

Make Matter Make Sense: Inside Out / Outside In

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*"Good material often stands idle for want of an artist;
make the experiment, and you will find it so."*

— Seneca, 1– 100 AD

*"The cosmos is within us. We are made of star-stuff.
We are a way for the universe to know itself."*

— Carl Sagan, 1980

*"We live in a world that we have not yet learned to look at.
We need to relearn to think about space."*

— Marc Augé, 1992



I saw.

I knew.

I felt.

I imagined.

I touched.

I became.

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My life would have been much less enriched had I not laid my hands on an electron microscope about two decades ago. For that, I will forever be grateful to those who paved the way hundreds of years ago and those who have built it further through to our time; especially my former Ph.D. supervisor Prof. Dr. Mehmet Ali Gülgün who first

sat me down in front of an electron microscope without knowing he was playing Cupid in a love affair to come.

Last but not least, my heart and solidarity goes out to anyone who is not (only) enjoying the world of the invisible but (also) dealing with invisible conditions, encouraging and inspiring me everyday while doing so: May your barbed wires be cut off one day!

Peace,
İstem

Abstract

This manuscript deliberates over our place in the nano-space through building connections between spaces of different scales. Starting with our relation with materials, the instruments, and methods we use in science to study them, it goes through a journey of seeking for meaning, sense, and empathy, ultimately landing onto the thought that the experience of scientific practice itself could be a work of art. As done with the very instrument of focus in this work, the scanning electron microscope, it *scans through* six different *frames*, to be stacked up in the end to form the final *image*: “Matter Matters”, “Worlds within Worlds: Magnitudes, Rooms and Scale-Hopping”, “In Love with the Machine”, “Now You See, Now You Don’t: Sense It All / Know It All”, “Shedding It All Off: the Scientist as Alice, Science as Experience, Experience as Art”, and “Intimacy and Empathy”. It closes with prospects and reflections on relations between science and art.

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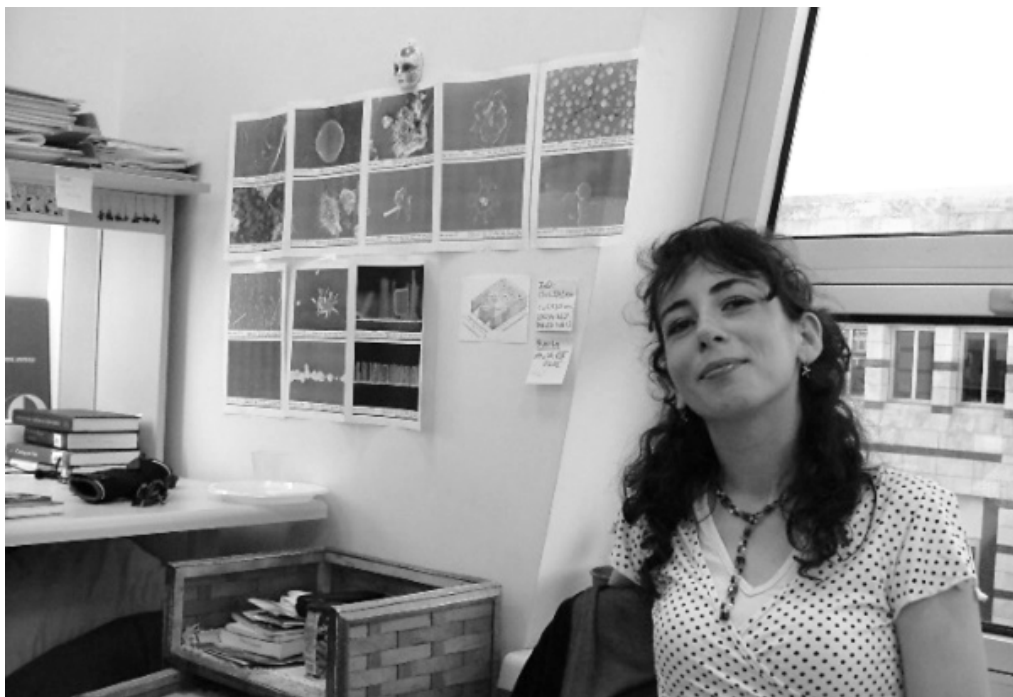
Preface

This manuscript is an attempt to revisit and rethink of practice in nano-science, feeding off of post-scientific experiences in art practice tied together with ideas borrowed as inspiration from philosophy and sociology. The framing research question I ask is “where is our place in the nano-space?”

This whole journey started when I was introduced to scanning electron microscopy in 2006 during my doctoral studies in materials science and engineering. Yet I believe the seeds of it were sown much earlier, when I grew a fascination of observing insects and the like as a kid. When started looking at even smaller entities using this technology later in life, the lines between animate and inanimate started to blur—and so did that between real and fantastic. Slowly but surely, I started to develop another understanding of the whole process of a microscopy session. During those long hours, even all-nighters in an underground, windowless room, with just me and *the machine*, I could not escape having *adventures*, occasionally swaying away from my main task of obtaining data for constructing knowledge about my field of research. That is when the borders of my *research* became permeable to just *searching* for something, just for the sake of searching and interacting with, without the expectation of obtaining *results*. During that period, being privileged enough to have the opportunity to spend that many hours with a microscope, I might have collected more seemingly random images with no apparent scientific value than those that contributed to my scientific practice at the time, but with a feeling that I was going somewhere in doing so. You might see it on my face, posing with joy in front of said images hung on the wall of my former office. I seem to not be able to escape that sensation even after decades.

Fast forward to 2018, after first living as a scientist followed by a period of “scientific hiatus”, I decided to go back to that “world”, this time through a different door, via my study in the Master of Arts degree program of Art & Science at the University of Applied Arts Vienna. This new door opened to a new perspective for me, and with that I started

a new exploration. The path of this exploration has been directed by the questions: What do the nano-structures tell us when we relate them to our regular scale? To what extent can we have an excursion in the nano-scale similar to a walk in nature? What artistic outcomes does this experience produce? Can the experience itself be the art? How does the observer's or researcher's own identity change during this exploration? How does one *exist* in that environment? Where does the *intimacy* I build with the nano-sized entities take me? What novel bridges are there to be built between the macro-world and the nano-world, helping us making sense of it all, via *turning things inside-out and outside-in*? With this, aside from utilizing my personal passions, I think both the microscope chamber and the nano-scaled world that is inaccessible to the human eye opens up further for non-scientific exploration and art practice; not just as "art and science" but also as "science and art", "art or science", "science or art", "art in science", "science in art", etc.



The author in her former office at Sabancı University, Faculty of Engineering and Natural Sciences, 2006.
(Photo by Ahu Parry)

Frame-Work

Just like the frames we scan to obtain images of samples with a scanning electron microscope, the content of the manuscript is structured in “frames”, to be stacked up to form the final *image*.

Frame 1: Matter Matters

Everything is made of something. Some scientists take onto themselves to study how that happens and what comes next. That field of research is called “materials science and engineering”, examining the inter-relations between the processing, structure, properties, and performance of what anything is made of [1, 2]. Many scholars and experts would agree that materials science is a critical field for the development of both technology and society, in an endless range of activities varying from developing alternative “green” materials for numerous applications to waste management, from enabling production of clean energy sources to making super-fast computation possible through “advanced” materials [2, 3].

It is definitely not only in our time that materials science has had such impact: Certain materials have given their names to the historical eras defined by the “three-age system” in the Western world: stone age, iron age, and bronze age [4–6]. With the “silicon age” and the “nano-age” reflecting on the advancements in semi-conductor technology and others, this trend is clearly still followed [6, 7]. It would not be unreasonable to say that it would continue in the future; not only for the sake of advancing technology but also carrying a “humanistic mission” for the “prosperity of societies in the future” [3].

The *human aspect* of engaging with materials is not only in terms of the large societal goals we are aiming to achieve. In his highly educational yet entertaining book “Stuff Matters: Exploring the Marvelous Materials that Shape Our Man-Made World”, Mark Miodownik lists the main classes of materials not as “ceramics, metals, polymers, and composites” as materials scientists traditionally do [1], but as “indomitable, trusted, fundamental, delicious, marvelous, imaginative, invisible, unbreakable, refined, immortal” [7], paying special attention to how we interact with them as substantial elements of life—it is not for no reason that the word “marvelous” is in the title. We see other manifestations of such emotional connection with matter elsewhere. For

example, when writing about “perspectives on materials research landscape”, John Evans depicts materials to be “wonderful” [8], with the anticipation of the novel developments that the field would bring to our lives, as it has done before. Similarly, in his Introduction to “Fifty Materials that Make the World”, apart from telling us about the history of most used materials from aluminum to diamond, cotton, graphite or wood, Ian Baker puts forward the importance of sharing the “excitement” of materials science [6].

Our interactions with materials is not through a single point of contact. When thinking especially within the greater perspective of reaching “sustainable development goals”, an emerging “materials ecology” is defined, with several streams of material applications and required advancements are seen to be intertwined [9]. With a significant twist, designer Neri Oxman defines the same term in a completely different context: as “developing holistic products, characterized by property gradients and multi-functionality—placing humanity in harmony with nature” [10]. To Oxman, “material ecology explores the idea that artificial matter continuously informs our environment and therefore should be informed by it”, describing the term as “an interdisciplinary research initiative that undertakes design research in the intersection between architecture, engineering, computation, biology and ecology”, where “material is interpreted merely as any physical entity which corresponds and reacts with its environment” [11]. Elsewhere she states that “material is not subordinate but progenitor” [12]: the material with its structure and properties shape our interaction and experience with the object that it is made of. An example of her design aligning with this philosophy could be seen in Fig. 1, whereas extensive demonstrations could be found in the archives of the exhibition with the same name at the Museum of Modern Art [10, 13].

As much as the above examples manifest a sense of *humanity* in our interaction with materials, they all still contain, a prominent, if not dominant, angle of functionality and pragmatism. The continuation of this text will lean towards searching for ways to strip

our view off of that notion, leaving a *direct and emotional bond* between the human and the material. I will explore that path within the *weeds* of the nano-world.



Figure 1. "Imaginary Beings (Doppelgänger)" by Neri Oxman and W. Craig Carter, 2012: A piece in a series that "explores the functions of the human body—skeletal, pulmonary, muscular— offering a conceptual proposition for how natural tissues and biological processes might be developed or replicated digitally in the future." [14].

Frame 2: Worlds within Worlds: Magnitudes, Rooms and Scale-Hopping

In his famous speech “There’s Plenty of Room at the Bottom” in 1959, physicist Richard Feynman manifested his vision for what we today call “nanotechnology” [15]. Through various thought experiments, he pointed out to the endless possibilities that would open up by accessing the crystallographic, atomic and subatomic scales (as depicted in Fig. 2 and 3). That access would be (and since then, has been) possible via advances in microscopy and other devices, allowing us manipulate matter on an atomic scale [16–18]: With today’s electron microscopes (EM) we can reach magnifications up to 10 million, enabling atomic resolution, thus opening the *inner space* for us to see and interact with [17–21].

By “plenty of room”, Feynman meant the vast space between electrons and nuclei of an atom as well that between atoms of a material themselves. It would be fair to add to that the technological potential accessing that scale carries (as in “room for improvement”). That is all, without a doubt, scientifically and technologically valid (as being continuously demonstrated in the world we currently live in); but what does it all mean elsewhere—say, for *the artist*?

Display of scientific imagery has been popular for quite some time now [22]. About two centuries ago, people were gathering in the English Opera House for the *spectacle* of Adam Walker's “Eidouranion: a vast astronomical machine that provided views of celestial phenomena, scaled to London’s largest theatres” (Fig. 4) [23–25]. Arguably not to that extent yet still for the view of the public, there has sure been *artistic* approaches to the nano-world in the last decades, mainly through *beauty competitions* [26–28]. I have by no means any stance against these events, having participated in some myself. However, the current project aims to go beyond both “science visualization” as a tool and pure aesthetic aspects as criteria. I instead pose questions such as “How do we *exist*

in that room? How does our understanding [29] and *canvas* expand by observing a whole other world? Where does this all sit in the “battle between what we see and what we know” [30–32], or better yet, what we “feel”?”

Here might be a good place to point out to the fact that the nano- or sub-nano (or simply, *atomic*) scales are not the only worlds we are *alien* to. In fact, when speaking of “alien”, we most often refer to outer space; in other terms, the *galactic scale*. Literature is no stranger to humans *scale-hopping* as such: Alice [33–35] and the Little Prince [36] do a very good job at that, undoubtably *building empathy with the other worlds* along the way. On a more technical note, an early example of a *continuum* between the smallest and the largest scales could be found in the film “Powers of Ten” by the designer couple, the Eameses [37]. Thinking of such a continuum is not the only way for us to connect to those worlds, though. Our connection to the outer space is readily hidden inside our very inner space: the atoms that we are made of. As Carl Sagan has famously said, “we are made of star stuff” [38, 39]—all the elements that make up everything that we know of (see Fig. 5 [40]), including ourselves, have originated inside the nuclei of distant stars and reached us via those stars’ spectacular last chapter of their evolution. These elements could all be traced back to their specific event of origin, thanks to astrophysics and spectroscopy (Fig. 6) [41]. We further use that atomic knowledge as a tool for our hypothetical communication with the aliens: the messages of the Pioneer 10 [42] and Voyager 1 and 2 spacecrafts [43] all carry a depiction of the hydrogen atom’s “hyperfine transition” (Fig. 7). Using that diagram as such a tool has been decided on based on the fact that hydrogen is by far the most abundant (~ 74 % by mass) element in the universe [44, 45], and the hope that “aliens” know that as well.

Let’s come back from distant stars to our own land for now. Two main fields have expanded through bringing the building blocks of nature into our sight: architecture and materials science. The former builds macro-structures inspired by nature (Fig. 8) [46–52], and the latter does the same in nano-scale, reproducing physical functionalities through structural modification (Fig. 9) [53–59]. Such attempts of “bio-mimicking”

could be taken as examples of *bringing inside-out*, where there is still a lot to explore [60, 61].

Despite all its societal benefits, nanotechnology is not immune to negative impact, ethical problems, environmental risks and related criticism, as extensively studied in the field of “science and technology studies”. Some scholars even go as far as saying “Nanotechnology raises problems for democracy, as much as it makes it necessary to consider democracy itself as a problem” [62, 63], while others focus more on environmental, public health issues and societal perception of nanotechnology at large [64, 65].

Yet I wonder: What if we free ourselves from functionalities, practicalities, technological benefits, environmental risks or societal concerns while interacting with the nano-world? What would we be left with then? Borrowing the concept from Barbara Imhof: What new meaning would be revealed through an artistic study on forms in inter-dimensions that “transgresses our understanding of reality and the way we perceive space [66]”?

