National Aeronautics and Space Administration

muSSTAR

miniature unmanned airborne Sunphotometer for Sun-Tracking Atmospheric Research

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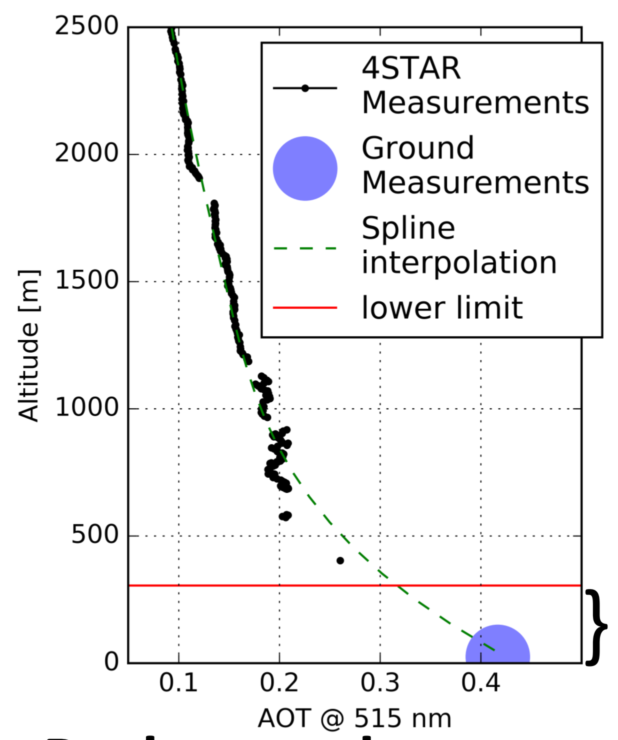
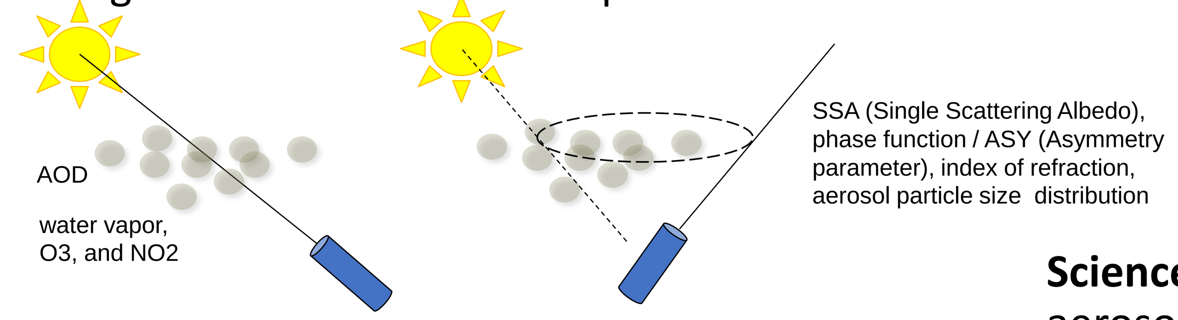
Concept:

Put a sunphotometer on a unmanned airborne system to profile lowest atmospheric layers, for addressing links between boundary layer composition and satellite measurements. Potential research application for linking AOD (Aerosol Optical Depth) to air quality, or for aerosol optical properties for retrieving ocean color from atmospheric reflectances.





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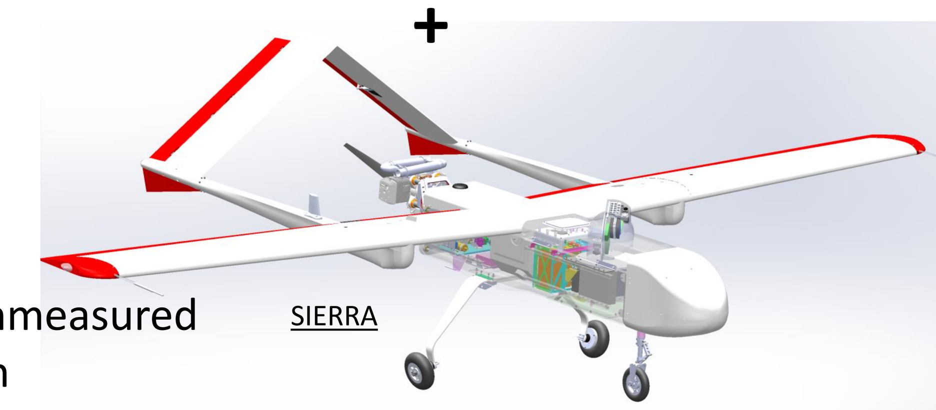


