RESEARCH ARTICLE

Making Time with Amateur Astronomers and Orbital Space Debris: Attunement and the Matter of Temporality

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Abstract

This paper compares the material practice of amateur astronomers with that of archaeologists, specifically arguing that they engage with materials and time in distinct but complementary ways. In particular, the paper outlines the ways in which amateur astronomers become attuned to the temporal cycles and rhythms of extraterrestrial materials as they gaze into the night sky, much like how archaeological practitioners must get to know the taphonomic processes involved in the formation of archaeological sites. Finally, it is argued that for these reasons astronomers might offer insights into the investigation of orbital space debris – a topic of interest among archaeologists of outer space – and materials that produce their own threatening and nested temporalities.

Introduction

In this paper, I discuss astronomy as a form of material practice that is distinct from but related to archaeology. Specifically, I consider the implications of how archaeologists and astronomers relate to the materiality of time.

Keywords: amateur astronomy; archaeology; orbital space debris; temporality

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While the *temporality of materials* normally refers to how objects are impacted by time as an external force, archaeology is arguably unique for its careful attention to *materials as time*. The material mediation of time is at issue not only with the specific objects archaeologists uncover and curate, but also with the taphonomic processes that they must understand in order to investigate the deposition of objects and their transformation over various periods of time (Schiffer 1987; Dawdy 2006). Distinct regions and layers of the Earth involve different taphonomic conditions, which can influence the preservation and distribution of material remains. For the archaeologist, uncovered remains represent distinct temporal periods and processes of formation.

In astronomical practice, by contrast, materials not only stand for time: they produce it. To begin with, human representations of time began with astronomical objects. Consider clocks: they record seconds, minutes and hours as part of a formal, ever-repeating cycle. Representing time as a continuum of divisible units in this way is central not only for Newtonian physics, but also for the homogenous and empty spacetime of the nation-state and the creation of value in capitalism.[1] And yet, clock time is not an independent substance merely *represented by* nonhuman objects. Clock time may be essential to capitalism and nation-states, but was invented by neither. Clock time is *dependent upon* and *made possible by* the self-organizing processes and rhythmic cycles of terrestrial relations with nonterrestrial objects in the universe. This fact often goes unacknowledged, arguably because "[o]ver time, the means we created to track celestial activity were inverted, and became what Lewis Mumford calls a mechanism to synchronize our actions" (Sousanis 2015, 109). Most obviously, time comes from the relatively stable rotation of the Earth on its axis and its relatively stable orbit around the Sun. But representations of time also depend on the relatively stable orbits of much more distant objects (e.g. Polaris, the North Star) as seen by observers on the ever-orbiting Earth. Without careful and deliberate observation of astronomical objects and events over the years, clock time would not be possible.[2]

Archaeology and astronomy are not normally discussed in conjunction, but the emergence of an archaeology of outer space (Capelotti 2004, 2010; Gorman 2005, 2009a, 2009b; Schiffer 2013; O'Leary 2006, 2015) would suggest more overlap than is normally assumed. In this paper, I explain some of the problems that make amateur astronomy difficult in the city of Binghamton, located in the Southern Tier of New York State (though astronomers anywhere on Earth are beset by similar dilemmas). First, I consider how astronomers relate to temporality; I then discuss this in connection with the archeology of outer space and space debris.

While the distances that separate astronomers from the objects they observe are

1. In this sense, clock and calendar time seem to stand opposed to the temporal experiences of living beings and their dependence on contextually rich environmental relations. For Barbara Adam, clocks and calendars represent *nontemporal time*: time that is "decontextualized and disembodied from events", and that is "established as an universally applicable, abstract, empty and neutral quantity that accords all hours the same value" (Adam 1998, 66).
2. While new theories of spacetime have called into question the "stability" of such local and galactic movements, they continue to rely on astronomical observation. Einstein's theory of relativity, credited with complicating the taken-for-granted observation of stellar phenomena, still relied for validation on the 1919 solar eclipse and Mercury's perihelion advance (Topper 2013).

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usually thought of as spatial rather than temporal, on occasion they also relate to materials in a similar way as do archaeologists. The first objection to this claim might be that astronomers are much more distant from the objects they study and their observations are therefore more fragmented and less reliable than those of archaeologists. However, recent innovations in archaeological geophysics resemble astronomy much more clearly. Ground-penetrating radar, magnetometry and resistivity are used to locate and analyze materials buried deep beneath the soil that may be otherwise inaccessible (Larson *et al.* 2003). Similarly, with the use of binoculars or a reflector or refractor telescope, astronomers classify distant objects on the basis of their perceptible qualities.

