# REVEALING THE TRUE FACEOF TITAN WITH PHYSICAL SIMULATION

> 1.35 billion kilometers away lies the only other body than Earth in the solar system that has liquid on its surface, Saturn's moon Titan. It is a primary target for scientists, who have sent the Cassini-Huygens mission around Saturn and on Titan to gather data and understand how this world came to be. However, for the general public, not much has been seen. In this article, we will show how physical simulation means helped create the most realistic images of what a human would see on Titan, based on cutting-edge scientific data.
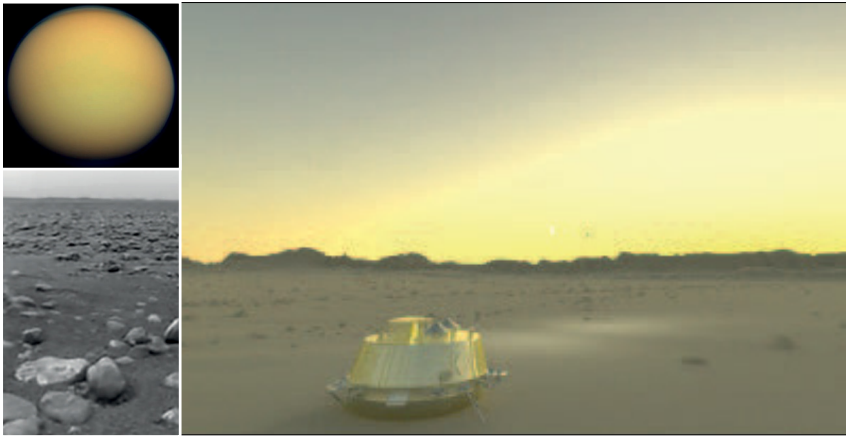
TITAN, THE MOON WITH AN ATMOSPHERE

Titan is the largest moon of Saturn. It is a mighty solid surface body of our solar system, bigger than Mercury or our Moon. It remained enigmatic until the 14th of January 2005, when Huygens, a lander attached to the Cassini orbiter, touched down on this foggy world. Until then, what we knew about Titan was that it was shrouded by a dense nitrogen atmosphere with an orange haze, so thick that the surface was not visible from space. Huygens showed us a worl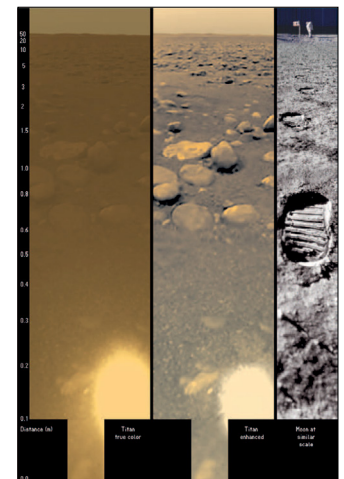d full of riverbeds and lakebeds, pebbles, sand, and mountains. With the help of the eventual 126 Cassini flybys of Titan, the veil faded and we now know much more about this strangely familiar world. It has a methane cycle similar to the water cycle of the Earth, lakes of methane and ethane, and clouds of methane that sometimes rain heavily and form large rivers. The pebbles are in fact chunks of water ice that have been carried by the rivers. All this is possible because of the surface temperature of -179°C or -290°F. From the surface itself, Huygens returned many images of a single viewpoint. The imaging sensors, conceived in the late 1980s, provided low-resolution images but were also coupled to spectrometers and photometers in the DISR (Descent Imaging / Spectral Radiometer) instrument. Huygens acquired data about the Titanian world's optical properties, both upwards and downwards during all its descent through the atmosphere, and of the surface when close enough, with the help of an embedded lamp. These data, published in many scientific articles, were not used for public outreach. This paper will now present how ANSYS OPTIS used this scientific information to show how Titan looks like from a human viewpoint.

HOW WOULD WE SEE TITAN IN REAL LIFE?

That is the question. Since the pictures provided by Huygens were not satisfactory enough, only remained the optical data provided by the probe. The French film makers Jonathan Tavel et Frédéric Ramade, who were creating a documentary about Titan titled Last call for Titan, were looking for a solution to see what a human would see if standing on the surface of Titan, and create the most realistic insights of this moon. They reached out for ANSYS OPTIS, specialized in optical and light simulation and virtual reality solutions. DISR data provided many spectral, solar aureole, polarization and imaging data [Tomasko05]. Average spectrum and brightness level were used to create the image on the left from the original Huygen picture [Karkoschka16]. On the left-hand side, this is close to what a human would see on Titan, on the right-hand side, the contrast was enhanced to better see the features of the image.

