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ATV Flight Control Monitoring Implementation & Comparison with Flight Data

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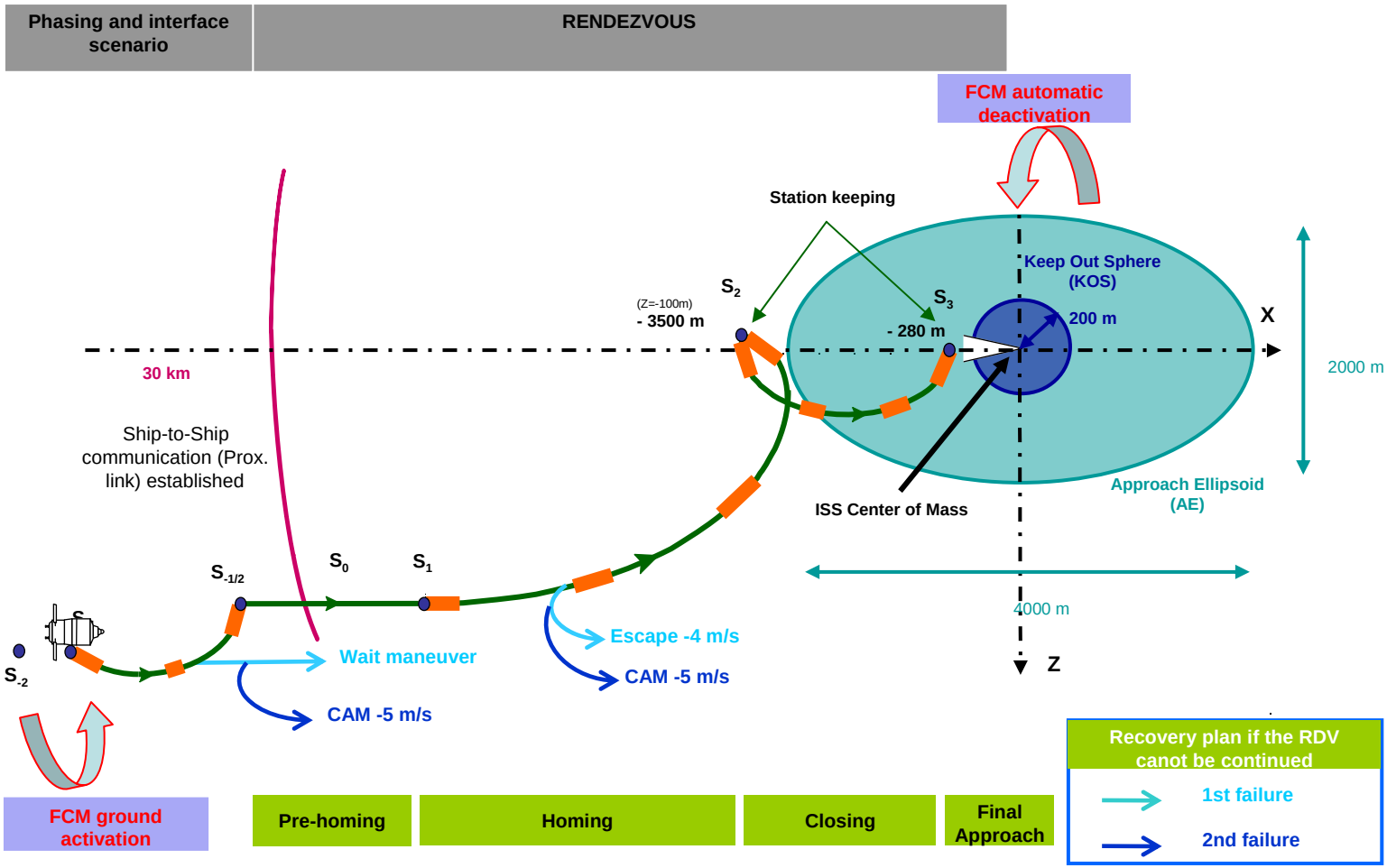
ATV mission

- The Automated Transfer Vehicle is an unmanned spacecraft capable to autonomously rendezvous and dock to the International Space Station. It comprises a pressurized cargo carrier accessible to the crew and unpressurized avionics and propulsion bays.

- ATV provides support services to the International Space Station (ISS) during six months following its docking to the Russian Service Module (Zvezda).

- The main mission objectives are:
  - **Propulsive support to ISS**
  - **Delivery of cargo, water and gas, and retrieval of wastes,**
  - **ISS refuelling**

ATV safety design and mission profile



FCM's role in ATV's safety concept

- Two main concepts are applied to assure ISS safety during ATV's rendezvous and departure operations:
  1. To detect hardware or software failures, isolate and initiate a vehicle reconfiguration to safely continue the rendezvous/departure or to initiate a retrograde manoeuvre if necessary to maintain a safe trajectory with respect to the ISS.
  2. To monitor ATV's dynamic behaviour and trajectory with respect to to ISS and to initiate a retrograde manoeuvre if pre-defined safety thresholds are exceeded.

