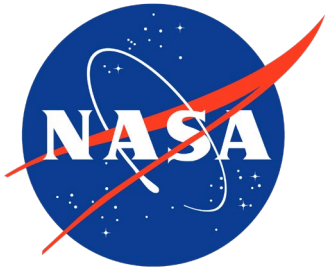
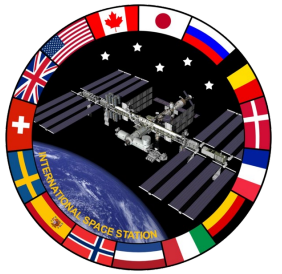


JUNE 18-22, 2023

CVPR

VANCOUVER, CANADA



Find My Astronaut Photo

Alex Stoken[1] Kenton Fisher[2]

NASA Earth Science and Remote Sensing Unit

Jacobs Technology[1]

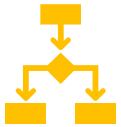
NASA Johnson Space Center[2]

Jacobs

Overview

A Brief History of Astronaut Photography

Barriers to Geolocation



The Find My Astronaut Photo Framework

Finding a Discriminative Matcher

The AIMS Dataset

Results

A Brief History of Astronaut Photography

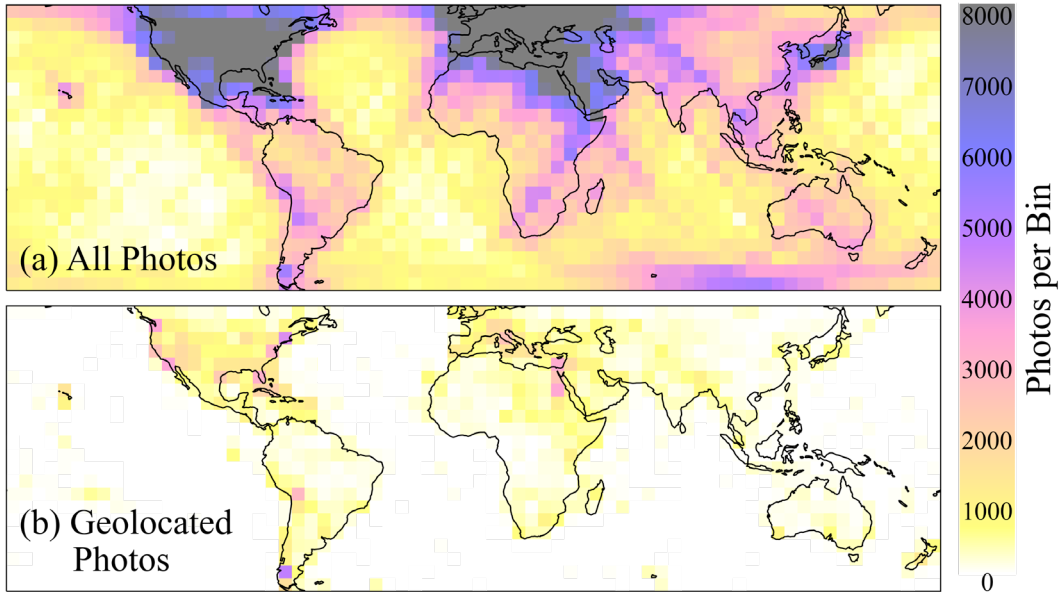
- Astronauts have taken photos of the Earth from space for over 60 years
- The **Earth Science and Remote Sensing (ESRS)** Unit at JSC, manages the **collection and hosting** of Earth observation images from the ISS and past NASA spacecraft
- Imagery is used for research, disaster response, and public engagement

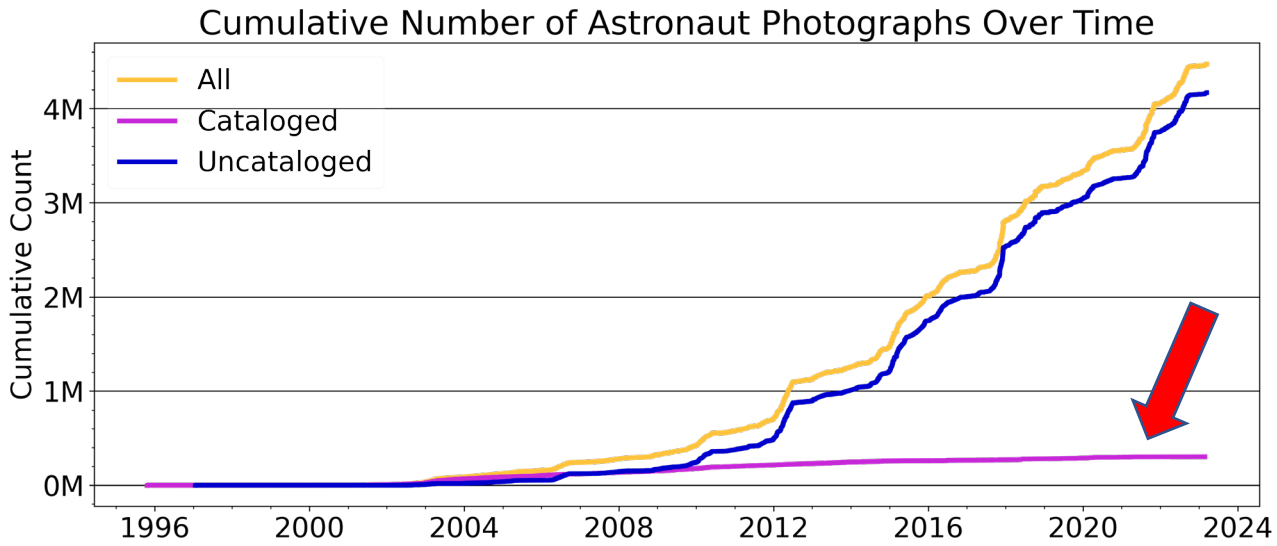
A Brief History of Astronaut Photography