Scientists used the massive amount of other data to infer the atmospheric constitution at different altitudes and created several models of the atmosphere that could fit the observation of lighting conditions from the surface [Larson14, Doose16]. They created what is called a radiative transfer model of Titan's atmosphere, that reproduced the features of the atmosphere as observed during Huygens' descent. The properties of the haze at different altitudes can be easily extracted from this kind of model. Finally, the spectral information and reflectance of the surface over various areas in natural and artificial lighting conditions provided useful surface optical properties information.

On the left: human view of Titan, on the right: the same view with an enhanced contrast

The key now was to translate planetary science into the world of optical simulation. Creating a new image of the surface of Titan is not just about displaying a high-resolution image. It is also about answering a few questions visually: what would the human eye see? How will we perceive colors? What would the sun look like through this thick atmosphere? How far could we see? What would be the effect of artificial light in this environment, for example, to prepare for future exploration missions? Is it possible to bring a new kind of realism to film-making, as well as show how a physicsbased 3D renderer can create a perfect visualization of a new world based on actual scientific data?

PHYSICAL SIMULATION TO CREATE AN ACCURATE VISUALIZATION OF TITAN

Erich Karkoschka and Lyn Doose, researchers at the University of Arizona, a part of the team that designed the DISR instrument, shared with ANSYS OPTIS their model of surface and atmosphere, fitted from the in-situ measurements. They have a 31-layer radiative transfer model, starting from 500 km altitude down to the surface. Each layer has parameters for the scattering and absorption of light at 86 wavelengths between 477 and 700nm, 477nm being the minimal wavelength for the visible spectrometer of DISR. Bluer light is almost entirely absorbed by the atmosphere, so not having data on it has no significant impact on the final results. The result of the radiative transfer at each layer and wavelength provides solar irradiance (direct illumination), diffuse irradiance and a map of radiance data for the whole sky.

ANSYS OPTIS's SPEOS radiometric rendering software[1] is all about using precise and measured data. The goal here is to create images of what a human would see if he/she were standing on the surface of Titan, so we will use the Visual Ergonomics feature of the software, in which radiometric information is converted into accurate 3D synthesis images. The input data and the data manipulated during simulation are fully spectral, and the computation we apply to the data follows the laws of physics.

What do we need to simulate the surface of a world?

ILLUMINATION	SURFACE GEOMETRY	SURFACE MATERIALS	ATMOSPHERE
The direct sunlight and diffuse atmosphere.	All the objects that can appear in the landscape.	The reflectance of the surface and all the objects.	The behavior of light between objects of the scene, near the surface.

ILLUMINATION

On Titan just like on Earth, there are two types of natural light:

- Direct sunlight, absorbed by the molecules of the atmosphere, here mostly methane and the orange haze.

- The sky itself, which radiates light, which is strongly scattered by aerosols and other molecules. These two different light sources are available on the surface of planets with an atmosphere.

The direct sun irradiance, through the thick atmosphere of Titan, is very faint.
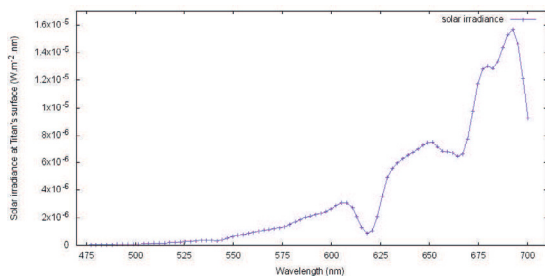
Aerosols scatter the light a lot in the upper atmosphere, and methane is a strong absorbing molecule at some wavelengths. The spectrum of the sun as it reaches the surface is shown below.

The power of this irradiance is about 0.84 mW/m². Saturn is in average at 9.55 AU (astronomical unit), with 1 AU being the average distance between the Earth and the Sun. In Titan's sky, the sun is in average 9.05 times smaller than in Earth's sky.

We obtain the illumination as a result of the last layer of the radiative transfer model, together with the contribution of the diffuse atmosphere.