SIERRA

Background on sunphotometry

Sunphotometry involves quantifying the atmospheric constituents and their properties that obscured the sun's direct beam. NASA Ames is a leader in airborne sunphotometry.

- AATS-6, AATS14, 4STAR flight instrument heritage
- AERONET for measuring aerosol around the world
- Pandora for refining trace gas

Hexacopter

Science Traceability matrix

Title	Science Goals	Science Objectives	Scientific Measurement requirement			Instrument Requirements		Projected Performance	Mission Functional Requirements (Top Level)
			Observables	Physical parameters	accuracy / resolution	measurement	accuracy / resolution		
Air Quality - climate	"Advance the understanding of changes in the Earth's radiation balance, air quality, and the ozone layer that result from changes in atmospheric composition" (2014 NASA Science Plan, Atmospheric Composition)	Quantify the link between radiation balance and air quality in the lowest layer of the atmosphere	Aerosol vertical profile	Aerosol optical thickness, vertically resolved	0.02 at 500nm, 10 points across boundary layer	solar direct beam transmittance measurements	2% radiometric, pointing accuracy 0.3 deg	adequate	vertical profile up to and past boundary layer (1.5 km)
			Air quality	Ozone, NO2	<5 DU for ozone, <0.5 DU for NO2	spectral solar direct 380 nm - 670 nm (Segal-Rozenhaimer et al., 2014)	0.7 nm resolution	330-900 nm at 0.36 nm	Increase time on station
				PM 2.5 particle mass concentration, as represented by AOD	fine mode AOD < 0.02	transmittance at 5 wavelengths (O'Neill et al, 1998)	<2% radiometric	380, 500, 675, 1020, 1635 nm	co-locate with ground sites and bad air quality
			Radiation budget	Albedo	10%	upwelling or downwelling irradiance	radiometric 10%	adequate	access upwelling radiation from below horizon
				AOD	AOD < 0.02	solar direct beam transmittance measurements	2% radiometric, pointing accuracy 0.3 deg	adequate	clear view to sun
				Aerosol properties	SSA +/- 5%, ASY +/- 10%	principal plane and almucantar sky radiances (Dubovik et al., 2001; Pistone et al., 2019)	sky radiances accuracy < +/- 5%, pointing knowledge of 0.5 deg near sun, 20 deg in backscatter	adequate, with camera tracking and computer vision	clear view to sky, acquire full 2D sky scan within 1km
Aerosol processes	"Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system" (2014 NASA Science Plan, Climate Variability and Change)	Better resolve the near surface atmospheric processes for creation of aerosol that are influenced by surface emissions (coastal environments and near forest)	Aerosol near surface	AOD, vertically resolved	0.02 at 500nm, in sea salt zone / above tree canopy	solar direct beam transmittance measurements	2% radiometric, pointing accuracy 0.3 deg	adequate	clear view to sun, near surface, minimum safe altitude, in sea salt zone
			aerosol properties	SSA, ASY, size distribution,	SSA +/- 5%, ASY +/- 10%,	principal plane and almucantar sky radiances	sky radiances accuracy < +/- 5%, pointing knowledge of 0.5 deg near sun, 20 deg in backscatter	adequate, with camera tracking and computer vision	clear view to sky, acquire full 2D sky scan within 1km

Technical Approach:

