



Astrobiology and the Ultraviolet World

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Abstract Astrobiology is normally envisaged as the scientific endeavor preoccupied with the search for life beyond Earth. What remains underappreciated, however, is that it is also a hotbed of transversal thinking. It links disciplines that have historically grown up in isolation from each other—such as solar physics, atmospheric science, dermatology, and ophthalmology (eye biology)—in remarkable ways. And even though these links may cast new light on the question of extraterrestrial life, they are an interesting topic of study in their own right. The present study illustrates this ethnographically, by using the angle of ultraviolet. Specifically, I focus on the ultraviolet spectrum to examine how astrobiologists look at celestial bodies, planetary atmospheres, the skin, and the eye. More generally, this article is a reflection on how outer space can be apprehended from a humanities perspective.

Keywords astrobiology, anthropology, art and science, ultraviolet

Introduction

Ostensibly, astrobiology is the scientific endeavor preoccupied with the search for life beyond Earth. What remains underappreciated, however, is that it is also a hotbed of transversal thinking. It links disciplines that have historically grown up in isolation from each other—such as solar physics, atmospheric science, dermatology, and ophthalmology (eye biology)—in remarkable ways. And even though these links may cast new light on the question of extraterrestrial life, they are an interesting topic of study in their own right. I aim to illustrate this ethnographically, by using the angle of ultraviolet. We are all familiar with UV as the radiation that causes sunburn, but UV-sensitive instruments also play a crucial role in the contemporary exploration of outer space. Technically, ultraviolet has a shorter wavelength than visible light (between 10 and 380 nm) and remains invisible to the human eye—it is, paradoxically, “invisible light.” Specifically, I focus on the ultraviolet spectrum to examine how astrobiologists look at celestial bodies, planetary atmospheres, the skin, and the eye. At first sight, there appears to be little overlap between the disciplines of astrophysics, atmospheric science, dermatology, and ophthalmology. New insights into the biology of the eye, the reasoning goes, are unlikely to lead physicists to revise their theories of the Sun. And what

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happens in the sky is assumed to be of an entirely different nature than what occurs in our skin. You could say there is a certain predisposed-ness to the core subjects of these four scientific fields: the Sun shines, the sky (with regard to ultraviolet) screens, the skin touches, the eye sees. To posit that the Sun sees or that the sky touches tends to be regarded as absurd and to claim that the eye has an intrinsic shine is bound to be dismissed as outdated.

The presumption is that there exists an obvious fundamental difference between such phenomena as a star, a planetary atmosphere, animal skins, and eyes. Yet this compartmentalization is beginning to founder; what remains understudied is that each of these respective things are always “an amalgam of the conceptual and actual,” as Stefan Helmreich has formulated it.¹ In a similar vein, others have noted that the traditional divisions between scientific disciplines seem to become much less neat in space research; my investigation here is thus embedded in a wider line of current research in the social sciences and the environmental humanities. In a pioneering article on the anthropology of outer space, Gisli Pálsson already pointed to intriguing similarities between the exploration of the cosmos and that of the genome, that is, “the universe within” our human bodies.² Comparing their idioms of voyaging and mapping, he has illustrated that the sciences of astrophysics and molecular biology are much more closely related than conventionally assumed, and he has underlined that this is not just because they use similar languages and metaphors. In a piece in which she outlines the contours of a political ecology of outer space, Valerie Olson has shown how environmental science spills over into astronomy; what is currently happening is the making of an environmental solar system, as she calls it—a heliospheric ecology.³ With her colleagues Debora Battaglia and David Valentine, she has proposed a “space-inclusive anthropology,” an endeavor that aims to expose anthropological questions to the environments of outer space and space-on-Earth⁴ (one thing astrobiologists and anthropologists have in common is their love for terrestrial fieldwork: the former often work in so-called extreme environments or analog sites that share certain features with Mars and/or other extraterrestrial bodies). The present study can be seen as my attempt to specify what such a space-inclusive anthropology might look like. And without spoiling my narrative, I can reveal it probably looks somewhat different from what you may have expected. At Cambridge I once went to a lecture where Bruno Latour developed this strange argument that contemporary science, at its best, exhibits many parallels with sixteenth-century forms of knowledge such as astrology and alchemy.⁵ When I first heard this I have to admit I was skeptical, but now I think there is something to it.

1. Helmreich, *Sounding the Limits of Life*, xvii.

2. Pálsson, “Lucy in the Sky.”

3. Olson, “Political Ecology in the Extreme.”

4. Battaglia, Valentine, and Olson, “Relational Space.”

5. Cf. Latour, “Attempt at a ‘Compositionist Manifesto.’”

To be clear: my intention here is not to critique the space sciences. I certainly do not mean that astrobiology is a modern form of astrology, but insofar as it emphasizes a whole new range of both literal and symbolical connections between macrocosm and microcosm the comparison is pertinent.

Before I start it is useful to delineate more precisely what I mean by astrobiology and to say a few words about my methodology. As a scientific field astrobiology is very much an interdisciplinary endeavor. Apart from the disciplines I have just mentioned, it comprises astrophysics, geochemistry, microbiology, planetary science, and a number of other natural sciences. It has its own institutions, networks, journals, and regular conferences. It is championed by the world's major space organizations such as NASA and the European Space Agency (ESA). The field is by and large oriented toward the "hard" sciences but historians of science, philosophers, anthropologists, and artists are also involved, albeit to a much more limited degree. For my purposes here I adopt the broader definition, including natural and social scientists as well as representatives from the arts and humanities. I refrain from distinguishing a priori between "professionals" and "amateurs." But I do not include UFO enthusiasts and believers in alien abduction. That is not to say that the latter are unworthy of consideration;⁶ given my focus on ultraviolet they simply fall outside the scope of this particular investigation. Since 2010, I have conducted ethnographic fieldwork and interviewed astrobiologists at various locations in the United Kingdom, France, Sweden, Denmark, Germany, Belgium, Poland, and the United States (e.g., at the headquarters of the European Southern Observatory in Garching near Munich, at the Jet Propulsion Laboratory in Pasadena, California, at the Observatoire de Paris in Meudon, France). Over that period, I have attended a considerable number of seminars, workshops, and conferences (e.g., the 2013 European Planetary Science Congress in London, the recent conferences of the European Astrobiology Network Association, the 2016 International Venus Conference in Oxford). I have also spoken with contemporary artists and social scientists with an interest in cosmology, and partly base my work on an extensive literature review of how outer space has been apprehended from a humanities perspective.

