March - Sept 2008

Feb to June 2011

March – Oct 2012

June to Nov 2013

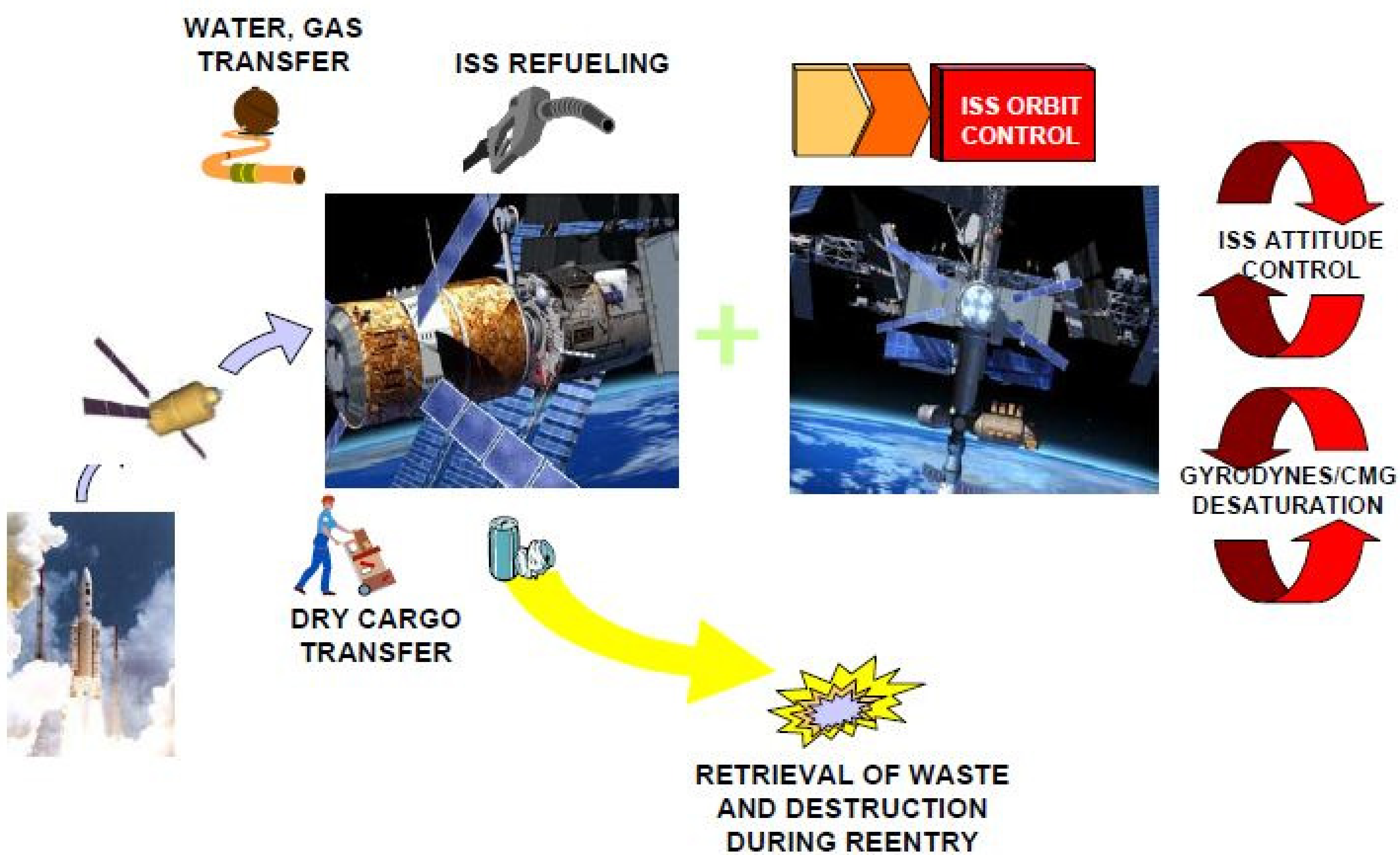
July 2014 – Feb 2015

The ESA Automated Transfer Vehicle

Charlotte Beskow
ATV1-5: 1999-2015: Crew Tasks, Operations Interface,
Deputy MM ATV2, Deputy RPSE for ATV 3 – 5, EST for ATV1-5

ATV: Mission

The purpose of the Automated Transfer Vehicle (ATV) was to provide support services to the International Space Station (ISS) during six months following its docking to the Russian Service Module (Zvezda). This led to a complex mission:



ATV: Design -> Implementation

The challenges were many….

We needed to get from here To here

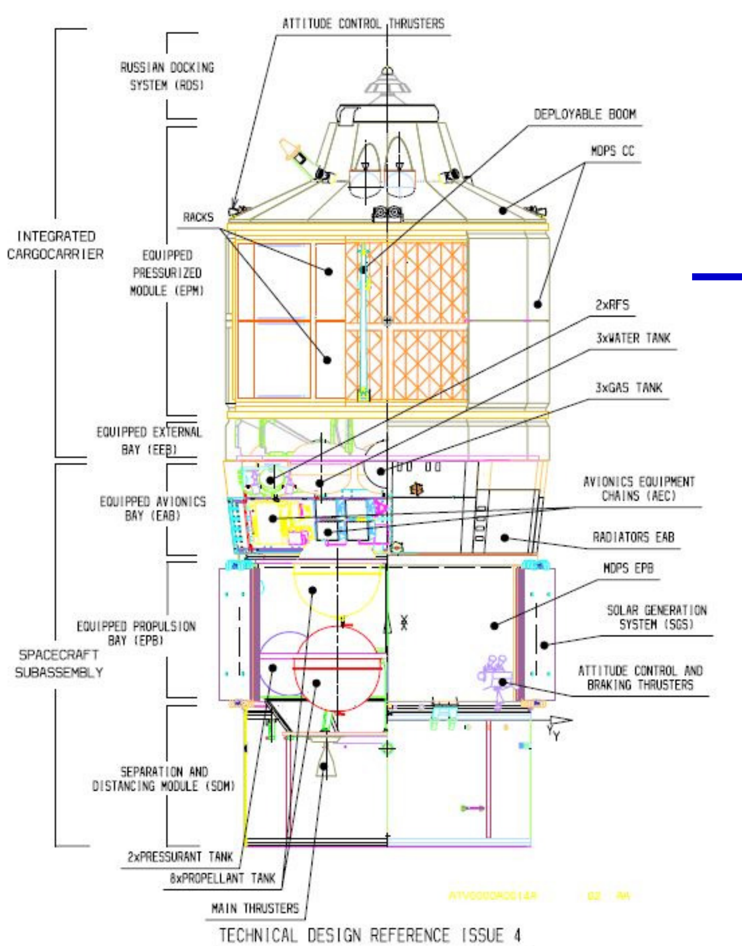


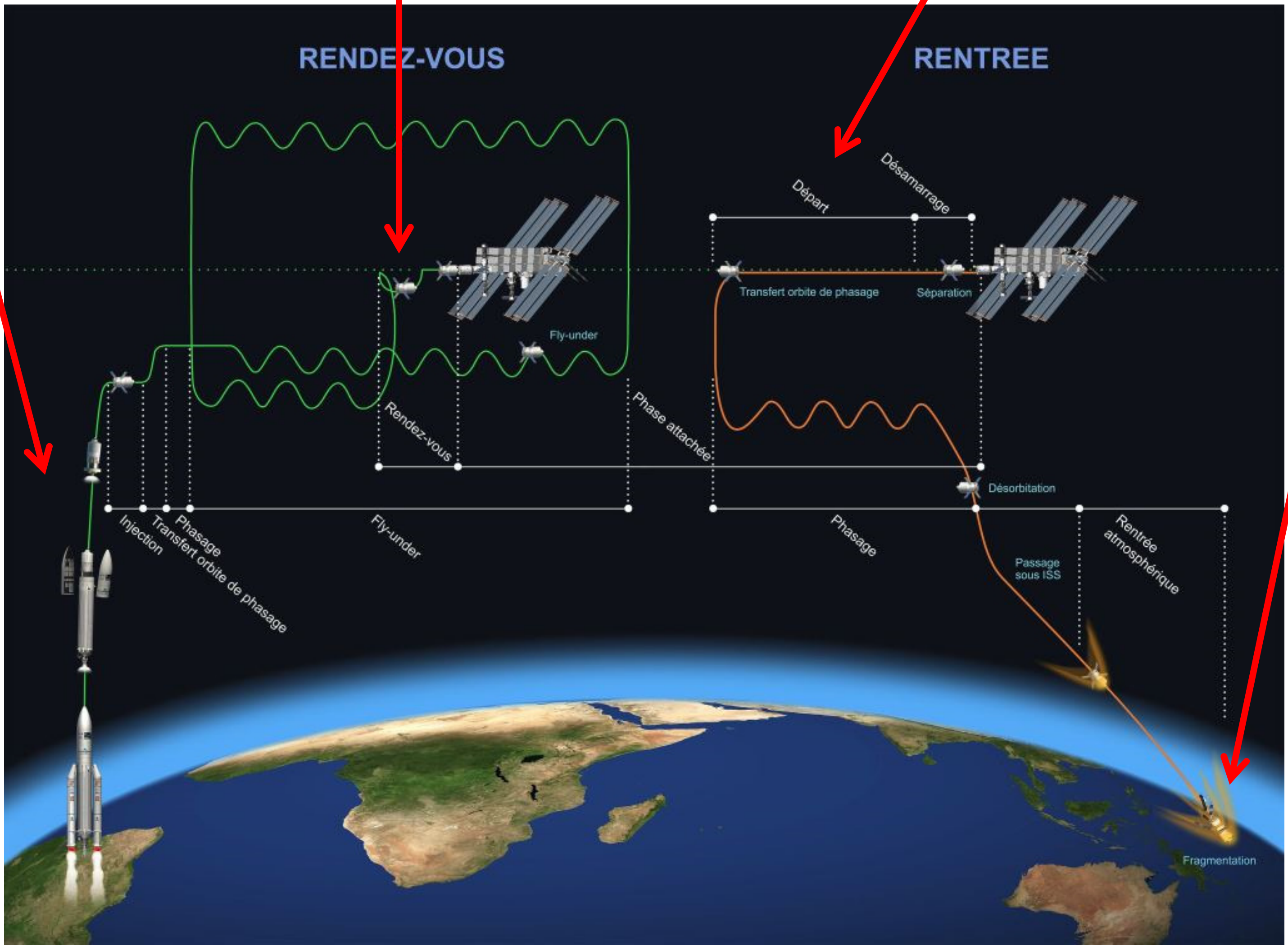
Figure 2-2: General View of the ATV

ATV: The Mission

Then from here

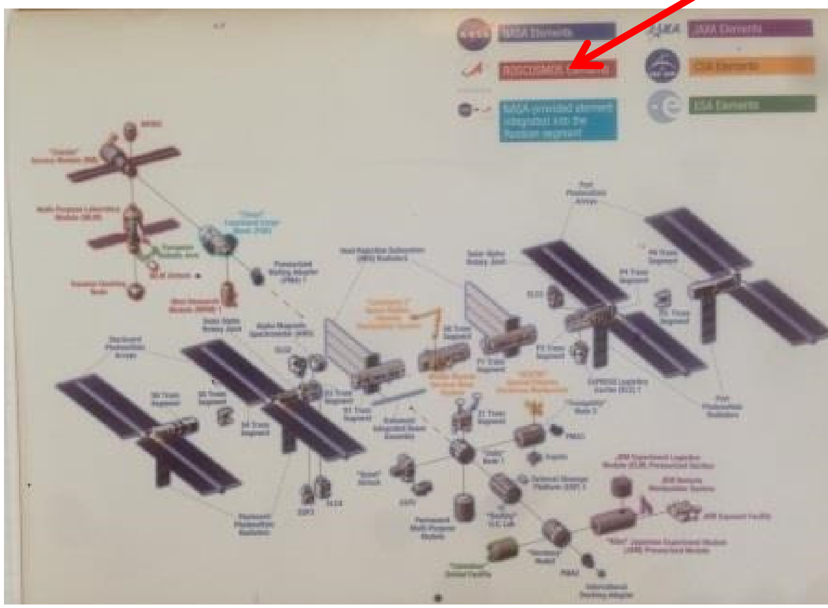
To here

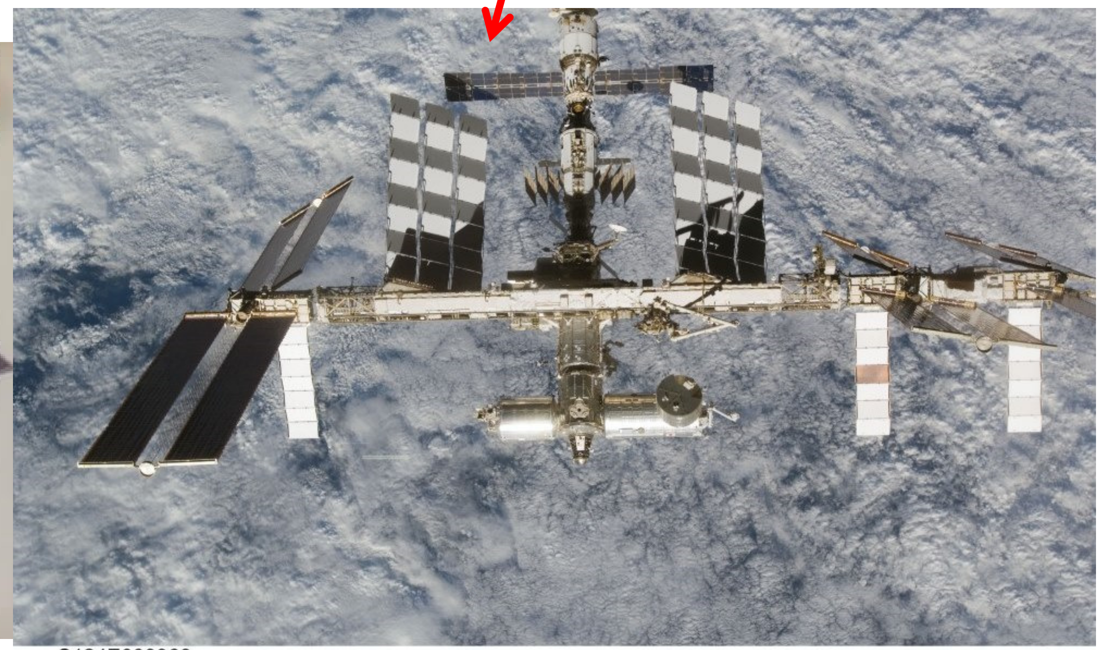
and eventually to here



ISS: Idea to Reality

While at the same time ISS had to get from here to here





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The US Shuttle was instrumental in bringing up all the large elements, such as CMGs (Control Momentum Gyros), elements of the Truss, modules such as Destiny and Columbus..
Sheer logistics was one aspect , political support in the participating states another…
… then in Feb 2003 there was a more serious event

