ExoMars finds new gas signatures in the martian atmosphere

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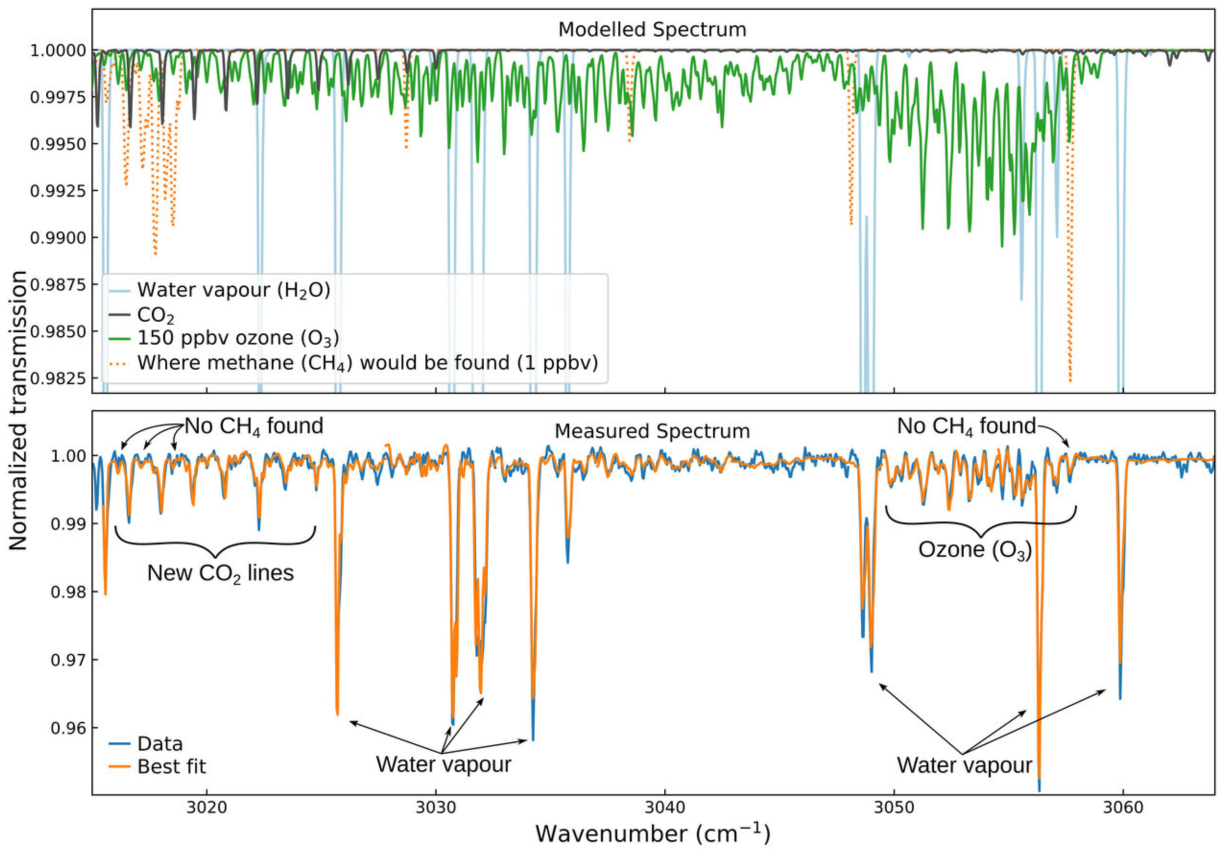


This graph shows an example of the measurements made by the Atmospheric Chemistry Suite (ACS) MIR instrument on ESA's ExoMars Trace Gas Orbiter (TGO), featuring the spectral signatures of carbon dioxide (CO2) and ozone (O3). The bottom panel shows the data (blue) and a best-fit model (orange). The top panel shows the modelled contributions from a variety of different gases for this spectral range. The deepest lines come from water vapour (light blue). The strongest O3 feature (green) is on the right, and distinct CO2 lines (grey) appear on the left. The locations of strong methane features (orange) are also shown in the modelled contributions, though methane is not observed in the TGO data. Credit: K. Olsen et al. (2020)

ESA's ExoMars Trace Gas Orbiter has spotted new gas signatures at Mars. These unlock new secrets about the martian atmosphere, and will enable a more accurate determination of whether there is methane, a gas associated with biological or geological activity, at the planet.

