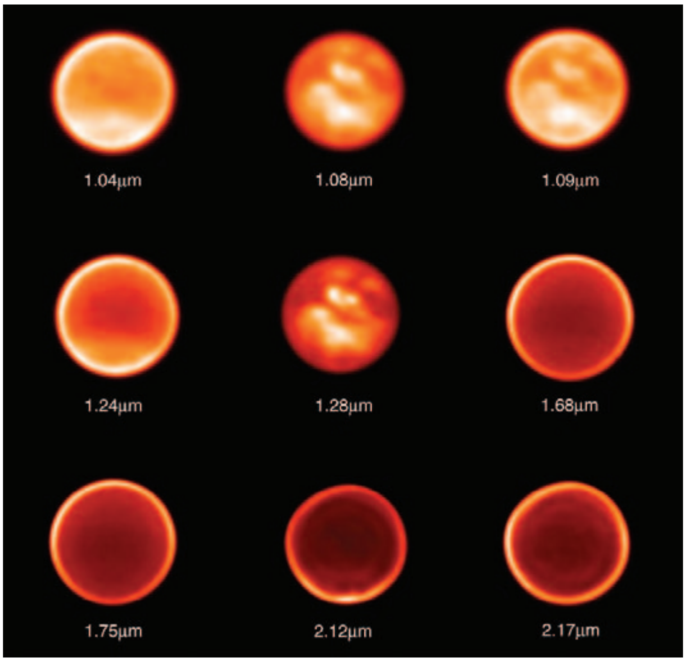


Figure 2: Images of Titan taken on November 26, 2002 through nine different filters to probe different altitudes, ranging from the stratosphere to the surface. On this night, a stable "seeing" (image quality before adaptive optics correction) of 0.9 arcsec allowed the astronomers to attain the diffraction limit of the telescope (0.032 arcsec resolution). Due to these good observing conditions, Titan's trailing hemisphere was observed with contrasts of about 40%, allowing the detection of several bright features on this surface region, once thought to be quite dark and featureless.

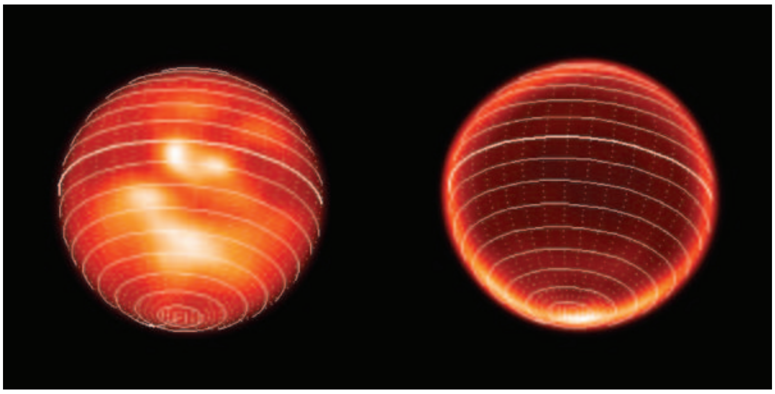


Figure 3: Titan images obtained with NACO on November 26th, 2002. Left: Titan's surface projection on the trailing hemisphere as observed at 1.3 µm, revealing a complex brightness structure thanks to the high image contrast of about 40%. Right: a new, possibly meteorological, phenomenon observed at 2.12 µm in Titan's atmosphere, in the form of a bright feature revolving around the South Pole.

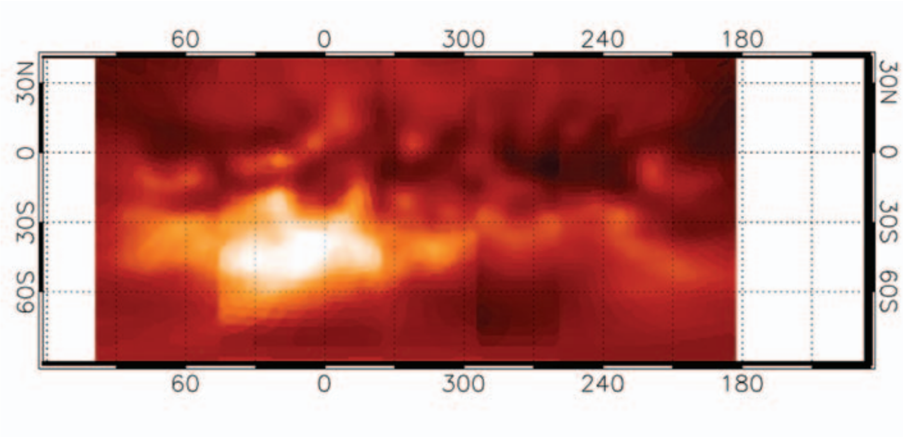
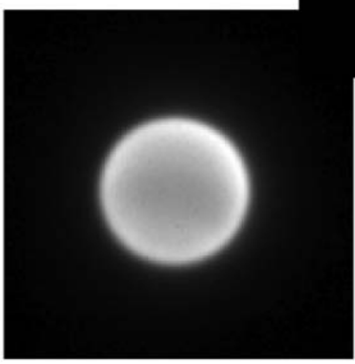


