Simple Planner on Mars2020

General Overview

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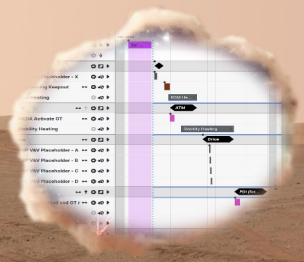
December 5th, 2024



JPL Clearance URS 330005 CL#24-6429

Introduction

Simple Planner is flight and ground system that enables the Mars2020 Perseverance Rover to **adjust to unexpected state**, such as Martian temperature fluctuations or battery performance and **activity execution feedback**, such as activities failing, ending earlier or later than expected.

Simple Planner development began in 2016, and its first use was October 5th, 2023

This talk provides a general overview of how Simple Planner fits within the larger JPL space autonomy landscape, how Simple Planner fits within Mars2020's mission objectives, and Simple Planner development.

Simple Planner Presentations

December 5th, 2024	General Overview | Elyse Moffi
January 14th, 2025	Flight Software and V&V | Dan Gaines & Shreya Parjan
January 29th, 2025	Ground System | Andrea Connell
February 4th, 2025	Operations Rollout | Nick Waldram

Today's talk

All talks will be recorded and archived on JPL Tube
All slides will be available on ai.jpl.nasa.gov

Simple Planner in Context

A Brief History of Automated Mission Planning and Spacecraft Autonomy

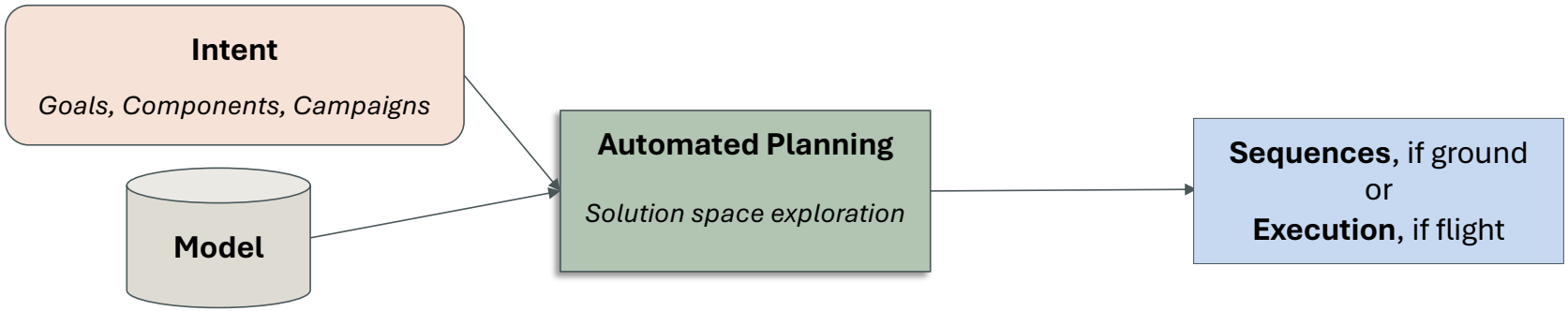
What is automated planning?

Automated planning uses a model of actions, states, and resources to produce plans that:

- **Achieve desired intent**(s) through combinations of actions
- **Respect spacecraft safety** constraints of the system
- **Respect resource constraints** such as time of day, energy and data volume

Automated planning can be used:

- In a fully automated “lights-out”, closed-loop mode
- By human operators to amplify their intent and rapidly explore the planning possibility space.



Automated planning motivation

Ground-based

- Reduction in operations effort, shorter build timelines | **EO–1, ECOSTRESS, OCO-3, EMIT**
- Responsive enough to inform development-phase policies and software designs | **ECOSTRESS, EMIT, NISAR**
- Enabled development of multiple contingencies | **Rosetta, NISAR**
- In many cases, increased reliability

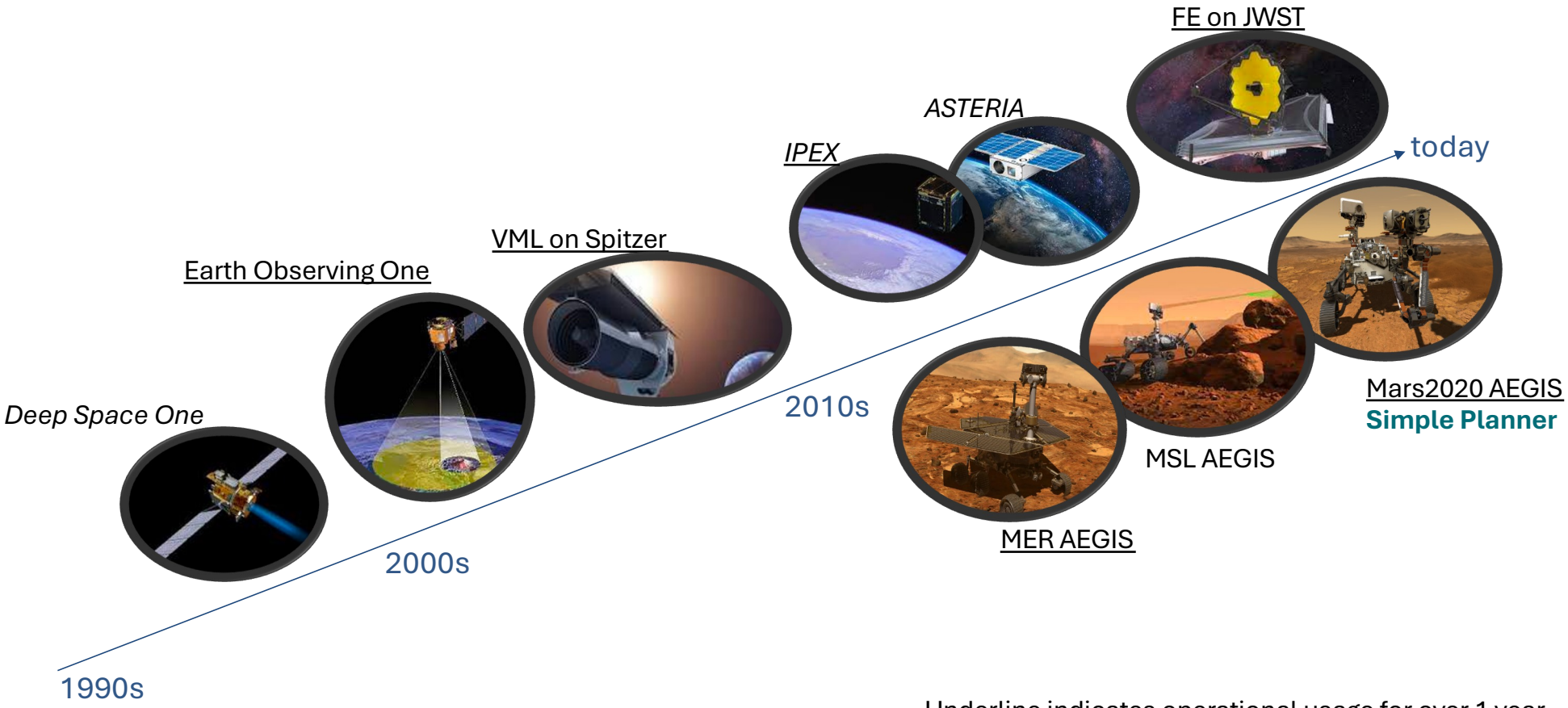
Onboard

- Timely response, increased efficiency | **Mars Rovers**
- Better knowledge in-situ of activity execution, resources | **Mars2020**
- Resilient to communications blackout, delay | **Mars Rovers, Europa Lander**

