LARGE RIPPLES IN GALE CRATER (MARS): MORPHOLOGY AND DYNAMIC. S. Silvestro[1,2], D.A. Vaz[3,4], H. Yizhaq[5], C. Popa[1], N. Deniskina[1], F. Esposito[1], [1]INAF Osservatorio Astronomico di Capodimonte, Napoli, Italy (silvestro@na.astro.it), [2]SETI Institute, Carl Sagan Center, 189 North Bernardo Avenue, Mountain View, California 94043, USA, [3]CITEUC - Centre for Earth and Space Research of the University of Coimbra, Portugal, [4]CERENA, Lisboa, Portugal, [5]Department of Solar Energy and Environmental Physics, Ben-Gurion University of the Negev, Israel

Introduction: Martian large ripples (LRs) sculpt the slope of the dark dunes recently visited by the NASA MSL Curiosity rover [1-3]. Like impact ripples on Earth, LRs on Mars have been initially considered transverse to the wind and they have been widely used to derive wind conditions on the martian surface and to back-model winds over the dunes [4-6]. However, recent studies have demonstrated that LRs are dynamically different from terrestrial impact ripples [3,7]. In addition, like current ripples on Earth, LRs in Gale crater show sinuous crestlines and slip faces [2]. In this report, we show that LRs in Gale Crater have a wide morphological variability, they present both sinuous and straight crestlines and they locally arrange in a complex square-pattern. We also show that the sinuous/straight ripple classes have an oblique/longitudinal dynamic and that they are probably shaped by a bi-directional wind regime

Methods: We performed this analysis by using HiRISE images covering the dark dunes in Gale crater. Images are orthorectified and coregistered in socet-set/COSI-Corr [3,8]. In addition, we use Curiosity's camera images to give an in-situ perspective of the LRs.

LRs Morphology: We identified three main ripple's categories. *Sinuous ripple pattern:* mainly found on the dune flanks or in between dunes (Fig. 1a), these ripples appear sinuous on HiRISE images and lack Y junctions (Fig. 1b). Unlike current ripples that migrate transversely to the flow, multi-temporal analysis of HiRISE data indicates that the sinuous LRs evolve obliquely, with the whole pattern translating to the south (Fig. 1b). MSL images show that they have sharp crests and secondary arms or spurs (Fig. 1c). Ripples showing a similar morphology and dynamic have been also detected in Herschel crater where they cover about 97 % of the rippled area [7,8]. *Straight ripple pattern:* ripples that appear straight on HiRISE images (Fig. 2) are mainly located behind topographic highs, on longitudinal dune elements and on gently sloping surfaces (see Figs. S4 and S5 in [3]). Straight ripples trend at 41° and show clearly recognizable Y junctions that migrate along the ripple crestlines. The longitudinal Y junction migration clearly indicates the longitudinal dynamic of these bed forms, which behave like longitudinal subaqueous dunes in water tank experiments [10]. Further evidence for the longitudinal dynamic of the straight LRs come from the COSI-Corr displacement map, which show displacement vectors aligned parallel to the ripple crests. We propose that a bi-directional flow regime with divergence angle between 90 to 180 degrees [11] could be responsible for the formation of the straight ripple pattern. MSL Curiosity has recently visited straight LRs on sol 1601 (Fig. 2b). Unlike the sinuous ripples imaged at the Namib Dune site, straight LRs show a more symmetrical crest, do not display signs of grainfall/grainflow structures and are sculpted by secondary impact ripples indicating along-crest sand transport direction (Fig. 2b). *Square ripple pattern.* This ripple arrangement is the most pervasive in the study area [3] and seems to be common in other areas on Mars (see the Arabia and Meridiani examples described in [4]). Locally, we can see a transition between the straight and the square ripple pattern, especially behind topographic obstacles (Fig. 2). The square pattern consists of two sets of crestlines that intersect at right angle (41° and 322° to the North) (Fig. 2c). We propose two potential flow configurations to explain the contemporaneous presence of two crests: 1) a reworking scenario where each crestline react to a different wind and 2) a bi-directional flow configuration in which the two crestlines sets co-evolve under the influence of two winds transporting approximatively the same amount of sediment [10,11]. In this latter scenario, both crests are oblique to the formative wind (see Fig. 3 in [3]). Images acquired by MSL Curiosity show that the square pattern is 3-dimensional confirming previous analysis performed with HiRISE by using the modified H-index [3,7]. The 41° ripple crests meander in correspondence of the 322° crests, a characteristic that is also observed in complex dune pattern [12].

Discussion: Our analysis show that the morphology and dynamic of Martian LRs is different from terrestrial impact ripples. All the ripple classes described in this report seem to be influenced by two different winds, which blew in the time span covered by the overlapping HiRISE images. A bidirectional wind regime with two main flows blowing off the crater/Aeolis mons slopes and converging over the dune field can probably explain the observed dune/ripple configuration and the SW oriented sand flux direction [1]. Further monitoring by

MSL Curiosity will shed light on the dynamic of the LRs described in this report.