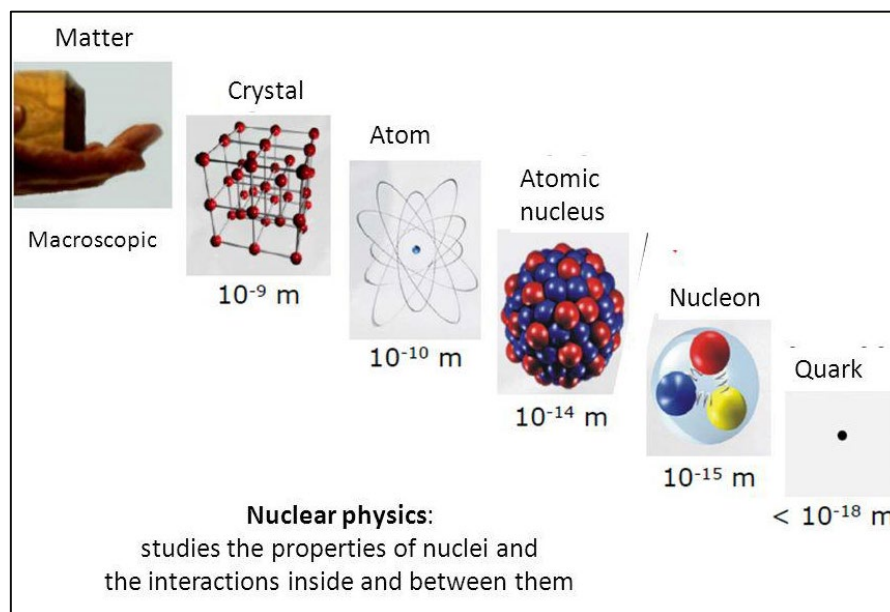


Figure 2. Scales of objects and matter (© Magdalena Kowalska / CERN / ISOLDE Team (adapted from [67])).

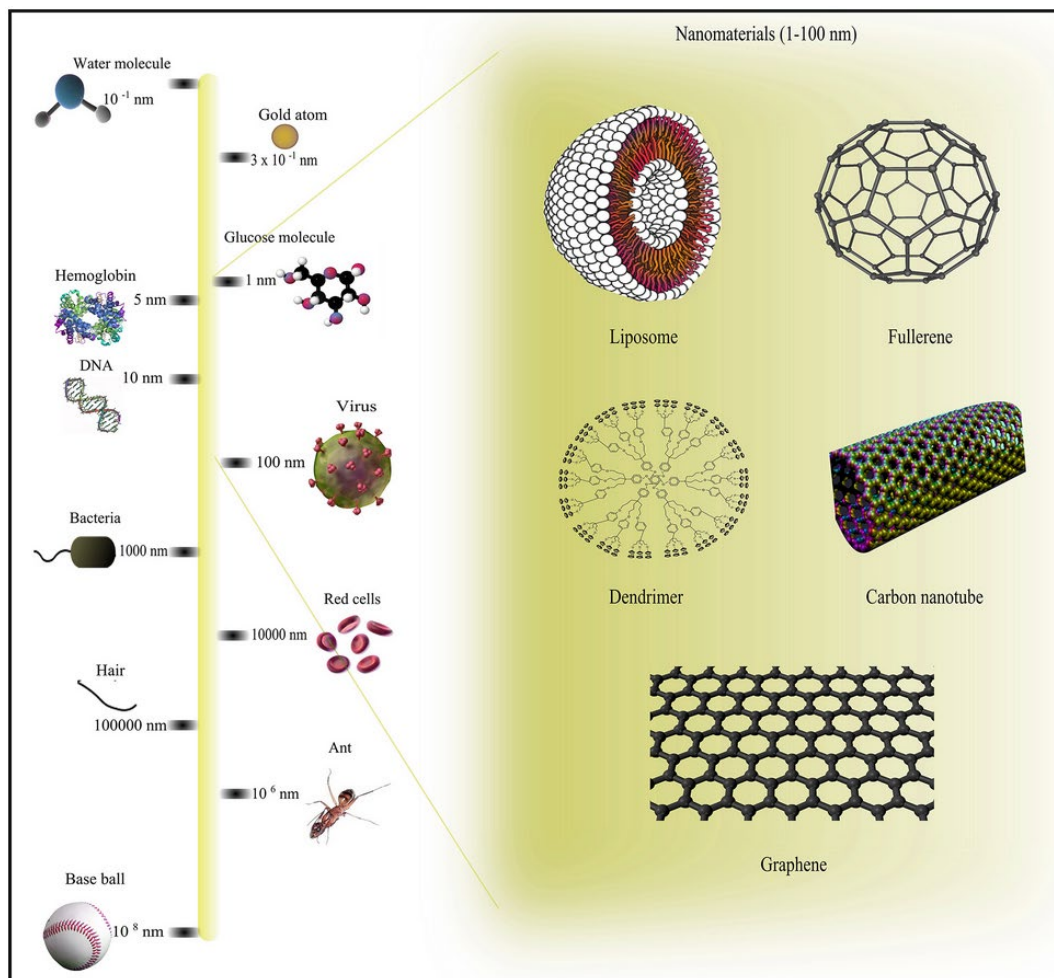
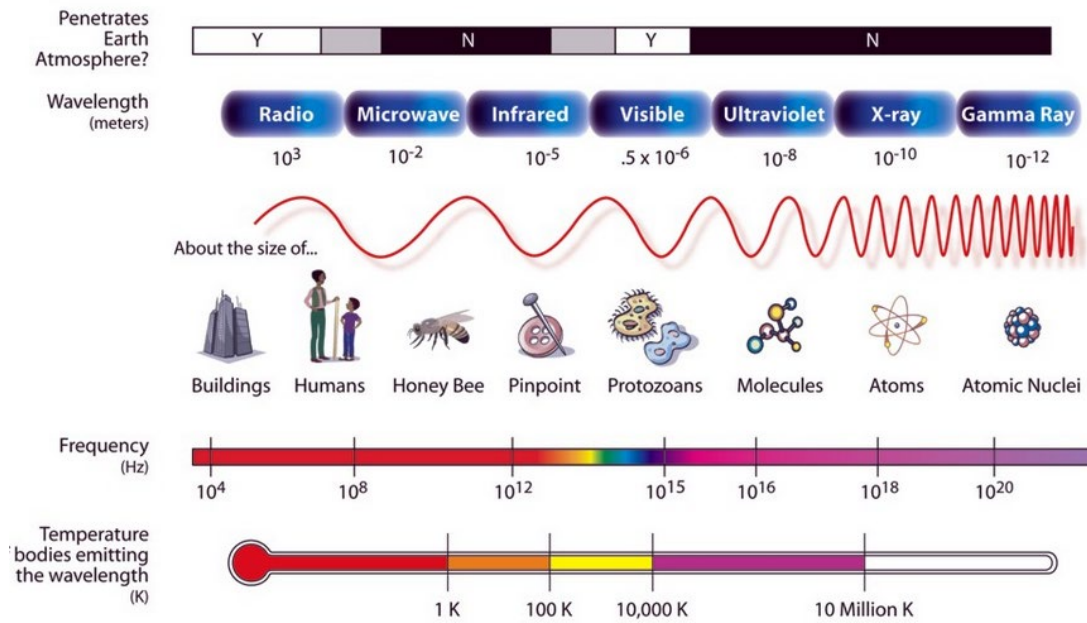


Figure 3. Top: The electromagnetic spectrum [68]. Bottom: Size of various nano-objects and materials within a wider scale [46].

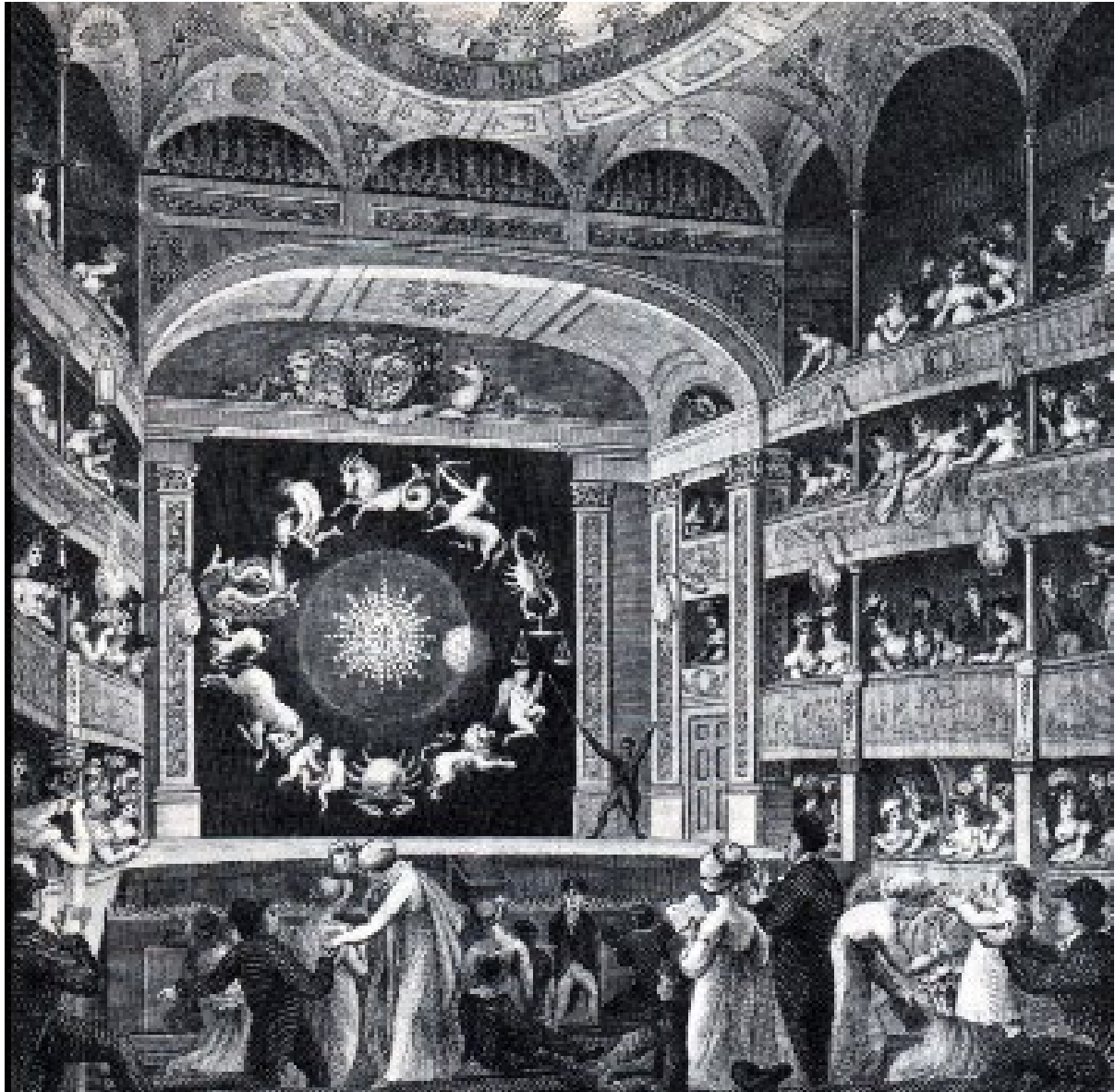


Figure 4. Adam Walker's Eidouranian exhibited at the English Opera House, 1817 (original publication unknown) [23].

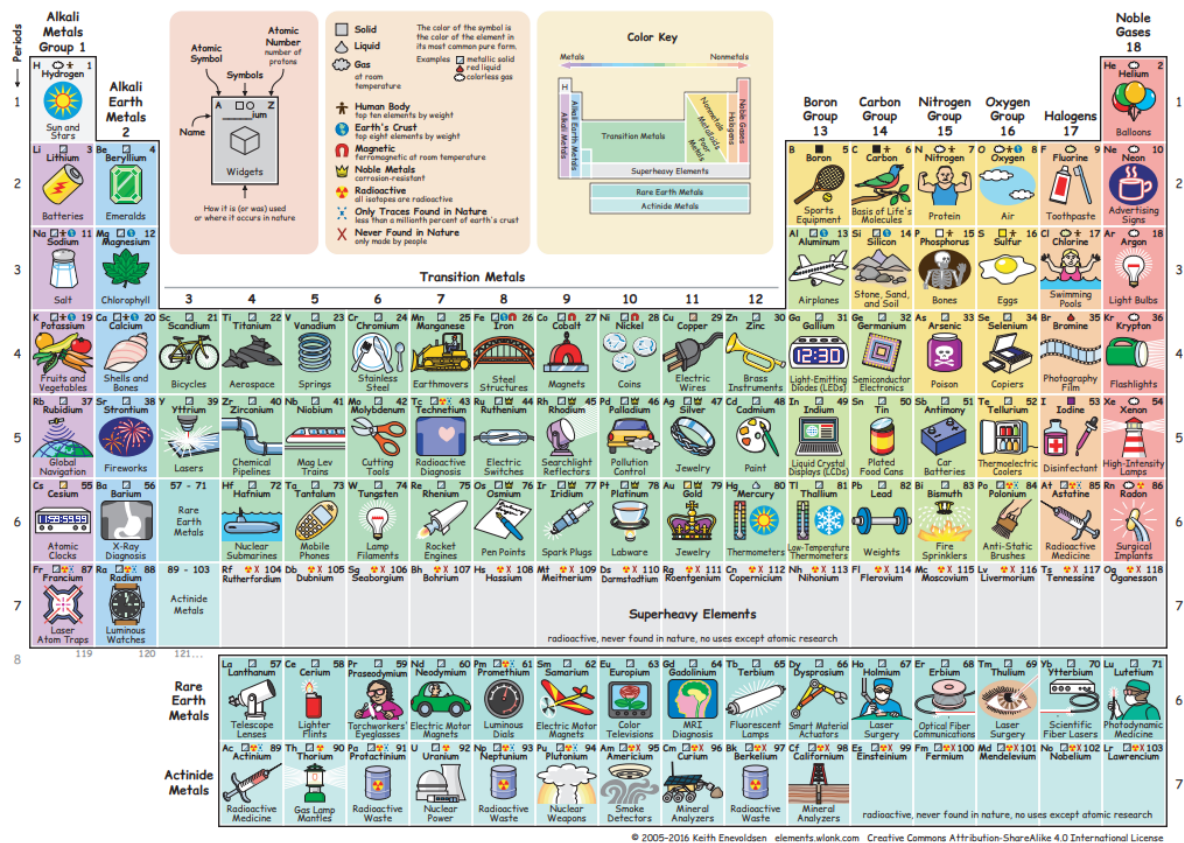


Figure 5. "The Periodic Table of Elements, in Pictures" [40].

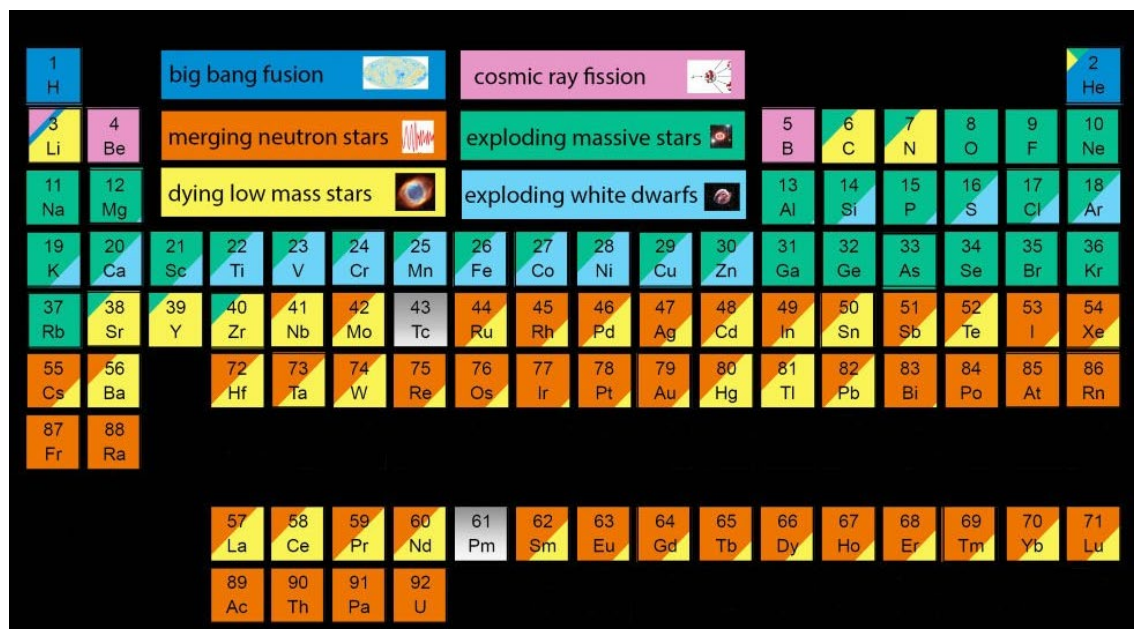


Figure 6. "The Origin of the Solar System Elements" (by Jennifer A. Johnson) [41].

