Indicators for localized regions of heavier species in the lunar surface from CHACE on Chandrayaan-1

Chandra's Altitudinal Composition Explorer (CHACE) has been a unique experiment on the Moon Impact Probe (MIP) – a micro satellite riding piggyback on Chandrayaan-1, India's first mission to the Moon. CHACE, based on a quadrupole mass spectrometer, was intended to get the altitudinal and latitudinal composition of the tenuous lunar ambience, a 'first of its kind' attempt and has yielded significant results, including the first 'direct detection of water', revealing the sunlit-side ambient pressure to be at least two orders of magnitude larger than expected and also showing the dominance of CO_2 and H_2O in the lunar atmosphere[1,2]. In addition, the relative composition of the noble gases and their isotopes revealed significant north–south asymmetry in the radiogenic activity of the lunar interior[3]. All the above results pertained to the dominant species and/or species for which identification is not an issue.

Careful analysis of the 650 spectra obtained from ~ 100 km to the lunar surface and covering a latitude range (40 N–85 S) with unprecedented spatial (~ 250 m) and temporal resolution (~ 4 sec) reveals significant grouping of heavier species (> 60 amu) in localized regions. Figure 1 depicts some sample spectra corresponding to different lunar latitudes in the longitude region 12–15 E. The mass spectra obtained from the quadrupole instrument have been subjected to all the instrumental corrections like mass discrimination of the analyser, relative sensitivity of the detector, etc. and have been normalized to the total pressure measured by the ionization gauge, which itself was calibrated for total pressure measurements. Due corrections to the dominant gas have also been made. Details of the data-handling procedure, including ruling out the possible effects of instrument and the satellite-related contaminants have been dealt with in detail in the literature [1,2] and will not be elaborated here. In this brief note, no attempt is made to identify the species either. They could be elemental or complex molecules. These heavier species start showing up from ~ 5 N lat. and continued their presence with varying strengths as the spacecraft moved towards the South Pole. A mass peak corresponding to 94 amu started appearing at sweep number 190 (~ 8 N) with a partial pressure of 6×10^{-9} torr. It was at its maximum amplitude of 2×10^{-8} torr over a latitude of 5 S (sweep number 250) and lasted up to scan number 321 (~ 22 S), beyond which its intensity slowly decreased and eventually merged with the noise level. In general, 80 amu coexisted with 94 amu. However, there are occasions when 80 amu became stronger than 94 amu by nearly a factor of two (scan number 370 and beyond). Mass numbers 77, 78 and 79 that showed up in sweep number 210 (~ 3.5 N) are seen to become stronger intermittently during the MIP transit. All the above observations are believed to be a reflection of lunar surface heterogeneity and a positive indication for localized regions that are abundant with heavier elements/species. This result has the potential to form a base for any future exploration. The above point becomes clearer in the following discussion.

The Earth's moon is known to have a surface boundary exosphere (SBE), which means that there are no interatomic/molecular collisions mainly due to the particle number density being extremely low and, as a consequence, each one of the atmospheric species has its own altitudinal distribution occupying the same volume. The atoms and molecules would have ballistic trajectories and the lighter species, by virtue of their larger scale height are free to escape into the interplanetary medium once they have enough kinetic energy to overcome the gravitational pull of the Moon. Having a background information on the lunar surface temperature both during sunlit conditions (~ 400 K) and otherwise (~ 150 K) and keeping in mind the latitudinal variation of the surface temperature, it could be seen that only the lightest of the species, viz. hydrogen would have enough energy to escape into the interplanetary medium, that too only up to ~ 75° lat. All the other species would be gravitationally bound, unless some additional energy is supplied to them. This makes the lunar atmosphere unique in the sense that the atmospheric composition measurements directly reflect the lunar surface properties. After successfully delineating the surface temperatures using the scale height of noble gases and showing excellent agreement with the spectroscopically determined values[2] and after duly accounting for the scale height variations, the latitudinal distribution of the atmospheric species has been obtained and reported in the literature[2].

In the present communication, emphasis is given to the higher mass numbers. As MIP raced towards the South Pole, appearance and disappearance of different species in the amu range (65–100) became conspicuous. Though the relative concentration of these species is significantly low, often forming less than a few percentage of the dominant species, due to the sensitivity of the instrument, their signatures are very clear.

In fact, Apollo-17 measurements using a mass spectrometer that was left on the lunar surface by the astronauts did show similar groups of heavier species[4]. However, the spectra were believed to have been contaminated due to degassing from the suits of the astronauts and also from the large quantity of materials taken and left behind by them on the lunar surface. Under such a notion, many of the genuine species of lunar origin were also left out. After Apollo-17, which itself was the first attempt to measure the tenuous atmospheric composition of the Moon, it was the CHACE experiment on Chandrayaan-1's MIP that made an attempt to measure the lunar atmospheric composition after more than four decades. This 'one shot' experiment was free from many of the limitations of the LACE (Apollo-17) experiment and had clearly indicated a complex lunar atmosphere, though tenuous, with CO_2 and H_2O as the dominant species[2].

