# IMPROVING **MARS 2020** ROVER PLANNING

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MHCI+D Capstone 2019

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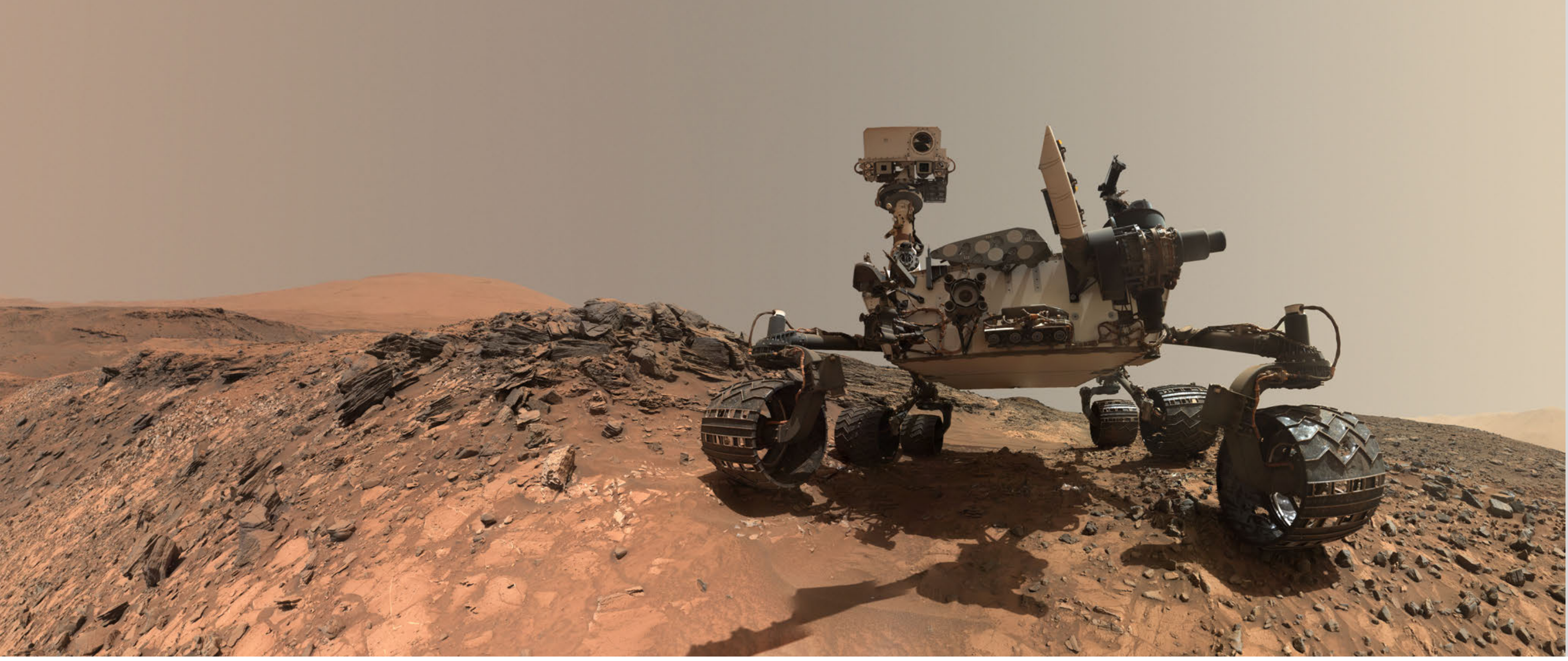
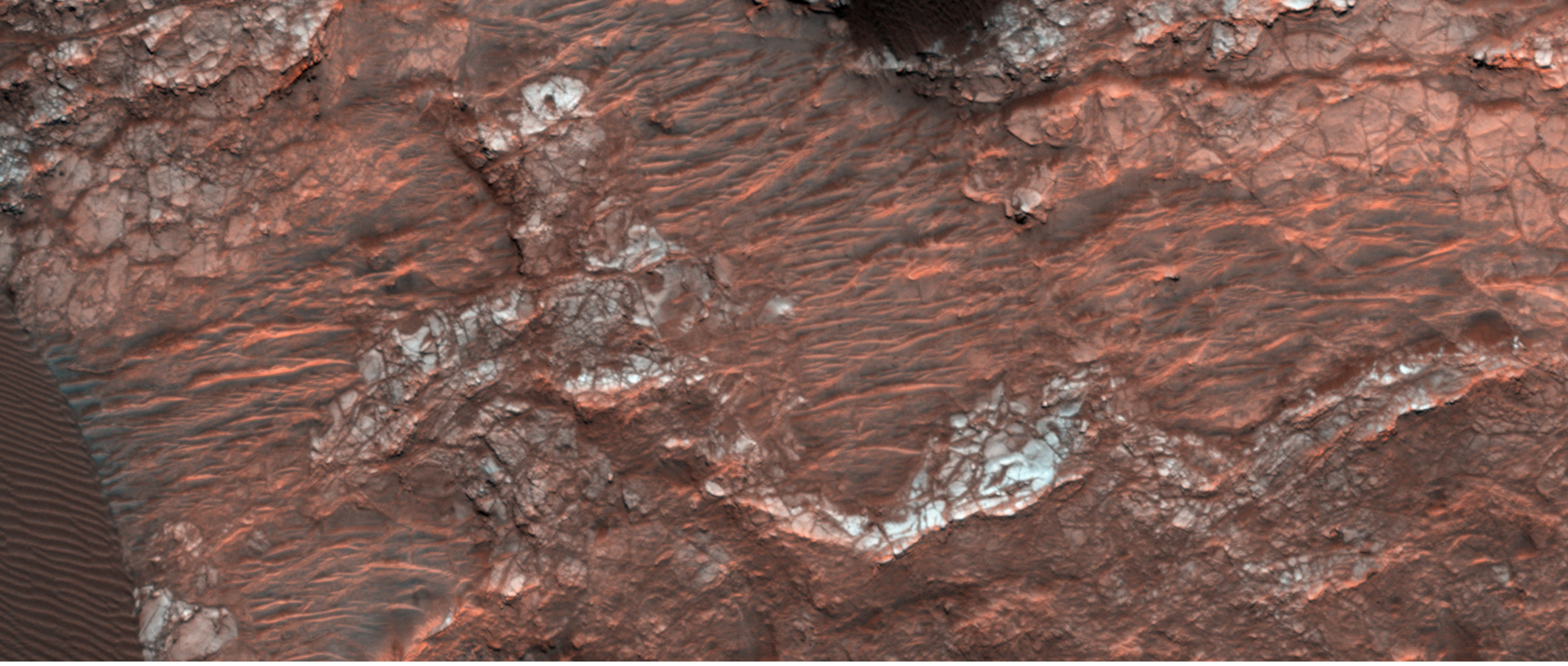
Last but not least, we want to embody NASA's culture of Heritage. We have included a detailed research plan, interview guide, and transcripts along with this report so that the team next year and learn and build upon our work.



# TABLE OF CONTENTS



# EXECUTIVE SUMMARY

In preparation for its upcoming launch, NASA Jet Propulsion Laboratory's Mars 2020 mission is working to reduce the amount of time spent planning rover operations in order to facilitate more time for scientific discovery. Rover planning at JPL is a complex decision-making problem, requiring consensus among various scientific and engineering domains competing for resources when choosing a course of action. This is complicated further by a fragmented tool ecosystem, geographical distribution of teams, and the fact that Mars' distance requires all activities occur asynchronously.

NASA Jet Propulsion Laboratory tasked us with finding some way of reducing deliberation time between these competing stakeholders in order to facilitate greater scientific discovery. We conducted an extensive literature review and 18 specialist interviews in order to gain a holistic understanding of Martian science and rover mission operations. We distilled this research into 8 insights to further our understanding of the problem space, direct us towards appropriate design opportunities, and inform our design requirements. With these insights in mind, we saw an opportunity to help scientists better understand and predict the impact of atmospheric opacity on rover instrumentation and data. We hope to increase data transparency and shift a traditionally tactical planning effort toward the campaign level. This will reduce the time needed for scientists to decide on a course of action and make more efficient use of the rover's limited resources.

# INTRODUCTION

NASA Jet Propulsion Lab (JPL) is preparing for its upcoming mission, Mars 2020. This mission is the next stage in NASA's long-term effort of robotic exploration on Mars with multiple scientific goals, including searching for previous signs of life on Mars, characterizing the planet's climate and geology, and preparing for potential human exploration [1].

An accurate understanding of weather on Mars is critical to the success of the mission since there are several cases where conditions on Mars dictate where and how science experiments are conducted. For example, dust levels can dictate camera operability, temperature can affect rover power, the sun's position can affect the timing and feasibility of operations [2].

The Mars 2020 rover will run on nuclear power and as a result, it will have a longer operation time. NASA's internal policy dictates an equal amount of time planning and operating the Mars 2020 rover. This means that planning teams need to meet a daily 5-hour planning window, requiring quickly accessible data and an efficient decision-making process [3]. Seamless collaboration among the science, engineering, and instrument teams is crucial in order to meet this timeline.

Mission planning is dependant on geographically distributed teams comprised of individuals with varying skill sets and knowledge backgrounds. These teams rely on ad-hoc meetings, PowerPoints, and a company-wide wiki for communication. On previous NASA missions, breakdowns in communication have caused costly delays, wasted resources, and even irreparable damage to instrumentation [4]. Due to this lack of tool cohesion and improper documentation, the science intent often gets lost in the process further exacerbating collaboration efforts.

Over 10 weeks, our team conducted extensive secondary and primary research into various topics regarding the Mars 2020 operations. This includes Martian weather, scientific intent, team collaboration, and data visualization. Based on learnings from secondary research, we chose semi-structured interviews, directed storytelling, and iterative diagraming as 3 main methods for our research activity. We selected JPL scientists, engineers, and data visualization experts as the research population. A tailored guide was created for each interview participant based on their background, experience, and involvement with past and current Mars missions. We then used coding as a primary framework to synthesize insights and arrive at design requirements.

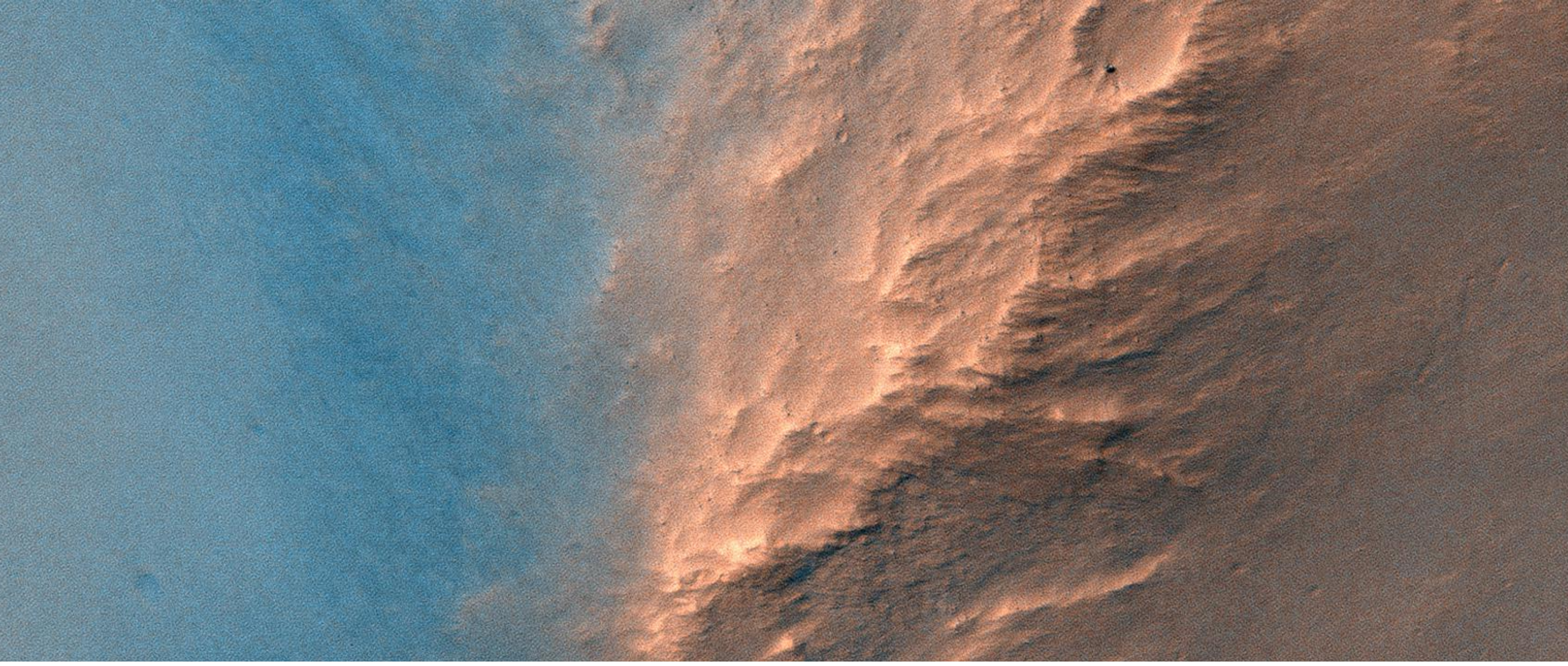
From our research, we identified 3 potential directions:
1. Helping scientists understand the effects of tau on instrumentation and data.
2. Preserving science intent to aid collaboration and decision making among operation teams.
3. Visualizing weather on Mars to provide scientists with data context with respect to the terrain.

