A Researcher-Tended Suborbital Experiment

Robert Ferl
Anna-Lisa Paul

UF | UNIVERSITY of FLORIDA

UF Space Plants Laboratory

https://hos.ifas.ufl.edu/spaceplantslab/
A-L Paul & R.J. Ferl

NATIONAL ACADEMIES
Sciences
Engineering
Medicine

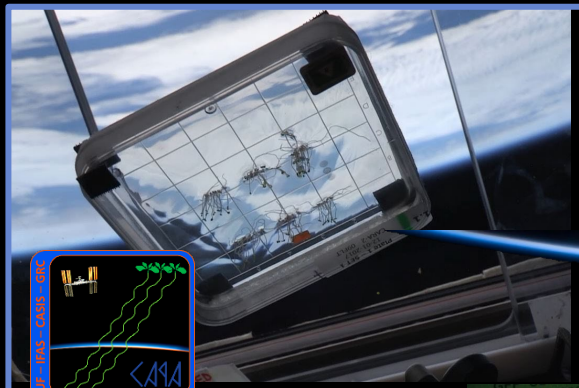
CBPSS October 9, 2024

UF Space Plants Laboratory

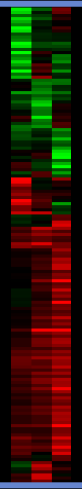
Plant responses to novel environments…
Insights relevant to Space exploration

- Sustained micro-*g* on the ISS
- Transient micro-*g* on
- Mixed experience on automated suborbital
- exploring the transition

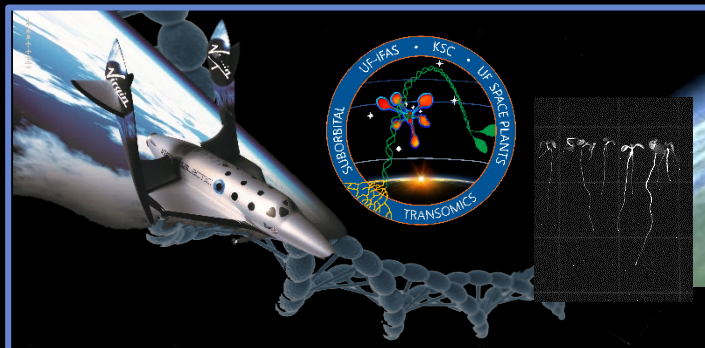
Orbital (ISS)

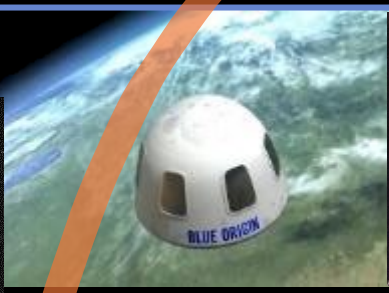


Flight Analogs



Parabolic and
F104 aircraft





Suborbital - Virgin Galactic and Blue Origin
6 experiments between 2018-2024

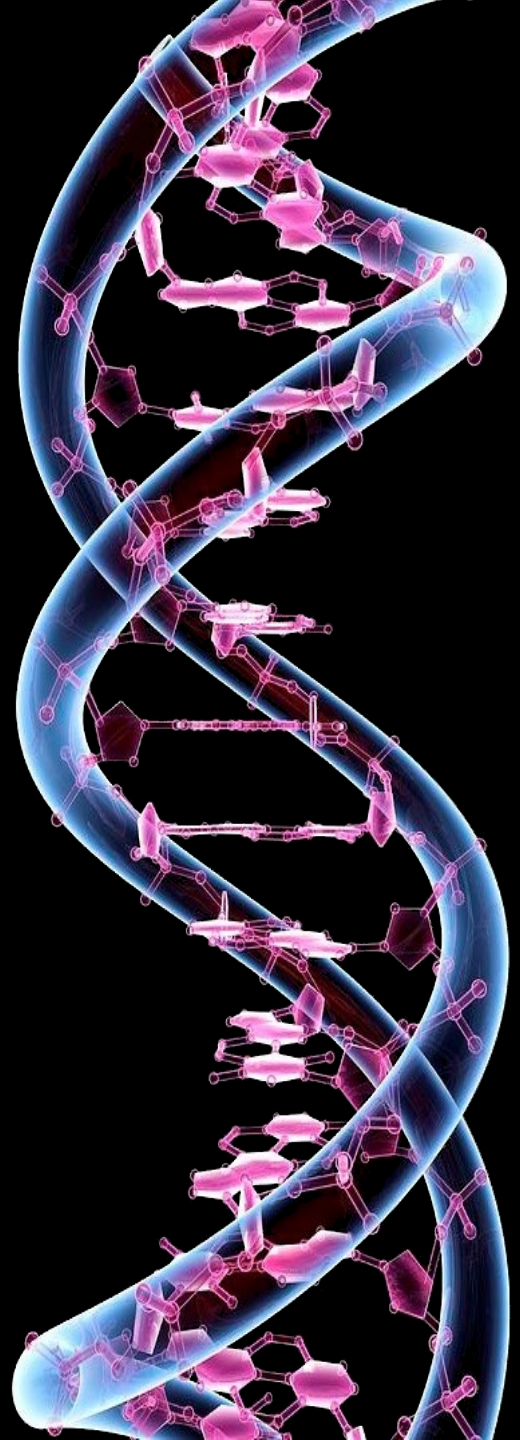
Fluorescent Imaging for Ca-mediated signal transduction and reporter gene redistribution, and post-flight transcriptomes

Spaceflight Experiments

Two basic kinds of data:

Collecting informative imaging on orbit

Harvesting and preserving on orbit for subsequent analyses

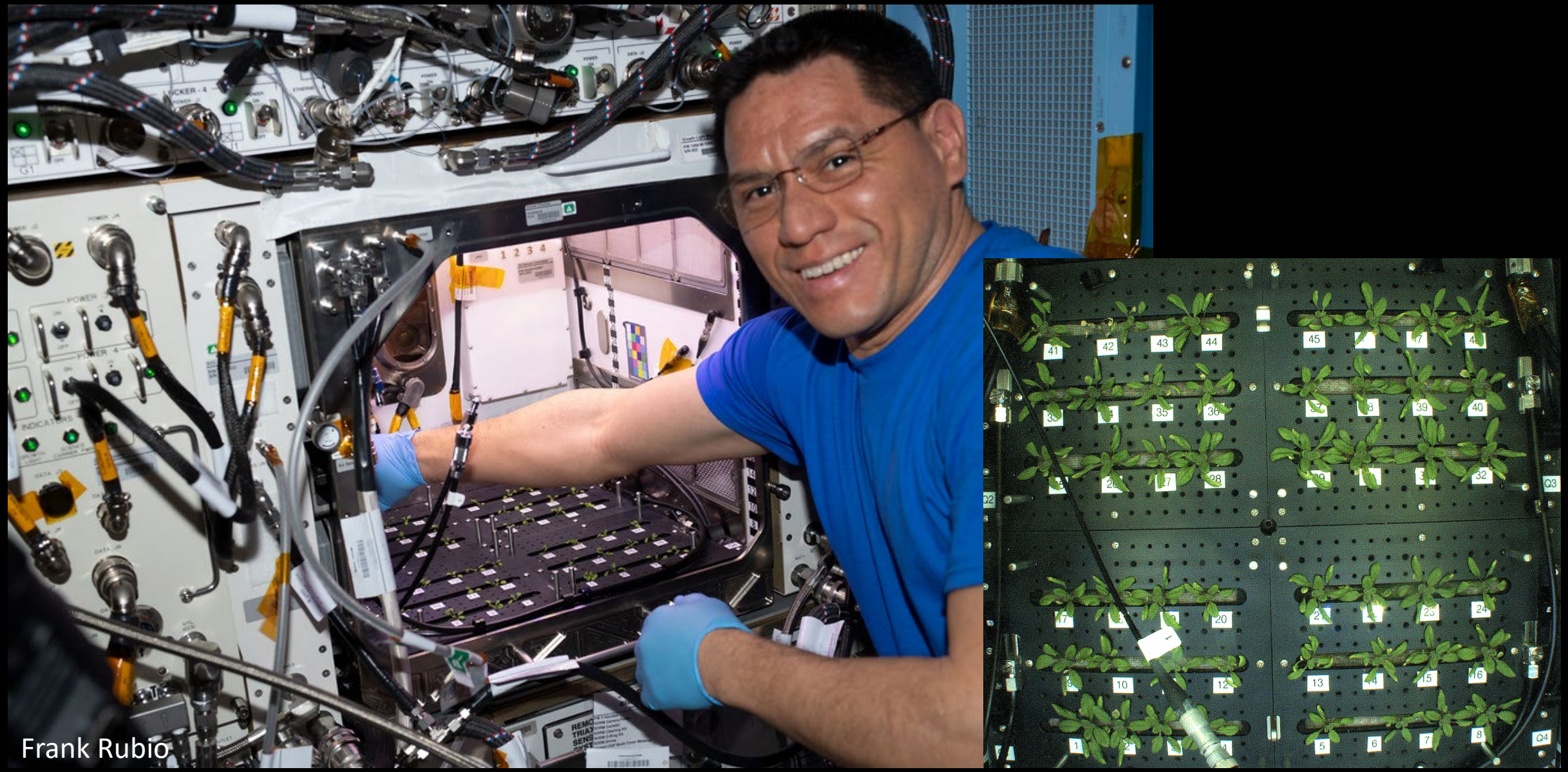


Both approaches require a crew member to conduct the experiment for the researcher who proposed it.

Peggy Whitson

Spaceflight Epigenome – (EpEX / APEX-04)

Spaceflight Epigenetics– (EpEX-2 / PH03)



Frank Rubio

Researchers train astronauts to conduct their experiment.





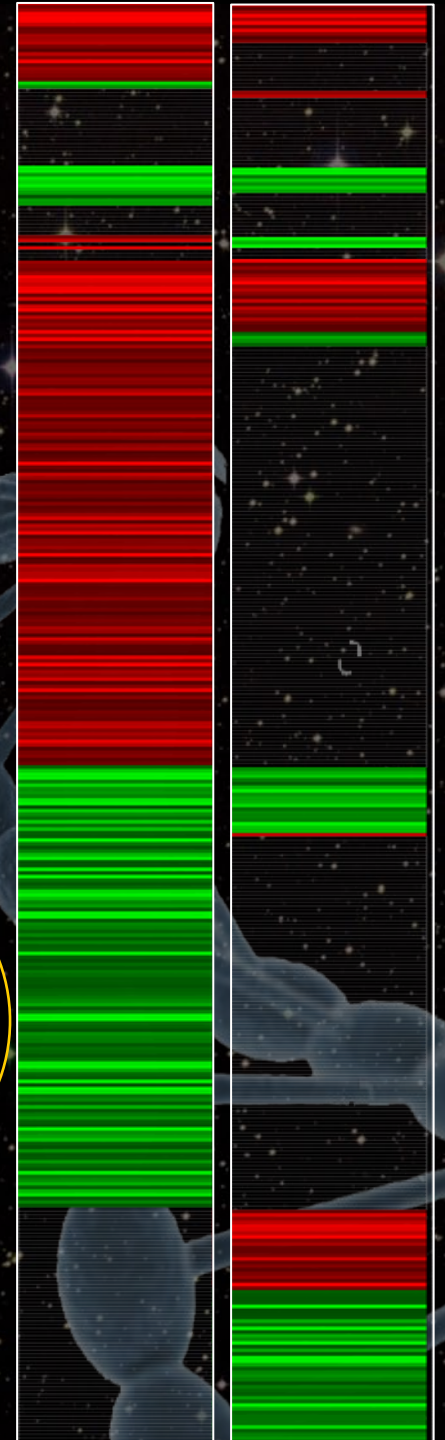

Platforms accessible for researchers:

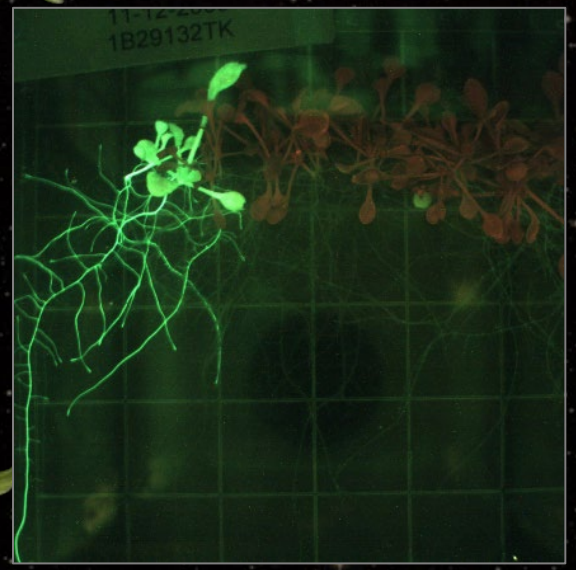
- Parabolic aircraft
- Performance jets
- Other research vessels and exploration environments