In short, my method is first and foremost ethnographic and is based on multi-sited fieldwork. On the whole, access to "the field" was surprisingly easy, and no doubt this has to do with the fact that astrobiology is such an interdisciplinary enterprise: its practitioners are not afraid to speak to researchers in fields that are different from their own and are generally keen to look at issues from unconventional angles. That open-mindedness and their willingness to go outside their own comfort zone turned out to my advantage. If you are an astrophysicist who tries to reach out to microbiology or geochemistry, engaging with an anthropologist is not such a big step. The fact that I had already published a book on cultural conceptions of life (I have done research on animism) also worked in my favor—to be sure, not everybody took me seriously

6. Cf. Battaglia, *E.T. Culture*.

(probably for good reason!), but at least I was perceived by astrobiologists as someone who is concerned with the same basic questions as they are, albeit from a social scientific angle.

Shining

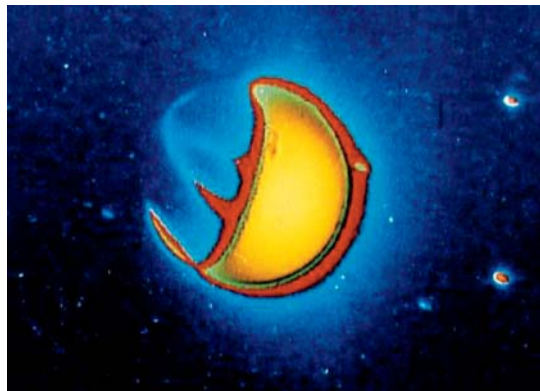
The photographer Bjørn Rørslett, who specializes in ultraviolet imaging, emphasizes that the Sun changes its appearance dramatically when depicted in the ultraviolet spectrum: “Because the UV light field is very diffuse, the sun becomes a hazed area instead of the commonly seen bright sun-star.”⁷ This distinctiveness of the ultraviolet Sun is also evident on images made by spacecraft such as NASA’s Solar Dynamics Observatory. At specific wavelengths, coronal loops appear, and sometimes you can discern huge prominences extending from the star’s surface. Ultraviolet spectrometers and telescopes operating in space give us a more precise impression than photographs taken from the ground, as the terrestrial atmosphere absorbs most ultraviolet emissions (more specifically those in the far range between 100 and 320 nm, technically known as UV-C and UV-B). Rørslett’s photographs only depict the Sun in the near-ultraviolet or UV-A range (320 to 400 nm). Planetary scientists sometimes suggest that this shift from the visible to the ultraviolet has considerable potential to shake up conventional ways of looking at the solar system. “We tend to think about the Sun as something very special,” one of my interlocutors at an astrobiology conference told me, “but perhaps that is unwarranted.” What he meant is that various other celestial bodies in our direct cosmic neighborhood are much more Sun-like than usually recognized—and this becomes more readily discernable from an ultraviolet perspective.

From the lunar surface, astronauts of NASA’s Apollo 16 mission obtained imagery from our own Earth in the far-ultraviolet range. They thus obtained the first full view of an extensive hydrogen bubble enveloping our home planet, the so-called geocorona. More recent observations, such as those carried out by the Galileo spacecraft, have confirmed the huge extent of this hydrogen corona. The geocorona is now estimated to stretch from 1,000 km to 100,000 km above the terrestrial surface (i.e., more than fifteen times the radius of Earth). “What is important,” my interlocutor explained, “is that the geocorona constantly shines—and it particularly shines in the ultraviolet range.” This airglow or earthshine occurs both on the day and the night hemisphere of Earth. From the International Space Station, it is visible with the naked eye as a faint green glow encircling Earth. But that is not all, for the aurorae also glow in both the ultraviolet and the visible range. Usually thought of as exclusive features of the polar sky, the aurorae do expand significantly during geomagnetic storms. They also exhibit a whole range of intricate behaviors.⁸ What you get is not just a constant ultraviolet glow (besides the shine visible to the human eye) but a whole range of ultraviolet intensifications, expansions, breakups, flickerings, and flamings as well as ultraviolet waves, streamers,

7. Rørslett, “Ultraviolet Sun.”

8. Mauk and Bagenal, “Comparative Auroral Physics,” 31.

Figure 1. Earth (the yellow part is the dayside of the globe) and its geocorona (in red). Camera operated by astronaut John W. Young.



draperies, and spirals. One of the participants at an astrobiology conference in Szczecin, Poland, commented on our planet's intricate ultraviolet glow as follows: "We do not realize how Sun-like the Earth is." The scientific terminology is indeed telling: earth-shine/sunshine, geocorona/(solar) corona, auroral flaming/solar flares, and so on (fig. 1).

But Earth is not the only planetary body that shines in the ultraviolet. Gas giants such as Jupiter and Saturn possess fairly dramatic aurorae that encircle their magnetic polar axes and are particularly intense in the ultraviolet part of the spectrum. Yet astrobiologists are more interested in some of their respective moons, which also have distinctive ultraviolet features. One of their favorite targets, Saturn's biggest satellite, Titan, is a case in point. With its distinctively thick atmosphere and its surface dotted with liquid methane/ethane lakes, Titan is generally considered as Earth's closest analogue in the solar system.⁹ For one thing, its ultraviolet airglow is similar to that of Earth: "Although the [nitrogen] UV dayside airglow of Titan is far weaker than its terrestrial counterpart due to its greater distance from the Sun, the solar driven processes controlling the emergent features from the upper atmosphere are remarkably similar."¹⁰ In 2009 a rare opportunity arose when Titan passed into Saturn's shadow, and its airglow could be measured without direct influence of solar UV radiation;¹¹ the Cassini spacecraft established that the Moon has an intrinsic glow in the ultraviolet and in the visible range of the spectrum. Robert West, one of the Cassini imaging team's lead researchers, remarked that "it's a little like a neon sign."¹²

In sum, there is a variety of celestial bodies that shine in the ultraviolet range in our solar system, and this does not just include the Sun but also Earth and various other planets and moons. As ultraviolet shiners, the Sun and many of the planetary bodies that orbit it are essentially alike—the only difference is that our star emits UV radiation in much greater quantities; this is what my first interlocutor meant when he stated that the Sun was perhaps not as unique as we tend to assume. How, you may

9. E.g., Raulin and Owen, "Organic Chemistry and Exobiology on Titan."

10. Stevens et al., "Production of Titan's Ultraviolet Nitrogen Airglow," 16.

11. West et al., "Titan Airglow during Eclipse."

12. "Titan Glows in the Dark."



Figure 2. Jerusalem artichoke in human vision (left), simulated butterfly vision (middle), and simulated bee vision (right), photographed by Klaus Schmitt. Both butterflies and bees can see into the near-ultraviolet (UV-A). Used with permission.

wonder, is all this related to astrobiology's ongoing search for extraterrestrial life? Crucially, ultraviolet shining is not limited to the macro-scale of heavenly bodies. At the micro-scale, it is ubiquitous as well, and it can be used as a marker for life. I first learned about this when I attended an astrobiology conference in Stockholm some years ago. On that occasion, I happened to get caught up in a conversation about honeybees with two other attendees. It was during a coffee break, and my two companions went on about bees' capacity to find nectar by means of ultraviolet signposts or "landing marks" on the flowers they visit.

