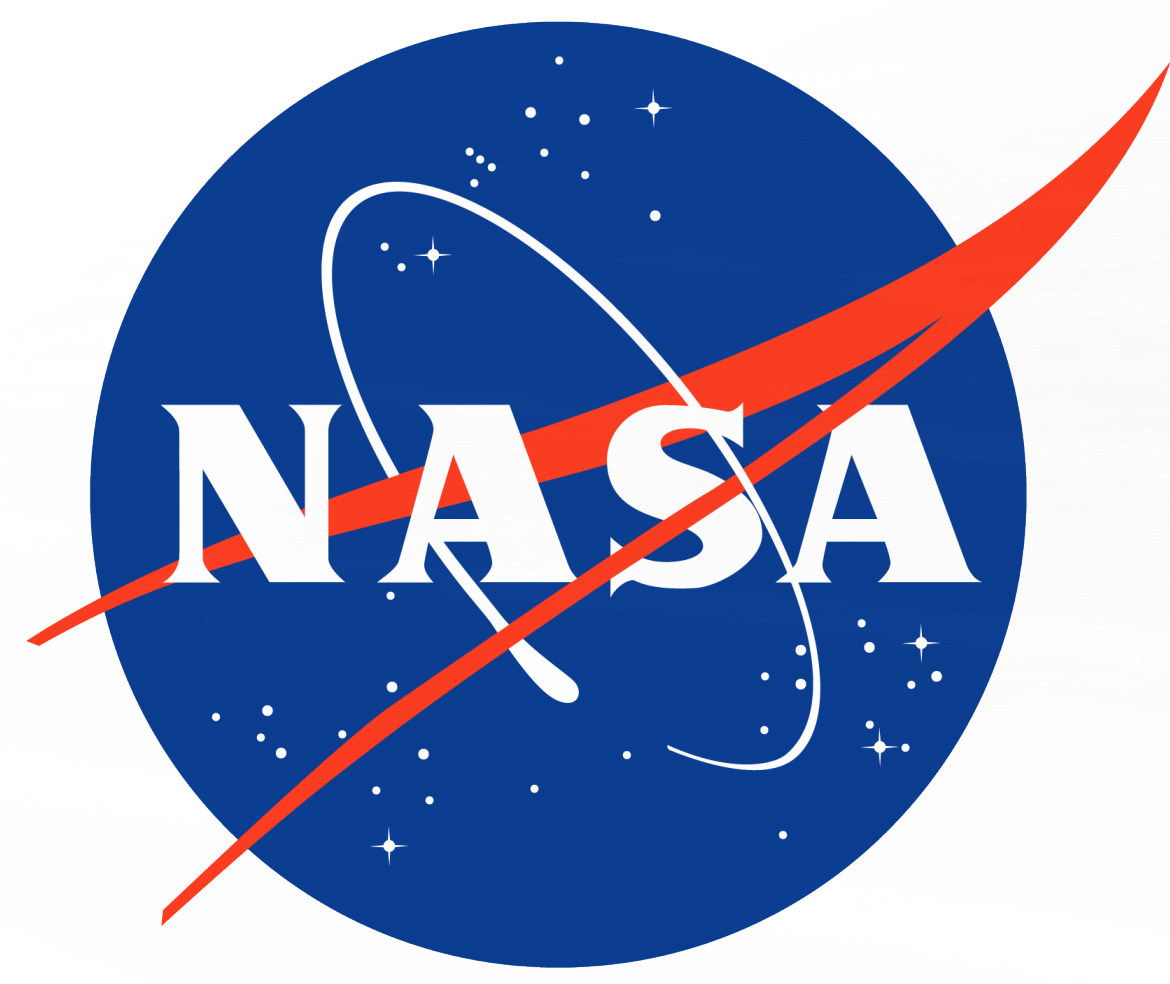
