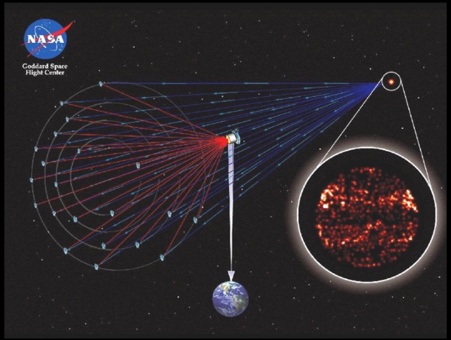
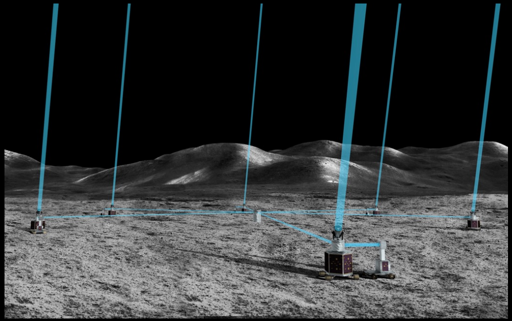
Imaging the Surfaces of Distant Stars with Sub-Milli-Arcsec Resolution: Artemis-enabled Stellar Imager (AeSI)

NIAC Phase 1 Orientation 2024





Dr. Kenneth Carpenter

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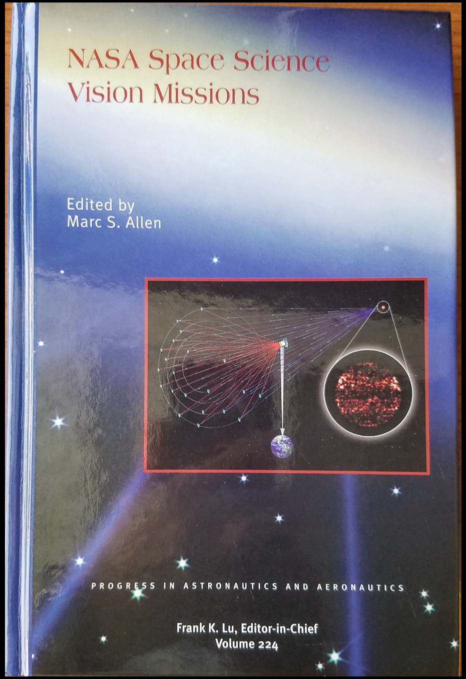
NIAC Fellow 2024
HST Operations Project Scientist; RST Ground System Scientist
NASA Goddard Space Flight Center

Why put Interferometers in Space or on the Moon?

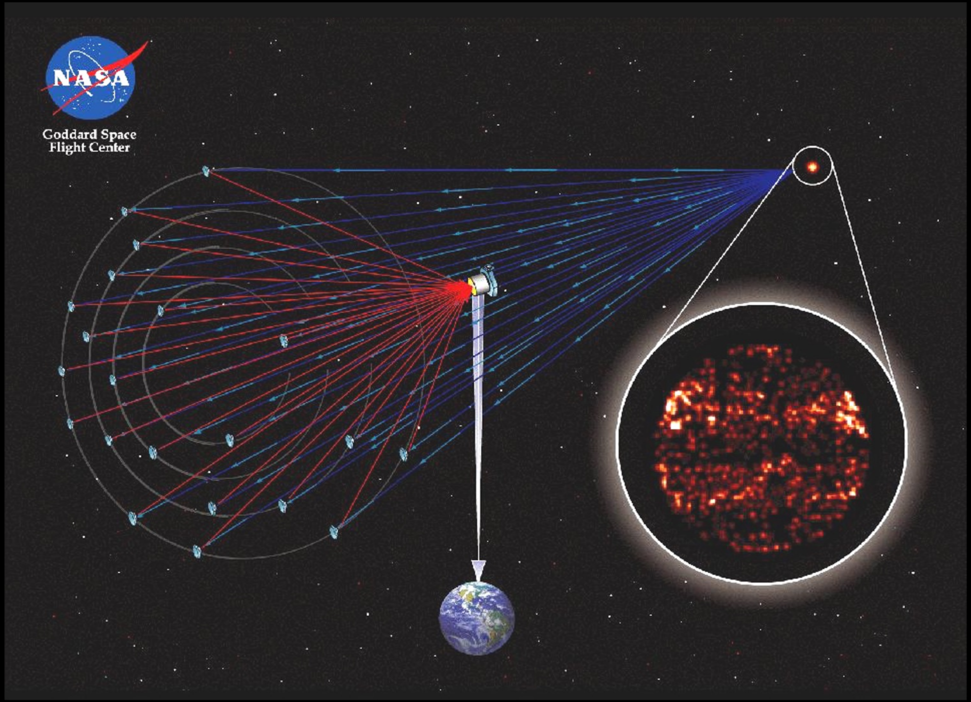
Ultimately required for extending the wavelength coverage and angular resolution needed to study the Universe in high-definition.

