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A tool for nanosatellite functional verification: comparison between different in-the-loop simulation configurations

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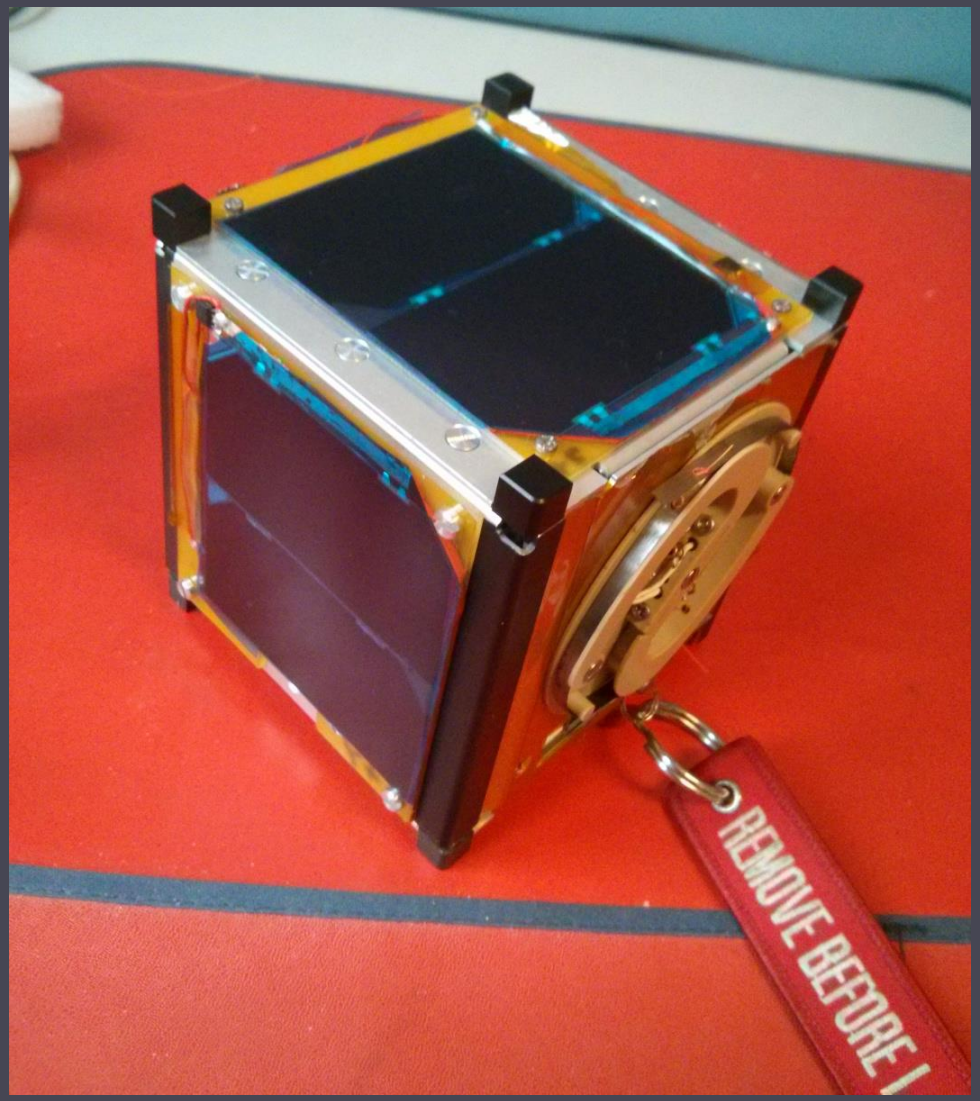
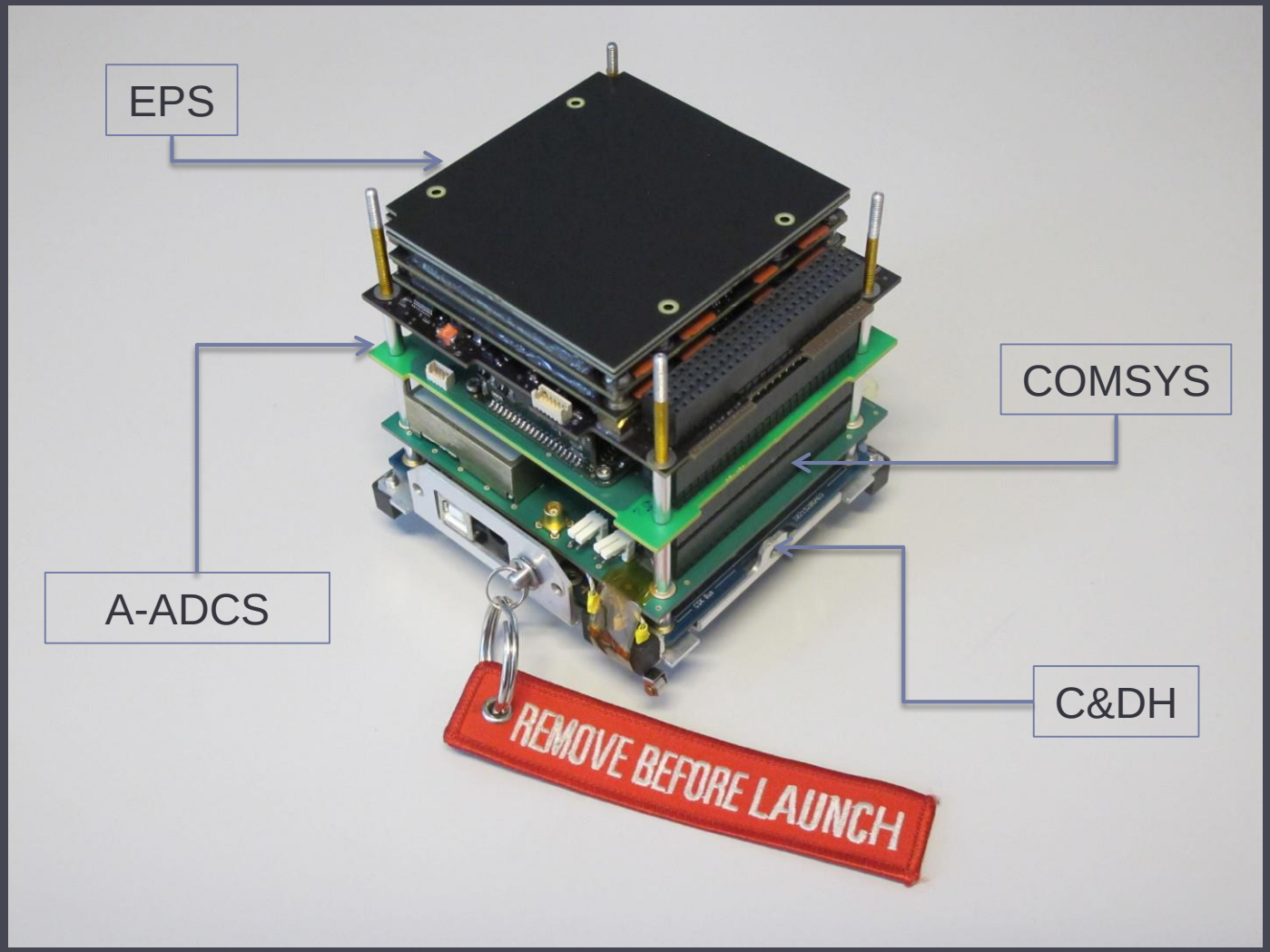
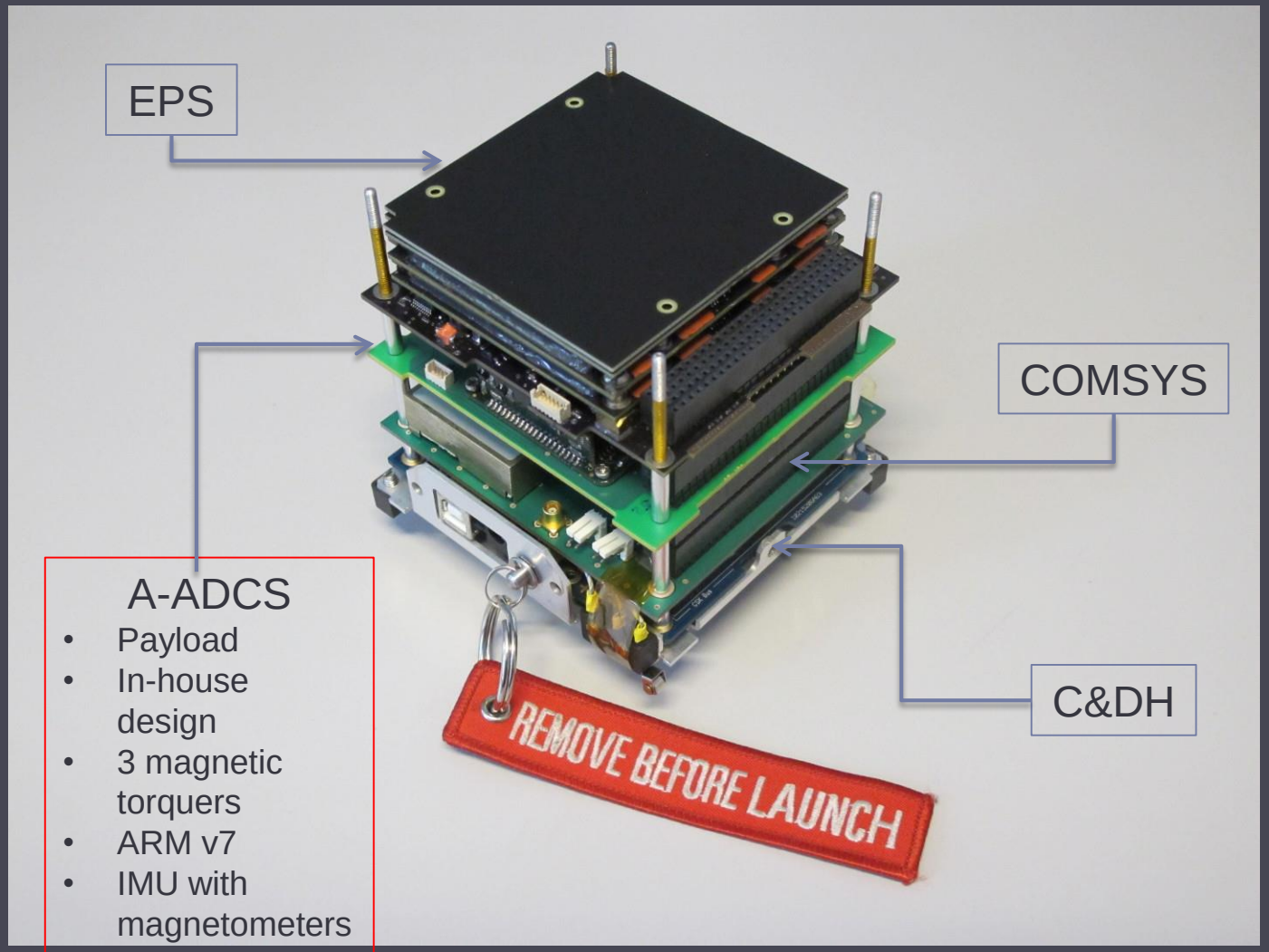
Department of Mechanical and Aerospace Engineering

