MULTI-TIER MULTI-AGENT AUTONOMOUS ROBOTIC PLANETARY SURFACE/SUBSURFACE RECONNAISSANCE FOR LIFE

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Introduction: A fundamentally new scientific mission concept for remote planetary surface and subsurface reconnaissance recently has been devised [1-3] that soon will replace the engineering and safety constrained mission designs of the past, allowing for optimal acquisition of geologic, paleohydrologic, paleoclimatic, and possible astrobiologic information of Mars, Titan, and other extraterrestrial targets. Traditional missions have performed local, ground-level reconnaissance through rovers and immobile landers, or global mapping performed by an orbiter. The former is safety and engineering constrained, affording limited detailed reconnaissance of a single site at the expense of a regional understanding, while the latter returns immense datasets, often overlooking detailed information of local and regional significance.

A "tier-scalable" paradigm integrates multi-tier (orbit⇔atmosphere⇔surface/subsurface) and multi-agent (orbiter(s)⇔blimps⇔rovers, landers, drill rigs, sensor grids) hierarchical mission architectures [1-3], not only introducing mission redundancy and safety, but enabling and optimizing intelligent, unconstrained, and distributed science-driven exploration of prime locations on Venus, Mars, Io, Europa, Ganymede, Titan, Triton, and elsewhere, allowing for increased science return, and paving the way towards fully autonomous robotic missions.

In the highly automated scenario, the satellites command and control the airborne units autonomously, and the airborne units autonomously command and control the ground-level reconnaissance agents (Fig. 1). This system integrates satellites with inexpensive balloons/blimps (airships) and ground-level agents (rovers, fixed landers, e.g., Beagle 2, and sensors). The airborne units and ground-level agents can be inexpensive enough (in terms of capital cost and operational resources) to allow for the deployment of numerous agents that collectively can address specific science-driven questions. Multiple ground-level agents in conjunction with airborne units collectively can explore the same science target with a complementary suite of instruments.

Prime Candidates for High-risk Scientific Exploration: Non-traditional autonomous missions to remote planetary bodies will be necessary [1-4], primarily to allow intelligent and unconstrained access to scientifically interesting terrains on planetary bodies of the Solar System not currently feasible with conventional missions, including: (1) canyons (e.g., Valles Marineris on Mars, or Devana Chasma, a big rift valley on Venus), (2) mountain ranges (e.g., Thaumasia highlands on Mars, Isthar Terra on Venus), (3) sites of suspected magmatic-driven uplift and associated tectonism and possible hydrothermal activity (e.g., plume-related activity such as hypothesized for the central part of Valles Marineris and the Warrego Valles rise on Mars, and Maxwell Montes on Venus), (4) polar ice caps (e.g., Mars), (5) ice deposits within impact basins (e.g., Mercury and Moon), (6) volcanoes of diverse sizes and shapes (e.g., Venus and Mars), (7) putative ancient accreted terrains and associated volcanism (e.g., Mars), (8) regions indicating potential recent hydrologic activity such as spring-fed seeps (e.g., Mars), and (9) chaotic terrain (e.g., source areas of the circum-Chryse outflow channel system on Mars). All of these geologic terrains, including other regions of interest on other planetary bodies of the Solar System, are particularly crucial for astrobiologic-oriented exploration in general [5], and sample return missions in particular [4].

Applications of Tier-scalable Mission Architectures: A multi-tier, hierarchical mission architecture would overcome the inherent challenge of geologic planetary surface exploration [1-3]: airborne agents (orbiters in conjunction with balloons/blimps) possess overhead perspectives at different length scales/resolutions, which could provide guidance to ground-based agents (e.g., mobile rover units). For example, one of the airborne agents over Melas Chasma (Fig. 2), the central part of Valles Marineris on Mars, could detect scientifically interesting features, such as a methane plume and/or elevated heat flow, or transient geologic events (e.g., a giant landslide that initiates on the walls of Valles Marineris), hydrologic events (e.g., water seeps), or atmospheric events. Such an airborne agent would then map out methane concentration profiles and acquire terrain images that subsequently could be processed through automated feature-extraction algorithms, such as with the *Automated Geologic Field Analyzer (AGFA)* [6]. The feature data would be analyzed by science prioritization algorithms to choose potential targets for close examination by subsequently deployed sensors or rovers and for determining safe passages to their designated targets. At the respective targets, the rovers would conduct in situ science experiments and thereby gather data that complement the remote sensing data, obtained by the airborne units. In addition, such a system could help direct rovers equipped with a driller or immobile drill rigs to locales of detected elevated heat flow, methane, and/or near-surface groundwater in order to analyze and sample return.

