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Extra-terra incognita: Martian maps in the digital age

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Abstract

Science and technology studies (STS) and critical cartography are both asking questions about the ontological fixity of maps and other scientific objects. This paper examines how a group of NASA computer scientists who call themselves The Mapmakers conceptualizes and creates maps in service of different commitments. The maps under construction are those of alien Mars, produced through partnerships that NASA has established with Google and Microsoft. With the goal of bringing an experience of Mars to as many people as possible, these maps influence how we imagine our neighbouring planet. This paper analyzes two attributes of the map, evident in both its representation and the attending cartographic practices: a sense of Mars as dynamic and a desire for a democratic experience of Mars in which up-to-date Mars data can be intuitively accessed not only by scientists but by lay users as well. Whereas a democratic Mars promises users the ability to decide how to interact with the map and understand Mars, dynamic Mars imposes a more singular sense of Mars as a target of continued robotic and maybe even human exploration. Because maps of Mars have a different (and arguably less complex) set of social and political commitments than those of Earth, they help us see how different goals contradict and complement each other in matters of exploration and state-craft relevant both to other worlds and our own.

Keywords

cartography, democracy, maps, Mars, NASA, open source

Introduction

On Thursday evenings, San Francisco's California Academy of Sciences, a science museum in Golden Gate Park, keeps its doors open late into the evening, dims the lights, brings in DJs, and hosts an event called NightLife. With drinks in hand, visitors check

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out exhibits and pop into the planetarium for a virtual view of the night sky. I attended a NightLife in the spring of 2010 to hear a presentation by Aaron,[1] the head of a small research group called 'the Mapmakers' based at NASA Ames Research Center located in nearby Mountain View, CA. This team of computer scientists-turned-cartographers is partnered with Microsoft and Google to transform the terabytes of planetary image data NASA has collected over the years into digital maps of Mars and other planets. Tonight, Aaron was showing off the highest resolution map they had ever made of the Red Planet.

Aaron's voice filled the dark room as he explained to the audience the origin of the different images of Mars that were projected onto the planetarium's dome. He began by displaying a 19th-century map of Mars charted by the astronomer Percival Lowell before segueing into what he was most excited to show: the mappings he and his fellow Mapmakers had rendered in 3-D. Aaron seamlessly moved from the 2-D historic map to the contemporary 3-D map and took the audience on a simulated ride through a giant Martian canyon known as Valles Marineris. The switch to the 3-D canyon fly-through was greeted with gasps and applause from the audience. Anyone who had been distracted during the historical prelude was now engaged by the experience of zooming across an alien surface. With a captivated audience, Aaron used his maps to explain a bit about the geologic history of Mars, describing a theory about seasonal water flow across the surface. Aaron told the audience that when he learned that Mars might once have hosted oceans and rivers, the planet transformed from a boring, featureless 'rock in space' to a 'truly vibrant place'.

The Mapmakers' software allows for the experience of exploring another planet from the comfort of one's couch. I spent six months as a participant observer with the Mapmakers, understanding how their technical work of 'wrangling' (as one Mapmaker described it) planetary data resulted in online and desktop applications that allowed anyone with an Internet connection to experience the shift, as Aaron put it, of Mars from rock to place.

In critical cartography, the 'processual' approach, or the post-representational turn, is a call for analysts not to assume that maps are finished products, but rather things that are 'always in the process of becoming' (Kitchin et al., 2011, 2013: 2). Web 2.0 cartographies, like Google Earth and even Google Mars (an extension of Google Earth produced by the Mapmakers), are rich sites from which to elaborate upon this analysis, as users can both navigate and even augment these maps, offering numerous instantiations of maps as things constantly undergoing use and revision (Bittner et al., 2013). Focusing on the process of both creating and using maps shifts the analytic gaze away from the quiddity of the map by destabilizing cartography's fundamental assumption that 'the world can be objectively known and faithfully mapped using scientific techniques that capture and display spatial information' (Kitchin et al., 2013: 1). Prior constructivist approaches to cartography (Harley, 1989; Pickles, 2004; Wood and Fels, 1992), then, are extended by arguing that not only is the map a text to be read, it is also a text constantly rewritten by its makers and users.

Science and Technology Studies (STS) is also concerned with how objects and worlds are made and understood. The map, even a map of Mars, is a ready point of entry for such a discussion. STS scholars have of late begun to reimagine what it means to create objects – and how we should or can study world-making – through the language of ontology as enacted in practice. Writing about the purported 'ontological turn', Woolgar and Lezaun (2013) offer, 'It is an effort to circumvent epistemology and its attendant language of representation in favor of an approach that addresses itself more directly to the

composition of the world' (p. 322). Though STS has long conceptualized scientific objects (including maps) as things with ontological security only because of scientific work (Daston, 2000; Hacking, 1983; Latour and Woolgar, 1986), and thus as things open to multiple uses and interpretations (Messeri, 2010; Star and Griesemer, 1989), scholars are now asking whether there might be 'forms of difference that cannot be reduced to a disparity of "worldviews"' (Woolgar and Lezaun, 2013: 322). This is a call to focus not on how different contexts invest different meanings in an object, but how the object is 'enacted' in different, multiple ways (Mol, 2002). STS scholars ask how diverse practices enact the seemingly same object as different (see Law and Mol, 2008). Mars is removed in space from its mapmakers and map users and it cannot be enacted in the same physical ways as proximal objects. But the map nonetheless can illustrate the different, even conflicting norms and meanings attached to Mars and, as I will demonstrate, can shape the material possibilities of future interactions. Bringing in ideas from critical cartography can show how maps are not just representations but also practices.

My engagement with STS's ontological turn extends certain moves made by constructivist approaches, while also considering practices that produce multiple conflicting or commensurate 'becomings' of scientific objects:

> The purpose of researching ontology, then, would not be to arrive at a better formulation of the reality of the world, or of the ways in which the world is real, but to interfere with the assumption of a singular, ordered world (Woolgar and Lezaun, 2013: 323).