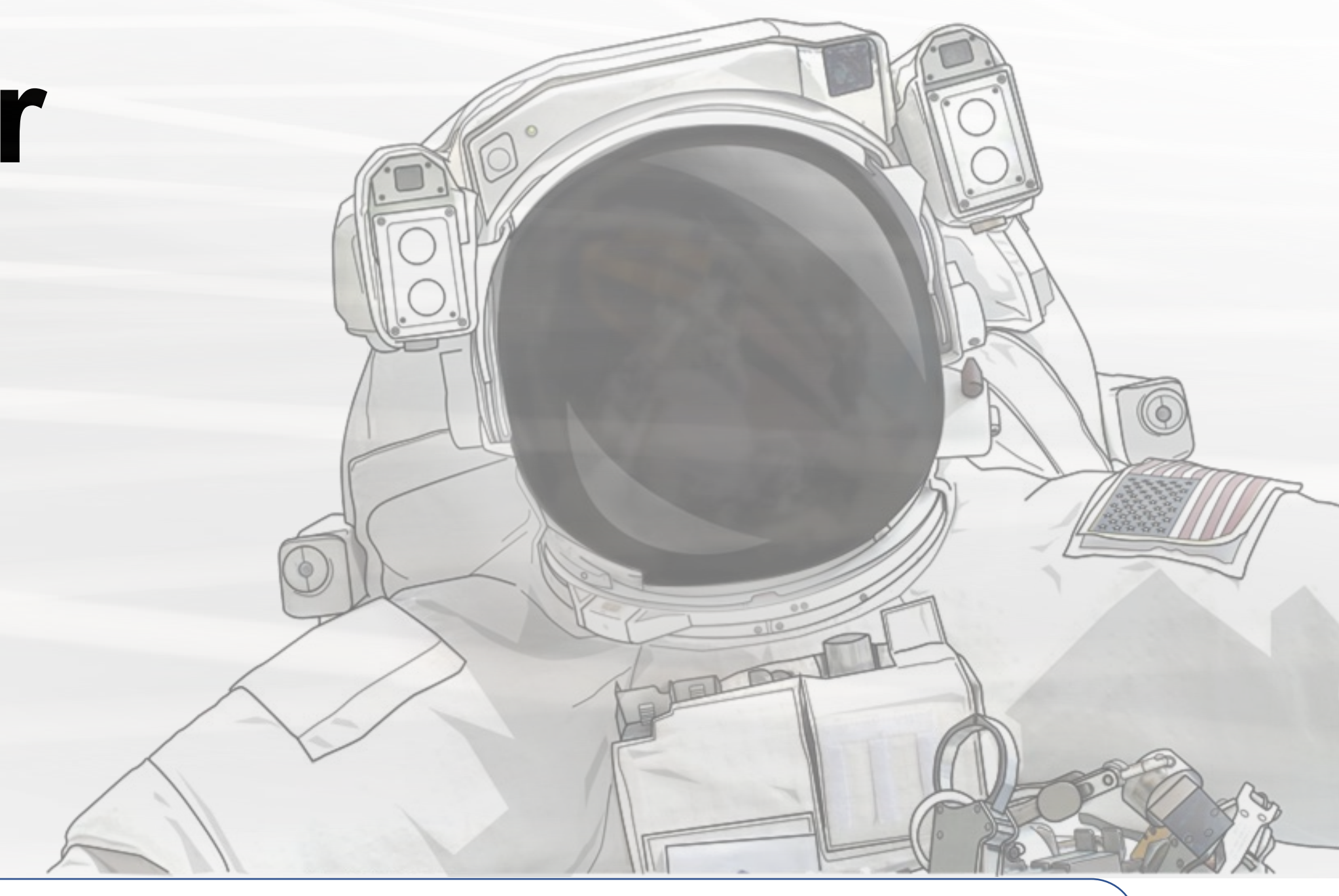




