INTERREG SUDOE SOE1/P4/E0437
Wildfire Picosatellite Constellation & UAVs Remote Sensing: Active fire mapping and management

# LSTS

## University of PORTO

*UAVs with Software Defined Radio and Infrared Technologies*

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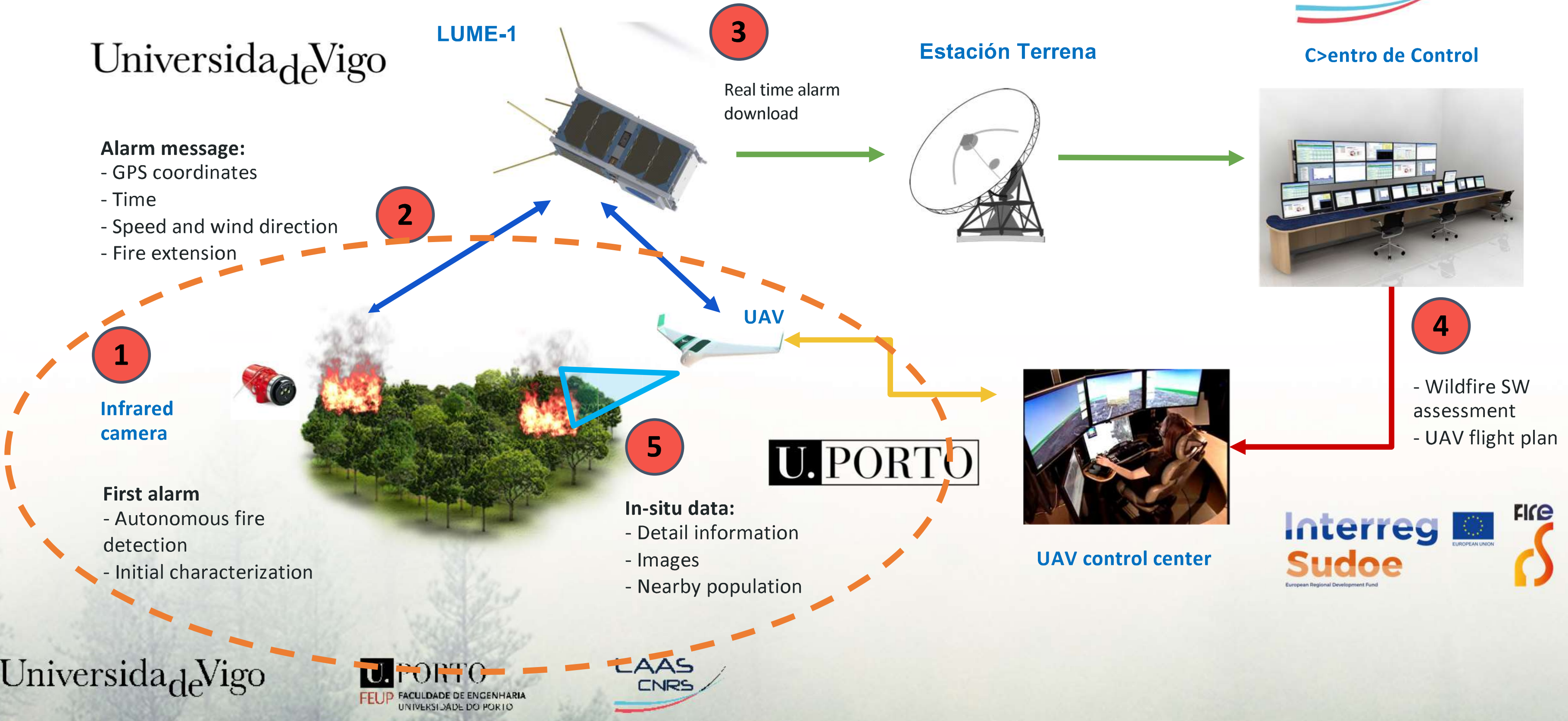
# Fire-RS Project Architecture

