ADS-B over Satellite

Coherent detection of weak Mode-S signals from Low Earth Orbit

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Overview

- ***Introduction***
- Background
- Mode S Signal Processing
- Results
- Summary and Outreach

Project “ADS-B over Satellite”

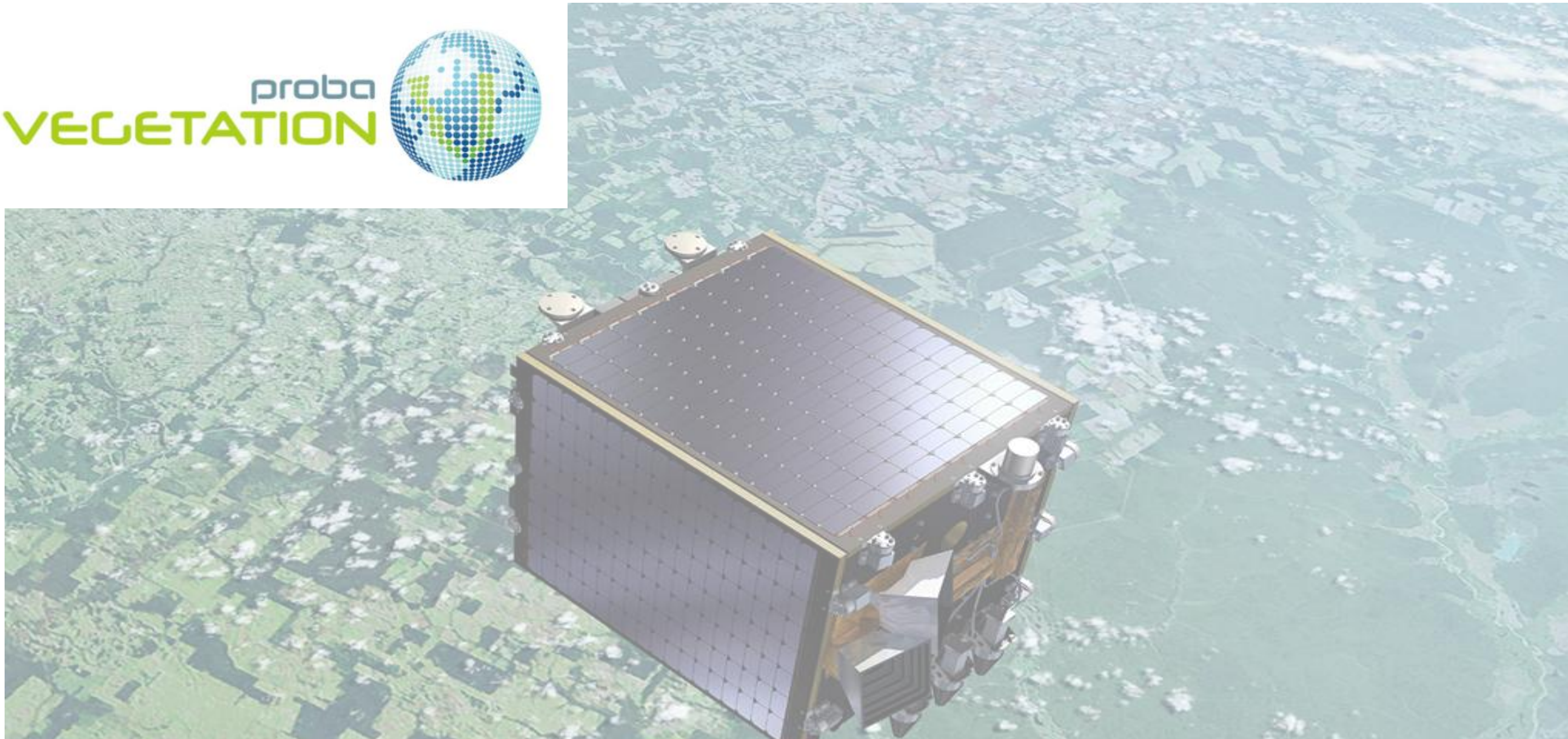
- **Objectives:** Proof of Concept: Feasibility of satellite-based ADS-B Surveillance
  In-Orbit Demonstration on ESA-Satellite PROBA-V
- **Project Duration:** 1st Q. 2011 until End of 2nd Q. 2014 DLR R&D funding
  3rd Q. 2015 until End of 4th Q. 2016 ESA GSTP funding
- **Cooperation:** Institute of Space Systems (RY), Bremen, Germany
  Institute for Flight Guidance (FL), Braunschweig, Germany
  Flight Calibration Services (FCS), Braunschweig, Germany

Project “ADS-B over Satellite”

- Contributions:

Institute of Space Systems (DLR)	Lead, Development and Assembly of a space-qualified ADS-B Receiver and Antenna, Data evaluation
FCS Flight Calibration Services (FCS)	Development of ADS-B receiver
Hamburg University of Applied Sciences (HAW)	Development of ADS-B Antenna
Institute of Flight Guidance (DLR)	Verification Concept and Evaluation of ADS-B Data
SES TechCom / ESA:	Provision of Data Server
Air Services Australia, ISAVIA - Icelandic Civil Aviation Administration, NAV Portugal:	Provision of Data

proba VEGETATION



- ESA small satellite PROBA-V
- Prime Contractor QinetiQ Space
- Launch Date: 6/7 May 2013 (04:06:31 CEST 7 May; 23:06:31 local time 4 May), Launch Mass ~140 kg
- Orbit: SSO, 820 km altitude, crossing the equator every morning between 10:30 and 11:00 local time
- Data handling/communication with Satellite via Ground Station Redu/Belgium

