Dianne Bos and Doug Welch inside *Light Echo* installation, 2009, McMaster Museum of Art, image courtesy of Dianne Bos and Doug Welch

DIANNE BOS AND DOUG WELCH

In conversation with

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McMaster University
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We met with artist Dianne Bos and astrophysicist Doug Welch at McMaster University in Hamilton, Ontario on a rainy spring day in April 2019. Although our interview took place in a university board room, it quickly felt like we might well have been conversing in a living room in one of their homes. They demonstrated that special easy-going rapport of close friends who genuinely enjoy being in each other's company. Listening back on our conversation, we were struck by how much we all laughed. We tried to preserve this spirit in the transcription that follows.

Overall, Dianne and Doug showed great generosity in reflecting on their research—and the joy and humour they exude about their mutual interest in science, art, and the universe at large is inspiring.

We left dreaming of careers in astronomy—and, while realistically this is not in the stars for us, the experience has certainly made us look at the stars differently.

Pinhole photography is a process involving a simple light-proof camera or box with one or more small apertures instead of a conventional lens. When light passes through the aperture, it projects an inverted image on the back of the camera or box. This is known as a 'camera obscura' effect. Pinhole cameras have an infinite depth of field with no lens distortion, so everything appears in focus. Long exposure times result in the blurring or disappearance of objects in motion. A pinhole camera can be used with film to capture an image, or used without film for the projection effects alone. Multiple apertures are used for special effects such as multiple projections or the ability to take photographs in spherical or cylindrical perspective.

Globular clusters are collections of densely packed ancient stars that are bound together by gravity in a spherical formation, orbiting a galactic core. Extremely luminous, the average cluster is 100,000 times brighter than the Sun. They are the oldest objects associated with our galaxy, containing some of the first stars to be born, with the ages of those so far measured dating from 11 billion to 13 billion years old. To date, more than 150 globular clusters have been discovered in the Milky Way, with some of the larger galaxies containing as many as 13,000.

Spiral galaxies were first described in 1936 by Edwin Hubble in his classic book *The Realm of the Nebulae*. As their name suggests, typically have noticeable, bright spiral features. They also often have a central, tightly concentrated 'bulge' of older stars and a supermassive black hole. The spiral pattern of bright, young stars appears in the rotating flat disk which also has gas and dust.

A light echo is a physical phenomenon produced when the light rays of a luminous transient event, such as a supernova, is scattered by particles of dust in the galaxy, reaching Earth at a delay relative to the direct path between the transient event and the Earth. A fantastically energetic stellar explosion at the end of massive star's life, a supernova can produce enough light to exceed the luminosity of an entire galaxy of a million, million stars. The material debris from the outburst often seeds new star formation. Doug Welch was part of a team of astronomers that developed a new subtractive method for detecting the apparent motion of light echoes, enabling them to study the asymmetry of supernovae events, among other characteristics. Moreover, the team demonstrated that, due to the time delay caused by the non-direct path taken by the scattered light, a supernova event may be observed again hundreds of years after it originally occurred.

JENN: When we talk about deep time storytelling, we are approaching it with the view that it is, by necessity, a collaborative endeavour that extends outwards in time and space—geographically and historically. With this in mind, we're interested in thinking about the combined research strategies used to reconstruct images of the past as well as visions of the future. It's a narrative composed of fragments, of traces, of pieces of a puzzle—and we don't necessarily know how it's all going to interconnect. But collaborating in the piecing together of the pieces, goes a long way toward reconstructing the bigger picture and helping to fill in the gaps.

With that as our starting point, I'm wondering if you could talk about your collaboration for your 2009 project, *Light Echo*, and how it has informed your individual practices?

DOUG: My wife's an artist and Dianne's an artist, and we both lived in Dundas, Ontario, which is a very tight community artistically. It turns out that Dianne is very interested in astronomy, and we'd both done photography in the past. We each had our own dark rooms and were intrigued by alternative imaging techniques.

DIANNE: We thought, "We've got to do a project together!" It took years. I was doing pinhole photography, which I'm still doing, using alternative photography techniques. We were talking about astronomers using a technology that doesn't involve a lens because a lens will alter the way that light cuts in when they're looking at objects in deep space. Where we ended up was really different from what we first imagined. Initially we were looking at building a camera together. Doug was the first person I saw working with 3D printing. He was using it to print pinhole devices that were like little telescopes, and he gave me some of the prototypes that he had made.

Doug was likewise very interested in the multi-aperture cameras I was making, where the apertures were in the patterns of star formations. I made globular clusters, as well as spiral galaxies, some of which are quite recognizable. For every star, I punched a hole in a panel, and if the star was bright, I would punch a bigger hole. It was pretty straight forward, and some panels had 500 stars in them. I was photographing things with these panels to create a galaxy of images. When I showed Doug some of the very first versions of these, he said that the way I was looking at light was similar to astronomers. Although my take was kind of the 'folk art' version of this, he made a connection.

DOUG: One of the things that brought us together was my research on supernova light echoes. Astronomers have been studying supernovae for a long, long time. But the last one that was visible to the naked eye was in 1604 before all of modern scientific instrumentation, and before there were any straightforward, accurate ways to measure them. We now understand what they are, how important they are in measuring the universe, how important they are in helping galaxies make stars, etc. But the problem is we haven't had a nearby supernova that we could study in great detail, and if we did, we wouldn't know

what its aftermath would look like in a couple of hundred years. So, light echoes were something that my research group chanced upon accidentally. It was a source of noise in what we were trying to do, and it took us months and months to figure out what was actually going on.

DIANNE: Because you thought they were imperfections in the imaging or light scattering off optics …

DOUG: Yes, and when we finally found out what these fuzzy artifacts in our images were, we recognized that it was a way to see outbursts of supernovae that happened hundreds of years ago. You could still see the outburst itself.

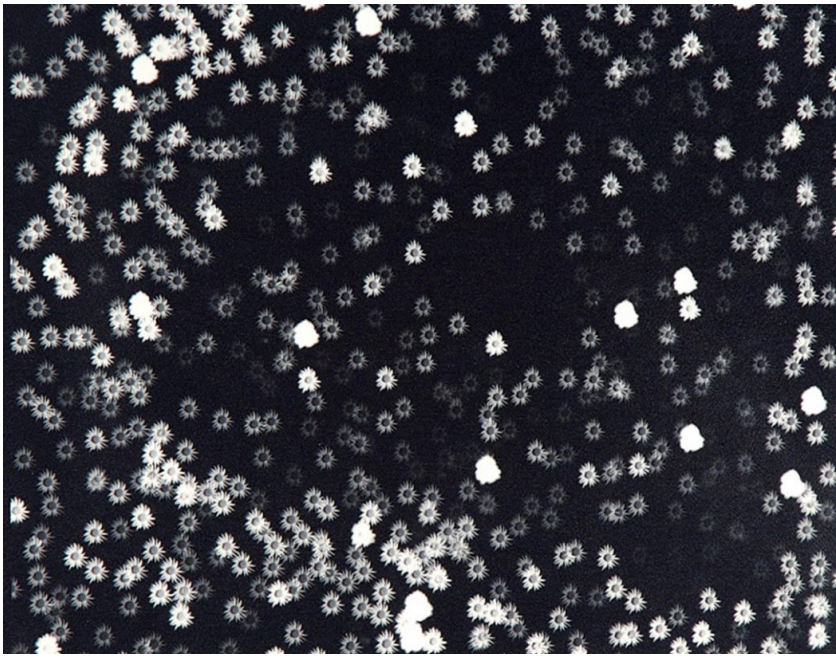
DIANNE: It's still travelling through space as we speak! [laughter]

DOUG: Yes, it's still heading towards us. That light, that outburst, passed us hundreds of years ago, but it got scattered off something, so that longer path it takes can be visible many years later for us. That began our discussion and interaction about the ways in which the memory of the universe is preserved by these expanding light fronts. It also ironically allowed us to look at these objects three-dimensionally for the first time. As an astronomer, you're stuck on Earth. [laughter] You can see the star from this one perspective, and that's it, you can't move around the object. But echoes actually give you the opportunity to look at it from different directions.

