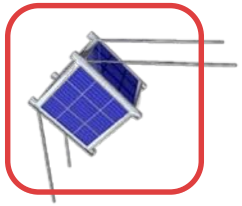
CRAFT PROSPECT

A Space Engineering Practice

15th November 2018, ESA Phi-Week

CubeSats for OnBoard Realisation of Autonomy

Craft Prospect Today



Mission & System Engineering

Enabling Technologies & Services

Novel Mission Applications

Products
e.g. Forwards Looking Imager

MISSION CONSULTANCY

Revenue

RESPONSIVE OPERATIONS

Enables

KEY AUGMENTATION SERVICE

Throughout all investing in the development of systems engineering and processes

Opportunity

- Growth in **demand for real-time actionable** data from space
- **Resource-constrained small satellites** dominating manifests
- **Intensive applications** like space video and IoT communications
- Need to manage complex **networked concept of operations**
- Existing **operational paradigms outdated**
- Rapidly evolving **consumer-driven autonomy** market

=> Develop common product components to enable more responsive operations

What is responsive operations?

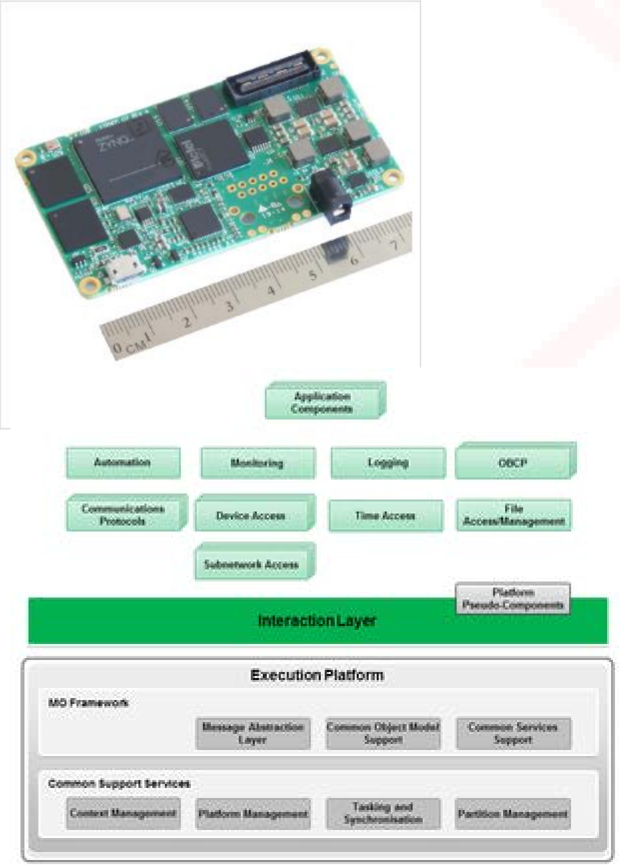
- Shift in the concept of operations paradigm

- (Near) real-time actionable delivery
- Onboard autonomy and decision making
- Bypassing the human in the loop
- Retasking assets on-the-fly
- Networks of networks: sensing, processing, delivering

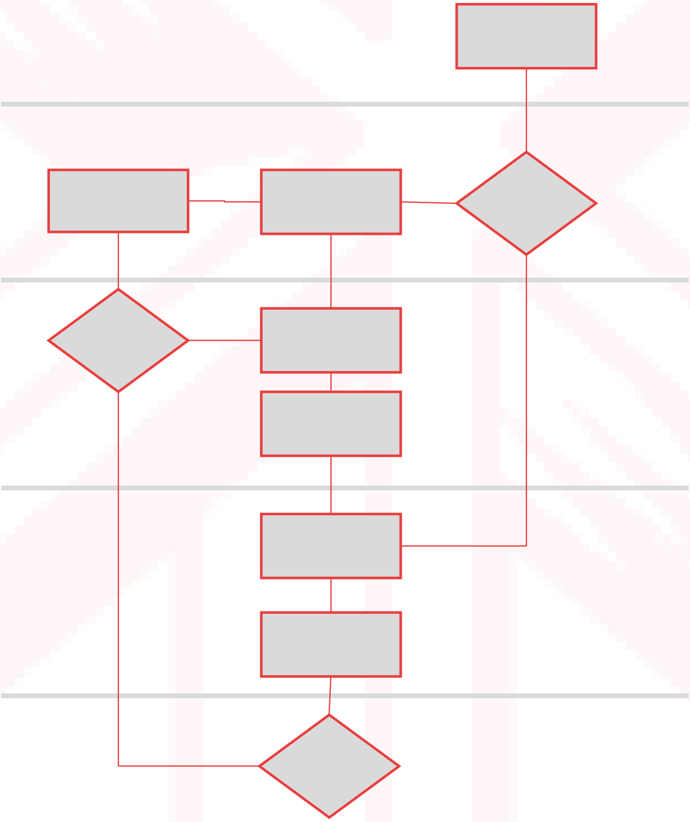
Machine learning	Blockchain
Adaptive comms	Emerging standards
Data fusion	Internet of things

