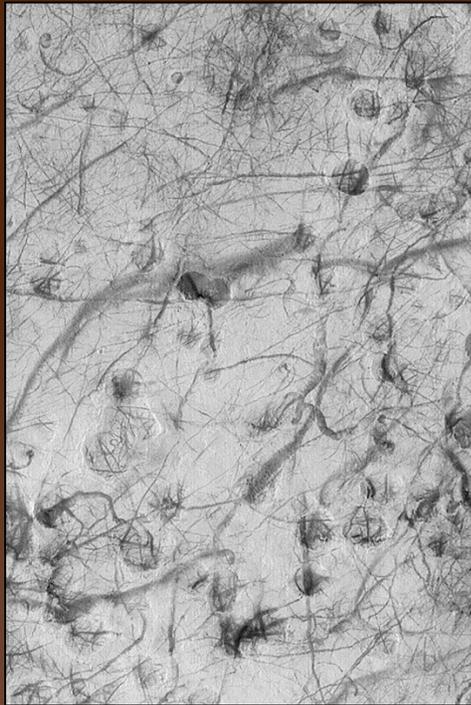




# Detecting Changes on Mars with Dynamic Landmarking



MOC E11-02045 (5/03)

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MOC S13-00818 (12/06)



# Dynamic Landmarking

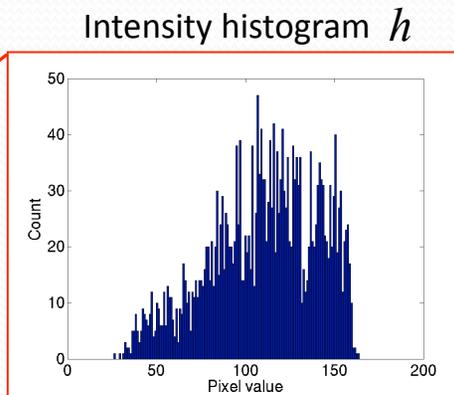
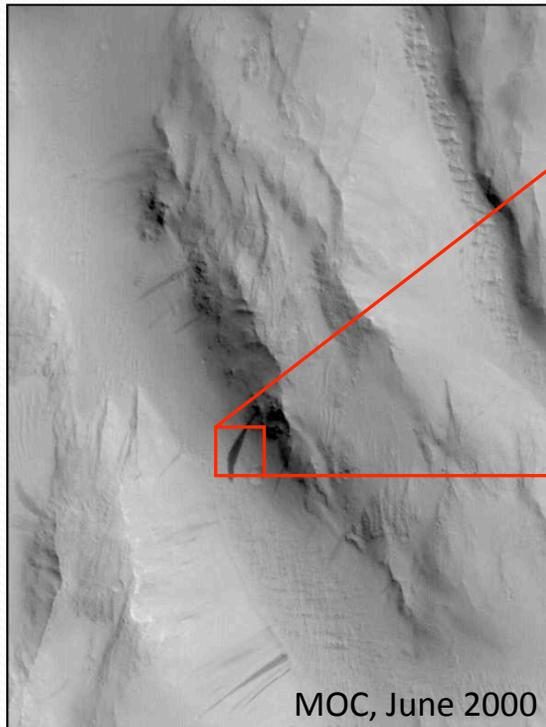


What is interesting?

# Landmark Detection: Contrast-Weighted Histogram Saliency

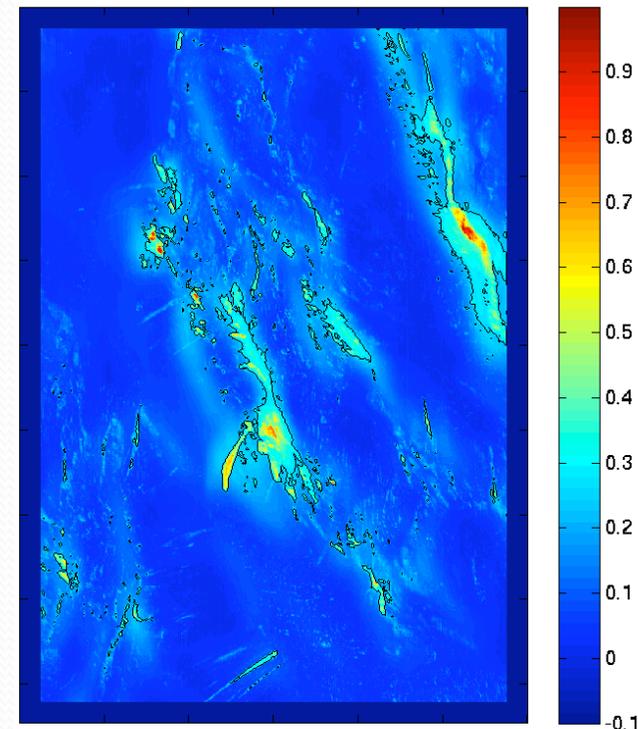
- For each pixel, compute saliency with respect to window

$$S(p) = \sum_{i=0}^{255} h(i) |p - i|$$



Auto-select saliency  
threshold,  
filter small landmarks

Saliency Map (win=50x50)





# Landmark Detection Results

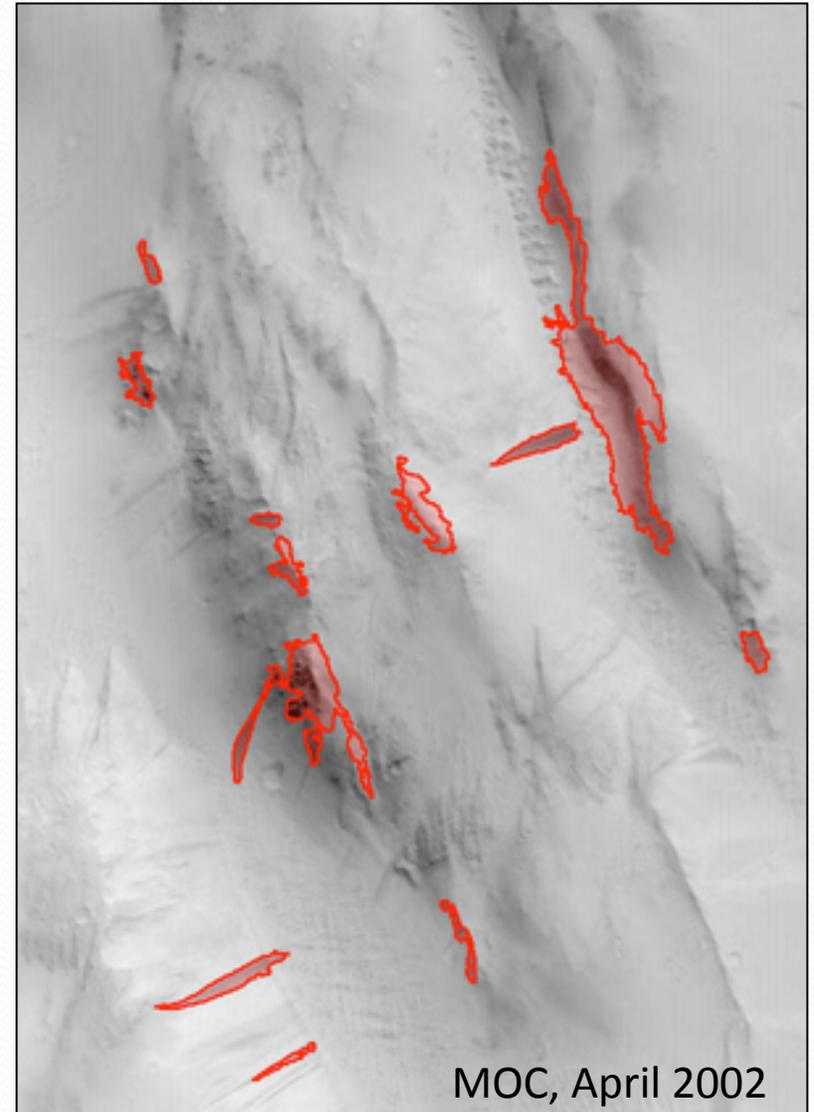
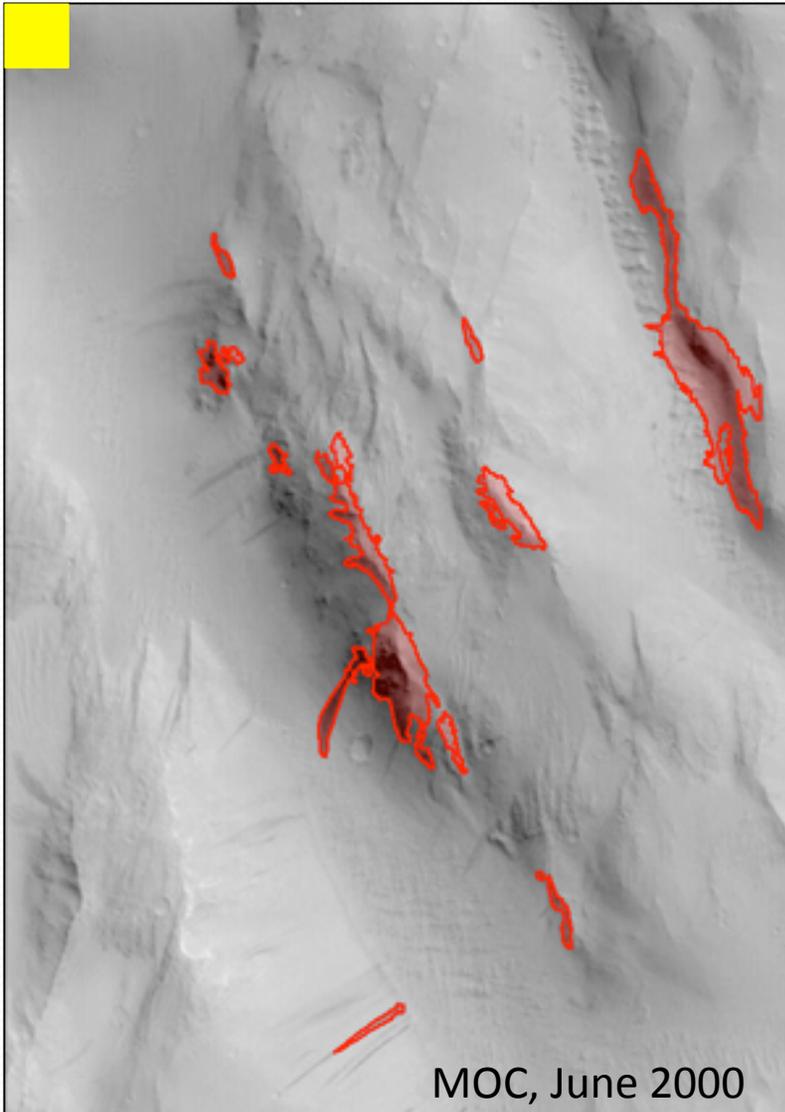


