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COMMENTARY

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Key Points:

- HCl, a gas of potentially volcanic origin, is present on Mars, verified by satellite and terrestrial observatories
- The near-global spatial distribution of HCl is revealed and compared to water vapour and dust
- The ultimate origin of HCl may be outgassing or related to surface salts, while the seasonal cycle is controlled by photochemistry

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Chlorine on the Surface, Chlorine in the Air, What Is the New Global View of the Martian Chlorine Cycle?

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Abstract Atmospheric hydrogen chloride (HCl, or hydrochloric acid) has strong links to volcanic activity on Earth. If it is present in the atmosphere of Mars, it could hint at active magmatic processes, or the outgassing from the remnants of recently dormant volcanoes. It has been sought in the Martian atmosphere using terrestrial telescopes and was a target for the ExoMars Trace Gas Orbiter (TGO) mission. Since it was found by TGO, the terrestrial telescopes have returned to their hunt, and the recent study by Faggi et al. (2025), https://doi.org/10.1029/2025je009105 presents the results of a multi-year campaign to study the global distribution of HCl across the Martian surface. In this commentary, we will examine the importance of HCl, its context in the broader chloride cycle on Mars, how we have gotten to this point, and the implications the new study has on our understanding of its origins.

Plain Language Summary Hydrogen chloride is a gas emitted by volcanoes on Earth. It has been hunted on Mars as a sign of recent volcanic activity, and was found with the ExoMars Trace Gas Orbiter (TGO), whose main objective is to find rare gases in the Martian atmosphere that tell us about biological or geological activity there. This commentary examines the recent results presented by Faggi et al. (2025), https://doi.org/10.1029/2025je009105 on a campaign to measure HCl in the Martian atmosphere from the Earth. From a telescope on Earth, the measurements cover the whole surface of Mars revealing how HCl is distributed and how that changes over a year. Here, we discuss the context of these results and their implications for chlorine deposits seen on the surface.

1. Commentary

Chlorine on Mars has proven a growing enigma that keeps giving us new mysteries. In a new paper, Faggi et al. (2025) show the distribution of atmospheric hydrogen chloride (HCl) over nearly a full Martian year as seen with the iSHELL spectrometer at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea. This is no simple feat, HCl has been long sought in the Martian atmosphere by Earth-based telescopes and robotic explorers. This study was achieved through a combination of improved spectroscopic tools and the knowledge of HCl's seasonal behaviour since its first discovery using the Atmospheric Chemistry Suite (ACS) on ESA's ExoMars Trace Gas Orbiter (TGO) (Korablev et al., 2021; Olsen et al., 2021).

The IRTF observations see the integrated column abundance, the total amount of atmospheric HCl from the top down, which is mostly sensitive to the lowest, densest layers of the atmosphere and distinct from the vertical profiles observed with TGO. The ground-based observations see most of the visible disc of Mars, giving unprecedented spatial coverage, which is a major limitation of the solar occultation measurements made with TGO.

HCl is an important gas in the Martian atmosphere due to its strong relationship with volcanic activity, one of the main sources of HCl on Earth (the largest tropospheric source being sea-salt aerosols). The primary objective of the TGO mission is to detect any gases in the Martian atmosphere that may come from ongoing activity, that is, due to a biosphere or active geology. Therefore, we are hunting for things like methane, a biosignature, or gases that have chlorine or sulfur in them, such as HCl or SO_2. TGO has so far found and characterized HCl (Olsen et al., 2024a, 2024b) but not found signs of methane or other organic molecules (Knutsen et al., 2021; Montmessin et al., 2021), or sulfur-bearing molecules (Braude et al., 2022). HCl and methane will break down in sunlight and eventually form other stable molecules in a one-way path. They are expected to have lifetimes of only a few hundred years, so any detection now means that there is a present source.

