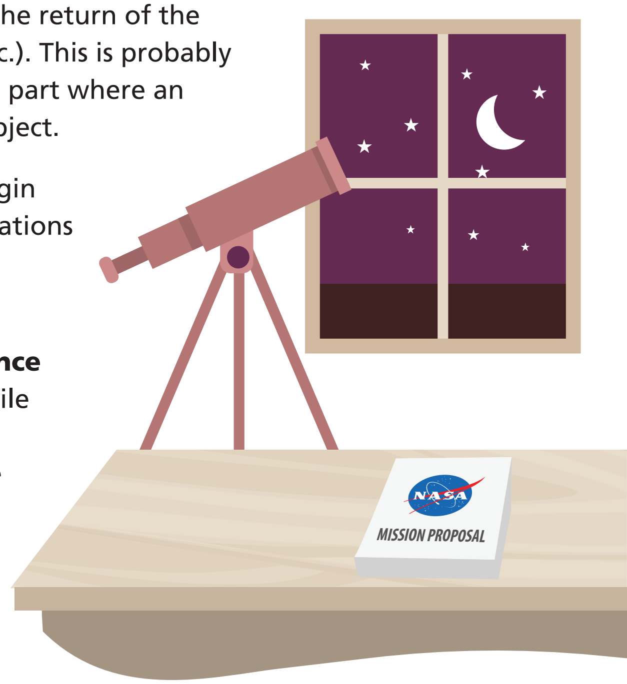
Data Collection:
A Mission-Long Process

National Aeronautics and Space Administration

1 Begin Data Collection at the Very Beginning

The reward for all the effort and resources poured into a space mission is the return of the data obtained from some object in space (like a planet, moon, asteroid, etc.). This is probably why many people think that data collection for a mission involves only the part where an instrument is actively acquiring measurements from or about that space object.

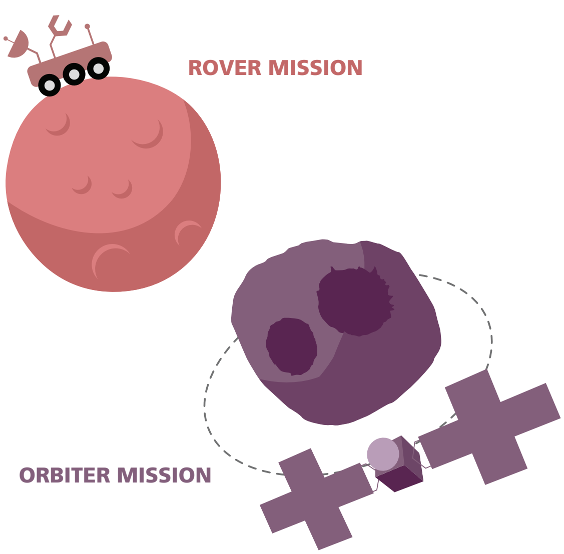
But this understanding of data collection is too narrow. Before you can begin collecting data from the space object, you must first design a set of observations for your science instruments to collect. You must also determine how this data will be collected.



Preparing for data collection is the first step to constructing a science plan for a mission. For Psyche, we started the data collection process while writing the mission proposal. In fact, from the proposal, we have already designed a set of observations for our time at the Psyche asteroid, because knowing what and how we needed to observe at Psyche determined the types and specifications of the instruments we needed to build.

2 Understand Your Mission

When planning the data collection for a space mission, you must take the type of mission into account: Orbiter missions and rover missions are fundamentally different and so require different approaches to data collection.



