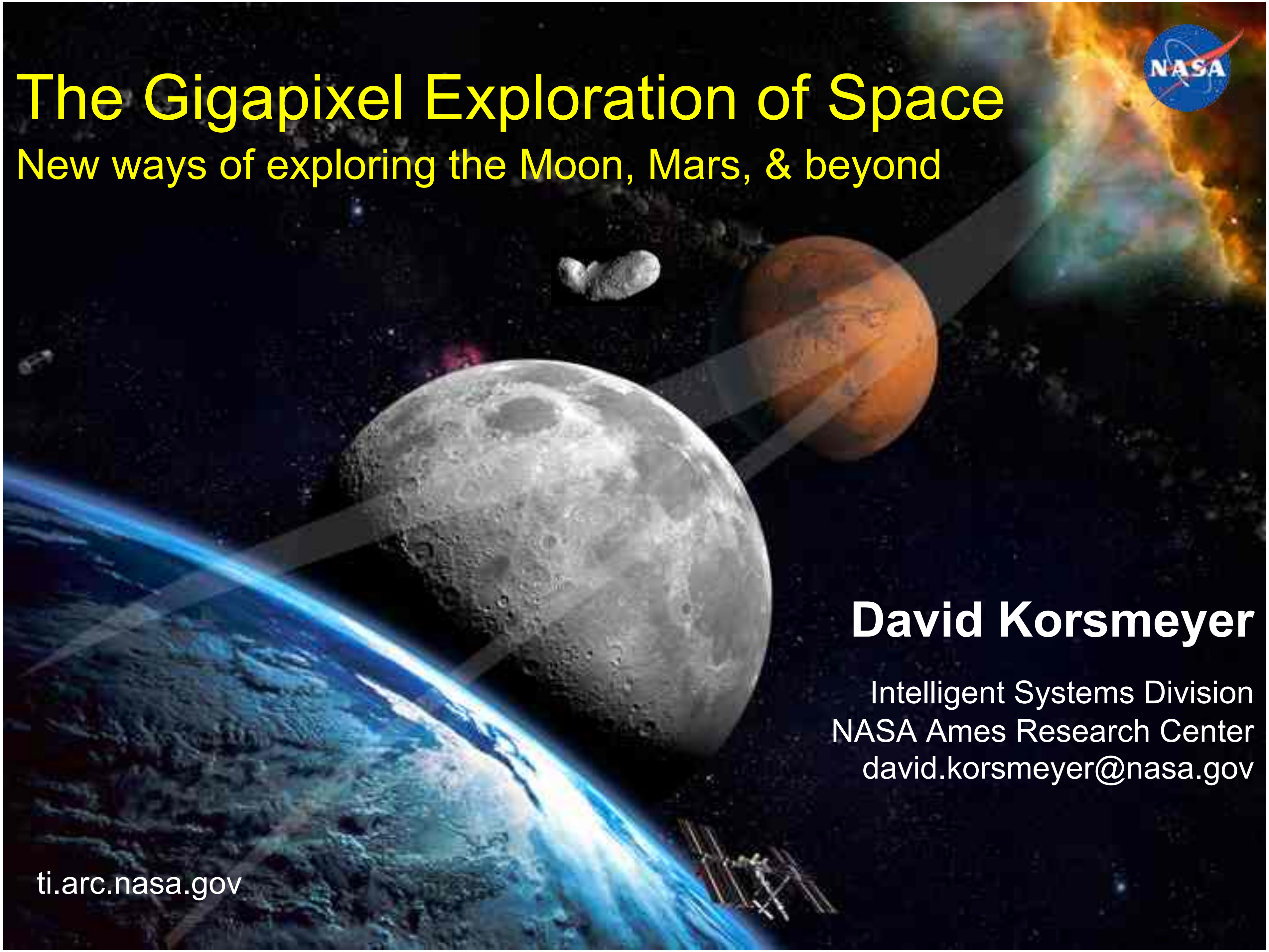
The Gigapixel Exploration of Space

New ways of exploring the Moon, Mars, & beyond



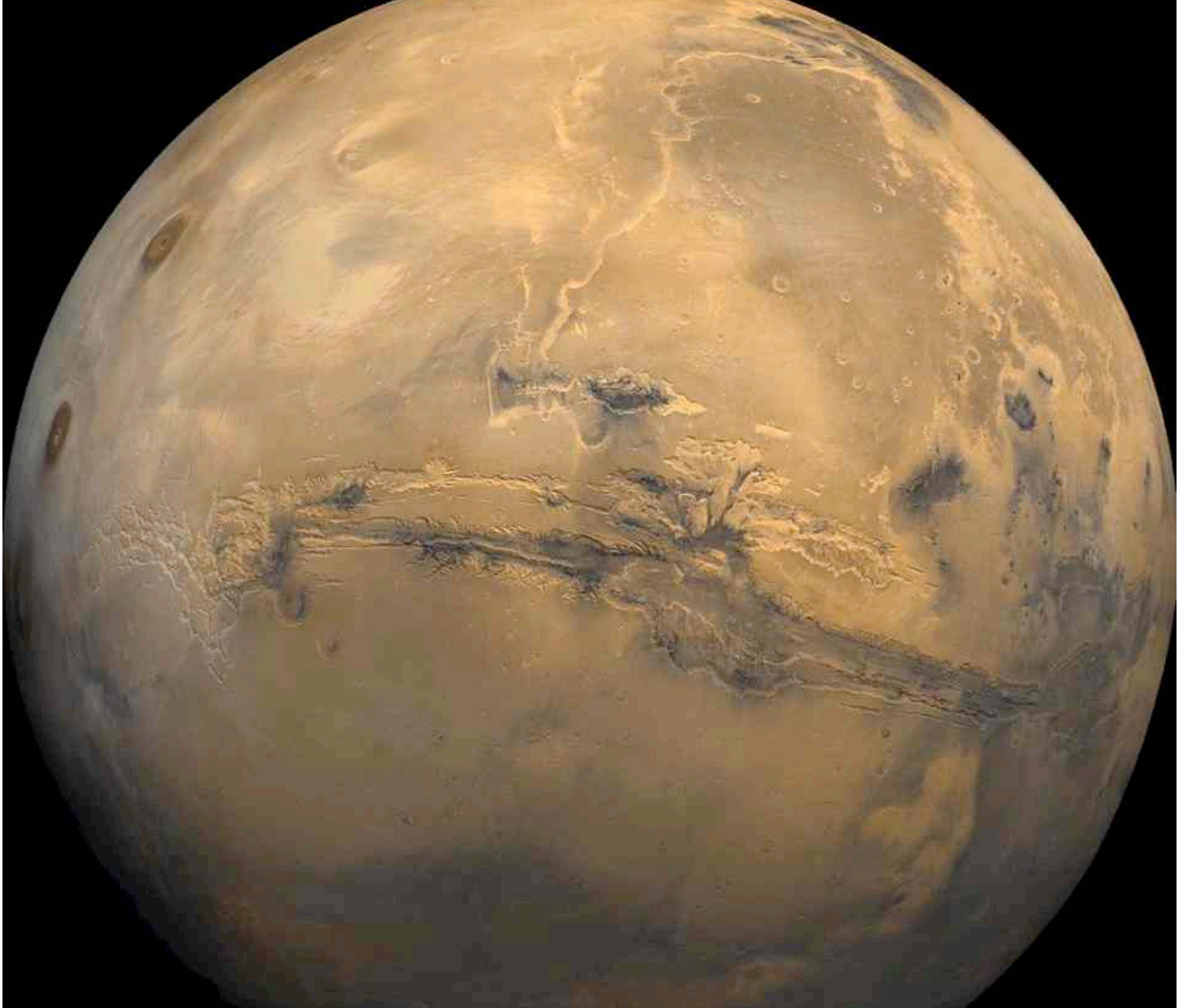
David Korsmeyer

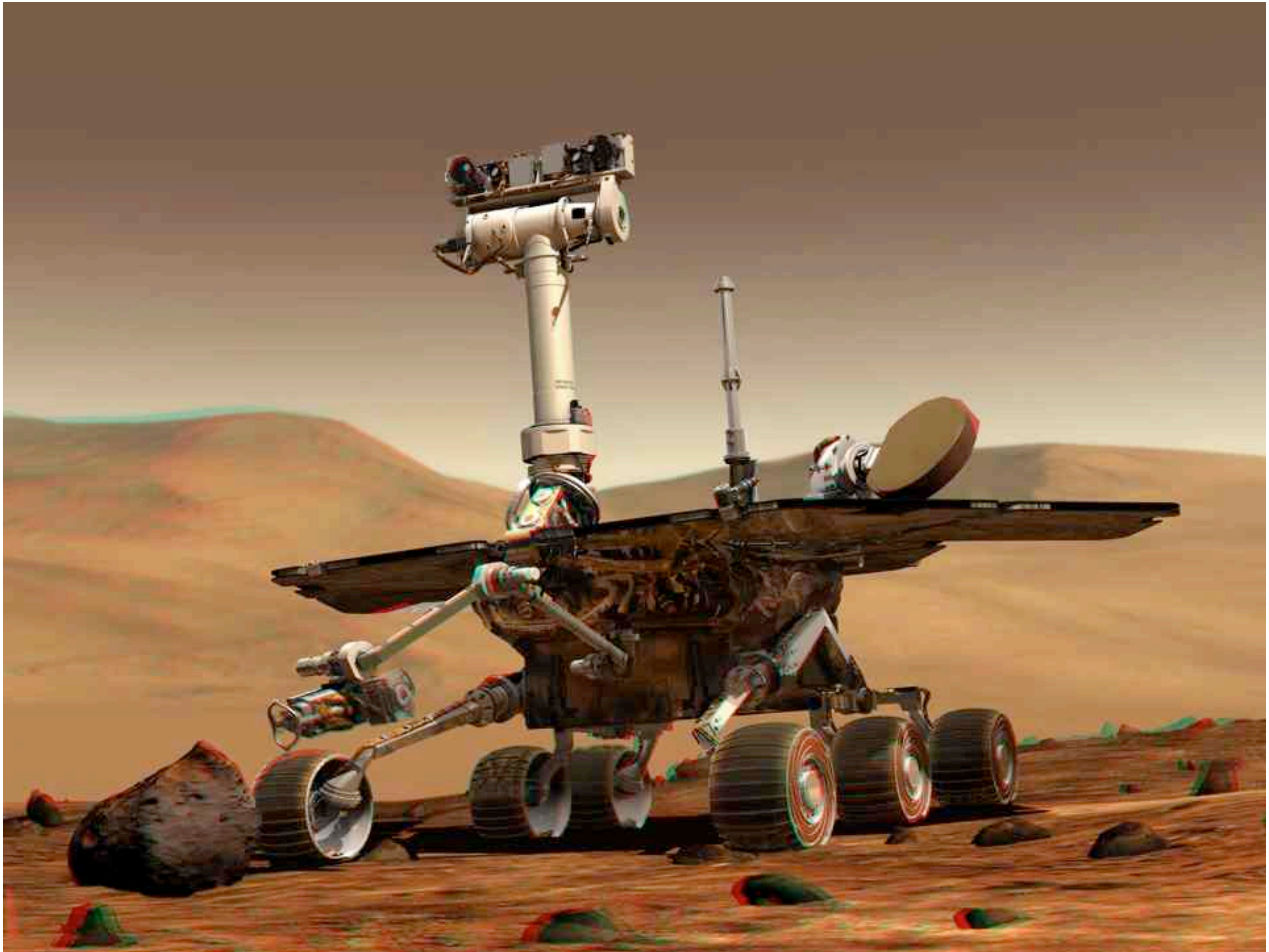
Intelligent Systems Division
NASA Ames Research Center
david.korsmeyer@nasa.gov

ti.arc.nasa.gov

NASA Ames Research Center

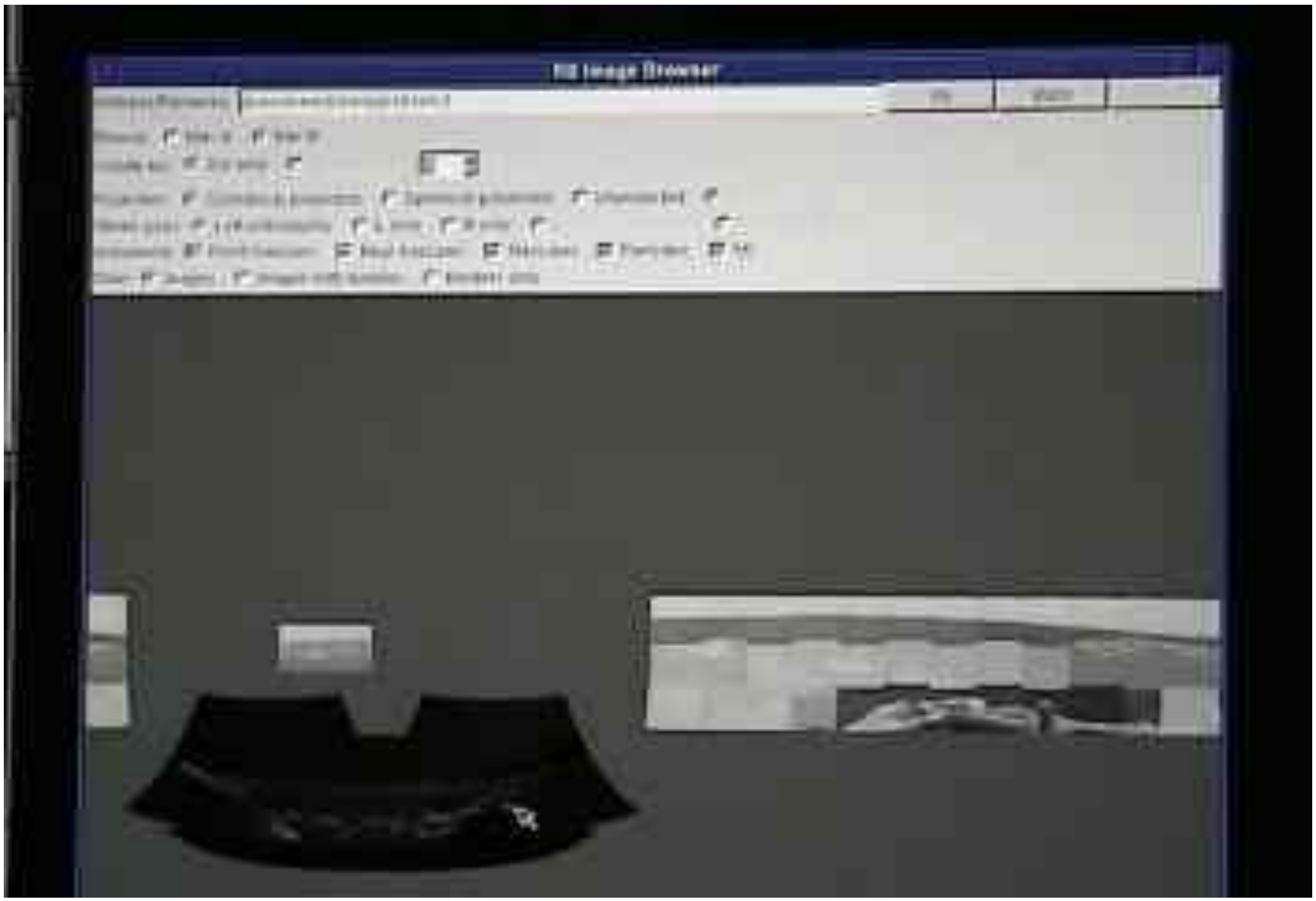
The San Francisco Bay Area location provides a highly skilled workforce for strategic research aligned with the mission leveraging computer science and information technology

