IMPACT RATE ON MARS IMPLIED BY SEISMIC OBSERVATIONS. N. Wójcicka[1], G. Zenhäusern[2], G. S. Collins[1], S. C. Stähler[2], I. J. Daubar[3], M. Knapmeyer[4], J. F. Clinton[5], D. Giardini[2], S. Ceylan[2]. [1]Department of Earth Science and Engineering, Imperial College London, United Kingdom; [2]Institute of Geophysics, ETH Zurich, Zurich, Switzerland; [3]Earth, Environmental, and Planetary Sciences, Brown University, RI, USA; [4]DLR Institute of Planetary Research, Berlin, Germany; [5]Swiss Seismological Service, ETH Zurich, Zurich, Switzerland; (E-mail: n.wojcicka18@imperial.ac.uk).

Introduction: The current impact rate on Mars is uncertain and has been previously estimated using orbital imagery of the surface [1] as well as by extrapolating large crater counts over geologic timescales [2]. Seismology provides an alternative means of measuring the current impact rate on Mars.

Thus far, six nearby seismic events recorded by InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport [3]) on Mars, classified as Very High Frequency (VF) events [4], were confirmed to be impact-related, thanks to the prominent 'chirp' signal attributed to the atmospheric disturbance during impact [5, 6]. Whilst the 'chirp' part of the signal is only detectable at short distances, the similarities between confirmed impact-generated signals and other VF events suggest that other impact-related signals may have also been recorded, but have not yet been identified in the data. Furthermore, the unique characteristics of VF events make them compatible with an impact source. The spatial distribution of VF events is compatible with a uniform distribution of impacts across the martian surface, and a distance dependent detection threshold. The magnitude-frequency distribution of VF events follows a power law whose slope, when converted to a crater size-frequency distribution, is broadly consistent with previous estimates of cratering rate on Mars. The long coda in the seismic signal has been interpreted as a result of a shallow source [7], such as an impact.

In this work, we tentatively attribute an impact source to the VF events and analyse the novel constraints this places on the current impact rate on Mars.

Methods: In order to estimate the cratering rate from a set of impact-generated seismic events, two key elements are required: (a) a workflow for converting the seismic signal properties to crater diameter, and (b) an impact detectability (minimum detectable crater size as a function of distance) estimate that provides a measure of the Area Time Factor (ATF).

Seismic moment vs crater diameter One of the key parameters used to characterise seismic events is seismic moment (M_0), linked to seismic moment magnitude (M_W) via:

$$M_W = \frac{2}{3}(\log_{10} M_0 - 9.1). \quad (1)$$

Insights from numerical modelling [8, 9] show that the value of seismic moment is proportional to impact momentum (p), which scales as a power law with crater diameter (D):

$$M_0 = cD^n, \quad (2)$$

where n can range between 3–3.6 depending on what target material parameters are assumed. Here, we use the six confirmed impacts detected by InSight [5] to constrain the constant c in equation (2). Fig. 1 shows the seismic moment computed for the four impact events as a function of their observed crater diameters (effective diameter is used for crater clusters). The least-squares relationship through the data is given by:

$$M_0 = (8.8 \pm 2.5) \times 10^8 D^{3.3}. \quad (3)$$

As more impacts are discovered and associated with a seismic event, this relationship will be further refined.

Detectability of impacts on Mars A set of recorded seismic signals generated by impacts on the Moon [10], Earth [11, 12] and Mars [5] show that seismic amplitude (peak P-wave amplitude) v, when scaled by impact momentum p, decreases with distance as $x^{-1.56}$ ($v \propto px^{-1.56}$). As $M_0 \propto D^n$ (equation (2)), it follows that $v \propto D^n x^{-1.56}$. The impact detectability curve can hence be defined as the maximum distance (x_{max}) at which a crater of diameter D would be detectable by InSight:

$$x_{max} = aD^{n/1.56}, \quad (4)$$

where a is a proportionality constant. Here we determine the value of a based on the distribution of VF events as shown in Fig. 2. x_{max} in equation (4) defines a spherical segment around the receiver. The area of this segment is used a the Area component of the Area Time Factor (ATF). The time component is computed as the total low noise recording time of the seismometer in Earth years. This results in a cratering rate in km^{-2}yr^{-1}.

