

## Motivation of Content-Based Search

Images collected by NASA planetary science missions are curated by the Cartography and Imaging Sciences Discipline Node (Imaging Node) of the Planetary Data System (PDS). These holdings currently include more than 39.3 million products that span 22 missions, with targets that include Mars, the Moon, Mercury, Jupiter, Saturn, Venus, and more. Some example Mars surface images taken by the Curiosity rover of Mars Science Laboratory (MSL) mission are shown in Figure 1.

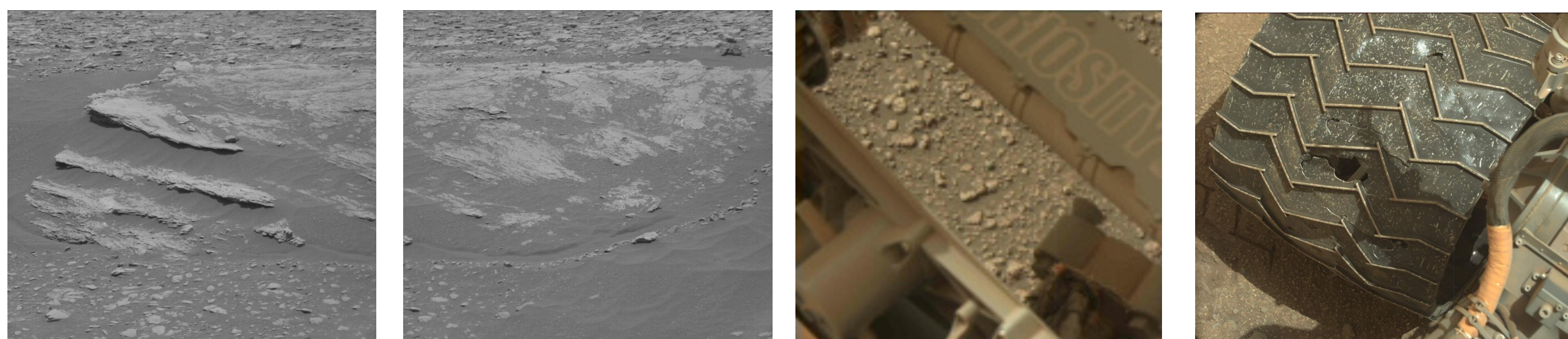


Figure 1. Example Mars images taken by the Curiosity rover of Mars Science Laboratory Mission.

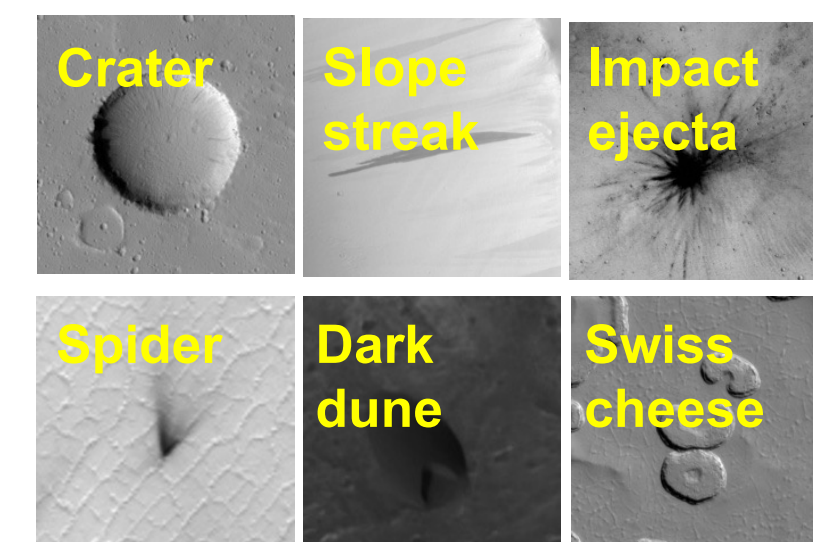
**Problem:** How to effectively find images of interest from 39.3 million images archived at the PDS Imaging Node? For example, how to find images taken by the Curiosity rover of MSL mission that contain wheels (the right-most image shown in Figure 1).

**Solution:** Content-based image classification to quickly find images of interest.

## 1. Machine Learning Classifiers

**HiRISENet:** CNN Classifier for Mars Orbital Images

**HiRISENet** (Wagstaff et al., 2021) was created to classify images collected by the High Resolution Imaging Science Experiment (HiRISE) camera onboard the Mars Reconnaissance Orbiter (MRO) mission.