Leverage with co-development of 5STAR instrument under directed funding. Miniaturize the radiometer electronics, data acquisition and sun-tracking robotics using micro-controllers. Limit environmental conditions for simpler temperature and stability control. Incorporate aircraft heading to supplement sun-tracking. TRL 1 currently, with end goal of TRL 3 (extended goal:4)

Deliverables and Completion Status:

- Miniaturize electronics for light collection (03/2020, SD,SL)
  - Plan, specify requirements and budget (09/2019, SD) 100%
  - Design, review and test bread-board design (03/2020, RD) 50%
- Miniaturize sun-tracking electronics (01/2020, RD, SL)
  - Plan, specify requirements and budget(09/2019, RD) 100%
  - Design, review and develop prototype design (01/2020, RD, AT) 10%
- Prototype engineering plan and purchase list (03/2020, SD, SL) 50%
- Plan for interface between instrument and UAS (12/2019, RD) 25%

Approach: Co-develop 2 instruments for missions on mid-size and small unmanned aerial systems (SIERRA and Hexacopter)

SIERRA Mission (230 kg MTOW UAS)	Requirements	Hexacopter Mission (15 kg MTOW UAS)
0-3.5 km	Altitude	0-1 km
~900 km	Range	~1 km
Long distance	Advantage	Vertical profiling
AOD above coastal environments	Anticipated science	AOD to PM 2.5
9 discrete radiometer wavelengths, 350-1700 nm grating spectrometers	Measurements	5 discrete radiometer wavelengths, 330-900 nm grating spectrometer (un-cooled)

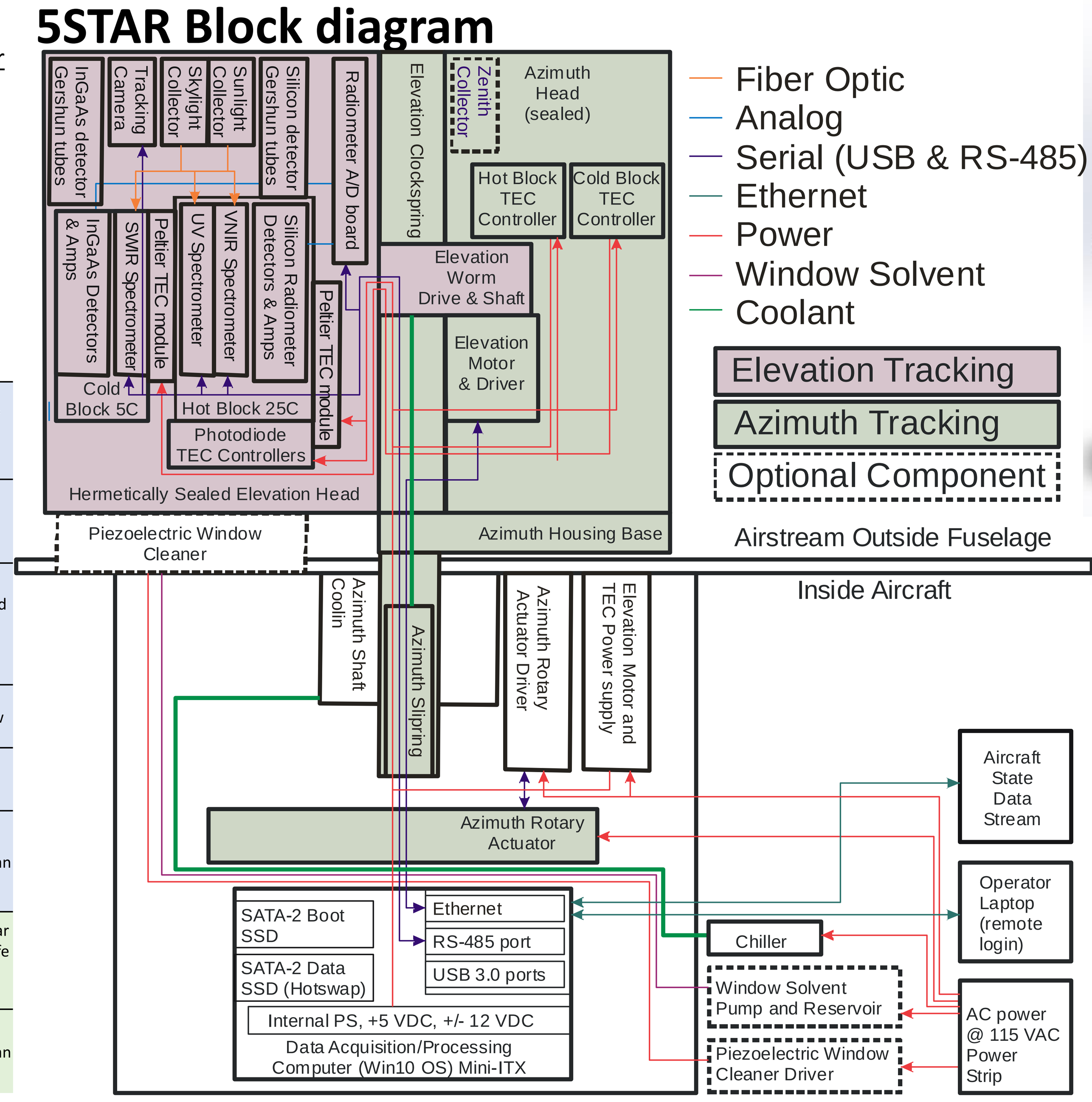
Science goal: Ocean color correction and low level aerosol process refinement, by linking satellite column AOD measurements to near-ground / near-sea surface / near tree tops measurements.

