CheMinX: A Next Generation XRD/XRF Instrument for Quantitative Mineralogy and Geochemistry on Mars

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Introduction: X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses provide the most diagnostic and comprehensive mineralogical and geochemical characterization of rocks and soils by any spacecraft-capable technique, improved upon only by sample return and analysis in terrestrial laboratories [1].

XRD coupled with XRF can provide the quantitative mineralogy and crystal chemistry necessary to characterize depositional environments and habitability. If a putative biosignature is detected, does it / did it exist in a habitable environment? Post-emplacement mineralogical alterations ("taphonomy") can preserve signs of biogenicity or erase them; such alterations can be characterized with XRD/XRF.

The MSL-CheMin Instrument: The first X-ray diffractometer flown in space is the CheMin instrument on the MSL *Curiosity* rover [2] (figs. 1-2). In its second analysis on Mars, CheMin identifed and characterized a habitable environment in an ancient lakebed, the first such identification in the solar system and the criterion for MSL mission success [3-5].

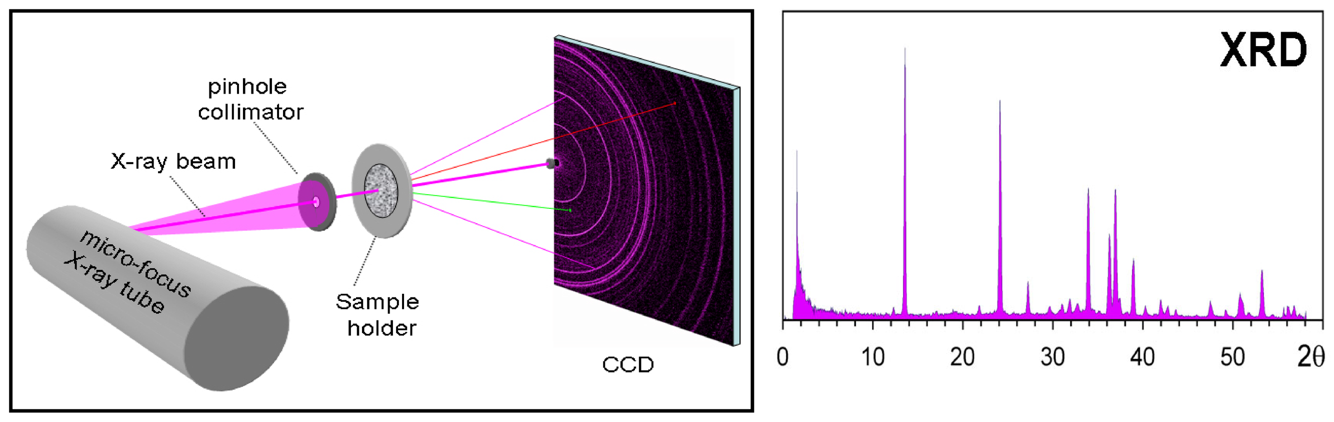

Fig. 1: Geometry of CheMin. (Left) Diffracted CoKα photons (magenta) from the X-ray tube are detected by an energy-discriminating CCD. (right) XRD 2θ pattern obtained by summing diffracted photons about the central beam.

