
National Aeronautics and Space Administration
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NASA Flight Opportunities
Advancing NASA Technology Priorities: Cryogenic Fluid Management
Florian Chavagnat, Ph.D. Candidate, Massachusetts Institute of Technology (MIT)
Jason Hartwig, Ph.D., Research Aerospace Engineer, NASA's Glenn Research Center
Alexander Van Dijk, Technologist, NASA's Flight Opportunities program
Community of Practice Webinar Series – January 4, 2023
Session will start at 10 a.m. PT – Please mute your microphone and turn off your camera
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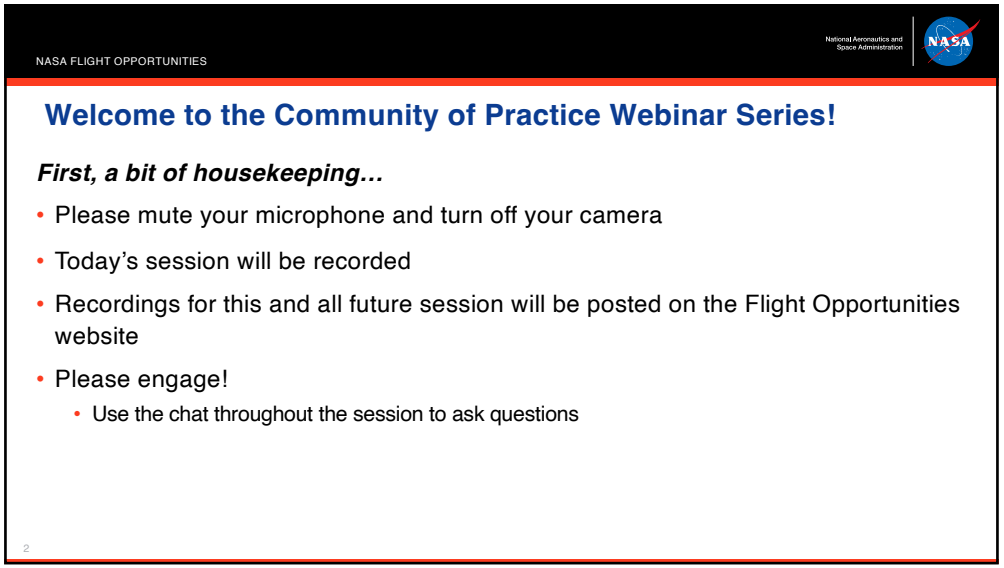
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Welcome to the Community of Practice Webinar Series!
First, a bit of housekeeping…
Please mute your microphone and turn off your camera
Today's session will be recorded
Recordings for this and all future session will be posted on the Flight Opportunities website
Please engage!
Use the chat throughout the session to ask questions
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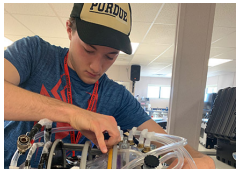
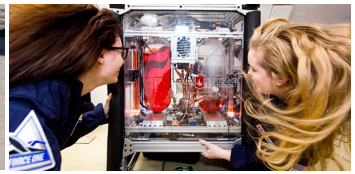
Flight Opportunities Mission

The Flight Opportunities program facilitates **rapid demonstration** of promising technologies for space exploration, discovery, and the expansion of space commerce through **suborbital testing with industry flight providers**.





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Join us for future Community of Practice webinars!

Watch our website and newsletter for next month's topic

nasa.gov/directorates/spacetech/flightopportunities/newsletter

Future webinars

- Webinars are held 1st Wednesday of each month at 10 a.m. PT
- Topics will be announced in the Flight Opportunities newsletter and website
- Session recordings will be posted on the Flight Opportunities website
- Let us know session topics you would like to see covered