DIANNE: When you're talking about that light, you're looking into the past. So, even though it was visible on Earth in 1604, when did the light that you're seeing actually happen? It was hundreds of years ago, a long time ago. Doug and I were engaging this idea of looking at 'old' light to in order to look back at the past. In looking at the time period when the supernova would have been seen on Earth, historians and astronomers also researched past records in China because they had better documentation of things that were happening in the night sky then. They were interested in whether there was anything else written about this, because when supernovae happen, it is often for a short period of time and you don't know exactly when it's going to occur. Some of the things you look at are really short, lasting only a couple of hours. So, if someone sees it, then you try to get a telescope pinned on it. It often takes a network of people around the world to see it, and then it disappears. For example, when the Cas A Supernova occurred in the late 1600s, there was no record of it in Europe.

DOUG: Interestingly, the supernova remnant Cas A was first recorded as a radio source. Then when someone decided to look in that direction and were able to pin down the general location, they found this small remnant of a supernova. You needed a big telescope to take a long image. However, there was no report of any object seen by the naked eye at that time in the late 1600s. So, it was a bit of a mystery and was one of the objects I worked on.

The youngest known remnant of a supernova explosion in the Milky Way, Cassiopeia A, or Cas A, is located in the constellation Cassiopeia. It is the brightest extrasolar radio source in the sky, and although its light first reached Earth at the end of the seventeenth century, there are no historical sightings recorded from that period. There is speculation that the light from the explosion was absorbed by interstellar dust or may have been obscured by the previous shedding of the massive star's outer layers. The world's first radio astronomer, Grote Reber, recorded Cas A. It was optically identified in 1950. The expansion shell of the remnant is expanding at approximately 4,000 to 6,000 kilometres per second and will continue to do so for thousands of years.



Dianne Bos, *Dark Globule in Milky Way*, 2001, silver gelatin pinhole photograph, 14" x 10", image courtesy of Dianne Bos

Appearing in the Milky Way in 1604 in the constellation Ophiuchus, Kepler's Supernova (SN 1604) was named after the German astronomer, mathematician, and astrologer, Johannes Kepler. Although he wasn't the first to record it, Kepler—as imperial mathematician and astrologer to Emperor Rudolph II—systematically studied the object, tracking it for a year. He published his observations in 1606 in his work *De Stella Nova*. It was the last supernova event in our galaxy to be observable by the naked eye. Kepler's astronomical observations ultimately helped overturn the prevailing Aristotelian belief that the heavens were static and unchanging.

Meteorology is the scientific study of events that happen in the Earth's atmosphere—the layer of gases that surround the planet and make life possible—with a strong focus on predicting weather phenomena. Such events are largely described in relation to temperature, air pressure, water vapour, mass flow, and how these change over time.

Also known as B Cassiopeia or SN1572, Tycho's Supernova appeared in November 1572 and is named after the Danish astronomer Tycho Brahe. The last of the so-called 'naked eye astronomers', Tycho recorded his observations without the use of telescopes. Appearing in the constellation Cassiopeia, SN1572 is a Type Ia supernova, meaning that it occurred in a binary system where one of the stars involved was a white dwarf. Tycho combined his analysis of the supernova with those of other independent observers in his extensive work, *De nova et nullius aevi memoria prius visa stella* ("*Concerning the Star, new and never before seen in the life or memory of anyone*"), published in 1573. It is considered one of the most important observation events in the history of astronomy.

There are only about half a dozen known supernovae in our own galaxy in the last thousand years and the last one reported was in 1604—known as Kepler's Supernova. Since they're so rare, the night sky mostly didn't appear to do much. Stars were there in the same patterns, night after night, century after century. The planets wandered around a bit, which was a bit of a mystery. But the prevailing wisdom of the Church at the time was that the heavens were separate from the Earth, and the heavens were more perfect; they didn't get disturbed, and anything that did happen in the sky was assumed to be a meteor—that's where we get the term meteorology. Lightning, actual meteors (we now know what they are), and other imperfections, were basically considered atmospheric because no one could tell any differently. The supernova of 1572—Tycho's Supernova—happened during this period when people started to inquire and measure the things they observed in the sky, even without advanced instruments. But they just couldn't excuse the things they saw in 1572. [laughter] The supernova was up there for everybody to see, brighter than any star in the sky and it was clearly changing with time. Tycho managed to show that it couldn't possibly be in the atmosphere. It was attached to the heavens, whatever that meant.

DIANNE: Yes, that was the image we used from this woodcut—Tycho observing the supernova.

DOUG: It's a very early photograph! [laughter]

DIANNE: Yes! It's weird what we ended up doing as an art piece. We went back and forth thinking about the ideas and artists in that time

period. I have always been interested in Vermeer, partially because of my Dutch background. He did a painting called *The Astronomer*, and another called *The Geographer*. In the first, there's an astronomer with an astrolabe, books on his desk, and a window to the outside. Apparently, Vermeer used a camera obscura or pinhole camera to do his paintings. These cosmic events occurred when he was alive. It's interesting to speculate that Vermeer was in his studio at that time, working on this painting of an astronomer, while all of this was happening in the night sky. At first, I was going to make a pinhole camera in a room, and then Doug started experimenting with LEDs, and it was really interesting.

DOUG: The LEDs could mimic the night sky, even with the twinkling of the stars, which is due to our atmosphere. [laughter] But also, we decided that we'd create the section of the sky in which these two supernovae were located about the same time, and we'd show how they would have appeared and disappeared, sped up of course, along with the twinkling of the sky in that period.

DIANNE: I was looking into the Golden Age in Holland focusing on art and exploration, and I read something about how this contemporary moment in time, right now, is also a golden age of astronomy. I was interested in the meshing of these two golden ages 500 years apart. So, we recreated a box that would be Vermeer's studio, and you would only look in on it through a window. He would always paint by the light coming in through his studio window. The idea was that the viewer would peer in on this kind of time capsule. I tried to ensure that everything in the room was from that time period. The installation was exhibited at the McMaster Museum and they happen to have paintings from that period in their collection. There were over $3 million worth of paintings on the wall of our recreated studio, including a portrait of Rembrandt's father. The Museum even had one of the maps that's in Vermeer's painting! It's amazing! Then we used the LED technology to recreate the night sky on the back corner of the room. You couldn't enter the room, but you could look through the window.

DOUG: The far upper corner of the room was 'torn away' revealing this night sky.

DIANNE: Yeah, it was like the back of the room just disappeared into darkness. Initially I had wanted to use candlelight to replicate the lighting technology of Vermeer's day. [laughter] Instead, I had a candle holder from that time period. But my Dad made this thing that flickered and would have been the same lumen intensity as candlelight.

DOUG: Yes, for some reason they didn't want us to use real candles! [laughter]

DIANNE: It sat on the desk along with paintbrushes, pottery, maps, and so on. There were frames on the wall. But we painted the room so that it went from this ochre colour into blackness. We made this beautiful triangle of the night sky that fit into the corner and it gave the illusion that the corner of the room just disappeared. It had this

Johannes Vermeer (1632-1675) was a painter of the Dutch Baroque period, specializing in genre paintings depicting scenes of middle class domestic life. A Catholic artist in a Calvinist state, he resided mostly in Delft, enjoying moderate success during his lifetime, but falling into relative obscurity after his death. Today, he is recognized as one of the greatest painters of the Dutch Golden Age. Vermeer's painting techniques have been the source of debate, prompting speculation that he used a camera lucida, a camera obscura, and curved mirrors to paint his interiors. British artist David Hockney and American physicist Charles M. Falco have been main proponents of this theory. The idea was also popularized in the 2013 documentary *Tim's Vermeer*, in which the inventor Tim Jenison recreates Vermeer's painting *The Music Lesson* (1662-65) using a camera obscura and a comparator mirror.

Dubbed "the original smartphone" by *Smithsonian Magazine*, the astrolabe is a multifunctional device used for centuries by European and Islamic societies to tell time, track the yearly calendar, navigate location, and chart the stars. Astrolabes date to the Roman Empire and were actively used through to the eighteenth century. A model of the celestial sphere, its name roughly translates in Greek as 'star taker.' They varied in size and form and could be fabricated in wood or metal. In general, an astrolabe was composed of a central 'mater' disk, holding a stack of plates (tympans) of the Earth's latitudinal lines. A circular framework sat over top called a 'rete' indicating the positions of the stars, which was free to rotate. A pivotal straight rule helped line up with time measurements along the edge of the mater, while a pivotal siting device on the back, helped to calculate the altitude of the stars.

