SAFELY NAVIGATING THE SURFACE OF VENUS: MODEL CHECKING A MECHANICAL OBSTACLE AVOIDANCE SENSOR IN NUXMV

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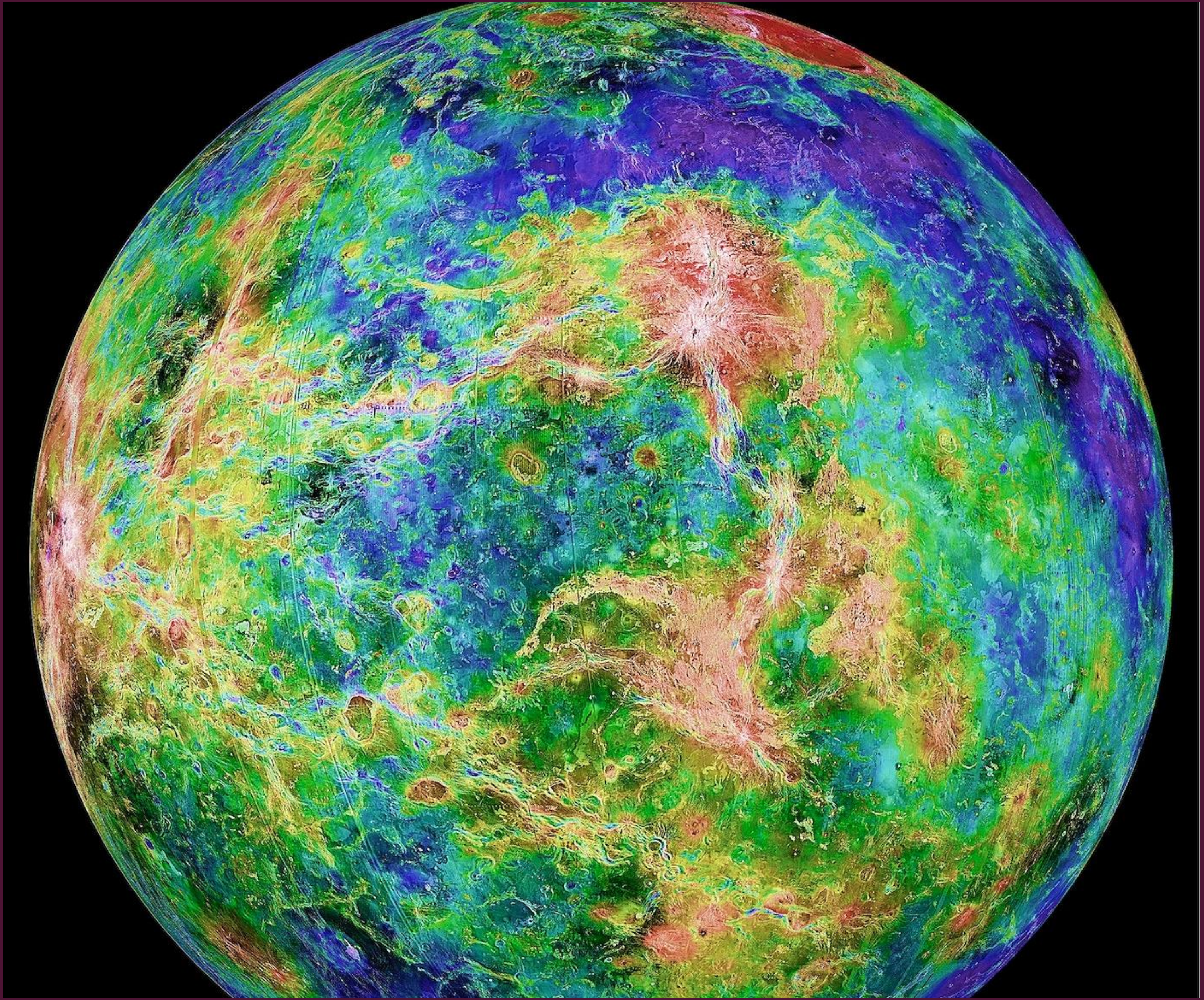
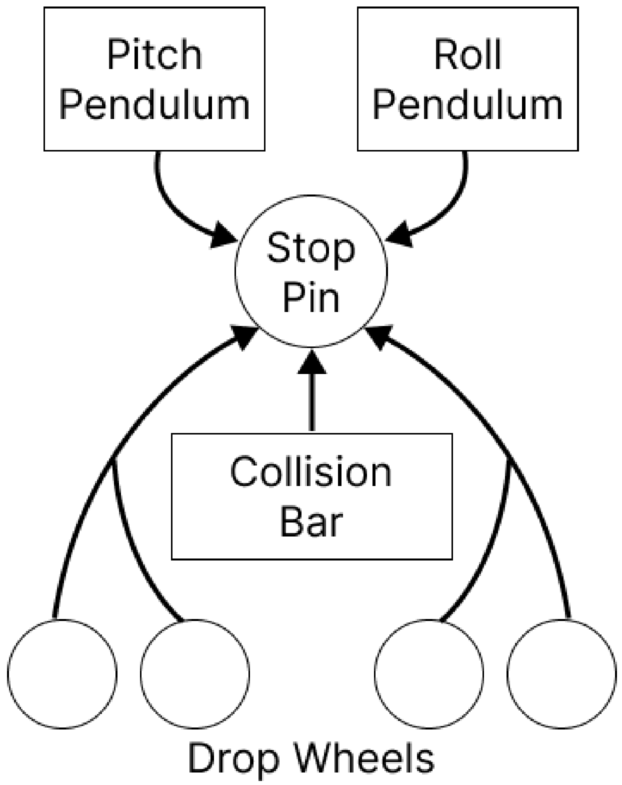
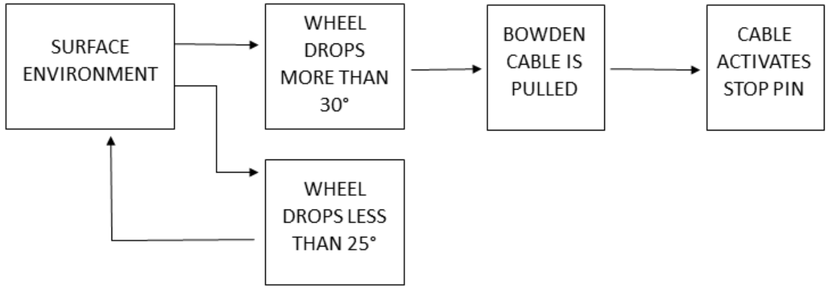