Significant usage in Mission Design and Analysis, orbiters and flybys

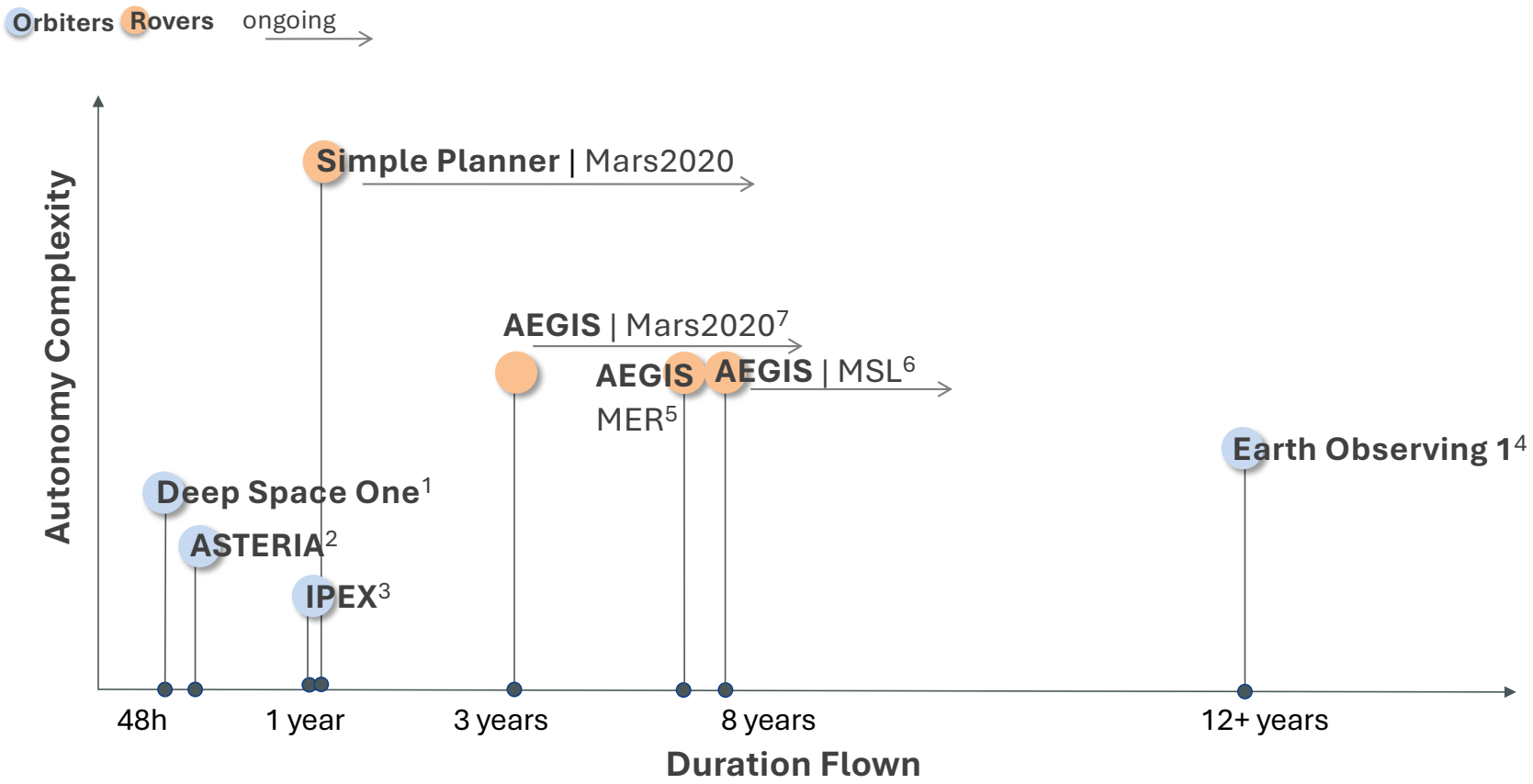
Onboard usage is more limited

Autonomy software in flight is rarer than ground



Underline indicates operational usage for over 1 year.
Italic indicates technology demo.

Mars2020 presents a leap in vehicle and autonomy complexity



[1]Jónsson, Morris, Muscettola, et al. (2000).
[2]Chien, Doubleday, Thompson, et al. (2017).
[3]Troesch, Mirza, Hughes, et al. (2020).
[4]Chien, Sherwood, Tran, et al. (2005).
[5]Estlin, Bornstein, Gaines, et al. (2012).
[6]Francis, Estlin, Doran, et al. (2017).
[7]Verma, Maimone, Gaines, et al. (2023).

MARS 2020
PERSEVERANCE

Simple Planner in Context

A Very Brief History of Mars Curiosity and Perseverance Rovers

Family portrait

SOJOURNER
Planned: 7 Sols
Actual: 83 Sols
100m driven

SPIRIT
Planned: 90 Sols
Actual: 6 Earth years
7.7km driven

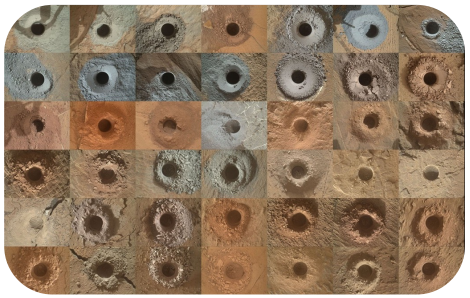
OPPORTUNITY
Planned: 90 Sols
Actual: 14 Earth years
45.2km driven

CURIOSITY
Planned: 1 Martian year
Actual: 12+ Earth years
32.4km driven
42 powderized rock samples

PERSEVERANCE
Planned: 1.5 Martian Year
Actual: 3+ Earth years
30km driven
25 rock samples

INGENUITY
Planned: 5 flights
Actual: 72 flights
17.7km flown
Tech Demo

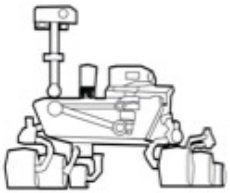
Proximity Science



MSL v Mars2020 Design Overview

MSL

Accomplishments



MARS YEARS:
1.25

DISTANCE COVERED:
10.6 km

SAMPLES COLLECTED:
2 scooped
6 drilled samples

1.25 MARS YEARS

context

Identical
Majority of Hardware
Flight Software Architecture
Majority of FSW code

Similar
Science Instruments

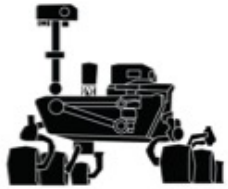
New
L1 Requirements
Sample Caching and Handling

Mars2020 HAD to be more productive per Sol relative to MSL.

Onboard autonomy was a piece in solving Surface mission productivity.

M2020

Requirements



MARS YEARS:
1.25

DISTANCE TO COVER:
15 km

SAMPLES TO COLLECT:
20 drilled samples

Simple Planner is Mars2020's solution for onboard activity scheduling & execution.

MARS 2020 PERSEVERANCE

Productivity Challenge: Predicting Rover Resource Usage[8]

Activity resource estimation is difficult

Largely due to difficulty in **predicting activity duration and actual temperatures**

Resources: **time, energy, data**

Operations takes conservative approach

Typically overestimate and add margin

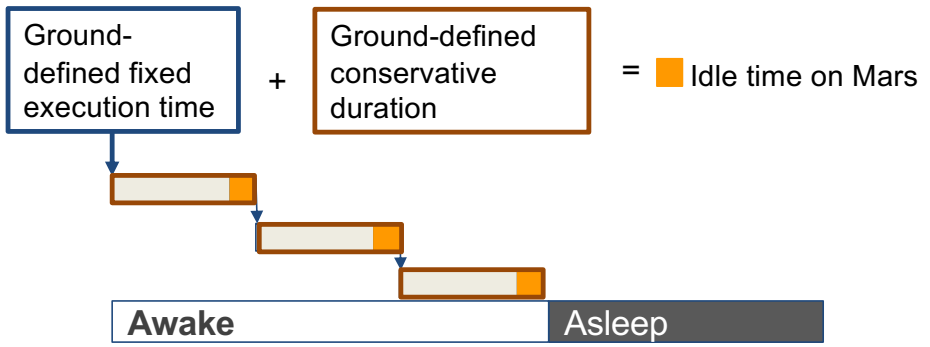
Can unnecessarily limit activity

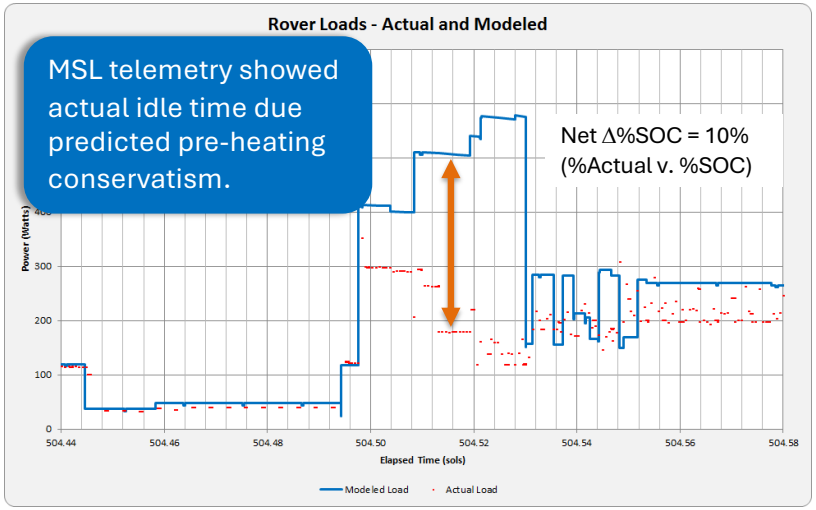
Results in unused vehicle resources

Simple Planner approach

Move resource management on-board by giving vehicle knowledge of energy state, pre-heat status, data volume, activity execution time ranges.

