

Effects of Spaceflight on Plants Using GLDS-38

Curricular Unit
Teacher Materials

OVERVIEW

Plants play a central role in human survival on earth. Conversely, they will play a critical in life support systems for space exploration. To understand the effects of space flight on Plants NASA's plant science research focuses on understanding how plants sense and respond to gravity, the role of gravity and microgravity in plant development and reproduction, the effects of gravity and microgravity on plant metabolism and transport, the synergistic effects of microgravity, radiation, and electromagnetism, and the role plants will play in recycling life support systems for space exploration.

In this unit students will describe the basic structure and function of plants, understand how plants grow, acquire energy and reproduce, learn about plant genes, genomes and genetics, and analyze plant omics data to explore the effects of spaceflight on plants.

Video: Science at NASA Astronauts Learn Gardening in Space ([Astronauts Learn Gardening in Space | Video - YouTube](#))

CONTENT OBJECTIVES

- Describe the structure and function of a plant cell
- Identify major plant organs and describe the structures and functions of stems, leaves, and roots
- List requirements for plant growth and consider the challenges of growing plants in space
- Identify characteristics of a model organism for plant research
- Interpret data visualizations
- Use evidence to evaluate the impact of spaceflight on plants

PACING AND SCHEDULING

This set of five activities can take between 3 – 5 days in a traditional 55-minute long class period, depending on depth of knowledge expected, prior student knowledge associated with positioning of the unit in existent curriculum, and time allotments for intended student groupwork within the activities. Additional suggestions are included in the Teacher Materials (Answer Keys) of each activity.

This unit could be taught after an overview of eukaryotic organisms or as an introduction to plant sciences. It can also be incorporated proximally to or within a unit on gene expression and/or cell signaling.

TEACHING METHODS

Background Information

The first lesson focuses on understanding the basic structure and function of flowering plants or **angiosperms**. These are the dominant form of plants on earth today. A flowering plant has an above ground component, the **shoot**, and a below ground component, the **root**. The shoot includes more obvious structures such as the **stem** and **leaves** but is also where you will find the **shoot apex**, **leaf primordium**, and **axillary buds**. Below the soil line you will find the root system which includes the **root apical meristem**, **primary root**, **lateral roots**, and **root hairs**.

*Teachers may choose to include this background information, if relevant to their curriculum, but this information is not directly informative to the lessons in this unit: Angiosperms are divided into **monocots** and **dicots** based on differences in some of these main structural features. The most well-known of these are the number of **cotyledons** or seed leaves. Monocots have one cotyledon and dicots have two. Some other key features to look at include the vein patterns on leaves, the number of petals or flowering parts, the type of root system, and organization of **vascular tissue** in the stem.*

Vascular tissue along with the **epidermis** and **ground** tissue make up the plants tissue systems. The epidermis of the leaf is usually covered in a **waxy cuticle** to prevent water loss. Pores called **stomata** are found in the epidermis of the leaf. The size of these pores are controlled by **guard cells**. The stomata allow CO₂ to enter the leaf and O₂ to escape. They also allow water vapor to escape the plant so that water may be drawn up through the roots.

In the root epidermis, some of the cells will develop into root hairs. These are thin-walled cells that will facilitate the absorption of water and nutrients from the surrounding environment. These cells also interact with soil bacteria and play a role in the **symbiotic relationship** between roots and these bacteria. Root hairs develop near the root apical meristem and are lost as the root ages just like the cells of our skin.

Vascular tissue is arranged in bundles of **xylem** and **phloem** that travel through the plant. Xylem is responsible for transporting water up through the plant from the roots. The phloem transports carbohydrates from the leaves throughout the plant.

Plants share many of the same cellular structures present in other **eukaryotic** cells. Their cells are surrounded by a **plasma membrane**, their genetic material is in the form of **DNA**, and they synthesize their proteins using **ribosomes**. Although plants share many structures with animals, they differ in important ways. Plant cells are enclosed by a **cell wall**, made of cellulose. The cell walls are traversed by tunnels called **plasmodesmata**. They contain **chloroplast** which are the site of **photosynthesis** and a prominent **central vacuole**.

