Newsletter Interview

GRAVNET: TAKING THE SEARCH FOR GRAVITATIONAL WAVES TO A NEW FREQUENCY

Interview with Claudio Gatti, particle physics researcher at INFN Frascati National Laboratories, and one of the creators of GravNet, the project awarded a 10-million-euro ERC Synergy Grant

The European Research Council received this year 548 applications for the Synergy Grant 2024, the grant that encourages and promotes scientific collaborations; and chose, among the 57 winning projects, GravNet, *A Global Network to Search for High Frequency Gravitational Waves*. Ambitious in its goals and novel in its method, this project could revolutionise the study of phenomena such as primordial black hole mergers and ultralight dark matter, and will require, over the six years of the grant, very different skills and resources shared among Germany, Spain and Italy. The four researchers leading GravNet are in fact Matthias Schott of the University of Bonn, Diego Blas of the Spanish Institute of High Energy Physics, Dmitry Budker of the Helmholtz Institute at the Johannes Gutenberg University of Mainz, and Claudio Gatti of INFN Frascati National Laboratories (LNF). We met with Claudio to hear about the project, from its conception to its future prospects.

What is GravNet and what are its goals?

GravNet will be the first global network of detectors to search for high-frequency gravitational waves, i.e., detectors searching for signals in the mega to gigahertz band. If current instruments, such as LIGO and Virgo, in fact move within the 100 hertz band, and future instruments, such as the LISA mission, dedicated to detecting gravitational waves in space, aim at even lower frequencies, GravNet aims to probe a new, very interesting and very challenging region. Indeed, it will be really difficult to intercept signals, but if we succeed, these would be primordial signals, dating back to the first split second of the universe. Today, we can look as far back as 400,000 years after the Big Bang, thanks to cosmic background radiation, and then experimentally

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light dark matter, to search for these high-frequency gravitational waves.

Let's talk about machines. Which technologies will be employed?
Radio frequency cavities, which are currently the most promising technology for our purposes. These are closed metal cavities, in which energy is accumulated in the form of radio frequency electromagnetic fields. The signal bounces between the walls of the cavity, which amplifies it, much like a resonance chamber in a musical instrument. In our case, the signal from the high-frequency range should convert into photons in the presence of an intense magnetic field, because of an unpronounceable effect, the inverse Gertsenshtein effect. This phenomenon has never yet been observed, so we would be in the presence of a double result.

What information could we obtain from it?
Firstly, we would have seen a high-frequency gravitational wave, which we do not expect to originate from standard astronomical sources, such as coalescences of black holes or neutron stars, which reach frequencies of at most a few kilohertz; at much higher frequencies, and therefore for much faster objects, there is no such astronomical background that could conceal primordial signals. There are also models according to which the presence of particular kinds of dark matter can generate these gravitational waves. One very popular model, for example, predicts that dark matter is not matter beyond the Standard Model, but ordinary matter that collapsed during the inflation phase of the universe into primordial black holes. These primordial black holes should be very light, and their coalescence should produce high-frequency gravitational waves, since the frequency is inversely proportional to the mass of the object. It is an interesting hypothesis, and what is more, it would be a viable candidate for the search for dark matter. Currently, there is no longer any preferred model in this sense, we search for dark matter everywhere: we search for WIMPs in underground laboratories, we search at the Large Hadron Collider at CERN, we search for dark photons, axions, or other scalar and pseudoscalar particles such as those hypothesised by string theory. If dark matter was to consist of these extremely light black holes, there would be no need for physics beyond the Standard Model to explain it.

In short, the prospects are many and the project time is limited. What is the partial goal of these six years and what obstacles do you expect to encounter in achieving it?
We have made no promises, precisely because it is a long and difficult road. Rather, it is a programme, a beginning. Indeed, I am convinced that what drove the ERC committee to make this award was precisely the intention to usher in a new way of observing the universe. Concretely, we hope to replicate what happened in the optical field: it started with optical astronomy, then moved on to infrared, ultraviolet, radio waves, and today astronomical investigation ranges from radio waves to X-rays, so it reaches much higher energies. From the electromagnetic wave spectrum, sources such as pulsars have emerged, that no one expected, and that's kind of our goal as well: to open a new window. As for the challenges, the project is very concrete, it is divided into very specific phases. We are already working on the first detector network, because it is impossible to observe
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fro g antennas, extract the data, and work on
dat ere is a lot of work to be done, but I don't
exp the activities that will involve the LNF.

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matter of building all the missing components: a resonant radio frequency cavity of approximately four cubic metres in volume, a large cryostat to bring it to a temperature close to absolute zero, and all the equipment needed to use it. Nothing extraordinary, but it is still in a limited time frame to write the design, issue the tender, start construction, get the machine up and running, and activate all the skills in the laboratory. Added to this is the work on signal reception, i.e., once the antenna has been built, equip it with devices that are very sensitive to electromagnetic signals resulting from the Gertsenshtein effect.

Do you already have an idea of how to approach this next phase?
Yes, on the signal reception front, we will continue the work of the last few years on superconducting qubits, very sensitive sensors at the limit of single microwave photons. The idea we are pursuing is that of coincidence between two counters, which is usually applied to classical phototubes: if you have a scintillator and an ionising particle arrives, the scintillator emits photons; you then arrange two phototubes that see some of these photons, and if you have signals from both phototubes, you are sure that it is a real signal and not random noise. The only limitation is that with this classical technology, each phototube reads different photons, whereas in the quantum world it is possible to do "non-destructive" readings, where the photon is not absorbed and its presence has an effect on the quantum phase of the qubit. In other words, you arrange two or more qubits and read the effect of the single photon on all the qubits, avoiding random noise. Currently, we are able to simulate the entire quantum system, we have made progress, but making it work inside an experiment is not trivial. In short, two antennas, one of which is to be built from scratch, plus the quantum part... we certainly have plenty of work for six years!

So GravNet was born as a collector of all your interests?
GravNet was rather born out of a bold proposal by Matthias Schott, who managed to overcome all my hesitations. When he came to me, I was more oriented toward axions, which he is also involved in, by the way. Over the past ten years, drawing on the expertise already present at LNF – radio frequency used in accelerator machines, cryogenics, which had always been used for magnets, and superconductivity, for which a laboratory had already been inaugurated – I dedicated myself to COLD, a cryogenics and radio frequency laboratory. And now I can pool the skills I have acquired with those of my colleagues in GravNet**:** Dmitry, for example, already has experience on the networks and signal combination front, operating a global network of magnetometers that search for topological defects in the universe; and Diego was among the first to write about high-frequency gravitational waves. The fact that we all have such solid research experience certainly gave substance to the proposal and played a key role in the award of the grant.

Speaking of the grant, it is a very large amount of money, 10 million euros, do you already know how to inv

Of ... ersion of the QUAX antenna (for which we do not ... and in the construction of the new antenna, the ... moment, we have four young post-docs in the CO ... les, but we will also need new people, for both the ... nent of the infrastructure operating costs over the

You ... ambitious project, so how did you react to wir

I am by nature a bit conservative, but when they proposed the idea, I actually thought, "this is so crazy that it could win". These kinds of projects require ambition, innovation, but also feasibility, and *feasibility* does not necessarily mean producing a scientific result: a road is promised, along which the necessary technology is implemented and, perhaps, new ground broken. It is an exciting prospect, to which personal satisfaction is also added. For me, to be able to implement a project we have been working on for years, and to be able to start an experiment inside an INFN national laboratory, bringing in international collaboration, is a great source of pride. I was born here in Frascati, professionally speaking, and now I am growing up with my research projects, the young people who already feel these laboratories as their own.