



Machine Learning for Planetary Science Images to Support Content-Based Search and Discovery

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Jet Propulsion Laboratory, California Institute of Technology

& Columbia University

Intern under Kiri Wagstaff and Steven Lu

Summer 2019



Jet Propulsion Laboratory
California Institute of Technology

About Me

- CS M.S. student at Columbia University (expected spring '20)
- Third summer internship at MLIA under Kiri Wagstaff
 - Continued research during the school year
- Interests in interpretable, explainable, and/or robust machine learning and deep learning

Motivation

- Increasing volume of image data in all fields

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PDS Image Atlas

Perform a text search like "mars crater" or "cassini rings", or a more advanced search like "TARGET_NAME:enceladus"

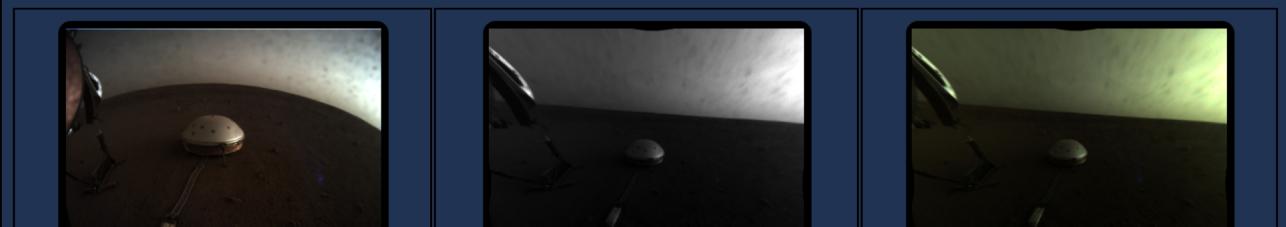
Show results for
(click to remove filter)

Results: 24 Page: < 1 2 3 ... 1424026 1424027 > displaying 1 to 24 of 34176647

Mission

- 2001 mars odyssey (2978555)
- cassini (916565)
- chandrayaan-1 (21645)
- clementine (1996197)
- galileo (20123)
- insight (89952)
- juno (34690)
- lcross (2651)
- lunar orbiter (2991)
- lunar reconnaissance orbiter (4243818)
- magellan (72818)
- mars exploration rover (7075303)

[Thumbnail View](#) [List View](#) Add field to sort by: START_TIME Select All Images: On Page In Query



Motivation

- Increasing volume of image data in all fields
- Accessing, searching, and browsing such collections is difficult and expensive
- Existing work on supervised content-based search
- However, scientific discovery arises from unexpected observations



Show results for
(click to remove filter)

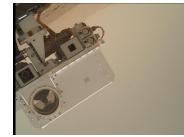
Narrow your search by selecting a facet below

▼ Mission

2001 mars odyssey (2978555)
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mars science laboratory (12626010)
messenger (1309800)
new horizons (15179)
phoenix (256433)
viking lander (6585)
viking orbiter (61693)
voyager (312225)

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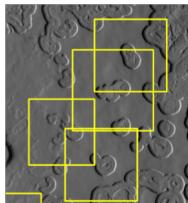
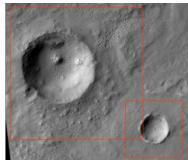
▼ MSL Image Content

Image Class

apxs (170)
apxs cal target (5)
chemcam cal target (150)
chemin inlet open (1120)
drill (630)
drill holes (3985)
drt front (20)
drt side (120)
ground (347740)
horizon (88865)
inlet (1340)
mahli (45)
mahli cal target (445)
mastcam (265)
mastcam cal target (23860)
observation tray (5170)
portion box (310)
portion tube (840)
portion tube opening (390)
rems uv sensor (95)
rover rear deck (535)
scoop (4560)
turret (3025)
wheel (9150)

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MRO HiRISE Image Content

Image Class (MRO HiRISE RDRs Only)

bright dune (897)
crater (216)
dark dune (37)
impact ejecta (2)
slope streak (18)
spider (32)
swiss cheese (22)

Number of Bright Dunes



Number of Craters



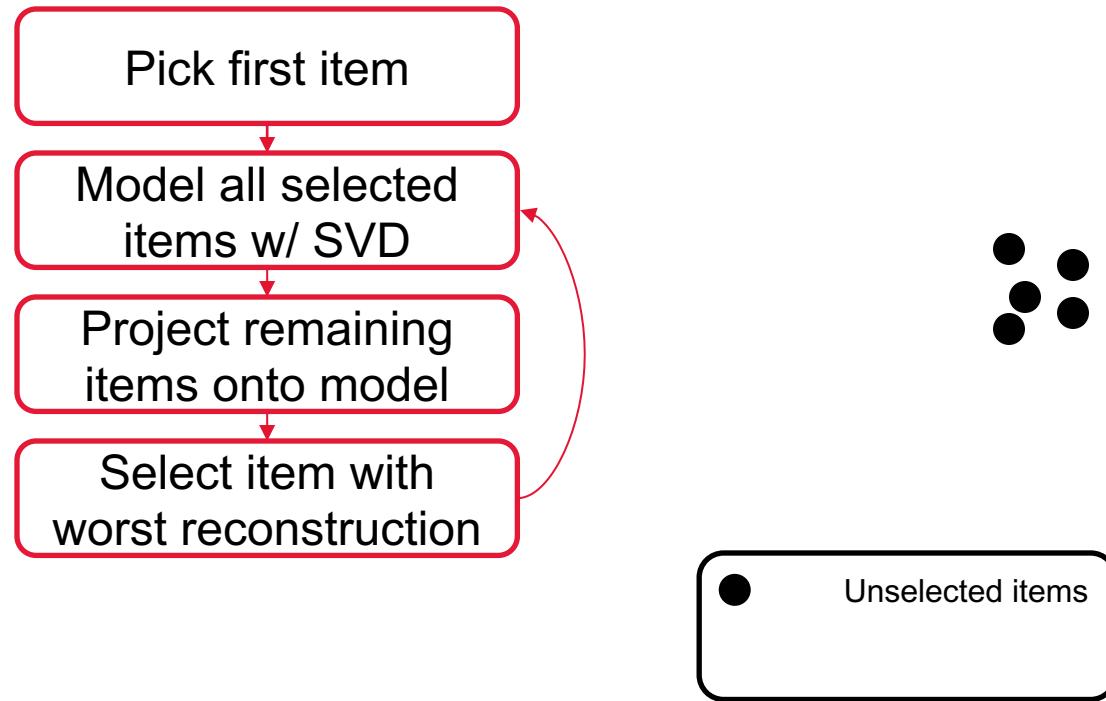
- 1. The DEMUD Algorithm**
- 2. DEMUD Parameter Optimization**
- 3. PDS Atlas Implementation**

DEMUD and Novelty Detection

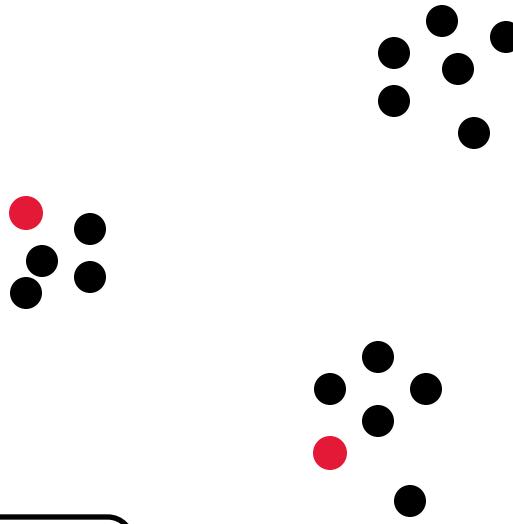
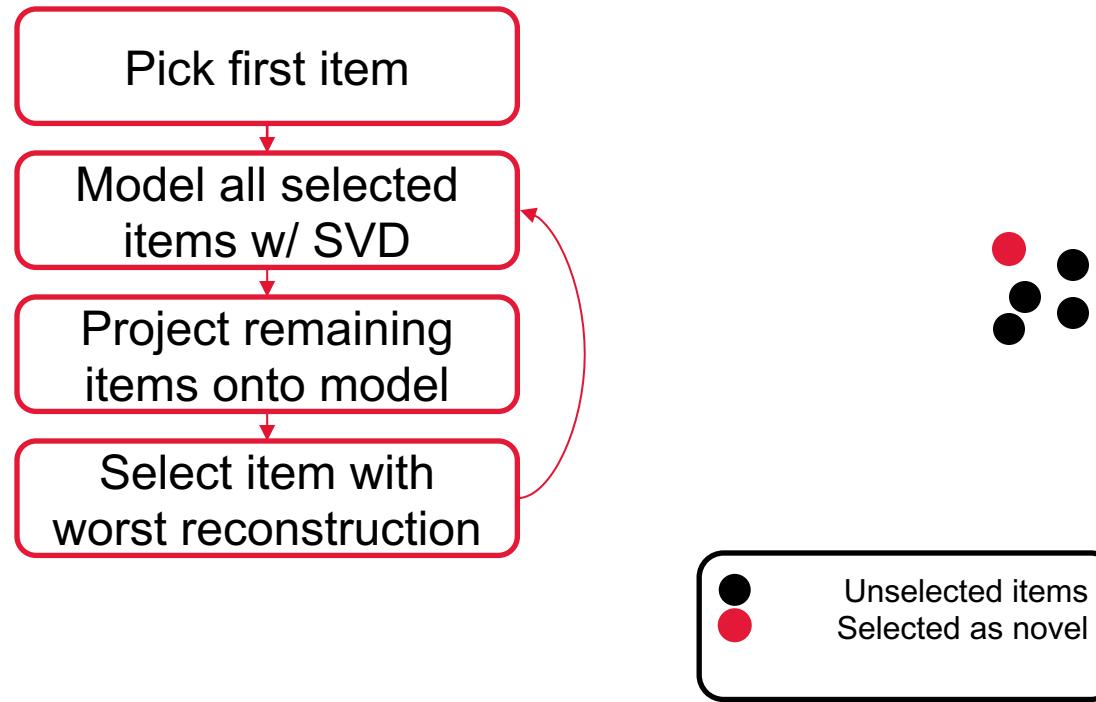
- An unsupervised novelty detection algorithm
 - No human labels necessary
- Prioritizes interesting data by attempting to discover all existing classes as quickly as possible
- Provides explanations for its prioritizations

