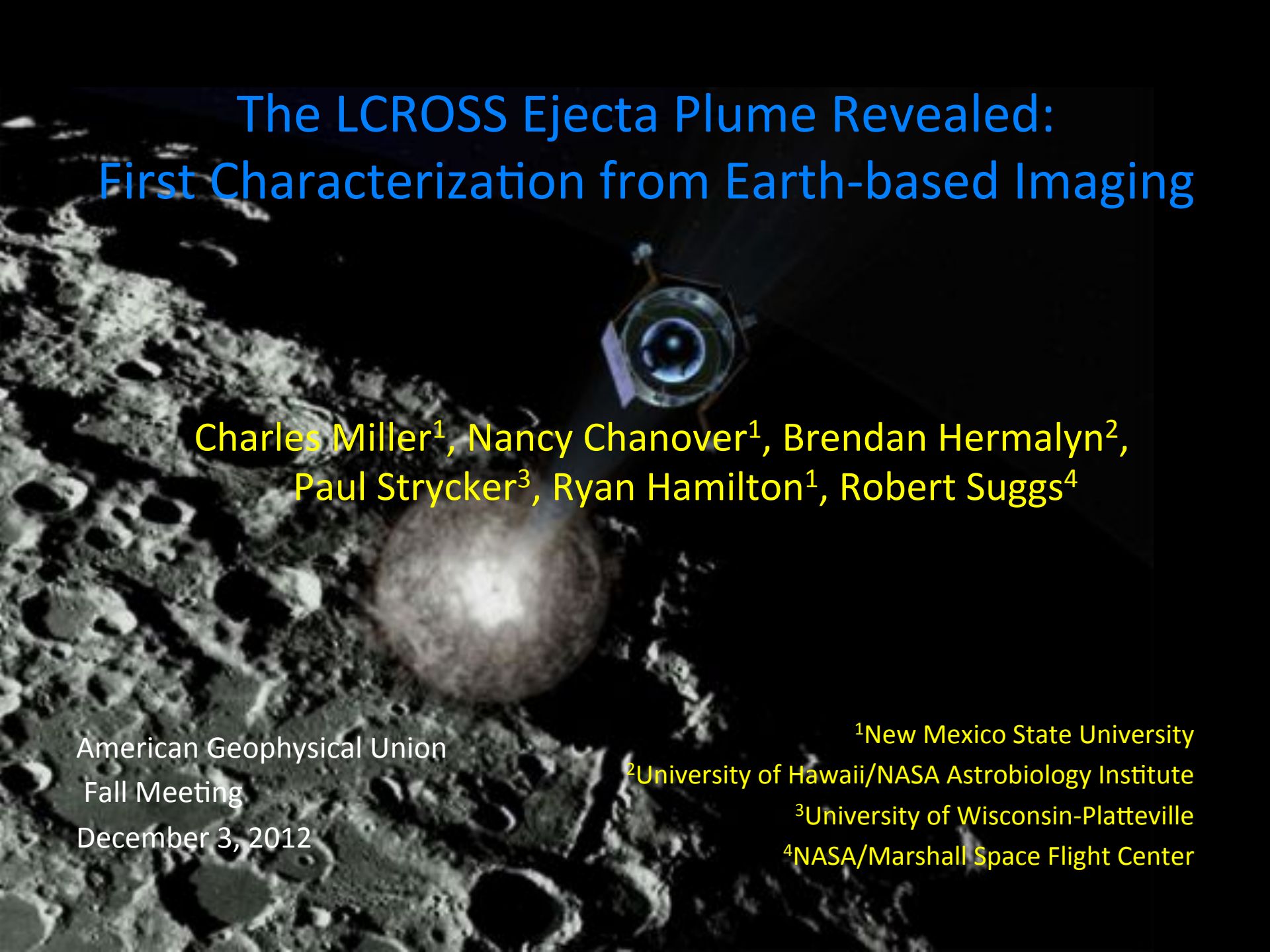
The LCROSS Ejecta Plume Revealed: First Characterization from Earth-based Imaging



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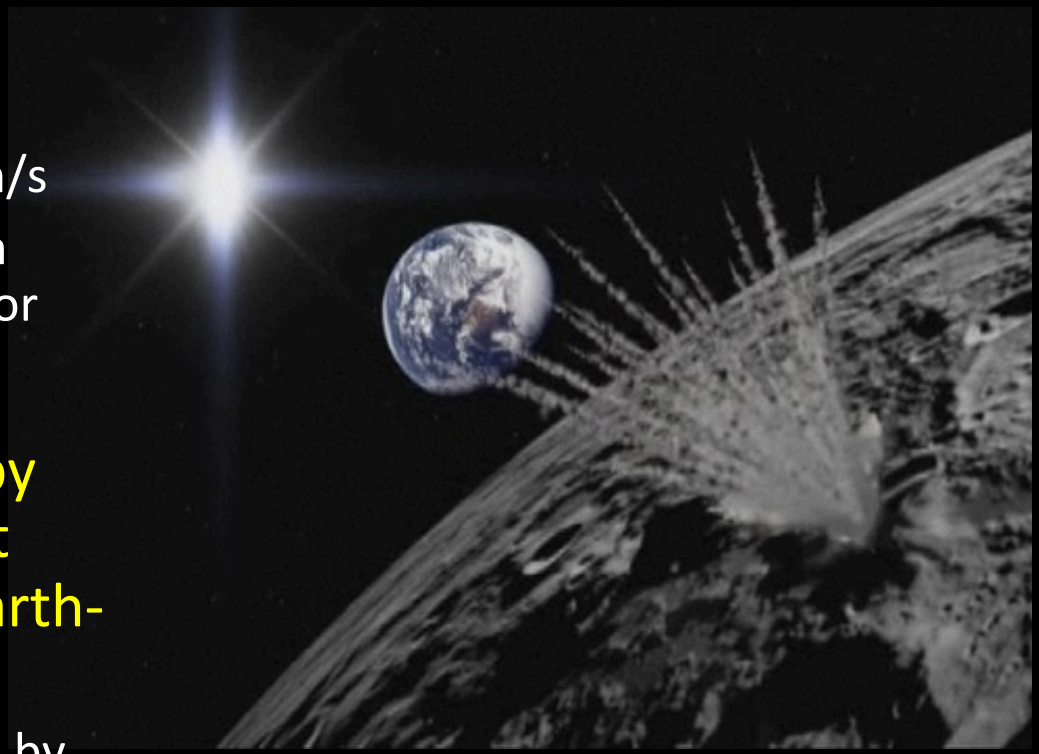
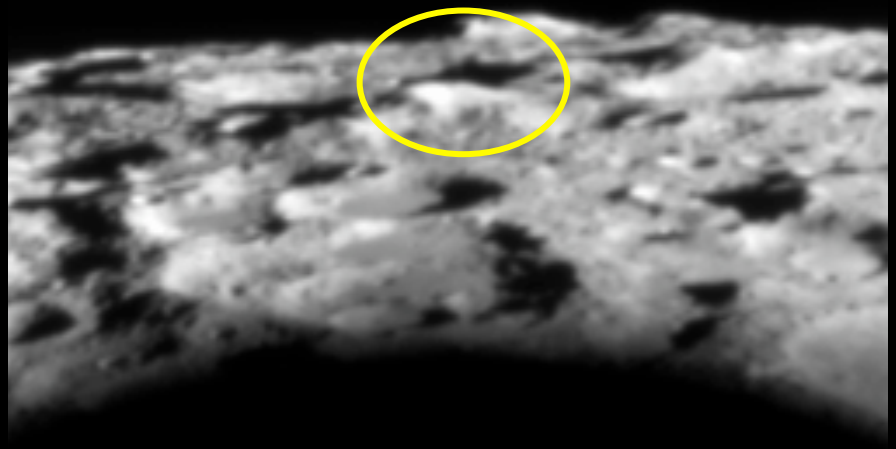
[4]NASA/Marshall Space Flight Center