Image: ©ESA

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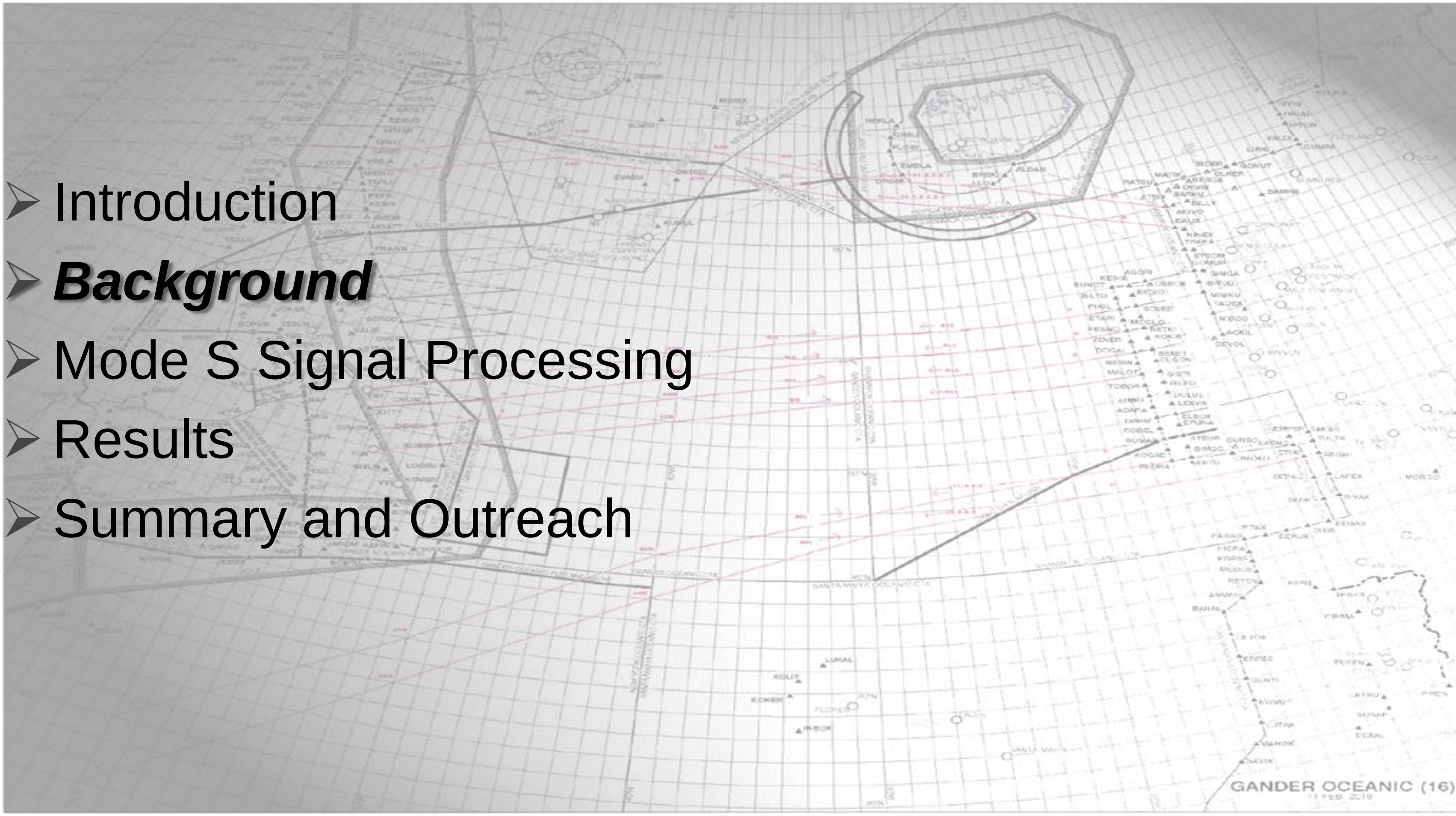
Overview



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Air Traffic surveillance today….

- Transoceanic Routes, underdeveloped Regions:
  - – Non-Radar Airspace (NRA)
  - – Procedural: Pilot's Position Reports via Voice Radio (1~2 hours)
  - – ADS-C: Automatic position reporting via data link (~15min)
  - – ATN or FANS1/A ("ACARS"), Satcom / Inmarsat or HFDL

No continuous Air Traffic Surveillance available

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… and the Consequences for Non Radar Airspace

- Future Air Traffic Management has to deal with worldwide increasing air traffic without surveillance capacities
- Ample Separation Distances in NRA
- non-efficient Use of Airspace, leading to higher fuel consumption and higher carbon emissions
- Expensive and time-consuming SAR Measures in case of emergency

The next generation Air Traffic Management must transform procedural to controlled airspace!

GANDER OCEANIC (16)

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Background: ADS-B

Automatic – It is always working, without external stimulus
Dependent – It relies on external GNSS data
Surveillance – It provides surveillance services
Broadcast – It is always broadcasting, independent of any participant

ADS-B includes surveillance data e.g.

- Airborne position (cpr. encoded Latitude, Longitude)
- Identity and Category,
- Airborne Velocity,
- Barometric Altitude,
- Call Sign, …

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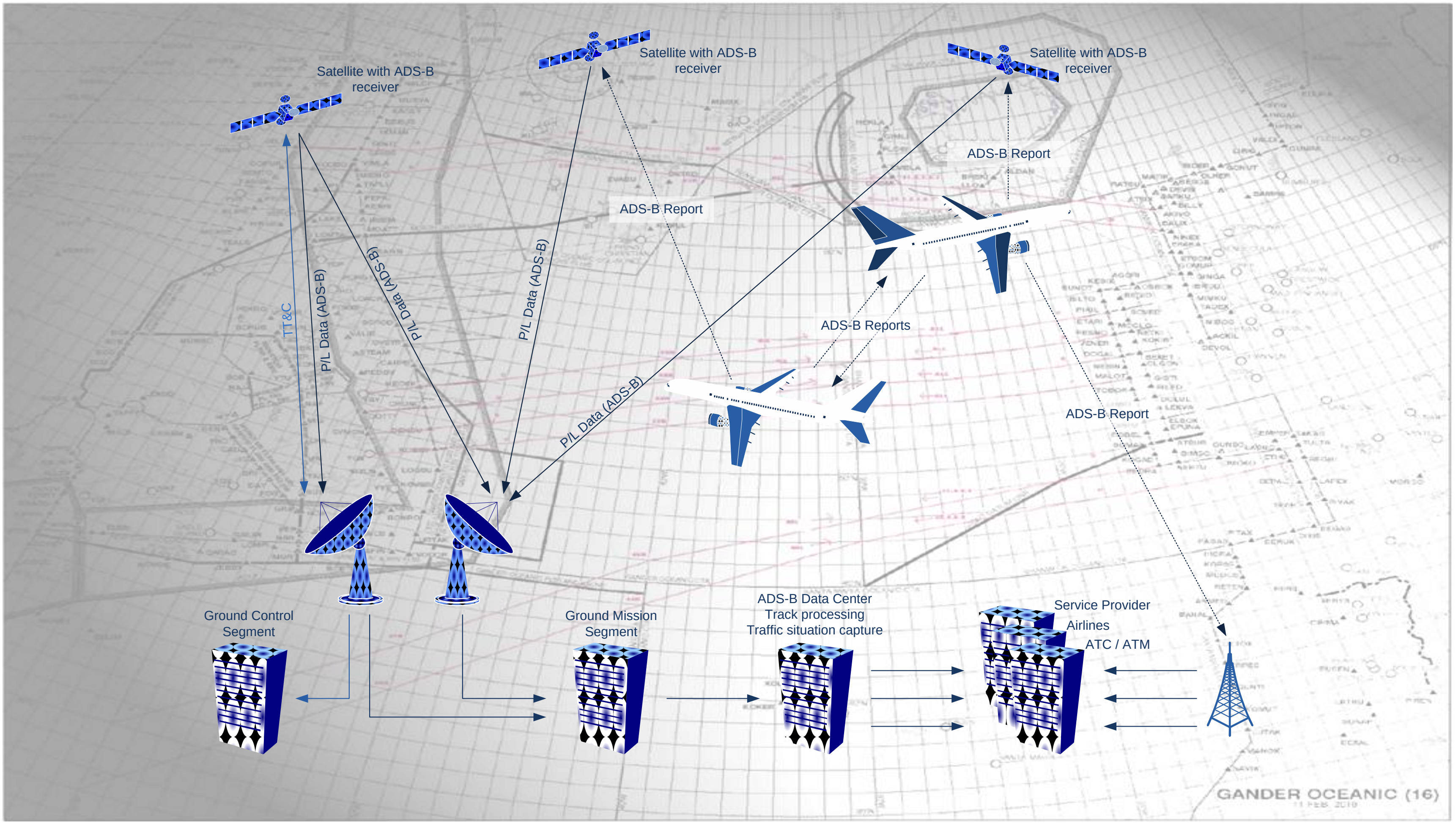
Satellite based Reception of 1090ES ADS-B