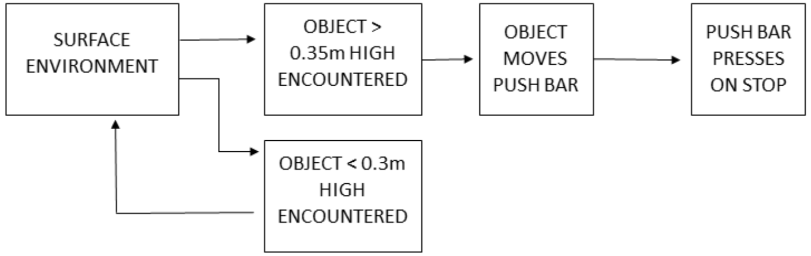
HOW DO WE NAVIGATE THE SURFACE OF HELL?

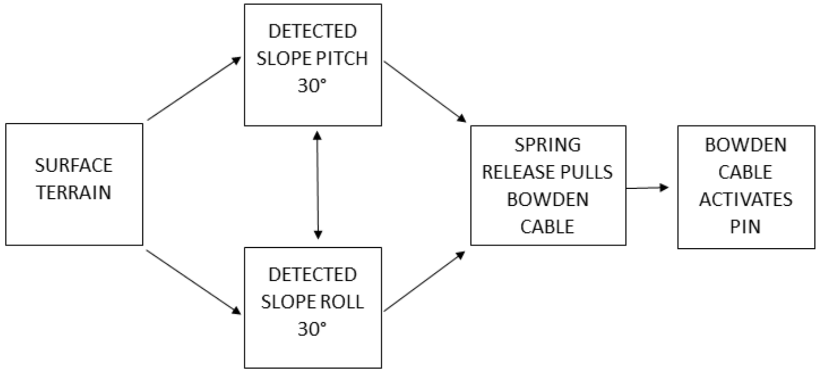
Avoid	Steep slopes and inclines
Avoid	Large rocks and other obstacles
Avoid	Holes and cliffs