Framework needs

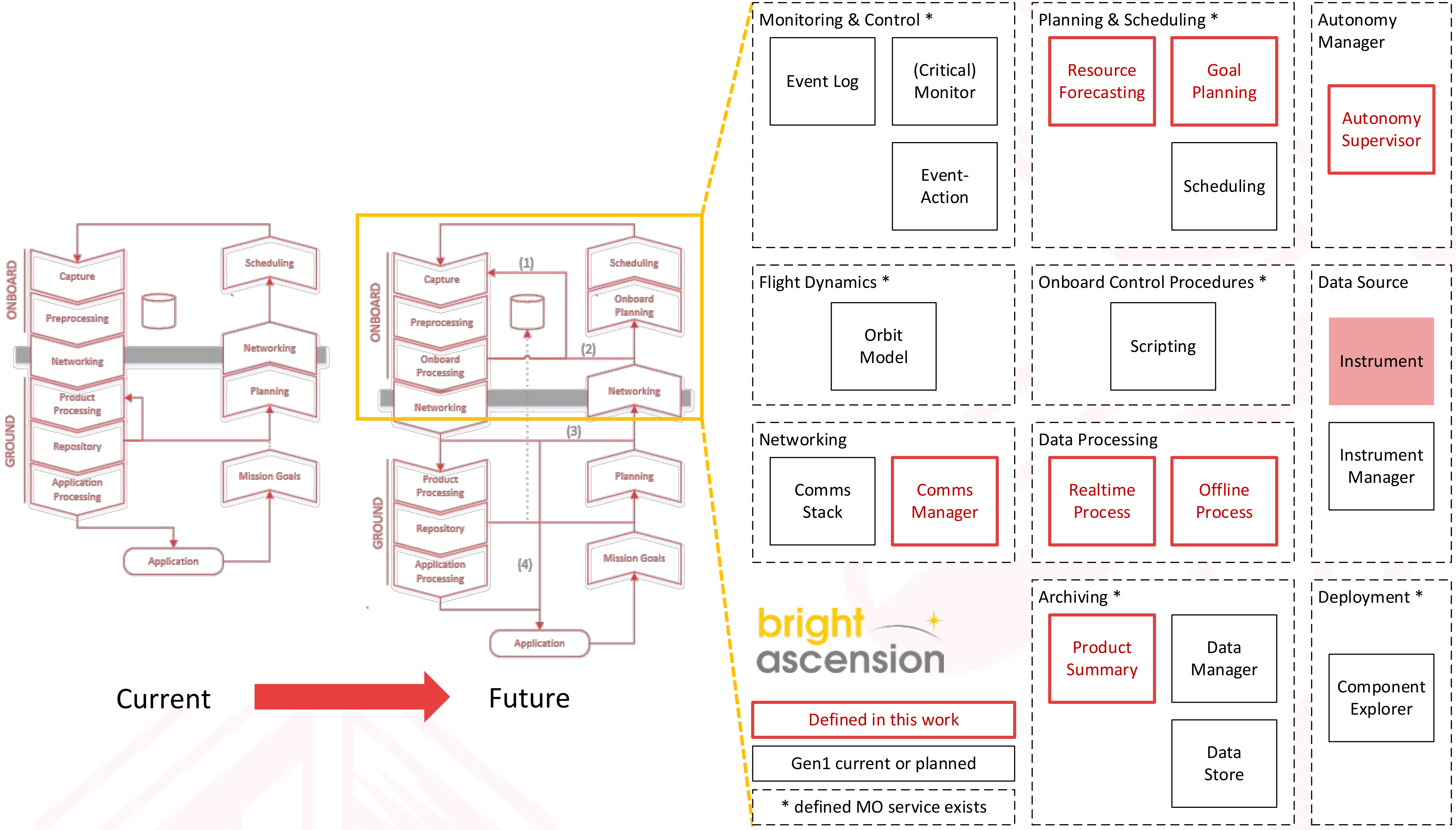
Align to/extends existing approaches



Interfaces to existing software/hardware

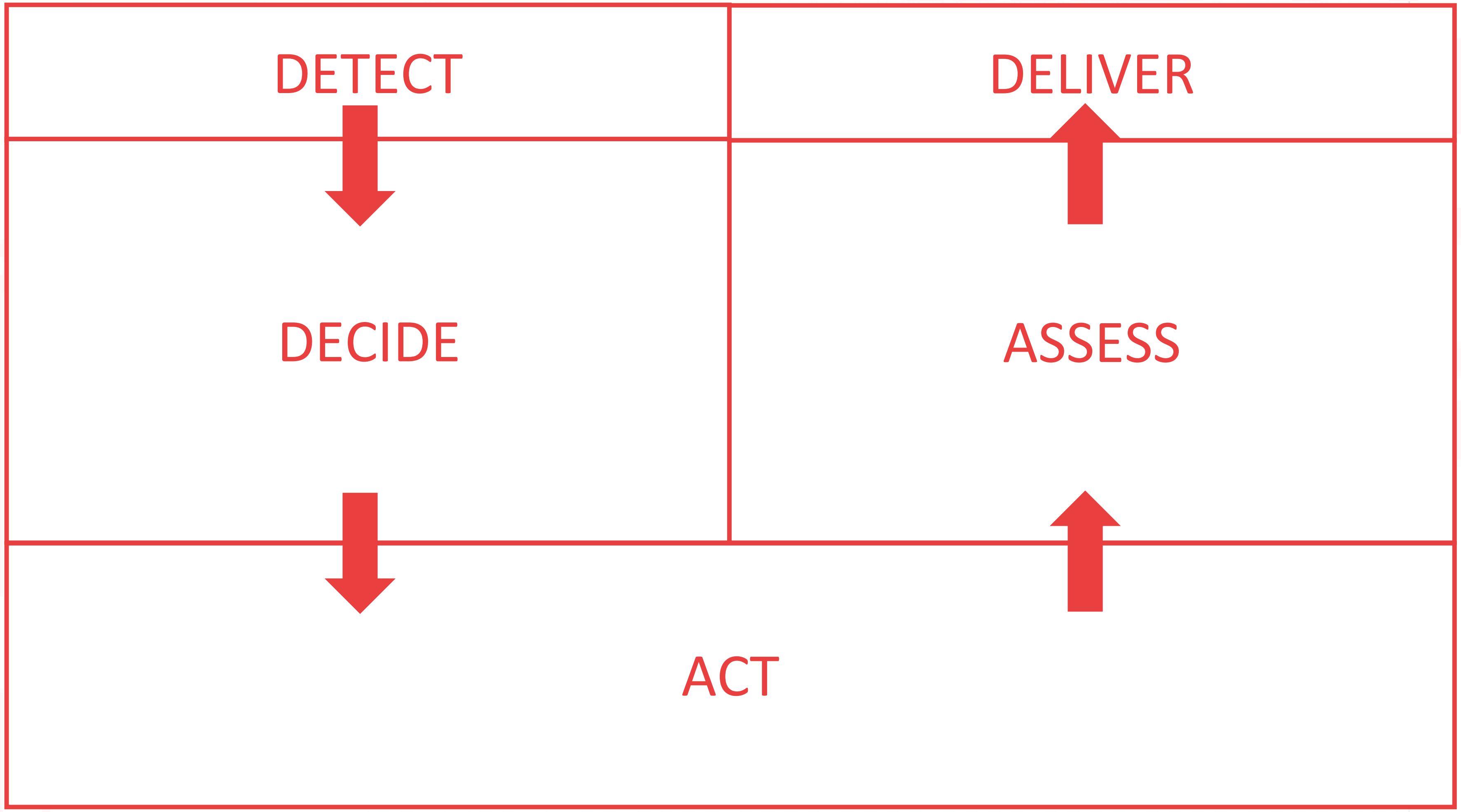


Allows robust fault detection, isolation and recovery

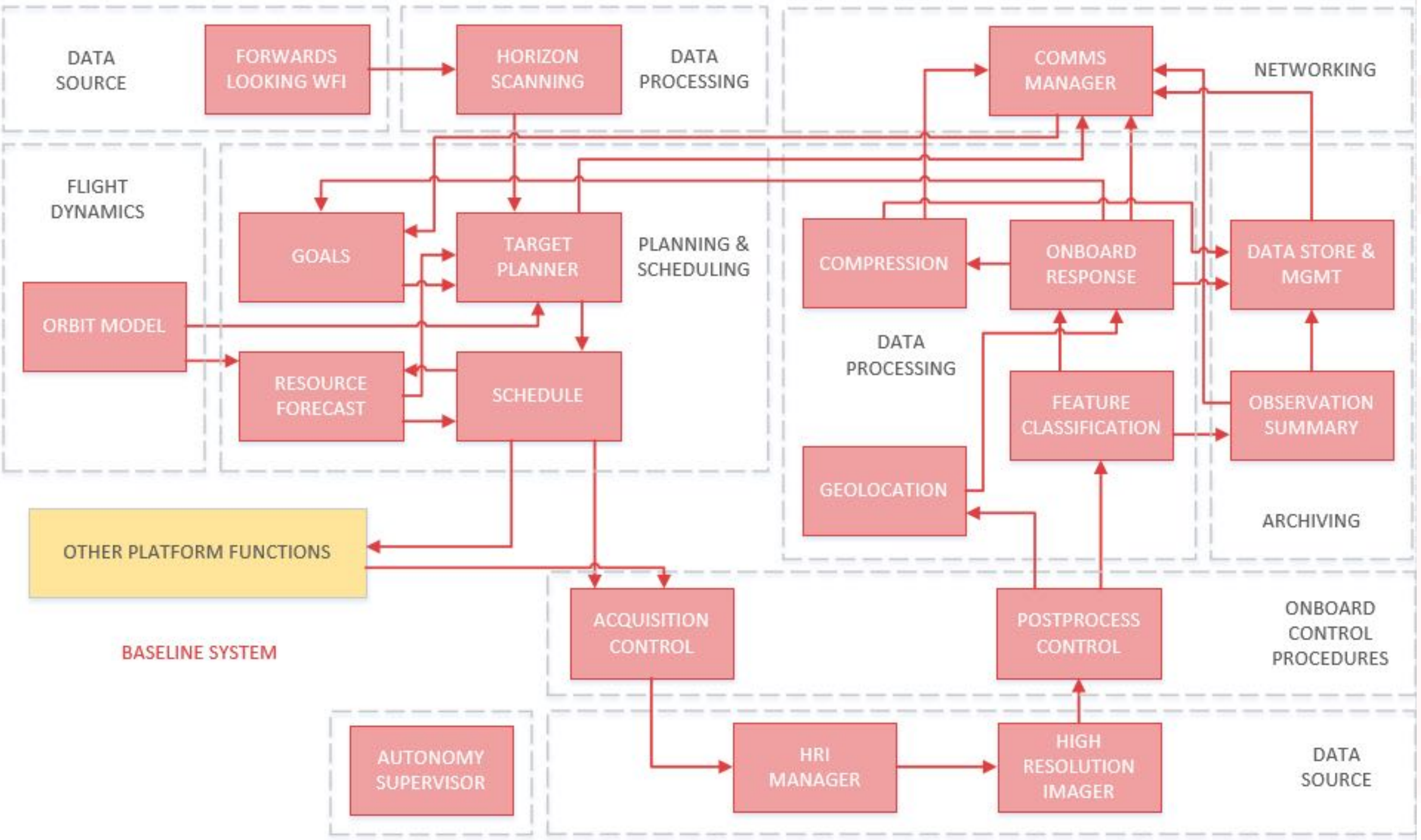

ONBOARD
GROUND
Capture
Preprocessing
Networking
Product Processing
Repository
Application Processing
Scheduling
Networking
Planning
Mission Goals
Application
Current
Future
Capture
Preprocessing
Onboard Processing
Networking
Scheduling
Onboard Planning
Networking
(1)
(2)
(3)
(4)
Product Processing
Repository
Application Processing
Planning
Mission Goals
Application
Monitoring & Control *
Event Log
(Critical) Monitor
Event-Action
Planning & Scheduling *
Resource Forecasting
Goal Planning
Scheduling
Autonomy Manager
Autonomy Supervisor
Flight Dynamics *
Orbit Model
Onboard Control Procedures *
Scripting
Data Source
Instrument
Instrument Manager
Networking
Comms Stack
Comms Manager
Data Processing
Realtime Process
Offline Process
Archiving *
Product Summary
Data Manager
Data Store
Deployment *
Component Explorer
bright ascension
Defined in this work
Gen1 current or planned
* defined MO service exists