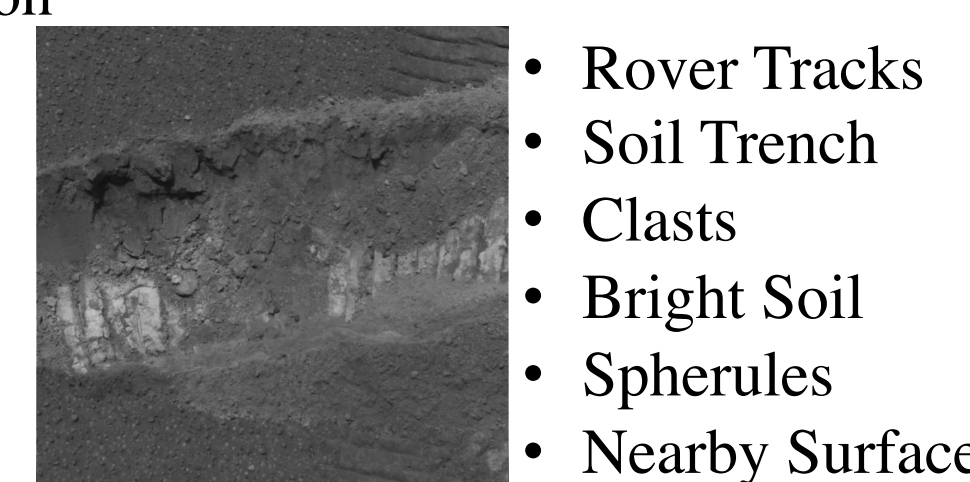
**MSLNet:** Hybrid Classifier for Mars Surface Images

**MSLNet** (Wagstaff et al., 2021) was created to classify images collected by the Mast Camera (Mastcam) and Mars Hand Lens Imager (MAHLI) instruments mounted on the Mars Science Laboratory (MSL) mission's Curiosity rover.



**MERNet:** Ensemble Classifier for Mars Surface Images

**MERNet** (Lu et al., 2022) was a multi-label convolution neural network (CNN) that classifies images collected by the Panoramic Camera (Pancam) instrument mounted on Mars Exploration Rover (MER) mission's Spirit and Opportunity rovers. MERNet is an ensemble of 5 CNN classifiers.



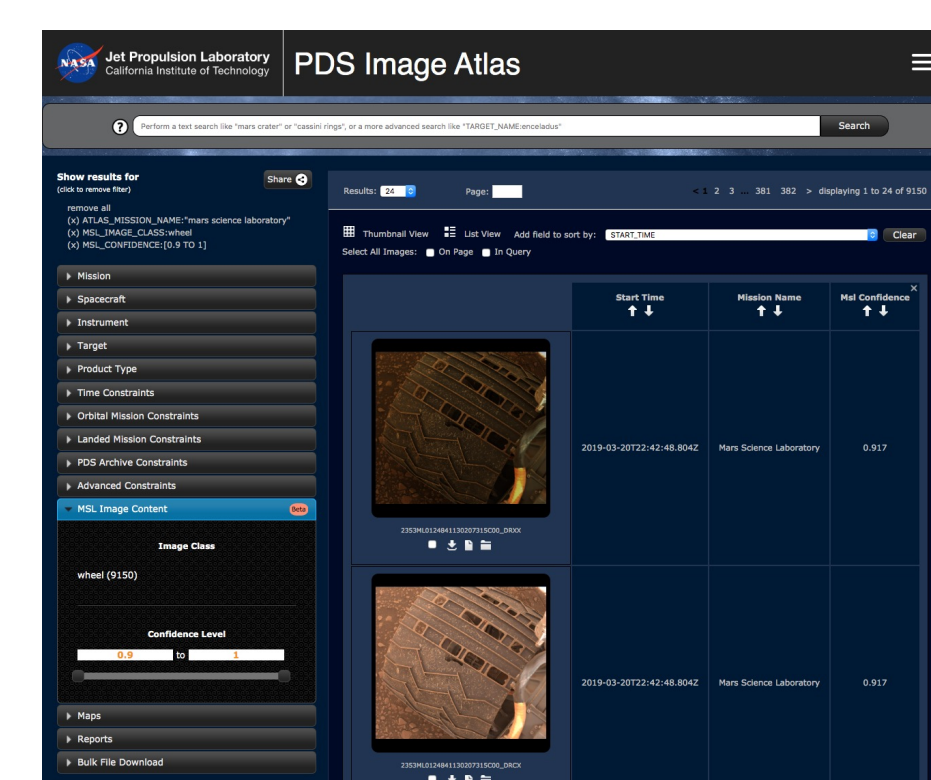
**Early work:** Cassini and Galileo Classifiers

The **Cassini** classifier (Stanboli et al., 2017) was created for classifying images collected by the ISS instrument from the Cassini orbiter. The **Galileo** classifier was created to classify Europa images collected by the SSI instrument from the Galileo orbiter.