MOC, June 2000



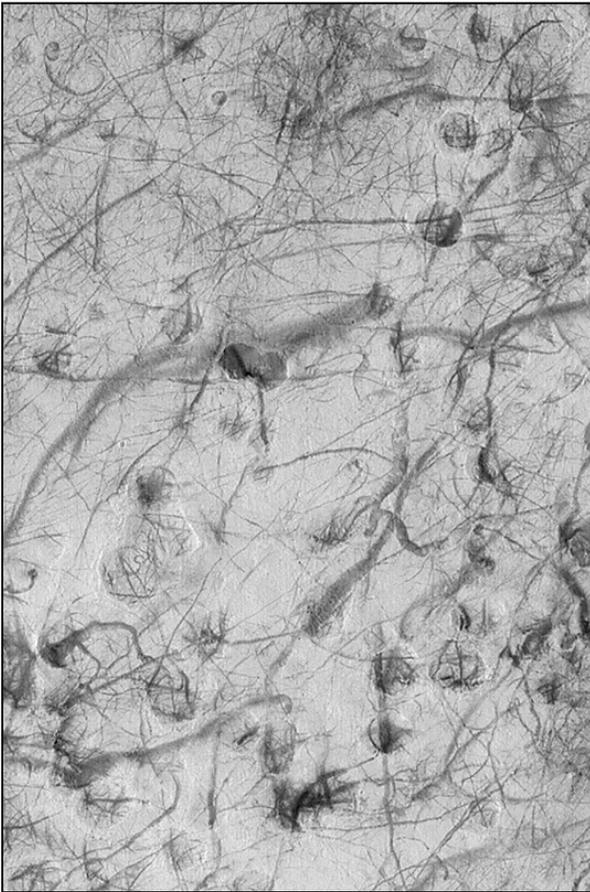
MOC, April 2002

# Landmark Detection Results

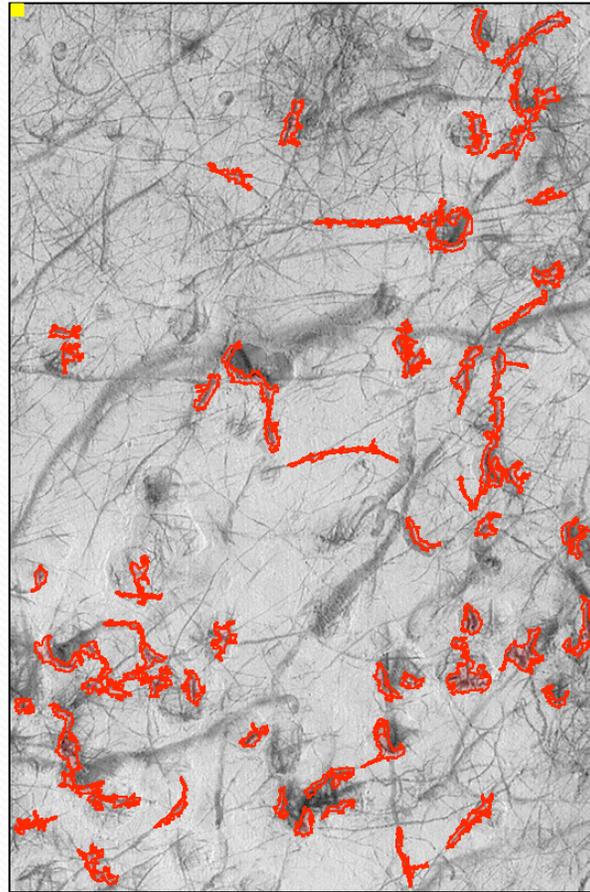


# Landmark Detection: Dust Devil Tracks

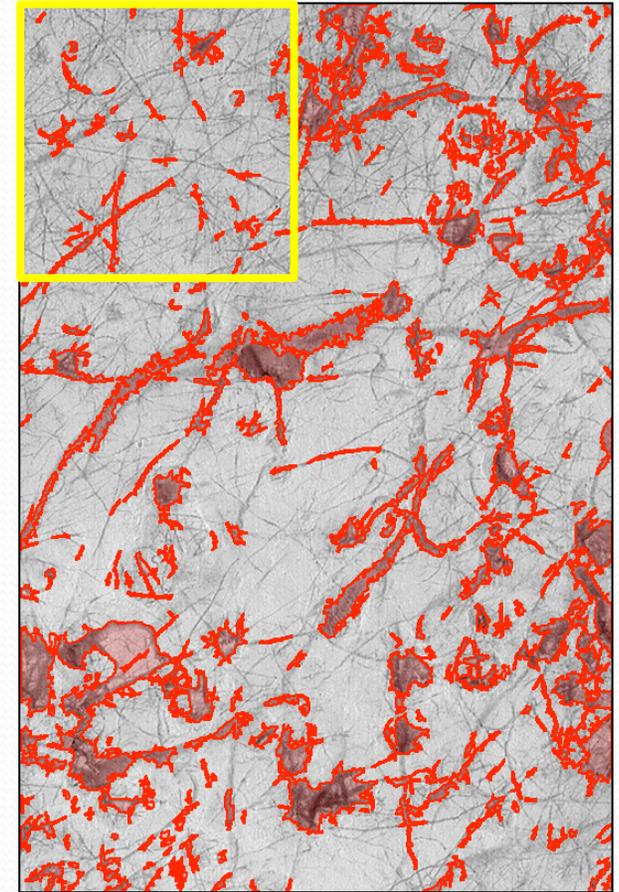
MOC E11-02045



Window size = 10



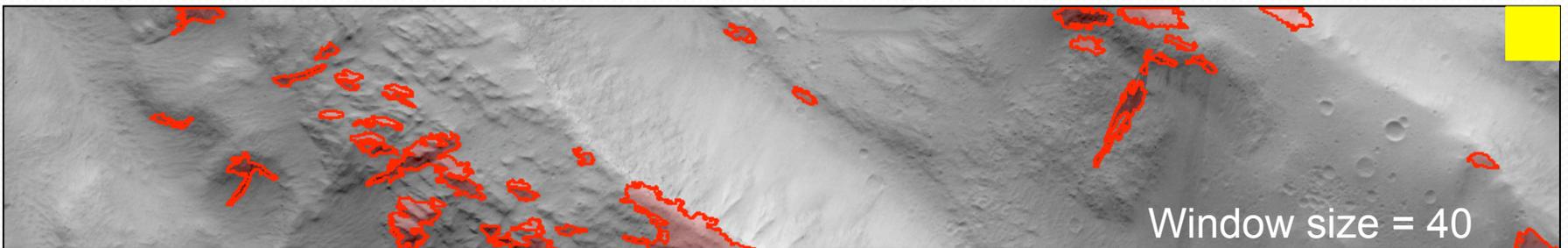
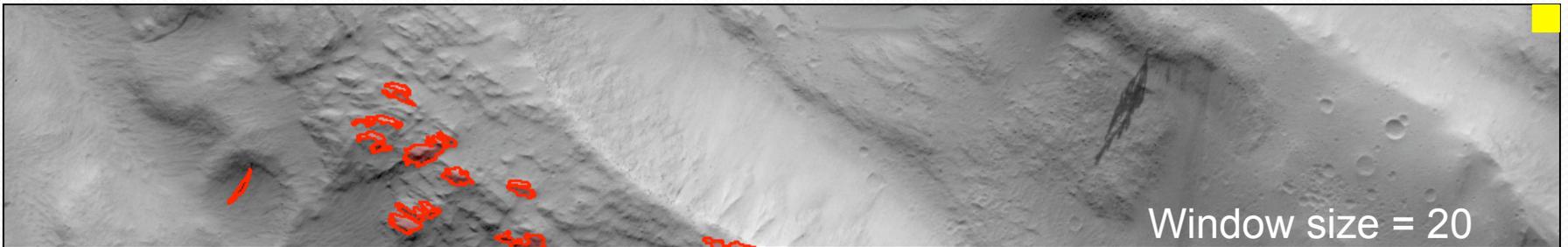
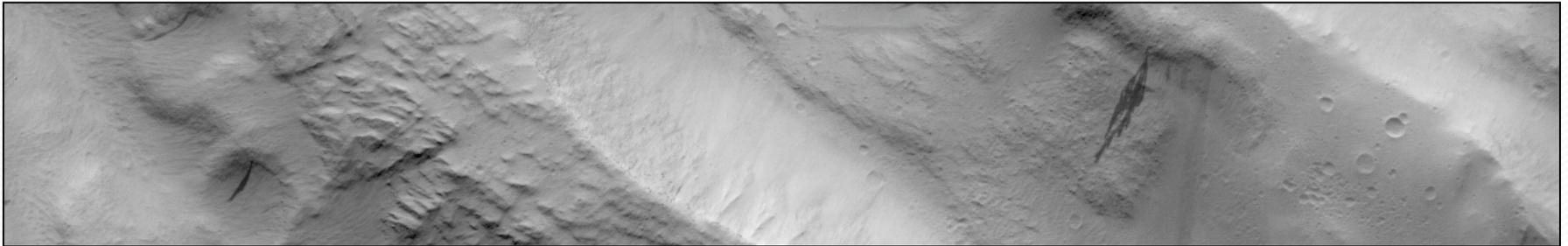
Window size = 250