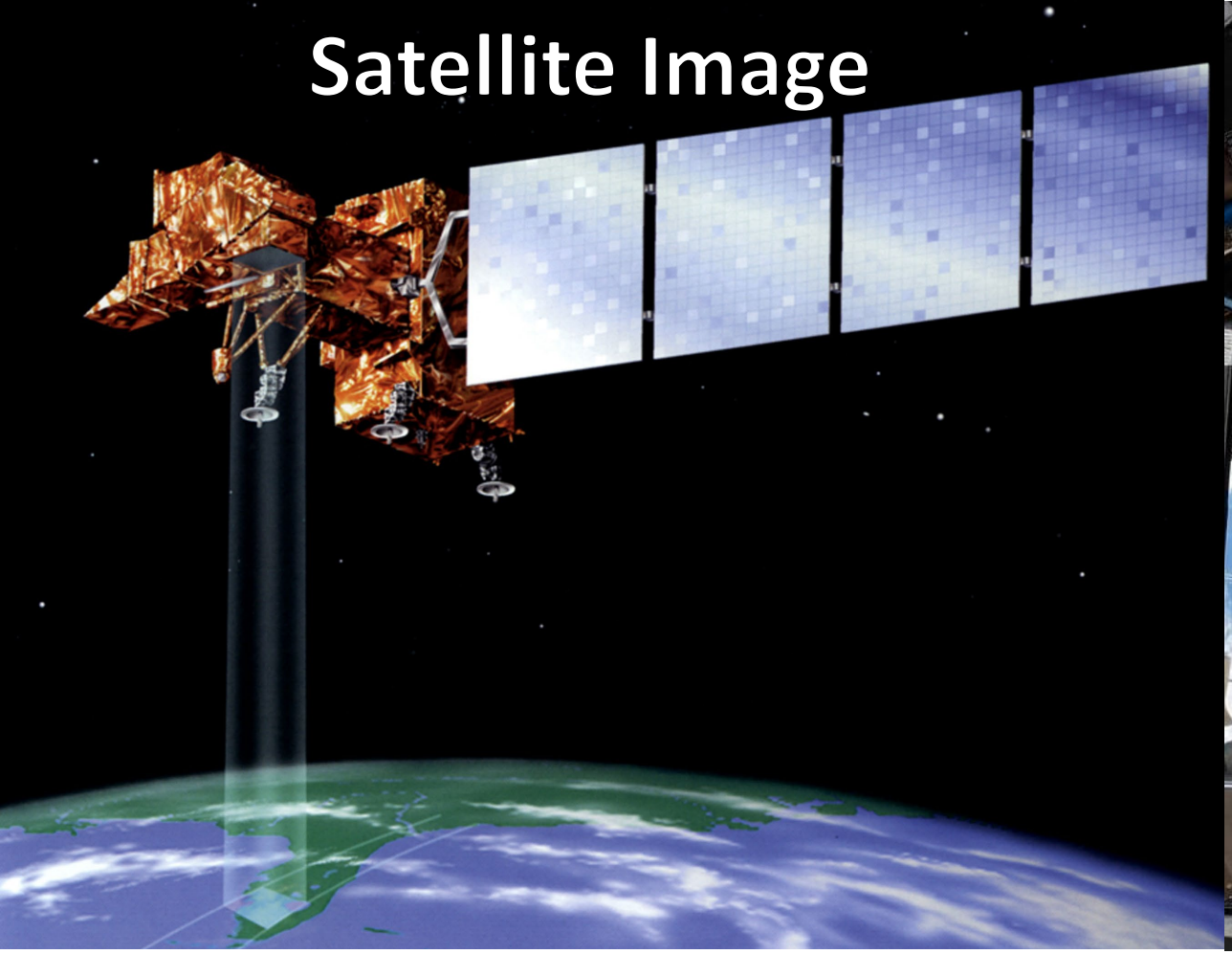
- Today, astronaut photography primarily takes place from the **International Space Station (ISS)**
  - 400 km above Earth's surface in Low Earth Orbit
  - Orbits the Earth 16 times per 24 hours

A Brief History of Astronaut Photography

- Global, **4 million** photo collection, increasing by 100,000 photos every 6 months
- **Missing critical geolocation data for 90% of images**
  - 10% of existing geolocation data is from manual human search and labeling







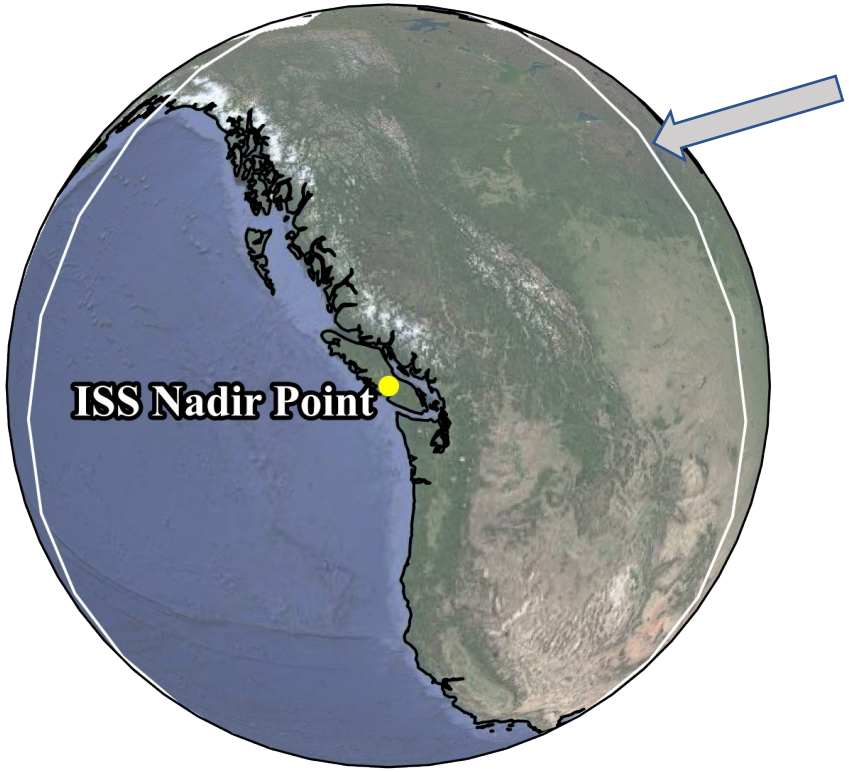
Acquisition Conditions	
Known spacecraft position and attitude	✓
Known camera orientation	✗

Barriers to Geolocation


2,500 km away!