Wagstaff, Kiri L., et al. "Guiding Scientific Discovery with Explanations Using DEMUD." AAAI. 2013
Wagstaff, K. L., N. L. Lanza, and R. C. Wiens. "Unusual ChemCam Targets Discovered Automatically in Curiosity's First Ninety Sols in Gale Crater, Mars." Lunar and Planetary Science Conference. Vol. 45. 2014.

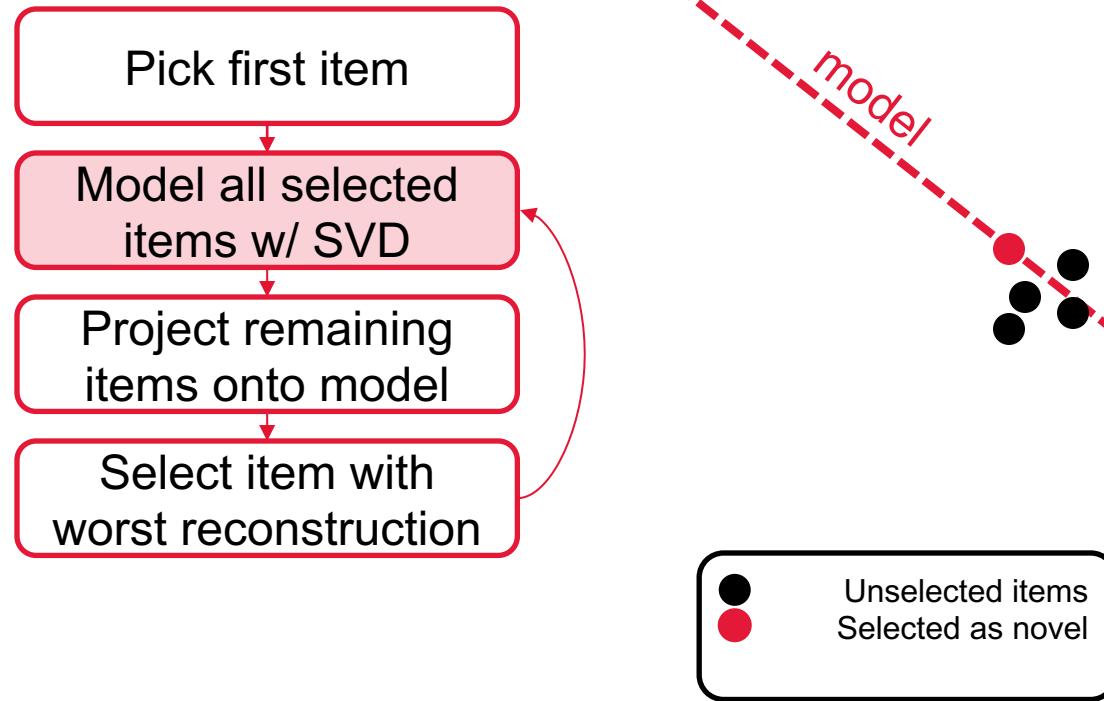
DEMUD in Detail



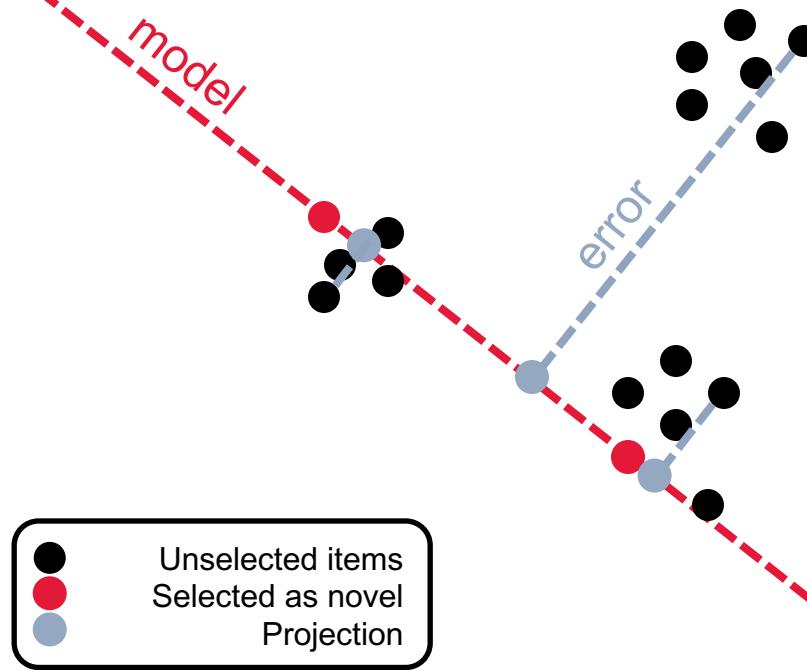
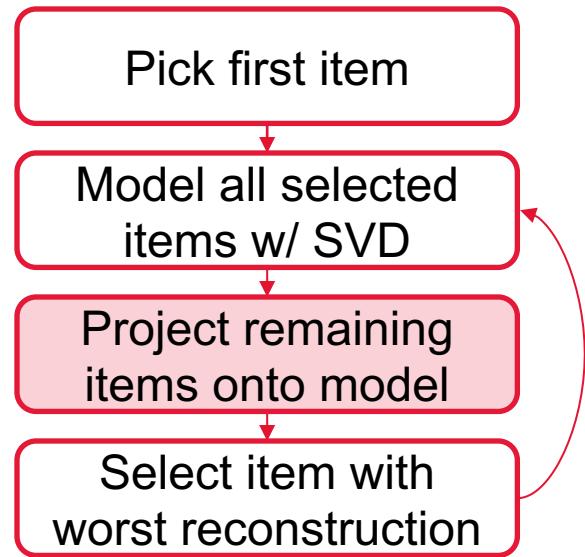
DEMUD in Detail



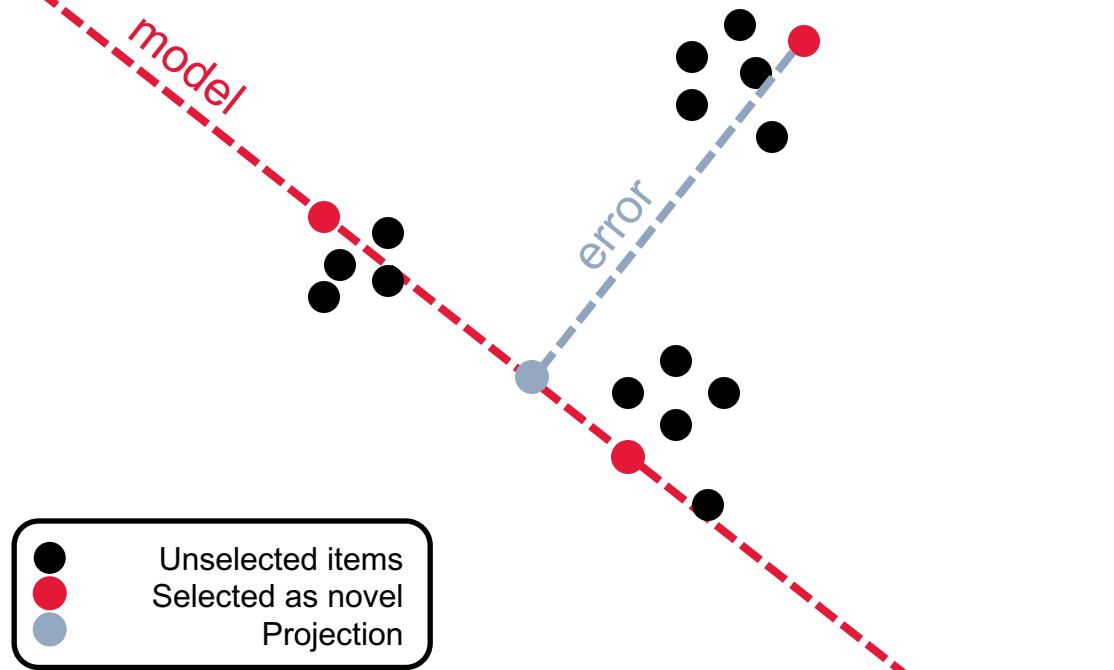
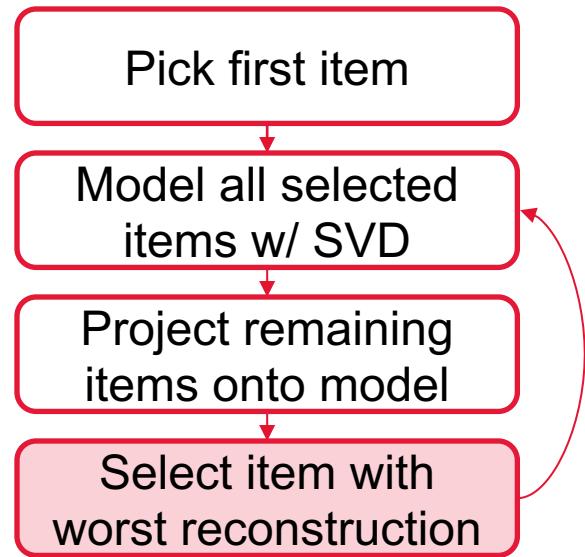
DEMUD in Detail