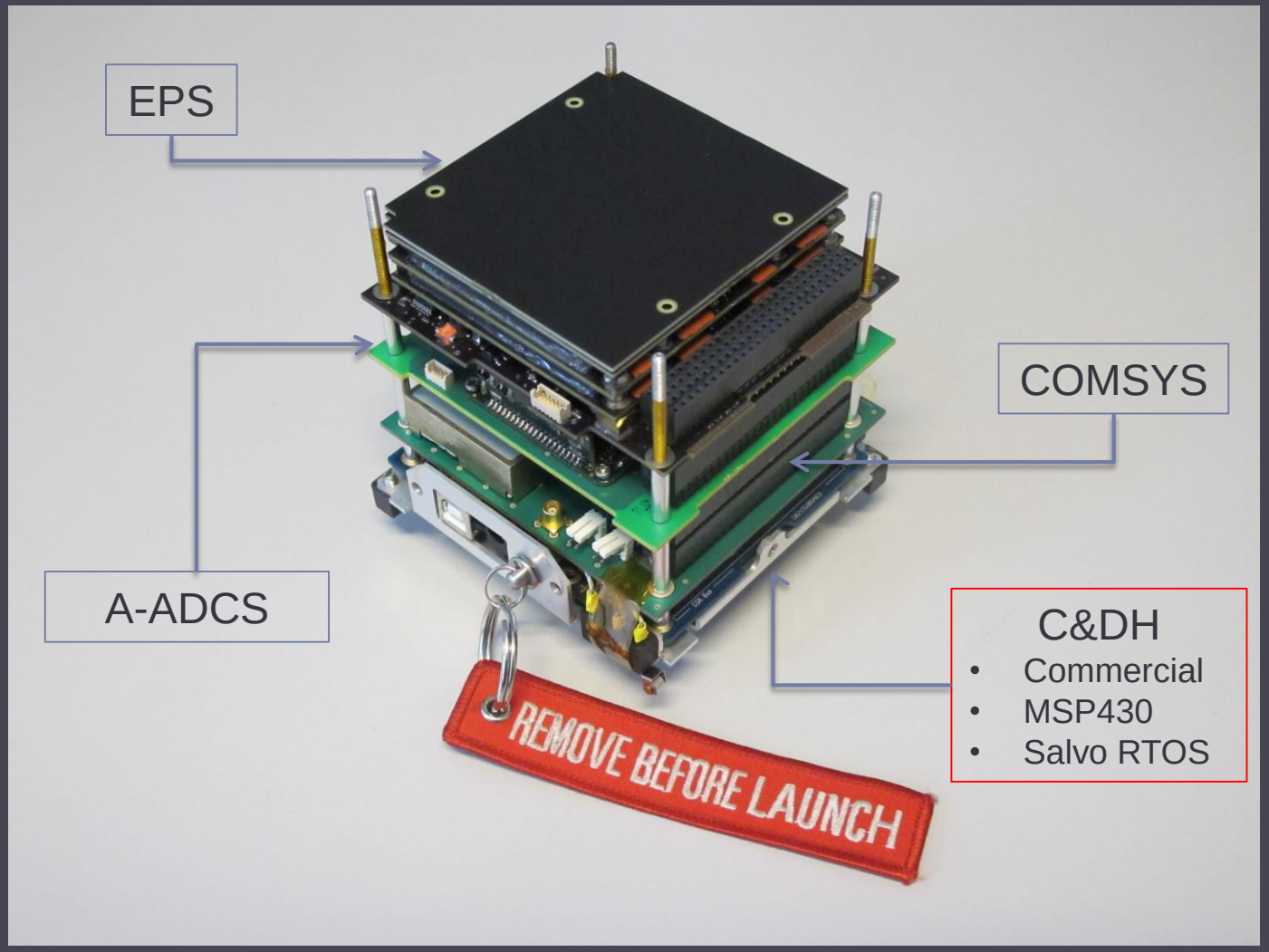
OUTLINE

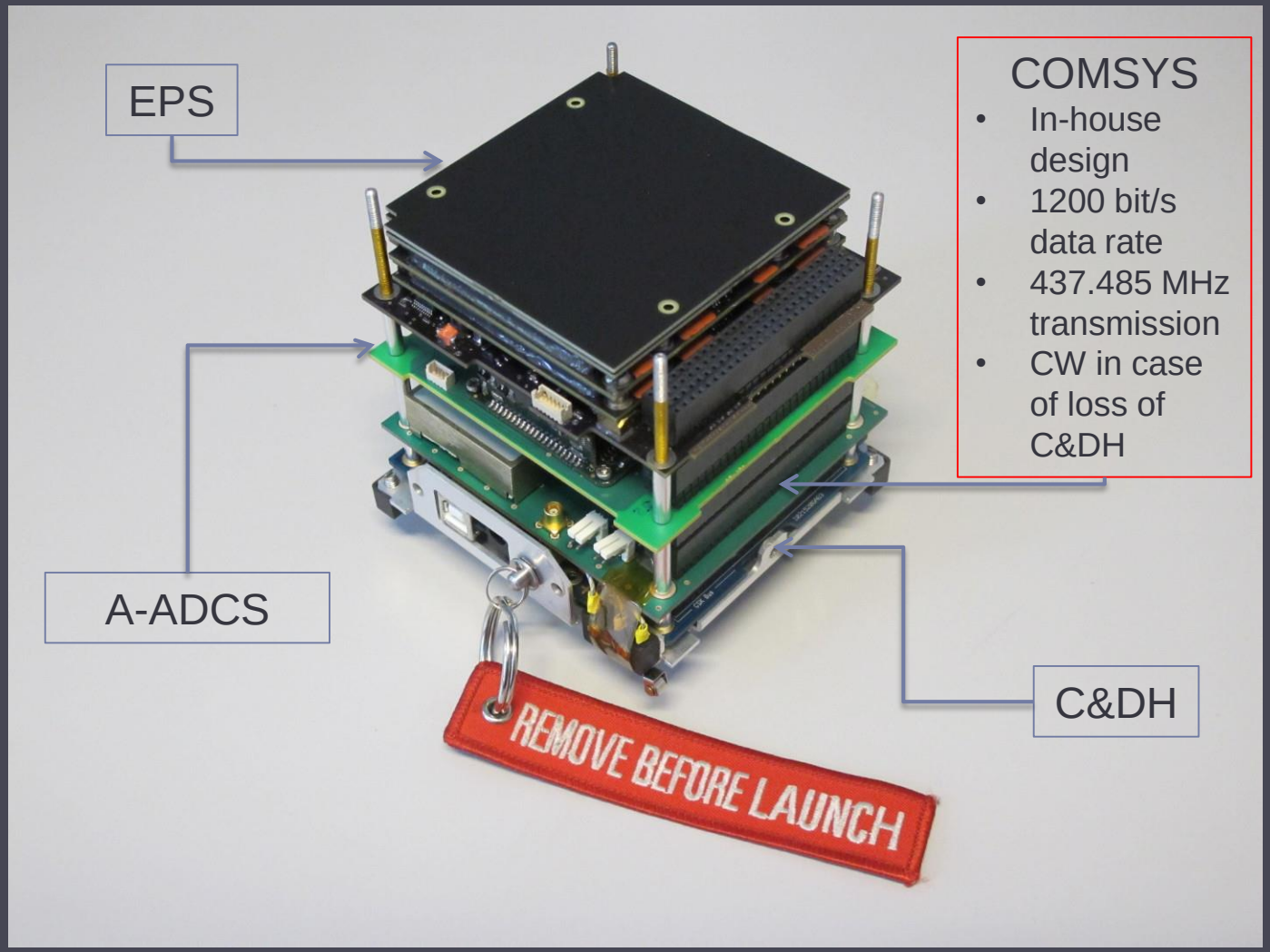
- e-st@r-II CubeSat
- StarSim
  - Key features
  - GUI brief description
- AIL, SIL, CIL, HIL
  - Presentation of a few key examples
- Comparison
  - Results of intermediate simulation sessions
  - Results on Hardware-in-the-Loop simulations