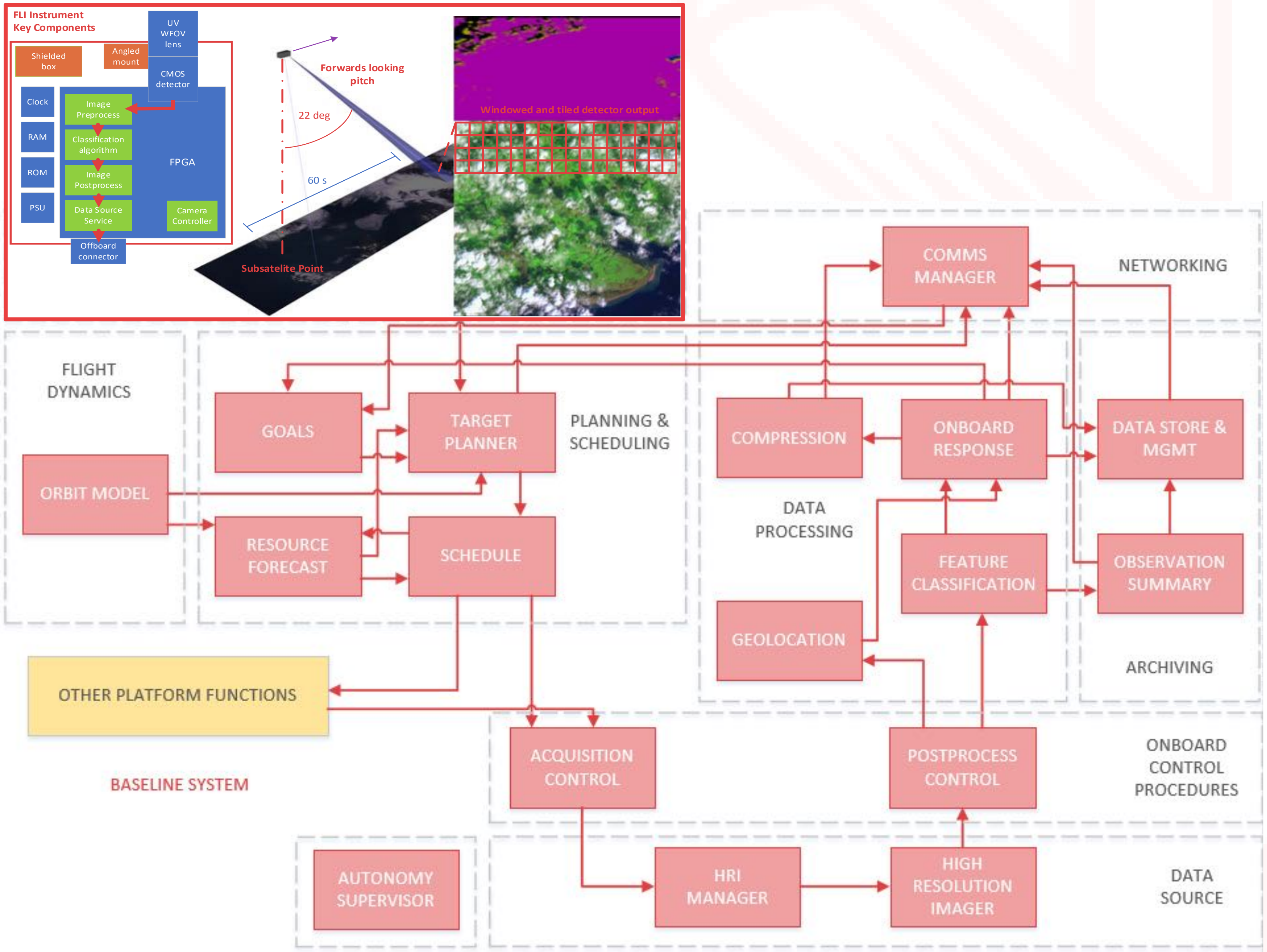

2:57 PM
ATLAS
Monday, May 16, 2016
5X5 SPLIT TRAINING
Body Boost
220
118
29:33
Exercise Name
Reps
Lbs
Form
Dumbbell Thruster
Dumbbell Thruster
Dumbbell Thruster
SUMMARY
FREESTYLE

Reference Onboard Architecture

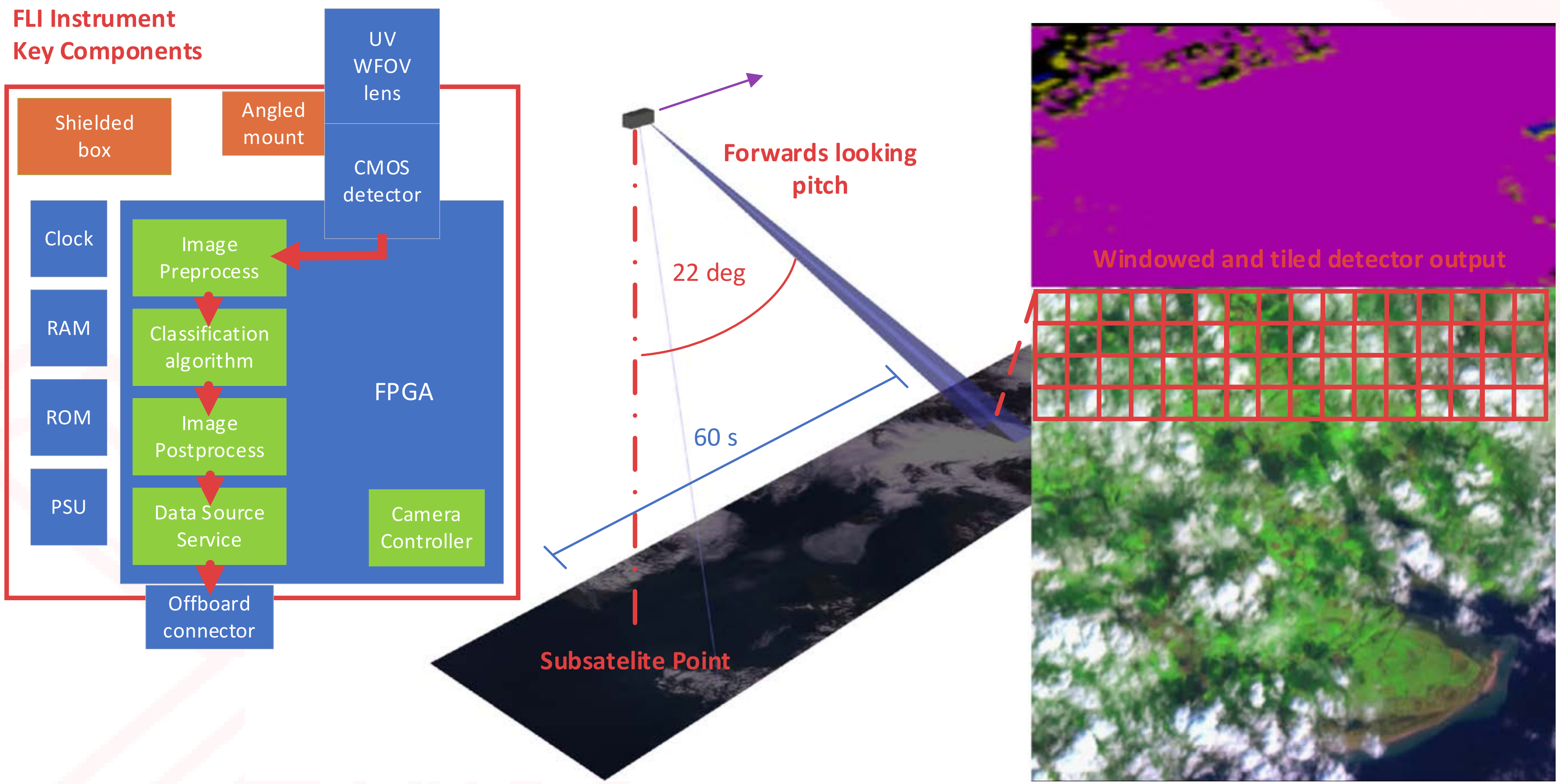


Reference Onboard Architecture



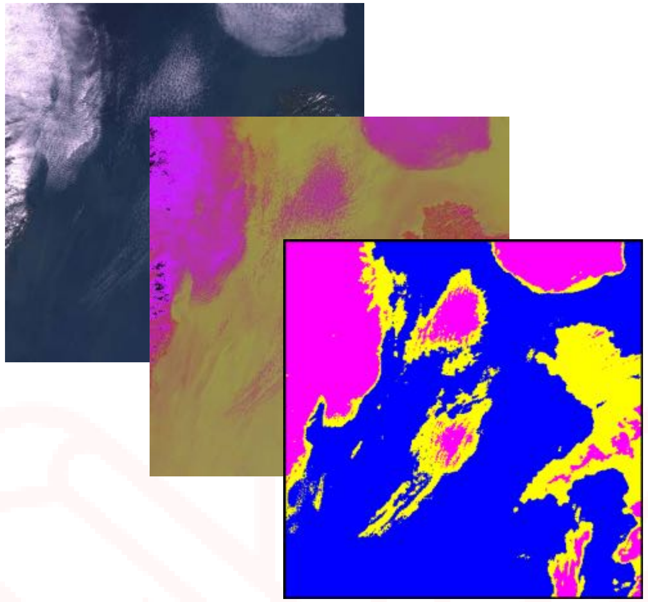

FLI Instrument
Key Components
Shielded box
Angled mount
UV WFOV lens
CMOS detector
Clock
RAM
ROM
PSU
Image Preprocess
Classification algorithm
Image Postprocess
Data Source Service
FPGA
Camera Controller
Offboard connector
Forwards looking pitch
22 deg
60 s
Subsatelite Point
Windowed and tiled detector output
FLIGHT DYNAMICS
ORBIT MODEL
GOALS
TARGET PLANNER
RESOURCE FORECAST
SCHEDULE
PLANNING & SCHEDULING
COMMS MANAGER
NETWORKING
COMPRESSION
ONBOARD RESPONSE
DATA STORE & MGMT
DATA PROCESSING
FEATURE CLASSIFICATION
OBSERVATION SUMMARY
GEOLOCATION
ARCHIVING
OTHER PLATFORM FUNCTIONS
BASELINE SYSTEM
ACQUISITION CONTROL
POSTPROCESS CONTROL
ONBOARD CONTROL PROCEDURES
AUTONOMY SUPERVISOR
HRI MANAGER
HIGH RESOLUTION IMAGER
DATA SOURCE