Improving Metabolic Workload Estimation Accuracy for Planning and Analyzing Exploration Traverses

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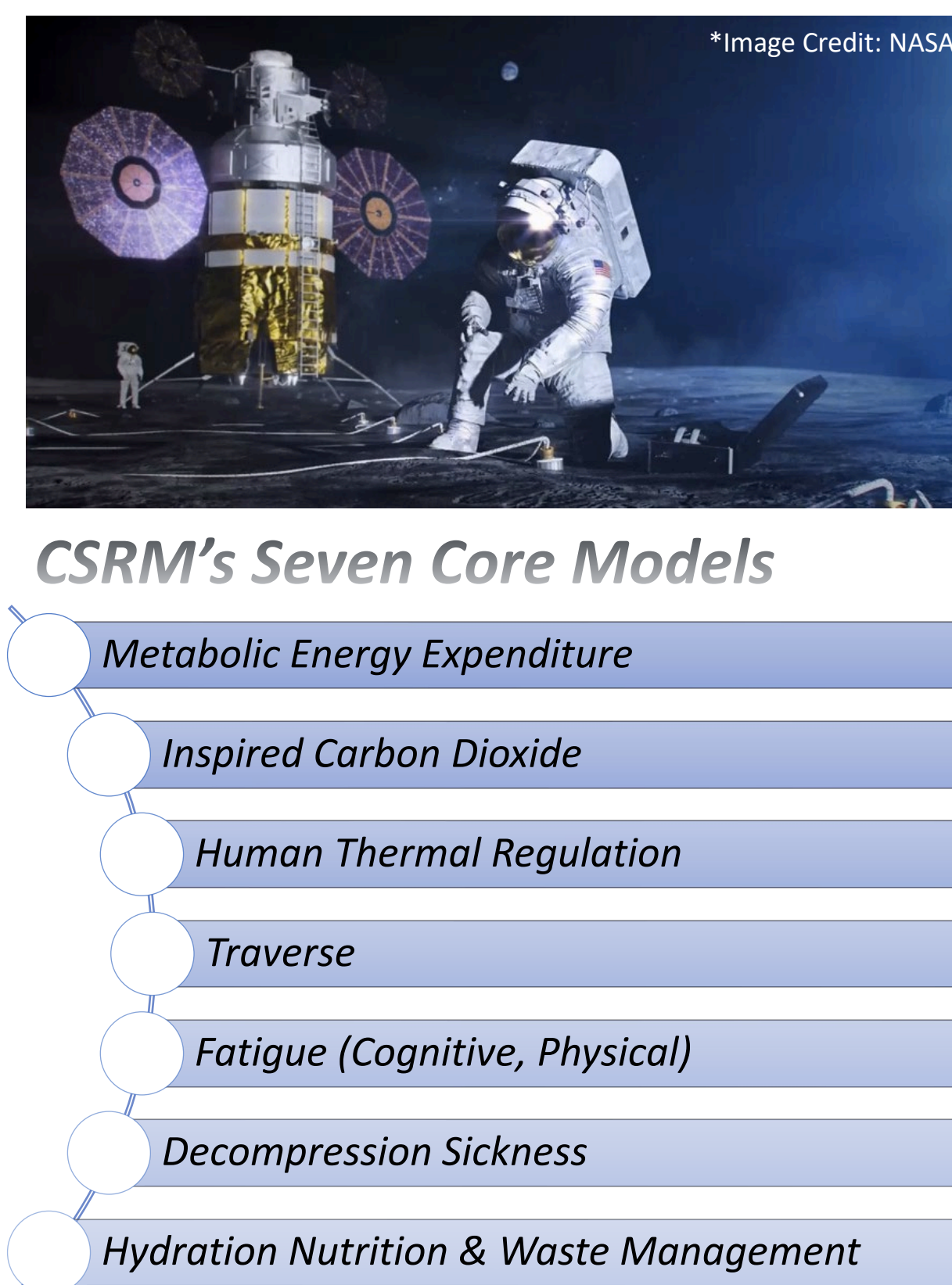


Abstract

- A novel method is suggested to reduce estimation error on metabolic workload during surface extravehicular activity (EVA) traverse.
- Operational Relevance — Assistive tools to efficiently plan exploration EVAs will be necessary for mission success.

