Image: Edited by AnMo

# Enabling New Science with Ancient Mechanical Technology: The Automaton Rover for Extreme Environments (AREE)

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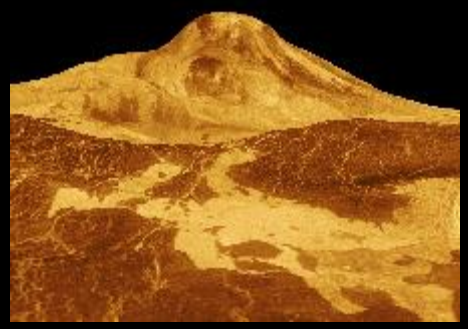
Sept. 6, 2016

**Jet Propulsion Laboratory**
California Institute of Technology

NIAC
NASA Innovative Advanced Concepts

# Why Automata on Venus?



## Longitudinal Science

What are diurnal temperature fluctuations?

How do wind speed and pressure vary?

Is there seismic activity on Venus and to what extent?

What is the make up of the interior of the planet?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Background: Soviet Space Agency
Additional processing: Don P. Mitchell and wanderingspace.net



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# An Inspiring Legacy

Automata have been demonstrated over centuries


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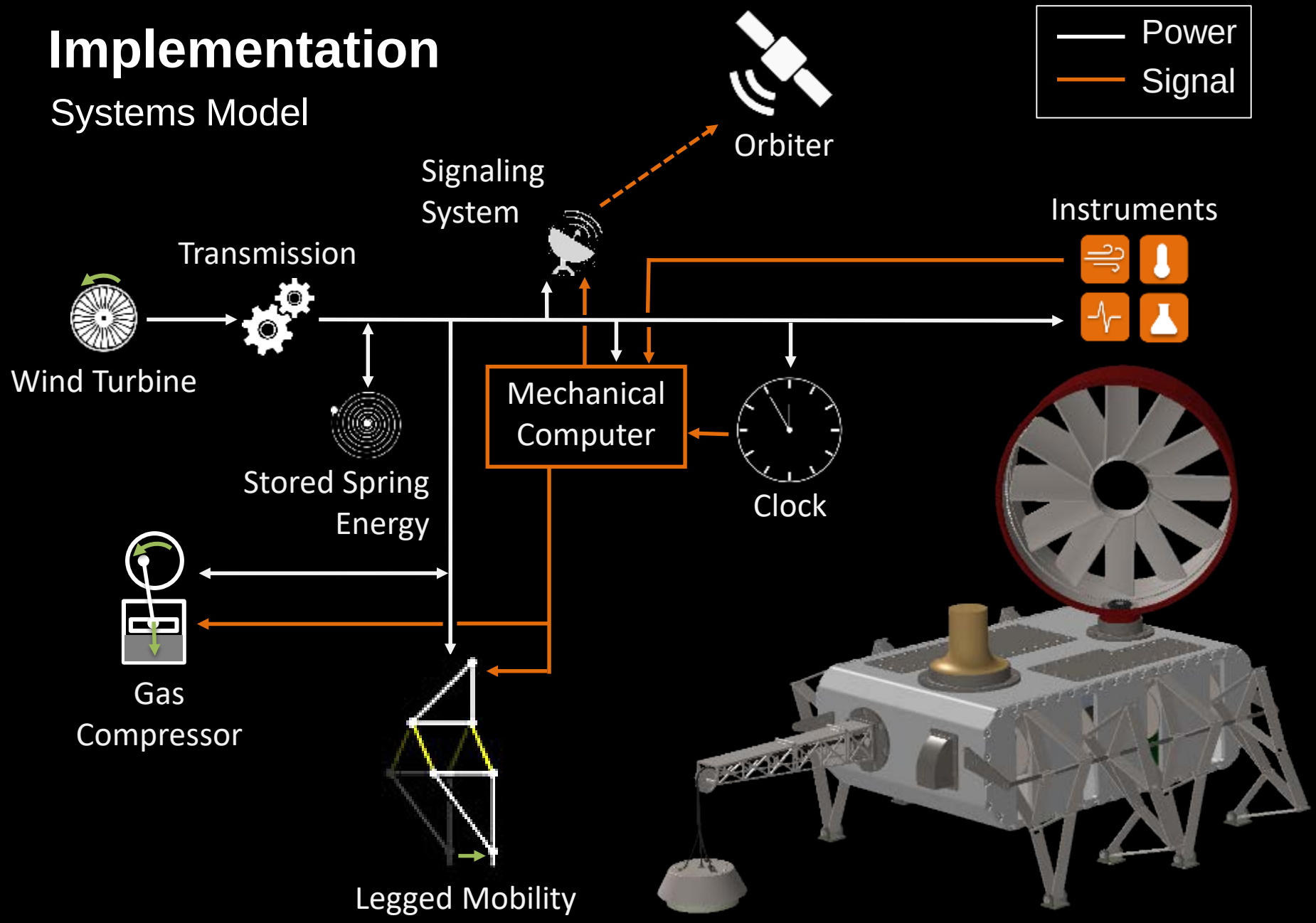
# Implementation

