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Advanced Exploration Systems Division

Operation and Development Status of the Spacecraft Fire Experiment (*Saffire*)

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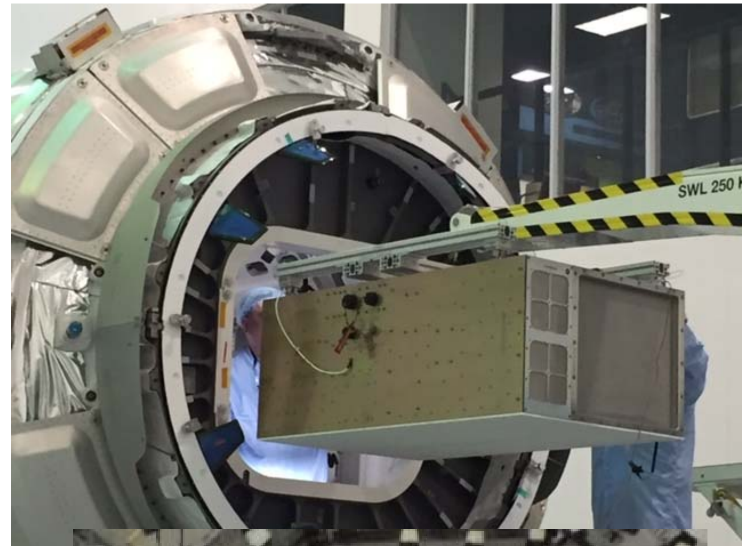
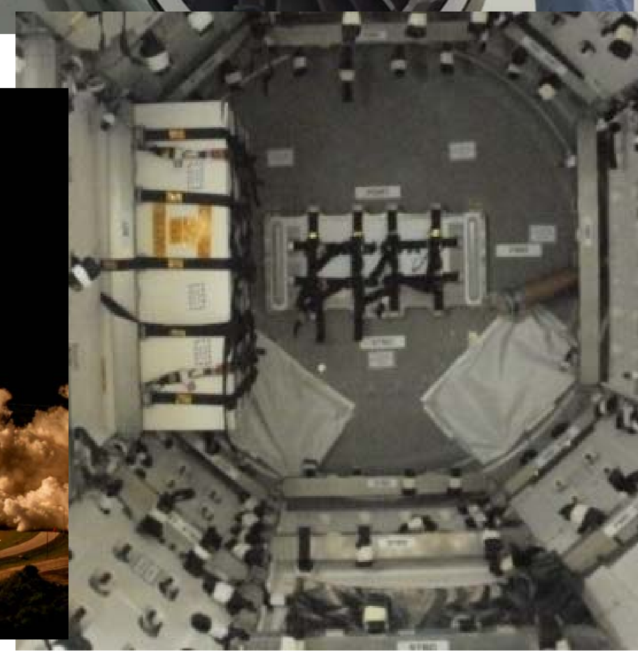
Spacecraft Fire Safety Demonstration

- Project Background and Objectives
- Saffire Hardware
- Flight Operations
- Preliminary Results
- Spacecraft Fire Safety Technology Needs
- Saffire-IV-VI Objectives and Plans





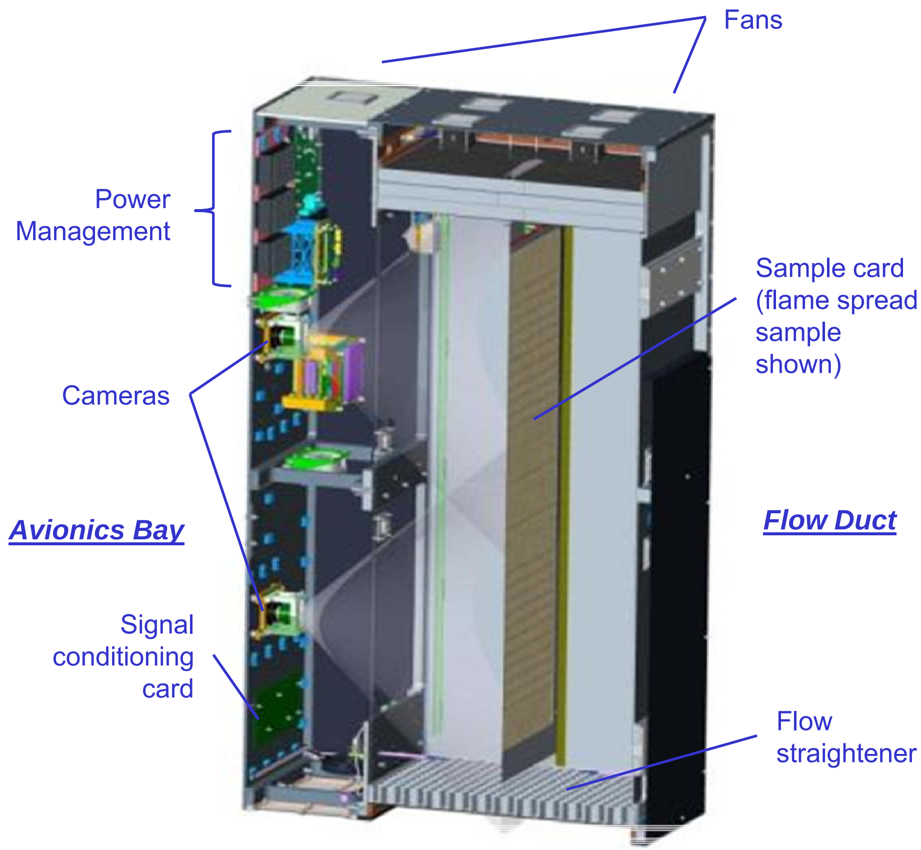
Saffire-I, II, & III Overview

Needs:

- *Low-g flammability limits for spacecraft materials*
- *Definition of realistic fires for exploration vehicles*
  - *Fate of a large-scale spacecraft fire*

Objectives:

- *Saffire-I*: Assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release)
- *Saffire-II*: Verify oxygen flammability limits in low gravity
- *Saffire-III*: Same as Saffire-I but at different flow conditions.



- *Data obtained from the experiment will be used to validate modeling of spacecraft fire response scenarios*
- *Evaluate NASA's normal-gravity material flammability screening test for low-gravity conditions.*

Saffire module consists of a flow duct containing the sample card and an avionics bay. *All power, computer, and data acquisition modules are contained in the bay. Dimensions are approximately 53- by 90- by 133-cm*

Sample Card Holder Configurations

➢ Sample card and samples are the only differences between the three flight units

Saffire-I, -III Sample Card

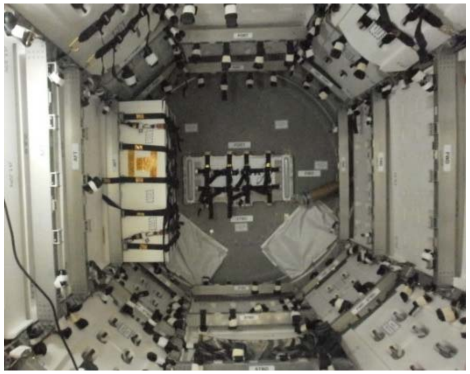
Composite fabric (SIBAL cloth)
(75% cotton – 25% fiberglass by mass)
(0.4 m x 0.95 m)