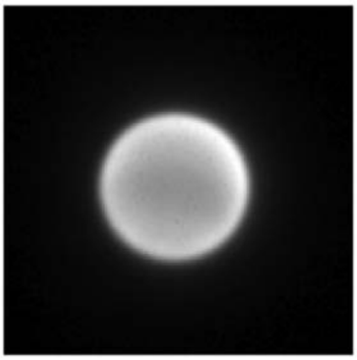
Figure 4: This shows the clearest view of Titan's surface available so far. It was obtained through a "transparent", narrow spectral window with the 8.2-m VLT YEPUN telescope and the NACO adaptive optics instrument operated in the Simultaneous Differential Imager (SDI) mode. It covers about three-quarters of the full surface and has an image resolution (sharpness) of 0.06 arcsec, corresponding to 360 km on the surface. One degree of longitude on the equator corresponds to 45 km on Titan's surface. The brightness is proportional to the surface reflectivity. The nature of the various regions is still unknown although it is speculated that the darkest areas may indicate the extent of reservoirs of liquid hydrocarbons.

Quadrant 1: 1.600 µm

Quadrant 2: 1.575 µm



Quadrant 3: 1.625 µm



Quadrant 4: 1.625 µm

Figure 5 shows four images of Titan, obtained simultaneously with the NACO adaptive optics instrument in the SDI observing mode with the corresponding wavebands indicated. The individual images have a diameter of 0.86 arcsec and have here been magnified for clarity. As explained in the text, the images obtained at wavelengths 1.575 and 1.600 µm penetrate right to the surface while the images at 1.625 µm show the comparatively featureless atmosphere.