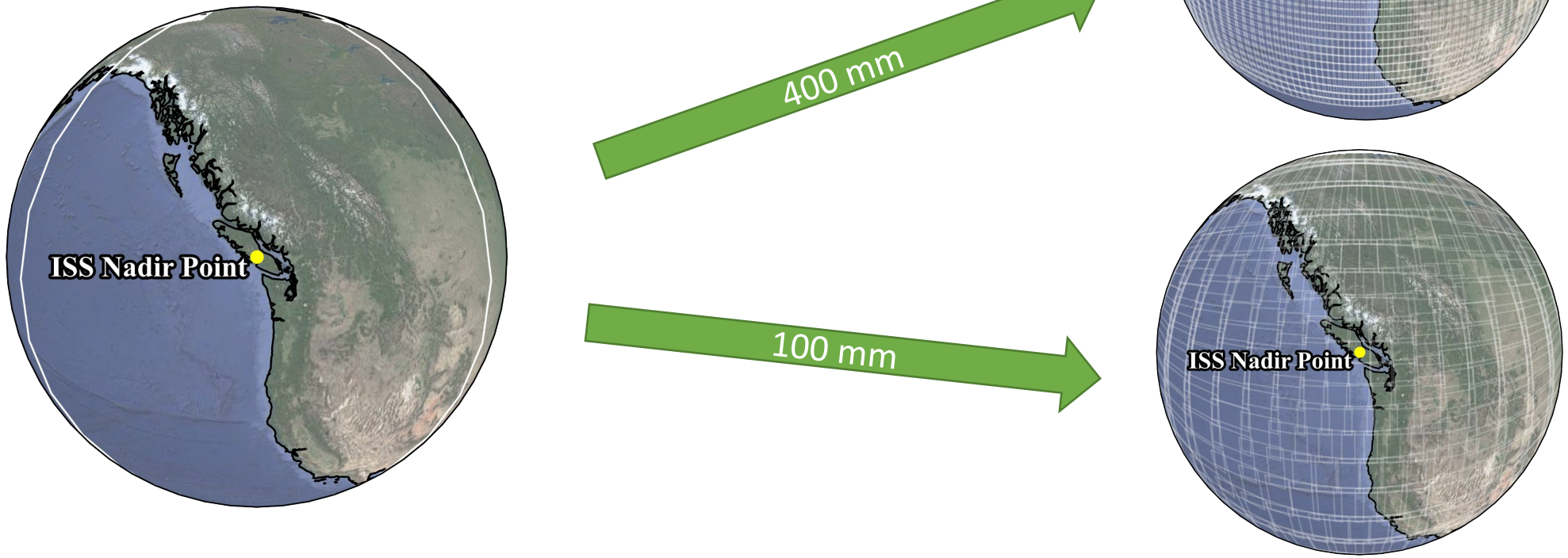

ISS062-E-40033 02/20/2020
NIKON D5, Focal Length: 400 mm
Shutter: 1/1000
Aperture: 8.0
ISO Speed: 400
Focus Mode: AF-S

How on Earth do we find where on Earth?



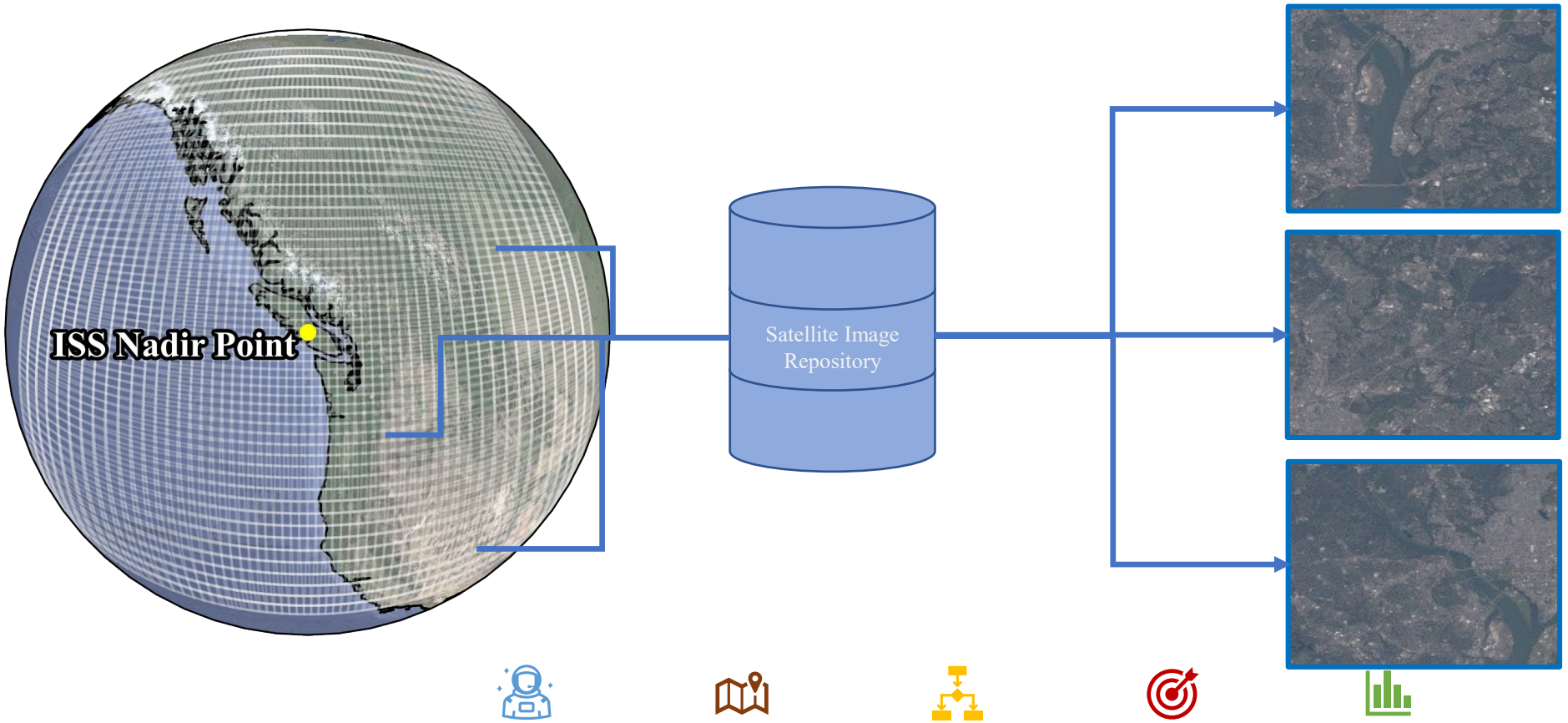
How on Earth do we find where on Earth?

1. **Discretize visible Earth area** into patches based on camera focal length
   - Different focal lengths will result in different ground fields of view and different patches