This lesson introduces the basic structure and function of plants and begins to unfold the idea that plants are impacted by conditions in space. The lessons that follow will provide a more detailed look at the biology of plants including plant development, physiology, metabolism, and plant genes and the potential impacts of spaceflight on those processes.

Discussion and Direction of Instruction

Further instructions and information are provided in the supplementary file that accompanies this curricular unit, especially for items 4 & 5 in this list.

1. Engage students in a discussion about the major plant organs. Emphasize that plants only have a few major organs, roots, stems, buds, flowers, and leaves. Teachers may choose to focus on the roots, stems, and leaves, but should note that flowers develop from buds which are distinct organs from leaves. Teachers could show buds in the "axils" of leaves (where the petiole meets the stem) and explain that those buds can develop into flowers or into lateral stems that can bear many flowers and/or leaves. Gene expression within a bud determines how it develops (if it stays dormant or develops into a flower or lateral stem etc). Have students complete **Activity 1: Labeling the parts of a flowering plant.**
2. Engage students in a discussion about model organisms. Encourage students to think about why we use model organisms and what would make an organism an ideal candidate for plant research. Have students complete **Activity 2: Model organisms.**
3. Introduce students to factors of space flight. Break students out in groups of two to three students. Give each group a large piece of paper and have them research and think about how and why plants would be impacted in space. Have students report and discuss what they found with the class.
4. Once students have a general understanding of the impacts of spaceflight on plants, introduce the Metadata and have students follow along using **Activity 3: Meta Data Analysis.** Once the students understand the protocols and factors, have them look at **Activity 4: Arabidopsis GLDS-38 MA-plot for Spaceflight: FLT vs GC.** Guide students in understanding the significance of the MA-plot and how this relates to their previous discussion on the effects of spaceflight on plants.
5. Now that students have the general understanding that gene expression is altered in space, let's look at a volcano plot in order to quickly identify specific genes that have significantly changed as a result of spaceflight. Introduce students to volcano plots. Have students complete **Activity 5: Arabidopsis GLDS-38 Volcano Plot.** Guide students in understanding the volcano plot.

CURRICULAR CONTENT

For this curricular unit, all of the associated worksheets (teacher versions) are embedded into the next pages of this document but each of the materials are also available in its own student worksheet + teacher answer reference file.