[1] http://www.OPTIS-world.com/product-offering-lightsimulation-virtual-reality-software/SPEOS

The diffuse aspect of the atmosphere makes the sky a larger contributor to the surface illumination. Starting from a tabulated numbers file, data from 11 elevations, 38 azimuths and 86 wavelengths, we made a conversion and interpolated it to get a spectral environment map. Just convert this map to RGB at the end of the process, and you get the view hereafter.
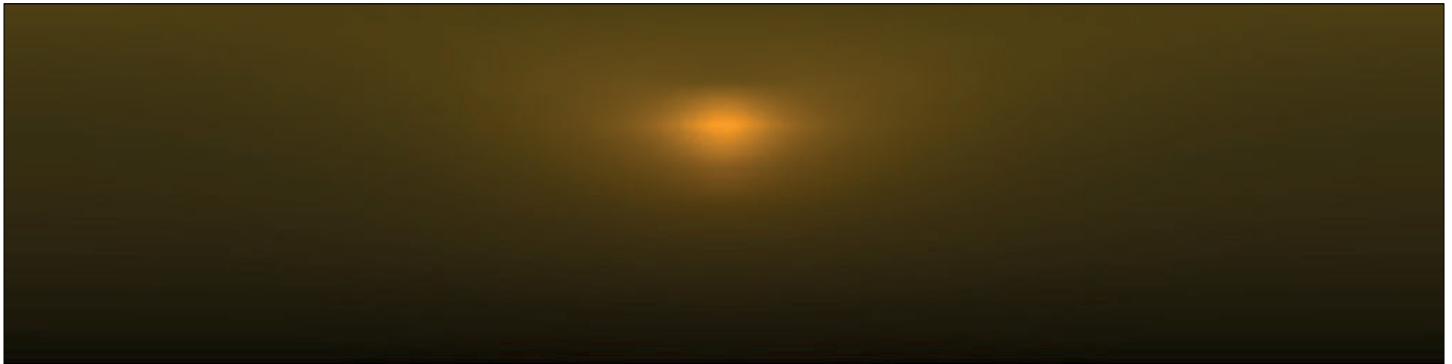
RGB view of the atmosphere of Titan based on Huygens' data

In computer graphics, an environment map is an image that mimics the effect of the surrounding environment and is used to illuminate a scene. In our case, the environment map is more than an image: it contains full and real spectral data. The first result we obtain when combining direct sunlight and diffuse atmosphere data is that the sun is visible in Titan's sky. Even with a fraction of its light reaching the surface, it is bright enough for us to see it inside the relatively bright solar aureole.

SURFACE GEOMETRY
Huygens provided only very low-resolution data about the actual surface of Titan. Huygens' descent has provided several images of the surface of Titan at different altitudes, showing lakebeds, riverbeds, mountains from a distance, but showing only a lakebed with pebbles in one direction from close-up. This was not enough to reconstruct a terrain for a 3D rendering. For a surface view, we could not use data from Cassini's radar or infrared sensors because we needed a higher resolution. For the simulation, we had to recreate a plausible lakebed landscape with pebbles from this data, to be as close as possible to the original view of Huygens.

SURFACE MATERIAL
The reflectance of the surface and all the objects or materials has been measured by DISR near the surface and on the surface, with the additional help of the surface science lamp[2]. To simulate this part, we used the latest data published in scientific papers [Karkoschka12, Karkoschka16] as well as some yet unpublished data from Erich Karkoschka. Huygens observed two types of terrain during its descent, a dark one, and a brighter one.

• Bright terrain: In the final stages of the descent, Huygens did not fly over bright terrain long enough to obtain its reflection spectra. Only the reflectance is approximately known for this kind of terrain.

• Dark terrain: Analysis showed that dark areas are lower in altitude, in lakebeds, such as where Huygens landed for instance, as if rain had washed down the darker rocks from mountains. For this darker ground, a model of reflectance and reflection spectrum has been established [Karkoschka12, Karkoschka16].

Huygens observed various areas of intermediate brightness, which seems to match a linear interpolation of reflectance laws between the brighter and darker materials. It was also shown that the pebbles are brighter than the dark areas, so we used the reflectance function of the brighter areas for the simulation of pebbles while keeping on using the spectrum of darker areas.