DETECT: Forwards Looking Imager

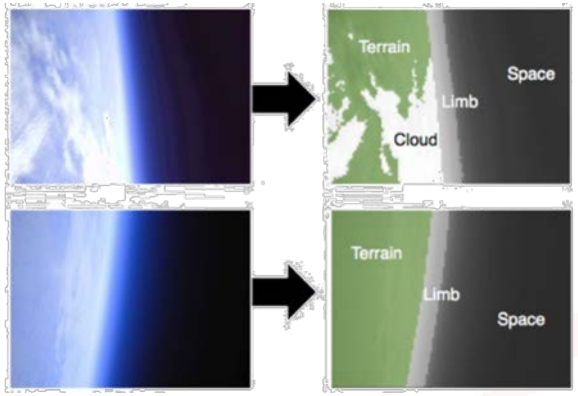


- Target prioritisation
- Resource assignment
- Payload repointing/slew
- Constellation task reassignment

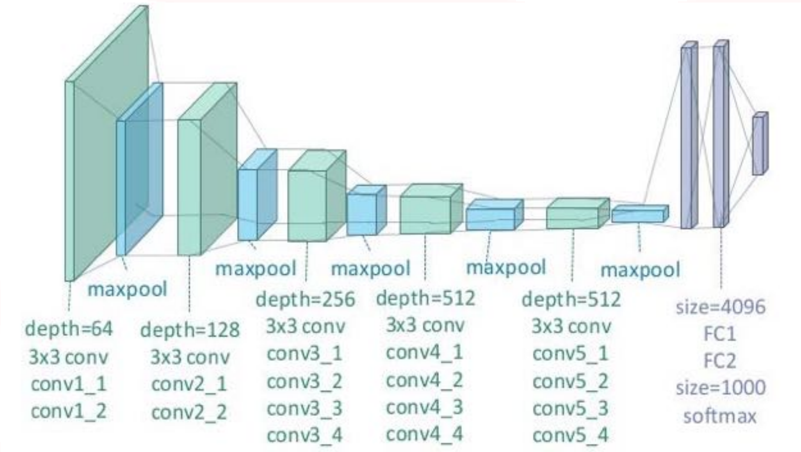
FLI Algorithm Downselect

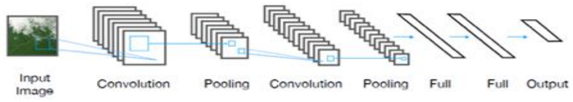


Fmask



TextureCam



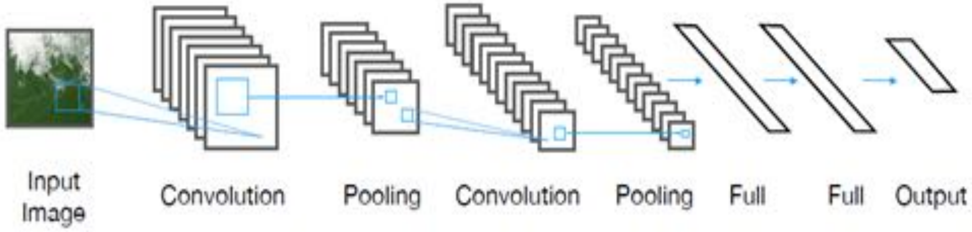


Deep learning

Increasing applicability across domains

Deep learning

- Applied transfer learning to existing CNN
- Modified open source VGG
- Trained using Planet Labs classification tiles
- < 1 hr training
- < 1 s inference



{ 'agriculture', 'cultivation',
'primary', 'road' }

Simonyam K & Zisserman A, "Very deep convolutional networks for large scale image recognition," arXiv preprint arXiv:1409.1556, 2014.

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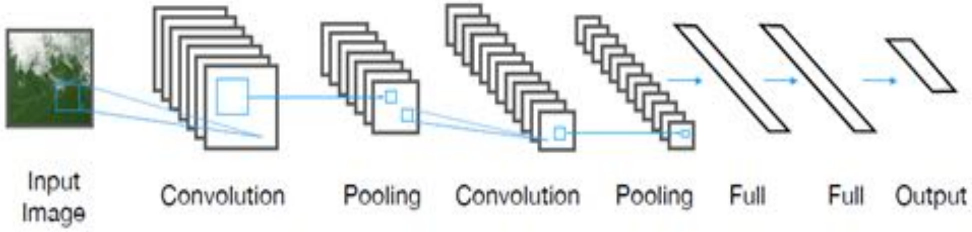


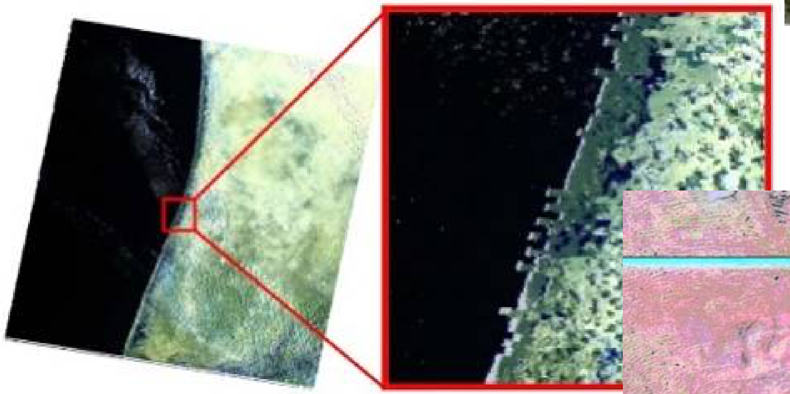
{ 'agriculture', 'cultivation', 'habitation', 'partly_cloudy', 'primary', 'road' }

Simonyam K & Zisserman A, "Very deep convolutional networks for large scale image recognition," arXiv preprint arXiv:1409.1556, 2014.

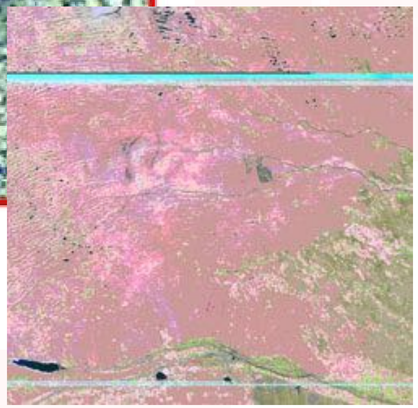
Implementation challenges

- Power and processing constraints
- Access to applicable Level 0 training data
- Ground reference points
- Incorporating anomalies
- Onboard systems interfacing
- Meeting operational regulations
- Demonstrating mission assurance
- Parallax error due to forwards looking