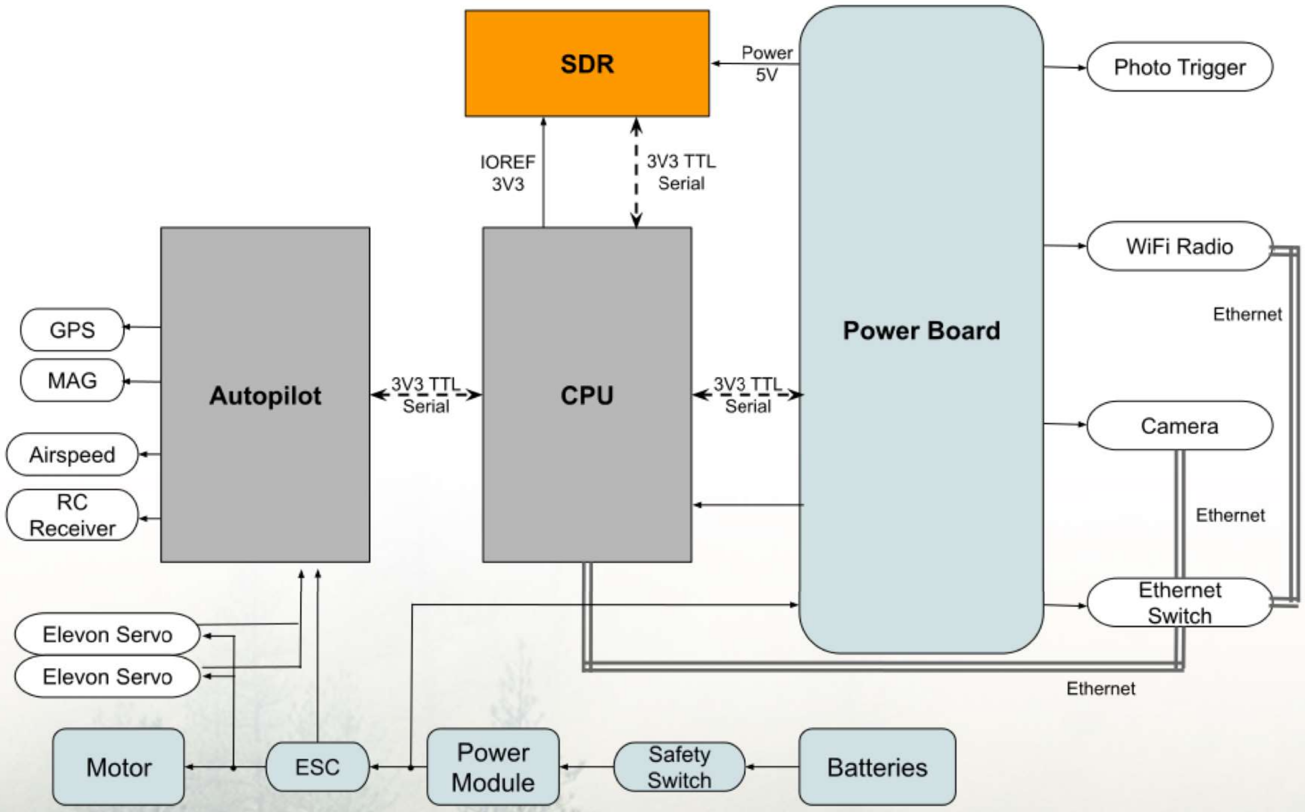
Budget of 2.1M€



# UAV Platform

- **X8** Skywalker Fixed-Wing (COTS platform).
- Modified by LSTS to meet project requirements:
  - Added avionics for **automated flight** and necessary **range** and **endurance** (20km, 50min).
  - Integration within LSTS Toolchain.

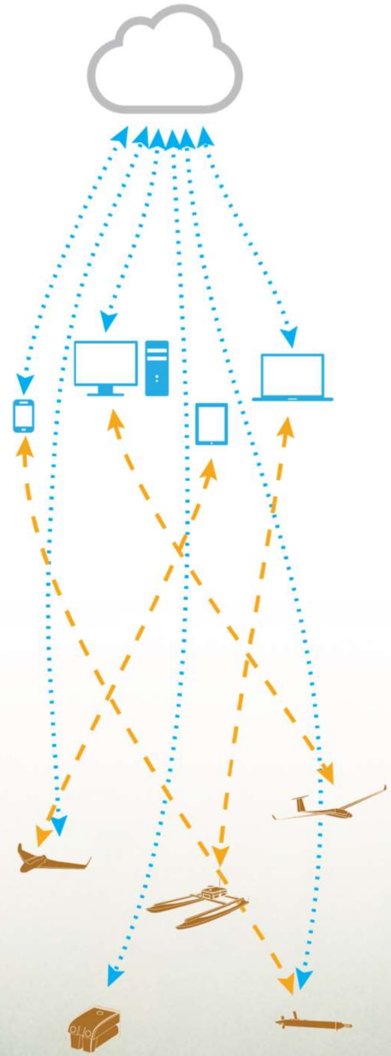
# UAV Avionics




- Fully **Electrical** (LiPo batteries)
- Pixhawk running **ArduPlane** v3.5.2
- CPU (BBB) running **DUNE** (onboard software of LSTS Toolchain)
- 2.4 GHz Wi-Fi
- 433MHz RC link

# LSTS Toolchain

- Open-Source (available on github.com/LSTS).
- Software suite for **mixed-initiative** control (humans in the planning and control loops) of **networked heterogeneous unmanned systems**.
- Capable of handling communication challenged environments.
- More information on lsts.pt/toolchain.