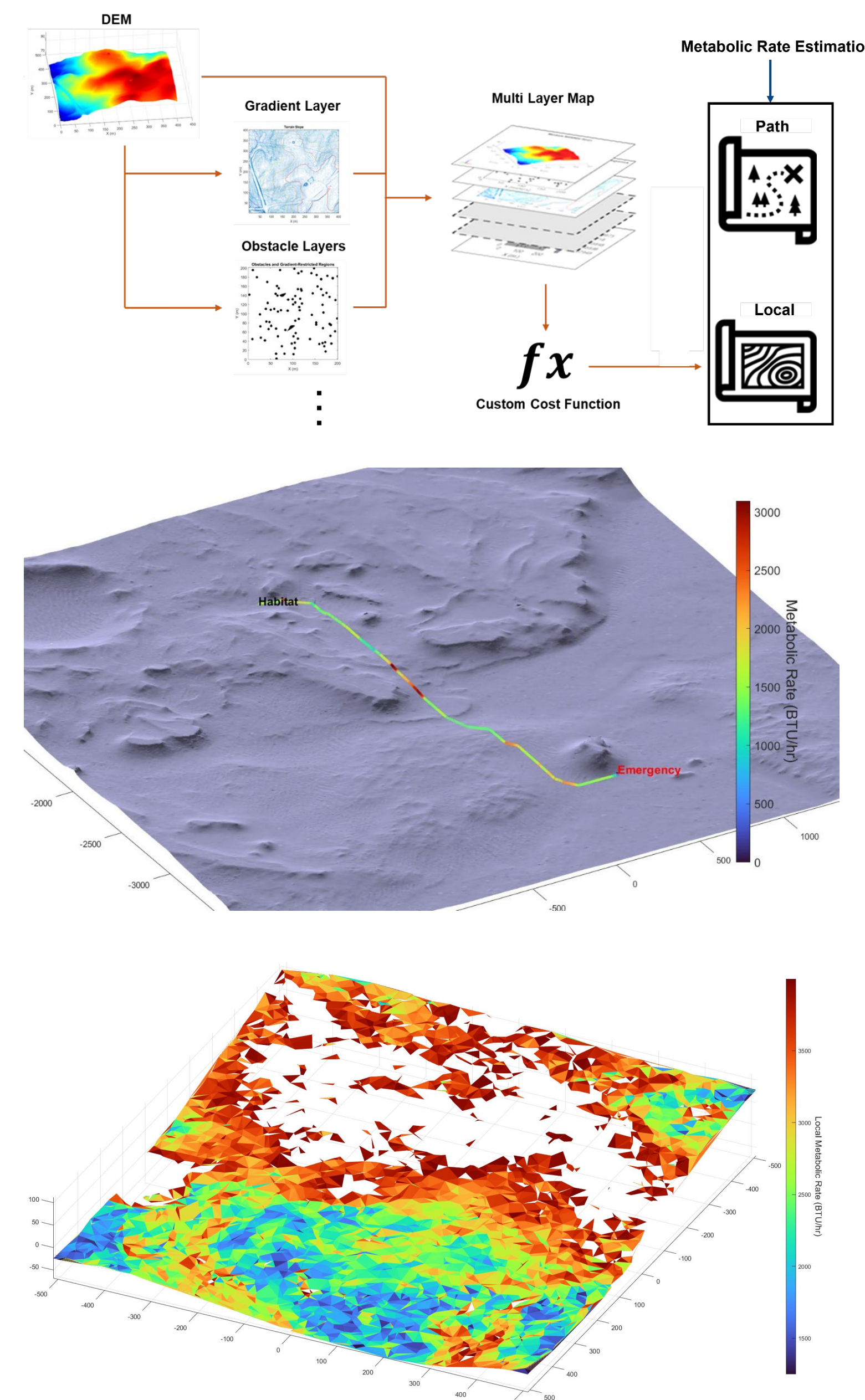