Spanning the late sixteenth and seventeenth centuries, the Dutch Golden Age denotes a period when the Dutch Republic was a foremost economic power and a leader in trade, science, and art. Fostering a relatively tolerant intellectual climate, the Dutch Republic attracted a number of renowned scientists and scholars from other parts of Europe, including French philosopher René Descartes and English philosophers John Locke and Thomas Hobbes. Advances were likewise made in astronomy and physics, such as the discovery of the wave theory of light and the invention of the pendulum clock by Dutch astronomer and mathematician, Christiaan Huygens. Dutch Baroque architecture and art also flourished, particularly painting. Dutch artists became leaders in history painting, portraits, landscapes, genre painting and still life, demonstrated through the work of such artists as Rembrandt van Rijn, Frans Hals, Jan Steen, and Johannes Vermeer.

Dianne Bos and Doug Welch, 2009, *Light Echo*, mixed media installation at McMaster Museum of Art, image courtesy of Dianne Bos and Doug Welch

The Wizard of Oz is a 1939 musical film starring Judy Garland. Based on the 1900 children's novel by L. Frank Baum, the film tells the story of a young Kansas girl, Dorothy, and her dog Toto, who get swept away by a tornado to the magical land of Oz. They embark on a journey to find the Wizard of Oz in the Emerald City, who they are told can help them go home. Along the way, they encounter witches and munchkins, as well as a dim-witted Scarecrow, a heartless Tinman, and a cowardly Lion who join the pair on their quest. In the end, it is revealed that the Wizard is no more than smoke and mirrors, an ordinary man behind a curtain, and that they all possessed the ability to obtain what they desired all along.

sort of twinkling effect. It was an installation, but in a way, it was like creating a surrealist painting. People would watch and wait because they wanted to spot the supernovae going off in this little grid of light work. It was a bit like the Wizard of Oz going on behind there, with hidden computers and all that.

DOUG: Another really interesting thing was how the work flipped the time aspect. For most of us, as for Vermeer, everything is experienced in real time, so the sky more or less appears constant. But in this instance, the room was constant, and it was the sky that was changing in real time.

JENN: I think what is so seductive about the idea of an echo, is that it represents an opportunity to re-experience something in a delayed way. The echo is a variable copy, it's never quite the same thing as the original event. But though it may be fragmented, it's still a re-experience. The echo creates a simultaneity between the past and the present. The idea that we can view an event in the present that happened at the end of the sixteenth century is amazing. I think that's part of the allure of the narrative impulse behind deep time research, questioning what we want from it in attempting to reconstruct the past. It's creating an interconnectivity that allows you

to see something, in a way, through someone else's eyes, someone that you could never possibly meet in any other capacity.

DOUG: Yes, and there's a difference between what you want or what you'd like to be able to experience and what you're given. [laughter] Very much like history!

DIANNE: It all kind of fit together. We certainly didn't foresee what the end creation was going to look like, but for me it was one of the best projects I have ever worked on. Even just as a work in a gallery, I thought it was beautiful. It was really nice because it brought in Doug's astronomy students, as well as art students. Doug programmed a number of related astronomy lectures around it, which was great.

DOUG: They seemed to be very happy with it on campus because it brought a whole mixture of viewers into the Museum, who would normally not go in the door.

DIANNE: Here again, we're presenting different ways of looking at history and time. It worked really well in terms of telling a very long story.

But I'm curious, Doug, when Jenn talks about 'deep time' what does it mean to you?

DOUG: What does it mean to you, Jenn?

JENN: Oh, my goodness, where do I start? I think I'd rather hear what it means to you! [laughter] But generally, when I think about deep time, I think about deep reading in some sense. With questions around deep time, the temptation is often to think backwards, to look backwards into time that has past. But deep time is also about thinking forwards in trying to tell the story of us. I think there's an innate impulse in humans to search for clues to deep time—fossil hunting, for example. Our ability to grasp such expansive time frames are mathematically beyond our human experience and even, arguably, our comprehension. It's very difficult for most people to wrap their heads around numbers that exceed the millions or even billions of years. Sometimes natural artifacts, such as fossils, help make a concept—that is otherwise so abstract—material.

It can likewise be challenging to comprehend a universe where even time itself has a starting point, a birth. It is amazing to think that there was a time, if you will, when even time did not exist. For me, that is one of the biggest fascinations—the idea that time itself only started with the 'Big Bang'. Before that, what was there? Can we really comprehend what 'nothing' means in that context? I think it's all part of our human need to grapple with mortality in some way...

More recently, I have approached deep time through the lens of geology, writing on the work of a couple of artists that deal with deep time issues and the Anthropocene from a geological perspective.

The Big Bang theory is the leading scientific explanation of how the universe began. It contends that the universe started with a singularity (an extremely hot, dense concentration – much smalled than an atom) that expanded over the past 13.8 billion years into the current cosmos. NASA estimates that a second after the universe was born, the temperature was 5.5 billion degrees Celsius. As it cooled, the primordial soup photons and high-energy particles produced protons, neutrons, and electrons which eventually often combined into neutral atoms. For the first 380,000 years, the universe was not transparent since free electrons caused it to scatter light. Once the electrons combined into atoms, this early light, or 'afterglow', known as the Cosmic Microwave Background (CMB), could be detected at any later epoch. Since events prior to the birth of the universe are not (yet) measurable, it is generally assumed that time began with the Big Bang.

First identified by eighteenth century Scottish Geologist James Hutton, an unconformity marks a break or junction in normal sedimentary deposits where two rock formations, created at different moments in history, adjoin. Such interruptions in the stratigraphic record ultimately provide evidence of evolutionary shifts in geologic time. Hutton was interested in unconformities to prove the geologic theory of Plutonism, which he developed in his *Theory of the Earth*, published in 1788. The theory, also known as Volcanism, posits that the Earth's intrusive igneous rock, such as granite and basalt, originates from molten magma deposited by volcanic activity on the sea bed, where it was reformed and solidified into sedimentary layers of rock by pressure and heat, before resurfacing. One of the best examples of a geologic unconformity identified by Hutton is found at Siccar Point in Berwickshire on the East coast of Scotland.

The main preoccupation of German Philosopher Martin Heidegger (1889-1976) is the ontological question of the nature of Dasein (or Being). Laid out in his 1927 volume *Being and Time*, Heidegger's sense of time arises in pursuit of this question and is relevant because of the fundamental historicity of existence. For Heidegger, time is the horizon on which this questioning occurs, though he attempts to dispense with "vulgar" ideas of time that are linear, uniform, and infinite. Time should be understood as the (non-linear) unity of three dimensions ("ecstases')—future, present, and past. Simply put, for Heidegger, we ***are*** time. Yet, as Heidegger acknowledged himself, the ideas in *Being and Time* are unfinished, and thus the question of Being ultimately remains hanging.

In *The Order of Time*, Italian physicist and author Carlo Rovelli argues that time is not what it seems to be, it is more than simply a measure of change. Rovelli builds on Einstein's theory of 'spacetime' gravity, where space and time are treated the same, gravity is not a force but rather a property of spacetime, and time moves more slowly where gravity is at its strongest, allowing for spacetime to warp. In this, time shifts with both mass and velocity, and is thus different at every point in the universe. Yet even spacetime, Rovelli suggests, is a simplification. He maintains that reality, as we experience it, is just a complex network of events onto which we project a subjective idea of past, present, and future. (trans., Simon Carnell and Erica Segre, New York: Riverhead Books, 2018)

DOUG: So, from the perspective of not that long ago [laughter]…

JENN: Yes, not as long as the universe at large, but still deep! [laughter] In particular, I wrote about the work of Canadian artist Meghan Price. She was making a tapestry based on an illustration from a book written by the eighteenth-century Scottish geologist James Hutton, considered the first book on geology. Meghan was particularly interested in geological unconformities, which reminds me very much of what you refer to as astral 'smudges'. Doug, I recently listened online to your artist's talk for the launch of *Light Echo* and heard you speak about your research on light echoes, which was very informative. I love the idea of astral 'smudges' or 'noise'—it reminded me immediately of unconformities. An unconformity does not represent 'missing time'. It is the anomaly, if you will, that makes you pay attention to a shift in time. I imagine that one of the challenging aspects about research in astronomy is the mass collection of data, which is only raw information until you read it, until you know what you're looking for. Maybe you don't even know what you're looking for, but you have to be able to recognize the sign posts along the way.

