Application of CFS to a Lunar Rover:
Resource Prospector (RP)

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The Hunt for Lunar Volatiles

Clementine (1994):
Curious bi-static radar findings at the poles...
Water-ice?

Lunar Prospector (1998):
Shadowed craters contain elevated Hydrogen levels…
Water-ice?

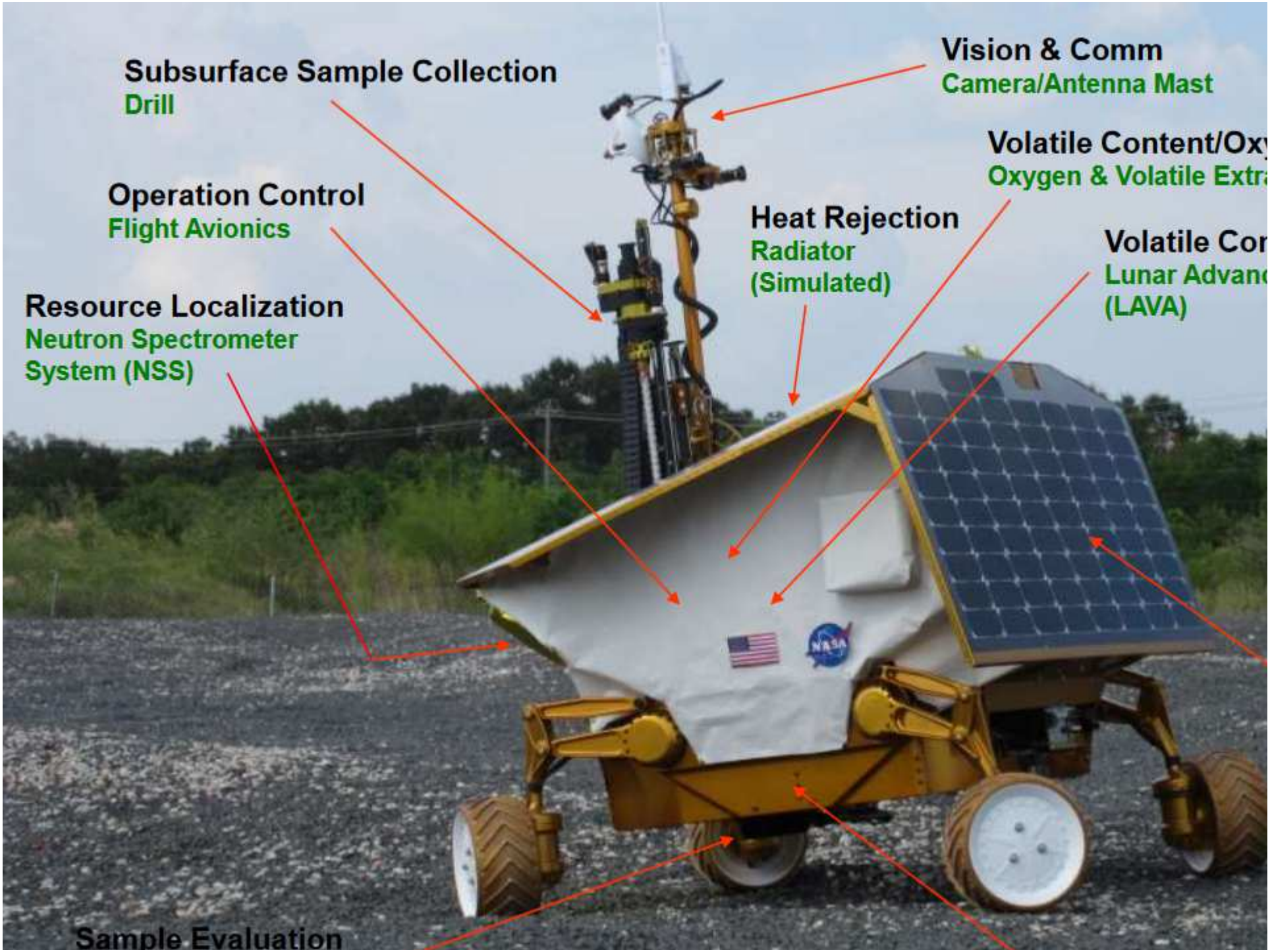
LCROSS/LRO (2009):
Yes! Water-ice. *How is it distributed?*