Gain Correction



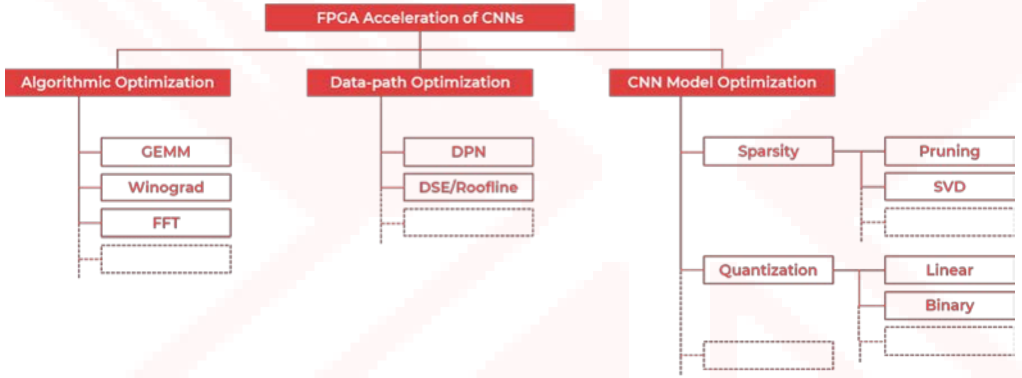
Pixel Alignment



Sun Glint

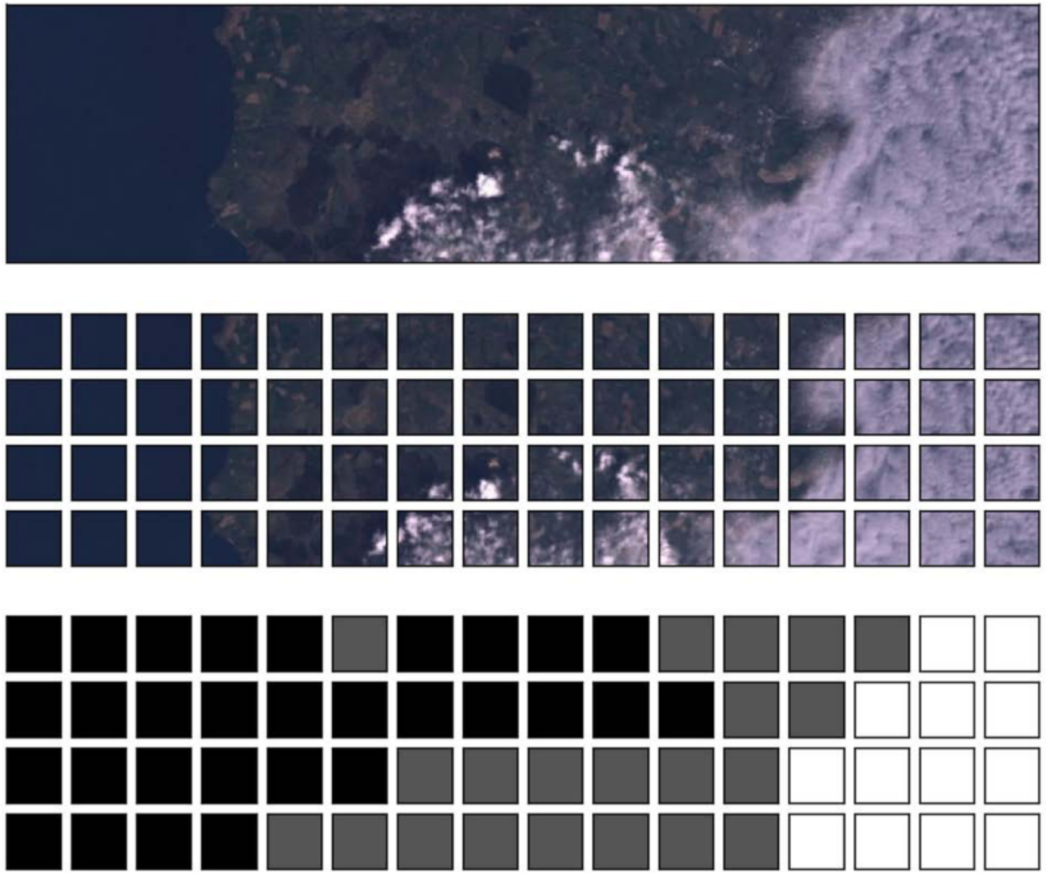
Enabling strategies

- Target FPGA with known flight heritage
- Tools to enable rapid synthesis from high level languages to embedded
- Evaluation of a number of optimization pipelines and approaches
- Adapted existing open source libraries for image processing and deep learning
- Discretisation/quantisation of the convolutional neural network
- Creating a system-in-the-loop test including distortions and anomalies

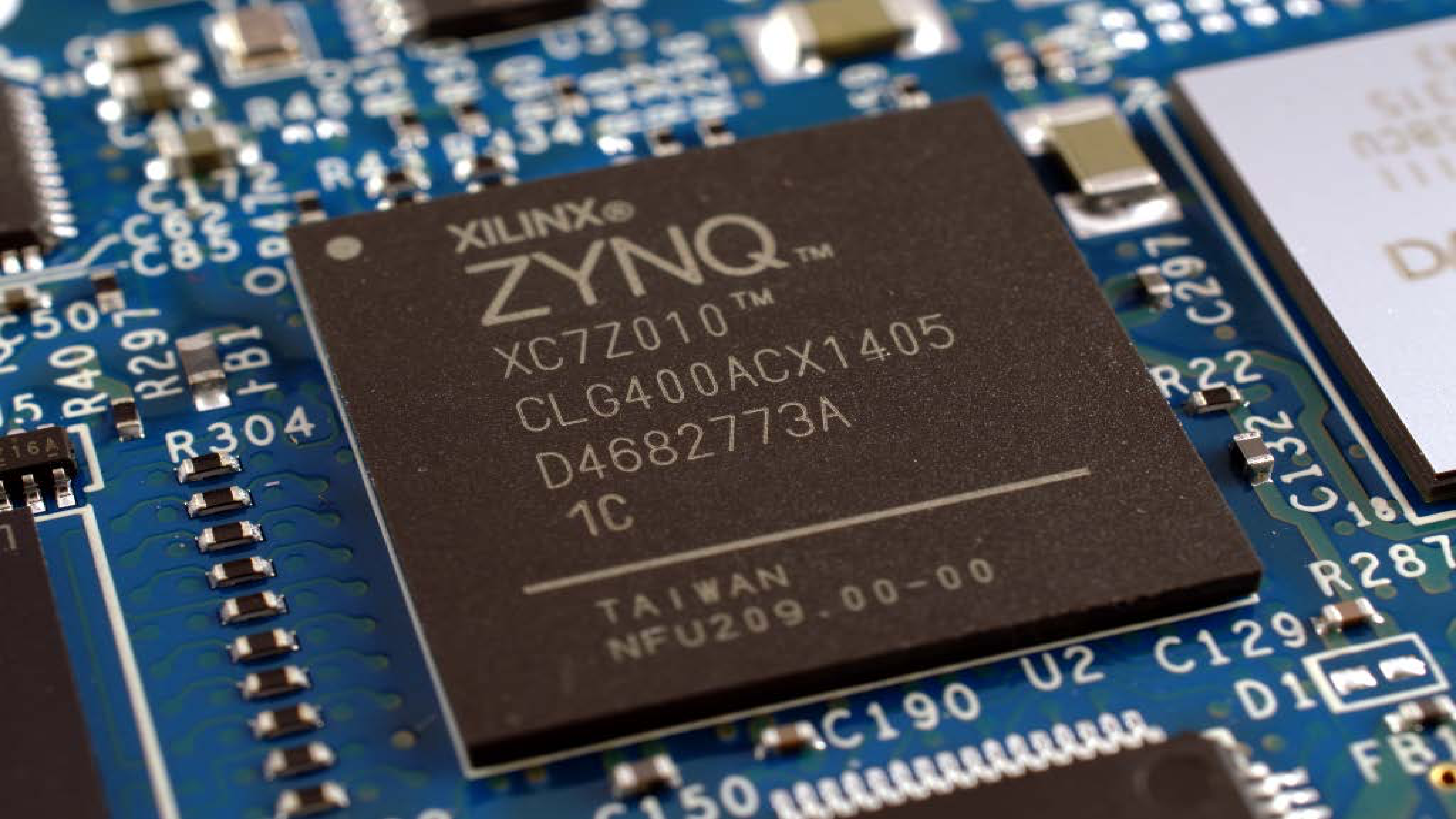


Name	Interface	Devices	Design Space Exploration	Year
fpgaConvNet	Caffe & Torch	Xilinx SoC	Global Optimiser (Simulated Annealing)	May 2016
DeepBurning	Caffe	Xilinx SoC	Heuristic	Jun 2016
Angel-Eye	Caffe	Xilinx SoC	Heuristic with Analytical Model	Jul 2016
ALAMO	Caffe	Intel SoC & Standalone	Heuristic	Aug 2016
Haddoc2	Caffe	Xilinx & Intel Standalone	Deterministic	Sep 2016
DnnWeaver	Caffe	Xilinx & Intel	Custom Search Algorithm	Oct 2016
Caffeine	Caffe	Xilinx Standalone	Exhaustive over Roofline Model	Nov 2016
AutoCodeGen	Proprietary	Xilinx Standalone	Heuristic with Analytical Model	Dec 2016
FINN	Theano	Xilinx SoC & Standalone	Heuristic	Feb 2017
FP-DNN	TensorFlow	Intel Standalone	Algorithmic	May 2017
Snowflake	Torch	Xilinx SoC	Heuristic	May 2017
SysArrayAccel	C	Intel Standalone	Exhaustive over Analytical Model	Jun 2017
FFTCodeGen	Proprietary	Intel HARP	Roofline and Analytical Models	Dec 2017

Test case



- Image is split into tiles
- Cloud detection payload classifies each segment with a single label:
  - Clear
  - Partly cloudy
  - Cloudy
- Payload pointing controller avoids cloudy regions and targets clear regions