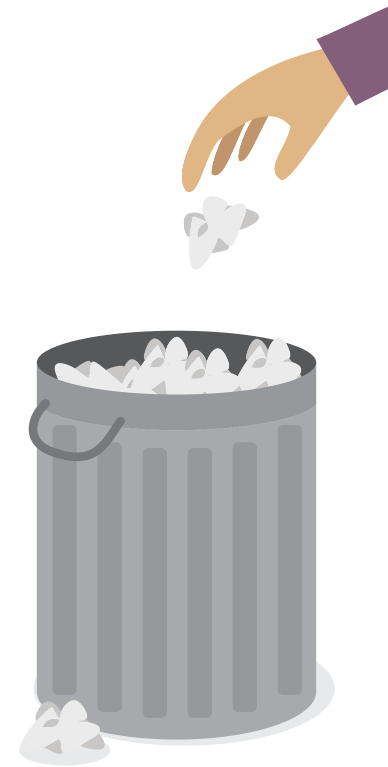
For **rover missions**, scientists study images returned by the rover and use that data to decide what to go back to for further investigation. In other words, for a rover mission, information from previous observations is rapidly incorporated into upcoming observations.

In contrast, for **orbiter missions** (like Psyche), scientists cannot pick and choose the data that are collected because the orbiter is constantly moving and cannot just "go back." In Psyche's case, the spacecraft will map the whole asteroid, covering it with a variety of observations. We know that we'll get the data we need so long as we reach the end of our primary mission (21 months in orbit).

So a rover mission calls for more open-ended (tactical) data collection methods while an orbiter mission generally calls for much more strategic planning.

For Psyche, that advance planning process helps us from the start of the mission to predict the characteristics of our observations—what the lighting conditions are going to be like, how many pictures we are going to take, what kind of overlap they are going to have, and what we are going to be able to do with them. This data collection process always starts far in advance of actually giving commands to the spacecraft and executing them, and it is a process that gets done over and over again.

3 Be Prepared to Redo EVERYTHING



If you're the kind of person who likes to be finished with a task after completing it once, then planning spacecraft observations will frustrate you! To plan spacecraft observations, you must **embrace the need to rethink, remodel, or redo** a task when circumstances change suddenly—even if you've already worked hard on it.

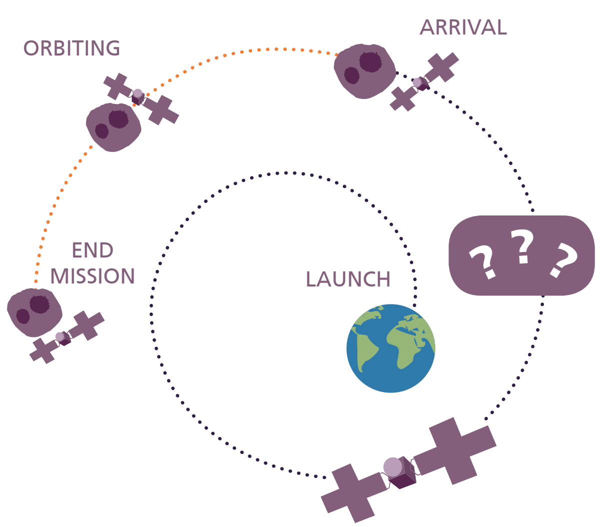
To give an example, suppose you're working very diligently on something, but then the planned spacecraft trajectory changes. You will need to redo the whole thing to adjust to this new trajectory. Of course, the process is always easier the second time through because you've already done the initial work and you're familiar with it. So the more you experience these adjustments, the more you become aware of how specific types of changes, such as in the trajectory or in the timing, will impact observations.

This iterative process may seem bothersome, but it is really helpful because, as the mission progresses and something unexpected happens at the last minute, you already have in your mind a range of changes you can make to address the problem right away.

4 Accept and Welcome the Uncertainty

While unexpected situations can occur during any mission, this method of pre-planning data collection may require that you **accept uncertainty as well as change**.

For the Psyche Mission, we have embraced the fact that, due to the spacecraft's use of electric propulsion, the specific timing of the observations (in terms of where we are around the surface of Psyche) is going to remain unknown until almost the last minute.



