Terrestrial Planets Pre Paper
5 November 1998
Paul Withers

Na and K in the lunar atmosphere

Apollo view of the lunar atmosphere

Scientists since Galileo have searched for a lunar atmosphere. Prior to the Apollo era occultations had placed an small upper limit on the surface pressure but no atmosphere had been detected. The small surface pressure meant that any atmosphere would be effectively collisionless.

The Apollo program measured a dayside surface number density of ~10^7 molecules per cm^3 and a nightside surface density of ~10^5 molecules per cm^3. The dayside results were heavily contaminated by outgassing from Apollo instruments, astronauts and the lunar module. The dayside result is an upper limit to the dayside surface number density. The nightside results are believed to be uncontaminated.

The only species positively identified as constituents of the lunar atmosphere by the Apollo program were He and Ar with surface number densities of ~2 x 10^3 atoms per cm^3. Other species like H, O, C, H_2, CO, S and Xe which were predicted to be present along with He and Ar were constrained by small upper limits.

At the end of the Apollo era only a small fraction of the atmosphere had been identified.

A similar story can be told for Mercury. Mariner 10 detected He, H and O in the Mercurian atmosphere with their total pressure significantly below the upper limit on the atmospheric pressure.

Na and K in the lunar atmosphere

There are many similarities between the lunar and Mercurian atmospheres and surface enviroments. A striking example of this was given in the late 1980s when Na and K were detected in both atmospheres using ground-based observation. The species are detected via their famous D lines at .59 and .77 um respectively. Emission in these wavebands from the surface is far greater than the atmospheric emission, making observations very challenging.

The concentrations of both species in both atmospheres are much smaller than the upper limits on atmospheric number density.

The nature of the in situ Apollo observations of individual species is very different to that of the remote ground-based observations. The former gave surface number densities at the Apollo 17 site over a period of a few lunar days. The latter give number densities at heights >50 km above the lunar surface. Measurements are not made regularly in time and there is sparse coverage away from the subsolar point.

The current observational data on Na and K in the lunar atmosphere may be summed up as follows:
Low number densities (~40 atoms per cm^3 for Na, ~10 for K)
Non-thermal vertical distribution, can usually be fit by a thermal population (~350K, dominant at lower altitudes) and a suprathermal population (~2000K, dominant at higher altitudes)
Dayside approximates an exosphere, nightside approximates a coma
Strong latitudinal dependence, falls off faster than the cosine of the latitude

Current work in the field of the lunar atmosphere falls into four categories:
Searches for other atmospheric constituents (e.g. Mg, Ca, Fe, Si)
Observations of Na and K
Theory to explain the lack of any other species detections in the decade since the discovery of Na and K
Theory to explain the character of the Na and K atmospheres

This paper focuses on explaining the character of the Na and K atmospheres.

Modeling Na and K in the lunar atmosphere

Once in the atmosphere the forces acting on an alkali atom are well understood. These are gravity, coriolis and centrifugal forces due to the non-inertial lunar rest frame and solar radiation acceleration. Solar photons in the D line region, when absorbed and reradiated, transfer net antisunward momentum to the atom. As the atom Doppler shifts around in the Fraunhofer line in the solar spectrum the radiation acceleration alters. There are two components to this Doppler shift; the Moon-Sun motion and the atom-Moon motion. Note that the radiation acceleration changes with the orbit of the Moon around the Earth and the Moon around the Sun.

Three processes are generally considered plausible sources of alkali atoms in

the atmosphere:
Impact vaporization
Photon simulated desorption
Solar wind ion sputtering

In each of these processes, for a given incident flux the alkali atom flux into the atmosphere will vary with surface temperature and composition. The incident fluxes for each of these processes have different characteristics:

The flux of micrometeoroids onto the lunar surface is uniform.
The flux of photons onto the lunar surface varies as the cosine of dayside latitude and is negligible on the nightside.
The flux of solar wind ions onto the lunar surface varies as the cosine of dayside latitude and is negligible on the nightside. It is also negligible for approximately two days either side of full Moon when the Moon is within the Earth's magnetosphere.

The question of replenishing the alkali atoms in the surface layer is also important.

When an alkali atom impacts the surface it may only interact for a short period of time before returning to the atmosphere with a new speed and direction or it may be adsorbed for a longer period. Adsorbed atoms may be released to the atmosphere by any of the three source processes or by thermal desorption. Thermal desorption is not a primary source of alkali atoms. It can only release atoms which have previously been in the atmosphere.

This is generally modeled with an impacting atom having some probability of sticking to the surface. If the atom rebounds it has a velocity selected from a distribution parameterized by the incident energy and the surface temperature. In the same way that thermal desorption is not a primary source, sticking to the surface is not a primary sink.

The main primary sink for the alkali atoms is photoionization. Ionized atoms are transported by the solar wind, either into space or back to the surface, from which they can later be recycled.

Processes involving the lunar surface layer are not well constrained by experiment. The lunar surface layer is very difficult to replicate in the laboratory as it is rough on the atomic scale due to eons of ion sputtering and micrometeoroid bombardment.

Neither the source processes nor the surface impact of an alkali atom are well understood. Most modeling to date has used a dayside source flux which is either uniform or proportional to the cosine of latitude and the impact model described above. My aim in this paper will be to compile a library of atmospheres for a range of source populations, stickiness probabilities and rebound velocity distributions. Then future observations can be compared to the library to constrain the parameters.

References

Apollo era:
Morgan & Stern, 14 May 1991, Eos, Vol. 72, No. 20, pp 225 - 228
Feldman & Morrison, Nov 1991, Geo. Res. Lett., Vol. 18, No. 11, pp 2105 - 2108

First Na, K Detections:
Potter & Morgan, 5 August 1988, Science, Vol. 241, pp 675 - 680
Tyler et al, September 1988, Geo. Res. Lett., Vol. 15, No. 10, pp 1141 - 1144
Potter & Morgan, December 1988, Geo. Res. Lett., Vol. 15, No. 13, pp 1515 - 1518
Kozlowski et al, November 1990, Geo. Res. Lett., Vol. 17, No. 12, pp 2253 - 2256

Source and impact theories:
Morgan et al, 1989, Proc. LPSC 19, pp 297 - 304
Morgan & Shemansky, 1 February 1991, JGR, Vol. 96, No. A2, pp 1351 - 1367
Sprague et al, 1992, Icarus, Vol. 96, pp 27 - 42
Morgan & Killen, 1997, Planet. Space Sci., Vol. 45, No. 1, pp 81 - 94

Modeling:
Ip, November 1991, Geo. Res. Lett., Vol. 18, No. 11, pp 2093 - 2096
Smyth & Marconi, 10 April 1995, Ap. J., Vol. 443, pp 371 - 392
Flynn & Mendillo, 25 November 1995, JGR, Vol. 100, No. E11, pp 23271 - 23278