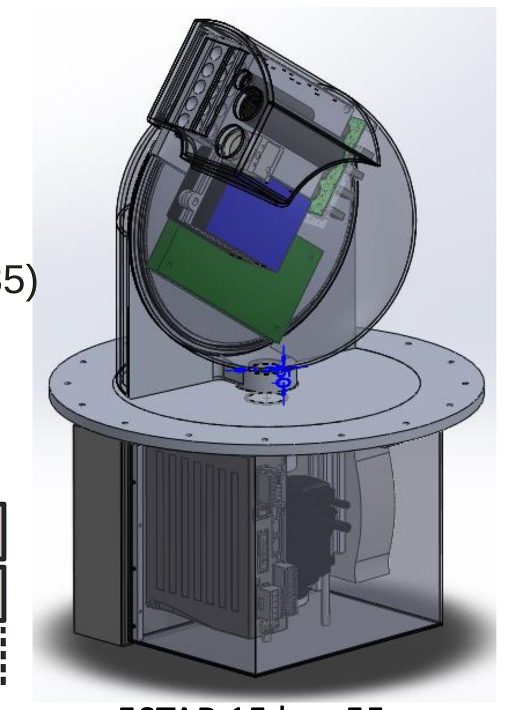
Aircraft / instrument requirements:
- Full capability science instrument based on 5STAR design, TRL 5.
- Zenith port (optics must be sun viewing)
- Need GPS and attitude information
- Downlink of data as stretch goal

4STAR (heritage) 23 kg, .76m high, Plus 55 kg rack.