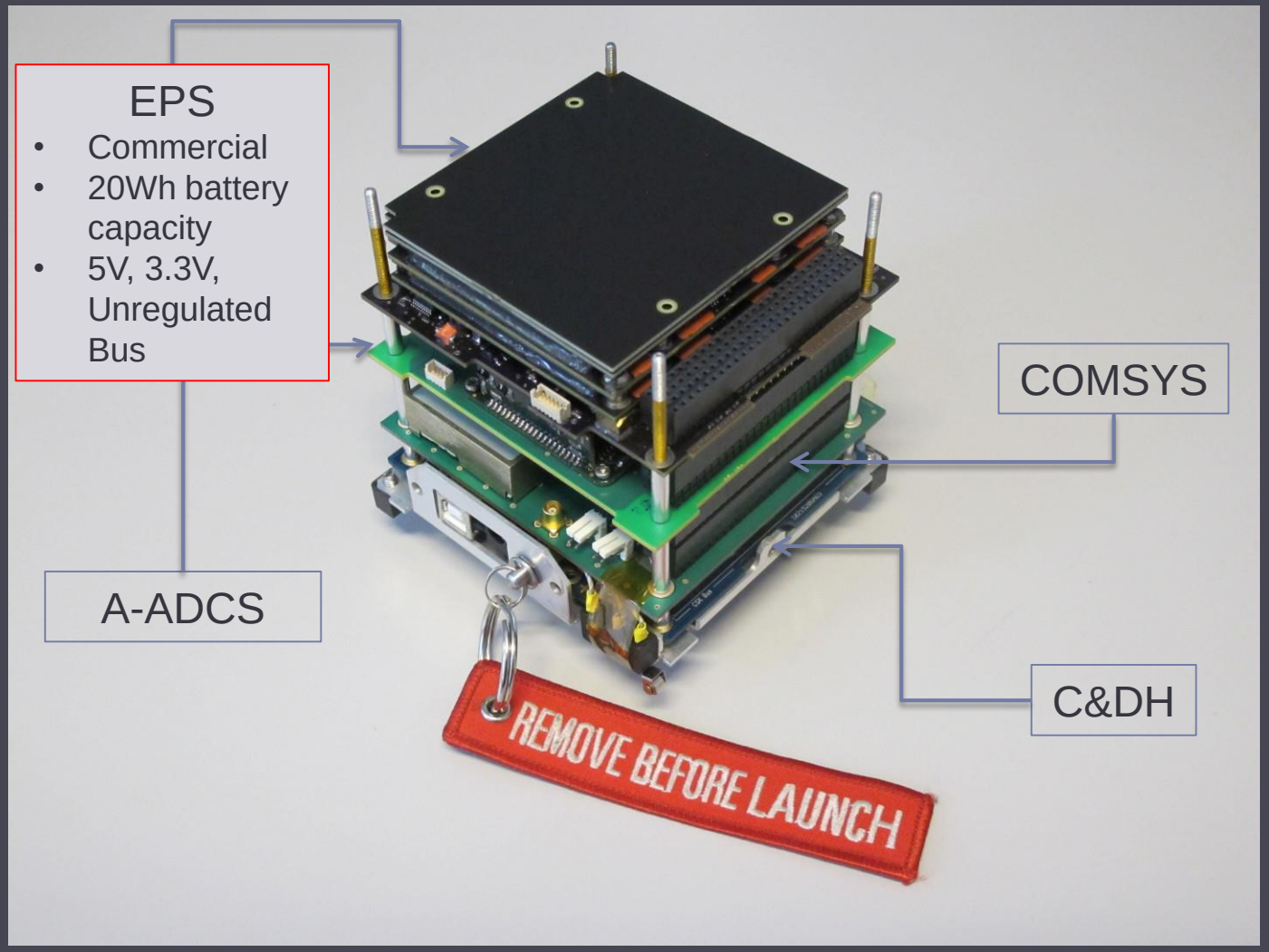

REMOVE BEFORE

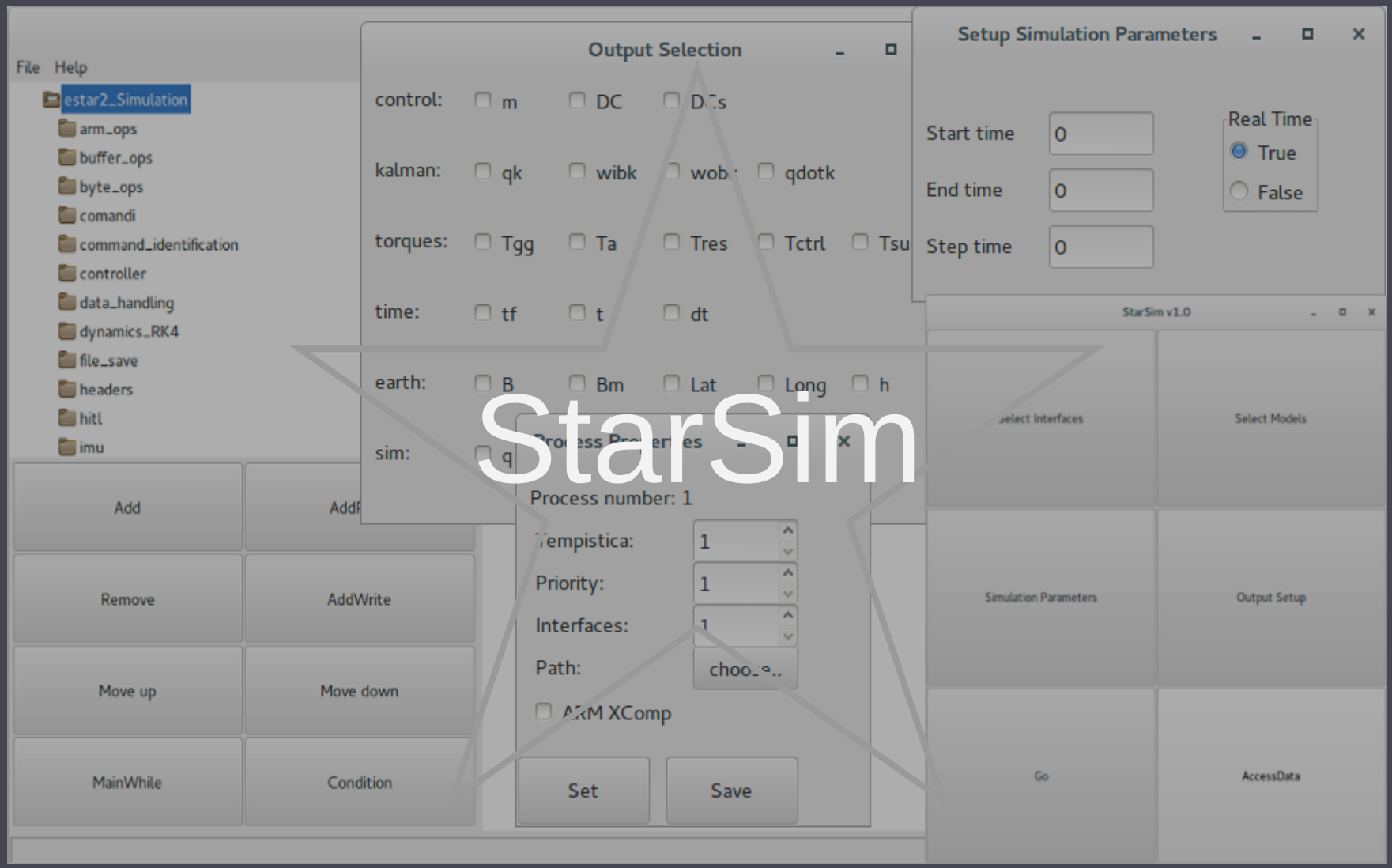

EPS
COMSYS
A-ADCS
C&DH
REMOVE BEFORE LAUNCH


EPS
COMSYS
C&DH
A-ADCS
• Payload
• In-house design
• 3 magnetic torquers
• ARM v7
• IMU with magnetometers
REMOVE BEFORE LAUNCH

