STARTS Residency Public Report
Atom Chasm

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Abstract The *Atom Chasm* residency focused on the development of a laser-cooled ion trap enabling purely optical observations of individual atoms and quantum jumps. After several scaled up prototypes, the team started designing a computer-controlled linear trap coupled with a unique magnification system. Instead of having to look into the eyepiece of a microscope extending from an ion trap, viewers experience a constellation of glowing atoms as if it were hovering in the darkness of outer space. With the support of two quantum optics laboratories, each of the collaborators contributed to the ambitious staging of the first ever atomic-scale artwork. The sensorial and philosophical impact of the installation has served as the guidepost towards which the collective aligned its efforts. Though the project is close to completion, there are still a few important steps before it can be premiered.

I. INTRODUCTION

Might it be possible for the weirdness of the quantum world to be directly perceived by our senses? Could we thence unveil the origins of this weirdness, and boldly face what can and cannot be ultimately perceived and comprehended about physical reality? Such questions have been stirring our minds and steering our artistic practice from the very start. Simultaneously comprising multi-sensory environments, philosophical inquiries and scientific experiments, our artworks and performances necessarily entail uncharted perceptual territory. Although the originators of quantum theory were convinced that perceiving, let alone manipulating individual atoms would forever remain a mere thought experiment, their conclusions were decisively inverted by the invention of the laser-cooled ion trap. Not only did it enable the first observations of a single atom's quantum behaviour, it is currently paving the way to quantum computers and exotic physics beyond the Standard Model.

II. ARTWORK

The primary focus of our residency was the development of *Atom Chasm*, a laser-cooled atom observatory probing the slippery frontier between quantum and quotidian reality. The first artwork to ever be presented on the atomic scale, *Atom Chasm* is an immersive ion trap installation, enabling audiences to intimately confront the very foundations of the physical world as well as such paradoxical phenomena as quantum jumps. Considered "irreconcilable with the very foundations of quantum mechanics"[Schrödinger, Statistical Thermodynamics], the existence of quantum jumps was feverishly debated from the moment Niels Bohr hypothesised them in 1913. All doubt was finally cast aside when quantum jumps were discovered in single ion (ionised atom) experiments during the 1980s. Crowning this discovery was the inestimable surprise of quantum jumps' retinal visibility. Among the researchers who initiated the laser-cooled single atom trap, there was a shared pursuit and appreciation of the experiment's poignant sensorial impact. The experiment was conducted "in the spirit of Mach, to observe visually" [W. Neuhauser, M. Hohenstatt, P. E. Toschek, and H. Dehmelt, Localized visible Ba+ mono-ion oscillator]. In December 2017, we were privileged to witness this mind-blowing experiment at Rainer Blatt's quantum optics lab at Innsbruck University – the hallowed setting where the Dalai Lama had his single atom experience. After adapting to the darkness for a few minutes, we were utterly transfixed as the laser-induced light emitted by a barium ion directly entered our eyes. Unlike a representation of the atom's light emission captured on a microchip, the purity and physical connectivity of this starry light far surpassed our wildest premonitions.

In *Atom Chasm* this state-of-the-art experiment is dramatically enhanced by enabling the observation of an ensemble of ions undergoing quantum jumps. They are perceived as sudden disappearances and reappearances of individual atoms. Sensorial enhancements have also been implemented by means of unique large field-of-view optics as well as live sonifications of quantum jumps. Instead of having to look into the eyepiece of a microscope extending from an ion trap, viewers experience a constellation of glowing atoms as if it were hovering in the darkness of outer space.

Atoms suspended in an ion trap agglomerate into a latticework known as a Coulomb crystal – a remarkable class of spatially ordered matter that emerges from a delicate balance between trapping forces acting on ions and their mutual Coulomb repulsion. In order to explore this exotic state of matter as macroscopically as possible, we ended up creating an additional artwork while designing the electrode configuration of *Atom Chasm.* Entitled *Hilbert Hotel*, this installation evokes the seemingly infinite number of orbital states that can be occupied by ions suspended in a looped electrical potential. How can a fully occupied hotel of infinite scale accommodate an infinite influx of new guests? David Hilbert was among a contingent of mathematicians, stretching back to Zeno, who pondered such questions of infinitesimal spatial granularity. *Hilbert Hotel* is a curvilinear ion trap that electrically levitates its myriad microscopic guests. These hollow glass microspheres float along startlingly square-shaped orbits tracing the quadrupolar electric fields that keep them airborne.

There was also a second prototype that emerged into an artwork. Known as *Quantum Lattice,* this installation was presented at a high-profile exhibition, "Beauty before Wisdom", at the Landesmuseum, Innsbruck. The exhibition featured works by more than thirty artists, linking

contemporary artistic practice with scientific research of recent centuries, from psychology and geology to neuroscience and quantum physics.

III. METHODOLOGY

The production process has been a multilateral effort, combining the forces of two preeminent quantum optics laboratories, Robert Löw's group at the 5th Physics Institute (Stuttgart University) and the Quantenbit group of Ferdinand Schmidt-Kaler (Mainz University), with consultations from Tommaso Calarco, Head of the Quantum Control Institute (Jülich Research Centre).