The Trace Gas Orbiter (TGO) has been studying the Red Planet from orbit for over two years. The mission aims to understand the mixture of gases that make up the martian atmosphere, with a special focus on the mystery surrounding the presence of methane there.

Meanwhile, the spacecraft has now spotted never-before-seen signatures of ozone (O3) and carbon dioxide (CO_2), based on a full martian year of observations by its sensitive Atmospheric Chemistry Suite (ACS). The findings are reported in two new papers published in *Astronomy & Astrophysics*, one led by Kevin Olsen of the University of Oxford, UK and another led by Alexander Trokhimovskiy of the Space Research Institute of the Russian Academy of Sciences in Moscow, Russia.

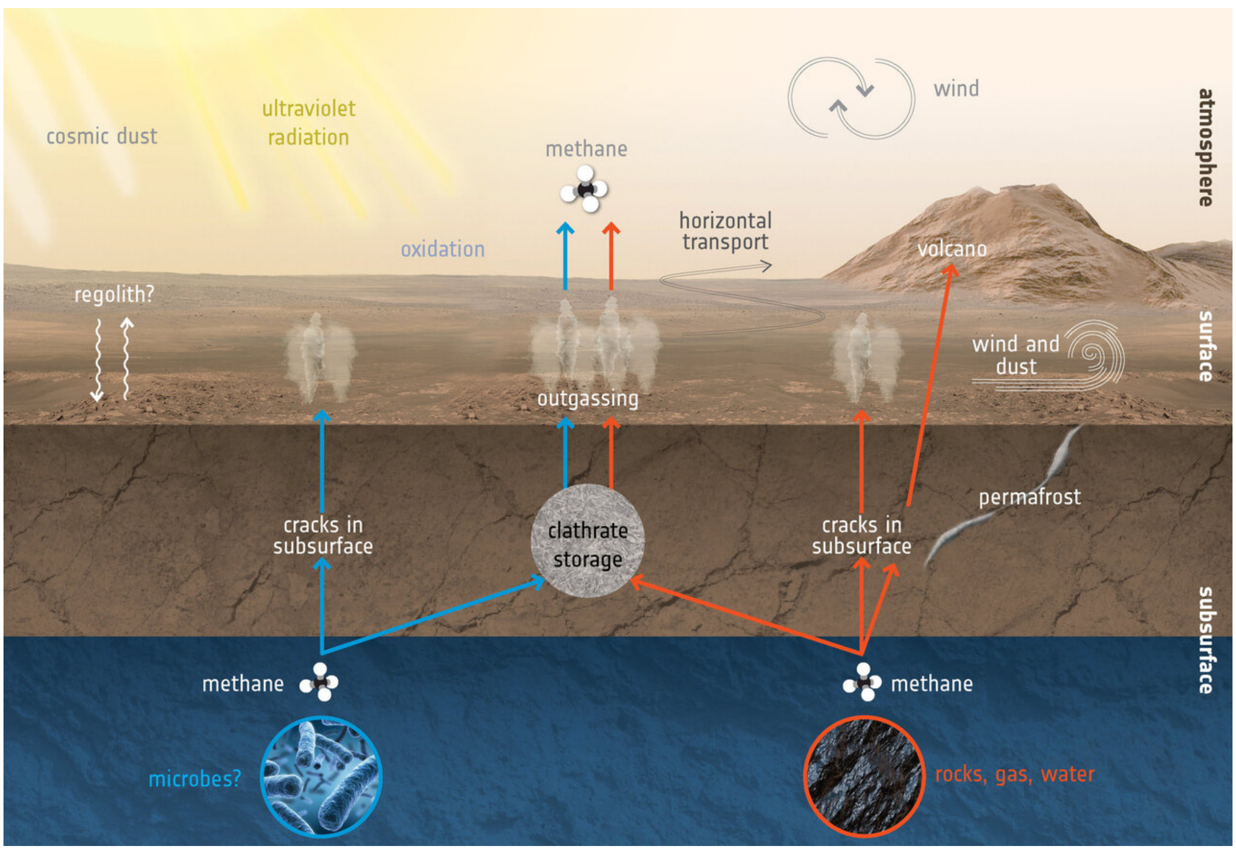
"These features are both puzzling and surprising," says Kevin.

