CAMERA–LIDAR HAZARD DETECTION AND AVOIDANCE SYSTEM: FLIGHT TEST RESULTS

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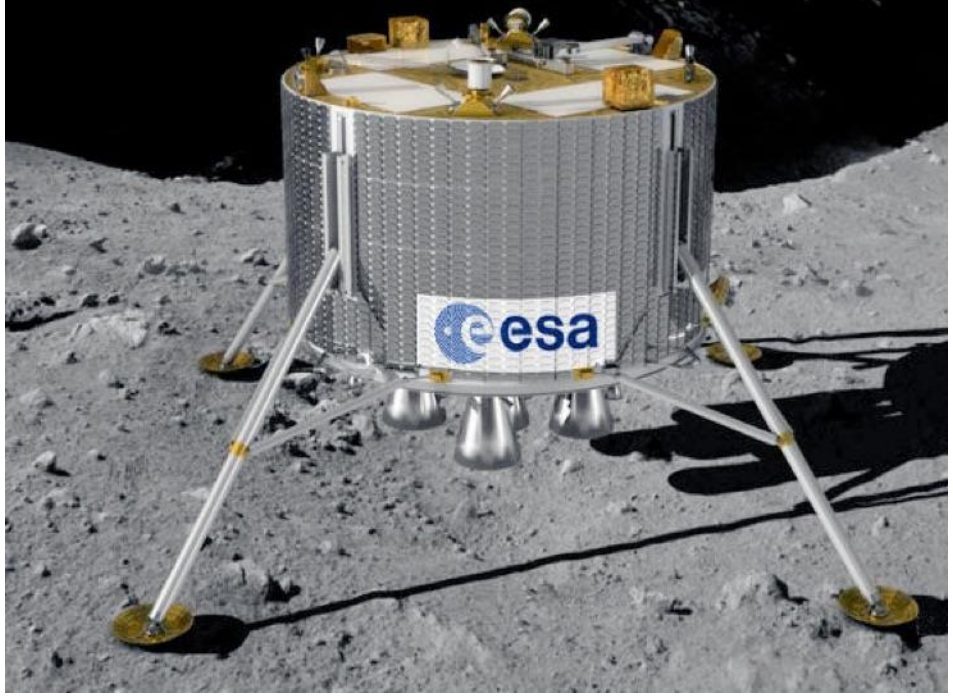
Space

Flight Control & Machine Vision, Mechanisms, Smart Optical Sensors



Remote Sensing

Mapping, Agriculture, Forestry

MAPP

REMOTE SENSING

MAPP.IT

MAPP

Satellite
Multispectral Image
10 m/pixel
update every 5 days
global

Online App
Algorithm generated insights
for farmers to take action
without expert knowledge

