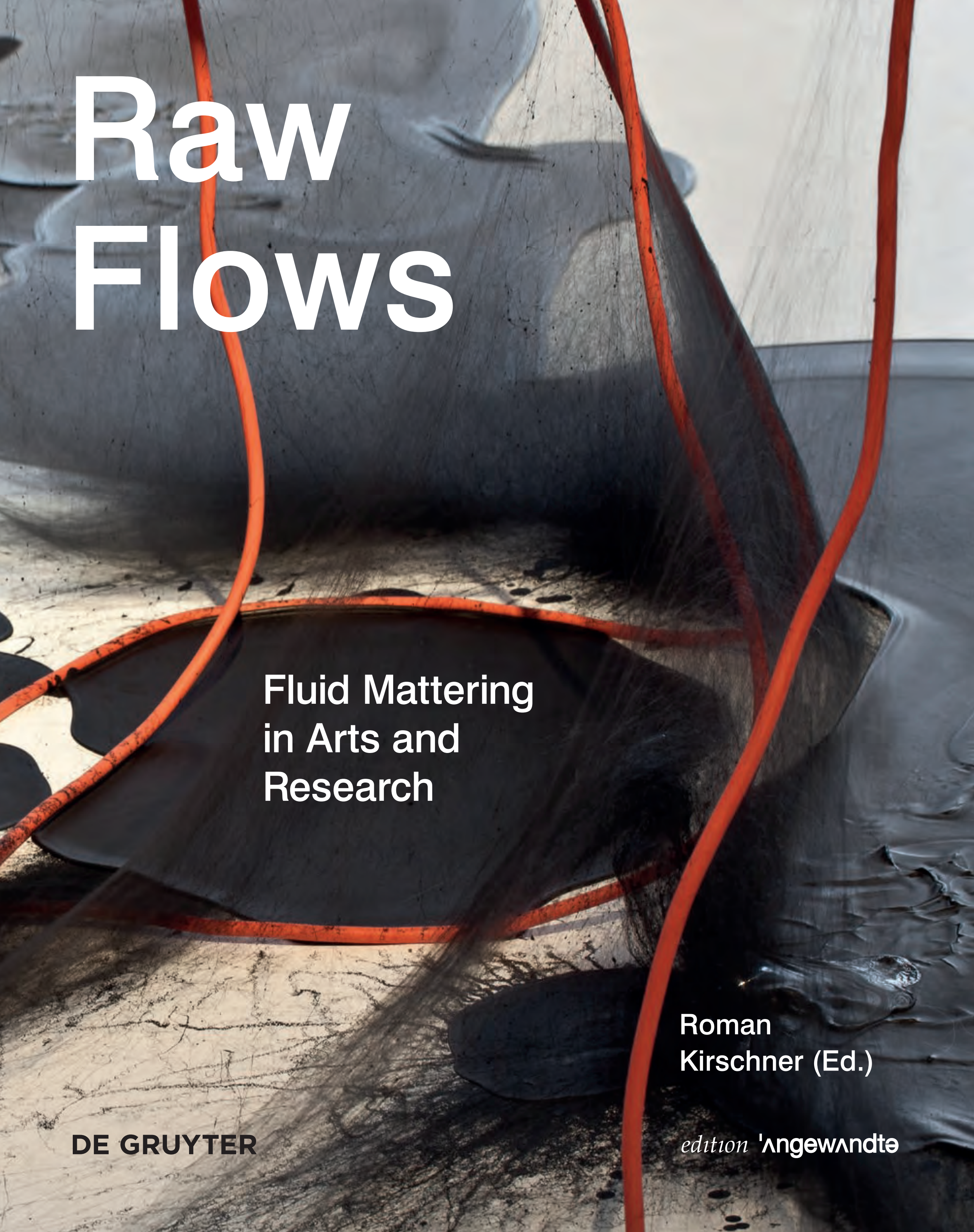

Raw Flows

Fluid Mattering in Arts and Research

Roman Kirschner (Ed.)