The new study by Faggi et al. (2025) is extremely timely, as it builds on several years of TGO observations that identified some of the atmospheric chemistry governing HCl, the clear seasonality that HCl exhibits, and the implication of not finding sulfur at the same time. There may be an extremely tight link between atmospheric HCl and deposits on the surface, which may be lifted as dust, or created through deposition. Currently, the atmospheric chemistry that drives its seasonal cycle is not fully understood. In fact, the seasonality defies expectations—HCl should be the long-lived resident species of chlorine in the atmosphere and indicate some sort of volcanic source, something that is hard to reconcile with the behaviour of HCl.

On the Martian surface, chlorine has been known since the days of the Viking missions, with Clark et al. (1976, 1982) identifying Cl in the Martian fines analyzed by both Viking landers. The chlorine observations were tied to one of the more controversial aspects of the Viking program—the detection of chloromethane and dichloromethane in the Gas Chromatograph-Mass Spectrometer. These unexpected results were written off as terrestrial contamination at the time since the result was not very strong and the compound could not be explained. Recent re-analysis by McKay et al. (2025) within the context of the known presence of surface perchlorates and an atmospheric chlorine cycle suggest Viking may have been the first observation of such salts.

The first observations of the widespread distribution of chloride minerals across the Martian surface came from the THEMIS instrument on 2001 Mars Odyssey (Osterloo et al., 2008). Shortly after, the first identification of a chloride compound, rather than just the presence of chloride (a limitation of orbital spectrometers), came from the Wet Chemistry Lab on the Phoenix lander (Hecht et al., 2009). Since then, extensive studies have been conducted on the distribution of chloride minerals across the Martian surface with instruments on Mars Express (Wray et al., 2009) and Mars Reconnaissance Orbiter (Murchie et al., 2009).

The Phoenix mission found the perchlorate anion (ClO_4^-) which would form a salt on the surface with another element such as magnesium or calcium. This was a very exciting result, itself spurring a flurry of interest in the modeling and experimentation communities and many follow-up studies by satellites and the Curiosity (Glavin et al., 2013) and Perseverance (Scheller et al., 2022) rovers. On one hand, these salts may allow for liquid, flowing brines under current Martian conditions. On the other, their discovery reshaped our understanding of Martian soil chemistry, water stability, organics preservation, and history of habitability. Perchlorate is not alone either, there should be an abundance of simpler salts, like the familiar NaCl, or bearing magnesium, iron, or calcium, distributed across the Martian surface with strong ties to ancient seas (Glotch et al., 2016).

The massive level of activity within the community that resulted from the Phoenix discovery was aimed at understanding where surface perchlorate came from and how long ago it was formed. A strong tie to the atmosphere came from Catling et al. (2010) and Smith et al. (2014), who built an atmospheric model for Mars based on a study of the salt formations in Chile's Atacama Desert. In their hypothesis, volcanic eruptions on Mars eject HCl into the atmosphere. Over time, sunlight breaks HCl apart and oxygen bonds form with the chlorine, eventually leading to the formation of perchlorate which can be deposited on the surface.

Now, with the detection of HCl in the contemporary Martian atmosphere, we are once again seeing a flurry of activity by the science community making new observations, performing experiments, and building climate models.

The first reported attempt to measure the abundance of HCl in the Martian atmosphere came from Krasnopolsky et al. (1997). They used observations made in 1988 using the Kitt Peak National Observatory and a Fourier transform spectrometer from Goddard Space Flight Center. While HCl (nor methane) was not found, they reported an upper limit for their analysis of 2 parts-per-billion-by-volume (ppbv). The observations were made at solar longitudes (L_s) 222°. The solar longitude is the position of Mars in its orbit around the Sun in degrees defined by its axial tilt in the same way as Earth, with 0° and 180° at the equinoxes and 90° and 270° the solstices. Therefore, these observations were made during the southern spring, right at the start of the Martian dusty seasons.

This was followed up by Hartogh et al. (2010) who used the *Herschel* Space Telescope in 2010 to set a new low upper limit of 0.2 ppbv. Those observations were made at L_s 77°, or toward the end of the southern fall, a much colder, drier, and less dusty period. Villanueva et al. (2013) performed a detailed survey of the Martian atmosphere between 2006 and 2010, but were unable to detect HCl, setting an upper limit of 0.6 ppbv. They made six observations at L_s 12°, 83°, 324°, and 352° using powerful high-resolution infrared spectrometers (CRIRES, NIRSPEC, CSHELL) at high-altitude observatories (VLT, Keck-2, NASA-IRTF).

