The Planeterrella: A planetary auroral simulator

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Summary

This article presents a plasma physics experiment which makes it possible to produce polar lights. The experiment, named Planeterrella, involves shooting electrons onto a magnetised sphere placed in a vacuum chamber. Inspired by Kristian Birkeland's Terrella, but with several different configurations and technical improvements, the experiment allows the user to simulate and visualise simple geophysical and astrophysical situations. Several Planeterrellas are now used across Europe and the USA. The design of the original experiment and the expertise of its first authors are shared freely with any public institute and are outlined in this article.

Polar lights: A magnificent natural spectacle

Aurorae have always excited people's imaginations and have given rise to many legends and beliefs. These beautiful coloured lights, caused by the interplay between solar activity and the Earth's magnetic field, blaze across the night sky in regions near the magnetic poles.

For the lights to occur, enough electrons and protons must reach us from the Sun either via the solar wind, or due to a solar eruption that has thrown out a cloud of these particles, which have intercepted the Earth as they cross its orbit.

When these conditions are fulfilled a diffuse aurora, starting 100–150 kilometres above the observer, and falling towards the ground, turns the sky green. Sometimes this green veil dances like a curtain at an open window, forming the well-named auroral curtain (Figure 1). Above this curtain the sky can glow cardinal red at about 200 kilometres altitude. If a solar flare has

***Figure 1.** An auroral curtain. The intensity is so low that the background stars can be seen throughout. The small spot in the very middle of the picture is not a star, but a comet. Credit: G. Gronoff*

Figure 2. *Planeterrella III. Credit: J. Lilensten*

occurred, new colours can appear down to about 80 kilometres and the aurora patterns can shift on timescales of minutes.

Few people have the chance to admire aurorae. To have such an opportunity, one must travel to high magnetic latitudes, with cloudless conditions and no urban lights or moonlight to swamp out the aurora. Even in the best conditions one can spend hours in the snow, head to the sky, and wait in temperatures that can dip below –30°C with no guarantee of a light show. It was for this reason that the Planeterrella[1] was created — to bring aurorae to the public.

Kristian Birkeland's Terrella

During the 19th century, geographers established that aurorae occur preferentially around the magnetic poles, forming what we now call auroral ovals. In the same century work in electromagnetism led to theories about charged particles such as electrons.

At the end of the 19th century, the Norwegian physicist Kristian Birkeland, an experimental genius, had the idea to shoot a beam of electrons — known as a cathode ray — onto a magnetised sphere suspended in a vacuum chamber. To his mind, the cathode was the Sun and the rays represented the expanding solar atmosphere — later dubbed the solar wind (Parker, 1958) — and the magnetised sphere was the Earth.

In the course of his life, Birkeland built up to 14 variations of his experiment, which he called the Terrella. With it, he succeeded in producing the first laboratory demonstration of the mechanism of aurorae, by obtaining coloured emissions organised along auroral ovals.

The Planeterrella: An improvement on the Terrella

After we had built several Terrellas, we conceived — with the help of many colleagues — a new experiment allowing many more configurations than the original Terrella. For example, rather than suspending the sphere from a fixed rod, making it very difficult to change its design and settings, the sphere is placed on a rod that can move and be adjusted in height (Lilensten et al., 2009).

In addition, the magnet in the Planeterrella can also be set in any desired direction. A simple metal tube acts as an electrical duct and is attached to a wheel inserted into a slot in a curved bracket, so that it can be moved and positioned as required.

In the original Terrella configuration, it was not possible to have two spheres as they were hung on wires, and so would attract or repel each other due to their magnetic fields. With the Planeterrella, the rods are rigid, allowing configurations with more than one sphere.

This flexibility allows the user to study various different star–planet configurations. Usually, there are two moving spheres and one electric duct in the Planeterrella. The duct can be used to replicate the work of Kristian Birkeland.

The Planeterrella set-up

The Planeterrella developed by this team uses a vacuum chamber with a capacity of 50 litres and a diameter of 50 centimetres. The first generation of the Planeterrella, made in 2007, used cylindrical vacuum chambers made of Plexiglas, but newer models use better designed glass chambers, which are visually more dramatic (Figure 2).

The inner spheres have diameters of 10 centimetres and 5 centimetres. While Birkeland used copper, the Planeterrella spheres are manufactured from a non-magnetic metal — aluminium, which is a good electrical conductor.

The vacuum should be of the order of 1–10 Pascal, and can therefore be obtained with a primary pump.