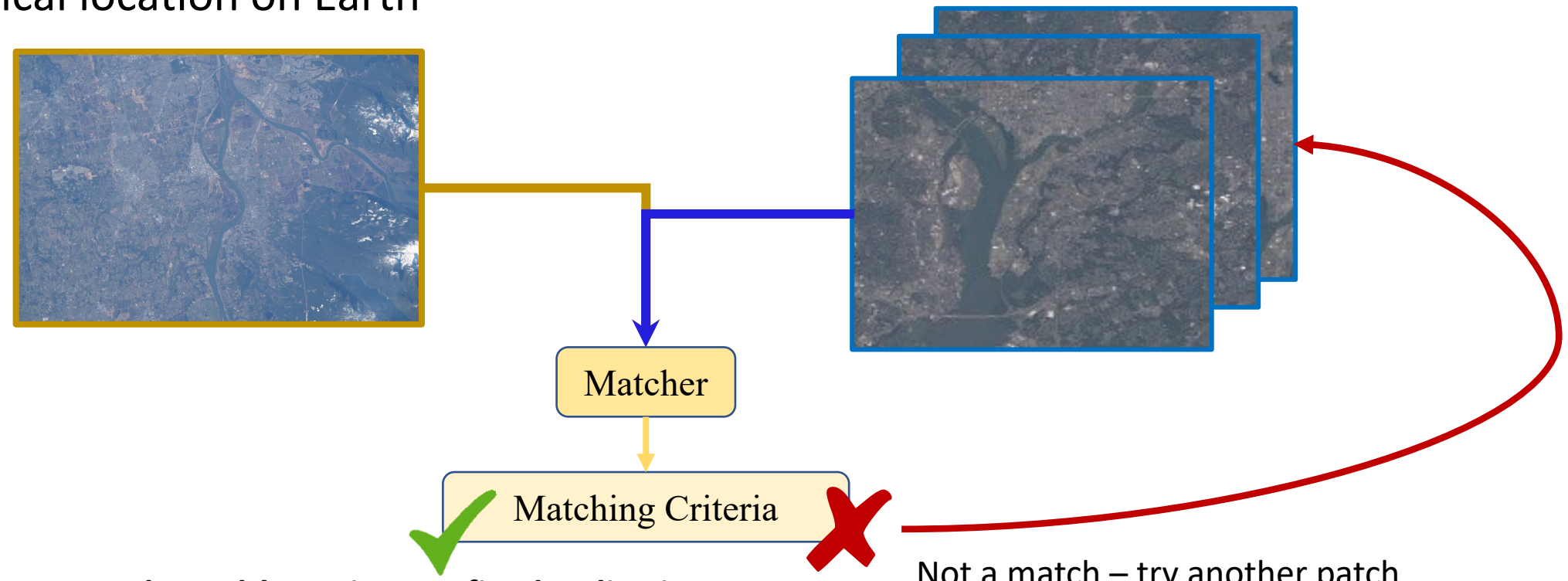
How on Earth do we find where on Earth?

2. For each patch, generate a **satellite reference image** with the extent of the patch
   - Satellite images are geolocated during acquisition

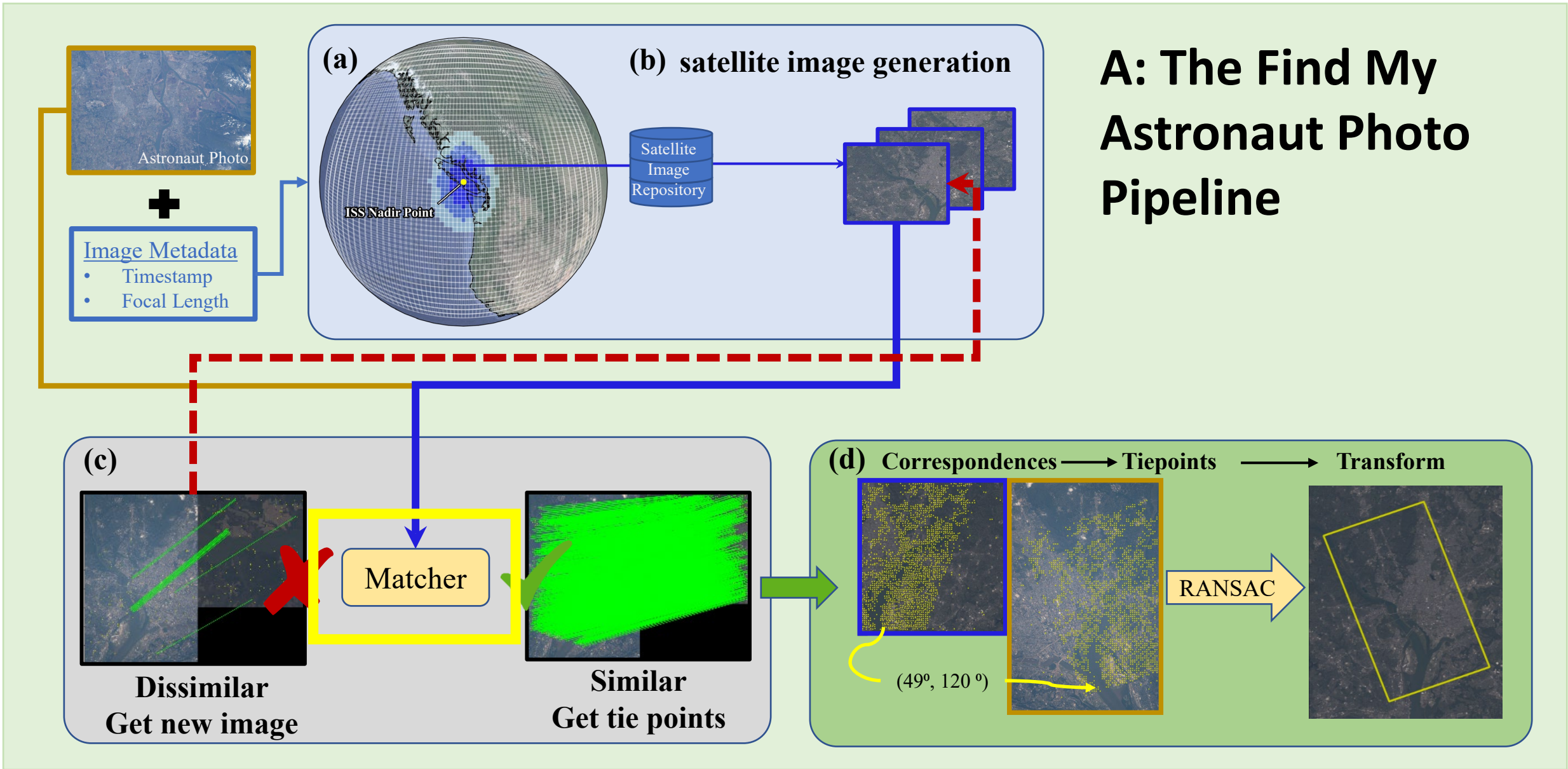


How on Earth do we find where on Earth?

3. Using an image matching method, determine if the patch represents the same physical location on Earth



Q: How on Earth do we find where on Earth?