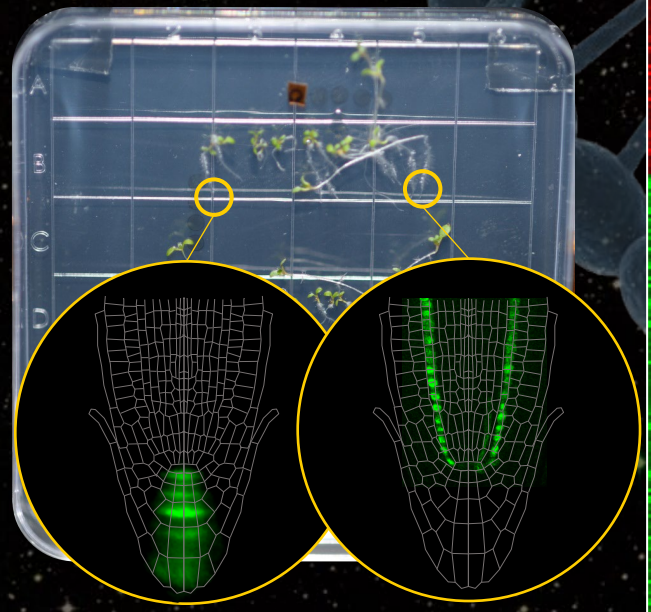
F104 Video

RGF (AT5G64770)

XTH12 (AT5G57530)



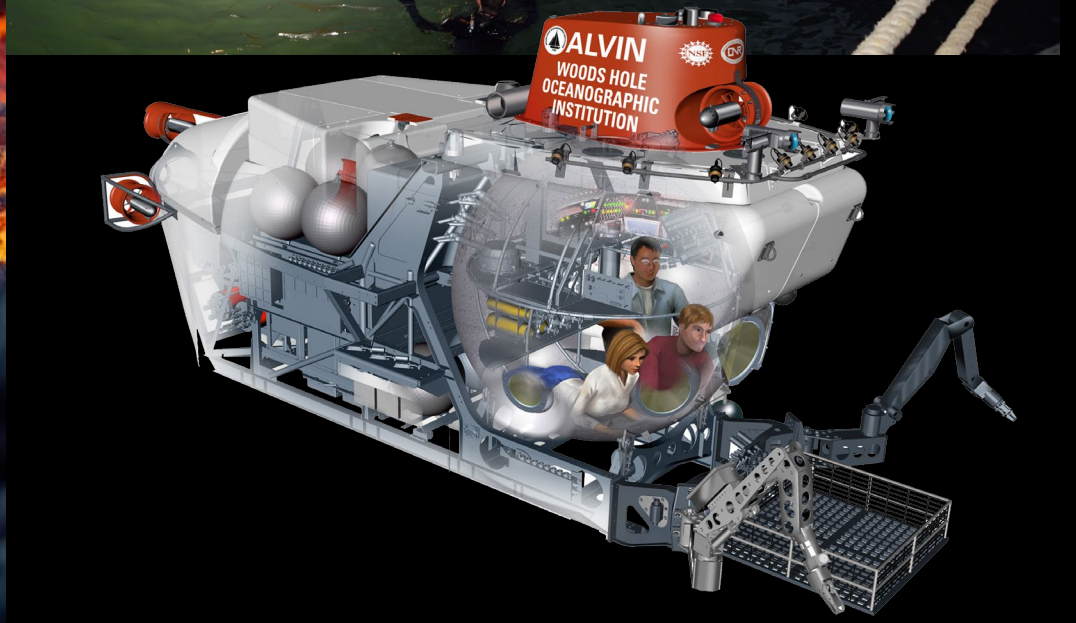




The kinds of data we get back…

Research in challenging environments require specialized tools and protocols –

Technology Development

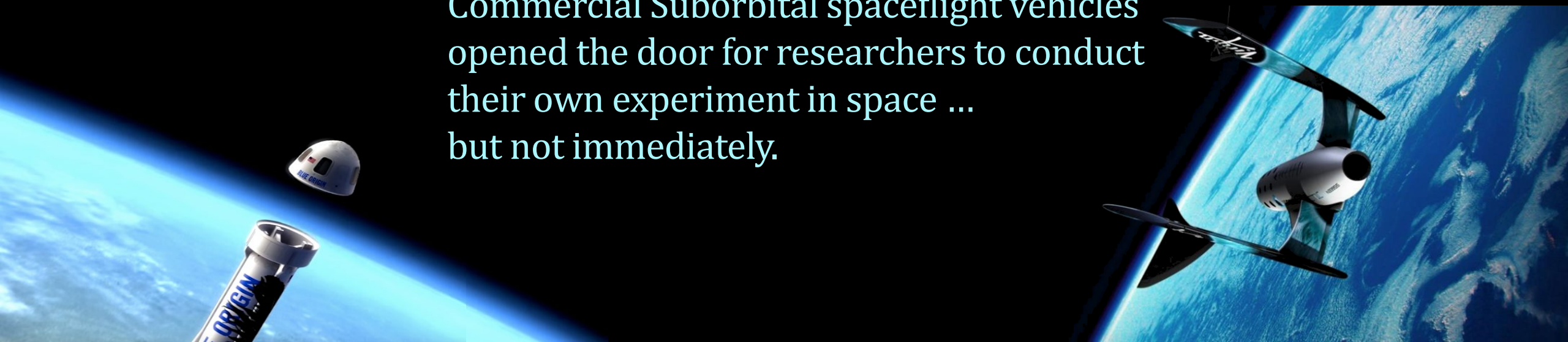


Technology Development for Research on Suborbital Vehicles

- Science in modern commercial suborbital vehicles (CSV) is young – since about 2018
- All early science was automated / autonomous
  - Imaging data over the course on the flight
  - And accumulated impact of the environment

- Early CSVs were not designed for humans – just payloads
- Then CSVs that were designed for humans, were not designed for science payloads

Commercial Suborbital spaceflight vehicles opened the door for researchers to conduct their own experiment in space …
but not immediately.



A Proposal to NASA FO for Human-Tended Research in Suborbital Vehicles

Robert Ferl and Anna-Lisa Paul,
University of Florida, Gainesville

Technology demonstration of Kennedy Space Center Fixation Tubes on a suborbital vehicle that could be used to study gene expression changes during transition from Earth gravity to microgravity and better understand flight effects on organisms.

The launch providers will be **Blue Origin** and **Virgin Galactic.**

NASA Flight Opportunities Program grant #80NSSC18K1294

Human Tended Space Biology: Tools for Suborbital Genomics and Gene Expression

Technology Need

The successful application of a simple, hand-held, human-deployed device that can be used to fix time-critical bio samples in flight.

- Current ISS- and performance aircraft-proven hardware is the Kennedy Space Center Fixation Tube (KFT)
- The rapid-deployment of KFT by suborbital crew is needed to fill the gap in knowledge of how organisms initiate physiological adaptation to the spaceflight environment

Technology Concept

The small, self-contained fixation tube (the KFT) is designed to be rapidly deployed by crew to preserve biological material at investigation critical time points in flight.

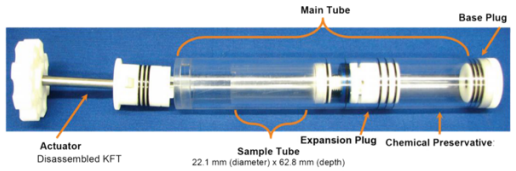
- KFTs are pocket-sized and can be stowed in crew flight suit or other easily accessible stowage deployed by vehicle crew

Technology Development Team

PI – Dr. Robert J. Ferl
CoPI – Dr. Anna-Lisa Paul
Interdisciplinary Center for Biotech Research
Horticultural Sciences, Plant Molec. and Cell Bio
University of Florida, Gainesville FL

Test Apparatus

Standard KFT hardware pre-loaded with biological samples and primed for optimal deployment speed by vehicle crew member at the experiment-relevant time points designated by Research Team.



Flight Requirements/Objectives

Two Flights

- Preflight, tubes pre-loaded with plants and fixative, and then sealed (three layers of containment of liquid)
- Loaded tubes handed to flight crew, who stows them in accessible area
- Crew activates hardware at three critical stages of flight: 1*g* before boost, beginning of zero *g*, end of zero *g*, and then at the end of flight

Technology Advancement

1. **Expands the utilization of spaceflight hardware into suborbital application to collect heretofore impossible biological data from this transitional environment.**
2. **This application enables the elucidation of the gravity transition transcriptome, which is completely unknown.**

Technology End Users

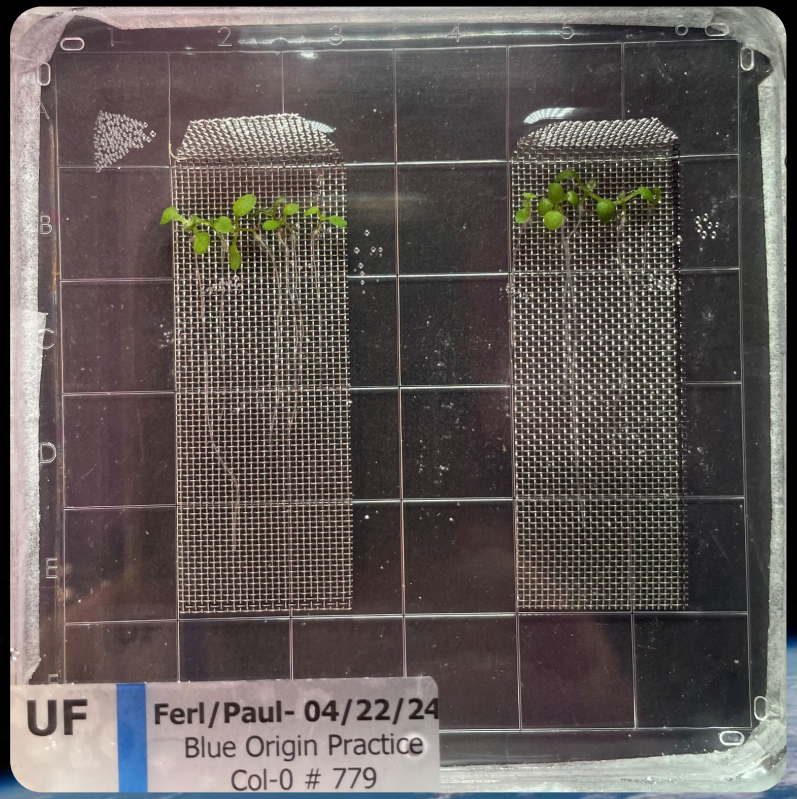
Any biological researcher interested in capturing molecular and structural changes in an organism in the transition from variable gravity environments. KFTs used in this way could also have applications in material sciences and fluid physics.

Technology Area: Human Health, Life Support, and Habitation Systems

Submitted November 2017

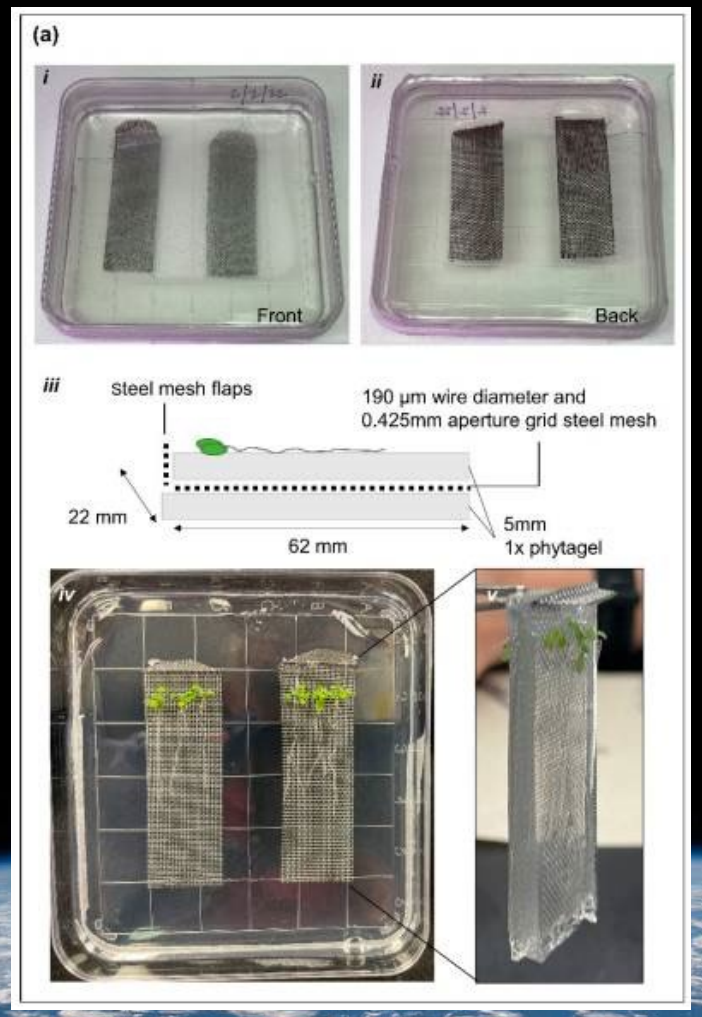
Developing the technology to capture molecular-level change in transit

Modified KFTs to act as benign transient, plant growth habitats



Haveman NJ, Zhou M, Callaham J, Strickland HF, Houze D, Manning-Roach S, Newsham G, Paul AL, Ferl RJ (2022) *Utilizing the KSC Fixation Tube to Conduct Human-Tended Plant Biology Experiments on a Suborbital Spaceflight*.