In low-thrust missions, the amount of available thrust depends on the amount of available power. The power output of the spacecraft will be calibrated during cruise (the time the spacecraft is traveling from Earth to its destination), which will determine the thrust profile. But even with a known calibration, there is always some uncertainty in thrust performance. Each thrust segment will need to be evaluated and adjusted to optimize the performance of future thrust segments.

So, even when the spacecraft is only a few months away from entering an orbit around Psyche, the **timing of where exactly we will be for our planned observations could be uncertain by as much as six weeks**! To address this, our approach is to design a set of routine mapping observations that will be valid no matter what the timing is when we arrive.

Psyche has never been visited by a spacecraft before, so all estimates (to date) of its mass, radius, spin and axis orientation are based on our remote measurements. As a result, there is significant uncertainty in these estimates. The spin axis orientation determines what fraction of the surface is in sunlight (and can therefore be imaged), so updating this information as soon as possible is important for data collection.

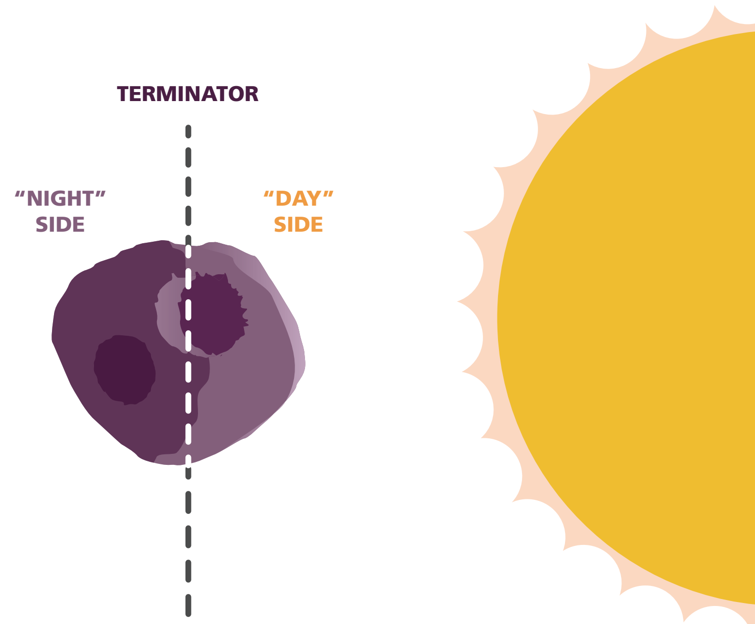
As we get closer to Psyche, we know that our understanding of the spin axis will be refined, so we'll have to redesign our mapping observations to take that into consideration. Thus, they will need to be flexible enough to allow us to make these adjustments.

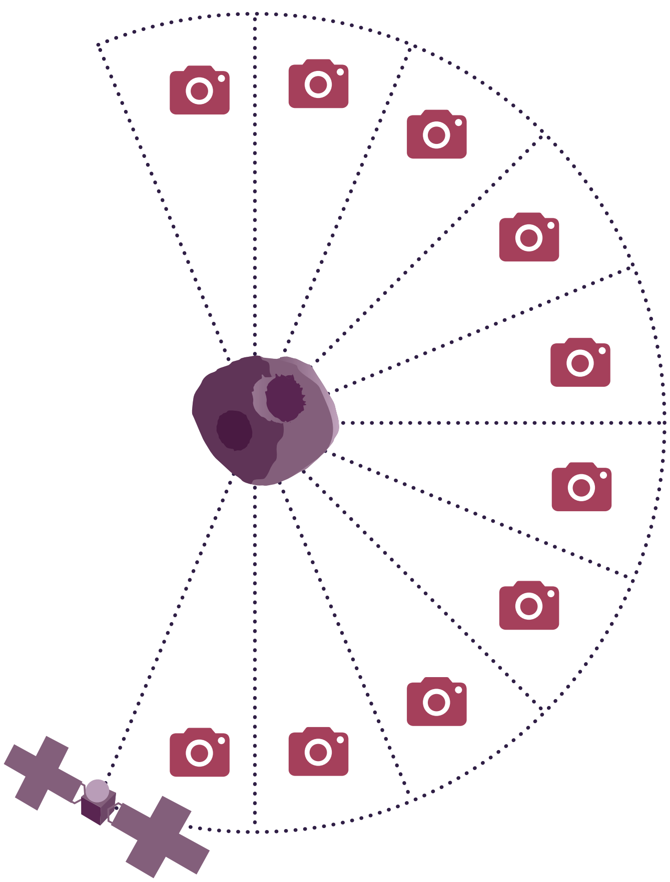
5 Plan Ahead Extensively for Data Collection