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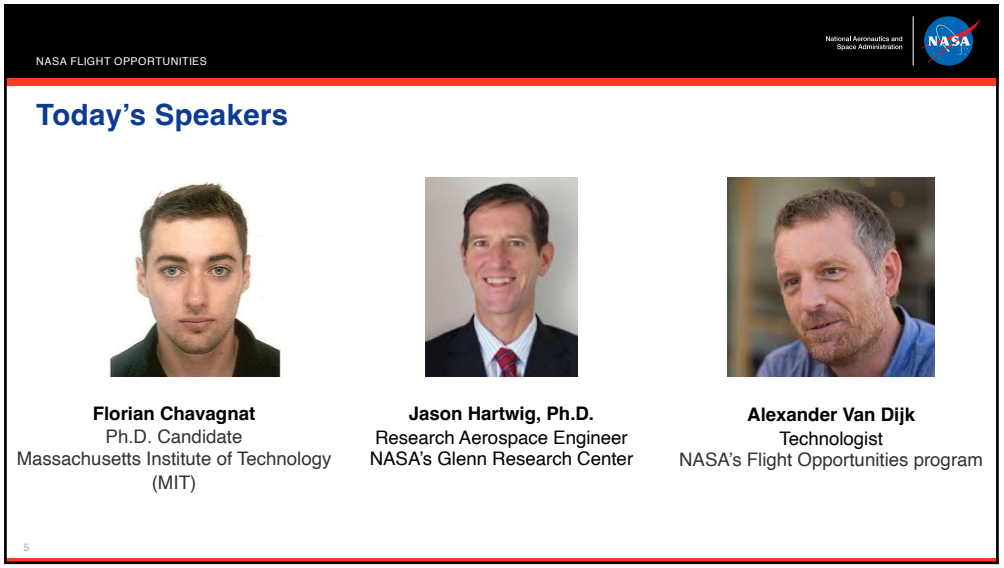
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Today's Speakers
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NASA's Glenn Research Center
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Technologist
NASA's Flight Opportunities program
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January 2023 I Florian Chavagnat
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Multiphase closure modeling development for application to cryogenic boiling

January 4th Presentation

Florian Chavagnat
Massachusetts Institute of Technology
Department of Nuclear Science and Engineering

RESEARCH MOTIVATIONS

- **Two major development pathways to extend the range of cryogenic engines**

Orbital fuel depots

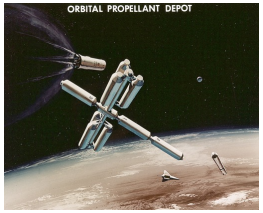


Figure: Concept of cryogenic orbital fuel/oxidizer depot by NASA (1971)

In-space re-ignitable engines

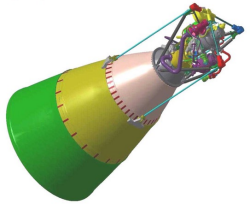


Figure: Vinci ESA cryogenic rocket engine with re-ignition capability delivering on multiple orbits

In-Situ Propellant Production

Figure: Moon production of cryogenic propelant

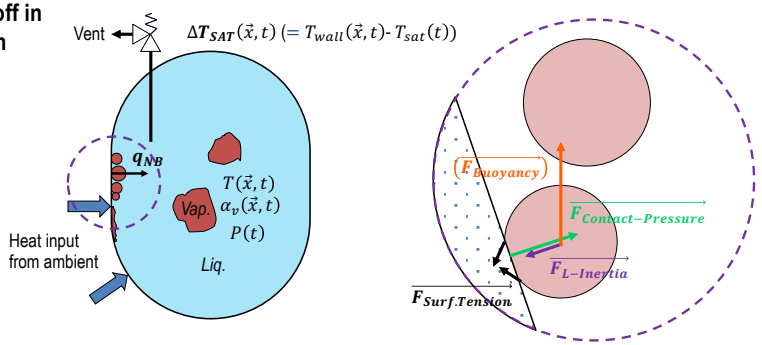
RESEARCH MOTIVATIONS

- How to estimate $q_{NB} = f(\Delta T_{SAT})$, in particular in microgravity?