DOUG: Exactly.

JENN: And then, of course, there's the phenomenological reading of time, which is much more in my wheelhouse as an anthropologist. The idea that people are not *in* time, they *are* time. That is, Heidegger's sense of time, that we embody time. It is not something separate from us, it is something that *is* us.

DOUG: Something that we experience.

JENN: Exactly. So, after that lengthy explanation, what do *you* think about deep time? [laughter]

DOUG: It's interesting, obviously I share a lot of those same mantras. For me, my whole universe took this huge step when I was about eight years old and I was given my first telescope. I realized that the world that everyone was experiencing was just this tiny capsule of what is out there. And what is out there, we now know, works the same way, but is not the same at all. As you look further and further away, you see more and more fascinating variations of what the universe does. But you also recognize that things like life are inevitable. We do have one direct example for this—us! [laughter] In the greater scheme of things, the universe knows how to make life, and it does so fairly easily. So, then the question is, what does that do for us? How does that change the way we look back at the universe? Does it give meaning to our existence in some way that we value or not? And different people have very different reactions to that.

DIANNE: It's funny, I started reading a book called *The Order of Time* by Carlo Rovelli. It's been getting a lot of attention lately. Since he was a kid, Rovelli's been interested in researching time. I brought my copy of it here with me. One of my peeves as a photographer who's always

been a sort of 'anti-photographer photographer,' is the whole idea of the 'decisive moment'. It has always bothered me because I don't like the idea of freezing things in time. To me, it isn't an accurate representation of how we live and how things happen. I feel like photography is a technology that probably came out of the spirit of painting, of freezing things so you could preserve them. But in terms of the representation of the world, things are moving through and we're less in one place than we think we are. I can verify this when I take a pinhole photograph and everyone disappears. This is evident in some of the earliest photography. For example, one of the first daguerreotypes was taken on a busy street in Paris. But the only human visible, is the one person standing still—the guy with his foot up, having his shoes polished.

As a musician, when I first discovered pinhole photography, I felt that the images were more like pieces of music, representing passages of time. I'd make jokes about pinhole, like this is how a tree sees the Earth, or a rock, or something. [laughter] But then I come across Rovelli, and he says exactly that—that time is action, that time is a flow like music. And I thought, "Wow!"—because he was describing time in a similar way to how I was feeling.

DOUG: H.G. Wells deeply understood time and actually has this wonderful sequence near the end of his book *The Time Machine* where he's basically doing pinhole photographs.

DIANNE: Really? That's amazing.

JENN: I love that you brought music into the conversation because music not only embodies a duration of time and the way it unfolds, but time is embedded in music's very composition and the way it is constructed.

Sound is one of the things I keep thinking about with regards to light echoes. Doug you said something earlier that resonated with me, that "light is the universe's memory." I'm interested in how an echo builds an image, both visually and aurally. It calls to mind the recent photograph that's been constructed of a black hole event horizon. It's different kind of image making—from radio waves. It leads us to ask: How do we construct a singular image with multiple apertures? How do you coordinate multiple perspectives to come up with something that is, in that moment, singular?

Also, Dianne, to return to what you were saying as a photo-based artist, how do we resist that 'capture'? With pinhole photography and camera obscuras, the camera doesn't have to capture, it doesn't have to contain film. It's more about the optical phenomenon, however fleeting, that it creates.

DIANNE: Yes, I'm increasingly interested in creating walk-in environments now. In 2018, as part of *The Midnight Sun Camera Obscura Project*, I built a multi-aperture room called *Star Shed* on the McMaster campus, where pinholes in the walls mirrored what

Invented by French artist Louis-Jacques-Mandé Daguerre (1787-1851), a daguerreotype is a unique photographic image on a highly polished, silver-plated sheet of copper treated to make it light sensitive. It was the first publicly accessible photographic process, developed by the artist as a way to capture the fleeting images observed in his camera obscura (a wooden box with a lens at one end and a frosted sheet of glass at the other). One of his earliest daguerreotypes was an image known as *The View of the Boulevard de Temple*, which was taken in 1838 from his window in Paris, overlooking the busy street below. The long exposure time (ten to twelve minutes) failed to capture the motion of people and traffic, giving the illusion of an apparently empty street. The only visible humans are a shoeshiner and his client, standing still long enough to be photographically captured.

The Time Machine by H.G. Wells is a classic science fiction novella about time travel, first published in serial form in 1895. Wells was the first to describe a 'time machine', which has since become a staple in futuristic science fiction books and films. The novella tells the story of an inventor, the Time Traveler, who builds a time travel device in which he journeys to the year 802,701. Reflecting Well's socialist political leanings, the future society is divided into the unproductive surface-dwelling leisure classes, the Eloi, and the oppressed underground-dwelling working class, the Morlocks. Having no other means of sustenance, the Morlocks surface at night to feed off of the Eloi. Narrowly escaping, the Time Traveler briefly returns to his own time period, before embarking on a journey 30 million years in the future, where he encounters a dying Earth and the last living creatures.

In astrophysics, an event horizon marks the edge or boundary of a black hole—a point of no return—beyond which nothing, not even light, can escape, and where time dilation becomes infinite. A black hole is not empty space, but rather a massive amount of matter condensed into a very small volume. Its mass is concentrated into a singular point deep in its core which cannot be seen. Black holes are usually formed from the remnants of a giant star from a supernova explosion. Astronomers can only infer the presence of a black hole by examining their effect on nearby matter; it cannot be observed directly with telescopes. However, in April 2019, scientists released the first photos ever taken of an event horizon by coordinating radio wave data captured in 2017 from eight radio dish telescopes across five continents (1.3 millimetres in wavelength, invisible to the naked eye). The collected data was synched within a billionth of a second and processed by a supercomputer for almost two years to create the images.

was happening in the sky during the day. We don't often think about stars during the day. However, in this work, the Sun created a pattern of constellations as they would be seen in the Southern skies. The light would bounce off of objects in its path, basically creating this kaleidoscopic image of the surrounding environment on the shed walls, projected upside-down and in reverse.

When I make one of these chambers, I make multiple holes, and each hole has a different perspective, so the echo is created from different angles. As with a hologram, you create a 3D image. You could take that information and probably put it together in a computer program to create a 3-dimensional object.

I was a facilitator at a residency called *Slow-Mo* in the Banff Centre for the Arts a while ago, and the topic was time, so I had Doug came out to talk…

DOUG: …to give a physicist's interpretation on how we measure time and aspects of time that people don't often appreciate.

DIANNE: It really opened my eyes to alternative ways of seeing light and working with it in a different way—in some ways trying to pull it apart. It made me think about cameras. I hated photography initially because I kept thinking, "Here's a device that has everything measured out for me—the f-stop, the shutter speed, and so on. But I want to control that stuff, and maybe I don't even want one lens, etc." So, when I realized

Dianne Bos installing *Star Shed*, 2018, mixed media camera obscura installation at McMaster University, *The Midnight Sun Camera Obscura Project* curated by Josephine Mills, image courtesy of Dianne Bos

Dianne Bos in *Star Shed*, 2018, mixed media camera obscura installation at McMaster University, *The Midnight Sun Camera Obscura Project*, curated by Josephine Mills, image courtesy of Dianne Bos

that you can make a camera pretty easily, it was a real epiphany. The first pinhole I made was in 1979—and it was an image outside in the garden by Gairloch Gallery in Oakville. I had just got a job there after I graduated from university. I set up the camera and opened the shutter for about twelve minutes. I just guessed. It was a foggy day and people were moving through the park. When I developed the image, I thought "Oh my God. This is a passage of time. I can relate to this." If that one image hadn't turned out, I probably would never have done all this! [laughter] There was a 50/50 chance it wouldn't have worked. At that point too, it was pre-internet. There were two funky little books on how to make pinhole cameras and you communicated with people by mail. In a way, the whole advent of new technologies has changed the way people look at the 'low tech'. There's been a kind of revival—the 'slow movement'.

JENN: Pinhole is an ancient technology and can occur naturally. During eclipses, for example, or with sunlight filtering through the leaves of trees onto a sidewalk. It happens all the time!