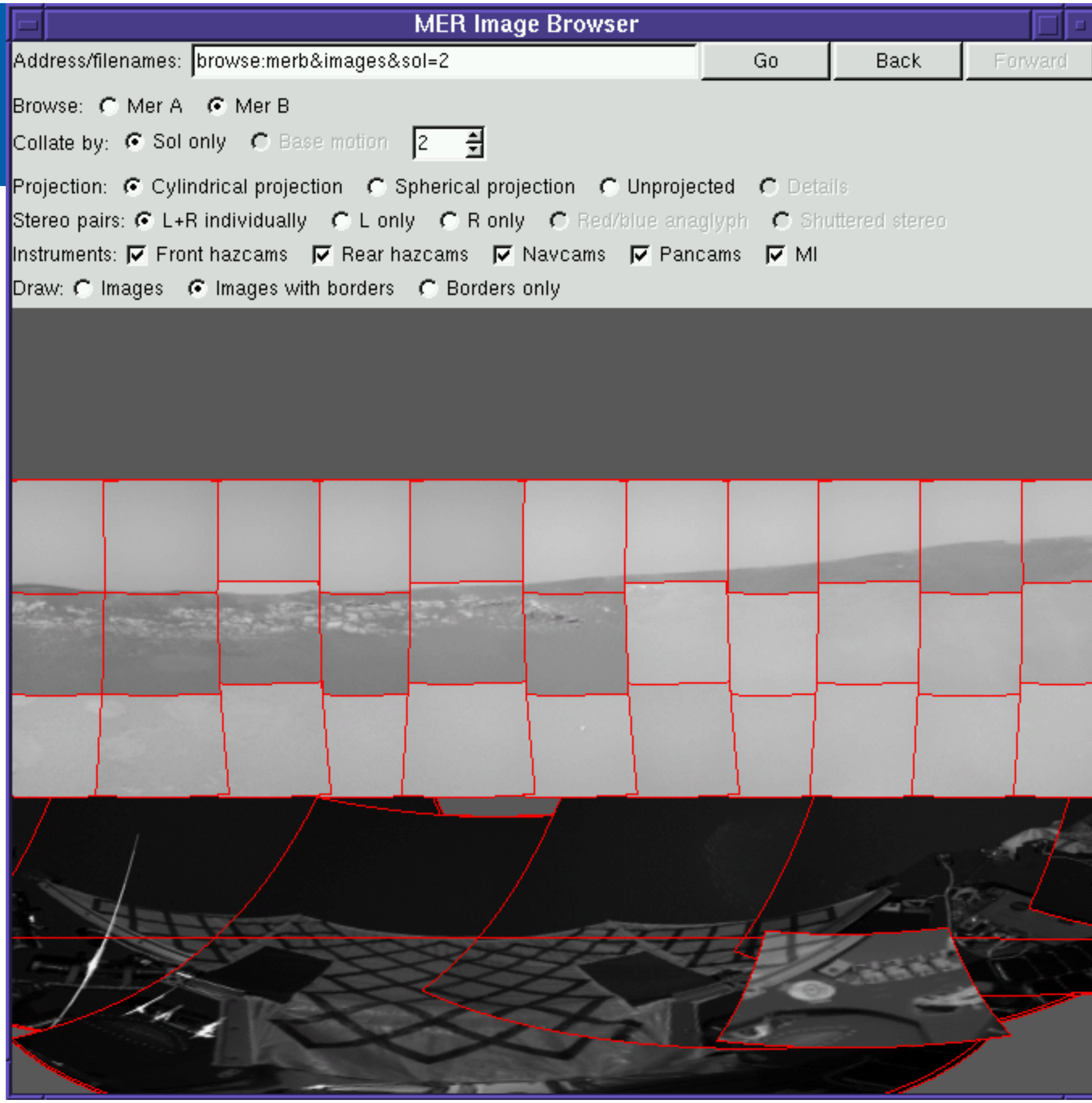




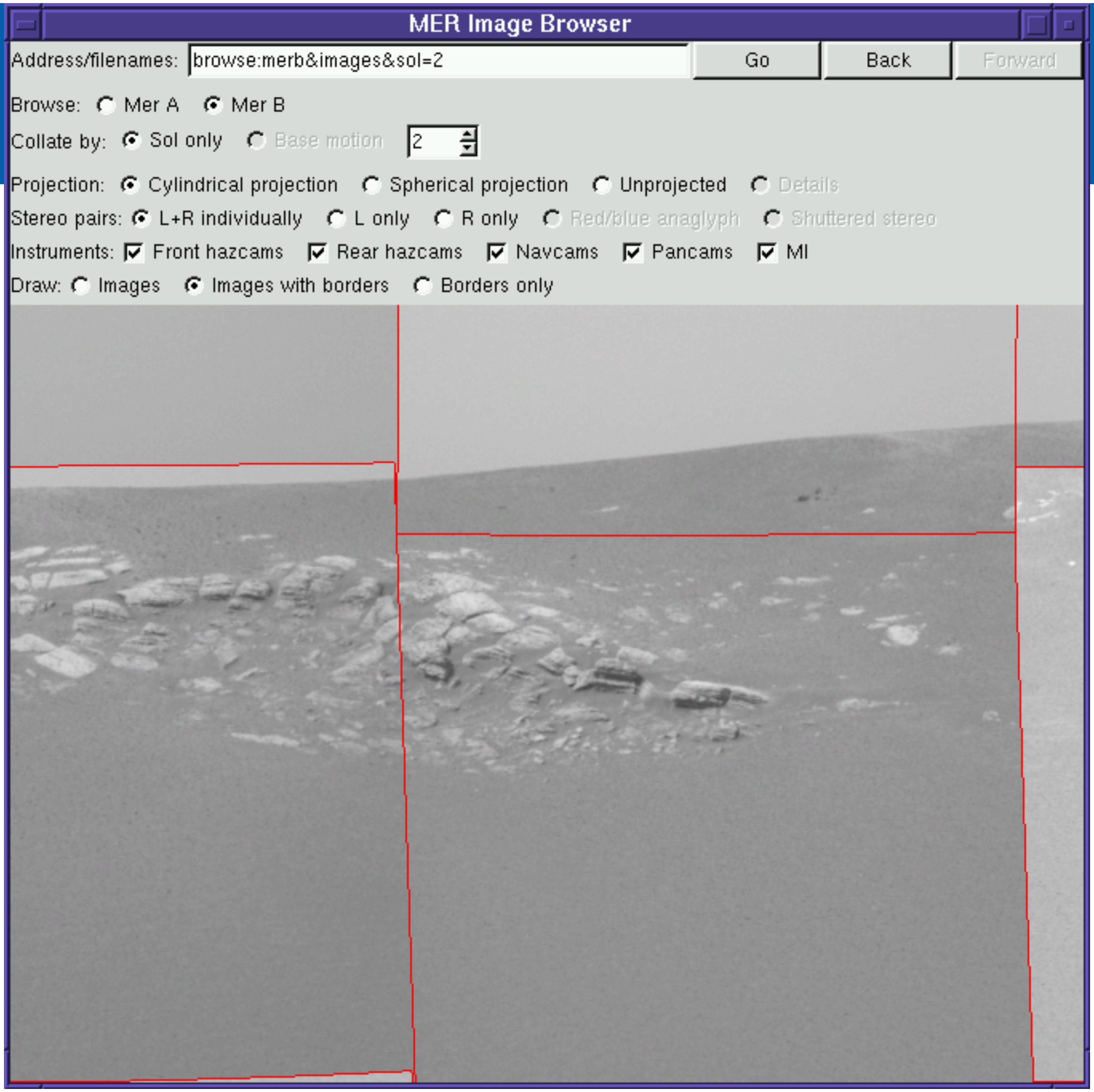
Exploring large panoramas for Mars

MER Image Browser was developed at Ames and was used in MER operations for interactively exploring panoramas

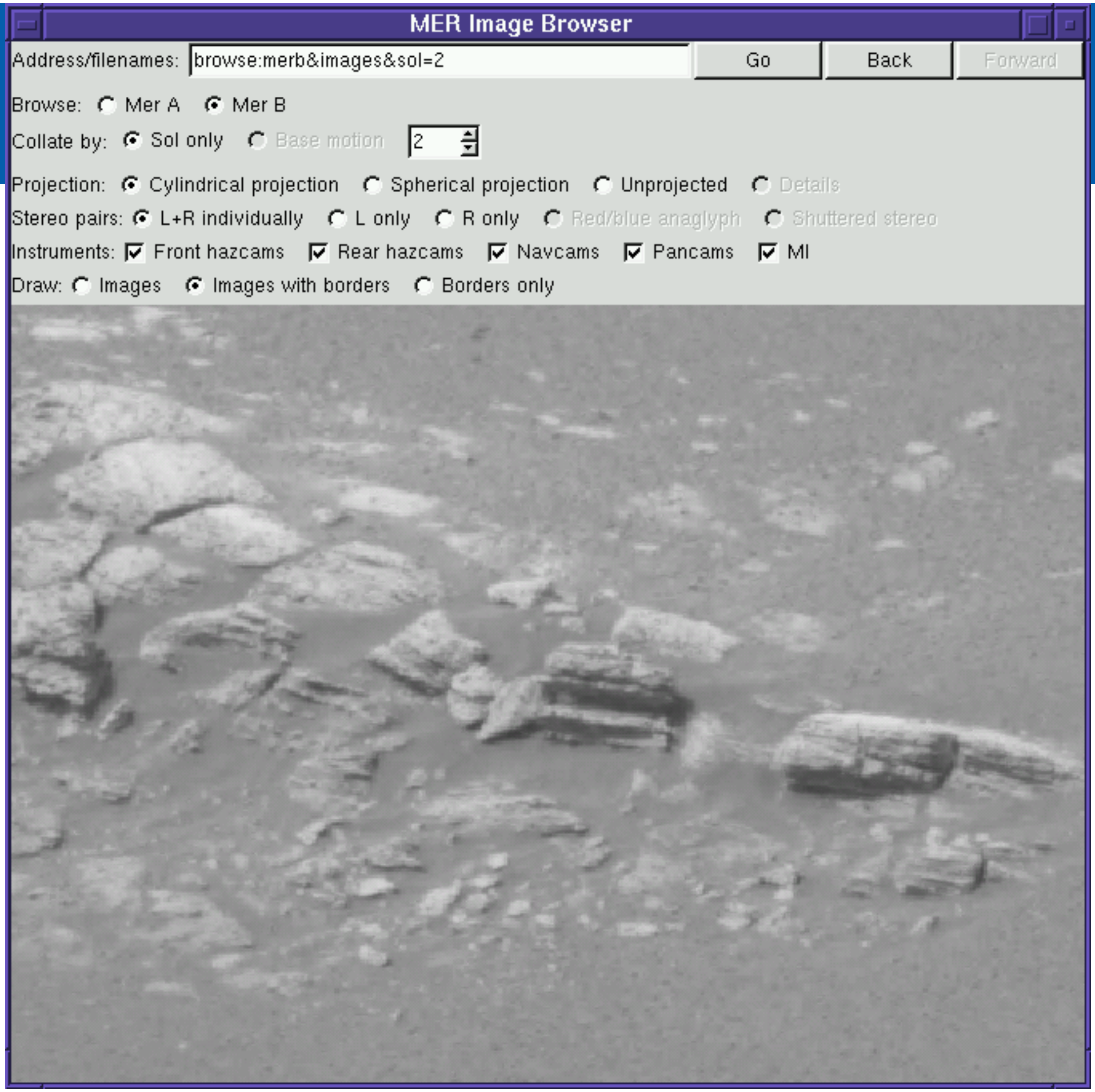




MER Landing Full panorama



Zooming to 6X shows rock outcrop



Zooming to 14X reveals layers

Zooming to 40X: We've found bedrock!

A (short) History of the Gigapan software

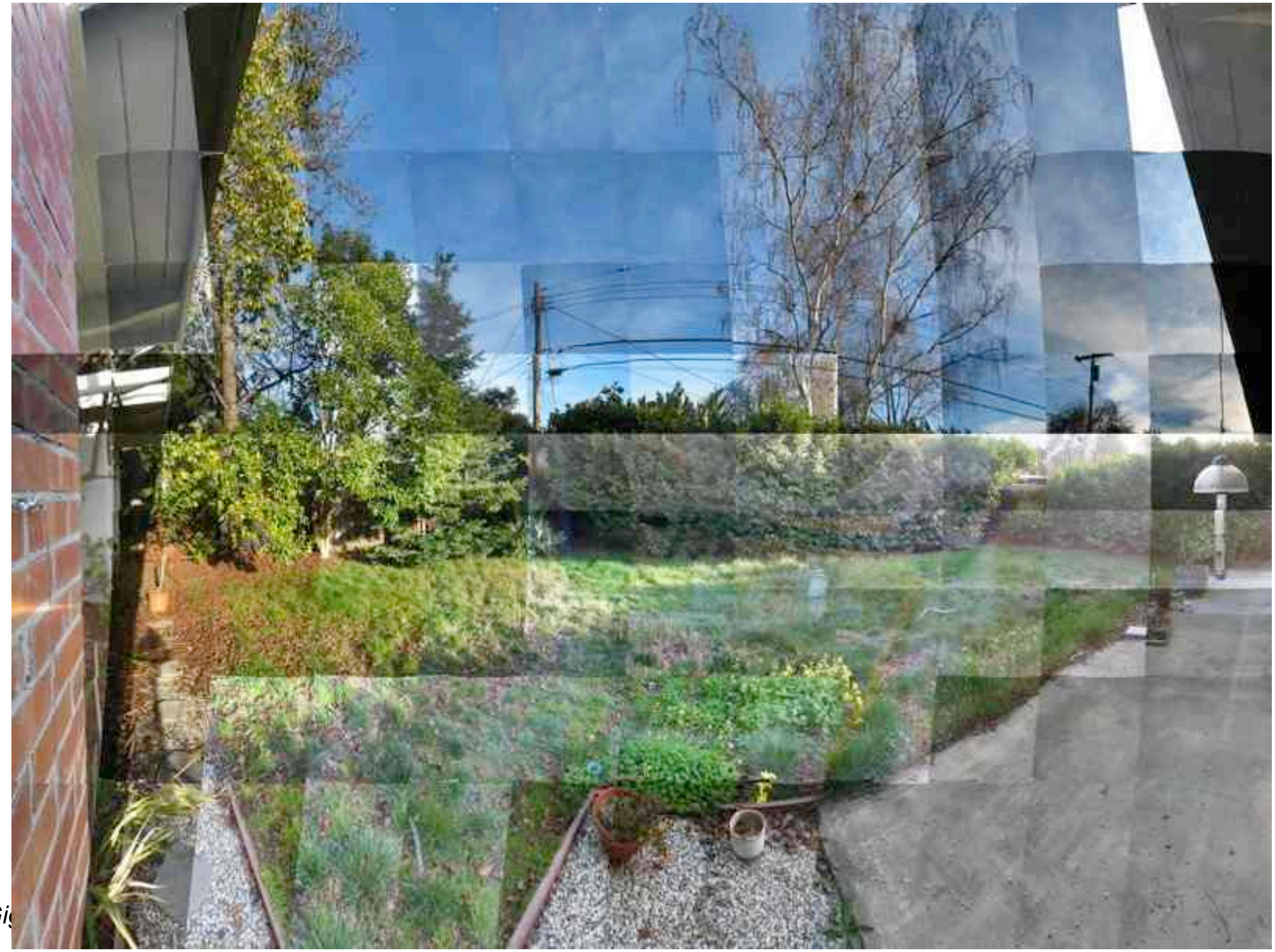
- In 2004, Randy Sargent, Larry Edwards, Matt Deans, and Anne Wright are working at NASA Ames Research Center in the robotics group run by Illah Nourbakhsh
- They developed methods for integrating multiple images from the Mars Exploration Rover quickly
- Randy became infatuated with the panoramas from Mars, both explorable on computers and printed on big banners on the wall
- Randy used some of the software Ames developed to mosaic images on the fly and to zoom around to explore; these later became the basis for the GigaPan stitcher and viewer
    - (caveat: JPL who also produced mosaics that might not have been as explorable, but were the "official" products)
- Illah and Randy talked whether they could make something very low-cost that would do the same thing here on Earth. => Global Connection

Gigapixel Panoramas

With consumer-grade digital cameras, Gigapixel panoramas are cheap and easy to capture

This prototype device developed by Randy's team began capturing half-gigapixel panoramas in a backyard in California every half-hour starting in August 2004

Panorama of yard



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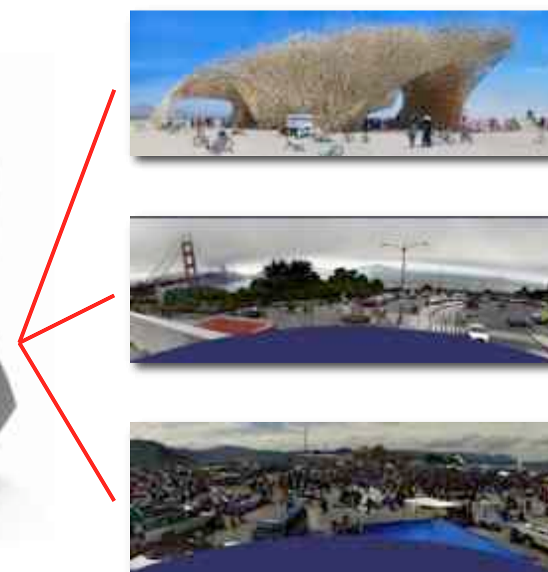
Global Connection (GC)

Goals

- Use spatial images to connect, inform, and inspire
- Create explorable imagery
- Encourage global citizenship and understanding

GigaPan

- Gigapixel panoramas
- Low-cost (~$300) robotic pan/tilt head + stitching software
- Education, exploration & science
- Community, culture & journalism



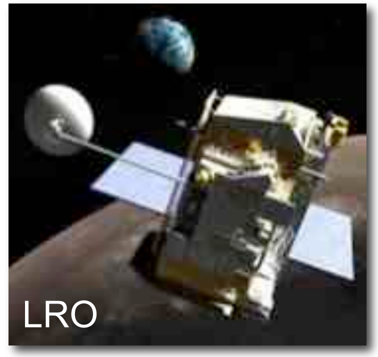
Partners CMU, Google, Nat'l Geographic, NASA

gigapan.org

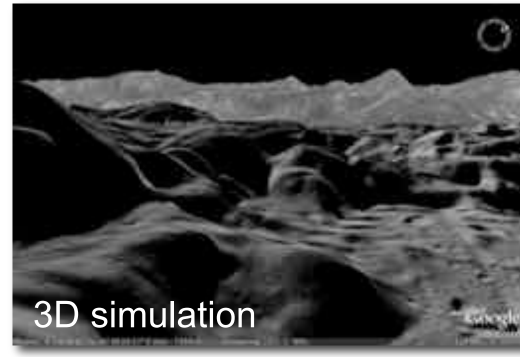
NASA Exploration: What's Changed Since Apollo?

