Monitoring from Orbit whether Mars is still Seismically Active

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To probe a planetary body for its internal stress state seismometers can be used. Seismometers need to be installed on the surface. They can provide at best a single-point measurement.

There is a process by which information about the stress state inside the crust can be obtained globally by remote sensing from a satellite.

Key is the recognition that peroxy defects exist in all igneous rocks. Peroxy defects are pairs of oxygen in the valence state 1-. They are electrically inactive but extremely sensitive to stressing. When a peroxy bonds break, two types of electronic charge carriers are generated, electrons and holes. The electrons are trapped in the broken peroxy bonds, but the holes have the remarkable ability to flow out of the stressed rock volume, traveling fast (up to 100 m/s) and far (up to tens, even hundreds of kilometers).

When the holes arrive at the planetary surface, they accumulate at topographic highs. There they can recombine to form peroxy bonds. This reaction is exothermal, meaning that the two O\(^-\) participating in the recombination become vibrationally very hot, equivalent to about 20,000 K. During de-excitation, the peroxy bonds emit infrared photons at energies corresponding to the downward transitions in the vibrational manifold. This process gives rise to well defined IR emission bands beyond about 10 \(\mu\)m.

This excess IR emission in the thermal IR band and its distinct spectroscopic signature are indicators of stresses waxing and waning deep below the surface.

Figure 1: When rocks are stressed, peroxy defects become activated, releasing highly mobile positive hole charge carriers, h\(^+\), chemically equivalent to O\(^-\) in a matrix of O\(^2-\).

The h\(^+\) accumulate at the surface, recombine to form peroxy bonds. The newly formed peroxy bonds emit in the thermal IR 10-14 \(\mu\)m (TIR)

Figure 2: On Earth, tectonic stresses before major earthquakes lead to TIR emissions known as “TIR Anomalies”. Here a plot of TIR anomalies 3 days before an M=6.3 earthquake in Italy, derived from the night-time cooling curves of geostationary weather satellite data [L. Piroddi et al (2014) Geophys. J. Intern'l. 197, 1532-1536].

Figure 3: Close-up of TIR anomalies associated with the M=6.3 L’Aquilla earthquake, clearly showing that the stimulated IR emission comes mostly from the mountains on either side of the valley, where the epicenter was located. TIR maps can be obtained from geostationary IR imagers with broadband response over 10-14 \(\mu\)m.

Figure 4: If a hyperspectral imager is available, it will be possible to extract unique spectroscopic information such as the vibrational de-excitation emission bands arising from the downward quantum transitions during the thermalization of peroxy bonds formed by the recombination of positive hole charge carriers. [Courtesy of J. Scoville, GeoCosmo]

Outlook for Mars

Since the stress-induced activation of peroxy defects is extremely sensitive to low stress levels, it is to be expected that even very small stresses deep in the martian crust will lead to recognizable TIR emissions from the surface of Mars

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