Even when there are uncertainties, it is still necessary to **plan for the conditions of data collection** once we arrive at a space object.

For the Psyche Mission, because we are still missing specific information (such as the spin axis and where Psyche will be in its orbit when we arrive), we've developed a way to make observations intentionally repetitive and to link them to "geometric events" on the asteroid body, such as when the spacecraft crosses Psyche's equator or poles.

The geometric events that are most important for taking images are when we cross the "terminators"—when we go from the "night" side of the asteroid (facing away from the sun) to the "day" side (facing toward the sun) or vice versa.





We only want to take images while the spacecraft is in the light, so these "terminator crossing" geometric events are what we use to determine the timing of the imaging observations. We must take advantage of every moment that the spacecraft is on the day side of the asteroid. Timing is crucial. But because we are still uncertain about the exact timing, we actually need to plan to start taking images a little before the spacecraft crosses from dark to light.

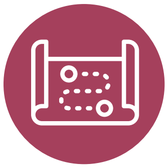
For example, we might arrange the image sequence to take the first picture 10 minutes before the spacecraft is supposed to cross from night to day. Then it can take images at regular increments until we cross back over into night.

Depending on where the spacecraft is in its path, the frequency of taking images may change. For instance, because the spacecraft will go faster when it passes over the equator than when it passes over the poles, the pictures will need to be taken more frequently in this area so that they will still overlap each other.

We need them to overlap because the goal is to take pictures that form a continuous path across large swaths of the asteroid's surface. It's like when you use a camera to take a series of pictures that you want to connect in a panorama. This ensures that we won't miss any data between one image and the next.

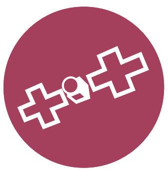
6 Integrate Expertise on the Team

The Psyche team is comprised of smaller subgroups, each with specific tasks and expertise. Most groups are involved in data collection in some way, particularly during active data collection at the asteroid.

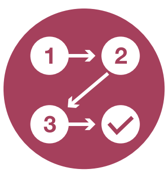


One of the key components of the Psyche team is the **navigation team**. The people on this team help to mitigate uncertainties about timing by continually providing the rest of the team with updates on the spacecraft's trajectory. The trajectory is the backbone of our observation plan.

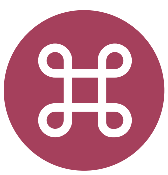
On another team are the **science planners**, who examine the details of where we want to collect data with the instruments.



On the **spacecraft team**, some members make sure that the spacecraft stays at a safe altitude above the asteroid's surface.