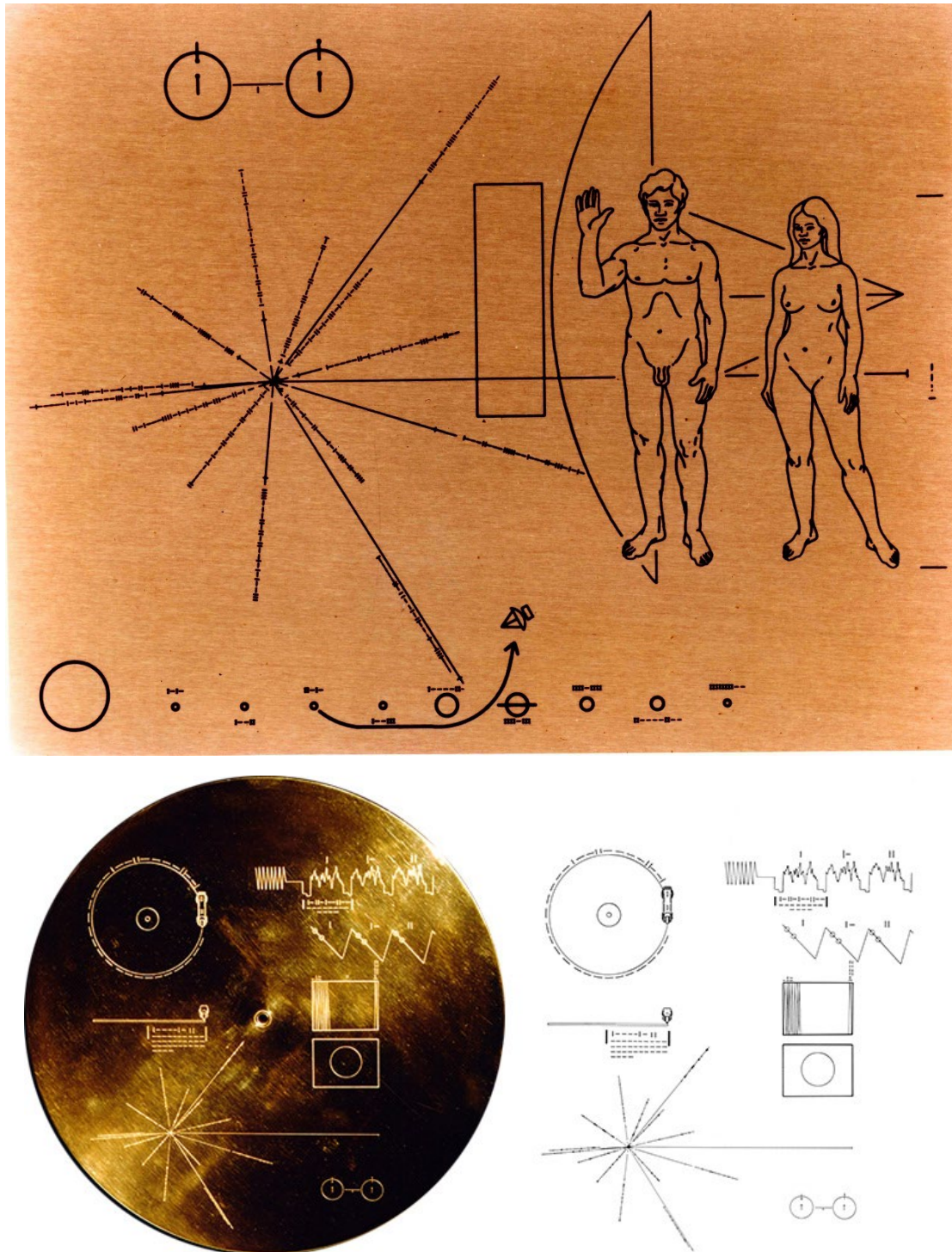


Figure 7. Some visual messages we have sent out to deep space, in hopes of “saying hello” to aliens [39]. Top: the Pioneer plaques (Credit: NASA Ames [42]), bottom: The cover of “the Golden Record” carried by the Voyager spacecrafts (Credit: NASA/JPL [43]). On the top-left of the Pioneer’s plaque and on the bottom-right of that of Voyagers is the depiction of the hydrogen atom in its two lowest states: two circles with a connecting line and the digit 1 to indicate the time interval associated with the transition from one state to the other. It is to be used as the fundamental time scale in deciphering and decoding the rest of the messages on the plaques and the record.

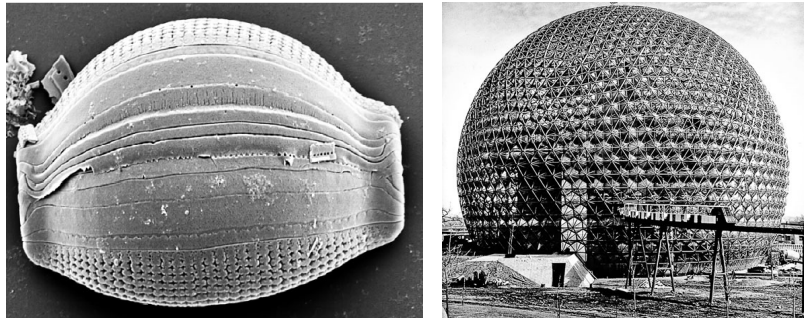


Figure 8. Left: a diatom shell. Right: the Montreal Biosphere designed by Buckminster Fuller, 1967 (adapted from [48]).

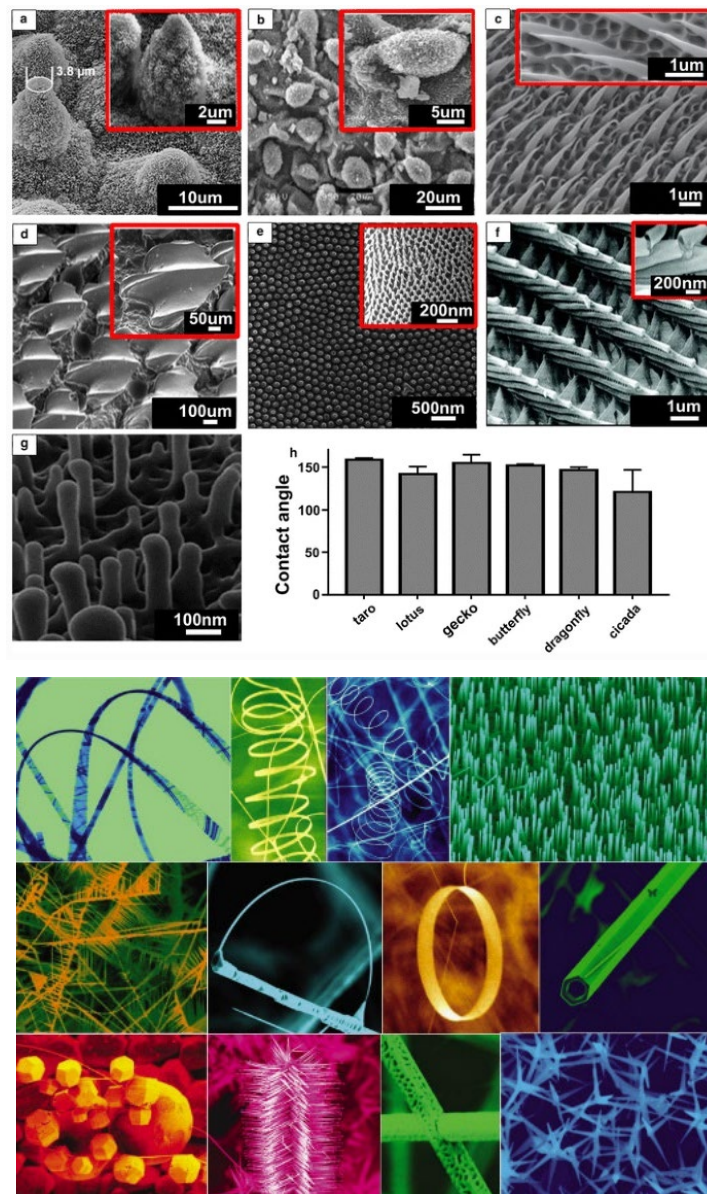


Figure 9. Left: Various plant and animal organs under an electron microscope [55]. Right: Nanostructures of zinc oxide [69].

Frame 3: In Love with the Machine

The four inter-connected pillars of materials science (processing, structure, properties and performance) have “materials characterization” at the center [1]. Three cornerstone classes of materials characterization techniques could be stated as microscopy, spectroscopy and crystallography [70–72]. Among those, electron-microscopy to study morphology [20, 21] and x-ray diffraction to study the crystal structure [73] hold special places in my heart, stemming from my own scientific practice.

In “Laboratory Life: The Construction of Scientific Facts”, Latour and Woolgar lay out an extensive anthropological study and critique of scientific practices, partially involving the role of scientific instruments [74]. When writing about a nuclear magnetic resonance (NMR) spectrometer, for instance, they state: “The spectrum produced by a nuclear magnetic resonance (NMR) spectrometer would not exist but for the spectrometer. It is not simply that phenomena depend on certain material instrumentation; rather, the phenomena are thoroughly constituted by the material setting of the laboratory”, calling the outcome to be *artificial reality* rather than an *objective entity*. Further, when criticizing the importance a group of scientists gave to the use of a mass spectrometer in a certain study, they claim “The mass spectrometer is the reified part of a whole field of physics; it is an actual piece of furniture which incorporates the majority of an earlier body of scientific activity. The cost of disputing the generated results of this inscription device has been enormous.” The crucial role of these type of instruments in constituting scientific information and the subsequent critique coming from the field of philosophy and sociology could in fact continue for ages to come. What I would rather like to focus on here instead is how scientific instruments become integral parts of *a scientist* (as opposed to the larger practice of producing information), as if *extensions*, not unlike how smart devices have fast become extensions of an average person’s body. I would argue that, not unlike that with another *being*, the long and tedious hours a scientist spends with a device creates a special type

of bond between the two. Personal experience confirms that we start projecting our *humanity* onto them, as this bond develops. The devices we use, in time become *characters* in our life, rather than mere *tools*.

This type of interaction starts with the importance we give to having one of those devices in our laboratory. In “The Matter Factory – A History of the Chemistry Laboratory”, Peter J. T. Morris says “The history of chemistry has to be more than just the history of chemical theories; it has to include the history of chemical practice and chemical culture” [75]. Certainly, this practice has scientific instruments as prominent actors. In his book, Morris depicts the image in Fig. 10 to be “not untypical of a works of a laboratory at the lower end of the scale in the 1930s”. He goes on to say “The poverty of the laboratory (is) revealed by the torn lab coats worn by the chemists (...) However, note in the midst of this scientific poverty the presence of a large microscope, which is ostentatiously placed here for the benefit of the photographer – not least because it could not have been used in that position for lack of light.” Ostentatious or not, there is no argument about the major role of a microscope in a chemistry, physics, or materials science laboratory, showing us things we would otherwise not be able to see even under the best light.

We have definitely come a long way since the 1930s in terms of or “seeing” capabilities. 1930s incidentally also mark the start of the development of electron microscopes, where an intense and confined electron beam takes over the job of light, taking us over the limit of our human eye’s resolving power (0.1–0.2 mm) and that of the best “visible light” (or “optical”; see Fig. 3 for the visible portion of the electro-magnetic spectrum) microscopes (2000 Angstroms = 0,0002 mm) [76, 77]. Fig. 11 shows us what a typical (scanning) electron microscope looks like, where Fig. 12 depicts the elements for and the process of image formation: with the electron beam instead of visible light, magnetic lenses instead of optical lenses for confinement and (de)magnification, an electron detector instead of our eyes, and a screen coupled with an electronic interface to turn the detected signals into images that we can “observe”. As such, we cannot

actually “see” with electrons, but we do use them as tools to obtain images that we could. To me, this is where *the magic* begins.

But let’s talk about another visual tool for a moment. Although not the “inventor” of the microscope, Galileo is considered to be one of the first users of it [76]. Still, it would be fair to say that the “occhiolino” that he derived from his telescopes was an important milestone for microscope technology (Fig. 13, [78]). I see this bond between a telescope and a microscope as another agent simultaneously connecting us to “the very small” to the “very far”. Although, Galileo’s telescope carries yet another function for this current work: In “Becoming-media: Galileo’s Telescope”, Joseph Vogl says: “Above all, the history and theory of media must address the singular scenes or situations where media (more strictly: the functions and functioning of media) come into existence in a coming together of heterogeneous elements—apparatuses, codes, symbolic systems, forms of knowledge, specific practices, and aesthetic experiences. The following analysis examines a prominent and exemplary case. In 1610 Galileo Galilei, in *Sidereus nuncius* (News from the Stars), speaks of incredible messages transmitted from the stars to the telescope, from telescope to eye, eye to hand, and then, in black and white, to paper, book, and reader. But this event contains more than just a demonstration of Copernicanism, more than the arrival of a new cosmology, more than the birth of a startling new view of the heavens scribbled down in just a few nights. In addition, this event marks a change in how the meaning of seeing and visibility is determined, as well as the meaning of the relationship between the eye, the gaze, and the viewed object. Furthermore, this event also involves a technological transformation— in Galileo’s hands and before his eyes, the telescope fundamentally changes its nature from the simple device supposedly brought to Italy by Dutch lens grinders, displayed at fairgrounds, and eventually plagiarized by Galileo. The device now gives data of a unique kind: having been an instrument, it becomes a medium. How can we describe these historical steps, this transformation, as the telescope’s “becoming-media”?” [79]. In light of this analysis, I add to my previous view: having started as a *tool*, now the microscope becomes a *medium* in addition to being a *character*. This goes in line with

my question previously posed in Frame 2: “How do we *exist* in that room?” I would now extend the spectrum of that room to include not only the atomic space but also the chamber of an electron microscope (Fig. 14).

All of these bring me back to the underlying motivation of this project: paying homage to and showing my love for this device that opened up wondrous worlds to me. I have previously produced and exhibited an art work with the same motivation, probably not so surprisingly titled “In Awe of the Portal” (Fig. 15). While showcasing *accidental and unworthy* electron micro-graphs of *failed* samples that would be excluded from a collection of those that would go into a scientific publication about the work in relation to them, the textual part of the artwork contained the words “*beam, inadvertent, treasure, priceless, broken, gasp, dive, detached, mesmerizing, serendipity, invaluable, imperfect, wonder*”, reflecting my emotional connection with my practice and the microscope. I believe those feelings or the anticipation of what is to come could be read on my face in Fig. 16, the one on the left being taken at the start of a microscopy session which was the first in several years. Luckily, more often than not, you could find colleagues with whom you could talk to about your feelings for the microscope rather than only scientific findings (Fig. 17). As a more physical demonstration, I would say that I feel a similar sense of gratitude while hugging a microscope (which was possible due to the instrument being *injured* and thus not in use at the time) as to while hugging a tree: *a mixture of being grounded and being swept off my feet*, and ultimate gratitude (Fig. 18). That is why I would agree with the following statement by the open education resource “The Virtual Microscope (VM) for Earth Sciences” and adapt it to an electron microscope: “*Tragically, very few people own a (polarizing) microscope*” [80].