[2] http://www2.mps.mpg.de/images/projekte/cassini/disr/disrview2.jpg

ANSYS OPTIS' software uses a spectral BRDF for material definition. A BRDF is a bi-directional reflection distribution function; it is used to know in |which direction light will be scattered by a surface depending on where it comes from. Three functions were used to create the spectral BRDF of the dark surface:

• A reflectance law, that provides a reflectance factor from the incidence and emission angles. This law comes from [Karkoschka16] and is a linear interpolation between Lambert and Lommel-Seeliger reflection laws:

$$I/F \approx (1-f)\mu_0 + 2f\ \mu_0/(\mu+\mu_0)$$

We used values of f = 0.45 for dark terrain and 0.20 for the bright terrain, as suggested in the publication.

• A phase function, that takes into account the phase angle in the reflectance factor. This one was suggested by Erich Karkoschka:
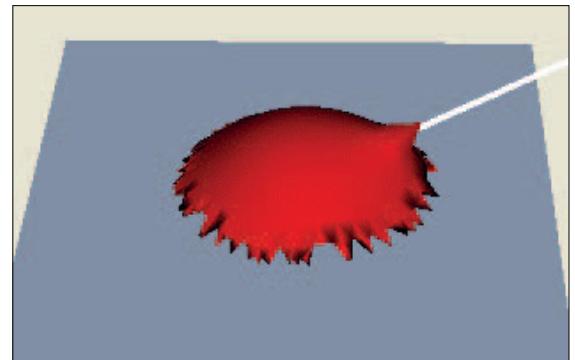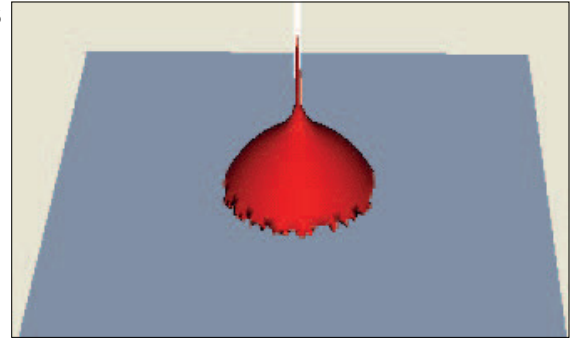
$$I/F \approx 0.45(1+50\alpha)^{-0.15}$$

The product of the reflectance law and the phase function gives a value that can be used for BRDF, with a cosine factor.

• A formula, that fits the spectrum for dark areas [Karkoschka 2012]:

$$I/F(\lambda) = I/F(750)\ \exp(0.911 - 9.15 \text{ x } 10^{-4}\ \lambda - 9.5 \text{ x } 10^{7}\ \lambda^{-3}$$

Model of emission distribution for a light beam on Titan

Here are representations of the BRDF with ANSYS OPTIS Labs. The white line is the incident light ray, and the red bulb the emission distribution for this reflected ray.

ATMOSPHERE AND ATMOSPHERIC EFFECTS NEAR THE SURFACE
It is very common to consider that the open space has no interaction with light, that it is a mere vacuum. However, in planetary atmospheres, scattering and absorption can have a significant impact on theperceived image, especially for landscapes at a distance. The 31st and last layer of the radiative transfer model is starting at 2km, and its optical properties can be used to model a scattering volume near the surface, around objects.

