FRONTIERS

Guide of Good Practices

Emmanuel Chaniotakis (Ellinogermaniki Agogi),
With the support of :
Dr. Valerio Boschi (INFN/Virgo); Prof. Stavros Katsanevas (EGO);
Dr. Giulia Vannoni (PCCP); Giada Rossi (EGO); Prof. C. Kourkoumels (IASA);
Stylianos Vourakis (IASA); Prof. Margaret Farren (DCU); Joan Dempsey (DCU); Maria Luisa Almeida (NUCLIO)

DCU ELLINOGERMANIKI AGOGI NUCLIO EGO EUROPEAN GRAVITATIONAL OBSERVATORY IASA Université de Paris

Erasmus+
This project is funded by the European Union.

Contents

1.Introduction

Attracting students' attention by presenting contemporary Nobel Prize winning ideas in Physics and by offering activities that are closely related to new technological achievements and everyday life is one of the keys to stimulate students and contribute to the discovery of the next generation of innovators. Students are always fascinated by cutting – edge experiments and are eager to find out as much as they can about them.

The FRONTIERS project, aimed to demonstrate how Nobel Prize winning Physics can be systematically integrated in the school curriculum. To achieve that, FRONTIERS brought together outreach teams from large scale research infrastructures in frontier Physics that can offer access to rich scientific databases and resources in a variety of fields that can provide a catalyst for science learning. Schools, Universities and Research Centres acted as mediators, organising information – tailored to the needs of their communities – across scientific disciplines and providing tools for understanding complex scientific research, making science understandable and interesting to the public.

FRONTIERS involved numerous teachers in the design and development of innovative classroom activities in collaborative way by developing a network where teachers collaborated with other teachers but also with the outreach teams of large-scale research infrastructures. Being part of a professional network encouraged interaction and provided them with opportunities to enrich their practices and professional context through cooperation within and between schools, universities, and frontier research institutions, collaborative reflection, development and evaluation of instruction, exchange of ideas, materials and experiences, quality development, cooperation between teachers, students and researchers and support and stimulation from research.

The main objectives of FRONTIERS were the following:

- The selection of a series of scientific research outreach programs that successfully introduce the scientific methodology in school science education, by utilizing existing research infrastructures of frontier research institutions enriched with online tools
- The integration of these initiatives under a common educational approach and development of the FRONTIERS Demonstrators that could be exploited and widely used from the educational communities in Europe and beyond.
- The creation of virtual learning communities of educators, students and researchers and involve them in extended episodes of playful learning.
- The systematic validation of the proposed approaches and activities in order to identify their impact in terms of the effectiveness and efficiency.

- The design and implementation of a systematic raising awareness strategy that will contribute to the effective communication of the project's results and outcomes.

The Sars-CoV2 pandemic has suddenly reshaped the landscape of formal and informal education worldwide. At first, direct contacts between the general public, including teachers and students, and Research Infrastructures (RI) and scientific institutions were abruptly put on hold. However, the shift in lifestyle and general perception both of scientists and the general public towards online activities unexpectedly brought up creative solutions adapted to the new situation but extendable beyond the limits of the pandemic. In order to make sure that the FRONTIERS teacher trainng activities and implementation activities would continue to run smoothly, from the beginning of 2020, the project consortium shifted all said activities to the online, transforming the crisis into an opportunity to reach out to audiences in countries beyond our reach in the initial implementation plan of the project.

This document presents the main project outcomes, namely: Development of Educational Resources; Organization of teacher training activities; Building a strong community of practice and highlights best practices identified throughout the project implementation. The document was developed in the framework of FRONTIERS Intellectual Output 5.

2.The FRONTIERS pedagogical design and resources

3.1: The FRONTIERS pedagogical design

Pedagogical Content Knowledge (PCK) is defined by Shulman as a combination of "content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding". It is seen as the "knowledge to make subject matter accessible to students". The TPACK framework consists of technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK). The TPACK framework with its focus on technology, pedagogy and content knowledge was used as a basis for developing the FRONTIERS pedagogical (or inquiry) framework.

The FRONTIERS framework has a three-part approach and is thoroughly described in Intellectual Output 2 of the project (https://zenodo.org/record/5084991).

(i). technology/ tools embedded in the demonstrator /resource.

(ii). pedagogical knowledge which in this case is the inquiry-based learning approach

(iii) content knowledge, which is the Physics knowledge

The Demonstrators are a set of innovative educational activities that offer access to provide unique scientific resources in frontier physics to teachers. The FRONTIERS pedagogical knowledge was used in the preparation of the Demonstrators/resources. The 3-phase pedagogical process included: (i) Orientation, (ii) Exploratory and (iii) Consolidation. The FRONTIERS pedagogical (or inquiry framework) features are explained in Table 1.

Table 1. FRONTIERS Pedagogical (or inquiry) features explained

Question Or Statement	Students begin learning process through a scientifically orientated question or statement on a scientific topic.
Evidence	Students look for, obtain evidence from which to investigate the question or statement.
Analyze	Students analyze the evidence to discern a possible answer.
Explain	Students formulate an explanation for their answer to the question or statement based on their analyses of the evidence.

Connect	Students connect new explanation with current scientific knowledge to build upon and increase overall understanding of current topic.
Communicate	Student communicate and justify explanation – bringing connections together to formulate a concurrent and systematic, incremental structure to the acquired knowledge on the topic.
Reflect	Students reflect on what they have learned.

3.2: The FRONTIERS Educational Resources

The pedagogical framework is implemented in the FRONTIERS Demonstrators (Intellectual Output 2: **https://zenodo.org/record/5084991**) . These Demonstrators are structured in a way which follows the inquiry-based approach that promotes school and research centers collaboration. Most of the demonstrators offer access to some of the unique experimental facilities and detectors in the world (CERN, EGO-Virgo, remote telescopes) and at the same time offer the use of interactive tools which that the students can use in their school settings. The students, through the demonstrators, get involved in a series of innovative activities and get familiarized become familiar with the scientific methodology. The students not only analyze data from the cutting-edge detectors, but also make their own observations using robotic telescopes, try to identify significant events among "noise" signals, and look for scientific information existing in large repositories and archives. (In all demonstrators the added value of the scientific Infrastructures that support the process is well described and analyzed). In general, the usage of the designed scenarios and activities represents and describes the overall implementation of the FRONTIERS approach).

The demonstrators cover include different physics research areas such as non-accelerator physics, high-energy physics, detection of gravitational waves, cosmology, astronomy, optics and magnetism. The demonstrators provide access to a wide range of unique scientific infrastructures3, offer different levels of complexity are also addressed to and cater for students of different age groups.

Overall, The FRONTIERS consortium developed 21 Demonstrators, available in 5 Languages (English, Greek, Portuguese, Italian, French) ready to use in the classroom as well as 20 educational scenarios developed by teachers trained throughout the project's duration in the fields of: Gravitational Wave Astronomy; Astroparticle Physics; Astrophysics and High Energy Physics. Interested educators are invited to utilize the full set of educational resources and can find them here: www.frontiers-project.eu/frontiers-educational-resources.

Fig.1: FRONTIERS Educational Resources (www.frontiers-project.eu/frontiers-educational-resources)

The resources are divided according to the subject module they follow and are supplemented with :

- **Recorded teacher training workshops** that teachers who want to introduce the relevant FRONTIERS topics to their classroom can watch and get self-trained. The recordings are supplemented with all the training material provided ((http://www.frontiers-project.eu/past-international-training-events/), as well as with opportunities for future training.

- **Recorded virtual visits to 4 Large Research Infrastructures** that can be used by teachers to offer their students a tour to authentic research environments and show students how research is done in these infrastructures (High Energy Physics: Virtual Visit to the ALICE and ATLAS experiments at CERN; Astroparticle Physics: Virtual Visit to the Pierre Auger Observatory; Astrophysics: Virtual Observation with the Faulkes Telescopes; Gravitational Wave Astronomy: Virtual Visit to the Virgo Interferometer). Furthermore, the FRONTIERS team offers an opportunity to schools which want to perform virtual visits themselves to issue a request and get in contact with the relevant research infrastructures.

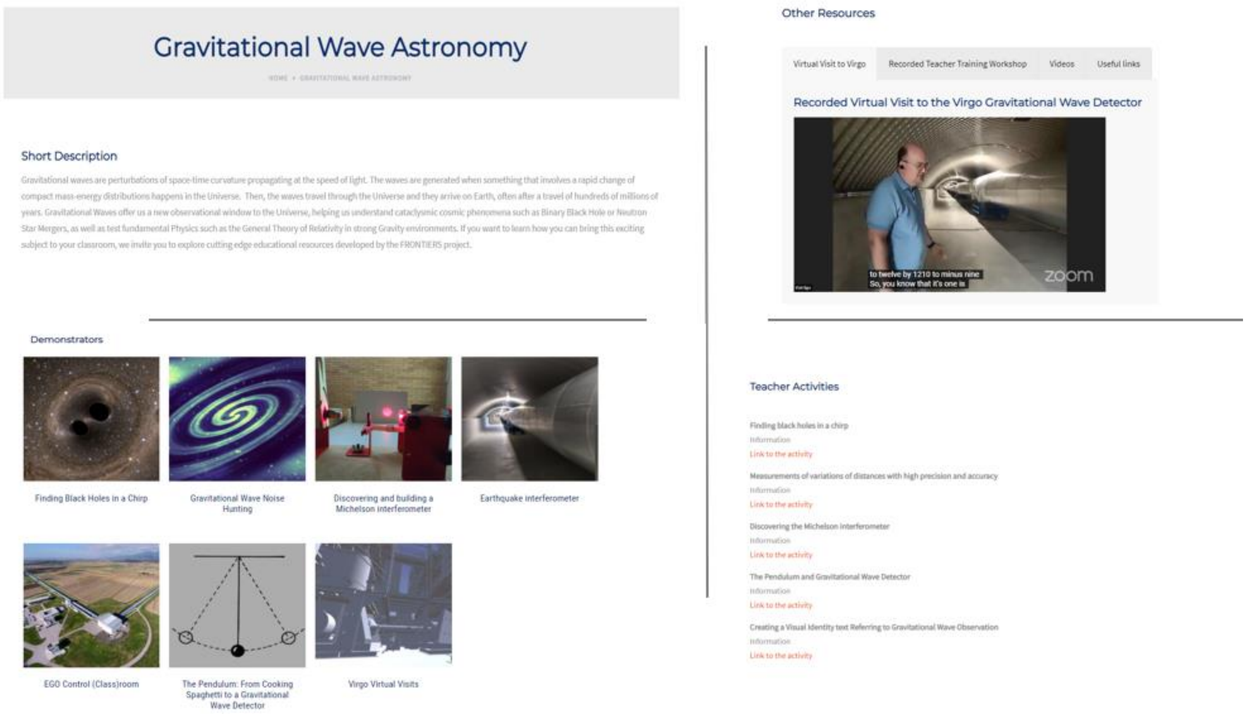


Fig.2: Anatomy of the educational resources presented in the FRONTIERS Gravitational Wave Module (http://www.frontiers-project.eu/gravitational-wave-astronomy/ ; Top Left: Short description; Bottom Left: FRONTIERS Demonstrators; Top Right: Recorded teacher training workshops, virtual visit to Virgo and useful links; Bottom Right: Resources created by teachers).

3.The FRONTIERS community of practice and teacher training

3.1 The FRONTIERS Community of Practice

FRONTIERS has focused on the development of strong national and international communities of practice that include researchers, teachers, students, and general public. The communities are built and maintained through a variety of online tools, like dedicated pages on the ODS portal, google classrooms, and a strong Facebook community (https://www.facebook.com/frontierseu/). Through the network of the community a constant support is offered to teachers by the experts composing the project.(FRONTIERS Intellectual Output 3: https://zenodo.org/record/3461647). The community channels can be immediately accessed through the FRONTIERS Website: http://www.frontiers-project.eu/community/.

More than 800 teachers from all over Europe as well as Asia and Latin America were engaged in the FRONTIERS activities, while more than 150 teachers participated in the intensive training courses of FRONTIERS, developed their own educational resources and implemented activities with more than 1,500 primary, middle and high school students, while more than 10,000 students were mobilized by the project activities and presence in the media. FRONTIERS maintains a strong presence in the social media: The reach of the dissemination of FRONTIERS activities is higher than 150,000 throughout the years of the project's online presence to the World Wide Web and includes countries beyond those of the participating project partners. Furthermore, FRONTIERS has developed an e-Twinning toolkit in order to disseminate the project outcomes and resources to one of the strongest communities of practice in Europe.

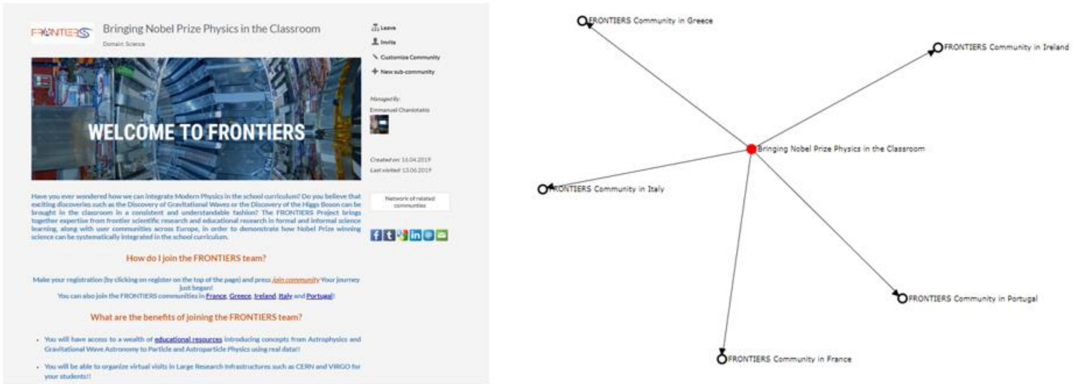


Fig. 3: Snapshot of the FRONTIERS Community in Open Discovery Space (http://www.frontiers-project.eu/community/)

3.2 Organization of Teacher Training Activities

Overall, FRONTIERS organized more than 15 short term national training events for teachers both face to face and online as well as three large scale international training activities for teachers as well as numerous implementation activities with students. In the framework of the project activities, FRONTIERS pioneered the organization of virtual visits to Large Research Infrastructures in Physics (Virgo, CERN, Pierre Auger Observatory) for teacher training, student education as well as public outreach.