Astronomers and archaeologists can also be fruitfully compared in terms of the analogies they make, classifying interstellar objects in relation to Earth and the Solar System (see Denning 2013, 302–307; Messeri 2016, 135–144). My focus in this paper is not, though, on the acts of interpretation that astronomers and archaeologists commonly engage in to measure and make meaningful history. Rather, I explore how material forms and processes similarly constrain the temporality of their practice, whether or not this influence is explicitly recognized. Many of these material forms and processes are taken-for-granted conditions of life on Earth, so at first glance they may appear neutral or unimportant. Yet, material conditions need not be noticed to afford certain actions and deny others. The nature of the Earth's rotation, for instance, is a condition for the possibility of amateur astronomy, but simultaneously a limiting constraint (if part of the earth's surface always faced the Sun the stars would never be visible there, whereas they would be easier to watch in places where it was always night).

My descriptions are a composite based on the local astronomers I have met and interviewed since beginning research in 2015. Since I am interested in how material conditions inform the temporality of their practice, this is worth discussing in more detail. This temporality can be understood in at least two, contrasting ways. It can be taken to refer to how actions take place in time, where temporality is like an unchanging backdrop for the actions unfolding within it. This would fit with, for example, the philosophy of becoming and duration associated with figures such as Henri Bergson and Gilles Deleuze. However, Graham Harman contrasts this approach to time with that of Bruno Latour, for whom "[c]ertain negotiations between actants lead to something asymmetrical or irreversible, and this is what we call time" (Harman 2009, 30). My approach is closer to that of Harman and Latour, where the temporality of practice refers to how relations between materials generate practical relations with time as a consequence.

I argue, first, that becoming a good astronomer does not mean asserting mastery over the universe, but becoming attuned to terrestrial and cosmic temporalities. Tim Ingold (2014) characterizes attunement as "undergoing" a creative process with nonhuman materials. If amateur astronomy can be said to be like archaeology in this sense, in the penultimate section I discuss an archaeological example to which astronomers are connected. Drawing from the growing literature on the archaeology of outer space exploration, I consider the problem of orbital space debris as a peculiar archaeological assemblage which arguably calls for an astronomer's attunement to the multiple, nested temporalities produced by diverse materials.

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Avocational Astronomy as Archaeological Attunement

The use of telescopes is normally regarded as a way of bridging distance, but they are also all about timing. Imagine the night sky as the Earth turned upside down, with amateur astronomers acting much like archaeologists who have to become intimately familiar with the conditions that interfere with their observation of objects, and that distort or conceal their attempts to curate the past.

The night sky is not often thought of as a layered medium equivalent to the soil, but there are similarities. The further below the ground one peers, the older the conditions one can observe. The further one peers into deep space, the more time loses any semblance of Newtonian simultaneity – one perceives not simply "the past" but many layered pasts reaching all the way back to the echo of the Big Bang. Outer space is also outer time: most of what can be observed with telescopes is a virtual reality of scattered traces (Jay 2012, 119–132).

Moreover, the atmosphere is not a transparent vacuum. The space beyond Earth's gravity is populated by its own taphonomic relations and processes, not just stars, planets and nebulae (Gorman 2015, 2017). This includes gravitational forces, solar winds, magnetic fields and light itself (Emhoff 2009). Whereas the creation of abstract clock and calendar time means harnessing the regularity of astronomical materials, accounting for the influence of atmospheric and cosmic taphonomy on one's ability to observe is very different. In order to observe the night sky closely, a would-be astronomer has to become attuned to the spatio-temporal conditions of terrestrial and cosmic processes, to the polychronic rhythms that constrain and shape life on the ground (Adam 1998), as well as atmospheric conditions and astronomical events. Astronomers have no control over these constraints and can only strategize to anticipate when interference is minimal and conditions are ideal for observing – or should be, if nothing unexpected happens.

Attunement is a form of creative openness to activity without action as normally defined. According to Ingold (2014), attunement need not assume instrumental activity, where a human agent masterfully shapes the world toward a pre-determined end. Instead, attunement is a process of growing together to achieve emergent and open-ended outcomes. Archaeologists arguably become attuned to the things they find insofar as the discovery of abandoned things involves, to a certain extent, the possibility of being surprised and of material assemblages directing archaeological attention, affect and effort (Pétursdóttir 2014). In a similar way, one does not *make* astronomical observations, but rather *undergoes* them.