DE GRUYTER

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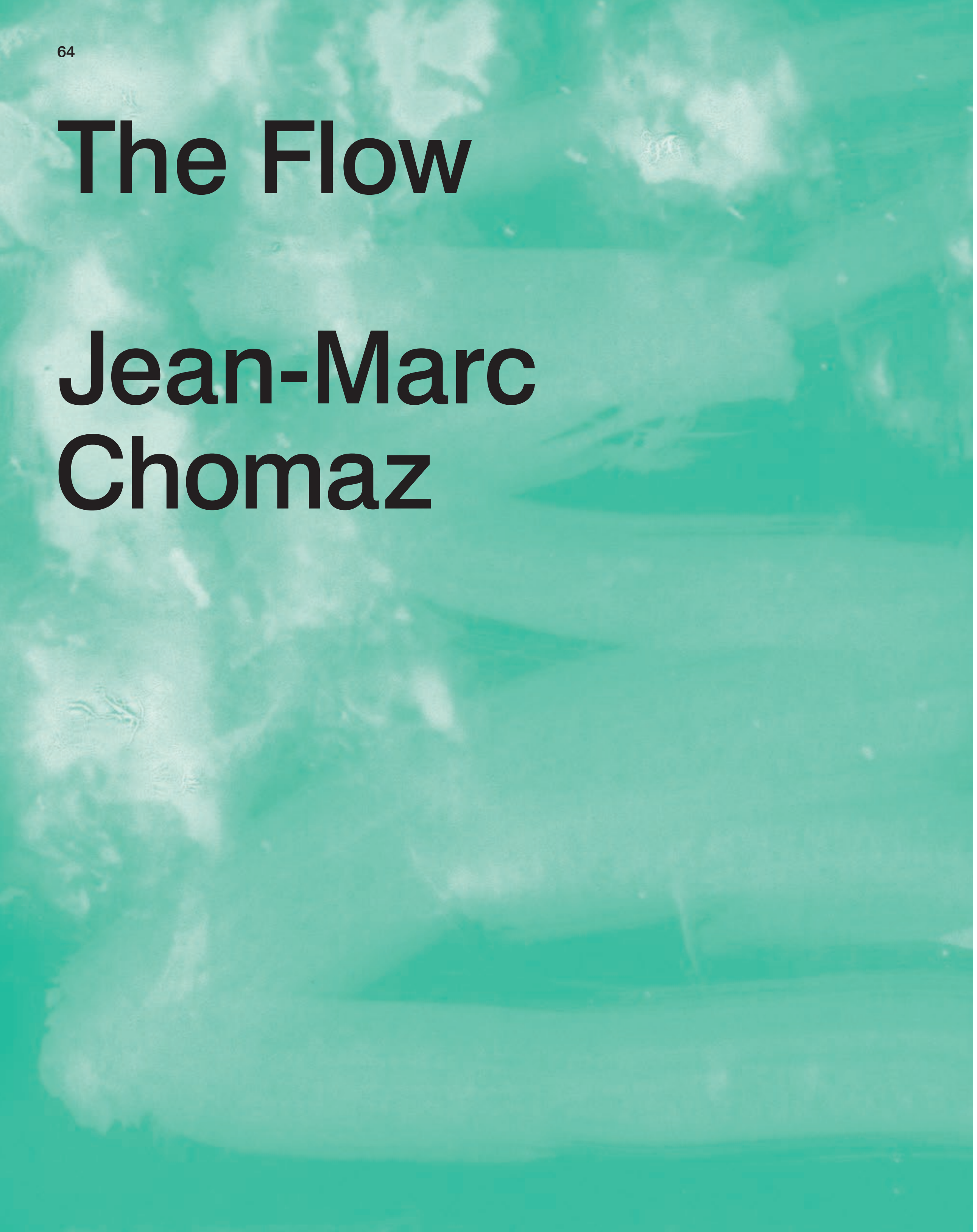

The Flow

Jean-Marc Chomaz

Science views the universe as a dynamic system, from the cosmic to human to subatomic scale; as a trajectory rushing through the ages; as a gigantic flow which shapes all structures and textures, visible or invisible to the naked eye. Following Arnold, we will use the term *the Flow* to refer to Anosov's flow, which is defined as the bundle of all trajectories of all the restless particles in our universe, and of all the degrees of freedom in the emptiness of space. The Flow is the effective form science is bound to invent; a form composed of motion, matter, and trajectories. Our current perspective, that of an expanded reality made more tangible by technology, is only a snapshot: an image of the Flow at a particular instant that we perceive of as *our age*. Our observations of the depth of the sky do not capture an ancient point in the age of the universe, but rather intercept it on its race to the future: particles, photons, and neutrinos, emitted during an ancient transformation from one energy form to another, propagating in continuous interaction with the rest of the universe. In what we perceive of as *the present*, these particles and processes are transformed by our extended senses into images that the electrons in our brains can make sense of.