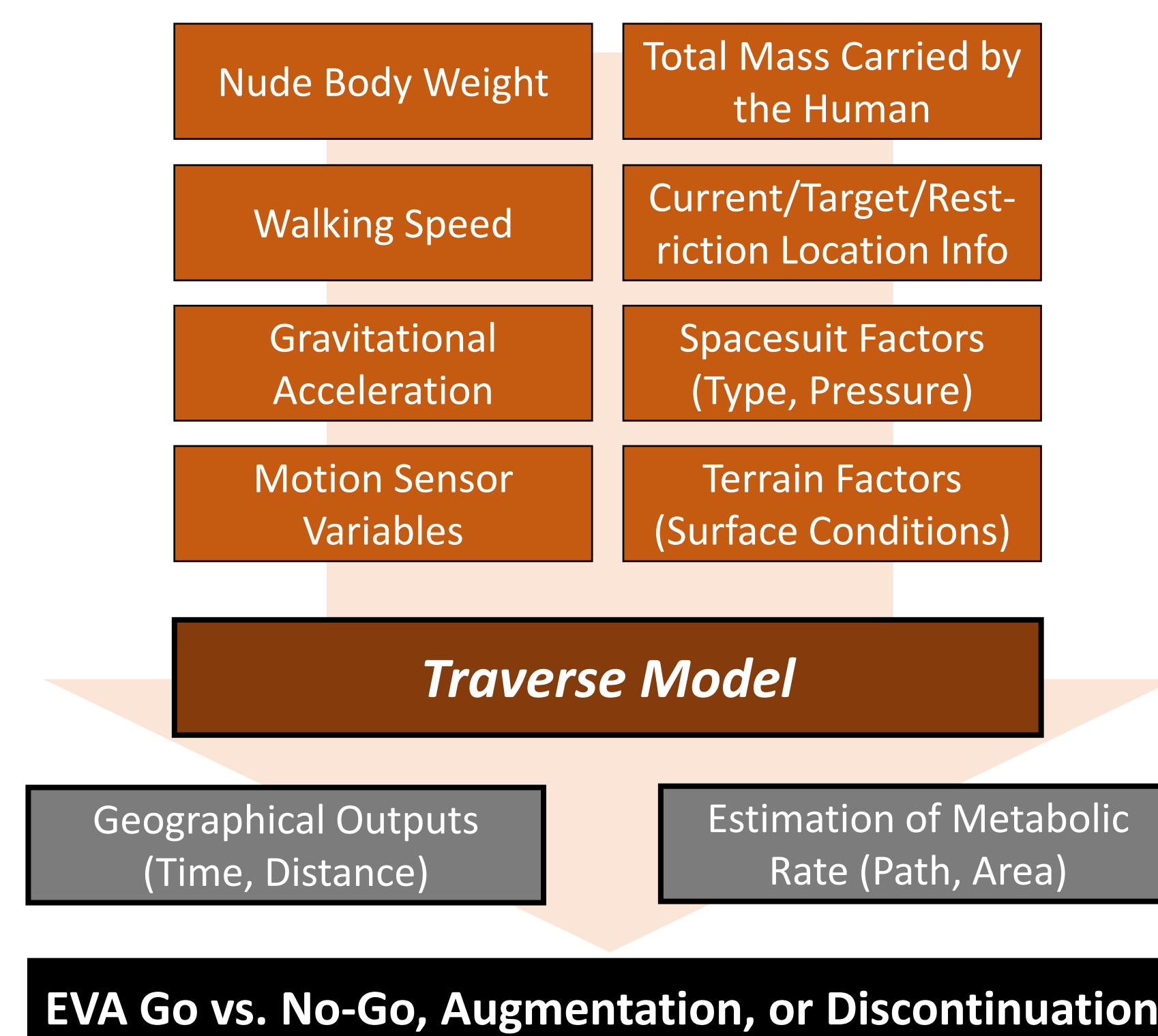
Crew State & Risk Model (CSRM)

