CUBESPEC - ENABLING SPECTROSCOPY FROM A CUBESAT PLATFORM

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ABSTRACT

CubeSpec is an in-orbit demonstration CubeSat mission in the ESA technology programme, developed and funded in Belgium. The goal of the mission is to demonstrate high-spectral-resolution astronomical spectroscopy from a 6-unit CubeSat. The prime science demonstration case for the in-orbit demonstration mission is to unravel the interior of massive stars using asteroseismology by high-cadance monitoring of the variations in spectral line profiles during a few months. The technological challenges are numerous. The 10x20cm aperture telescope and echelle spectrometer have been designed to fit in a 10x10x20cm volume.

Under low-Earth orbit thermal variations, maintaining the fast telescope focus and spectrometer alignment is achieved via an athermal design. Straylight rejection and thermal shielding from the Sun and Earth infrared flux is achieved via deploying Earth and Sunshades. The narrow spectrometer slit requires arcsecond-level pointing stability using a performant 3-axis wheel stabilised attitude control system with star tracker augmented with a fine beam steering mechanism controlled in closed loop with a guiding sensor. The high cadence, long-term monitoring requirement of the mission poses specific requirements on the orbit and operational scenarios to enable the required sky visibility.

CubeSpec is starting the implementation phase, with a planned launch early 2024. A full engineering qualification model and a flight model will be constructed and tested in the course of 2022 and 2023. In this contribution we will give an overview of the mission, the technology developments and the qualification status of the satellite and its components.

1. MISSION OBJECTIVES

Over the recent years, several astronomical space telescopes on small spacecraft platforms and CubeSats have developed, launched and operated succesfully [1, 2]. Several performant imaging and photometric instruments demonstrated the complementarity of small platforms in the astronomical instruments landscape. Building a spectroscopic mission on a CubeSat platform is more challenging. The CubeSpec in-orbit demonstration mission goal is to demonstrate high-spectral-resolution astronomical spectroscopy from a 6-unit CubeSat. The science case is described in full detail in [3].

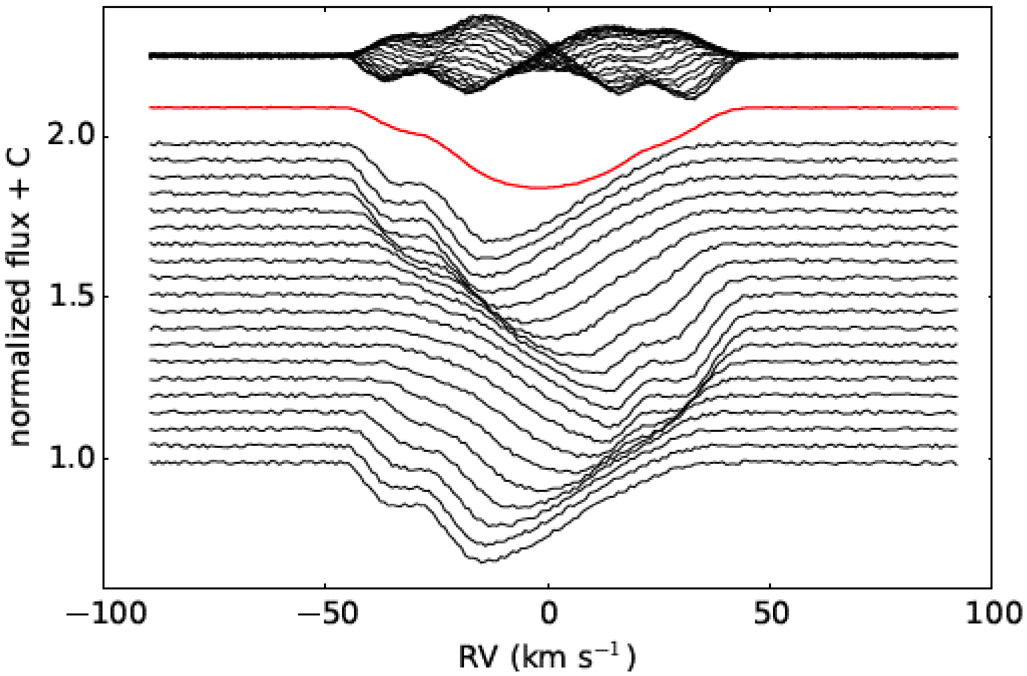

Figure 1 The shape of a spectral line in the spectrum of a massive star changes in time due to the oscillations of the star. The figure (adapted from [3]) shows the simulated variations in the line profile for one pulsation cycle of the star β Cep at a spectral resolving power of 55000, measured at a cadence of 15min.