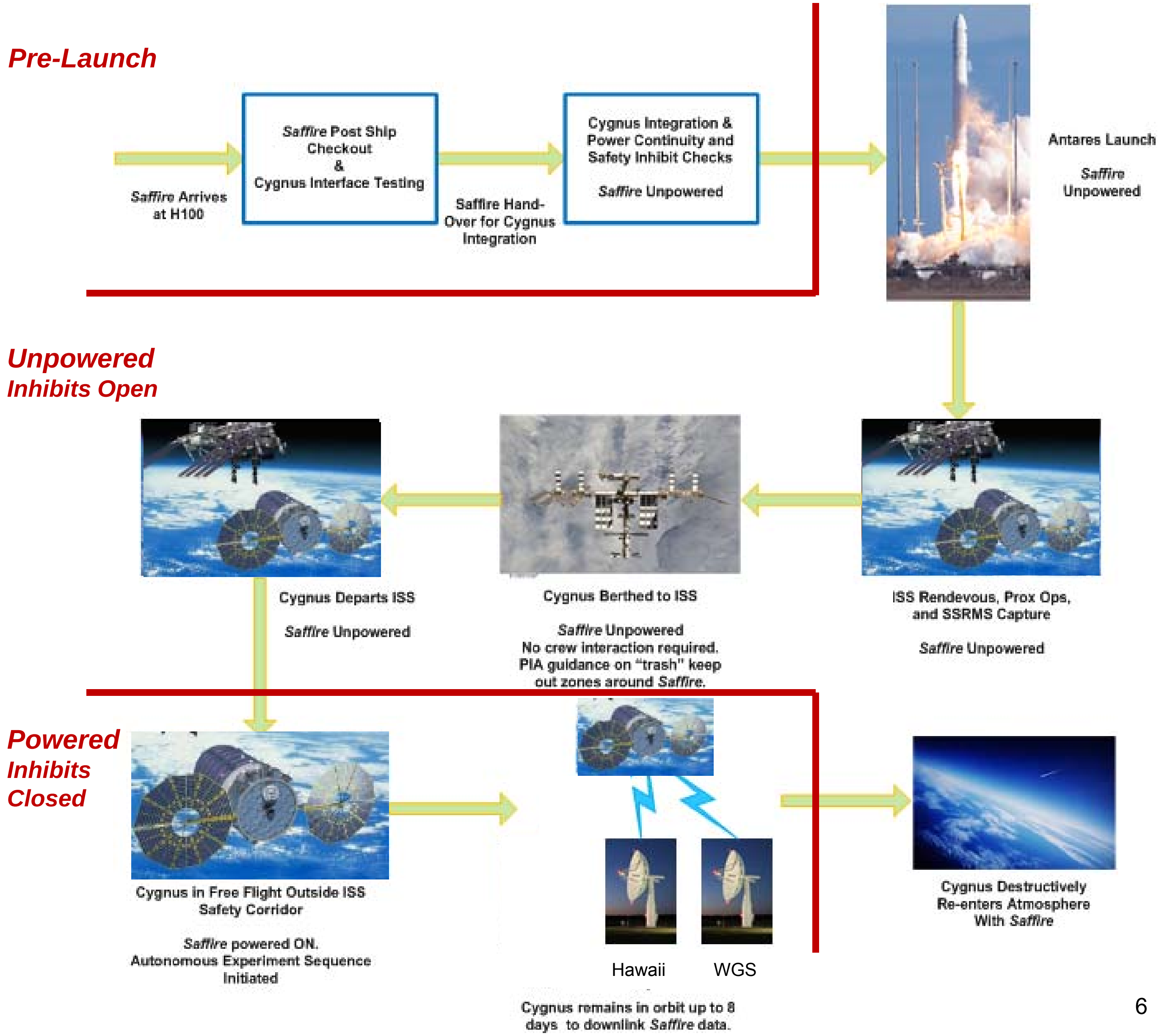
Saffire-II Sample Card

Saffire-II Samples (5 cm x 29 cm)

- PMMA (flat and structured)
- Silicone (3 thicknesses, different ignition direction)
- SIBAL
- Nomex (with PMMA ignition)

Operations Concept

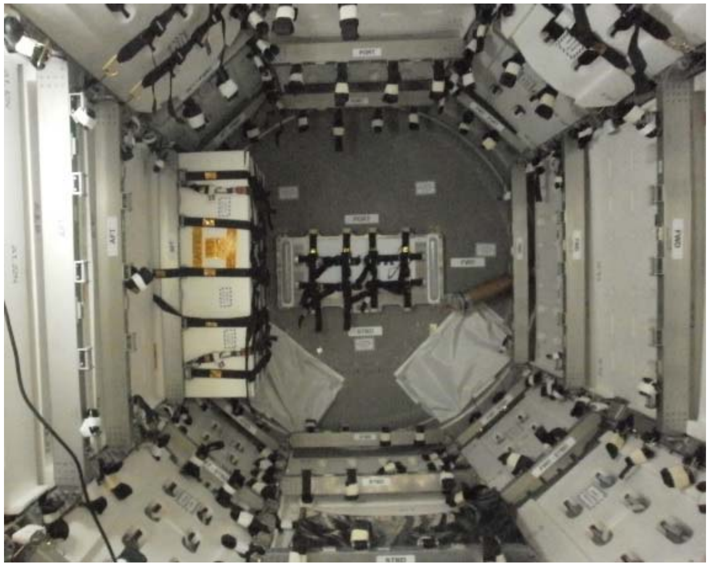




Saffire-I Integration
January 2016

Saffire-I Integration. *NASA-KSC*

Saffire-I hardware strapped into the Cygnus Pressurized Cargo Module



Saffire-I Launch and Berthing
March 22

- **Successful launch of Saffire-I onboard Cygnus OA-6 (SS Rick Husband) on March 22**
  - Orbital ATK reported that OA-6 had a nominal ascent.
    - Spacecraft Mission Director reported to the Saffire team “Vehicle is good. PCM is good. All inhibits in place. Enjoy the ride.”

Launch of OA-6 on March 22 carrying Saffire-I

Saffire-I photograph taken by the ISS crew following initial ingress to the PCM

- **OA-6 Pressurized Cargo Module (PCM) berthed to the ISS on Saturday, March 26 with crew ingress into the PCM on March 27**
  - The crew took on-orbit photographs of Saffire-I *(right)*

Saffire-I Operations

June 14-20, 2016

NASA and Orbital ATK teams at MCC-Dulles (above) and Flight Operations-GRC (right) conducted and monitored Saffire-I operations