A CLOCKWORK ROVER – SYSTEM AND ABSTRACTIONS



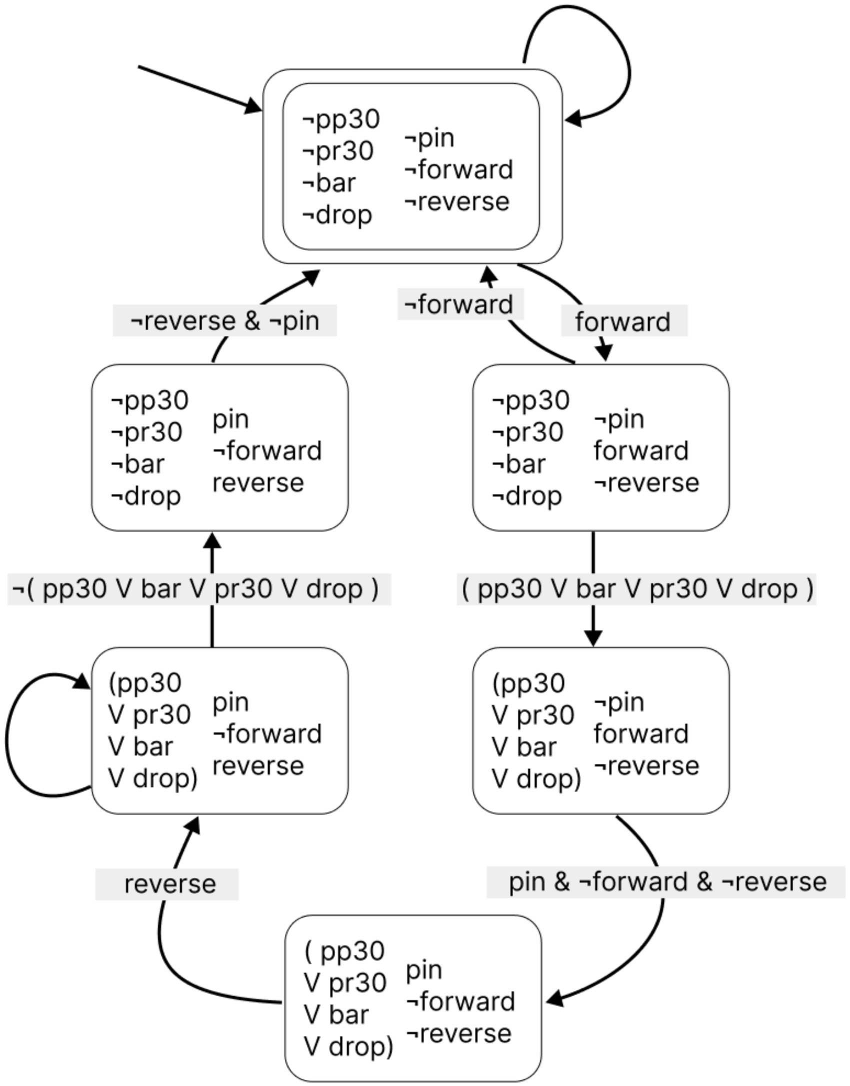




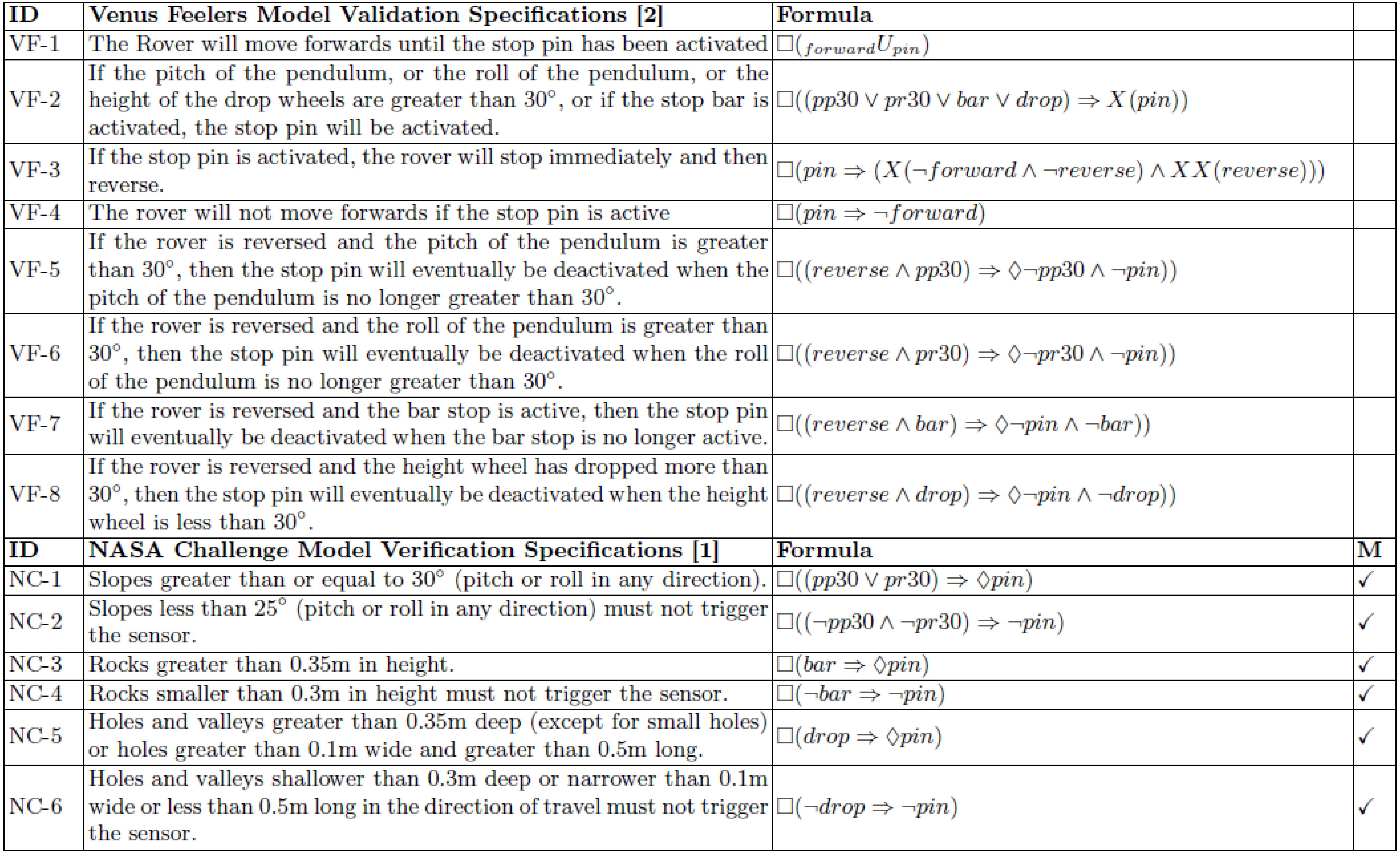


REDUCING THE STATE SPACE

- Each module can be abstracted as a **1 or 2 variables**
- System input variables are **independent** of each other
- State space reduces from 62 to 6