DOUG: Yes, one of the things I love to do is go out hiking, and very early on as an amateur astronomer, I realized that when you walk across the forest floor you see all the overlapping solar images—those are all pinhole images of the sun from the light coming through the trees…

DIANNE: Aristotle wrote about it. They don't have to be holes, it just has to be an aperture of some sort. The thing that verifies that these are images of the sun is that when there is an eclipse you see a whole bunch of eclipses on the ground.

In the fourth century, the Greek philosopher Aristotle (384-332 C.E.) described the pinhole effect of light from a solar eclipse passing through the gaps in the leaves of a tree, projecting images of the eclipsed sun on the ground. His observations are recorded in his work *Problems XV*: "Why is it that an eclipse of the sun, if one looks at it through a sieve or through leaves, such as a plane-tree or other broadleaved tree, or if one joins the fingers of one hand over the fingers of the other, the rays are crescent-shaped where they reach the earth? Is it for the same reason as that when light shines through a rectangular peep-hole, it appears circular in the form of a cone?"

Arab mathematician and physicist Ibn al-Haytham (Latinized in the West as Alhazan) (965-1040) is credited with inventing the camera obscura and was the first to provide an accurate geometrical analysis of an image projected through a pinhole. In his seven volume *Kitab al-Manazir* (*Book of Optics*) written between 1011-1021, he was also the first to explain that vision is processed by the brain, occurring when light reflects off an object and then passes through the eyes. The treatise was translated into Latin at the end of the twelfth or early thirteenth century and went on to influence countless scholars through the ages including Leonardo da Vinci, Galileo Galilei, Réné Descartes, Johannes Kepler, and Isaac Newton.

Plato's cave is a theory of perception put forward by the Greek philosopher Plato in his work *The Republic* (380 B.C.E.), in which he draws a distinction between people who mistake empirical observation for truth and those who recognize that real knowledge can only be known through philosophical reasoning. It is written as a dialogue between Plato's brother Glaucon and his tutor Socrates, who narrates an allegorical story in which three prisoners, who have spent their entire lives in a cave, observe the shadows of passing animals and people cast on the cave wall. Since they know nothing of the outside world, they perceive the shadows as real. They play a game in which they guess which shadows will appear next, and the one who guesses most accurately is called a 'master of nature'. One prisoner eventually escapes and is shocked by what he discovers, realizing that his former world view was wrong. He recognizes the Sun as the source of life and returns to the cave to share his discoveries. But the other two prisoners refuse to believe him and threaten to kill him if he sets them free. Scholarly analysis generally interprets the story through an epistemological lens or a political one.

DOUG: When we had the partial eclipse recently, I brought solar filters so people could look at it directly. But what people loved most, were the crescents formed by the tree pinholes..

DIANNE: They're so sharp too! It's kind of amazing—the fact that we're surrounded by images of the sun. It's almost religious! [laughter]

DOUG: On a clear day, you're still seeing overlapping images of the sun. They all overlap so it looks like they're all constant.

DIANNE: I have a theory too about how long people have been observing that. In the tenth century, an Arab physicist named Alhazan made a camera obscura. There were also discoveries in China. But I think it was recognized much earlier, when people took shelter in caves, and so on. For sure someone threw an animal hide over a tented entrance with a spear hole pierced in the side, and they're sitting there as the sun rises and going, "What the…?!" [laughter] Plato's cave is not just a metaphor… You know, I've been waiting. My hope is to find a cave drawing for it! [laughter] It will happen! It will prove me correct!

DOUG: Yes, then a bunch of people went out and hung their animals upside down so they'd be right-side-up when they painted them! [laughter]

DIANNE: Even better! [laughter]

I want to go back to Rovelli, for a moment. His big idea is that there is a difference between things and events. I'd like to read this quote from *On the Order of Time*:

> *We cannot think of the physical world as if it were made of things, of entities. It simply doesn't work. What works instead is thinking about the world as a network of events…*
> *A few examples: a war is not a thing, it's a sequence of events. A storm is not a thing, it's a collection of occurrences. A cloud above a mountain is not a thing, it is the condensation of humidity in the air that the wind blows over the mountain. A wave is not a thing, it is a movement of water, and the water that forms it is always different. A family is not a thing, it is a collection of relations, occurrences, feelings. And a human being? Of course it's not a thing; like the cloud above the mountain, it's a complex process, where food, information, light, words, and so on enter and exit.… A knot of knots in a network of social relations, in a network of chemical processes, in a network of emotions exchanged with its own kind. For a long time, we have tried to understand the world in terms of some primary substance. Perhaps physics, more than any other discipline, has pursued this primary substance. But the more we have studied it, the less the world seems comprehensible in terms of something that is. It seems to be a lot more intelligible in terms of relations between events.*

I keep thinking of this all the time, trying to envision all of these elements interacting.

JENN: I agree with all of this. At the same time, I think we sometimes have a desire to pause time, to capture a moment even though we recognize that the moment is an event-in-flux, the fleeting click of a shutter. I think this is part of the seduction of photography for many people—not for everyone, perhaps, but for some. It's a desire to hold onto something a little longer because time is relentless.

DIANNE: I know! But I keep trying to think about *why* we want to stop time. Is it something learned or ingrained? Do chimpanzees want to stop time? Do any other species actually think of that? I think about other cultural perspectives. In traditional Islamic art, for example, the depiction of living beings was forbidden. If the camera was developed based on that philosophy, the whole idea of taking pictures of people may not have been a desire at all. It could have been completely taboo.

In Islamic art, the practice of avoiding the representation of living beings is known as aniconism. In part, it originates from the prohibition against idolatry and the belief that only God should create living forms. While this restriction is not overtly stated in the Quran, it appears in the Hadith, a record of the actions and sayings of the prophet Mohammed. Although there are varied interpretations of this proscription in different parts of the world, traditional Islamic art has largely focused on calligraphic and geometric patterns and forms historically.

DOUG: There are choices.

DIANNE: Yes, exactly. I wonder if some of our beliefs are just that we're trained to see the world in a certain way, while other things remain invisible to us? When Doug goes outside and looks at pinhole images of the Sun on the ground, he knows he's seeing dappled light and how it works. You can point that out to somebody and they're blown away by it.

JENN: I'm wondering if you could talk about that moment of recognition? With light echoes, for example, how did you know you were seeing something significant and not just a 'smudge'?

DOUG: Yes, it was very exciting! It was also a discovery in which the whole group had assembled various pieces of information. It wasn't just one person drilling all the way down to the answer on their own. Somebody had to compile the list, somebody else had to plot it, somebody had to measure things and figure out roughly how fast they appeared to be moving in the sky. Another realization was that this could have been done a long time ago; we've had the ability to make the discovery of light echoes for ages, but people loved summing their compiled images, not differencing or subtracting them.

JENN: Can you explain the subtraction process involved in creating the images?

DOUG: When you take an image of the night sky from the Earth, in particular, it gets blurred out a lot by a whole variety of factors, mainly because the air in the atmosphere is bubbling a little bit all the time. It inserts this motion so that you only see the true corrected image over about ten centimetres. If you have a big telescope, it's going to mix up all those motions so that you get this blurry star showing up in the focal point of your imager. So, we take exposures, we make sure we get rid of all the instrumental effects, and then we come back another time and take another exposure. We see all the stars essentially as perfect pin pricks that are smoothed out by whatever the bubbling in the air was that night. So, we have to take into account all the slightly different

shapes of the stars in the two separate images, and then we make it so that they all have the same total amplitude, the same brightness, and then we subtract them. And all of the constant stars go away, and only the objects that have changed in the image are left to notice.

In the past, that method has been used for things like discovering minor planets, or discovering comets, because they would have moved with time, or supernovae in other galaxies… But what was really strange about our particular discovery, was this was a motion on the sky that was huge. Motions on the sky that are huge only belong to our Solar System normally. But the way supernovae are formed meant that we could see on very short time scales—years, months—where this blurry smudge had apparently moved its position. The dust itself wasn't moving its position, it was the illumination that was changing its position. The dust was staying exactly where it was all the time. This would have been a big enough effect that you could have documented it photographically for about the last hundred years. You could even have arguably done it in the dark room. Some things add more noise, and some things reduce noise. Sometimes, it turns out that your signal is the noise! [laughter]

JENN: When you're looking at these images, are you analyzing them visually or mathematically—or both simultaneously?