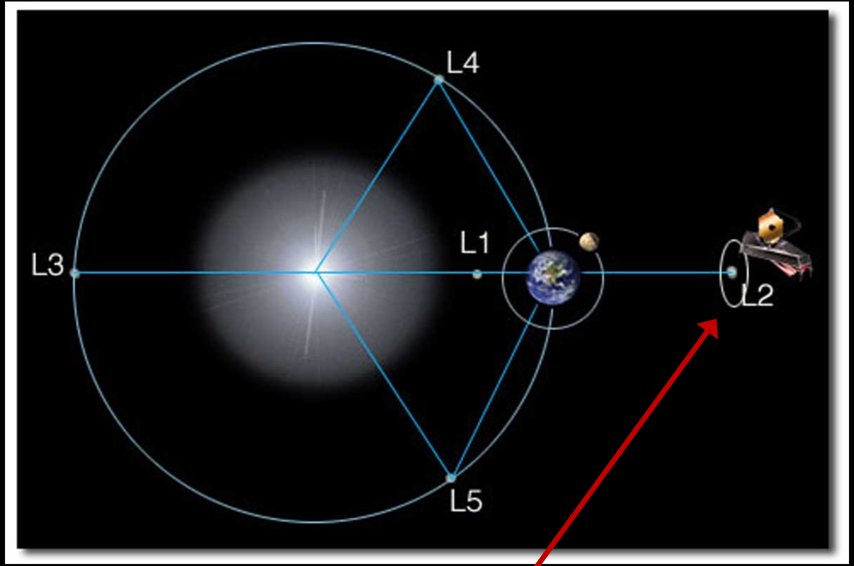
- Broader wavelength coverage
- Higher angular resolution
- Observe continuously over long time periods
- More stable environment
- No atmosphere, no turbulence, beams coherent over larger scales



