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ESSSA Group

NASA

# Lunar Impact Flash Locations

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# Overview

A bright impact flash detected by the NASA Lunar Impact Monitoring Program in March 2013 brought into focus the importance of determining the impact flash location.

A process for locating the impact flash, and presumably its associated crater, was developed using commercially available software tools.

The process was successfully applied to the March 2013 impact flash and put into production on an additional 300 impact flashes.

The goal today: provide a description of the geolocation technique developed.

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# Impetus for locating flashes

- Bright impact flash on 17 March 2013
  - Thought to have produced a fresh crater detectable by Lunar Reconnaissance Orbiter (LRO)
  - LRO needed an accurate search area to begin looking for the crater
- Geolocation workflow was developed to provide coordinates to LRO
  - Rough process used for 17 March flash → LRO found the crater!
  - Refined process put into production on 300 impacts

# Linking flash to fresh crater

- Idea of linking observation of an impact flash with its crater is an appealing one
- Provides "sanity checks" for
  - NASA photometric calculations
  - Crater scaling laws developed from hypervelocity gun testing
- Luminous efficiency estimates can be made by combining flash and crater measurements, assuming a crater scaling law

# Terminology

| | |
|---|---|
| Geolocation | Process of identifying the real-world spatial location of an object. |
| Georeferencing | Method used to associate an image with a map of real-world locations |

# Geolocation workflow

1. Create video segment
2. Determine flash centroid
3. Define & setup basemap
4. Georeference flash images
5. Transform flash coordinates
6. Determine flash location
7. Apply refraction correction
8. Determine uncertainties

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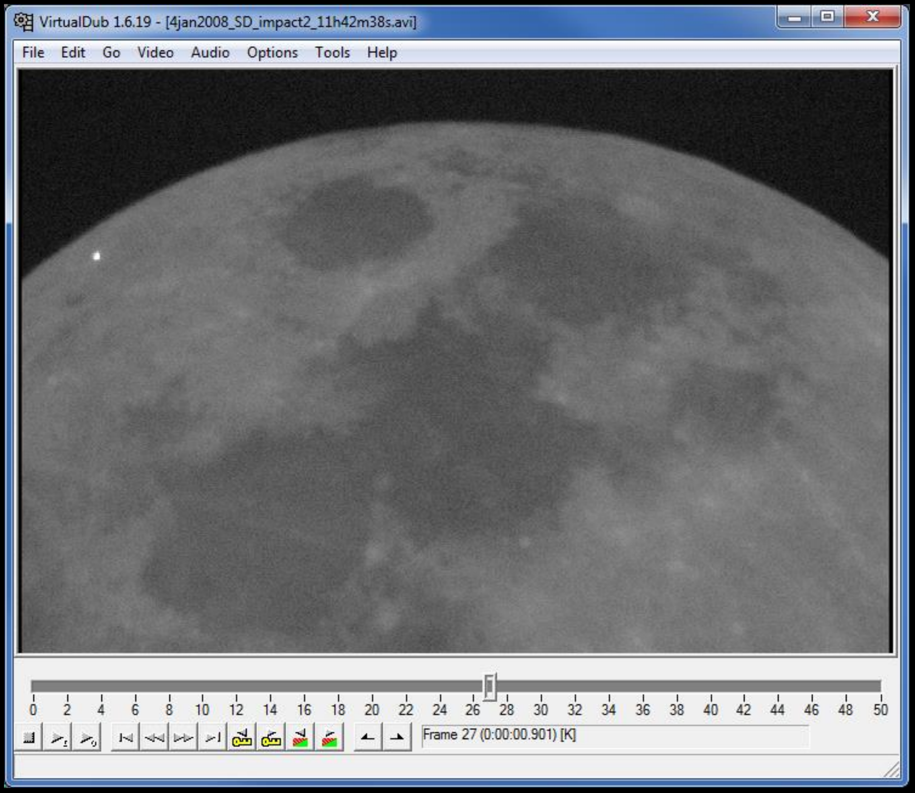
# 1. Create video segment