High cadence, high resolution time series of measurements of the shape of spectral lines in the spectrum of high mass stars allows to unravel the internal structure. The spectral line shape changes due to the oscillations of the star. The internal structure determines how the star can oscillate, and different oscillations will result in different changes in the spectral line shape.

With the CubeSpec in-orbit demonstration mission, we will monitor about 5 stars at a time. In order to sample the typical pulsation period of β Cep pulsators (8-24 hours) about 10 times per period, we aim at 1 to 2 observations of every star every 100 minutes for 100 days.

The CubeSpec mission is designed as a generic spectroscopic mission. We aim at building recurring versions of the mission with a short development time and cost. Minimal changes in the optical configuration of the spectrometer and/or onboard software should allow to build CubeSpec missions optimised for a variety of astronomical science cases. Secondary science cases identified for forthcoming CUBESPEC implementations with minor optical / software configuration changes include chromatic asteroseismology Solar type stars, absolute flux calibration of stellar models, observing diffuse interstellar bands, characterising stellar activity and exoplanet spectroscopy. During the in-orbit demonstration mission we already plan to demonstrate some of these.

2. SPACECRAFT LAYOUT

The spacecraft is launched in a folded configuration of 6 CubeSat units (6U - 10x20x30cm). Four units (10x20x20cm) are allocated to the optical payload (telescope and high-resolution spectrograph). Two units (10x20x10cm) are reserved for the spacecraft avionics and the payload electronics. After launch, two 20x20x30cm solar panels are deployed under an angle of 45degrees. The deployable Sun shade protects the detector radiator panel from illumination from the Sun. The deployable Earth shades protects the telescope from heating by the Earth infrared flux and optical straylight.