Implications: *Multi-tier multi-agent autonomous robotic planetary surface/subsurface reconnaissance* will lead to an improved understanding of the geologic/geomorphic/pedologic, water, climate, and possible biologic history of Mars and other extraterrestrial targets, through means similar to the approach taken by geologists and biologists here on Earth. This includes confirming working hypotheses such as in the case of Mars, whether (a) the mountain ranges contain a greater diversity of rock types than just volcanic, (b) sites of suspected hydrothermal activity are indeed hydrothermal environments, or (c) prime candidate sites of potential life-containing habitability actually contain extant or fossil life or life forms [7-9]. Moreover, tier-scalable autonomous reconnaissance missions afford a first-of-a-kind opportunity to scout and discover potential habitats and possible life [5].

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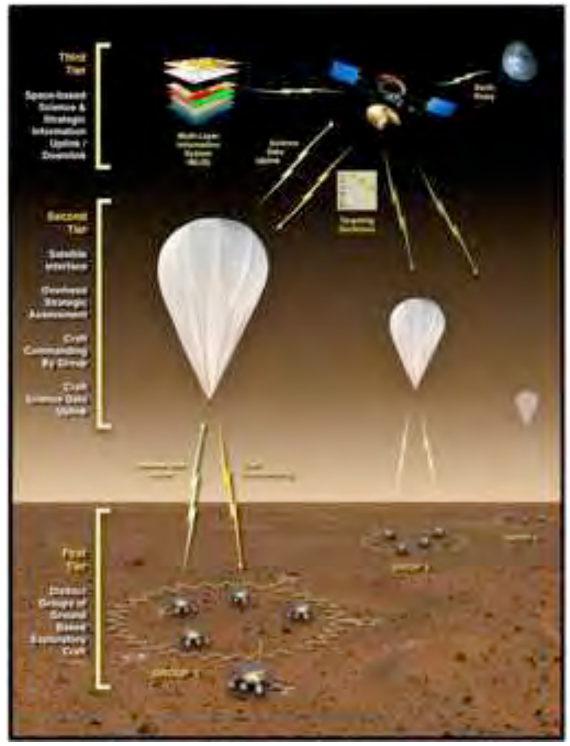

Fig. 1. Tri-level hierarchical multi-agent architecture for autonomous remote planetary exploration [1-3].

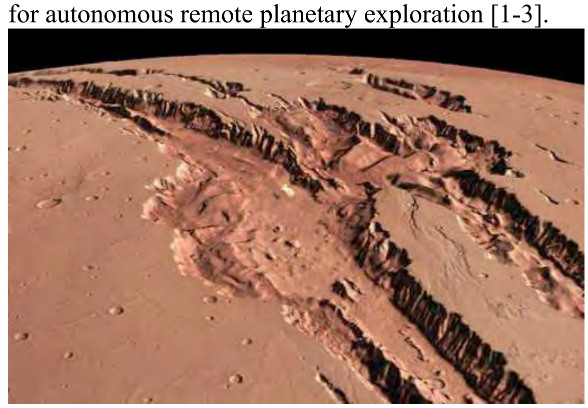

Fig. 2. 3-D oblique view, exemplifying an airborne agent (blimp/airship) performing intelligent reconnaissance over Melas Chasma, the central part of the vast canyon system Valles Marineris on Mars (see also [1]). Part of the reconnaissance would include surveying the canyon walls, homing in on stratigraphic sequences, hovering above landslide and valley floor deposits, and identifying targets for subsequent deployment of ground-based agents such as miniature rovers and immobile sensors. Target features of special scientific interest may include diversity of rock types, high heat flow, surface/near-surface water or moisture, and methane plumes, contributing to the success in identifying potential life-containing habitats. (Note that for visual purposes the blimp/airship is not drawn to scale).