Kaguya

Chandrayaan



LRO



3D simulation

Phoenix

Dante II

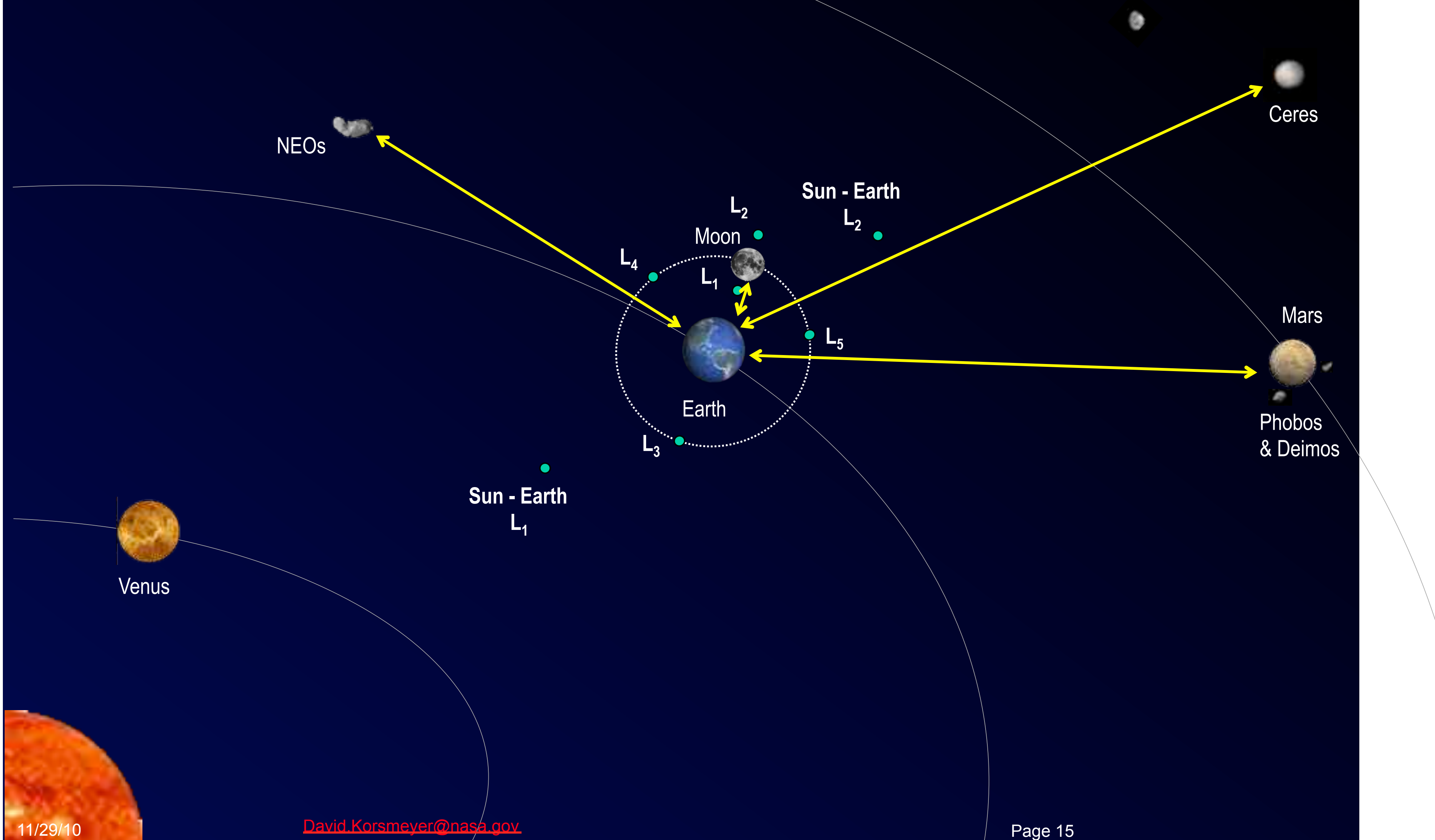
Zoe

MER, Sojourner, MSL

ATHLETE, K10, Chariot

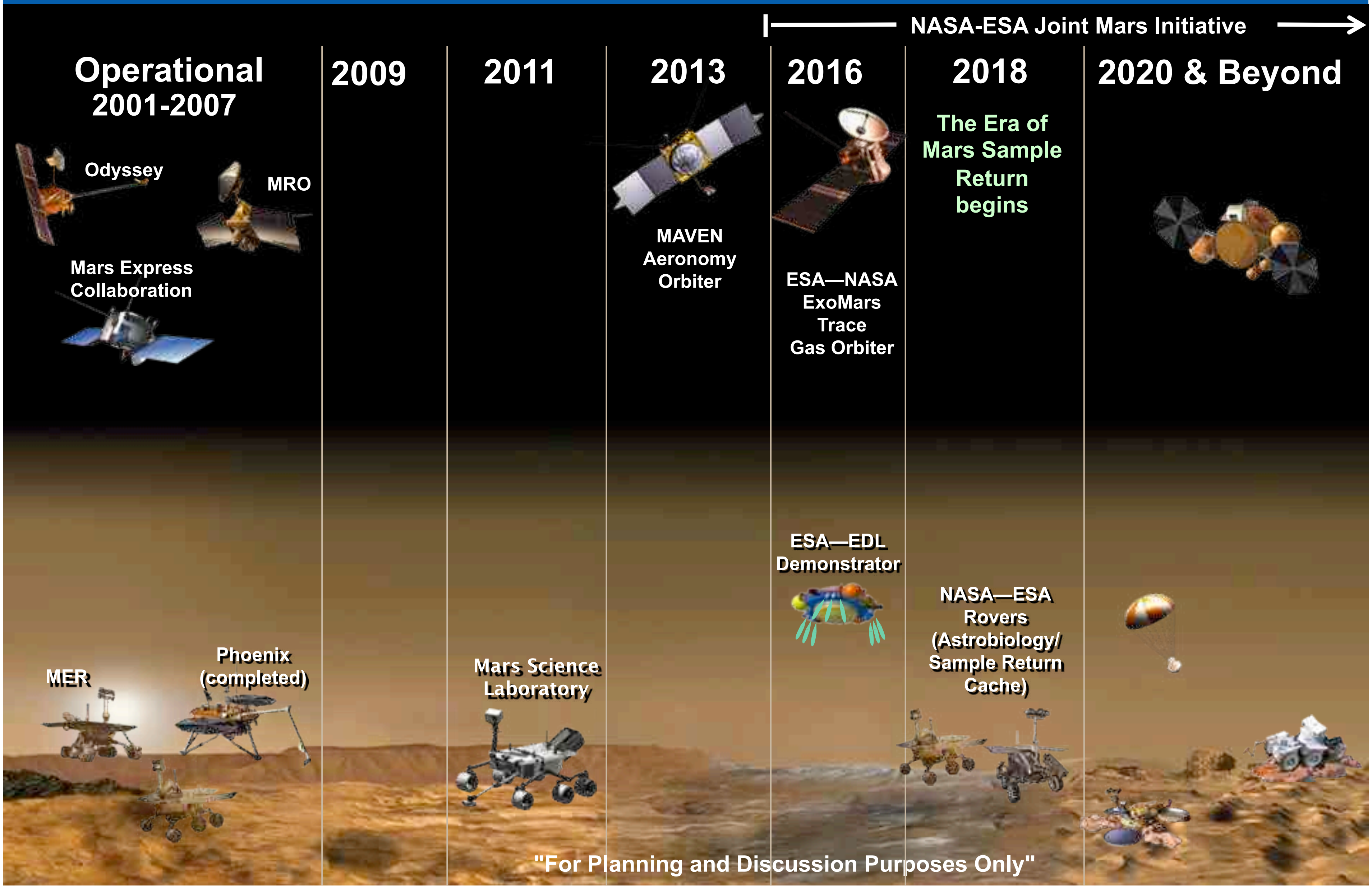
NASA's Exploration Targets

Tele-robotically explore planetary surfaces

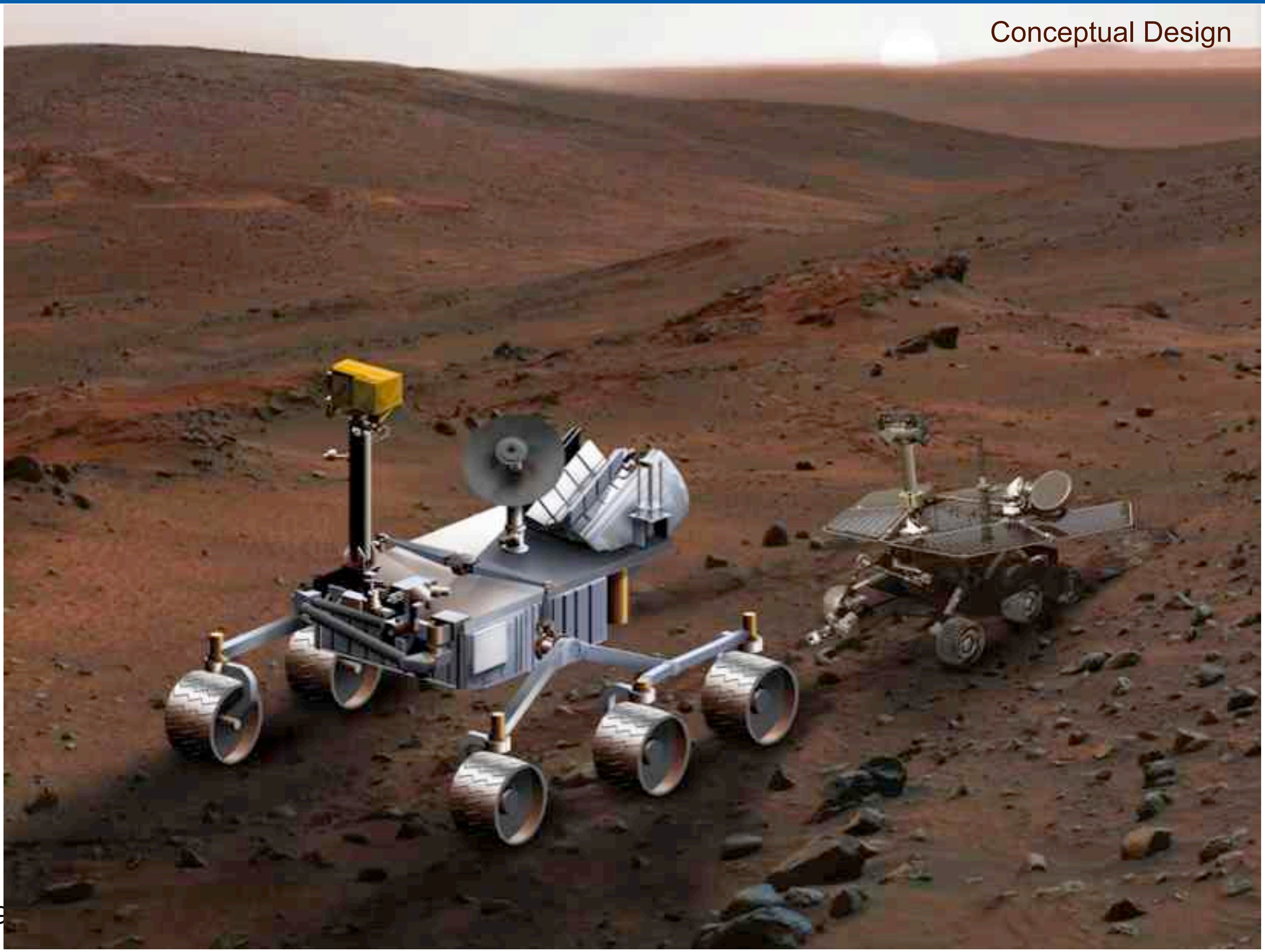


David.Korsmeyer@nasa.gov

Planned Joint NASA-ESA Mars Program



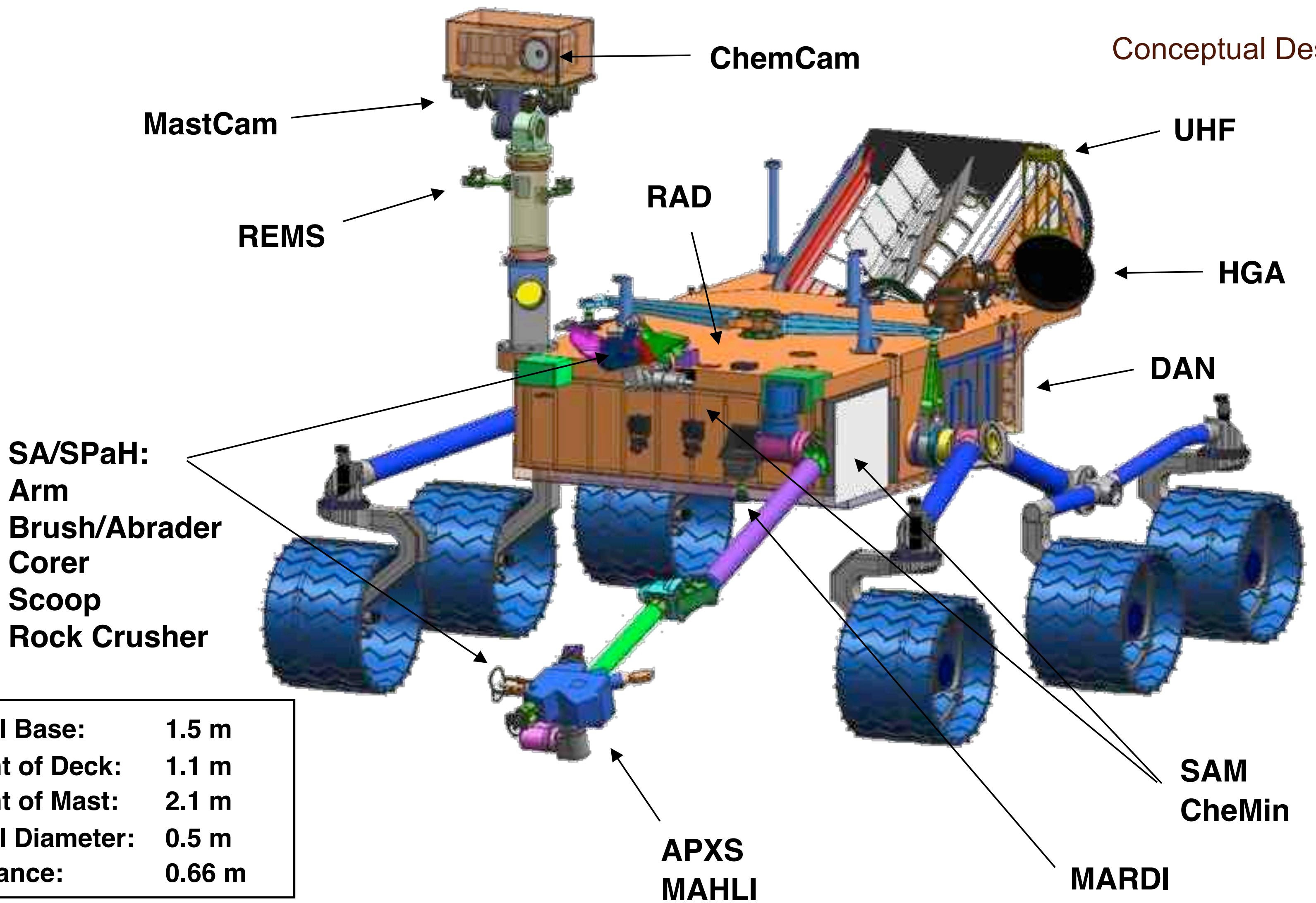
Mars Science Lab comparison with MER



G

MSL's Rover Configuration

Conceptual Design

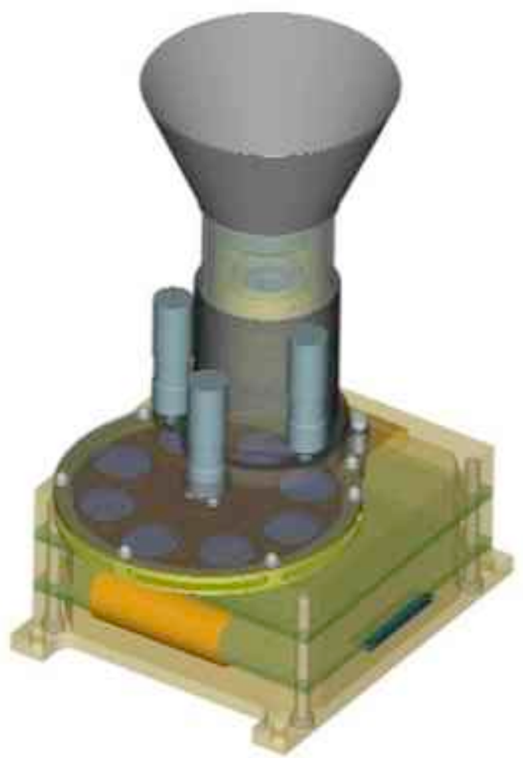


Wheel Base:	1.5 m
Height of Deck:	1.1 m
Height of Mast:	2.1 m
Wheel Diameter:	0.5 m
Clearance:	0.66 m

MSL's Mast Camera (MastCam)

Principal Investigator: Michael Malin