Enable more autonomy on vehicle and let the vehicle **manage wake/sleep and energy usage.**





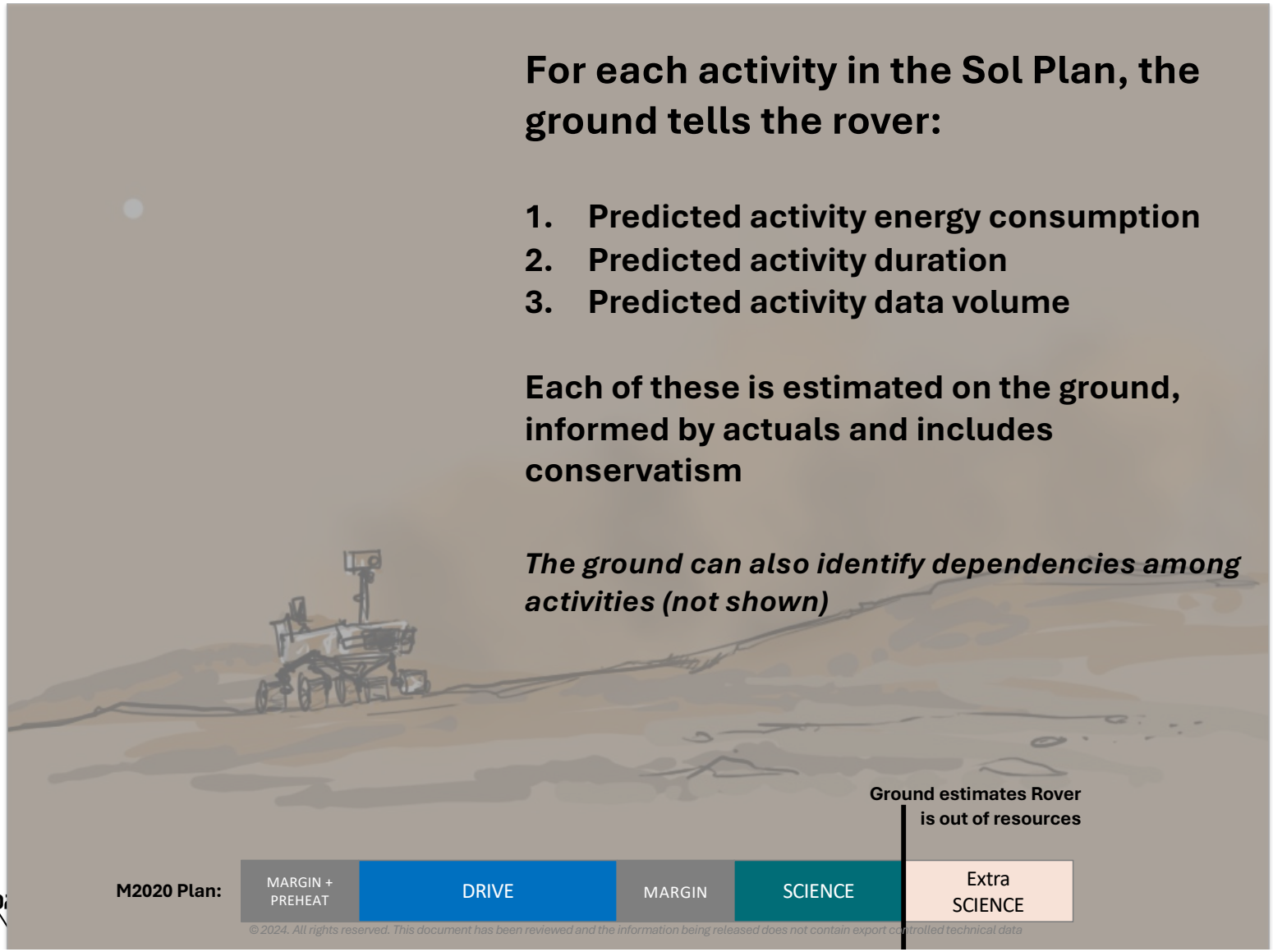
[8]Gaines, Doran, Justice, et al. (2016)

For each activity in the Sol Plan, the ground tells the rover:

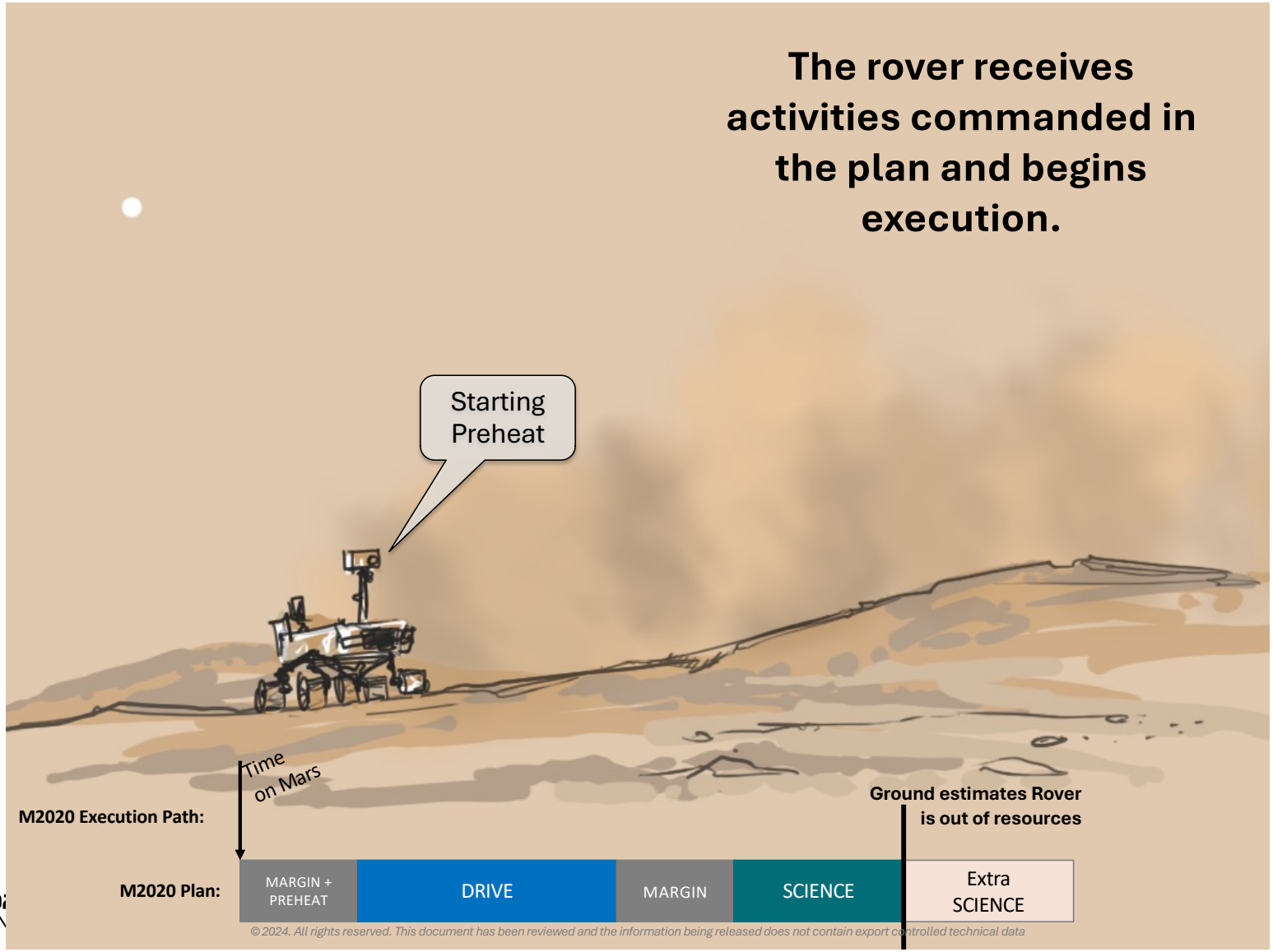
1. Predicted activity energy consumption
2. Predicted activity duration
3. Predicted activity data volume

Each of these is estimated on the ground, informed by actuals and includes conservatism