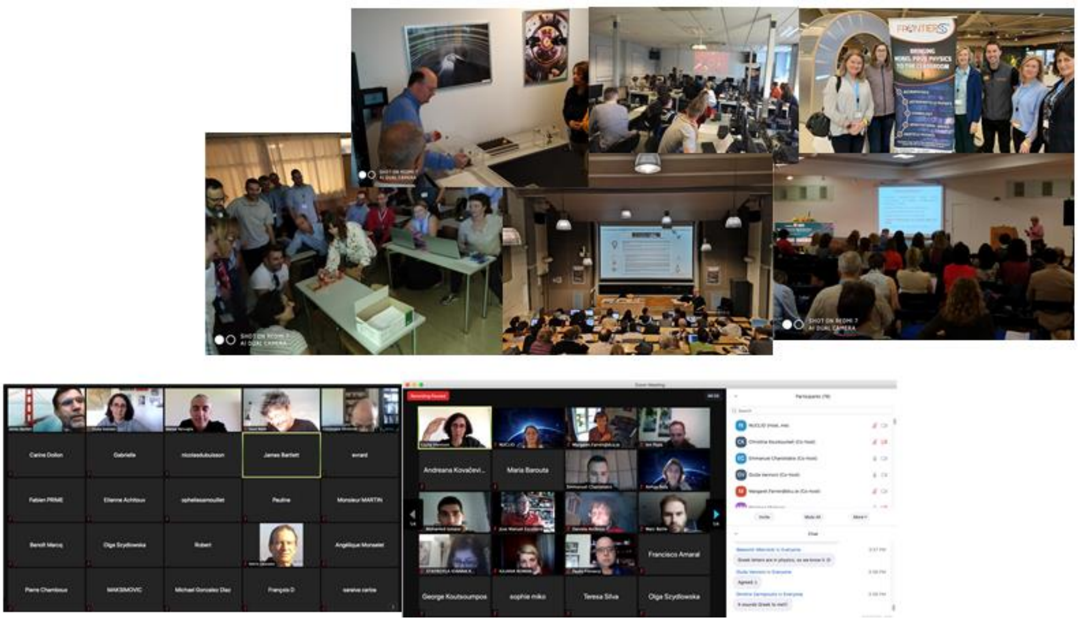


Fig.4: Teacher professional development in FRONTIERS before (up) and during (down) the pandemic

Sections 3.2.1 and 3.2.2 showcase selected good practices for teacher training at International and National Level which have the following characteristics: The collaboration between researchers and teachers; the authentic setting; the capacity building of educators transforming them from receivers of new knowledge and ideas to creators of their own educational content.

3.2.1 Best practices for teacher training at International Level

During 2020 and 2021, two e-Summer and one e-Winter Schools were organized (Summer Schools organized by Ellinogermaniki Agogi and Winter School by University of Paris) engaging teachers from Chile to Sri-Lanka while more than 10 national events took place online in the consortium countries (Ireland, Greece, Italy, France and Portugal). These events represent a good practice of the project as they allowed to train a large community of teachers beyond the European borders.

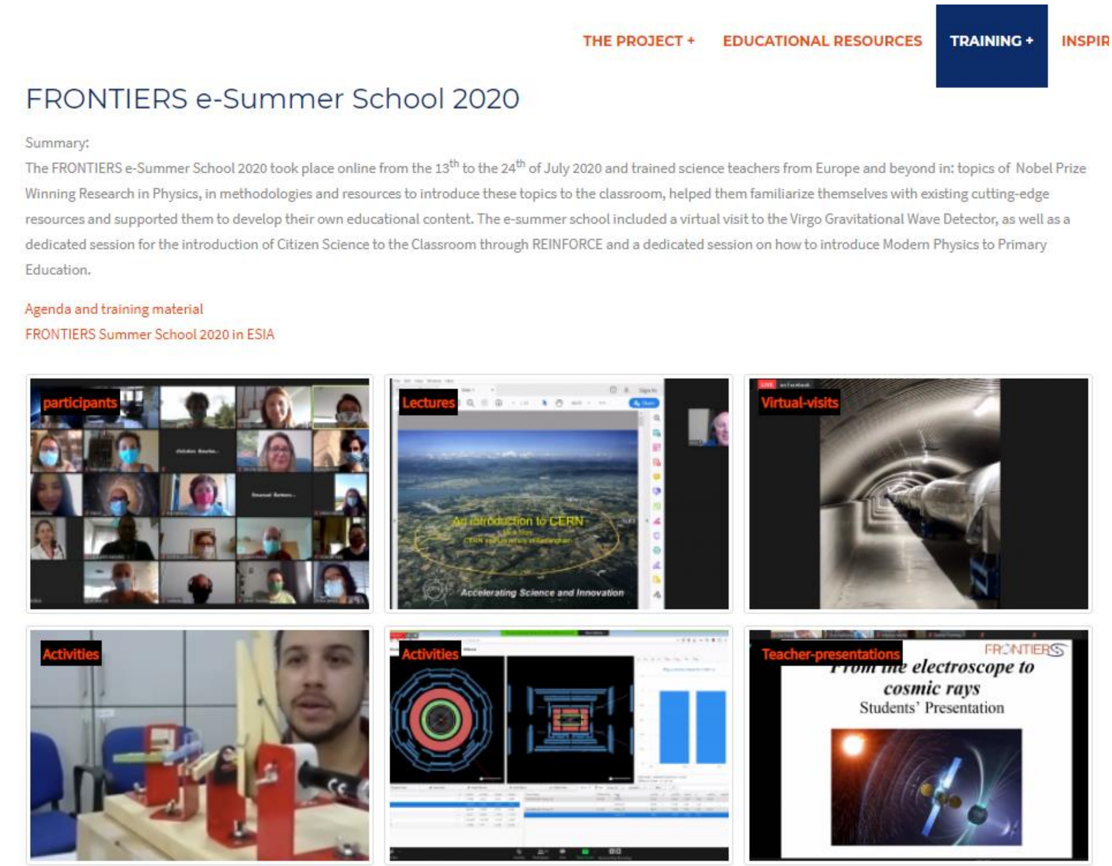


Fig.5 FRONTIERS Past International teacher Training events (http://www.frontiers-project.eu/past-international-training-events/).

The pandemic offered the unexpected opportunity to create truly global connections and extend the reach of the project. Moreover, we were able to transfer the acquired expertise from in-person to online without any detectable impact on the efficacy of the training. Thanks to the assessment and evaluation tools developed in the project, we were able to infer that the teachers' self-efficacy improvement brought by training was unaffected by the online only format. Moreover, we were able to transfer the acquired expertise from in-person to online without any detectable impact on the efficacy of the training. Participants participated in a variety of activities, including: Speeches, Hands-on or virtual online activities, virtual visits to Research Centers, focus groups as well as organization in groups to co-develop their own educational "Curricular Connections" that can be subsequently transferred to their classrooms. Thanks to the assessment and evaluation tools developed in the project, we were able to harvest valuable findings from the international training events (presented in detail in Intellectual Output 4). Two key findings were that:

-The teachers' confidence with Nobel Prize Physics content improved regardless the online format of the summer and winter schools.

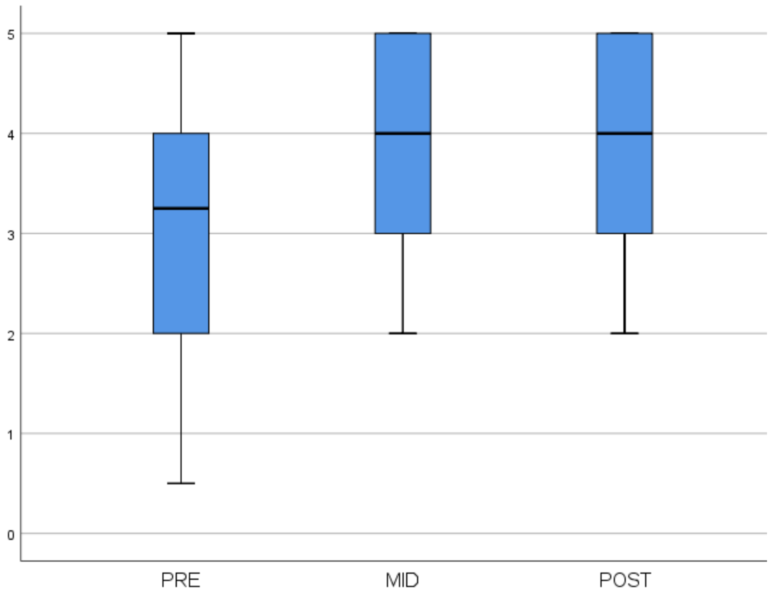


Fig. 6 : FRONTIERS Summer School 2020 teachers'(N=54) self reported confidence with content knowledge of Nobel Prize Physics before, mid-term and after the end of the Summer School.

- Teachers who participated in the project's international training activities were not aware of the existence of educational resources to support the introduction of Nobel Prize Physics to the Classroom. After the events this picture changed.

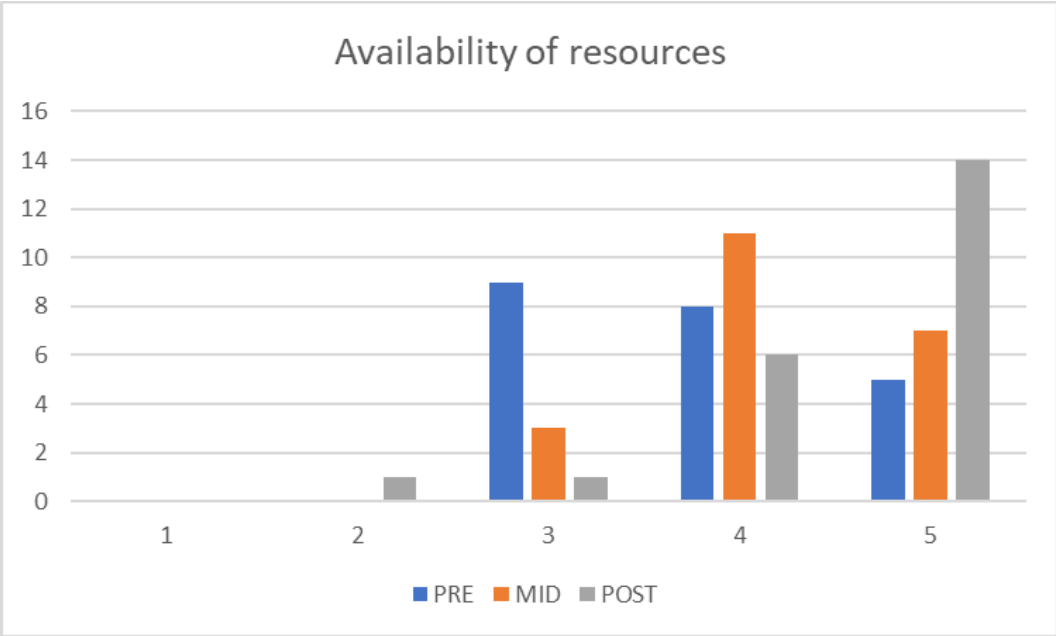


Fig. 7: FRONTIERS Summer School 2020 teachers'(N=54) statement for the availability of resources before, during and after the Summer School.

3.2.2 Best practices for teacher training at National Level

Black Holes and Gravitational Waves in the Classroom

A 2-day online teacher training workshop on black holes and gravitational waves for Greek teachers was organized by Ellinogermaniki Agogi and IASA with the support of EGO in December 2020 with the participation of more than 100 Greek Teachers. During the first day, the FRONTIERS team had the opportunity to present to the participants the Physics of Gravitational Waves, guide them through a virtual visit to the Virgo Gravitational Wave Detector, discuss with them the history and new paradigm of Gravitational Observation and present educational activities that can help incorporate these activities to the school curricula.

During the second day of the FRONTIERS workshop for Greek teachers on Black Holes and Gravitational Waves, professor Theocharis Apostolatos from the University of Athens introduced the participants to fundamental aspects of General Relativity and Black holes and guided them through the discoveries that earned Penrose, Genzel and Ghez the 2020 Nobel Prize in Physics. Teachers were introduced to the dedicated FRONTIERS educational scenarios on black holes and the expansion of the universe and engaged in a fruitful discussion regarding the introduction of these topics to the school classroom.

Fig. 8: Agenda of the Black Holes and Gravitational Waves in the Classroom Workshop

High Energy Physics in the school Classroom

At 18-19 February 2021, IASA in cooperation with EA organized a two-day event dedicated to High Energy physics and aimed mainly towards high school teachers (although more than 100 teachers of all levels were allowed to participate). On the first day Prof Chatzifotiadou, a member of the ALICE experiment of CERN gave a talk titled "Introduction to the LHC, the ALICE experiment and heavy ion physics". Following that a virtual visit to the ALICE experiment was hosted by prof. Chatzifotiadou. The participating teachers had the opportunity to follow a guided tour of the detector and the ALICE control room and discuss with the host about the details of the experiment. The last event of the day was a presentation of the FRONTIERS high energy physics scenaria developed by IASA and aimed towards high school students. The second day began with a talk by the University of Crete prof. Kyritsis titled "Elementary particles from experiment to theory". Following that the citizen science activity "New Particle Search at LHC" developed by IASA was presented. With this activity, the general public, including students can help scientists look for long lived particles that have not yet been discovered. The day was concluded with a round table discussion on the activities presented and way of introducing them to Greek classrooms. The agenda of the event in Greek can be found here: https://indico.ea.gr/event/1/.

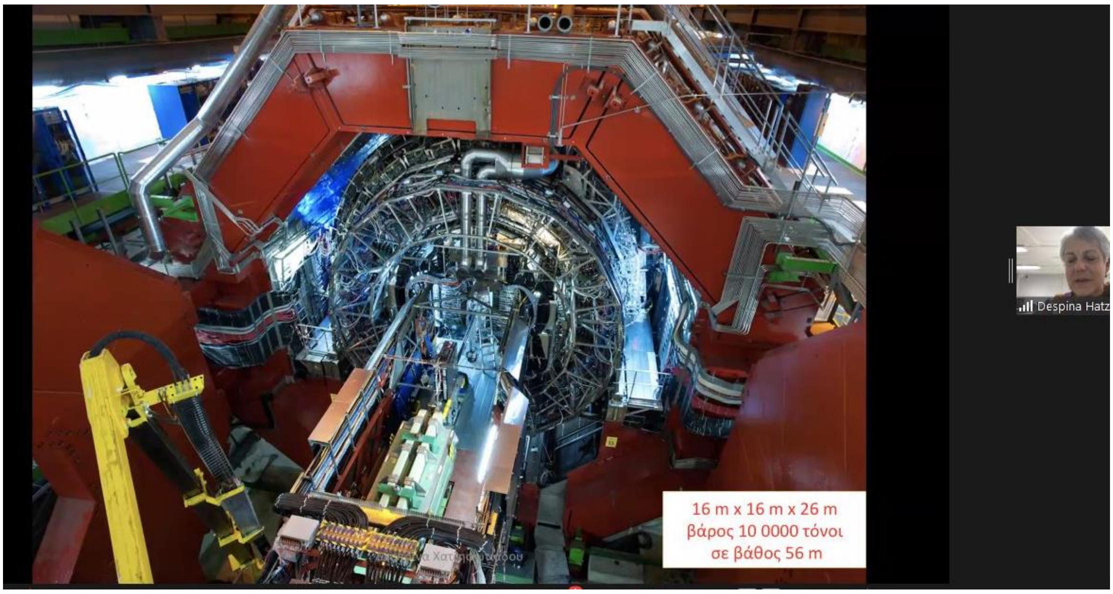


Fig. 9: Virtual Visit to the ALICE experiment during the High Energy Physics in the Classroom workshop.