Figure 10. An image that is “not untypical of a works of a laboratory at the lower end of the scale in the 1930s”. Credit: Daily Herald Archive, National Media Museum, Science & Society Picture Library (adapted from [75]).



Figure 11. A field-emission scanning electron microscope (FE-SEM) from Zeiss [81].

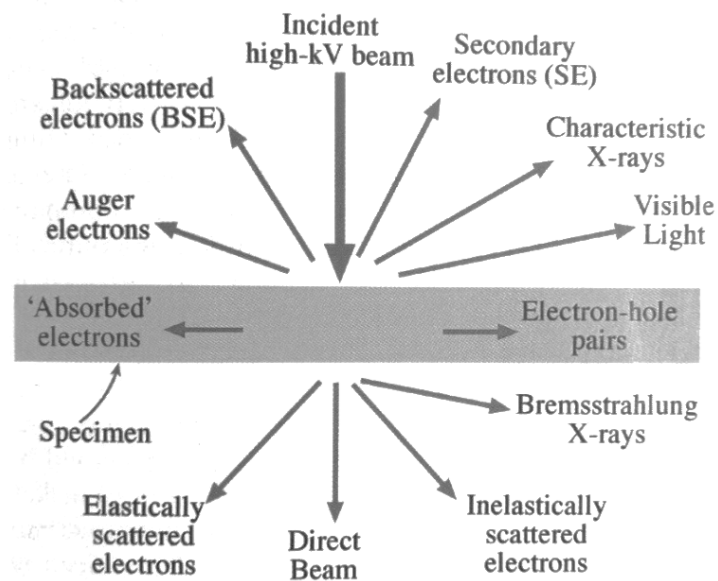
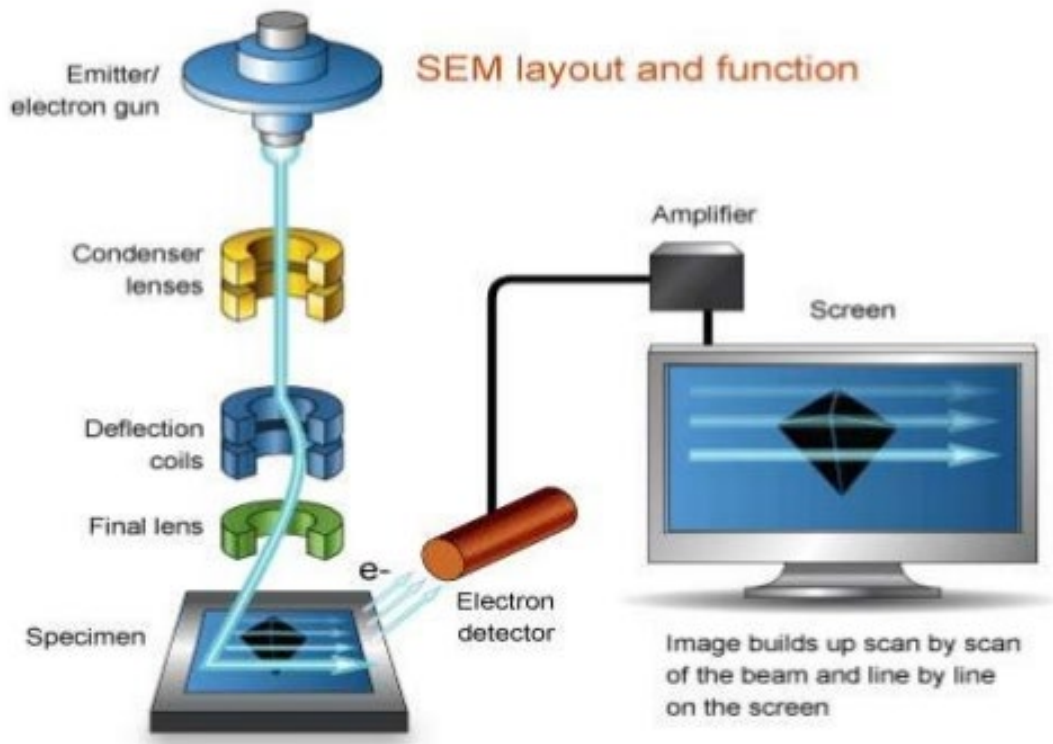


Figure 12. Top: Inner components of a typical electron microscope, from the electron source to image formation (adapted from [82]). Bottom: Interaction of electrons with matter. The thick arrow directed downwards represents the electron beam hitting the material specimen depicted with the rectangle. All the other arrows pointing towards various directions represent the outcomes of this interaction. “secondary electrons (SE) and “back-scattered electrons” (BSE) are mostly used for image formation, where most of the others provide supplementary chemical information (adapted from [77]).



Figure 13. The “occhiolino”, designed first by Galileo Galilei (1624). The one on the image is believed to be of Giuseppe Campani. Credit: the Museo Galileo [83]. Adapted from [78].



Figure 14. The sample chamber of a scanning electron microscope with the front door that holds the sample mount open. On the chamber top, the electron gun mechanism could be seen. (Taken at the electron microscopy lab of the Institute of Conservation, University of Applied Arts Vienna, April 2022.)

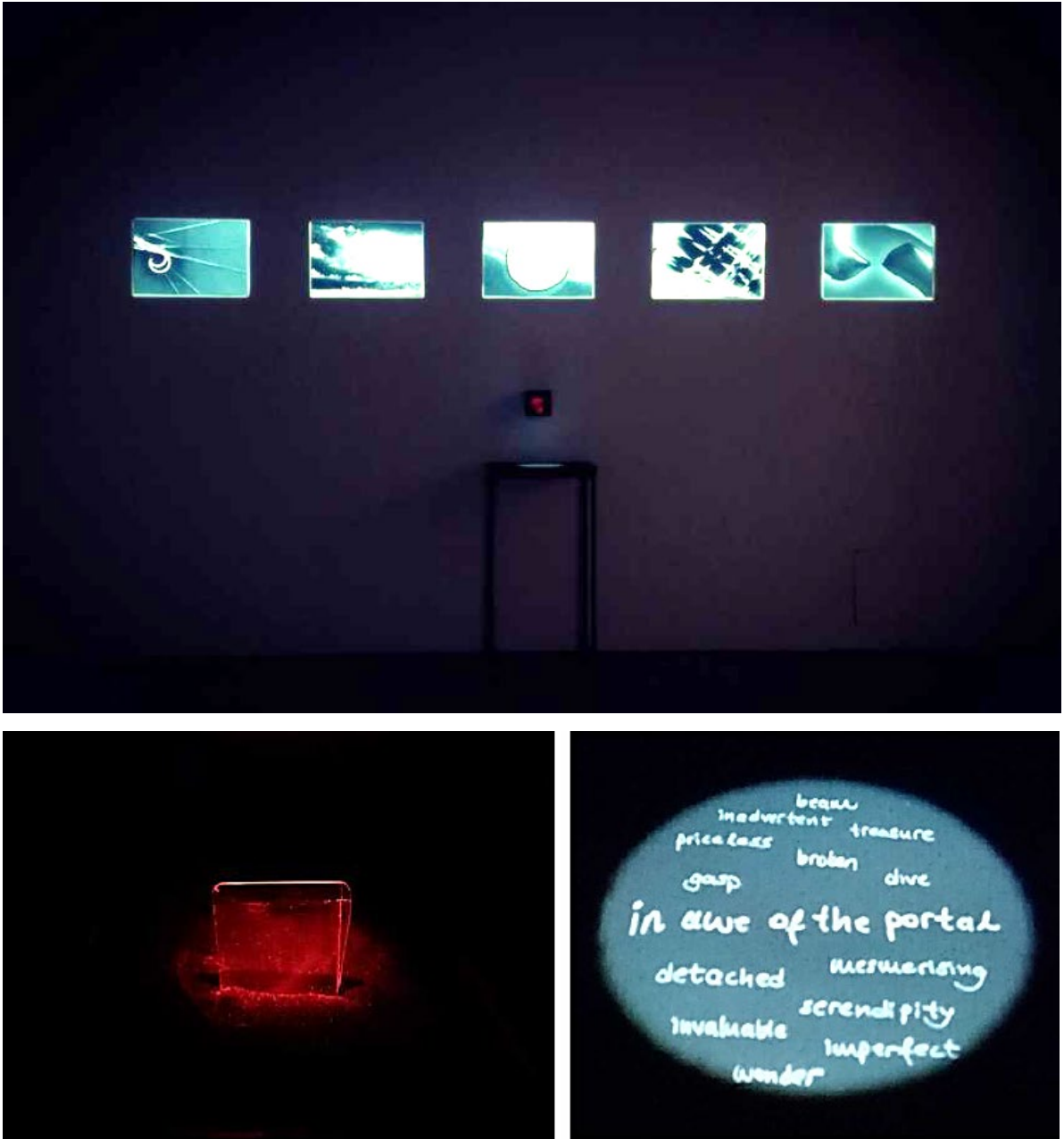


Figure 15. "In Awe of the Portal", İstem Özen, 2019, as in the exhibition "Data Loam: Sometimes Hard, usually Soft." [84–86].



Figure 16. The author working with microscopes at different times. Left: Scanning Electron Microscope; Right: Optical Microscope in a “clean room”.



Figure 17. Two scientists, or rather, people, discussing the possible fate of an *injured* electron microscope, sharing the love and compassion they have for the instrument. (Dr. Özen in conversation with Prof. Johannes Weber, taken at the Institute of Conservation, University of Applied Arts Vienna, April 2022.)



Figure 18. Hugging a microscope (2022) with the same gratitude when hugging a tree (2013). (Photo on the right by Johannes Weber.)

Frame 4: Now You See, Now You Don't: Sense It All / Know It All

As much as Feyerabend was not pleased with and famously argued against in “Against Method” [87], “the scientific method” is our current and widely accepted tool for constructing knowledge in science practice. It follows a cycle of observation, hypothesis formation, experimentation, analysis and drawing conclusions, only to continue with a new cycle with posing new questions derived from the outcomes of the previous one. It is framed by, among others, “scientific realism; aiming the truth, sometimes getting close to it” [88].

As put in a review of Daston and Lunbeck’s “Histories of Scientific Observation” [89]: “Observation is the most pervasive and fundamental practice of all the modern sciences, both natural and human. Its instruments include not only the naked senses but also tools such as the telescope and microscope, the questionnaire, the photographic plate, the notebook, the glassed-in beehive, and myriad other ingenious inventions designed to make the invisible visible, the evanescent permanent, the abstract concrete. Yet observation has almost never been considered as an object of historical inquiry in itself” [90]. Observation is for sure fundamental but is not the only one—Priyamvada Natarajan summarizes, in review of the same work, the path towards *experimentation* rising up in hierarchy against *observation*: “Daston and Lunbeck argue that observation and experiment started to emerge as coupled forms for organizing scientific experience in the sixteenth and seventeenth centuries. Prior to this, they were seen as distinct activities. Then later, in the eighteenth and nineteenth centuries, they were seen as working together with concrete roles; observations were conceived of as permitting discovery, while experiments tested and provided proof. However, starting in the 1820s there was yet another shift in perception, and experiment was considered the active form of enquiry, while observation was relegated to passive collection of data. The associated prestige of these two activities also was redefined—experiment was seen as the more creative and original endeavor, while observations began to be

seen as merely the recording of data that required no expertise and could be accomplished by untrained assistants” [91].

As observation is one of the first steps of this method, it would be inevitable to think of its relation in forming out *opinions* or *information*. Then comes the question: “are we objective in interpreting what we see?”. In “Ways of Seeing”, John Berger says “Seeing comes before words. The child looks and recognizes before it can speak. But there is also another sense in which seeing comes before words. It is seeing which establishes our place in the surrounding world; we explain that world with words, but words can never undo the fact that we are surrounded by it. The relation between what we see and what we know is never settled” and adds “The way we see things is affected by what we know or what we believe” [30, 31]. While Berger says these mostly in the context of fine arts and popular culture, I cannot help but think if the same notion of “never settling” is true for science as well. Or better yet, could we think of scientific images the same way we think of works of fine arts or popular culture?

Here, Peter Galison and Caroline A. Jones come to the rescue, discussing the relation between scientific imaging and artistic work in “Picturing Science, producing Art” [92]: “Here, we take aim at a specific epistemological question: What do we know when we see? The more “wondrous” the image, the more loaded the question becomes. While their objects ranged from rocks to saints and from bees to peasants, the artists and natural philosophers of the early modern period linked seeing to knowing in revealing ways. The wonders examined here presuppose (and enforce) specific worldviews—located in particular knowledges of the thing seen”. They further mention Joseph Koerner to claim *imagery* not only being *a maker of knowledge* but also *a manifestation of a worldview*. In a review of Galison and Jones’ above work, specifically about the article in the quote, Jonathan Gilmore says “Peter Galison’s “Judgment Against Objectivity” offers an ambitious historicization of the relation between scientific objectivity and the techniques of representation, specifically in the representation of astronomical atlases. While too many contemporary histories and sociologies of science

are content with the bare assertion that the concept of scientific objectivity has changed over time, Galison provides a specific demonstration of how such a change is embedded in the material, technical, and practical changes in scientific pictorial representations. These changes bring with them a change in the identity of what would constitute an “objective” creator or recorder of the image. So as the place of the ideal recorder is occupied, successively, by the genius, the manufacturer, and the trained expert, the objective picture is reconceived, successively, as a quasi-metaphysical image, a mechanical image, and an image that requires judgment for its data to be discerned” [93]. One criticism Gilmore brings is: “There is, further, an unexplored explanatory assumption in many of these essays that changes in scientific representation can be identified as changes in the concept of representation per se and, a fortiori, representation in the visual arts. No doubt it is sometimes precisely in appeal to the well-articulated protocols of scientific practice that insight can be gleaned into how the culture as whole, and thus artists and their audiences, conceived of the nature of pictorial representation. But this is assumed too uncritically in many of these essays and in cultural studies as a whole, a field in which this volume finds a natural place. Is there no sense in which artistic practice might depart from, be immune to, or contradict the notions of representation inherent in contemporary sciences? (...) It is precisely through treating art and science as notions circumscribing different domains, that the interference and interdependence between one and the other can be comprehended” [93]. In another review of the same work by James Elkins, we read “First, it is possible to use non-art images and ideas to explain fine art. In following that agenda—the most common in art history—one adduces images from science, popularized science, or technology to explain painters' practices” [94]. Elkins continues by saying that this view “risks devaluing non-art images to the role of explanatory footnotes. Science and technology fade into a kind of uniform backdrop for the artists' explorations of surrealism, aesthetics, gender, eroticism, and identity. Second, tables can be turned so that art, or visual culture more generally, can be used to explain images in contemporaneous science or technology.” Elkins lays out further arguments

on history of visibility as: "Images from science and art can work in tandem to explain more general cultural phenomena. (...) Histories of visibility can only become richer by joining forces with actual, ongoing scientific research and with histories written by scholars who prefer to keep technology at arm's length. Fourth, it is possible to try mixing disciplinary approaches, to use art-historical criteria to interpret scientific images, and vice versa. (...) A final possibility, logically speaking, is to stop using the distinction between art and non-art images. Recently it has become possible to imagine a very general "History of Images," sliding back and forth, apparently at random, between "important" fine art and "ancillary" technological and scientific images. (...) Such a "History of Images" wouldn't claim that the art/non-art distinction can simply be dismissed—it is inescapable in Western culture—but it would allow itself different agendas at different moments, moving without friction between images normally sequestered in different interpretive regimes".