Likewise, in critical cartography, the post-representational turn interferes with the assumption that maps are singular, ordered objects. In framing maps as 'ontogenetic', one understands them as 'simultaneously being produced *and* consumed, authored *and* read, designed *and* used, serving as representation *and* practice' (Kitchin et al., 2011: 17, emphasis in original). This last coupling of representation and practice deserves note, especially as applied to inscriptions of scientific objects. Sismondo (2015), drawing on Mol's work, has pointed out that representations are important to ontological projects in so far as they are understood as practices. Representations in and of themselves do not produce multiple ontologies but index important sites of practice. In what follows, I will focus on how the Mapmakers produce maps of Mars, revealing the technical work and ideological commitments that animate these cartographic inscriptions that are simultaneously representations and practices.

Extraterrestrial maps are informative boundary cases because they are mappings not of our own world, but of entirely other worlds. Mars can act as a laboratory of sorts, as a location seemingly anesthetized from the Earthly politics and socialities that deeply inform terrestrial maps. The production of extraterrestrial mappings offers a novel site at which to play with ontological theories. Only a few geographers or cartographers have considered mappings of other worlds (Lane, 2011; Wood, 2010). However, anthropologists and geographers have underscored the potential of social studies of outer space as a productive medium for reflecting on our own terrestrial groundings (Valentine et al., 2009, 2012; cf. MacDonald, 2007). Outer space opens up ontologies because it flexes ideas of being. As aliens and otherings are incorporated into analysis, terrestrial orientations and attending assumptions of sociality are unmoored (Battaglia, 2006). Not only

are we asking if it could be otherwise, but extraterrestrial maps further ask if we can be elsewhere (cf. Messeri, 2016).

The analysis that follows draws on ethnographic data surrounding the construction and release of Mars maps in Google Earth and Microsoft Research's WorldWide Telescope collected during my time at Ames. During this period, I was a member of the Mapmakers, a team comprised of six men in their twenties and thirties, working alongside them in an open office and attending NASA and NASA-Microsoft meetings. Though not involved in the coding of the maps, I was part of the day-to-day work of the group: my job was to facilitate the production of two signature 'tours' of Mars for release in a special 'Mars mode' of WorldWide Telescope that would feature the latest cartographic product of the Mapmakers. I will discuss these tours in greater detail in the second half of the paper, when I explain how the Mapmakers expect Mars to be 'seen' and 'experienced' by users. The Mapmakers portray Mars as 'dynamic', and in so doing help to further NASA's mission to explore, and even colonize, outer space.[2]

The opening vignette of Aaron's talk at NightLife exemplifies how he sees, and wants others to see, this dynamism of Mars. Aaron described water flow and shared his imagination of Mars as 'vibrant'. The 3-D Marsscape fly-through further allowed the audience to experience Mars in the way Aaron imagines it. The public nature of both Aaron's talk and the maps suggests that alongside this dynamism, the Mapmakers also wish to make Mars 'democratic', a world for all people to explore in their own way, on their own time. Through its map, Mars is meant to be used and made in personal ways. And yet tracing the production of these maps will highlight an ontological friction. Imposing a singular understanding of Mars (dynamic) undercuts the Mapmakers' goal of facilitating widely accessible, personal, customizable (democratic) understandings and explorations of the Red Planet. 'How people explore' and 'who explores' is both asked and answered by powerful state and corporate entities: NASA, Google, and Microsoft. The stated desire that the government and these companies express for citizen participation conflicts with the top-down infrastructure that underpins these projects (see Chun, 2011).

The contradictions in this mapping project stem in part from a failure to recognize that mapping Mars is fundamentally different from mapping Earth. Scholars analyzing terrestrial maps often emphasize that maps are practices perhaps even more so than representations: they do not reflect but rather create territories (Anderson, 1991; Edney, 1997; Ramaswamy, 1999). Further, the lived experiences of places both reinforce and push back on what maps express. Yet, aside from robotically mediated interactions, there is no lived experience of Mars. The map has, as Baudrillard (1983) famously diagnosed of the coming age, quite literally preceded the territory. This should not serve to diminish the map of Mars. Rather, the territory created by these maps necessitates analytic attention to understand how these digital interactions might constrain or direct future, material actions.

Making Mars for everyone

Aaron once described for me the origin of the Mapmakers. Fresh from completing a master's degree in computer science at MIT, he had been working at Ames for only a few months when he met a planetary scientist in a different group. This scientist, Steve, expressed to Aaron that he was frustrated that he did not have the resources to build 3-D

models of Mars. The data were there, but producing such models was prohibitively expensive. As Aaron described, he and Steve

> had this notion that we wanted to build this automated tool so we could build a lot more models and *democratize* the whole process and *get the data out there to the people* so they could have access to it and hopefully make more discoveries and whatnot (emphasis added).

As the Mapmakers' work progressed and partnerships with Google and Microsoft flourished, the process of building 3-D models of Mars became not only a deliverable for planetary scientists like Steve, but also for the public more broadly. As Aaron showed off at NightLife, 3-D maps of Mars were no longer elusive, as they had been for Steve. Thanks to years of software development by the Mapmakers, they were available at the click of a button. Democracy, as evoked by Aaron above, was about bringing a multi-dimensional experience of Mars to many people and was also, importantly, about making discoveries through the exploration of these maps and models. The Mapmakers and their mappings establish Mars as a place that is available for all people to explore and discover.

Democratizing Mars not only describes the expectation of how users should experience the map, but also directs the process of constructing and coding these maps, particularly through a commitment to open source software development. Thus the 3-D representations that allow for a democratic experience by users are coupled with technical practices that reinforce this same ideal. The valuing of democracy in the development process is entangled with the end product. Thus, as I describe below, the idea of 'democracy' is manifested in terms of the accessibility of data and of tools.

My purpose in describing the Mapmakers' practices is first to discern what they mean when describing their work as democratizing and second, to understand how the benign and earnest democracy of the Mapmakers is torqued when emanating from NASA, an institution whose mission is entwined with empire building.[3] Farman (2010) has argued that the digital satellite maps of Google Earth, especially their interactive functionality, are in the service of charting a 'digital empire'. While he shows that users can in fact use the software as a means of challenging such an empire, my focus on the dynamic Mars shows that this challenge does not happen for maps of Mars. Thus, my discussion of democratic Mars focuses on the tension inherent in how the Mapmakers tie together democracy with openness amidst the broader institutional ecology of NASA.