SI Info: https://hires.gsfc.nasa.gov/si/

SI Concept from Vision Mission (VM) Study

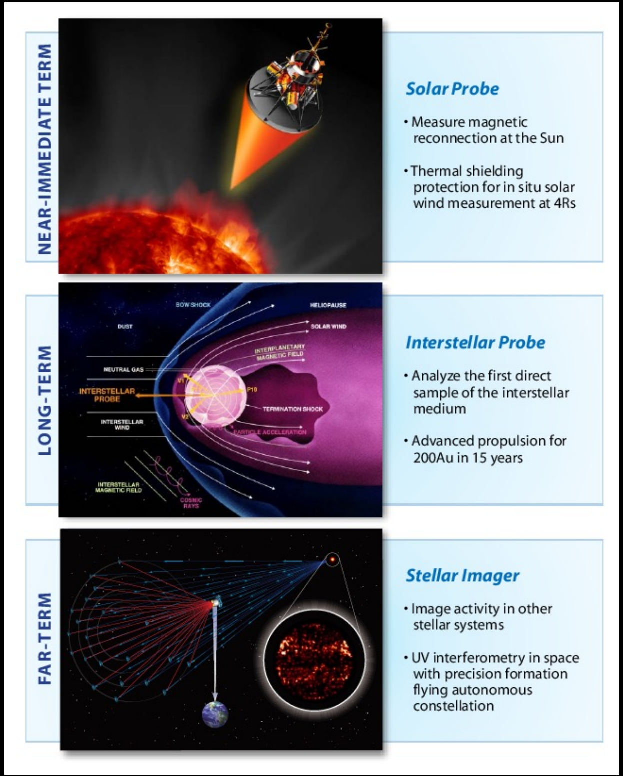




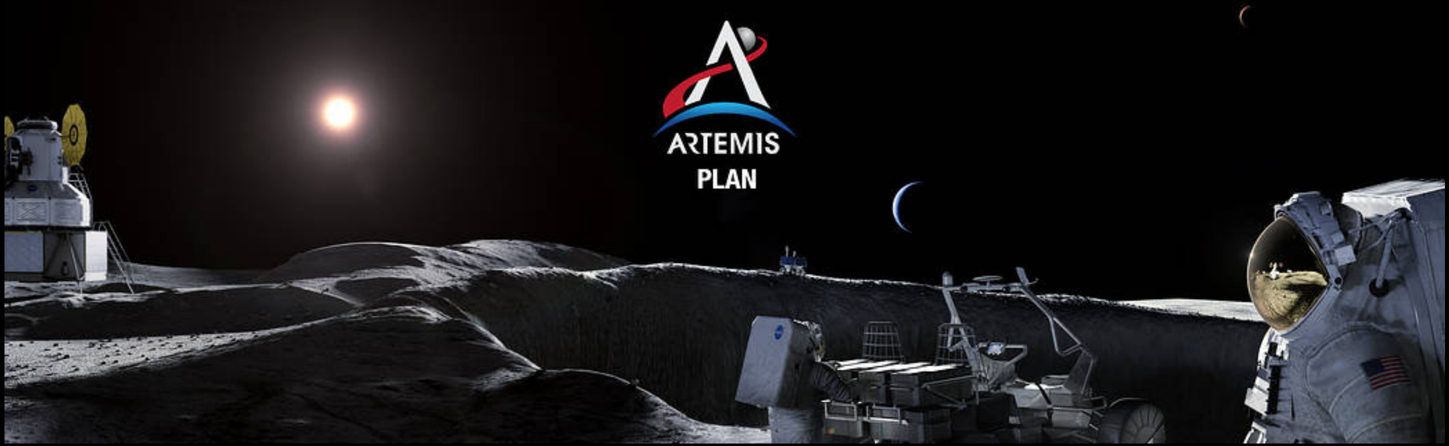
- A 0.5 km diameter UV-optical Interferometer near Sun-earth L2
- 30 primary mirrors, controlled by 1 hub; ***200x the angular resolution of HST***

Stellar Imager *is* hard….

- Significant Technology Hurdles
  - Precision formation-flying of ~ 30 spacecraft
  - Precision metrology over multi-km baselines
  - Autonomous Control of entire system
  - How do we test on ground before launch?
- But VM Study showed possible & in 2009 SI was in the Long-Term NASA Strategic Plan
- Development of "Vision Missions" like SI have been slowed, but the dreams continue…



Heliophysics Division Landmark Discovery Missions



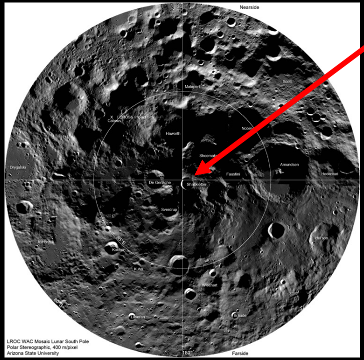
A NEW HOPE:

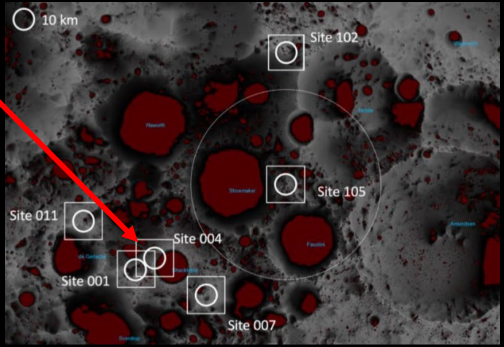
COOPERATION WITH THE ARTEMIS HUMAN SPACEFLIGHT LUNAR PROGRAM

New Opportunity for Space Interferometry: Cooperation with Artemis

- The environment is changing with the Artemis Program establishing a permanent lunar human presence, starting with a base near the lunar south pole
- Even now, there is interest in small science experiments that could take advantage of the infrastructure; the scale of those opportunities will grow
- Our NASA Innovative Advanced Concepts (NIAC) program is thus studying the possibility of constructing a large-baseline, UV/optical interferometer near a human base to leverage off that infrastructure, "Artemis-enabled Stellar Imager (AeSI)"

