Astrobee

A free-flying robot for the International Space Station

Terry Fong

Intelligent Robotics Group
NASA Ames Research Center

terry.fong@nasa.gov

Robots for Human Exploration

Motivation

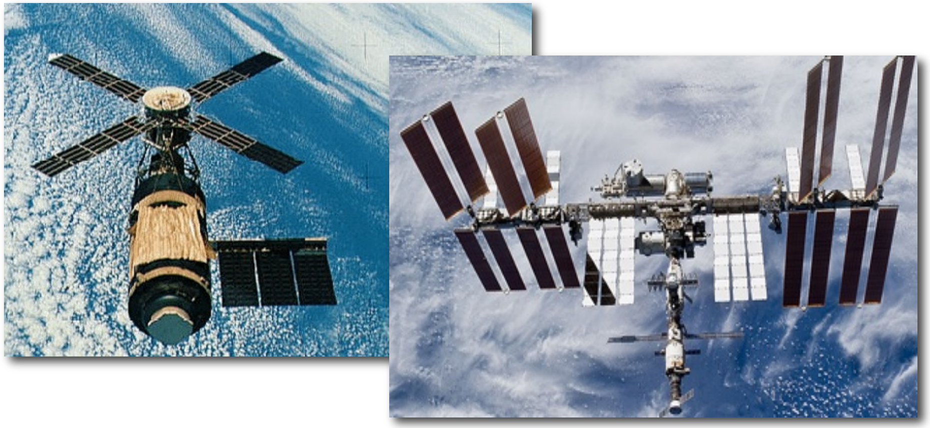
- Help **maintain** human spacecraft
- **Enhance** crew productivity
- Perform work **before**, in **support**, and **after** humans

In-Flight Maintenance (IFM)

- Must perform IFM to keep spacecraft in a safe and habitable configuration
- Many IFM tasks are tedious, time-consuming, repetitive & routine
- Many IVA/EVA tasks cannot be done using only fixed sensors / actuators

Unmanned mission phases

- Setup spacecraft prior to human arrival (e.g., Mars exploration)
- Contingency situations (maintain vehicle when humans have to leave)



IN-FLIGHT MAINTENANCE TASKS

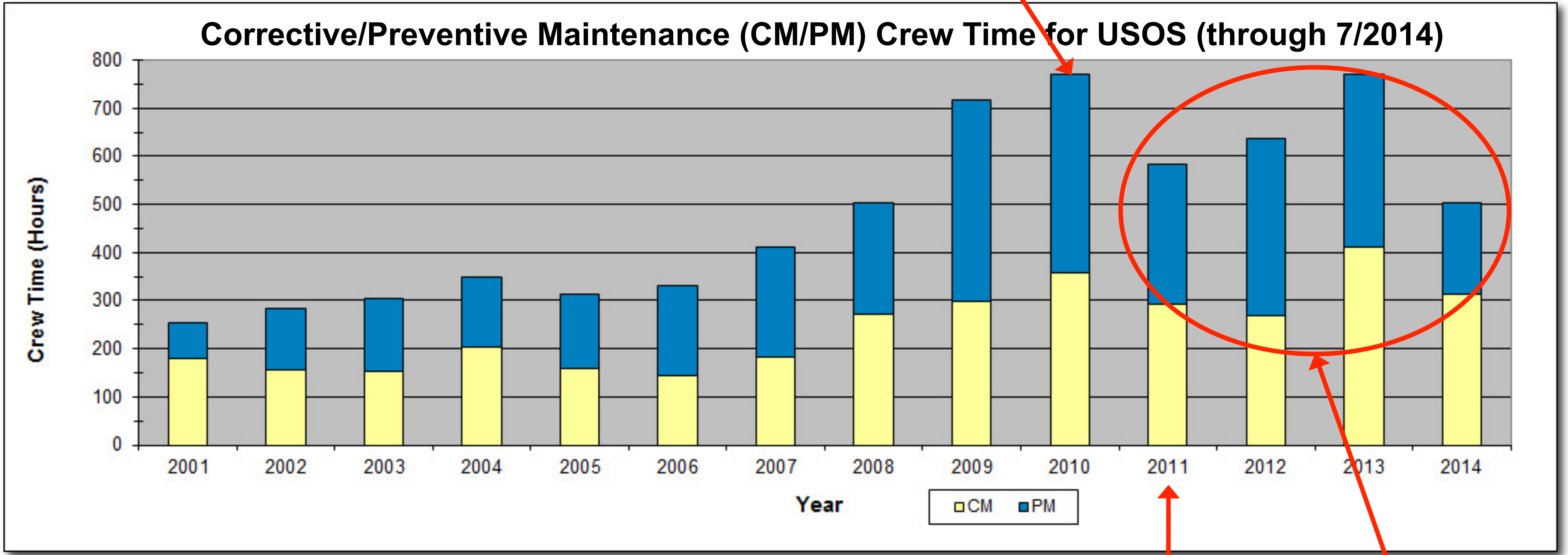
Inspect & monitor
- Provide mobile camera views
- Routine surveys and inventory
- Check payload status / health

Routine maintenance
- Change air/water filters
- Perform water draw/input on ECLSS
- Payload adjustment & trouble shooting

Contingency response
- Assess environment after fire event
- Assess & repair Leaks/MMOD damage
- Power cycle/reboot electrical equipment
- Actuate mechanisms (hatches, valves, etc.)

ISS In-Flight Maintenance Statistics

770 hours
= 2 hr/day avg.
$50M+ crew-time



Final Assembly

Preventive Maint.
330 hr/yr avg.

Source: ISS On-orbit Logistics Supportability Assessment Report, Aug 2014

ISS In-Flight Maintenance

Extra-Vehicular Activity (EVA)

- Not enough crew time to do everything (only 1 EVA per year)
- Crew must always carry out "Big 12" contingency EVA's
  - Maintain electrical power system
  - Maintain thermal control system
- Worksite prep & tear down requires 2-3 hr per EVA

Intra-Vehicular Activity (IVA)

- Crew spends **a lot** of IVA time on maintenance (40+ hr/month)
- Routine surveys require 12+ hr/month
  - Air quality, lighting, sound level, video safety, etc.
- Crew must always carry out contingency IVA surveys
  - Find and repair leaks, combustibles, etc.

Repetitive and Routine IVA Tasks on ISS

Camera positioning

- Many cameras are used for IVA work
- Crew has to manually reposition video cameras monitored by mission control
- Camera are essential for many tasks
  - Safety surveys
  - Equipment and payload inspections
  - Crew "over the shoulder" views during IVA activities

Logistics

- Crew must locate equipment and materials needed for IVA work
  - Crew spends **up to 1 hr per day** manually searching for items
  - **6,000+ "lost" items in ISS Inventory**
- Automated logistics is a key HEOMD priority for ISS and future missions

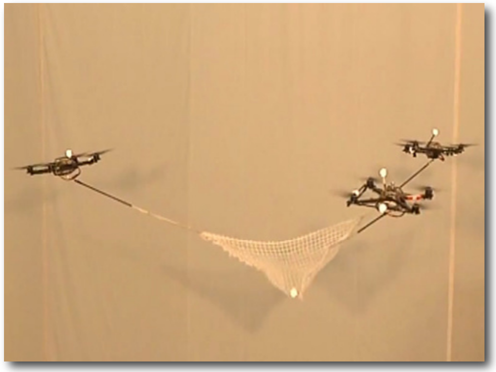
Assistive Free-Flyer (AFF)

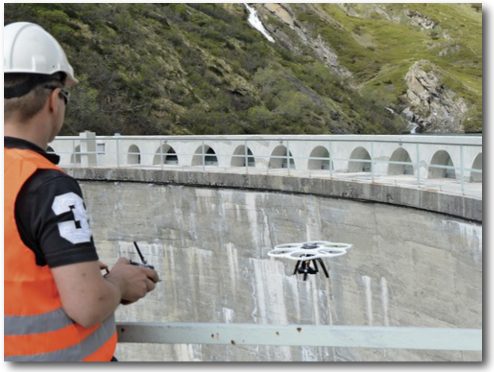
What are AFF's?

