COMPACT ACOUSTIC INSTRUMENTATION FOR STUDYING IN-SITU THE MARTIAN POLAR CO₂ CYCLE. R. D. Lorenz, Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721 (rlorenz@lpl.arizona.edu)

Introduction
Compact and robust instrumentation can monitor the temperature, pressure and gross composition of the near-surface martian atmosphere. This could place important constraints on the CO₂ condensation process (frost vs snow), as well as meteorology at large. Accommodation on a penetrator or hard lander allows delivery in a low-cost or piggyback mission. Measurements proposed include, speed of sound and wind-speed and direction via acoustic measurements, total pressure and temperature via conventional means and possibly CO₂ partial pressure measurement by tunable diode laser. Interleaved battery-powered landers are suggested as an alternative to the technical challenges of long-lifetime landers in polar winter.

Speed of Sound Measurement
Measurement of the speed of sound was proposed as early as 1966 [1] as a diagnostic of composition in the Martian atmosphere. The technique shows promise for the in-situ investigation of the atmospheres of the outer planets [2], and a speed of sound sensor is flying to Saturn’s satellite Titan on board the Huygens probe [3]. Furthermore, an acoustic resonance sensor is being flown to measure windspeed (0-40 ms⁻¹) and direction (to 3°) as part of the environmental sensors package [4] on the British Beagle 2 lander on the ESA Mars Express mission.

The speed of sound in an ideal gas depends on the relative molecular mass and ratio of specific heats of the gas mixture. Argon and Carbon Dioxide are near-end-members for these quantities (M_Ar = 40, M_N₂ = 28, M_CO₂ = 44 ; γ_Ar = 1.667, γ_N₂ = 1.4, γ_CO₂ = 1.3). If the CO₂ in Mars’ seasonal caps forms by direct condensation onto the surface as frost, then the local near-surface atmosphere will become compositionally enriched in the ‘trace’ gases N₂ (present in the global atmosphere at 2.7%) and Ar (1.6%). This enrichment decreases the relative molecular mass, and increases the ratio of specific heats; both factors would tend to increase the speed of sound.

As an example, at 150K, the ‘regular’ atmosphere has a speed of sound of about 193 m/s, while if the CO₂ were depleted by half, the speed of sound would rise (roughly) to 196 m/s. It should be straightforward to measure the speed of sound to 1 part in 1000, if temperature effects on the instrument are well-calibrated.

If CO₂ condenses instead as snow [5], and settles from high altitudes, the atmosphere should be much more well-mixed, and no such depletion should be observed.

Performing speed of sound measurements in four directions allows the wind direction and speed to be determined in three dimensions - three sensors in a plane allow the azimuth and speed to be measured.

Thus a speed of sound measurement could form a valuable comprehensive element of a landed meteorology package. Although the high-sensitivity acoustic array detectors as might be required for a sodar are sensitive to alignment considerations, a simple short pathlength speed of sound sensor need only individual sensing elements which can be extremely robust. Pathlengths for the acoustic measurement need only be a few centimeters, so no deployable elements are required – the sensors can be hard-mounted onto the lander.

Absorption Measurement
The absorption of near-IR by CO₂ makes its abundance easy to measure. In principle a simple absorption cell with a stable source would be able to detect the CO₂ partial pressure. A tunable diode laser [6] source may make long-term calibration more robust since the absorption band itself can be accurately measured against a continuum. Note that a long pathlength may not be necessary for the large partial pressures of CO₂, so a mirrored Herriot cell and the associated optical alignment may not be necessary.

Knowing temperature and total pressure facilitates interpretation of the absorption spectrum, but the spectrum alone may yield important constraints on these parameters as well as the CO₂ number density.

Total Pressure
A robust pressure sensor [7] using silicon micro-machined technology was developed for the DS-2 mission, but had to be discarded for packaging considerations.

It might be interesting to combine this ‘conventional’ measurement with an ion mobility pressure [8] meas-
urement, which is also sensitive to gas composition. This sensor, using the radioactive source from a smoke detector, is also compact and robust.

**Temperature**

It is difficult to accurately measure the temperature of a tenuous gas - in particular because the radiative balance of the sensor, rather than the thermodynamic temperature of the gas, can dominate the sensor temperature. However, careful radiative design and sensor mounting will allow simple thermocouples or RTDs to make useful measurements.

**Combining Measurements**

Any of the sensors described above would produce useful information if an adequate time-series of measurements were made (notably pressure measurements). The synergy between the various sensors is powerful: if composition is known from the combination of total pressure and CO₂ partial pressure, then the speed of sound measurement becomes a good gas thermometer, and with separate surface temperature measurement allows excellent constraints on the heat budget of the surface.

The combination of sensors allows the unambiguous resolution of the various environmental parameters. Since each is quite simple and inexpensive, their combination in a single package is advocated. This also allows scientifically for ‘graceful degradation’, in that useful measurements can still be made if one or more sensors fail, at impact for example.

**Instrument Platforms**

All of the sensors described above should survive landing decelerations of tens of thousands of g. They can thus be emplaced on small landers without requiring airbags or parachutes. Such landers of mass ~1-2kg can be manufactured cheaply and delivered several at a time as secondary payloads.

Ideally, long-term sensing would be performed by each platform, to study seasonal change. This may challenge available battery performance, especially at low polar temperatures and given the impact survivability constraints. On the other hand, if suitable orbital communications infrastructure exists, the mission could last many weeks. The main power consumer on DS-2 was the soil analysis experiment and the radio. Without the energy cost of soil heating, and expected improvement in communications power performance, a DS-2 energy budget applied to the measurements described here could last many weeks.

The alternative, radioisotope power, is probably difficult to accept politically. If battery-powered landers are made small and cheap enough, however, they might be delivered in salvos, such that measurements from one salvo overlap with measurements from another. In other words, it may be easier to build and deliver many short-lived landers than to meet the challenges of long lifetime.

**Conclusions**

Several flight-ready sensing techniques, all of which have mass requirements of only a few grams each, can be combined to study the CO₂ condensation/sublimation cycle. They are robust enough to be accommodated on landers or penetrators like DS-2 without deployable decelerators like parachutes, making them amenable to low-cost delivery in large numbers. Overlapping short-lived missions may prove more cost-effective for this application than the (power) challenges of landers with long lifetimes through the polar winter.

**References**