DOUG: We have to do both. Using modern imagers, we have to process these things with the computer, but we have not yet discovered a good way to identify them automatically. I have a former student now in the Masters program at Guelph, who is taking some of our light echo images and trying to find a decent way to identify them automatically. It's a big problem because no two of them look alike.

DIANNE: Astronomers don't observe the sky…

DOUG: No, they don't look at the sky anymore.

DIANNE: Which is just sad. [laughter] You're one of the few who do! You have a nice telescope at home, but some of your work involves visiting the world's great telescopes.

DOUG: Yes, but as they develop bigger and bigger telescopes, it becomes more and more automated and the data is getting better and better. In some sense, that's the way it should be. We wouldn't have been able to do any of this by eye on the spot at the time. We very much needed these big computers, these huge amounts of data. The project I was doing that led to this, has a terabyte's worth of images, and so without that processing power, we could never have gotten to the stage of seeing the differences with our eyes alone. But I have had several graduate students that actually have found things just by looking at the difference images because that's the most efficient way so far.

DIANNE: It's amazing. But you often go to visit these massive telescopes.

Dianne Bos, *The Sleeping Green. No man's land 100 years later, Hill 62, Earth to Sky*, 2015-2019, chromogenic print, 1/1, image courtesy of Dianne Bos

DOUG: More and more it's to be on a Board of Directors. [laughter] I have been to both Hawaii and Chile about fifty times each. I love Chile especially because you get the Andes around you, and it's just spectacular to be in a dark site in the Southern Hemisphere where the sky is so endless.

JENN: I have read that the sky in the Southern Hemisphere is vastly understudied compared to the Northern Hemisphere, at least in terms of the historical records. This is interesting in terms of reading the sky—and its differences—and also in terms of how 'the selection bias' affects what you see.

DOUG: Very much so. You recognize that, in some respects, the people who were not in Europe or Western countries probably ended up paying a lot more attention to the sky and understood its variations much better historically. It's certainly the case that the supernovae we detected in the Large Magellanic Cloud, which were among the first ones we saw, were visible to the naked eye six hundred years ago, and there were tens or hundreds of thousands of people who saw them—unlike many of the supernovae from the Northern Hemisphere in more recent times, and even at the same time. The connections to the universe and with anything in the sky were stronger in the Southern Hemisphere, where people weren't hiding out in castles and forts… [laughter]

One of two irregular dwarf galaxies orbiting the Milky Way, the Large Magellanic Cloud (LMC) is a prominent feature in the Southern Celestial Hemisphere, along with its sister galaxy, the Small Magellanic Cloud. The LMC is one of our closest galactic neighbours, 163,000 light years from Earth. It has been observed for centuries by Indigenous peoples in Australia, Africa, and South America, and is depicted in ancient petroglyphs from the Atacama desert in Chile. The LMC was described from the first millennium in Western Asia, and from the sixteenth century in Europe.

JENN: You have said, Doug, that when you go out in the world, you find things. You have to be experiencing things, to see things. A lab record isn't necessarily an indication that something has been seen or understood.

DOUG: Yes, very much. One of the things I wanted to bring up that I never hear described, is that people are very fond of talking about how we experience the universe, but if you start understanding how light bends and bounces off many things, and how it is behind our ability to see anything, you start to see the world differently. I'm seeing you because there was a light echo bouncing off of you a couple of billionths of a second ago. But as you ramp up towards the speed of light, all sorts of things happen, and one of them is, as you close in on the speed of light, the whole universe gets focused down into a point of light right in front of you. So, in some respects, it's the ultimate pinhole! [laughter] I don't know if you remember from *Star Wars* when the Millennium Falcon makes a leap to hyperspace, all the stars streak out like this… But it actually goes the opposite way, all the stars streak in towards this point directly in front of you—and directly behind you, but behind you is so red-shifted that there's no light left. If you're going very close to the speed of light—if you're a photon—you arrive when you leave.

In physics, a photon is an elementary particle, representing the smallest discrete amount or quantum of electromagnetic radiation, such as light and radio waves. Photons are always in motion, travelling at the speed of light in a vacuum. They have zero mass and rest energy, and may be created or destroyed when radiation is absorbed or emitted. Although the concept of light particles had been around for centuries, the term photon was not coined until 1926 by physical chemist Gilbert Lewis.

JENN: I feel like that all the time actually! [laughter] I recently watched the film *Clara*, for which Doug was a science advisor. It made me think of your collaboration because, in a way, the film is about reconciling the artistic vision with the scientific vision and learning how to see differently. In truth, believing that these two disciplines are not naturally in sympathy with one another is more of a modern affliction or hurdle than a historical one. But it occurs to me that the desire to imagine possible futures is often associated more with the arts than the with the empirical sciences. However, it must be a strategy that you employ in science as well because you are making educated assumptions about possible outcomes, while looking towards something that perhaps hasn't yet been discovered or hasn't been experienced. What role, for both of you, does that 'speculative impulse' play in the work that you do?

Written and directed by emerging Canadian filmmaker Akash Sherman, *Clara* (2018) is a romantic science fiction film telling the story of a cynical astrophysicist, Isaac, who searches for signs of intelligent extraterrestrial life with the assistance of a struggling artist, Clara. Focused on the dynamics of this unexpected collaboration, the film explores themes of personal loss, creative vision, and existential angst through the lens of quantum time.

DOUG: I would say that one commonality is that you have to be a good observer. There are tensions in fields like physics that conduct simulations to learn about interactions that are not obvious to tease out—and, of course, it's a discipline that encourages you to observe things whenever you can. But unless you are a really good observer, like a good artist or an anthropologist, you don't see the new things with simulations. There's a wonderful saying—"simulations are doomed to succeed". [laughter] You only get out what you put into something, basically! If you haven't asked a big enough question, you don't gain new insight from a simulation—it will always be missing something. It's very much like our experience of being an observational scientist or an artist—you have to understand the limits that are put on what you are attempting to understand. If you're out painting in a field, the light is shifting during the day, and if you're painting inside, the light is likewise a different colour at different times of day. And the light in

the arctic is very different than the light at the equator. So unless you're primed and understand your limitations and what is being revealed to you, you don't see the discoveries, even though they're there to be made.

DIANNE: Yes, and also there's the problem of looking past something. To see the light echo, for example, you had to recognize that it wasn't just an aberration. Because you weren't looking for it, you initially didn't see it.

DOUG: It was turning up so often, we had to figure out what it was. When we did our first work in a nearby galaxy, which was still pretty far away, we said, "well, if we can do it there, we must be able to do it in the Milky Way, where motions would be much faster on the sky." When we got our Milky Way data and looked at it, there were light echoes in 5% of our images!

DIANNE: That is amazing! Thinking about shared interests, the other thing we have in common is our mutual love of science fiction writing and movies.

JENN: That's a great segue from speculation! As Doug was saying, for speculation to work for you, you have to draw on experience. With science fiction, although it is speculative, it's based on what we already know. It predicts based on experience. There's also a separate question here about the role of fiction in science, in terms of a field of practice…

DIANNE: Well, Doug likes really bad science fiction, which you wouldn't expect! [laughter] It always shocks me. He's a very generous reader! There are some parodies of sci-fi films, which he loves—*Galaxy Quest*, for example…

JENN: It's his outlet from the serious science! [laughter]

DOUG: It's like, we're all going to die soon enough anyway! [laughter]

JENN: A lot of science fiction is dystopic or apocalyptic—what does that say in terms of our vision and expectations of the future?

DIANNE: Pretty accurate! [laughter] With the science fiction that's coming out, we have enough vision to imagine it developing into something, which it often does. With writers like William Gibson, for example, you sometimes wonder how much his writing influenced people in certain directions, even though it was still fiction when he was writing it.

I was making a list of the books that I like and they're all books that deal with time in really interesting ways—whether it bounces back and forth like *Cloud Atlas*, or it does things that ends up meshing points of time together. I was also thinking about one of the books that Doug told me about way back when, by Neil Stephenson—*Snow Crash*. I read a lot of Neil Stephenson. His latest one came out in 2015, called *Seveneves*. They're epically huge books. But *Seveneves* is a really interesting

Galaxy Quest is a 1999 science fiction comedy film, starring Tim Allen, Sigourney Weaver, Alan Rickman, Tony Shalhoub, and Sam Rockwell. It follows the story of a group of washed up television stars of a 1970s sci-fi show, scraping a living together from re-runs and sci-fi conventions. They are abducted by aliens who, believing the show depicted real events, recruit the actors to help defeat the oppressive regime ruling their own Solar System. A parody of sci-fi series such as *Star Trek*, the film has achieved cult status.