NASA Ames is a hybrid of government Big Science and Silicon Valley start-up cultures. At this site, open source initiatives find an interesting bedfellow in NASA's neo-imperial mission. Ames is located in the heart of Silicon Valley, just eight miles southeast of Stanford University. This region of the Bay Area is a flat coastal expanse bordered by the San Francisco Bay to the east and the Santa Clara Mountains, which are green in the summer and sandy brown in the winter, to the west. One- and three-story buildings quietly announce themselves along suburban roads with simple signs that read 'Hewlett Packard', 'Xerox PARC', and 'Apple'. More recently, Yahoo, Facebook, and Google have established themselves there. NASA Ames is situated between Motorola and the Computer History Museum.

In the world of NASA, Ames flies below the radar. It does not have the bureaucratic power of Headquarters, the high profile Rover missions of the Jet Propulsion Laboratory,

nor the experience with human space flight of Houston. Since its founding as a military base for the National Advisory Committee for Aeronautics in the 1940s, the precursor to NASA, directors have tried to carve out various niches for Ames. In the 1960s and '70s, engineers and scientists at Ames began building ties with the technological talents blooming in the Bay Area. In the 1990s, as Ames was facing a review and the threat of a closure was palpable, the director doubled down on the approach of making Ames NASA's technology center. Ames partnered with universities on the East Coast to open 'Silicon Valley' branches on its sprawling campus. During the following decade, Ames sought to make itself indispensable to NASA by becoming the IT resource for the whole organization – an increasingly necessary part of any mission, human or robotic (Bugos, 2000).

When I arrived at Ames in 2010, the Center was in a secure place, thanks to these earlier initiatives and the continued push by Center director Pete Worden to strengthen ties with the tech world. I came to Ames in order to work with Aaron and the Mapmakers as part of a larger ethnographic project on contemporary practices in planetary science. The Mapmakers work within the Intelligent Robotics Group (IRG), whose projects range from data mining to remote robotic operations. IRG runs itself more like a startup than like a cog in the NASA machine. Members of this group dress casually, teasing their colleagues when they have to don a suit and tie for visits to NASA Headquarters in Washington, D.C. There are no strict office hours, but instead an attitude that one should simply work however long it takes to complete a task, often leading people to arrive late and leave even later.

The half-dozen members of the Mapmakers came to NASA not because of expertise in planetary science, but because of an amateur enthusiasm for outer space. They apply techniques from computer science and robotics – such as computer vision – to planetary mapping. Steve is the only traditionally trained planetary scientist of the group, and he offers the occasional scientific corrective for the otherwise software-heavy work of the group. None are trained cartographers, but they see their research as continuing the work of traditional cartographers charged with mapping unknown territories. During my first week, Aaron gave me his well-worn copy of John Noble Wilford's (1981) *The Mapmakers* as mandatory reading. Wilford's book ends with a discussion of extraterrestrial mapping and NASA's Mapmakers understand their work as picking up that torch and carrying it forward.

As a result of NASA Ames's push to partner with tech companies, the Mapmakers work with Google and Microsoft to provide planetary maps for Google Earth and Microsoft's WorldWide Telescope. These maps are meant for public consumption, to excite lay users about space exploration. In one sense, this small group is playing an extremely large role in the popular understanding of what Mars is like as a place. Their digital maps are probably the most seen visualizations of Mars, thanks to promotion by Google and Microsoft. How they choose to depict the Red Planet, and more importantly the practices that are embedded in these representations, carries weight beyond the scientific world. When I arrived, the Mapmakers had already delivered a Mars map for Google Earth and were beginning to work on a similar map for Microsoft.

To claim that the Mapmakers strive to make Mars democratic is to make an assertion not only about the final representations but also about the cartographic practices that

feed into these mappings. Design decisions made by the Mapmakers appeal to an open-source ethos – a commonly held desire in the tech community to make code available to users (see Crampton, 2009). The Mapmakers democratize Mars on two levels: through their open-source initiatives and through the map itself, which brings NASA's planetary data to a wider audience.

The Mapmakers have been implementing open-source solutions since the group's earliest days. The early encounter between Aaron and Steve-occurred while Aaron was devising a fast way to process stereo pairs – images that when fused create the illusion of 3-D – taken by satellites to automatically generate 3-D terrain models of Mars. He called this piece of software 'Stereo Pipeline' and hoped it would be useful to scientists at Ames and elsewhere. Steve was a supporter of this project, and he and Aaron became the first two members of the Mapmakers. They took it as their mission to democratize the process of working with planetary data by creating an accessible tool and, further, making it open source.

In 2009, Aaron and Steve, aided by two other members of the Mapmakers, Max and Seth, released the alpha version of an open source Stereo Pipeline. By 2010, when I was working with the Mapmakers, several other open source initiatives were ongoing. Stereo Pipeline and a data management system called the Plate Filesystem are the two main components of the Mapmakers cartographic software, and the team was working toward making them both as open as possible. As already described, the Mapmakers operate differently than does NASA more broadly, and in striving to make their software open, the group had to confront their institutional reality, which favored a more conservative, less open engineering approach. Seth (the 'hacker' of the Mapmakers and thus the one assigned to oversee the open source initiative) had to navigate many levels of bureaucracy, as he described it, before Headquarters would give permission to release their code. Once the permission was granted, Seth uploaded the code to Github (a website that hosts code, facilitates network sharing and manages version control). When he announced this achievement at a Mapmakers meeting in May 2010, everyone applauded and showed genuine excitement for this accomplishment. Welcome to 'this brave new world of open source', Aaron intoned.

Kelty (2008) writes about the culture of the Free Software community and its attendant geeks. He describes the community as a 'recursive public', a public that maintains the means by which it came together as a public. Geeks, Kelty shows, care deeply for initiatives like Free Software and Open Source and the ideologies they represent. They 'use technology as a kind of argument, for a specific kind of order: they argue *about* technology, but they also argue *through* it' (Kelty, 2008: 29). One argument that the Mapmakers propagate is that NASA's data, produced through public funds, *should* be available and, further, available to manipulate, to all who are interested.