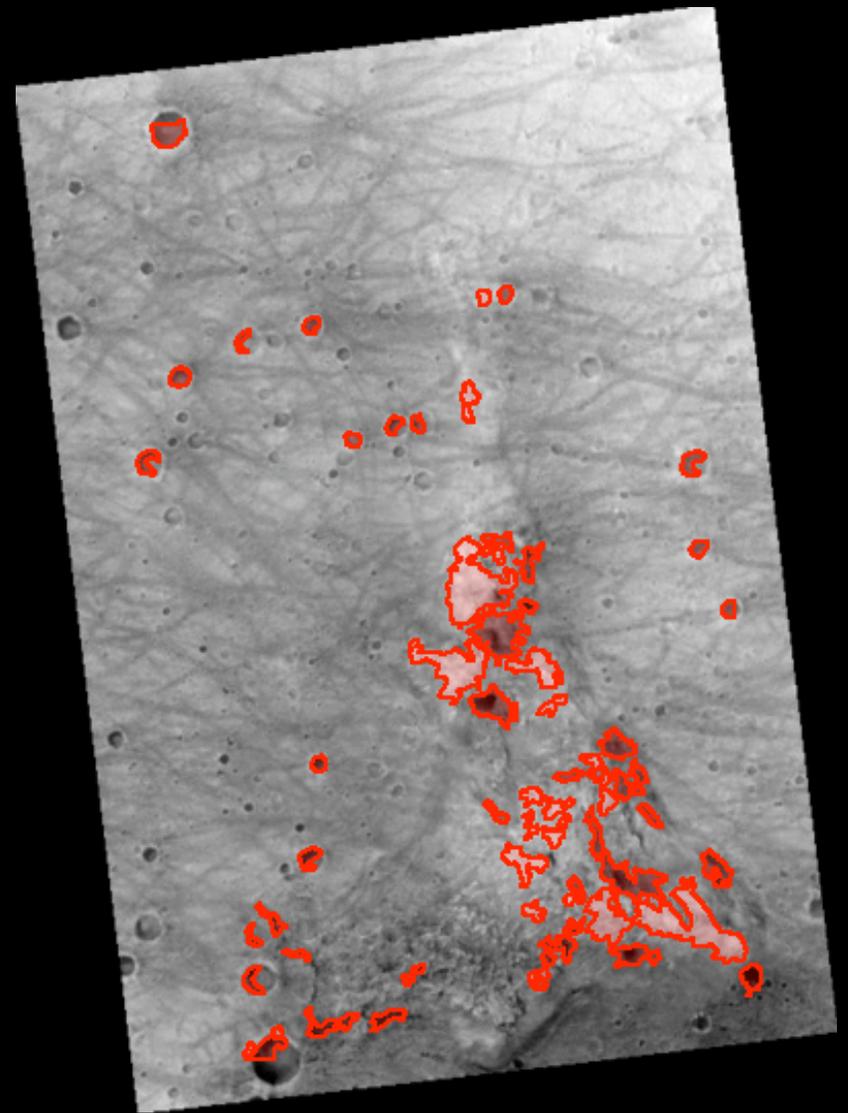
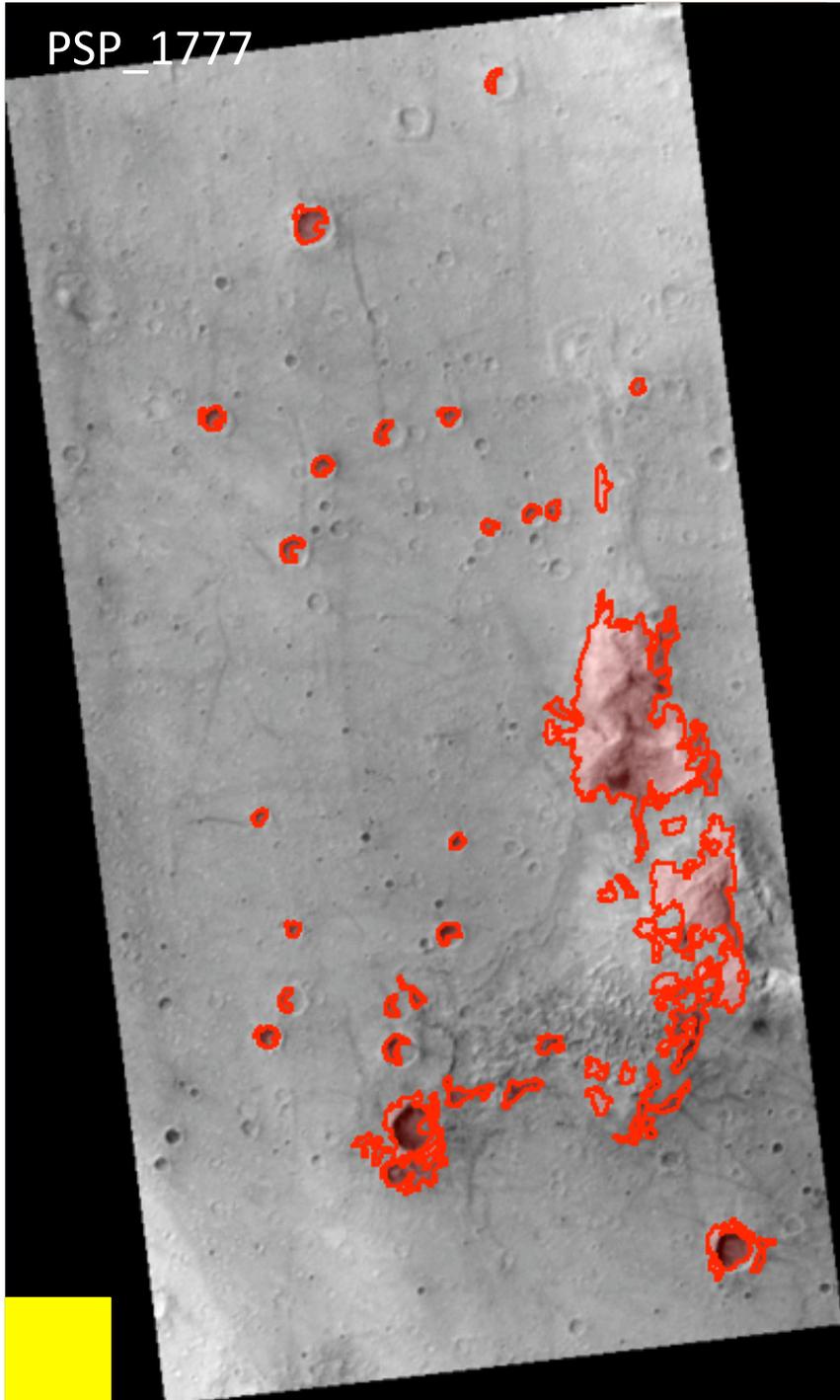
# Landmark Detection: Dark Slope Streaks

MOC E03-02374



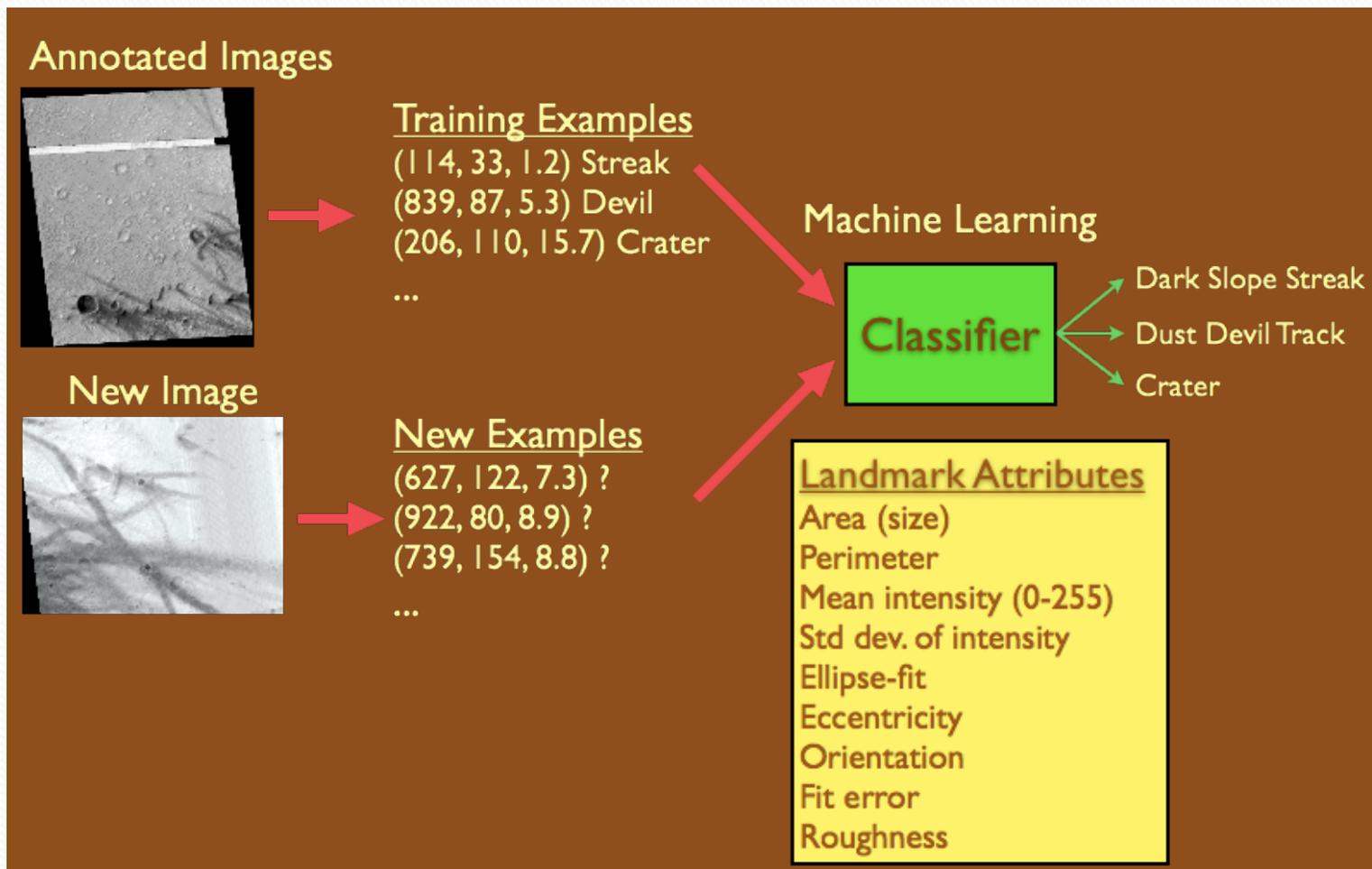
PSP\_1777

PSP\_3689



# Landmark Classification

- Machine Learning classifier, using extracted attributes

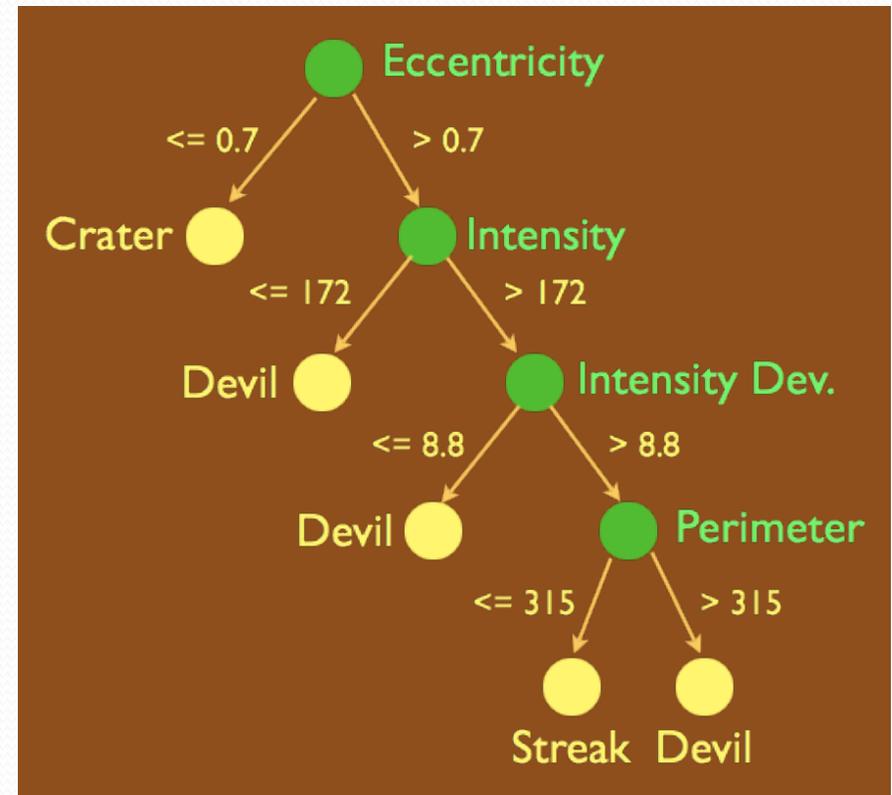


# Learned Classifiers

- Based on 767 manual landmarks
  - 41 craters
  - 70 dark slope streaks
  - 656 dust devil tracks