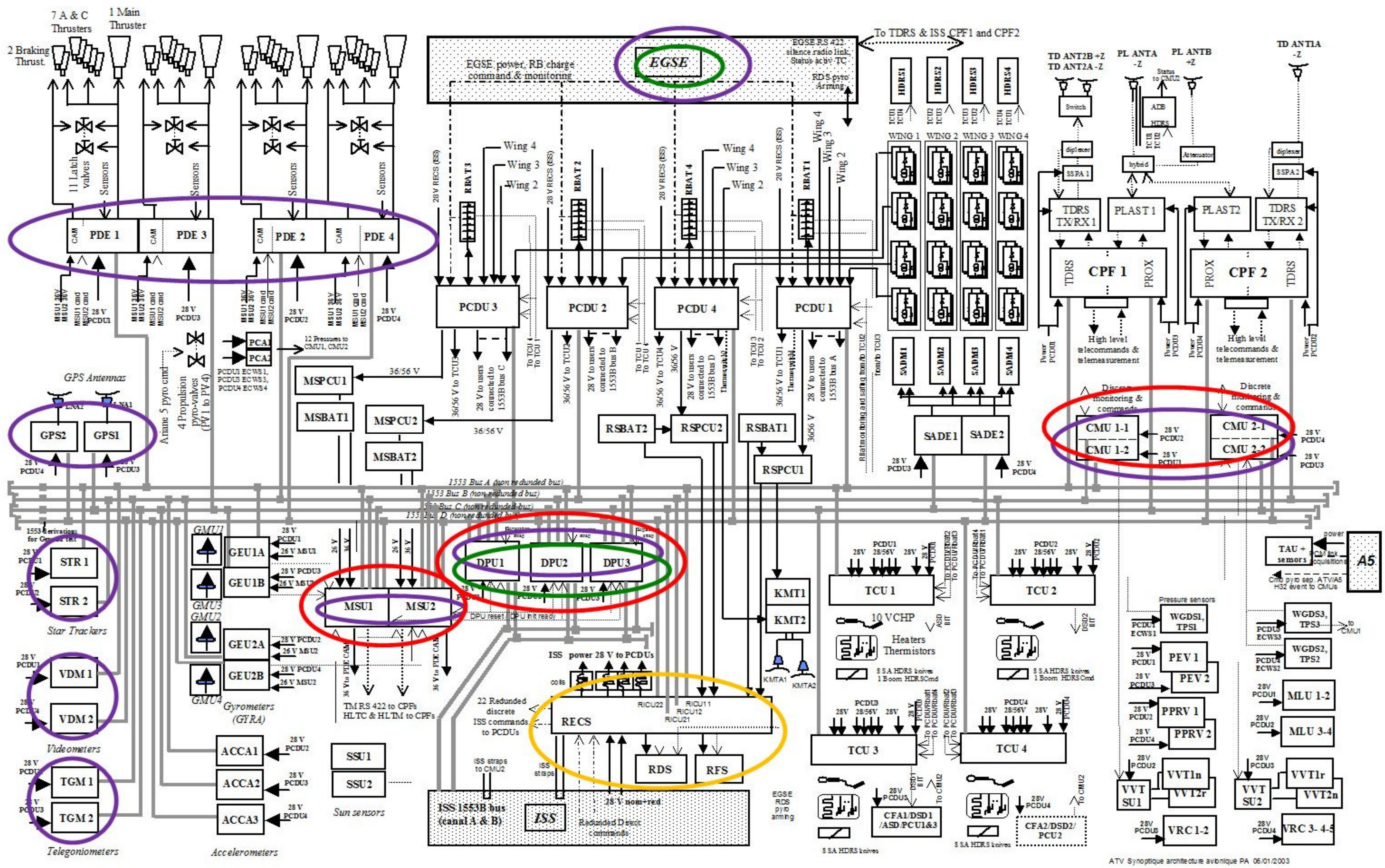
ATV Lessons Learnt : FDIR

FDIR = Failure Detection Isolation and Recovery

The unmanned ATV flew to a manned space station
=> stringent safety requirements

ATV needed to be FT/FS ie Failure Tolerant (FT) and Fail Safe (FS)
This meant that :
after a first failure all functions were still available
after a second failure ATV would be safe with respect to ISS and Ground

ATV :Resulting Design



ATV : The Integrated Russian System

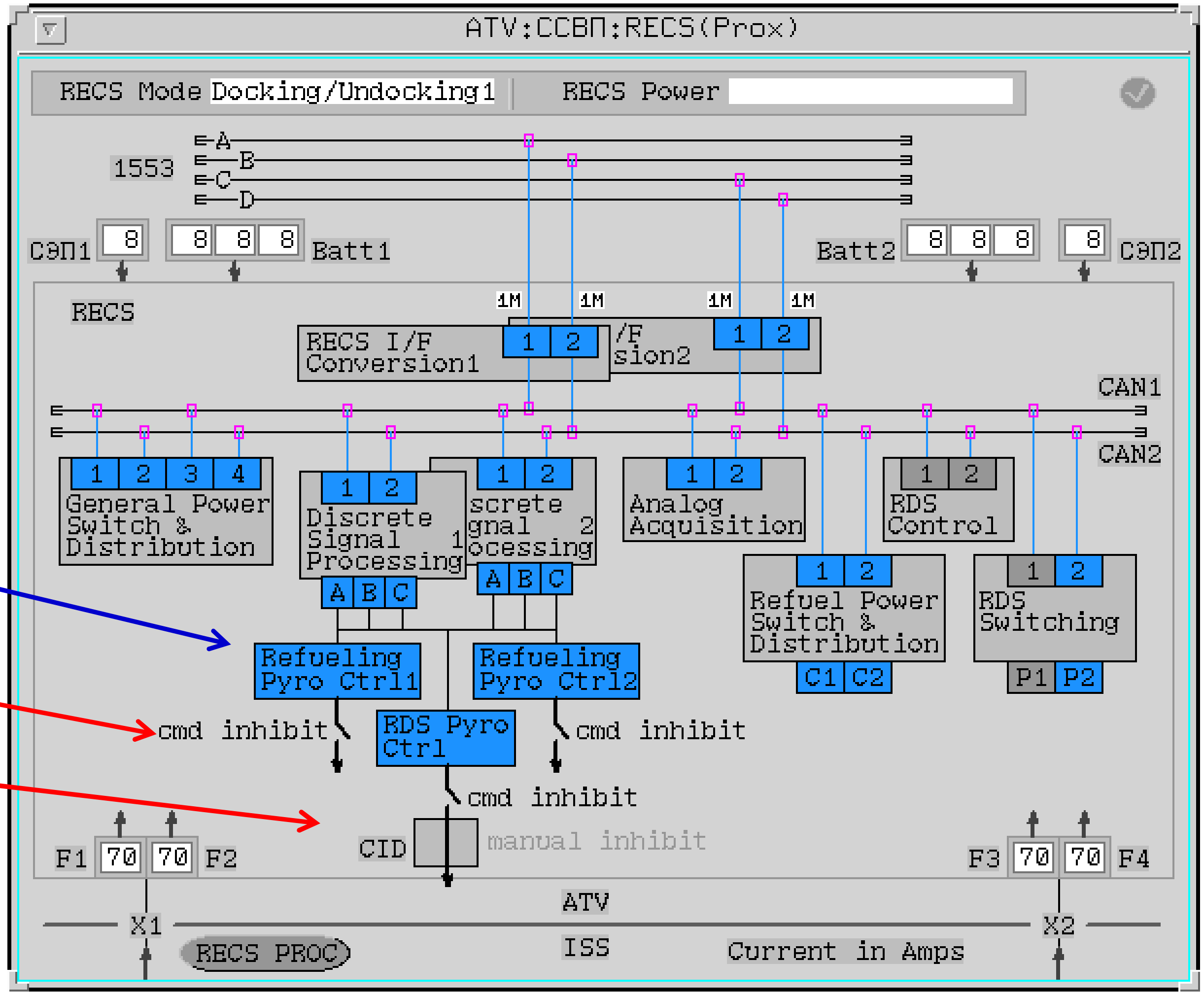
The Russian Equipment Interface Control System (RECS): performed multiple functions

Docking
Refuelling
Data connection
Power connections

In total ATV carried 16 electronic boxes inside the ATV ICC

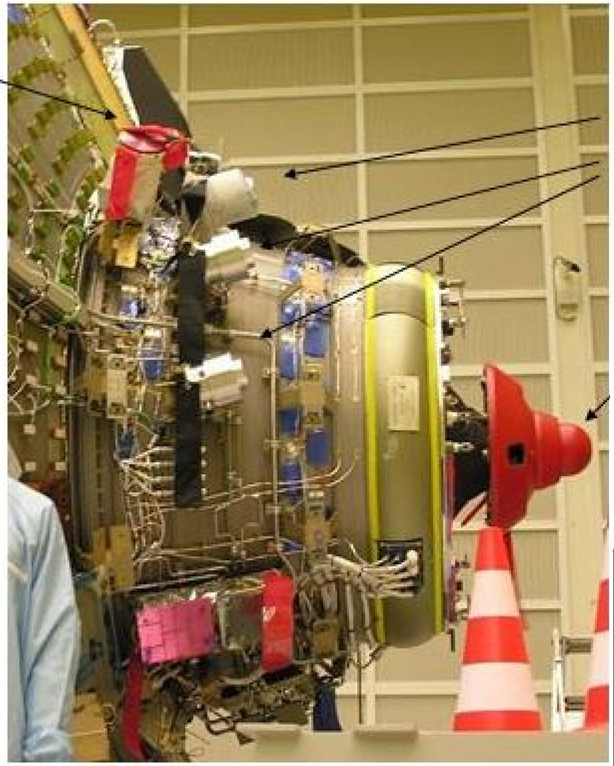
Refuelling pyro control
nominal operation < departure
Docking pyro control
off nominal operation

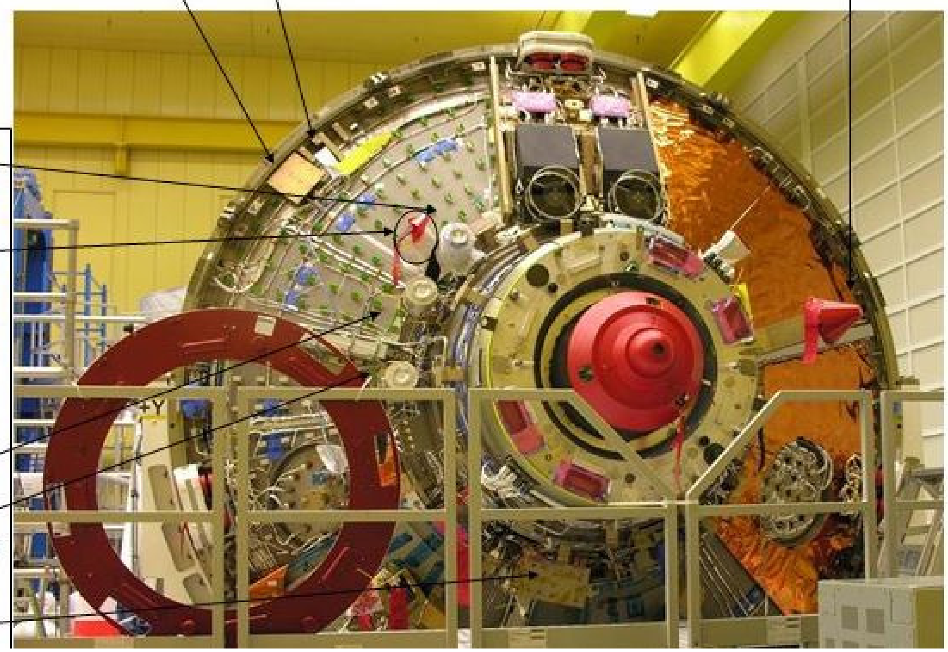
Pyro inhibits in attached phase
manual switch