Drone
Multispectral Image
5 cm/pixel
on-demand
3rd party local operations

UNMANNED AERIAL SYSTEMS

Platforms

S20: Fixed wing 2kg, 2h

S250: Fixed wing 25kg, 10h

AVERT: Rotating, 25kg

VTOL: Fixed wing 2kg

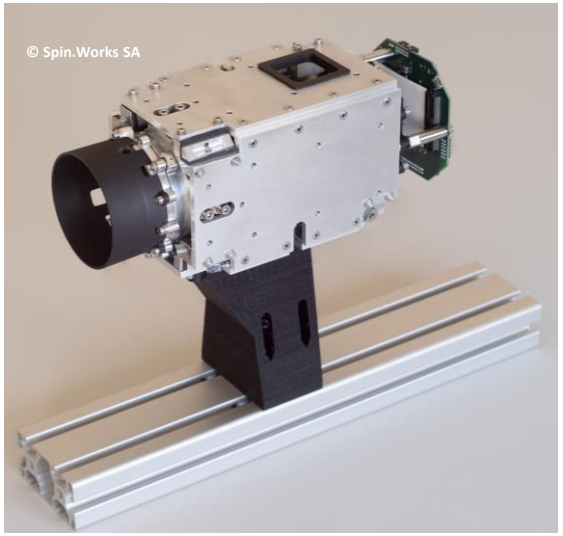
UP: nano satellite

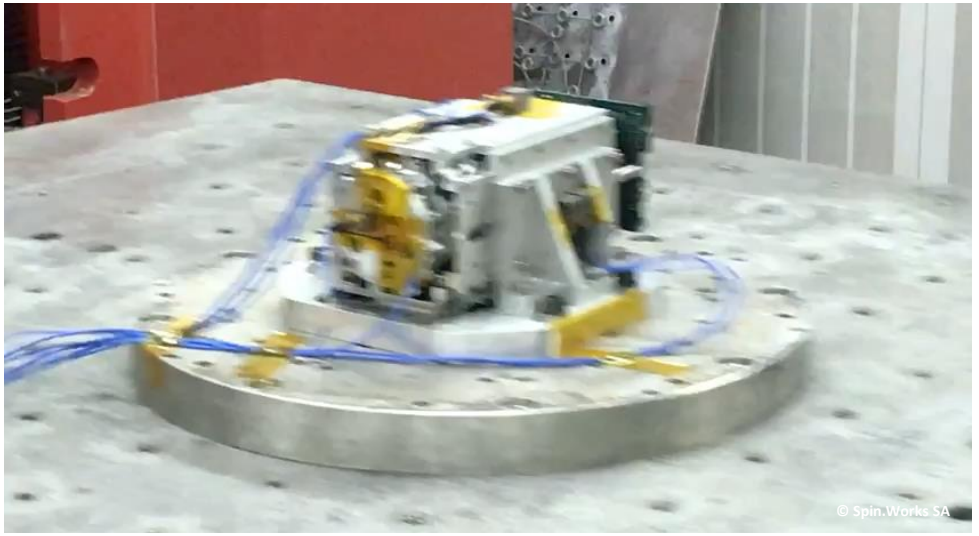
PAYLOAD

Payload

INFANTE: CubeSat camera

LITMUS: micro LIDAR





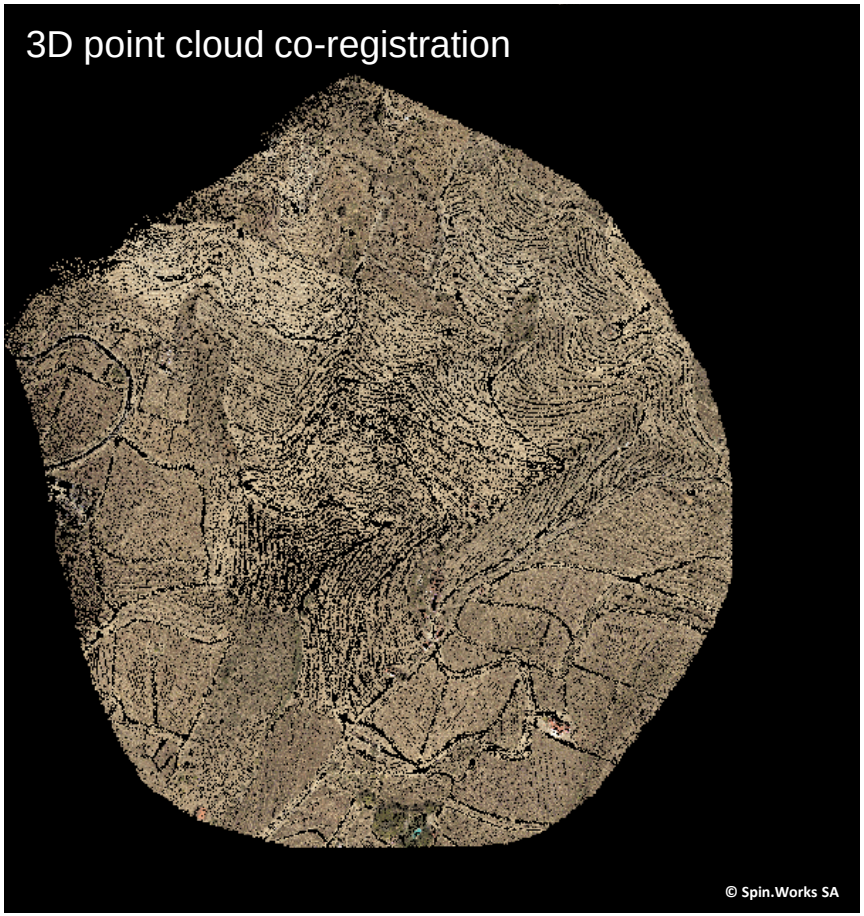
EARTH OBSERVATION – PROCESSING – DATA

Data

AINGEO: hi-res geo (ESA)

CORDS: co-register (ESA)

ML: Machine Learning



HAZARD DETECTION AND AVOIDANCE

Hazard Detection and Avoidance (HDA)

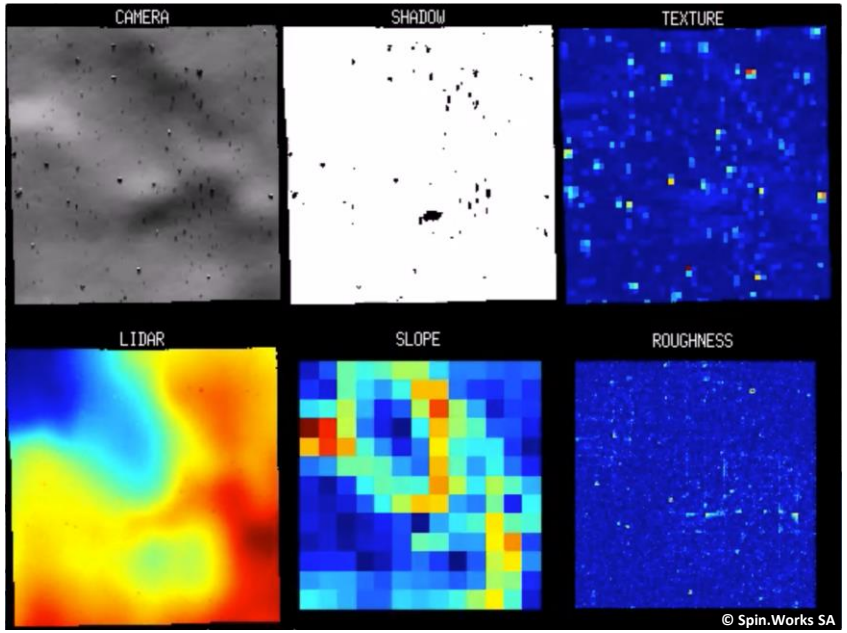
- Key technology for autonomous **Safe** **Precision Landing**

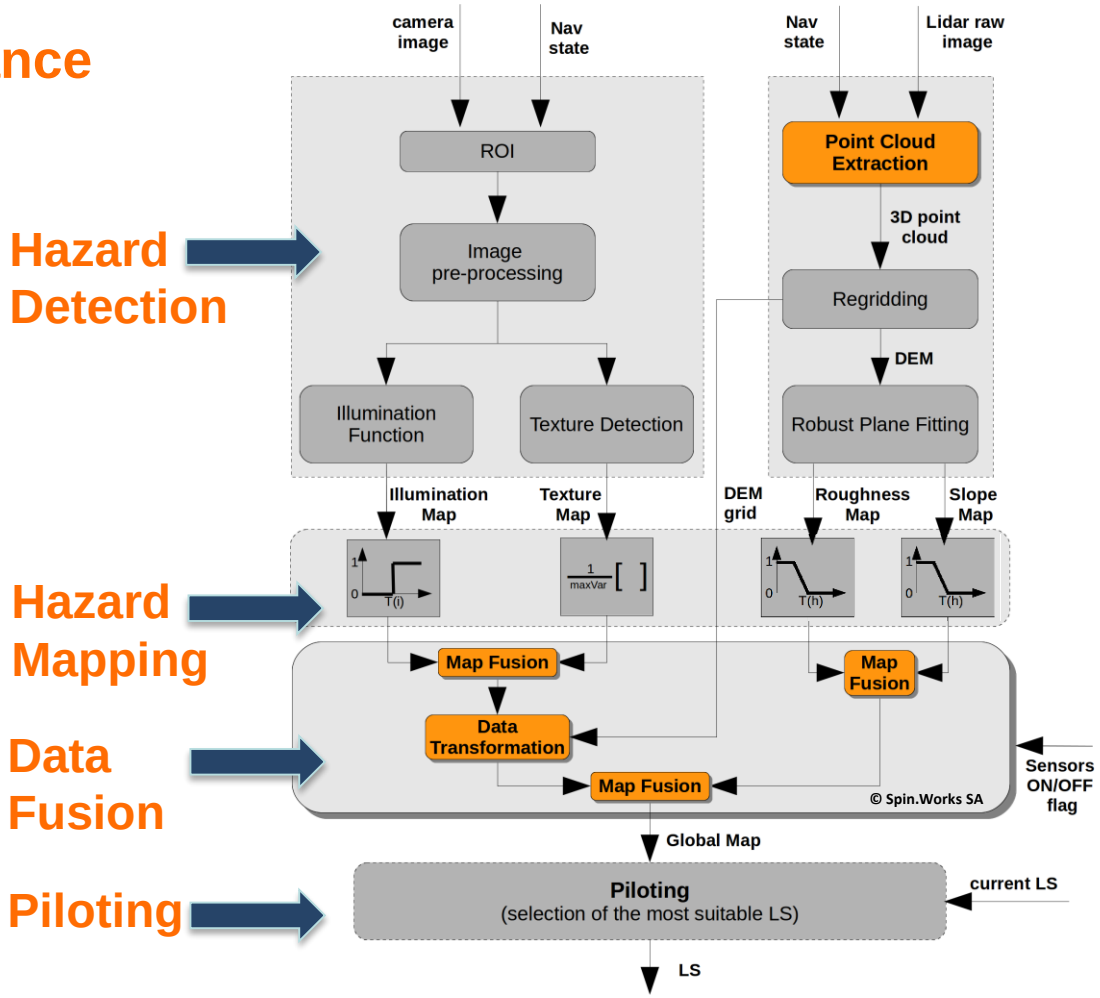
HDA System Design Challenge:

- Minimum sensor suite to enable Hazard Detection (mass, power, Hazard Detection)
- Heterogenous Data Fusion (sensor data, information, etc.)
- HDA strategy (trajectory, #HDA opportunities)
- Onboard memory and processing power
- HDA real time software safe site selection <10sec
- Enable Safe Landing anytime anywhere (Moon, Mars, Minor bodies).

