A PRO-AM COLLABORATION TO ALLOW NEW DISCOVERIES AT MARS

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Abstract. Several features have been either predicted or briefly observed in the night upper atmosphere of Mars, namely, blue, green and red aurorae on one side, and high altitude cloud systems on the other. These cannot always be observed by the current armada of spacecrafts but may be revealed through a tremendous observational effort from the Earth. This can only be achieved by a strong international collaboration of astrophotographers and professional astrophysicists. In this article, we show what should be expected from positive observations, why the space instruments are not equipped to do these observations and how to coordinate this effort through a large Pro-Am collaboration.

Keywords: Mars, ionosphere, thermosphere, aurorae, clouds

1 Introduction

The planet Mars has always fascinated mankind. A lot of efforts have been devoted by several space agencies to reveal all its mysteries. Yet, the current set of space instruments are missing some features. The largest ones may partly escape their fields of investigation, especially if they are faint and if they occur at night. This is the case for at least two of them: the visible aurorae and the upper atmospheric night clouds. The incredible task force of astrophotographers could largely compensate for these shortcomings with ground based observations. This is what will be explored in this paper.

2 Visible Mars aurorae: predicted but not yet observed

In 2005, Bertaux et al. (2005) measured an enhancement of UV emissions in the upper atmosphere of Mars with the SPICAM (Bertaux et al. 2000) instrument on board Mars Express (ESA). Using an electron transport code (Lilensten et al. 2015), it was shown that this emission was due to electron precipitation of solar origin, with energies of a few tens of eV (Leblanc et al. 2008). Using the ASPERA-37 instrument, the same authors showed that the crustal magnetic fields, when organised into cusp-like structures, can accelerate solar wind electrons and trigger the observed UV aurorae. It also creates long-lived and active magnetic flux tubes (Dubinin et al. 2009) (altitude of typically 130 km, width of 20 to 150 km) in which the electron energy flux is of the order of 10^4 $W.m^{-2}$. An intriguing feature is that the UV auroral activity was observed on several subsequent orbits during more than two weeks, implying a stable existence of aurorae. Lately, structures called "plumes" were observed in the visible range up to 1000 km height for about 10 days at the morning terminator (Sánchez-Lavega et al. 2015). The authors suggest that these structures are due to ice particles reflecting solar radiation, mentioning auroral emissions as an alternative possibility. The NASA spacecraft MAVEN confirmed the Mars UV aurorae (Schneider et al. 2015) and could even analyse their behaviour during a strong space weather event (Schneider et al. 2018) In 2015 it was predicted experimentally and theoretically that the mars aurorae should also emit in the visible range (Lilensten et al. 2015). Indeed, the UV aurorae on Mars have a counterpart in the visible spectral range, specifically at 412 nm and 434 nm, i.e. in the blue part of the visible spectrum.

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The Fox Duffendack Barker bands responsible for these emissions correspond to the $\tilde{A}^2\Pi_u - \tilde{X}^2\Pi_g$ transition of CO_2^+ and its blue part represents about 7% of the total production. Moreover, the presence of atomic oxygen should trigger red (630 nm) and green (557.7 nm) aurorae, similarly to the Earth ones. These emissions were predicted to happen mainly in the southern hemisphere above the magnetic anomalies (Acuña et al. 2001). Under the assumption of vertical magnetic field lines, the altitude of the maximum emission was predicted to occur around 140 km (blue and green) and 160 km (red) and higher in case the field lines are inclined. The first red line thermospheric Martian observation occurred on the dayside (Gérard et al. 2020) originating from solar radiation excitation.
One of the most exciting features in the blue, red and green aurorae prediction is that they should be visible with the naked eye. On the Earth, the definition of aurorae is quite fuzzy. In the absence of a given official intensity threshold to determine whether an emission is an aurora, one can simply state that a visible aurora occurs when it is visible to the naked eye. The thermospheric and ionospheric emissions at Mars should be visible with the naked eye, and therefore be quoted as visible aurorae.

3 Cloud system in the upper Martian atmosphere : Observed while not predicted.

The Red Planet is not the subject of continuous monitoring programs by professional ground-based astronomers. Only amateur astronomers carry out this work around periods of opposition. They contribute to several participatory science databases, such as ALPO Japan `https://alpo-j.sakura.ne.jp/indexE.htm` and PVOL `http://pvol2.ehu.eus/pvol2/`. Driven by the above predictions of visible aurorae in the upper atmosphere of Mars, one of the co-authors of this work (JLD) gathered a group of 10 astrophotographers amateurs spread across all continents in 2018. They were connected to a group of astrophysicists in order to constitute a solid team. The idea is that when the Earth and Mars are in opposition, it should be possible to picture the Mars aurorae from the Earth at the beginning or at the end of the night. A good opposition occurs about every second year.
On November 17, 2020, 2 of the 10 observers were able to photograph Mars: Frenchmen Christophe Pellier and Emmanuel Beaudoin. Their data, acquired under excellent conditions, made it possible to follow a huge cloud structure located at the terminator for 3 hours in a row through different filters. The images show the formation emerging from the night, clearly separated from the terminator. Its evolution was followed until the sun rose beneath the cloud. The cloud dissipates shortly afterwards. What was observed here is atypical in two respects: not only is the cloud complex gigantic in relation to the planet, it is also located at an altitude of 92 km. This altitude is comparable to that of noctilucent clouds regularly observed on Earth at high latitudes around the summer solstices (Lilensten et al. 2022).
Detailed analysis of the photometric data showed that the cloud scatters light at all visible wavelengths, with a maximum in the red. This suggests that the light is scattered by dust, water ice or CO_2 particles. The dust hypothesis has been ruled out as incompatible with observations, but water and CO_2 are good candidates. Water ice clouds, for example, have already been observed at this altitude and in this season (Clancy et al. 2019; Stcherbinine et al. 2020). However, water is rare on Mars, and spectroscopic detections to date show that water ice crystals are usually very small at this altitude, with a typical size of around 0.1 to 0.5 μm. However, the photometric data obtained on November 17, 2020 suggest that they are rather larger particles of 1 to 2 μm, which would make this cloud atypical, beyond its unusual dimensions (Clancy et al. 2007; Montmessin et al. 2007; Vincendon et al. 2011; Määttänen et al. 2010; Clancy et al. 2019). CO_2, on the other hand, is abundant, and is the main component of the Martian atmosphere. Previously observed CO_2 clouds at these altitudes may be composed of ice crystals of this size. However, the observation was obtained outside the typical season for CO_2 clouds, and these are usually a few hundred km or even 1000 km across, but never 3000 km, which would also make this cloud an atypical event.
Such structures could originate in the cosmic rays through the nucleation of ice crystals at this altitude, especially as the structures observed are on the edge of a magnetic zone. However, it is rather hazardous to draw conclusions from a single set of observations.