While developing Stereo Pipeline, Aaron found himself building what he described as 'amazing 3-D models of Mars', and only his close collaborators were seeing them. To him, the next logical step was to figure out a way to share these views with as many people as possible. NASA's new partnership with Google proved to be a perfect way for Aaron to achieve this goal. The map was built using these open-source tools, but had a wider circulation, thus making it a more powerful technology with which to argue for a democratized Mars. Mars in Google Earth was released on February 2, 2009 and the NASA press release

enthused that it 'brings to everyone's desktop a high-resolution, three-dimensional view of the Red Planet'. Both the Mapmakers and the larger NASA organization describe Mars as a place governed by the open source ethos of access for all.

In the spring of 2010, the Mapmakers were busy creating a similar Mars map for Microsoft Research's WorldWide Telescope (WWT). As with the Google map, this would be a globe that could be rendered in 3D thanks to Stereo Pipeline, but the Mapmakers also wanted to improve upon their first map by stitching in higher resolution imagery. This proved a significant technical challenge, made possible only with the improvement of their other open-source tool, the Plate Filesystem.

The highest resolution imagery of Mars comes from a camera called HiRISE (short for High Resolution Imaging Science Experiment), mounted on the Mars Reconnaissance Orbiter that has been imaging Mars since 2006.[4] The pictures it takes can resolve objects that are less than a meter across. From orbit, it has taken pictures of the Phoenix Polar Lander and resolved the Mars Rover tracks. It has taken pictures of individual boulders rolling down a hill. Because the resolution is so high, after four years HiRISE had only imaged one percent of the planet. The challenge for the Mapmakers was to take this one percent that is spread over the surface, figure out how to process the terabytes of information contained in this set, and embed these images in the global map. If accomplished, the user would not be relegated to hovering above the surface, but could zoom down to a resolution at which one could see the ripples on sand dunes, tilt the perspective so as to view a landscape of the region, and feel as if he or she was standing on the ground. Though HiRISE images are available to the public, this would be the first time they were embedded in a map and thus the first time the public could intuitively explore them.

The decision about which data to include in the map was one guided by the Mapmakers' internal definition of democracy as accessibility. Another way that we can see this commitment manifested in their technical practice, thus prioritizing one of several possible Martian ontologies, is their choice of cartographic projection. When making Mars for Google Earth, the Mapmakers had to use the same map projection for Mars that Google engineers used for Earth, the Simple Cylindrical projection; this is similar to the classic Mercator Projection in that latitudes and longitudes are parallel.

All projections create distortions and different projections imply different socio-political structures (relevant here is Corner, 1999). The Mercator projection, for example, orients toward the north and distorts distances near the poles, making the landmasses in the northern hemisphere appear larger than they might otherwise. The Simple Cylindrical projection used in Google Earth similarly distorts the terrestrial – and consequently Martian – poles. For Google Earth, this is not important because, as Mapmaker Steve exaggeratedly put it in a public talk, on Earth 'no one cares about the poles'.

On Mars, however, the poles are extremely important for science, as they contain the only known deposits of water ice on the planet and experience seasonal melting. Consequently, they have been extensively imaged. For WWT, the Mapmakers were able to implement a different projection for planetary mapping, one that was meant to be more egalitarian when it came to distortions, developed by Microsoft Research. This projection, the Tessellated Octahedral Adaptive Subdivision Transform, or TOAST, is based on Buckminster Fuller's Dymaxion projection. Fuller based his projection on a modular triangular structure that could be unfolded and re-oriented in different ways so as to

neither overly distort one region nor statically favor one landmass over another. Thanks to the TOAST projection, WWT depicts the poles no differently than it does any other Martian region. The choice of this projection created an 'egalitarian' surface in so far as more of the data were properly displayed. Further, this projection does not presume one region of Mars to be more important than any other, seemingly positioning Mars as a uniformly neutral territory.

Returning to the question posed at the start of this section, what do the Mapmakers and NASA more broadly mean when they invoke democracy or earnestly frame their work in terms of accessibility? In general, any claim that simply making data available on the Internet equates to democracy is dubious (see Hindman, 2008). Haklay (2013) specifically examines how this false claim propagates across various geographies that populate Web 2.0 platforms. Not only are there barriers to access, but there are also knowledge barriers that limit participation to the few who have adequate technical skills to truly interact with novel mapping software. New cartographic technologies are just as likely to reinforce inequalities as they are to flatten them (see Crutcher and Zook, 2009). Haklay (2013) notes that in the conversations of participatory and critical GIS, democracy is often understood as simply making available to a broader segment of the population technology or information that used to belong to the elite (p. 56). Attending to how the Mapmakers and NASA talk about the maps of Mars, we see several different ideals that 'democracy' comes to stand for, including this problematic claim but also a desire for increased participation in both science and the greater mission of exploration.

With respect to the idea of democracy as simply affording access, Aaron explicitly states that his motivation for these mapping projects is to make NASA planetary imagery intuitively accessible to the public, not only to scientists. Aaron recalls that when he first arrived at NASA,

> accessing Mars data in general was just really hard. It took me a year and a half, two years to really come up to speed on how to work my way through all of the data sets in the archival data systems, the Planetary Data System. And so, the desire to make NASA's data more easily accessible was growing stronger. … And I knew that if it was hard for me to access the data then it was really hard for the general public for sure to access the data.

As Mapmaker Jesse put it,

> I want anyone who wants to be able to explore all the awesome data that NASA has, be that planetary data or astronomical data. Cool stuff should be discoverable – folks in the general public should be able to just jump on the Internet and explore this stuff.

At the same time, Aaron acknowledges that the open-source mapping tools they develop are not exactly user-friendly and are mostly adopted by a handful of scientists for their research and presentations. The kind of interaction with the data to which the Mapmakers aspire must be left to the interfaces designed by Google and Microsoft. This speaks to a slightly different kind of democracy, one that allows for egalitarian participation, which Haklay describes as one that he finds more meaningful but also harder to achieve. Google and Microsoft both offer an interface that invites participation, WWT has a

'communities' feature, and both allow users to make their own maps of Mars. While scientists with whom I spoke at NASA Ames have found the possibility of annotating the map of Mars in Google Earth to be helpful in their research, there is less evidence that the lay user can make sense of these features. Such shortcomings do not negate the central goal of the Mapmakers, but point to the limitations of their practices in facilitating the desired experience of Mars for the broader public.