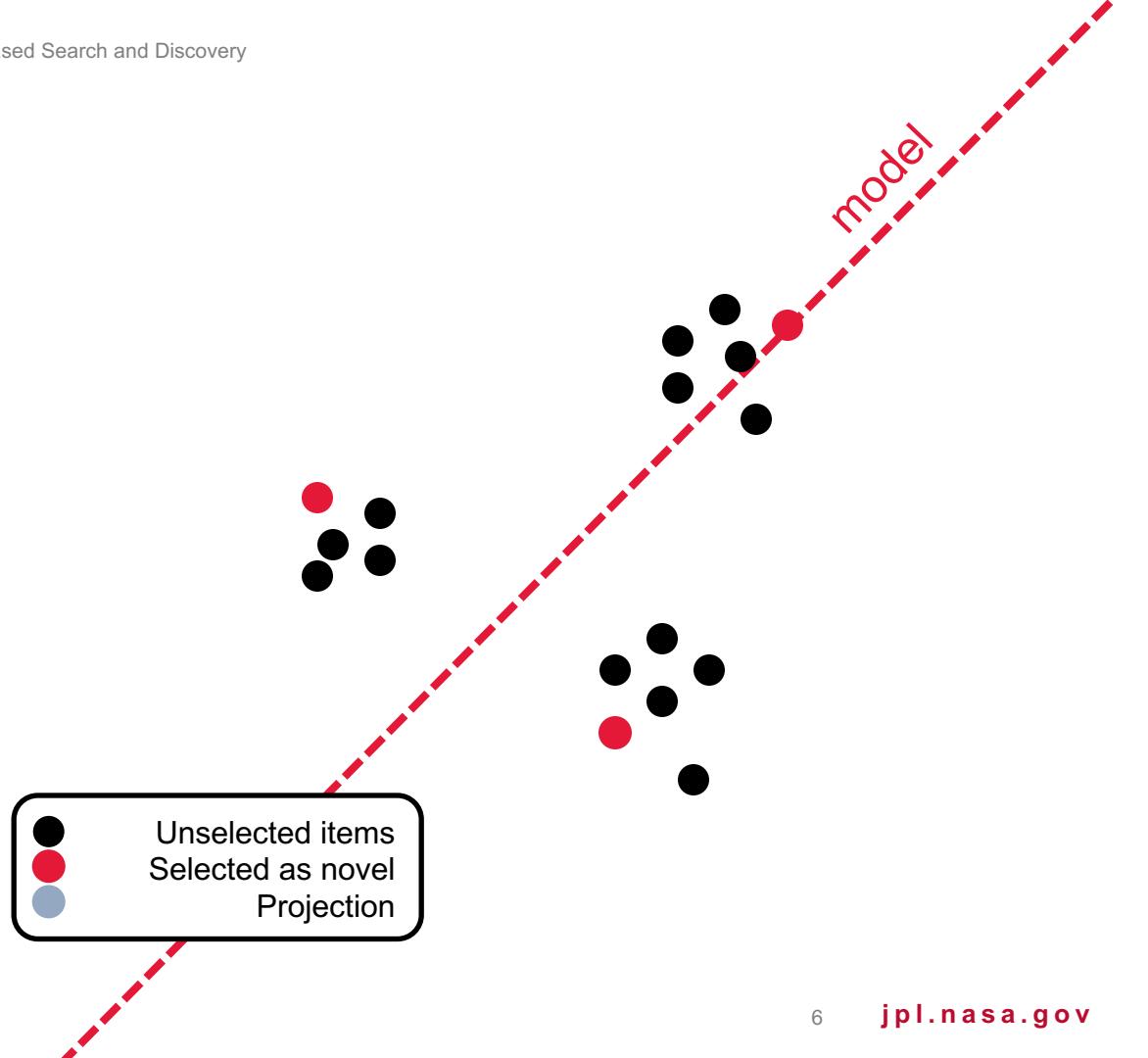
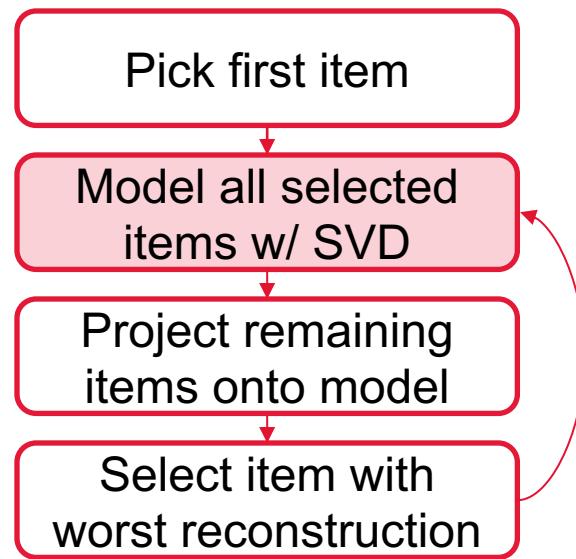
DEMUD in Detail



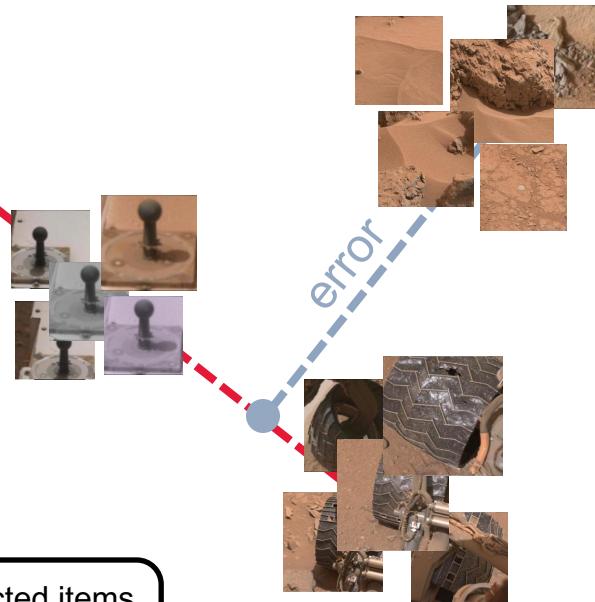
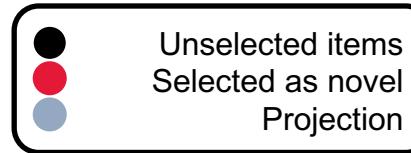
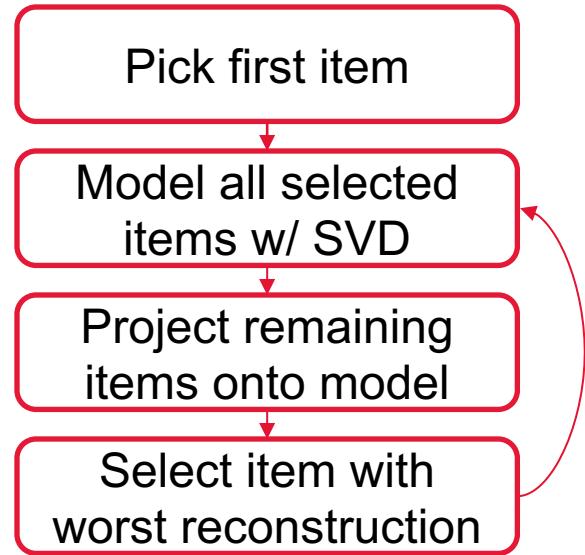
DEMUD in Detail