RP (2022):
Prospect for water-ice on human scales and demo ISRU processing

Resource Prospector

- Mission to Lunar Pole to search for and characterize the water ice
  - What form (eg. Snow or Ice lens?)
  - How much water is there?
  - How deep is it?
- Lunar Rover with:
  - Prospecting instruments to search for ice deposits
  - Drill to extract samples from the subsurface
  - Oven to bake the samples and scientific instruments to study its contents
- Developed and demonstrated a first prototype in 2015
- Currently scheduled to launch in 2022

RP Storyboard


Subsurface Sample Collection
Drill
Vision & Comm
Camera/Antenna Mast
Volatile Content/Oxy
Oxygen & Volatile Extra
Operation Control
Flight Avionics
Heat Rejection
Radiator
(Simulated)
Volatile Cor
Lunar Advanc
(LAVA)
Resource Localization
Neutron Spectrometer
System (NSS)
Sample Evaluation

RP15 Distributed Operations Test testing

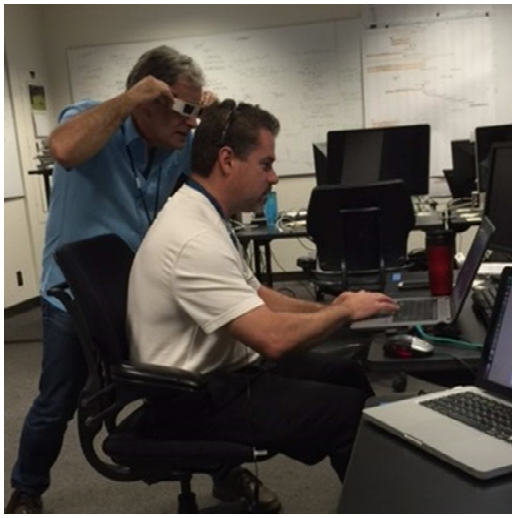
2015-08-21

NASA-ARC Mission Control room driving RP15 rover

RP15 rover @ NASA-JSC Rock Yard

NASA-KSC Payload Control room

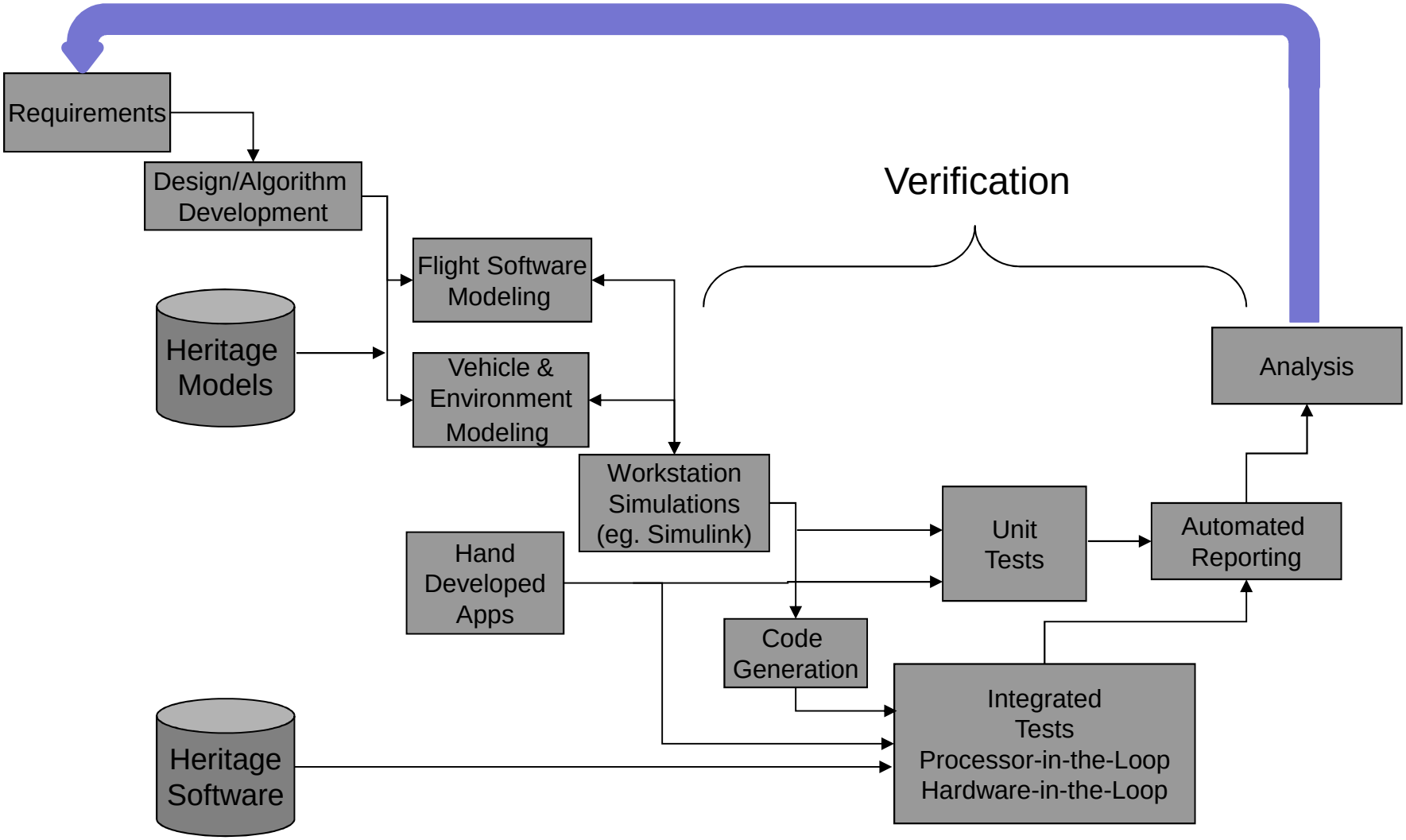
NIRVSS Payload Operations



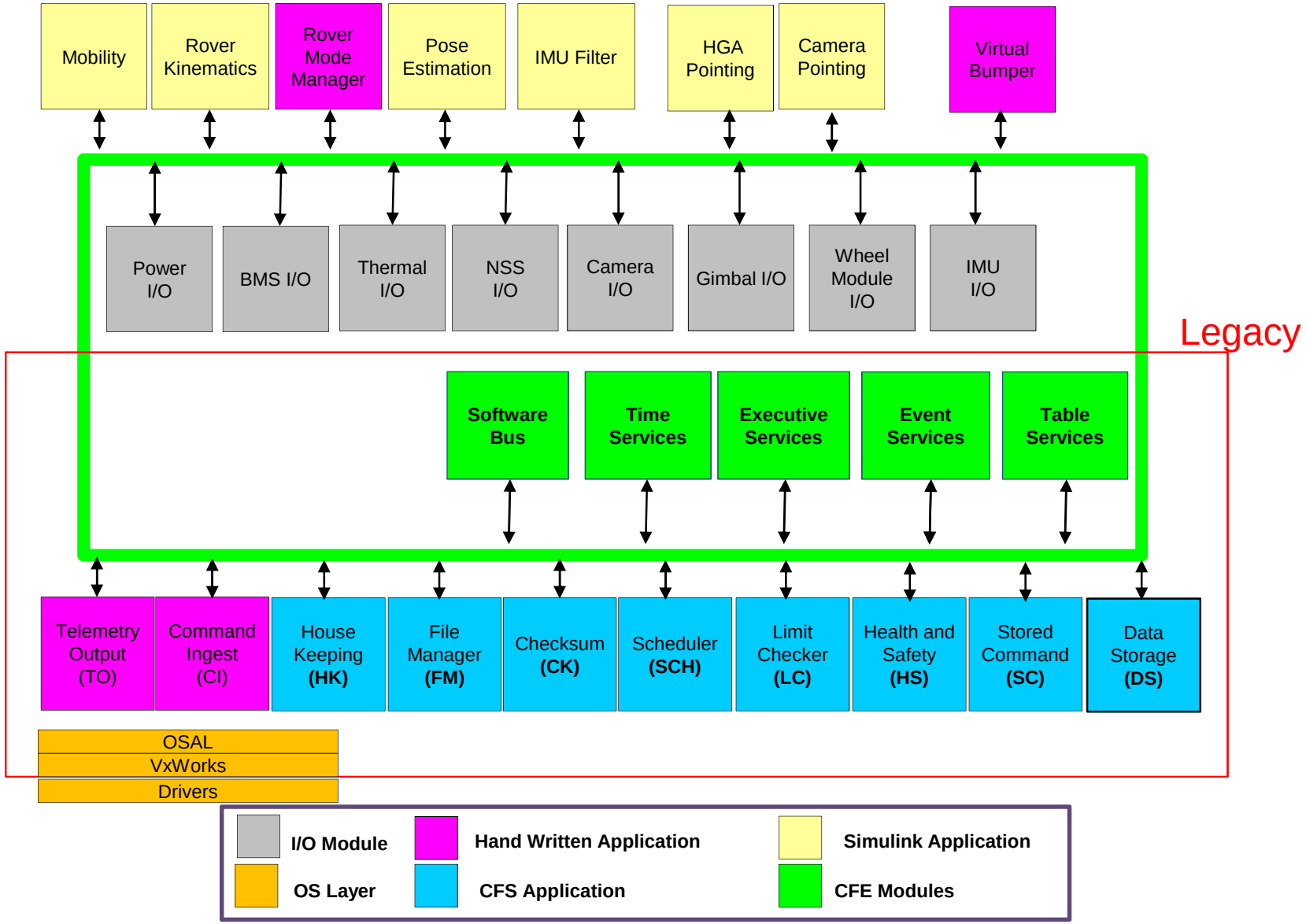
Software Process

- Guiding documents:
  - NASA Software Engineering Handbook
  - 7150.2B NASA Software Engineering Requirements
  - NASA-STD-8739.8 NASA Software Assurance Standard
  - APR8070.2 Class D Spacecraft Design & Environmental Test
- Processes based on LADEE experience
  - Incremental Development Process
  - FSW Model based development technique
- Leverage Heritage Software
  - VxWorks, CFE/CFS, & LADEE C&DH Software
  - JSC Rover Control Software
  - Ames Rover Software (VERVE, Mapping, Path Planning, Hazard Detection, etc).
- Incremental Development:
  - 6 Builds, 2 releases
    - Each build has “theme of development” for focusing activities
    - First release fully functional – occurs prior to start of Rover I&T
    - Second release for bug fixes and late changes to requirements – occurs during Rover I&T
  - Test Early, Test Often