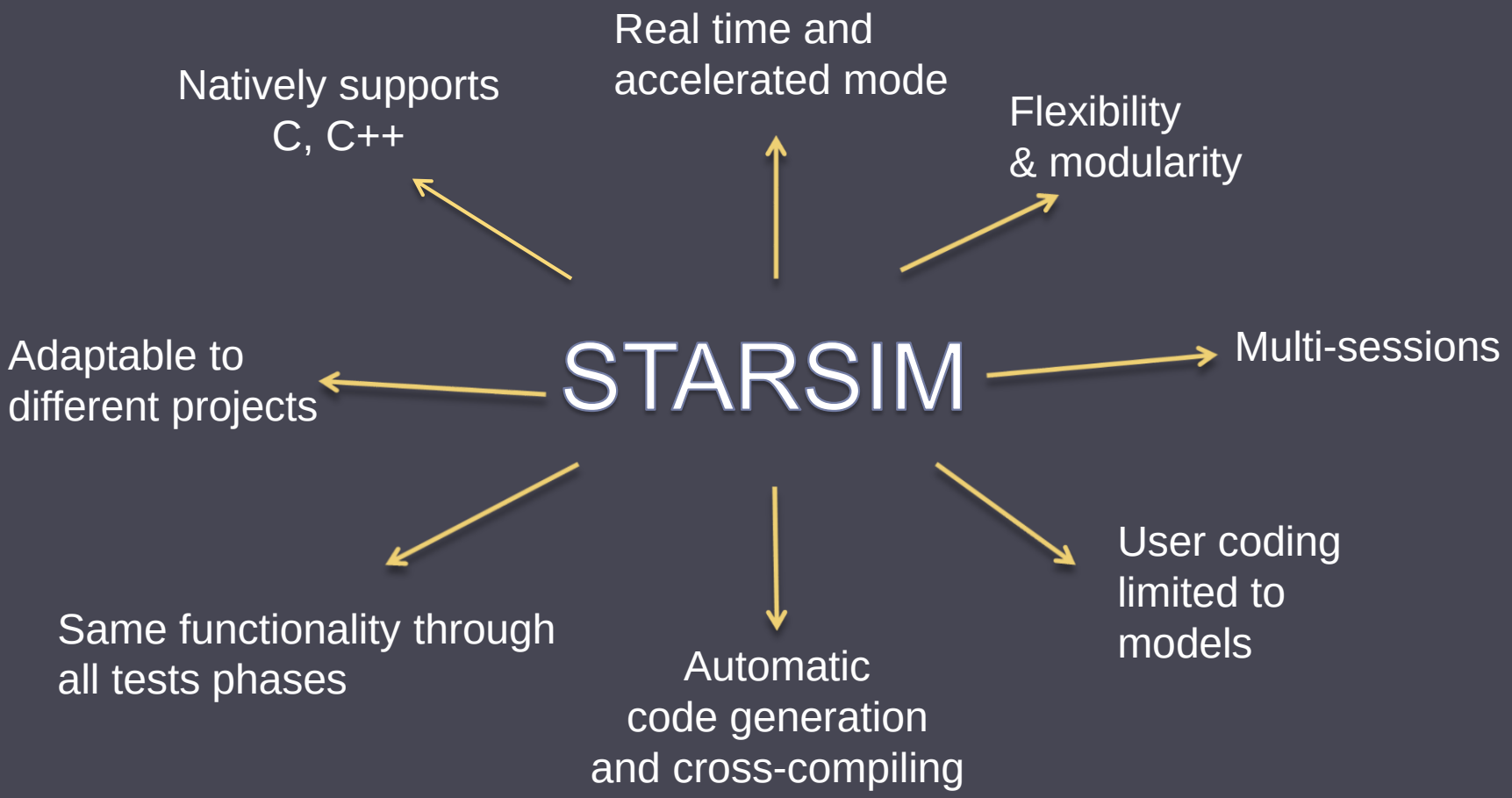

EPS
COMSYS
A-ADCS
C&DH
• Commercial
• MSP430
• Salvo RTOS
REMOVE BEFORE LAUNCH

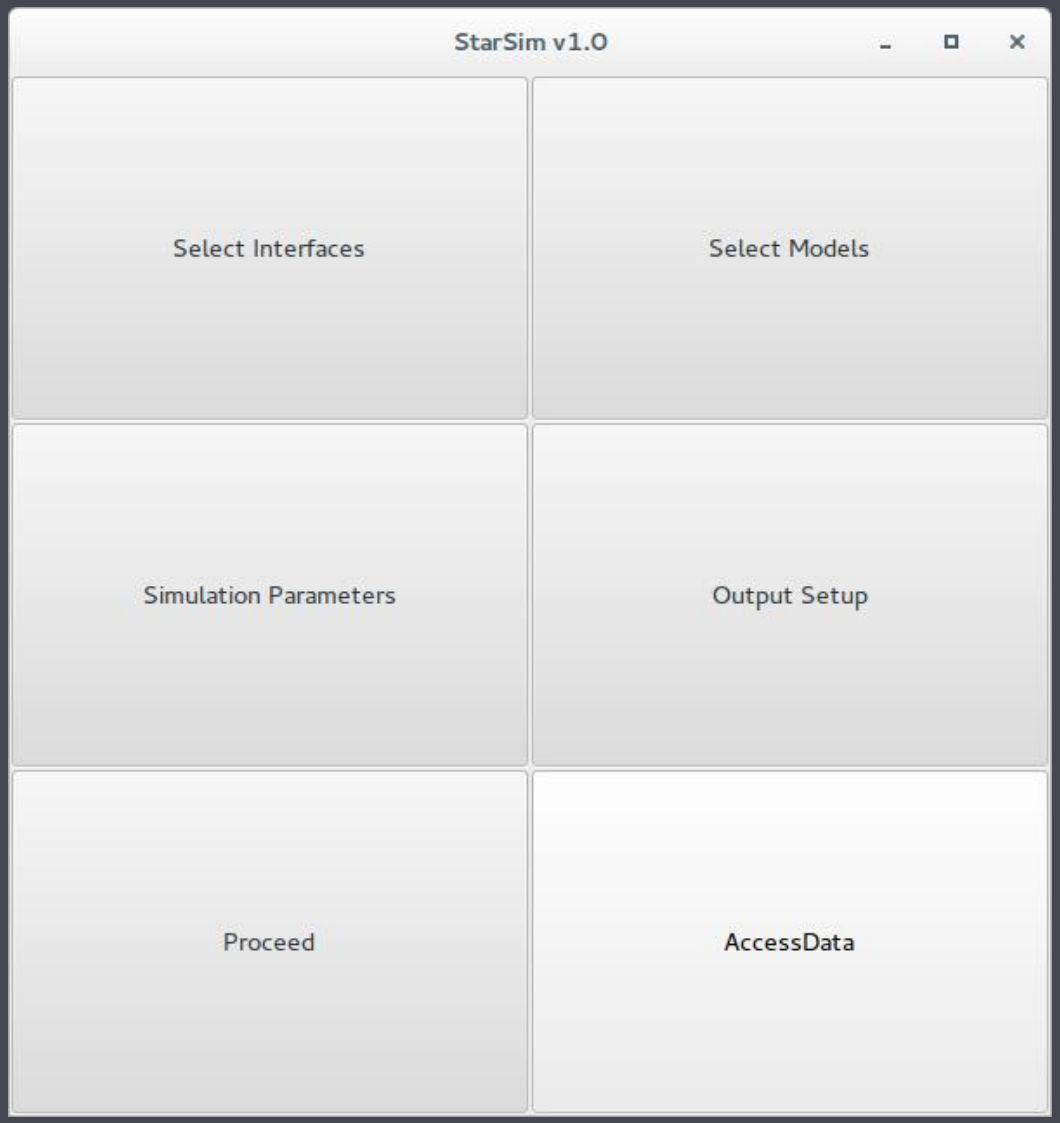

EPS
A-ADCS
C&DH
COMSYS
• In-house design
• 1200 bit/s data rate
• 437.485 MHz transmission
• CW in case of loss of C&DH
REMOVE BEFORE LAUNCH


EPS
• Commercial
• 20Wh battery capacity
• 5V, 3.3V, Unregulated Bus
COMSYS
A-ADCS
C&DH
REMOVE BEFORE LAUNCH


StarSim
Output Selection
Setup Simulation Parameters
File Help
estar2_Simulation
arm_ops
buffer_ops
byte_ops
comandi
command_identification
controller
data_handling
dynamics_RK4
file_save
headers
hitl
imu
control:
kalman:
torques:
time:
earth:
sim:
Start time
End time
Step time
Real Time
True
False
StarSim v1.0
Select Models
Simulation Parameters
Output Setup
Go
AccessData
Add
Remove
AddWrite
Move up
Move down
MainWhile
Condition
Process number: 1
Priority:
Interfaces:
Path:
Set
Save

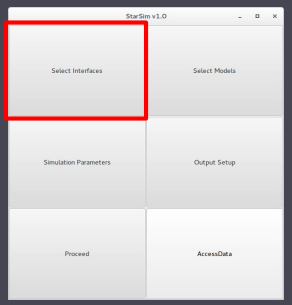
Need of a single “infrastructure” independent of the complexity of the test and from the development stage of the project

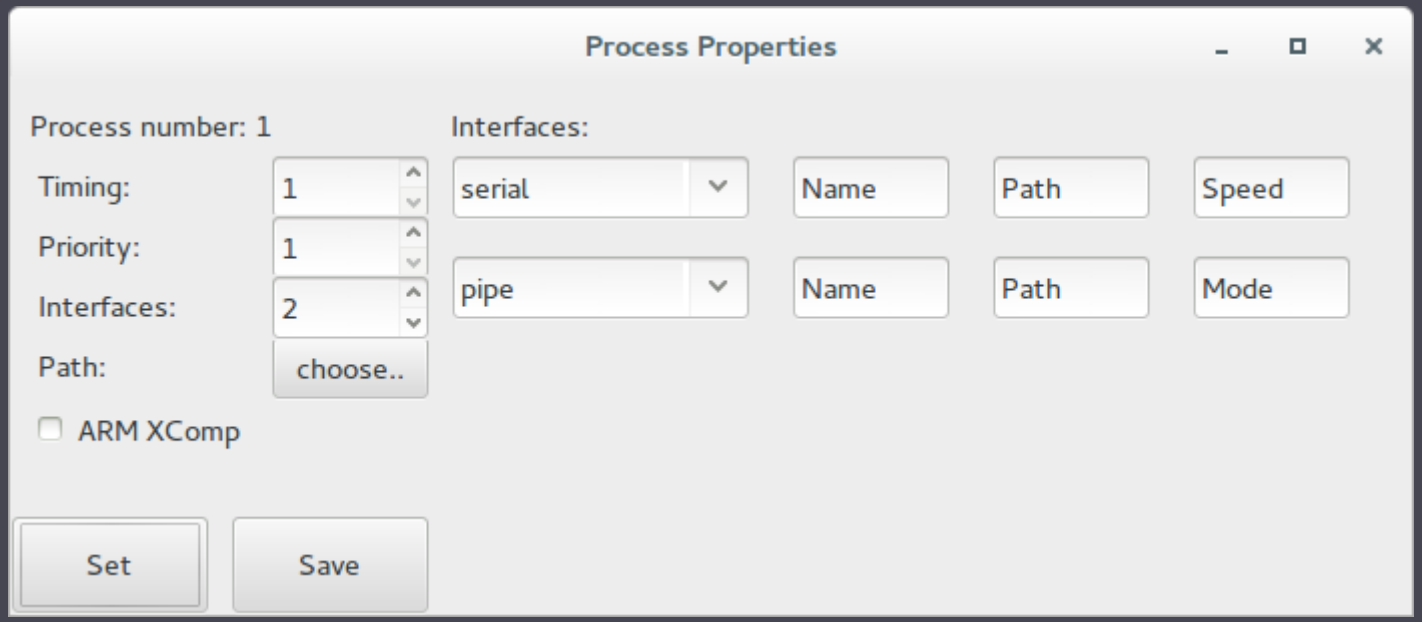



StarSim v1.0
Select Interfaces
Select Models
Simulation Parameters
Output Setup
Proceed
AccessData

Simulation properties setup

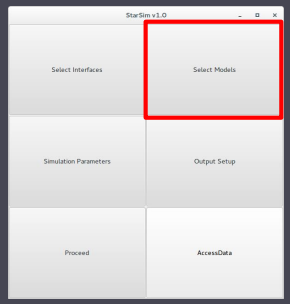
- Scheduling and priorities definition
- Interfaces for each process with connection parameters setup
- Cross-compile flag