The topic of bee vision may appear far removed from that of the quest for life in outer space (it certainly did to me), but what I did not fully realize at the time is that astrobiology also provides a stimulus to look at familiar life, here on Earth, in novel ways (fig. 2).¹³ A 2001 news release by NASA's Jet Propulsion Laboratory was tellingly entitled "Bee Vision: The Latest Buzz in Space Exploration." In it, Shouleh Nikzad announced the development of a new chip that can pick up weak ultraviolet signals. The device was directly inspired by honeybees' capacity to detect UV patches on certain flowers. The chip has great potential for astrobiology, according to Nikzad, because "what may appear as a lifeless environment in visible light could come alive when seen in ultraviolet."¹⁴ So ultraviolet shining is not a phenomenon that exclusively occurs on the planetary scale—many biological organisms glow too. Moreover we—humans—also shine, for our skin is characterized by a low-level luminescence.

The work of the biophysicist Fritz-Albert Popp is particularly relevant in this respect.¹⁵ Popp is one of the pioneers of biophotonics, a burgeoning research field that investigates the "ultraweak" light emission from living cells. The active tissues of every

13. Cf. Helmreich, *Alien Ocean*; Helmreich, *Sounding the Limits of Life*.

14. "Bee Vision."

15. E.g. Cohen and Popp, "Biophoton Emission of Human Body," and Popp and Yan, "Delayed Luminescence of Biological Systems."

biological organism permanently emit a small amount of photons in the spectral range between 260 and 800nm (i.e., including ultraviolet and visible light). To be sure, our eyes are not adapted to discern this “skin-light,” and even if they could, it would be overwhelmed by the light of the Sun. What intrigues astrobiologists is that exposure to ultraviolet radiation significantly increases the glow of our skin, just as the UV flux of a solar flare intensifies the terrestrial aurora. Planetary scientists are specifically interested in global “plantshine,” which can be considered an indicator for the health of vegetation worldwide. This is the basic idea behind a proposed ESA satellite that will track this botanical shine, which is explicitly compared to the glow of human skin on Astrobiology Web: “Radiant skin is considered a sign of good health in humans, but plants also glow when they are well.” Such a satellite would also be useful to identify chlorophyll absorption in the earthshine spectrum. Astrobiologists hope that this can help to calibrate chlorophyll in the spectrum of alien planets and thus to detect extraterrestrial vegetation.

But it is not just our skin that glows: our eyes possess an intrinsic shine too. The existence of idioretinal light, that is, the sensation of light in the absence of external stimuli is well attested. The function of this inherent eyeshine generated by the random firing of nerves is generally assumed to be keeping the retina in a state of readiness so that it can perceive external light when necessary. The acclaimed light artist James Turrell, whose work is very much in tune with certain developments in contemporary astrobiology, can be mentioned here. In installations such as his *Dark Pieces* the distinction between light “out there” and “in here” is deliberately blurred. As Craig Adcock has put it: “in the darkness that enfolds Turrell’s dim projection, viewers can not always distinguish between the random idioretinal noise within their own visual systems and the actual light coming into those systems through the lenses of the eyes.”¹⁶ The problem is not fundamentally different from the one confronted by the NASA teams exploring the airglow of moons such as Titan, as discussed earlier. When the Cassini spacecraft observed it during an eclipse, Saturn’s shadow revealed an otherwise invisible moonshine, just as Turrell’s installation reveals an otherwise unnoticeable eyeshine. And when the Hubble Space Telescope first measured its ultraviolet airglow in the mid-1990s, observers struggled to distinguish emissions of terrestrial origin (i.e., the geocorona) from those of the moon itself, just as the *Dark Pieces* make you wonder whether the light comes from “here” or “there.”

Screening

The study of screens occupies a central place in astrobiology. And the terrestrial atmosphere, which protects terrestrial life from different kinds of solar and cosmic radiation, is a key point of interest.¹⁷ The column of ozone occurring in the stratosphere at an

16. Adcock, *James Turrell*, 108.

17. E.g. Rettberg and Rothschild, “Ultraviolet Radiation in Planetary Atmospheres and Biological Implications,” 233.

altitude from 20 to 30 km above the surface is generally seen as one of its most crucial features. This ozone layer absorbs a range of ultraviolet radiation, especially in the most damaging spectral ranges, known as UV-B and UV-C. It is this ozone screen that makes our planet capable of supporting life: “On Mars which has no ozone layer to protect it, solar UV rays strafe the surface with deadly effect, leaving the apparently lifeless planet without the simplest of organic molecules in the upper millimetres of exposed Martian soil.”¹⁸ Remarkably, astrobiologists have a penchant for stressing the atmosphere-like qualities of biological life. They would often point out to me that, on land, the plant canopy fulfills a role that is remarkably similar to that of the ozone layer in the sky, as it absorbs not only visible light but also (near-)ultraviolet radiation or UV-A. Of course, the ozone layer is also a product of terrestrial life itself. After all, it is chemically formed from oxygen, the atmospheric “waste” of photosynthetic plants. As such, it constitutes what astrobiologists call a “biomarker.”

Yet to say that our neighbor planet Mars has no ozone layer at all is exaggerated: it does actually have one, but it is partial and very weak. A small amount of ozone is produced during the winter in its polar regions. It is thought to be generated by the interaction of carbon dioxide (of which the Martian atmosphere consists of 95 percent) and solar radiation. From a purely UV perspective, Mars is actually not an inhospitable planet. The astrobiologist Charles Cockell has pointed out that the equatorial regions of Mars receive similar levels of UV-A radiation to those of temperate regions on Earth: “Insects, lizards, and other animals with UV-A dependent vision perform well at those latitudes on Earth.”¹⁹ Space missions such as NASA’s Mars Science Laboratory and ESA’s ExoMars have confirmed that the current Martian UV flux, even though significantly higher than in the past, does not in itself prevent life. But the most promising advances in the understanding of planetary UV screens derive from novel kinds of experimentation. More specifically, I refer to the space exposure experiments conducted from the International Space Station, pioneered by people such as Gerda Horneck in the 1980s and 1990s.

The inspiration came from research on so-called extremophiles, organisms that are resilient in a range of “extreme” circumstances. When it was realized that bacteria such as *Deinococcus radiodurans* are tolerant to very large amounts of ultraviolet radiation, space researchers surmised that they might very well survive in space. And tests have since shown that this is indeed the case. Some even speculate about an interplanetary ecology with extremophiles like *Deinococcus* hitchhiking on meteorites, which Earth and Mars occasionally exchange. Moreover, a wide range of macroscopic organisms—including fungi, algae, land plants, and animals—have turned out to be relatively tolerant to the harsh conditions of outer space as well. Leopoldo Sancho, Rosa de la Torre, and Ana Pintado have exposed different lichens to space in ESA’s BIOPAN facilities, located on the outer shell of an Earth-orbiting satellite. All of them exhibited

18. “NASA Mission Will Track Earth’s Ozone.”