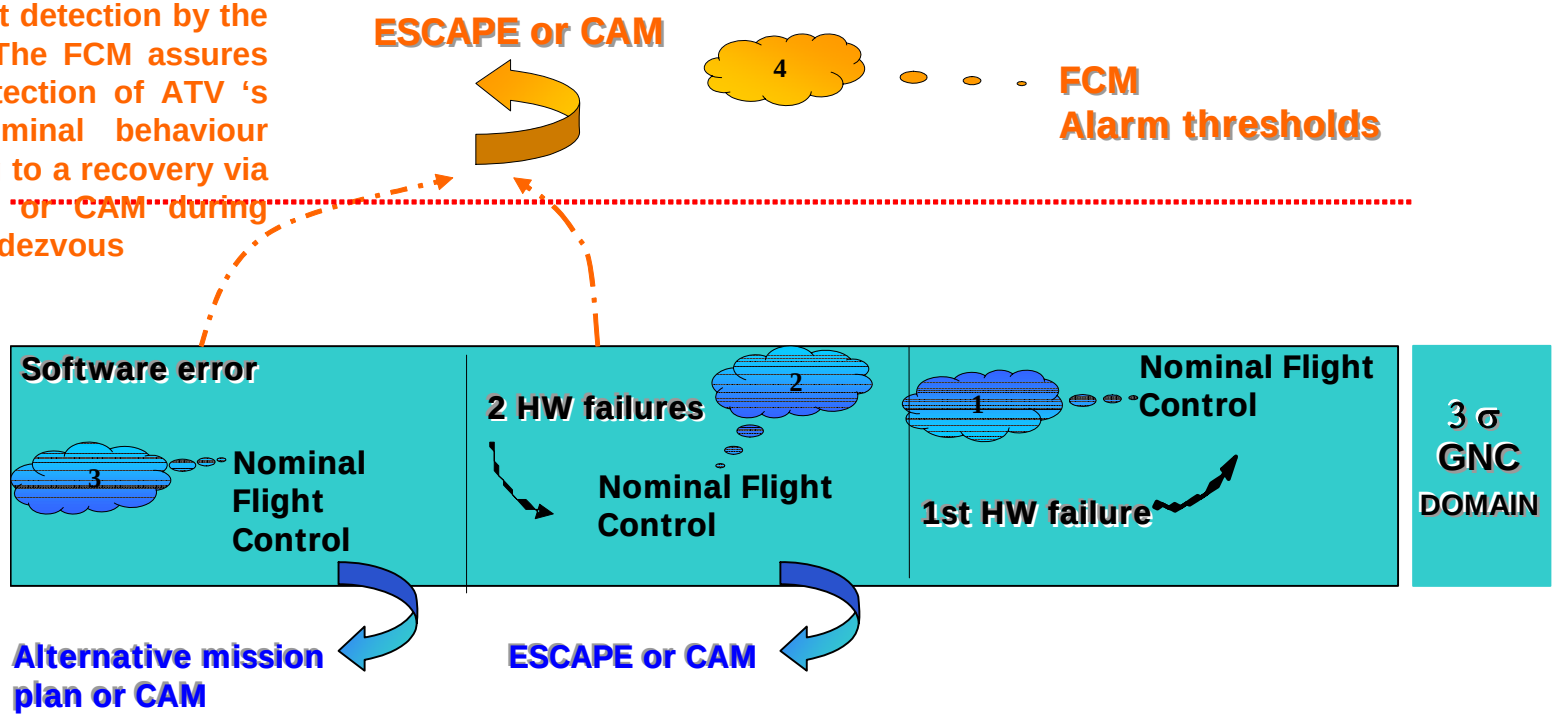
- The first is aimed at directly monitoring for failures while the second is aimed at monitoring "unexpected behaviour at vehicle". This paper addresses the second point and how it has been implemented in the FCM function.

FCM implementation & safety rules

- FCM is an **on-board monitoring** layer; It monitors trajectory parameters and compares them to pre-defined corridors
- When a **contingency situation** is detected (trespassing of a corridor limit), the FCM function **triggers an Escape manoeuvre or CAM**
- The corridor limits (FCM thresholds) were defined to ensure the safety of the ISS in case of contingency
- The **ISS safety criteria** depend on the phase of the flight**:**
  - For the Homing and Closing phases: All ATV trajectories including recovery manoeuvres must remain outside the Keep Out Sphere during at least 24 hours
  - For the Final approach: ATV shall not exceed specified position, velocity, attitude and attitude rate thresholds relative to ISS within the required approach corridor, and in case of a recovery manoeuvre the ATV shall remain inside the requested clearance corridor when inside the KOS, and stay outside the AE for at least 24h after leaving the AE.

FCM's role in ATV's safety concept

Without detection by the FDIR- The FCM assures the detection of ATV 's off nominal behaviour leading to a recovery via escape or CAM during the rendezvous



Depending on the SW error, the detection could be done by the FDIR without FCM alarm triggered , the recovery could be:

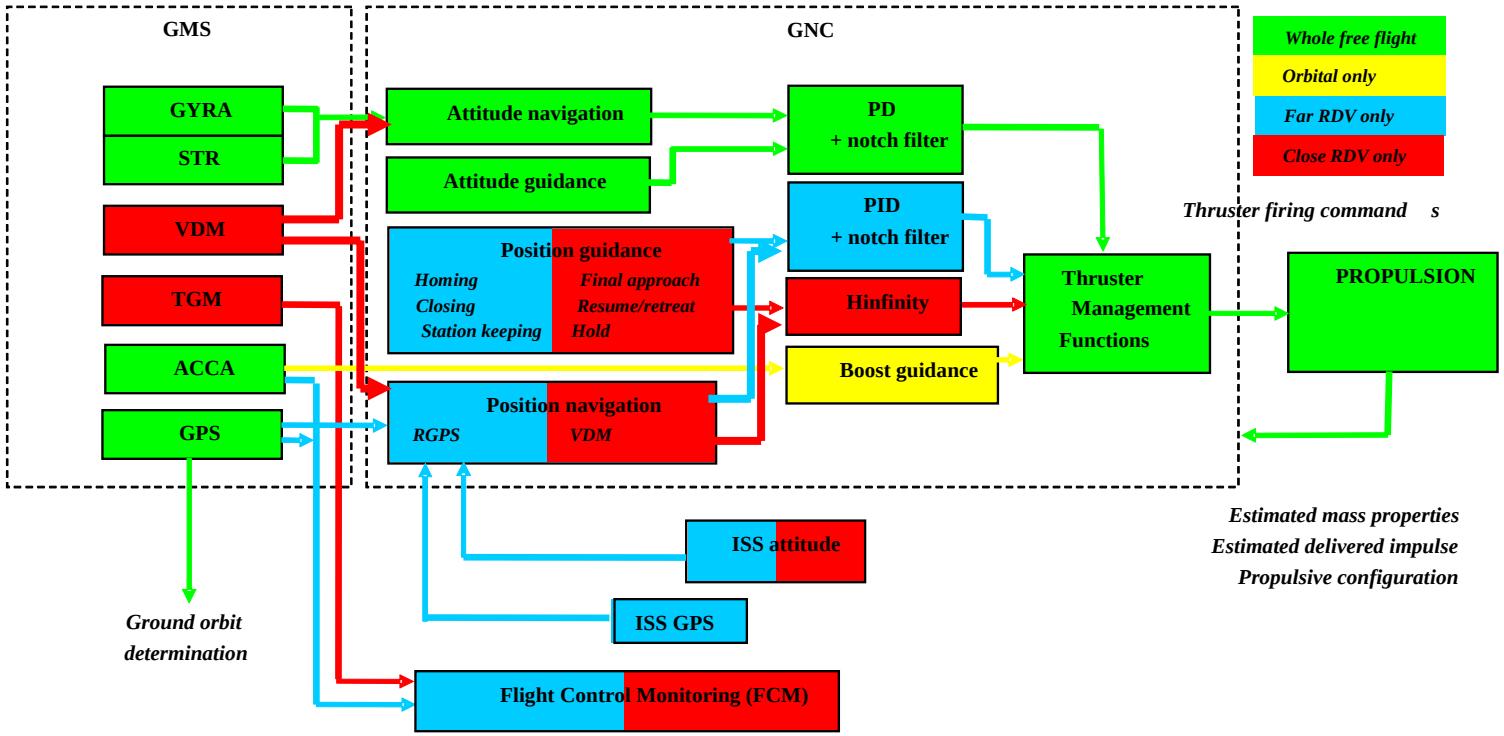
- a CAM
- an Escape
- or a mission continuation

Depending on the 2 HW failures detected, the recovery could be:

- a CAM
- an Escape
- or a mission continuation

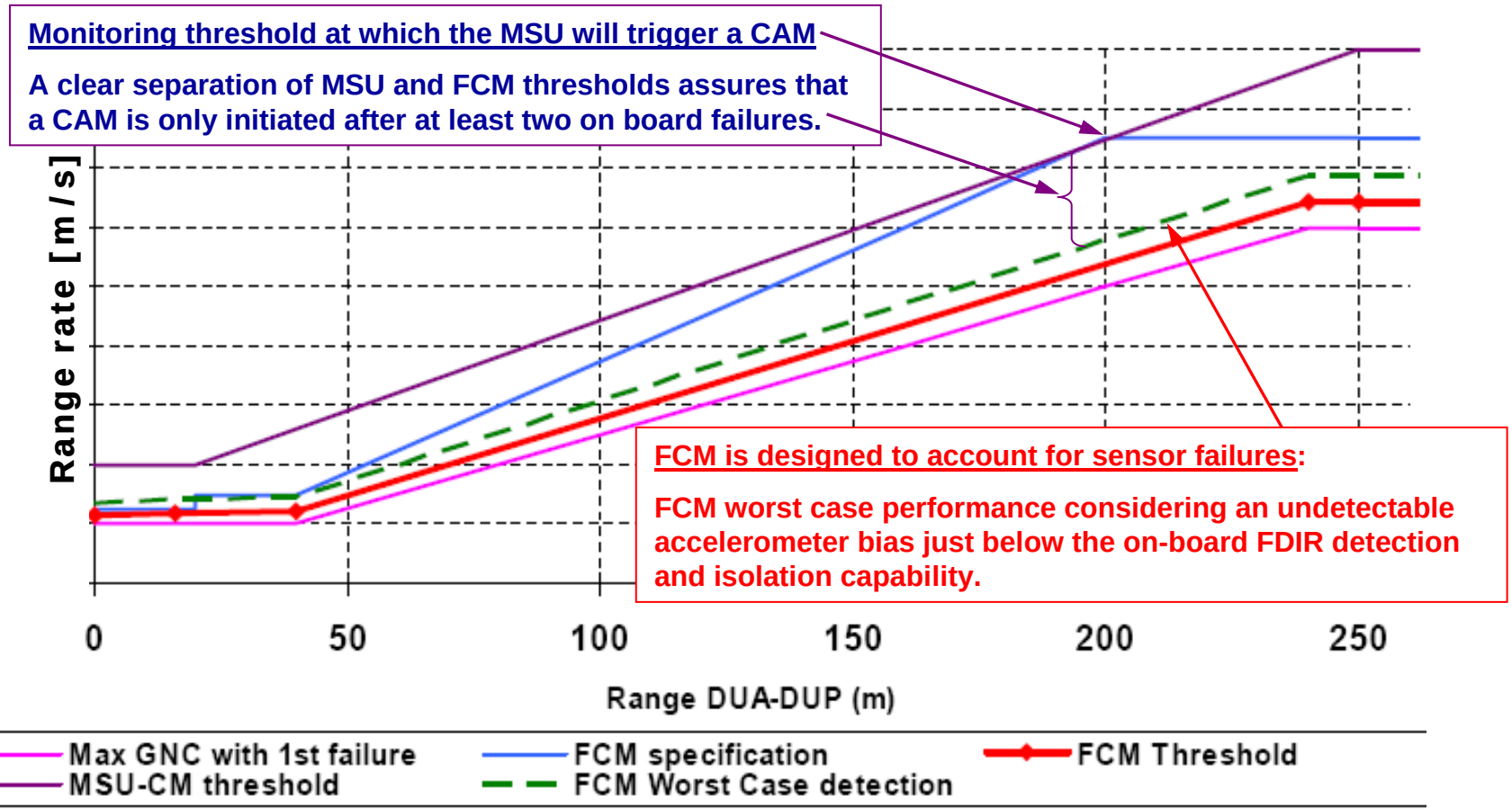
First failure is detected by the Nominal flight control (FDIR) and isolated . The mission is either continued or a retreat or hold is triggered.