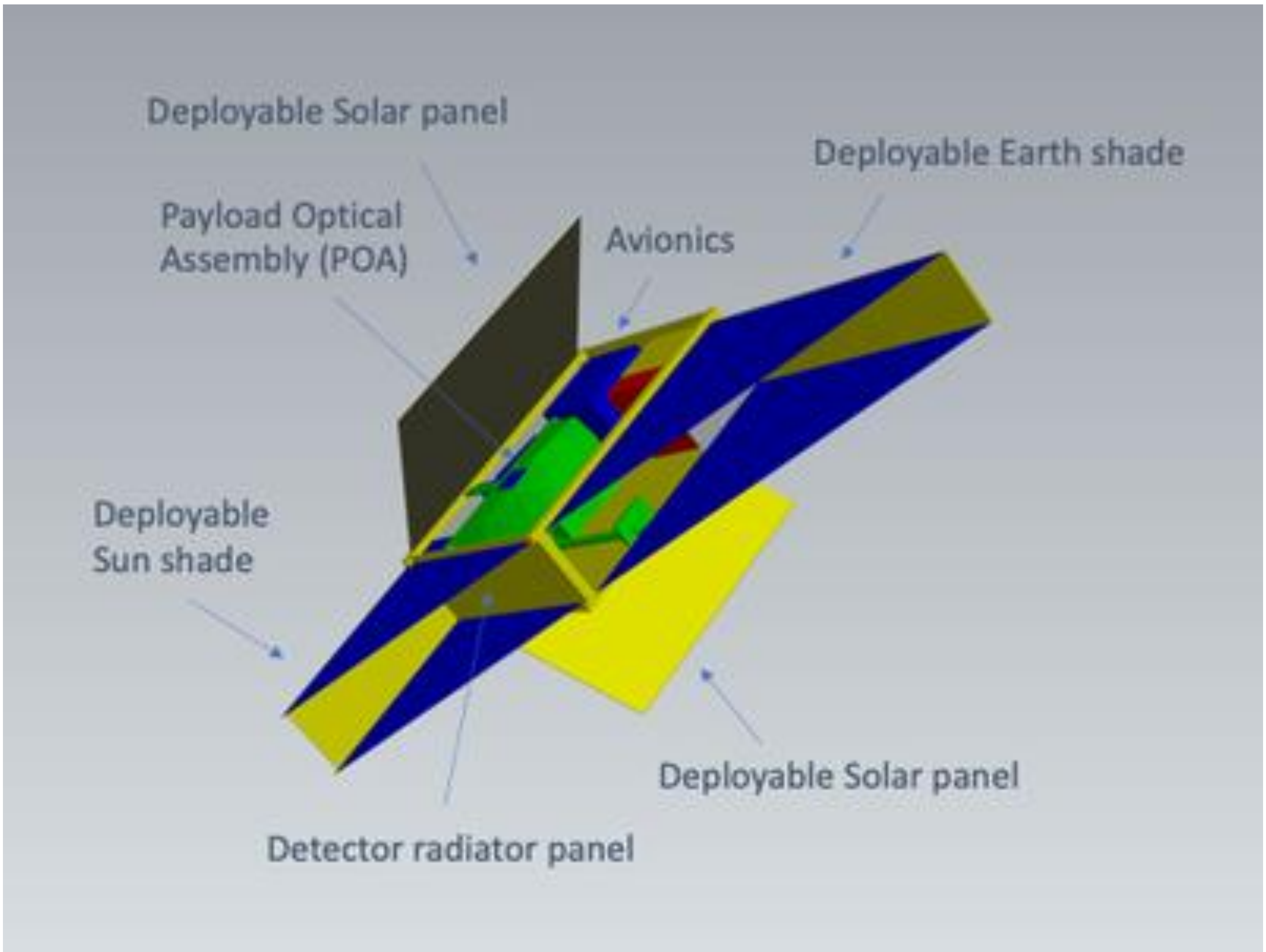

Figure 2 Deployed spacecraft configuration

3. PAYLOAD

The heart of the scientific payload is a telescope and high-resolution spectrometer. The telescope and spectrograph fit in a 4U volume (10x20x20cm). The telescope is a rectangular off-axis Cassegrain telescope. The primary mirror has a clear aperture of 83x190mm and a focal length of 1600mm. The spectrograph optics are mounted on an optical bench on the back of the primary mirror. The telescope beam first hits a beam steering mirror, which is used to correct for pointing errors and image the telescope PSF on the spectroscope entrance slit which measures 2.6" by 6.5" only.

The optical design is generic to be able to tune future CubeSpec implementations for different spectral resolutions and wavelengths. The design is compatible

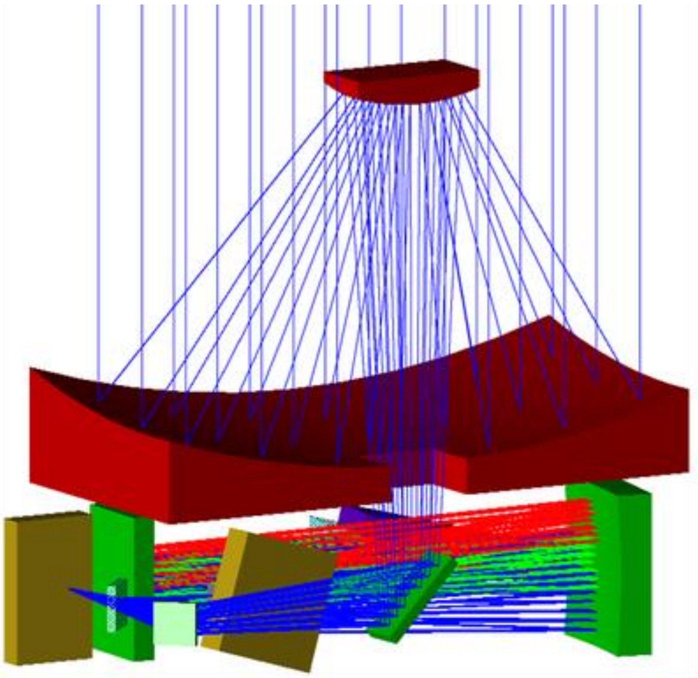

Figure 3 Optical layout of the scientific payload

with tuning the spectral resolution from low (R~50) to high (R~75000) and the wavelength coverage between 250 and 1000nm.