ATV : The ISS docking interface

nnn



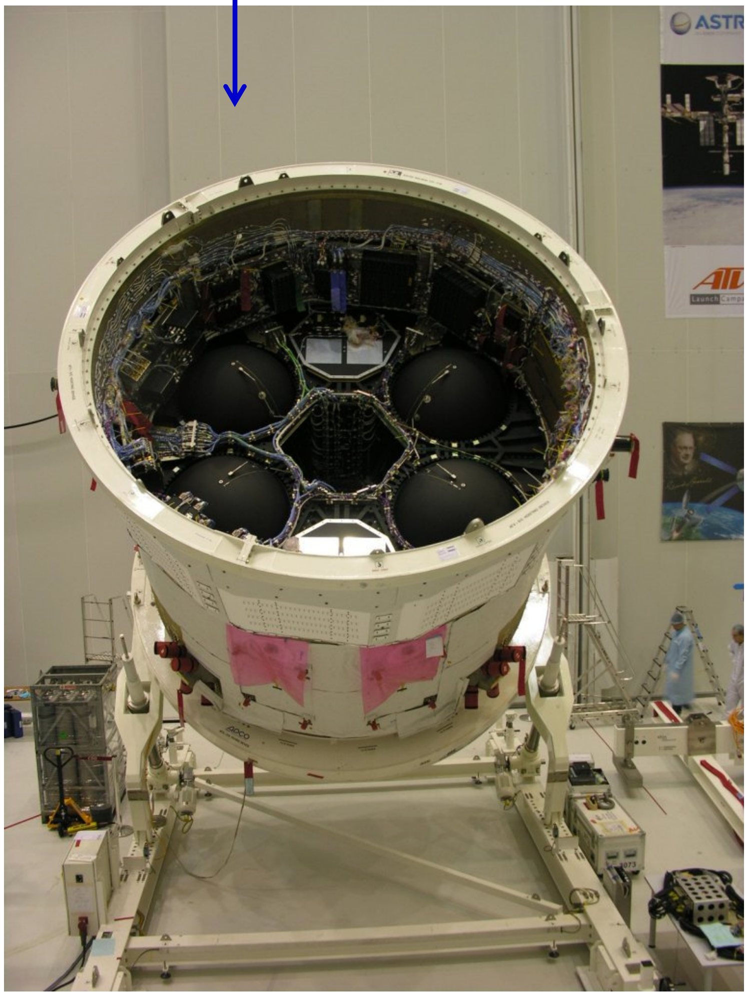


ATV : The ISS docking interface

human spaceflight & operations ATV : Cargo and Services for ISS

Complex mission : multiple types of Cargo and services: water dry cargo

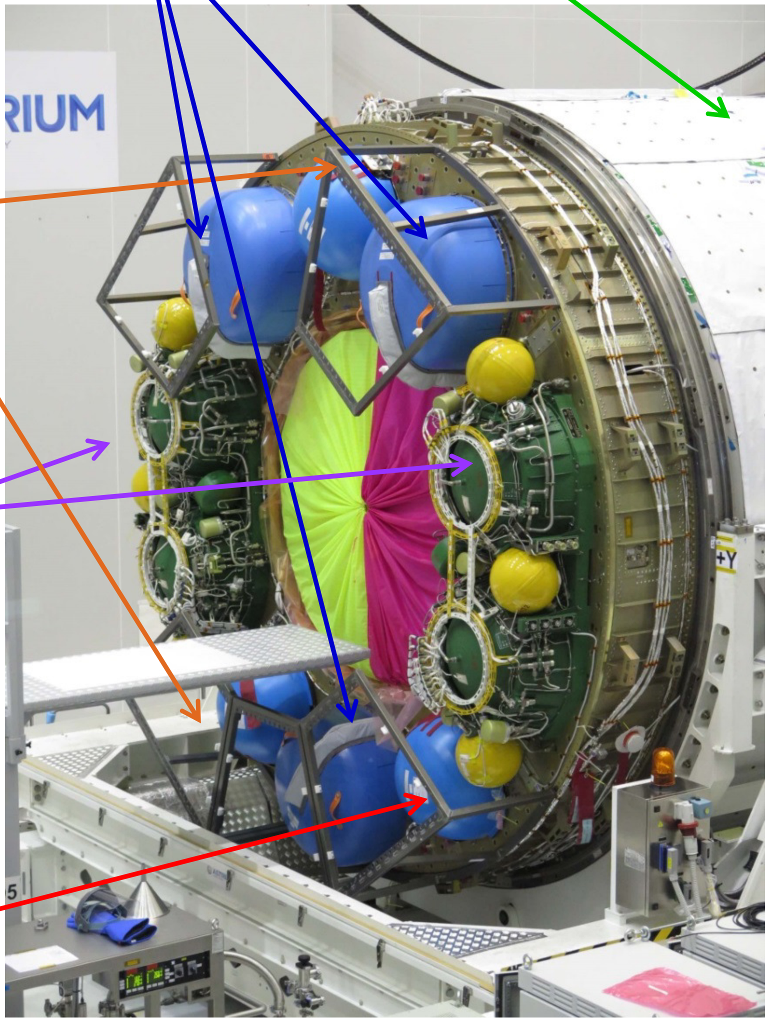
ATV fuel for ISS prop support



gas type 2

Russian fuel for SM

Gas type 1

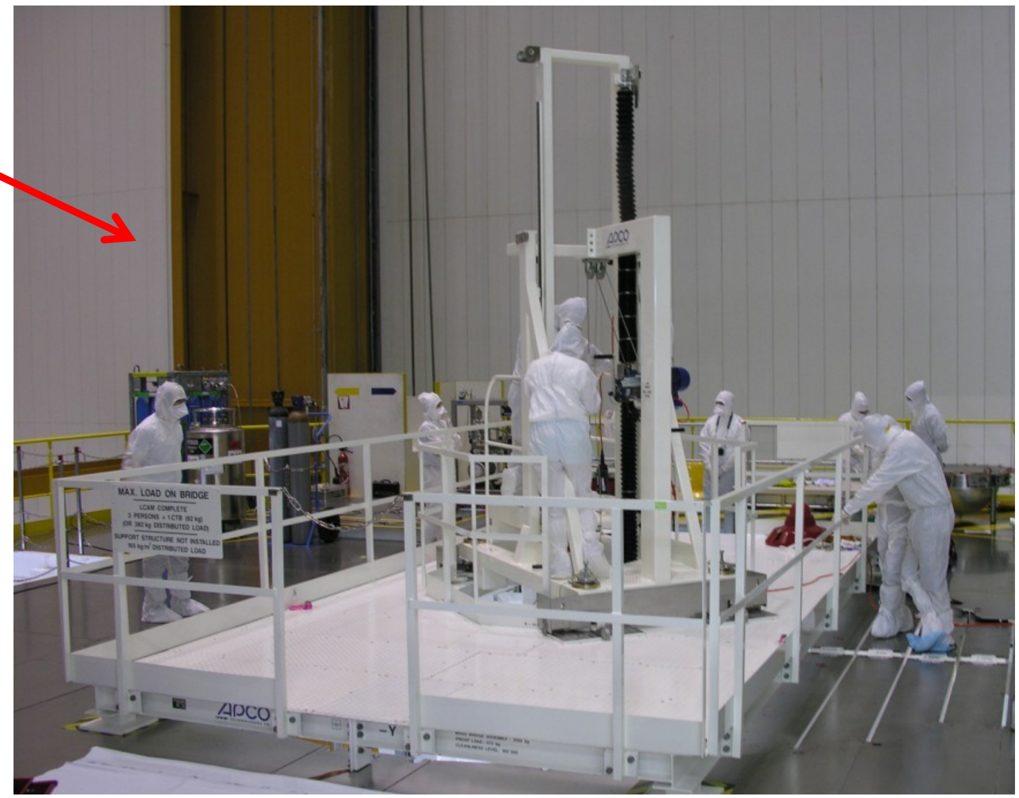


ATV on Ariane 5 : Late Cargo Loading

ATV Launch campaign activities : Loading Late Cargo at L – 13 working days

ATV is on top of the integrated Ariane 5 launcher

1 day and two shifts were available for this task, platform was disinfected before and after



ATV: Freeflight and Rendezvous with ISS:

ATV-AS-SOR-4000-04 - Rendezvous with ISS
Issue – Revision A
- Page 63 -

Chapter 2 **Operational scenarios**

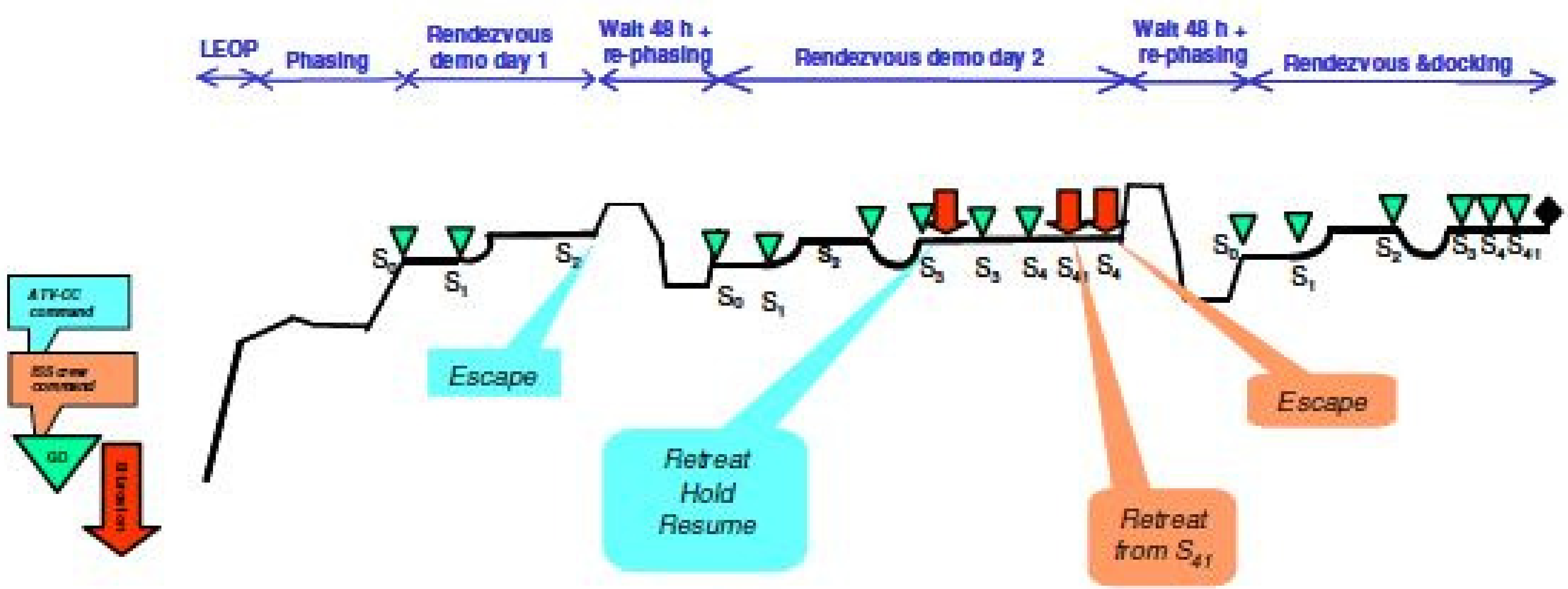


Figure 2.4-1 : ATV 1st flight scenario synopsis

ATV: Freeflight and Rendezvous with ISS:

3.1. ISS SAFETY

The Approach Initiation (AI) is defined as the point in the trajectory plan at which the approaching vehicle executes a burn that will cause its resulting dispersed (3-sigma) trajectory to penetrate the Space Station Approach Ellipsoid. S_2 is the approach initiation point.

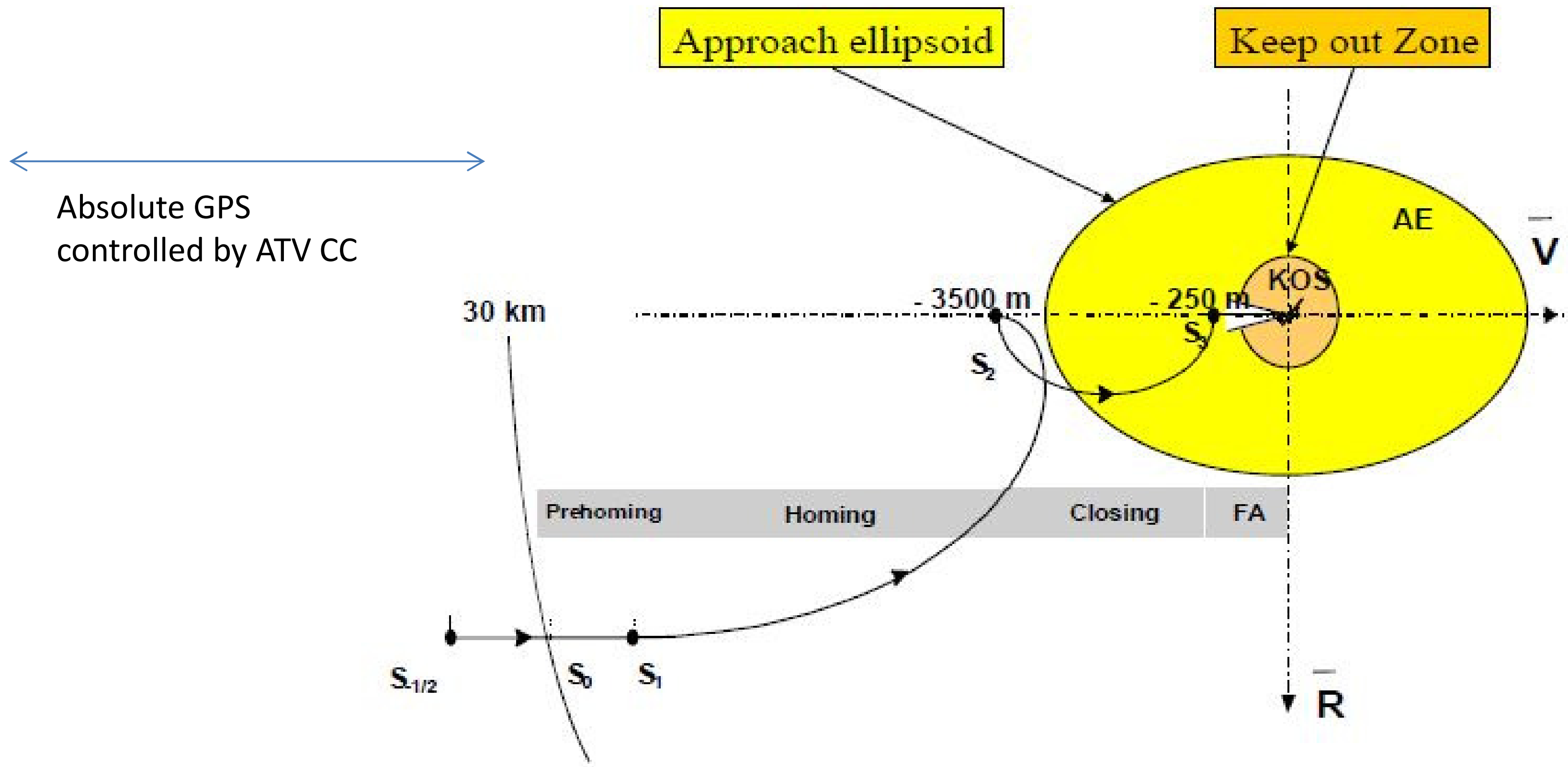
The safety volumes are:

The approach ellipsoid:

The current dimensions of the Approach Ellipsoid (AE) correspond to an ellipsoid of 4 km x 2 km x 2 km centered at the Space Station center of Mass, with the major axis along the V-bar direction.