HYBRID CAMERA-LIDAR HAZARD DETECTION AND AVOIDANCE SYSTEM (H²DAS)

Hybrid Hazard Detection & Avoidance (H²DAS)

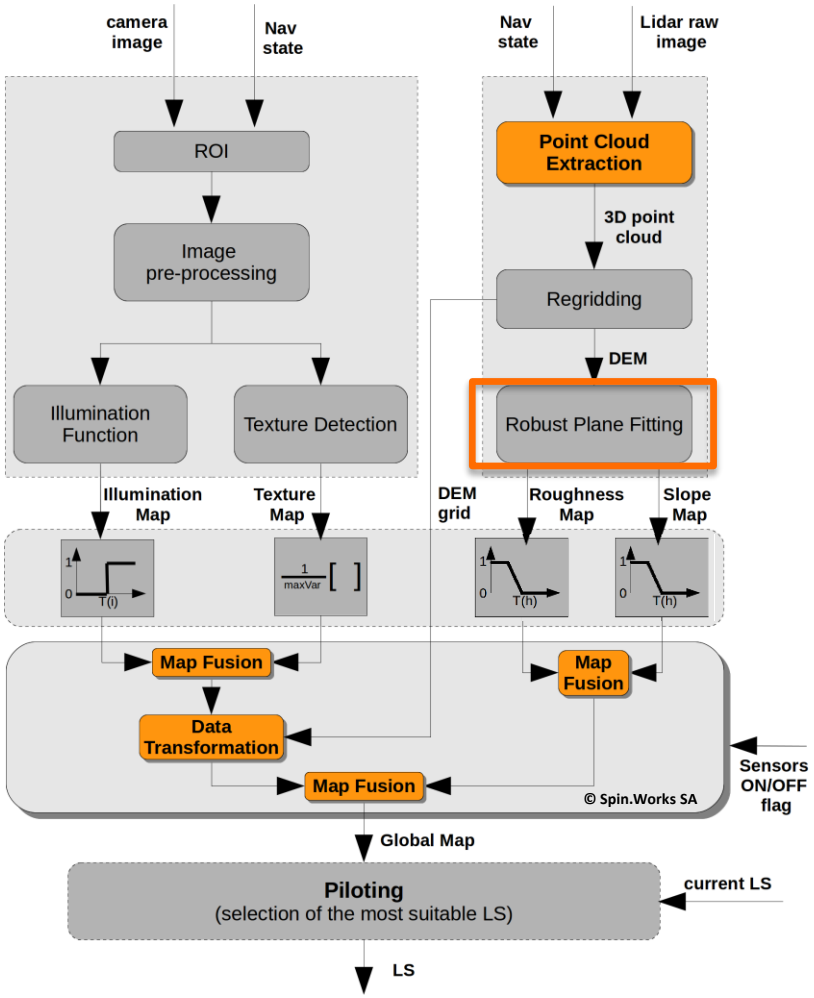




HYBRID CAMERA-LIDAR HAZARD DETECTION AND AVOIDANCE SYSTEM (H²DAS)

H²DAS real-time sw (FPGA accelerated)

- **RTEMS real-time operating system**
- **Firm deadline of 10 seconds**
- Flight hardware with CPU clocked at 36MHz takes 16 seconds to execute all H²DAS tasks
- **H²DAS CPU+FPGA accelerated version returns a Safe Landing Site in 8 seconds**
- The **hardware accelerated version** uses a **modified Sobel filter** and a **mean filter** to extract the slopes and terrain roughness