Classifier	Accuracy
Neural Network	95%
Decision Tree	94%
Support Vector Machine	91%

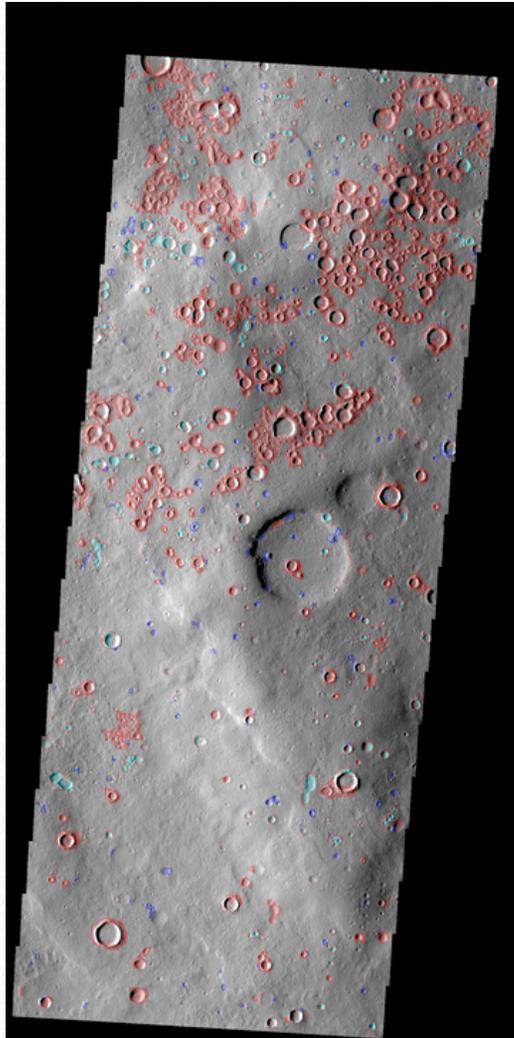
Learned Decision Tree



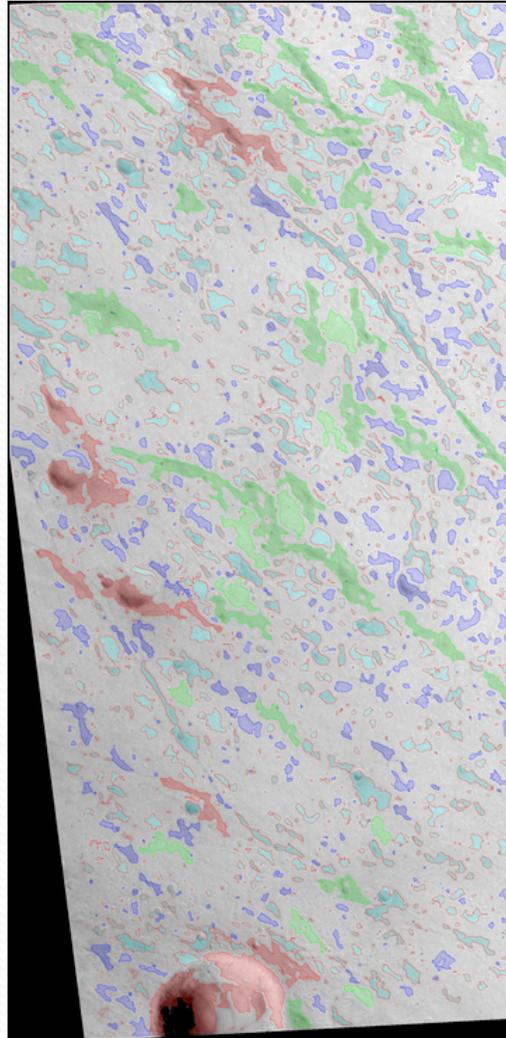


Crater  
Devil  
Streak  
Unknown

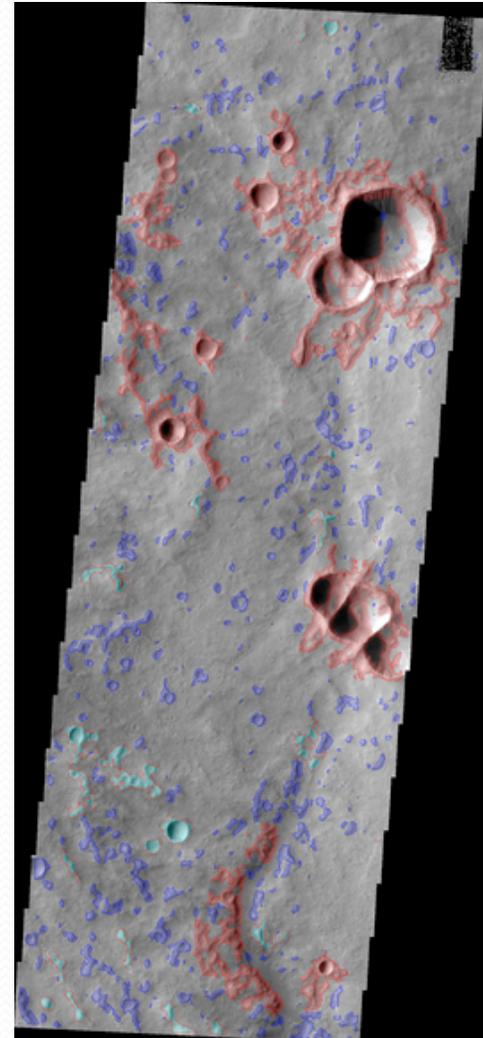
# Classified Landmarks



THEMIS



MOC



THEMIS

# Change Detection



+

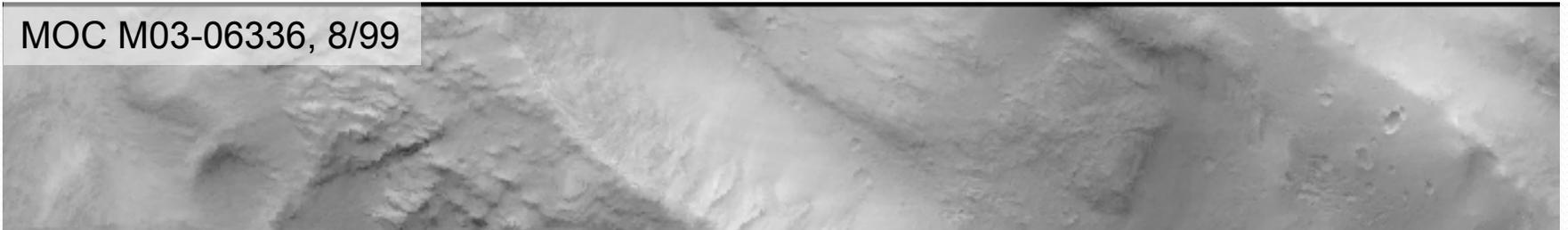


= ?