On another note, in "The Technical Image: A History of Styles in Scientific Imagery", Bredekamp says: "The project set out from the research hypothesis that the forms of imagery are of no less import than the content and objects they show. Images in natural sciences are a good example: they do not passively render the findings they serve to represent; they generate and inform them with the distinctive qualities of their own sphere. The transformation of observations, findings, and insights into images partakes actively in the constitution of knowledge. With this active capacity, the production and employment of imagery represent a cultural technique of the first rank" [22]. It might be useful here to mention that Bredekamp defines these images as follows: "Our objects of study are "technical images" in the sense that they are not artistic, instead primarily originating in the fields of science, technology, and medicine; they are predominantly instrument-based or the results of imaging procedures".

Finally, quoting Karen Barad: "Mattering is simultaneously a matter of substance and significance, most evidently perhaps when it is the nature of matter that is in question, when the smallest parts of matter are found to be capable of exploding deeply

entrenched ideas and large cities. Perhaps this is why contemporary physics makes the inescapable entanglement of matters of being, knowing, and doing, of ontology, epistemology, and ethics, of fact and value, so tangible, so poignant” [95].

In light of the above and inspired by my own scientific practice, I would say the following:

First telescopes brought the very far to near us, then visible-light microscopes brought the very small to our sight, all thanks to our knowledge on *magnification*. Yet, these have not been the only tools for us in *making the invisible visible*. The end of the 19th century gave us x-ray imaging, for the first time allowing us to *look inside* without having to have ourselves cut open (Fig. 19). Their scientific and technological impact aside, I often think of the psychological impact such advances that we now take for granted made on people at the time. Moreover, I think of what thoughts they have invoked in relation to life and *being*. Could we use these tools to *make the permanent evanescent*, or *the concrete abstract*, instead of vice versa? Does the image given to us have to be “wonderous” to invoke important questions? Isn’t being able to obtain that image wonderous on its own? Or, the fact that I see completely different images just by using different detectors (Fig. 20)? Yes, this technology allows us to figure out so much about materials; but can we really say that the *sample* is completely idle here? Am I not having a conversation with it while observing it? Are the atoms *happy to be figured out*? Or, as unpleasant to think as it is: am I *invading the privacy* of an entity here? Is my sample welcoming me or would it rather be left alone?

When I am sitting by an electron microscope, how does what I see contribute to or change my world view? What do I learn from it, apart from, say, how certain atoms move amongst others in certain ways? Do I take any *life lessons* out the process? In that, could I act as “a subjective creator and recorder of the image” instead of an objective one who is after scientific knowledge? Could I use this tool designed to seek ultimate *reality* to pose *fantastical* questions? How do I make sense of the world through it, next to making sense of the inner workings of my object? And what

alternative senses are created in this *room* where there is no real touching or seeing in the way we know them, and certainly no hearing, tasting or smelling? How would someone be inspired by the *delicate* movement of a very short (225 μm) and thin (5–7 μm ; about 10–14 times thinner than average hair) crystal rod pushing a ball of gold (Fig. 21) [96]? What changes in a person, being able to make that happen merely by shining light or electrons on it? What does one know after that happens, apart from the physical phenomena behind the process and the properties of the materials or samples involved? Apart from “the production and employment of imagery representing a cultural technique of the first rank”, what areas of culture does the practice of obtaining and observing these images contribute to? What do the *branches of a serendipitous tree swaying in the electron wind* tell me (Fig.22, left, and Fig. 31, bottom)? Who can say that the *choreography of the microscope* itself in providing that is not worth an audience?

Could we flip some previous questions posed by scholars as quoted in this Frame on their heads and ask: Is there no sense in which scientific practice might approach, be infused by, or align with the notions of representation inherent in contemporary art? Is it possible to use scientific images to explain human nature? What is a “scientific image” anyway? I do not think it is fair to say that an image is “scientific” just because it is obtained via tools that are commonly used in scientific practice. Without the scientific method surrounding it aiming to reach a sound statement, it would be just an “image” like any other one, independent of what tool it is obtained with, be it a nature scenery on Earth or that on Mars, even when taken by the most technologically ambitious equipment (Fig. 22). After all, you could practice science with just your very own eyes. Furthermore: who is to say that *artistic images* would not be a product of scientific equipment, *just as they are*? Especially in the era art of trans-, trans-media and digital arts? Or does the transiency both in art and in science, *i.e.* something only imaginable in the past becoming achievable today, make the image not artistic anymore?

In “Scientist as Rebel, Freeman Dyson argues “Science in its everyday practice is much closer to art than to philosophy. When I look at Godel's proof of his undecidability theorem, I do not see a philosophical argument. The proof is a soaring piece of architecture, as unique and as lovely as Chartres cathedral” [97, 98]. Is the scientist then turning into an artist here—producing the work *while looking, seeing, knowing, feeling, connecting, relating, understanding*, and thus ultimately *being there* in what she is looking at, even *becoming* one with it?

There are endless contemporary discussions about the relation between science and art, which I do not intend to expand on here. From Leonardo da Vinci through Sonia Sheridan (*e.g.*, Artist in the Science Lab [99]) to our contemporaries, we see many different ways of how this relation manifests from an artist's point of view. Numerous such works also use the tool of *making the invisible visible*; *e.g.*, Victoria Vesna by bringing the deep sea life to our sight (Fig. 23), while Wendelin Pressl by creating an illusion of observing distant planets while actually looking at an object a mere meter away, through an equipment of his own making (Fig. 24); to name just a couple.

Ultimately: Could *being an artist in the lab* answer to the above questions? Why so, then? Could one not *just be*?



Figure 19. X-ray image by Wilhelm Conrad Röntgen of his wife Bertha, taken in 1895 at the Physics Institute in Würzburg. © Archive of the German Roentgen Museum, Remscheid-Lennep. [100].

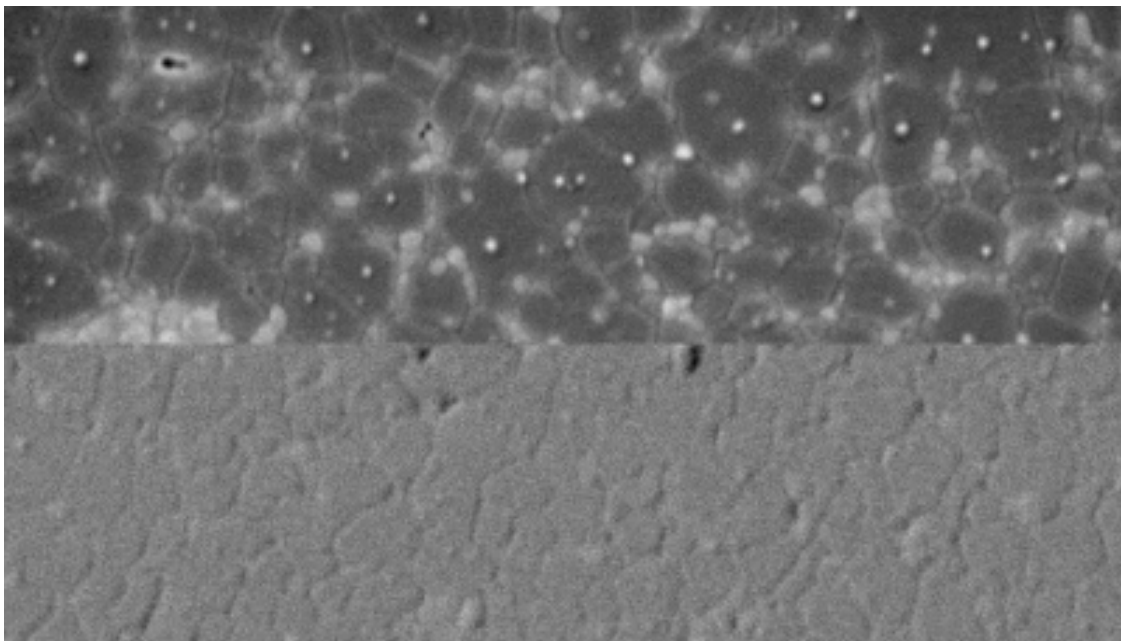


Figure 20. Zr-doped Al. Top: backscattered electron analysis to determine chemical composition. Bottom: secondary electron analysis to study topography (by Twisp, public domain).

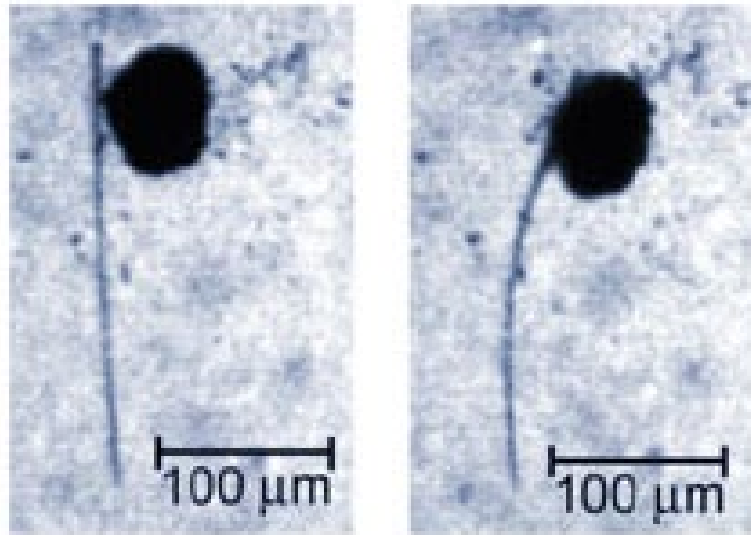


Figure 21. A thin whisker of a rod-like crystal bends when exposed to ultraviolet light, pushing a gold micro-particle that is 90 times heavier. [96]



Figure 22. Three images with their respective makers. Left: A zinc oxide nano-tree under a scanning electron microscope (credit: İstem Özen). Middle: A green yard, photographed by a smart-phone camera (credit: İstem Özen). Right: A photograph of a Martian landscape taken by the Curiosity rover (credit: NASA/JPL).



Figure 23. Noise Aquarium, Victoria Vesna [101].



Figure 24. Apparatus to observe the surface of the moon, Wendelin Pressl [102, 103].

Frame 5: Shedding It All Off: the Scientist as Alice, Science as Experience, Experience as Art

The previous frame ended with pointing out to possible shifts in the identity of a scientist as she sits in front of a microscope. At this point it might be useful to go through some remarks about a scientist's identity in literature. In "Laboratory Life", as reviewed by Shapin, Latour argues: "Scientific laboratories and the devices they contain exist to produce "inscriptions". Sometimes the laboratory's inhabitants say that certain inscriptions and literary productions pertain to specific bits of natural "reality". (...) The purpose of all their various and expensive inscription devices seems to be the production of what they call "facts"" [104]. This, in a way, implies that there is nothing else a scientist could be after, or *interact with* while working in a laboratory, other than anything that leads to the direct construction of scientific knowledge. In "Physics Needs Philosophy. Philosophy Needs Physics", Rovelli gives us more to work with: "Our general knowledge is the result of the contributions from vastly different domains, from science to philosophy, all the way to literature and the arts, and our capacity to integrate them. Those philosophers that discount science, and there are many of them, do a serious disservice to intelligence and civilisation, in my opinion" [105]. With this in hand, I would say that a scientist could also make use of contributions from vastly different domains, also from those inside of a laboratory, even when being there with the aim of producing scientific knowledge in the first place.

As this is a point where the line between science and art might be blurring for the actor, say, in this case, the microscopist, it is time to revisit the relation between the two. Going back to the Introduction in Galison and Jones' "Picturing Science, Producing Art": "Analytic attempts to distinguish "art" and "science" often founder at the boundaries drawn between them. Do the alligators that hang from the ceiling in the late Renaissance cabinet of wonders at Wurms form part of the history of scientific classification, or part of the history of aesthetics? (...) Art, Baudelaire maintained, began

when the deadening industrial-mechanical ethos of science could be forcibly set aside. In the production within laboratories and studios, in the power and ambition of art and science to capture the world, in the variegated and evolving audiences that art and science demanded (or even created), the two realms have been separated, and their resulting relations described variously as markers of the premodern, signposts of the modern, and charged conduits into the postmodern. What much of this focus on "art" and "science" as discrete products ignores are the commonalities in the practices that produce them. Both are regimes of knowledge, embedded in, but also constitutive of, the broader cultures they inhabit" [92]. Speaking of *knowledge*, we cannot escape thinking of *objectivity* vs. *subjectivity*. Galison and Jones continue: "'Objectivity", in its widespread usage, is one of the most vaunted attributes of science in both popular and scholarly accounts. Some notion of objectivity motivates most analyses of what separates the production of science from the production of art, with "subjectivity" the shadow term that is held to separate art from science. And yet, as the authors of this section demonstrate, neither category is stable or sufficient- not for artists and not for scientists." I would shy away from making strong claims about the possible role of subjectivity in producing scientifically sound knowledge. However, I think there definitely is "room for subjectivity" inside pockets of time during a scientific practice. What your identity would be while inside those pockets or where it leads you could of course be debated.

Another term that is significant to me in the above text is "the audiences that art and science demanded (or even created)". I think it is reasonable to state that the meaning or feeling an art work conveys is highly dependent on who the audience is: their culture, education, background, "artistic literacy", etc. It would even be more reasonable to claim the same for a scientific work—why there is a field of "science communication" exists is precisely for this reason: it would be hard to grasp the content of a scientific text without the required literacy and knowledge of its background, even for an expert but just from a different field, especially with today's highly specialized network of research fields. Let's think of this in terms of an image obtained via tools of science:

who would get *what* from it? Previously I had put forward the idea that an image should not necessarily be labeled, or “appropriated”, as *scientific* solely due to being obtained with tools that are more common to scientific work than other practices. I have also argued that a scientist, during her practice, could every now and then stray away from *seeking to know something, even just for the fun of it*. Now I am asking the question: what changes for you when you know more about what you are looking at? In “Science for Art’s Sake”, Steve Nadis, when speaking of the MIT biology research affiliate and genetics artist Joe Davis, says: “The relationship between science and art has been explored extensively in recent years. But most ventures in this area have involved artists working in traditional media, inspired by the theories or practice of science. Davis, on the other hand, directly engages the techniques of science in his art.” and quotes Davis: “Drawing a picture of something you don’t understand is just not good enough. Art is about communicating. How can you convey something you don’t have a clue about?” [106]. In relation to that, I wonder: What does it change for a painter to know the chemistry behind how pigments work, or for a light artist to know more about the electro-magnetic spectrum (Fig. 3, top) and our relation to it? Or, when I exhibit an electron micrograph as it is, or create an artwork using it as an *ingredient*, what changes for my audience if they knew the physics behind it vs. not? I occasionally witness art lovers or even scholars purposefully leaning towards the latter, as if knowing more about the backstory would take away from the artistic value of it. That is a very personal choice that anyone is for sure free to make, and I would think it to be a temporal one. Yet in my view, knowing more about *the science of things* does not only not take away from *the art of them*, but even *expands our artistic canvas to work on*.