Buoyancy-driven bubble departure, doesn't apply in micro-gravity!

$$\frac{q_{NB}}{\Delta T_{SAT}} \propto \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \Delta T_{SAT}{}^2$$

Case of boil-off in a tank (e.g., in microgravity)



HEAT FLUX PARTITIONING MODEL (HFP)

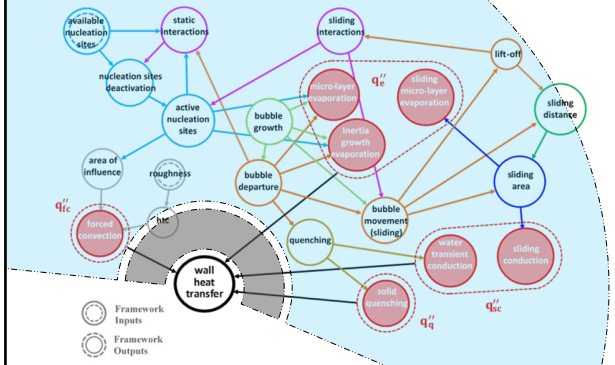
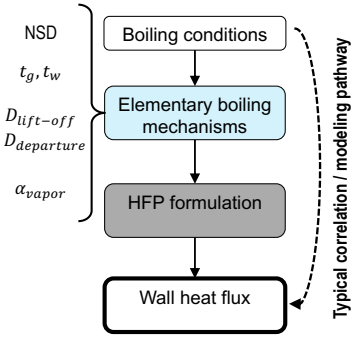
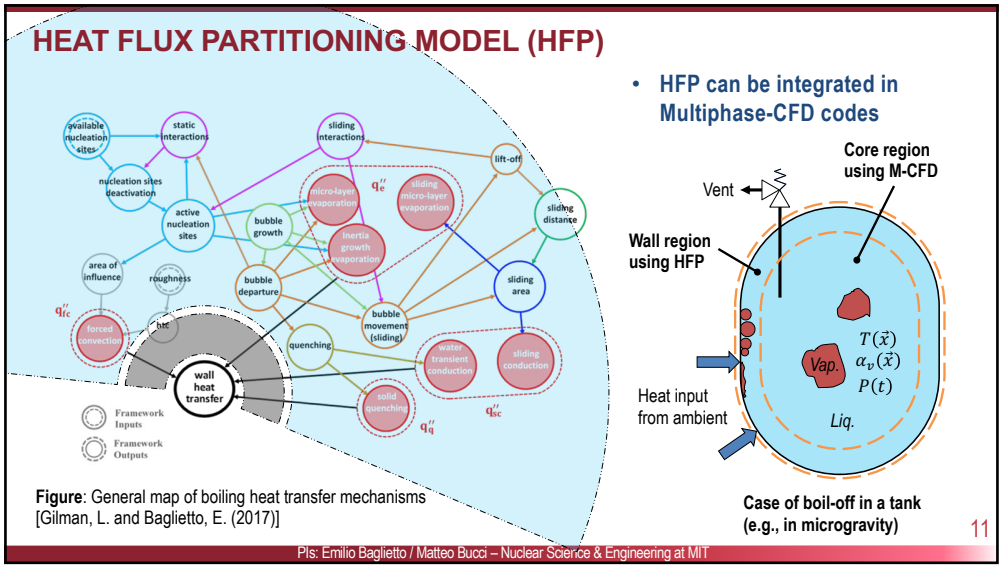


Figure: General map of boiling heat transfer mechanisms [Gilman, L. and Baglietto, E. (2017)]