Imagine that you are an amateur astronomer in the Southern Tier of central New York State – specifically, in the semi-rural outskirts of the city of Binghamton. No matter where you are, you will have to wait until nighttime to see anything beyond the Sun or maybe the Moon (unless, of course, you are planning to observe the Sun – its spots, flares, eclipse or corona). How long must one wait? The time at which you can finally observe outer space is based, firstly, on the local conditions that are best for observing. In the Binghamton area, amateur astronomers affiliated with the Kopernik Observatory can refer to its website, which routinely updates "Sky Conditions" for visitors to reference (see Figure 1).

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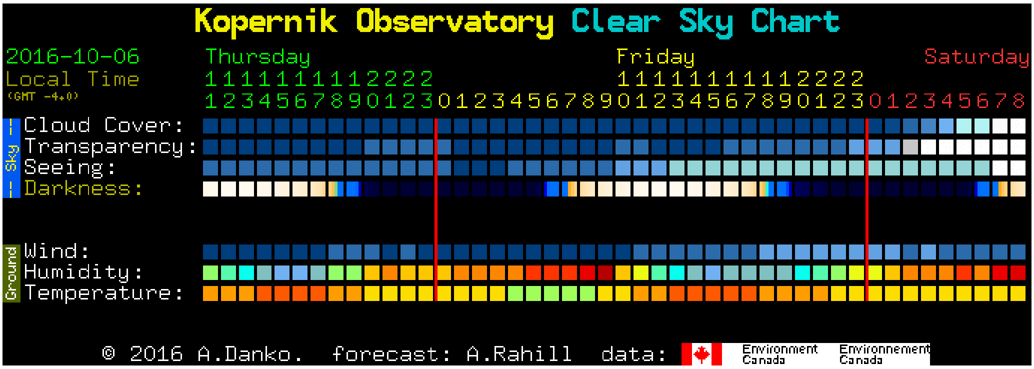

FIGURE 1. Example of a Clear Sky Chart.

Before deciding when to observe, you can plan what time of night will have the best combination of limited cloud cover, increased transparency and overall darkness. Also important and worth nothing are the conditions on the ground for that night. High wind and humidity can also make it harder to observe the night sky, by interfering with your use of a telescope. If it is too windy, it is hard to remain stationary with your telescope in place. If it is too humid, the lens may become difficult to peer through. Depending on seasonal climatic cycles these conditions will vary. And since conditions are right for observing so rarely, it can be said that processes and forms that interfere with amateur astronomy (wind, clouds, the Sun…) are only occasionally, and only ever temporarily, absent.

Using a telescope begins by finding a good place to see at night. If it is a mobile telescope – and most of those owned by amateurs are – then an astronomer in the Northern Hemisphere has to first align its position relative to Polaris, the so-called North Star, which is conveniently positioned in a seemingly "fixed" position relative to the Earth's rotational axis.[3] With a carefully aligned telescope, it is easier to identify objects using coordinates on star charts. Precise alignment also makes it possible to identify new and anomalous objects in the night sky – that is, those that have not already been documented over many centuries of observation.

Once the telescope is set up, its position is apparently fixed in place. When observing, the astronomer keeps his or her body still as well, bending back and knees to conform to the angle of the scope. By fixing yourself in place, you are holding still as the Earth rotates on its axis and astronomical objects gradually move with it. For this reason, if you want to track an object, you will need to change position. Compare this to conventional archaeological excavation, which Matt Edgeworth (2010, 141) describes as "perhaps the most embodied of scientific methods" given how readily most (but not all) human artifacts can be handled and circulated on a relatable, human scale. By way of contrast, Edgeworth reviews both vast and infinitesimal artifacts, from oil rigs to nanoscale transistors, which refuse such embodied relating and call for alternative forms

3. The Earth's relationship to other stars changes over time and, millennia from now, it is predicted that an astronomer in Earth's Northern Hemisphere will use the star Vega to align their telescopes to Polar North. Of course, not only is Polaris not fixed in place, it is over 400 light years away, meaning that the image we see in the night sky is a visible trace of what and where Polaris once was, not what and where it is now.

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of archaeological attunement. The embodied practices of amateur astronomers – the hunched-over stillness of an astronomer becoming one with a telescope – provides one illustration of how this can be done.