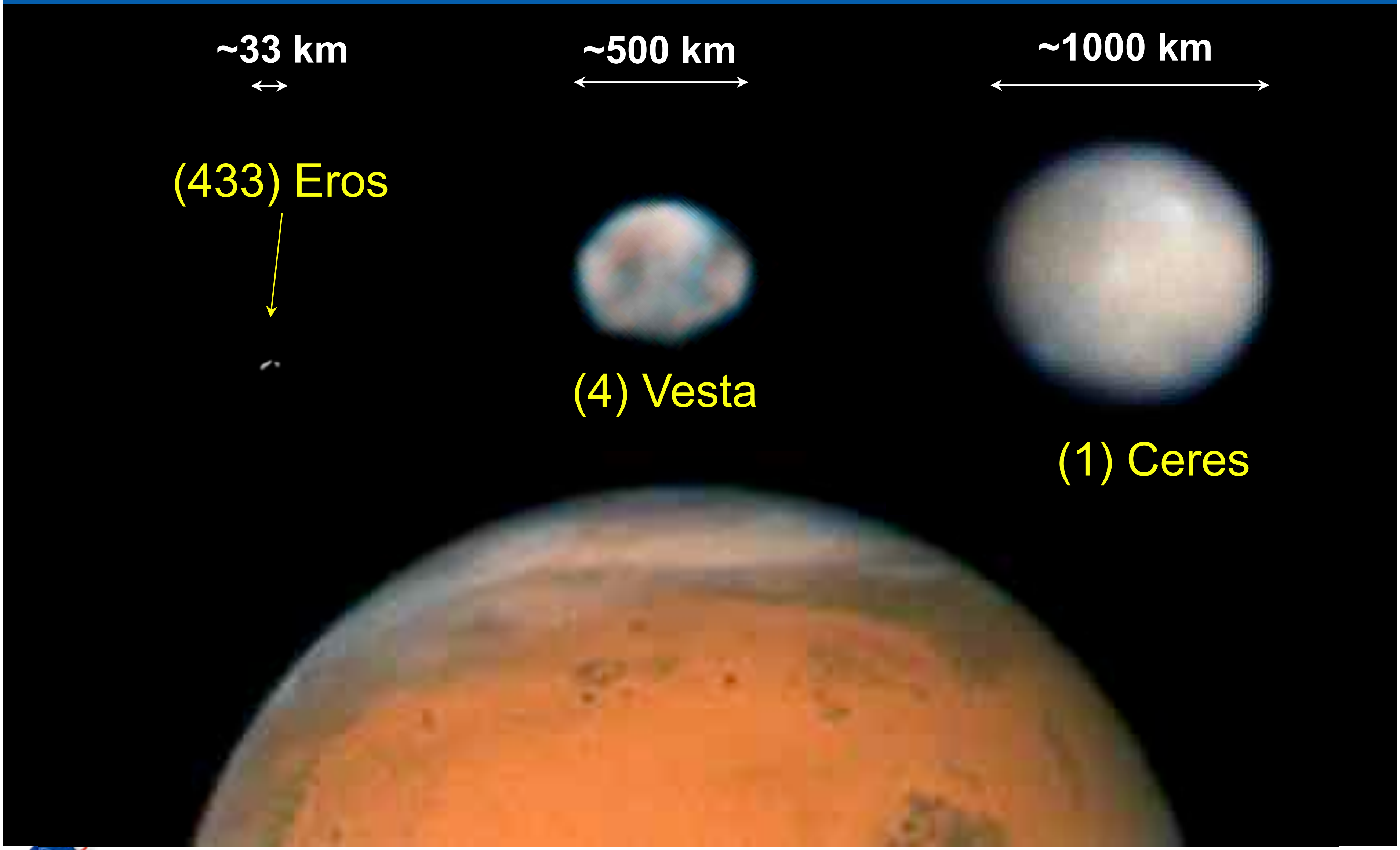
Malin Space Science Systems



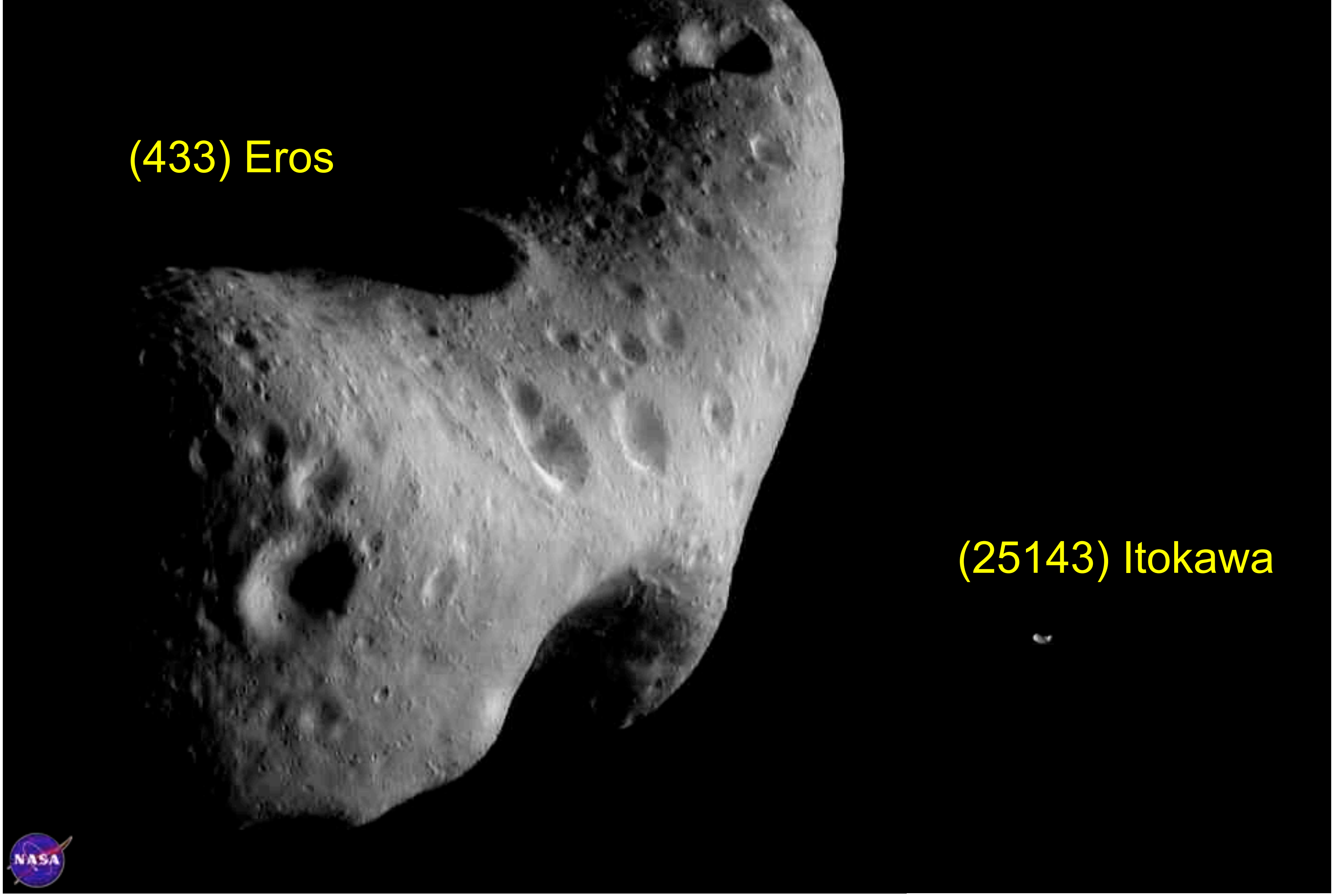
MastCam observes the geological structures and features within the vicinity of the rover

- Studies of landscape, rocks, fines, frost/ice, and atmospheric features
- Stereo, zoom/telephoto lens: 15X, from 90° to 6.5° FOV
- Bayer pattern filter design for natural color plus narrow-band filters for scientific color
- High spatial resolution: 1200×1200 pixels (0.2 mm/pixel at 2 m, 10 cm/pixel at 1 km)
- High-definition video at 5 FPS, 1280×720 pixels
- Large internal storage: 256 MByte SRAM, 8 GByte flash

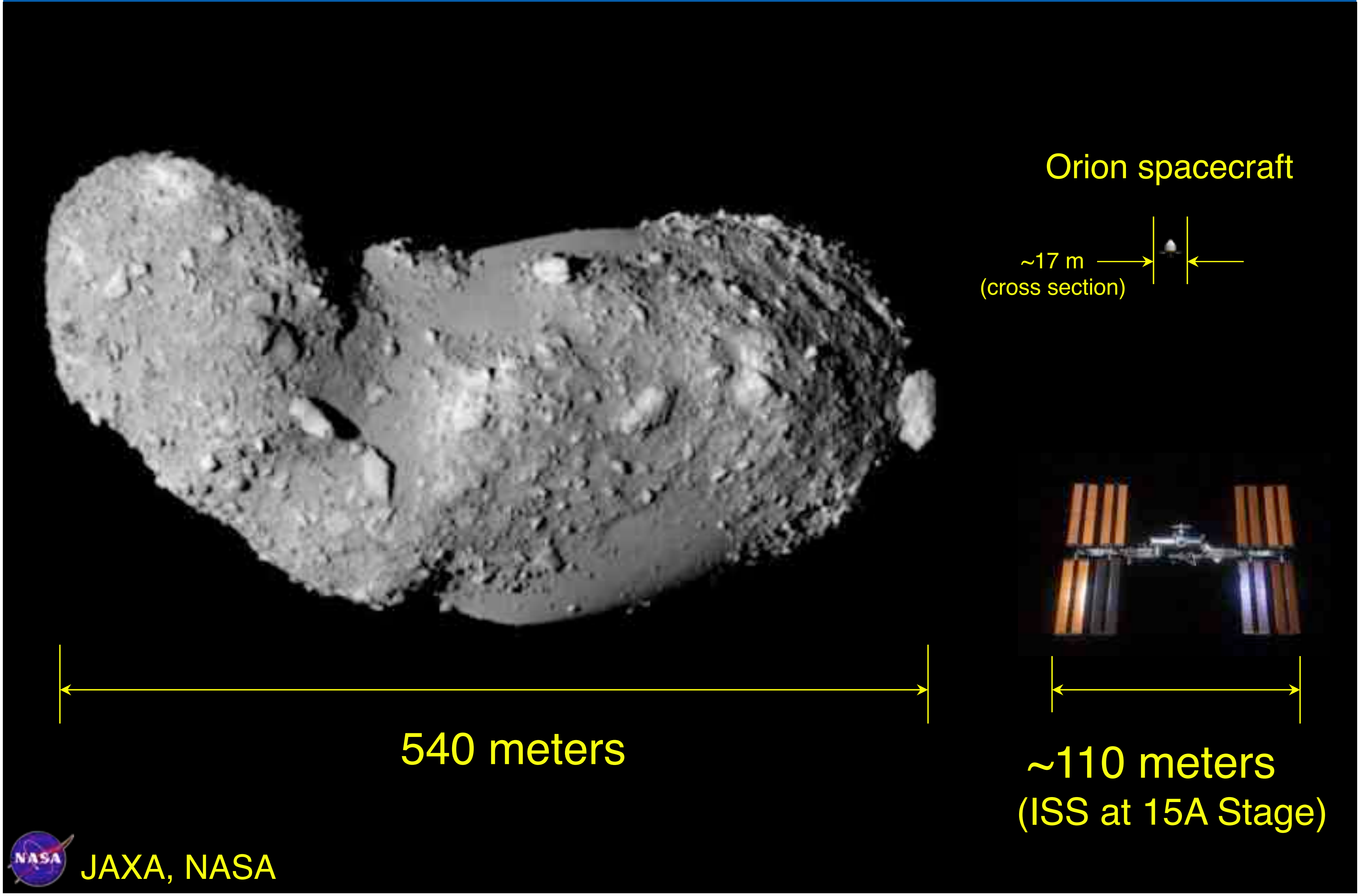
Comparison of Asteroids (to scale)