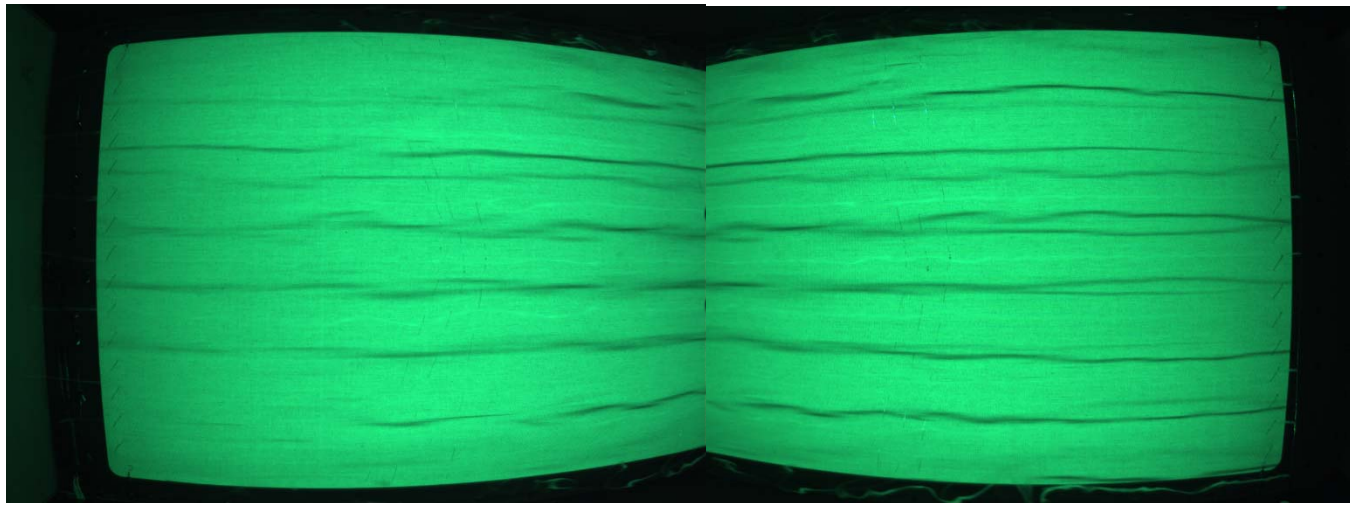
- **Operations received considerable coverage on social media**
  - NASA GRC and AES

- **OA-6 unberthed from the ISS at 9:30 a.m. EDT on June 22**
- **Saffire-I was powered on at 2:23 p.m.**
- **RUN command was sent at 4:41 p.m.**
  - Ignition at 4:44 p.m.
- **Cygnus smoke detector readings received at 4:52 p.m.**

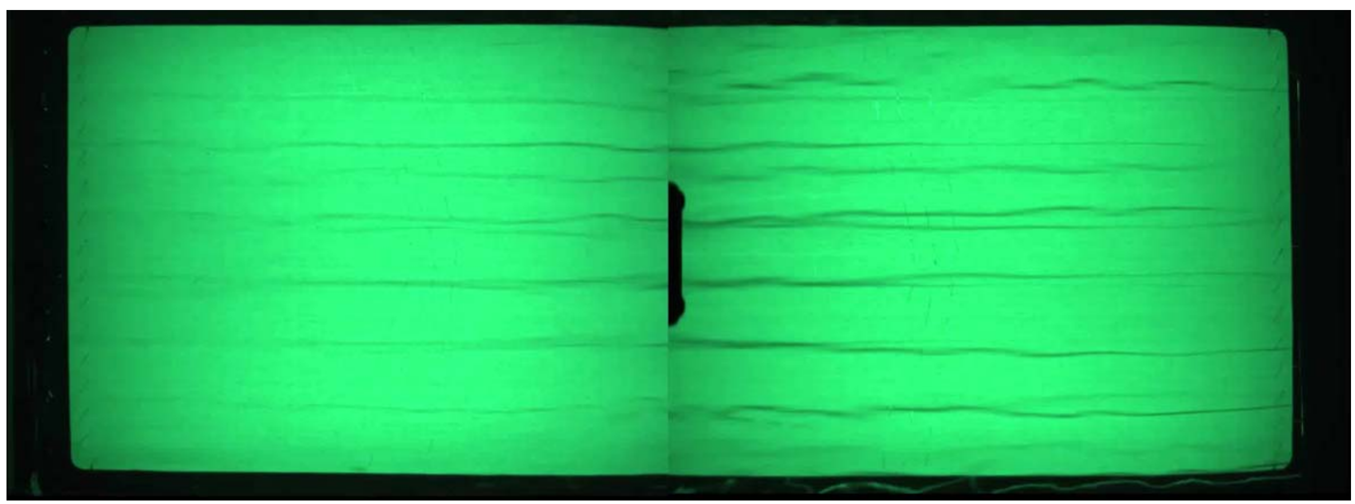
Saffire-I Operations
Smoke Flow Visualization (Pre-Test)

- **Smoke line visualization of the flow in the Saffire-I duct.**
  - *(Top) smoke line image with lens distortion.*
  - *(Bottom) Image with distortion correction showing later smoke lines.*
  - *The flow is from right to left.*

Camera 1 and 2 images as recorded (with distortion)