Identification of the masses is a challenge in itself and no attempt is made here in this direction. Based on the arguments provided in the earlier cited publications, the observed masses are not contaminants as one tends to treat them at the first instant. If they had been so, they should have registered their presence all through with the same intensity and it cannot be intermittent or localized as had been observed. It should also be noted that even as the spacecraft was

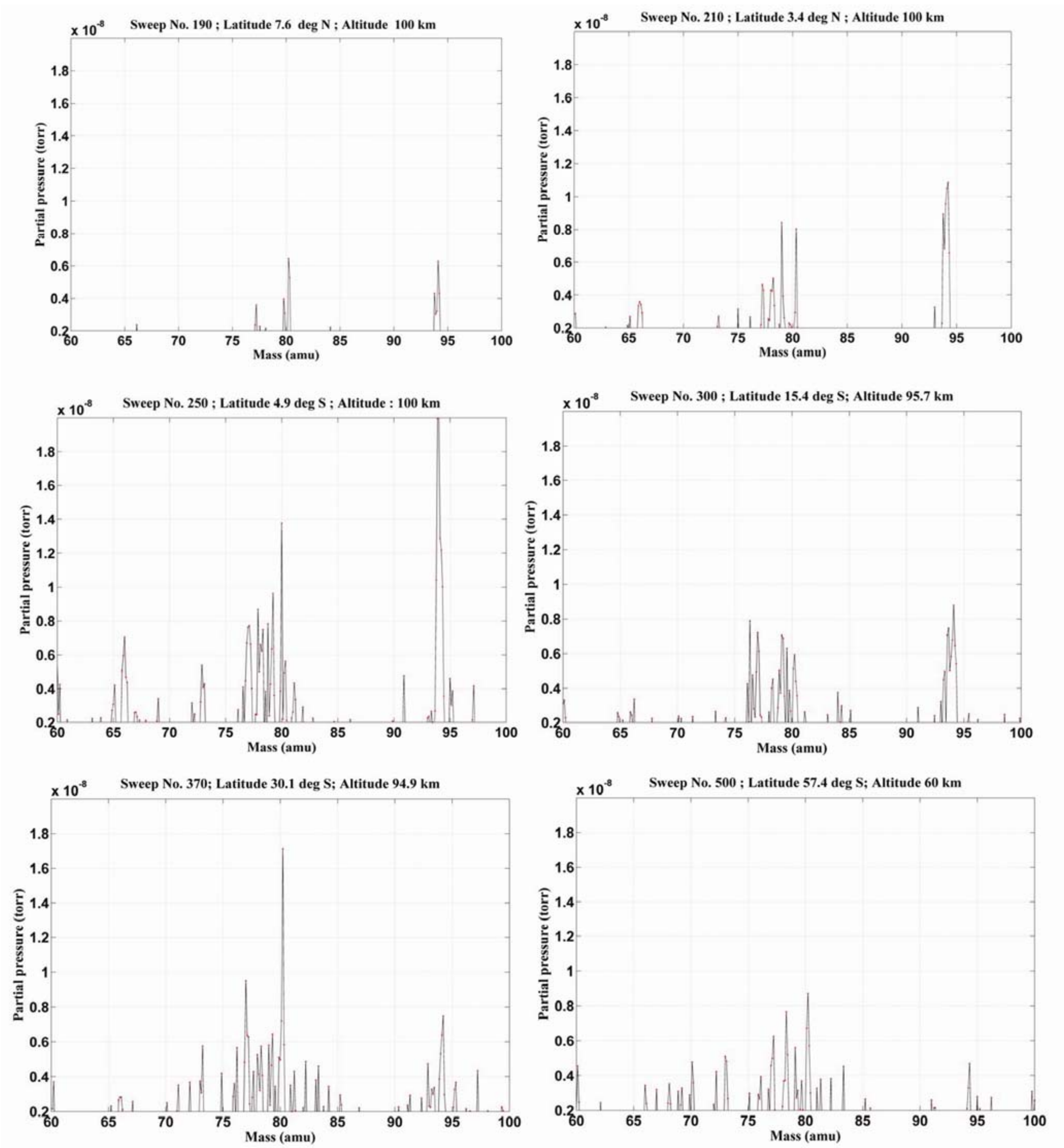

Figure 1. Sample mass spectra of the lunar ambience in the range 60–100 amu as the Moon Impact Probe of Chandrayaan-1 mission raced towards the South Pole. The sweep number and the corresponding lunar latitudes and altitudes are also given in each panel.

steadily descending from 100 km, the partial pressure of these species did not build up as would have been the case if there had been some sort of uniform distribution; in fact, the partial pressure of 94 amu decreased significantly.