XILINX®
ZYNQ™
XC7Z010™
CLG400ACX1405
D4682773A
1C
TAIWAN
NFU209.00-00

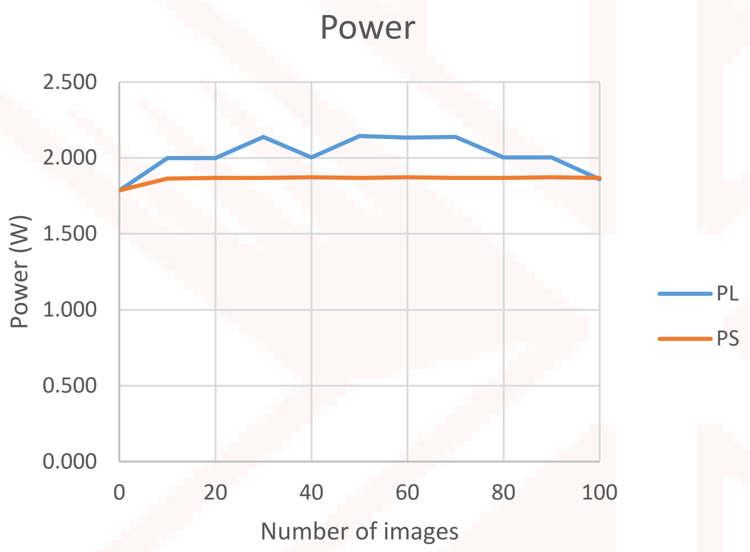
Results

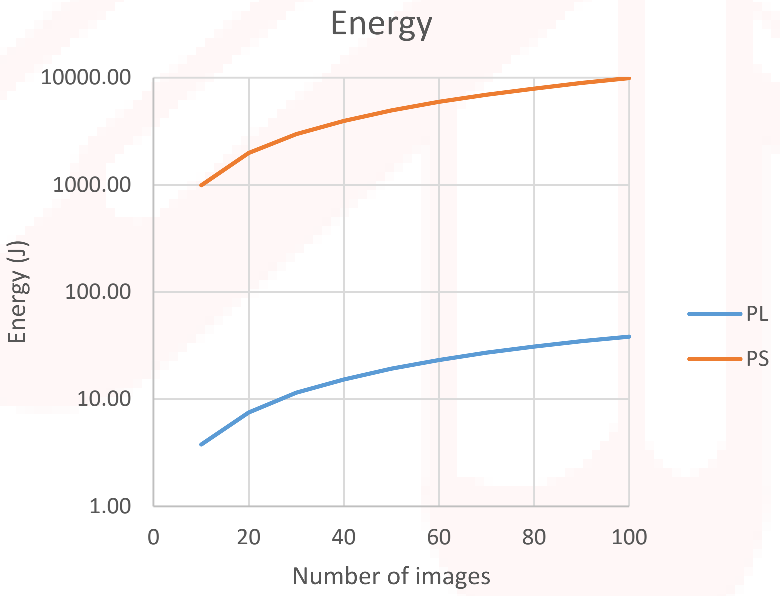
Model	Initialisation[1]	Inference[2]
Pre-optimal	7.06 s	3.63 s
Pre-acceleration (PS)	0.36 s	52.9 s
Accelerated (PS+PL)	0.36 s	0.19 s

(1) Initialisation is always in PS. Involves loading neural network libraries and creating NN object.

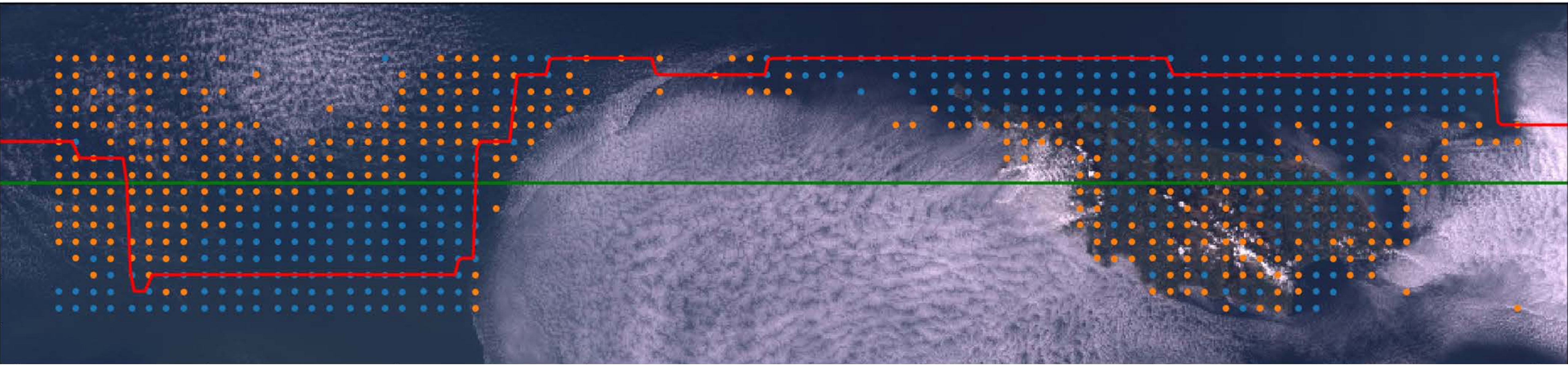
(2) Inference performed on single image split into tile segments and batch classified

Accuracy of 97% achieved against human evaluated tiles, now being formally benchmarked





Payload cloud avoidance



- Inference model is deployed on FPGA, allowing real-time cloud detection
- At the area access rate in LEO we can extract features at 60% max loading
- < 2 W, < 5 s from capture through to planning output

- Engineering Models of the Forwards Looking Imager MVP now available
- Delivered to first customers for third party performance and interface testing
- Tools for adapting to a range of real-time feature detection applications

Ongoing development

Extending core computing capability with additional low power processing nodes

intel Movidius™

Adapting and embedding third party algorithms for different spectral bands and use cases

GSI

Global Surface Intelligence

CORTEXICA

VISUALLY EMPOWERING BUSINESS

Interfacing with existing flight heritage sensors and camera systems

XCAM

TELEDYNE e2v

Everywhereyoulook™

Drone testing

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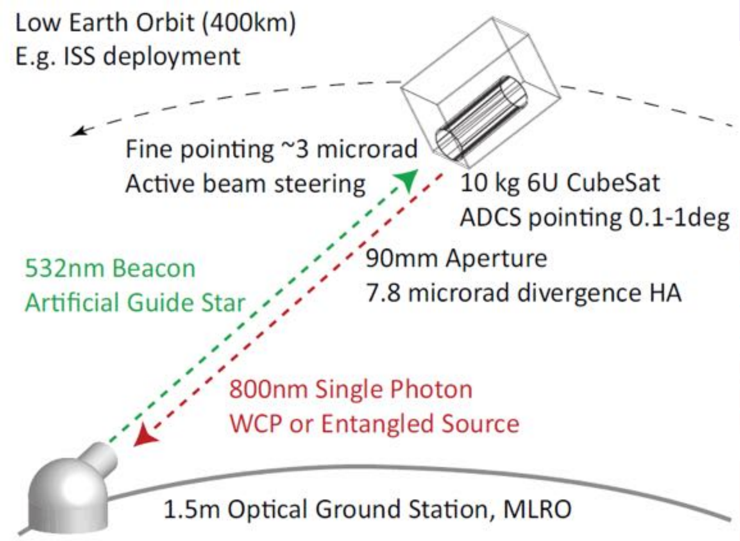
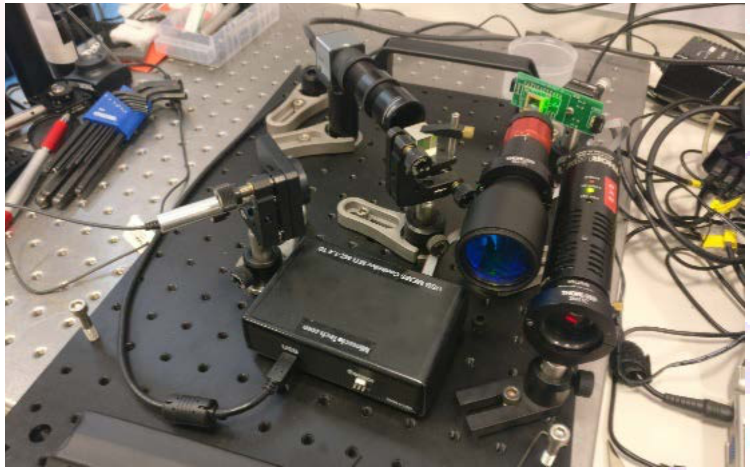
Responsive Operations for Key Services

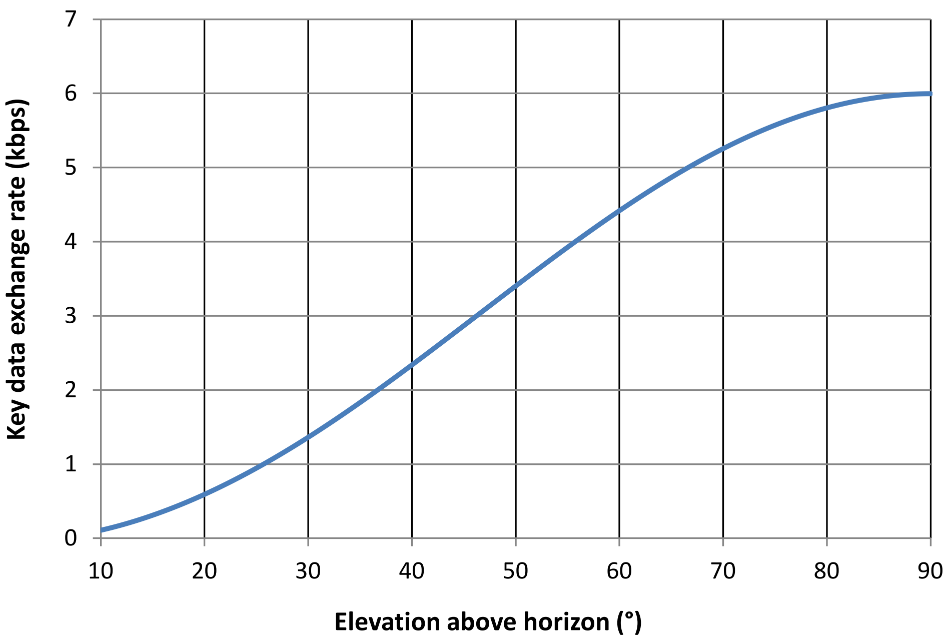
- Maximise utility of high power and bandwidth Quantum Key Distribution (QKD) payload
- Towards delivery of secret keys for securing BT telecoms infrastructure
- In-Orbit Demonstration opportunity for FLI and autonomy framework
- Onboard ML to support real-time planning and signal identification