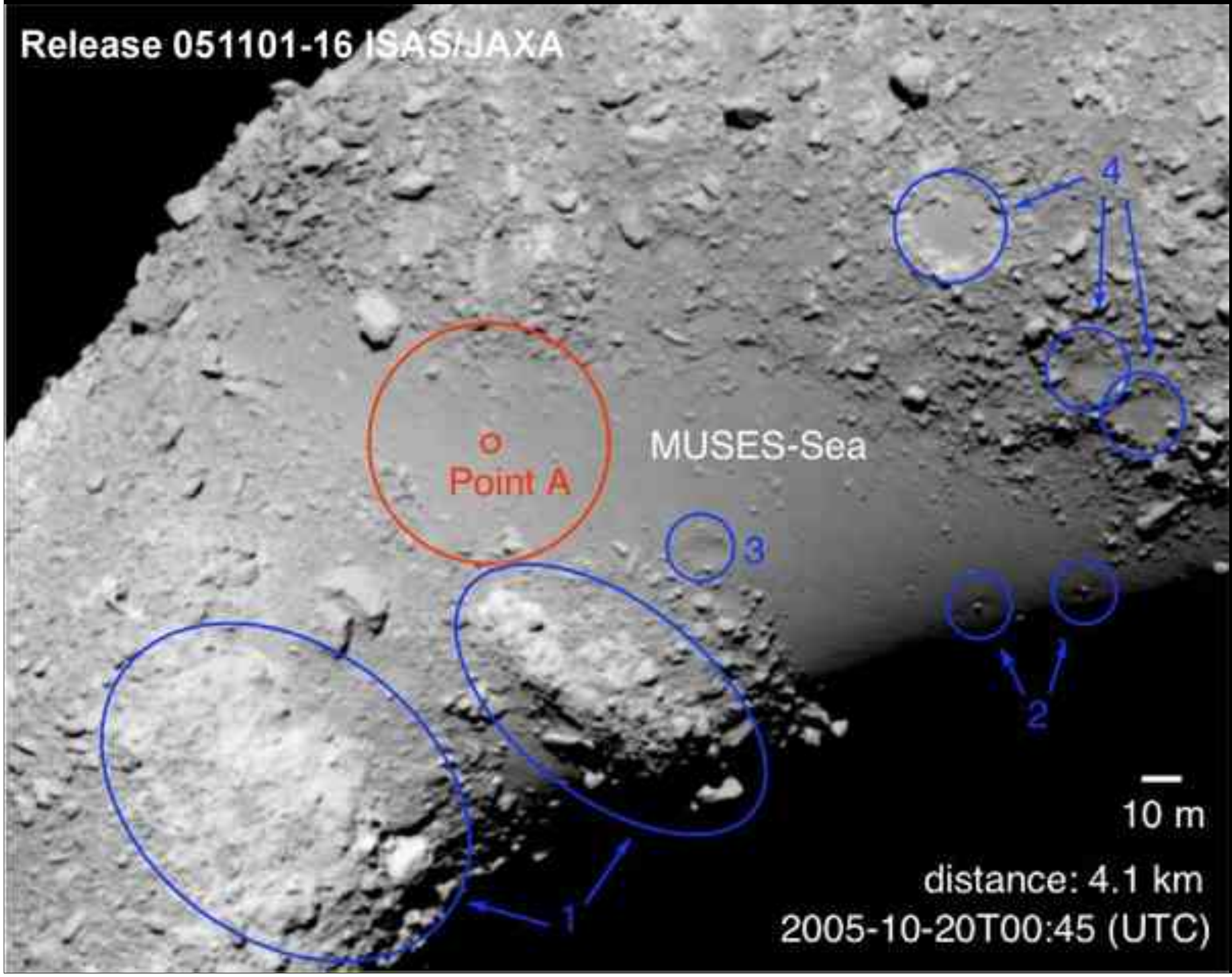
The Two “Visited” Asteroids



Asteroid Itokawa, ISS and Orion



Hayabusa Touchdown Site Candidate A: Muses Sea – JAXA Mission



Largest smooth terrain located between the “Head” and “Body” of the Otter-like [shape of Itokawa]

~60 m across at its widest point.

Hayabusa Touchdown Site Close-Up

h = 80 m

h = 68 m

h = 63 m

(Spatial Resolution: 6-8 mm/pixel)

Gigapixel Planetary Mapping

Purpose

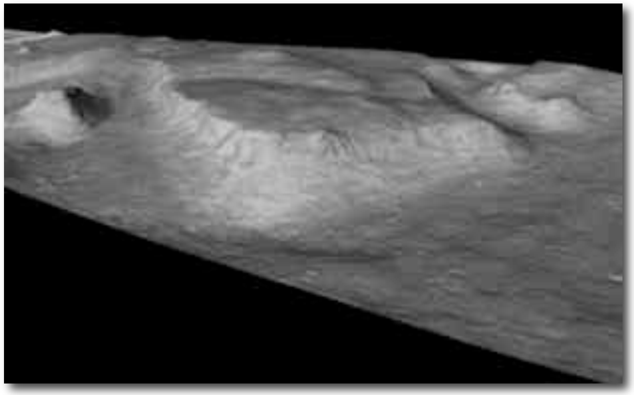
- High-quality digital maps
- On-line access
- Very rapid updates

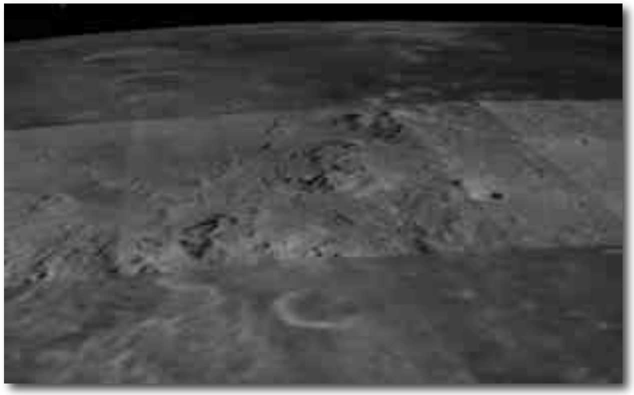
Data processing

- Orbital imagers (Moon, Mars, etc.)
- Image base maps
- 3D terrain reconstruction (DEM's)

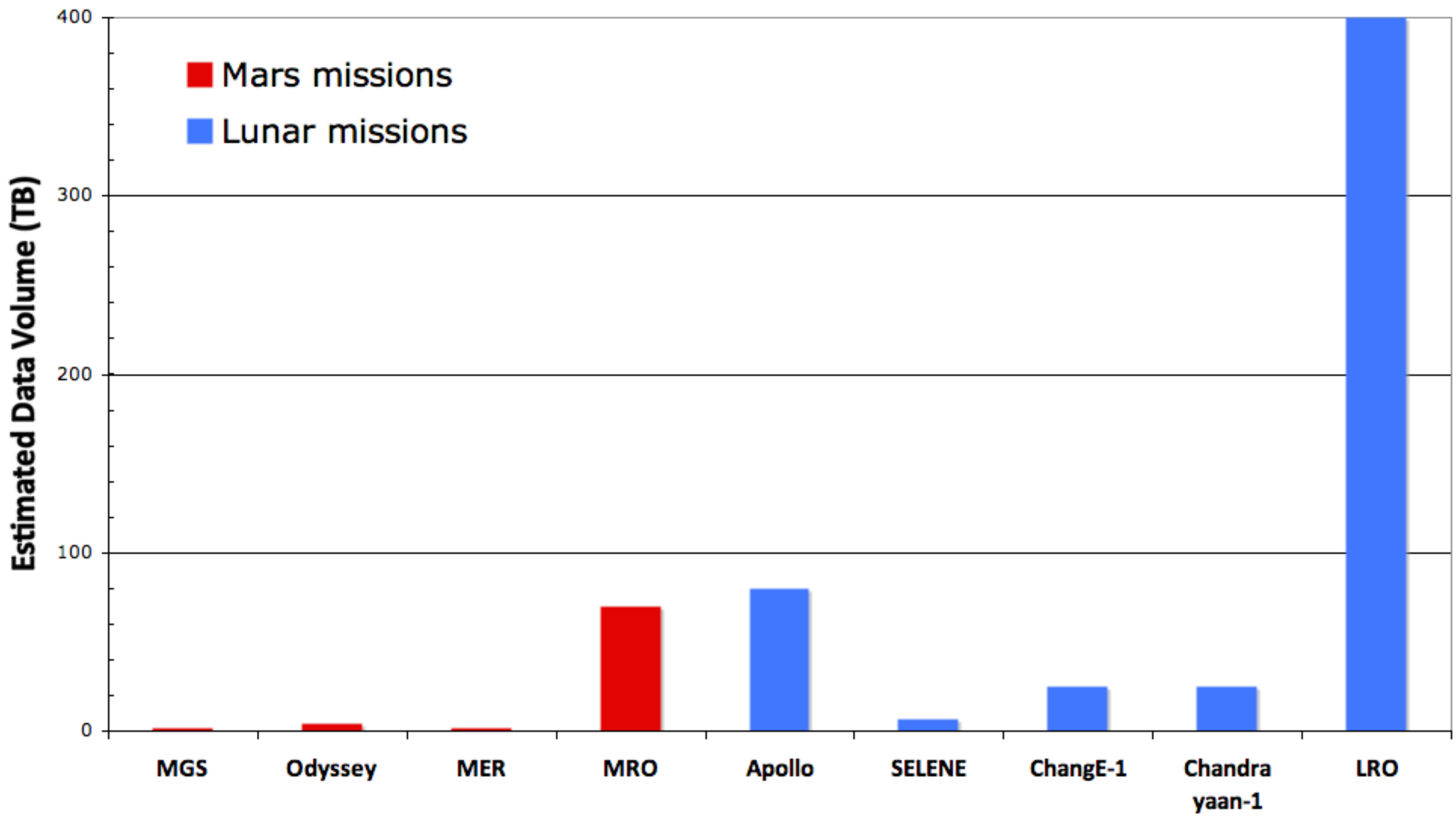
Data fusion & retrieval

- OGC standards (WMS, WFS)
- Geobrowser markup (KML, WTML)
- Image metadata (GeoTIFF, etc.)





Planetary Data Firehose



Source: B. Archinal, L. Gaddis, et al. (2007)
"Urgent Processing and Geodetic Control of Lunar Data"
Workshop on Science Associated with the Lunar Exploration Architecture

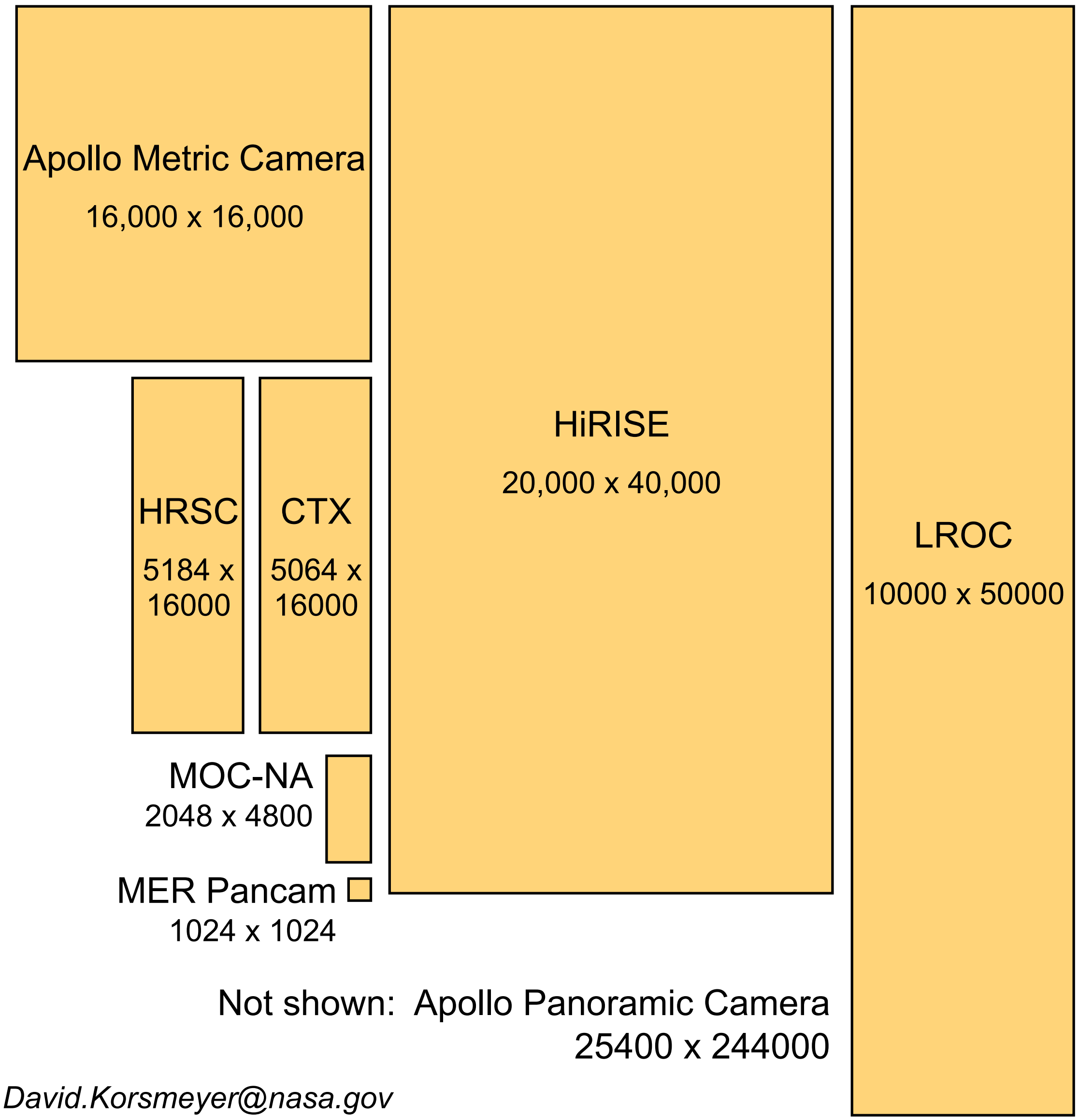
Planetary Data Firehose

Traditional mapping

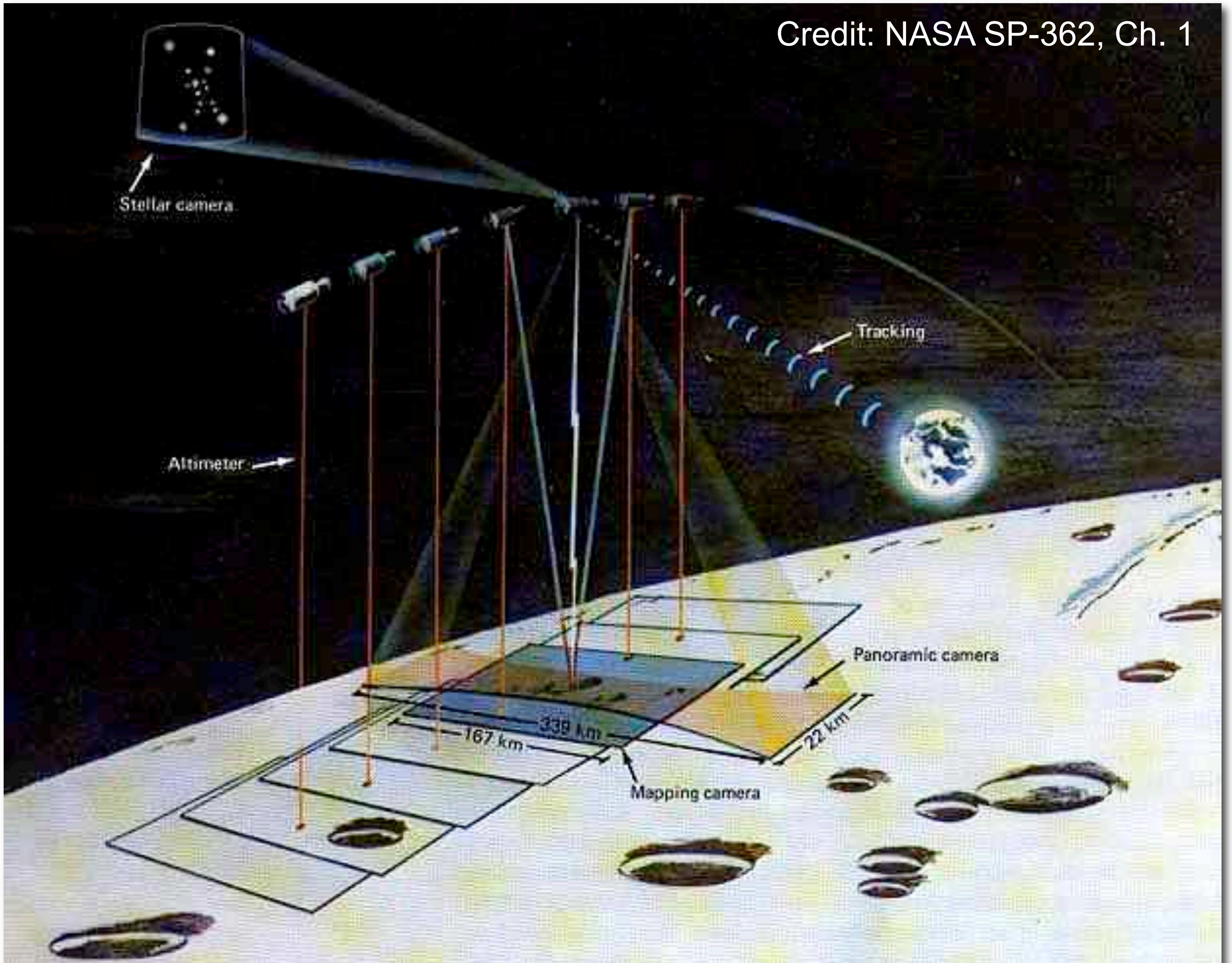
- Human-intensive cartography
- Manual control & error analysis
- Maps take years to complete