Finally, NASA's gesture toward democracy, though not in conflict with the Mapmakers' goals, emphasizes yet another mission of promoting Mars as a site of exploration. When Microsoft and the Mapmakers released their map in July 2010, NASA issued a press release in which its chief technology officer enthused: 'By providing the Mars dataset to the public on the WorldWide Telescope platform, we are enabling a whole new audience to experience the thrill of space.' Ames director Pete Worden is also quoted: 'Our hope is that this inspires the next generation of explorers to continue the scientific discovery process.'[5] In the first quote, democracy as broader access is being invoked. Worden expands that to emphasize participation, suggesting that allowing access to scientific data to people at a young age will encourage them to pursue a career in science. The expectation of active users is bolstered by the words 'experience', 'explorers', and 'discovery process', phrases consonant with NASA's mission. That Mars can be mapped elevates it from a 'rock in space', as Aaron described it to his audience at NightLife, to a territory that can be explored. We can see this logic even more clearly when turning to the expectations the Mapmakers have for the user experience of the map. In order to establish Mars as not only democratic but also as a dynamic and exciting site of exploration, they must enroll users to see the map in a particular way.

Bringing Mars to life

The map is intended for all, but it is expected that users will interact with Mars as a place of exploration. Whereas a democratic Mars suggests a freedom and multiplicity of use, there is an underpinning ontological stability with which the Mapmakers wish to imbue their map. To see how they attempt to stabilize an ontology (even as their democratic ethos resists such stabilization), I turn to the tours of Mars I helped produce for WWT, and to the particular ways of seeing that these tours promote. The user, I argue, is meant to experience Mars as an alive, dynamic place; a place worthy of continued research and financial investment. Mars, in these tours, is worthy of NASA's larger project of exploration. For the metaphor of exploration to have salience, Mars must be established and maintained as a place and thus as something capable of being explored. The map and its attending tours do just this.

De Certeau (1988), in his *Practice of Everyday Life* draws a distinction between the map and the tour. The map is static, and presents nothing more than a relationship between spaces. The tour actively moves through the space, transforming it into what de Certeau calls 'practiced place'. For de Certeau, the tour signals immersion and active participation. He further observes that the tour was not always divorced from the map. Pre-modern maps used to contain itineraries (for example pilgrimages, stops, travel times): 'The tour to be made is predominant in them' (De Certeau, 1988: 120). However, with respect to the current, scientific map, 'in the course of the period marked by the

birth of modern scientific discourse … the map has slowly disengaged itself from the itineraries that were the condition of its possibility.'

This separation between map and tour, between representation and experience, is a distinction that the processual approach in critical cartography finds it productive to deconstruct. The digital map of Mars lends credence to this position, and is a striking case because here the tours are explicitly embedded within the map: to experience Mars *is* to experience the map.[6] Taking a more terrestrial example of how representation and experience co-construct one another, Del Casino and Hanna (2006) examine the use of a map of historic Fredericksburg, VA. Showing how guides and tourists produce and consume maps, their analysis positions the map as a thing always becoming. The map informs the experience of place, and the experience of place informs the reading of the map.

Like the guides and tourists of Fredericksburg, the Mapmakers have annotated the Mars map to highlight points of interest (Figure 1). Instead of an historic trolley to navigate between these spots, visitors to Mars can take a tour, an audiovisual movie that orients a user of the map to both the history and science of Mars, but also instructs the user as to a particular way of seeing Mars. The tours of Mars further present Mars as a particular kind of place, one that is alive and dynamic. De Certeau, with Del Casino and Hanna, sees touring as a process that allows for less structured, more user directed interaction with place. One can read the tours of Mars in a similar way: they offer to users examples of how to interact with the map in order to enrich their personal exploration. And though the Mapmakers consider the aesthetic of dynamism and immersion to be part of the democratizing nature of Mars maps, I suggest that there is another way to read this commitment to dynamism, which highlights how this way of seeing Mars as animate is important because it justifies publicly investing funds in space exploration. Thus, I argue that despite the overtones of personalized exploration that these tours emit, the Mapmakers and my own representation of Mars as dynamic through these tours encourage users in turn to imagine and understand a Mars reflective of NASA's mission of conquest. The democratic ontology of Mars – one in which Mars can be personally, freely, and multiply experienced – comes into conflict with this more singular ontology.

Touring Mars

Microsoft Research requested that the Mapmakers include two tours to accompany the 2010 release of the Mars map in WWT. When I began my participant observation, I was tasked with producing these tours. I was instructed to work with prominent Mars scientists, who would collaborate on the script and narrate each tour. As a result, I worked with NASA Goddard's Jim Garvin, a former Chief Scientist of NASA, and Carol Stoker, a scientist at Ames who was the principal investigator for the 2008 Mars Phoenix Lander. As I pulled together the written and visual components of the tours, Garvin, Stoker, and the Mapmakers taught me how to see Mars the way they did; in turn, their way of seeing becomes impressed upon users.