Ripples
Communications hub for data dissemination and situation awareness

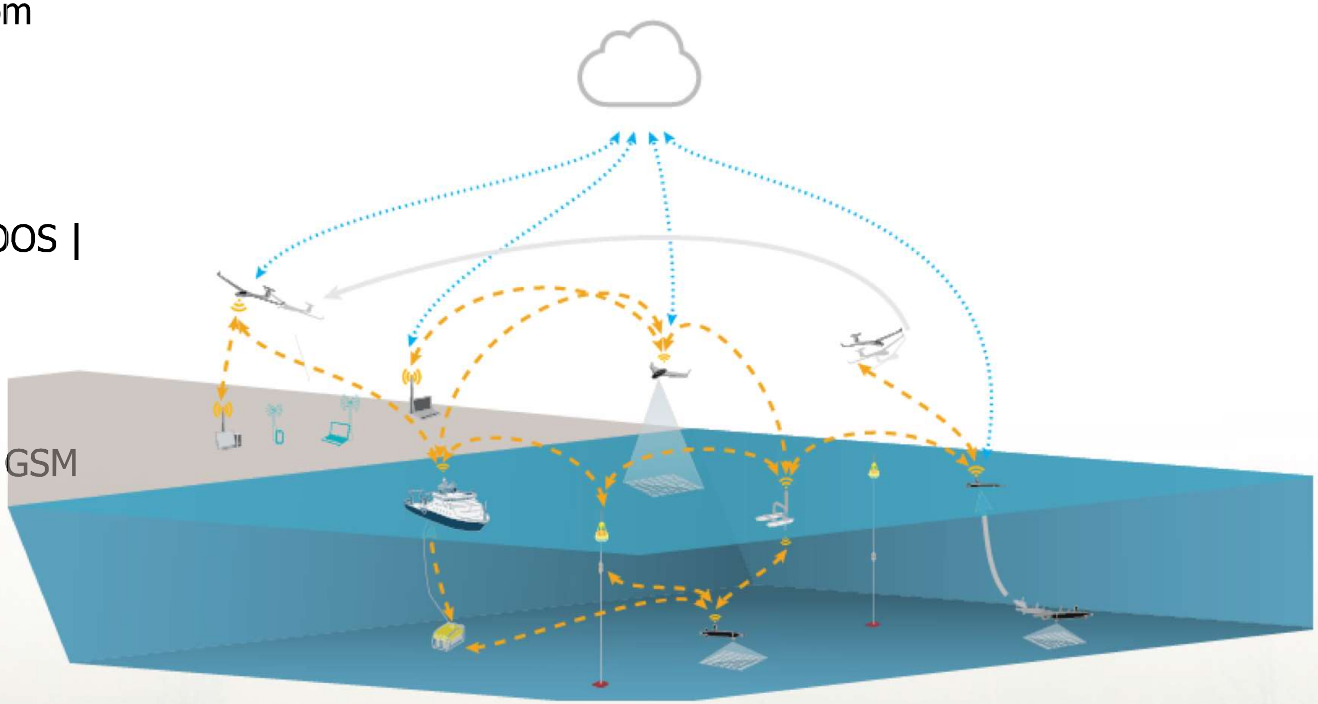
Neptus
World Representation
Planning
Simulation
Execution
Analysis

IMC
Inter-Module Communication protocol

DUNE
Uniform Navigational Environment
On-board Software

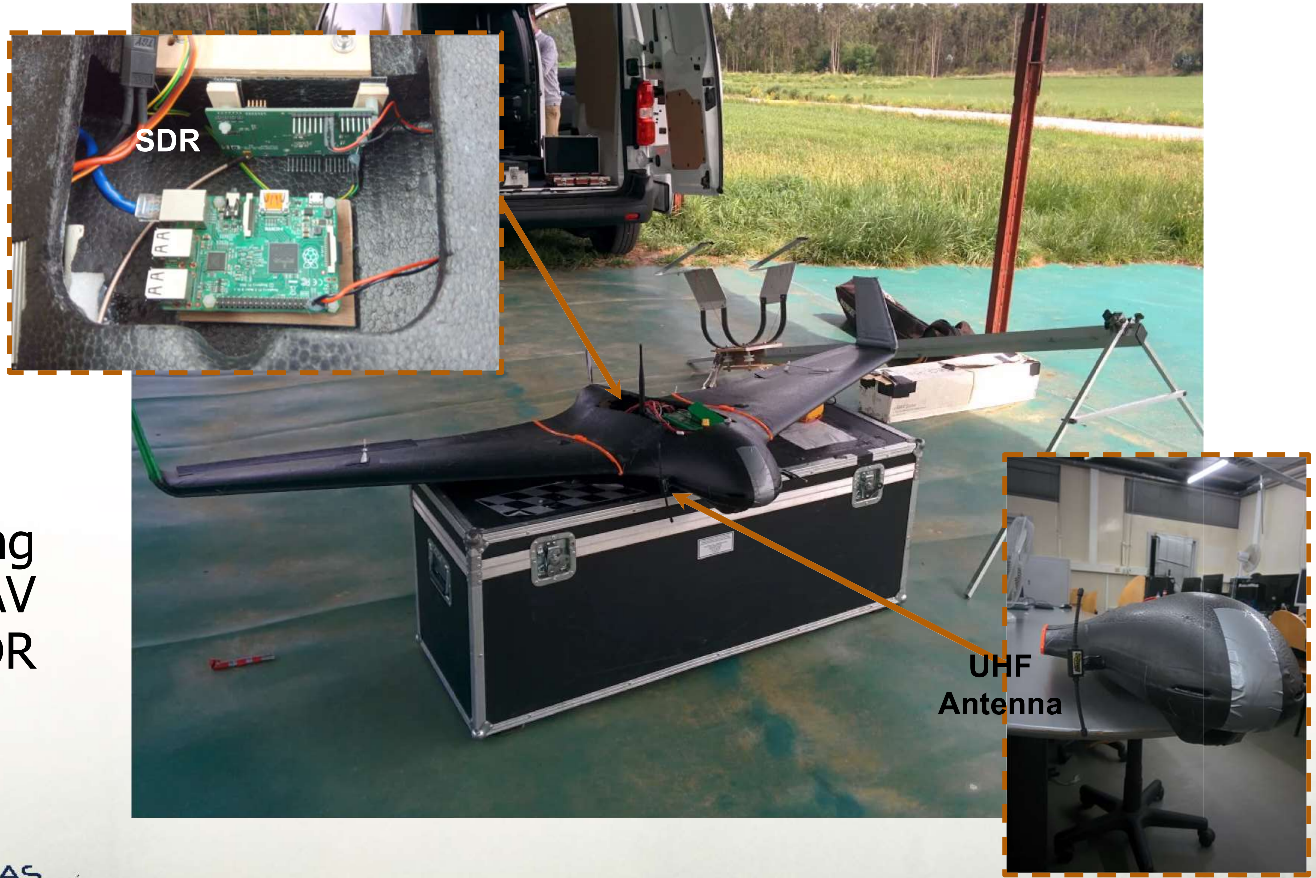
# LSTS Toolchain - Major strengths

- Scalable with other systems (from different manufacturers);
- Scalable with other architectures/protocols (ROS | MOOS | JANUS);
- Compatible with other communication solutions (3/4G | GSM | Iridium | Wi-Fi | ...);
- "Budget oriented".