Image resolution

- Imagers keep getting better
- High-res digital scans of old film



Automated Stereo Image Processing



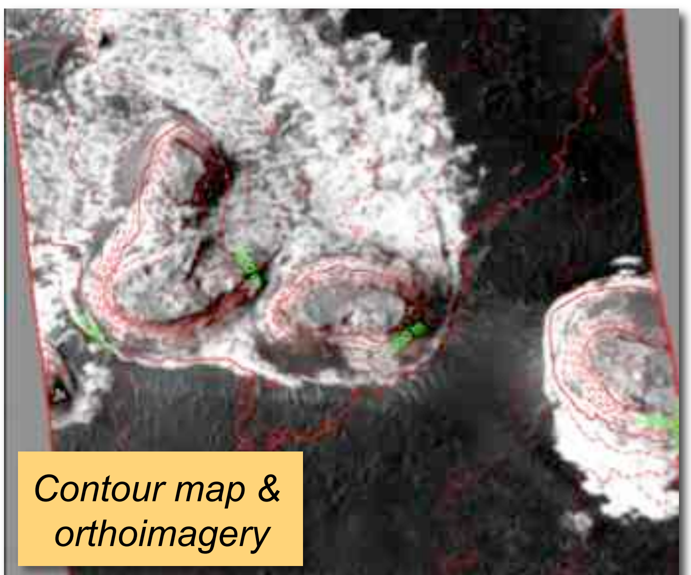
Automated Stereo Image Processing

Problem

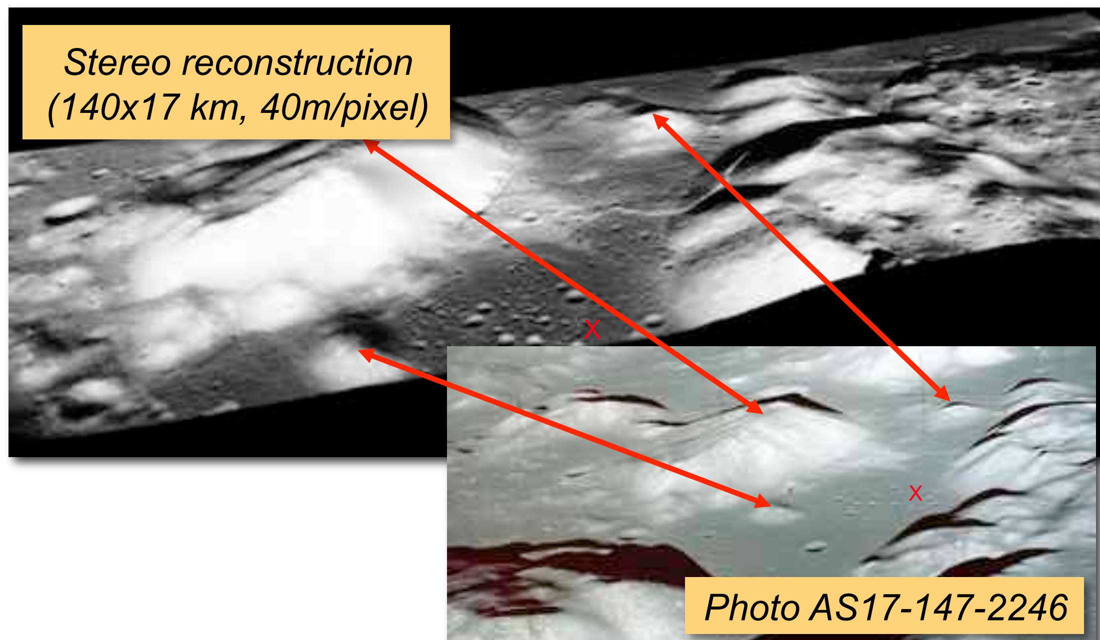
- Multiple images from different viewing angles
- Compute 3D terrain model with no human intervention

Open-source C++ packages

- NASA Ames Stereo Pipeline
- NASA NeoGeography Toolkit
- NASA Vision Workbench



Contour map & orthoimagery

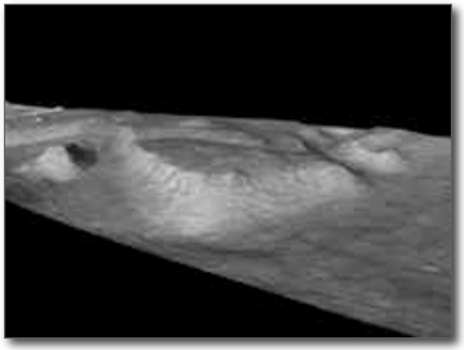


Stereo reconstruction (140x17 km, 40m/pixel)

Photo AS17-147-2246

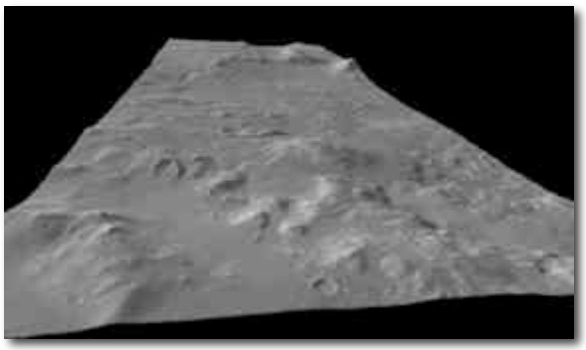
M. Broxton and L. Edwards (LPSC 2008)
"The Ames Stereo Pipeline: Automated 3D surface reconstruction from orbital imagery"

Mars Terrain Models



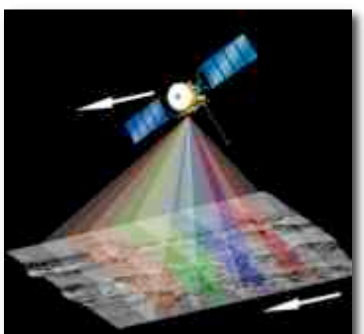
MGS MOC Narrow Angle

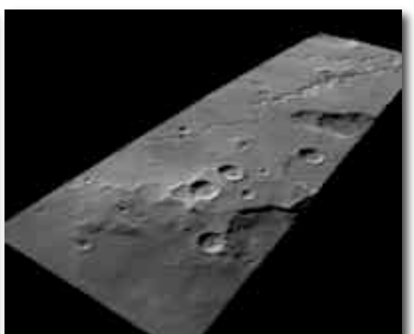
- Collaboration with Malin Space Science Systems
- Adapted Ames Stereo Pipeline to orbital images



MRO Context Imager (CTX)

- Collaboration with CTX Team
- Provided rapid turn-around stereo modeling

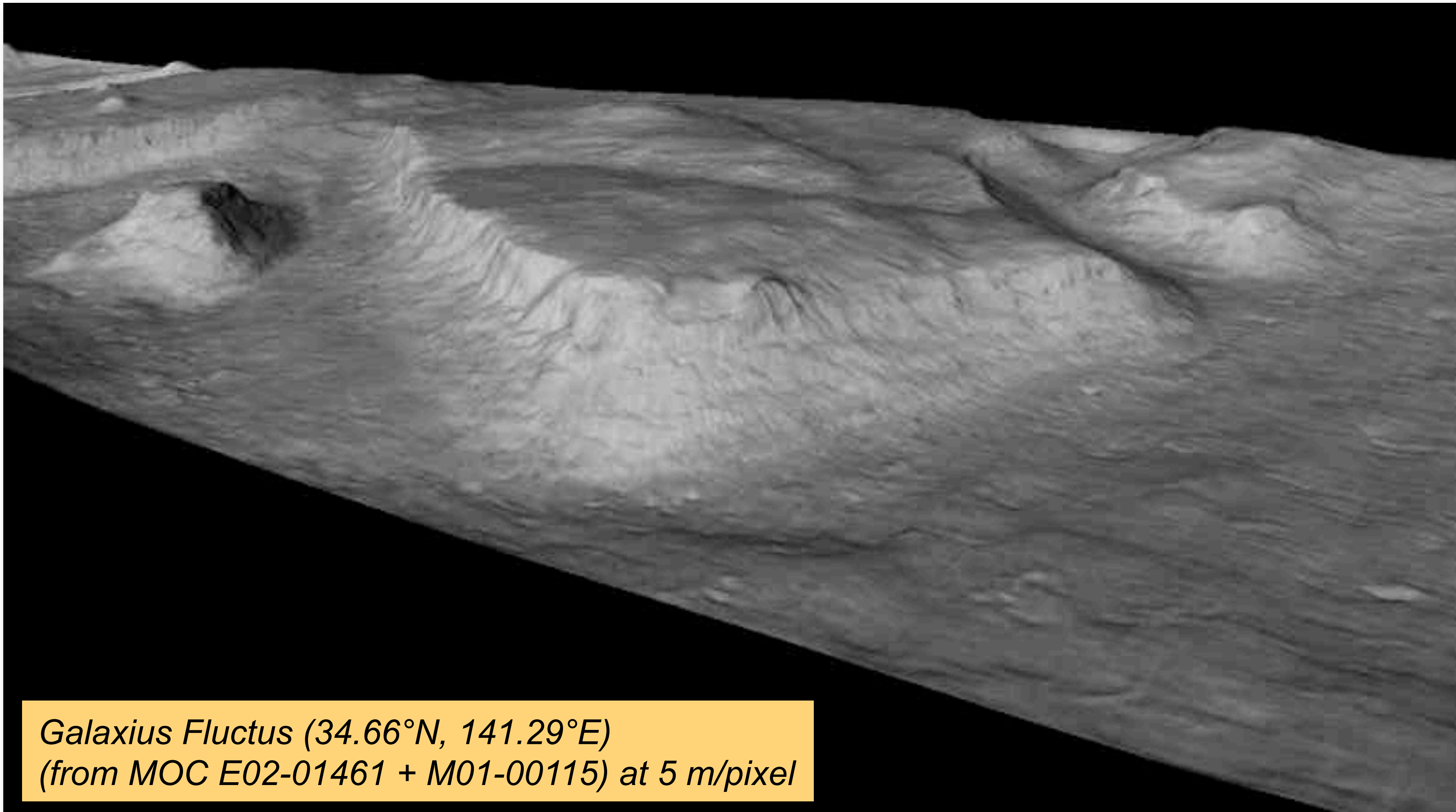




Mars Express HRSC

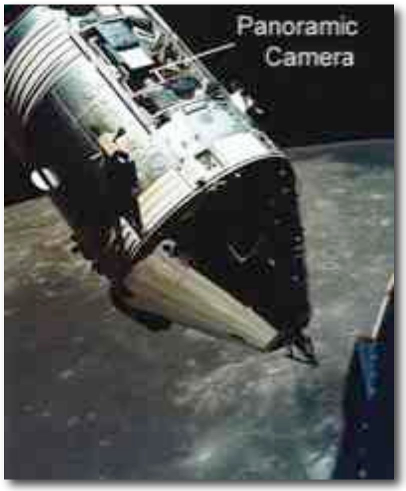
- Collaboration with USGS, DLR
- Formal comparison of Digital Elevation Model (DEM) products
- Four controlled data sets

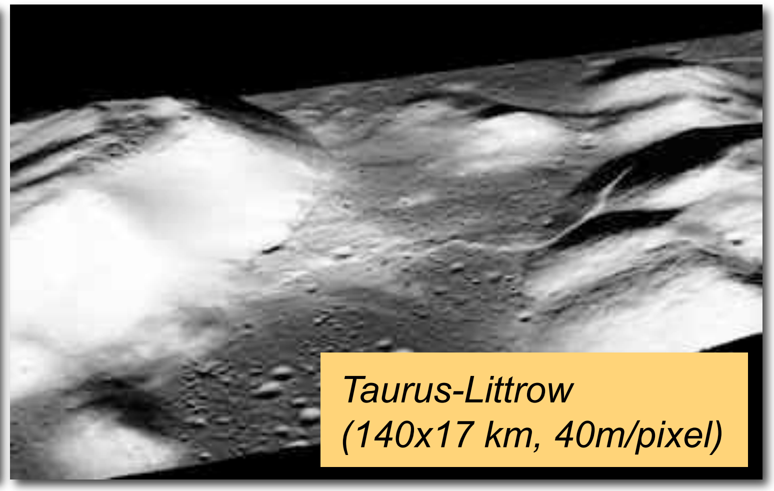
Mars Terrain Models



Galaxius Fluctus (34.66°N, 141.29°E)
(from MOC E02-01461 + M01-00115) at 5 m/pixel

Lunar Terrain Models





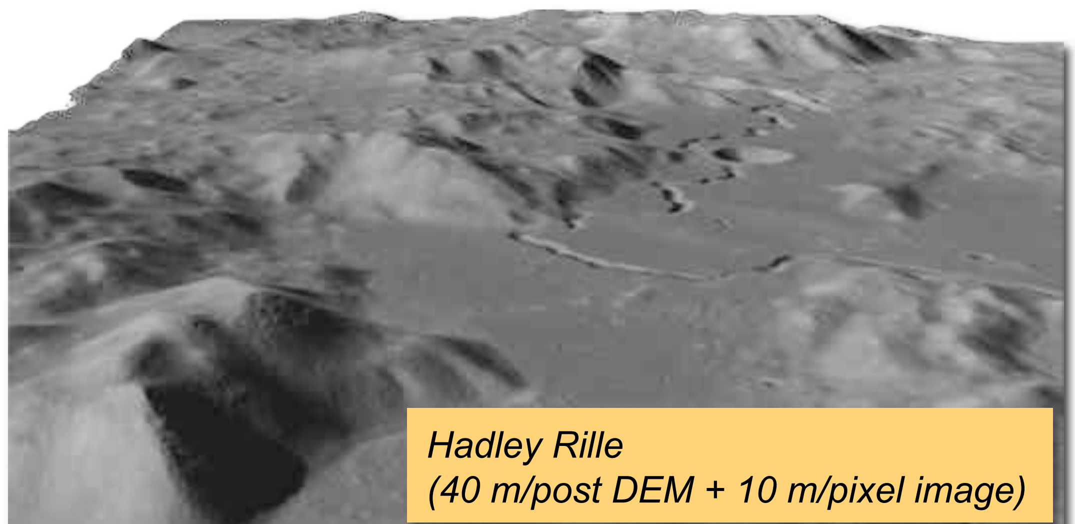
Taurus-Littrow
(140x17 km, 40m/pixel)

Apollo Panoramic Camera

- 3D terrain model of Taurus-Littrow valley (Apollo 17)
- Featured at the Hayden Planetarium (American Museum of Nat. History)

Apollo Metric Camera

- Systematic creation of image maps & DEMs
- Refinement of the Lunar geodetic control network (with USGS)
- NASA Lunar Mapping & Modeling Project



Hadley Rille
(40 m/post DEM + 10 m/pixel image)

Lunar Terrain Models

Apollo Image Archive project

- **apollo.sese.asu.edu** (Mark Robinson, ASU)
- Photogrammetric scans of original Apollo films (200 pixel/mm, 14-bit)

