ASSESSING GALE CRATER AS A POTENTIAL HUMAN MISSION LANDING SITE ON MARS

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Introduction: Mars is the "horizon goal" for human space flight [1]. Towards that endeavor, one must consider several factors in regards to choosing a landing site suitable for a human-rated mission including: entry, descent, and landing (EDL) characteristics, scientific diversity, and possible insitu resources [2]. Selecting any one place is a careful balance of reducing risks and increasing scientific return for the mission.

"Go where you know": There are tens of proposed landing sites for robotic missions with varying scientific interest, as well as the handful of locations currently visited by successfully landed spacecraft. For the former, sites such as Eberswalde delta, Holden crater, and Mawrth Vallis has received extensive orbital coverage and analysis during the MSL landing site selection workshop and are well characterized. In addition, 'runner up' candidates for that mission are now on the list for evaluation for the Mars2020 rover, e.g. Jezero Crater or Nili Fossae, and contain equal (though not fully processed) orbital data for reference [3]. For legacy and current missions to Mars, three are landers, and one lander/ rover, with limited visible areal extent: Viking 1 Viking 2, Phoenix, and Pathfinder/Sojourner. The remaining rover missions, MER Spirit, MER Opportunity, and MSL Curiosity offer the most ground truth over several to tens of kilometers both in and outside their nominal landing ellipses. While the HiRISE instrument provides unprecedented detail of Mars' surface to current and future missions, the insitu observations of rock density, soil mechanics, temperature fluctuations, dust opacity, radiation (via Curiosity), traversability, not to mention insitu science, are not directly measureable or resolvable by orbital assets. While we can certainly make well-educated and higher-order assessments of landing sites, revisiting anywhere we've gone before can only reduce risk by removing uncertainty or shrinking errors bars in landing site analysis. Insitu data decreases risk compared to other potential landing sites that have never been visited because of this ability to remove the unknown at the surface; albeit we've been very successful over the past two decades with landed missions. However, a human-rated mission will likely require reducing risk by an order of magnitude, thereby requiring an order of magnitude better data than we currently have; only insitu data provides this level of certainty. From a financial perspective, insitu data is 'priceless' for a human-rated mission, not replicable for other sites.

EDL: Like all missions, Mars' elevation limits landing sites to those with a fairly deep atmospheric well to assist in aerobraking and parachute deceleration in preparation for landing. Previous missions have targeted areas below the 0 km Martian elevation line [3]. Thermal requirements have kept landing sites with ~30 degrees of the equator, except for the short-lived Phoenix mission (by design). Most proposed landing sites meet these criteria, as well as basic rock abundance, relief, dust, and thermal inertia requirements all likely suitable for a human mission as well.

Insitu resources: While there are many technologies yet to be devised for resource extraction, we can look at the one resource that provides breathable air, sustenance, and fuel: water. Besides the poles, water-ice deposits have been found near the surface down to latitudes as low as ~43 degrees [4]. If a mission wanted to drill to potential subsurface ice-water reservoirs, being closer to the poles would be advantageous. However, many landing sites have water bound in there constituent rocks (e.g. clays) to serve as a 'mining' resource. Results from the CHEMCAM instrument aboard Curiosity have also reported higher water abundance in soils [5]. Dune sands/ripples/soils, where available, may provide an additional resource for water extraction technologies.

Why Gale crater: The following is a breakdown of reasons Gale crater makes an excellent landing site for the first human mission to Mars.

EDL: Gale crater is one of the lowest elevation landing sites at ~4.5 km MOLA elevation, well below Meridiani Planum (~-1.4 km) and Gusev Crater (-1.9 km) [3]. This increased atmospheric density will decrease requirements for landing from increased velocity reduction with parachutes or other methods like low-density supersonic deceleration. Dynamic entry data and a well-understood atmospheric profile, including additional seasonal data (temperature, pressure, wind speed) from the Rover Environmental Monitoring Station [REMS] package onboard Curiosity for at least a Martian year, adds to reducing uncertainty during any landing. These atmospheric measurements, as a whole, are unique to this locale.

Radiation: The thick 'air' also provides more radiation protection than other sites. Back-of-the-envelope extrapolations from [6] indicate ~25-32 gm/cm^2 shielding at 90-degree elevation (i.e. directly overhead); 6-8 gm/cm^2 more shielding than Gusev or Meridiani.