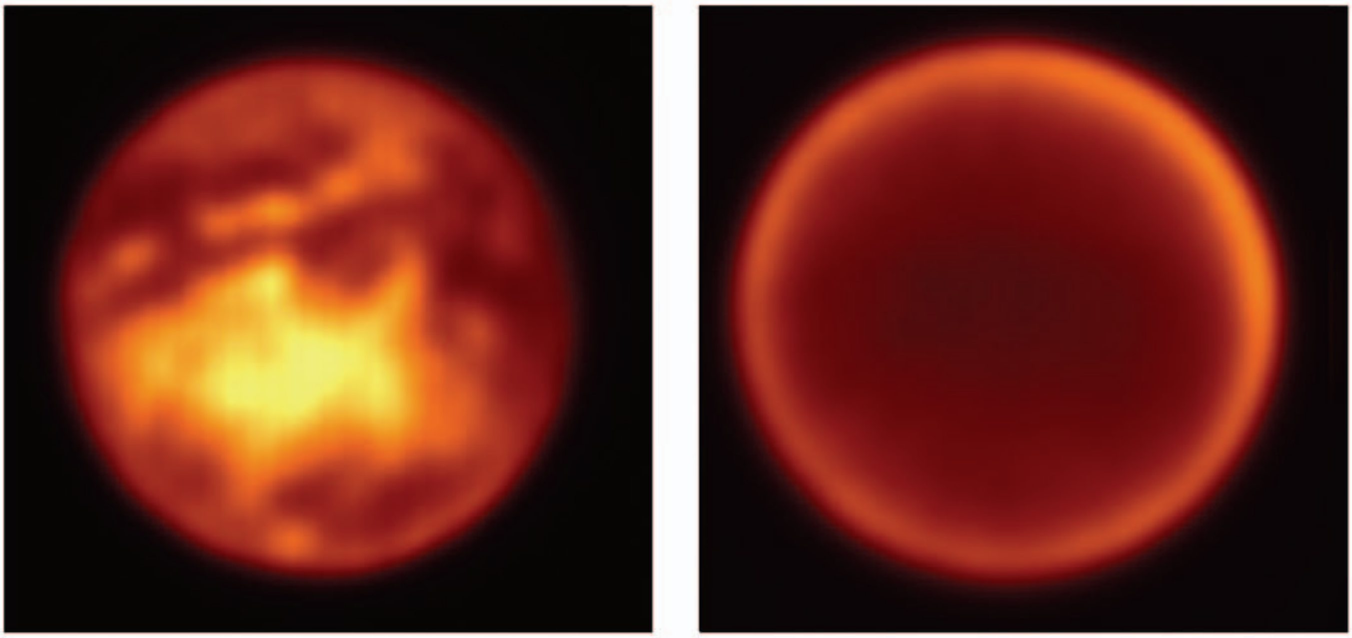


Figure 6 shows simultaneous images of Titan, obtained on February 7, 2004, with NACO in SDI mode. Left: at 1.575 µm with a clear view towards the surface. Right: at 1.625 µm, where the atmosphere appears entirely opaque.

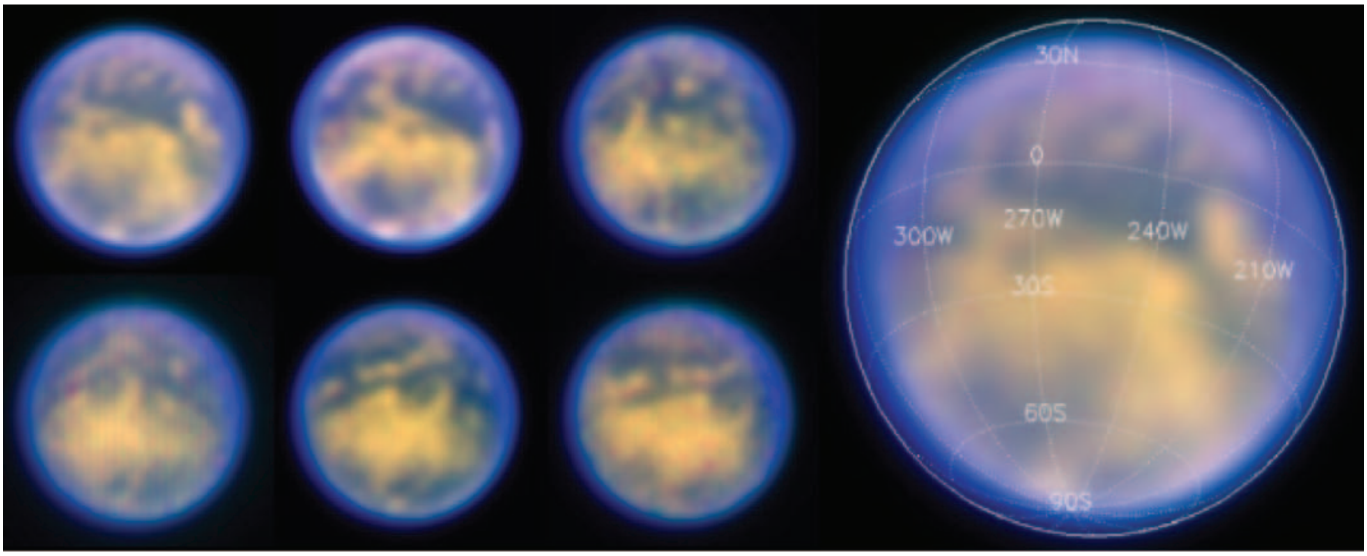


Figure 7 shows views of Titan, obtained on six nights in February 2004. At the right, the image from the first night (Feburary 1-2, 2004) has been enlarged for clarity and the coordinate grid on Titan is indicated. The images are false-colour renderings with the three SDI wavebands as red (1.575 µm; surface), green (1.600 µm; surface) and blue (1.625 µm; atmosphere), respectively.