Teaching the Universe (Enseigner l'Univers)

The teachers training workshop "Enseigner l'Univers", organized by FRONTIERS partner PCCP, took place, fully online, on the 6th – 7th May 2021.The workshop was included in the official teacher training offer of both the Académie de Paris and Académie de Créteil (two of the three school departments of the Paris area). Thanks to this format the organizing team were able to train 36 teachers rather than the 30 that we initially proposed to the Academies. The workshop involved 15 researchers of the APC laboratory as well as other laboratories in Paris and saw the exceptional participation of Prof. Joseph Silk, who gave an introductory lecture about present status and open problems in cosmology. Moreover, in addition to the traditional courses about astroparticle physics and cosmology, a new course about Higgs boson physics was proposed. The PCCP fully exploited the experience and tools developed in FRONTIERS, both for teachers practicals and for the evaluation of the workshop itself. The workshop was organized over two days, via Zoom. One and a half days were dedicated to 1 hour lectures from researchers in cosmology and astroparticle physics. Half a day was dedicated to practical workshops on FRONTIERS Demonstrators. The teachers could choose between a cosmology activity on the Hubble law or a gravitational activity on the Michelson interferometer and the detection of gravitational waves. Both workshops were managed by the PCCP team participating in FRONTIERS. Teachers feedbacks was extremely very positive. A common positive feedback concerned the level of depth of the subjects treated, as well as the participation of so many different researchers, each one an expert in a different field of cosmology and astroparticle physics. One negative remark was about the duration of the workshop: given the amount of information given, a three-day workshop would be more suited, with shorter sessions each day. This remark was prompted by the fully online nature of the workshop.

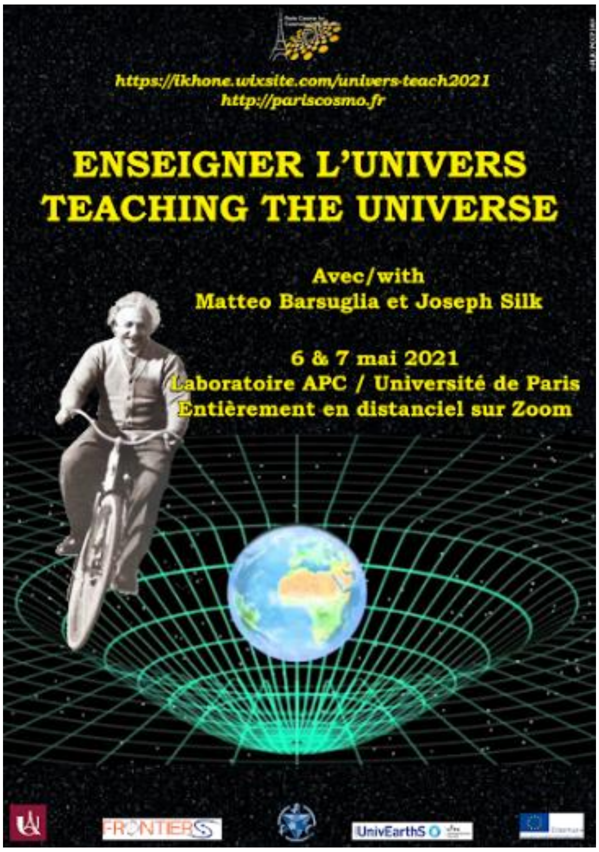


Fig. 10: Poster of the Teaching the Universe 2021 Teacher Training Workshop

Observing the Universe from the Classroom

Observing the Universe from the classroom was a teacher training workshop, organized by NUCLIO in July 2021 with the participation of 24 teachers which included a demonstration on how to use Robotic Telescopes at school to engage students towards modern Astronomy and hence, modern Physics. The event was streamed online in order to reach out to the general public. A short introduction before the live observation helped everyone understand the basics of the event. When the actual observation started, it was easy to explain what is happening, and choosing an object that doesn't require much exposing time allowed participants to get a wonderful first picture after a few minutes. The reactions of the participants were very enthusiastic - whenever a new image was acquired, there was great excitement to see it and lots of exclamations. Even though it was not a long event, it hd a strong impact, showing that modern facilities, like a 2m telescope, can be used by students in the classroom.

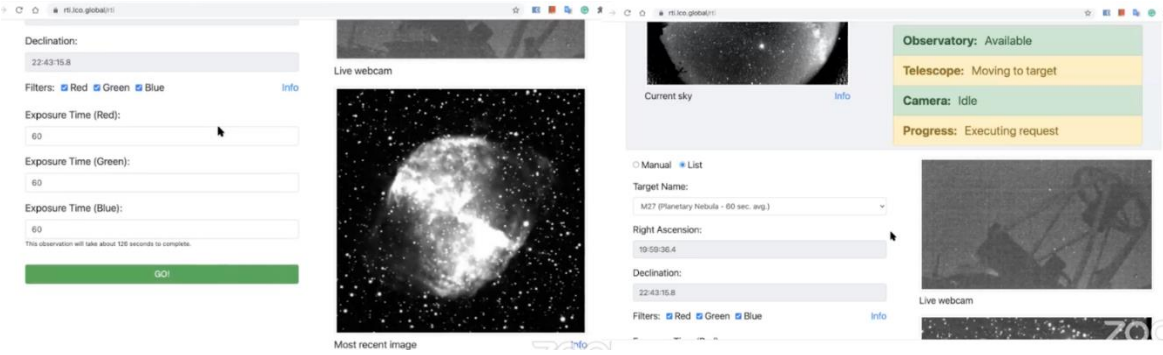


Fig.11: Screenshots from the "Observing the Universe from the Classroom" live session with the Faulkes Telescopes.

4. Reaching out to the General Public

The high level of engagement in the FRONTIERS website and social media (Please consult Intellectual Output 4), with more than 1100 registered members and post reach to more than 150,000 users overall, offered the project consortium the opportunity to reach out to the General Public in an effective fashion, co-organizing activities with high impact in terms of users and interactions. As FRONTIERS is first and foremost an education oriented project, we designed activities that can first of all have an impact to educational stakeholders (teachers and students) and enhance our public footprint through sharing and streaming to social media.

Some of the events organized in this framework as well as activities for public engagement that FRONTIERS supported are presented below:

Virtual Visits to Large Research Infrastructures in Physics

Virtual Visits to Large Research Infrastructures in Physics and Astronomy have proven a successful way to introduce teachers and students to the work and discoveries taking place there. They are particularly appealing to a large community of citizens (definitely to teachers) and have the potential to engage a large number of citizens world-wide simultaneously. A series of virtual visits have been implemented with teachers and general public in the framework of FRONTIERS Winter School (organized by PCCP: https://indico.ego-gw.it/event/133/) and FRONTIERS Summer School (organized by Ellinogermaniki Agogi: https://indico.ea.gr/event/4/) 2021.

The visits were to: Virgo GW detector (2 visits with the collaboration of the EGO team and the Virgo outreach Group); Pierre Auger Observatory (2 Visits with the collaboration of Conicet and the Pierre Auger Outreach Group); ATLAS experiment at CERN (1 visit with the support of IASA and the collaboration of the ATLAS outreach group); ALICE experiment at CERN (1 visit with the support of IASA and INFN and the collaboration of the ALICE outreach group).

The Methodology utilized included two levels of participation

Lv.1 : Teachers connected via Zoom who were able to interact directly with the tour guides and presenters either via voice or via Zoom chat, as well as answer polls.

Lv.2: General Public connected via facebook live streaming in FRONTIERS webpage (www.facebook.com/frontierseu) . They were able to interact via chat. A person from the visit would be there and would make sure to answer questions or share them to the presenters so that they would answer them.

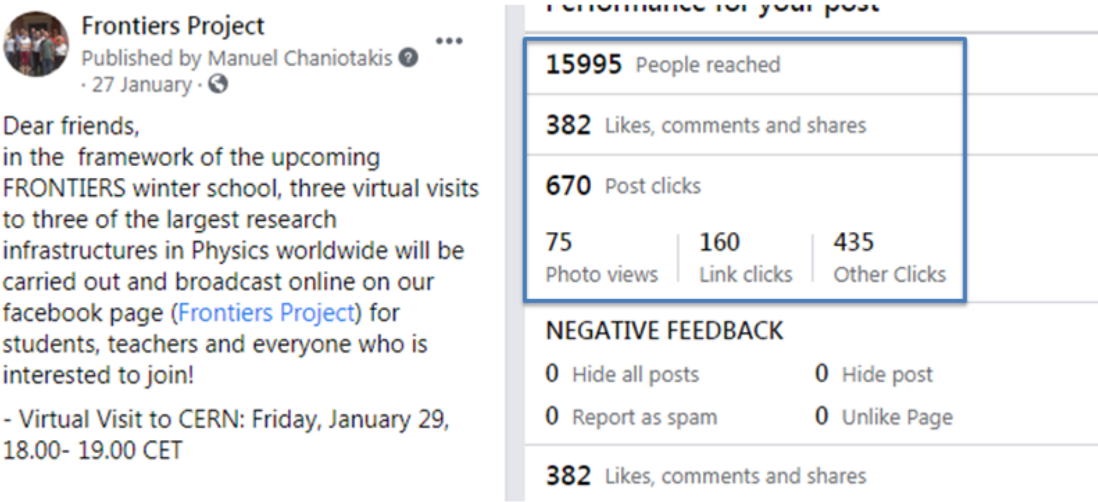


Fig. 12: Snapshot of the social media post disseminating the virtual visits for Pierre Auger, Virgo and CERN that took place in the FRONTIERS winter school.

A very high number of people reached through our dissemination in social media due to strong community of FRONTIERS and broad interest for the visits. Research Infrastructures were utilized as catalysts to engage the general public, while FRONTIERS provided a single place for multiple interdisciplinary visits and a structure to solidify knowledge.

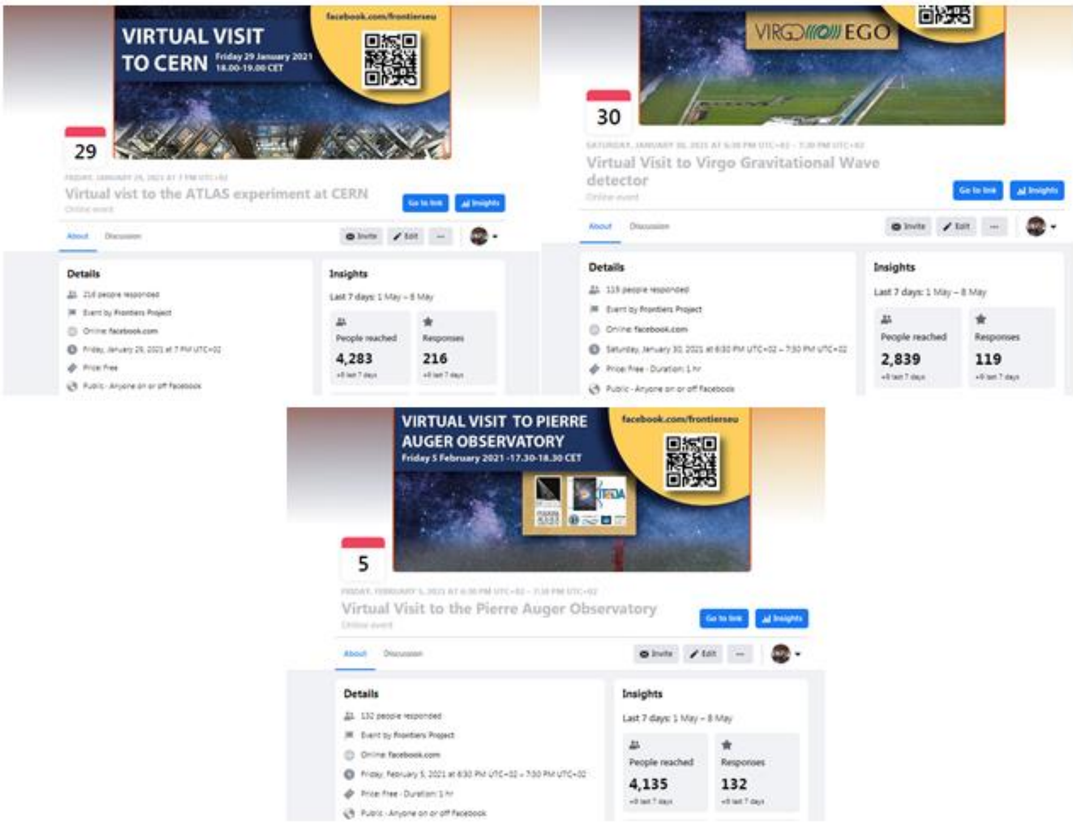


Fig. 13: Event pages for the three virtual visits organized in the framework of the

FRONTIERS Winter School 2021, highlighting the high reach of the events as well as the high response rate.

