THEMIS OBSERVES POSSIBLE CAVE SKYLIGHTS ON MARS. G. E. Cushing[1,2], T. N. Titus[1], J. J. Wynne[1,2], P. R. Christensen[3], [1]U.S.G.S. 2255 N. Gemini Dr. Flagstaff, AZ 86001, gcushing@usgs.gov, [2]Northern Arizona University, Flagstaff, AZ 86011, [3]Arizona State University, Tempe, AZ 85287.

Introduction: Here we report the discovery of seven candidate skylight entrances into subterranean caverns (Figure 1). All seven are located on the flanks of Arsia Mons (southernmost of the massive Tharsis-ridge shield volcanoes), a region with widespread collapse pits and grabens which may indicate an abundance of subsurface void spaces [1,2].

Motivation: Subterranean void spaces may be the only natural structures on Mars capable of protecting life from a range of significant environmental hazards. With an atmospheric density less than 1% of the Earth's and practically no magnetic field, the Martian surface is essentially unprotected from micrometeoroid bombardment, solar flares, UV radiation and high-energy particles from space [3,4,5,6]. Additionally, intense dust storms occur planet wide, and some regions exhibit temperature ranges that can double over each diurnal cycle [7]. Besides general geological interest, there is a strong motivation to find and explore Martian caves to determine what advantages these structures may provide future explorers. Furthermore, Martian caves are of great interest for their biological possibilities because they may have provided habitat for past (or even current) life [5,6,8].

Preserved evidence of past or present life on Mars might only be found in caves [5,6,8], and such a discovery would be of unparalleled biological significance [3]. Cave deep zones on Earth generally maintain constant climate conditions [9,10] which are ideal for the preservation of organic material. Accordingly, Martian caves are among the most desirable targets for astrobiological exploration [11,12,13,14].

Observations: The Mars Odyssey Thermal Emission Imaging System (THEMIS) collected the majority of data for this study [15]. From a nadir perspective, THEMIS observes both visible and thermal-infrared wavelengths during the afternoon (~ 1500-1700 hrs), and IR wavelengths only for early-morning observations (~ 0300-0500 hrs.) [15].

The inspection of dark, circular pit-like features at visible wavelengths (VIS band 3, ~.654 μm) gave our first indication of potential skylight openings (nadir-pointing observations prevent us from determining whether these are caverns or deep vertical shafts). To aid in visualization, we have informally named these 'seven sisters' on Arsia Mons as: Dena, Chloë, Wendy, Annie, Abbey, Nikki and Jeanne (Figure 1). Most of the candidates are adjacent to collapse pits or are directly in-line with collapse-pit chains, and appear to have formed by similar processes. They are visibly distinct from collapse pits, however, by a lack of visible (sunlit) walls or floors. These proposed skylights also lack the visible characteristics (such as raised rims or ejecta patterns) that would associate them with impact craters. Thermal behaviors furthermore confirm they are not misidentified surface features such as dark sand or rock.

Diameters generally range between 100-252 m (estimated from THEMIS VIS at 18 m/pixel for most images). Only minimum depths can be calculated (because the floors are not illuminated by the sun in THEMIS observations) and range between 73-96 m (diameter ÷ tan(incidence angle)). However, a fortunate MOC observation of Dena at ~2 p.m. (R0800159) actually does show an illuminated floor, allowing us to tightly constrain the depth using a 1-D photoclinometry routine. This routine returns a depth of ~130 m for the illuminated floor, while the minimum depth estimated from the THEMIS observation is only ~80 m.

Because THEMIS IR observes at 100-m resolution, cavern skylights with diameters much smaller than that are probably not thermally distinguishable from regular temperature variations on the surface.

Discussion: Analyses of the candidates suggest they are not of impact origin, not patches of dark surface material, and are likely skylight openings into subsurface cavernous spaces. Visible observations show dark holes with sufficient depth that no illuminated floors (incidence angles ≥ 61.5°) can be seen from a nadir perspective (Thermal-infrared data suggest temperatures inside these features remain nearly constant throughout each diurnal cycle. Figure 2 shows afternoon temperatures for Annie that are warmer than the shadows of adjacent collapse pits, and cooler than sunlit portions. Meanwhile, nighttime temperatures for this candidate are warmer than all nearby surfaces. Such is the behavior we would expect of a cavern floor that receives little or no daily solar insolation [9,10].

Wendy, Dena, Annie and Jeanne are the strongest candidates because they have the most complete data sets; i.e., they have both VIS and diurnal IR coverage, and they are large enough to be clearly identified at 100-m resolution. Chloë, Abbey and Nikki are also strong candidates because they have the same visible and thermal characteristics as the other candidates. Their minimum depths could not be constrained, however, because of late-afternoon observations when the sun is too low to shine deeply into the pits.

Conclusion: Additional observations are necessary—particularly those at different times of day and from an off-nadir perspective. These candidates cannot be physically explored with our current state of technology because the targets are too small and specific, and the atmosphere at these elevations is too thin for a lander to slow down or maneuver sufficiently to reach them. The astrobiological significance may also be reduced at these elevations because microbial life, if it ever existed on Mars, may not have occurred at these elevations. However, possible evidence of liquid water at the Martian surface was recently identified by Malin, et al. (2006) [16]. If liquid water does exist at or near the surface, then caves at lower elevations could hold natural reservoirs, greatly improving the possibilities for past or present microbial life.