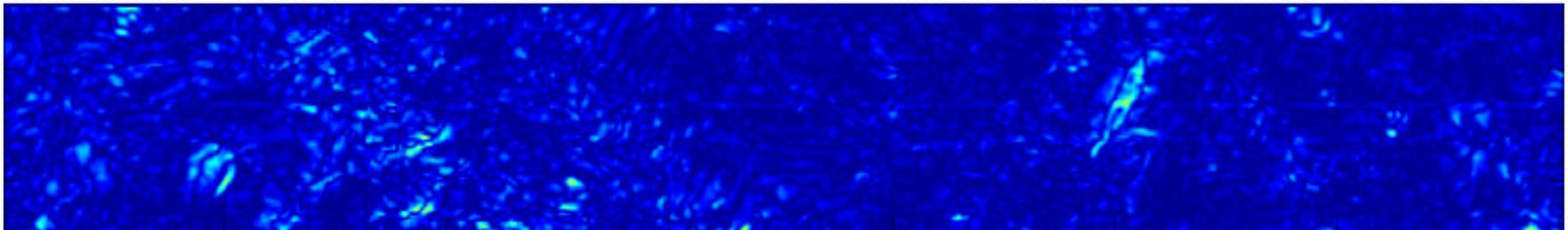


# Change Detection: Image Registration and Differencing

MOC M03-06336, 8/99



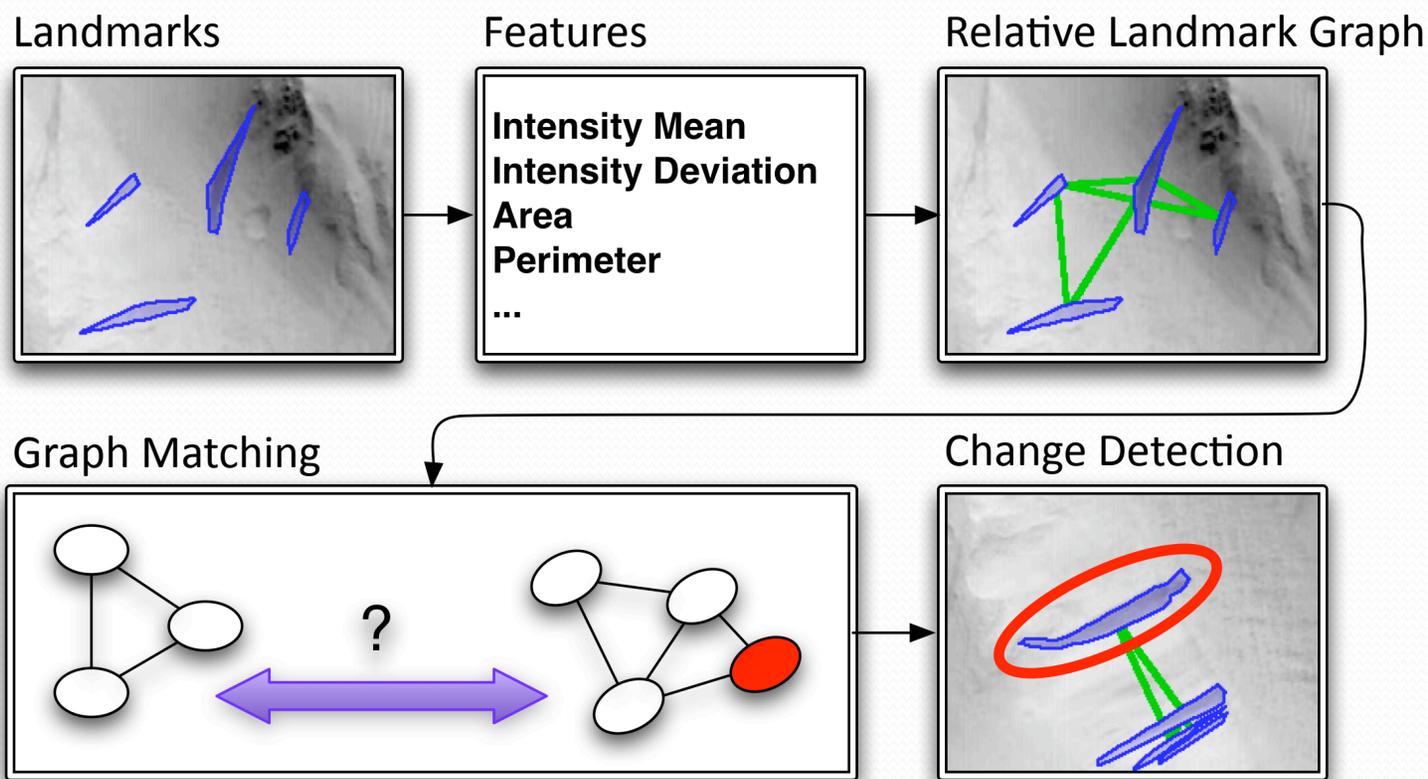
MOC E03-02374, 4/01



To interpret changes, can perform landmarking on difference image.



# Change Detection: Landmark Graph Matching



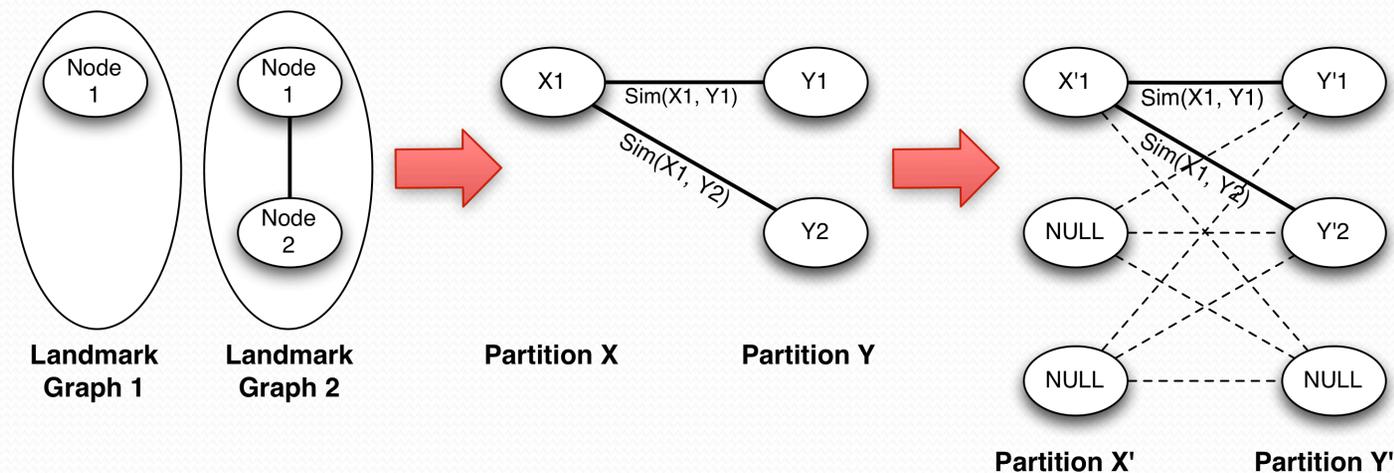
Julian Panetta (Caltech), summer internship, 2009

# Landmark Matching

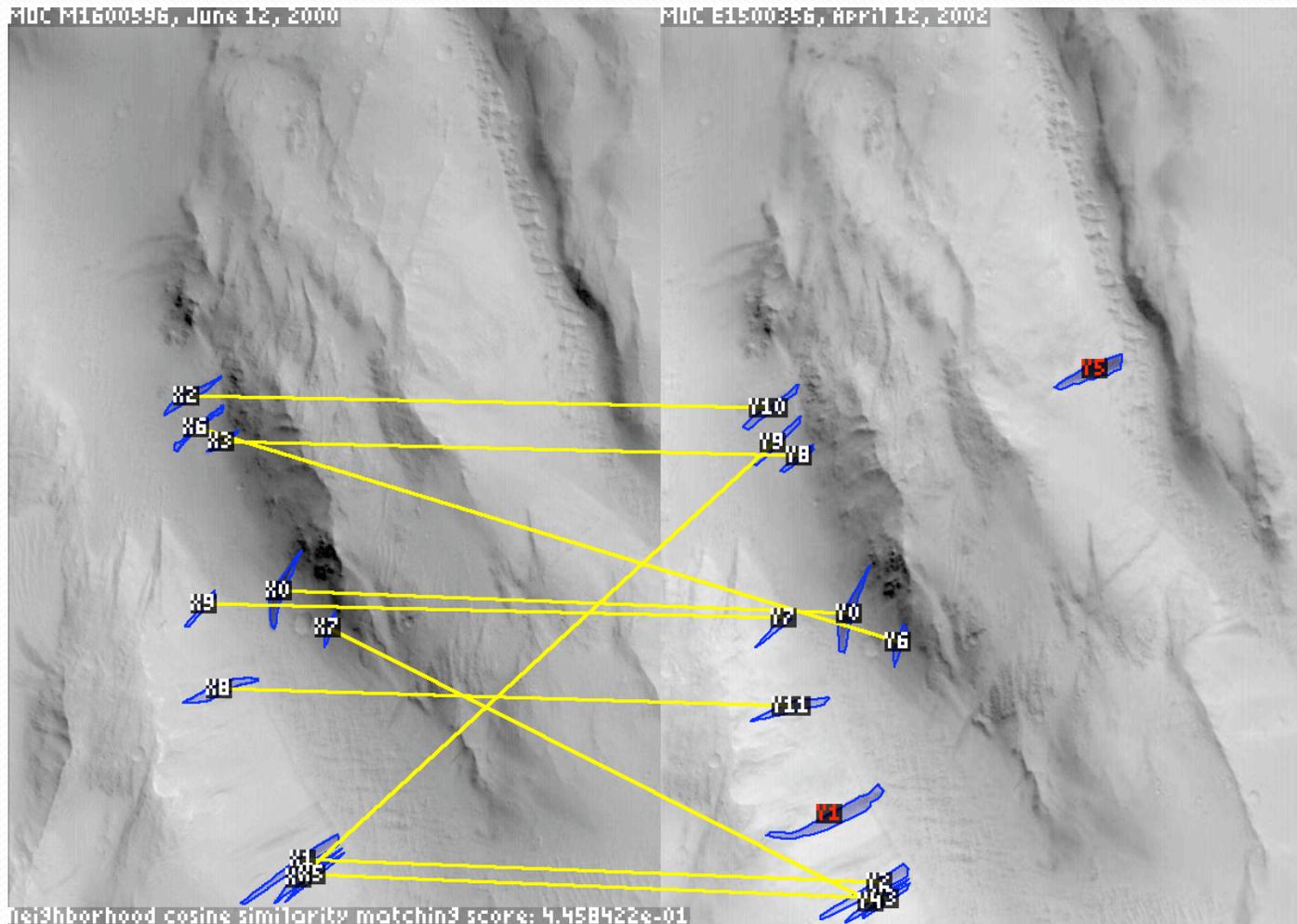
- Hungarian/Kuhn-Munkres algorithm [Kuhn, 1955]:
  - Finds best assignment (matching), using landmark similarity

$$Similarity(L_1, L_2) = \frac{F(L_1) \cdot F(L_2)}{\|F(L_1)\| \|F(L_2)\|}$$

- We allow non-matches by adding “dummy landmarks” (with similarity 0)



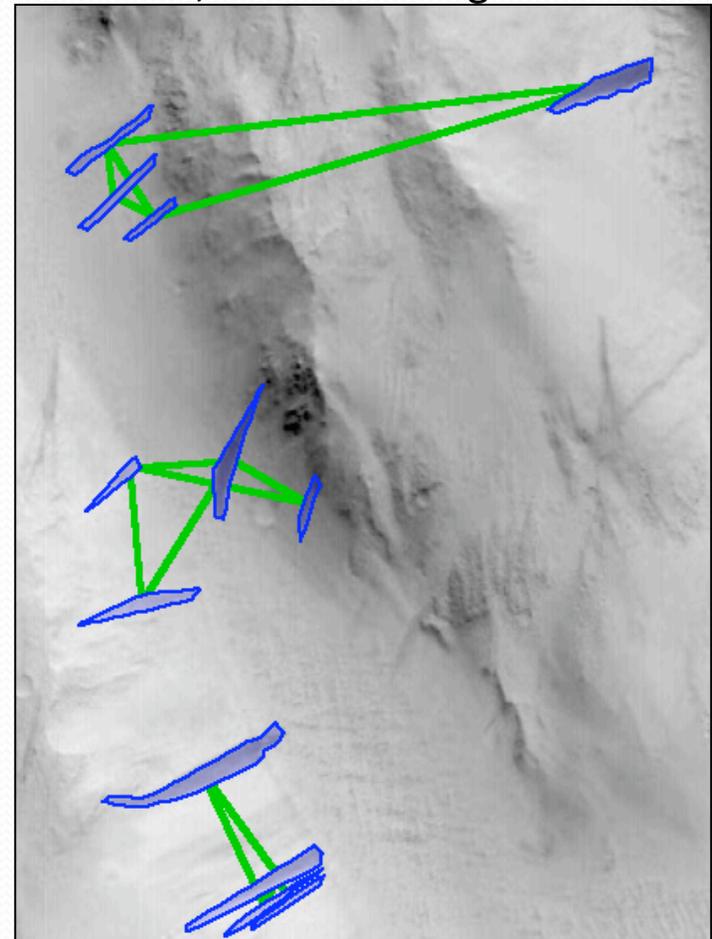
# Changes in Manual Landmarks (k=0)



# Relative Landmark Graph

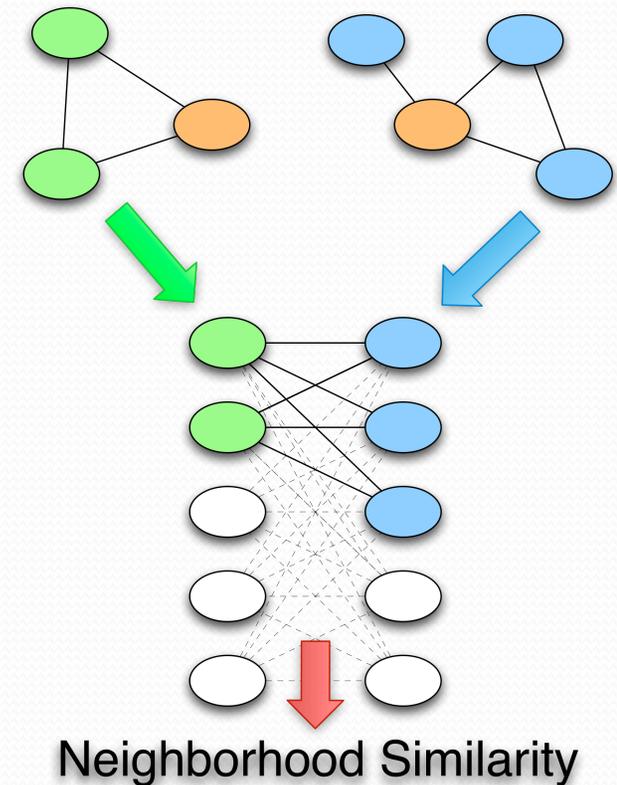
- Invariance to camera orientation
- Nodes: landmarks + features
  - Intensity, area, perimeter, ellipse fit, etc.
- Edges: k-nearest neighbors
  - Using Euclidean distance
  - Choice of k?