The Keep Out Zone:

The keep-out zone is a safety sphere (Keep out sphere KOS) centered on the Space Station center of mass, with a radius of 200 m, which shall be entered only following pre-defined approach corridors.



Safety volumes

ATV: Freeflight and Rendezvous with ISS:

ATV: Freeflight and Rendezvous with ISS:

ViDeoMeter Navigation
Laser beam sent from ATV, reflectors located on ISS RS SM module

Relative GPS : SW in ATV uses data from ATV GPS receiver and ISS RS GPS receiver (at least 4 common satellites in view)

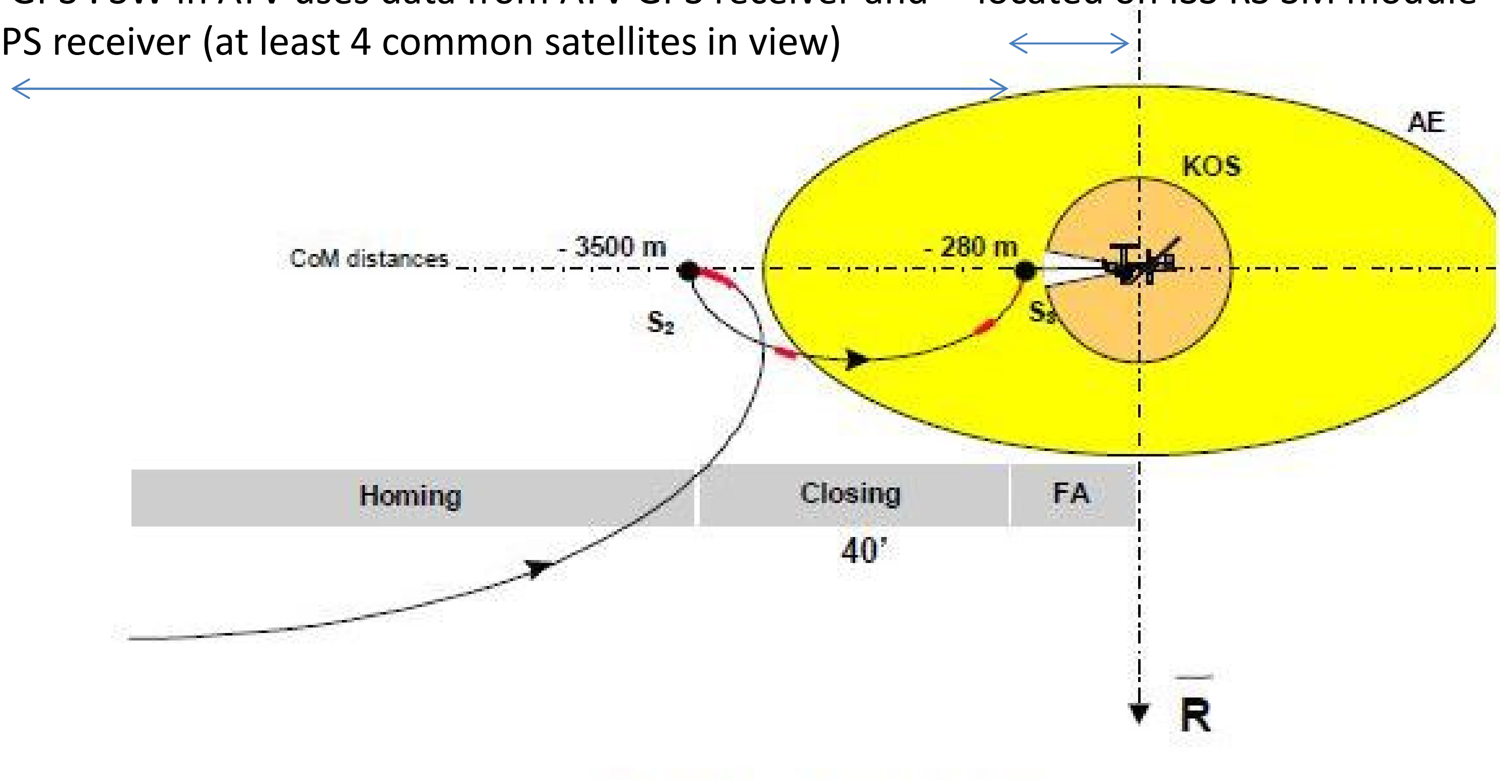
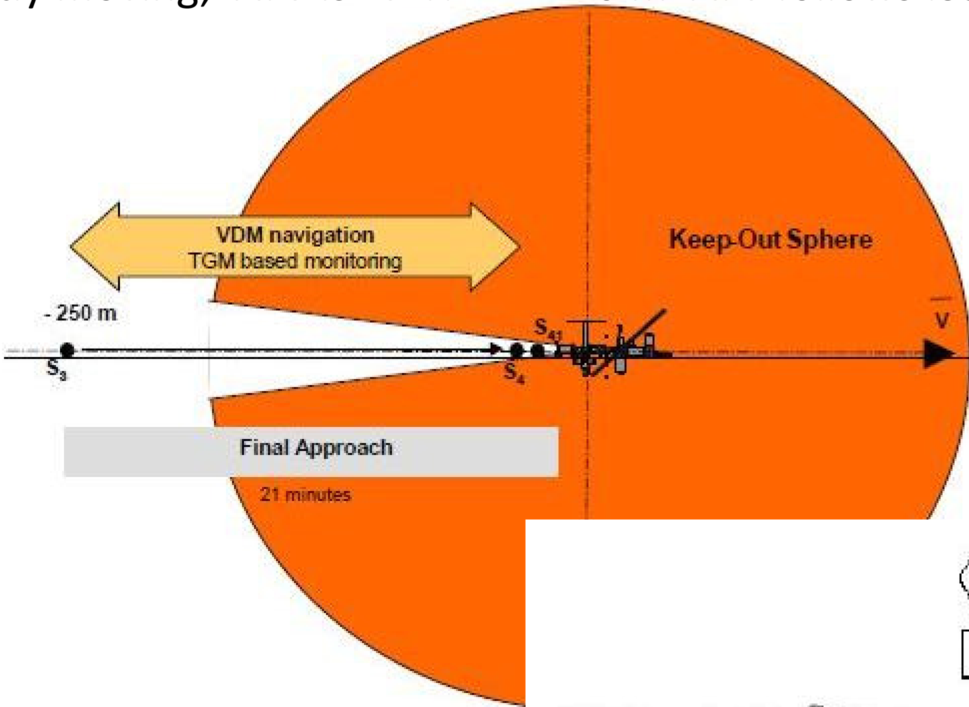


Figure 4.8-1 : Closing synopsis

ATV: Freeflight and Rendezvous with ISS:

Final approach 250 m -> 20m -> 12 meters

ISS gently moving, ATV is LVLH <- 20 m ATV follows ISS movements relative attitude nav



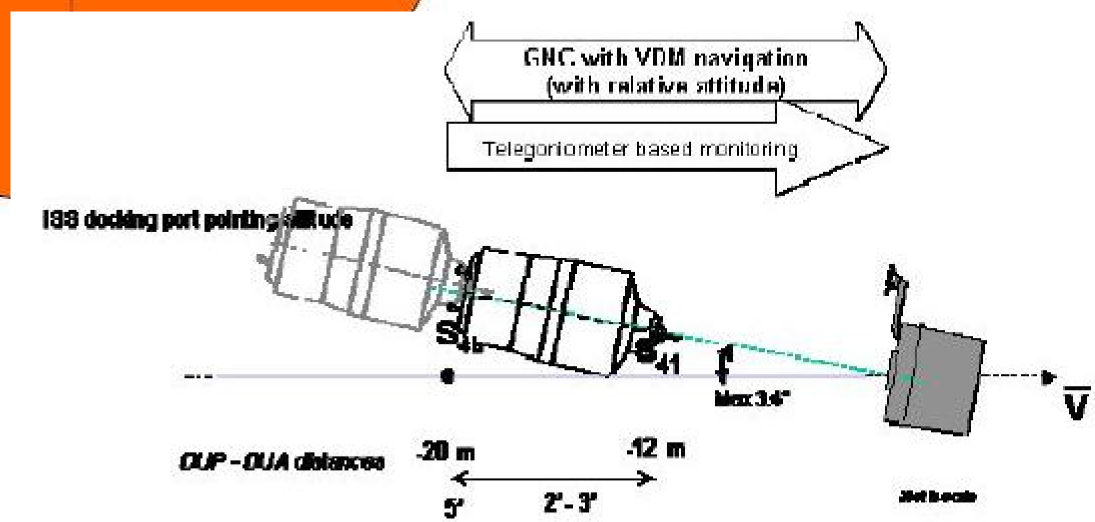


Figure 4.14-1 : Forced translation from S_4 to S_{41}

ATV Lessons Learnt : Challenges

Communication Paths

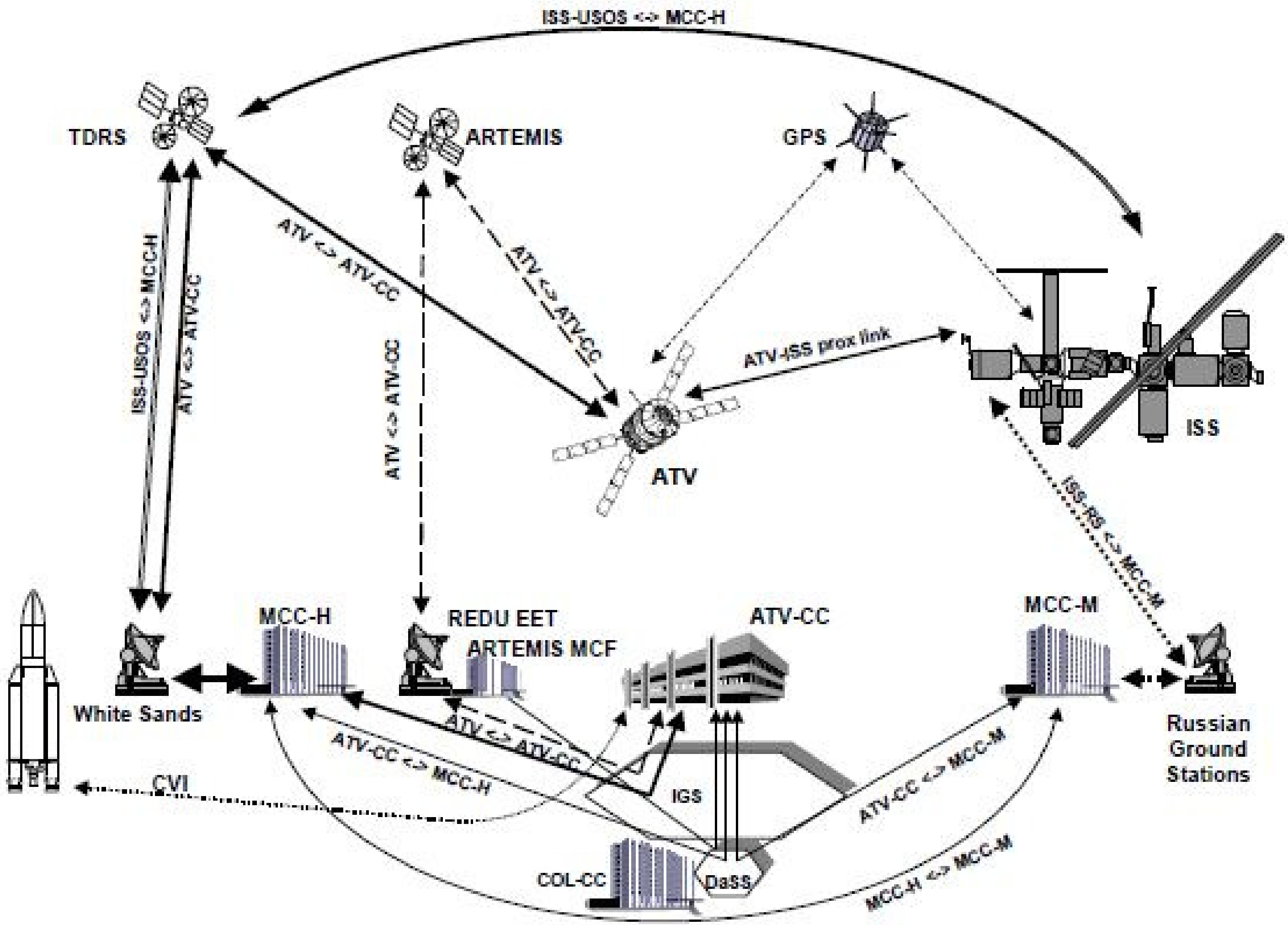


Figure 2.1-1: General Communication Architecture during ATV flight

ATV Lessons Learnt : FDIR

Failures were extensively discussed in the operations team. Decisions were captured in the System Operations Reference (SOR) document.