19. Cockell and Blaustein, *Ecosystems, Evolution, and Ultraviolet Radiation*, 204.

almost the same photosynthetic activity after the exposure as before, which proves that they can survive massive solar and cosmic radiation. Lichens are in fact symbiotic: they are composed of *Cyanobacteria* (monera), *Ascomycetes* (fungi), and *Chlorophyceae* (plants). The cooperation between those three is so effective it almost appears as if they have their own miniature ozone layer. Moreover, bringing them into space has revealed that they behave very much like “little Earths,” or as Sancho and his colleagues have put it: “Lichens can be compared to a micro-ecosystem that simply and compactly integrates the Earth’s main metabolic processes, autotrophy and heterotrophy, and involves three biological kingdoms: [Monera, Fungi and Plantae]. Arguably, it is hard to imagine a biological system that better summarizes the characteristics of life on Earth.”²⁰ What we have here is yet another example of astrobiologists’ inclination to emphasize the atmosphere-like or indeed the planet-like qualities of biological organisms. Time and again, the concept of “atmosphere” is extended beyond the gaseous planetary envelope it conventionally denotes; as ultraviolet shields, the terrestrial ozone layer and lichens are basically equivalent.

But astrobiology’s ultimate goal is to detect ultraviolet screens on exoplanets. Such screens are envisaged as global “biomarkers” or “biosignatures.” The work of Mark Silverman on the polarized nature of the ultraviolet sky is particularly relevant in this respect.²¹ One of the most basic characteristics of terrestrial life is its chiral asymmetry. That is, some of its principal components have a preferential handedness. Amino acids are always “left-handed,” and sugars are always “right-handed”; their respective mirror-molecules, while theoretically possible, are not found in any living organism. What fascinates Silverman is that the sky also has a preferential handedness. He points out that skylight is highly polarized, especially at twilight (when the relative amount of ultraviolet radiation is highest). Humans normally cannot discern this polarization pattern but animals with UV vision can. Bees, birds, and river fishes such as trout and salmon are believed to use it for navigational purposes, as a kind of celestial compass. So the ultraviolet sky is signposted: left-handed polarized light predominates in the morning, right-handed in the afternoon. The sky is chiral, just as the mammals we are and terrestrial life more generally.

And Silverman is convinced that this link between biological and atmospheric homochirality provides a great opportunity for astrobiology: “If alien life bears any similarities at all to life on Earth, it will be, I believe, in the chiral asymmetry of their molecular constitution. The rest, then, is a question of optics: can one detect chiral asymmetry by light scattering? The answer . . . is clearly ‘yes.’”²² In principle, one of my informants suggested, you can drive this whole argument even further. You could say that we, humans, are much more atmosphere-like than we usually realize. Our skin and our eyes,

20. Sancho, de la Torre, and Pintado, “Lichens,” 104.

21. Silverman, *Waves and Grains*.

22. *Ibid.*, 295.

in particular, have a lot in common with the terrestrial atmosphere. The melanin in our skin and the chlorophyll of the plant canopy are pigments with a different molecular composition, to be sure, but in terms of their capacity to screen ultraviolet radiation their similarity is arguably more salient than their difference. As UV absorbers, the pigments of our skin (just like those of the canopy) are akin to the ozone layer—they never produce light, but only take it away. Whereas the atmosphere serves as a protective barrier for Earth, the skin does the same for our body. In the words of Nina Jablonski: “The skin of humans, like that of all tetrapods, acts as a sun shield to protect the body from most solar UV radiation.”²³ And what goes for the human skin also goes for the other part of our body that is directly exposed to ultraviolet radiation, namely, the human eye. The lenses of our eyes act as an ozone layer of sorts: they absorb ultraviolet radiation, but do not transmit it.

Touching

What is a skin? And what does it mean to touch? These questions have been closely entwined with the search for extraterrestrial life ever since the incipience of astrobiology. One of its great pioneers, James Lovelock, famously envisaged Earth as a living organism with a skin (i.e., the terrestrial atmosphere). In his much debated Gaia theory, he provocatively suggested that clouds must be viewed as the hair or the fur of our planet. In contemporary writings, the notion of planetary skins is still very much present, as evidenced by such quotes as the following: “Some of the most startling findings about Jupiter’s icy moons come from measurements that peered indirectly beneath their skins.”²⁴ Or: “Methane is an especially intriguing material [which contributes] to the warming of the upper skin of the atmosphere [of the outer planets in our Solar System].”²⁵ Other telling examples are the “tiger stripes”—four parallel furrows near the southern pole on Saturn’s moon Enceladus—and the characterization of the surface of Triton (Neptune’s largest moon) as “cantaloupe terrain,” because of its resemblance to the skin of a specific kind of melon. Astrobiologists have addressed the question of touch in original ways, by pondering the link between organism and planet and by comparing skins at both the micro and the macro level.

At the planetary scale, astrobiologists are intrigued by the problem of how celestial bodies touch each other. To be sure, the traditional model of a solar system in which the planets orbit a central star as discrete billiard balls, completely independent from each other and separated by millions of kilometers of empty space, has been interrogated for a long time. But astrobiologists have been among its firmest and most consistent critics. Planets and moons do actually touch each other in various ways, but this may only become apparent from a UV perspective. The moons Io, Europa, and

23. Jablonski, “Evolution of Human Skin and Skin Color,” 586.

24. Pappalardo, “Jupiter’s Water Worlds,” 35; emphasis added.

25. Baines and Delitsky, “Seas of Saturn,” 72; emphasis added.

Ganymede leave ultraviolet “footprints” on Jupiter. And Enceladus’s geysers-like plume of water vapor induces similar auroral emissions on Saturn. What happens is that these electrically conducting satellites generate a current system linking them to the magnetospheres of their respective parent planets. Many astrobiologists are also fascinated by solar touch. It has been known for a long time that space weather is determined by solar wind pressure. But different planets give way in different ways. The ionosphere of Earth, which has a relatively strong magnetic field, may be relatively little affected but Venus, which lacks such an intrinsic field, is much more malleable. During a recent solar storm ESA’s *Venus Express* spacecraft observed that its ionosphere ballooned almost like the tail of a comet, acquiring the shape of a gigantic teardrop.²⁶ In fact, any kind of auroral activity—whether terrestrial or extraterrestrial—could be read as an expression of the Sun’s touch.