Life (Basel) 12 (11). doi:10.3390/life12111871



The First Human-Tended research on a Suborbital Vehicles

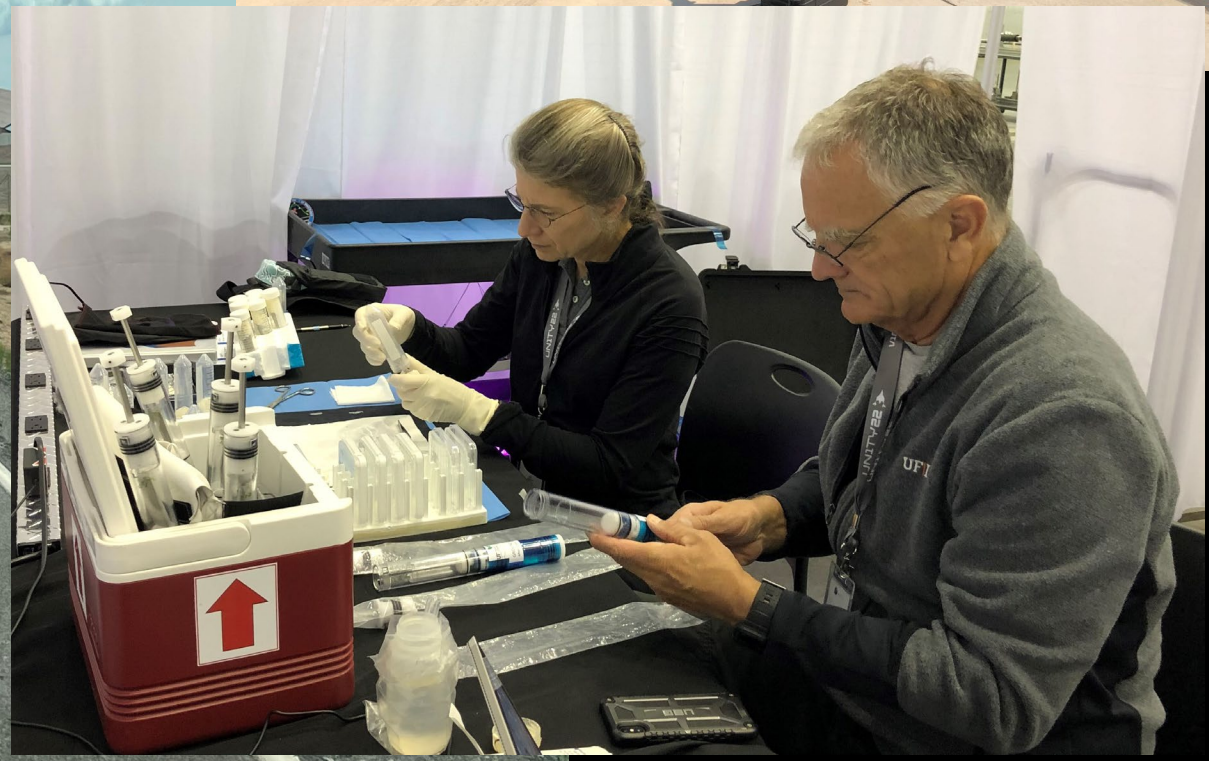
Virgin Galactic *VSS Unity* 22 mission, 11 July 2021

The human tending was VG Crew Sirisha Bandla

Human-Tended VSS Unity 22

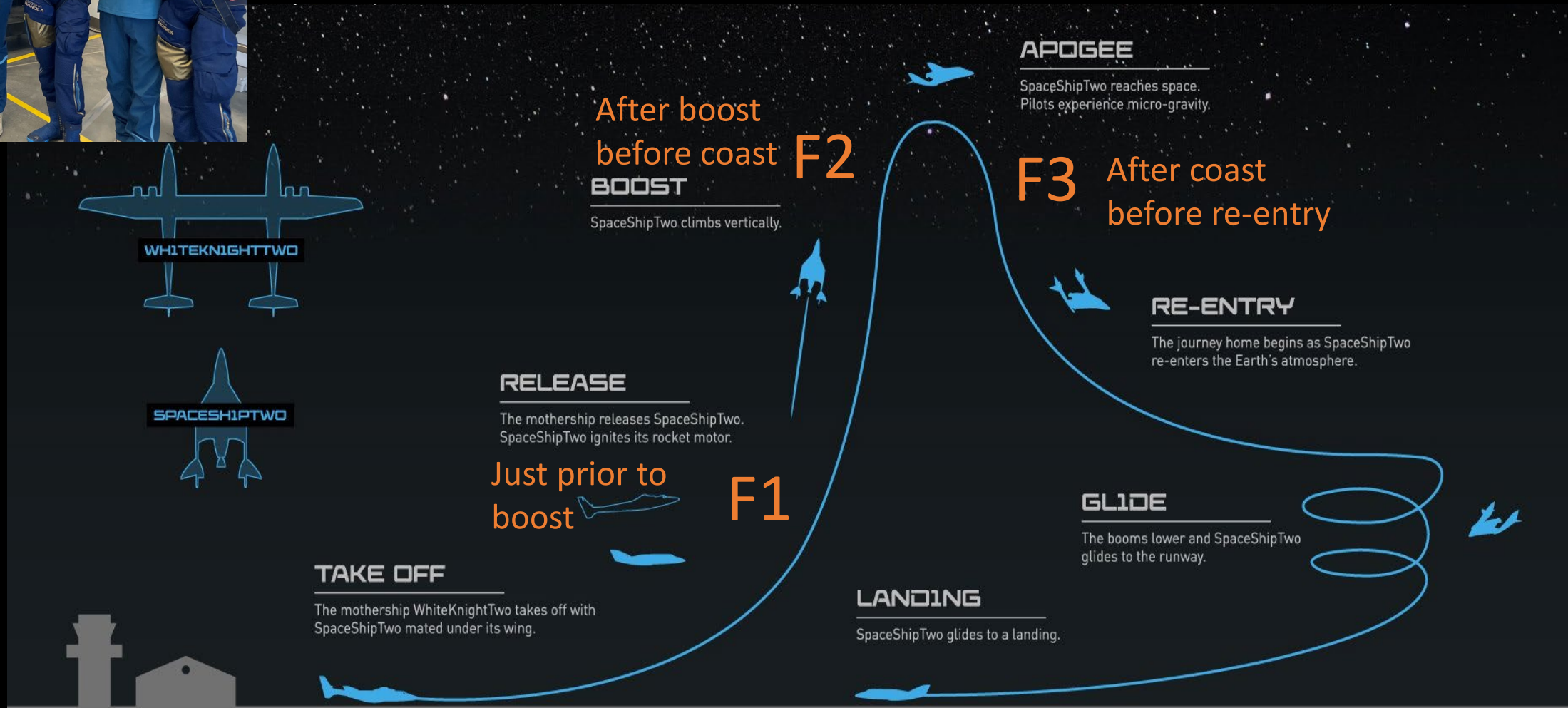
Prepping for a remote-location experiment -

You bring your lab with you



VSS Unity 22
Flight crew
and our
support folks
(in light blue)

Science Question:
Primary physiological adaptation vs long term acclimation
First few minutes and seconds in space is unexplored territory