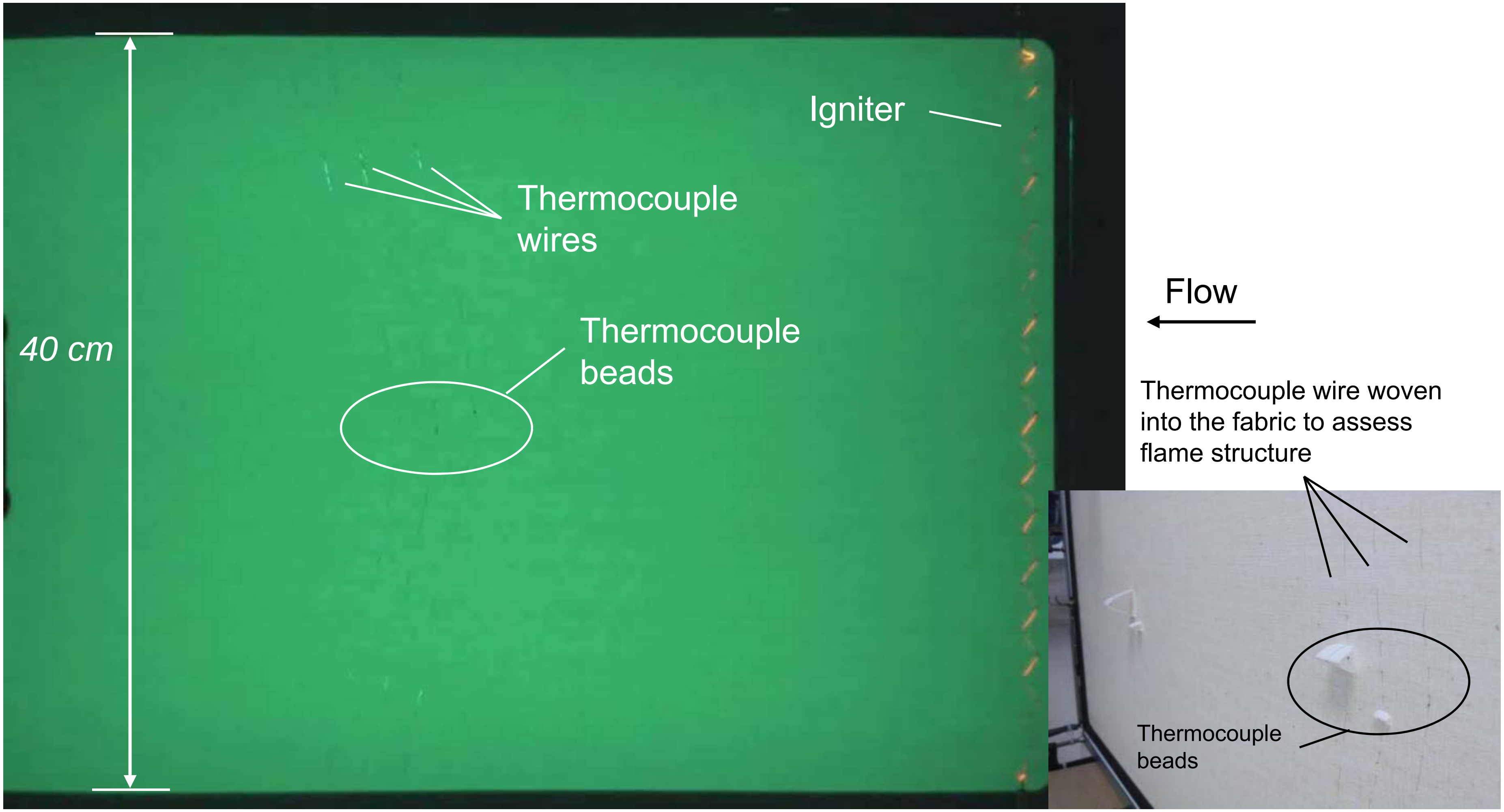


← Flow



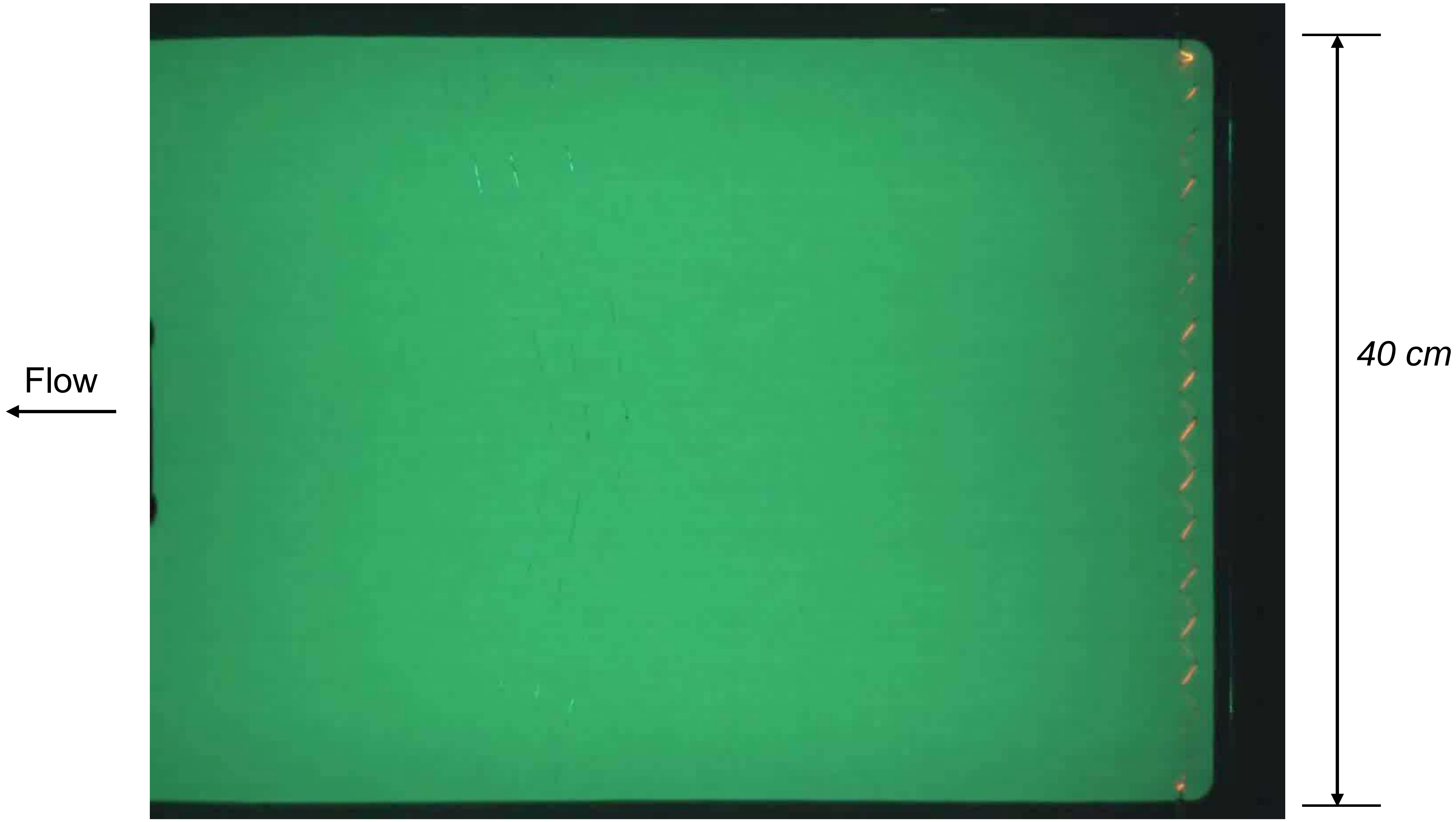
Camera 1 and 2 images with distortion correction

Saffire-I Operations
Concurrent Flow Igniter



Saffire-I sample material at the beginning of the concurrent (upstream) burn.
Thermocouple wires are sewn into the sample material with thermocouple beads at various heights in the center of the sample.

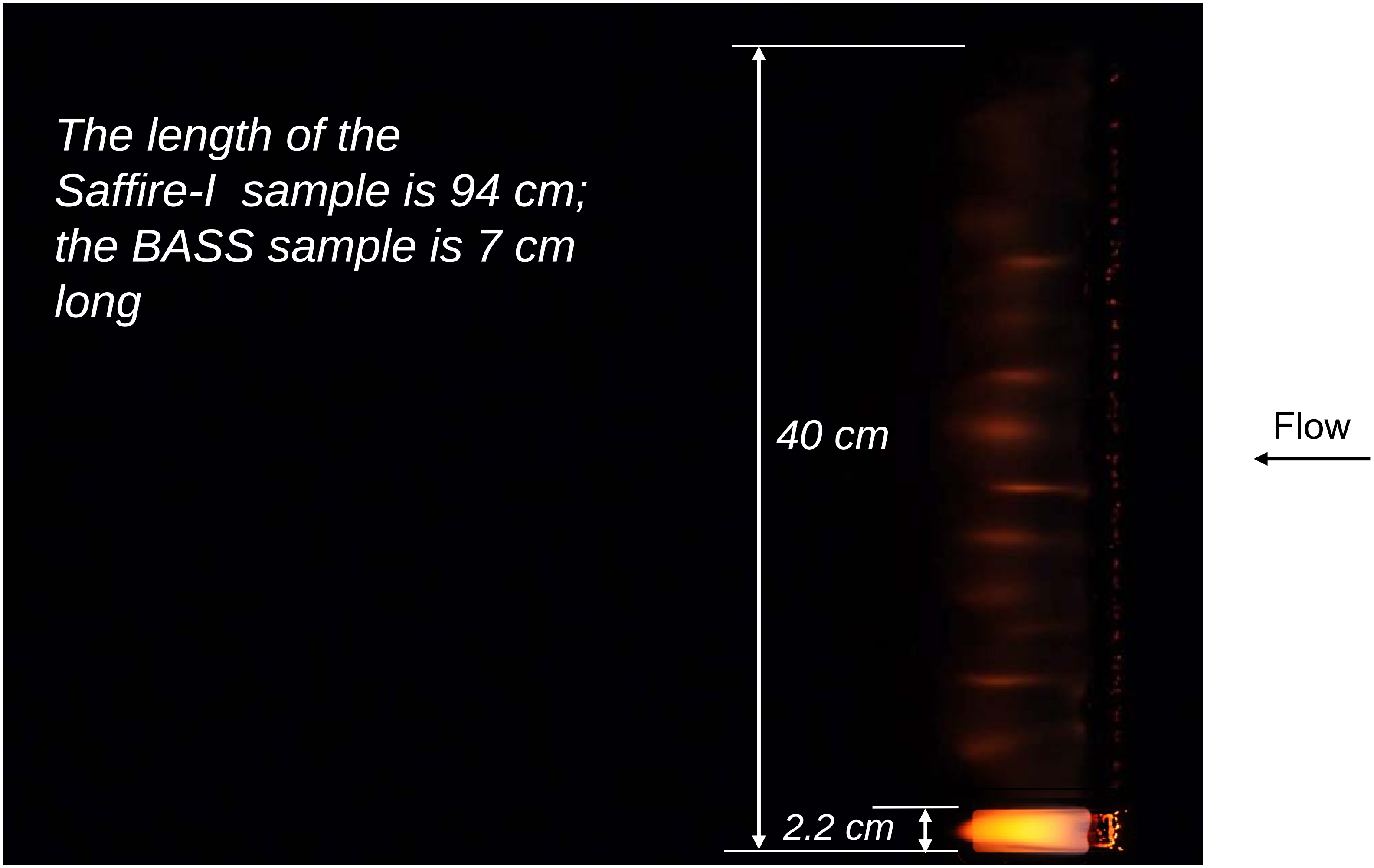
Saffire-I Operations
Concurrent Flow Igniter