ATV design and mission description

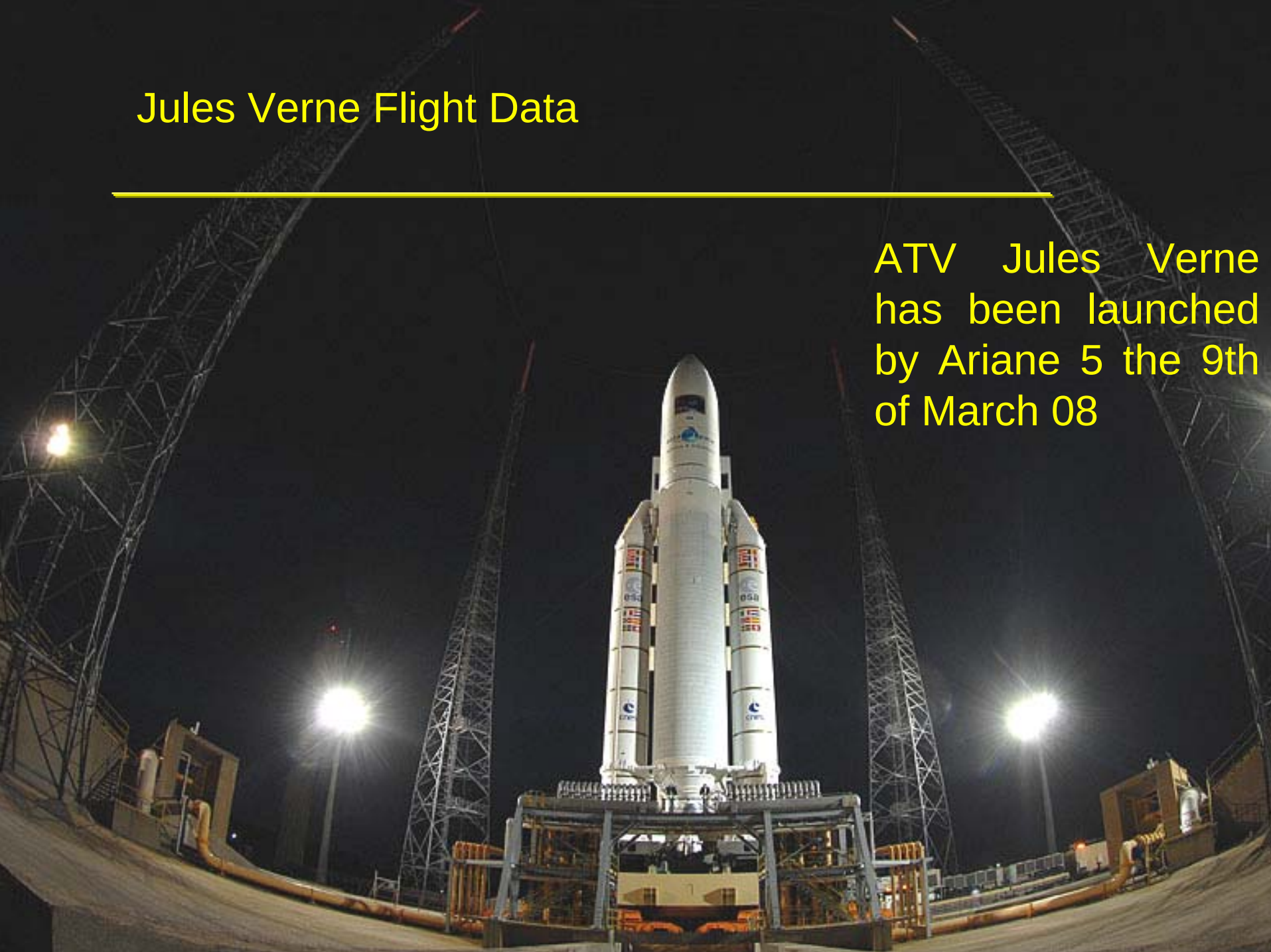


ATV design and mission description

***Example of a threshold tuning:* Range rate monitoring during the final approach**



Jules Verne Flight Data



ATV Jules Verne has been launched by Ariane 5 the 9th of March 08

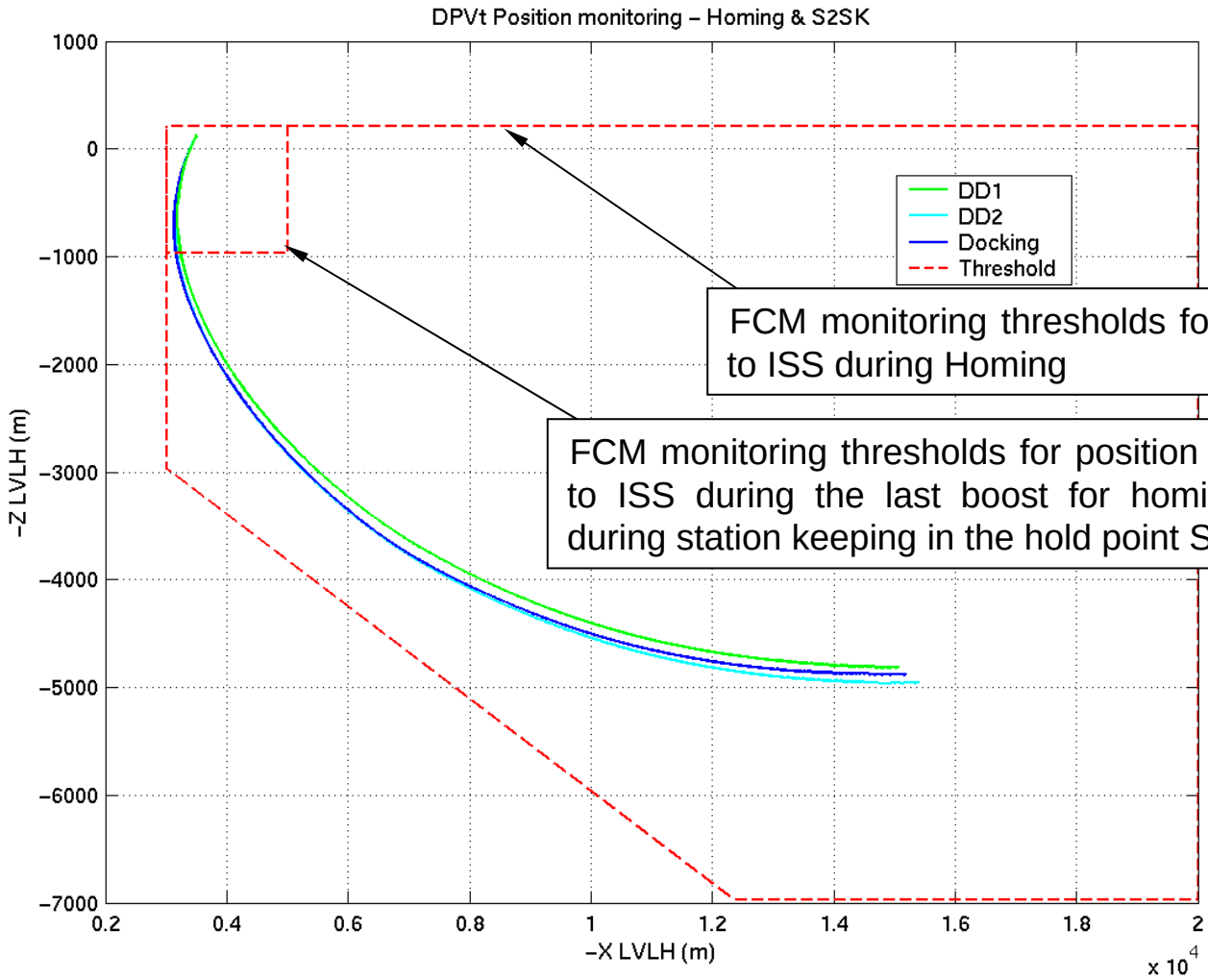
ATV has successfully docked to the ISS the 3rd of April 08 after Dedicated demonstration manoeuvres (DD1 –DD2 & CAM manoeuvre) in order to confirm the safe behaviour before final docking

Jules Verne flight FCM monitoring during Homing and Closing

ATV JV during DD1,DD2 and the actual day of docking, the performance of the vehicle :

- was quite similar for the 3 runs
- was well within the FCM monitoring thresholds

And the Nominal mission was executed (without contingency manoeuvres) up to docking