We decided to move forward with direction #1 as it is well-scoped and aligned the most with our insights and design requirements.

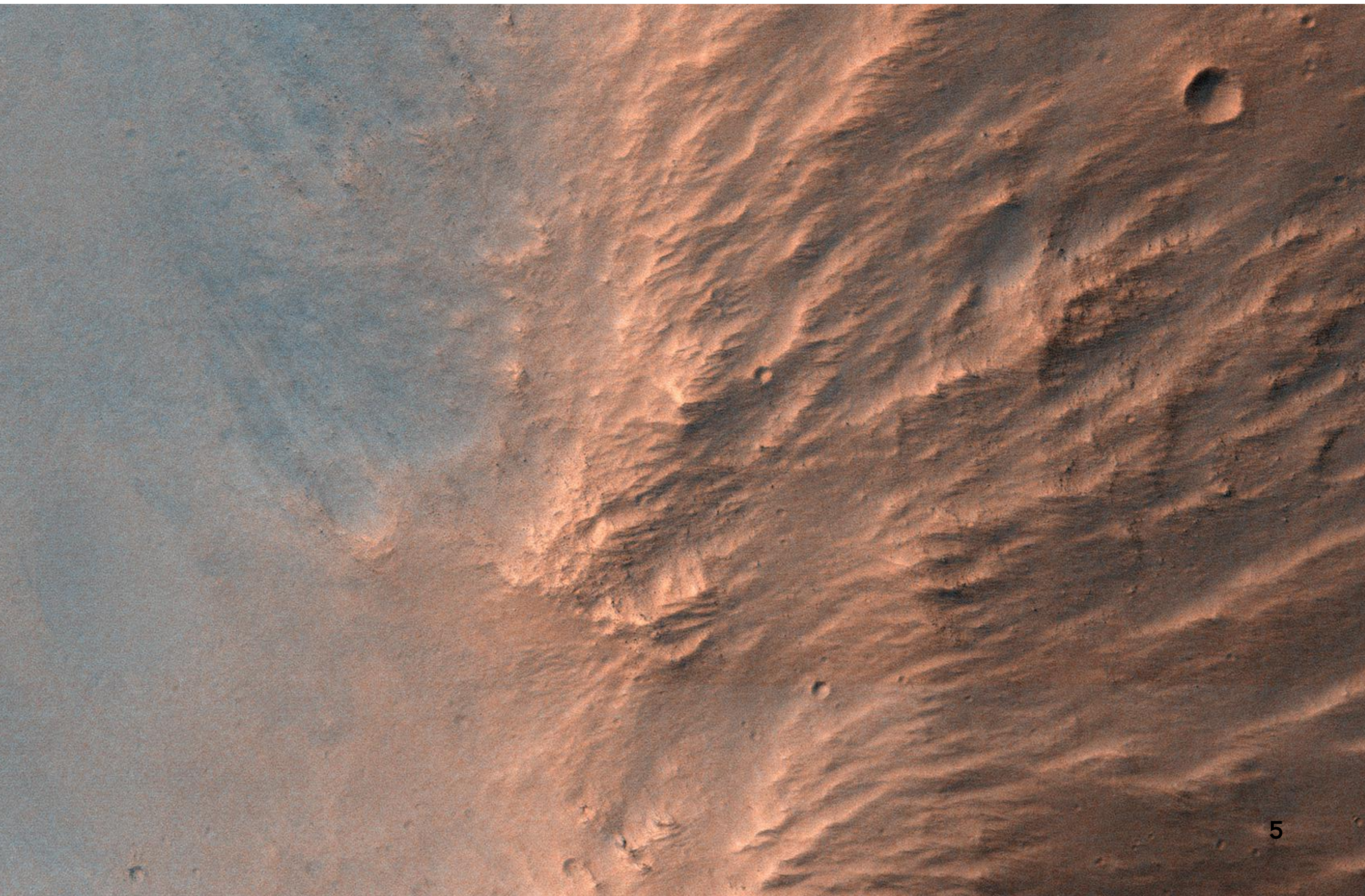
There are 3 limitations to our research process: time, mission confidentiality, and location. Since NASA has a complex organizational structure, it is difficult to get a comprehensive picture of team collaboration and dynamics within 10 weeks. Second, the Mars 2020 mission is still evolving; information regarding operations and planning have not yet been finalized and can only be shared among internal employees. Third, our team conducted research remotely. This set a constraint in the type of method that could be used; ethnographic methods such as contextual inquiry or observational method which would have been a strong learning resource weren't a viable option.

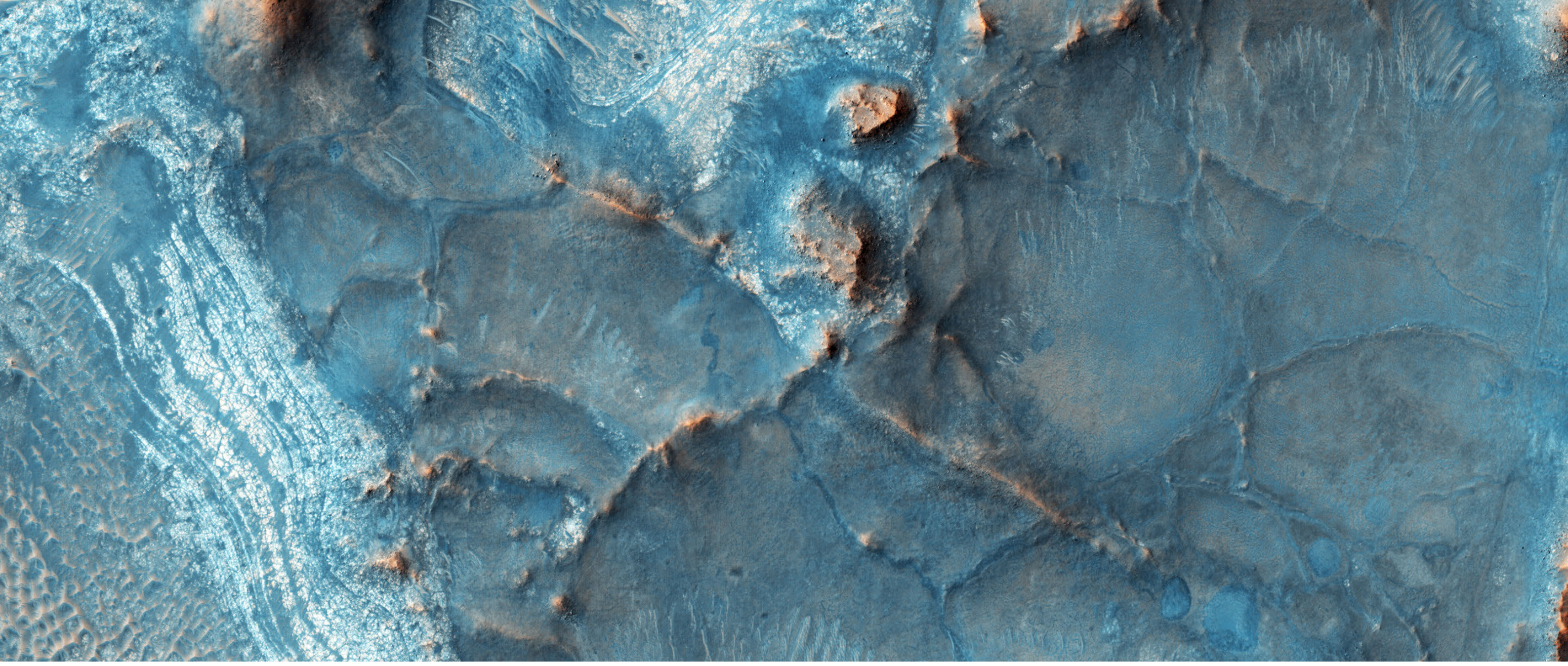
# CHALLENGE STATEMENT

How might we help scientists understand and predict the effects of tau on instrumentation and data?



# 01 Background





# LITERATURE REVIEW

## Past Missions

NASA's Mars Exploration Program (MEP) was designed to study Mars as a planetary system using a variety of landers, rovers, and orbiters. Each mission builds upon previous research and innovations to continue to push to new discoveries. The goal of the program is to understand the geological and atmospheric processes on Mars, to study the planet's potential to sustain life, and to gather information that might help plan possible future human exploration on Mars. The original theme of Mars exploration was to "Follow the Water" as water is an indication of an environment that can support life. When past missions found evidence that water used to exist on the Martian surface, the Mars exploration theme evolved to "Explore Habitability," with the purpose of seeking additional chemical elements that were necessary for life [5]. Finally, with findings from the Curiosity rover, MEP marked a transition to the upcoming Mars 2020 mission, shifting the theme to "Seek Signs of Life".

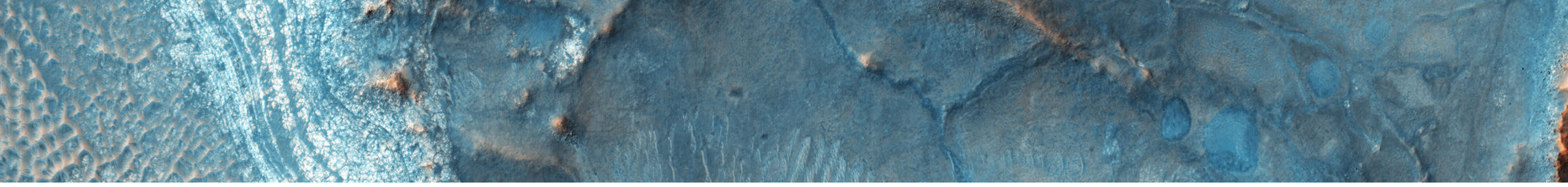
## Mars 2020

With findings from Curiosity rover, MEP marked a transition to the upcoming Mars 2020 mission, shifting the theme to "Seek Signs of Life". The Mars 2020 program has 4 long-term science goals.

**1** Determine whether life ever existed on Mars
The rover will conduct studies on the Martian surface and seek biosignatures from rock samples.

**2** Characterize the climate of Mars
The rover will look for for evidence of ancient habitable environments where microbial life could have existed in the past.

**3** Characterize the geology of Mars
Each layer of rock provides information about past Martian environmental conditions, revealing the history of how Mars' crust and surface evolved through time. The study could be further extrapolated to uncover the history of Earth itself. Current and future rovers will cache geological samples to be studied in the future.