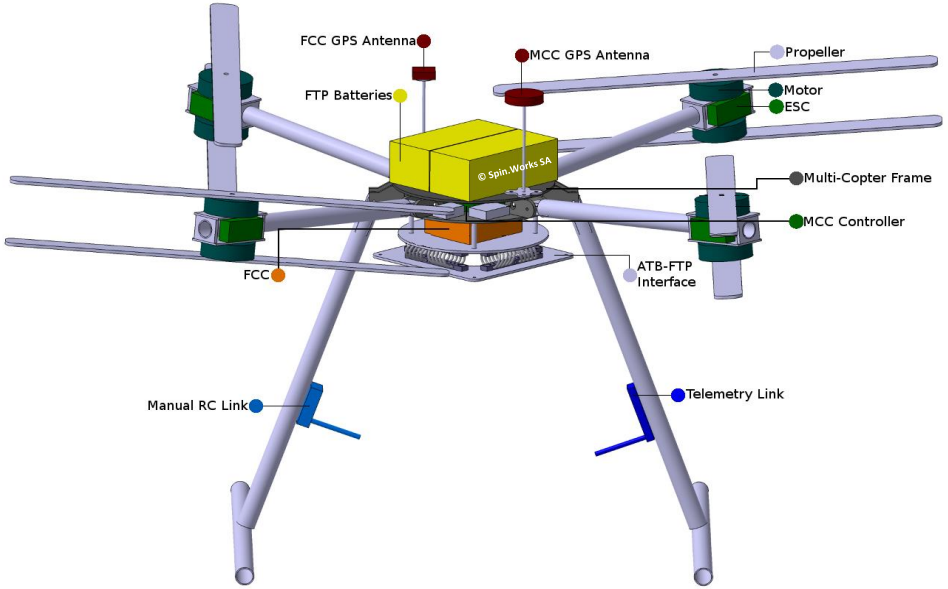


FLIGHT TEST PLATFORM

FLIGHT TEST PLATFORM

Platform Summary

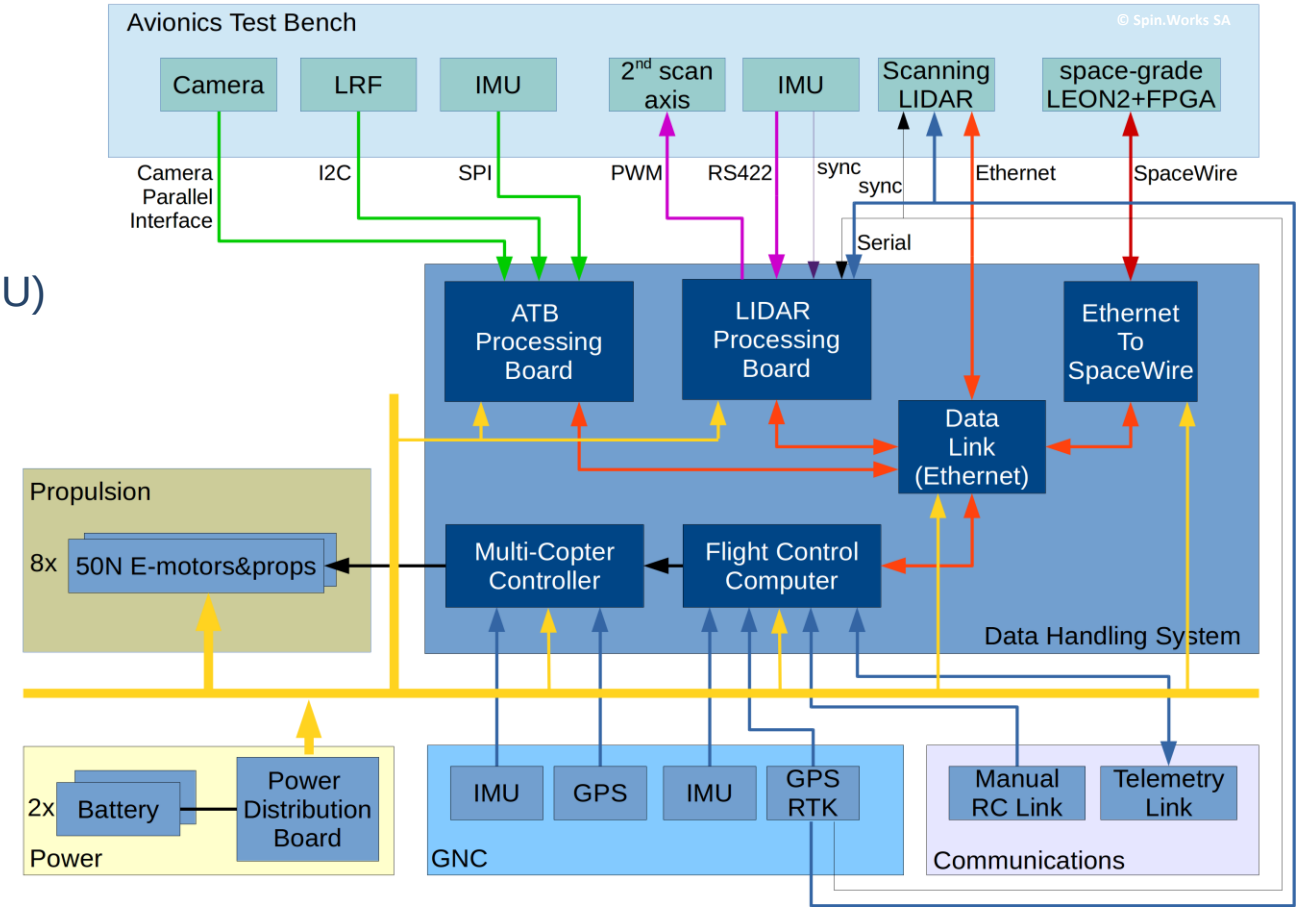
Dimensions [m]	Platform Weight [Kg]	Maximum Take-off Weight [Kg]	Flight Time [min]	ATB Dimensions [cm]	ATB Weight [Kg]
1.9 x 1.9 x 0.78	13	24	9 / 13	33 x 33 x 29	6.8



AVIONICS TEST BENCH

Avionics Architecture

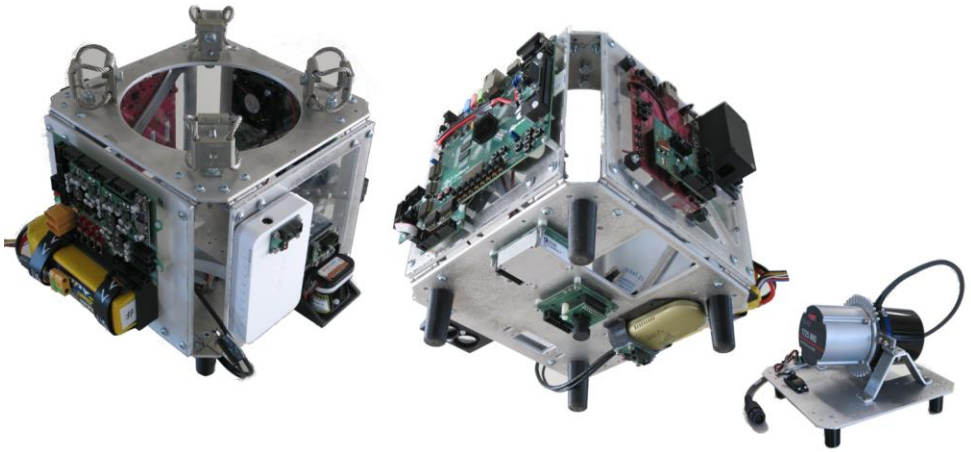
- Flight Test Platform (FTP)
- Avionics Test Bench (ATB)
  - Camera
  - Laser Range Finder (LRF)
  - Inertial Measurement Unit (IMU)
  - LiDAR System
  - Space-grade LEON2+FPGA
  - ATB Processing Board



Avionics Test Bench (ATB)

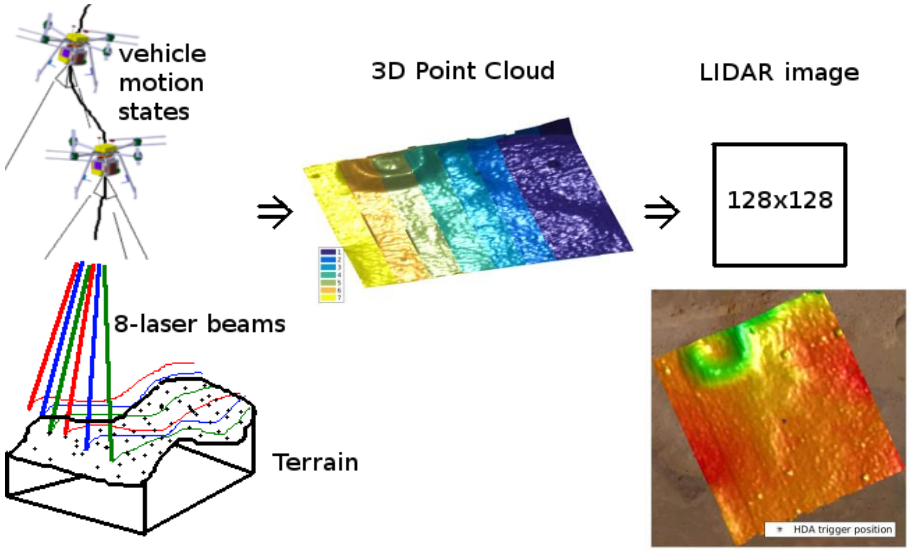
- VN&HDA sensor suite (Camera, LIDAR, IMU, LRF)
- Visual Based Navigation (VBN) Computer:
  - Zedboard
  - ARM Cortex-A9 hard-core CPU @ 665MHz
  - Zynq-7020 FPGA (from Artix family) @ 66MHz
- HDA Computer:
  - Planetary Landing Descent Processing Unit (PLDPU)
  - LEON2 soft-core CPU @ 36MHhz
  - ProAsic3E FPGA @ 18MHz

VBN Computer



LIDAR Imaging System

- -Quanergy M8 scanning LIDAR Laser Unit,
- -KVH 1725 high accuracy FOG IMU,
- -PYNQ (CPU+FGPA) LIDAR Processing Board,
- -2nd scanning axis mechanism (servo actuated)
- -GPS time&position solutions and PPS signal.