Shackleton Crater South Pole





AeSI Team

Mission concept under development by NASA/GSFC in collaboration with experts from Industry, Universities, and Astronomical Institutes

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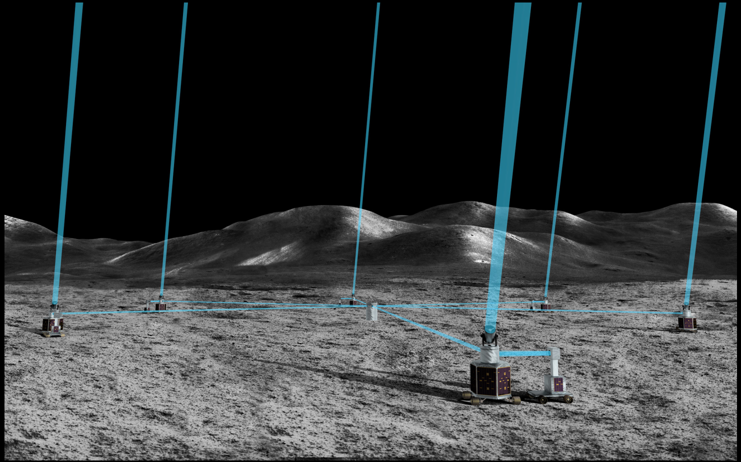
High Level *AeSI* Phase 1 Study Schedule

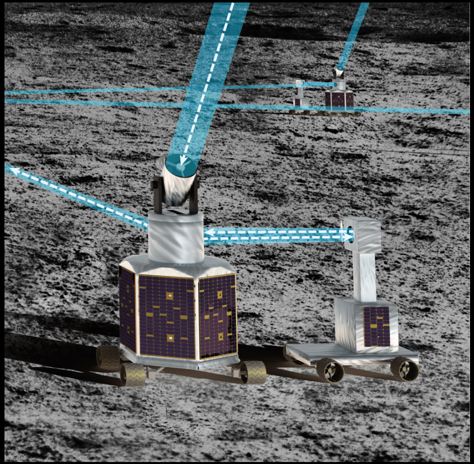
March	April	May	June	July	August	September	October	November	December
3/19&20 : NIAC Phase 1 Orientation						9/10-12: NIAC Symposium			
	Internal Team work and preparation for IDC Study								
	Pre-meetings with IDC								
					Hybrid architectural study with IDC, MDL, IDL				
						Address IDC recommendations, complete Team Tasks and Final Report			
								Initial Prep for Phase II	

March 19-20	NIAC Phase 1 Orientation
April - July	Internal Team Work and Preparation for IDC Study
April - July	Pre-meetings with IDC
mid July/mid August	Hybrid architectural study with IDC, MDL, IDL
Sept 10-12	NIAC Symposium
Sept - Dec	Address IDC recommendations, complete Team Tasks and Final Report
Nov/Dec	Initial prep for Phase II

AeSI: Innovations

- **Build**: a 0.5 km baseline UV-Optical interferometer on the Moon
- **Novel technologies**: dust repellers, rovers to move delay-line optics and primary mirror stations on surface, hub to combine beams from reconfigurable stations
- **Eliminate:** the need for precision formation flying
- **Science**: support broad spectrum of science investigations
- **Timing**: can build as soon as infrastructure available on the Moon





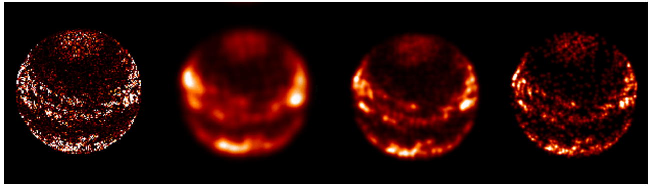
(Britt Griswold/GSFC)

What Will *AeSI* See?