Crucially—many of my interlocutors insisted—the micro level is not separate from the macro level. We, biological organisms, are touched by the Sun too. And we, humans, are directly affected by the ambient levels of ultraviolet radiation. Even though UV radiation is invisible, it is not true that humans are completely unable to perceive it. By means of our skin, we are capable of feeling ultraviolet: tanning and suffering from sunburn are among the most obvious manifestations. The human skin, the biologist Lars Olof Björn notes, is “the largest organ of the body and one which is most exposed to external insults [including] UV radiation from the Sun.”²⁷ Characterizations such as this one point to a parallel with the macro level: just as the atmosphere shields our planet, the skin protects our body. Both Earth and humans are fortresses of sorts; the frequent usage of this precise image is something that astrobiology, atmospheric science, and dermatology have in common. And it is not difficult to draw further parallels. When a biophysicist explained to an audience of astrobiologists that the ultra-weak emission of biophotons increases after sunbathing, he used the following comparison: “Our skin glows more intensely after intense ultraviolet exposure, just as the terrestrial aurorae become more vigorous during a solar storm.”

Yet ultraviolet radiation has many “positive” effects as well. A phrase I often heard is that life on Earth is addicted to sunlight. Just as do plant leaves, our skin harvests light. Just as does their chlorophyll, our melanin absorbs ultraviolet radiation. In fact, UV absorption drives the production of vitamin D in our bodies—in that sense we are all heliophages or “eaters of the Sun,” as one of the participants in an astrobiology workshop put it to me. And we are also “eaters of the sky,” she added, because a significant portion of our daily ultraviolet intake comes indirectly from the sky rather than directly from the Sun. The idea that solar radiation can be understood as a form of nutrition is also frequently alluded to by the light artist James Turrell, whom I mentioned earlier. The sky, for him, is something you are in direct contact with, something you touch:

26. “Tail of Venus and the Weak Solar Wind.”

27. Björn, *Photobiology*, 553.

“We drink light as vitamin D through the skin—it is actually food.”²⁸ The development of our bones and the calcification of our skeleton do indeed depend on the synthesis of vitamin D in our skin. The correspondence that is crucial here is the one between skin and sky. I have already expanded on planetary skins and on the equivalence between atmospheres and the organ that envelops our body.

Turrell has complemented this widely shared astrobiological intuition by showing that the same kind of correspondence also can be perceived from inside the mass of air that surrounds us. The sky, beheld by an attentive eye, is not less skin-like than the alien atmospheres beheld by some telescope. Roden Crater, the extinct volcano he has patiently been transforming into an extraordinary sky-observatory in the past few decades, can be seen as a poetic statement of that precise point. Craig Adcock, his biographer, writes: “On a clear day from the top of Roden Crater, visitors can see far into the distance. They can look out over the huge expanses of the surrounding desert. At night, they can see even further. When the sun is up, the upper atmosphere is illuminated by sunlight making the sky visible as a skin of color stretching from horizon to horizon, a fact that explains the etymological relationship between ‘skin’ and ‘sky.’”²⁹ Turrell’s ambition is to “bring the sky down” into the personal space of the viewer. He aims to reveal skylight as something we are in direct contact with—as something we touch and that touches us. One should never take for granted, he warns us, that the sky is something “up there.” And many of those who have been lucky enough to visit the underground rooms and tunnels at Roden Crater do indeed report experiencing the sky “dropping down” onto the volcano.

This stretched conception of what it means to touch is not merely the idiosyncratic idea of one artistic genius. Authors of phenomenological bent have formulated strikingly similar propositions. Juhani Pallasmaa, for example, is convinced that any kind of sensory perception is a form of touching: “All the senses, including vision, are extensions of the tactile sense; the senses are specializations of skin tissue, and all sensory experiences are modes of touching and thus related to tactility.”³⁰ Pallasmaa insists that our eyes touch, and he suggests that, through vision, we touch the Sun and the stars. So whereas our feet touch Earth, our eyes touch the Sun. From this viewpoint, we are as much sunlings as earthlings.

Seeing

What is an eye? And what does it mean to see? Here are two further questions at the heart of contemporary astrobiology. One of the things that its focus on the ultraviolet spectrum reveals is that the ideal of absolute vision is being challenged. Ever since the development of technological eyes capable of perceiving things beyond the scope of

28. Turrell, “Artist James Turrell Speaks about Light.”

29. Adcock, *James Turrell*, 158.

30. Pallasmaa, *Eyes of the Skin*, 10.

ordinary human vision, absolute vision has been a central goal of the natural sciences. Think of the Hubble Space Telescope, which “stands in a long succession of human endeavours to create the ultimate form of sight—one that is all powerful and rigorously objective, untouched, as it were, by human hand.”³¹ I do not claim that all practitioners of astrobiology have distanced themselves from this grandiose project of absolute vision, but their burgeoning interest in the ultraviolet universe certainly has made many of them acutely aware that all vision—whether it involves natural or artificial eyes—is inevitably partial. A quarter of a century ago the anthropologist and philosopher of science Donna Haraway already argued that there is no such thing as neutral vision—even the images of the most sophisticated instruments are always mediated.³² All there is, she concluded, are highly specific visual possibilities. The night sky human observers are familiar with is indeed only one among many possible skies overlaid on top of each other. The ultraviolet universe looks remarkably distinct from the visible one we are all familiar with. For an alien with UV vision, one astrobiologist told me, most stars would fade significantly. But very young and very old ones—both of which are very hot and hence radiate a lot of UV—would stand out more prominently.

The awareness that our human eyes are just one kind of eyes among many others has become more widespread. The ongoing debate about so-called false color images illustrates this perfectly. One of the protagonists, Robert Hurt, is an astronomer who works as a visualization expert for NASA’s Spitzer Space Telescope mission. In a 2013 blog post entitled “The Frightful Fallacy of ‘False Color,’” he does not mince his words: “What I hate is the horrifically terrible, yet disturbingly ubiquitous term ‘false color.’”³³ He explains: “Why do I hate this term so much? I mean, after all, images that don’t show things the way our eyes see them aren’t true, are they? Bull*%\$t!” To illustrate his point Hurt refers to a rather wonderful image of Neptune, showing that planet through a red, a green, and an infrared filter. The colors we see on this image, he emphasizes, are very real ones, just not exactly those our eyes perceive. And there is nothing false about that at all, he insists. To debunk the idea of misrepresentation, he uses a linguistic comparison: “When we take a piece of prose that we cannot read and present it in our own language would we call that a false text? Of course not. We would call it a translation.” In the same way, the colors in astronomical images produced by Spitzer are not “phony” (as one hapless reviewer described them, to Hurt’s considerable irritation) but translations for our eyes, remapping infrared and ultraviolet into the blue, green, and red we are familiar with. One should always bear in mind, Hurt suggests, that what is visible always depends on who looks: “Somewhere on some other planet, there might be some infrared-viewing aliens debating over the colors in images that their astronomers observed in our visible light spectrum. Let’s hope they don’t conclude that the