For the in-orbit demonstration mission, the echelle diffraction grating, the prism cross disperser and the detector are chosen to deliver a spectral resolution of R=55000, wavelength range between 420 and 620nm.

The science sensor selected for CUBESPEC is the Gpixel GSENSE2020BSI. It is a back-illuminated CMOS sensor with 2k x 2k 6.45um pixels. The detector exhibits a read noise of 1.6e-, dark noise of 1.1e-/s at -16deg C and has a 90dB dynamic range. We are characterising the detector in the lab (fringing, blooming, saturation, bigger fatter effect, gain stability, etc). The same sensor is used for the fine guidance system. The detector readout is done using in-house developed readout electronics. We use an identical sensor for the fine guidance system (see below)

In order to provide a flat illumination and wavelength calibration reference, the instrument has an on-board calibration source. Two LEDs are coupled to a fiber injecting a beam through a hole in the secondary mirror. This hole is located in the shadow of the M2 and the fiber exit lens is matching the beam speed of the telescope. The white light LED is directly coupled into the fiber coupler. The wavelength reference LED passes through a compact fabry perot, delivering a regularly spaced wavelength reference fringe pattern.

The spectrograph optical design has been tuned to optimise the echelle spectral order arrangement on the detector, avoiding key spectral lines to be on the order edges. The 420-620nm wavelength range is split in 37 spectral orders. The red orders are partly truncated by the detector size. The detector is rotated by 17degrees to align the slit with the detector columnss. A spectral resolution element is sampled in 3x8 pixels and the inter-order spacing varies betwen 18 and 35 pixels, enabling a good order separation.