SOR was edited by ESA's Prime contractor based on inputs from
- ESA/Industry Flight Segment, ESA/CNES Ground Segment
- NASA Flight Operations (Mission Control -Houston)
- RSCE designers as well as Flight Operations (Mission Control -Moscow)
- NASA Crew office, Astronauts and the European Astronaut Center

For every part of the mission SOR addressed
who did what, when and how

For every part of the mission SOR addressed
what if …. Then…. Else ….

In total there were 14 volumes

- ATV-AS-SOR-4000-01-3A.pdf
- ATV-E-AS-SOR-4000-02_9A_LEOP.pdf
- ATV-E-AS-SOR-4000-03_13A_Phasing.pdf
- ATV-E-AS-SOR-4000-04_14A_RDV.pdf
- ATV-E-AS-SOR-4000-05_13B_docking.pdf
- ATV-E-AS-SOR-4000-06_15A_attached.pdf
- ATV-E-AS-SOR-4000-07_10A_prop_supp.pdf
- ATV-E-AS-SOR-4000-08_11A_Ref.pdf
- ATV-E-AS-SOR-4000-09_6B_Dry_Cargo.pdf
- ATV-E-AS-SOR-4000-10_12A_L_G.pdf
- ATV-E-AS-SOR-4000-11_10A_Undock.pdf
- ATV-E-AS-SOR-4000-12_9A Deorbit.pdf
- ATV-E-AS-SOR-4000-14_11A_surv_FF.pdf

ATV Lessons Learnt : FDIR

Many types of failures have to be assessed HW failure, behaviour , operator error

FU	what last entry line 457 blue = part of JMB CCC case	phas	S-1/2 -S0	S0-S1	S1-S3	S3	S3-S4	hold	S4	S4-S3	S4-S41	S41	S41-S4	S41-1stc	1stc-S41	escape	detection by
GMS	2nd failure ACCA	R&D	A	A	A	H	A	H	H	R	A	H	R	A	R	E	*ACCA FU/FDIR. MVM detects double failure and triggers Mayday=> SURVIVAL*
GNC	angular rate > 1.2 deg/s	R&D			A	H	A	H	H	R	A	H	R	A	R		GMS FU threshold changes from 1.5 to 1.2 at S1
GMS	angular rate > ~~1.5~~ 1.6 deg/s	R&D	A	A												E	GMS FU threshold changes from 1.5 to 1.2 at S1
PFS	coarse monitoring angular rate > ~~1.5~~ 1.6 deg/s	R&D										H	R	A	R		PFS / MSU
PFS	coarse monitoring angular rate > ~~1.5~~ 1.6 deg/s	R&D	A	A	A	H	A	H	H	R	A						PFS / MSU
ATV	no acquisition of earth pointing attitude	R&D				H		H									ATV CC
ATV	ATV deviates > 9 deg from LVLH	R&D							H		A	H		A			ATV CC
ATV	specified attitude (earth pointing) not held (+/- 45)	R&D					A			R							ATV CC
ATV	specified attitude (yaw steering) not held	R&D				H		H									ATV CC
ATV	specified attitude (yaw steering) not held	R&D	A	A													ATV CC
ATV	Inadvertent triggering of RB CAM	R&D												A	R		Crew
none	CAM test 2 (crew) failed => Crew can not send cmds	R&D		A													*crew*
CMS	2nd failure	R&D														E	*CMS FU / FDIR. MVM detects failure and triggers mayday => SURVIVAL*

Bla

Se

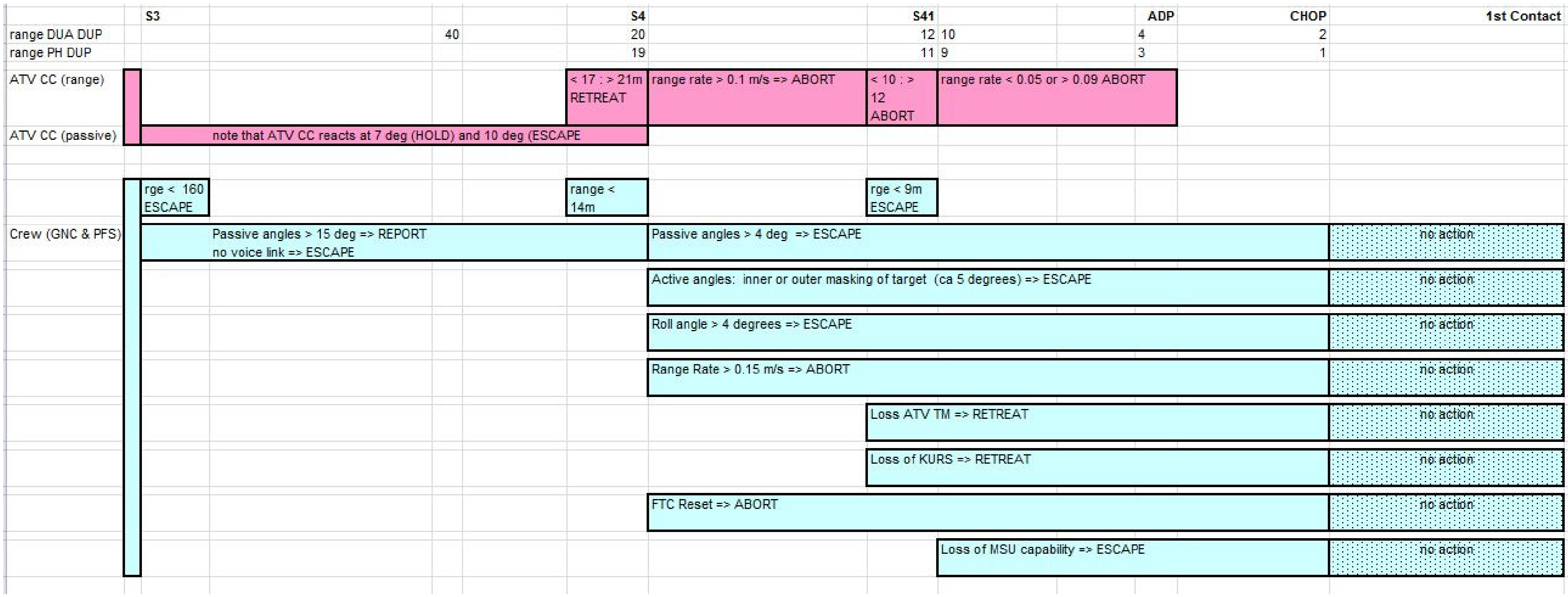
ATV: Freeflight and Rendezvous with ISS:

Several layers of monitoring

	S3		S4	S41	ADP	CHOP	1st Contact
range DUA DUP	350 m dp (380 ISS CoM)	40	20	12 10	4	2	
range PH DUP			19	11 9	3	1	
MVM (FAS)	FDIR (1st and / or 2 nd failure => ABORT / ESCAPE / RETREAT depending on eqt and failure)						
GMS (FAS)	Sensor monitoring : VDM n / VDM r and TGM n / TGM r => ESCAPE						
	Angular rate > 1.2 deg / s => ESCAPE						
FCM (FAS)	GNC Consistency: difference btw commanded and estimated attitude > 13 deg => ABORT				GNC Consistency > 13 deg: Attitude monitoring => ABORT		
	Approach angle (TGM (range + LOS) + attitude) > 7.85 - 6.5 => ESCAPE (reqt is 45 deg)			I > 6.5-8 deg I => ESCAPE	Appr angle > 8 - 12.5 deg		Appr angle > ? => ?
	Range rte (TGM + ACCA (x component)) (>profile 0.643-0.121) => ESCAPE	> 0.121=> ESC	Range rate > 0.121 - 0.115 => ESCAPE				Range rate > ? => ?
	Sensor consisten 250 -100m:Th profile 11m - 3.2 m 100m - 40m: Th profile 3.2 m - 1m	Th : 1.0 - 0.63m	Sensor monitoring VDM/TGM range Threshold : 20 - 3m : 0.63 - 0.2		after 3m (2 m PH - DUA) Th = 0.2		
	Transversal CoM velocity wrt LVLH frame (TGM+ ACCA (y and z components) (ranges are DUA DUP) profile 260 - 220m: 0.345 - 0.339 m/s, 220 - 20m 0.099 - 0.07 m/s => ESCAPE		profile 20m - 0m : value > 0.070 (20m) - 0.047 m/s (0m) => ESCAPE				
		Transversal Probe Head position monitoring (ranges are DUA DUP) (TM range/LOS) Th: 40m- 18.25m	Th 18.25 m - 0.91m : 1.23 - 0.28 m => ESCAPE				
			Transversal Probe Head velocity monitoring (ranges are DUA DUP)				
FTCP Synchro	MSU monitors FTCP health (SW or critical HW failures(MAYDAY) => FTC health status down at least 10s) => ABORT						
MSU health	MSU monitors it's health (MSU1 monitors MSU2 and vice versa, slave can take over as master) no monitoring after CAM triggering						
Coarse Monitoring (MSU)	Range rate (TGM range) > profile 0.9 - 0.2 => ABORT		Range rate (TGM) > 0.2 m/s => ABORT	(Jan 05: disabled after S41, TBC by EADS)			
	Absolute angular rate (DTG) > 1.5 deg /s => ABORT			(Jan 05: disabled after S41, TBC by EADS)			
	Mean chaser altitude monitoring Zm (ACCA)			(Jan 05: disabled after S41, TBC by EADS)			

ATV: Freeflight and Rendezvous with ISS:

Monitoring : ATV CC and Crew : checks and actions



All set

1) Launch on Ariane 5 : a fully loaded ATV weighed 20 tons at departure => AR5 ca 780 tons

ATV CC : Control room layout : Main control Room ATV 2 – ATV 5

NASA / RSCE Mission Director Flight Director Ground Systems

EST

VET

ATV Lessons Learnt : Mission Highlights

ATV CC : Control room
layout ATV 2- 5 :
EST rooms M27 M34

Camera image

EST Team for ATV4

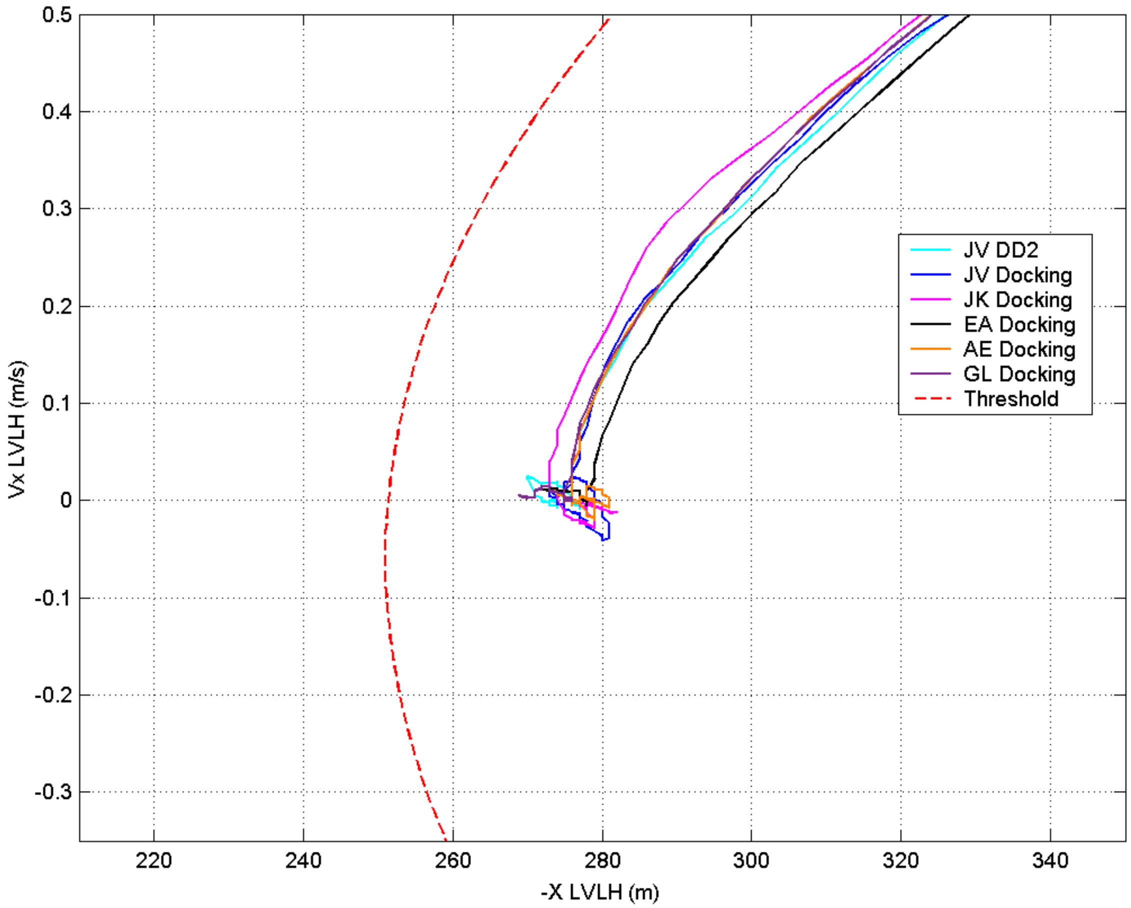
ESTLs	6
COM	3 (2 on ATV1)
CONFIG	4 (3 on ATV1)
ECLS /WGDS	3 (1 on ATV1)
Crew	4 (6 on ATV1)
DH	2 (3 on ATV1)
DRS	3 + 7 RSCE (2+7) +2/3 ESA in MCC-M
GNC	5 (4 on ATV1)
GMS	4 (same)
RMCA	3 (same)
RFS	1 + RSCE (same) + 2/3 ESA in MCC-M
PRO	4 (same)
PWR	3 (2 on ATV1)
Safety	4 (same)
Thermal	3 (2 on ATV1)