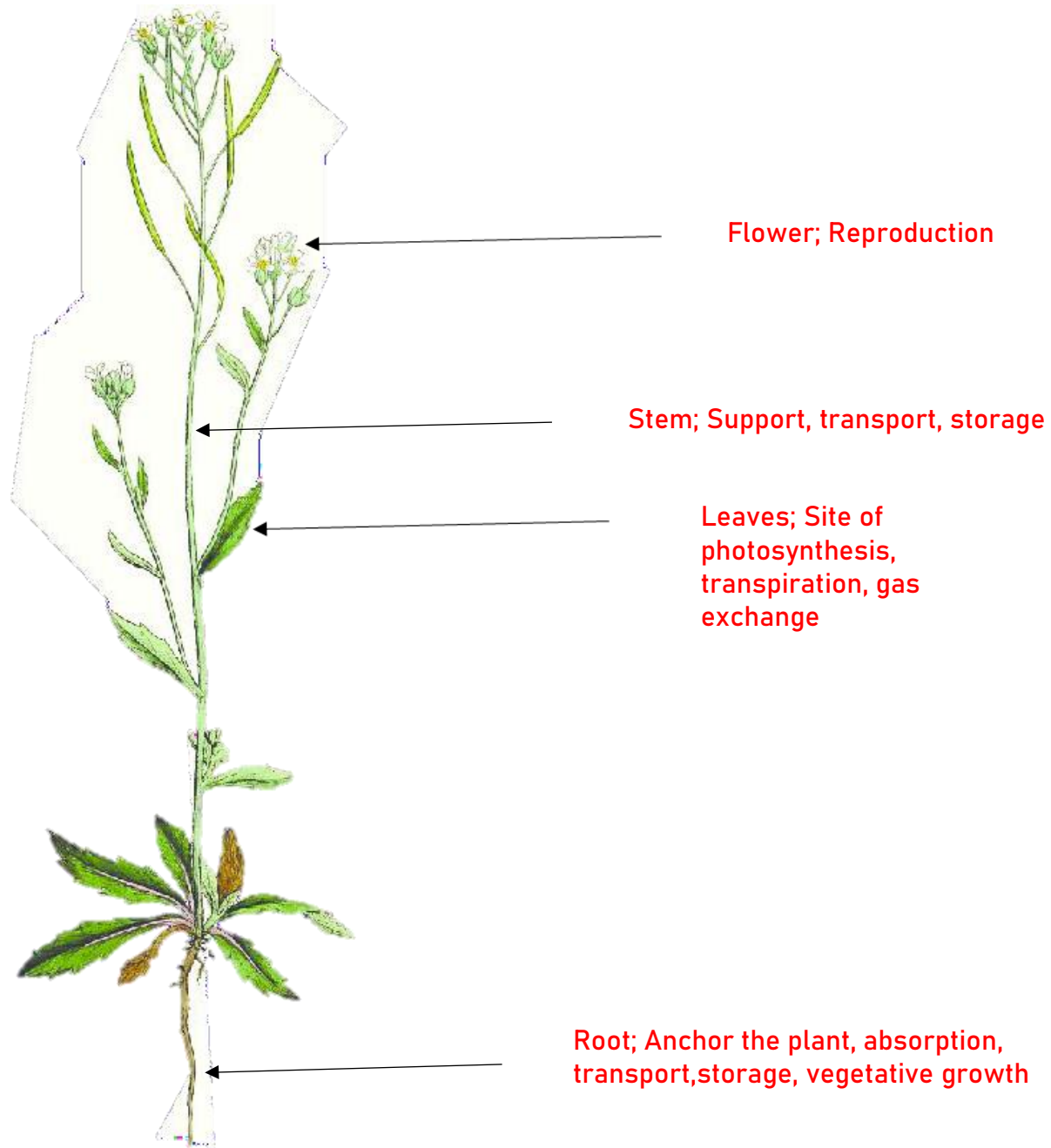
Supplemental Teacher Instructions are provided after the Activity sheets in order to help teachers prepare for **Activity 4** and **Activity 5** of this unit.

Red text indicates additional notes to/annotations for teachers or target responses expected of students.

Activity 1: Labeling the Parts of a Flowering Plant

Instructions: Label the parts of the model plant and write a function for each part.

Teacher's Note: If a live sample of this plant is available, have students observe each of the structures on the live plant. Wild mustard plants can often be found as a common weed in parking lots or fields.



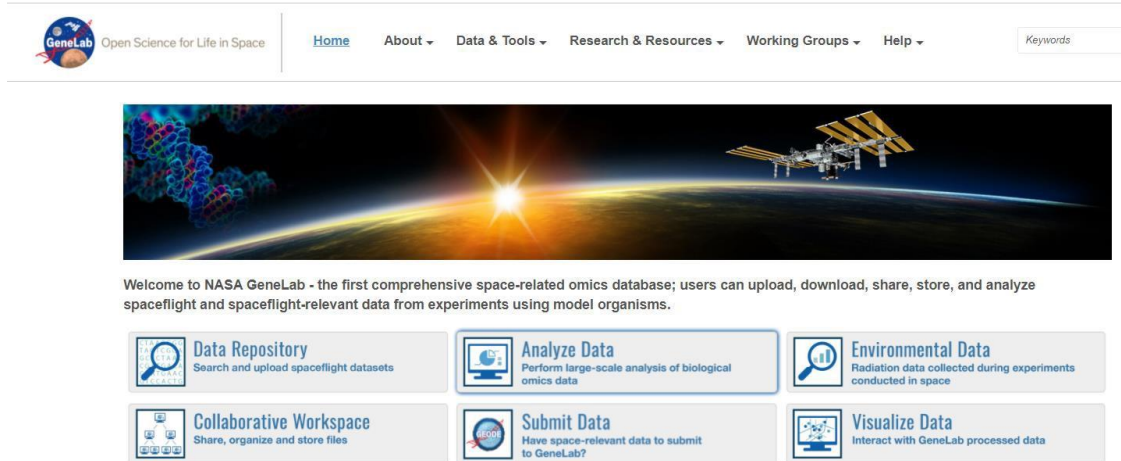
Brassica Image Credit: Yang, C., Zhang, C., Lu, Y., Jin, J., & Wang, X. (2011). The mechanisms of brassinosteroids' action: from signal transduction to plant development. *Molecular plant*, 4 4, 588-600

