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Discover the secrets of the highest-energy Universe

The CTAO Virtual Tour

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Abstract. This paper presents the application "Discover the secrets of the highest-energy Universe with the CTAO".
This virtual tour was developed as part of the activity "Virtual Reality" of the work package "Outreach" of the Italian Plan for Resilience and Recovery (PNRR) Cherenkov Telescope Array Plus (CTA+)(website CTA+ 2024). This initiative is coordinated by the National Institute of Astrophysics (INAF) in collaboration with the INFN, the Universities of Bologna, Bari, Siena and Palermo and the Politecnico of Bari.
Accessible through a Meta Quest 3 headset, the virtual tour was developed in partnership with ASSA Vitruvio s.r.l., offering an immersive experience that brings users closer to the cutting-edge science of the CTAO.

Key words. INAF, Virtual tour, CTAO, Cherenkov, high energies, gamma rays, virtual reality

1. Introduction

The Cherenkov Telescope Array Observatory (CTAO) (website CTAO 2024)is the next-generation, ground-based gamma-ray Observatory featuring two arrays at distinct sites, equipped with three classes of telescopes: Large-Sized Telescopes (LSTs), Medium-Sized Telescopes (MSTs) and Small-Sized Telescopes (SSTs). It leverages the Cherenkov effect to unlock the mysteries of the high-energy Universe. However, explaining these complex concepts solely through words to a general audience can be a challenging task.
How could we engage the public, and keep attention and engagement at high level?
The INAF is deeply involved in the CTAO, and as part of the "Outreach" work package

of the PNRR Cherenkov Telescope Array Plus (CTA+) initiative, the researchers designed the ”Virtual Reality” activity to create an immersive virtual tour of the telescope arrays located in Chile and the Canary Islands (Spain), in order to popularize this science.
This virtual tour around the telescopes shows the objectives of the Observatory, how the telescopes are structured and how they work, the science and the technology behind them, and some of the high-energy sources they study in the Universe.
As noted by Chen J. et al. 2024, the use of immersive and interactive virtual reality in education “provide students with challenging real-world experiences”. And VR is effective on student engagement in learning.
In addition, VR promotes democratization and equity in science (Dick E. et al. 2024). This tool can not only bring the sites closer to people who are geographically far from them, but it also serves as an inclusive tool, as it will allow people with motor impairment, who cannot access the sites, to experience a visit to the telescopes.
According to Lampropoulos G.& Kinshuk 2024, in learning environments that integrate virtual reality and gamification, the motivation and the engagement of the students increase. Moreover, through active involvement, students develop their skills and improve learning outcomes. Therefore, gamified virtual reality can be considered an effective educational tool.
The VR of the CTAO is an immersive virtual experience, characterized by a gamified dynamic and a high sense of realism, and users can experience first-hand the CTAO sites and the implemented technology, through autonomous and interactive navigation. Among the gamification elements and mechanisms integrated in the virtual reality environments of the CTAO, there are some interactive educational experiences.
In addition to exploring the various telescopes, users can enter a virtual ”meta room” where they can, for example, build a telescope or interact with a supernova 3D model (the 3D models of astrophysical phenomena were developed by the INAF Palermo Observatory within the 3DMAP-VR project (Orlando S. et al. 2024).
A friendly robot, Cicer-One, accompanies the users and interacts with them on demand.
Feedback from users who have experienced the CTAO VR confirms that the use of VR headsets and controllers, combined with the concept of virtual tours, sparks curiosity, stimulates interest, and encourages participation. The immersive 3D environments heighten emotional impact, while the educational activities and simulations within the VR provide significant learning opportunities.

2. The Virtual Tour of the CTAO

We describe here the VR tour realization, views and interactions in detail.

2.1. On board the spaceship

At the very beginning of the experience, the players are on board a spaceship, characterized by a large horizontal glass that touches the floor in the control area, from which it is possible to look outside.
Inside the spacecraft, the users find themselves in the company of a friendly robot, Cicer-One, who introduces itself and explains that it will accompany them to explore the CTAO, the world’s largest ground-based gamma-ray Observatory, with significant involvement from Italy.
At this point the large glass of the spacecraft, from which you could see the Earth, is darkened and becomes a monitor, on which a video is released, which in a few seconds provides a general introduction to the CTAO, showing some gamma sources, telescopes and explaining some general concepts on the science of Cherenkov telescopes.
At the end of the video, the user can choose which of the two CTAO sites to visit first, by clicking on the corresponding icon on the spaceship’s control panel.
Once the destination is selected, the spacecraft approaches the chosen location, allowing a global overview of the Observatory’s array of

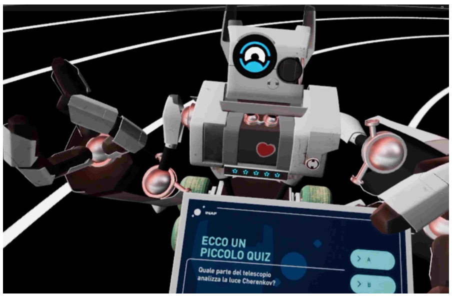

Fig. 1. The robot Cicer-One.