4STAR integrated on C130

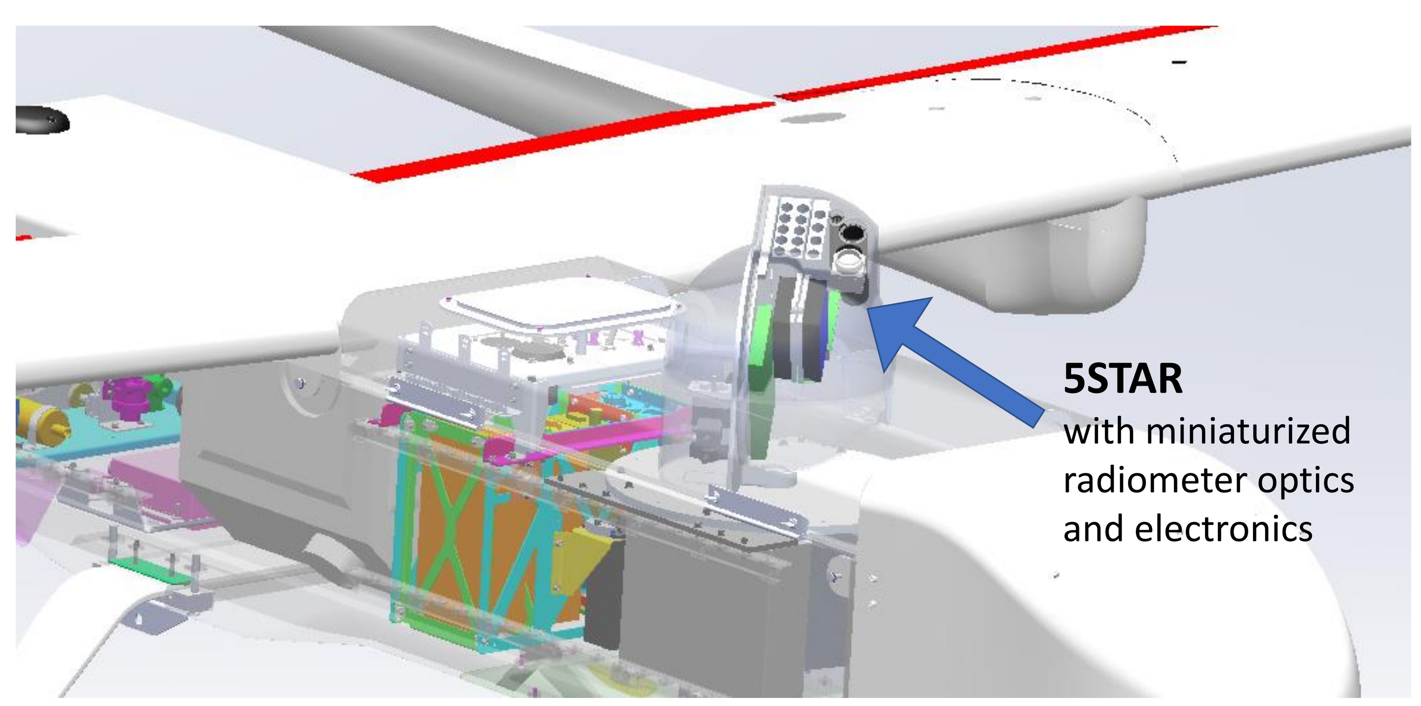
5STAR Block diagram





5STAR 15 kg, .55m high, fully contained.