LCROSS Mission Overview

- Upper stage booster for LRO dropped onto the floor of Cabeus crater on 09 October 2009
  - Impact velocity = 2.5 km/s
  - Impact angle of 85° with respect to the crater floor
  - Impact mass of 2000 kg
- Observed from above by Shepherding Spacecraft (SSC), from LRO, and Earth-based observatories
  - Volatiles (H_2O) detected by SSC

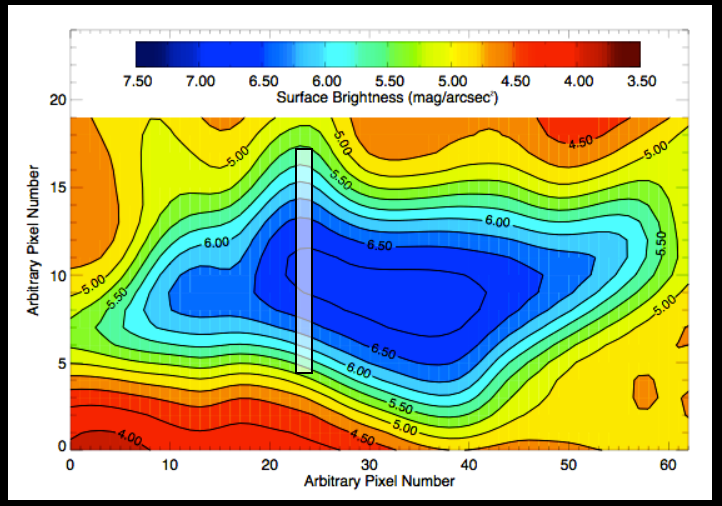


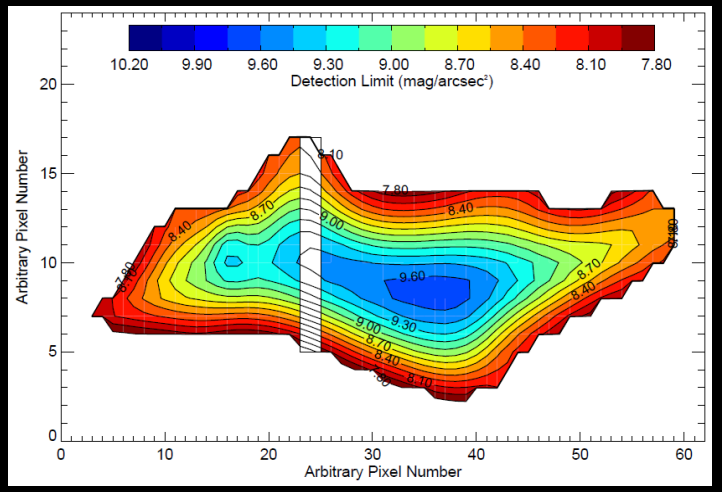
Apache Point Observations



- APO 3.5 m + Agile visible light frame transfer camera
- 0.5 sec exposures
- 0.46km/pix (0.26”/pix)
- Seeing around 1.3”
- V-filter + ND

Chanover et al. 2011 - JGR





V-band upper limit of 9.5 mag/arcsec^2

Principal Component Analysis (PCA) Filtering

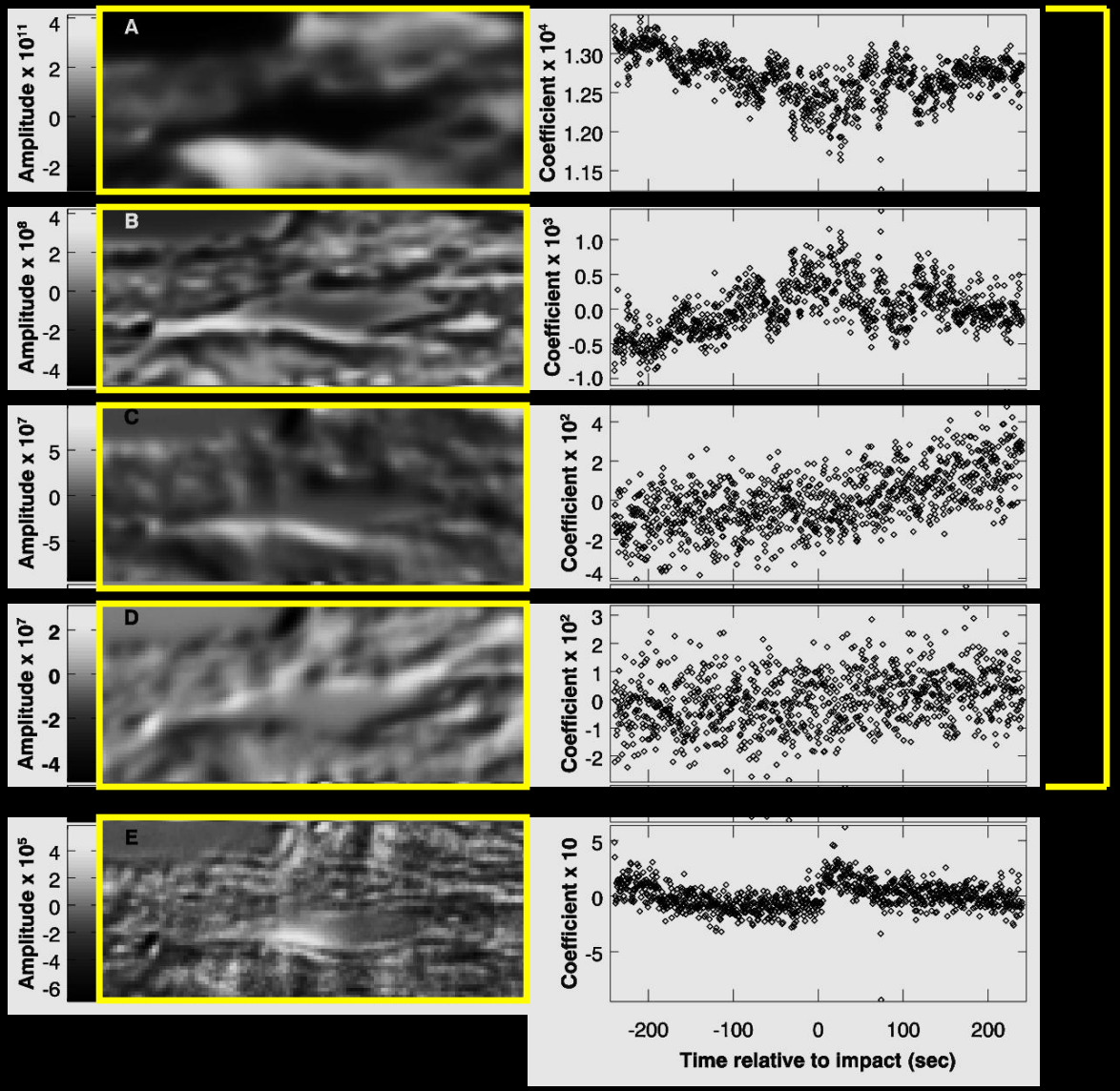
Component 1
Average image

Component 2
Seeing (PSF width)