DEMUD in Detail

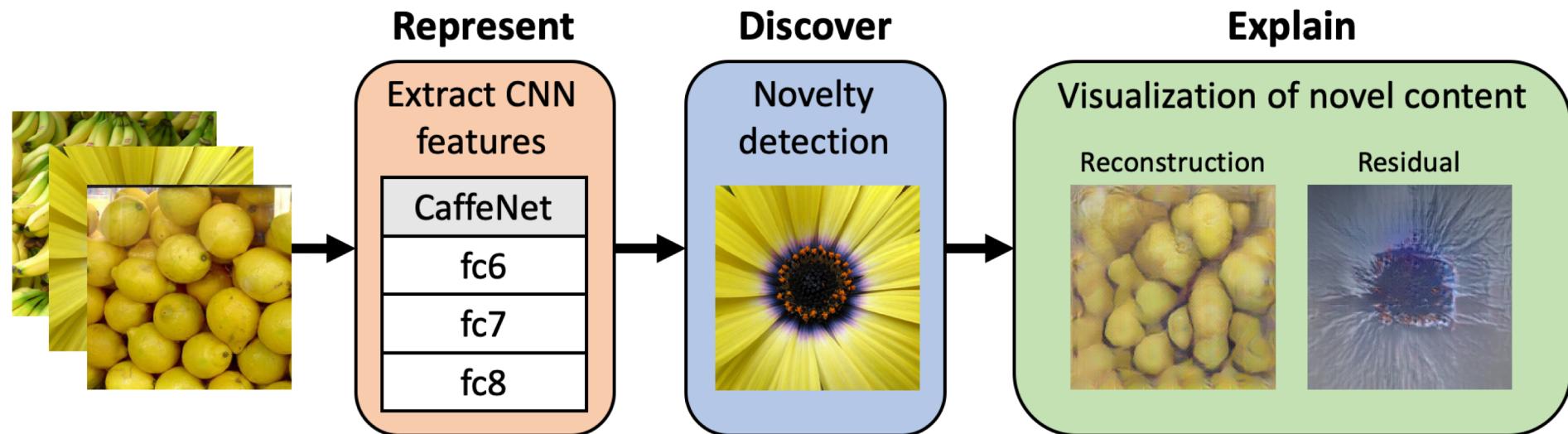


DEMUD in Detail



Alice Stanboli, & Kiri Wagstaff. (2017). Mars surface image (Curiosity rover) labeled data set (Version 1.0.0) [Data set]. Zenodo. <http://doi.org/10.5281/zenodo.1049137>

Visualizing Image Content to Explain Novel Image Discovery



<https://jakehlee.github.io/visualize-img-disc>

Project Timeline

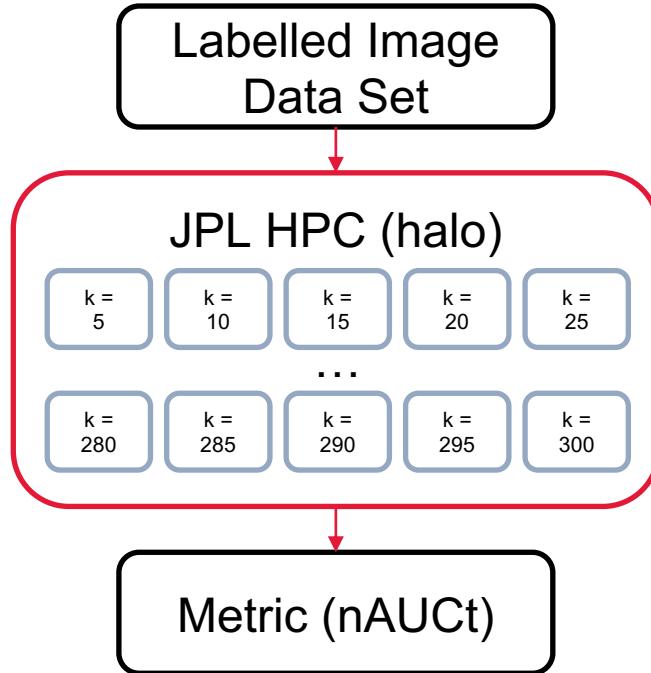
- 
- Summer 2017:** Content-based image discovery proof-of-concept
 - Fall 2017 / Spring 2018:** Experimentation & initial explanation visualization
 - December 2017:** Presented at NIPS Symposium as invited talk
 - July 2018:** Presented at ICML Workshop on Human Interpretable ML
 - Summer 2018:** Significantly improved visualization
 - Fall 2018 / Spring 2019:** Writeup and user study
 - Summer 2019:** Finalization and journal submission

DEMUD Parameter Optimization

Parameter Sensitivity Experiment

- Parameter k in SVD determines how many principal components to keep when reconstructing
 - At a high level, determines the capacity of the model to learn
- Previously set arbitrarily to 50
 - When SVD is used for dimensionality reduction, $k \ll d$
- How does k affect discovery performance?

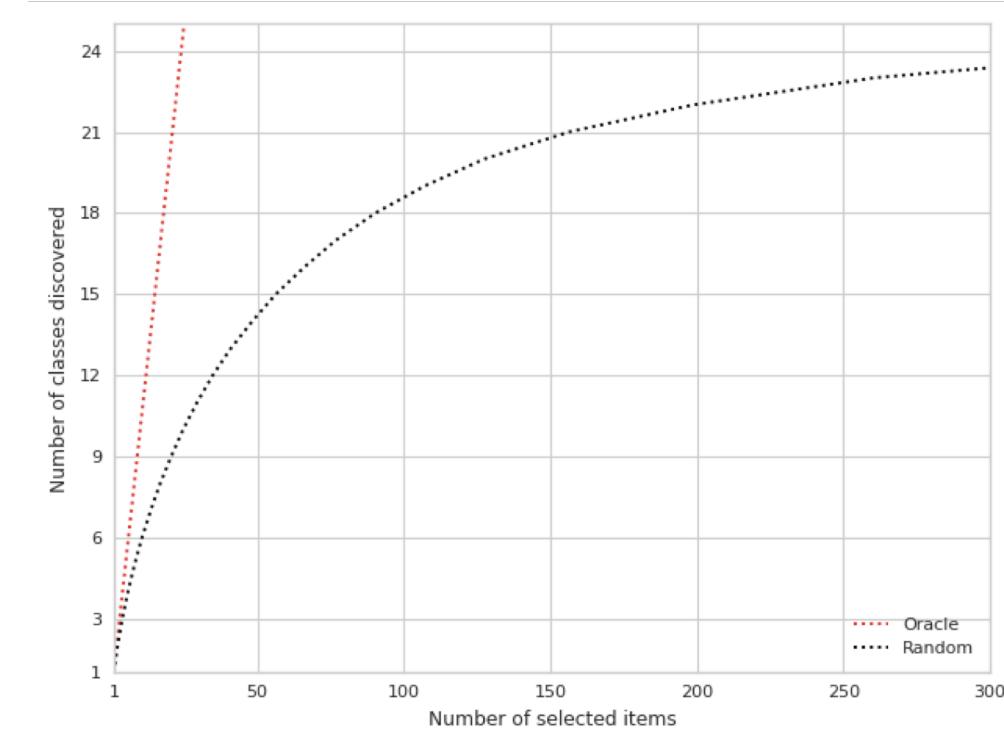
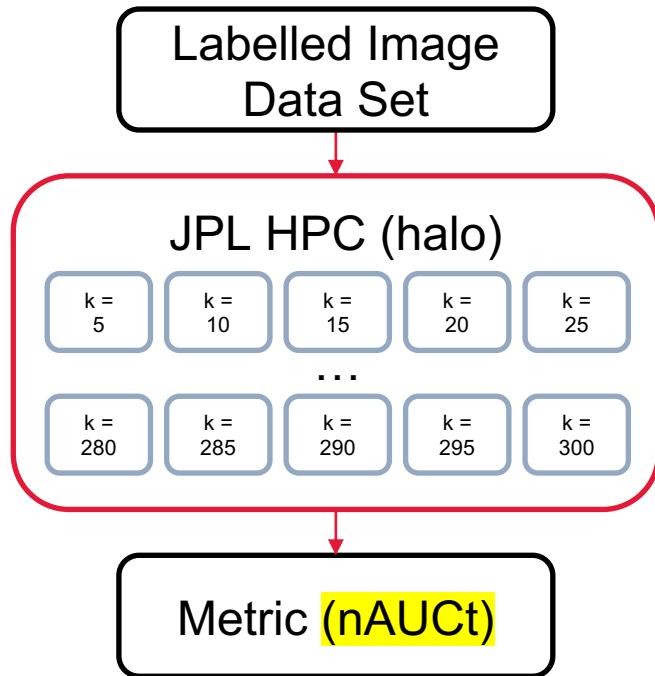
Parameter Sensitivity Experiment