We now know that HCl abundances can be between 2 and 8 ppbv and that it exhibits a strong seasonality, appearing when it the spring and summer in the southern hemisphere, with peak abundances occurring between 200° and 300°. The timing is the most likely may explain why these teams were unable to find HCl, but set such low upper limits for the gas (Hartogh et al., 2010; Krasnopolsky et al., 1997; Villanueva et al., 2013).

In fact, immediately after the ACS team announced the detection of HCl, a new study with IRTF was planned to validate the discovery and seasonality. Aoki et al. (2024) made two observations in 2020 at L_s 273° and 306°, in the middle of summer in the southern hemisphere, and finally made a detection of 1–4 ppbv! Faggi et al. (2025) directly builds upon that study with a longer series of observations that examine the different seasons on Mars.

Faggi et al. (2025) made an additional 20 observations during 2021 and 2022 covering the southern spring, summer, and fall seasons. Beginning with the southern spring, they found about 3 ppbv of HCl around the equator right away, at L_s 200°. This is right after the equinox and corresponds to the start of the southern dusty season. The southern hemisphere begins to tilt toward the Sun at the same time that Mars' orbit brings it closest to the Sun. This causes the south polar cap to sublimate, increasing the density of the Martian atmosphere which allows its winds to pick up more dust. The dust, in turn, leads to the atmosphere heating and expanding. What the TGO teams found, and this study further confirmed, is that HCl is strongly tied to this seasonal activity, especially with water vapour.

By the end of southern spring, HCl is observed at 4–5 ppbv and through the summer this increases to 6 ppbv. During the fall period, the HCl abundances have fallen to less than 1 ppbv, and are so close to the noise level of the instrument that they are not considered definitive. Theirs is an equatorial enhancement seen at L_s 29° that corresponds to an increase in water vapour.

At first, HCl presented a pretty big mystery. It was expected to be a sign of volcanic activity, but no other sulfur gases were found. The first observations showed it appearing very suddenly right after the 2018 global dust storm, but at very high northern and southern latitudes (Korablev et al., 2021). This distribution was hard to imagine as coming from a volcano. It also disappeared right as the dusty period settled down, seemingly closely tied to the dust activity. In Korablev et al. (2021) we postulated that the behaviour was seasonal and we made the subsequent detections with relief in the following Mars-year while the paper was going through peer-review (Aoki et al., 2021; Olsen et al., 2021).

Since then, we've been able to strengthen the link between HCl and water vapour, but have also shown that HCl does not depend on the amount of dust in the air (Olsen et al., 2024a, 2024b). The new results that Faggi et al. (2025) have found show the distribution of dust, water vapour, and HCl across the full disc of Mars, giving an unprecedented look at how they are distributed and related.

The link to water vapour is due to photochemistry. When solar radiation breaks water down into H and OH, this leads to the formation of HO_2 which is the reactant for Cl to form HCl. We also think that when water vapour freezes, HCl may be sticking to the ice.

The atmosphere still needs an incoming source of chlorine to stabilize the abundance of HCl over time. This may be a reverse path that sees perchlorate breaking down again (Taysum et al., 2024). It may also be related to the other surface salts, such as NaCl—a major terrestrial source of HCl. Energetic processes may be able to break down these salts to release the chlorine ions for reactions in the gas-phase. For example, we have been looking into electrostatic discharges that may occur during dust storms (Wang et al., 2023) and these types of discharges were just found on Mars this year (Chide et al., 2025)!

We are also still excited about the possibility that some sort of gas seepage is occurring—the remnants of some sort of underground, ancient, dormant volcano or magma reservoir that is slowly revealing its secrets to us, little by little. Faggi et al. (2025) give an excellent review of the possible processes in play.

Conflict of Interest

The author declares no conflicts of interest relevant to this study.

Data Availability Statement

Data were not used, nor created for this research.

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