Video of the first 30 seconds of the Saffire-I concurrent (upstream) burn. *The green LED is on for 1 second and off for two seconds (1 second out of three). Shorter times indicate missing downlinked frames.*

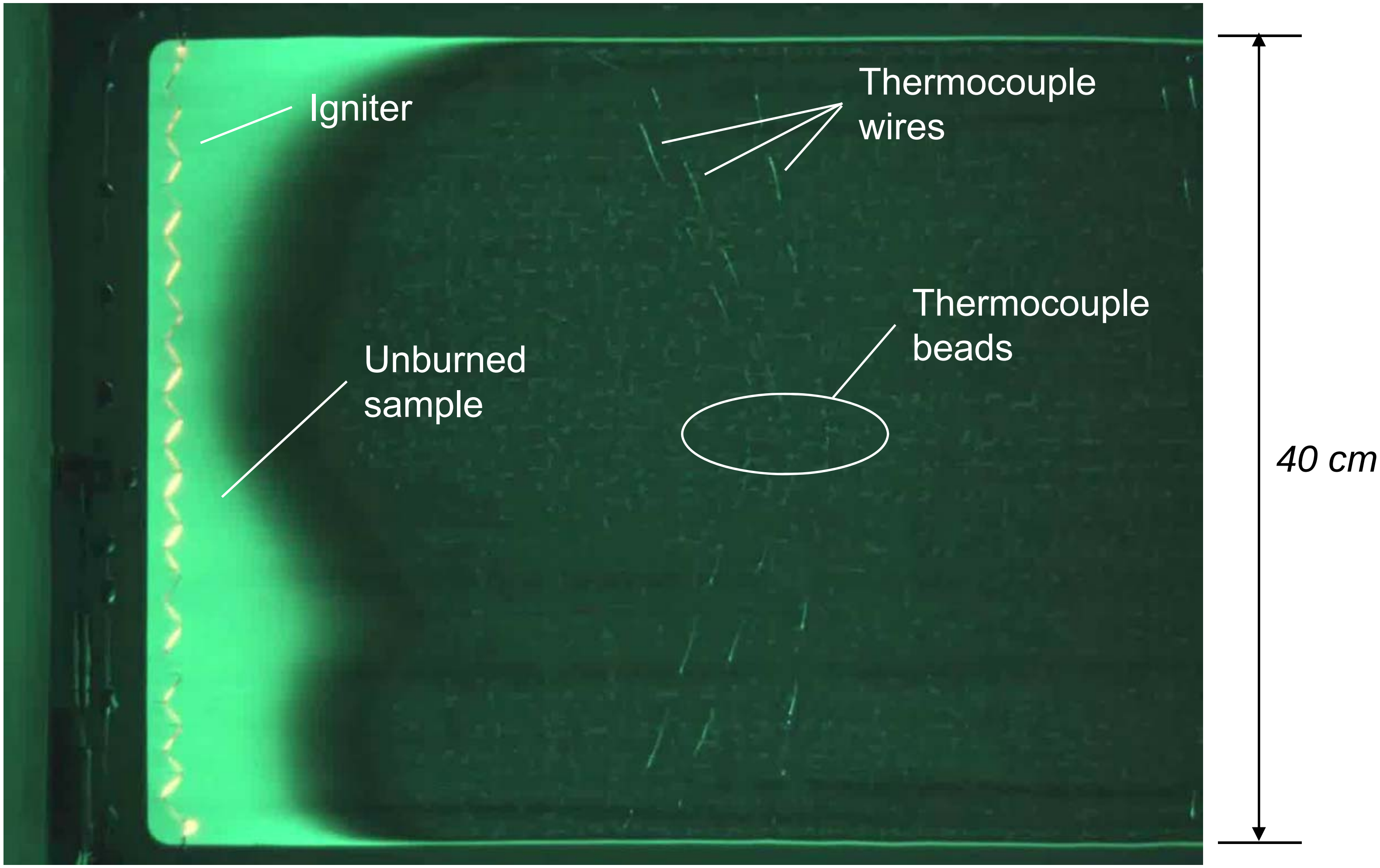
Saffire-I Operations

So, how big is the flame?



Saffire-I flame compared to a flame from the Burning and Suppression of Solids (BASS) experiment conducted in the Microgravity Science Glovebox . *Camera exposures and gains are different between the two experiments.*