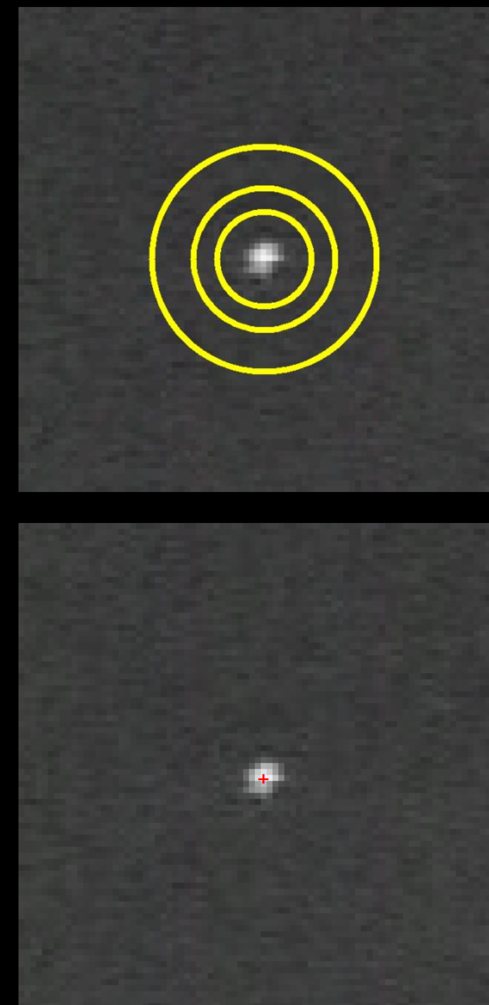
- Identify video frame(s) containing impact flash
- Use VirtualDub to create short video segment containing impact flash




Flash video segment in VirtualDub

# 2. Determine flash centroid

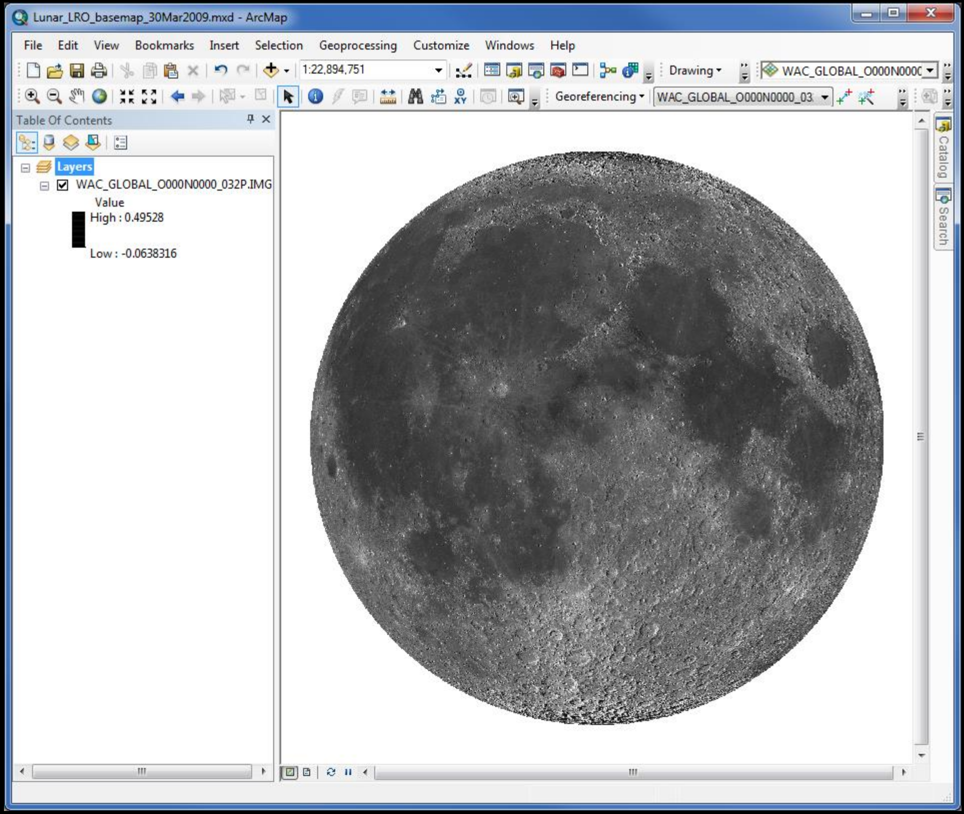
- Import video frame into MaximDL
- Calculate flash centroid location in image coordinates, $(x,y)$ in pixels
- Export video frame as TIFF image



Record $(\overline{x_f}, \overline{y_f})$

# ArcMap

- Part of the ArcGIS software suite developed by Esri
- Off-the-shelf solution for georeferencing lunar impact imagery




ArcMap interface with lunar basemap

# 3. Define & setup basemap

- Load lunar basemap into ArcMap
  - Source: http://wms.lroc.asu.edu/lroc/view_rdr/WAC_GLOBAL
  - LRO-created orthographic projection of the lunar surface
  - resolution = 32 pixels/deg, center = (0° N, 0° E)
- Adjust basemap display to account for lunar libration
  - JPL Horizons sub-observer lat/lon used to adjust map center coordinates

LRO basemap centered at (0°N,0°E)