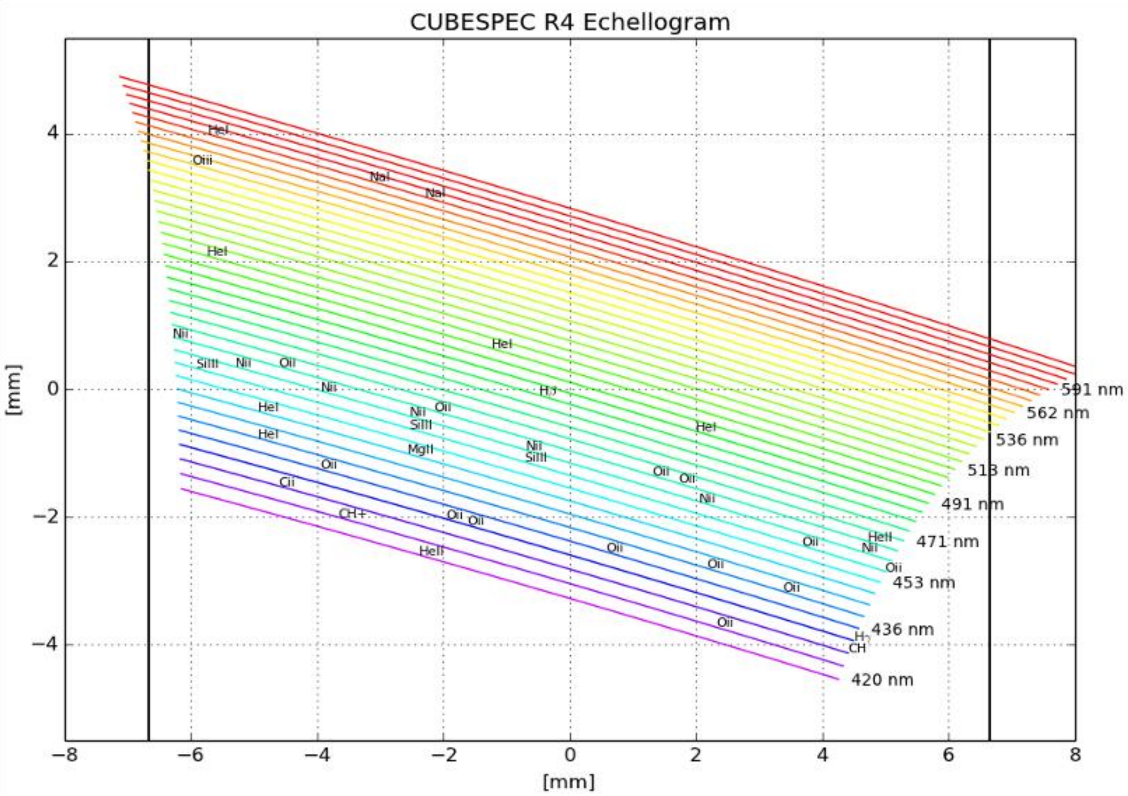

Figure 4 The 37 Echelle spectral orders are imaged on the detector, rotated by 17 degrees to align spectral lines with the detector columns. The design was optimised to avoid important spectral lines to fall on the order edges.

The CubeSpec optical design results in a very high efficiency. On a magnitude mV=4 star, we can obtain a high signal-to-noise, high-resolution spectrum in 15minutes (R=55000, Texp=15min, SNR=200).

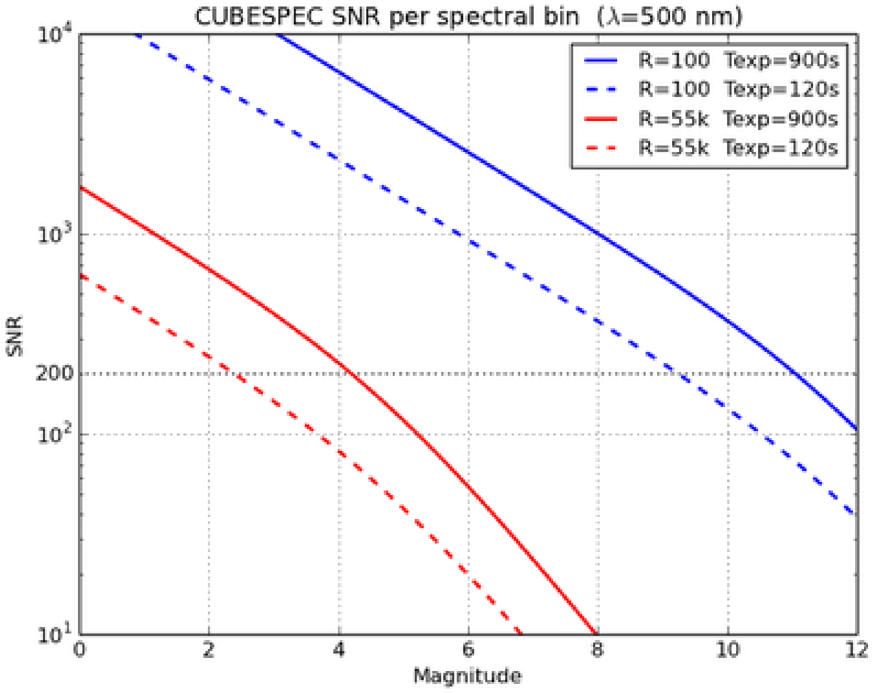

Figure 5 Predicted CUBESPEC sensitivity from radiometric modeling. The curves show the signal-to-noise-ratio (SRN) of the recorded spectra as a function of brightness (magnitude) of the star observed. The red curves show the sensitivity when recording a high resolution (R=55000) spectrum in 900seconds (solid line) and 120 sec (dots). The Blue curves show the sensitvity when measuring a low resolution (R=100) spectrum by binning detector pixels.

4. ATTITUDE CONTROL

The pointing requirements of the CUBESPEC payload are mainly determined by the dimensions of the slit at the spectrograph focus. To ensure sufficient throughput of star light passing the slit, an Absolute Pointing Error (APE) is in the range of arcseconds. Since the spectral quality will not be affected by spacecraft jitter, the requirement on the Relative Pointing Error (RPE) can be relaxed.

