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Making cosmic particle accelerators visible and audible

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In a collaboration between astroparticle physicists, animation artists from the award-winning Science Communication Lab, and musician Carsten Nicolai (a.k.a. Alva Noto), two cosmic particle accelerators have been brought to life: the massive binary star Eta Carinae, and the exploding star, which resulted in the gamma-ray burst GRB190829A. For Eta Carinae, the computer-generated images are close to reality because the measured orbital, stellar and wind parameters were used for this purpose. Particle acceleration in the jet of GRB190829A has also been animated at a level of detail not seen before. The internationally acclaimed multimedia artist Carsten Nicolai, who uses the pseudonym Alva Noto for his musical works, exclusively composed the sound for the animations. The multimedia projects aim at making the discoveries more accessible to the general public, and to mediate scientific results and their reference to reality from an artistic point of view.

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1. Introduction

Outreach and education are becoming more and more important in the communciation of scientific results to the public. This effort is not limited to the communication of interesting discoveries, but increasingly also to educate the public how science and fundamental research work in general. In particular astronomy and astrophysics results attract significant interest. Animations and artist's impressions of astrophysical objects have long been used to visualise how objects look that may not be resolvable by telescopes. In recent years, visualisation and animation software has reached a level of complexity, which makes it feasible to visualise astrophysical objects with realistic/physical inputs and to go much beyond the established "artist impressions". Although there is no sound in space, the sonification of an animation would add another dimension to the audience's experience, making it more immersive. The multimedia project presented here aims at making the discoveries of two gamma-ray sources, namely the colliding-wind binary Eta Carinae, and the gamma-ray burst (GRB) GRB190829A more accessible to the general public, and to mediate scientific results and their reference to reality from an artistic point of view. It is an attempt to bring the areas of science and art together. The paper is organised as following: some background of how the multimedia project was realised is given in section 2. The multimedia animation of Eta Carinae is presented in Chapter 3. The physics inputs, level of realism as well as the animation visualisation and sonification are discussed in more detail. Chapter 4 will present the multimedia animation of GRB190829A in the same manner and also highlight differences to the Eta Carinae project in terms of the practical realisation. Chapter 5 will discuss the lessons learnt from the cooperation and outline future prospects of projects like this.

2. The process of developing and realising the multimedia project

DESY has established a cooperation with the design studio Science Communication Lab [1] in Kiel a few years ago. High-impact scientific results and other projects are communicated to the public through innovative visual animations. For the two projects presented in this work, the cooperation was extended to include Carsten Nicolai a.k.a. Alva Noto [2] to compose soundtracks for the animations. The baseline for the animations is usually the scientific publications, which introduce the science questions that have been studied and present the scientific results. From this input, a first script for the animation is developed, which introduces the audience to the astrophysical object, the measurement and the detection with instruments on Earth. Animation artists from Science Communication Lab and scientists involved in the measurement, together develop a script for the animation. At this point the main source of information needs to be chosen. There are two different inputs that we used for the Eta Carinae and GRB190829A animations. For Eta Carinae, mainly real data was used to capture the dynamics of the system (see Chapter 3), whereas for GRB190829A, physical processes as implemented in the animation software have been used to approximate conditions in the GRB. The software used to create the animation is *MAXON Cinema4D* [3] for 3D computer animation, modeling, simulation, and rendering. The *xParticles* [4] plugin was used to support Newtonian Gravity as well as fluid dynamics (e.g. fire, smoke, or grains). Additionally, also the *TurbulenceFD* [5] fluid dynamics plugin has been used. Individual scenes are then produced in a wireframe model, iterated among the participants and at the end put together to form the full animation. Once the full animation including all scenes was available as wireframe model, Carsten Nicolai started to compose the soundtracks. Some final adjustments to the animation and sound were done before the full rendering of the video was initiated. The two multimedia projects are discussed in more detail in the following.

3. Visualisation and sonification of Eta Carinae's gamma-ray emission

Eta Carinae is a massive stellar binary system 7500 lightyears away from Earth, and situated in the Carina arm of the Milky Way. It is one of the most enigmatic objects in the night sky and has been studied as early as in 1595 when a Dutch expedition to the East Indies with navigator Pieter Keyser mapped the southern stars [6]. Nowadays, astronomical measurements across all wavelengths suggest that the system is composed of two very massive stars ($\sim$ 100 and $\sim$20 times the mass of the Sun) that orbit each other on a very eccentric orbit every 5.54 years. During the closest encounter, the stars approach each other at a distance corresponding to the distance between the Sun and Mars, (Fig. 1, left). The conditions in this system are very extreme with the more massive star losing almost an entire solar mass of material within only 2000 years due to its dense winds. When the two stellar winds collide they form a colliding wind region in which gas is heated to temperatures, where the gas shines in X-rays. At the same time wind particles are accelerated to Teraelectronvolt energies in shocks in the colliding wind region and produce gamma rays. Gamma rays have been detected with the LAT instrument onboard of the Fermi satellite [7] and, more recently, with the H.E.S.S. telescopes situated in Namibia [8]. It is the first system of this kind detected at such high energies and the origin of the gamma-ray emission remains somewhat elusive.