LRO basemap centered at (7.2°N,7.0°W) to georef flash 2006 Sep 28

# 4. Georeference flash image

General steps for georeferencing an image

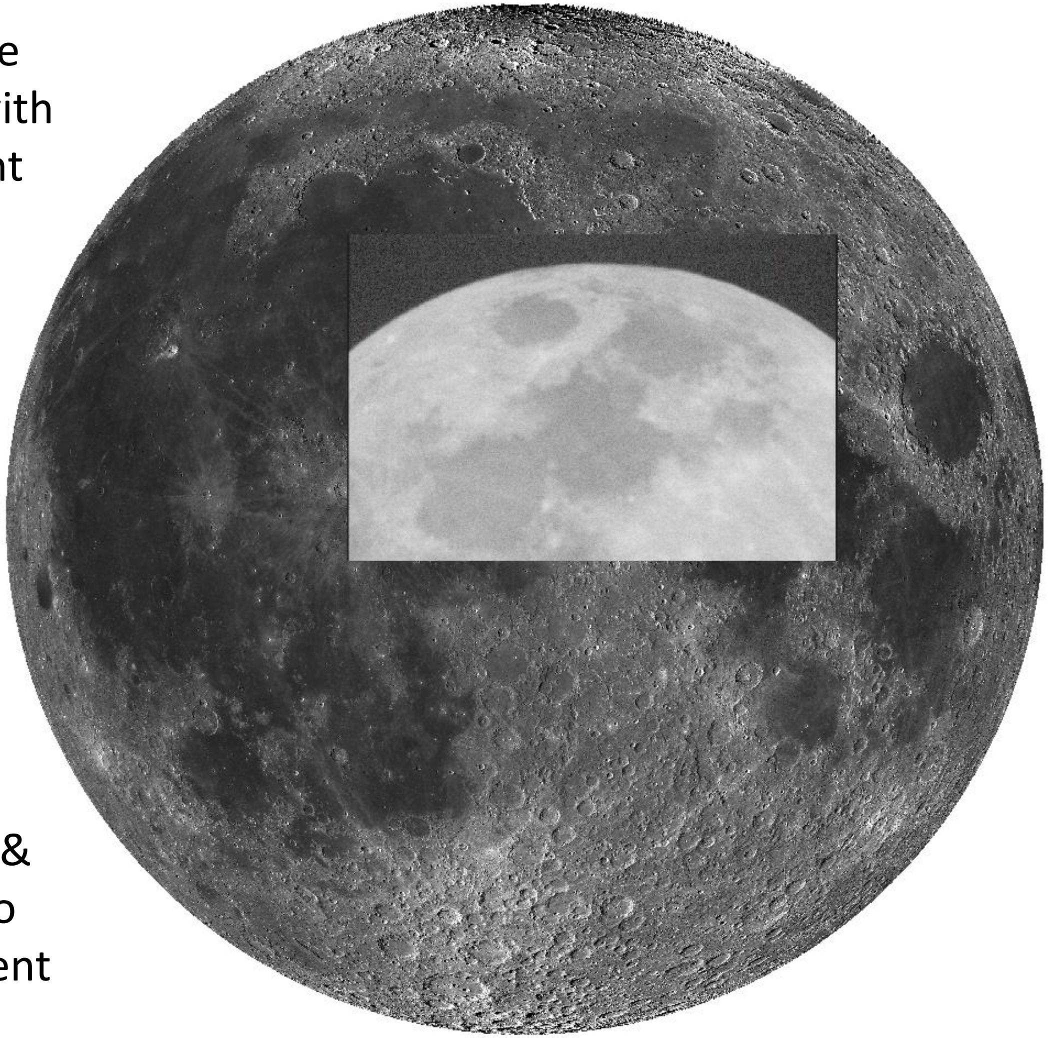
1. Overlay image on the basemap
2. Link known positions in the image ($x$,$y$) to known positions in the map ($x'$,$y'$) using control points
3. Save the transformation used to align the image to the map
4. Save fit error estimate for use in uncertainty determination

