Project Plan

1. Project Title:
SpaceCraft Autonomy and Onboard AI for Next Generation Space Systems
(Part of the SpaceCraft Autonomy Research Lab: SCARLET-α)

2. Project Summary:
Spacecraft autonomy has been recognised as a key enabler of the next-generation space systems that aim at increasing responsiveness and continuity of space-based observations, covering large areas with higher resolutions, minimizing communication and data access latencies, and reducing costs of both the space and ground segments.

Spacecraft autonomy encompasses onboard autonomous decision-making capabilities that enable the space segment to continue mission operations and to survive critical situations without relying on ground segment intervention. It relates to all aspects of spacecraft operations, including continuous mission planning and execution on board, real-time spacecraft control outside ground contact, maximisation of mission objectives in relation to the available onboard resources and capabilities of other spacecraft, and system robustness in presence of on-board failures and external uncertainties.

This project aims at addressing the above requirements by developing novel concepts, methods and technologies to provide new AI-based spacecraft autonomy capabilities for the next-generation space systems, such as dynamically networked formations of heterogeneous satellites. It focuses on high impact areas of spacecraft autonomy and onboard AI as identified and prioritised with the industry and defence partners, including:

- WP1: Onboard processing and actionable intelligence
- WP2: Small spacecraft and constellation resilience
- WP3: Dynamic optimisation of constellation resources
- WP4: Real-time tasking and resource allocation

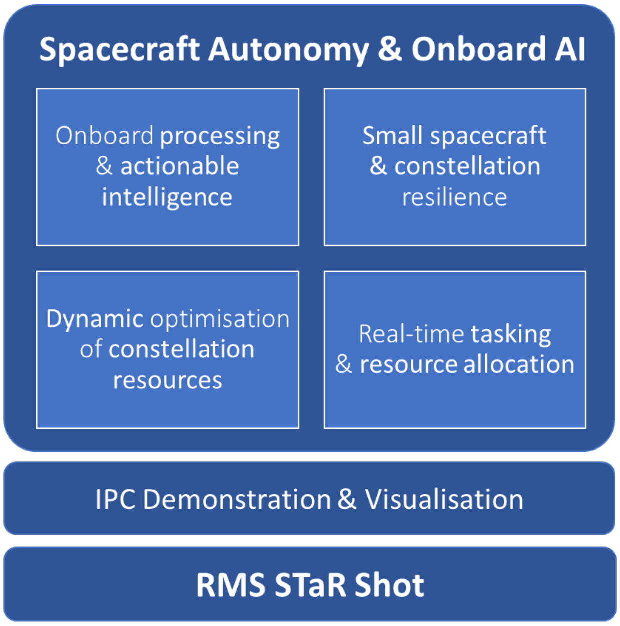
The output of this project is a set of autonomous algorithms, demonstrating their capability through software simulations with use-cases provided by the industry partners and DST. This project will leverage and contribute to the IPC Capability Demonstrator that will support the pathways for demonstrations, translation and commercialisation of the developed technology solutions with the industry and defence partners in the context of RMS STaR Shot.

3. Project Objectives

Spacecraft autonomy encompasses onboard autonomous decision-making capabilities that enable the space segment to continue mission operations and to survive critical situations without relying on ground segment intervention. It relates to all aspects of spacecraft operations, including continuous mission planning and execution on board, real-time spacecraft control outside ground contact, maximisation of mission objectives in relation to the available onboard resources and capabilities of other spacecraft, and system robustness in presence of on-board failures and external uncertainties.

This project addresses the key issues in the high priority areas of spacecraft autonomy and onboard AI as identified with the industry and defence partners:

- Onboard processing and actionable intelligence
- Small spacecraft and constellation resilience
- Dynamic optimisation of constellation resources
- Real-time tasking and resource allocation



WP3: Dynamic optimisation of constellation resources
The resource management in satellite constellations will require dynamic optimization strategies which can handle many objectives, large state-action pairs, rapidly changing environments, decentralized configurations, while demonstrating low computational and memory burdens. This is motivated by the fact that satellite constellations involve many satellites, operate in time-varying conditions, handle massive and uncertain requests while being constrained by limited computational and memory resources on board. The main challenges for optimised resource allocation in such highly dynamic environments include its large scale and the lack of complete control over the resources (and payloads), and the uncertainty about user requests and resource availability due to unexpected events.
This focus area aims at developing a comprehensive and cutting-edge AI technological solution for dynamic optimisation of adaptive resource allocation in the next-generation space systems. This research objective is achieved by answering the following research questions:

RQ 3.1 How to reduce complexity and improve efficiency of dynamic resource optimisation with spatio-temporal clustering of geographically distributed user stations and changing user requests?

RQ 3.2 How to optimise dynamic resource allocations in satellite constellations with Dynamic Deep Q Networks?

RQ 3.3 How to distribute resource optimisation in satellite constellations with Distributed Dynamic Deep Q Networks?

RQ 3.4 How to use AI to accurately predict and quantify expected resource burdens and communicate that across the constellation, ground stations and end-users?

Achieving autonomy in space requires proper addressing all these fundamental and practical issues related to dynamic optimisation of constellation resources. The above research questions will be answered in the context of the assumed mission and use-cases defined in collaboration with the industry partner and end-users.

WP4: Real-time tasking and resource allocation

Real-time tasking is a key capability of the next-generation space systems that aim at increasing responsiveness and continuity of space-based observations, covering large areas with higher resolutions, minimising communication and data access latencies, and reducing costs of both the space and ground segments. It will allow the users to remotely observe, both sporadically and continuously, on the earth surface information (i.e., land, ocean, air, and space), and access other services from satellites, such as data processing, relay, up-link and down-link services on-demand. It requires real-time continuous allocation of satellite resources within constellations to fulfill the user requests on-demand and assure the requested services are provided in a cost-effective and quality-assured manner.

This focus area aims at developing novel AI-based technology solutions for real-time tasking and satellite resource allocation to achieve efficiency and continuity of the satellite services offered as virtual satellites. It will include 1) a virtual marketplace accepting user requests and tasking/allocating virtual satellites to offer satellite resources as a service; 2) Efficient, real-time allocation of satellite resources in the constellation required to satisfy user requests and ensure effective ready-to-use provision of virtual satellite services to users; 3) dynamic re-tasking and re-allocation of resources within the constellation to ensure continuity of provided satellite services during unexpected and uncertain events.
The key research questions and challenges include:

RQ 4.1 What are autonomy approaches needed across the space constellation operating system to provide dynamically reconfigurable virtual satellite services and resources?

RQ 4.2 How to perform real-time satellite tasking to allow users to commission satellites and quickly capture images of specific areas according to specific parameters and requirements based on a virtual marketplace?

RQ 4.3 How to efficiently ensure the continuity of satellite services in constellations, where satellite resources are dynamically allocated to serve user requests as virtual satellites, and re-allocated when satellites move or become unavailable, etc.?

Achieving autonomy in space requires proper addressing of all these fundamental and practical research questions related to real-time tasking and satellite resource allocation. The above research questions will be answered in the context of the assumed mission and use-cases defined in collaboration with the industry partner and end-users.