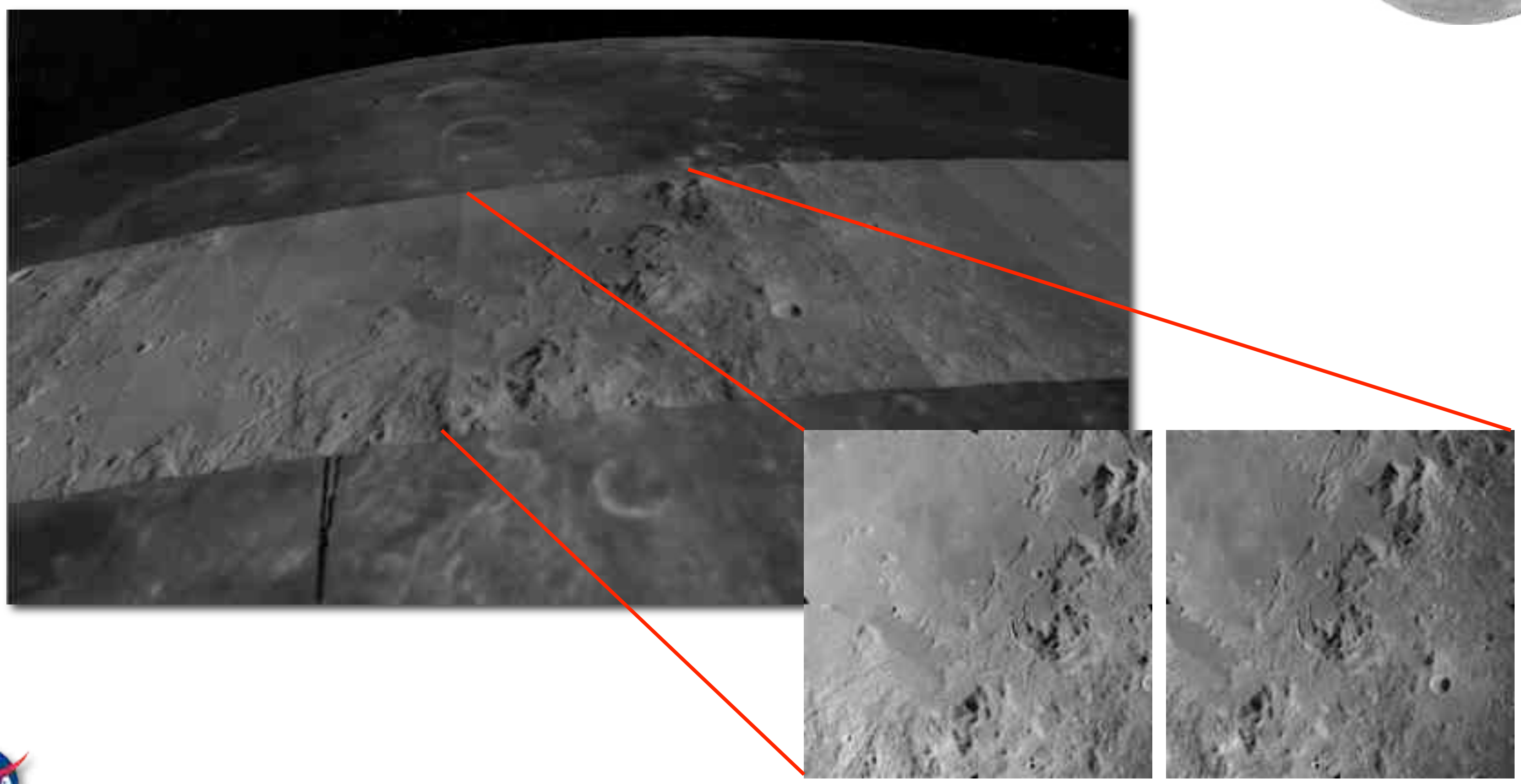
Apollo Mapping Camera

AS15-M-0081 was one of the first images to be scanned …

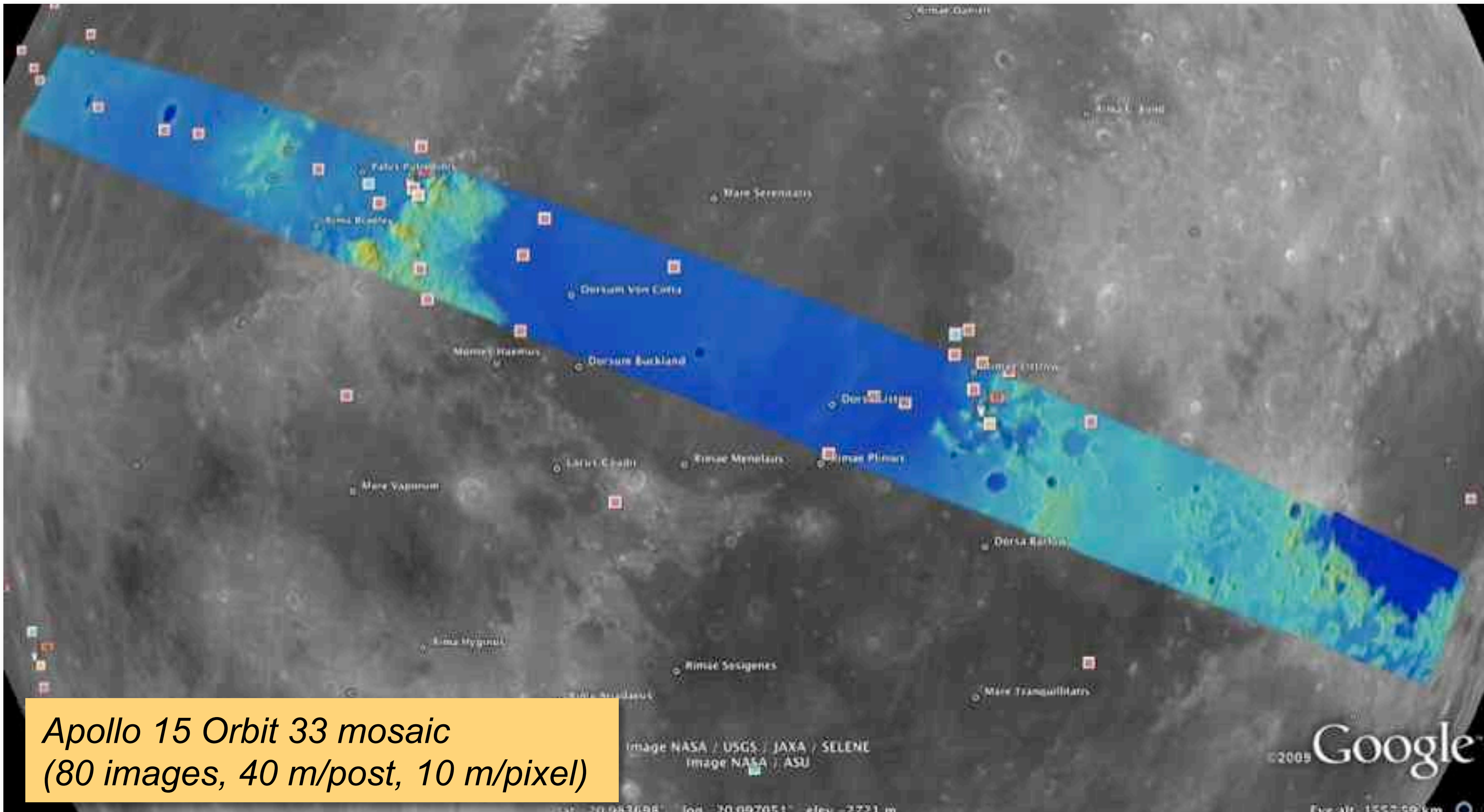
Lunar Terrain Models

Large-scale mapping

- Systematic reconstruction of the "Apollo Zone"
- Stereo vision & mosaicking of Apollo Metric Camera scans
- 8,000 stereo pairs from Apollo 15-17



Apollo 15 Orbit 33



Apollo 15 Orbit 33 mosaic
(80 images, 40 m/post, 10 m/pixel)

M. Broxton, A. Nefian, et al. (ISVC 2009)
"3D Lunar terrain reconstruction from Apollo Images"

Coming Soon …

Complete Mars HiRISE Mosaic

- Mars Reconaissance Orbiter HiRISE imager
- Each image: 20,000 x 50,000 pixels

Mosaic stats

Tile Dimensions	256 x 256 pixels
Root Tiles / Image	15,000
Tile Space	25 KB
Tiles Total	229 million
Total Mosaic Size	5.7 TB

NASA’s Participatory Exploration

Purpose

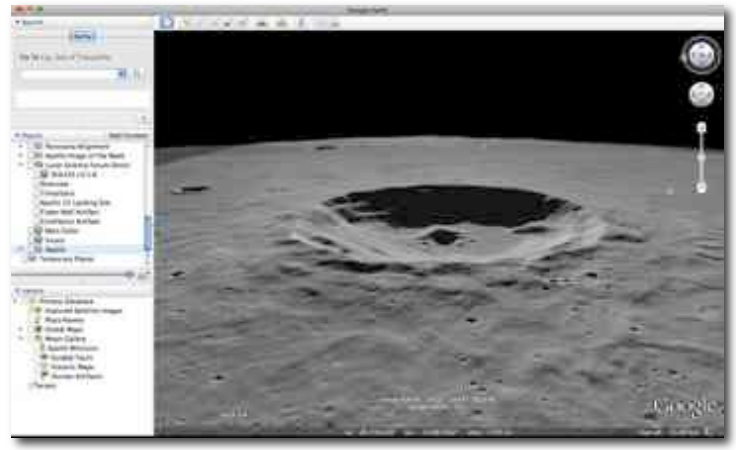
- Enable everyone to actively participate in NASA missions
- Explore space in **bold**, new ways
- Engage & educate students

NASA data for everyone

- Easy access to planetary data
- Reach millions of users (very low barrier to entry)
- Neo-geography browsers (Google Earth, WorldWideTelescope)

Citizen science

- Volunteers help perform science
- Informal & formal education
- Social networking



NASA Data for Everyone

Our goals

- Make NASA's geospatial data universally and easily accessible
- Enable millions of people to find and use NASA data
- Improve planetary science & exploration missions

How do we do this?

- Process raw data into maps (mosaics, terrain models, etc)
- Support geo-browsers & GIS platforms through open standards
- Provide incremental updates, so that data can be shared in near real-time

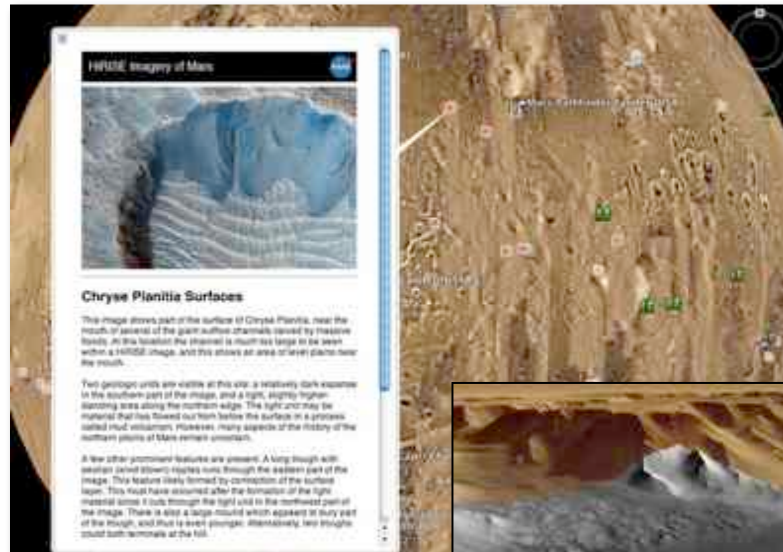
Mars in Google Earth

a.k.a. “Google Mars 3D”

- Launched Feb. 2, 2009
- Co-developed with Google
- Built in to Google Earth v5

Content

- Global maps: topography, infrared, historical, etc.
- Imager footprints & overlays: HiRISE, CTX, MOC, etc.
- MER tracks & panoramas
- Tours (Bill Nye & Ira Flatow)
- Live from Mars: THEMIS images within hours
- And much more …



R. Beyer, M. Broxton, et al. (AGU 2009)
”Visualizing Mars data and imagery with Google Earth”

Moon in Google Earth

a.k.a. “Google Moon”

- Launched July 20, 2009
- Co-developed with Google
- Built in to Google Earth v5

Content

- Global maps: topography, geologic, historical, etc.
- Spacecraft imagery: Apollo, Clementine, Lunar Orbiter
- 3D models of spacecraft, landers, and crew rovers.
- Tours (Andy Chaikin, Buzz Aldrin & Jack Schmidt)
- And much more …

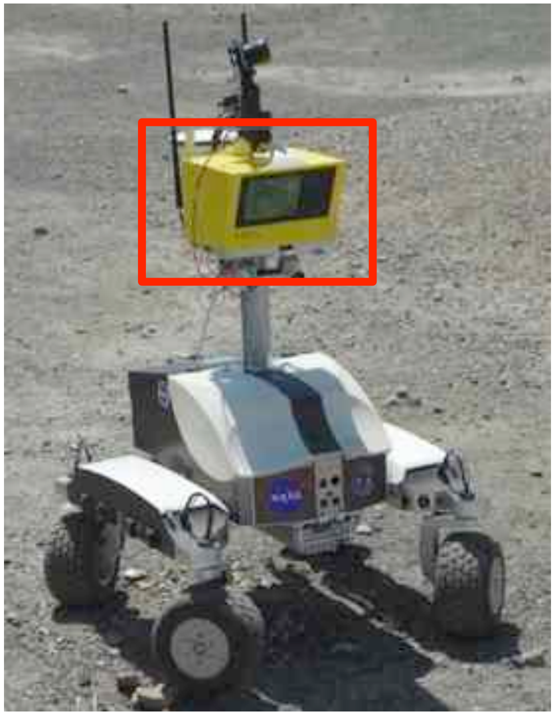
M. Weiss-Malik, T. Scharff, et al. (AGU 2009)
”Visualizing Moon data and imagery with Google Earth”

Lunar Analog Site (2009)

Black Point Lava Flow

- 65 km N of Flagstaff, AZ
- Analog of the “Straight Wall” (Mare Nubrium / Rupes Recta)
- Basaltic volcanic rocks & unit contacts

Surface Robotic Recon Instruments

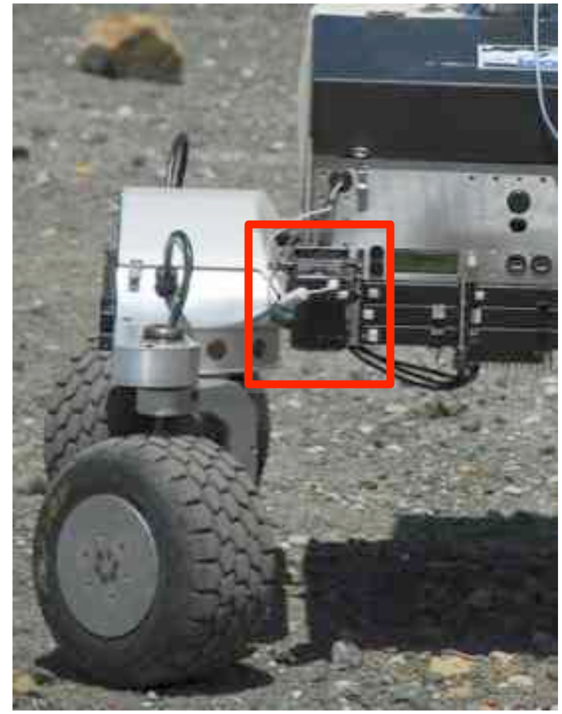


3D scanning LIDAR

- 3D topography measurements
- 5mm @ 500m
- Oblique views not possible from orbit

GigaPan

- Oblique, wide-angle, color, context views
- 60x180 deg
- >100x resolution of orbital images



Microscopic Imager

- High-res, close-up, color, terrain views
- 33 micron / pixel
- >7,000x resolution of orbital images