RLG, 2 nearest neighbors



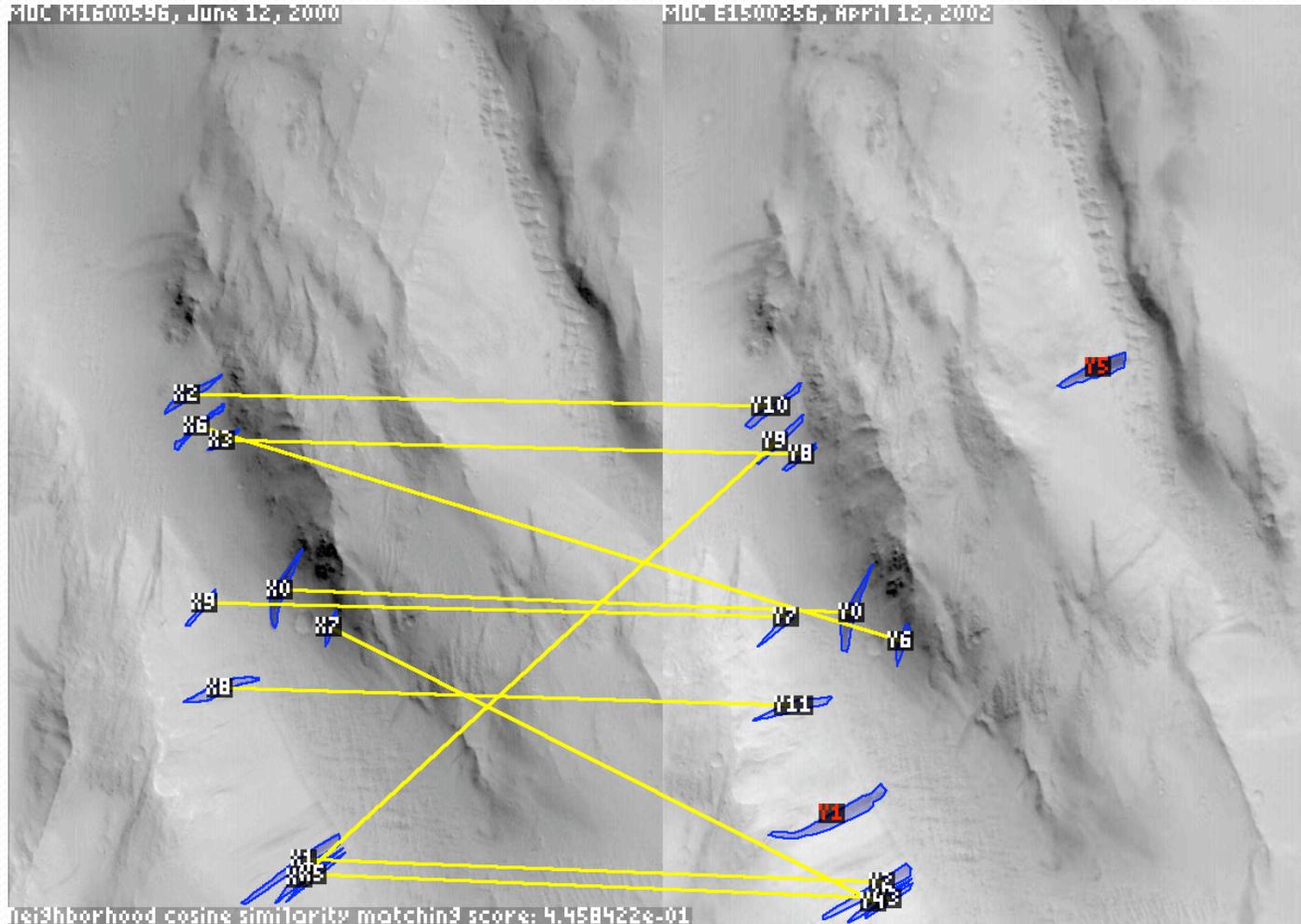
# RLG Graph Matching

- Regular matching ignores connectivity
- Solution:
  - Motivated by [Chevalier et al., 07]
  - Augment landmark similarity with neighborhood similarity
  - Average to get match score