# 4. Georeference flash image

Start with video frame
TIFF

# 4. Georeference flash image

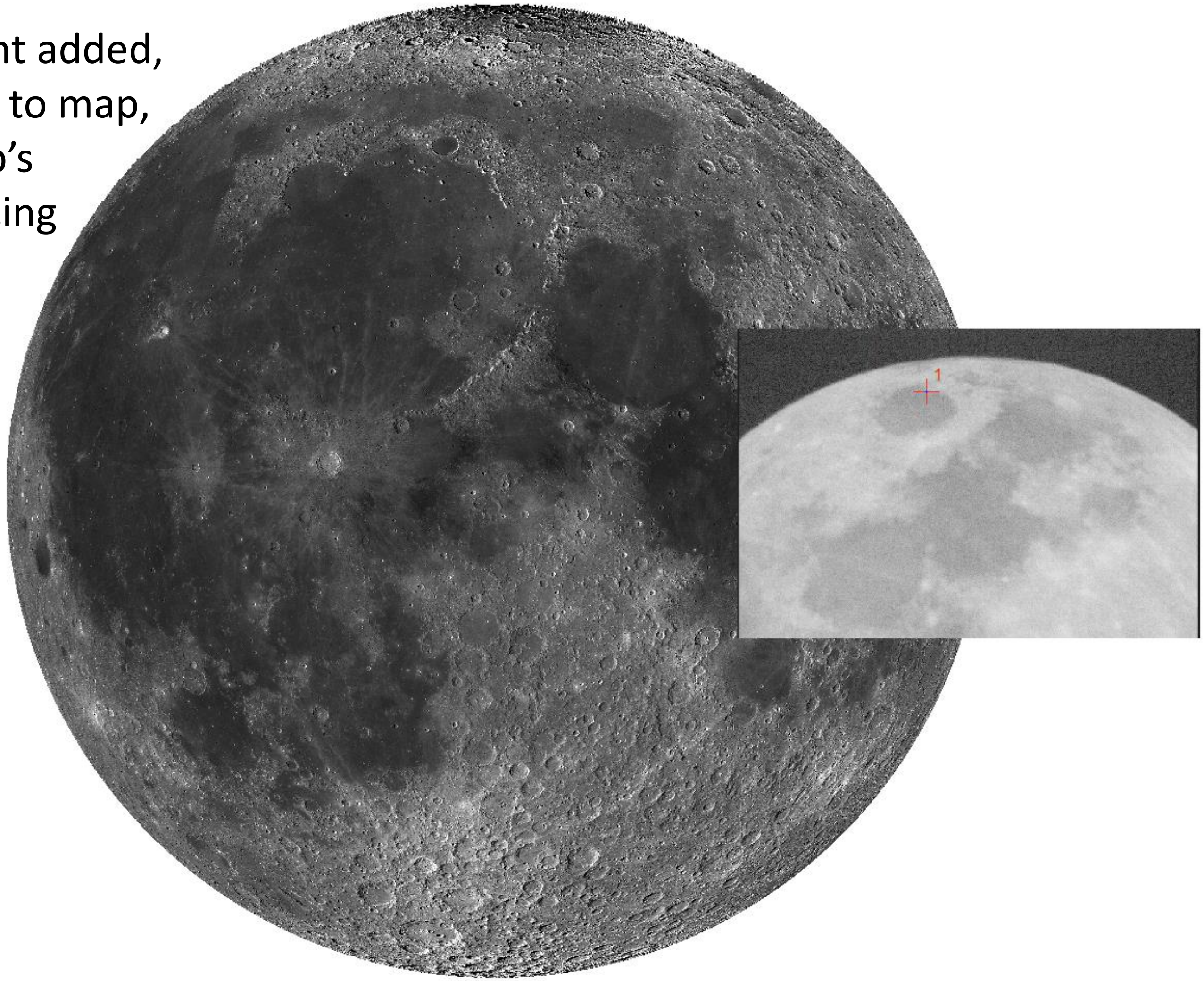
Overlay video frame TIFF on basemap with libration adjustment