**4** Prepare for Human Exploration
The rover is demonstrating key technologies for using natural resources in the Martian environment for life support and fuel. It is also monitoring environmental conditions so mission planners get a better understanding of how to protect future human explorers.

## Relevant instruments and spacecraft

**The Mars Environmental Dynamic Analyzer (MEDA)** is the instrument attached to the Mars 2020 rover that will help scientists gather information about weather on Mars. MEDA measures a wide range of variables such as temperature, wind speed and direction, humidity, and the size of dust particles in the Martian atmosphere [6].

**Mars Reconnaissance Orbiter (MRO)** is a spacecraft orbiting Mars since 2006 [7]. The mission goal is to study the Martian atmosphere and terrain, including the history of water flows on or near the planet's surface. It also serves as a key data relay station for other Mars missions. On May 15, 2019, it completed 60,000 orbits around Mars [7].

**Mars Atmosphere and Volatile Evolution (MAVEN)** is a satellite developed to study the Martian atmosphere and its composition. It has recently provided significant data around the loss of water and atmosphere on Mars and the role solar storms play [8].

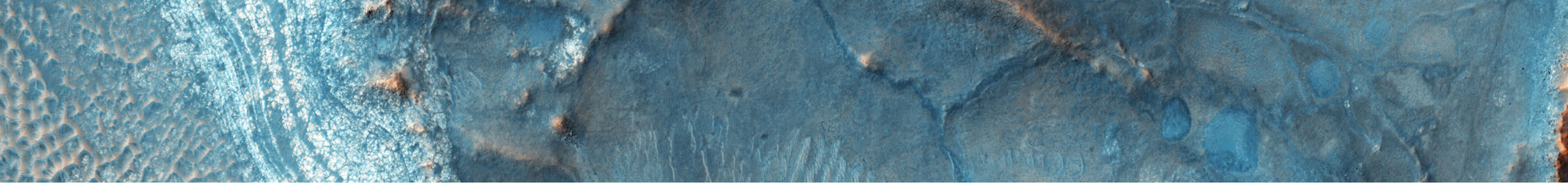
**Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)** is a Mars lander that aims to study the "inner-space" of Mars: its crust, mantle, and core. It seeks to uncover how Mars was formed and evolve over time along with determining the tectonic activity on the red planet [9].

## Weather variables and implications

**Atmospheric Opacity**
Similar to the effect of water on Earth, dust dominates the surface of Mars and dictates most of its atmospheric conditions. Dust storms significantly reduce power on solar-dependent rovers, due to obscurement and settling of dust on the rover's arrays [10]. This obscurement risk has been somewhat mitigated in the Mars 2020 mission through the use of a nuclear power core, but meteorological data still holds significant mission planning repercussions. For example, the amount of dust particles in the atmosphere affects the optical opacity measurement ($\tau$) which dictates camera operability, exposure times, and image quality [11]. Depending on the visibility, rover planners may also delay science activities that depend on external camera data [12]. Similarly, dust storms could damage delicate instruments and rover planners would need to know when to retract them in order to increase their longevity [13].

* ($\tau$) - Tau, a measure of optical depth, or how much sunlight cannot penetrate the atmosphere. In the Martian context, it directly relates to how much dust present in the atmosphere

**Temperature**
Temperature is critical to rover operations, especially for Mars 2020 since the rover is running on nuclear power. Temperature profile includes near-surface air temperature and ground temperature. Near-surface air temperature affects rover powers as it influences how much heat is needed to warm up rover instruments. The rover also radiates heat which affects the surrounding soil temperature [14]. Understanding ground temperature, in this case, helps the operation team separate natural temperature effects from artificial ones to account for data error and uncertainty.



### Wind
Wind can raise dust from the surface into the atmosphere, absorbing solar radiation and acting as an internal heat source. Near-surface wind speed and wind direction can have a direct influence on dust behavior and the formation of dust devils [15].

### Atmospheric pressure
Atmospheric pressure and thermally driven tides are factors contributing to dust storm creation [16]. Understanding the effects of pressure and thermal tides can help scientists study and predict dust storm formation and behavior.

### Relative humidity
Understanding water is critical for future human missions since it is a prerequisite for Earth-type life. Hence the study of relative humidity and its water vapor content is a paramount of scientific interests as it helps scientists identify the presence and behavior of water on Mars [17].

### Radiation
Radiation from space and the sun can alter traces on Martian rocks which inhibits scientists from learning about the history of Mars. Measuring radiation will also help scientists measure habitable conditions and prepare for future human missions [18].

### Seasonal and Interannual variability
All weather variable characteristics and patterns vary significantly depending on the time of the year. Studying how each variable behaves differently allows the operation teams to plan rover operations and scientific experiments at both short-term and long-term planning. For example, regional dust devils happen more frequently during the summer months [19]. Understanding this cycle helps the engineering team identify good windows for the rover's dust-cleaning schedule [20].

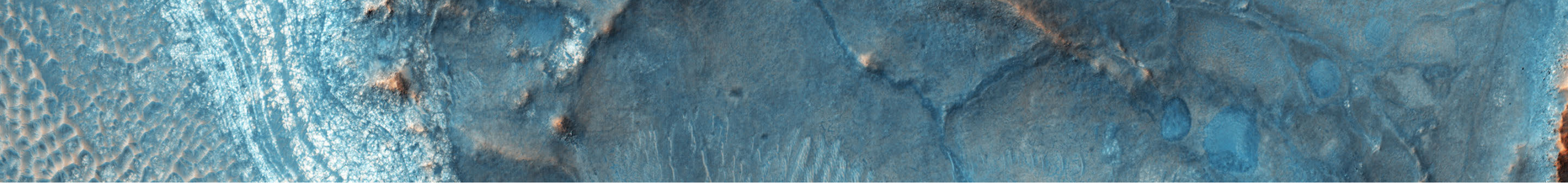
## Remote Collaboration

Approximately 3 months from the date of the mission's launch, the team begins transitioning to operate via a distributed operations network, centralized at JPL. This enables the remote science teams to work remotely for the duration of the mission. The teams communicate with one another through telecommunication and video-conferencing software. This method of communication and collaborative work presents a set of complications may impact productivity. Research has found that videoconferenced discussions tend to be less social and more task-oriented than face-to-face discussions [21]. As a result, these meetings tend to be less efficient than face-to-face ones [22].

Remote collaboration is made more challenging when the collaboration occurs asynchronously. Research in the area of asynchronous collaboration has reported the success of view sharing, discussion, graphical annotation, and social navigation in addressing the challenges of asynchronous collaboration [23].

## Decision-making process at high stake environment

In high-stakes domains, different roles and responsibilities must often work together to make decisions while geographically dispersed. While shared mental and situation awareness models are likely to be largely similar across an organization, some differences will persist as a result of distance, misaligned goals, and analytical methods. When these sense-making frameworks break, they present a risk to team cohesion and, ultimately, the project itself [4].



A mental model is defined as an internal representation of objects, actions, situations, or people [24]. They include knowledge of a system and of the relationships contained within them, supplying a "mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" [25]. Many studies have found that the greater the degree of overlap between the team members' mental models, the better that team performs [26], particularly if those shared mental models are accurate [27]. As such, an up-to-date and accurate mental model is imperative to effective decision-making processes in a high-stakes environment.

Team situation awareness is a shared understanding across the team of what is happening and what is going to happen due to well-defined campaign level goals. This allows a predictable process to occur in both nominal and abnormal events. When team situation awareness breaks down, predictability suffers, and communication becomes more difficult, if not impossible [4].

Closed-Loop communication is employed to prevent these breakdowns through stating the current action to reinforce trust between team members and providing a check on assumptions. This involves three steps: (1) A sender transmits, (2) A receiver accepts and acknowledges receipt, and (3) The original sender acknowledges the receipt message. This simple method is extremely effective by making what is usually implied overt - leaving no room for assumption [28].

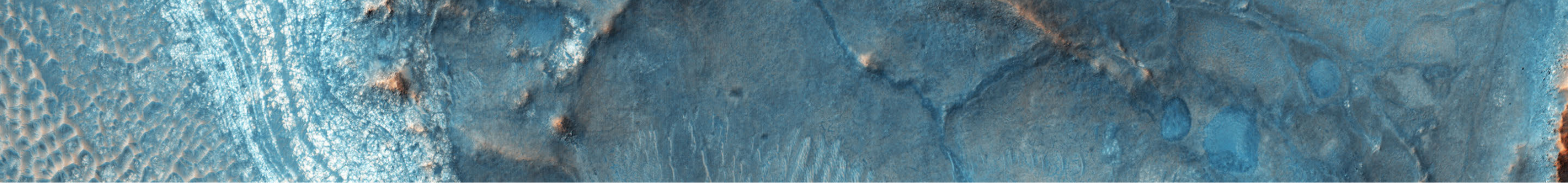
When breakdowns do occur, decision-makers employ recovery functions. These are ways of repairing a broken line of communication in the decision-making process [29]. One such method is the incident report which is used to assess breakdowns through open lines of communications and classification so that an organization may learn from and prevent future errors [30].

Despite safeguards and constructs meant to prevent breakdowns of decision-making capabilities, breakdowns will inevitably still occur in high-stakes distributed systems. Research suggests that informational (lack of information) and evaluative (a misunderstanding of information) disconnects lead to mental model and team situation awareness degradation, which in turn causes operational (difference in expected and actual actions) disconnects. Utilizing this model, they suggest that by focusing on the former, you can prevent the later from occurring [4]. These studies highlight the importance of ensuring all information is uniformly shared and understood in a decision-making process.

## Visualizing Scientific Data

Web-based data visualization tools have become more accessible, sophisticated, and interactive due to the profusion of open source software and tool kits. While the commercial industry has adopted multiple applications of data visualization, the scientific domain still faces a wide range of challenges due to the inability to accommodate the specific nature of scientists' needs. There are many factors that contribute to this problem but two critical ones of note are: the method of data collection and the scale of scientific data [31].

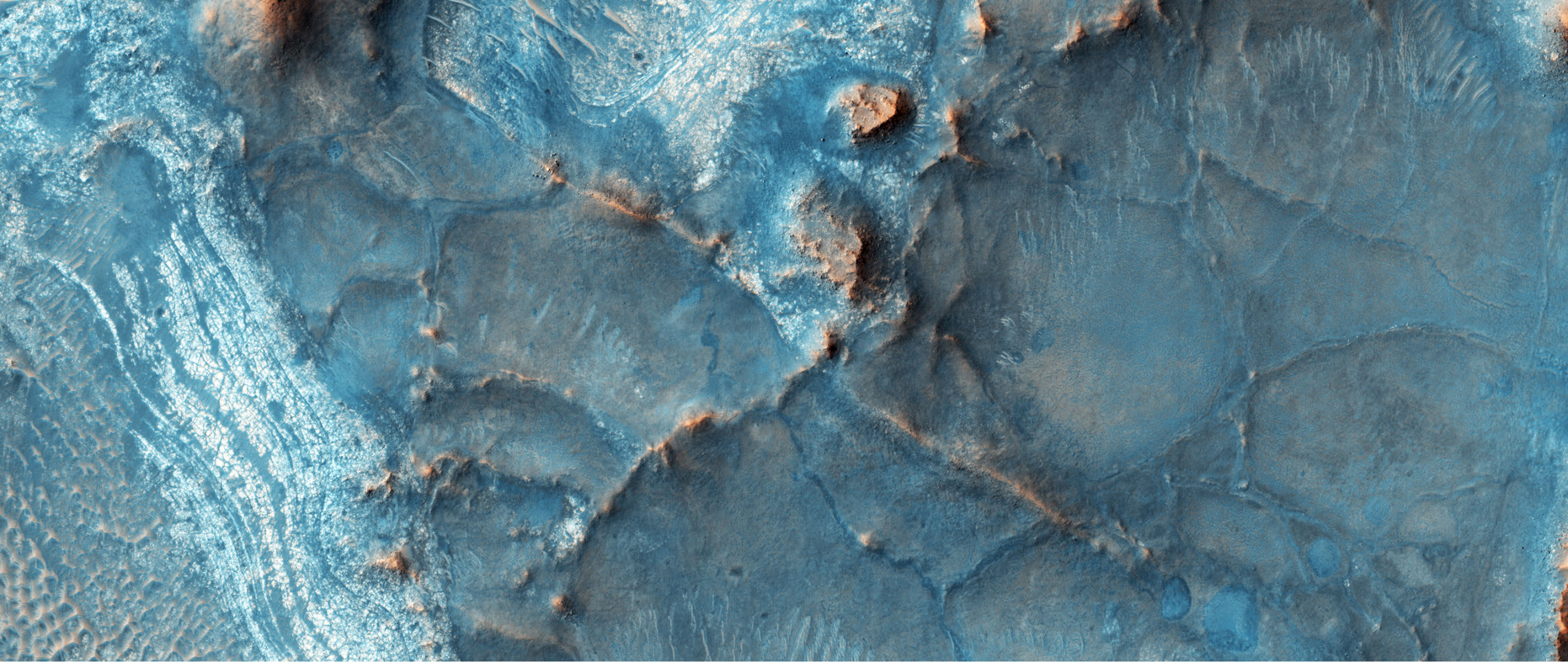
Collecting scientific data is difficult and instrument-specific. Depending on the source, each data variable comes in with a specific measurement, accuracy, or resolution [32]. Even though scientists have a good understanding of their own data and have means to make sense of raw data, getting the same intuitions from data across multiple instruments or from an unfamiliar research



area is difficult [31]. The second challenge is data scalability; scientific research requires a continuous influx of better data at a growing scale. Without live linking and quick data integration within internal tools, data visualization becomes its separate entity. As new data accumulates, the visualization quickly becomes outdated; it no longer reflects new findings and patterns [31].