Activity 2: Model Organisms

| | What is one area of research in which this organism is used? | Why is it a good model organism for this area of study? | What else makes it a good model organism? |
|--|--|---|---|
| Fruit fly <i>(Drosophila melanogaster)</i> | Learning and memory | Human genes involved in learning and memory are similar to those in the fly. | <ul style="list-style-type: none"> • short life cycle • inexpensive and easy to raise • studied extensively, so a lot is known about it • genome sequenced |
| Wall cress <i>(Arabidopsis thaliana)</i> | Plant development | Small number of genes compared to many plants, and the genes can be easily manipulated. | <ul style="list-style-type: none"> • short generations • easy to pollinate • lots of seeds • can be grown year-round in a greenhouse • genome sequenced • no specialized growth reqs. • Primarily self-fertilizing |
| Nematode (EXAMPLE: <i>Caenorhabditis elegans</i> —called <i>C. elegans</i>) | Animal development | Its nearly transparent body lets researchers see and image stages of development. | <ul style="list-style-type: none"> • multicellular, but not an extensive number of different cells • easy to raise • short life cycle • genome sequenced |
| Rodents (EXAMPLE: mouse, <i>Mus musculus</i>) | Human disease | The mouse is a mammal, so it shares more genes with us than nonmammalian model organisms. | Relative to other mammals that are studied, such as dogs, the mouse <ul style="list-style-type: none"> • has short generations • is easy to raise • genome sequenced |

Activity 3: GLDS-38 Meta Data Analysis

Instructions: Navigate a web browser to [NASA GeneLab: Open Science for Life in Space](https://www.nasa.gov/genelab)



Once on the site, click on **Data Repository** and search for **GLDS-38**.

GLDS-38

All GeneLab NIH GEO EBI PRIDE ANL MG-RAST

Search Filters (GeneLab Only)

Project Type Factors Organisms Assay Type Clear

Show Only: Studies With Visualizations

Page 1 of 13 (Total Studies: 320) Next >
Studies Per Page: 25

Transcriptional profiling of livers from mice flown on Rodent Research Reference Mission-1 (RRRM-1)

| Organisms | Factors | Assay Types | Release Date | Description |
|--------------|---|-------------------------|--------------|---|
| Mus musculus | Spaceflight Age Duration Euthanasia Location Dissection Condition | transcription profiling | 26-May-2021 | In the Rodent Research Reference Mission (RRRM-1), forty female BALB/cANNTac mice were flown on the International Space Station. To assess differences in outcomes due to age, twenty 10-12 week-old and... |

Transcriptional profiling of roots and shoots from Brachypodium distachyon seedlings flown on the ISS

| Organisms | Factors | Assay Types | Release Date | Description |
|-----------|---|-------------------------|--------------|---|
| | Spaceflight Accession Organism Part | transcription profiling | 20-May-2021 | Most major cereal grain crops are monocots. Yet, most investigations of plant adaptation to the spaceflight environment have been carried out on the dicotyledonous model plant, Arabidopsis thaliana. I... |

This will bring you to the study that we will be analyzing in this curricular unit, [Proteomics and Transcriptomics analysis of Arabidopsis Seedlings in Microgravity](#).