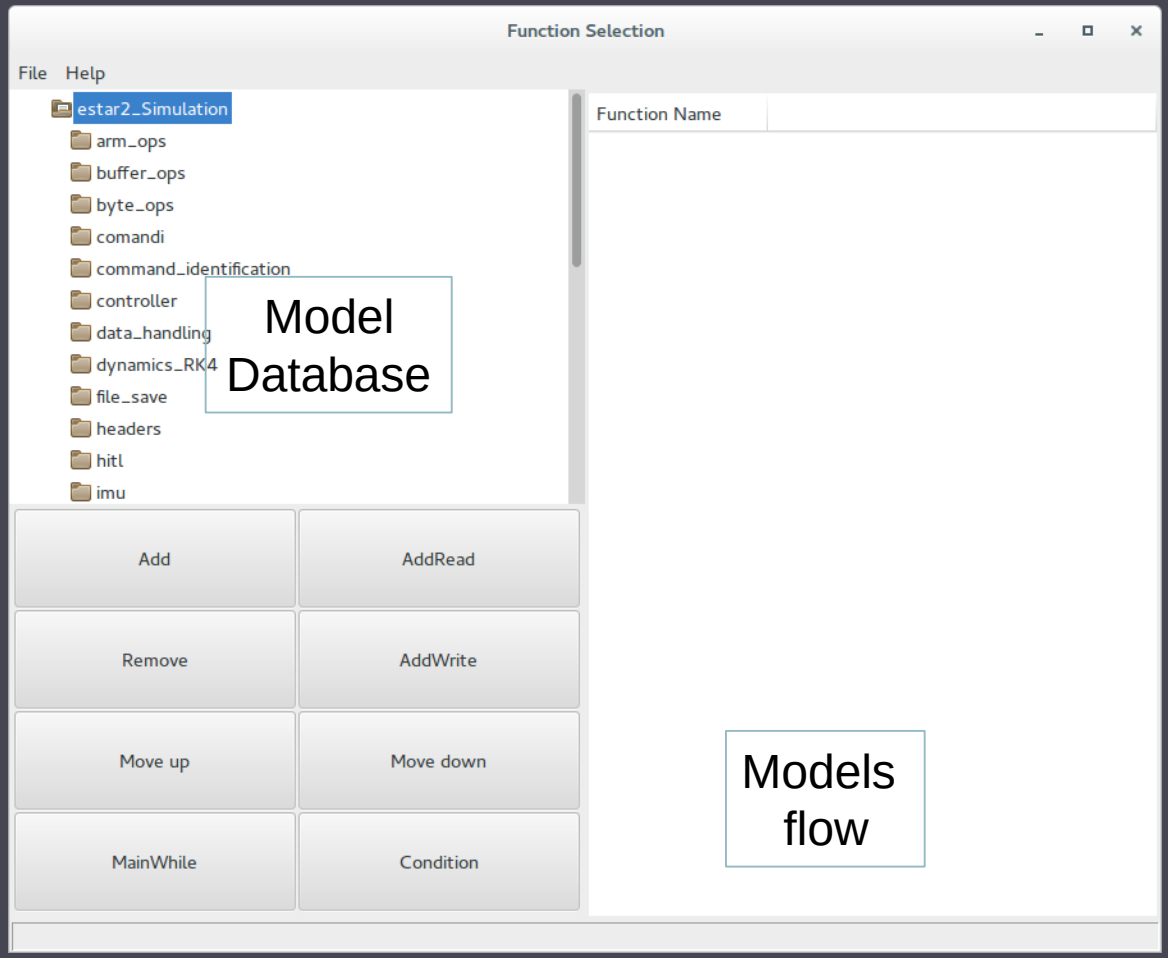


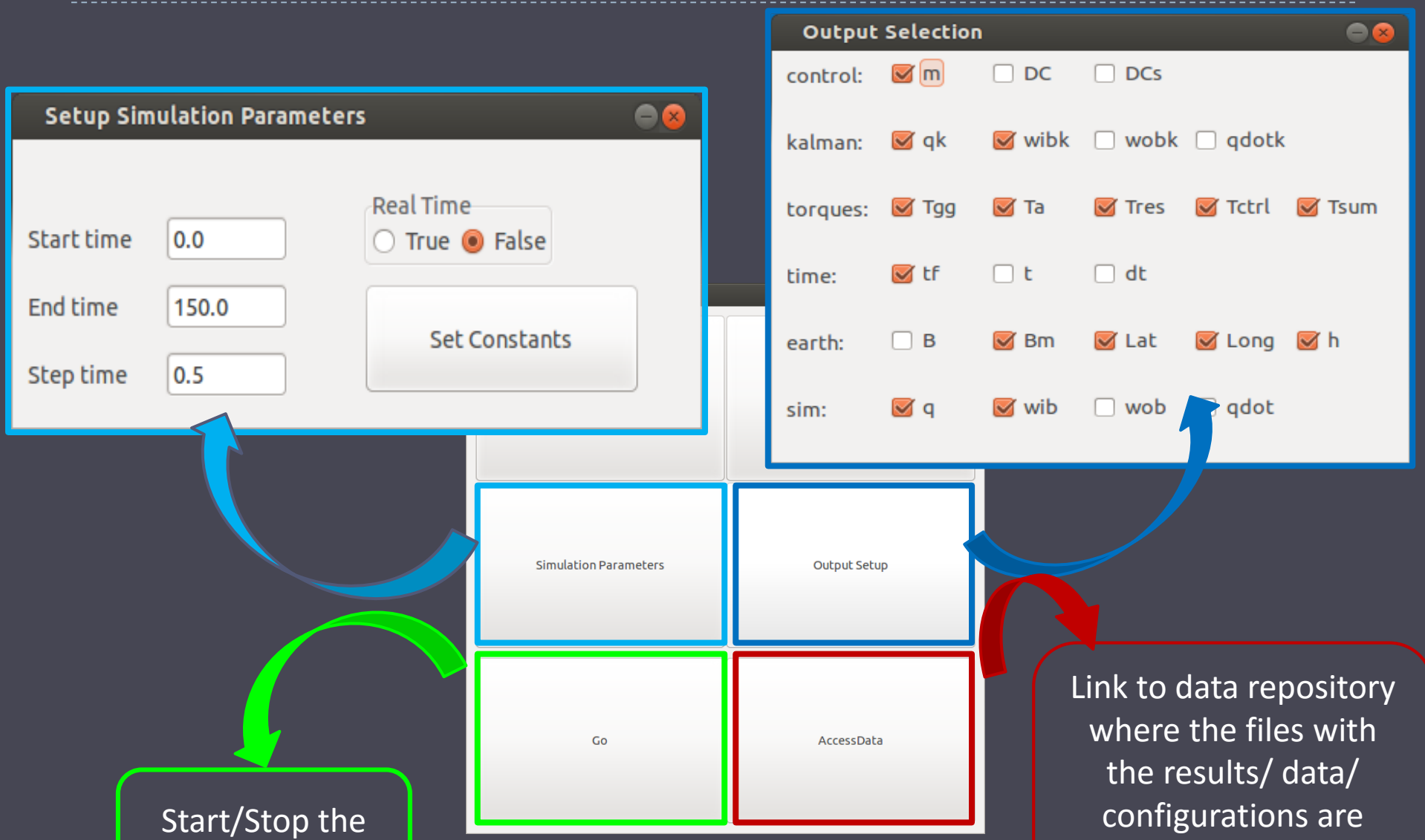


Simulation flow setup – model selection

- Database explorer
- Drag & drop action, or command buttons
- Simulation flow definition
- Open/Save functions

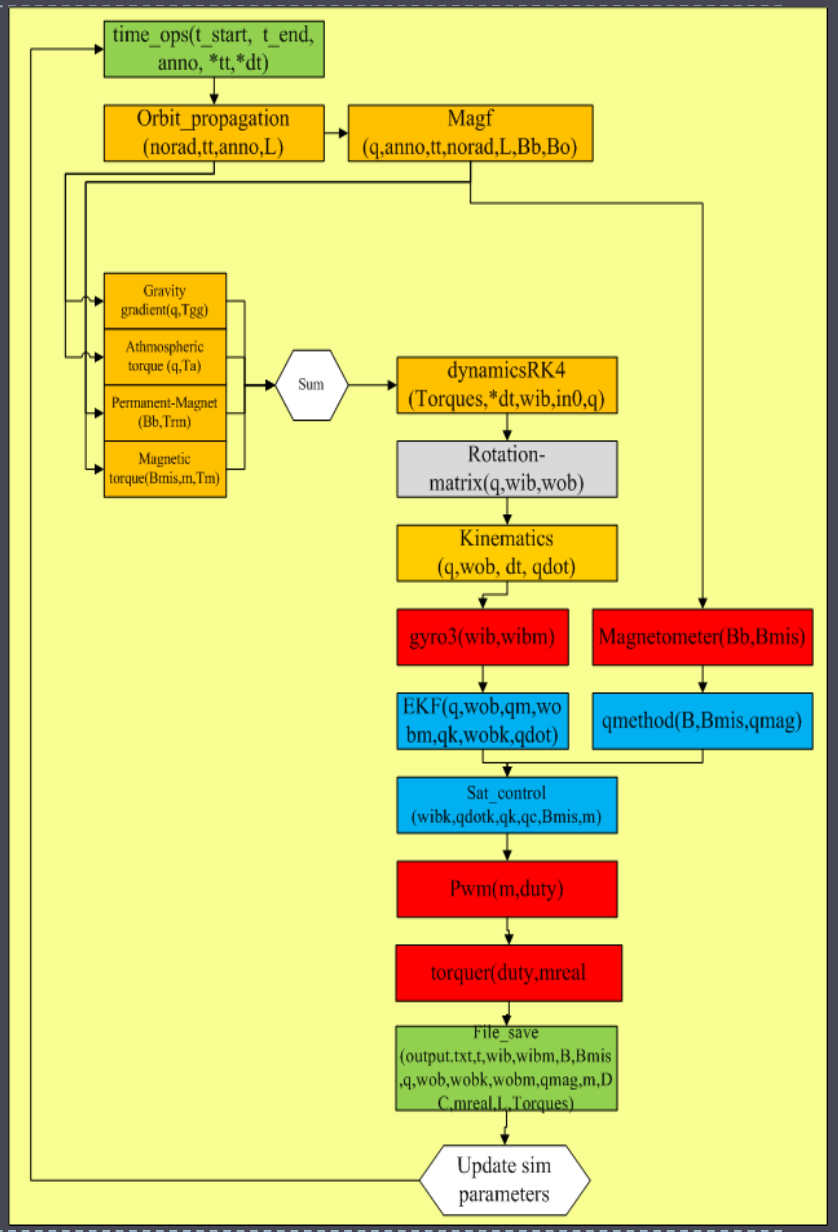





Output Selection
control: m DC DCs
kalman: qk wibk wobk qdotk
torques: Tgg Ta Tres Tctrl Tsum
time: tf t dt
earth: B Bm Lat Long h
sim: q wib wob qdot
Setup Simulation Parameters
Start time 0.0
End time 150.0
Step time 0.5
Real Time
True False
Set Constants
Simulation Parameters
Output Setup
Go
AccessData
Start/Stop the simulation
Link to data repository where the files with the results/ data/ configurations are saved

AIL simulations (ADCS)

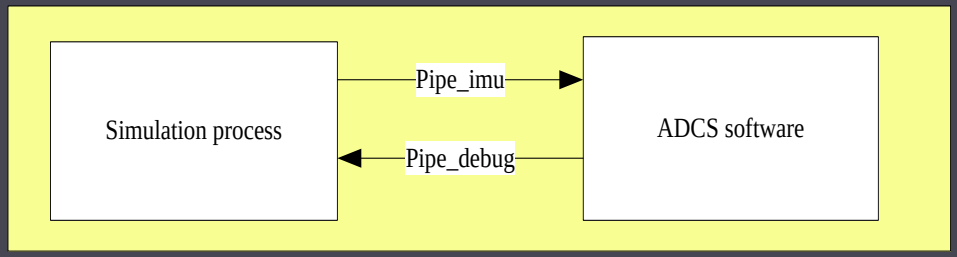
Simulation process

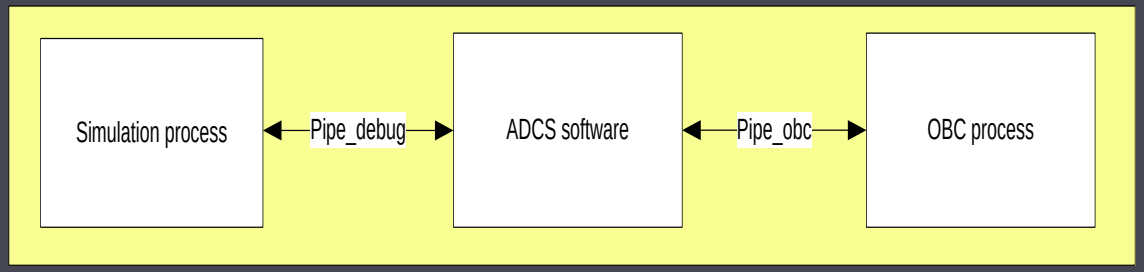


- Only one process runs on the Simulation Unit;
- Neither SW nor HW interfaces are required.

SIL simulations (ADCS)