Off site, many
Contractors : yes

Total EST On / OFF	85
RDV / undock ON site	57
Attached ON site	45

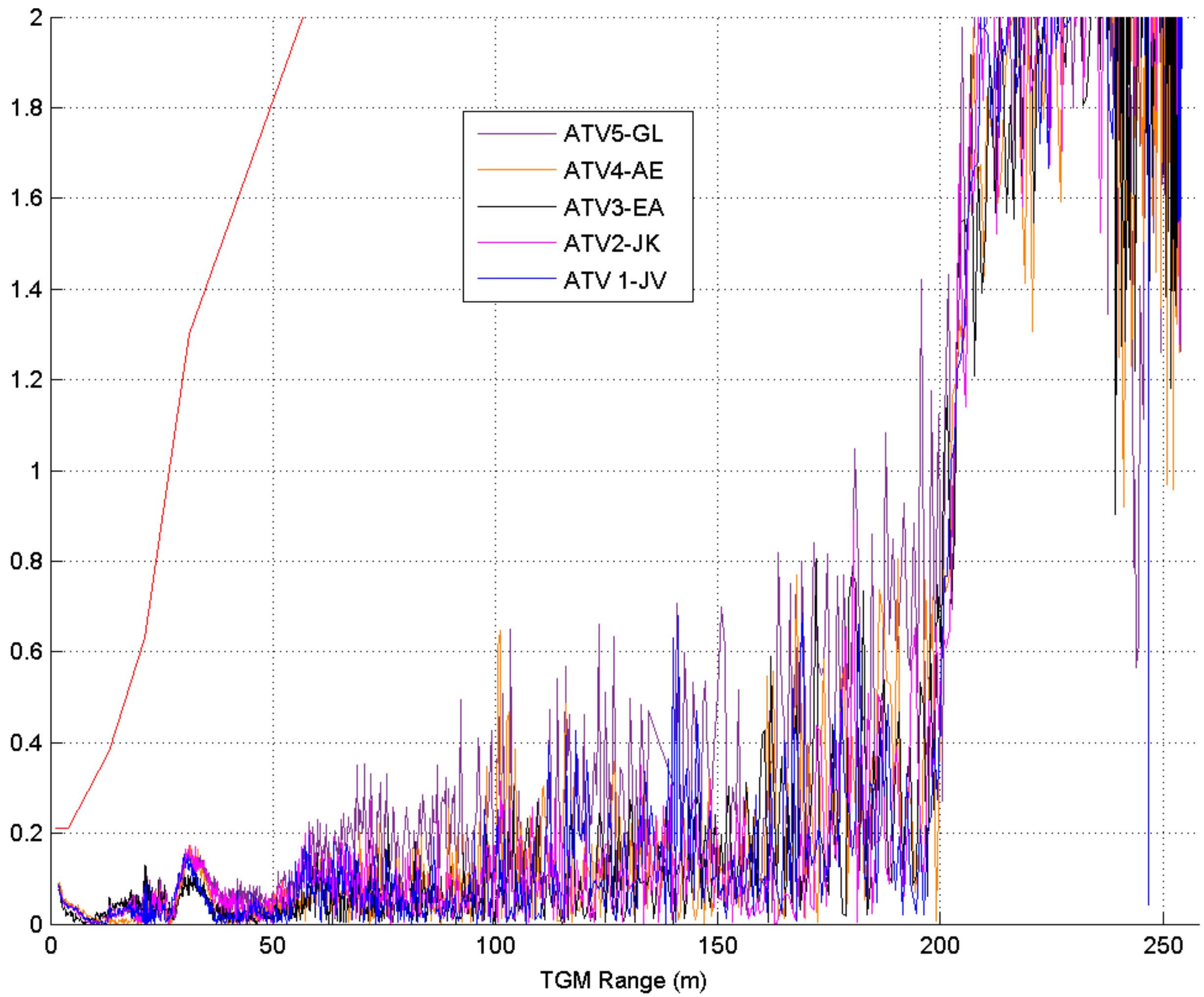
ATV – FAR RENDEZVOUS GPS NAVIGATION

- Less than 10 m difference among 6 ATV Far Rendezvous trajectories arriving in S3
- Robustness of GNC illustrated during ATV-4 rendezvous with the loss of a complete propulsion chain due to thruster pressure sensor failure during Homing first boost
- ATV finished rendezvous on different propulsive configuration

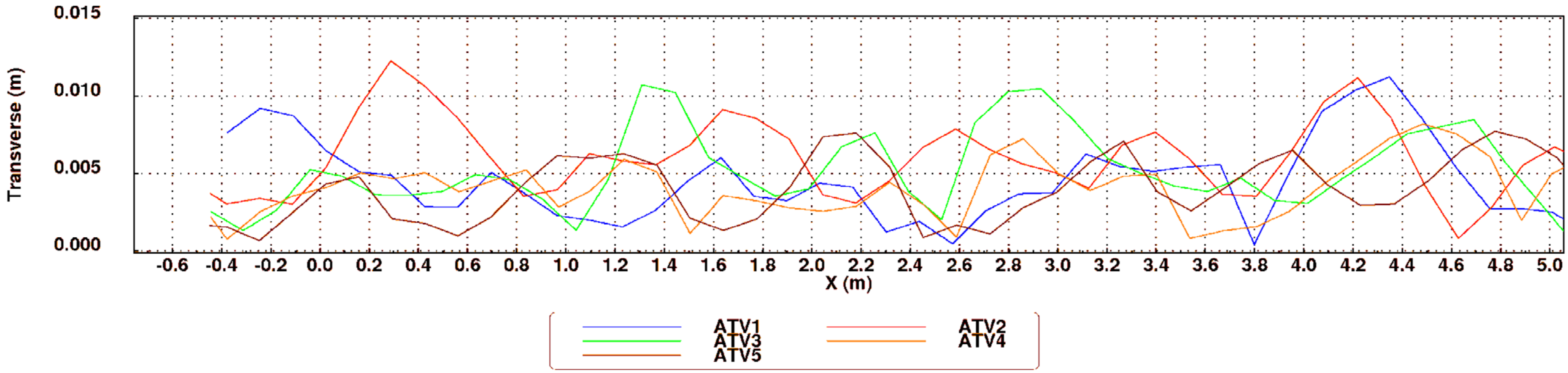


ATV – CLOSE RENDEZVOUS TGM / VDM RANGE DIFFERENCE

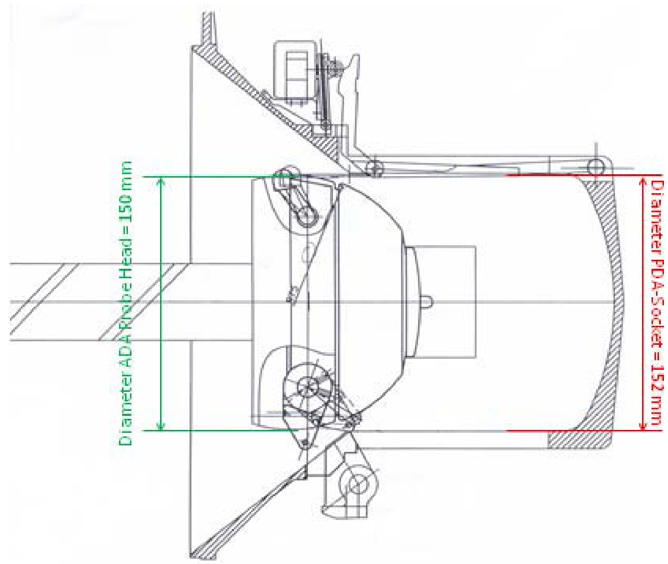
- Range difference of 2-3m above 200m: due to limitation of VDM at this range
- Below 200m, the range is consistent within less than 1m
- Below 50m, range is consistent within 0.1m except for small period around 30m



ATV – CLOSE RENDEZVOUS DOCKING ACCURACY



	ATV1-JV	ATV2-JK	ATV3-EA	ATV4-AE	ATV5-GL
Transverse position at contact (mm)	7.7	3.7	2.6	2.2	2.0
Time between first contact and capture (ms)	760 (~17mm)	500 (7-10mm)	400 (<10mm)	Direct Capture	Direct Capture



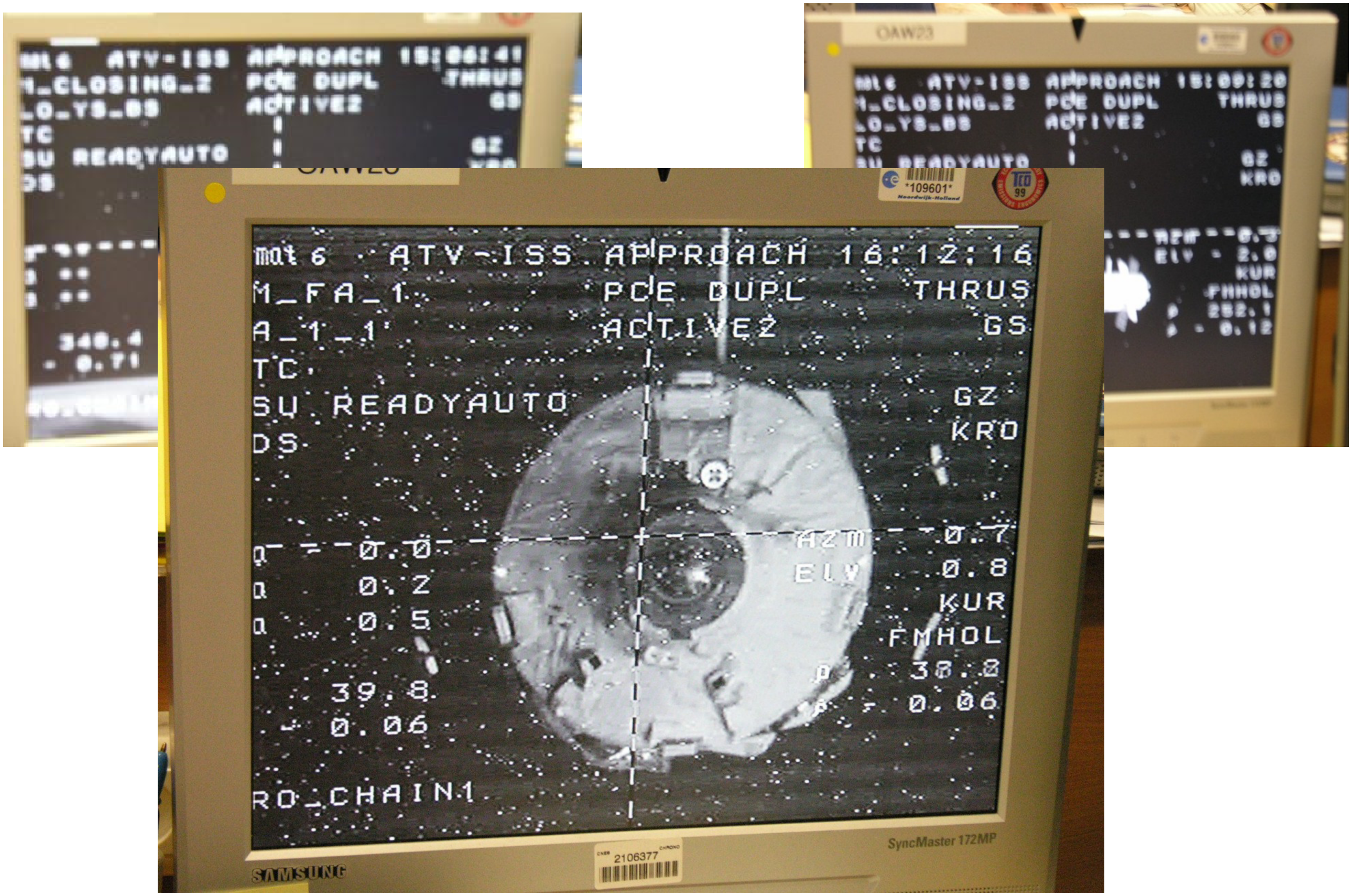
- ❑ Docking accuracy specification is 100mm
- ❑ ATV-4 & ATV-5 achieved less than 2mm accuracy with direct capture of the Probe-Head