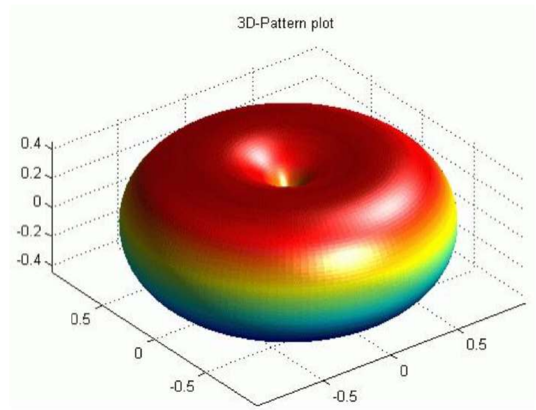
# SDR Technology

- Integration of UVIGO's user terminal onboard:
  - **HumSAT** v1.0, v1.5 and **v2.0**
  - Antenna selection and testing.
- Driver in DUNE for handling communications between UAV and satellite (through SDR terminal).



# Challenges

- Antenna selection and installation:
  - Chosen small omnidirectional dipole to allow belly landing and still have the better radio pattern.
  - Tested with bigger dipoles and monopoles antennas, but performance was similar.
- Limited power transmission allowed onboard:
  - 3W of HumSAT terminals is OK for the UAV, but proved to be short during tests with the real satellite.
  - Adding power amplifier up to 10W not feasible.

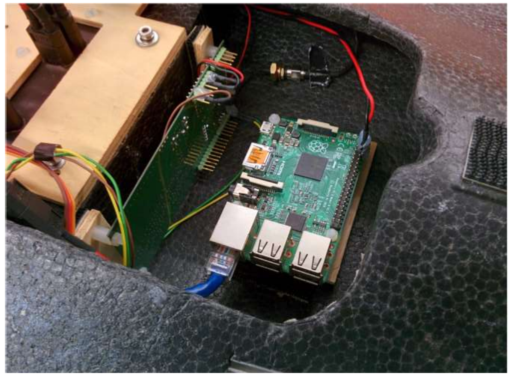


Dipole antenna radio pattern.

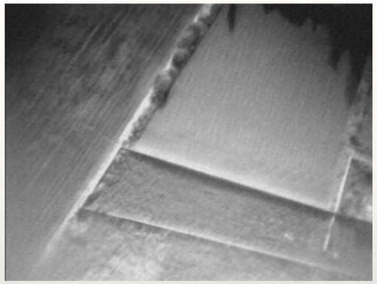
# IR Technology

- Installation and calibration of an **IR camera in NADIR**, with framegrabber for live stream.
- **Auxiliary CPU** (RASPi-2) to handle Vision Tasks:
    - Driver for creating **geotagged stills** from IR camera feed.
    - FireMapper task (developed by LAAS) - processes the images and outputs **FireMaps** for SAOP.

Flir Tau 2

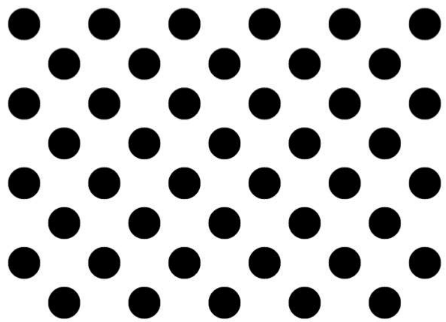
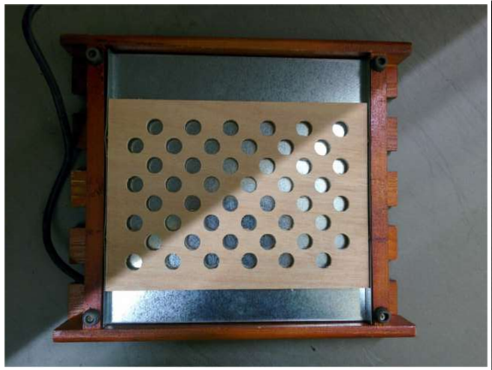
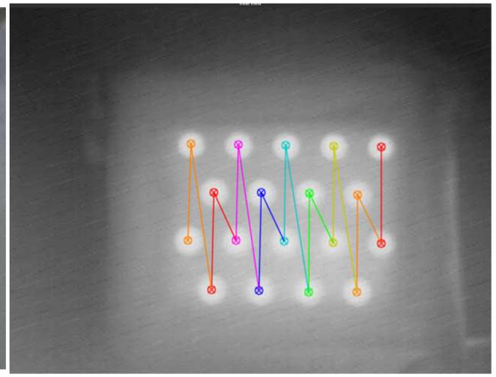


Auxiliary CPU



# Challenges

- IR camera calibration process!