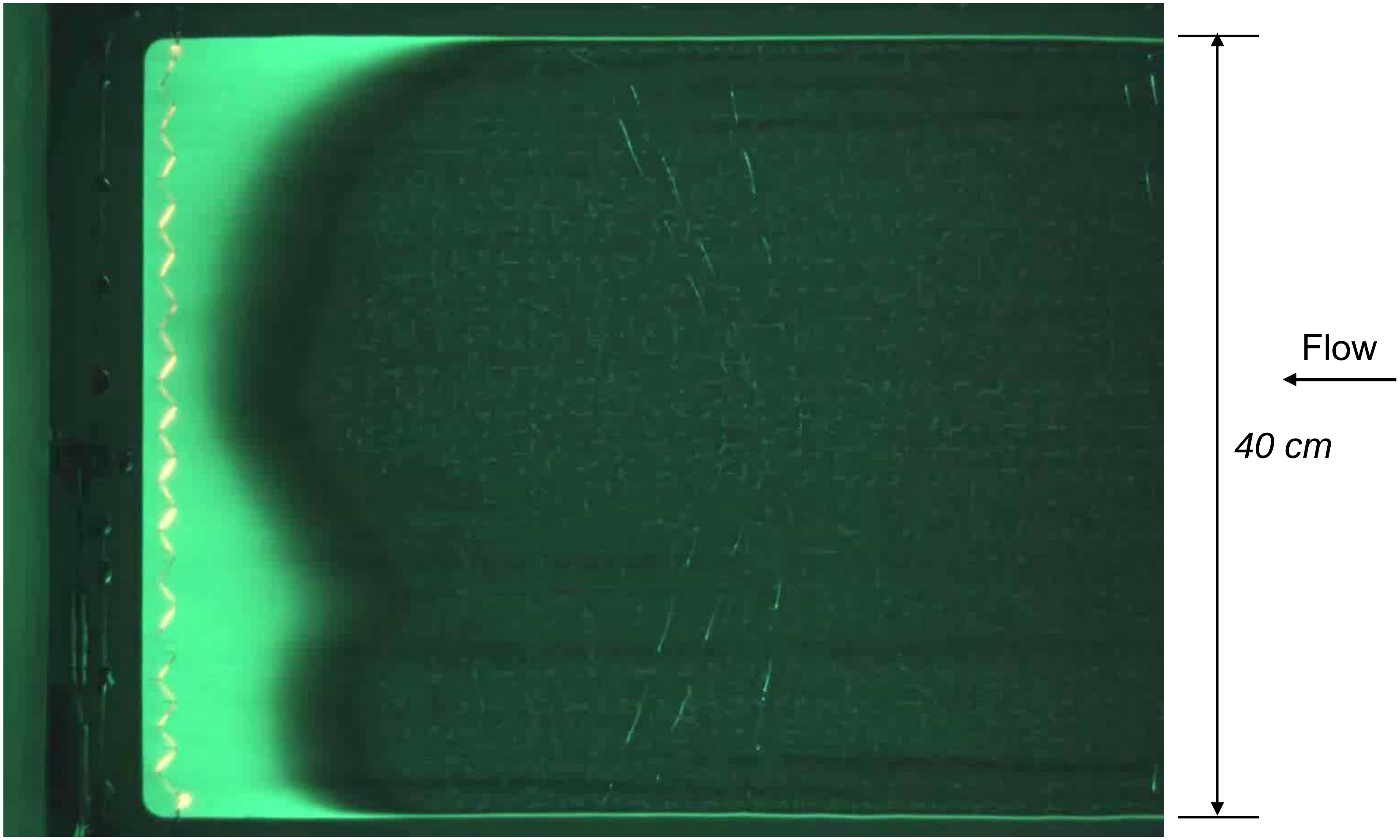
Saffire-I Operations
Opposed Flow Igniter



Saffire-I sample material at the beginning of the opposed flow (downstream) burn. *The light portion of the image is sample material unburned from the concurrent burn. A second set of thermocouple wires are sewn into the sample material with thermocouple beads at various heights in the center of the sample.*

Saffire-I Operations

Opposed Flow Igniter



Video of the Saffire-I opposed flow (downstream) burn. *The green LED is on for 1 second and off for two seconds (1 second out of three). Shorter illumination durations indicate missing downlinked frames.*

Saffire-I
End-of-Mission

- Saffire-I relays were opened at 9:41:48 p.m. on June 19, 2016 ending the mission
- Cygnus OA-6 deployed CubeSat experiments on June 20
- Cygnus de-orbited on June 21, 11:29 p.m.

Saffire-I Future Analysis

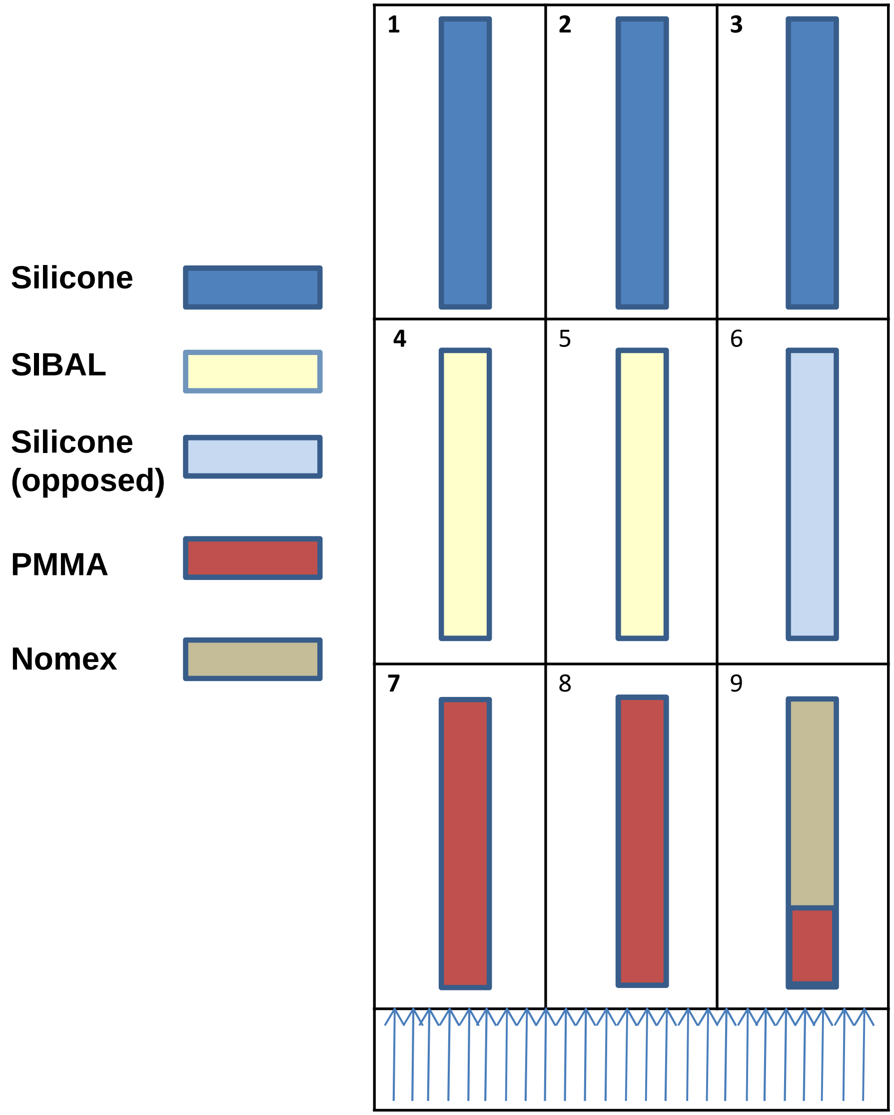
- Location of pyrolysis front, flame base, and flame length vs. time for concurrent and opposed flame spread (rate of flame spread)
- Pulsation frequency of the concurrent flame
- Comparison with computational models of the concurrent and opposed flow flames
- Pressure and temperature rise of the Cygnus vehicle during combustion
- Transport of smoke aerosol in the Cygnus vehicle
- Estimate of the free volume of the Cygnus vehicle
- Impact on operation of Saffire-II and III

- Analyses will be performed by researchers from NASA and the International Topical Team and published in various papers
  - Data will also be posted to NASA Physical Sciences Informatics System (psi.nasa.gov)