Additionally, major scientific problems nowadays rely on the interdependence and integration of data from multiple sources and instruments. The role of visualization for complex data needs to evolve beyond aesthetic representation. It has to support scientists in forming hypothesis and exploring alternatives throughout the research life cycle [31].

Jim Gray described his vision of data-intensive science and called for a generic set of tools that could accommodate scientists through 3 main activities: data capture, curation, and analysis [33]. First, data needs to be holistically captured both at the mega-scale and a milli-scale [32]. Curation starts with identifying the right data structures to map into various stores. It must include the schema and the necessary metadata in order to integrate across instruments and make data interpretation become explicit [32]. Data analysis includes a set of activities such as workflow pipeline, the use of databases, analysis and modeling, and then visualization.



# JPL STRUCTURE

## Science Team Roles [34]

SOWG Chair: Leads the science team in tactical meetings and helps them reach a consensus for daily planning.

Science Uplink Representative (SUR): Represents science during the uplink process and documents any changes to the science plan.

SOWG Documentarian: Documents the science intent behind activities and any scientific breakthroughs.

Long Term Planner (LTP): Presents material that summarizes current rover activities and ensures the tactical plan is in line with the campaign goals.

Science Theme Lead (STL): Represents a specific science theme group (STG) during meetings and advocates for their desired observations.

Science Theme Group (STG) Member: Analyzes instrument data, develops and tests hypotheses.

Payload Downlink Lead (PDL) - Instrument Specific: Verifies and monitors the health and status of the received instrument data.

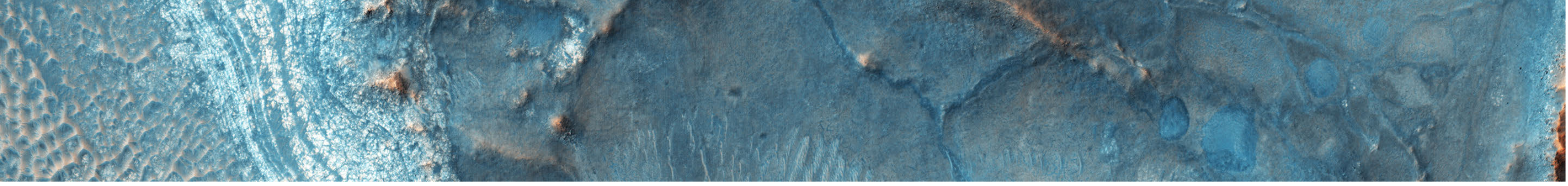
Payload Uplink Lead (PUL) - Instrument Specific: Creates instrument sequences and assess the compatibility of uplink commands with operational constraints.

## Science Team Meetings (Tactical)

Science Kickoff Meeting: Scientists come together to review the data from the previous day and determine their highest priority science observations for the day.

Science & Engineering Tag-Up: Engineers and scientists meet so that engineers can inform scientists of any restrictions that they need to be aware of for that particular day.

Science Operations Working Group (SOWG) Meeting: This is the main tactical meeting where scientists and engineers have their discussions about the next day's targets.



## Science Team Meetings (Campaign)

Principal Investigator (PI) Team Meeting: Instrument team meeting to discuss strategies for operations, scientific hypotheses, and findings.

Science Discussion Meeting: Science team members present science results, discuss working hypotheses, and campaign plans.

Project Science Group Meeting: Scientists discuss campaign issues, staffing and scheduling of roles.

MSL Science Team Meeting: Happens approximately once every 6 months to discuss status, results, and strategies of the mission.

## Workflow/Meeting Challenges

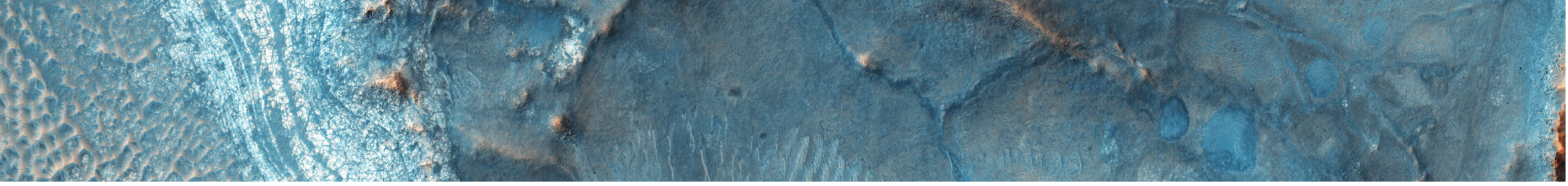
One of the challenges of the Mars Exploration Laboratory missions compared to other NASA missions, is the degree to which operations are impacted by the ever changing environmental variables. The operations teams can use previously captured orbital images to guide future activities, but these images don't capture all the information needed to decide what the rover's next target will be. As a result, planning happens daily based on the comprehensive data which is only available after the rover sends back the prior day's activities. Teams need to be reactive and responsive to this data in order to quickly develop the next day's plan which also aligns to the mission's long-term science goals [34].

NASA has introduced three categories of mission planning: tactical, supratactical and campaign. Tactical refers to the short-term, daily planning activities which include analyzing the most recent data, coming to a consensus about the next desired science observations, and generating new commands for the following day. Campaign planning refers to activities that focus on develop long-term plans spanning weeks or months to achieve the mission's high-level objectives. The supratactical stage provides a bridge between the long-term plan and the day-to-day processes [34].

A typical day's tactical meeting is 8 hours long and begins with a limited "uplink" window in which the team sends new commands to the rover. Throughout the day, there are periods of "downlink" where the teams receive data back from the rover; for example, this can include measurements from instruments or pictures that the rover has captured. Teams of scientists, rover planners, and engineers work together to make sense of this data and decide on the next course of action which will achieve scientific goals while still maintaining the rover's safety. Coming to a consensus about the next day's activities is a difficult process because various science teams must advocate for their plans. Additionally, scientists sometimes need to convince the engineering teams to implement specific plans that could put the rover at risk of lower power or instrument damage.

## Science Intent

Science intent is the context around how a given activity fits into the larger picture of the mission. This context is used to determine a tactical list of goals, as well as prioritization of the overall task, given its relative importance [35]. Clear communication of scientific intent is a critical step in planning both scientific and engineering activities during planning meetings. Engineering needs this information in order to plan activities on a cadence so as not to inadvertently interfere with the scientific activities by calibrating instruments during a longitudinal study [36]. Historical knowledge of intent can be a useful tool in streamlining goal generation and prioritization. It prevents duplicative work



over time as previous discussions may be applicable to past debates [35].

Proper communication of scientific intent during rover operations is a subject of hot debate, but some common practices have emerged throughout the years. Generalists aggregate information and distill it to be understandable across the organization. This communication is largely done via annotated PowerPoint decks, which act as one of the few widely used tools across the organization [37].

This method works well in terms of communicating current intent, but breaks down when there is a need to access historical intent. The information is not easily searchable or accessible after its initial dissemination, so if a scientist needed to reference previous discussions around the scientific intent of an activity, she would have to sift through hundreds of PowerPoint decks [36].

## Internal Tools

ASTTRO
The Advanced Science Targeting Tool for Robotic Operations (ASTTRO) is used by rover planners and scientists for selecting rover targets. The tool reconstructs the Martian terrain from images taken by the rover as scene visualization for situational awareness. The operation teams can tag target coordinates, scientist, and specific instrument, etc. as metadata. However, the tool currently only has limited information regarding the sun and doesn't include weather information.

PowerPoint
The science team uses Microsoft PowerPoint as the main tool to communicate scientific findings and proposals during meetings and planning discussions. While PowerPoint is a commonly acceptable tool with an easy learning curve, it doesn't provide all necessary capabilities to ensure effective communication. PowerPoint doesn't help preserve the context of the conversation. Science intent, critical discussions, detailed clarifications, and situational nuances tend to get lost in the process.

MSLICE
The Mars Science Laboratory InterfaCE (MSLICE) is a planning tool that helps scientists and engineers prepare for rover activities on a daily basis. It models the energy and time of all the instruments and intended activities on the rover's traverse in order to optimize scientific data and ensure rover safety.

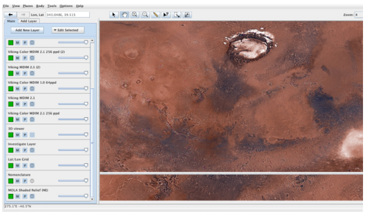
# COMPETITIVE ANALYSIS

The competitive analysis helped our team explore existing tools in various domains, assess their pros and cons, and draw insights on how we might utilize existing features for our own design. We approached the competitive analysis with the intention to assess a variety of tools related to collaboration, communication, mapping, and data visualization. The analysis included translational products to better understand how other fields approach solving issues related to collaboration in time-pressing situations.

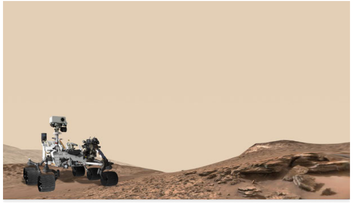
Based on our research, we identified five important criteria to measure the tools against: transparency, customization, shareability, comparability, and annotation. For each criteria, there was at least one tool that did a great job at mastering the interaction design. This could potentially serve as reference point for our team when we move into the ideation process.

A more detailed version of our competitive analysis can be found in the Appendices.