- HFP similar to "divide and conquer" method




HEAT FLUX PARTITIONING MODEL (HFP)
available nucleation sites
static interactions
sliding interactions
lift-off
nucleation sites deactivation
micro-layer evaporation
sliding micro-layer evaporation
sliding distance
active nucleation sites
bubble growth
inertia growth evaporation
area of influence
roughness
bubble departure
sliding area
forced convection
htc
bubble movement (sliding)
quenching
water transient conduction
sliding conduction
wall heat transfer
solid quenching
Framework Inputs
Framework Outputs
• HFP can be integrated in Multiphase-CFD codes
Core region using M-CFD
Vent
Wall region using HFP
Heat input from ambient
Vap.
Liq.
Case of boil-off in a tank (e.g., in microgravity)
Figure: General map of boiling heat transfer mechanisms [Gilman, L. and Baglietto, E. (2017)]
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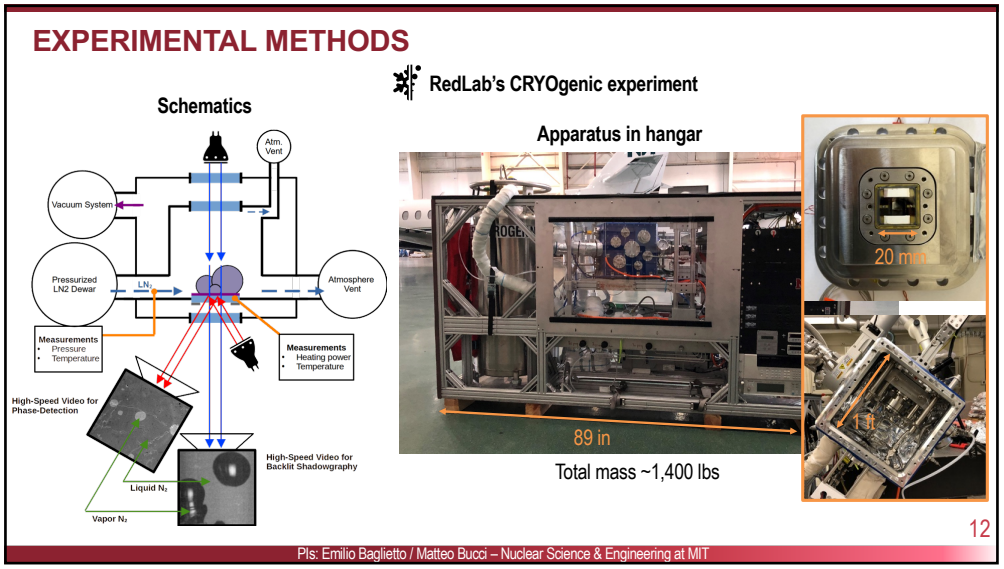
EXPERIMENTAL METHODS
Schematics
Atm. Vent