- Small free-flying robots that assist humans *(Szafir, Mutlu, & Fong 2013)*
- AFF's perform exploration, surveillance, inspection, mapping, transport, etc.
- AFF's are often co-located with human and operate in human environments

Key design issues

- Autonomy
- Ecological fit
- Human-robot interaction
- Morphology
- Navigation
- etc.





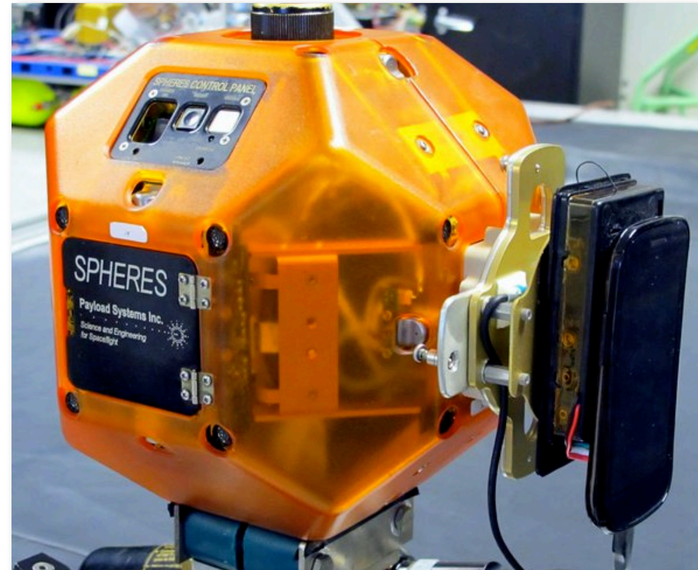
Smart SPHERES (2011 - 2014)

Mobility: SPHERES satellite

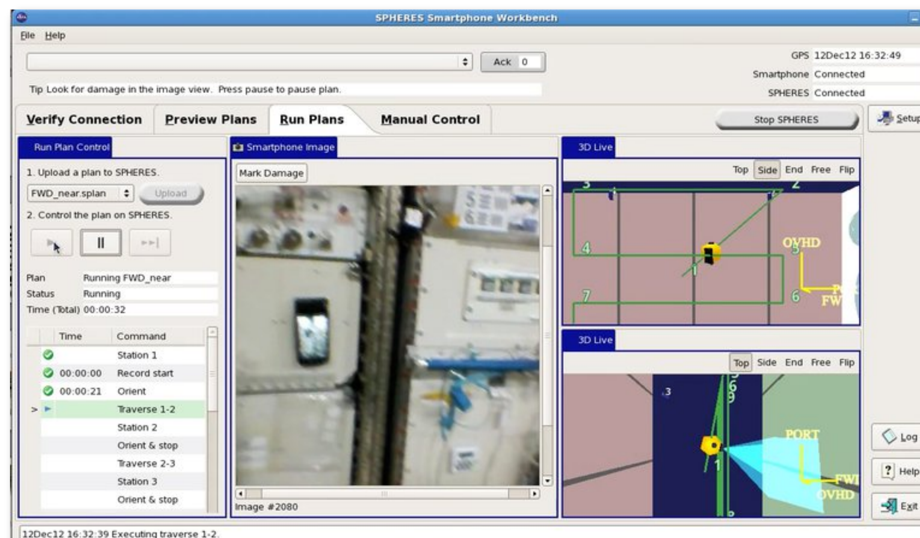
- IVA free-flyers (NASA / DARPA / MIT)
  - 22 cm diameter, 4 kg
  - Cold-gas propulsion + AA batteries
  - External sonar beacon localization
- 3 units installed on ISS (2006)
  - 52+ test sessions, 340+ hr crew time

Computing: Google Nexus-S

- Android smartphone
  - 1GHz Cortex A8 (ARM) + GPU, 512 MB RAM, 16 GB flash
  - 3-axis gyro, 3-axis accel., two color cameras
  - 802.11 b/g/n (Wi-Fi)
- Robotics software
  - RAPID middleware
  - Basic teleop + command sequencing
  - Ground control user interface