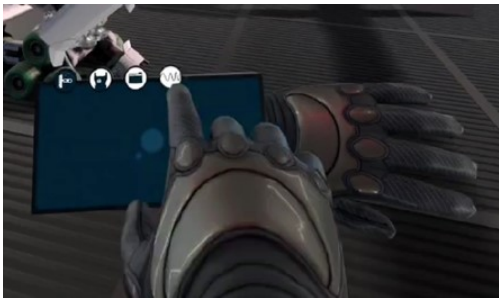

Fig. 2. The arm tablet.

telescopes, before teleporting its passengers to Earth.

2.2. The robot Cicer-One

Cicer-One is a robot with anthropomorphic features, which was created by INAF for the Virtual Reality software developed in 2019 to present the ASTRI and SKA projects.
While in the first VR Cicer-One guides continuously the players in the experience, in the CTAO VR it responds when prompted, allowing users the freedom to explore the sites at their own pace.
Moreover, compared to the previous version, Cicer-One has a new feature. It can detach his display from the chest to provide it to the user, thus facilitating the interaction, the vision of some videos and the reading of some texts.

2.3. The arm tablet

On the left forearm of the player, there is a display and a console with 4 circular buttons that recall the 4 main functions of the ”Arm tablet”:
• Teleport into the spaceship
• Cicer-One recall
• Glossary
• The electromagnetic spectrum and Gamma rays
When you click the ”Spaceship” button, the display asks for confirmation of your choice and tele-transports you to the spaceship.
If you click the button “Cicer-One recall”, immediately the robot comes and interacts with you.

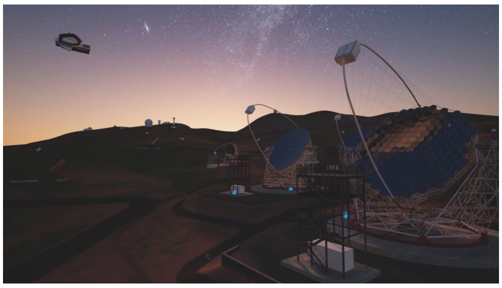

Fig. 3. The Northern Array (La Palma). Note in the upper left part of the figure in the sky the spaceship where the player finds itself at the beginning.

The glossary helps users in the comprehension of some difficult words and scientific concepts. Clicking the button “The electromagnetic spectrum and Gamma rays” the user can understand better what light consists of, in which wavelength the gamma rays are positioned and what energies the CTAO investigates.

2.4. Walking around the telescopes

If the users choose to visit the Northern site of the CTAO, they will be teleported to the island of La Palma, Spain, exactly on the Roque de los Muchachos. If they decide to visit the Southern site of the CTAO, they will be teleported to Chile in the Atacama desert.
The player is trasported to the year 2035, when the Observatory is completed, and land at dawn, thus having the possibility to see the Milky Way above them, with a minimum of light that allows them to admire the view and

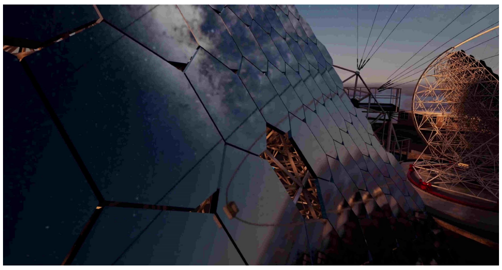

Fig. 4. A close-up of the mirror of an LST within the VR.

the distribution of telescopes, and to remain astonished by the dimension of Large-Sized Telescopes (LSTs) and their agility in rotating.

Walking around the telescopes of the two arrays, players can freely choose where to go and what to visit. Moreover, they find many hotspots on some telescopes, in the sky and on Cicer-One's display, highlighted in light blue, which activate some interactive experiences.

2.5. Science and technology behind the tour

The CTAO virtual reality tour allows users to acquire knowledge by first-hand experiences and the presence of many hotspots that provide insight in the various arguments. Players can see repositioning of the LST telescopes, move above the scaffold of the LST in order to see in detail the mirror and the camera of the telescope. Or, for example, one of the MST telescopes is in a "rest" position, with the camera on the appropriate ground support.
Entering the hotspot near the camera, the doors that protect it open and Cicer-One explains that the camera is the eye of the telescope.
Using the button on the Arm tablet, the user can also discover how the CTAO telescopes "see". Some hotspots give also the chance to move to a meta room, where they are invited to drag and drop parts of the telescope, and place them in the positions and to obtain a 3D model of the telescope. Each time a component is placed, Cicer-One correctly explains what it is for.
Players can also decide to interact with Cicer-One, the robot proposes a small quiz, to let them understand why the location on the Roque de los Muchachos in La Palma and the location in the Atacama desert in Chile were chosen to build the two arrays of the CTAO. In particular, at La Palma the clouds are formed between the 1.000 and the 2.000 meters and the site on the Roque de los Muchachos is located at 2.396 meters above the sea, providing optimal conditions for astronomy; as for the Southern array, since the Atacama desert is one of the most remote and Earth's dry land, it is an ideal environment for Astronomical observations.
Moreover, players can discover how the CTAO telescopes work through a small video projected by the robot. They will learn that CTAO's telescopes will capture the "Cherenkov light" – namely the fast flashes of blue light created when the gamma rays interact with the Earth's atmosphere - to study high-energy gamma rays. In particular the CTAO covers a very broad gamma ray energy range (20 GeV to 300 TeV), thanks to its three classes of telescope: four LSTs in the Northern hemisphere optimized for its low-energy range (20 to 150 GeV), 14 MSTs on the CTAO-South array site and nine MST on CTAO-North, for its core energy range (150 GeV to 5 TeV), and up to 37 SSTs in the Southern hemisphere to extend the energy range above 5 TeV.