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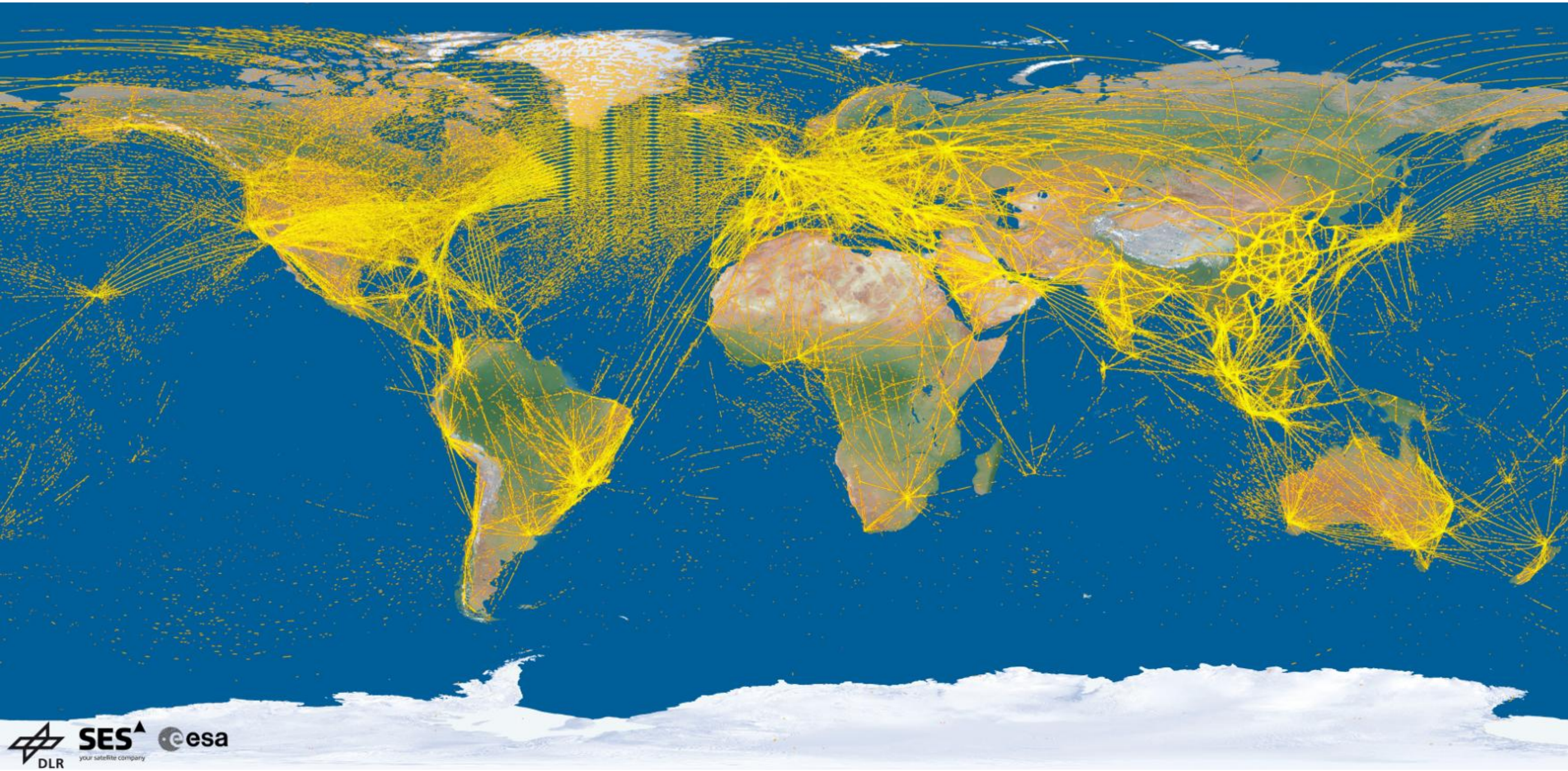
DLR Satellite vs. Flightradar24