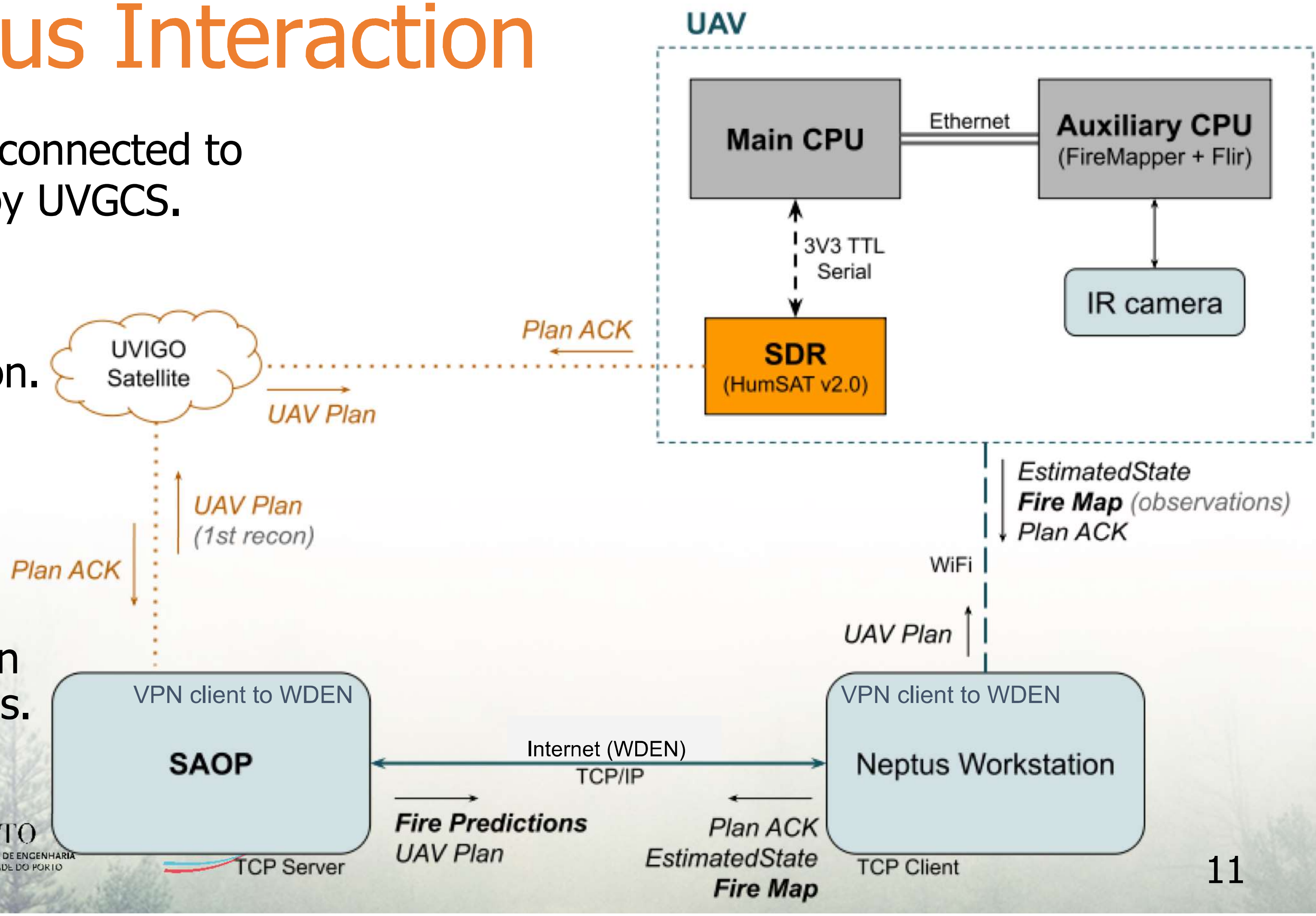




Asymmetrical circle pattern and heat sourced using during calibration process (on the right).

- Reaching a solution that yielded good results in the stitching of the stills (after projection onto the terrain).

# SAOP/Neptus Interaction

- SAOP and Neptus both connected to WDE network created by UVGCS.
- SAOP generates plans for the UAV to fly over the predicted fire location.
- UAV executes plan and based on the acquired data it outputs a new FireMap to SAOP.
- SAOP updates prediction of the fire sent to Neptus.