Solar-type star at 4 pc in CIV line

Model

SIsim images

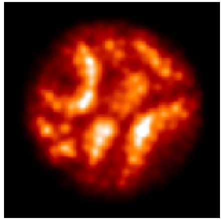


Baseline: 125m 250m 500 m

Evolved giant star at 2 Kpc in Mg H&K line

Model

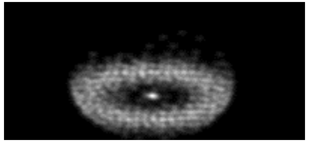
SIsim image (2mas dia)



Baseline: 500 m

SI imaging of planet forming environments: magnetosphere-disk interaction region

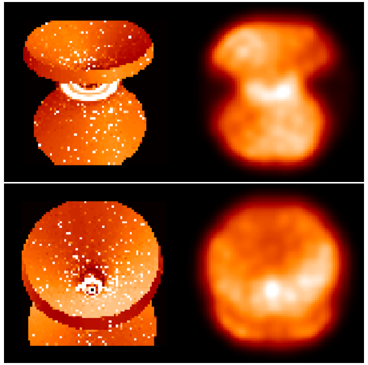
0.1 mas



SI simulation in
Ly α–fluoresced H2 lines

Baseline: 500 m

SI imaging of nearby AGN will differentiate between possible BELR geometries & inclinations



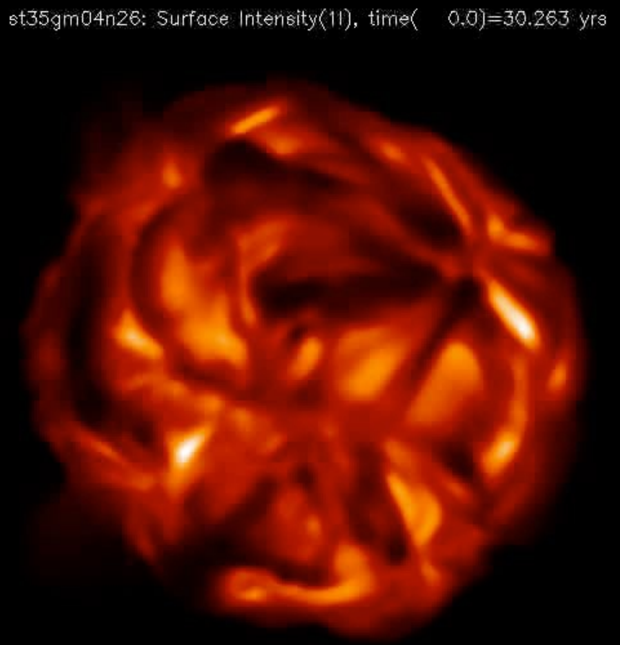
0.1 mas

model

SI simulations in CIV line
(500 m baseline)

… And, *AeSI* will see motions of and *within* objects on timescales that would have astonished previous generations

- nearby stars will move across the sky as we watch
- physical processes will be directly visible
  - mass transfer in binaries
  - pulsation-driven surface brightness variation and convective cell structure in giants & supergiants
  - jets in young solar systems



Artemis-enabled ***Stellar Imager (AeSI)***

is a UV-Optical, space-based interferometer for 0.1 milli-arcsecond spectral imaging of stellar surfaces and interiors and of the Universe in general.

It will resolve for the first time the surfaces and interiors of sun-like stars and the details of many other astrophysical objects & processes, e.g.:

Magnetic Processes in Stars

activity and its impact on planetary climates and on the origin and maintenance of life;

stellar structure and evolution

Stellar interiors

in solar and non-solar type stars

Infant Stars/Disk systems

accretion foot-points, magnetic field structure & star/disk interaction

Hot Stars

hot polar winds, non-radial pulsations, envelopes and shells of Be-stars

Cool, Evolved Giant & Supergiant Stars

spatiotemporal structure of extended atmospheres, pulsation, winds, shocks

Supernovae & Planetary Nebulae

close-in spatial structure

Interacting Binary Systems

resolve mass-exchange, dynamical evolution/accretion, study dynamos

Active Galactic Nuclei

transition zone between Broad and Narrow Line Regions;