The discovery of potential skylight openings into Martian caves is an exciting step towards future exploration and discovery. New spacecraft orbiting Mars, with greater observational capabilities, can observe these candidates at higher resolutions, at different times of day, from different perspectives and in different wavelengths. Future observations will provide more substantial information about the characteristics and history of these features. A planet-wide search for similar targets is currently underway—particularly for those existing at lower elevations. This discovery presents us with new insights and new challenges for the future of Mars exploration.

References: [1] Ferrill, *et al*. (2003) *LPSC XXXIV*; [2] Wyrick, *et al*. (2004) *JGR*, 109(E6); [3] Mazur *et al.* (1978) *Space Sci. Rev*. v.22, 3-34; [4] Kuhn and Atreya (1979) *J. Mol. Evol*. v.14, 57-64; [5] Boston, *et al.* (2004) *STAIF* v.699 1007-1018; [6] Schulze-Makuch *et al.* (2005) *JGR*, 110(E12); [7] Cushing and Titus (2005) *GRL*, v. 32; [8] Frederick (2000) *Concepts and App. for Mars Exp*. 114; [9] Tuttle and Stevenson (1978*) Nat. Cave Mgmt. Symp. Proc.*; [10] Howarth (1980) *Evolution* v.34; [11] Grin *et al.* (1998) *LPSC XXIX*; [12] Boston (2000) *Geotimes* 45(8) 14-17; [13] Boston *et al.* (2001) *LPSC XXXII*; [14] Parnell *et al.* (2002) *Astrobio.* v.2(1), 43-57; [15] Christensen (2004) *Space Sci. Rev.* v.110(1); [16] Malin (2006) *Science* v.314 1574-1577.

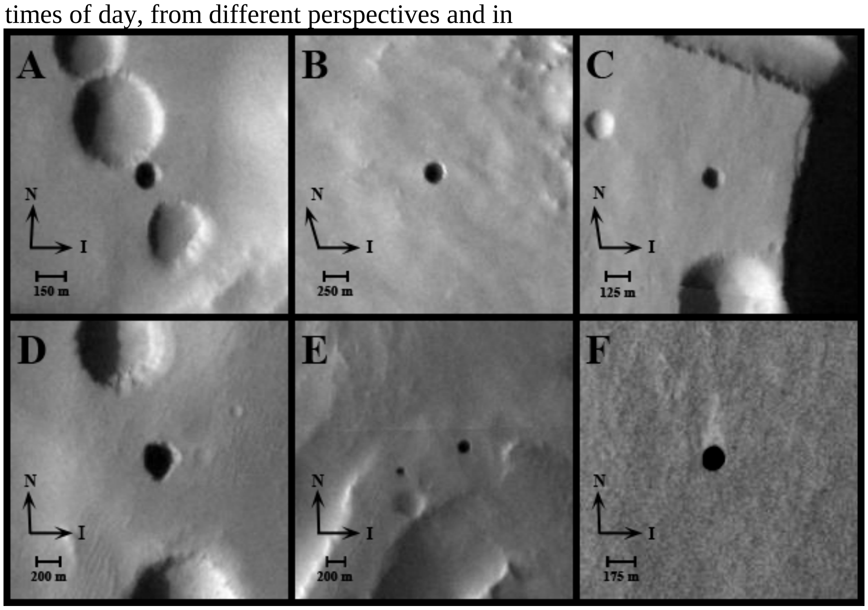

Figure 1: Seven proposed cave skylights. Clockwise from upper-left: Dena, Chloë, Wendy, Annie, Abbey, Nikki and Jeanne. Arrows signify direction of solar illumination (I) and direction of North (N). Respective image IDs are: 18053001, 13448001, 17716001, 18340001, 14334002 and 18315002. To facilitate our photoclinometry routine, each candidate has been map-projected with the sun coming from the 9 o'clock direction.

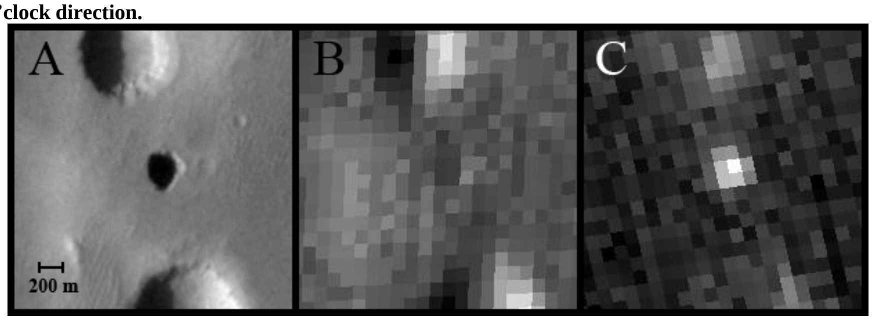

Figure 2: THEMIS VIS and IR images show diurnal thermal behavior of a candidate cave skylight. [A] is the visible image, [B] is an afternoon IR image observed concurrently with the VIS (~1500 hrs), and panel [C] is an early-morning observation at 0400 hrs. This example represents the typical thermal behavior for all of our candidates.