SPHERES with Google Nexus S smartphone

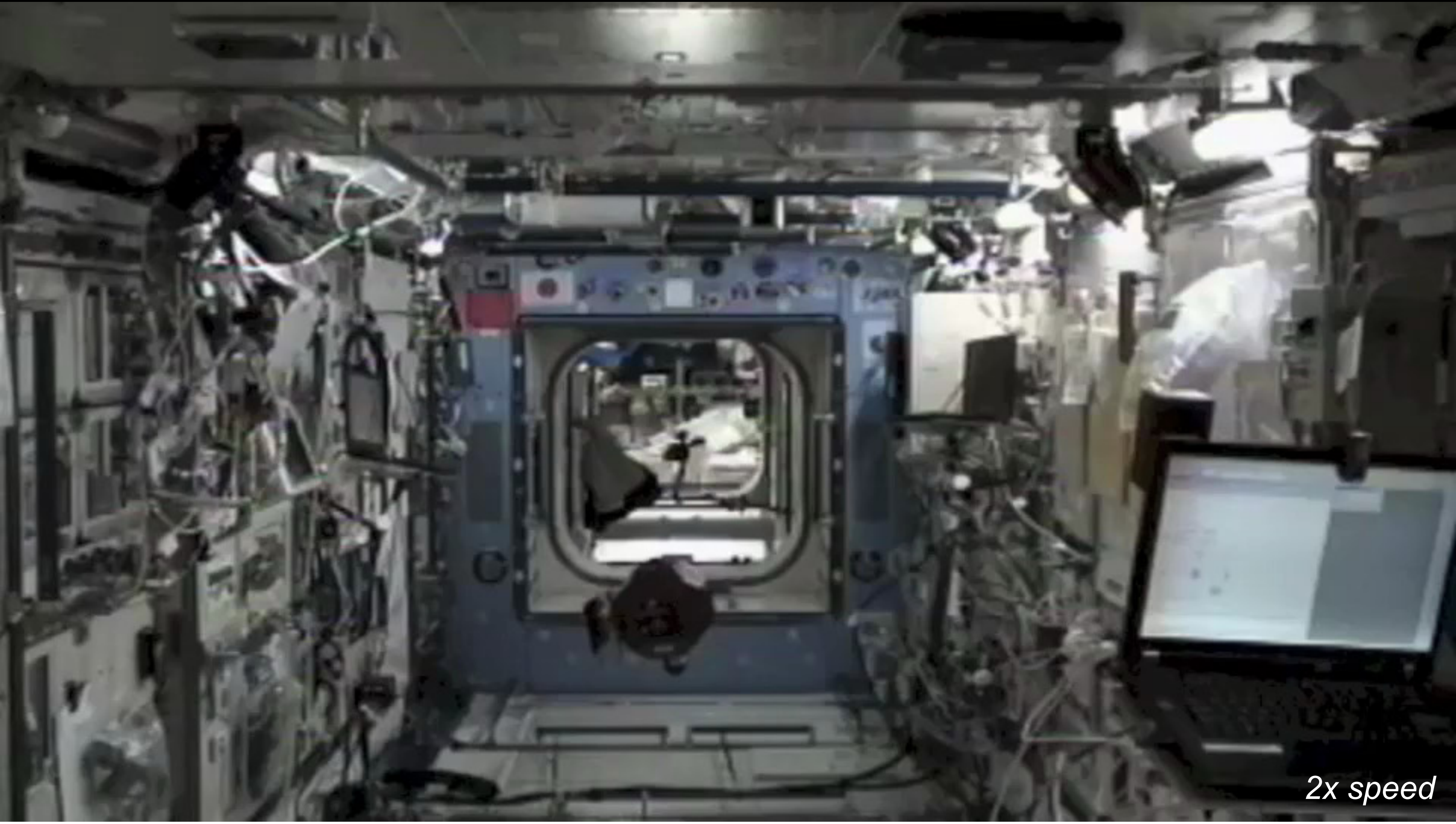


Ground Control User Interface

Smart SPHERES on ISS

Luca Parmitano working with Smart SPHERES in the ISS Japanese Experiment Module

IVA Survey with Smart SPHERES



December 12, 2012 (ISS Japanese Experiment Module)
Crew: Kevin Ford, Expedition 33 Commander

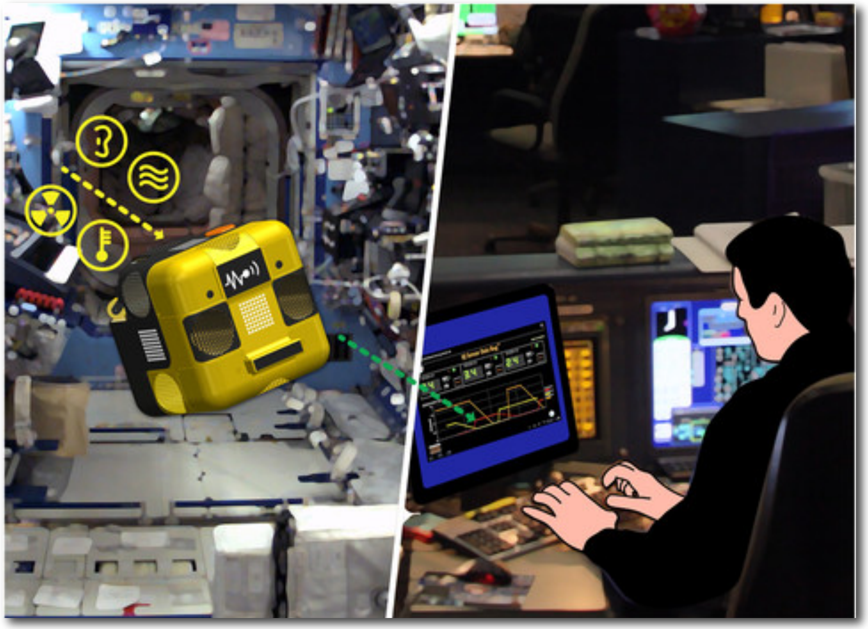
Astrobee IVA Free-Flying Robot

Overview

- Free flying robot for **inside** the ISS
- Astrobee will be used by flight controllers for mobile sensing and camera tasks
- Astrobee will succeed SPHERES as a microgravity robotic testbed

Automated operations

- Automated task execution / notification (ground supervisory control)
- Autonomous perching & station keeping
- Autonomous free-flyer docking / resupply



Telerobotic sensor platform

- 6-DOF localization (no beacons): structured light (Kinect) + stereo vision
- Environment sensors and monitoring algorithms (air quality / CO2)
- RFID sensor for sparse area inventory (key component of automated logistics)

Open and extensible platform

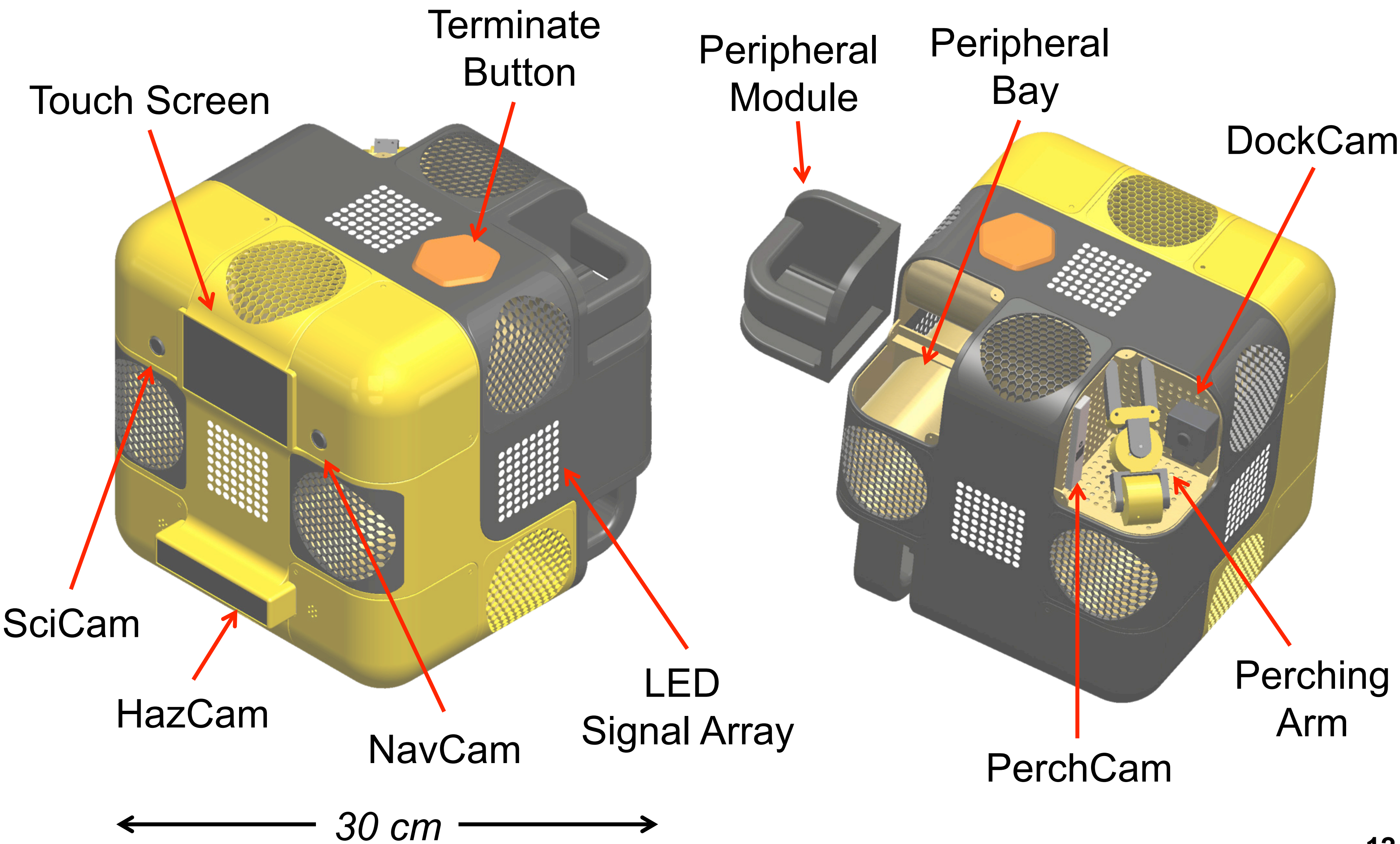
- Expansion port (mechanical, data, & power) for new payloads
- High-level programming interface (protects safety critical functions)
- Support microgravity experiments and E/PO (robotic competitions)

Why "Astrobee"?