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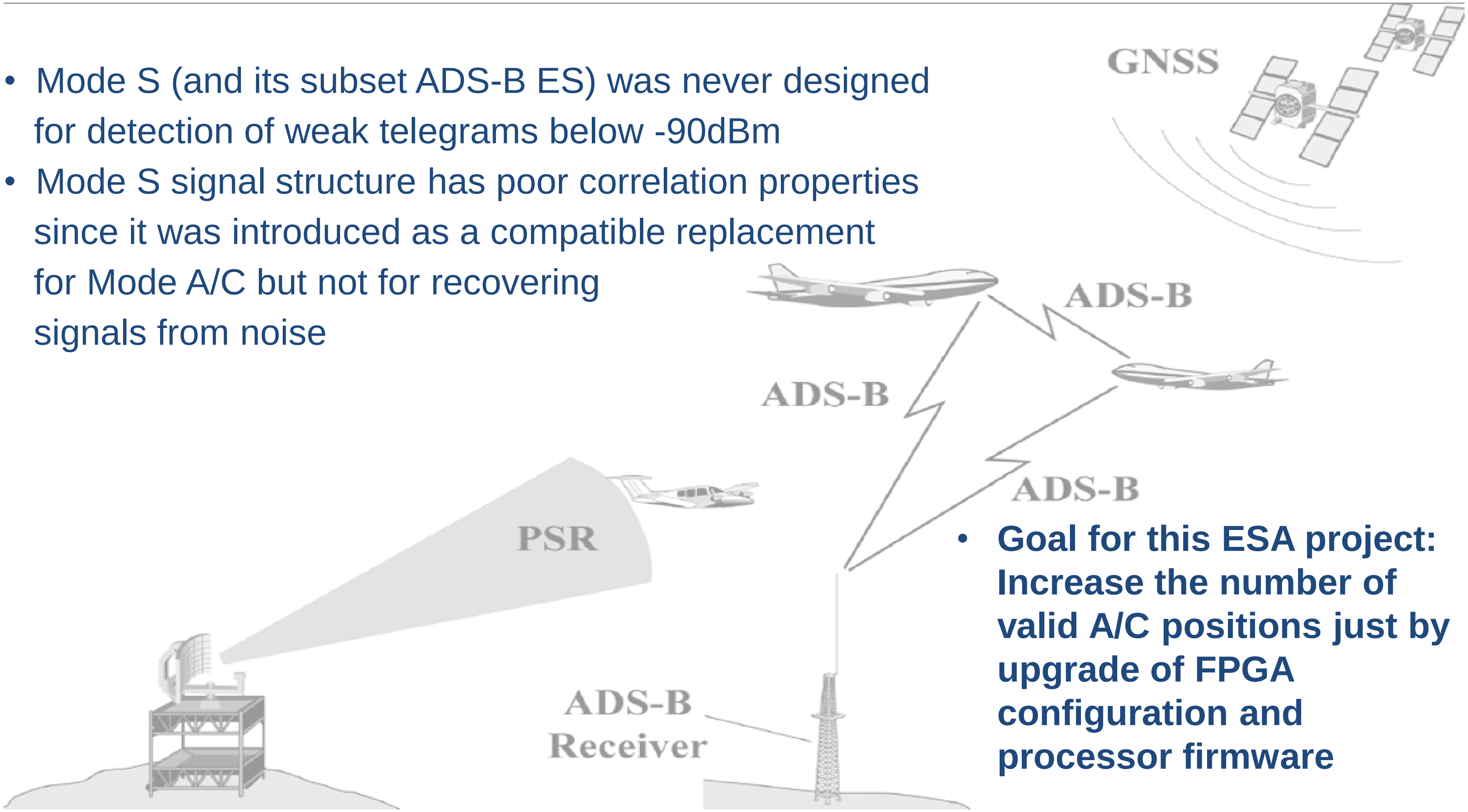
Mode S Properties

- Mode S (and its subset ADS-B ES) was never designed for detection of weak telegrams below -90dBm
- Mode S signal structure has poor correlation properties since it was introduced as a compatible replacement for Mode A/C but not for recovering signals from noise



- **Goal for this ESA project: Increase the number of valid A/C positions just by upgrade of FPGA configuration and processor firmware**

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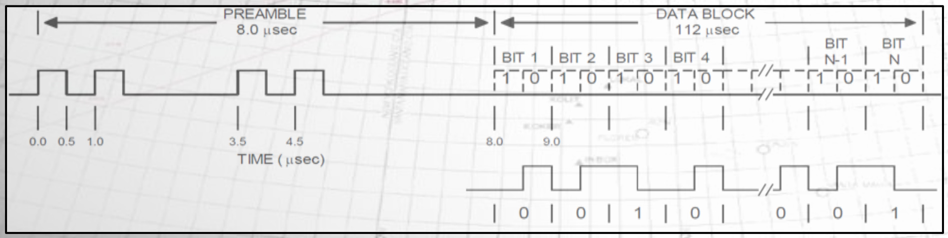
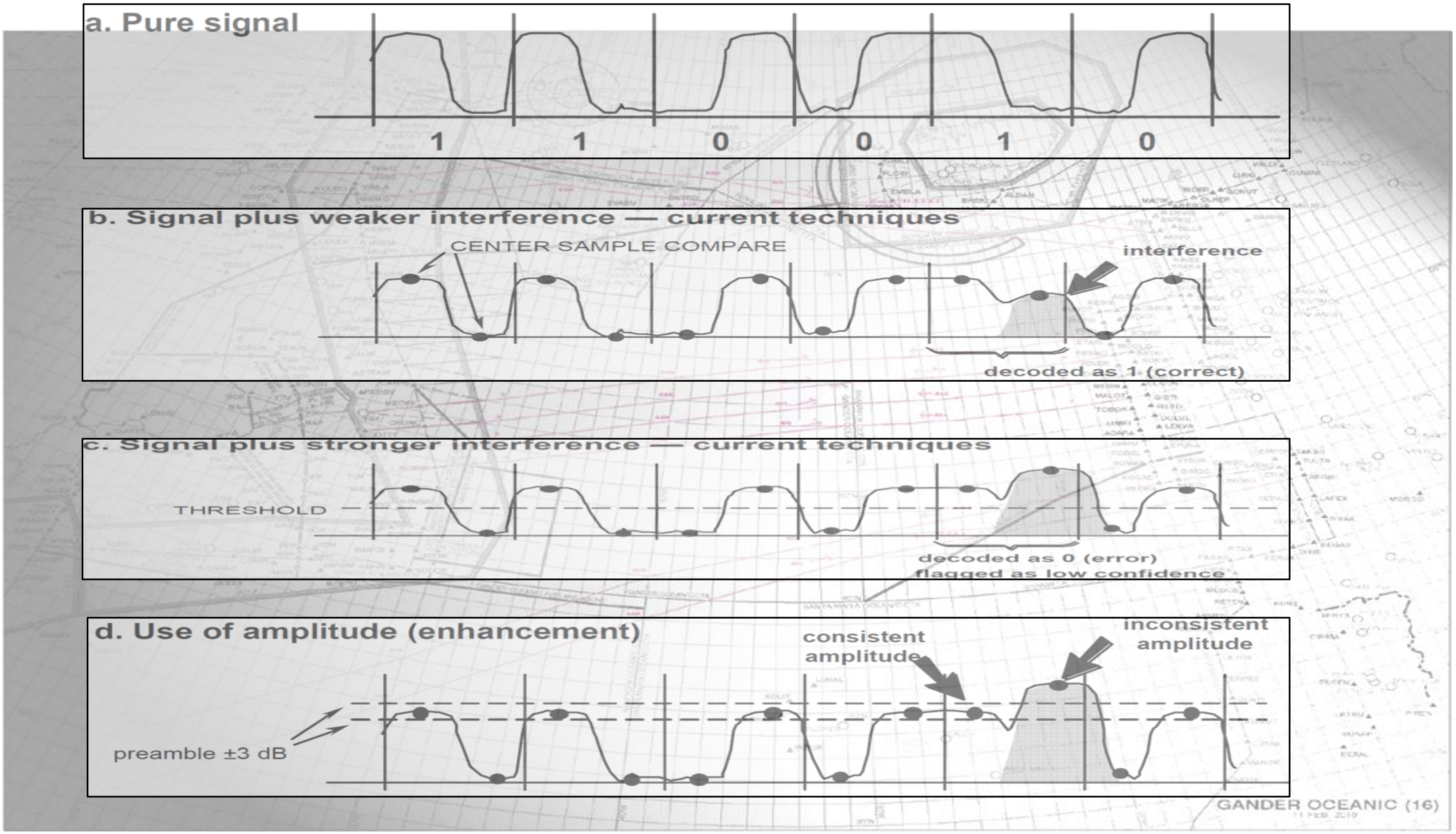
Mode S Signal Processing