Specifications	Flight Tests
Image size [pixels]	128 x 128
Field of View [deg]	25
Pixel angular res. [mrad]	3.4
Range accuracy [cm] (3-sigma @ altitude)	10 @ 83m
Sensor Technology	Scanning LIDAR
Frame rate [Hz]	1/10s < x < 1/5s

TEST SITE
(MARS ANALOGUE TERRAIN)

TEST SITE


- >15,000 m²
- Natural soft & hard slopes
- Limestone & Clay
- 6.9% rock coverage
- Landscaping
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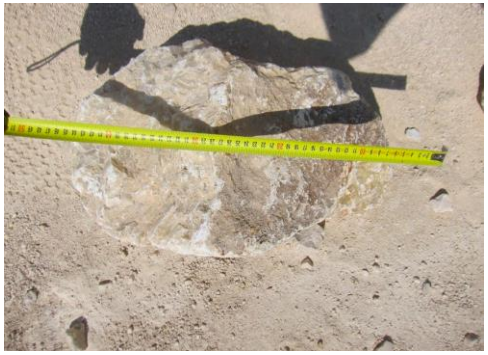
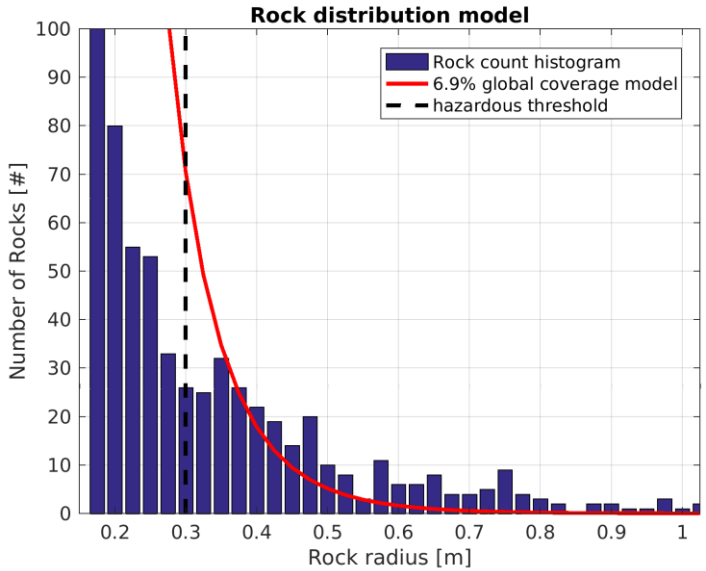
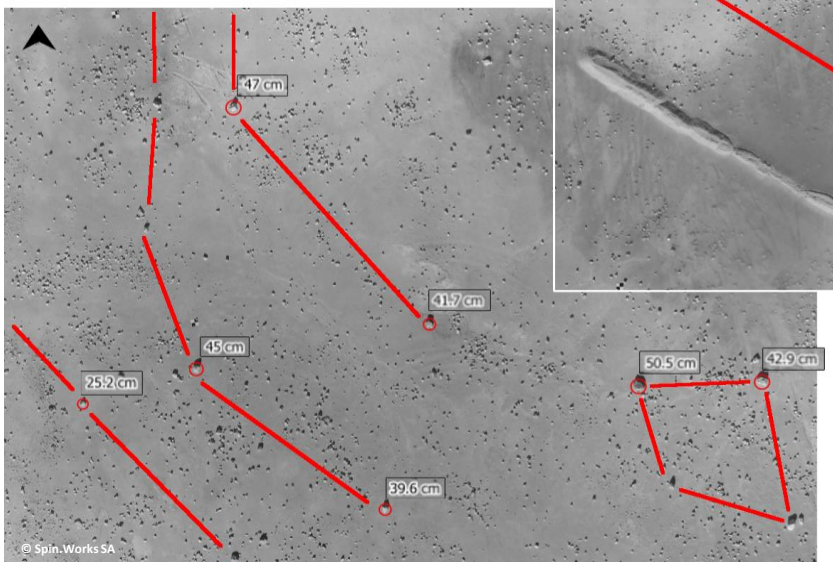
TEST SITE

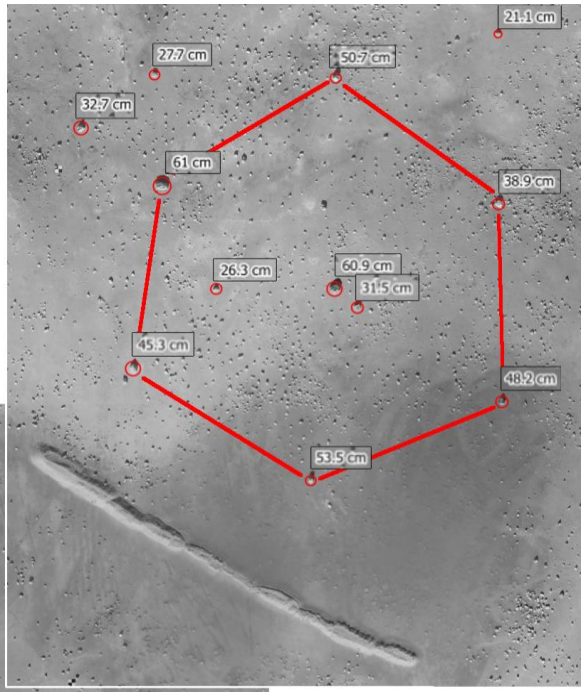


TEST SITE

Safety rate	AVERT Test Site
Slopes	88.80%
Roughness	90.54%
Illumination	99.33%
Global Safety rate	79.09%