Component 3
x alignment jitter

Component 4
y alignment jitter

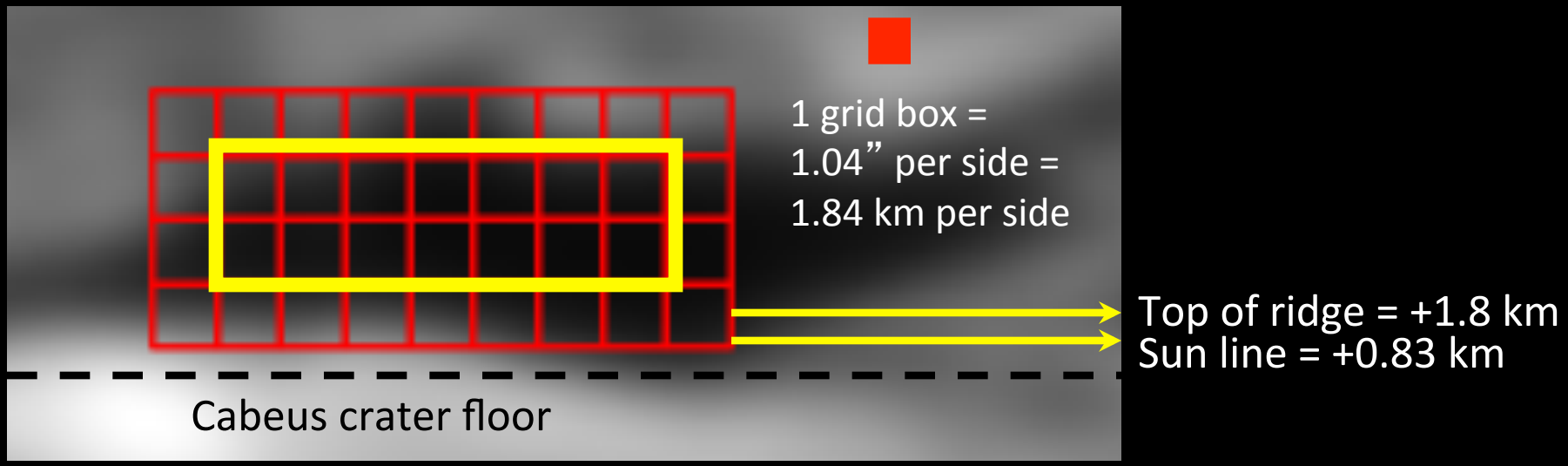
Component 20
Plume



PCA Filter

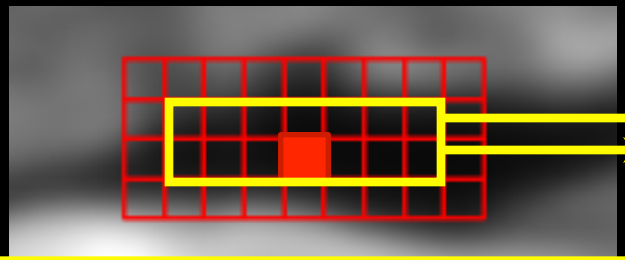
Remove
1st four
components
from image
sequence

Brightness Plot Grid



- Summed 16 pixels/grid box (4 x 4)
- Boxcar time average over 5 frames (2.5 sec)
- Plotted summed 16 pixel values for each grid box over time

Observed Plume Light Curves



Total counts per 4x4 pixel box (DN)

4000
3000
2000
1000
0

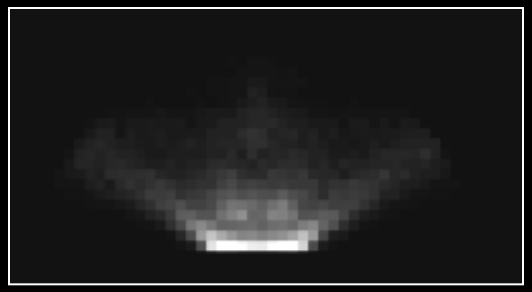
Observed
No plume

0 20 40 60

Time after impact (seconds)

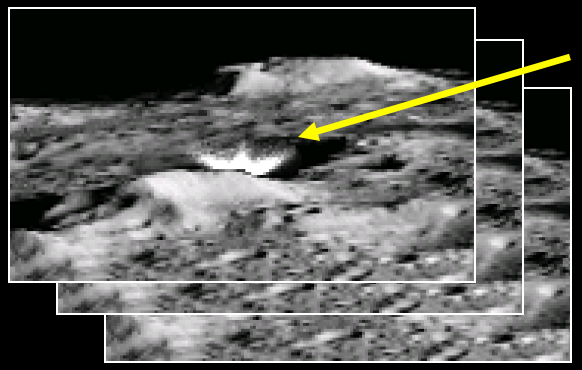
Synthetic Plume Verification

1



- 3-D Ballistic particle plume simulation
  - Initial velocities
  - Initial ejection angles
  - Based on laboratory impacts reported by Hermalyn et al., 2012
- Extract plume brightness maps at 0.5 sec intervals at pixel resolution of 0.46 km

2



- Create "perfect" sequence of plume capture maps + computer generated lunar landscape

