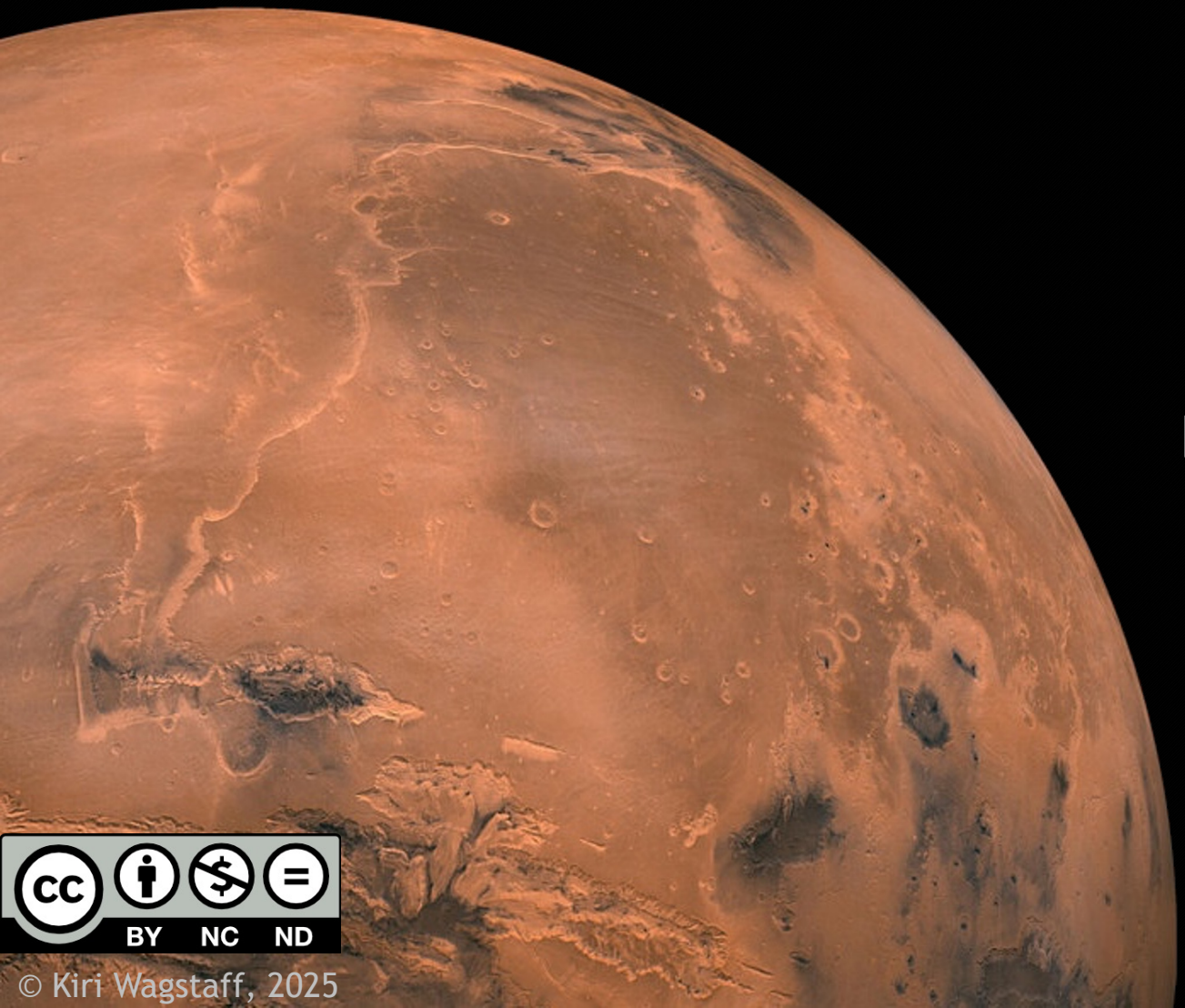
How can AI help us explore and understand the universe?



Kiri L. Wagstaff

Special Advisor on AI

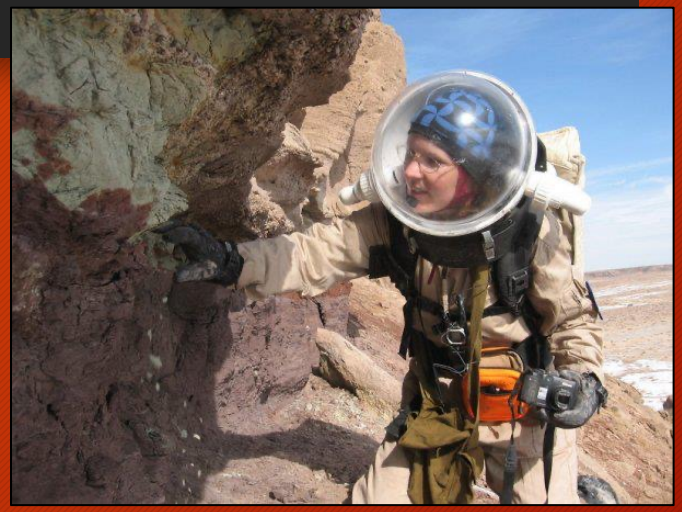
OSU Libraries

November 3, 2025

OSU AI Club

Dr. Kiri Wagstaff

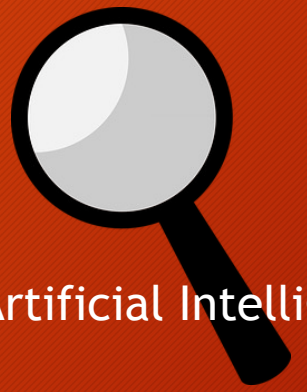
- Researcher – Ph.D. Computer Science
  - NASA Jet Propulsion Laboratory (2003-2022)
  - AI and machine learning for space exploration
  - Mars rover operations (Opportunity rover)
  - Fellow of the Association for the Advancement of Artificial Intelligence (AAAI)
- Educator – Oregon State University since 2019
  - “Machine Learning Challenges in the Real World”
  - “How to Be Less Wrong: A Study in Common Misconceptions”
  - AI Advisor to U.S. Senator Mark Kelly (2023-2024)
  - Special Advisor on AI for the OSU Libraries



Mars Desert Research Station

U.S. Congress

Tools in the quest for scientific discoveries



Artificial Intelligence

"Equipped with our five senses –
along with telescopes and microscopes and mass spectrometers and seismographs and magnetometers and particle accelerators and detectors sensitive to the entire electromagnetic spectrum –
we explore the universe around us and call the adventure science." – Edwin Hubble

What is AI?

- There is no widely agreed-on definition
  - Even among AI researchers

- “Artificial intelligence is the intelligence exhibited by machines and software.”
  – Wikipedia

- “AI refers to computer systems capable of performing tasks that typically require human intelligence, such as reasoning, learning, perception, and language understanding.”
  – ISO (International Organization for Standardization)

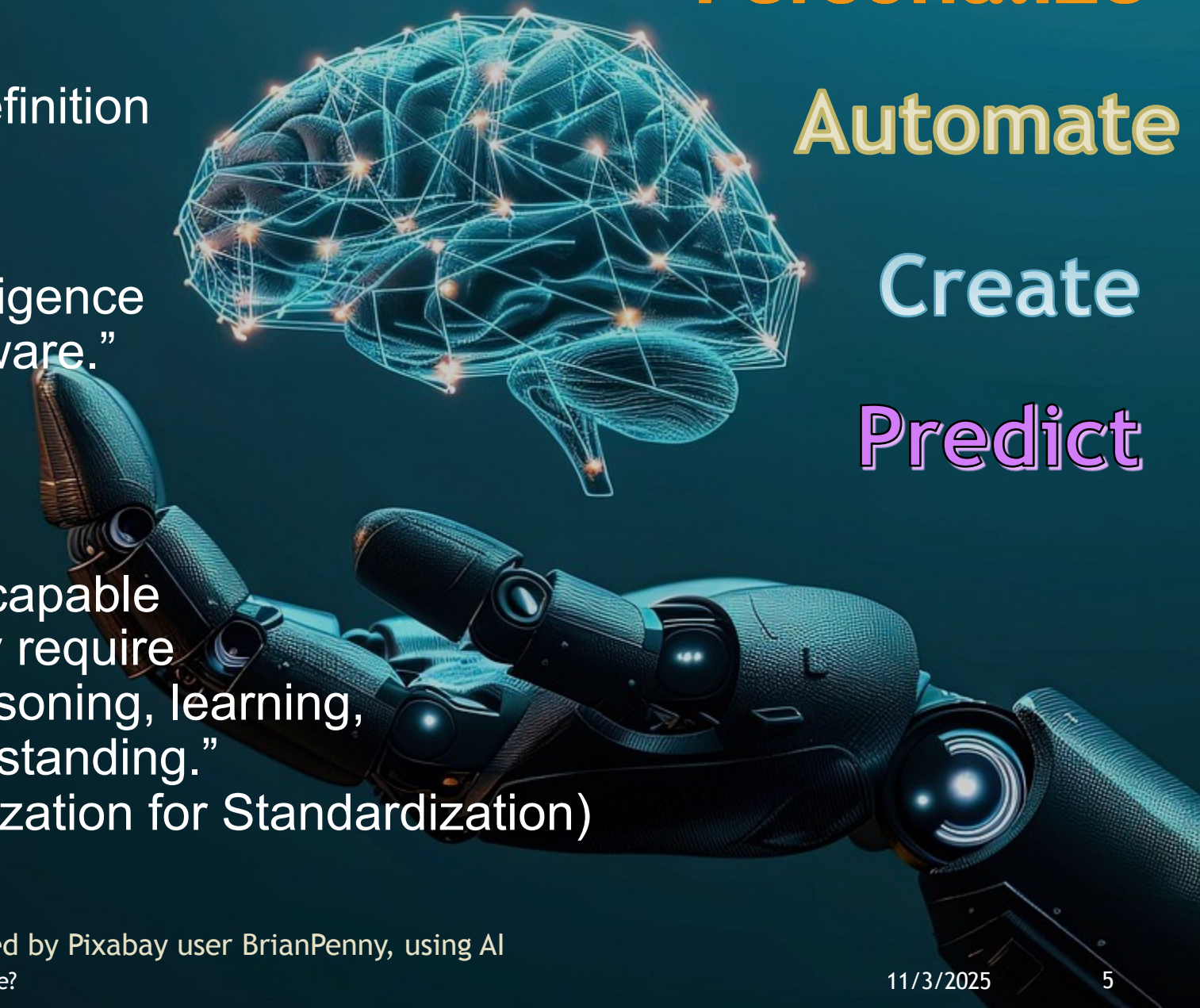
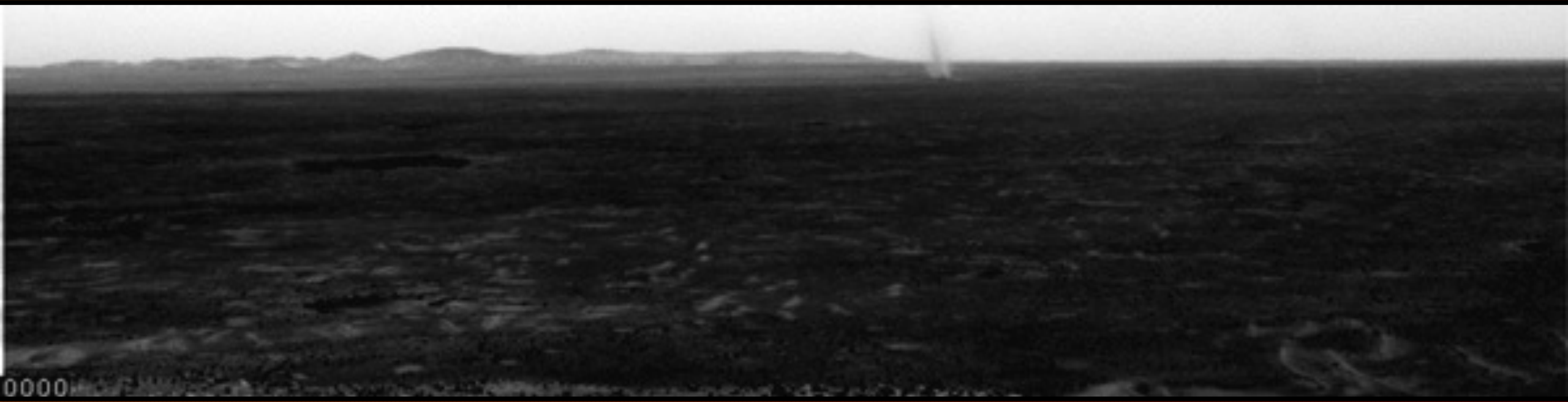