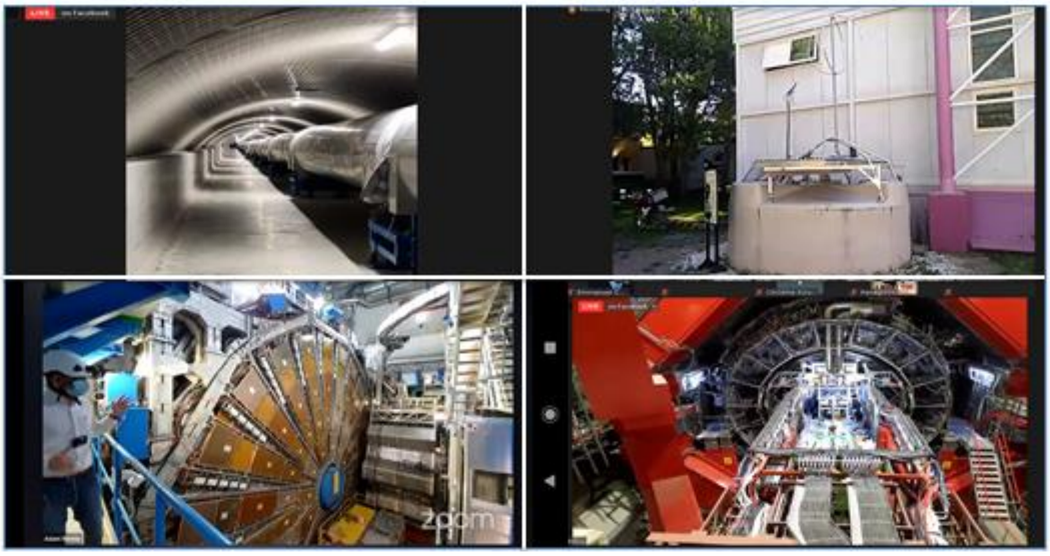


Fig. 14: Moments from the Virtual Visits to the General Public organized by FRONTIERS (Top left: Virgo; Top Right: Pierre Auger Observatory; Bottom left: ATLAS experiment at CERN; Bottom right: ALICE experiment at CERN).

By "embedding" VV open to general public within the structured framework of a FRONTIERS training event, we were able to reach at least 70 teachers per visit, with peaks of over 100, on Zoom, and more than 50 Facebook users in parallel. In total, between 2000 and 4000 people were reached by each VV on Facebook. Furthermore, utilizing assessment tools developed in the framework of FRONTIERS, including online learning analytics as well as content analysis, the FRONTIERS team were able to offer the collaborating outreach teams support and feedback on how to maximize user engagement and retention.

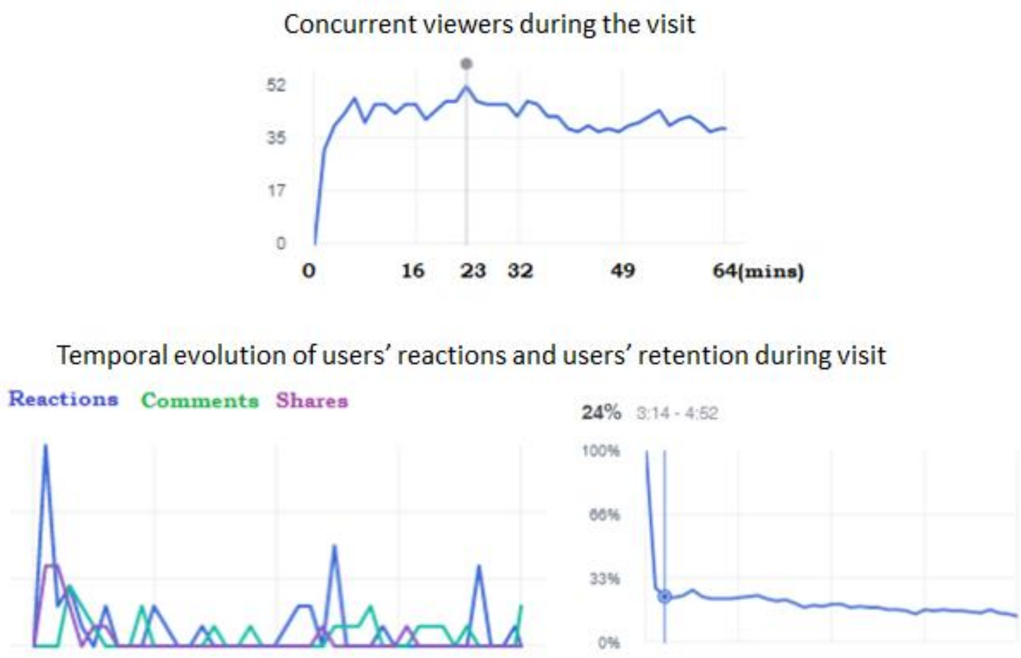


Fig. 15: Assessing engagement during a virtual visit to Virgo (Top: Concurrent users; Bottom left: temporal evolution of users' reactions; Bottom right: Temporal evolution of users' retention).

The first results on the virtual visits co-organized by FRONTIERS were presented in the Communicating Astronomy to the Public 2021 Conference by Dr. G. Vannoni (PCCP); Dr. Valerio Boschi (EGO/Virgo) and Emmanuel Chaniotakis (Ellinogermaniki Agogi) and can be found here: https://www.youtube.com/watch?v=WJrLefExCuE&feature=youtu.be

Online Observation of the Great Conjunction of Jupiter and Saturn by Ellinogermaniki Agogi

During this live event organized in the framework of FRONTIERS and disseminated by the project's social media, a simultaneous observation of the Great Conjunction of Jupiter and Saturn took place from both the North (EA Observatory) and the South Hemisphere (Boyden Observatory). The event included: introductory presentations from experts, a virtual visit to the Boyden Observatory and observation from both hemispheres conducted by the teams of the two observing sites. It was organized in the framework of International collaboration between three observatories: EA school observatory in Greece, Skinakas Observatory in Greece, Boyden Observatory in South Africa, under the auspices of the Consul General of Greece in Johannesburg and was streamed online on Youtube both in English and in Greek languages: https://youtu.be/ZfqYIyWxRv4 .To monitor user engagement and retention, YouTube metrics were utilized. The Great Conjunction Event reached more than 50,000 views in Youtube with more than 1,600 concurrent viewers and 1,800 chat messages exchanged. Overall, 225,000 impressions were made on YouTube which led to 1,964 watch hours for the videos.

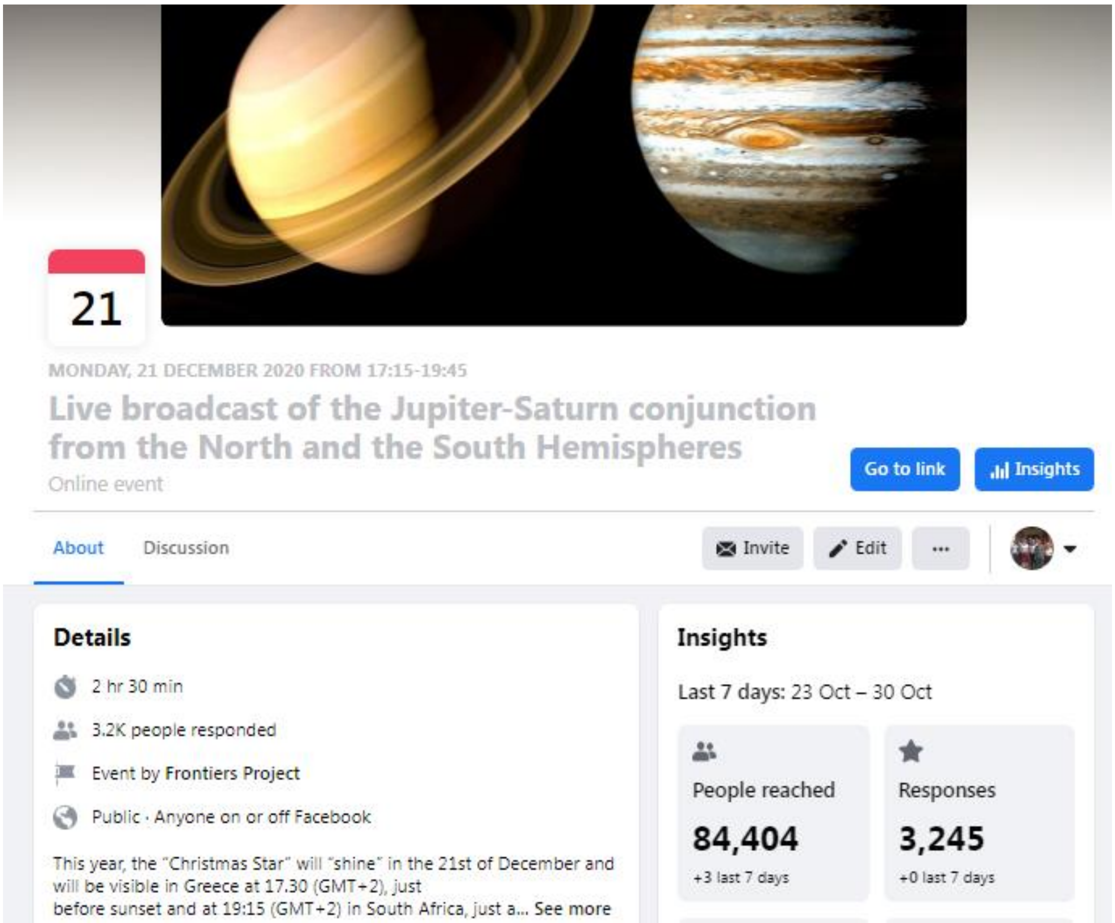


Fig.16: Snapshot of the event of the live broadcast organized by FRONTIERS

Development of an outreach center in France

Beyond the organization of online events such as the ones presented above, the FRONTIERS activities and methodology have contributed in the development of a "FRONTIERS oriented" outreach center in France by PCCP. Learning from the experience of teacher training and student implementation, the PCCP identified the need to have a dedicated physical space at the laboratory APC for outreach activities with the general public and, more specifically, with school students. Therefore, starting at the end of 2020, a dedicated space was identified and a series of pedagogical fully functioning scientific instruments were acquired, spanning the subjects of astroparticle physics and multimessenger astronomy. The Centre will comprise a series of pedagogical fully functioning scientific instruments covering the subject areas of interest for the APC laboratory following the subject themes of the most relevant FRONTIERS Demonstrators. More specifically:

- A Michelson interferometer that can perform a variety of experiments and that will be use to show the working principle of a gravitational wave interferometer.

- A series of pendula that can be used both to explain fundamental oscillatory phenomena as well as the seismic isolation system of ground-based gravitational wave detectors.

- A portable optical telescope for observations of the night sky.

- An agreement for use on demand of one Belisama detector (particle scintillator detector).

- 3D prints of real gravitational wave signals. This technique is rapidly emerging in outreach worldwide for the multiple possibilities that it offers for inclusion of disabled visitors as well as very young children.

- A series of large-format astrophysical prints as supporting material.

The instrumentation of the Outreach Centre will be expanded with time while the physical installation of the Centre is underway. The Outreach Centre will be used in the mid and long term during visits to APC of external public (students, teachers, visitors, journées portes ouvertes, etc.). In the short term, PCCP will use the Centre for remote lectures with school teachers and students (see FRONTIERS best practice: "Le Cosmos dans mon école").

5.FRONTIERS Best practices for school education

A series of online implementation activities were organized both by teachers and by researchers, when face to face activities were not possible due to the pandemic, engaging directly more than 2000 students and mobilizing more than10000 students overall. An ambitious program of bringing Large Research Infrastructures closer to the school classroom through Virtual Visits to the Virgo Gravitational Wave Detector and to the CMS and ALICE experiments at CERN, along with Virtual Observation nights was implemented benefitting directly more than 800 students from the consortium countries and beyond. The lessons learned from the shift to online were that even though face to face activities are in general preferred by all parties (students, teachers, researchers), online activities piloted in FRONTIERS such as Virtual Visits have the potential to engage a large number of citizens World-wide simultaneously in a meaningful way. The activities presented below were considered as best practices based on the following criteria:

- Offering authentic research experiences to students.
- Supporting an organizational change, from the typical school teacher- student paradigm to a researcher- teacher- student synthesis.
- Introducing research centers as stakeholders in school education.
- Supporting national and international collaboration between teachers and students.
- Implementing activities outside the school curriculum successfully despite the pandemic crisis.

5.1 Virtual Visits to the Virgo Gravitational Wave Detector for Students

A three-month-long program of virtual visits to schools was co-organized by FRONTIERS project and EGO and the Virgo collaboration with the coordination of Ellinogermaniki Agogi School in Greece and with the support of the EU funded REINFORCE project. The program invited teachers trained in Gravitational Wave Astronomy in the framework of FRONTIERS and REINFORCE projects to perform virtual visits with their students, offering them educational resources for an introduction of the topic to the classroom and designing an assessment framework and tools to assess the impact and educational merits of the visit. In total, 7 time slots were reserved for these virtual visits, in which more than 617 students and 24 teachers from 24 schools from 8 countries participated (Greece (15); Italy (2); Romania (2); France (1); Pakistan (1); Portugal (1); Bangladesh (1); Austria (1)) and offered feedback.

Structure of the Visit

Virtual visits were streamed to students live via Zoom. They were moderated by an education researcher of Ellinogermaniki Agogi (Emmanuel Chaniotakis) and the field work was carried out by researchers and support staff of EGO/Virgo. They were filmed through a mobile phone streaming directly to the Zoom call, are led by a EGO/Virgo researcher, who accompanies the visitors through various areas of the Virgo experiment. The structure of the tour allows the visitor to explore Virgo and find out about its mission: from the theory of how interferometry works and how it can be used to listen to the cosmos to the extraordinary experimental challenges that need to be overcome in order to accomplish that.

The visit, lasting about 90-120 mins, is composed of the following episodes:

1. Introductory seminar
2. Exhibits located in the hall of the EGO Main Building
3. Virgo Tunnel
4. Central Building

A visit to the control room of Virgo was made when this was possible.

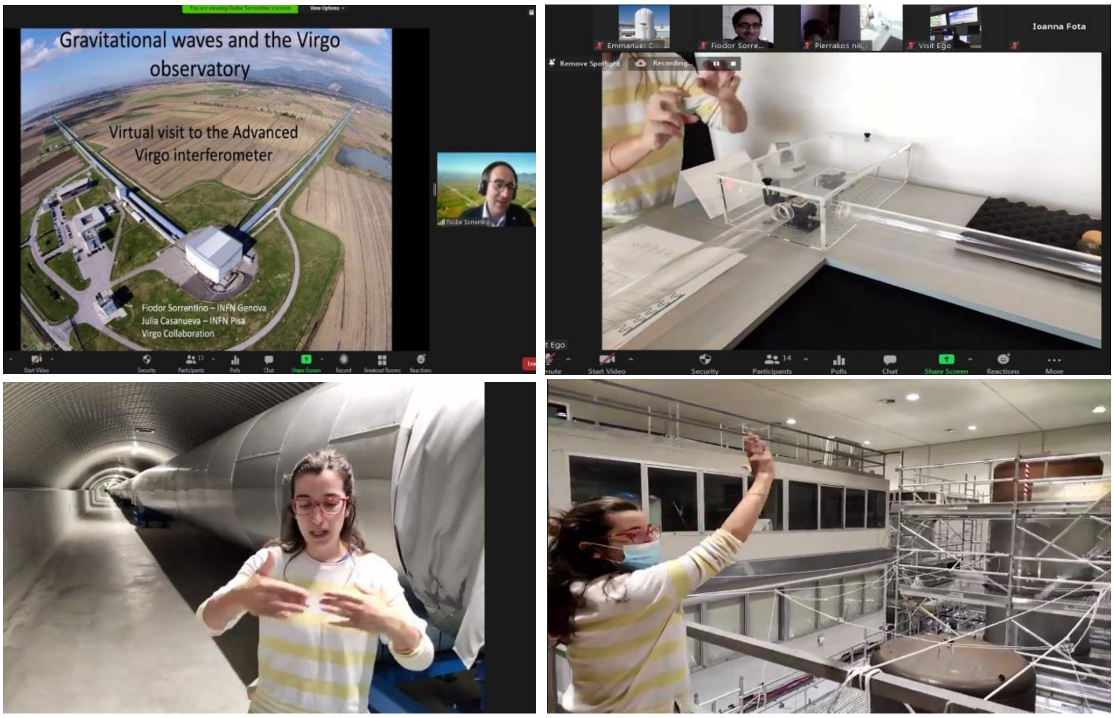


Fig.17: The main episodes of the visit to Virgo.