**Ongoing work:** LROC and Mars 2020 classifiers  
For more information about the Lunar Reconnaissance Orbiter Camera (LROC) classifier, please check [AGU poster 109717](#).

## 2. PDS Image Atlas

- High confidence classification results are deployed on the PDS Image Atlas.
- The PDS Image Atlas provides unique capabilities for users to find data of interest.
  - Support metadata-based search
  - Support content-based search
- The PDS Image Atlas is publicly accessible at URL <https://pds-imaging.jpl.nasa.gov/search>
- The next generation PDS Image Atlas will be launched soon

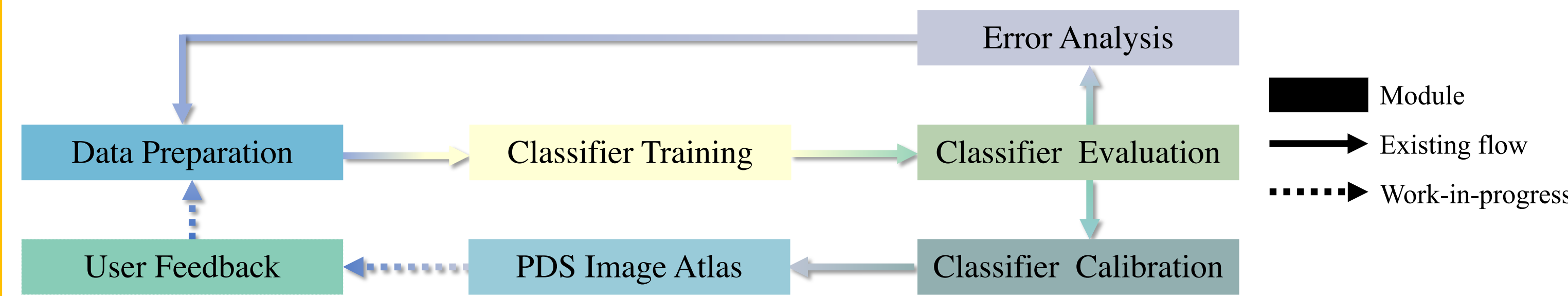


### MSL rover wheel degradation over time



## 3. Machine Learning Techniques

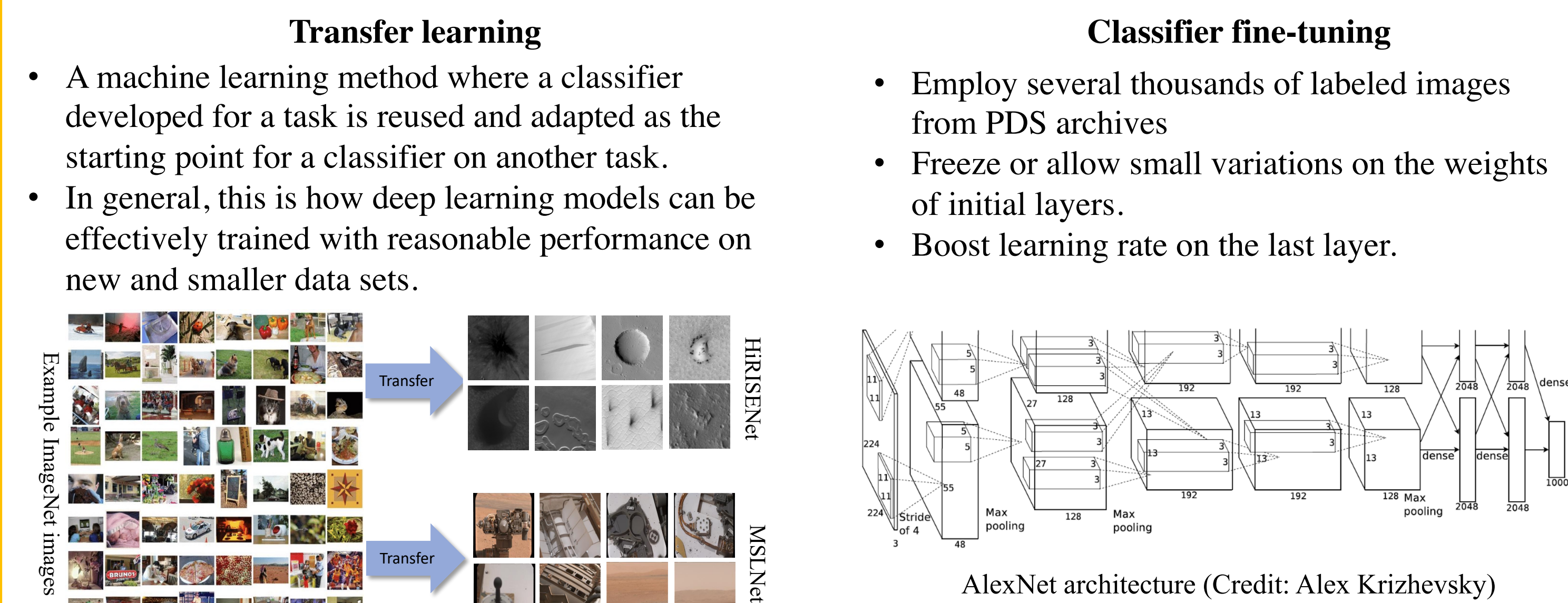
### Machine Learning Pipeline Overview



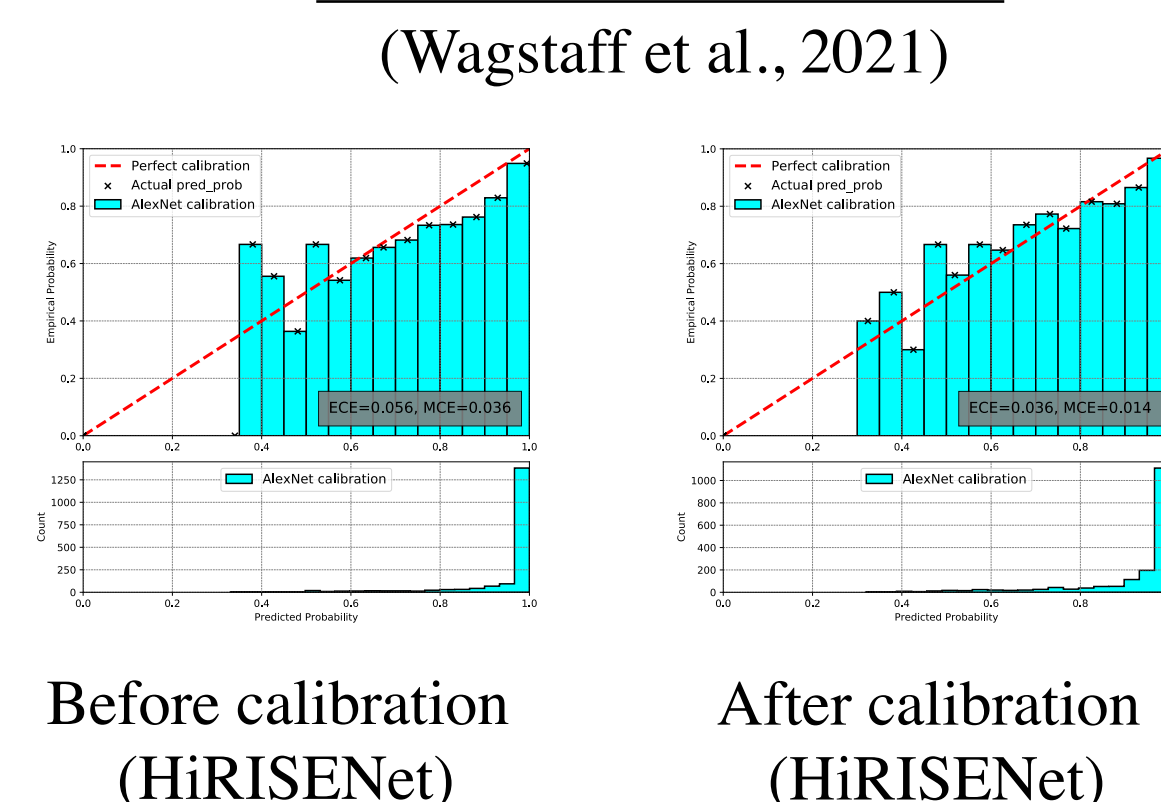
### Machine Learning Data Preparation



### Classifier Training



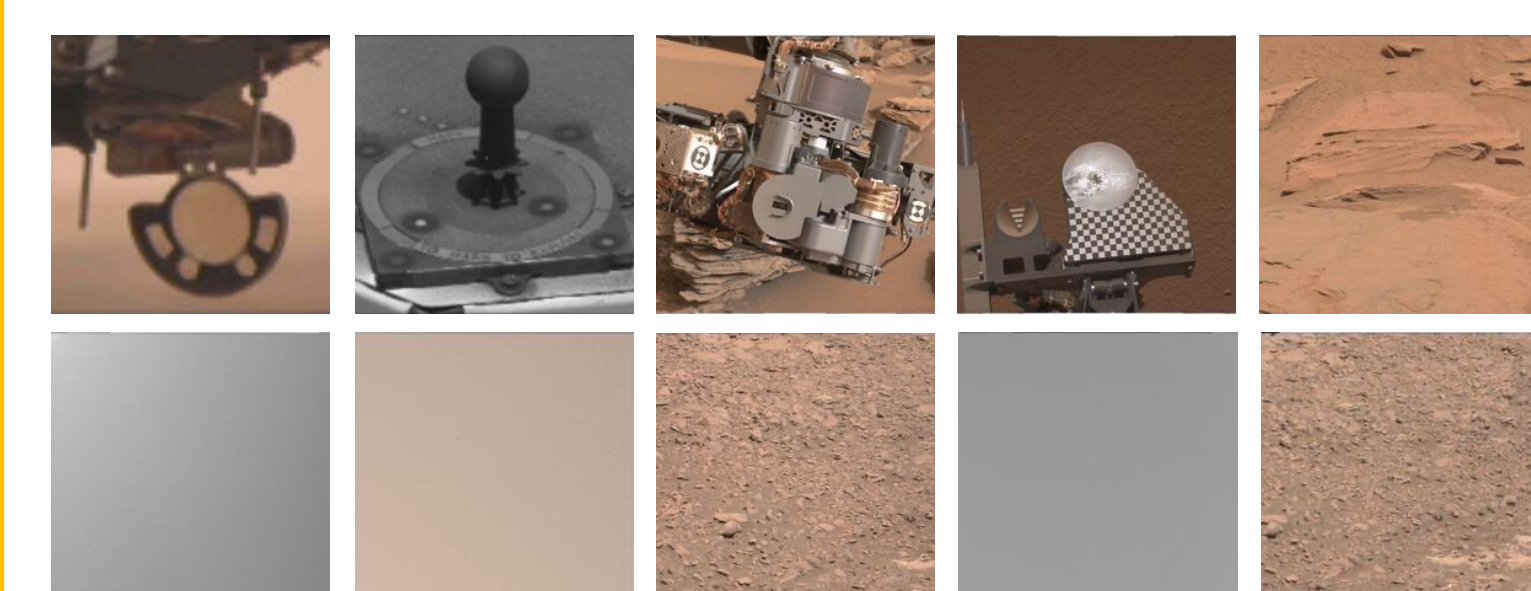
### Classifier Calibration



### Data driven image labeling approach

(Wagstaff and Lu, 2020)