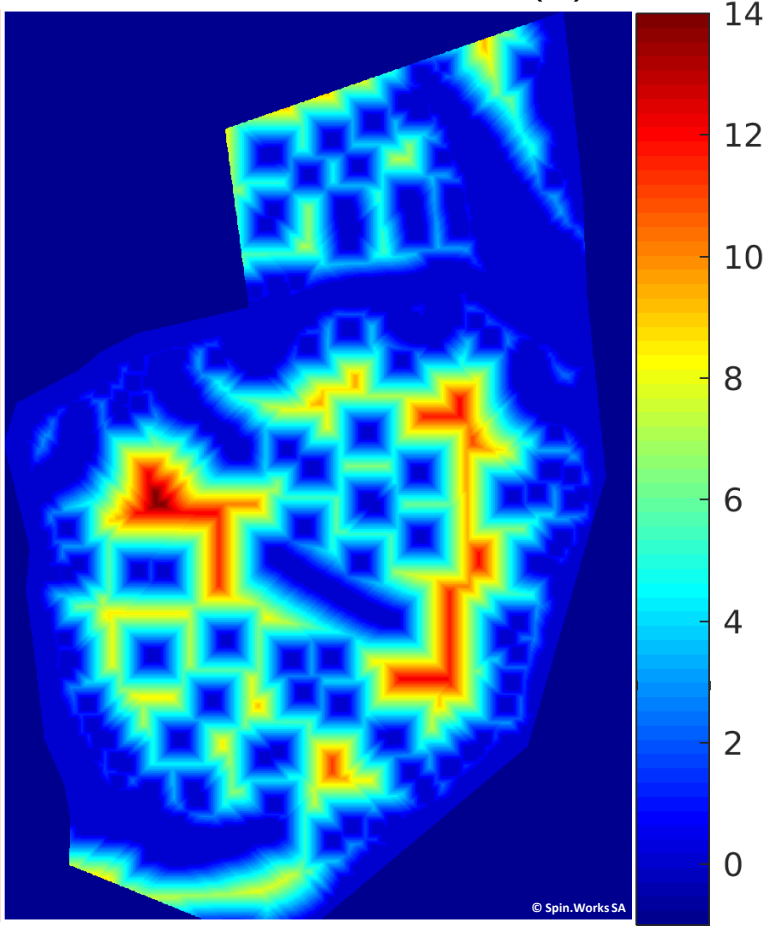


TEST SITE

Camera image

Ground truth (bool)

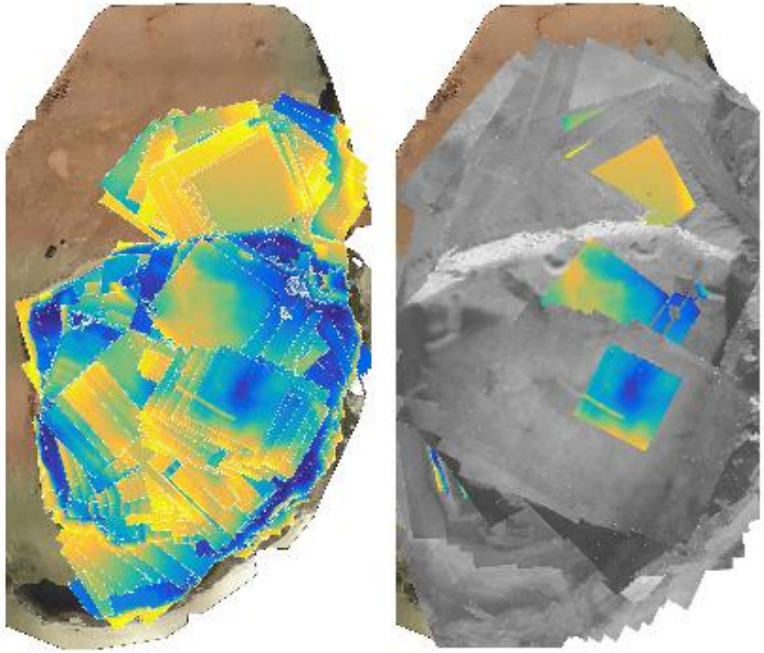
distance-to-nearest-hazard (m)

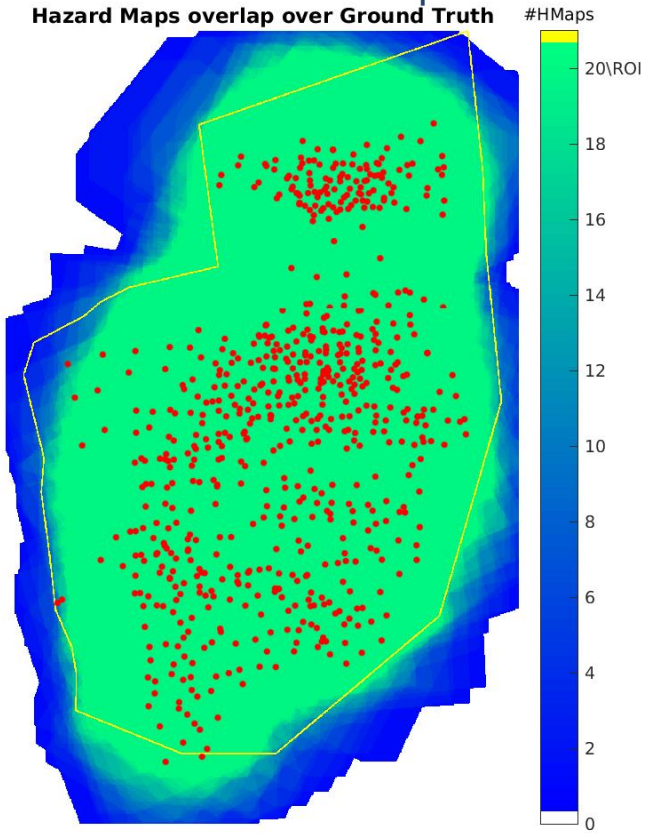


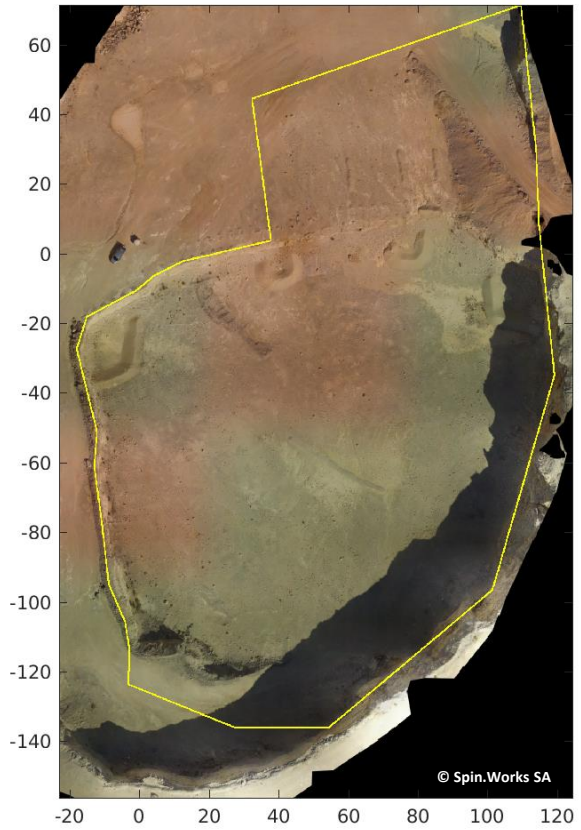
AVERT SYSTEM
SAFE SITE SELECTION
FLIGHT TEST CAMPAIGN

Safe Site Selection (SSS) Flight Test Campaign

- Test H²DAS in a fully representative terrain & assess its performance
- 671 SSS tests executed
- Test site coverage 100%.