When the ground trajectory of MIP was projected over the lunar surface, it is interesting to see that the former crossed over the fringe of the KREEP region rich in potassium and rare earth elements that show large surface heterogeneity[2,3]. Since CHACE is the only experiment that has provided both latitudinal/altitudinal variation of the lunar exospheric composition so far, the variations recorded with respect to the heavier species could be associated with the lunar surface heterogeneity. With the launch of Lunar Atmosphere and Dust Environment Experiment (LADEE) by NASA on 7 September 2013, where emphasis is given to the lunar exospheric composition and also the near-lunar dusty environment over the equatorial plane, some of the CHACE findings are likely to be vindicated. Further, unlike in the case of CHACE, which was a 'one shot' mission, the distinct advantage of LADEE which would be an orbiting spacecraft initially at around 250 km and later coming down as low as 20 km, with an anticipated lifetime of ~ 3 months, is that the whole of the lunar globe is likely to be covered over the equatorial plane. This would clearly bring out the spatial heterogeneity indicated by India's CHACE experiment, in addition to the inferences on the lunar day and night pressure differences.

1. Sridharan, R., Ahmed, S. M., Das, T. P., Sreelatha, P., Pradeepkumar, P., Naik, N. and Supriya, G., *Planet. Space Sci*., 2010, **58**, 947–950.
2. Sridharan, R., Ahmed, S. M., Das, T. P., Sreelatha, P., Pradeepkumar, P., Naik, N. and Supriya, G., *Planet. Space Sci*., 2010, **58**, 1567–1577.
3. Sridharan, R., Das, T. P., Ahmed, S. M., Supriya, G., Bhardwaj, A. and Kamalakar, J. A., *Adv. Space Res*., 2013, **51**, 168–178.
4. Hoffman, J. H., Hodges Jr, R. R. and Evans, D. E., In Proceedings of the 4th Lunar Science Conference, *Geochim. Cosmochim. Acta, Suppl. 4*, 1973, pp. 2865–2875.

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Lessons from Kedarnath tragedy of Uttarakhand Himalaya, India

The complete destruction by Mandakini River in Kedarnath on 16 and 17 June 2013 could not have been avoided. Yet, the number of casualties would have been far less had the mushrooming growth of hotels, lodges and dharmshalas not been allowed in Kedarnath. This has been one of the worst Himalayan tragedies in recent years in which the exact number of people buried/perished is not known as thousands are still missing. Almost the entire Rambara and a large part of Gaurikund and many villages of Mandakini valley were also wiped out. The flash flood and attendant debris flow was undoubtedly an irrepressible natural hazard. However, its worst impact must be viewed in the perspective of high vulnerability (of this area) mainly attributed to rampant construction activity for commercial purpose in Kedarnath, Rambara and Gaurikund in the close proximity of Mandakini River and also the uncontrolled floating population of pilgrims. It was the worst-case scenario with an area of very high vulnerability (man-made) experiencing flash floods and debris flow induced by torrential rains, Chorabari lake collapse and mobilization of glacial material[1]. This correspondence discusses the measures aimed at reducing the vulnerability of this area in the future.

About 131 years ago in 1882 only the Kedarnath temple and four to five huts (chhan in local parlance) existed in the region.

Some decades ago, the holy shrines of Uttarakhand did not witness heavy influx of floating population of pilgrims and tourists. Also, there was no rampant construction activity on active and old flood plains and lower terraces of rivers and on critical hill slopes. Our rising population, economic growth and improved lodging facilities due to rapid transformation in the livelihood strategies of locals have drastically increased the influx of pilgrims and tourists in this region.

A few years back, the pilgrims used to start their journey from Gaurikund to Kedarnath on foot or by pony early in the morning just to ensure their return to Gaurikund by afternoon on the same day. This was because there were few lodges/ hotels in Kedarnath and even far lesser number of such facilities in Rambara, which is a transit point midway between the 14 km long pony route from Gaurikund to Kedarnath.

The area is geodynamically unstable with neotectonic movements and high frequency of landslides, including rock falls, debris flow and ground subsidence[2,3]. The source of the Mandakini River is formed by Chorabari and an unnamed companion glacier. The settlement of Kedarnath is just 500 m below the snout of these glaciers and the terminal moraine hump is about 275 m high from the outwash plain over which Kedarnath is situated (GSI, unpublished). Examination of satellite images indicates that this outwash plain might have been reworked by the Mandakini River in the past and a major part of Kedarnath till 16 June 2013 was located on the old flood plain (T_1 terrace). However, the famous Kedarnath temple constructed on a man-made raised platform seems to be located on a higher terrace of the Mandakini River. The moraine ridges running parallel and subparallel to the upper Mandakini valley are conspicuous in Kedarnath and further downstream up to Garuriya and Ghindurpani. After the flash floods and debris flow of 16 and 17 June 2013 (although flood water of the Mandakini River has receded), it would not be geologically incorrect to say that the completely devastated settlement of Kedarnath today lies on the active flood plain of Mandakini River that may be flooded again in the near or far future in the event of torrential rains and or due to mobilization of glacial material.

Critical slopes on the hillside and flash flood-prone banks on the river side restrict the capacity of the Himalayan shrines of Yamunotri, Gangotri, Kedarnath, Badrinath and a number of habitations such as Gaurikund and Rambara (on the way to Kedarnath) and Janki chatti (on the way to Yamunotri) to safely accommodate the growth of 3–4-storied hotels and lodges.