A CubeSat ADCS typically has a bandwidth of around 0.1 Hz, which is insufficient to compensate high frequency disturbances. A secondary control loop with a Fine Guidance Sensor (FGS) and a Fast Steering Mirror (FSM) using piezo-actuators compensates these high frequency disturbances.

The arcsec ADCS for CubeSpec is derived from the ADCS with flight heritage on the 3U ESA IOD CubeSat SIMBA. It is a performant 3-axis wheel stabilised attitude control system with star tracker.

The ADCS controls the attitude error of the spacecraft, while the FGS and FSM control the line-of-sight error of the payload. The FSM control loop will be activated once the ADCS control loop has brought the target within the field of view of the FGS.

5. THERMAL CONTROL SYSTEM

To keep the detector radiator shielded from illumination by the Sun, and to avoid optical straylight and heating of the telescope by the Earth albedo and infrared flux, two deployable Sun and Earth shields are foreseen. They are based on a deployable panel and two triangular kapton foils that are unfolded when the spring loaded panel is deployed after launch.

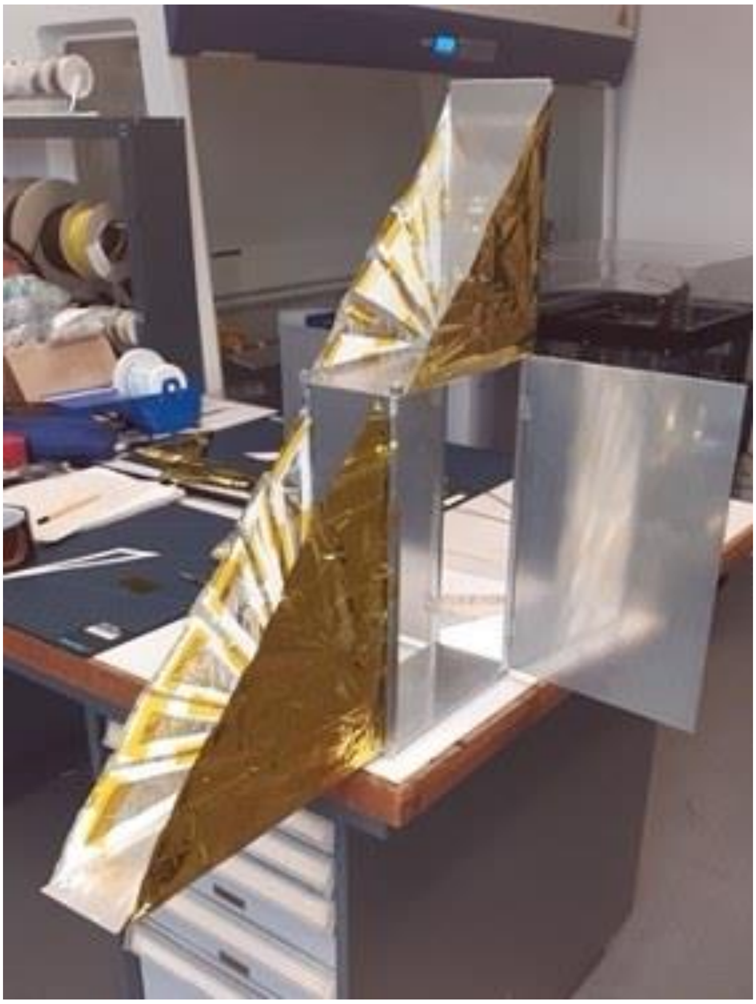

Figure 6 Breadboard model of the deployable Earth and Sunshades.

6. ELECTRICAL ARCHITECTURE

The CUBESPEC platform is based on the Space Inventor satellite platform. The overall platform bus is communicating via CAN with the CSP protocol. Figure 7 shows the CUBESPEC electrical architecture with different subsystems:

- Power: The Power subsystem preliminarily consists of a maximum power point tracker module (MPPT-P3) that receives the solar array inputs, a battery package (BAT-P3), and a power distribution unit (PCDU-P3).
- OBDH: The On-Board Data Handling is performed by Space Inventor OBC-P3.
- ADCS: Composed by the Arcsec ADCS, a GPS receiver, and a set of Fine Sun Sensors.