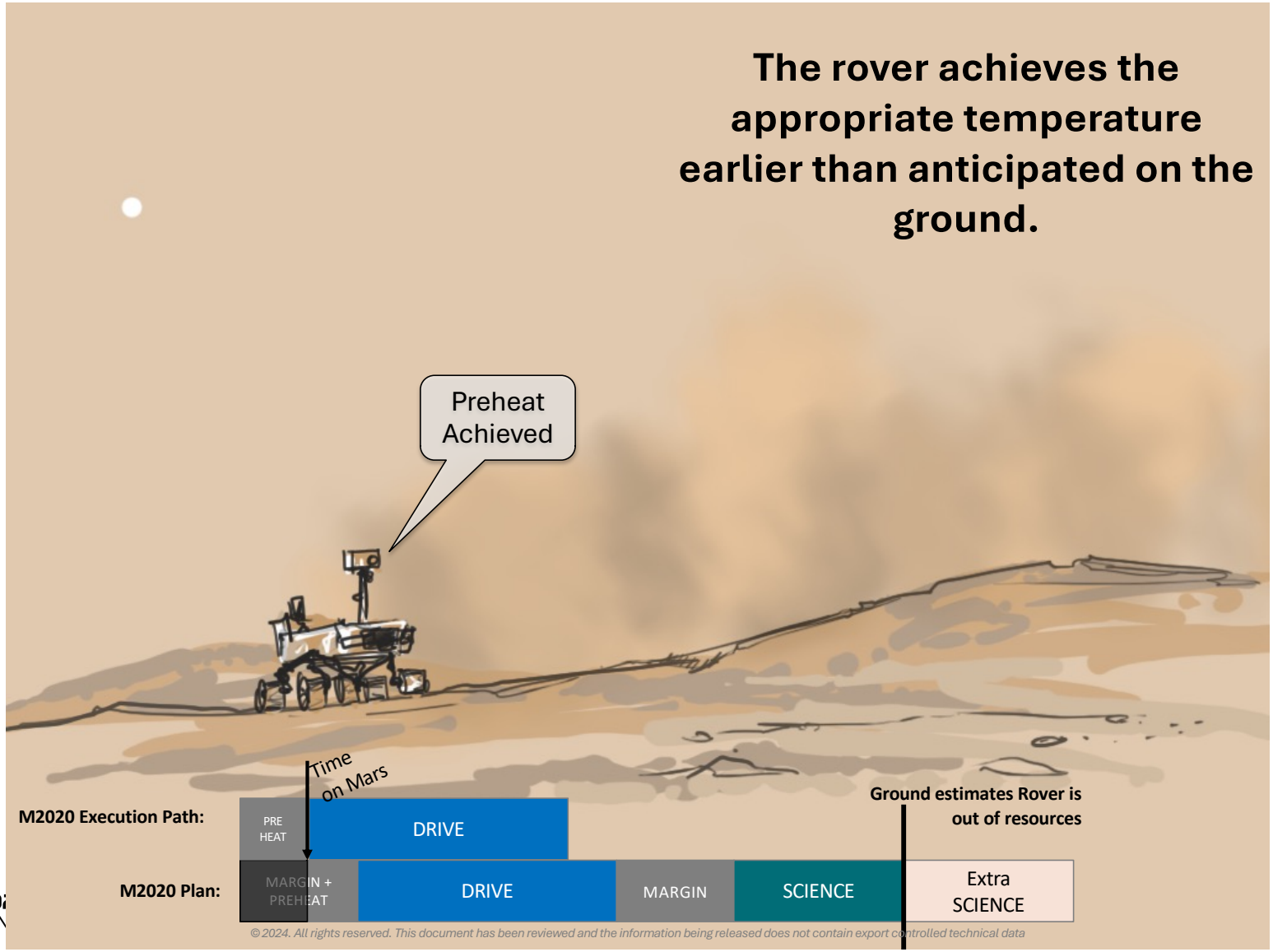
The ground can also identify dependencies among activities (not shown)



The rover receives activities commanded in the plan and begins execution.

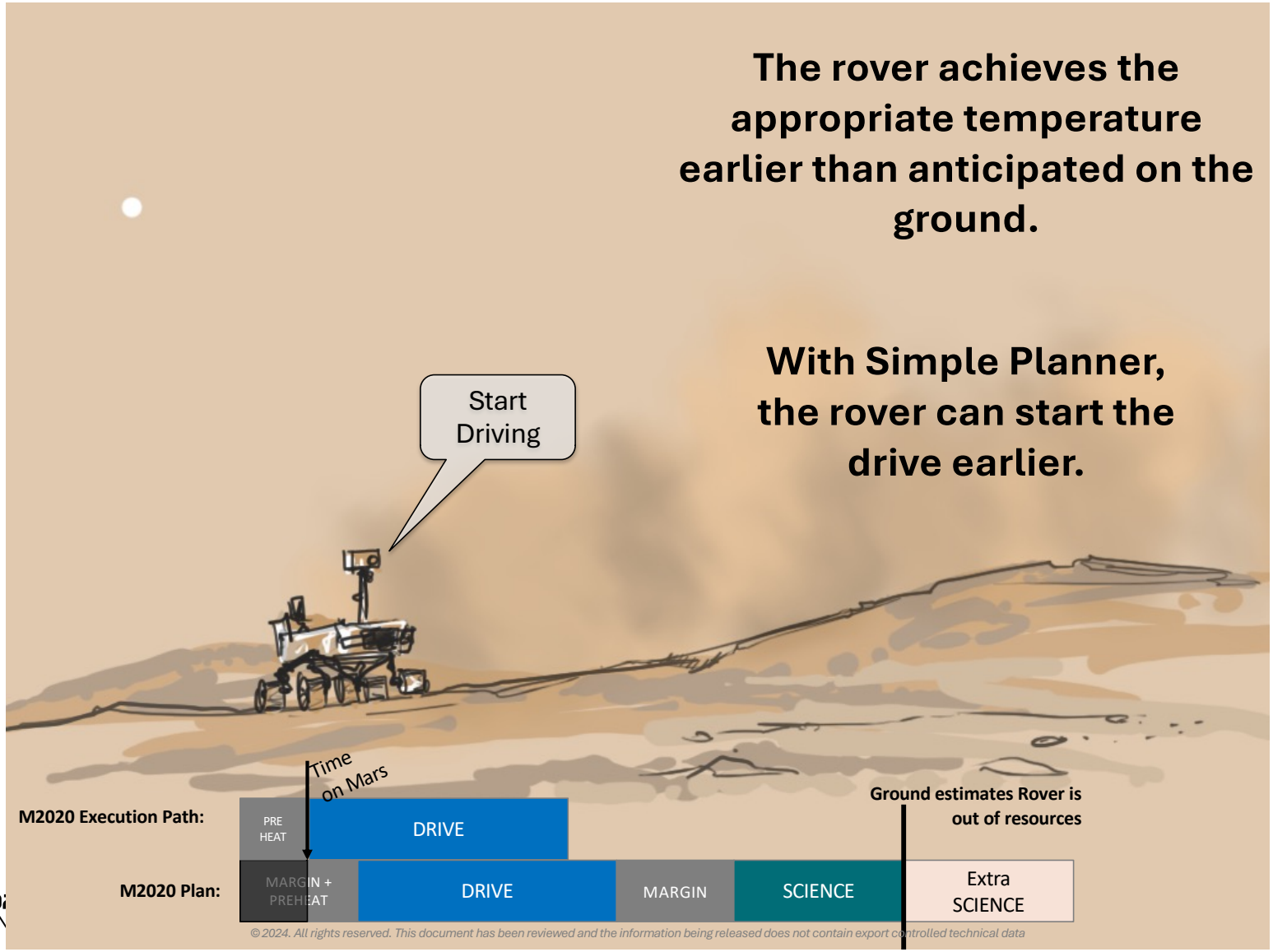


The rover achieves the appropriate temperature earlier than anticipated on the ground.