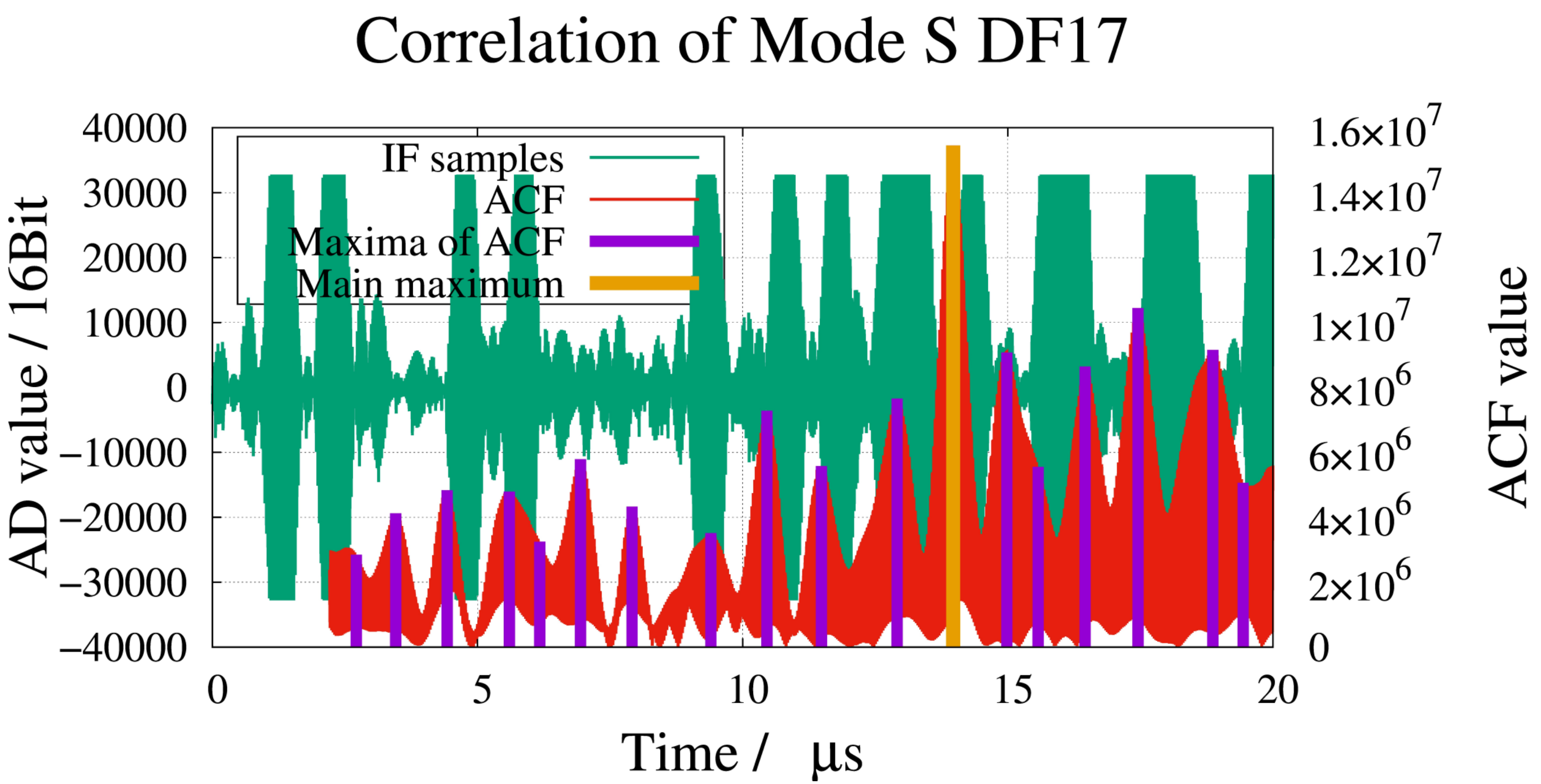
- Two approaches: **Partially** (non) (1) and **fully coherent** (2) telegram detection can be implemented in FPGA
- (1) was active from launch till 2016 and used the amplitude and phase of 9 consecutive single pulses: 4 preamble and 5 format bits
- Method allows to detect telegrams down to -104dBm (this level with poor probability of detection)
- Method (2) takes a full mutual phase coherence of these 9 pulses for granted to work
- This is true for all modern airliner transponders since the transmitted pulses are amplified from a stable TCXO local clock source



Mode S Signal Processing



Autocorrelation function of fully-coherent method



- Band pass signal (IF samples) show beginning of “strong” telegram at -95dBm
- Signal strength is limited at ADC, 16Bit full scale is reached