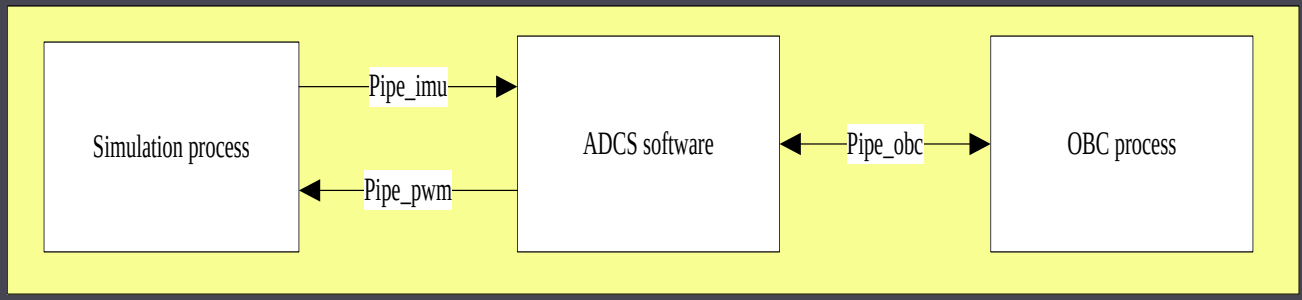
IMU communication
2 processes, 2 pipes



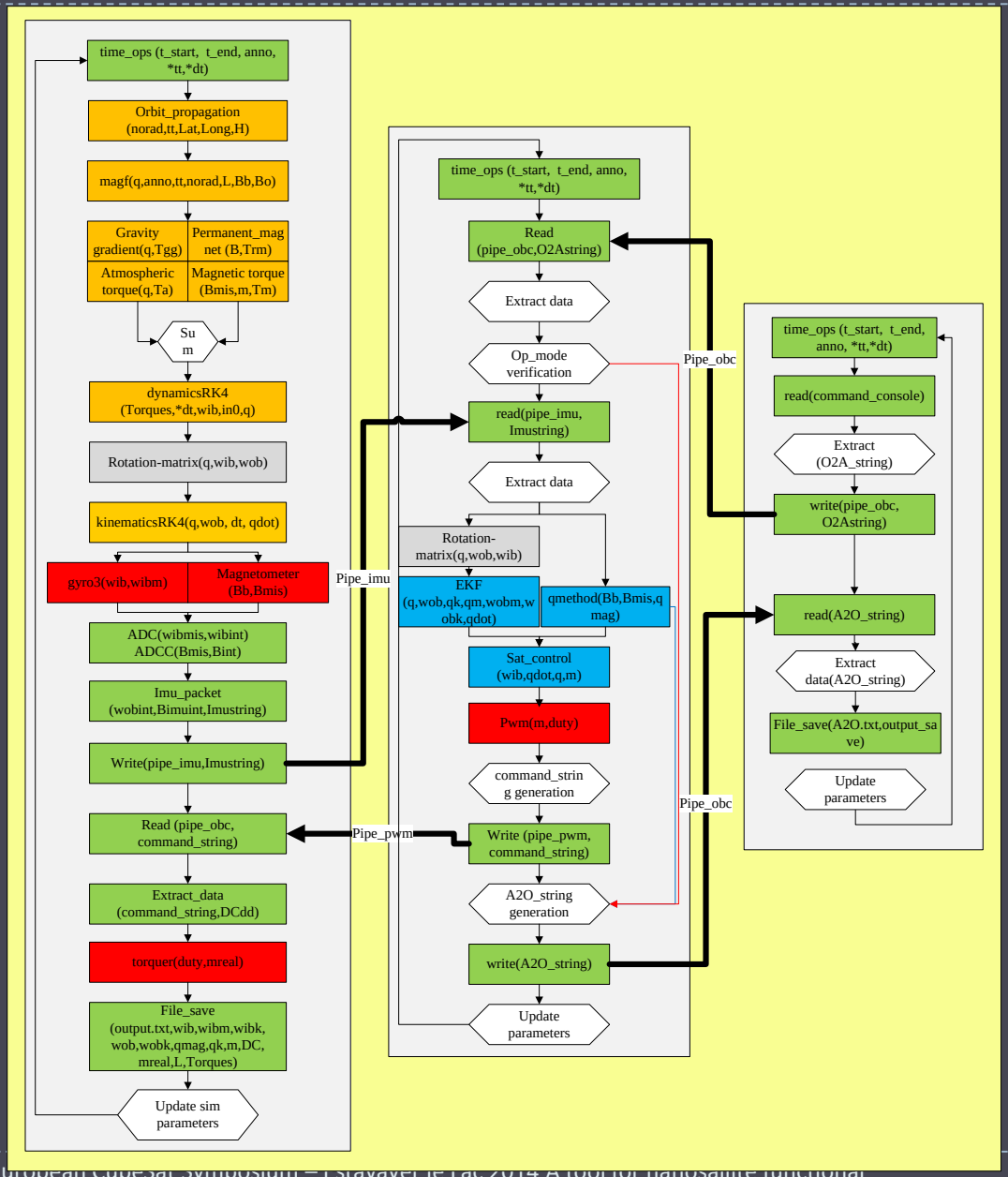


OBC/ADCS communication:
3 processes, 2 pipes

Integrated subsystem verification:
3 processes, 3 pipes

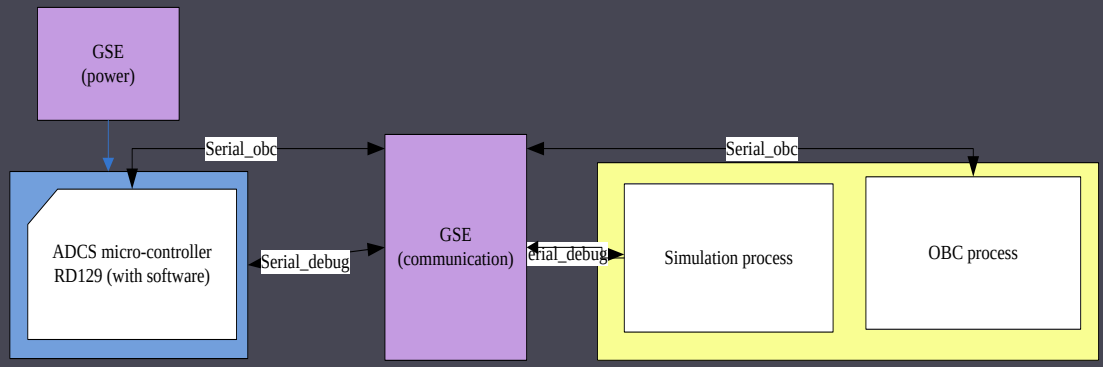


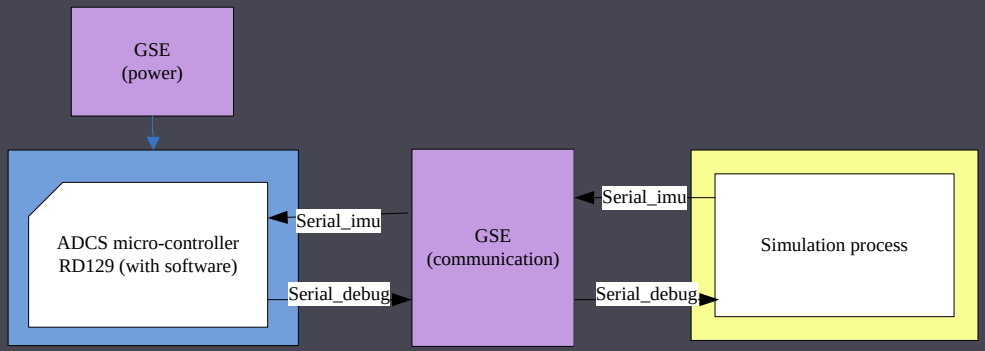
Simulation process



CIL simulations

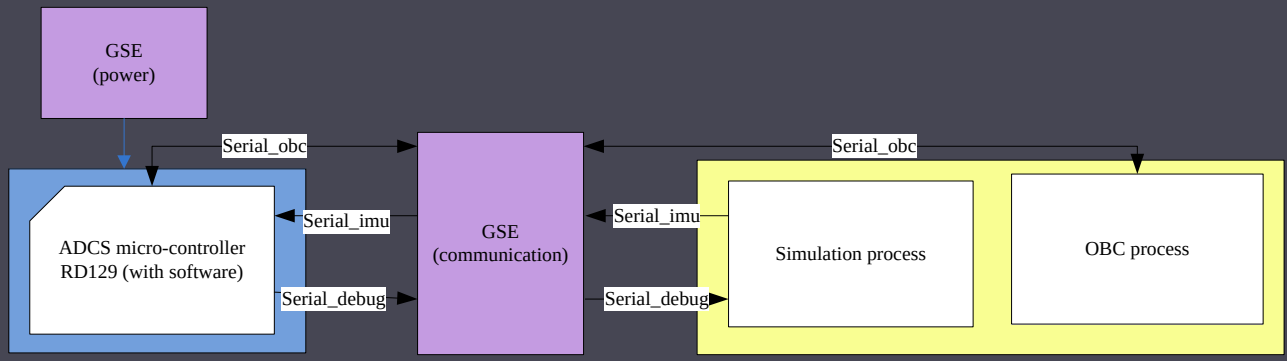
OBC/ADCS verification:
2 processes, 2 serial communications, 1 process on embedded system, 2 GSE