## Mapping Tools



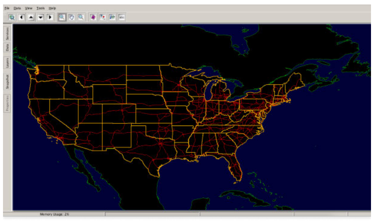
JMARS



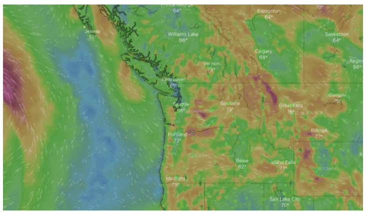
Access Mars

Google Earth Pro

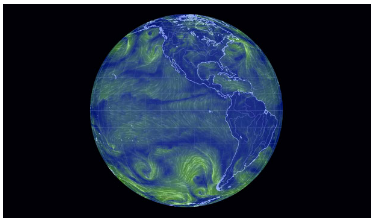
## Weather Tools



NOAA Weather and Climate Toolkit (WCT)

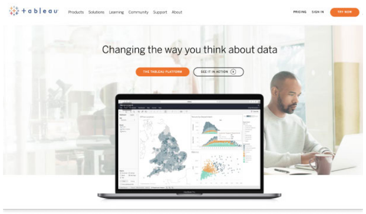


Windy



NullSchool

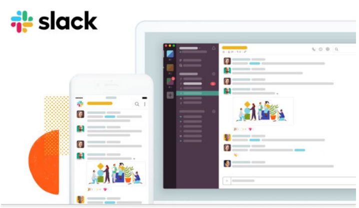
## Data Visualization Tools



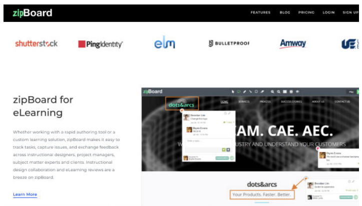

Tableau


The Pudding

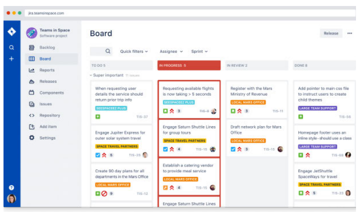
## Collaboration Tools



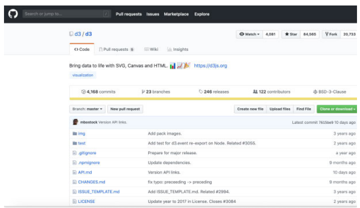

Slack




zipBoard



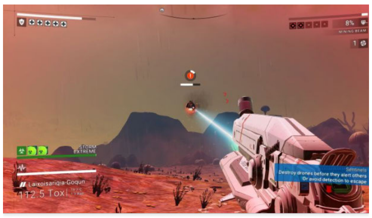

Jira



GitHub

## Translational Tools

War Room



No Man's Sky

Bartending

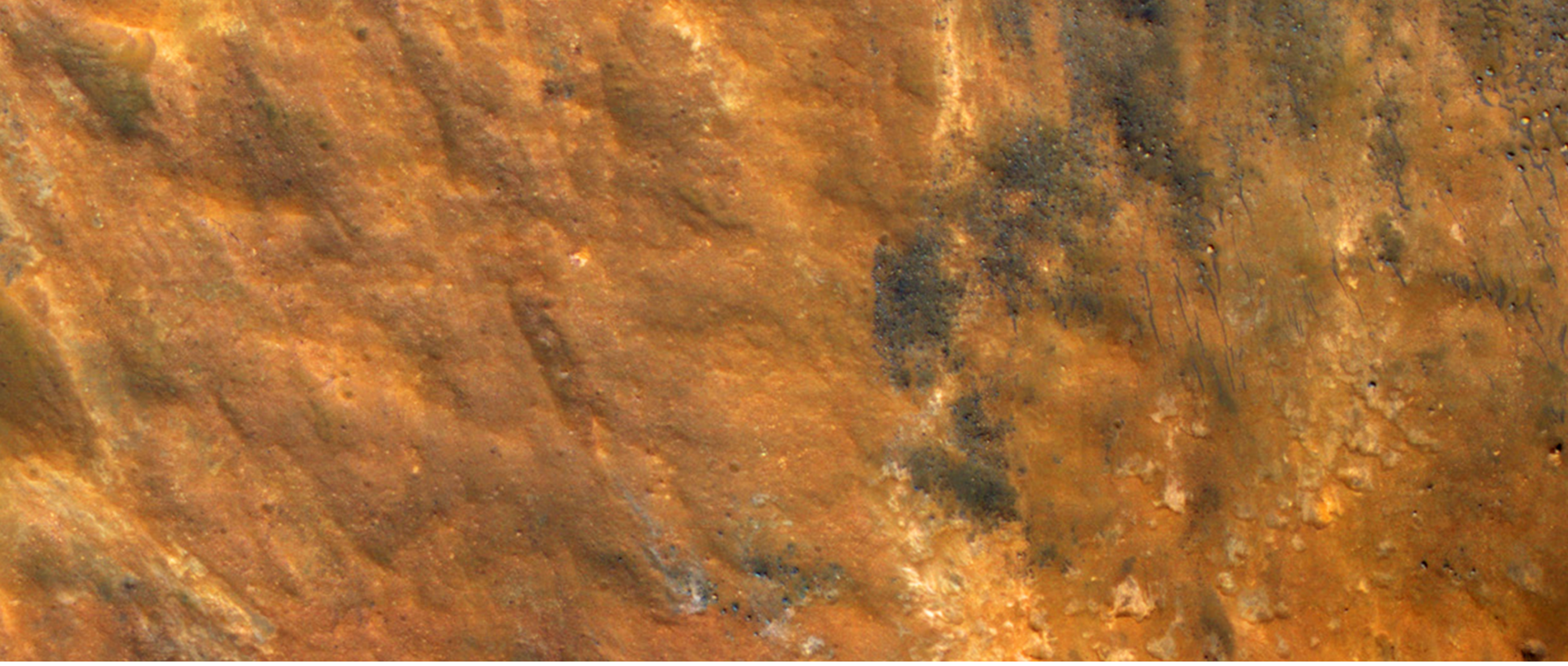
## Key Findings

**01** **Provide Collaborative Experiences:** Users should be able to have shared experiences when collaborating. A way to enhance collaboration is allowing users the ability to share their work with each other. Most JPL scientists use web-based tools when processing and analyzing weather data.

**02** **Add context to data when possible:** Metadata plays an important role in providing additional contexts to data. A data point should have relevant metadata, tags, comments, and annotations so that users can interpret the dataset with a common ground. It could be enhanced if users can interact with the visualization, hovering over a data point to view more information.

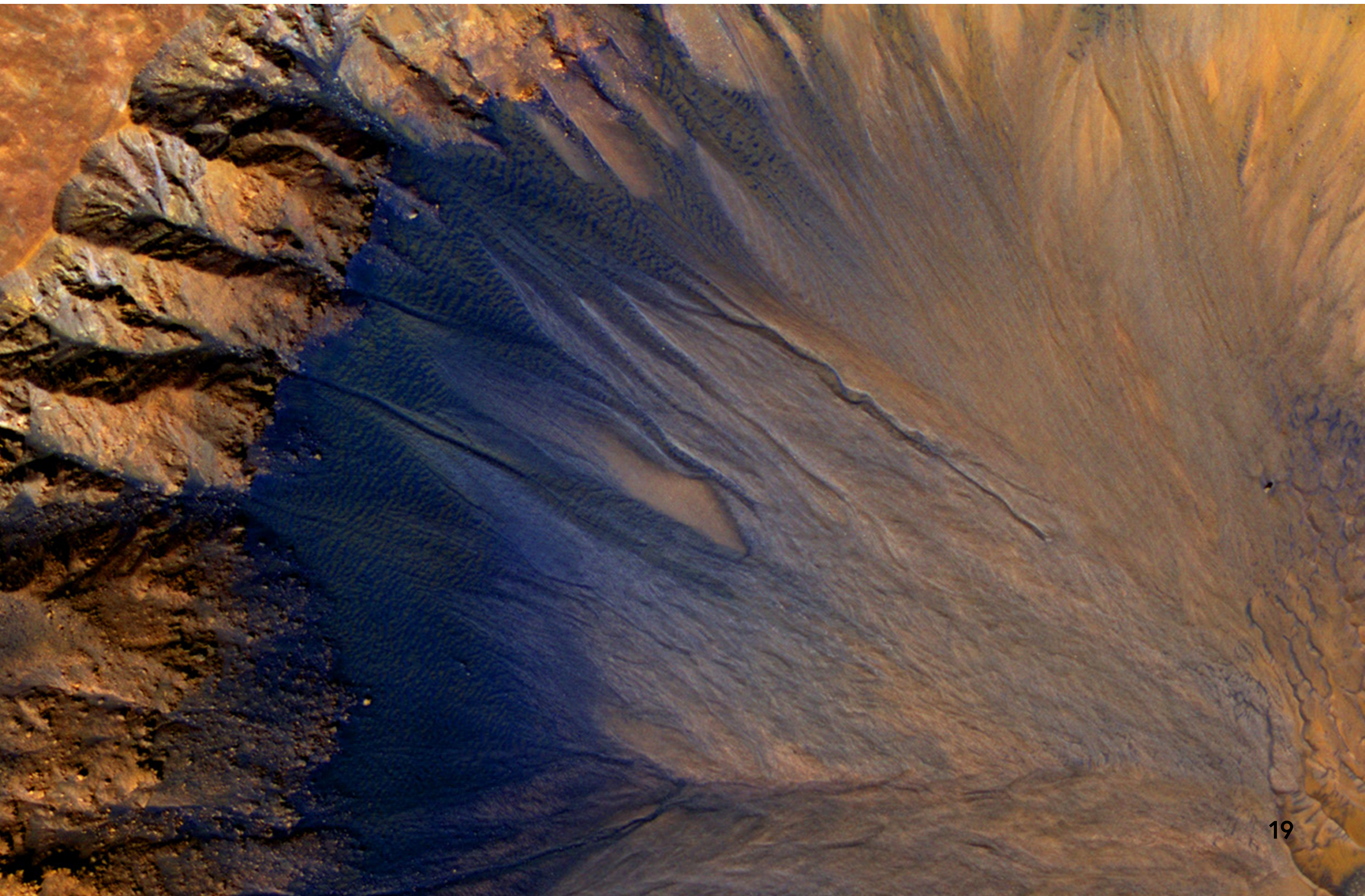
**03** **Trace back to raw data:** When conducting data analysis or exploring a dataset, scientists prefer to have access to the raw data so that they can conduct a variety of analysis and manipulate different visual presentations.

**04** **Enhance customization:** Customization can add significant values when analyzing data. Each user has a different need and a preferred method for exploring and manipulating dataset. This also extends to having the capability to adjust the tool bars, layout, customize the codes to accommodate personal needs.



# 02

## Research



# GUIDING QUESTIONS

## What is the typical workflow for rover mission planning and what collaborative and operational challenges do they face?

Rover operations require collaboration between rover planners, scientists, engineers and other stakeholders. Understanding their typical workflow will help us uncover any flaws which could lead to a disconnect in their mental models regarding weather.

## What tools and technology does the mission operation team currently use, or plan to use, to collaborate and assess weather information for mission planning?

Decomposing the tools that are currently being used for mission planning, with a focus on the ones that involve weather analysis, will help us uncover any limitations with the current technology which could act as opportunities during our design process.

## What weather information does the mission operation team need to know and how do they use this information in making time-sensitive decisions?

There are a number of different weather variables that have varying levels of impact on short-term and long-term mission planning operations. We hope to understand what weather variables the mission operations team prioritizes, how often they examine them and how they interpret them to make decisions.

# PARTICIPANTS

## 01 Weather Experts

We needed to interview Martian weather experts in order to better understand the domain and the needs of the field. We also were interested in the types of weather events they were interested in, and the tools they use to analyze and share data.

## 02 Rover Mission Personnel

We were interested in speaking to rover mission personnel such as engineers, drivers or planners to gain a full picture of the collaboration and workflow involved in a high stakes environment.

## 03 Data Visualization Experts

Data visualization experts provided us with information on best practices for communicating data to others.

# METHODS

## 01 Semi-Structured Interviews

For each of our participants and experts, we created a list of questions that were tailored to each individual to guide our interviews. Their responses to the prepared questions led to new questions and dictated the direction of the conversation. This method opened up a window into our participants' mental models and decision making processes.