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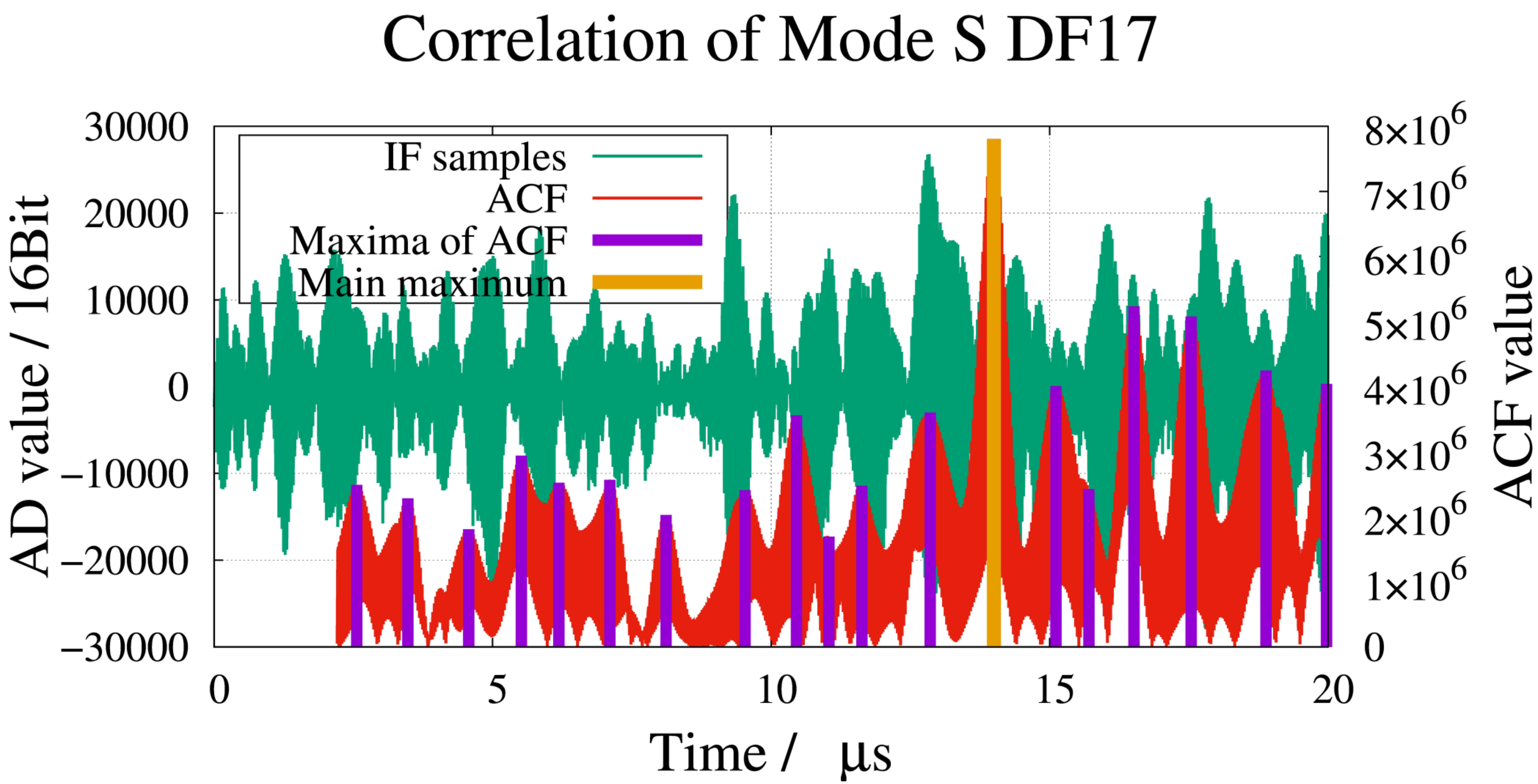
Autocorrelation function of fully-coherent method



- Beginning of weak Telegram (-106dBm)
- Mode S preamble hardly visible but ACF shows distinct maximum