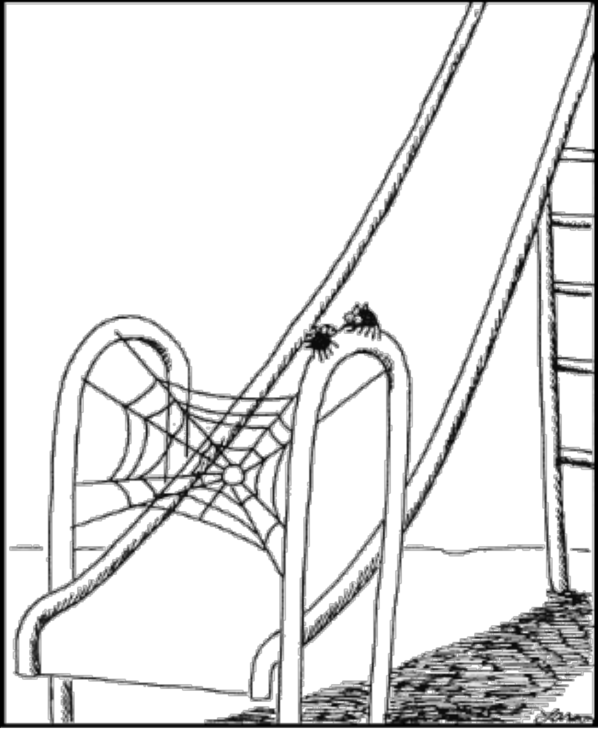
origin & orientation of jets;

distances

The Current State of Space Interferometry

- "Yeah, that can't be good."
  - Sheriff Jack Carter/Eureka
- "It was the best of times,
  it was the worst of times, ...
  the spring of hope,...
  the winter of despair...
  we had everything before us, we had nothing before us..."
  - from a "Tale of Two Cities"/Dickens
- "Risk. Risk is why we're here. It is what this (starship) interferometer is all about."
  - James T. Kirk/ST:TOS

However...



"If we pull this off, we'll eat like kings."

The Farside/Gary Larson, courtesy of Gerard van Belle

Backup Charts

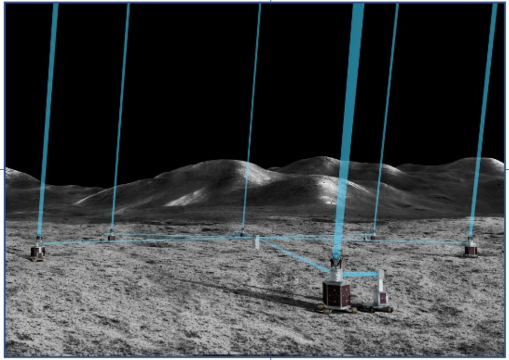
A Lunar Long-Baseline Optical Imaging Interferometer: *Artemis-enabled Stellar Imager (AeSI)*

Innovation

- **Build:** a 0.5 km baseline UV-Optical imaging interferometer on the Moon
- **Comparison to alternative approaches:** sparse apertures required for next great step in angular resolution – mirror diameters too large for monolithic or segmented designs. Will assess if better than free-flying option.
- **Novel technologies:** rovers to move delay-line optics and primary mirror stations, hub to combine beams from stations in variable configurations, improved dust mitigation, technologies for long-baseline space interferometers, robotic assistants.

Impact

- **Boldly expands realm of the possible**: many studies of free-flying space interferometers exist, but only limited studies of lunar designs (e.g., farside radio)
- **Begins the technical journey** towards resolving surface features and weather patterns on the nearest exoplanets and enabling an entire fleet of space interferometers covering wavelengths from the X-ray to the far-IR
- **Superb prospects:** ground-based interferometry works; forthcoming infrastructure makes a lunar surface architecture both practical and compelling.



Mission

- ***The Artemis-enabled Stellar Imager (AeSI)*:** 0.5 km diameter UV/Optical imaging interferometer on the lunar surface (~south pole)
- **Scalable:** can start with a small number of mirrors and increase gradually
- **Science:** resolve stellar surfaces & interiors and the central engines of AGN's
- **100x higher resolution than HST and JWST** to resolve stellar surfaces, black holes, and dynamic activity across the Universe on spatio-temporal scales previously impossible.

Approach

Address problems specific to interferometers on the lunar surface: dust mitigation, how to accommodate delay lines without massive structures, mitigation of impact of seismic activity, determine support needed from human infrastructure, and the need and usefulness of support by robotic assistants.

End Goals: Determine optimal methods for moving optics and combining beams from variable configurations, and optimal architecture. Develop a plan for evolving the facility over time, using an optimized mix of humans & robots by end of Phase 1.