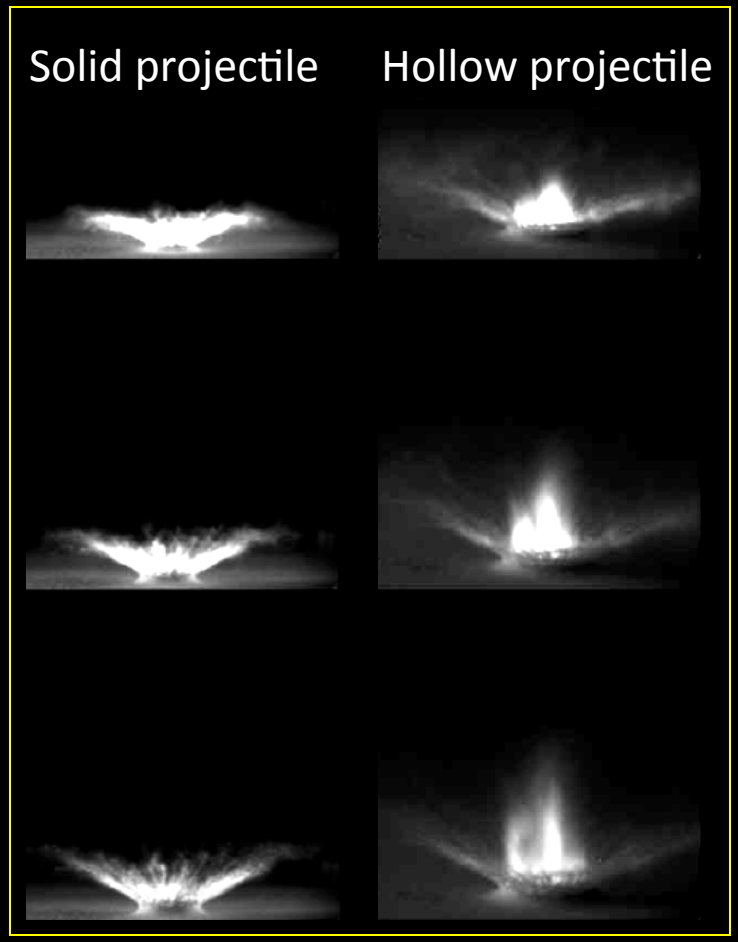
3

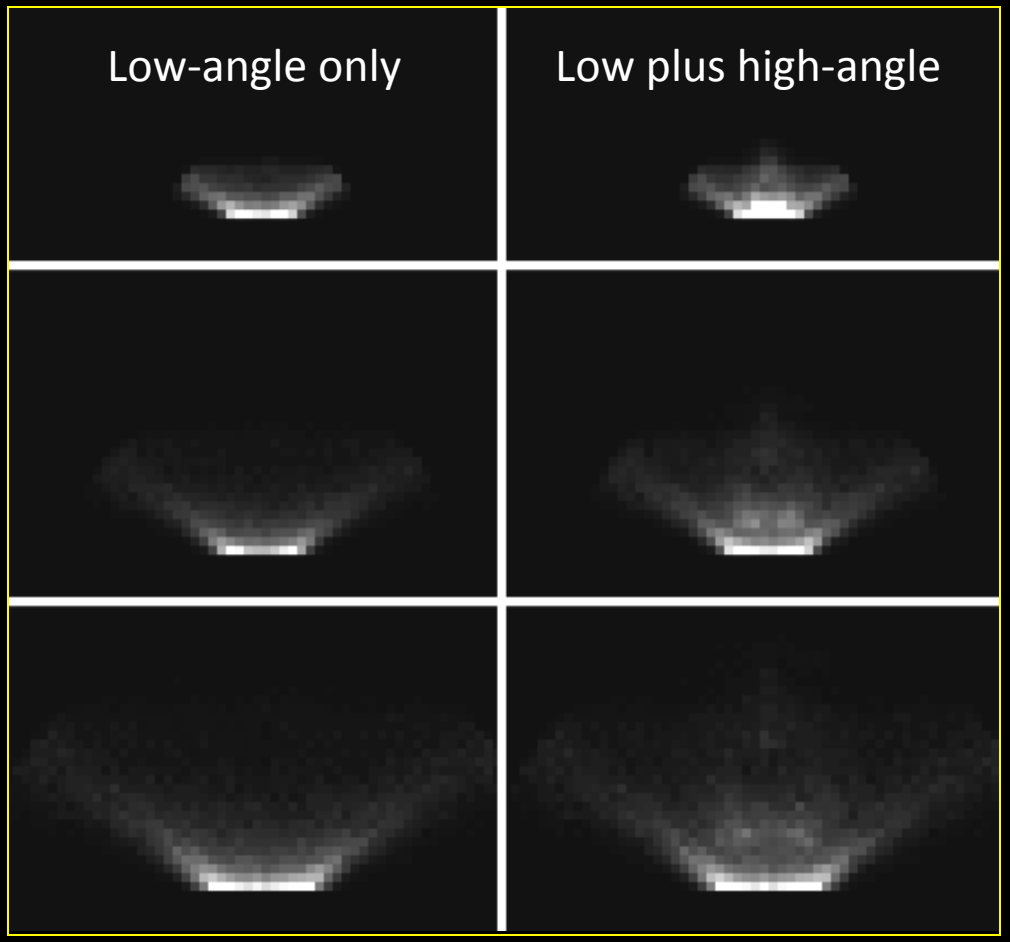
- Add seeing distortions, frame alignment mismatches, and noise
- Extract brightness curves using same PCA filter as real data