Garvin was enthusiastic about his tour from the start. He came to our first teleconference with several ideas for a tour that would get people excited about Mars. His first idea was to build a tour based on a white paper he had authored that detailed future landing sites for a human mission to Mars. Another suggestion was for a tour highlighting what

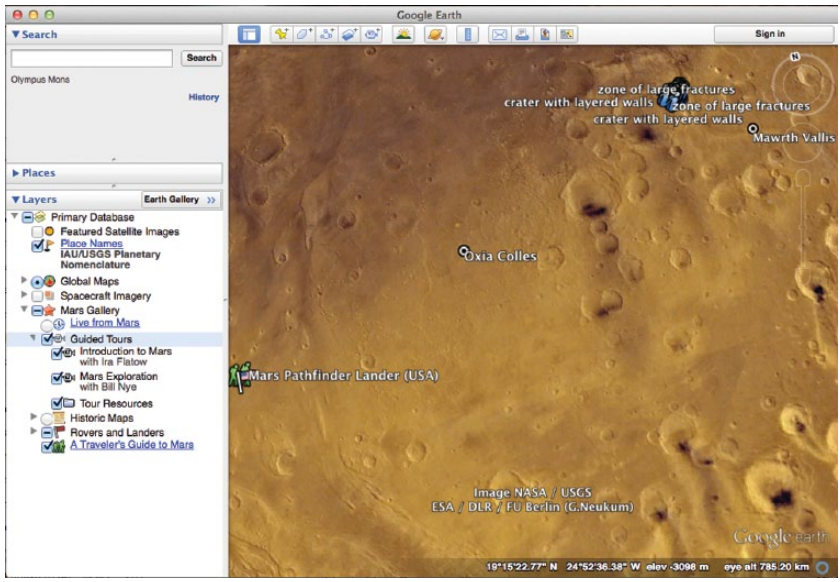

Figure 1. Screen shot from Mars in Google Earth, with point of interest annotated.

he called 'exotic Mars'. He explained that we forget how alien Mars is because we so often try to understand it through terrestrial analogies. This second possibility would review spots on Mars that are 'so non-terrestrial'. We decided to pursue the first idea. Since these tours are meant to be broadly educational, Aaron and I decided that this tour should begin with a geological history of Mars and then conclude with the possible human landing sites.

The script I wrote alluded to a changing Mars. I discussed how each era of Mars – Noachian, Hesperian, and the present Amazonian – was characterized by different geological processes. Volcanic activity and meteor impacts shaped the surface of the planet today, as seen in satellite images. I ended the section of the tour that discussed the different eras of Mars in this way: 'The remaining water dried up but volcanic activity continued, and the Mars we know settled into existence.' Though I wrote about Mars's past with dynamism, I suggested that Mars today is not as exciting as it once was. When Garvin edited this script, he made a few changes, destabilizing the sedate Mars I presented. He included that the water 'mostly' dried up and the Mars we 'think we' know settled into existence. He added an additional sentence: 'However, Mars is a dynamic world, with dramatic climate upheaval and we have barely begun to "read its textbooks" even over the past millions of years.' Garvin wanted to establish that Mars is not a solved mystery but an evolving world in need of more study.

Stoker's tour marked Mars as dynamic in a different way. Her tour, which I helped to create, was based on her experience as a Co-Investigator on the Mars Phoenix Lander. She had been in charge of assessing the habitability of the Phoenix landing site. An area on Mars is defined as habitable if it is 'capable of supporting living organisms with capabilities similar to terrestrial microbes' (Stoker et al., 2010), or if there is evidence of

present or past life. Thus habitability can be a claim about a site's current state or about how it used to be. Results from Phoenix provided a 'tantalizing glimpse' of a 'potentially habitable' area and the team recommended a more rigorous search for life near Phoenix's landing site in the north polar region of Mars. The mystery of whether or not Mars has ever hosted life remains open and should, on this model, be an inspiration for future missions.

Stoker and Garvin recorded the narration of the tours and I created the fly-over of the Martian Map, with overlays of additional pictures and text as needed. The first tour I visualized was Stoker's. In WWT, I stitched together slides of Mars rotating, a zoom in to one region of Mars, a zoom out and then back in to another, and various pans. This was how I intuitively thought to interact with the map. I got a draft of the tour done in time for a meeting with Microsoft, at which Aaron was going to present the first signature tour. The night before the meeting, Aaron told me he did some quick polishing. The Microsoft team loved what he showed them. After he returned from the meeting, we watched the changes he made together at my desk and I realized that the visual feel was completely different from what I had produced. I had kept approaching the globe perpendicularly from above. To switch between locations, I would zoom out, rotate the globe, and zoom back in. The movement I created was stilted and remained disconnected from any kind of *experience* of the planet. Cosgrove (2001) calls this the Apollonian eye: the disinterested and objective view of the Earth from above. However, Aaron almost always presented Mars from a tilted vantage point, so the viewer felt as though he or she was on a ship orbiting the planet. My cinematography made Mars feel more static, whereas Aaron's made Mars feel more dynamic and interactive, inviting the user to imagine being an astronaut in orbit, dipping down to the surface here or there to explore a new site. It had never occurred to me to present the Mars map the way he did, a way in which the user had a more dynamic experience. Effectively, he trained me to see Mars as he did, so that I could create the same feel for the second tour. He constructed a particular (and for me non-intuitive) gaze that, through the tour, would be many people's first encounter with the map. As he said after we watched Stoker's tour together, 'Really make it feel like you're flying around Mars.'

These tours, then, are not a subversive experience of Mars, as de Certeau might desire, but an assertion of Mars as an interesting, scientific place. Moreover, the tour postpones the promise of these maps, because before the user can enjoy an immersive and personal experience he or she must first be taught the norms of seeing in this world. Calling these introductions 'tours' draws attention to this initial role that the user plays: that of a tourist. The expert-guided tours construct what Urry (2002: 3) has called the 'tourist gaze', reserved for 'places out of the ordinary'. Certainly Mars is a place out of the ordinary, and one that visitors need help contextualizing. As Vertesi (2015) has observed, it is not only the lay Martian tourist who needs help with their gaze. Riffing on Wittgenstein's 'seeing as', Vertesi describes the work of the Mars Rover science team as 'drawing as', taming a network of planets, robots, people, screens, gestures, photographs, and inscriptions in order to stabilize the many ways one *might* see Mars into how it *ought* to be seen. Practices of seeing-as and drawing-as enroll scientific allies, and these tours can similarly be understood as extending this more structured way of seeing Mars beyond scientific communities. Though the hope is that *users* of WWT will be precisely that – users, not

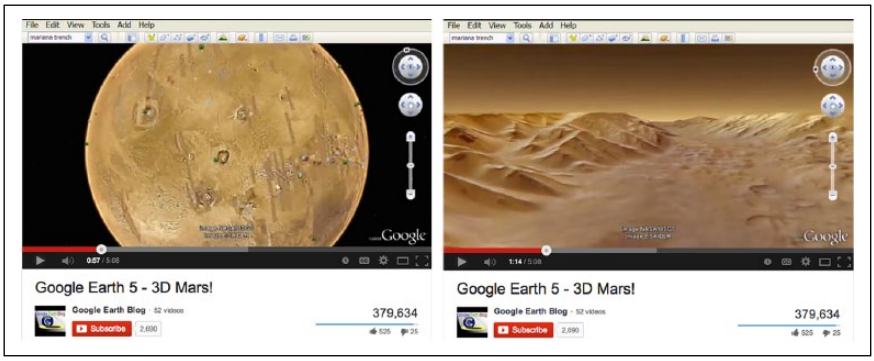

Figure 2. Screen shots of view from above and view from the surface of Mars in YouTube tour of Mars in Google Earth.

gazers –, in order to provide that personal experience of exploration, these tours first establish ways and destinations of navigation.