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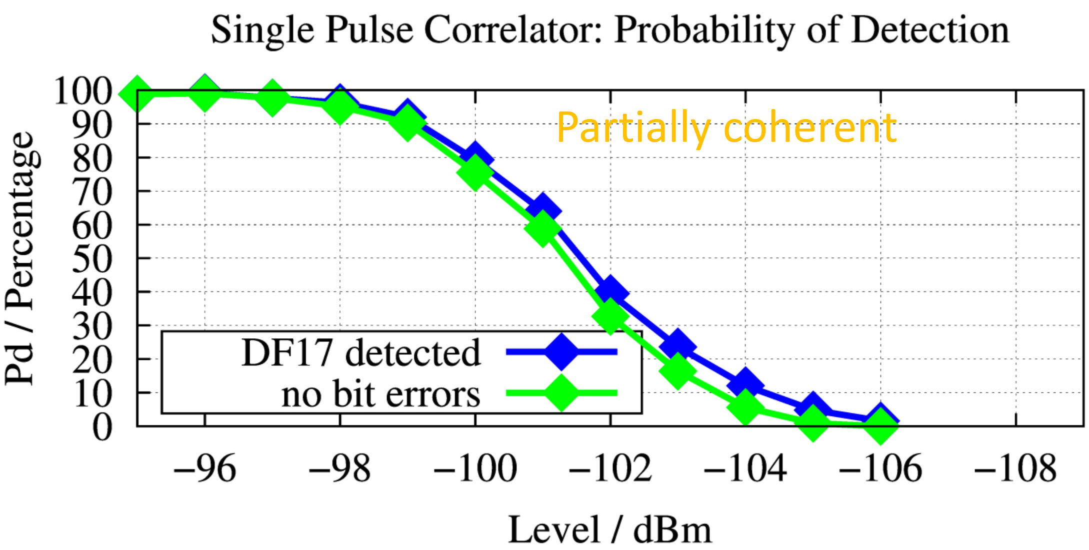
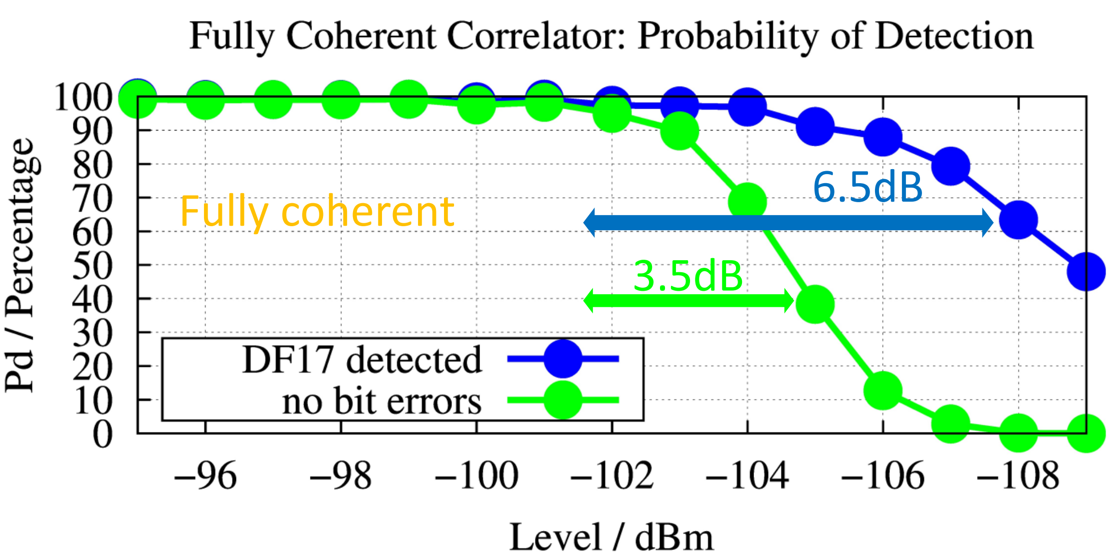
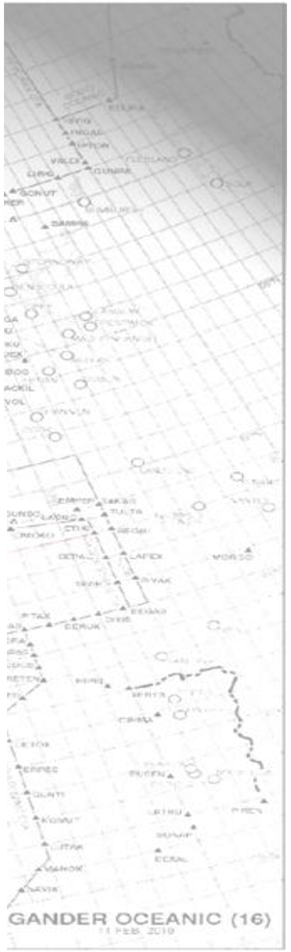
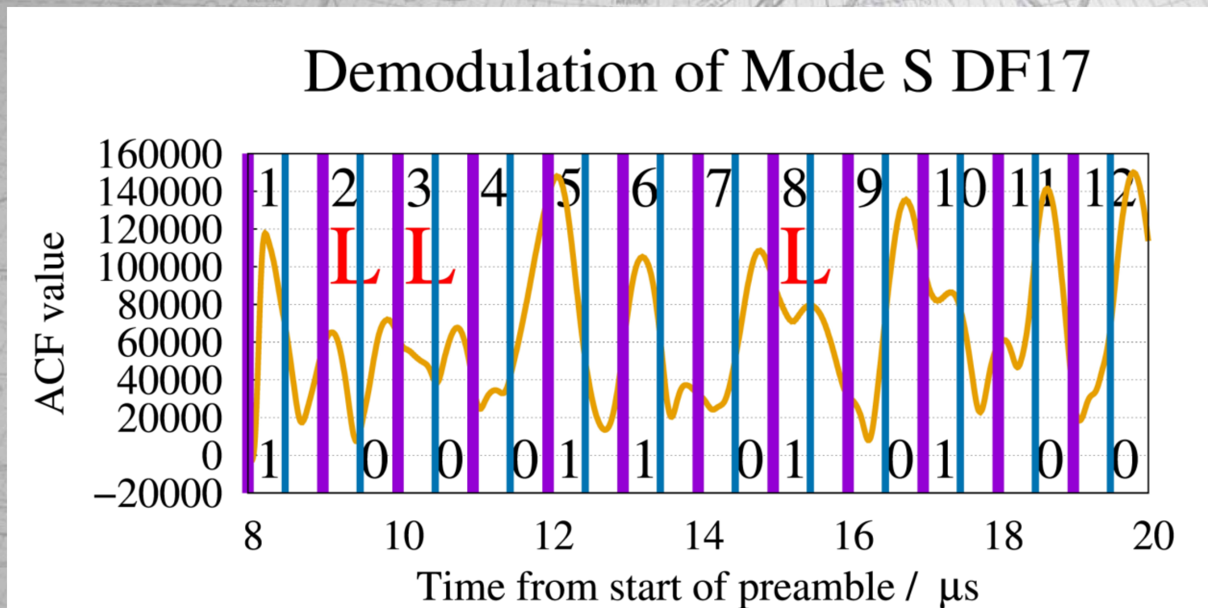
Comparison of process gain







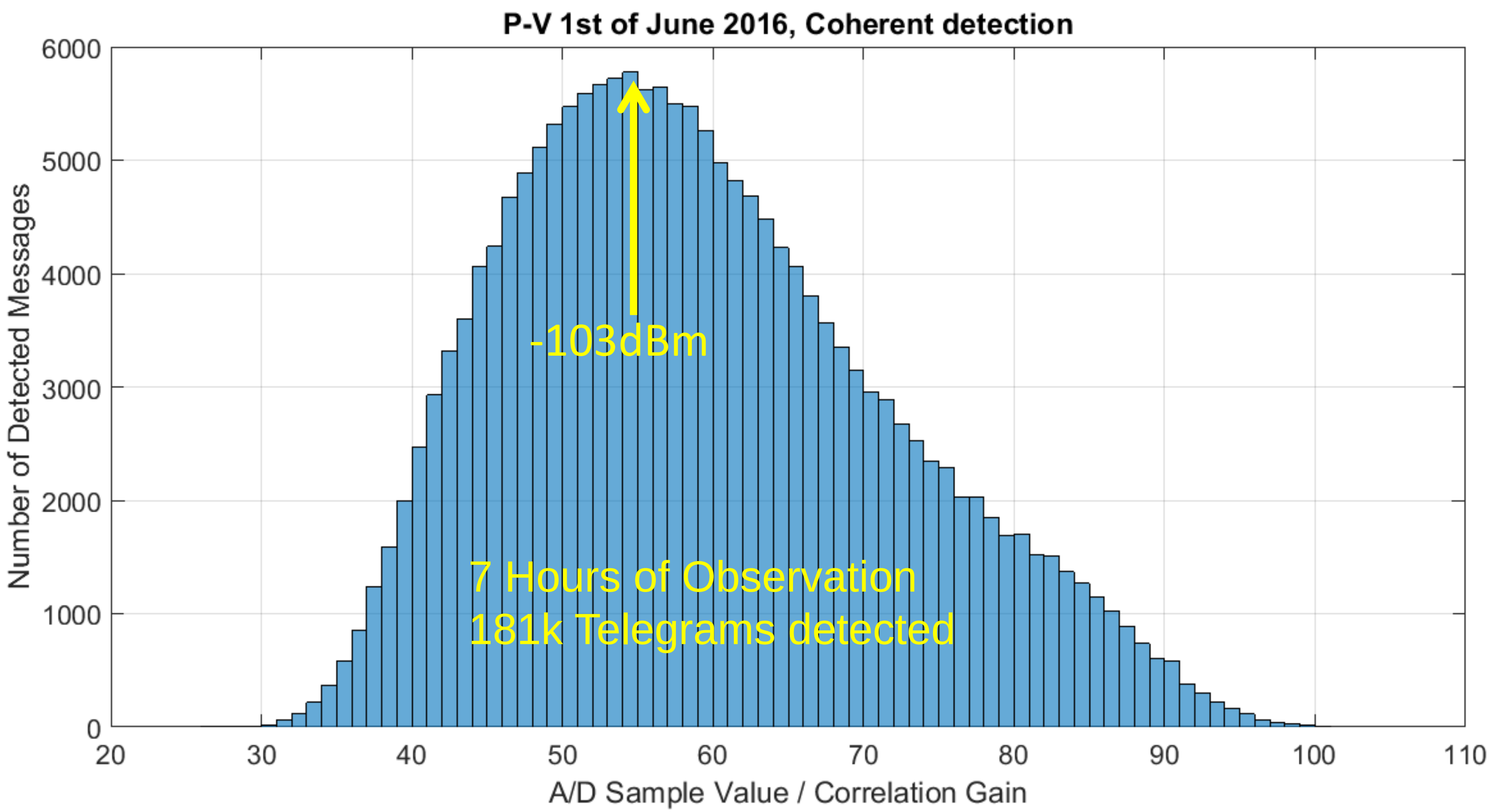
Generation of “Low-confidence Bits”



