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A Finmeccanica / Thales Company

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**FLEXIBILITY & AUTONOMY IN MARS EXPRESS  
PLANNING USING LMP**

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## **OVERVIEW**

- ✦ Introduction
- ✦ MPS2012 - Activity Planning
- ✦ Possible avenues for AI
- ✦ Conclusion

## **MARS EXPRESS MISSION**

- ✦ Launched in June 2003, arrived end of 2013
- ✦ Carries 7 main instruments
  - ✦ Aspera, Spicam, HRSC, PFS, MARSIS, MARS, VMC
  - ✦ Transmitters used for Radio Science experiments
- ✦ Mission changed initially due to post launch power issues
  
- ✦ FCT use a EKLOPS based MPS developed by VEGA
  - ✦ Many evolutions since launch
  - ✦ Enhancements driven by user missions
  
- ✦ We will focus here on the evolutions needed due to the Spacecraft Anomaly of November 2011 – MPS2012

## ON-BOARD COMMAND EXECUTION CHAIN

Previously Nominal  
On-board Operation



Execution Stack  
Max.167 TCs



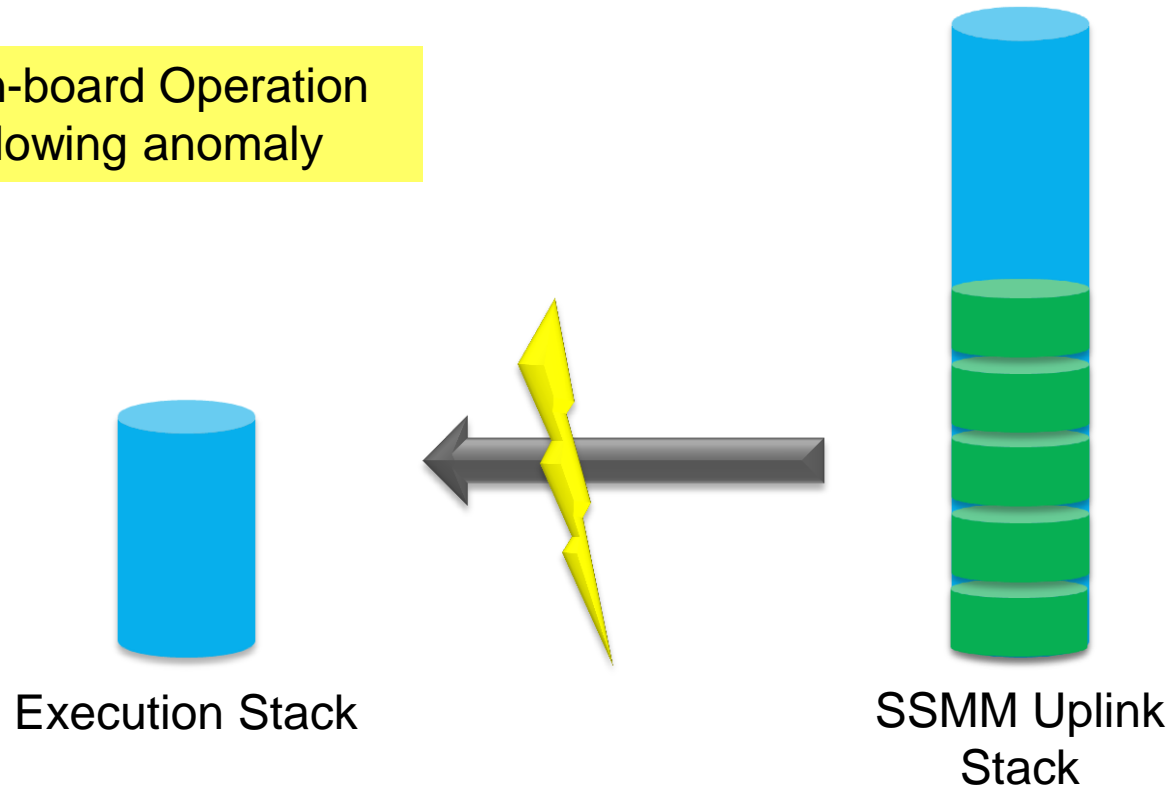
SSMM Uplink Stack  
~3600 TCs

Flawless operation since launch...