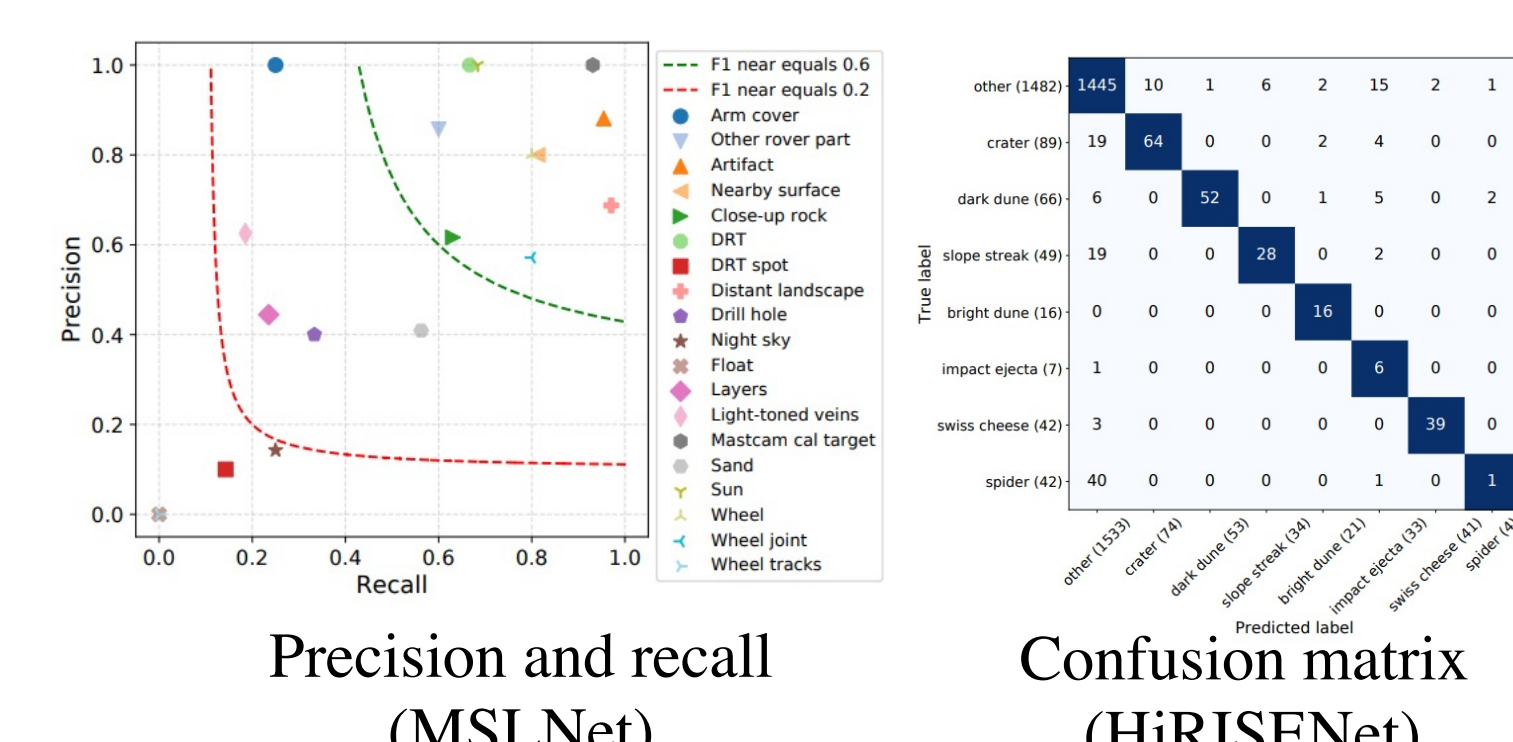
Employed DEMUD (Wagstaff et al., 2013) to incrementally select the most interesting or novel images to label.



Top row: 5 **most** novel MSL images selected by DEMUD  
Bot row: 5 **least** novel MSL images selected by DEMUD