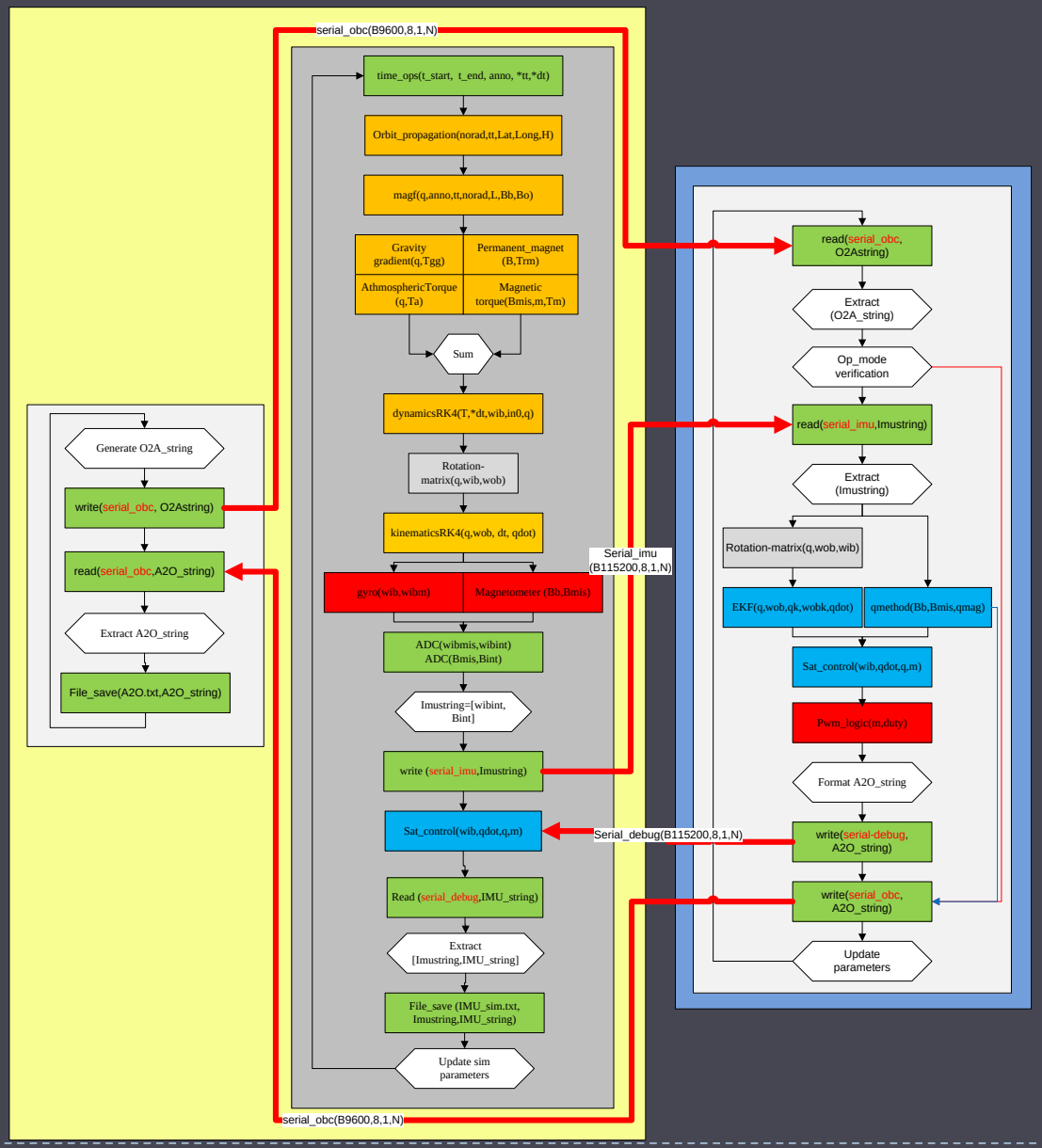


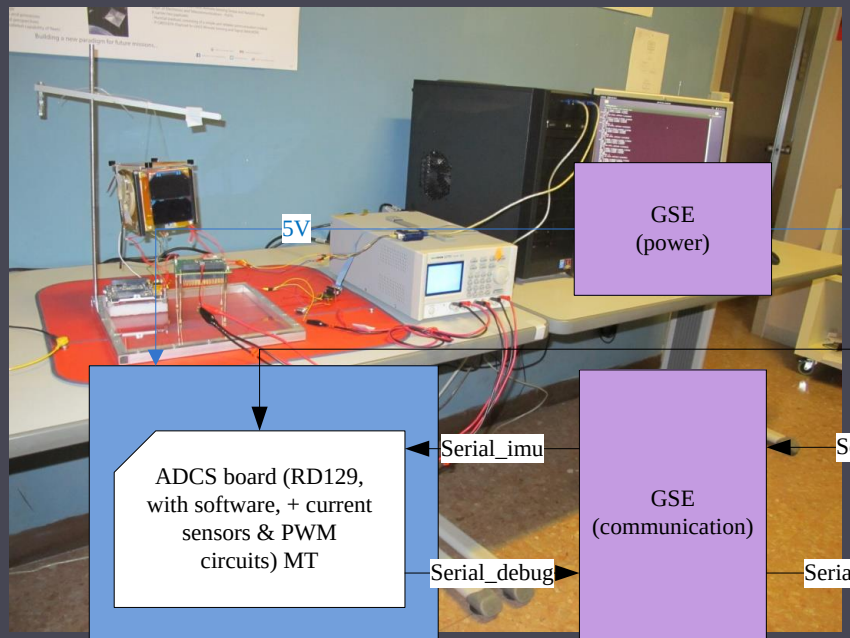


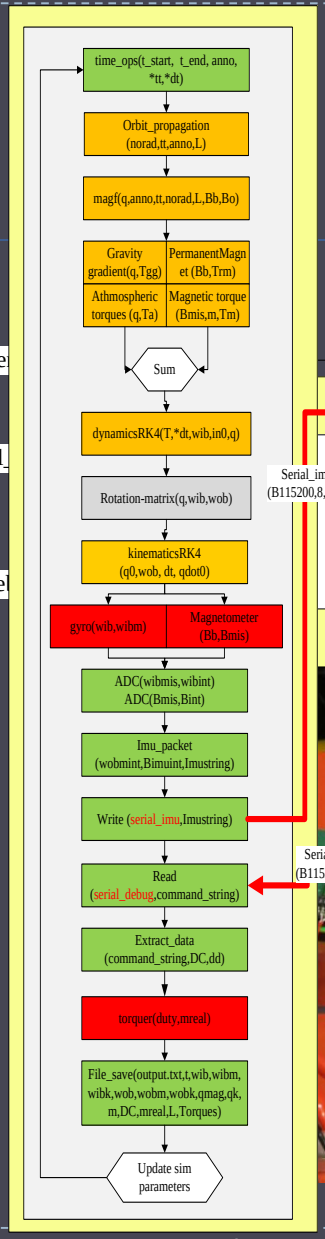
IMU communication verification:
1 process, 1 serial communication, 1 process on embedded system, 2 GSE

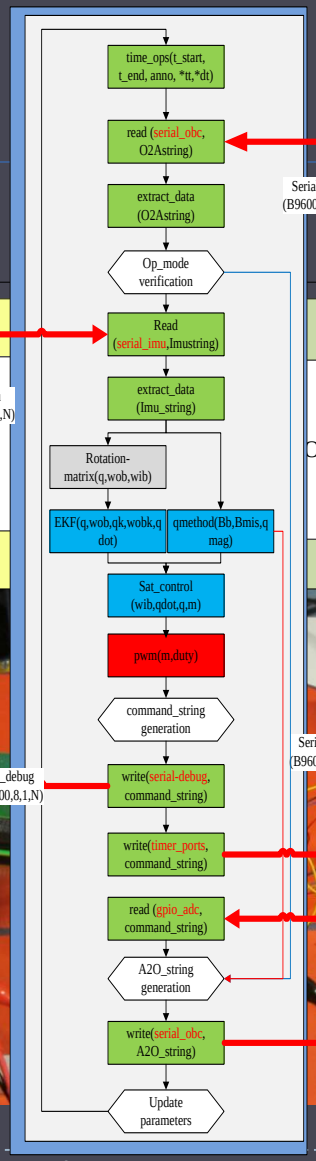
RT and synchronization verification:
2 processes, 3 serial communications, 1 process on embedded system, 2 GSE

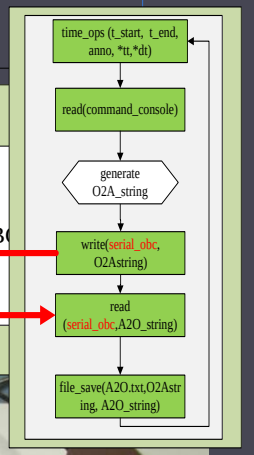


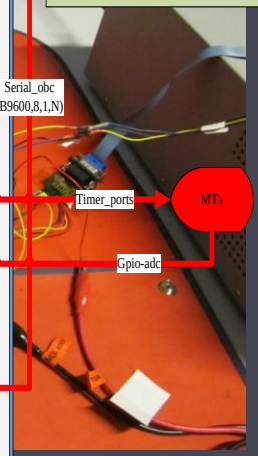

serial_obc(B9600,8,1,N)
time_ops(t_start, t_end, anno, *tt,*dt)
Orbit_propagation(norad,tt,Lat,Long,H)
magf(q,anno,tt,norad,L,Bb,Bo)
Gravity gradient(q,Tgg)
Permanent_magnet (B,Trm)
AthmosphericTorque (q,Ta)
Magnetic torque(Bmis,m,Tm)
Sum
dynamicsRK4(T,*dt,wib,in0,q)
Rotation-matrix(q,wib,wob)
kinematicsRK4(q,wob, dt, qdot)
gyro(wib,wibm)
Magnetometer (Bb,Bmis)
ADC(wibmis,wibint) ADC(Bmis,Bint)
Imustring=[wibint, Bint]
write (serial_imu,Imustring)
Sat_control(wib,qdot,q,m)
Read (serial_debug,IMU_string)
Extract [Imustring,IMU_string]
File_save (IMU_sim.txt, Imustring,IMU_string)
Update sim parameters
serial_obc(B9600,8,1,N)
Generate O2A_string
write(serial_obc, O2Astring)
read(serial_obc,A2O_string)
Extract A2O_string
File_save(A2O.txt,A2O_string)
Serial_imu (B115200,8,1,N)
Serial_debug(B115200,8,1,N)
read(serial_obc, O2Astring)
Extract (O2A_string)
Op_mode verification
read(serial_imu,Imustring)
Extract (Imustring)
Rotation-matrix(q,wob,wib)
EKF(q,wob,qk,wobk,qdot)
qmethod(Bb,Bmis,qmag)
Sat_control(wib,qdot,q,m)
Pwm_logic(m,duty)
Format A2O_string
write(serial-debug, A2O_string)
write(serial_obc, A2O_string)
Update parameters







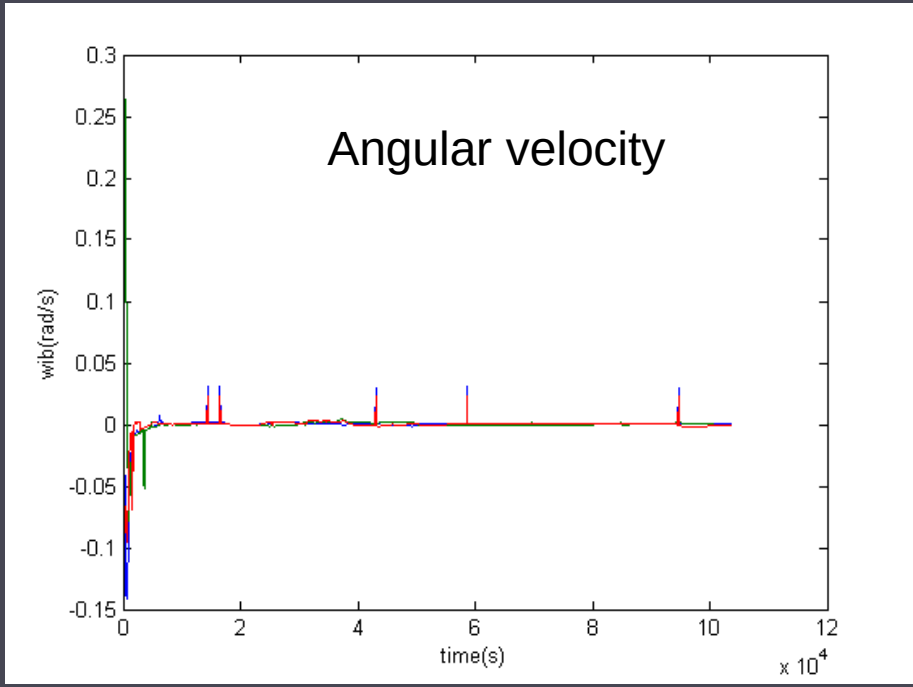


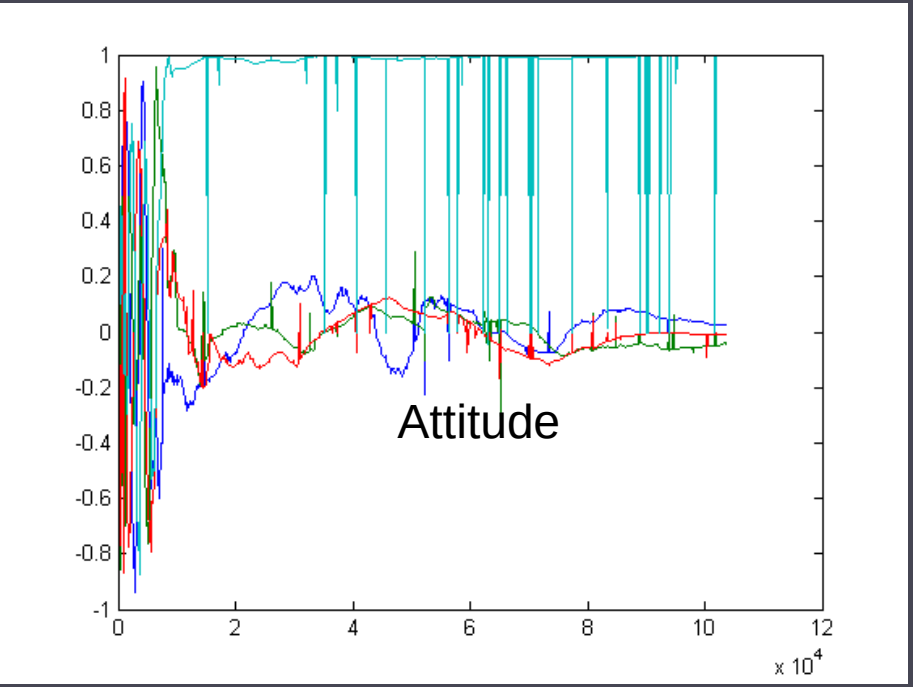


Serial_imu (B115200,8,1,N)
Serial_debug (B115200,8,1,N)
Serial_obc (B9600,8,1,N)
Serial_obc (B9600,8,1,N)
Timer_ports
Gpio-adc