## 02 Directed Storytelling

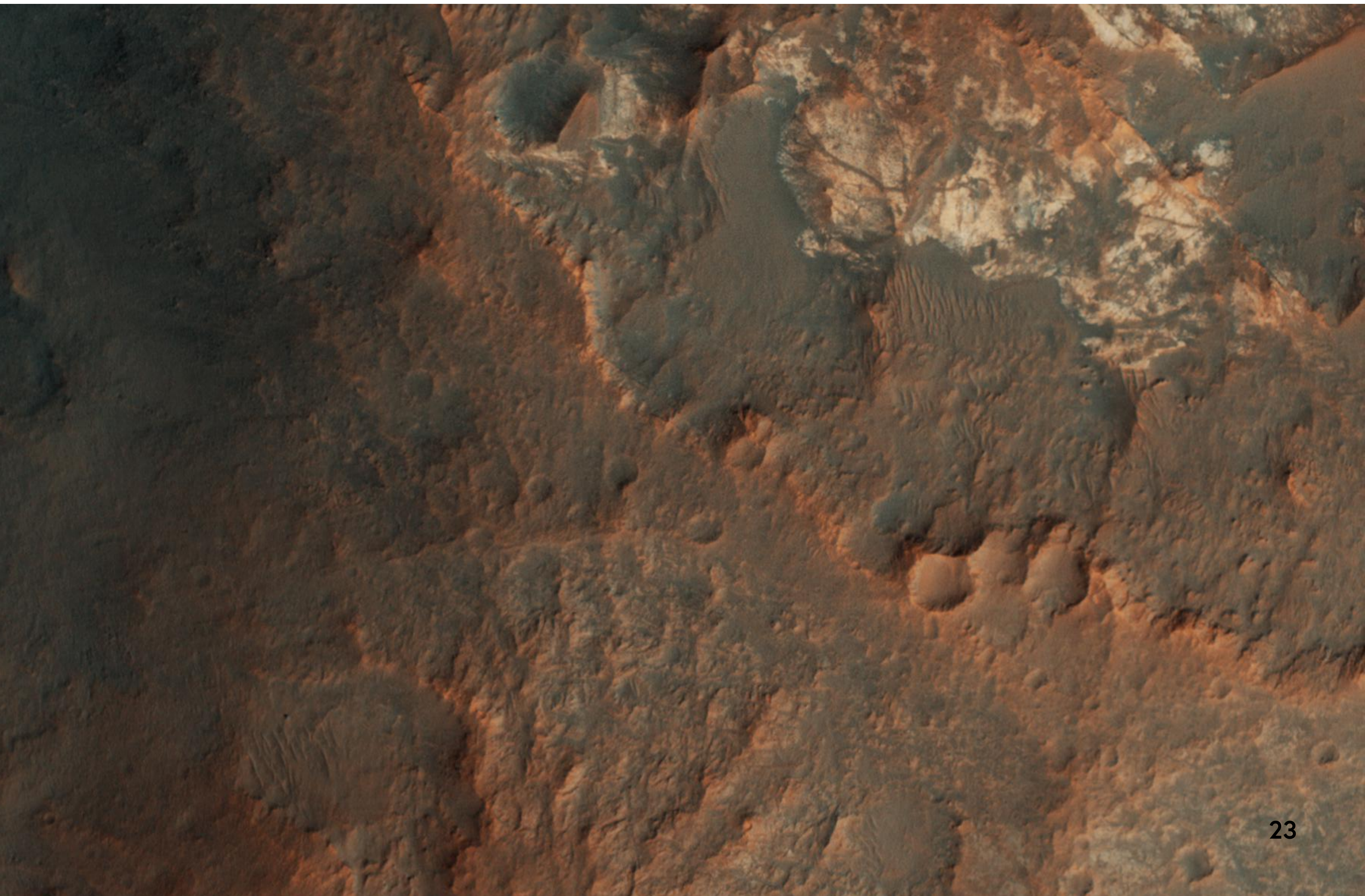
Participants were asked to talk about a past experience in detail. The questions were centered around events that sparked fear and/or required highly collaborative work. We aimed to understand our participant's perspectives during these experiences and better understand communication breakdowns, motivations, and actions taken.

## 03 Iterative Diagramming

In order to better understand the needs of scientists and engineers during the rover planning process, we needed to be able to conceptualize the structure of these planning meetings. We constructed a diagram based on information we gather from the literature. Participants were shown our sample diagram and were given time to offer changes or corrections.

# 03

## Results



# INSIGHTS

## 01
Meeting the proposed 5-hour operational timeline is unattainable unless rover teams shift focus to long-term goals.

## 02
Weather no longer poses a critical risk to rover safety, but still must be considered due to its impact on instruments and power constraints.

## 03
Weather on Mars is relatively predictable, however, there is no weather forecasting despite its potential applications to long-term planning purposes.

## 04
Unavailable atmospheric opacity ($\tau$) measurements in internal tools negatively impacts operational efficiency.

## 05
Despite tactical disagreements and the varying cultures, rover safety takes precedence because without a rover, there is no scientific discovery.

## 06
In the conflict between mission groups, the only shared language is data. Even then, every specialty has its own dialect, leading to misunderstandings.

## 07
Data is more revealing when contextualized with other observations. Existing tools do not have this capability, hindering scientific discovery.

## 08
The use of numerous custom-built tools is "both a feature and a bug"; it makes output inconsistent, but leads to advancement through productive scientific discussions.

01

## Meeting the proposed 5-hour operational timeline is unattainable unless rover teams shift focus to long-term goals.

The Mars 2020 mission duration is set to last 90 sols and during that time the rover planning structure will need to be at a campaign (long-term) level. After the initial 90 sols, the nominal mission comes to an end and for the remainder of the rover lifetime, planning meetings can continue at a tactical (short-term) level with mission planning process becoming more reactive. For the first 90 sols, JPL has suggested a 5-hour planning meeting limit. In past rover missions, early planning process often required 12-hour meetings to reach consensus. For this reason, many of the JPL personnel that we spoke to expressed concerns that the 5-hour timeline could result in sacrifices to tactical planning and opportunistic scientific exploration. The timeline leaves little room for discussions and proposals outside of the campaign level.

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*"In the very beginning, it took about 12 hours to just send one day's worth of uplink to Curiosity. I think it reduced down to an average of like seven to eight. On really great days, [...], they got really close to five. " - P8*

*"A lot of what we do is discovery-driven science. You drive to a new place, and you had a plan, and all of a sudden, someone says, wow, that's so cool. Let's go check that out. And, and that's a trade to be made. " P11*

*" My understanding is that the way they're kind of doing it is basically removing all decision making from the tactical process, it will all be planned in that strategic time window, which is going to take forever, because you're going to have the same kind of debates going on. " P3*

# 02 Weather no longer poses a critical risk to rover safety, but still must be considered due to its impact on instruments and power constraints.

Unlink past missions, the Mars 2020 rover is nuclear-powered, which means that the weather won't pose that same critical risk. Weather still needs to be considered because of its impact on the rover's instruments. For example, dust storms still need to be closely monitored because the rover's cameras need to avoid dust on the lenses which would hinder the team's ability to take necessary images. Additionally, temperature affects the accuracy of certain instruments on the rover, so unless it was closely monitored data could be misconstrued.

On a tactical level, there's only a certain amount of power available for exploring and collecting scientific data. To optimize data collection, science teams need to be dynamic, flexible, and willing to shift priorities in response to weather events or new findings.  This also means seizing the opportunity to collect as much data during unexpected situations.

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*"The Mars 2020 rover isn't going to be as critically in danger when it comes to storms because it's now nuclear powered [...] But dust storms [prevent us from taking] proper pictures." - P2*

*[Engineering] is going to get touchy about pointing the cameras very high up elevation wise when there is a lot of dust in the atmosphere. Atmospheric observations may be curtailed because you don't want to get your camera stuck pointing at the sky with a bunch of dust falling out of it. - P15*

*"It can get very very cold on Mars, that cold can be really bad for electronics. And so that means that when it gets too cold, you have to run heaters to do things to make sure there's no damage to electronics." - P13*

# 03 Weather on Mars is relatively predictable, however, there is no weather forecasting despite its potential applications to long-term planning purposes.

Due to the lack of oceans, weather events on Mars can be predicted up to one Martian year (687 Earth days) in advance with variance of only a few weeks. This predictability is not surprising as Martian weather conditions are controlled by several factors that do not change much from year to year: seasonal heating from the sun, polar melting, and topographical features such as mountains. Despite this cadence, there is no tool to let mission teams know the weather forecast along the planned rover path. This presents an opportunity to aid the mission teams by surfacing expected weather conditions to facilitate proactive instrument and science activity planning, moving planning away from day-of tactical planning as is required by the Mars 2020 5-hour uplink goal.

*"Scientists [predicted]...that Mars was going to get a really big dust storm and it did. That's why Opportunity no longer works, but they were able to predict it fairly well and that's because there's this pattern pretty frequently that occurs on Mars." - P2*

*We always know there's a dust season on Mars which is typically associated with the summer. There's typically a more cloudy season as the seasons change. [..] So at least on a seasonal cycle, things are fairly predictable. - P3*

*You actually plot the predictive temperature [...], it changes your access scale up to that much lower. I don't know what the temperature will be precisely, but here's the predicted range, add that to the chart, because that's the context in for the decision you're making. - P10*

# 04 Unavailable atmospheric opacity (τ) measurements in internal tools negatively impacts operational efficiency.

The visibility measurement (tau) indicates how much dust is present in the atmosphere. This information affects 3 main stakeholders: science, engineering, and image processing teams. The engineering team ensures the safety of the rover and its instruments by taking into consideration how the rover's arm should move, the angle of the movement, and the topography of the terrain. However, current rover targeting tools (i.e., ASTTRO), without tau information, do not inform scientists of the engineering feasibility of their target requests. The lack of tau information also creates a communication setback between scientists and the image processing personnel. Both parties need to understand the amount of dust in the atmosphere to estimate image exposure and processing time in order to produce the highest image quality.

*Before [scientist] go off and start harassing the folks that do the image processing to get it into the pipeline of what's wrong and why is this broken? It's a lot nicer to go, 'oh, okay, I'm dealing with the local dust storm, kick the tau up for a day or two.'.- P15*

*I could see how [tau] might impact the way people think about things. And people generally keep it in mind, but I've never seen it in the planning tool. -P16*

*You're trying to take photos that have the same sort of lighting across a long traverse because you're comparing [rocks color and sizes]. If the lighting [of the image] changes halfway through your traverse, then it's a problem. - P7*

# 05 Despite tactical disagreements and the varying cultures, rover safety takes precedence because without a rover, there is no scientific discovery.

During daily tactical meetings, engineers and scientists work together to decide on the next day's targets. This can sometimes lead to disagreements due to differing priorities and cultures. Scientists want to explore as much as possible to meet the mission's scientific goals, while engineers are concerned about the rover's safety and functionality. This leads to situations where scientists are more risk tolerant than engineers. These discussions tend to be difficult for both sides because engineers are trained to be quantitative and binary, while scientists are less apt to quantify the trade-off of risk and reward due to the uncertain and imperfect nature of science. At the end of the day, they will negotiate and find an acceptable level of risk to ensure rover safety is not compromised while still advancing science.

*"It's very difficult for the science teams when you're doing [planning] trades, to be as quantitative and sure of ourselves as the engineering team [...] I wouldn't call it a conflict, but you know, just different culture expresses itself." - P14*

*"Engineers, of course, are extremely cautious..[..] we don't want to stand on the science, because, of course, that's how we get our next round of funding. [...] it's a balance, [...] in order to make sure that we're doing the best we can with the science collection, while also keeping the rover safe." - P11*

*"You kind of have to argue with them... 'Well, I'm the engineer, and I'm not going to do what you want, because I don't believe it will be safe for the rover.' And that typically is when they'll actually back off"  - P3*

# 06 In the conflict between mission groups, the only shared language is data. Even then, every specialty has its own dialect, leading to misunderstandings.

During daily planning activities, scientists must form a consensus on the rover's intended activities. Data drives these contentious discussions, but each scientific domain has it own unique practices, methodologies, and jargon to account for which makes it difficult for those from other domains to follow. Complicating matters, most scientists are admittedly bad at simplifying their data for specialists outside of their domain. Generalists, attempt to translate across domains, but they are in short supply and struggle with disparate toolsets. If scientific intent is not clearly understood by the planning committee, it will be difficult for a proposal to be granted resources and scientific opportunities may be missed. Planning may be hindered by unclear context around why a past decision was made. Further, planning around competing and complementary activities may not be able to take place at all if the intent is unclear.