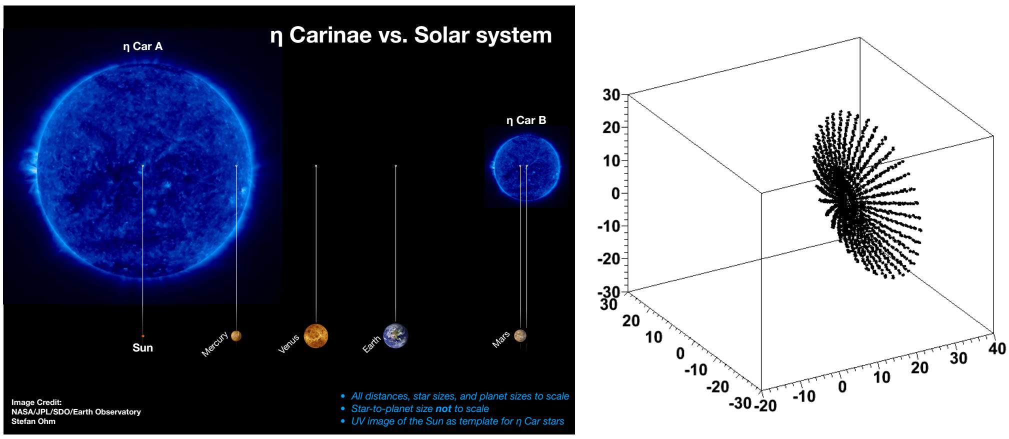

Figure 1: Left: Sketch of the Eta Carinae binary system during periastron compared to the solar system. Right: Grid points used to map the time-dependent shape of the shock cap, based on [9].

3.1 Realism and physics input

The aim of the visualisation was to strike a balance between reaching a certain level of realism while being visually appealing and not overloading the viewer with information. The most important ingredients to capture the dynamics of the stars and their extreme properties were provided by using the measured orbital parameters and inferred stellar properties [see **?** , and references therein].

Thereby we were able to show the time-dependent movement of the stars along their orbits and with the realistic speeds (the stars move faster when they are closer). The second major ingredient was the colliding wind region, which was derived using the Canto et al. (1996) [9] representation, who make use of the momentum balance between the two stellar winds. The shock cap was parametrised using a grid of 36 azimuthal and 82 radial points and used to guide the simulation (Fig. 1, right). Together with the stars, the shock cap is not static, but moving in space, and the gas inflowing from the two stars mixes and is ejected outwards ballistically from the edge of the shock cap. A limitation of the animation was reached when showing the gas density difference between the two stellar winds and the much denser colliding wind region. Here a compromise had to be made to maintain the undisguised view into the entire system and all its components. With realistic density contrasts, one or multiple system components would have been hidden.

3.2 Output and media coverage

The final animation comprises 3:40 minutes of runtime, includes embedded text in two languages (English [10] and German [11]), and a picture-in-picture view of the X-ray and gamma-ray lightcurve along the orbit. The different parts of the system and the scientific results are built up one after another, starting with the two stars, their orbit, their winds, the colliding wind region, and the production of X-ray and gamma-ray emission. Apart from a top-side view into the system (Fig. 2, left), where the focus point is towards the center-of-mass of Eta Carinae, one scene towards the end is set in the shock cap, with the focus point at the contact discontinuity. Material from both stellar winds flows towards the viewer on the top/bottom side of the screen (Fig. 2, right). The gamma-ray emission is visualised through individually produced photons that originate partly in the colliding wind region, and partly in the outflowing material. Thereby, we tried to capture the still uncertain origin of the gamma-ray emission. Given the complexity of the content that is conveyed to the viewer, explanatory text was embedded in the video itself and meant to guide the viewer through the different parts of the animation. To anker the view, a 3D grid of coordinates was put in the animation to provide a reference frame.