# Changes in Manual Landmarks (k=0)



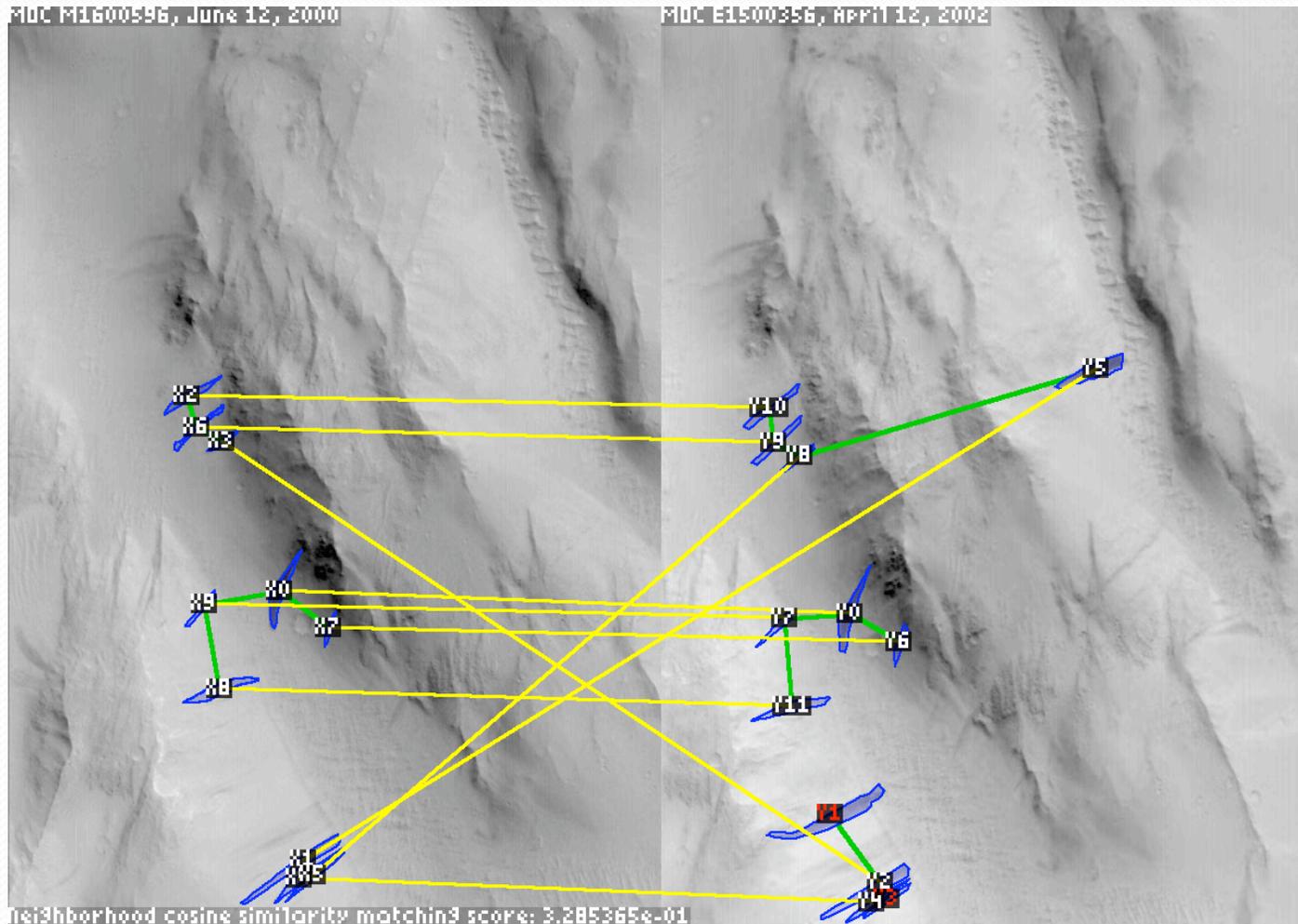
RLG Edges  
Matching  
New

6/10 correct  
matches

2/2 correct  
changes

2 new streaks

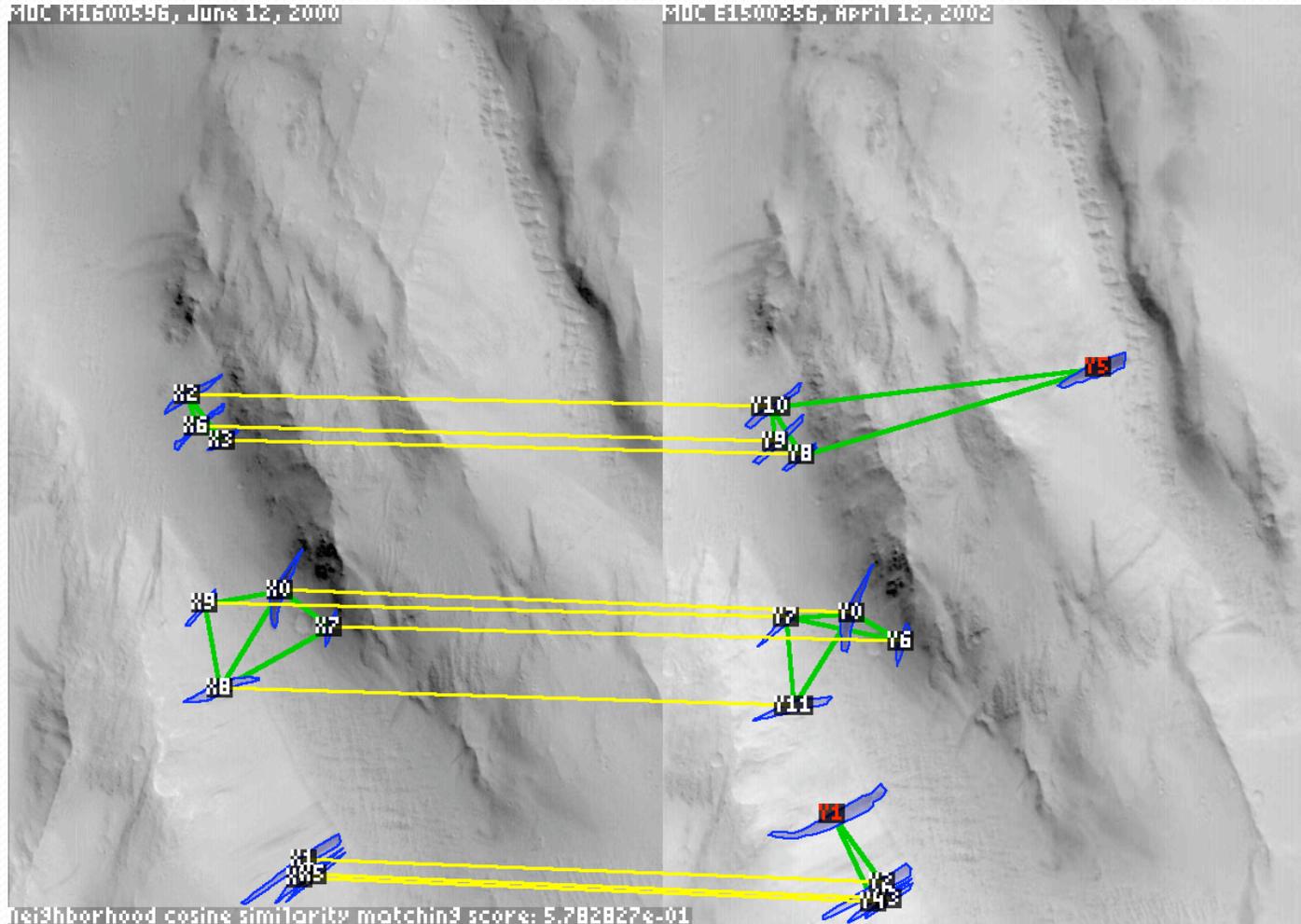
# Changes in Manual Landmarks (k=1)