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On the hazy Titan, the diffuse lighting is stronger than direct light from the Sun. It appeared that simulating the consequences of the atmosphere in the light of the simulated scenes would play a significant role in the final aspect of the images, but as we got the additional data required to do this simulation, we saw that at ground level, visibility is about 30km in the visible spectrum. In other words, for small scenes, the difference would be unnoticeable.
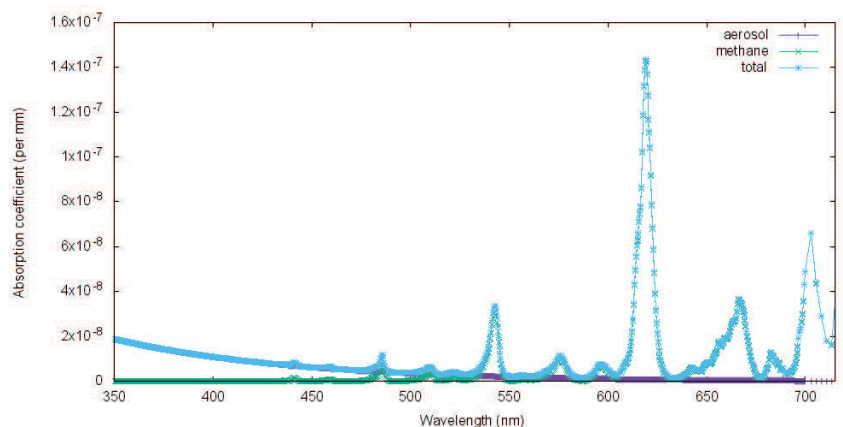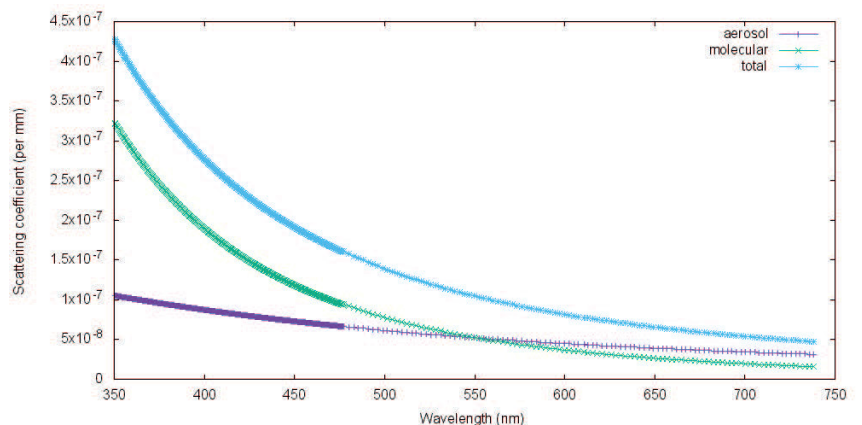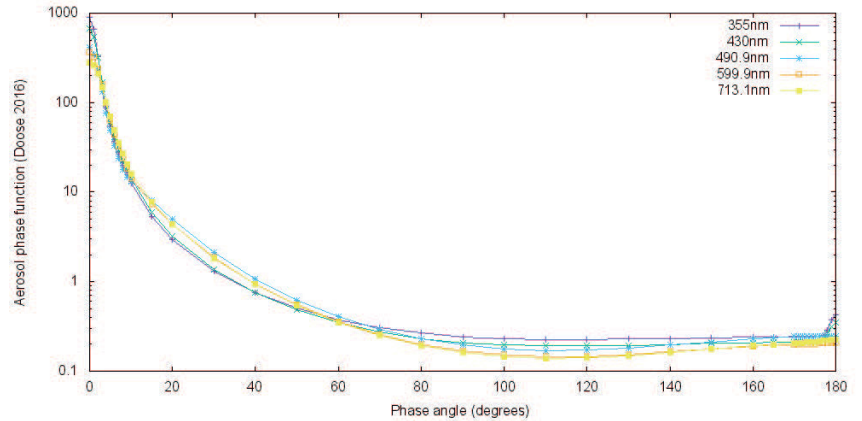
Atmospheric effects are:

• The absorption of light, where the atmosphere absorbs a ray of light.

• The scattering of light, where a beam of light is bounced in other directions when interacting with the atmosphere.

Two types of each are significant on Titan and had to be simulated. For absorption, gaseous and liquid methane, with a 5% constitution of the atmosphere at ground level, plays a major part. Like many organic molecules, it has deep absorption bands, meaning that it is opaque to some wavelengths.

The other main source of absorption is the organic Titan aerosol, forming the orange haze, and whose Earth laboratory-created analogs are called Tholins. These aerosol particles absorb more blue light than red, explaining the orange color of the moon. Scattering is dominated in bluer wavelengths by Rayleigh scattering, just like on earth. This effect makes our Earth sky blue. The coefficient below represents a probability that an incoming light ray will be scattered, but there is another parameter: the scattering phase function. This function represents the probability for the outgoing direction of a scattered ray.

It is mostly forward scattering on Titan, meaning that most rays continue in the same direction, but a few are backscattered, or side scattered, especially in bluer wavelengths.