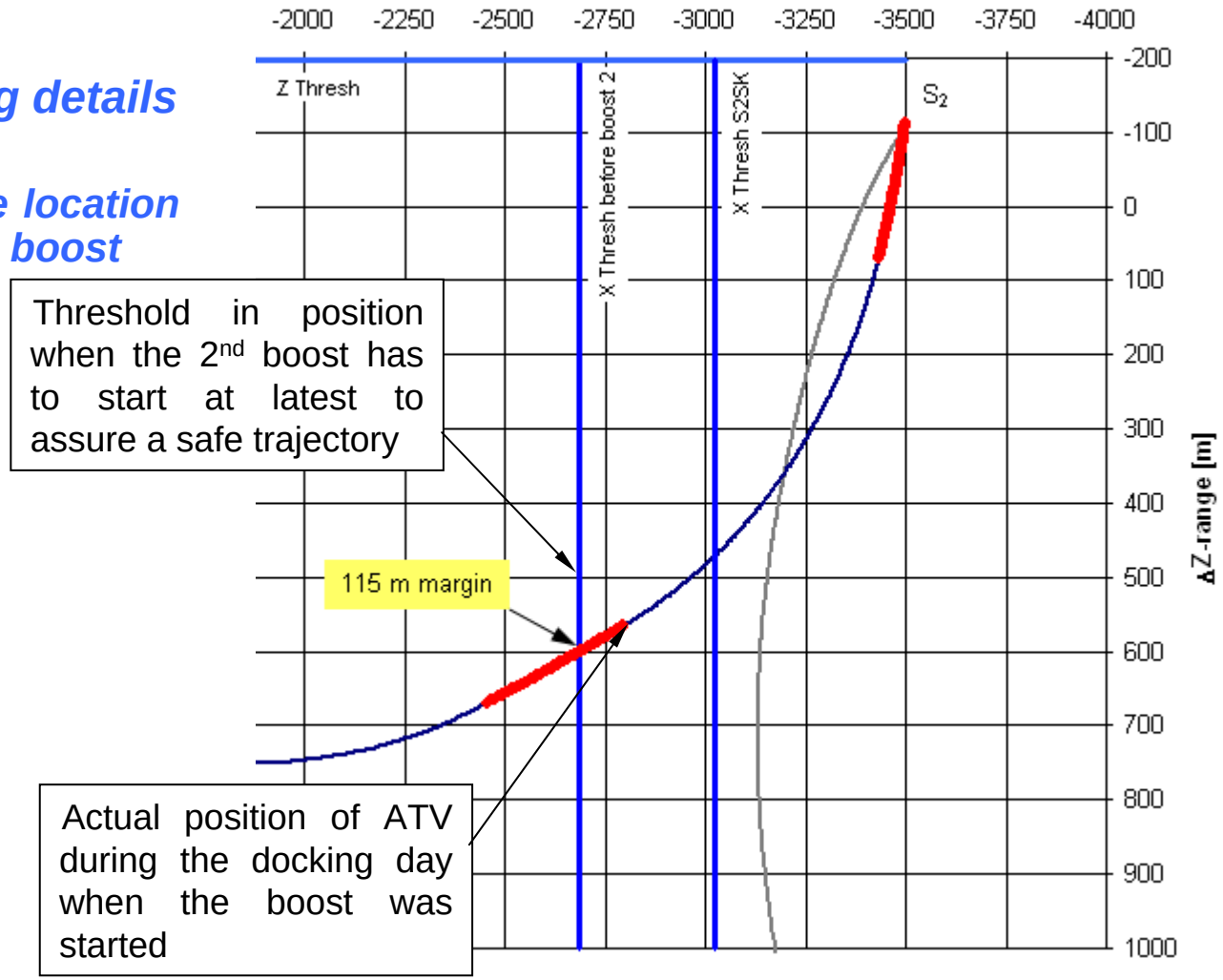


FCM monitoring thresholds for position relative to ISS during Homing

FCM monitoring thresholds for position relative to ISS during the last boost for homing and during station keeping in the hold point S2