2 new streaks



# Changes in Manual Landmarks (k=2)



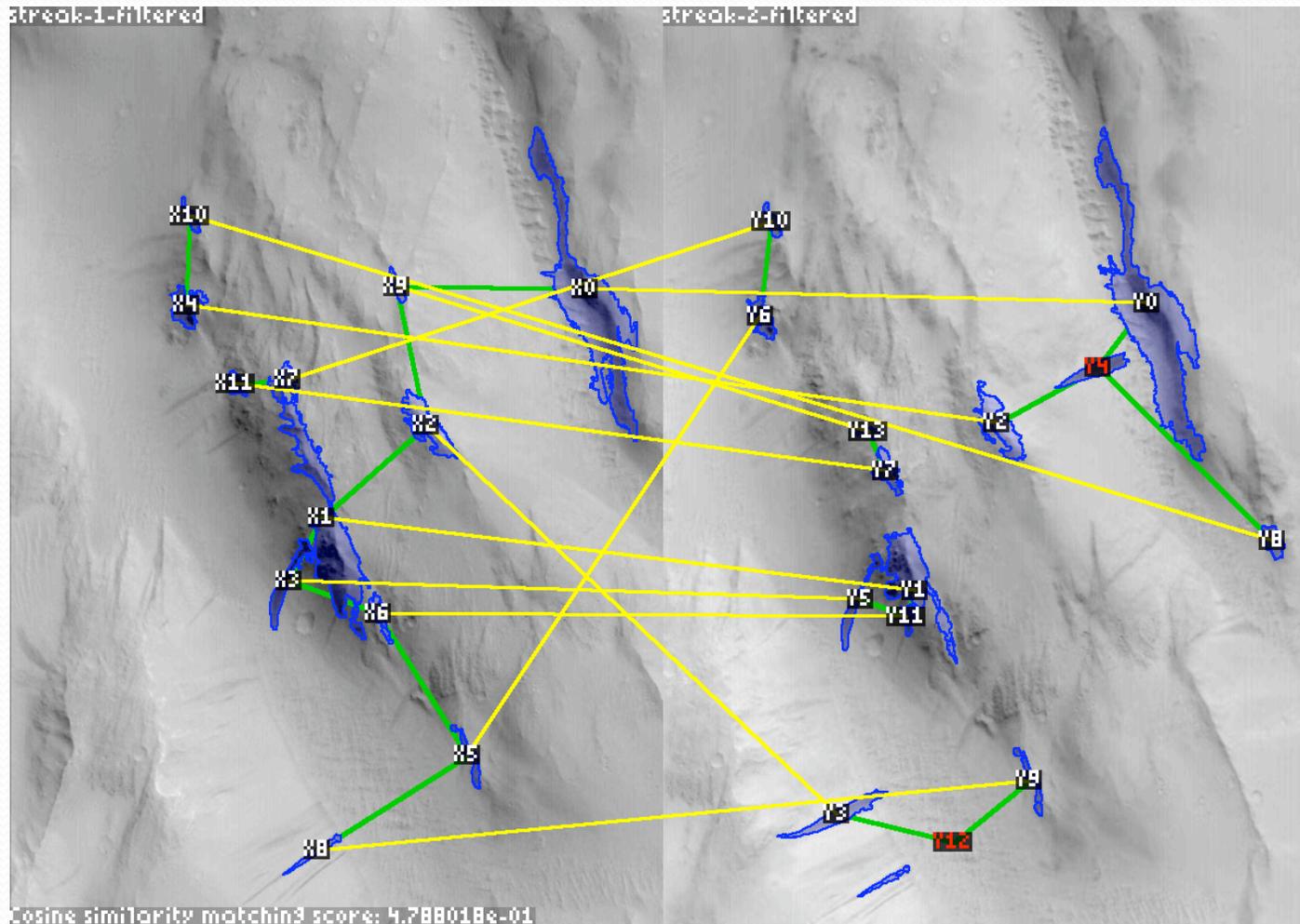
RLG Edges  
Matching  
New

10/10 correct matches

2/2 correct changes

2 new streaks

# Changes in Detected Landmarks



RLG Edges  
Matching  
New

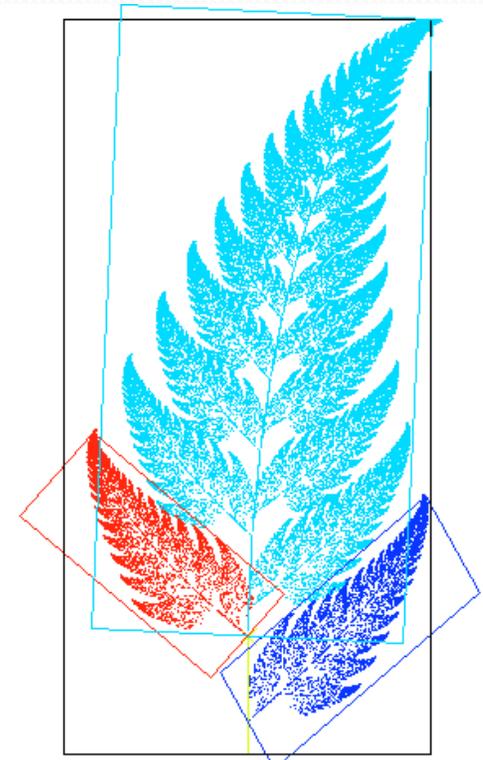
3/12 correct matches

1/2 correct changes

2 new streaks

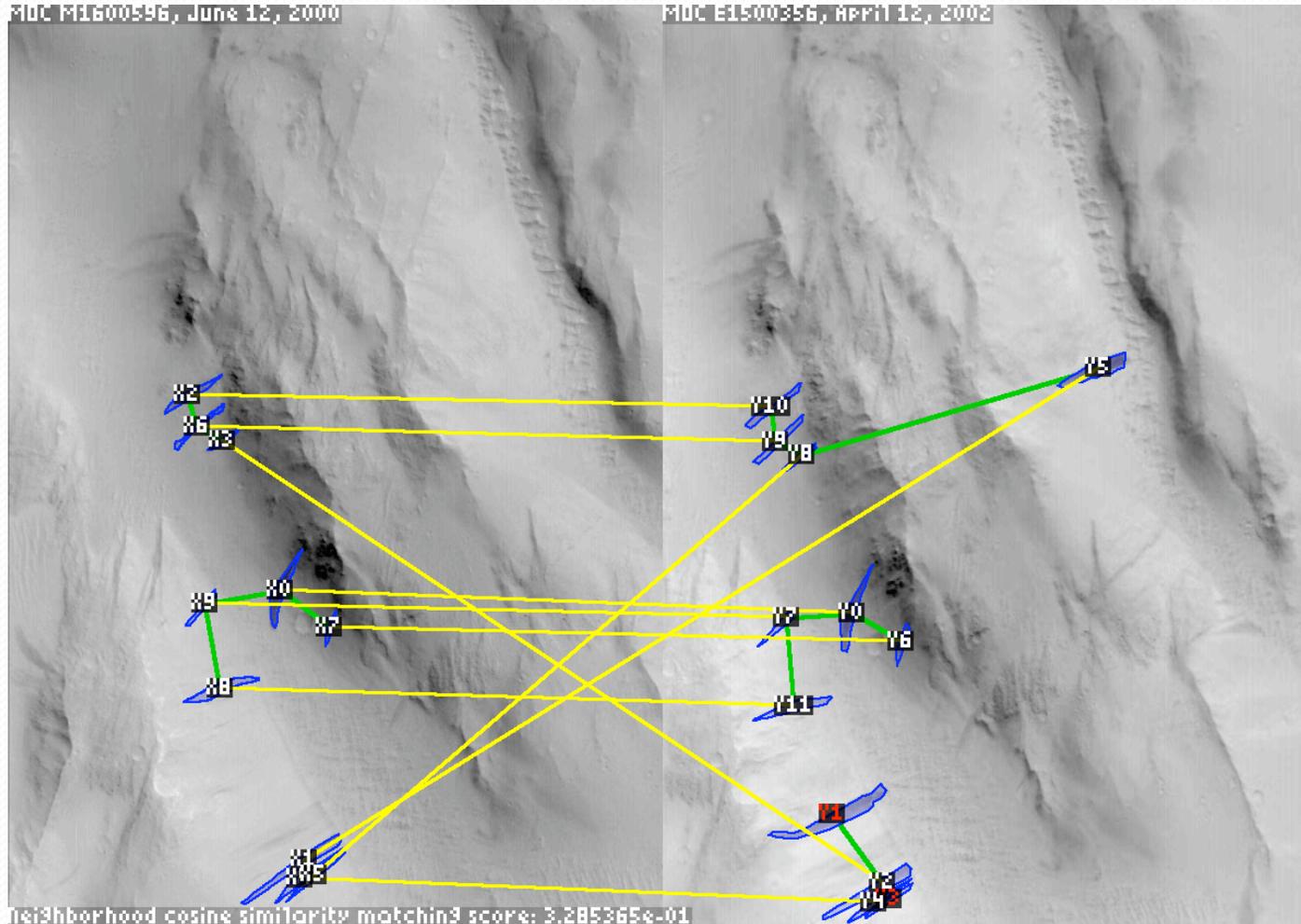
# More Robust: Affine Transformation

- Mars and landmarks form a rigid surface
  - Landmarks cannot arbitrarily move around
  - Affine: rotation, translation, scaling, shear
- Enforce affine transformation
  - Start with initial RLG-based matching
  - RANSAC [Fischler & Bolles, 1981]: repeatedly pick 3 matched pairs, estimate affine transform, compute match error, pick best
    - Match error: sum of distances from landmarks to closest match, after transform is applied
  - Assign match using transform
    - Can detect both new and vanished!



Affine self-similarity

# Changes in Manual Landmarks (k=1)



RLG Edges  
Matching  
New

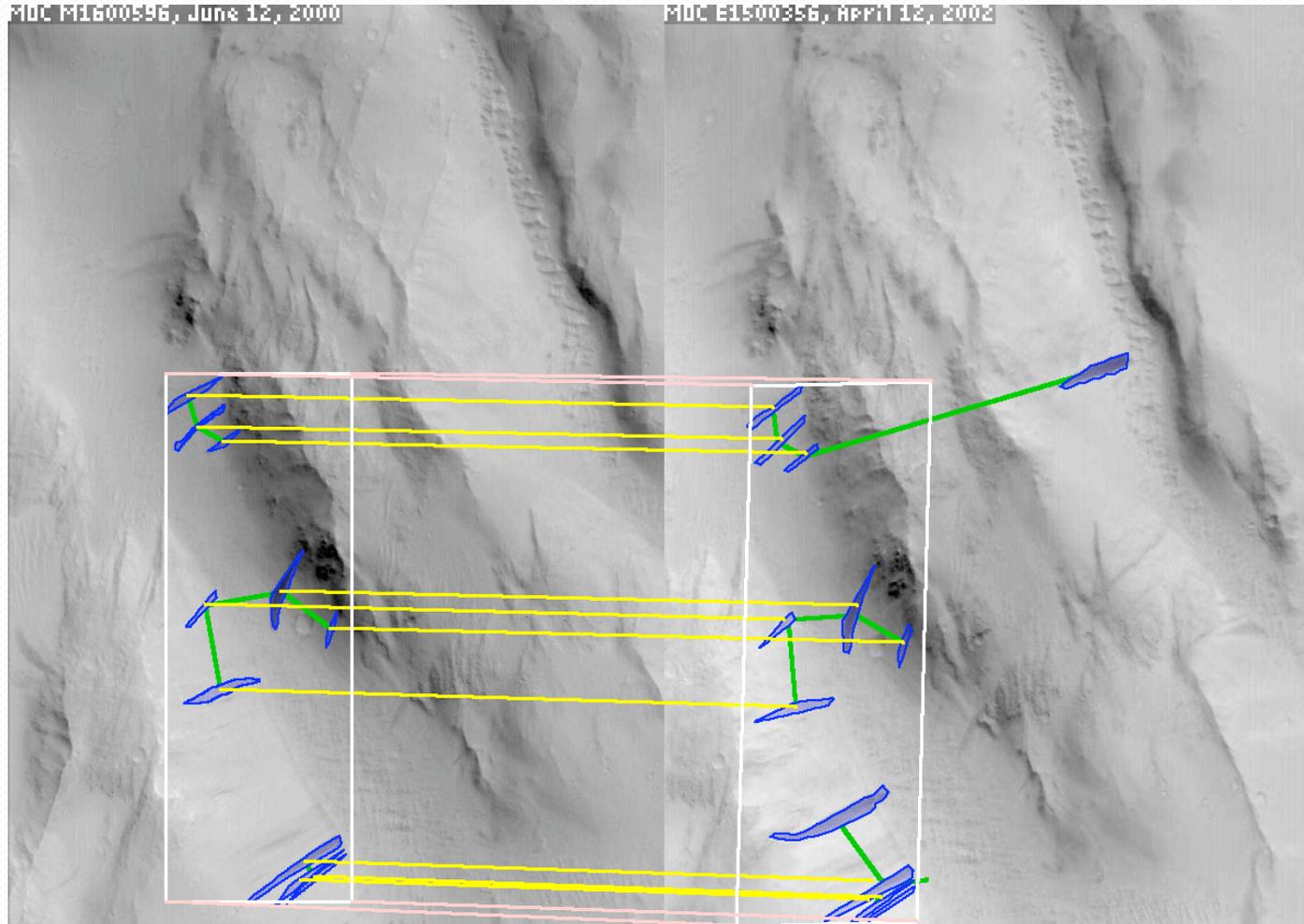
7/10 correct matches

1/2 correct changes

2 new streaks



# Manual Landmarks (k=1) w/Affine



RLG Edges  
Matching  
New  
Transform

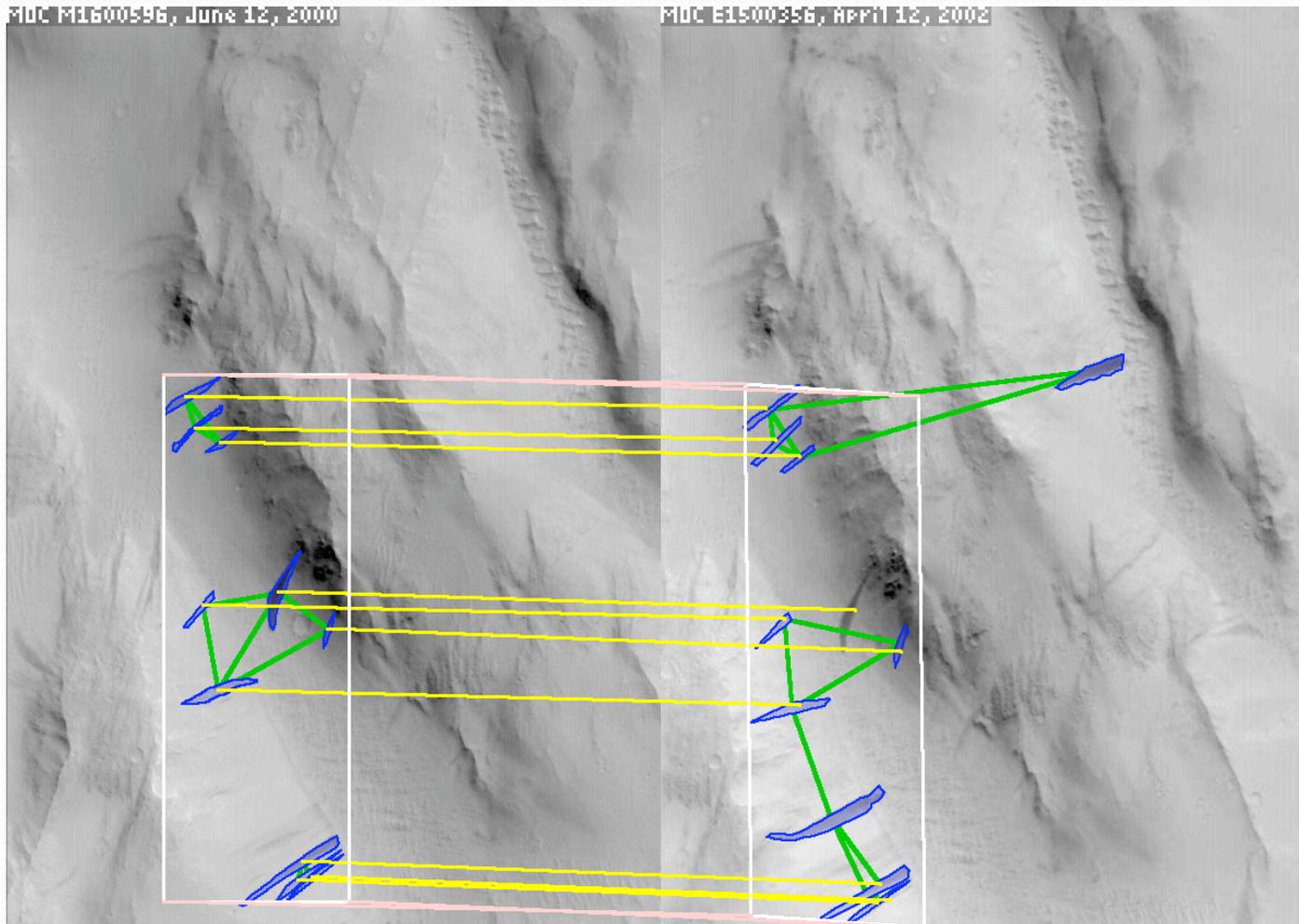
10/10 correct matches

2/2 correct changes

2 new streaks



# Detecting New and Vanished



RLG Edges  
Matching  
New  
Transform

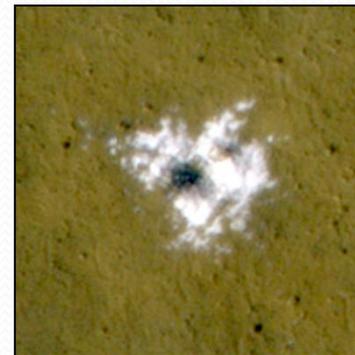
8/8 correct  
matches

4/4 correct  
changes

2 new streaks + 2 vanished streaks

# Summary

- Landmarks: obtain image content, change detection
- Future Work
  - Change detection across instruments, e.g., MOC/THEMIS
  - Analyze other features: fresh impact craters, wind streaks
  - Augment PDS image meta-data to enable content-based searching
- More info:
  - <http://landmarks.jpl.nasa.gov/>
  - [kiri.wagstaff@jpl.nasa.gov](mailto:kiri.wagstaff@jpl.nasa.gov)



Vastitas Borealis  
(Nov. 1, 2008, HiRISE)



Syrtris Major  
(July 12, 2004, THEMIS)