The screenshot shows the GeneLab website interface. At the top, there is a navigation bar with the GeneLab logo and the tagline 'Open Science for Life in Space', followed by menu items: Home, About, Data & Tools, Research & Resources, Working Groups, and Help. The NASA logo is also present. Below the navigation bar is a search bar containing 'GLDS-38'. Underneath the search bar are checkboxes for 'All', 'GeneLab', 'NIH GEO', 'EBI PRIDE', and 'ANL MG-RAST'. A section titled 'Search Filters (GeneLab Only)' contains dropdown menus for 'Project Type', 'Factors', 'Organisms', and 'Assay Type', along with a 'Clear' button. Below this is a 'Show Only' section with a checkbox for 'Studies With Visualizations'. The search results section shows 'Search results for: GLDS-38 using filter(s):' and 'Total Search Results Found: 1'. A dropdown menu for 'Sort by Relevance' is set to '25'. The first result is titled 'Proteomics and Transcriptomics analysis of Arabidopsis Seedlings in Microgravity' with a URL: <https://genelab-data.nrc.nasa.gov/genelab/accession/GLDS-38>. A small icon of a plant in a pot is shown next to the title. The description below the icon reads: 'On Earth plants are constantly exposed to a gravitational field of 1G. Gravity affects a plant in every step of its development. Germinating seedlings orient their radicle and hypocotyl and growing plants position organs at a specific Gravitropic Set-point Angle dictated by the asymmetric distribution of auxin depending on the gravity vector. Hence gravitropism is one of the fundamental growth responses in plants. For any experiment studying the effects of gravity on plants the ultimate control...'. Below the description are metadata fields: 'Organism: Arabidopsis thaliana', 'Factor: Spaceflight Preservat...', 'Assay Type: protein expression pr...', 'Accession: GLDS-38', and 'PI/Contact: Sarah Wyatt'. The 'Release/Publication Date: 01-Nov-2015' is also listed.

Click on the hyperlink that corresponds to the study “[Proteomics and Transcriptomics analysis of Arabidopsis Seedlings in Microgravity](#)”.

1. According to the **Study Description**, what is one of the fundamental growth responses in plants? What is the ultimate control for any experiment studying the effects of gravity in space?

Gravitropism

Microgravity in space

2. What is the model organism for this study?

Arabidopsis thaliana

3. In the **Samples** section under **Factor Value**, what two groups are being compared in the study? What is being compared?

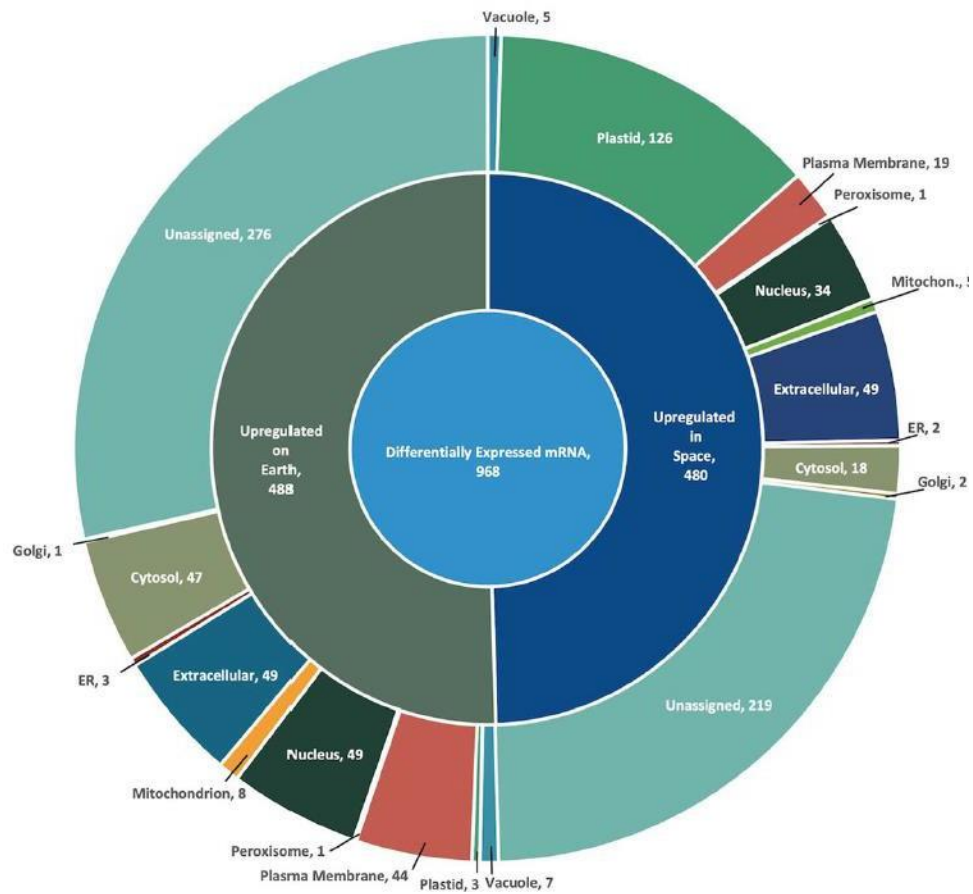
Possible Answers: Spaceflight and ground control (conditions) OR RNAlater or liquid nitrogen (preservation method)