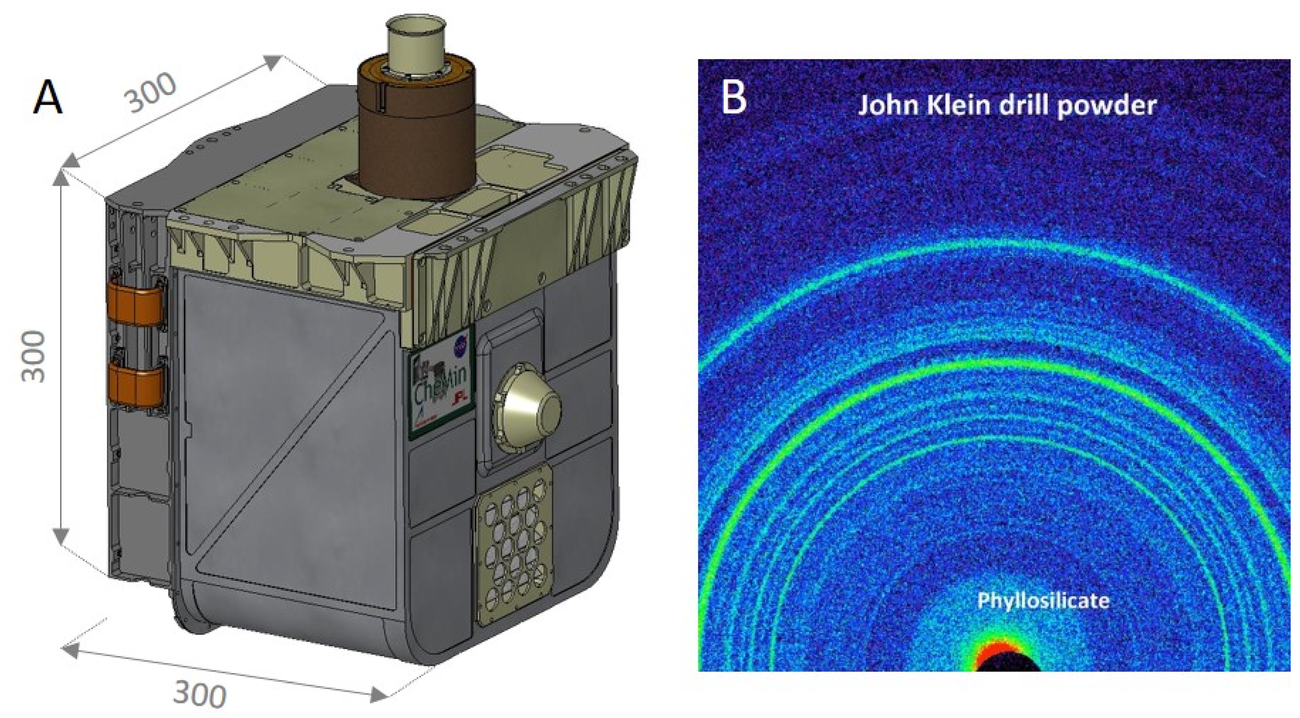

Fig. 2: (A) The MSL-CheMin instrument, with dimensions (in mm), mass is 10.5 kg. (B) An example of 2D XRD data from the "John Klein" sample, drilled from the first habitable environment identified by Curiosity. Pattern resolution is ~0.35° 2θ.

CheMinX: A Next-Generation XRD/XRF Instrument [6]: Improvements in X-ray technology coupled with lessons learned during a decade of CheMin operations on Mars by our team have guided the design of CheMinX, a next generation XRD/XRF instrument intended for future Mars rovers and landers. Improvements include:

- CheMinX will use an array of 4 Hybrid Pixel Detectors (HPDs) in place of MSL-CheMin's CCD.
- CheMinX will employ "single use" cells.
- CheMinX will employ a Silicon Drift Detector (SDD) to directly measure the XRF composition.

CheMinX Design: CheMinX (Fig. 3) is half the mass, one third the volume, and requires substantially less energy and time per analysis than MSL-CheMin. The transmission XRD geometry of CheMinX is similar to that of MSL-CheMin (fig. 1) but uses different components and a different layout to optimize its geometry and improve 2θ resolution. CheMinX uses a SDD in reflection geometry to provide an improved XRF measurement of the sample. The instrument uses sample cells that are are redesigned for a more compact and lower cost sample handling subsystem. A fixed tuning fork is combined with multiple single-use cells in a cartridge/dispenser arrangement to address the issue of clogged or contaminated sample cells experienced with MSL-CheMin.