VSS Unity 22 Flight Profile
KFTs with activated at F1, F2, F3, and on the ground

G Ground control

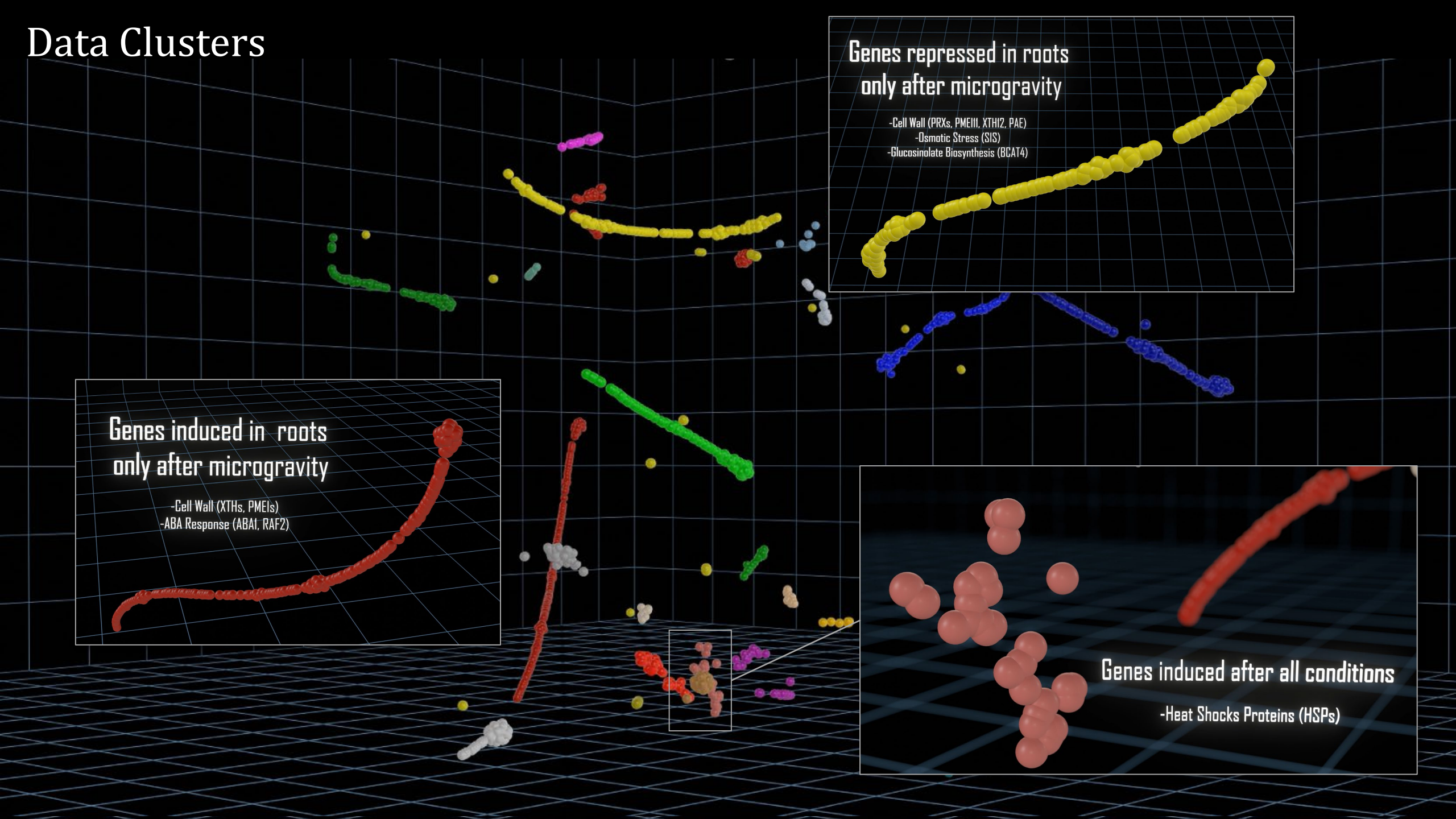

Human-Tended *VSS Unity 22*

Human-Tended *VSS Unity 22*
Data and Lessons Learned

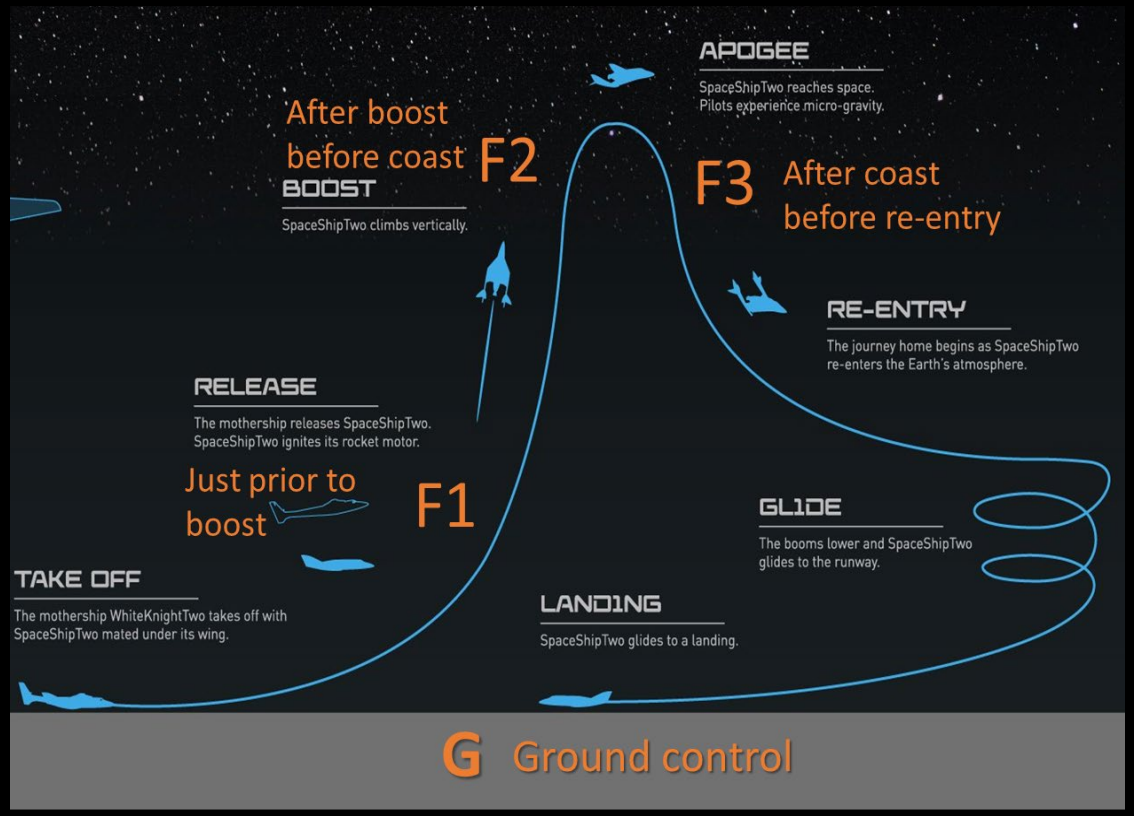
- Pre-flight environment considerations – it was hot
- Ground Control ops coordination – comms
- In-flight crew operations

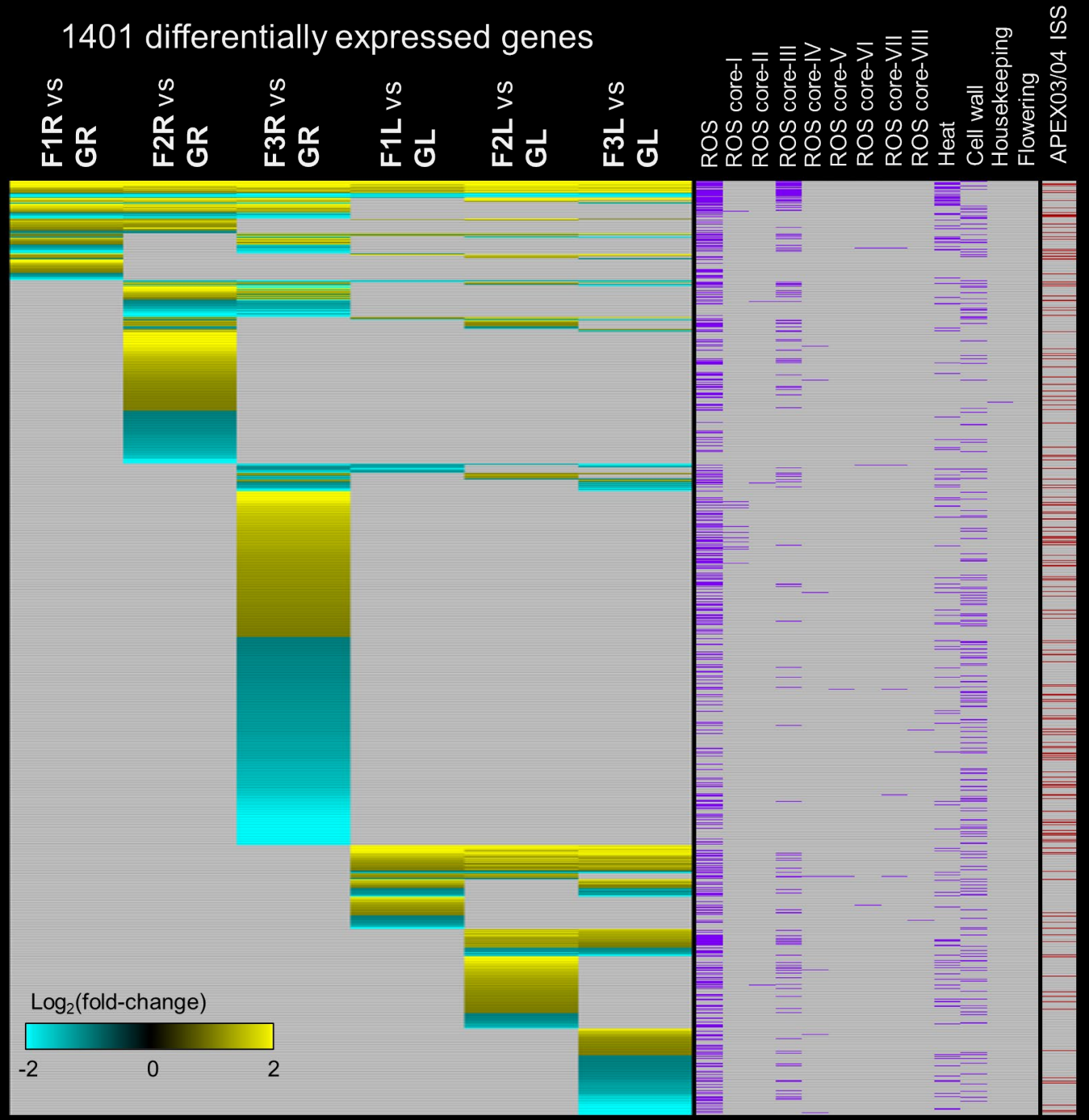
Data Clusters

Data Clusters



Transcriptome data from each timepoint compared to Ground Controls





Ferl RJ, Zhou M, Strickland HF, Haveman NJ, Callaham JB, Bandla S, Ambriz D, Paul AL (2023) *Transcriptomic dynamics in the transition from ground to space are revealed by Virgin Galactic human-tended suborbital spaceflight*.

NPJ Microgravity 9 (1):95. doi:10.1038/s41526-023-00340-w

The First Researcher-Tended experiment on a Suborbital Vehicle

Blue Origin NS-26 / H8 mission, 29 August 2024

The human tending this experiment was one of the PI's
- Rob Ferl

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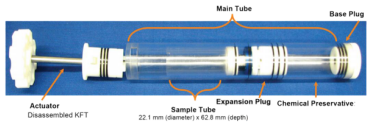

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Technology Area: Human Health, Life Support, and Habitation Systems

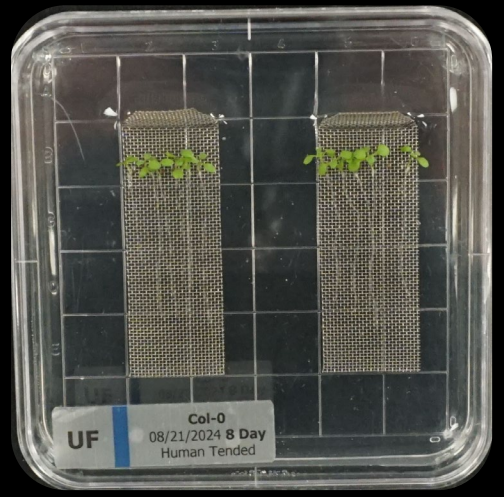
Submitted November 2017

NASA original Flight Opportunities Program Technology Development grant #80NSSC18K1294, Plus, BPS support for conducting transcriptomics on Blue Origin flight.

Researcher-Tended Blue NS-26

Replicated experimental design
Precisely coordinated ground controls
Extensive preparations and practice

- KFTs as a wearable payload
- Experimental design to minimize extraneous stimuli in flight ops
- Four time points
  - 2 KFTs per timepoint
  - 8-10 plants per KFT
- Four time-coordinated ground controls
  - 2 KFTs per timepoint
  - 8-10 plants per KFT



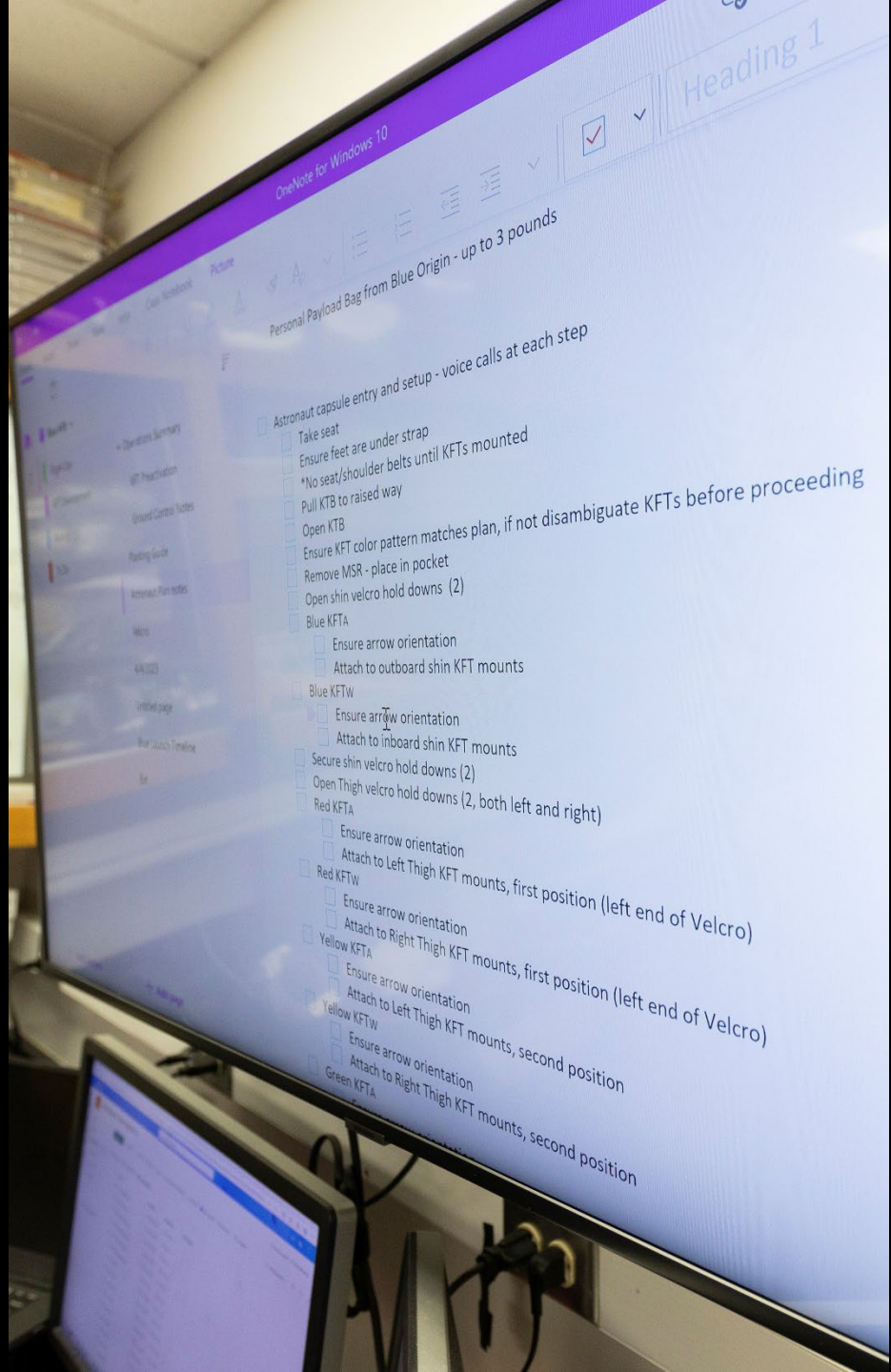
Unique equipment, biology format, and tools