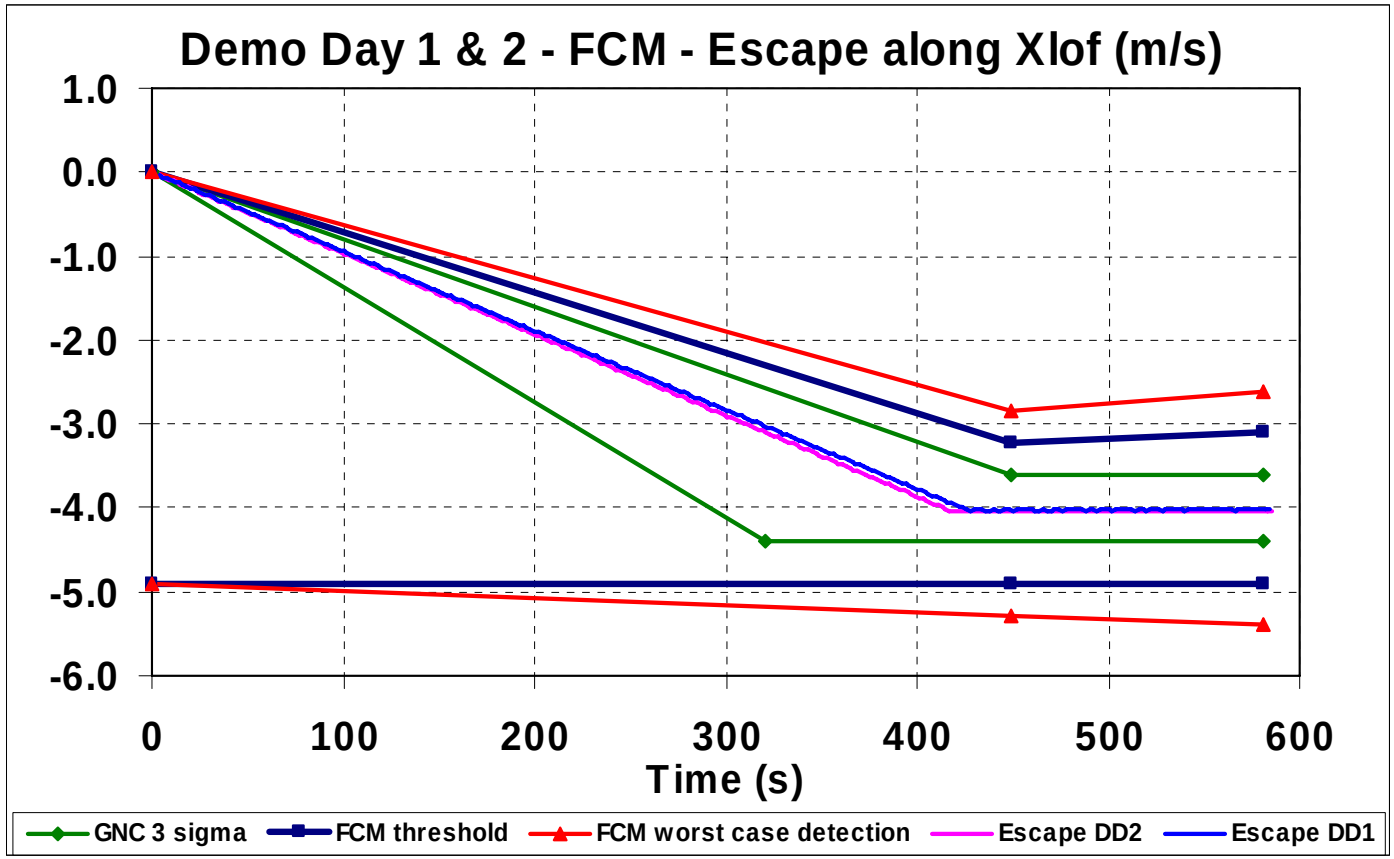
FCM monitoring details e.g.

Monitoring of the location of the 1st Closing boost



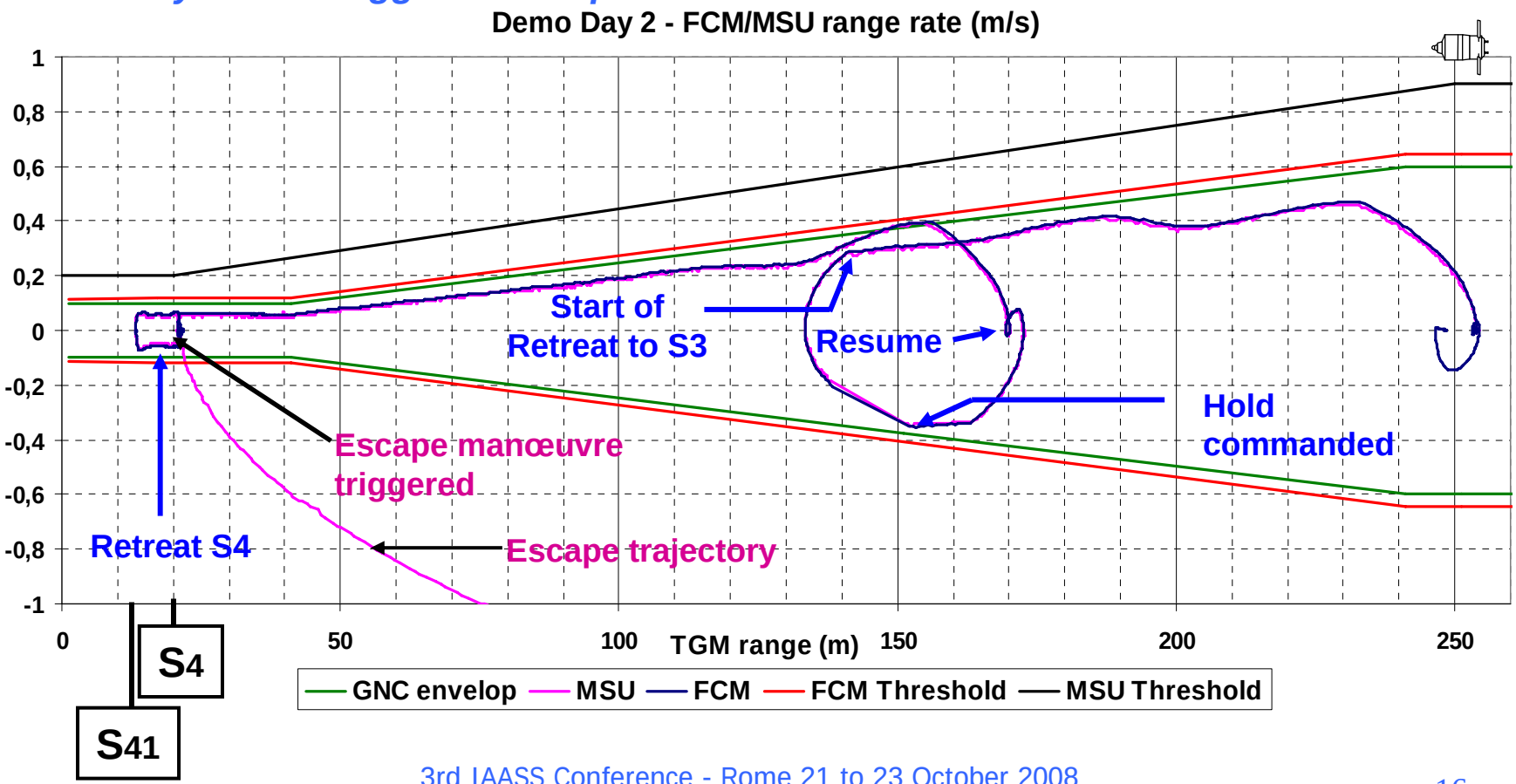
Escape maneuver (-4 m/s) tested at end of DD1 and DD2