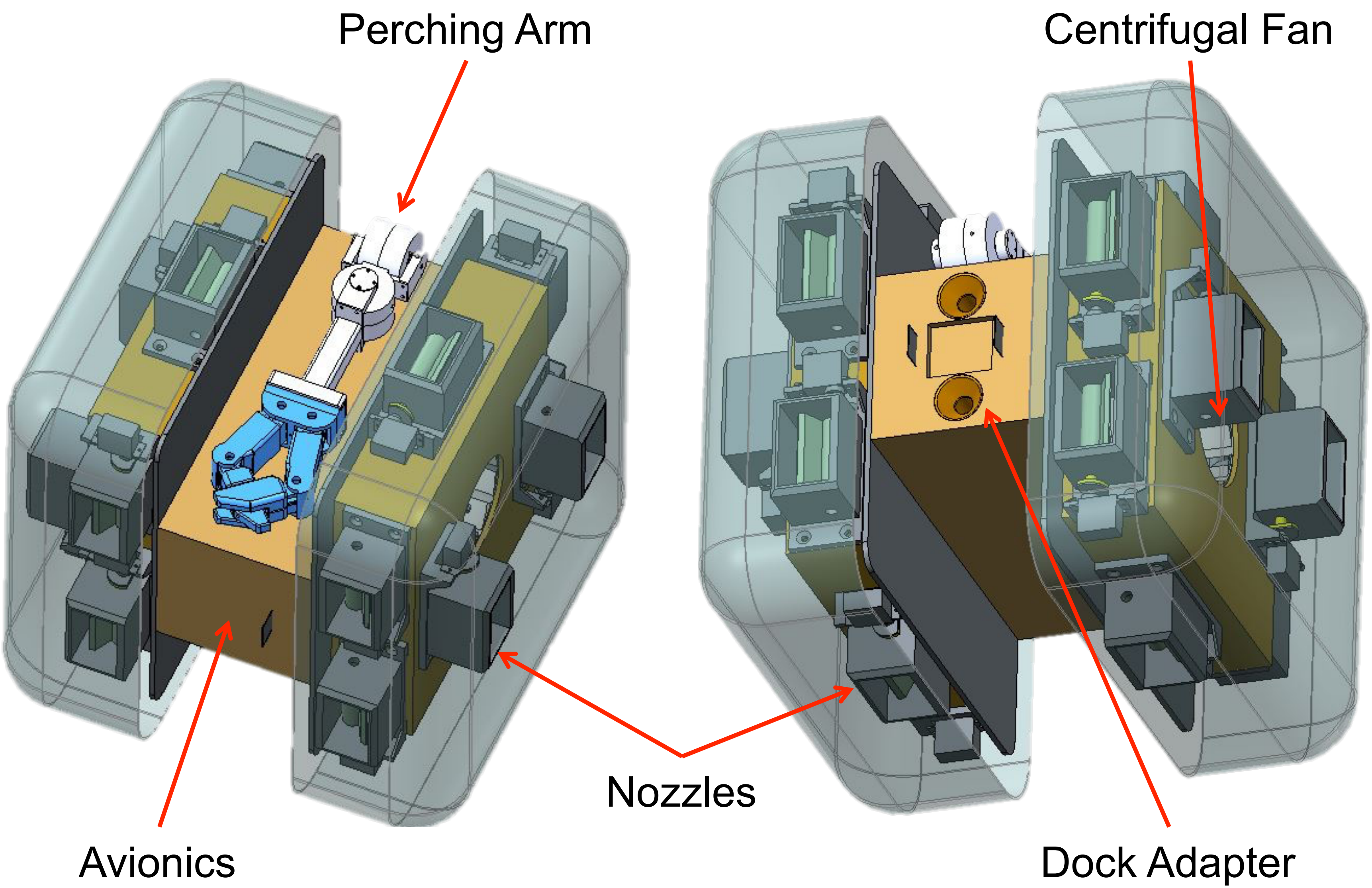
TopCoder challenge

- Announced at NY ComicCon
- 818 registrants (record for this type of challenge)

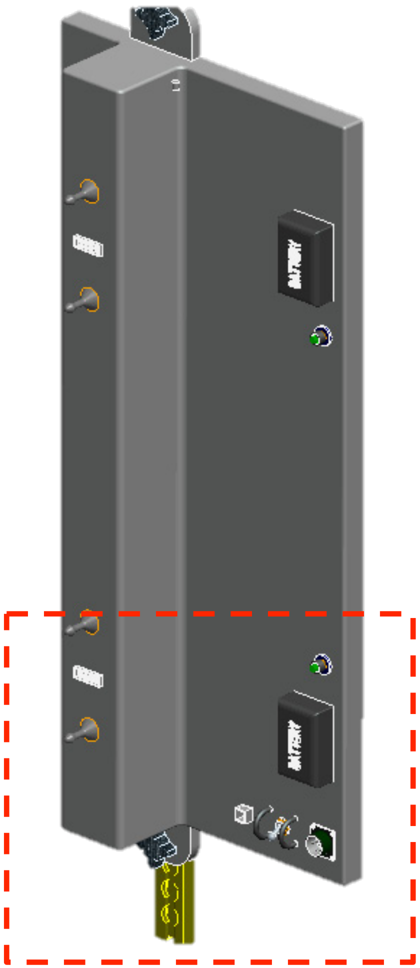
Point Design (Feb 2015)



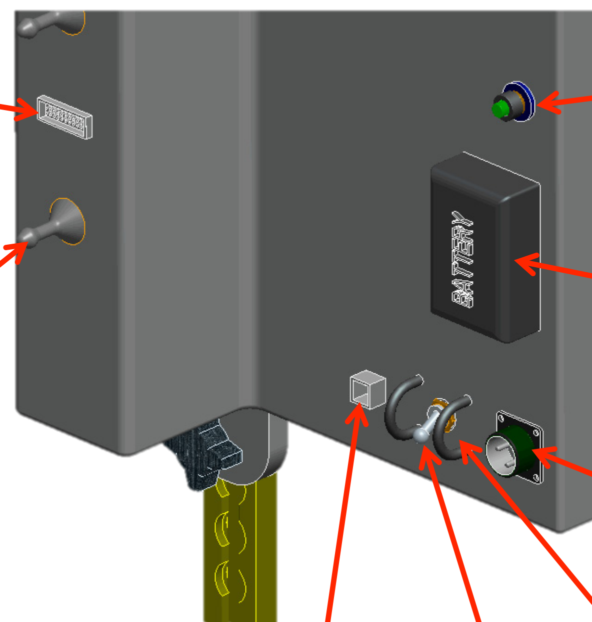
Point Design (July 2015)



Dock Design (July 2015)



14” x 30” x 3.25”



Avionics

Low-Level Processor (LLP)