The sonification was based on the final animation, which pre-defined the appearance and disapperance of different sound elements as well as their transition to form the final soundtrack. After an initial exchange on the content of the animation (the stars, the winds, particle acceleration in magnetic fields, and the extreme conditions in the system) Carsten Nicolai developed the soundtrack from a sound artist's perspective. The process of developing the soundtrack and Carsten Nicolai's view have been captured in a interview that was released together with the press release and animation [12]. The English and German YouTube videos have been viewed ~13400 and ~2800 times, respectively.

4. Visualisation and sonification of the gamma-ray burst GRB190829A

Triggered by the detection of X-ray emission from a long GRB using the Swift satellite, the H.E.S.S. telescopes initiated follow-up observations from the ground in the gamma-ray regime as soon as GRB190829A was visible to H.E.S.S. under favourable conditions. A real-time analysis of the data taken on site resulted in a detection of a new gamma-ray source at the position of this GRB. The gamma-ray signal was detected also in the following two nights, with a fading

Figure 2: Two extracted stills from the Eta Carinae animation, showing the top-down view into the system, including the stars, colliding wind region, gamma-ray emission as well as explanatory text (left). A side-view into the colliding wind region is shown with the two star sizes to scale (right). Copyright: DESY, Science Communication Lab.

intensity. Spectroscopic observations established GRB190829A to be much closer to Earth than typical GRBs. Moreover, the GRB emission was later accompanied by an afterglow from the subsequent supernova explosion. The temporal and spectral X-ray and gamma-ray measurements challenge current models for the non-thermal emission from long GRBs and have been published in the *Science* journal (see [13] for further details and references).

4.1 Realism and physics input

This unique discovery and its physics implications motivated the second cooperation between Science Communication Lab, Carsten Nicolai and DESY members. Similar to Eta Carinae, the aim was to bring the scientific result to life, make it more accessible to the general public, and to mediate its reference to reality from an artistic point of view [14].

Due to the cosmological distance to GRB190829A, no telescope could resolve the system, which is why the visualisation was mainly guided by unresolved (but time-dependent) measurements from optical, X-rays and gamma rays, as well as by established theoretical models. The size of the collapsing star with respect to the jet and the jet opening angle are inspired by measurements and in particular the relativistic boosting factor, Γ. The shape of the jet are guided by theoretical models of jet breakouts like in [15]. The head of the jet depicts the different regions where particles are believed to be accelerated, i.e. the forward and reverse shocks; and the contact discontinuity. The outflowing material in the jet was realised through a fluid simulation, which is constantly fed with new material. This representation does not necessarily resemble the likely situation in the GRB, as it is believed that energy was fed into the jet in the launching event and that particles are picked up from the interstellar medium and subsequently get accelerated. Instead, we use a test particle that is coupled to the outflowing jet material, is deflected in magnetic fields and emits synchrotron emission. Figure 3 (left) shows a wireframe snapshot of the outflowing gas cloud, with a test particle emitting photons. The emission of synchrotron photons predominatly in the forward direction reflects the relativistic beaming effect. Figure 3 (right) shows different realisations of the relavistic beaming in the emitted photons. The rapid radial drop of intensity of the gamma rays that are launched from the head of the jet follows current state-of-the-art models as well.

The visualisation of the X-ray and gamma-ray photons arriving on Earth adds another layer of realism. CAD models of the Swift satellite and the H.E.S.S. telescopes give the viewer a much

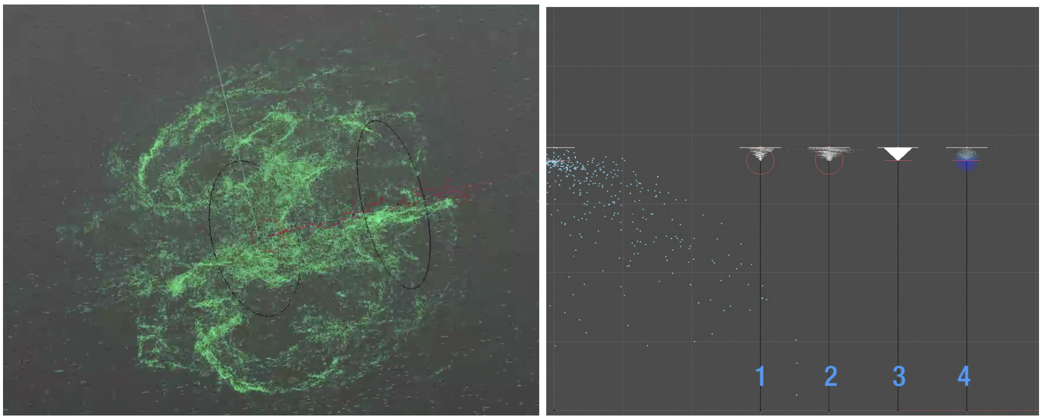

Figure 3: Two wireframe screenshots of individual scenes in the animation. The left hand side shows the gas cloud to which a test particles is coupled and gets deflected. The right-hand side shows different attemps at illustrating the relativistic beaming and emission of photons from the head of the jet. Copyright: DESY, Science Communication Lab.