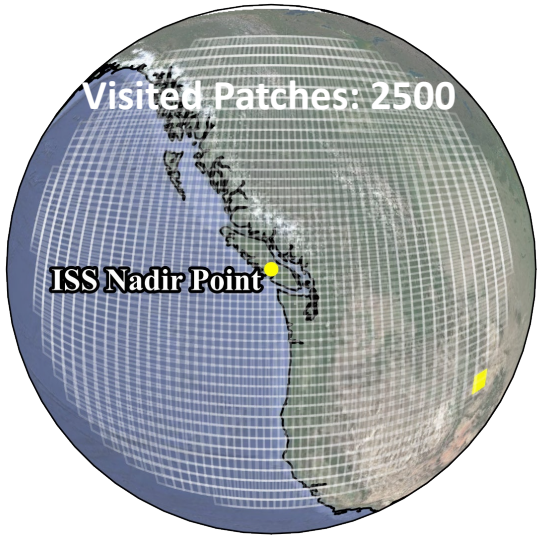
Finding a strong matcher

Challenge

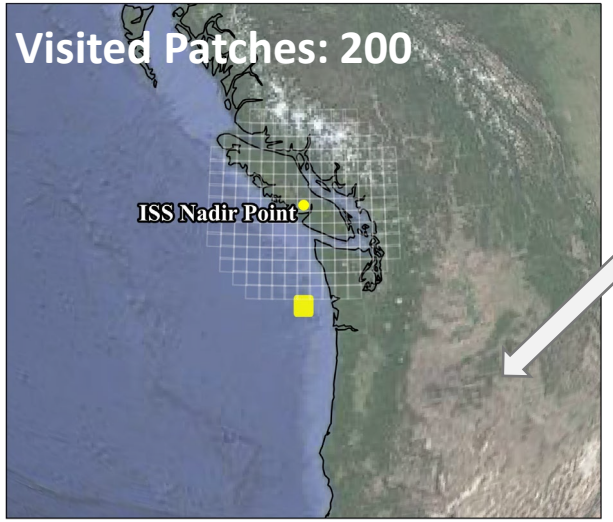
- Finding the **best** match requires checking each patch
  - For higher focal length imagery, there can be 10,000+ patches
  - Checking just one patch is resource intensive

Requirement

- Matcher **must** be discriminative we can determine criteria such that we need not visit every patch if we find a **good** match (**early stopping)**



Good Match



We don't need to check this space!

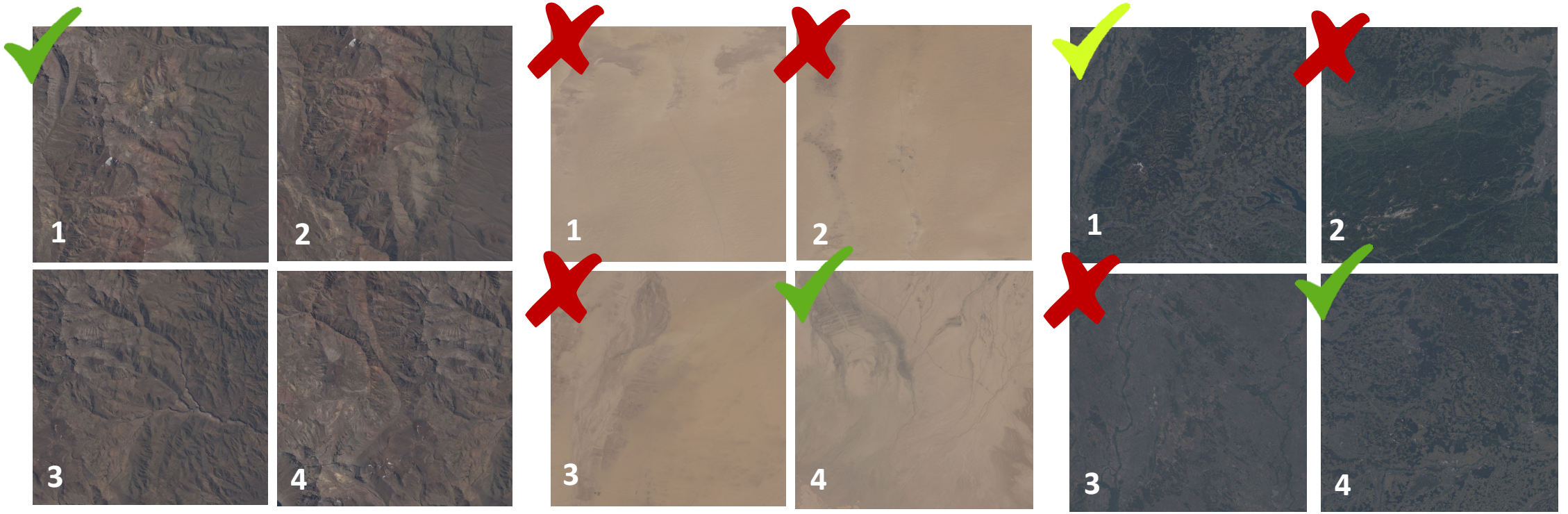
Finding a strong matcher

Challenge

- Many areas on Earth appear similar or have little texture

Requirement

- Matcher and matching criteria must minimize false positives



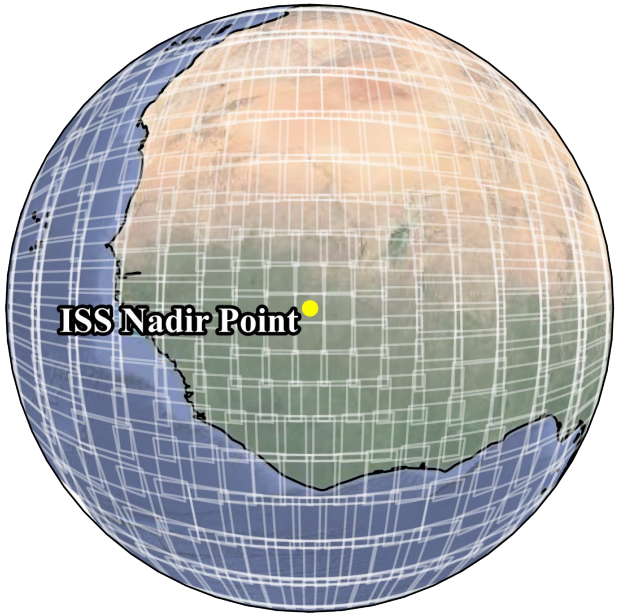
Finding a strong matcher

Challenge

- Each astronaut photo has a unique set of patches that vary in scale and location

Requirement

- We cannot precompute features for patches – no static database
- Scale robustness allows for more leniency in patch generation