## Systems Model





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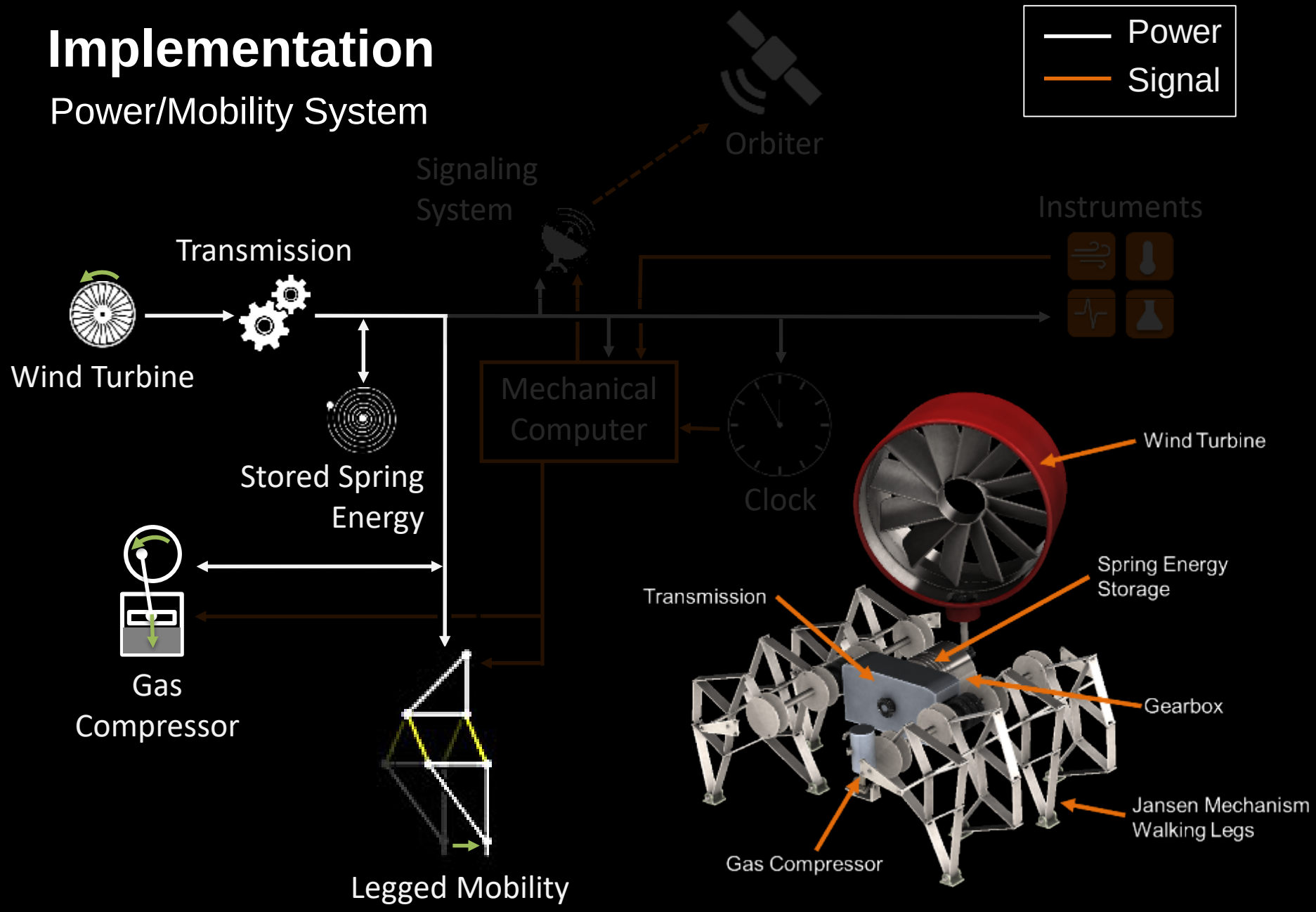
# Implementation