"They lie over the exact wavelength range where we expected to see the strongest signs of methane. Before this discovery, the CO_2 feature was completely unknown, and this is the first time ozone on Mars has been identified in this part of the infrared wavelength range."

The martian atmosphere is dominated by CO_2, which scientists observe to gauge temperatures, track seasons, explore air circulation, and more.

Ozone—which forms a layer in the upper atmosphere on both Mars and Earth—helps to keep atmospheric chemistry stable. Both CO_2 and ozone have been seen at Mars by spacecraft such as ESA's Mars Express, but the exquisite sensitivity of the ACS instrument on TGO was able to reveal new details about how these gases interact with light.

Observing ozone in the range where TGO hunts for methane is a wholly unanticipated result.



How methane is created and destroyed on Mars is an important question in understanding the various detections and non-detections of methane at Mars, with differences in both time and location. Although making up a very small amount of the overall atmospheric inventory, methane in particular holds key clues to the planet's current state of activity. This graphic depicts some of the possible ways methane might be added or removed from the atmosphere. One exciting possibility is that methane is generated by microbes. If buried underground, this gas could be stored in lattice-structured ice formations known as clathrates, and released to the atmosphere at a much later time. Methane can also be generated by reactions between carbon dioxide and hydrogen (which, in turn, can be produced by reaction of water and olivine-rich rocks), by deep magmatic degassing or by thermal degradation of ancient organic matter. Again, this could be stored underground and outgassed through cracks in the surface. Methane can also become trapped in pockets of shallow ice, such as seasonal permafrost. Ultraviolet radiation can both generate methane – through reactions with other molecules or organic material already on the surface, such as comet dust falling onto Mars – and break it down. Ultraviolet reactions in the upper atmosphere (above 60 km) and oxidation reactions in the lower atmosphere (below 60 km) acts to transform methane into carbon dioxide, hydrogen and water vapour, and leads to a lifetime of the molecule of about 300 years. Methane can also be quickly distributed around the planet by atmospheric circulation, diluting its signal and making it challenging to identify individual sources. Because of the lifetime of the molecule when considering atmospheric processes, any detections today imply it has been released relatively recently. But other generation and destruction methods have been proposed which explain more localized detections and also allow a faster removal of methane from the atmosphere, closer to the surface of the planet. Dust is abundant in the lower atmosphere below 10 km and may play a role, along with interactions directly with the surface. For example, one idea is that methane diffuses or 'seeps' through the surface in localized regions, and is adsorbed back into the surface regolith. Another idea is that strong winds eroding the planet's surface allows methane to react quickly with dust grains, removing the signature of methane. Seasonal dust storms and dust devils could also accelerate this process. Continued exploration at Mars – from orbit and the surface alike – along with laboratory experiments and simulations, will help scientists to better understand the different processes involved in generating and destroying methane. Credit: European Space Agency

Scientists have mapped how martian ozone varies with altitude before. So far, however, this has largely taken place via methods that rely upon the gas' signatures in the ultraviolet, a technique which only allows measurement at high altitudes (over 20 km above the surface).

The new ACS results show that it is possible to map martian ozone also in the infrared, so its behaviour can be probed at lower altitudes to build a more detailed view of ozone's role in the planet's climate.