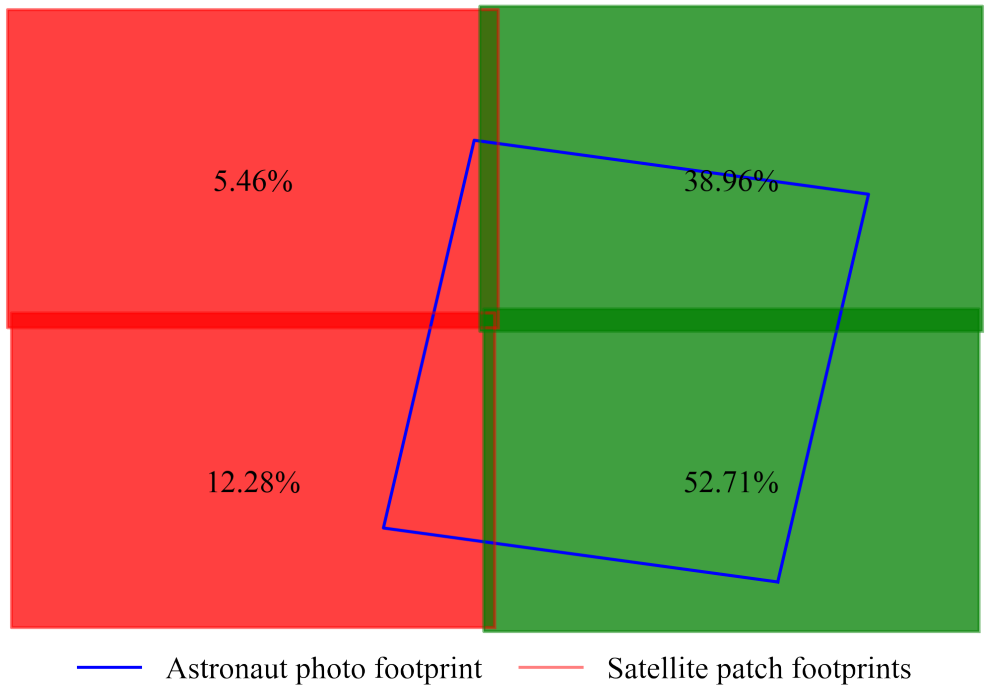
Finding a strong matcher

Challenge

- Patches will have incomplete overlap with astronaut photos

Requirement

- Matcher must be robust to “occlusion”