The Flow is tremendously complex. Even if each individual particle obeys elementary deterministic rules, collective forms emerge at all scales in time and space transcending the rules individual particles are submitted to. Our senses interpret these collective structures as mental images or projections: n-dimensional objects or concepts that are a pale perception of the complexity of forms which shape the spatio-temporal Flow. However, our minds unconsciously detect these complex morphodynamics when they occur at our scale of time and space – for example, the mystery of clouds arises from their apparently still yet ever-changing form. Evelina Domnitch and Dmitry Gelfand's *Camera Lucida* installation has succeeded in manifesting the Flow in a technological setting. It consists of a spherical tank inside which sonoluminescence is generated via the interaction of three transducers to produce intense ultrasonic beams. In doing so, the installation creates evanescent boreal auroras and evokes a universe that seems to emanate from our own thoughts.

Science continuously proposes partial representations of the Flow, at cosmic, geologic, or subatomic scales of time and space, which are aimed at describing morphodynamics compatible with present observations. These models project a form where matter, space, and time are in motion, allowing our imagination to screen and insinuate scenarios with the feeling of embracing a larger view of the Flow than our minds may ever be able to grasp.

In an objective sense, science gives physical existence to the Flow by formulating simple rules of symmetry, conservation, and causality. Mathematics can therefore be regarded as a language that represents the Flow in a mental form, revealing unforeseen principles and phrases that, when formulated, allow for definitive new tests to challenge accepted measurements. Invariably, newly formulated observations will question the Flow model, and scientists will be compelled to discard their old constructions and build a new language: a novel mathematical grammar with new physical verbs that will generate a new mental projection of the Flow to explain both past and present data. All of the hypotheses – however poetical they may be – that the reinvented language may generate should be patiently written, and their effects carefully tested against the observations in the expectation to discover an inconsistence, a dissonance in the real that will bring us once again roll the stone of knowledge from the base to the top of the mountain, free and happy to reformulate the world.

Mixing and segregation are two processes that shape the Flow at all scales of time and space, and explain the textures of the instantaneous images our minds project. In the present model of the cosmic Flow, the initial uniformly composed dense cloud of particles expand into space, and then concentrate under the action of gravity from vanishing fluctuations. The induced segregation of mass and momentum creates primitive, massive stars that transform primordial matter into heavier atoms, which rapidly blow outward into the present dusty universe; where, from gigantic dark clouds, galaxies arise. This ancient period of the Flow is presently tested with computers, which implement the language of mathematics to automatically create new generations of phrases called *results*, and to compare predictions of the texture of the 3 Kelvin Background Radiation with present observations. This proto-universe model is certainly different from the real Flow, but confronting the model with the present should enable the validation of assumptions about these remote ages and the explanation of the current distribution of galactic clusters. It is particularly conjectural and fascinating, because the remnants of these primordial epochs are hidden from us, behind the blossoms of particles emitted during explosions of these primordial-stars, explosions nearly synchronized since occurring at approximately the same instant after the Big start of the Flow.

Inside actual galaxies, stars are constantly being generated by the high energy interaction of molecular clouds, which create shockwaves that in turn produce fluctuations and gravitational collapse. These galactic clouds are made up of dust and molecules; they diffuse the light of the stars behind or within them,