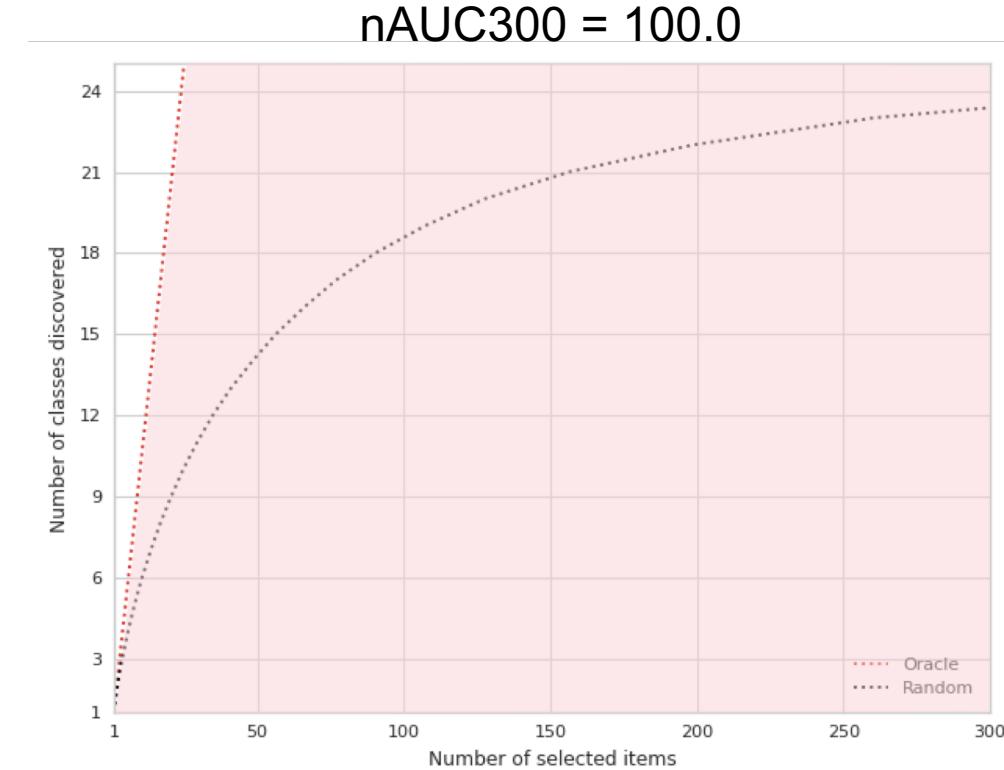
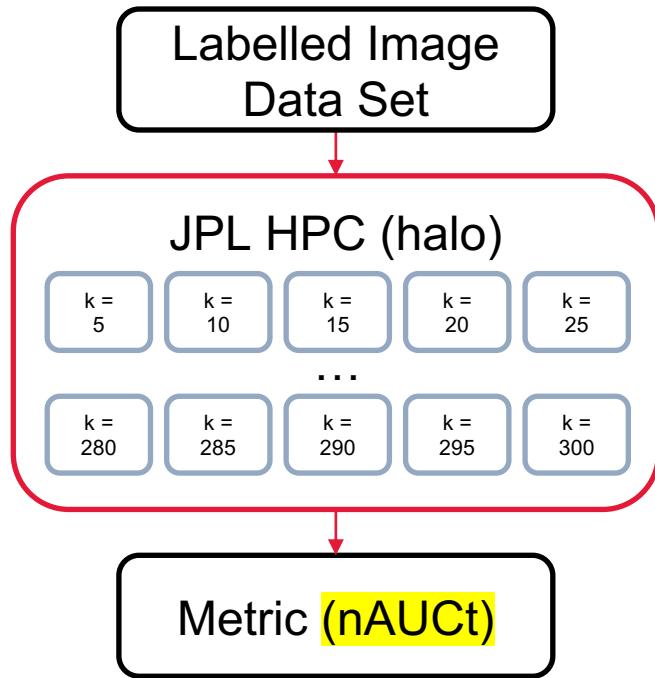
- Data set includes 6712 images from 25 classes collected by various instruments on MSL (Curiosity Rover)
- Labelled data set is used for metrics only – method does not require labeling

Alice Stanboli, & Kiri Wagstaff. (2017). Mars surface image (Curiosity rover) labeled data set (Version 1.0.0) [Data set]. Zenodo.
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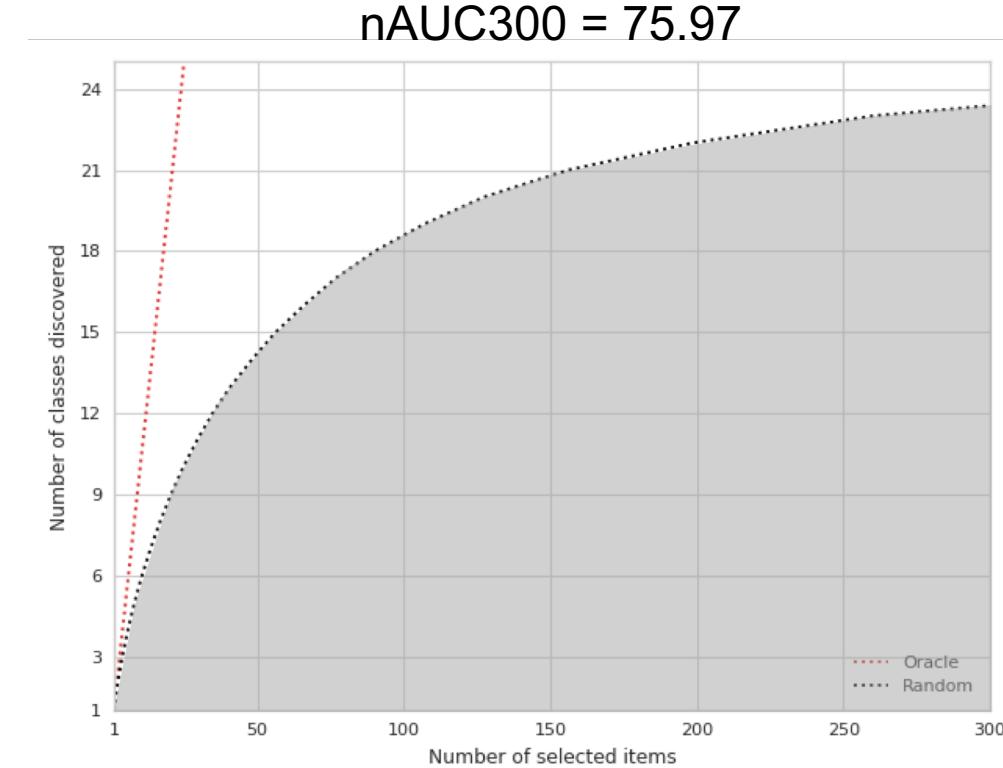
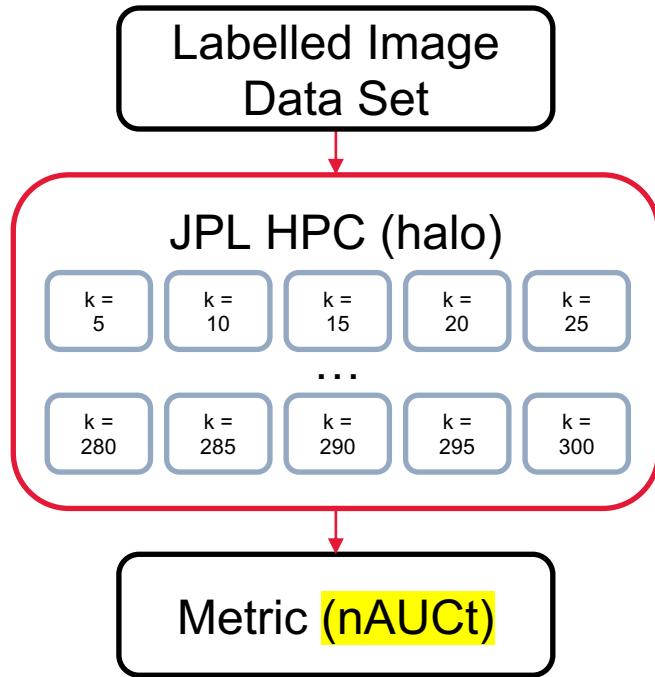
Parameter Sensitivity Experiment