ANSYS OPTIS software represents these material properties with an anisotropic BSDF data file. Once we have gathered all required data, we create this BSDF data file and run simulations. The following image shows the slight difference observed between a simulation with (left) and a simulation without (right) these atmospheric effects, in a 2.5km distance line of sight. With it, mountains appear more yellow or orange, less contrasted, and the missing sky data near the horizon is smoothed out.
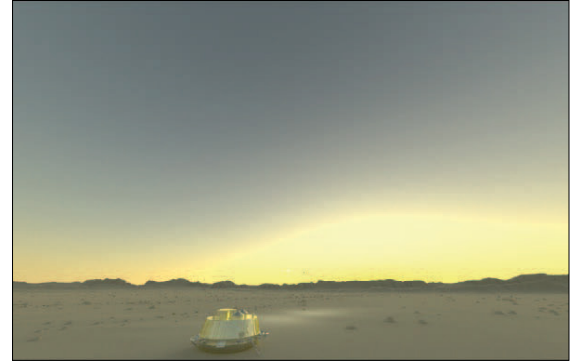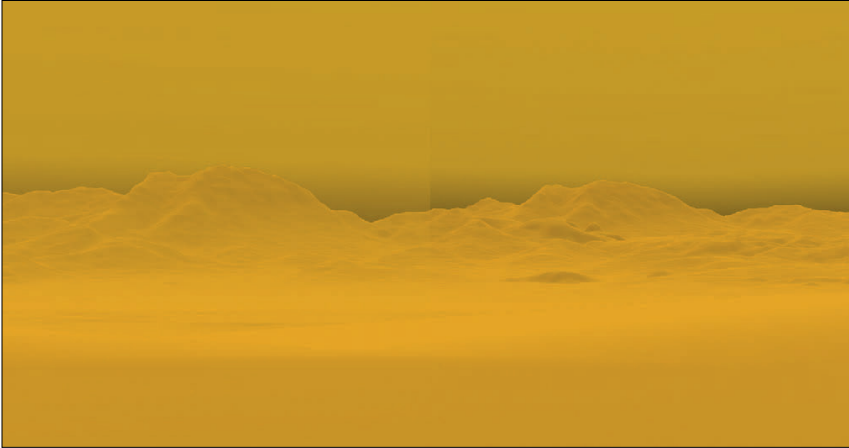
Titan simulation with atmospheric effects on the left and without atmospheric effects on the right

This simulation of a large scene opens the way to Earth atmosphere simulation with SPEOS. It already has a cloudless model of the sky with a positionable sun, as depicted below with the Titanian surface and Huygens model, 10 minutes after sunset on the left image (it is still brighter than the luminosity on Titan during the day) and in daylight on the right. Bridges to atmosphere simulation software such as MODTRAN have already been demonstrated to obtain spectral sky radiance for various atmospheric conditions and could be made to automatically add the volume optical properties to the simulations.
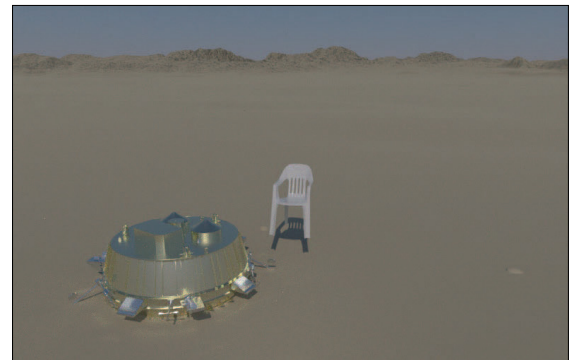
Views of Titan's surface, the Huygens probe and a plastic chair with their real materials, illuminated by an Earth sky
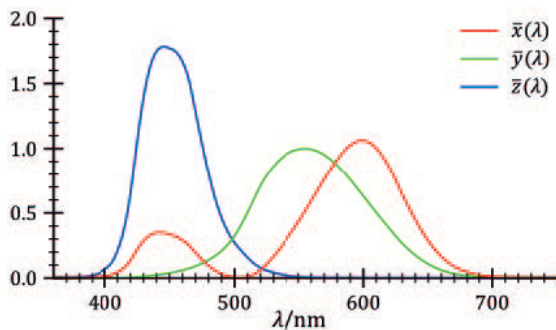

RESULTS AND HUMAN VISION

You will see below a few images created from simulation results generated with SPEOS. From radiometric data, we have to create images by converting spectra into RGB values for displays. There are many ways to do this conversion, and significant interpretation bias can occur. Our real-time software and image creation tools use CIE 1931 XYZ color space. For a given spectrum, one XYZ value is calculated based on the sensitivity of the three human eye color sensors (see chart). The chromaticity stored in the X and Z values is accurately representing what a human would see, but computer screens or printers are not able to display the whole range of colors, called a gamut. The Titan simulations below are outside the gamut, hence converting these XYZ values to RGB values for image presentation requires special attention. By projecting the XYZ value on the gamut, we can obtain the closest displayable color. The colors on Titan are more orange or more saturated than they look like in the images below.