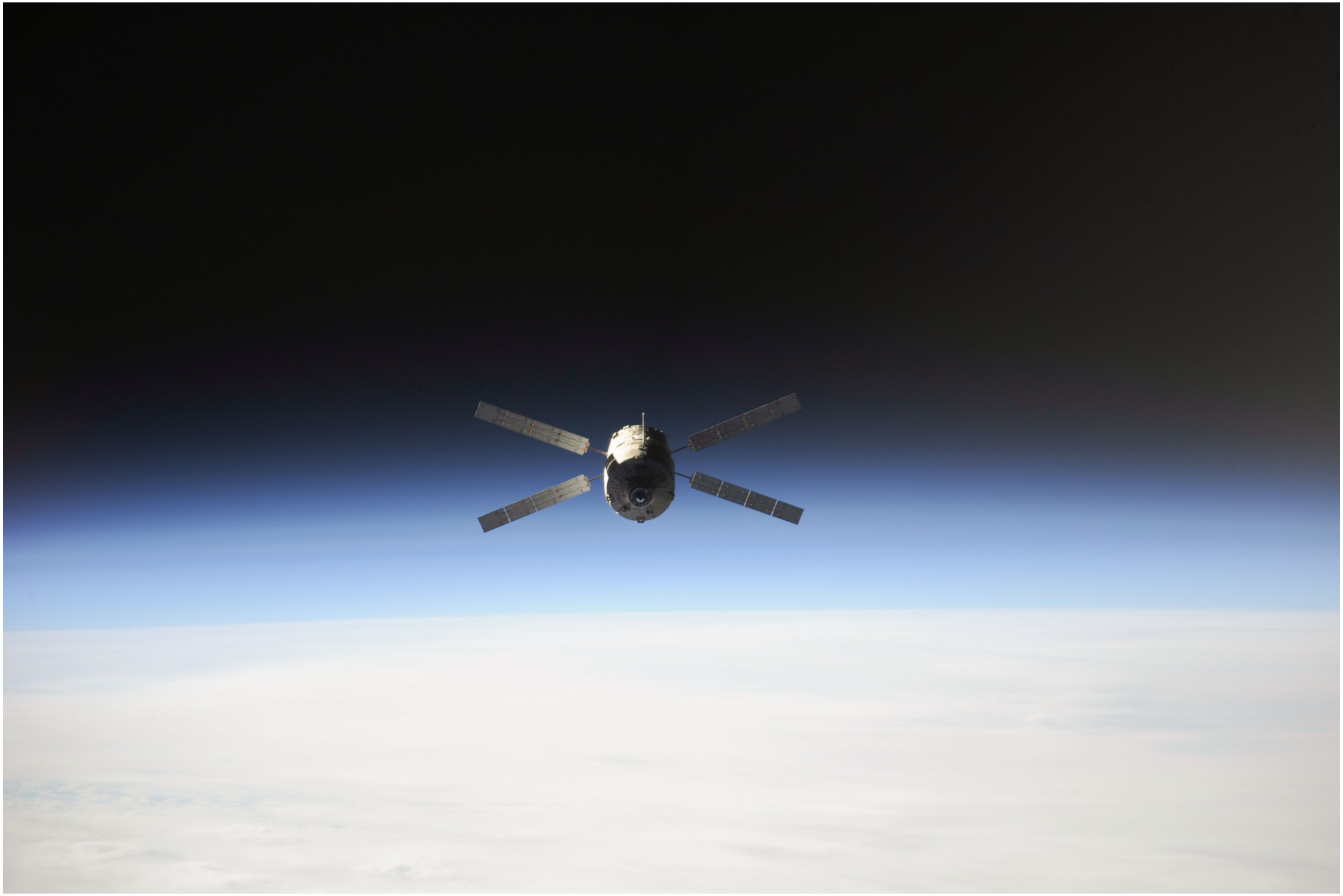
ATV : Approach to ISS as seen by Crew

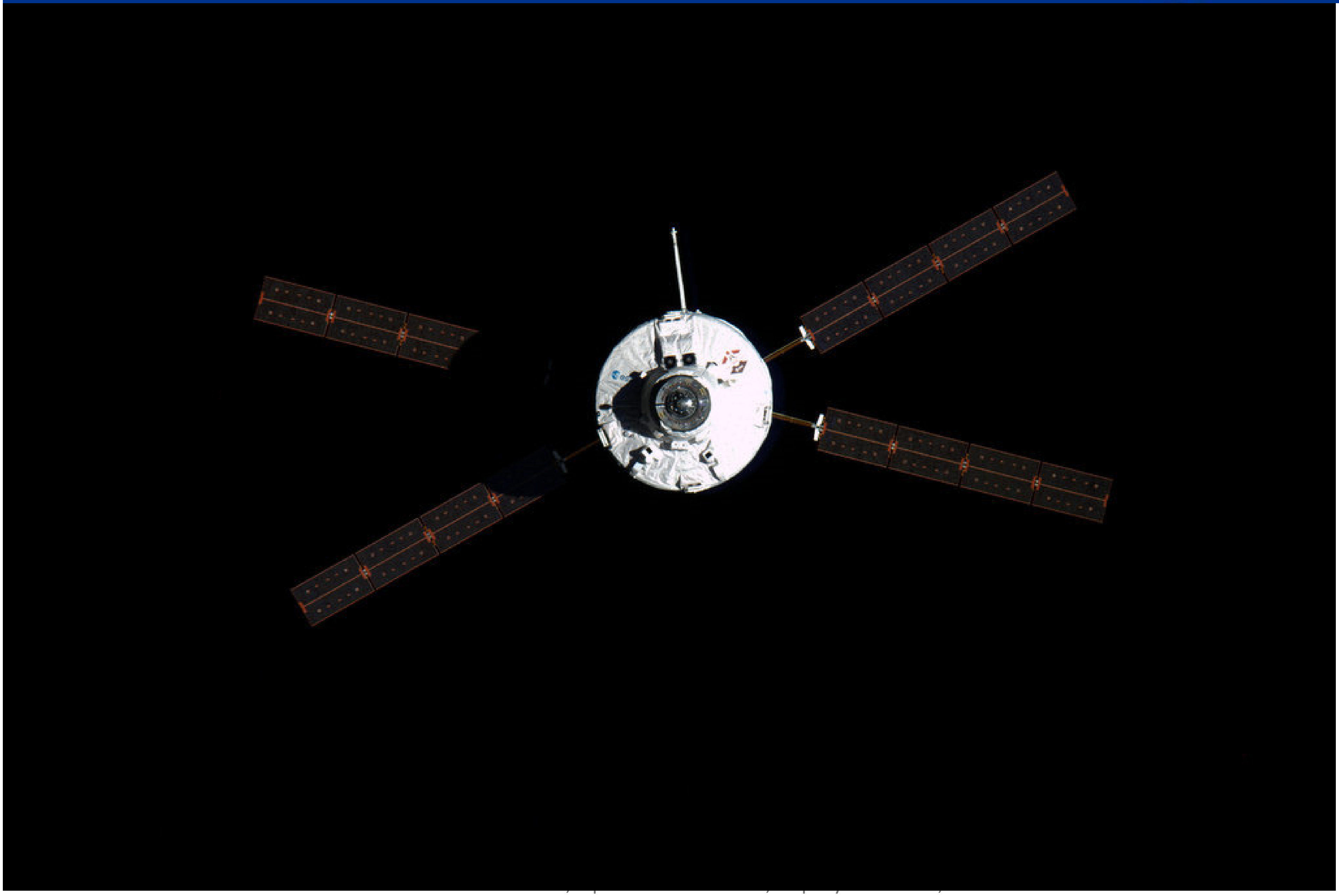
ATV 1 Demo Day 2 15:04 and 15:09

ATV : Approach to ISS as seen by Crew

ATV 1 Demo Day 2 and 16:12







ATV: Freeflight and Rendezvous with ISS:

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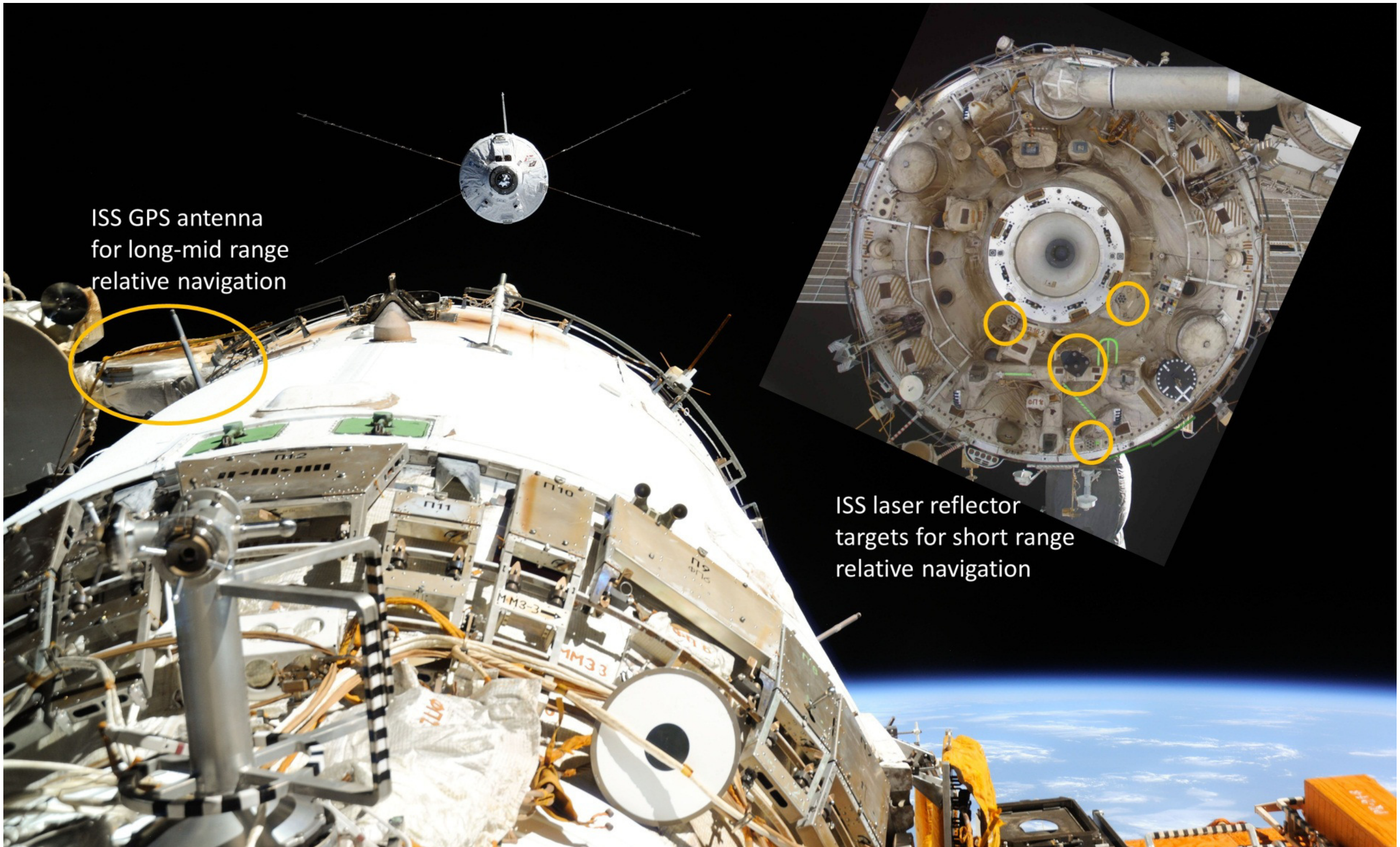
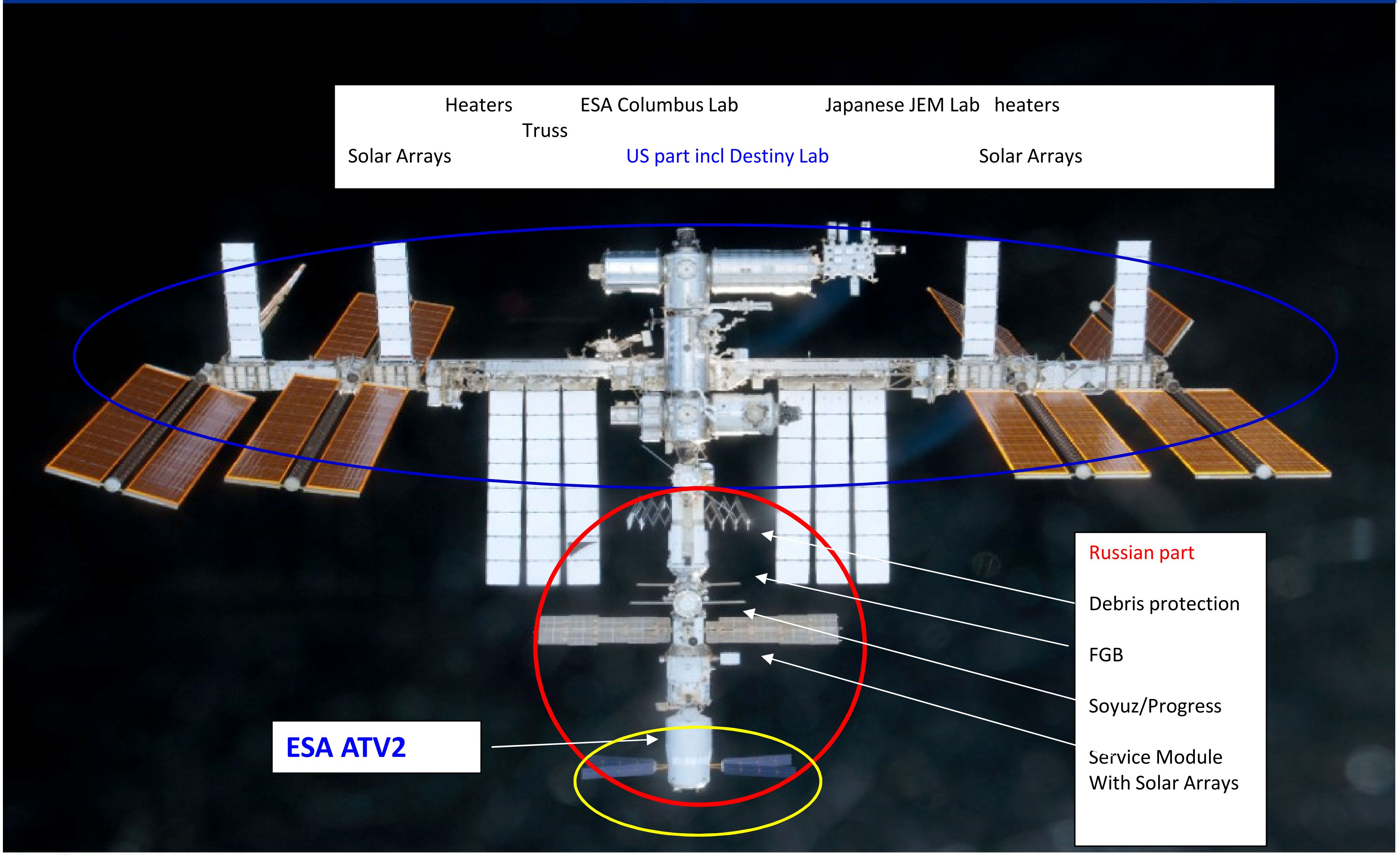


