SINUOUS AURORA ON MARS: EXPLORING A NEW PHENOMENON WITH DATA AND MODELS

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A new perspective on the Martian atmosphere
The Emirates Mars Mission (EMM) is focused on understanding matter/energy transport and the connections within and between the Martian lower and upper atmospheres, with remote-sensing investigations in the infrared, visible, and ultraviolet. Its large orbit facilitates the first systematic synoptic imaging of the atmosphere, allowing near-complete geographic and diurnal coverage approximately every 10 days over a full Martian year [1].

Martian Aurora. The Mars thermosphere (~100-200 km altitude) is influenced both from below by conditions (temperatures, dust, clouds etc.) in the lower atmosphere and from above by conditions in the near-space environment. On the nightside, the primary influence from above is the precipitation of electrons colliding with, and exciting, atoms and molecules. When sufficiently energetic and abundant, these electrons cause atmospheric airglow known as discrete or diffuse aurora. The former is caused by broad energetic charged particle precipitation across the whole nightside during extreme solar wind disturbances [2], while the latter is typified by discrete regions of electron precipitation and hence ultraviolet emission [3], and is the focus of this work.

EMUS Observations of Discrete Aurora. The Emirates Mars Ultraviolet Spectrograph (EMUS) on board EMM measures in the extreme and far ultraviolet (85-190 nm) and is well-suited to studying aurora due to a) EMM's high altitude vantage point and regular observation cadence and b) its high sensitivity. The specific auroral observations are from the U-OS2 observation mode designed to study Mars' inner corona and includes significant coverage of the night side [4], as shown in figure 1.

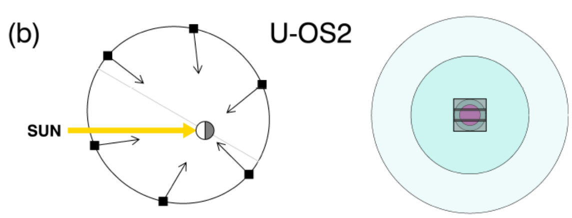

Figure 1: (left) EMM orbit and typical observation set for U-OS2. Right: box comprised of observation swaths across Mars' inner corona (<1.6 Mars radii).

Spectrum: Emission is strongest at the 130.4 nm oxygen line (^{3}S decay to ground state ^{3}P), though it is also observed in oxygen features at 98.9 nm, 102.7 nm, and 135.6 nm and a number of CO, C, and Ar emissions. EMUS has collected nearly 1000 synoptic observations of the Mars nightside have revealed at least three distinct types of discrete Aurora: 1) crustal field aurora, appearing in regions of mostly radial crustal magnetic fields, 2) patchy discrete aurora, observed away from strong crustal fields, and 3) sinuous discrete aurora, extending from the Terminator typically thousands of kilometers onto the nightside, away from crustal fields.

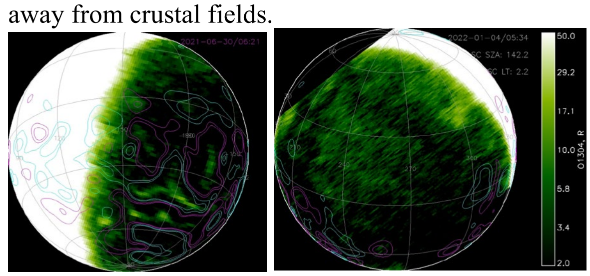

Figure 2: examples of (a) crustal field aurora and (b) patchy discrete aurora. 10, 20 nT contours of radial magnetic field strength of 400 km altitude overplotted.

Sinuous Discrete Aurora (SDA). This phenomenon is observed in approximately 5% of observations and is characterized by 2 primary attributes: morphology and the local time of its intersection with the terminator. Various morphologies are shown in figure 3. Dusk SDA does not occur preferentially for any particular interplanetary magnetic field (IMF) orientation, while Dawn and Midnight SDA appear to show a preference for northeastward IMF directions. Dusk SDA observed about twice as often as Dawn or Midnight SDA.

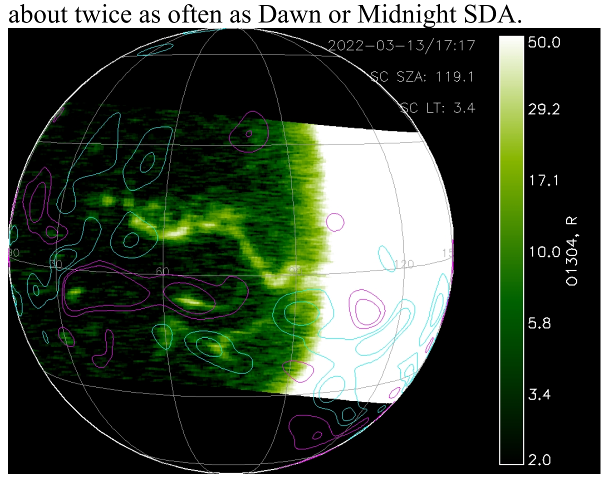

Figure 3a: Serpentine discrete aurora morphology observed near the dawn Terminator