Preparing to observe takes time, but in the process the object makes of time a scarce resource. Such scarcity is not only conceptual, but also corporeal. Along with adjusting your body's spatial position, you will have to wait for your eyes to adjust to the darkness. This involves a literal bodily transformation. The photoreceptors in our eyes are rod and cone cells, which specialize in night and color vision, respectively. The transition to night vision is the process whereby your rod cells take on more of the work of processing the limited light available. Because of their location in the eye – away from the center, or fovea – rods cells produce clearer night vision out of the corner of one's eye. Peripheral night vision is therefore superior to looking at objects directly. It is for this reason that astronomers learn to use averted vision as they look at objects in the night sky or at the images generated by telescopes.

Some astronomers are lucky: their peripheral vision is better and their eyes transition to night vision quite rapidly. Others have worse peripheral vision and/or say they need to wait for an hour or more before they can see in the darkness. If you are an experienced astronomer, you will know when your night vision has kicked in and your body is ready. However, no matter how quickly one's eyes adjust, it can be frustrating when light pollution suddenly interferes and the body loses its sensitivity to the darkness. Many ideal observing sites are high off the ground and located far from the light pollution encountered in most urban areas (Gandy 2017). Even in the semi-rural outskirts of Binghamton, unexpected lights can ruin one's night vision. Cars unexpectedly pull up with their high beams on, fireworks and spotlights unexpectedly erupt into the night sky… When this happens, all one can do is turn away and wait for the body to become attuned to night once again, hoping the ideal conditions are not lost.

Beyond the time of night and the time of season, an amateur astronomer will typically venture out on special occasions, when specific cosmic phenomena are expected to reveal themselves. Phases of the Moon – its fullness, color, and occlusion – are the most obvious cases. There are also meteor showers that appear on a predictable schedule every year. The Perseids, for example, appear in mid-July to mid-August every year, as Comet Swift-Tuttle orbits the Solar System and periodically releases a stream of debris that burns up in Earth's atmosphere as it passes our vicinity. Other phenomena are far rarer, like Comet Hale-Bopp, which is only visible from Earth every few thousand years, depending on whether other objects interfere with its gravitational orbit.

In addition to periodic events such as these, there are also less predictable and unexpected experiences, when new objects or processes are discovered, or exhibit qualities that challenge previous knowledge of outer space. Just as one hopes that terrestrial cycles afford access to these special events when they occur, one also hopes that other objects in their own orbits will comply. If the Moon is too bright, for example, it can pollute the night sky with light, and that can make it hard to develop adequate night vision. It is not only artificial phenomena that can disturb night vision, in other words. The Moon's intense luminosity can similarly distract from other, far dimmer phenomena and make observing more difficult. That being said, unlike the less predictable interruption

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of high beams from nearby traffic, the phases of the Moon, and the relative brightness of celestial objects in general, can be anticipated and planned for in advance.[4]

There are potential solutions to these challenges. Telescopes can be fixed in place, automated and/or connected to only virtually. Professional astronomers need not schedule observation for particular times if they can log in to peer through massive telescopes located at various locations around the world – it is always night somewhere, after all. Even in these instances, however, astronomical observation is shaped, distorted and influenced by the layered, material medium of the sky and outer spacetime. In the case of amateur astronomers, attunement to multiple and nested temporalities is only made more apparent.

Temporalities of Orbital Space Debris

It is not only terrestrial and cosmic materials that make time for amateur astronomers – so do artificial materials and processes. On the one hand, there are artificial objects that astronomers sometimes want to observe, like the path of the International Space Station (ISS). The astronomers I have met tend to regard objects like the ISS with excitement and interest. Many are old enough to remember a time when the only artificial object in the night sky was Sputnik 1, launched in 1957. On the other hand, there are artificial products that confuse and frustrate amateur astronomers and space agencies alike.

Let us say that you have set up your telescope to observe a scheduled meteor shower and hope to capture an image of a meteor crashing to Earth. After months of waiting for the event, weeks of waiting for the right lunar and climatic conditions, days of monitoring the local Sky Chart, and hours preparing your scope and body, you finally get the picture you want. Then you learn, from a knowledgeable source in person or online, that in fact the time you recorded your image did not coincide with the official appearance of the shower. Moreover, you are informed that the bright glow of the object burning up upon re-entry is more consistent with a bit of metallic waste than an ice-covered space rock.