TRANSLATING ENGLISH TO LTL



ID	Venus Feelers Model Validation Specifications [2]	Formula	
VF-1	The Rover will move forwards until the stop pin has been activated	$\Box(_{forward}U_{pin})$	
VF-2	If the pitch of the pendulum, or the roll of the pendulum, or the height of the drop wheels are greater than 30°, or if the stop bar is activated, the stop pin will be activated.	$\Box((pp30 \vee pr30 \vee bar \vee drop) \Rightarrow X(pin))$	
VF-3	If the stop pin is activated, the rover will stop immediately and then reverse.	$\Box(pin \Rightarrow (X(\neg forward \wedge \neg reverse) \wedge XX(reverse)))$	
VF-4	The rover will not move forwards if the stop pin is active	$\Box(pin \Rightarrow \neg forward)$	
VF-5	If the rover is reversed and the pitch of the pendulum is greater than 30°, then the stop pin will eventually be deactivated when the pitch of the pendulum is no longer greater than 30°.	$\Box((reverse \wedge pp30) \Rightarrow \Diamond\neg pp30 \wedge \neg pin))$	
VF-6	If the rover is reversed and the roll of the pendulum is greater than 30°, then the stop pin will eventually be deactivated when the roll of the pendulum is no longer greater than 30°.	$\Box((reverse \wedge pr30) \Rightarrow \Diamond\neg pr30 \wedge \neg pin))$	
VF-7	If the rover is reversed and the bar stop is active, then the stop pin will eventually be deactivated when the bar stop is no longer active.	$\Box((reverse \wedge bar) \Rightarrow \Diamond\neg pin \wedge \neg bar))$	
VF-8	If the rover is reversed and the height wheel has dropped more than 30°, then the stop pin will eventually be deactivated when the height wheel is less than 30°.	$\Box((reverse \wedge drop) \Rightarrow \Diamond\neg pin \wedge \neg drop))$	
ID	**NASA Challenge Model Verification Specifications [1]**	**Formula**	**M**
NC-1	Slopes greater than or equal to 30° (pitch or roll in any direction).	$\Box((pp30 \vee pr30) \Rightarrow \Diamond pin)$	✓
NC-2	Slopes less than 25° (pitch or roll in any direction) must not trigger the sensor.	$\Box((\neg pp30 \wedge \neg pr30) \Rightarrow \neg pin)$	✓
NC-3	Rocks greater than 0.35m in height.	$\Box(bar \Rightarrow \Diamond pin)$	✓
NC-4	Rocks smaller than 0.3m in height must not trigger the sensor.	$\Box(\neg bar \Rightarrow \neg pin)$	✓
NC-5	Holes and valleys greater than 0.35m deep (except for small holes) or holes greater than 0.1m wide and greater than 0.5m long.	$\Box(drop \Rightarrow \Diamond pin)$	✓
NC-6	Holes and valleys shallower than 0.3m deep or narrower than 0.1m wide or less than 0.5m long in the direction of travel must not trigger the sensor.	$\Box(\neg drop \Rightarrow \neg pin)$	✓

BUT WAIT – HOW DO WE KNOW OUR MODEL IS CORRECT?