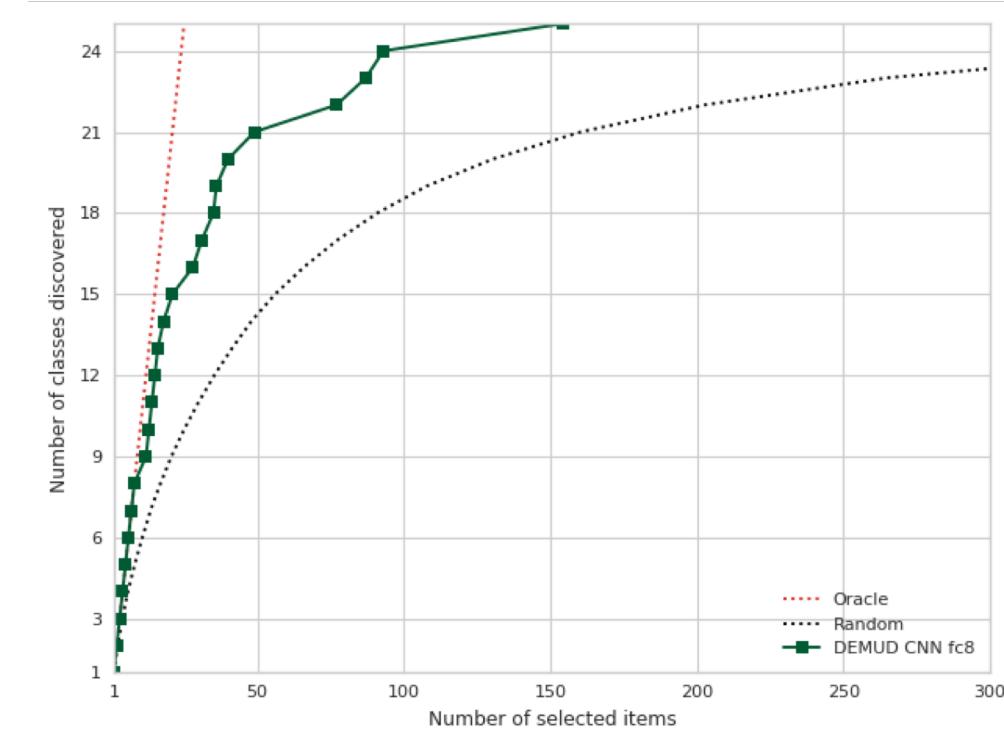
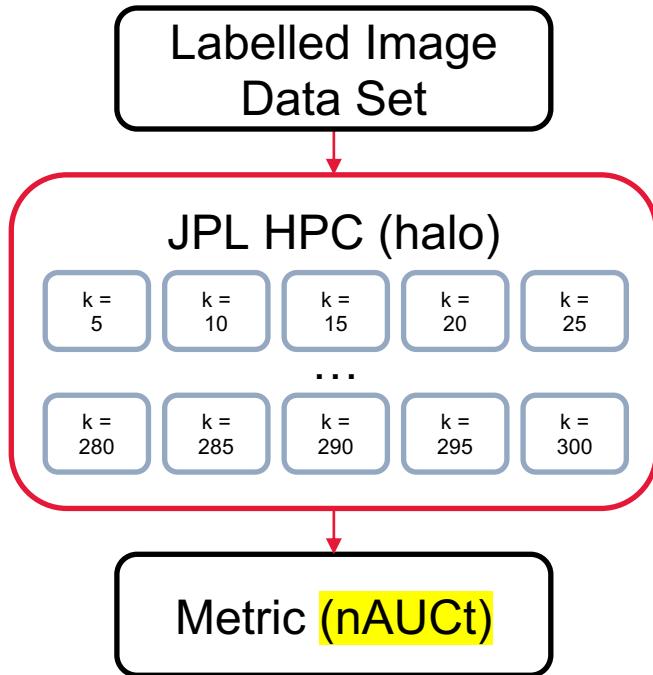
Parameter Sensitivity Experiment



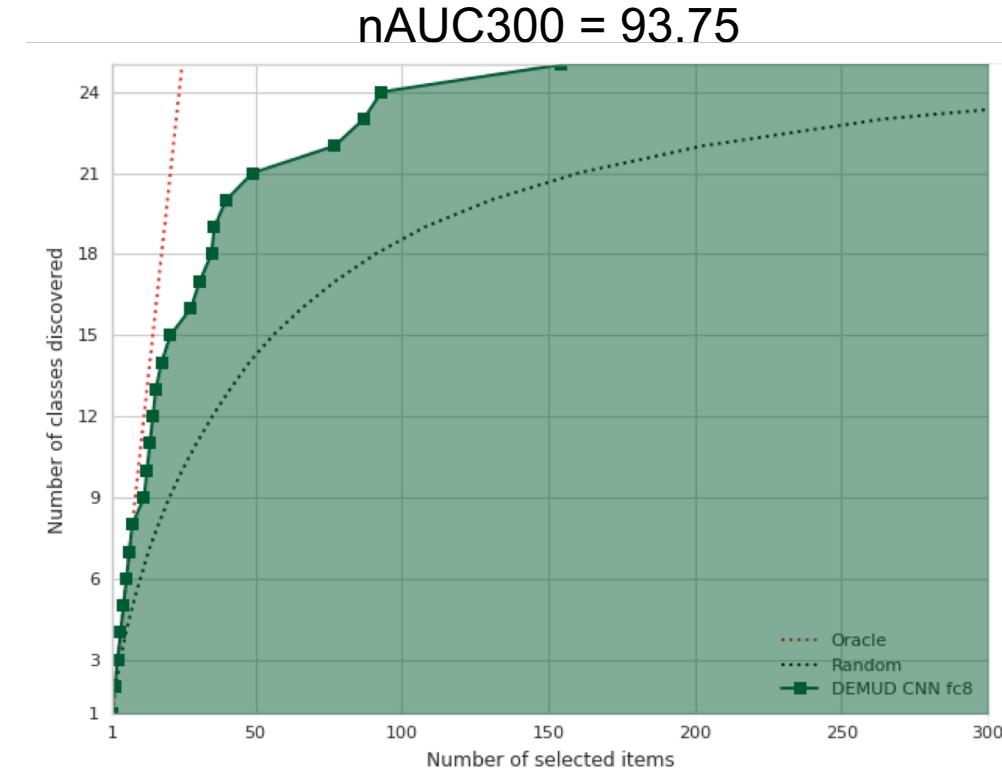
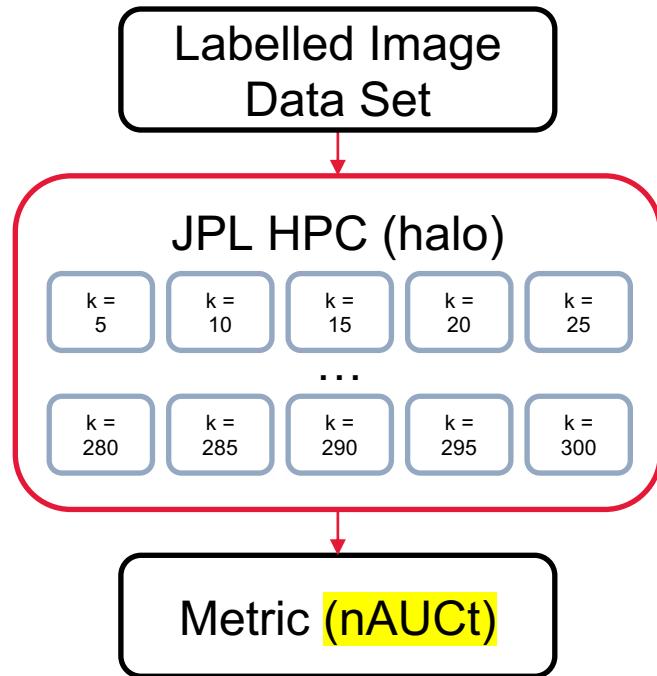
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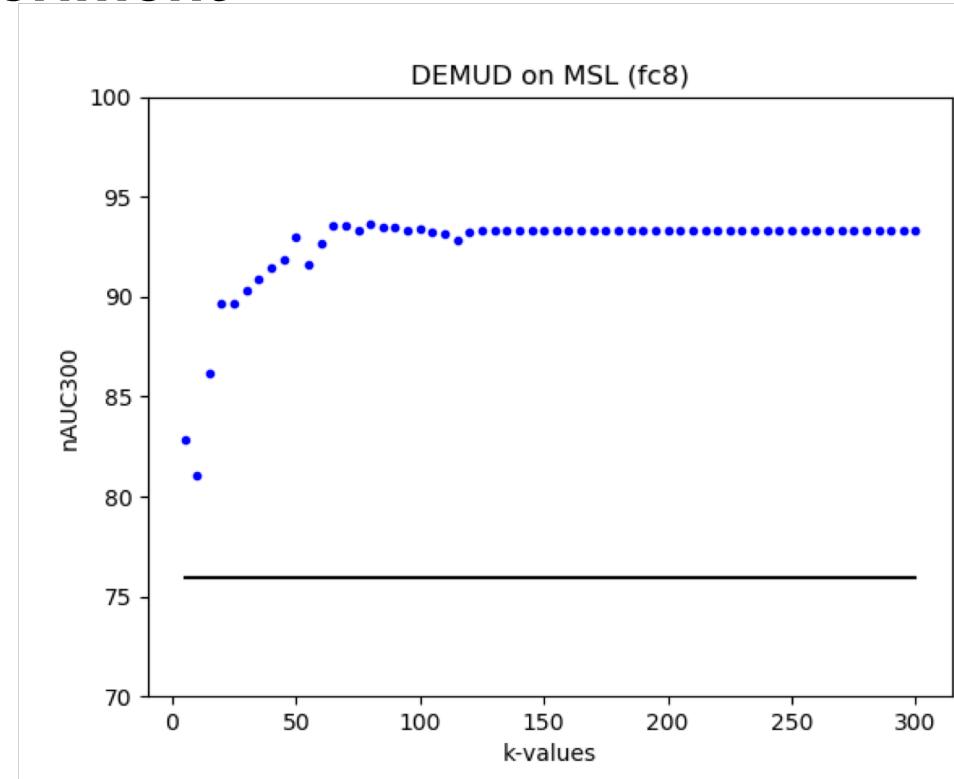
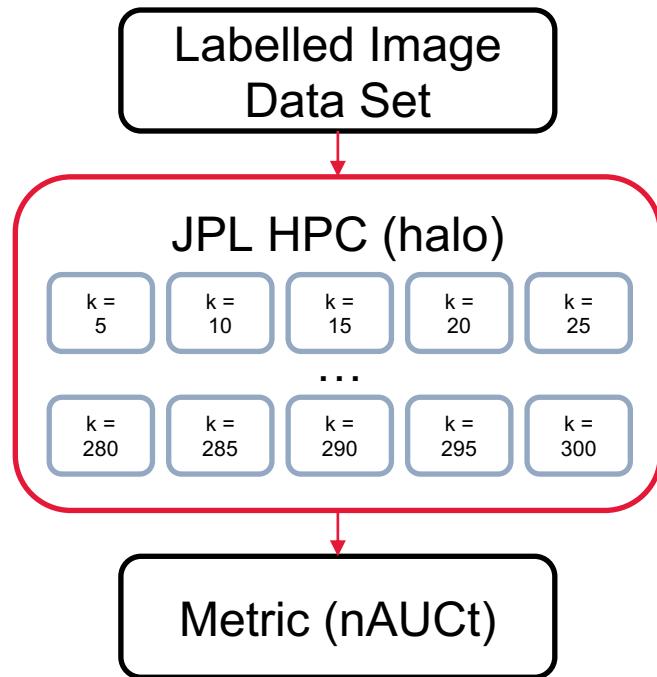
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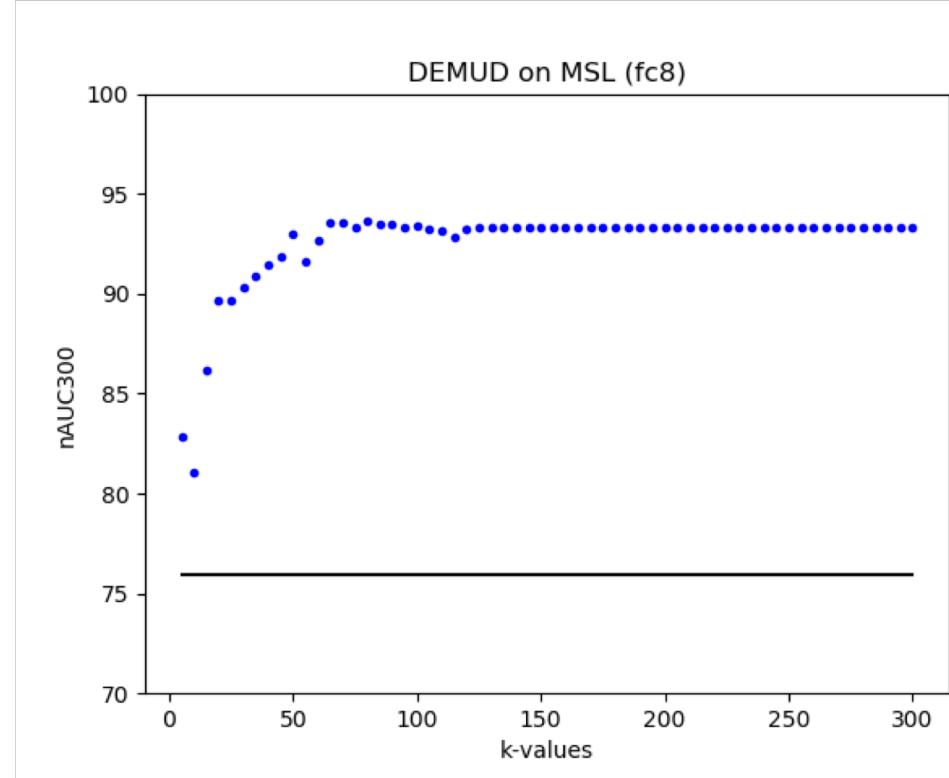
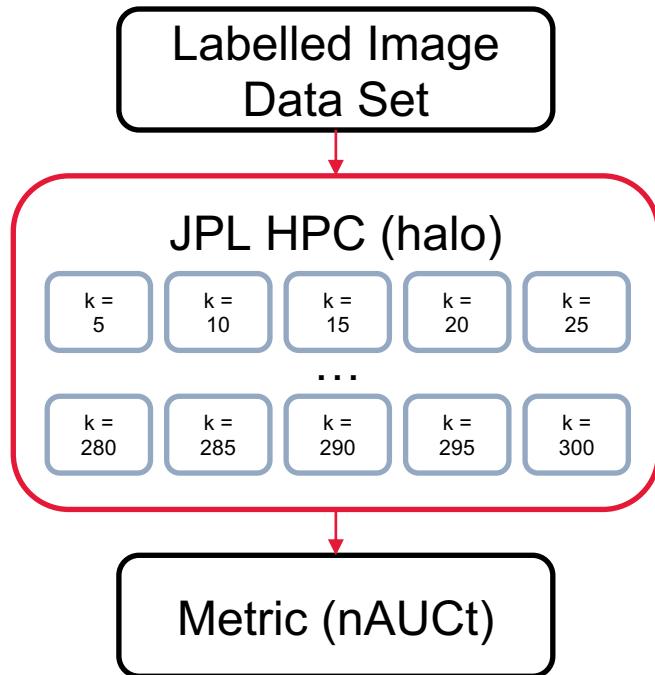
Parameter Sensitivity Experiment