In “Science Is an Art”, François Le Lionnais makes even a stronger claim for the relation between science and art: “I would not like the title of this essay to be misinterpreted. It is definitely not an attempt to claim that the arts are sciences or that art is science. It is quite the opposite idea that I propose to discuss, as the reader will clearly see. I do not intend, either, to deal with the complex and fascinating relations linking the sciences and the arts, which are irrelevant here. What I intend is to persuade, if not to

prove, that science is an art like painting, architecture or music. Indeed, it would be hardly any exaggeration and certainly no jest on my part to maintain that there should be a discipline of the aesthetics of science. (...) Science is not concerned with the discovery or creation of beauty; it seeks only the truth. But science, for better or worse, is pursued by men—and the achievement of its ideals, as in all human activity—be it humble, moderate or great—cannot be attained in a climate completely devoid of emotion. The result is that, though science does not in any way aim to become an art, an art it inevitably is. I claim an aesthetics of science to be justifiable and I go so far as to believe that it merits being taken into consideration by aestheticians. (...) If one sees in science one of the most powerful forces of human evolution, then one must recognize that its vitality springs from its artistic savour. If science were not an art, society would have to resign itself to progress without scientists. And, if from the beginning of history up to the present day, the human adventure, this amazing human adventure, has been what we all know it to be, for better or worse, it is due not only to science as science but also to the fact that science is an art” [107].

The above analysis begs the question “what makes science art”? I seek the answer to that in the identity of the actor, as in the beginning of this frame. In “The Scientist as Rebel”, Freeman Dyson says: “The public, having found out that the traditional image of the scientist as a secular saint is false, has gone to the opposite extreme and imagines us to be irresponsible devils playing with human lives. Dürrenmatt has held up the mirror to us and has shown us the image of ourselves as the public sees us. It is our task now to dispel these fantasies with facts, showing to the public that scientists are neither saints nor devils but human beings sharing the common weaknesses of our species” [97, 98]. Now we can start thinking of the scientist, in this case, the microscopist, as *a mere member of its species* (together with all the mental dilemmas of momentarily having to choose between technical vs. emotional, empirical vs intuitional, scientific vs. societal, etc.). If we are thinking about this within the walls of the microscopy room, why not think of *what she sees while in that room* as the territory that this being, even temporarily, *exists in*? Via *scale-hopping*? Not unlike Alice in Wonderland [33, 34]?

It is for a reason that a scientist's mind could go to Alice when practicing going down to a much smaller scale than what we normally live in. When explaining their achievements in size reduction in 3D lithography (an important tool for nano-electronics), Ed Boyden used a similar analogy (Fig. 25) [108, 109]. This example, however, is still about a highly application-driven concept. I would like to repeat the questions I have posed at the end of Frame 2: What if we free ourselves from functionalities, practicalities, technological benefits, environmental risks or societal concerns while interacting with the nano-world? What would we be left with then? To expand further, in very crude terms: What happens when you *take the science out*? My answer to that would be *adventures*, not unlike those of Alice, possibly with a sense of *escapism*? Clues to the answer to this question lies, again, among the "keywords" I have selected to present with my related art work "In Awe of the Portal" (Fig. 15): *accidental, wonderlands, portal, dive, dimensions, curiosity, gasp, inadvertent, serendipity, wonder*.

The above brings me to how one sees what she is looking at under an electron microscope. If the activity is an adventure, the nano-surface under examination is then the field where the adventure takes place. During the course of my electron microscopy practice, I initially was compelled by correlating nano-imagery with the macroscopic world we live in, *bringing the inside out* (Fig. 26 and 27). This view quickly shifted towards seeing the images *as they are*, emphasizing the inherent value they carry apart from their scientific significance or the lack thereof (Fig. 28). My interest later moved towards *my place in what I see*, thus *bringing the outside in* (Fig. 29), imagining *new landscapes to explore and experience*. Nanotechnology allows creating such landscapes to walk on, still "alien" although being completely "natural" (Fig. 30 and 31). At this point I am reminded of Marc Augé's "non-places" which are "seen to not hold enough significance to be "places" due to their inherent transience and the anonymity of its temporary visitors" [110, 111]. The sub-macron space depicted as "plenty of room at the bottom" by Feynman could then be regarded as a "non-place" by someone not connected to the field of nanoscience. But I would argue that this could quickly change when one starts interacting with it first-hand. I liken this interaction to a walk in nature,

the nano-structured surface being, for example, a meadow, the microscope's joysticks being your legs, and the electron gun being the Sun. This leaves us with the nano-structures on the surface as various elements of nature in the meadow, possibly in alignment with Karen Barad's view on atoms being "critters" [112].

The performative aspects of such a nano-inspection, in turn, reminds of John Dewey's claim: "The actual work of art is what the product does with and in experience" [113]. Flipping this around, I ask: Could the whole experience in a nano-space be the art itself? Also by Dewey: "When artistic objects are separated from both conditions of origin and operation in experience, a wall is built around them that renders almost opaque their general significance, with which esthetic theory deals. Art is remitted to a separate realm, where it is cut off from that association with the materials and aims of every other form of human effort, undergoing, and achievement. A primary task is thus imposed upon one who undertakes to write upon the philosophy of the fine arts. This task is to restore continuity between the refined and intensified forms of experience that are works of art and the everyday events, doings, and sufferings that are universally recognized to constitute experience." Could we then think of something similar for scientific findings or images? Could we take the experience that a scientist goes through during her work and see it in connection with her personal life: everyday events, doings, joys and sufferings? I have tried to reflect on this in an earlier work, where the extensive and dedicated time I had spent in the laboratory was placed as the time I wish I could have spent with my grandparents instead, the dissertation that came out of it placed as a coffee table book, and the visualization of some significant findings of my scientific work framed and put up on the wall instead of family portraits; all placed in an imaginary room at my grandparent's home (Fig. 32).

Going back to thinking about a nanoscience practice as an *experience*, I would like to present one last quote. When astronaut Rusty Schweikart was on his spacewalk during the Apollo 9 mission, a mishap on his partner's camera gave him "the experience of a lifetime: being unemployed in space for 5 minutes" (Fig. 33) [114]. When he was asked

by the commander to stay put while the camera was being fixed, he realized that he had nothing to do during that time but “just be a human”: not an engineer, not a scientist, not an astronaut, “using the opportunity to appreciate what is going on”. After talking about how incredibly spectacular the view of the Earth he saw as he swung around in space, holding onto the spacecraft with one arm was, he continues: “How did I get here? (...) What does it mean when I say “who am I”? Am I me or am I us? That is very clear that you are there as a representative of the human kind.” [115]. He later went on to say that he thinks his mission is “to share this experience with humanity” [114]. I am often left with a similar sense of a spectacular experience and motivation to share it with the world, after I examine the nano-world; an experience I see similar to going to outer space (although I have not done so just yet). *Just being a human in the nano-scale landscape*. Sometimes leaving traces behind on where I *step* (Fig. 34), but mostly *looking, seeing, experiencing, connecting, relating, leaving traces, being, and final, becoming*.

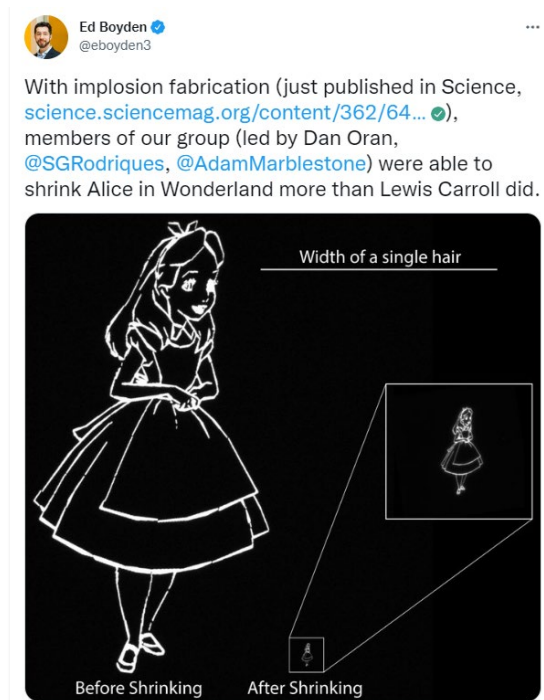


Figure 25. A scientist announcing their success in developing a new strategy for the direct assembly of 3D nanomaterials using optically patterned hydrogels as scaffold, that when dehydrated, shrunk 10-fold, which pushed the feature sizes down to the nanoscale [108, 109].



Figure 26. Likening an electro-micrograph of a damaged metal-oxide thin film (left) to a cloudy sky photographed by a digital camera (both images by İstem Özgen).



Figure 27. Left: Hugging a tree in 2013, amid a public uprising that was started to protect a green park from being demolished (photo by Aytanga Akyürek). Right: Detail from the art work “Chronically Translucent” by the author, 2022, from the exhibition “From There Through Here” at Künstlerhaus, Vienna [116–118]. Bottom: A “nano-tree” grown on a zinc oxide thin film surface, as seen under an electron microscope (by İstem Özen).

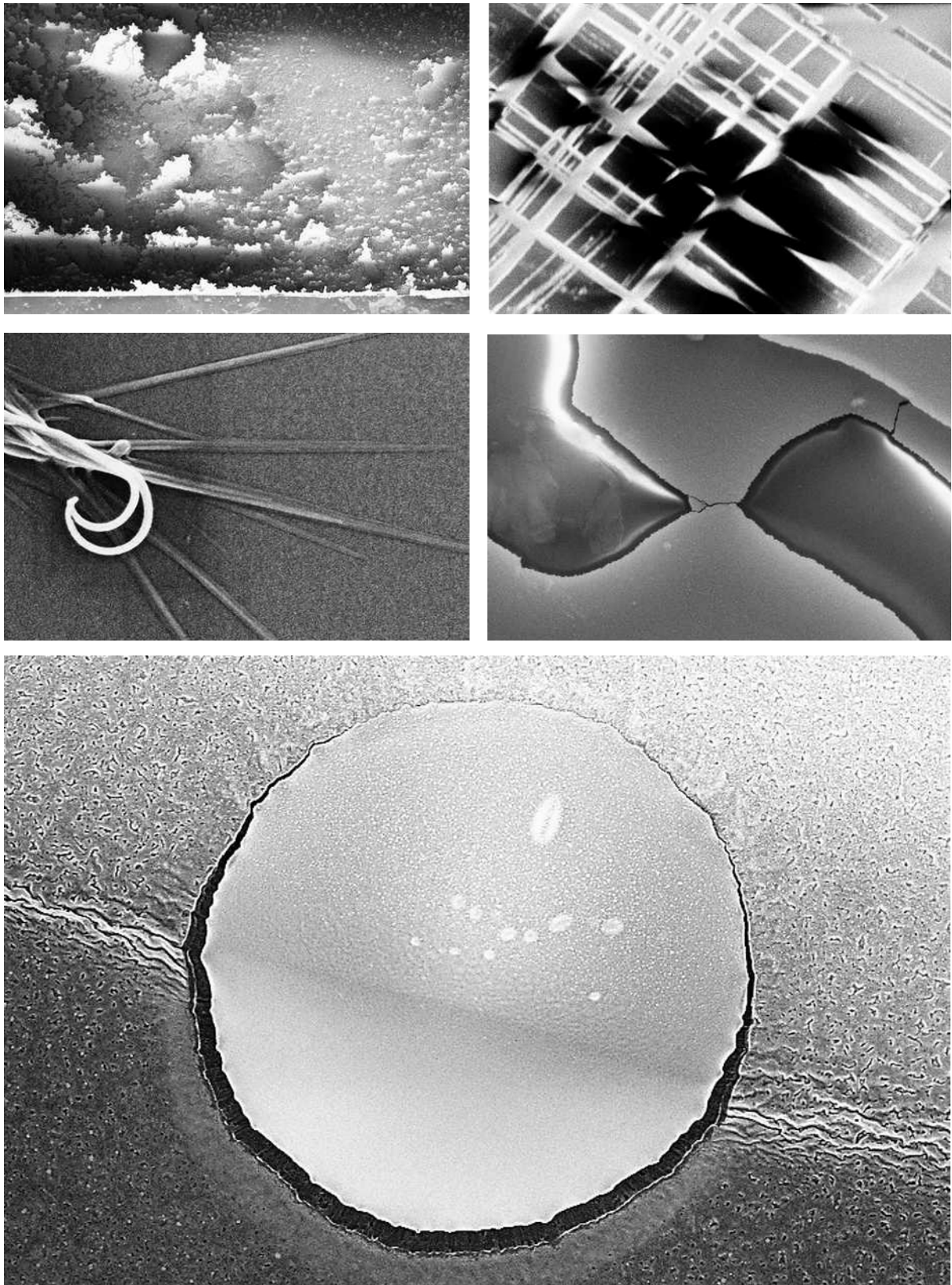


Figure 28. Details of the electron micrographs used in “In Awe of the Portal” in Fig. 15.

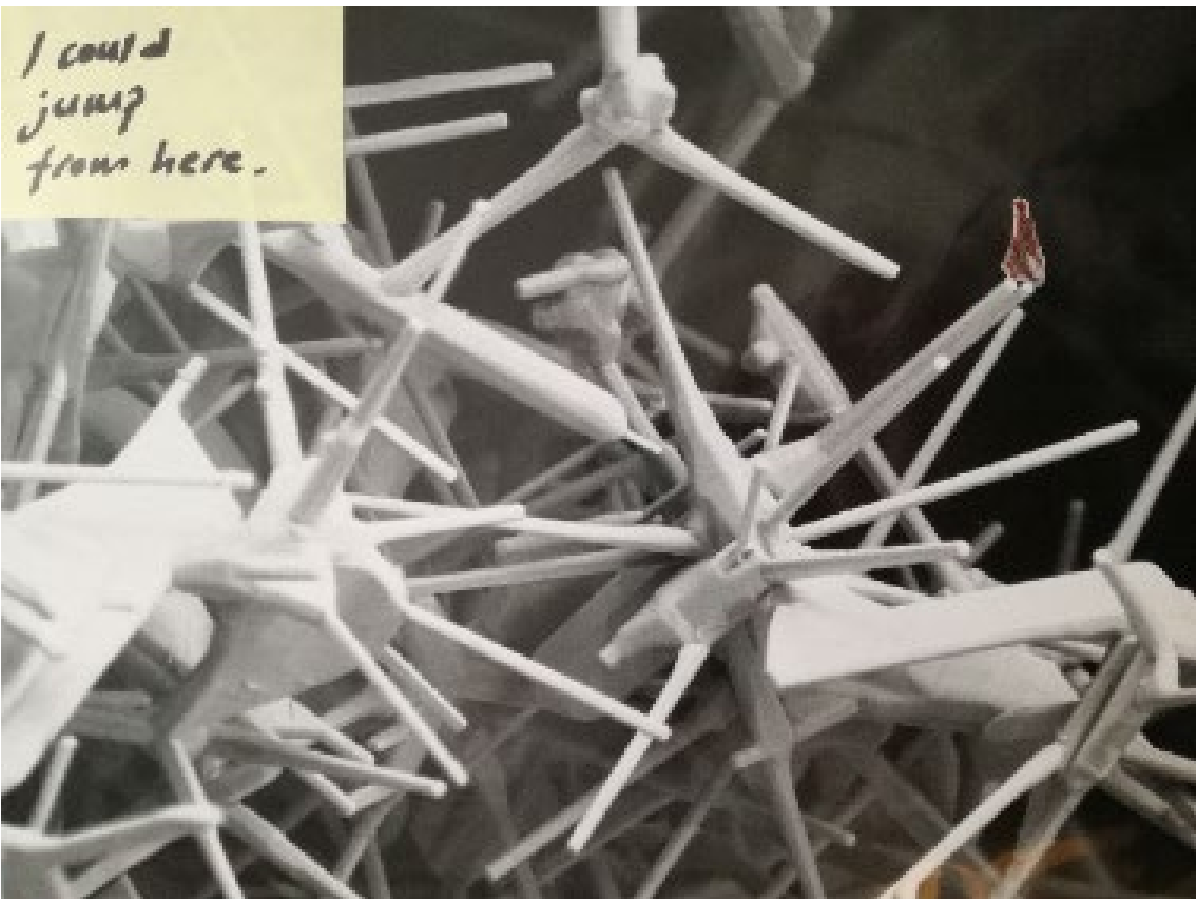


Figure 29. Artistic interpretations based on the author's previous scientific research. Top: ZnO films on glass [119–121]. Bottom: ZnO nano-particles (electron micrograph credit: Çınar Öncel, in [122]).