Another problem is the dynamic range or scaling of brightness values. RGB images for general purpose are limited to 8-bit per channel precision, 256 values. However, when input images' luminance varies from several orders of magnitudes, how can we translate this to images?

ANSYS OPTIS has developed a Human Vision Lab. Instead of applying the simplest linear mapping of brightness levels, the human vision tool mimics the vision of the human eye. From the different brightness levels of the image, the eye adaptation and the glare are simulated. The difference is evident if we consider the Titan image of a wide field including the solar aureole and Huygens probe.
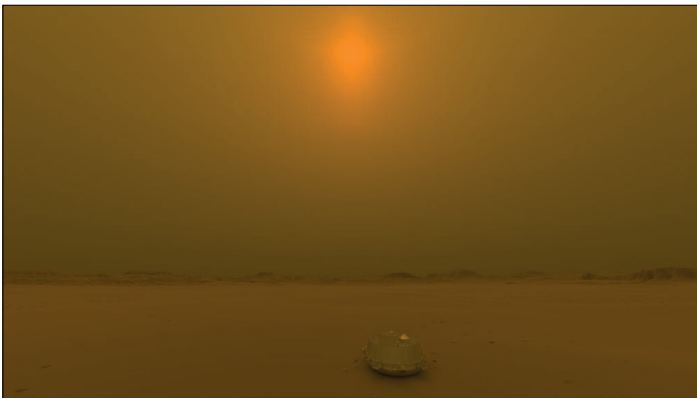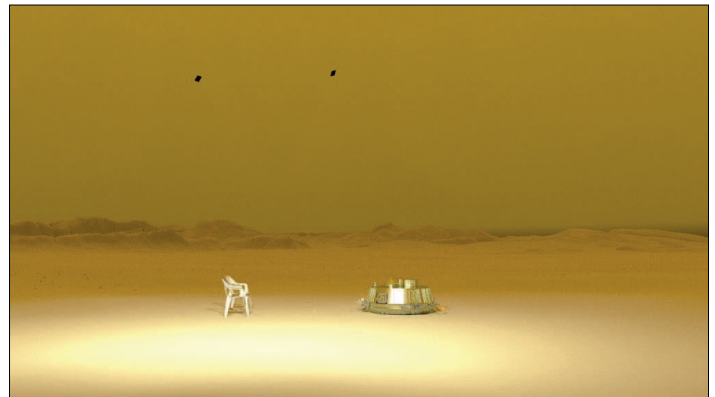

Linear gamma-mapped rendering
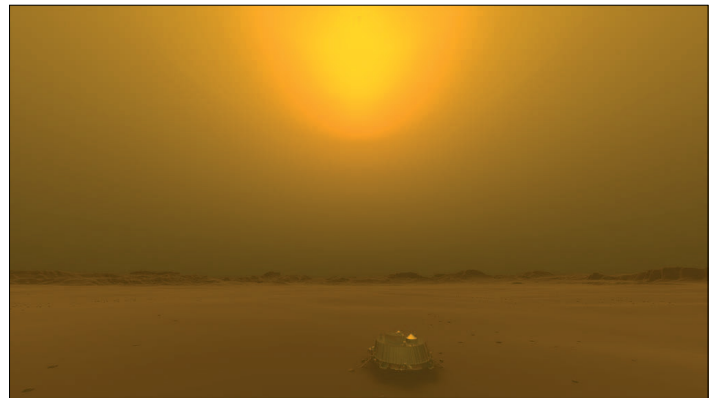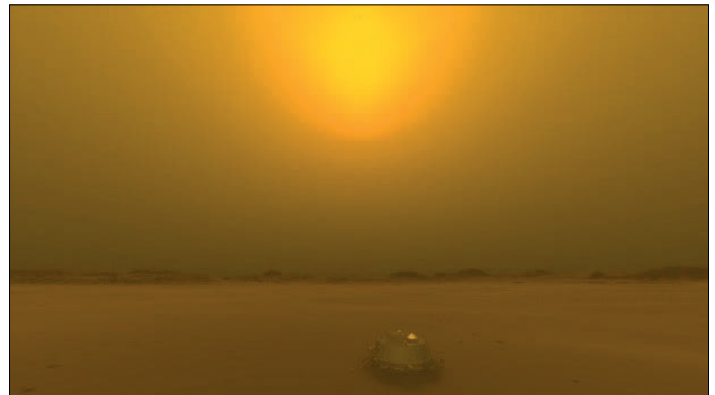