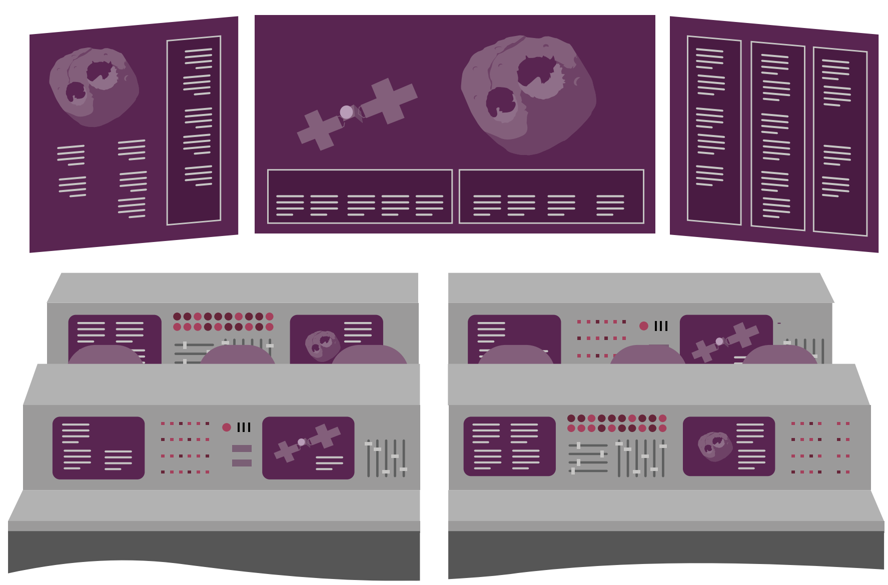
Then there's the **sequence team**. This subgroup takes the files that are being developed by the science team and integrates the sequence of commands for data collection with the other sequences needed to run the spacecraft.



There are also people on the **specific instrument teams** who build specific instrument commands because each instrument has its own operators who know the ins and outs of that instrument.

After all of these people have collaborated, observation sequences (lists of individual commanded actions such as "take a picture at this particular time") are produced, which everyone reviews. These sequences usually go through two review cycles. In the first review, someone may identify a problem, and everyone then goes off to rethink, remodel, and rebuild the sequence. By the second review, everything is usually ready to go.

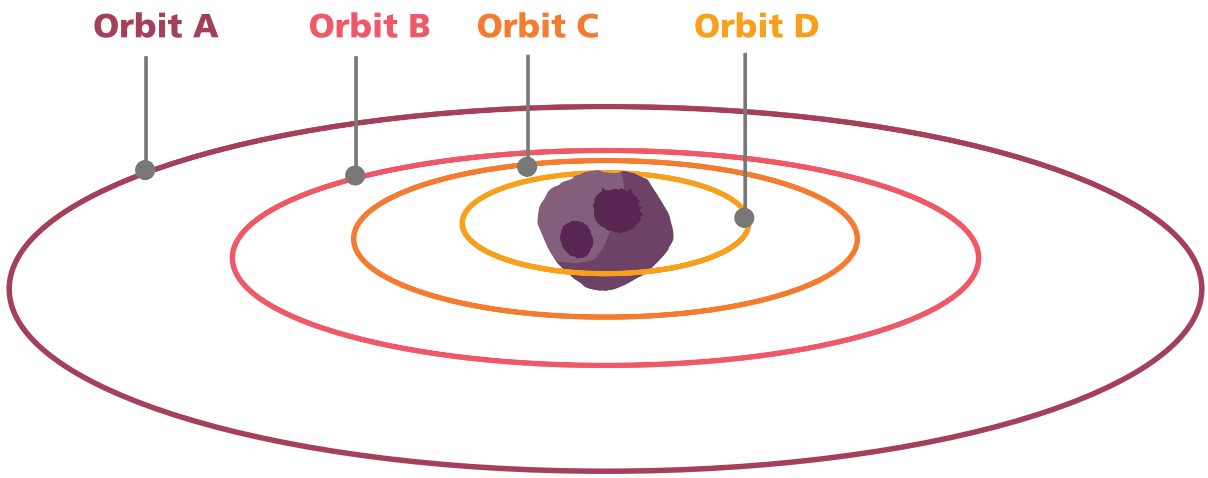
Last, the **mission control team** sends the commands up to the spacecraft via NASA's Deep Space Network (DSN). With that, the command files finally reach the spacecraft! The observation data (images, magnetic field measurements, or gamma-ray detections) are acquired by the instruments, transferred to the spacecraft, and stored in its memory until the next time it has contact with the DSN, at which point the spacecraft sends the collected data back to Earth.



