ASTRO SCOUT

Autonomous Soft-growing Transformable RObotic System for Surface & Cavity Observation via Unfurling Toolset

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INTRODUCTION & MOTIVATION

Lunar pits — over 200 identified — reach depths >100 m with funnel-like openings. Subsurface lava tubes connect to cave networks at stable **17°C** — shielded from radiation. They are prime human settlement candidates and stratigraphic analysis.

Problem: No existing robot can access confined subsurface spaces. Vine robots grow via tip-localized **eversion**. They require no grip, traction, or joints while passively conforming to irregular terrain.

200+	>100 m	17 °C
Lunar Pits Identified	Pit Depth Reach	Lava Tube Isothermal

MISSION CONCEPT

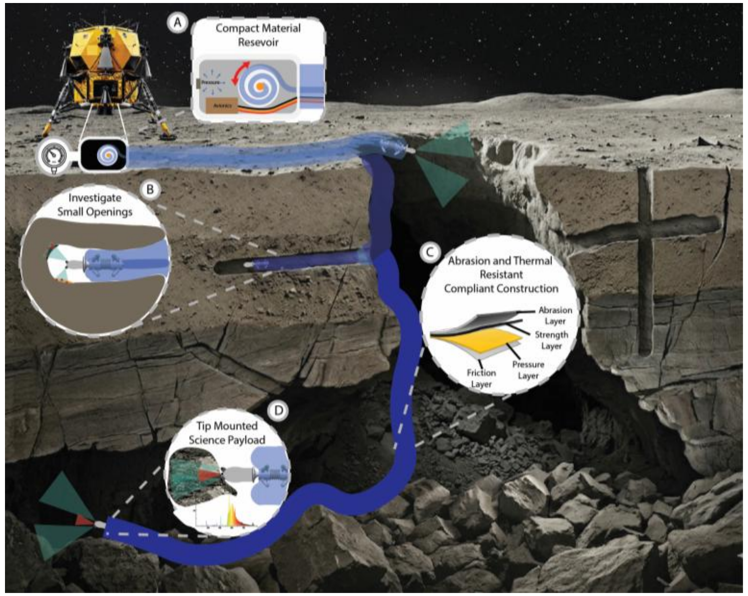


Fig. 1 — Soft growing robot deploys from lander rim, descends pit wall, enters crevices, and performs contact science in the lava tube.

1. **Deploy & Pressurize —** Lander lowers base; N_2 exceeds eversion pressure
2. **Spool Control —** Motorized spool meters growth; tension monitors behavior
3. **Descent Mapping —** Stereo cameras map pit wall during eversion toward pit
4. **Crevice Access —** Body deforms passively to enter sub-nominal openings
5. **Floor Exploration —** Continues growing for spatial coverage within the pit

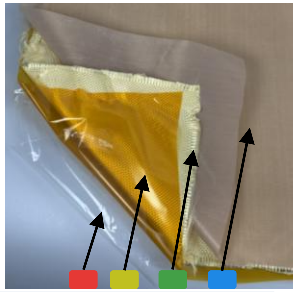
SYSTEM DESIGN — MEMBRANE ARCHITECTURE

Outer: PTFE-coating
Abrasion resistance, high reflectivity/absorption ratio

Structural: Woven Vectran or Kevlar
Strength restraint, load-bearing under eversion pressure

Barrier: Aluminized Kapton FN
Gas barrier, thermal shielding, vacuum heritage

Inner: FEP Liner
Low gas permeability, minimum friction during eversion



Working Fluid: Nitrogen (N_2) — gaseous above −196°C, chemically inert, spaceflight heritage. Open-loop control with partial recovery on retraction.