- Bit demodulation employs weighting function to determine energy in half chips
- If difference in energy is low, then confidence in data bit is low

Distribution of Signal Levels for one satellite pass

Receiver calibration over frequency and level



- This distribution from PROBA-V shows the ACF of non-coherent correlator
- Maximum at -99dBm - Broader “shoulder” expected with new method (2)

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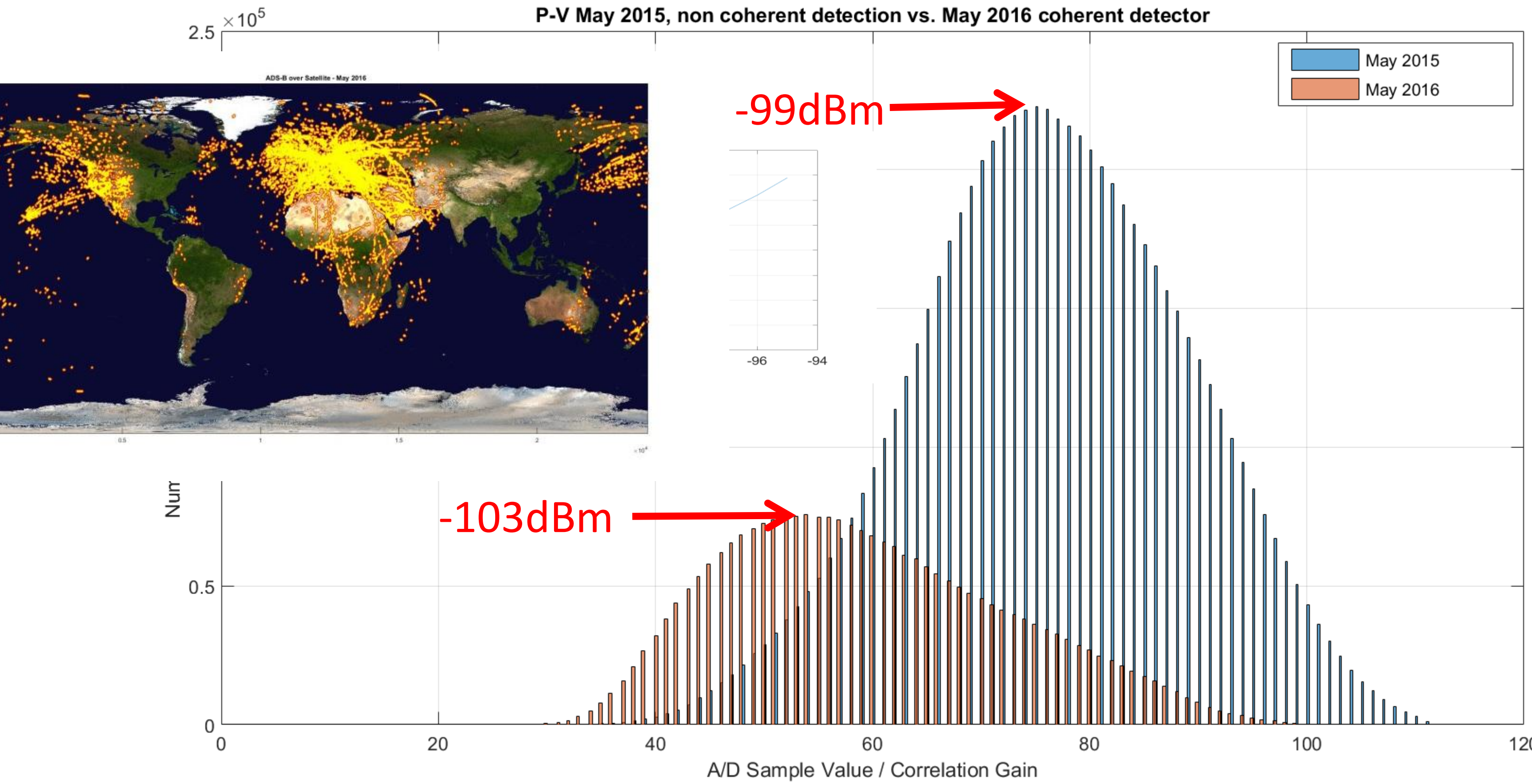
Distribution of Signal Levels for one satellite pass



- This distribution from PROBA-V shows the ACF of non-coherent and coherent correlator
- Maximum at -103dBm - Loss of ~75-80% Data due to Lack of Memory

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Summary and Conclusions

- Fully coherent correlation method has a minimum of 3.5dB gain over partially-coherent technique
- Detection down to -109dBm possible
- Significantly increased Number of valid detected telegrams
- Using the low confidence bits, there is an additional chance to recover some defective telegrams; this to be tested with real data
- Disadvantage: significant increase in power consumption of 50% since many more registers are switching at 105MHz

Thank you for your Attention!

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