William Gibson is an American-Canadian science fiction writer, credited with pioneering the genre known as 'cyperpunk'. His early work in the 1970s focused on near future technologies, cybernetics, and computer networks prior to the invention of the World Wide Web in 1990. Gibson was the first to use the term "cyberspace" to refer to the interconnected networks of digital technologies, a concept popularized in his 1984 debut novel *Neuromancer*.

Written by David Mitchell, *Cloud Atlas* is a speculative fiction novel set in multiple geographical and temporal frames. Published in 2004, the narrative consists of six entangled stories, spanning the nineteenth century South Pacific, 1930s Belgium, 1970s California, present-day Britain, futuristic dystopian Korea, and post-apocalyptic Big Island of Hawaii. Centred on the theme of reincarnation, the novel won the British Book Award for Literary Fiction and was shortlisted for the Man Booker prize. *Cloud Atlas* was adapted for film in 2012, starring Tom Hanks, Halle Barry, and Jim Broadbent.

Published in 1992, Neil Stephenson's science fiction novel *Snow Crash* takes place in twenty-first century Los Angeles following a global economic collapse. Private corporations have taken over governments world-wide, and global capitalism has gone rogue. Within the Metaverse, a collective virtual space, the main character (a hacker, named Hiro Protagonist) is offered a datafile called Snow Crash. It contains a DNA altering virus with real-world implications. Connected to the legend of the Tower of Babel and computer coding based on the ancient Sumerian ur-language, it allows brain function to be programmed. The novel helped popularize the term 'avatar' and influenced the development of several virtual globe programs, such as Google Earth.

speculation about an asteroid hitting the Moon and shattering it. It's bad for the Earth because they realize that all these bits of the shattered Moon are not going to stay up where they are; there's a time frame of when it's all going to rain down onto Earth. The book looks at all these different scenarios, like if the Earth inevitably just becomes a flaming fireball, where can people go to survive for 5,000 years because they figure it will take that much time for things to calm down enough to live. So, some people go into space because technology is advanced enough, but how do you live in space for that long? And then some go underwater, and some go into caves…

DOUG: You know that's a fairly similar idea to the beginning of *Rendezvous with Rama*.

DIANNE: Oh yeah?

DOUG: Yeah, I loved *Rendezvous with Rama*. It took me some time to realize that the 'lead in' was also very interesting. The idea is that there was some big impact on the Earth, which was fairly disastrous but not big enough to wipe out the species. So, they decide to start monitoring the sky for other possible collisions, which is something that has been happening in the last 30 years very intensively, and they pick up on this object that obviously is coming from interstellar space. The beauty of Clarke's vision is that the characters go in thinking "this is all about us", but then it turns out that it's just this thing passing through that was going close to the Sun so that it could get some more energy and grow some more plants, and now it's going back out into space! It's not about us at all! [laughter]

JENN: Well, we struggle with that—not seeing ourselves as the centre of the universe! [laughter]

DIANNE: Well, it's like that strange asteroid that came leaning by the earth, you've probably heard about it?

DOUG: Yes, Oumuamua. I actually have a close connection with the guy who discovered it—Robert Weryk. He's now in Hawaii, but he was at the University of Western and we put together a bright meteor camera…

DIANNE: What do you think about all the people speculating about what it is? Because it's not a straightforward shape—it's not a ball and doesn't look like other asteroids. It's like a long splinter. Well-known scientists are speculating that it could be one way to travel from another galaxy.

DOUG: It's a completely reasonable thing to suggest and I think astronomer Avi Loeb knew the story would be picked up widely so why not bring it up? There's clearly stuff out there, going between the stars. You can examine all the possible reasons why and then figure out how to test them.

DIANNE: It's a weird pattern that it's coming in on…

First published in 1973, *Rendezvous with Rama* is a science fiction novel by Arthur C. Clarke. The story follows the detection of a massive cylindrical object (54 kilometres long and 20 kilometres in diameter) heading towards the sun, in the year 2131. Sent to investigate, a team of explorers from Earth discover the peaceful alien world of Rama on board the spacecraft, including a towering sea with cities dotted around the circumference. Some drama unfolds when colonists from Mercury perceive the foreign spacecraft as a threat and send a nuclear missile to detroy it (defused by the Earth explorers). Eventually the Earth voyagers disembark, and the Rama ship exits the Solar System in the direction of The Large Megallanic Cloud. Several sequels followed the book's release. It remains one of Clarke's most celebrated works.

Discovered on October 19, 2017 by Canadian astronomer Robert Weryk, Oumuamua (designated 1I/2017 U1) is the first known interstellar object of its type to be detected in our Solar System. The object has attracted wide speculation and debate due to its curious characteristics, including its unusual spin, its unusual, very asymmetric shape, and its unexpected trajectory. While some contend it's a natural object, Harvard astronomers Shmuel Bialy and Avi Loeb have suggested that Oumuamua could be an extraterrestrial solar-powered lightsail or a probe created by an alien civilization. Observed using the Pan-STARRS telescope in Hawaii, the object's name originates from the Hawaiian words 'ou' meaning 'reach out for' and 'mua' meaning 'first'. Before this, the name Rama was considered, after Arthur C. Clarke's classic sci-fi novel *Rendezvous with Rama* (1973) about a mysterious interstellar spacecraft.

Abraham (Avi) Loeb is an Israeli-American theoretical physicist, specializing in astrophysics and cosmology. He is the founding director of Harvard University's Black Hole Initiative, the first interdisciplinary centre dedicated to the study and understanding of black holes. In October 2018, Loeb co-authored a scientific paper with Shmuel Bialy on an unusual interstellar object known as Oumuamua, attracting wide-spread attention in the popular media for his speculation that the object "may be a fully operational probe sent *intentionally* to Earth's vicinity by an Alien civilization." (Shmuel Bialy and Abraham Loeb, "Could Solar Radiation Pressure Explain "Oumuamua's Peculiar Acceleration?", *Astrophysical Journal Letters*, 868(1), November 2018).

DOUG: Yes, it's called a hyperbolic orbit. It's not bound to any particular star.

DIANNE: So it doesn't go around the Sun right?

DOUG: No, it's scattered by the Sun and it will do so many millions of years off some other random star. Much like Rama! [laughter]

JENN: As an astronomer, what's your take on the possibility of encountering an exoplanet that supports life? And in relation to this, can you explain Fermi's paradox?

DOUG: Yes, those two things are related, but it's certainly the case that there are planets out there that will develop life and have developed life. All those things are basically inevitable. We now know, which we didn't know 30 years ago, that every single time you build a star you build planets. So, there are way more planets than what we thought there were even twenty years ago. Some of them are going to be at the right distances from the star and will have liquid water and very similar sets of chemistry to the Earth. They're out there.

The Fermi Paradox states that if intelligent wayfaring life developed on any of these planets, it would very quickly colonize the whole galaxy or another galaxy, but probably not between galaxies. And if you statistically work through a reasonable set of numbers then you would think, "Well, where are they?" If such extraterrestrial life exists, we should see evidence for it. It's not an unreasonable question at all, but it does have a bunch of suppositions on it. I think it indicates a very interesting colonial mind set, for instance. [laughter]

DIANNE: Recently they've discovered a site related to the big asteroid that hit Earth at the end of the Cretaceous Period, 66 million years ago that wiped out all the dinosaurs. Paleontologists found a place in North Dakota that shows evidence of a giant wave action event that occurred after the main impact. It shows the fossilized remains of fish, mammals, dinosaur bones, burned trees, etc., all piled up on top of each other.

DOUG: Yes, and they found tektites, remnants of molten material from the Earth that was heated to the point of being liquid then cooled into tiny glass beads. It didn't hit escape velocity, so it came back down to Earth pretty quickly, and embedded in fish and other lifeforms.

DIANNE: It's embedded in their gills. When that asteroid hit, debris flew up off the Earth and landed on the Moon. They say that stuff may have even landed on Mars from the impact.