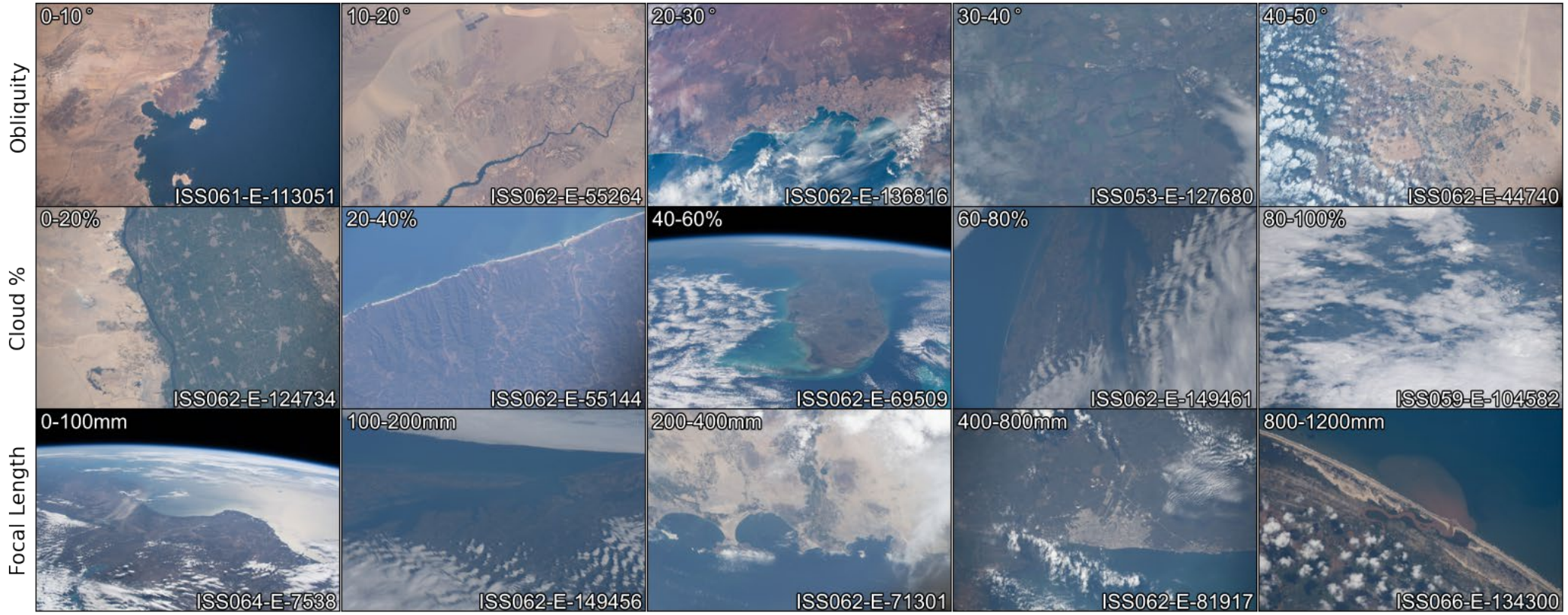
Finding a strong matcher

Challenge

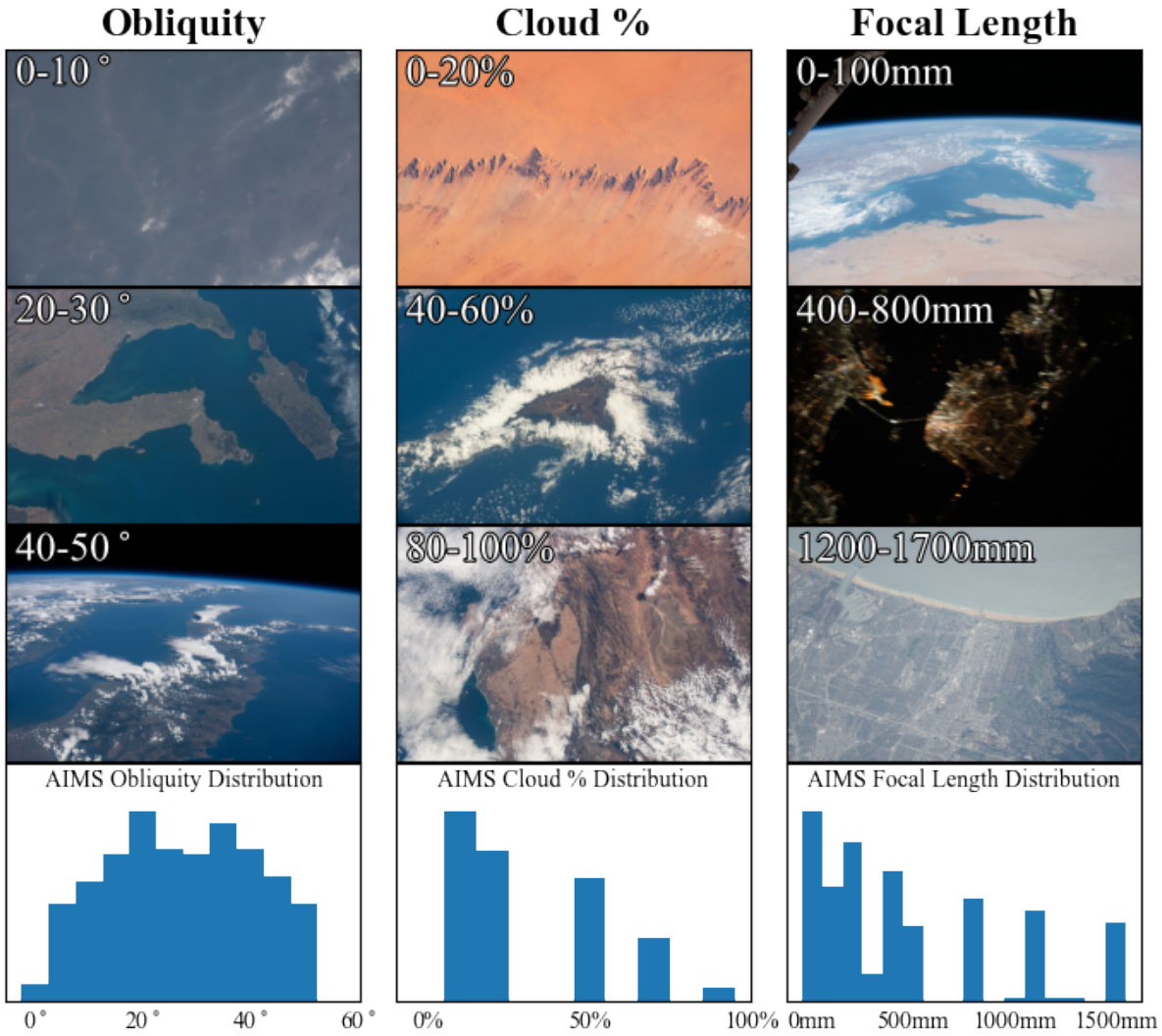
- No canonical orientation (North is not always up)
- Variable illumination conditions and seasonality
- Can be nadir or highly oblique

Requirement

- Robust to rotation, illumination, occlusion, and viewing angle



Astronaut Image Matching Subset (AIMS)



- 323 astronaut photographs with expert human localization information
- Variation across
  - Obliquity
  - Cloud % (occlusion)
  - Focal length (field of view/scale)
  - Orientation (North angle)
- Astronaut photos, patch definitions, ground truth correct patches, satellite reference images released
- Evaluative dataset for image matching

Input	Astronaut photo, indexed satellite ref. images
Output	Index of best matching reference image
Scoring	Precision/Recall

https://eol.jsc.nasa.gov/BeyondThePhotography/AstronautPhotographyImageMatchingSubset