Orbital Data

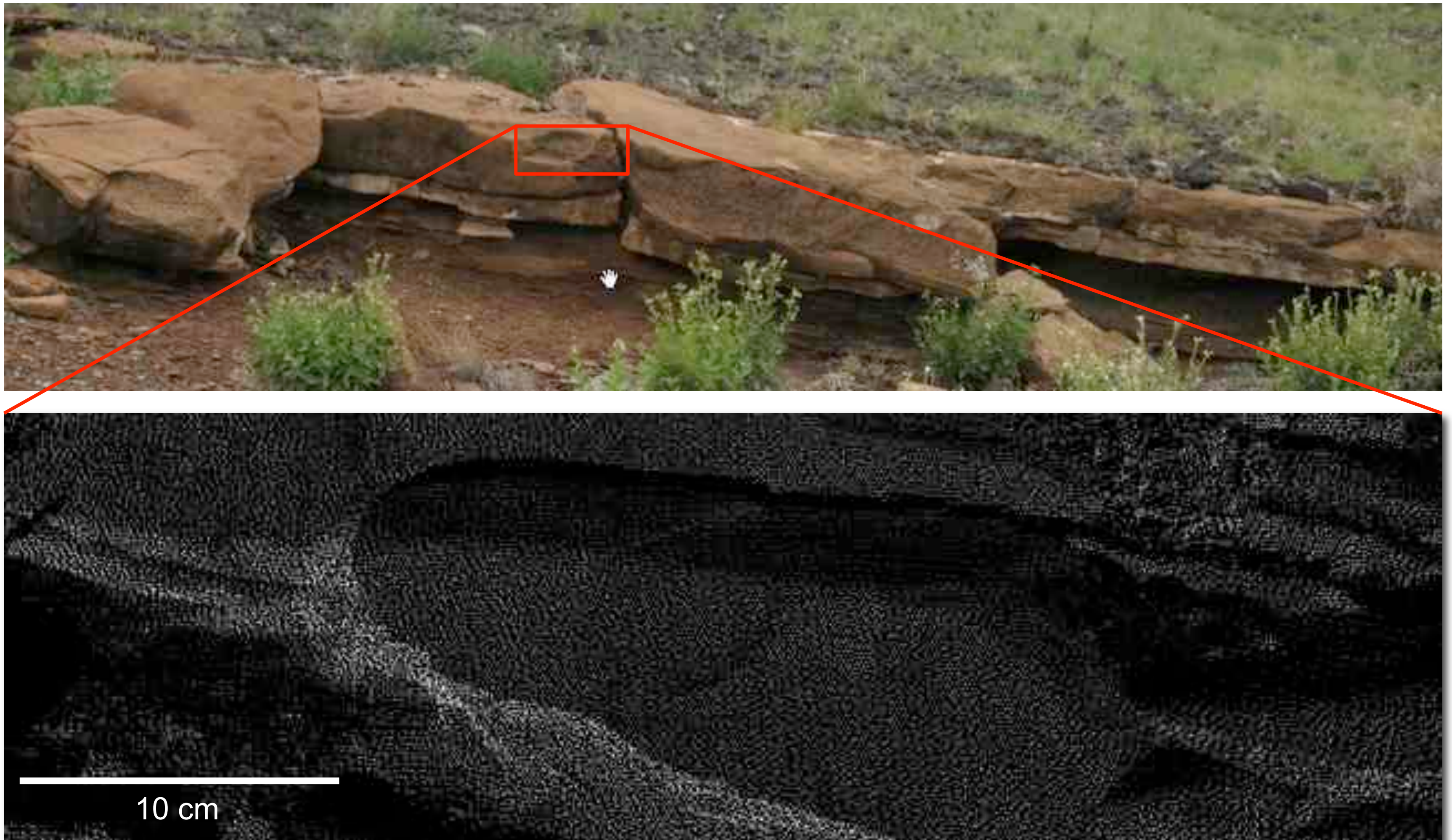
Digital Globe QuickBird (60 cm/pixel)

Surface Data

GigaPan panorama close-up

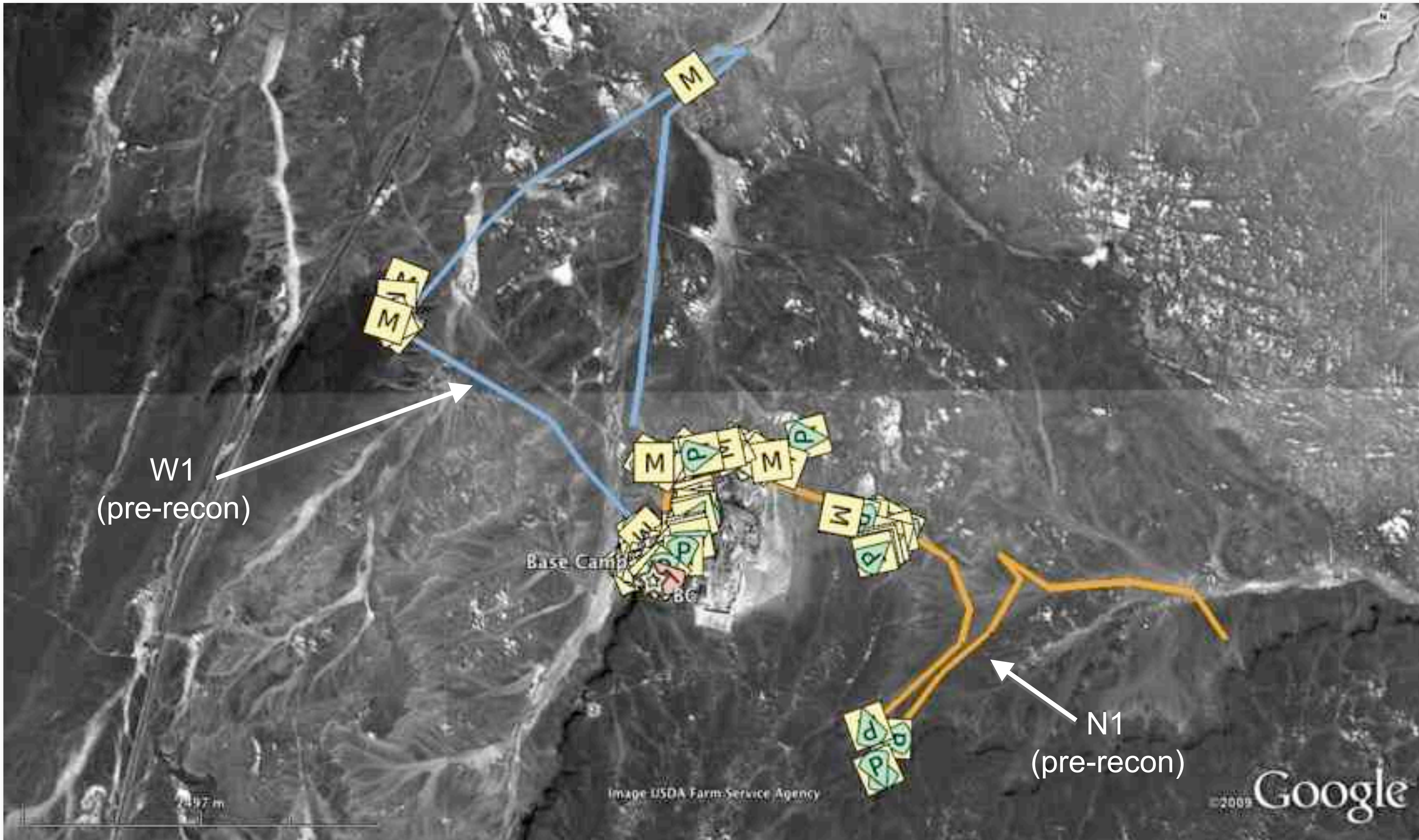
Terrain image (55 microns / pixel)

Surface Data

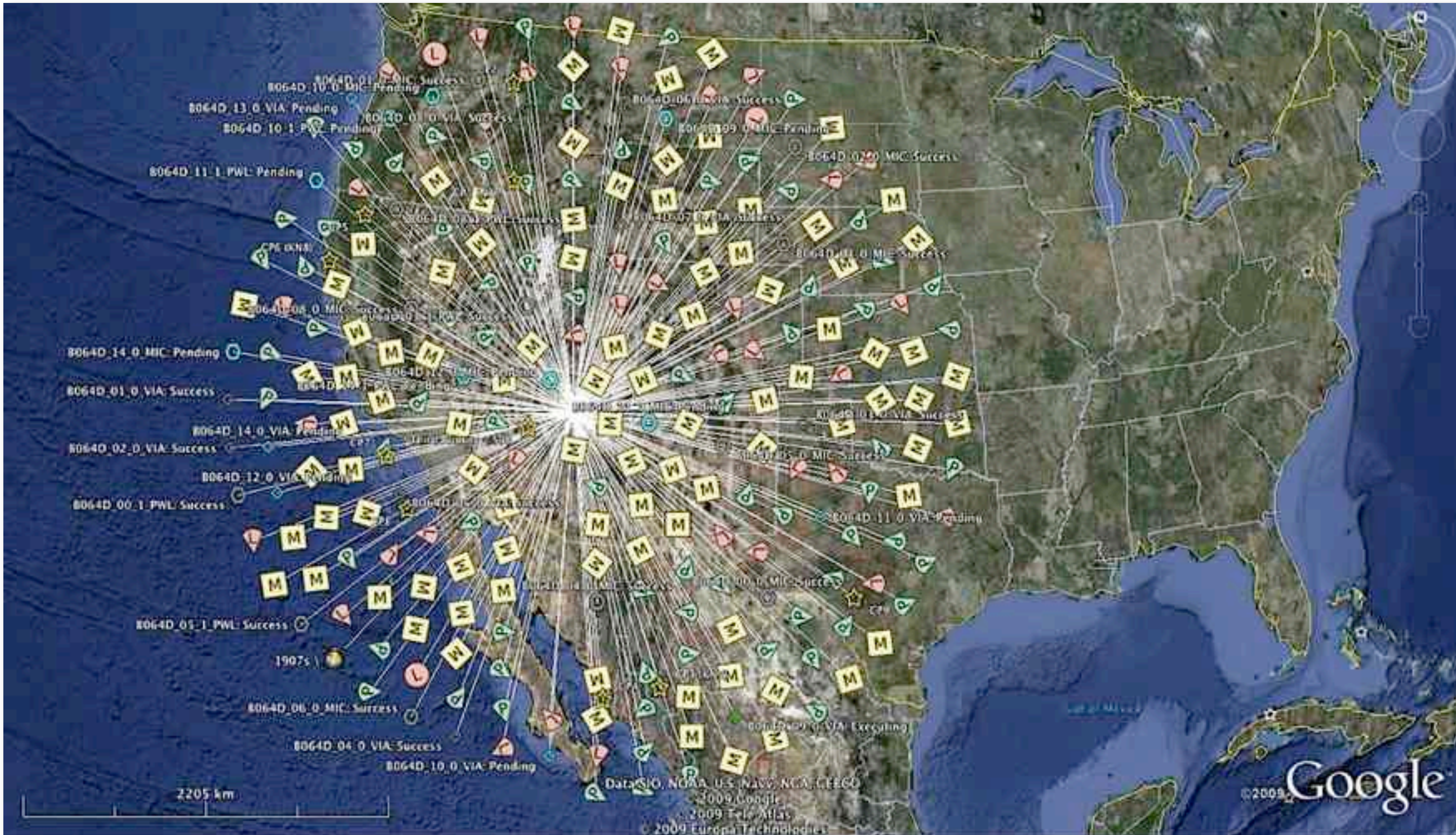


3D scanning LIDAR (250 m range, 3 mm depth resolution)

Collected Recon Data



Collected Recon Data



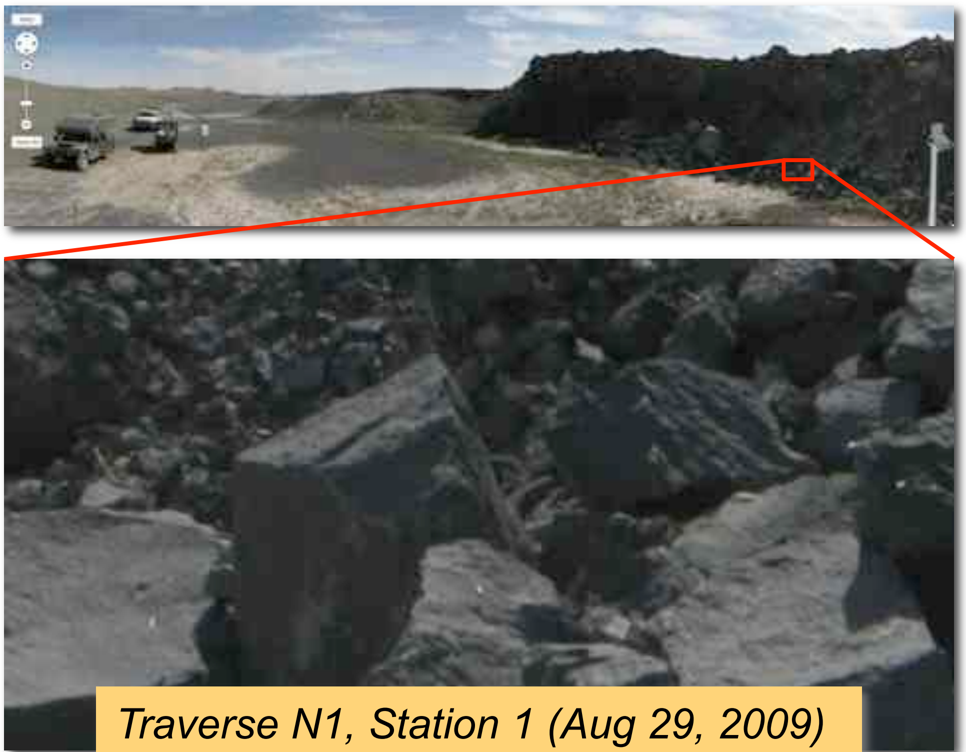
8.5 GB data collected (52 hrs of robotic recon operations)

39 LIDAR scans, 75 GigaPan, and 95 terrain images

GigaPan on the Lunar Electric Rover

Desert RATS 2009

- GigaPan “Voyage” (rugged pan-tilt + embedded processing/server)
- Remotely operated by science backroom (ground control)
- Context & high-resolution imaging for field geology



Traverse N1, Station 1 (Aug 29, 2009)
290x40 deg panorama (112 images)

Participatory Exploration for D-RATS 2010

Objectives

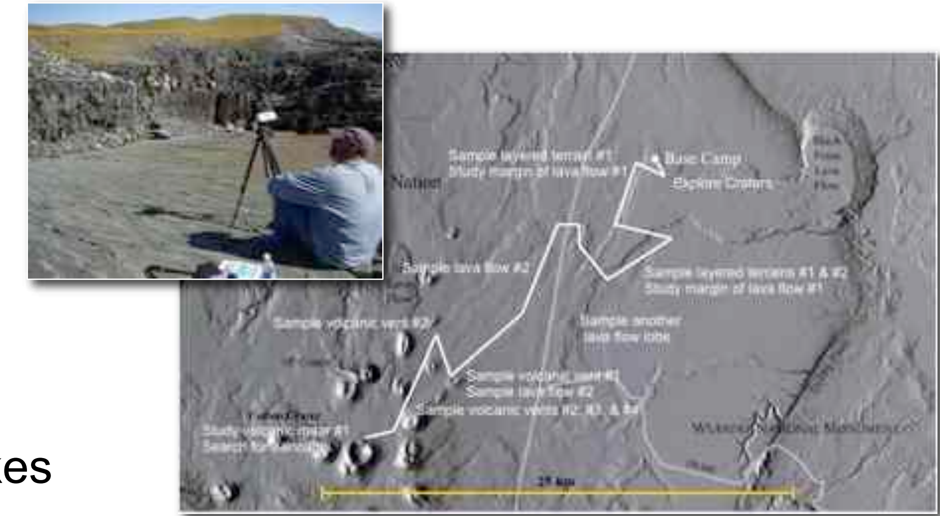
- Citizen science using GigaPan
- Involve public & students

Pre-test (Dec 2009 – May 2010)

- Manually take GigaPans on preliminary LER traverse plan
- Public explores panoramas, takes snapshots & adds comments
- On-line discussion w/ scientists (places to stop, tasks, etc.)
- Public input for final plan

Field-test (Aug – Sept 2010)

- Take GigaPan panoramas from LER & publish via gigapan.org
- Public explores panoramas & discusses discoveries w/ scientists



NASA's Exploration of the Solar System

- Generates some of the most diverse (heterogeneous), data rich (multi-scale, multi-type).
- Gathers Micro-scale data in a Macro-scale Context
- Largely (multi-spectral) image-based assessments
- Relative (location) context of the imagery gained is critical data

Gigapixel-scale Exploration is here to stay