Image's brightness & contrast adjusted to emphasize prominent features

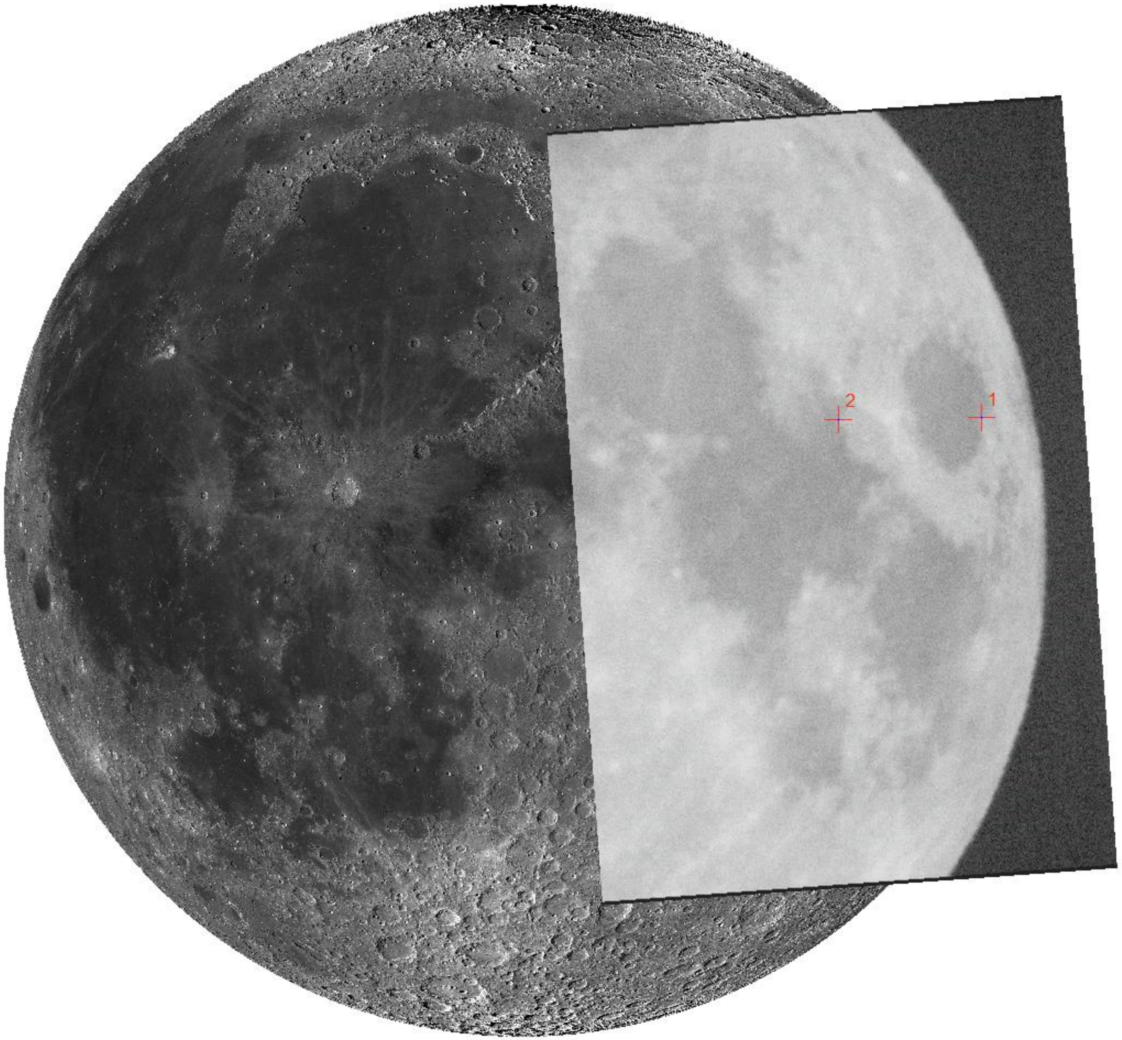
# 4. Georeference flash image

1 control point added, linking image to map, using ArcMap's "Georeferencing Toolbar"