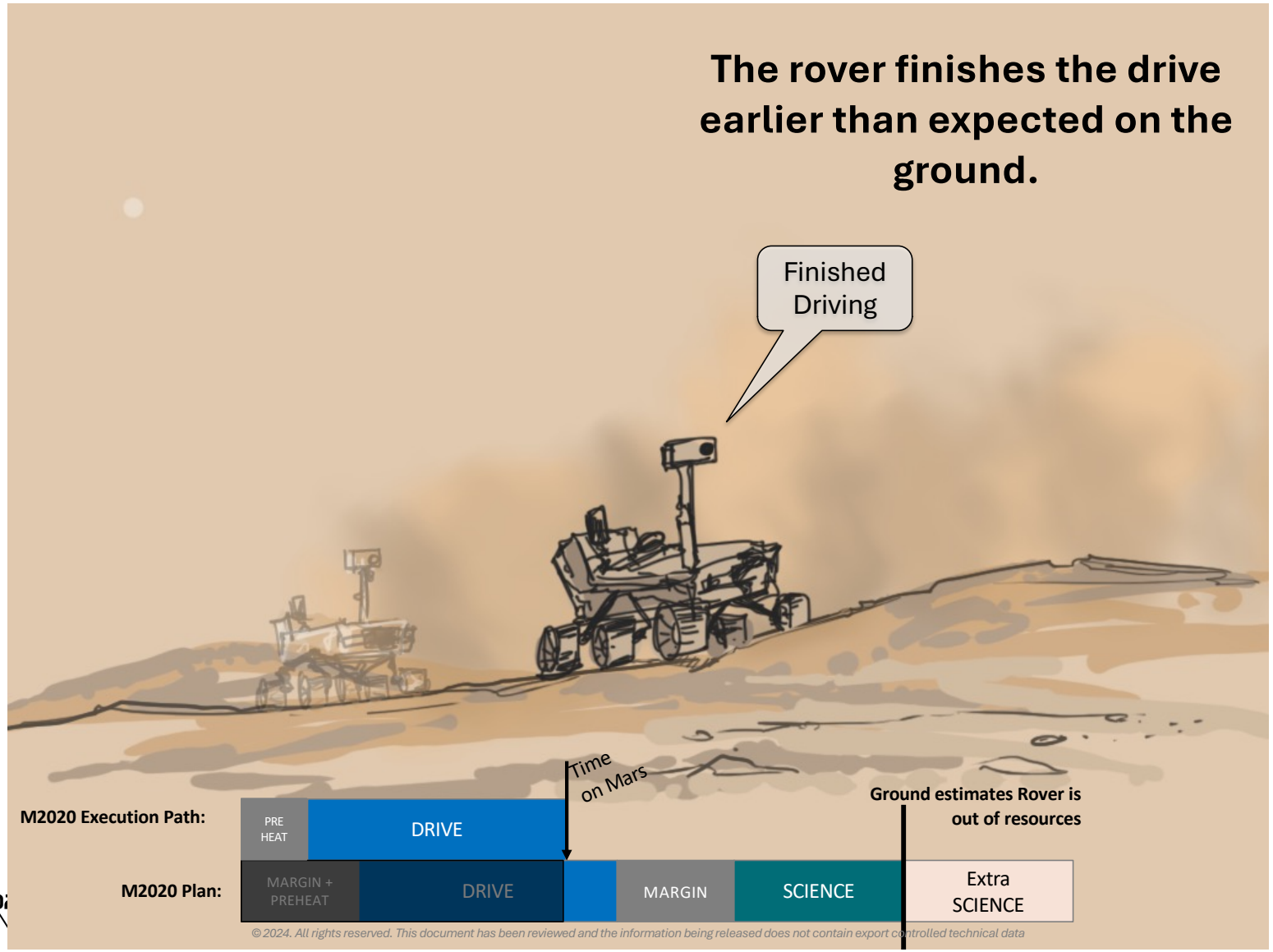


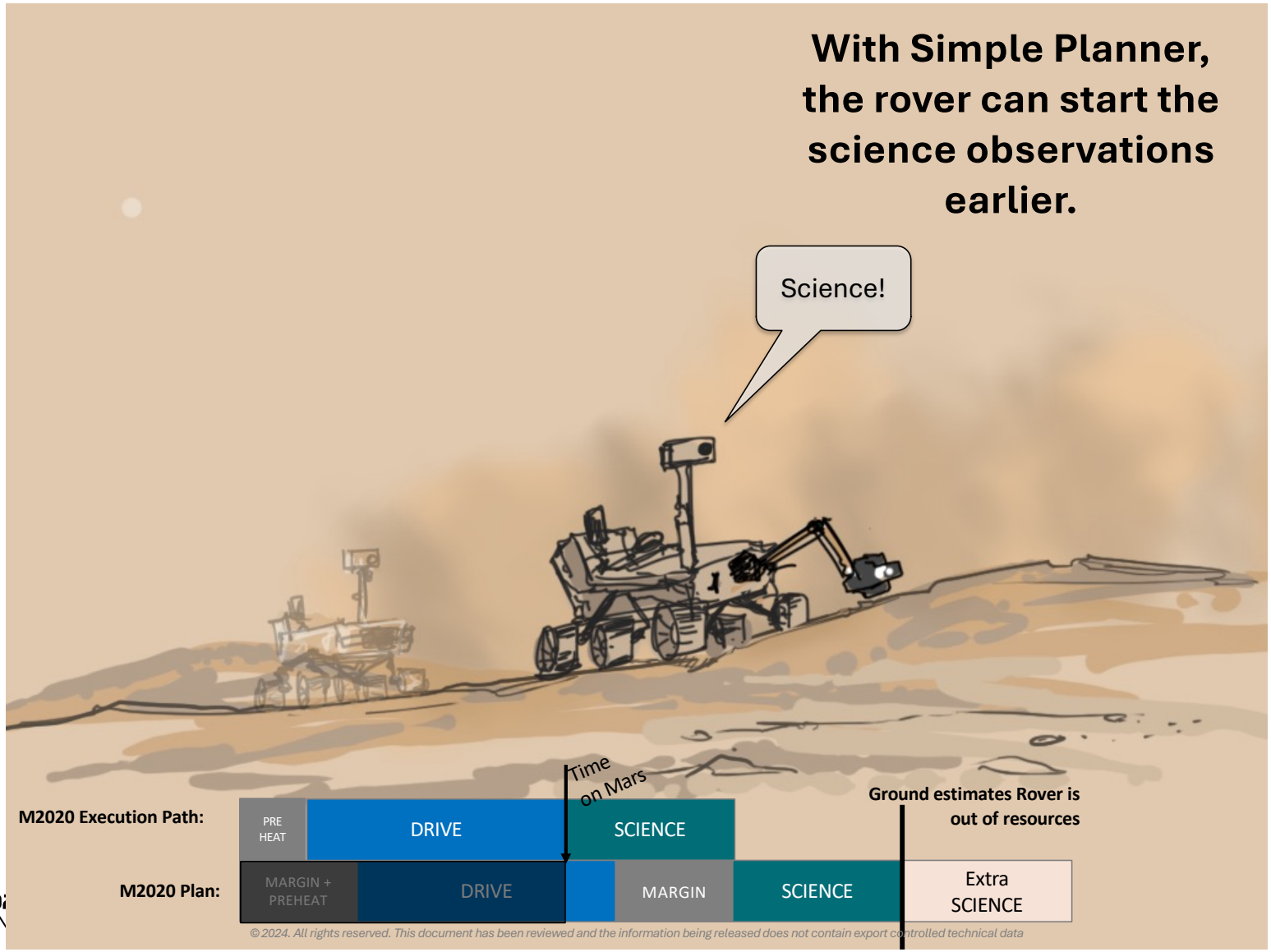
The rover achieves the appropriate temperature earlier than anticipated on the ground.

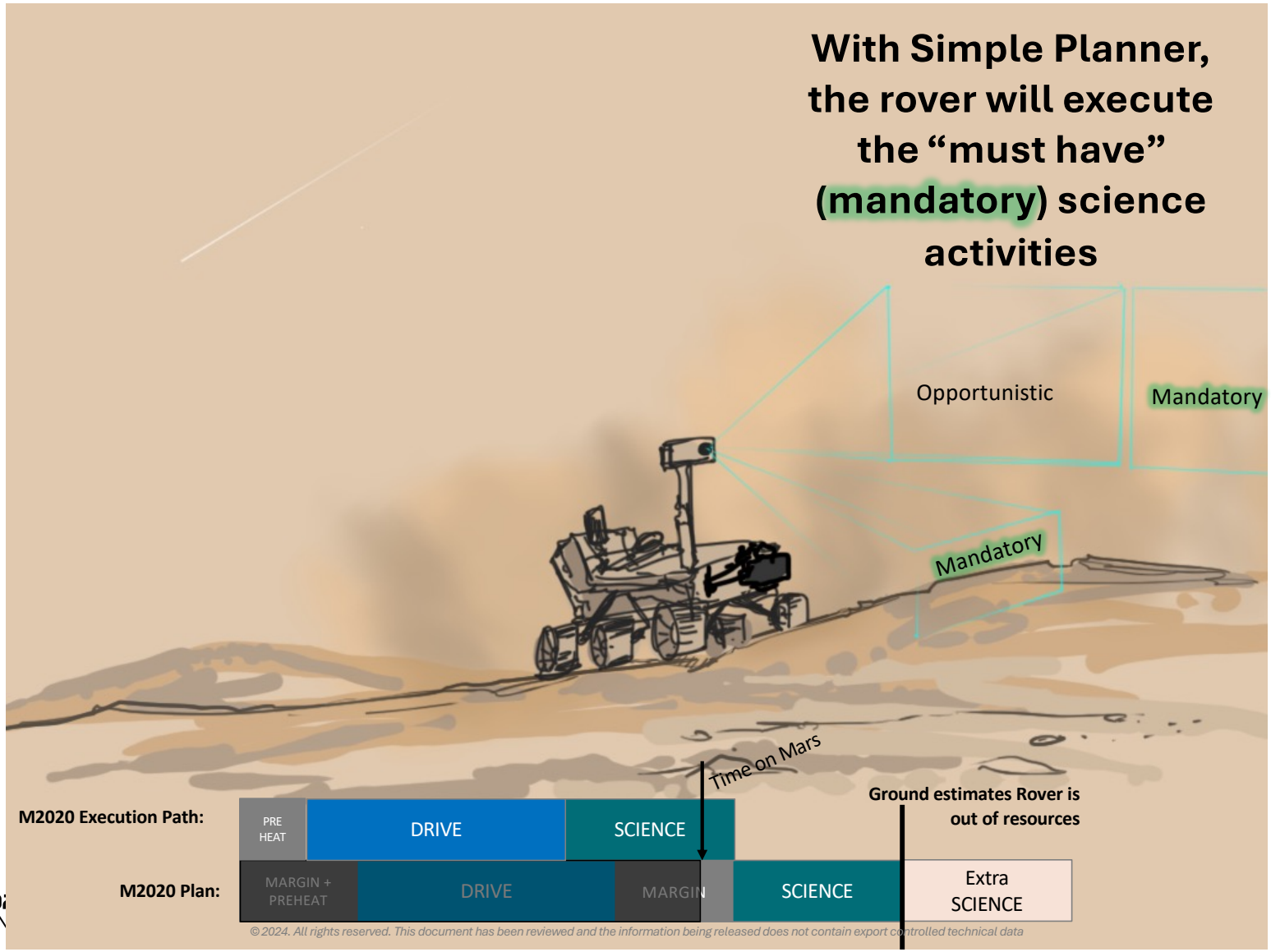
With Simple Planner, the rover can start the drive earlier.