This has happened to astronomers I have met, who are understandably disappointed. Their disappointment is easy to understand when one considers the temporal constraints they underwent to creatively capture an object they thought was a natural material traveling the Solar System, only to discover it was merely an unidentifiable and unremarkable bit of junk. However, I do not mean to suggest that artificial objects are always less interesting than natural ones. As noted above, the ISS in particular is often sought after – and not merely for observation. It is one of the only objects that can be directly communicated with by the public: on occasion, the Kopernik Observatory in New York State asks questions of the crew on behalf of visiting schoolchildren. Similarly, some natural phenomena, like the Moon, are so familiar and so readily observable with the naked eye that they are far less appealing, despite their significance.

Astronomers can in this regard be compared to archaeologists of the contemporary, who also must overcome a natural tendency to assign cultural value to some of the objects they observe, in contrast to others. Overcoming this tendency, according

4. In some cases, the fluctuation of predictable light sources can actually aid in indirect observation, as with exoplanet astronomy (Messeri 2016).

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to Beck *et al.* (2009), means avoiding pre-judging what is encountered. For amateur astronomers, there are some cases where all is not known about even a familiar object: for instance, it is generally acknowledged by the amateurs I've met that, given the age of the enormous, distant star Betelgeuse, it could go supernova at any moment, forever altering the night sky with which they are familiar. They also know this has probably "already happened", but evidence of this past event just hasn't reached Earth… yet. It is not only seemingly "natural" surprises that one should be ready for, moreover. Most amateurs are also familiar with the peculiar star KIC 8462852, nicknamed "Tabby's Star", whose habit of dimming strangely was noted by in 2011 by citizen scientists looking through the public data from the Kepler Space Telescope.[5] One popular explanation for the star's strange behavior is that a hypothetical alien megastructure has been created to harness a sun's energy. Here too, being prepared to encounter the exceptional is part of the thrill of amateur observing – and the star in question is over 1200 light years from Earth, about twice as far as Betelgeuse, meaning that whatever is being observed could well have changed in the dozen centuries it took for traces of light to reach us.

At the same time, though, amateur astronomers do get accustomed to knowing what they are looking at and looking for, and when the thing that enters their field of vision, natural or artificial, is not what they were seeking, it is usually regarded as a waste of time – one's own human time as well as the limited and limiting nonhuman times upon which one depends to observe, since all of these resources are finite. For this reason, space debris mistaken for a meteor is an insult to the intense practical and corporeal investment required to undergo astronomical observation.

Sputnik 1 was not only the beginning of space exploration and the age of satellites. Its launch also represented the beginning of the pollution of space with human waste (see Damanjov 2016). Space junk or space debris comes in the form of the subsidiary materials intentionally or inadvertently discarded after helping satellites to escape Earth's gravity as well as the satellites themselves.[6] Some of these objects are broken down by interactions with other bits of debris and physical processes while in orbit, but may continue orbiting the Earth all the same. There are details records of the over 6000 satellites that have been launched since 1957, but even so they can be difficult to locate and identify from the ground. Lost and disused satellites and their accompanying materials are subject to temporal rhythms of near-Earth orbit, as are functional satellites. Depending on the altitude, objects in orbit either circle the planet at low Earth orbit (LEO), medium Earth orbit (MEO) or geostationary orbit (GEO), and this also affects their relative velocity, with objects further away moving more slowly. The ISS is located about 250 miles above the surface of the Earth in LEO and moves about 17,500 mph, whereas satellites in GEO are located about a hundred times further above the Earth and travel at less than half that velocity. The difference with orbiting debris is that disused space junk has lost attitude control, meaning that its orientation becomes more haphazard as it tumbles through space (Aghili 2012).

5. For a recent discussion see Koren 2017.
6. The Tesla car launched into space by Elon Musk in February 2018 indicates a future in which space debris will also be intentionally created by private individuals for self-publicity or other purposes. Thanks to Richard Bartholomew for drawing this example to my attention.