FIRST: Practice and operations at the Blue Origin West Texas Launch Facility

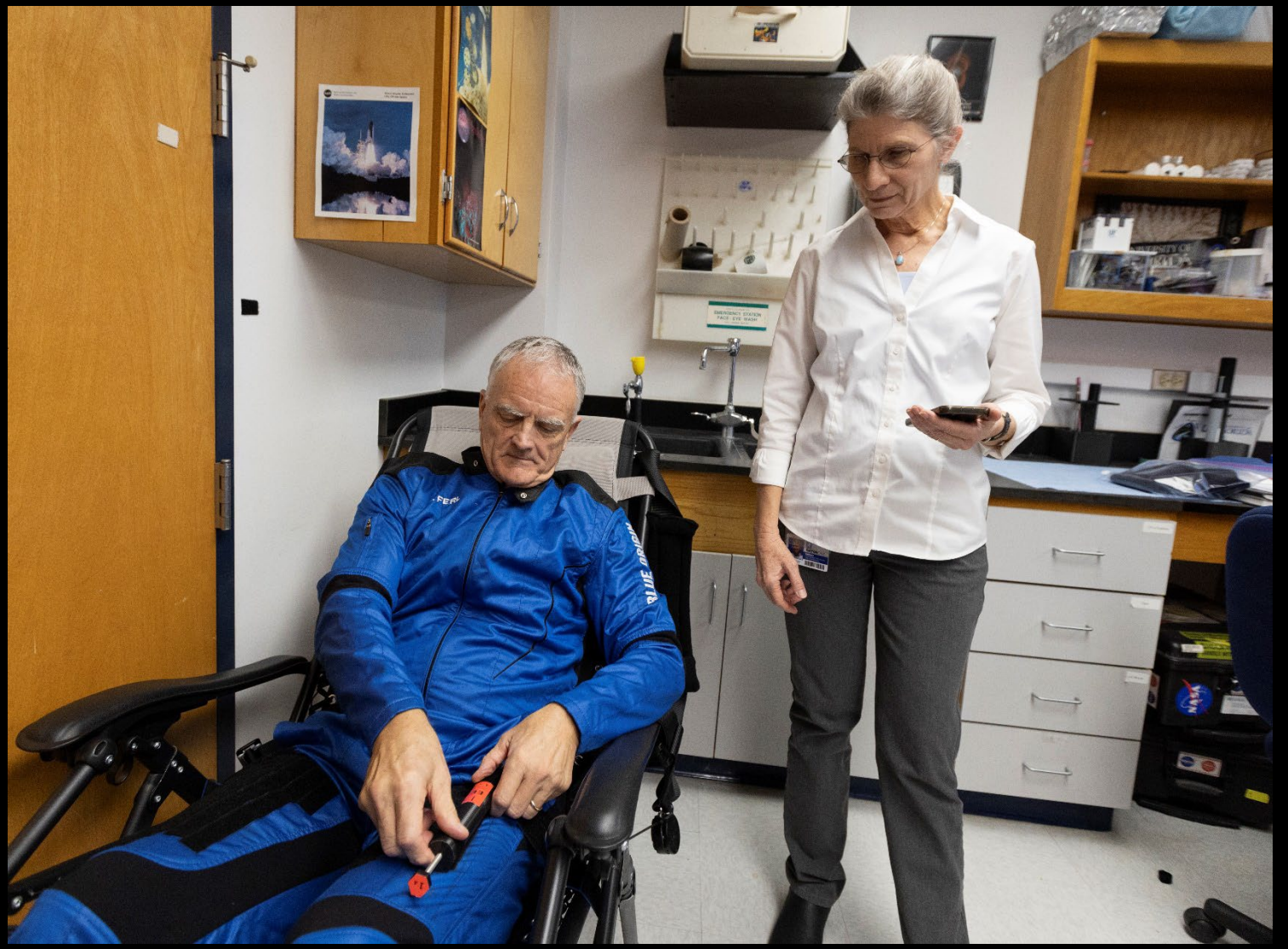
Inside the capsule mock-up

SECOND: Practice at UF

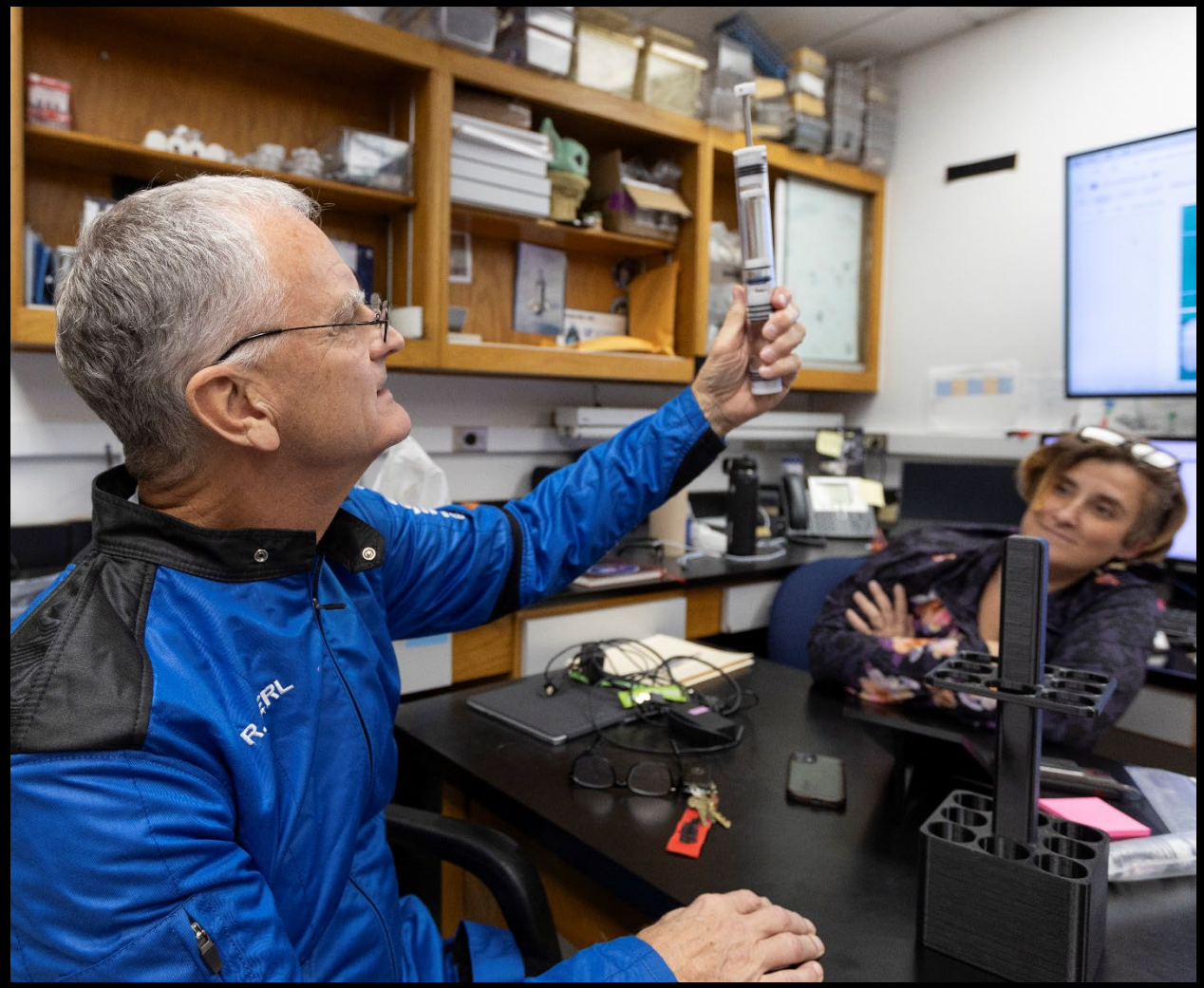
We set-up a mock flight capsule chair in one of our labs to practice operations and drill time-lines



Practice in the UF Space Plants “space garage” leading up to Flight



KFT actuation and timing

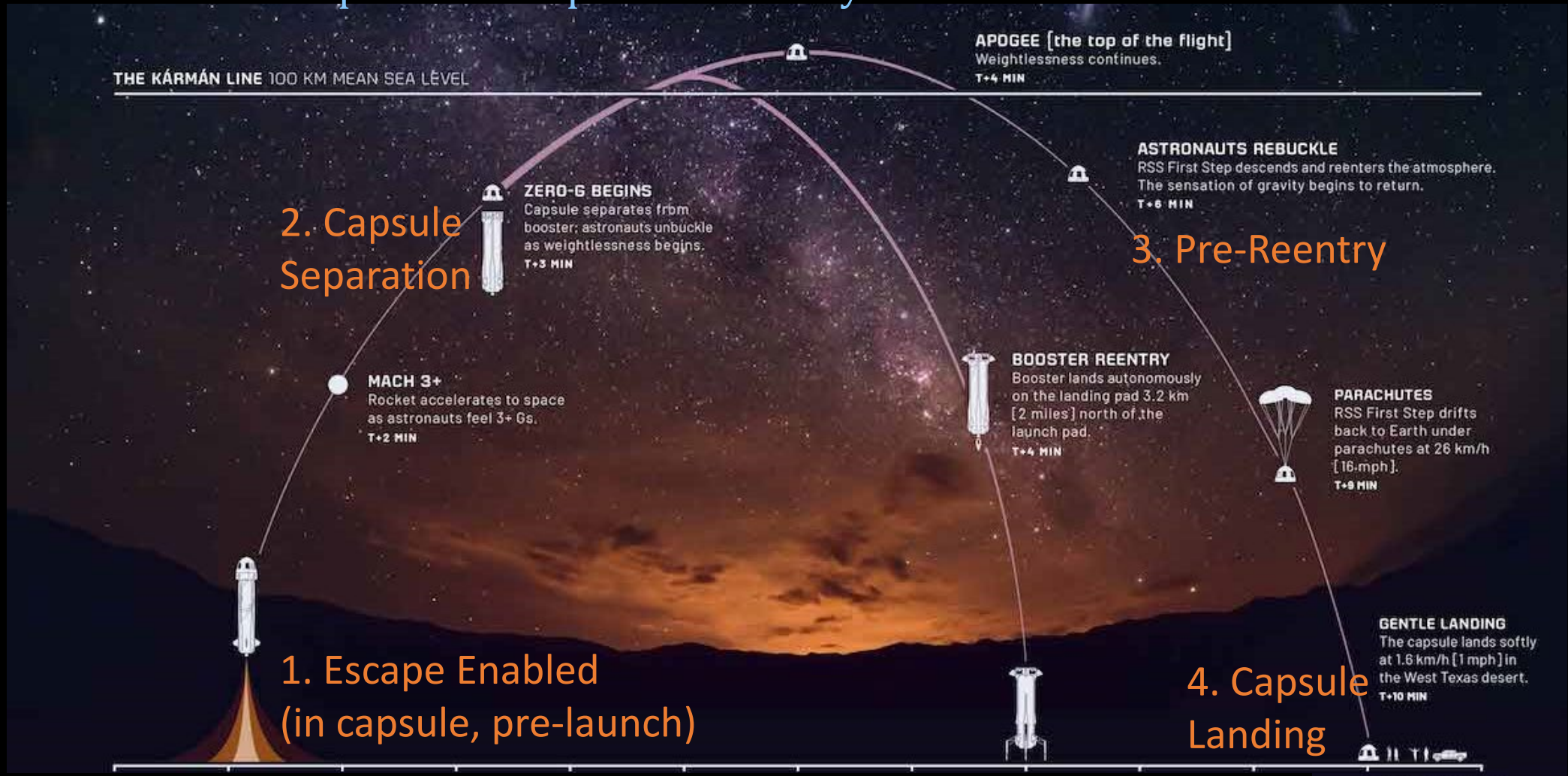


- Practice to gain “muscle memory” for all operations in flight
- Mental preparation (consultation with sports stress psychologist, Dr. Garrett Beatty)
- Flight to Ground coordination to ensure accurate timeline for both

Science Question:

Primary physiological adaptation vs long term acclimation

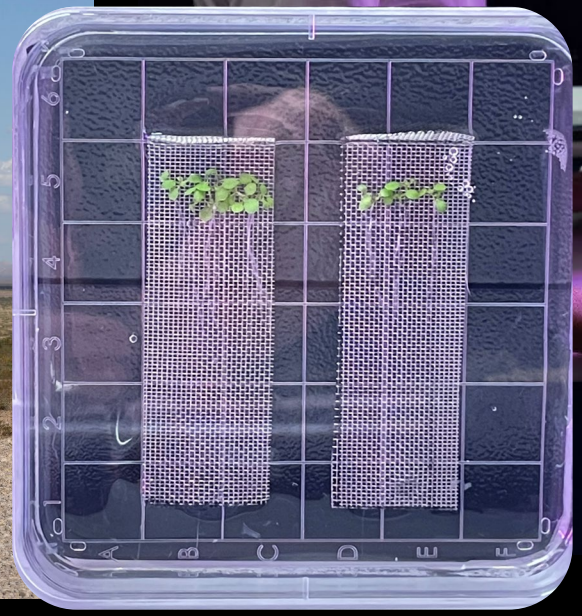
First few minutes and seconds in space is unexplored territory

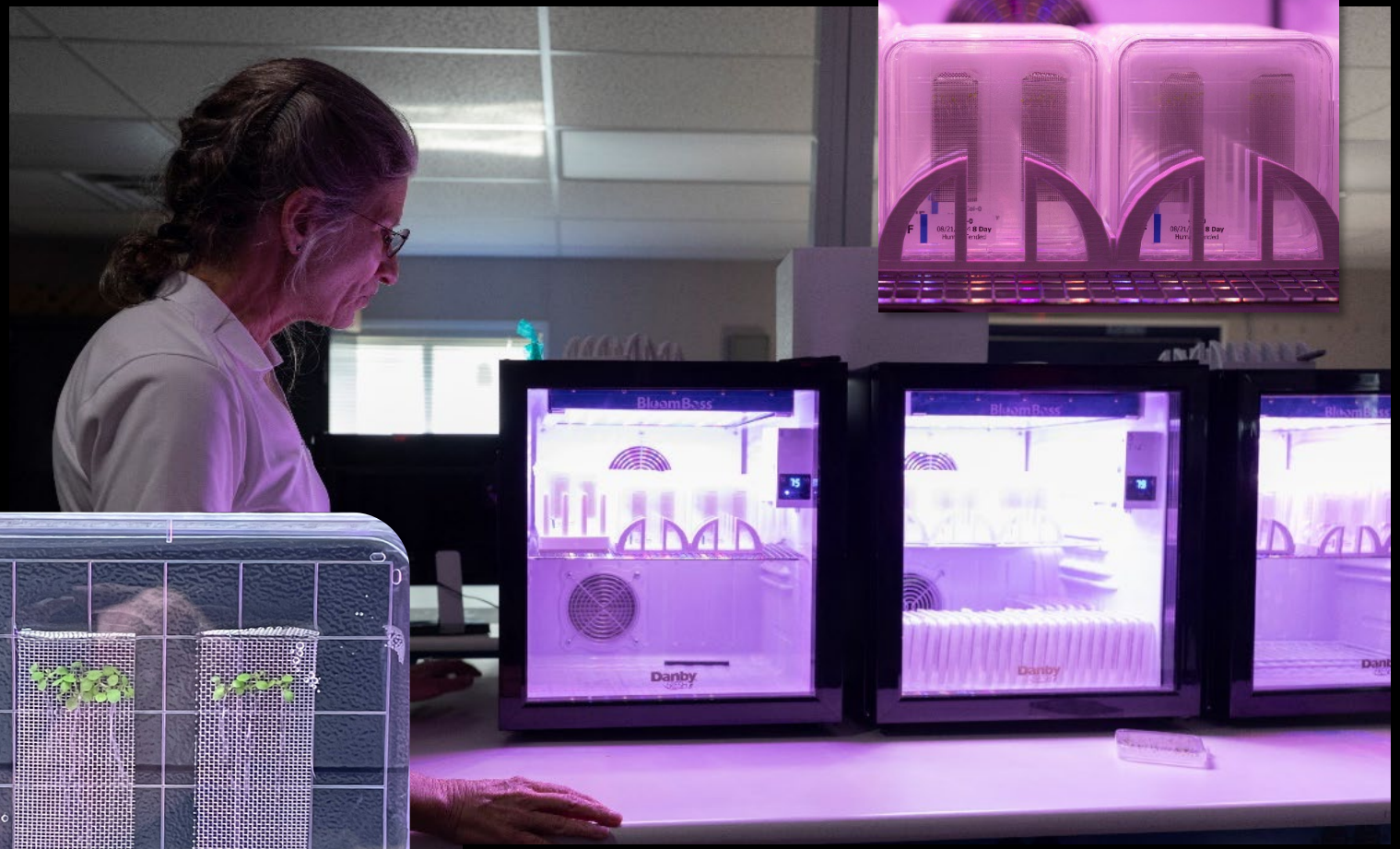


New Shepard Flight Profile

KFTs with activated at 1.EE, 2.CS, 3.RE, 4.LD, and on the ground at same timepoints

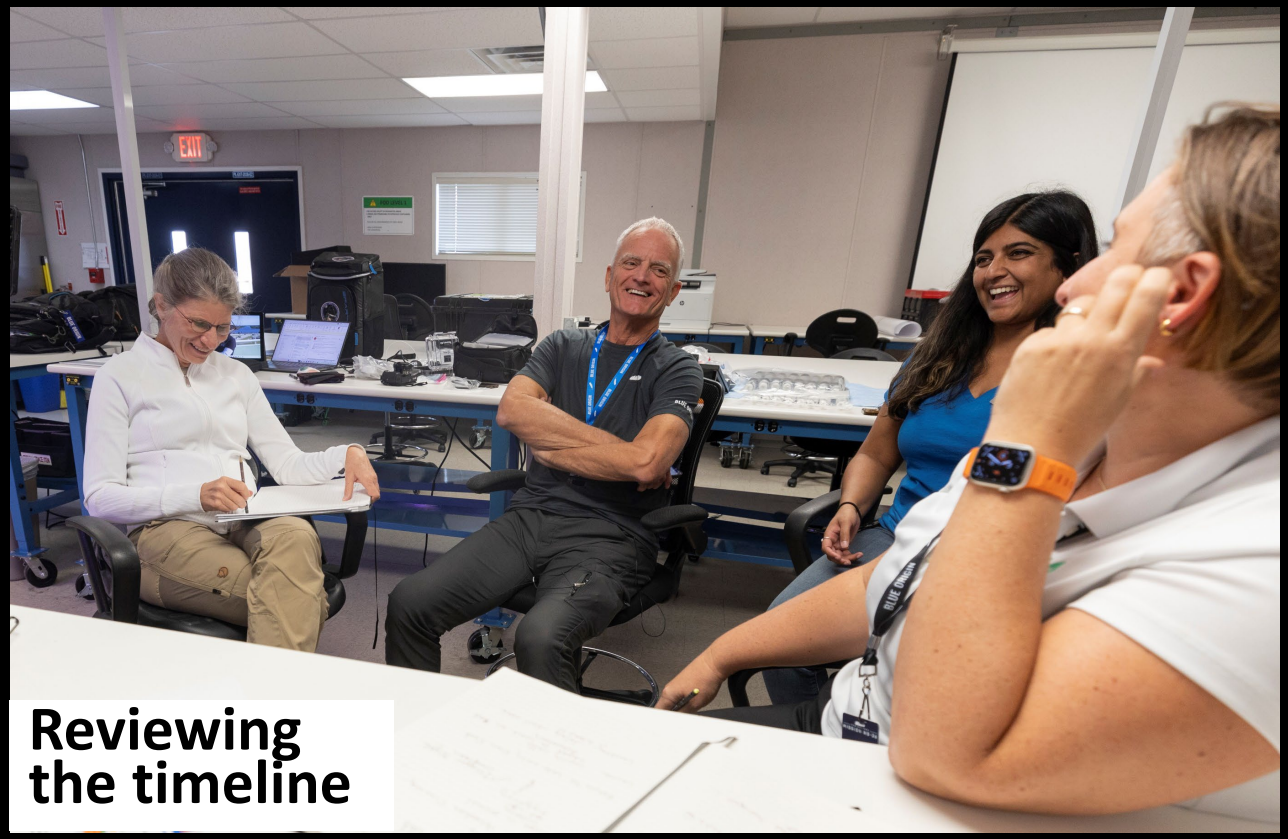
Travel and set-up - Blue Origin West Texas Launch Facility





Hundreds of Petri plates containing the plant “coupons” for the KFTs delivered and grown in the LS1 Payload Facility