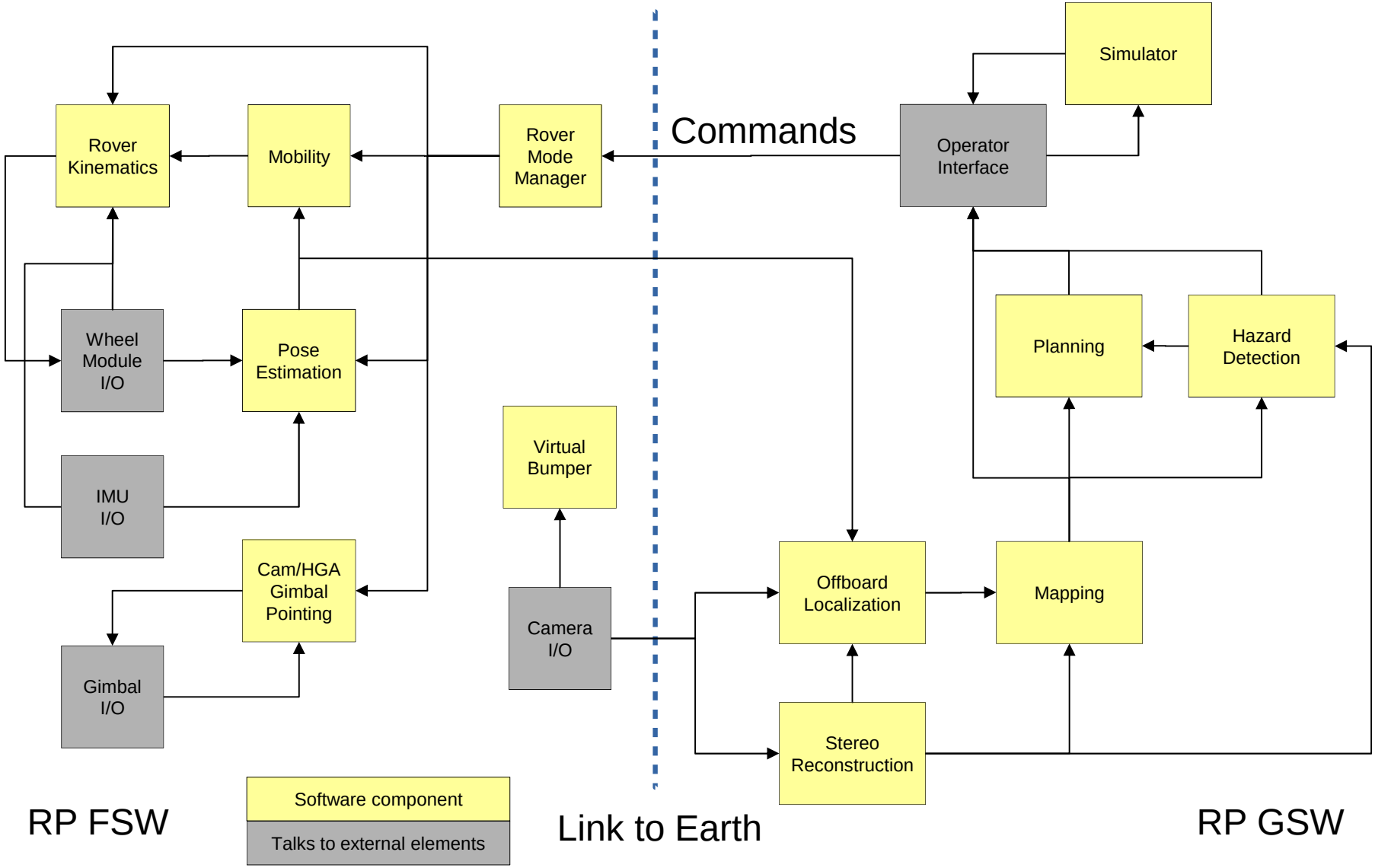
RFSW Model Based Development



RFSW Modules



Rover Software Operation



Results

- RP15 mission in a year met all objectives
  - Rover (and Software) developed on time and within cost constraints
  - Successful demonstration of remote operations
  - Demonstrated effective use of heritage software (CFE/CFS, JSC Controls) and processes (LADEE).
    - CFE/CFS architecture did not impose significant limitations
      - Distributed control system allowed reasonable control loop frequencies
      - Event based sequences not necessary with human-in-the-loop decision making and limited autonomy
      - Limit Checker sufficient for “phone home” fault management approach

Future Software Challenges

- Impact of limited visibility, shadows, and occlusions
  - Stereo and Localization studies using Lunar Lab Environment
- Communication Delays and Limited Bandwidth
  - Studying impact of onboard compression algorithms
- Impact of Excessive Slip and Embedding
  - Ongoing analysis and testing
- Multi-path effects and potential loss of Comm
  - Fault Management discussions ongoing
- How to drive effectively given constraints
  - Development of high fidelity driving conops simulator