MARS ORBITERS FOR SURFACE, ATMOSPHERE AND IONOSPHERE CONNECTIONS (MOSAIC).

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Science Background: Asymmetric seasonal insulation, aridity, and the radiative importance of dust primarily distinguish atmospheric structure and dynamics on Mars compared with Earth [e.g. 1]. The last two decades have seen a significant increase in the amount and variety of observations characterizing the thermal structure and basic composition of the Mars atmosphere, from the surface to the exosphere. The picture that has emerged so far forms the basis for understanding the physical processes that control the current Martian climate, from the general circulation [2, 3], to the role of clouds [4] and photochemistry [5], the development of dust storms (both local [6, 7] and global [8, 9]), and channels and rates of atmospheric escape [10-13].

However, despite this progress, we are still largely ignorant of many of the physical processes that drive matter and energy flow between and within the various atmospheric reservoirs (fig. 1). Unraveling Mars' present-day climate processes and their inter-connections leads us to three questions:

1. How do volatiles (e.g. H_2O and CO_2) move between the subsurface, surface, and atmosphere?
2. How does the Martian lower-middle atmosphere respond on regional and global scales, to the diurnal and seasonal cycles of insolation?
3. How does coupling with the lower atmosphere combine with the influence of space weather (solar wind, energetic particles and EUV) to control the upper atmospheric system (thermo-sphere, ionosphere, exosphere, magnetosphere) and drive atmospheric escape?

The Mars Orbiters for Surface, Atmosphere, Ionosphere Connections (**MOSAIC**) is a mission concept to address these questions through eight science investigations (table to the right).

Needed measurements. Understanding the physical processes governing and linking the dynamic reservoirs of Mars' climate system requires coordinated simultaneous measurements of these reservoirs under a representative range of driving conditions, both internal (seasons, dust) and external (solar wind, solar EUV, energetic particle storms).

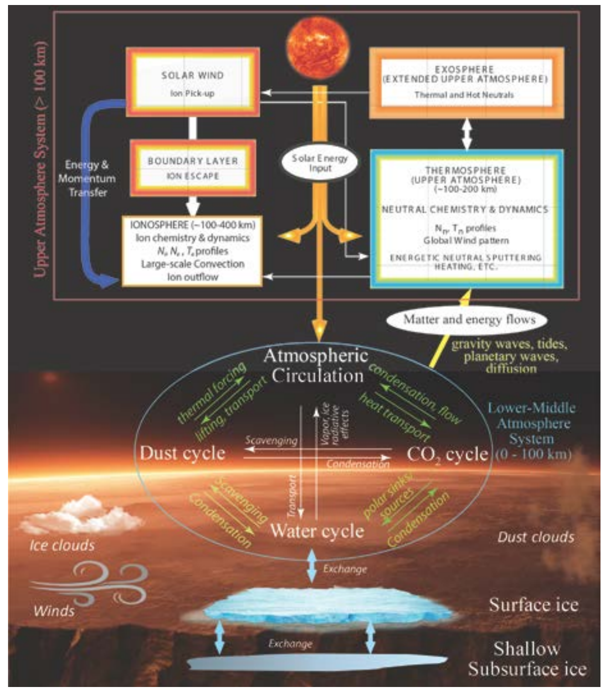

Figure 1: Expected connections between Martian climate domains that MOSAIC will systematically explore.

MOSAIC Investigations
1. Measure the three-dimensional distribution of ice from the surface to 10 m below.
2. Measure the geographic and altitude distribution of pressure, winds, aerosol concentrations, water vapor, ozone, and temperatures in the Mars lower and middle atmosphere.
3. Measure the complete diurnal and geographic behavior of the atmosphere and evolution of Martian dust and ice clouds.
4. Measure the global 3-D composition, structure, and winds in Mars's thermosphere.
5. Measure the global 3-D structure of Mars ionosphere.
6. Measure the 3-D density and temperature structure of Mars's hydrogen and oxygen exospheres.
7. Measure (from multiple viewpoints) magnetic field and topology and fluxes of light and heavy ions across Mars's bow shock, through magnetosheath, down magnetotail, and into and out of the Martian upper atmosphere and ionosphere.
8. Measure magnetic field and plasma conditions in the upstream solar wind, and solar extreme ultraviolet irradiance.

Scientific platforms. These investigations require simultaneous measurements, both in-situ and remotely-sensed, by a range of scientific instruments mounted on diverse orbital platforms, as shown below in fig. 2.