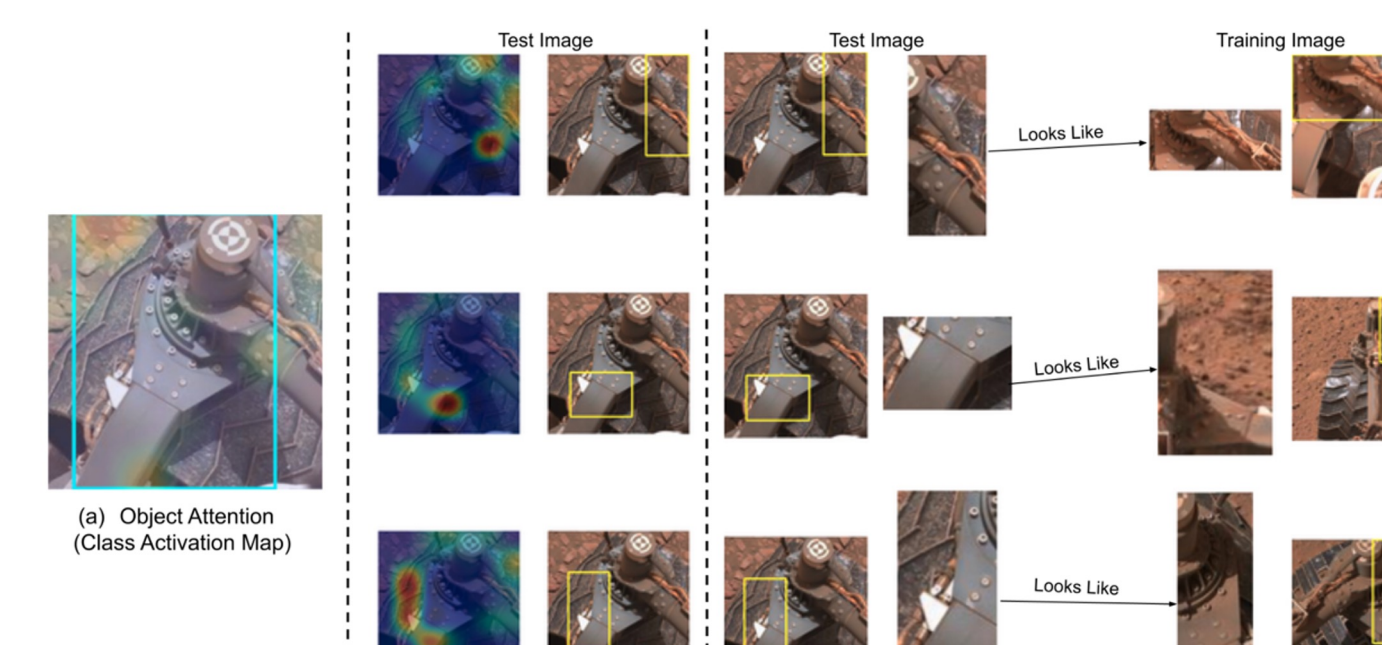
### Classifier Evaluation

(Wagstaff et al. 2021)



### Classifier Explainability

Employed ProtoPNet architecture (Chen et al., 2019) to explain MSLNet classification results.