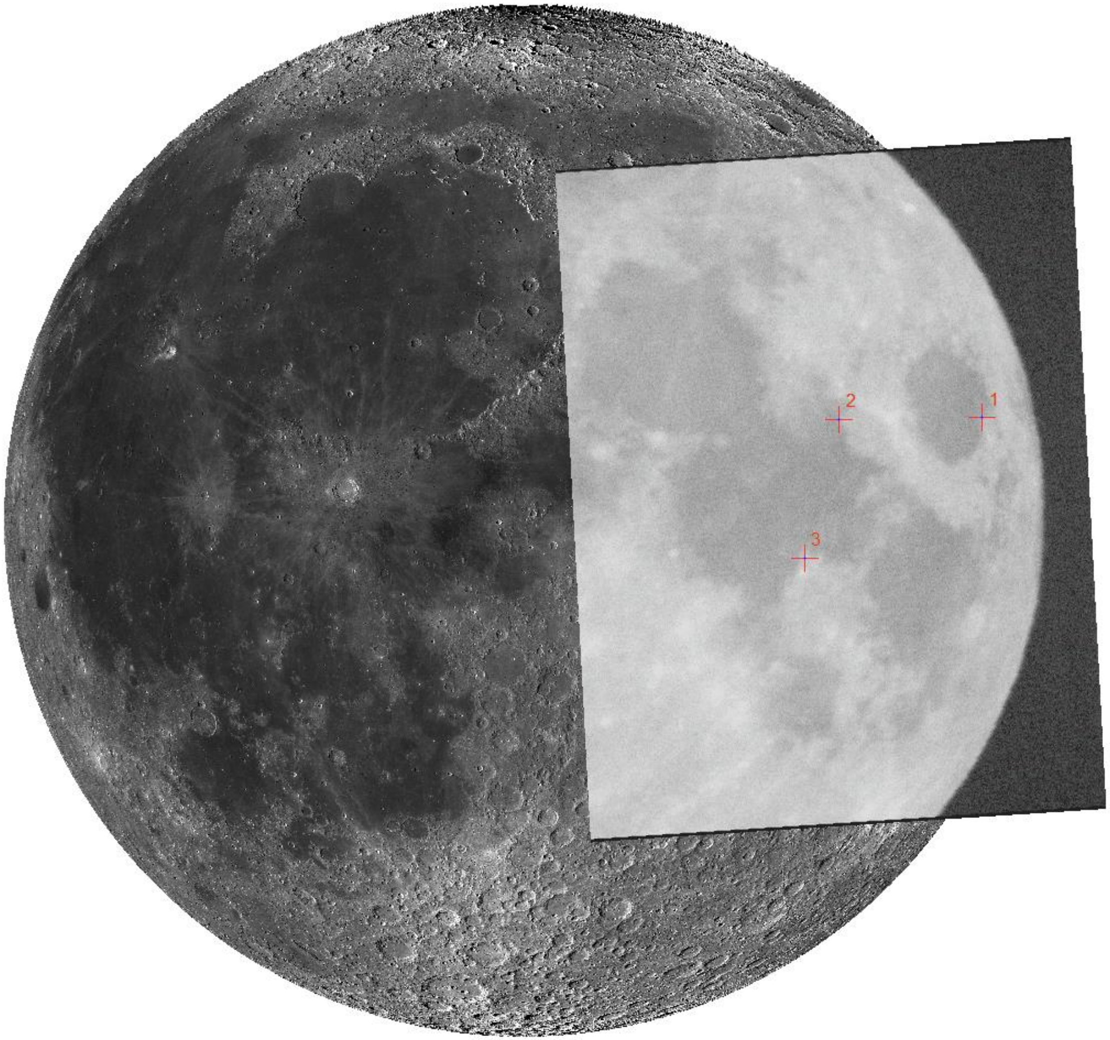
# 4. Georeference flash image

2 control points



# 4. Georeference flash image

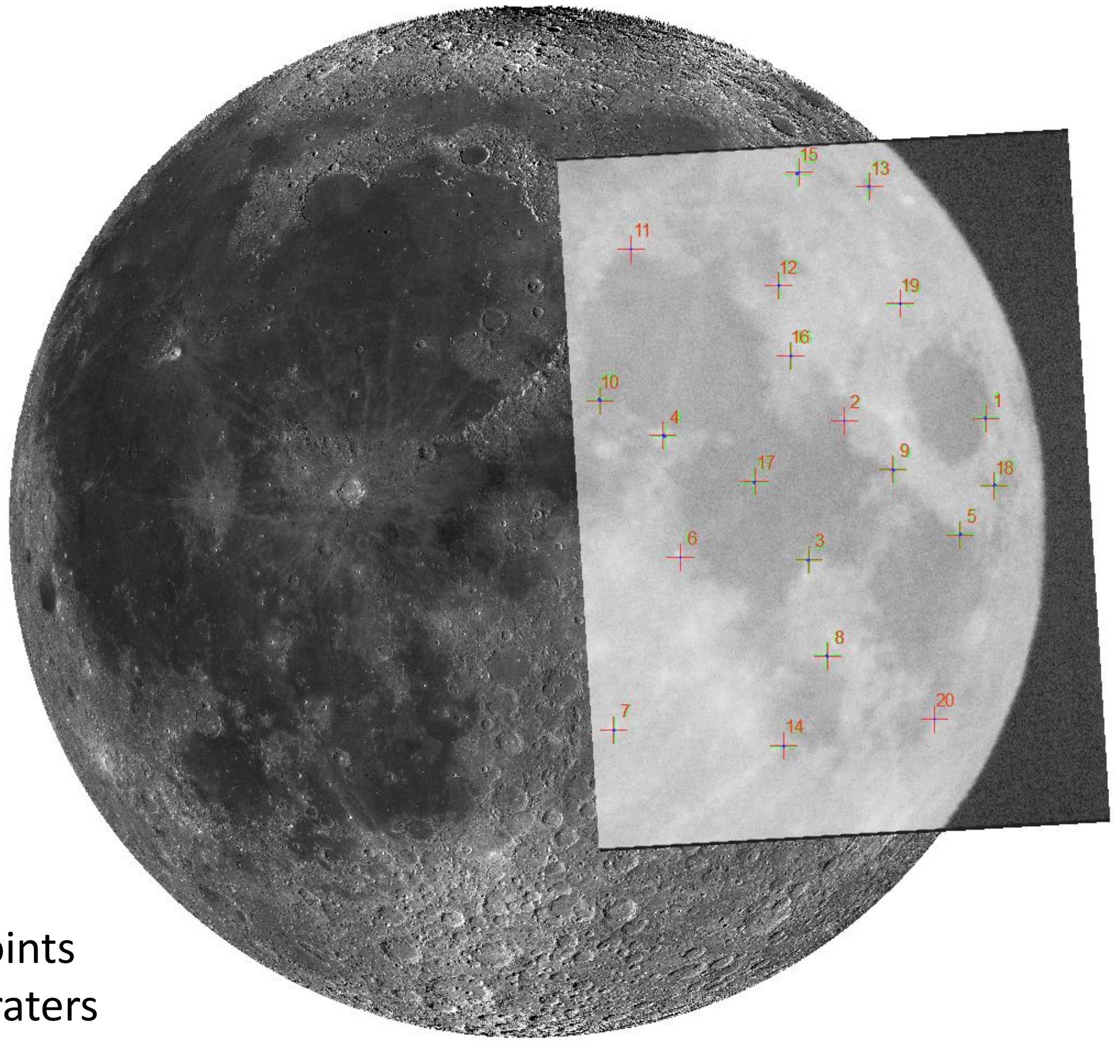
3 control points



# 4. Georeference flash image



20 control points

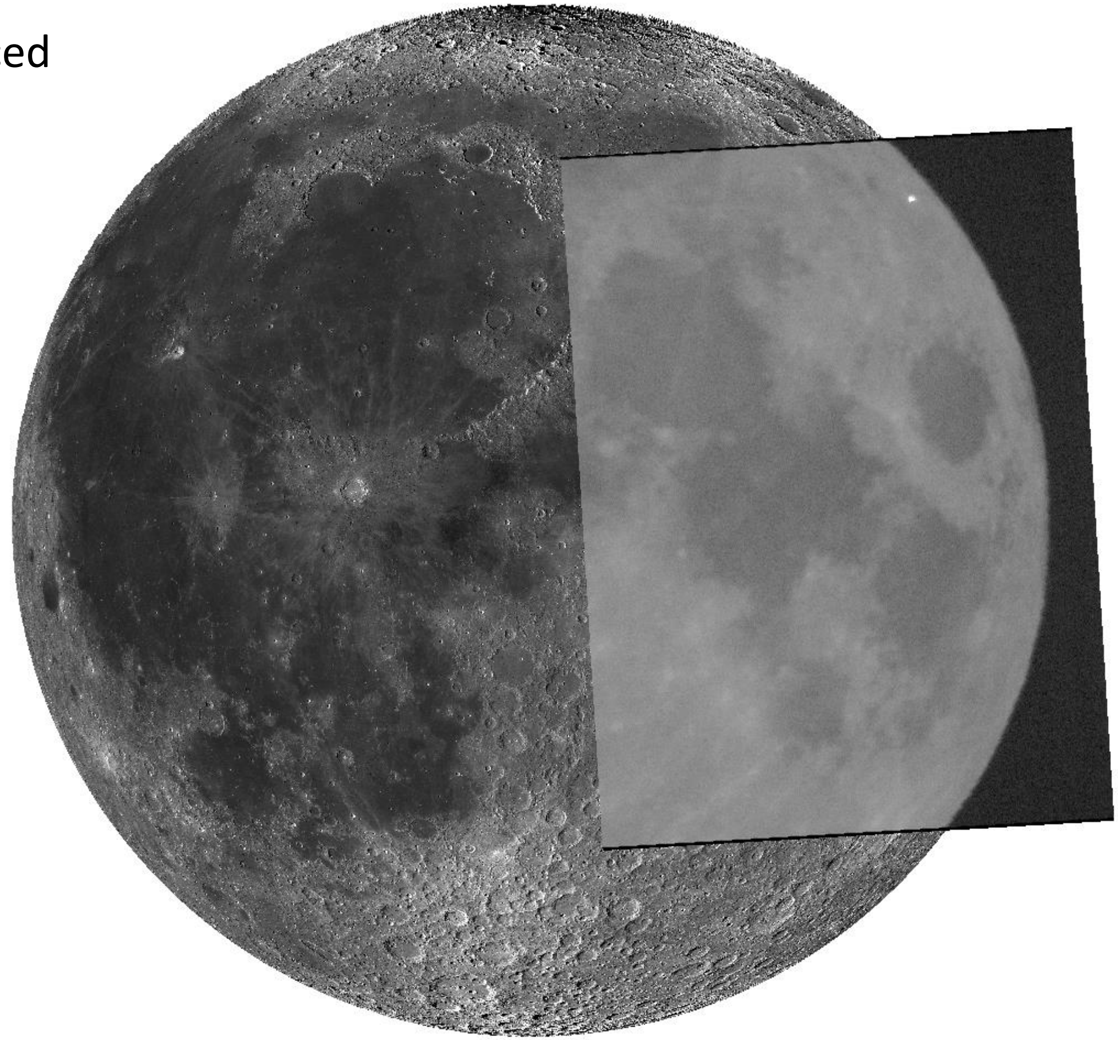



Typical control points

- High albedo craters
- Transitions between mare & highland

# 4. Georeference flash image

Final georeferenced impact image



# 4. Georeference flash image

- ArcMap uses control points and a least-squares fitting algorithm to determine a 1st order polynomial transformation