31. Kemp, *Seen/Unseen*, 242.

32. Haraway, *Simians, Cyborgs, and Women*, 190.

33. See “Frightful Fallacy of ‘False Color.’”

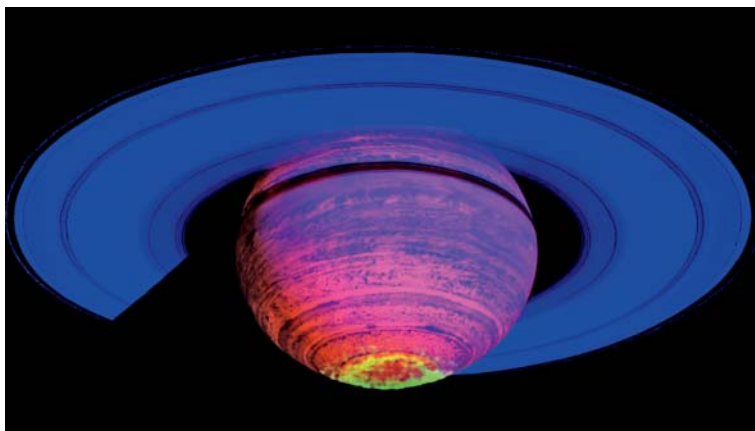


Figure 3. According to its Wikipedia caption, this is a “false-colour composite image showing the glow of auroras streaking out [near] Saturn’s south polar region”

colors we can see are phony!” In sum, Hurt proposes to think in terms of translated colors instead of false colors.

Another astronomer, Christian Ready, has underlined that the notion of “true” or “natural” colors is as flawed as that of false colors.³⁴ An image of Saturn in washed-out cream and brown tints is usually assumed to represent its natural colors (i.e., as a human astronaut would see it); but what about mantis shrimp or any other animal with highly developed UV vision? They would perceive a far richer image, including Saturn’s ultraviolet aurorae, which remain imperceptible to the unassisted human eye. Consequently, an image such as this one is not a false color image (fig. 3). Yet saying that humans are entirely incapable of perceiving ultraviolet is too simplistic. First of all, there is the perplexing fact that we all are perfectly equipped to see into the near-UV, at least in principle. The photoreceptive molecules in our eyes (rhodopsin) can detect radiation beyond the violet without any problem. It is just that these rays are blocked by the lenses of our eyes.

Actually, there are a few documented cases of human UV vision. The medical condition known as aphakia causes greatly increased sensitivity to ultraviolet, usually among people of a certain age whose lenses have been removed in cataract surgery. William Stark, who is aphakic himself, describes ultraviolet stimuli as desaturated blue/violet, “though somewhat whitish.”³⁵ I say “people of a certain age” because the lenses that ocular surgeons implant nowadays do generally contain UV-blocking pigments. With the advance of ophthalmic technology, aphakic patients are becoming a relic of the past. One of the most famous cases is that of the great impressionist painter Claude Monet, who developed an aphakic eye toward the end of his life. The well-known water lily paintings that grace the walls of the Orangerie des Tuileries in Paris bear witness to his visual aging process. The coloration of some of his last paintings is unusually garish and dominated by “cold” green-blue tones. Water lily flowers appear

34. Ready, “Stop Calling Them False Color Images.”

35. Stark and Tan, “Ultraviolet Light,” 377.

white to ordinary human observers, but Monet's bluish pigments captured something of the ultraviolet light bouncing off the petals. His late paintings are indeed strikingly reminiscent of the ultraviolet images of contemporary photographers such as Klaus Schmitt.

The paradoxical status of ultraviolet as invisible light certainly has prompted both natural scientists and artistic researchers to rethink conventional definitions of the eye and what it means to see. Could our skin be an eye as well? Or—even more outrageously—could celestial bodies be envisaged as eyes in the sky? You do not necessarily need eyes to get information carried by light, the biologist Michael Gross points out, for we have other light sensors too: “Hang on—is this a shadow falling at the back of my knee?”³⁶ In a study of brittlestars, the anthropologist Karen Barad has demonstrated that for this marine organism it is not just the case that its visual system is embodied—actually, its very being is a visualizing apparatus.³⁷ Developing this idea in a comparable study on cup corals, her colleague Eva Hayward has coined the term “fingeryeyes” to explore, as she puts it, a multispecies arena where sensoriums overlap, a haptic-optic characterized by the synesthetic interplay between vision and touch.³⁸ Skin vision is also well documented among land animals such as chameleons; a blind chameleon is still capable of taking on the coloration of its surroundings (including its ultraviolet surroundings, for they can perceive UV-A). What is more, there are good indications that human skin can “see” colors and forms too. The case of Rosa Kuleshova, who apparently could distinguish colors with her skin and was able to read newsprint blindfolded, by means of her fingertips, is just one striking instance of this little studied phenomenon of skin-vision.

But what it means to see can be stretched even further. Multispecies approaches such as Hayward's are helpful because they show how touching by eye and seeing with tact slide into each other, but they are still too limited insofar as they only focus on those entities that are traditionally defined as “alive.” And these limitations become more obvious as soon as you consider things at the planetary scale. Two early twentieth-century authors who are still sparking debate in astrobiology are the Soviet physicist Sergey Ivanovich Vavilov and the Estonian biologist Jakob von Uexküll. “For many centuries,” Vavilov wrote in his classic book *The Human Eye and the Sun*, “it was taught that the sun and the eye were brothers, that they were manifestations of the same kindred fire and that shining is seeing and seeing is shining.”³⁹ Uexküll completed Goethe's famous aphorism that “If the eye were not Sun-like, the Sun's light it would not see” with the corollary that “If the Sun were not eye-like, it could not shine in any sky.”⁴⁰ By which he meant, as the anthropologist Tim Ingold has recently specified, that

36. Gross, *Light and Life*, 83.

37. Barad, “Queer Causation and the Ethics of Mattering,” 334.

38. Hayward, “Fingeryeyes.”

39. Vavilov, *Human Eye and the Sun*.

40. Uexküll, *Foray into the Worlds of Animals and Humans*, 190.

“the sun we perceive in the sky, and that lights the world of our experience, can exist only through its essential correspondence with the eye. And conversely, as Goethe had observed, the eye can see only by virtue of its correspondence with the sun.”⁴¹ The maverick art theorist/cosmologist James Elkins goes even further than that: why, he wonders, shouldn’t vision be universal?⁴² In a provocative book, *The Object Stares Back*, he forcefully argues that everything we see does in fact look back: “Every object sees us; there are eyes growing on everything. . . . To see is to be seen, and everything I see is like an eye, collecting my gaze, blinking, staring, focussing and reflecting, sending my look back to me.”⁴³ Our gaze, so to speak, has an echo, and the world is therefore full of eyes. This kind of idea, one of my more philosophically inclined astrobiology acquaintances indicated, actually has a long but somewhat forgotten history.