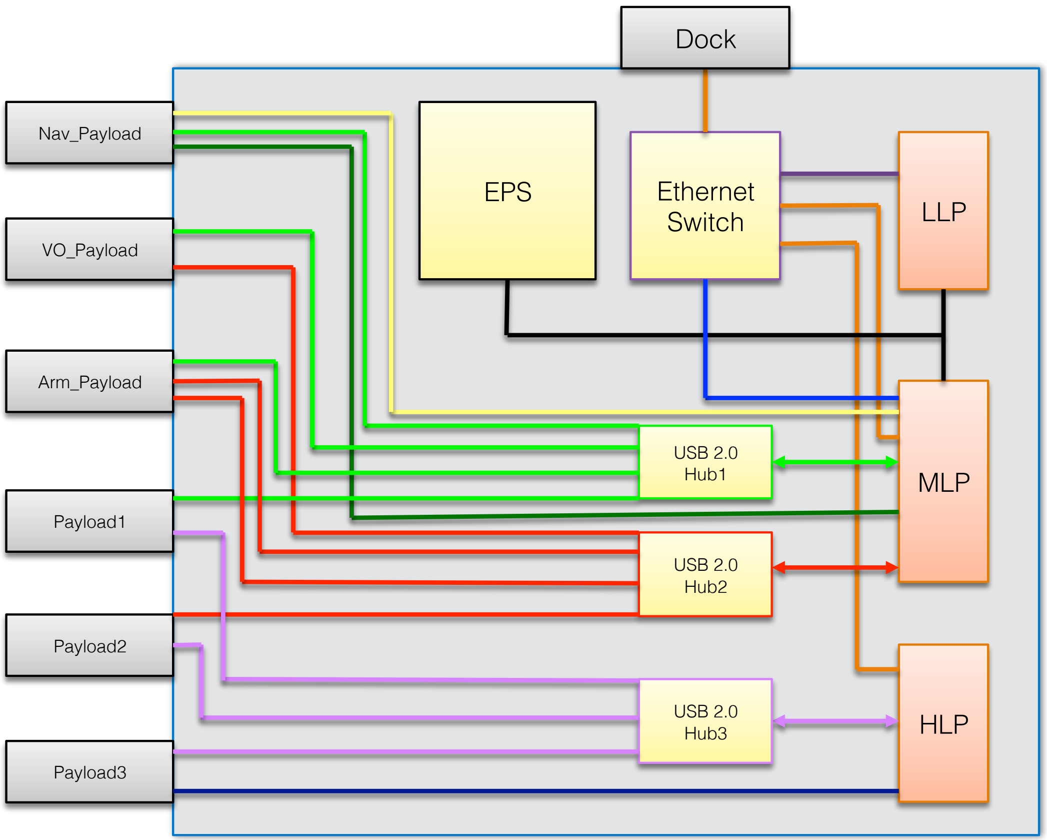
- Minimal “critical” code
- Hard real-time
- Motion control, high rate sensor processing
- Significant code V&V

Mid-Level Processor (MLP)

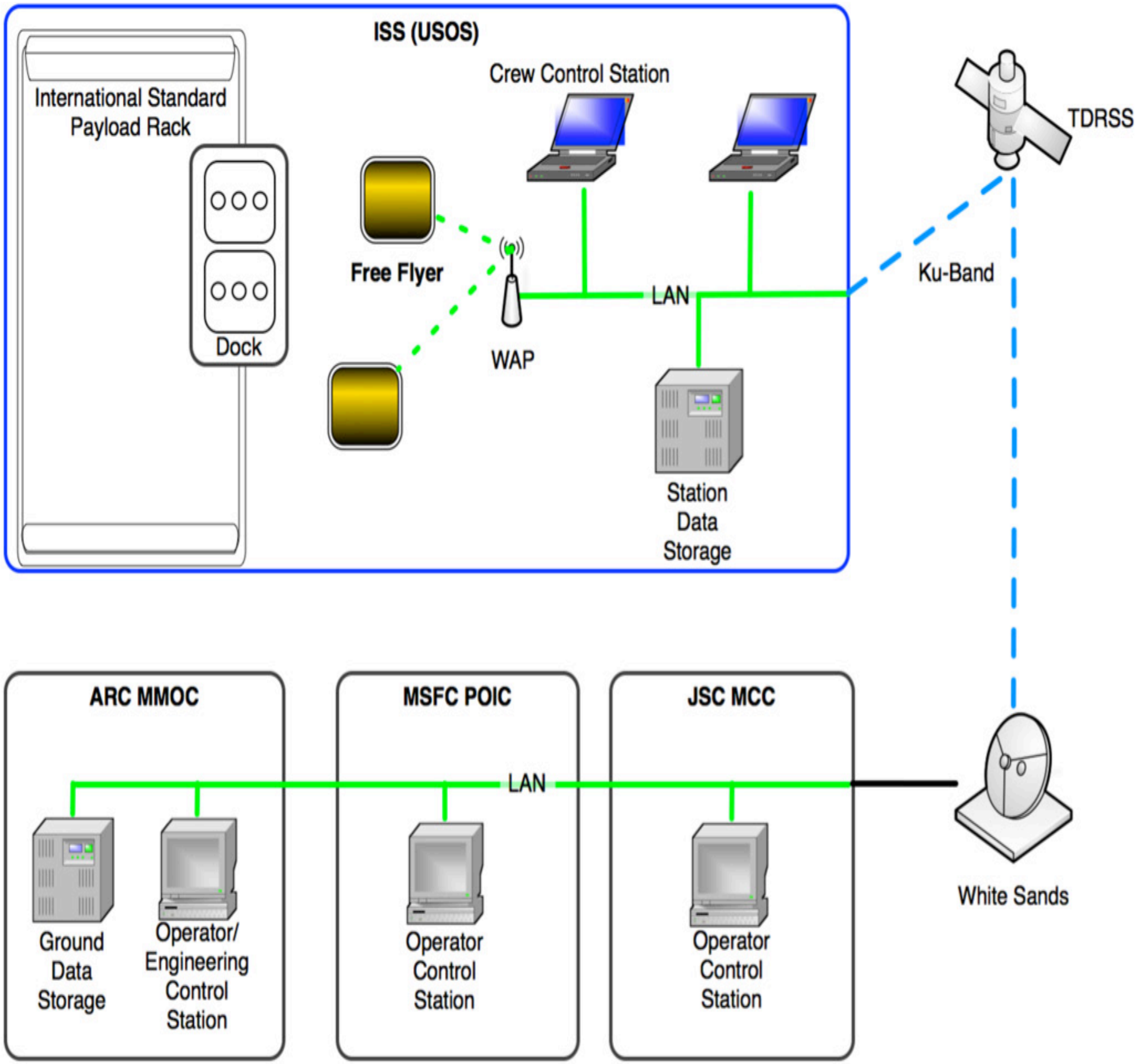
- Most “core” code
- Obstacle detection, handrail tracking, navigation, arm control
- Medium level code V&V

High-Level Processor (HLP)