Parameter Sensitivity Experiment



Parameter Sensitivity Experiment



Conclusion: use maximum *k*-value

PDS Atlas Implementation

Novelty Detection for the PDS Atlas



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California Institute of Technology

PDS Image Atlas



Perform a text search like "mars crater" or "cassini rings", or a more advanced search like "TARGET_NAME:enceladus"

Search

Show results for
(click to remove filter)



Narrow your search by selecting a facet below



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Results: 24

Page: 1

< 1 2 3 ... 1424026 1424027 > displaying 1 to 24 of 34176647



Thumbnail View



List View

Add field to sort by:

START_TIME



Select All Images: On Page In Query



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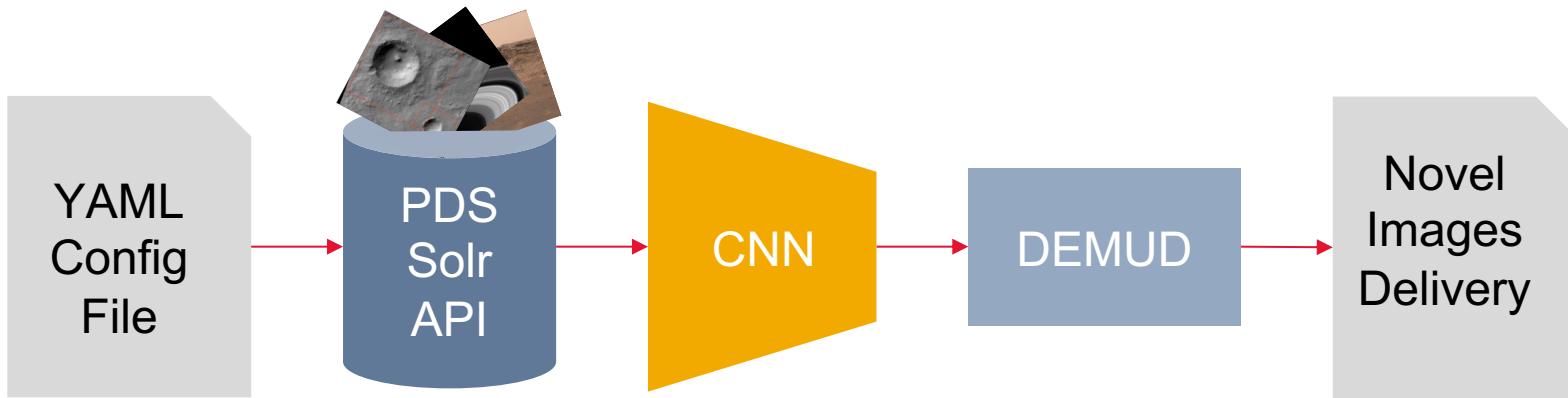