The voltage should be greater than 500 volts for a current of the order of a tenth of a milliamp. At the moment, the Planeterrella uses permanent rare earth magnets, 0.5 centimetres long. The magnetic field strength is approximately 0.5 tesla at the surface of the magnets — roughly three orders of magnitude larger than that of Earth's surface magnetic field.

Demonstrable phenomena

The Planeterrella can be configured in several ways to allow numerous space phenomena to be seen. If one sphere is connected to the anode — the positive electrical pole of the power supply — and the electric duct to the cathode — the negative pole — then the Planeterrella represents a planet receiving a flux of electrons.

With a low-intensity dipolar magnetic field, the audience sees auroral ovals (Figure 3). With a stronger field, one can visualise the generation of Van Allen belts and polar cusps.

A sphere connected to the cathode becomes a star shooting out a stellar

Figure 3. *Auroral ovals. Credit: D. Bernard*

wind made of electrons. This allows the audience to see a shock zone between this star and the second sphere, which is connected to the anode. This configuration mimics a bow shock (Figure 4). A bow shock is a region where two streams of gas collide, usually between a magnetosphere — the region of space near an astronomical object in which charged particles are controlled by that object's magnetic field — and an ambient medium; so for planets with a magnetic field the bow shock is located at the boundary where the stellar wind meets the planet's magnetosphere[2]. In this region the speed of a stellar wind abruptly drops and the solar wind is sculpted into characteristic formations reminiscent of the crest of a wave made by a ship moving through water, showing how the bow shock gained its name.

Figure 4. *Bow shock around the very young star, LL Ori. Credit: NASA/ESA and The Hubble Heritage Team STScI/AURA*

Other phenomena demonstrated by the Planeterrella are further from astrophysical reality and closer to analogies, like the formation of the solar corona and coronal holes (Figure 5) on the anode-connected sphere.

The Planeterrella can also help to visualise night-side aurorae on Uranus and Neptune, which cannot be observed directly. The magnetic axes of these planets are strongly tilted relative to the privileged direction of the arrival of electrons. This is relatively easy to mimic with the Planeterrella, by positioning the electric duct connected to the cathode above the magnetic pole of a sphere connected to the anode.

The economic model and collaboration

The cost of a complete Planeterrella is 8000 to 10 000 euros. However, this cost can easily be reduced in practice, as components such as vacuum pumps, generators or cables are often available on loan from host universities.

In agreement with the French national organisation for scientific research (CNRS), the Planeterrella has not been patented. Instead, we have produced a gentleman's agreement, under which we are committed to providing plans and assistance with the construction, provided that the applicant is affiliated to a public institute. In return, the applicant agrees not to disclose this process and must share progress and plans for the Planeterrella, and credit our institute on the demo table.

We have found that, because scientists are used to sharing research, directors may sign the agreement even if the funding is not acquired, which is reassuring. Planeterrellas are always built in a spirit of collaboration.

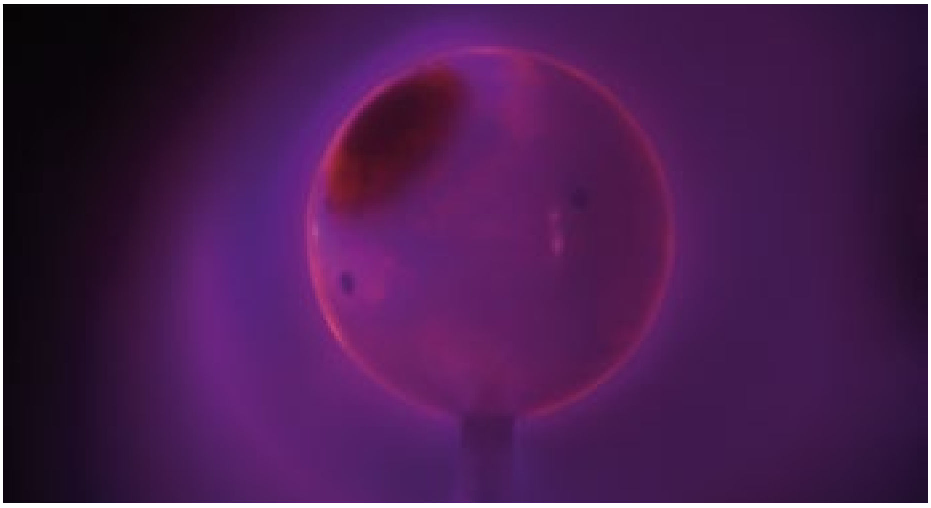

Figure 5. *The solar corona and a coronal hole. Credit: C. Simon*

Current and future projects

Seventeen Planeterrellas now exist in France — including at the Observatoire de Paris, Université Pierre et Marie Curie, Université de Toulouse and the Institut universitaire de technologie (IUT) de Bourges — as well as in Belgium, Switzerland, England, Scotland, Ireland, Spain, at CERN in Geneva, and in the USA — including NASA Langley, University of California, Los Angeles (UCLA) and Princeton. Agreements have been signed with Italy, Norway and Hong Kong. A Planeterrella for the science museum Palais de la Découverte in Paris was commissioned in June 2014 and a recent project aims to build Planeterrellas in Algeria and Tunisia.