7 Schedule Data Downlinks

Once the spacecraft reaches orbit and starts collecting observations, we need a way to **retrieve that data**. Early in the Psyche Mission, we will send commands to the spacecraft ("uplink") about once a month. Using those commands, the spacecraft will take images, or acquire other data, of the surface for a specified number of orbits, and then it will send the data back ("downlink").

Early in the mission, downlink takes place when the spacecraft is on the dark side of Psyche. Because we won't be able to take images in the dark, we will use those periods to retrieve the data that have been collected. How frequently the spacecraft sends back data will depend on its orbit. We have four planned orbits for Psyche, named A, B, C, and D. Each one gets successively closer to the asteroid. In Orbits C and D, each period on the dark side is very short, so a different strategy is needed.



In **Orbit A**, the spacecraft will take 32.5 hours to complete a single circuit. For half of that orbit, the spacecraft will be on Psyche's day side, observing the surface of the asteroid for about 16 hours. Then, when it's on the night side, the spacecraft will point its main antenna toward Earth and send back all of the data it just acquired. Thus, every 16 hours or so, we will receive the data that the spacecraft collected while it was on the asteroid's day side.

In the next orbit, **Orbit B**, it will take 11.2 hours for the spacecraft to complete one lap around Psyche. The procedure for this orbit will be similar to the one for Orbit A, but at this point the spacecraft will be crossing the terminators about every 5.6 hours, so the downlinks will happen much more frequently. With such rapid turnarounds, the focus will be on monitoring the spacecraft's "health" and saving the data that come down for future processing and analysis. We also won't be sending up new command sequences as frequently as we did when the spacecraft was in Orbit A.

When the spacecraft gets to **Orbits C** and **D**, the procedures change a bit. The underlying principles are the same as they were for Orbits A and B, but because Orbit C will take only 6.5 hours to complete, and Orbit D will take a trifling 4.1 hours, we must time the downlinks differently.

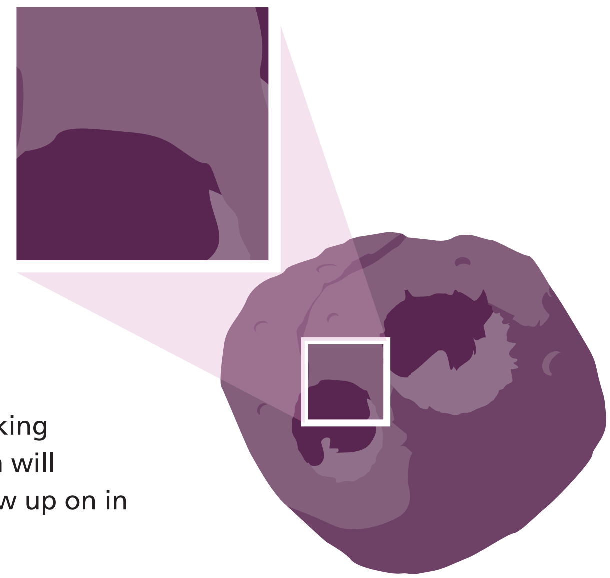
In Orbits A and B, the spacecraft will have time to point itself toward Earth while it's on Psyche's night side—and turn back before it reaches the day side again. However, in Orbits C and D, it cannot possibly turn every time it crosses the terminator between the light and dark sides—otherwise it would do nothing but turn!

So what we'll do for Orbit C is keep the spacecraft pointed at the asteroid so it can collect data for twelve orbits, and then turn it back toward Earth and downlink the data for four orbits. This way, the spacecraft will be observing 75% of the time and sending data back 25% of the time. This will be the same for Orbit D, except collecting data will take 21 orbits and sending it back will take 7 orbits. This means that the team will learn what the spacecraft has been doing about once every 3.5 days.