5STAR integrated on SIERRA UAS

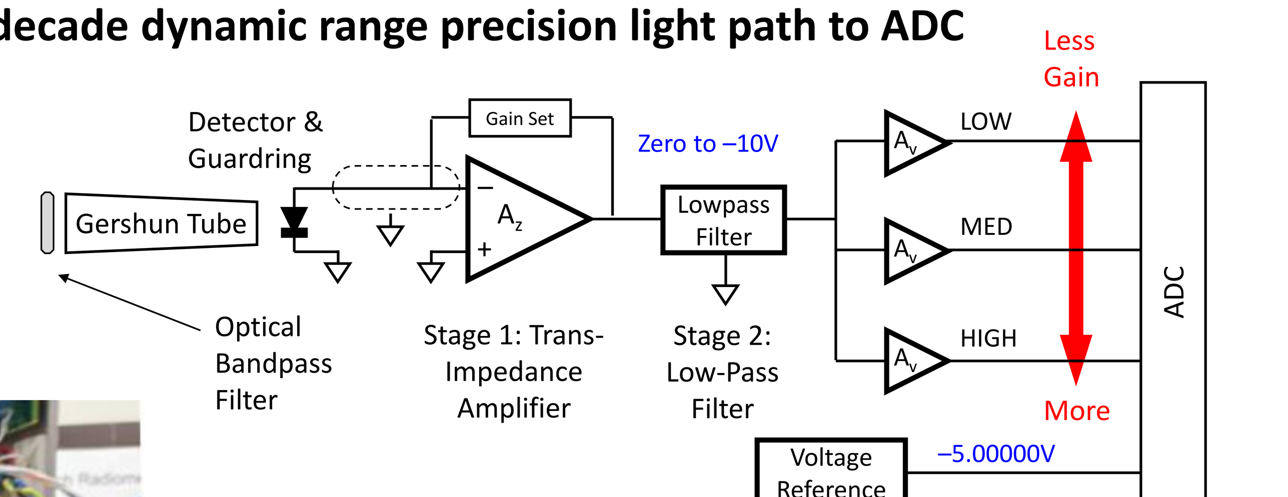


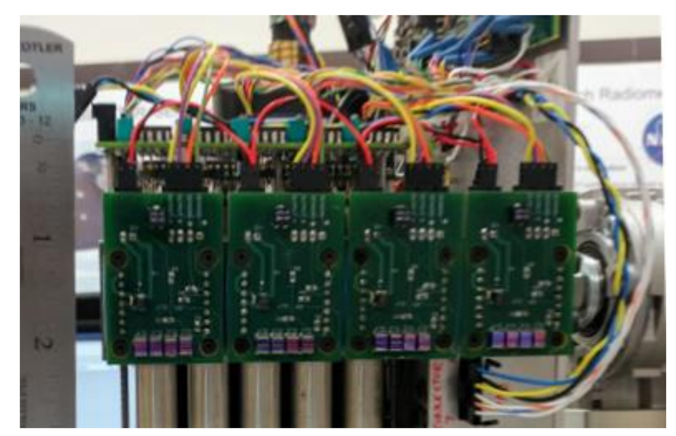
Science goal: Link between local bad Air Quality and satellite column measurements of aerosol.

Aircraft/instrument requirements:
Potential aircraft: DJI Matrice 600, hexacopter (See Ved Chirayath IRAD)
Instrument requirements:
- New small weight and power (SWAP) design, <5 kg, limited science capability)
- Integrated on the top of aircraft (optics must be sun viewing)
- Need GPS and attitude information
- Control of aircraft heading within 30°
- Downlink of data as stretch goal

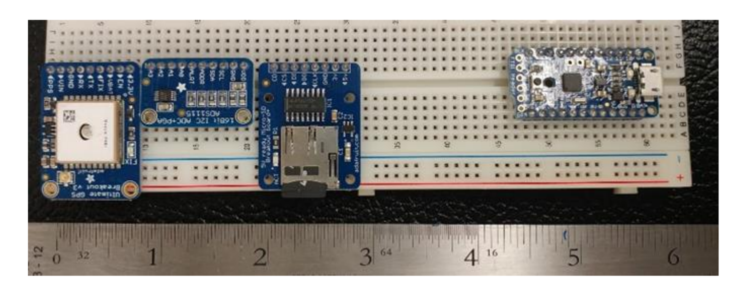
Anticipated new instrument capabilities:
- Sunphotometer with hyperspectral (330 – 900 nm) and discrete channels (380, 500, 675, 1020, and 1640 nm), for AOD, water vapor, O3, and NO2
- Sky scan for retrieval of aerosol intensive properties (e.g., Absorption, phase function)

New electronics:
Multi-decade dynamic range precision light path to ADC





Flight prototype of 5STAR optical and amplifier board assembly



Breadboard ultralight design with integrated amplifiers and A/D converters

Alignment with Ames and NASA:

This funding proposal is aimed at amplifying NASA Ames' Core Competency: "Aviation Management for Testing UAV Systems." NASA's science plan for atmospheric composition and its plan for climate variability and change are used as the governing direction for this research.

Future Prospects:

Plan to develop instrumentation through funding from the NASA ESTO program, specifically an Airborne Instrument Technology Transition (ROSES-AITT) call. Future use for NASA's PACE validation (NASA ROSES 2018 call, A. 48 PACE System Vicarious Calibration) and validation of urban aerosol impacting health, focus of NASA's EV-M mission, MAIA.