Bla bla:

- Second level

ATV: Historical Overview



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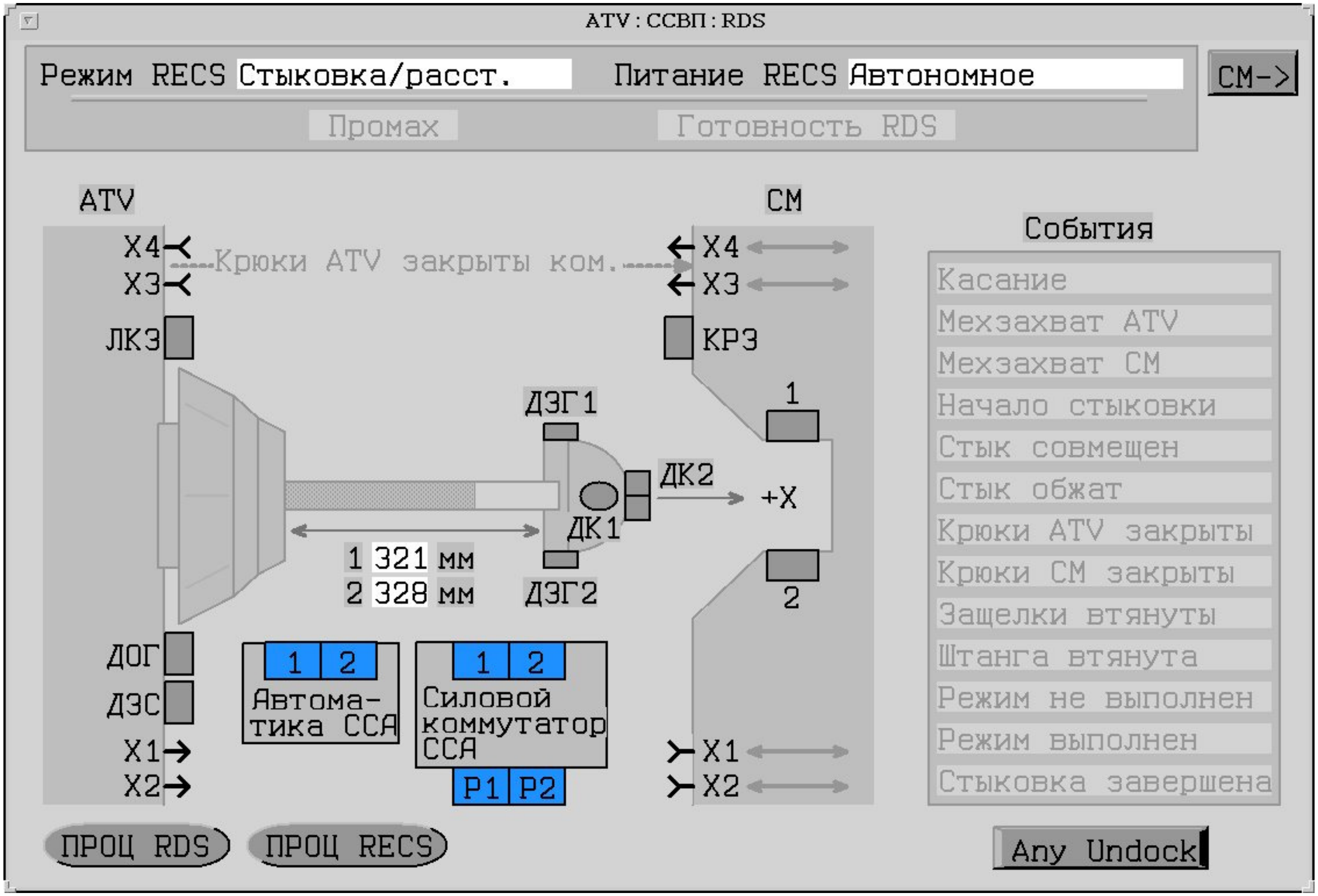
Some final words on the automated docking and the refuelling of the ISS

ATV : The ISS docking interface

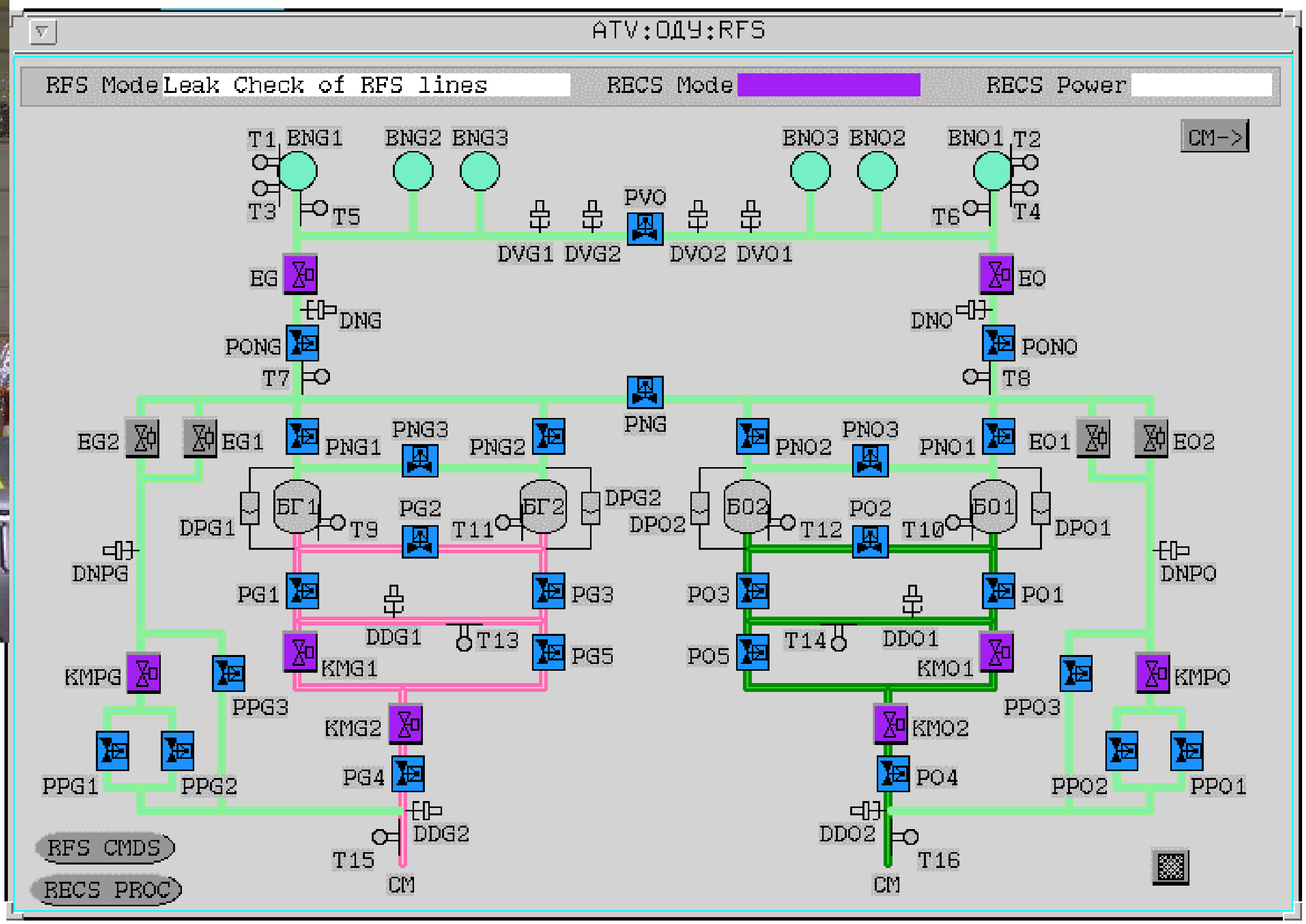
Crew laptop display showing the docking sequence



The combined refuelling system ATV and ISS

yellow tanks are the He pressurisation tanks (3+3)

green tanks contain fuel (2) and oxidiser (2)

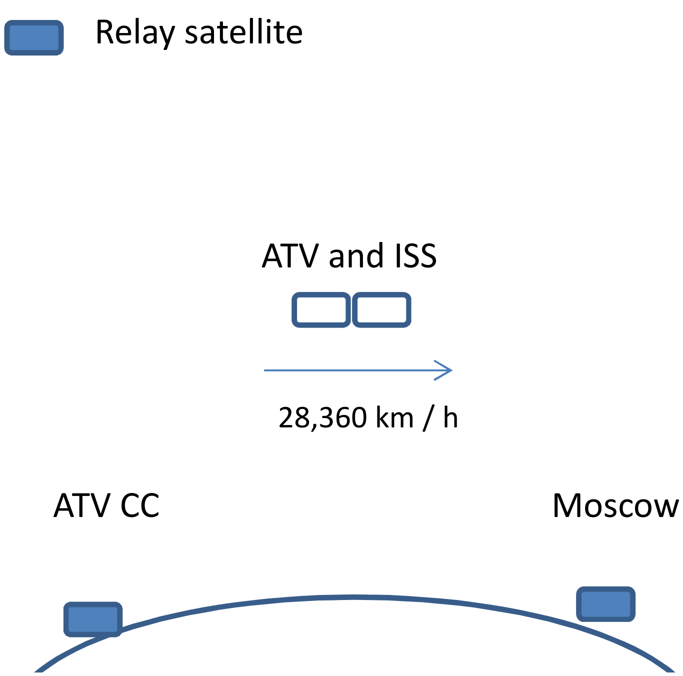


Actual installation on ATV

schematic
for ISS crew

ATV : Refuelling the ISS

ATV carried 860 kg of Russian propellant to the ISS. The sequence of refuelling was Leak check, Pressurisation , Fuel Transfer and Purging.
ATV CC set up the ATV, Experts in ATV CC and in Moscow monitored the transfer
The actual sequences were pre-programmed and automatic



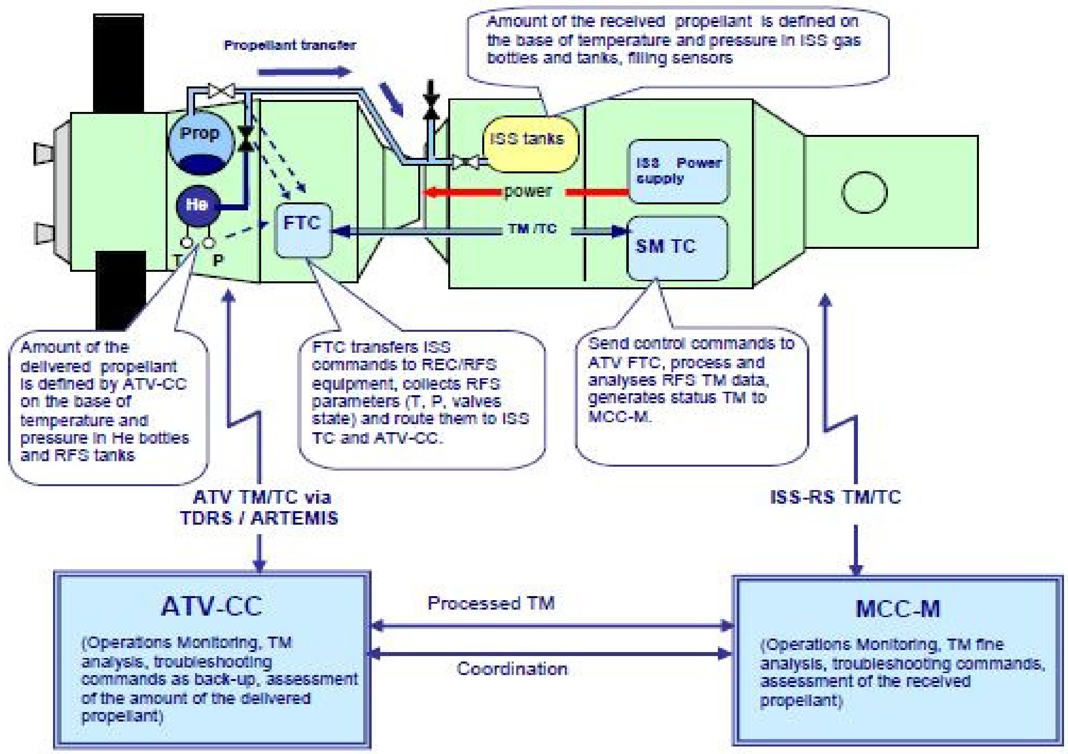


Figure 2.5-4 : Simplified scheme of the propellant transfer operations