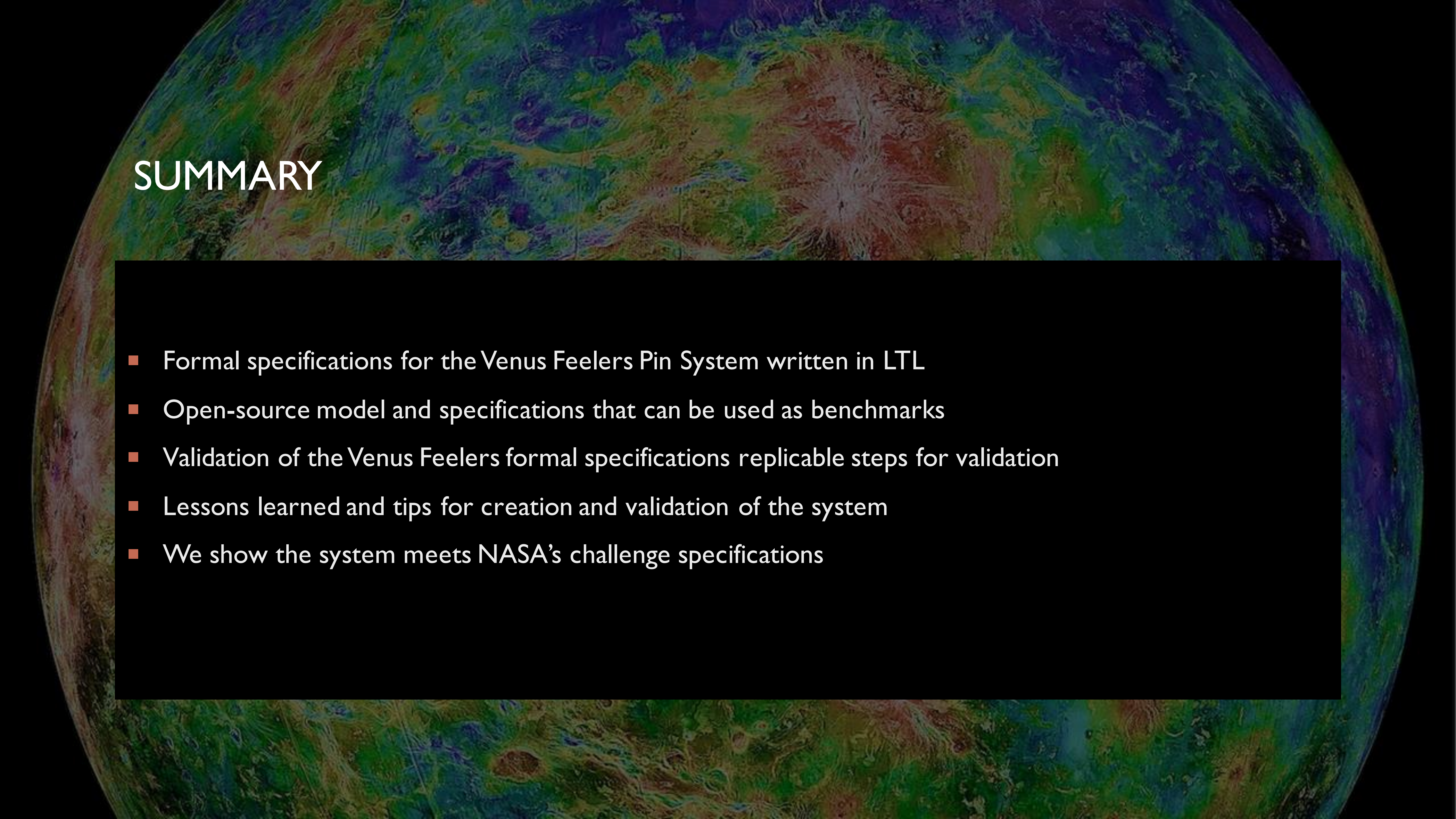
- Checking our model against the validation specifications
- **No discrepancies** were found
- Disclaimer: **only** for the physical portion of the system

VERIFICATION RESULTS

- Counterexample traces returned for **all** negations of LTL properties!
- System vacuously true if the rover **never moves**
- System vacuously true if the rover **reverses forever**
- No detection system **behind** the rover
- No system to allow the rover to **change direction**

FUTURE WORK

- Review LTL verification specifications with JPL engineers
- Expand formal specifications for future cyber system component
- Continually update model as development continues
- Make sure future bugs addressed
- Use this study for project-based learning



SUMMARY

- Formal specifications for the Venus Feelers Pin System written in LTL
- Open-source model and specifications that can be used as benchmarks
- Validation of the Venus Feelers formal specifications replicable steps for validation
- Lessons learned and tips for creation and validation of the system
- We show the system meets NASA’s challenge specifications