creating intricate patterns which incite our imagination to see familiar shapes or animals. They resemble atmospheric clouds, since they obey a similar law of mixing and segregation to preserve rotational invariance resulting in the conservation of angular momentum. Coherent structures appear to physically manifest these laws, while at the same time, mixing occurs; cloud plumes are chaotically transported, folded, and stretched at spatial and temporal scales compared to which humanity's existence is but a mere blink. The structures eventually condense into proto-stars wherein the laws of conservation of angular momentum and energy of agitation are balanced by gravitational collapse. Proto-stars transfer their momentum to dusty accretion disks from which, by a process still hidden from us, planets emerge – like a giant whirlpool concentrating the surrounding clouds into proto-planets. Again matter segregates, under the simultaneous action of gravity and rotation which defines planetary composition. Volatile elements then combine to form ethereal, yet superficial layers called oceans or atmospheres, the compositions of which vary amazingly when we consider our immediate surroundings: the carbon dioxide- and nitrogen-dominated Venus or the hydrogen- and helium-rich Jupiter. Thermal forcing of the atmosphere by the Sun or by internal heat sources induce convective motion that forms vortices to conserve angular momentum. These vortices structure the atmosphere, transporting heat and chemicals around but in isolation from the planetary core, while at the same time promoting the mixing of surrounding fluids via stirring and folding at their periphery. Minor constituents undergo phase changes amid liquids, solids, or gases that render both the folds and core visible: this creates clouds which can appear white when made of water (on Venus, Earth, and Jupiter, for instance) and multicolored when made of sulphuric acid, ammonia ice, or ammonium hydrosulfide). Among all of these cloudy maelstroms, the Great Red Spot of Jupiter, first been observed by Galileo, is clearly the most recognizable. The mechanisms responsible for its existence and color are still debated, but what is known is that The Great Red Spot is a vortex preserved from dispersion by the conservation of its angular momentum, which creates a barrier against mixing with the external fluid and secures its colorful segregation. Our project, *Luminiferous Drift*, in collaboration with Evelina Domnitch and Dmitry Gelfand, aims to examine a recently discovered stable coherent structure at the south pole of Saturn that strongly resembles a white hexagon. It is believed to have been created by destabilization of the shear present at the edge of the circumpolar vortex, shear that acts as a barrier against mixing shapping the edges of the hexagone. Our installation will

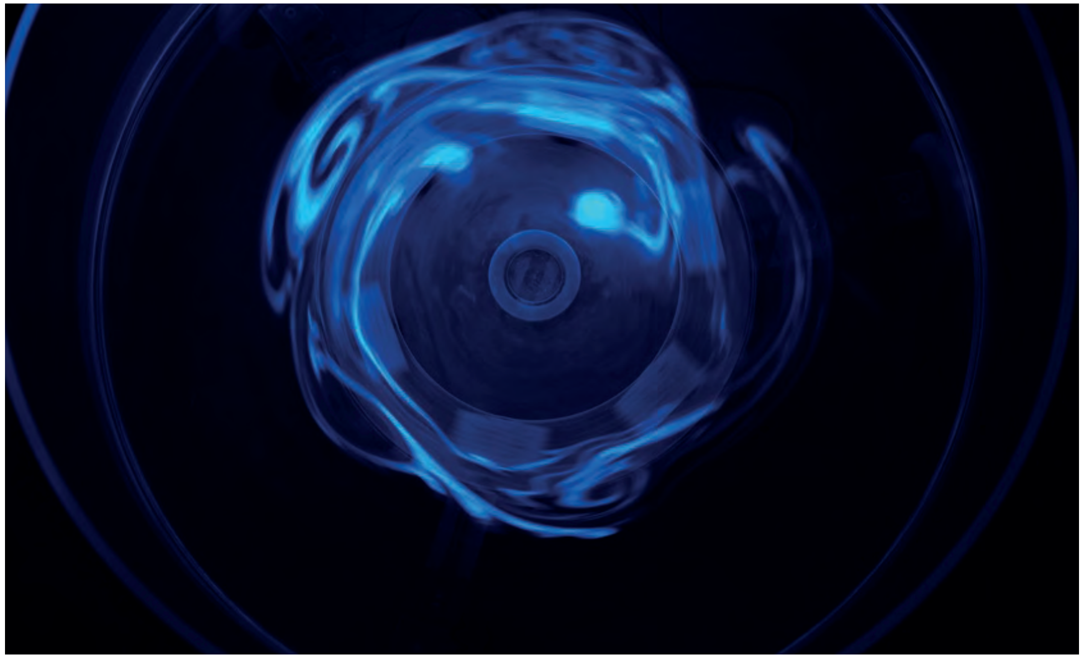

Fig. 1: *Luminiferous Drift* Installation, Evelina Domnitch, Dmitry Gelfand, and Jean-Marc Chomaz as created for the exhibition Wetware, curated by Jens Hauser and David Familian.

mechanically reproduce the vortex and the shear, and via the segregation of bioluminescent proto-cells, will also explore the potential future of Saturn's vortex from the perspective of climate change immanence in the universe.