- During long-duration exploration class spaceflight missions, crew will be unable to rely on mission control and real-time ground biomedical support.
- Performing EVAs during these exploration class missions will necessitate a level of autonomy beyond our current capability.
- The CSRM developed at National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) is a modular framework to predict and monitor crewmember's physical and cognitive state during EVA and associated risk implications.



Traverse Model

- The traverse model is one component of the CSRM framework that aims to:
 - Accurately estimate the metabolic cost of ambulation in simulated planetary exploration EVAs.
 - Explore optimization methods for minimizing the metabolic cost via traverse path planning.
- Model Inputs and Outputs



Method

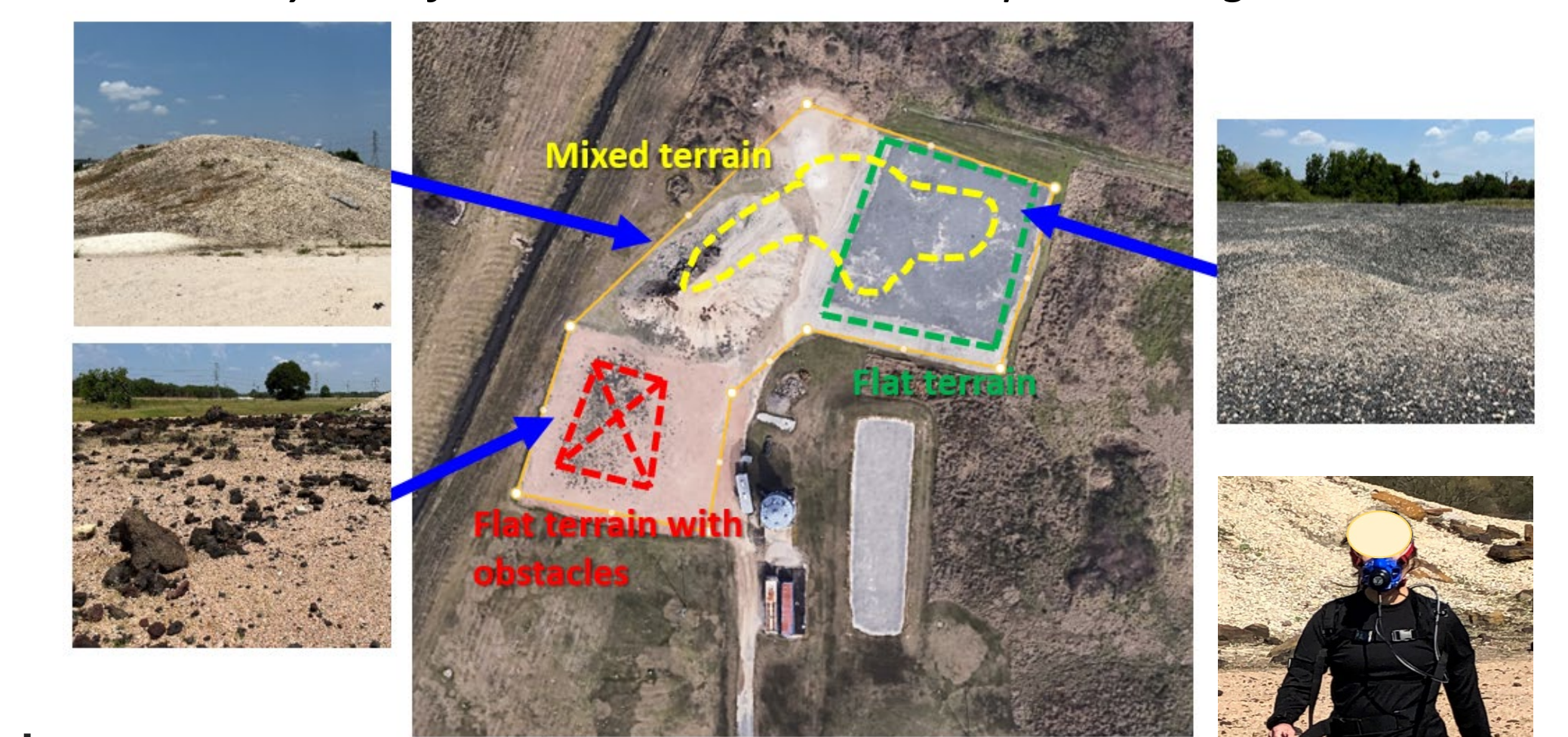
- Decision support tools for planning EVA traverses utilize path information, metabolic expenditure, etc.¹ However, the model employed for estimating metabolic rate builds upon an equation derived from laboratory treadmill data.²
- We aimed to improve the estimation accuracy of metabolic rate and provide a novel approach based on the modified field use Pandolf load carriage equation,³ which combines factors for applying walking speed models, gravitational accelerations, metabolic adaptation delays.
- A pilot study was conducted with four healthy adult subjects were instrumented with the K5 wearable metabolic system (COSMED, Italy), providing metabolic rate (BTU/h), walking speed (m/s), and GPS information. Subjects were tasked with traversing the terrain at JSC's Rock Yard, consisting of shallow craters, sand dunes, a hill, and a rock field, with durations up to 20 minutes at a self-paced speed.

Field Metabolic Rate Estimation Model

$$M_p = (M_b \cdot CF) \cdot DF \text{ (where * is being convoluted.)}$$
$$M_p = 1.5 \cdot W \cdot G + 2.0 \cdot G \cdot (W+L) \cdot (L/W)^2 + \eta \cdot G \cdot (W+L) \cdot (1.5V^2 + 0.35 \cdot V \cdot S)$$
$$CF = \eta \cdot [(S \cdot G \cdot (W+L) \cdot V) / 3.5 - ((W+L) \cdot (S+6)^2 / W) + (25 \cdot V^2)]$$
$$V = -0.01 \cdot S + 0.75 \text{ (Apollo traverse speed model)}$$
$$DF = (1/D) \cdot e^{-(1/D)}$$

where the model variables are final energy consumption (M_p), the estimated metabolic rate by the Pandolf equation (M_p), the correction factor (CF) in watts, and the delay factor (DF), body weight (W), external load (L) in kg, walking speed (V), slope grade (S) as a percentage, terrain coefficient (η), gravitational factor (G), and delay (D).