During the first phase, we designed the electrode configuration and the optical magnification system. To the facilitate the former task, we decided to build several large-scale ion traps with various electrode configurations. These room temperature traps can suspend relatively large particles (compared to atoms), such as spores or glass microspheres, observable without optics – just with the help of a carefully shaped laser beam. The development of the optical system called for a computer model of our future ion trap. Otherwise it would not have been possible to flawlessly calculate the eventual lens specifications for a maximal field of view and optimal light output.

The second phase involved the design of the laser-cooling and laser-excitation systems, which must be scrupulously interlocked for the ions to maintain their positions and their glow. The last stage of production, which is currently reaching completion, consists of: intercalibrating all of the aforementioned elements as well as the ion oven and ultra-high vacuum chamber; programming a computer-controlled feedback system; testing the real-time sonification of quantum jumps.

IV. CO-CREATION PROCESS

It has been an immense pleasure and privilege to work with such a dedicated team of co-authors, working together as horizontally as possible. Every aspect of the endeavor has been a shared responsibility, from the conceptual plain to the hands-on engineering; from aesthetics to laser physics and quantum control. Nonetheless, certain experiments and calibrations could only have been conducted under the auspices of our incomparable ion trap experts, Robert Löw Ferdinand Schmidt-Kaler.

Even though the duration of the residency may not have been long enough to fully complete such an ambitious artwork, enough time was provided for conceiving and implementing a variety of sequentially evolving experiments. This continuous dialogue between theory and experiment is a quintessential part of our creative process. Each iteration of an idea is met with empirical criteria, such as perceptual and aesthetic impact, as well as technical feasibility and robustness. To stage *Atom Chasm* in a public space – beyond the luxurious confines of a quantum optics lab – there is a multitude of challenges that must be surmounted, all of which have to be factored into the

artwork before each and every experimental implementation. For example, the temperature in the room cannot vary by more than half a degree.

V. IMPACT

The linear Paul trap, upon which *Atom Chasm* is based, might pave the way to the first quantum computers. Though only in its infancy, the rapidly evolving field of quantum informatics (encompassing a vast spectrum of disciplines from quantum optics and cryptography to tabletop cosmology) offers a powerful means of tackling numerous global emergencies. "Now, previously untapped aspects of quantum theory are ready to be used as a resource in technologies with far-reaching applications, including secure communication networks, sensors for biomedical diagnostics and fundamentally new paradigms of computation".[Quantum Manifesto: A New Era of Technology, 2016] *Atom Chasm* seeks to raise awareness of this invaluable roadmap to pivotal, visionary solutions for the imminent future.

Perhaps no less significant than its potential applications, the capacity to directly perceive the light emitted by individual atoms entails a transformative philosophical and emotional experience as well as an inversion of an overgrown cultural tendency: since time immemorial, and especially in the arts, there has been an "idolatry of gigantism", an urge for expansion, whereby the spectacular is often synonymous with being of spectacular scale. Hopefully this bias has no longer any place in science, but it still persists culturally.

The challenges that humanity is facing today, such as a limited amount of resources and collapsing ecosystems for human and non-human inhabitants of our planet, call for a radical shift in our cultural framework. The aforementioned problems are but a flip-side of the expansionist way of thinking and problem-solving. Quantum physics from its early days provided a fertile, sometimes even scandalous intellectual ground for challenging our fossilized cultural predispositions. Artists of the early 20th century were roused by such provocations, and contemporary artists will soon be spurred by the conundrums surrounding the second quantum revolution. "There is more room at the bottom" are the legendary words with which Nobel laureate Richard Feynman simultaneously ushered in the second quantum revolution and the age of nanotechnology. Miniaturization and ephemeralisation have become the dominant recent tendencies in humanity's meandering quest for knowledge and interconnectivity. This pursuit of the infinitesimal is gradually finding its expression in the arts, leading to a reevaluation of physical limitations and mental potentialities. Eventually, the clumsy gigantism of the past might lose its grasp of our civilization.

VI. ART-SCIENCE INTER-RELATIONSHIPS

The residency was so well organised and funded that it gave us the capacity to visit the 5th Physics Institute on three separate occasions. With each week-long visit we were able to integrate ourselves ever more deeply into the quantum optics community, attending lectures by internal and guest speakers, demonstrating our prototypes, and passionately discussing the open problems of low energy physics.

VII. FUTURE DIRECTION AND ACTIONS

The programme will continue beyond the framework of STARTS as we reach the final stages of the artwork's execution. Once complete, the next challenge will be to find an appropriate venue both for the premiere and eventually for the permanent display of *Atom Chasm.* Because of the highly demanding efforts involved in setting up the artwork (a procedure requiring up to two weeks), it would be ideal to find an establishment that would be able to continuously exhibit the installation among its permanent collection. Even beyond the finalization of the artwork, there is no shadow of a doubt, on the part of each team member, that our collaborative pursuits will fruitfully progress deep into the future.

VIII. CONCLUSION

STARTS did a great job with the closing events and exhibition, featuring quite a variety and immense quality of projects. This gave us the opportunity to meet numerous amazing artists and researchers. The venue, Centquatre, could not have been more optimal in terms of the vastness of audience demographics, technical support and multiplicity of settings. We strongly salute the organisation's emphatic efforts to gather the residency teams on an annual basis for conferences, reports and artistic presentations. Besides the other aforementioned reasons, the STARTS programme truly differed from former residencies due to its continuous communicative impetus, which culminated beautifully at Centquatre.

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