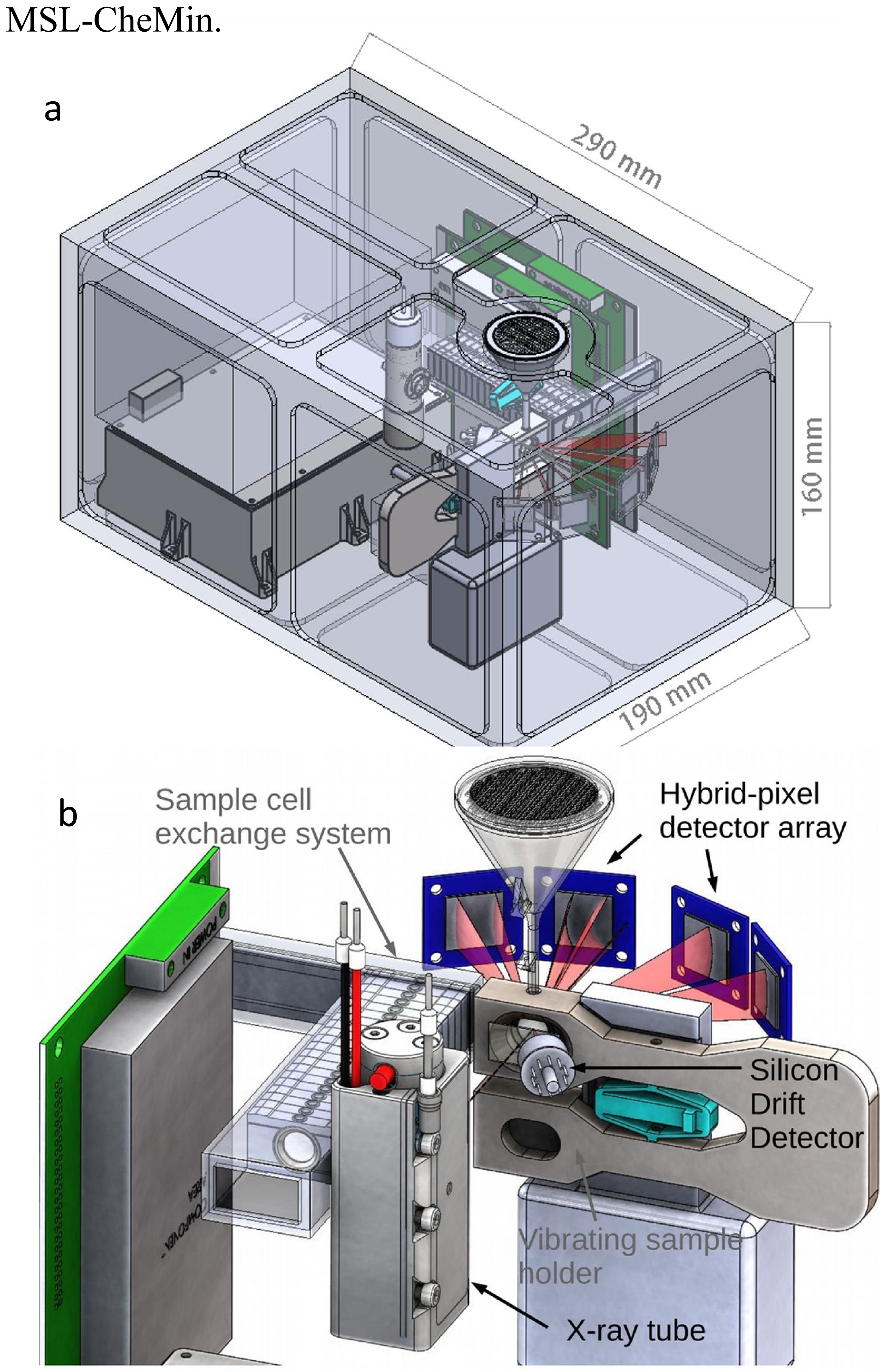

Fig 3: Preliminary mechanical design of the CheMinX flight instrument. (a) Instrument with dimensions (in mm); projected mass is 5 kg. (b) Sample handling subsystem for the vibrated sample method based on single-use cells in a cartridge dispenser system.

Hybrid Pixel Detectors (HPDs) for XRD: An array of 4 Hybrid Pixel Detectors replace the single CCD detector of MSL-CheMin. HPDs are radiation-hard, do not require cooling and can operate under high flux conditions (Fig 4). In a configuration like Fig. 3, this results in decreased analysis times and improved 2θ resolution along with much reduced power requirements. An array of 4 HPDs increases the 2θ resolution from 0.3° to 0.18°, sufficient to identify and quantify 3-pyroxene systems.