Unravelling the methane mystery

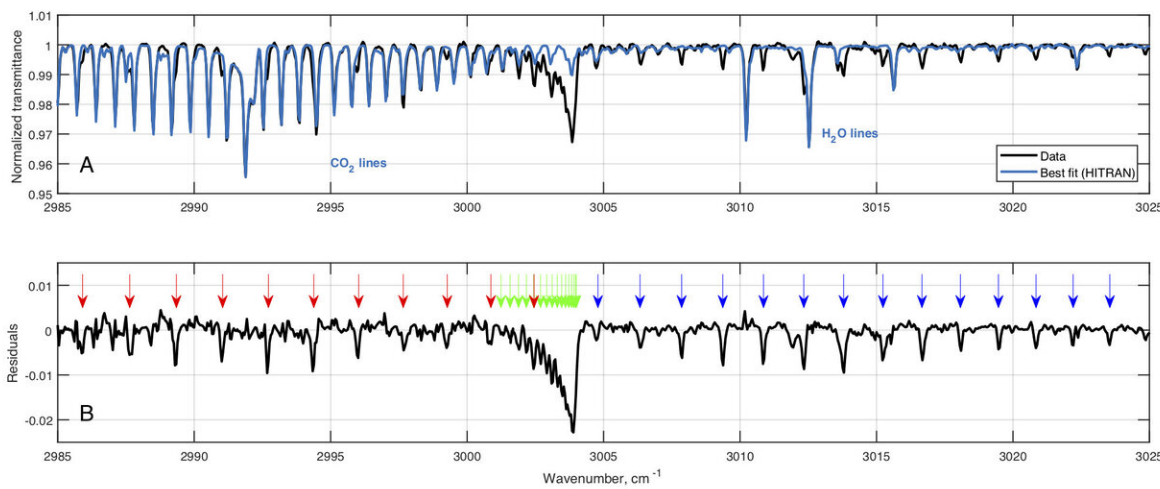
One of the key objectives of TGO is to explore methane. To date, signs of martian methane—tentatively spied by missions including ESA's Mars Express from orbit and NASA's Curiosity rover on the surface—are variable and somewhat enigmatic.

While also generated by geological processes, most of the methane on Earth is produced by life, from bacteria to livestock and human activity. Detecting methane on other planets is therefore hugely exciting. This is especially true given that the gas is known to break down in around 400 years, meaning that any methane present must have been produced or released in the relatively recent past.

"Discovering an unforeseen CO_2 signature where we hunt for methane is significant," says Alexander Trokhimovskiy. "This signature could not be accounted for before, and may therefore have played a role in detections of small amounts of methane at Mars."

The observations analysed by Alexander, Kevin and colleagues were mostly performed at different times to those supporting detections of martian methane. Besides, the TGO data cannot account for large plumes of methane, only smaller amounts—and so, currently, there is no direct disagreement between missions.

"In fact, we're actively working on coordinating measurements with other missions," clarifies Kevin. "Rather than disputing any previous claims, this finding is a motivator for all teams to look closer—the more we know, the more deeply and accurately we can explore Mars' atmosphere."



This graph shows a new CO_2 spectral feature, never before observed in the laboratory, discovered in the martian atmosphere by the Atmospheric Chemistry Suite (ACS) MIR instrument on ESA's ExoMars Trace Gas Orbiter (TGO). The graph shows the full extent of the magnetic dipole absorption band of the $^{16}O^{12}C^{16}O$ molecule (one of the various 'isotopologues' of CO_2). The top panel shows the ACS MIR spectra (shown in black) along with the modelled contribution of CO_2 and H2O (shown in blue); the model is based on the HITRAN 2016 database. The bottom panel shows the difference between data and model, or residuals, revealing the structure of the absorption band in detail. The calculated positions of spectral lines are marked with arrows, in different colours corresponding to different 'branches' of the absorption band (red stands for the P-branch, green for the Q-branch and blue for the R-branch). Credit: A. Trokhimovskiy et al. (2020)