On Earth, cloud dynamics are better understood, and also involve a similar mechanism of mixture and segregation. The processes from which they originate determine their texture. As we all know, Earth's white clouds are composed of water droplets or water ice crystals that condensate when an air mass is cooled down, generally by upward movement due its own buoyancy, topographical features such as mountains, or colder air masses flowing beneath it. It may also cool down due to heat loss or mixture with colder air. A summertime thermal plume, rising above a cotton field, produces a clear-sky cumulus cloud, and soil moisture condenses out of the rising hot streams of thin air.

Stormy weather is generated by a similar but far more dramatic process. When hot, humid, saturated air, often of tropical origin, is pushed upward by cold

northern air, a potentially catastrophic sequence of events occurs. The moisture condenses when the depressurized air, moving upward and releasing its latent heat, warms the air and accelerates its ascent; at the same time, rain, rain is coming down, all over the intruding lower layer of fresh air cooling it more. This process progresses even faster, consequently destabilizing the entire region. A mountain standing against the wind will also force air to rise, which can then condense into layers of lenticular clouds when the humidity and vertical displacement are large enough. Amazingly, these topography-based clouds appear stationary, even though they originate from the fast displacement of air as it continuously enters and exits the clouds. Often, the air will oscillate up and down as it moves away from the mountain, producing a spatial echo of its shape. On occasion, clouds can become trapped or twisted into vortices because of mountains or other topographic features, producing the kinds of vortex streets that impressed the first cosmonauts by the arabesques they traced over our paper planet.

These topographic effects, when associated with the trade winds, explain rainfall on the windward sides of tropical islands and many other microclimates, as well as the drier and sunnier weather on the west cost of Leeward islands. Although topographic clouds are periodic in terms of space, other types of cloud patterns are periodic in terms of time. Sea breezes, for example, are diurnally evolving cloud patterns that commence when cold air from the sea moves inland during the day, upwardly displacing warmer air from the land, and generating a band of clouds that hug the shoreline until nightfall, when the wind reverses direction as the land cools off faster than the sea. Mountain breezes are similarly heated by the Sun on the *adret* (or sun-receiving) side of a mountain, only to then be cooled in the shade of the *ubac* (or sun-deprived) side as they spill down into the valley.

All clouds have distinctive shapes that arise from the very process of their generation. Plumes and cumulus borders are rounded by horizontal vortices that mix the cloudy air with the drier surrounding air, evaporating the droplets. High altitude stratus clouds are torn apart by chaotic motions induced by large-scale horizontal vortices. Lenticular clouds or caps may either appear extraordinarily smooth like flying saucers, or more paste-like when the wind is stronger or the stratification becomes weaker.

Clouds can also form large-scale patterns resembling planetary circulation, like in the case of a tropical convection band that is surrounded by a clear, dry subsidence zone. Then, at mid latitude, the scenic band of rainy depression, coming from the Rossby wave undulating on the northern potential vorticity, appears as a distinguishable vortex in the sky. Again, these patterns are made visible by the transportation of moisture, either vertically or horizontally, via vortices at all scales of space and time. Because of the conservation of angular momentum, the gyroscopic effect prevents fluid in the vortex from mixing, in contrast to the strongly mixing outside vortices, both of which are impelled by the same ever-present stretching and folding of space.