## Power/Mobility System





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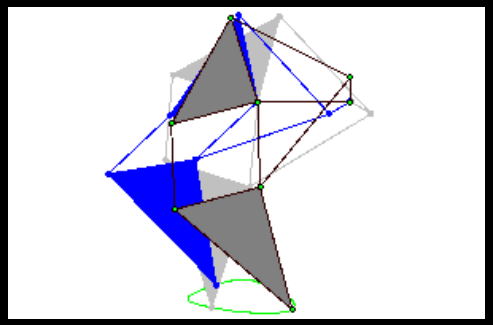
# Locomotion Trade Space

## Wheels

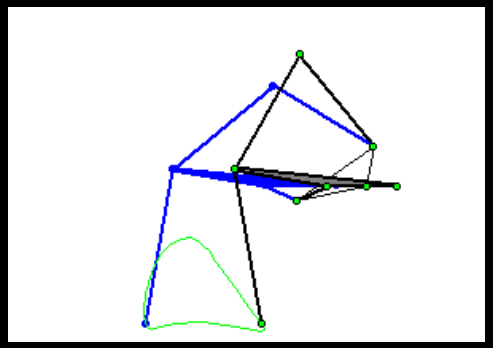
## Tracks

## Legged Mechanisms

Jansen Linkage



Klann Linkage

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# Estimating Power Required

Quick estimations on order of magnitude are required

$$P_{wind}=0.5A\eta\rho v^3$$

$v = 0.3\text{-}1.3\ \mathrm{m/s}$

$v = 0.6\ \mathrm{m/s}$ (average)

$\rho = 65\ \mathrm{kg/m^3}$

$A = 1.8\ \mathrm{m^2}$ (assuming 1.5 m turbine)

$\eta = 50\%$ (Honeywell's Windtronic Turbines an average efficiency of 56% and cut in speed of 0.2 m/s)

$P_{\mathrm{wind}} = 141\ \mathrm{W}$ (peak)

$P_{\mathrm{wind}} = 14\ \mathrm{W}$ (average)

$P_{\mathrm{wind}} = 0.8\ \mathrm{W}$ (min)

Sojourner had peak production of 16W

Spirit/Opportunity had peak production of 141W

Venus Fact Sheet" Available: http://nssdc.gsfc.nasa.gov/planetary/factsheet/venusfact.html.
"WT6500 Wind Turbine," Feb. 2011. Available: https://www.northerntool.com/downloads/charts/385488.pdf
"Mars Exploration Rover Mission: The Mission" Available: http://mars.nasa.gov/mer/mission/spacecraft_rover_energy.html