Finding a Discriminative Matcher

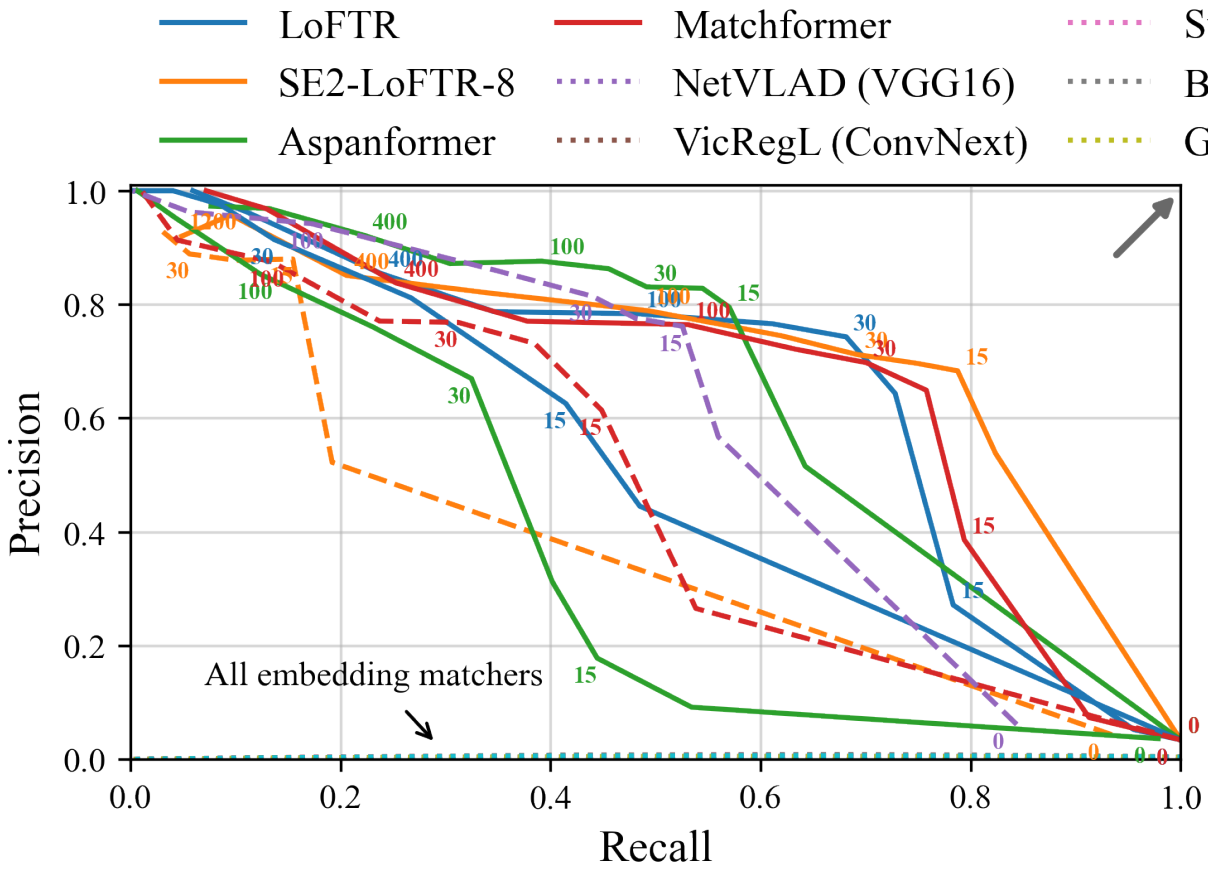
Evaluation

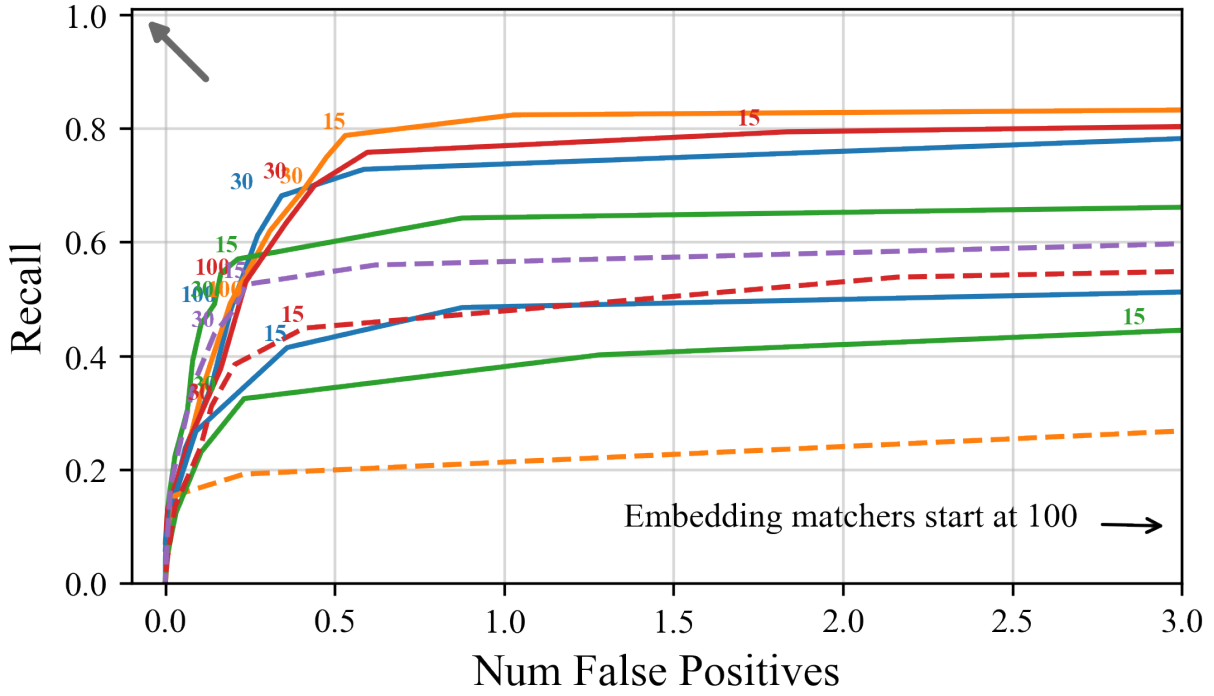
1. Run the Find My Astronaut Photo Pipeline on the AIMS set with each of the matchers to find optimal match criteria
2. Compare models using the optimal criteria for each method
3. For best performing class, evaluate the impact of **image size** and **relative scale**

Matcher Type	Embedding-based	Detector-based	Detector-free
Match Criteria	L2 Distance	Number of Inliers	
	Top-1		
Matcher	NetVLAD (VGG16)	SIFT	LoFTR
	GeM (Resnet-152)	SuperPoint + SuperGlue	SE2-LoFTR-8
	DINO (ViT)	D2-Net	Matchformer
	SwAV (Resnet-50 Wide-5)		Aspanformer
	Barlow Twins (Resnet 50)		Patch2Pix
	VicRegL (ConvNext)		DKM (v2)




Results – Determining Optimal Criteria





- Embedding based matchers **are not discriminate enough** in this setting
- Using **number of inliers** as matching criteria, detector free matchers offer the best trade off between precision and recall

Results - AIMS Set Performance

	Average Precision					
AIMS Split	SE2-L	Aspan	MF	SP-SG	D2-Net	DKM
1.0x scale	**0.61**	0.48	0.56	0.49	0.39	0.38
1.5x scale	**0.52**	0.33	0.44	0.50	0.43	0.32
2.0x scale	0.25	0.21	0.21	**0.41**	0.37	0.25
Low cloud	**0.62**	0.50	0.56	0.52	0.40	0.42
High cloud	0.49	0.36	**0.54**	0.31	0.28	0.14
North up	**0.62**	0.47	0.55	0.56	0.47	0.47
All other	**0.51**	0.09	0.06	0.14	0.06	0.04

- Detector based matchers most robust to **scale** changes
- Matchformer is most robust to **occlusion**
- SE2-LoFTR is most robust to **rotation** (it is trained specifically for this setting)
- Other matchers are quite poor for large rotations

We choose **SE2-LoFTR** to power Find My Astronaut Photo



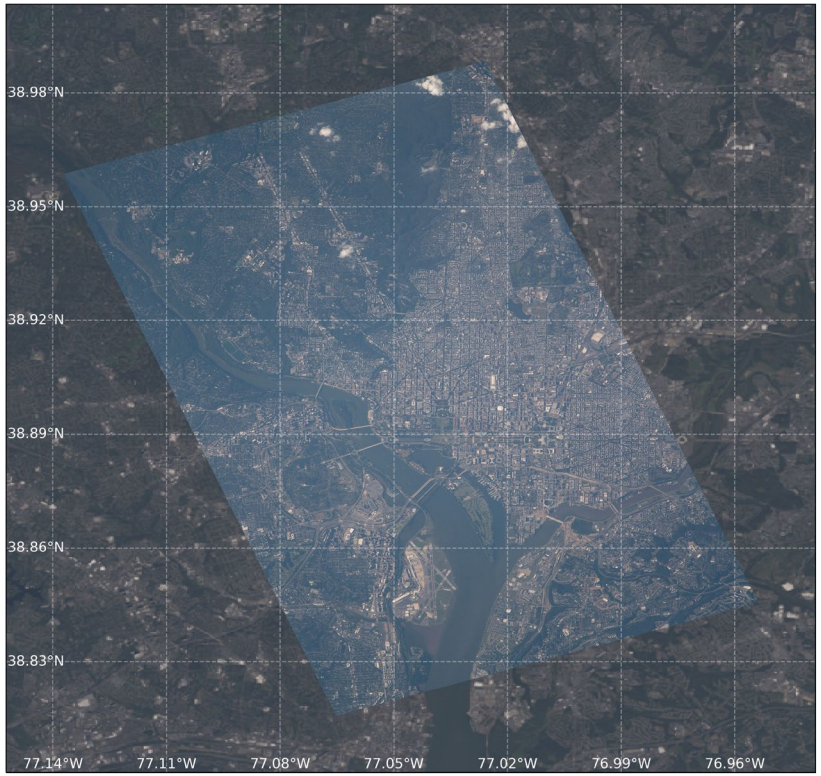


Results

Acknowledgements and Next Steps

Total Images Found: 57,354

- Explore additional matchers and matching methods
- Engineering improvements to the pipeline to increase per photo speed
- Add support for nighttime photography



Thanks to the Image Matching Workshop organizers, reviewers, and the image matching community!

https://eol.jsc.nasa.gov/

Results