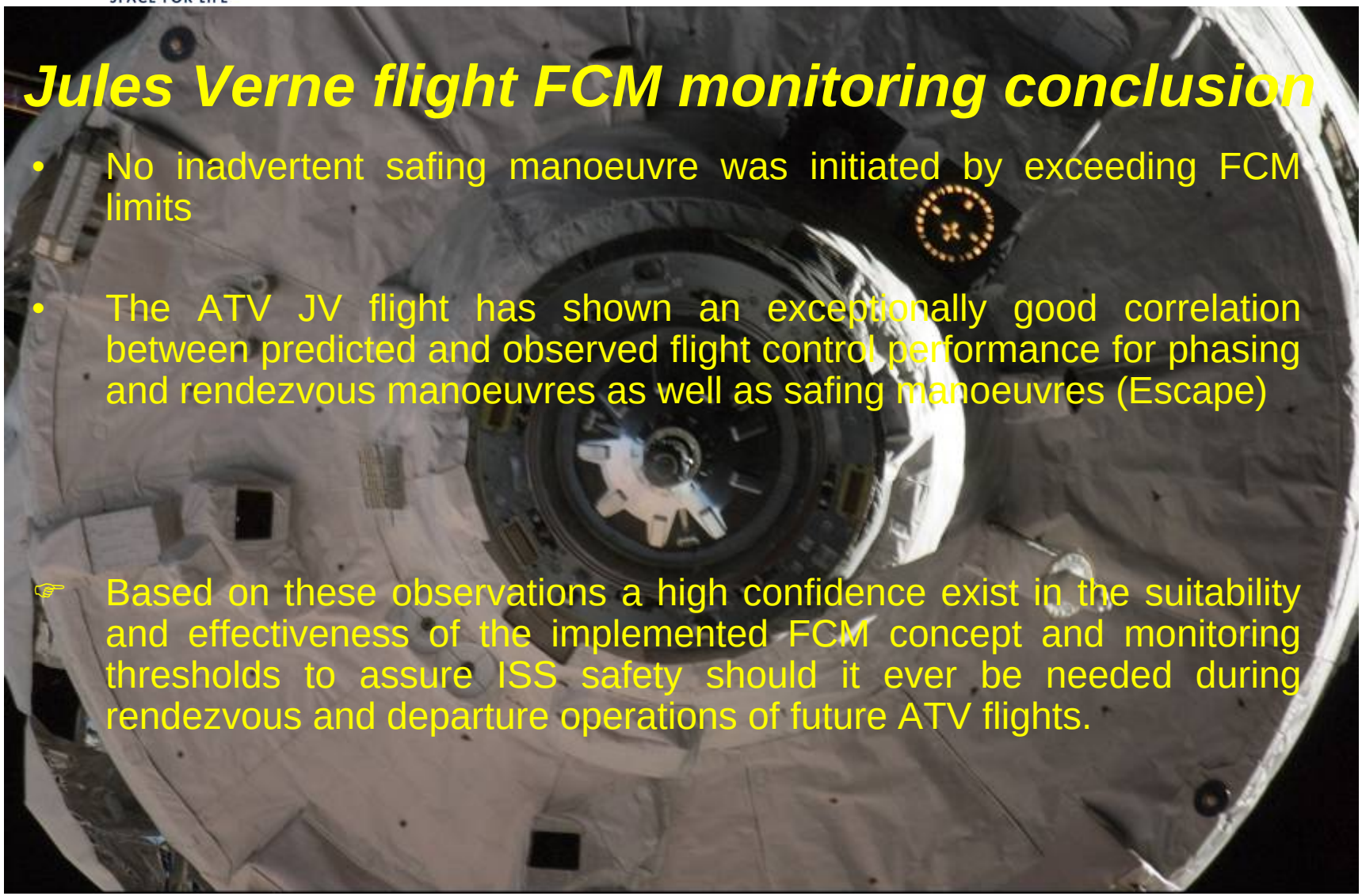
- ISS safety entirely ensured by FCM during Escape



FCM monitoring during the Final Approach

Final rendezvous manoeuvre down to 11 m (S41) with a retreat-hold-resume sequence and finally a crew triggered Escape.





Jules Verne flight FCM monitoring conclusion

- No inadvertent safing manoeuvre was initiated by exceeding FCM limits
- The ATV JV flight has shown an exceptionally good correlation between predicted and observed flight control performance for phasing and rendezvous manoeuvres as well as safing manoeuvres (Escape)

☞ Based on these observations a high confidence exist in the suitability and effectiveness of the implemented FCM concept and monitoring thresholds to assure ISS safety should it ever be needed during rendezvous and departure operations of future ATV flights.