Overall layout of the JSC's Rock Yard and path along the terrain



References

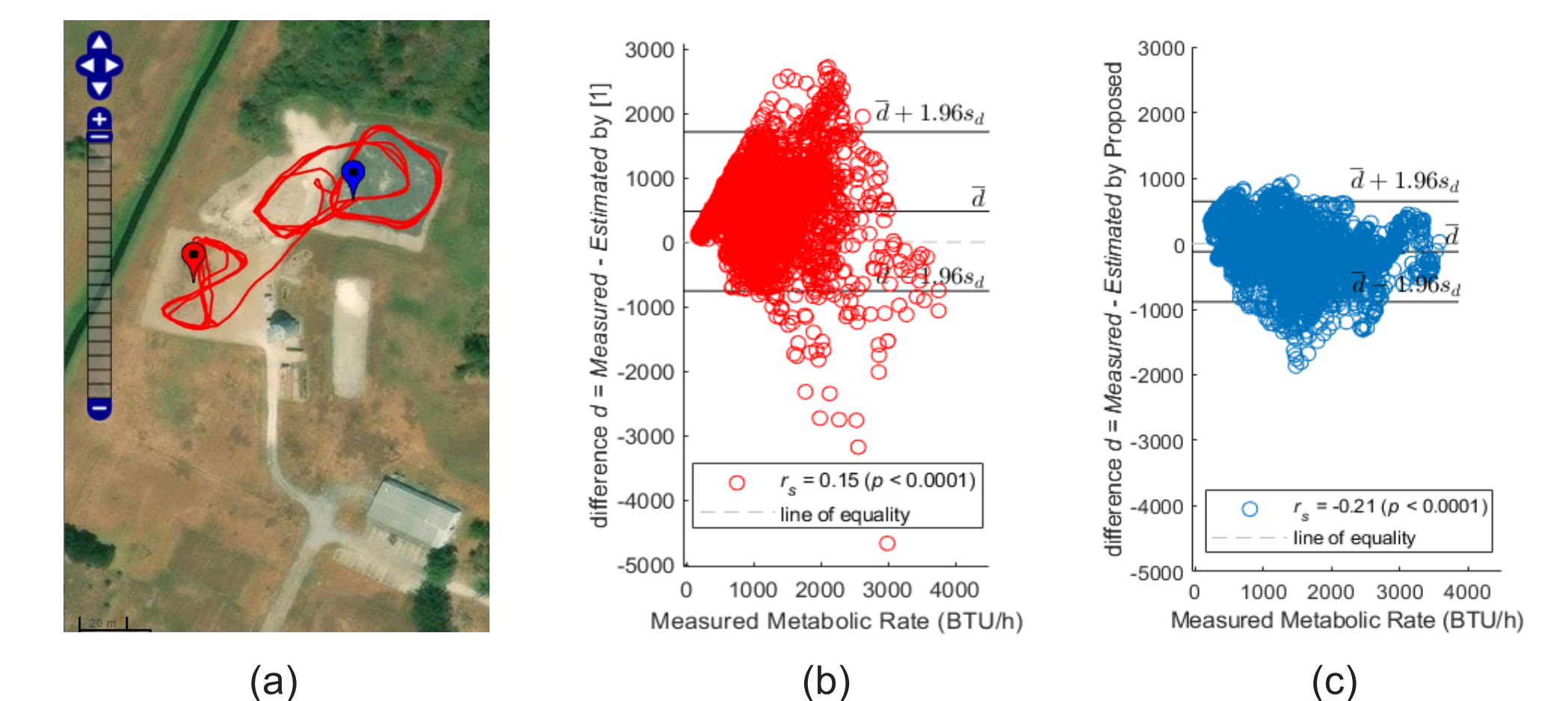
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Results

- This pilot study showed that the proposed method predicts the metabolic rate of open-field ambulation measured by K5 with improved accuracy.

Regression Coefficients

Method		Estimate	Standard Error
Conventional ¹	(Intercept)	234.82	21.87
	x	0.50	0.01
Proposed	(Intercept)	201.80	16.00
	x	0.95	0.01



(a) Example of a walking path (red line) at Rock Yard, Bland-Altman plots (b) the conventional method¹ and (c) the proposed method of estimating metabolic rate

Conclusion & Future Work

- Preliminary results show higher estimation accuracy of metabolic workload with the novel method compared to the conventional method. Supportive tools in planning EVA traverses may require a field-purposed model rather than a laboratory-based model to estimate metabolic rate during EVA ambulation robustly and accurately.
- Future work is ongoing to estimate the workload of ambulating in candidate Lunar South Pole landing sites to refine suited workload modeling and prediction efforts.

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