While the additional atmospheric shielding yields only an incremental improvement in protection from Galactic Cosmic Radiation (GCR) and solar proton events compared to other landing sites, more is better for any long-term mission. There is likely some additional shielding to be gain from the crater walls, though this doesn't mitigate the majority of overhead radiation. More importantly, the RAD instrument onboard Curiosity initial results from ~300 sols [7] indicates 0.64 +-0.12 millisieverts/day or ~1.01 Sv for a Mars mission at this location. Hardware can now be tuned with insitu measurements to meet the radiation hazard at this location.

Terrain: In terms of terrain hazards, ~10 km of engineering camera (NAVCAM and HAZCAM) and mobility data provide an unprecedented level of terrain information, excluding the Opportunity rover (>40 km). While Meridiani is likely the smoothest and safest of any landing site [3], Gale is rated as safe as other landing sites with terrain hazards sampled and well understood throughout its traverse to Aeolis Mons.

Scientific Diversity: Going with 'what we know', the Peace Vallis delta deposits [8], confirmed habitable environments [9], evidence of a lake [9], insitu methane observations [10], and existence of indigenous Martian carbon both ancient and active [11], not to mention the yet fully explored 5 km sedimentary stack of Mt. Sharp (Aeolis Mons) is a scientific cornucopia for an human mission to expand upon and explore. Gale crater is also one of, if not the, only site with access to both northern plains and southern highland material within a relatively short distance (~20 km). While other sites offer the possibilities of meandering rivers (Eberswalde), extensive clay deposits (Mawrth Vallis), sabkha/lake/sea deposits (Meridiani), and carbonates (Gusev), we know right now that Gale has many of these elements, if not more variety, than other sites can definitively offer.

Insitu Water Resources: There is little chance of near-surface water-ice for resource utilization, but water bound in minerals and loose grains could serve as a water source. Some 'easy' water may come extracting adsorbed atmospheric water in ripple and dune sediments [5] and estimated 3-6 weight% in amorphous sediments at Rocknest [12]. Gale crater's depth might assist in locating a deep aquifer source through drilling. Groundwater inventories could be within a few hundred meters depth from the inner depths of Gale, assuming an initial global water layer between 10-100m [13]. Lack of readily available water in any form is a problem for the vast majority of proposed landing sites near the equator; however Gale crater provides a clear advantage of depth for accessing groundwater aquifers and a known quantity of adsorbed and 'mineralized' water that can be planned for based on insitu measurements.

***Reference Mission*:** Reference design missions have been generated for the human exploration for Mars, a recent one being Mars design reference architecture (DRA) 5.0 [2]. Though Gale crater can easily meet all the science and engineering goals I-V in DRA 5.0, two mission types were proposed: "short-stay" with 30-90 days on the surface (500-650 days total) and "long-stay" with 500+ days on Mars (~900 days total). "Short-stay" missions were ruled out partially because of insufficient time for assessing and collecting diverse samples. Gale crater offers crustal material within ~20 km at the rim, Aeolis Mons (Mt. Sharp) clay to sulfate transition within ~15 km, primary alluvial fan material <5 km and fluvially derived conglomerates and clays, some lacustrine, upon landing in many areas of the current MSL ellipse. The Isidis/Syrtis reference landing site in DRA 5.0 had most scientific features well beyond the safe 'walk-back' distance of ~20 km from a centrally located habitat. Many known scientific outcrops at Gale crater are well within this distance if the human habitat where placed within the current MSL landing ellipse. For a human first mission to Mars, distance to outcrops would be close, safe, and pre-characterized sufficiently by Curiosity to allow short or long-stay missions.

Conclusion: Gale crater is a scientifically fascinating site on Mars with abundant *existing* orbital and ground data for assessing a future human mission to Mars. The deep atmosphere provides substantial EDL margin unique to this location. A well-characterized radiation environment provides hallmarks for designing habitats and assessing daily exposure limits for extravehicular activities. The MSL science team has already shown Gale crater to harbor ancient habitable environments and abundant liquid water in the past. A human mission to this location could be done safely and with assurance to what we'd find on arrival and the strong potential for future discoveries.

References: [1] Pathways to Exploration, ISBN: 978-0-309-30507-5, 2014. [2] Human Exploration of Mars DRA v5.0, NASA-SP-2009-566, 2009. [3] Golombek et al., *Space Sci Rev*, 2012. [4] Byrne et al., *Science*, 2009. [5] Meslin et al., *Science*, 2013. [6] Simonsen & Nealy, *NASA Tech. Paper 3300*, 1993. [7] Hassler et al., *Science*, 2014. [8] Palucis et al., *JGR*, 2013. [9] Grotzinger et al., *Science*, 2013. [10] Webster et al., *Science*, 2014. [11] NASA/JPL press release,http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1767, 2014. [12] Leshin et al., *Science*, 2013. [13] Clifford, *JGR*. 1993.