Results: Preliminary results show that if the VF events are all impact-related they correspond to crater sizes 3–30 m in diameter (diamonds in Fig. 2). For the confirmed

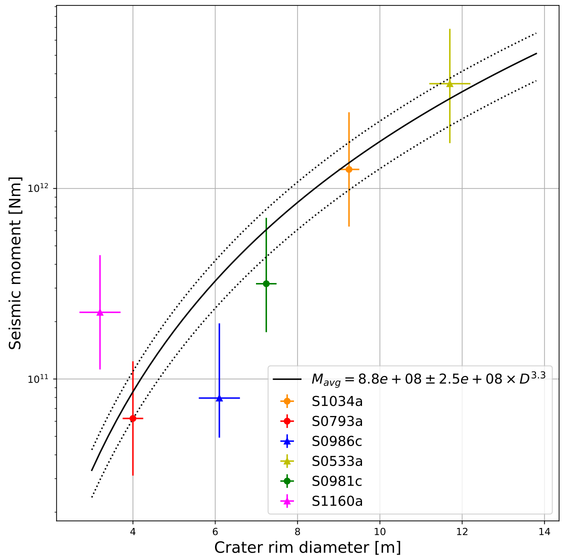

Figure 1: The seismic moment as a function of observed crater size (circle indicates a single crater and triangle a crater cluster's effective diameter) for the six seismically detected nearby impacts (see [5] and [6], this meeting). The solid and dotted lines indicate the least-squares fit to the data and its uncertainty.

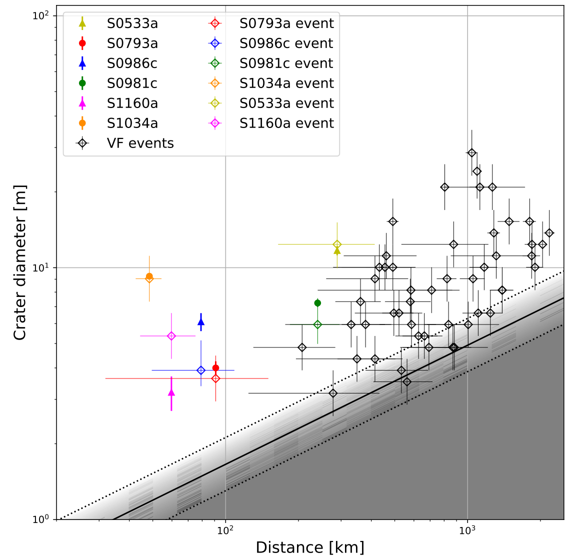

Figure 2: Impact detectability with distance as a function of crater size. The hollow diamonds show predicted crater diameters for all VF events using equation 2. Colour-coded markers represent the VF events attributed to observed craters (filled circled) or crater clusters (filled triangles). The black line marks the detectability limit defined by equation 4. No VF events are detectable inside the dark grey region or beyond 37°.

impacts, the seismic magnitudes were recomputed based on the distance from the receiver at which the crater was observed. The distribution of estimated crater diameters implies a cumulative rate $N(\geq 8\text{m}) = 1 - 4 \times 10^{-6}$ $\text{km}^{-2}\text{yr}^{-1}$. This cratering rate is ∼3–5 times higher than estimates derived from orbital imaging [1], but is consistent with widely used crater isochron models [2]. The rates derived from orbital imaging could represent an underestimate, due the difficulty in detecting small craters and being restricted to dusty areas. Our results show that seismology is an efficient tool for determining impact rates. Furthermore, the higher rate predicted here could suggest a recent increase in impact rate, for example due to an asteroid breakup.

Conclusions: We present a method for determining the corresponding crater size based on seismic magnitude of marsquakes of suspected impact origin recorded by InSight. We also update the seismic detectability curve for impacts as a function of crater size and distance, which is necessary for deriving a cratering rate from crater counts. We use this method to derive a new estimate of the present rate of small crater production on Mars. Our workflow will be further revised as more impact-generated seismic events are confirmed.

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References: [1] Daubar, I. J. et al. (2013) *Icarus*, 225:506–516. [2] Hartmann, W. K. (2005) *Icarus*, 174:294–320. [3] Banerdt, W. B. & Russell, C. T. (2017) *Space Science Reviews*, 211:1–3. [4] Böse, M. et al. (2021) *Bulletin of the Seismological Society of America*, [5] Garcia, R. F. et al. (2022) *Nature Geoscience 2022*, 10:1–7. [6] Daubar, I. J. et al. (2023) *Lunar and Planetary Science Conference*. [7] Driel, M. van et al. (2021) *Journal of Geophysical Research: Planets*, 126:e2020JE006670. [8] Wójcicka, N. et al. (2020) *Journal of Geophysical Research: Planets*, 125. [9] Rajšić, A. et al. (2021) *Journal of Geophysical Research: Planets*, 126:e2020JE006662. [10] Latham, G. et al. (1970) *Science*, 170:620–626. [11] Brown, P. et al. (2008) *Journal of Geophysical Research*, 113:E09007. [12] Kenkmann, T. et al. (2009) *Meteoritics & Planetary Science*, 44:985–1000.