VERTICAL EXPLORATION USING TETHERS. P.W. Bartlett,[1,2] S. Heys[3], Z. Drozdowski, T. Kennedy, and M. Wagner[4], [1]Logical Expression LLC; 544 Park Ave. #31; Brooklyn, NY 11205, [2]Bartlett@LogicalExpression.org, [3]The Manufactory, [4]ProtoInnovations.

Introduction: The majority of planetary exploration to date has employed orbiters, landers and rovers to observe planetary surfaces. While much has been learned from these observations, most of the observable surfaces are flat and horizontal, representing a snapshot in geologic time. Effort and chance are relied upon to access features that reveal previous epochs or rare astrobiological evidence. Vertical exploration can access geologic past and difficult but challenging features. This type of exploration has been limited to date, not because it is low in priority but because it has not been feasible technologically. Developments are needed to provide more controlled, reliable vertical exploration. One critical development that would enable a range of craft to access a range of geologic features is a robotic tether system. Recent research shows the promise of such a system. Steep slope driving vehicles, deep drills and aerial platforms could all employ a robotic tether system to access features such as gully walls on Mars, subsurface glaciers on multiple bodies, and ices and liquid bodies on moons of the outer planets.

Locations to Explore: Opportunities for exploration on Mars, outer planets and elsewhere on upcoming missions include: cliff faces, gully walls, boreholes, fissures, and surface ices and liquids. Gullies, as seen below located near Gorgonum Chaos on Mars, show evidence of geologically recent outflows of water from subsurface ice deposits [1].

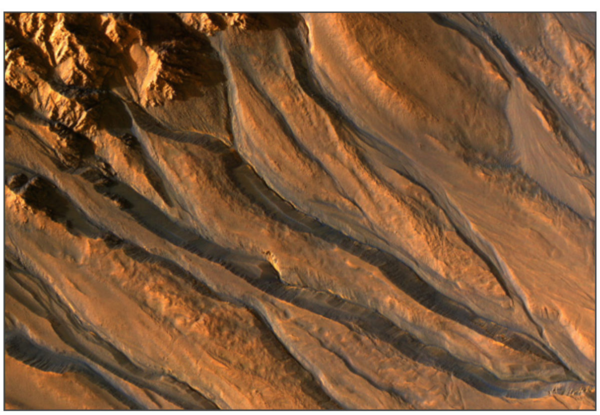

Figure 1: Gullies Near Gorgonum Chaos
Credit: NASA/JPL/University of Arizona

Recent evidence from MRO suggests the presence of subsurface glaciers on Mars that could be accessed via drilling [2]. Some hypothesize the existence of caves on Mars with at least partially vertical orientation [3]. There is astrobiological interest in caves since they could provide a more habitable environment, sheltering from radiation. Titan, Enceladus and other outer planetary bodies may harbor surface ices, hydrocarbon lakes, open fissures and subsurface ices and liquids. These features all share a challenge in terms of gaining access to them in a sufficiently reliable manner for a robotic spacecraft mission. Recent developments of a tethered system give confidence that it could enable access to these features.

Steep Slope Mobility: A typical mobile robot functions well on level ground and looses traction and control authority on steep slopes. A tether leading from one rover to one or more cooperating robots on level, high ground, can let the rover maintain traction and control authority. Researchers have investigated variations on this concept, on platforms such as Cliffbot [4]. The main benefit is shown in the diagram below.

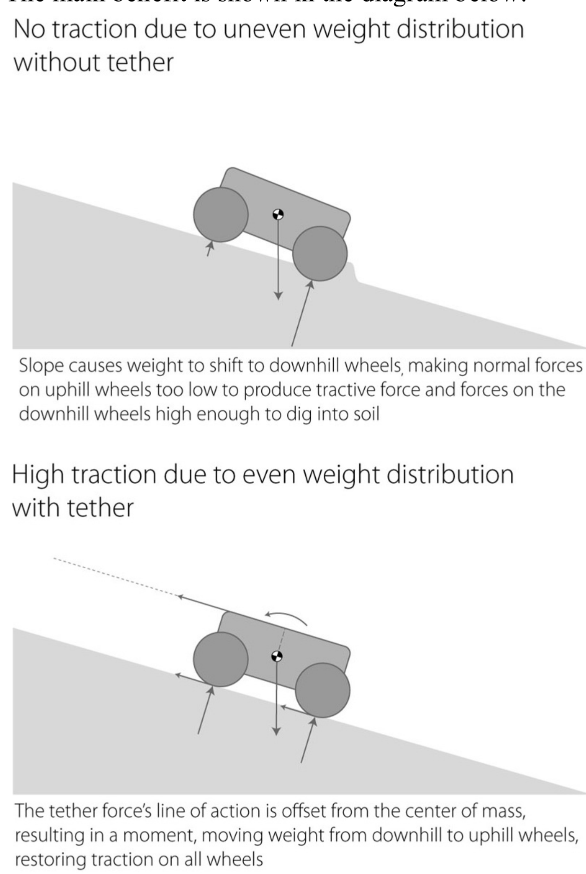

Figure 2: Diagram of tethered mobility benefits

In addition to driving on steep slopes, the downhill vehicle could access features of interest by moving in other modes such as free repelling where contact with the surface is lost intermittently. The design of the tether, the hardware that spools and unspools the tether, the sensing elements, and the controls system that operates it, are all essential to its success. The thorough integration of the spooler to the overall vehicle system is also crucial.