Inside the Payload Facility – Pre-Flight operations



Reviewing the timeline

Pre-Flight operations – Astronaut sampling

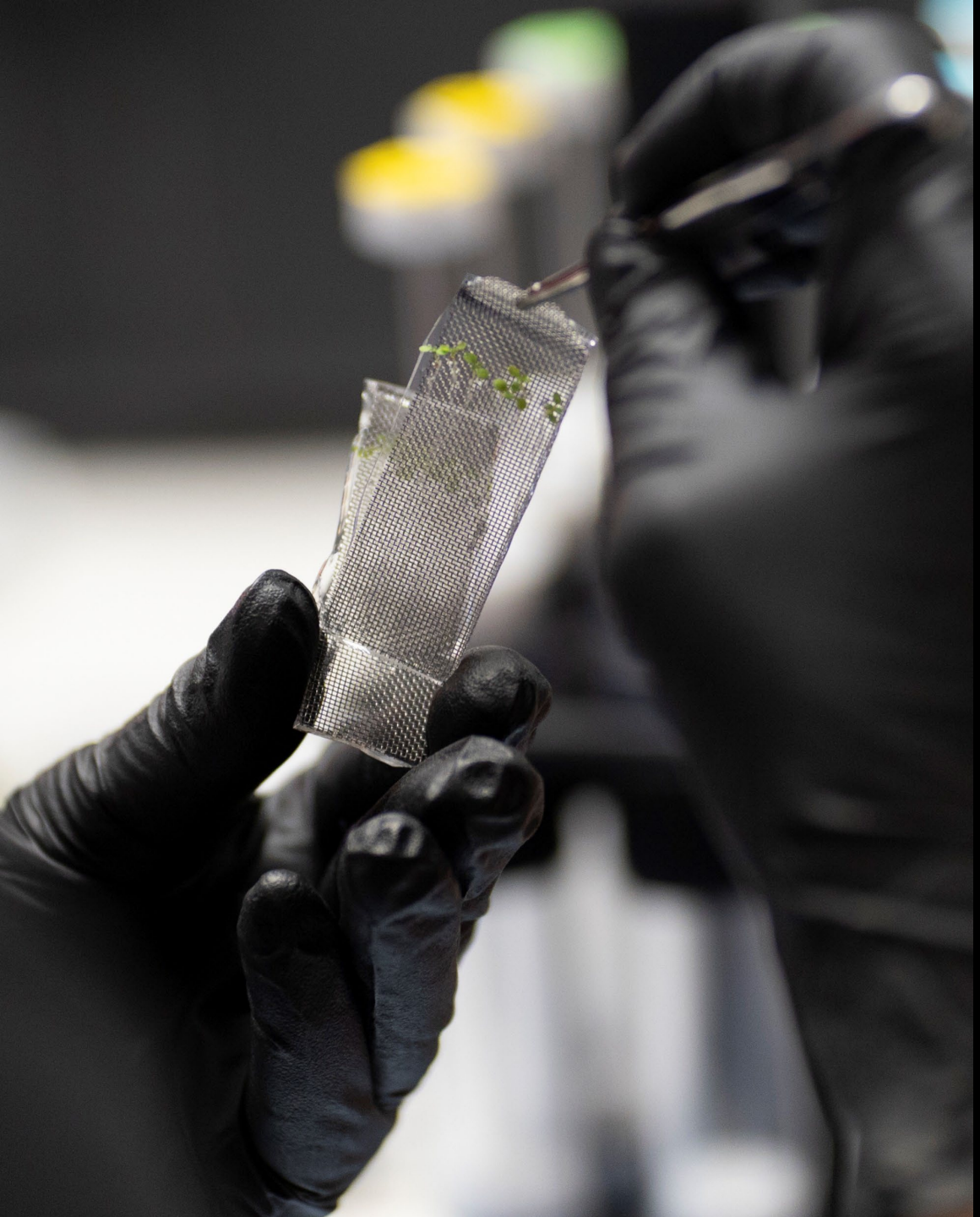
In cooperation with Chris Mason

- Note that this is an area of active development across flights and platforms

Pre-Flight operations – Flight Day ops start at 04:00

Pre-Flight operations – Flight Day Preparation of KFT tubes


BLUE ORIGIN




Flight and Ground Control KFTs prepared simultaneously

Flight and Ground Control KFTs placed in KFT Transport Bags simultaneously –

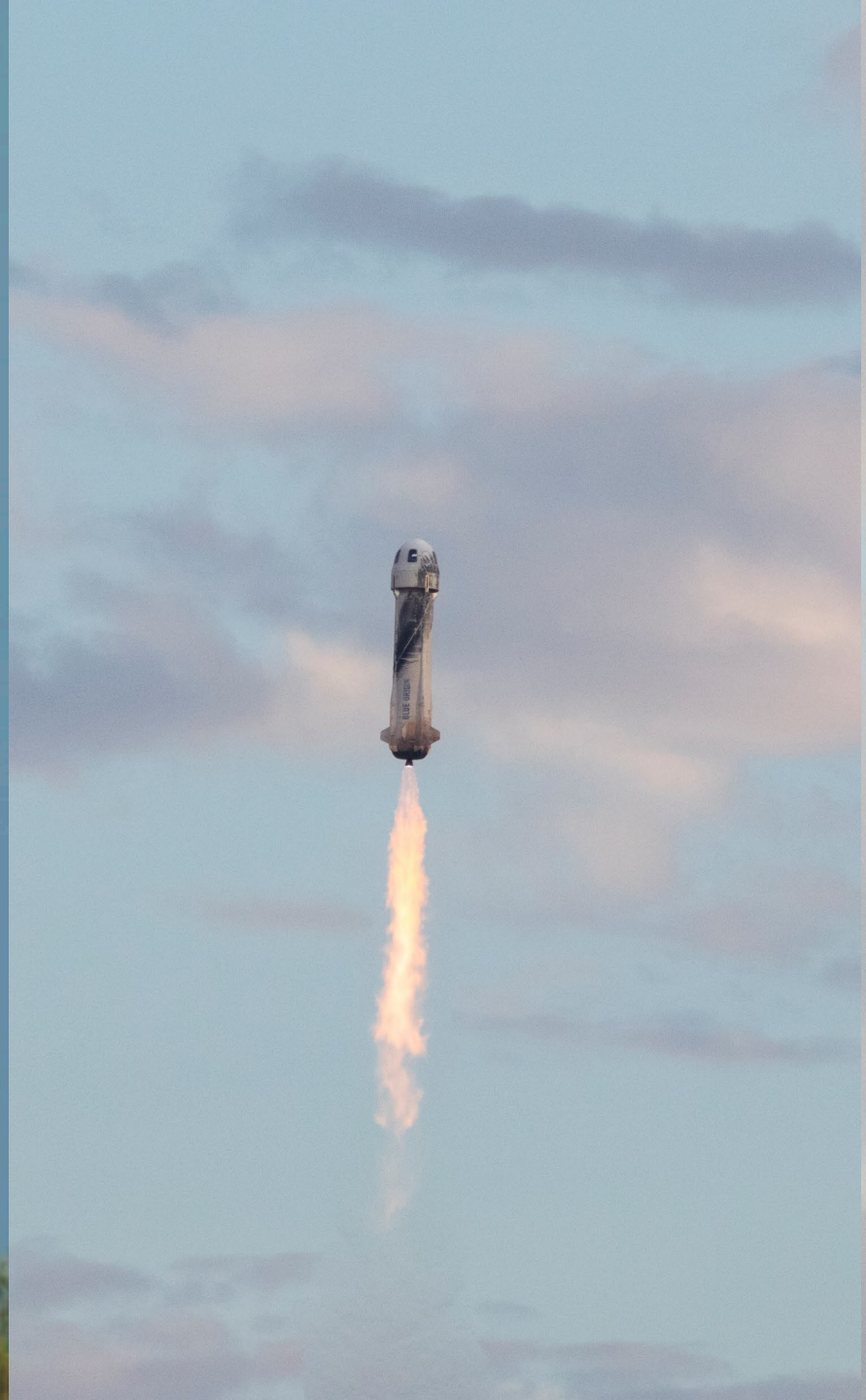
- attention to timing and physical parallelism

Flight KTB hand-over for delivery to capsule to await astronaut entry

Ground Control operations during the flight

Ground Control operations during the flight

Launch and capsule landing



Researcher ops in flight


Researcher
ops in flight
BLUE ORIGIN
Thinkware U1000 v1.00.13 12.0 V 1980.01.02 03:50:13

Researcher ops in flight


FERL


RSS FIRST STEP
-Z
R. FERL

ORIDA GATORS

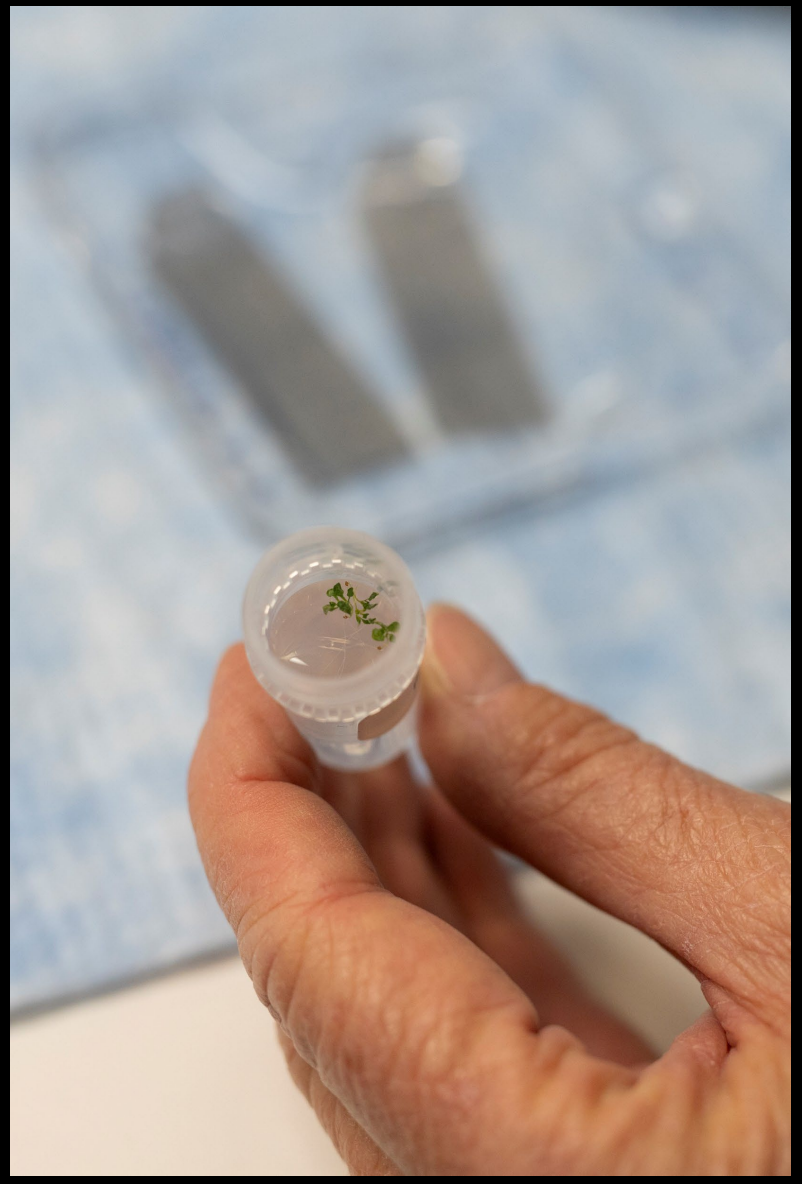
Going to work in the field

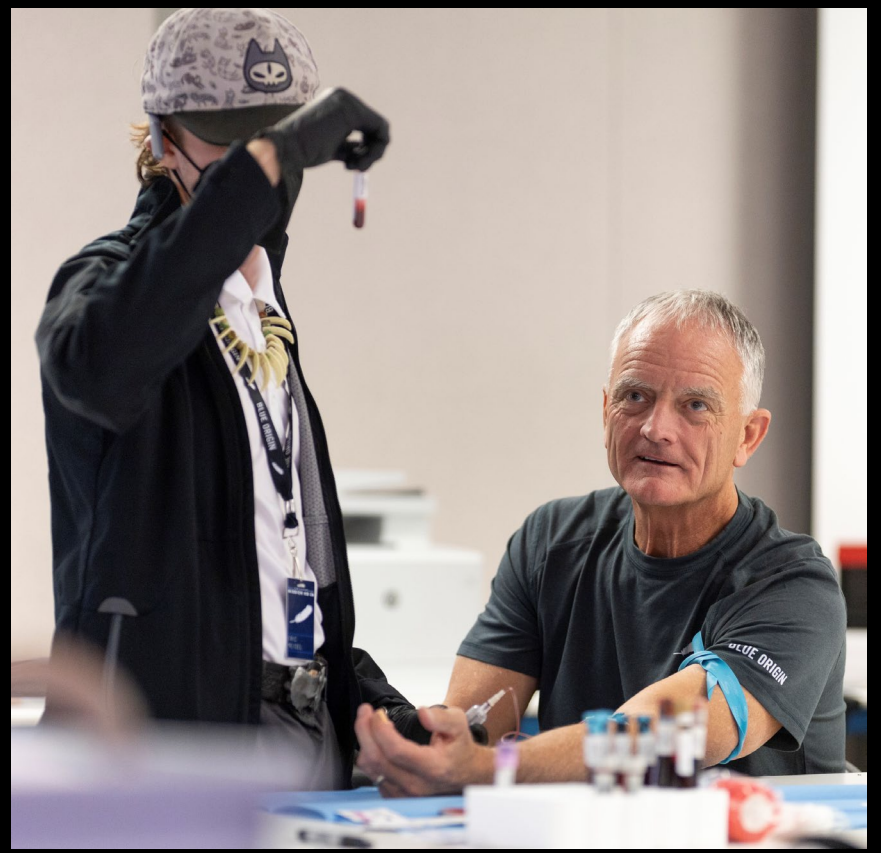

R. FERL
NS26
BLUE
ORIGIN
LD


LD

Welcome back to the Payload Lab

Post-Flight operations – De-integrating KFTs and Astronaut sampling

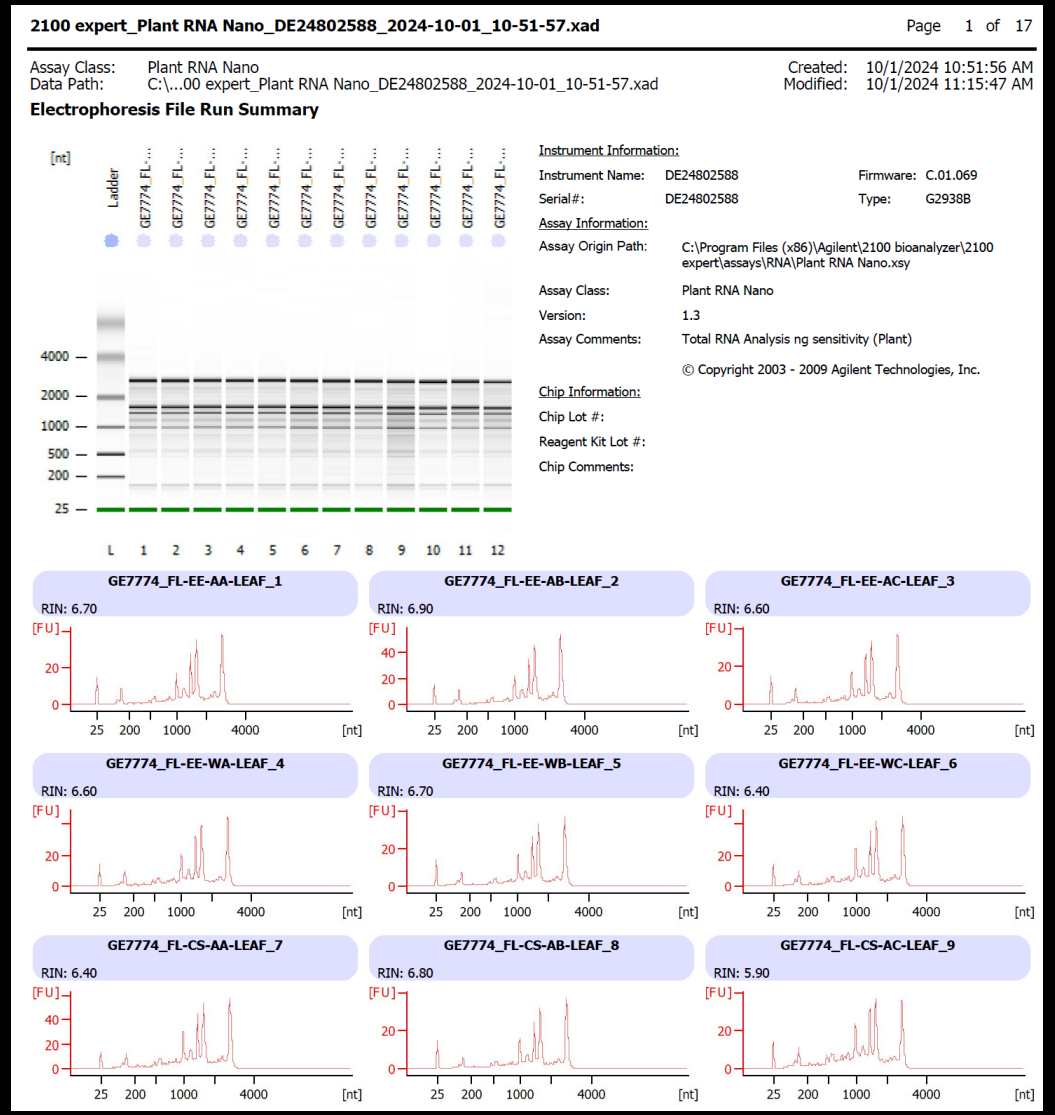




96 Samples currently bring sequenced for transcriptome analyses

Blue Origin H8-N26 samples 2024-08-29 - Treatments comprise: two conditions (FLT vs GC), four timepoints (EE, CS, RE, LN), two tissues (Leaf, Root), six replicates for each treatment (A=A-grid, B=B-grid, C=A+B-grid mix)