Image created by Pixabay user BrianPenny, using AI

1. Use AI in places humans can’t go

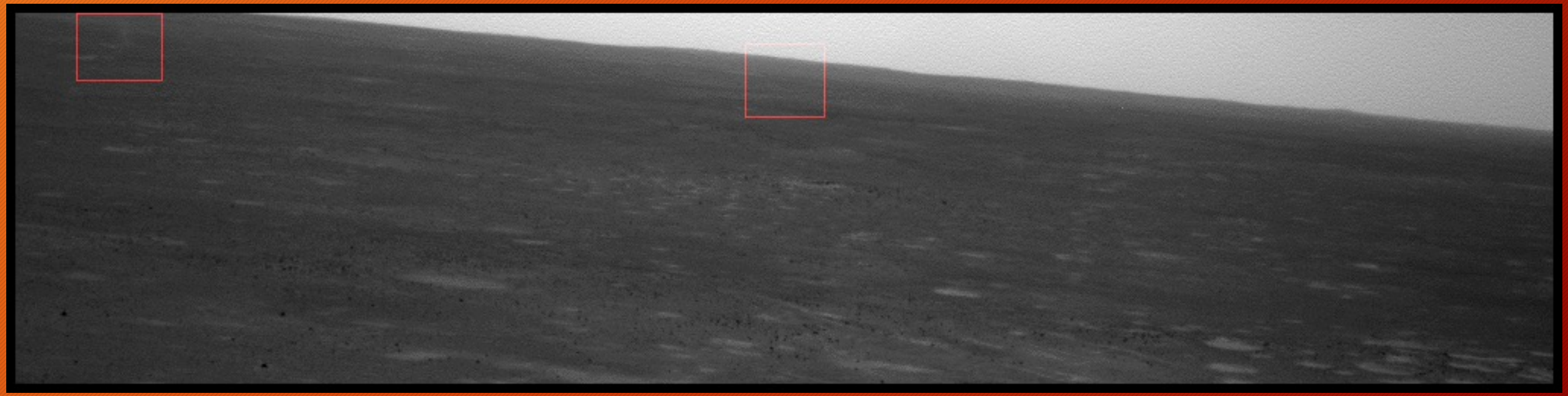
- A signal takes 20-40 minutes to go to Mars and back
- Meanwhile, exciting things are happening on Mars



Spirit Mars rover, Sol 568 (August 5, 2005) – Image credit NASA/JPL/Texas A&M

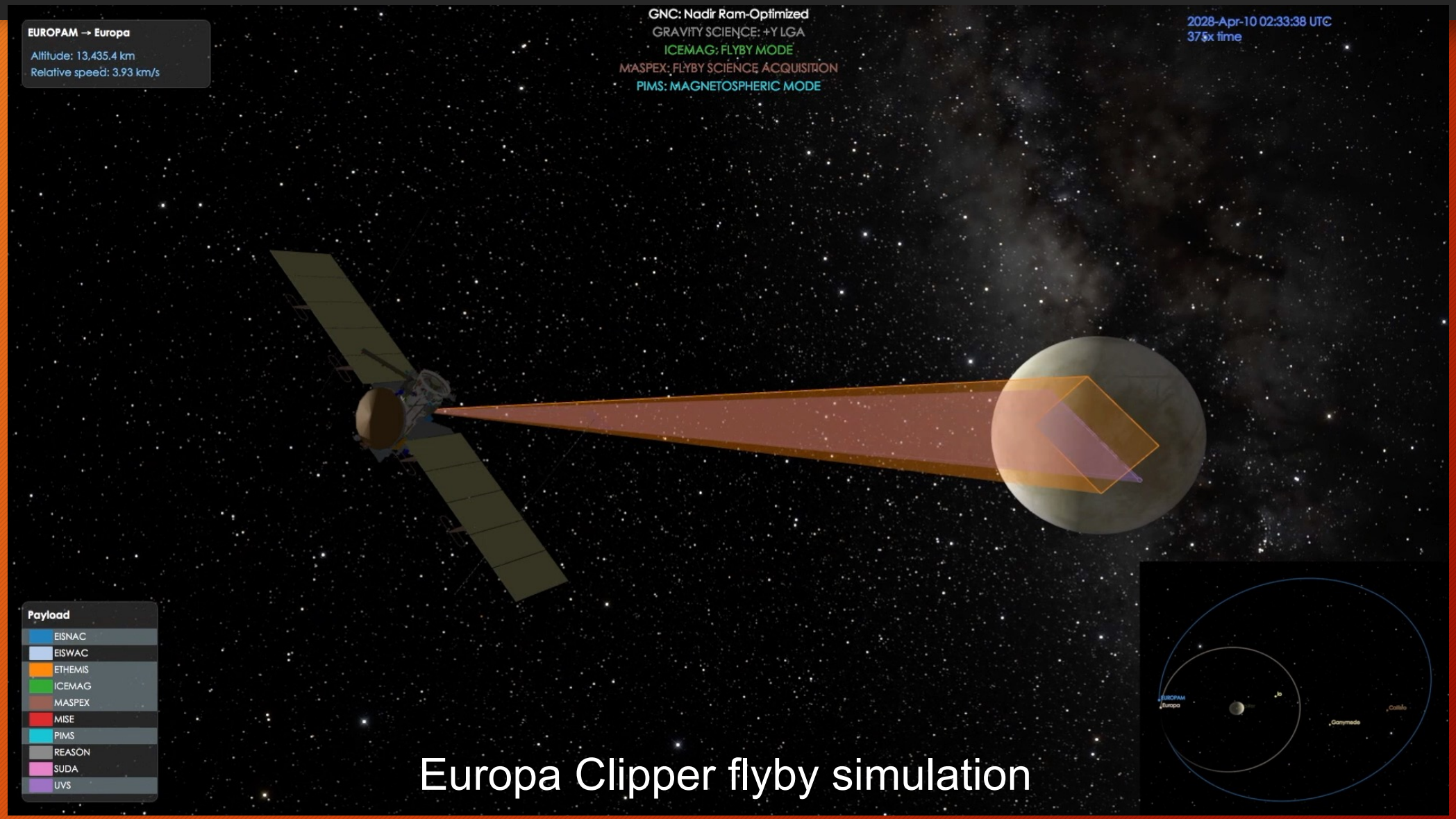
1. Use AI in places humans can’t go

- A signal takes 20-40 minutes to go to Mars and back
- Meanwhile, exciting things are happening on Mars
  - Use AI to detect interesting events and capture data to send back to Earth – no other way to respond fast enough
  - 70% reduction in data volume sent back to Earth; but carefully weigh risks and benefits



A. Castaño et al., 2007. *Machine Vision Applications* 19:467-482.

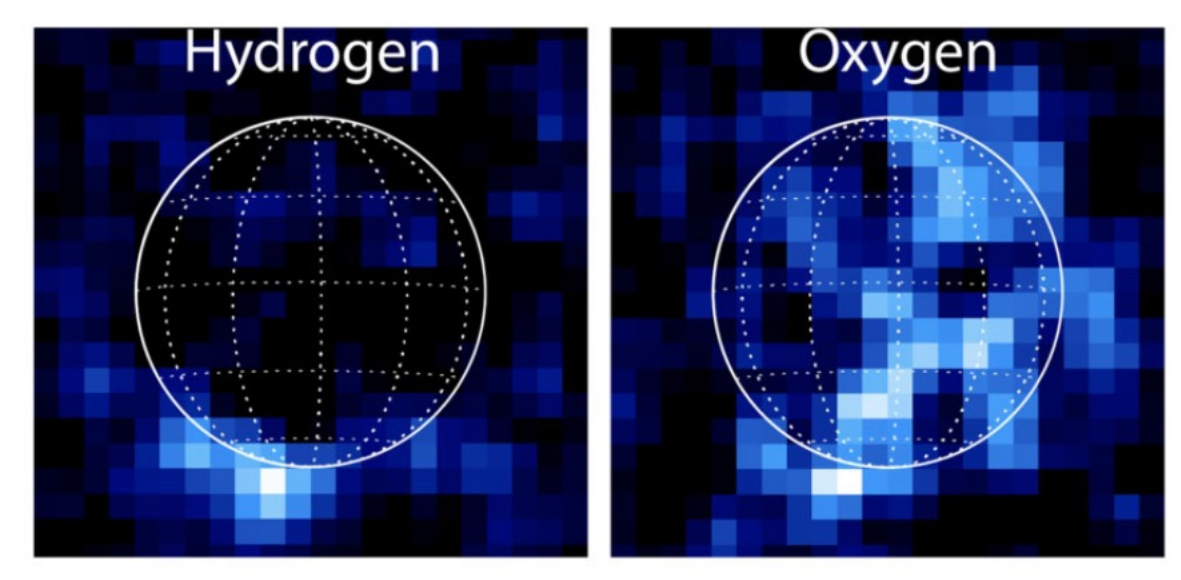
Jupiter’s moon Europa: Up to 1 light-hour from Earth!



Europa Clipper flyby simulation

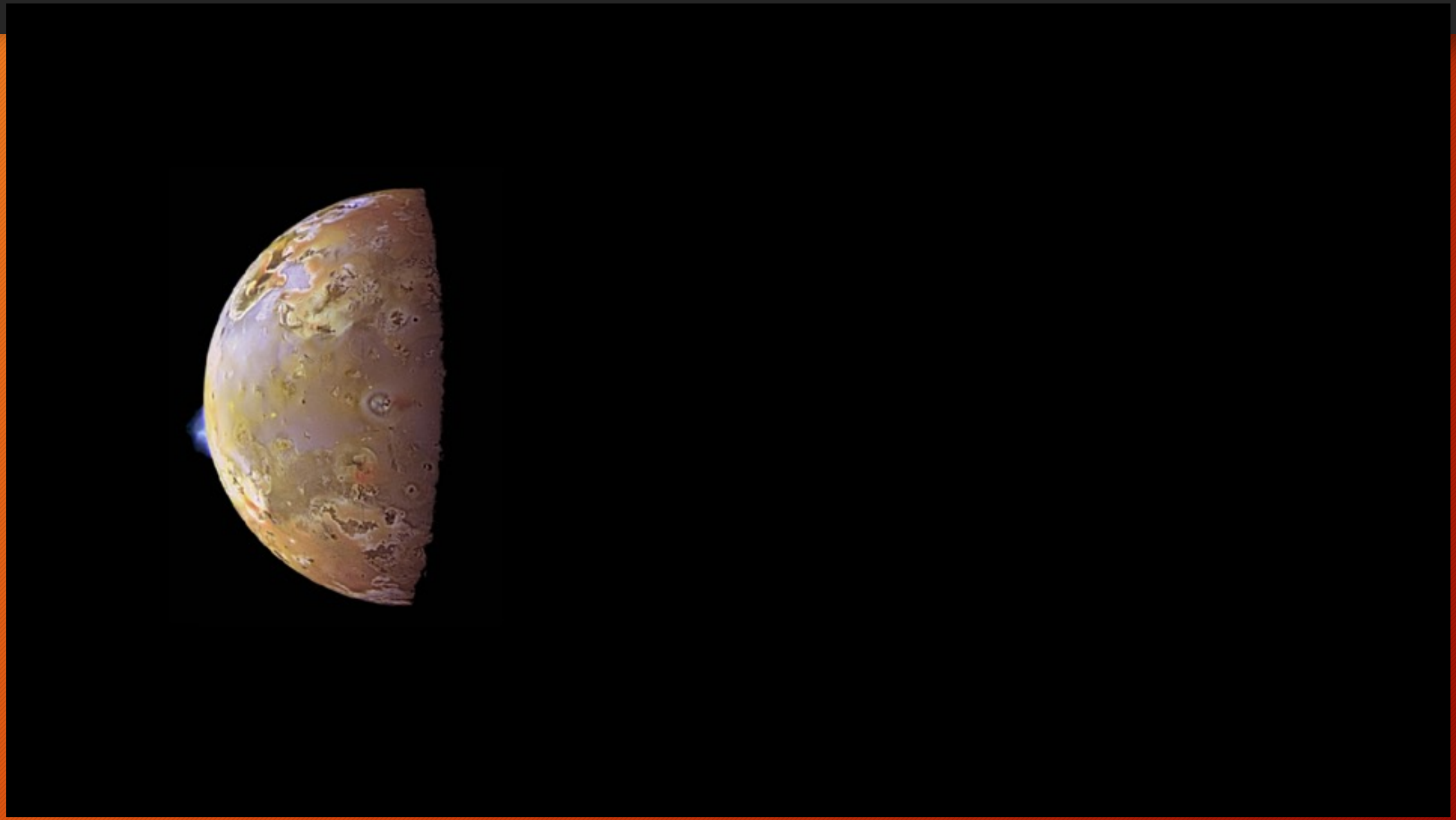
Could Europa have icy plumes?