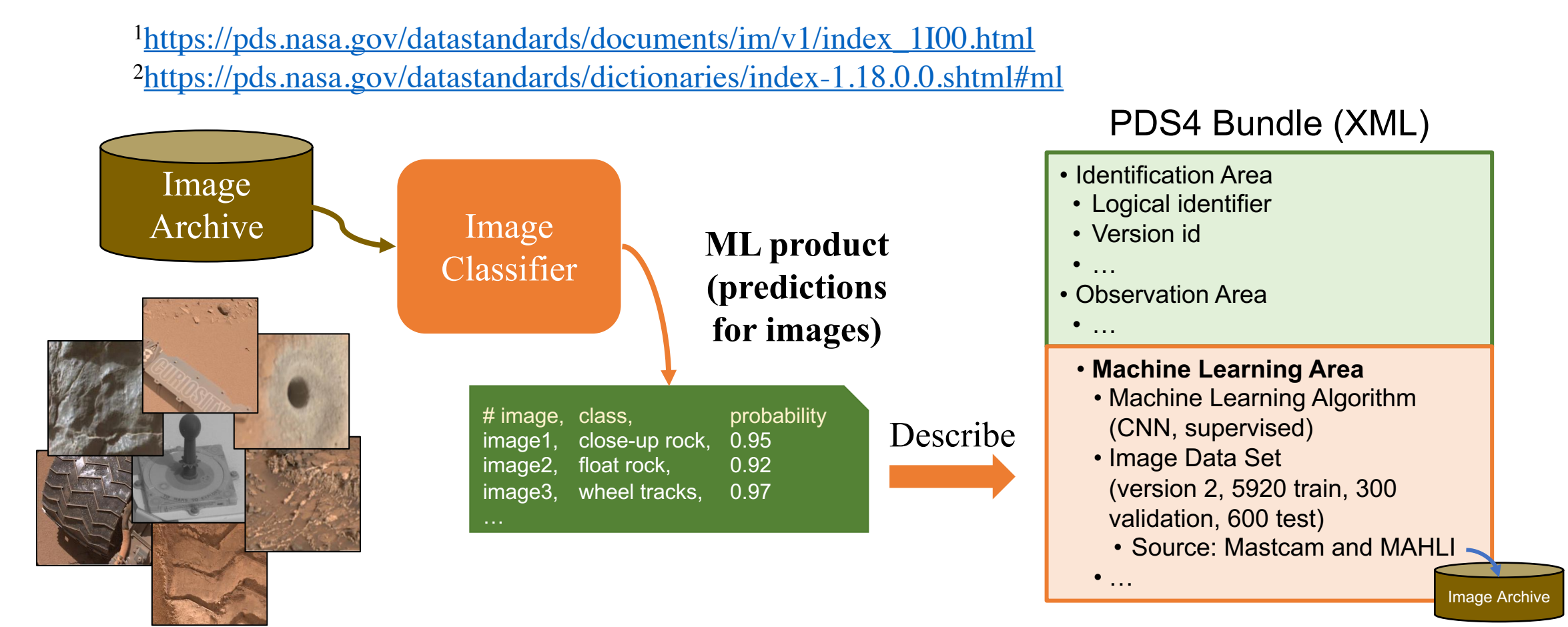


MSLNet Case based classifier result reasoning

## 4. Machine Learning Operationalization

### Step 1: Machine Learning Products Delivery

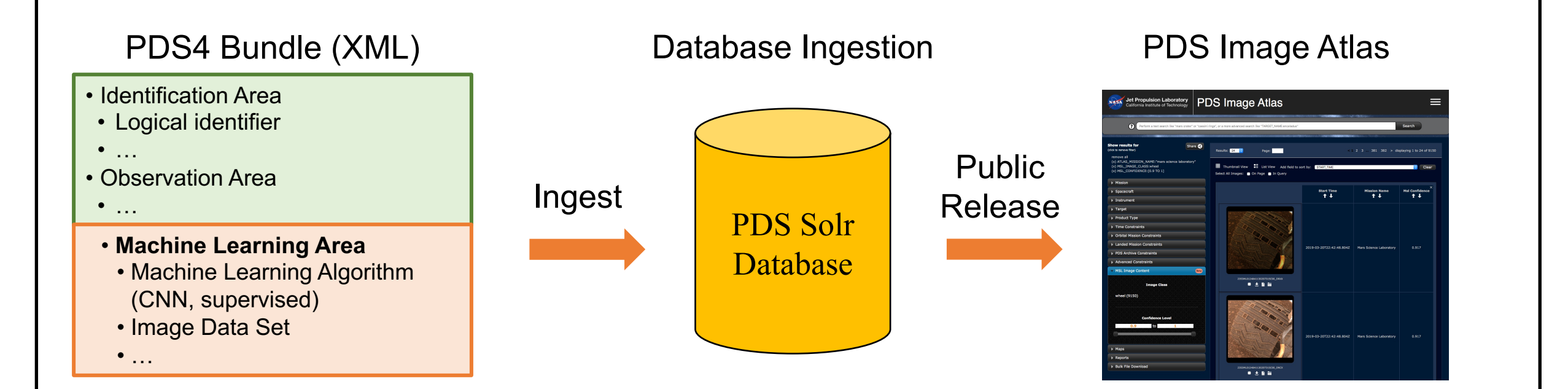
Machine learning products are delivered to the PDS Imaging Node in PDS4 bundles. The PDS4 bundles are described using PDS4 Information Model<sup>1</sup> and Machine Learning Analysis Dictionary<sup>2</sup>. For more information, please see [iPoster 1196514](#).



### Step 2: Machine Learning Products Deployment

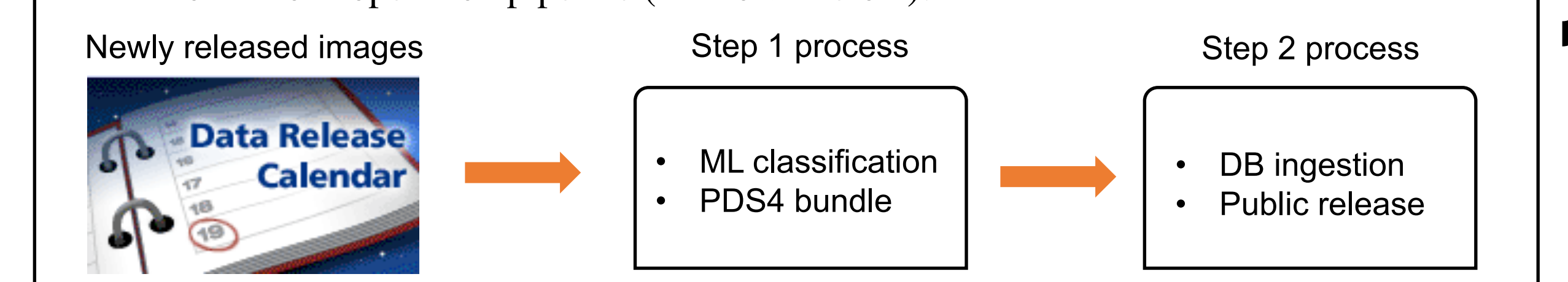
Machine learning PDS4 bundles are first ingested into PDS Solr database, and then made publicly accessible via PDS Image Atlas website<sup>3</sup>.

<sup>3</sup><https://pds-imaging.jpl.nasa.gov/search>



### Step 3: Continuous Operation

Active planetary science missions periodically deliver image observations to the PDS Imaging Node. The newly delivered images will be processed using the continuous operation pipeline (as shown below).



Next step

Fully automate ML operation on AWS cloud

## References

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## Acknowledgements

We thank the Planetary Data System for funding and enthusiastically supporting this work. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. Copyright 2022 California Institute of Technology. U.S. Government sponsorship acknowledged.