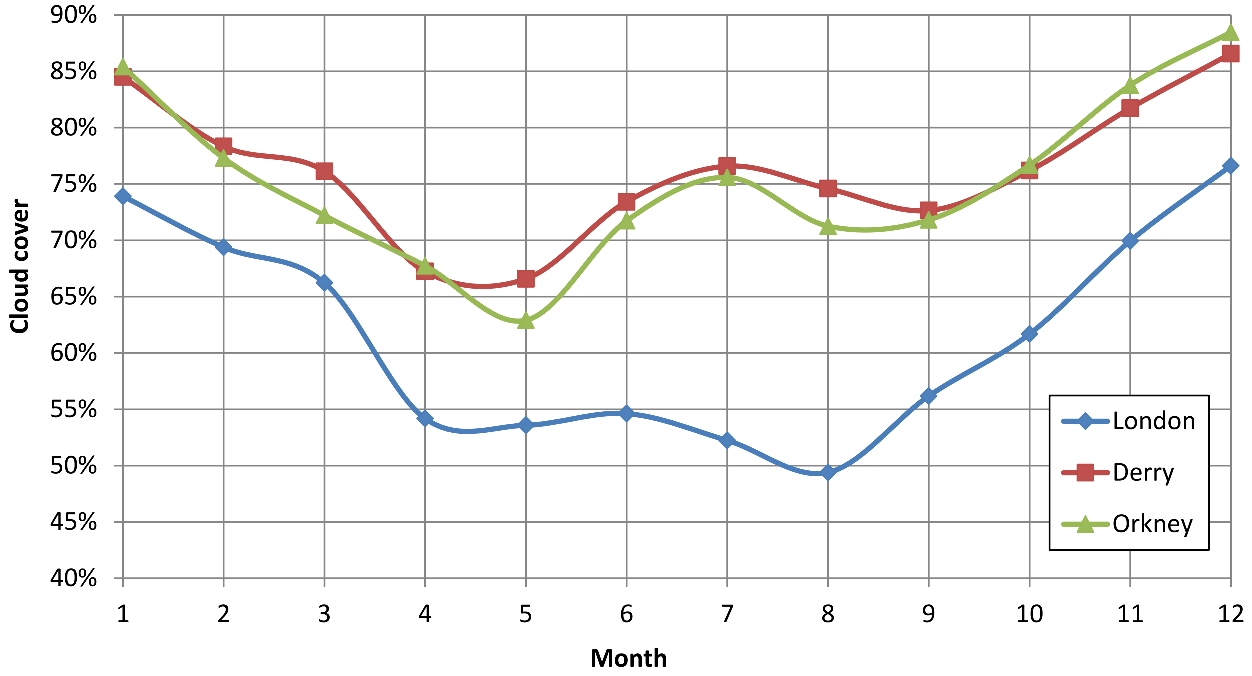




Key rate and ground visibility

Key exchange rate as a function of elevation angle (optimal conditions)





Cloud cover data inferred from Met Office derived Sunshine hours data

Using AI for informing onboard

Using developed software and FLI to deliver a responsive operations

Summary

- Overall **framework for autonomy** and enabling algorithms presented for COBRA
- **Forwards looking imager** EM on flight representative hardware, with 1-2 min look-ahead
- Acceleration of enabling algorithms embedded into FPGA **300x faster** (PS vs PS+PL)
- Toolchain to rapidly develop and test from **high level languages to embedded** prototyped
- **Real time feature detection** for the area access rates in LEO demonstrated at < 2 W
- Application and training optimisation of deep learning for **cloud detection** case
- **System-in-the-loop** simulation developed to allow end to end testing of the imaging system
- Flight ready variant now in development and to environmental test in 2019
- Towards flight opportunity in the **Responsive Operations for Key Services** IOD

Acknowledgements

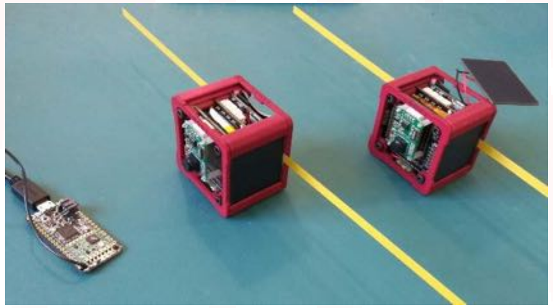
"Onboard Data Autonomy for Next Generation of EO Nanosatellites"

"Augmenting Emerging Quantum Key Distribution Networks with CubeSats"

Smart Contracts for Responsive Operations

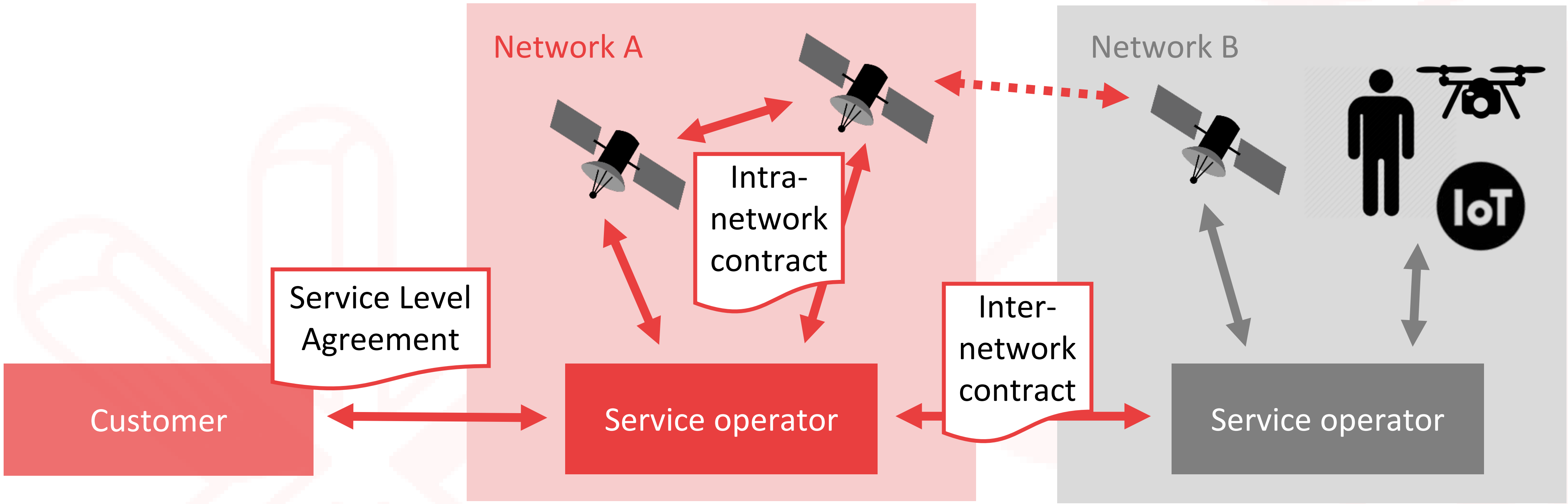
- As AI-enabled automation and autonomy become standard and multiple networks of satellites emerge…

- Automatic tasking of assets
- Enable trading of satellite onboard resources
- Tracing and verifying workflows
- Attribution in multi-sourced products



- Non-homogenous intelligent CubeSats to augment wider EO or telecoms networks in Space 4.0