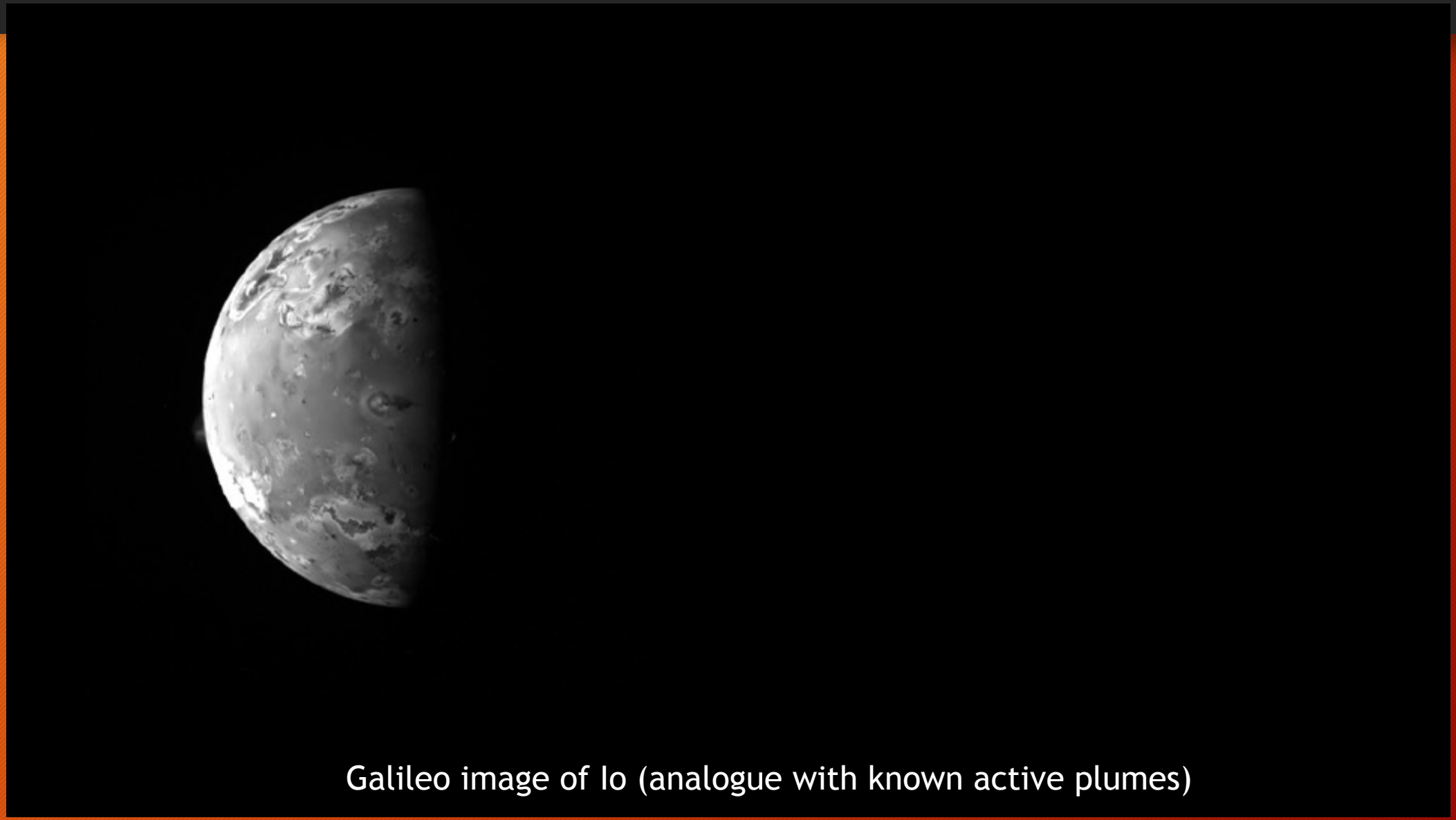
- Tantalizing observation from 2014 using Hubble Space Telescope



[Roth *et al.*, 2025]

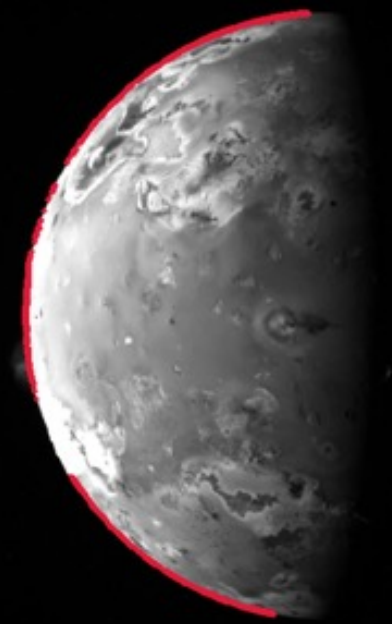
- What will we see up close?





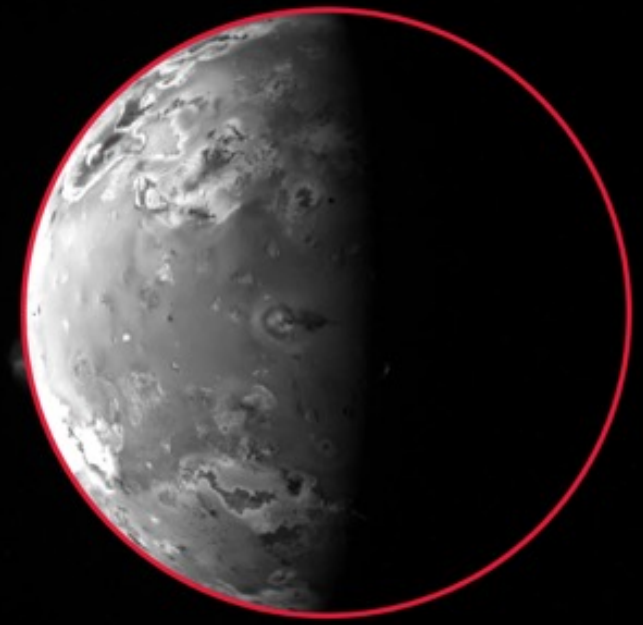
Galileo image of Io (analogue with known active plumes)

Step 1: Detect Edges



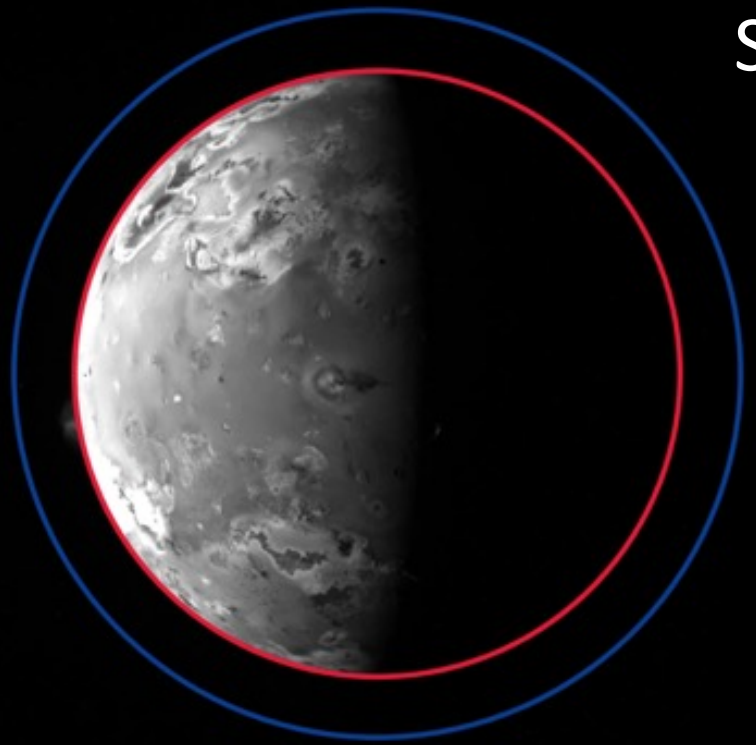
Galileo image of Io (analogue with known active plumes)

Step 2: Fit Limb Model



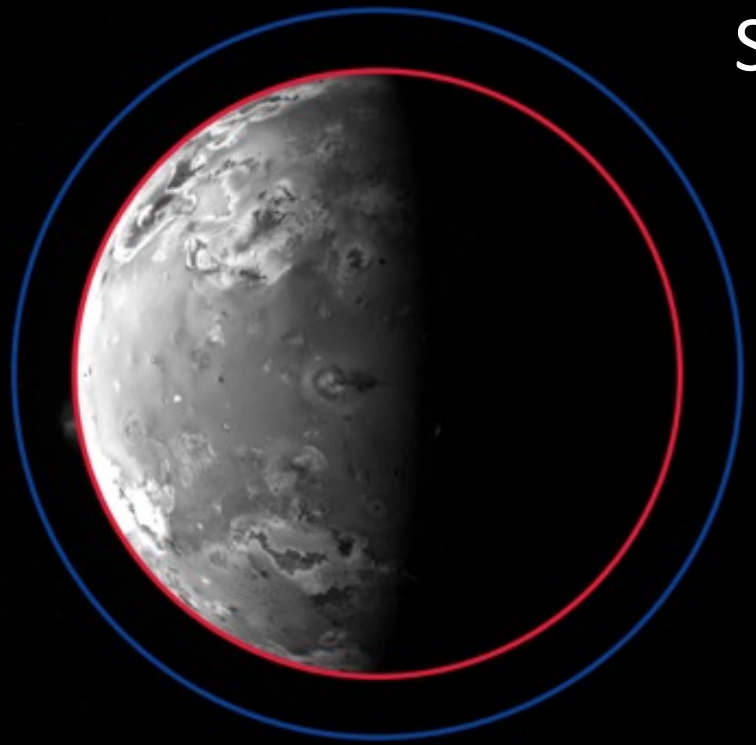
Galileo image of Io (analogue with known active plumes)

Step 3: Search within annulus



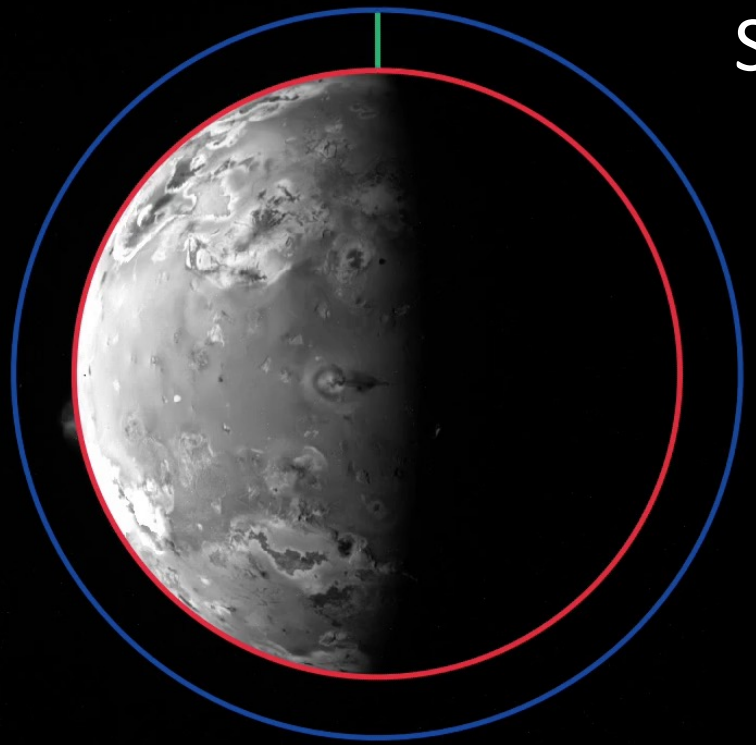
Galileo image of Io (analogue with known active plumes)

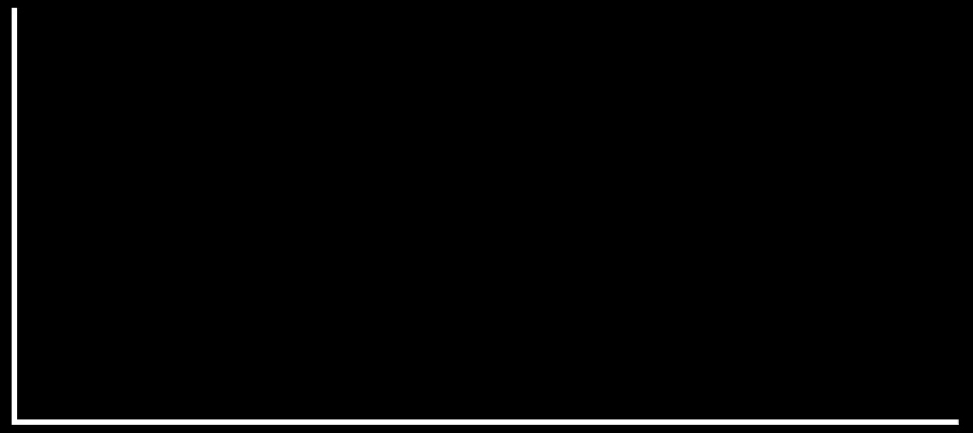
Step 3: Search within annulus



Galileo image of Io (analogue with known active plumes)