After each of these the visitors are encouraged to ask questions, on average about 5 minutes are dedicated to the questions after each episode.

Preparation of the Visit

The preparation of the Virgo visits for schools started in February 2021.

-7 time slots ranging from April 2021 to June 2021 in which Virgo researchers had availability to support a visit were identified.

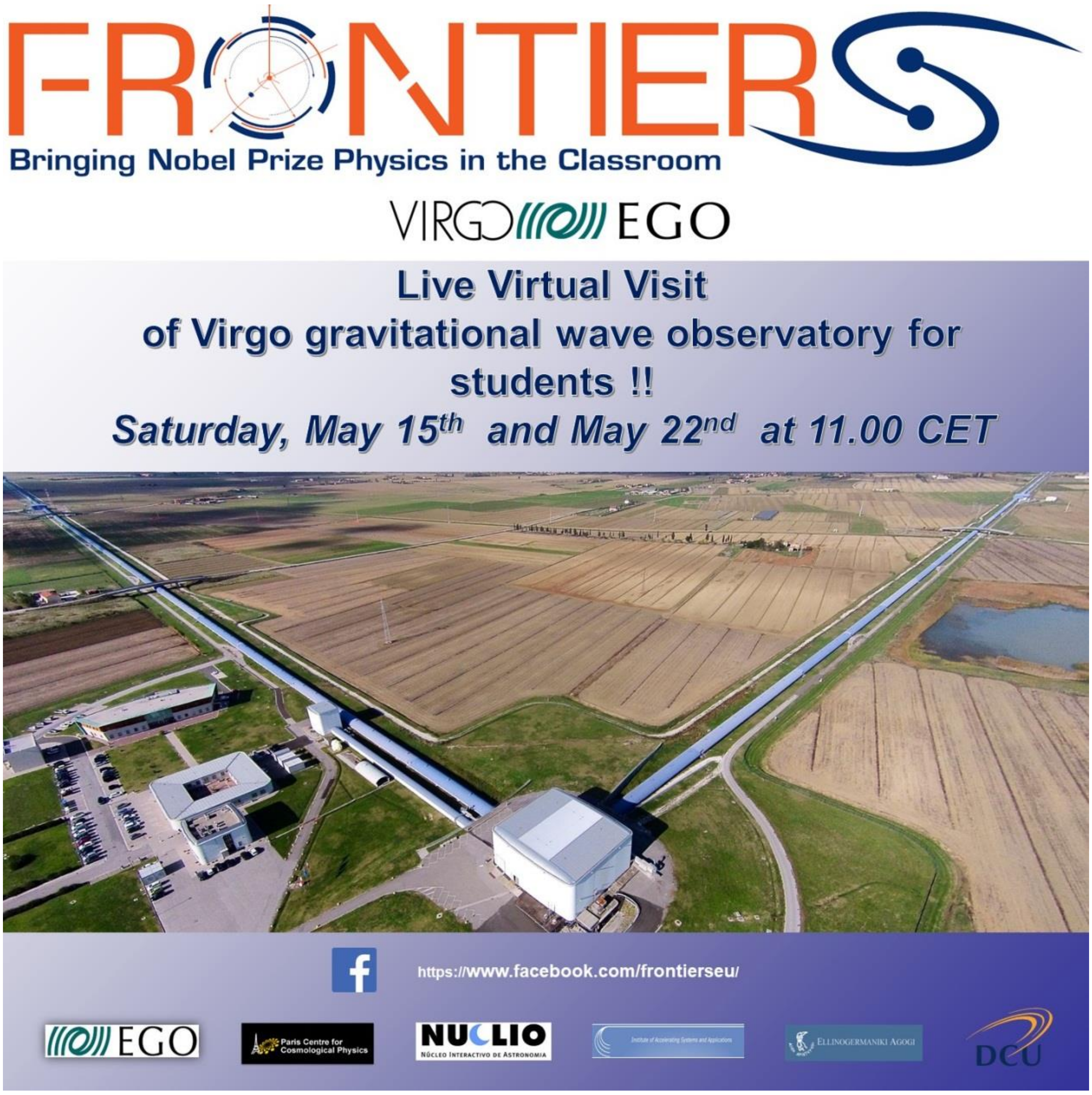


Fig. 18: One of the calls for school participation in the Virgo Virtual Visits in May 2021(http://www.frontiers-project.eu/vvvirgo/)

- A call for schools interested to join the visit was issued. As this was a piloting event with limited availability of timeslots, the organizing team issued the call only to teachers had been previously trained in Gravitational Wave Astronomy and Modern Physics during the online professional development summer and winter schools conducted in the framework of FRONTIERS and REINFORCE EU projects (Winter School 2021: https://indico.ego-gw.it/event/133/;Summer School 2020: https://indico.ego-gw.it/event/73/). Out of the 134 teachers invited, 29 teachers from 29 schools accepted the invitation and engaged 617 students overall.

- Each visit included from 1 to 10 schools, with total participation ranging from 33 to 220 students per visit and an average of 27 students per school per visit. The following table shows the relevant demographics.

- A dedicated evaluation framework and evaluation instrument (described in Intellectual Output 4) was designed by Mr E.Chaniotakis, EA with the support of Dr Valerio Boschi

(INFN/Virgo) and delivered to all participating students as well as a report instruments was designed for teachers.

Table 2: School distribution in the visit timeslots

Date	Nr of schools	Nr of students	Country (Schools)
20/4/2021	1	80	Greece (1)
4/5/2021	2	54	Greece (1) | Italy (1)
8/5/2021	3	37	Bangladesh (1)| Brazil (1) | Greece (1)
15/5/2021	2	33	Portugal (1)| Romania (1)
18/5/2021	5	114	Greece (4)|France (1)
22/5/2021	7	79	Greece (2) | Romania (2) | Italy (1) | Austria (1) | Brazil (1)
25/5/2021	9	220	Greece (7) | Pakistan (1) | France (1)
Sum	29	617	Greece(16) | Italy (2) | France (2) | Portugal (1) | Romania (3) | Austria(1) |Brazil (2)| Pakistan(1)|Bangladesh(1)

Teacher preparation

- Every teacher was sent an email with guidelines upon their registration. They were offered a set of open educational resources upon registration and were encouraged to use them in order to give an introductory presentation to the students. The resources included: A pre- recorded virtual visit to Virgo to help teachers orient themselves; Selected videos on YouTube; Educational Activities developed by the FRONTIERS and REINFORCE projects for in-classroom use; recorded professional development courses delivered by the FRONTIERS and REINFORCE project teams.

- Every teacher was also offered a link to the pre – and the post – questionnaires with the following guideline:

"Students to fill the pre-questionnaire at least 2 days before the visit and ideally before the introductory lecture delivered by the teachers; Students to fill the post questionnaire the latest 2 days after the visit; Teachers should fill an accompanying report for evaluation purposes".

- Teachers were offered continuous support for their preparation before and their feedback after the visit via email.

Implementation of the visit

- 75% of the teachers did a preliminary presentation on average 3 days before the visit and offered students the pre – questionnaire after this presentation.

-Each visit was done via Zoom. A unique link was created per timeslot and offered to all teachers registered in that timeslot. The average visit duration was 90 minutes. The visit would start with a brief welcome message by the education researcher (author) and the researchers involved in the visit and then continue with the episode structure of the visit described previously. The majority of students joining the visit would do it from their personal computers at home (since in many countries like Greece there was a quarantine due to the SARS-CoV2 pandemic). In some cases, such as in Italy and Romania, students would be in their classrooms: the teacher would have one laptop connected to ZOOM and would broadcast the screen in a projector where all students would be able to see.

- Upon completion of the visit, students were asked to fill the post questionnaire. The majority of students offered their answers within 7 days of the visit. The endeavor to collect both pre and post responses can be considered quite difficult, more than the usual effort, due to the circumstances of the pandemic situation.

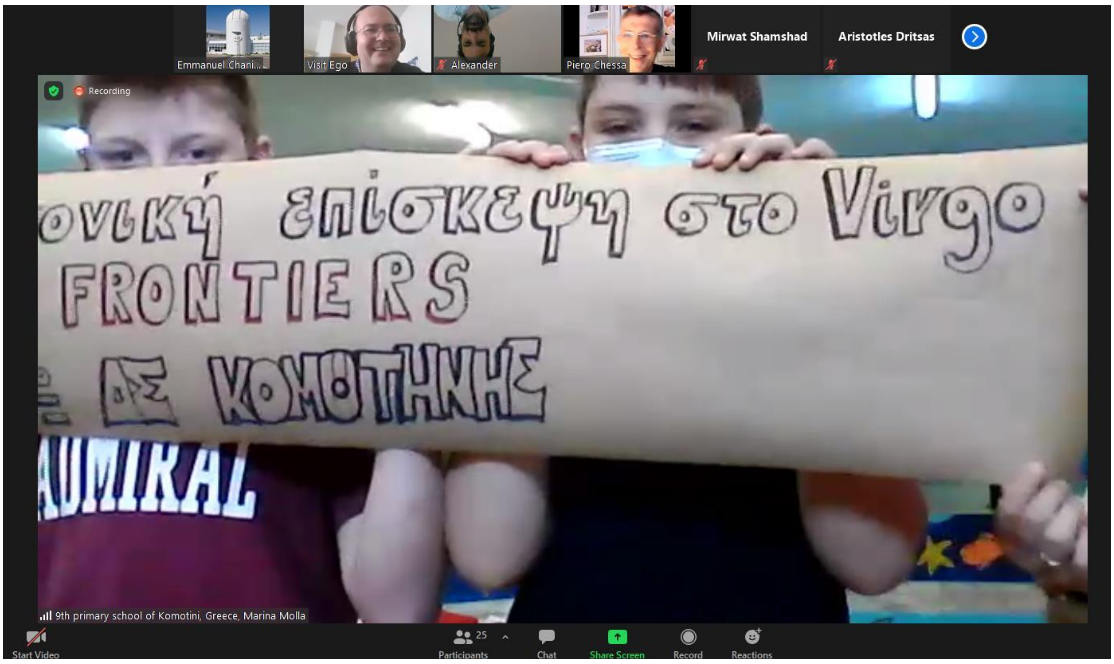


Fig. 19: Screenshot from one of the visits to Virgo co-organized by FRONTIERS

Follow up

Students interested to expand upon what they learned during the visit were invited to create 1-2 min long videos explaining what gravitational waves are, how we detect them and what Virgo is. Students who successfully created their own content were awarded with a certificate and their videos were shared in the website, youtube channel and social media of FRONTIERS. All the student videos can be found in the FRONTIERS Youtube channel (https://www.youtube.com/channel/UCN9_qrwQdOb_gKUxFq-8ohg).

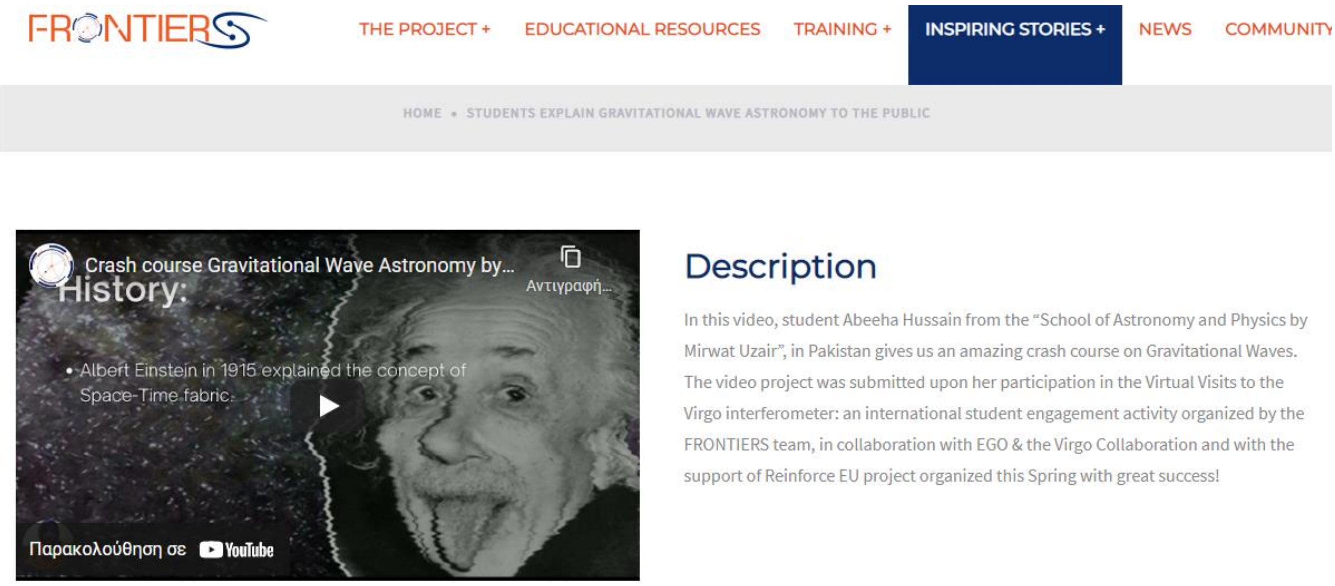


Fig. 20: An inspiring story of FRONTIERS: The video produced by student Abeeha Hussain from Pakistan explaining Gravitational Waves and Virgo to the general public (http://www.frontiers-project.eu/students-explain-gravitational-wave-astronomy-to-the-public/)

Student prior knowledge:

- Newtonian Mechanics
- Waves and wave interference

Learning Outcomes:

After this activity, students should be able to:

- Have an idea of what are gravitational waves
- Have an idea of what is a laser interferometer and how it works
- Have an idea of the challenges of the experimental detection of Gravitational Waves.