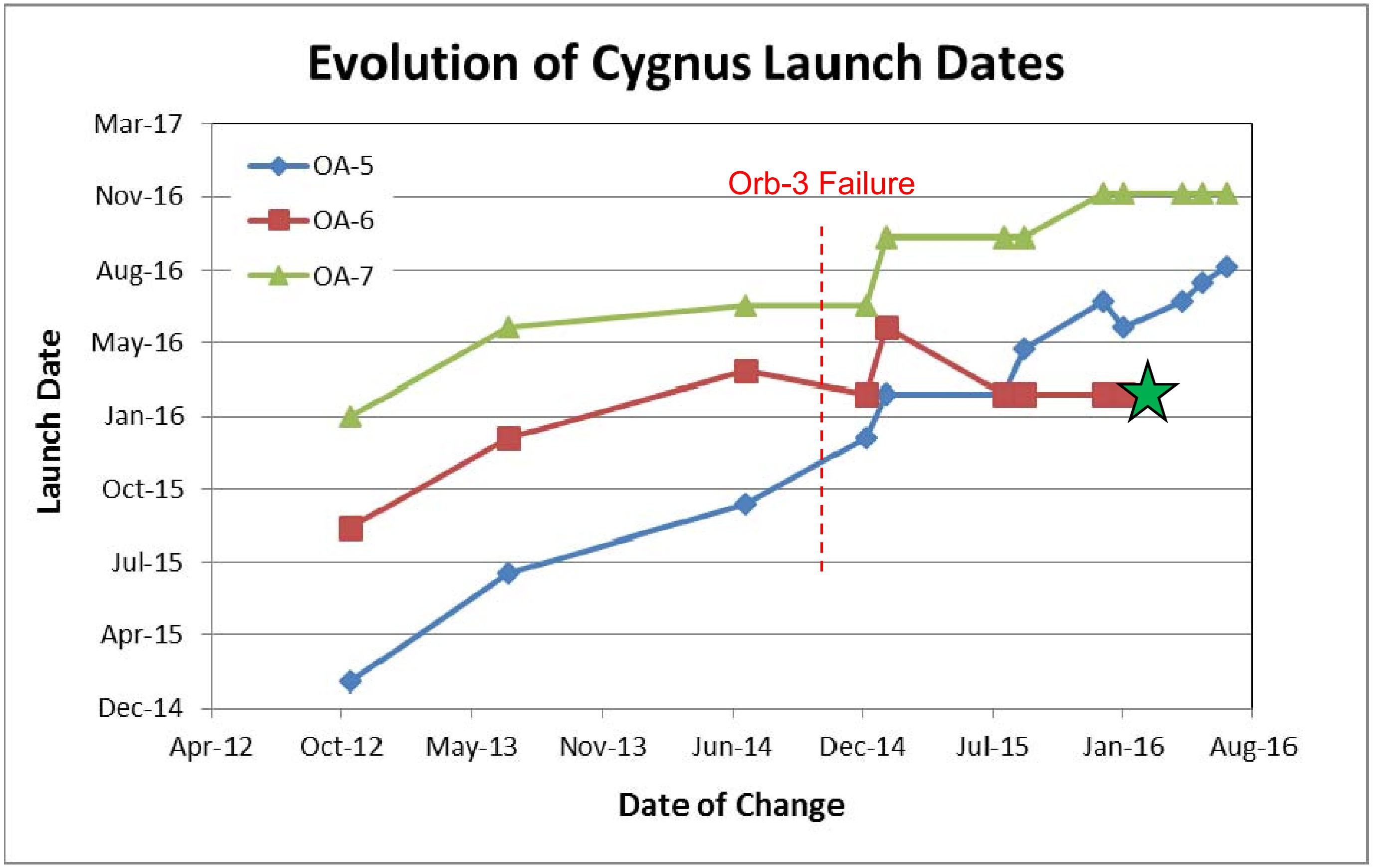
Saffire-II
Samples

- Samples are 5 cm x 29 cm
- Four different sample materials
  - Concurrent and opposed for Silicone
- Motivation
  - Previous low-g data (small scale)
  - Material flammability limits
  - NASA-STD-6001 Test 1
  - Spacecraft fire safety strategy
- Thermocouples mounted on the SIBAL and Nomex samples

- Saffire-III sample material will be the same as Saffire-I
  - Flow will be close to 30 cm/sec as opposed to 20 cm/sec for Saffire-I



Spacecraft Fire Safety Demonstration
Saffire-II and III Launch Dates



- **Orb-3**
  - Launch occurred on October 28, 2014 which would have been its fourth to the International Space Station and the fifth of an Antares launch vehicle
  - Fifteen seconds after liftoff a failure of propulsion occurred in the first stage
- **OA-5 launch NET 8/23 with deberth on September 10 (as of 7/8/2016)**

What's Next for Saffire?

- **Fire Safety System Maturation Team have defined fire safety needs for exploration vehicles**
  - Low and partial-gravity material flammability
  - Fire detection
  - Fire suppression
  - Emergency crew mask
  - Post-fire (combustion product) monitoring
  - Post-fire cleanup
  - Fire scenario modeling and analysis
- **NASA's Advanced Exploration Systems Division has authorized the development of Saffire-IV-VI to address remaining capability and technology gaps**
  - Following the Saffire-I-III flights, conduct additional tests of material flammability but include fire detection, suppression, and clean-up capabilities
  - International Topical Team helping to define science objectives

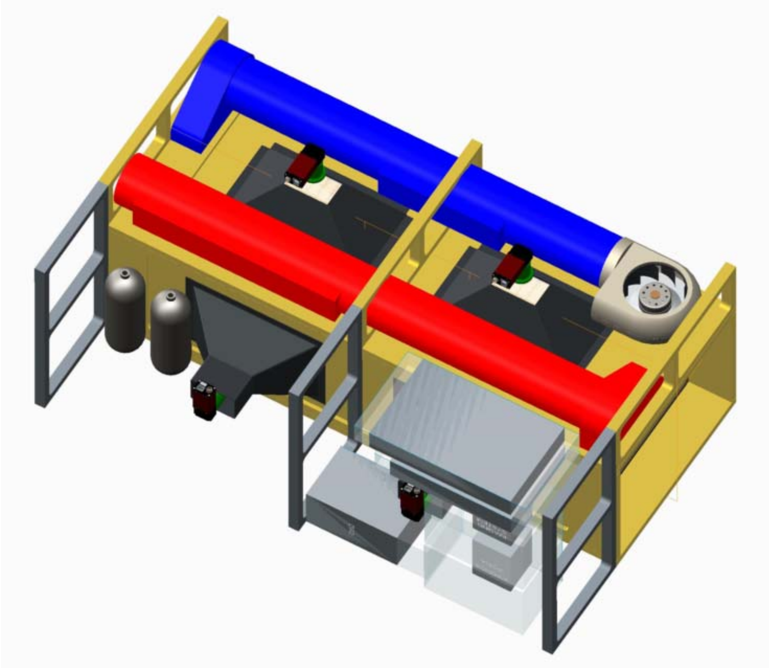
Saffire-IV, V, and VI Overview

Needs:

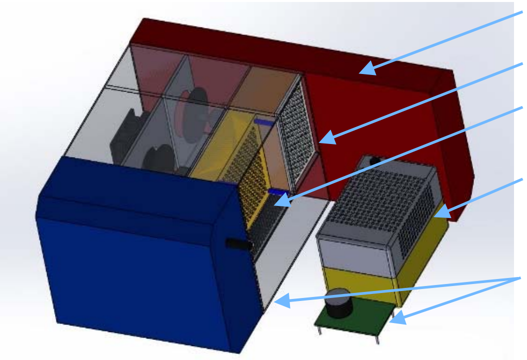
- *Demonstrate spacecraft fire detection, monitoring, and cleanup technologies in a realistic fire scenario*
- *Characterize fire growth in high O_2/low pressure atmospheres*
- *Provide data to validate models of realistic spacecraft fire scenarios*

Objectives:

- *Saffire-IV*: Assess flame spread of large-scale microgravity fire (spread rate, mass consumption, heat release) in exploration atm
- *Saffire-V*: Evaluate fire behavior on realistic geometries
- *Saffire-VI*: Assess existing material configuration control guidelines
- All flights will demonstrate fire detection, monitoring, and cleanup technology

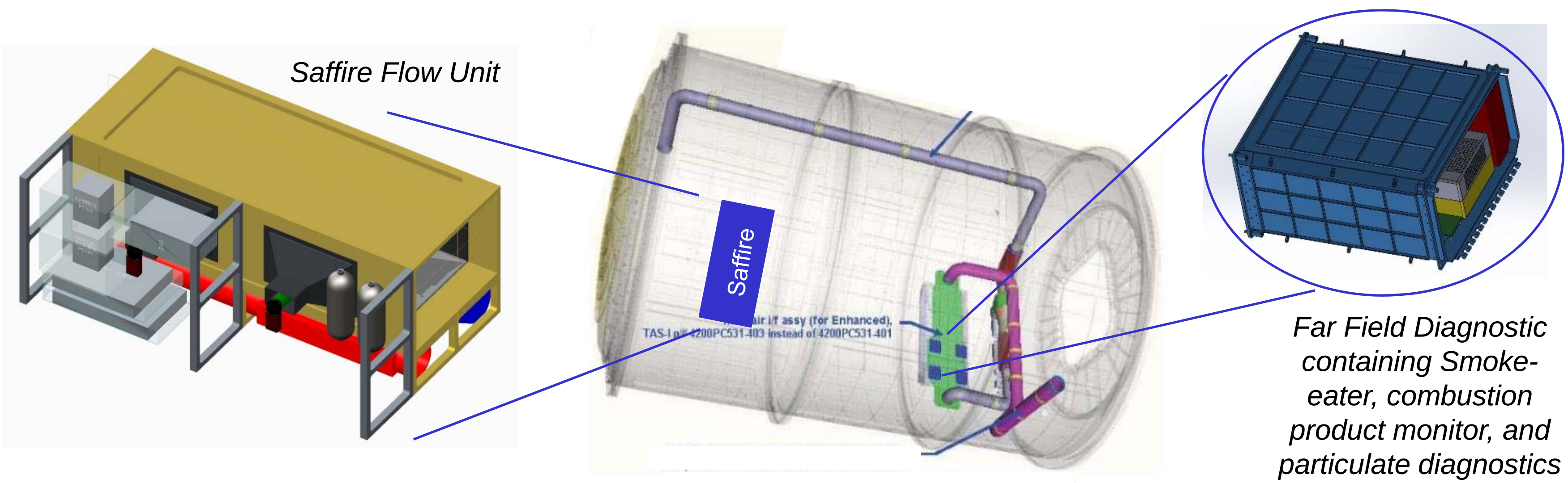


Conceptual design of Saffire-IV-VI experiment module.
Dimensions are approximately 53- by 90- by 133-cm. additions from previous Saffire include side view of sample card and oxygen addition.



Saffire-IV, V, and VI Status

- Conducted a TIM in February 2016 with GRC Project Team and developers of post-fire monitoring and cleanup technologies
  - Set-up regular design meetings with engineering teams
- Developing experiment hardware concept that meets preliminary objectives
- Reviewed Saffire-IV, -V, and –VI with NASA Fire Safety SMT & stakeholders on April 6
  - Strongly supported flammability objectives and gave suggestions for technology demonstration objectives
- Plan to conduct Mission Concept Review/System Requirement Review on August 3
  - CDR in Dec 2015/Jan 2016 timeframe



Spacecraft Fire Safety Demonstration Objectives

Area	Objective	Comment	Saffire-I, II, III	Saffire-IV, V, VI	Ground
Fire behavior/modeling:	Quantify growth and end state of realistic fires in spacecraft and their influence on vehicle habitability	Require to validate computational models	X	X	
Fire growth/dynamics	Flame behavior in complex geometries	More realistic configurations than Saffire-I, II, and III		X	
	Flame behavior for planar and complex geometries in exploration atmospheres	Elevated O_2, lower P; compare with Saffire-I, II, III; supplement small-scale tests in CIR		X	
	Measure flame behavior over large-scale planar surfaces	Continues Saffire-I and III investigations	X	X	
Post-fire monitoring	Demonstrate performance of prototype Orion and ISS CPM	Demonstration of prototype flight hardware		X	X
Fire Detection	Obtain data to validate transport and detection models	Required for model development		X	X
	Demonstrate fire detection with multi-moment sensors	Demonstrate capability to reject nuisance alarms			X
	Evaluate performance of hybrid fire detection (smoke and gaseous products)	Combustion product detection by prototype combustion product monitor			X
Post-fire monitoring	Quantify rate of decay of gas species after a spacecraft fire	Required for model development		X	X
Post-fire cleanup	Quantify atmosphere cleanup rate with prototype smoke-eater	Demo of prototype flight hardware		X	X
Fire Suppression	Performance of low-momentum water mist suppression	Effectiveness of fire ports using water mist fire suppression			X

BACKUP

Summary of Spacecraft Fire Safety Needs

Technical Area	Tech Goal addressed	Gap
Low- and partial-gravity Material Flammability	Accurate definition of the risk from material flammability in low-g (identify material flammability limits in low-g environment)	• Quantification of risk from NASA-STD- 6001 Test 1 normal-g data • Growth rate of fire hazard
Fire Detection	Common fire detectors for exploration. Early fire detection from structurally integrated distributed sensors	• Particle size discrimination • Adaptation of state-of-art technology
Fire Suppression	ECLS-compatible and re-chargeable fire extinguisher	• Scaling to vehicle • Size of critical fire
Emergency Crew Mask	Emergency breathing apparatus with filtering respirator	• Flame resistant • One size fits all • Can be donned in 5 sec • Resists chemical breakthrough
Post-fire (combustion product) monitoring	Contingency air monitor for relevant chemical markers of post-fire cleanup	• Measurement of CO, CO_2, HF, HCl, HCN • Battery-operated • Hand-held • Calibration duration 1-5 years
Post-fire/leak Clean-up	Contingency air purifier for post-fire and leak cleanup	• Stand-alone • Low (integrated) power, low mass/volume
Fire Scenario Modeling and Analysis	Definition of a realistic spacecraft fire to size	• Validated models of impact of a large scale fire on the spacecraft volume and cabin conditions • Analysis to size fire suppression and cleanup equipment based on vehicle parameters

Saffire

NASA

NASA