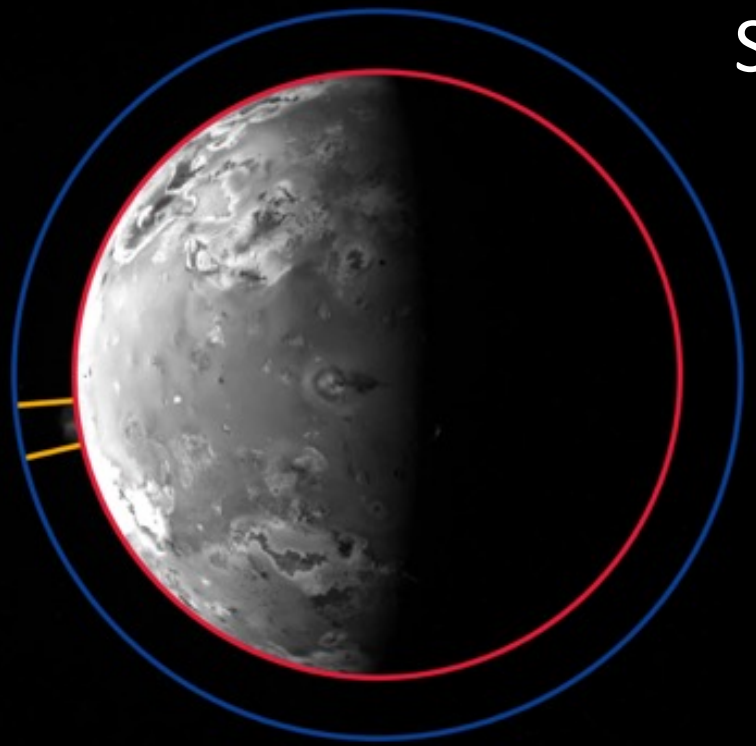
Step 3: Search within annulus

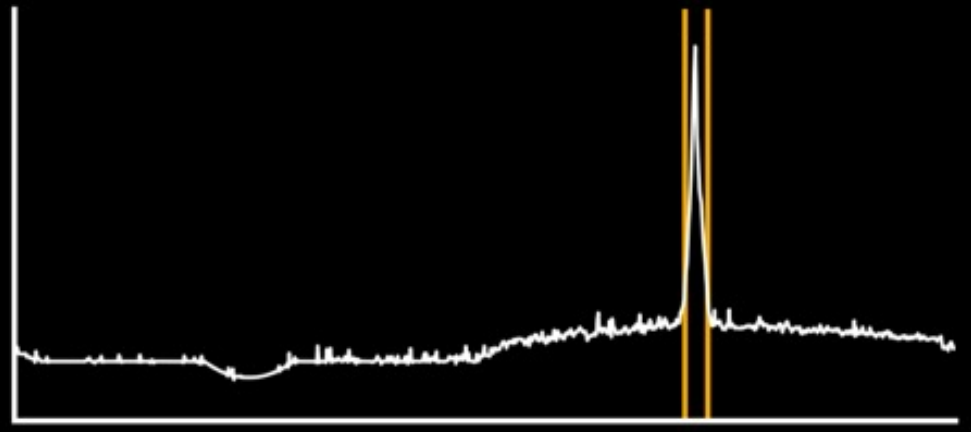




Galileo image of Io (analogue with known active plumes)

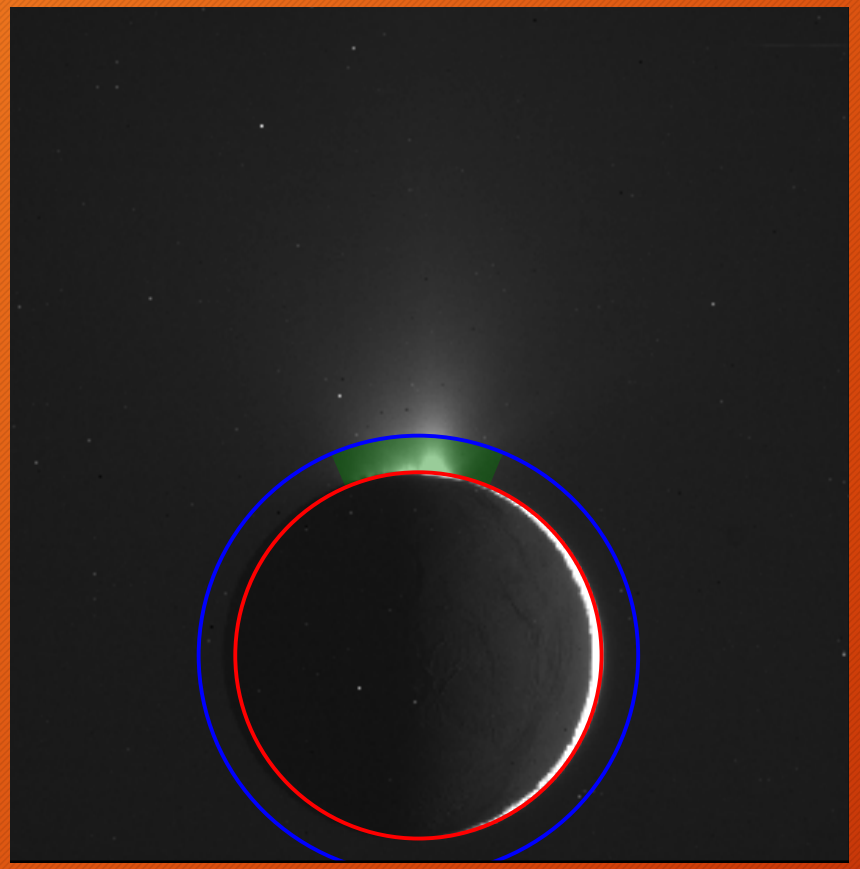
Step 4: Find peaks in intensity

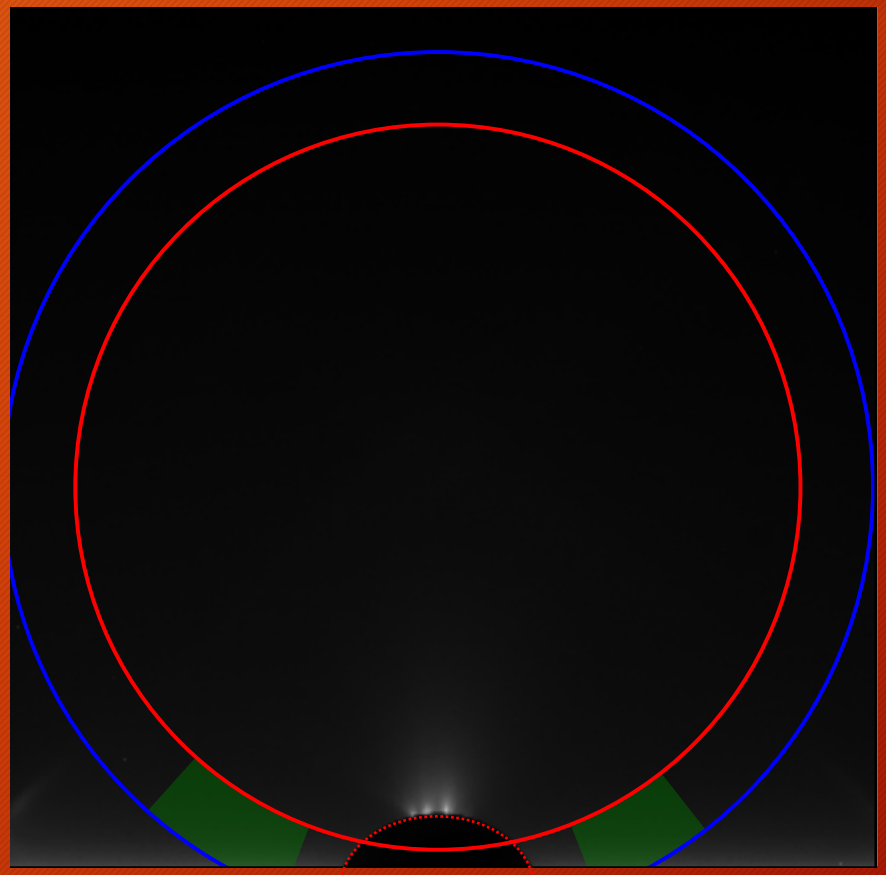




Galileo image of Io (analogue with known active plumes)

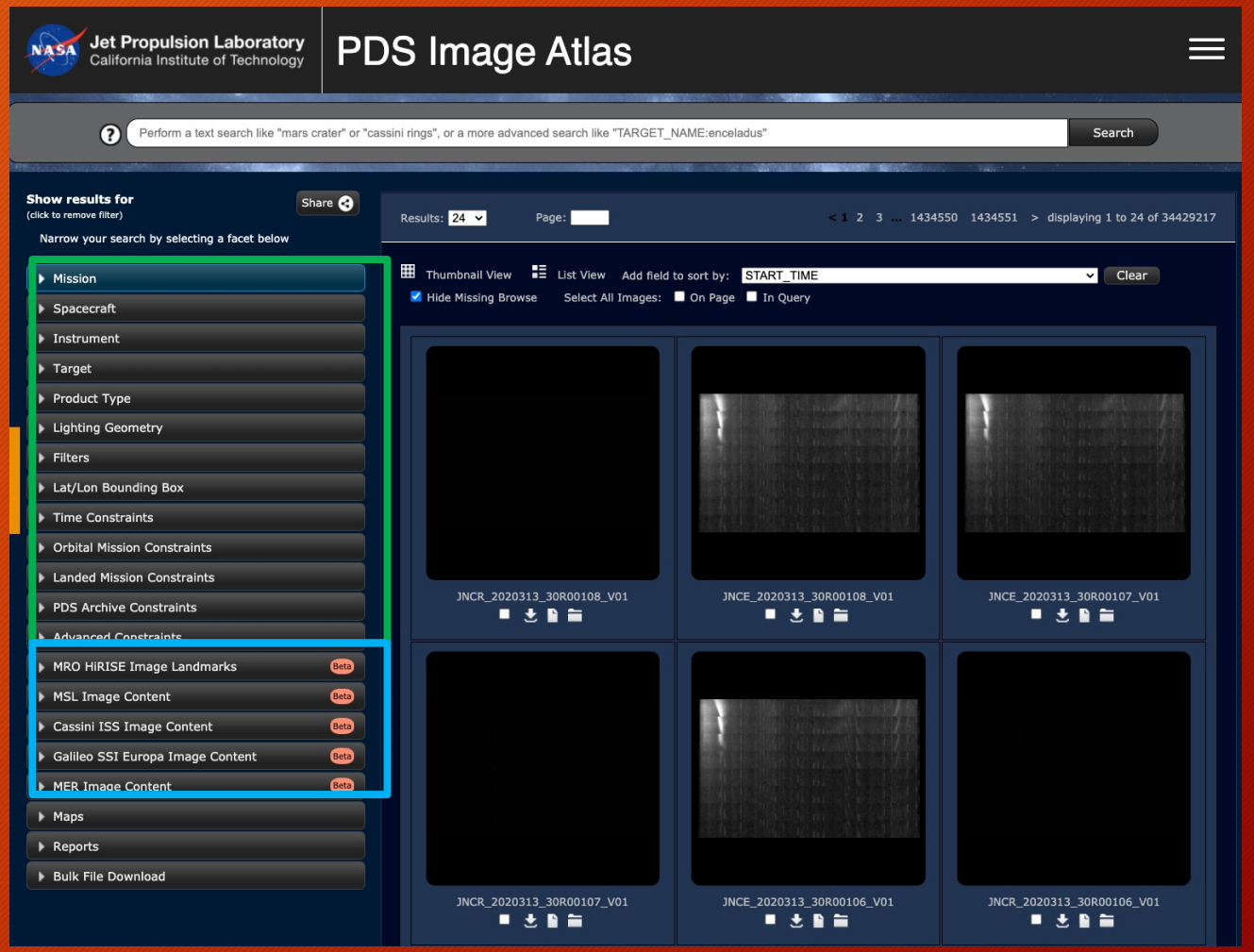
Plumes from Enceladus (moon of Saturn)