4. Under the **Protocol** section, how was nucleic acid extracted? What platform was used to sequence it?

Extracted using RNeasy Plant mini extraction kit

Sequenced using Illumina HiSeq 2500

5. Look at the figure below.



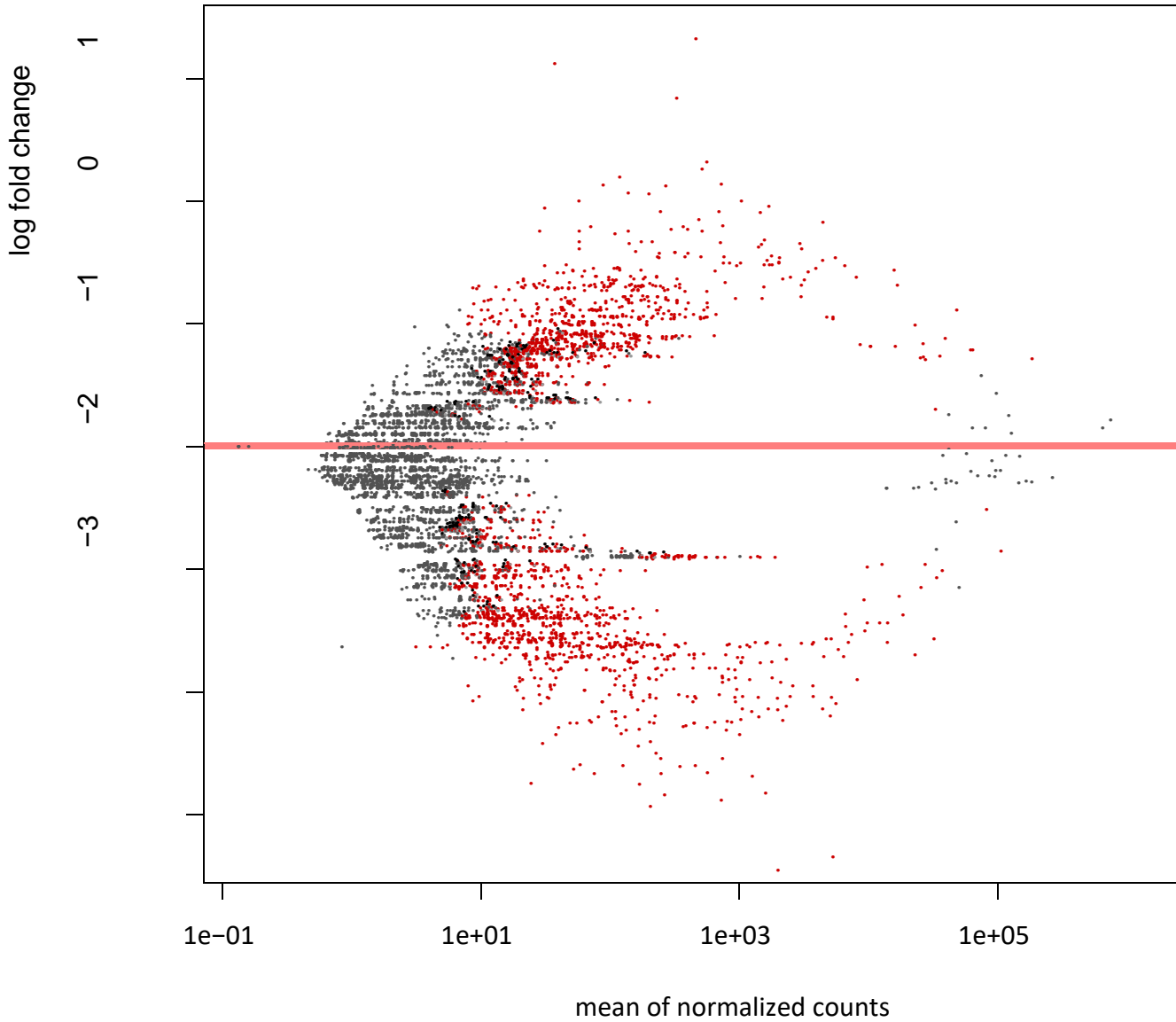
The figure shows an overview of transcripts differentially expressed during spaceflight. How do the upregulated in space compare to those on earth?