Until the anomaly

## ON-BOARD COMMAND EXECUTION CHAIN

On-board Operation following anomaly



**Commanding not guaranteed to be transferred correctly anymore**

## **WHAT DID THIS MEAN FOR THE MISSION**

- ✦ Initially several Hardware Safe Modes for the spacecraft
  - ✦ Expensive on solid fuel and time consuming to recover from
- ✦ Change of strategy needed to ensure safe operation of the Satellite
  - ✦ Couldn't rely on transfer of commands via bus from SSMM
  - ✦ Limited to execution queue for commanding (max. 167 commands)
  - ✦ Use of Sub-Schedule ID to enable/disable commanding on a file level
- ✦ Updates to supporting tools to support changes
  - ✦ Checking tools needed to be modified
  - ✦ FCT procedure re-written for new situation
  - ✦ MPS needed to support new concepts and facilitate more automation
- ✦ **Activity based scheduling strategy conceived**

## DEFINING AN ACTIVITY WINDOW

- Can be defined based on pointing timeline
  - e.g. Start at Slew before non-Earth pointing, end at Slew end after non-Earth pointing



```
fact(?id1, S/C Pointing, SLEW, ?st, ?et)
^nextFact(?st, S/C Pointing, NADIR, ?nadirSt, ?nadirEt, ?id2)
^nextFact(?nadirSt, S/C Pointing, SLEW, ?nst, ?net, ?id3)
->activity(?newid, Activity, Window, ?st, ?et)
```

## DEFINING AN ACTIVITY WINDOW

- ✦ Can be defined by an instruments commanding
  - ✦ e.g. Start at instrument switch on, end at instrument switch off



```
fact(?id1, Instrument, ON, ?onSt, ?onEt)
^nextFact(?st, Instrument, OFF, ?offSt, ?offEt, ?id2)
->activity(?newid, Activity, Window, ?onSt, ?offEt)
```