Connection to School Curricula:

- Waves
- Wave interference and interferometry
- Gravitational Field

Lessons Learned

A sample of N=101 out of 600 students who provided both pre- and post- evaluations. Students display high levels of satisfaction and enjoyment of the visit. The findings indicate that students demonstrate a statistically significant increase in confidence to explain Virgo to a friend (33.3% increase; $p<0.05$), statistically significant increase in familiarity with vocabulary items related to Gravitational Wave (GW) production and detection principles (22% increase; $p<0.05$) as well as familiarity with items related to technical aspects of GW measurement (15.7% increase; $p<0.05$), an increase in their understanding of wave interference and interferometry (77% increase; $p<0.05$) and a significant increase in their fluency describing Gravitational Waves (29.7% increase; $p<0.05$). No changes were observed regarding students' science motivation as well as their attitude regarding Large Research Infrastructures in Physics. Students highlight that the main barrier for their better understanding was the language barrier (all visits were delivered in English) and technical and sound problems. All participating schools expressed their interest to join again the visits in the school year 2021-2022.

5.2 Virtual Visits to the ALICE experiment at CERN for Students

On 17-18/5/2021 IASA organized two virtual visits to the ALICE experiment of CERN hosted by prof. Chatzifotiadou (INFN). The visits were open to all students who were interested in participating. The events started with a talk about CERN, high energy physics and the ALICE experiment. Following that, the virtual visit took place. The students had the chance to see the ALICE control room as well as the experiment itself and discuss with prof. Chatzifotiadou about the details of ALICE and the work at CERN. Overall, two virtual visits were organized in which 330 students from 14 schools participated. The vast majority were high school students (290).

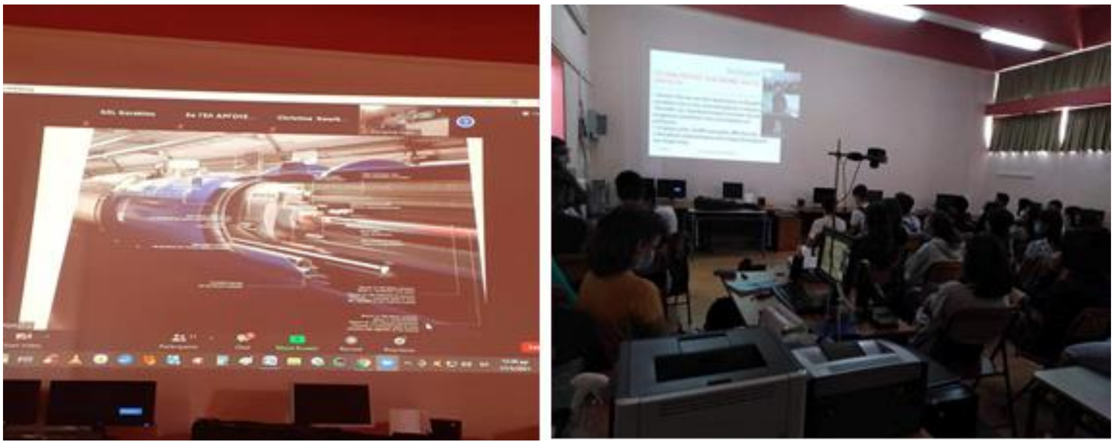


Fig.21: *Moments from the ALICE virtual visit at CERN for students from Greece*

Student prior knowledge:

-Fundamental forces

-Structure and particles of the atom

-Basic electrostatics – like and unlike charges

Learning Outcomes:

After this activity, students should be able to:

- Explain the fundamental forces
- Explain what the ALICE experiment is and what it searches for
- Explain what CERN is and what is its mission

Connection to School Curricula:

No direct connection to school curricula exists. However, this activity can be done as an after school hours activity.

Lessons Learned

The virtual visits to the ALICE experiment were met with great enthusiasm from the participating teachers and students. Even though both teachers and students stated that they would prefer the visit to happen physically, they were fascinated with the idea of accessing one of CERN's greatest experiments virtually. Students commented positively on the tour guide's explanations and were happy that the visit was organized in their native language, a fact that helped them understand better the terms discussed.

5.3 Le Cosmos dans mon Ecole (The Cosmos in my school)

“Le Cosmos dans mon école” is a program developed with the support of FRONTIERS for students in France, which brings researchers directly into schools (https://www.pariscosmo.fr/en/extension-and-education/pccp-program-for-high-school-students/).

Fig.22: Prof. Matteo Barsuglia (PCCP) introducing cosmology to students during the Cosmos dans mon Ecole workshop.

Upon request of a school (usually middle or high school), the PCCP team organizes a two-to-three hour workshop with students directly in their school on topics in multimessanger astronomy and cosmology. The format is fully based on the inquiry-based approach adopted by FRONTIERS and builds on the experience and the lessons learnt with the Demonstrators and with the teacher training events. At the time being, the action focuses on school of the Paris area (Région Ile-de-France) but it could easily be implemented at national or European level. The activity is planned in presence in schools. However, due to the limitations imposed by the Covid pandemic, during the first lockdown, in May and June 2020, the PCCP tested new possibilities of direct interaction with teachers and students online.

Each workshop is organized together with the involved teacher beforehand, therefore specific topic and format may change each time. Nonetheless, topics focus on Cosmology, Gravitation Waves, and the Physics of the Universe. The usual format foresees an introduction to the topic by our researchers. The introduction is usually built to question the students, by asking questions and reaching the answer step by step. In the second part of the workshop, a practical activity can be proposed (i.e. by using the NIKHEF pedagogical Michelson interferometer) or a Virtual Visit to the Virgo experiment, or a reflection session with students. During the activity the teacher forms part of the audience.

The face to face event of 2020 had a duration of 3 hours and included 57 students aged 16-18 in France.

Student prior knowledge:

- No specific knowledge required.

Learning Outcomes:

After this activity, students should be able to understand:

- Basic concepts on gravitation
  Speed of light
- Basic concepts on light interference
- Basic concepts on the nature and properties of a black hole
- The idea of an expanding Universe and the Big Bang
- A sense of the scientific method and the daily life of a researcher

Connection to School Curricula:

- Waves and interference
- Speed of light

Lessons Learned

Teachers and students feedbacks were very positive. It was particularly appreciated that researchers would take the active step to go into schools. Another highlight was the virtual visit to Virgo (in Chelles) directly from the classroom.

Students were fascinated by the concepts of black holes and light speed and the expansion of the Universe. Students asked many questions during the workshop and tried to find good answers to the questions asked by the researchers.

The 2-hour format, chosen especially with middle-school pupils and to accommodate school schedule, is short to include a satisfactory hands-on activity as well as a Virtual Visit. Therefore, the second activity was preferred to the first one, as it is a unique opportunity that students would not otherwise get.

5.4 Online Particle Physics Masterclasses

45 students from Greek high schools participated in this 2021's Masterclasses organized by IASA. Due to the covid-19 restrictions the event was held online and the students connected either from their home or their school. The goal of the workshop is to allow the students to be high energy physics researchers for a day. To learn about the world of particle physics, the work being done at CERN and to experience firsthand how new particles are discovered. In addition to that, at the end of each day, like in an international research collaboration, they join a video conference for discussion and combination of their results with those of other groups.

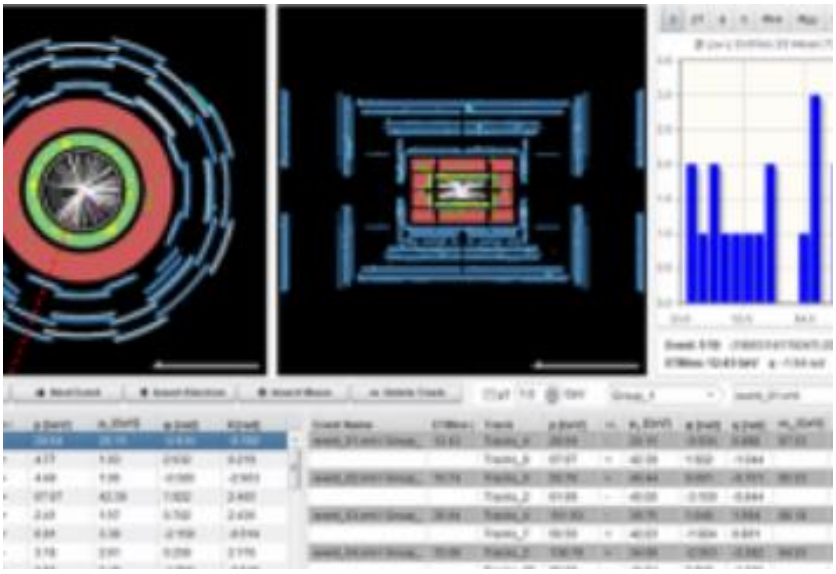


Fig.23: Part of students' exercise using the HYPATIA Software in the framework of the e-Masterclasses.

The goal of the workshop is to familiarize the students with high energy physics, the work being done at CERN (and the LHC in particular) and to demonstrate how new particles are discovered. The activity begins with lectures on the basics of particle physics and why it is important. The students learn about the fundamentals of particle detector operation and the way particles interact with them and leave a characteristic signature according to their different types. The students, who most likely have never came in contact with particle physics, are shown what a real researcher does, and how new particles are discovered. This gives students a realistic and exciting look at the research being done at CERN and stimulates an enthusiastic interest in it. Aster the lectures the students perform a hands-on activity in which they use the HYPATIA event display to identify Z and Higgs bosons and construct histograms of their masses. At the end of the day their results are combined and through a videoconference with schools from other countries they can share and compare their results.

Student Prior knowledge:

Students should have a prior understanding of basic physics, electromagnetism, the structure of the atom and fundamental forces.

Learning outcomes:

Student should be able to:

- Understand what matter is made of and how different particles interact with each other
- Understand the fundamental force in nature and what role each one plays
- Recognize events containing Z and Higgs boson decays
- Recognize the proper tracks to calculate the Z and Higgs invariant masses

Connection to school curricula:

This activity was not connected to school curricula. However, parts of the activity expand upon momentum, energy and charge conservation which are discussed in the curriculum of the first and second grade of senior high school in Greece.

Lessons Learned

Despite the difficulties added by having to organize the event in an on-line format, student response to the distributed questionnaires was overwhelmingly positive. Students reported that they learned a lot about particle physics, elementary particles, the universe itself, etc. These are all subject areas that are not covered at all by the school curriculum.

When the event is held face-to-face it is easier for the researchers to provide assistance to each student individually while they are analyzing their data. However even in this format the students did very well and their results were on-par with those of previous years. In general the students did not seem to have significant difficulties due to the on-line nature of the workshop (installing java, HYPATIA, events, videoconference software etc).

5.5 AstroParty Calls: An e-twinning project

In school year 2020-2021, science teachers Emanuel Bettencourt(Portugal), Nidia Fidalgo (Portugal), Marco Nicolini (Italy) and Celine Winter (France), teachers trained in the Astroparticle Physics module of the FRONTIERS Summer School 2020, together with Kalle Vaha-Heikkila launched an e-twinning project called "AstroParty Calls". The participant teachers had created a teacher activity for the monitoring of atmospheric muons with a cloud chamber and decided to implement the activity as a joint collaborative project.

AstroParty Calls, aimed to enable students to detect cosmic particles through the assembling and use of cloud chambers.This challenging lab was a common lab performed Europe wide by pupils of different schools in different countries, to be able to compare the observations and exchange the experiences and skills got during this activity. (For a full account of the project please find the participating teachers' presentation at the FRONTIERS Winter School: https://indico.ego-gw.it/event/133/contributions/1964/subcontributions/181/attachments/1245/2176/Astro%20Party%20calls%20-%20FrontiersWinterSchool.pptx).

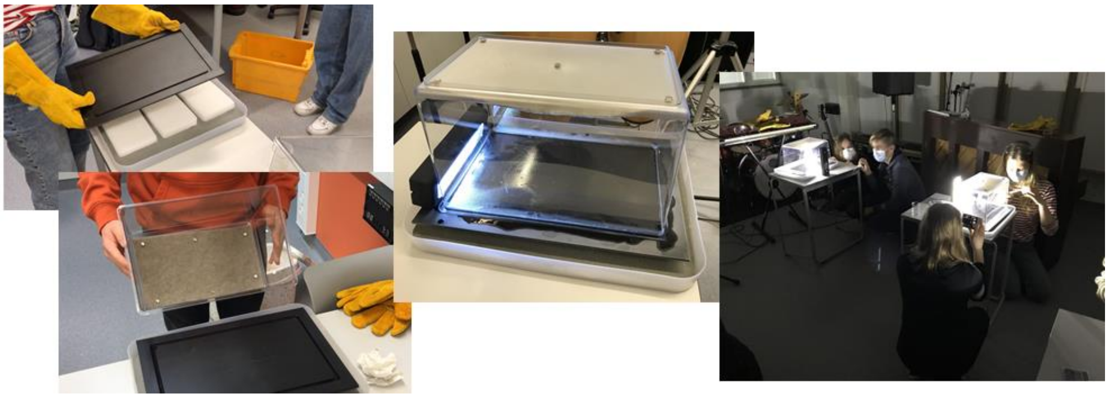


Fig.24 : Snapshots of the assembly of cloud chambers in the framework of the AstroParty Calls project.

The aims of the project were to:

- Share ideas on how to present modern physics or part of it to the students.
- To propose a shared Europe wide cloud chamber activity that allows pupils to detect astroparticles and see traces of their passage.
- Compare detected traces in the cloud chambers at different latitudes, longitudes, altitudes.

The work process was:

- The selection of approximately 15 students per school (a club, a class or part of it) between 14-18 years old;
- To build simple cloud chambers based on dry ice (one each 4/5 students);
- To record observations with cameras to get videos, if possible slow-motion videos or time-lapse;
- Data analysis and discussions on what has observed to take place in all schools;
- Observations, videos and conclusions to be shared amongst schools;

Student Prior knowledge:

-Atom constitution, atomic representation (atomic number and number of mass), the evolution of atomic model.
-Scales.
-Type of elementary particles that exist and their origin.

Learning outcomes:

By the end of this descriptor, students should be able to:

- describe the principles of operation of a cloud chamber.
- explain what happens when ionizing radiation enters the cloud chamber.
- discuss qualitatively the properties of a muon track observed in a cloud chamber.
- explain what happens when I change the overburden and the altitude of the location of the cloud chamber.