References: [1] Silvestro S. et al. (2013) *Gelogy 41* (4), 483–486 [2] Lapotre et al., (2016) *Science 353*, 55-58 [3] Silvestro S. et al., (2016) *GRL 43* (16), 8384-8389 [4] Silvestro S. et al., (2011) *GRL 38* (20), 8384-8389 [5] Liu & Zimbelmann (2015) *Icarus 261*, 169-181 [6] Jackson et al., (2015) *Nat. Commun. 6*, 8796 [7] Vaz D. et al., (2017) *Aeol. Res. In press* [8] Bridges et al., (2012) *Nature 485*, 339-342 [9] Cardinale et al., Icarus 265, 139-148 [10] Reffet et al., (2010) *Geology 38* (6), 491-494 [11] Rubin (2012) *Earth Sci. Rev. 113*(3-4), 176-185 [12] Ewing et al. (2010) *JGR 115*, E08005.

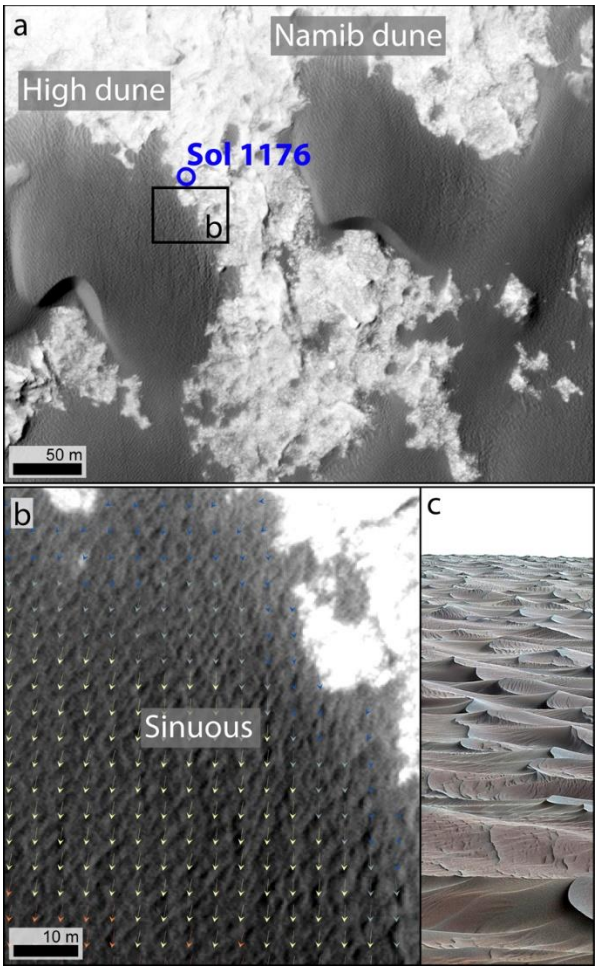

Fig. 1: a) Dunes visited by MSL Curiosity b) Sinuous large ripples overlaid by the COSI-Corr displacement vectorial field color-coded by magnitude c) Curiosity view of the sinuous LRs on sol 1176.

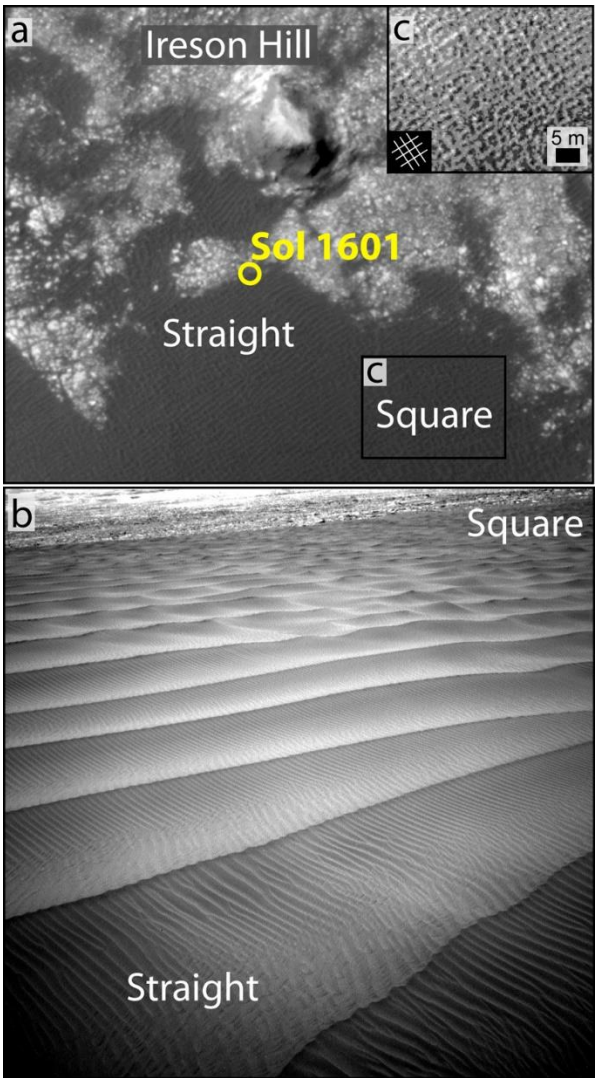

Fig. 2: a) Straight and square large ripple patterns as seen by the HiRISE camera b) Curiosity image acquired on sol 1601 showing the transition between square and straight LRs c) Detail of the square large ripple pattern.