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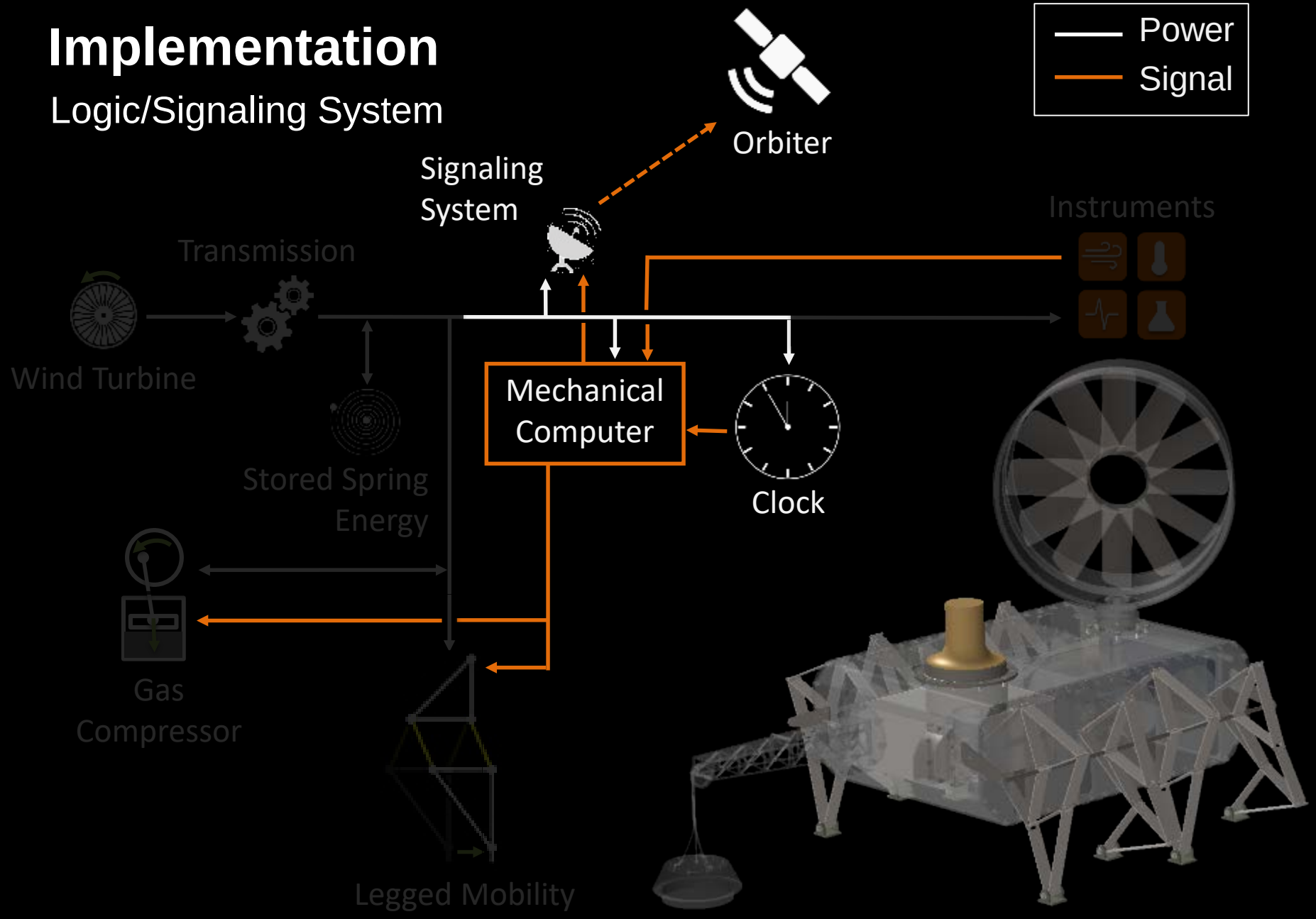
# Implementation

## Logic/Signaling System





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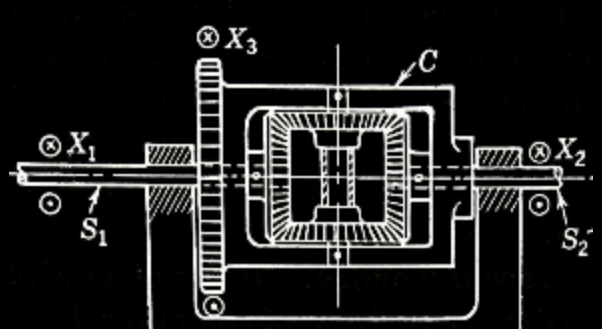
# Mechanical Computing

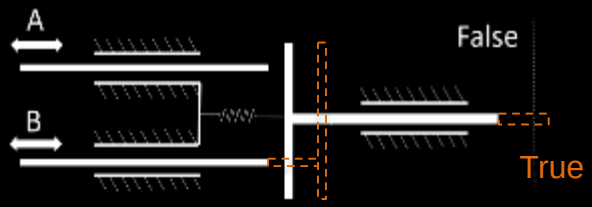
## Analog




$$X_1 + X_2 = X_3$$

Image: Glenns Mueseum

## Digital




*OR Gate*

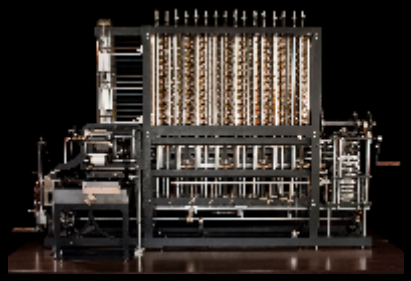
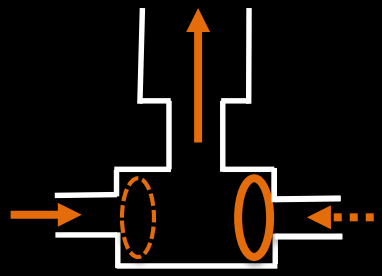