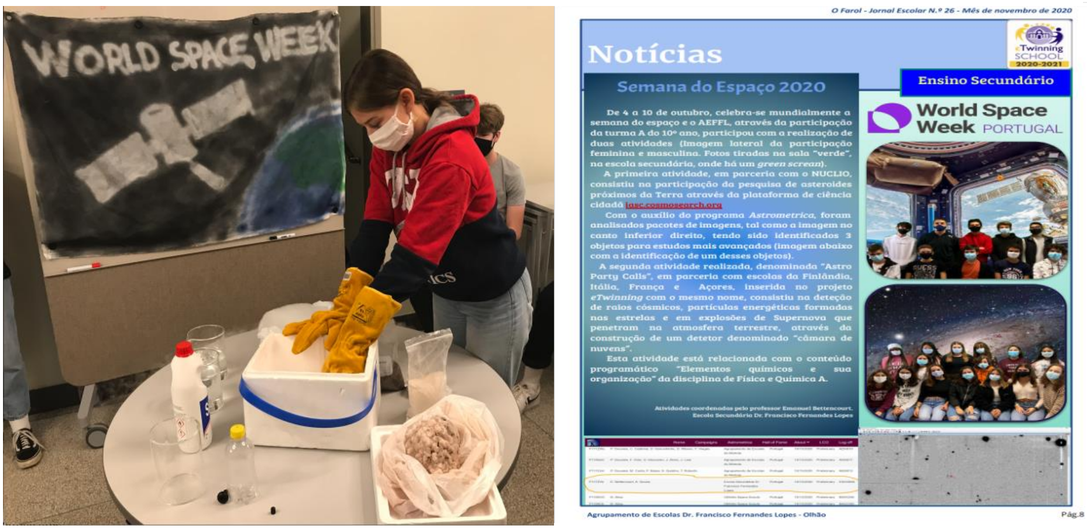
Connection to school curricula:

PORTUGAL:
10th grade- Unit 1.1 - Mass and atomic size
12th grade -Unit 3.2 - Introduction to quantum physics; Unit 3.3 - Atomic nucleus and radioactivity
FRANCE: radioactivity
10th grade: conservation of mass and charges
11th grade: nucleosynthesis, fission, fusion, half-live
12th grade optional: (N,Z) diagram; alpha, beta, gamma radiations ; exponential decay
ITALY:
10th grade: Astronomy, Kinematics
12th grade: Thermodynamics, conservation of mass and charges.
13th grade (Italy has 5 upper secondary grades): Astronomy, Radioactive decay, Nuclear forces, The Atom, Lorentz Force between charged particles and magnetic fields, Energy.

Lessons Learned

The idea of the project was to prepare a hands-on activity ready to be used for all physics teachers (but also astronomy and chemistry), that can be implementd in any school where physics is taught, so that some parts of modern physics are easily accessible or at least approachable to students and help improve student's knowledge about astroparticles physics and nobel prizes.

Even though the pandemic and quarantine made it difficult to implement the activities, and materials such as dry ice were quite scarce and difficult to acquire, especially in remote locations like Azores, the project was successful with one of the participating teams had the opportunity to present the activities done in World Space Week in Portugal. The activity was disseminated in the participating school journals and in twinspace and follow up activities were organized in participating schools, such as the assembly and data acquisition from a Cosmodetecteur in France.



O Farol - Jornal Escolar N.º 26 - Mês de novembro de 2020

Notícias

eTwinning SCHOOL 2020-2021

Semana do Espaço 2020

De 4 a 10 de outubro, celebra-se mundialmente a semana do espaço e o AEFFL, através da participação da turma A do 10º ano, participou com a realização de duas atividades (imagem lateral da participação feminina e masculina. Fotos tiradas na sala "verde", na escola secundária, onde há um *green screan*).

A primeira atividade, em parceria com o NUCLIO, consistiu na participação da pesquisa de asteroides próximos da Terra através da plataforma de ciência cidadã iasc.cosmosearch.org

Com o auxílio do programa *Astrometrica*, foram analisados pacotes de imagens, tal como a imagem no canto inferior direito, tendo sido identificados 3 objetos para estudos mais avançados (imagem abaixo com a identificação de um desses objetos).

A segunda atividade realizada, denominada "Astro Party Calls", em parceria com escolas da Finlândia, Itália, França e Açores, inserida no projeto *eTwinning* com o mesmo nome, consistiu na deteção de raios cósmicos, partículas energéticas formadas nas estrelas e em explosões de Supernova que penetram na atmosfera terrestre, através da construção de um detetor denominado "câmara de nuvens".

Esta atividade está relacionada com o conteúdo programático "Elementos químicos e sua organização" da disciplina de Física e Química A.

Ensino Secundário

World Space Week PORTUGAL

Agrupamento de Escolas Dr. Francisco Fernandes Lopes - Olhão

Pág.8

Fig. 25: Presence of AstroParty Calls in World Space Week 2020: (Recorded video can be found here: https://www.facebook.com/aeffl/videos/990316561485892)

The next steps include a paper on the utilization of simple cloud chambers will be written at the end of the activity by all the teachers, with which the experience will be shared, with results, troubleshooting, observations, validation, educational value, student's workbook and teacher guide.

5.6 Searching for Exoplanets

The topic of the activity was exoplanets and how scientists detect them. The activity was based on the "Discovering Alien Worlds Demonstrator" and was implemented with 10, 15 year old students from the High School of Karpenisi under the tutelage of Mr Dimitris Zarmpoutis, Physicist. The activity was implemented in 4 hours in an out-of-school setting (student club) and required the use of personal computers. At the first part the students tried to understand what exoplanets are, why it took so long to certify their existence and how is it possible to find them and estimate their mass and radius. At the second part students used real data and with the contribution of the application "salsaJ" they learned how to do photometry like scientists and they discover an exoplanet by themselves. Finally, the students who participated in this activity were invited to participate in the Europlanet Society Conference 2020 in the

Event “EPSC goes live for schools” co-organized by the FRONTIERS project (https://www.europlanet-society.org/epsc-2020-goes-live-for-schools/).

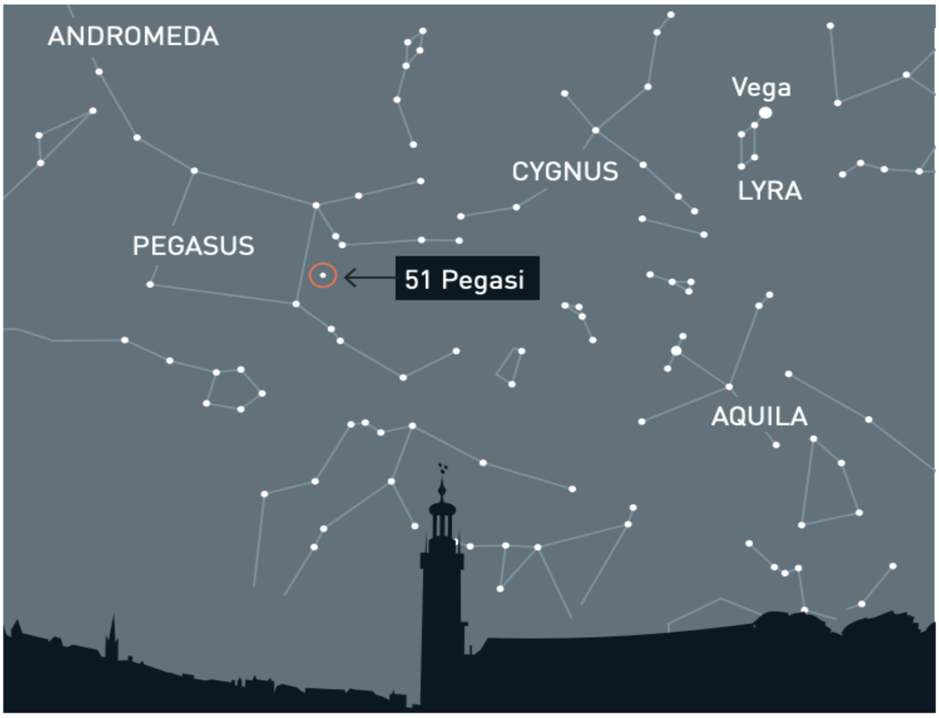


Fig. 26: Image used in the presentation to the students

The activity we made was based on the frontiers demonstrator “Searching for alien worlds” which it refers to exoplanets and the ways scientists are trying to detect them.

The implementation of the activity was done at the school year 2020-21 without physical presence because of covid-19 pandemic so the teacher and students used the meeting platform “webex”.

The teacher and each of his 10 students participated to their meetings from home. They made 4 internet meetings and each of them lasted about 1 hour. Because the Greek school curriculum doesn’t include astronomy at all and students had no idea of these topics, the teacher had to dedicate the first 2 hours for introducing to the basic concepts and found out that it was more difficult than he thought.

They talked about stars, planets, our solar system, galaxies, space distances etc. At the third meeting the teacher explained the steps of the activity and what they supposed to do. He also did some examples to show them how the software salsaj works and for the following meeting he asked them for homework to install the application “salsaj” to their pc, to download the pictures of three stars that there were in the respective frontiers demonstrator, to do the photometry and process the data they had collected with the use of excel as the demonstrator indicates. Of course, their last meeting of the activity was actualized after enough days (about a week) because there were many things that kids had to do. At the interim there was communication among the teacher and his students and among students because, as expected, there were several problems they faced at their attempt, almost at every step of it. Finally at their last remote meeting every student described to the rest of us how it went and what were him/her results and we compare them. Then two of the students (only they expressed the desire to do this), made to the rest a brief presentation of their work. Finally they had a round table discussion were we described our impressions of their innovative experience. After the end of the implementation, the participating teacher and students were connected to the EPSC goes live for schools conference to offer students an authentic experience and interaction with leading researchers on the topic that they had covered.

Student Prior knowledge:

It is not required for students to have significantly high level of knowledge for this activity. Basic knowledge of using pc and simple maths of their school are enough for them

Learning outcomes:

After this activity students should be able to :

- Describe what exoplanets are and why it took so long to find them
- Install a software application at their pc
- Analyze data with excel
- Doing photometry with salsaj and check if around a star orbits an exoplanet
- Present their results to their classmates

Connection to school curricula:

Greek school curriculum doesn't include astronomy so there wasn't direct connection of this activity with it. The teacher applied it at an out of school activity. If someone wants they can do it implicitly near topics such as circular motion or analysis lab's data with diagrams etc

Lessons Learned

Quoting Mr Zarmpoutis: "The impressions of the activity were great. Students really loved this as they said at the end at the round table and it happened for many reasons. Firstly, astronomy is a topic that attracts everyone not only students and in my opinion it's a mistake its absence from the Greek school curriculum. Secondly, kids loved the fact that we talk about discoveries that happened only few years ago not some centuries before as these we teach usually at school. Thirdly they were really impressed of the fact that they made calculations by themselves similar with these that real sciences do and they came to a result. It was also very beneficial that during the implementation of the activity students were involved with things that it was demanded to grow digital skills such as the installation of salsaj and the data editing with excel. If I had to say something negative I would refer that the absence of directly connection with the curriculum makes difficult the implementation of activities like this in the classroom if we factor in that as it became clear it takes plenty of time to be completed with the proper way."

5.7 From the Electroscope to Cosmic Rays

Through the activity "From the Electroscope to Cosmic Rays" students created their own electroscope and experimented on its use to detect charges in different objects. They made their own conclusions about how we charge and discharge an electroscope and learned about the story of Victor Hess and the detection of cosmic rays. The activity was implemented with 13, 11 year old students at the Primary School of Kanalia in Corfu by Mrs Marianna Barouta, teacher, and is based on the same named activity produced by her and Mr Panagiotis Kanychis as part of their training in the FRONTIERS Summer School 2020. The activity lasted 90 minutes and was an in-school intervention connected to the school curriculum.

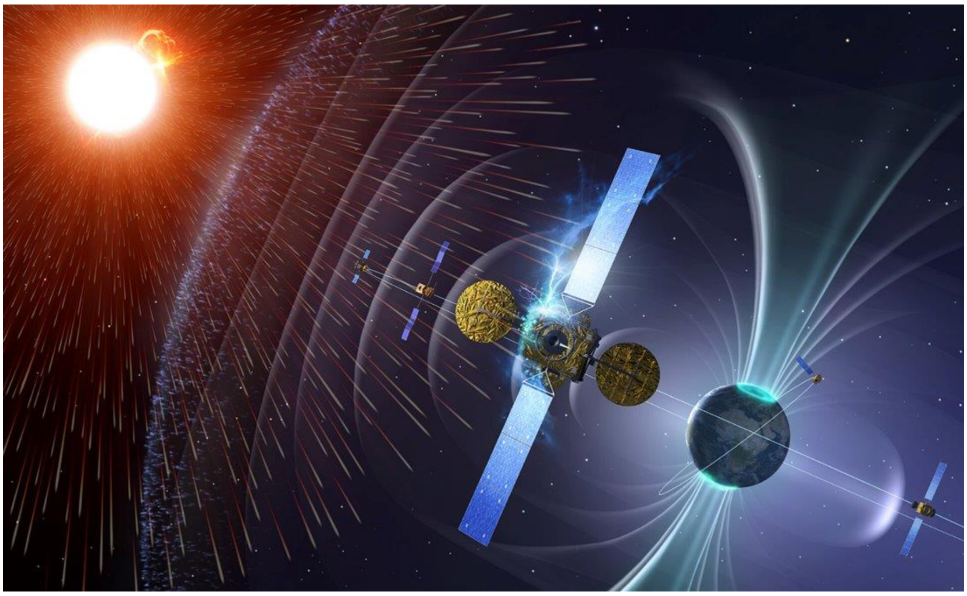


Fig.27 : Image presented to students during the implementation of the activity.

In the beginning of the class students were asked to comment on the Image above and express their thoughts and ideas about what they see. After that, they were asked a few questions about the atom's structure and static electricity in order to activate their prior knowledge. They explained that two opposite charges attract each other while to alike charges repel each other. Consequently, they constructed their own electroscope, using simple materials, and they were asked to explain and write down what they observe when they rub the straw to the tissue and get the straw close to the wire outside of the glass jar.

After charging the electroscope they are encouraged to think of ways they can discharge it. They touch the wire with their hand and explain again what they observe (the electroscope is discharged). The next step includes the demonstration of a video about discharging the electroscope (through radiation and X-rays) and a discussion about how different factors affect the electroscope's discharge time.

In the final phase of the activity student watch the video with the discovery of cosmic rays from Victor Hess in 1912, after exploring variations in the atmosphere's level of radiation. We discussed about Hess's assumption that radiation increased at greater altitudes and students were asked to brainstorm about where did this radiation come from. After introducing the concept of cosmic rays, they asked their questions and suggested to conduct further research in order to learn more about the topic.