The rover finishes the drive earlier than expected on the ground.

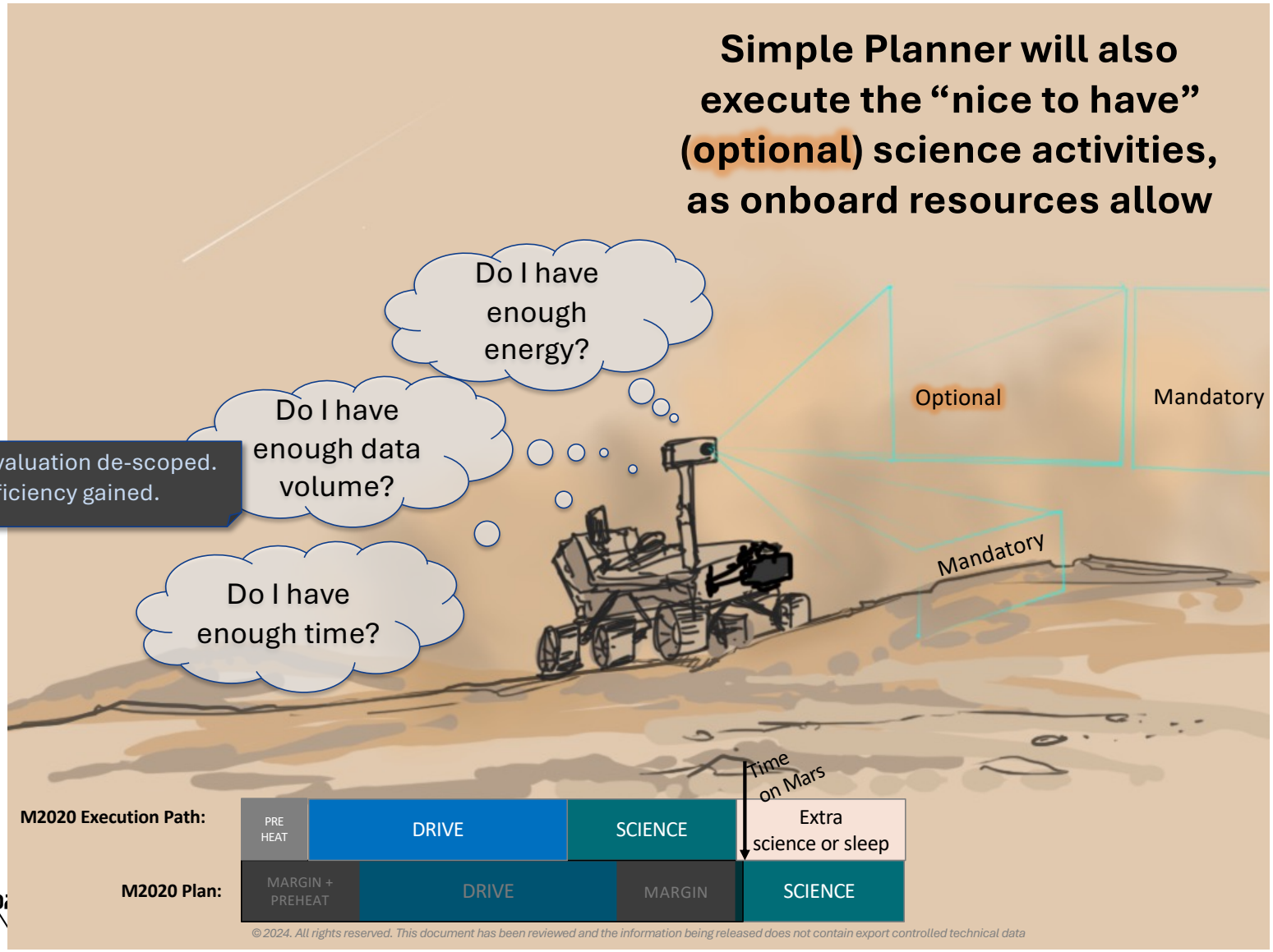






Simple Planner will also execute the “nice to have” (optional) science activities, as onboard resources allow

Data volume evaluation de-scoped. Not enough efficiency gained.



Why Simple?
This is not an optimal planner.

Design for the big areas of inefficiencies, it's OK to leave some resources "on the table".

How Simple Is it?
As simple as it needed to be to fit within a heritage architecture and schedule.

As simple as it could be while maintaining a tight flight-ground coupling

Simple Planner Development

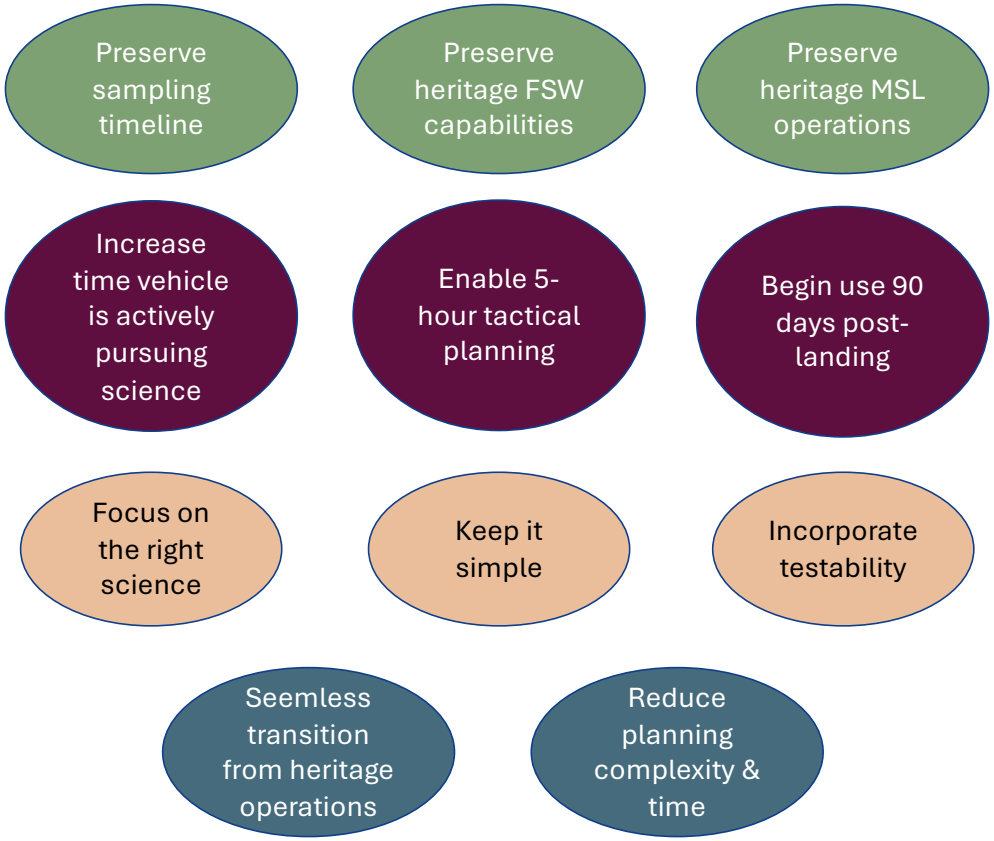
Simple Planner Stakeholders & Concerns

Science| Farley, Williford, & Stack, Spanovich
PSE | Bernard, Breitenbach, Welch
Flight System Management | Srinivasan, Samuels, Bareh
Mission System Management | Trosper, Wilson, Amadore
Flight Software Management | Haleski, Scandore

Surface Phase Lead | Trosper
Pre-PDR Surface Operability Lead | Reeves
ECR Originator | Harmon, Reeves, Moffi
Surface Coordination & Execution Lead | Moffi
JPL Artificial Intelligence Group | Chien, et al.
Europa Lander | Reeves

FS On Board Planner| Kuhn, Reich, Waldram, Parjan, et al.
FS Thermal | Stragier, Lyra, Novak, et al.
FS Power | Bowles-Martine, et al.
FS Sequencing | Lenda, et al.
Flight Software | Gaines, Rabideau, Skeggs, et al.