Human Vision Lab rendering
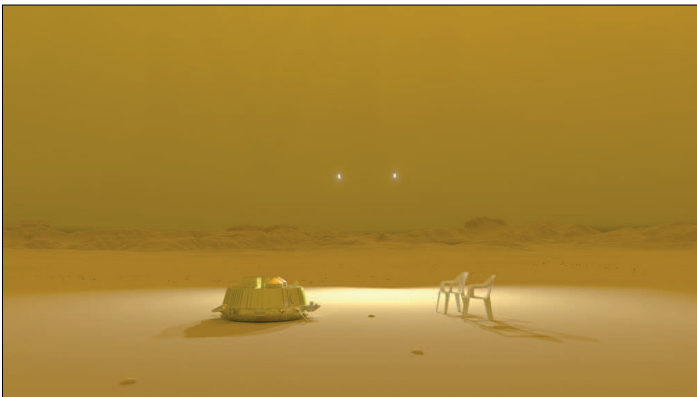
With artificial lighting, two 6500K white LED and white plastic chairs as a brainreference object

From the other side: the chairs appear with a color close to the color of the LED spot lights

At night

Human vision of the natural scene at a very wide angle

TOWARDS VIRTUAL REALITY

The simulation created in SPEOS can be used to run radiometric analyses, to create the images above, but also to create 360-degree images. By creating two 360° images, one at the presumed position of each eye, we can display a 3D immersive view of the simulation in a headmounted display or on any 3D display. These images are very accurate and are the first real experience of immersion on the surface of Titan with actual scientific data used for modeling.

However, the 360 visualizations are from a fixed point of view. Several of them can be created, but that is not sufficient to be able to "walk on Titan". ANSYS OPTIS' real-time and virtual reality software comes to the rescue: products such as Theia-RT[3] can render in realtime physics-based scenes, with different rendering techniques and some approximations. We are working on using the complex spectral data used for this simulation into this real-time engine, to offer more interactive experiences at the surface of Titan, in virtual reality immersion.

CONCLUSION

We have used the latest scientific data available to date to create images representing what a human would see on the surface of Titan. These images allowed film makers to integrate more realistic shots in their documentary. These images are also used for scientific public outreach, and the simulations can even be used by scientists to prove their models if needed.

The ANSYS OPTIS technology enables to turn data into very realistic images. Thanks to its physics-based behavior, as long as precise data is available, the visual result will be realistic. The data used is usually acquired by laboratory measurement means, but this project shows that any data can be in fact transform into accurate, physicsbased visualizations.

Now, it is also possible to visualize these simulations with modern head mounted displays, for an enhanced feeling of immersion, a virtual reality experience both scientists and the public are always eager to see.

ADDITIONAL RESOURCES

THE DOCUMENTARY

Last Call For Titan, a film by Jonathan Tavel and Frédéric Ramade

Directed by Frédéric Ramade

Production: Blanche Guichou / AGAT Films & Cie

Coproduction: ANSYS OPTIS and NHK

With the participation of France 5

With the support of the CNC (Centre National de la Cinématographie) and Procirep/Angoa

See also: www.OPTIS/titan.com

[3] http://www.optis-world.com/product-offering-light-simulation-virtualreality-software/theia-rt-software-evaluation-vizualization-real-time

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FOR MORE INFORMATION

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Vincent Hourdin holds a Ph.D. in computer science from the University of Nice – Sophia Antipolis. In 2013, he joined ANSYS OPTIS as a research and development project manager for a joint project with Airbus on human interactions in virtual reality. Passionate about astronomy and space exploration, he has managed the Titan Simulation Project at ANSYS OPTIS during the past 2 years.

ABOUT ANSYS OPTIS

ANSYS OPTIS, the virtual prototyping company, brings life and emotion to all industrial projects. Its world-leading solutions pave the way for a revolutionary design process: towards zero physical prototypes. Since 1989, ANSYS OPTIS offers its knowhow in light and human vision simulation into leading CAD/CAM software and dedicated immersive virtual solutions. This synergy creates true-to-life virtual mock-ups which are used as real decision-making tools. Today, more than 2500 clients in over 50 countries already trust ANSYS OPTIS and innovate day after day with its solutions to ensure the look and safety of their designs, reduce their ecological footprint and bring their future products faster on the market.

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