VIRTUAL UNIVERSES

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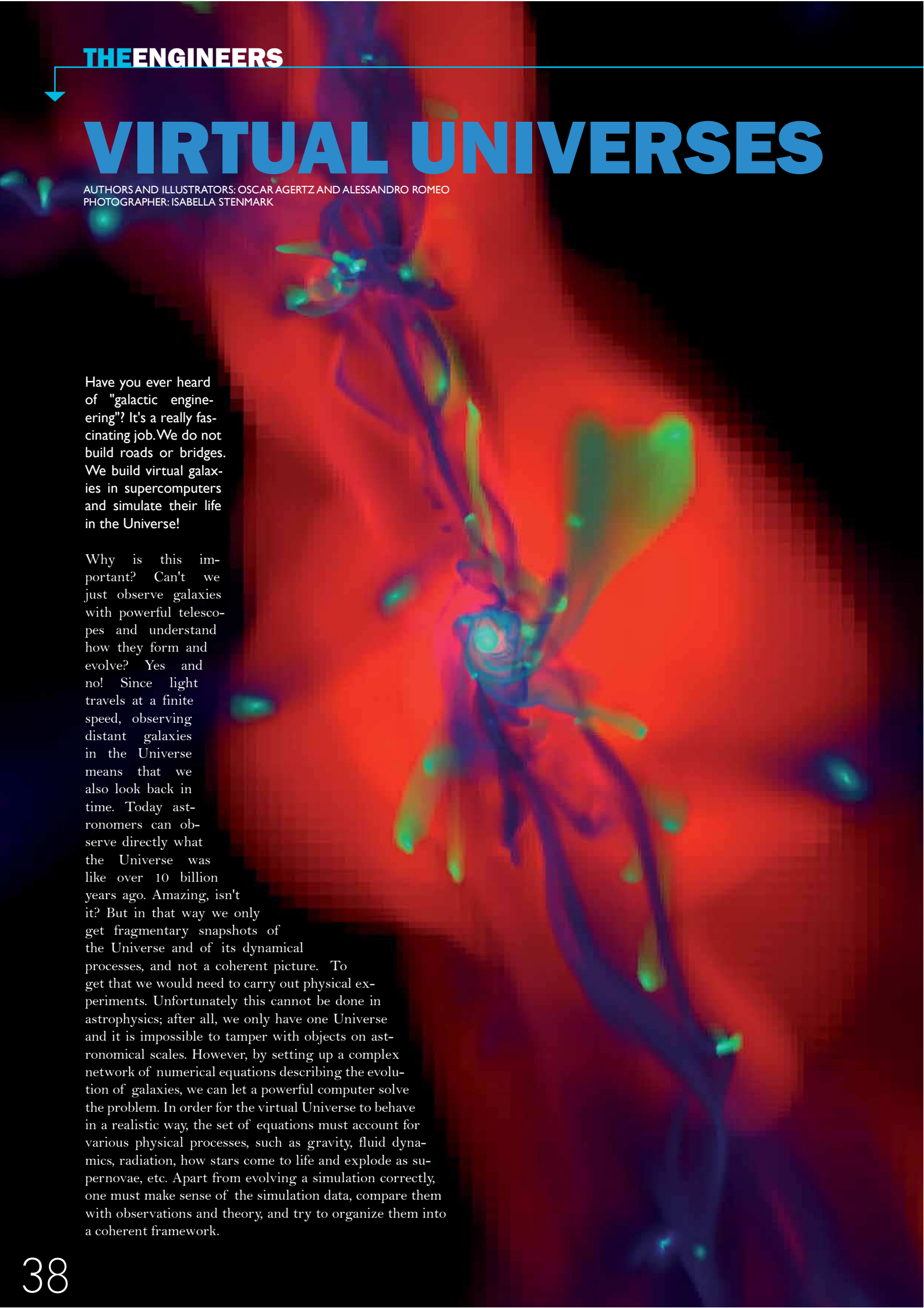

Have you ever heard of "galactic engineering"? It's a really fascinating job. We do not build roads or bridges. We build virtual galaxies in supercomputers and simulate their life in the Universe!

Why is this important? Can't we just observe galaxies with powerful telescopes and understand how they form and evolve? Yes and no! Since light travels at a finite speed, observing distant galaxies in the Universe means that we also look back in time. Today astronomers can observe directly what the Universe was like over 10 billion years ago. Amazing, isn't it? But in that way we only get fragmentary snapshots of the Universe and of its dynamical processes, and not a coherent picture. To get that we would need to carry out physical experiments. Unfortunately this cannot be done in astrophysics; after all, we only have one Universe and it is impossible to tamper with objects on astronomical scales. However, by setting up a complex network of numerical equations describing the evolution of galaxies, we can let a powerful computer solve the problem. In order for the virtual Universe to behave in a realistic way, the set of equations must account for various physical processes, such as gravity, fluid dynamics, radiation, how stars come to life and explode as supernovae, etc. Apart from evolving a simulation correctly, one must make sense of the simulation data, compare them with observations and theory, and try to organize them into a coherent framework.

Alessandro Romeo (left) and Oscar Agertz (right).

In the past decades, our theoretical understanding of galaxy formation has been guided by computer simulations. Since the first pioneering analogue simulation by the Swedish astronomer Erik Holmberg in 1941, who used a large set of lightbulbs to represent patches within individual galaxies, numerical galaxy formation has made remarkable progress; fast supercomputers with tens of thousands of cores are now every-day tools for many theoretical astrophysicists. In spite of that, the creation of a realistic model of the entire Universe inside a computer still remains elusive. At the moment, the Universe is just too complicated and too large to model at high resolution even for the fastest supercomputers. However, individual pieces of the puzzle can be studied, for example the assembly of individual galaxies like our own Milky Way.

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Are you curious to see one such simulation? Have a look at the image to the left. This is a snapshot from a recent state-of-the-art supercomputer simulation of galaxy assembly, carried out on the zBox supercomputer at the University of Zürich, showing a large patch (almost a million light years across) of the Universe more than 10 billion years ago. In the very centre we see an extended star-forming disc of gas being assembled. Cold dense gaseous filaments (in blue) pierce through the cosmic gas, feeding the protogalaxy with fresh material. This rapid gas accretion makes the disc very turbulent, and we observe supermassive (up to a billion times more massive than our own sun) gas clouds condensing via gravitational instabilities. Tenuous gas falls into the deep potential well from all directions. This gas is subsequently shocked, leading to a reservoir of hot gas (in red) around the galaxy, extending many hundred of thousand light years away. A multitude of tiny dwarf galaxies can be seen zooming through this hot gaseous halo, sometimes even merging directly with the central galaxy. To these galaxies, the hot halo gas appears as a strong wind, stripping them of interstellar gas (in green). Several billion years later, gas accretion slows down and the galaxy evolves in a more quiescent fashion. Evolving the simulation to our current epoch leads to a galaxy similar to our own Milky Way.

What do we learn from this type of simulation? In this specific example, astrophysicists got an insight of how galaxies accrete their gas, and how it shapes large disc galaxies at this cosmic epoch. Peculiar supermassive clumps in large young galaxies have been observed for over a decade. Thanks to this type of simulation, we can provide an explanation for their physical origin.

"Galactic engineering" is a rapidly progressing area of astrophysics, thanks to the ever increasing power of computers and smarter algorithms. The fantasy of many astrophysicists to simulate the perfect virtual Universe will hopefully be realized in a not too distant future.

Do you want to join the team of "galactic engineers"? Follow the Master's programme in Physics and Astronomy, and in particular the course Astrophysical Dynamics (FAS010). Welcome!