Borehole Instruments: Many geologic and astrobiological goals require subsurface exploration on Mars and elsewhere. Drilling is an accepted means of subsurface access where precision of operations must be high and energy expenditure must be low. The two regimes of drilling employ continuous pipe or wireline [5]. In the wireline regime in particular, a robust tether is required to lower the downhole mechanism to perform the drilling task. In either regime, the lowering of downhole instruments with a robotic tether is likely, to make observations of the borehole wall and to take samples.

Sensing from Aerial Platforms: For missions to Mars, Titan, and other planetary bodies with significant atmospheres, balloon-based aerobots are being seriously considered [6]. Aerobots can take advantage of winds to travel great distances at a low altitude. Remote sensing instruments would likely be complemented by an *in situ* sensing package, that would either accept samples from the surface or be lowered to the surface. Either of these activities likely would require a robotic tether transmitting power, data and structural loads. Such a tether system could enable more *in situ* sensing opportunities than would be feasible if the aerobot needed to touch down each time.

Spooler Design: Recent NASA funded research & development by the authors extended previous DARPA supported and other work on tether systems. The recent work addressed the range of NASA applications for tethers, the sensitivities in the design space, tether designs for passing power, data & structural loads, spooler designs and controls for increased reliability, and the integration of a robotic tether system in vehicles and other systems.

The breadboard robotic spooler shown in Figure 3, consists of three main sections: the spool, levelwind, and fairlead. The spool is an actively driven drum around which the tether is wrapped. The levelwind is a linear actuator that dictates the lay of the tether onto the spool. And the fairlead is an active mechanism that guides the tether into the system, from a wide range of angles. These three motions must be synchronized with one another for reliable operation.

The main novel approach in this design is that the fairlead actively maintains tension on the tether within the spooling system, using a force sensor for feedback. This functionality lets the system reliably pay out and reel in tether, whether the tether outside the spooler system is taught, varying in tension, or laying loose on the ground. Another promising investigation is the potential for communicating over the power conductors. This common terrestrial technology, termed powerline communication, shows promise for space flight implementation and for reducing the tether size and adding redundancy modes.

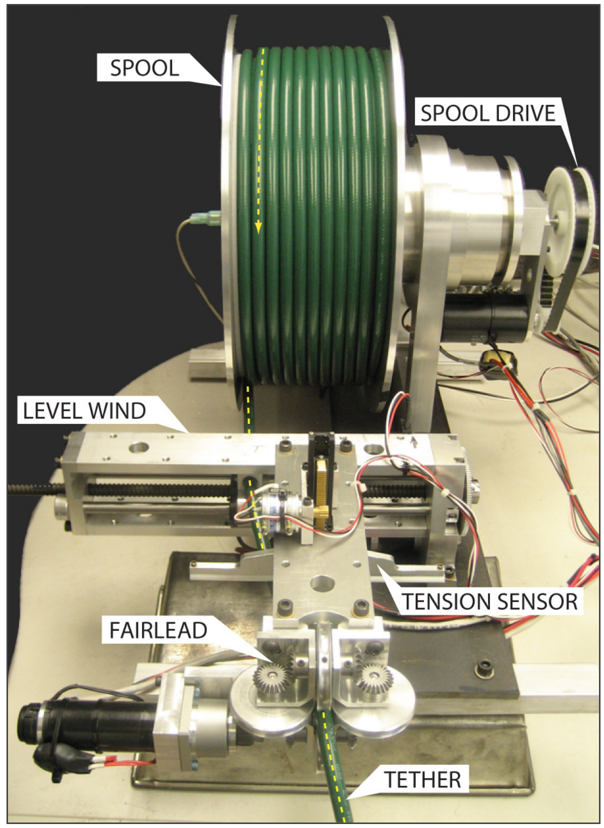

Figure 3: Robotic spooler breadboard hardware

Other Applications: There are many areas that could employ highly reliable, robotic tether systems. Orbital spacecraft such as Space Station and satellites are investigating tethered mobile robots and tether power production. Human exploration missions to the lunar surface will require reliable cable & umbilical handling. Marine applications frequently use tethers in ROVs, AUVs & ocean floor wireline drilling. Efforts are being made to learn from and transfer technology to these communities.

References: [1] Head J., et al., *PNAS*, vol. 105 no. 36, September 9, 2008. [2] Plaut J. J. (2008) *AGU*. [3] Cushing, G. (2007) *GRL*, 34. [3] Mumm, E., et al. (2004) *Autonomous Robots*, 16. [4] Zacny, K., Cooper, G. (2006) *Planetary and Space Science*, 54, Issue 4. [5] Jones, J., et al. (2005) *43rd AIAA Aerospace Sciences Meeting and Exhibit.*