Two Component Synthetic Plume

NASA Ames Vertical Gun

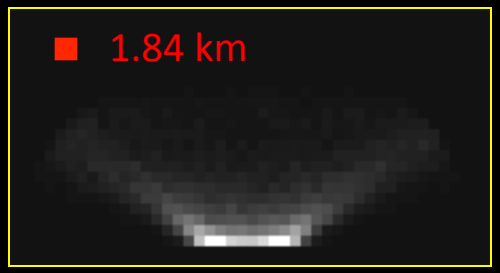
Simulation

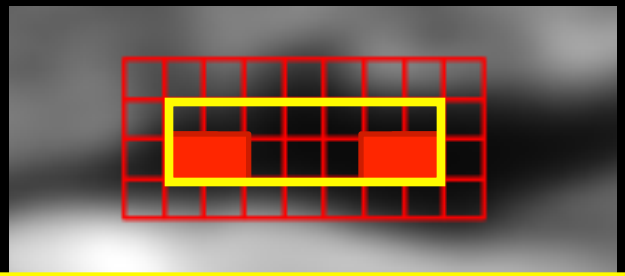




Schultz et al. 2010, Hermalyn et al. 2012

Low-angle Synthetic Plume

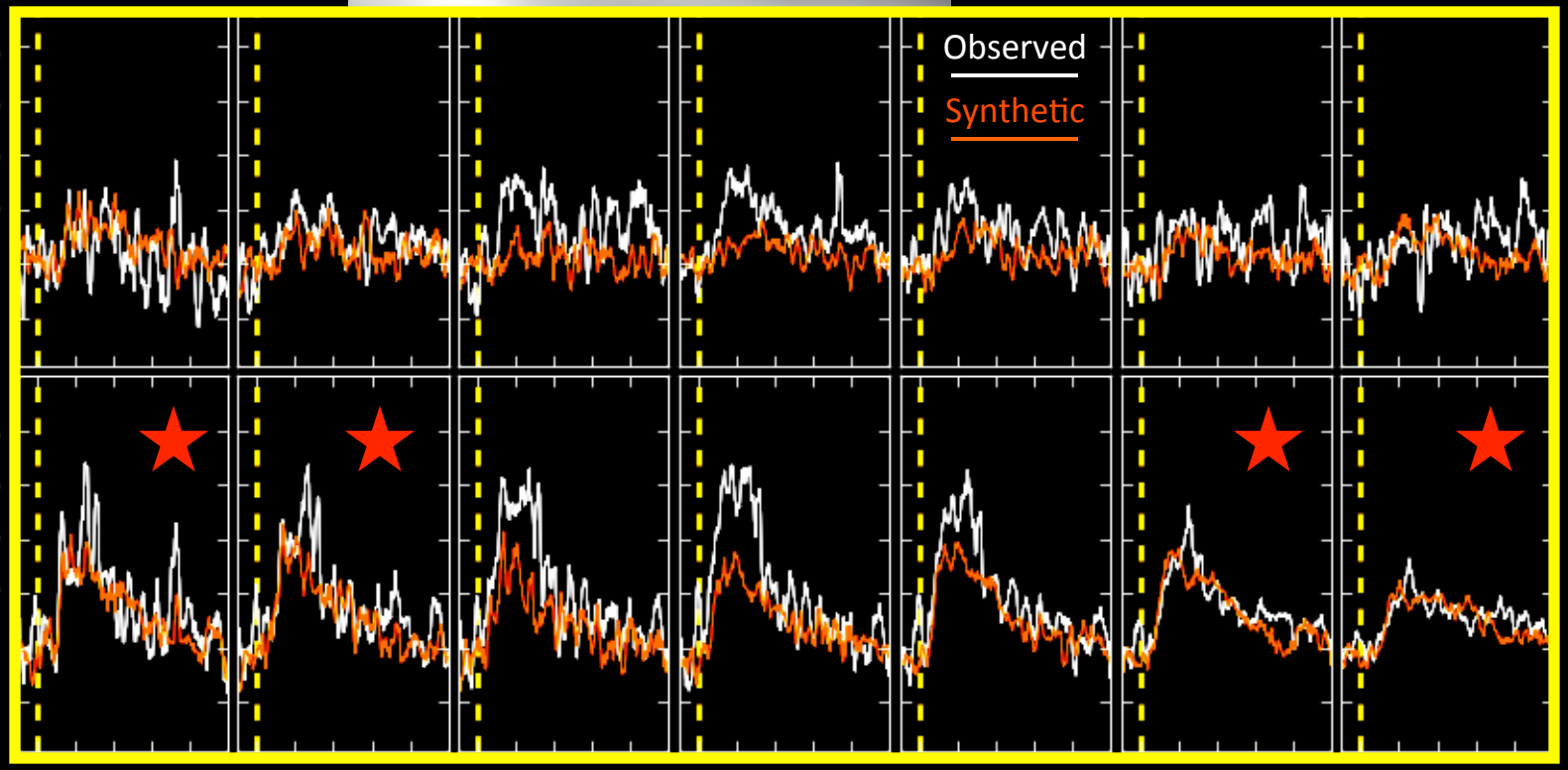




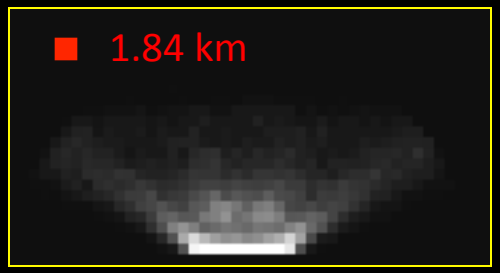
Best match

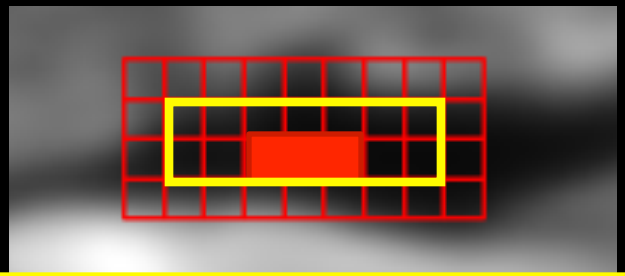
Ejection angles = 35° ± 5°

Max velocity = 500 m/s



Add Conical High Angle Plume

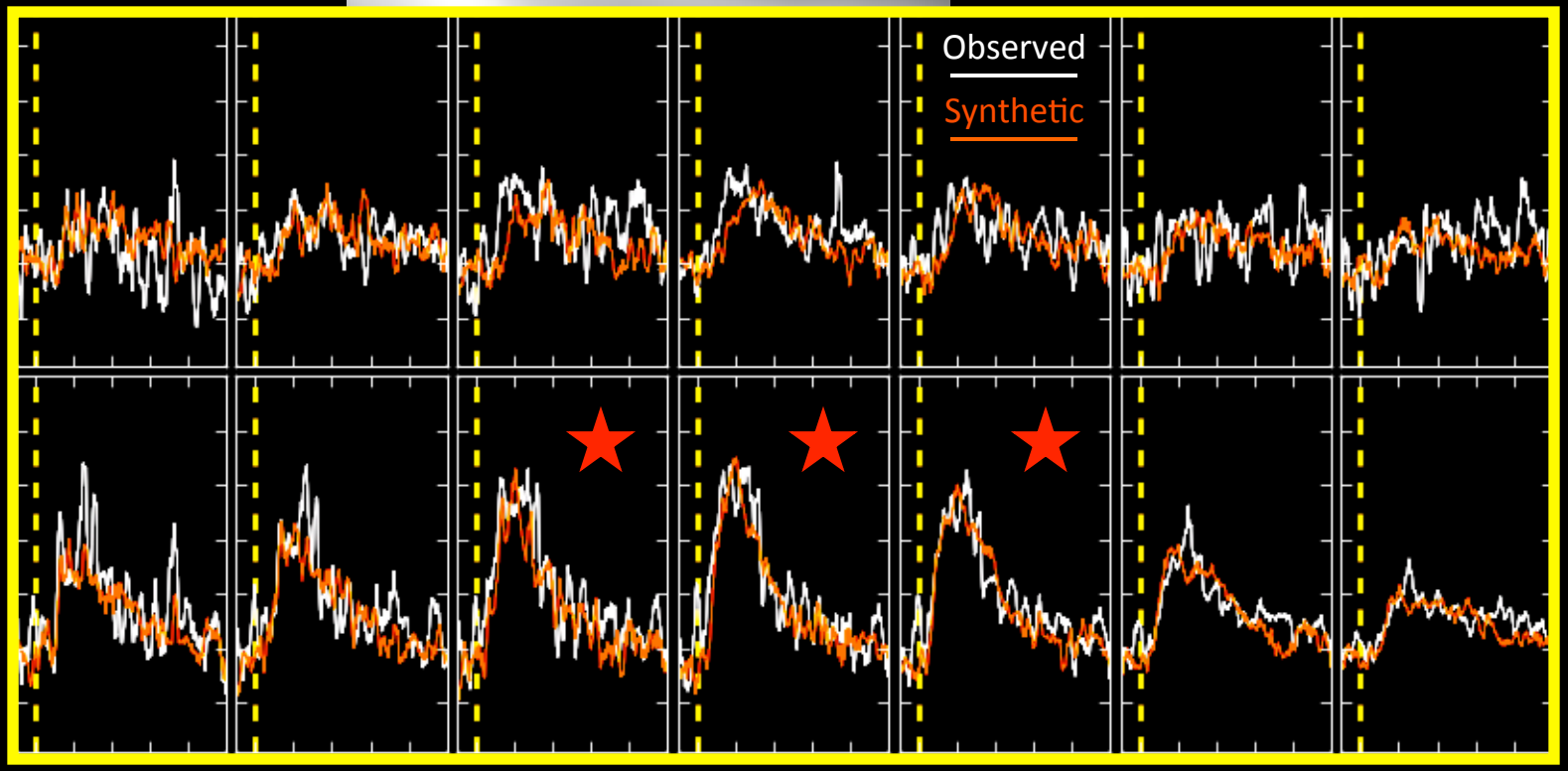




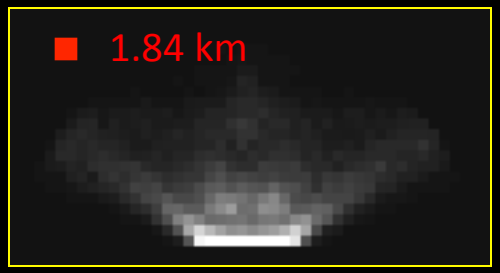
Best match

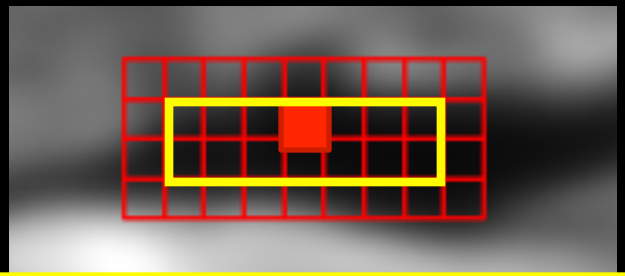
Ejection angles = 55° - 75°

Velocities = 150 - 400 m/s



Add Central High Angle Plume

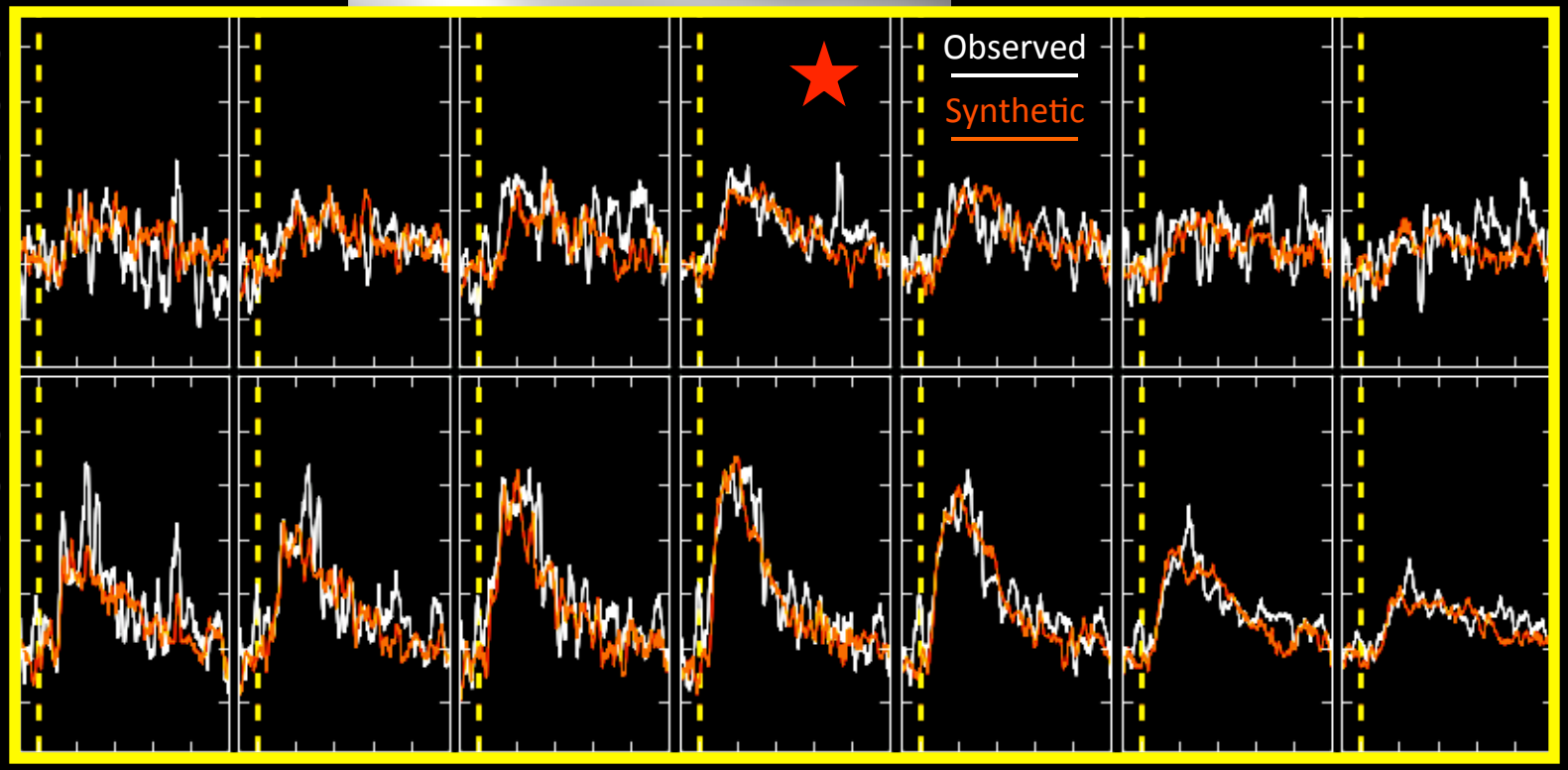




Best match

Ejection angles = 75° - 90°

Velocities = 300 - 500 m/s



Plume Brightness and Mass Estimates

V-band surface brightness (mag/arcsec^2)

Observed plume	Best match synthetic plume (before atmospheric distortion, noise, and PCA filter)
9.99 @ impact +16 s (max)	9.60 @ impact +11.5 s (high-angle)
10.25 @ impact +20 s	9.91 @ impact +20 s

- Optical depth at impact +20 s