Conclusion

At the outset I noted that astrobiology ostensibly presents itself as the scientific endeavor preoccupied with the search for life beyond Earth. Yet who or what is alive, exactly? What my account of the ultraviolet world indicates is that the devil—as always—is in the way the question is asked. Astrobiology is arguably the human endeavor that sounds the limits of life in the most comprehensive manner in the present day and age.⁴⁴ But it also consistently challenges mainstream definitions of life and nonlife; so-called bio-signatures and other received categories are questioned time and again, as this article amply illustrates. The anthropologist Elizabeth Povinelli has written that “in the natural, social, and philosophical sciences, ‘life’ acts as a foundational division between entities that have the capacity to be born, grow, reproduce, and die and those that do not: biology and geology, biochemistry and geochemistry, life and nonlife.”⁴⁵ Yet she underlines that this ontological division can also be thought otherwise, for this dominant, modern arrangement is ultimately also a parochial arrangement. In Povinelli’s view, this otherwise has already emerged in a variety of guises: in the academic arena, climate change, anthropocene, indigenous cosmologies, and animism are among those that are most in vogue today.

The present study suggests that astrobiology could be added to that list. Insofar as it surpasses the classic life/nonlife division and it refashions bios as we know it, astrobiology can indeed be grasped as one among many “anthropologies of life,” to use an expression coined by Gisli Pálsson.⁴⁶ In addition, it could perhaps be understood as an innovative pathway toward a “sensory anthropology” as proposed by Sarah Pink—that is, “an approach to doing anthropology that is informed by theories of the senses

41. Ingold, *Life of Lines*, 98–99.

42. Elkins, *Object Stares Back*, 48.

43. *Ibid.*, 51.

44. Cf. Helmreich, *Sounding the Limits of Life*.

45. Povinelli, “Geontologies of the Otherwise.”

46. Pálsson, *Nature, Culture, and Society*, 2.

originating outside anthropology.”⁴⁷ To say that we need to “rethink our taken-for-granted modes of human experience . . . by recontextualising them in terms of the entire sensorium of other living beings” as Cary Wolfe has put it in a book on posthumanism, is laudable but it is not enough.⁴⁸ For this kind of approach implicitly stages sensing as the sole privilege of biological organisms and excludes entities such as moons, planets, and stars a priori. In other words, it unreflectively operates within the confines of the classic life/nonlife division exposed by Povinelli. In that respect, astrobiology tends to be more radical than what you find in the literature on posthumanism: could it be that celestial bodies are also sensing bodies but that this remains invisible as long as you remain trapped in a dominant framework that divides the biological and the geological in a very peculiar way? Why not envisage stars and planets—just like brittlestars or cup corals—as “optical gropers,” “tactful seers,” or astronomical “fingeryeyes”?⁴⁹

One of the foremost characteristics of astrobiology is that its practitioners have a penchant for what one might call conceptual stretching. And this tendency becomes more manifest from a UV perspective. As ultraviolet shiners, biological organisms and planetary bodies are more Sun-like than they usually get credit for. As ultraviolet screeners, the plant canopy, our skin, and the lenses of our eyes are not that different from the ozone-layer up in the sky. In that specific sense, organisms are more atmosphere-like than usually realized. Moreover, it is not just that our skin is sky-like, the sky—as we have seen—can also be envisaged as skin-like. The etymological link between the two terms is maybe not a coincidence. The capacity to touch is also extended to our eyes (e.g., Turrell insisting that looking is always a haptic activity), to planets (e.g., Jupiter’s “skin” marked by the UV “footprints” of its moons), and to the sun (e.g., solar wind deforming planetary atmospheres and engendering aurora displays). In a similar vein, the concept of seeing is stretched: if such a thing as skin-vision exists, in principle everything with a skin can see. Chameleons can see into the UV spectrum with their eyes (as traditionally defined), but their outer body, in its entirety, can also be conceived of as an ultraviolet eye. Moons, planets, and the Sun can be (and have been) envisaged as eyes as well—when you watch them, they “look back,” to use James Elkins’s phrase.

Investigating the solar system—so it appears—is no longer the privilege of solar physics or planetary science; it can also be studied “dermatologically” and as an extension of ophthalmology. The reverse is also true. At the micro level, the study of biological organisms and some of their major organs can also be approached “astronomically”—that is why extremophile lichen are understood as miniature planets and light-emitting humans can be seen as little suns. Why this kind of conceptual stretching is so prevalent within astrobiology remains an open question. But what is clear is that traditionally separate disciplines such as solar physics, atmospheric science, dermatology, and

47. Pink, “Future of Sensory Anthropology/The Anthropology of the Senses,” 337.

48. Wolfe, *What Is Posthumanism?*

49. Cf. Hayward, “Fingeryeyes,” 582.

ophthalmology have begun to spill over into each other. The anthropologist and astronomer Anthony Aveni has shown that ancient sky-watching peoples such as the Babylonians and the Maya did not compartmentalize their knowledge of the universe into discrete and independent fields of study.⁵⁰ They were “integrators” rather than “differentiators,” as he put it. More recently Helmreich has characterized astrobiology as adisciplinary or undisciplinary rather than interdisciplinary; it is a breeding ground for what he calls “athwart theory,” whereby meanings wander and words are unfastened “from etymology toward new rhetorical energies.”⁵¹ If it is true that modern science is a highly compartmental affair, this study has demonstrated that contemporary astrobiology goes against the current—it is very much an enterprise of integrators and a cradle of definitional instability.

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References

- Adcock, Craig. *James Turrell: The Art of Light and Space*. Berkeley: University of California Press, 1991.
- Aveni, Anthony. *Conversing with Planets: How Science and Myth Invented the Cosmos*. New York: Times Books, 1992.
- Baines, Kevin H., and Mona L. Delitsky. “The Seas of Saturn.” In *Alien Seas: Oceans in Space*, edited by Michael Carroll and Rosaly Lopes, 71–79. Berlin: Springer, 2013.
- Barad, Karen. “Queer Causation and the Ethics of Mattering.” In *Queering the Non/Human*, edited by Moreen Giffney and Mira J. Hird, 311–38. Aldershot, UK: Ashgate, 2008.
- Battaglia, Debora, ed. *E.T. Culture: Anthropology in Outerspaces*. Durham, NC: Duke University Press, 2005.
- Battaglia, Debora, David Valentine, and Valerie Olson. “Relational Space: An Earthly Installation.” *Cultural Anthropology* 30, no. 2 (2015): 245–56.
- “Bee Vision: The Latest Buzz in Space Exploration.” *Jet Propulsion Laboratory News*, October 2001. www.jpl.nasa.gov/news/news.php?feature=487.
- Björn, Lars O. *Photobiology: The Science of Life and Light*. Berlin: Springer, 2008.
- Cockell, Charles S., and Andrew R. Blaustein, eds. *Ecosystems, Evolution, and Ultraviolet Radiation*. Berlin: Springer, 2001.
- Cohen, S., and Fritz-Albert Popp. “Biophoton Emission of Human Body.” *Indian Journal of Experimental Biology* 41, no. 5 (2003): 440–45.
- Elkins, James. *The Object Stares Back*. San Diego: Harvest Books, 1996.
- “The Frightful Fallacy of ‘False Color.’” *AstronomyVIZ*, 2013. astronomyviz.wordpress.com/2013/07/23/the-frightful-fallacy-of-false-color/.
- Gross, Michael. *Light and Life*. Oxford: Oxford University Press, 2002.