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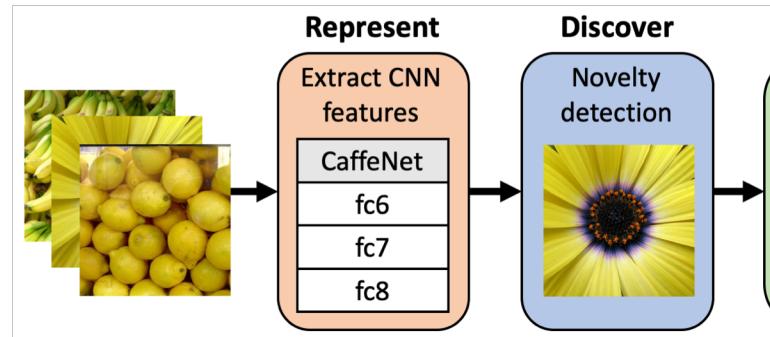
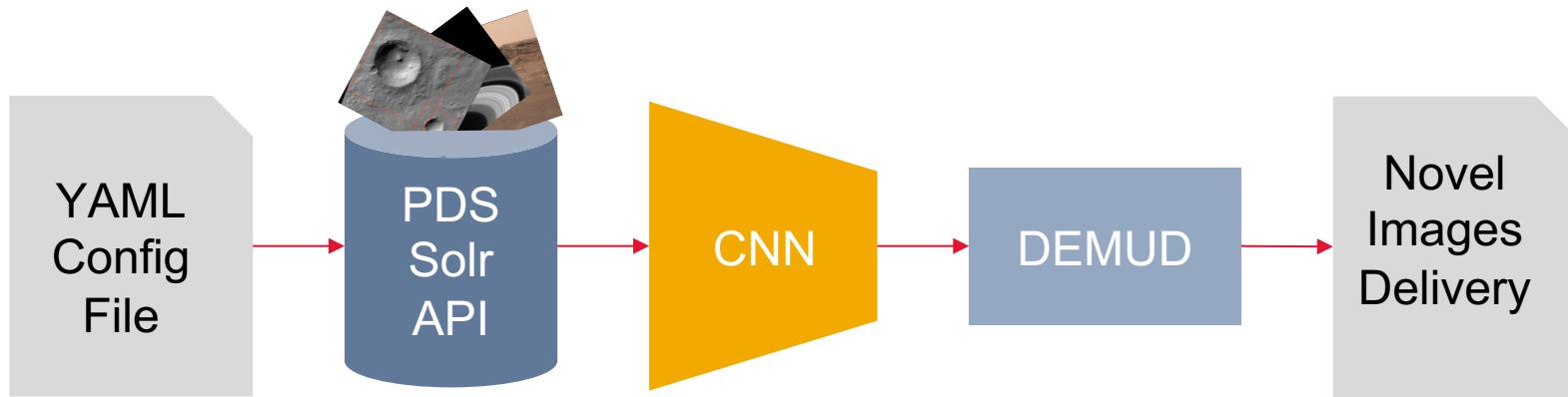
Novelty Detection for the PDS Atlas

- Images sorted reverse-chronologically inadvertently creates clusters of similar content
 - Gives the impression of little variety in content
 - Barrier of entry for users browsing around
- **Solution:** Display images by novelty and diversity

Novelty Detection Pipeline for the PDS Atlas

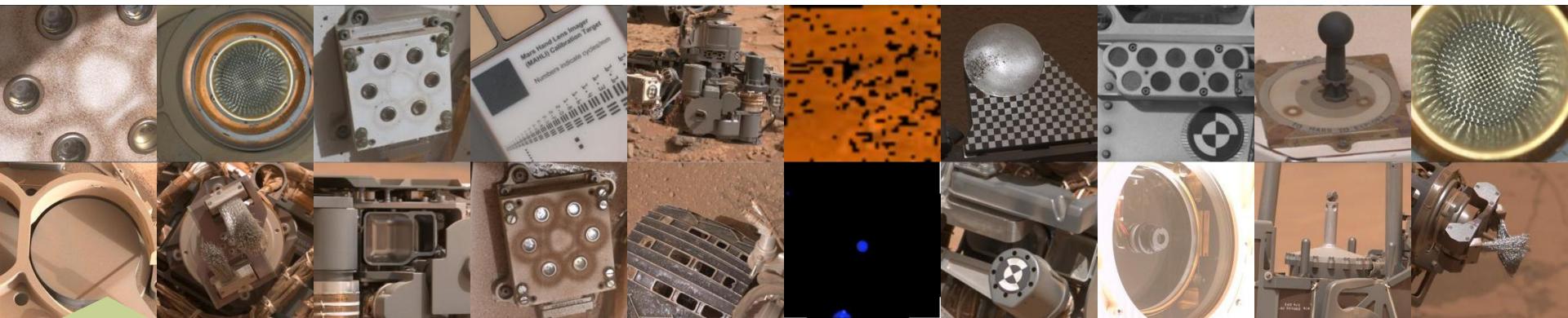


Novelty Detection Pipeline for the PDS Atlas



Preliminary Results

MSL labeled data set (25 classes, 6712 images)



20 most novel

20 least novel



Preliminary Results

InSight IDC/ICC EDR images (1858)



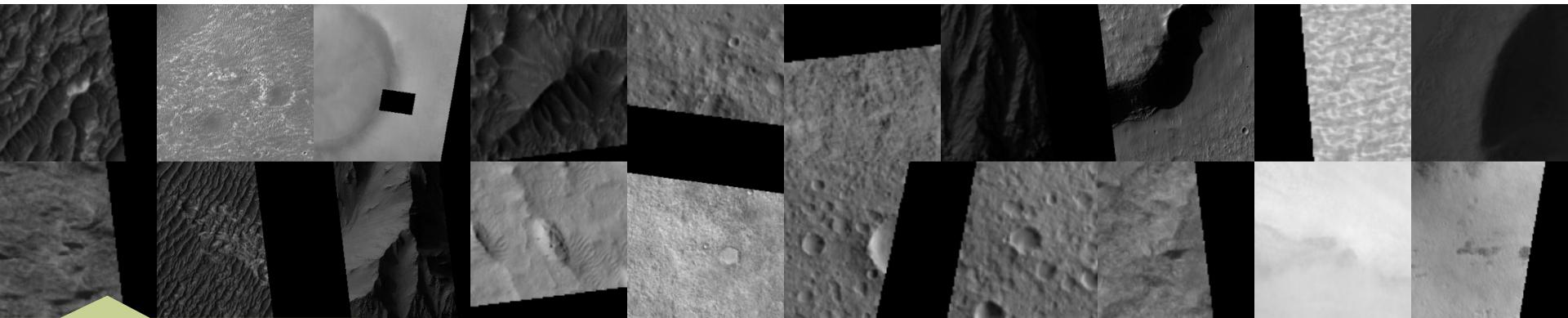
20 most novel

20 least novel



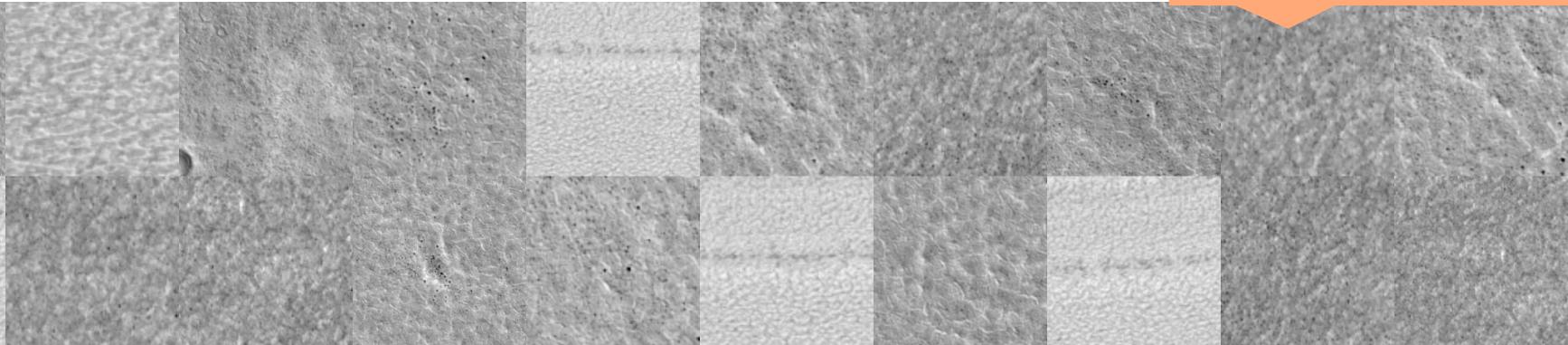
Preliminary Results

HiRISE cropped landmarks (1310 from 10 images)



20 most novel

20 least novel



Atlas Front-End Beta

Show results for
(click to remove filter)

Share 

(x) ATLAS_MISSION_NAME:insight

▼ Mission

insight (89026)

► Spacecraft

► Instrument

► Target

► Product Type

► PDS Archive Constraints

► Advanced Constraints

► Maps

► Reports

► Bulk File Download

Featured images

X



Results: 24 

Page: 

< 1 2 3 ... 3709 3710 > displaying 1 to 24 of 89026

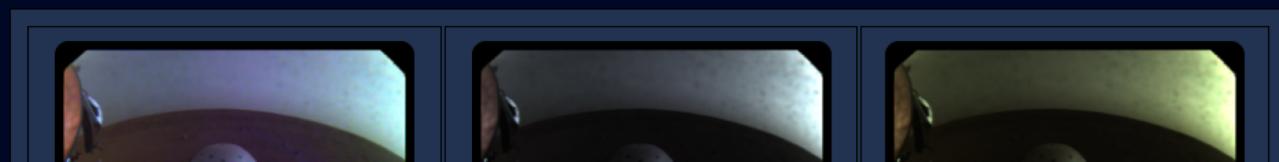
 Thumbnail View

 List View

Add field to sort by: START_TIME 

 Clear

Select All Images: On Page In Query



Future Work

- Mature deliverable generation process
- Ongoing integration into PDS Atlas
- Scale up HiRISE landmarks experiment
- Journal paper review process

- Additional research projects inspired by this work
- Graduate with M.S. in Spring 2020
- Pursue Ph.D. programs

Thank you!

- Kiri Wagstaff
- Steven Lu
- Kevin Grimes
- Paul Ramirez & Sue LaVoie
- Planetary Data System Imaging Node
- Lukas Mandrake
- MLIA interns