  - 0.0017 (albedo=0.17) to 0.0042 (albedo=0.07)
- Total mass above Sun height @ +20 s
  - 2470 kg to 6000 kg (average = 3477 kg)
    - Particle radius 2.5 μm and density of 3300 kg/m^3
  - High angle plume 22% of illuminated mass

Future Modeling Improvements

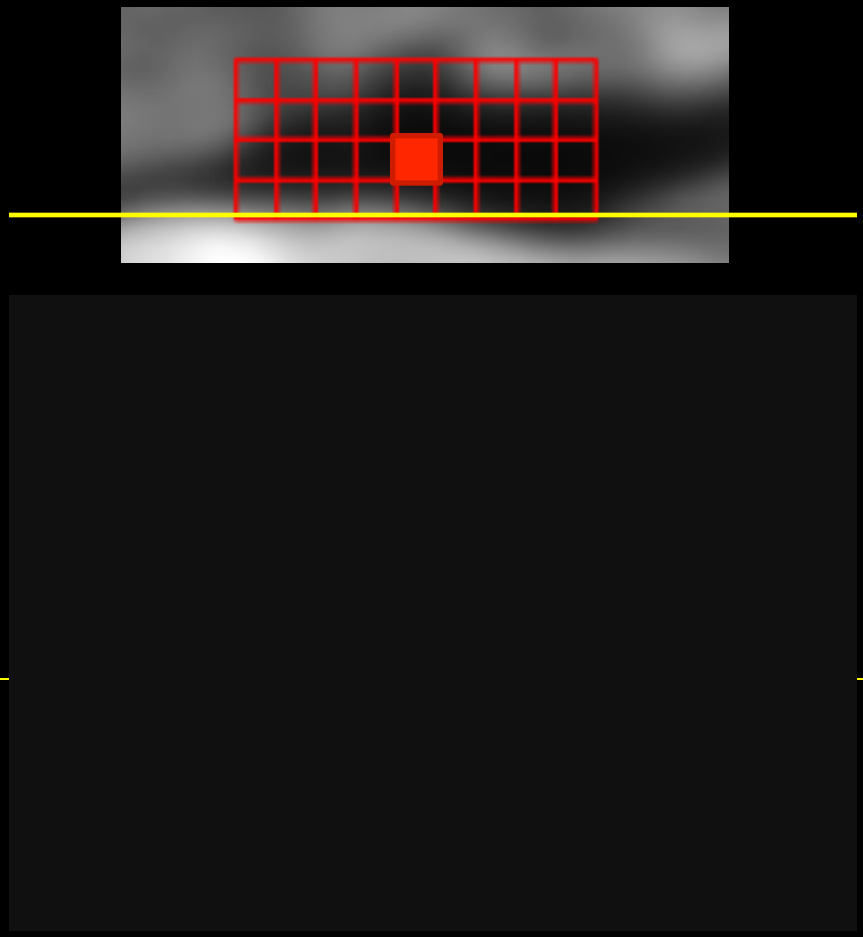
- Introduce a particle size-velocity distribution
  - Simulation model currently assumes all particles equal size/brightness
- Introduce a particle albedo-velocity distribution
- Streamline the verification procedure to allow automated parameter optimization

Summary

- Positive LCROSS plume detection in V-band
- Two component plume simulation needed to match observed light curves
  - Low-angle plume of 35° ± 5°
  - High-angle plume of 55 - 75° (conical) and 75 - 90° (central) with different low velocity cutoffs
- Maximum V-band plume brightness at impact +16 s of 9.99 mag/arcsec^2 (z=3.6 km)
  - Peak optical depth of 0.0017 to 0.0042
  - Illuminated mass @ impact +20 s of 2470 - 6000 kg
  - High-angle plume is 22% of total illuminated mass

Questions

Real Time Best Match Plume Simulation



Albedo Change with Depth?