Among the possible experiences, through the hotspots in the sky, users can discover possible Gamma-ray sources, such as AGN, supernova remnants and pulsars and can interact with the 3D models of the objects and gain information about them.

3. Other products developed from the CTAO VR

The CTAO VR experience is very full of contents and details and it can take a long time. It depends on the user's interests and choices. But when we deal with a large number of people, it is important to manage the time of the activity. This is the reason why we produced a ten-minute 360° immersive video of the CTAO, which is really useful at science festivals and big events. Moreover joysticks are not needed. Furthermore, we developed a planetarium

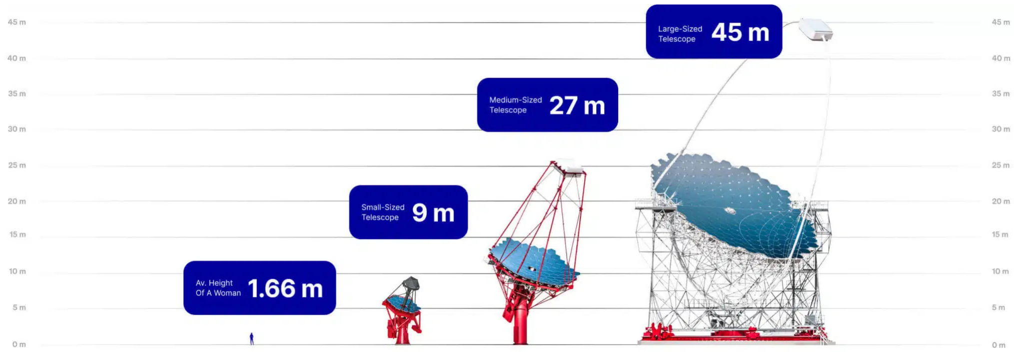

Fig. 5. Relative sizes of the three classes of telescopes compared to that of a person. Credits: CTAO.

show, also extracted from the VR to disseminate the CTAO to classes and for educational purposes.
In the future, the VR of the CTAO will be also translated into English and all the products will be made available through the CTAO and INAF channels as Open-Access Tools, to promote the free use and sharing of scientific knowledge.

Fig. 6. Trying the CTAO's VR in Cape Town (August 2024).

4. Dissemination activities

The VR of the CTAO was presented in many national scientific meetings and a demo of the English version of the virtual tour was presented in international meetings, such as the European Astronomical Society Annual Meeting 2024, last July, the IAU General Assembly in Cape Town last August, and the 8th Heidelberg International Symposium on High-Energy Gamma-Ray Astronomy.
On all the occasions the CTAO virtual reality received great appreciation.
Aside from the scientific meetings, people of different ages and interests made the experience of the CTAO's VR during education and outreach events. In general the feedback was enthusiastic, although some people had difficulty in moving around the virtual environment and managing the controllers and the educational experiences, thus feeling frustrated.

5. Conclusions

Creating an immersive virtual reality for the two CTAO observation stations allows people to experience the landscape of the Observatory and the technology first-hand and the CTAO's virtual reality seems to be a valuable tool for explaining engagingly the CTAO and its objectives, including the scientific research aspect of the Observatory. Even to a non-expert audience. The use of visors and controllers and the idea of virtual tours stimulate curiosity, interest and participation in the audience and 3D rendering of the environment makes the context highly immersive and of high emotional impact.
The CTAO VR gives the public a chance to experiential learning.
According to (Sun F.-R., et al. 2024) stu-

Fig. 7. A young student tries the CTAO VR during the SHARPER event for the European Researchers' Night 2024 in Palermo (27 September 2024).

dents' interest and enthusiasm for learning increases in a VR technology-based learning situation. Furthermore, there is a significant change in students' learning engagement and a significant increase in students' academic performance, problem-solving skills, and critical thinking skills.
We found that the activities and the simulations integrated into the VR of the CTAO effectively engaged both students and the general public, while also helping participants acquire new skills. Unfortunately, we have not already had the chance to formally assess its impact on learning or determine which scientific concepts were actually understood, or which sections of the tour were most or least visited.
In fact, we are planning to develop tests to gather feedback in terms of learning, satisfaction and usability of the tools provided. These assessments will also help us evaluate whether the VR experience influences students' motivation to study scientific subjects, particularly astronomy. Additionally, these tests will enable us to compare the effectiveness of the various tools used in the virtual environment.

Authors

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Website of CTAO, www.ctao.org/