*For us to be able to communicate our ideas in a compelling way to the rest of the [scientists], the graphics need to be easy to understand for a non-specialist. If I tried to present something like this to geologists, they'd just say 'What is this noise? Take it away.' - P1*

*The geologist has his own kind of knowledge that comes from his expertise. The atmospheric scientists would have a different set of knowledge. Sometimes that's helpful, but also sometimes comes in the way of them seeing the data from the other person's perspective. So, how do you help them maybe step into each other's shoes? - P10*

# 07 Data is more revealing when contextualized with other observations. Existing tools do not have this capability, hindering scientific discovery.

Context and integration of metadata can reveal unexpected findings, allowing scientists to arrive at new insights. For example, pairing temperature with rock colorization may lead to new hypotheses or present scientific opportunities that were not evident when analyzing rock colorization in isolation. Often times scientists create their own tools to analyze and visualize data in order to meet their scientific needs. These tools are not created with output integration in mind. As a result, this creates a fragmented tool ecosystem and a lack of ability to integrate datasets from multiple sources to provide context or comparative views. An example of this came to light during an interview when the participant expressed that the Mars Weather Service lacked the ability to view data over multiple days, which would allow scientists to observe weather patterns that occur temporally. These gaps in tool capabilities cause a need for workarounds that may not support efficient analyses.

*"It would be nice if I could overlay one sol another. Like we expect that the meteorology is going to repeat kind of on a daily basis." - P1*

*"For meteorology, time of day is crucial. So if there were a nice way to be able to compare and contrast a couple of different days, that would be really helpful. Instead of looking at the left half of this plot and the right half. You'd have to visually try to compare this feature to that feature, and that would be awkward." - P1*

*"I then come up with a result... I believe my results but I believe it a lot more if I can compare it to something else." - P16*

# 08 The use of numerous custom-built tools is "both a feature and a bug"; it makes output inconsistent, but leads to advancement through productive scientific discussions.

Every scientist has their own way of analyzing data, and they often end up building their own tools to meet their personal needs. At face value, this is problematic because the existence of multiple tools means a multitude of output forms. One scientist's output could be a visualization while another's is a data table. Additionally, although the input is the same, they may end up with completely different results through differing methodologies. The resulting output inconsistencies and the discussions around them are difficult because it takes time for different stakeholders to understand one another's output. However, these different ways of analyzing the same data helps advance science because it could lead to the detection of patterns which validates hypotheses, or to

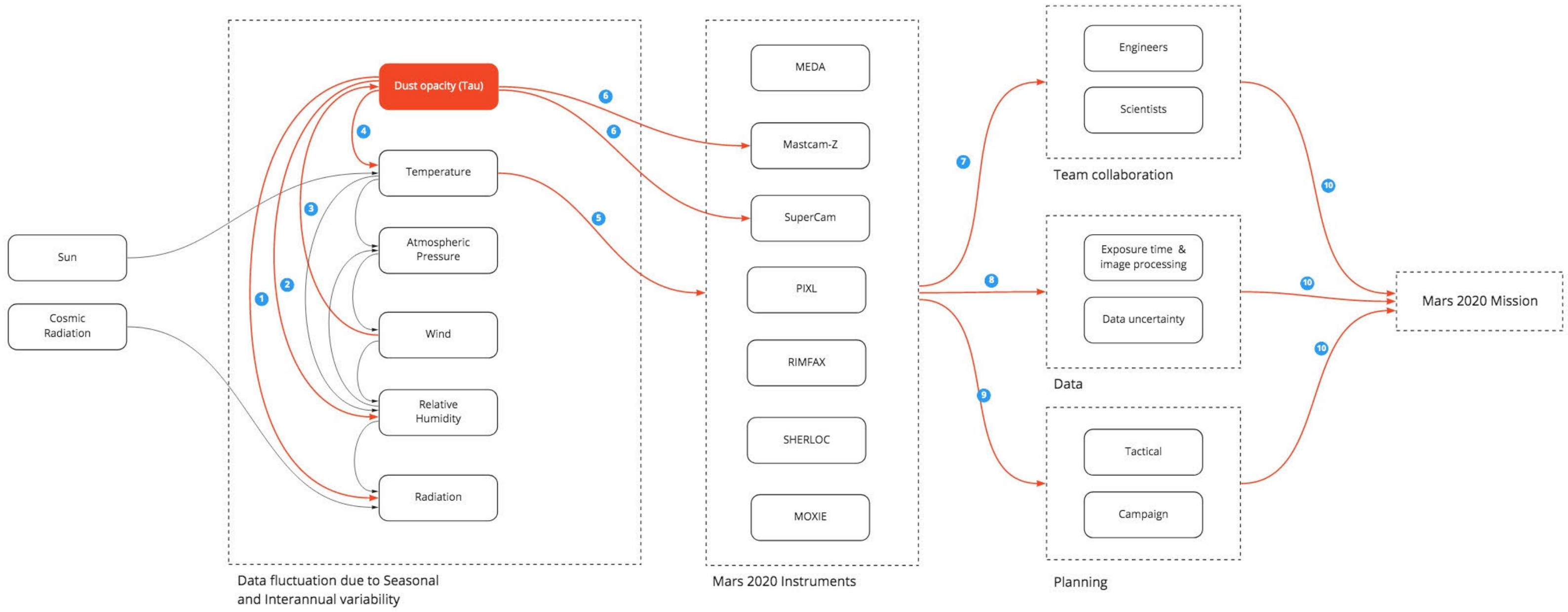
*"Discrepancies aren't always bad, they just reflect that science is imperfect, we don't have all the tools, and they're not perfect. Our understanding of even how to build the tools to get the results is not perfect. So often, it's good to have healthy competition." - P14*

*"Sometimes, it's difficult to have the same collaborative tool because you don't use the same language. You don't have the same purpose with respect to the data, you don't have the same research code. So, you end up using your own tool because that's faster. And that's easier to customize." - P17*

*"For a given set of recorded data, there are definitely people giving different interpretations or different explanations, but I think that's how the science commands you in general." - P4*

# ARTIFACT

## Atmospheric Opacity (Tau) and its impact on the Mars 2020 mission



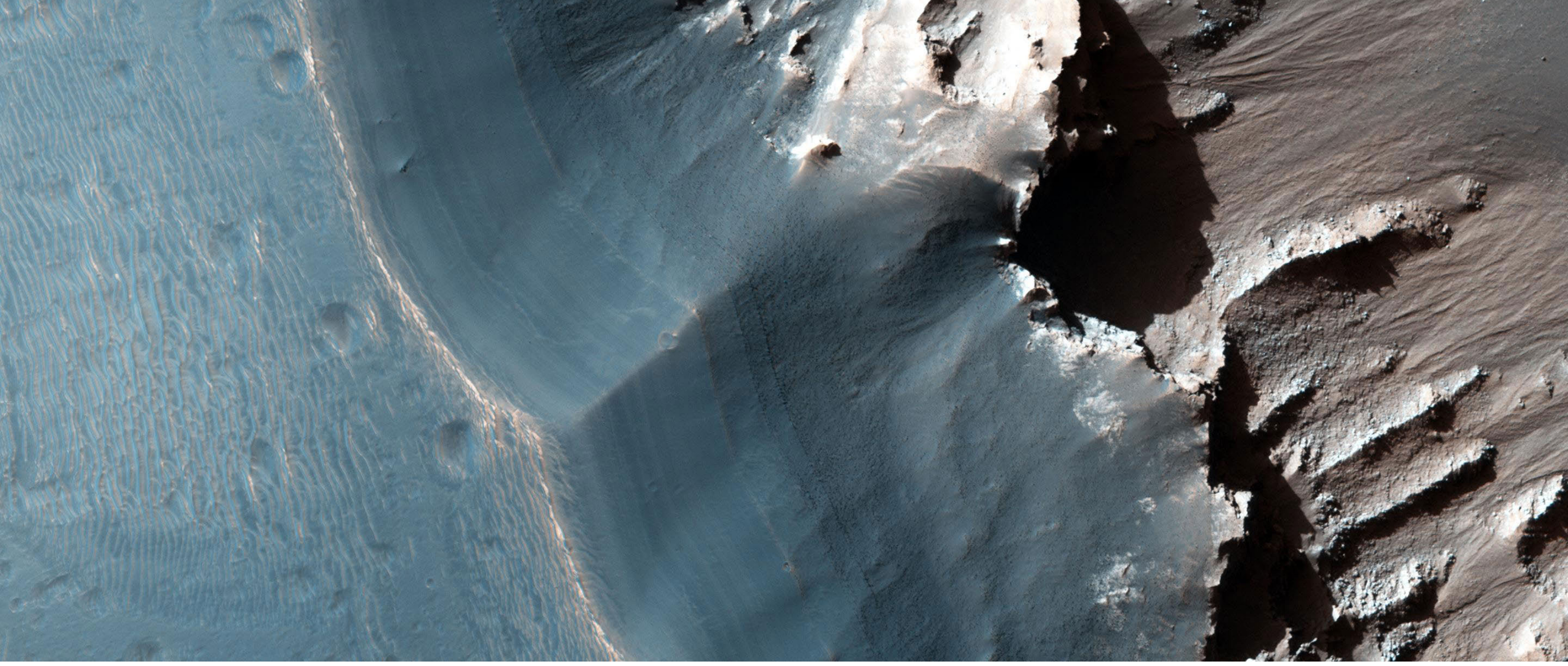

Color orange = Tau related

Arrow = Direct effect

1. Dust can absorb solar radiation which influence atmospheric temperature
2. Dust thrusts water into the upper atmosphere, interfering with Martian water cycle
3. Wind can lifts dust from the surface to the air, a critical factor in dust devil and dust storm formation
4. 5. Dust moderates atmospheric temperature which influences the amount of power rover uses to heat instruments.
6. Dust particles pose potential hazard for camera lens
7. Tau measurements create engineering constraints which affects team collaboration
8. Amount of dust in the atmosphere affects camera exposure time and image processing
9. Knowing the tau in advance can help the teams prioritize and plan strategically
10. All the components mentioned will affect the Mars 2020's overall mission.

# 04

## Discussion



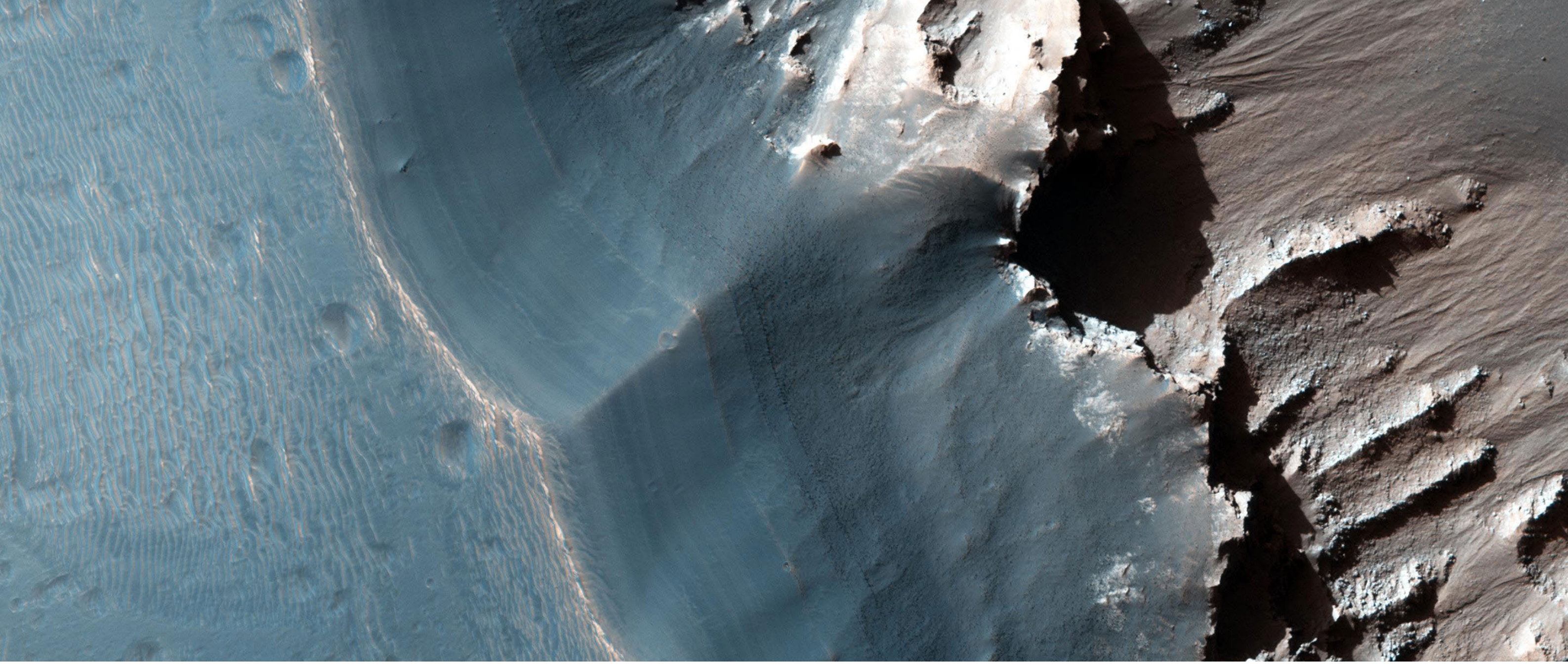
# DESIGN OPPORTUNITIES

## Express the impact of atmospheric opacity on instrumentation

Atmospheric opacity poses a threat to rover instruments, image exposure time, and data processing. We are interested in exploring ways to help scientists understand this impact on their work and how it pertains to the overall mission.