Seeing Mars

In a YouTube video released by the Google Earth blog in 2009 to promote the newly released Mars map, a Google employee gives a tour of Mars, providing the voice-over narration as he zooms in and pans over the digitally rendered surface. At one point, the tour guide zooms in to Valles Marineris and tilts the view of the map such that the viewer is no longer staring down at the canyon, but can see the horizon (Figure 2). This shift in vantage point, similar to the one Aaron encouraged me to adopt in my tour, is greeted with enthusiasm by the narrator. 'You can zoom around and pretend you're on the surface of Mars or flying around Mars. This is so cool. I mean this is like exploring another planet from the comfort of your home.'[7] The guide marvels at how the top-down view is replaced by one situated on the surface. This is a new way of seeing Mars afforded by these maps, and is 'cool' because it suggests that one can more adequately appreciate what it would feel like to visit Mars. The excitement over this view of the surface can be contrasted with what De Certeau (1988: 92) described as a perverse pleasure of viewing New York City from the top of the World Trade Center. Like the Apollonian view, 'looking down' on the city was a vista afforded by technology. Though he found it awesome, it concealed the places he considered most important – the alleyways and in-between areas that people use to move through the city. However, if the history of viewing and mapping Earth can be written as a move from situated to lofted vantage points, representing and experiencing Mars proceeds in the opposite direction. Scientists began with a global picture of Mars and have only recently descended to the surface. Thus, the pleasure de Certeau describes in his view from above is the same pleasure that the user gets from peering at a perspectival view of the Martian surface. This is a new way of seeing Mars, and one that is not obvious but must be taught.

The tours I helped construct emphasized this 'situated' vantage point. Just as with the YouTube video, they are attempts to teach the user how to see Mars in this specific way. Such a situated perspective is often written about as analytically subversive, as a way to

counteract the objective 'god trick' of the view from nowhere (Haraway, 1988). However, on Mars, the perspectival positioning on the surface is still a product of satellite images and thus still must necessarily be considered in the context of the state power, in this case NASA, responsible for its production.[8]

Making a territory legible is both the result of, and a condition of success for, statecraft (Scott, 1998). Satellite imagery is increasingly used as a tool of legibility. As Dodge and Perkins observe in a theme issue of *Geoforum* on 'The "view from nowhere"? Spatial politics and cultural significance of high-resolution satellite imagery', this technology ushers in new ways of seeing. 'The avowedly naturalistic look of the virtual globe shrouded in satellite imagery is beginning to replace the world map of nation-states as the default meta-geography of the media' (Dodge and Perkins, 2009: 497; see also Wood and Fels, 1992: 49-51). One can think of this new way of seeing as an instantiation of the Apollonian eye. However, Kingsbury and Jones (2009) argue that satellite imagery does not necessarily have to be read as solely Apollonian: The user's ability to freely navigate the map can open up a more playful way of seeing the map, a Dionysian eye. These satellite maps, then, make newly visible a tension between conquering and liberating views.

With Mars, we see this tension play out as satellite imagery is used to invite a feeling of immersion and play, even as the way of seeing that structures the tours reinforces NASA's exploratory mission.[9] When Microsoft released the new Mars map and tours in WorldWide Telescope on July 12, 2010, the press release on the NASA Ames homepage read: 'NASA and Microsoft Research are bringing Mars to life with new features in WorldWide Telescope.'[10] These maps of Mars and their attendant tours are meant to enliven Mars.

Mars science has enjoyed a decade of interest and financial support, thanks to the high profile Mars Exploration Rovers, *Spirit* and *Opportunity*, and the more recently launched Mars Science Lab, *Curiosity*. Though they have sent back enchanting, full color images of the Martian surface (panoramas that are viewable in the digital maps here discussed), they have also failed to detect organic life on Mars. Given that one of NASA's primary motivations for studying Mars has been, since the Viking landers of the 1970s, to search for life (Dick and Strick, 2004), should this null finding cause NASA to stop increasing its Mars investment?

More likely, NASA will continue Mars research by re-defining what it means for Mars to be 'alive'. Rather than relying on an organic sense of the word, NASA frames Mars as geologically alive, positioned as a mysterious and changing world. The portrayal of Mars as dynamic by the Mapmakers establishes Mars as an ontologically stable place (i.e., a place that exists as a place) that awaits human explorers. Further, NASA relies on the map (as a map) to make this argument. Even as it is tempting and often fruitful to 'de-ontologize' the map (Pickles, 2004), actors have strategic reasons for maintaining the map's claim to simply represent what exists. NASA benefits from this understanding of the map when it draws on the longstanding metaphor between outer space and the American frontier (see Dittmer, 2007; Limerick, 1992). Aaron explicitly connected the frontier, exploration, and the role played by the map:

> before places, like California for example, are settled and before we really are living and being at a place … there are people who start the process of exploring those places and mapping them

> out. … By mapping out the moon and Mars and other places in the solar system, we're laying some type of groundwork that other people will build on in the future.

Even as the Mapmakers strive to offer a map that is democratized and free to be altered and experienced in a multitude of ways, this vision is constrained by the overarching expectation of solar system exploration.