- Communications: The subsystem can be divided into TT&C and Payload data. The TT&C is performed by Space Inventor VHF transceiver TTC-P3, while the Payload data is transferred via a S/X-band transceiver (STTC-P3).

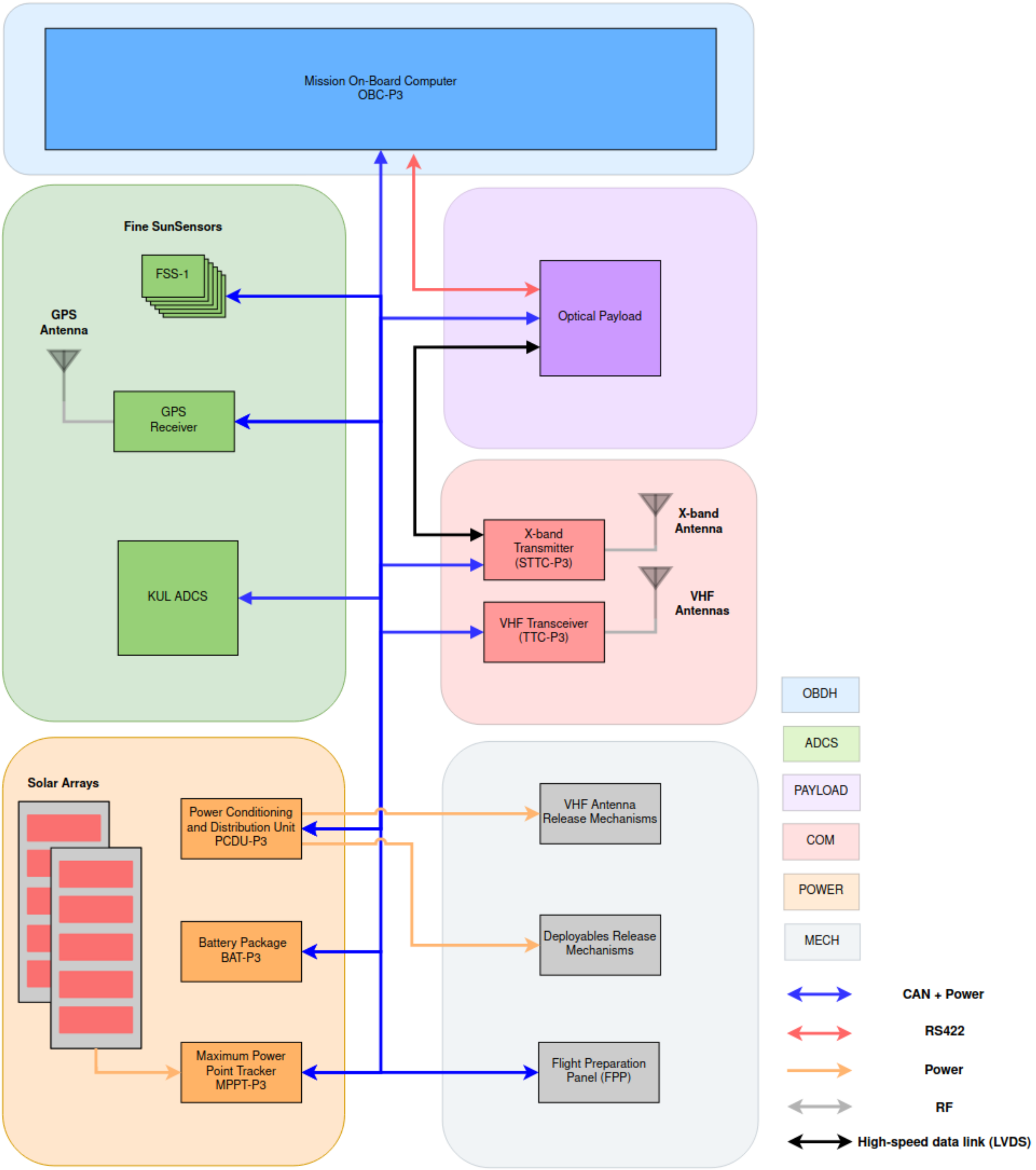

Figure 7 CUBESPEC electrical functional block diagram

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