## Use the predictability of Martian weather to help teams shift from short-term to long-term planning.

Knowing what to expect on upcoming sols makes it possible to plan instrument usage better. We want to explore how to help scientists optimize instrument selection.



# DESIGN REQUIREMENTS

## 01 Facilitate debate

The advancement of scientific knowledge stands to benefit from disagreement as dissent breeds productive debate in order to reconcile conflicts. Our tool needs to facilitate healthy discussion between differing points of view in order to drive scientific advancement.

Insight 3, 8

## 02 Prioritize customization and flexibility

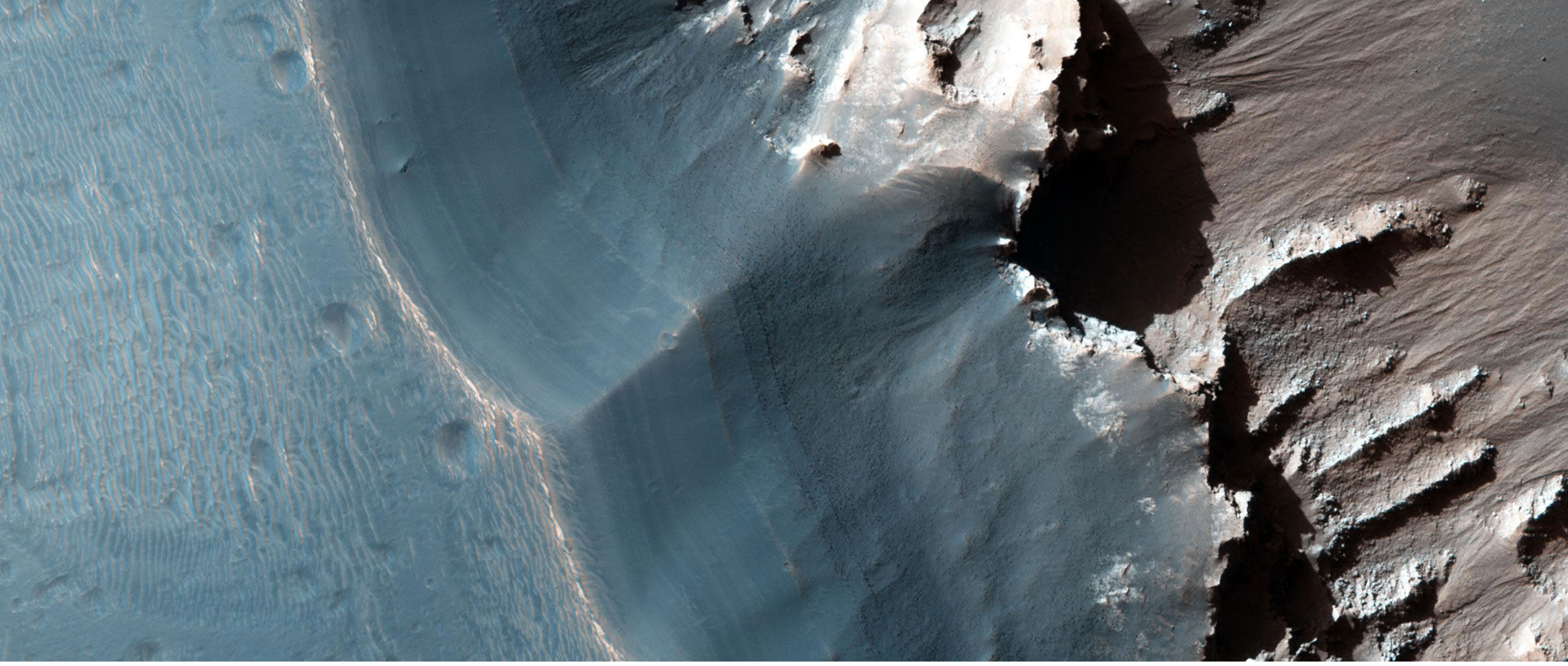
Scientific discoveries stem from finding novel ways to analyze and interpret data. To promote further exploration, the tool needs to provide scientists the ability to explore a dataset in various ways without disrupting existing work preferences.

Insight 6,7,8

## 03 See through the same lens

Scientists are using their own tools and this could lead to misunderstandings about the meaning of their output. As a result, enabling shared mental models is crucial in order to ground conversations

Insight 2, 3, 4, 5, 6



# DESIGN REQUIREMENTS

## 04 Show how it fits in bigger picture

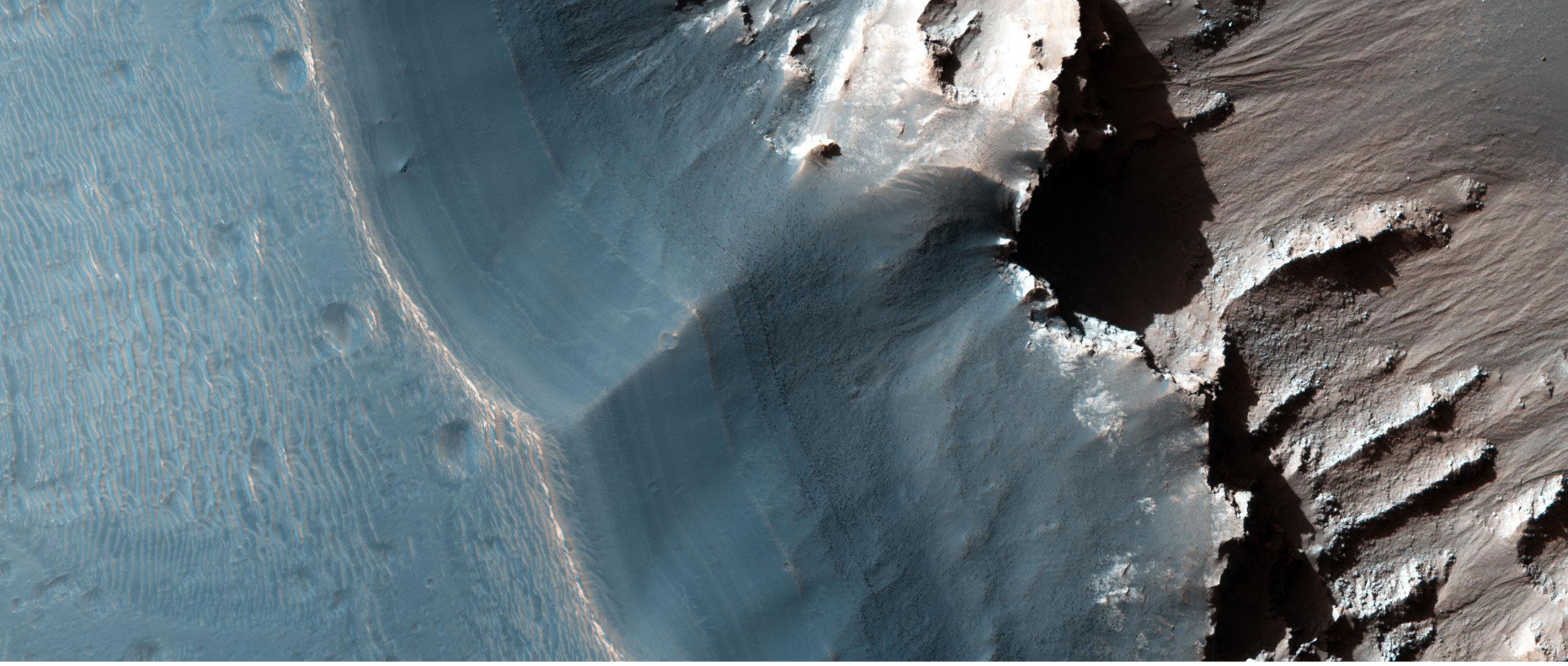
Scientists and engineers should understand how their work impacts each other and the overall mission. This can be done through contextualizing data to provide a comprehensive view of the situation.

Insight 1, 2, 3, 4, 5, 7

## 05 Stay transparent

Understanding the history of data is just as important as understanding what it means. To scientists, knowing the provenance of data facilitates trust, exposes caveats, and helps ground the conversations.

Insight 4, 6, 7



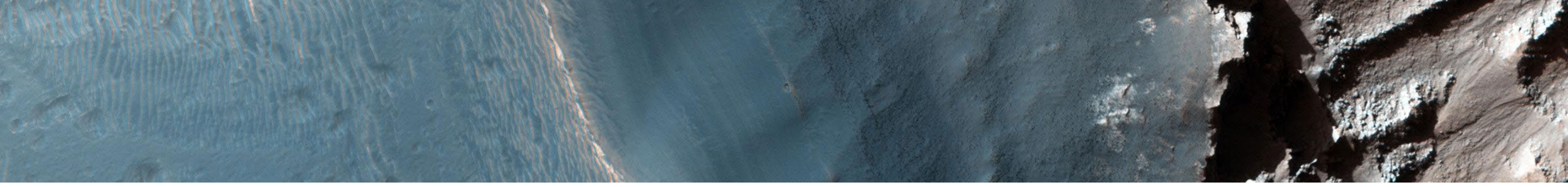
# NEXT STEPS

**01** Follow-up interviews with relevant experts how it fits in bigger picture

**02** Conduct focused research on tau and its impact on instruments

**03** Iterate design requirements as needed

**04** Begin the ideation process



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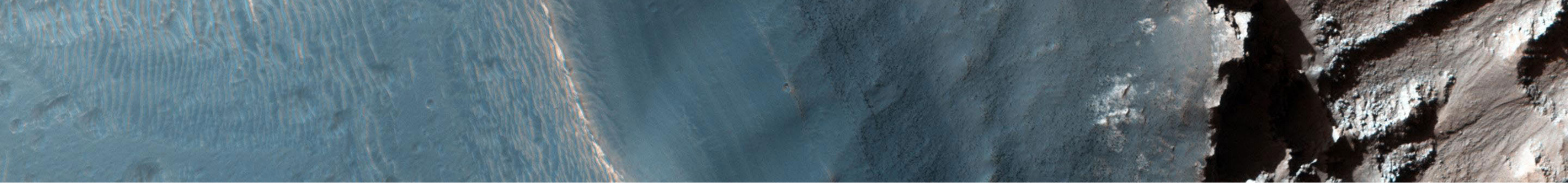

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