## DEFINING AN ACTIVITY WINDOW

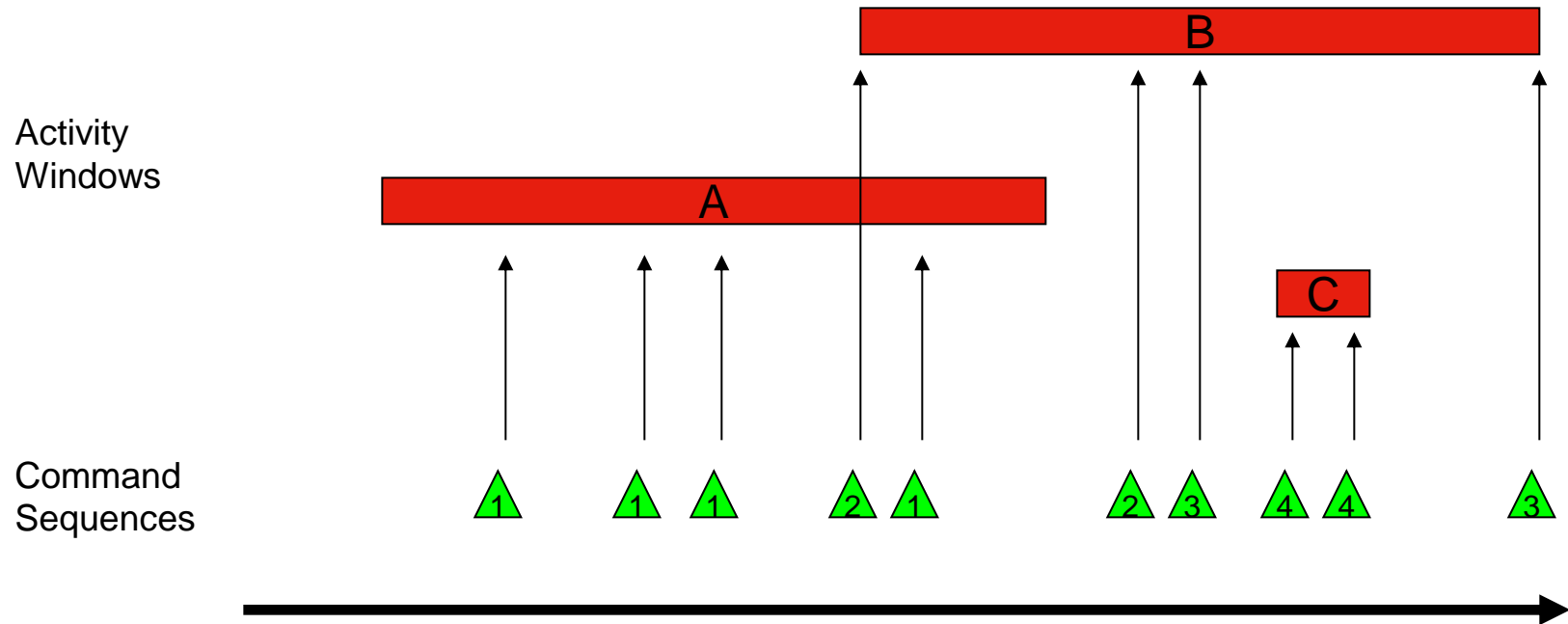
- ✦ Can be more complex
  - ✦ e.g. Start at first instrument of three instruments minus a instrument specific offset, end after last instrument switch off plus an instrument specific margin



```

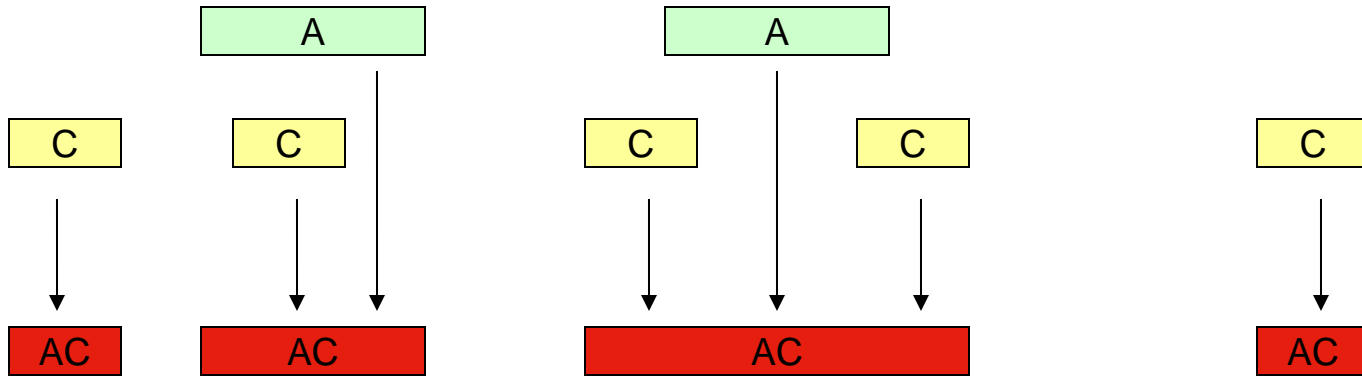
fact(?id1, Instrument1, ON, ?on1st, ?on1et) ^nextFact(?on1st, Instrument1, OFF, ?off1st, ?off1et, ?id2)
^?real1st <- ?on1st - 000.00:00:10.000 ^?real1et <- ?off1et + 000.00:00:20.000
^fact(?id3, Instrument2, ON, ?on2st, ?on2et) ^nextFact(?on2st, Instrument2, OFF, ?off2st, ?off2et, ?id3)
^?real2st <- ?on2st - 000.00:01:10.000 ^?real2et <- ?off2et + 000.00:02:20.000
^overlap(?real1st, ?real1et, ?real2st, ?real2et, ?ost, ?oet)
^fact(?id4, Instrument3, ON, ?on3st, ?on3et) ^nextFact(?on3st, Instrument3, OFF, ?off3st, ?off3et, ?id5)
^?real3st <- ?on3st - 000.00:02:10.000 ^?real3et <- ?off3et + 000.00:01:20.000
^overlap(?real3st, ?real3et, ?ost, ?oet, ?ost2, ?oet2)
...
->activity(?newid, Activity, Window, ?st, ?et)
  