Answers will vary

Example: More plastid genes are upregulated in space than on Earth

Activity 4: Arabidopsis GLDS-38 MA-plot for Spaceflight: FLT vs GC

Instructions: Look at the MA plot below and answer the questions.



1. What do the dots represent?

A gene or feature

2. What do the red dots represent?

These are genes that were significantly changed

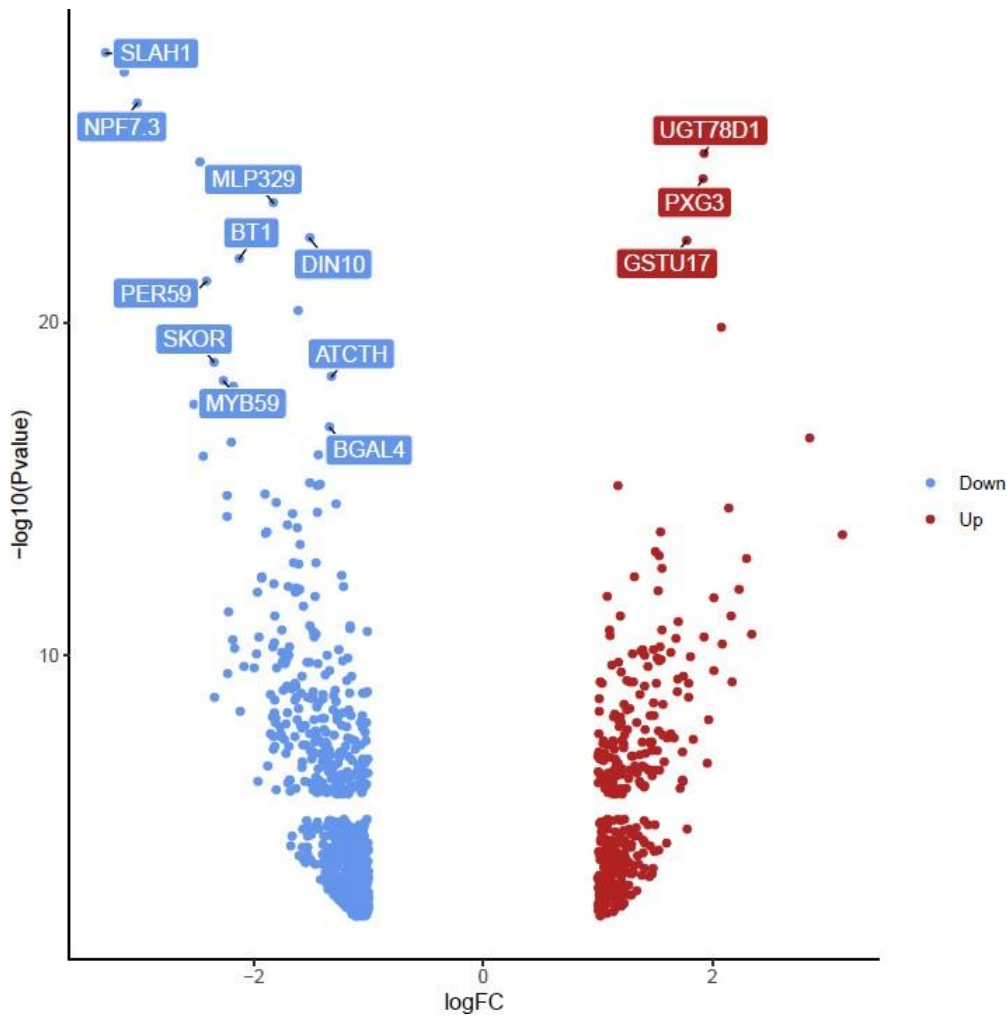
3. **After discussing the impacts of spaceflight on plants and looking at the MAplot, what can you infer?**