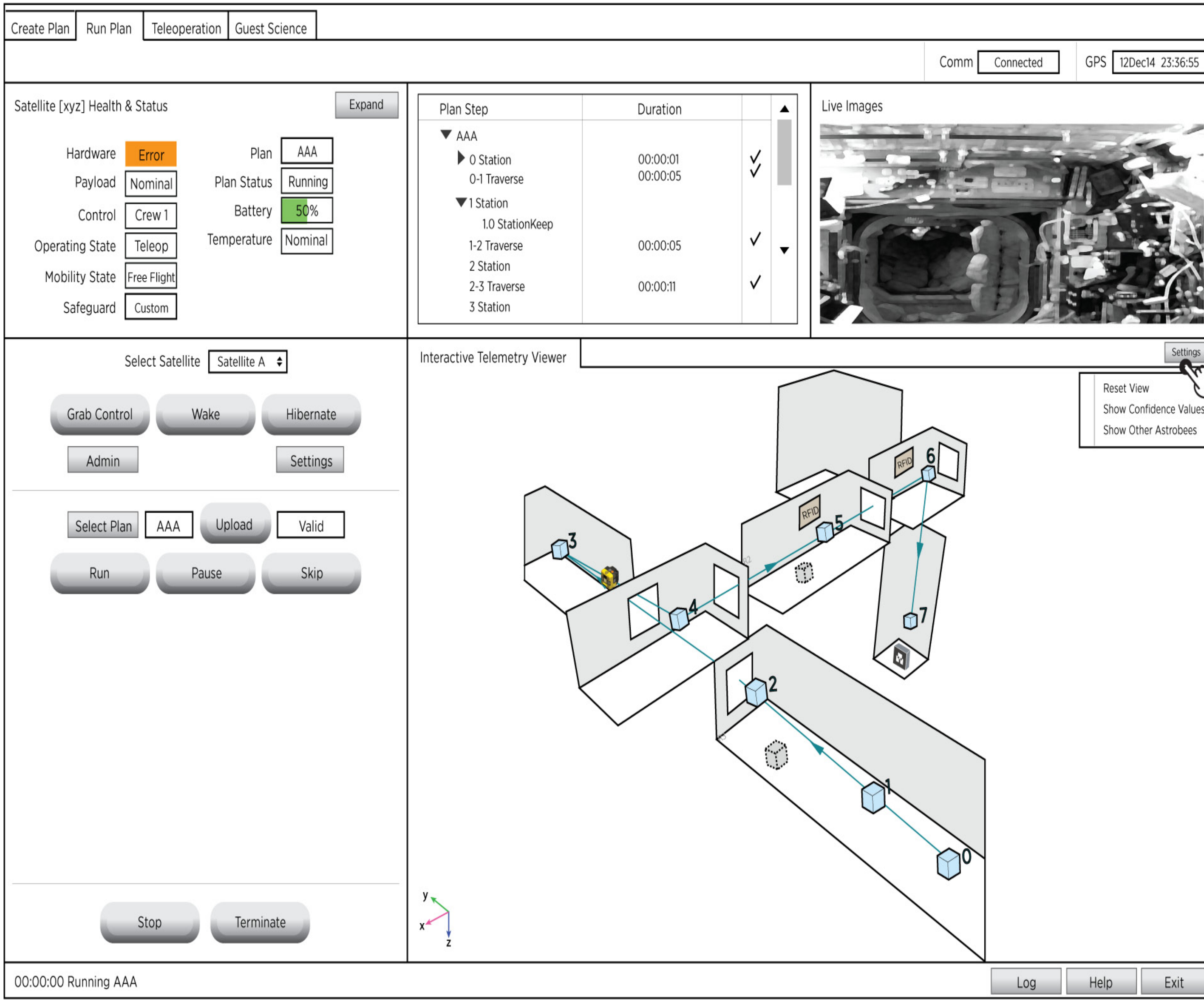
- On-board interface control
- Guest science (payload) code



Communication



Control Station Mockup



Performance Requirements

Operations

- Free-flight throughout US Operating Segment (USOS)
- Holonomic motion (instantaneous thrust in any direction)
- 20-40 cm/s for up to 9 hr “sortie”

Minimize crew time

- Certify for autonomous operations (in USOS)
- Auto docking & recharge
- Modular design for quick repair

Avoid pre-defined keepout zones

- Module walls, known obstructions, zones near vents
- Areas specified by ground operator or crew

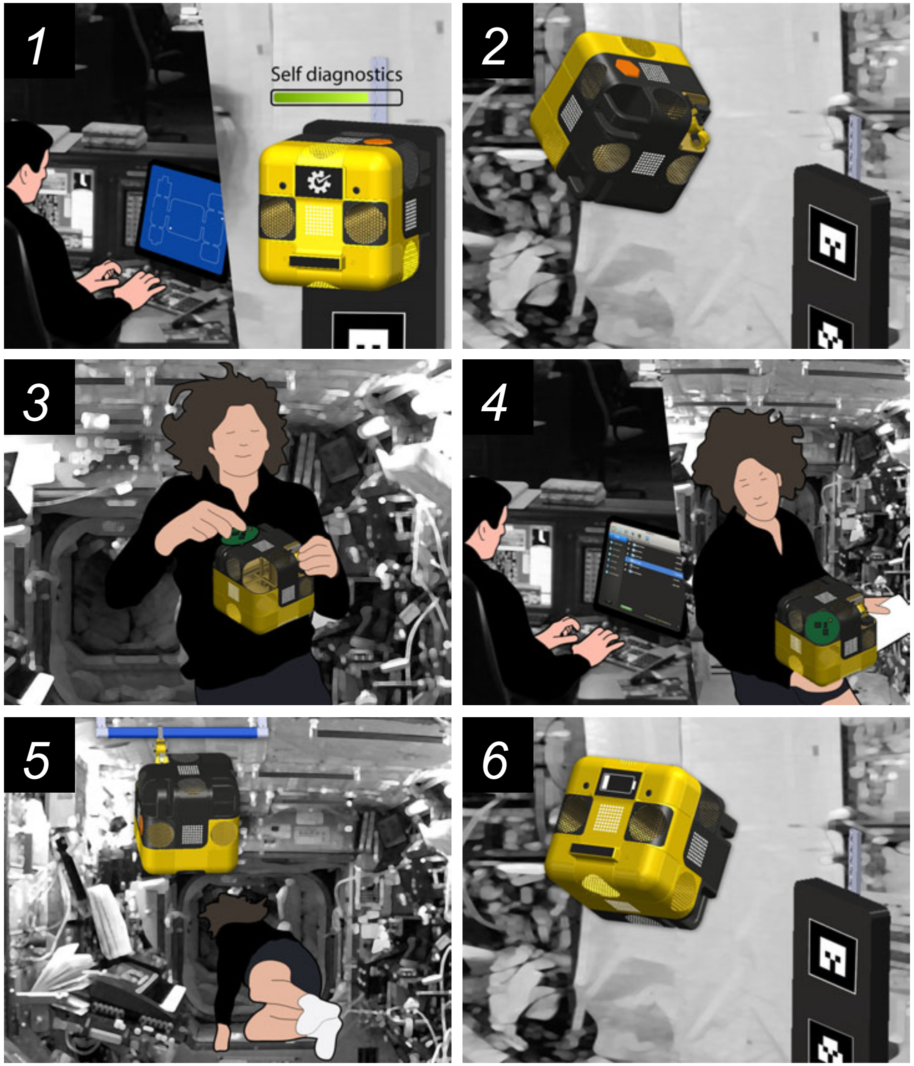
Avoid collision

- Detect static and dynamic hazards
- Bring robot to stop prior to collision

Modes

- Remote: manual control, supervisory control
- On-board: payload control (guest science), auto dock