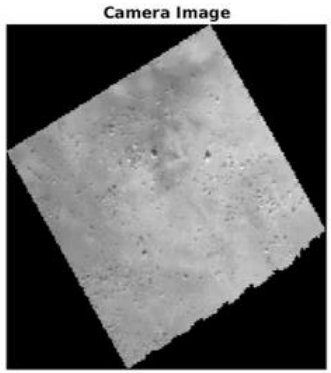


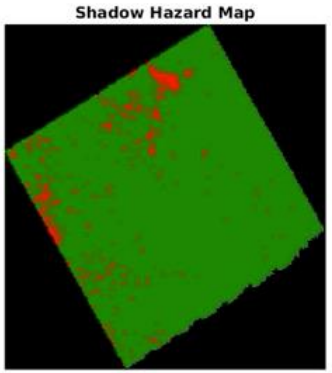


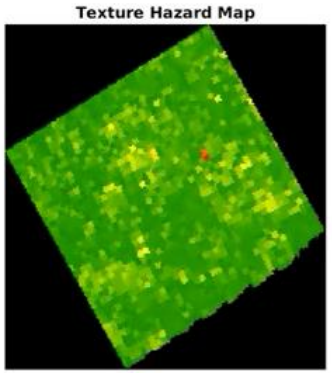


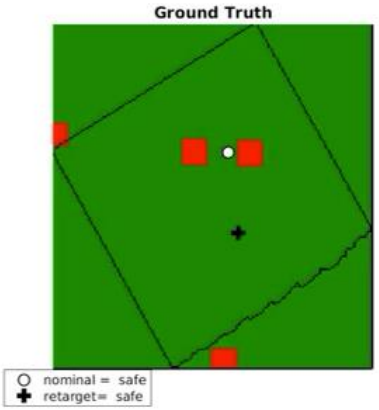
Safe Site Selection (SSS) HDA Results

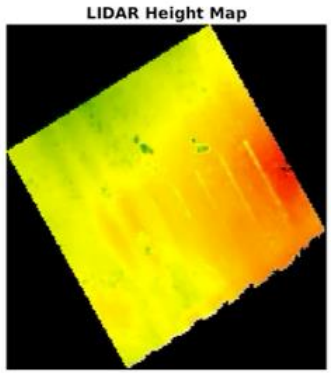
-“The HDA system shall have a probability of safe site selection > 99%”

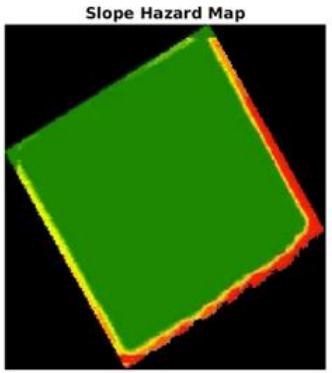


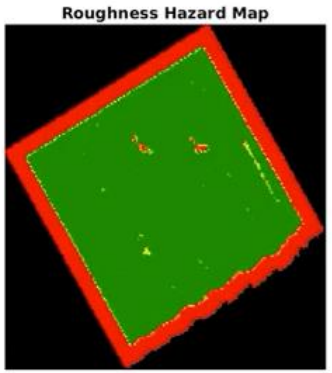


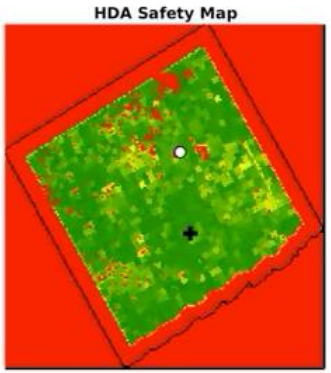












Safe Site Selection (SSS) HDA Results

- -"The HDA system shall have a probability of safe site selection > 99%"
- -671 SSS tests/data points flying at about 80m height AGL @ test site
- -SSS batch processed 2 times by the PLDPU (Camera+LIDAR & Camera only)

	H²DAS	
LIDAR	**ON**	**OFF**
Number of SSS points (# SSS)	671	
Nominal safe blind landings (#safe nominal LS)	597 (89.0%)	
Required diverts (#unsafe nominal LS)	74 (11.0%)	
HDA safe retargeting (**PSSS**) (#safe retargeting LS)	669 (**99.7%**)	659 (**98.2%**)
HDA Miss-detections (#unsafe retargeting LS)	2 (0.3%)	12 (1.8%)