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Different kinds of space debris in orbit have been identified, at different sizes, in different volumes and different regions. Based on cataloged records reviewed by Klinkrad (2010), for instance, sodium-potassium alloy droplets, which escape from reactors, are only found in LEO, in very small sizes, in relatively low amounts. Pieces of slag from solid rocket motor firings are also typically much smaller than 10cm, but are found at a range of orbits and in largest amounts at a greater distance from the Earth's surface. However, the spatial density of debris larger than 10 cm tends to be greater in general in LEO, and these objects typically appear to be the product of deliberate explosions (Klinkrad 2010, 2). As these different forms of debris move, sometimes at tens of thousands of miles per hour, they occasionally collide with one another and splinter into additional smaller fragments. There are an estimated half a million pieces of orbital space debris today, only a fraction of which can be tracked by space agencies like NASA. Around 12,000 pieces are at least 10 cm in size and have been catalogued, which include "breakup fragments, spent upper stages, and retired payloads" (Liou *et al.* 2010, 648). Using the publicized data from the US Department of Defense's Space Surveillance Network, there have been numerous models generated to display the problem of space debris as it has accumulated over time. In time-lapse videos, one can visualize the Earth as if it were sloughing off dandruff: hundreds of thousands of tiny flecks that encircle it at various distances. These models can also give the impression that the archaeology of space debris must come to terms with spatial conditions of near-Earth orbital patterns; but, as astronomical observation shows us, these conditions are temporal as well as spatial.

Since Einstein, it has been argued that gravitational force is a product of the way spacetime is actively curved in the vicinity of objects with considerable mass (Topper 2013, 104). For this reason, objects in orbit around Earth exist out of sync with clock time on the ground. Adjusting for Earth's curvature of spacetime facilitates better control of and communication with satellites in orbit (see Ciufolini *et al.* 1998). To put it simply, the spacetime of orbital space debris is curved differently relative to spacetime on the surface of Earth, where the planet produces time differently. Unlike functional satellites, which can be manipulated and brought in sync with the designs of those on the ground, the alternative spatio-temporal rhythms of space debris represent a distinct risk to other things (and persons) in orbit. As such, they also represent a potential barrier to further human exploration and exploitation of space.

For one thing, space debris is potentially dangerous to spacecraft. Space debris is partly assessed by treating returning spacecraft in a way they were never intended for: as a "hypervelocity impact capture medium", as they are dented more by artificial objects than natural meteorites (Bernhard *et al.* 1997). The impetus for tracking and modeling space debris thus comes from the temporal possibilities they threaten. Alice Gorman (2015) describes space debris as an emergent assemblage that takes on new spatio-temporal properties, even when compared with other objects orbiting the Earth. This is most clearly represented in the idea of the Kessler Syndrome (Kessler and Cour-Palais 1978). This theory predicts a "cascade of random collisions that create so much debris the Earth is enveloped and cut off from space" (Gorman 2015, 42). This includes a feedback process whereby objects continually collide and spread out, converting Earth orbits, especially in LEO, into a hazardous environment filled with tiny

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fragments. Space debris would circle eternally overhead like a cloud of bullets awaiting a target, trapping us in fear on the surface. Gorman points out that it is unclear that such a dire situation has emerged or necessarily will. Whether it is likely to take hold or not, the Kessler Syndrome actually reflects anxiety about the unexpected and emergent spacetime of materials orbiting the Earth. The time they threaten is increasingly incorporated into fantasies of space travel. For example, this provided an element of horror in the recent and very successful science-fiction film *Gravity* (2013), where space debris was depicted as a monstrous threat – like a swarm of abiotic locusts – that cycled the Earth with an alien regularity: without warning they descend and annihilate spacecraft or slaughter hapless astronauts.

It may be that these risks are being somewhat amplified by filmmakers and space agencies; yet, the threat of damage from orbital space debris is at least somewhat real. The ISS had to perform approximately eight evasive maneuvers during its first decade of operation in order to avoid collisions with debris. Calculations are normally performed at least three times a day to determine risks of collision over the subsequent 72 hours; if the chance of collision with a large enough object is determined to be greater than one in ten thousand, then maneuvers are planned and executed (see Johnson and Klinkrad 2009). Here is an account of a recent incident, written by representatives from the ESA and NASA assigned to space debris:

> The last collision avoidance maneuver by ISS occurred on 27 August 2008 when a fragment from the Kosmos 2421 spacecraft was projected to pose a collision risk of 1 in 72, i.e., 0.014 […]. This piece of debris was one of more than 500 cataloged debris released from Kosmos 2421 during three major fragmentation events from March to June 2008. At the time of these fragmentations, Kosmos 2421 was only about 60 km above the orbit of the ISS. As these debris decayed down through the ISS orbit, the number of potentially threatening conjunctions each month increased by a factor of three. (Johnson and Klinkrad 2009, 5)

Occasionally, these objects also fall from the sky, as occurred in December of 2016 when a large object came seemingly out of nowhere and smashed a man's van in Milwaukee, Wisconsin (Lemoine 2016). Wisconsin is also where a fragment of Sputnik 4 crashed down from the sky in 1962. The occasion is still celebrated in one town as "Sputnikfest", including a pageant to determine the annual "Miss Space Debris" (David 2013).