2. Use AI to understand what's in our data archives

- You can search NASA images by specifying *prior* info
  (prior = known before image is collected)
  - Mission
  - Instrument
  - Target
  - Location
  - Time / orbit number
- You want to search by *content*
  (only known after image is collected)
  - Crater, dune, impact, streak, …
  - Layers, sand, drill hole, sky, …



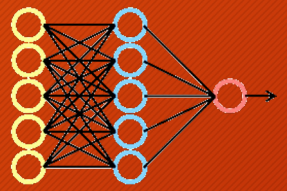
http://pds-imaging.jpl.nasa.gov/search/

Machine learning for image content annotation

- Transfer learning: "Fine-tune" a neural network trained on Earth images to work on Mars images
- Deployed on >1M Mars rover images

ImageNet data set
[Russakovsky et al., 2015]

Train

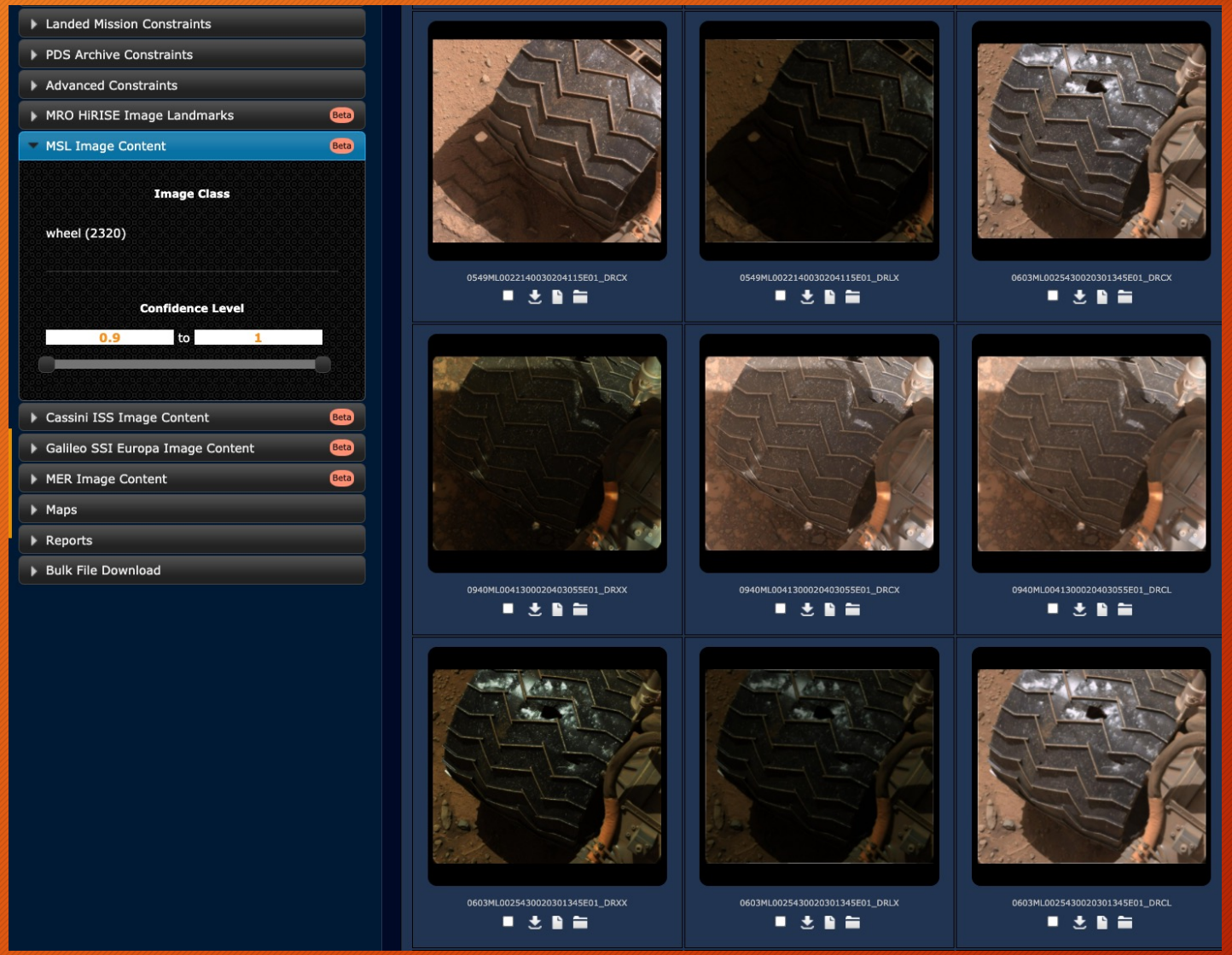


Transfer

[Wagstaff et al., *IAAI* 2018; 2021]

PDS image search for “wheel”