The formation of clouds, however, is not so simple, since without hydrophilic dust–called condensation nuclei–no cloud could form, even if the air was oversaturated. The energy needed to form even the first infinitesimal drop is much too large to be incited by random encounters of agitated water molecules. Water does not condense into droplets spontaneously, but rather into small hydrophilic particles which allow them to take on a finite size, larger than that at which they would evanesce. But when the rain falls it washes out these particles and clears up the sky–and indeed, it looks different, deeper, after the rain. The condensation nuclei must then be regenerated. Amazingly, these nuclei mainly come from the ocean, as salt particles from dried sea spray or as biological particles from the marine water, both of which are formed directly at the singular cusp of wave breaking against the wind, as well as through an explosion of micro air droplets formerly trapped beneath the broken waves. A similar chaotic process that moves masses of moisture around the planet, transports and spreads sea-born nuclei throughout the atmosphere and across the surface of the Earth. The nature, density, and size of the condensation nuclei influence the *albedo*, or optical density and reflectivity of the clouds' texture. Amazingly the atmosphere is permanently seeded and inhabited by plankton, which deepens the relationship between clouds and the ocean. In our project, *Luminiferous Drift*, we use synthetic biology to produce luciferine protein encapsulated in vesicles to reproduce the luminescence of some of the Earth's Phytoplankton. These vesicles, in the scenario of the project's installation, are strongly related to life at its origin, to the air encompassing oceans, and to extraterrestrial life. The barely *luminous* hexagon that starts vacillating in the installation is a reference and probe to the curiosity of Saturn's current vortices.

When humans started burning their fossil past in order to power their industrial future, they not only released greenhouse gasses but also anthropogenic condensation nuclei such as sulfate, nitrate, and ammonium. The first types warmed the atmosphere, while the second types increased the density of the clouds and, by reflecting solar radiation back into space, cooled the atmosphere. Simply put, man-made clouds did somewhat compensate for global warming by hiding the

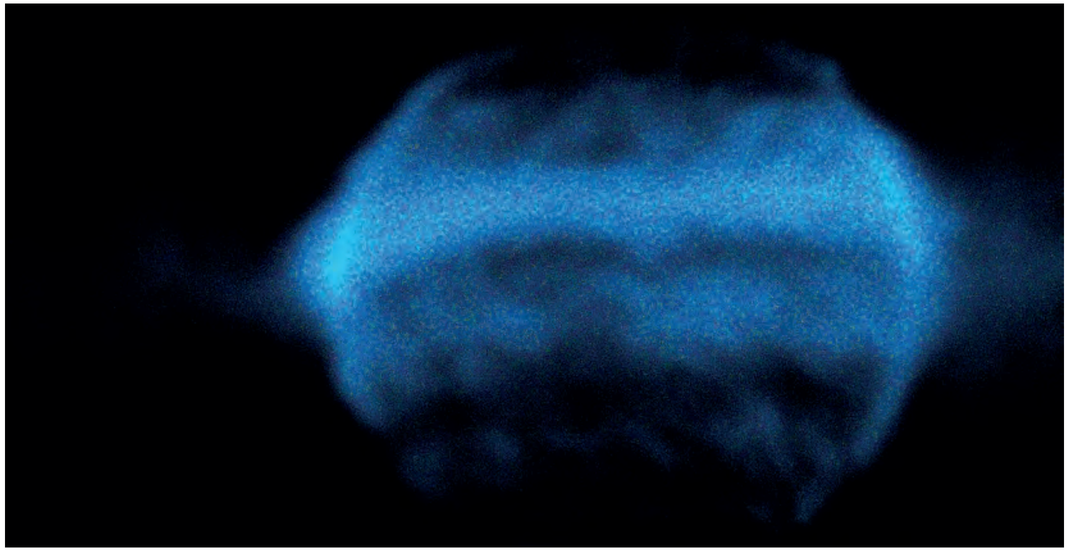

Fig. 2: *Exoplanet*, Salon des Réalités Nouvelles, Paris 2015. The installation Exoplanet is an intimate inverted cosmos inhabited by the bioluminescence of living phytoplankton Pyrocistis Noctiluca. Pale blue pulses draw a vortex, an evanescence of spirals and stripes. Sparks are produced by the oxidation of the luciferin, a protein photosynthesized during the day by living cells.

greenhouse effect. However, because man-made clouds did produce acid rain, the United Nations succeeded in regulating their emission while unraveling the imminent greenhouse gas catastrophe. This catastrophe is in motion within the Flow; its dynamics are hard to predict, as they are leading to an unprecedented balance of the biosphere, atmosphere, ocean and *homo-economicus-sphere*.