Image: ComputerHistory.org

## Pneumatic Digital



*OR Gate*

Image: M. Rhee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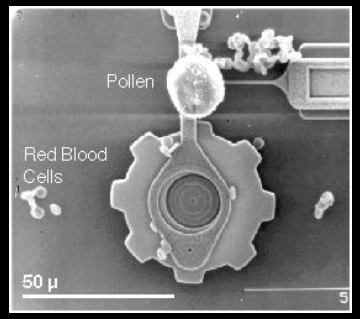
# Estimating Size of Program/Memory

A quick estimation




A single gate could be within 50x50x15µm

(Gears have been fabricated at Sandia on this scale)

0.4m x 0.4m plate could hold 64 million gates.

If each gate is a bit, this is equivalent to 8 megabytes

Soujourner had 7.68 megabytes

*Five Level Surface Micromachining Technology Design Manual.*, Sandia National Laboratories, 2012.

"Mars Pathfinder FAQs - Sojourner" Available: http://mars.jpl.nasa.gov/MPF/rover/faqs_sojourner.html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# Signaling Trade Space

## Records and Balloons

## RADAR Targets

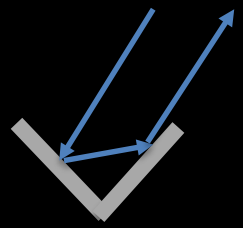

Image: Bin im Garten

## Vacuum Tube/Spark Gap Transmitter

Image: Joe Haupt


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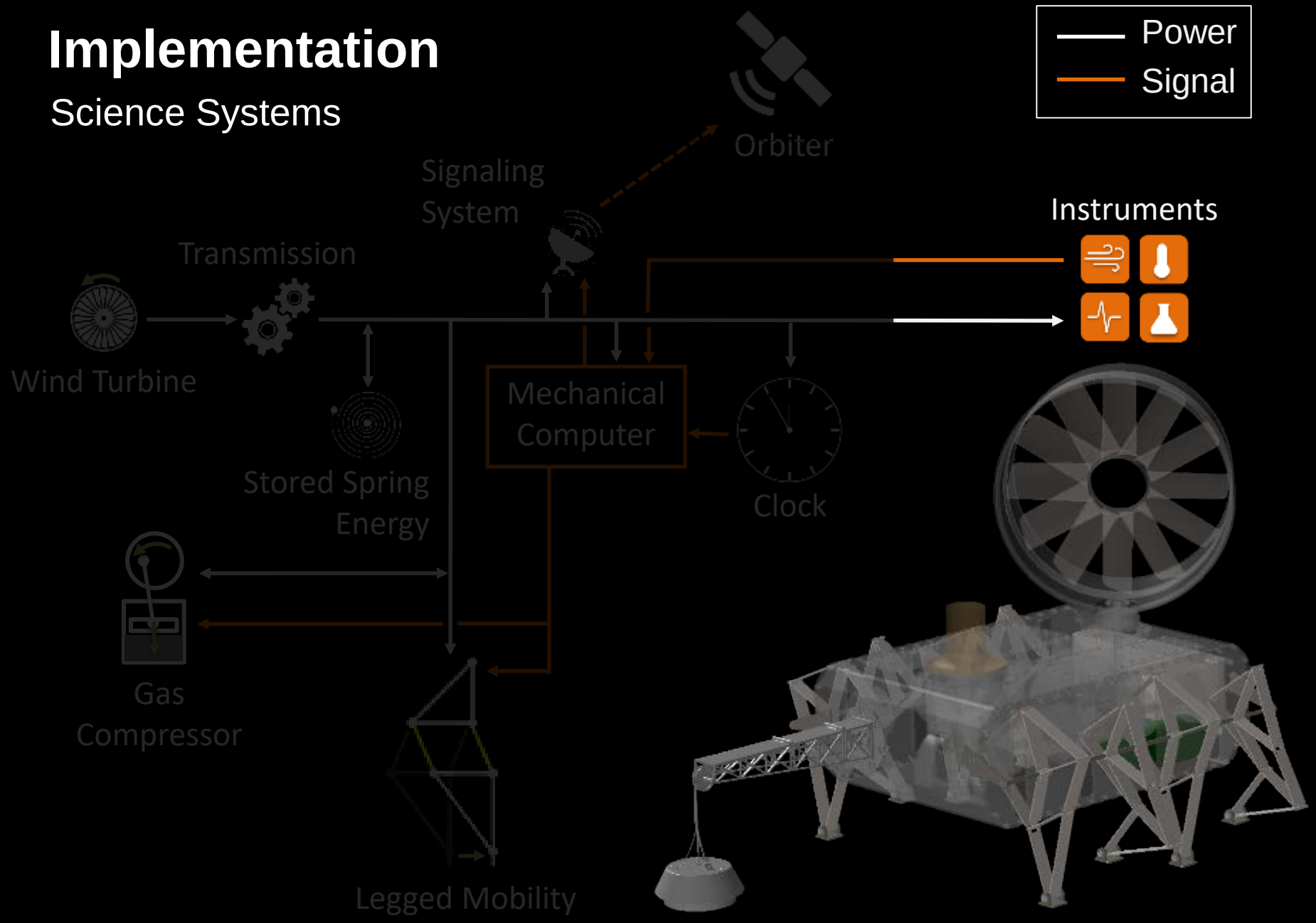
# Implementation