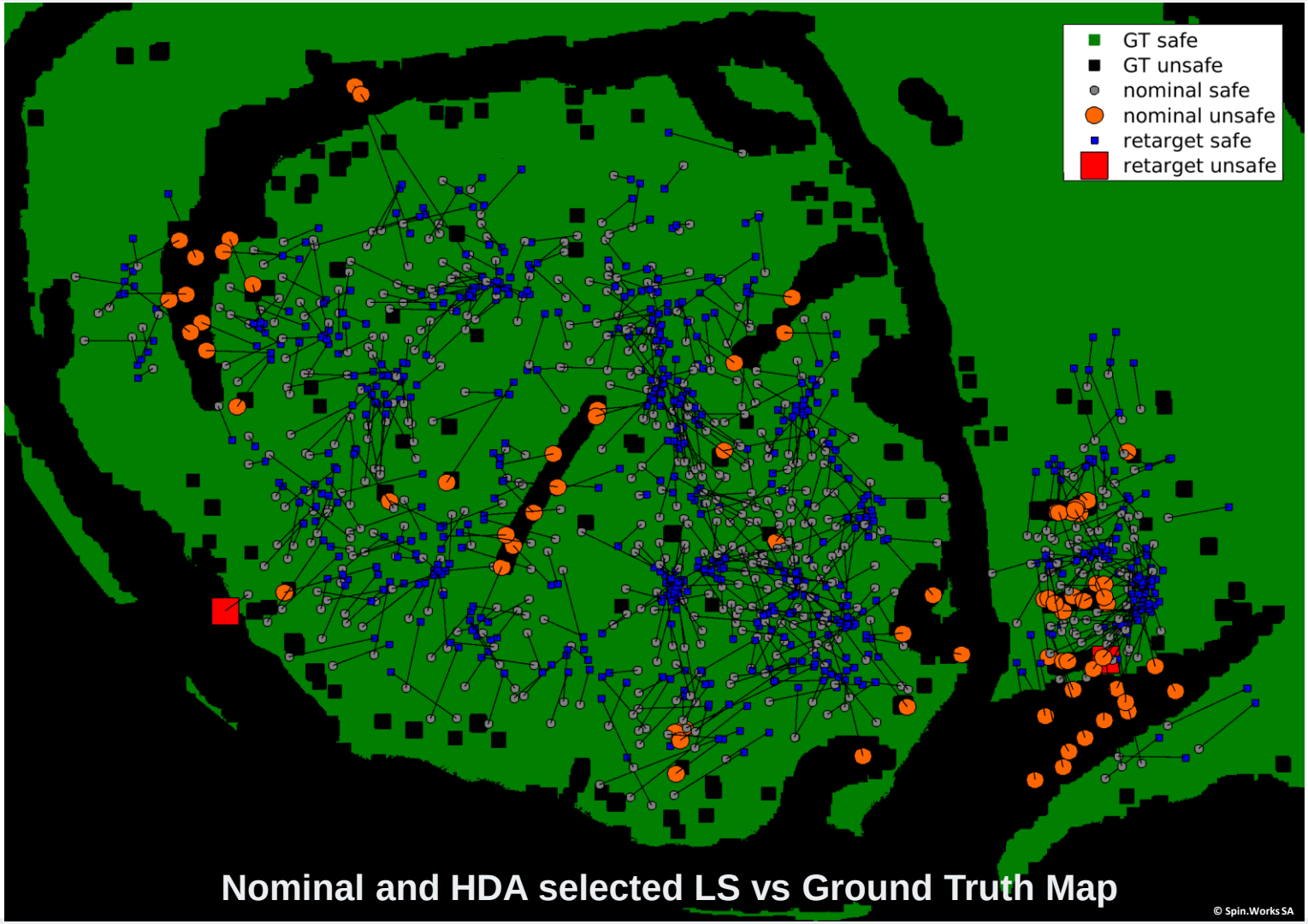
Safe Site Selection (SSS) HDA Results

Confidence levels

- H^2DAS meets the target PSSS with confidence levels of at least 95%

HDA algorithm		H^2DAS	
LIDAR		**ON**	**OFF**
Selected Landing Sites			
Max. allowed prob. of failure (Pfmax)		1%	10%
Flight Tests	HDA measured prob. of SSS	**99.7%**	**98.2%**
	Confidence level (CL) for Pfmax	**96.4%**	**>99.9%**
SIL TDM (Earth)	HDA measured prob. of SSS	99.7%	90.5%
	Confidence level (CL) for Pfmax	>99.9%	63.2%
SIL MPL (Mars)	HDA measured prob. of SSS	99.8%	89.8%
	Confidence level (CL) for Pfmax	>99.9%	41.8%

SAFE SITE SELECTION FLIGHT TEST CAMPAIGN



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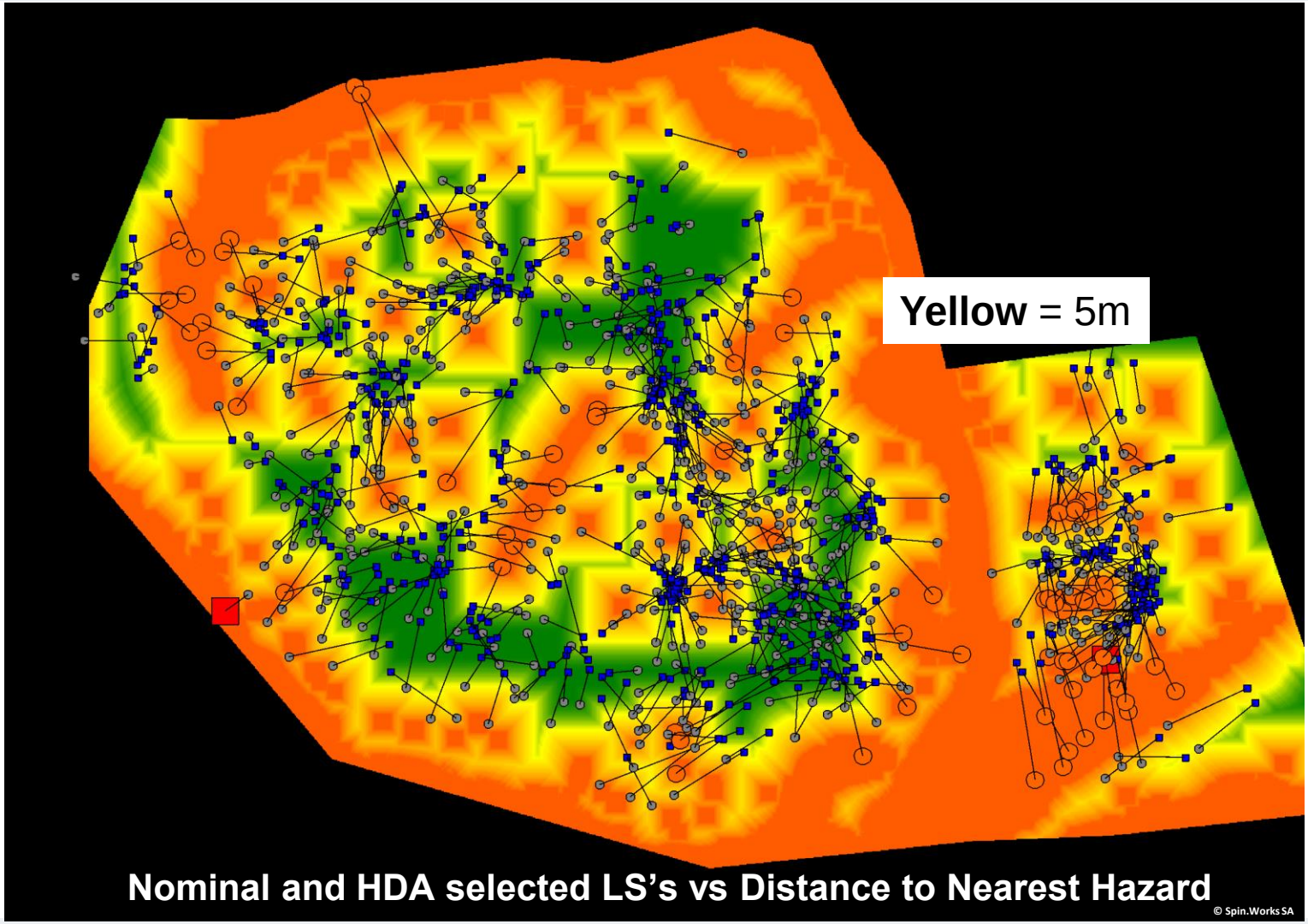


More than 650 Safe Site Selection
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THANK YOU !

TEST SITE

-Mars Analogue

AVERT SYSTEM

-Fully-functional, flying, AVERT System

-Suitable for Flight Testing small scientific payload that fits within 30x30x30cm^3 up to 8kg