Maximising return from assets



thanks

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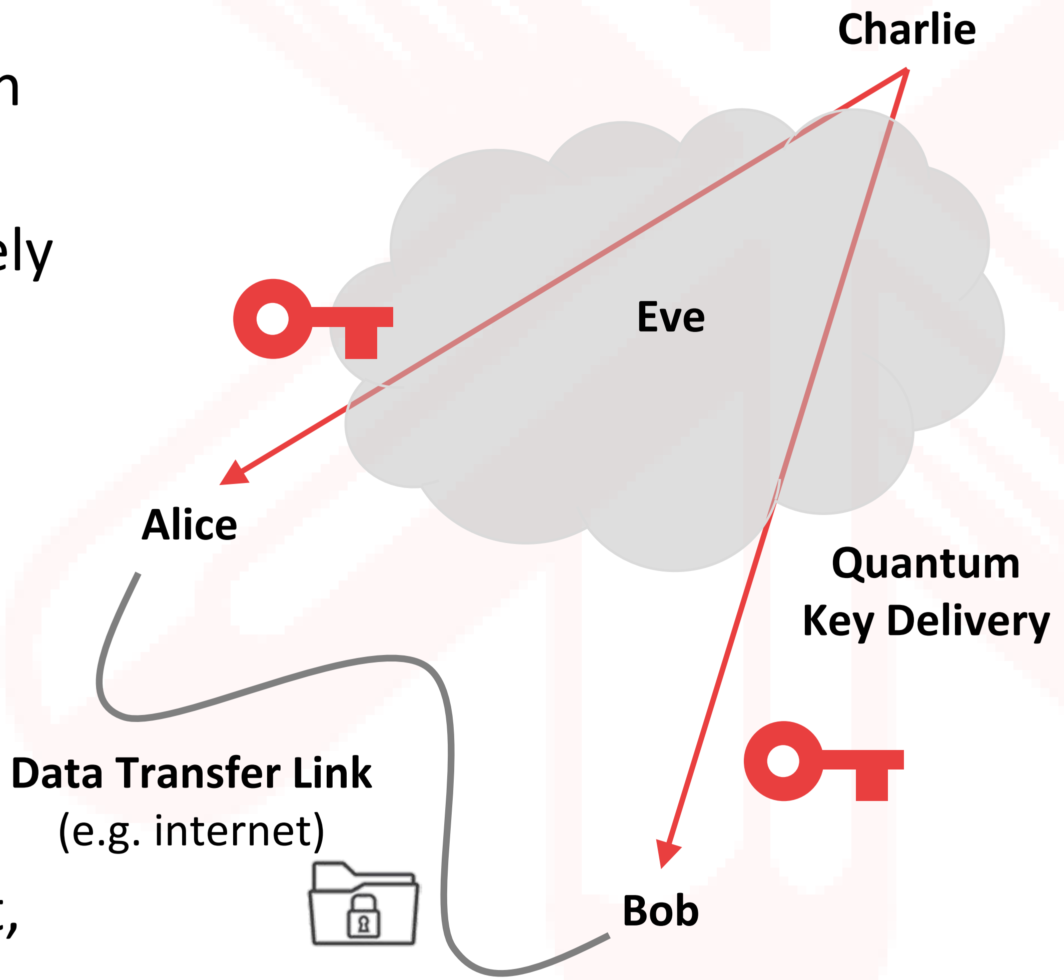
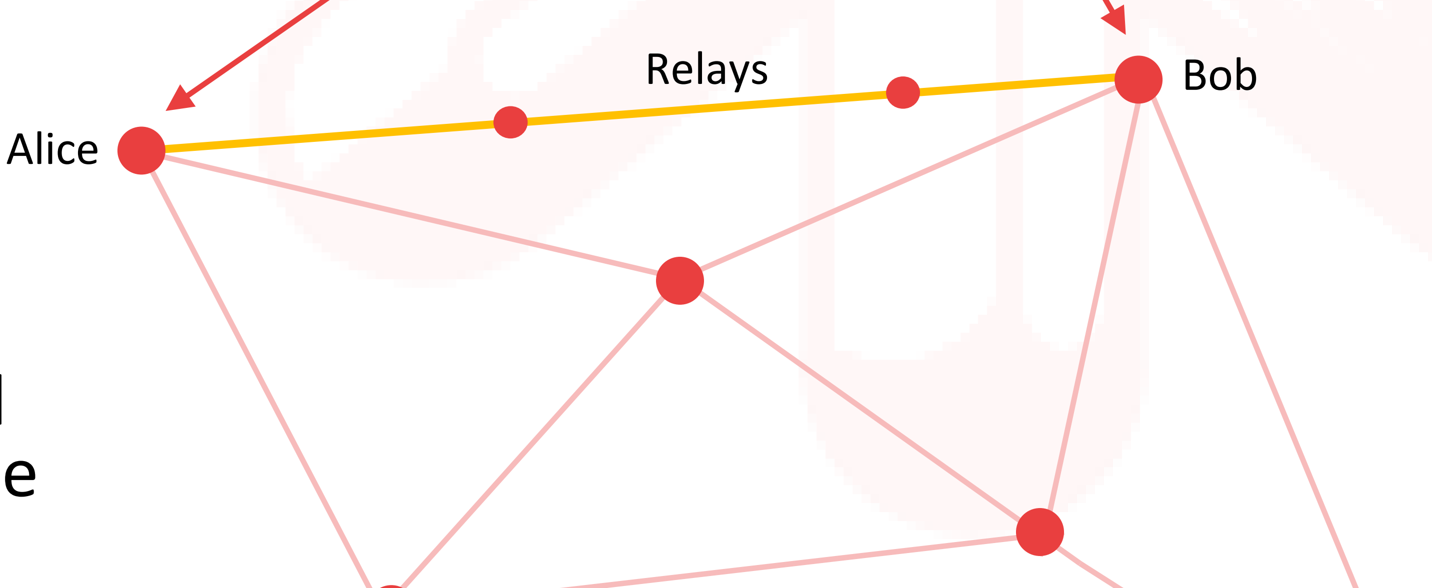
Quantum Keys for Cybersecurity

- Secret keys are an essential tool for encryption and authentication
- Quantum Key Distribution (QKD) is a completely alternate way of creating a key
- Instead of mathematical complexity it uses fundamental physics
- It relies on the physical properties of photons for security
- It may be distributed by a third party (Charlie) to Alice and Bob
- Even if Eve intercepts part of the key in transit, and that part is not used



Why Space?

- QKD networks are now emerging on the ground
- Photons have limited range requiring relays, due to
  - Attenuation within fibre optics or dense atmosphere makes signal weak
  - Line of sight if in free-space due to physical obstacles and curvature
- Relays are expensive to implement, maintain, and represent a point of weakness for attack
- Space assets can deliver keys as independent channel for point to point key delivery
- Negates need for widespread relay infrastructure to operate



Why CubeSats?

This is the first time a new global multi-domain service and market has emerged with CubeSats able to augment from the outset; how does that change its delivery and deployment?

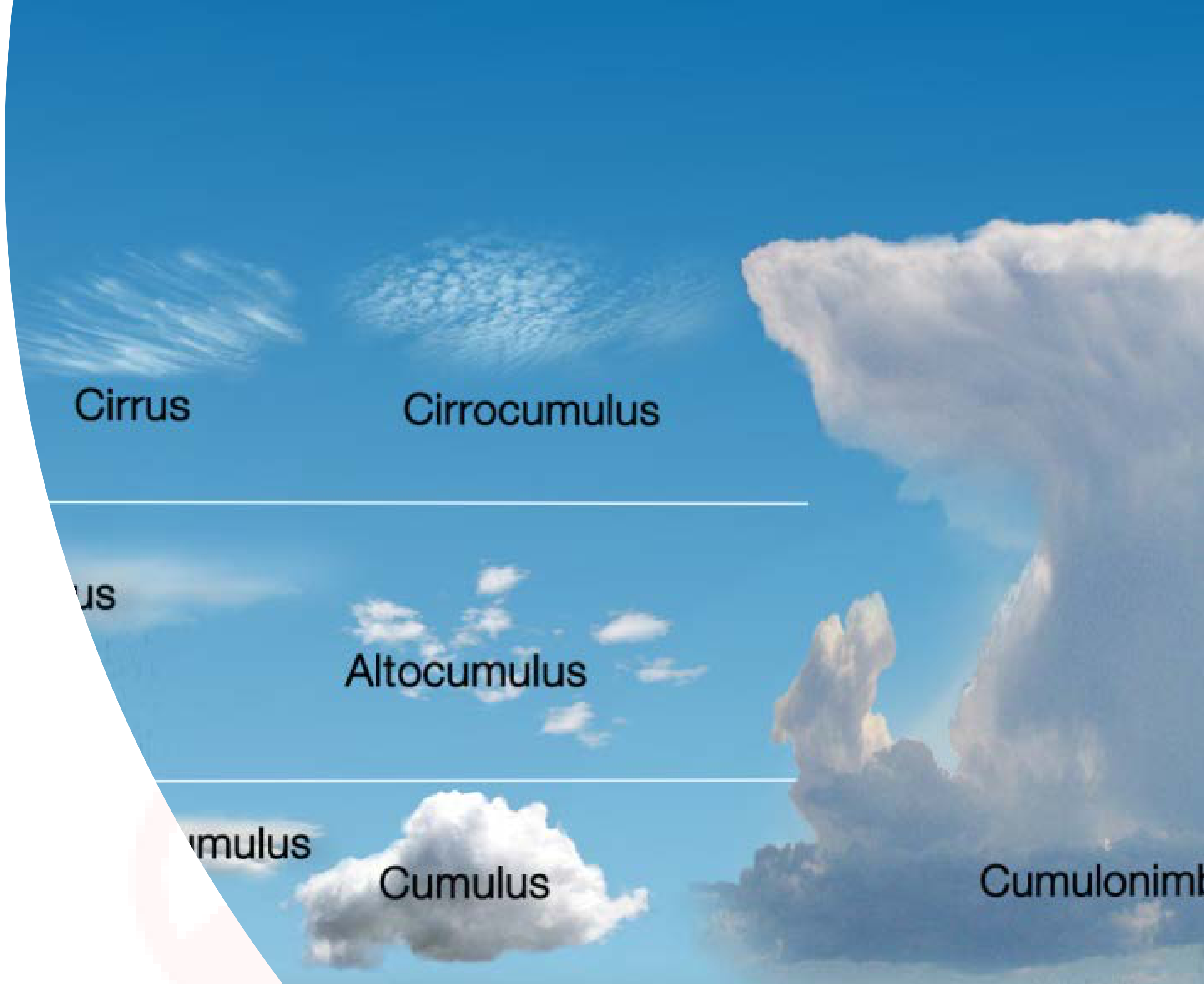
Phase I: during initial deployments

- Provide test services to **characterise the service** against emerging standards
- **Derisking infrastructure** upgrades and deployment in critical systems
- Develop **operational understanding** to deliver a QKD Service satellite network
- Supporting the **rapid deployment** of assets and new technology

Phase II: as key services emerge

- **Smoothing of demand** where networks experiences elevated key requests
- **Gap filling capacity** where infrastructure unavailable or not yet deployed
- **Alternate key channels** where it does not meet minimum security requirements
- **Responsive key delivery** to locations outside of emergent infrastructure





Not every cloud is equal…

Credit: earthobservatory.nasa.gov