## Science Systems





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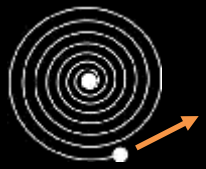
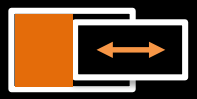
# Science with Automata

**Wind Speed**

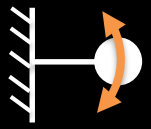
**Temperature**



**Pressure**



**Seismic Events**



**Sample Analysis**

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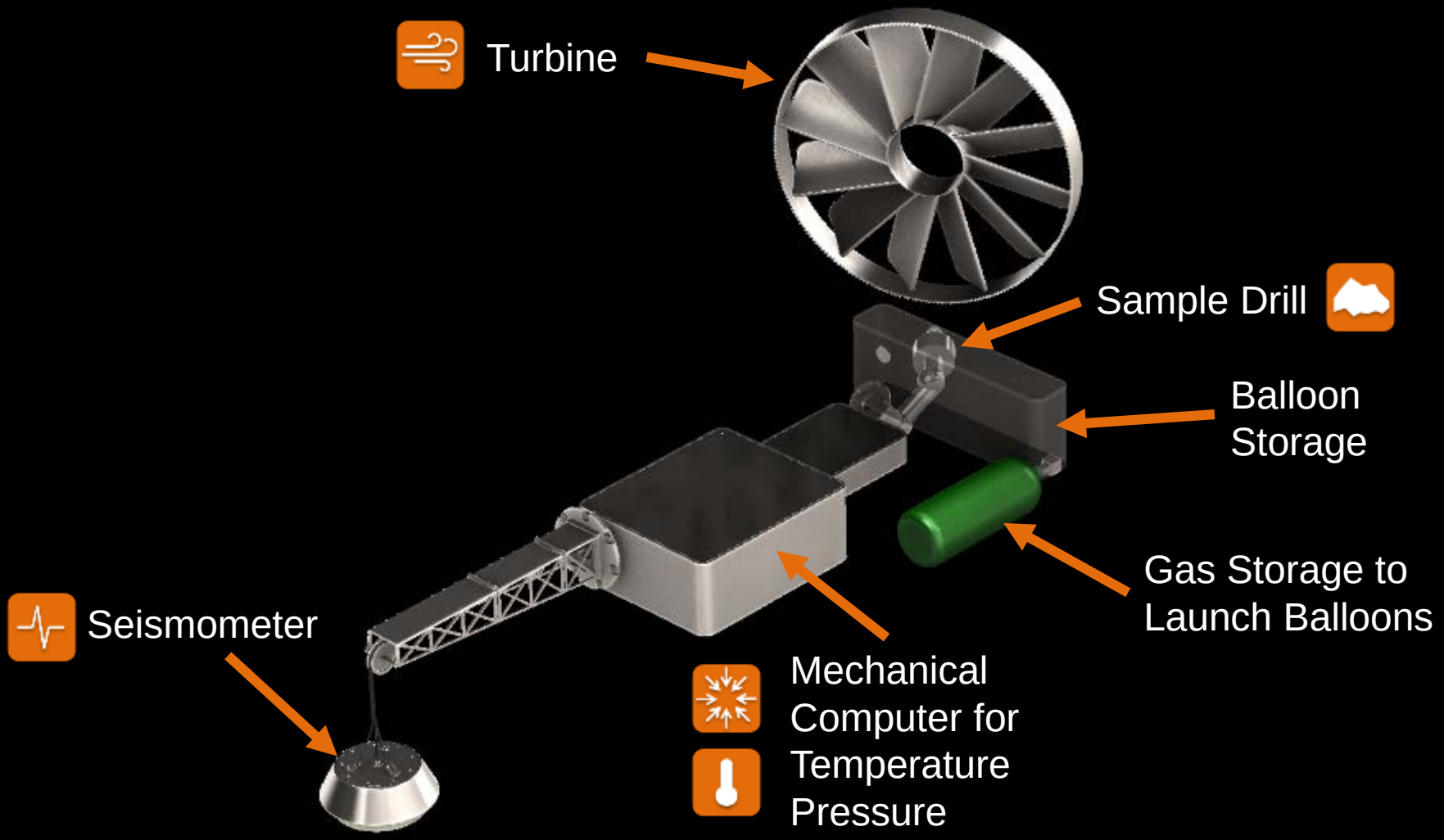
# Science Systems