75 - 90°
300 - 500 m/s

55 - 75°
150 - 400 m/s

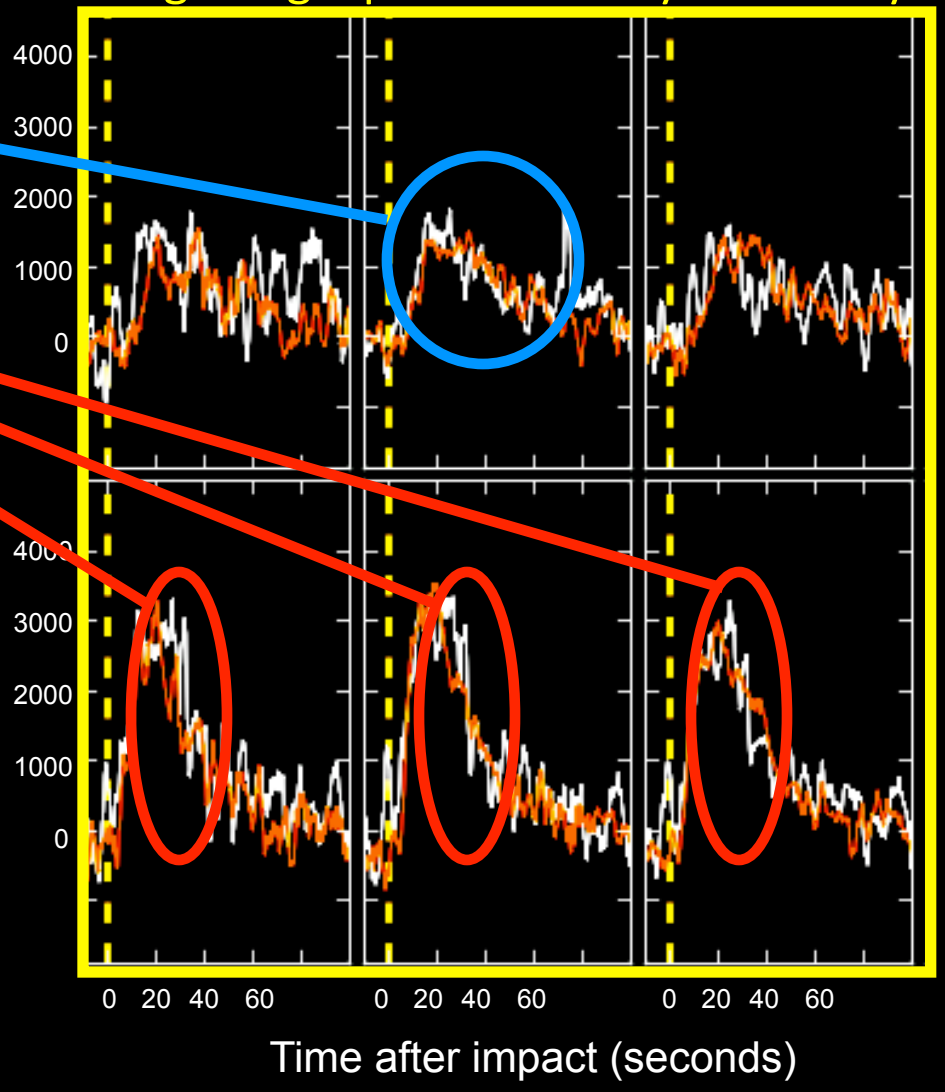
Regolith depth

Dark

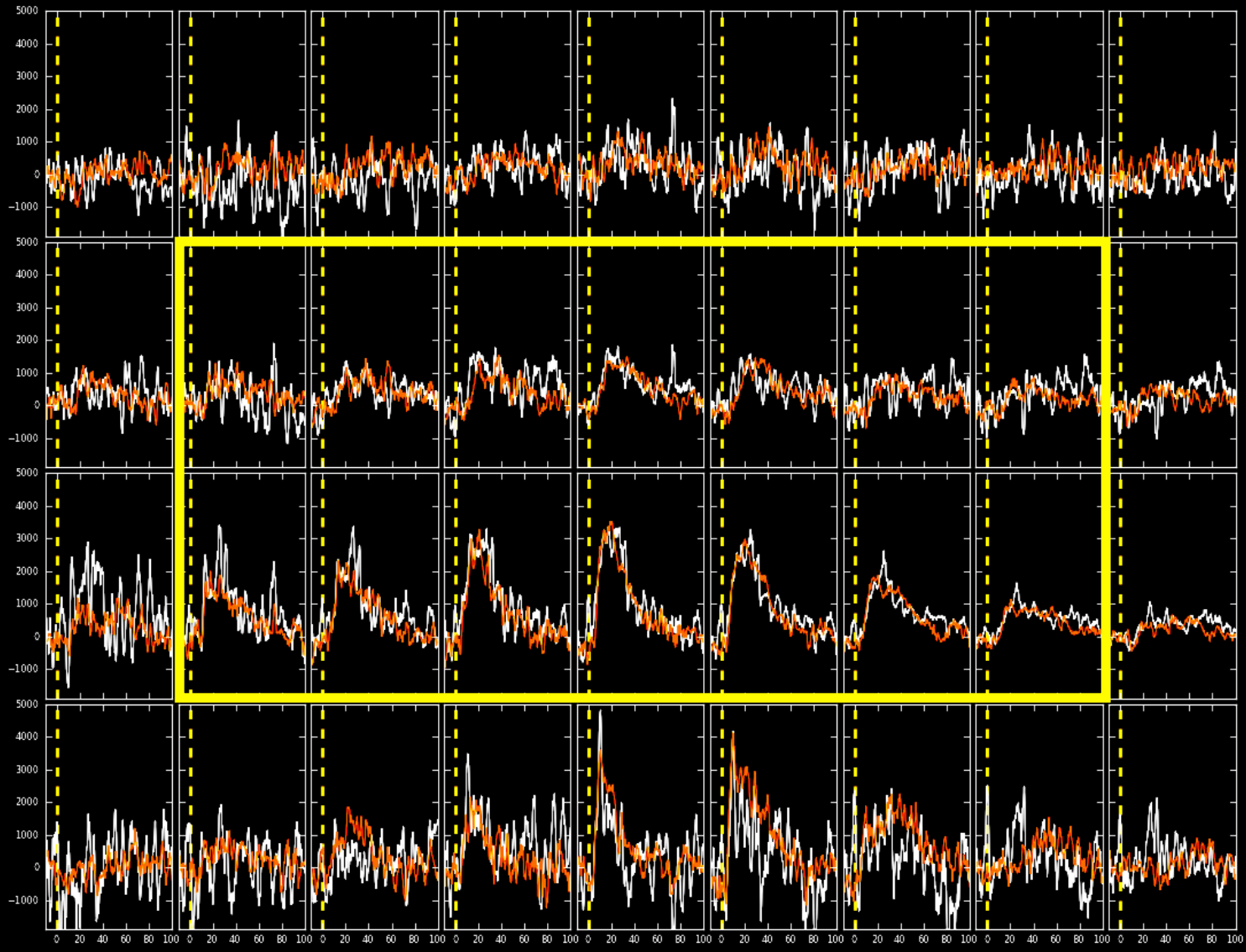
Bright

Dark

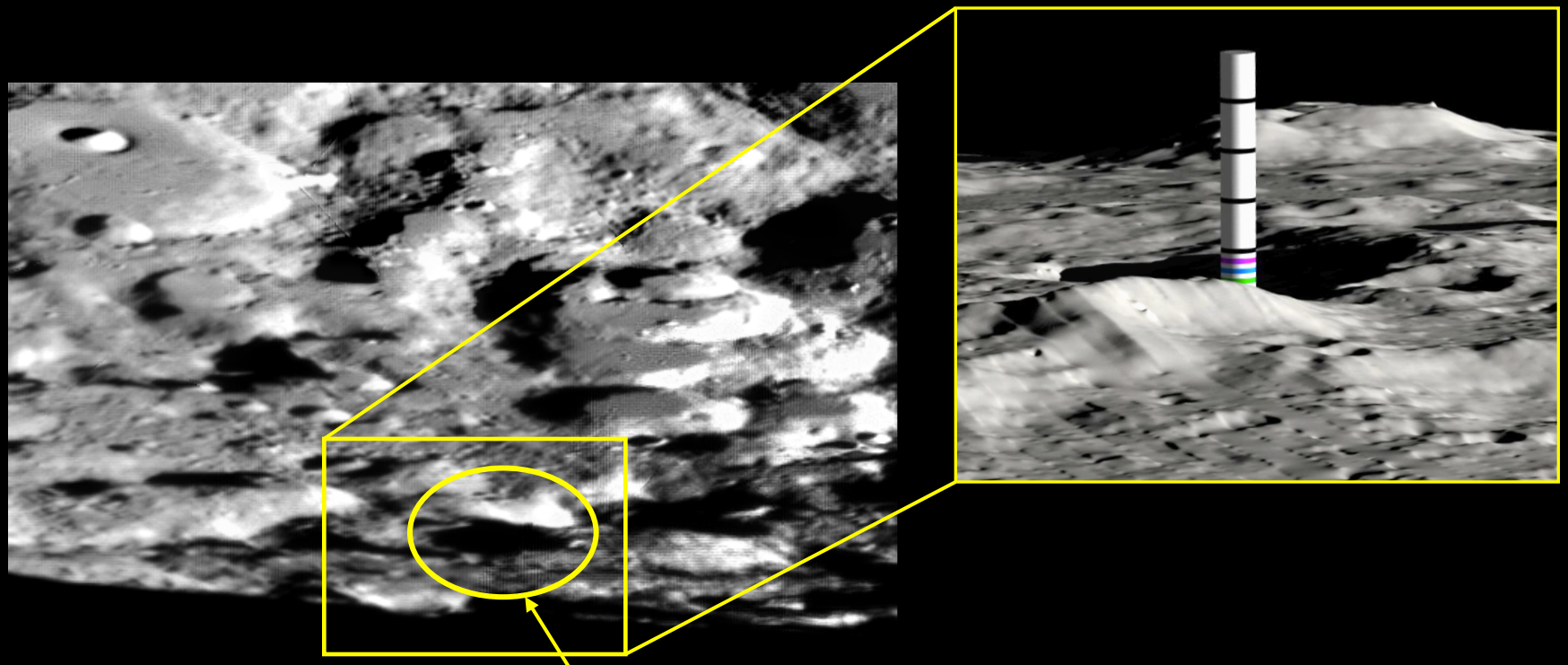
High-angle plume velocity sensitivity



Best Match Synthetic Plume



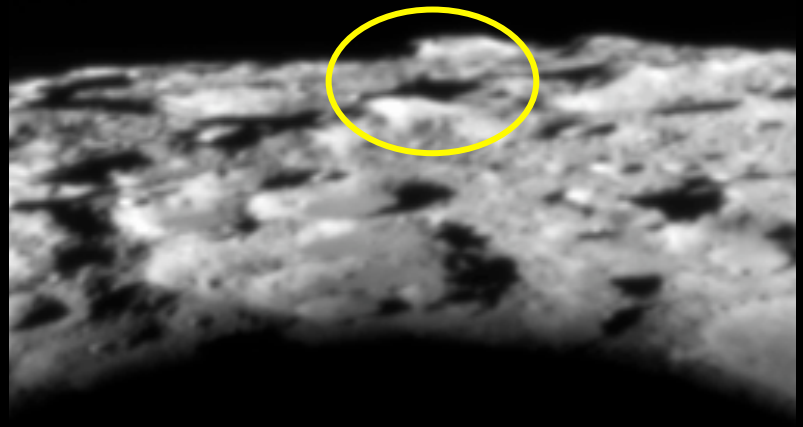
Impact Site



NMSU / MSFC
Tortugas Observatory 24"
0.9 - 1.7 µm InGaAs Camera

Impact site
Cabeus crater

Apache Point Observations