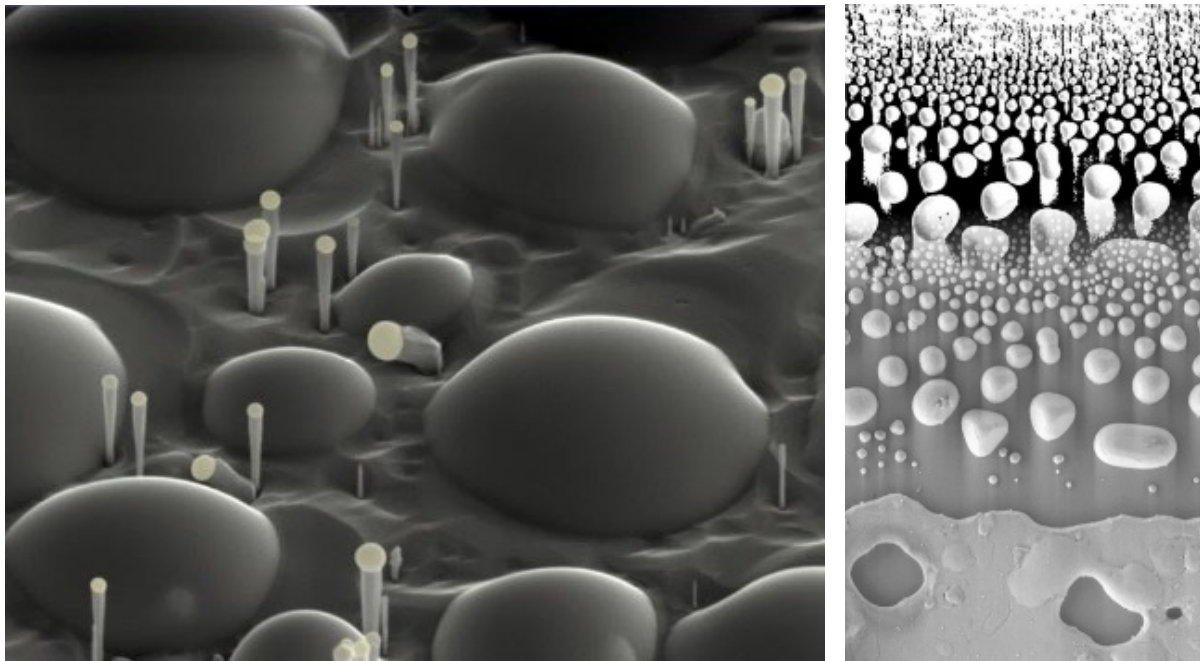


Figure 30. Left: “Night in Utopia”, Pia Weinmann, 2010. [26]. Right: “Dissolution of a Silver Layer”, Eva Muturo, 2006 [26].

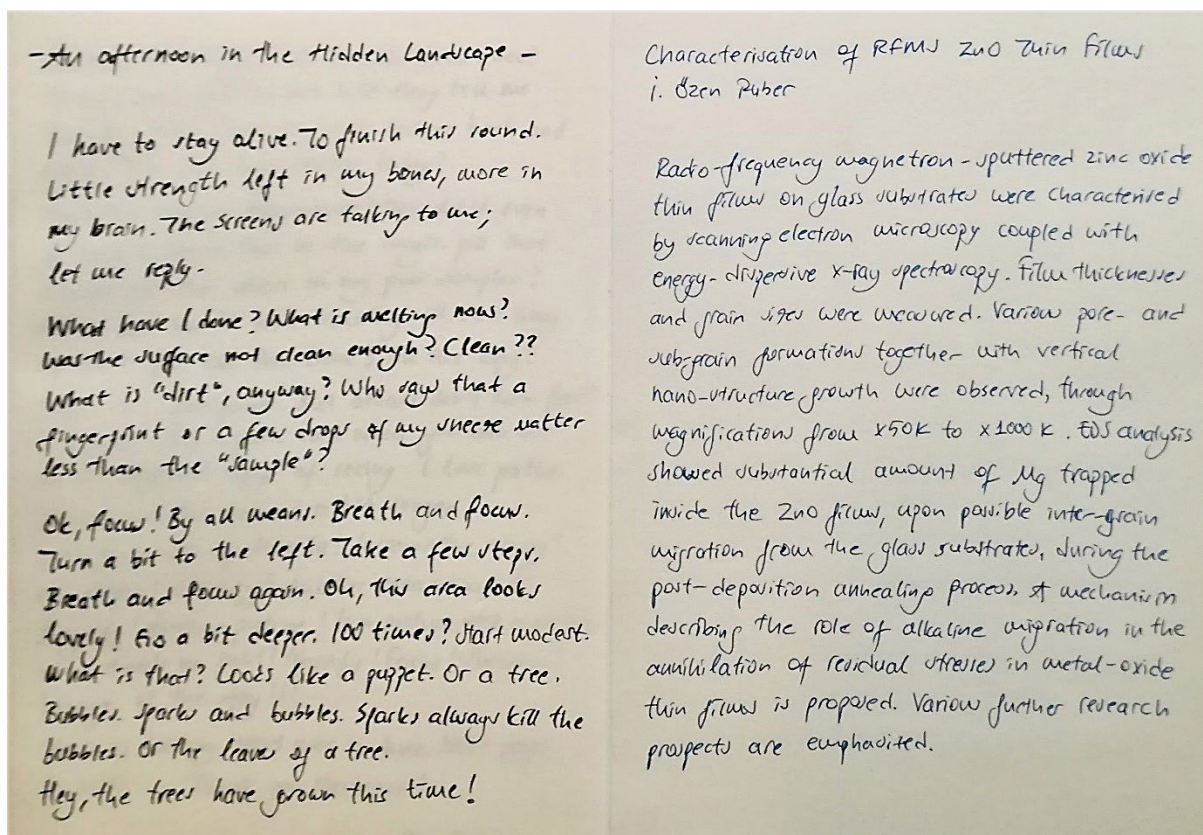


Figure 31. An afternoon in the Hidden Landscape, İstem Özen, 2017, within the Workshop: “Writing research as ethico-onto-epistemic practice” [123].



Figure 32. “A Room of Her Own” exhibited during Angewandte Open House 2018 (İstem Özen, 2018).



Figure 33. Astronaut Russell Louis "Rusty" Schweickart at the porch of the Lunar Module (Spider) during Apollo 9 (photo by astronaut David Scott, credit: NASA Image and Video Library).

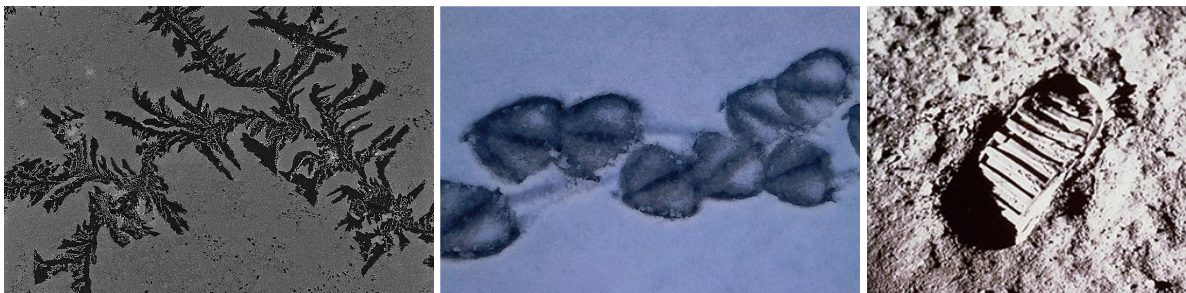


Figure 34. Left: Chemical and morphological inhomogeneity on a metal oxide thin film surface, as seen under an electron microscope (by İstem Özen). Middle: Bird footsteps on snow-covered ice, Vienna (by İstem Özen). Right: First footprint on the Moon (credit: NASA).

Frame 6: Intimacy and Empathy

I started this manuscript by talking about materials and our possible *humane* approach to them. This approach, for either a dedicated scientist or artist, could go as far as becoming sort of an *obsession*. For instance, in his book “Stuff Matters: Exploring the Marvelous Materials that Shape Our Man-Made World”, Mark Miodownik talks about his “obsession” with steel: “How is it that this one material does so much for us, and yet we hardly talk about it? It is an intimate character of our lives—we put it in our mouths, use it to get rid of unwanted hair, drive around in it—it is our most faithful friend, and yet we hardly know what makes it tick” [6]. At this point it would be fair of me to say that my material of obsession has been zinc oxide (ZnO), which I spent many dedicated years trying to *understand*, starting with my doctoral studies in Materials Science and Engineering at Sabancı University and continuing beyond that—not in an *infatuation* kind of way, but more as in *not being able to leave it behind*. Even when not working with it anymore, it seems to be still in my life, at least in the form of its atoms: zinc in the supplements I am taking for health and oxygen in the air I breathe and water I drink, keeping me alive like the rest of us. I often think about what happens to the zinc I ingest, where it goes in my body. Then I think of where it is found in Earth’s crust—I look up zinc mines that are the nearest to where I live and fantasize of a trip of the atoms from those into my cells. But the fantasy does not stop there: Zinc is known to have come to Earth via exploding massive stars and white dwarfs (a later step in the evolution of a star with a relatively low initial mass [124] (Fig. 6)—as most other elements, including the ones constituting “the building blocks of life” [125] have as well. Speaking about the universe, Carl Sagan had said when opening his famous documentary series Cosmos with the chapter “The Shores of the Cosmic Ocean”: “Some part of our being knows this is where we came from. We long to return. And we can, because the cosmos is also within us. We're made of star stuff” [39]. That makes me think of my “microscopist” identity in a different way: Am I a then perhaps a *micronaut* (or *nanonaut*) trying to trace her life back to the ancient stars, to *home*?

I would like to take a moment here and touch on another term Miodownik used when talking about steel: “intimacy”. As I have pointed out to earlier, I take the nano-scale world I observe within a material sample under a microscope to be an extension of the macro-scale world we practically live in. For that specific period of time, I *live in that* world. My personal life gets embedded into it. I have *adventures* there. I *communicate* with it. I nurture *passion* through it. When I am done, I *miss* it. When I cannot access a microscope, I *long for it*. When I can use it again, I *light up*. Eventually, I start viewing myself and the world around me through a lens of the physics that run that world and the types of interactions that manifest based on that: not just that of the nano-structures but also the atoms themselves that make up those structures.

To study atoms, you need what we call “diffraction” in physics: “the spreading or bending of (light) waves (or particles, as in the case of electrons or atoms) as they pass through an aperture or round the edge of a barrier” [124]. An x-ray or an electron beam allows us to do that because of having dimensions close to that of between individual atoms in a solid. The diffracted waves subsequently interfere with each other, producing regions of reinforcement and weakening. We observe a “signal” when there is “constructive interference”—a “peak” in the case of x-ray diffraction, and “diffraction spots or rings” in the case of electron diffraction [73, 77]. That is one common way we interact with planes of atoms in a crystalline solid (Fig. 35). In doing that repeatedly, I sometimes start “seeing diffraction spots everywhere I look” (Fig. 36). To note, those spots are not the atoms themselves; they are just keys for us to interpret them. When thinking of the very atoms of my “material of obsession”, zinc oxide, I have to refer to the representation of its crystal structure as seen in Fig. 37. While some modern art works remind me of *bringing such structures inside-out* (Fig. 38), I see *shadows* of them also when practicing ancient art forms (Fig. 39). In “Diffracting Diffraction: Cutting Together-Apart”, Karen Barad says: “Diffraction is not only a lively affair, but one that troubles dichotomies, including some of the most sedimented and stabilized/stabilizing binaries, such as organic/inorganic and animate/inanimate. Indeed, the quantum understanding of diffraction troubles the very notion of dichotomy – cutting into two –

as a singular act of absolute differentiation, fracturing this from that, now from then” [126]. Barad might here be talking about a complete different type of diffraction; yet it might still not be going too far off of me to say that the diffraction that I practice becomes an additional tool for me in understanding and interacting with the world, not only in a physical but also a conceptual manner, with all the conflicts and dichotomies I struggle with being diluted, in the most *intimate* way possible.

To me, there is one last step to the path of intimacy, though: *becoming*. Within the concept of “entanglement”, Barad says “Existence is not an individual affair. Individuals do not preexist their interactions; rather, individuals emerge through and as part of their entangled intra-relating.” She then adds that matter and meaning are iteratively reconfigured through each intra-action, and that they are “inextricably fused together” and cannot be dissociated [95]. If inside a microscopy laboratory, my sample, my instrument and myself are all *matters*, then there must be meaning in us being “fused together”, or better yet, me becoming the very crystal structure I am looking into, at least as a thought experiment (Fig. 40), reminiscent of an 18th century *scientific* illustration (Fig. 41).

Moving from here, I remember a writer of short stories once telling me that the reason he writes is “to make sense of the world” [127]. Then, reciting Augé one more time: “What is new is not that the world lacks meaning, or has little meaning, or less than it used to have; it is that we seem to feel an explicit and intense daily need to give it meaning: to give meaning to the world, not just some village or lineage” (p. 24 of [110]). As such, I see my “entanglement” and interactions with matter and machine as a way to *make sense of my existence and to find meaning*, both when practicing science and otherwise. It is my way of creating an intimacy with nature, with the part that is hidden “down there”. Maybe by finding what I have in common with it, or just by being humbled by what I reveal, comparable to my experience with some real critters, namely the ants who invaded my room as I write this text; who have intrigued, challenged and humbled me by their intelligence and perseverance. They have eventually made me

embrace the privilege of being able to observe them so up close and give up trying to gently sway them away with the fear of accidentally stepping on them if I let them stay (Fig. 42). Therefore it is, and will probably continue to be, an *intentional* method of experiencing this world, although sometimes leaning towards *escapism*. While, as Carl Sagan put it, the cosmos is within us and “we are a way for the cosmos to know itself” [39], studying the nano-cosmos becomes a way for me to know myself and the world. This, for me, is one way towards *empathy*, hence *peace*, both on the inside, and for the people of the world, if only more of them could see what I do.