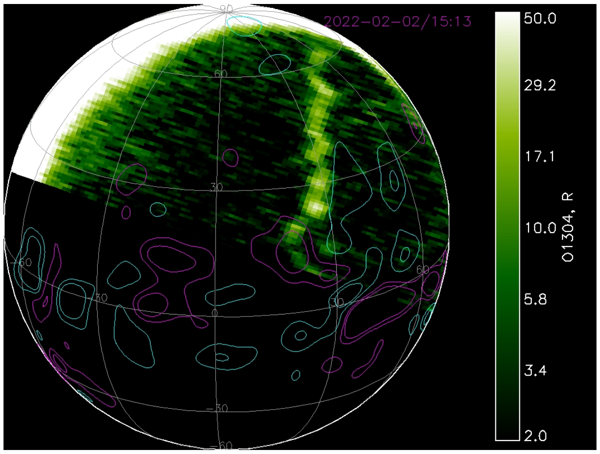

Figure 3b: Linear discrete aurora morphology observed originating near local midnight.

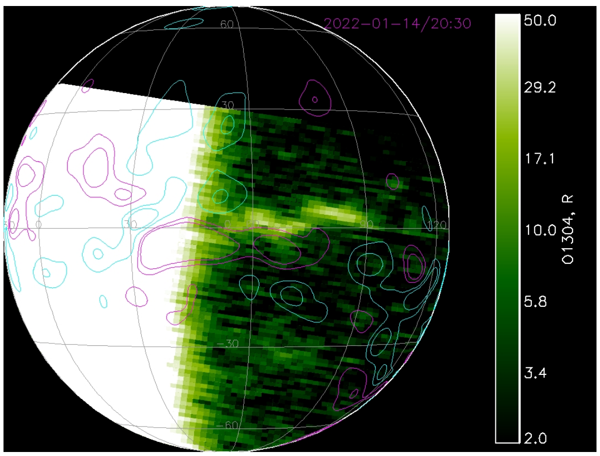

Figure 3c: Short/'lumpy' discrete aurora morphology observed originating near local dusk.

Sinuous Aurora Type:	**Midnight**	**Dawn**	**Dusk**
Morphologie(s):	Linear	Various	Various
Occurrences:	16	12	22
Faint (<15 R)	6	8	6
Medium (15-30 R)	4	3	8
Bright (>30)	6	1	8
Interplanetary Magnetic Field Preference	Northeast	Northeast	None

Interpretation: Sinuous Discrete Aurora reflect conditions whereby particular magnetic topologies connect the nightside atmosphere to a source of abundant electrons, whether dayside photoelectrons or sufficiently energetic magnetotail/sheath electrons. In particular, midnight sinuous discrete aurora appear to be a projection of the tail current sheet, a persistent but highly variable feature of Mars' double-lobed magnetotail resulting from the draping of the IMF around the conducting obstacle of Mars' dayside ionosphere. This interpretation is supported by magnetohydrodynamic (MHD) simulations, showing that the orientation of the tail current sheet approximately matches the orientation of the midnight aurora shown in Figure 3b.

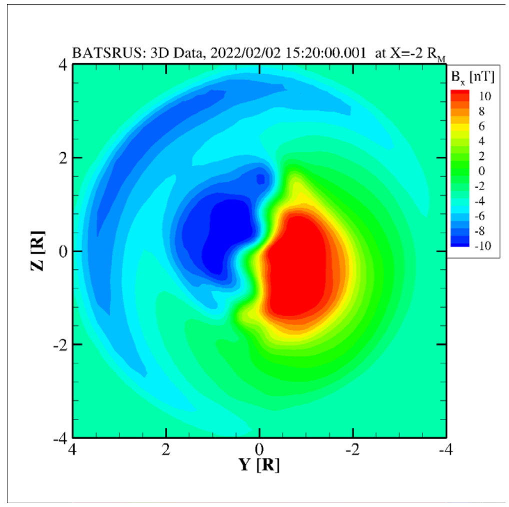

Figure 4: x-component of magnetic field in Mars' magnetotail from MHD simulation using the same conditions as those present for the observation in figure 3b.

Looking forward: Simultaneous observations of electron precipitation from the MAVEN and Mars Express spacecraft during times of detected aurora will continue to shed light on this enigmatic and highly dynamic phenomenon.

References: [1] Amiri S. et al., 2021, Space Science Reviews, 218, 4 [2] Schneider, N. M., et al. 2015, Science, 350, [3] Bertaux, J. L., et al. 2005, Nature, 435, 790, [4] Holsclaw, G. et al. 2021, Space Science Reviews, 217, 79. [5] Lillis et al., 2022, GRL, 49.