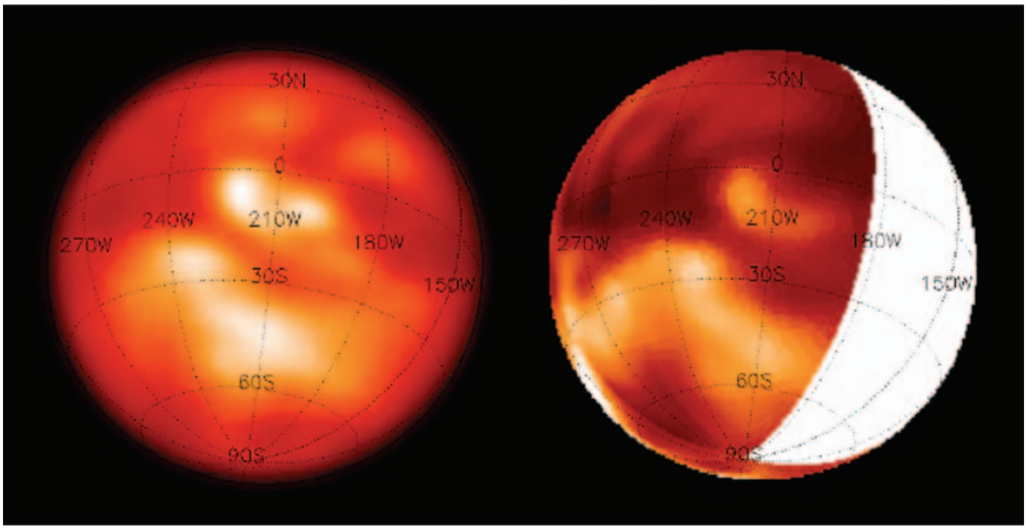


Figure 8: Earlier image of Titan by NACO, obtained in a waveband at 1.3 µm that does not perfectly match an atmospheric window (cf. Fig. 3) is compared to a new SDI-NACO image of the same region (right). The greater clarity and contrast of the latter is evident; it is due to the smaller degree of "atmospheric contamination".

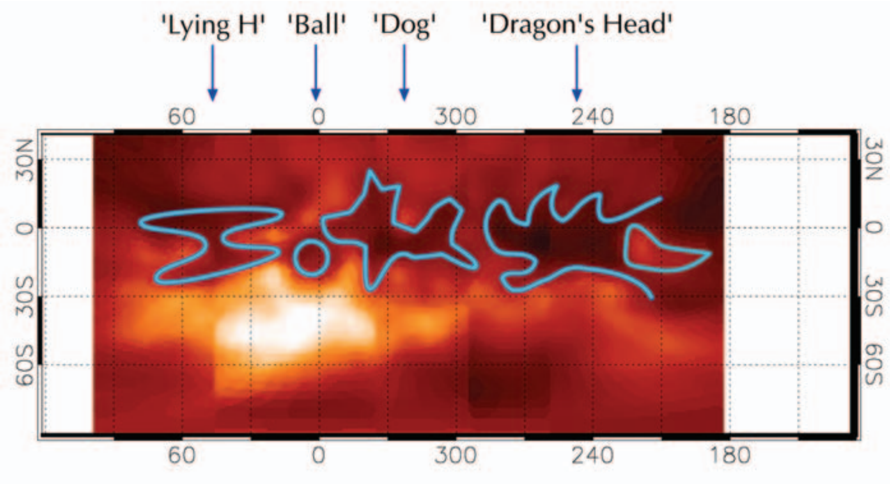


Figure 9 identifies the low-reflection areas now seen on the surface of Titan and which were given provisional names by the research team [2]; see the text.

variations in methane opacity. This permits sounding of different altitudes ranging from the stratosphere to the surface. Titan harbours a north-south asymmetry at 1.24 and 2.12 µm, while the opposite is observed with filters probing higher altitudes, such as 1.64, 1.75 and 2.17 µm. A high-contrast bright feature is observed at the South Pole and is apparently caused by a phenomenon in the atmosphere, at an altitude below 140 km or so. This feature was found to change its location on the images from one side of the south polar axis to the other during the week of observations.

SDI Views of Titan: the Quest for the Surface

To best observe the surface of Titan, one ideally looks in a spectral band in which the atmosphere is completely transparent. In February 2004, another team [2] working at the VLT obtained images of Titan's surface through a spectral window near wavelength 1.575 µm with unprecedented spatial resolution and with the lowest contamination of atmospheric condensates to date.

They accomplished this during six nights in February 2004, at the time of the commissioning phase of a novel high-contrast imaging mode for the NACO adaptive optics instrument on the 8.2-m VLT YEPUN telescope, using the Simultaneous Differential Imager (SDI, [3]). This novel optical device provides four simultaneous high-resolution images (Fig. 5) at three wavelengths around a near-infrared atmospheric methane absorption feature.

The main application of the SDI is high-contrast imaging for the search for substellar companions with methane in their atmosphere, e.g. brown dwarfs and giant exoplanets, near other stars. However, as the present photos demonstrate, it is also superbly suited for Titan imaging.

Titan is tidally-locked to Saturn, and hence always presents the same face towards the planet. To image all sides of Titan (from the Earth) therefore requires observations during almost one entire orbital period, 16 days. Still, the present week-long observing campaign enabled the team to map approximately three-quarters of the surface of Titan.