Science Operations| Milkovich, Steadman, Maxwell, Francis, et al.
Robotic Operations | Hartman, Kuhn, et al.
MOS Downlink | Siegfriedt, Mcgill, et al.
MOS Uplink | Lohr, Biehl, Hazelrig, Siegfriedt, Waldram, et al.
GDS APSS | Guduri, Ramaswamy, Connel, et al.

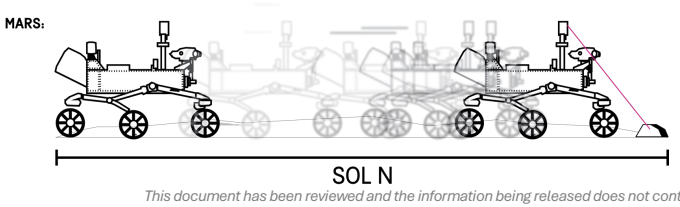


Simple Planner Summary

MSL/M2020 Plan:

MSL Execution:

M2020 Execution:



- **Aug 2015 | ECR Passed**
- Dec 2016 | Surface Phase PDR
- **Feb 2017 | MS/FS bi-weekly WG instantiated**
- June 2017 | MS Design Simulation
- **July 2017 | FSW capability baselined**
- Aug 2017 | Simple Planner FSW Wkshp
- Sep 2017 | Simple Planner E2E Peer Review
- Nov 2017 | Surface Phase CDR Part 2
- **August 2018 | Simple Planner E2E Test**
  Tactical Sim & Val Design Review
- May 2019 | Surface FSW v6 delivered
- **April 2020 | Simple Planner Paused**
- May 2022 | Simple Planner Resumed
- **May 2023 | First Time Activities in operations**
- July 2023 | ORR, ORT & Thread Tests
- **October 2023 | Simple Planner First use**

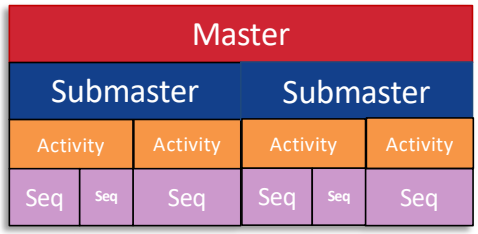
Legend

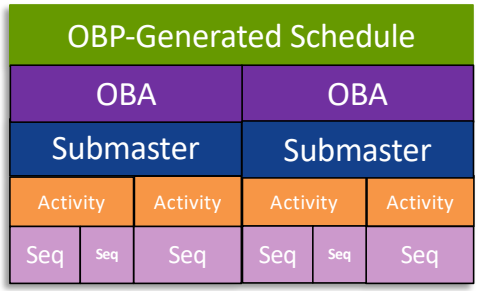
- Design
- Prototyping
- V&V
- Implementation
- Operations

MARS 2020 PERSEVERANCE

Simple Planner vs MSL Surface Commanding

Orchestration Function	Master/Sub Orchestration	Simple Planner Orchestration
Dispatch execution instructions	**Master Sequence**	**On Board Plan File (OBPF)**
Group sequences for dispatch	**Submaster**	**On Board Activity**
Constraints	Honored via **ground** checks	Honored **onboard** via OBPF
Cleanups	**Always** executes	**Conditionally** executes (rare)
Execution timing & ordering Heating Rover shutdown Rover wakeup	**Fixed** planned on the ground includes margin	**Flexible** criteria provided via OBPF real-time onboard decisions
Use available onboard resources	**N/A**	**On Board Planner**





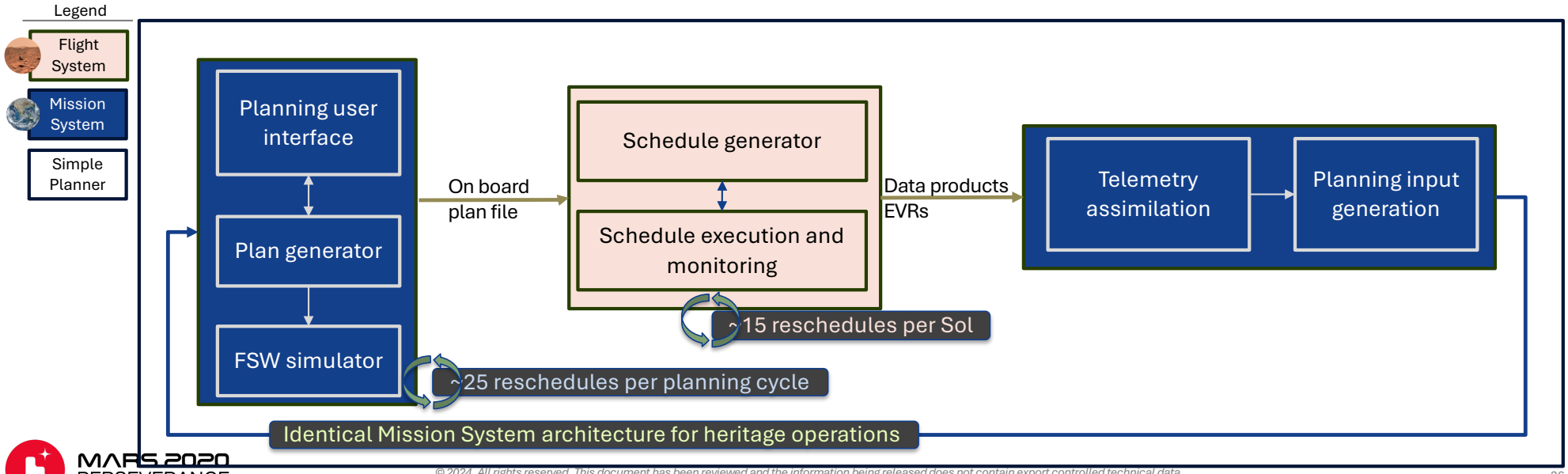
MARS 2020 PERSEVERANCE

Simple Planner vs. Onboard Planner

Simple Planner (SP) - End-to-end autonomous onboard activity scheduling capability, encompassing both Mission System and Flight System elements

Onboard Planner (OBP) - The flight software (FSW) portion of Simple Planner, autonomous scheduler

Mission System (MS) – the ground tools and operators, including the automated ground scheduler, flight software simulation, dashboards, and constraint-based planning



Crawl Before We Walk (Development)

What if…

- Simple Planner implementation is not well understood and underscoped?
- Other system areas force implementation attention elsewhere and delays Simple Planner?
- FS and MS implementation become out of sync?

Mitigations…

- Collaboration with FS and MS though working group meetings
- Step-wise, capability-based V&V
- Early and often E2E testing

Simple Planner Phase	Capabilities	Ops Productivity Impact
SP1: The Accordion	Constraint-based planning Idle time recovery (naps) Battery shunting management	Simplifies planning process Better battery management
SP2: Medium	Optional activities Expanding drives up to SOC limit	Remote science optional activities make use of idle time
SP3: Full	UHF pause/resume Arm instruments	5-hour timeline, Sol path advancement

Crawl Before We Walk (Actual)

What if…

- Simple Planner implementation is not well understood and underscoped?
- Other system areas force implementation attention elsewhere and delays Simple Planner?
- FS and MS implementations become out of sync?

Mitigations…

- Collaboration with FS and MS though working group meetings
- Step-wise, capability-based V&V
- Early and often E2E testing

"Simpler" Simple Planner provides enough efficiency gains to meet Mission objectives.

Enabled faster return to sampling after faults

Remained active during sampling Sols

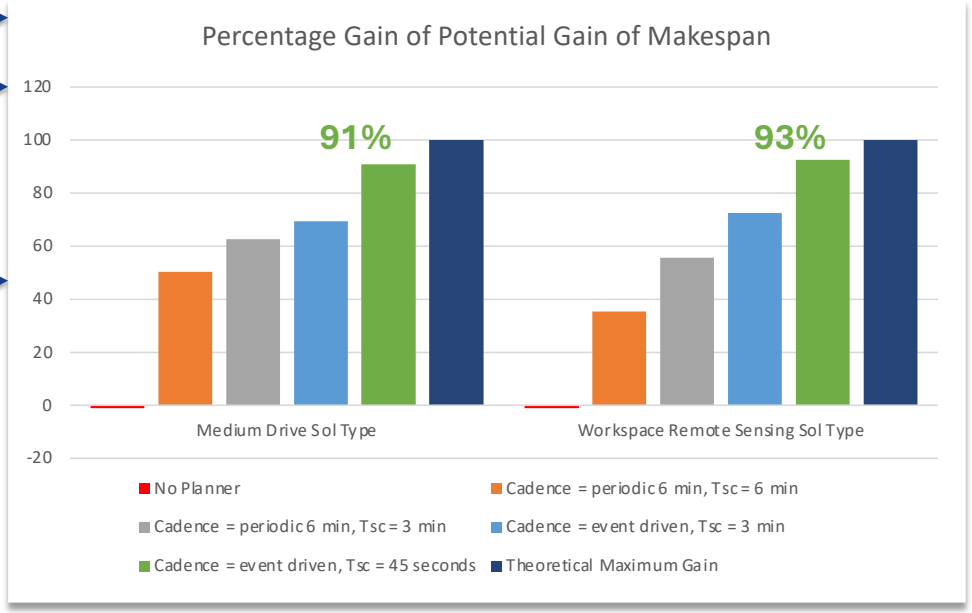
Preserved battery health for extended operations