According to Dickens and Ormrod (2007, 153), space debris is arguably even more meaningful as both barrier and bridge to desirable futures. These hoped-for futures involve, for instance, further exploration and exploitation beyond LEO and into the very valuable and legally contested domain of geostationary orbit, where satellites can more easily analyze from and transmit data to the entire planet (Collis 2009). This also includes NewSpace initiatives that seek to extend capitalism and empire beyond the limits of the Earth, whether to mine asteroids or colonize Mars (Dickens and Ormrod 2007; Dickens 2009). These initiatives provide a clear motivation to clean up the polluted and risk-filled environment in the vicinity of Earth. From this admittedly interested perspective, the presence of space debris limits the utilization of LEO, MEO and GEO, creating risks for

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any state and/or capital investment. Insofar as space debris influences assessments concerning the utilization of outer space for various ends, it directly mediates the futures that space agencies and industries imagine possible and desirable.

To manage these risks requires attunement. Space agencies must first be able to find the objects and predict their strange movements. As with contract archaeologists, experts are called upon to manage those materials that might otherwise interfere with the success of productive enterprises of extraction, construction and consumption. The primary difference is that, where contract archaeology, and cultural resource management generally, endeavor to protect the objects they curate from destruction by human industry, in astronomical CRM the risks are reversed: it is those voyaging into space who potentially have something to fear from leftover remains, and not the other way around.

As Gorman makes clear, the primary difficulty with an archaeological analysis of space debris is the issue of distance and a lack of "direct field experience" (Gorman 2015, 33). Remote sensing can only provide fragmentary glimpses of objects large enough to capture. In short, the objects are too small and space is too big. In this regard, archaeology becomes much like astronomy. Amateur astronomers could be seen as ideally positioned to aid in such research, in fact, as they can cover more of the spacescape than even a very large centralized government telescope (Marshall *et al.* 2015). Beginning after the launch of Sputnik 1, amateur citizen scientists known as "Moonwatchers" (named after Operation Moonwatch, a Smithsonian project), helped form a global network of satellite trackers who provided crucial information to space agencies and governments throughout the Cold War (see McCray 2008). Given the secrecy that has surrounded a great many satellites, furthermore, such efforts arguably also help to democratize scientific knowledge. A more recent example is the crowd-sourced effort to scan space in search of the elusive and acclaimed Planet 9. And, perhaps more importantly, amateur astronomers have developed the patience to undertake this, having had to routinely undergo attunement to multiple temporal constraints in order to follow their passion.

It therefore is not surprising that in 2012, DARPA (Defense Advanced Research Projects Agency, the US Department of Defense's projects agency created after Sputnik 1 launched) proposed to enroll amateur astronomers in their hunt for space debris. The goal, they claimed, was to supplement the DoD's Space Surveillance Network with a new program called SpaceView. Astronomers would help DARPA track the debris so that they could launch a satellite recycling robot, called the Phoenix; initially, it was hoped that this would be ready by 2017, although it is still in development. The Phoenix would find the debris identified by astronomers and use the parts to support new space missions. The European Space Agency and NASA have announced a similar goal, without any mention of the use of amateur astronomers. The appeal of recycling space debris is that it turns the threat into a resource that can make up for the enormous terrestrial funds and resources that are needed to launch objects into Earth's orbit and beyond. With the help of amateur astronomers, space debris would not only be a form of cultural resource to manage – as it is typically imagined within the archaeology of outer space – but a material foundation for new and emergent futures.

Precisely because amateur astronomers are used to undergoing attunement to terrestrial and cosmic temporalities, however, they may not answer the call. Those astronomers

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that I have met are skeptical of DARPA's plans (which, like many proposals to capture and clean up the orbital environments of Earth, have yet to materialize). Amateur astronomers are too aware of the trials undergone to peer through the media of sky and space, the time it would take to find something small and unexpected. Perhaps more importantly, this is free labor that they would rather use for more satisfactory ends. Space debris, after all, is usually thought of as noise that disrupts their careful efforts at observation.