Student Prior knowledge:

Students should be familiar with the knowledge below:

- Atom's structure.
- Opposite charges attract each other and like charges repel each other.
- When we rub a plastic straw on a tissue, the straw is negatively charged.
- When we rub a tissue on a plastic straw, the tissue is positively charged.

Learning outcomes:

After this activity, students should be able:

- To remember and explain the structure of the atom and what is static electricity.
- To explain what happens between two opposite and two alike charges.
- To construct their own electroscope.
- To observe and explain what happens when they rub the straw on the tissue and then get the straw close to the copper wire out of the jar.
- Brainstorm and explain their ideas after learning about the story of Victor Hess and the detection of the cosmic rays.
- Ask their questions about cosmic rays.
- Collaborate and enjoy the class.

Connection to school curricula:

The activity is connected to the science of 5th grade of Greek Primary School. Relative chapters: "Static electricity" and "The electroscope".

Lessons Learned

Quoting Mrs Barouta: "The evaluation was implemented through my observations and personal notes, as well as from the children's thoughts and feelings about the whole activity. I noticed that they worked together and encouraged each other to express their ideas and the topic of cosmic rays triggered their interest and curiosity to engage even more with modern science physics and space science. They were also more confident to explain their assumptions from the experiment and their observations, something that can be considered as a way of formative assessment through the implementation of the activity. The present activity can be adapted according to the needs and interests of each class and can be enriched with activities that include arts."

6.Future Outlook

This report summarizes the work and best practices of the implementation of the FRONTIERS EU project. The FRONTIERS consortium, true to their mission of introducing Nobel Prize Physics to the Classroom continues its activities beyond the end of the project funding, including the organization of online and face to face teacher training activities, the development of educational resources with and for educators and the expansion of our community, moving from FRONTIERS project to the FRONTIERS Network, an international network of teachers, researchers and stakeholders with a common vision of introducing cutting edge research in Physics to the school classroom.

ANNEX:

Proposal of a FRONTIERS Toolkit for eTwinning

Project metadata

Difficulty Level	Intermediate
Level	16 to 19
Key competencies	Mathematical, science, technology and engineering
Subjects	Physics, Mathematics

Project Kit Description

Have you ever wondered how we can integrate Modern Physics in the school curriculum? Do you believe that exciting discoveries such as the Discovery of Gravitational Waves or the Discovery of the Higgs Boson can be brought in the classroom in a consistent and understandable fashion?

The FRONTIERS project brings together expertise from frontier scientific research and educational research in formal and informal science learning, along with user communities across Europe, in order to demonstrate how Nobel Prize winning science can be systematically integrated in the school curriculum.With this kit, schools are invited to build collaborative projects aiming to introduce Nobel Prize Winning Research in Physics, in the fields of High Energy Physics, Astroparticle Physics, Astrophysics and Gravitational Wave Astronomy. To achieve that, interested educators are invited to utilize the full set of educational resources developed in the framework of the FRONTIERS Erasmus+ Project (www.frontiers-project.eu/frontiers-educational-resources).
The project resources contain:

- **21 inquiry-based and technology enhanced educational scenarios** developed by experts in the four scientific fields in question and translated in 5 languages (English, Greek, French, Italian, Portuguese) which can serve as standalone lessons themselves or as a source of inspiration for teachers who want to design their own lessons.

- **20 educational activities**, connected to school curricula and ready to be used by other teachers, produced by groups of teachers who have received training in the international training events of FRONTIERS.

- **Recorded teacher training workshops** that teachers who want to introduce the relevant FRONTIERS topics to their classroom can watch and get self-trained. The recordings are supplemented with all the training material provided ((http://www.frontiers-project.eu/past-international-training-events/), as well as with opportunities for future training.

- **Recorded virtual visits to 4 Large Research Infrastructures** that can be used by teachers to offer their students a tour to authentic research environments and show students how research is done in these infrastructures (High Energy Physics: Virtual Visit to the ALICE and ATLAS experiments at CERN; Astroparticle Physics: Virtual Visit to the Pierre Auger Observatory; Astrophysics: Virtual Observation with the Faulkes Telescopes; Gravitational Wave Astronomy: Virtual Visit to the Virgo Interferometer). Furthermore, the FRONTIERS team offers an opportunity to schools which want to perform virtual visits themselves to issue a request and get in contact with the relevant research infrastructures.

- **Access to a strong community of practice** including more than 800 teachers from all over the world (http://www.frontiers-project.eu/community/) in order to search for like minded individuals in order to co-organize activities with their schools, as well as a highly responsive mechanism to support teachers. The community is supplemented by the FRONTIERS repository in Open Discovery Space (https://portal.opendiscoveryspace.eu/node/854226) where teachers can upload their Open Educational Resources.

Proposed activities that can be implemented from this toolkit:

This toolkit holds information and examples of research in the frontiers of Physics and offers a multitude of hands-on and online tools to help bring this research to the school classroom in a broad range of Physics subjects. Teachers are encouraged to utilize the aforementioned resources and plan their own collaborative projects with their students and peers. Proposed activities can be adapted to the need of the participating institutions, from the organization of short termed activities which require the building of a detector (such as a cloud chamber), to the organization of joint long term initiatives such as the observation of solar rotation or the monitoring of the seismic activity in the Virgo detector site and can be enriched with activities such as virtual visits to research centers. Some indicative proposed activities can be found below:

Proposed activity 1: Building a cloud chamber for my school

In this activity, students can be introduced to the Physics of Cosmic Rays (http://www.frontiers-project.eu/astroparticle-physics/) and use simple materials to build their own cloud chambers (http://www.frontiers-project.eu/demonstrators/cloud-chamber/). Students can take measurements of the muon rate in their location and map the muon rates with respect to latitude.

Proposed activity 2: Joint Analysis of High Energy Particle Collision Data

In this activity, students can be introduced to High Energy Physics (http://www.frontiers-project.eu/high-energy-physics/) and explore real data taken by the ATLAS experiment at CERN in order to identify the Higgs and the Z bosons. They can utilize the citizen science methodology and support scientists to optimize the algorithms for the identification of exotic particles at CERN: https://www.zooniverse.org/projects/reinforce/new-particle-search-at-cern

Proposed activity 3: Gravitational Wave Noise Hunting

In this activity, students can be introduced to Gravitational Wave Astronomy (http://www.frontiers-project.eu/gravitational-wave-astronomy/) and explore real data of the Virgo Detector and the effect of earthquakes on the sensitity and discovery potential of the detector (http://www.frontiers-project.eu/demonstrators/earthquake-interferometer/). Then, they can collaborate with scientists of the Virgo collaboration and among themselves to optimize the Virgo detector by detecting noise patterns in the detector (http://www.frontiers-project.eu/demonstrators/gravitational-wave-noise-hunting/).

Pedagogical Objectives

This toolkit aims to:

- Help bridge the gap between research in Physics and school education through authentic learning experiences including the interaction with researchers, the use of scientific instruments and databases as well as commonly understandable instruments for authentic assessment of learning results through a series of learning scenarios.

- Introduce students to some of the key ideas for the development of Physics in the 20th and 21st century in an understandable and hands-on way.

- Motivate and train students to increase their digital literacy through the use and analysis of real scientific data from detectors, telescopes or interferometers.

- Introduce the culture of international collaboration towards the achievement of scientific output, as it is done in Large Research Infrastructures, to students and transfer it to the classroom through the proposed activities.

- Foster a culture of researcher- educator-student collaboration through joint activities such as virtual visits to research centers which require bi-partisan collaboration.

- Inspire students to become authors of their own educational content in cutting edge research.

- Inform students about the advancements of science taking place in the EU and beyond, the importance of the European initiatives for fundamental research and their impact to our lives.

Introduction of Partners

Preparatory activities for teachers

A school interested to implement activities of FRONTIERS initiates an e-twinning project. The school that initiates the project invites other teachers to join. Upon the establishment of the participating schools, a series of preparatory meetings among teachers are organized in order for everyone to: i. be familiarized with the relevant content knowledge; ii. Identify the insertion points to their curricula; iii. Make an action plan of the project; iv. Prepare relevant lesson plans.

A first curriculum and localized implementation plans are proposed to be drafted early in the project lifetime, taking into account the school time frame (vacations, exams etc). It is proposed that a series of regular meetings via online platforms (such as Zoom, Skype, Webex) are pre- arranged and that a platform for asynchronous collaboration (such as the twinspace facilities, Edmodo or Slack) is also considered in order to facilitate the coordination of the school activities. The teachers create a blog where the main activities of the project will be posted.

Introduction of students

After the participating teachers establish their action plan and select the topic of their interest to investigate with their students out of the FRONTIERS resources, the project partners need to be introduced. This is an essential first step!! It is proposed that students utilize a collaborative online platform such as padlet (https://padlet.com/) which has been prepared by the teachers according to school and country. Students are proposed to write a short comment that describes them and add a photo of themselves, making sure that they follow e-safety regulations (http://blog.whooosreading.org/classroom-internet-safety-policy/) as well as protocols that are to be supervised by their teachers. As an example, personal details should never be shared and students should be careful with what they post. Students can also create a short presentation of their team and embed it in a TwinSpace page, so that everyone can get to know the different teams. Example tool: Google Slides.

Orientation

Upon the introduction of the teams and the scheduling of the upcoming meetings, the students are asked to revisit the proposed action plan and help finalize it. After a mutual agreement is achieved, a series of ice-breaking activities (many ideas can be found in the twinspace) are to be organized in order for the teams to get to know each other as well as learn how to use the twinspace tools and the tools that have been identified as optimal for the project implementation.

Next, the teachers organize a joint short presentation of the proposed activity and afterwards invite students to brainstorm in order to create a communication kit (a logo and a leaflet) of their project. In order to increase the students' interest, they can organize: a discussion with a researcher or a virtual visit to an associated Large Research Infrastructure utilizing the support mechanism of the FRONTIERS consortium (for example, if the activity they plan to do is related to the FRONTIERS Gravitational Wave Astronomy module, they can request a virtual visit to the Virgo Gravitational Wave Detector).

In order to ensure the proper flow of the project as well as the students' increase of sense of ownership, It is important that after the orientation phase, roles are divided among students: for example the students who will be responsible for writing in the project blog will have to be identified and can come from more than one teams. Furthermore, it is important that students keep a logbook of their individual or their group's work (can be done using Google Docs) in order to learn the bookkeeping procedures that scientists use as well.

Communication- Collaboration

Communication among members of the groups will be arrange in a regular basis through the organization of meetings through online platforms (Zoom, Skype, Webex, other) as well as through the use of asynchronous e-learning tools (such as forums in the twinspace). It is proposed that the channels of communication between teams as well as the appropriate timeframe and schedules (for example a regular monthly meeting) are pre- decided among both teachers and students after the first introduction among groups is made.

Collaboration should be an important concern of participating teachers. If the activity they choose does not explicitly require collaboration (for example joint measurements from different locations) and can be done individually, then collaboration and team building activities need to be identified from the beginning of the project and be connected with project milestones. Such activities can be:

- Collaboration among students from different groups to write in the project blog (Described in the orientation phase);

- Collaboration among students to create a project communication kit (a logo and a leaflet, a youtube channel and others. *Milestone: Initiation of the project*);
- Collaboration among students to organize a joint presentation of the project outcomes online (for example through Live Streaming on Twinspace or Youtube. *Milestone: End of the project*);
- Collaboration among students to prepare a joint publication in a journal for school education best practices (such as the Open Schools Journal for Open Science https://ejournals.epublishing.ekt.gr/index.php/openschoolsjournal/index. *Milestone: End of the project*).

Evaluation & Assessment

Assessment of students

Students' content knowledge

The present toolkit introduces Modern Physics to the classroom with a focus on cutting edge research taking place in Large Research Infrastructures such as Virgo, CERN or other. This translates into a challenge both for the teachers, since they are invited to teach topics usually beyond the reach of school curricula, and for the students who are exposed to advanced scientific topics that require a good grasp of Physics and math as well as conceptual change towards modern scientists' way of thinking. It is thus proposed that students' grasp of the content knowledge of the respective projects they will participate in is one of the main themes of the assessment. The educational resources proposed in the kit description contain a series of content knowledge questions that could help in this account. Furthermore, to assess students' evolution of understanding of the topics at hand, it is proposed that student journals are kept and time is dedicated for reflection on what they have learned.

Students' motivation

Introducing the topics proposed in this topic for a long term intervention such as an eTwinning project is expected to enhance students' science motivation as well as their potential career aspirations in science. It is proposed that students are asked both before and after the implementation of the project about these topics using already available and weighted instruments, such as the Science Motivation Questionnaire (SMQ II).

Students' collaboration

As this toolkit is expected to foster collaboration among students both within their schools and with students from other schools, it is proposed that the teachers participating in a project investigate students' conception of the collaboration. This can be done through adaptation of existing instruments, through focus group discussions or interviews.

Project evaluation

On a teacher level, the participating teachers could reflect on their experience and on how the project helped them improve their own instruction. This could be achievable also through the use of existing self-reflection tools tailored to the needs of teachers.

On project level, it is proposed that students, teachers and parents are surveyed anonymously regarding the effectiveness and impact of the project as well as their enjoyment and interest in it. This can be done through the development of a short survey or through round-table interviews and is achievable through the use of online tools such as: kahoot.

Follow- Up

The following actions could be done as a follow-up:

At Student level:

- Students should be encouraged to present their activities in live events (for example through live streaming in the twinspace or Youtube), as well as in student oriented conferences.
- The project blogspot could become public so that students are able to disseminate their work.
- Students along with their teachers should be encouraged to publish results and best practices of their project in dedicated journals (such as the Open Schools Journal for Open Science https://ejournals.epublishing.ekt.gr/index.php/openschoolsjournal/index)

At School Level:

- Depending on the nature of the project implemented, the participating schools can organize follow up activities such as in situ visits in the associated Large Research Infrastructures, setting up small exhibitions and showcasing their work, inviting local researchers to their school to give talks, organize cascade events where students of the project teams can cascade their findings to the public, or participation in Science Fairs as well as High profile European Events such as the European Researchers' Night.

- As a follow-up of projects inspired by the present toolkit, it is proposed that participating schools endeavor to submit mobility applications for students and teachers funded under the Erasmus+ scheme, in order to strengthen and expand their collaboration as well as enrich it with further activities.

At teacher level:

- Teachers who participate in said projects are encouraged to pursue further training in the topics in question: such training can be obtained , for example, through the Teacher Academies of the European School Innovation Academy (https://esia.ea.gr/)