Vacuum System
Pressurized LN2 Dewar
Atmosphere Vent
Measurements
Pressure
Temperature
Measurements
Heating power
Temperature
High-Speed Video for Phase-Detection
High-Speed Video for Backlit Shadowgraphy
Liquid N2
Vapor N2
RedLab's CRYOgenic experiment
Apparatus in hangar
89 in
20 mm
1 in
Total mass ~1,400 lbs
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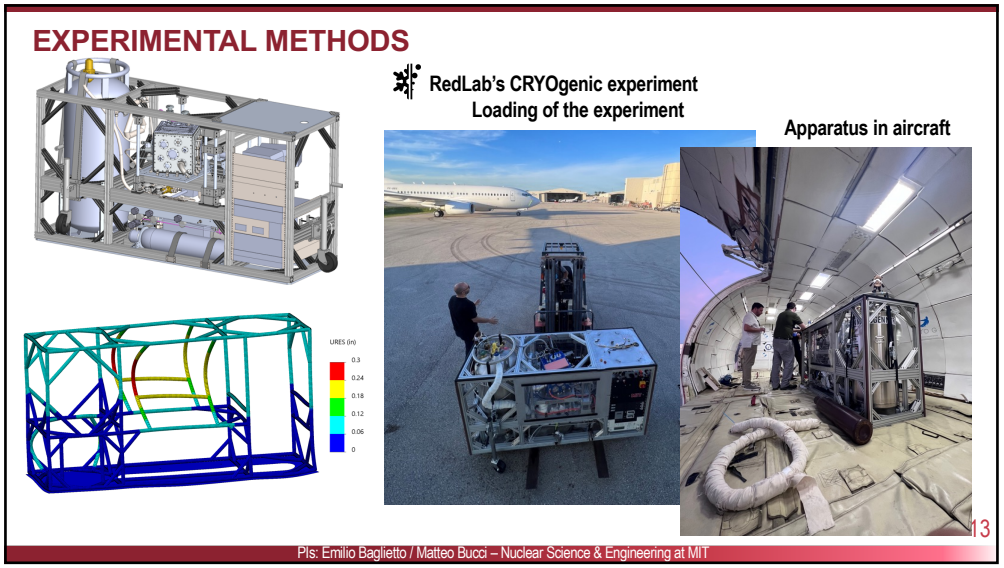
EXPERIMENTAL METHODS
RedLab's CRYOgenic experiment
Loading of the experiment
Apparatus in aircraft
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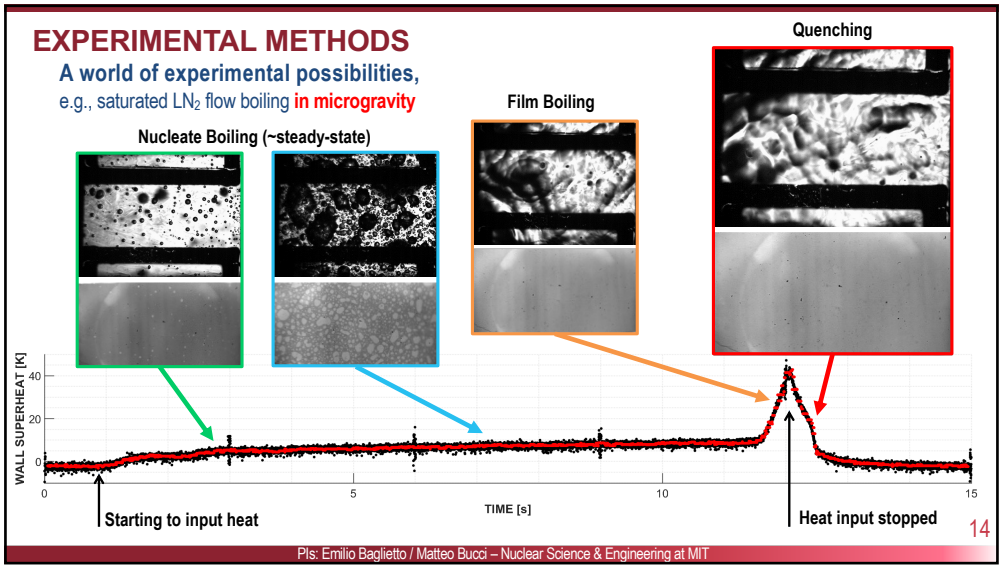
EXPERIMENTAL METHODS
A world of experimental possibilities,
e.g., saturated LN_2 flow boiling in microgravity
Nucleate Boiling (~steady-state)
Film Boiling
Quenching
WALL SUPERHEAT [K]
TIME [s]
Starting to input heat
Heat input stopped
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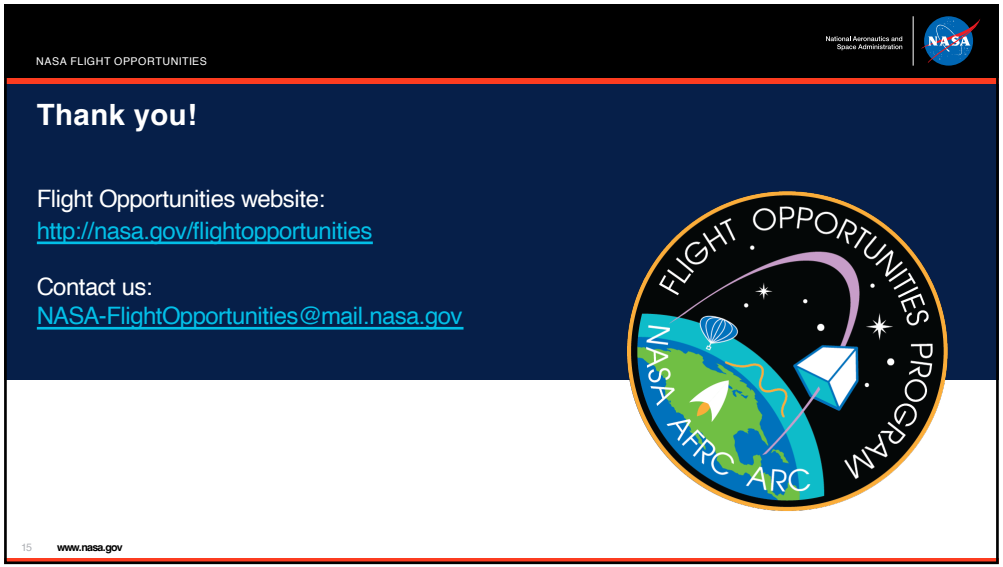
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