Realising the potential of ExoMars

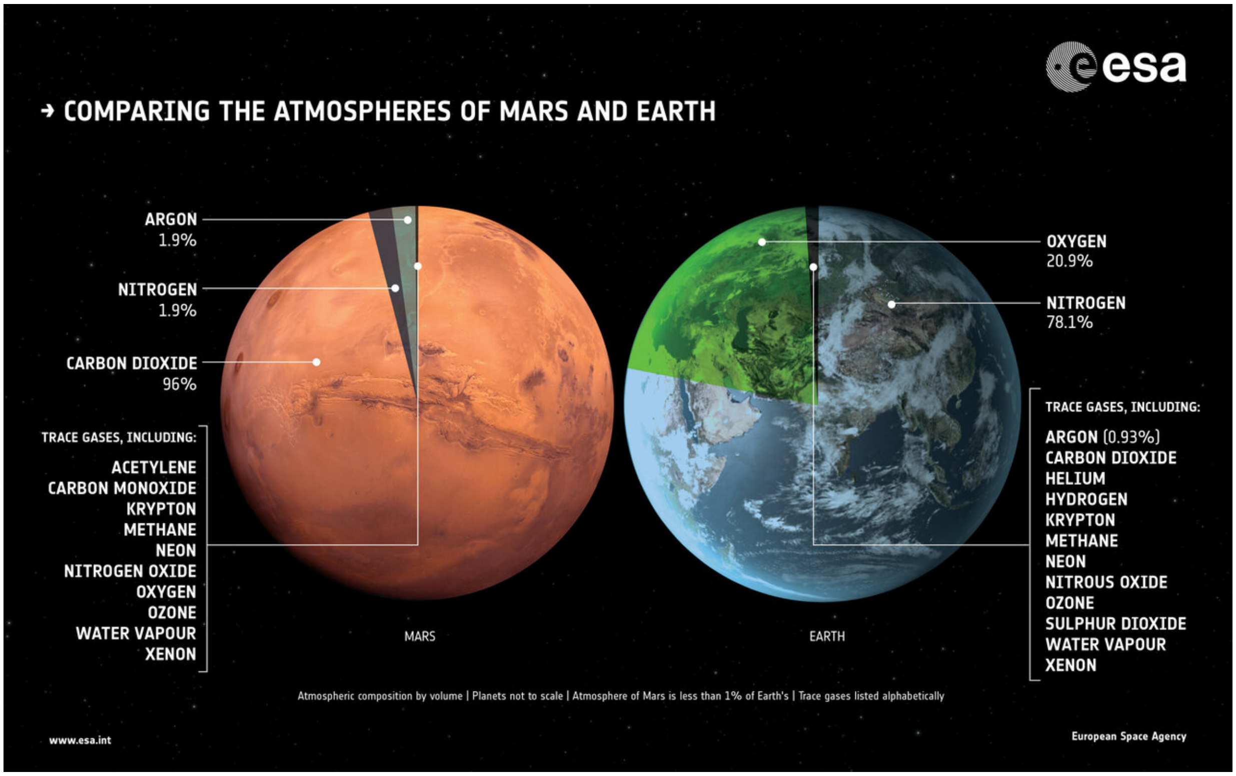
Methane aside, the findings highlight just how much we will learn about Mars as a result of the ExoMars programme.

"These findings enable us to build a fuller understanding of our planetary neighbour," adds Alexander.

"Ozone and CO_2 are important in Mars' atmosphere. By not accounting for these gases properly, we run the risk of mischaracterising the phenomena or properties we see."

Additionally, the surprising discovery of the new CO_2 band at Mars, never before observed in the laboratory, provides exciting insight for those studying how molecules interact both with one another and with light—and searching for the unique chemical fingerprints of these interactions in space.

"Together, these two studies take a significant step towards revealing the true characteristics of Mars: towards a new level of accuracy and understanding," says Alexander.



Comparing the atmospheres of Mars and Earth. Credit: European Space Agency

Successful collaboration in the hunt for life

As its name suggests, the TGO aims to characterise any trace gases in Mars' atmosphere that could arise from active geological or biological processes on the planet, and identify their origin.

The ExoMars programme consists of two missions: TGO, which was launched in 2016 and will be joined by the Rosalind Franklin rover and the Kazachok landing platform, due to lift off in 2022. These will take instruments complementary to ACS to the martian surface, examining the planet's atmosphere from a different perspective, and share the core objective of the ExoMars programme: to search for signs of past or present life on the Red Planet.

"These findings are the direct result of hugely successful and ongoing collaboration between European and Russian scientists as part of ExoMars," says ESA TGO Project Scientist Håkan Svedhem.

"They set new standards for future spectral observations, and will help us to paint a more complete picture of Mars' atmospheric properties—including where and when there may be methane to be found, which remains a key question in Mars exploration."

"Additionally, these findings will prompt a thorough analysis of all the relevant data we've collected to date—and the prospect of new discovery in this way is, as always, very exciting. Each piece of information revealed by the ExoMars Trace Gas Orbiter marks progress towards a more accurate understanding of Mars, and puts us one step closer to unravelling the planet's lingering mysteries."

More information: A. Trokhimovskiy et al. First observation of the magnetic dipole CO2 absorption band at 3.3 µm in the atmosphere of Mars by the ExoMars Trace Gas Orbiter ACS instrument, *Astronomy & Astrophysics* (2020). DOI: 10.1051/0004-6361/202038134

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