50. Aveni, *Conversing with Planets*, 14.

51. Helmreich, *Sounding the Limits of Life*, 91–92.

- Haraway, Donna. *Simians, Cyborgs, and Women. The Reinvention of Nature*. London: Free Association Books, 1991.
- Hayward, Eva. "Fingeryeyes: Impressions of Cup Corals." *Cultural Anthropology* 25, no. 4 (2010): 577–99.
- Helmreich, Stefan. *Alien Ocean: Anthropological Voyages in Microbial Seas*. Berkeley: University of California Press, 2008.
- . *Sounding the Limits of Life: Essays in the Anthropology of Biology and Beyond*. Princeton, NJ: Princeton University Press, 2016.
- Ingold, Tim. *The Life of Lines*. London: Routledge, 2015.
- Jablonski, Nina. "The Evolution of Human Skin and Skin Color." *Annual Review of Anthropology* 33 (2004): 585–623.
- Kemp, Martin. *Seen/Unseen: Art, Science and Intuition from Leonardo to the Hubble Telescope*. Oxford: Oxford University Press, 2006.
- Latour, Bruno. "An Attempt at a 'Compositionist Manifesto.'" *New Literary History* 41 (2010): 471–90.
- Mauk, Barry, and Fran Bagenal. "Comparative Auroral Physics: Earth and Other Planets." In *Auroral Phenomenology and Magnetospheric Processes*, edited by Andreas Keiling, Eric Donovan, Fran Bagenal, and Tomas Karlsson, 3–26. Washington, DC: AGU Books, 2012.
- "NASA Mission Will Track Earth's Ozone." *Astrobiology Magazine*, April 2013. www.astrobio.net/topic/solar-system/earth/nasa-mission-will-track-earths-ozone/.
- Olson, Valerie. "Political Ecology in the Extreme: Asteroid Activism and the Making of an Environmental Solar System." *Anthropological Quarterly* 85, no. 4 (2012): 1027–44.
- Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. London: Wiley, 2005.
- Pálsson, Gisli. "Lucy in the Sky: Celestial Bodies." In *Nature, Culture and Society: Anthropological Perspectives on Life*, 105–12. Cambridge: Cambridge University Press, 2016.
- . *Nature, Culture, and Society: Anthropological Perspectives on Life*. Cambridge: Cambridge University Press, 2016.
- Pappalardo, Robert T. "Jupiter's Water Worlds: Water Lurks beneath the Surfaces of Europa, Ganymede, and Callisto." In *Alien Seas: Oceans in Space*, edited by Michael Carroll and Rosaly Lopes, 35–44. Berlin: Springer, 2013.
- Pink, Sarah. "The Future of Sensory Anthropology/The Anthropology of the Senses." *Social Anthropology/Anthropologie Sociale* 18, no. 3 (2010): 331–40.
- Popp, Fritz-Albert, and Yu Yan. "Delayed Luminescence of Biological Systems in Terms of Coherent States." *Physics Letters A* 293, no. 1–2 (2002): 93–97.
- Povinelli, Elizabeth. "Geontologies of the Otherwise." Theorising the Contemporary, Cultural Anthropology website. Accessed February 23, 2017. culanth.org/fieldsights/465-geontologies-of-the-otherwise.
- Raulin, Francois, and Tobias Owen. "Organic Chemistry and Exobiology on Titan." *Space Science Reviews* 104 (2002): 377–94.
- Ready, Christian. "Stop Calling Them False Color Images." Personal website, 2013. christianready.com/2013/07/25/stop-calling-them-false-color-images/.
- Rettberg, Petra, and Lynn J. Rothschild. "Ultraviolet Radiation in Planetary Atmospheres and Biological Implications." In *Astrobiology: The Quest for the Conditions of Life*, edited by Gerda Horneck and Christa Baumstark-Kahn, 232–42. Berlin: Springer, 2002.
- Rørslett, Bjørn. "The Ultraviolet Sun." Accessed March 26, 2014. www.naturfotograf.com/index2.html.
- Sancho, Leopoldo G., Rosa de la Torre, and Ana Pintado. "Lichens, New and Promising Material from Experiments in Astrobiology." *Fungal Biology Reviews* 22, no. 3–4 (2008): 103–9.
- Scmitt, Klaus. "Royal Botanic Garden Exhibition: Tropism Exhibit including Simulated Bee and Butterfly Vision." *Photograph of the Invisible Word*, August 4, 2015. <http://photographyoftheinvisibleworld.blogspot.com/2015/08/royal-botanic-garden-edinburgh-tropism.html>.
- Silverman, Mark P. *Waves and Grains: Reflections on Light and Learning*. Princeton, NJ: Princeton University Press, 1998.

- Stark, William S., and Karel E. W. P. Tan. "Ultraviolet Light: Photosensitivity and Other Effects on the Visual System." *Photochemistry and Photobiology* 36, no. 3 (1982): 371–80.
- Stevens, Michael H., J. Gustin, J. M. Ajello, J. S. Evans, R. R. Meier, A. I. F. Stewart, L. W. Esposito, W. E. McClintock, and A. W. Stephan. "The Production of Titan's Ultraviolet Nitrogen Airglow." *Journal of Geophysical Research* 116 (2011): A05304.
- "The Tail of Venus and the Weak Solar Wind." ESA Venus Express website, January 2013. sci.esa.int/venus-express/51315-the-tail-of-venus-and-the-weak-solar-wind/.
- "Titan Glows in the Dark." *Astrobiology Magazine*, November 2012. www.astrobio.net/topic/solar-system/saturn/titan/titan-glows-in-the-dark/.
- Turrell, James. "Artist James Turrell Speaks about Light." December 2013. www.youtube.com/watch?v=koTTtAqv2OI.
- Uexküll, Jakob von A *Foray into the Worlds of Animals and Humans*. 1934. Minneapolis: University of Minnesota Press, 2010.
- Vavilov, Sergey I. *The Human Eye and the Sun*. 1927. Oxford: Pergamon, 1965.
- West, Robert A., J. M. Ajello, M. H. Stevens, D. F. Strobel, G. R. Gladstone, J. S. Evans, and E. T. Bradley. "Titan Airglow during Eclipse." *Geophysical Research Letters* 39 (2012): L18204.
- Wolfe, Cary. *What Is Posthumanism?* Minneapolis: University of Minnesota Press, 2010.