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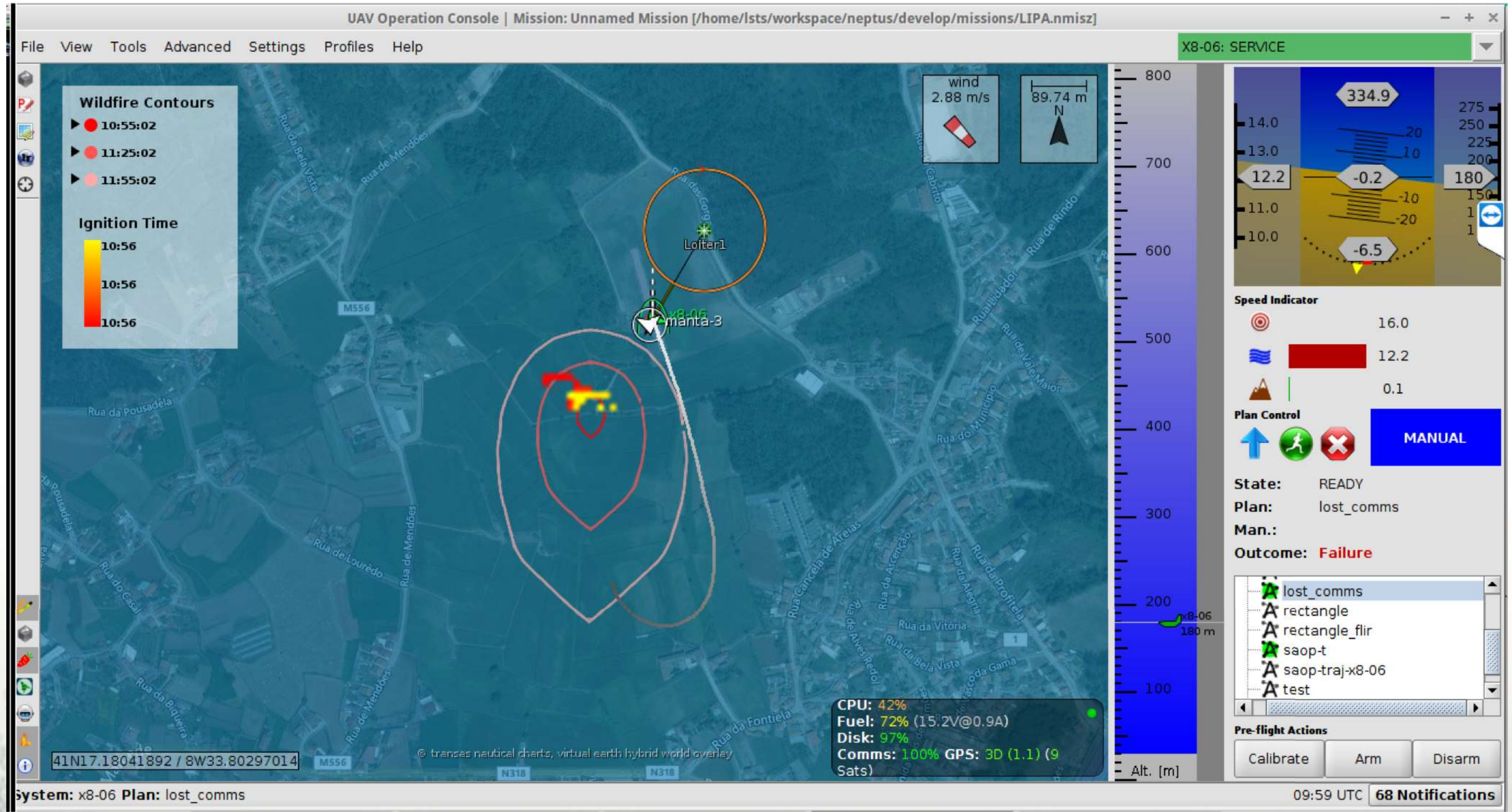
# SAOP/Neptus Interaction

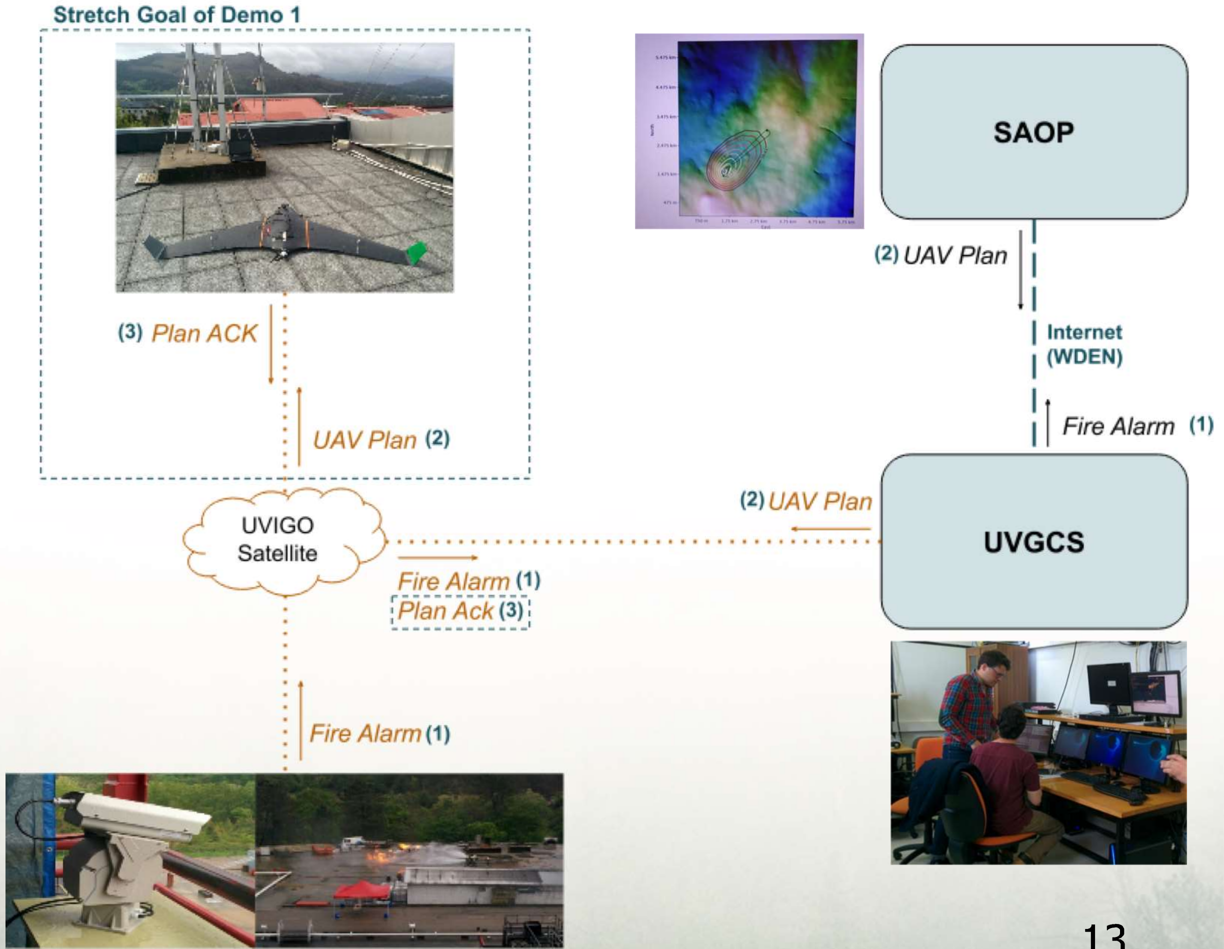
- Developed Neptus **plugin** to handle interaction with SAOP.
- *Fire predictions* received from SAOP are represented on the console map (current and future).
- *Fire observations* acquired during UAV flights are painted in real time on the console map.