Climate engineering, another of Pandora's temptations, would be an energy industry-led attempt to control the climate by creating planet-size clouds whose purpose is to introduce acidic nuclei into the high atmosphere. Is it reasonable to control such a large part of the Flow, so gigantic when compared to human scale? Is it ethical? Or shall humans just burn their wax wings, imagining themselves as rivals to the Sun, not leaving enough hope to flow with their divine ambitions?

1 Vladimir Igorevitch, Arnold: *Chapitres supplémentaires de la théorie des équations différentielles ordinaires* (Translated from French by Djilali Embarek), Editions Mir Moscou 1978; in English: Vladimir Igorevitch, Arnold: *Lectures on partial differential equations*, Springer 2004

Biographies

JEAN-MARC CHOMAZ is a physicist and artist. His scientific research encompasses areas such as the dynamics of soap films, global instability, vortex breakdown, geophysical and stratified fluids, and biomechanics. He is a director of research, professor and chair at the University of Paris-Saclay, where he co-founded the Hydrodynamics Laboratory he co-directed from 1990 to 2013. With more than 25 different artworks, performances and installations, his art practice aims at exploring the sensory and emotional foundations of science.

EVELINA DOMNITCH AND DMITRY GELFAND create sensory immersion environments that merge physics, chemistry and computer science with uncanny philosophical practices. Having dismissed the use of recording and fixative media, their installations exist as ever-transforming phenomena offered for observation. In order to engage such ephemeral processes, the duo has collaborated with numerous scientific research facilities.

KARMEN FRANINOVIĆ is professor for interaction design at Zurich University of the Arts. Her research focuses on enactive approaches to cognition and design, responsive environments, sonic interaction, creative methods and active materials. Karmen founded Zero-Th studio and Enactive Environments Lab, whose work has been shown internationally at venues such as MoMA Ljubljana, Cambridge Junction, and Centre Pompidou.

INGE HINTERWALDNER is visiting professor for modern and contemporary history of art and imagery at Humboldt University in Berlin. Her current research interests are the relationships between the arts, sciences and technology, model theory and operativity of images, temporality in the visual arts, computer-based art and architecture.

ROMAN KIRSCHNER works in the fields of plastic arts and art-based research. From 2012 until 2016 he led the project Liquid Things – Research on Active and Transitive Materials at the University of Applied Arts Vienna. His art projects have been shown in numerous exhibitions in the USA, South America, Europe and Asia. In his current research he is developing a paradigm of material activity in the plastic arts.

ESTHER MOÑIVAS is professor for art history and aesthetics at Nebrija University, Madrid. She holds a doctorate from Complutense University and is currently leading the Nebrija Group of cross-sectional surveys in contemporary artistic creation (ETCC). Her ongoing research interests are new media and materials in current artistic creation, intersecting creative processes between art and science, and the aesthetics of fluid materials.

HANS-JÖRG RHEINBERGER is honorary professor for the history of science at the Technische Universität Berlin and holds an honorary doctorate from ETH Zürich. Formerly director of the Max Planck Institute for the History of Science in Berlin, he is a member of the Berlin-Brandenburgische Akademie der Wissenschaften and the Leopoldina. His current research interests are the history and epistemology of experimentation and the relationship between the sciences and the arts.

BENJAMIN STEININGER is a cultural and media theorist, historian of science and technology, and curator in Vienna. He has written a book on the history of the German motorway system and a dissertation on the industrial history of chemical catalysis in the 20th century. His main research fields are the cultural history of energy and acceleration and the history and theory of the materials of modernity: fuels, fossil raw materials and building materials.

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Matter is in flux. Its flows can be encountered on different scales of space and time. The characteristics of these flows influence researchers in their active and direct material engagement. Raw Flows investigates how fluidity and flow carve their specific paths into experimental practices and thinking patterns.

This book is a result of the art-based research project *Liquid Things*. It gathers contributions from arts, history of science, fluid dynamics, design, art history and cultural studies. The inclusion of these fields offers a diversified perspective on the material property and general phenomenon of fluidity. Within this spectrum, the book explores fluidity's entanglement with becoming and change, asking which roles it plays in relation to the epistemic, the aesthetic and the experiential.

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