VINE ROBOT EVERSION PRINCIPLE

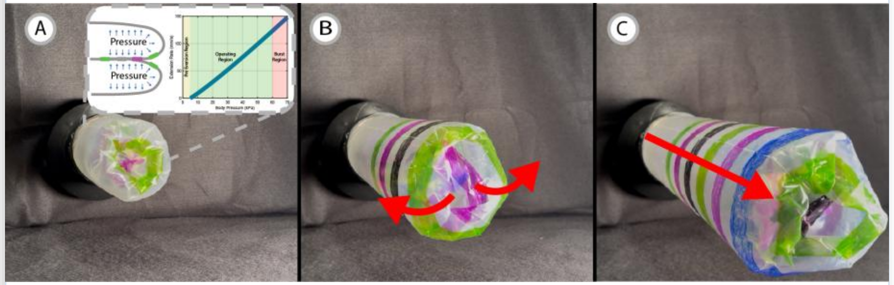


Fig. 2 — (A) Membrane stowed below eversion pressure (B) Material exits at tip (C) Deployed robot extends outward from tip

TIP INSTRUMENTATION & SCIENCE GOALS

CAM — **Stereo Camera Pair**
3D mapping of pit wall stratigraphy and tube morphology during descent and horizontal exploration

VNIR — **Reflectance Spectrometer**
350-1000 nm range, <200 g, LED illumination. In-situ mineralogical ID of exposed basalt and multilayer stratigraphic features

ENV — **Environmental Suite**
Temperature, radiation & pressure sensors measuring habitability across full 260 m deployment path

COMPARISON WITH EXISTING CONCEPTS

Capabilities	ASTRO SCOUT	Moon Diver (Axel)	DAEDELUS	ReachBot
Confined Space Access	Deformable body enters sub-nominal openings	Limited to tether-accessible walls and robot sized apertures	Cannot enter openings smaller than sphere diameter	Boom may reach into crevices, body cannot enter
Terrain independence	No traction or grip required	Needs wheel traction on slopes and flat areas	Needs rollable floor surface and adequate actuator deployment	Needs convex grasp features on walls
Repositioning Capability	Limited; retract and re-grow with constrained path control	Full repositioning via tether winch and wheel motion	Free mobility on floor	Full 3D repositioning
Vertical descent capability	Grows downward under gravity and pressure	Rappels up to allowable tether length	Lowered on tether	Climbs using boom tension
Mechanical Complexity	1 motor + 1 pressure regulator for basic design	2-wheel motors + winch + instrument actuators	Internal mobility actuators + LiDAR rotation	8 booms + 8 grippers + steering
Stowage Volume ratio	Membrane on spool; body is the tether	Rover-type vehicle + separate tether	Rigid sphere + separate tether	Central body + 8 stowed booms
Payload Capacity	Lightweight tools and sensors	Multiple contact and proximity science tools	Small proximity science payloads	Proximity science suite SuperCam

Strong Capability · Limited Capability · Absent Capability

Table 1 — Soft-Growing Robot vs Moon Diver, DAEDALUS, ReachBot.

FEASIBILITY ANALYSIS

Thermal Feasibility

Radiative equilibrium model (no atmosphere). PTFE outer layer (α=0.20, ε=0.85): **66°C equilibrium on sunlit surface** — within all material limits. Lava tube: converges to isothermal 17°C wall.

66°C	≤66°C	17°C
Sunlit Surface	Skylight Zone	Lava Tube

Mass Budget (260 m, 127 mm diam.)

Membrane 31 kg (68%) · N_2 1.5 kg · Avionics ~13 kg → Total ≈ 45.5 kg

45 kg	260 m	40 kPa	TRL 9
Total System Mass	Deployment Reach	Eversion Pressure	Heritage Materials

CONCLUSION & FUTURE WORK

- Unique niche: terrain-independent confined-space access impossible for any rigid platform
- Four-layer composite (PTFE-Vectran / Kapton FN / FEP) satisfies all radiation, thermal & outgassing requirements
- Passive thermal feasibility confirmed — 66°C surface equilibrium, 17°C lava tube convergence

Future: Eversion validation of composite · Lunar analog field tests · Multi-sensor tool exchange · Tactile membrane via proprioception