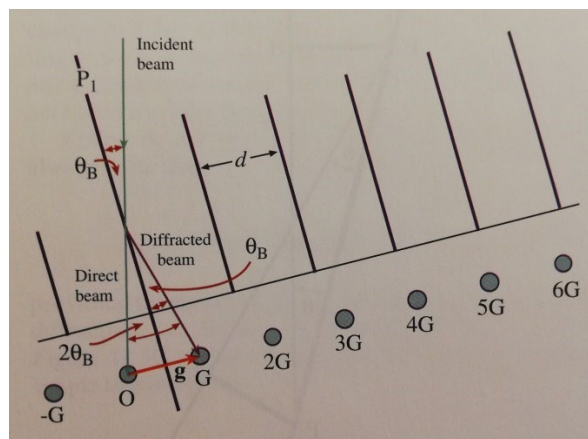
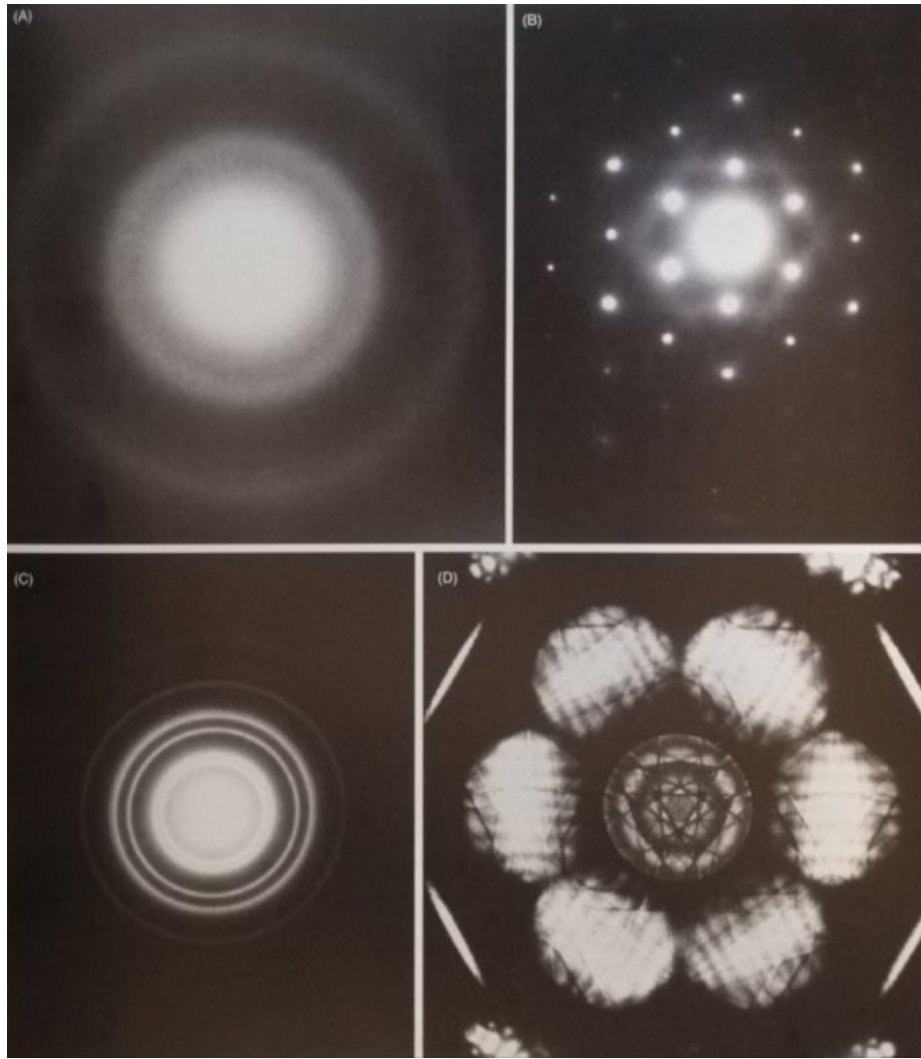


Figure 35. Top: “Several kinds of diffraction patterns obtained from a range of materials: (A) amorphous carbon, (B) an aluminum single crystal, (C) polycrystalline gold, (D) silicon illuminated with a convergent beam of electrons. Bottom: Formation of “diffraction spots” (reciprocal-lattice points) labelled from $-G$ through $6G$, as the incident electron beam is diffracted through a set of atomic planes a distance d apart from each other, in a crystalline solid under a transmission electron microscope (TEM). Both images from [77].

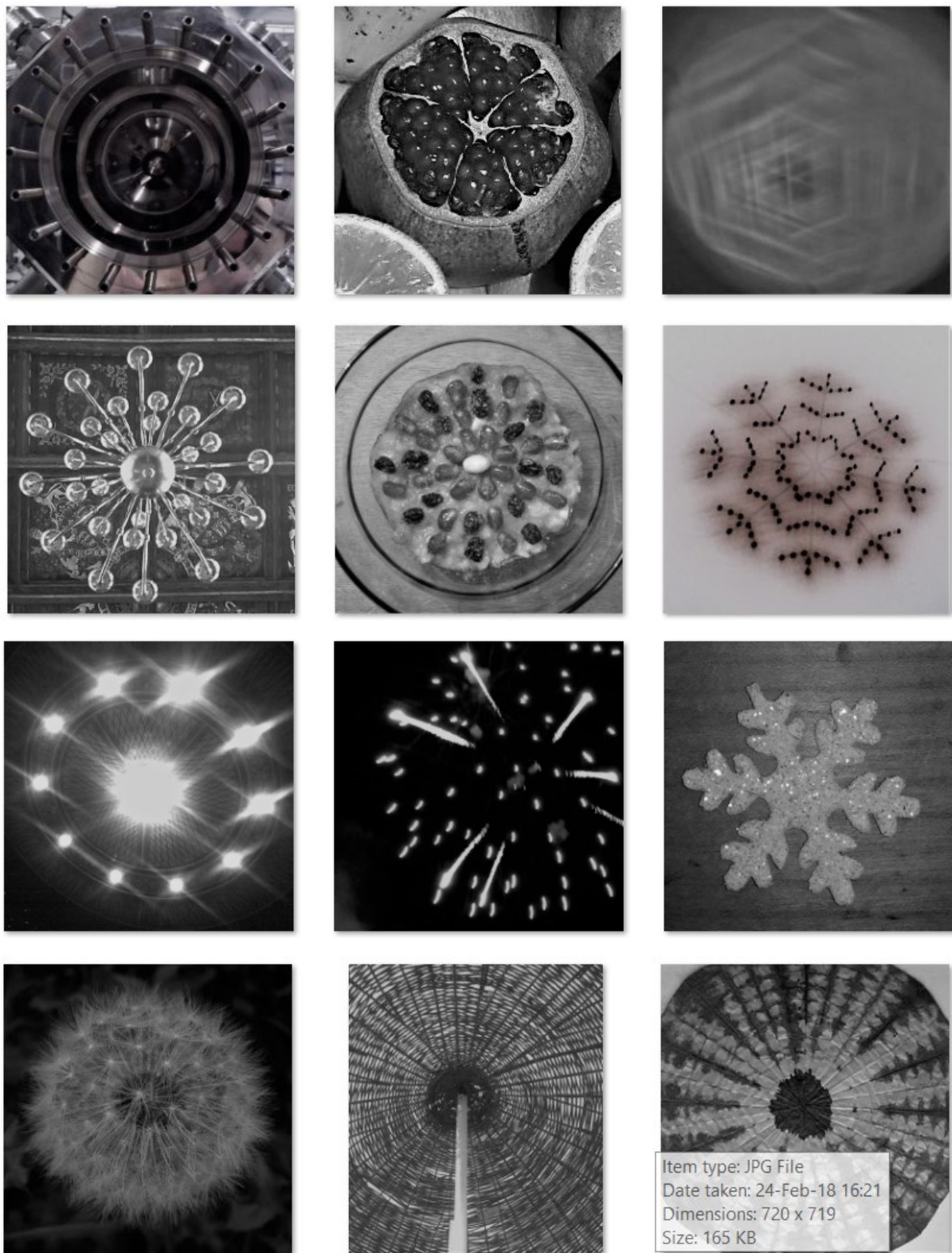


Figure 36. A collection of digital photographs of various macroscopic objects (İstem Özen, 2018).

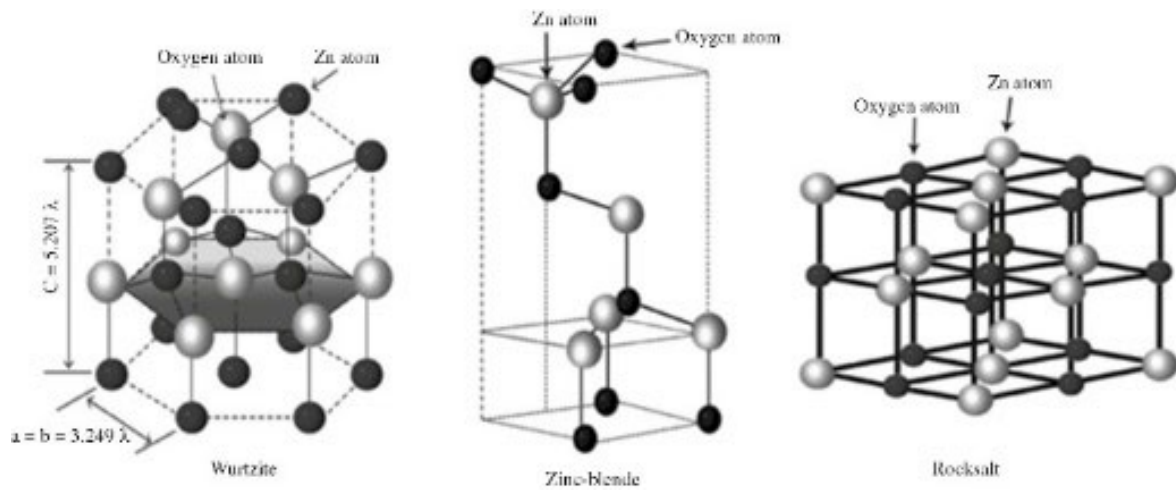


Figure 37. Atomic structure of ZnO crystals [128].



Figure 38. "Uprise", Canan Dagdelen, 2015 (Photo © Rupert Steiner) [129].



Figure 39. Suminagashi by İstem Özen, 2014.

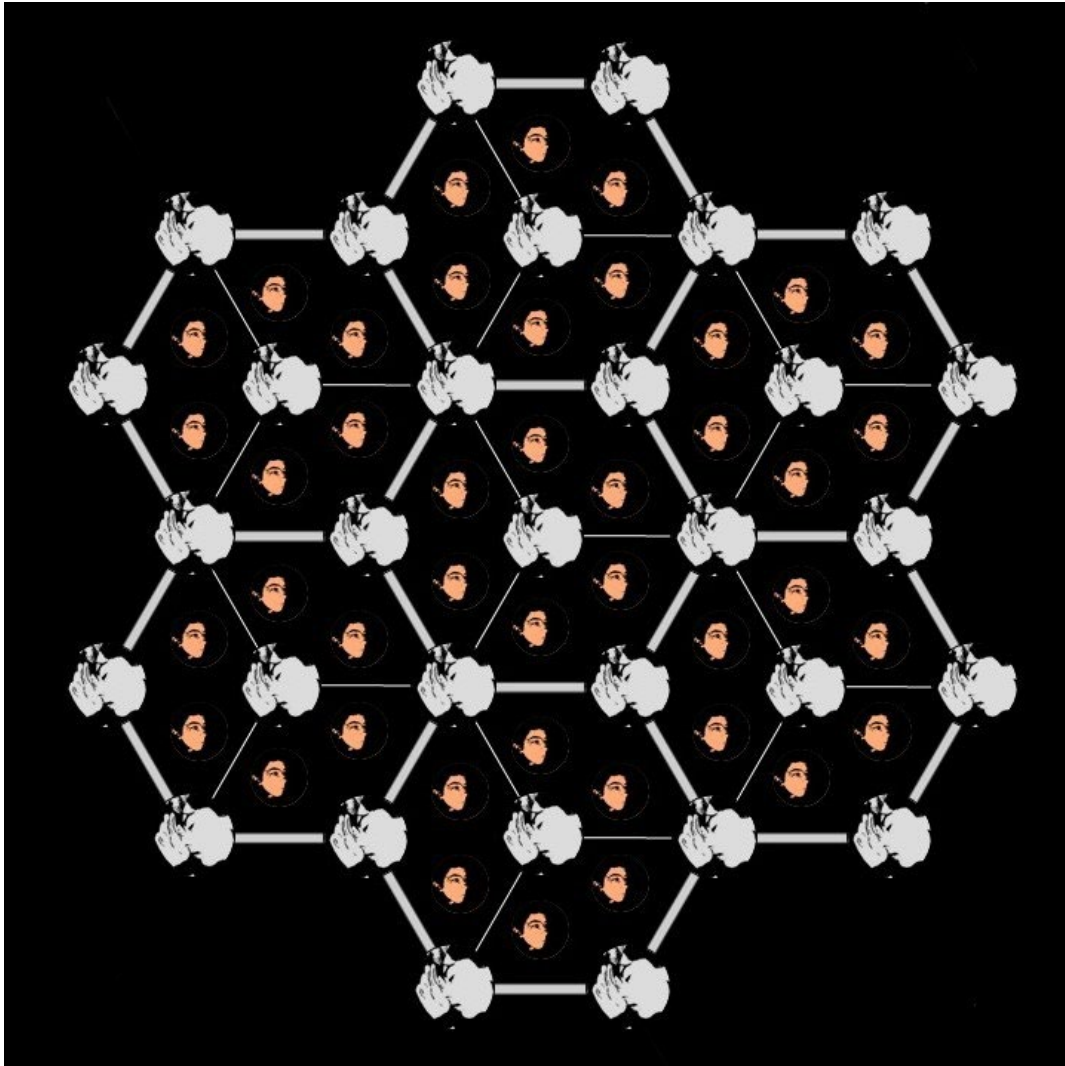


Figure 40. "Becoming"(İstem Özen, 2022).



Figure 41. Comparison of depictions of a hydrachnid larva: "a distinctive maculation showing the likeness of a human face, a man furrowing his brows as he is glancing side-ways" (in [130] and [131], adapted from [22]).



Figure 42. Ants; either minding their own business in the balcony as when I started this project (top; 2020) or trying to invade my flat as I am writing this text (bottom, 2022), bringing me simultaneous joy and anxiety as I try my hardest not to step on them.

Postface

Completion of this manuscript is for me also the completion of one full circle of a journey in any possible combination of the words “science” and “art”. It does not claim to fully propose a philosophical theory but plays with some ideas from philosophy and sociology that spark questions and connections in my mind with the *matter in my hand*. Those questions and connections act as the pieces that build my *yellow brick road* that have meanwhile led me back to science after a rather long hiatus, this time with more joy and new insights.

In my own quest for relating science to art, I have tried to avoid a strong focus on aesthetics, functionality benefits and appropriation. I have pursued stripping the process down to “*relatability and meaning*”, “*feeling and sensing*”, “*connecting and narrating*”, “*extending and sharing personal space*”, and “*conveying personal experiences*”. In that, I have tested my own boundaries to how far I could go away from my *scientific habits*, sometimes happily finding out that I do not necessarily have to do so, partially agreeing with Dyson in “Science is a human activity, and the best way to understand it is to understand the individual human beings who practice it. Science is an art form and not a philosophical method” [97, 98].

From here, I intend to continue to inquire the limits to how much the concepts and methods in basic sciences can diffuse into philosophy, social sciences and arts (and vice versa). What is for sure is sometime soon I will sit in front of an electron microscope again and start searching, as I cannot wait to visit my nano-tree again and the longing to end.

I would like to close with some reflections on spending time with that tree:

Time is up.

But I just want to go around in here,

round and round,

up and down,

in and out,

in this hidden landscape where there's no light, no sound, no smell for us but only magical sights.

Magical? Come on!

It couldn't be more real than this!

*İstem Özen
Vienna, 2022*

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