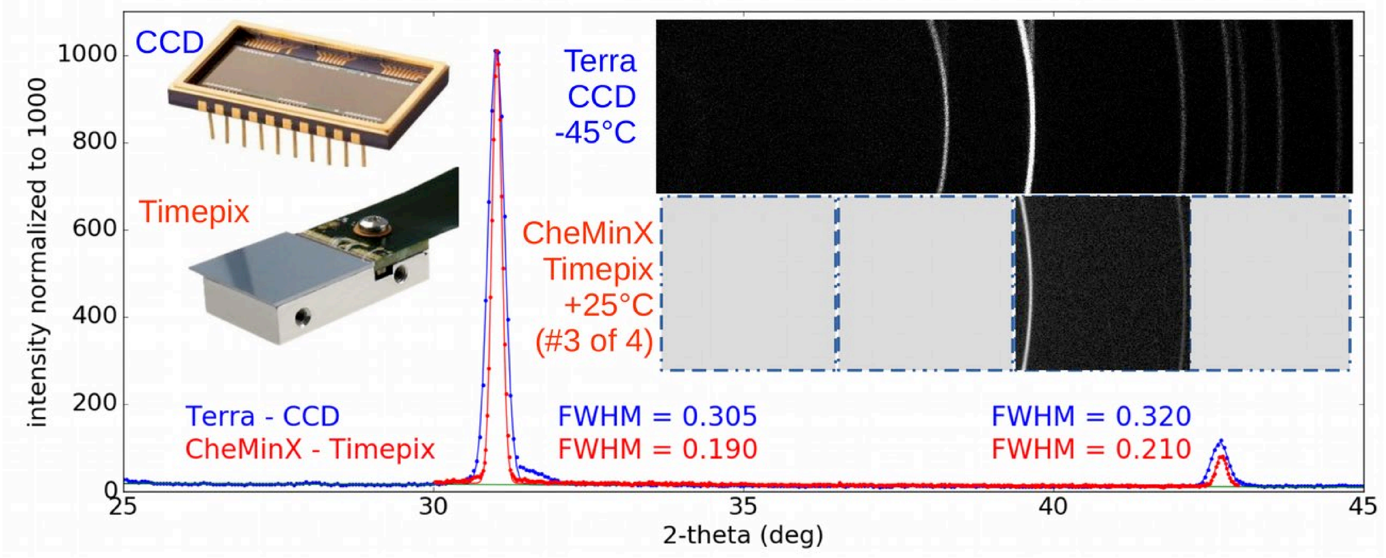

Fig 4: Comparison of XRD data of quartz using a CCD based Terra [3] vs. a HPD detector placed twice as far from the sample. HPDs don't require cooling; the CCD must be hermetically sealed in a chamber and cooled to -45C. This preliminary measurement verifies the improved resolution of CheMinX.

Discussion: CheMinX [6,7] is suitable for deployment on MER-class rovers with the inclusion of a miniature drilling system [8]. The instrument is identified as a payload element of Mars Life Explorer (MLE), one of the missions chosen by the Planetary Decadal Survey for development in the coming decade [9]. Fig. 5 shows the preliminary design of the MLE lander, intended to search for signatures of life and understand the habitability of near-surface ice.