8 Narrow Down the Target for Observation

Throughout the mission, we will be planning observations to assure that we collect enough data to make a complete global map of the asteroid. Given the amount of coverage we'll get in Orbits A, B, and C, we are confident that we will record everything on the surface.

It won't be until we get down to Orbit D (the closest orbit to the asteroid) at the very end of the mission that the "footprints" of the data will be too small to fully cover the surface. As the spacecraft gets closer, its field of vision will shrink, and we would need a greater number of images to construct a global map. So many images would be required, in fact, that we will not have the downlink capability to return a full global map at this resolution.



Orbit D will offer the science team an opportunity to **get a closer look at specific targets**. These targets will be carefully thought out. During its time in Orbits A, B, and C, the spacecraft will observe the surface repeatedly from different angles. We will be making maps and topography models from this data, which the science team will then use to identify the most important targets that we should follow up on in higher resolution.

While we will continue to blanket the surface with observations from Orbit D, planning in advance to fully investigate every target of interest is an important part of the data collection process.

9 Gather and Cross-check the Data

The specific data products (images or other types of data) that the spacecraft will send back have been planned literally years in advance. But because of the uncertainties and the changes we have to deal with, we won't know if the commands we send to the spacecraft will actually give us what we want.

Once received, all collected data will go through a series of processes that will return different types of data products. The instrument team will use those files to compare the commands sent to the spacecraft with what the spacecraft actually acquired.

For example, we will get images of the asteroid's surface, but we won't know exactly which part of the surface they are from. We will have to go back to the navigators, who will reconstruct the actual trajectory that the spacecraft followed, using data sent back from the spacecraft and landmarks on the surface.

Using that information and various other tools, the image processing team will locate where each picture of the surface came from and "stitch" them together into image mosaics.

Mosaics contextualize the data we collect. It is hard to get a sense of what the surface of an astronomical body looks like if you can see only one image at a time. But when individual images are overlapped accurately and stitched together, it is possible to see the whole surface at once. With those mosaics, we will have the first basic look at the data.

10 Analyze and Archive the Data

Each image the spacecraft takes will be calibrated for different color filters. Once we have our mosaics, we'll be able to apply these calibrations to the data. Then we'll distribute them to the science team.

This is when the actual data analysis will begin, when the team will try to understand what we're seeing on the surface and answer our fundamental science questions about Psyche.

You might be tempted to think that data collection ends here. However, even after the data are collected and prepared for analysis, one final step remains: All the data must be archived so that the information can be stored, accessed, and shared in the future.

Even while scientists begin probing the datasets for answers, some team members will start preparing them for archiving. There are very specific formats and protocols that must be followed in order for the datasets to be accepted by NASA's Planetary Data System (PDS), a public online repository that provides "a long-term archive of digital data products returned from NASA's planetary missions" (https://pds.nasa.gov/). Some of us will be working on that, providing descriptive information for each image, which we will put in something we call the "header" or "label" file.

For example, when someone accesses an image, the header file will show the date and time it was taken, the latitude and longitude of the center and corners of the image, the spacecraft's altitude above the surface, the exposure time, the effective resolution, and how much (and in what ways) the image was compressed. Users need to have access to all of this information to make sense of the data, so everything is recorded in these headers.

Once the datasets have been prepared, our team reviews them once more. When they are ready, they will be submitted to the PDS. A set of independent reviewers from all around the country will then check our data files and make sure that everything is consistent and that we've supplied all of the information required for interpreting these data. If their review turns up anything that needs to be fixed, we'll have a chance to take it back, make the corrections, and submit it for another review.

Once everything has been approved, each dataset will be filed away in an archive that can be accessed by anyone in the public, any time, in perpetuity! This marks the true end of data collection.