4 Why are these features not observed from space?

Exploration of Mars by spacecraft constitute most of today's discoveries since the first successful flyby of Mars on 14 - 15 July 1965, by NASA's Mariner 4 (Branigan 1965).Today, three operational rovers operate on the surface of Mars, the NASA's Curiosity (Kerr 2012), and Perseverance (Stack et al. 2020) rovers, and the CNSA

Zhurong rover. Eight orbiters are currently operational: Mars Odyssey (Saunders et al. 2004), Mars Express (Schmidt 2003), Mars Reconnaissance Orbiter (Zurek & Smrekar 2007), Mars Orbiter Mission (Srivastava et al. (2015) and references herein), MAVEN (Leblanc et al. (2018) and references herein), the Trace Gas Orbiter (Metcalfe et al. 2018), the Tianwen-1 orbiter (Liu et al. 2020), and the Hope Mars Mission. The harvest of results from this fleet may lead to underestimation of the possibilities offered by observations from the surface of the Earth, but such observations have already revealed their potential for cloud characterisation (Parker et al. 1999; Erard 2000; Bell et al. 2001; Sánchez-Lavega et al. 2015).
Despite this series of efforts, neither the expected visible counterpart of aurorae nor a large upper atmospheric cloud system similar to that discussed in section 3 have been observed with these spacecrafts. The reasons could be:

- Both features are difficult to observe at a global scale from Mars orbit due to the limited field of view of these observations whose primary objective is high spatial sampling. Some spacecraft instruments are dedicated to the monitoring of Mars at global scale and low resolution (e.g., VMC onboard Mars Express, see Hernandez-Bernal et al. (2021)). However, it is difficult to follow the dynamics of a given cloud or an aurora using such dataset obtained from a spacecraft moving along its orbit.
- In order to make these observations, one needs cameras with high sensitivities working in the visible range at night. When these spacecrafts were conceived, the visible aurorae were known, and therefore no-one imagined to propose such an expensive camera in the payload. This is a well identified problem in scientific research: Why should one spend a lot of money if there is no chance to make an observation?
- The phenomena discussed here look rare. In the field of surveillance, amateur observations from Earth can really make a difference.

5 Why are these features not observed by professional ground based telescope?

The only reason is that in order to get observation time on these large telescopes, one needs to answer to proposals ways in advance. The selected proposals receive dedicated times of observation. There is no guaranty that the allowed slots can fulfill the positive observation conditions dooming these proposal to failure. There is of course an alert mode, but even on alert, there is no guaranty of success. Only a long continuous observation of Mars can lead to achieve this challenge.

6 The solution ahead: Earth-based observations by astrophotographers

Amateur observations from Earth can make a contribution in several areas, namely (1) the large field of view (large-scale phenomena) and (2) the possibility of making many and continuous observations, seeing temporal evolution and identifying rare events. This is the case for the two features above. On 17 November 2020, Mars and Earth were close to each other with a relative distance of 0.55 AU. Mars solar longitude was 316°. This allowed observing the upper atmosphere of Mars from the Earth at a global scale over the course of several hours. This clearly demonstrates that observing Mars from Earth allows following cloud formation and dissipation over several hours with a broad field of view. The same argument applies to auroras. However, such an effort needs good conditions to be successful, namely:

- The two planets should be close to opposition. This condition is mandatory in order to see part of the Mars nightside from the Earth. The next opposition will occur in December, 2024.
- The number of observers should dramatically expand to reach a hundred scattered over all the continents. This permits to observe Mars 24 hours a day and to insure that there are permanently observers free of cloud cover.
- The observers should be equipped with several color filters. For the current 2020 observations, we used white, red, green blue and UV filters. These allowed to perform a spectrum analysis and to compare with radiative transfer calculations.
- As for the aurorae, the solar activity should be high in order maximize the chances. The solar wind usually screens the cosmic rays, but this effect is not sufficient to fully stop them and prevent the observation of upper atmospheric clouds. In December 2024, the solar activity will be close to its peak, providing perfect conditions.

7 Conclusions

The authors of this contribution are willing to coordinate such a large scale campaign: observing Mars from allover the Earth in order to make the first observation of the Mars visible aurorae, and / or to confirm the discovery of the upper atmospheric clouds and to help characterizing and understanding them. Should you be interested, please contact either Jean Lilensten (`jean.lilensten@univ-grenoble-alpes.fr`) or Jean-Luc Dauvergne `jl.dauvergne@cieletespace.fr`. As for the 2022 paper, all the contributors will co-sign the resulting publication in case of positive detection.

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