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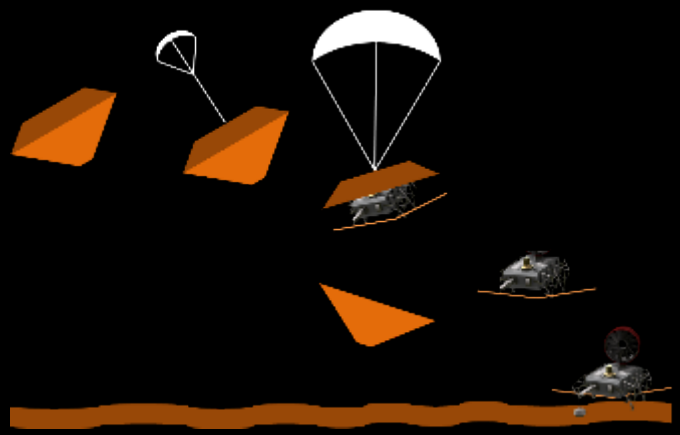
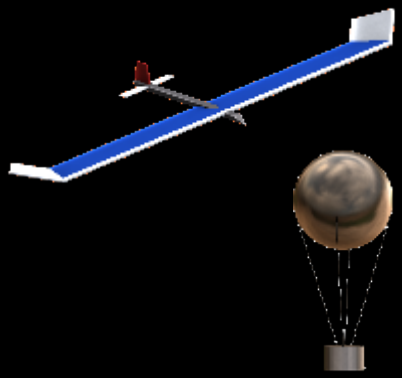
# Supporting Systems

**EDL System**



**Orbiting Radar**

**Drone**

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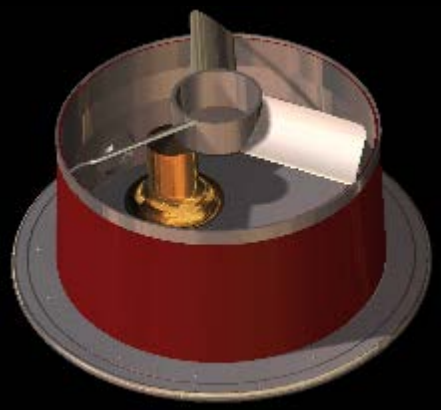
# Alternative Architectures

To Enable In-Situ Science

Tumbleweed

Weather Station(s)

Passive Instruments



Flagship Augmentation

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Background: ESA/J. Whatmore


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