Conclusion

There is a sense in which both astronomical and archaeological practice share a peculiar temporal multiplicity or polychronicity. They are both material practices directed at traces in the present, about things in the past, for the sake of the future. That is, no matter what form they take, their true object is not the actual rays of light or fragments of material they have access to in the present, but the past reality these stand for and enable us to better imagine (whether distant celestial objects or human societies as they once were). And no matter whether the goal of what they do is preserving a memory or engaging in positive social change, they are striving toward a hoped-for future where the memory lasts and/or people are better off (cf. McGuire 2008). I have argued that amateur astronomy in general, and the observation of space debris in particular, demonstrate how materials can do more than stand for time's passing, but also produce a temporality all their own, with which one can become more or less attuned. This raises the question of whether such time is uniform or multiple.

Adam (1995, 1998) and Connolly (2013) both argue that the universe consists of multiple, nested and semi-autonomous temporalities. Similarly, the heirs of Einsteinian relativity in contemporary astronomy have developed not one master clock but a "family of time scales" which include Universal Time, International Atomic Time, Coordinate Universal Time and "apparent time", among others (Seidelmann and Seago 2011). By contrast, Ingold and Hallam (2007) and Ingold (2012, 2014) usefully direct our attention to the role of the nonhuman as productive of temporality. However, according to Georgina Born, they rely on a "monotemporality of becoming" that fails to acknowledge "the plural temporalities in operation both in human and nonhuman life and in cultural production" (Born 2015, 365). Based on the experiences of amateur astronomers and the phenomenon of orbital space debris, one could argue not only that materials are time, but that these times are multiple, nested and emergent.

The tendency in the growing archaeology of outer space has been to look at documented evidence from the vantage point of the ground – but, unlike amateur astronomers, not through telescopes. This does not make the evidence they have gathered less important, but it does mean that the material practices involved, of observing and becoming attuned, is different. The archaeological curation of objects in outer space not only consists of a new form of cultural resource management or heritage research, although it is that as well (see Barclay and Brooks 2009; Idziak 2013). Rather than helping us merely to record the past, it may, as Gorman (2014, 2015) argues, help us understand the emergence of new temporalities. In particular, she associates observation of outer space with the Anthropocene, which "cannot be understood without reference to space. The Sun, Moon, and electromagnetic environment shape and drive

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the climate of the Earth" (Gorman 2014, 90). To reckon with such unsettling temporal possibilities, one need only turn to astronomical practice, which has long facilitated new ways of imagining the universe's ultimate beginnings and endings… from the Big Bang and Big Crunch, to the Milky Way's eventual collision with the Andromeda Galaxy, and the inevitable incineration of the Earth as it is engulfed by our aging Sun, which itself will eventually die. If anything, astronomers must be open to many futures, many endings. The difference between these disastrous, imagined futures and those associated with space debris is that, by limiting the exploitation of orbital regions and the exploration of the universe, space debris serves as a temporal blockage of sorts – one that not only frustrates us in the present but delays or eliminates possibilities, including the possibility of future escape from the climatic and climactic disasters that await a humanity that may be prevented from ever safely leaving Earth behind.

Perhaps space debris can never be mastered and will only multiply. If so, it would have to be attuned to as yet another constraining nonhuman force, mediating access to desired and hoped-for views of, and futures in, space. One might assume that the main limitation confronting the archaeology of outer-space exploration is the lack of access to the remains floating in orbit or crashing into the earth. Archaeologists of outer space have developed novel ways to study what they rarely can grasp and handle, measure and collect, but amateur astronomers have far more experience, being passionate about things to which they have no direct access. I have no reason to endorse DARPA's view, that amateur astronomers are interested or able to provide new data, *per se*. What I think they represent, instead, is an alternative sensibility, one cultivated over many generations, whereby knowledge practices are *undergone* rather than *mastered*. This is true not only of amateurs, those I have focused on, but of professionals as well. Exoplanet astronomers, for instance, are tasked with imagining worlds from the slightest glimpse of planets many light-years away (Messeri 2016). Not only do archeologists of space debris have a closer target, in space and in time: they also know much more about the world from which these metal pests emerged. If they became more familiar with an astronomical sensibility, one premised on distance and attunement, restraint and constraint, they might discover a set of practices that has grown in the absence of such relative mastery, subject to processes of formation and deformation not unlike what conventional archaeologists encounter amid the Earth's beguiling surface.

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