Conclusion: Mappings and explorations

In a primer on the subject of *Planetary Mapping*, Greeley and Batson (1990: 1) begin with a direct statement of why mapping other planets is important: 'Throughout history, maps and charts have played an integral role in the exploration of Earth. Their importance holds true for Solar System exploration as well.' Not only do they draw the connection between mapping and exploration, but they also emphasize the apolitical and even acultural nature of these maps: 'Planetary maps depict the forms and structures of natural surfaces, in contrast to terrestrial maps dominated by political boundaries and cultural features' (p. 80). However, the assertion that such maps are purely scientific is precisely their political and cultural claim. The technical practice of the Mapmakers, while desiring to construct a map that can be practiced in multiple ways, ultimately promotes Mars as a secure and singular object defined by its scientific potential, and thus worthy of NASA's exploration. To conclude, I will consider how this tension between 'democratic' and 'dynamic' Mars winds its way through the exploration project beyond the realm of the map.

The YouTube video that I discussed earlier introduces Mars in Google Earth as allowing one to explore Mars from the comfort of one's home. Not only the map, but also exploration is being positioned as a personal experience. Anyone, the video suggests, can become a desk chair explorer. This sentiment extends beyond the map and is one that can be found in other NASA projects. The Center in charge of the Mars Rovers, the Jet Propulsion Laboratory, hosts a website called 'Be a Martian'. Its home page welcomes the visitor to the 'age of virtual exploration' and invites him or her to sign up for an account (Martian citizenship) or enter on an 'anonymous tourist visa'.[11] Of the many featured activities, one asks the user to 'Find your inner explorer: Help map Mars' by tagging photos returned by the Mars rovers. The introductory video, which offers a brief history of mapping Mars, begins with a broad statement that brings citizens into the project of exploration: 'Mars exploration is a civilization endeavor, no longer restricted to the intrepid few, but to all who wish to share in the journey of discovery.'

The website tags this activity as occurring within the 'citizen science lab'. 'Citizen science', as the term is generally used today, describes scientific projects that depend on amateurs to either collect data (e.g., local weather conditions) or process data (as with the case above when labeling Mars images) (see Raddick et al., 2009; Silvertown, 2009). For the latter type, scientists implement citizen science projects to tackle tremendous amounts of data that computers are not suited to process. Similar to the project on 'Be a Martian', a popular citizen science portal, Zooniverse, asks users to look through Mars images and mark fan-shaped deposits to aid in the study of Martian weather patterns.

Though these projects claim to empower citizens, turning them into explorers, there is still a clear hierarchy between the scientist requesting a specific kind of data and the

citizen conforming. Recently, in addition to asking for time from citizens, some exploration projects are asking for money. The planetary exploration start-up company, Planetary Resources, began on Kickstarter (a website that hosts crowd funded projects) a page to fund 'ARKYD: A Space Telescope for Everyone'.[12] As is common for Kickstarter projects, different donations earn different rewards. The biggest promotion is that for a $25 pledge, where one can take a '(digital) space selfie': one's self portrait will be displayed on the telescope's external screen, and an image will be captured with the Earth in the background. The Apollonian eye is itself democratized and seemingly made synonymous not with the state, but with the citizen.

The dynamism and democracy embedded in the map are simultaneously contradictory and complementary. While Mapmakers deem the aesthetics of dynamism to be desirable because it allows for a more immersive experience by the user, thus enhancing the democratic project, this dynamism also underscores and enhances NASA's exploratory mission. Though exploration might be itself undergoing a process of democratization, the scope of the project is still ultimately state-sponsored, politically motivated, and hierarchically ordered. Extraterrestrial mappings show the tensions between state-directed and citizen-motivated exploration and are useful objects to think with when considering how power relations are maintained, collapsed, or upended in more Earthly contexts.

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Notes

1. The names of the Mapmakers are pseudonyms. I refer to senior scientists and NASA officials by their full, real names.
2. The map of Mars has always been a medium for presenting arguments for contemporary understandings of Mars. Aaron's allusion to Percival Lowell in the NightLife presentation offers one example. Peering through his telescope at the end of the 19th century, Lowell saw what others before him had inscribed on their maps: a systematic pattern of linear features crisscrossing the surface. Phonetically translating Giovanni Schiaparelli's Italian word *canali*, Lowell called these formations canals and, in drawing them on his map, proclaimed them as evidence for the existence of a technologically advanced civilization on Mars. Lowell's maps, riddled with sharp lines and named canals, simultaneously represented Mars and argued for a particular way of knowing Mars (see Lane, 2005, 2011). Lowell portrayed Mars as a (once) living, dynamic planet. Mars is not a static scientific object, but a mercurial cultural product (Markley, 2005).
3. Democracy and imperialism are closely associated in the context of NASA, whose space race mission was precisely to show that democratic governance (as opposed to communist rule) was the most effective way to accomplish extraterrestrial imperialism (see McDougall, 1985).

4. HiRISE has a program called HiWish, which allows non-team members to suggest surface locations to photograph. This has led to NASA officials referring to HiRISE as 'the people's camera' and HiWish as 'participatory exploration'. The democratic ethos spreads beyond the maps, a point to which I will return in the conclusion.
5. Available at: http://www.nasa.gov/home/hqnews/2010/jul/10-163_Microsoft_Mars.html (accessed on 31 May 2016).
6. Lammes (2009) has pointed out that, more generally, in digital maps, a technology de Certeau could not have predicted, his distinction between static maps and mobile tours collapses.
7. Available at: http://www.youtube.com/watch?v=8QtXFLL7Y2g (accessed on 31 May 2016).
8. Helmreich (2011) provides an example of how the god trick is similarly obscured in another digital mapping project, Google Ocean.
9. This tension is similar to what Pickles (2004: 13) has called the double crisis of representation, in which state cartography produces maps and thus democratizes access to information while simultaneously embedding specific (state) interests within these maps.
10. 'NASA – NASA Ames Home,' http://www.nasa.gov/centers/ames/home/index.html (accessed on 12 July 2010).
11. Available at: http://beamartian.jpl.nasa.gov/welcome (accessed on 18 May 2016).
12. Available at: http://www.kickstarter.com/projects/1458134548/arkyd-a-space-telescope-for-everyone-0 (accessed on 31 May 2016).

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