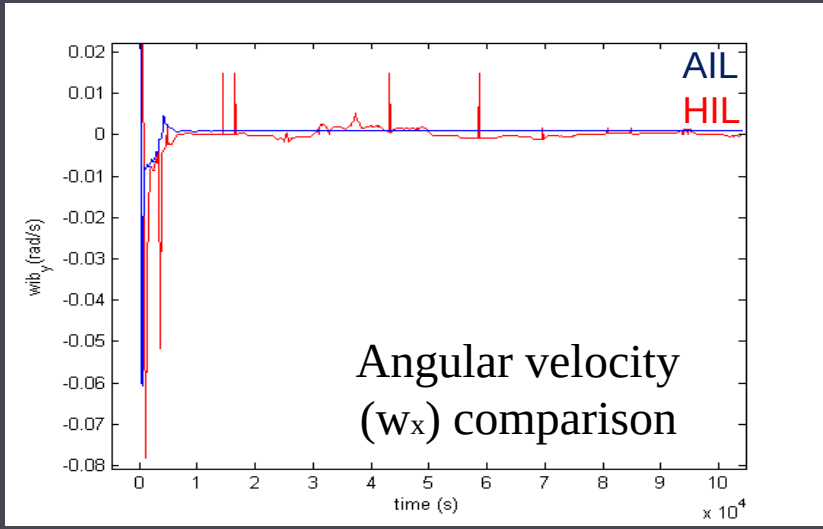
- Software in the Loop
  - No errors in IMU-ADCS board communications
  - No errors in OBC-ADCS communications
- Controller in the Loop
  - No packet is lost in ADCS-OBC but about 1.2% of packets are corrupted
  - No packet is lost in IMU-ADCS board communications but about 2% of packets are corrupted
- 3% of IMU packets are lost. No error arises after the data extraction, thanks to IMU sampling of high enough frequency

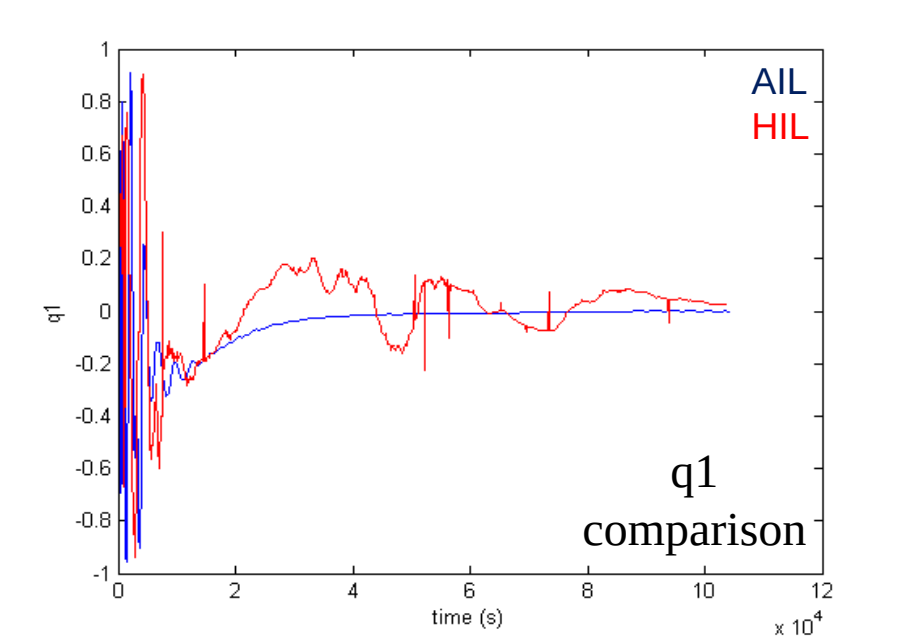
Controller in the Loop early results





Comparison HIL vs AIL

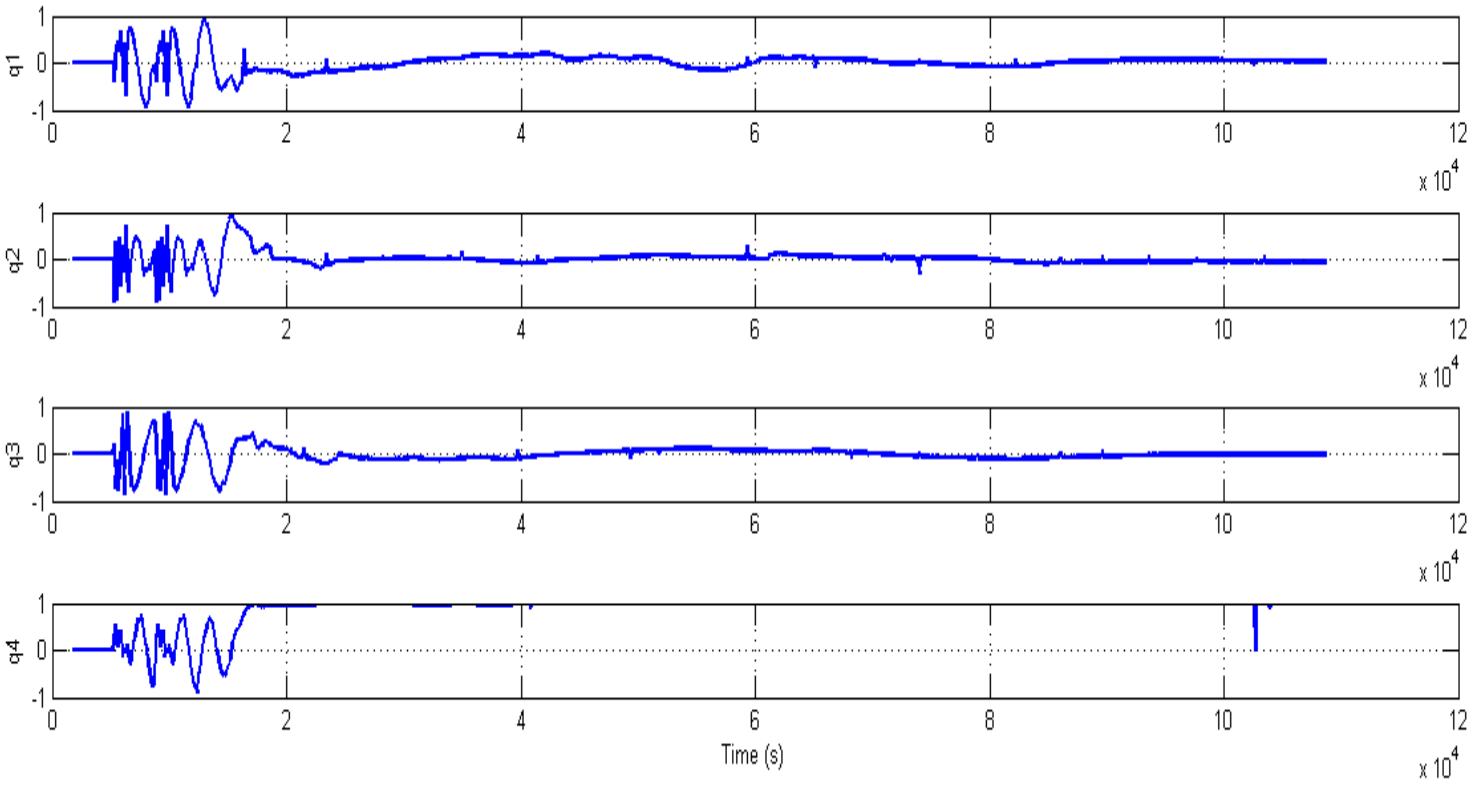




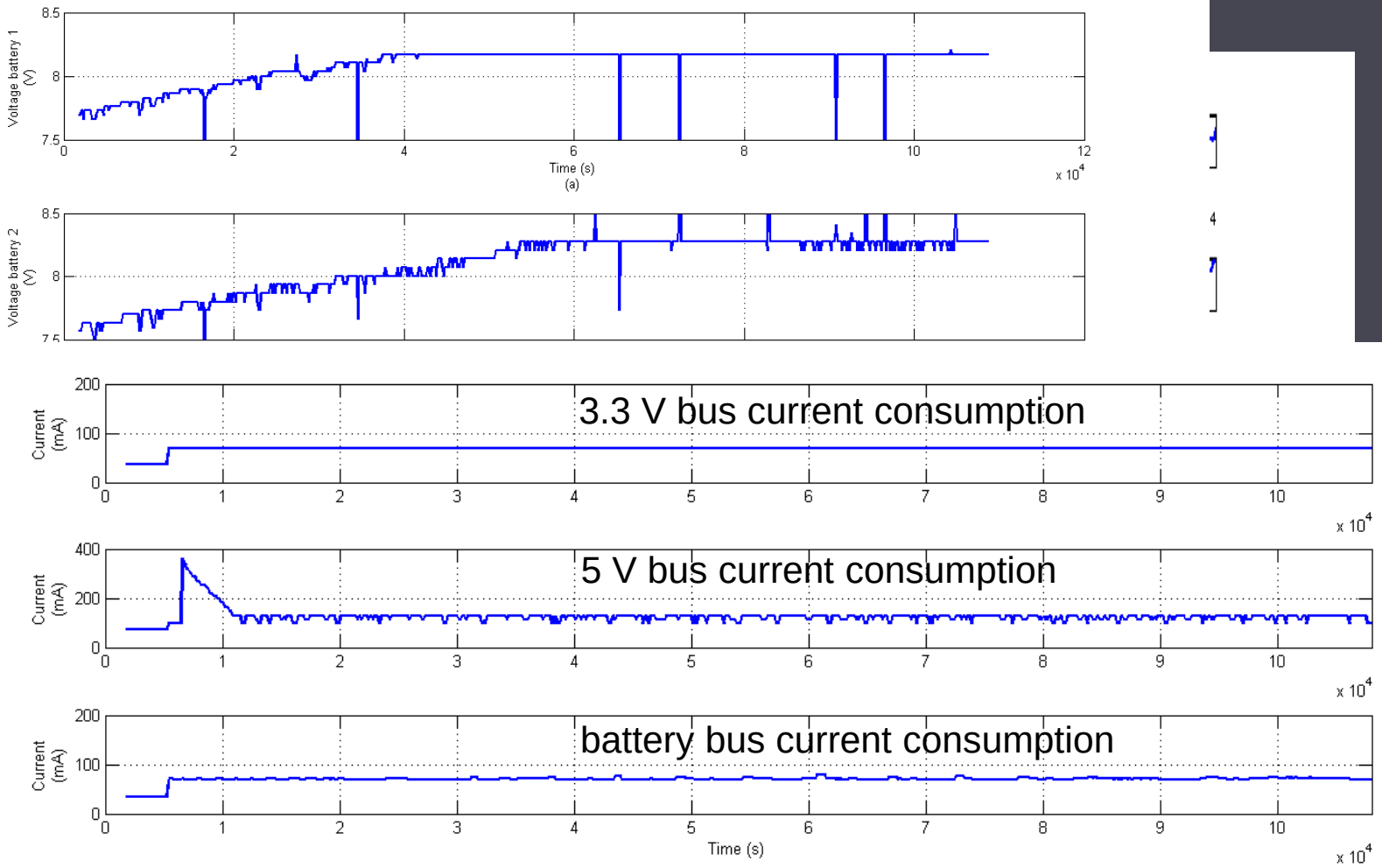
Power consumption for detumbling and acquisition phases:

- AIL: 1750 mW
- HIL: 2540 mW

HIL simulation for integrated system: results (I)



HIL simulation for integrated system: results (II)



THANK YOU FOR YOUR ATTENTION

QUESTIONS AND COMMENTS ARE WELCOME!

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