	ID code for RNASeq	Sample Description
1	FL-EE-AA-LEAF	FLIGHT Escape Enabled, Aisle A LEAF, BOH8-20240829
2	FL-EE-AB-LEAF	FLIGHT Escape Enabled, Aisle B LEAF, BOH8-20240829
3	FL-EE-AC-LEAF	FLIGHT Escape Enabled, Aisle C LEAF, BOH8-20240829
4	FL-EE-WA-LEAF	FLIGHT Escape Enabled, Window A LEAF, BOH8-20240829
5	FL-EE-WB-LEAF	FLIGHT Escape Enabled, Window B LEAF, BOH8-20240829
6	FL-EE-WC-LEAF	FLIGHT Escape Enabled, Window C LEAF, BOH8-20240829
7	FL-CS-AA-LEAF	FLIGHT Capsule Sep, Aisle A LEAF, BOH8-20240829
8	FL-CS-AB-LEAF	FLIGHT Capsule Sep, Aisle B LEAF, BOH8-20240829
9	FL-CS-AC-LEAF	FLIGHT Capsule Sep, Aisle C LEAF, BOH8-20240829
10	FL-CS-WA-LEAF	FLIGHT Capsule Sep, Window A LEAF, BOH8-20240829
11	FL-CS-WB-LEAF	FLIGHT Capsule Sep , Window B LEAF, BOH8-20240829
12	FL-CS-WC-LEAF	FLIGHT Capsule Sep , Window C LEAF, BOH8-20240829
13	FL-RE-AA-LEAF	FLIGHT ReEntry, Aisle A LEAF, BOH8-20240829
14	FL-RE-AB-LEAF	FLIGHT ReEntry, Aisle B LEAF, BOH8-20240829
15	FL-RE-AC-LEAF	FLIGHT ReEntry, Aisle C LEAF, BOH8-20240829
16	FL-RE-WA-LEAF	FLIGHT ReEntry, Window A LEAF, BOH8-20240829
17	FL-RE-WB-LEAF	FLIGHT ReEntry, Window B LEAF, BOH8-20240829
18	FL-RE-WC-LEAF	FLIGHT ReEntry, Window C LEAF, BOH8-20240829
19	FL-LN-AA-LEAF	FLIGHT Landed, Aisle A LEAF, BOH8-20240829
20	FL-LN-AB-LEAF	FLIGHT Landed, Aisle B LEAF, BOH8-20240829
21	FL-LN-AC-LEAF	FLIGHT Landed, Aisle C LEAF, BOH8-20240829
22	FL-LN-WA-LEAF	FLIGHT Landed, Window A LEAF, BOH8-20240829
23	FL-LN-WB-LEAF	FLIGHT Landed, Window B LEAF, BOH8-20240829
24	FL-LN-WC-LEAF	FLIGHT Landed, Window C LEAF, BOH8-20240829
25	GR-EE-AA-LEAF	GROUND CONTROL Escape Enabled, Aisle A LEAF, BOH8-20240829
26	GR-EE-AB-LEAF	GROUND CONTROL Escape Enabled, Aisle B LEAF, BOH8-20240829
27	GR-EE-AC-LEAF	GROUND CONTROL Escape Enabled, Aisle C LEAF, BOH8-20240829
28	GR-EE-WA-LEAF	GROUND CONTROL Escape Enabled, Window A LEAF, BOH8-20240829
29	GR-EE-WB-LEAF	GROUND CONTROL Escape Enabled, Window B LEAF, BOH8-20240829
30	GR-EE-WC-LEAF	GROUND CONTROL Escape Enabled, Window C LEAF, BOH8-20240829
31	GR-CS-AA-LEAF	GROUND CONTROL Capsule Sep, Aisle A ROOT LEAF, BOH8-20240829
32	GR-CS-AB-LEAF	GROUND CONTROL Capsule Sep, Aisle B LEAF, BOH8-20240829
33	GR-CS-AC-LEAF	GROUND CONTROL Capsule Sep, Aisle C LEAF, BOH8-20240829
34	GR-CS-WA-LEAF	GROUND CONTROL Capsule Sep, Window A LEAF, BOH8-20240829
35	GR-CS-WB-LEAF	GROUND CONTROL Capsule Sep, Window B LEAF, BOH8-20240829
36	GR-CS-WC-LEAF	GROUND CONTROL Capsule Sep, Window C LEAF, BOH8-20240829
37	GR-RE-AA-LEAF	GROUND CONTROL ReEntry, Aisle A LEAF, BOH8-20240829
38	GR-RE-AB-LEAF	GROUND CONTROL ReEntry, Aisle B LEAF, BOH8-20240829
39	GR-RE-AC-LEAF	GROUND CONTROL ReEntry, Aisle C LEAF, BOH8-20240829
40	GR-RE-WA-LEAF	GROUND CONTROL ReEntry, Window A LEAF, BOH8-20240829
41	GR-RE-WB-LEAF	GROUND CONTROL ReEntry, Window B LEAF, BOH8-20240829
42	GR-RE-WC-LEAF	GROUND CONTROL ReEntry, Window C LEAF, BOH8-20240829
43	GR-LN-AA-LEAF	GROUND CONTROL Landed, Aisle A LEAF, BOH8-20240829
44	GR-LN-AB-LEAF	GROUND CONTROL Landed, Aisle B LEAF, BOH8-20240829
45	GR-LN-AC-LEAF	GROUND CONTROL Landed, Aisle C LEAF, BOH8-20240829
46	GR-LN-WA-LEAF	GROUND CONTROL Landed, Window A LEAF, BOH8-20240829
47	GR-LN-WB-LEAF	GROUND CONTROL Landed, Window B LEAF, BOH8-20240829
48	GR-LN-WC-LEAF	GROUND CONTROL Landed, Window C LEAF, BOH8-20240829
49	FL-EE-AA-ROOT	FLIGHT Escape Enabled, Aisle A ROOT, BOH8-20240829
50	FL-EE-AB-ROOT	FLIGHT Escape Enabled, Aisle B ROOT, BOH8-20240829
51	FL-EE-AC-ROOT	FLIGHT Escape Enabled, Aisle C ROOT, BOH8-20240829
52	FL-EE-WA-ROOT	FLIGHT Escape Enabled, Window A ROOT , BOH8-20240829
53	FL-EE-WB-ROOT	FLIGHT Escape Enabled, Window B ROOT, BOH8-20240829
54	FL-EE-WC-ROOT	FLIGHT Escape Enabled, Window C ROOT, BOH8-20240829
55	FL-CS-AA-ROOT	FLIGHT Capsule Sep, Aisle A ROOT, BOH8-20240829
56	FL-CS-AB-ROOT	FLIGHT Capsule Sep, Aisle B ROOT, BOH8-20240829
57	FL-CS-AC-ROOT	FLIGHT Capsule Sep, Aisle C ROOT, BOH8-20240829
58	FL-CS-WA-ROOT	FLIGHT Capsule Sep, Window A ROOT, BOH8-20240829
59	FL-CS-WB-ROOT	FLIGHT Capsule Sep , Window B ROOT, BOH8-20240829
60	FL-CS-WC-ROOT	FLIGHT Capsule Sep , Window C ROOT, BOH8-20240829
61	FL-RE-AA-ROOT	FLIGHT ReEntry, Aisle A ROOT, BOH8-20240829
62	FL-RE-AB-ROOT	FLIGHT ReEntry, Aisle B ROOT, BOH8-20240829
63	FL-RE-AC-ROOT	FLIGHT ReEntry, Aisle C ROOT, BOH8-20240829
64	FL-RE-WA-ROOT	FLIGHT ReEntry, Window A ROOT, BOH8-20240829
65	FL-RE-WB-ROOT	FLIGHT ReEntry, Window B ROOT, BOH8-20240829
66	FL-RE-WC-ROOT	FLIGHT ReEntry, Window C ROOT, BOH8-20240829
67	FL-LN-AA-ROOT	FLIGHT Landed, Aisle A ROOT, BOH8-20240829
68	FL-LN-AB-ROOT	FLIGHT Landed, Aisle B ROOT, BOH8-20240829
69	FL-LN-AC-ROOT	FLIGHT Landed, Aisle C ROOT, BOH8-20240829
70	FL-LN-WA-ROOT	FLIGHT Landed, Window A ROOT, BOH8-20240829
71	FL-LN-WB-ROOT	FLIGHT Landed, Window B ROOT, BOH8-20240829
72	FL-LN-WC-ROOT	FLIGHT Landed, Window C ROOT, BOH8-20240829
73	GR-EE-AA-ROOT	GROUND CONTROL Escape Enabled, Aisle A ROOT, BOH8-20240829
74	GR-EE-AB-ROOT	GROUND CONTROL Escape Enabled, Aisle B ROOT, BOH8-20240829
75	GR-EE-AC-ROOT	GROUND CONTROL Escape Enabled, Aisle C ROOT, BOH8-20240829
76	GR-EE-WA-ROOT	GROUND CONTROL Escape Enabled, Window A ROOT, BOH8-20240829
77	GR-EE-WB-ROOT	GROUND CONTROL Escape Enabled, Window B ROOT, BOH8-20240829
78	GR-EE-WC-ROOT	GROUND CONTROL Escape Enabled, Window C ROOT, BOH8-20240829
79	GR-CS-AA-ROOT	GROUND CONTROL Capsule Sep, Aisle A ROOT, BOH8-20240829
80	GR-CS-AB-ROOT	GROUND CONTROL Capsule Sep, Aisle B ROOT, BOH8-20240829
81	GR-CS-AC-ROOT	GROUND CONTROL Capsule Sep, Aisle C ROOT, BOH8-20240829
82	GR-CS-WA-ROOT	GROUND CONTROL Capsule Sep, Window A ROOT, BOH8-20240829
83	GR-CS-WB-ROOT	GROUND CONTROL Capsule Sep, Window B ROOT, BOH8-20240829
84	GR-CS-WC-ROOT	GROUND CONTROL Capsule Sep, Window C ROOT, BOH8-20240829
85	GR-RE-AA-ROOT	GROUND CONTROL ReEntry, Aisle A ROOT, BOH8-20240829
86	GR-RE-AB-ROOT	GROUND CONTROL ReEntry, Aisle B ROOT, BOH8-20240829
87	GR-RE-AC-ROOT	GROUND CONTROL ReEntry, Aisle C ROOT, BOH8-20240829
88	GR-RE-WA-ROOT	GROUND CONTROL ReEntry, Window A ROOT, BOH8-20240829
89	GR-RE-WB-ROOT	GROUND CONTROL ReEntry, Window B ROOT, BOH8-20240829
90	GR-RE-WC-ROOT	GROUND CONTROL ReEntry, Window C ROOT, BOH8-20240829
91	GR-LN-AA-ROOT	GROUND CONTROL Landed, Aisle A ROOT, BOH8-20240829
92	GR-LN-AB-ROOT	GROUND CONTROL Landed, Aisle B ROOT, BOH8-20240829
93	GR-LN-AC-ROOT	GROUND CONTROL Landed, Aisle C ROOT, BOH8-20240829
94	GR-LN-WA-ROOT	GROUND CONTROL Landed, Window A ROOT, BOH8-20240829
95	GR-LN-WB-ROOT	GROUND CONTROL Landed, Window B ROOT, BOH8-20240829
96	GR-LN-WC-ROOT	GROUND CONTROL Landed, Window C ROOT, BOH8-20240829



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Researchers need to be part of their experiment

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Go boldly.