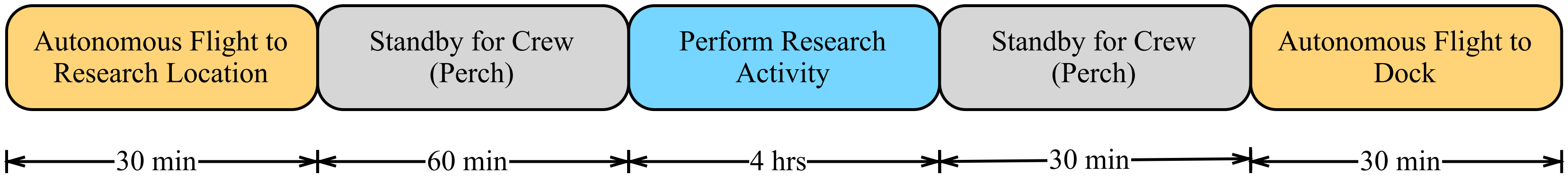
Microgravity Research Scenario



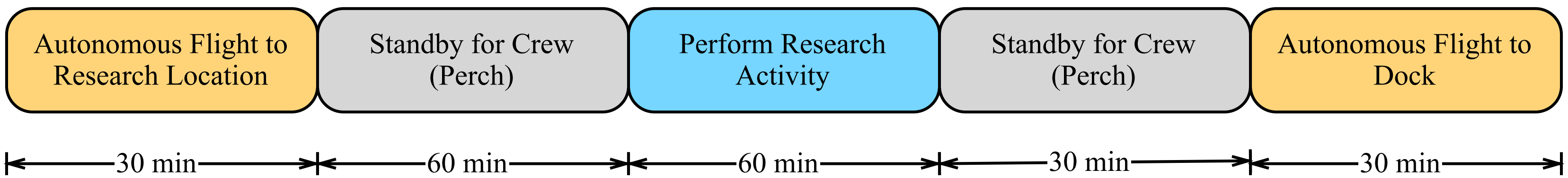
	Sequence of Events
1	Prior to research activity, ground operator loads experimental software, free flyer does self-diagnostics.
2	Free flyer undocks and moves to experimental module.
3	Astronaut attaches external hardware to free flyer.
4	Ground operator sets up individual tests, and astronaut initializes tests.
5	Free flyer perches to wait while astronaut pauses for EPO Event.
6	Astronaut detaches hardware and then free flyer returns to dock.

Microgravity Research Timelines

Low Intensity (6.5 hr)



High Intensity (3.5 hr)



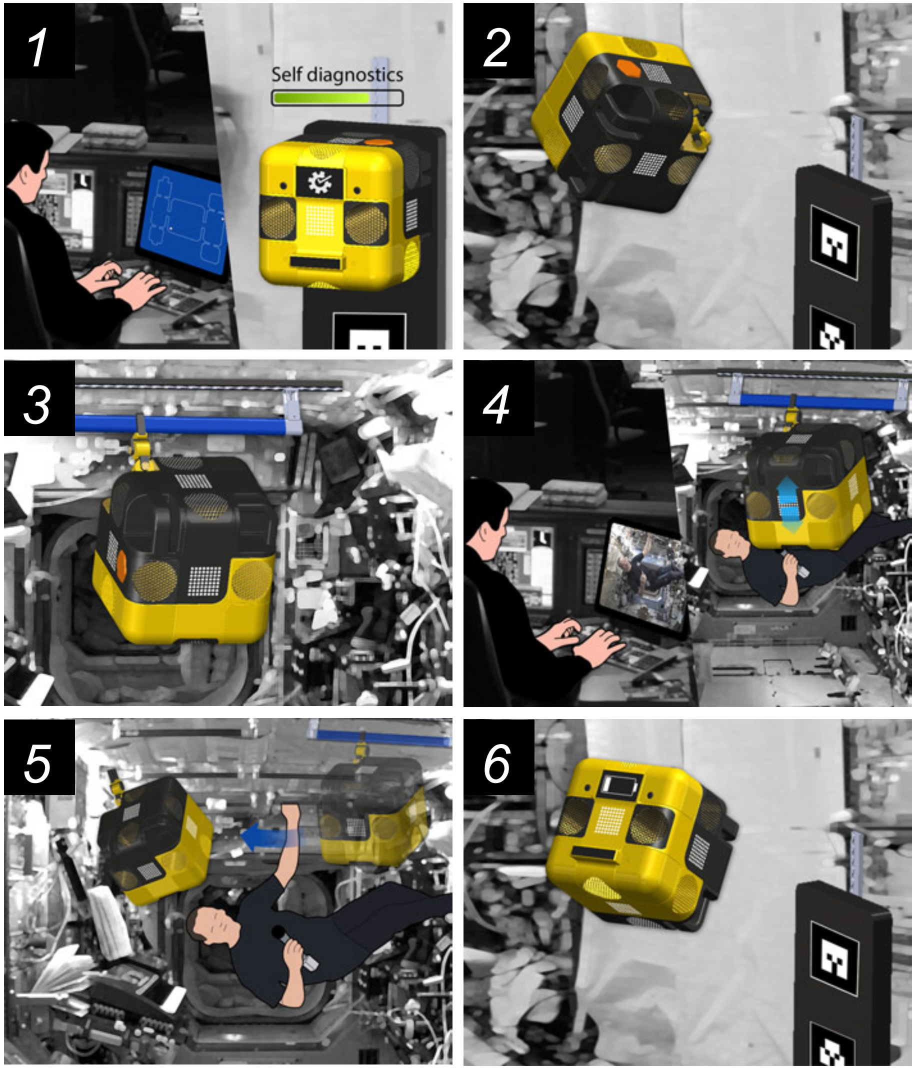
Microgravity Research Payloads

Guest science

- Researchers can provide arbitrary code
- Most guest science code runs in sandbox, uses high-level control API
- Peripheral bays and peripheral ports

Class	Description	Requirement
Small	Payloads too light to affect mobility	Host payload and operate in all modes with full performance, without tuning controls
Medium	Typical payload that fits in peripheral bay, not too massive or unbalanced	Host payload and operate in all modes; reduced performance, some testing and controls tuning may be needed
Special	Other payloads	Assess on a case-by-case basis