The Planeterrella received Europlanet's first international award for public activities in 2010 and the French national prize, Le goût des sciences (Taste for Science), in 2012.

Figure 6*. A classroom demonstration of the Planeterrella. Credit: C. Simon*

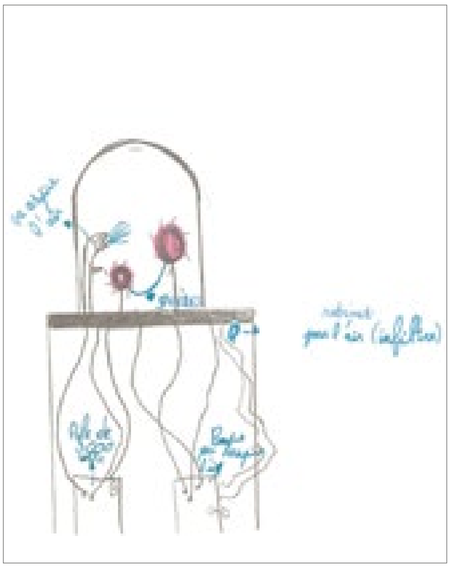

Figure 7. *This drawing was made by Arnaud, a 10-year-old student from Vienne, France, after his visit to the Planeterella with his class.*

Outcomes: The anticipated and the unexpected

The Planeterrella was designed to be shown in classes or at public exhibitions (Figure 6), but has enjoyed increasing success, and been used for unexpected purposes (Lilensten et al., 2013).

Students have used the Planeterrella for their class projects, artists have found inspiration from it and, in 2013, a professional company created the first artist's show around the Planeterrella. This new artistic dimension multiplies and diversifies the public audience and brings another form of mediation to the dissemination of knowledge in astronomy.

It also serves as an educational tool and has been used at different universities for spectral analysis, by engineering students who perform technical studies to improve it and as a test for Masters' projects in numerical modelling.

Perhaps the most touching outcome is that many school children send drawings of the Planeterrella, which are posted on the Planeterrella website after the demonstrations (Figure 7).

Conclusion

We recently estimated that about 65 000 people of all ages across Europe and the USA have seen aurorae thanks to this experiment. The Planeterrella to be built at the Palais de la Découverte will drastically multiply these audience numbers and once the ongoing projects are finalised, there will also be Planeterrellas in North Africa and Asia. As a result, the number of people who will discover auroral phenomena and have a chance to explore the environment of space will continue to grow. It's very easy to obtain a copy of the plans to build your own Planeterrella: just contact the first author of this article!

Acknowledgements

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Links

[1] Project website: http://planeterrella.osug.fr/?lang=en/

[2] http://en.wikipedia.org/wiki/Bow_shock

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Biographies

Jean Lilensten in an astronomer specialising in the impact of solar activity on the upper atmospheres of the planets. Jean is deeply involved in outreach activities, and, as well as developing the Planeterrella, has published 11 books for various audiences, from children to researchers.

Carine Briand is an astronomer at the Paris Observatory. She studies plasma instabilities, and in particular those related to the strong radio emissions produced during periods of solar activity. Apart from her scientific activity, she teaches at the Pierre et Marie Curie University (Paris) and is involved in numerous public outreach and education projects.

Laurent Lamy is a radio astronomer at LESIA, Observatoire de Paris. He studies the planetary magnetospheres of the Solar System and their auroral processes with a multi-instrumental approach. He managed the building of the Planeterrella at the Observatoire de Paris.

Baptiste Cecconi is a radio astronomer at LESIA, Observatoire de Paris. He is an expert in Solar System and planetary low frequency radio astronomy. He is also involved in the development of the Solar System virtual observatory and managed the realisation of the Planeterrella at the Observatoire de Paris.

Mathieu Barthélemy is an associate professor at Grenoble University. He is a specialist in radiative transfer in planetary atmospheres andspectroscopy. Working on planetary auroral emissions, he develops both models and observational devices especially for Earth polar auroral observations.