Simple Planner Phase	Capabilities	Ops Productivity Impact
SP1: The Accordion	Constraint-based planning Idle time recovery (naps) Battery shunting management	Simplifies planning process Better battery management
SP2: ~~Medium~~ Full	Optional activities Expanding drives up to SOC limit	Remote science optional activities make use of idle time Sol path advancement <7 hour tactical timeline
~~SP3: Full~~	~~UHF pause/resume~~ ~~Arm instruments~~	~~5-hour timeline, Sol path advancement~~

MARS 2020 PERSEVERANCE

Simple Planner Gains Quantified (Development)

- Mission Planning performance sensitivity analysis evaluated that Simple Planner reduces the overall prime mission timeline by ~70 Sols.
- Partnership with Technology, AI Group R&TD allowed for rapid prototyping, pre-V&V.[9]
  - Scheduling complexity analysis
  - Scheduling invocation analysis
  - Activity grouping architecture
  - Flight-Ground responsibility split
- Leveraged MSL as-flown data
- Leveraged Mars2020 as-flown data
  - Savings in total mission energy production
  - Effectively ”buys back” years in RTG aging



MARS 2020 PERSEVERANCE

[9]Chi, Chien, Agrawal, et al. (2018)

Simple Planner Gains Quantified (Actual)

Consistent **savings in total energy use capability**

- Perseverance battery capacity using heritage planning **<<** Perseverance battery capacity using Simple Planner

Added nearly **800 meters of drive distance**

- Tens of meters of additional distance per drive, as far as 75m for an individual drive

Quicker recovery and re-attempts from failed activities

- On Sols 942 and 947 the sample collection attempts failed. SP powered off the rover after each failed attempt, saving ~1000W-h, or **nearly 40% of the battery's charge**, and enabling re-attempts on the next Sol (versus a recharge Sol)

MARS 2020
PERSEVERANCE

Simple Planner & Instrument Operations

Success for Simple Planner depends on acquiring **meaningful science data**

- Scientists, not engineers, determine what is meaningful
- Concern that "shiny & new" Simple Planner would have negative impacts on science
  - Focus shifts to debugging or discovering Simple Planner emergent behaviors
- Instrument teams and Science leadership engaged early and often with the Simple Planner development team
  - Not *too much* to lose focus on other priorities, just enough to keep them apprised of status and gather their use cases.

Instrument operations controls Simple Planner

- Able to restrict scheduling flexibility for time-critical or activity-dependent observations
- Energy and Sol Path savings flow back to more available time for science

"TL; DR: "optional" is our friend with OBP" – scientist in response to a dust devil movie running 2 hours earlier than planned, at a time more conducive to acquiring the observation.

MARS 2020 PERSEVERANCE

Operations

Constraint Based Planning deployed August 25th, 2023

On Board Planner deployed October 5th, 2023

Simple Planner used for **204** tactical planning cycles
(as of November 2024)

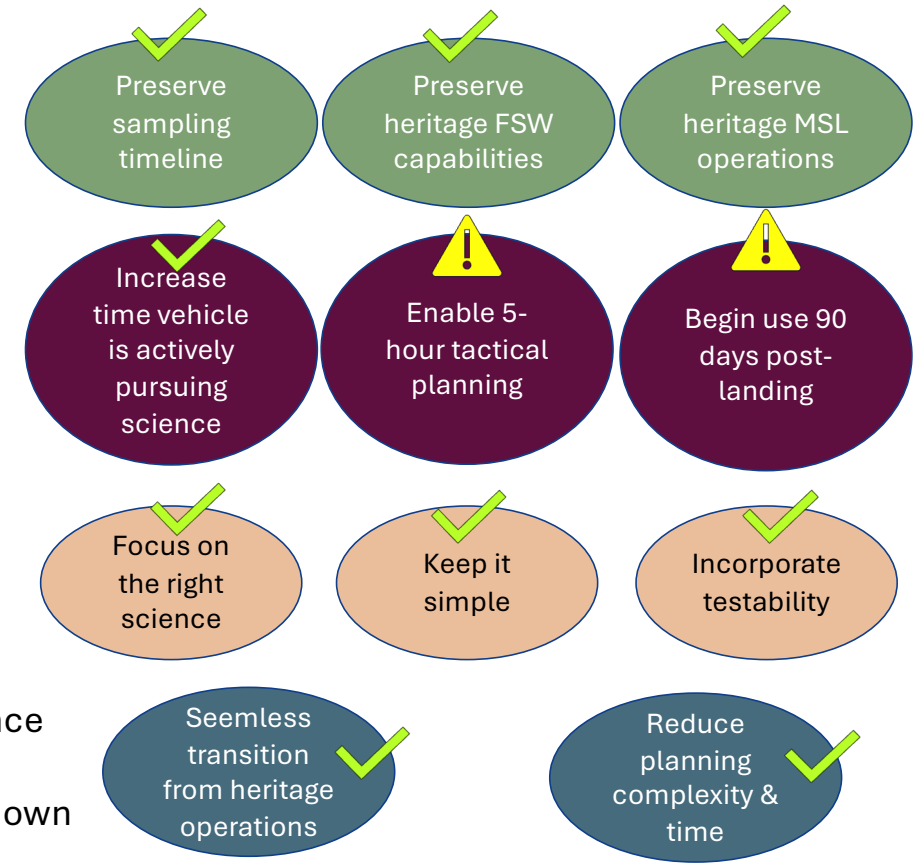
Tactical Timeline is averaging 6.5 hours

To date, Mars2020 has not reverted from Simple Planner
(besides Solar Conjunction and FSW update)

Simple Planner remains enabled for Sample Sols

Science sites arrived at faster thanks to additional drive distance

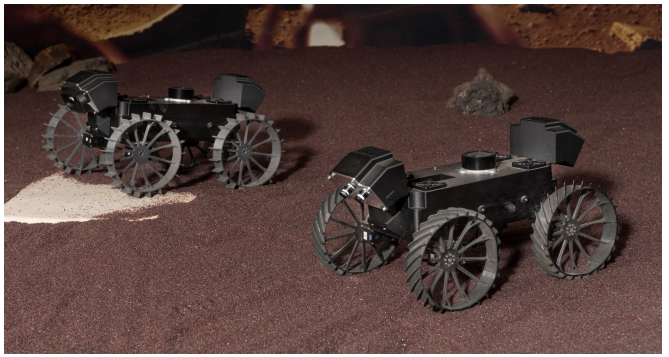
19 Simple Planner ISAs, none required Simple Planner stand down



What's Next for On Board Autonomy?

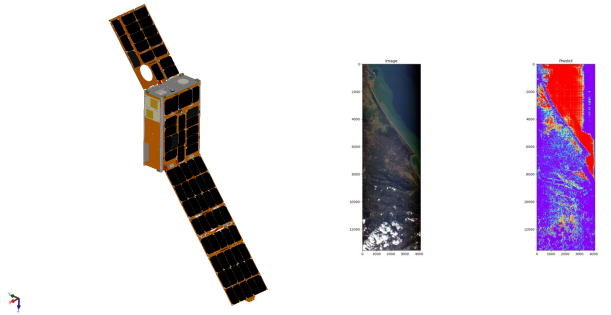
CADRE[10]

- Demonstrate autonomous coordination across rovers for joint mapping and measurements (ground penetrating radar).
- late 2025 mission



Federated Autonomous MEasurement (FAME)[11]

- Multiple spacecraft jointly observing and interpreting science events – volcanic eruptions, flooding, wildfires, …



[10] de la Croix, Rossi, Aguilar, et al. (2024)
[11] Chien, Zilberstein, et al. (2024)

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References

[1] A. K. Jónsson, P. H. Morris, N. Muscettola, K. Rajan, B. D. Smith, Planning in interplanetary space: Theory and practice, in AIPS'00: Proceedings of the Fifth International Conference on Artificial Intelligence Planning Systems (2000), pp. 177–186.

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[3] M. Troesch, F. Mirza, K. Hughes, A. Rothstein-Dowden, R. Bocchino, A. Donner, M. Feather, B. Smith, L. Fesq, B. Barker, B. Campuzano, MEXEC: An onboard integrated planning and execution approach for spacecraft commanding, in Workshop on Integrated Execution (IntEx) /Goal Reasoning (GR), International Conference on Automated Planning and Scheduling (ICAPS IntEx/GP 2020), Nancy, France, 19 to 30 October 2020.

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