http://pds-imaging.jpl.nasa.gov/search/



Kiri Wagstaff

Steven Lu

Kevin Grimes

Gary Doran

Thamme Gowda

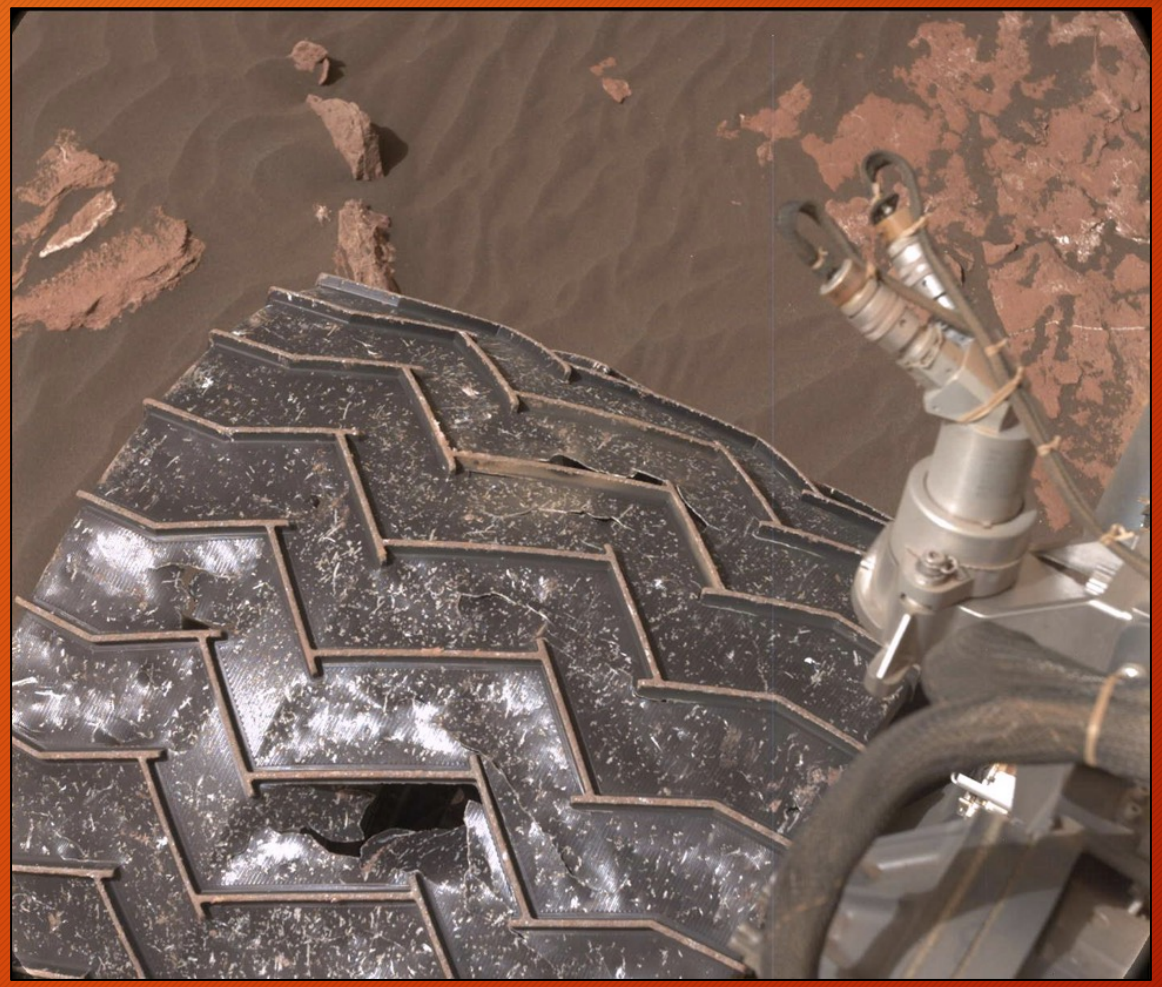
Emily Dunkel

August 2012

December 2013

http://pds-imaging.jpl.nasa.gov/search/

November 2016



http://pds-imaging.jpl.nasa.gov/search/

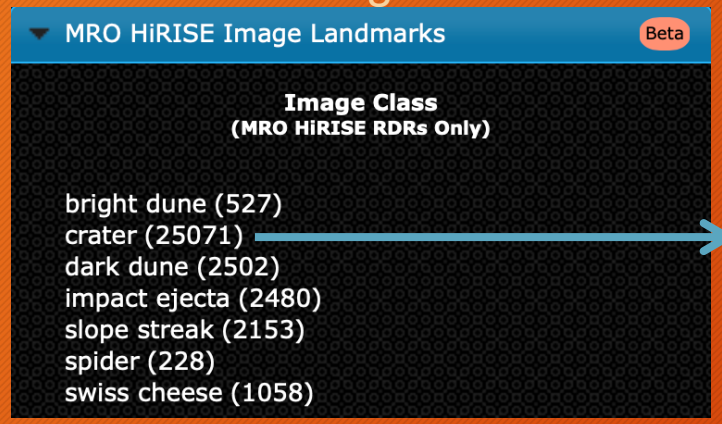
March 2020

http://pds-imaging.jpl.nasa.gov/search/

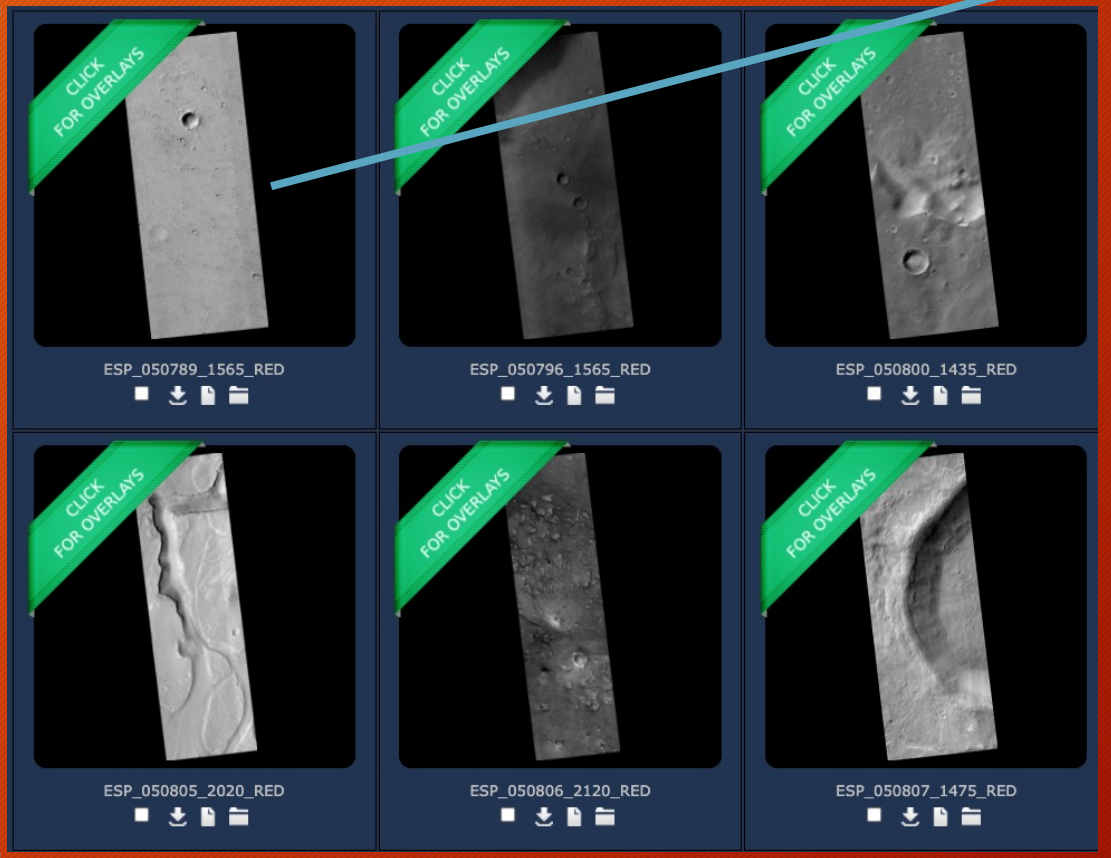
It works for orbital images, too

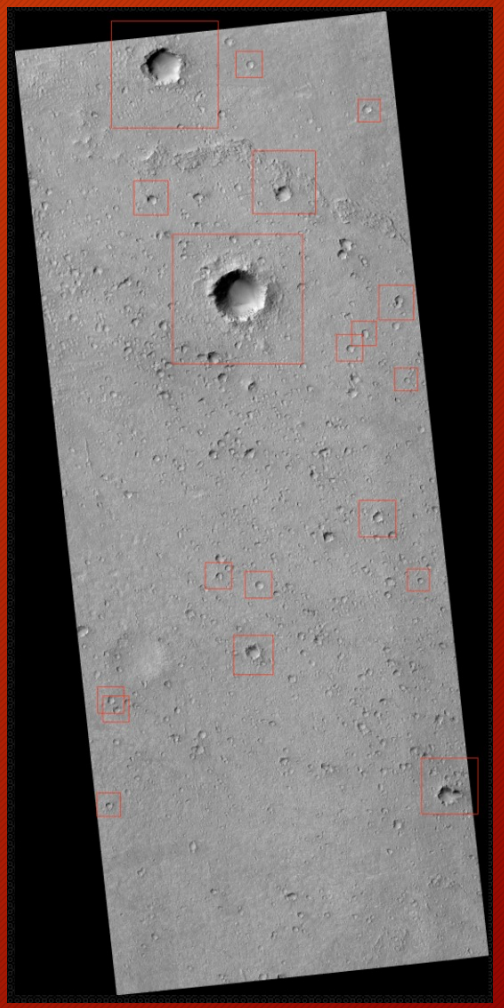
- E.g., search for images containing craters
- Shows landmarks with >= 0.9 probability
- Landmarks are localized