DOUG: Mars is more of a stretch… Maybe Venus. It's easier to get to.

DIANNE: Yes, so that's one way that material from Earth could get to other planets in our Solar System. It's possible other life forms could evolve that way if there were the basic elements of life…

In astrodynamics, there are two types of orbits: bound and unbound, determined in relation to solar and/or gravitational forces. A hyperbolic orbit is the unbound trajectory of an object around a central body, such as the Sun or a planet, with enough speed to escape the central body's gravitational pull. In the planetary system, all bodies larger than dust particles are subject to solar gravitational pull. As they get closer to planets, planetary gravity takes over, but the orbital characteristics remain the same. Objects on elliptical orbits are bound to the Sun, while objects on unbound, hyperbolic trajectories will eventually leave the Solar System. All hyperbolic orbits are also escape trajectories.

An exoplanet (or extrasolar planet) is a planet that orbits a star outside our Solar System. To date, there are over 4,000 confirmed exoplanets found in over 3,000 systems. There is a special interest in Earth-sized planets, as scientists search for signs of extraterrestrial life. It is estimated that approximately one in five Sun-like stars host an exoplanet. Using archived data from NASA's Hubbell telescope from 2016 and 2017, astronomers at University College London in the United Kingdom, have discovered a water vapour signature, as well as evidence of hydrogen and helium, in the atmosphere of a distant exoplanet known as K2-18B. The exoplanet was discovered by NASA'a Kepler telescope in 2015 and has a mass eight times greater than Earth's. The so-called "super-Earth" orbits a small red dwarf star in the constellation Leo and is the only planet outside our Solar System known to have water and the temperatures to support life.

Named after the Italian-American physicist Enrico Fermi, the Fermi Paradox asks—Where are all the aliens?! Legend has it, that this question was first asked by Fermi in the 1940s in casual conversation with fellow physicists. Fermi speculated that if there are billions of Sun-like stars, billions of years older than our Solar System, there is a high probability that they contain planets capable of supporting intelligent life. Some of these should have a reasonable knowledge of rocket technology and therefore should be able to rapidly colonize the entire galaxy. The paradox is that there is no evidence of this. Astrophysicist Michael H. Hart expanded further on this idea in a 1975 paper. Explanations for the lack of evidence of extraterrestrial life include such arguments as: it is extremely rare to find the exact conditions to create, support, and evolve life; OR advanced civilizations go extinct quickly; OR extraterrestrial life is out there, but we cannot see it. Yet.

Tektites are small natural silicate glass objects formed by molten terrestrial debris from the rapid heating and cooling of quartz-rich rocks resulting from meteorite impacts. The earliest recorded descriptions of tektites were written by Liu Sun in China in about 900 B.C.E.

DOUG: Here at McMaster University, astrophysicists have teamed up with the soft matter specialists at the Origin of Life Lab and are beginning to do experiments to see what specific combinations and conditions produce life. This is just one of those things where it's just amazing to be alive. It's happening in our lifetime.

In terms of exoplanets, *Clara* was a really fun experience for me.

JENN: Yes, I thought the story of an astronomer collaborating with an artist was a noteworthy art/life parallel. [laughter]

DOUG: There was an earlier piece of science fiction that I thought the Director had possibly drawn from called *Timescape*, which basically makes use of entanglement for similar purposes.

JENN: Perhaps you could explain entanglement further from a deep time perspective? My understanding is that it's a theory that is trying to solve the problem of time…

DOUG: Yes, it's trying to get around the practicalities of time… [laughter]

JENN: Exactly, by allowing two different photon particles to share an existence despite being separated physically, and neither can be described without entangling the other in the description.

DOUG: That's probably as good as how I would explain it! [laughter]

JENN: I had to read it over many times before I got my head around it. [laughter] But in a way, the impetus behind this entire conversation has been around such entanglements, whether it's in the broader universe or whether it's in the sense of collaboration. But I think that *Clara*, to get back to your point, is interesting—though maybe the end was a bit of a stretch with the Bob Dylan. [laughter]

DIANNE: Oh my God, I've got to see it now!

JENN: I won't give it away…

DOUG: One of the wonderful things about *Clara*, and we were talking about this earlier, is that they understood the spirit of not following the herd, not sticking with the simulation, and looking for the things that nobody else is really sensitive to looking for. It's not just a good idea, it's that extra element of creation that wasn't available to one of a hundred other different people.

JENN: Einstein said that creativity is "combinatory play", that it's about making connections. A number of other people have stated similar ideas, including Steve Jobs who said that creativity is really just the ability to make connections between things. I like that idea. That's what an artist does, you are looking for the anomalies all the time, the unconformities, the connections, and conveying them in some way.

Published in 1980, *Timescape* is a science fiction novel by American author Gregory Benford. The story is written from two equidistant points in time: 18 years after the book's publication (1998) and 18 years prior to the book's publication (1962). In the future apocalyptic timescape, the Earth is laid waste by ecological and socio-political disasters and is on the verge of mass extinctions, prompting a group of scientists to attempt to warn people in the past using tachyon technology. The 1962 timeline focuses on a young scientist at the University of California, San Diego, who discovers a source of noise in a physics experiment that turns out to be Morse code. This coded message from the future is designed to warn the past without creating a paradox in the future in which the warning becomes redundant.

Born Robert Allen Zimmerman in 1941, singer-songwriter Bob Dylan is one of the most iconic figures of the 1960s and continues to influence contemporary music and pop culture. He is best known for his folk songs of peace and civil liberty, such as "Blowin' in the Wind" (1963) and "The Times They Are A-Changin'" (1964), which became anthems for both the civil rights and anti-Vietnam War movements. Dylan received the Presidential Medal of Freedom in 2012. In 2016, at the age of 75, he was the first musician to be awarded the Nobel Prize in Literature.

Renown as the theoretical physicist behind the theory of relativity, Albert Einstein (1879-1955) believed in the "combinatorial" nature of creativity. In a letter written in 1945 to French mathematician Jacques S. Hadamard, Einstein writes: "taken from a psychological viewpoint… combinatory play seems to be the essential feature in productive thought—before there is any connection with logical construction in words or other kinds of signs which can be communicated to others." (quoted by Maria Popova, "How Einstein Thought: Why "Combinatory Play" is the Secret of Genius", *brainpickings*, 2013/08/14).

Steve Jobs (1955-2011) was an early pioneer of personal computers and the co-founder, with Steve Wozniak, of Apple Computers. In an interview with WIRED magazine in 1996, Jobs said that, "Creativity is just connecting things. When you ask creative people how they did something, they feel a little guilty because they didn't really **do** it, they just **saw** something. It seemed obvious to them after a while. That's because they were able to connect experiences they've had and synthesize new things… Unfortunately, that's too rare a commodity. A lot of people in our industry haven't had very diverse experiences. So they don't have enough dots to connect, and they end up with very linear solutions without a broad perspective on the problem. The broader one's understanding of the human experience, the better design we will have." (interview with Gary Wolf, "Steve Jobs: The Next Insanely Great Thing", *WIRED*, 02. 01. 96).

Dianne Bos, *The Sleeping Green. No man's land 100 years later, Hill 62, Earth to Sky*, 2015-2019, chromogenic print, 1/1, image courtesy of Dianne Bos

DIANNE: We're sensitive to them. Its more than even looking, connections pop up.

DOUG: Another thing that I've come to appreciate about art, partly because my wife is an excellent artist, is that you really need to make choices or draw out certain scales or aspects. You don't want to represent everything with the exact dimensionality and precision that everybody else sees. You want to create a new experience by reducing the palette or stretching the length of time over which the information is accumulated, etc. There are a lot of different choices you can make, and people don't appreciate that. A lot of people think, "Oh I just need a camera and I can produce good art. It only takes one choice." [laughter]

JENN: It's like trying to find the sculpture in a slab of marble. It's there, but you have to see it. I like something that you were both talking about at the beginning of the conversation—that, if it's coordinated just right, the world can become a camera. But you can also make the smallest thing become a camera, as well. It's seizing that moment or opportunity for noticing or experiencing something as you're seeing it.

DOUG: And even though you may have seen the same thing a thousand times, you need to recognize that one time when it's different. Seeing the new thing that a lot of other people may also have seen before but perhaps didn't appreciate.