Answers will vary.

Example: Gene expression in plants is affected by space flight. Some genes are impacted more than others.

Activity 5: Arabidopsis GLDS-38 Volcano Plot

Instructions: Look at the volcano plot below and answer the questions.



1. What do the blue dots on the volcano plot represent?
Significantly down regulated genes
2. What do the red dots on the volcano plot represent?
Significantly upregulated genes
3. Which gene was the most downregulated? Upregulated?
Down regulated-SLAH1, Upregulated-UGT78D1
4. Go to [TAIR - Home Page \(arabidopsis.org\)](http://TAIR-Home-Page(arabidopsis.org)) and search for the function of these genes. Propose reasons that explain why regulation of these genes would change in space. (You will learn more about genes and their expression in a future lesson.)
Answers will vary

REFERENCES

GLDS-38 Dataset. Wyatt, SE. (2015). "Proteomics and Transcriptomics analysis of Arabidopsis Seedlings in Microgravity", GeneLab, Version 10, DOI: 10.26030/p03c-xa96.

GL4HS Manual: GeneLab for High School Bioinformatics Manual. Blaber, Elizabeth. 2021.

Video: Science at NASA Astronauts Learn Gardening in Space ([Astronauts Learn Gardening in Space | Video - YouTube](#))

Video: NASA Social: Growing Plants in Space (<https://youtu.be/3kspnEQKrcY>)

Video: ISS Update: Plants in Space (<https://www.youtube.com/watch?v=xLYeZKDv0lg>)

STANDARDS ALIGNMENT

Florida Science Standards: SC.912.N.1.1-7, SC.912.E.5.7-8, SC.912.L.14.3, SC.912.L.14.8, SC.912.L.16.3, SC.912.L.16.5, SC.912.L.16.6, SC.912.L.17.6, SC.912.L.18.5, SC.912.L.18.7, SC.912.L.18.8, SC.912.L.18.9

NGSS AP Biology Science Practices

- Visual Representations 2.C- Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.
- Representing and Describing Data 4.B- Describe data from a table or graph, including a. Identifying specific data points. b. Describing trends and/or patterns in the data. c. Describing relationships between variables.
- Argumentation 6.C- Provide reasoning to justify a claim by connecting evidence to biological theories.

AP Biology Standards

- IST-2.A.1- Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.
- IST-2.D.1- Gene regulation results in differential gene expression and influences cell products and function.

AUTHOR

Monique Salazar, iMater Preparatory Academy (Hialeah, FL)

Edited by GL4HS Staff