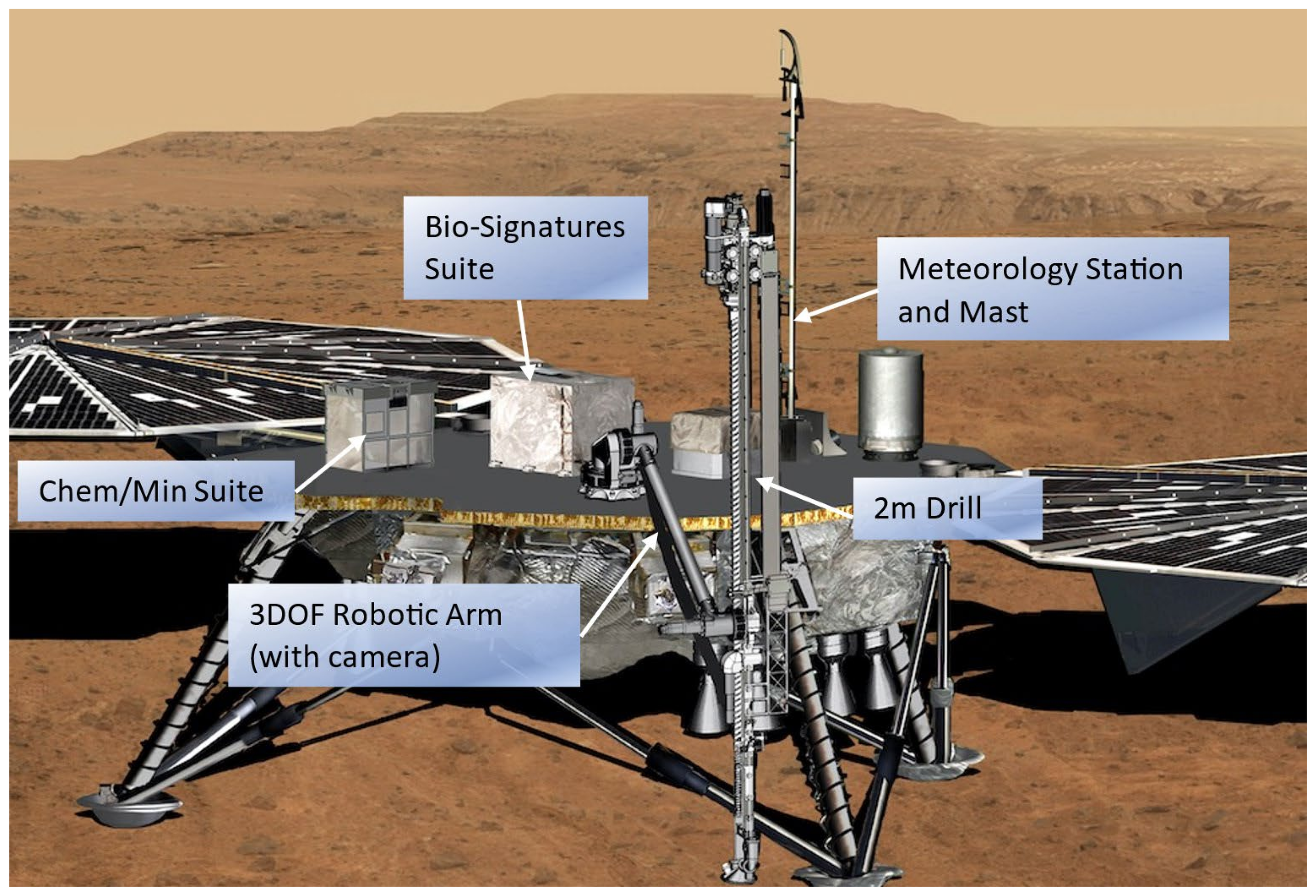

Fig 5: Artist's concept of the Mars Life Explorer lander, showing the payload elements, including the Chem/Min (CheMinX) XRD/XRF instrument. Drilled and powdered samples will be obtained at approximate 20 cm intervals for a total of 10 analyses over the 2 M depth of drill penetration.

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References: [1] Velbel M.A. (2018) *Am. Min.*, **103**, 837-838. [2] Blake D.F. et al. (2012) *Space Sci. Rev.*, **170**, 341-478, 10.1007/s11214-012-9905-1. [3] Grotzinger J.P. et al. (2013) *Science*, **343**, 10.1126/science.1242777. [4] Vaniman D.T. et al. (2013) *Science*, **343**, 10.1126/science.1243480. [5] Bristow T.F. et al. (2015) *Am. Min.* **100**, 824-836. [6] Sarrazin P. et al. (2019) *LPSC* **50**, #2236. [7] Rampe et al., (202) *Bulletin of the AAS*, **53(4)**, https://doi.org/10.3847/25c2cfeb.a4a55445 [8] Blake, et al., (2021) *Bulletin of the AAS*, **53(4)**, https://doi.org/10.3847/25c2cfeb.a7226c13 [9] Planetary Decadal Survey 2023-2032, p. B3.