A new map of the surface of Titan (in cylindrical projection and covering most, but not all of the area imaged during these observations) is shown in Fig. 4. For this, the simultaneous "atmospheric" images (at waveband 1.625 µm) were "subtracted" from the "surface" images (1.575 and 1.600 µm) in order to remove any residual atmospheric features present in the latter. The ability to subtract simultaneous images is unique to the SDI camera.

This truly unique map shows the fraction of sunlight reflected from the surface – bright areas reflect more light than the darker ones. The amount of reflection (in astronomical terms: the "albedo") depends on the composition and structure of the surface layer and it is not possible with this single-wavelength ("monochromatic") map alone to elucidate the true nature of those features.

Nevertheless, recent radar observations with the Arecibo radiotelescope have provided evidence for liquid surfaces on Titan, and the low-reflection areas (dark in Fig. 4 and 9) could indicate the locations of those suspected reservoirs of liquid hydrocarbons. They also provide a possible source for the replenishment of methane that is continuously lost in the atmosphere because of decomposition by the sunlight.

Presumably, the bright, highly reflective regions are ice-covered highlands.

A comparison of Fig. 8 with Fig. 3 obtained through another filter is useful. It demonstrates the importance and gain of clarity of employing a filter that precisely fits the atmospheric window. It also provides independent confirmation of the reality of the gross features, since the observations are separated by 15 months in time.

Over the range of longitudes which have been mapped in Fig. 4, it is obvious that the southern hemisphere of Titan is dominated by a single bright region centered at approximately 15° longitude. (Note that this is not the so-called "bright feature" seen in HST images at longitude 80°–130°, an area that was not covered during these VLT observations).

The equatorial area displays the above mentioned, well-defined dark (low-reflection) structures. In order to facilitate their identification, the team decided to give these dark features provisional names – official names will be assigned at a later moment by the *Working Group on Planetary System Nomenclature* of the *International Astronomical Union* (IAU WGPSN). From left to right, the SDI team has referred to these features informally as: the "lying H", the "dog" chasing a "ball", and the "dragon's head".

More VLT observations of Titan will be made in the coming months, with the goal of assisting the Cassini-Huygens team in the interpretation and understanding of what will certainly be a rich and complex flow of information about this enigmatic moon.

Notes

[1] The results presented at the beginning of this article are based on an article published in *Astronomy & Astrophysics* (A&A 417, L21-24, 2004): "VLT/NACO adaptive optics imaging of Titan" by E. Gendron et al. The team is composed of Eric Gendron, Athéna Coustenis, Pierre Drossart, Michel Combes, Mathieu Hirtzig, François Lacombe, Daniel Rouan, Claude Collin, and Sylvain Pau (LESIA, Observatoire de Paris, CNRS, France), Anne-Marie Lagrange, David Mouillet, Patrick Rabou (Laboratoire d'Astrophysique, Observatoire de Grenoble, France), Thierry Fusco (ONERA) and Gérard Zins (ESO).

[2] The SDI work is described in detail in a research paper "First surface map of Titan at 1.575 microns" by M. Hartung et al., in press in *Astronomy & Astrophysics*.The team is composed of Markus Hartung (ESO-Chile), Laird M. Close (Steward Observatory, University of Arizona, Tucson, USA), Rainer Lenzen, Tom M. Herbst and Wolfgang Brandner (Max-Planck Institut for Astronomie, Heidelberg, Germany), Eric Nielsen and Beth Biller (Steward Observatory, University of Arizona, Tucson, USA), and Olivier Marco and Chris Lidman (ESO-Chile).

[3] The novel Simultaneous Differential Imager (SDI) is a special set of optics mounted into the near-infrared camera CONICA on VLT YEPUN. It is comprised of a double calcite Wollaston prism responsible for the quad beam splitting and a special four-quadrant narrow-band filter that is located directly in front of the detector. It was developed and deployed by Laird Close (Steward Observatory, University of Arizona) and Rainer Lenzen (Max-Planck-Institut für Astronomie in Heidelberg) in collaboration with ESO. NACO is an abbreviation of NAOS/CONICA. The NAOS adaptive optics corrector was built, under an ESO contract, by Office National d'Etudes et de Recherches Aérospatiales (ONERA), Laboratoire d'Astrophysique de Grenoble (LAOG) and the LESIA and GEPI laboratories of the Observatoire de Paris in France, in collaboration with ESO. The CONICA infra-red camera was built, under an ESO contract, by the Max-Planck-Institut für Astronomie (MPIA) (Heidelberg) and the Max-Planck Institut für Extraterrestrische Physik (MPE) (Garching) in Germany, in collaboration with ESO.