# Demonstration 1

**Objective of UAV Stretch Goal:** Test UAV-Satellite link quality performance.

- UAV test on the rooftop, using similar UVGCS's dipole antenna, but with no power amplifier.
- HumSAT driver behaviour:
  - Keeps checking if received any package from satellite;
  - Keeps transmitting a small "Plan ACK" message to the satellite.

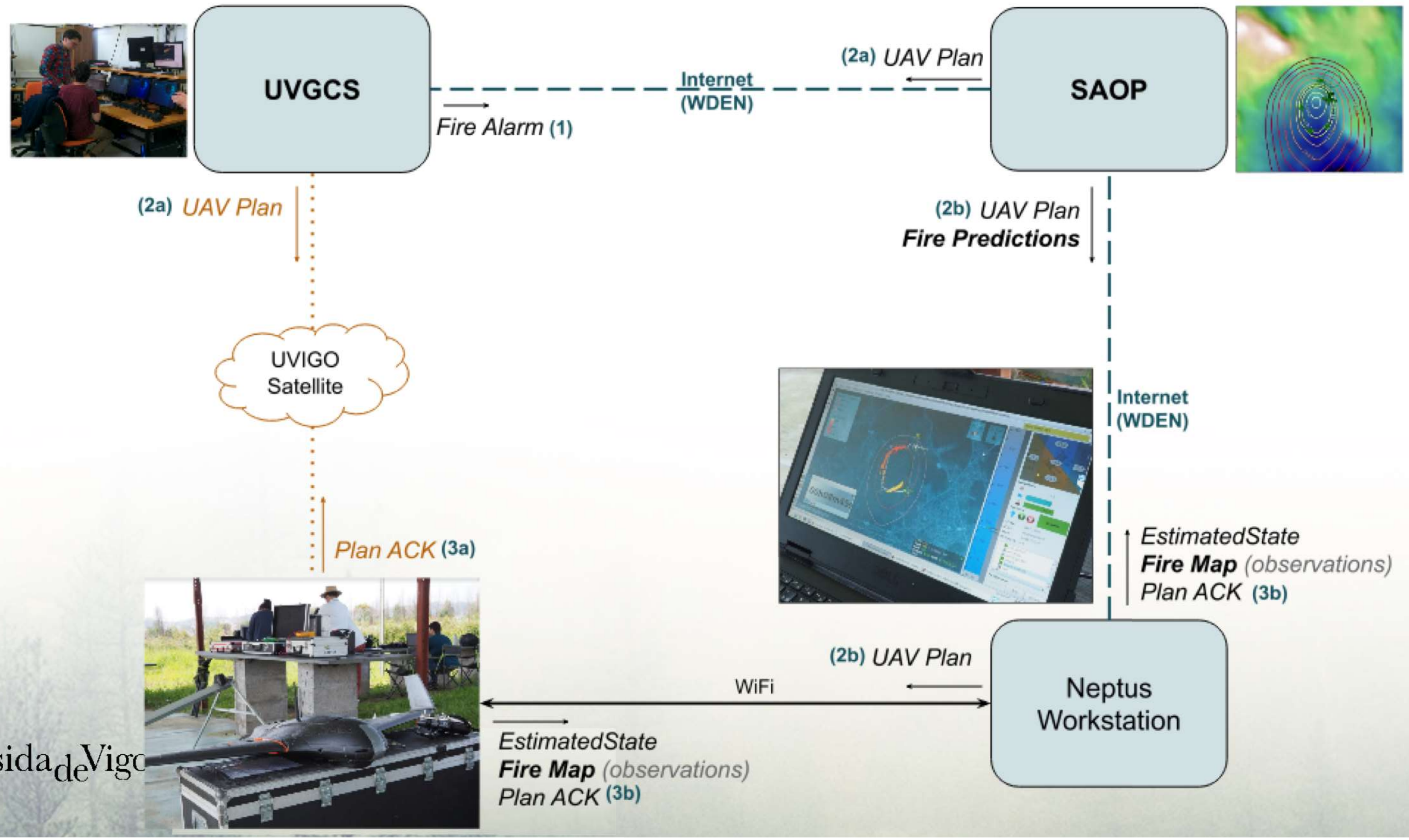


# Results

- Validated connection of the UAV to the WDEN.
- Validated messages sent by the UAV to the WDEN (Plan ACK).
- **UAV transmitted successfully a message to the satellite!**
  - Happened during satellite passage on the 22nd April.
  - UAV received ACK from the satellite confirming successful reception of the message sent by the UAV.
  - UVGCS didn't received the message from the satellite though - it's likely there wasn't enough time left on the window passage for the satellite to retransmit to UVGCS (only 2min).

Performance with UVIGO's antenna seemed to be similar to previous setup, but since both setups weren't tested in parallel more testing should be done.