PDS Image Atlas

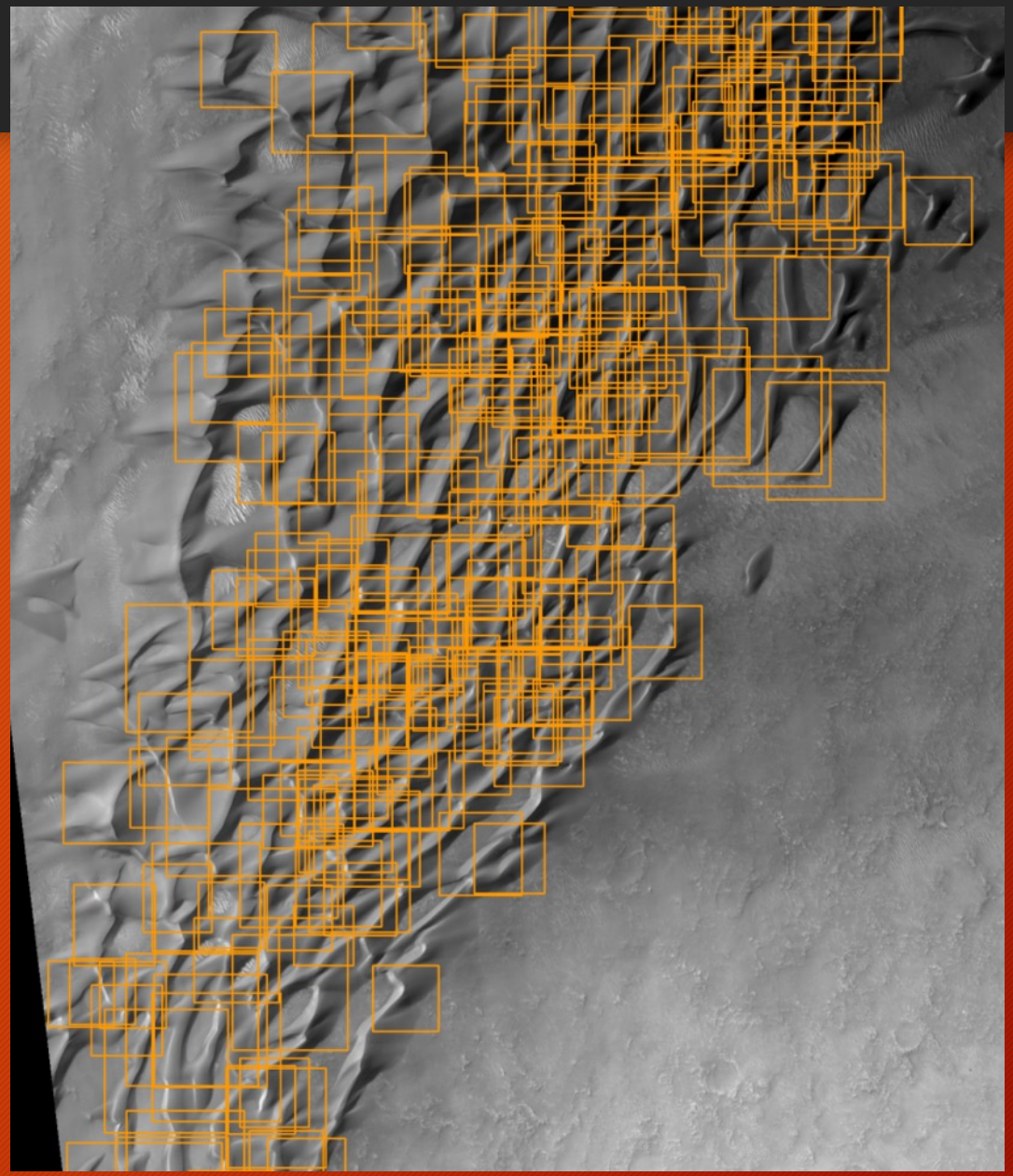


First 6 results from “crater” search

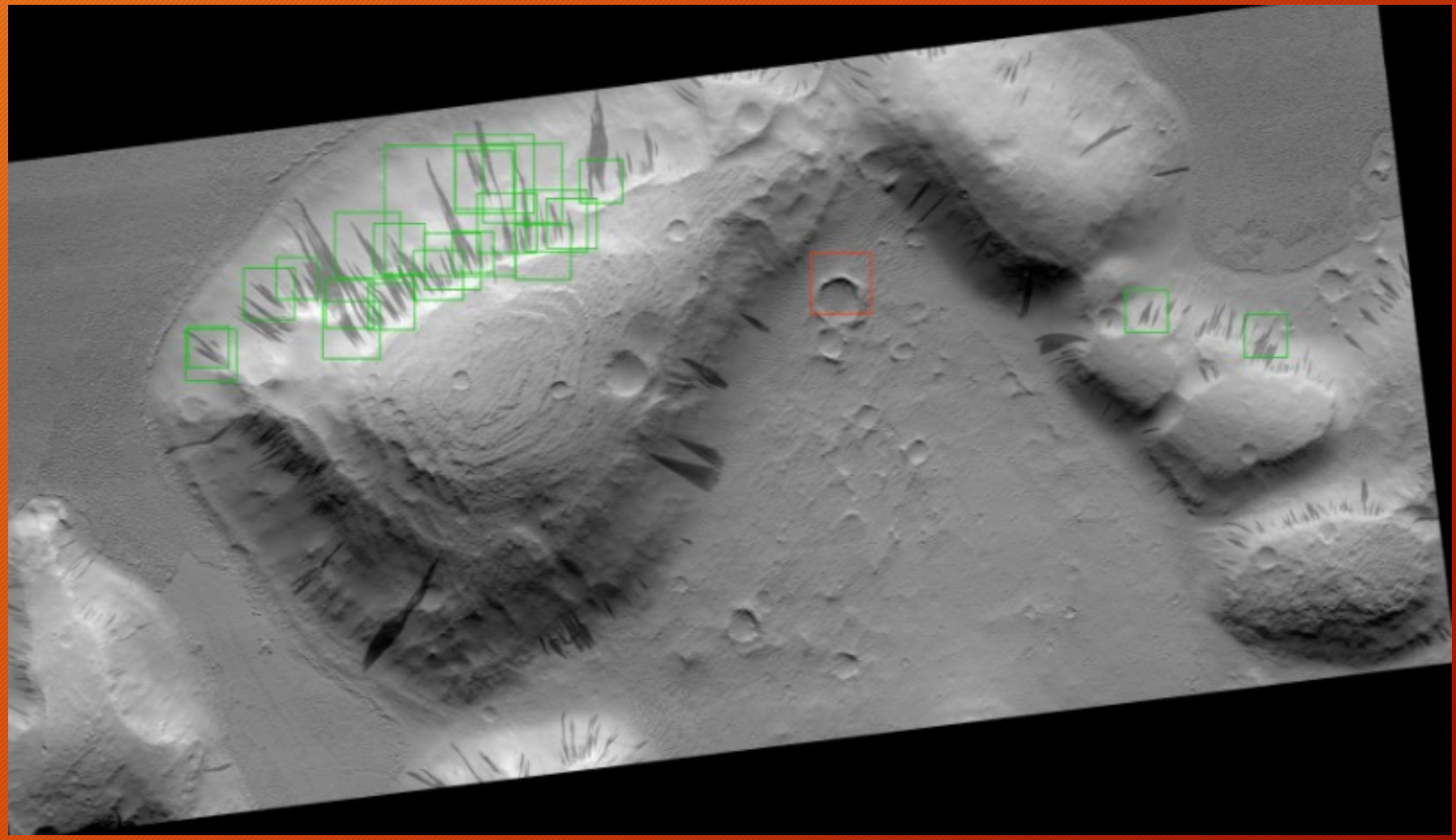




Dark dunes

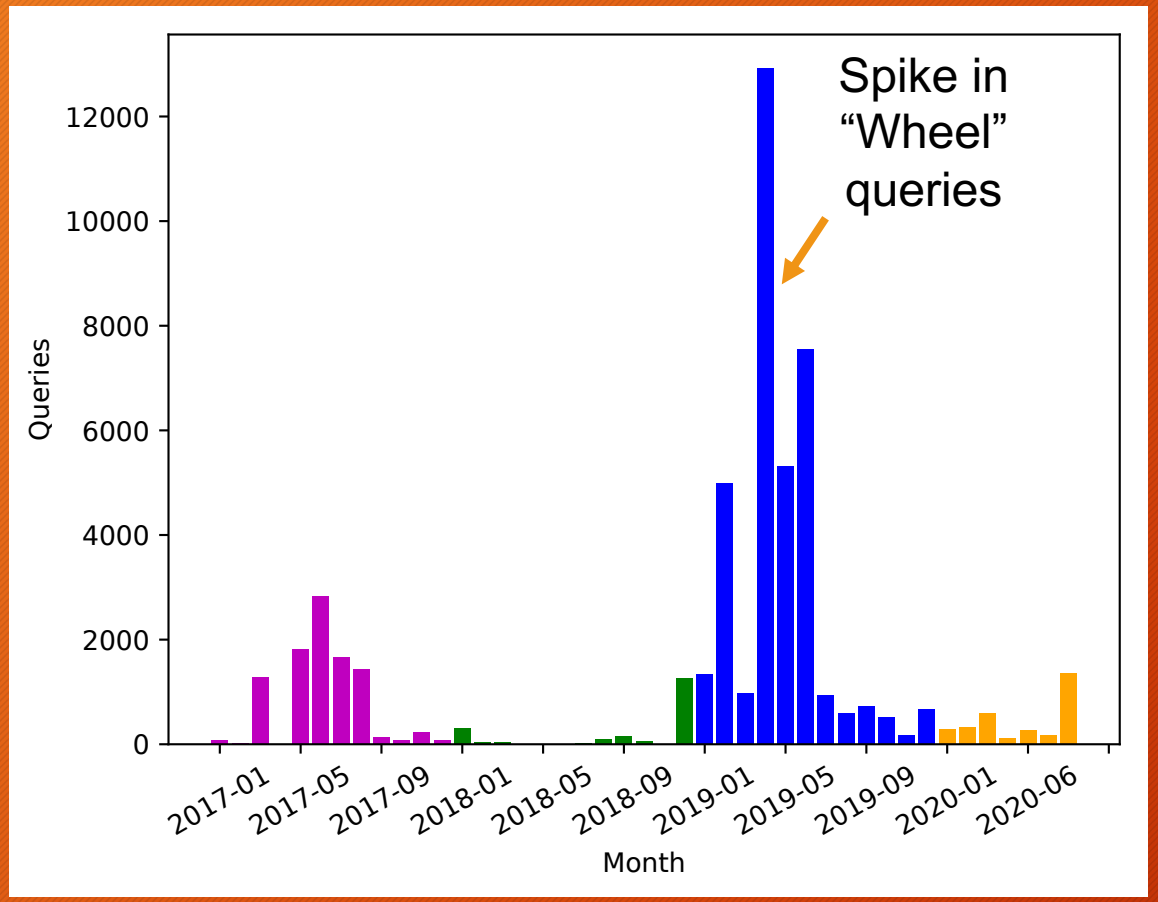


Dark slope streaks

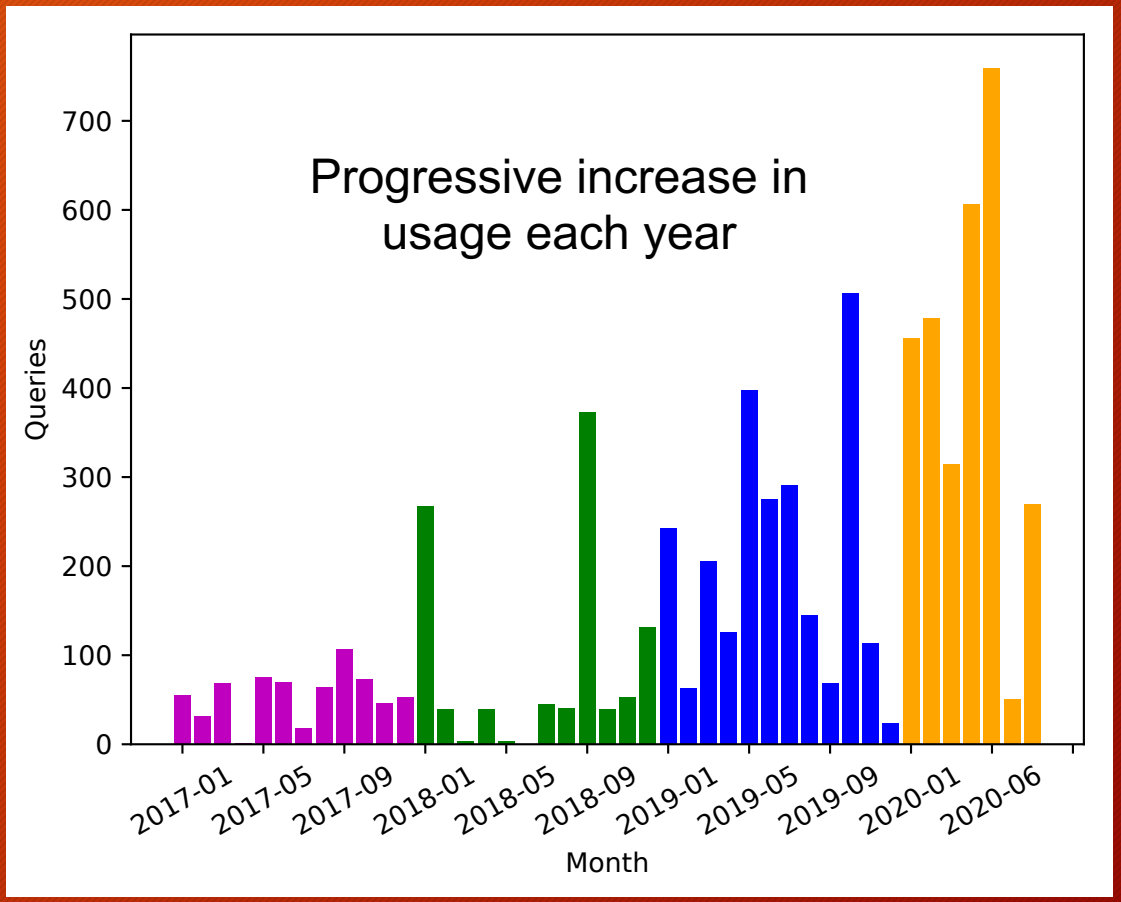


Content-Based Searches Over 3.5 Years

MSL (rover)



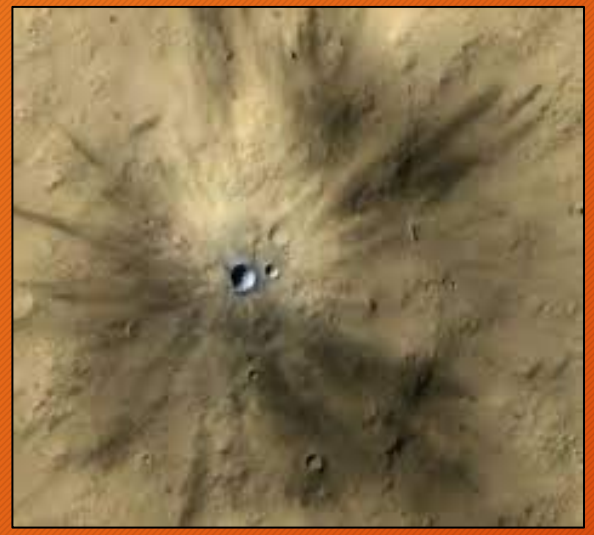
HiRISE (orbiter)



(Color-coded by year)

3. Use AI to search an entire planet

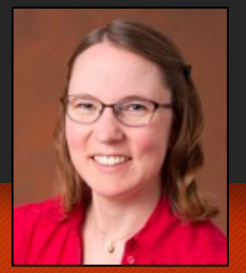
- Mars orbital images show evidence of recent meteorite impacts on Mars



Credit: NASA/JPL-Caltech/MSSS/UA

Credit: NASA/JPL-Caltech/UA

- ~1000 have been manually catalogued
- Previous orbital image classifier uses HiRISE data; this covers only ~3% of the planet
- To find more, we need an image classifier for CTX (global) data



Kiri Wagstaff

Ingrid Daubar

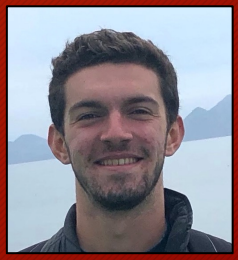
Michael Munje

Gary Doran

Valentin Bickel

Joe Pate

Annabelle Gao



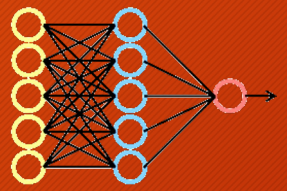
Daniel Wexler

Fresh impact image classifier

- Transfer learning: "Fine-tune" a neural network trained on Earth images to work on Mars images
- Deployed on 12 TB of Mars orbiter images

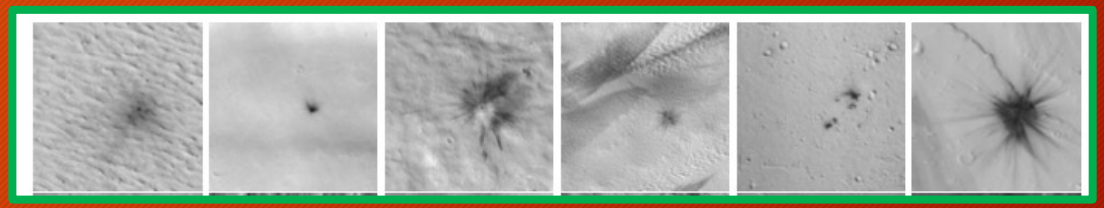
ImageNet data set
[Russakovsky et al., 2015]

Train

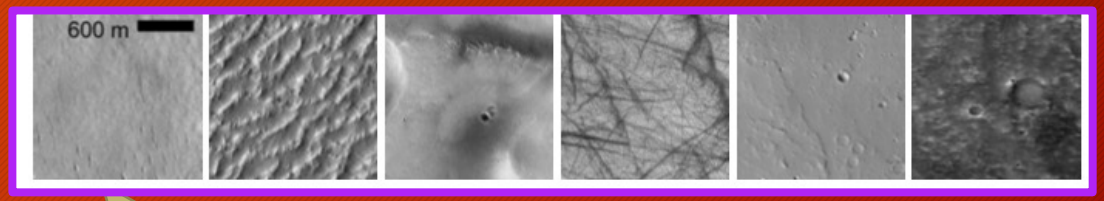


Transfer

Fresh impacts



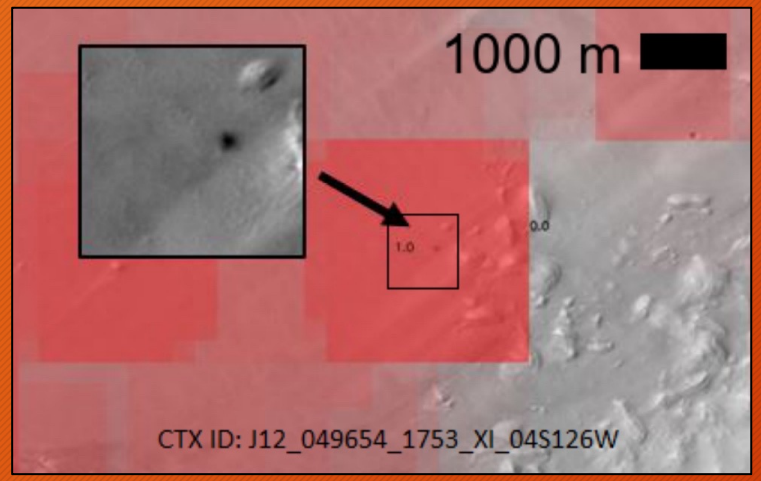
Not impacts



[Wagstaff et al., *Icarus* 2022]

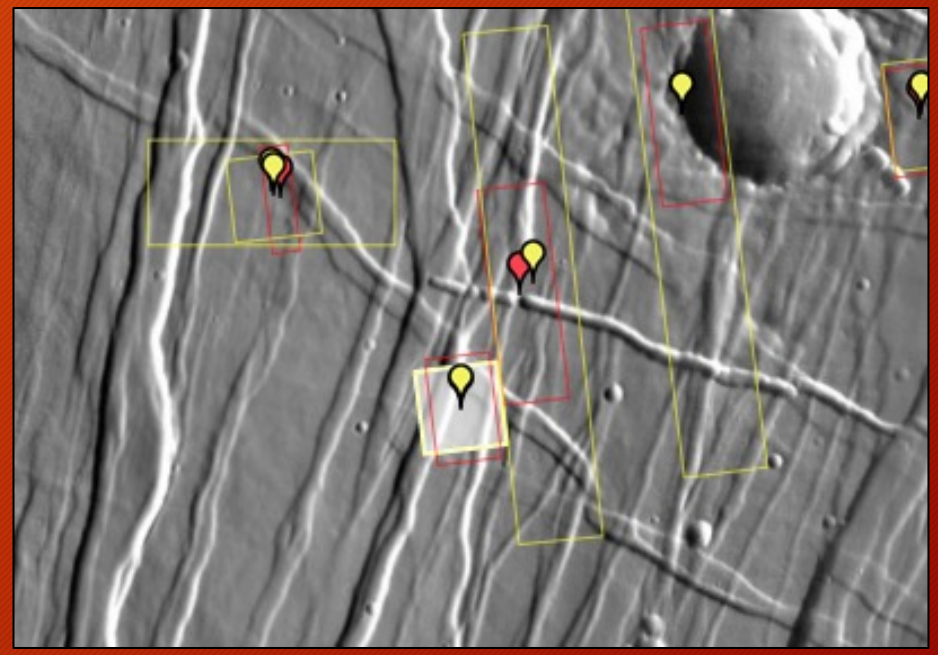
Hunting for new Mars impacts

- Slide classifier window over global Mars images
  - 2 billion classifications
  - A cluster of ~500 CPUs took a week (~5 sec/image)
  - Manual hunt (40 min/image) would require ~8.5 person-years (no breaks!)



[Munje et al., 2020]

https://www.uahirise.org/hiwish/



- Possible new impact? Request high-resolution image with HiWish!