```

## ASSIGNMENT OF SEQUENCES TO ACTIVITY WINDOWS



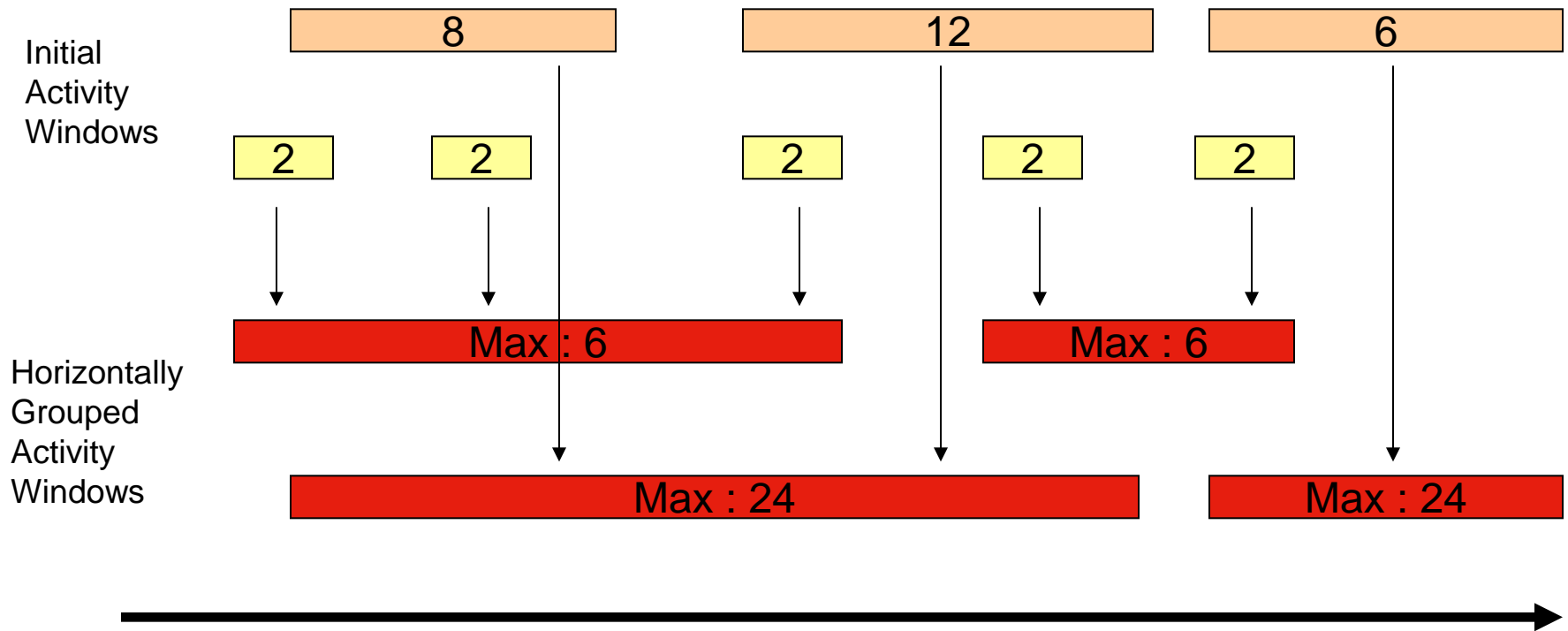
## VERTICAL GROUPING

Initial  
Activity  
Windows



Vertically  
Grouped  
Activity  
Windows

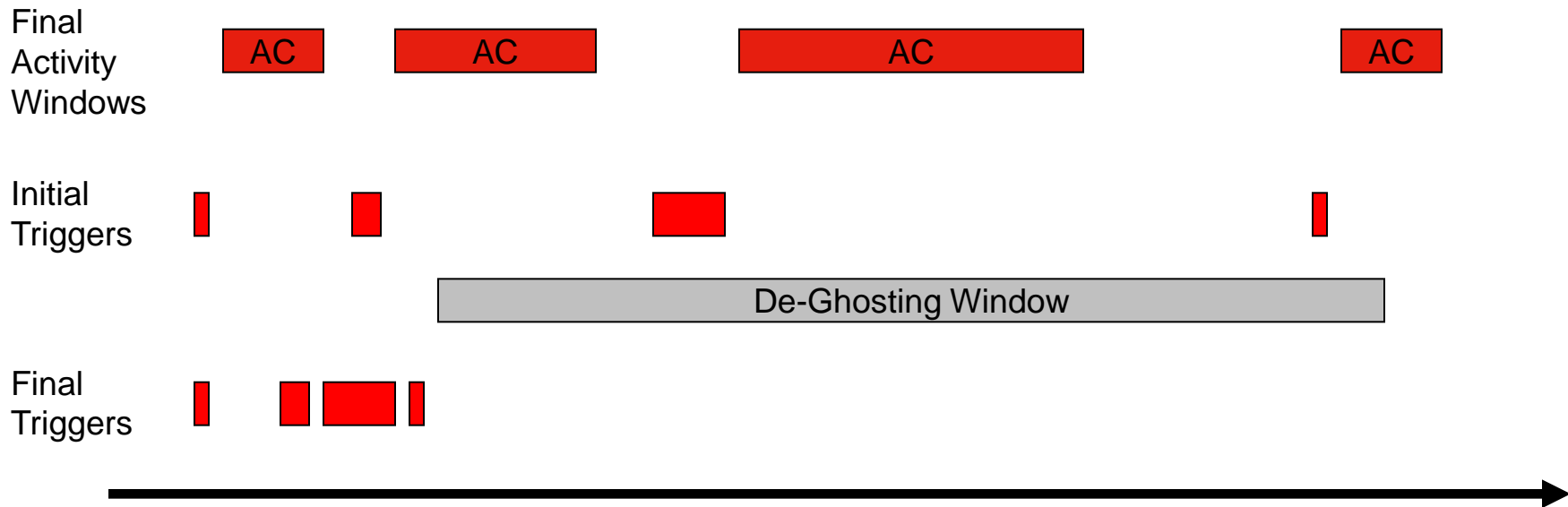
## HORIZONTAL GROUPING



## **OTHER ISSUES TO CONSIDER**

- ✦ Many small schedules produced as files
- ✦ Files have to be loaded onto the spacecraft SSMM
- ✦ Additional trigger schedule required to load these smaller schedules onto the execution stack from the SSMM
- ✦ Trigger schedule takes up valuable execution stack space
- ✦ Triggers require time to load schedule (~2 seconds per TC)
  
- ✦ Nature of SSMM file stack restrictive
  - ✦ Deletion of files can happen at any time
  - ✦ Files space only released if no files higher in the stack
  - ✦ Files removed from within the stack creates so called Ghost files
  - ✦ Only 256 files can be held in file stack
  - ✦ **Needs periodic de-Ghosting activity to clean file stack**

## DE-GHOSTING OF TRIGGERS



## **WHERE CAN AI BE APPLIED**

- ✦ Intelligent planning of transfer triggers
  - ✦ Even out capacity of short-term stack
  - ✦ Allow for more commanding due capacity release
- ✦ Guided uplink of activity stack files
  - ✦ May reduce build-up of ghost files
  - ✦ Possibly providing in-planning de-ghosting through careful loading of stack files to short-term stack
- ✦ Others?
  - ✦ Needs more thought

## **CONCLUSION**

- ✦ Mars Express MPS shown to be flexible and adaptable through cross-mission evolutions and enhancements.
- ✦ Quickly evolving mission strategies successfully handled through use of LMP rules
- ✦ More automation brought in to FCT planning/scheduling chain leading to saved time
- ✦ Several possibilities for AI introduction
- ✦ Still work-in-progress with more needed changes in the pipeline



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- Questions?
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