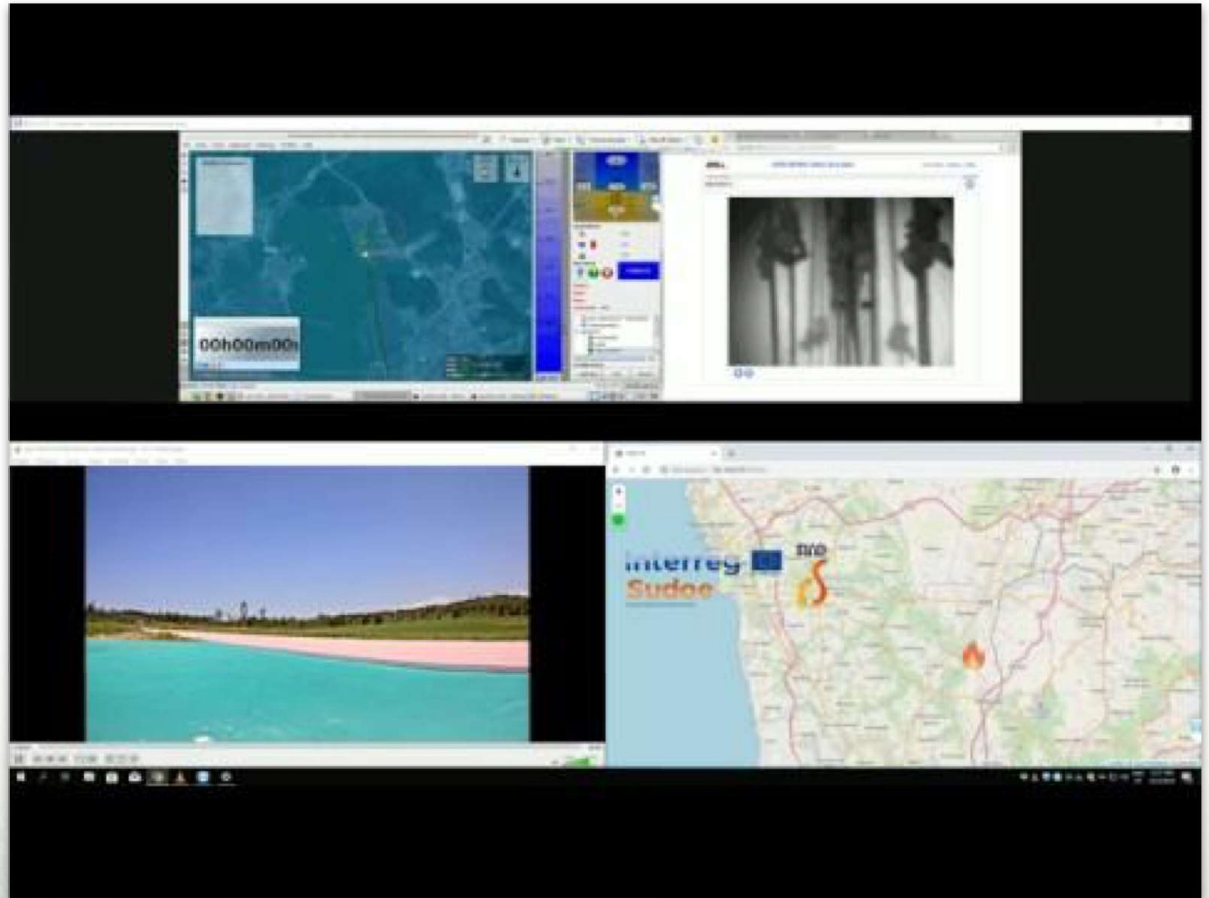
# Demonstration 2



# Challenges

- Generating a virtual WildFire -> MORSE simulator
- Generating images with observations of the virtual fire taking into account current position and attitude of the real UAV -> MORSE simulator
- Live feed of everything that is happening at the airfield back at UPORTO, where the stakeholders were -> TeamViewer and IP forwarding

# Challenges



# Challenges

- Improve satellite communications with UAV:
  - Added a **relay ground station** on the UAV basestation, equipped with UVIGO's custom antenna and a power amplifier, if available.
    - The relay ground station retransmits to the UAV all traffic from/to the satellite, so for the UAV it's as if it wasn't there ("transparent" node).
    - The SDR setup on the UAV only has to be able to establish communications with the relay ground station.

Antennas of the relay ground station installed at LIPA airfield, for the demonstration 2.

# Results

- Fire-RS workflow validated in the field successfully.
- Communications between all systems validated (including over different interfaces - satellite link, WDEN, WiFi).
- SAOP/Neptus interaction worked very well:
  - Both Neptus and SAOP operators were receiving data from the counterpart, with no significant delay being perceived.
- Relay Ground Station (**with no power amplifier**) failed to communicate with the real satellite (meaning, the UAV also didn't):
  - UVGCS, which has a power amplifier, was able to communicate successfully with the satellite.
  - After the satellite window passage was over, a satellite simulator was powered on to proceed with the demonstration - successfully.

# Conclusions and Lessons Learned

- The value of a system such as the one proposed in Fire-RS was validated and showcased in operational environments, being perceived as very promising by the stakeholders that attended both demonstrations.
- An amateur band for this type of satellite was proven not to be the best choice for this type of satellite.
  - 437MHz turned out to be already very crowded, with a lot of external interferences, which didn't help performance of communications.
- The main limitation on the small SDR terminals weren't the antennas, but the transmission power (a very likely consequence from the 437MHz).
  - If the **relay ground station** at the UAV basestation has a power amplifier, **it can work as a valid workaround** though - as results from demo 2 shows.