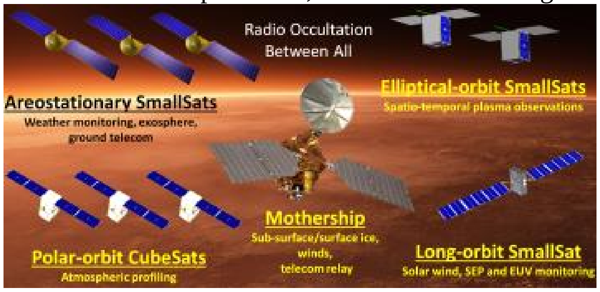

Figure 2: MOSAIC multi-platform measurement concept

The mothership and polar smallsats have low-altitude, high inclination circular orbits, accommodating nadir views of the surface and lower atmosphere, as well as limb views of the lower and upper atmosphere (Investigations 1, 2, 3, 4, 5). The large mass of some of the instruments (e.g. shallow radar, LIDAR, wind interferometer) necessitate at least one of these platforms being a traditional large (> 1000 kg) spacecraft, capable of measuring many upper and lower atmospheric variables (e.g. winds, pressure, temperature, aerosols, H_2O etc.). The smallsats are spaced in local time and monitoring a subset of lower atmosphere variables (e.g. temperature, aerosols), some at lower fidelity (e.g. H_2O). Three to four smallsat areostationary platforms (~17,000 km altitude), spaced equally in longitude, provide complete diurnal and geographical coverage of the atmosphere up to ~70° north and south latitude (Investigations 2 and 3) and views of the H & O exospheres (Inv. 6). Next, two to three smallsats in MAVEN-type elliptical orbits with periapses of ~150 km and apoapses of 5000 – 7000 km provide multi-point plasma measurements (Investigations 5, 7). Last is a sun-pointed solar wind monitoring platform, which needs to be far from the Mars-solar wind interaction, in a large circular orbit (> 10,000 km or areostationary, e.g. could share with "A"). All except the mothership will be small (< 100 kg) satellites, primarily using the mothership to relay their data back to Earth.

Precise Doppler tracking between each pair of orbiters will enable vertical profiling of the ionosphere and the neutral atmosphere with dense spatial and temporal coverage not possible through traditional spacecraft-to-Earth occultations.

Relevance to human exploration. The MOSAIC concept would also 1) globally characterize shallow water ice for resource exploitation (i.e. water, air, fuel), 2) provide the atmospheric measurements needed to enable accurate hazard forecasting in terms of pressure, wind and dust and 3) demonstrate essential elements of a robust telecommunication network such as deep space optical communication and delay-tolerant networking.

Decadal Survey Concept Study: We are currently undertaking a detailed study of the MOSAIC concept under NASA's Planetary Mission Concept Study (PMCS) program. The science team is broken up by topic into 7 subgroups to identify measurement requirements and instrument resources and technical readiness. Figure 3 shows the concept study science team divided into these groups.

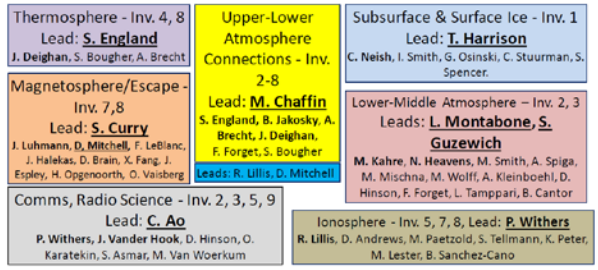

Figure 3: MOSAIC team structure, groups and associated investigations. Bolded: Co-Is. Non-bolded: collaborators.

The leads of each subgroup are working with the overall science leads and mission design teams (A-Team and Team-X) at JPL, to conduct technical and scientific trades and establish workable mission point designs, evaluate likely modular costs for the orbiter constellation and produce a detailed report for the Decadal Survey by June 2020. The planned concept study schedule is shown in figure 4.

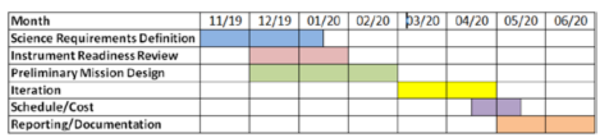

Figure 4: MOSAIC Concept Study schedule. Colors do not correspond to any other figure or table.

References:

[1] Wolff, M. J. et al., *book chap*., (2017), [2] Forget et al. (1999), *JGR*, 104, 24155-24175, [3] Bougher et al. (2015), *JGR*, 120, 311-342, [4] Clancy R. T., book *chap*. (2017) [5] Chaffin M. S. et al. (2017), *Nat. Geosci*., 10, 174-182, [6] Rafkin, S. C. et al. (2009), *JGR*, 114, [7] Heavens, N. G. et al. (2017), *J. Atmo. Sci*., 74, 1011-1037, [8] Heavens, N. G. (2019) *J. Atmo. Sci*., 76, 3299-3326, [9] Bottger, H. M. et al. (2004), *GRL*, 31, [10] Chaffin, M. S. et al. (2018) *JGR*, 123, 2192-2210, [11] Lillis, R. J. et al. (2017), *JGR*, 122, 3815-3836, [12] Dong, Y. et al. (2015), *GRL*, 42, 8942-8950, [13] Dubinin, E. et al. (2017), *JGR*, 122, 11285-11301.