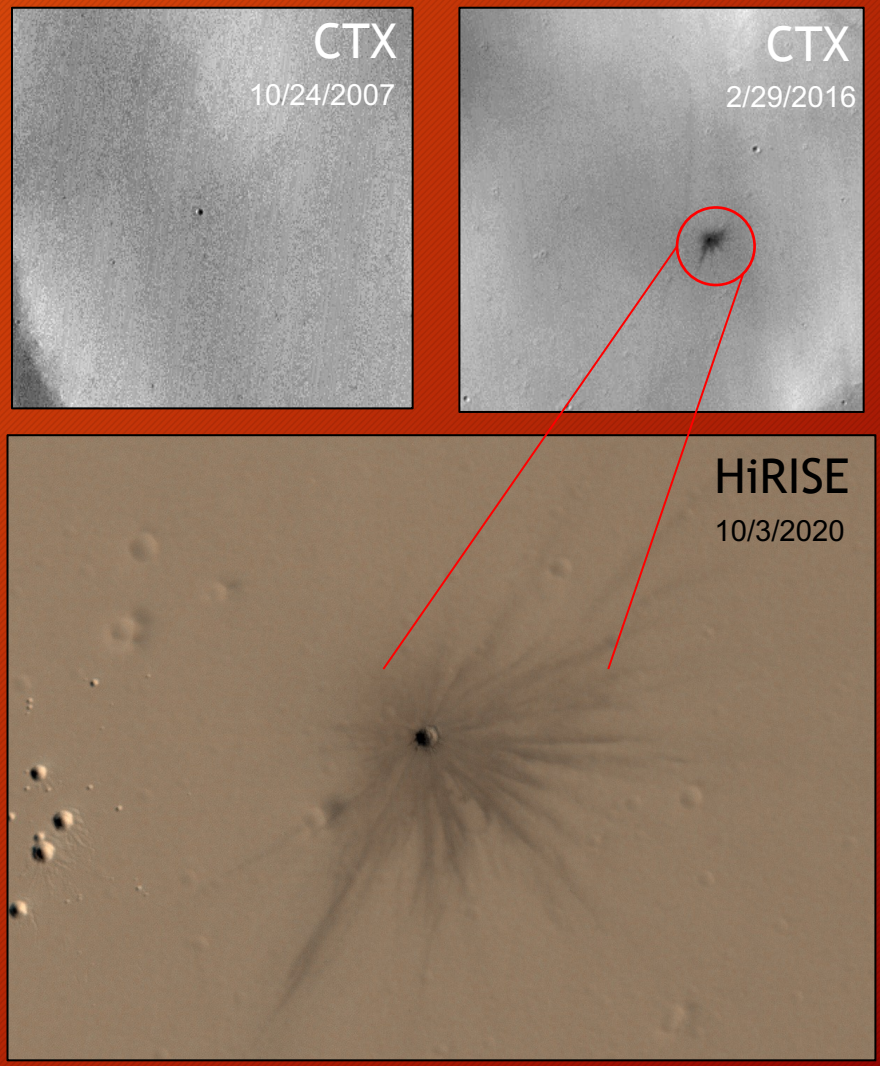
New Mars impact discoveries

Noctis Fossae

CTX: 6 m/pixel

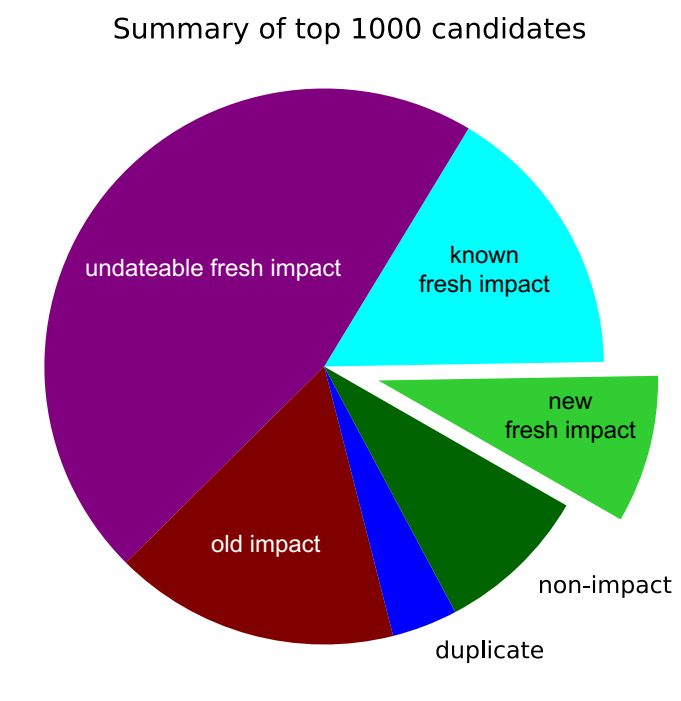
HiRISE: 0.3 m/pixel

Noctis Labyrinthus



70+ new Mars impact discoveries

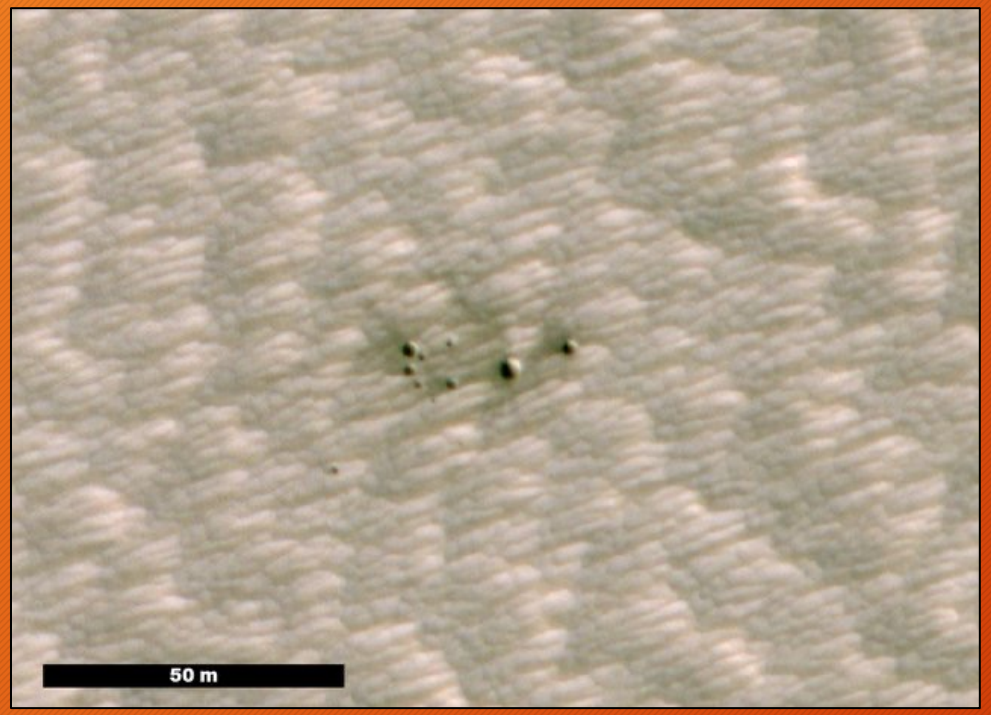
- >1,000,000 candidates with P(impact) >= 0.99
- Group by location and time, then manually review the top 1000 (by probability)
  - New impact? Request high-resolution image with HiWish



- 99 already known (confirmation)
- 69 new discoveries
- 465 are impacts without a “before” image (undateable)
- 166 old impacts
- Only 90 (9%) non-impacts

Where's the generative AI?

1. Can it annotate image content? (E.g. Image caption generation)



Please generate a caption for this image of the Martian surface.

ChatGPT:

Caption:

High-resolution image of the Martian surface captured by NASA's HiRISE camera aboard the Mars Reconnaissance Orbiter, showing the landing site of the Curiosity rover in Gale Crater. The dark spots and streaks mark the descent stage impact and the rover's touchdown area on the patterned surface of Mars. Scale bar: 50 meters.

We want to know what's out there, not what *could* be out there (great for sci-fi stories, but not for science)

- Generative AI creates a common / likely caption, not an accurate one

Where's the generative AI?

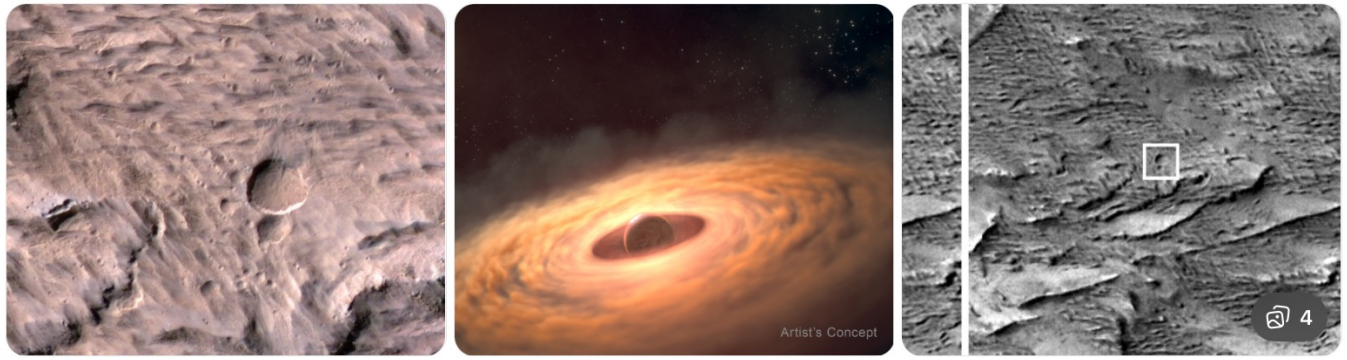
2. Can it find the fresh impact craters?

Find me all the fresh impact craters on Mars.

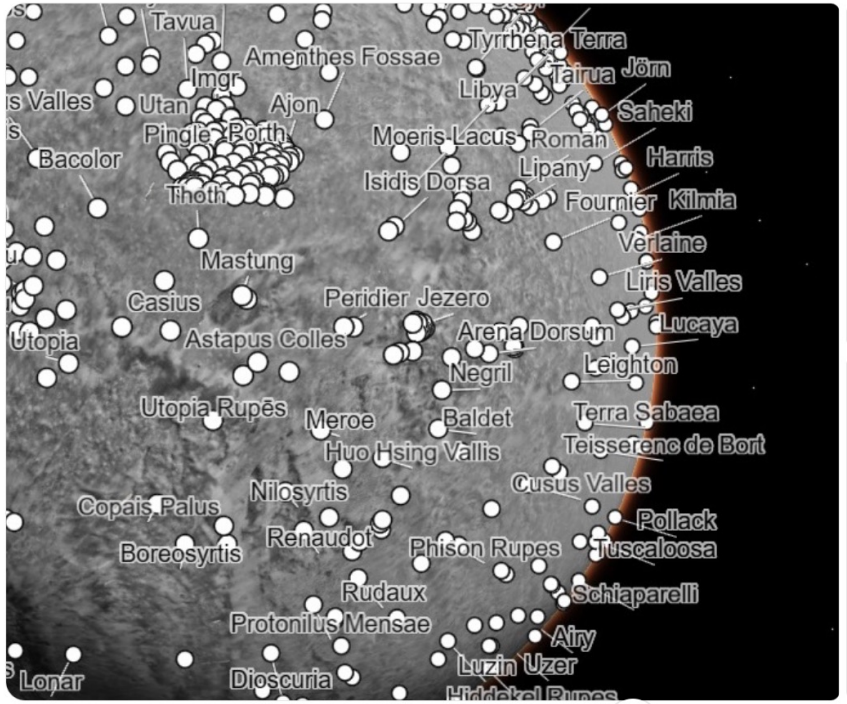
ChatGPT:

🔍 **Some example "fresh" craters**

1. **~48.5 m diameter crater**: Located at ~3.34° N, 219.38° E, formed between March 27–28, 2012.



Here is a **map-view of fresh impact craters on Mars**:



3. More relevant: generative techniques for spacecraft design, hypothesis generation, etc.

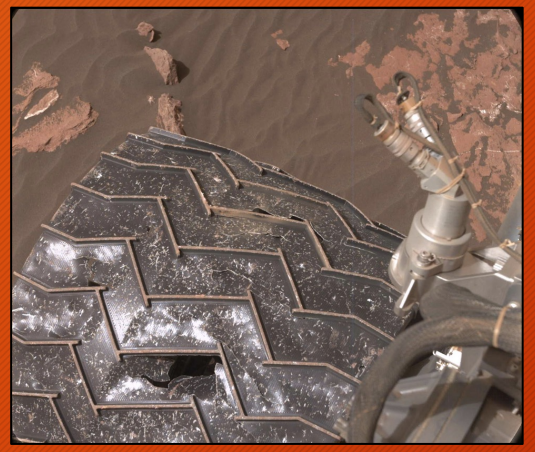
Actual caption: These labels show *named geographic features* on Mars. Someday, people from Earth will visit these places! Image via NASA/ JPL-Caltech/ MSSS.

So: How can AI help us explore and understand the universe?

- Classification and discovery methods help accelerate science

Detect events of interest (e.g., dust devils!) onboard a rover or orbiter

Classify and annotate large data archives to enable content-based search



Quickly scan global data sets for features of interest (fresh impacts)

- ML leverages, but does not replace, human expertise
  - Human review is a key part of this process (and it takes time and effort!)
  - ML/AI can focus attention where it is most likely to pay off

Contact: wkiri@wkiri.com