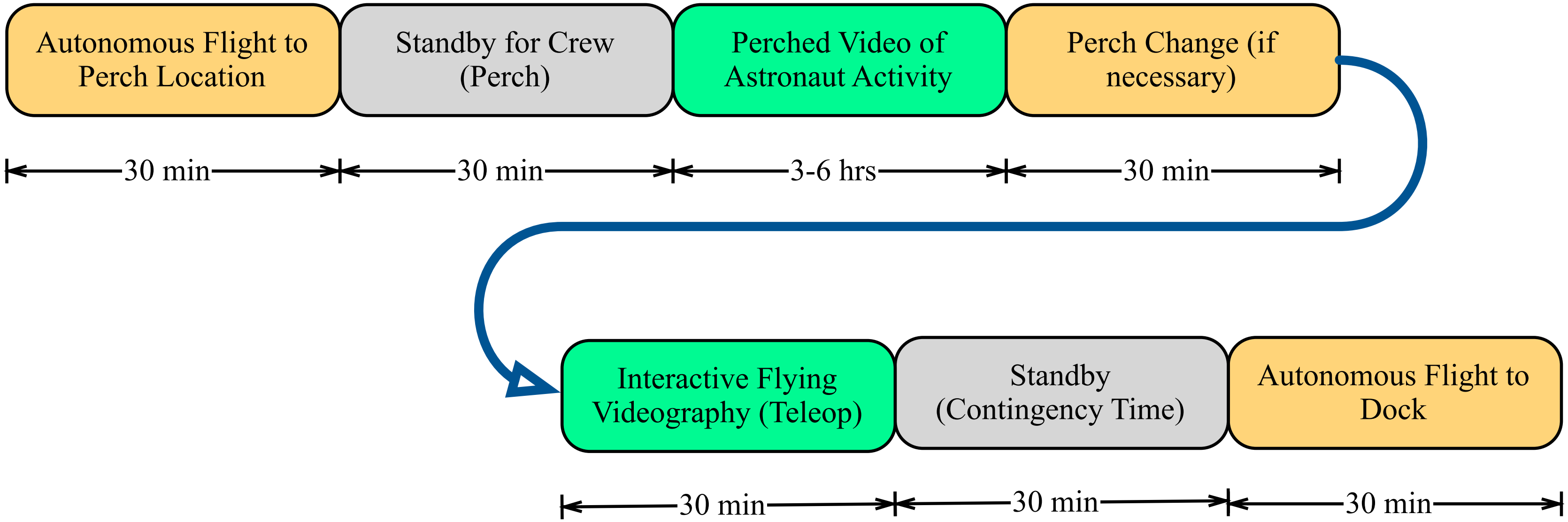
Mobile Camera Scenario



	Sequence of Events
1	30 mins before crew activity, ground operator initializes free flyer. Free flyer does self diagnostics and operator gives module and perch location.
2	Free flyer undocks and flies to module.
3	Free flyer perches to wait for activity.
4	During activity, ground operator makes adjustments to pan/tilt as astronaut moves around.
5	Ground operator moves to new perch because astronaut is blocking view.
6	After activity, free flyer returns to dock for charging

Mobile Camera Timeline

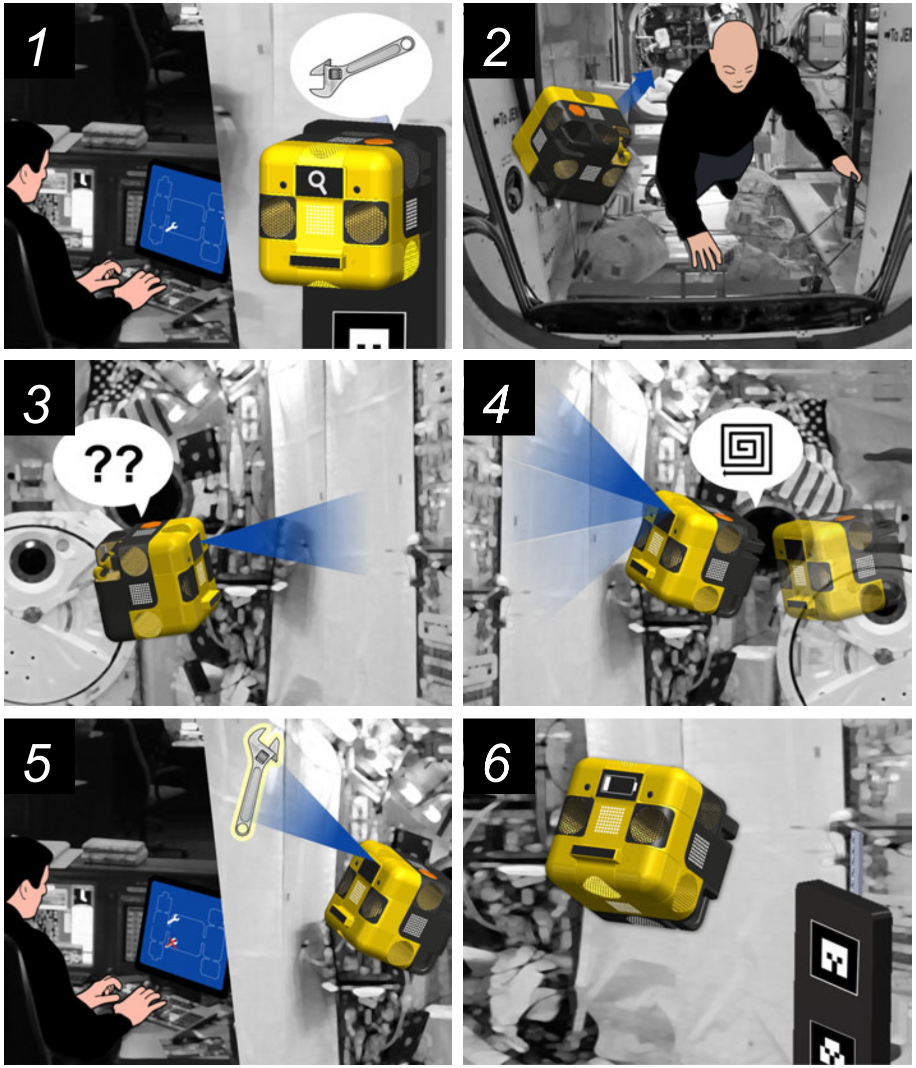
Flying and Perching (6-9 hr)



Communication Loss

- During LOS, Astrobee continues to hold its position, recording and storing video on-board
- At AOS, resumes downlinking the live video stream

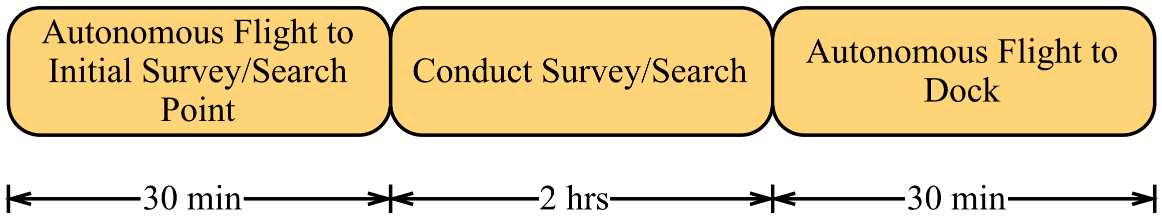
Survey / Search Scenario



	Sequence of Events
1	One day in advance of crew activity, ground controller activates the free flyer, uploads tool ID and expected location, and initiates SEARCH function.
2	Free flyer undocks and heads to suspected location. Free flyer avoids astronauts and equipment along the way.
3	Free flyer scans the expected location with its RFID reader, but the tools is not there.
4	Free flyer initiates automated search pattern.
5	Free flyer locates tool at the other side of the module and updates logistics database.
6	Free flyer returns to dock.

Survey / Search Timeline

Environment / Inventory Flights (3 hr)



Communication Loss

- During LOS, continues to operate, recording and storing measurements on-board
- Transmits completed survey data file on return to dock
- Downlinks the RFID and location of found items

Astrobee Partners

Human Exploration Telerobotics 2 project (STMD GCD)

- Astrobee core development (NASA Ames and JPL)

SPHERES program (HEOMD ISS)

- Development & test facilities
- ISS facility infusion customer

Logistics Reduction project (HEOMD AES)

- RFID Reader (external payload) for Astrobee

Autonomous Systems Operations project (HEOMD AES)

- RFID data management for Astrobee

2015 SBIR (STMD)

- Z5.01 “Payload Technologies for Assistive Free-Flyers”
- Awarded 3 Phase 1 projects

2015 Early Stage Innovation (STMD)

- Topic 1: “Payload Technologies for Assistive Free-Flyers”
- Mirrors SBIR subtopic, but targets academia (proposals under review)

Questions?