more realistic understanding of how the instruments scientists operate look like. The space-view towards Earth features the Swift satellite in the foreground, which detects X-rays, but also shows a realistic geographical map of Namibia and South Africa in the background. Very-high-energy photons are punching into Earth's atmosphere and initiate particle showers, which shine in blue light. The size of the particle showers are not to scale as they would not be visible from such a large distance. Finally, the movement of the H.E.S.S. telescopes tracking the GRB over three nights, while being parked in during the day, is also a realistic resemblence of the actual observations and how they have been conducted. The three main elements of the animation, namely the jet breakout and launch, the jet propagation, particle acceleration and gamma-ray production, as well as the detection by instruments on Earth are displayed in three screenshots in Figure 4.

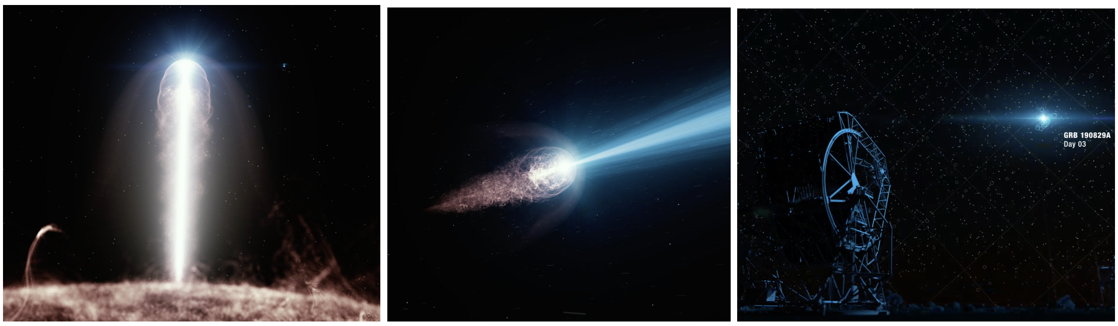

Figure 4: Shown are three screenshots of the jet breakout from the star and its launch (left), the propagation of the jet, particle acceleration and gamma-ray production (middle), and the detection with the H.E.S.S. telescopes (right). Copyright: DESY, Science Communication Lab.

4.2 Output and media coverage

The final animation has a length of 1:50 minutes. Shorter versions for distribution on social media have been produced – most importantly two reels of 30-second length that were used on

Instagram. As for the Eta Carinae video, the animation has been uploaded to YouTube, but in this case using the subtitle option of YouTube itself, rather than embedding the text in the video. This has the advantage that one can use one video link for multi-lingual distribution and to support visually impaired viewers. The YouTube video [16], which was released at the same time as the *Science* paper and accompanied by extensive press coverage (e.g. [14]) was viewed more than 220,000 times in less than two weeks. On average, people watched 80% of the video, indicating that those that didn't stop the playback immediately, most likely watched the animation till the end.

The sonification by Carsten Nicolai was again based on the final animation, which pre-defined the different sound elements and their transition to form the final soundtrack. Also for this project, Carsten Nicolai developed the soundtrack from a sound artist's perspective. For the GRB190829A soundtrack, an underlying beat was included that should take the viewer/listener through this highly dynamic system. A dedicated social media campaign on Instagram and Twitter highlighting the sound aspect of the cooperation was developed and realised in cooperation between the social media teams of Carsten Nicolai, DESY, and Science Communication Lab. The animation including the soundtrack was uploaded as a second YouTube video on July 1st, 2021 [17] resulting in more than 1100 views in four weeks. The Instagram feature received more than 3000 views via the Alva Noto, Science Communication Lab and DESY channels.

5. Future prospects

To our knowledge, this is the first multimedia project of this kind in astrophysics. It offers a unique way to communicate scientific results beyond the astronomy-interested public, and aims at approaching an audience with a specific interest in (audio-visual) art. The cooperation between Science Communication Lab, Carsten Nicolai and DESY scientists is planned to be continued and feature other cosmic particle accelerators. In the future we plan to approach projects like this even more from the sound perspective, by e.g. composing the soundtrack first and compiling the visualisation (and scientific content) based on the soundtrack.

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PoS(ICRC2021)1391