- APO 3.5 m + Agile visible light frame transfer camera
- 0.5 sec exposures
- 0.46km/pix (0.26”/pix)
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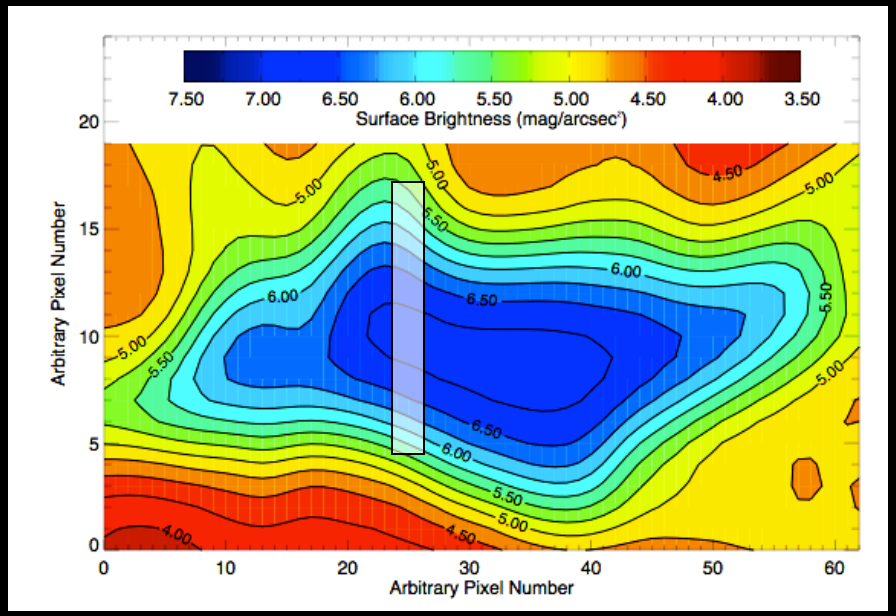
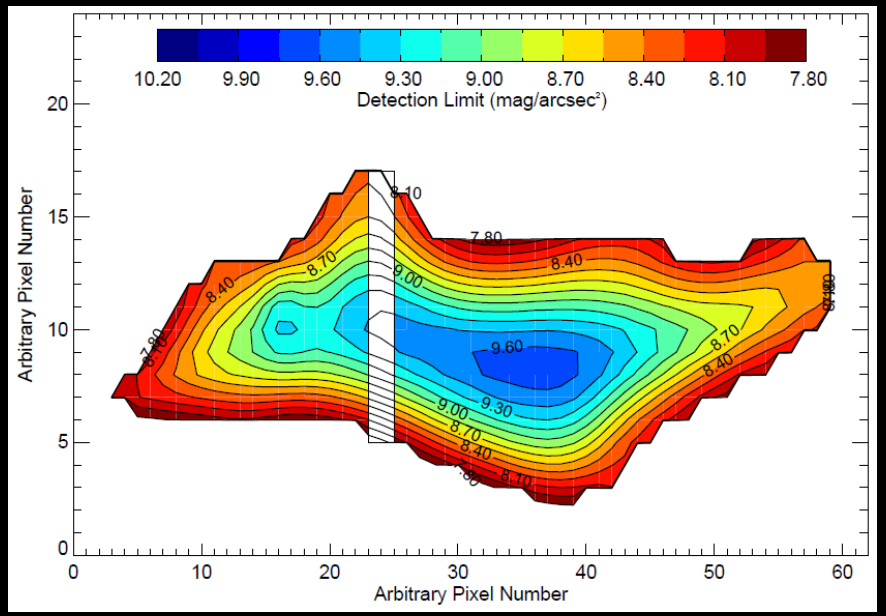
Observation Limits

- Upper plume surface brightness limit of 9.5 magnitudes/arcsec^2

Chanover et al. 2011 - JGR



Calibrated per-pixel V-band surface brightness map of Cabeus crater



Per-pixel 3-σ V_band noise limit map