$$x' = Ax + By + C$$
$$y' = Dx + Ey + F$$

- Transforms image coordinates (*x*,*y*) in pixels to basemap coordinates (*x'*, *y'*) in meters
  - (*x'*, *y'*) is the orthographic projection of the 3D Moon onto a 2D plane
- Parameters A-F are determined by the control points: they scale ($m_x$, $m_y$), shear/skew (*k*), rotate (*t*), and translate all coordinates in the image to map coordinates

$$A = m_x \cos t \qquad B = m_y(k \cos t - \sin t) \qquad C = translation\ in\ x\ direction$$
$$D = m_x \sin t \qquad E = m_y(k \sin t + \cos t) \qquad F = translation\ in\ y\ direction$$

# 4. Georeference flash image

- Applying the transformation to each control point yields a residual error $\varepsilon$

- ArcMap displays $\varepsilon$ for each control point and calculates the root means square (RMS) error

$$RMS\ error = \sqrt{\frac{\sum_{i=1}^{n} \varepsilon_i^2}{n}} \qquad n = \#\ of\ control\ points$$

- The RMS error is saved for subsequent uncertainty calculations

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# 5. Transform flash coordinates

- ArcMap transforms image coordinates to map coordinates,

$$(x, y) \rightarrow (x', y')$$

- The same transformation is used for the flash centroid,

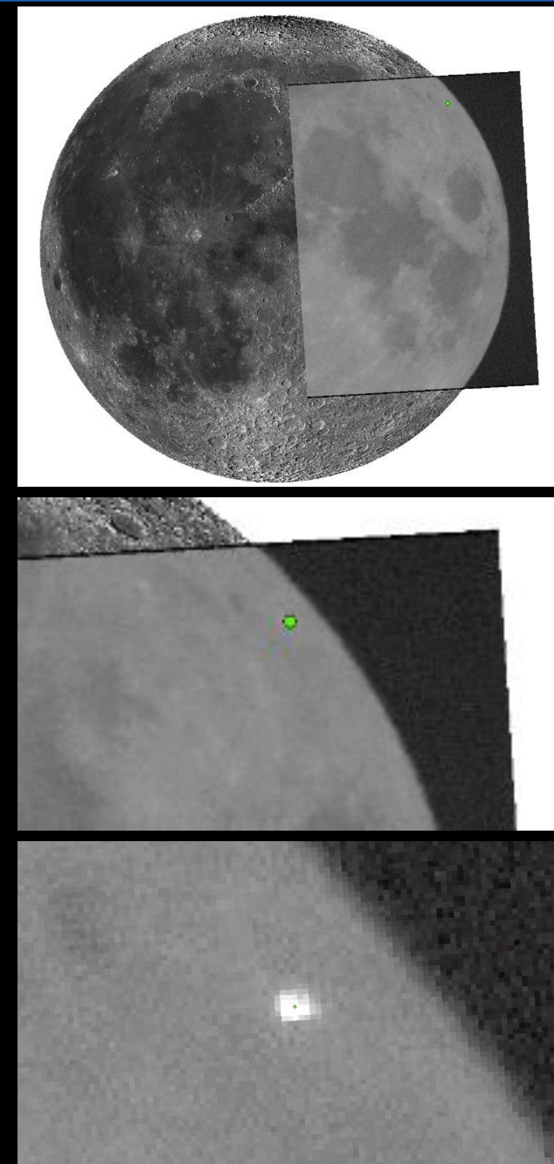
$$(\bar{x}_f, \bar{y}_f) \rightarrow (\bar{x}_f', \bar{y}_f')$$

  determined in Maxim DL

- Custom code read in the world file containing the transformation parameters. Output is flash location in meters on the orthographic projection plane.

# 6. Determine flash location

- Input flash location $(\bar{x}_f{}', \bar{y}_f{}')$ to ArcMap's "Go to XY" tool
- Read & record selenographic coordinates (λ, φ) transformed by ArcMap
- Place marker at flash location, add point to database and shapefile



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